SUMMARY OF THE NATIONWIDE ANALYSIS OF THE COST EFFECTIVENESS OF THE U.S. GEOLOGICAL SURVEY STREAM-GAGING PROGRAM (1983-88)

By W.O. Thomas, Jr., and K.L. Wahl

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SUMMARY OF THE NATIONWIDE ANALYSIS OF THE COST EFFECTIVENESS OF THE U.S. GEOLOGICAL SURVEY STREAM-GAGING PROGRAM (1983-88)

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ABSTRACT

A nationwide analysis of the cost effectiveness of the U.S. Geological Survey stream-gaging program indicated that surface-water data collected in this program are used in a wide variety of applications. Uses of the data collected at a typical gaging station fall into an average of 2.6 different data-use categories. On the basis of an analysis of data uses, only about 2 percent of the stations operated nationwide were recommended for discontinuance in the near future. Of the 303 stations at which the alternative methods of flow routing and statistical techniques were applied, the simulated flows were within 10 percent of the observed daily flows at least 85 percent of the time at only 24 stations. Indications are that simulated flows generally are not accurate enough for most uses. On the basis of a sample of 13 States, about a 10 percent increase in stations is needed to improve the characterization of regional hydrology. Using the methodology summarized in this report, the operation of the nationwide stream-gaging program was shown to be cost effective in that (1) the standard error of the streamflow records could not be significantly reduced by changing operating practices, given the present (1983-88) budget and (2) the present budget could not be significantly reduced while maintaining the current level of accuracy of streamflow records.

INTRODUCTION

The U.S. Geological Survey (USGS) is the principal Federal agency collecting surface-water data in the United States. The data are collected in cooperation with about 1,000 State and local governments and other Federal agencies. The foundation of this stream-gaging program is the operation of about 7,000 continuous-record gaging stations for which daily mean discharges are computed, archived, and published. These data are stored in the USGS National Water Data Storage and Retrieval System (WATSTORE) and are published annually by State in Water Resources Data reports.

The USGS completed a nationwide analysis of their stream-gaging program during 1983-88. The objective of this study was to define and document the most cost-effective methods of furnishing streamflow information. The study involved three phases: (1) an analysis of the data uses and availability and documentation of the sources of funding for each streamflow station; (2) an evaluation of the utility of using less-costly alternative methods, such as hydrologic flow routing models and statistical methods, to provide the needed streamflow information; and (3) an analysis of the cost-effective operation of the stream-gaging program that relates the accuracy of the streamflow records to various operating budgets (Fontaine and others, 1984). A different number of streamflow stations was used in each phase of the analysis, but the areal extent of the overall study was nationwide. This report summarizes the results of the nationwide analysis.

The analyses conducted as part of this nationwide study were performed by hydrologists in District offices throughout the Water Resources Division, USGS. The reports describing the analyses for the individual States are listed in Appendix A. For some States, the data-use and cost-effective analyses were described in separate reports. Therefore, for some States, two reports are listed in Appendix A.

DATA-USE ANALYSIS

The first phase of the analysis was to identify the uses and availability of data collected in the stream-gaging program and to document the sources of funding for each streamflow station. The relevance or utility of a stream-gaging program is related to the uses of data collected in the program. The uses of data from the USGS stream-gaging program were determined through a survey of cooperators who were supporting the data-collection effort and other known users of the data. Several other organizations and individuals use data from the stream-gaging program but these uses cannot be easily documented. Two of the objectives of the data-use analysis were to categorize the uses of the data and to determine if the data uses justified the continued operation of all gaging stations.

Data Use Categories

The following definitions were used to categorize each known use of streamflow data for each daily-flow gaging station. As will be illustrated later, data uses for a given station may be included in more than one category. The nine categories and the definitions follow:

(1) Regional hydrology -- data largely unaffected by man-made storage or diversion and useful in developing regional relations between watershed and streamflow characteristics;

(2) Hydrologic systems -- used for accounting of water through hydrologic systems, including regulated systems, and for defining current hydrologic conditions;

(3) Legal obligations -- used to satisfy a legal responsibility of the USGS, such as treaties, compacts and decrees;

(4) Planning and design -- used for planning and designing of a specific project such as a reservoir, levee, water-treatment facility or hydropower plant;

(5) Project operation -- used on an ongoing basis to assist water managers in making operational decisions such as reservoir releases, hydropower operations or diversions;

(6) Hydrologic forecasts -- used to provide information for flood- and water-supply forecasting;

(7) Water-quality monitoring -- used for the interpretation of water-quality or sediment data;

(8) Research -- collected for a particular research or water-investigation study; and

(9) Other -- uses that do not fit into the eight categories above. These include, for example, recreational purposes such as providing data for canoeists, rafters and fishermen.

Uses of the Data

Moss and others (1985) and Scott and Moss (1986) previously published interim results for the nationwide stream-gaging program evaluation. Data uses were updated by Thomas and others (1990), Wahl and Condes (1990), and Wahl and others (1990). This report consolidates information from previous reports and provides the most complete summary to date of the data-use analysis. Table 1 summarizes the total number and percent of stations in each data-use category. Included in the tabulation are 6,238 of the approximately 7,000 stations operated by USGS during 1983-88.

Table 1.--Number of U.S. Geological Survey daily-discharge stations in each data-use category, 1983-88

Category of data use	Total stations number	Total stations percent
Regional Hydrology	3,227	51.7
Hydrologic Systems	3,572	57.1
Legal Obligations	238	3.8
Planning and Design	938	15.0
Project Operation	2,447	39.2
Hydrologic Forecasting	2,442	39.1
Water Quality	2,307	37.0
Research	603	9.7
Other	609	9.8
Total uses	16,383	
Total stations	6,238	
Average categories of data use per station	2.6	

As illustrated in table 1, data from more than 50 percent of the stations are used for regional-hydrology purposes and/or to define hydrologic systems. Both of these categories of use are important in attempting to address issues of national or regional scope. Data for 37-39 percent of stations are used for hydrologic forecasting, project operation and/or water-quality monitoring purposes. Data from 15 percent of the stations are used for planning and design of a specific water-resources project such as a reservoir or navigation system. The remaining three categories are each relevant to less than 10 percent of the total number of stations, but nevertheless are important. The percentage of daily-discharge stations in each data-use category, as given in table 1, is illustrated in figure 1. The number of daily-discharge stations in each data-use category for each state is given in Appendix B1.

Although stations are usually established for a specific reason, the data collected are useful for many purposes. The data in table 1 and figure 1 show that, on average, there are 2.6 categories of data use per station. These uses are for those agencies financially supporting the stream-gaging program and other known users of the data. It is not possible to easily determine data uses of other agencies not supporting the program.

The uses of data from about 20 percent of the stations analyzed fall into a single data-use category. The percentage of stations in a single data-use category is shown in table 2 and illustrated in figure 2. The greatest number of the stations in only a single data-use category fall into the regional-hydrology (34.4 percent) and the hydrologic-systems (30.2 percent) categories.

Table 2.--Number of U.S. Geological Survey daily-discharge stations in a single data-use category, 1983-88

Category of data use	Single-use stations number	Single-use stations percent
Regional Hydrology	430	34.4
Hydrologic Systems	378	30.2
Legal Obligations	6	0.5
Planning and Design	38	3.0
Project Operation	183	14.6
Hydrologic Forecasting	25	2.0
Water Quality	58	4.6
Research	85	6.8
Other	49	3.9
Total stations	1,252	100.0

Of the 1,252 stations in only a single data-use category, 60 stations were identified as not having sufficient justification to continue their operation. Most of these stations were in the regional-hydrology category. In addition, 69 stations operated for short-term special projects were recommended for discontinuance at the completion of the projects. Most of these stations were in the research category. The 129 stations that were suggested for discontinuance represent only about 2 percent of the 6,238 stations analyzed which indicates that the data collected in the USGS program are important for making water-resources decisions.

Except for single data-use category stations, the above data do not show the total number of use categories applicable to each station. That information is provided in the following table. As can be determined from table 3, 1,543 stations have four or more data-use categories. The percentage of stations falling into a specified number of data-use categories, as given in table 3, is illustrated in figure 3. The number of daily-discharge stations in each State falling into 1-8 data-use categories is given in Appendix B2.

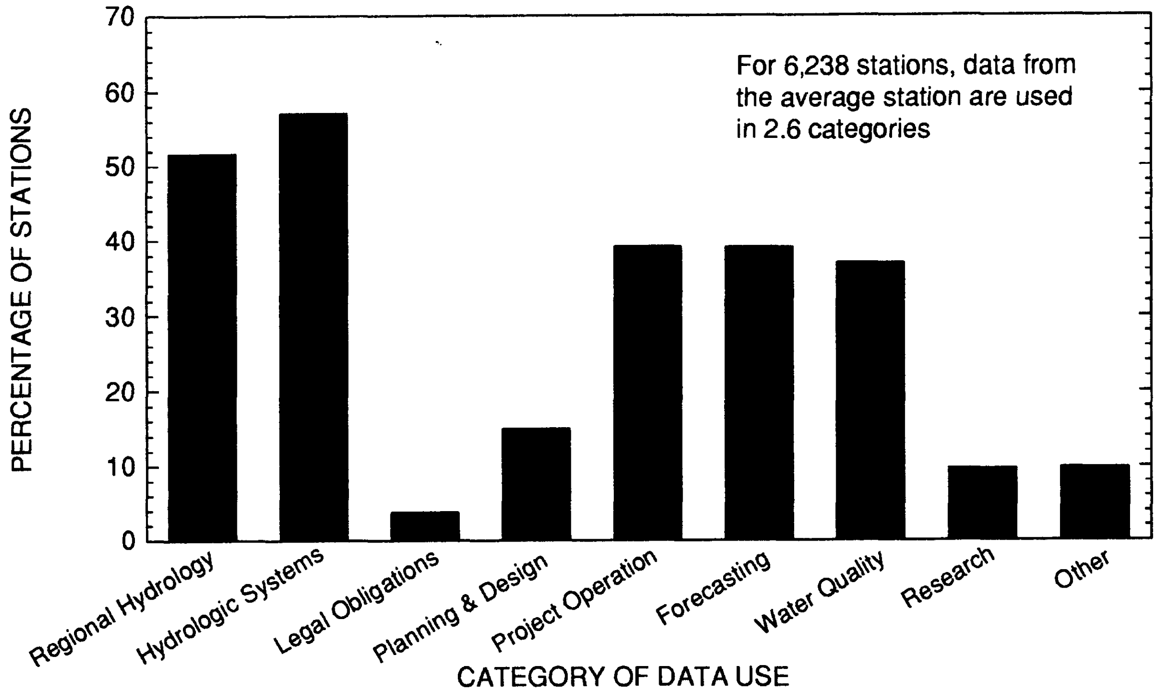

Figure 1. Distribution of U.S. Geological Survey daily-discharge stations by data-use category (from Wahl and Condes, 1990).

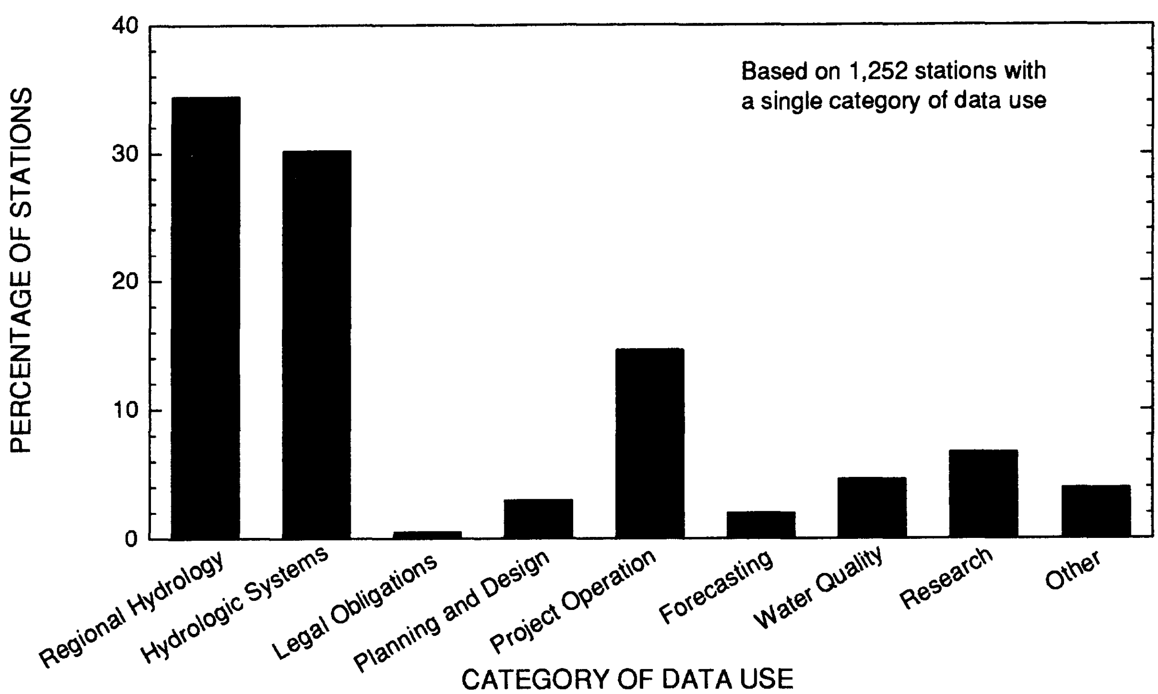

Figure 2. Distribution of U.S. Geological Survey single-purpose daily-discharge stations by data-use category (from Wahl and Condes, 1990).

Table 3.--Number and percentage of U.S. Geological Survey daily-discharge stations with the indicated number of data-use categories, 1983-88

Number of data-use categories	Number of stations	Percent of stations
1	1,252	20.07
2	1,857	29.77
3	1,586	25.43
4	977	15.66
5	422	6.77
6	120	1.92
7	22	0.35
8	2	0.03
Total	6,238	100.00

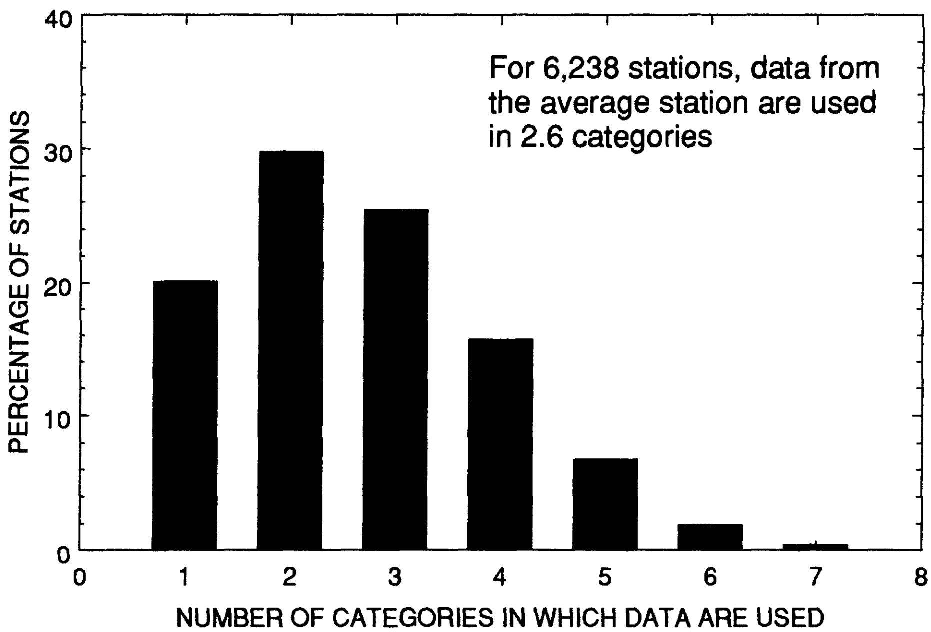

Figure 3. Distribution of U.S. Geological Survey daily-discharge stations as a function of the number of data-use categories (from Wahl and Condes, 1990).

Another objective of the data-use analysis was to relate the data uses to the agency or agencies funding the stream-gaging program. Approximately 1,000 State, Federal and local agencies fund the USGS stream-gaging program. The sources of funding can be classified into four categories:

Federal - funds that have been directly allocated to the USGS,
Other Federal Agency (OFA) - funds that have been transferred to the USGS by OFAs,
Cooperative (COOP) - funds that come jointly from USGS cooperative-designated funding and from a non-federal agency or a private concern under the auspices of a Federal agency,
Other non-federal - funds that are provided entirely by a non-federal agency or a private concern under the auspices of a Federal agency.

For the 6,238 stations included in the data-use analysis, 11.8 percent were supported by Federal funding, 31.5 percent were supported by OFA funding, 63.2 percent were supported by COOP funding and less then 1 percent were supported entirely by non-federal funding. Because a given station may have more than one source of funding, the percentages given earlier do not add up to 100 percent.

EVALUATION OF ALTERNATIVE METHODS

The second phase of the analysis was to evaluate alternative methods to stream gaging, such as hydrologic flow-routing and statistical methods, for providing the needed streamflow information. The hydrologic flow-routing and statistical methods used in the analysis were described by Fontaine and others (1984) and will not be described here.

Candidate stream-gaging stations for the alternative-methods analysis were generally pairs of stations on large streams with minimal tributary inflow in the reach between stations, or stations on streams in adjacent watersheds having similar watershed and climatic characteristics. For the hydrologic flow-routing method, the objective was to route daily discharges from an upstream site to a downstream site and compare the routed flows with the observed flows. In the statistical approach, daily discharges were estimated for one station on the basis of daily discharges at nearby sites. The statistical methods utilized either multiple-regression techniques or the MOVE.1 technique as described by Hirsch (1982).

The alternative methods of obtaining streamflow information--hydrologic flow routing and/or statistical analysis--were applied at 303 streamflow stations in 41 States (State of Hawaii includes the Pacific Trust Territories) and Puerto Rico. The objective was to evaluate if these alternative methods can provide streamflow records of sufficient accuracy. Of course, the desired accuracy of the data is a function of the intended usage and is often difficult or impossible to determine. Some reasonable guidelines are selected in this report for evaluating the results of the alternative-method analysis. The alternative-methods analyses are described in greater detail in the State reports listed in Appendix A. The results of the alternative-methods analysis for each State and Puerto Rico are summarized in Appendix C.

For the 303 stations used in this phase of the study, flow-routing methods were applied at 106 stations, statistical methods were applied at 261 stations and both methods were applied at 64 stations. A streamflow record at a USGS gaging station is rated good when the daily discharges are within 10 percent of their true values 95 percent of the time. Therefore, as a comparison of the results from the alternative-methods analysis to this criterion, the percent of time and number of stations for which the daily flows are within 10 percent of the observed streamflow are summarized below.

Percent of time daily discharges are within 10 percent of observed values	Number of stations
≥ 75	42
≥ 85	23
≥ 95	1

The required accuracy and the uses of the simulated daily discharges obviously will determine if the flow-routing and/or statistical methods are suitable alternatives to operating a continuous-record gaging station. If the criterion is to have a simulated record equivalent to a "good" streamflow record, then the simulated flows are suitable at one station out of the 303 stations in the analysis. However, if having at least 85 percent of the flows within 10 percent was sufficient for the intended usage, then the simulated data at 24 stations are suitable.

In general, the simulated flows were judged not to be of sufficient accuracy for the intended usage. In all States studied, analysts using their own criteria determined that simulated daily discharge for only six stations were of sufficient accuracy for the intended usage. Even though the alternative methods were generally not accurate enough to simulate entire years of daily-discharge record, these methods should be of some utility for estimating daily-discharge records during periods of missing record.

The objectives of the alternative-methods analysis were to evaluate deficiencies or gaps in the stream-gaging program as well as redundancy of data collection. On the basis of previous regional studies, and the geographic distribution and watershed characteristics of the existing stations, many analysts recommended the establishment of additional stations in their State to characterize regional hydrology. A quick review of the State cost-effectiveness reports listed in Appendix A indicated that analysts in 13 States recommended the establishment of 119 new stations, about a 10 percent increase in the programs in those 13 States. Analysts in other States pointed out the need for new gaging stations in certain areas but did not recommend a specific number. Therefore, the need for new stations to characterize regional hydrology far outnumbers the number of stations where alternative methods could be reasonably applied.

COST-EFFECTIVENESS ANALYSIS

The objective of the cost-effectiveness analysis was to identify stream-gaging strategies that would minimize the sum of error variances of instantaneous discharge for all stations in the program under various operating budgets. This analysis was undertaken in two major steps. First, uncertainty functions relating the variance (in percent squared) of instantaneous discharge to the number of visits/discharge measurements per year were developed for all stations whose operation was to be continued. These uncertainty functions were then used in a mathematical program, called the Traveling Hydrographer, to determine the number of annual visits/discharge measurements needed at each station to minimize the sum of the variances across all stations in the program given the operating budget. A brief description is given herein of the uncertainty functions and the Traveling Hydrographer program. Additional details on the program are available in reports by Moss and Gilroy (1980) and Fontaine and others (1984).

Uncertainty Functions

As noted earlier, uncertainty in streamflow records is measured in this study as the average relative variance of the estimation of instantaneous discharge. The accuracy of a streamflow estimate depends on how that estimate was obtained. Three situations are considered in this study: (1) streamflow is determined from measured discharge and correlative stage data (primary data) using a stage-discharge relation, variance defined as V_f, (2) streamflow is reconstructed using data from nearby stations (secondary data) because primary correlative data (such as stage) are missing, variance defined as V_r, and (3) primary and secondary data are unavailable for estimating streamflow, variance defined as V_e. The average relative variance (V) is estimated as

$$V = \varepsilon_f V_f + \varepsilon_r V_r + \varepsilon_e V_e, \qquad (1)$$

where $\varepsilon_f + \varepsilon_r + \varepsilon_e = 1$ and ε_f, ε_r and ε_e, are respectively the fractions of time that the primary recorders are functioning, that secondary data are available from nearby stations and that primary and secondary data are unavailable.

The fraction of time that each source of error is relevant is a function of both the frequency at which the water-stage recorders are serviced and the reliability of the equipment. The values of ε_r and ε_e are generally much smaller than ε_f.

The values of ε_r, ε_e and ε_f are evaluated in the following manner. The time τ since the last service visit until failure of the stage recorder or recorders at the site is assumed to have a negative-exponential probability distribution truncated at the next service time; the distribution's probability density function is

$$f(\tau) = ke^{-k\tau}/(1-e^{-ks}), \qquad (2)$$

where

k is the average time to failure in units of $(\text{day})^{-1}$,
e is the base of natural logarithms, and
s is the interval between visits to the site in days.

It is assumed that, if a recorder fails, it continues to malfunction until the next service visit. Thus the fraction of time, ε_f, that the recorder can be expected to operate properly is

$$\varepsilon_f = 1\text{-}E[d]/s, \tag{3}$$

where E [.] is the expected value of the random variable contained in the brackets and d is the down time of the recorder between visits. Downtime is defined as

$$\begin{aligned} d &= s\text{-}\tau \text{ if a failure occurs,} \\ d &= 0 \text{ if no failure occurs,} \end{aligned} \tag{4}$$

as is shown in figure 4. The expected value of the down time, E[d], can be evaluated using equation 2 yielding the following equation

$$E[d] = (ks + e^{-ks} - 1)/k. \tag{5}$$

Substituting equation 5 into equation 3 and simplifying results in

$$\varepsilon_f = (1\text{-}e^{-ks})/ks. \tag{6}$$

In application 1/k, the average time to failure is determined from equation 6 by substituting values for s, the service interval, and ε_f, the fraction of time the recorder is working. The values of s and ε_f are determined from a known visitation frequency by analyzing the lost stage record. Once k is determined for given values of s and ε_f, then ε_f can be determined for any desired visitation frequency.

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

$$\varepsilon_e = 1 - [2(1\text{-}e^{-ks}) + 0.5(1\text{-}e^{-2ks})]/(ks). \tag{7}$$

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

$$\varepsilon_r = 1 - \varepsilon_f - \varepsilon_e = [(1\text{-}e^{-ks}) + 0.5(1\text{-}e^{-2ks})]/ks. \tag{8}$$

The relative variance, V_f, of the errors when the primary recorder is functioning is determined by Kalman-filtering theory by analyzing a time-series of differences (residuals) between the logarithm of measured discharge and the logarithm of discharge from the stage-discharge relation. The time-series of residuals is assumed to be a first-order Markovian process that has an underlying Gaussian (normal) distribution (Moss and Gilroy, 1980).

The relative variance, V_r, of errors during periods of reconstructed streamflow records is estimated on the basis of correlation between daily mean discharges at the site of interest and nearby sites.

τ = Time to failure
s = Service interval
d = Down time (missing stage record)
$d = s - \tau$
δ_n = Time of visit n

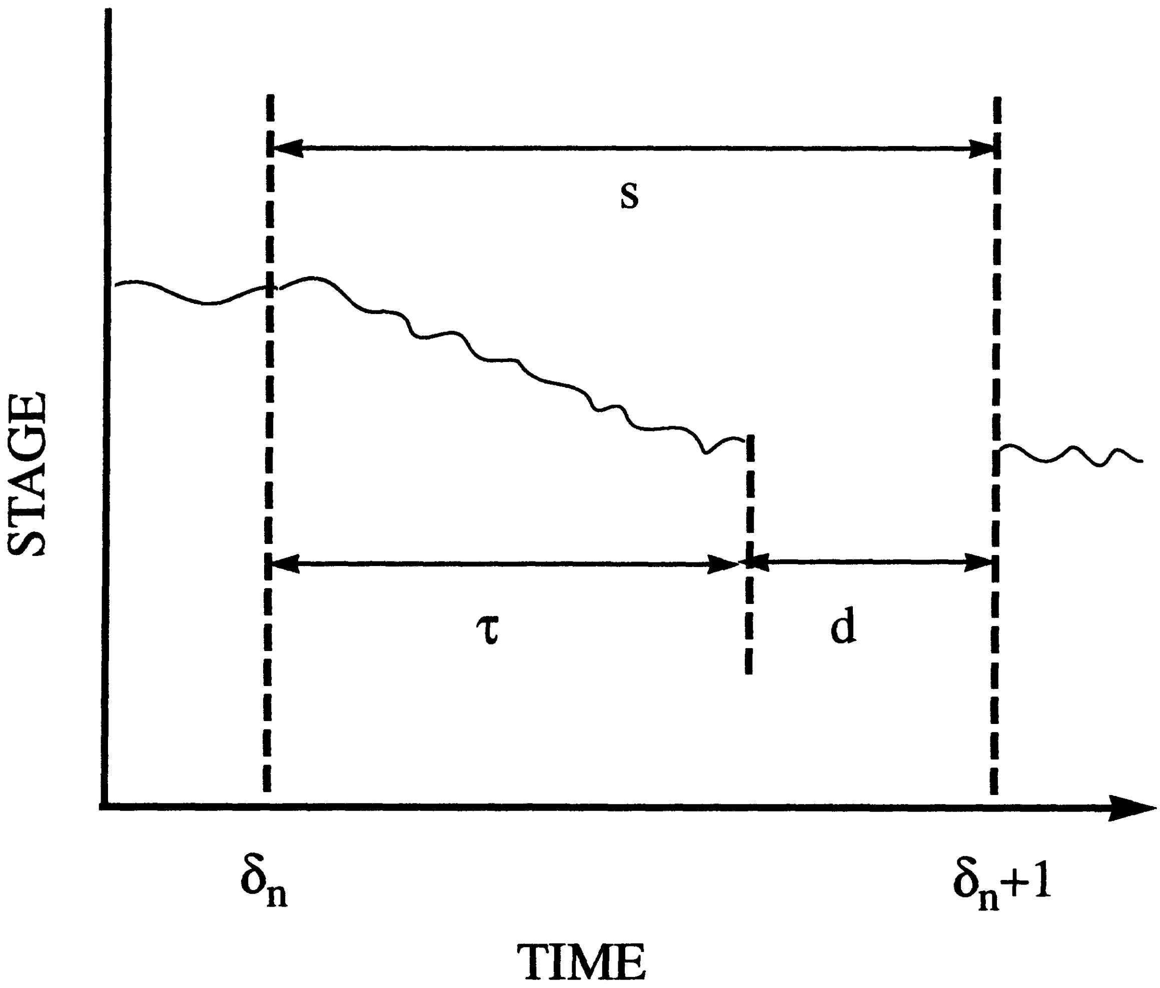

Figure 4.--Definition of down time for a single station.

The relative variance, V_e, of errors during periods when neither primary or secondary data are available is estimated from the variance of the mean value of discharge over the period of record. The variance of the mean value of discharge is estimated as the square of average coefficient of variation of historical daily mean discharges at the site of interest. This estimate of variance of the mean discharge may be high relative to the variance associated with discharge estimates based on recession hydrographs, climatic records, observer notes, etc. Provisions were provided in the cost-effective programs for overriding the effect of V_e by always estimating the variance of reconstructed records by correlation with one or more nearby stations or from other data sources.

Because errors in streamflow estimates are the result of three different sources with widely varying precisions, the resultant distribution may differ significantly from a normal or lognormal distribution. The resulting average estimation variance (V) cannot be interpreted as a measure of a given proportion of errors as in the case of the normal distribution. When primary and secondary data are unavailable, the relative error variance V_e may be very large. This could yield correspondingly large values of V in equation 1 even if the probability e_e is quite small. Many analysts chose not to use V_e directly but to always estimate the variance of reconstructed records with correlation with nearby stations or other data sources.

A new parameter, the equivalent Gaussian spread (EGS), was introduced to assist in interpreting the results of the analyses. The value of EGS was determined so that approximately two thirds of the errors in instantaneous discharge will be within plus or minus EGS percent of the reported values (Fontaine and others, 1984).

The Traveling Hydrographer Program

The Traveling Hydrographer Program attempts to allocate among gaging stations a predefined budget for the collection of stream-flow data in such a manner that the field operation is the most cost effective possible. The set of decisions available to the analyst is the frequency of use (number of times per year) of each of a number of routes that may be used to service the gaging stations and to make discharge measurements. A route is defined for a set of one or more stations as the path that takes the hydrographer from his/her base of operations to each station and back to base. A route will have associated with it an average cost of travel and average cost of servicing each station along the way.

Special requirements for visits to each station must be defined to meet requirements for periodic maintenance, servicing the recording equipment, or periodic sampling of water quality. Such special requirements are considered to be inviolable constraints in terms of the minimum number of visits to each station. Routes must be established to recognize these constraints.

The Traveling Hydrographer Program is used to determine the number of times that the routes are used during a year such that (1) the budget for the program is not exceeded, (2) the minimum number of visits to each station is made, and (3) the total uncertainty in the network is minimized.

Cost-Effective Resource Allocation

The combination of the Kalman-filtering techniques (Moss and Gilroy, 1980) and the Traveling Hydrographer Program constitute a set of techniques called Kalman filtering for Cost-Effective Resource Allocation (K-CERA). The K-CERA analysis was completed for 3,857 stations in 41 States and Puerto Rico. However, uncertainty functions were developed for only 3,436 stations. Uncertainty functions could not be developed for the remaining 421 stations because of the lack of discharge measurements and the inappropriateness of the assumption that the errors (residuals) in the instantaneous discharge followed a first-order Markovian process.

In general, current (1983-88) operating procedures imply that on average of 8-9 visits per year are made to each gaging station. For the 3,436 stations analyzed, the temporal average standard error per station (TASEPS) for current operating procedures for the statewide stream-gaging programs evaluated, varied from about 10 to 36 percent with a weighted TASEPS of 20.9 percent. The total budget for the 41 States and Puerto Rico under current (1983-88) operating procedures was $21,984,100. By altering field activities (visiting sites with high uncertainty more frequently and sites with low uncertainty less frequently), the weighted TASEPS can be reduced to 18.8 percent. Conversely, the current weighted average standard error of 20.9 percent could have been achieved with a reduced budget of $21,028,600, a reduction in total budget of $955,500 (about a 4 percent reduction). The conclusion from this phase of the analysis was that the current operation of the USGS stream-gaging program was cost effective.

Equivalent Gaussian Spread (EGS) values were only computed for 23 States representing 1,751 stations of the 3,436 stations for which uncertainty functions were defined. These EGS values ranged from 4.2 to 16.5 percent for the various Statewide programs with a median value of 8.5 percent. Assuming these 23 States are representative of all stations used in the uncertainty analysis, this implies that two thirds of the time the error in estimating the instantaneous discharge is on the order of plus or minus 8.5 percent. The 1,751 stations appear to be representative since the weighted average standard error for those stations (20.9 percent) is the same as that for all stations analyzed. The cost-effectiveness analysis is summarized by State in Appendix D.

Analysis of Lost-Stage Record

The standard errors and EGS values reported above are influenced by the amount of missing or lost stage record per year. In general, the missing stage record varied from 2-12 percent for the various statewide programs with a nationwide average of about 5 percent (18 days per year). Generally, for the nationwide analysis, the percentage of lost-stage record was not varied according to the type of equipment at the site. An analysis of the amount of lost-stage record was performed for 1,100 gaging stations in 13 States in the Central Region of the Water Resources Division (WRD), USGS by K. L. Wahl and R. R. Shields (written commun., 1989) and is summarized in Figure 5 to illustrate the sources or causes of lost-stage records.

Some WRD offices maintain detailed and systematic records of the cause and amount of lost-stage record, whereas others have records covering only broad categories. For offices without systematic records of lost stage record, the amount of loss due to individual causes was taken from station analyses written for individual stations each year. The accuracy of the breakdown of the total amount of lost record into various categories depends, therefore, on the degree of definition given in the station analyses. Lost-stage record was assigned to the eight categories described below:

Sensor--Sensor failure includes all losses due to problems with orifice lines or well-intake systems. Such problems include silted, frozen, or broken orifice lines and intakes that are silted, frozen, broken or isolated from the channel.

Manometer--Manometer malfunctions include all associated equipment except batteries and orifice lines; gas leaks are included in this category.

Power--Power failure includes batteries for timers, manometers, and recorders.

Recorder--Recorder failure includes both digital and graphic recorders.

Timer--Timer failure includes both digital and graphic recorder timers.

Vandalism--Includes all losses associated with vandalism.

Oversight--Includes factors that can be generally attributed to human error, such as leaving a graphic-recorder pen off the chart, a timer unplugged, intake valves closed, or permitting the strip chart or tape to run out.

Other--Includes anything not covered in the other seven categories. Such things as mice chewing into wiring of recorder timers might be listed here.

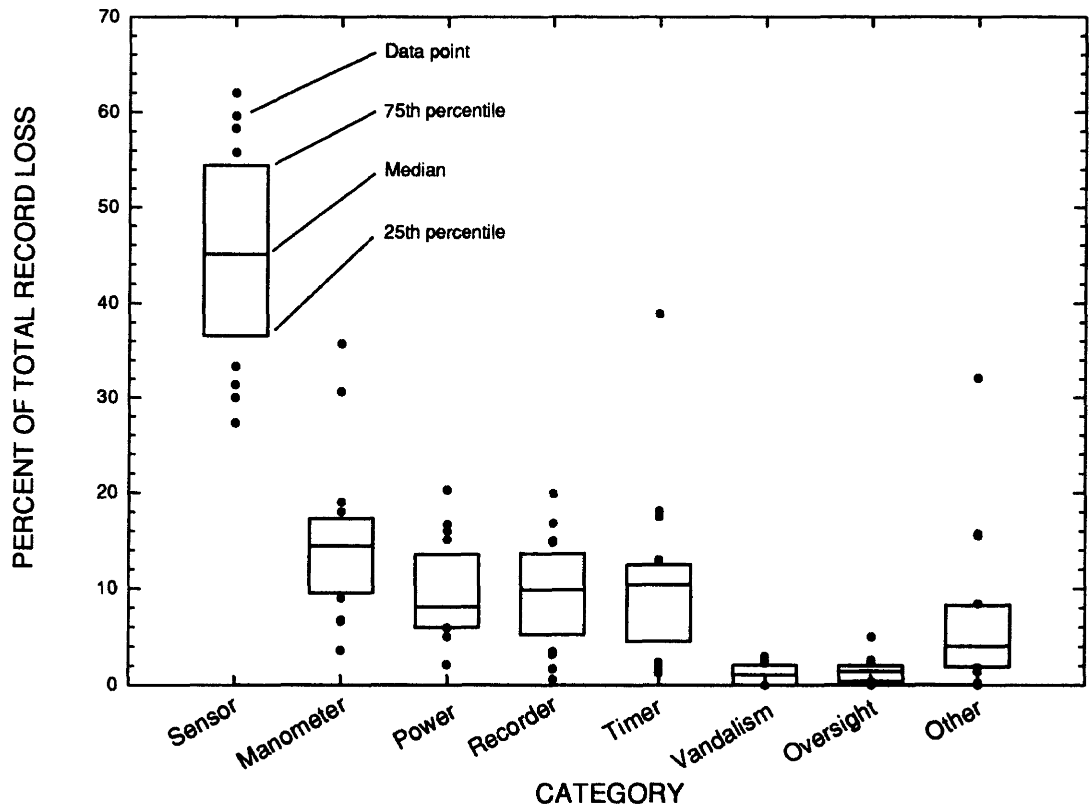

Figure 5. Causes of net lost stream-gaging record in the Central Region of the Water Resources Division, U.S. Geological Survey. [Boxes show the quartile range; data points outside the quartile ranges are plotted.]

The data included in the study of lost record represent more than 5,700 station-years of record from about 1,100 streamflow stations in the WRD's 13-state Central Region. The data generally are not identified by an individual State because comparisons between individual States may be misleading. Sample sizes, periods of record examined, frequency of site visitation, and progress in updating equipment all influence the statistics. Median values of the percentage of net lost record for the various categories can be used, however, for comparisons between categories. Two States, Kansas and Wyoming, provided data on two distinct time periods. These data were entered separately, so medians are based on 15 data points.

The average annual record loss ranged from 3 to 12 percent of the total record for the 13 Districts in WRD's Central Region and averaged 5.7 percent, about 21 days per station per year. By far the most frequent cause of lost stage record is from problems with sensors. The next most frequent cause of lost record is malfunctioning of the manometer or associated equipment. The sum of the median amounts of loss from these two sources is almost 60 percent of the total loss.

Timer failure, shown in Figure 5 as causing 10 percent of the record loss, is currently (1993) not a major problem. An updated solid-state timer was adopted by the WRD in 1983. Introduction of that timer produced a dramatic decrease in timer-related lost record as shown by the Kansas data in Figure 6 (data provided by R. K. Livingston, U.S. Geological Survey, written commun., 1983). Data collected in Oklahoma confirm the dramatic reduction in timer-related record loss. Much of the data for the timer category of Figure 5 predates the introduction of the improved timer.

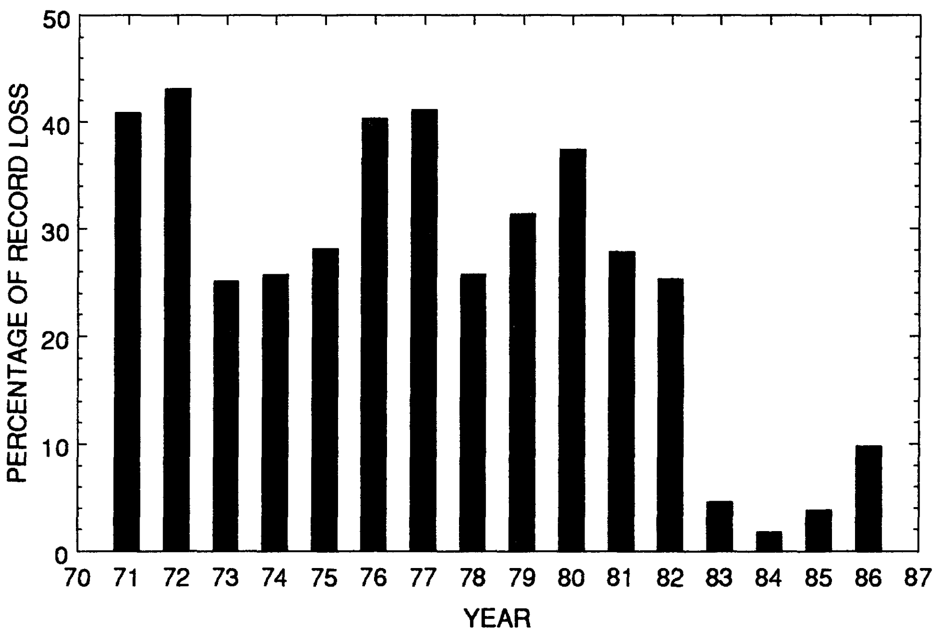

Figure 6. Timer-caused loss of stream-gaging record in Kansas (modified by K.L. Wahl and R.R. Shields, U.S. Geological Survey, written commun., 1989, from data reported by R.K. Livingston, U.S. Geological Survey, written commun., 1983)

Net lost record percentages were generally largest in States that experience relatively large amounts of snow and ice. Colorado and Wyoming reported that record loss for the winter period was two to three times as great as record loss for the rest of the year.

Keeping records of the causes and amounts of lost stage record is useful in attempting to improve data collection activities. Such records allow accurate appraisals of the consequences of changes in equipment and operation. As illustrated in Figure 5, significant reductions in stage record loss can be achieved through improvements in sensors and manometers.

To evaluate the effects of missing stage record on the overall accuracy of the streamflow records, some analysts developed uncertainty functions and ran the Traveling Hydrographer Program under the assumption that the instrumentation gave a complete stage record throughout the year. Results computed for conditions with and without missing record were compared. For current (1983-88) operating procedures, an analysis of 29 different studies indicated that about one third of the weighted average standard error was attributed to errors that occurred during periods of missing stage record. If it is assumed that this is representative of all States in the cost-effective analysis, then the weighted average standard error would be reduced from 20.9 to 13.7 percent by assuming no missing record. Nearly all analysts recognized that a major portion of the total standard error was due to missing stage record and they suggested that satellite data relay, landline telemetry and/or observers be utilized to reduce missing record.

SUMMARY AND CONCLUSIONS

The data-use analysis documented that many uses are being made of data collected in the USGS stream-gaging program with data uses falling into an average of 2.6 data-use categories per gaging station. Only about 2 percent of the stations were recommended for discontinuance in the near future based on analysis of data uses.

Of the 303 stations at which flow routing and/or statistical techniques were applied, there was only 24 stations where simulated flows were within 10 percent of the observed daily flow, at least 85 percent of the time. Indications are that simulated flows are not generally of sufficient accuracy for most uses. Based on a sample of 13 States, a 10 percent increase is needed in the number of unregulated stations to improve the characterization of regional hydrology.

The cost-effective analysis demonstrated that (1) the accuracy of streamflow records could not be significantly improved by changing operating practices given the budget then in use because altering field activities results in a reduction in weighted average standard error from 20.9 to 18.8 percent, and (2) significant budget reductions could not be gained while maintaining the pre-existing level of accuracy ($955,500 reduction in budget or about 4 percent of the total budget).

In addition to demonstrating that the USGS stream-gaging program is cost effective, other benefits have accrued from the analysis. The cost-effectiveness techniques have provided an objective way to compare the relative accuracy of streamflow records at several locations as a function of the number of visits to the station. Managers of the stream-gaging program are now more aware of the relative accuracy of streamflow records and the factors contributing to this accuracy. The amount of missing-stage record has been shown to be the largest contributing factor, and an objective method is now available for evaluating this factor. The use of telemetry at a large percentage of USGS stream-gaging stations should contribute to a reduction in missing-stage record and result in more accurate streamflow records.

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APPENDIX A.--Reference list of U.S. Geological Survey reports on cost-effectiveness of stream-gaging program and data-use analysis reports.

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Alaska:

Lamke, R.D., 1984, Cost-effectiveness of the stream-gaging program in Alaska: U.S. Geological Survey Water-Resources Investigations Report 84-4096, 100 p.

Arkansas:

Darling, M.E., and Lamb, T.E., 1984, Cost-effectiveness of the U.S. Geological Survey stream-gaging program in Arkansas: U.S. Geological Survey Water-Resources Investigations Report 84-4084, 62 p.

California (Northeastern):

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Colorado:

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Connecticut:

Shepard, T.B., and Weiss, L.A., 1988, Cost-effectiveness of the U.S. Geological Survey's stream-gaging program in Connecticut: U.S. Geological Survey Water-Resources Investigations Report 85-4333, 63 p.

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Hawaii:

Matsuoka, I., Lee, R., and Thomas, W.O., Jr., 1985, Cost-effectiveness of the stream-gaging program in the Hawaii District: U.S. Geological Survey Water-Resources Investigations Report 84-4126, 76 p.

Idaho:

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Illinois:

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Indiana:

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Kansas:

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Kentucky:

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Louisiana:

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Minnesota:

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Montana:

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Nebraska:

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Nevada:

Arteaga, F.E., 1990, Cost effectiveness of the stream-gaging program in Nevada: U.S. Geological Survey Water-Resources Investigations Report 87-4213, 68 p.

New Hampshire/Vermont:

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Appendix B1.--Summary, by State, of the number of U.S. Geological Survey streamflow stations in each data-use category.

	DATA USES											
STATE	RH	HS	LO	PD	PO	HF	WQ	Res	Other	Total Uses	Total Stations	Average Uses
AK	91	40	0	36	7	21	38	17	4	254	110	2.31
AL	27	52	0	5	12	21	16	5	0	138	72	1.92
AR	34	29	1	4	34	11	23	0	1	137	49	2.80
AZ	75	30	3	51	60	52	21	3	36	331	99	3.34
CA.N	30	73	0	15	49	24	19	9	2	221	127	1.74
CO	33	213	44	3	35	19	102	92	1	542	352	1.5
CT	22	33	0	10	25	17	30	1	20	158	60	2.63
DC	0	1	0	0	0	1	1	0	1	4	1	4.00
DE	12	12	0	0	1	5	11	0	12	53	12	4.42
FL.JAC	15	17	0	1	1	1	2	0	0	37	20	1.85
FL.MIA	0	4	9	0	0	1	4	0	44	62	46	1.35
FL.ORL	81	86	0	27	21	1	23	0	0	239	94	2.54
FL.TAL	41	45	3	1	2	11	22	1	0	126	47	2.68
FL.TAM	49	56	0	1	8	17	44	0	6	181	57	3.18
GA	64	51	0	11	34	31	36	1	0	228	98	2.33
HI	56	65	0	1	0	0	7	0	5	134	124	1.08
IA	64	46	0	0	91	74	16	6	0	297	122	2.4
ID	85	108	3	43	84	76	49	13	14	475	156	3.04
IL	88	87	0	37	17	52	96	90	0	467	138	3.38
IN	121	45	16	46	73	108	66	3	4	482	173	2.79
KS	73	88	5	2	92	114	115	0	0	489	140	3.5
KY	50	65	0	1	48	43	18	1	0	226	97	2.33
LA	34	5	2	16	20	9	22	5	0	113	68	1.66
MA	15	55	0	5	23	9	22	10	1	140	76	1.84
MD	63	63	0	0	25	18	80	18	44	311	86	3.62
ME	28	24	0	0	18	26	6	8	5	107	51	2.10
MI	109	52	0	0	55	25	11	5	11	268	129	2.08
MN	65	11	5	26	49	44	18	4	0	222	96	2.31
MO	59	91	0	31	60	70	46	0	0	357	100	3.6
MS	53	9	0	13	25	32	6	0	0	138	62	2.23
MT	75	206	20	26	74	90	79	85	47	702	218	3.2
NC	115	29	0	12	37	25	101	20	0	339	146	2.32
ND	40	78	6	11	55	53	93	5	26	367	94	3.9
NE	64	122	14	15	120	87	41	3	4	470	145	3.2
NH-VT	35	13	0	0	34	28	3	7	3	123	73	1.68
NJ	87	29	3	7	37	33	41	10	2	249	101	2.47
NM	77	117	36	2	35	12	54	4	0	337	143	2.4
NV	48	6	0	0	59	11	14	16	2	156	81	1.93
NY	83	161	0	9	93	99	52	12	0	509	174	2.93
OH	82	50	12	58	83	110	52	10	67	524	127	4.13
OK	45	91	11	6	51	51	41	1	1	298	123	2.4
OR	114	1	0	0	157	121	73	0	65	531	231	2.30
PA	145	27	3	4	67	61	142	8	14	471	221	2.13
PR	44	14	0	29	0	5	30	9	0	131	50	2.62
RI	5	5	0	7	1	2	10	5	0	35	15	2.33
SC	32	48	0	13	38	9	18	2	0	160	76	2.11
SD	73	103	1	64	54	90	37	47	0	469	106	4.4
TN	60	34	0	14	30	18	21	2	8	187	88	2.13
TX	170	427	0	76	140	357	171	20	6	1367	391	3.5
UT	17	193	31	88	106	69	41	10	3	558	214	2.6
VA	59	69	0	1	38	38	70	2	72	349	75	4.65
WA	66	29	4	32	37	51	57	33	62	371	182	2.04
WI	63	22	0	7	11	31	9	0	0	143	89	1.61
WV	9	15	1	7	36	20	42	0	16	146	74	1.97
WY	82	127	5	64	85	38	45	0	0	446	139	3.2
TOTAL	3227	3572	238	938	2447	2442	2307	603	609	16383	6238	2.6
PERCENT	51.7	57.1	3.8	15.0	39.2	39.1	37.0	9.7	9.8			

CA.N - NORTHERN CALIFORNIA
FL.JAC - JACKSONVILLE SUBDISTRICT AREA IN FLORIDA
FL.MIA - MIAMI SUBDISTRICT AREA IN FLORIDA
FL.ORL - ORLANDO SUBDISTRICT AREA IN FLORIDA
FL.TAL - TALLAHASSEE SUBDISTRICT AREA IN FLORIDA
FL.TAM - TAMPA SUBDISTRICT AREA IN FLORIDA

Appendix B2.--Summary, by State, of the number of U.S. Geological Survey streamflow stations with data uses in given number of data-use categories.

STATE	1	2	3	4	5	6	7	8	Total Stations
AK	16	56	26	9	3	0	0	0	110
AL	21	37	13	1	0	0	0	0	72
AR	2	16	22	8	1	0	0	0	49
AZ	12	20	25	20	12	7	3	0	99
CA.N	64	41	16	6	0	0	0	0	127
CO	195	130	23	3	1	0	0	0	352
CT	18	14	14	8	4	2	0	0	60
DC	0	0	0	1	0	0	0	0	1
DE	0	0	1	6	4	1	0	0	12
FL.JAC	5	14	0	1	0	0	0	0	20
FL.MIA	37	6	1	2	0	0	0	0	46
FL.ORL	6	45	31	12	0	0	0	0	94
FL.TAL	4	19	16	6	0	2	0	0	47
FL.TAM	0	11	27	17	2	0	0	0	57
GA	28	31	20	17	2	0	0	0	98
HI	114	9	1	0	0	0	0	0	124
IA	27	41	23	30	1	0	0	0	122
ID	11	36	34	37	30	6	2	0	156
IL	10	17	49	39	18	5	0	0	138
IN	25	58	41	38	8	3	0	0	173
KS	3	25	39	46	27	0	0	0	140
KY	27	29	29	10	2	0	0	0	97
LA	29	33	6	0	0	0	0	0	68
MA	27	31	14	4	0	0	0	0	76
MD	4	18	23	20	15	5	1	0	86
ME	12	20	13	5	1	0	0	0	51
MI	32	59	32	6	0	0	0	0	129
MN	24	26	27	10	6	2	1	0	96
MO	10	6	37	20	19	8	0	0	100
MS	12	25	9	16	0	0	0	0	62
MT	10	59	66	49	24	8	2	0	218
NC	19	67	48	10	2	0	0	0	146
ND	0	14	27	22	17	13	1	0	94
NE	8	28	49	44	13	3	0	0	145
NH-VT	36	25	12	0	0	0	0	0	73
NJ	17	25	33	18	8	0	0	0	101
NM	17	69	47	9	1	0	0	0	143
NV	30	35	11	4	1	0	0	0	81
NY	14	43	65	47	5	0	0	0	174
OH	4	10	33	35	22	16	6	1	127
OK	23	44	40	13	3	0	0	0	123
OR	50	84	75	20	2	0	0	0	231
PA	56	107	47	8	3	0	0	0	221
PR	3	23	16	6	2	0	0	0	50
RI	3	6	3	3	0	0	0	0	15
SC	22	28	20	4	2	0	0	0	76
SD	0	3	22	29	35	13	4	0	106
TN	33	18	27	8	2	0	0	0	88
TX	16	63	139	121	48	4	0	0	391
UT	33	72	50	33	18	5	2	1	214
VA	0	1	6	23	33	12	0	0	75
WA	32	49	65	28	6	2	0	0	182
WI	25	39	17	8	0	0	0	0	89
WV	24	31	11	7	0	1	0	0	74
WY	2	41	45	30	19	2	0	0	139
TOTALS	1252	1857	1586	977	422	120	22	2	6238
PERCENT	20.1	29.8	25.4	15.7	6.8	1.9	0.3	0.0	100

CA.N - NORTHERN CALIFORNIA
FL.JAC - JACKSONVILLE SUBDISTRICT AREA IN FLORIDA
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FL.TAL - TALLAHASSEE SUBDISTRICT AREA IN FLORIDA
FL.TAM - TAMPA SUBDISTRICT AREA IN FLORIDA

Appendix C.--Summary, by State, of the total number of applications of alternative methods to streamgaging and the number within a given accuracy.

STATE	TRIALS		JOINT	NUMBER OF STATIONS WITH DAILY DISCHARGES WITHIN 10 PERCENT A GIVEN PERCENT OF TIME		
	REGR	ROUT	APPL.	75%	85%	95%
ALABAMA	5	5	5	0	0	0
ALASKA	6	0	0	0	0	0
ARKANSAS	3	3	3	0	0	0
CALIFORNIA (NORTHERN)	10	4	2	2	1	0
CONNECTICUT	3	2	0	1	0	0
FLORDIA (ORLANDO)	1	9	1	4	2	0
GEORGIA	18	10	3	4	1	0
HAWAII	7	0	0	1	1	0
IDAHO	9	2	2	1	0	0
ILLINOIS	6	1	0	1	1	0
INDIANA	3	2	2	1	1	0
IOWA	11	3	0	1	1	0
KANSAS	8	0	0	0	0	0
KENTUCKY	0	3	0	0	0	0
LOUISIANA	1	1	0	0	0	0
MAINE	4	2	0	1	1	0
MARYLAND/DELAWARE/DC	5	6	3	4	0	0
MASSACHUSETTS	5	3	3	0	0	0
MICHIGAN	10	6	6	2	1	0
MINNESOTA	24	0	0	1	1	0
MISSISSIPPI	2	2	2	2	0	0
MISSOURI	2	1	1	1	1	0
NEBRASKA	18	0	0	1	1	0
NEVADA	18	4	4	0	2	0
NEW HAMPSHIRE/VERMONT	4	2	2	0	0	0
NEW JERSEY	5	3	3	2	1	0
NEW YORK	6	0	0	0	0	0
NORTH CAROLINA	3	3	3	2	0	0
NORTH DAKOTA	13	1	1	1	1	0
OHIO	5	1	1	0	0	0
OKLAHOMA	7	0	0	0	0	0
PENNSYLVANIA	8	3	3	2	1	0
RHODE ISLAND	2	1	1	0	0	0
SOUTH CAROLINA	4	2	2	1	0	0
VIRGINIA	3	4	1	2	1	0
WASHINGTON	8	8	3	3	2	1
WEST VIRGINIA	6	6	6	0	2	0
WISCONSIN	1	2	0	1	0	0
WYOMING	2	1	1	0	0	0
PUERTO RICO	5	0	0	0	0	0
TOTALS	261	106	64	42	23	1

Appendix D.--Summary, by State, of the analysis of the cost effectiveness of the U.S. Geological Survey stream-gaging program.

STATE	STATIONS USED IN ANALYSIS	CURRENT TASEPS (Percent)	OPTIMUM TASEPS (Percent)	CURRENT BUDGET ($1000)	REDUCTIONS+ ($1000)	EGS (Percent)
ALABAMA	58	29.3	26.4	328.4	8.6	9.2
ALASKA	98	18.4	16.8	1539	99	
ARKANSAS	47	33.3	32.6	292.2	2.2	*
CALIFORNIA (NORTHERN)	127	12.9	12.0	747	34	*
CONNECTICUT	41	14.5	11.7	267	8	5.6
FLORDIA (ORLANDO)	66	27.8	27.8	467	0	*
GEORGIA	98	17.2	16.1	497.8	11.5	*
HAWAII	122	21.0	17.7	413	32	6.2
IDAHO	156	33.7	21.4	781	21	13.3
ILLINOIS	138	36.5	20.8	768	50.5	*
INIDANA	163	25.2	23.0	823	23	12.5
IOWA	73	11.4	10.5	592	27	*
KANSAS	85	20.8	18.3	793.8	14.8	*
KENTUCKY	21	28.5	26.9	223.5	3.5	12.2
LOUISIANA	56	34.6	31.5	423	23	10.3
MAINE	45	17.7	16.1	180.3	10.3	4.2
MARYLAND/DELAWARE/DC	90	11.8	11.4	465.3	4.3	6.0
MASSACHUSETTS	63	12.3	12.0	353	6	*
MICHIGAN	121	12.1	11.1	718.1	7.9	4.5
MINNESOTA	77	24.4	20.6	198	19	*
MISSISSIPPI	55	26.6	22.6	486	28	12.6
MISSOURI	23	17.9	16.9	218.9	0	7.6
NEBRASKA	101	12.3	11.0	908.5	35.5	*
NEVADA	77	28.5	26.1	465.5	21.5	16.5
NEW HAMPSHIRE/VERMONT	60	17.9	16.6	297	12	*
NEW JERSEY	101	24.9	22.0	569	15	*
NEW YORK	169	13.2	11.0	1068	72	4.8
NORTH CAROLINA	146	18.6	16.7	777.6	15.6	6.7
NORTH DAKOTA	29	25.0	21.6	248.1	5.3	16.5
OHIO	103	29.2	27.6	682	2	11.3
OKLAHOMA	56	22.6	19.1	617.1	2.1	*
PENNSYLVANIA	211	15.2	13.7	1199	109	*
RHODE ISLAND	15	9.7	9.2	60.5	1.5	*
SOUTH CAROLINA	75	16.9	15.5	417.2	22.2	8.5
VIRGINIA	75	10.1	9.0	446	15.5	5.6
WASHINGTON	168	13.3	11.5	1112	60	*
WEST VIRGINIA	74	24.6	21.0	410	40	12.3
WISCONSIN	73	13.8	10.1	557.3	38.7	5.5
WYOMING	46	13.2	11.6	264	14	5.1
PUERTO RICO	34	20.6	18.8	310	10	*
TOTALS/AVERAGE	3436	20.9	18.8	$21,984.1	$955.5	

+Reduction in current budget that could be achieved by altering field activities and still achieve the current TASEPS
*not determined

*U.S. G.P.O.:1993-301-077:80041