COST-EFECTIVE STREAMGAGING STRATEGIES FOR THE LOWER COLORADO RIVER BASIN

By E. J. Gilroy and M. E. Moss

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ABSTRACT

As an aid to the administration of the Colorado River Compact of 1922, certain streamgaging stations were established by the U.S. Geological Survey where the flow of the main river, its tributaries and subsequent diversions, and return flows were to be measured. The U.S. Supreme Court ruling (Arizona versus California, 1963) on the relative rights of two of the Lower Basin States--California and Arizona--led to a major increase in streamgaging activity by the Geological Survey in the Lower Basin.

The effectiveness of the resulting data in the administration of the Compact and implementation of the court ruling is analyzed.

The streamgaging operations of 60 stations currently operated in the Lower Colorado River Basin are assessed from a cost-effective viewpoint using the sum of the uncertainties associated with estimating the annual mean discharge at each station as an inverse surrogate for the economic worth of data. The current service center for each station--either Blythe, California, or Yuma, Arizona--was not changed but the available funds were shifted from the operation of one station to another and, in some cases, from one office to the other, as efficiency dictated. The analysis shows that the current budget can be expended in such a way as to reduce the current level of uncertainty by 54 percent. Alternatively, the current level of uncertainty can be attained with a reduction of 53 percent in the current annual budget of $296,500.

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INTRODUCTION

The techniques developed in Moss and Gilroy (1980) to assess the cost effectiveness of streamgaging operations in the Lower Colorado River Basin and applied in that report to nineteen stations serviced from the Blythe (CA) Field Office are applied to forty-one stations serviced out of the Yuma (AZ) Subdistrict Office of the U.S. Geological Survey. The application is further extended by considering the total of 60 stations operated as one system by keeping the stations serviced out of the same offices as in the separate analyses but allowing the available funds to be shifted from one office to the other as efficiency dictates. A brief summary and review of the streamgaging networks of the Lower Colorado River Basin and the fundamental variables of the technique developed in Moss and Gilroy (1980) are presented below for the sake of completeness.

Figure 1 shows the drainage basin of the Colorado River Basin divided into the Upper Colorado River Basin and the Lower Colorado River Basin. The dividing line is the drainage divide between surface waters that flow into the river upstream from Lees Ferry, Arizona, and those that reach the river downstream from Lees Ferry. Table 1 lists those stream gages in the lower basin that are considered by the U.S. Geological Survey as being operated primarily in support of the compact and subsequent legal interpretation of the Compact. These gages are serviced primarily from the Yuma, Arizona, Subdistrict Office and the Blythe, California, Field Office of the

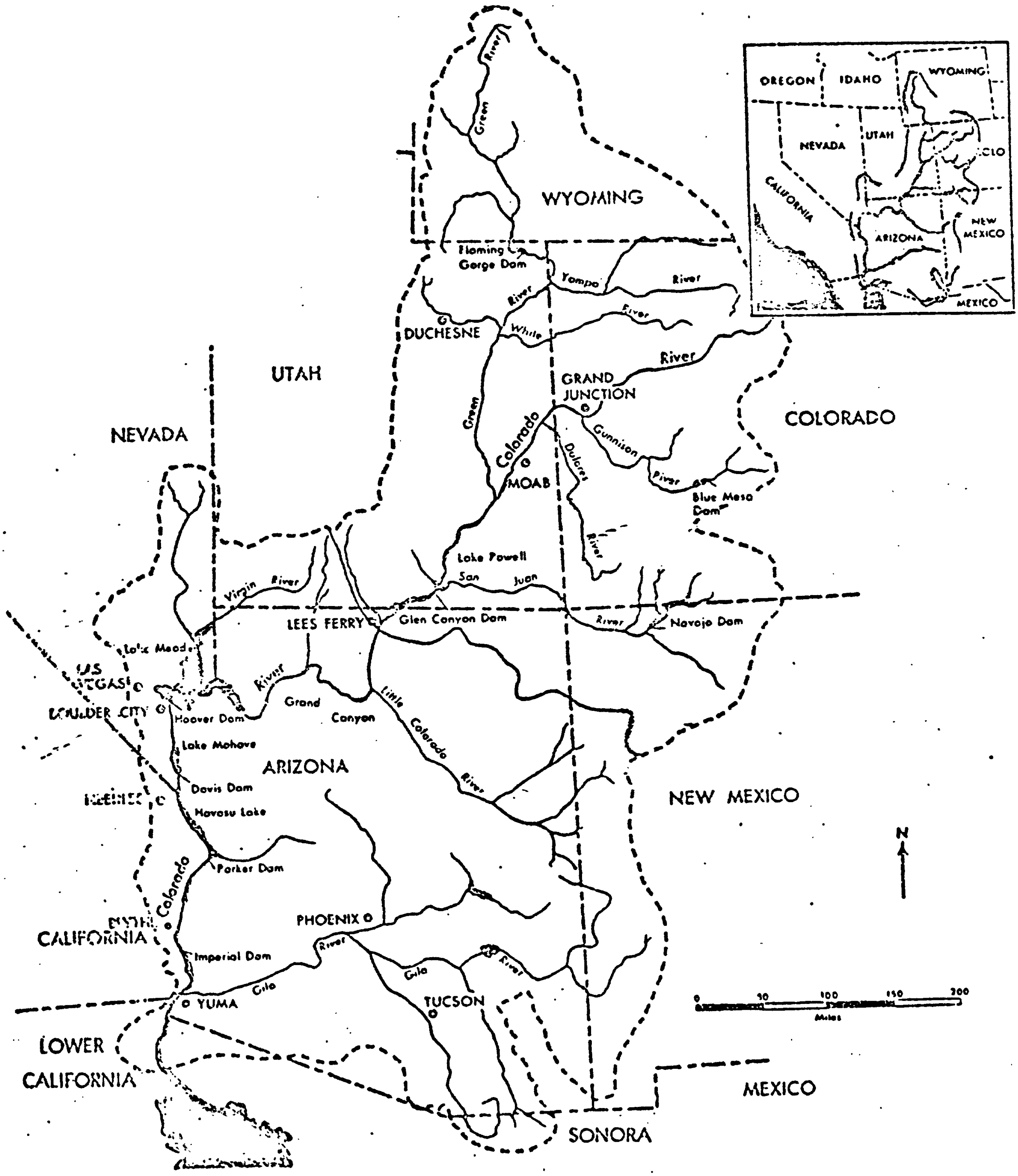

Figure 1.--The Colorado River drainage basin.

Table 1.--Gaging stations of the Lower Colorado River Basin network.

Station No.	Station name
09402500	Colorado River near Grand Canyon, Ariz.
09421500	Colorado River below Hoover Dam, Ariz.-Nev.
09423000	Colorado River below Davis Dam, Ariz.-Nev.
09423550	Topock Marsh Inlet near Needles, Calif.
09423650	Topock Marsh Outlet near Topock, Ariz.
09424150	Colorado River Aqueduct near Parker Dam, Ariz.-Calif.
09427520	Colorado River below Parker Dam, Ariz.-Calif.
09428500	Colorado River Indian Reservation Main Canal near Parker, Ariz.
09428505	Gardner Lateral Spill near Poston, Ariz.
09428510	Poston Wasteway near Poston, Ariz.
09429000	Palo Verde Canal near Blythe, Calif.
09429010	Colorado River at Palo Verde Dam, Ariz.-Calif.
09429030	Colorado River Indian Reservation Palo Verde Drain near Parker, Ariz.
09429060	Colorado River Indian Reservation Lower Main Drain near Parker, Ariz.
09429130	Palo Verde Irrigation District Olive Lake Drain near Blythe, Calif.
09429155	Palo Verde Irrigation District F Canal Spill near Blythe, Calif.
09429160	Palo Verde Irrigation District D-10-11-2 Canal Spill near Blythe, Calif.
09429170	Palo Verde Irrigation District D-10-11-5 Canal Spill near Blythe, Calif.
09429180	Palo Verde Irrigation District D-23 Canal Spill near Blythe, Calif.
09429190	Palo Verde Irrigation District D-23-1 Canal Spill near Blythe, Calif.
09429200	Palo Verde Irrigation District C Canal Spill near Blythe, Calif.
09429210	Palo Verde Irrigation District C-28 Canal Upper Spill near Blythe, Calif.
09429220	Palo Verde Irrigation District Outfall Drain, near Palo Verde, Calif.
09429225	Palo Verde Irrigation District Anderson Drain near Palo Verde, Calif.
09429230	Palo Verde Irrigation District C-28 Canal Lower Spill near Blythe, Calif.

Station No.	Station name
09429280	Cibola Lake Inlet near Cibola, Ariz.
09429290	Cibola Lake Outlet near Cibola, Ariz.
09429490	Colorado River above Imperial Dam, Ariz.-Calif.
09429500	Colorado River below Imperial Dam, Ariz.-Calif.
09520500	Gila River near Dome, Ariz.
09522000	Colorado River at Northerly International Boundary, above Morelos Dam, near Androde, Calif.
09522400	Mittry Lake Diversion at Imperial Dam, Ariz.-Calif.
09522500	Gila Gravity Main Canal at Imperial Dam, Ariz.-Calif.
09522600	North Gila Main Canal near Yuma, Ariz.
09522650	North Gila Canal Number 2 near Yuma, Ariz.
09522700	Wellton-Mohawk Canal near Yuma, Ariz.
09522800	South Gila Canal near Yuma, Ariz.
09522850	Gila Gravity Canal at Pumping Plant near Yuma, Ariz.
09522900	Unit B Main Canal near Yuma, Ariz.
09523000	All American Canal near Imperial Dam, Ariz.-Calif.
09523200	Reservation Main Canal near Yuma, Ariz.
09523400	Titsink Canal near Yuma, Ariz.
09523600	Yaqui Canal near Yuma, Ariz.
09523800	Pontiac Canal near Yuma, Ariz.
09523900	Walapai Canal near Yuma, Ariz.
09524000	Yuma Main Canal at Siphon Drop Power Plant near Yuma, Ariz.
09524500	Diversions from Yuma Main Canal below Siphon Drop Power Plant
09525000	Yuma Main Canal Wasteway at Yuma, Ariz.
09525500	Yuma Main Canal below Colorado River Siphon at Yuma, Ariz.
09526000	Diversions from Yuma Main Canal
09527000	Pilot Knob Power Plant and Wasteway near Pilot Knob, Calif.
09527500	All American Canal below Pilot Knob Wasteway, Calif.
09527900	Mittry Lake Outlet Channel near Yuma, Ariz.
09528600	Laguna Canal Wasteway near Yuma, Ariz.
09528800	Levee Canal Wasteway near Yuma, Aria.
09529000	North Gila Drain Number 1 near Yuma, Ariz.

Station No.	Station Name
09529050	North Gila Drain Number 3 near Yuma, Ariz.
09529100	Fortuna Wasteway near Yuma, Ariz.
09529150	North Gila Main Canal Wasteway near Yuma, Ariz.
09529160	South Gila Pump Outlet Channel Number 3 near Yuma, Ariz.
09529200	Bruce Church Drain near Yuma, Ariz.
09529240	South Gila Pump Outlet Channel Number 2 near Yuma, Ariz.
09529250	Bruce Church Wasteway near Yuma, Ariz.
09529300	Wellton-Mohawk Main Outlet Drain near Yuma, Ariz.
09529360	South Gila Pump Outlet Channel Number 1 near Yuma, Aria.
09529400	South Gila Drain Number 2 near Yuma, Ariz.
09529420	South Gila Terminal Wasteway near Yuma, Ariz.
09529440	South Gila Pump Outlet Channel Number 4 near Yuma, Ariz.
09529600	All American Canal Intercept Number 7 near Bard, Calif.
09529700	All American Canal Intercept Number 6 near Bard, Calif.
09529800	All American Canal Intercept Number 2 near Bard, Calif.
09529900	All American Canal Intercept Number 3 near Yuma, Ariz.
09530000	Reservation Main Drain Number 4 at Yuma, Ariz.
09530200	Yuma Mesa Outlet Drain at Yuma, Ariz.
09530400	All American Canal Intercept Number 11 near Yuma, Ariz.
09530500	Araz Drain 8-B near Yuma, Ariz.
09531800	Wellton-Mohawk M.O.D.E. Number 2 above Morelos Dam, Ariz.
09531850	Cooper Wasteway above Morelos Dam, Ariz.
09531900	Wellton-Mohawk M.O.D.E. Number 3 below Morelos Dam, Ariz.
09532500	Eleven Mile Wasteway below Morelos Dam, Ariz.
09533000	Twenty-One Mile Wasteway near San Luis, Ariz.
09533300	Wellton-Mohawk Drain at Ariz.-Sonora Border near San Luis, Ariz.

Station No.	Station name
09534000	Yuma Valley Main Drain near San Luis, Ariz.
09534300	West Main Canal Wasteway at Arizona-Sonora Boundary near San Luis, Ariz.
09534500	East Main Canal Wasteway at Arizona-Sonora Boundary near San Luis, Ariz.

U.S. Geological Survey. Figure 2 is a schematic of the network of stream gages serviced from the Blythe Field Office. The station on the Colorado River below Hoover Dam (09421500) is serviced from the Yuma Office because it is part of the U.S. Geological Survey's National Stream Quality Network (Ficke and Hawkinson, 1975). Figure 3 is a schematic of the network of stream gages serviced from the Yuma Subdistrict Office.

The uncertainty in the estimation of annual mean discharge serves in this study as an inverse surrogate for the economic worth of data. Uncertainty at a particular stream gage is either the variance of the error of estimate of annual mean flow past the gage or its square root, the standard deviation. A unit of uncertainty is assumed to be as deleterious at any one stream gage as it is at any other in the network. Therefore, the objective function is taken to be the sum of the uncertainties at all the stations in the system. The uncertainty in the annual mean discharge is a function of the frequency of visits that are made to the gage to service the recording equipment and to make discharge measurements. The site-specific parameters of each uncertainty function are determined by the time series structure of the residuals from the rating at the site and by the measurement error variance at the site. The uncertainty curves for the stations serviced from the Blythe Field Office are given in Moss and Gilroy (1980). The uncertainty curves for the stations serviced from the Yuma Subdistrict Office are given in Gilroy (unpub. data 1982).

For reasons given in Moss and Gilroy (1980) the network manager's decision variables are taken to be the number of times a year that a particular route of travel is used. A route is defined as a set of one or more gages and the least cost travel that takes the hydrographer from his home base to each of the gages and back to base. A route will have associated with it an average cost of

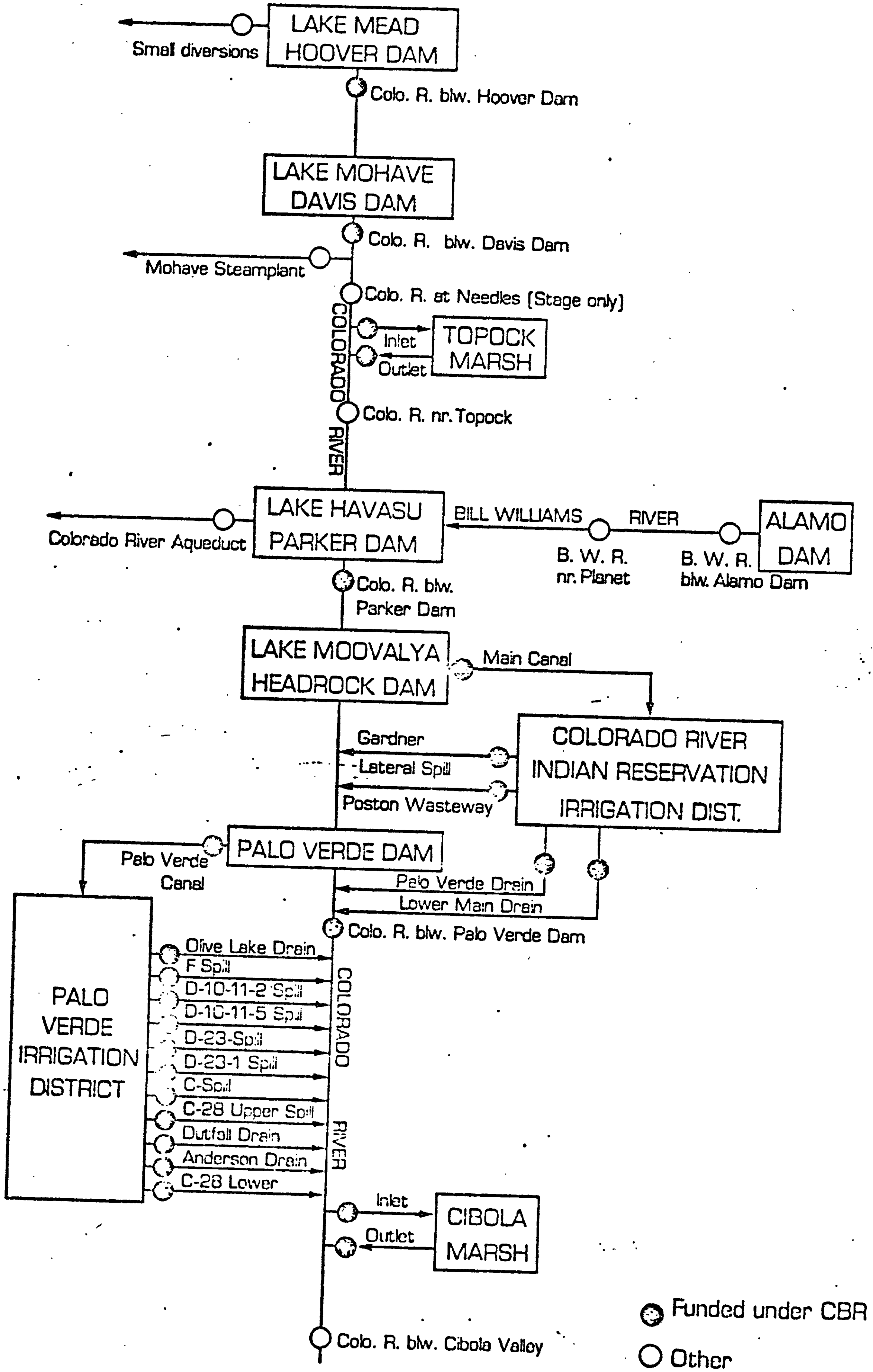

Figure 2.--Schematic of stations serviced from the Blythe Field Office

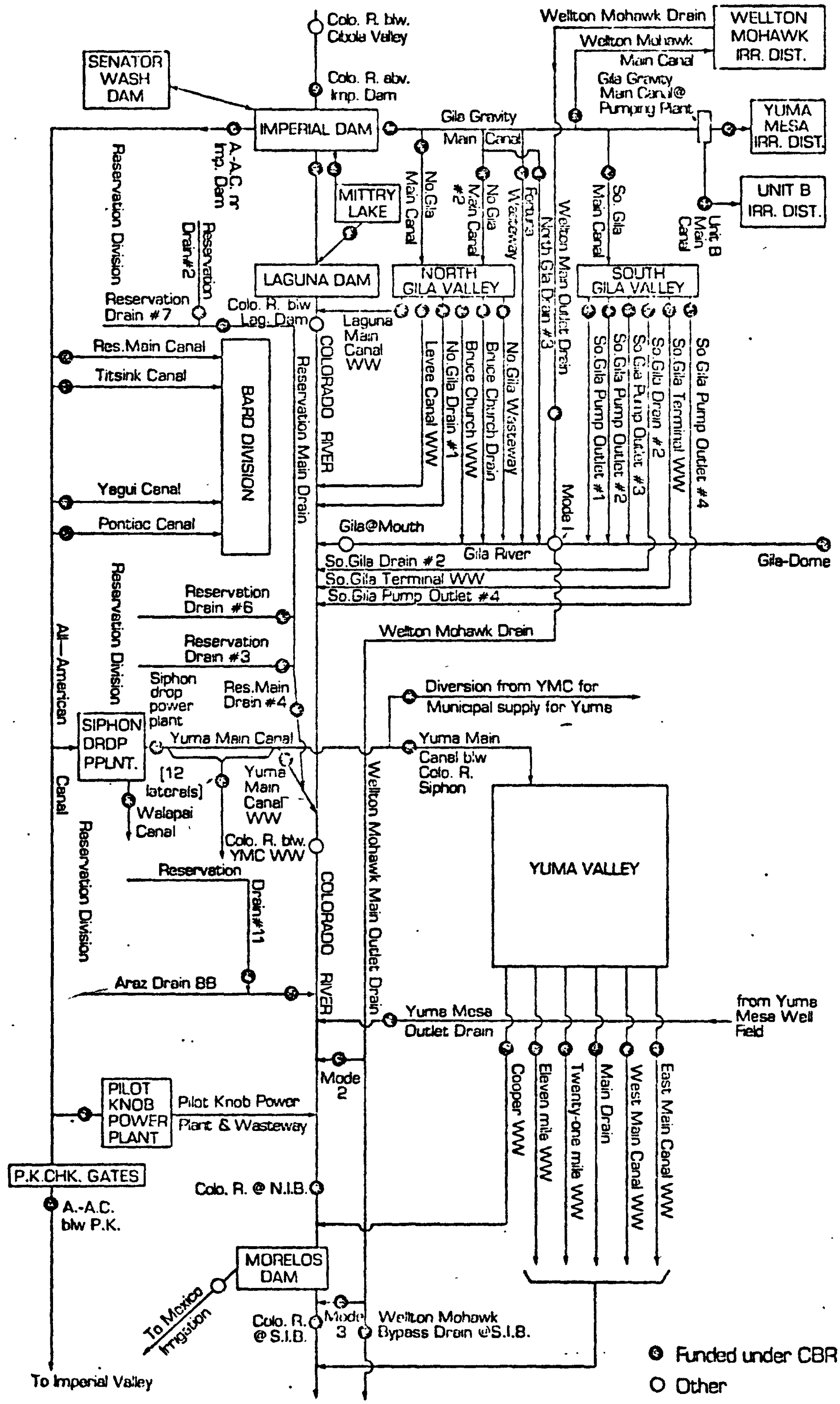

Figure 3.--Schematic of stations serviced from the Yuma Subdistrict Office.

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 almost always will contain the path to each stream gage with that gage as the lone stop and return to the home base in order that the individual needs of a stream gage can be considered in isolation from the other gages.

Another step in this part of the analyses is to determine any special requirements for visits to each of the gages for such things as necessary periodic maintenance or rejuvenation of recording equipment or required periodic sampling of water quality data. For such stations a minimum of six or twelve visits per year may be a constraint.

The final step is to use all of the above to determine the number of times, N_i, that the i-th route for $i = 1, 2, \ldots, NR$, 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 4 presents this step in the form of a mathematical program. Figure 5 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, $((\omega_{ij}))$, 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 travel time and any related per diem and operation, maintenance, and rental costs of vehicles. The sum of the products of β_i and N_i for $i = 1, 2, \ldots, NR$ is the total travel cost associated with the set of decisions $\underline{N} = (N_1, N_2, \ldots, N_{NR})$.

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

$V \equiv$ 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 4.--Mathematical programing form of the optimization of the routing of hydrographers.

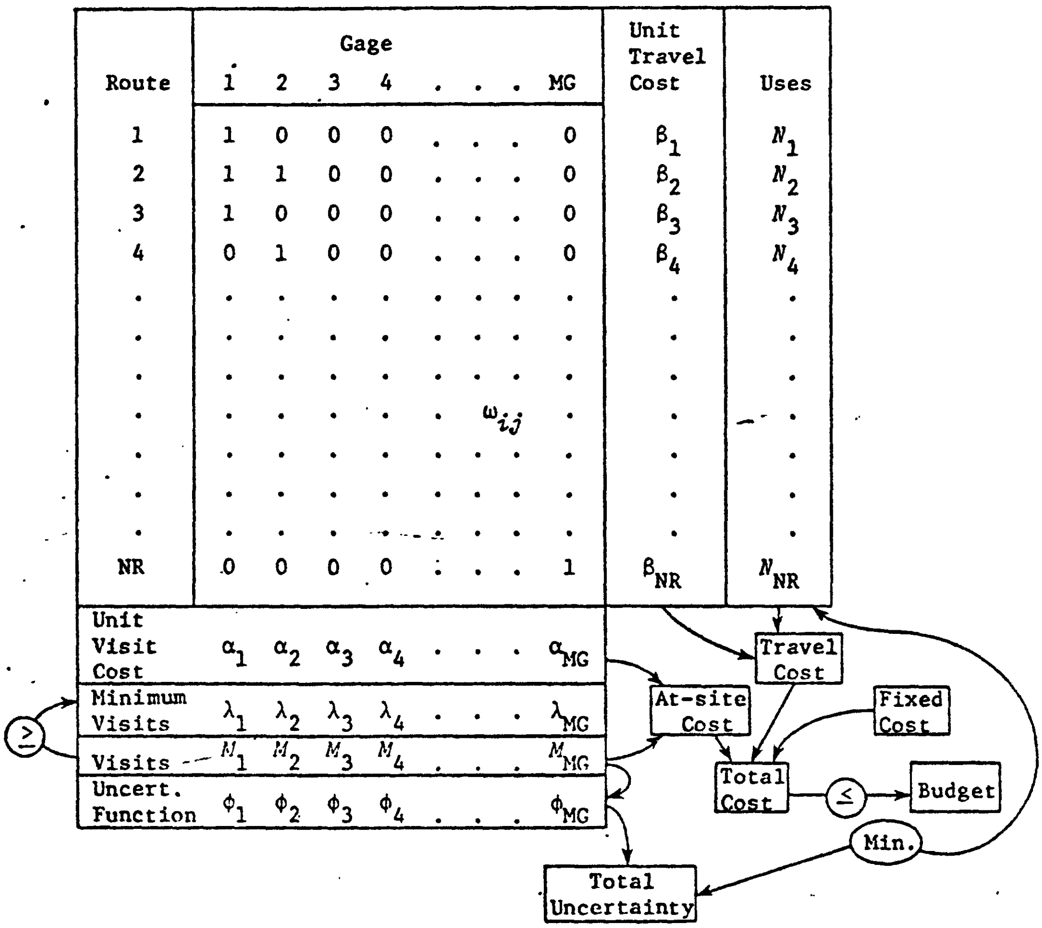

Figure 5.--Tabular form of the optimization of the routing of hydrographers.

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 constraints of minimum visits is denoted by the row λ_j, $j = 1, 2, \ldots, MG$. The row of integers M_j, $j = 1, 2, \ldots, MG$ 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 or variance of the estimates of annual discharges at the MG stations is determined by summing the uncertainty functions, ϕ_j evaluated at the value of M_j from the row above it, for $j = 1, 2, \ldots, MG$.

The next section of the report presents the results of the separate analyses of the network of stations serviced from the Yuma Subdistrict Office and--for the sake of completeness--of the network of stations serviced from the Blythe Field Office. The Blythe Field Office results are reproduced directly from Moss and Gilroy (1980).

The two networks are then considered as one from a budgetary perspective in that they compete with each other for the available dollars while still being segregated from a station servicing stance.

YUMA SUBDISTRICT OFFICE

UNIT COSTS OF STREAMGAGING

Personnel of the Arizona District Office and the Yuma Subdistrict Office developed the required cost data that are shown in table 2 (J. D. Camp, written communication, November 1980). The set of practical routes also defined in table 2 were also developed by the Arizona District personnel. Overhead is charged as 42 percent of the gross budget.

RESULTS

The cost figures and the route definitions given in the last section were used with uncertainty relations given in a report by Gilroy (unpub. data 1982) to find cost-effective strategies for several possible budgets. Three sets of minimum visit constraints--one, six, and twelve visits per year to each of the 41 gaging stations in the analysis--were considered. The one-visit minimum is a lower limit on the accuracy that can be obtained for annual mean discharge but is not feasible with the equipment that is currently in use to record the correlative data. This equipment should be serviced bimonthly--six visits per year--in order that reasonably continuous records of the correlative data be available. However, if monthly mean discharges must be computed at the end of each month, twelve visits per year to each station would be necessary.

Table 3 provides the annual visit-frequencies currently used for the 41 stations serviced from the Yuma Subdistrict Office and the resulting total uncertainty. This uncertainty and the cost of the current operation are shown as a point in figure 6. As can be seen in figure 6, a similar level of uncertainty in annual mean discharge can be achieved for a budget of $150,700 with a six-visit minimum or for $163,000 for a twelve-visit minimum. Table 3 shows the changes in station visitation frequency resulting from these two latter strategies.

Route	Unit cost, in dollars	9429490	9429500	9420500	9522400	9522500	9522600	9522650	9522700	9522800	9523000	9523200	9523400	9523600	9523800	9523900	9524000	9525000	9525500	9527000	9527500	9527900	9528600	9528800	9529000	9529050	9529150	9529160	9529240	9529250	9529300	9529360	9529400	9529420	9529440	9529600	9529700	9529800	9529900	9530000	9530400	9530500
		Station																																								
1	29	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	26	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	32	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	32	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	25	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	20	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	22	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	16	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	28	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	24	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	21	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	21	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	19	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
28	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
29	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
30	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
31	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
32	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
33	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
34	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
35	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
36	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
37	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
38	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
39	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
40	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
41	22	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
42	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1
43	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	33	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	12	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
48	33	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
49	31	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	33	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	25	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
52	33	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	22	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	30	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
55	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
56	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Visit cost in dollars		0	65	52	20	39	26	26	46	39	33	26	26	26	26	26	39	33	39	39	39	26	20	26	26	13	26	26	26	20	26	26	13	26	26	20	20	20	20	39	20	20
Fixed cost in dollars		624	5350	2550	1450	2540	1730	1860	2710	2600	2080	2080	1180	1500	1500	1500	3120	1580	3030	2070	2280	1550	910	1500	1890	1020	1780	1420	1970	1320	1970	1950	700	1500	1500	1020	1020	1020	1020	3440	1020	1030

Table 2.--Unit costs and route definitions for the Yuma Subdistrict Office.

Table 3.--Gaging strategies for the Yuma Subdistrict Office showing number of visits per year to each station.

Station	Six-Visit Minimum*	Twelve-Visit Minimum*	Current Operation	Six-Visit Minimum+	Twelve-Visit Minimum+
09429490#	0	0	0	0	0
09429500	51	39	27	14	15
09520500	26	20	27	9	12
09522400	6	12	25	6	12
09522500	57	46	39	20	20
09522600	6	12	25	6	12
09522650	6	12	25	6	12
09522700	6	12	25	6	12
09522800	6	12	25	6	12
09523000	208	145	12	31	24
09523200	6	12	25	6	12
09523400	6	12	17	6	12
09523600	6	12	17	6	12
09523800	6	12	17	6	12
09523900	6	12	17	6	12
09524000	38	28	27	13	12
09525000	6	12	25	6	12
09525500	19	16	27	6	12
09527000	61	47	13	21	21
09527500	6	12	12	6	12
09527900	6	12	25	6	12
09528600	6	12	16	6	12
09528800	6	12	17	6	12
09529000	6	12	25	6	12
09529050	6	12	12	6	12
09529150	6	12	25	6	12
09529160	6	12	25	6	12
09529240	6	12	25	6	12
09529250	6	12	18	6	12
09529300	6	12	25	6	12
09529360	6	12	25	6	12
09529400	6	12	7	6	12
09529420	6	12	17	6	12
09529440	12	24	17	12	24
09529600	6	12	5	6	12
09529700	6	12	5	6	12
09529800	6	12	5	6	12
09529900	6	12	5	6	12
09530000	6	12	38	6	12
09530400	6	12	5	6	12
09530500	6	12	12	6	12
Budget, in thousands of 1980 dollars	186.0	186.0	186.0	150.7	163.0
Uncertainty, in ft^3/s	16.7	18.9	29.6	29.6	29.6

*Constant cost network.

+Constant uncertainty network.

#No measurements. Only fixed cost of office work.

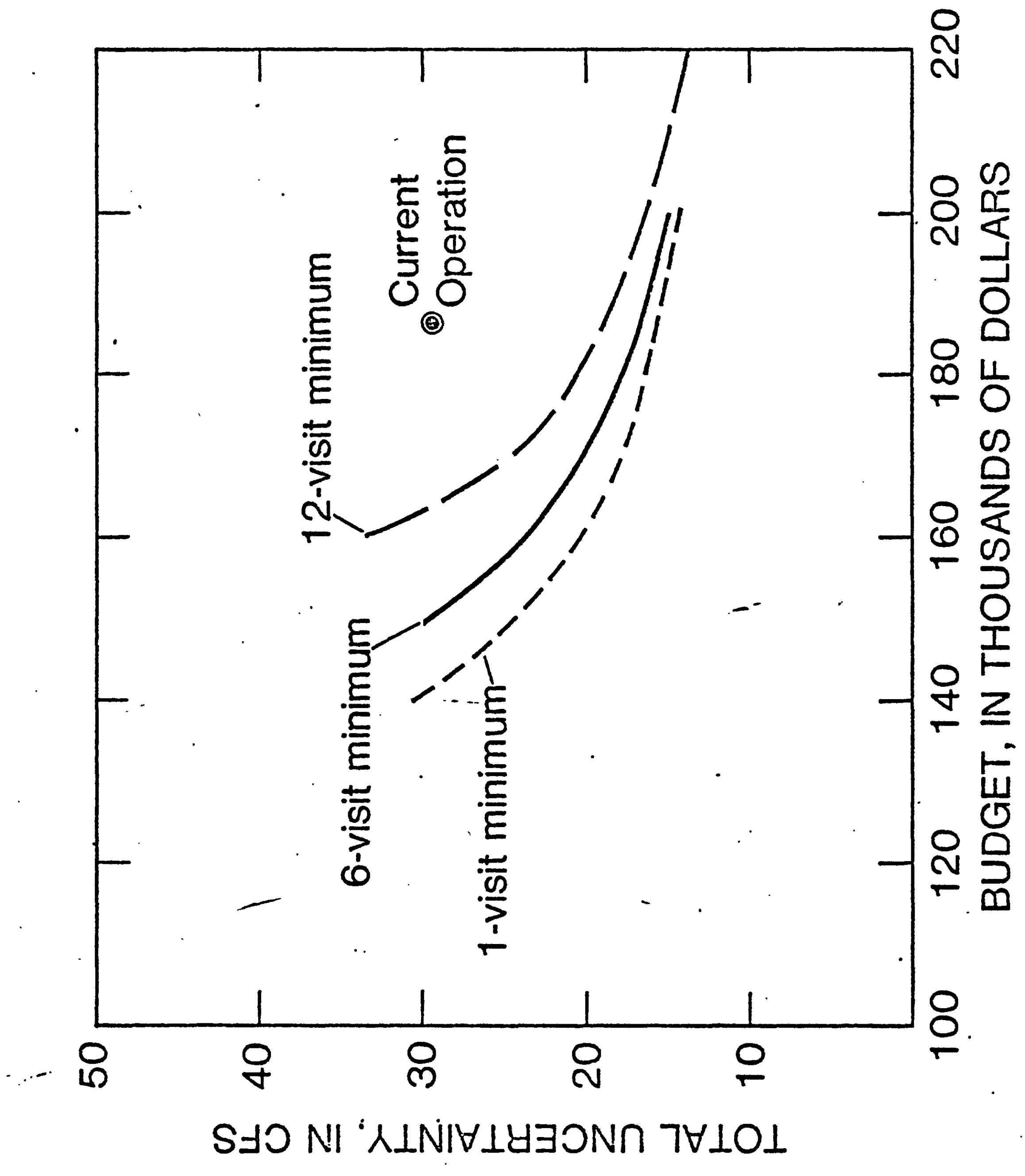

Figure 6.--The total uncertainty of cost-effective schemes and of the current operation of the Yuma Subdistrict Office.

Figure 6 shows that the current budget of \$186,000 can be expended in such a way that the total uncertainty in annual mean discharge estimates can be reduced from the level currently obtained. For a twelve-visit-per-year minimum, the total uncertainty can be reduced to 18.9 ft^3/s from 29.6 ft^3/s. For a six-visit-per-year minimum, the total uncertainty can be reduced to 16.7 ft^3/s. Table 3 shows changes in station visitation frequency under these alternative strategies. Figure 6 shows other levels of uncertainties for various budgets.

THE BLYTHE FIELD OFFICE

UNIT COSTS OF STREAM GAGING

Personnel of the Arizona District Office, the Yuma Subdistrict Office, and the Blythe Field Office developed the required cost data that are shown in table 4 (Moss and Gilroy, 1980). The set of practical routes, also defined in table 4, were jointly developed by the authors and Arizona District personnel.

RESULTS

Cost figures of table 4 were used in conjunction with the uncertainty relations defined in Moss and Gilroy (1980) to specify cost-effective strategies for several possible budgets.

Currently (1980) a minimum of 12 and a maximum of 29 visits are made to any of the gaging stations. However, discharge measurements are not made each time a station is visited. Table 5 provides the visit-frequencies currently used and the resulting total uncertainty, which are integrated with the cost data and presented as a point on figure 7. Figure 7 reveals that a similar level of uncertainty in annual mean discharge can be obtained

Table 4.--Unit costs and route definitions for the Blythe Field Office.

Route	Unit cost, in dollars	Station 09423000	09423550	09427520	09428500	09428505	09428510	09429000	09429010	09429030	09429060	09429130	09429155	09429155	09429180	09429190	09429200	09429210	09429220	09429230
1	145	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	240	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	115	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	115	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	115	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	90	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	120	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	40	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
9	35	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
10	35	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
11	55	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
12	55	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
13	55	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
14	50	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
15	35	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
16	20	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
17	25	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
18	35	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
19	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
20	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
21	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
22	65	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
23	70	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
24	35	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0
25	55	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Visit cost, in dollars		45	40	65	65	15	20	58	60	60	25	15	15	0	15	0	15	0	25	15
Fixed cost, in dollars		2480	3510	2600	2860	1560	5200	2990	4490	780	1430	780	1560	390	1170	390	1430	390	1890	1300

Table 5.--Gaging strategies for the Blythe Field Office, showing the number of visits per year to each station.

Station	Six-Visit Minimum*	Twelve-visit Minimum*	Visits Per Year Current Operation	Six-visit Minimum+	Twelve-visit Minimum+
09423000	44	37	29	26	25
09423550	6	12	27	6	12
09427520	42	35	29	27	26
09428500	8	12	29	6	12
09428505	6	12	27	6	12
09428510	7	13	27	6	12
09429000	6	12	27	6	12
09429010	74	61	29	43	42
09429030	6	12	12	6	12
09429060	6	12	27	6	12
09429130	6	12	12 1/	7	12
09429155	6	12	18 2/	6	12
09429170	6	12	12 1/	6	12
09429180	6	12	18 2/	6	12
09429190	6	12	12 2/	6	12
09429200	6	12	18 1/	6	12
09429210	6	12	12 2/	6	12
09429220	6	12	24 3/	6	12
09429230	6	12	18 1/	6	12
Budget, in Thousands of 1980 Dollars	110.9	110.9	110.9	95.0	101.0
Uncertainty, in ft^3/s	87	94	113	112	112

*Constant cost network

+Constant uncertainty network

1/ Six discharge measurements

2/ No discharge measurements (totalizing meter)

3/ Twelve discharge measurements

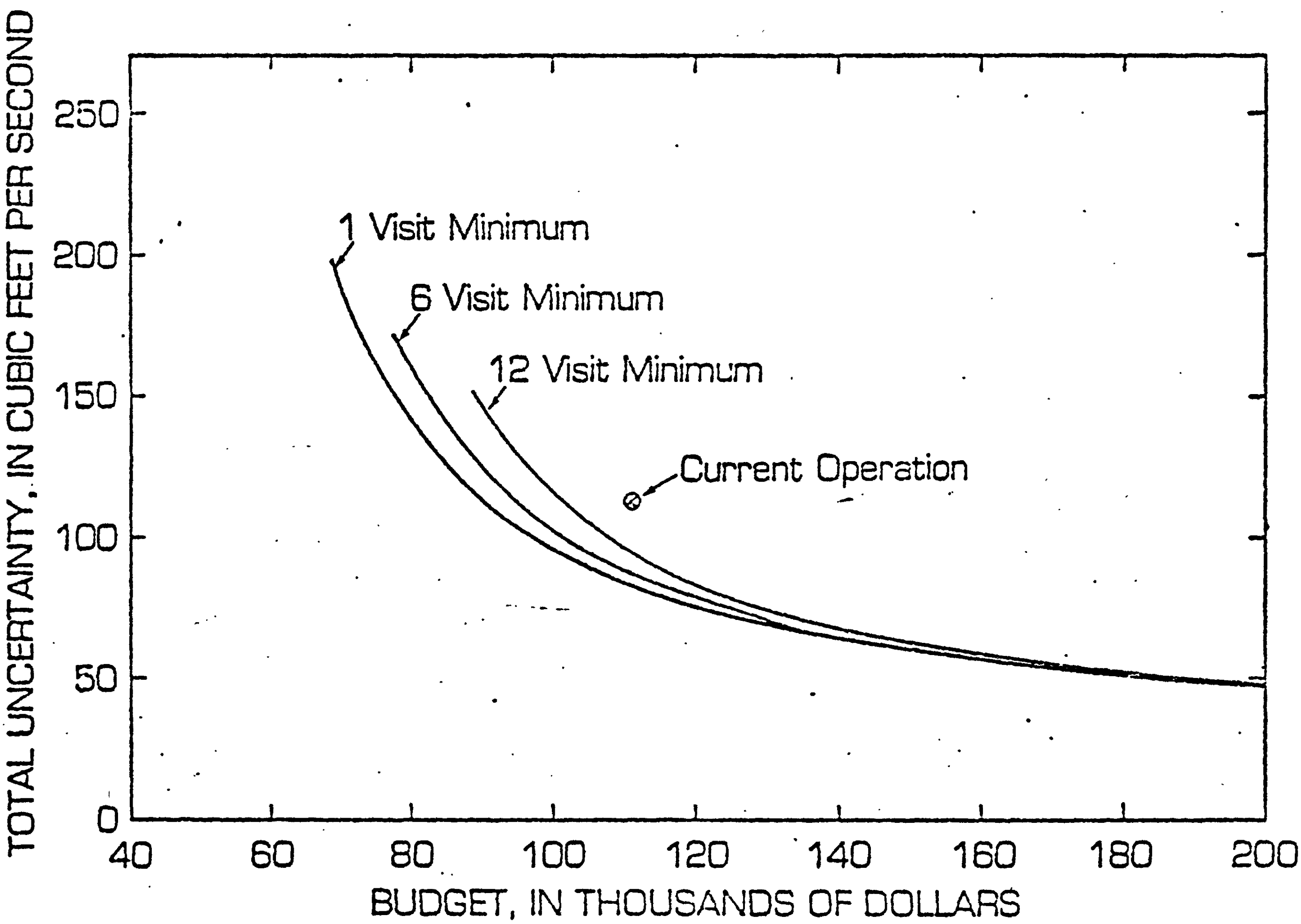

Figure 7.--The total uncertainty of cost-effective schemes and of the current operation of the Blythe Field Office.

for a budget of about $95,000 with a six-visit minimum or for about $101,000 for a twelve-visit minimum. The changes in visit frequency entailed by these two latter strategies also are presented in table 5.

The budget for current operations, $110,900, can be expended so as to reduce the total uncertainty in annual-mean-discharge estimates below that derived under the current scheme. If monthly discharge must be computed currently, the total uncertainty can be reduced from 113 ft^3/s to 94 ft^3/s by increasing the frequency of discharge measurement at the three gaging stations on the mainstem of the Colorado River (09423000, 09427520, and 09429010) at the expense of reduced measurement frequency at several stations not on the mainstem of the Colorado River. Increases and decreases in measurement frequency can be determined by comparing visit-frequencies in table 5.

An additional reduction of 7 ft^3/s of uncertainty from 94 to 87 can be obtained by relaxing the constraint of a twelve-visit minimum at each site to a six-visit minimum. This difference of 7 ft^3/s of uncertainty in the annual-mean-discharge estimates can be considered a cost of supplying timely monthly-discharge estimates.

JOINT OPERATION OF THE TWO OFFICES

Figure 8 graphically shows the relative uncertainties and dollars spent for the two operations by plotting the curves in figure 6 and figure 7 on the same scale. In the current operation Blythe accounts for 94 percent of the total variance of $(117\ ft^3/s)^2$ in the annual mean flows at the 61 stations serviced out of the two offices but only 37 percent of the combined budget for the two offices is expended on stations serviced from the Blythe

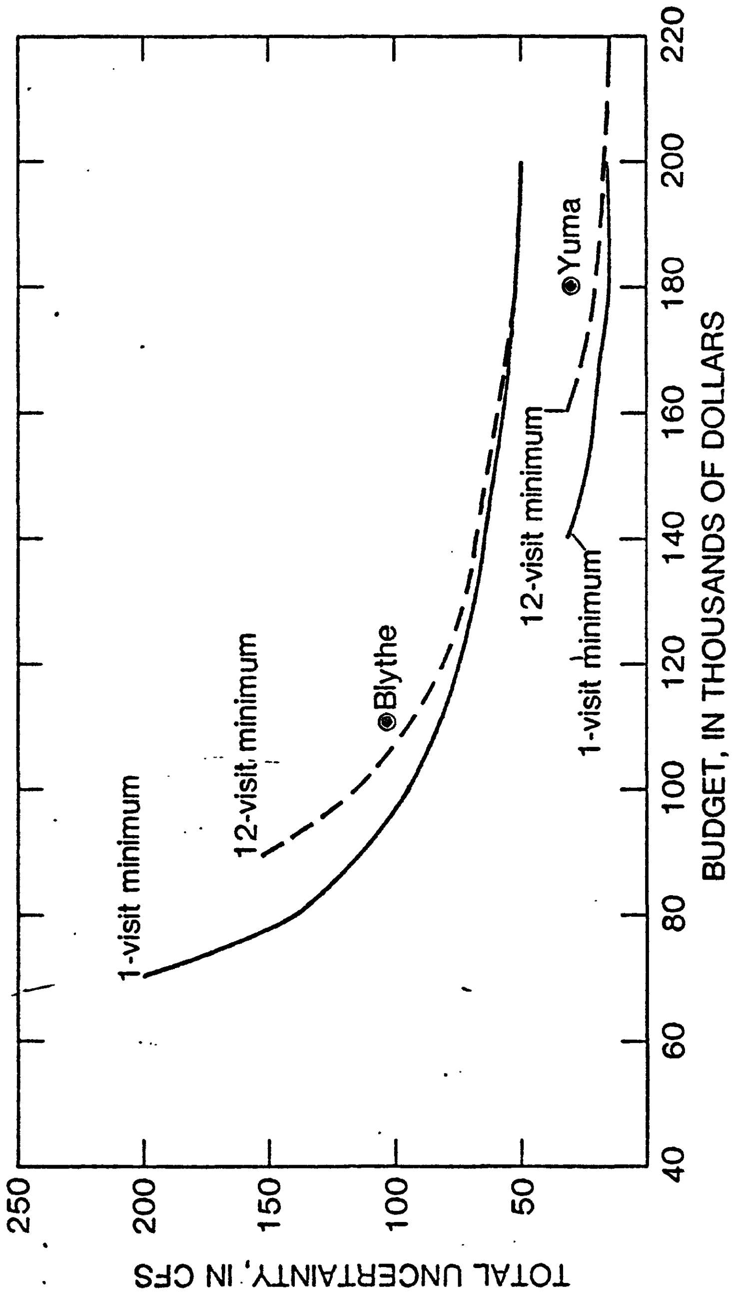

Figure 8.--The total uncertainty of cost-effective schemes and the current operation of the Blythe Field Office and the Yuma Subdistrict Office operated independently.

Field Office. This observation indicates that an opportunity exists for reducing the total uncertainty associated with the annual mean flows at the stations serviced by both offices by shifting some of the combined budget from the Yuma office to the Blythe office.

The optimization procedures described in Moss and Gilroy (1980) can take advantage of this opportunity in the following way. The 25 routes and 19 stations in table 4 and the 41 stations and 56 routes in table 2 are combined into a large station-route matrix of 60 stations and 81 routes. The first 19 entries in each of the first 25 rows of the new matrix are mapped directly from table 4. The last 41 entries in each of the last 56 rows are mapped directly from table 2. The last 41 entries in each of the first 25 rows of the new matrix are all zeroes denoting that no stations of the Yuma Subdistrict Office are visited from the Blythe Field Office. The first 19 entries in each of the last 56 rows are all zeroes denoting that no stations of the Blythe Field Office are visited from the Yuma Subdistrict Office. Let A be the 25 by 19 matrix of zeroes and ones given in table 4 and let D be the 56 by 41 matrix of zeroes and ones given in table 2. Let B be a 25 by 41 matrix of all zeroes and let C be a 56 by 19 matrix of all zeroes. Then the station-route matrix, F, for the joint operation of the Blythe and Yuma station is given by the partitioned matrix

$$F = \begin{bmatrix} A & B \\ C & D \end{bmatrix} .$$

The unit costs for the routes and stations stay the same as shown in tables 2 and 4. The uncertainty curves associated with the sixty stations stay the same as the curves used in the separate analyses.

The two budgets are now combined into one budget of $296,000 and the available dollars can be shifted for expenditure from one office to another but by reason of the definition of the matrix F the stations service centers remain as they were in the separate analyses.

RESULTS

Table 6 provides the visit frequencies currently used and the resulting total uncertainty associated with the whole network operated jointly from the Yuma and Blythe offices. Also provided in table 6 are constant cost and constant uncertainty annual visiting strategies for the joint operation of the whole Yuma-Blythe network of stations under both the six-visit and twelve-visit minimum constaints.

Of the sixty stations in the Lower Colorado River Basin serviced from the Yuma Subdistrict Office and the Blythe Field Office there are forty-three stations for which only monthly flows are published or flows for several stations are published as total return flows. Seven to ten years of annual mean flow data were readily available for these forty-three stations. Using these data in a Bayesian analysis the posterior mean and variance of the annual mean flow at each station were computed and used as estimates of the mean annual mean flow and the uncertainty in the annual mean flow for the case of no future measurements being made. The Bayesian analysis is given in Box and Tiao, 1973, particularly on pages 32, 93 and 145. This measure of uncertainty was then compared to the uncertainty at the station under the condition of six measurements being made each year. The difference in these uncertainties was then divided by the annual fixed cost of operating the station thus obtaining a measure of the reduction in uncertainty per dollar obtained by continuing the station in operation. Table 7 displays the relevant data for these forty-three stations ranked according to this uncertainty reduction per dollar. A clear dichotomy exists in the uncertainty reduction between the

Yuma operations showing number of visits per year to each station.

Station	Six-Visit Minimum*	Twelve-Visit Minimum*	Current Operation	Six-Visit Minimum+	Twelve-Visit Minimum+
09423000	88	68	29	27	26
09423550	6	12	27	6	12
09427520	77	60	29	27	26
09428500	14	12	29	6	12
09428505	6	12	27	6	12
09428510	11	12	27	6	12
09429000	6	12	27	6	12
09429010	128	103	29	46	41
09429030	6	12	12	6	12
09429060	6	12	27	6	12
09429130	6	12	12	6	12
09429155	6	12	6	6	12
09429170	6	12	6	6	12
09429180	6	12	6	6	12
09429190	6	12	6	6	12
09429200	6	12	6	6	12
09429210	6	12	6	6	12
09429220	7	12	12	6	12
09429230	6	12	6	6	12
09429490#	0	0	0	0	0
09429500	16	12	27	6	12
09520500	7	12	27	6	12
09522400	6	12	25	6	12
09522500	21	15	39	7	12
09522600	6	12	25	6	12
09522650	6	12	25	6	12
09522700	6	12	25	6	12
09522800	6	12	25	6	12
09523000	27	15	12	6	12
09523200	6	12	25	6	12
09523400	6	12	17	6	12
09523600	6	12	17	6	12
09523800	6	12	17	6	12
09523900	6	12	17	6	12
09524000	12	12	27	7	12
09525000	6	12	25	6	12
09525500	6	12	27	6	12
09527000	21	18	13	8	12
09527500	6	12	12	6	12
09527900	6	12	25	6	12
09528600	6	12	16	6	12
09528800	6	12	17	6	12
09529000	6	12	25	6	12
09529050	6	12	12	6	12
09529150	6	12	25	6	12
09529160	6	12	25	6	12
09529240	6	12	25	6	12
09529250	6	12	18	6	12
09529300	6	12	25	6	12
09529360	6	12	25	6	12
09529400	6	12	7	6	13
09529420	6	12	17	6	12
09529440	12	24	17	12	24
09529600	6	12	5	6	12
09529700	6	12	5	6	12
09529800	6	12	5	6	12
09529900	6	12	5	6	12
09530000	6	12	38	6	12
09530400	6	12	5	6	12
09530500	6	12	12	6	12
Budget, in thousands of dollars	296.5	296.5	296.5	239.8	261.
Uncertainty in ft^3/s	69.2	77.3	117.0	117.0	117.0

*Constant Cost Network

+Constant Uncertainty Network

#No measurements. Only fixed cost of office work.

Table 7.--Bayesian results for forty-three stations.

Station	Fixed Cost	Posterior Variance	Uncertainty For Six Visits Per Year	Uncertainty Reduction Per Dollar
9528600	910	0.00	0.000	0.00000
9523400	1180	0.02	0.014	0.00000
0528800	1500	0.02	0.000	0.00002
9529800	1020	0.04	0.002	0.00004
9530400	1020	0.05	0.001	0.00005
9529400	700	0.04	0.006	0.00005
9529050	1020	0.08	0.001	0.00008
9529900	1020	0.09	0.015	0.00008
9529600	1020	0.13	0.006	0.00013
9529420	1500	0.23	0.000	0.00015
9529150	1780	0.66	0.006	0.00037
9530500	1030	0.63	0.016	0.00060
9523800	1500	0.95	0.001	0.00063
9523600	1500	1.21	0.065	0.00077
9529700	1020	1.51	0.208	0.00127
9529250	1320	1.93	0.000	0.00146
9529000	1890	3.32	0.134	0.00169
9429230	1300	2.92	0.012	0.00224
9522800	2600	7.90	0.341	0.00291
9523900	1500	4.72	0.038	0.00312
9522650	1860	6.90	0.262	0.00357
9529360	1950	9.15	0.651	0.00436
9429030	780	5.34	1.701	0.00467
9429155	1560	7.72	0.000	0.00495
9429210	390	2.26	0.000	0.00579
9530000	3440	22.45	1.430	0.00611
9523200	2080	16.60	0.538	0.00772
9529440	1500	12.56	0.010	0.00837
9527900	1550	13.60	0.146	0.00868
9429190	390	3.94	0.000	0.01010
9429130	780	9.77	0.679	0.01165
9429170	390	5.89	0.000	0.01510
9529160	1420	23.72	0.068	0.01666
9529240	1970	37.72	0.598	0.01884
9522600	1730	38.90	0.028	0.02247
9429220	1890	111.01	44.415	0.03524
9429200	1430	75.46	0.103	0.05270
9429180	1170	64.10	0.023	0.05477
9428505	1560	97.42	0.003	0.06245
9529300	1970	146.09	0.849	0.07373
9428510	5200	3712.00	117.428	0.69126
9429060	1430	1619.50	10.946	1.12486
9522700	2710	3456.10	10.069	1.27160

top forty and the bottom three stations listed in this table. The forty stations chosen by this method for reduced measurement are given in table 8. The first eleven stations are operated out of the Blythe Field Office while the remaining twenty-nine stations are serviced from the Yuma Subdistrict Office.

The uncertainty contributed to the total uncertainty by the posterior variance of these forty discontinued stations is $(27.1\ ft^3/sec)^2$.

Table 9 lists the twenty stations remaining in the reduced network along with several gaging strategies compared with the current operation. Figure 9 graphically displays the possibilities of alternative levels of uncertainties obtainable by using cost-effective visiting strategies for these remaining twenty stations. Figure 10 displays the current operation and the total sixty station network opposed to the reduced network for the constraint of twelve-visits per year.

For a constant budget of $296,500 the reduced network will yield an uncertainty level of 53.2 ft^3/sec for the twelve visits per year constrained solution. The six-visit constraint only yields a further reduction of 0.4 ft^3/sec.

If the uncertainty level is allowed to remain at 117 ft^3/sec a reduction in the budget of $156,500 from the current level of $296,500 can be achieved by a cost effective strategy under a constraint of twelve visits per year. A six-visit per year constraint yields only an additional reduction of $8,400.

These combinations of uncertainties and costs are used for purposes of example. The most desirable strategy may lie anywhere along the curve describing the tradeoff between cost and uncertainty.

Table 8.--Gaging stations of the Lower Colorado River for which reduced measurement frequencies would be most beneficial to the cost effectiveness of the streamgaging network.

Station No.	Station Name
09428505	Gardner Lateral Spill near Poston, Ariz.
09429030	Colorado River Indian Reservation Palo Verde Drain near Parker, Ariz.
09429130	Palo Verde Irrigation District Olive Lake Drain near Blythe, Calif.
09429155	Palo Verde Irrigation District F Canal Spill near Blythe, Calif.
09429170	Palo Verde Irrigation District D-10-11-5 Canal Spill near Blythe, Calif.
09429180	Palo Verde Irrigation District D-23 Canal Spill near Blythe, Calif.
09429190	Palo Verde Irrigation District D-23-1 Canal Spill near Blythe, Calif.
09429200	Palo Verde Irrigation District C Canal Spill near Blythe, Calif.
09429210	Palo Verde Irrigation District C-28 Canal Upper Spill near Blythe, Calif.
09429220	Palo Verde Irrigation District Outfall Drain near Palo Verde, Calif.
09429230	Palo Verde Irrigation District C-28 Canal Lower Spill near Blythe, Calif.
09522600	North Gila Main Canal near Yuma, Ariz.
09522650	North Gila Canal Number 2 near Yuma, Ariz.
09522800	South Gila Canal near Yuma, Ariz.
09523200	Reservation Main Canal near Yuma, Ariz.
09523400	Titsink Canal near Yuma, Ariz.
09523600	Yaqui Canal near Yuma, Ariz.
09423800	Pontiac Canal near Yuma, Ariz.
09523900	Walapai Canal near Yuma, Ariz.
09527900	Mittry Lake Outlet Channel near Yuma, Ariz.
09528600	Laguna Canal Wasteway near Yuma, Ariz.
09528800	Levee Canal Wasteway near Yuma, Ariz.
09529000	North Gila Drain Number 1 near Yuma, Ariz.
09529050	North Gila Drain Number 3 near Yuma, Ariz.
09529150	North Gila Main Canal Wasteway near Yuma, Ariz.
09529160	South Gila Pump Outlet Channel Number 3 near Yuma, Ariz.
09529240	South Gila Pump Outlet Channel Number 2 near Yuma, Ariz.
09529250	Bruce Church Wasteway near Yuma, Ariz.

Station No.	Station Name
09529300	Wellton-Mohawk Main Outlet Drain near Yuma, Ariz.
09529360	South Gila Pump Outlet Channel Number 1 near Yuma, Ariz.
09529400	South Gila Drain Number 2 near Yuma, Ariz.
09529420	South Gila Terminal Wasteway near Yuma, Ariz.
09529440	South Gila Pump Outlet Channel Number 4 near Yuma, Ariz.
09529600	All American Canal Intercept Number 7 near Bard, Calif.
09529700	All American Canal Intercept Number 6 near Bard, Calif.
09529800	All American Canal Intercept Number 2 near Bard, Calif.
09529900	All American Canal Intercept Number 3 near Yuma, Ariz.
09530000	Reservation Main Drain Number 4 at Yuma, Ariz.
09530400	All American Canal Intercept Number 11 near Yuma, Ariz.
09530500	Araz Drain 8-B near Yuma, Ariz.

Table 9.--Gaging strategies for the reduced network serviced jointly from the Blythe Field Office and the Yuma Subdistrict Office showing number of visits per year to each station.

	Visits Per Year				
Station	Six-visit Minimum*	Twelve-visit Minimum*	Current Operation@	Six-visit Minimum+	Twelve-visit Minimum+
09423000	203	201	29	29	28
09423550	6	12	27	6	12
09427520	169	165	29	29	27
09428500	26	26	29	6	12
09428510	30	29	27	6	12
09429000	29	27	27	6	12
09429010	241	237	29	48	45
09429060	10	12	27	6	12
09429490#	0	0	0	0	0
09429500	35	35	27	6	12
09520500	18	18	27	6	12
09522400	6	12	25	6	12
09522500	41	42	39	7	12
09522700	6	12	25	6	12
09523000	128	125	12	6	12
09524000	27	24	27	7	12
09525000	6	12	25	6	12
09525000	6	12	25	6	12
09525500	14	12	27	6	12
09527000	43	40	13	8	13
09527500	6	12	12	6	12
Budget, in Thousands of 1980 Dollars	296.5	296.5	296.5	131.6	140.0
Uncertainty, in ft^3/s	52.8	53.2	117	117	117

*Constant Cost Network

+Constant Uncertainty Network

@Current operation includes costs associated with stations not shown in this reduced network.

#No measurements.

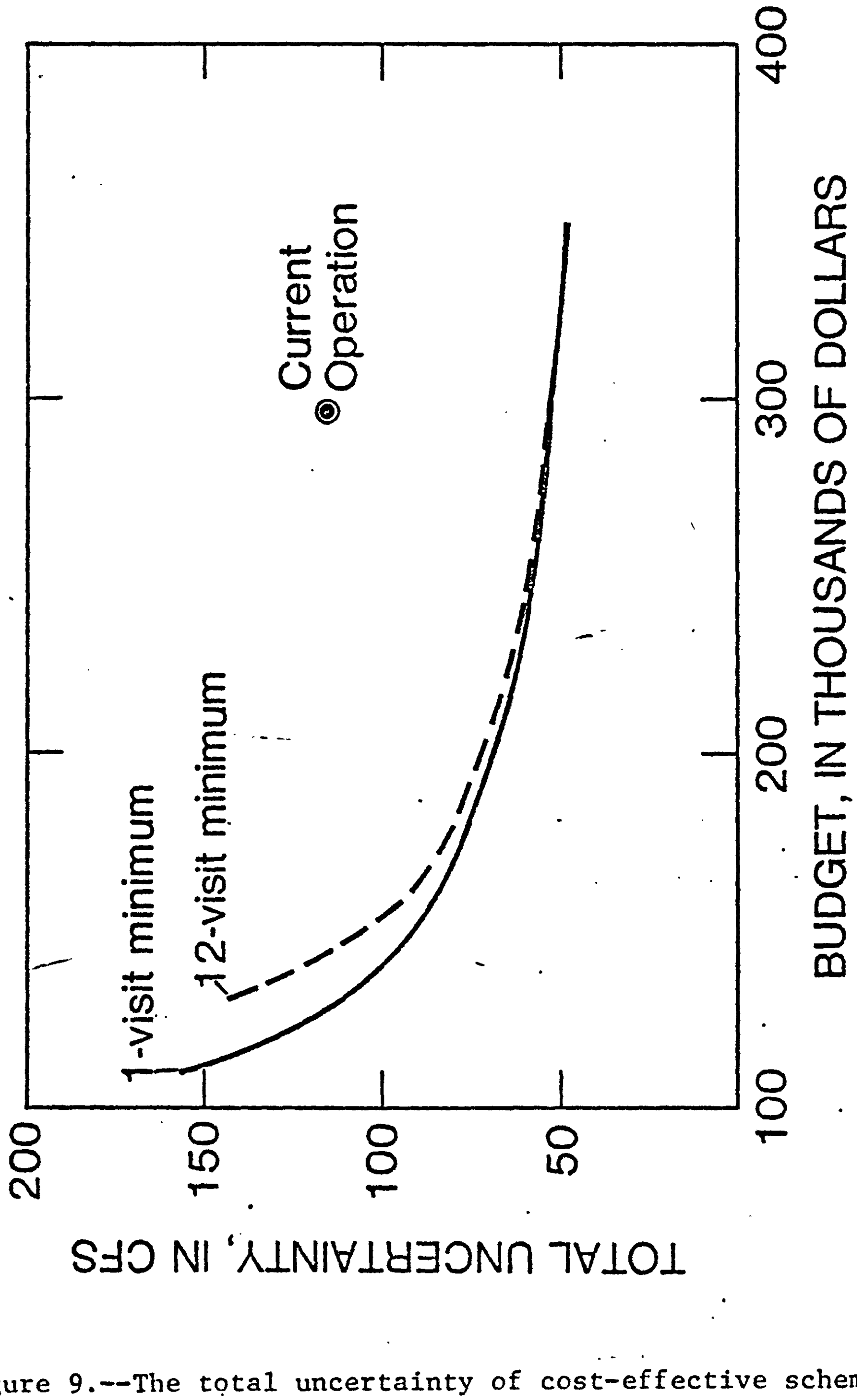

Figure 9.--The total uncertainty of cost-effective schemes and of the current operation of the reduced Blythe-Yuma network operated jointly.

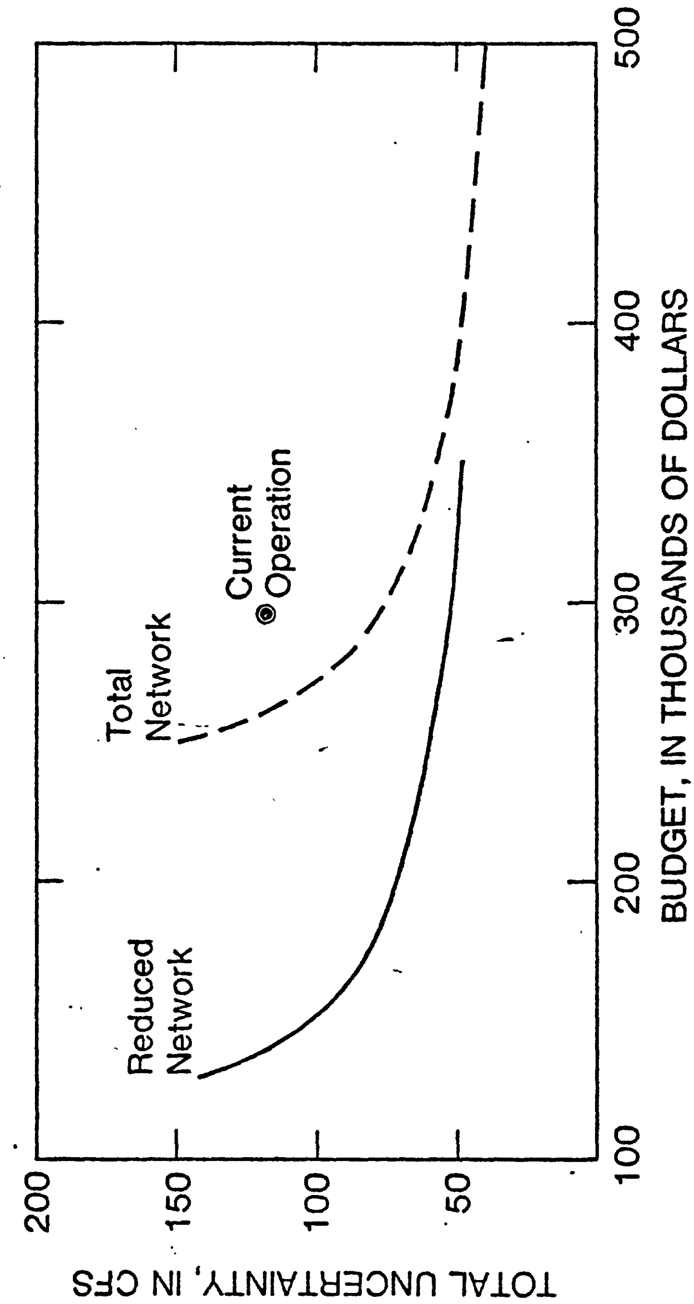

Figure 10.--The total uncertainty of cost-effective schemes and the current operation ofthe total Blythe-Yuma network and the reduced network (12 visits per year minimum).

CONCLUSIONS

The procedures given in Moss and Gilroy (1980) for determining uncertainty-cost relationships were applied to 19 stations serviced from the Blythe Field Office and 41 stations serviced from the Yuma Subdistrict Office. For the disjoint operation of the two networks and a constant budget for each office, cost-effective measurement frequencies were found which reduced the level of uncertainty inherent in the currently used mesurement scheme from 117 ft^3/s to 95.9 ft^3/s if monthly measurements are required and to 88.5 ft^3/s if only six measurements per year are needed. If the combined budget for the two offices is allowed to be allocated to those stations dictated by cost efficiency, then the current level of uncertainty of 117 ft^3/s can be reduced to 77.3 ft^3/s for monthly measurements and to 69.2 ft^3/s for six measurements per year. Further, if measurements are discontinued at forty drains and the historical mean and variance of the annual mean discharge are taken as the appropriate estimators according to a Bayesian estimation scheme, the level of uncertainty can be reduced to 53.2 ft^3/s or 52.8 ft^3/s for monthly and bimonthly visitation schemes respectively in the reduced network. The summary for this constant budget assumption is given in table 10.

Maintaining the current level of uncertainty in the total network can be achieved with reduced budgets of $264,000 for a twelve-visit per year constraint or $245,700 for a six-visit per year constraint as opposed to the current budget of $296,500 if the two sets of stations are operated separately. If the sixty stations are operated jointly from a budgetary stance while still maintaining their current service centers, further savings to $261,000 for a twelve-visit-per-year requirement and to $239,800 for a six-visit-per-year mandate are possible. Again, as in the constant budget case, if measurements

Table 10.--Summary of uncertainty levels in ft^3/s given a constant budget of $296,500 in 1980 dollars for alternative network operations.

	Disjoint Operation	Joint Operation	Joint Operation and 40 Drains Discontinued
CURRENT	117.0	117.0	117.0
12 visits/ year	95.9	77.3	53.2
6 visits/ year	88.5	64.2	52.8

Table 11.--Summary of budgetary levels in thousands of 1980 dollars given a constant uncertainty of 117.0 ft^3/s for alternative network operations.

	Disjoint Operation	Joint Operation	Joint Operation and 40 Drains Discontinued
CURRENT	296.5	296.5	296.5
12 visits/ year	264.0	261.0	140.0
6 visits/ year	245.7	239.8	131.6

at the 40 drains are discontinued, the present budget of $296,500 can be reduced to $140,000 and to $131,600 for the twelve- and six-visits-per-year constraints respectively, while still maintaining the current level of uncertainty in the estimates of the annual mean discharge at all 60 stations. Table 11 summarizes these constant uncertainty results.

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