COST-EFFECTIVENESS OF THE STREAM-GAGING PROGRAM IN NEBRASKA

By Glenn B. Engel, Kenneth L. Wahl, and Judith A. Boohar

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WILLIAM P. CLARK, Secretary

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Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey, WRD
406 Federal Building
100 Centennial Mall, North
Lincoln, NE 68508

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FACTORS FOR CONVERTING INCH-POUND TO METRIC (SI) UNITS

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

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ABSTRACT

This report documents the results of a study of the cost-effectiveness of the streamflow information program in Nebraska. Presently, 145 continuous surface-water stations are operated in Nebraska on a budget of $908,500. Data uses and funding sources are identified for each of the 145 stations. Data from most stations have multiple uses. All stations have sufficient justification for continuation, but two stations primarily are used in short-term research studies; their continued operation needs to be evaluated when the research studies end.

Simulation may provide information of acceptable accuracy for certain data uses at one Niobrara River gage; present data uses, however, require that the gage be continued.

The present measurement frequency produces an average standard error for instantaneous discharges of about 12 percent, including periods when stage data are missing. Altering the travel routes and the measurement frequency will allow a decrease in standard error of about 1 percentage point with the present budget. Standard error could be decreased to about 8 percent if lost record could be eliminated.

A minimum budget of $822,000 is required to operate the present network, but operations at that funding level would result in an increase in standard error to about 16 percent. The maximum budget analyzed was $1,363,000, which would result in an average standard error of 6 percent.

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. The Geological Survey presently (1983) is operating 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, needs to 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 Geological Survey presently (1983) is undertaking another nationwide analysis of the stream-gaging program that will be completed within 5 years 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 obtaining and providing streamflow information.

For every continuous-record gaging station, the first phase of the analysis identifies the principal uses of the data and relates these uses to funding sources. In addition, gaging stations are categorized as to whether the data are available to users in a real-time sense, on a daily basis during floods, on a periodic basis, or at the end of the water year.

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

The third and final phase of the analysis involves the use of Kalman-filtering and mathematical-programing techniques to define strategies for the 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 individual stations. A steepest-descent optimization program uses these uncertainty functions, information on practical stream-gaging routes, the various costs associated with stream gaging, and the total operating budget to identify the visit frequency for each station so that total uncertainty in the overall network is minimized.

This report is patterned after a prototype study for the State of Maine (Fontaine and others, 1984). Much of the material describing the general methods is taken from the report by Fontaine and others (1984). This report is organized into five sections; the first being an introduction to the stream-gaging activities in Nebraska and to the study itself. The middle three sections each contain discussions of an individual phase of the analysis. Because of the sequential nature of the phases and the dependence of subsequent phases on the previous results, a summary of the individual phases is made at the end of each of the middle three sections. The entire study, is summarized in the final section.

History of Stream-Gaging in Nebraska

The stream-gaging program in Nebraska has evolved through the years as Federal, State, and local needs for surface-water data have increased. Although some records had been collected since 1891, a systematic collection of streamflow records in Nebraska was not begun by the Geological Survey until 1894. On August 18, 1894, Congress appropriated funds for a nationwide stream-gaging program, as an amendment to the Sundry Civil Bill. Six gaging stations were established in Nebraska in 1894.

Early streamflow records were obtained for irrigation needs, but by 1912 several small plants were using water power for generating electricity and development of more hydroelectric power was under consideration. Lack of streamflow records for this purpose was recognized as a deterrent to future development of water power. The State Engineer, in his report of September 1, 1912, suggested that a survey of the potential water power from streams and possible powerplant locations would undoubtedly stimulate the development of water power (Brice, Shaffer, and Stuthmann, 1970).

Formal cooperation between the Geological Survey and the State of Nebraska was started in 1906, but was terminated in 1914 by the State because special investigations on the North Platte and Platte Rivers required attention of the entire State hydrographic staff. At that time 14 gaging stations were being operated. By 1927, the number of continuous-record stations had decreased to 8.

As a part of investigations for the U.S. Army Corps of Engineers starting in 1928, the Geological Survey established 15 gaging stations. In August 1931, the formal cooperative stream-gaging program with the State was resumed, and the program has been continuous since that time. By 1932, 55 gaging-stations were in operation.

Major floods of 1935 in the Republican River basin, and those of 1940, 1944, 1947, 1950, and 1951 in river basins throughout the eastern part of the State, caused residents of the valleys to seek flood-control projects. This resulted in an accelerated collaborative stream-gaging program with the U.S. Army Corps of Engineers to obtain data on which to plan flood-control works (Brice, Shaffer, and Stuthmann, 1970).

With the advent of the Missouri River Basin program in Nebraska in 1946, stream-gaging activity expanded in areas where the U.S. Bureau of Reclamation was developing irrigation projects. Funds were appropriated by Congress to the Department of the Interior to obtain water-resources information needed for the development of the Missouri River basin.

After streamflow data became available, the Nebraska Department of Roads began using flood stages, discharges, and frequencies in the design of bridges. Need for design data also led to establishment in 1951 of a Statewide network of crest-stage gages on small drainage basins. As many as 119 crest-stage gages were operated under this program. Subsequent to the publication of a report on the magnitude and frequency of floods in Nebraska by Beckman (1976), operation of this network was terminated. At present (1983) only eight crest-stage gages are operated for the U.S. Army Corps of Engineers.

The study by Brice, Shaffer, and Stuthmann (1970) described the development of Nebraska's surface-water program to meet the future needs of water-data users. At the time of that study, the Nebraska program had 156 continuous-record gages, which included 5 reservoir gages.

The number of gages decreased to 139 by 1977. In 1978, the Nebraska Department of Water Resources initiated an expansion program through the State Federal Cooperative Program. At present (1983) there are 145 continuous gages being operated on rivers and streams in Nebraska and 5 on reservoirs. The historical number of continuous-record gages operated within Nebraska is given in figure 1.

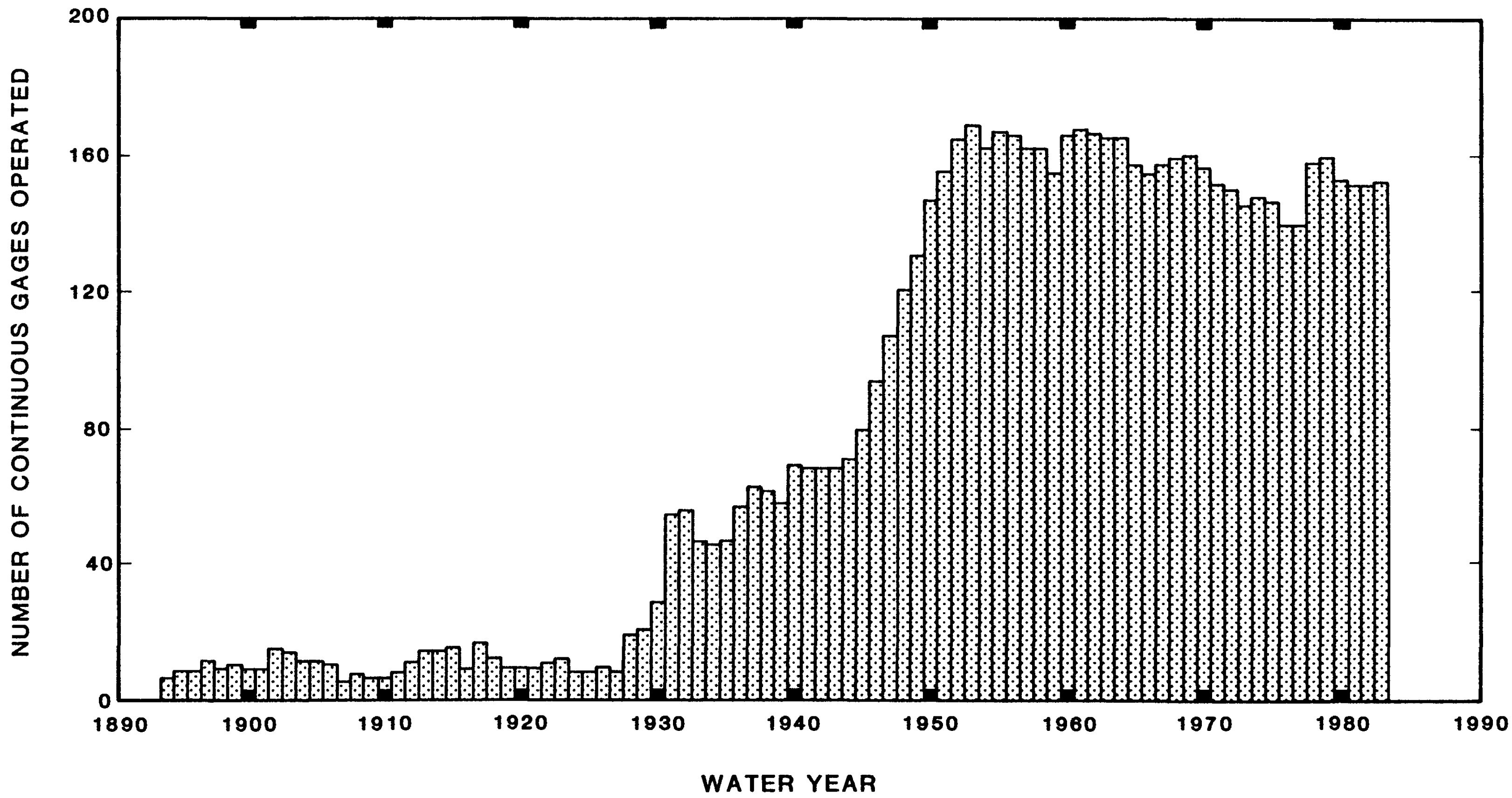

Figure 1.--History of continuous stream gaging.

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Current Stream-gaging Program in Nebraska

Nebraska has an abundant water supply that generally is suitable for all uses. The distribution, however, is not uniform; in some areas the supply is abundant and in others it is meager. Because agriculture is the principal industry in the State, the development of the water supplies has been, for the most part, oriented to the land. Largest developments have been for irrigation and for storage of flood water to prevent flooding the land. A considerable quantity of the water supply has been allocated to development of power, but only a small quantity to industrial use (Brice, Shaffer, and Stuthmann, 1970). Many gaging stations are operated in the State to monitor streamflows affected by these developments.

About 7.5 million acres are irrigated in Nebraska, with about one-fifth by surface water and four-fifths by ground water. Nearly every stream in the State is affected to some degree by diversions for irrigation. Some streams, however, are affected so little that they can be considered as natural-flow streams. Many gaging stations are operated in the State on streams affected by irrigation development in order to define the altered system.

For convenience, the State may be divided into 13 river basins (fig. 2). These are the same basin designations used by the Nebraska Natural Resources Commission, previously called the Nebraska Soil and Water Conservation Commission in preparation of the Framework Study for the State Water Plan (Nebraska Soil and Water Conservation Commission, 1971). Some of the basins are complete drainage units, some are parts of drainage units, and others are groupings of small drainage units that are hydrologically similar (Engberg, 1980). Location of the gaging stations is shown in figure 3.

The operation of the gaging-station network is shared by Geological Survey and Nebraska Department of Water Resources personnel as part of the cooperative program. Review and quality control responsibilities are the Geological Survey's. The Department of Water Resources operates some continuous stream gages as part of their own management program. Those gages are not included in this analysis.

The distribution by basin of the 145 stream gages in the Nebraska program and operated by the Geological Survey and the Department of Water Resources is as follows: White River-Hat Creek-1, Niobrara-21, Missouri River tributaries-3, North Platte-14, South Platte-3, Middle Platte-8, Loup-19, Lower Platte-10, Elkhorn-15, Nemaha-4, Republican-34, Big Blue-8, and Little Blue-5. The cost of operating these 145 stream gages during fiscal year 1983 was $908,500.

The official U.S. Geological Survey station number and name, drainage area, period of record, and mean annual flow for the 145 stations are given in table 1. Station identification numbers used throughout this report are the last six digits of the Geological Survey's eight-digit downstream-order station number; the first two digits of the standard Geological Survey station number for all stations used in this report are 06. Also, if the last two digits of the station number are zero they are omitted from tables in this section.

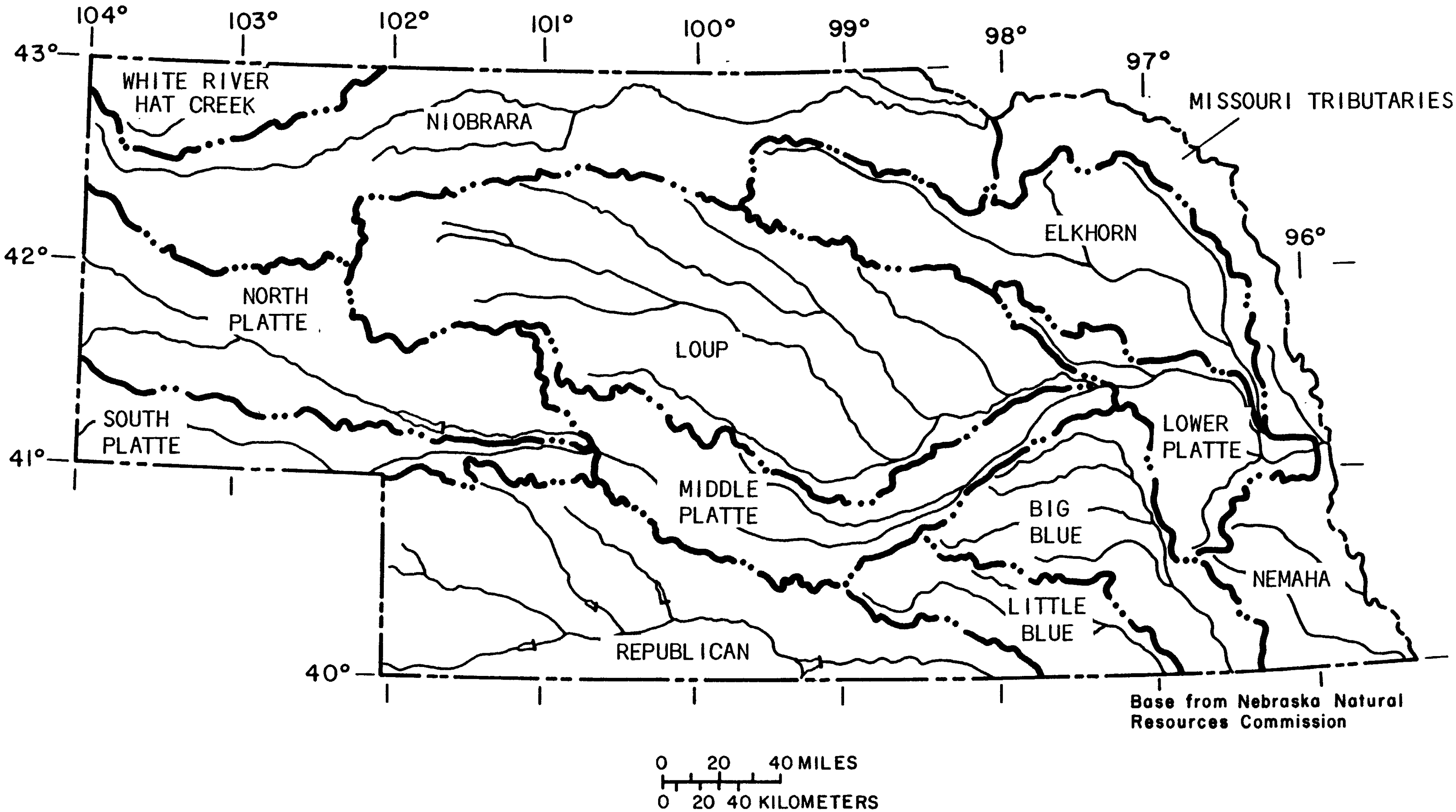
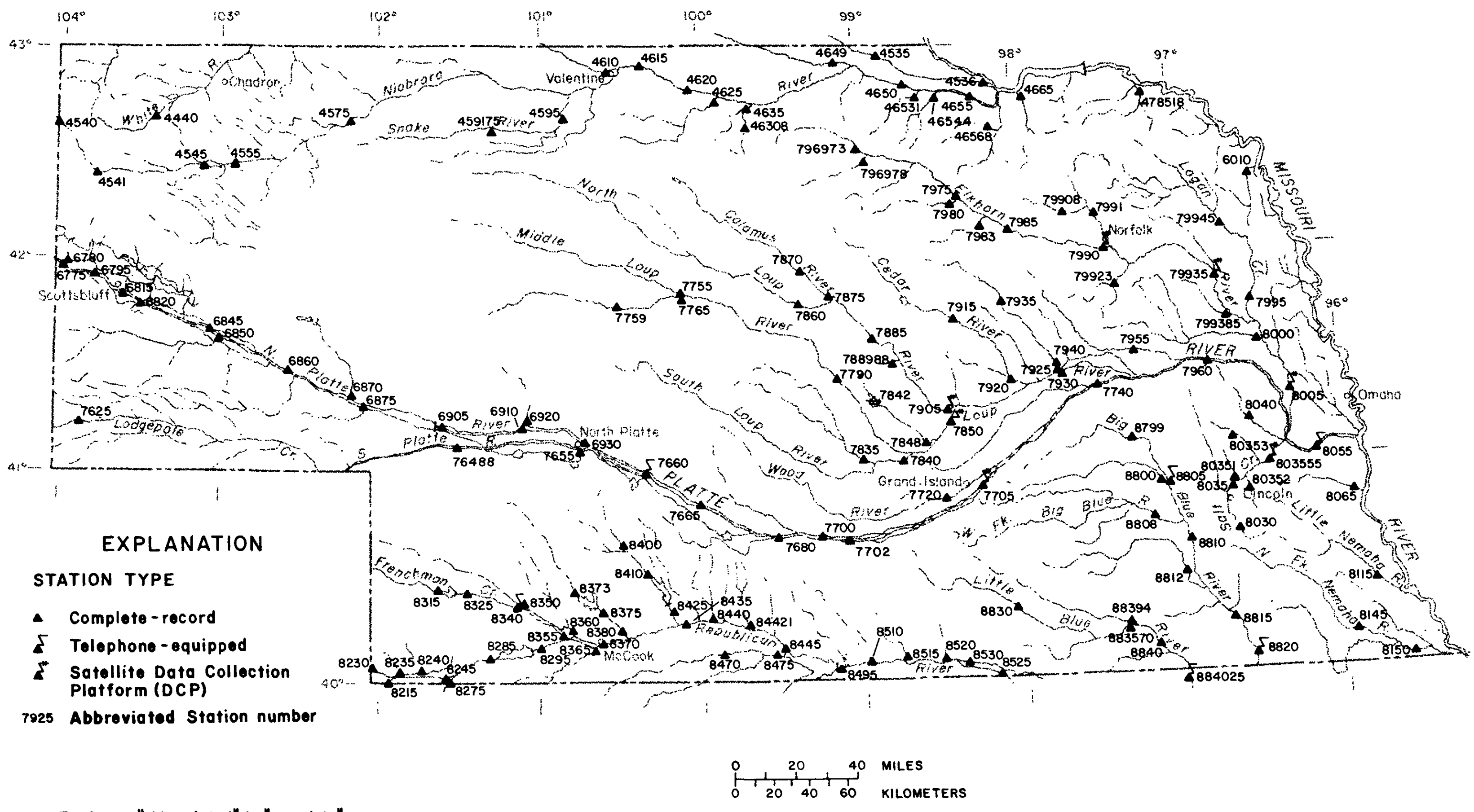


Figure 2.--River basins.



Note: To change "abbreviated" to "complete" station number, prefix with "06" and add zero's required to give eight digits.

Figure 3.--Location of active surface-water gaging stations.

Table 1.--Selected hydrologic data for stations in the surface-water program

[mi², square miles; ft³/s, cubic feet per second]

Station number (06-)	Station name	Drainage area (mi²)	Period of record (water year)	Mean annual flow[1] (ft³/s)
4440	White River at Crawford	313	1931-43, 1948-	19
4535	Ponca Creek at Anoka	505	1949-	43
4536	Ponca Creek at Verdel	812	1958-	71
4540	Niobrara River at WY-NE State line	450	1956-	4.0
4541	Niobrara River at Agate	840	1958-	14
4545	Niobrara River ab Box Butte Reservoir	1,400	1947-	29
4555	Niobrara River bl Box Butte Reservoir	1,460	1947-	26
4575	Niobrara River near Gordon	4,290	1928-32[2], 1946-	116
459175	Snake River at Doughboy	405	1982-	-----
4595	Snake River near Burge	660	1947-	196
4610	Minnechaduza Creek at Valentine	390	1948-	34
4615	Niobrara River near Sparks	8,090	1946[2], 1947-	767
4620	Niobrara River near Norden	8,390	1953-	862
4625	Plum Creek at Meadville	600	1948-75, 1977-	109
463080	Long Pine Creek near Long Pine	------	1980-	-----
4635	Long Pine Creek near Riverview	390	1948-54, 1955-	140
4649	Keya Paha River near Naper	1,630	1958-	128
4650	Niobrara River near Spencer	12,100	1908-09[3], 1913-14[2], 1915[3], 1927-36, 1940-	1,460
465310	Eagle Creek near Redbird	206	1979-	-----
465440	Redbird Creek at Redbird	157	1981-	-----
4655	Niobrara River near Verdel	12,600	1938-40, 1958-	1,571
465680	North Branch Verdigre Creek near Verdigre	137	1980-	-----
4665	Bazile Creek near Niobrara	440	1952-	81
478518	Bow Creek near St. James	304	1979-	-----

1/ Used 1951-80 reference period or period of record, if between 5 and 29 years.
2/ Monthly discharge only for some periods published in WSP 1309.
3/ Gage heights only.

Table 1.--Selected hydrologic data for stations in the surface-water program--Continued

Station number (06-)	Station name	Drainage area (mi^2)	Period of record (water year)	Mean annual flow 1/ (ft^3/s)
6010	Omaha Creek at Homer	168	1946 4/, 1947-	33
6775	Horse Creek near Lyman	1,570	1931-	76
6780	Sheep Creek near Morrill	362	1932-	58
6795	North Platte River at Mitchell	24,300	1901-11, 1912-13 3/, 1916-19 5/, 1920-22 4/, 1923-	671
6815	Gering Drain near Gering	------	1931-45, 1949-	56
6820	North Platte River near Minatare	24,700	1916, 1917-18, 1919, 1922, 1923-30 4/, 1931-	906
6845	North Platte River at Bridgeport	25,300	1896-1900 6/, 1902-06, 1915, 1916-22 4/, 1923-	1,210
6850	Pumpkin Creek near Bridgeport	1,020	1931-	27
6860	North Platte River at Lisco	26,700	1916, 1917 4/, 1931-	1,290
6870	Blue Creek near Lewellen	1,190	1931-	67
6875	North Platte River at Lewellen	28,600	1931 5/, 1940-	1,440
6905	North Platte River near Keystone	29,300	1917, 1939, 1940, 1941 6/, 1942-	481
6910	North Platte River near Sutherland	29,800	1917, 1931-33 5/, 1935, 1936-	471
6920	Birdwood Creek near Hershey	940	1931-	151
6930	North Platte River at North Platte	30,900	1895-1930 4/, 1931-	719
7625	Lodgepole Creek at Bushnell	1,361	1932 4/, 1933-	9.3

1/ Used 1951-80 reference period or period of record, if between 5 and 29 years.
3/ Gage heights only.
4/ Monthly discharge only for some periods published in WSP 1310.
5/ Irrigation seasons only.
6/ No winter records.

Table 1.--Selected hydrologic data for stations in the surface-water program--Continued

Station number (06-)	Station name	Drainage area (mi^2)	Period of record (water year)	Mean annual flow 1/ (ft^3/s)
764880	South Platte River at Roscoe	------	1983-	-----
7655	South Platte River at North Platte	24,300	1897, 1914, 1915, 1917-31 4/, 1932-	365
7660	Platte River at Brady	56,200	1937, 1938-39 4/, 1940-	634
7665	Platte River near Cozad	56,500	1932, 1937-40 4/, 1941-	538
7680	Platte River near Overton	57,700	1914 3/, 1914-30 4/, 1931-	1,440
7700	Platte River near Odessa	58,100	1937-38 4/, 1939-	1,350
7702	Platte River near Kearney	------	1982-	-----
7705	Platte River near Grand Island	58,800	1934-	1,380
7720	Wood River near Alda	628	1954-	11
7740	Platte River near Duncan	60,900	1895-1900 5/, 1901-09, 1910-11 7/, 1912-15, 1928-	1,510
7755	Middle Loup River at Dunning	1,850	1945-	402
7759	Dismal River near Thedford	960	1967-	192
7765	Dismal River at Dunning	2,040	1932, 1945-	324
7790	Middle Loup River at Arcadia	5,040	1937-	647 (1963-80)
7835	Mud Creek near Sweetwater	707	1946-	35
7840	South Loup River at St. Michael	2,350	1944-	229
7848	Turkey Creek near Dannebrog	66.2	1966-70, 1979-	12

1/ Used 1951-80 reference period or period of record, if between 5 and 29 years.
3/ Gage heights only.
4/ Monthly discharge only for some periods published in WSP 1310.
5/ Irrigation seasons only.
7/ Gage heights and discharge measurements only.

Table 1.--Selected hydrologic data for stations in the surface-water program--Continued

Station number (06-)	Station name	Drainage area (mi^2)	Period of record (water year)	Mean annual flow[1/] (ft^3/s)
7850	Middle Loup River at St. Paul	8,090	1895-1915[4/], 1928-	996 (1963-80)
7860	North Loup River at Taylor	2,280	1937-	471
7870	Calamus River near Harrop	983	1931-39[7/], 1955-64[7/], 1977[7/], 1978-	-----
7875	Calamus River near Burwell	1,060	1941-	311
7885	North Loup River at Ord	3,750	1937-38, 1952-	869
788988	Mira Creek near North Loup	------	1980-	-----
7905	North Loup River near St. Paul	4,290	1895-1915, 1928[4/]-	935
7915	Cedar River near Spalding	762	1945-53[4/], 1958-	157
7920	Cedar River near Fullerton	1,220	1931-32, 1941-	239
7925	Loup River Power Canal near Genoa	------	1937-	1,632
7930	Loup River near Genoa	14,400	1928-32, 1944-53, 1954-55[8/], 1956-	532
7940	Beaver Creek at Genoa	647	1941-	117
7955	Shell Creek near Columbus	270	1947-75, 1978-	37
7960	Platte River at North Bend	77,100	1949-	4,020
796978	Holt Creek near Emmet	------	1979-	-----
7975	Elkhorn River at Ewing	1,400	1947-	160
7980	South Fork Elkhorn River near Ewing	314	1947-53, 1960-72, 1977[9/]-	61
7983	Clearwater Creek near Clearwater	210	1961-64, 1978-	33
7985	Elkhorn River at Neligh	2,200	1931-58, 1960[4/]-	307

1/ Used 1951-80 reference period or period of record, if between 5 and 29 years.
4/ Monthly discharge only for some periods published in WSP 1310.
7/ Gage heights and discharge measurements only.
8/ Monthly discharge only.
9/ Prior to 1977, published as "at Ewing" at different site and datum.

Table 1.--Selected hydrologic data for stations in the surface-water program--Continued

Station number (06-)	Station name	Drainage area (mi^2)	Period of record (water year)	Mean annual flow 1/ (ft^3/s)
7990	Elkhorn River at Norfolk	2,790	1896-1903 6/, 1946-	470
799080	Willow Creek near Foster	137	1975 8/, 1976-	8.8
7991	North Fork Elkhorn River near Pierce	700	1960-	79
799230	Union Creek at Madison	174	1979-	-----
799350	Elkhorn River at West Point	5,100	1973-	698
799385	Pebble Creek at Scribner	204	1979-	-----
799450	Logan Creek at Pender	731	1966-	121
7995	Logan Creek near Uehling	1,030	1941-	185
8000	Maple Creek near Nickerson	450	1952-	56
8005	Elkhorn River at Waterloo	6,900	1899-1903, 1911-15, 1928 4/-	1,220
8030	Salt Creek at Roca	167	1951-	42
8035	Salt Creek at Lincoln	684	1950-	205
803510	Little Salt Creek near Lincoln	43.6	1969-	12
803520	Stevens Creek near Lincoln	47.8	1969-	13
803530	Rock Creek near Ceresco	119	1970-	28
803555	Salt Creek at Greenwood	1,051	1952 10/-	279
8040	Wahoo Creek at Ithaca	271	1950-	76
8055	Platte River at Louisville	85,800	1953 11/-	5,700
8065	Weeping Water Creek at Union	241	1950-	84
8115	Little Nemaha River at Auburn	793	1949-	279
8145	North Fork Big Nemaha River at Humboldt	548	1953-	196
8150	Big Nemaha River at Falls City	1,340	1944-	580

1/ Used 1951-80 reference period for period of record, if between 5 and 29 years.
4/ Monthly discharge only for some periods published in WSP 1310.
6/ No winter records.
8/ Monthly discharge only.
10/ Prior to 1972, record furnished by Corps of Engineers.
11/ 1961-73, published as Platte River at South Bend at different site.

Table 1.--Selected hydrologic data for stations in the surface-water program--Continued

Station number (06-)	Station name	Drainage area (mi^2)	Period of record (water year)	Mean annual flow[1/] (ft^3/s)
8215	Arikaree River at Haigler	1,640	1932[4/]-	19
8230	North Fork Republican River at CO-NE State line	1,360	1931[4/]-	36
8235	Buffalo Creek near Haigler	260	1941-	7.0
8240	Rock Creek at Parks	20	1941-	14
8245	Republican River at Benkelman	4,830	1895, 1902-06, 1947[4/]-	86
8275	South Fork Republican River near Benkelman	2,740	1895, 1902-06, 1931-32, 1937[4/]-	42
8285	Republican River at Stratton	8,450	1950-	131
8295	Republican River at Trenton	8,620	1947[4/]-	71
8315	Frenchman Creek near Imperial	880	1941-	62
8325	Frenchman Creek near Enders	950	1946-	60
8340	Frenchman Creek at Palisade	1,110	1895-96, 1950-	85
8350	Stinking Water Creek near Palisade	1,500	1950-	41
8355	Frenchman Creek at Culbertson	2,770	1913-15[7/], 1931[4/]-	92
8360	Blackwood Creek near Culbertson	320	1946-	6.4
8365	Driftwood Creek near McCook	360	1946-	10
8370	Republican River at McCook	12,310	1931-32, 1955[4/]-	187
8373	Red Willow Creek ab Hugh Butler Lake	600	1961-	28
8375	Red Willow Creek near McCook	740	1941-47, 1958-60[12/], 1961[4/]-	25
8380	Red Willow Creek near Red Willow	830	1939-	25

1/ Used 1951-80 reference period for period of record, if between 5 and 29 years.
4/ Monthly discharge only for some periods published in WSP 1310.
7/ Gage heights and discharge measurements only.
12/ Annual maximums only.

Table 1.--Selected hydrologic data for stations in the surface-water program--Continued

Station number (06-)	Station name	Drainage area (mi^2)	Period of record (water year)	Mean annual flow 1/ (ft^3/s)
8400	Fox Creek at Curtis	74	1951-58, 1960-70 12/, 1978-	7.4
8410	Medicine Creek ab Harry Strunk Lake	770	1950-	67
8425	Medicine Creek bl Harry Strunk Lake	880	1950 4/-	65
8435	Republican River at Cambridge	14,520	1945-	284
8440	Muddy Creek at Arapahoe	246	1951-72, 1978-	15
844210	Turkey Creek at Edison	74.6	1978-	-----
8445	Republican River near Orleans	15,640	1948-	286
8470	Beaver Creek near Beaver City	1,950	1937 4/-	19
8475	Sappa Creek near Stamford	3,740	1946 4/-	51
8495	Republican River bl Harlan County Dam	20,760	1953-	272
8510	Center Creek at Franklin	74	1948-56, 1961-68 12,13/, 1968-75, 1978-	7.6
8515	Thompson Creek at Riverton	279	1948-56, 1961-68 13/, 1962-68 12/, 1978-	30
8520	Elm Creek at Amboy	39.2	1948-54, 1959 12/, 1961-77 12/, 1954-77 13/, 1978-	21
8525	Courtland Canal at NE-KS State line	------	1955-	78
8530	Republican River near Guide Rock	20,040	1950-	346
8799	Big Blue River at Surprise	345	1964-	27

1/ Used 1951-80 reference period for period of record, if between 5 and 29 years.
4/ Monthly discharge only for some periods published in WSP 1310.
12/ Annual maximums only.
13/ Occasional low-flow measurements; crest-stage at present site and datum.

Table 1.--Selected hydrologic data for stations in the surface-water program--Continued

Station number (06-)	Station name	Drainage area (mi^2)	Period of record (water year)	Mean annual flow 1/ (ft^3/s)
8800	Lincoln Creek near Seward	446	1954-73, 1974 14/ -	44
8805	Big Blue River at Seward	1,101	1954 14/ -	111
8808	West Fork Big Blue River near Dorchester	1,206	1958-	168
8810	Big Blue River near Crete	2,716	1945 15/ -	346
8812	Turkey Creek near Wilber	460	1960-	80
8815	Big Blue River at Beatrice	3,900	1911-15 4/, 1954 16/, 1960-65 16/, 1967-69 16/, 1971-74 16/, 1975-	609
8820	Big Blue River at Barneston	4,447	1932-	832
8830	Little Blue River near Deweese	979	1953-72, 1975-	143
883570	Little Blue River near Alexandria	1,557	1959-72, 1974-	230
883940	Big Sandy Creek at Alexandria	607	1980-	-----
8840	Little Blue River near Fairbury	2,350	1908-15, 1929 4/ -	381
884025	Little Blue River at Hollenberg, KS	2,752	1973-74 16/, 1974-	467

1/ Used 1951-80 reference period or period of record, if between 5 and 29 years.
4/ Monthly discharge only for some periods published in WSP 1310.
14/ Monthly discharge only for some periods published in WSP 1730.
15/ Prior to October 1953, discharges only for stages above 12 ft due to backwater from dam downstream until 1952; and diurnal fluctuation from powerplant upstream during 1952-53.
16/ Discharge measurements only.

USES, FUNDING, AND AVAILABILITY OF CONTINUOUS STREAMFLOW DATA

The relevance of a stream gage is defined by the uses made of the data produced from the gage. The uses of the data from each gage in the Nebraska 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 and are defined later.

Data-Use Classes

The following definitions were used to categorize each known use of streamflow data for each continuous 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 use, the effects of man on streamflow are not necessarily small, but the effects are limited to those caused primarily by land-use and climatic changes. Large quantities 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.

Sixty-two stations in the Nebraska network are classified in the regional-hydrology category. Three of the stations are special cases in that they are designated bench-mark or index stations. Hydrologic bench-mark stations are part of a national network of 57 stations operated in watersheds that are relatively free from manmade alteration; the network is intended to define long-term trends. Index stations are used to prepare a national monthly summary of water conditions. Of the 62 stations in the regional hydrology category, 1 also is a hydrologic bench-mark station and 2 are index stations.

Hydrologic Systems

Stations that can be used for accounting, that is, to define current hydrologic conditions and the sources, sinks, and fluxes of water through hydrologic systems including regulated systems, are designated as hydrologic systems stations. They include diversions and return flows and stations that are useful for defining the interaction of water systems.

The bench-mark and index stations also are included in the hydrologic-systems category because they are accounting for current and long-term conditions of the hydrologic systems that they gage. Depending on streamflow conditions in any particular year, water may have to be allocated among users by the Nebraska Department of Water Resources. This may be needed statewide or in only a few river basins. Many stations are used by the Department of Water Resources for administration of water rights throughout the State. These stations are included under this category.

Also included in this category are stations used for accounting of flows in irrigation-project areas developed by the U.S. Bureau of Reclamation and of flood control projects developed by the U.S. Army Corps of Engineers. The Platte River and Republican River are mainly controlled, and stations on these streams are in this category. One station, North Platte River at Lisco, (686000) also is used as an index of hydrologic conditions in the controlled North Platte River system.

Legal Obligations

Some stations provide records of flows for the verification or enforcement of existing treaties, compacts, and decrees. This category contains those stations that the U.S. Geological Survey is required to operate to satisfy a legal responsibility. The Republican River Compact designates the U.S. Geological Survey to operate gaging stations needed for the equitable distribution of water among Colorado, Kansas, and Nebraska. Eleven gaging stations are used for this purpose. Also included in this catgegory are three gaging stations that the Geological Survey has been asked to operate in cooperation with other agencies. Niobrara River at Wyoming-Nebraska State Line (454000) is used for the Upper Niobrara River Compact and is operated in cooperation with the Nebraska Department of Water Resources. Two gaging stations are operated in cooperation with Kansas-Nebraska Big Blue River Compact Administration - Big Blue River at Barneston (882000) and Little Blue River at Hollenberg, Kansas (884025).

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 instituted for such purposes and where this purpose is still valid.

Thirteen stations used by the U.S. Bureau of Reclamation for planning and design of irrigation projects are in this category. Also included in this category is one station used by the U.S. Department of Agriculture and the U.S. Environmental Protection Agency for a project investigating pollution control through water conservation practices - Maple Creek near Nickerson (800000). Another gaging station included here is one that is used by the Little Blue Natural Resources District in planning a water project in the Little Blue River basin - Little Blue River near Alexandria (883570).

Project Operation

Gaging stations in this category are used, on an ongoing basis, to assist water managers in making operational decisions such as reservoir releases, hydropower operations, or diversions. The project-operation use generally indicates 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.

Many stations are included in this category: Those used by the Nebraska Department of Water Resources for water-rights administration as explained under "hydrologic systems," those used by U.S. Bureau of Reclamation and irrigation districts in project areas, those used by the Corps of Engineers and Bureau of Reclamation in reservoir operations, those used at hydropower facilities, and so forth.

Hydrologic Forecasts

Gaging stations in this category are regularly used to provide information for hydrologic forecasting by agencies other than the U.S. Geological Survey. These 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. The hydrologic forecast use generally indicates that the data are routinely available to the forecasters on a rapid-reporting basis. On large streams, data may only be needed every few days.

Stations in the Nebraska program included in this category are those that have been designated by the National Weather Service as being needed for flood forecasting. In addition to the National Weather Service, other agencies may use the information from the stations during floods particularly, the Nebraska State Civil Defense Agency, U.S. Army Corps of Engineers, Nebraska Department of Water Resources, and Natural Resources Districts in the State. Eighty-seven stations are in this category. Fifteen of these stations provide instantaneous data through telemetry equipment.

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. Stations operated as part of the National Stream-Quality Accounting Network (NASQAN) are included in this category. NASQAN stations are operated to define both areal variability and trends in stream quality.

One such station in the program is a designated bench-mark station and seven are NASQAN stations. Water-quality samples from bench-mark stations are used to indicate water-quality characteristics of streams that have been and probably will continue to be relatively free of man's activities.

Other stations shown in this category are stations where water-quality monitoring is being conducted through MRB funding for U.S. Bureau of Reclamation planning and stations that are part of the monitoring network of the Nebraska Department of Environmental Control.

Research

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

Three stations in the Nebraska program would be in this category: two stations on Long Pine Creek (463080 and 463500), where the U.S. Department of Agriculture and State agencies are involved in a study of the watershed, and the Platte River near Kearney (770200), where interaction of the Platte River and the ground-water reservoir is being investigated.

Other

In addition to the eight data-use classes described above, four stations on the Lower Platte and Elkhorn Rivers are used by the Nebraska Game and Parks Commission to provide streamflow information for canoeists.

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. Federal-State cooperative program.--Funds that come jointly from U.S. Geological Survey's 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 and 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 done at the site may not be the same as those identified herein.

Frequency of Data Availability

Frequency of data availability refers to the times at which the streamflow data may be provided to the users. In this category, four distinct possibilities exist. Data can be provided by direct-access telemetry equipment for immediate use (includes both telephone-accessed equipment and satellite data-collection platforms), by telephone calls, usually daily, made by local observers or U.S.Geological Survey personnel directly to the National Weather Service during floods, by periodic release of provisional data, or in publication format through the annual data report published by the Geological Survey for Nebraska (U.S. Geological Survey, 1981). These four categories are designated T, C, P, and A, respectively, in table 2. In the current Nebraska program, data for all 145 stations are made available through the annual report, data from 15 stations are available on a real-time basis, data from many stations are relayed directly to the National Weather Service, and at least some data are released on a provisional basis at the majority of stations.

Data-Use Presentation

Data-use and ancillary information are presented for each continuous gaging station in table 2, which contains an explanation of the numerical values used for describing information conveyed. The entry of an asterisk in the table indicates that no explanation is required.

Summary of First Phase of Analysis

A review of the data used in funding information presented in Table 2 indicates that the data from most stations in the Nebraska network have multiple uses. Many of the gaging stations are used on an ongoing basis for accounting and for project operation. Although stations may have been established for one specific purpose, the availability of the data have, in itself, produced other uses for the data. Two stations are used primarily for research or short-term investigation; Long Pine Creek near Long Pine (463080), and Platte River near Kearney (770200). These two stations could be discontinued at the end of the projects; however, Long Pine Creek represents natural flow conditions upstream from the Ainsworth Irrigation Project area return flows, and Platte River near Kearney will likely be a valuable station for a continuing analysis of the gains and losses in that reach of the Platte River. Because of these considerations, the continued operation of these stations need to be evaluated when the research projects end.

No stations were excluded from the second and third parts of this analysis based only on the present uses of the data.

Table 2.--Data use, funding, and data availability for stations in the surface-water program
[Frequency of data availability: A, annual data report; P, periodic release of provisional data; C, telephone calls; T, telemetry]

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
4440	1	2			2							3		A P
4535	1				4						5			A P
4536	1	2			2,4	6						3		A P C
4540	1	2	7		2							3		A P
4541	1	2			2							3		A P
4545	1	2,8			2,8							3		A P
4555		2,9			2,9							3		A P
4575		2,10			2							3		A P
459175	1				11							3		A
4595		12			12							3		A P
4610		2			2,13							3		A P

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-rights administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
4. U.S. Army Corps of Engineers, operation of Missouri River system.
5. U.S. Army Corps of Engineers.
6. National Weather Service, river and flood forecasting.
7. Upper Niobrara River Compact (Wyoming-Nebraska).
8. Inflow to Box Butte Reservoir and national index station.
9. Operation of Box Butte Reservoir and Mirage Flats Irrigation Project.
10. Includes return flows from Mirage Flats Irrigation Project.
11. Inflow to Merritt Reservoir.
12. Operation of Merritt Reservoir and Ainsworth Irrigation Project.
13. Minnechaduza power project.

Table 2.--Data use, funding, and data availability for stations in the surface-water program--Continued

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
4615		2		14	2	6	14			*				A P C
4620		2		15	2	6	16				16			A P T
4625	1	2,17			2	6						3		A P C
463080	1							18				3		A P
4635		2,17		14	2	6	14	18		*				A P C
4649	1	2			2							3		A P
4650				14	19	6				*				A P C
465310	1	20										3		A P
465440	1	20									15			A P
4655					4	6	21,22				5			A P C

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-rights administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
4. U.S. Army Corps of Engineers, operation of Missouri River system.
5. U.S. Army Corps of Engineers.
6. National Weather Service, river and flood forecasting.
14. U.S. Bureau of Reclamation, investigation and planning.
15. Planning and design for O'Neill Irrigation Project.
16. U.S. Bureau of Reclamation, project planning.
17. Includes return flows from Ainsworth Irrigation Project.
18. Long Pine Creek Watershed Project -- U.S. Department of Agriculture and State agencies.
19. Spencer power project.
20. Assessment of pre-o'Neill Irrigation Project conditions -- will convey return flows.
21. NASQAN station.
22. Nebraska Department of Environmental Control, monitoring network.

Table 2.--Data use, funding, and data availability for stations in the surface-water program--Continued

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
465680	1	2			2							3		A P
4665	1	2			2,4	6					5			A P C
478518	1											3		A P
6010	1				4					*	5			A P
6775		2,23			2,23							3		A P
6780		2,23			2,23							3		A P
6795		2,23			2,23							3		A P
6815		2,23			2,23							3		A P
6820		2,23			2,23							3		A P
6845		2,23			2,23	6						3		A P T
6850		2,23			2,23	6						3		A P C
6860		2,23			2,23	6	21					3		A P C
6870	1	2,23			2,23							3		A P
6875		2,23			2,23,24	6						3		A P C

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-rights administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
4. U.S. Army Corps of Engineers, operation of Missouri River system.
5. U.S. Army Corps of Engineers.
6. National Weather Service, river and flood forecasting.
21. NASQAN station.
23. Accounting and assessment of Platte River irrigation projects.
24. Inflow to Lake McConaughy.

Table 2.--Data use, funding, and data availability for stations in the surface-water program--Continued

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
6905		2,23			2,23,25	6						3		A P C
6910		2,23			2,23	6						3		A P C
6920	1	2			2							3		A P
6930		2,23			2,23	6						3		A P C
7625	1	2			2	6						3		A P C
764880		2,23		16	2,23	6	22					16		A P C
7655		2,23			2,23	6						3		A P C
7660		2,23			2,23	6						3		A P C
7665		2,23			2,23	6						3		A P C
7680		2,23			2,23	6	14,22					3		A P C
7700		2,23			2,23	6						3		A P C
7702		26			26			26				27		A P
7705		2,23			2,23	6	22					3		A P T

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-rights administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
6. National Weather Service, river and flood forecasting.
14. U.S. Bureau of Reclamation, investigation and planning.
16. U.S. Bureau of Reclamation, project planning.
22. Nebraska Department of Environmental Control, monitoring network.
23. Accounting and assessment of Platte River irrigation projects.
25. Outflow from Lake McConaughy.
26. To assess gains and losses in upstream reach of Platte River.
27. Central Platte Natural Resources District.

Table 2.--Data use, funding, and data availability for stations in the surface-water program--Continued

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
7720	1	2,23			2,23	6						3		A P C
7740		2,23		14	2,23	6	21			*				A P C
7755	1											3		A
7759	1,28	28					28			*				A
7765	1											3		A
7790		2,29			2,29	6						3		A P C
7835	1	2				6	22					3		A P C
7840	1	2				6	14					3		A P C
7848		2,30										3		A
7850		2		14		6	14			*	5			A P T
7860		31		14	31	6				*				A P C

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-rights administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
5. U.S. Army Corps of Engineers.
6. National Weather Service, river and flood forecasting.
14. U.S. Bureau of Reclamation, investigation and planning.
21. NASQAN station.
22. Nebraska Department of Environmental Control, monitoring network.
23. Accounting and assessment of Platte River irrigation projects.
28. Hydrologic benchmark station.
29. Diversions for irrigation upstream from station, for U.S. Bureau of Reclamation, Sargent and Farwell Units, and for Middle Loup Public Power and Irrigation District canals.
30. Return flows from Farwell Unit.
31. North Loup Public Power and Irrigation District, operation of system.

Table 2.--Data use, funding, and data availability for stations in the surface-water program--Continued

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
7870	1			32							16			A
7875	1			32						*				A
7885		2,31			2,31							3		A P
788988		33			33							3		A
7905		2,31			2,31	6	14			*	5			A P T
7915	1					6						3		A P C
7920		2			2	6	14			*				A P C
7925		34			34	6	21					3		A P C
7930		2,34			2,34	6	21			*				A P C
7940		2			2	6	22					3		A P C
7955	1					6						3		A P C

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-rights administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
5. U.S. Army Corps of Engineers.
6. National Weather Service, river and flood forecasting.
14. U.S. Bureau of Reclamation, investigation and planning
16. U.S. Bureau of Reclamation, project planning.
21. NASQAN station.
22. Nebraska Department of Environmental Control, monitoring network.
31. North Loup Public Power and Irrigation District, operation of system.
32. U.S. Bureau of Reclamation, planning and design for North Loup irrigation project.
33. Assessment of pre-North Loup project conditions -- will convey return flows.
34. Loup River Public Power District, operation of system.

Table 2.--Data use, funding, and data availability for stations in the surface-water program--Continued

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
7960		35			4	6	22		36		5	3		A P C
796978	1											3		A
7975	1	2		14	2					*				A P
7980	1											3		A
7983	1											3		A P
7985	1	2			2	6						3		A P C
7990	1	2		14	2,4	6	22			*	5			A P T
799080	1	2			2,37							3		A
7991	1	2			2,4	6					5			A P C
799230	1	2			2							3		A P
799350		2			2,4	6	22		36		5			A P T
799385	1	2			2							3		A P
799450	1	2			2	6	22					3		A P C
7995	1	2			2	6						3		A P C

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-rights administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
4. U.S. Corps of Engineers, operation of Missouri River system.
5. U.S. Army Corps of Engineers.
6. National Weather Service, river and flood forecasting.
14. U.S. Bureau of Reclamation, investigation and planning.
22. Nebraska Department of Environmental Control, monitoring network.
35. Accounting for conditions of Platte River system.
36. Nebraska Game and Parks Commission, flow conditions for canoeists.
37. Inflow to Willow Creek Reservoir.

Table 2.--Data use, funding, and data availability for stations in the surface-water program--Continued

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
8000	1	2		38	2	6				*				A P C
8005	1				4	6	21,22		36	*	5			A P T
8030		2,39			2,39	6					5	3		A P C
8035		39			39	6					5			A P C
803510	1	2			2							3		A P
803520	1											3		A P
803530	1	2			2							3		A P
803555		39			39	6	22				5			A P T
8040	1					6				*	5			A P C
8055		35			4	6	21,22		36	*	5			A P T
8065	1					6						3		A P C
8115	1	2			2	6	22					3		A P C

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-rights administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
4. U.S. Army Corps of Engineers, operation of Missouri River system.
5. U.S. Army Corps of Engineers.
6. National Weather Service, river and flood forecasting.
21. NASQAN station.
22. Nebraska Department of Environmental Control, monitoring network.
35. Accounting for conditions of Platte River system.
36. Nebraska Game and Parks Commission, flow conditions for canoeists.
38. U.S. Department of Agriculture and U.S. Environmental Protection Agency - Maple Creek watershed project.
39. U.S. Army Corps of Engineers, operation of Salt Creek basin reservoirs.

Table 2.--Data use, funding, and data availability for stations in the surface-water program--Continued

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
8145	1	2			2	6				*				A P C
8150	1					6	22				5	3		A P C
8215		2	40		2	6				*				A P C
8230	1		40							*				A
8235	1	2	40		2					*				A
8240		2	40		2					*				A
8245		2,41			2	6	22					3		A P C
8275		41	40			6				*				A P C
8285		2			2,42	6					5	3		A P C
8295		2,41			2,43	6	14					3		A P C
8315	1	2			2,44							3		A
8325		2,41			45,46							3		A P

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-rights administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
5. U.S. Army Corps of Engineers.
6. National Weather Service, river and flood forecasting.
14. U.S. Bureau of Reclamation, investigation and planning.
40. Republican River Compact.
41. Accounting for conditions of Republican River system.
42. Inflow to Swanson Lake.
43. Outflow from Swanson Lake.
44. Inflow to Enders Reservoir.
45. Outflow from Enders Reservoir.
46. U.S. Bureau of Reclamation, Frenchman-Cambridge Irrigation Division, Frenchman Unit.

Table 2.--Data use, funding, and data availability for stations in the surface-water program--Continued

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
8340		2,41			2,46	6						3		A P T
8350		2,41			2,46	6						3		A P C
8355		2,41	40		2,46	6	14			*				A P C
8360		2,41	40		2,46	6				*				A P C
8365		2,41	40		2,47	6				*				A C
8370		2,41			2,46	6					5			A P T
8373	1	2			2,48	6						3		A P C
8375		2,41			2,49,50							3		A P
8380		2,41	40		2,50	6				*				A P C
8400	1	2			2							3		A

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-rights administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
5. U.S. Army Corps of Engineers.
6. National Weather Service, river and flood forecasting.
14. U.S. Bureau of Reclamation, investigation and planning.
40. Republican River Compact.
41. Accounting for conditions of Republican River system.
46. U.S. Bureau of Reclamation, Frenchman-Cambridge Irrigation Division, Frenchman Unit.
47. U.S. Bureau of Reclamation, Frenchman-Cambridge Irrigation Division, Meeker-Driftwood Unit.
48. Inflow to High Butler Lake.
49. Outflow from High Butler Lake.
50. U.S. Bureau of Reclamation, Frenchman-Cambridge Irrigation Division, Red Willow Unit.

Table 2.--Data use, funding, and data availability for stations in the surface-water program--Continued

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
8410	1	2,41			2,51	6						3		A P C
8425		2,41			2,52,53	6						3		A P C
8435		2,41			2,53	6						3		A P C
8440	1	2			2							3		A
844210	1	2			2							3		A
8445		2,41			2,53,54	6	14,22				5			A P C
8470		2,41			2	6						3		A P C
8475		41	40		54	6				*				A P C
8495		2,41			2,55,56	6					5			A P C

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-rights administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
5. U.S. Army Corps of Engineers.
6. National Weather Service, river and flood forecasting.
14. U.S. Bureau of Reclamation, investigation and planning.
22. Nebraska Department of Environmental Control, monitoring network.
40. Republican River Compact.
41. Accounting for conditions of Republican River system.
51. Inflow to Harry Strunk Lake.
52. Outflow from Harry Strunk Lake.
53. U.S. Bureau of Reclamation, Frenchman-Cambridge Irrigation Division, Cambridge Unit.
54. Inflow to Harlan County Reservoir.
55. Outflow from Harlan County Reservoir.
56. U.S. Bureau of Reclamation, Bostwick Irrigation Division, Franklin Unit.

Table 2.--Data use, funding, and data availability for stations in the surface-water program--Continued

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
8510	1	2			2							3		A
8515	1	2			2	6						3		A P C
8520	1	2			2							3		A
8525		2,41	40		2,57					*				A P
8530		2,41			2,57	6	22					3		A P C
8799	1	2			2	6						3		A P C
8800		2			2	6	22					3		A P C
8805		2			2	6	22					3		A P T
8808		2			2	6	22			*				A P C

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-rights administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
6. National Weather Service, river and flood forecasting.
22. Nebraska Department of Environmental Control, monitoring network.
40. Republican River Compact.
41. Accounting for conditions of Republican River system.
57. U.S. Bureau of Reclamation, Bostwick Irrigation Division, Courtland Unit.

Table 2.--Data use, funding, and data availability for stations in the surface-water program--Continued

Station Number (06)	Data use									Funding				Frequency of data availability
	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water-quality monitoring	Research	Other	Federal program	OFA program	Federal-State coop. program	Other non-Federal	
8810		2			2	6	22				5	3		A P C
8812		2			2	6	22					3		A P C
8815		2			2	6	22					3		A P C
8820		2	58		2,59	6	22					58		A P T
8830	1	2		14	2	6	22			*				A P C
883570		2		60	2							60		A P
883940		2			2							3		A P
8840		2			2	6					5			A P C
884025			58				14,22					58		A P T

EXPLANATION

1. For providing general hydrologic knowledge and defining trends.
2. State of Nebraska, water-righrs administration.
3. Nebraska Department of Water Resources, program coordinator for other State agencies.
5. U.S. Army Corps of Engineers.
6. National Weather Service, river and flood forecasting.
14. U.S. Bureau of Reclamation, investigation and planning.
22. Nebraska Department of Environmental Control, monitoring network.
58. Big Blue River Compact Administration.
59. Norris Public Power, Barneston powerplant.
60. Little Blue Natural Resources District.

ALTERNATIVE METHODS OF DEVELOPING STREAMFLOW INFORMATION

The second phase of the analysis of the stream-gaging program was to investigate alternative methods of providing daily streamflow information in lieu of operating continuous-flow gaging stations. The objective of this phase of the analysis was to identify gaging stations where alternative technology, such as flow-routing or statistical methods, could provide accurate estimates of daily mean streamflow efficiently. No guidelines exist concerning suitable accuracies for particular uses of the data; therefore, judgment was required in deciding whether the accuracy of the estimated daily flows would be adequate for the intended purpose.

The data uses at a station affect whether or not information can potentially be provided by 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 adequate if flows are highly correlated between sites. Gaging stations in similar watersheds, located in the same physiographic and climatic area, also may have potential for alternative methods.

Discussion of Methods

Desirable attributes of a proposed alternative method are: (1) The proposed method needs to be computer oriented and easy to apply, (2) the proposed method needs to have an available interface with the U.S. Geological Survey's WATSTORE Daily Values File (Hutchison, 1975), (3) the proposed method needs to be technically sound and generally acceptable to the hydrologic community, and (4) the proposed method needs to provide a measure of the accuracy of the simulated streamflow records. Because of the short duration of this analysis, only two methods were considered; those methods are hydrologic routing and regression.

Stations in the Nebraska stream-gaging program were screened to determine their potential for use of alternative methods, and selected methods were applied at those stations where the potential was high. The applicability of alternative methods to specific stream-gaging stations is described in this section of this report.

Description of Flow-Routing Model

Hydrologic flow-routing methods use the law of conservation of mass and the relationship between the storage in a reach and the outflow from the reach. The hydraulics of the system are not considered. The methods usually require only a few parameters, and the reach is not subdivided. A discharge hydrograph is required at the upstream end of the reach, and the computations produce a discharge hydrograph at the downstream end. Hydrologic routing methods include the Muskingum, Modified Puls, Kinematic Wave, and the unit-response flow-routing methods. The unit-response method uses one of two routing techniques—storage continuity (Sauer, 1973) and diffusion analogy (Keefer, 1974, Keefer and McQuivey, 1974).

Computer programs for the unit-response method can be used to route streamflow from one or more upstream locations to a downstream location. The model treats a stream reach as a linear one-dimensional system in which the downstream hydrograph is computed by multiplying (convoluting) the ordinates of the upstream hydrograph by the unit-response function and lagging them appropriately. The model has the capability of combining hydrographs, multiplying a hydrograph by a ratio, and changing the timing of a hydrograph.

Daily flows usually can be routed using a single unit-response function (linearization about a single discharge) to represent the system response. However, if the routing coefficients vary significantly with discharge, linearization about a low-range discharge results in overestimated high flows that arrive late at the downstream site, and linearization about a high-range discharge results in low-range flows that are underestimated and arrive too soon. Multiple linearization (Keefer and McQuivey, 1974), in which separate unit-response functions are defined for different ranges of discharge, minimizes this problem.

Determination of the system's response to an upstream pulse is not the total solution for most flow-routing problems. The convolution process makes no accounting of flow from the intervening area between the upstream and downstream locations. Ungaged inflows usually are estimated by multiplying known flows at an index gaging station by an adjustment factor (for example, the ratio of drainage area at the point of interest to that at the index gage).

In both the storage-continuity and diffusion-analogy methods, the routing parameters are calibrated by trial and error. The analyst must decide if suitable parameters have been derived by comparing the simulated discharge to the observed discharge.

Description of Regression Analysis

Simple- and multiple-regression techniques also can be used to estimate daily flow records. Unlike hydrologic routing, regression methods are not limited to locations where an upstream station exists on the same stream. Regression equations can be computed that relate daily flows (or their logarithms) at a station (dependent variable) to daily flows at another station or at a combination of upstream, downstream, or tributary stations. The independent variables in the regression analysis can include stations from different watersheds.

The regression method is easy to apply, provides indices of accuracy, and is widely used and accepted in hydrology; the theory and assumptions are described in numerous textbooks such as Draper and Smith (1966) and Kleinbaum and Kupper (1978). The application of regression methods 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 commonly is used for estimating daily mean discharges:

$$Y_i = B_o + \sum_{j=1}^{n} B_j X_j + e_i \qquad (1)$$

where

Y_i = daily mean discharge at station i (dependent variable),

X_j = daily mean discharge(s) at n station(s) j (independent variables); these values may be lagged to approximate travel time between stations i and j,

B_o and B_j = regression constant and coefficients, and

e_i = the random error term.

The above equation is calibrated (B_o and B_j are estimated) using observed values of Y_i and X_j. These observed daily mean discharges can be retrieved from the WATSTORE Daily Values File (Hutchison, 1975). The values of discharge for the independent variables may be observed on the same day as discharges at the independent station or may be for previous or future days, depending on whether station j is upstream or downstream of station i. During calibration, the regression constant and coefficients (B_o and B_j) are tested to determine if they are significantly different from zero. A given independent variable is retained in the regression equation only if its regression coefficient is significantly different from zero.

The regression equation needs to be calibrated using one period of time and verified or tested using a different period of time to obtain a measure of the true predictive accuracy. Both the calibration and verification periods need to be representative of the expected range of flows. The equation can be verified by: (1) Plotting the residuals (difference between simulated and observed discharges) against both the dependent and the independent variables in the equation, and (2) plotting the simulated and observed discharges versus time. These tests are needed to confirm that the linear model is appropriate and that there are no time trends reflected in either the data or the equation. The presence of either nonlinearity or bias requires that the data be transformed (for example, by converting to logarithms) or that a different form of model be used.

The use of a regression relation to produce a simulated record at a discontinued gaging station causes the variance of the simulated record to be less than the variance of an actual record of streamflow at the site. The reduction in variance is not a problem if the only concern is with deriving the best estimate of a given daily mean discharge record. If, however, the simulated discharges are to be used in additional analyses where the variance of the data are important, least-squares regression models are not appropriate. Hirsch (1982) discusses this problem and describes several models that preserve the variance of the original data.

Potential for Use of Alternative Methods

A two-level screening process was applied to gaging stations in Nebraska to evaluate the potential for use of alternative methods. The first level was based only on hydrologic considerations; the only concern at this level was whether it was hydrologically possible to simulate flows at a given station from information at other gages. The first-level screening was subjective; there was no attempt at that level to apply any mathematical procedures. Those stations that passed the first level of screening were then screened again to determine if simulated data would be acceptable in view of the data uses shown in table 2. Even if simulated data were not acceptable for the given data uses, the analysis continued. Mathematical procedures were applied to determine if it were technically possible to simulate data. This was done under the assumption that the data uses may change in the future. Where data uses required continuation of gaging, however, the result was predetermined to be that although alternative methods were technically possible, they were unacceptable given the present uses of the data.

Combinations of stations identified in the first level of screening are listed in table 3. The location of these stations is shown in figure 3. Correlation coefficients were determined for the combinations of stations shown in table 3 to eliminate from consideration those stations that showed little correlation with corresponding stations. Combinations of stations that were highly correlated were passed on to the regression analysis described on the following pages. Hydrologic routing methods were not applied because of the large number of combinations examined and because data uses dictated that a gaging station must remain in operation at all sites that showed promise for use of alternative methods.

Regression Results

Correlation and regression methods were used on all the combinations of gaging stations shown in table 3. The initial results showed that regression methods would be unacceptable for many of the possible sites; stations for which the initial results were not promising were eliminated from further consideration. Those stations included the following combinations from table 3: Ponca Creek, upstream reach of Niobrara River, Long Pine Creek, both the North Platte and Platte Rivers, Dismal River, downstream reach of Elkhorn River, Logan Creek, Republican River, and the Big Blue River.

There were several reasons why the preceding combinations of gages produced unacceptable results. However, the most common reasons related to the importance of ground water discharge at several stations and to the variable effects of diversions and return flows. The effect of ground water is typified by the Dismal River. The upstream station (775900) derives almost all flow from the Sandhills; as a consequence, the flow has little variability. However, the downstream gage (776500) receives a limited quantity of direct runoff and discharge is much more variable than at the upstream station.

Table 3.—Combinations of stations used in alternative-methods analysis [Underscore indicates that data use in table 2 includes forecasting or legal obligations]

Drainage basin	Combinations of stations investigated				
Ponca Creek	453500	453600			
Niobrara River	454000	454100	454500		
Niobrara River	461500	462000			
Long Pine Creek	463080	463500			
Niobrara River	465000	465310	465440	465500	
North Platte River	690500	691000			
Platte River	768000	770000	770500	774000	
Dismal River	775900	776500			
Elkhorn River	797500	798000	798300	798500	
Elkhorn River	798500	799000	799100	799230	799350
Logan Creek	799450	799500			
Salt Creek	803500	803510	803520	803530	803555
Republican River	821500	823000	823500	824000	824500
Republican River	824500	827500	828500		
Big Blue River	879900	880000	880500	880800	881000
Big Blue River	881000	881200	881500		
Little Blue River	883570	883940	884000		
Little Blue River	884000	884025			

The Platte River is affected by many diversions and by return flows from irrigated land. The relationship between flood discharges along the mainstem is good, but low flows are only poorly correlated. The Big Blue River is another example where diversions from the channel preclude correlation of discharges during periods of low flow.

The results of regression analyses are presented in table 4 for selected combinations of gages. Numerous models, including both linear and logarithmic forms, were investigated; all that appear to yield reasonable results are presented. All variables shown in the table are statistically significant at the 0.01 level. The standard error of estimate for models, in the units of cubic feet per second, is not useful directly because the data are not homoscedastic (variance not constant throughout range of flow). Therefore, the individual errors were converted to percentage deviations, and the standard deviation of those percentage values was defined. That is the value reported in the table for the linear models.

Only the Niobrara River near Verdel (465500) appears to be a true candidate for the application of alternative methods. Two periods were used in the calibration process, water years 1972-75 and 1980-82. Records for several tributary stations only were available for the later period. Because the model using the tributary stations appeared to be significantly better than the model using only the Spencer gage (465000) and the 1972-75 data, a regression was run using the 1980-82 data and only the Spencer gage. These results also were significantly better than the model using the same station, but with data from the earlier period of record. This indicates that the apparent improvement results from the period of record rather than from an improved form of the model.

Computational procedures for the Verdel station have changed in recent years so that correlation with other stations is now used as an aid in computing the discharge record during periods of missing or questionable stage record. This "designed in" correlation probably is the reason that the recent period seems to give better accuracy using the alternative-method analysis. The hydrologic forecasting data use (table 2) now requires that the Verdel gage be continued. If the data requirements change in the future, the Verdel gage could be considered a candidate for alternative methods. However, the calibrated models need to be tested against data that is truly independent.

The models presented in table 4 for the other stations are not adequate for synthesizing a streamflow record in lieu of operating a gaging station. They may be useful in reconstructing records where data are missing. In general, the logarithmic form of the model for Elkhorn River (798500), Salt Creek (803555), and Little Blue River (884000) tends to show less bias than the linear form.

Table 4.—Summary of regression results for mean daily streamflow [Variable names starting with Q are mean daily discharges, in cubic feet per second; those starting with L are in base 10 logarithms of mean daily discharge]

Station and model	Standard error (percent)	Percentage within indicated percent range			Calibration period (water years)
		5	15	25	
462000 Niobrara River near Norden, Nebraska					
L462000 = 0.00463 + 1.02 (L461500)	15	—	—	—	1980–82
Q462000 = -139 + 138 (Q461500)	14	32	80	93	1980–82
465500 Niobrara River near Verdel, Nebraska					
L465500 = 0.120 + 0.975 (L465000)	15	—	—	—	1972–75
Q465500 = 61.4 + 1.06 (Q465000)	23	42	78	91	1972–75
L465500 = 0.115 + 0.973 (L465000)	7.5	—	—	—	1980–82
Q465500 = 42.9 + 1.04 (Q465000)	7.2	68	94	100	1980–82
L465500 = 0.243 + 0.890 (L465000) + 0.045 (L465310) + 0.043 (L465440)	7.6	—	—	—	1980–82
Q465500 = 25.8 + 0.985 (Q465000) + 0.476 (Q465310) + 2.60 (Q465440)	7.2	72	96	100	1980–82
798500 Elkhorn River at Neligh, Nebraska					
L798500 = 0.555 + 0.500 (L797500) + 0.100 (L798000) + 0.451 (L798300)	15	—	—	—	1980–82
Q798500 = 27.5 + 1.13 (Q797500) + 0.492 (Q798000) + 1.74 (Q798300)	24	24	65	83	1980–82
Q798500 = 24.6 + 1.08 (Q797500 + Q798000 + Q798300)	28	26	66	82	1980–82
803555 Salt Creek at Greenwood, Nebraska					
L803555 = 0.384 + 0.791 (L803500) + 0.060 (L803520) + 0.180 (L803530)	20	—	—	—	1980–82
Q803555 = -21.4 + 1.23 (Q803500) + 3.52 (Q803510) + 3.00 (Q803520) + 1.17 (Q803530)	27	25	64	83	1980–82
884000 Little Blue River near Fairbury, Nebraska					
L884000 = -0.119 + 1.00 (L884025)	21	—	—	—	1980–82
Q884000 = -53.2 + 0.896 (Q884025)	30	15	40	59	1980–82
L884000 = 0.415 + 0.565 (L883570) + 0.432 (L883940)	22	—	—	—	1980–82
Q884000 = 22.6 + 1.11 (Q883570) + 0.817 (Q883940)	27	16	42	61	1980–82
Q884000 = 25.8 + 1.01 (Q883570 + Q883940)	27	14	42	68	1980–82

Summary of Second Phase of Analysis

None of the stations investigated presently are suitable for the application of alternative methods. Only at the Niobrara River near Verdel (465500) is the accuracy of the regression relation sufficient to consider discontinuing the gage, and the data uses now require that the gage be continued. If the data uses change in the future, this gage could be considered for the application of alternative methods. However, the calibrated models need to be verified against data not used in the calibration.

COST-EFFECTIVE RESOURCE ALLOCATION

Discussion of the Model

A set of techniques called K-CERA (Kalman filtering for Cost-Effective Resource Allocation) was developed by Moss and Gilroy (1980) to study the cost-effectiveness of networks of stream gages. The original application of the technique was to analyze a network of stream gages operated to determine water consumption in the Lower Colorado River Basin (Moss and Gilroy, 1980). Because of the water-balance nature of that study, the minimization of the total variance of errors of estimation of annual mean discharges was chosen as the measure of effectiveness of the network. This total variance is defined as the sum of the variances of errors of mean annual discharge at each site in the network. This measure of effectiveness tends to concentrate stream-gaging resources on the large rivers and streams where discharge and, consequently, potential errors (in cubic feet per second) are greatest. Although this may be acceptable for a water-balance network, considering the many uses of data collected by the U.S. Geological Survey, concentration of effort on large rivers and streams is undesirable and inappropriate.

The original version of K-CERA was therefore altered 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 percent; average instantaneous discharge, in cubic feet per second; or average instantaneous discharge, in percent (Fontaine and others, 1983). The use of percentage errors effectively gives equal weight to large and small streams. In addition, 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 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 (Fontaine and others, 1984) and was incorporated into this study.

Brief descriptions of the mathematical program used to minimize the total error variance of the data-collection activity for given budgets and of the application of Kalman filtering (Gelb, 1974) to the determination of the accuracy of a stream-gaging record are presented by Fontaine and others (1984); that description is reproduced in the Supplemental Information section at the end of this report. For more detail on either the theory or the applications of the K-CERA model, see Moss and Gilroy (1980) and Gilroy and Moss (1981).

Application of the Model in Nebraska

The first two phases of this analysis showed that operation of the current network of stream gages in Nebraska needs to be continued. The existing stream-gage network was, therefore, analyzed by the K-CERA technique to evaluate the current operation and to consider alternative operating schedules. The results of this third and final phase of the analysis are described in the remainder of this section.

The model assumes the uncertainty of discharge records at a given gage to be derived from three sources: (1) Errors that result because the stage-discharge relationship is not perfect (applies when the gage is operating); (2) errors in reconstructing records based on records from another gage when the primary gage is not operating; and (3) errors inherent in estimated discharge when the gage is not operating and no correlative data are available to aid in record reconstruction. These uncertainties are measured as the variance of the percentage errors in instantaneous discharge. The proportion of time that each source of error applies is dependent on the frequency at which the equipment is serviced.

Definition of Variance When Station is Operating

The model used in this analysis assumes the difference (residual) between instantaneous discharge (measurement discharge) and rating curve discharge is a continuous first-order Markov process. The underlying probability distribution is assumed to be Gaussian (normal) with a zero mean; the variance of this distribution is referred to as process variance. Because the total variance of the residuals includes error in the measurements, the process variance is defined as the total variance of the residuals minus the measurement error variance.

Computation of the error variance about the stage-discharge relation was done in three steps. A long-term rating was defined, generally based on measurements made during 3 or more water years, and deviations (residuals) of the measured discharges from the rating discharge were determined. A time-series analysis af these residuals defined the 1-day lag (lag-one) autocorrelation coefficient and the process variance required by the K-CERA model. Finally, the error variance is defined within the model as a function of the lag-one autocorrelation coefficient, the process and measurement variances, and the frequency of discharge measurements.

In the Nebraska program analysis, definition of long-term rating functions was complicated by the fact that most stream gages in Nebraska are affected by backwater from ice for about 3 months during the year. Rating curves based on open-water measurements are not applicable during the ice-affected periods.

In the pilot study for Maine, winter rating curves were replaced with regression relations relating the discharge at the ice-affected station to the discharge at an ice-free station. The model used this relationship in place of a standard stage-discharge relationship, and uncertainties of the ice-affected and ice-free periods were evaluated separately (Fontaine and others, 1984). This approach does not work well in Nebraska because of the distances between gages and the variability of flow resulting from the temporary storage and subsequent release of ice. Reliable discharge records during the winter can presently be produced only by making periodic visits and measurements to document the degree of ice effect.

Review of past discharge records indicates that the average period of significant ice effect lasts about 3 months in Nebraska, generally from about mid-December to mid-March. The decision was made that, regardless of ice-free period visit requirements, 3 visits will continue to be made during the winter season. The model was then applied only to the approximately 9 months (275 days) that are virtually free from ice effect.

Long-term rating curves applicable to ice-free periods were defined for each station used in the evaluation. In some cases, existing ratings adequately defined the long-term condition and were used in the analysis. At a majority of gages, however, this was not the case, and a new rating had to be developed. The rating function used was of the following form:

$$LQM = B1 + B3\ (\ LOG(GHT - B2)) \qquad (2)$$

where

LQM = the logarithmic (base e) value of the measured discharge, and
GHT = the recorded gage height corresponding to the measured discharge.

The constants B1, B2, and B3 were determined by a non-linear regression procedure (Helwig and Council, 1979) and have the following physical interpretation: B1 is the logarithm of discharge for a flow depth of 1 foot, B2 is the gage height of zero flow, and B3 is the slope of the rating curve.

The residuals about the long-term rating for individual gages defined the total variance. A review of discharge measurements made in Nebraska indicated that the average standard error of open-water measurements was about 3 percent. The measurement variance for all gages therefore was defined as equal to the square of the 3-percent standard error. The process variance required in the model is, thus, the variance of the residuals about the long-term rating minus the constant measurement variance.

Time-series analysis of the process variance was used to compute sample estimates of the lag-one autocorrelation coefficient; this coefficient is required to compute the variance during the time when the recorders are functioning.

The values of lag-one autocorrelation coefficient, measurement and process variance, length of season (275 days), and data from the definition of missing record probabilities are used jointly to define uncertainty functions for each gaging station. The uncertainty functions give the relationship of error variance to the number of visits, assuming a measurement is made at each visit. Examples of typical uncertainty functions are given in figure 4. The uncertainty curve for station 466500 is representative of stations with a large process variance and that for station 787000 represents stations with relatively small process variance. Lag-one autocorrelation coefficients are approximately 0.99 for both stations.

The residuals about rating curves for many stations in Nebraska do not approximate a continuous first-order Markov process. These stations have significant changes in ratings resulting from channel changes, usually resulting from periodic floods. These may shift with each flood, but will not necessarily return to the original rating after a change. In addition, several stations apparently have discontinuous ratings that change as the flow regime changes. These regime changes can occur as a result of changes in stage, water temperature, or suspended-sediment load. In either case (channel change or regime change), the process may be Markovian, but is not continuous as there is no meaningful long-term rating. In addition, records at 6 stations were too short to define the process variance. A total of 44 of the 145 stations analyzed were excluded from the analysis because the records were either too short or did not appear to meet the assumptions of the model. Those stations are listed in table 5.

Table 5.—Stations with no defined uncertainty function

454000	762500	799385	828500
457500	764880	800000	829500
459175	765500	803510	831500
461500	766500	803520	836000
464900	768000	803530	838000
465000	770200	814500	847000
465440	775900	821500	847500
465500	776500	823000	851000
687000	792500	823500	851500
690500	793000	824000	852500
691000	799350	827500	853000

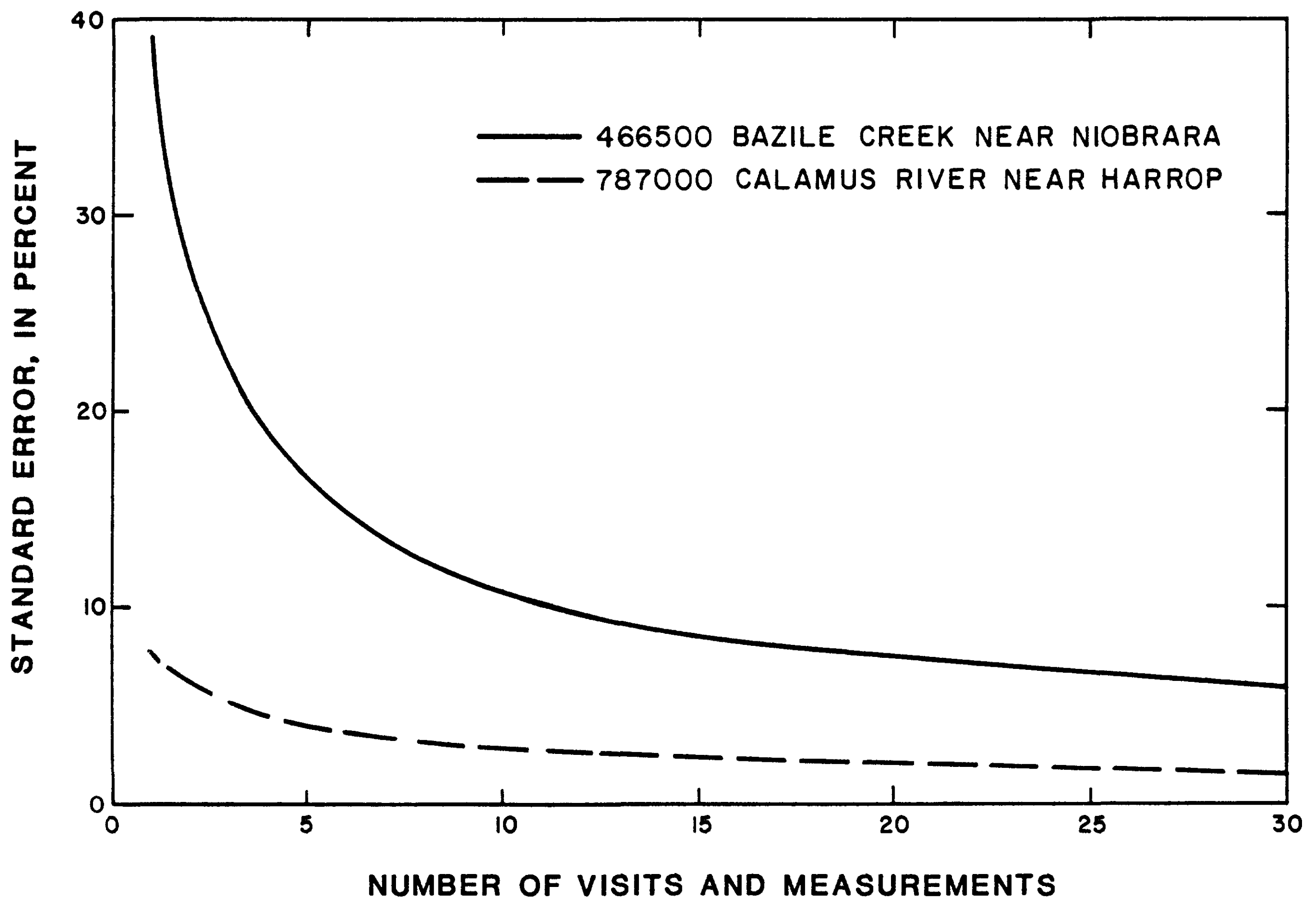


Figure 4.--Typical uncertainty functions for instantaneous discharge.

Definition of Variance When Record is Lost

When stage record is lost at a gaging station, the model assumes that the discharge record is either reconstructed using correlation with another gage or estimated from historical discharge for that period. Fontaine and others (1984, p. 24) indicate that the fraction of time a record must be either reconstructed or estimated can be defined by a single parameter in a probability distribution of times to failure of the equipment. The reciprocal of the parameter defines the average time, since the last servicing visit, to failure. The value of average time to failure varies from site to site depending on the type of equipment at the site and on exposure to natural elements and vandalism. In addition, the average time to failure can be changed by advances in the technology of data collection and recording equipment.

Data collected in Nebraska in recent years were reviewed to define the average time to failure for recording equipment and stage-sensing devices. Little change in technology occurred during the period examined, and stream gages were visited on a consistent pattern of about 15 visits per year. During this period, gages were found to be malfunctioning an average of about 5 percent of the time. Because the K-CERA analysis in Nebraska was confined to a 9-month non-winter period, there was no reason to distinguish between gages on the basis of their exposure or equipment. The 5 percent lost record and a visit frequency of 12 times in 9 months (275 days) were used to determine an average time to failure of 221 days after the last visit. This average time to failure was used to determine the fractions of time, as a function of the frequency of visits, that each of the three sources of uncertainty were applicable for individual stream gages.

The model defines the uncertainty as the sum of the multiples of the fraction of time each error source (rating, reconstruction, or estimation) is applicable and the variance of the error source. The variance associated with reconstruction and estimation of a discharge record is a function of the coefficient of cross correlation with the station(s) used in reconstruction and the coefficient of variation of daily discharges at the station. Daily streamflows for the last 30 water years were used to define seasonally-averaged coefficients of variation for each station. In addition, cross-correlation coefficients (with seasonal trends removed) were defined for various combinations with other stations.

In current practice, many different sources of information are used to reconstruct periods of missing record. These sources include, but are not limited to, recorded ranges in stage (for graphic recorders with clock stoppage), known discharges on adjacent days, recession analysis, observer's staff-gage readings, weather records, highwater-mark elevations, and comparison with nearby stations. However, most of these techniques are unique to a given station or to a specific period of lost record. Using all the information available, short periods (several days) of lost record usually can be reconstructed quite accurately. Even longer periods (more than a month) of missing record can be reconstructed with reasonable accuracy if observer's readings are available. If, however, none of these data are available, long reconstructions can be subject to large errors. The present study could not reasonably quantify the uncertainty associated with all the possible methods of reconstructing missing record at the individual sites.

Historically, operating procedures have caused most periods of missing record to be measured in days rather than months. Given the low cross-correlations and the relatively high variability of flow that usually occurs in Nebraska, the model undoubtedly overstates the uncertainty associated with short periods of missing record. Therefore, in Nebraska, a lower limit of 0.95 was placed on the cross-correlation coefficient. In reconstructing records, the cross-correlation coefficient was, therefore, used as a surrogate for the knowledge of basin response that remains unquantified in the present model. This assumption is believed to be reasonable for short periods of missing record; it probably causes the uncertainty to be understated for long periods of lost record.

Uncertainty functions were defined for 101 of the 145 stations operated in the Nebraska streamflow information program. The statistics used to define those uncertainty functions are shown in table 6.

Discussion of Routes and Costs

Although there are only 145 continuous surface-water stations in the network, crest-stage gages (operated to record peak stages), low-flow partial-record stations, ground-water observation wells, and water-quality stations are serviced on the same field trips. The operating budgets for these other types of stations are not included in the surface-water budget being analyzed; however, the investigation could not ignore the additional mileage required to include these stations on field trips. These stations were, therefore, added to the 145 continuous surface-water stations to define the mileages associated with practical operating routes. These added stations acted as null stations in the analysis in that there were no uncertainty functions or annual operating costs defined. There were 76 null stations included in the analysis, and routes were defined for a total of 221 stations, including the null stations.

As indicated in a preceding section, uncertainty functions could not be defined for 44 of the 145 continuous surface-water stations. These 44 stations were treated like null stations except that all operating costs were included in the analysis.

Minimum visit constraints were defined for each of the 221 stations prior to defining the practical service routes. Minimum visits are dependent on the types of equipment and uses of the data. For example, water-quality samples generally are required on a monthly basis, so those stations where samples are collected must be visited at least once a month (or 9 times in the 275-day open-water season). Nebraska personnel estimated that visits to each gage were required about every other month just to maintain the equipment. Therefore, unless a more stringent requirement existed, a minimum of 4 visits during the 275-day season were specified for all gages.

Table 6.—Summary of statistics used to define uncertainty functions.

Station number	Lag-one autocorrelation coefficient	Process -variance	Coefficient of variation
444000	0.990*	0.0210	0.41
453500	.975	.1000**	2.47
453600	.992	.1000**	2.05
454100	.964	.0055	.38
454500	.940	.0069	.56
455500	.990*	.0099	.89
459500	.952	.0026	.61
461000	.968	.0231	.51
462000	.989	.0123	.28
462500	.990*	.0623	.33
463080	.990*	.0026	.34
463500	.986	.0599	.34
465310	.984	.1000**	.80
465680	.990*	.0293	.80
466500	.992	.0945	1.20
478518	.955	.0514	.63
601000	.971	.0924	1.76
677500	.986	.0289	.72
678000	.968	.0321	.94
679500	.966	.0196	1.05
681500	.990	.1000**	.48
682000	.955	.0080	.88
684500	.963	.0100	.76
685000	.856	.0059	.78
686000	.825	.0062	.72
687500	.538	.0035	.70
692000	.962	.0117	.13
693000	.988	.0217	.93
766000	.950	.0120	1.70
770000	.985	.1000**	1.12
770500	.961	.1000**	.80
772000	.990*	.0294	2.00
774000	.967	.1000**	1.15
775500	.990*	.0034	.14
779000	.989	.1000**	.60
783500	.976	.0453	1.35
784000	.994	.0955	.89
784800	.983	.0206	1.13
785000	.986	.1000**	.64
786000	.954	.0204	.40

Table 6.—Summary of statistics used to define uncertainty functions (continued).

Station number	Lag-one autocorrelation coefficient	Process -variance	Coefficient of variation
787000	0.987	0.0050	0.15
787500	.990*	.0070	.26
788500	.989	.0603	.34
788988	.990*	.1000**	.40
790500	.992	.0366	.46
791500	.990	.0112	.38
792000	.986	.0345	.68
794000	.950	.0214	.97
795500	.971	.0213	1.82
796000	.969	.0409	.72
796978	.989	.1000**	.90
797500	.987	.0604	1.07
798000	.965	.0348	.64
798300	.498	.0069	.58
798500	.991	.1000**	.79
799000	.987	.0900	.79
799080	.978	.0207	.56
799100	.991	.0730	1.18
799230	.990*	.0125	.66
799450	.993	.0738	1.23
799500	.977	.0315	1.40
800500	.985	.0292	1.03
803000	.963	.1000**	2.33
803500	.875	.0112	1.64
803555	.990	.0311	1.74
804000	.997	.1000**	1.85
805500	.976	.0473	.77
806500	.984	.1055	1.91
811500	.978	.0653	2.04
815000	.943	.0358	2.21
824500	.943	.0512	1.17
832500	.990*	.0936	1.26
834000	.977	.0122	.65
835000	.985	.0094	.62
835500	.961	.0653	.86
836500	.981	.0744	1.71
837000	.990*	.0244	.93
837300	.980	.0054	.71
837500	.976	.0063	1.08
840000	.994	.1000**	.60

Table 6.—Summary of statistics used to define uncertainty functions (continued).

Station number	Lag-one autocorrelation coefficient	Process -variance	Coefficient of variation
841000	0.997	0.0485	0.98
842500	.990	.0275	1.25
843500	.976	.0626	.86
844000	.962	.0412	1.60
844210	.987	.0454	.55
844500	.974	.0652	1.16
849500	.983	.0770	1.93
852000	.984	.0386	.50
879900	.946	.1000**	2.78
880000	.967	.0347	1.94
880500	.964	.0311	2.13
880800	.973	.0161	1.43
881000	.990*	.0128	1.61
881200	.983	.1000**	2.11
881500	.990*	.0493	1.20
882000	.521	.0084	1.75
883000	.996	.0876	1.50
883570	.982	.1000**	1.39
883940	.996	.0538	.80
884000	.985	.0561	1.60
884025	.992	.0324	1.10

Note: Process variance units are base e logarithms, squared.
* —Assigned value.
** —Limited to 0.1000 based on graphical analyses.

Practical routes to service the 221 stations were determined after consultation with personnel responsible for maintaining the stations and with consideration of the uncertainty functions and minimum visit requirements. A total of 91 routes were identified to service all the stream gages in Nebraska. These routes included all possible combinations that describe the current operating practice, alternatives that were under consideration as future possibilities, routes that visited certain key stations, and combinations that grouped proximate gages where the levels of uncertainty indicated more frequent visits might be useful.

The costs associated with the practical routes are divided into three categories. Those categories are fixed costs, visit costs, and route costs and are defined in the following paragraphs. Overhead is, of course, added to the total of these costs.

Fixed costs typically include charges for equipment rental, batteries, electricity, data processing and storage, maintenance, and miscellaneous supplies, in addition to supervisory charges and the costs of computing the record. Average values for Nebraska generally were applied to individual stations. However, costs of record computation and supervision form a large percentage of the cost at each gaging station and can vary widely. These costs and unusual equipment costs were determined on a station-by-station basis from past experience.

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 depending on the difficulty of the measurement, size of the channel, and quantity of and complexity of equipment serviced. Average visit times were estimated for each station based on historical operations. This time was then multiplied by the average hourly salary of the hydrographers in Nebraska to determine total visit costs.

Route costs include the vehicle cost associated with driving the number of miles required to cover the route, the cost of the hydrographer's time while in transit, and any per diem associated with the time needed to complete the trip.

The model was run on a 275-day period with the added requirement that 3 visits will continue to be made during the remaining 90 days of the year. The fixed costs were computed on an annual basis, but the visit and route costs are only applied when a trip is made. In order that all costs could be applied on an annual basis, the visit and route costs for the three winter visits were added to the fixed costs for each station.

Results

The "Traveling Hydrographer Program" uses the uncertainty functions along with the appropriate cost data, route definitions, and minimum visit constraints to optimize the operation of the stream-gaging program. The objective function in the optimization process is the sum of the variances of the errors of instantaneous discharge (in percent) for the entire gaging-station network.

The current practices were simulated to define the total uncertainty associated with present practice. This was done by restricting the specific routes and number of visits to each stream gage to those now being used. This was done only to compute the standard errors of present practice; no optimization was done. The restrictions were then released and the model was allowed to define optimal visit schedules for the current budget. The optimization procedure was repeated for other possible budgets. The results for both the present operation and the optimal solutions are shown in figure 5 and in table 7.

The Equivalent Gaussian Spread (EGS) shown in table 7 was introduced by Fontaine and others (1984, p. 26); their definition is repeated in the Supplemental Information section of this report. The approximate interpretation of EGS is, "Two-thirds of the errors in instantaneous streamflow data will be within plus or minus EGS percent of the reported value."

The analysis was repeated for each budget under the assumption that no stage record is lost. Those results, labeled "Without missing record" in figure 5, show the average standard errors of estimate for instantaneous discharge attainable if perfectly reliable systems were available to measure and record stage.

The results in figure 5 and table 7 are based on the assumption that a discharge measurement is made each time that a station is visited. The percentage values also represent only the 9 months that are virtually free from ice effect. No estimate is made of the probable errors during ice-affected periods. The upper curve in figure 5 represents the minimum level of uncertainty that can be obtained for a given budget and existing technology.

Assumptions made in the model need to be kept in mind when interpreting these results. Residuals about the ratings for 44 of the 145 stations in the surface-water network were judged to not follow the first-order Markov process assumed in the model. At about one-third of the remaining 101 stations, the assumption of a Markov process was questionable, but the stations were retained in the analysis. This was done under the belief that, while the absolute values of standard error may be incorrect, the values had relative significance. Perhaps of more importance, these 44 stations without uncertainty functions had little impact on the optimization procedure. Because uncertainty functions were undefined, the 44 stations were treated as null stations and were visited the specified minimum number of times (in Nebraska, this was monthly). If the budget changed, the number of visits for these 44 stations stayed at the minimum because increasing or decreasing the visits had no impact on the objective function. In practice, significant parts of any budget increase or decrease would be directed toward those stations.

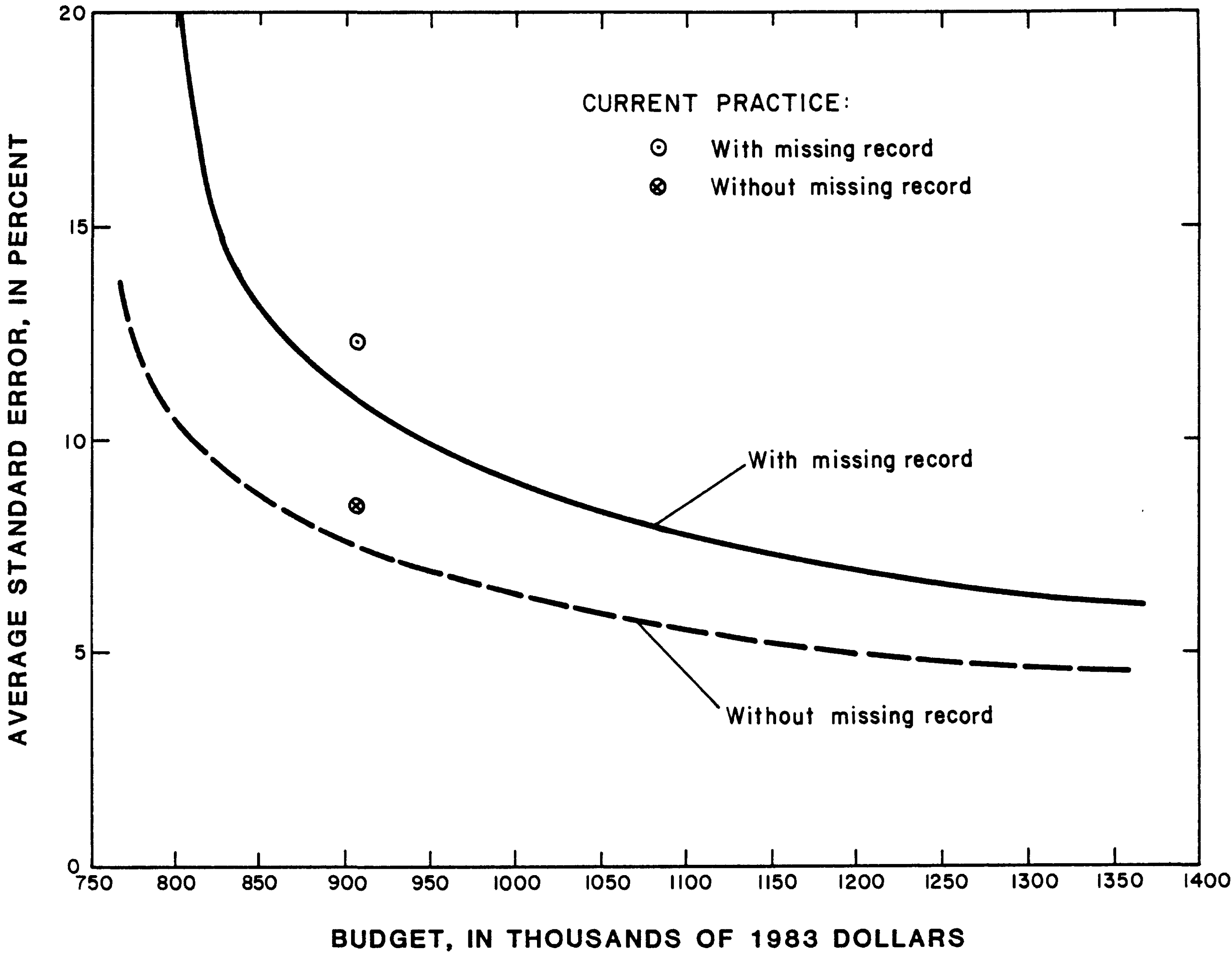


Figure 5.--Relationship between average standard error per station and budget.

Table 7.— Selected results of the analysis

Station number	Standard error of instantaneous discharge, in percent; Equivalent Gaussian Spread, in percent; and number of visits per season				
	Budget, in thousands of 1983 dollars				
	Current operation	Optimized values			
	908.5	822	908.5	999	1363
444000	5.2	8.3	6.5	5.2	3.2
	4.5	7.0	5.5	4.5	2.8
	12	5	8	12	31
453500	21.2	22.3	15.7	12.1	8.3
	11.6	12.1	8.8	6.9	4.8
	12	11	20	32	66
453600	17.9	18.9	13.3	10.3	7.0
	10.3	10.8	7.8	6.1	4.3
	12	11	20	32	66
454100	4.9	8.2	5.6	5.9	3.9
	4.3	6.4	4.8	5.0	3.4
	12	4	9	8	20
454500	6.9	10.1	7.1	5.9	3.9
	5.8	7.6	6.0	5.1	3.4
	12	5	11	17	41
455500	7.2	12.6	7.6	5.9	3.6
	3.2	5.1	3.3	2.7	1.8
	12	5	11	17	41
459500	5.5	10.4	6.4	5.5	3.6
	3.4	4.9	3.7	3.4	2.4
	12	4	9	12	26
461000	8.6	13.7	9.8	8.6	5.9
	8.1	12.3	9.2	8.1	5.6
	12	4	9	12	26
462000	4.0	4.7	4.7	4.0	2.7
	3.6	4.2	4.2	3.6	2.5
	12	9	9	12	26
462500	7.5	12.9	8.7	7.5	5.2
	7.4	12.4	8.5	7.4	5.0
	12	4	9	12	26

Table 7.— Selected results of the analysis (continued).

Station number	Standard error of instantaneous discharge, in percent; Equivalent Gaussian Spread, in percent; and number of visits per season				
	Budget, in thousands of 1983 dollars				
	Current operation	Optimized values			
	908.5	822	908.5	999	1363
463080	3.0	5.9	3.5	3.0	1.9
	1.7	3.0	2.0	1.7	1.2
	12	4	9	12	26
463500	8.7	10.0	10.0	8.7	5.9
	8.6	9.8	9.8	8.6	5.8
	12	9	9	12	26
465310	10.8	11.3	8.3	6.5	4.6
	9.5	10.0	7.3	5.8	4.1
	12	11	20	32	66
465680	7.7	8.6	6.8	8.6	5.7
	5.3	5.8	4.7	5.8	4.0
	12	10	15	10	21
466500	9.9	10.4	7.6	5.9	4.3
	8.3	8.7	6.4	5.0	3.7
	12	11	20	32	66
478518	14.2	17.4	14.2	12.2	8.5
	13.9	16.9	13.9	11.9	8.3
	12	7	12	17	36
601000	19.6	26.2	19.6	16.3	11.0
	15.6	20.2	15.6	13.1	8.8
	12	7	12	17	36
677500	7.9	11.6	6.5	5.2	3.4
	6.2	8.8	5.2	4.2	2.8
	12	6	17	26	61
678000	10.4	14.9	8.7	7.0	4.5
	8.2	11.2	6.9	5.6	3.7
	12	6	17	26	61
679500	14.3	22.2	11.5	9.0	5.6
	8.1	11.4	6.8	5.5	3.5
	12	6	17	26	61

Table 7.— Selected results of the analysis (continued).

Station number	Current operation 908.5	Optimized values 822	908.5	999	1363
	Standard error of instantaneous discharge, in percent; Equivalent Gaussian Spread, in percent; and number of visits per season — Budget, in thousands of 1983 dollars				
681500	9.7	16.7	9.3	7.2	4.5
	9.3	16.0	9.0	6.9	4.3
	12	4	13	22	58
682000	11.6	23.7	11.0	8.2	5.1
	5.9	9.6	5.7	4.5	3.0
	12	4	13	21	48
684500	10.4	18.1	9.9	7.9	4.9
	6.0	9.1	5.8	4.8	3.1
	12	5	13	19	45
685000	8.7	12.5	9.3	7.6	4.6
	7.0	8.0	7.2	6.4	4.1
	12	5	10	18	62
686000	10.8	12.4	10.4	8.5	5.4
	7.5	7.9	7.4	6.6	4.5
	12	9	13	21	60
687500	9.9	18.8	11.4	9.2	6.8
	6.2	7.5	6.4	6.1	5.5
	12	4	9	14	32
692000	6.0	8.5	6.7	7.0	4.2
	6.0	8.3	6.7	7.0	4.2
	12	4	9	8	28
693000	11.8	17.0	9.1	7.1	4.4
	5.3	7.2	4.2	3.4	2.3
	12	7	18	27	62
766000	21.0	33.7	16.8	13.2	7.9
	7.6	10.4	6.4	5.3	3.4
	12	6	17	25	60
770000	15.3	27.3	12.3	10.3	6.7
	9.9	16.4	8.2	7.0	4.7
	12	5	17	23	50

Table 7.— Selected results of the analysis (continued).

Station number	Standard error of instantaneous discharge, in percent; Equivalent Gaussian Spread, in percent; and number of visits per season — Budget, in thousands of 1983 dollars: Current operation 908.5	Optimized values 822	Optimized values 908.5	Optimized values 999	Optimized values 1363
770500	8.7	12.3	9.1	8.0	5.7
	6.8	9.4	7.1	6.3	4.5
	24	13	22	28	54
772000	17.2	18.1	13.2	10.2	6.8
	9.5	9.9	7.5	5.9	4.1
	12	11	19	30	65
774000	18.3	21.0	15.4	13.9	9.5
	17.0	19.4	14.4	12.9	8.9
	12	9	17	21	44
775500	2.1	3.7	2.6	3.7	2.8
	1.9	3.2	2.3	3.2	2.5
	12	4	8	4	7
779000	10.0	13.3	10.0	7.6	5.4
	9.4	12.4	9.4	7.1	5.1
	12	7	12	21	41
783500	13.7	12.6	10.7	8.0	5.4
	10.0	9.3	7.9	6.0	4.1
	12	14	19	33	70
784000	9.5	11.1	9.1	8.7	6.2
	7.2	8.5	6.9	6.6	4.9
	12	9	13	14	26
784800	9.9	19.6	11.8	9.1	6.2
	5.8	10.2	6.7	5.3	3.8
	12	4	9	14	28
785000	7.2	9.8	7.5	6.6	4.8
	6.6	9.1	6.9	6.2	4.5
	24	13	22	28	54
786000	9.0	12.2	9.7	7.4	4.8
	8.8	11.7	9.5	7.2	4.7
	12	5	10	19	46

Table 7.— Selected results of the analysis (continued).

Station number	Standard error of instantaneous discharge, in percent; Equivalent Gaussian Spread, in percent; and number of visits per season — Budget, in thousands of 1983 dollars: Current operation 908.5	Optimized values 822	908.5	999	1363
787000	2.7	4.5	4.1	3.7	2.5
	2.6	4.2	3.8	3.5	2.4
	12	4	5	6	14
787500	3.2	5.7	5.1	4.6	2.9
	2.7	4.6	4.1	3.8	2.5
	12	4	5	6	14
788500	7.8	11.0	8.5	6.8	4.4
	7.6	10.7	8.4	6.6	4.3
	12	6	10	16	38
788988	10.0	13.0	10.0	7.5	5.4
	9.8	12.8	9.8	7.4	5.3
	12	7	12	21	41
790500	4.2	5.7	4.4	3.9	2.9
	3.7	5.0	3.9	3.4	2.6
	24	13	22	28	54
791500	4.2	7.8	4.9	3.9	2.7
	3.3	5.8	3.9	3.1	2.2
	12	4	9	14	28
792000	8.0	9.4	6.7	6.0	4.1
	6.6	7.7	5.5	5.0	3.5
	12	9	17	21	44
794000	11.5	13.2	9.7	8.8	6.1
	9.5	10.7	8.2	7.4	5.2
	12	9	17	21	44
795500	15.2	16.9	12.4	9.9	6.6
	7.6	8.3	6.4	5.3	3.6
	12	10	17	25	53
796000	11.4	13.1	9.6	8.7	6.0
	10.6	12.1	9.0	8.1	5.6
	12	9	17	21	44

Table 7.— Selected results of the analysis (continued).

Station number	Standard error of instantaneous discharge, in percent; Equivalent Gaussian Spread, in percent; and number of visits per season				
	Budget, in thousands of 1983 dollars				
	Current operation	Optimized values			
	908.5	822	908.5	999	1363
796978	11.2	11.8	8.5	6.7	4.7
	9.5	10.0	7.3	5.8	4.1
	12	11	20	32	66
797500	11.3	15.4	11.9	9.6	6.4
	8.6	11.4	9.0	7.4	5.0
	12	7	11	16	35
798000	10.9	13.8	11.4	9.6	6.5
	10.3	12.9	10.8	9.0	6.1
	12	7	11	16	35
798300	9.0	10.0	9.1	8.6	7.8
	8.3	8.5	8.3	8.1	7.6
	12	7	11	16	35
798500	10.2	13.7	10.7	8.8	5.9
	8.8	11.8	9.2	7.6	5.1
	12	7	11	16	35
799000	11.5	15.2	12.0	9.9	6.6
	10.4	13.7	10.8	8.9	6.0
	12	7	11	16	35
799080	7.5	9.8	7.8	6.4	4.3
	6.5	8.4	6.8	5.6	3.8
	12	7	11	16	35
799100	11.5	15.8	12.0	9.8	6.4
	8.0	10.7	8.3	6.8	4.6
	12	7	11	16	35
799230	5.9	8.2	6.2	5.0	3.3
	3.5	4.7	3.7	3.1	2.1
	12	7	11	16	35
799450	11.1	13.2	11.1	9.1	6.1
	6.9	8.1	6.9	5.8	3.9
	12	9	12	17	36

Table 7.-- Selected results of the analysis (continued).

Station number	Standard error of instantaneous discharge, in percent; Equivalent Gaussian Spread, in percent; and number of visits per season				
	Budget, in thousands of 1983 dollars				
	Current operation	Optimized values			
	908.5	822	908.5	999	1363
799500	12.9	17.7	12.9	10.6	7.1
	8.2	10.8	8.2	6.9	4.7
	12	7	12	17	36
800500	7.1	7.1	7.1	7.1	6.2
	4.9	4.9	4.9	4.9	4.3
	21	21	21	21	27
803000	24.3	20.9	16.1	13.8	9.5
	18.3	15.9	12.4	10.6	7.4
	12	16	26	35	71
803500	14.9	19.6	14.9	13.0	8.6
	9.2	10.3	9.2	8.6	6.3
	12	7	12	16	38
803555	13.8	16.6	12.1	9.9	6.7
	5.5	6.5	4.9	4.1	3.0
	12	9	15	21	42
804000	14.5	20.5	14.5	12.2	7.5
	5.3	7.1	5.3	4.6	3.1
	12	7	12	16	38
805500	8.4	8.4	8.4	8.4	6.8
	7.6	7.6	7.6	7.6	6.2
	21	21	21	21	31
806500	18.3	20.4	15.6	12.7	8.8
	12.5	13.8	10.7	8.8	6.2
	12	10	16	23	46
811500	18.4	20.5	15.6	12.8	8.9
	11.4	12.6	9.8	8.1	5.8
	12	10	16	23	45
815000	20.4	22.5	17.5	14.4	10.2
	13.1	14.0	11.6	9.8	7.0
	12	10	16	23	45

Table 7.— Selected results of the analysis (continued).

Station number	Standard error of instantaneous discharge, in percent; Equivalent Gaussian Spread, in percent; and number of visits per season				
	Budget, in thousands of 1983 dollars				
	Current operation	Optimized values			
	908.5	822	908.5	999	1363
824500	17.0	19.2	16.5	12.9	8.6
	15.4	17.1	15.0	11.8	7.9
	12	9	13	22	50
832500	12.7	16.1	10.9	9.4	6.4
	9.2	11.6	8.0	6.9	4.8
	12	8	16	21	44
834000	6.8	8.5	5.8	5.0	3.5
	5.2	6.3	4.5	3.9	2.7
	12	8	16	21	44
835000	5.8	7.3	4.9	4.2	2.9
	3.8	4.7	3.3	2.9	2.0
	12	8	16	21	44
835500	15.4	16.7	13.5	10.4	7.1
	14.6	15.9	12.8	9.9	6.8
	12	10	16	27	57
836500	16.5	20.9	14.0	12.1	8.1
	11.4	14.1	9.8	8.5	5.8
	12	8	16	21	44
837000	8.2	9.2	7.0	5.2	3.6
	4.8	5.4	4.2	3.3	2.3
	12	10	16	27	57
837300	6.1	7.8	5.6	4.6	3.0
	3.3	4.0	3.1	2.6	1.8
	12	8	14	20	44
837500	8.8	11.3	8.0	6.5	4.2
	3.9	4.7	3.6	3.0	2.1
	12	8	14	20	44
840000	8.3	10.2	7.6	6.4	4.3
	7.3	9.0	6.7	5.7	3.9
	12	8	14	20	44

Table 7.— Selected results of the analysis (continued).

Station number	Standard error of instantaneous discharge, in percent; Equivalent Gaussian Spread, in percent; and number of visits per season				
	Budget, in thousands of 1983 dollars				
	Current operation	Optimized values			
	908.5	822	908.5	999	1363
841000	8.1 3.8 12	10.4 4.7 8	7.4 3.6 14	6.0 3.0 20	4.0 2.2 44
842500	10.4 5.1 12	13.3 6.4 8	9.5 4.7 14	7.7 4.0 20	5.0 2.7 44
843500	9.8 8.9 20	9.8 8.9 20	9.8 8.9 20	8.0 7.3 30	5.4 4.9 65
844000	16.3 11.9 12	19.0 13.5 9	12.7 9.5 19	10.6 8.0 27	7.0 5.3 59
844210	8.0 7.3 12	9.4 8.5 9	6.4 5.8 19	5.4 4.9 27	3.7 3.4 59
844500	14.5 12.4 12	15.1 12.9 11	11.1 9.5 20	9.5 8.2 27	6.1 5.3 64
849500	17.6 11.1 12	26.8 16.0 6	16.8 10.6 13	14.0 9.0 18	9.2 6.0 39
852000	8.1 7.6 12	11.5 10.6 6	7.8 7.3 13	6.6 6.2 18	4.5 4.2 39
879900	28.7 21.4 12	31.5 23.0 10	24.1 18.4 17	19.7 15.2 25	13.3 10.4 53
880000	17.2 10.2 12	20.3 11.8 9	14.1 8.6 17	12.5 7.7 21	8.4 5.3 44

Table 7.— Selected results of the analysis (continued).

Station number	Standard error of instantaneous discharge, in percent; Equivalent Gaussian Spread, in percent; and number of visits per season				
	Budget, in thousands of 1983 dollars				
	Current operation	Optimized values			
	908.5	822	908.5	999	1363
880500	18.4	21.7	15.0	13.4	8.9
	10.1	11.6	8.5	7.7	5.3
	12	9	17	21	44
880800	12.1	12.8	9.6	8.6	5.6
	6.4	6.7	5.2	4.7	3.2
	12	11	18	22	49
881000	12.3	13.0	9.6	8.5	5.5
	3.6	3.8	2.9	2.7	1.8
	12	11	18	22	49
881200	19.5	20.5	15.4	13.8	9.0
	12.6	13.2	10.1	9.1	6.0
	12	11	18	22	49
881500	10.9	12.1	9.2	7.6	5.3
	6.8	7.5	5.9	4.9	3.5
	12	10	16	23	45
882000	15.5	16.9	13.8	12.1	9.9
	9.3	9.4	9.1	8.8	8.1
	12	10	16	23	45
883000	12.3	14.7	11.7	11.2	7.3
	5.8	6.7	5.5	5.3	3.6
	12	9	13	14	30
883570	15.9	14.6	15.2	11.8	7.9
	12.8	11.8	12.3	9.6	6.5
	12	14	13	21	45
883940	7.3	5.3	6.9	4.7	3.4
	4.6	3.4	4.3	3.1	2.3
	12	21	13	26	51
884000	14.4	19.9	13.7	12.2	7.5
	8.8	11.8	8.4	7.5	4.8
	12	7	13	16	39

Table 7.— Selected results of the analysis (continued).

Station number	Standard error of instantaneous discharge, in percent; Equivalent Gaussian Spread, in percent; and number of visits per season				
	Budget, in thousands of 1983 dollars				
	Current operation	Optimized values			
	908.5	822	908.5	999	1363
884025	9.3	11.1	9.3	9.3	6.0
	4.9	5.7	4.9	4.9	3.3
	12	9	12	12	26
average per station	12.3	15.5	11.0	9.0	6.1
	—	—	—	—	—
	—	—	—	—	—

Note: The average per station is the square root of the average station variance.

The current operating policy results in an average standard error of estimate of non-winter streamflow of about 12 percent. This policy is based on a budget of $908,500 to operate the 145-station stream-gaging program. For periods without missing record, the present standard error is slightly more than 8 percent. These figures are within about 1 percent of the optimum values of standard error for the present budget. Average standard errors could apparently be improved about 1 percentage point by altering the route schedules to more frequent visits to the sites where uncertainty is large and less frequent visits to sites where uncertainty is small.

A minimum budget of about $822,000 is required to operate the program; a budget of less than this does not permit proper service and maintenance of the gages and recorders, and optimal solutions could not be reached. Stations would have to be eliminated from the program if the budget was less than this minimum. At the minimum budget, the average standard error is about 16 percent, an increase of about 50 percent compared to the accuracy possible under the present budget.

The maximum budget analyzed was $1,363,000, an increase of about 50 percent compared to the present budget. This resulted in an average standard error of estimate of about 6 percent. Thus, a 50 percent increase in the budget would almost halve the optimum average standard error obtainable under the current budget.

For the minimal operational budget of $822,000, the impacts of lost record add about 7 percent to the average standard error. At present budget levels, missing record adds about 4 percentage points to the average standard error. With a budget of $1,363,000, stations would be visited more frequently, and missing record would add less than 2 percentage points to the average standard errors. Thus, improvements in equipment can have a very positive impact on uncertainties of instantaneous discharges.

Summary of Third Phase of Analysis

As a result of this phase of the analysis, the following conclusions can be made:

1. The travel routes and measurement frequencies now in use needs to be modified to decrease the per station average standard error with the present budget of $908,500. The average standard error can be decreased by about 1 percentage point.

2. Any decrease in budget would be accompanied by a decrease in stations; increases in the present average standard errors would be unacceptable.

3. Attempts need to be made to increase the operating budget by 10 percent. A 10-percent increase in budget combined with modification of travel routes and measurement frequency would decrease the average standard error to about 9 percent from the present value of about 12 percent.

4. Methods for decreasing the probabilities of missing record need to be explored; missing record presently increases the average standard error by about 4 percentage points or about 50 percent. These methods might include improved instrumentation and increased use of local observers and satellite relay of data.

SUMMARY

Currently, there are 145 continuous stream gages being operated in Nebraska at a cost of $908,500. Data from most stations have multiple uses. Present uses of the data require that operation of all gages be continued. Two stations are used primarily for research and short-term investigations. However, those stations are located in critical areas and will probably prove useful beyond the duration of the research projects.

The current policy for operation of the 145-station program requires a budget of $908,500 per year. The travel routes and measurement frequencies now in use can be modified to decrease the average standard error by 1 percentage point while maintaining the present budget. These modifications need to be made.

Any decrease in the current budget would be accompanied by discontinuing gaging stations because increasing the standard error is unacceptable. The minimum budget for which a solution could be obtained was $822,000, but that budget results in about a 50-percent increase in the presently attainable average standard error.

A major component of the error in streamflow records is caused by loss of record at the stream gages because of malfunctions of sensing and recording equipment. Upgrading of equipment and development of methods to minimize lost record appear to be key actions required to improve the reliability and accuracy of the streamflow data generated in the State.

Future studies of the stream-gaging program need to include investigation of the optimum ratio of discharge measurements to total site visits as well as investigation of cost-effective ways of decreasing the probabilities of lost record.

One station was identified for which streamflow records probably could be simulated based on an upstream station. However, that station, Niobrara River near Verdel, is currently used in forecasting and must be continued. If data uses for this station change so that simulated data are acceptable, alternative methods could be explored.

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SUPPLEMENTARY INFORMATION

The following description of the computations and mathematical relations, together with illustrations, is taken from Fontaine and others (1984, p. 22-26).

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 of a 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 lone 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 i^{th} 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 6 represents this step in the form of a mathematical program. Figure 7 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,

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

$V \equiv$ 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 6.--Mathematical-programing form of the optimization of the routing of hydrographers.

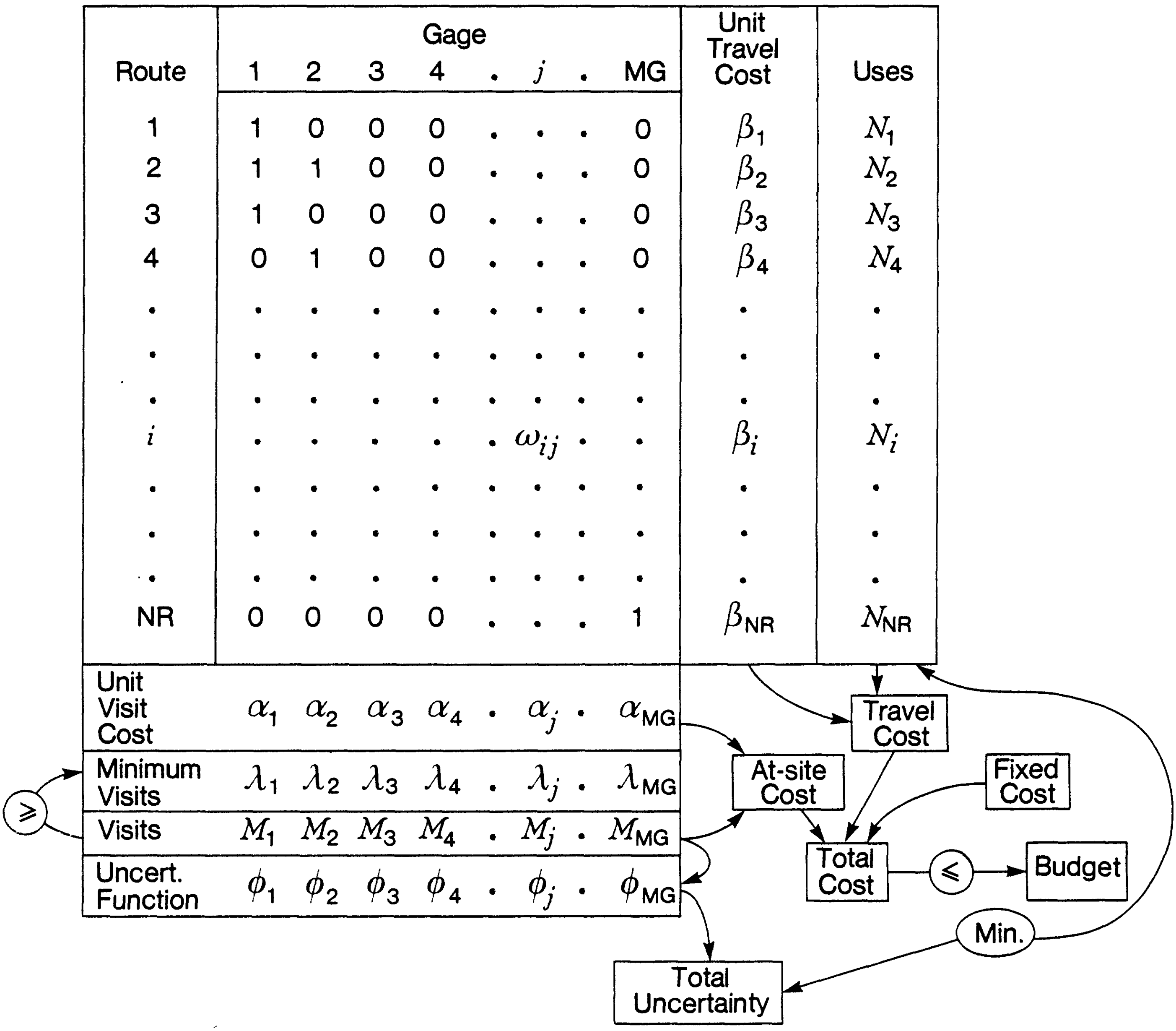

Figure 7.--Tabular form of the optimization of the routing of hydrographers.

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 $\underline{N} = (N_1, N_2, ..., N_{NR})$.

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.

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 cost of operating the network. The total cost of operating the network equals the sum of the travel costs, the at-site 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 $j = 1, 2, ..., MG$.

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 variance of the percentage errors of estimation of instantaneous discharges. This uncertainty is derived from three sources: (1) an error derived from uncertainties in the stage-discharge relationship (rating curve) or other functions that relate discharge to primary correlative data collected at the stream gage, (2) an error derived from reconstruction of streamflow records when the primary correlative data are missing, and (3) an error derived during periods when secondary data are not available to reconstruct streamflow records. The variances of the errors from these sources are weighted by the fractions of time that each can be expected to occur and combined to estimate the expected error variance, which is the dependent variable of an uncertainty function. This relation can be expressed:

$$V_T = \varepsilon_f V_f + \varepsilon_r V_r + \varepsilon_e V_e \qquad (3)$$

where

V_T is the expected total error variance,

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

V_f is the variance of the first error source described above,

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 variance of the second error source,

ε_e is the fraction of time that no data are available to compute streamflow records, and

V_e is the variance of the third error source.

The fractions of time that each source of error is relevant are functions of the frequencies at which the recording equipment are serviced. It is assumed that the primary and secondary sites are serviced at the same frequency and at about the same times.

The time, τ, since the last service visit until failure of the recorder or recorders at the primary site is assumed to have a probability distribution that is defined by the truncated negative exponential family, that is

$$f_\tau = ke^{-k\tau}/(1-e^{-ks}) \quad (4)$$

where

f_τ is the probability density of failure times,

k is a coefficient, and

e is the base of natural logarithms.

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

$$\varepsilon_f = 1 - E[d]/s \quad (5)$$

where

d is downtime of the primary recorders,

E[·] is the expected value of the random variable contained within the brackets, and

s is the interval between visits to the site.

E[d] is derivable from equation 4, as is shown in the Appendix.

The fraction of time, ε_e, that no records exist at either the primary or secondary sites also can be derived from a bivariate application of equation 4. It is assumed that the times to failure at the primary and secondary sites are independent of each other and that they both have identical probability density functions for failure times.

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

$$\varepsilon_r = 1 - \varepsilon_f - \varepsilon_e. \tag{6}$$

The 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 measured discharge and the rating curve discharge. The rating curve discharge is determined from a relationship between discharge and some correlative data, such as water-surface elevation for the gaging station. The measured discharge is the discharge determined by field observations of depths, widths, and velocities. The following variables are defined:

$$x_2(t) = \ln\left(q_T(t)\right) - \ln\left(q_R(t)\right), \tag{7}$$

where $x_2(t)$ is the instantaneous difference between the true discharge, $q_T(t)$, and the rating curve discharge $q_R(t)$. The variable $x_2(t)$ represents the true variability about the rating curve, but $x_2(t)$ is an unobservable random variable because $q_T(t)$ is unobservable. The residuals that are available to the analyst include measurement errors but also contain information about the structure of $x_2(t)$. These residuals, $z(t)$, are defined as:

$$z(t) = x_2(t) + v(t) = \ln\left(q_m(t)\right) - \ln\left(q_R(t)\right), \tag{8}$$

where

$v(t)$ is the measurement error, and

$q_m(t)$ is the measured discharge.

In the Kalman-filter analysis, the time series of $z(t)$ is analyzed to determine three site-specific parameters for each uncertainty function. The Kalman filter used in this study assumes that the difference $x_2(t)$ is a continuous first-order Markovian process that has an underlying Gaussian (normal) probability distribution with a zero mean and a variance (subsequently referred to as process variance) equal to $q/2\beta$. The variable q is the spectral density of the white noise that drives the Markovian process, and β is the reciprocal of the correlation time of the Markovian structure of $x_2(t)$. The 1-day autocorrelation coefficient, ρ, of $x_2(t)$ is a function of β. The variance of $z(t)$, α_z^2, is therefore defined as

$$\alpha_z^2 = q/2\beta + r \tag{9}$$

where r is the variance of the measurement error $v(t)$. The three parameters, q, β, and r, are computed by analyzing the statistical properties of the time series of residuals $z(t)$. 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 variance of the errors of estimation of discharge 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 also is no concurrent data at other sites that can be used to reconstruct the missing record at the primary site, there would be 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 error variance during periods of no concurrent data at nearby sites. 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 variation, C_v, squared is an estimate of the required error variance V_e. Because C_v varies seasonally and the times of failures cannot be anticipated, a seasonally averaged C_v is used:

$$C_v = 100\left(\frac{1}{365}\sum_{i=1}^{365}\left(\frac{\sigma_i}{\mu_i}\right)^2\right)^{1/2} \qquad (10)$$

where

σ_i is the square root of the variance of daily discharges for the i^{th} day of the year, and

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

The variance, V_r, of the 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 sites. The correlation coefficient, ρ_c, between the streamflows with seasonal trends removed (detrended) 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 ρ_c^2. Thus, the fraction of unexplained variance, that is the error in reconstructed records at the primary site, is $(1 - \rho_c^2)$. If the error variance is expressed in units of percentage squared, as is the case in this study, an estimate of the potential variance of streamflow for any day of the year is C_v^2 as was defined in the paragraph above. Thus, V_r can be estimated as $(1 - \rho_c^2)C_v^2$.

It is assumed in this study that the differences between the logarithms of the computed discharges and the true discharges at each instance are normally (Gaussian) distributed with a mean of zero and a variance of either V_f, V_r, or V_e depending on whether the at-site streamflow recorder was functioning (f), whether the record was reconstructed (r) from another primary source of data, or whether the record was estimated (e) without the aid of other concurrent data. Therefore, the resulting a priori distribution of errors is not normally distributed in terms of the logarithms of discharge data. This lack of normality causes difficulty in interpretation of the resulting errors of estimation, that is, the square root of the uncertainty contained in the streamflow record. If the logarithmic errors were normally distributed, approximately two-thirds of the time the true logarithmic error would be within the range defined by plus and minus one standard error from the mean. The lack of normality caused by the multiple sources of error increases the percentage of errors contained within this range above that of a Gaussian probability distribution of logarithmic errors with the same standard deviation.

To assist in interpreting the results of the analyses, a new parameter, equivalent Gaussian spread (EGS), is introduced. The parameter EGS specifies the range in terms of equal positive and negative logarithmic units from the mean that would encompass errors with the same a priori probability as would a Gaussian distribution with a standard deviation equal to EGS; in other words, the range from -1 EGS to +1 EGS contains about two-thirds of the errors. For Gaussian distributions of logarithmic errors, EGS and standard error are equivalent. EGS is reported herein in units of percentage and an approximate interpretation of EGS is, "Two-thirds of the errors in instantaneous streamflow data will be within plus or minus EGS percent of the reported value."