COST EFFECTIVENESS OF THE STREAM-GAGING PROGRAM IN NORTHEASTERN CALIFORNIA

By S. H. Hoffard, V. F. Pearce, Gary D. Tasker, and Harry W. Doyle, Jr.

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CONVERSION FACTORS

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

Multiply inch-pound units	By	To obtain SI units
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second - day (ft^3/s - days)	2,447	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

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ABSTRACT

This report documents the results of a cost-effectiveness study of the stream-gaging program in the Redding, Sacramento, and Tahoe City field office areas of northeastern California. Data uses and funding sources for 127 continuous-record gaging stations operated by the U.S. Geological Survey are identified. One station was suggested for removal from the cooperative program because of insufficient use of data.

Flow-routing and multiple-regression models were developed to simulate records for 10 gaging stations to test less expensive methods of providing streamflow information. Only the models for the Klamath River near Seiad Valley and the Feather River near Nicolaus may be sufficiently accurate to warrant discontinuing the stations. Further investigation to determine the acceptability of the model accuracies is needed.

An operations-analysis program known as K-CERA was used to analyze current gaging-station operating procedures and to determine the most cost-effective service routes and frequency of visits.

The current budget (1984) for operation of the 127-station program is $747,000. With this budget and using the present operating plan, the average standard error of estimate of streamflow records is 12.9 percent. The overall level of error could be decreased to 12.0 percent using computer-selected service routes and visit frequencies. The present average standard error of 12.9 percent could be maintained with a budget of $729,000, using the computer-selected service routes and visit frequencies.

A minimum budget of $726,000 is required to operate the 127 gaging stations; a budget less than this does not permit proper service and maintenance of the gages and recorders. At the minimum budget, the average standard error is 13.5 percent.

Implementation of the computer-selected routes, and refinement of input to the K-CERA analysis is suggested along with continued use of the program to aid in developing network operation plans.

INTRODUCTION

The U.S. Geological Survey is the principal Federal agency collecting surface-water data in the Nation. The data are collected in cooperation with State and local governments and other Federal agencies. In 1983, the Geological Survey operated approximately 8,000 continuous-record gaging stations throughout the Nation. Some of these records extend back to the turn of the century. Any activity of long standing, such as the collection of surface-water data, should be reexamined at intervals, if not continuously, 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 Survey, in 1983, undertook another nationwide analysis of the stream-gaging program that will be completed over a 5-year period with 20 percent of the program being analyzed each year. The objective of this analysis is to define and document the most cost-effective means of furnishing streamflow information.

For every continuous-record gaging station, the analysis identifies the principal uses of the data and relates these uses to funding sources. Gaged sites for which data are no longer needed are identified, as are deficient or unmet data demands. In addition, gaging stations are categorized as to whether the data are available to users in a real-time sense, on a provisional basis, or at the end of the water year.

The second aspect of the analysis is to identify less costly alternative methods of furnishing the needed information; among these are flow-routing models and statistical methods. The stream-gaging program is no longer considered a network of observation points, but rather an integrated information system in which data are provided both by observation and synthesis.

The final part of the analysis involves the use of Kalman-filtering and mathematical-programming techniques to define strategies for operation of the necessary stations that minimize the uncertainty in the streamflow records for given operating budgets. Kalman-filtering techniques are used to compute uncertainty functions (relating the standard errors of computation or estimation of streamflow records to the frequencies of visits to the stream gages) for all stations in the analysis. A steepest-descent optimization program uses the uncertainty functions, along with information on practical stream-gaging routes and associated costs, and the total operating budget, to identify the visit frequency for each station that minimizes the overall uncertainty in the computed streamflow. The stream-gaging program resulting from this analysis will meet the expressed water-data needs in the most cost-effective manner.

The standard errors of estimate given in this report are those that would occur if daily discharges were computed through the use of methods described in this study. No attempt has been made to estimate standard errors for discharges that are computed by other means. Such errors could differ greatly from the errors computed in the report. The magnitude and direction of the differences would be the function of methods used to account for shifting controls and for estimating discharges during periods of missing record.

This report is organized into five sections, the first is an introduction to the stream-gaging program in California and to the study itself. The middle three sections are discussions of individual steps of the analysis. Because of the sequential nature of the steps and the dependence of subsequent steps on the previous results, conclusions are given at the end of each of the middle three sections. The study, including all conclusions, is summarized in the final section.

This report is the first of three reports planned to evaluate the stream-gaging program of the Geological Survey in California. Operation of the program is currently the responsibility of 10 field offices. This report discusses the stream-gaging program which consists of 127 continuous-record gaging stations in the Sacramento River, Klamath River, Honey Lake, and Truckee River basins operated by personnel in the Redding, Sacramento, and Tahoe City field offices (see pl. 1). Forthcoming reports will include the San Joaquin River basin, as well as the coastal basins from Oregon to the Mexico border, and the closed basins in southeastern California.

History of the Stream-Gaging Program

The first gaging station in California established by the Geological Survey in April 1895 was on the Sacramento River at Jelly's Ferry, near Red Bluff. Several stations were established in the San Joaquin River basin in 1895-96, and three stations were established in southern California. The stream-gaging program increased rapidly due to the need for streamflow data for irrigation, hydropower, and water rights. By the end of 1903 (the first year of cooperation with the State of California), there were 55 gaging stations operated by the Survey. Daily gaging-station records were published in Part 11 Geological Survey Water-Supply Papers every 10 years from 1900-80. The number of records published is shown in table 1. Many records were furnished by Federal, cooperative, and other Federal agency funded stations. No reservoir or lake records are included.

Continuous-record gaging stations for which streamflow data are published are listed in table 2. About three-fourths of the gaging stations listed in the 1982 annual data report "Water Resources Data for California" have been operated by the U.S. Geological Survey. The program had a steady growth from 1900-70 with a rapid decline from about 1970 to present (tables 1 and 2). Much of the growth of the California stream-gaging program was the result of the need of the California Department of Water Resources (DWR) for runoff information to develop the California Water Plan. By 1970, the plan was well established and large expenditures for data collection could no longer be justified.

TABLE 1. Number of daily gaging-station records published, 1900-80

Year	Number of daily records
1900	19
1910	78
1920	169
1930	297
1940	339
1950	418
1960	763
1970	891
1980	712

TABLE 2. Daily records published for 1982 water year

Cooperator Stations	
USGS operated	333
Cooperator operated	22
Other Federal Agencies Stations (Operated by USGS for other Federal Agencies)	104
Federal Stations (Operated by USGS, all Federal funding)	8
FERC Stations (Operated by private power companies as license requirement)	135
Total	602
USGS operated stations	445

The first documented California network evaluation was conducted by Crippen and Beall (1970) using streamflow records collected through the 1967 water year. The evaluation used concepts and procedures developed by Benson and Carter (1973). That report presented many regression equations useful in estimating streamflow characteristics for ungaged sites, but the report was not particularly useful in guiding the development of the stream-gaging program.

During 1967-72, a substantial reduction in the USGS-DWR program occurred. Many stations dropped by DWR were picked up in the cooperative programs with other agencies. People in both DWR and the USGS were concerned, however, that key stations might inadvertently be discontinued. This concern lead to a new network appraisal. The basic method of appraisal was (1) the selection of a network of primary stations which would be continued indefinitely, and (2) the testing of the adequacy of records at the remaining nonprimary stations by regression analysis with selected primary stations, using annual discharge. The principal objective of the evaluation was to establish the primary network; it presented no evaluation of the cost effectiveness of stream-gaging practices.

Current Stream-Gaging Program

The area of operation for the Redding, Sacramento, and Tahoe City field offices is bounded on the north by the Oregon-California State line, on the east by the Nevada-California State line, and on the south by the approximate basin divide between the Mokelumne and Stanislaus Rivers and an imaginary line through Stockton to Antioch. The western boundary is the crest of the Klamath Mountains, Trinity Alps, Yolla Bolly Mountains, and lesser ridges extending southward to the Sacramento-San Joaquin Delta. (See plate 1.) The principal hydrologic unit in the area is the Sacramento River basin with a drainage area of 26,000 mi^2 at the confluence with the San Joaquin River. About 4,000 mi^2 of the Mokelumne and Calaveras River basins in the San Joaquin River drainage system also is included in the study area. The northern area includes 6,000 mi^2 of the Klamath River basin and the eastern area includes about 700 mi^2 of the Lake Tahoe-Truckee River basin and 4,000 mi^2 of the Honey Lake basin and other closed basins in the Modoc and Lassen Counties. The total area covered by the operations of the Sacramento, Redding, and Tahoe City field offices is about 41,000 mi^2.

The Sacramento River and its tributaries are the backbone of the California Water Plan, and supply approximately 4.5 million acre-ft annually for export to the San Joaquin Valley and southern California via the California Aqueduct and the Delta-Mendota Canal. Irrigation diversions of streamflow within the Sacramento Valley range from 4.3 to 5.0 million acre-ft annually (A. K. Williamson, U.S. Geological Survey, written commun., 1983). Approximately 80 hydroelectric plants on the Sacramento River and its tributaries have a total generating capacity of about 5,600 megawatts. Because of this intensive use of water, a large number of gaging stations have been operated many years by the Survey, local agencies, and private power companies for management purposes and to collect project design data. A relatively small number of gaging stations are operated solely as hydrologic index stations; some management stations, however, serve a dual purpose as both accounting stations and index stations.

In 1983, there were 127 continuous-record gaging stations operated by the U.S. Geological Survey in the study area. Table 3 shows the number of stations in each principal basin, the field office servicing the stations, and the proposed 1984 fiscal year budget for operating the stations.

Selected hydrologic data, including drainage area, period of record, and mean annual flow, for the 127 stations are given in table 4. Station identification numbers are the Geological Survey's eight-digit downstream-order station number. Table 4 also provides the complete name of each station.

TABLE 3. 1984 budgets and number of gaging stations in the Redding, Sacramento, and Tahoe City field office areas

Field office area	1984 fiscal year budget	Number of stations per basin				Total
		Klamath River	Sacramento River	Truckee River	Honey Lake	
Redding	$229,000	9	28	--	2	39
Sacramento	$314,000	--	53	--	--	53
Tahoe City	$204,000	--	18	17	--	35

TABLE 4. Selected hydrologic data for stations in the stream-gaging program for northeastern California

[All stations are in California except as noted. Station name: Only current station names are shown. Some station names have been changed one or more times since the initial establishment, and locetions may have changed slightly. For a complete history of name and location changes, readers are referred to the latest California Water Resources Data report (U.S. Geological Survey, 1982). Average discherge: Discharge values are from the 1982 California Water Resources Deta reports (U.S. Geologicel Survey, 1982). No values are shown for stations with less than 5 years of published record]

Station No.	Station name	Drainage area (mi^2)	Period of record	Average discharge (ft^3/s)
		Redding field office		
10356500	Susan River at Susanville	184	February 1917 to June 1921; October 1950 to current year	92
10358500	Willow Creek near Susanville	90.4	October 1950 to current year	34
11341400	Sacramento River near Mt. Shasta	135	October 1959 to current year	246
11342000	Sacramento River at Delta	425	October 1944 to current year	1,153
11344000	North Fork Pit River at Alturas	212	October 1971 to current yeer	60
11345500	South Fork Pit River near Likely	247	October 1928 to current yeer	78
11348500	Pit River near Canby	1,431	January 1904 to December 1905; May 1929 to current year	242
11355010	Pit River below Pit No 1. Powerhouse, near Fall River Mills	3,761	August 1975 to current year	1,678
11355500	Hat Creek near Hat Creek	162	July 1926 to September 1929; April 1930 to current year	139
11370500	Sacramento River at Keswick	6,468	October 1938 to current year	8,479
11371000	Clear Creek at French Gulch	115	July 1950 to current year	213
11372000	Clear Creek neer Igo	228	October 1940 to current year	458
11374000	Cow Creek near Millville	425	October 1949 to current year	672
11375810	Cottonwood Creek near Olinda	395	August 1971 to current year	426
11375870	South Fork Cottonwood Creek near Olinda	371	November 1976 to current yeer	450
11375900	South Fork Cottonwood Creek at Evergreen Road, near Cottonwood	397	June 1982 to current year	--
11376000	Cottonwood Creek near Cottonwood	927	October 1940 to current year	844
11376550	Battle Creek below Coleman Fish Hatchery, near Cottonwood	357	October 1961 to current year	502
11377100	Sacramento River above Bend Bridge, near Red Bluff	8,900	January 1892 to current year	13,120
11379500	Elder Creek neer Paskenta	92.4	October 1948 to current year	99
11381500	Mill Creek near Los Molinos	131	September 1909 to August 1913; October 1928 to current yeer	300
11382000	Thomes Creek at Paskenta	203	October 1920 to current year	285
11383500	Deer Creek near Vina	208	October 1911 to December 1915; March 1920 to December 1937; January 1939 to current year	313
11384000	Big Chico Creek near Chico	72.4	May 1930 to current yeer	143
11387200	Stony Creek abova Black Butte Lake, near Orland	623	October 1980 to current year	--
11387990	South Diversion Canal near Orland	--	July 1955 to current year	101
11388000	Stony Creek below Black Butte Dam, near Orland	738	July 1955 to current year	620
11389950	Little Butte Creek at Magalia	11.4	October 1968 to current year	15
11390000	Butte Creek near Chico	147	October 1930 to current year	402

TABLE 4. Selected hydrologic data for stations in the stream-gaging program for northeastern California--Continued

Station No.	Station name	Drainage area (mi^2)	Period of record	Average discharge (ft^3/s)
		Redding field office--Continued		
11405300	West Branch Feather River near Paradise	110	October 1957 to current year	295
11516530	Klamath River below Iron Gate Dam	4,630	October 1960 to current year	2,149
11517500	Shasta River near Yreka	793	October 1933 to December 1941; December 1944 to current year	184
11519500	Scott River near Fort Jones	653	December 1941 to current year	650
11520500	Klamath River near Seiad Valley	6,940	October 1912 to September 1925; July 1951 to current year	4,025
11521500	Indian Creek near Happy Camp	120	September 1911 to September 1921; December 1956 to current year	423
11523200	Trinity River above Coffee Creek, near Trinity Center	149	September 1957 to current yeer	410
11525500	Trinity River at Leviston	719	August 1911 to current year	1,703
11525600	Grass Valley Creek at Fawn Lodge, near Leviston	30.8	November 1975 to current year	40
11525655	Trinity River below Limekiln Gulch, near Douglas City	812	April 1981 to current year	--
		Secramento field office		
11308900	Calaveras River below New Hogan Dam, near Valley Springs	363	January 1961 to current year	212
11312000	Bear Creek near Lockeford	47.4	October 1930 to current year	12
11316800	Forest Creek near Wilseyville	20.8	July 1960 to current year	22
11317000	Middle Fork Mokelumne River at West Point	68.4	October 1911 to current year	61
11318500	South Fork Mokelumne River near West Point	75.1	October 1933 to current year	81
11319500	Mokelumne River near Mokelumne Hill	544	October 1927 to current year	963
11323500	Mokelumne River below Camanche Dam	627	October 1904 to current year	788
11325500	Mokelumne River at Woodbridge	661	May 1924 to current year	580
11329500	Dry Creek near Galt	324	October 1926 to September 1933; Ocotber 1944 to current year	114
11333000	Camp Creek near Somerset	62.6	October 1954 to current year	78
11333500	North Fork Cosumnes River near El Dorado	205	August 1911 to December 1941; October 1948 to current year	197
11335000	Cosumnes River at Michigan Bar	536	October 1907 to current year	74
11336580	Morrison Creek near Sacramento	53.4	July 1959 to current year	18
11389000	Sacramento River at Butte City	12,075	October 1938 to current year	13,130
11389500	Sacramento River at Colusa	12,090	April 1921 to October 1939; June 1940 to current year	11,390
11390500	Sacramento River below Wilkins Slough, near Grimes	12,926	October 1938 to current year	10,060
11394500	Middle Fork Feather River near Merrimac	1,062	October 1951 to current year	1,368
11395030	South Fork Feather River below Little Grass Valley Dam	25.9	October 1927 to September 1933; October 1960 to current year	94
11395200	South Fork Feather River below	37.7	October 1960 to current year	146

TABLE 4. Selected hydrologic data for stations in the stream-gaging program for northeastern California--Continued

Station No.	Station name	Drainage area (mi^2)	Period of record	Average discharge (ft^3/s)
	Sacramento field office--Continued			
11395500	Oroville-Wyandotte Canal near Clipper Mills	--	October 1927 to September 1941; October 1953 to current year	9
11396000	Lost Creek near Clipper Mills	30.0	October 1927 to September 1941; October 1948 to current year	20
11396200	South Fork Feather River below Forbestown Dam	87.5	July 1962 to current year	54
11396310	Miners Ranch Canal below Ponderosa Dam, near Forbestown	--	October 1962 to current year	201
11396330	Bangor Canal below Miners Ranch Reservoir, near Oroville	--	January 1963 to current year	16
11396400	Sucker Run near Forbestown	18.7	June 1965 to current year	24
11407500	South Honcut Creek near Bangor	30.6	October 1950 to current year	35
11408850	Middle Yuba River near Camptonville	136	August 1967 to current year	302
11408880	Middle Yuba River below Our House Dam, near Camptonville	145	October 1968 to current year	120
11409300	Oregon Creek at Camptonville	23.0	August 1967 to current year	66
11409400	Oregon Creek below Log Cabin Dam, near Camptonville	29.1	August 1968 to current year	33
11413000	North Yuba River below Goodyears Bar	250	October 1930 to current year	743
11413100	North Yuba River above Slate Creek, near Strawberry	351	June 1968 to current year	1,139
11413300	Slate Creek below Diversion Dam, near Strawberry Valley	49.4	October 1960 to current year	202
11413520	North Yuba River below New Bullards Bar Dam, near North San Juan	490	August 1966 to current year	142
11417500	South Yuba River at Jones Bar, near Grass Valley	308	October 1940 to September 1948; April 1959 to current year	435
11418000	Yuba River below Englebright Dam, near Smartville	1,108	October 1941 to current year	2,445
11418500	Deer Creek near Smartville	84.6	June 1935 to current year	126
11421000	Yuba River near Marysville	1,339	October 1943 to current year	2,448
11422500	Bear River below Rollins Dam, near Colfax	105	August 1915 to June 1917; November 1949 to September 1953; August 1964 to current year	359
11424000	Bear River near Wheatland	292	October 1928 to current year	453
11425000	Feather River near Nicolaus	5,921	April 1943 to current year	7,894
11425500	Sacramento River at Verona	21,251	October 1929 to current year	18,730
11427000	North Fork American River at North Fork Dam	342	October 1941 to current year	798
11431800	Pilot Creek above Stumpy Meadows Lake	11.7	October 1960 to current year	23
11433040	Pilot Creek below Mutton Canyon, near Georgetown	21.1	June 1961 to current year	27
11433500	Middle Fork American River near Auburn	614	October 1911 to current year	1,290
11433800	North Fork American River below Auburn Damsite, near Auburn	973	May 1972 to current year	1,761
11442500	South Fork American River below Silver Creek, near Pollock Pines	449	August to December 1923; November 1969 to current year	385

TABLE 4. Selected hydrologic data for stations in the stream-gaging program for northeastern California--Continued

Station No.	Station name	Drainage area (mi^2)	Period of record	Average discharge (ft^3/s)
		Sacramento field office--Continued		
11443500	South Fork American River near Camino	493	October 1922 to current year	132
11445500	South Fork American River near Lotus	673	May 1951 to current year	1,412
11446500	American River at Fair Oaks	1,888	November 1904 to current year	3,739
11452500	Cache Creek at Yolo	1,139	January 1903 to current year	512
11454000	Putah Creek near Winters	574	July 1930 to current year	512
		Tahoe City field office		
10336600	Upper Truckee River near Meyers	33.1	October 1960 to current year	64
10336610	Upper Truckee River at South Lake Tahoe	54.9	October 1971 to September 1974; October 1976 to June 1977; October 1977 to June 1978; March 1980 to current year	113
10336626	Taylor Creek near Camp Richardson	16.7	October 1968 to current year	46
10336645	General Creek near Meeks Bay	7.44	July 1980 to current year	21
10336660	Blackwood Creek near Tahoe City	11.2	October 1960 to current year	37
10336676	Ward Creek at State Highway 89, near Tehoe Pines	9.7	October 1972 to current year	26
10336689	Snow Creek at Tahoe Vista	4.43	July 1980 to current year	3
10336759	Edgewood Creek near Stateline, NV	3.2	October 1982 to current year	--
10336780	Trout Creek near Tahoe Valley	36.7	October 1960 to current year	36
10337500	Truckee River at Tahoe City	507	July 1895 to February 1896; March 1900 to current year	243
10338500	Donner Creek at Donner Lake, near Truckee	14.3	November 1909 to August 1910; January 1929 to October 1935; January 1936 to March 1938; July to October 1938; January 1939 to February 1943; June 1943 to December 1953; May 1955 to December 1957; October 1958 to current year	34
10339400	Martis Creek near Truckee	39.9	October 1958 to current year	24
10340500	Prosser Creek below Prosser Creek Dam, near Truckee	52.9	October 1942 to December 1950; June 1951 to current year	87
10343000	Independence Creek near Truckee	8.1	November 1902 to September 1907; November 1909 to June 1910; August 1968 to current year	27
10343500	Sagehen Creek near Truckee	10.5	October 1953 to current year	12
10344400	Little Truckee River above Boca Reservoir, near Truckee	146	June 1903 to October 1910; September 1939 to current year	190
10344500	Little Truckee River below Boca Dam, near Truckee	173	January 1911 to September 1915; January 1939 to current year	183
10346000	Truckee River at Farad	932	September 1899 to current year	792
11401500	Indian Creek near Crescent Mills	739	January 1906 to December 1909; September 1911 to March 1918; October 1930 to current yeer	547
11402000	Spanish Creek above Blackhawk Creek, at Keddie	184	October 1933 to current year	270
11407900	Middle Yuba River below Jackson Meadows Dam, near Sierra City	38.3	October 1964 to current year	114

TABLE 4. Selected hydrologic data for stations in the stream-gaging program for northeastern California--Continued

Station No.	Station name	Drainage area (mi^2)	Period of record	Average discharge (ft^3/s)
	Tahoe City field office--Continued			
11408000	Milton-Bowman Tunnel Outlet near Graniteville	--	May 1928 to September 1930; February 1931 to current year	73
11414000	South Yuba River near Cisco	51.8	April 1942 to current year	200
11416000	Bowman-Spaulding Canal Intake near Graniteville	--	October 1927 to current year	159
11416500	Canyon Creek below Bowman Lake	28.3	January 1927 to current year	36
11421760	Dutch Flat No. 2 Flume near Blue Canyon	--	October 1965 to current year	341
11421780	Chicago Park Flume near Dutch Flat	--	November 1965 to current year	617
11421790	Bear River below Dutch Flat AfterBay, near Dutch Flat	21.5	December 1965 to current year	30
11427940	Rubicon-Rockbound Tunnel near Meeks Bay	--	December 1963 to current year	105
11428000	Rubicon River at Rubicon Springs, near Meeks Bay	31.4	February 1910 to March 1914; October 1956 to current year	54
11428300	Buck-Loon Tunnel near Meeks Bay	--	November 1963 to current year	135
11429500	Gerle Creek below Loon Lake Dam, near Meeks Bay	8.01	August 1962 to current year	8
11430000	South Fork Rubicon River below Gerle Creek, near Georgetown	47.6	February 1910 to June 1914; August 1961 to current year	22
11441500	South Fork Silver Creek near Ice House	27.5	October 1924 to current year	76
11441900	Silver Creek below Camino Diversion Dam	171	October 1960 to current year	85

USES, FUNDING, AND AVAILABILITY OF CONTINUOUS STREAMFLOW DATA

The relevance of a stream gage is defined by the uses that are made of the data that are produced from the gage. The uses of the data from each gage in the California program were identified by a survey of known data users. The survey documented the importance of each gage and identified gaging stations that may be considered for discontinuation.

Data uses identified by the Survey were categorized into nine classes, defined below. The sources of funding for each gage and the frequency at which data are provided to the users also were compiled.

Data-Use Classes

The following definitions were used to categorize each known use of streamflow data for each stream gage.

Regional Hydrology

For data to be useful in defining regional hydrology, a stream gage must be largely unaffected by manmade storage or diversion. In this class of uses, the effects of man on streamflow are not necessarily small, but the effects are limited to those caused primarily by land-use and climate changes. Large amounts of manmade storage may exist in the basin providing the outflow is uncontrolled. These stations are useful in developing regionally transferable information about the relationship between basin characteristics and streamflow.

Thirty stations in the study area are in the regional hydrology data-use category. Nine of these stations are used as indices of runoff in various sectors of the study area for monthly reports on hydrologic conditions prepared by the California Department of Water Resources, and by the U.S. Geological Survey. The 30 regional hydrology stations are shown on plate 1. The establishment or classification of stations for regional hydrology in northeastern California is not considered feasible because (1) much of the terrain of this area is capped by porous lava flows which have diverse effects on the runoff, (2) correlation between gaging-station records is generally poor in this area, and (3) no single station can be regarded as an index.

Hydrologic Systems

Stations that can be used to define current hydrologic conditions and sources, sinks, and fluxes of water through hydrologic systems including regulated systems, are designated as hydrologic system stations. They include diversions and return flows and stations that are useful for defining the interaction of water systems. Currently, there are 73 stations in the study area that fit the hydrologic systems category.

Legal Obligations

Gaging stations may be established to provide streamflow records for the verification or enforcement of existing treaties, compacts, and decrees. The legal obligation category is for those stations that the U.S. Geological Survey is required to operate to satisfy a legal responsibility.

There are no stations in the study area that exist to fulfill a legal responsibility of the U.S. Geological Survey.

Planning and Design

Gaging stations in this category of data use are used for the planning and design of a specific project (for example, a dam, levee, floodwall, navigation system, water-supply diversion, hydropower plant, or waste-treatment facility) or group of structures. The planning and design category is limited to those stations that were established for such purposes and where this purpose is still valid.

Currently, 15 stations in the study area are being operated for planning or design purposes.

Project Operation

Gaging stations in this category are used on an ongoing basis to assist water managers in making operational decisions related to reservoir releases, hydropower operations, or diversions. Operation use generally implies that the data are routinely available to the operators on a rapid-reporting basis. For projects on large streams, data may only be needed every few days or perhaps monthly.

There are 49 stations in the study area that are used in this manner; 47 of these are used to aid operators in the management of reservoirs and control structures that are part of hydropower production systems. The remaining two stations are used to assist wastewater-treatment plant operators.

Hydrologic Forecasts

There are 24 gaging stations in this category regularly used to provide information for hydrologic forecasting. These forecasts might be flood forecasts for a specific river reach, or periodic (daily, weekly, monthly, or seasonal) flow-volume forecasts for a specific site or region, or forecasts of inflows to reservoirs that are a part of hydropower-generating systems. The hydrologic forecast use generally implies that the data are routinely available to the forecasters on a rapid-reporting basis. On large streams, data may be needed only every few days or monthly for snowmelt runoff predictions.

Water-Quality Monitoring

Gaging stations where regular water-quality or sediment-transport monitoring is being conducted and where the availability of streamflow data contributes to the utility or is essential to the interpretation of the water-quality or sediment data are designated as water-quality monitoring sites. Nineteen such sites exist in the study area.

Three stations in the study area are designated as National Stream Quality Accounting Network (NASQAN) sites, and are part of a nationwide network established to assess water-quality trends of key streams. Ten stations (including the NASQAN stations) are sites where sediment samples are being collected for sediment-transport investigations.

Research

Gaging stations in this category are operated for a specific research or water-resources study. Typically, these are only operated for a few years.

Nine stations in the study area are used in the support of research activities in the vicinity of Lake Tahoe. The streamflow data are used to evaluate the loading of natural and anthropogenic constituents on the health of Lake Tahoe.

Other

In addition to the eight data-use classes described above, three stations incidentally are used frequently to provide streamflow information for recreational planning, primarily for canoeists and rafters.

Funding

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

1. Federal program.--Funds that have been directly allocated to the U.S. Geological Survey.

2. Other Federal Agency (OFA) program.--Funds that have been transferred to the U.S. Geological Survey by other Federal Agencies.

3. Coop program.--Funds that come jointly from U.S. Geological Survey cooperative-designated funding and from a non-Federal cooperating agency. Cooperating agency funds may be in the form of direct services or cash.

4. Other non-Federal.--Funds that are provided entirely by a non-Federal agency or a private concern under the auspices of a Federal agency. In this study, funding from private concerns was limited to license and permit requirements for hydropower development by the Federal Energy Regulatory Commission. Funds in the category are not matched by U.S. Geological Survey cooperative funds.

In all four categories, the identified sources of funding pertain only to the collection of streamflow data; sources of funding for other activities, particularly collection of water-quality samples, that might be carried out at the site may not necessarily be the same as those identified herein. Nineteen entities currently are contributing funds to the stream-gaging program in northeastern California.

Frequency of Data Availability

Frequency of data availability refers to the times at which the streamflow data may be furnished to the users. In this category, three distinct possibilities exist. Data can be furnished by direct-access telemetry equipment for immediate use, by periodic release of provisional data, or in publication format in the annual data report for California (U.S. Geological Survey, 1982). In the current program, data for all 127 stations are available through the annual report, data for 17 stations are available on a real-time basis, and data are released on a provisional basis for 58 stations.

Data-Use Presentation

Data-use and ancillary information for each gaging station are presented by field office in tables 5, 6, and 7.

Conclusions Pertaining to Data Uses

Of the 127 stations evaluated in the study area, 79 are required for project operation or for Federal Energy Regulatory Commission license requirements, 30 are operated to support sediment and water-quality investigations and research, 24 are used for hydrologic forecasts, and 15 are operated to obtain flow data for designing dams, diversions, and flood conveyance facilities. Many of these stations serve two or three functions.

Only 30 of the 127 stations operated provide regional hydrology data relatively unaffected by manmade regulation. The use of regional hydrology data has increased rapidly because of renewed interest in developing small hydroelectric-generation plants. In the last 3 years, the California District has processed correspondence concerning applications to install over 840 small generating plants (Robles, J. N., U.S. Geological Survey, oral commun., 1983). Regional hydrologic data are necessary for estimating the power potential at the majority of these sites.

In the past few years, many cooperating agencies have had difficulty funding streamflow monitoring because of recent legislation limiting the assessment of real property taxes. Many gaging stations with regional and local accounting value have been discontinued for lack of funds. Stations in the DWR cooperative program have been evaluated annually. The results of program "trimming" is evidenced in table 1. Consequently, only one station was found that does not appear to have sufficient data use to justify continuance in the cooperative stream-gaging program. Station 11389950, Little Butte Creek at Magalia, measures leakage from Magalia Reservoir and some infrequent spill. Most of the streamflow is stored or diverted above the station. The 1969-82 flow-duration analysis for this site shows the discharge to be less than 1 ft^3/s 70 percent of the time. The primary use of the record is to monitor dam leakage as a safety precaution; the record has little hydrologic significance. It is suggested that the station be discontinued or funded on a total repay basis.

Nine gaging stations in the Lake Tahoe area are designated as research support stations. These stations are operated on tributaries to Lake Tahoe and supply streamflow data needed to quantify sediment transport and associated nutrient loading, which is slowly increasing the algal productivity and decreasing the clarity and esthetic appeal of Lake Tahoe. These stations probably will be operated for an additional 5 to 10 years, until a wide range of hydrologic conditions have been sampled.

TABLE 5. Data use, funding sourca, and data availability for gaging stations in the Redding fiald office araa

Uses:

1, State Watermaster program, allocation of irrigation water;
2, NASQAN station;
4, long-term gaging station;
5, monitor outflow, Lake Siskiyou;
7, monitor flood flows, Corps of Engineers study;
9, monitor outflow, West Valley Reservoir;
10, monitor inflow, Lake Britton;
11, measure outflow from Keswick Resarvoir;
12, flood forecast, Sacramento River system;
14, monitor outflow, Whiskeytown Resarvoir;
16, Cottonwood Creek sediment, water quality, and ground-water investigations;
17, monitor flow, Coleman powerhouse operation;
18, key station for regulating flow, upper Sacramento River system;
20, periodic sediment sampling;
21, project operation, Los Molinos Water District;
22, recreation and rafting;
23, project design, Eel River Diversion;
24, total load sediment station;
25, Black Butte Reservoir project operation, U.S. Corps of Engineers;
26, monitor outflow, Magalia Reservoir;
29, monitor outflow, Scott River basin;
30, monitor outflow Lewiston Reservoir;
31, Trinity River restoration project;
63, Federal Energy Regulatory Commission hydropower licensing requirements.

Funding:

2, NASQAN station;
3, State of California Department of Water Resources;
6, Siskiyou County;
8, Modoc County Public Works;
13, U.S. Bureau of Reclamation;
15, U.S. Corps of Engineers;
27, Paradise Irrigation District;
28, Pacific Power and Light Company.

Data availability:

A, annual;
P, provisional;
T, telamatry.

Station No.	Usas									Funding				
	Regional hydro-logy	Hydro-logic systems	Legal obli-gations	Planning and dasign	Projact opera-tion	Hydro-logic forecasts	Water-quality moni-toring	Resaarch	Other	Fed-eral pro-gram	OFA pro-gram	COOP pro-gram	Other non-Faderal	Data availa-bility
10356500	--	--	--	--	1	--	2	--	--	2	--	3	--	A
10358500	4	--	--	--	--	--	--	--	--	--	--	3	--	A
11341400	--	--	--	--	5	--	--	--	--	--	--	6	--	A
11342000	4	--	--	--	--	12	--	--	22	--	--	3	--	A,P
11344000	--	--	--	7	--	--	--	--	--	--	--	8	--	A
11345500	--	--	--	--	9	--	--	--	--	--	--	3	--	A
11348500	--	--	--	--	1	12	--	--	--	--	--	3	--	A,T
11355010	--	10	--	--	--	--	--	--	--	--	--	3	--	A
11355500	4	--	--	--	1	--	--	--	--	--	--	3	--	A
11370500	--	--	--	--	11	12	2	--	--	2	13	--	--	A,P,T
11371000	4	--	--	--	--	--	--	--	--	--	--	3	--	A
11372000	--	--	--	--	14	--	--	--	--	--	13	--	--	A,P
11374000	4	--	--	--	--	12	--	--	--	--	13	--	--	A,P,T
11375810	--	--	--	16	--	--	16	--	--	--	15	--	--	A,P
11375870	--	--	--	16	--	--	16	--	--	--	15	--	--	A,P
11375900	--	--	--	16	--	--	16	--	--	--	15	--	--	A
11376000	4	--	--	16	--	12	16	--	--	--	15	3	--	A,P
11376550	4	--	--	--	17	12	--	--	--	--	--	3	--	A,P
11377100	--	18	--	--	11	12	20	--	--	--	15	--	--	A,P,T
11379500	4	--	--	--	--	--	--	--	--	--	--	3	--	A
11381500	--	4	--	--	21	--	--	--	22	--	--	3	--	A,P
11382000	4	--	--	23	--	--	24	--	--	--	--	3	--	A,P,T
11383500	4	--	--	--	--	--	--	--	22	--	--	3	--	A
11384000	--	4	--	--	--	--	--	--	--	--	--	3	--	A
11387200	--	--	--	--	--	--	24	--	--	--	--	3	--	A
11387990	--	--	--	--	25	--	--	--	--	--	15	--	--	A,P,T
11388000	--	--	--	--	25	12	--	--	--	--	15	--	--	A,P,T
11389950	--	--	--	--	26	--	--	--	--	--	--	27	--	A,P
11390000	4	--	--	--	--	12	--	--	--	--	--	3	--	A,T
11405300	4	--	--	--	--	--	--	--	--	--	--	3	--	A
11516530	--	63	--	--	--	--	--	--	--	--	--	--	28	A,P,T
11517500	--	4	--	--	--	--	--	--	--	--	4	--	--	A,P
11519500	4	29	--	--	--	--	--	--	--	--	--	3	--	A,P
11520500	--	4	--	--	--	--	--	--	--	--	--	3	--	A
11521500	4	--	--	--	--	--	--	--	--	--	--	3	--	A
11523200	4	--	--	--	--	--	--	--	--	--	--	3	--	A
11525500	--	--	--	--	30	--	--	--	--	--	13	--	--	A,P
11525600	--	--	--	--	31	--	24	--	--	--	--	3	--	A,P
11525655	--	--	--	--	31	--	24	--	--	--	--	3	--	A

TABLE 6. Data use, funding source, and data availability for gaging stations in the Sacramento field office area

Uses:

2, NASQAN station;
4, long-term gaging station;
12, flood forecast, Sacramento River system;
42, Nevada Irrigation District FERC;
44, project operation, New Hogan Dam flood control;
45, Sacramento-San Joaquin Delta inflow;
46, project operation, East Bay Aqueduct;
48, project operation, Wood Bridge Irrigation District;
50, Consumnes River water development;
51, planning and design, Stone Lake development;
53, Butte Basin flood flow project;
54, California Water Project operation;
56, Feather River flow accounting;
58, Marysville Dam project;
59, National Water Conditions report;
60, Auburn Dam project;
61, Georgetown Public Utility District;
63, Federal Energy Regulatory Commission hydropower licensing requirements.

Funding:

2, NASQAN station;
3, State of California Department of Water Resources;
13, U.S. Bureau of Reclamation;
15, U.S. Corps of Engineers;
43, Sacramento Municipal Utility District;
47, East Bay Municipal Utility District;
55, Oroville-Wyandotte Irrigation District;
57, Yuba County Water Agency;
62, Eldorado Irrigation District Sofar Dam project.

Data availability:

A, annual;
P, provisional;
T, telemetry.

Station No.	Uses									Funding				Data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	COOP program	Other non-Federal	
11308900	--	--	--	--	44	--	44	--	--	--	15	--	--	A,P,T
11312000	--	--	--	--	46	--	--	--	--	--	--	47	--	A
11316800	4	--	--	--	46	--	--	--	--	--	--	47	--	A
11317000	--	4	--	--	46	--	--	--	--	--	--	47	--	A
11318500	--	4	--	--	46	--	--	--	--	--	--	47	--	A
11319500	--	46	--	--	46	--	--	--	--	--	--	3	--	A
11323500	--	46	--	--	46	--	--	--	--	--	--	47	--	A
11325500	--	48	--	46	--	45	2	--	--	2	--	3	--	A,T
11329500	4	--	--	--	--	--	--	--	--	--	--	3	--	A
11333000	--	3	--	50	--	--	--	--	--	--	--	3	--	A
11333500	--	4	--	50	--	--	--	--	--	--	--	3	--	A
11335000	4	--	--	50	--	12	--	--	--	--	--	3	--	A
11336580	--	--	--	51	--	--	--	--	--	--	15	--	--	A
11389000	--	53	--	--	19	--	--	--	--	--	--	3	--	A
11389500	--	--	--	--	--	12	--	--	--	--	--	3	--	A
11390500	--	--	--	--	--	12	--	--	--	--	--	3	--	A,T
11394500	4	--	--	--	54	--	--	--	--	--	--	3	--	A
11395030	--	63	--	--	--	--	--	--	--	--	--	--	55	A,P
11395200	--	63	--	--	--	--	--	--	--	--	--	--	55	A,P
11395500	--	63	--	--	--	--	--	--	--	--	--	--	55	A,P
11396000	--	63	--	--	--	--	--	--	--	--	--	--	55	A,P
11396200	--	63	--	--	--	--	--	--	--	--	--	--	55	A,P
11396310	--	63	--	--	--	--	--	--	--	--	--	--	55	A,P
11396330	--	63	--	--	--	--	--	--	--	--	--	--	55	A,P
11396400	--	4	--	--	--	--	--	--	--	--	--	55	--	A
11407500	4	56	--	--	--	--	--	--	--	--	--	3	--	A
11408850	--	63	--	--	--	--	--	--	--	--	--	--	57	A
11408880	--	63	--	--	--	--	--	--	--	--	--	--	57	A
11409300	4	63	--	--	--	--	--	--	--	--	--	--	57	A
11409400	--	63	--	--	--	--	--	--	--	--	--	--	57	A
11413000	4	--	--	--	--	--	--	--	--	--	--	3	--	A
11413100	--	63	--	--	--	--	--	--	--	--	--	--	55	A,P
11413300	--	63	--	--	--	--	--	--	--	--	--	--	55	A,P
11413520	--	--	--	--	57	--	--	--	--	--	--	--	57	A
11417500	--	3	--	--	--	57	--	--	--	--	--	3	--	A
11418000	--	--	--	--	57	--	--	--	--	--	--	--	57	A
11418500	--	3	--	--	--	--	--	--	--	--	--	3	--	A,P
11421000	--	56	--	58	--	--	--	--	--	--	--	3	--	A,P
11422500	--	--	--	--	42	--	--	--	--	--	--	--	42	A
11424000	--	56	--	--	54	--	--	--	--	--	--	3	--	A
11425000	--	4	--	--	54	12	--	--	--	--	--	3	--	A,T
11425500	--	4	--	--	--	12	--	--	59	--	--	3	--	A
11427000	4	--	--	60	--	--	--	--	59	--	13	--	--	A,P
11431800	4	--	--	--	61	--	--	--	--	--	--	61	--	A
11433040	--	61	--	--	61	--	--	--	--	--	--	61	--	A
11433500	--	--	--	--	60	--	--	--	--	--	13	--	--	A
11433800	--	--	--	--	60	--	--	--	--	--	13	--	--	A,P,T
11442500	--	63	--	--	--	--	--	--	--	--	--	--	43	A,P
11443500	--	63	--	--	--	--	--	--	--	--	--	--	43	A,P
11445500	--	--	--	62	--	--	--	--	--	--	13	62	--	A,T
11446500	--	4	--	--	13	--	--	--	--	--	13	--	--	A,P
11452500	--	--	--	--	54	12	--	--	--	--	--	3	--	A
11454000	--	45	--	--	54	12	--	--	--	--	13	--	--	A

TABLE 7. Data use, funding source, and data availability for gaging stations in the Tahoe City field office area

Uses:

4, long-term gaging station;
32, Lake Tahoe monitoring project;
34, monitor outflow, Fallen Leaf Lake;
35, U.S. Forest Service;
36, Federal Watermaster, daily operation;
37, U.S. Geological Survey Central Region sediment project;
39, monitor outflow, Stampeed Reservoir;
40, monitor outflow, Boca Reservoir;
41, flood forecast, Truckee River system;
63, Federal Energy Regulatory Commission hydropower licensing requirements.

Funding:

3, State of California Department of Water Resources;
13, U.S. Bureau of Reclamation;
15, U.S. Corps of Engineers;
33, Interagency Tahoe monitoring group;
38, University of California at Berkeley;
42, Nevada Irrigation District;
43, Sacramento Municipal Utility District.

Data availability:

A, annual;
P, provisional;
T, telemetry.

Station No.	Uses: Regional hydrology	Uses: Hydrologic systems	Uses: Legal obligations	Uses: Planning and design	Uses: Project operation	Uses: Hydrologic forecasts	Uses: Water-quality monitoring	Uses: Research	Uses: Other	Funding: Federal program	Funding: OFA program	Funding: COOP program	Funding: Other non-Federal	Data availability
10336600	4	--	--	--	--	--	--	32	--	--	--	3	--	A
10336610	--	32	--	--	--	--	32	32	--	--	--	--	33	A
10336626	--	34	--	--	35	--	--	--	--	--	35	--	--	A,P
10336645	--	32	--	--	--	--	32	32	--	--	--	--	33	A
10336660	4	32	--	--	--	--	32	32	--	--	--	3	33	A
10336676	--	32	--	--	--	--	32	32	--	--	--	--	33	A
10336689	--	32	--	--	--	--	32	32	--	--	--	--	33	A
10336759	--	--	--	--	--	--	32	32	--	--	--	--	--	A
10336780	4	32	--	--	--	--	32	32	--	--	--	3	33	A
10337500	--	32	--	--	36	36	--	--	--	--	--	3	--	A,P
10338500	--	36	--	--	36	--	--	--	--	--	--	3	--	A,P
10339400	--	36	--	--	36	--	--	--	--	--	15	--	--	A,P
10340500	--	36	--	--	36	--	--	--	--	--	--	3	--	A,P
10343000	--	36	--	--	36	--	--	--	--	--	--	3	--	A
10343500	4	--	--	--	--	--	37	37	--	--	--	--	38	A
10344400	--	39	--	--	39	--	--	--	--	--	13	--	--	A,P
10344500	--	40	--	--	40	--	--	--	--	--	--	3	--	A,P
10346000	--	36	36	--	36	41	--	--	--	--	--	3	--	A,P,T
11401500	--	4	--	--	--	--	--	--	--	--	--	3	--	A
11402000	4	4	--	--	--	--	--	--	--	--	--	3	--	A
11407900	--	63	--	--	--	--	--	--	--	--	--	--	42	A,P
11408000	--	63	--	--	--	--	--	--	--	--	--	--	42	A,P
11414000	4	--	--	--	--	--	--	--	--	--	--	3	--	A
11416000	--	63	--	--	--	--	--	--	--	--	--	--	42	A,P
11416500	--	63	--	--	--	--	--	--	--	--	--	--	42	A,P
11421760	--	63	--	--	--	--	--	--	--	--	--	--	42	A,P
11421780	--	63	--	--	--	--	--	--	--	--	--	--	42	A,P
11421790	--	63	--	--	--	--	--	--	--	--	--	--	42	A,P
11427940	--	63	--	--	--	--	--	--	--	--	--	--	43	A,P
11428000	--	63	--	--	--	--	--	--	--	--	--	--	43	A,P
11428300	--	63	--	--	--	--	--	--	--	--	--	--	43	A,P
11429500	--	63	--	--	--	--	--	--	--	--	--	--	43	A,P
11430000	--	63	--	--	--	--	--	--	--	--	--	--	43	A,P
11441500	--	63	--	--	--	--	--	--	--	--	--	--	43	A,P
11441900	--	63	--	--	--	--	--	--	--	--	--	--	43	A,P

Many of the 15 stations presently operated for planning and design purposes will eventually be discontinued when the design projects are completed or when the cost of continued operation clearly exceeds the information value. At this time, no design or water-resources planning stations will be discontinued on this basis.

In summary, no regional hydrology or hydrologic systems gaging stations were identified for discontinuance; the network of these stations has been trimmed frequently and vigorously. One project-operation station, Little Butte Creek at Magalia, is suggested for discontinuance, because of limited use of data. In about 5 years, some of the 45 research and planning-design stations should be discontinued, but all are presently needed.

ALTERNATIVE METHODS OF DEVELOPING STREAMFLOW INFORMATION

The second step of the analysis of the stream-gaging program is to investigate alternative methods of providing daily streamflow information in lieu of 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 stream gage. No guidelines exist concerning suitable accuracies for particular uses of the data; therefore, judgment is required in deciding whether the accuracy of the estimated daily flows is suitable for the intended purpose. The data uses at a station will influence whether a site has potential for alternative methods. For example, those stations for which flood hydrographs are required in a real-time sense, such as hydrologic forecasts and project operation, are not candidates for the alternative methods. Likewise, there might be a legal obligation to operate an actual gaging station that would preclude using alternative methods. The primary candidates for alternative methods are stations that are operated 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, located in the same physiographic and climatic area, also may have potential for alternative methods.

All stations in the Redding-Sacramento-Tahoe City stream-gaging program were categorized as to their potential use of alternative methods and selected methods were tried at many 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 California analysis and documents why these specific methods were chosen.

CONROUT Unit-Response Flow-Routing Model

A review of river systems with two or more gaging stations and neglible intervening regulation identified seven stations that showed potential for flow-modeling applications. An evaluation of each of the seven stations and their associated system of upstream stations enabled a decision to be made as to which stations had a good, fair, or poor potential for modeling. If a station was classified as having good potential then these criteria were met:

1. The system has no or little regulation, it is essentially a natural system;

2. There are no diversions such as irrigation;

3. The system is free from backwater effects;

4. Intervening ungaged area is small, preferably less than 20 percent; and

5. An index station or stations are available for estimating the flow response from the intervening ungaged area.

These criteria are desirable because they best meet the conditions for application of the CONROUT unit-response flow-routing model (Doyle and others, 1983).

It is seldom found that all the criteria are met and other reasons may exist for wanting to simulate streamflow data at a particular station. Seven station networks were analyzed of which four systems were identified where flow-routing techniques appeared feasible:

1. Klamath River system;
2. Feather River system;
3. Sacramento River system;
4. Indian and Spanish Creeks system.

Klamath River Flow-Routing Analysis

The purpose of the Klamath River flow-routing analysis is to investigate the potential for use of the CONROUT model for streamflow routing to simulate daily mean discharges at station 11520500, Klamath River near Seiad Valley, Calif. (fig. 1). In this application, as with the other three systems that were modeled, a best-fit model for the entire flow range is the desired product. Streamflow data available for this analysis are summarized in table 8.

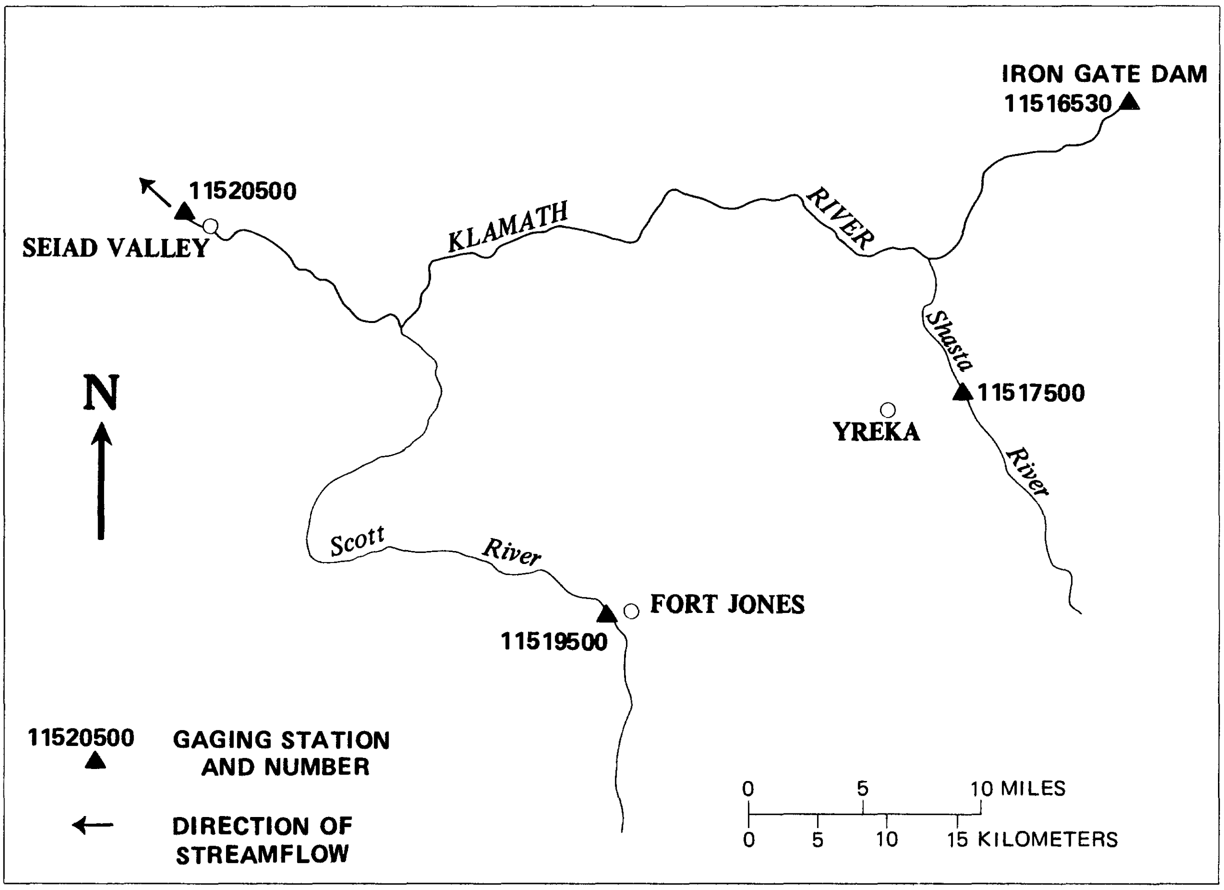

FIGURE 1. – Klamath River study area.

The distance between the two gages on the Klamath River is 36.8 miles. Two tributaries join the Klamath River 14.6 and 23.8 miles upstream from station 11520500. Intervening ungaged drainage area between stations 11516530 and 11520500 is 864 mi^2 or 12.4 percent of the total drainage area contributing to the Seiad Valley site. Station 11519500 with a drainage area of 653 mi^2 was selected as the index station to estimate the flow response from the intervening ungaged area.

To simulate the daily mean discharges, the approach was to route the flow along the Klamath River from Iron Gate Dam to Seiad Valley using the diffusion analogy method with a single linearization. Flow also was routed along the Scott River and combined with the Klamath River at its confluence. Since the Shasta River gage is near its confluence with the Klamath, flows from the Shasta River were added directly to the Klamath River flow (routed from Iron Gate Dam) at the confluence. The intervening drainage area was accounted for by using data from station 11519500 adjusted by a drainage-area ratio. The total discharge at Seiad Valley was the summation of the routed discharge along the Klamath River and an adjusted discharge from station 11519500.

TABLE 8. Gaging stations used in the Klamath River flow-routing analysis

Station No.	Station name	Drainage area (mi^2)	Period of record
11516530	Klamath River below Iron Gate Dam	4,630	October 1960 to current year
11517500	Shasta River near Yreka	793	October 1933 to December 1941; December 1944 to current year
11519500	Scott River near Fort Jones	653	December 1941 to current year
11520500	Klamath River near Seiad Valley	6,940	October 1912 to September 1925; July 1951 to current year

Data for the 1980 water year were used to calibrate the model while 1981 and 1982 water year data were used to verify the model. The model requires concurrent data for all stations used in the analysis, and while concurrent data also were available for water years 1961-79, only the last 3 years were used. In restricting the analysis to the most recent data for comparison, the model will represent present conditions. Previous undocumented changes in the system might invalidate the model's application to the earlier period.

To route flow in the Klamath River system, it was necessary to determine the model parameters C (floodwave celerity) and K (wave dispersion coefficient). The coefficients C and K are functions of channel width (W) in feet, channel slope (S) in feet per foot (ft/ft), the slope of the stage discharge relation (dQ/dY) in square feet per second (ft^2/s), and the discharge (Q) in cubic feet per second (ft^3/s) representative of the reach in question and are determined as follows:

$$C = \frac{1}{W}\frac{dQ}{dY} \tag{1}$$

$$K = \frac{Q}{2SW} \tag{2}$$

Values for C and K were computed from information obtained at stations 11516530, 11519500, and 11520500. The discharge Q, for which initial values of C and K were linearized was the long-term mean daily discharge at each of these stations. Also, at each station, the channel width, W, was obtained from width-discharge relationships; channel slope, S, was determined from gage-elevation information; and dQ/dY, was determined from the rating curves by bracketing the mean discharge and computing for an incremental change in gage height the associated change in discharge. There were four reaches in which routing were performed and average values of C and K were computed for each reach by averaging the values computed at the stations. Along the Klamath River, adjustments were made to C and K in proportion to the distance each reach was upstream from station 11520500. Table 9 identifies each reach and final calibrated values of C and K used for routing flow through the reach.

To simulate flow from the intervening ungaged drainage area of 864 mi^2, a drainage-area ratio was calculated by dividing the ungaged drainage area by the drainage area at the index station 11519500 (653 mi^2) and multiplying the flow at the index station by this ratio. The initial ratio of 1.32 was adjusted to 1.34 during calibration.

TABLE 9. Calibrated model parameters for Klamath River system reaches

Reach	Begin (B) End (E)	Length (mi)	C (ft/s)	K (ft^2/s)
1	(B) Station 11516530 (E) Klamath River at mouth of Shasta River	13.00	6.375	1,342
2	(B) Klamath River at mouth of Shasta River (E) Klamath River at mouth of Scott River	9.15	7.000	1,840
3	(B) Station 11159500 (E) Mouth of Scott River	18.40	4.670	459
4	(B) Klamath River at mouth of Scott River (E) Station 11520500	14.65	7.440	2,150

During calibration, C and K were varied, as well as the computed drainage-area ratio. The best fit single linearization model used the originally determined C, K, and slightly adjusted drainage-area ratio. Table 10 presents the results of the routing model for simulated flows at station 11520500. This summary includes the 1980 water year from October 1, 1979 to September 30, 1980. It can be noted that the mean error for 366 days is 5.8 percent with a volume error less than 1 percent. The bottom half of table 10 lists the percent of total observations that had errors less than or equal to 5, 10, 15, etc. percent.

Table 11 presents summary statistics for the verification period--1981 and 1982 water years. The results in table 11 are comparable to the calibration results.

The flow model developed for the Klamath River system produced very good results. This indicates that computed model parameters, selected index station, and calculated drainage-area ratio can be expected to give optimum results. Certainly, the small amount of ungaged area and a representative index station contributed significantly to these results.

Figure 2 is a comparison of the measured and simulated discharge at station 11520500 during high flow in January 1980. The fit for this period is very good as was the fit for other periods used in the comparison.

Feather River Flow-Routing Analysis

The purpose of the Feather River flow-routing analysis is to investigate the potential for use of the CONROUT model for streamflow routing to simulate daily mean discharges at station 11425000, Feather River near Nicolaus, Calif. (fig. 3). Streamflow data available for this analysis are summarized in table 12.

The distance between the upstream and downstream gages on the Feather River is 36.2 miles. Three tributaries join with the Feather River at 3.0, 18.7, and 29.9 miles upstream from station 11425000. Intervening ungaged drainage area between stations 11407150 and 11425000 is 583 mi^2 or 9.85 percent of the total drainage area contributing to the Nicolaus site. Station 11407500 with a drainage area of 30.6 mi^2 was selected as the index station to estimate the flow response from the intervening ungaged area. Although the index station is on a rather small drainage area, it was the only site that did not have considerable regulation. The other two tributaries have many diversions for irrigation.

TABLE 10. Calibration results of routing model for station 11520500

1980 Water Year Summary

Mean absolute error (percent) for 366 days = 5.8
Mean - error (percent) for 253 days = -6.2
Mean + error (percent) for 113 days = 5.0
Modeled volume = 1,321,710 ft^3/s - days
Measured volume = 1,325,723 ft^3/s - days
Volume error (percent) = -0.30
RMS error (percent) = 7.6

Percent of total observation	Amount of error (percent)
56	≦5
84	≦10
93	≦15
98	≦20
99	≦25
1	>25

TABLE 11. Verification results of routing model for station 11520500

1981 and 1982 Water Year Summary

Mean absolute error (percent) for 730 days = 6.4
Mean - error (percent) for 437 days = -5.6
Mean + error (percent) for 293 days = 7.5
Modeled volume = 2,971,071 ft^3/s - days
Measured volume = 2,966,621 ft^3/s - days
Volume error (percent) = 0.15
RMS error (percent) = 9.5

Percent of total observation	Amount of error (percent)
54	≦5
85	≦10
92	≦15
96	≦20
97	≦25
3	>25

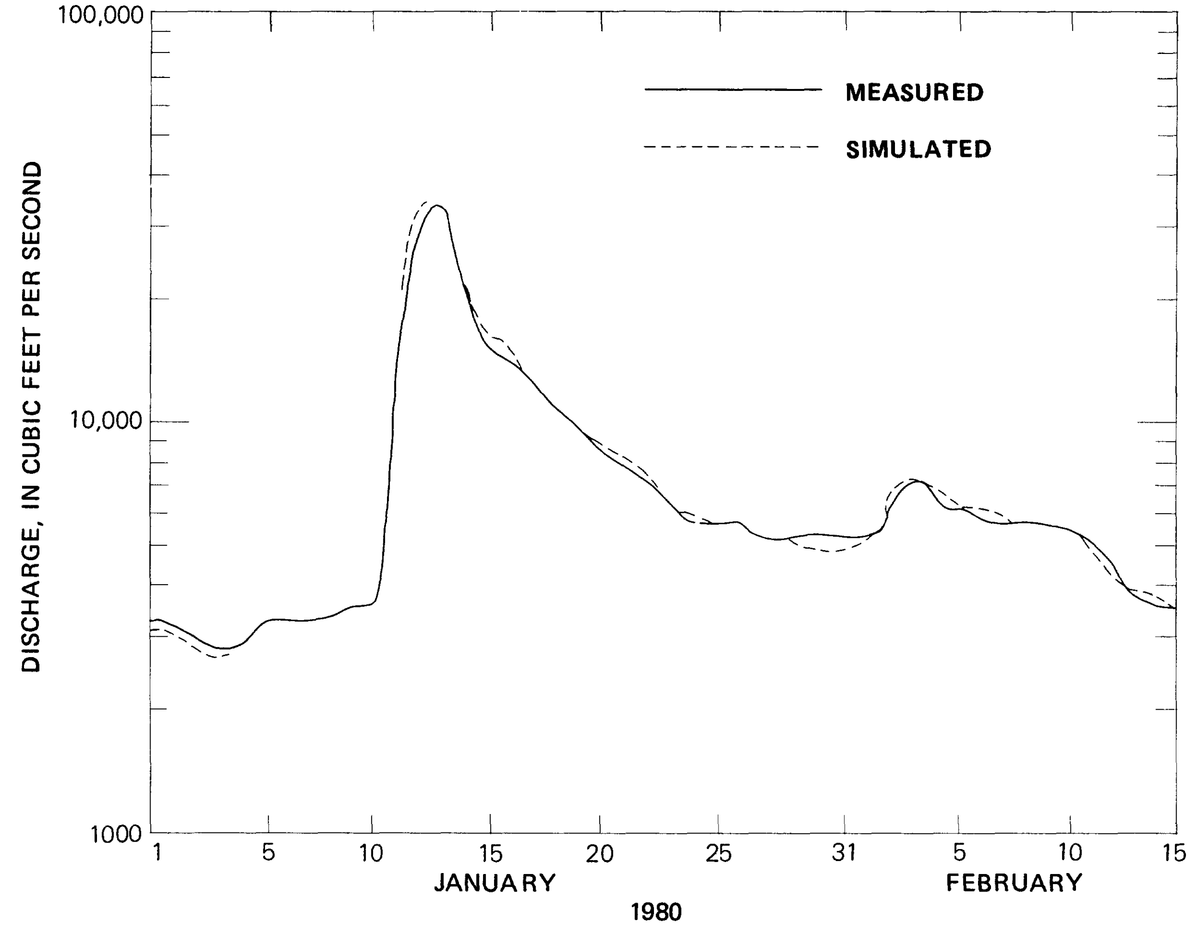

FIGURE 2. – Comparison of measured and simulated discharge at station 11520500.

The Feather River system has several disadvantages, and initially it was considered a poor choice for modeling. Besides the many diversions and the regulation, there are periods of time when streamflow at station 11425000 is affected by backwater from the Sacramento River. The Feather River flows into the Sacramento River not far downstream from Nicolaus. When high flows occur on the Sacramento River, backwater effects at Nicolaus are pronounced. There is no backwater effect when the Sacramento River is at low flow. Therefore, when backwater occurs on the Feather River at Nicolaus an alternative procedure has been developed to compute the actual flow at Nicolaus. This procedure is mostly a summation of flows upstream from gaging stations 11407150, 11407500, 11421000, and 11424000 and the intervening ungaged area (583 mi^2). The ungaged flow is computed as a factor times the flow at station 11407500.

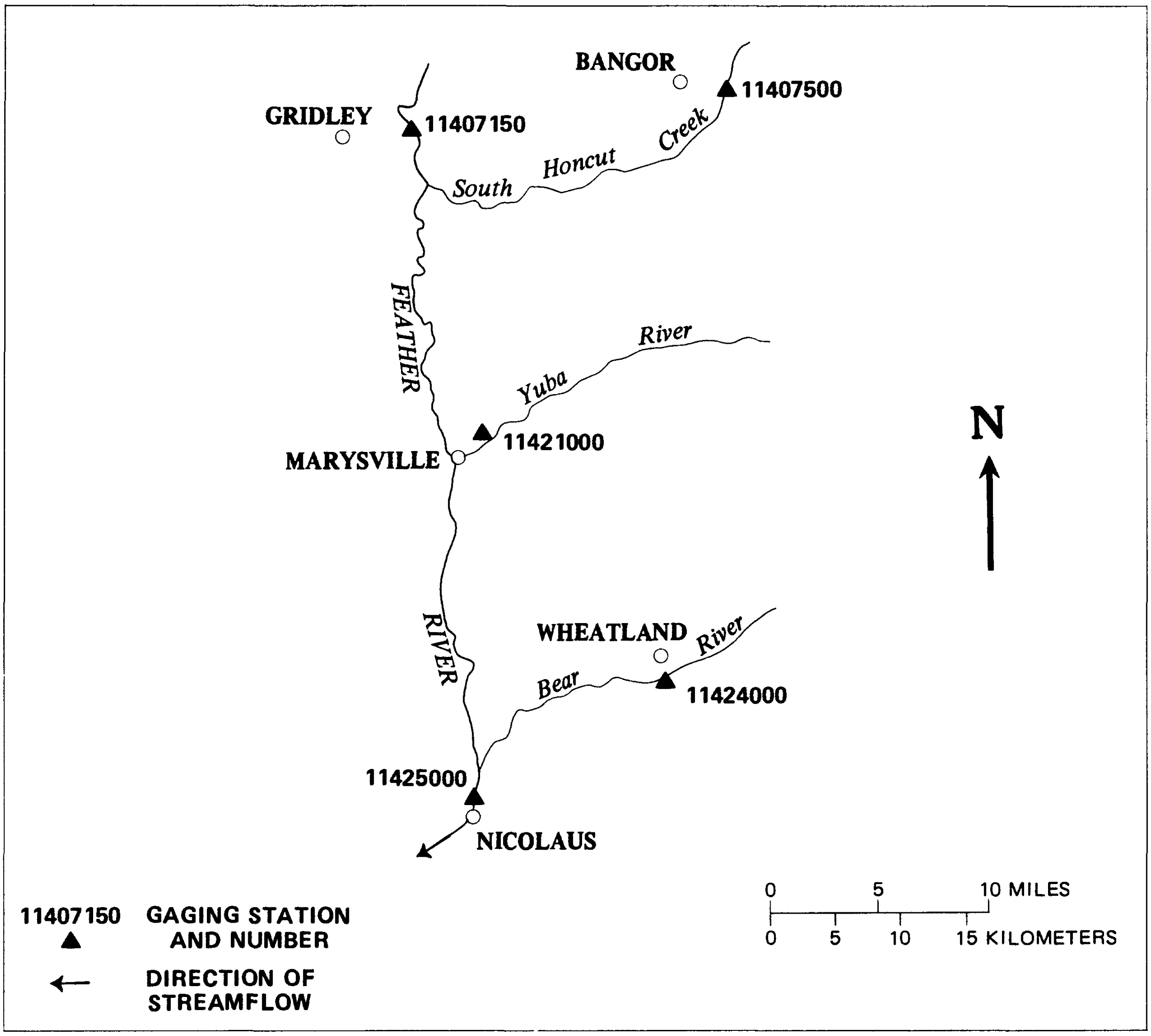

FIGURE 3. – Feather River study area.

To simulate the daily mean discharges, the approach was to route the flow along the Feather River from Gridley to Nicolaus using the CONROUT unit-response model with the single linearization option of the diffusion analogy method. Flows also were routed along the three tributaries and combined with Feather River flow at each tributary mouth. The intervening ungaged drainage area was accounted for by using discharge data from station 11407500 adjusted by a drainage-area ratio.

Data for the 1980 water year were used to calibrate the model. The verification period was selected as the 1974 and 1975 water years.

TABLE 12. Gaging stations used in the Feather River flow-routing analysis

Station No.	Station name	Drainage area (mi^2)	Period of record
11407150[1]	Feather River near Gridley	3,676	October 1964 to current year
11407500	South Honcut Creek near Bangor	30.6	October 1950 to current year
11421000	Yuba River near Marysville	1,339	October 1953 to current year
11424000	Bear River near Wheatland	292	October 1928 to current year
11425000	Feather River near Nicolaus	5,921	April 1943 to current year

[1] Records furnished by California Department of Water Resources.

Model parameters C and K, as previously defined for the Klamath River analysis, were computed for each routed reach for the long-term daily mean discharge. The procedure outlined in the Klamath River discussion section was used to compute average model parameter values. These computed model parameter values produced very poor results during calibration. The high computed values for K unrealistically spread the flow over too long a time period. Therefore, K was reduced in subsequent calibration runs. K equal to 19,000 ft^2/s produced the best agreement between simulated and measured flows at station 11425000. K values for two of the tributaries (11407500 and 11424000) were used in the final calibrated model as originally computed. Floodwave celerities C also were varied from the computed values. Although the calibration was not as sensitive to C as it was to K, the best fit condition was for an average C equal to 2.10 throughout the Feather River system. Table 13 identifies each reach and final calibrated values of C and K used for routing flow through the reach.

To simulate flow from the intervening ungaged drainage area of 583 mi^2, a drainage area ratio was calculated by dividing the ungaged drainage area by the drainage area at index station 11407500 (30.6 mi^2) and multiplying the flow at the index station by this ratio, 19.06. However, during calibration the smallest errors in volume were obtained by adjusting this ratio to 16.80. Table 14 presents the calibration results of the routing model for simulated flows at station 11425000.

TABLE 13. Calibrated model parameters for Feather River system reaches

Reach	Begin (B) End (E)	Length (mi)	C (ft/s)	K (ft^2/s)
1	(B) Station 11407150 (E) Feather River at mouth of Honcut Creek	6.23	2.10	19,000
2	(B) Station 11407500 (E) Mouth of Honcut Creek	20.56	2.10	190
3	(B) Feather River at mouth of Honcut Creek (E) Feather River at mouth of Yuba River	11.22	2.10	19,000
4	(B) Station 11421000 (E) Mouth of Yuba River	6.00	2.10	19,000
5	(B) Feather River at mouth of Yuba River (E) Feather River at mouth of Bear River	15.70	2.10	19,000
6	(B) Station 11424000 (E) Mouth of Bear River	11.63	2.10	1,838
7	(B) Feather River at mouth of Bear River (E) Station 11425000	3.02	2.10	19,000

TABLE 14. Calibration results of routing model for station 11425000

1980 Water Year Summary

Mean absolute error (percent) for 366 days = 6.5
Mean - error (percent) for 234 days = -5.4
Mean + error (percent) for 132 days = 8.4
Modeled volume = 3,986,240 ft^3/s - days
Measured volume = 3,983,620 ft^3/s - days
Volume error (percent) = 0.07
RMS error (percent) = 15.0

Percent of total observation	Amount of error (percent)
58	≦5
90	≦10
94	≦15
96	≦20
97	≦25
3	>25

The mean error for the 1980 water year was computed as 6.5 percent with a total volume error of 0.07 percent. Table 14 shows even better results than for the Klamath River system as 90 percent of the total observations had errors less than or equal to 10 percent. Table 15 presents similar information for the verification period--1974 and 1975 water years. The verification results were not as good as the calibration results because the model uses the average for an entire year instead of considering seasonal effects. The accuracy probably was affected by the large return flows from the rice fields during the summer months.

The model developed for the Feather River system produced the best overall calibration and verification results of the four systems analyzed, but only slightly better than the Klamath River model. This probably results from the methodology used to reconstruct the measured flow data at station 11425000, which in principle is similar to the CONROUT model procedures but without any actual flow routing.

TABLE 15. Verification results of routing model for station 11425000

1974 and 1975 Water Year Summary

Mean absolute error (percent) for 730 days = 8.4
Mean - error (percent) for 338 days = -6.2
Mean + error (percent) for 392 days = 10.2
Modeled volume = 9,099,475 ft^3/s - days
Measured volume = 9,069,110 ft^3/s - days
Volume error (percent) = 0.33
RMS error (percent) = 20.1

Percent of total observation	Amount of error (percent)
47	≦5
79	≦10
91	≦15
94	≦20
95	≦25
5	>25

Figure 4 is a comparison of the measured and simulated discharge at station 11425000 for high flow during February and March 1980. The fit for this period is very good as was the fit for other periods used in the comparison.

Sacramento River Flow-Routing Analysis

The purpose of the Sacramento River flow-routing analysis is to investigate the potential for use of the CONROUT model for streamflow routing to simulate daily mean discharges at station 11342000, Sacramento River at Delta, Calif. (fig. 5). Streamflow data available for this analysis are summarized in table 16.

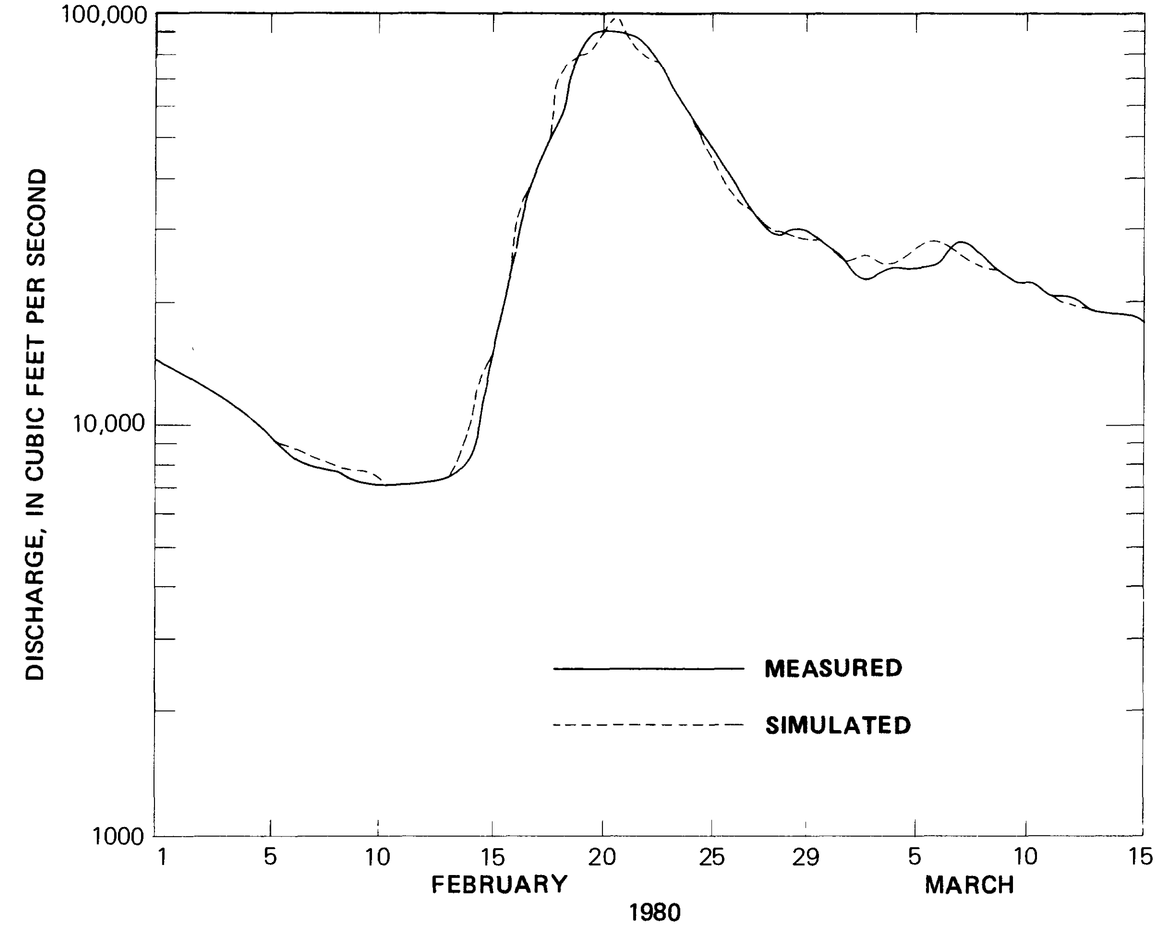

FIGURE 4. – Comparison of measured and simulated discharge at station 11425000.

The distance between the upstream and downstream gages on the Sacramento River is 35.4 miles. All the intervening drainage area between the two stations is ungaged, which is 290 mi^2 or 68.2 percent of the total drainage contributing to the Delta, Calif. site. The selected index was station 11523200 which has a drainage area of 149 mi^2. This station lies west of the Sacramento River basin and outside the study area.

To simulate the daily mean discharges, the approach was to route the flow along the Sacramento River from Mt. Shasta to Delta using the CONROUT unit-response model with the single linearization option of the diffusion analogy method. The intervening ungaged drainage area was accounted for by using data from station 11523200 adjusted by a drainage-area ratio.

Data for the 1980 water year were used to calibrate the model. Verification data were selected as the 1981 and 1982 model years.

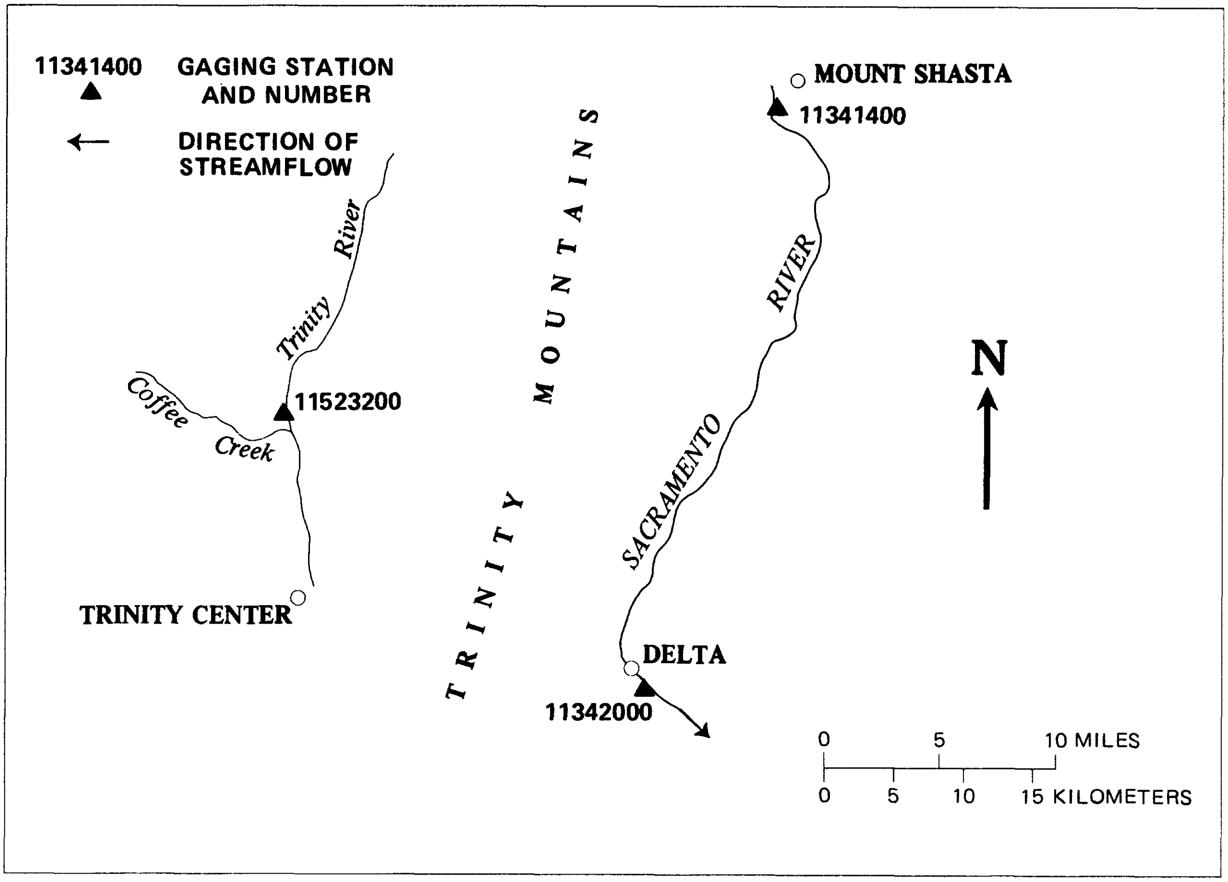

FIGURE 5. – Sacramento River study area.

TABLE 16. Gaging stations used in the Sacramento River flow-routing analysis

Station No.	Station name	Drainage area (mi^2)	Period of record
11341400	Sacramento River near Mt. Shasta	135	October 1959 to current year
11342000	Sacramento River at Delta	425	October 1944 to current year
11523200	Trinity River above Coffee Creek, near Trinity Center	149	October 1957 to current year

Model parameters C and K were computed for the reach between stations 11341400 and 11342000 for the long-term mean daily discharge. Table 17 identifies the reach and the computed values of C and K that were used for routing flow through the reach. The final best fit during calibration was obtained with the computed values given in the table.

To simulate flow from the intervening ungaged drainage area of 290 mi^2, a drainage-area ratio was calculated by dividing the ungaged drainage area by the drainage area index station 11523200 (149 mi^2) and multiplying the flow at the index station by this ratio, 1.94. During calibration, the best volume errors were obtained by adjusting this ratio to 2.27. Table 18 presents the calibration results of the routing model for simulated flows at station 11342000.

Although the volume error was small, the mean error for the 1980 water year was computed as 31.0 percent. These results were poor and could not be improved during calibration. Therefore, the verification analysis was performed using the defined model for the 1981 and 1982 water years. Table 19 presents the verification results.

The verification analysis also produced poor results because of the large intervening ungaged area in the Sacramento River system. Almost 70 percent of the drainage area contributing to station 11342000 is ungaged, therefore, the only acceptable model would be an index station that produced a similar hydrologic response. Even this was not obtainable. The index station selected was the best of two potential index stations. However, its location was on the far side of the mountainous western divide of the Sacramento River basin.

Figure 6 is a comparison of the measured and simulated discharge at station 11342000 for high flow during February and March 1980. Although the simulated and measured responses measured are somewhat similar, the misrepresentation of the intervening flow produces higher simulated flows than measured flows at times and the opposite at other times.

TABLE 17. Calibrated model parameters for Sacramento River system reaches

Reach	Begin (B) End (E)	Length (mi)	C (ft/s)	K (ft^2/s)
1	(B) Station 11341400 (E) Station 11342000	35.40	7.140	434

TABLE 18. Calibration results of routing model for station 11342000

1980 Water Year Summary

Mean absolute error (percent) for 366 days = 31
Mean - error (percent) for 190 days = -25.0
Mean + error (percent) for 176 days = 37.5
Modeled volume = 428,576 ft^3/s - days
Measured volume = 427,902 ft^3/s - days
Volume error (percent) = 0.16
RMS error (percent) = 39.7

Percent of total observation	Amount of error (percent)
8	≦5
16	≦10
27	≦15
35	≦20
46	≦25
54	>25

TABLE 19. Verification results of routing model for station 11342000

1981 and 1982 Water Year Summary

Mean absolute error (percent) for 730 days = 32.5
Mean - error (percent) for 518 days = -26.1
Mean + error (percent) for 212 days = 48.0
Modeled volume = 896,949 ft^3/s - days
Measured volume = 954,884 ft^3/s - days
Volume error (percent) = -6.1
RMS error (percent) = 39.4

Percent of total observation	Amount of error (percent)
5	≦5
11	≦10
17	≦15
27	≦20
42	≦25
58	>25

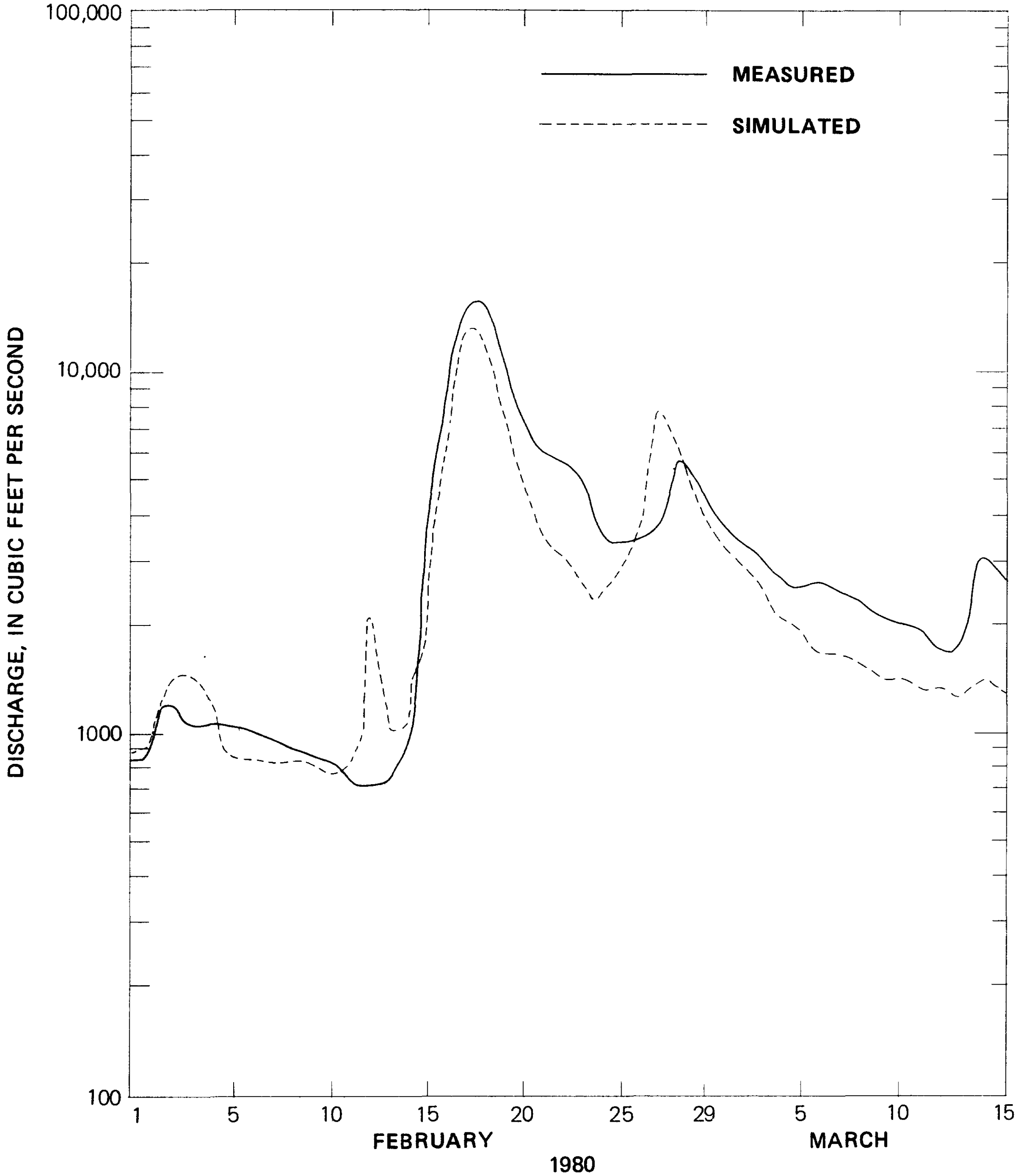

FIGURE 6. – Comparison of measured and simulated discharge at station 11342000.

Indian and Spanish Creeks Flow-Routing Analysis

The purpose of the flow-routing analysis for Indian and Spanish Creeks is to investigate the potential for use of the CONROUT model for streamflow routing to simulate daily mean discharges at station 11403000, East Branch of North Fork Feather River near Rich Bar, using streamflow records collected on Indian and Spanish Creeks (fig. 7). Station 11403000 was recently discontinued, but this analysis was made to test the feasibility of synthesizing additional records. Streamflow data available for this analysis are summarized in table 20.

The confluence of Indian and Spanish Creeks is 17.7 miles upstream from station 11403000. The distances from the confluence to the Indian Creek and Spanish Creek gages are 6.4 and 6.1 miles respectively. The intervening ungaged drainage area is 102 mi^2 or 9.95 percent of the total drainage area contributing to the Rich Bar site. The selected index station was the Spanish Creek site with a drainage area of 184 mi^2.

To simulate the daily mean discharges, the approach was to route the flow along the Indian and Spanish Creeks to the confluence, and then route the combined flow to Rich Bar. The CONROUT unit-response model with the single linearization option of the diffusion analogy method was used in the flow routing. The intervening ungaged drainage area was accounted for by using discharge data from station 11402000 adjusted by a drainage area ratio.

TABLE 20. Gaging stations used in the Indian and Spanish Creeks flow-routing analysis

Station No.	Station name	Drainage area (mi^2)	Period of record
11401500	Indian Creek near Crescent Mills	739	January 1906 to December 1909; September 1911 to March 1918; October 1930 to current year
11402000	Spanish Creek above Blackhawk Creek, at Keddie	184	October 1933 to current year
11403000	East Branch of North Fork Feather River near Rich Bar	1,025	October 1950 to September 1961; December 1967 to September 1982

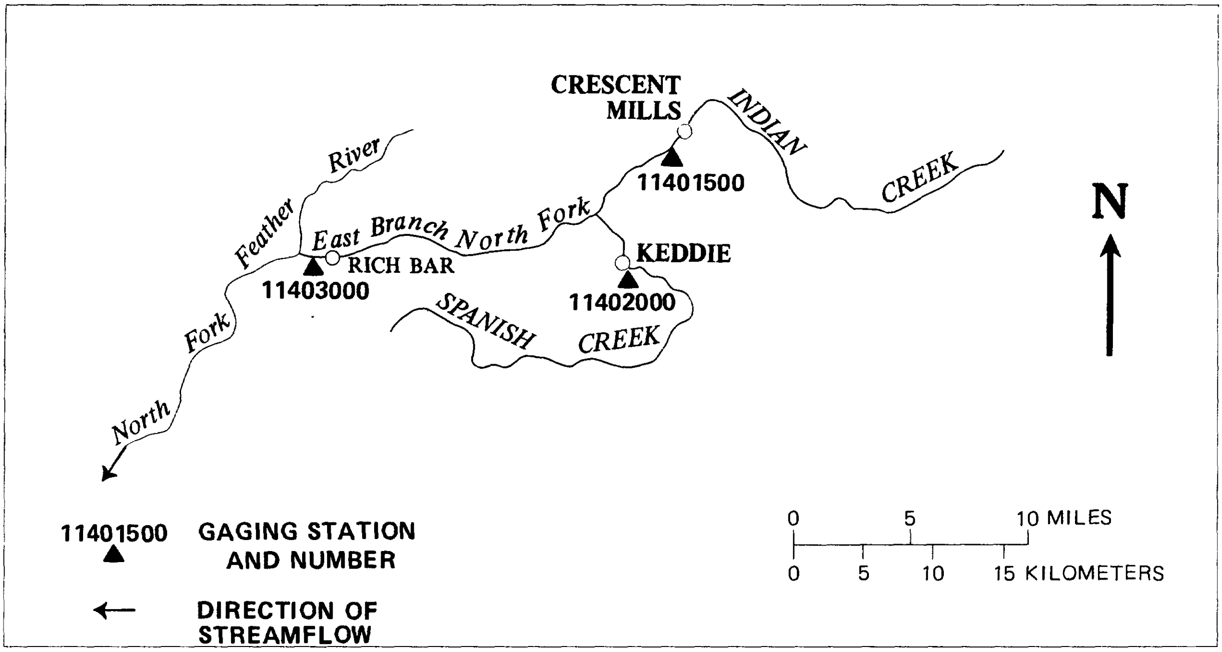

FIGURE 7. – Indian and Spanish Creeks study area.

Data for station 11403000 for the 1980 water year were used to calibrate the model. Verification data were selected from the 1981 and 1982 water years.

Model parameters C and K were computed for each reach for the long-term mean daily discharge. Table 21 identifies each reach and the computed values of C and K that were used for routing flow through the reach. The final best fit during calibration was obtained with these computed values.

To simulate flow from the intervening ungaged drainage area of 102 mi^2, a drainage area ratio was calculated by dividing the ungaged drainage area by the drainage area at index station 11402000 (184 mi^2) and multiplying the flow at the index station by this ratio, 0.55. Table 22 presents the calibration results of the routing model for simulated flows at station 11403000.

The volume error was 7.94 percent with an average mean error of 12.0 percent. Seventy-five percent of the data had computed errors less than or equal to 15 percent. Table 23 presents the results of the verification analysis. Although not as poor as the Sacramento River results, these results are not as good as the Klamath River and Feather River analyses.

TABLE 21. Calibrated model parameters for Indian and Spanish Creeks system reaches

Reach	Begin (B) End (E)	Length (mi)	C (ft/s)	K (ft^2/s)
1	(B) Station 11401500 (E) Confluence of Indian and Spanish Creeks	6.39	3.620	300
2	(B) Station 11402000 (E) Confluence of Indian and Spanish Creeks	6.08	4.250	200
3	(B) Confluence of Indian and Spanish Creeks (E) Station 11403000	17.70	3.620	300

TABLE 22. Calibration results of routing model for station 11403000

1980 Water Year Summary

Mean absolute error (percent) for 366 days = 12
Mean - error (percent) for 201 days = -11.5
Mean + error (percent) for 165 days = 12.6
Modeled volume = 436,181 ft^3/s - days
Measured volume = 404,108 ft^3/s - days
Volume error (percent) = 7.9
RMS error (percent) = 16.8

Percent of total observation	Amount of error (percent)
22	≦5
53	≦10
75	≦15
87	≦20
92	≦25
8	>25

TABLE 23. Verification results of routing model for station 11403000

1981 and 1982 Water Year Summary

Mean absolute error (percent) for 730 days = 15.5
Mean - error (percent) for 606 days = -17.7
Mean + error (percent) for 124 days = 4.5
Modeled volume = 928,456 ft^3/s - days
Measured volume = 962,743 ft^3/s - days
Volume error (percent) = -3.6
RMS error (percent) = 19.0

Percent of total observation	Amount of error (percent)
22	≦5
36	≦10
50	≦15
70	≦20
81	≦25
19	>25

The verification analysis produced a better volume comparison, but the mean errors and other computed statistics show that the results are poorer than the calibration results. Figure 8 is a comparison of measured and simulated discharge at station 11403000 during December 1979 to January 1980. The hydrographs for simulated and measured flow are very similar, especially at higher flows. There is a trend for the lower simulated flows to be less than measured flows, especially in the summer. There are some small reservoirs upstream from the gages at Indian and Spanish Creeks. Releases from them could invalidate the intervening ungaged area flow relationship and cause the underestimation.

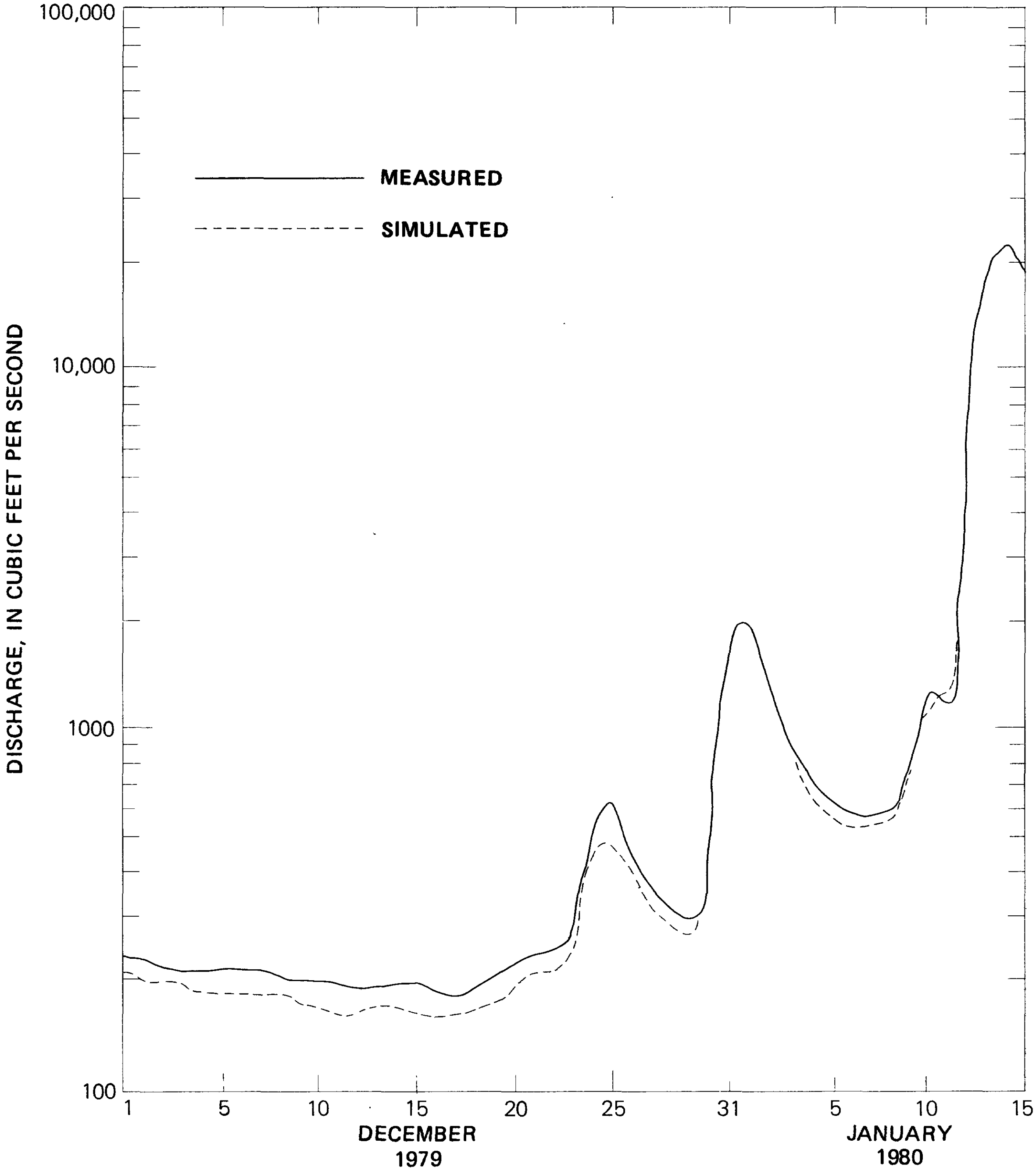

FIGURE 8. – Comparison of measured and simulated discharge at station 11403000.

Description of Regression Analysis

Simple- and multiple-regression techniques also can be used to estimate daily flow records. Regression equations can be computed that relate daily flows (or their logarithms) at a single station to daily flow at a combination of upstream, downstream, and (or) tributary stations. This statistical method is not limited, like the flow-routing method, to stations where an upstream station exists on the same stream. The explanatory variables in the regression analysis can be stations from different watersheds, or downstream and tributary watersheds. 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 and illustrated by Riggs (1973) and Thomas and Benson (1970). Only a brief description of regression analysis is provided in this report.

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

$$y_i = B_o + \sum_{j=1}^{P} b_j x_j + e_i \tag{3}$$

where

y_i is daily mean discharge at station i (dependent variable),
x_j is daily mean discharge at nearby stations (explanatory variables),
B_o and b_j are regression constant and coefficient, and
e_i is the random error term.

Equation 3 is calibrated (B_o and b_j are estimated) using values of y_i and x_j. These daily mean discharges can be retrieved from the WATSTORE Daily Values File. The values of x_j may be discharges measured on the same day as discharges at station i or may be for previous or future days, depending on whether station j is upstream or downstream from station i. Once the equation is calibrated and verified, future values of y_i are estimated using values of x_j. The regression constant and coefficients (B_o and b_j) are tested to determine if they are significantly different from zero. A given station j should only be retained in the regression equation 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 on a different period of time to obtain a measure of the true predictive accuracy. Both the calibration and verification periods should be representative of the range of flows that could occur at station i. The equation should be verified by (1) plotting the residuals e_i (difference between simulated and measured discharges) against the dependent and all explanatory variables in the equation, and (2) plotting the simulated and measured discharges versus time. These tests are intended to identify if (1) the linear model is appropriate or whether some transformation of the variables is needed, and (2) there is any bias in the equation such as overestimating low flows. In this report these tests indicated that a linear model with y_i and x_j, in cubic feet per second, was appropriate. The application of linear-regression techniques to 10 watersheds in California is described in a subsequent section of this report.

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.

Results of Regression Analysis

An analysis of the data uses presented in table 5 identified nine stations at which a regression model might be a viable alternative to continuous gaging as a means of providing daily streamflows. These nine stations were Sacramento River at Delta (11342000), Mill Creek near Los Molinos (11381500), Deer Creek near Vina (11383500), Big Chico Creek near Chico (11384000), North Yuba River below Goodyears Bar (11413000), Feather River near Nicolaus (11425000), Middle Fork American River near Auburn (11433500), Klamath River near Seiad Valley (11520500), and Indian Creek near Happy Camp (11521500).

Linear-regression techniques were applied to all nine of the selected sites. The streamflow record for each station considered for simulation (the dependent variable) was regressed against streamflow records at other stations (explanatory variables) during a given period of record (the calibration period). "Best fit" linear-regression models were developed and used to provide a simulated streamflow record that was compared to the measured streamflow record. The percent difference between the simulated and actual record for each day was calculated. The results of the regression analysis for each site are summarized in table 24.

The streamflow records during the calibration period were not reproduced with an acceptable degree of accuracy at stations 11381500, 11384000, 11433500, and 11521500. Results for the other five stations were considered good enough to test during a verification period. These results are shown in table 25. The verification periods were selected to coincide with the periods used to verify the flow-routing models for comparison.

The regression model performed poorly during the verification period for stations 11342000, 11413000, and 11433500. Only 29, 21, and 11 percent, respectively, of the daily flow produced by the model were within 5 percent of the gaged flows at these sites. The model performed much better for stations 11425000 and 11520500 where 53 percent of the model flows were within 5 percent of the gaged flows, and over 80 percent of the model flows were within 10 percent of gaged flows.

TABLE 24. Summary of calibration for regression modeling of mean daily streamflow at selected gaging stations

[Q_{xxxx} indicates daily discharge at station xxxx]

Station No.	Model	Percent of simulated flows that were within the indicated percent of actual flows: 90	95	Calibration period (water years)
11342000	$Q_{3420} = 79.3 + 2.96Q_{3710} + 0.855Q_{3414} + 0.656Q_{5232}$	16	22	1977-79
11381500	$Q_{3815} = 22.4 + 0.799Q_{3835} + 0.298Q_{3900} - 0.625Q_{3840}$	31	38	1977-79
11383500	$Q_{3835} = 31.6 + 0.136Q_{3820} + 0.791Q_{3840} + 0.285Q_{3900}$	18	23	1977-79
11384000	$Q_{3840} = -36.5 -0.305Q_{3815} - 0.095Q_{3820} + 0.786Q_{3835} + 0.164Q_{3900}$	94	107	1977-79
11413000	For October through March:			
	$Q_{4130} = 4.34 + 0.608Q_{4131}$	25	30	1975-80
	For April through June:			
	$Q_{4130} = 42.4 + 0.71_{4131}$	19	25	1975-80
	For July through September:			
	$Q_{4130} = 21.1 + 0.727Q_{4131}$	19	21	1975-80
11425000	For April through September:			
	$Q_{4250} = 7.14 + 0.983Q^*_{407150} + 8.83^*_{4075} + 1.07Q_{4210} + 1.164Q_{4240}$	13	16	1975-80
	For October through March:			
	$Q_{4250} = 371 + 1.10Q^*_{407150} + 8.51Q^*_{4075} + 0.712Q_{4210} + 1.46Q_{4240}$	24	33	1975-80
	* indicates daily values lagged by 1 day			
11433500	$Q_{4335} = 102 + 0.452Q_{4338} + 0.202Q_{4270}$	126	141	1975-80
11520500	For March through May:			
	$Q_{5205} = 175 + 1.08Q_{516530} + 0.704Q_{5175} + 1.959Q_{5195}$	10	14	1975-80
	For June through February:			
	$Q_{5205} = 38.2 + 1.01Q_{516530} + 1.76Q_{5275} + 1.86Q_{5195}$	11	15	1975-80
11521500	$Q_{5215} = -20.6 + 0.1996Q_{5195} + 0.032Q_{5205} + 0.046Q_{5325}$	82	98	1977-79

TABLE 25. Summary of verification for regression modeling of daily streamflow at selected gaging stations

Volume error: Calculated as 100 (mean of observed flows for verification period less mean of predicted flows for verification period)/(mean of observed flows for verification period).

Station No.	Mean error (percent)	RMS error (percent)	Volume error (percent)	Percent of total observations with errors less than or equal to the indicated percent					Verification period (water year)
				5	10	15	20	25	
11342000	10.0	12.7	-7.0	29	60	79	91	95	1981-82
11413000	12.9	14.6	([1])	21	44	66	79	88	1974-75
11425000	6.2	8.3	-1.2	53	82	93	96	98	1974-75
11433500	20.8	18.8	([1])	11	24	37	38	64	1974-75
11520500	6.0	8.2	-2.1	53	87	95	97	98	1981-82

[1] Not computed.

Conclusions Pertaining to Alternative Methods of Data Generation

The use of the two alternative methods of obtaining discharges at gaging stations indicate that it would be possible to reproduce the daily record for 11520500. Additional study will be necessary to see if the decreased accuracy using the alternative methods will meet the requirements of the data users.

The regression analysis used for 11425000 works better than the present method of routing flows because it uses one computer program instead of a series of programs. The coefficients will be refined more by sampling drought and wet years as well as normal years to see if there is a change in coefficients depending on flow conditions.

In summary, nine gaging stations were considered for replacement by synthesized information, but only two stations, 11520500 (Klamath River near Seiad Valley) and 11425000 (Feather River near Nicolaus), merit further investigation. Both stations will be continued in operation until the models can be shown to be acceptably accurate alternatives to continuous-record gaging stations.

COST-EFFECTIVE RESOURCE ALLOCATIONS

Introduction to Kalman Filtering for Cost-Effective Resource Allocation (K-CERA)

In a study of the cost effectiveness of a network of stream gages operated to determine water consumption in the Lower Colorado River Basin, a set of techniques called K-CERA were developed (Moss and Gilroy, 1980). Because of the water-balance nature of that study, the measure of effectiveness of the network was chosen to be the minimization of the sum of variances of errors of estimation of 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, in the broader context of the multitude of uses of the streamflow data collected in the U.S. Geological Survey's Streamflow Information Program, this tendency causes undue concentration on larger 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 of the following streamflow variables: annual mean discharge in cubic feet per second, annual mean discharge in percentage, average instantaneous discharge in cubic feet per second, or average instantaneous discharge in percentage. 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. For these reasons, this study used the K-CERA techniques with the sums of the variances of the percentage errors of the instantaneous discharges at all continuously gaged sites as the measure of the effectiveness of the data-collection activity.

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

Brief descriptions of the mathematical program used to optimize cost effectiveness of the data-collection activity and of the application of Kalman filtering (Gelb, 1974) to the determination of the accuracy of a stream-gaging record are presented below. For more detail on either the theory or the applications of K-CERA, see Moss and Gilroy (1980), Gilroy and Moss (1981), and Fontaine and others (1984).

Description of Mathematical Program

The program, called "The Traveling Hydrographer," attempts to allocate among stream gages a predefined budget for the collection of streamflow data in such a manner that the field operation is the most cost effective possible. The measure of effectiveness is discussed above. The set of decisions available to the manager is the frequency of use (number of times per year) of each number of routes that may be used to service the stream gages and to make discharge measurements. The range of options within the program is from zero usage to daily usage for each route. A route is defined as a set of one or more stream gages and the least cost travel that takes the hydrographer from his base of operations to each of the gages and back to base. A route will have associated with it an average cost of travel and average cost of servicing each stream gage visited along the way. The first step in this part of the analysis is to define the set of practical routes. This set of routes frequently will contain the path to an individual stream gage with that gage as the only stop and return to the home base so that the individual needs of a stream gage can be considered in isolation from the other gages.

Another step in this part of the analysis is the determination of any special requirements for visits to each of the gages for such things as necessary periodic maintenance, rejuvenation of recording equipment, or required periodic sampling of water-quality data. Such special requirements are considered to be inviolable constraints in terms of the minimum number of visits to each gage.

The final step is to use all of the above to determine the number of times, N_i, that the ith route for i = 1, 2, ..., NR, where NR is the number of practical routes, is used during a year such 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. Figure 9 represents this step in the form of a mathematical program. Figure 10 presents a tabular layout of the problem. Each of the NR routes is represented by a row of the table and each of the stations is represented by a column. The zero-one matrix, (ω_{ij}), defines the routes in terms of the stations that comprise it. A value of one in row i and column j indicates that gaging station j will be visited on route i; a value of zero indicates that it will not. The unit travel costs, β_i, are the per-trip costs of the hydrographer's traveltime and any related per diem and operation, maintenance, and rental costs of vehicles. The sum of the products of β_i and N_i for i = 1, 2, ..., NR is the total travel cost associated with the set of decisions $\underline{N} = (N_1, N_2, \ldots, N_{NR})$.

The unit-visit cost, α_j, is comprised of the average service and maintenance costs incurred on a visit to the station plus the average cost of making a discharge measurement. The set of minimum visit constraints is denoted by the row λ_j, j = 1, 2, ..., MG, where MG is the number of stream gages. The row of integers M_j, j = 1, 2, ..., MG specifies the number of visits to each station. M_j is the sum of the products of ω_{ij} and N_i for all i and must equal or exceed λ_j for all j if $\underline{N}$ is to be a feasible solution to the decision problem.

$$\underset{\underline{N}}{\text{Minimize}}\ V = \sum_{j=1}^{MG} \phi_j \, (M_j)$$

$V \equiv$ total uncertainty in the network

$\underline{N} \equiv$ vector of annual number times each route was used

$MG \equiv$ number of gages in the network

$M_j \equiv$ annual number of visits to station j

$\phi_j \equiv$ function relating number of visits to uncertainty at station j

Such that

Budget $\geq T_c \equiv$ total cost of operating the network

$$T_c = F_c + \sum_{j=1}^{MG} \alpha_j M_j + \sum_{i=1}^{NR} \beta_i N_i$$

$F_c \equiv$ fixed cost

$\alpha_j \equiv$ unit cost of visit to station j

$NR \equiv$ number of practical routes chosen

$\beta_i \equiv$ travel cost for route i

$N_i \equiv$ annual number times route i is used (an element of $\underline{N}$)

and such that

$$M_j \geq \lambda_j$$

$\lambda_j \equiv$ minimum number of annual visits to station j

FIGURE 9. – Mathematical-programing form of the optimization of the routing of hydrographers.

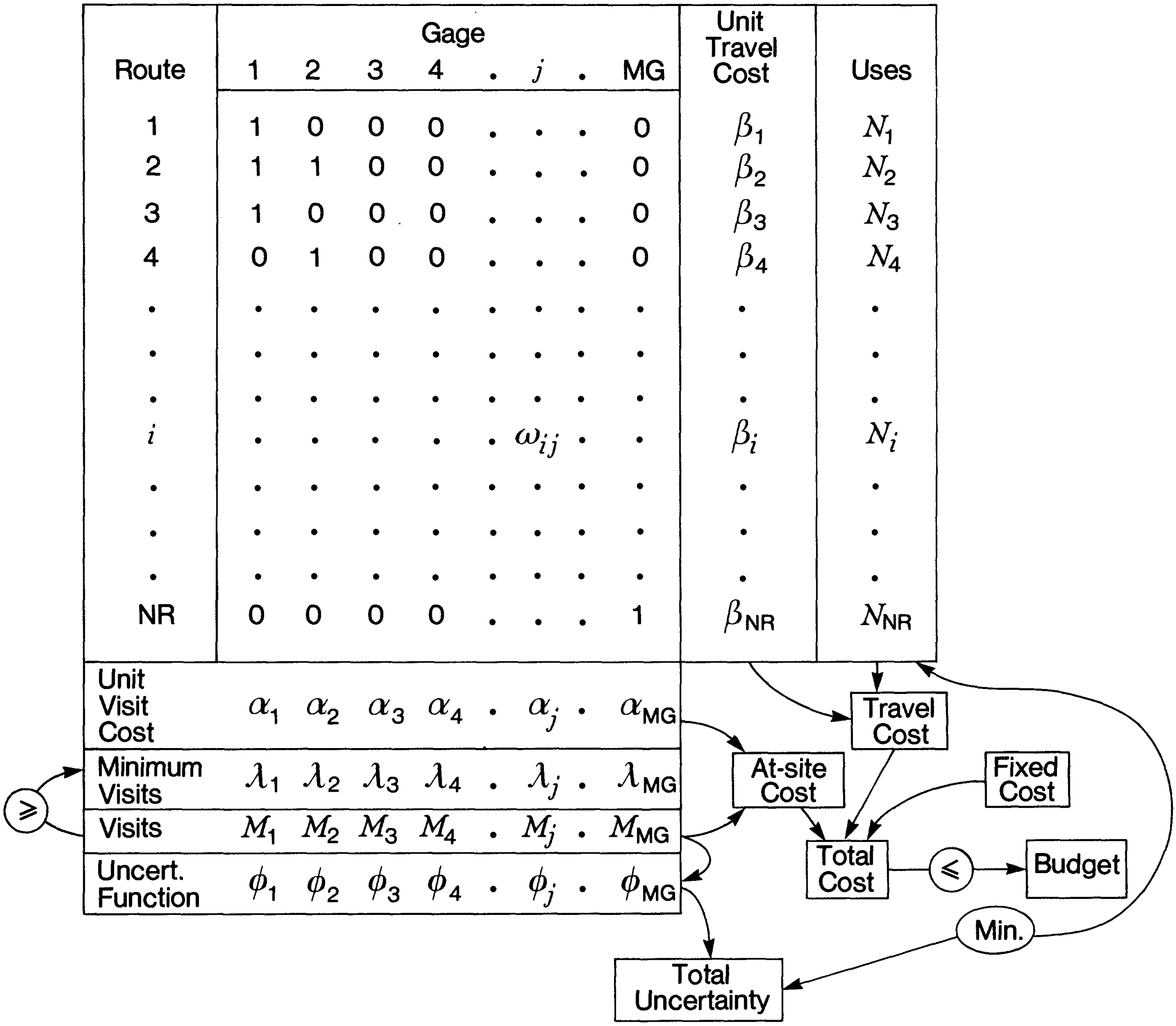

FIGURE 10. – Tabular form of the optimization of the routing of hydrographers.

The total cost expended at the stations is equal to the sum of the products of α_j and M_j for all j. The cost of record computation, documentation, and publication is assumed to be influenced negligibly by the number of visits to the station and is included along with overhead in the fixed costs of operating the program. The total cost of operating the network equals the sum of the travel costs, the onsite costs, and the fixed cost, and must be less than or equal to the available budget.

The total uncertainty in the estimates of discharges at the MG stations is determined by summing the uncertainty functions, ϕ_j, evaluated at the value of M_j from the row above it, for $j = 1, 2, \ldots, MG$.

As pointed out in Moss and Gilroy (1980), the steepest descent search used to solve this mathematical program does not guarantee a true optimum solution. However, the locally optimum set of values for $\underline{N}$ obtained with this technique specify an efficient strategy for operating the network, which may be the true optimum strategy. The true optimum cannot be guaranteed without testing all undominated, feasible strategies.

Description of Uncertainty Functions

As noted earlier, uncertainty in streamflow records is measured in this study as the average relative variance of estimation of 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) primary and secondary data are unavailable for estimating streamflow. The variances of the errors of the estimates of flow that would be employed in each situation were weighted by the fraction of time each situation is expected to occur. Thus the average relative variance would be

$$\bar{V} = \varepsilon_f V_f + \varepsilon_r V_r + \varepsilon_e V_e$$

with (4)

$$1 = \varepsilon_f + \varepsilon_r + \varepsilon_e$$

where

$\bar{V}$ is the average relative variance of the errors of streamflow estimates,

ε_f is the fraction of time that the primary recorders are functioning,

V_f is the relative variance of the errors of flow estimates from primary recorders,

ε_r is the fraction of time that secondary data are available to reconstruct streamflow records given that the primary data are missing,

V_r is the relative variance of the errors of estimation of flows reconstructed from secondary data,

ε_e is the fraction of time that primary and secondary data are not available to compute streamflow records, and

V_e is the relative error variance of the third situation.

The fractions of time that each source of error is relevant are functions of the frequencies at which the recording equipment is serviced.

The time τ since the last service visit until failure of the recorder or recorders at the primary site is assumed to have a negative-exponential probability distribution truncated at the next service time; the distribution's probability density function is

$$f(\tau) = ke^{-k\tau}/(1-e^{-ks}) \qquad (5)$$

where

k is the failure rate in units of $(\text{day})^{-1}$,

e is the base of natural logarithms, and

s is the interval between visits to the site in days.

It is assumed that, if a recorder fails, it continues to malfunction until the next service visit. As a result,

$$\varepsilon_f = (1-e^{-ks})/(ks) \qquad (6)$$

(Fontaine and others, 1984, eq. 21).

The fraction of time ε_e that no records exist at either the primary or secondary sites can also be derived assuming that the time between failures at both sites are independent and have negative exponential distributions with the same rate constant. It then follows that

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

(Fontaine and others, 1984, eqs. 23 and 25).

Finally, the fraction of time ε_r that records are reconstructed based on data from a secondary site is determined by the equation

$$\begin{aligned} \varepsilon_r &= 1 - \varepsilon_f - \varepsilon_e. \\ &= [(1-e^{-ks}) + 0.5(1-e^{-2ks})]/(ks) \end{aligned} \tag{7}$$

The relative variance, V_f, of the error derived from primary record computation is determined by analyzing a time series of residuals that are the differences between the logarithms of measured discharge and the rating curve discharge. The rating curve discharge is determined from a relationsip between discharge and some correlative data, such as water-surface elevation at the gaging station. The measured discharge is the discharge determined by field observations of depth, width, and velocities. Let $q_T(t)$ be the true instantaneous discharge at time t and let $q_R(t)$ be the value that would be estimated using the rating curve. Then

$$x(t) = \ln q_T(t) - \ln q_R(t) = \ln [q_T(t)/q_R(t)] \tag{8}$$

is the instantaneous difference between the logarithms of the true discharge and the rating curve discharge.

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 an estimate, $q_c(t)$, that is a better estimate of the stream's discharge at time t. The difference between the variable $\hat{x}(t)$, which is defined

$$\hat{x}(t) = \ln q_c(t) - \ln q_R(t) \tag{9}$$

and x(t) is the error in the streamflow record at time t. The variance of this difference over time is the desired estimate of V_f.

Unfortunately, the true instantaneous discharge, $q_T(t)$, cannot be determined and thus x(t) and the difference, $x(t) - \hat{x}(t)$, cannot be determined as well. However, the statistical properties of $x(t) - \hat{x}(t)$, particularly its variance, can be inferred from the available discharge measurements. Let the observed residuals of measured discharge from the rating curve be z(t) so that

$$z(t) = x(t) + v(t) = \ln q_m(t) - \ln q_R(t) \tag{10}$$

where

v(t) is the measurement error, and

$\ln q_m(t)$ is the logarithm of the measured discharge equal to $\ln q_T(t)$ plus v(t).

In the Kalman-filter analysis, the z(t) time series was analyzed to determine three site-specific parameters. 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 variance (subsequently referred to as process variance) equal to p. A second important parameter is β, the reciprocal of the correlation time of the Markovian process giving rise to x(t); the correlation between $x(t_1)$ and $x(t_2)$ is $\exp[-\beta|t_1-t_2|]$. Fontaine and others (1984) also define q, the constant value of the spectral density function of the white noise which drives the Gauss-Markov x-process. The parameters, p, q, and β are related by

$$\mathrm{Var}[x(t)] = p = q/(2\beta) \tag{11}$$

The variance of the observed residuals z(t) is

$$\mathrm{Var}[z(t)] = p + r \tag{12}$$

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

If the recorder at the primary site fails and there are no concurrent data at other sites that can be used to reconstruct the missing record at the primary site, there are at least two ways of estimating discharges at the primary site. A recession curve could be applied from the time of recorder stoppage until the gage was once again functioning or the expected value of discharge 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 of no concurrent data at nearby stations. If the expected value is used to estimate discharge, the value that is used should be the expected value of discharge at the time of year of the missing record because of the seasonality of the streamflow processes. The variance of streamflow, which also is a seasonally varying parameter, is an estimate of the error variance that results from using the expected value as an estimate. Thus the coefficient of variation squared $(C_v)^2$ is an estimate of the required relative error variance V_e. Because C_v varies seasonally and the times of failures cannot be anticipated, a seasonally averaged value of C_v is used:

$$\bar{C}_v = \left(\frac{1}{365} \sum_{i=1}^{365} \left(\frac{\sigma_i}{\mu_i} \right)^2 \right)^{\frac{1}{2}} \tag{13}$$

where

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

μ_i is the expected value of discharge on the i^{th} day of the year, and

$(\bar{C}_v)^2$ is used as an estimate of V_e.

The variance V_r of the relative error during periods of reconstructed streamflow records is estimated on the basis of correlation between records at the primary site and records from other gaged nearby sites. The correlation coefficient ρ_c between the streamflows with seasonal trends removed at the site of interest and detrended streamflows at the other sites is a measure of the goodness of their linear relationship. The fraction of the variance of streamflow at the primary site that is explained by data from the other sites is equal to $\rho_c{}^2$. Thus, the relative error variance of flow estimates at the primary site obtained from secondary information will be

$$V_r = (1 - \rho_c^2)\bar{C}_v^2. \tag{14}$$

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 causes difficulty in interpretation of the resulting average estimation variance. 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 3 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 it is assumed that the various errors arising from the three situations represented in equation 3 are log-normally distributed, the value of EGS was determined by the probability statement that

$$\text{Probability } [e^{-EGS} \leqq (q_c(t) \ / \ q_T(t) \leqq e^{+EGS}] = 0.683 \tag{15}$$

Thus, if the residuals in $q_c(t)$ - 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 of K-CERA

No firm decision has been made at this time to discontinue any gaging station because of insufficient data use, or because the record can be synthesized with acceptable accuracy. All 127 continuous recording, Survey-operated gaging stations have therefore been included in the K-CERA analysis. The results are described below.

Definition of Missing-Record Probabilities

As was described earlier, the statistical characteristics of missing stage or other correlative data for computation of streamflow records can be defined by a single parameter, the value of k in the truncated negative exponential probability distribution of times to failure of the equipment. In the representation of $f(\tau)$ as given in equation 5, the average time to failure is $1/k$. The value of $1/k$ will vary from site to site depending upon the type of equipment at the site, temperature and humidity, sediment deposition in wells and over intakes and orifices, and the frequency of vandalism.

No long-term individual station missing-record information to estimate $1/k$ was available in the study area, but average missing-record percentages for the last few years have been computed in each field office area. The Redding field office has averaged only 1.5 percent missing record in the last 6 years; nearly every station has an auxiliary recorder. The Tahoe City field office has averaged about 1 percent loss because of a large number of local observers and auxiliary recorders. The Sacramento office averaged 3.6 percent loss in 1980 and 1981. Each field office chief used their average missing-record percentage as a base figure for estimating the probable missing record at individual stations. The base figure was adjusted up or down subjectively by the office chiefs based on their knowledge of the station equipment, environmental conditions, vandalism, and availability of observers.

The missing record of computations were based on the usual frequency of visits for each station. This varied from 6 measurements per year at some stations with very stable ratings to 16 measurements per year at some project stations.

Definition of Cross-Correlation Coefficient and Coefficient of Variation

To compute the values of V_e and V_r of the needed uncertainty functions, daily streamflow records for each of the 127 stations for the last 30 years or the part of the last 30 years for which daily streamflow values are stored in WATSTORE (Hutchinson, 1975) were retrieved. For each of the stream gages that had 3 or more complete water years of data, the value of C_v was computed and various options, based on combinations of other stream gages, were explored to determine the maximum ρ_c. For the stations that either had less than 3 water years of data, or did not correlate with other stations because of regulation, values of C_v and ρ_c were estimated subjectively on the basis of coefficients for similar stations and probable correlation with other hydrologic information such as rainfall records, periodic stage observations, and release-valve settings.

For some stations, correlative data other than nearby streamflow records are always available, such as hydropower-generation records, dam-release records, or observer readings of stage. In these cases, a third correlation coefficient, R_2, has been estimated which reduces the variance that would otherwise be computed for periods when the station recorder is not working and no correlative streamflow record for nearby stations is available.

The set of parameters for each station and the index stations used to determine the cross-correlation coefficient are listed by field office in tables 26, 27, and 28 (at the end of report).

Kalman-Filter Definition of Variance

The determination of the variance V_f for each gaging station required the execution of three distinct steps: (1) long-term rating analysis and computation of residuals of measured discharges from the rating, (2) time-series analysis of the residuals to determine the input parameters of the Kalman-filter streamflow records, and (3) computation of the error variance, V_f, as a function of the time-series parameters, the discharge-measurement-error variance, and the frequency of discharge measurement.

Long-term rating curves, based on 50 to 100 discharge measurements made under typical or present control conditions were determined for 122 of the 127 stations. Five stations did not have a sufficient number of discharge measurements to establish viable average curves. The majority of curves were determined graphically, using selected input points. A computer program created a rating table from the input points, and then computed and stored the measurement residuals. Some of the simpler ratings were computed using a nonlinear-regression model program. The residuals were analyzed statistically to determine if the summation of residuals was near zero, and to determine if long-term time trends existed. Residuals were automatically adjusted for time trends in nearly all cases.

Next, the residuals were input to a computer program, along with estimates of measurement error to compute a sample estimate of a lag-one autocorrelation coefficient (ρ). The process variance, or error due to changing channel conditions, also was computed in this step. The computed ρ, process variance, and estimated measurement variance for each gaging station by field office are shown in tables 29-31 (at the end of report). The autocovariance parameters summarized in tables 29-31 and coefficients from the missing-record statistical analysis summarized in tables 26-28, were input to another computer program which computed uncertainty functions for each station. The uncertainty functions give the relationship of total-error variance to the number of discharge measurements made within a given time period. In figure 11, the uncertainty functions for three stations have been graphed to show some of the variation encountered.

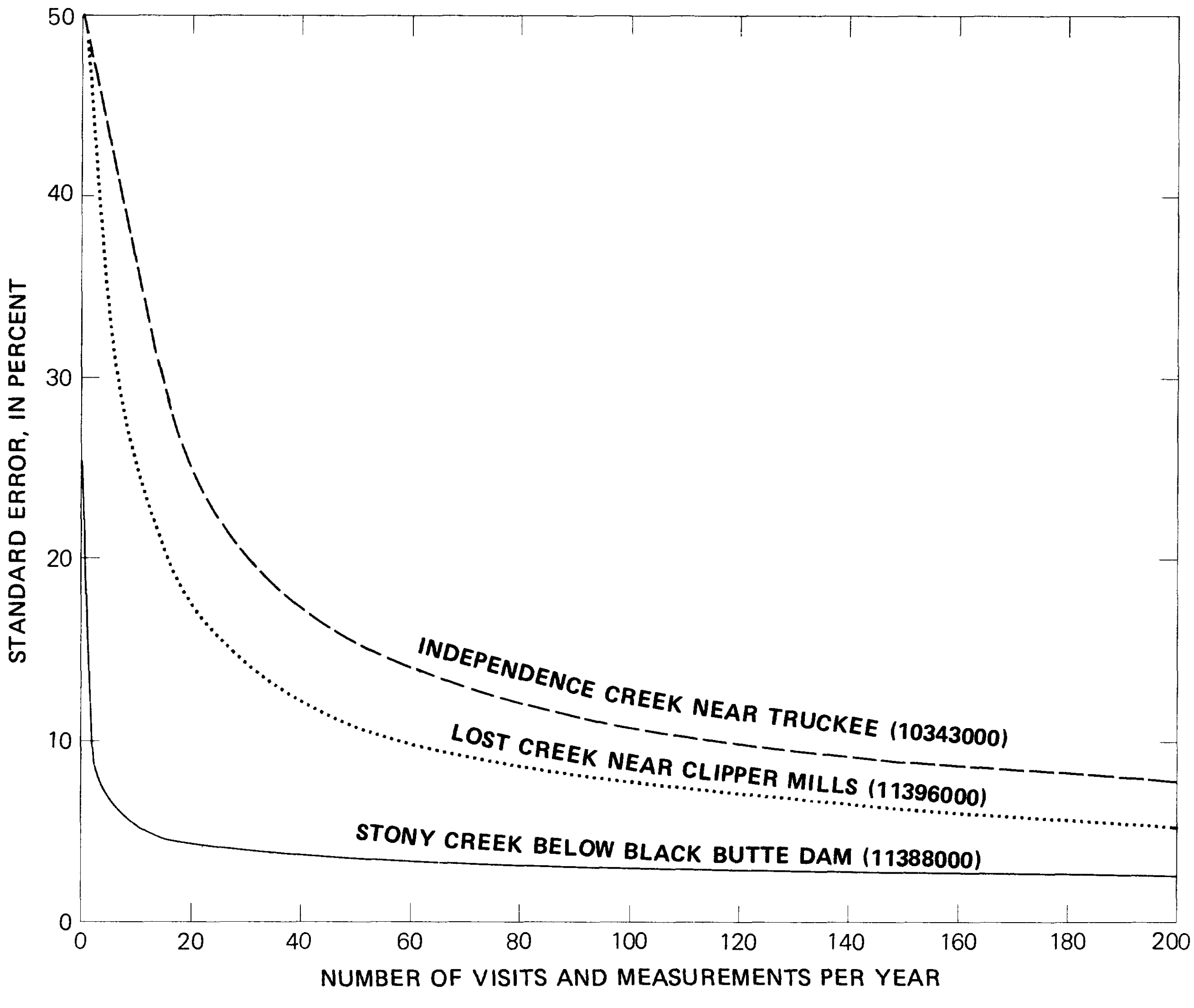

FIGURE 11. – Typical uncertainty functions for instantaneous discharge.

For the five stations which did not have enough discharge measurements for the autocovariance analysis, the autocorrelation coefficients, process variances, and measurement variances were estimated using values derived for similar nearby stations with longer records. These estimates, plus estimated missing-record coefficients were used to generate uncertainty functions for the relatively new station.

Gaging-Station Service Routes

Probable routes to service the 127 gaging stations were determined after consulting with the field office chiefs in Redding, Sacramento, and Tahoe City, and after reviewing the uncertainty functions. These routes include the routes used in the current operating practice, a large number of seldom used and untried routes, routes that visit certain key individual stations, and combinations that group proximate gages where the levels of uncertainty indicated more frequent visits might be useful. These routes and the stations visited are summarized in tables 32-36 (at the end of report).

In the Sacramento and Tahoe City offices, routes had to be grouped into summer and winter categories because of changing modes of travel in the high Sierras, depending on snow and road conditions. Twenty-nine of the Tahoe City and Sacramento stations are visited by helicopter during 5 to 6 months of the year. In the summer, these stations are visited by auto, hiking, and boating. Some truck routes are feasible year round, but some longer routes can only be used in the summer when driving conditions are better.

The costs for each station were divided between the actual visit costs (based on the average time spent at a station) and the fixed costs incurred in operating a station. The fixed costs include equipment rental, batteries or other power costs, routine station maintenance, data analysis time, computer time, stream-gaging equipment maintenance and replacement; auxillary equipment, vehicle and shop maintenance, time costs, and contingency costs for nonroutine high-water measurements and unscheduled maintenance visits. These costs were averaged out among the stations. There is no benefit in distributing the costs more precisely among stations because the station fixed costs must be totaled and subtracted from the operating budget to determine funds available for the routine station visits.

Visit costs are those associated with paying the hydrographer 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 based on an analysis of discharge measurement data available. This time was then multiplied by the average hourly salary of hydrographers in each office to determine total visit costs.

Route costs include the cost of the hydrographer's time while in transit and any per diem associated with the time required to complete the trip. Vehicle mileage costs were not included in the route costs, in that vehicle costs are included in California District overhead. Helicopter rental costs were included in many winter route costs in the upper Sierra region.

K-CERA Results

The "Traveling Hydrographer" program uses the uncertainty functions along with the appropriate cost data and route definitions to compute the most cost-effective way of operating the stream-gaging program. In this application, the first step was to simulate the current practice and determine the associated total uncertainty. To accomplish this, the number of visits being made to each stream gage and the specific routes that are being used to make these visits were fixed. The resulting average errors of estimation for the current practice in Redding, Sacramento, and Tahoe City are plotted as points in figure 12 and are 13.9, 14.0, and 10.2 percent respectively.

The curves in figure 12 represent the minimum level of average uncertainty that can be obtained for a given budget with the existing instrumentation and technology. The curves were defined by several runs of the "Traveling Hydrographer" program with different budgets. The summer-winter route differentiation used in the Sacramento and Tahoe City field offices created a small problem in defining the optimum summer-winter split in fiscal year budgets to obtain the minimum average standard error for the combined summer-winter seasons. This was handled by making several computer runs using different budget splits until a split was found that produced the minimum average summer-winter standard error for the selected fiscal-year budget level.

The current-practice and minimum-uncertainty results of the many runs of the "Traveling Hydrographer" have been summarized for Redding, Sacramento, and Tahoe City field offices in tables 37, 38, and 39 (at the end of report), respectively. These tables show the standard error, equivalent Gaussian spread, and the number of measurements at each station for the current practice and for five assumed budget levels.

Some constraints were applied to the "Traveling Hydrographer" program. A minimum visit frequency was assigned to each station based on servicing requirements of the recording equipment, required frequency of visits for water quality and sediment sampling, required frequency of furnishing current-record computations, and occasionally the frequency of vandalism. For a few stations, the uncertainty functions were held constant after a selected number of measurements to discourage the program from allocating more money for measurements to improve the record accuracy. This constraint was applied because the accuracy required at these sites was not as great as desired at the remaining sites, in the authors' judgment.

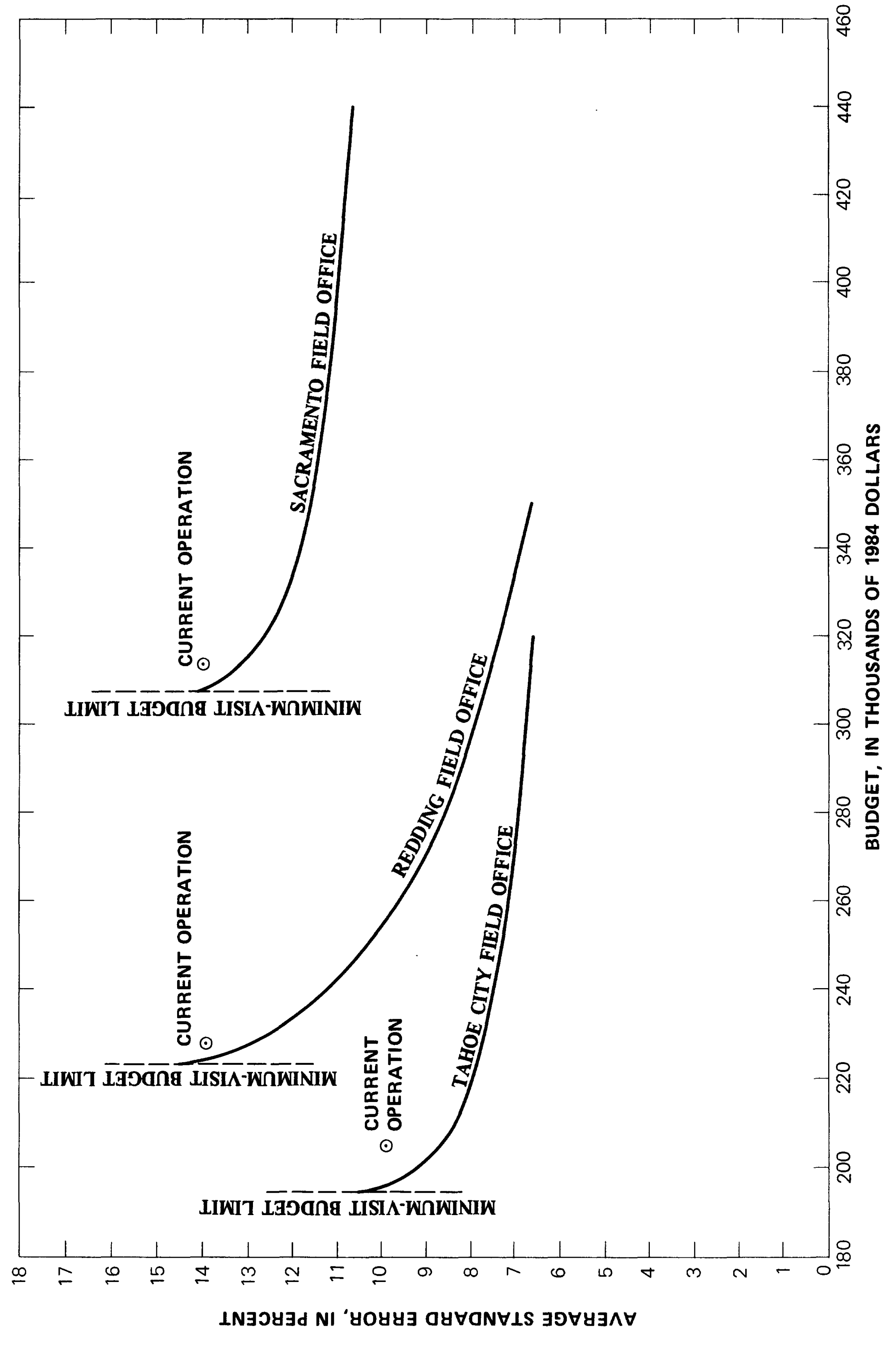

FIGURE 12. – Average standard error-budget curves for Redding, Sacramento, and Tahoe City field offices.

Figure 12 indicates that with the current (1984) budget, the average standard error for the Redding stations could be reduced from 13.9 percent to 13.0 percent by using the computer-selected routes and visit frequencies. The Sacramento average standard error could similarly be reduced from 14.0 to 13.2 percent, and the Tahoe City average could be reduced from 10.2 to 8.9 percent. The overall study-area standard error would be reduced from 12.9 to 12.0 percent. Overall standard error was computed as the weighted average standard error based on the number of stations in each field office.

The curves in figure 12 also show that the current standard error level could be maintained with a slightly reduced budget using the computer-selected routes and visit frequencies. The 1984 fiscal year budget of $747,000 could be reduced to $729,000, a reduction of 2.5 percent, without increasing the standard error, assuming that all of the computer output is viable.

Familiarity with the stations and the record's use is fundamental to the proper use of the "Traveling Hydrographer" program. The program's single objective is to minimize the total variance for all the program, which in turn emphasizes putting much more time and money into measurements at the stations with the poorest ratings. Occasionally, a station that appears to need more measurements is in reality adequately rated for the uses made of the record.

The emphasis the "Traveling Hydrographer" places on increasing the number of measurements at stations with high uncertainty functions is evident from the results for station 10343000, Independence Creek near Truckee. The present number of measurements is about seven per year, but the K-CERA program calls for 31 measurements (1984 budget level), if no maximum visit constraint is applied. This would reduce the standard error from the present 41 percent to 19 percent. Truckee River at Farad, a key accounting station, would be measured only six times per year using the selections made by the "Traveling Hydrographer" program for the 1984 budget. Six more measurements per year would reduce the standard error at this station by only 1 percent, but this gain in accuracy might have more impact than reduction of the Independence Creek standard error by 22 percent.

Considerable personal judgment must be used in applying the results of the "Traveling Hydrographer" program. For example, the Independence Creek (station 10343000) measurements will be held to 12 per year because recent channel work has removed a beaver dam that had been adversely affecting the rating. The beavers have not returned for several months, and there is hope that the more stable new rating will continue to prevail.

With the minimum visit constraints placed in the program, the smallest budget the Redding office could operate on is $224,000, with a resulting minimum average standard error of 14.5 percent. The minimum budget for Sacramento is $308,000, and the average error would be 14.2 percent; the minimum Tahoe City budget is $194,000 with an error of 11.3 percent. The overall minimum-budget standard error is 13.5 percent. A budget less than the total minimum of $726,000 would not permit proper service and maintenance of the gaging stations.

Increasing the Redding 1984 budget by 50 percent would decrease the average standard error from 13.0 to 6.9 percent. A 50-percent increase in the Sacramento budget would decrease the error from 13.2 to about 10.4 percent, and a 50-percent increase in the Tahoe City budget would lower the error from 8.9 to about 6.9 percent.

Consideration was given to combining the budgets of the three field offices and running the "Traveling Hydrographer" program for all 127 stations at one time to determine the optimum routes and frequencies to obtain the lowest overall standard error for the study area. This was not done because the optimized operation would only affect about 25 percent of the total California District gaging stations. Ideally, the entire California network should be analyzed as a unit if the objective function is the minimization of the Districtwide average standard error. Perhaps after all 10 of the California field office networks have been analyzed separately, this can be done.

Conclusions from the K-CERA Analysis

As a result of the K-CERA analysis, the following suggestions are offered:

1. Evaluation of the K-CERA results and refinement of the program input should be continued. Additional investigation into the acceptable standard error at each station is necessary to establish a maximum limit on the number of measurements per year. All cooperators and many data users were contacted by letter to determine what they felt were acceptable error levels, but the responses were not received in time to use in the present analysis.

2. The routes and route-use frequencies selected by the final "Traveling Hydrographer" run should be put into use promptly and to the fullest extent the District operations management considers feasible. There probably will be personnel limitations that prevent the full implemention of the "Traveling Hydrographer" output.

3. The station uncertainty functions generated by K-CERA should be used to focus attention on the most unsatisfactory stations in the network. Efforts should be made to obtain funds to either improve the station equipment and rating conditions, relocate the stations, or cover the costs to make the additional measurements if an exceptionally large number of measurements is needed to reduce the standard error.

4. The "Traveling Hydrographer" should become a standard operation tool for aiding decisions on route changes whenever a station is added to or dropped from the network. With modified input, it should be used to distribute gaging stations among the field offices for the most cost-effective operation.

SUMMARY

Currently, there are 127 continuous-record gaging stations operated by the U.S. Geological Survey in the Redding, Sacramento, and Tahoe City field offices. The total cost for the 1984 fiscal year will be $747,000. Nineteen separate sources of funding support this program, and eight categories of use have been identified for the streamflow data.

The analysis of data use identified only 1 of the 127 present gages as having a questionable reason for being maintained in the cooperative stream-gaging program. The decision to discontinue this station or to continue operation on a full repay basis is awaiting the outcome of discussions with the cooperator. Nine stations are being operated for sediment and water-quality research projects, and will be discontinued in 5 to 10 years. Of the remaining stations, 100 are needed for a variety of combined design, operation, FERC requirement, and forecasting purposes. Only 30 stations are operated for regional hydrology purposes. All of these stations are considered essential.

The investigation of alternative methods to produce streamflow information indicated only two stations where daily discharge records could be synthesized with possibly acceptable accuracies. Multiple-regression models for the Klamath River near Seiad Valley, and the Feather River near Nicolaus look promising and discussions with be held with the cooperating agencies to determine if the model results are acceptable substitutes for the streamflow records.

Current field operations procedures would result in an overall average standard error of 12.9 percent for the streamflow records, at the 1984 fiscal year budget level. The K-CERA analysis shows that the average error could be reduced to 12.0 percent using stream-gaging routes and frequencies selected by the "Traveling Hydrographer" program. A few contradictions exist in the present output from the "Traveling Hydrographer," and professional judgment will be required to select routes and frequencies to be used. The selected routes and frequencies should become the routine field operation plan, to the extent personnel constraints allow.

The K-CERA analysis should be used in the future to select cost-effective routes and measurement frequencies whenever gaging stations are added to or deleted from the program. The use of K-CERA to define the most cost-effective distribution of gaging stations among field offices also should be investigated.

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TABLE 26. Statistics of record reconstruction, Redding field office

Station No.: *, regulated stream; #, less than 3 years of record available, therefore, C_v and ρ_c are estimated.
C_v: Coefficient of variation of deseasonalized daily discharges.
ρ_c: Cross correlation coefficient with daily discharges at nearby stations; e, estimated for correlation with observed or telemetered flow data.
R_2: Lowest cross correlation coefficient likely because of assured availability of nearby hydrologic records.

Station No.	C_v	ρ_c	R_2	Source of reconstruction records
*10356500	1.47	0.649	--	10358500; 11345500; 11348500
10358500	.779	.605	--	10356500; 11344000; 11345500
*11341400	.898	.857	--	11342000; 11371000; station downstream from dam; release data available
*11342000	.956	.857	--	11341400; 11372000
11344000	1.21	.633	--	10358500; 11345500; 11348500
*11345500	.747	.544	--	10356500; 11344000; 11348500
11348500	1.18	.698	--	11344000; 11345500; 11355010
*11355010	.403	.90e	0.90	11348500; station downstream from powerhouse; flow data available
11355500	.235	.464		10358500
*11370500	.622	.917	.90	11377100; station downstream from dam; release data available
11371000	1.06	.906	--	11342000; 11372000; 11525600
*11372000	1.60	.504	--	11371000
11374000	1.22	.873	--	11376000; 11376550
11375810	1.00	.866	--	11375870; 11376000
11375870	1.24	.832	--	11375810; 11375900

TABLE 26. Statistics of record reconstruction, Redding field office--Continued

Station No.	C_v	ρ_c	R_2	Source of reconstruction records
#11375900	1.10	0.86	--	11375870
11376000	1.04	.874	--	11374000; 11375810; 11375870
11376550	.616	.861	--	11376000; 11381500
*11377100	.616	.917	0.90	Telemetered data available
11379500	1.42	.832	--	11375870; 11382000
11381500	.906	.954	--	11376550; 11383500
11382000	1.34	.865	--	11379500; 11387200
11383500	.971	.963	--	11381500; 11384000
11384000	1.19	.899	--	11383500; 11390000
*#11387200	.50	.90	.80	11382000; outflow data available from downstream reservoir
*11387990	.40	.90e	.90	Canal station; telemetered data available
*11388000	.40	.90e	.90	Station downstream from dam; release data available
*11389950	1.57	.90e	.90	11390000; 11405300; station downstream from dam; release data available
11390000	.880	.883	--	11384000; 11389950; 11405300
11405300	1.79	.765	--	11389950; 11390000
*11516530	.517	.90e	.90	11520500; station downstream from dam; release data available
*11517500	.734	.733	--	11519500; 11521500

TABLE 26. Statistics of record reconstruction, Redding field office--Continued

Station No.	C_v	ρ_c	R_2	Source of reconstruction records
11519500	1.06	0.830	--	11521500; 11523200
*11520500	.627	.935	--	11516530; 11519500; 11521500
11521500	.955	.781	--	11517500; 11519500
11523200	1.08	.876	--	11341400; 11371000; 11519500
*11525500	.50	.90e	0.90	Station downstream from dam; release data available
11525600	.715	.388	--	11371000
*#11525655	.50	.80	.80	Upstream reservoir; release data available

TABLE 27. Statistics of record reconstruction, Sacramento field office

Station No.: *, regulated stream.
C_v: Coefficient of variation of deseasonalized daily discharges.
ρ_c: Cross correlation coefficient with daily discharges at nearby stations; e, estimated for correlation with observed or telemetered flow data.
R_2: Lowest cross correlation coefficient likely because of assured availability of nearby hydrologic records.

Station No.	C_v	ρ_c	R_2	Source of reconstruction records
*11308900	0.40	0.95e	--	Station downstream from dam; release data available
11312000	1.000	.700	--	11329500
11316800	1.017	.953	--	11317000; 11318500
11317000	1.037	.909	--	11316800; 11318500
11318500	1.042	.980	--	11316800; 11317000
*11319500	.98	.80e	--	Several reservoirs upstream
*11323500	.70	.90e	0.90	Station downstream from dam; release data available. Telemetry
*11325500	.70	.70e	.70	Station downstream from dam; release data available
11329500	.700	.850	--	11312000
11333000	1.437	.632	--	11431800
11333500	1.237	.920	--	11335000
11335000	1.287	.920	--	11333500; telemetry
11336580	1.50	.60	--	Urban runoff, poor correlation
11389000	.654	.962	--	11389500 (below 30,000 ft^3/s)
11389500	.481	.985	--	11389000; 11390500 (below 30,000 ft^3/s)
11390500	.407	.974	--	11389500 (below 30,000 ft^3/s); telemetry

TABLE 27. Statistics of record reconstruction, Sacramento field office--Continued

Station No.	C_v	ρ_c	R_2	Source of reconstruction records
11394500	1.092	0.955	--	11396400; 11413000; 11413300
*11395030	.90	.90e	0.90	Station downstream from dam; release data available
*11395200	.90	.90e	.90	Station downstream from dam; release data available
*11395500	.70	.70e	--	Canal station, poor correlation
*11396000	1.40	.60e	--	Station downstream from dam; release data available
*11396200	.90	.90e	.90	Do.
*11396310	.85	.85e	--	Canal station, poor correlation
*11396330	.70	.70e	--	Do.
11396400	.950	.807	--	11394500; 11407500; 11413000
11407500	1.911	.632	--	11396400
11408850	1.001	.656	.65	11408880; telemetry
*11408880	1.45	.65e	.65	Station downstream from dam; release data available
11409300	1.091	.727	.72	11396400; telemetry
*11409400	.80	.98e	.90	Station downstream from dam; release data available
11413000	1.004	.942	--	11413100
11413100	.888	.942	--	11413000
*11413300	.90	.90e	.90	Station downstream from dam; release data available
*11413520	1.20	.95e	.85	Do.
*11417500	1.374	.833	--	11413000

TABLE 27. Statistics of record reconstruction, Sacramento field office--Continued

Station No.	C_v	ρ_c	R_2	Source of reconstruction records
*11418000	1.090	0.987	0.98	Upstream hydropower plants
*11418500	1.30	.70e	--	Reservoirs and diversions upstream
*11421000	1.240	.987	--	11418000
*11422500	1.10	.90e	.90	11424000; station downstream from dam; release data available
*11424000	1.562	.583	--	11422500; station downstream from dam
*11425000	1.20	.90e	.90	Telemetry
*11425500	1.10	.95e	.90	Do.
11427000	1.269	.872	--	11335000; 11431800
11431800	1.035	.755	--	11335000; 11427000
*11433040	1.50	.80e	--	Station downstream from dam
*11433500	1.112	.848	--	11427000; 11433800
*11433800	.885	.875	--	11427000; 11433500
*11442500	1.40	.90e	.90	Telemetry
*11443500	1.40	.40e	--	Station dwonstream from dam
*11445500	.881	.928	.92	PGE station upstream
*11446500	1.02	.97e	.95	Station downstream from dam; release data available
11452500	1.35	.82e	.80	Telemetry
*11454000	1.05	.97e	.95	Station downstream from dam; release data available

TABLE 28. Statistics of record reconstruction, Tahoe City field office

Station No.: *, regulated stream; #, less than 3 years of record available, therefore, C_v and ρ_c are estimated.
C_v: Coefficient of variation of deseasonalized daily discharges.
ρ_c: Cross correlation coefficient with daily discharges at nearby stations; e, estimated for correlation with observed or telemetered flow data.
R_2: Lowest cross correlation coefficient likely because of assured availability for nearby hydrologic records.

Station No.	C_v	ρ_c	R_2	Source of reconstruction records
10336600	1.06	0.896	--	10336610; 10336660
10336610	1.00	.90	--	10336600; 10336780; sediment observer
*10336626	1.03	.765	--	10336600; 10338500; occasional readings by U.S. Forest Service personnel
#10336645	1.00	.90	--	10336660; 10336676; sediment observer
10336660	1.24	.948	--	Do.
10336676	1.10	.910	--	10336660; sediment observer
#10336689	1.00	.90	--	Do.
#10336759	1.00	.90	--	10336600; 10336780; sediment observer
10336780	.639	.861	0.86	10336600; sediment observer
*10337500	.50	.95e	--	Daily observer readings
*10338500	1.20	.628	--	10336626; occasional observer readings
*10339400	.50	.90e	--	Station downstream from dam; release data available
*10340500	.50	.90e	--	Do.
*10343000	.50	.70e	--	Station downstream from dam
10343500	1.03	.869	.86	10336660; 11414000; sediment observer

TABLE 28. Statistics of record reconstruction, Tahoe City field office--Continued

Station No.	C_v	ρ_c	R_2	Source of reconstruction records
*10344400	0.50	0.90e	--	Station downstream from dam; release data available
*10344500	.50	.90e	--	Do.
*10346000	.699	.536	0.53	10336600; telemetry
11401500	1.18	.834	--	11402000
11402000	1.18	.834	--	11401500
*11407900	1.47	.736	.73	11408000; station downstream from dam; release data available
*11408000	1.38	.736	.73	11407900; observer reads twice weekly
11414000	1.39	.752	--	10336660
*11416000	.549	.826	.82	Observer reads daily
*11416500	2.39	.90	--	11408000; station downstream from dam; release data available
*11421760	.50	.90e	--	Telemetry
*11421780	.50	.90e	--	Do.
*11421790	.50	.90e	--	Station downstream from dam; release data available
11427940	1.62	.958	--	11428300
*11428000	1.85	.541	--	11414000
*11428300	1.65	.958	--	11427940
*11429500	.50	.80e	--	Observer reads three times weekly
*11430000	.50	.80e	--	Observer reads twice weekly
*11441500	.50	.90	--	Station downstream from dam; release data available
*11441900	1.92	.90	--	11414000; telemetry

TABLE 29. Autocovariance analysis for Redding stations

[See table 4 for station name. RHO: Lag-one autocorrelation coefficient]

Station No.	RHO	Process variance (log base 10)^2	Measurement variance (log base 10)^2
10356500	0.990	0.00547	0.00030
10358500	.986	.00032	.00027
11341400	.350	.00039	.00026
11342000	.910	.00004	.00022
11344000	.905	.00228	.00022
11345500	.985	.00075	.00022
11348500	.972	.00092	.00021
11355010	.531	.00001	.00014
11355500	.450	.00002	.00030
11370500	.942	.00013	.00011
11371000	.000	.00091	.00024
11372000	.949	.00144	.00022
11374000	.992	.02112	.00014
11375810	.991	.04702	.00017
11375870	.977	.02592	.00021
11375900	.980	.03000	.00020
11376000	.981	.00098	.00021
11376550	.000	.00005	.00022
11377100	.890	.00001	.00016
11379500	.942	.00133	.00024
11381500	.985	.00122	.00021
11382000	.968	.00643	.00022
11383500	.504	.00029	.00026
11384000	.991	.00186	.00019
11387200	.980	.03000	.00020
11387990	.969	.00970	.00019
11388000	.000	.00019	.00023
11389950	.969	.04034	.00033
11390000	.984	.00026	.00021
11405300	.989	.01535	.00018
11516530	.887	.00001	.00014
11517500	.986	.00208	.00027
11519500	.917	.00114	.00019
11520500	.998	.00095	.00012
11521500	.996	.00677	.00023
11523200	.988	.00716	.00021
11525500	.974	.00064	.00027
11525600	.983	.00100	.00030
11525655	.931	.00001	.00019

TABLE 30. Autocovariance analysis for Sacramento stations

[See table 4 for station name. RHO: Lag-one autocorrelation coefficient]

Station No.	RHO	Process variance (log base 10)^2	Measurement variance (log base 10)^2
11308900	0.994	0.00127	0.00023
11312000	.500	.00309	.00017
11316500	.995	.10490	.00032
11317000	.992	.10750	.00030
11318500	.623	.00629	.00024
11319500	.975	.00101	.00018
11323500	.945	.00016	.00029
11325500	.971	.00167	.00024
11329500	.965	.12970	.00021
11333000	.912	.00098	.00026
11333500	.981	.05263	.00019
11335000	.989	.00233	.00026
11336580	.984	.00927	.00029
11369000	.957	.00015	.00017
11369500	.837	.00007	.00015
11390300	.970	.00004	.00012
11394500	.972	.00030	.00023
11395030	.931	.00351	.00045
11395200	.930	.00012	.00008
11395500	.931	.00032	.00008
11396000	.992	.02954	.00075
11396200	.862	.00272	.00053
11396310	.971	.00038	.00023
11396330	.933	.00067	.00023
11396400	.379	.00332	.00043
11407500	.971	.00173	.00030
11408350	.996	.00497	.00030
11408880	.999	.00770	.00017
11409300	.984	.00386	.00008
11409400	.997	.06540	.00017
11413000	.878	.00024	.00008
11413100	.976	.00050	.00017
11413300	.980	.00012	.00008
11413520	.995	.02759	.00047
11417500	.900	.00023	.00017

TABLE 30. Autocovariance analysis for Sacramento stations--Continued

Station No.	RHO	Process variance (log base 10)^2	Measurement variance (log base 10)^2
11418000	0.988	0.00022	0.00030
11418500	.921	.00101	.00017
11421000	.989	.00029	.00008
11422500	.984	.00012	.00008
11424000	.992	.01262	.00030
11425000	.950	.00019	.00008
11425500	.984	.00015	.00008
11427000	.967	.00006	.00047
11431800	.995	.00179	.00047
11433040	.520	.00040	.00068
11433500	.949	.00017	.00008
11433800	.970	.00017	.00008
11442500	.992	.00018	.00017
11443500	.800	.00019	.00008
11445500	.986	.00013	.00017
11446500	.602	.00012	.00017
11452500	.405	.00010	.00030
11454000	.970	.00096	.00017

TABLE 31. Autocovariance analysis for Tahoe City stations

[See table 4 for station name. RHO: Lag-one autocorrelation coefficient]

Station No.	RHO	Process variance (log base 10)^2	Measurement variance (log base 10)^2
10336600	0.987	0.00583	0.00030
10336610	.980	.01727	.00030
10336626	.966	.00725	.00047
10336645	.904	.00177	.00030
10336660	.977	.00281	.00030
10336676	.974	.00519	.00047
10336689	.975	.00342	.00030
10336759	.975	.00342	.00030
10336780	.975	.00342	.00030
10337500	.986	.00442	.00017
10338500	.345	.00504	.00030
10339400	.985	.00506	.00030
10340500	.932	.00097	.00030
10343000	.985	.10000	.00047
10343500	.965	.00045	.00030
10344400	.644	.00036	.00030
10344500	.848	.00112	.00047
10346000	.991	.00066	.00017
11401500	.837	.00037	.00017
11402000	.924	.00068	.00030
11407900	.920	.00050	.00030
11408000	.840	.00030	.00030
11414000	.922	.00046	.00030
11416000	.373	.00023	.00017
11416500	.991	.01367	.00030
11421760	.960	.00049	.00030
11421780	.957	.00008	.00017
11421780	.557	.00006	.00008
11427940	.989	.00513	.00030
11428000	.982	.00577	.00030
11428300	.962	.00121	.00030
11429500	.980	.00019	.00030
11430000	.973	.00013	.00030
11441500	.989	.00074	.00030
11441900	.955	.00024	.00030

TABLE 32. Routes that may be used to visit stations in the Redding field office area

[Negative eight-digit numbers represent stations other than continuous-record gaging stations operated by USGS that must be periodically visited by a hydrographer]

Route No.	Stations serviced on the route				
1	11376550	11377100	11379500	11381500	11382000
	11383500	11384000	11387200	11387990	11388000
	11389950	11390000	11405300		
2	11379500	11381500	11382000	11383500	11384000
	11387200	11387990	11388000	11389950	11390000
	11405300				
3	11341400	11342000	11516530	11517500	11519500
	11520500	11521500	11523200	11525500	11525600
	11525655				
4	11376550	11377100	11381500	11383500	11384000
	11389950	11390000	11405300		
5	11341400	11342000	11516530	11517500	11519500
	11520500	11521500	11523200		
6	10356500	10358500	11344000	11345500	11348500
	11355010	11355500			
7	11341400	11342000	11516530	11517500	11519500
	-11511400	-11516500			
8	11381500	11383500	11384000	11389950	11390000
	11405300				
9	11379500	11382000	11387200	11387990	11388000
10	11377100	11384000	11387200	11387990	11388000
11	11377100	11384000	11389950	11390000	11405300
12	11377100	11382000	11387200	11387990	11388000
13	11344000	11345500	11348500	11355010	11355500
14	11341400	11342000	11516530	11517500	11519500
15	11516530	11517500	11519500	11520500	11521500

TABLE 32. Routes that may be used to visit stations in the Redding field office area--Continued

Route No.	Stations serviced on the route				
16	11381500	11384000	11389950	11390000	11405300
17	11383500	11384000	11389950	11390000	11405300
18	10356500	10358500	11355500	11374000	
19	11370500	11374000	-11371600	-11371700	
20	11371000	11372000	11375810	-11370000	
21	11375810	11375870	11375900	-11375815	
22	11523200	11525500	11525600	11525654	
23	11342000	11516530	-11511400	-11516500	
24	11525500	11525600	-11525400	-11525430	
25	11387200	11387990	11388000		
26	10356500	10358500	11355500		
27	11375810	11375900	-11375815		
28	11375870	11375900	-11375815		
29	11341400	11342000	-11341360		
30	11525500	-51125400	-11525430		
31	11371000	11372000	11375810		
32	11375810	11375870	11375900		
33	11371000	11372000	-11370000		
34	11516530	11517500	11519500		
35	11379500	11382000			
36	11376000	11376550			
37	11375810	11376000			

TABLE 32. Routes that may be used to visit stations in the Redding field office area--Continued

Route No.	Stations serviced on the route	
38	11376550	11377100
39	11525600	11525655
40	11371000	11525500
41	11370500	11374000
42	11342000	11516530
43	11375810	11375900
44	11375870	11375900
45	11376000	11377100
46	10356500	10358500
47	11525655	-11341360
48	11371000	11525600
49	11525500	11525655
50	11523200	11525500
51	11523200	11525600
52	11341400	11516530
53	11372000	11374000
54	11525500	11525600
55	11341400	11342000
56	11371000	11372000
57	11375870	11375900
58	11525500	
59	11372000	

TABLE 32. Routes that may be used to visit stations in the Redding field office area--Continued

Route No.	Stations serviced on the route				
60	11374000				
61	11375810				
62	11375870				
63	11375900				
64	11376000				
65	11382000				
66	11384000				
67	11387200				
68	11387990				
69	11389950				
70	11405300				
71	11341400	11342000	11516530	11517500	11519500
72	11381500	11384000	11389950	11390000	11405300
73	11383500	11384000	11389950	11390000	11405300
74	11376550	11377100			
75	11525500	-11371600	-1137170	-11525430	
76	11341400	11342000	11516530	11517500	11519500
	11520500	11521500	11523200	-11525400	
77	11341400	11342000	11516530	11517500	11519500
	-11341360	-11511400	-11516500		

TABLE 33. Summer routes that may be used to visit stations in the Sacramento field office area

[Negative eight-digit numbers represent stations other than continuous-record gaging stations operated by USGS that must be periodically visited by a hydrographer]

Route No.	Stations serviced on the route				
1	11308900	11312000	11316800	11317000	11318500
	11319500	11323500	11325500	11329500	11333000
	11333500	11335000	-11325000		
2	11333000	11333500	11335000	11442500	11443500
	-11442700				
3	11333000	11333500	11335000	11431800	11433040
	11433500	11442500	11443500		
4	11408850	11408880	11409300	11409400	11413000
	11413520	11417500	11422500		
5	11395030	11395200	11395500	11396000	11396200
	11396310	11396330	11396400	11407500	11413100
	11413300	11421000	11424000	-11395150	
6	11394500	11395030	11395200	11395500	11396000
	11396200	11396310	11396330	11396400	11413100
	11413300	-11395150			
7	11425000	11425500			
8	11445500	11446500			
9	11452500				
10	11452500	11454000			
11	11431800	11433040			
12	11427000	11433800			
13	11422500	11427000			
14	11427000	11433500			
15	11335000	11336580			
16	11312000	11329500	11336580		
17	11312000	11325500	11336580		
18	11433500	11433800			
19	11408850	11408880	11409300	11409400	11413000
	11413520	11417500			

TABLE 33. Summer routes that may be used to visit stations in the Sacramento field office area--Continued

Route No.	Stations serviced on the route				
20	11407500	11418000	11418500	11421000	11424000
21	11418000	11418500			
22	11433800	11442500	11443500	11445500	
23	11308900	11312000	11316800	11317000	11318500
	11319500	11323500	11325500	11336580	
24	11389000	11389500	11390500	11425500	
25	11442500	11443500			
26	11389000				
27	11389000	-11407150			
28	11389500	11390500			
29	11394500	11395500	11396200	-11404500	
30	11394500	11395500	11396200		
31	11446500	11452500			
32	11454000				
33	11452500	11454000			
34	11452500				
35	11452500	-11390672			
36	11422500	-11422000			
37	11422500				
38	11445500	-11444500			
39	11445500				
40	11442500	-11442700			
41	11442500				
42	11308900	11312000	11319500	11323500	11335000
	-11308600				
43	11308900	11312000	11319500	11323500	11335000
44	11325500	11329500	-11325000		
45	11316800	11317000	11318500		
46	11421000	11424000			
47	11407500	11421000	11424000		
48	11425500				
49	11396310	11396400	11407500		
50	11395200	11395500	11396000	11396200	-11395150
	-11404500				

TABLE 33. Summer routes that may be used to visit stations in the Sacramento field office area--Continued

Route No.	Stations serviced on the route				
51	11394500	11395200	11395500	11396000	11396200
	11396330	-11395150	-11404500		
52	11333000	11333500	11445500		
53	11427000	11433800	11433500		
54	11422500	11418000			
55	11308900	11316800			
56	11308900	11319500	11323500	11325500	11329500
	-11325000				
57	11425000				
58	11333500	11445500			
59	11422500				
60	11395030	11396310	11396400	11407500	11413100
	11413300				
61	11396000				
62	11446500				
63	11319500				
64	11319500	-11308600			

TABLE 34. Winter routes that may be used to visit stations in the Sacramento field office area

[Negative eight-digit numbers represent stations other than continuous-record gaging stations operated by USGS that must be periodically visited by a hydrographer]

Route No.	Stations serviced on the route				
1	11308900	11312000	11316800	11317000	11318500
	11319500	11323500	11325500	11329500	11333000
	11333500	11335000	-11308600		
2	11333000	11333500	11335000	11442500	11443500
3	11333000	11333500	11335000	11431800	11433040
	11433500	11442500	11443500		
4	11408850	11408880	11409300	11409400	11413000
	11417500	11422500			
5	11395500	11396000	11396200	11396310	11396330
	11396400	11407500	11421000	11424000	
6	11395500	11396000	11396200	11396310	11396330
	11396400	11407500			
7	11425000	11425500			
8	11445500	11446500			
9	11446500				
10	11454000				
11	11431800	11433040			
12	11427000	11433800			
13	11422500	11427000			
14	11427000	11433500			
15	11335000	11336580			
16	11312000	11329500	11336580		
17	11312000	11325500	11336580		

TABLE 34. Winter routes that may be used to visit stations in the Sacramento field office area--Continued

Route No.	Stations serviced on the route				
18	11433500	11433800			
19	11408850	11408880	11409300	11409400	11413000
	11417500	11424000			
20	11407500	11418000	11418500	11421000	11424000
21	11418000	11418500			
22	11433800	11442500	11443500	11445500	
23	11308900	11312000	11316800	11317000	11318500
	11319500	11323500	11325500	11336580	
24	11389000	11389500	11390500	11425500	
25	11442500	11443500			
26	11389000				
27	11389000	-11407150			
28	11389500	11390500			
29	11396000	11407500			
30	11395500	11396200			
31	11446500	11452500			
32	11454000				
33	11452500	-11100000			
34	11452500				
35	11452500	-11390672			
36	11422500	-11422000			
37	11422500				
38	11445500	-11444500			

TABLE 34. Winter routes that may be used to visit stations in the Sacramento field office area--Continued

Route No.	Stations serviced on the route				
39	11445500				
40	11442500	-11442700			
41	11442500				
42	11308900	11312000	11319500	11323500	11335000
	-11308600				
43	11308900	11312000	11319500	11323500	11335000
44	11325500	11329500			
45	11316800	11317000	11318500		
46	11421000	11424000			
47	11407500	11421000	11424000		
48	11425500				
49	11396310	11396400	11407500		
50	11308900	11319500	11323500	11325500	11329500
	-11308600				
51	11308900	11316800	11317000	11318500	11319500
	11323500	-11308600			
52	11333000	11333500	11445500		
53	11394500	11395030	11395200	11413100	11413300
	11413520	-11395150			
54	11427000	11433800	11433500		
55	11425000				
56	11394500	11395030	11395200	11396000	11408850
	11408880	11413100	11413300	11413520	11417500
57	11427000				
58	11422500	11431800			

TABLE 35. Summer routes that may be used to visit stations in the Tahoe City field office area

[Negative eight-digit numbers represent stations other than continuous-record gaging stations operated by USGS that must be periodically visited by a hydrographer]

Route No.	Stations serviced on the route				
1	10336600	10336610	10336626	-10336625	
2	10336600	10336610	10336626		
3	10336600	10336610	10336780		
4	10336645	10336660	10336676		
5	10336626	10336645	10336660	10336676	-10336625
6	10336626	10336645	10336660	10336676	
7	10336610	10336689	10336759	-10336698	
8	10336610	10336689	10336759		
9	10336610	10336759	10336780		
10	10336600	10336610	10336626	10336645	10336660
	10336759	10336780	10336625		
11	10336600	10336610	10336626	10336645	10336660
	10336759	10336780			
12	10337500	-10337000			
13	10337500				
14	10340500	10344400	10344500	10346000	
15	10338500	10339400	-10339250	-10339380	
16	10338500	10339400			
17	10338500	10339400	10340500	-10339250	-10339380
18	10338500	10339400	10340500		
19	10337500	10338500	10339400	-10339250	-10339380

TABLE 35. Summer routes that may be used to visit stations in the Tahoe City field office area--Continued

Route No.	Stations serviced on the route				
20	10337500	10338500	10339400		
21	10337500	10338500	10339400	10340500	
22	10343000	10343500			
23	10343500	11401500	11402000		
24	11407900	11408000	11416000	11416500	-11407800
	-11415500				
25	11407900	11408000	11416000	11416500	
26	11414000	11421760	11421780	11421790	
27	10336600	11429500	11430000	11441500	11441900
	-11429350	-11441000	-11441100		
28	10336600	11429500	11430000	11441500	11441900
29	11427940	11428000	11428300		
30	10338500				
31	10336689	-10336698			
32	10336689				
33	11441500	11441900	-11429350	-11441000	-11441100
34	11401500	11402000			
35	10344500	10346000			
36	10343000				
37	11441500	11441900			

TABLE 36. Winter routes that may be used to visit stations in the Tahoe City field office area

[Negative eight-digit numbers represent stations other than continuous-record gaging stations operated by USGS that must be periodically visited by a hydrographer]

Route No.	Stations serviced on the route				
1	10336600	10336610	10336626	-10336625	
2	10336600	10336610	10336626		
3	10336600	10336610	10336780		
4	10336645	10336660	10336676		
5	10336626	-10336625			
6	10336626				
7	10336610	10336689	10336759	-10336698	
8	10336610	10336689	10336759		
9	10336610	10336759	10336780		
10	10336600	10336610	10336626	10336645	10336660
	10336759	10336780	-10336625		
11	10336600	10336610	10336626	10336645	10336660
	10336759	10336780			
12	10337500	-10337000			
13	10337500				
14	10340500	10344400	10344500	10346000	
15	10338500	10339400	-10339250	-10339380	
16	10338500	10339400			
17	10338500	10339400	10340500	-10339250	-10339380
18	10338500	10339400	10340500		
19	10337500	10338500	10339400	-10339250	-10339380
20	10337500	10338500	10339400		

TABLE 36. Winter routes that may be used to visit stations in the Tahoe City field office area--Continued

Route No.	Stations serviced on the route				
21	10343000				
22	11401500	11402000			
23	10343000	10343500	11407900	11408000	11416000
	11416500	-11407800	-11415500		
24	10343000	10343500	11407900	11408000	11416000
	11416500				
25	11427940	11428000	11428300	11429500	11430000
	-11429350				
26	11427940	11428000	11428300	11429500	11430000
27	11407900	11408000	11416000	11416500	11427940
	11428000	11428300	11429500	-11407800	-11415500
	-11429350				
28	11407900	11408000	11416000	11416500	11427940
	11428000	11428300	11429500		
29	11430000	11441500	11441900	-11429350	-11441000
	-11441100				
30	11430000	11441500	11441900		
31	11441500	11441900	-11441000	-11441100	
32	11441500	11441900			
33	11427940	11428000	11428300	11429500	11430000
	11441500	11441900	-11429350	-11441000	-11441100
34	11427940	11428000	11428300	11429500	11430000
	11441500	11441900			
35	11414000	11421760	11421780	11421790	
36	10336689	10336759	-10336698		
37	10336689	10336759			
38	10336759				
39	10336689				
40	10338500				

TABLE 37. Selected results of K-CERA analysis for the Redding field office

[Top line--standard error of instantaneous discharge, in percent; second line--equivalent Gaussian spread; third line--number of visits per year to site. Budget--*, indicates same budget level as current (1984) practice]

Station No.	Current practice	Budget, in thousands of 1984 dollars				
		224	229*	250	280	350
Average standard error per station, in percent ------	13.9	14.5	13.0	10.5	8.7	6.7
10356500	20.1	20.1	20.1	15.6	12.4	9.2
	8.4	8.4	8.4	6.5	5.2	3.9
	6	6	6	10	16	29
10358500	10.5	10.5	10.5	8.1	6.4	4.8
	2.5	2.5	2.5	2.0	1.6	1.2
	6	6	6	10	16	29
11341400	10.0	12.9	12.9	10.9	9.3	7.4
	4.7	4.9	4.9	4.7	4.7	4.5
	12	7	7	10	14	26
11342000	4.7	4.7	4.7	4.7	4.4	3.3
	1.3	1.3	1.3	1.3	1.3	1.1
	12	12	12	12	14	26
11344000	16.5	18.4	18.4	15.2	13.0	10.1
	10.0	10.4	10.4	9.7	8.8	7.3
	8	6	6	10	15	28
11345500	6.3	7.3	7.3	5.7	4.7	3.5
	3.3	3.7	3.7	3.0	2.5	1.9
	8	6	6	10	15	28
11348500	12.9	14.8	14.8	11.6	9.5	7.0
	4.7	5.2	5.2	4.3	3.6	2.8
	8	6	6	10	15	28
11355010	1.5	1.8	1.8	1.4	1.1	0.8
	0.2	0.2	0.2	0.2	0.2	0.2
	8	6	6	10	15	28
11355500	2.1	1.8	1.8	1.6	1.5	1.3
	1.0	1.0	1.0	1.0	1.0	1.0
	8	12	12	16	23	37

TABLE 37. Selected results of K-CERA analysis for Redding field office--Continued

Station No.	Current practice	Budget, in thousands of 1984 dollars				
		224	229*	250	280	350
Average standard error per station, in percent ------	13.9	14.5	13.0	10.5	8.7	6.7
11370500	3.3	3.3	3.3	3.3	3.3	3.3
	2.0	2.0	2.0	2.0	2.0	2.0
	12	12	12	12	12	12
11371000	10.2	13.2	10.5	9.8	9.0	8.1
	7.2	7.4	7.2	7.1	7.1	7.0
	12	6	11	14	20	36
11372000	22.8	22.8	17.8	13.5	10.8	8.1
	6.4	6.4	5.2	4.1	3.3	2.5
	12	12	20	35	55	99
11374000	16.1	15.5	15.5	12.0	9.9	7.7
	10.5	10.0	10.0	7.8	6.3	5.0
	12	13	13	21	31	51
11375810	16.8	14.5	15.5	11.8	9.3	7.3
	16.0	13.8	14.8	11.2	8.7	6.9
	12	16	14	24	39	64
11375870	23.4	23.4	19.2	15.7	12.8	10.0
	19.6	19.6	15.9	12.9	10.5	8.1
	12	12	18	27	40	66
11375900	21.0	21.0	17.7	13.1	11.2	8.7
	19.4	19.4	14.6	11.7	9.8	7.9
	12	12	17	31	42	69
11376000	15.1	15.1	14.4	11.3	8.8	6.7
	3.8	3.8	3.6	2.9	2.3	1.8
	12	12	13	20	32	54
11376550	3.6	3.2	4.0	3.9	4.0	3.5
	1.6	1.7	1.7	1.7	1.7	1.6
	12	16	9	10	9	13
11377100	2.7	2.7	2.7	2.7	2.7	2.7
	0.2	0.2	0.2	0.2	0.2	0.2
	12	12	12	12	12	12

TABLE 37. Selected results of K-CERA analysis for Redding field office--Continued

Station No.	Current practice	Budget, in thousands of 1984 dollars 224	229*	250	280	350
Average standard error per station, in percent ------	13.9	14.5	13.0	10.5	8.7	6.7
11379500	10.6	14.3	14.3	10.6	8.1	6.1
	6.2	7.5	7.5	6.2	5.0	3.9
	12	6	6	12	22	40
11381500	5.7	5.3	5.0	4.7	4.0	3.1
	4.7	4.4	4.2	4.0	3.6	2.6
	6	7	8	9	13	22
11382000	17.1	17.1	17.1	14.6	11.9	8.7
	11.3	11.3	11.3	9.6	7.9	5.8
	12	12	12	17	25	47
11383500	6.4	6.0	6.0	5.5	5.3	4.7
	4.0	4.0	4.0	3.9	3.9	3.8
	6	7	7	9	10	17
11384000	22.8	22.8	19.1	14.2	12.0	9.0
	3.9	3.9	3.3	2.5	2.1	1.7
	12	12	16	26	35	58
11387200	19.0	19.0	19.0	15.2	12.3	9.6
	19.0	19.0	19.0	15.1	12.2	9.6
	12	12	12	19	29	47
11387990	13.5	13.4	13.4	11.6	9.5	7.0
	13.4	13.4	13.4	11.5	9.4	6.8
	12	12	12	17	26	49
11388000	3.6	3.6	3.6	3.6	3.6	3.6
	3.2	3.2	3.2	3.2	3.2	3.2
	12	12	12	13	15	20
11389950	28.7	32.3	23.2	18.2	15.0	12.1
	27.5	31.1	23.7	17.3	14.0	11.4
	12	19	19	31	46	70
11390000	4.9	6.4	6.0	5.1	4.4	3.2
	1.7	2.1	2.1	1.8	1.6	1.2
	12	7	8	11	15	27

TABLE 37. Selected results of K-CERA analysis for Redding field office--Continued

Station No.	Current practice	Budget, in thousands of 1984 dollars				
		224	229*	250	280	350
Average standard error per station, in percent ------	13.9	14.5	13.0	10.5	8.7	6.7
11405300	30.8	30.8	24.3	19.2	15.5	11.7
	10.8	10.8	8.4	6.6	5.3	4.1
	12	12	19	20	46	80
11516530	2.3	2.3	2.3	2.3	2.1	1.5
	0.2	0.2	0.2	0.2	0.2	0.2
	12	12	12	12	14	26
11517500	8.8	11.3	11.3	9.6	8.1	6.0
	5.2	6.6	6.6	5.7	4.9	3.6
	12	7	7	10	14	26
11519500	11.2	14.1	14.1	12.1	10.5	8.0
	6.5	7.3	7.3	6.7	6.2	5.0
	12	7	7	10	14	26
11520500	4.4	4.4	4.4	3.7	3.0	2.1
	1.7	1.7	1.7	1.5	1.2	0.9
	6	6	6	8	12	23
11521500	11.5	11.5	11.5	10.0	8.1	5.9
	6.0	6.0	6.0	5.2	4.2	3.1
	6	6	6	8	12	23
11523200	13.4	13.4	13.4	11.6	9.1	7.0
	10.4	10.4	10.4	9.0	7.1	5.4
	6	6	6	8	13	22
11525500	3.2	3.2	3.2	3.2	3.2	3.2
	3.2	3.2	3.2	3.2	3.2	3.2
	12	12	12	12	12	12
11525600	7.9	7.9	7.9	7.6	6.6	4.7
	3.4	3.4	3.4	3.3	2.9	2.1
	12	12	12	13	17	34
11525655	6.0	6.0	6.0	6.0	5.8	4.4
	0.2	0.2	0.2	0.2	0.2	0.2
	12	12	12	12	13	22

TABLE 38. Selected results of K-CERA analysis for Sacramento field office

[Top line--standard error of instantaneous discharge, in percent; second line--equivalent Gaussian spread; third line--number of visits per year to site. Budget--*, indicates same budget level as current (1984) practice]

Station No.	Current practice	Budget, in thousands of 1984 dollars				
		308	314*	324	340	440
Average standard error per station, in percent ------	14.0	14.2	13.2	12.4	11.8	10.6
11308900	5.1	5.1	5.1	5.1	4.9	3.7
	5.0	5.0	5.0	5.0	4.8	3.6
	11	11	11	11	12	24
11312000	16.4	16.5	15.5	15.1	14.8	14.6
	13.1	13.1	12.9	12.8	12.7	12.6
	10	10	13	15	17	18
11316800	20.4	19.4	15.1	15.1	15.1	15.1
	20.3	19.3	15.0	15.0	15.0	15.1
	10	12	18	18	18	52
11317000	24.8	23.7	18.3	18.3	18.3	18.3
	24.6	23.5	18.1	18.1	18.1	18.3
	10	12	18	18	18	52
11318500	18.2	18.0	17.5	17.5	17.5	15.5
	17.9	17.8	17.5	17.5	17.5	15.5
	10	12	18	18	18	52
11319500	11.2	11.2	10.2	10.2	9.7	6.6
	4.2	4.2	3.9	3.9	3.7	2.6
	11	11	14	14	15	32
11323500	7.1	7.1	7.1	7.1	6.8	4.9
	2.2	2.2	2.2	2.2	2.1	1.7
	11	11	11	11	12	24
11325500	9.6	10.0	9.6	9.6	8.7	6.6
	5.4	5.6	5.4	5.4	4.9	3.7
	16	12	13	13	16	29
11329500	44.9	46.2	44.9	44.9	44.9	44.9
	44.6	45.8	44.5	44.5	44.5	44.7
	21	17	18	18	18	27

TABLE 38. Selected results of K-CERA analysis for Sacramento field office--Continued

Station No.	Current practice	Budget, in thousands of 1984 dollars				
		308	314*	324	340	440
Average standard error per station, in percent ------	14.0	14.2	13.2	12.4	11.8	10.6
11333000	15.0	14.3	12.3	11.6	10.9	7.9
	6.6	6.5	6.1	5.9	5.7	4.6
	7	8	11	13	15	30
11333500	27.4	27.8	22.5	20.8	20.2	20.2
	27.1	27.4	22.2	20.5	19.9	20.0
	10	11	15	17	18	30
11335000	5.7	5.0	4.1	3.6	3.5	3.3
	4.7	4.2	3.4	3.0	3.0	2.8
	9	13	18	23	24	27
11336580	20.7	22.7	19.1	16.8	16.8	16.8
	9.8	10.8	9.1	7.9	7.9	7.9
	12	10	14	18	18	18
11389000	3.2	3.2	3.2	3.2	3.2	3.2
	2.1	2.1	2.1	2.1	2.1	2.1
	8	8	8	8	8	8
11389500	2.0	2.0	2.0	2.0	2.0	2.0
	1.8	1.8	1.8	1.8	1.8	1.8
	8	7	7	7	7	7
11390500	1.3	1.3	1.3	1.3	1.3	1.3
	1.0	1.1	1.1	1.1	1.1	1.1
	8	7	7	7	7	7
11394500	6.5	7.1	7.1	7.1	7.1	4.5
	2.7	2.9	2.9	2.9	2.9	2.3
	8	7	7	7	7	17
11395030	10.8	11.5	11.5	11.5	10.8	7.3
	8.0	8.5	8.5	8.5	8.0	5.4
	8	7	7	7	8	20
11395200	8.8	8.3	8.0	8.0	8.0	5.9
	1.6	1.5	1.4	1.4	1.4	1.1
	8	9	10	10	10	19

TABLE 38. Selected results of K-CERA analysis for Sacramento field office--Continued

Station No.	Current practice	Budget, in thousands of 1984 dollars				
		308	314*	324	340	440
Average standard error per station, in percent ------	14.0	14.2	13.2	12.4	11.8	10.6
11395500	5.8	5.5	5.3	5.3	4.8	3.0
	2.3	2.2	2.1	2.1	2.0	1.3
	9	10	11	11	13	35
11396000	25.9	22.6	20.9	18.9	18.3	18.3
	14.2	12.3	11.3	10.2	9.8	12.9
	9	12	14	17	18	25
11396200	14.4	14.0	13.7	13.7	13.1	9.8
	11.5	11.3	11.2	11.2	10.9	8.6
	9	10	11	11	13	35
11396310	6.5	7.0	7.0	6.5	5.9	3.7
	3.0	3.1	3.1	3.0	2.8	1.8
	9	8	8	9	11	29
11396330	6.2	6.7	6.7	6.7	6.7	3.9
	2.7	2.9	2.9	2.9	2.9	1.8
	9	8	8	8	8	23
11396400	15.4	15.8	15.8	15.4	15.0	13.5
	13.4	13.5	13.5	13.4	13.4	12.9
	9	8	8	9	11	29
11407500	17.0	16.1	15.4	13.7	12.4	12.1
	6.3	6.0	5.8	5.2	4.8	6.2
	9	10	11	14	17	22
11408850	12.8	12.8	12.8	11.5	9.5	6.3
	4.7	4.7	4.7	4.2	3.5	2.4
	8	8	8	10	15	34
11408880	15.8	15.8	15.8	14.1	11.6	7.7
	2.9	2.9	2.9	2.6	2.2	1.6
	8	8	8	10	15	34
11409300	11.9	11.9	11.9	10.7	8.8	5.8
	7.5	7.5	7.5	6.7	5.5	3.7
	8	8	8	10	15	34

TABLE 38. Selected results of K-CERA analysis for Sacramento field office--Continued

Station No.	Current practice	Budget, in thousands of 1984 dollars				
		308	314*	324	340	440
Average standard error per station, in percent ------	14.0	14.2	13.2	12.4	11.8	10.6
11409400	12.2	12.2	12.2	10.9	9.0	6.1
	12.1	12.1	12.1	10.8	8.9	6.0
	8	8	8	10	15	34
11413000	5.1	5.1	5.1	4.8	4.1	3.0
	3.3	3.3	3.3	3.2	3.0	2.4
	8	8	8	10	15	34
11413100	6.8	7.3	7.3	7.3	6.8	4.3
	3.3	3.5	3.5	3.5	3.3	2.3
	8	7	7	7	8	20
11413300	8.5	9.1	9.1	9.1	8.5	5.6
	1.6	1.7	1.7	1.7	1.6	1.1
	8	7	7	7	8	20
11413520	12.6	12.6	12.6	12.0	11.2	8.0
	11.3	11.3	11.3	10.7	9.9	7.0
	8	8	8	9	11	24
11417500	11.2	11.2	11.2	10.0	8.3	5.6
	3.2	3.2	3.2	3.1	2.8	2.2
	8	8	8	10	15	34
11418000	2.4	2.4	2.4	2.4	2.0	1.3
	1.4	1.4	1.4	1.4	1.2	0.8
	12	12	12	12	17	40
11418500	14.6	15.2	15.2	15.2	12.4	8.2
	6.0	6.1	6.1	6.1	5.4	3.9
	12	11	11	11	17	40
11421000	3.3	3.3	3.2	2.7	2.6	2.6
	1.5	1.5	1.5	1.3	1.3	1.3
	12	12	13	17	18	18
11422500	9.5	11.4	11.4	9.1	7.7	4.9
	1.2	1.4	1.4	1.2	1.0	0.7
	11	8	8	12	17	43

TABLE 38. Selected results of K-CERA analysis for Sacramento field office--Continued

Station No.	Current practice	Budget, in thousands of 1984 dollars				
		308	314*	324	340	440
Average standard error per station, in percent ------	14.0	14.2	13.2	12.4	11.8	10.6
11424000	18.3	20.2	19.4	17.0	16.5	16.5
	8.0	7.9	7.6	6.7	6.4	6.4
	16	12	13	17	18	18
11425000	6.9	6.9	6.9	6.9	6.9	5.1
	2.7	2.7	2.7	2.7	2.7	2.2
	6	6	6	6	6	12
11425500	3.7	4.2	4.2	4.2	4.2	3.9
	1.5	1.6	1.6	1.6	1.6	1.5
	9	7	7	7	7	8
11427000	4.6	4.6	4.6	4.6	4.4	3.1
	1.1	1.1	1.1	1.1	1.1	0.8
	12	12	12	12	13	27
11431800	14.0	13.3	13.3	11.0	9.3	7.0
	3.2	3.0	3.0	2.5	2.2	1.7
	8	9	9	13	18	32
11433040	17.2	16.3	16.3	13.7	11.8	11.8
	4.7	4.7	4.7	4.6	4.5	6.4
	8	9	9	13	18	24
11433500	10.6	9.3	9.1	8.4	8.2	8.2
	2.3	2.1	2.1	1.9	1.9	1.9
	11	14	15	17	18	18
11433800	9.3	12.1	11.1	10.0	7.9	5.2
	1.9	2.3	2.2	2.0	1.7	1.2
	11	7	8	10	15	33
11442500	13.5	14.6	14.0	11.6	9.7	6.4
	1.1	1.2	1.1	0.9	0.8	0.5
	12	10	11	16	23	53
11443500	14.9	17.3	16.4	13.7	10.7	7.1
	3.0	3.1	3.1	2.5	2.8	2.2
	11	8	9	13	22	52

TABLE 38. Selected results of K-CERA analysis for Sacramento field office--Continued

Station No.	Current practice	Budget, in thousands of 1984 dollars				
		308	314*	324	340	440
Average standard error per station, in percent ------	14.0	14.2	13.2	12.4	11.8	10.6
11445500	5.4	4.6	3.9	3.5	3.5	3.0
	1.4	1.2	1.0	0.9	0.9	0.8
	8	12	16	19	19	27
11446500	3.0	3.1	3.1	3.1	3.1	3.1
	2.5	2.5	2.5	2.5	2.5	2.5
	9	8	8	8	8	8
11452500	13.6	11.8	13.6	10.8	8.9	6.1
	2.4	2.3	2.4	2.3	2.3	2.1
	9	12	9	15	22	51
11454000	5.2	5.5	5.5	5.5	5.5	4.3
	4.9	5.1	5.1	5.1	5.1	4.1
	8	7	7	7	7	13

TABLE 39. Selected results of K-CERA analysis for Tahoe City field office

[Top line--standard error of instantaneous discharge, in percent; second line--equivalent Gaussian spread; third line--number of visits per year to site. Budget--*, indicates same budget level as current (1984) practice]

Station No.	Current practice	Budget, in thousands of 1984 dollars				
		194	198	204*	230	300
Average standard error per station, in percent ------	10.2	11.3	9.6	8.9	7.9	6.9
10336600	7.7	9.3	7.4	6.4	4.9	3.8
	7.0	8.4	6.7	5.8	4.4	3.5
	16	12	17	23	39	68
10336610	13.5	14.9	11.9	10.0	7.6	5.7
	13.2	14.6	11.7	9.8	7.4	5.5
	20	20	27	38	66	118
10336626	13.9	13.9	11.5	9.0	7.0	5.4
	13.0	13.0	10.8	8.5	6.6	5.0
	10	10	16	27	44	77
10336645	7.7	8.0	7.5	6.6	5.1	4.0
	7.7	8.0	7.5	6.6	5.1	4.0
	15	13	16	26	50	86
10336660	7.9	8.5	7.6	5.9	4.3	3.3
	5.9	6.3	5.6	4.5	3.3	2.5
	15	13	16	26	50	86
10336676	9.1	9.4	8.5	6.8	5.0	3.8
	8.5	8.7	7.9	6.3	4.6	3.6
	14	13	16	26	50	86
10336689	6.9	7.5	7.5	6.1	4.7	3.5
	6.0	6.6	6.6	5.3	4.1	3.1
	18	15	15	23	40	73
10336759	7.3	7.6	7.0	6.2	4.9	3.7
	6.6	6.8	6.3	5.6	4.4	3.3
	15	14	16	20	34	63

TABLE 39. Selected results of K-CERA analysis for Tahoe City field office--Continued

Station No.	Current practice	194	198	204*	230	300
		Budget, in thousands of 1984 dollars				
Average standard error per station, in percent ------	10.2	11.3	9.6	8.9	7.9	6.9
10336780	8.5	8.5	7.4	6.4	5.0	3.6
	8.5	8.5	7.4	6.4	5.0	3.6
	8	8	11	15	27	52
10337500	5.7	6.1	6.1	5.5	4.2	3.1
	5.7	6.1	6.1	5.5	4.2	3.1
	14	12	12	15	26	50
10338500	19.6	19.6	18.6	17.3	15.3	12.7
	16.4	16.4	16.2	15.9	14.7	12.4
	13	13	18	31	79	191
10339400	6.7	7.0	6.7	5.5	4.1	3.0
	6.6	6.9	6.6	5.4	4.0	2.9
	13	12	13	20	38	75
10340500	5.7	5.9	5.9	5.6	4.2	2.8
	5.6	5.8	5.8	5.4	4.1	2.7
	12	11	11	13	29	73
10343000	33.9	40.3	31.0	31.0	31.0	31.0
	33.9	40.2	30.9	30.9	30.9	30.9
	10	8	12	12	12	12
10343500	3.3	3.9	3.4	3.4	3.3	3.0
	3.3	3.9	3.4	3.4	3.3	3.0
	10	5	9	9	10	23
10344400	4.6	4.8	4.8	4.8	4.6	3.9
	4.3	4.3	4.3	4.3	4.2	3.8
	9	6	6	6	9	38
10344500	7.1	7.6	7.6	7.6	7.3	5.5
	7.0	7.4	7.4	7.4	7.2	5.4
	12	6	6	6	9	38
10346000	2.0	2.7	2.7	2.7	2.3	1.2
	2.0	2.7	2.7	2.7	2.3	1.2
	12	6	6	6	9	38

TABLE 39. Selected results of K-CERA analysis for Tahoe City field office--Continued

Station No.	Current practice	Budget, in thousands of 1984 dollars: 194	198	204*	230	300
Average standard error per station, in percent ------	10.2	11.3	9.6	8.9	7.9	6.9
11401500	6.9	7.6	7.6	7.1	5.7	4.1
	4.2	4.3	4.3	4.2	4.0	3.3
	8	6	6	7	13	36
11402000	7.5	8.3	8.3	7.7	6.2	4.1
	5.2	5.4	5.4	5.3	4.7	3.3
	8	6	6	7	13	36
11407900	13.6	13.6	12.5	11.5	9.2	6.7
	4.5	4.5	4.3	4.2	3.5	2.8
	9	9	11	14	24	49
11408000	7.2	7.2	6.7	6.3	5.2	4.0
	3.7	3.7	3.6	3.5	3.2	2.7
	9	9	11	14	24	49
11414000	9.4	10.6	9.6	8.9	6.5	5.4
	4.3	4.5	4.4	4.3	3.6	2.7
	8	6	7	8	17	38
11416000	4.4	4.4	4.2	4.1	3.8	3.5
	3.5	3.5	3.5	3.0	3.3	3.2
	9	9	11	14	24	49
11416500	12.9	12.9	11.7	10.8	8.5	6.1
	10.3	10.3	9.4	8.6	6.8	3.7
	9	9	11	14	24	49
11421760	4.3	4.7	4.4	4.2	3.2	2.3
	3.8	4.1	3.9	3.8	2.9	2.1
	8	6	7	8	17	38
11421780	2.7	2.9	2.5	2.5	1.8	1.3
	1.6	1.8	1.7	1.6	1.3	0.9
	8	6	7	8	17	38
11421790	2.7	3.0	2.7	2.6	2.2	1.9
	1.8	1.8	1.8	1.8	1.8	1.7
	8	6	7	8	17	38

TABLE 39. Selected results of K-CERA analysis for Tahoe City field office--Continued

Station No.	Current practice	Budget, in thousands of 1984 dollars				
		194	198	204*	230	300
Average standard error per station, in percent ------	10.2	11.3	9.6	8.9	7.9	6.9
11427940	9.0	10.1	8.3	7.7	5.8	4.0
	8.3	9.4	7.7	7.2	5.4	3.7
	6	5	7	8	15	35
11428000	15.5	17.4	14.2	13.4	10.1	6.8
	10.8	11.9	10.1	9.5	7.1	4.9
	6	5	7	9	15	35
11428300	7.2	7.8	6.9	6.6	5.2	3.7
	6.4	6.7	6.1	5.9	4.8	3.4
	6	5	7	8	15	35
11429500	3.1	3.2	3.2	3.2	2.8	1.9
	1.9	2.0	2.0	2.0	1.7	1.2
	8	7	7	7	10	22
11430000	2.8	2.8	2.8	2.8	2.7	2.0
	1.7	1.7	1.7	1.7	1.6	1.3
	9	9	9	9	10	18
11441500	2.7	3.2	3.2	3.2	3.0	2.1
	2.3	2.8	2.8	2.8	2.6	1.8
	13	9	9	9	10	21
11441900	5.8	6.9	6.9	6.9	6.5	4.6
	2.4	2.6	2.6	2.6	2.6	2.0
	13	9	9	9	10	21