Cost Effectiveness of the Stream-Gaging Program In Nevada

By Freddy E. Arteaga

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"Inch-pound" units of measure used in this report may be converted to International System (metric) units by using the following factors:

Multiply	*By*	*To obtain*
Cubic feet per second (ft^3/s)	0.02832	Cubic meters per second (m^3/s)
Feet (ft)	0.3048	Meters (m)
Feet per foot (ft/ft)	0.3048	Meters per meter (m/m)
Feet per second (ft/s)	0.3048	Meters per second (m/s)
Miles (mi)	1.609	Kilometers (km)
Square feet per second (ft^2/s)	0.093	Square meters per second (m^2/s)
Square miles (mi^2)	2.590	Square kilometers (km^2)

COST EFFECTIVENESS OF THE STREAM-GAGING PROGRAM IN NEVADA

By Freddy E. Arteaga

ABSTRACT

The stream-gaging network in Nevada was evaluated as part of a nationwide effort by the U.S. Geological Survey to define and document the most cost-effective means of furnishing streamflow information. Specifically, the study dealt with 81 gaging stations that were under the direct operation of Nevada personnel as of 1983. Cost-effective allocations of resources, including budget and operational criteria, were studied using statistical procedures known as Kalman-filtering techniques. The possibility of developing streamflow data at ungaged sites was evaluated using flow-routing and statistical regression analyses. Neither of these methods provided sufficiently accurate results to warrant their use in place of stream gaging. The 81 gaging stations were being operated in 1983 with a budget of $465,500. As a result of this study, all existing stations were concluded to be necessary components of the program for the foreseeable future.

At the 1983 funding level, the average standard error of streamflow records was nearly 28 percent. This same overall level of accuracy could have been maintained with a budget of approximately $445,000 if the funds were redistributed more equitably among the gages.

The minimum budget analyzed, $390,000, would have resulted in an average standard error of about 42 percent. A budget less than this would not have permitted proper service and maintenance of the gages and adequate computation of records. The maximum budget analyzed, $1,164,000, would have resulted in an average standard error of 11 percent.

The study indicates that a major source of error is lost data. If perfectly operating equipment were available, the standard error for the 1983 program and budget could have been reduced to 21 percent. This can also be interpreted to mean that the streamflow data have a standard error of this magnitude during times when the equipment is operating properly.

INTRODUCTION

The U.S. Geological Survey is the principal Federal agency that collects surface-water data in the Nation. The collection of these data is a major activity of the Water Resources Division of the U.S. Geological Survey, in cooperation with State and local governments and other Federal agencies. As of 1984, the Geological Survey was operating approximately 8,000 continuous-record gaging stations throughout the Nation. Some of these records extend back to before the turn of the century. Any activity of long standing, such as the collection of surface-water data, should be reexamined at intervals because of changes in objectives, technology, or external constraints. The last systematic nationwide evaluation of the streamflow information program was completed in 1970 and is documented by Benson and Carter (1973).

The objective of the analysis presented herein is to define and document the most cost-effective means of furnishing streamflow information in Nevada, as part of a nationwide assessment. To accomplish this objective, a three-step evaluation is made. During the first step, principal uses of data collected at each continuous-record gaging station are identified and these uses are related to funding sources; gaged sites for which data are inadequate or no longer needed are identified; and gaging stations are categorized as to whether the data are available to users in a real-time sense, on a provisional basis, or only after the end of the water year.

During the second step, less costly alternatives of furnishing the needed information, such as flow-routing models and statistical methods, are identified. Stream-gaging activity no longer is considered a network of observation points, but rather an integrated information system in which data are provided by both observation and synthesis.

The final step of the evaluation involves the use of Kalman-filtering and mathematical programming techniques to define strategies for operation of the necessary stations that minimize uncertainty in streamflow records for given operating budgets. Kalman-filtering techniques (Gelb, 1974) are used to compute uncertainty functions (which relate the standard error of computation or estimation for a streamflow record to the frequency of station visits) for all stations evaluated. A mathematical programming technique known as "steepest descent optimization" uses these uncertainty functions--along with information on practical stream-gaging routes, various costs associated with stream gaging, and total operating budget--to identify the visit frequency for each station that minimizes the overall uncertainty in the streamflow record. The standard errors of estimate given in this report are those that would apply if daily discharges were computed through the use of methods described in this study. No attempt is made to estimate standard errors for discharges that are computed by other means. Such errors could differ greatly from the errors computed herein. The magnitude and direction of the differences would be functions of the methods used to account for shifting controls and to estimate discharge during periods of missing record.

This report is organized into four sections. The first describes stream-gaging activities in Nevada--past and present--as well as the sources of funding and the uses and availability of the data. The second section describes and tests flow-routing and regression analyses as alternative methods of developing streamflow information. The third section describes and applies methods for optimizing the cost effectiveness of resource allocation in the collection of streamflow data, and the final section summarizes the study described herein.

The first report in the current nationwide evaluation was produced for the State of Maine (Fontaine and others, 1984). The Nevada report is based in large part on that document. In fact, many of the general discussions herein, including much of the preceding introductory material, are taken from the Maine report.

The author is grateful for the assistance of the following U.S. Geological Survey personnel: T.M. Salazar, A.K. Lehmann, and W.A. Harenberg, of Boise, Idaho; J.A. Smath, of Augusta, Maine; J.R. Swartwood and S.L. Bellinghausen, of Carson City, Nev.; and W.H. Doyle, Jr., of Memphis, Tenn.

STREAM-GAGING PROGRAM IN NEVADA

History

The program of surface-water investigations by the U.S. Geological Survey in Nevada and immediately adjacent parts of California and Arizona has grown steadily through the years as Federal and State interest in water resources has increased. The Geological Survey began collecting streamflow data in 1889 with the establishment of a gaging station on the Truckee River near the Nevada-California State line (U.S. Geological Survey, 1960, page 409). During the next 6 years, additional gaging stations were established, including two in the Humboldt River basin of Nevada, three on the Carson River, one on the Walker River, and four in the Truckee River basins of California and Nevada. These first stations were operated primarily to evaluate the power and storage potential of major rivers in the State. From that modest beginning, the program gradually expanded until, in 1980, the U.S. Geological Survey operated 155 gaging stations of all types (including those on lakes, reservoirs, canals, and drains) in and adjacent to the State. Since 1980, the number of gaging stations in operation has decreased.

An ongoing study of the characteristics of peak flows in Nevada streams having drainage areas of less than 15 mi^2 was started in 1962. A study by Moore (1970) described the development of the surface-water program in Nevada and proposed a program to meet the future needs of water-data users. At the time of that study, the Nevada program consisted of 88 continuous- and 98 partial-record stations.

The number of continuous-record streamflow gages operated, or for which records were processed, by Nevada personnel of the Water Resources Division is given in figure 1. The figure includes 30 stream gages serviced by adjacent states but for which the records were processed by personnel in Nevada. This study deals with the 81 gages that were under the direct operation of Nevada personnel as of 1983.[1]

Program as of 1983

Nevada includes parts of three major drainage basins: the Colorado River basin, the Great Basin, and the Snake River basin. The location of these basins and the distribution of the 81 streamflow gages operated by personnel in Nevada as of 1983 are shown in figure 2. Twelve of the gages are in the Colorado River basin, 66 are in the Great Basin, and 3 are in the Snake River basin. The cost of operating these 81 gages and gages on eight lakes and reservoirs in fiscal year 1983 was $465,500. Streamflow records for these gages are published in annual water-data reports (for example, see U.S. Geological Survey, 1984).

As shown in figure 2, about two-thirds of the gages are located in the west-central part of the State, where most of the principal streams exist. Large areas almost totally devoid of gaging stations are evident throughout the remaining parts of the State.

Selected hydrologic data for the 81 stations, including drainage area, period of record, and mean annual flow, are given in table 1. The table also provides the official name and formal eight-digit, downstream-order number for each station. Index numbers 1 through 81 (table 1) are used throughout this report in place of the downstream order numbers.

Data Use

The relevance of a stream gage is determined by the usefulness of the data therefrom. The data collected from each gage in the Nevada program are herein assigned to one or more of nine usage categories: regional hydrology, hydrologic systems, legal obligations, planning and design, project operation, hydrologic forecasts, water-quality monitoring, research, and other uses not specified above. Sources of funding and frequency at which data are provided also were compiled. This survey has been made to document the relevance of each gage and identify gaging stations that could be discontinued without a significant loss of hydrologic knowledge in the State. The following sections describe the nine categories, and tables 2 and 3 show data uses on a station-by-station basis. Some stations have more than one purpose, and therefore fall into more than one category in the tables.

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[1] The 81 sites included 79 on streams and 2 on the Truckee Canal, east of Reno, Nev. Six of the stream sites were in California and one was in Arizona, but these sites were serviced by Nevada personnel. In addition, eight lakes and reservoirs are included in the routine operation of the surface-water network.

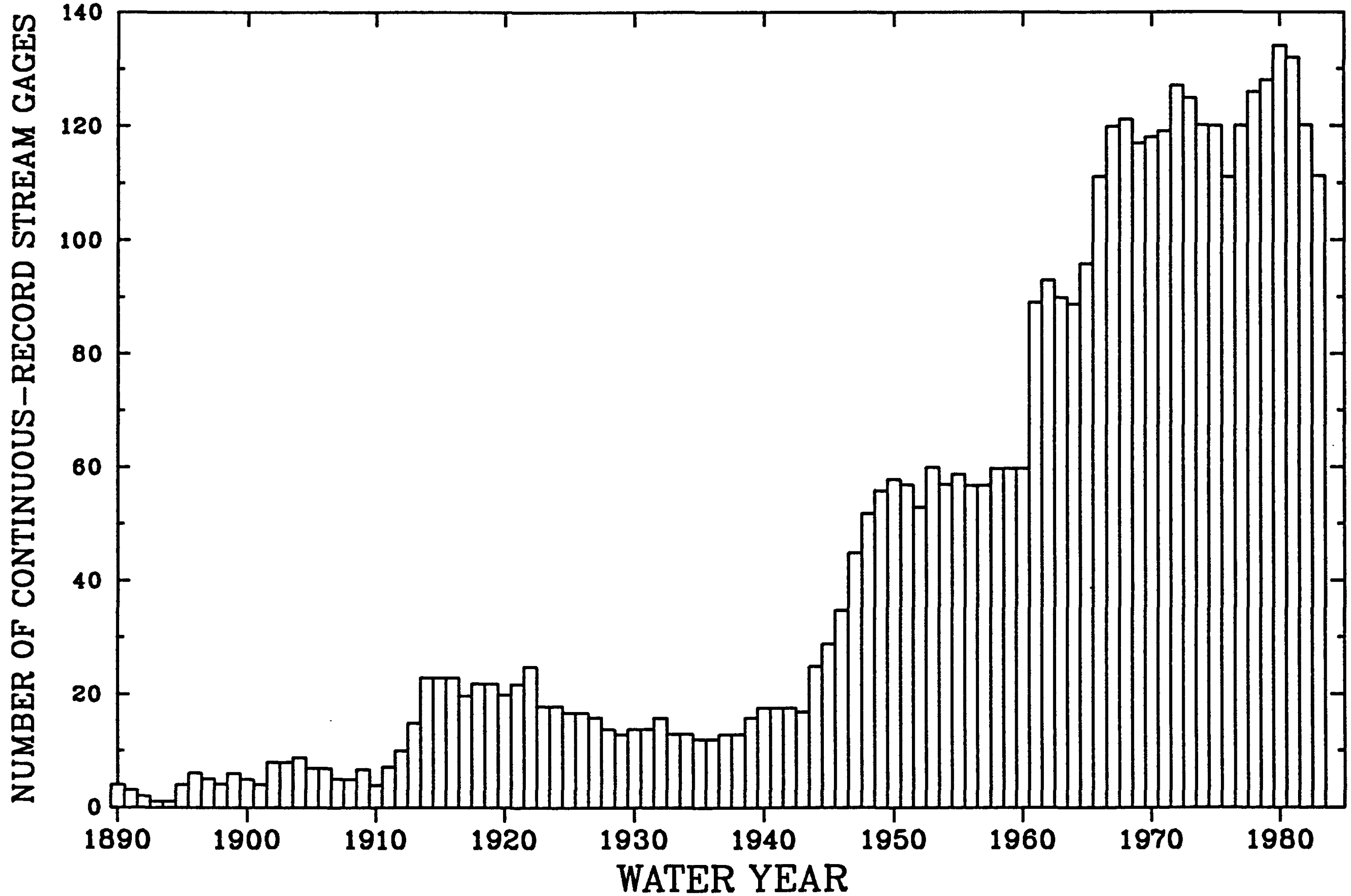


FIGURE 1.--Number of continuous-record gaging stations on streams, canals, and drains in and immediately adjacent to Nevada that have been operated by, or have had records processed by, U.S. Geological Survey personnel, water years 1890-1983.

A.

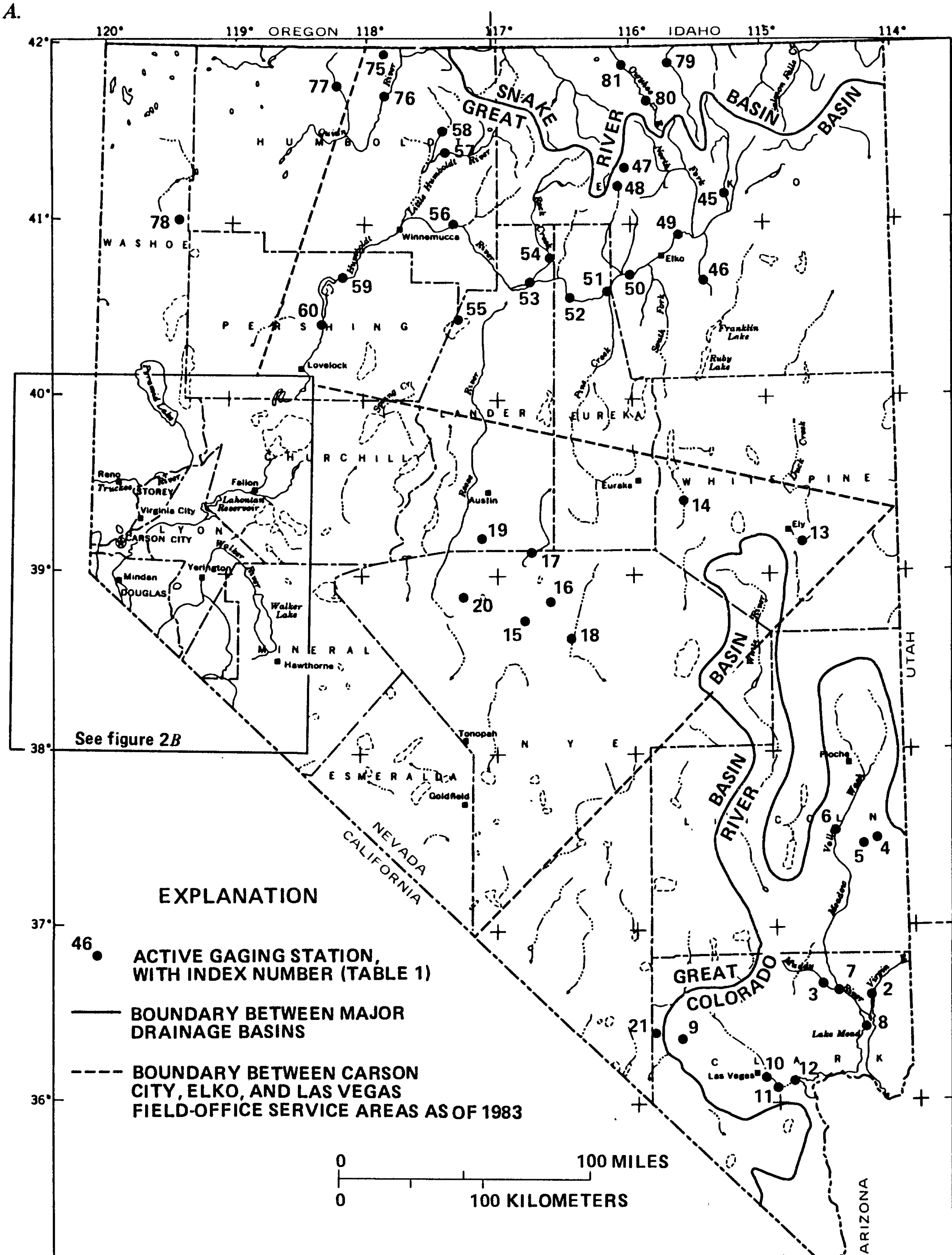


FIGURE 2.--Location of stream gages, water year 1983.

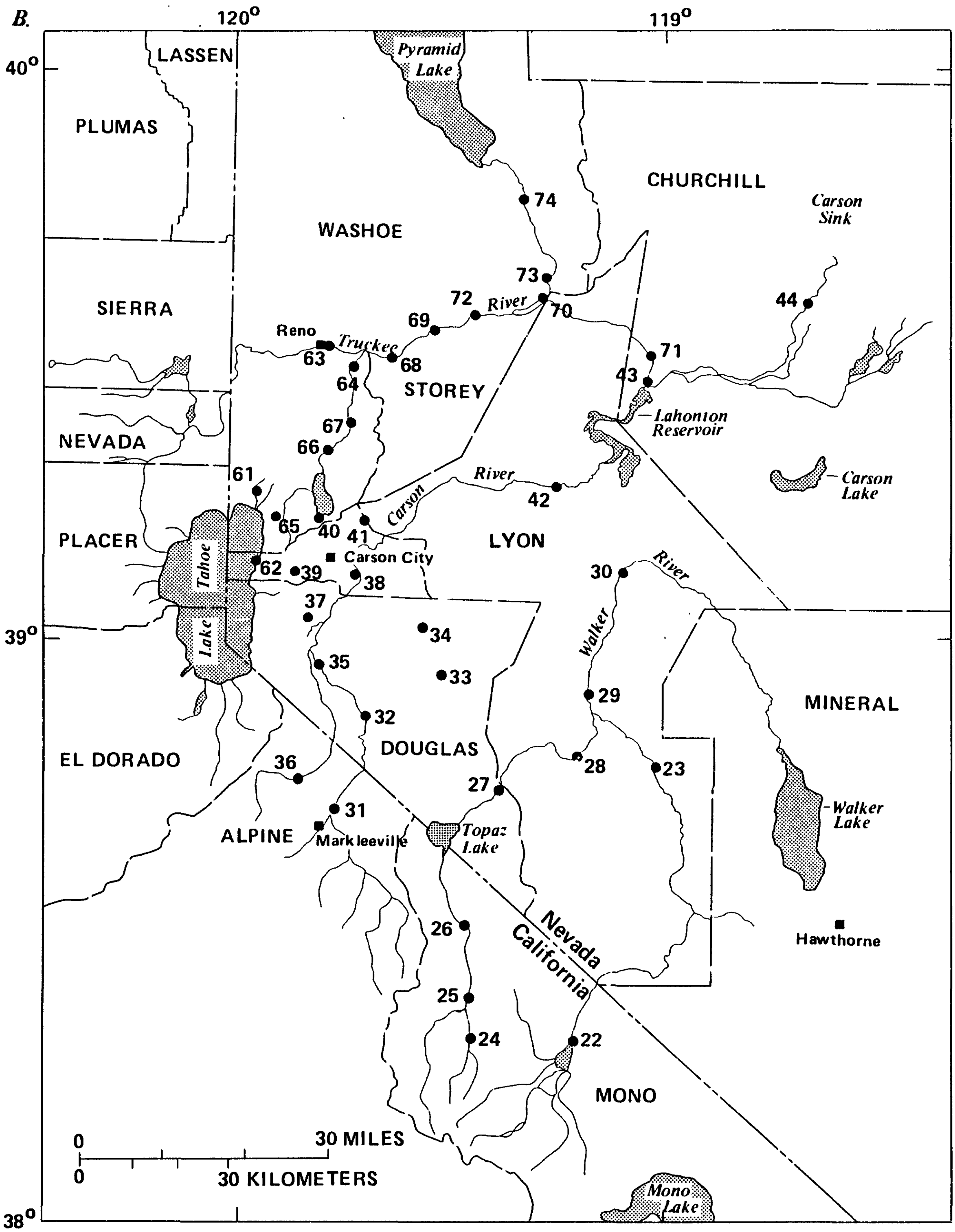


FIGURE 2.--Continued.

TABLE 1.--Selected information for stations in the Nevada stream-gaging program as of water year 1983

[All stations are in Nevada, except as noted]

Index number	Station number	Station name	Drainage area (square miles)	Period of record[1]	Mean annual flow[2] (ft^3/s)
1	09415000	Virgin River at Littlefield, Ariz.	5,090	Oct. 1929-	234
2	09415230	Virgin River above Halfway Wash	5,980	Oct. 1977-	317
3	09416000	Muddy River near Moapa	3,820	July 1913-Sept. 1915, Apr. 1916-Sept. 1918, June 1928-Oct. 1931, Apr.-July 1932, Oct. 1944-	41.5
4	09418200	Mathews Canyon Wash near Caliente	34	June 1958-	.72
5	09418300	Pine Canyon Wash near Caliente	45	June 1958-	1.79
6	09418500	Meadow Valley Wash near Caliente	1,670	Jan. 1951-Sept. 1960 Nov. 1964-	11.8
7	09419000	Muddy River near Glendale	6,780	Jan. 1904-Dec. 1906, Apr.-Oct. 1910, July 1913-Feb. 1914, Feb. 1950-	45.2
8	09419515	Muddy River above Lake Mead near Overton	8,310	Oct. 1978-	--
9	09419610	Lee Canyon near Charleston Park	9.2	Oct. 1963-	.026
10	09419679	Las Vegas Wasteway near East Las Vegas		May 1979-	--
11	09419700	Las Vegas Wash near Henderson	2,125	Feb. 1957-	44.4
12	09419800	Las Vegas Wash near Boulder City	2,193	Aug. 1969-	77.4
13	10244950	Steptoe Creek near Ely	11.1	June 1966-	7.03
14	10245800	Newark Valley tributary near Hamilton	157	Aug. 1962-	.184
15	10245900	Pine Creek near Belmont	12.2	Oct. 1977-	5.77
16	10245910	Mosquito Creek near Belmont	15.1	Oct. 1977-	3.09
17	10245925	Stoneberger Creek near Austin	35.6	Oct. 1977-	1.20
18	10249190	Willow Creek near Warm Springs	16.4	Oct. 1977	1.62
19	10249280	Kingston Creek below Cougar Canyon near Austin	23.4	Oct. 1966-	7.92
20	10249300	South Twin River near Round Mountain	20.0	Aug. 1965-	6.29
21	10251890	Peak Springs Canyon Creek near Charleston Peak	3.09	Nov. 1977-	--
22	10293000	East Walker River near Bridgeport, Calif.	359	July 1911-Sept. 1914, Oct. 1921-	140
23	10293500	East Walker River above Stronsider Ditch	1,100	Jan. 1947-	142
24	10295500	Little Walker River near Bridgeport, Calif.	63.1	Apr.-Aug. 1910, Oct. 1944-	51.3
25	10296000	West Walker River below Little Walker River near Coleville, Calif.	181	Apr. 1938-	259
26	10296500	West Walker River near Coleville, Calif.	250	Oct. 1902-July 1908, Mar. 1909-Sept. 1910, June 1915-Mar. 1938, May 1957-	274
27	10297500	West Walker River at Hoye Bridge near Wellington	497	May-Aug. 1910, July 1920-Sept. 1923, Mar. 1924-Aug. 1925, Oct. 1925-Sept. 1932, Oct. 1957-	238
28	10300000	West Walker River near Hudson	964	Aug. 1914-Mar. 1925, Jan. 1947-	187
29	10300600	Walker River near Mason	2,400	May 1974-	240

TABLE 1.--Selected information for stations in the Nevada stream-gaging program of water year 1983-Continued

Index number	Station number	Station name	Drainage area (square miles)	Period of record[1]	Mean annual flow[2] (ft^3/s)
30	10301500	Walker River near Wabuska	2,600	July 1902-Dec. 1904, Jan. 1905-July 1908, Jan. 1920-Sept. 1935, Jan. 1939-	158
31	10308200	East Fork Carson River below Markleeville, Calif.	276	Aug. 1960-	357
32	10309000	East Fork Carson River near Gardnerville	356	Jan. 1890-Dec. 1983, Oct. 1900-Dec. 1906, Jan. 1908-Dec. 1910, June-Oct. 1917, Dec. 1924-Sept. 1928, June-Sept. 1929, Oct. 1935-Dec. 1937, May 1939-	386
33	10309050	Pine Nut Creek near Gardnerville	10.14	Apr. 1980-	--
34	10309070	Buckeye Creek near Minden	46.3	Apr. 1980-	--
35	10309100	East Fork Carson River at Minden	392	Mar. 1974-	207
36	10310000	West Fork Carson River at Woodfords, Calif.	65.4	Oct. 1900-May 1907, Oct. 1938-	111
37	10310400	Daggett Creek near Genoa	3.82	Oct. 1965-Sept. 1983	1.93
38	10311000	Carson River near Carson City	886	May 1939-	401
39	10311100	Kings Canyon Creek near Carson City	4.06	June 1976-	1.38
40	10311200	Ash Canyon Creek near Carson City	5.20	July 1976-	2.84
41	10311400	Carson River at Deer Run Road near Carson City	958	Apr. 1979-	--
42	10312000	Carson River near Fort Churchill	1,302	Apr. 1911-	365
43	10312150	Carson River below Lahontan Reservoir near Fallon	1,801	Oct. 1966-	525
44	10312280	Carson River below Fallon		Oct. 1966-June 1967, July 1967-	46.9
45	10315500	Marys River above Hot Springs Creek near Deeth	415	Oct. 1943-Sept. 1980, Oct. 1981-	64.4
46	10316500	Lamoille Creek near Lamoille	25.0	May 1915-June 1923, Oct. 1943-	44.0
47	10317420	Mahala Creek near Tuscarora	4.48	Oct. 1979-	--
48	10317450	Gance Creek near Tuscarora	6.45	Oct. 1979-	--
49	10318500	Humboldt River near Elko	2,800	June 1895-Oct. 1902, Oct. 1944-	239
50	10321000	Humboldt River near Carlin	4,310	Oct. 1943-	347
51	10322500	Humboldt River at Palisade	5,010	Oct. 1902-Oct. 1906, July 1911-	373
52	10323400	Humboldt River near Dunphy	--	Oct. 1980-Sept. 1983	--
53	10323600	Humboldt River below Slaven Ditch near Argenta	--	Oct. 1980-Sept. 1983	--
54	10324500	Rock Creek near Battle Mountain	875	Mar.-July 1896, Mar. 1918-Sept. 1925, Mar. 1927-May 1929, Oct. 1945-	35.0
55	10326800	Fish Creek near Battle Mountain	64.7	Oct. 1977-Sept. 1979, Oct. 1980-	--
56	10327500	Humboldt River at Comus	12,100	Oct. 1894-Dec. 1909, Sept. 1910-Sept. 1926, Oct. 1945-	295
57	10329000	Little Humboldt River near Paradise Valley	1,030	Oct. 1921-June 1928, Oct. 1943-	24.3

TABLE 1.--Selected information for stations in the Nevada stream-gaging program of water year 1983--Continued

Index number	Station number	Station name	Drainage area (square miles)	Period of record[1]	Mean annual flow[2] (ft^3/s)
58	10329500	Martin Creek near Paradise Valley	172	Oct. 1921-	32.0
59	10333000	Humboldt River near Imlay	15,700	June 1935-Dec. 1941, Apr. 1945-	212
60	10335000	Humboldt River near Rye Patch	16,100	Jan. 1896-June 1898, June 1899-Dec. 1909, Sept. 1910-June 1917, Sept. 1917-Sept. 1922, Sept. 1924-Sept. 1930, Oct. 1930-Sept. 1932, Oct. 1935-Sept. 1941, Oct. 1943-	205
61	10336698	Third Creek near Crystal Bay	6.05	Oct. 1969-Sept. 1973, Feb.-Sept. 1975, Oct. 1977-	8.12
62	10336715	Marlette Creek near Carson City	2.86	Oct. 1973-	2.25
63	10348000	Truckee River at Reno	1,067	July 1906-Sept. 1921, June 1925-Sept. 1926, Jan. 1930-Dec. 1935, Jan.-Dec. 1943, Jan. 1946-	669.0
64	10348200	Truckee River near Sparks	1,070	April 1977-	604
65	10348460	Franktown Creek near Carson City	3.24	June 1974-	3.05
66	10348900	Galena Creek near Steamboat	8.5	Oct. 1961-	8.81
67	10349300	Steamboat Creek at Steamboat	123	Oct. 1961-	13.6
68	10350000	Truckee River at Vista	1,431	Aug. 1899-Dec. 1907, Jan. 1932-Dec. 1954, Oct. 1958-	794
69	10350400	Truckee River below Tracy	1,590	May 1972-	736
70	10351300	Truckee Canal near Wadsworth		Oct. 1966-	278
71	10351400	Truckee Canal near Hazen		Oct. 1966-	208
72	10351600	Truckee River below Derby Dam near Wadsworth	1,676	Jan. 1909-Dec. 1910, Jan.-Dec. 1916, Jan. 1918-July 1958, Oct. 1958-	339
73	10351650	Truckee River at Wadsworth	1,728	May 1965-	551
74	10351700	Truckee River near Nixon	1,827	Oct. 1957-	456
75	10352500	McDermitt Creek near McDermitt	225	Oct. 1948-	30.2
76	10353500	Quinn River near McDermitt	1,100	Oct. 1948-	35.2
77	10353600	Kings River near Orovada	20.5	Oct. 1962-Sept. 1968, Oct. 1976-	4.96
78	10353770	South Willow Creek near Gerlach	31.0	Aug. 1973-	.52
79	13161500	Bruneau River at Rowland	382	June 1913-Sept. 1918, Oct. 1966-	117
80	13174500	Owyhee River near Gold Creek	209	Mar.-Nov. 1916, Apr. 1917-Sept. 1925, Oct. 1936-	42.3
81	13176000	Owyhee River above China Diversion Dam near Owyhee	458	Mar. 1939-	145

[1] Dash following the most recent starting date indicates that the period of record continued beyond water year 1983.

[2] For period of record through water year 1982. Mean value not listed for stations having less than 5 years of record through September 1982.

TABLE 2.--Data uses, funding, and availability, water year 1983

[Data uses, funding sources, and data availability are indicated by the numbered items that follow the tabulation. Symbols: *, no explanatory item necessary; --, no use or funding source]

		Use							Funding source			
Index number	Station number	Regional hydrology	Hydrologic systems	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal	Other Federal agency	Cooperative	Data availability
1	09415000	*	--	--	36	5	--	--	*	--	--	37,39
2	09415230	--	--	--	--	9	--	--	*	--	--	37
3	09416000	--	--	31	--	--	--	--	--	--	19	37
4	09418200	--	--	32	--	--	--	--	--	1	--	37
5	09418300	--	--	32	--	--	--	--	--	1	--	37
6	09418500	*	--	--	--	--	--	--	*	--	--	37
7	09419000	*	--	31	--	--	--	--	--	--	19	37
8	09419515	--	--	5	--	9	--	--	--	34	--	37
9	09419610	*	--	--	--	--	--	--	--	--	35	37
10	09419679	--	--	5	--	5	--	--	--	34	--	37
11	09419700	--	--	5	--	5	--	--	--	34	--	37
12	09419800	*	--	5	--	5	--	--	*	--	--	37
13	10244950	8	--	--	--	8	--	--	*	--	--	37
14	10245800	*	--	--	--	--	--	--	--	--	18	37
15	10245900	*	--	--	--	--	--	--	*	--	--	37
16	10245910	*	--	--	--	--	--	--	*	--	--	37
17	10245925	*	--	--	--	--	--	--	*	--	--	37
18	10249190	*	--	--	--	--	--	--	*	--	--	37
19	10249280	--	--	31	--	--	--	--	--	--	19	37,39
20	10249300	8	--	--	--	8	--	--	*	--	--	37
21	10251890	*	--	--	--	--	--	--	*	--	--	37
22	10293000	--	--	12,13	11	--	--	--	--	--	14	37,39
23	10293500	--	--	40	--	--	--	--	--	--	2	37
24	10295500	*	--	41	--	--	--	--	--	--	14	37
25	10296000	*	--	12,13,41	11	--	--	--	--	--	14	37,39
26	10296500	*	--	40	10	--	--	--	--	--	2	37,38,39
27	10297500	--	--	17,40	--	--	--	--	--	--	2	37,39
28	10300000	--	--	40	--	--	--	--	--	--	2	37,39
29	10300600	--	--	42	--	--	--	--	--	--	16	37,39
30	10301500	--	43	40	--	9	--	--	--	--	19	37,39
31	10308200	*	--	41	--	--	--	--	--	--	14	37
32	10309000	*	--	41,42,44,17	10,11	--	29	--	--	--	27,28	37,38,39
33	10309050	*	--	--	--	--	45	--	*	--	--	37
34	10309070	*	--	--	--	--	45	--	*	--	--	37
35	10309100	--	--	42	--	--	--	--	--	--	16	37
36	10310000	*	--	41,42,44	10,11	--	29	--	--	--	14	37,38,39
37	10310400	*	--	--	--	--	45	--	--	--	20	37
38	10311000	*	--	41,42,48	10,11	--	29	--	*	--	--	37,38,39
39	10311100	*	--	17,44,46	--	--	--	--	--	--	24	37,39
40	10311200	*	--	17,44,46	--	--	--	--	--	--	24	37
41	10311400	--	--	42	--	--	--	--	--	--	16	37
42	10312000	--	--	41,44,47,48	11	9	9	29	--	--	19,33	37,39
43	10312150	--	--	7,41,47, 43,44,48	--	--	--	29	--	34	--	37,39
44	10312280	--	7	5,6,33 44,47,48	--	--	--	--	--	34	--	37,39
45	10315500	*	--	31	--	--	--	--	--	--	19	37,39
46	10316500	*	--	31	--	--	--	--	--	--	19	37
47	10317420	*	--	--	--	--	49	--	--	4	--	37
48	10317450	*	--	--	--	--	49	--	--	4	--	37
49	10318500	*	--	31	--	--	--	--	--	--	19	37
50	10321000	*	--	31	--	9	--	--	--	--	19	37
51	10322500	*	--	22,31	10,11	--	--	--	*	--	--	37,38,39
52	10323400	*	--	--	--	--	--	--	--	--	21	37
53	10323600	*	--	--	--	--	--	--	--	--	21	37
54	10324500	*	--	31	--	--	--	--	--	--	19	37
55	10326800	*	--	--	--	--	--	--	*	--	--	37

TABLE 2.--Data uses, funding, and availability, water year 1983--Continued

Index number	Station number	Use							Funding source			Data availability
		Regional hydrology	Hydrologic systems	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal	Other Federal agency	Cooperative	
56	10327500	*	--	31	--	--	--	--	--	--	19	37
57	10329000	*	--	31	--	--	--	--	--	--	19	37
58	10329500	*	--	31	--	--	--	--	--	--	19	37
59	10333000	*	--	31	--	--	--	--	--	--	19	37
60	10335000	--	--	31	--	9	--	--	--	--	19	37
61	10336698	*	--	--	--	--	--	--	*	--	--	37
62	10336715	--	--	46	--	--	--	--	--	--	24	37
63	10348000	--	--	41,44,48	42	--	29	--	--	--	23,25, 26	37,38,39
64	10348200	--	--	44	--	--	--	--	--	--	27	37,38,39
65	10348460	*	--	46	--	--	--	--	--	--	24	37
66	10348900	*	23	44	--	--	--	--	--	--	23	37,38,39
67	10349300	--	23	44	--	--	--	--	--	--	23	37,39
68	10350000	--	43	41,44,47	10	--	29	--	--	--	6	37,38,39
69	10350400	--	--	44,47,50	--	--	--	--	--	--	30	37,38,39
70	10351300	--	--	43,44,47,48	--	--	29	--	--	34	--	37,39
71	10351400	--	--	43,44,47,48	--	--	29	--	--	34	--	37,39
72	10351600	--	--	41,44,47,48	--	--	29	--	--	--	19,33	37,38,39
73	10351650	--	43	41,44,47,48	--	--	29	--	--	34	--	37,38,39
74	10351700	--	--	41,44,47,48	--	9	15	--	--	--	19,33	37,38,39
75	10352500	*	--	31	--	--	--	--	--	--	19	37
76	10353500	*	--	--	--	9	--	--	*	--	--	37
77	10353600	*	--	--	--	--	--	--	*	--	--	37
78	10353770	*	--	--	--	--	--	--	--	--	18	37
79	13161500	*	--	31	--	--	--	--	--	--	19	37
80	13174500	--	--	31	--	--	--	--	--	--	19	37
81	13176000	--	--	43	--	--	--	--	--	3	--	37

1. U.S. Army Corps of Engineers
2. U.S. Board of Water Commissioners
3. U.S. Bureau of Indian Affairs
4. U.S. Bureau of Land Management
5. Lower Colorado Salinity Project--U.S. Bureau of Reclamation
6. U.S. Courts, Federal Water Master
7. Recreational planning--U.S. Fish and Wildlife Service
8. U.S. Geological Survey Hydrologic Bench-Mark Network station
9. U.S. Geological Survey National Stream-Quality Accounting Network station
10. Flood forecasting--U.S. National Weather Service
11. Streamflow forecasts--U.S. Soil Conservation Service
12. Recreational planning--California Department of Fish and Wildlife
13. Transportation planning--California Department of Transportation
14. California Department of Water Resources
15. Biological studies--Colorado State University
16. Nevada Division of Environmental Protection
17. Recreational planning--Nevada Department of Wildlife
18. Nevada State Department of Transportation
19. Nevada State Engineer
20. Douglas County
21. Lander County Fair and Recreation Board
22. Irrigation-project management--Pershing County Water Conservation District
23. Water management--Washoe County
24. Carson City Public Works Department
25. City of Reno
26. City of Sparks
27. Carson-Truckee Water Conservancy District
28. Carson Water Subconservancy District
29. Water research activities--Desert Research Institute
30. Sierra Pacific Power Company
31. Water management--State of Nevada
32. Operation of flood-control project--U.S. Army Corps of Engineers
33. Truckee-Carson Irrigation District
34. U.S. Bureau of Reclamation
35. Clark County Public Works Department
36. Long-term index gaging station
37. Annual release in U.S. Geological Survey data report
38. Direct-access telemetry equipment for immediate use
39. Periodic release of provisional data
40. Interstate streamflow monitoring--U.S. Board of Wate Commissioners
41. Statewide water assessment--California Department of Water Resources
42. Environmental streamflow assessment--Nevada Division of Environmental Protection
43. Indian water-rights assessment--U.S. Bureau of Indian Affairs
44. Water management--U.S. Courts, Federal Water Master
45. Water-budget assessment--Douglas County
46. Water-budget assessment--Carson City
47. Irrigation project management--U.S. Bureau of Reclamation
48. Irrigation project management--Truckee-Carson Irrigation District
49. Water-use and range management--U.S. Bureau of Land Management
50. Hydropower-system operation--Sierra Pacific Power Company

TABLE 3.--Summary of data uses, funding, and availability, water year 1983

	Number of stations
DATA USE	
Regional hydrology	48
Hydrologic systems	6
Legal obligations	0
Planning and design	0
Project operation	59
Hydrologic forecasts	11
Water-quality monitoring	14
Research	16
Other uses	2
FUNDING SOURCE	
Federal (USGS)	19
Other Federal agencies	13
Cooperative program	50
Other non-Federal sources	0
DATA AVAILABILITY	
Annual publication	81
Direct-access telemetry	13
Periodic release	29

Regional Hydrology

Forty-eight stations in the Nevada network belong in the regional-hydrology category as of 1983 (figure 3). Two are "hydrologic bench-mark" stations, which indicate conditions in watersheds relatively free of man-made alteration and are used to define long-term trends. The remaining stations are used to define streamflow characteristics unique to each region.

Hydrologic Systems

Stations that can be used for accounting--that is, for defining current hydrologic conditions and the sources, sinks, and fluxes of water through hydrologic systems, including regulated systems--are designated as hydrologic-systems stations. They include gages that measure diversions and return flows and are useful for defining the consumptive use within a basin. Six Nevada stations were included in this category as of 1983.

Legal Obligations

Some stations provide records of streamflow for verification or enforcement of existing treaties, compacts, and decrees. The category includes only those stations that the U.S. Geological Survey is required to operate to satisfy a legal responsibility. No stations in Nevada were operated for this purpose as of 1983.

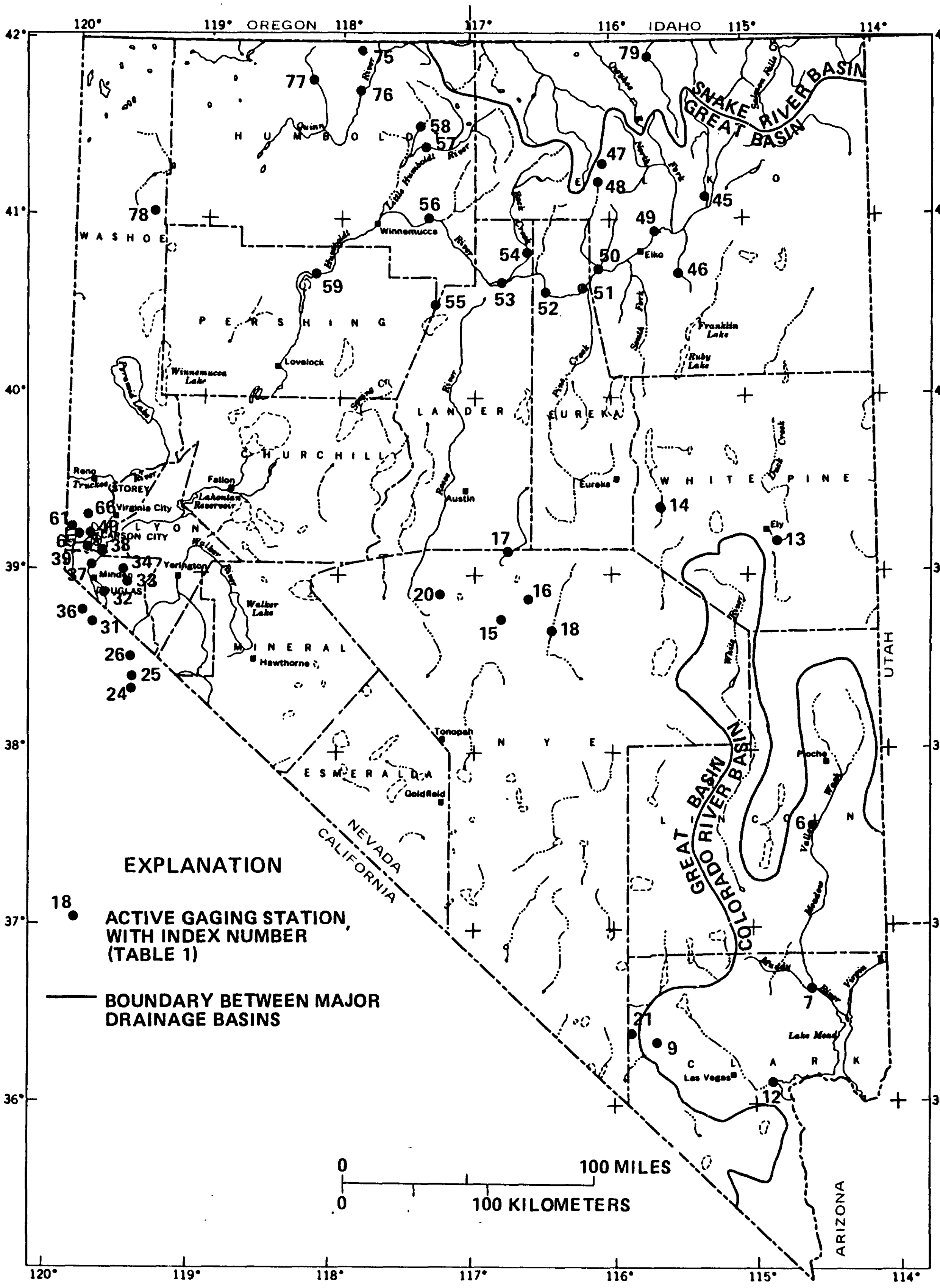


FIGURE 3.--Location of stream gages used to develop regional hydrologic information, water year 1983.

Planning and Design

Gaging stations in the planning-and-design category are installed specifically to provide information for construction of dams, levees, floodwalls, navigation systems, water-supply diversions, hydropower plants, and waste-treatment facilities, and are discontinued when the project is completed. None of the stations in the Nevada program as of 1983 were used for any of these purposes.

Project Operation

Gaging stations in the project-operation category provide data to assist water managers in making decisions concerning reservoir releases and diversions. This category of data is routinely available to water managers on a rapid-reporting basis. Data may be needed every few days, or even more frequently.

Fifty-seven stations in the Nevada program were in this category as of 1983, and most provided data to aid operators in managing control structures that are part of irrigation and flood-control systems. One station provided data for projects related to fish habitat.

Hydrologic Forecasts

Gaging stations in the hydrologic-forecasts category provide information for forecasting floods, determining inflow to reservoirs, or determining basin yield. These data are routinely available to forecasters in a rapid-reporting basis. In Nevada, these data are used by the U.S. National Weather Service, the U.S. Army Corps of Engineers, and the U.S. Soil Conservation Service. Additionally, the National Weather Service uses data from some stations to predict the probability of snow-melt floods. Eleven Nevada stations were in this category as of 1983.

Water-Quality Monitoring

Gaging stations where water quality is being monitored on a regular basis and where the availability of streamflow data contributes to the utility of the water-quality data or is essential to its interpretation are designated as water-quality-monitoring sites.

As of 1983, two such stations in the Nevada program were designated as hydrologic bench-mark stations and eight were part of the National Stream-Quality Accounting Network (NASQAN). Water-quality samples from bench-mark stations are used to indicate characteristics of streams that have been and probably will continue to be relatively free of man-made influence. NASQAN stations are part of a network designed to assess water-quality trends in the Nation's principal streams. An additional four Nevada stations were being operated as part of the Lower Colorado River Salinity Project.

Research

Gaging stations in the research category are operated for specific water-investigation studies. Typically, these stations are in existence for only a few years. Data from 16 stations in the Nevada program supported research activities in 1983.

Other Uses

In addition to the eight categories described above, two stations (Nos. 42 and 43 in table 1) provided information for other uses during 1983.

Funding Sources

The four sources of funding for the Nevada streamflow-data program are:

1. Federal.--Funds directly allocated to the U.S. Geological Survey from other Federal agencies.

2. Other Federal agencies.--Funds transferred to the U.S. Geological Survey by other Federal agencies. Funds in this category are not matched by Geological Survey cooperative funds.

3. Cooperative.--Funds contributed jointly by the U.S. Geological Survey and a non-Federal agency. Cooperating-agency funds may be in the form of direct services or cash.

4. Other non-Federal sources.--Funds provided entirely by a non-Federal agency or a private concern under the auspices of a Federal or non-Federal agency.

Tables 2 and 3 list and summarize funding sources for the 81-station Nevada program as of 1983.

Data Availability

Streamflow data may be furnished to users by direct-access telemetry equipment for immediate use, by periodic release of provisional data, or in data reports published annually by the U.S. Geological Survey. Data for all stations in the 1983 program were published in the annual report (Frisbie and others, 1984), data from 13 stations were made available within days after collecting it and data from 29 stations were released periodically on a provisional basis. Table 2 lists data availability on a station-by-station basis.

Evaluation of the Existing Program

In a pilot study by Robert R. Squires (U.S. Geological Survey, written communication, 1984), the procedure known as "Network Analysis for Regional Information" (NARI) was used in 1980 to evaluate the stream-gaging network in Nevada. The NARI procedure identifies contributions to error reduction for a regional regression analysis of statistical streamflow characteristics that would be expected from future stream-gaging activities. These activities mainly include the extension of data collection at existing gages and the establishment of new gages (Moss and others, 1982). Stream-discharge characteristics analyzed in the study were mean annual discharge, standard deviation of mean annual discharge, and flood-frequency exceedence probability (for a 2-percent chance of occurrence). Preliminary results of the NARI analysis in Nevada indicated that the accuracy of transferring streamflow data to ungaged sites could not be significantly increased by collecting more data at the gaged sites.

A review of the data-use and funding information presented in table 2 indicates that few stations are operated for a single purpose and that many stations are funded on a cost-sharing basis by more than one cooperator. Although table 2 illustrates the broad spectrum of data use, it does not document the relative importance of the various uses. Most stations have one primary use and more than one secondary use. Yet, even a single category of data use may be adequate justification to retain the station. The two most common primary uses of data in Nevada are in the project-operation and regional-hydrology categories. Most of the stations gage relatively large, regulated streams in areas of high economic interest. For these reasons, none of the 81 gaging stations that were in operation during 1983 are likely candidates for termination, unless alternative methods of data generation prove successful.

Figure 2 shows that few of the small streams in the uninhabited desert and mountain areas of central and southern Nevada were gaged as of 1983 (over the past 60 years, however, some sites there were gaged for 1-5 years in support of short-term studies). Thus, a major weakness in the current Nevada stream-gaging network is a lack of data on such streams; this makes an evaluation of regional streamflow characteristics difficult. Nearly 60 percent of the gaging stations operated to collect data for hydrologic-systems or project-operation uses are not well suited for assessment of regional hydrology. Therefore, additional stream gages would be useful on small, unregulated streams throughout Nevada, especially in the central and southern parts of the State where information is sparse. A minimum data base is necessary for evaluation of regional streamflow characteristics.

One way to develop a minimum data base for small-stream hydrology would be a revolving 10-year plan. Initially, five sites would be selected from the large number of small, ungaged basins in the mountain and desert parts of central and southern Nevada. Gaging stations would be operated for 10 years at these five sites. At the end of that time, the stations would be moved to another group of sites, and data collection would begin in the new basins. This process could be continued until an adequate data base is available.

ALTERNATIVE METHODS OF DEVELOPING STREAMFLOW DATA

The second step in the analysis of the stream-gaging program in Nevada is to investigate methods of providing daily streamflow information without operating continuous-record gaging stations. The objective of the analysis is to identify gaging stations where alternative technology, such as flow-routing or statistical methods, will provide information about daily mean streamflow in a more cost-effective manner than operating a continuous stream gage. No guidelines exist concerning suitable accuracies for particular uses of the data; therefore, judgment is required in deciding whether the estimated daily flows are of suitable accuracy for the intended purpose. The data uses at a station will influence whether a site has potential for alternate methods. For example, stations for which flood hydrographs are required in a real-time sense, for purposes such as hydrologic forecasts and project operation, are not candidates for the alternate methods. The primary candidates for alternate methods are stations upstream or downstream from other stations on the same stream. The accuracy of the estimated streamflow at these sites may be suitable because of the high redundancy of flow information between sites. Similar watersheds in the same physiographic and climatic area also may have potential for alternate methods of developing streamflow information.

All 81 stations in the Nevada stream-gaging program were categorized as to their potential for utilization of alternate methods, and selected methods were applied at 22 of the stations. The categorization of gaging stations and the application of the specific methods are described in subsequent sections of this report. This section briefly describes the two alternative methods that were used in the Nevada analysis and documents why these specific methods were chosen.

To be suitable for use, a proposed alternate method should: (1) be computer oriented and easy to apply; (2) have an available interface with the Daily Values File (Hutchinson, 1975) of the USGS National Water Data Storage and Retrieval System (WATSTORE), to permit easy calibration of the method; (3) be technically sound and generally acceptable to the hydrologic community; and (4) permit easy evaluation of the accuracy of the simulated streamflow records. These criteria were used to select flow routing and regression analysis as the two alternate methods of developing streamflow information in Nevada.

Flow Routing

Hydrologic flow-routing methods use the law of conservation of mass and the relation between the storage of water in a stream reach and the outflow from that reach. The hydraulics of the system are not considered. The method characteristically requires only a few input parameters and treats the reach in a uniform sense without accounting for variations in channel characteristics within the reach. Commonly, the input is a discharge hydrograph at the upstream end of the reach and the output is a similar hydrograph at the downstream end. Several different types of hydrologic routing are available, such as the Muskingum, modified Puls, kinematic-wave, and unit-response methods. The latter method was selected for the Nevada analysis. It uses two techniques, storage continuity (Sauer, 1973) and diffusion analogy (Keefer, 1974; Keefer and McQuivey, 1974). The computer program CONROUT that utilizes these two techniques of flow routing is described by Doyle and others (1983).

The unit-response method was selected because it fulfilled the four criteria noted above. Computer programs for the unit-response method can be used to route streamflow from one or more upstream locations to a downstream location. Downstream hydrographs are produced by the convolution of upstream hydrographs with their appropriate unit-response function. To apply this method at a downstream site however, an upstream gaging station must exist on the same stream. An advantage of this model is that it can be used for regulated stream systems; that is, flows can be routed through reservoirs if the operating rules of the reservoir are known. Calibration and verification of the flow-routing model are achieved using measured upstream and downstream hydrographs and measurements or estimates of intervening tributary inflows. The convolution model treats a stream reach as a linear, one-dimensional system in which the system output (downstream hydrograph) is computed by multiplying (convoluting) the ordinates of the upstream hydrograph by the unit-response function and accumulating them appropriately. The model has the capability of combining hydrographs, multiplying a hydrograph by a ratio, and changing the timing of a hydrograph. In the Nevada analysis, however, the model is used only to route an upstream hydrograph to a downstream point. Although the routing can be accomplished using hourly data, only daily data are used herein.

Three options are available for determining the unit-response function. Selection of the appropriate option depends primarily upon the variability of wave celerity (traveltime) and dispersion (channel storage) throughout the range of discharges to be routed. Adequate routing of daily flows can generally be accomplished using a single unit-response function (linearization about a single discharge) to represent the system response. However, if the routing coefficients vary drastically with discharge, linearization about a low-range discharge results in overestimated high flows that arrive late at the downstream site, whereas linearization about a high-range discharge results in low-range flows that are underestimated and arrive too soon. Where a single unit-response function does not provide acceptable results, multiple linearization (Keefer and McQuivey, 1974), which uses a family of unit-response functions to represent the system response, can be used.

Determining the response of the system to streamflow input at the upstream end of the reach is not a complete description of flow within the reach for most flow-routing problems. The convolution process does not account for contributions from the intervening area between the upstream and downstream sites. Where such contributions are largely or totally unknown, an estimating technique that can prove satisfactory in many instances is the multiplication of known flows at an index gaging station by a factor (for example, a drainage-area ratio).

The objective in either the storage-continuity or the diffusion-analogy technique of flow routing is to calibrate two parameters that describe (1) the relation between storage and discharge in a given reach and (2) the traveltime of flow passing through the reach. In the storage-continuity method, a response function is derived by modifying a translation hydrograph technique developed by Mitchell (1962, page C-9) to apply to open channels. A triangular pulse (Keefer and McQuivey, 1974) is routed through reservoir-type storage and then transformed to a unit response of desired duration using a summation-curve technique. The two parameters that describe the routing reach are K_s, a storage coefficient that is the slope of the storage-discharge relation, and W_s, the translation-hydrograph time base. These two parameters determine the shape of the resulting unit-response function.

In the diffusion-analogy theory, the two parameters requiring calibration are K, a wave-dispersion or damping coefficient, and C, the floodwave celerity. K controls the spreading of the wave (analogous to K_s in the storage-continuity method) and C controls the traveltime (analogous to W_s). In the single-linearization method, only one K value and C value is used. In the multiple-linearization method, C and K are varied with discharge, using a table of wave celerity (C) versus discharge (Q) and a table of dispersion coefficient (K) versus discharge.

In both the storage-continuity and diffusion-analogy methods, the two parameters are calibrated by trial and error. The analyst must decide if suitable parameters have been derived by comparing the simulated and measured discharges. The application of the CONROUT model was based on the following criteria:

1. Little or no regulation;
2. No diversions or, at most, only a few small ones;
3. No backwater effects;
4. Intervening ungaged areas are less than 20 percent of the total drainage area; and
5. Index stations are available for estimating flow response from the intervening areas.

These criteria are desirable because they best meet the conditions for application of CONROUT model. Criteria for satisfactory simulation of flow data were pre-established as simulated flows being within 5 percent of observed flows 95 percent of the time.

Regression Analysis

Simple- and multiple-regression analyses can also be used to estimate daily flow. Regression equations can be computed that relate daily flows (or their logarithms) at a single station to daily flows at upstream, downstream, or tributary stations, or a combination thereof. Thus, unlike the flow-routing method, this statistical procedure is not limited to sites where an upstream station exists on the same stream. The regression method has many of the same attributes as the flow-routing method in that it is easy to apply, provides indices of accuracy, and is generally accepted as a good tool for estimation. The theory and assumptions of regression analysis are described in several textbooks, such as Draper and Smith (1966) and Kleinbaum and Kupper (1978). The application of regression analysis to hydrologic problems is described by Riggs (1973) and by Thomas and Benson (1970). As a result, only a brief description is given here.

A linear-regression model of the following form was developed for estimating daily mean discharges in Nevada:

$$y_i = B_o + \sum_{j=1}^{p} B_j x_j + e_i \ , \qquad (1)$$

where y_i = daily mean discharge at site i (the dependent variable),
x_j = daily mean discharges at nearby sites j (explanatory variables),
B_o, B_j = regression constant and coefficient,
e_i = the random-error term, and
p = the number of explanatory variables.

The above equation is calibrated (that is, B_o and B_j are estimated) using measured values of y_i and x_j. These measured discharges can be retrieved from the WATSTORE Daily Values File. The values of x_j may be discharges observed on the same day as discharges at site i, or they may be for previous or subsequent days, depending on whether station j is upstream or downstream from site i. Once the equation is calibrated and verified, additional values of y_i are estimated using measured values of x_j. The regression constant and coefficient (B_o and B_j) are tested to determine if they are significantly different from zero. A given station j should be retained in the regression equation only if its regression coefficient (B_j) is significantly different from zero. The regression equation should be calibrated using one period of time and then verified or tested using a different period of time to ascertain the true predictive accuracy. Both the calibration and verification periods should be representative of the range of flows that could occur at site i. The equation should be verified by plotting the residual e_i (difference between simulated and measured discharges) against the dependent variable and all explanatory variables in the equation, and by plotting the simulated and measured discharges versus time. These tests are intended to identify (1) whether the linear model is appropriate or whether some transformation of the variable is needed, and (2) whether the equation shows any bias, such as overestimated low flows. These tests might indicate, for example, that a logarithmic transformation is desirable, that a nonlinear regression equation is appropriate, or that the regression equation is biased in some way. In this report, these tests indicate that a linear model, with y_i and x_j in cubic feet per second, is appropriate.

The use of a regression relation to synthesize data at a discontinued gaging station entails a reduction in the variance of the streamflow record relative to that which would be computed from an actual record of streamflow at the site. The reduction in variance, expressed as a fraction, is approximately equal to one minus the square of the correlation coefficient that results from the regression analysis.

Gaging Stations Chosen for Application of Alternative Methods

An analysis of the data uses presented in table 2 has identified several gaging stations for which alternative methods of providing the needed streamflow information would be useful. Four reaches in the Truckee River basin downstream from Reno showed potential for flow-routing applications and 18 stations in the four principal drainages of western Nevada (the Walker, Carson, Humboldt, and Truckee River basins) were chosen for regression analysis.

Application of Flow-Routing Analysis to the Lower Truckee River Basin

A map of the lower Truckee River basin is shown in figure 4. All reaches selected within the basin are influenced by diversions of varying magnitude. Intervening flows are minor in comparison to flows in the river, except within the Wadsworth-to-Nixon reach (from station 73 to station 74, figure 4 and table 1). In this reach, ground-water accretion has been reported by previous investigators (Van Denburgh and others, 1973, pages 42-43; Van Denburgh and Arteaga, 1985, page 11).

To route flow in the lower Truckee River, it was necessary to determine the model parameters C (floodwave celerity) and K (wave-dispersion coefficient). C and K are evaluated using the following equations representative of the reach in question, as follows:

$$C = (1/W)(dQ/dy), \text{ and} \tag{2}$$

$$K = Q/2SW, \tag{3}$$

where W = functions of channel width, in feet,
dQ/dy = the slope of the stage-discharge relation, in square feet per second,
Q = the discharge, in cubic feet per second, and
S = channel slope, in feet per foot.

Values for C and K were computed from information obtained at each set of stations. The discharge, Q, for which initial values of C and K were linearized was the long-term mean daily discharge at each station.

The channel width, W, was obtained from width-discharge relations; the channel slope, S, was determined using gaging-station altitudes; and dQ/dy was determined from the rating curves by bracketing the mean discharge and computing an incremental change in gage height for the associated change in discharge. Values of C and K for each reach were estimated by averaging the values at the bounding stations.

Reach 1--Vista to Tracy

To simulate the daily mean discharge of the Truckee River at Tracy (station 69), the flow was routed from Vista (station 68) to Tracy using the diffusion-analogy method with single linearization. The total computed discharge at Tracy was the routed discharge from Vista with no adjustment for the intervening ungaged area (the flow from this area is considered negligible in comparison to flow in the river itself).

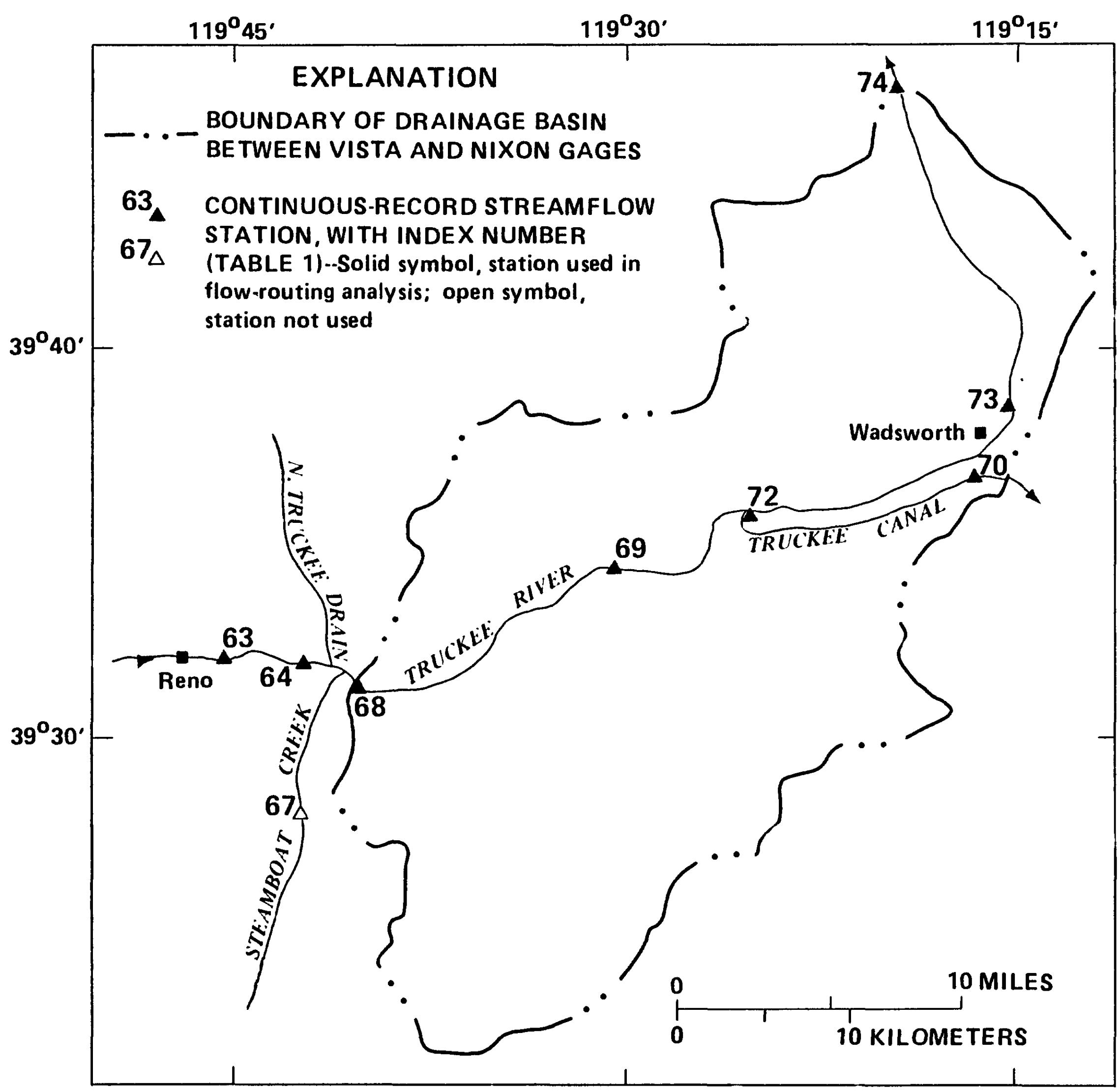


FIGURE 4.--Gaging stations in Truckee River basin downstream from Reno.

The distance between the two gages is 11.6 miles, and the intervening ungaged drainage area is 159 mi^2, or 10 percent of the total area contributing to the Tracy site. Gaging-station data available for this analysis are summarized in table 1.

Data for stations 68 and 69 for the period from October 1, 1979, to January 5, 1980, were used to calibrate the model, whereas data for the period from October 1, 1972, to May 31, 1983, were used to verify the model. Changes in the reach that would affect the flow regime during the verification period are assumed to have been minor. During calibration, C and K were varied; the best fit was with values of 4 ft/s and 1,800 ft^2/s, respectively. Table 4 presents the results of the routing model for simulating flows at the Tracy station.

TABLE 4.--Results of flow-routing analysis, lower Truckee River basin

			Mean error						
			Absolute		Negative		Positive		
Reach number	Stations (table 1)	Verification period	No. of days	Percent error	No. of days	Percent error	No. of days	Percent error	Total volume error (percent)
1	68,69	10/1/72-5/20/83	3,849	5.8	2,547	-6.0	1,302	5.2	-2.1
2	69,72	6/1/79-11/20/79	173	273	118	-331	55	150	-14.7
3	72,73	6/1/77-1/20/77	173	158	33	-15.4	140	192	42.1
4	73,74	10/1/65-9/30/82	6,209	11.0	3,497	-10.4	2,712	11.6	-2.3

	Percentage of total observations having errors less than:				
Reach number	5 percent	10 percent	15 percent	20 percent	25 percent
1	56	85	94	97	98
2	5	9	13	16	23
3	12	20	27	32	39
4	40	64	77	84	88

An analysis of the results indicates that flow-routing techniques would be an acceptable method for determining daily flow at the Tracy gage except (1) during infrequent storms within the drainage area between the two gages or (2) at flows less than 200 ft^3/s, when diversions for irrigation can cause an overestimation of flows reaching Tracy. During the verification period, the errors were greatest during November and December 1977. These errors may be attributable to difficulties in computing the daily flow during this time period or to possible inflow from the intervening ungaged area (figure 5). The impact of these errors on the overall results is minimal. Low flows (less than 100 ft^3/s) are of great importance in this reach during the summer, when the assimilation of treated sewage effluent is necessary to satisfy water-quality requirements of downstream water users.

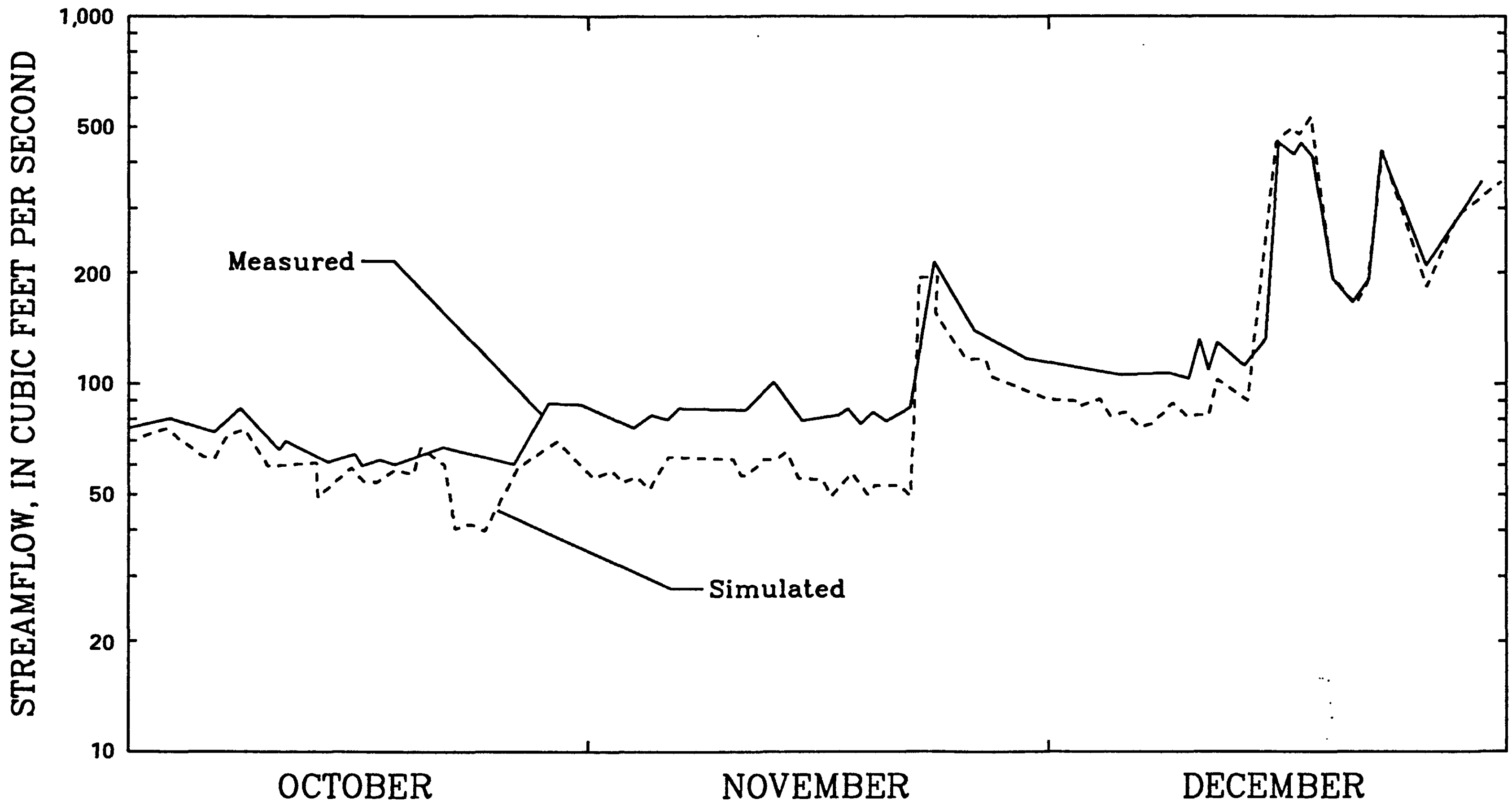


FIGURE 5.--Measured and simulated streamflow, Truckee River at Tracy, October-December 1977.

Reach 2--Tracy to Derby Dam

To simulate flows at the site immediately below Derby Dam (station 72, figure 4), the flow from station 69 (Tracy) was routed to Derby Dam, and the flow that is diverted from the river into the Truckee Canal at the dam, as recorded at station 70, was then subtracted. (This 31-mile canal carries flow from the Truckee River to Lahontan Reservoir for irrigation in the adjacent Carson River basin.)

The distance between the two gages on the Truckee River is 5.74 miles, and the ungaged area between stations is 86 mi^2, or 5 percent of the total area of 1,676 mi^2 contributing to the flow at Derby Dam. As in Reach 1, the flow response from this ungaged area is considered negligible in comparison to flow in the river itself; thus, no adjustment was made for the intervening area. Gaging-station data available for this analysis are summarized in table 1.

Calibration of C and K was limited to flow data for June-November during 1972-82. Travel times were satisfactorily matched by using values of 4 ft/s and 2,000 ft^2/s, respectively. The major difficulty in the calibration process was the inability to account for periodic return flows from the canal to the Truckee River in the 8.75-mile reach between the diversion dam and the canal gage. These return flows, which are diverted from the canal at two spill structures, re-enter the river downstream from station 72 (figure 4). Thus, subtracting canal flow at station 70 from the routed flow based on records for the Vista station (69) results in an overestimation of simulated flow at the river station immediately below Derby Dam (figure 6). Table 4 presents results of a typical calibration run. The results for the calibration periods are of poor quality, resulting in the conclusion that this reach of the Truckee River is not suited to the use of flow-routing techniques.

Reach 3--Derby Dam to Wadsworth

The 11.2-mile reach from Derby Dam (station 72) to Wadsworth (station 73) includes an intervening area of 48 mi^2, which represents 2.7 percent of the total contributing area at the Wadsworth gage (1,728 mi^2). Natural runoff from this intervening area was considered negligible, and thus no adjustments were made in routing flows from Derby Dam to Wadsworth. Flow in this reach is affected by irrigation diversions and return flows from small farms along the river, as well as by spills from the two structures on the adjacent canal (see discussion of Reach 2). Successful calibration of the flow model depends on the ability to compensate for the diversions, return flows, and spills--quantities that are not always known throughout the reach. Gaging-station data available for this analysis are summarized in table 1.

The selected values of C and K were 4 ft/s and 800 ft^2/s, respectively; they were applied to the period June 1-November 20 during 1972-82. These periods were selected to highlight the problem of diversions, return flows, and canal spill. Computed volume errors ranged from minus 23.9 percent in 1979 to plus 42.1 percent in 1977. The poorest overall results were those for 1977, as shown in table 4.

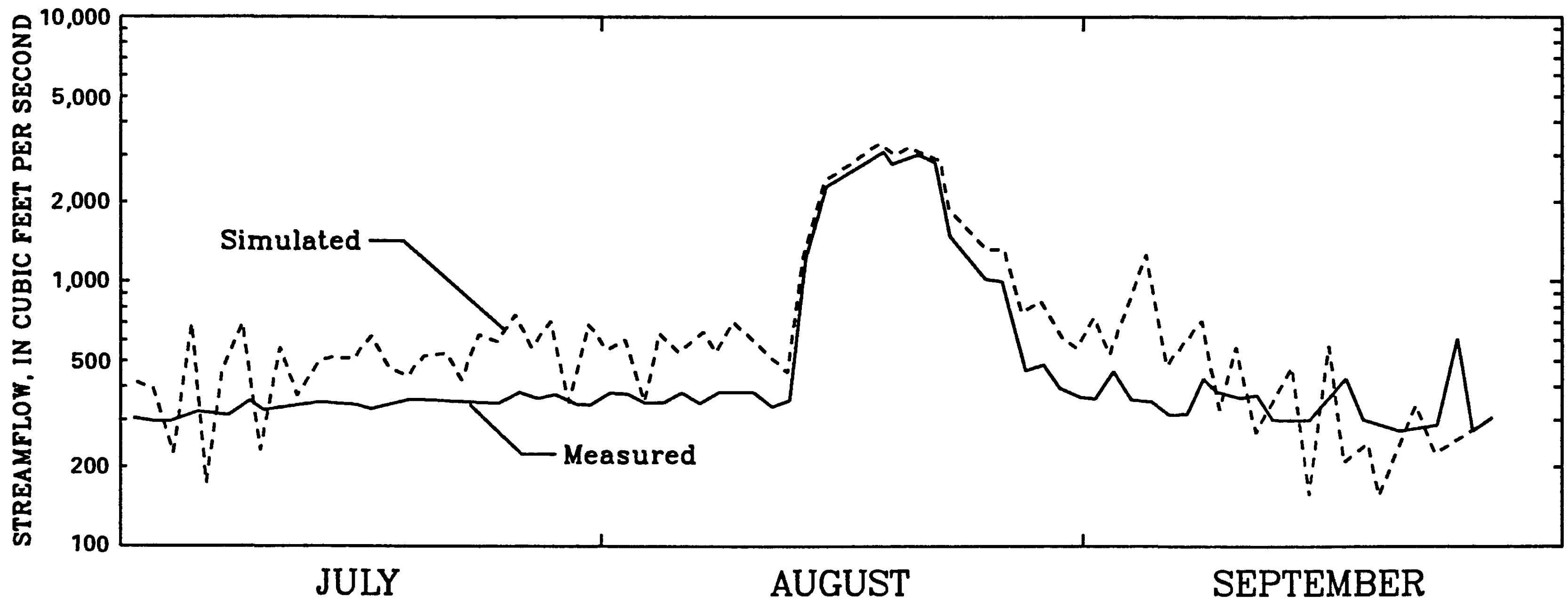


FIGURE 6.--Measured and simulated streamflow, Truckee River below Derby Dam, July-September 1972.

The analysis of the results selected for calibration indicates that the data for this reach are not adaptable to flow-routing techniques. The magnitude of the error is dependent on the flow volume below Derby Dam: the greater the volume of inflow to this reach, the less pronounced the error. Calibration is not possible at low flows. A typical low-flow condition, shown in figure 7, suggests the possibility that canal spills to the river downstream from Derby Dam may be a leading cause of calibration errors.

Reach 4--Wadsworth to Nixon

To simulate the daily mean discharges at Nixon (station 74), using the data for Wadsworth (station 73), the accretion from ground-water inflow within the 20.5-mile reach between Wadsworth and Nixon must be considered. For periods of low flow, this accretion has been estimated to average about 15 ft^3/s (Van Denburgh and others, 1973, page 42; Van Denburgh and Arteaga, 1985, page 11). If the ground-water accretion is assumed to be constant at 15 ft^3/s throughout the year, then a reasonable flow-routing strategy would be to add that quantity to the routed flow at Nixon.

Gaging-station data available for this analysis are summarized in table 1. Irrigation diversions and return flows within this reach were the sources of major errors during low-flow calibration attempts. Figure 8 shows the magnitude of errors for the period July-September 1977. The simplistic approach of adding a constant 15 ft^3/s to the routed flow, without accounting for seasonal consumptive use, eliminates the possibility of routing flows successfully in this reach. The data in table 4 reflect the poor results that occur when summer flows and winter flows are combined.

Application of Regression Analysis to Western Nevada Streams

Linear regression techniques were applied to six sites in the Walker River basin, three sites in the Carson River basin, five sites in the Humboldt River basin, and four sites in the Truckee River basin. The streamflow record for each station (the dependent variable) was regressed against streamflow records at other stations in the basin (the explanatory variables) during a given period of record (the calibration period). "Best-fit" linear regression models were developed and used to provide a simulated record of daily streamflow that was compared to the measured record. The percentage difference between the actual and simulated records for each day was calculated.

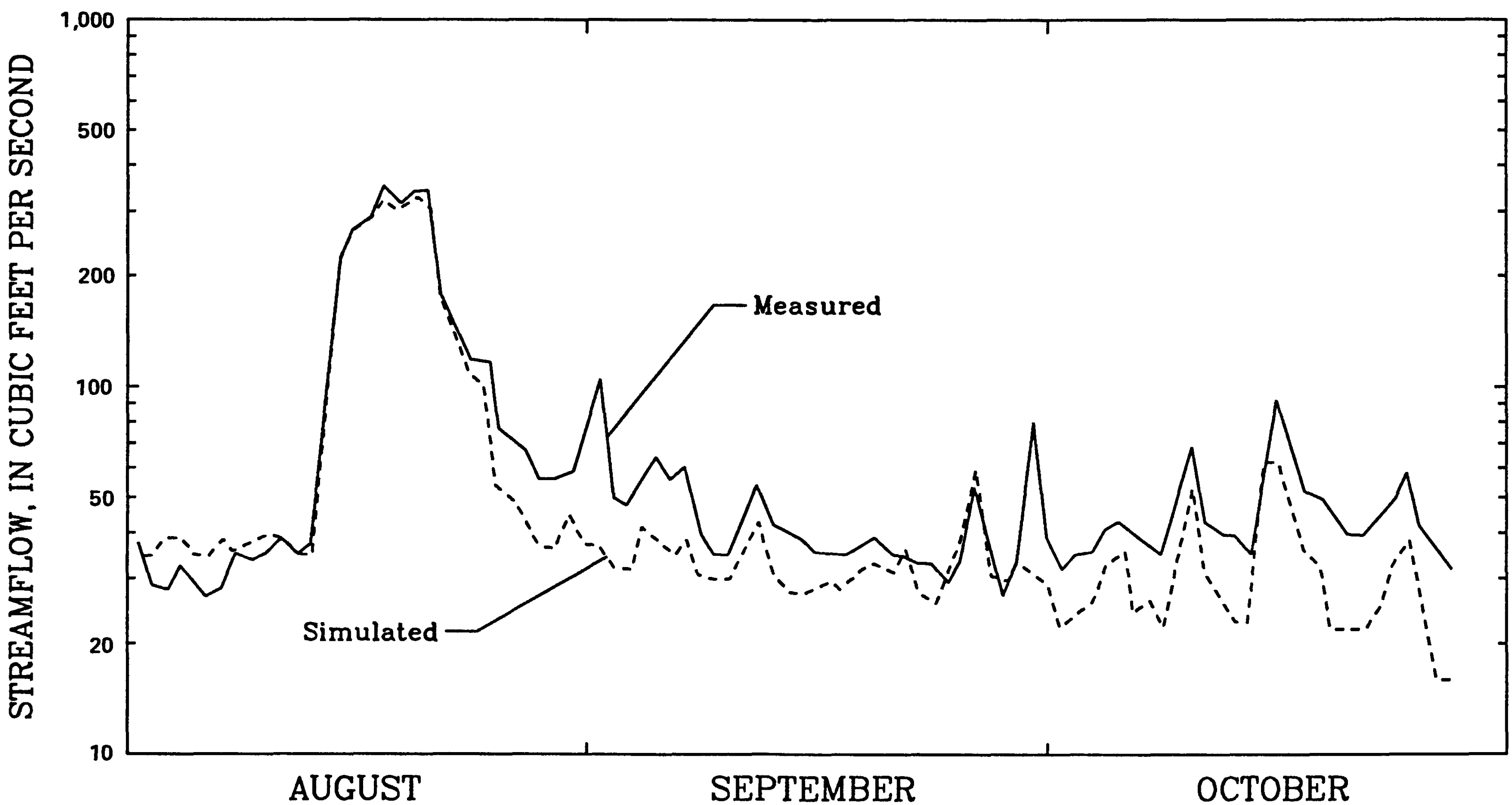


FIGURE 7.--Measured and simulated streamflow, Truckee River at Wadsworth, August-October 1972.

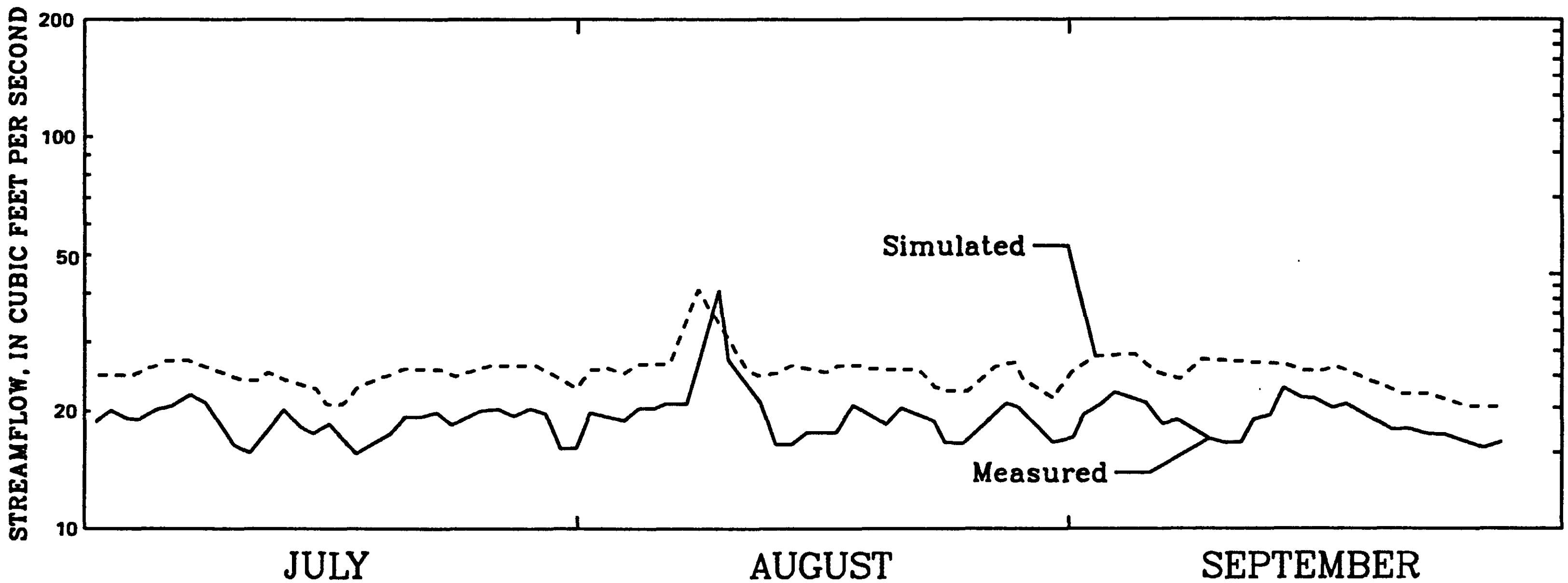


FIGURE 8.--Measured and simulated streamflow, Truckee River near Nixon, July-September 1977.

Walker River Basin

Six stations (Nos. 25-30, figure 9 and table 1) were selected for regression analysis. The results are summarized in table 5. The streamflow record at station 25 was not reproduced with an acceptable degree of accuracy using regression techniques and data from station 24. The simulated flows at the site were within 10 percent of the recorded flows only 32 percent of the time during the calibration period. The drainage area at station 24, 63.1 mi^2, represents only 35 percent of the total drainage area above station 25, and does not have runoff characteristics similar to those of the 118-mi^2 ungaged area.

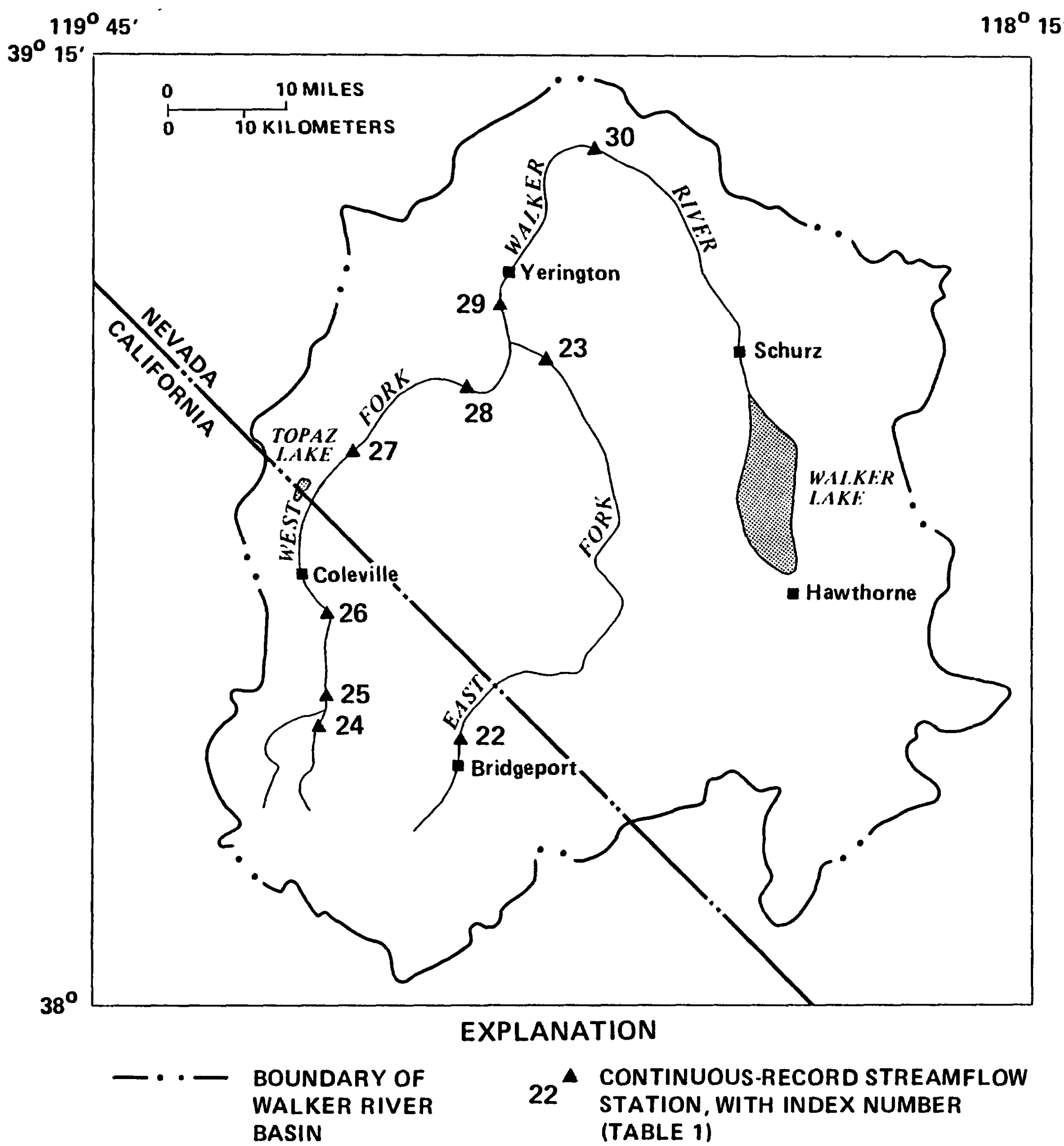


FIGURE 9.--Gaging stations in Walker River basin.

TABLE 5.--Summary of regression analyses, Walker River basin

[Calibration period, October 1981-September 1982. Symbol: --, regression and percentages not calculated]

Index number	Station number	Drainage area (square miles)	Regression equation[1]	Percentage of time during which simulated flow was within: 5 percent of actual flows	10 percent of actual flows
23	10293500	1,110	--	--	--
24	10295500	63.1	--	--	--
25	10296000	181	$Q_{25} = -34 + 5.77Q_{24}$	16	32
26	10296500	250	$Q_{26} = 13.8 + 0.97Q_{25}$	63	89
27	10297500	497	$Q_{27} = 25 + 0.84Q_{26}$	7	13
28	10300000	964	$Q_{28} = -41 + 0.76Q_{27}$	15	48
29	10300600	2,400	$Q_{29} = 67 + 0.87Q_{28} + 0.51Q_{23}$	16	29
30	10301500	2,600	$Q_{30} = -49 + 1.07Q_{29} - 0.29Q_{23}$	15	25

[1] Abbreviation "Q_{25}" means "flow at station 25, in cubic feet per second."

A more successful simulation of streamflow record was produced at station 26 by regressing with station 25. Here, runoff from the 69-mi² ungaged drainage area, 28 percent of the total drainage area above station 26, was represented satisfactorily with regression techniques. The simulated flows were within 10 percent of the recorded flows almost 90 percent of the time during the calibration period. However, during the verification period selected, October 1971-September 1982, the simulated data were within 10 percent of the actual record only 76 percent of the time, which is considered unsatisfactory.

Simulation of streamflow record at the remaining four stations, Nos. 27-30, was not satisfactory. The percent of days for which simulated flow was within 10 percent of actual flow ranged from 13 percent for station 27 to 48 percent for station 28. The flows at these four stations are affected to varying degrees by regulation, diversions, and return flows. These activities preclude the satisfactory application of regression techniques as used in this study. Additional data, analytical techniques, or both may be required to apply regression techniques to these stations.

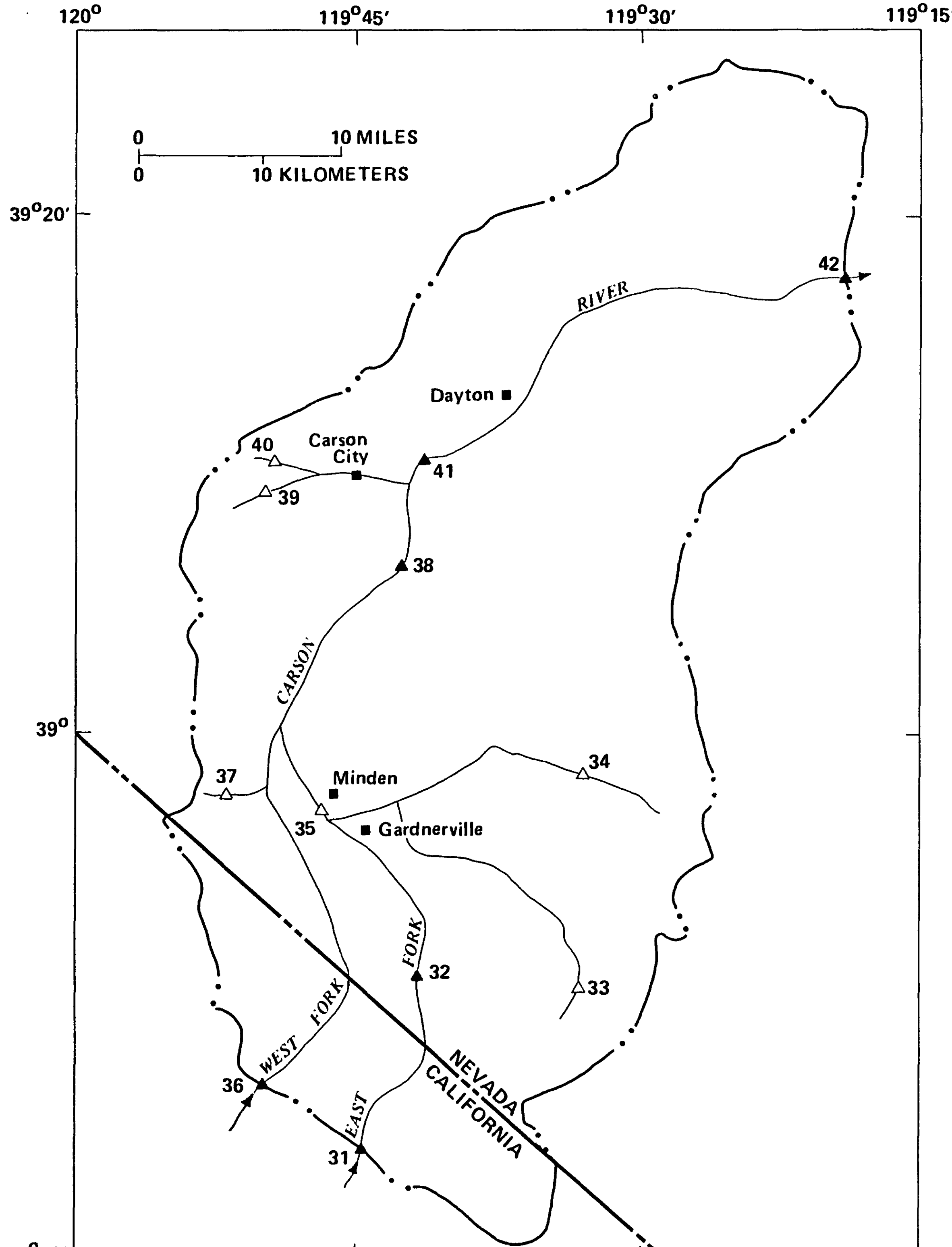
Carson River Basin

Stations 32, 38, and 41 (figure 10 and table 1) were selected for regression analysis. The streamflow record at station 32 was simulated for the following calibration periods: October-April, 1976-81; May-September, 1976-80; October-September, 1976-81; January-December, 1976-80. The calibration results varied depending on the period selected, indicating that different conditions at different times affect the flow regime in this reach. The poorest and best results are listed in table 6. The simulated flows at this site were within 10 percent of the recorded flows only 42 percent of the time during the period January-December 1980, but 95 percent of the time during the period May-September 1978. Overall results indicate that the streamflow record at station 32 was not reproduced with an acceptable degree of accuracy.

The regression model for station 38 included two explanatory variables, stations 32 and 36. The intervening ungaged area is 465 mi^2--nearly half the total drainage of 886 mi^2 above station 38. Many irrigation diversions and return flows exist above the station, and the flow is slightly regulated by several small reservoirs on tributaries. The regression results were the poorest calculated for the basin: simulated flows were within 10 percent of the recorded flows during only 21 percent of the calibration time period (October 1979-September 1980).

Station 41 was the final site in the Carson River basin selected for regression analysis. Drainage area at the site is 958 mi^2. The ungaged drainage area between stations 41 and 38 (72 mi^2) is less than 8 percent of the total; however, the intervening reach includes some farmlands which are irrigated by river water diverted just downstream from station 38. Thus, the ability to successfully regress these two stations depends primarily on the magnitude of diversions and flow in the reach: the larger the flow, the smaller the effect of diversions. The calibration period selected, April 1979 to September 1983, includes all the data available for station 41. The results indicate that the simulated flows were within 10 percent of the actual record during 76 percent of the calibration period. Mechanical problems at station 41 during this period resulted in some lost record, which had to be estimated. Possible errors in these estimations may have adversely affected the calibration results.

As more data become available in the Carson River basin, improvement in the regression results may be possible.



EXPLANATION

—· ·— BOUNDARY OF DRAINAGE BASIN BETWEEN GAGING STATIONS 31, 36, AND 42

▲ 36 △ 40 CONTINUOUS-RECORD STREAMFLOW STATION, WITH INDEX NUMBER (TABLE 1) -- Solid symbol, station used in flow-routing analysis; open symbol, station not used

FIGURE 10.--Gaging stations in upper and middle Carson River basin.

TABLE 6.--Summary of regression analyses, Carson River basin

[Symbol: --, regression and percentages not calculated]

Index number	Station number	Drainage area (square miles)	Regression equation[1]	Percentage of time during which simulated flow was within: 5 percent of actual flows	10 percent of actual flows	Calibration period
31	10308200	276	--	--	--	--
32	10309000	356	$Q_{32} = -2.81 + 1.01Q_{32}$	71	95	May-Sept. 1978
			$Q_{31} = 30.9 + 0.97Q_{31}$	24	42	Jan.-Dec. 1980
36	10310000	65.4	--	--	--	--
38	10311000	886	$Q_{31} = 32.7 + 1.35Q_{31} - 0.682Q_{36}$	9	21	Oct. 1979-Sept. 1980
41	10311400	958	$Q_{41} = -0.33 + 0.9Q_{38}$	49	76	April 1979-Sept. 1983

[1] Abbreviation format: "Q_{32}" means "flow at station 32, in cubic feet per second."

Humboldt River Basin

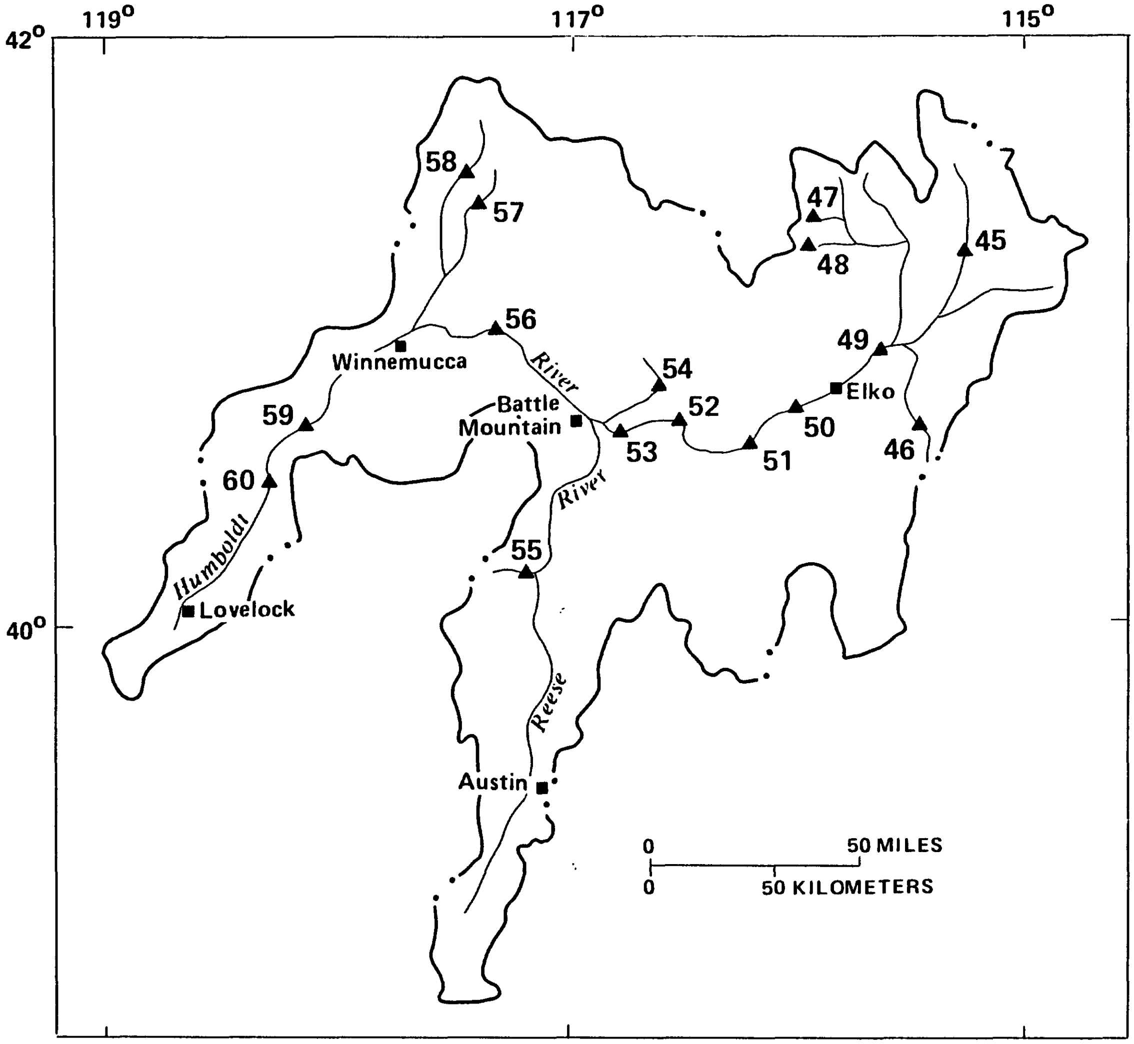
Five stations along the main stem of the Humboldt River (Nos. 49, 50, 51, 53, and 56, figure 11 and table 1), were selected for regression analysis. Substantial amounts of streamflow are diverted upstream from each station during the irrigation season. Nonetheless, regression analyses in the Walker and Carson River basins suggest that, at least, some degree of success might be expected in the Humboldt River basin. The results of the regression analysis, summarized in table 7, indicate that the effect of diversions is least pronounced for station 51, where the simulated flows were within 10 percent of the recorded flows 62 percent of the time. In contrast, results for station 56 indicate the simulated data were within 10 percent of the actual data only 13 percent of the time. Overall results imply that regression techniques will not provide satisfactory results in simulating streamflow at those stations.

TABLE 7.--Summary of regression analyses, Humboldt River basin

[Calibration period, October 1981-September 1982. Symbol: --, regression and percentages not calculated]

Index number	Station number	Drainage area (square miles)	Regression equation[1]	Percentage of time during which simulated flow was within: 5 percent of actual flows	10 percent of actual flows
49	10318500	2,800	--	--	--
50	10321000	4,310	$Q_{50} = 58.5 + 1.26Q_{49}$	9	21
51	10322500	5,010	$Q_{51} = 8.85 + 1.1Q_{50}$	24	62
52	10323400	--	$Q_{52} = 4.52 + 0.95Q_{52}$	15	28
53	10323600	--	$Q_{53} = -14.6 - 0.11Q_{54} + 0.99Q_{52}$	24	43
54	10324500	875	--	--	--
56	10327500	12,100	$Q_{56} = 38.8 + 0.79Q_{53}$	6	13

[1] Abbreviation format: "Q_{50}" means "flow at station 50, in cubic feet per second."



EXPLANATION

—· ·— BOUNDARY OF HUMBOLDT RIVER BASIN

54▲ CONTINUOUS-RECORD STREAMFLOW STATION, WITH INDEX NUMBER (TABLE 1)

FIGURE 11.--Gaging stations in Humboldt River basin.

Truckee River Basin

Regression techniques were applied to four stations on the Truckee River (Nos. 64, 68, 69, and 74, figure 4 and table 1); in two of the reaches, the results were used as a comparison with flow-routing data developed earlier in this report. Table 8 summarizes the results of the regression analyses. Station 64, not previously considered in the flow-routing analysis, was simulated with a regression model that included station 63 (2.92 miles upstream) as the explanatory variable. These two nearby stations have drainage areas of 1,070 and 1,067 mi^2, respectively; the difference is less than 1 percent. In this reach, only a few diversions are made for irrigation and they are of relatively small magnitude compared to the average flows in the river. However, when the river flow is less than 100 ft^3/s, which is infrequent, these diversions may be a source of appreciable error in any regression techniques.

Several calibration periods were used: May-September, 1977-80; May 1977-September, 1982; October-April, 1977-81; and October 1979-April 1982. The simulated flows for station 64 were within 10 percent of the recorded flows 77 percent of the time, using the data for May-September 1977, and 94 percent of the time using the data for October 1980-April 1981. Further improvement in the simulation was attempted using two separate models: one for flows greater than 100 ft^3/s and the other for flows less than 100 ft^3/s. During the 6-year period, October 1977 to September 1983, the flow was less than 100 ft^3/s on only 75 days. Errors were greatest during these low-flow periods, when diversions were a more significant component of the total flow. Thus, the low-flow model was not satisfactory. The high-flow model results were within 10 percent of the observed data 66 percent of the time in water year 1978 and 96 percent of the time in water year 1983. By combining both models, results slightly improved in water year 1978, but were unchanged from the high-flow model during the remaining water years 1979-83. Thus, neither model was satisfactory for simulating flows at station 64.

The streamflow record at station 68 was not reproduced with an acceptable degree of accuracy using regression techniques. Flow from the 361-mi^2 ungaged drainage area between stations 68 and 64 cannot be satisfactorily represented by using station 64 as the only explanatory variable. Runoff characteristics of the ungaged area are apparently dissimilar to those above station 64. The simulated flows were within 10 percent of the recorded flows only 70 percent of the time during the calibration period.

Two separate models were used to simulate flows at station 69; one for flows less than 100 ft^3/s and the other for flows greater than 100 ft^3/s. The calibration period selected was January 1977-December 1978. This period included 61 days during which the flow was less than 100 ft^3/s and 669 days with higher flows. Results obtained using the low-flow model were poor: the simulated flows were within 10 percent of the recorded flows only 49 percent of the time. The results from the combined models were better, and the simulated data were within 10 percent of the recorded data 76 percent of the time. In comparison, the simulated data using flow-routing techniques were within 10 percent of the recorded data 85 percent of the time during the calibration period (October 1972-May 1983).

TABLE 8.--Summary of regression analyses, Truckee River basin

[ft^3/s, cubic feet per second. Symbol: --, regression and percentages not calculated]

Index number	Station number	Drainage area (square miles)	Regression equation[1]	Percentage of time during which simulated flow was within: 5 percent of actual flows	10 percent of actual flows	Calibration period
63	10348000	1,067	--	--	--	--
64	10348200	1,070	$Q_{64} = -2.87 + 0.735Q_{63}$	51	77	May-Sept. 1977
			$Q_{64} = 16 + 0.949Q_{63}$	68	94	Oct. 1980-April 1981
68	10350000	1,431	$Q_{68} = 115 + 1.06Q_{64}$	38	70	Oct. 1979-April 1982
69	10350400	1,590	For $Q_{68}<100$ ft^3/s $Q_{69} = 36 + 0.33Q_{68}$ For $Q_{68}>100$ ft^3/s: $Q_{69} = -0.42 + 0.996Q_{68}$	[a]44	[a]76	Jan. 1977-Dec. 1978
73	10351650	1,728	--	--	--	--
74	10351700	1,827	For $Q_{73}>100$ ft^3/s: $Q_{74} = 13.5 + 0.9Q_{73}$ For $Q_{73}<100$ ft^3/s: $Q_{74} = 72.3 + 0.94Q_{73}$	[a]37	[a]61	Jan. 1980-June 1983

[1] Abbreviation format: "Q_{64}" means "flow at station 64, in cubic feet per second."

[a] Combination of the two regressions.

Station 74 was similarly evaluated with two models (for flows less than and greater than 100 ft^3/s). These models gave overall results nearly the same as those obtained from the flow-routing model (table 11). The simulated flows from the regression model were within 10 percent of the recorded flows during 61 percent of the calibration period (January 1980-June 1983), compared with 64 percent for the flow-routing model (calibration period, October 1965-September 1982). Overall results indicate that regression techniques will not provide satisfactory results in simulating streamflow at those stations.

Conclusions Regarding Alternative Methods of Data Development

The simulated data from both the flow-routing and regression applications were not sufficiently accurate to use these methods in lieu of continuous-record stream gages. Sites at which flows greater than 100 ft^3/s can be simulated appear to be those where the effect of diversions is proportionally small--namely, station 41 in the Carson River basin and stations 64 and 69 in the Truckee River basin. Before the utility of the two alternative methods can be further assessed, a thorough evaluation is needed regarding the adequacy of existing data. Information on diversions, return flows, ground-water accretion, and evapotranspiration would be helpful in reducing the errors presently produced by the models.

On the basis of the need for streamflow data (discussed earlier) and the unsuccessful application of alternative methods for data generation, all the 81 stream-gaging stations that constituted the 1983 program remain valuable components of the continuing program in Nevada.

COST-EFFECTIVE ALLOCATION OF RESOURCES

In a study of the cost effectiveness of a stream-gaging network operated to determine water consumption in the Lower Colorado River Basin, a set of statistical techniques called Kalman Filtering for Cost-Effective Resource Allocation (K-CERA) was developed (Moss and Gilroy, 1980). Because that study concerned water balance, the network's effectiveness was measured in terms of the extent to which it minimized the sum of error variances in estimating annual mean discharges at each site in the network. This measure of effectiveness tends to concentrate stream-gaging resources on the larger, less stable streams where potential errors are greatest. While such a tendency is appropriate for a water-balance network, it causes undue concentration on large streams. Therefore, the original version of K-CERA was extended to include, as optional measures of effectiveness, the sums of the variances of errors of estimation for the following streamflow variables: annual mean discharge and average instantaneous discharge, both of which are expressed in cubic feet per second and percent. To assess the effectiveness of data-collection activities in Nevada, the present study has applied the K-CERA techniques to the percentage errors of instantaneous discharges at all continuous-record gages. The use of percentage errors does not unduly weight activities at large streams to the detriment of records on small streams. In addition, the instantaneous discharge is the basic variable from which all other streamflow data are derived.

The original version of K-CERA also did not account for error contributed by missing stage data or other correlative data used to compute streamflows. The probabilities of missing records increases as the period between service visits to a stream gage increases. A procedure for dealing with missing records has been developed and was incorporated into this study.

The following two sections briefly describe (1) the mathematical program that optimizes cost effectiveness and (2) the application of uncertainty functions in determining the accuracy of stream-gaging records. More details on the theory and applications of K-CERA are presented by Moss and Gilroy (1980) and by Gilroy and Moss (1981).

Description of the "Traveling Hydrographer" Mathematical Program

The "Traveling Hydrographer" program allocates among stream gages a predefined budget for collection of streamflow data in the most cost-effective manner. The number of times per year that several alternative routes may be used to service stream gages and make discharge measurements are options in the mathematical program. The range of options is from zero usage to daily usage for each route. The most efficient route is also the most economical travel route among a set of stream gages. Average travel-time and servicing costs for each visited gage are included in the program.

The first step in the program is to define the set of practical routes. The set may contain the path to only a single stream gage, so the unique needs of that gage can be accommodated.

The next step is to determine special requirements of gages, such as necessary periodic maintenance, repair of recording equipment, or required periodic measurements and sample collection for determination of water quality. These special requirements are necessary constraints in terms of the minimum acceptable number of visits to each gage.

The final step is to use all the above information to determine the number of times each route should be used during a year so that: (1) The budget for the network is not exceeded, (2) the minimum number of visits to each station is made, and (3) the total uncertainty in the network is minimized. A more detailed discussion of this is presented by Fontaine and others (1984, pages 23-24).

Description of Uncertainty Functions

As noted earlier, uncertainty in streamflow records is measured in this study as the average relative variance of estimation of the instantaneous discharges. The accuracy of a streamflow estimate depends on how that estimate was obtained. Three situations are considered in this study: (1) streamflow is estimated from measured discharge and correlative data, using a stage-discharge relation (rating curve); (2) the streamflow record is reconstructed using secondary data at nearby stations because primary correlative data are missing; and (3) neither primary nor secondary data are available for estimating streamflow. The error variances for estimates of flow in each situation are weighted by the fraction of time each situation is expected to occur, and combined to estimate the expected error variance, which is the dependent variable of an uncertainty function. This relation can be expressed as:

$$\overline{V} = \epsilon_f V_f + \epsilon_r V_r + \epsilon_e V_e \, , \tag{4}$$

where $\bar{V}$ = average relative variance of the errors of streamflow estimates;
ϵ_f = fraction of time that the primary recorders are functioning;
V_f = relative error variance of flows estimated from primary recorders;
ϵ_r = fraction of time that secondary data are available to reconstruct streamflow records when primary data are missing;
V_r = relative error variance of flow estimates reconstructed from secondary data;
ϵ_e = fraction of time that primary and secondary data are not available to compute streamflow records; and
V_e = relative error variance when neither primary nor secondary data are available.

In addition:

$$\epsilon_f + \epsilon_r + \epsilon_e = 1. \tag{5}$$

The fraction of time that each source of error is relevant is a function of the frequencies at which the recording equipment is serviced. The time, τ, between the last service visit and failure of the recorder at the primary site is assumed to have a negative-exponential probability distribution that is truncated at the next service time. The probability-density function of the distribution is:

$$f_\tau = ke^{-k\tau}/(1 - e^{-ks}) \ , \tag{6}$$

where k = failure rate, in number of occurrences per day;
e = base of natural logarithms; and
s = interval between visits to the site, in days.

When a recorder fails, it is assumed to malfunction until the next service visit. As a result:

$$\epsilon_f = (1 - e^{-ks})/ks \tag{7}$$

(Fontaine and others, 1984, page 38, equation 21).

The fraction of time no records exist at either the primary or secondary site (ϵ_e) can also be derived by assuming that the times of failure are independent of each other and have negative exponential distributions with the same rate constant. It then follows that:

$$\epsilon_e = 1 - [2(1 - e^{-ks}) + 0.5(1 - e^{-2ks})]/ks \tag{8}$$

(Fontaine and others, 1984, equation 23 and pages 38 and 39).

Finally, it follows from equation (5) that the fraction of time records are reconstructed using data from a secondary site (ϵ_r) is:

$$\begin{aligned}\epsilon_r &= 1 - \epsilon_f - \epsilon_e \\ &= [(1 - e^{-ks}) + 0.5(1 - e^{-2ks})]/(ks). \end{aligned} \tag{9}$$

The relative variance of the error derived from primary record computation (V_f) is determined by analyzing a time series of residuals that are the differences between the logarithms of measured and of rating-curve discharges. The rating-curve discharge is determined from a relation between discharge and some correlative records, such as water-surface elevations at the gaging station. The measured discharge is the value obtained from field determinations of depth, width, and velocity. If $q_T(t)$ is the true instantaneous discharge at time t, and $q_R(t)$ is the value that would be estimated using the rating curve, then the instantaneous difference between the base-e logarithms of the true discharge and the rating-curve discharge [x(t)] would be:

$$x(t) = \ln q_T(t) - \ln q_R(t) \quad . \qquad (10)$$

In computing estimates of streamflow, the rating curve may be continually adjusted on the basis of periodic measurements of discharge. This adjustment process results in a better estimate, of stream discharge at time t [$q_c(t)$]. The difference between the variable $\hat{x}(t)$, which is defined as:

$$\hat{x}(t) = \ln q_c(t) - \ln q_R(t) \quad , \qquad (11)$$

and x(t) is the error in the streamflow record at time t. The variance of this difference [$x(t) - \hat{x}(t)$] over time is the desired estimate of V_f.

Unfortunately, true instantaneous discharge, $q_T(t)$, cannot be determined, and thus x(t) and the difference, $x(t) - \hat{x}(t)$, cannot be determined either. However, the statistical properties of $x(t) - \hat{x}(t)$, particularly its variance, can be inferred from the available discharge measurements. If the observed residuals between measured and rating-curve discharges are z(t), then:

$$z(t) = x(t) + v(t) = \ln q_m(t) - \ln q_R(t) \quad , \qquad (12)$$

where v(t) = measurement error, and
$\ln q_m(t)$ = base-e logarithm of the measured discharge, which is $\ln q_T(t)$ plus v(t).

In the Kalman-filter analysis, the z(t) time series for each gage was evaluated to determine three site-specific parameters, p, β, and r. The Kalman filter used in this study assumes that the time residuals x(t) arise from a continuous first-order Markovian process that has a Gaussian (normal) probability distribution with zero mean and a process variance, p. The second important parameter is β, the reciprocal of the correlation time of the Markovian process giving rise to x(t). The parameters p and β are related as follows:

$$\mathrm{Var}[x(t)] = p = q/2\beta \quad , \qquad (13)$$

where q is a constant (Fontaine and others, 1984, page 25).

The variance of the residuals z(t) is defined as:

$$\mathrm{Var}[z(t)] = p + r \quad , \tag{14}$$

where r is the variance of the measurement error v(t).

The three site-specific parameters, p, β, and r, are computed by analyzing the statistical properties of the z(t) time series. These are needed to define this component of the uncertainty relation. The Kalman filter utilizes these three parameters to determine the average relative variance of the errors of estimation for discharge as a function of the number of discharge measurements per year (Moss and Gilroy, 1980).

If the recorder at a primary site fails, and no suitable concurrent data are available for secondary sites, the discharge at the primary site can be estimated using at least two procedures: A recession curve could be applied from the time of recorder stoppage until the gage was once again functioning, or the historical daily mean for the period of missing data could be used as an estimate. The expected-value approach is used in this study to estimate V_e, the relative error variance during periods when no concurrent data are available for nearby stations. If the expected value is used to estimate discharge, the value chosen must take into account the time of year of the missing record because of the seasonal nature of streamflow fluctuation. The variance of streamflow, which also depends on season, is an estimate of the error that results from the use of an expected value. Thus, the coefficient of variation squared, C_v^2, is an estimate of the relative error variance V_e. Because coefficient of variation varies seasonally and the times of recorder failure cannot be anticipated, a seasonally averaged value of C_v is used:

$$\bar{C}_v = \left[\frac{1}{365} \sum_{i=1}^{365} \left(\frac{\sigma_i}{\mu_i}\right)^2 \right]^{1/2} , \tag{15}$$

where σ_i = standard deviation of daily discharges for the i^{th} day of the year, and

μ_i = expected value of discharge on the i^{th} day of the year.

The variance of the relative error during periods of reconstructed streamflow record, V_r, is estimated on the basis of correlation between records at the primary site and records from nearby stream gages. The correlation coefficient ρ_c between streamflow at the site of interest, with seasonal trends removed, and streamflow at the other sites, also adjusted to remove seasonal trends, is a measure of the linear relation. The fraction of the variance of streamflow at the primary site that is explained by data from the other sites is equal to ρ_c^2. Thus, the relative error variance of flow estimates at the primary site obtained from secondary information, V_r, is:

$$V_r = (1 - \rho_c^2)\, \bar{C}_v^2 \quad . \tag{16}$$

Because errors in streamflow estimates arise from three different sources with widely varying precisions, the resultant distribution of those errors may differ significantly from a normal or log-normal distribution. This lack of normality makes an interpretation of the resulting average estimation variance difficult. When primary and secondary data are unavailable, the relative error variance V_e may be very large. This could yield correspondingly large values of $\bar{V}$ in equation 4, even if the probability that primary and secondary information are not available (ϵ_e) is quite small.

A new parameter, the equivalent Gaussian spread (EGS), is introduced here to assist in interpreting the results of the analyses. If the various errors arising from the three situations represented in equation 4 are assumed to be log-normally distributed, the value of EGS can be determined using the following probability statement:

$$\text{Probability} \{e^{-EGS}<[q_c(t)/q_T(t)]<e^{+EGS}\} = 0.683 \quad . \qquad (17)$$

Thus, if the residuals $\ln q_c(t) - \ln q_T(t)$ were normally distributed, $(EGS)^2$ would be their variance. Here, EGS is reported in units of percent because EGS is defined so that nearly two-thirds of the errors in instantaneous streamflow data will be within plus or minus EGS percent of the reported values.

Application to Nevada Streams

Quantification of Uncertainty-Function Parameters

As described earlier, the statistical characteristics of missing stage or other correlative data for computation of streamflow records can be defined by the parameter k in the truncated negative exponential probability distribution of times to failure of the equipment. The value of k is a function of the number of days of missing record and the length of time between inspections of the equipment. The length of time varies from site to site and from year to year, depending on the type of equipment, the degree of exposure to and severity of natural elements, frequency of damage from flooding and vandalism. Some gages consistently lose more record than others, owing to vandalism and severity of winter conditions. The value of k can also be changed as a result of advances in the technology of data collection and recording. To estimate k in Nevada, actual data collection during water years 1981-83 was evaluated. During this period, technology changed little, and the stream gages were visited at a fairly consistent 4- to 6-week interval. The evaluation indicates that, with this visit frequency, an average gage can be expected to malfunction about 6 percent of the time. The amount of lost record ranged from about 1 percent at a few nearly ideal stations to more than 20 percent at some problem stations. The percentage of lost record and the average frequency of visits were used to determine the values of k and the dependent variables ϵ_f, ϵ_r, and ϵ_e (equation 4) for each of the 81 stream gages.

To compute values of V_e and V_r (equation 4) for the needed uncertainty functions, the daily streamflow records stored in WATSTORE (Hutchinson, 1975) for each of the 81 Nevada gaging stations was retrieved. For gages with three or more complete water years of data during the last 30 years, the value of the cross-correlation coefficient, C_v, was computed and various options, based on records for combinations of other stream gages, were explored to determine the maximum coefficient of variation, ρ_c. For the four stations that had less than 3 water years of data (Nos. 33, 34, 52, and 53), values of C_v and ρ_c were estimated subjectively on the basis of experience with similar nearby streams. Twenty-one additional stations were assigned the same estimated values because nearby stations were not available for computing C_v. The calculated or estimated values of C_v and ρ_c for each station are listed in table 9.

The determination of the variance V_f (equation 4) for each Nevada stream gage required three steps: (1) analysis of long-term rating-curve records, and a computation of residuals between measured and rating-curve discharges; (2) time-series analysis of the residuals to determine the input parameters for the Kalman-filter analysis; and (3) computation of the error variance V_f as a function of the time-series parameters, the error variance of discharge measurements, and the frequency of measurements.

For the Nevada analysis, a computerized rating function was used for all stations except Nos. 4, 5, 9, and 14, which had insufficient data. The rating function used was of the form:

$$\ln Q_m = \ln B_1 + B_3[\ln (GH - B_2)] \quad , \qquad (18)$$

where Q_m = measured discharge,

GH = recorded gage height corresponding to the measured discharge,

B_1 = discharge for a flow depth of 1 foot,

B_2 = gage height at zero flow, and

B_3 = slope of the rating curve.

The values B_1, B_2, and B_3 are determined by the application of a general linear model to solve for the dependent variable, measured discharge. The residuals resulting from this regression are the differences between measured and rated discharges.

TABLE 9.--Statistics for reconstruction of streamflow records

[Symbol: --, statistic not determined]

Index number[1]	Record lost (percent)[2]	Cross-correlation coefficient (C_v)	Coefficient of variation (p_c)	Stations used for reconstruction of records
1	20	1.2883	0.6867	2
2*	20	.7	.6	--
3*	20	.7	.6	--
4*	--	.7	.6	--
5*	--	.7	.6	--
6*	20	.7	.6	--
7	20	.6497	.6130	3, 6
8	20	.8330	.2397	7
9*	--	.7	.6	--
10*	20	.7	.6	--
11	20	.6478	.6237	10
12	20	.3681	.8754	11
13	10	.3739	.4661	15, 20
14*	--	.37	.6	--
15	10	.3879	.6403	13, 16, 17, 19, 20
16	10	.5306	.6521	15, 17, 19, 20
17	10	.7012	.4773	15, 16, 18
18	10	1.3805	.7976	15, 16, 17
19	10	.4900	.4909	15, 20
20	10	.6043	.6403	15
21*	20	.7	.6	--
22*	5	.7	.6	19, 23
23*	10	.7	.6	22
24	5	.6409	.9083	25, 26
25	5	.7626	.9803	24, 26
26	5	.7206	.9803	24, 25
27*	5	.7	.6	28
28*	10	.7	.6	27
29	10	.6645	.8525	22, 27, 30
30	10	1.0780	.8525	22, 27, 29
31	5	.8611	.9803	32
32	5	.8425	.9803	31
33*	5	.7	.6	34, 37, 39, 40
34*	5	.7	.6	33, 37, 40, 42
35	5	1.3443	.8355	32

TABLE 9.--Statistics for reconstruction of streamflow records--Continued

Index number[1]	Record lost (percent)[2]	Cross-correlation coefficient (C_v)	Coefficient of variation (p_c)	Stations used for reconstruction of records
36*	5	0.7	0.6	--
37	5	.6344	.5847	39, 40
38	5	1.0500	.9403	32, 36, 41, 42
39	5	.6688	.7449	37, 40
40	5	.5139	.7449	37, 39
41	5	.7910	.7903	36, 42
42	10	1.4233	.9403	32, 36, 38, 41
43*	10	.7	.6	--
44	10	1.7410	.5677	43
45	17	.9981	.6781	46
46	17	.5964	.6781	45
47	17	.9004	.8134	48
48	17	.4738	.8134	47
49	17	1.1826	.9530	45, 50, 51
50	17	.9624	.9878	49, 51
51	17	.8804	.9878	50
52*	17	.7	.6	--
53*	17	.7	.6	--
54	17	1.4965	.3736	20
55*	17	.7	.6	--
56	17	1.1794	.8715	51, 59
57	17	.9433	.5378	58, 76, 77
58	17	.9431	.6870	57, 76, 77
59	17	.8884	.8713	51, 56
60*	17	.7	.6	--
61	5	.5836	.5895	66
62*	5	.7	.6	--
63	1	.8534	.9789	64, 68, 69
64	1	.7909	.8603	63, 68, 69
65*	5	.85	.85	--
66	5	1.0021	.6555	39, 40
67*	5	.7	.6	66
68	1	.7869	.9789	63, 64, 67, 69
69	1	.6695	.9070	64, 60
70	10	.8294	.9428	69, 71, 72

TABLE 9.--Statistics for reconstruction of streamflow records--Continued

Index number[1]	Record lost (percent)[2]	Cross-correlation coefficient (C_v)	Coefficient of variation (p_c)	Stations used for reconstruction of records
71	10	0.9560	0.9428	69, 70, 72
72	1	1.6646	.9813	69, 70, 73, 74
73	1	1.2542	.9799	72, 74
74	1	1.4200	.9813	72, 73
75	17	1.237	.6776	76, 77
76	17	1.4669	.5754	75, 77
77	10	.6517	.6776	75, 76
78*	10	.7	.6	--
79	17	.6973	.6841	80, 81
80	17	2.2269	.6053	79, 81
81	10	.8917	.6841	79, 80

[1] Asterisk indicates station having less than 3 water years of data available, or nearby stations do not exist. Values of C_v and p_c are estimated.

[2] Percentage of the total record that was lost due to equipment failure.

For stations at which discharge measurements were affected only occasionally by backwater conditions such as ice, moss, or debris that collected on the control structure (natural or manmade), the rating curve was defined without the affected measurements. Fontaine (1982, page 27) previously documented the fact that during ice-free periods, existing rating curves generally defined the long-term rating function required in the analysis. At some Nevada stations, flow during periods of ice is small compared with flow during the rest of the year. For two of these stations (Nos. 22 and 66), the rating curve was defined only for the ice-free period, and discharge measurements made during midwinter were not included in the time series used to estimate the uncertainty for the station. Station 70 is affected by backwater conditions throughout the year; as a result, the fall (F) between station 70 and an auxiliary gage 0.3 mile downstream is routinely measured. Thus, a slight variation of equation 18 was used to compute the residuals for this station:

$$\ln Q_m = \ln B_1 + B_2(\ln GH) + B_3(\ln F) \quad . \qquad (19)$$

The time series of residuals between measured and rating-curve discharges is used to compute sample estimates of q and β (equation 13), two of the three parameters required to compute V_f, by determining a best-fit autocovariance function to the time series of residuals. Measurement variance, the third parameter, is determined from a standard error, which is assumed to be constant. For the Nevada program, all ice-free measurements used in the analysis (approximately 6,000) were assigned standard errors of 5, 8, or 10 percent, depending on field conditions at the time of measurement, and then averaged for each station. Thus, the measurement variance ranged from 5 to 10 percent.

As discussed earlier, q and β can be expressed as the process variance of the shifts from the rating curve and the 1-day autocorrelation coefficient of these shifts. Table 10 presents a summary of the autocovariance analysis expressed in terms of the 1-day autocorrelation (ρ), the process variance (β), and the measurement variance. The value of ρ was set to zero for stations 4, 5, 9, and 14 due to insufficient data as previously mentioned.

TABLE 10.--Summary of the autocovariance analysis

Index number	One-day autocorrelation coefficient (ρ)	Process variance [(log, base e)^2]	Measurement variance [(log, base e)^2]	Index number	One-day autocorrelation coefficient (ρ)	Process variance [(log, base e)^2]	Measurement variance [(log, base e)^2]
1	0.549	0.11306	0.0025	41	0.986	0.02508	0.0025
2	.980	1.0804	.0025	42	.992	.6639	.0025
3	.980	.00329	.0025	43	.991	.08635	.0025
4	.0	.003	.0025	44	.982	.33932	.00638
5	.0	.003	.0025	45	.976	.21412	.00638
6	.985	1.3013	.00638	46	.986	.09719	.0025
7	.996	.03447	.0025	47	.961	.50311	.00638
8	.986	.4804	.00638	48	.999	.41702	.00638
9	.0	.003	.0025	49	.986	.32113	.00638
10	.974	.00867	.0025	50	.428	.02292	.0025
11	.279	.06368	.00995	51	.965	.00550	.0025
12	.947	.08725	.0025	52	.988	.18916	.0025
13	.973	.00524	.00638	53	.793	.02358	.0025
14	.0	.003	.0025	54	.964	.73482	.0025
15	.997	.56873	.00638	55	.991	.41668	.00995
16	.994	.64868	.00995	56	.964	.34109	.0025
17	.988	.16715	.00995	57	.999	.54153	.0025
18	.982	.27324	.00995	58	.714	.0085	.0025
19	.969	.03407	.0025	59	.989	.14688	.0025
20	.987	.002216	.00638	60	.990	.74392	.0025
21	.995	.40278	.00638	61	.976	.06999	.00638
22	.975	.03893	.0025	62	.896	.08601	.00995
23	.996	.02790	.0025	63	.996	.01968	.0025
24	.996	.01925	.0025	64	.972	.00334	.0025
25	.985	.01360	.0025	65	.985	.04203	.00638
26	.969	.00707	.0025	66	.995	.51760	.00638
27	.991	.04951	.0025	67	.952	.00638	.00638
28	.979	.01350	.0025	68	.998	.0939	.0025
29	.991	.01272	.0025	69	.989	.04533	.0025
30	.967	.02074	.00638	70	.873	.02582	.00638
31	.984	.02494	.0025	71	.989	.73122	.00638
32	.979	.00336	.0025	72	.563	.00849	.0025
33	.994	.21002	.00995	73	.995	1.1422	.0025
34	.983	.48946	.00995	74	.950	.00137	.0025
35	.995	2.2082	.0025	75	.993	.85714	.00638
36	.949	.01763	.00638	76	.995	.48180	.00638
37	.983	.07151	.00995	77	.992	.10784	.00995
38	.991	.22766	.0025	78	.992	2.4387	.00995
39	.992	.11085	.00995	79	.976	.0109	.0025
40	.674	.00419	.00638	80	.993	.51364	.0025
				81	.976	.01378	.0025

The autocovariance parameters, summarized in table 10, and data from the definition of missing-record probabilities, summarized in table 9, are used jointly to define uncertainty functions for each gaging station. The uncertainty functions give the relation of total error variance to the number of visits and discharge measurements. Typical examples of uncertainty functions are given in figure 12 (assuming that a measurement was made during each visit).

Delineation of Alternative Routes for Stream-Gaging Trips

In Nevada, feasible routes to service the 81 stream gages were determined after consultation with personnel in the Hydrologic Data Section of the Nevada office and after review of the uncertainty functions. In summary, 49 alternative routes were selected to service all the 81 stream gages and 8 reservoirs and lakes in Nevada. The eight reservoirs and lakes are included in the overall cost of maintaining the program in Nevada. These routes included all possible combinations that describe the current operating practice, alternatives that were under consideration as future possibilities, routes that visited certain key individual stations, and combinations that grouped nearby gages where the levels of uncertainty indicated more frequent visits might be useful. These routes are summarized in table 11.

The costs associated with the practical routes must be determined. Fixed costs to operate a gage typically include equipment rental, batteries, electricity, data processing and storage, computer charges, maintenance and miscellaneous supplies, and analysis and supervisory charges. For Nevada, average values were applied to each station in the program for all the above categories.

The visit cost constitutes the hydrographer's salary for the time actually spent at a station servicing the equipment and making a discharge measurement. These costs vary from station to station and are a function of the difficulty and time required to make the discharge measurement. Average visit times were calculated for each station on the basis of an analysis of discharge-measurement data available. This time was then multiplied by the average hourly salary of hydrographers in the Nevada office to determine total visit costs.

Route costs include the vehicle cost associated with driving the number of miles it takes to cover the route, the cost of the hydrographer's time while in transit, and any per diem associated with the time it takes to complete the trip. These costs can vary widely, depending on how a trip is designed.

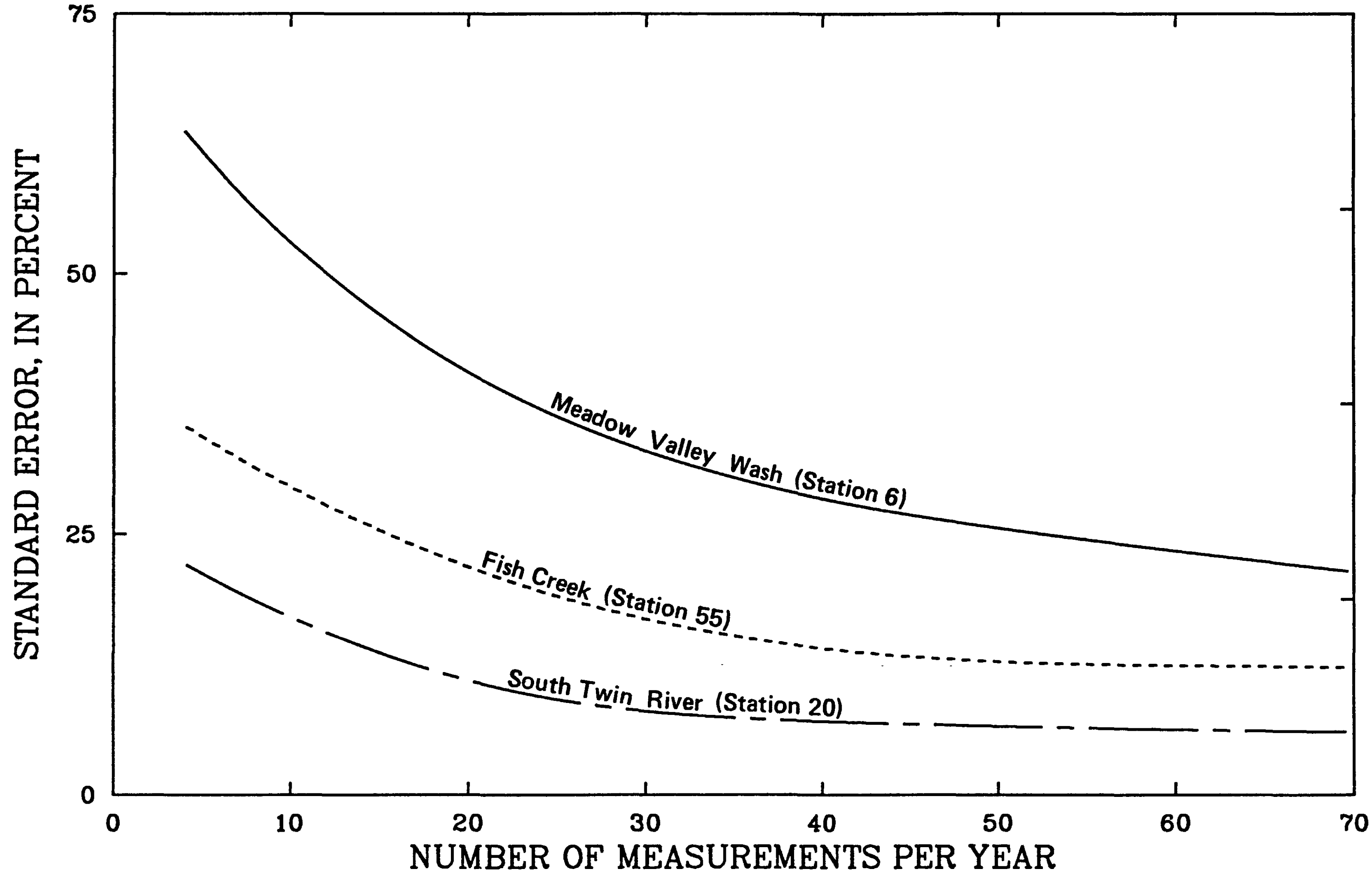


FIGURE 12.--Typical relations between number of streamflow measurements and standard error of streamflow determinations.

TABLE 11.--Alternative routes selected to service stream-gaging stations

Route number	Stations serviced[1]	Route number	Stations serviced[1]
1	13-20	26	27, 28
2	22, 24-26, 86-88	27	23, 29
3	1, 2, 4-6	28	30, 82
4	22, 24-26	29	33, 34
5	52-55	30	37, 61
6	56-58, 75	31	70, 71
7	66, 84, 85	32	45, 49
8	35, 39, 40	33	47, 48
9	62, 65, 89	34	3, 7
10	79-81	35	66
11	59, 60, 76	36	74
12	52, 53, 55	37	30
13	10-12	38	41
14	4-6	39	46
15	1, 2	40	50
16	63, 64	41	51
17	62, 65	42	8
18	67, 68	43	21
19	69, 72	44	47
20	42, 73	45	79
21	74, 83	46	80
22	77, 78	47	81
23	31, 36	48	54
24	32, 38	49	9
25	43, 44		

[1] Stations 1-81 are listed in table 1. Stations 82-89 are lake and reservoir gages serviced during stream-gaging trips as follows: 82, Walker Lake (station No. 10288500); 83, Pyramid Lake (10336500); 84, Washoe Lake (10348700); 85, Little Washoe Lake (10348800); 86, Upper Twin Lake (10290300); 87, Lower Twin Lake (10290400); 88, Bridgeport Reservoir (10292500); 89, Marlette Lake (10336710).

Results of Cost-Effectiveness Evaluation

The mathematical program "Traveling Hydrographer" (see earlier section) utilizes the uncertainty functions along with the appropriate route alternatives and cost data to compute the most cost-effective ways of operating the stream-gaging program and provides a standard error for each station and the average standard error of all stations. For Nevada, the first step was to simulate the current practice and determine the total uncertainty associated with it. To accomplish this, the number of visits being made to each stream gage in 1983 and the specific routes that were being used to make these visits were fixed. The resulting average standard error for practices in Nevada as of 1983, 28 percent, is plotted figure 13. The standard error for an individual station, in percent, is a measure of the average amount by which the discharge compacted with the Kalman filter for a specific site and point in time (instantaneous discharge) would differ from the true (measured) discharge at that time.

The missing record line in figure 13 represents the minimum level of average uncertainty that can be obtained for a given budget with the existing instrumentation and technology. The line was defined by several runs of the "Traveling Hydrographer" program with different budgets. Constraints on the operations, other than budget, are described in the following discussion.

To determine the minimum number of times each station must be visited, consideration was given only to the physical limitations of the method used to record data. The effect of visitation frequency on the accuracy of the data and amount of lost record is taken into account in the uncertainty analysis. In Nevada, a minimum requirement of four visits per year was used for all stations. This value was based on limitations of the batteries used to drive recording equipment, capacities of the uptake spools on the digital recorders, and the need to protect gages from freezing winter conditions in northern and central Nevada.

Minimum visit requirements also should reflect the need to visit stations for special reasons, such as water-quality sampling. In Nevada, all water-quality work is being done on separate trips not integrated with the surface-water field work and, therefore, did not influence minimum visit requirements.

The results in figure 13 and table 12 summarize the K-CERA analysis, which is predicated on a measurement of discharge each time a station is visited. In addition, figure 13 and table 12 are based on previously stated assumptions concerning both the time series of shifts to the stage-discharge relation and the methods of record reconstruction. Where a choice of assumptions was available, the assumption that would not underestimate the magnitude of the error variances was chosen.

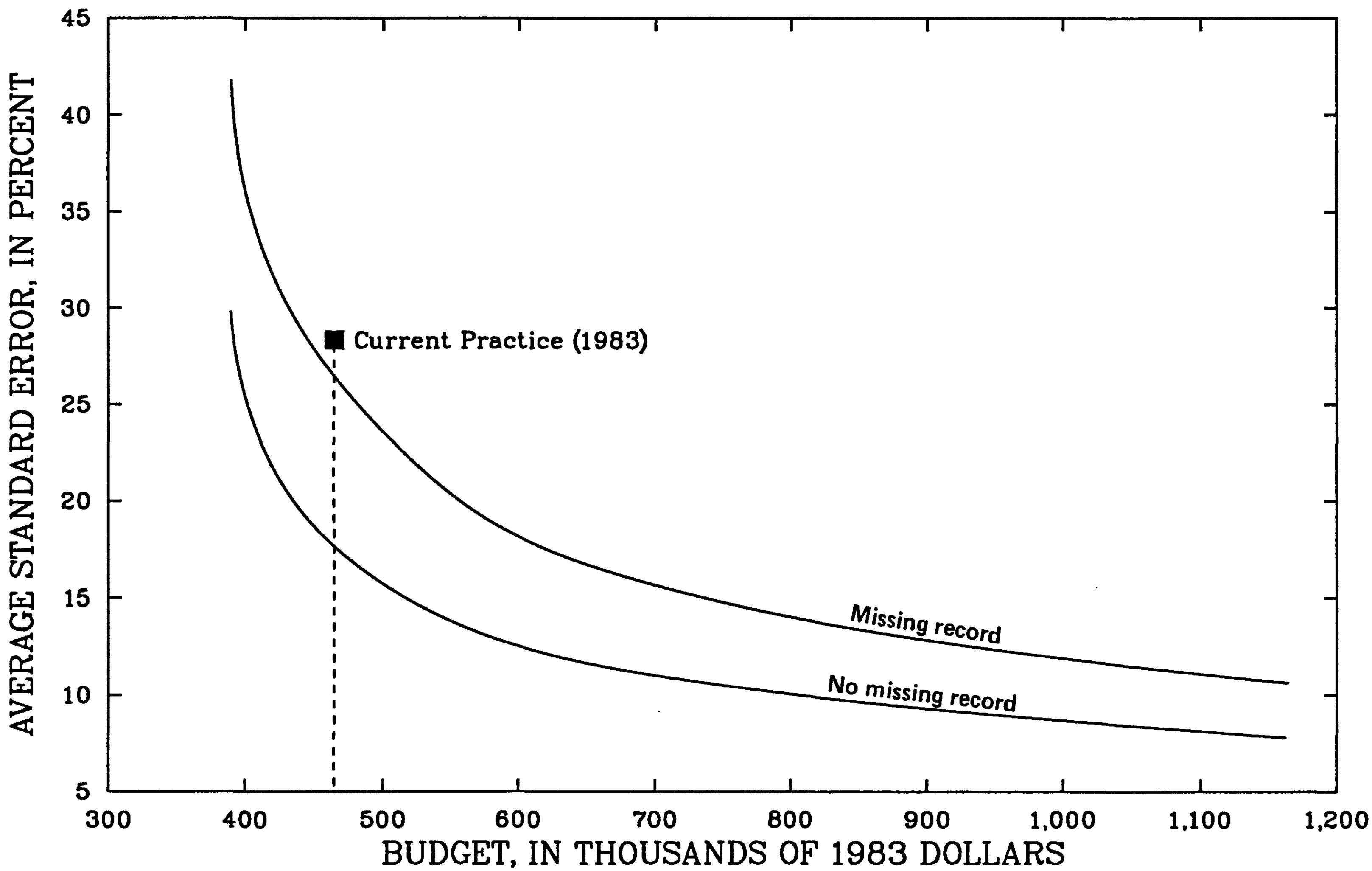


FIGURE 13.--Relation between stream-gagin budget and average standard error of streamflow determinations for entire Nevada program.

TABLE 12.--Results of K-CERA analysis for alternative budgets and operational procedures

Index number	Existing operations[1]	Alternative budget (in thousands of 1983 dollars)					
		390	430	465.5	744.8	931	1,164
	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits to site per year)						
1	58.2 [42.1] (12)	79.8 [57.4] (5)	54.0 [40.0] (15)	48.5 [37.4] (21)	32.0 [27.9] (90)	27.3 [24.1] (141)	24.1 [21.3] (193)
2	53.8 [53.4] (12)	73.4 [72.2] (5)	48.8 [48.1] (15)	41.7 [40.5] (21)	20.5 [18.4] (90)	16.4 [14.6] (141)	14.1 [12.4] (193)
3	29.0 [4.32] (12)	46.2 [31.0] (4)	33.1 [5.8] (9)	27.9 [4.0] (13)	15.1 [1.8] (45)	12.2 [1.4] (69)	10.0 [1.1] (103)
4	5.5 [5.58] (12)	5.5 [5.5] (4)	5.5 [5.5] (9)	5.5 [5.5] (16)	5.5 [5.5] (49)	5.5 [5.5] (65)	5.5 [5.5] (96)
5	5.5 [5.5] (12)	5.5 [5.5] (4)	5.5 [5.5] (9)	5.5 [5.5] (16)	5.5 [5.5] (49)	5.5 [5.5] (65)	5.5 [5.5] (96)
6	52.0 [51.4] (12)	77.6 [75.0] (4)	58.7 [58.4] (9)	45.6 [44.6] (16)	26.7 [24.4] (49)	23.3 [21.0] (65)	19.4 [17.2] (96)
7	26.8 [6.14] (12)	43.0 [28.6] (4)	30.7 [8.1] (9)	25.8 [5.7] (13)	14.0 [2.5] (45)	11.3 [2.1] (69)	9.3 [1.8] (126)
8	46.1 [34.8] (12)	67.3 [62.6] (4)	47.7 [36.8] (11)	41.9 [30.2] (15)	22.7 [13.6] (57)	18.8 [11.2] (86)	15.6 [9.2] (126)
9	5.5 [5.5] (12)	5.5 [5.5] (4)	5.5 [5.5] (4)	5.5 [5.5] (4)	5.5 [5.5] (4)	5.5 [5.5] (4)	5.5 [5.5] (4)
10	29.2 [7.5] (12)	42.7 [22.6] (5)	28.1 [7.0] (13)	25.5 [6.0] (16)	11.8 [2.4] (76)	9.3 [1.9] (123)	8.5 [1.7] (148)
11	34.4 [29.8] (12)	43.3 [36.5] (5)	33.8 [29.4] (13)	32.3 [28.5] (16)	25.2 [24.1] (76)	23.3 [22.5] (123)	22.4 [21.7] (148)
12	22.1 [21.3] (12)	27.7 [26.2] (5)	21.4 [20.7] (13)	20.0 [19.4] (16)	9.9 [9.5] (76)	7.9 [7.5] (123)	7.2 [6.8] (148)
13	10.5 [4.6] (12)	17.1 [7.9] (4)	15.6 [7.1] (5)	12.0 [5.3] (9)	7.3 [3.2] (26)	5.8 [2.5] (41)	5.2 [2.2] (52)
14	5.5 [5.5] (12)	5.5 [5.5] (4)	5.5 [5.5] (5)	5.5 [5.5] (9)	5.5 [5.5] (26)	5.5 [5.5] (41)	5.5 [5.5] (52)
15	16.2 [15.0] (12)	26.4 [25.8] (4)	24.0 [23.3] (5)	18.4 [17.2] (9)	11.3 [10.1] (26)	9.3 [8.2] (41)	8.4 [7.4] (52)
16	23.7 [22.4] (12)	39.0 [38.6] (4)	35.4 [34.8] (5)	27.2 [26.0] (9)	16.4 [15.0] (26)	13.2 [11.9] (41)	11.9 [10.7] (52)
17	23.4 [16.9] (12)	37.8 [30.8] (4)	34.6 [27.4] (5)	26.8 [19.8] (9)	16.2 [11.2] (26)	13.0 [8.8] (41)	11.7 [7.9] (52)

TABLE 12.--Results of K-CERA analysis for alternative budgets and operational procedures--Continued

Index number	Existing operations[1]	Alternative budget (in thousands of 1983 dollars) 390	430	465.5	744.8	931	1,164
	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits to site per year)						
18	35.0 [26.1] (12)	59.2 [46.3] (4)	53.5 [41.6] (5)	40.4 [30.6] (9)	23.7 [17.1] (26)	18.9 [13.6] (41)	16.8 [12.0] (52)
19	16.3 [11.8] (12)	25.1 [18.9] (4)	23.2 [17.4] (5)	18.4 [13.5] (9)	11.4 [8.0] (26)	9.2 [6.3] (41)	8.2 [5.6] (52)
20	15.2 [6.78] (12)	25.6 [12.9] (4)	23.1 [11.2] (5)	17.4 [8.0] (9)	10.4 [4.5] (26)	8.3 [3.6] (41)	7.4 [3.2] (52)
21	31.8 [19.7] (12)	49.8 [41.7] (4)	42.8 [32.2] (6)	34.5 [22.6] (10)	19.2 [10.2] (35)	16.2 [8.4] (50)	13.5 [7.1] (74)
22	16.3 [11.1] (12)	26.3 [18.0] (4)	26.3 [18.0] (4)	22.2 [15.3] (6)	13.1 [8.8] (19)	11.1 [7.4] (27)	9.1 [6.1] (40)
23	17.2 [4.3] (12)	29.2 [9.1] (4)	24.1 [6.6] (6)	22.4 [6.0] (7)	11.9 [2.9] (25)	9.8 [2.4] (37)	8.2 [2.0] (53)
24	7.54 [3.4] (12)	14.6 [6.4] (4)	14.6 [6.4] (4)	11.3 [5.0] (6)	5.8 [2.7] (19)	4.9 [2.3] (27)	3.9 [1.9] (40)
25	7.32 [5.2] (12)	15.1 [8.7] (4)	15.1 [8.7] (4)	11.5 [7.3] (6)	5.6 [4.2] (19)	4.5 [3.5] (27)	3.7 [2.9] (40)
26	7.1 [5.2] (12)	14.1 [7.8] (4)	14.1 [7.8] (4)	10.8 [6.8] (6)	5.5 [4.3] (19)	4.5 [3.6] (27)	3.7 [3.0] (40)
27	14.6 [7.7] (12)	24.7 [14.3] (4)	20.4 [11.4] (6)	17.8 [9.7] (8)	9.2 [4.7] (31)	7.6 [4.0] (46)	6.4 [3.4] (66)
28	17.7 [6.5] (12)	29.7 [12.1] (4)	24.6 [9.5] (6)	21.5 [8.1] (8)	11.1 [3.9] (31)	9.1 [3.2] (46)	7.6 [2.7] (66)
29	12.0 [4.3] (12)	22.6 [8.6] (4)	17.9 [6.5] (6)	16.4 [5.9] (7)	8.1 [2.9] (25)	6.5 [2.4] (37)	5.4 [2.0] (53)
30	20.4 [9.7] (12)	37.2 [16.4] (4)	27.3 [12.5] (7)	25.4 [11.8] (8)	12.6 [6.2] (30)	10.5 [5.2] (43)	9.0 [4.5] (58)
31	9.11 [7.2] (12)	18.0 [11.8] (4)	15.6 [10.7] (5)	13.9 [9.9] (6)	5.7 [4.8] (27)	4.8 [4.1] (38)	3.9 [3.3] (58)
32	6.75 [3.2] (12)	15.2 [5.1] (4)	9.9 [4.0] (7)	9.0 [3.8] (8)	3.8 [2.1] (28)	3.3 [1.9] (35)	2.7 [1.6] (49)
33	17.6 [13.1] (12)	26.5 [20.9] (5)	16.3 [12.0] (14)	15.3 [11.3] (16)	9.1 [6.7] (49)	7.7 [5.6] (69)	6.4 [4.8] (101)
34	33.1 [32.2] (12)	48.6 [48.3] (5)	30.7 [29.7] (14)	28.8 [27.8] (16)	16.6 15.7] (49)	14.1 [13.2] (69)	11.8 [11.1] (101)

TABLE 12.--Results of K-CERA analysis for alternative budgets and operational procedures--Continued

Index number	Existing operations[1]	390	430	465.5	744.8	931	1,164
		Alternative budget (in thousands of 1983 dollars)					
	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits to site per year)						
35	38.8 [36.7] (12)	51.6 [49.7] (7)	33.4 [31.3] (16)	33.4 [31.3] (16)	15.9 [14.5] (70)	13.0 [11.8] (106)	11.3 [10.3] (144)
36	15.7 [10] (12)	24.7 [14.1] (4)	22.6 [13.3] (5)	21.0 [12.6] (6)	11.0 [7.2] (27)	9.3 [6.1] (38)	7.6 [5.4] (70)
37	16.6 [12.8] (12)	22.6 [17.8] (6)	20.0 [15.6] (8)	19.0 [14.7] (9)	9.3 [7.0] (41)	8.5 [6.4] (49)	7.2 [5.4] (70)
38	17.8 [15.8] (12)	31.9 [27.8] (4)	23.8 [21.1] (7)	22.1 [19.6] (8)	11.4 [10.2] (28)	10.3 [9.1] (35)	8.7 [7.7] (49)
39	14.6 [11.1] (12)	18.9 [14.7] (7)	12.7 [9.6] (16)	12.7 [9.6] (16)	6.3 [4.7] (70)	5.1 [3.9] (106)	4.6 [3.5] (144)
40	10.0 [6.6] (12)	12.2 [7.0] (7)	9.1 [6.4] (16)	9.1 [6.4] (16)	5.9 [5.0] (70)	5.1 [4.4] (106)	4.5 [4.0] (144)
41	13.0 [6.9] (12)	20.4 [10.9] (5)	15.1 [8.0] (9)	17.2 [9.2] (7)	7.3 [3.9] (38)	5.9 [3.2] (58)	5.0 [2.7] (82)
42	30.3 [26.0] (12)	49.6 [41.8] (5)	30.3 [26] (12)	26.7 [23.0] (15)	14.1 [12.1] (50)	11.3 [9.8] (78)	9.7 [8.4] (106)
43	19.0 [10.5] (12)	28.9 [17.9] (5)	18.3 [10.0] (13)	16.1 [8.6] (17)	8.8 [4.6] (59)	7.1 [3.8] (90)	6.1 [3.3] (125)
44	49.7 [29.4] (12)	74.5 [48.7] (5)	47.8 [28.1] (13)	42.0 [24.1] (17)	22.7 [12.3] (59)	18.5 [10.0] (90)	15.7 [8.6] (125)
45	35.1 [27.1] (12)	47.6 [38.7] (6)	33.8 [25.9] (13)	30.7 [23.2] (16)	17.4 [12.4] (51)	14.4 [10.2] (75)	12.1 [8.6] (109)
46	19.8 [14.1] (12)	32.5 [26.2] (4)	24.0 [17.8] (8)	24.0 [17.8] (8)	11.7 [7.7] (35)	9.8 [6.4] (51)	8.1 [5.3] (75)
47	48.8 [48.2] (12)	67.4 [65.9] (4)	45.9 [45.2] (14)	41.0 [40.3] (18)	22.2 [21.2] (63)	18.7 [17.8] (89)	15.9 [15.1] (123)
48	12.8 [8.4] (12)	22.5 [16.2] (4)	14.0 [9.2] (10)	11.5 [7.6] (15)	7.9 [5.2] (32)	7.0 [5.0] (47)	5.6 [4.1] (77)
49	29.0 [24.3] (12)	43.0 [34.6] (6)	27.8 [23.4] (13)	24.6 [20.9] (16)	13.2 [11.4] (51)	10.8 [9.5] (75)	9.1 [7.8] (109)
50	19.7 [15.2] (12)	31.1 [16.7] (5)	22.4 [15.6] (9)	21.3 [15.4] (10)	15.4 [14.5] (31)	14.3 [13.9] (52)	12.9 [12.8] (98)
51	13.4 [5.2] (12)	31.0 [9.1] (4)	20.5 [7.1] (7)	20.5 [7.1] (7)	8.1 [3.8] (23)	6.4 [3.3] (31)	5.5 [3.0] (39)

TABLE 12.--Results of K-CERA analysis for alternative budgets and operational procedures--Continued

Index number	Existing operations[1]	Alternative budget (in thousands of 1983 dollars) 390	430	465.5	744.8	931	1,164
	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits to site per year)						
52	25.1 [18.2] (12)	40.7 [34.1] (4)	28.7 [21.6] (9)	21.8 [15.3] (16)	13.6 [9.0] (43)	11.1 [7.2] (65)	9.6 [6.3] (89)
53	24.1 [16.3] (12)	36.2 [22.0] (4)	26.7 [17.3] (9)	21.9 [15.3] (16)	15.5 [12.0] (43)	13.2 [10.3] (65)	11.5 [9.1] (89)
54	70.9 [61.6] (12)	92.2 [84.2] (6)	56.2 [46.8] (20)	51.4 [42.3] (24)	26.3 [20.1] (92)	21.4 [16.2] (139)	18.2 [13.7] (193)
55	28.0 [23.1] (12)	45.4 [42.1] (4)	32.1 [27.3] (9)	24.5 [19.7] (16)	15.4 [11.8] (43)	12.7 [9.7] (65)	10.9 [8.3] (89)
56	42.2 [39.1] (12)	64.4 [58.1] (4)	50.1 [46.3] (8)	40.8 [37.8] (13)	23.5 [21.3] (40)	20.0 [17.9] (55)	16.3 [14.6] (82)
57	29.2 [9.4] (12)	48.3 [21.6] (4)	35.3 [12.3] (8)	28.0 [9.0] (13)	16.3 [5.2] (40)	14.0 [4.5] (55)	11.5 [3.9] (82)
58	26.4 [10.3] (12)	44.3 [15.4] (4)	32.0 [11.4] (8)	25.5 [10.1] (13)	15.5 [8.1] (40)	13.6 [7.4] (55)	11.4 [6.5] (82)
59	22.2 [15.3] (12)	40.4 [29.4] (4)	27.9 [19.5] (8)	21.3 [14.6] (13)	12.0 [8.0] (38)	9.9 [6.6] (56)	8.0 [5.4] (85)
60	34.0 [31.5] (12)	54.8 [54.2] (4)	41.1 [39.2] (8)	32.7 [30.1] (13)	19.4 [16.7] (38)	16.1 [13.7] (56)	13.1 [11.0] (85)
61	17.3 [14.6] (12)	23.0 [19.8] (6)	20.6 [17.6] (8)	19.6 [16.6] (9)	9.7 [8.0] (41)	8.9 [7.3] (49)	7.6 [6.2] (70)
62	27.7 [26.2] (12)	34.3 [31.1] (4)	30.9 [28.7] (7)	30.1 [28.2] (8)	16.0 [15.1] (58)	15.0 [14.2] (67)	12.8 [12.1] (95)
63	3.9 [3.3] (12)	7.0 [5.6] (4)	7.0 [5.6] (4)	7.0 [5.6] (4)	4.3 [3.6] (10)	3.5 [3.0] (15)	3.0 [2.6] (20)
64	5.5 [3.4] (12)	9.2 [4.9] (4)	9.2 [4.9] (4)	9.2 [4.9] (4)	6.0 [3.6] (10)	5.0 [3.1] (15)	4.4 [2.7] (20)
65	13.8 [9.3] (12)	24.0 [15.9] (4)	18.2 [12.2] (7)	17.0 [11.4] (8)	6.3 [4.3] (58)	5.9 [4.1] (67)	5.0 [3.4] (95)
66	24.1 [18.1] (12)	41.2 [33.9] (4)	25.2 [19.1] (11)	25.2 [19.1] (11)	13.8 [10.0] (38)	11.4 [8.4] (56)	9.6 [7.1] (81)
67	13.9 [5.9] (12)	23.0 [8.7] (4)	20.8 [8.0] (5)	20.8 [8.0] (5)	10.2 [4.6] (23)	8.4 [3.9] (34)	7.1 [3.3] (49)
68	5.22 [4.9] (12)	9.0 [8.3] (4)	8.0 [7.4] (5)	8.0 [7.4] (5)	3.8 [3.6] (23)	3.2 [3.1] (34)	2.9 [2.8] (49)

TABLE 12.--Results of K-CERA analysis for alternative budgets and operational procedures--Continued

Index number	Existing operations[1]	390	430	465.5	744.8	931	1,164
		Alternative budget (in thousands of 1983 dollars)					
	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits to site per year)						
69	8.2 [7.7] (12)	13.7 [13.0] (4)	13.7 [13.0] (4)	13.7 [13.0] (4)	8.0 [7.5] (13)	6.6 [6.2] (19)	5.3 [5.0] (30)
70	17.5 [15.0] (12)	27.5 [18.4] (4)	18.6 [15.5] (10)	17.5 [15.0] (12)	11.7 [10.8] (38)	9.7 [9.1] (60)	8.7 [8.1] (77)
71	31.9 [31.0] (12)	54.6 [51.3] (4)	35.1 [34.0] (10)	31.9 [31.0] (12)	17.8 [17.3] (38)	14.3 [13.8] (60)	12.7 [12.2] (77)
72	9.8 [9.0] (12)	12.6 [9.5] (4)	12.6 [9.5] (4)	12.6 [9.5] (4)	9.7 [9.0] (13)	9.3 [8.9] (19)	8.8 [8.6] (30)
73	25.3 [25.2] (12)	40.1 [39.9] (5)	25.3 [25.2] (12)	22.5 [22.5] (15)	12.4 [12.3] (50)	10.0 [10.0] (78)	8.7 [8.7] (106)
74	4.4 [2.6] (12)	8.2 [3.5] (4)	8.2 [3.5] (4)	8.2 [3.5] (4)	5.8 [3.1] (7)	4.8 [2.8] (10)	4.2 [2.6] (13)
75	39.0 [29.5] (12)	65.2 [57.0] (4)	47.4 [37.7] (8)	37.5 [28.1] (13)	21.5 [14.9] (40)	18.5 [12.8] (55)	15.3 [10.6] (82)
76	45.5 [19.3] (12)	75.9 [43.4] (4)	55.3 [25.5] (8)	43.8 [18.4] (13)	25.9 [10.0] (38)	21.4 [8.3] (56)	17.5 [6.9] (85)
77	24.6 [16.9] (12)	29.6 [21.4] (4)	22.8 [15.5] (7)	19.2 [12.6] (10)	10.8 [6.7] (33)	9.2 [5.7] (46)	8.4 [5.2] (55)
78	71.2 [70.8] (12)	87.5 [85.2] (4)	65.8 [65.6] (7)	54.7 [54.6] (10)	29.8 [29.0] (33)	25.2 [24.4] (46)	23.1 [22.3] (55)
79	19.3 [6.5] (12)	33.0 [13.3] (4)	25.3 [9.0] (7)	17.3 [5.8] (15)	11.8 [3.8] (32)	9.8 [3.2] (46)	8.3 [2.7] (65)
80	66.3 [23.6] (12)	80.8 [31.4] (8)	54.2 [18.2] (18)	48.0 [15.8] (23)	24.8 [7.9] (87)	20.5 [6.6] (128)	17.0 [5.6] (188)
81	20.6 [7.0] (12)	35.6 [12.8] (4)	27.0 [9.3] (7)	18.5 [6.2] (15)	12.6 [4.2] (32)	10.5 [3.5] (46)	8.9 [3.0] (65)
Average standard error	28.5	41.9	30.5	26.1	14.8	12.4	10.7

[1] Budget ($465,000) and operational procedures in fiscal year 1983.

The 1983 program in Nevada required $465,500 to operate 81 stations, and had a 28-percent average standard error of estimate for the streamflow records obtained. The range in standard error was from a low of 4 percent, for station 63 (Truckee River at Reno), to a high of 71 percent, for station 78 (South Willow Creek near Gerlach). The average standard error could be reduced while maintaining the same budget of $465,500 by using better recording equipment, changing frequency of visits to gages, or both. The revised average standard error would decrease from 28 to 26 percent, but the extremes for individual sites would increase to 7 and 88 percent, for stations 63 and 78, respectively.

Alternatively, the average standard error would be 30 percent for a reduced budget of $445,000 and a redistribution of manpower and equipment. A budget decrease of 16 percent to $390,000 would increase the average standard error to 42 percent; the minimum standard error would be 7 percent (at station 63) and the maximum would be 92 percent (at station 54). A budget of less than $390,000 would not permit proper servicing and maintenance of gages and recorders. As a result, stations would have to be eliminated from the program.

The maximum budget analyzed was $1,164,000--2-1/2 times the 1983 budget; this resulted in an average standard error of 11 percent. The extremes of standard error would be 3 percent (at station 63) and 23 percent (at station 78). Doubling the 1983 budget to $931,000 in conjunction with a revised gage-servicing strategy would decrease the current average standard error by almost one half, to 12 percent. Overall, significant improvements in streamflow-record accuracy can be obtained if larger budgets become available.

The study indicates that a major error is due to lost data. If continuous data were available, the average standard error for the current program and budget could be reduced to 21 percent. This can also be interpreted to mean that the streamflow data would have a standard error of this magnitude during times when the equipment is operating properly if computed by the methods described. The curve labeled "No missing record" in figure 13 shows the average standard errors of estimate that could be obtained if completely uninterrupted data collection systems were available to measure and record data.

For an operational budget of $390,000, impacts of imperfect equipment are greatest; average standard errors increase from 26 percent at the current budget to 42 percent. A standard error less than 42 percent is not attainable with imperfect equipment at a budget less than $390,000.

At the other budgetary extreme of $1,164,000, in which stations are visited more frequently and the reliability of equipment is therefore less critical, average standard errors increased from 8 percent for completely reliable equipment to 11 percent for the current systems of sensing and recording hydrologic data. Thus, improved equipment would result in slightly improved streamflow measurements and records throughout the range of operational budgets that could be anticipated for the stream-gaging program in Nevada.

The type of analysis made above can also be applied to an evaluation of individual field-office activities in Nevada. The three offices servicing the Nevada stream-gaging network at the time of this study (1983) are in Carson City, Elko, and Boulder City (figure 2). Each office experiences different types of operational problems. In the Boulder City territory, for example, several stations gage ephemeral streams which usually are dry. Some Elko sites are temporarily affected by ice conditions which tend to decrease the accuracy of the record. Several Carson City gages are on mountain streams that have narrow channel widths or high flow velocities, or both, which result in poor measurement accuracy. In addition, the location of the field offices and their areas of coverage collectively define the route costs, which are a critical element in determining the most feasible solution to cost-effective operations.

The results of this field-office evaluation, shown in figure 14, imply that the smallest standard error of estimate for streamflow records, as a function of budget increases, is obtained from the Carson City operations, whereas the largest standard error is found in the Boulder City operations. In addition, the overall results of the network analysis for Nevada are, in part, governed by the inherent problems and number of stations in each field office territory (few runoff events throughout the year at some stations). In 1983, the Carson City stream-gaging operations involved 58 percent of the total number of gages (47 of 81), whereas the Boulder City operations, which account for the highest standard error, included only 16 percent of the gages (13 sites).

For the Carson City field operation, the required 1983 budget for the 47-station program was $271,000 and resulted in a standard error of 25 percent. A change in strategy (an increase or decrease in the number of visits to the group of gaging stations) with the same budget would result in a decrease to 21 percent. The 1983 Elko field operation required a budget of $120,700 to maintain 21 gages and resulted in a standard error of 35 percent. A change in strategy, but retaining the same budget, would result in a slight decrease, to 34 percent. The results of this analysis are shown in table 13. The 1983 Boulder City operation resulted in an average standard error of 36 percent, and required a budget of $74,700 to operate the 13-station program. If the same budget were maintained but initiating a different strategy the standard error would decrease from 36 to 32 percent.

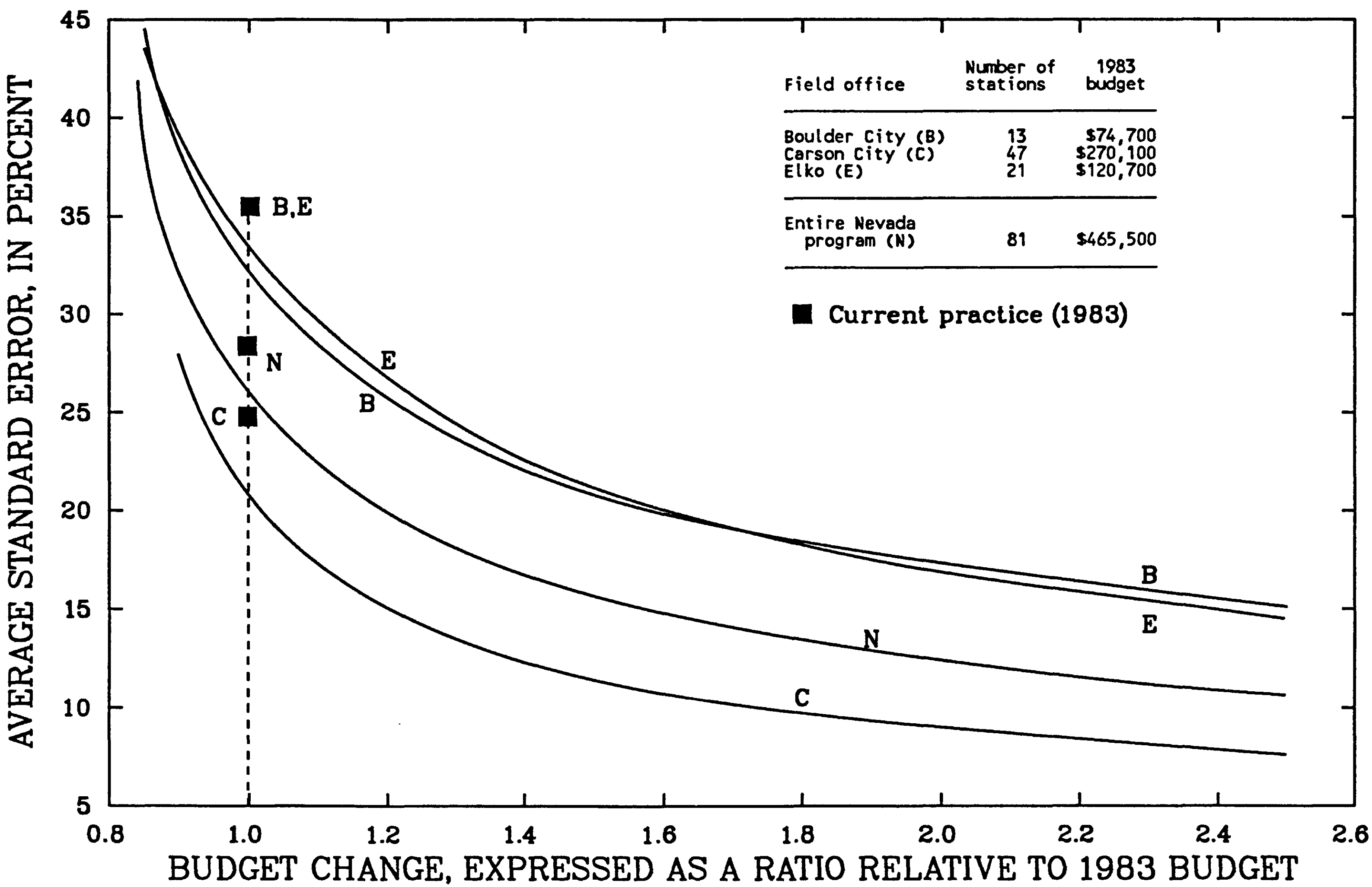


FIGURE 14.--Relation between stream-gaging budget and average standard error of streamflow estimates, by field office.

TABLE 13.--Results of K-CERA analysis, by field office

Index number	Existing operations[1]	Change in operational procedures
	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits to site per year)	
	BOULDER CITY OFFICE (1983 budget = $74,700)	
1	58.2 [42.1] (12)	50.0 [38.1] (19)
2	53.8 [53.4] (12)	43.8 [42.7] (19)
3	30.0 [4.3] (12)	25.2 [3.4] (16)
4	5.5 [5.5] (12)	5.5 [5.5] (14)
5	5.5 [5.5] (12)	5.5 [5.5] (14)
6	53.0 [52.6] (12)	49.5 [48.8] (14)
7	26.8 [6.3] (12)	23.4 [5.0] (16)
8	46.4 [35.6] (12)	41.1 [29.7] (16)
9	5.5 [5.5] (12)	5.5 [5.5] (4)
10	29.2 [7.6] (12)	25.5 [6.1] (16)
11	34.5 [29.8] (12)	32.3 [28.5] (16)
12	22.3 [21.6] (12)	20.3 [19.7] (16)
21	31.9 [20.3] (12)	38.2 [26.9] (8)
13	10.5 [4.6] (12)	12.0 [5.3] (9)
14	5.5 [5.5] (12)	5.5 [5.5] (9)
Average standard error	35.5	32.1
	CARSON CITY OFFICE (1983 budget = $270,100)	
15	16.2 [15.0] (12)	18.4 [17.2] (9)
16	23.7 [22.4] (12)	27.2 [26.0] (9)
17	23.5 [16.9] (12)	26.7 [19.8] (9)
18	35.0 [26.1] (12)	40.4 [30.6] (9)
19	16.3 [11.8] (12)	18.4 [13.5] (9)
20	15.2 [6.8] (12)	17.4 [8.0] (9)
22	16.3 [11.1] (12)	20.8 [14.2] (7)
23	17.2 [4.3] (12)	19.8 [5.1] (9)
24	7.5 [3.4] (12)	10.3 [4.6] (7)
25	7.3 [5.2] (12)	10.4 [6.8] (7)
26	7.1 [5.2] (12)	9.8 [6.4] (7)
27	14.6 [7.7] (12)	15.2 [8.1] (11)
28	17.7 [6.5] (12)	18.4 [6.8] (11)
29	12.1 [4.3] (12)	14.2 [5.1] (9)
30	20.4 [9.7] (12)	22.5 [10.6] (11)
31	9.1 [7.2] (12)	10.8 [8.2] (9)
32	6.7 [3.2] (12)	7.1 [3.3] (11)
33	17.6 [13.1] (12)	13.8 [10.1] (20)
34	33.1 [32.3] (12)	25.8 [24.7) (20)
35	38.8 [36.7] (12)	27.8 [25.7] (24)
36	15.7 [10.0] (12)	17.7 [11.0] (9)
37	16.6 [12.8] (12)	16.0 [12.3] (13)
38	17.8 [15.8] (12)	18.6 [16.6] (11)
39	14.6 [11.1] (12)	10.6 [8.0] (24)
40	10.0 [6.6] (12)	8.1 [6.1] (24)
41	13.1 [6.9] (12)	12.1 [6.4] (12)
42	30.3 [26.0] (12)	22.8 [19.6] (19)
43	19.1 [10.5] (12)	14.2 [7.5] (22)
44	49.7 [29.4] (12)	37.0 [20.8] (22)
61	17.3 [14.6] (12)	16.6 [14.0] (13)
62	27.7 [26.2] (12)	26.7 [25.3] (13)
63	3.9 [3.3] (12)	7.0 [5.6] (4)
64	5.5 [3.4] (12)	9.2 [4.9] (4)
65	13.8 [9.3] (12)	12.8 [8.6] (13)
66	24.1 [18.1] (12)	23.2 [17.3] (14)

TABLE 13.--Results of K-CERA analysis, by field office--Continued

Index number	Existing operations[1]	Change in operational procedures
	Standard error of instantaneous discharge, in percent [Equivalent Gaussian Spread] (Number of visits to site per year)	
67	13.9 [5.9] (12)	16.7 [6.9] (8)
68	5.2 [4.9] (12)	6.4 [6.0] (8)
69	8.2 [7.7] (12)	13.7 [13.0] (4)
70	17.5 [15.0] (12)	15.6 [13.9] (17)
71	31.9 [31.0] (12)	26.7 [25.9] (17)
72	9.8 [9.1] (12)	12.6 [9.5] (4)
73	25.3 [25.2] (12)	19.4 [19.4] (19)
74	4.4 [2.7] (12)	8.2 [3.5] (4)
77	24.6 [16.9] (6)	15.8 [10.1] (15)
78	105.6 [102.4] (6)	63.9 [63.9] (15)
Average standard error	24.9	20.6
	ELKO OFFICE (1983 Budget = $120,700)	
45	35.1 [27.1] (12)	33.8 [25.9] (13)
46	19.9 [14.1] (12)	25.6 [19.3] (7)
47	48.8 [48.2] (12)	48.8 [48.2] (12)
48	12.8 [8.4] (12)	12.8 [8.4] (12)
49	29.0 [24.3] (12)	27.8 [23.4] (13)
50	19.7 [15.3] (12)	23.7 [15.7] (8)
51	13.4 [5.2] (12)	20.5 [7.1] (7)
52	25.1 [18.2] (12)	24.2 [17.3] (13)
53	24.1 [16.3] (12)	23.5 [16.0] (13)
54	70.9 [61.6] (12)	62.4 [52.9] (16)
55	28.1 [23.2] (12)	27.0 [22.2] (13)
56	42.3 [39.2] (12)	40.8 [37.8] (13)
57	29.2 [9.4] (12)	28.1 [9.0] (13)
58	26.7 [11.3] (12)	25.7 [10.8] (13)
59	22.3 [15.3] (12)	23.4 [16.1] (11)
60	34.0 [31.5] (12)	35.4 [33.0] (11)
75	39.0 [29.5] (12)	37.5 [28.1] (13)
76	45.5 [19.3] (12)	47.5 [20.6] (11)
79	19.3 [6.5] (12)	18.6 [6.2] (13)
80	66.3 [23.6] (12)	59.4 [20.4] (15)
81	23.1 [13.7] (12)	22.2 [13.1] (13)
Average standard error	35.5	34.4

[1] Budget and operational procedures in fiscal year 1983.

Suggested Changes in the Nevada Stream-Gaging Program

As a result of this study, the following changes are suggested:

1. The field methods and office procedures used in the Nevada stream-gaging program could be changed to maintain the average standard error of estimate at about 28 percent at the 1983 budget level of approximately $465,500. The changes would result in some increases and some decreases in the accuracy of individual records. These changes include increasing the number of visits to stations with less accurate records and decreasing the number where data currently are sufficiently accurate. Also, it may be possible to detect malfunctioning equipment through the use of satellite telemetry stations and thus, reduce the amount of lost record through timely repairs.

2. The amount of funding for stations with accuracies that are not acceptable for the intended data uses could be renegotiated with the users.

3. Any funding made available by implementation of the first two proposals, or any new funding, could be used to establish new stream gages in central and southern Nevada, where data are sparse.

4. The K-CERA analysis could be rerun with new stations included when sufficient information about the characteristics of the new stations becomes available.

5. The cost effectiveness of critical elements of the program, such as methods for reducing the probability of missing record, increased use of local gage observers, and application of data relay by satellite, could be evaluated.

SUMMARY

As part of a nationwide effort by the U.S. Geological Survey, the stream-gaging network in Nevada was evaluated to define and document the most cost-effective means of furnishing streamflow information. Streamflow data collection in the State began in 1889 with the establishment of one gage in the Truckee River near the Nevada-California State line, and by 1980 had increased to 134 continuous-record stream, canal, and drain gages. This study deals with 79 streamflow gages and 2 canal-flow gages that were under the direct operation of Nevada personnel as of 1983. Cost-effective allocation of resources, including budget and operational criteria, were studied using Kalman-filtering techniques. Alternate methods for developing streamflow data were evaluated using flow-routing and regression analyses. Nowhere in Nevada did either method provide sufficiently accurate results to warrant its use in place of stream gaging.

In 1983, the 81 continuous-record gages were operated at a cost of $465,500. Twenty-one sources of funding contributed to this program, and nine data-use categories have been identified. The evaluation indicated that all stations in the current (1983) program should be retained. In spite of the size of the program, streamflow data for a large part of central and southern Nevada are sparse. Additional gaging stations in these areas would be helpful, if additional funds become available.

At the 1983 funding level, the average standard error of streamflow records was nearly 28 percent. The current (1983) overall level of record accuracy at these 81 sites could be maintained at a budget of $445,000, if the allocation of manpower and equipment among the gages were redistributed. Such a redistribution would allow additional money for establishing gages in data-deficient areas of the State.

The minimum budget analyzed, $390,000, would have resulted in an average standard error of about 42 percent. A budget less than this would not have permitted proper service and maintenance of the gages and adequate computation of records. The maximum budget analyzed, $1,164,000, would have resulted in an average standard error of 11 percent.

A major cause of data error is loss of primary record (stage or other correlative data) at stream gages, owing to malfunction of sensing and recording equipment. Upgrading equipment and developing strategies to minimize lost record would improve reliability and accuracy of the streamflow data generated in the State. If perfectly operating equipment were available, the standard error for the 1983 program and budget could have been reduced to 21 percent. This can also be interpreted to mean that the streamflow data have a standard error of this magnitude during times when the equipment is operating properly.

Future studies of the cost effectiveness of the stream-gaging program would be useful. These studies could include investigations of the optimum ratio of the number of discharge measurements to total site visits for each station, as well as cost-effective ways to reduce the probability of lost correlative data. For example, increased use of local gage observers and satellite relay of data could be evaluated as to their cost-effectiveness in providing streamflow data. Future studies of changes in demand for streamflow information, with subsequent addition and deletion of stream gages, would also be useful. These changes could affect the operation of other stations in the program because of the interdependence of data uses and data-collection costs among stations.

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