Methods to Estimate Annual Mean Spring Discharge to the Snake River Between Milner Dam and King Hill, Idaho

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Coefficient of determination. The ratio of the sum of squares of deviation due to regression to the total sum of squares corrected for the mean and used as a measure of the ability of the regression line to explain variations in the dependent variable or commonly defined as that fraction of the variance that is explained by the regression.

Gaging station. A site on a channel of flowing water where continuous records of gage height are collected and daily mean discharge is computed.

Gaging-station number. Gaging and miscellaneous discharge measurement stations are assigned 8-digit numbers for identification. The first two digits are a part number and refer to a major drainage basin. Part number 13 refers to the Snake River Basin. The six digits that follow are assigned on the basis of downstream order (numbers increase from headwaters to mouth).

Root mean square error. The square root of the ratio of the sum of the squared residuals to the number of cases less lost degrees of freedom or standard error of the regression.

Water year. The 12-month period October 1 through September 30, designated by the calendar year in which the period ends. Annual mean discharge was computed using the water-year timeframe.

METHODS TO ESTIMATE ANNUAL MEAN SPRING DISCHARGE TO THE SNAKE RIVER BETWEEN MILNER DAM AND KING HILL, IDAHO

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ABSTRACT

Many individual springs and groups of springs discharge water from volcanic rocks that form the north canyon wall of the Snake River between Milner Dam and King Hill. Previous estimates of annual mean discharge from these springs have been used to understand the hydrology of the eastern part of the Snake River Plain. Four methods that were used in previous studies or developed to estimate annual mean discharge since 1902 were (1) water-budget analysis of the Snake River; (2) correlation of water-budget estimates with discharge from 10 index springs; (3) determination of the combined discharge from individual springs or groups of springs by using annual discharge measurements of 8 springs, gaging-station records of 4 springs and 3 sites on the Malad River, and regression equations developed from 5 of the measured springs; and (4) a single regression equation that correlates gaging-station records of 2 springs with historical water-budget estimates. Comparisons made among the four methods of estimating annual mean spring discharges from 1951 to 1959 and 1963 to 1980 indicated that differences were about equivalent to a measurement error of 2 to 3 percent. The method that best demonstrates the response of annual mean spring discharge to changes in ground-water recharge and discharge is method 3, which combines the measurements and regression estimates of discharge from individual springs.

INTRODUCTION

Many springs and groups of springs discharge water from volcanic rocks that form the north canyon wall of the Snake River between Milner Dam and King Hill. The U.S. Geological Survey (USGS) has measured discharge periodically from many of these springs since 1902. Historical records document trends in spring discharge from the regional aquifer system and identify changes in water use and supply. Analyses of recharge to, change of storage in, and discharge from the eastern Snake River Plain regional aquifer system (Garabedian, 1992; Kjelstrom, 1986, 1995) were dependent largely on measured and estimated discharges from springs between Milner Dam and King Hill (fig. 1). Determining changes in discharge from springs is essential to understanding the hydrology of the eastern part of the Snake River Plain.

Prior to the diversion of water for irrigated agriculture on the eastern Snake River Plain, spring discharge varied as a result of changes in aquifer recharge from precipitation. As a consequence of increased irrigated agriculture since the late 1800's, the amount of spring discharge also has varied as a result of changes in recharge from surface-water irrigation and discharge from pumping of ground water. When the springs were first measured in 1902, discharge probably had been affected little by recharge from irrigation on the plain. From 1902 to the early 1950's, recharge from percolation of irrigation water applied north and east of the springs increased and caused a rise in ground-water levels and a corresponding increase in spring discharge. Subsequent steady decreases in spring discharges, beginning in the mid-1950's, were attributed to pumping of ground water for irrigation and more efficient irrigation practices.

At times during the irrigation season, no water was released to the Snake River downstream from Milner Dam. Spring discharge from the north side of the Snake River Canyon then constituted most of the streamflow at King Hill and the water supply for downstream use. Seeps and springs on the south side of the canyon, springs in the riverbed, and irrigation-return flows on

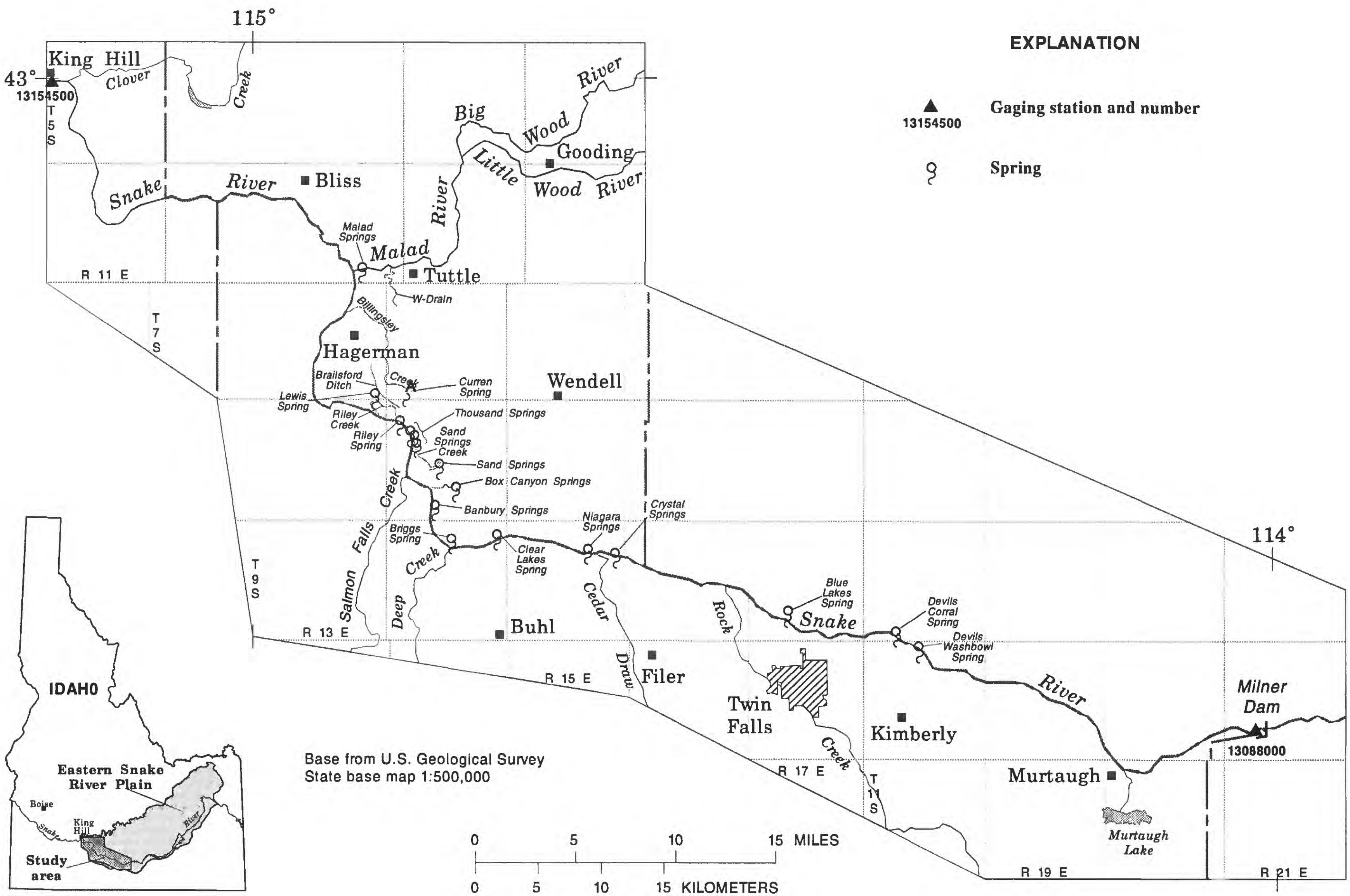

Figure 1. Study area and locations of selected springs and gaging stations.

Table 1. Gaging stations used to determine daily mean spring discharge along the Snake River between Milner Dam and King Hill

[Equation codes in parentheses relate to regression equations in tables 4 and 6]

Gaging-station No.	Gaging-station name	Period of record
13089500	Devils Washbowl Spring near Kimberly	April 1950 to September 1959, April 1985 to September 1992
13091000	Blue Lakes Spring near Twin Falls (BLU)	April 1950 to September 1992
13091500	Blue Lakes Spring Outlet near Twin Falls	May 1917 to December 1920
13093700	Niagara Springs near Buhl	October 1958 to October 1972
13094500	Clear Lakes Spring Outlet near Buhl	June 1917 to November 1920
13095175	Briggs Spring at head near Buhl (BRI)	April 1989 to September 1992
13095500	Box Canyon Springs near Wendell (BOX)	April 1950 to September 1992
13134000	Riley Creek below Lewis Spring near Hagerman	June 1951 to December 1959
13133500	Brailsford Ditch near Hagerman	June 1951 to December 1959

both sides of the canyon contributed small amounts of streamflow.

This report describes regression equations developed from continuous and annual spring discharge measurements from 1902 to 1993 to estimate annual mean discharge to the Snake River between Milner Dam and King Hill from individual springs, groups of springs, and all springs. The regression equation for all springs can be used for some years when most springs were not measured. Two previously developed methods—water-budget analysis and correlation of discharge measurements from 10 index springs with water-budget estimates—also were used to estimate annual mean discharge. Data and information presented can be used by managers, planners, and researchers to understand and quantify hydrologic changes on the Snake River Plain.

MEASUREMENTS OF SPRING DISCHARGE

Spring discharge has been determined from measurements and continuous records at gaging stations. Most springs that discharge to a channel have been measured at some time, and many have been measured annually since 1950. Discharge from nearly all springs was measured in 1902 (Nace and others, 1958, p. 16–18). Discharge from only a few springs was measured from 1903 to 1916. Discharge from most of the larger springs was measured in 1917 and 1924 (Stearns and others, 1938, p. 154–166). Discharge from 34 of the spring sites has been measured nearly every March or April from 1950 to 1959 and from 1963 to the present (1993). Prior to 1950, discharge was not always measured at the same location and, therefore, may not be directly comparable with other discharge measurements of that spring. Records of continuous daily mean discharge are available for several springs (table 1).

Gaging stations used to determine spring discharge often are installed upstream from some spring outlets and, occasionally, downstream from diversions. For example, some spring water enters the channel downstream from the continuous-record gaging station 13089500 at Devils Washbowl Spring (table 1). However, the annual discharge measurement gaging station 13089600 (table 2) is downstream from the entire spring discharge. Discharge measurements of Blue Lakes Spring Outlet (13091500) generally indicate some additional inflow downstream from the present gaging station (13091000). The cableway used to mea-

Table 2. Spring discharge along the Snake River between Milner Dam and King Hill, measured annually during 3- to 5-day periods, 1951–59 and 1963–93

[Equation codes in parentheses relate to regression equations in tables 4 and 6]

Gaging-station No.	Gaging-station name
13089600	Devils Washbowl Spring near Kimberly (DWB)
13090100	Devils Corral Spring (upper outlet) near Kimberly
13093400	Crystal Springs near Filer
13094500	Clear Lakes Spring Outlet near Buhl (CLR)
13095300	Banbury Springs near Buhl (BAN)
13132600	Sand Springs Creek near Hagerman (SAN)
13133800	Riley Creek near Hagerman (RIL)
13134600	Billingsley Creek near Hagerman (BIL)

sure discharge from Niagara Springs (13093700) was downstream from diversions; however, miscellaneous discharge measurements were made on the diversions to obtain total discharge. The gaging station at Box Canyon Springs (13095500) is used to determine discharge only from the upper spring outlets in Box Canyon; several outlets are located between the gaging station and the mouth of Box Canyon. A large part of the discharge is diverted to a covered flume near the mouth of Box Canyon. Discharge from Riley and Lewis Springs was determined by combining the discharge from Riley Creek (13134000) and Brailsford Ditch (13133500). After about 1957, the total discharge from the springs was not always measured because of additional diversions.

ESTIMATES OF SPRING DISCHARGE

Water-budget analysis of the Snake River and correlation of measurements from 10 springs with water-budget estimates have been used in previous studies to estimate annual mean discharge from the eastern Snake River Plain regional aquifer system. A brief overview of these methods is presented in the next two sections. Two additional methods were developed that used measurements and regression equations to estimate discharge from individual springs, groups of springs, or all springs. Descriptions of these two methods are presented in subsequent sections.

Water-budget method

Annual discharge from springs, including unmeasured springs and seeps, was estimated by water-budget analysis of the Snake River from Milner Dam to King Hill for water years 1902–66 (Thomas, 1969, p. 26). Discharge recorded at the gaging station on the Snake River at Milner Dam (13088000), plus estimates of tributary and irrigation-return flow, were subtracted from the sum of discharge recorded at the gaging station on the Snake River at King Hill (13154500) and measured and estimated streamflow diversions (fig. 1). The remainder was assumed to be spring discharge. Although the results generally were reasonable, a measurement error of 2 to 3 percent could have masked changes in spring discharge when streamflow in the Snake River exceeded several thousand cubic feet per second.

Index method

Kjelstrom (1986) correlated water-budget estimates with measured discharge from 10 springs. That correlation was used to index discharge measurements of the 10 springs with annual spring discharge from 1951 to 1959 and 1963 to 1980. Only Blue Lakes Spring and Box Canyon Springs were measured during 1960 through 1962, and water-budget estimates were used for those years in hydrographs presented by Kjelstrom (1986, 1992a). Annual mean spring discharge estimated by the index method always corresponded to the general trend of increase or decrease in measured spring discharge from year to year, whereas estimates from the water-budget method occasionally did not correspond with the general trend. Progressive modifications to diversion structures made discharge measurement difficult at several springs and, after 1985, Niagara Springs (one of the 10 index springs) was no longer measurable.

Combination method

Annual spring discharge from 1981 to 1992 (Kjelstrom, 1992a) was estimated from a combination of discharge measurements of eight springs, gaging-stations records of four springs and three sites on the Malad River, and regression equations developed from five of the measured springs. Ten additional regression equations were developed to produce estimates for years when measurements were not available. Various combinations of discharge measurements, gaging-station records, and regression results can be used to estimate annual spring discharge depending on the availability of measured discharge during any given year.

Discharge measurements at annual measuring stations (table 2) usually were made during 3- to 5-day periods in March or April, and discharges computed from gaging-station records (tables 1 and 3) were averaged for those days. Measured and computed discharges (table 1) were used as independent variables in regression equations (table 4) to estimate discharge from unmeasured springs and seeps. Discharge determined from measurements, gaging-station records, and regression equation estimates was combined. The resultant total discharge was converted to annual mean spring discharge (table 5) on the basis of the discharge computed from gaging-station records of Blue Lakes

Spring and Box Canyon Springs. The ratio of average discharge for the 3- to 5-day measurement period and annual mean discharge was determined for both gaging stations and averaged. The average ratio then was used to convert total spring discharge for the 3- to 5-day measurement period to annual mean spring discharge. Slight temporal changes in the ratios were apparent—the ratio for the 1951–64 period averaged 0.957; for the 1965–81 period, 0.943; and for the 1982–93 period, 0.969.

Discharge from springs in the Malad River Canyon, hereafter called Malad Springs, was computed by subtracting discharge of the Malad River near Gooding (13152500, table 3) from the sum of discharge of the Malad River near its mouth (Malad River near Bliss, 13153500) and discharge of the Malad River power flume near Bliss (13152940). Irrigation-return flow estimates based on the record of W-drain near Tuttle (13152895) also were subtracted from discharge of the Malad River near its mouth. The remainder was assumed to be discharge from Malad Springs and is subject to the accumulated error of measurement at the gaging stations.

Multiple regression techniques were applied to develop five equations that used measured spring discharge to estimate discharge from individual springs or groups of springs that presented measurement difficulties (table 4). Data used to develop the regression equation for Niagara Springs included monthly mean discharge computed from gaging-station records, as well as discharge measurements of Niagara Springs outside its period of continuous record. Although discharge from Niagara Springs is no longer measurable, the relatively low root mean square error indicates that

Table 3. Gaging stations used to determine discharge from springs in Malad River Canyon

Gaging-station No.	Gaging-station name	Period of record
13152500	Malad River near Gooding	October 1959 to September 1993
13152895	W-drain near Tuttle	August 1987 to November 1989
13152940	Malad River power flume near Bliss	June 1985 to September 1993
13153500	Malad River near Bliss	December 1984 to September 1993

the regression equation can adequately estimate spring discharge.

Discharge from Thousand Springs, some adjacent springs, and Sand Springs was determined by subtracting upstream from downstream discharge of the Snake River reach that contains the springs. This amount of discharge minus measured discharge in Sand Springs Creek hereafter is referred to as Thousand Springs discharge. A regression equation was developed to estimate Thousand Springs discharge when upstream discharge in the Snake River was high and normal measurement errors could constitute an unacceptably large proportion of spring discharge. Of 49 available discharge measurements, 22 that were made when discharge in the Snake River at the upstream site was less than 3,000 ft^3/s were chosen for the regression data set.

Diversion structures have prevented making discharge measurements near the mouth of Box Canyon for many years. The regression equation used to estimate discharge from spring outlets in the lower part of Box Canyon was developed from three measurements of total discharge from Box Canyon that were made before diversion structures were installed. Discharge from springs located mostly at the head of Box Canyon, recorded at the gaging station Box Canyon Springs near Wendell (13095500), was subtracted from

Table 4. Regression equations developed to estimate discharge from unmeasured springs (combination method) along the Snake River between Milner Dam and King Hill

[Equation codes in parentheses are identified in tables 1 and 2]

Unmeasured springs	Regression equations	No. of data sets	Root mean square error (percent of mean)	Coefficient of determination
Niagara	0.864 (BOX) + 0.34 (BLU) - 97	47	4	0.69
Thousand	4.21 (BOX) + 1.82 (SAN) - 620	22	5	.70
Lower Box Canyon	1.94 (CLR) - 552	3	1	.98
Lower Billingsley Creek	2.2 (BIL) + 84	16	8	.52
Miscellaneous springs and seeps	4.19 (BLU) - 117	36	9	.88

Table 5. Measured and estimated spring discharges used in the combination (1951–59 and 1963–93) or regression (1960–62) method to estimate annual mean spring discharge along the Snake River between Milner Dam and King Hill

[Discharge measurements made during a 3- to 5-day period in March or April of each year or average mean discharge from gaging-station record for the 3- to 5-day measurement period unless noted otherwise; measurement frequencies for named springs are identified in tables 1, 2, and 3; estimated discharges are shaded; regression equations in tables 4 and 6 were used to obtain estimated spring discharges; ND, no data; A, annual mean discharge]

Water Year	Spring discharge (in cubic feet per second) Devils Washbowl	Devils Corral	Blue Lakes	Crystal	Niagara	Clear Lakes	Briggs	Banbury	Box Canyon	Lower Box Canyon	Sand Springs Creek	Thousand Springs minus Sand Springs Creek	Riley Creek	Billingsley Creek at head	Lower Billingsley Creek	Malad	Miscellaneous springs and seeps	Three- to five-day total	Annual mean
1951	26	49	229	575	313	533	109	138	388	482	98	1,190	63	46	185	1,240	864	6,528	6,820
1952	24	48	224	495	296	528	106	133	412	472	97	1,290	62	45	183	1,300	842	6,557	6,800
1953	23	50	235	487	309	541	110	127	403	498	100	1,260	64	51	196	1,230	892	6,576	6,750
1954	24	53	227	495	321	528	109	128	400	472	99	1,240	65	47	187	1,210	855	6,460	6,760
1955	24	51	218	517	334	535	106	127	393	486	97	1,210	60	45	183	1,210	815	6,411	6,710
1956	23	52	219	548	294	527	111	118	380	470	96	1,150	70	49	163	1,260	819	6,349	6,750
1957	23	48	217	488	304	513	113	98	394	443	98	1,220	69	47	187	1,350	810	6,422	6,700
1958	20	51	224	496	295	506	105	120	394	430	94	1,210	73	46	171	1,270	842	6,347	6,570
1959	20	50	205	478	274	514	110	123	397	445	89	1,210	62	48	157	1,270	756	6,208	6,530
1960	ND	ND	A209	ND	ND	ND	ND	ND	A392	ND	ND	ND	ND	ND	ND	ND	ND	ND	6,280
1961	ND	ND	A197	ND	ND	ND	ND	ND	A374	ND	ND	ND	ND	ND	ND	ND	ND	ND	6,000
1962	ND	ND	A200	ND	ND	ND	ND	ND	A394	ND	ND	ND	ND	ND	ND	ND	ND	ND	6,200
1963	15	46	196	452	246	506	111	115	362	430	93	1,070	59	37	165	1,220	715	5,838	6,150
1964	17	45	201	432	243	486	110	112	378	391	87	1,130	65	35	163	1,250	738	5,883	6,190
1965	14	42	197	441	256	515	110	113	378	447	80	1,120	61	42	176	1,260	719	5,971	6,350
1966	16	46	190	475	259	535	110	111	374	486	94	1,130	63	45	183	1,230	688	6,035	6,580
1967	14	49	190	455	241	512	111	123	354	441	78	1,010	61	35	164	1,230	688	5,756	6,280
1968	15	52	204	439	301	504	108	117	373	426	88	1,110	62	39	176	1,280	751	6,045	6,400
1969	17	49	205	468	313	497	108	123	373	412	85	1,110	61	39	170	1,240	756	6,026	6,320
1970	16	52	208	487	302	484	108	118	379	387	86	1,130	61	46	188	1,260	769	6,081	6,380
1971	16	48	212	468	320	503	110	111	370	424	86	1,090	65	38	180	1,230	787	6,058	6,420
1972	16	49	190	492	325	516	110	120	377	449	96	1,140	66	41	185	1,250	688	6,110	6,560
1973	14	53	207	479	295	474	108	114	380	368	92	1,150	58	44	181	1,260	765	6,042	6,480
1974	12	41	212	430	259	493	113	111	384	404	90	1,160	72	40	172	1,270	787	6,050	6,360
1975	17	48	187	440	285	509	116	104	371	435	93	1,110	62	42	180	1,240	674	5,913	6,320
1976	15	49	196	487	282	501	118	124	371	420	91	1,110	62	42	186	1,240	715	6,009	6,310
1977	17	48	190	544	294	533	118	117	375	482	86	1,120	65	40	172	1,250	688	6,139	6,390
1978	13	48	198	459	240	478	102	106	351	375	84	1,010	74	26	151	1,180	724	5,619	5,870
1979	15	45	181	422	269	507	105	90	351	432	78	1,000	63	30	150	1,180	647	5,565	5,850
1980	13	53	181	439	240	511	109	120	357	439	77	1,020	63	32	154	1,230	647	5,685	6,110
1981	15	40	187	457	260	494	112	126	356	406	80	1,020	58	36	163	1,120	674	5,604	5,860
1982	14	40	181	459	279	497	107	92	353	412	77	1,010	50	35	161	1,230	647	5,644	5,760
1983	12	39	166	467	233	493	115	119	348	404	76	983	59	38	168	1,200	579	5,499	5,690
1984	15	47	173	470	292	511	105	129	368	439	87	1,090	61	44	181	1,230	611	5,853	6,030
1985	15	45	189	479	292	512	118	124	368	441	82	1,080	59	40	172	1,070	683	5,769	5,840
1986	13	44	179	456	283	541	104	123	369	498	86	1,090	72	37	165	1,270	638	5,968	6,350
1987	15	45	190	501	286	496	108	133	369	410	88	1,090	76	44	181	1,230	688	5,950	6,260
1988	13	43	192	480	277	476	105	129	357	371	87	1,040	77	36	163	1,260	697	5,803	5,970
1989	12	42	153	453	253	478	103	123	345	375	97	1,010	67	31	152	1,230	520	5,444	5,820
1990	12	38	178	461	269	484	106	126	353	387	80	1,010	75	33	157	1,160	633	5,562	5,610
1991	12	40	167	400	265	449	102	106	353	319	76	1,000	63	30	150	1,230	584	5,346	5,460
1992	14	37	156	398	245	456	106	114	335	333	74	925	75	27	143	1,170	534	5,142	5,190
1993	11	41	151	429	232	450	102	112	321	321	64	848	86	19	126	1,120	511	4,944	5,090

the total discharge from Box Canyon. Discharge from springs in lower Box Canyon correlated with measured discharge from Clear Lakes Spring Outlet and a regression equation was developed. The computed discharge from springs in lower Box Canyon correlated poorly with discharge recorded at the Box Canyon gaging station.

Total spring discharge to Billingsley Creek was difficult to determine because of several diversions. Although many springs discharge to Billingsley Creek, discharge measurements generally were made only just below the headwaters of Billingsley Creek near Curren Spring (fig. 1). These measurements were regressed with the total discharge in Billingsley Creek minus the discharge at the headwaters. Sixteen data sets that were believed to include most of the spring discharge to lower Billingsley Creek were used to develop the regression equation.

Discharge from miscellaneous springs and seeps was determined by subtracting the sum of measured and estimated spring discharges from total discharges estimated using the index method. Discharge from Blue Lakes Spring (13091000) correlated with discharge from miscellaneous springs and seeps and was the only independent variable used in the final regression equation (table 4).

Ten regression equations were developed for individual springs where annual discharge measurements have been made for most years since 1951 (table 6). Regression equations for most individual springs included all available data sets. Because of higher discharge in Riley Creek in recent years, the regression data set included only the last 10 measurements from 1986 to 1993 (including measurements in November 1986 and 1987). The cause of higher discharge in Riley Creek is unknown. The equations can be used to detect changes in the correlation of springs, and by comparing the equation estimates with discharge measurements, to estimate discharge when measurements are not made.

When measurements were not made for springs and creeks listed in table 5, discharge was estimated using regression equations shown in table 6. For example, to complete the compilation of table 5, the equations for Crystal, Clear Lakes, and Banbury Springs were used in 1972 when measurements could not be made because of high streamflow in the Snake River. Also, prior to installation of the cableway for the gaging station at the mouth of the Malad River in 1984, the Malad River was not measured some years because it could not be waded. The equation in table 6 was used for these years.

About 57 percent of total spring discharge in water year 1992 (table 6) was estimated from discharge measurements and gaging-station records. Seven springs where discharge was measured annually (table 2) accounted for about 23 percent of the total, discharge computed for four gaging stations (Devils Washbowl Spring included as a gaging station) accounted for about 12 percent, and discharge from Malad Springs accounted for about 22 percent. About 43 percent of

Table 6. Regression equations developed to estimate discharge from selected springs and creeks (combination method) and from all springs (regression method) along the Snake River between Milner Dam and King Hill

[Equation codes in parentheses are identified in tables 1 and 2]

Springs and creeks	Regression equations	No. of data sets	Root mean square error (percent of mean)	Coefficient of determination
Devils Washbowl	0.093 (BLU) + 0.062 (BOX) - 24.8	38	12	0.67
Devils Corral	0.84 (DWB) + 33	35	5	.56
Crystal	0.49 (BOX) + 0.71 (BAN) + 1.94 (SAN) + 36	36	4	.68
Clear Lakes	1.09 (SAN) + 0.55 (BOX) + 204	41	3	.63
Briggs	0.102 (CLR) + 57	31	2	.55
Banbury	0.87 (RIL) + 0.55 (BRI) + 1.8	31	5	.54
Sand Springs Creek	0.105 (CLR) + 0.26 (BOX) - 62	41	6	.63
Riley Creek	0.30 (BAN) + 0.51 (BRI) - 18	10	5	.70
Billingsley Creek	0.0574 (BOX) + 0.516 (SAN) - 29.7	38	8	.81
Malad	2.75 (BOX) + 216	18	2	.88
Total discharge from all springs	10.5 (BLU) + 8.3 (BOX) + 830	30	3	.70

total spring discharge was estimated using the five regression equations listed in table 4. About 31 percent of the total included Niagara Springs, Thousand Springs, springs in the lower part of Box Canyon, and spring discharge to Billingsley Creek. The remainder discharged to miscellaneous springs and seeps. About 5 percent included springs where discharge was measured or estimated one or more times in 1902 or from 1917 to 1924. The remaining 7 percent included many small springs that were unmeasurable, seepage through talus tailings, and springs in the riverbed.

Regression method

A single regression equation (table 6) was developed to provide an alternative method to estimate total discharge from all springs. The regression equation was derived from 30 data sets that correlated annual mean discharge from Blue Lakes Spring and Box Canyon Springs from 1951 to 1980 with historical water-budget estimates (Thomas, 1969; Kjelstrom, 1986). An advantage of this method is that it could be used to estimate discharge for periods of less than 1 year; however, areal and temporal changes in recharge could affect springs differently and would not be apparent using this method.

COMPARISON OF RESULTS AMONG METHODS

Estimates from the (1) water-budget method, (2) index method, (3) combination method, and (4) regression method were compared for water years 1951–59 and 1963–80. Generally, the differences in the four estimates of annual mean discharge among the four methods were about equivalent to measurement errors of 2 to 3 percent and the data sets were not shown to be statistically different. Root mean square errors ranged from 108 to 145 ft^3/s from paired comparisons of annual mean discharge determined by the four methods (table 7). Mean values for the four data sets ranged from 6,429 to 6,461 ft^3/s. On the basis of statistical checks for unequal variances, normal distribution, and outliers, all estimates of annual mean discharge seemed suitable for a standard t-test. Standard t-test values ranged from 0.005 to 0.477. Probabilities (p-values at 95-percent confidence intervals) shown in table 7 indicate the likelihood that the mean of the differences could be zero. For the paired comparisons among methods 1, 2, and 4, probabilities greater than or equal to 0.94 can be attributed to the development of methods 2 and 4 on the basis of the results from method 1. Probabilities for paired comparisons that included method 3 were lower because method 3 was developed independently of results from method 1. Although root mean square error and probability of differences indicate that methods 3 and 4 provide acceptable results, method 3 is preferred because it incorporates measured discharge from many springs and is more likely to account for local and regional changes in recharge and discharge that affect spring discharge and lag times.

Table 7. Root mean square error and p-values at 95-percent confidence intervals for paired comparisons from four methods used to determine annual mean spring discharge along the Snake River between Milner Dam and King Hill for water years 1951–59 and 1963–80

[Root mean square error values are greater than 1; p-values are less than 1. p-value shown is the probability that the mean of the differences from paired comparisons of the method estimates could be zero; ft^3/s, cubic feet per second]

	Root mean square error (ft^3/s)\p-values			
	Estimation method			
Estimation method	Water budget (1)	Index (2)	Combination (3)	Regression (4)
(1) Water budget		0.98	0.77	0.94
(2) Index	131		.79	.96
(3) Combination	145	108		.83
(4) Regression	144	126	115	

SUMMARY

Determining changes in spring discharge to the Snake River between Milner Dam and King Hill is essential to understanding the hydrology of the eastern part of the Snake River Plain. Changes in the discharge of springs have been caused mostly by irrigation development and changes in irrigation practices.

Discharge from nearly all springs was measured or estimated in 1902 and discharge from most springs was measured in 1917 and 1924. Since 1950, discharge from many of the springs has been measured each March at the same site; records of continuous daily mean discharge are available for several springs. Gaging stations at Blue Lakes Spring near Twin Falls and

Box Canyon Springs near Wendell have provided records of annual mean discharge since 1951.

Annual mean discharge from the springs has been estimated by the water-budget and index methods in previous studies and by the combination and regression methods developed for this study. For the water-budget method, gaging-station records of discharge at Milner Dam and King Hill and estimated and measured inflows and outflows between gaging stations were used. For the index method, discharge measurements from 10 springs were correlated with water-budget estimates. For the combination method, discharge measurements, gaging-station records, and regression equations were used. Multiple regression techniques were applied to develop five equations that used measured spring discharge to estimate discharge for individual springs or groups of springs that presented measurement difficulties. Records of discharge from gaging stations at Blue Lakes Spring and Box Canyon Springs were used to adjust discharge measurements in other springs to annual mean discharge. Regression equations also were developed to estimate discharge when measurements could not be made and can be used to detect changes in the correlation of springs for use in the combination method. For the regression method, annual mean discharge from Blue Lakes Spring and Box Canyon Springs was correlated with estimates from the water-budget method to provide estimates of annual mean discharge from all springs with a single regression equation.

Comparison of the estimates from the four methods for common periods of data availability indicated that differences were about equivalent to a measurement error of 2 to 3 percent and that data sets were not shown to be statistically different. The combination method is preferred because it uses measured discharge from many springs and is more likely to account for local and regional changes in ground-water recharge and discharge that affect spring discharge and lag times.

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