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Sediment Transport in the Lower Guadalupe and San Antonio Rivers

E. Holley

Texas Water Resources Institute

Texas A&M University

Technical Report No. 154

SEDIMENT TRANSPORT IN THE LOWER GUADALUPE AND SAN ANTONIO RIVERS

by

Edward R. Holley

This report is a joint effort between the Texas Water Resources Institute, Texas A&M University, and the Center for Research in Water Resources, The University of Texas at Austin. It is also published in identical form by CRWR as Technical Memorandum 92-1.

TEXAS WATER RESOURCES INSTITUTE
Texas A&M University
College Station, Texas 77843-2118

January 1992

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Research Project Completion Report

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CENTER FOR RESEARCH IN WATER RESOURCES

Bureau of Engineering Research • The University of Texas at Austin
Balcones Research Center • Austin, Texas 78712

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RESEARCH PROJECT COMPLETION REPORT

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SEDIMENT TRANSPORT IN THE LOWER GUADALUPE AND SAN ANTONIO RIVERS

by

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ABSTRACT

Texas law requires that fresh water inflows into coastal regions be maintained at adequate levels for an ecologically sound environment; however, very limited data are available on the relation between river flow and sediment transport to coastal regions. This study was undertaken to analyze existing data and to collect field data for the lower part of the Guadalupe River and the San Antonio River. The primary sampling locations were at the U. S. Highway 59 bridges in Victoria for the Guadalupe River and in Goliad for the San Antonio River.

No existing data on bedload transport were located. The first part of the analysis of existing data therefore centered on possible correlations of suspended sediment concentrations with simultaneous flow rate, with flow rates which occurred before the sediment concentrations were measured, with particle fall velocity, and with the phase of the hydrograph when the sediment samples were collected. The primary correlation was between the concentration and the simultaneous river flow rate. Even though there is a large amount of scatter in this correlation, none of the other variables was important enough for all of the data to provide any reduction in the scatter. The second part of the analysis of existing data related to which percentage of the flows carries which percentage of the suspended sediment. This analysis confirmed the conventional wisdom that the large majority of the suspended sediment is carried by the infrequent large flows.

Because of the very low flows which existed during most of the project period, somewhat more emphasis than originally planned had to be placed on the analysis of existing data. Nevertheless, several sets of field data were collected. A pumping sampling system was tested in order to provide enough sediment for grain size analysis. The concentrations of the pumped samples compared favorably with the traditional P-61 sampling technique. Therefore, this system was used for some of the samples. A few bedload samples were collected. Very limited data indicated that the bedload transport rates are much smaller than the suspended load transport rates. The two largest sets of data were collected on the Guadalupe River at Victoria in April 1990 and on the San Antonio River at Goliad in July 1990. The grain size distributions for various phases of the hydrographs showed very little variations, and there were also very small differences in the suspended grain sizes for the Guadalupe and San Antonio Rivers. For the particular events sampled during these two field trips, there appeared to be a good correlation between the flow rate and the sediment concentration for the test on the Guadalupe River while there was clearly a significant lag between the flow hydrograph and the suspended sediment hydrograph for the San Antonio River.

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1. INTRODUCTION

1.1 BACKGROUND

House Bill 2 of the 69th Texas Legislature says that "...a salinity, nutrient, and sediment loading regime [from freshwater inflows] adequate to maintain an ecologically sound environment in the receiving bay and estuary system..." must be maintained. Furthermore, the Texas Water Code refers to maintaining beneficial inflows, and in Section 11.147(a) states: "In this section, 'beneficial inflows' means a salinity, nutrient, and sediment loading regime adequate to maintain an ecologically sound environment in the receiving bay and estuary that is necessary for the maintenance of productivity of economically important and ecologically characteristic sport or commercial fish and shellfish species and estuarine life upon which such fish and shellfish are dependent." Many potential impacts on coastal waters due to possible changes in the freshwater inflows have been studied, but sediment loading from streams has received essentially no previous attention. Sediments are a necessary part of the water quality since they play an important role in maintaining the habitat and productivity of various species of fish, shell fish, aquatic organisms, etc. Previous suspended sediment data have typically been collected by the U. S. Geological Survey (USGS) at most monthly to quarterly, or by state agencies using a single measurement point at a cross section with extrapolation to estimate the total suspended sediment load. Bed load data have not been collected regularly, if at all. Furthermore, very few measurements have been made on grain sizes and size distributions, which are important in relation to how rapidly the sediments might be deposited after the river enters an estuary or a bay. No correlations have been done between sediment loads and stream flow rates or other significant variables.

1.2 OBJECTIVES

The primary objectives of this project were to investigate correlations between sediment transport and river hydraulics using previously collected data and to conduct field experiments to measure the amount and characteristics of both bed and suspended sediments entering one of the Texas bays for a variety of flow conditions.

1.3 SAMPLING LOCATIONS

The lower parts of the Guadalupe and San Antonio Rivers were chosen for this project because of the proposed Cuero 1 and Cuero 2 reservoir projects in the Guadalupe watershed and the proposed Applewhite reservoir project in the San Antonio watershed. The sampling locations were selected at the U. S. Highway 59 bridges in Victoria on the Guadalupe River and in Goliad on the San Antonio River (Fig. 1.3.1). These specific locations were chosen because they are the farthest downstream locations of USGS gaging stations which are also upstream of the confluence of the two rivers so that data could be collected for the two rivers separately. Measurements were made from the bridge in Victoria and from the USGS cableway just upstream of the bridge in Goliad. During the early part of the project, sampling from the State Highway 35 bridge was also considered, but this location was not used because there are two factors which mean that the flow at this location is not a natural riverine flow. One factor is that this location frequently has tidal influence so that the velocity may be near zero or directed upstream. The second factor is that there is an inflatable dam which is located between the Highway 35 bridge and the confluence of the Guadalupe and San Antonio Rivers and which is used for control of salinity intrusion.

The periods of record for gaging are 1934 to present for the Guadalupe River at Victoria and 1924 to 1929 and 1939 to present for the San Antonio River at Goliad. The statistics for Victoria are average flow rate = 1626 cfs before 1962 when regulation at Canyon Lake began and 1982 cfs after 1962; maximum flow rate = 179,000 on July 3, 1936 (before Canyon Dam was built); maximum flow rate after Canyon Dam was built = 105,000 cfs on September 2, 1981; and minimum flow = 14 cfs on August 20, 1956 (before Canyon Dam was built). At Goliad, average flow rate = 685 cfs; maximum = 138,000 cfs on September 23, 1967; and minimum = 1.2 cfs on June 16, 1956. These statistics are from Buckner et al. (1989) and from the Texas District Office of the USGS and are instantaneous values, not daily averages.

The drainage areas above the Victoria and Goliad gages are, respectively, 5198 mi^2, with 1432 mi^2 above Canyon Dam, and 3921 mi^2 (Buckner et al., 1989). Based on the daily average flows at the two stations, the frequency of occurrence of the daily discharges for 1966-1989 are given in Table 1.3.1 and are shown by the two curves on the left side of Fig. 1.3.2. (See Section 2.2 for the source of the data.) The flows during this period varied from 42 cfs to

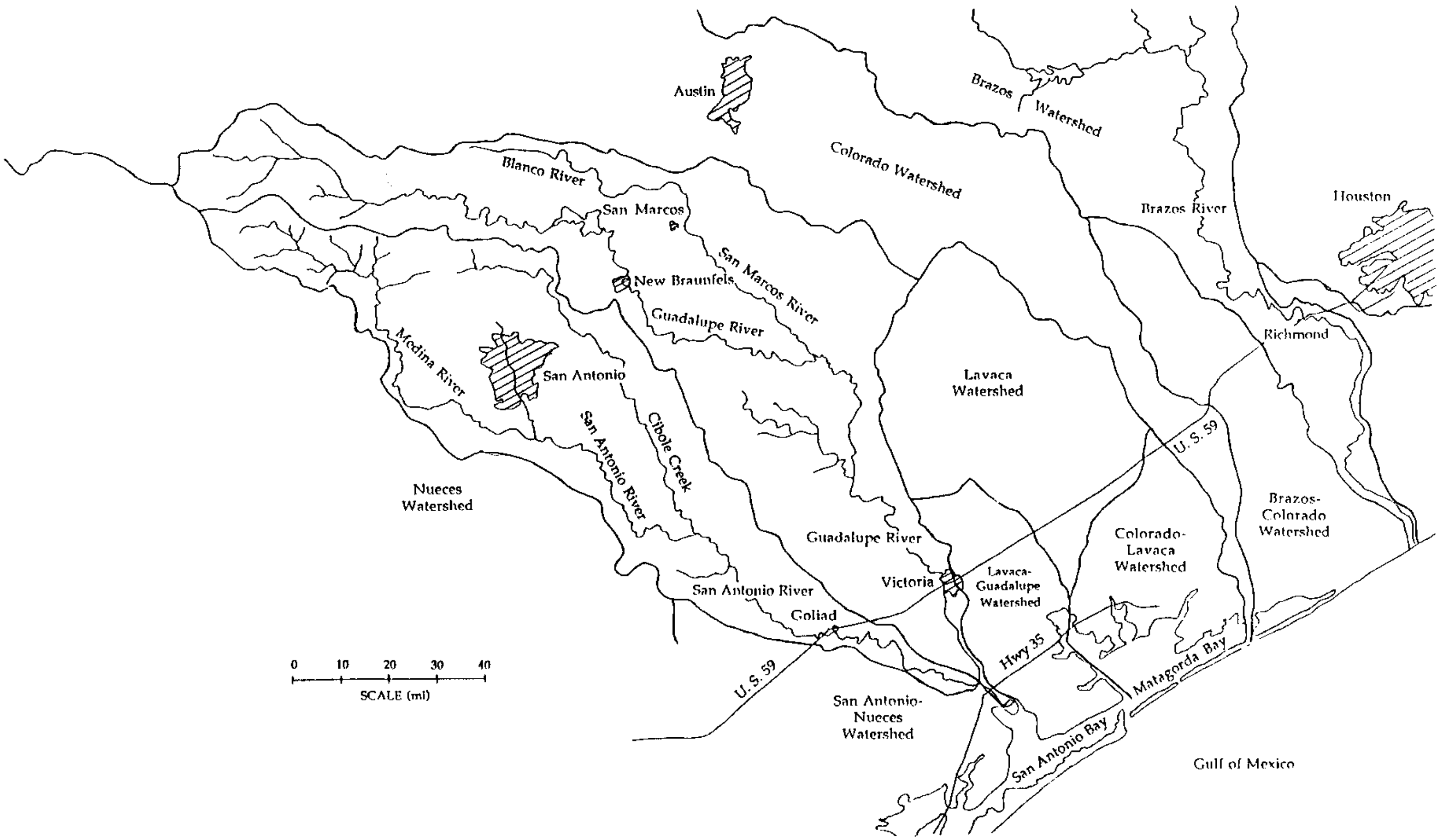

Fig. 1.3.1 - Watershed Map

Table 1.3.1 - Frequency of Occurrence of Daily Flow Rates for 1966-1989

Percent smaller	Flow Rates (cfs) Guadalupe River	San Antonio River
1	130	103
3	321	142
5	435	162
10	558	201
15	650	236
20	731	268
25	798	301
30	852	331
35	907	362
40	981	387
45	1080	415
50	1210	453
55	1350	496
60	1510	534
65	1680	594
70	1860	669
75	2080	785
80	2390	921
85	2900	1150
90	3940	1530
95	6740	2690
98	11100	5550
99	17000	8610
99.9	47200	25900
100	86900	121000

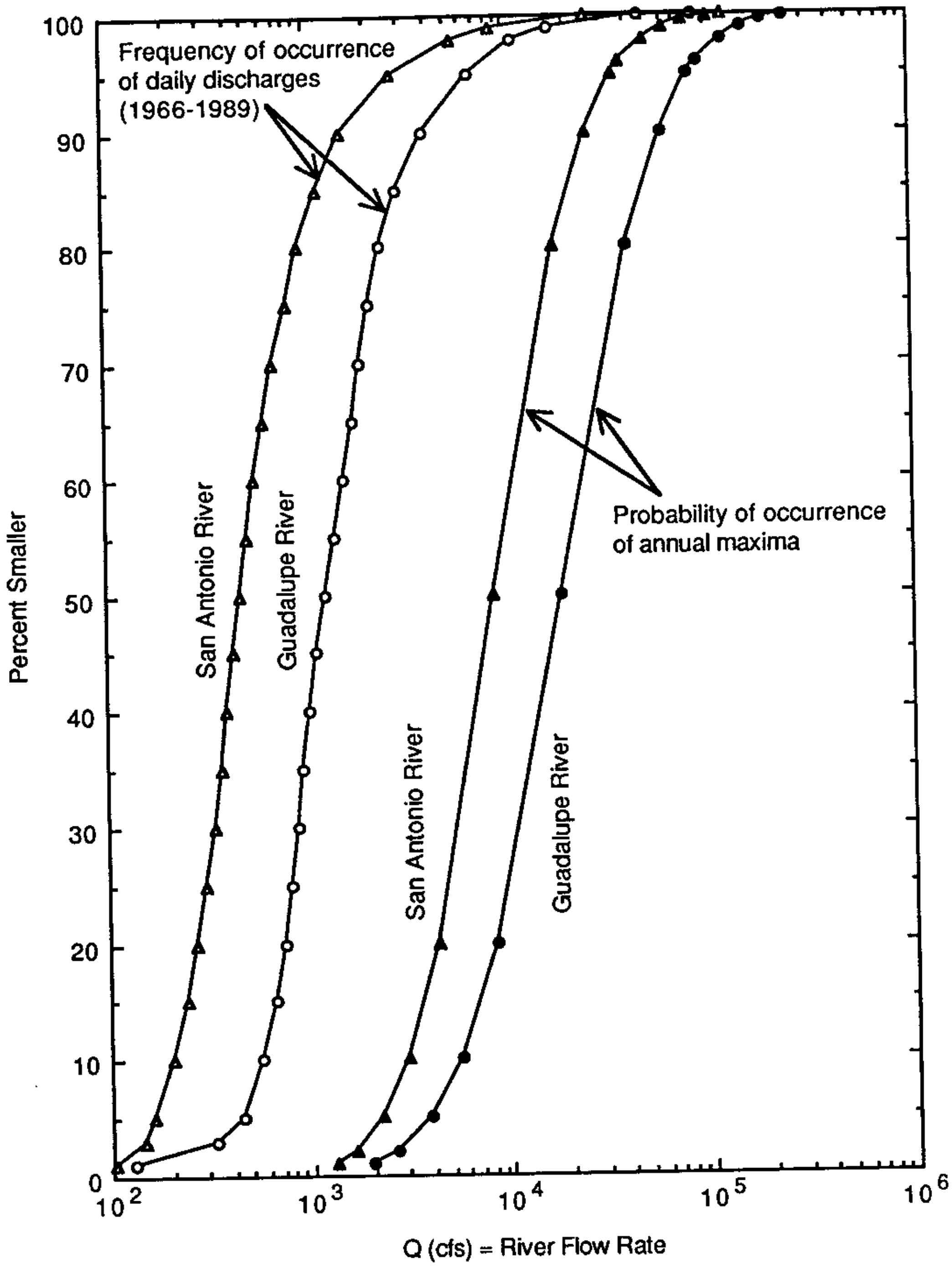

Fig. 1.3.2 - Discharge Probabilities

86,900 cfs for the Guadalupe at Victoria and 44 cfs to 121,000 cfs for the San Antonio at Goliad. For a given frequency of occurrence, the flows in the Guadalupe River are slightly less than twice as large as the flows in the San Antonio River. There can be significant intraday variations in the flow rates at the two stations, particularly when there is rainfall just upstream of the gaging stations and the flows from farther upstream are low. An example of flow readings at four-hour intervals is given in Fig. 1.3.3. Note that the flow went from 460 cfs to 2690 cfs in 18 hours. (The data in this figure are preliminary, uncorrected readings which were obtained on April 25, 1990.

The two curves on the right side of Fig. 1.3.2 are from the probability of occurrence of the annual maxima for the Guadalupe River at Victoria and the San Antonio River at Goliad as calculated by the Texas District Office of the USGS. (The data before and after construction of Canyon Dam on the Guadalupe River were all taken together in the analysis of annual maxima flows for the Guadalupe River.) For the annual maxima, the data are presented in Fig. 1.3.2 in terms of the percent of the annual maxima smaller than a given value. Having 80% smaller than a given discharge means that there is a 20% chance of that flow being exceeded or that the given flow has a five year return period. The same data are given in Table 1.3.2. Note that the maximum instantaneous flow of 138,000 cfs which occurred during this period has a probability of occurrence of less than 0.002 or a return period of greater than 500 years.

Because of unusually low flow conditions in the Guadalupe and San Antonio Rivers during a major part of this project (Figs. 1.3.4 and 1.3.5), some developmental tests were done in the Brazos River during the early part of the project. Also, the relative emphasis of the work was shifted so that somewhat greater emphasis than originally planned had to be given to analyzing existing data and somewhat less emphasis to collecting additional data. Nevertheless, several field trips were made and samples were collected during some large flow events.

2. ANALYSES OF EXISTING DATA

2.1 OBJECTIVE OF ANALYSES

The river flow rate (Q) is perhaps the most obvious variable with which to expect the suspended sediment concentration (C) to be correlated.

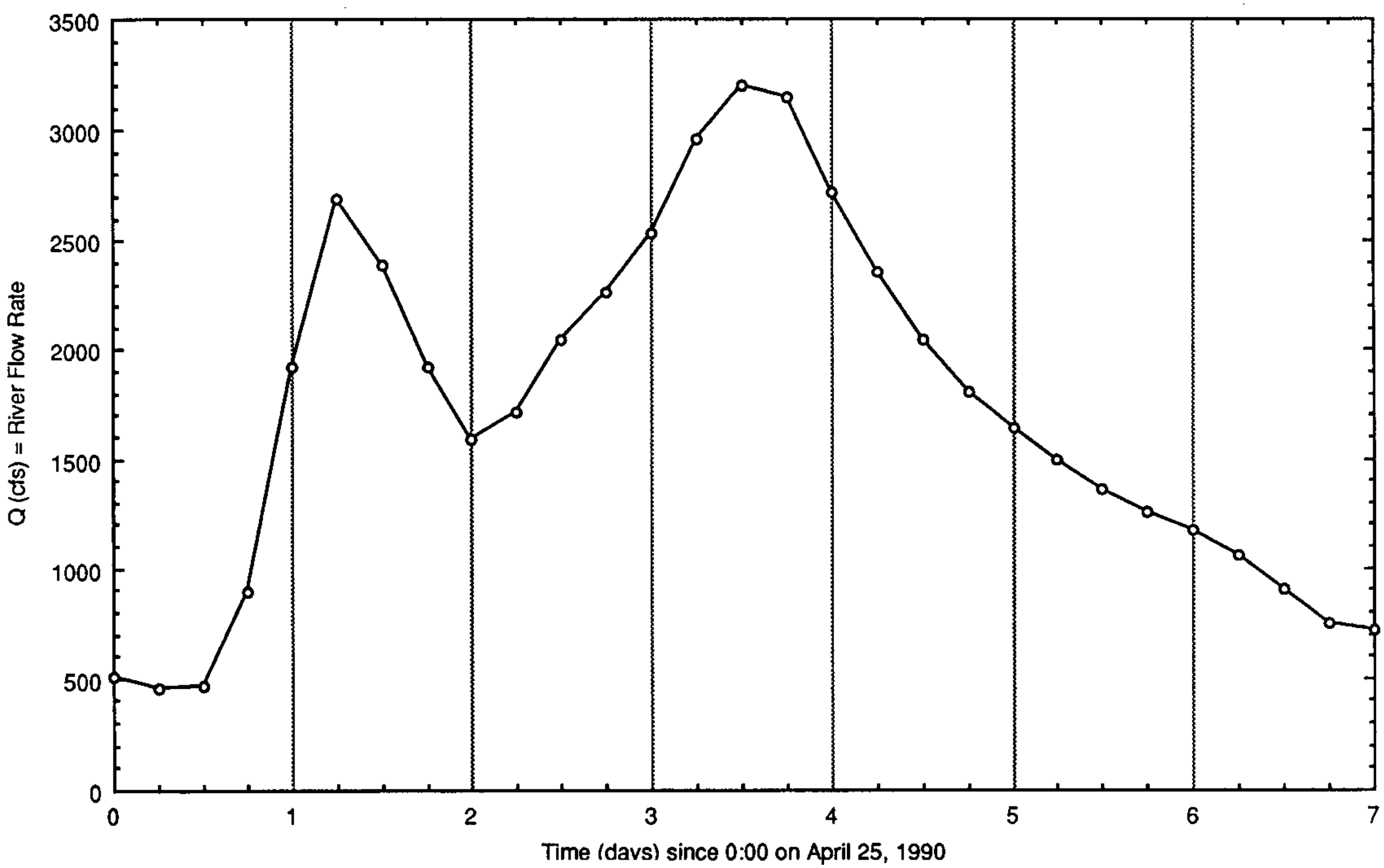

Fig. 1.3.3 - Intraday Variations in Flow Rate for Guadalupe River at Victoria

Table 1.3.2 - Distribution of Annual Maximum Flow Rates

Percent smaller	Probability of Occurrence	Return Period (years)	Flow Rates (cfs) Guadalupe River	Flow Rates (cfs) San Antonio River
1	0.99	1.01	1950	1290
2	0.98	1.02	2550	1590
5	0.95	1.05	3810	2200
10	0.9	1.11	5430	2950
20	0.8	1.25	8300	4210
50	0.5	2	18400	8450
80	0.2	5	40300	17300
90	0.1	10	60200	25200
95	0.05	20	83700	34600
96	0.04	25	92000	38000
98	0.02	50	121000	49700
99	0.01	100	154000	63400
99.5	0.005	200	192000	79300
99.8	0.002	500	250000	104000

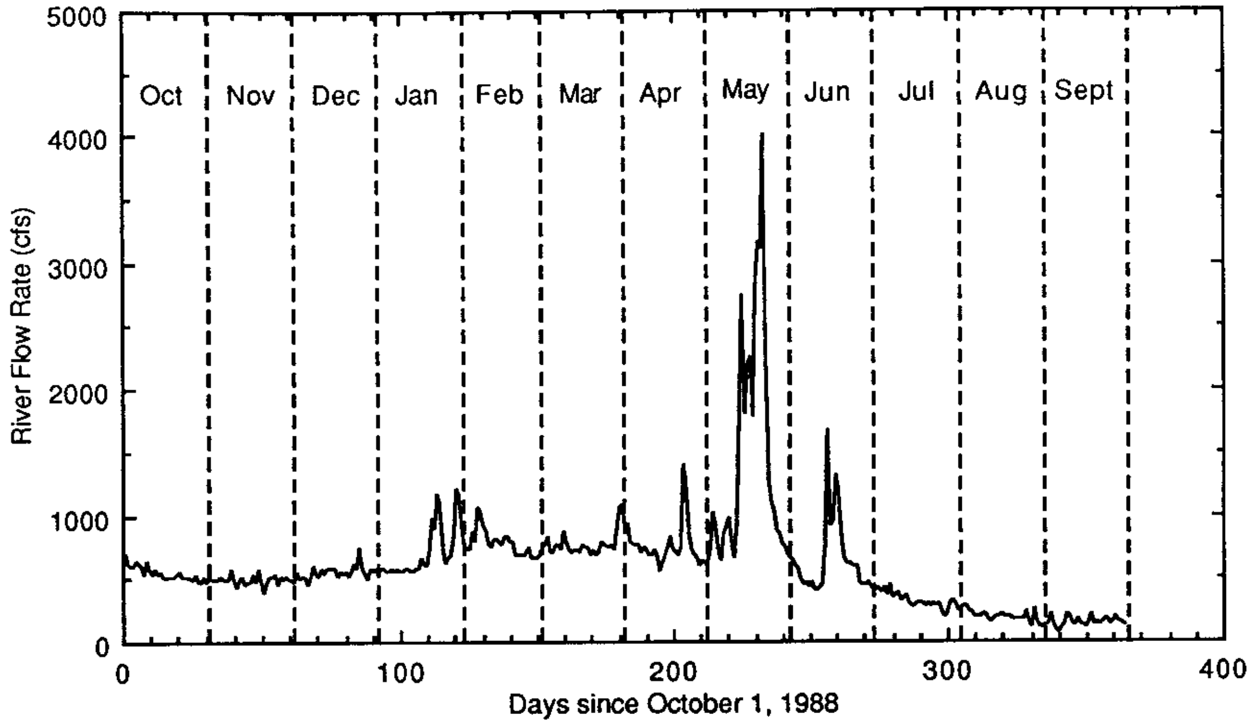

Fig. 1.3.4a - Daily Flows in Guadalupe River at Victoria for Water Year 1989

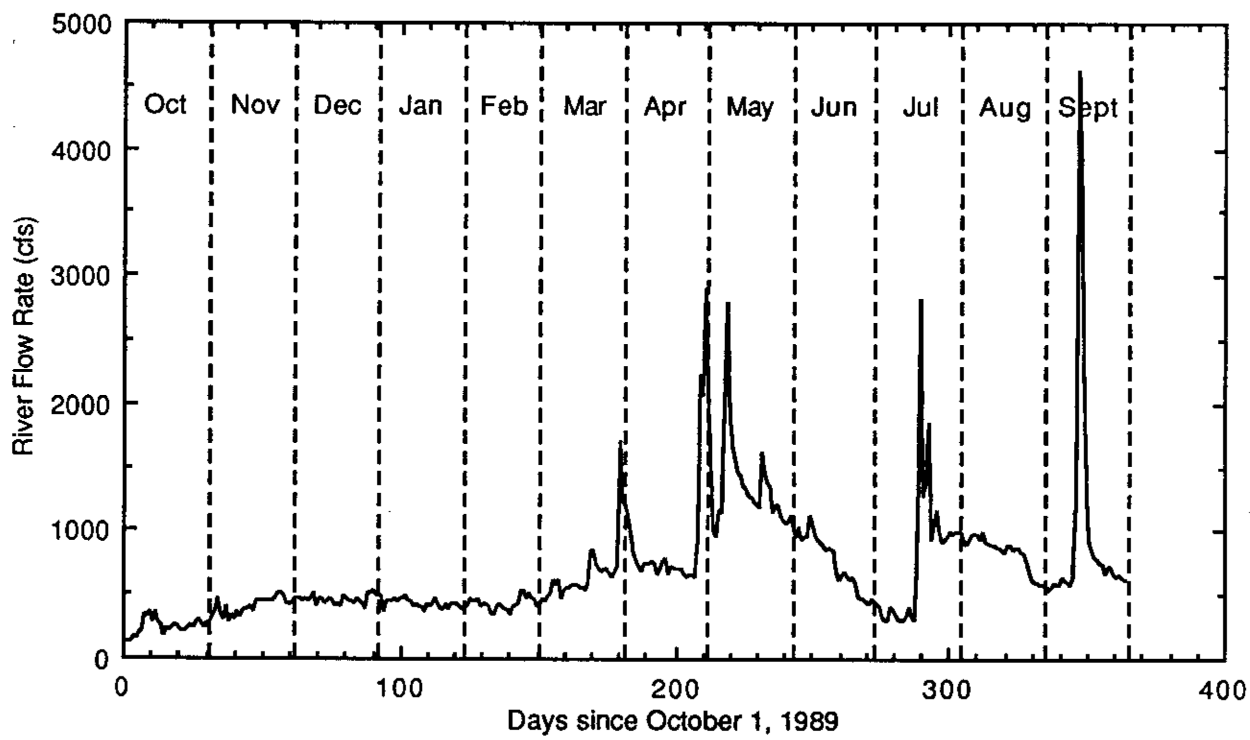

Fig. 1.3.4b - Daily Flows in Guadalupe River at Victoria for Water Year 1990

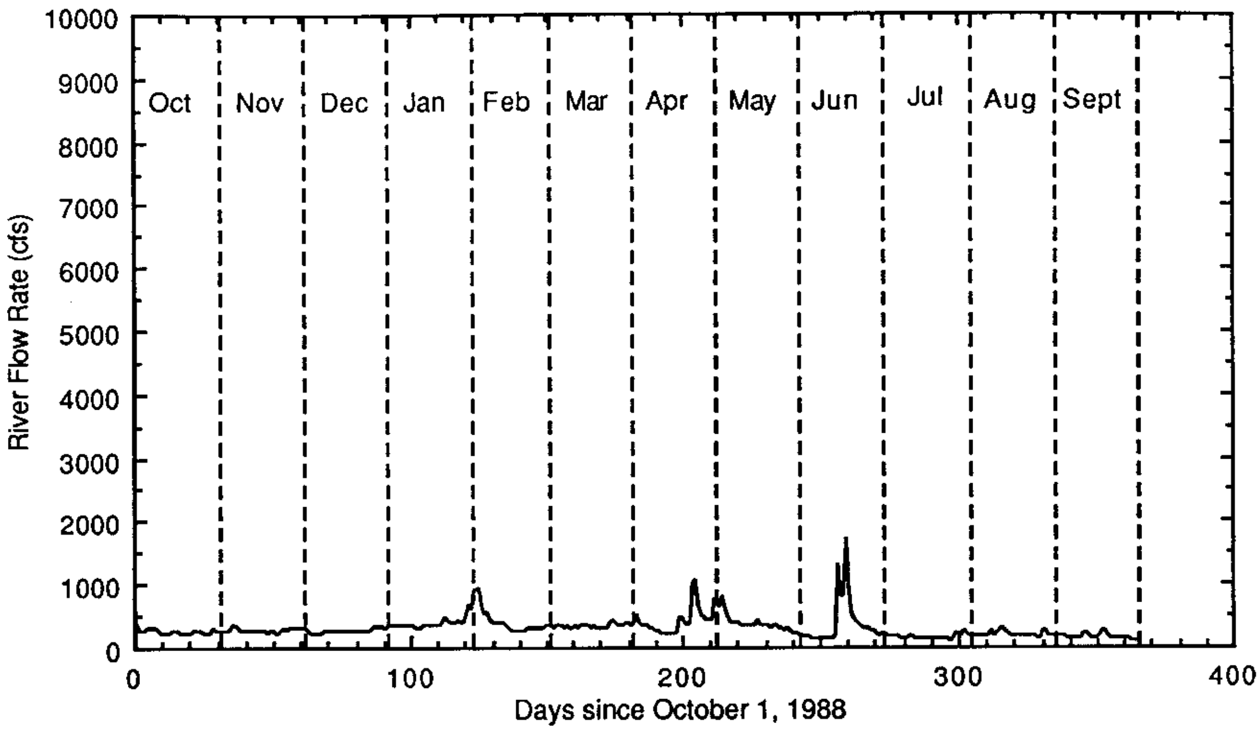

Fig. 1.3.5a - Daily Flows in San Antonio River at Goliad for Water Year 1989

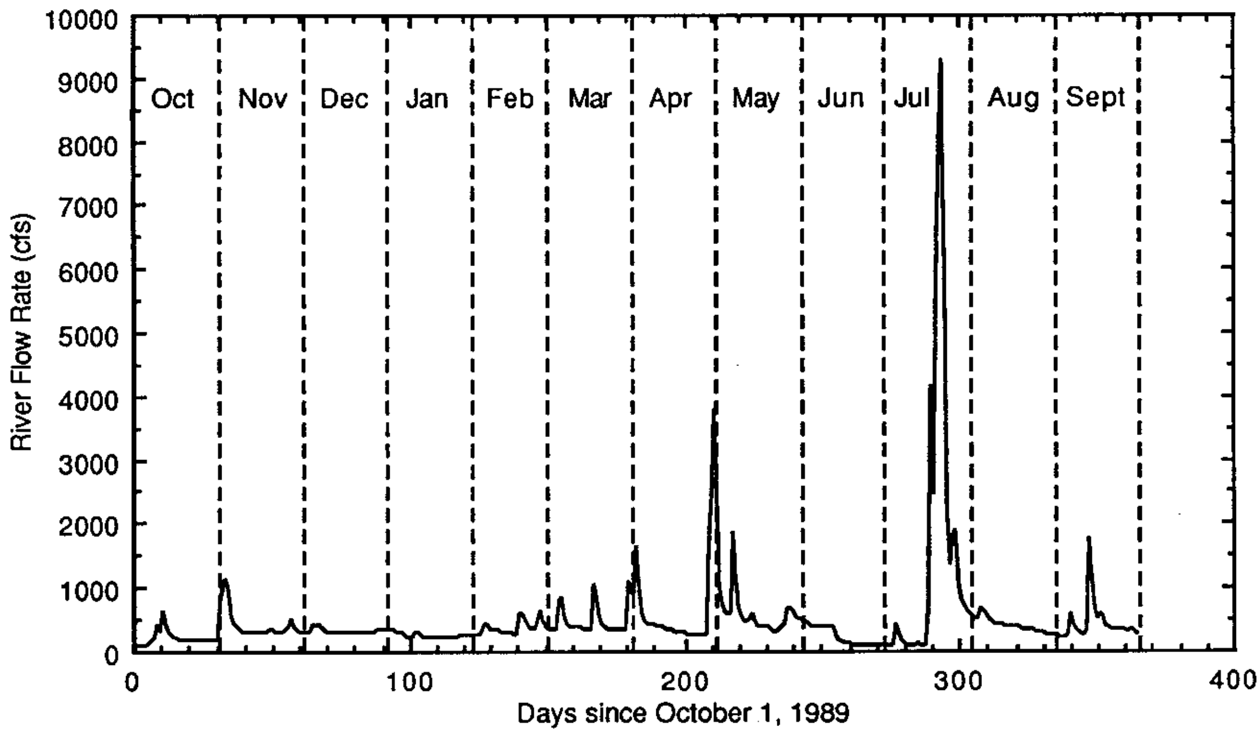

Fig. 1.3.5b - Daily Flows in San Antonio River at Goliad for Water Year 1990

Although there is a strong correlation between C and Q, the scatter in the graphs of C versus Q is about a factor of 10 (Section 2.3). Thus, it was decided to investigate the possible dependence of the concentration on other variables. The additional analyses were concerned with a possible lag in the correlation between C and Q (Section 2.4), the fall velocity of the particles (Section 2.5) as represented by the grain sizes and the water viscosity, and the phase of the hydrograph when the sediment samples were collected (Section 2.6). A summary discussion of the various possible effects is given in Section 2.7. The last objective of the analyses was to investigate the relationship between the cumulative sediment load and the frequency of occurrence of the flow rates (Section 2.8).

2.2 SOURCES OF DATA

Two primary sources were located for existing data on suspended sediment transport at the two stations of interest. No data on bedload transport were located. The primary source was the U. S. Geological Survey's data for the gaging stations at Victoria and at Goliad. These two stations are part of the National Stream-Quality Accounting Network. Data are collected on many water quality parameters, including suspended sediment, at these stations approximately once each quarter of the year. Buckner et al. (1989) stated that "suspended-sediment concentrations are determined from samples collected by using depth-integrating samplers. Samples usually are obtained at several verticals in the cross section, or a single sample may be obtained at a fixed point and a coefficient applied to determine the mean concentration in the cross sections." Multiple samples are composited, and the concentration of sediment is then measured. The fraction of the sediment smaller than 0.062 mm is also determined. No other analyses are done on the sediments on a routine basis. A computer file containing the data from 1972 to 1988 (the latest data available at the time of the analysis) was obtained from the Texas District Office of the USGS. The USGS data used in the analysis are given in Tables 2.2.1 and 2.2.2. For the Time column in these tables, the first three digits give the year without the leading 1, the next four are the month and day, and the last four are the military or 24-hr time.
The second source was data collected by the Texas Water Development Board during the period 1965-1975 (Mirabal, 1974; Dougherty, 1979). Even though these data were collected monthly, they were used primarily in the early

Table 2.2.1 - USGS Data for Guadalupe River at Victoria

Time	River Flow (cfs)	Temp (°C)	% smaller than 62 µm	Conc (mg/L)	Time	River Flow (cfs)	Temp (°C)	% samller than 62 µm	Conc (mg/L)	Time	River Flow (cfs)	Temp (°C)	% smaller than 62 µm	Conc (mg/L)
97301081410	1030	10.5		34	97611190905	2600	12.5	81	79	98012091330	848	17.0	96	16
97302141200	1270	13.5		52	97612161220	8300	13.0	90	205	98101071335	828	13.5	44	35
97303121220	1510	21.0		67	97701131815	2800	11.5	71	55	98102041045	807	12.5	63	45
97304170800	14300	19.0		709	97702171300	4400	15.5	74	90	98103051005	1120	18.5	79	59
97306251430	3880	25.5		281	97703171645	2200	21.0	82	66	98104091430	1270	22.5	90	134
97307261400	5540	28.0		272	97704141155	1900	22.0	78	81	98105150940	1560	24.0	94	102
97308291230		28.5	76	94	97705121830	5200	24.0	85	221	98106221407	16500	27.0	87	255
97309251700	1820	29.0	90	66	97706091345	2800	29.0	85	77	98107170851	2830	28.0	77	193
97310241620	7400	23.0	96	137	97707141700	1800	30.0	94	57	98108210930	2220	27.5	89	146
97311131700	2860	21.0	70	128	97708181430	1170	30.0	86	86	98109181000	2070	24.0	71	135
97312111245	2030	16.0	90	38	97709151510	1700	28.5	91	110	98111190850	2160	20.0	87	112
97401151820	3800	15.0		310	97710201525	870	23.5	80	90	98202101230	1070	10.5	70	57
97402201530	1680	19.0		32	97803161535	891	18.5	80	28	98203301840	936	20.0	66	96
97403191500	1390	24.0	77	40	97804241245	2800	22.0	97	431	98205031700	903	25.0	92	55
97404231145	1140	25.0	55	35	97805221245	736	28.5	86	13	98207261800	575	32.0	70	103
97405211050	1630		88	88	97806121155	1480	29.5	98	205	98209011445	457	30.5	77	74
97406251500	1130	30.0	90	52	97807171245	601	31.0	66	42	98210141500	806	21.0	66	78
97407231410	773	31.0	97	48	97808221130	5140	27.5	91	295	98301121700	565	14.0	42	33
97408281010	835	29.0	93	31	97809261320	2190	25.5	40	352	98304121800	1400	21.0	84	89
97409241305	2250	24.0	90	89	97810171330	1370	22.0	89	32	98308231200	563	31.0	90	64
97410231150	1230	22.0	82	26	97811071445	1720	19.5	94	187	98310121820	529	24.0	89	21
97411141330	3600	17.0	99	123	97812201350	957	17.0	43	21	98401171800	572	8.0	88	26
97412111335	2890	14.0	99	574	97901161445	3750	7.5	93	350	98404110915	502	22.0	67	73
97501301340	1900	20.0	89	22	97902211400	2450	13.0	93	78	98407111145	185	29.5	47	62
97502201445	5300	16.5	97	379	97903201633	2010	19.5	74	73	98410171610	1400	23.5	97	608
97503271425	2050	22.0	78	67	97904101330	3290	20.0	90	162	98501231700	1820	7.0	91	147
97504231440	1650	23.5	95	170	97905091645	4160	23.0	94	223	98505081030	1300	25.5	100	144
97505221415	2900	26.5	55	602	97906051450	5500	25.0	91	195	98507100930	2800	28.0	99	192
97506181445	6200	28.0	98	168	97907120903	2170	27.0	85	141	98510101000	922	24.5	96	64
97507171420	3120	27.0	77	498	97907311001	3800	28.5	96	299	98601161600	1470	13.0	81	46
97508201300	1840	30.0	75	40	97908291415	1460	28.0	90	64	98604231300	960	23.5	65	110
97509181400	1390	28.0	87	19	97910021308	1060	26.0	62	79	98609031830	463	30.0	93	41
97510231100	920	23.5	85	18	97911060957	940	19.5	76	83	98610231530	3660	23.0	76	114
97511201145	910	19.0	82	24	97912120917	783	15.0	42	65	98702111130	2110	16.0	88	52
97512101420	873	17.0	92	11	98001170935	776	16.5	63	77	98706231645	8520	28.0	95	331
97601221250	1070	14.5	69	9	98002120920	1070	10.5	92	63	98708191630	3260	28.0	93	135
97602260930	800	17.5	77	25	98003111540	821	20.0	70	51	98710141705	1320	22.5	83	55
97603251610	940	22.5	94	29	98004081450	763	22.0	90	53	98803011530	871	21.0	61	75
97604291335	3820	23.5	86	327	98005061435	708	26.0	70	75	98806291700	794	31.0	90	72
97605271145	3950	24.5	95	317	98006110830	1220	27.0	86	99	98808101550	1140	32.0	90	153
97606241135	2040	28.0	88	56	98007091420	726	31.5	98	63					
97607211530	2720	28.0	95	129	98008071045	399	30.0	89	72					
97608191300	1640	29.0	95	67	98009101438	7600	25.0	84	1210					
97609231605	1390	27.0	96	52	98010151100	786	25.0	77	54					
97610211215	3700	17.0	93	319	98011131355	770	20.0	73	32					

Table 2.2.2 - USGS Data for San Antonio River at Goliad

Time	River Flow (cfs)	Temp (°C)	% smaller than 62 µm	Conc (mg/L)
97210301230				742
97304181040		19.0		1260
97309171400				1720
97410240900	550	21.0	97	102
97411141245	858	16.5	99	145
97412120900	680	12.0	100	885
97501301300	650	21.0	97	111
97502210925	1350	17.5	95	250
97503271345	700	22.5	97	160
97504240930	620	24.0	97	138
97505221330	780	27.0	99	231
97506181400	1250	29.5	96	322
97507171340	871	26.5	99	187
97508210910	483	28.5	96	95
97509181320	517	27.0	99	700
97510221555	378	22.5	98	92
97511201415	375	19.0	97	71
97512101255	382	16.0	93	54
97601211410	405	14.0	95	67
97602251350	316	17.0	97	78
97603241350	305	20.5	92	398
97604281450	1120	24.0	98	493
97605261435	969	26.0	95	475
97606231425	516	29.5	98	137
97607211410	1260	28.0	95	417
97608181245	454	28.5	92	152
97609221400	1030	25.5	98	740
97610201510	1260	18.0	100	701
97611181550	1240	13.0	90	163
97612151400	2830	13.5	97	564
97701121415	1160	11.0	87	145
97702161340	1490	15.5	89	226
97703161525	973	21.0	93	122
97704131400	776	22.0	92	169
97705111440	1640	25.0	95	355
97706081300	1240	28.0	98	276
97707131440	621	30.0	96	109
97708171410	473	30.0	92	100
97709141510	544	28.0	94	112
97710191415	398	22.0	91	65
97711091615	1240	18.0	98	1240
97712081245	562	17.0	95	61
97801251440	481	11.5	77	67
97802161530	788	13.5	94	130
97803151455	532	20.0	96	78

Time	River Flow (cfs)	Temp (°C)	% samller than 62 µm	Conc (mg/L)
97804251600	2080	22.5	97	2450
97805231300	532	28.5	92	295
97806281000	371	29.5	88	87
97807190815	168	29.0	99	84
97808231215	787	29.5	97	181
97809280900	957	24.0	85	265
97810181030	610	19.0	36	243
97811080955	4420	16.5	94	2350
97812191345	544	17.0	93	46
97901171010	1080	10.5	91	358
97902221330	911	16.0	91	125
97903211637	1110	20.5	97	1380
97904101015	1520	20.5	93	260
97905081555	1630		99	100
97905091130	1650	23.5	87	390
97906060950	5940	23.0	73	706
97906061515	5750		85	77
97907111130	908	75	124	
97907301715	1800		96	106
97908011138	971	29.0	93	442
97908281005	660	28.0	96	148
97908281355	644		82	68
97910031154	342	25.0	97	67
97911051405	422	19.0	95	57
97912051338	456	16.5	96	54
98001151440	504	16.0	96	66
98002131444	504	13.0	85	55
98003101410	270	19.5	88	15
98004091240	386	21.0	97	113
98008051200	235	29.0	100	101
98009091115	7620	25.0	81	905
98010141330	243	24.0	100	50
98012100925	418	16.0	100	66
98101081050	361	13.0	97	60
98102021440	397	15.0	92	79
98103031355	503	19.0	92	69
98104100915	270	23.0	99	81
98105141232	425	25.0	65	186
98106231205	10400	29.0	88	262
98107161315	1350	29.0	90	380
98108201120	473	28.0	98	179
98109181350	1140	25.0	97	361
98111161330	693	21.0	87	149
98203291430	486	18.0	86	80
98205031524	315	25.0	96	51

Time	River Flow (cfs)	Temp (°C)	% smaller than 62 µm	Conc (mg/L)
98207261540	245	31.0	99	104
98208311810	246	30.5	98	85
98210131135	1620	17.5	83	1460
98301101630	406	14.0	82	57
98302221610	457	17.0	99	142
98304111800	320	22.0	58	138
98307111320	225	29.0	95	176
98310111410	329	25.0	93	66
98401161650	310	9.0	87	105
98402280900	321	13.0	98	63
98404091510	257	23.0	97	83
98407091450	145	30.0	96	78
98408211000	210	28.5	94	186
98410171200	1500	23.0	98	1840
98501221500	683	6.5	96	189
98503111500	411	24.0	97	70
98505071640	320	29.0	99	86
98507081355	3900	29.0	97	647
98510091415	290	23.5	99	98
98601141450	427	13.0	75	56
98602251600	313	18.5	95	38
98604231130	225	24.0	93	66
98607161000	468	28.0	95	208
98609031015	275	29.0	95	121
98610211115	612	21.5	100	234
98612081500	418	17.5	96	47
98702101230	1160	15.0	95	201
98704141415	816	21.0	80	89
98706231130	5960	28.0	96	793
98708181600	726	30.5	100	125
98710131500	448	23.0	98	85
98712141530	482	17.5	65	87
98803011135	485	21.0	94	62
98804121640	494	19.5	94	103
98806281400	219	31.0	91	104
98808091110	307	30.5	90	89

stages of planning the research rather than for detailed analyses. The primary reasons were that

(1) the average concentrations were obtained from one measurement which was extrapolated to an average concentration. Mirabal (1974) stated: "Samples were collected ... approximately 1 foot below the water surface near midstream. The percentage of suspended sediment by weight obtained from the sample is multiplied by the factor 1.102 to obtain the mean percentage of suspended sediment in the vertical profile."
(2) the period of record was not as great as for the USGS data,
(3) the data were presented as total sediment load for each month, but no explanation was given on how frequently sampling was done nor on how the individual samples were used to calculate the total load for the month, and
(4) there were no accompanying records of grain size or water temperature.

2.3 EFFECT OF SIMULTANEOUS RIVER FLOW RATES

The effect of river flow rates on suspended sediment is sometimes shown by a plot of suspended sediment load versus flow rate. Such graphs frequently appear to have a stronger correlation than actually exists, since the load is obtained as the product of two other directly measured variables, namely the concentration (C) and the flow rate (Q). Thus, a plot of load versus Q is really a plot of CQ versus Q, and the presence of Q on both the ordinate and the abscissa improves the appearance of the correlation. In the present analysis, the possible correlation with Q is investigated using only C versus Q.

The graphs of suspended sediment concentration versus river flow rate for the two gaging stations are shown in Figs. 2.3.1 and 2.3.2. The figures show the previously mentioned strong dependence on Q and also the scatter of a factor of about 10 between the minimum and maximum values of C for a given Q. The frequency of occurrence of the daily river flow rates is shown along the top axis of each graph. It can be seen that only a small fraction of the samples were collected for the large flows (which carry the majority of the total sediment load, Section 2.8).

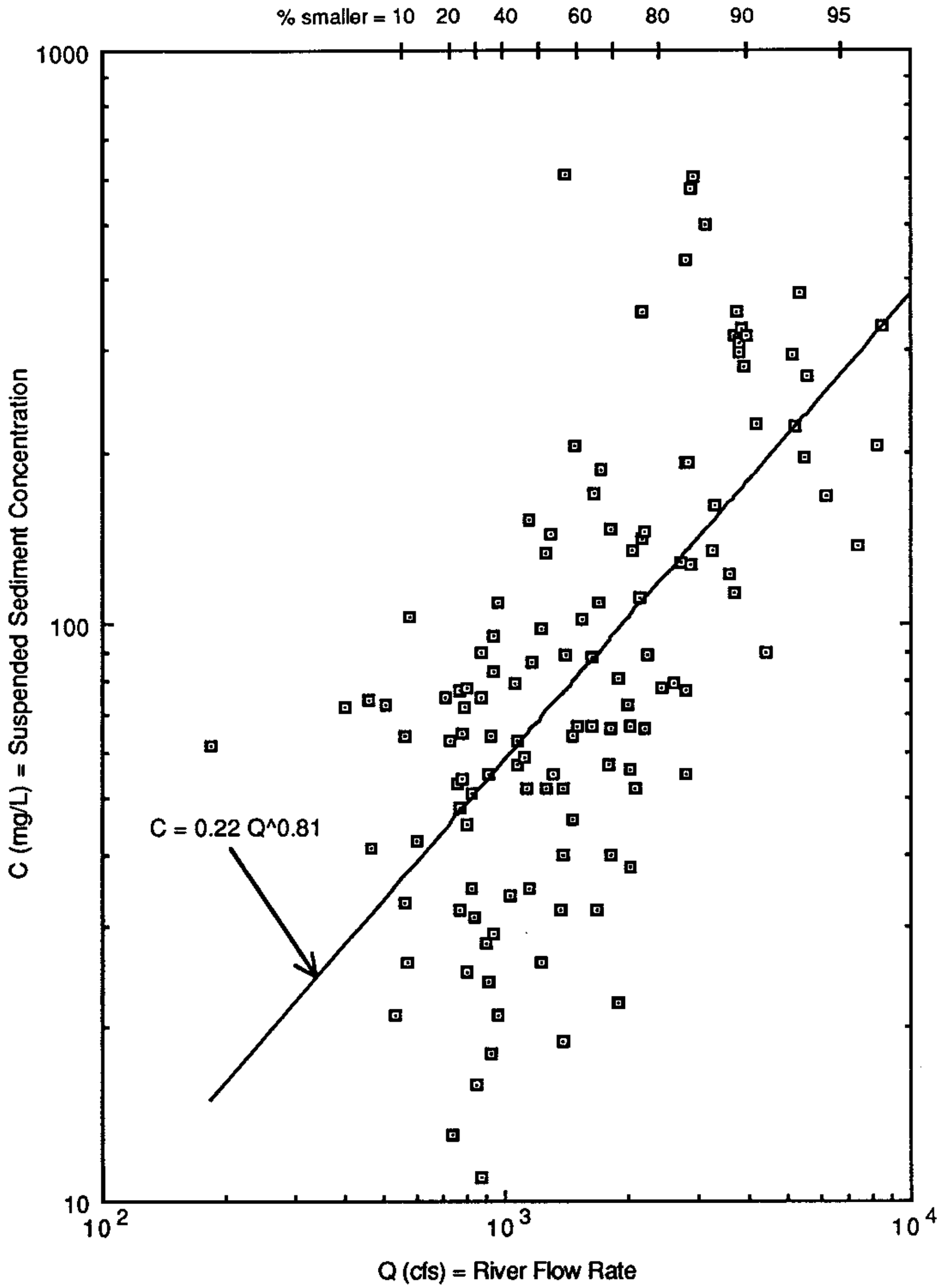

Fig. 2.3.1 - Correlation of Suspended Sediment Concentration with Flow Rate for Guadalupe River at Victoria (1973-1988)

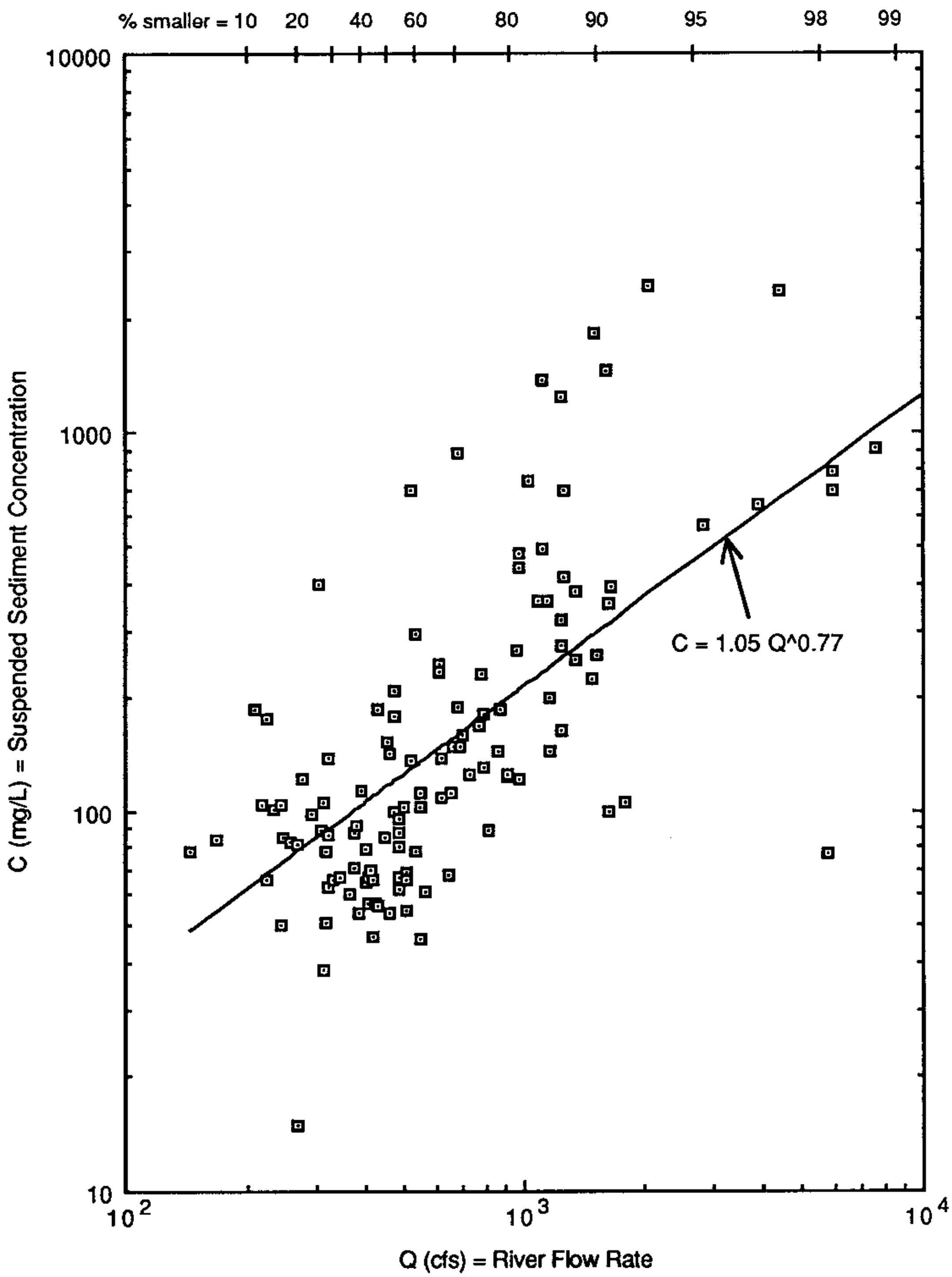

Fig. 2.3.2 - Correlation of Suspended Sediment Concentration with Flow Rate for San Antonio River at Goliad (1973-1988)

The figures include the least-squares line for the log-log graphs. (The line for the San Antonio River has the appearance of not being the best fit line, but the calculation was checked by different methods and always gave the same result.) Since the exponents on Q are approximately the same for the two rivers, the coefficients in the best-fit equations give an approximation of the relative amount of sediment being carried by the two rivers for the same Q. The coefficient of 1.05 for the San Antonio is about five times larger than the value of 0.22 for the Guadalupe, i.e., for a given flow, the concentrations in the San Antonio are about five times larger than in the Guadalupe. However, these relative concentrations do not mean that the San Antonio carries five times as much sediment as the Guadalupe since the flows in the San Antonio are smaller. The total amount of sediment carried by the two rivers is discussed in Section 2.8.

2.4 EFFECT OF LEADING RIVER FLOW RATES

Colby (1963) cited data from Heidel (1956) illustrating that a hydrograph of suspended sediment concentration may tend to lag behind a discharge hydrograph as the two hydrographs move downstream. This type of behavior may be primarily associated with runoff and a sediment source far upstream of the measurement point, so that the hydrographs travel a long distance through the channel. In both the Guadalupe and the San Antonio Rivers, there frequently is local runoff near the gaging stations so that the sediment source is also near the gaging station. Thus, there probably is no reason to expect, in general, that there would be a lagged correlation between the sediment concentration and the river flow. Nevertheless, for completeness, the possibility of such a correlation was examined for all of the data in Tables 2.2.1 and 2.2.2. For this correlation analysis, the daily average flow rate for zero to five days before the measured sediment concentrations were used. It was necessary to use leading flow rates rather than lagged concentrations since the concentrations were not measured daily. Correlations similar to those shown in Figs 2.3.1 and 2.3.2 were also determined between the sediment concentrations and the leading flow rates. The results are summarized in Figs. 2.4.1 and 2.4.2. As expected, there is no increase in the correlation for leading Q's relative to the Q's on the same day as the measured concentrations.

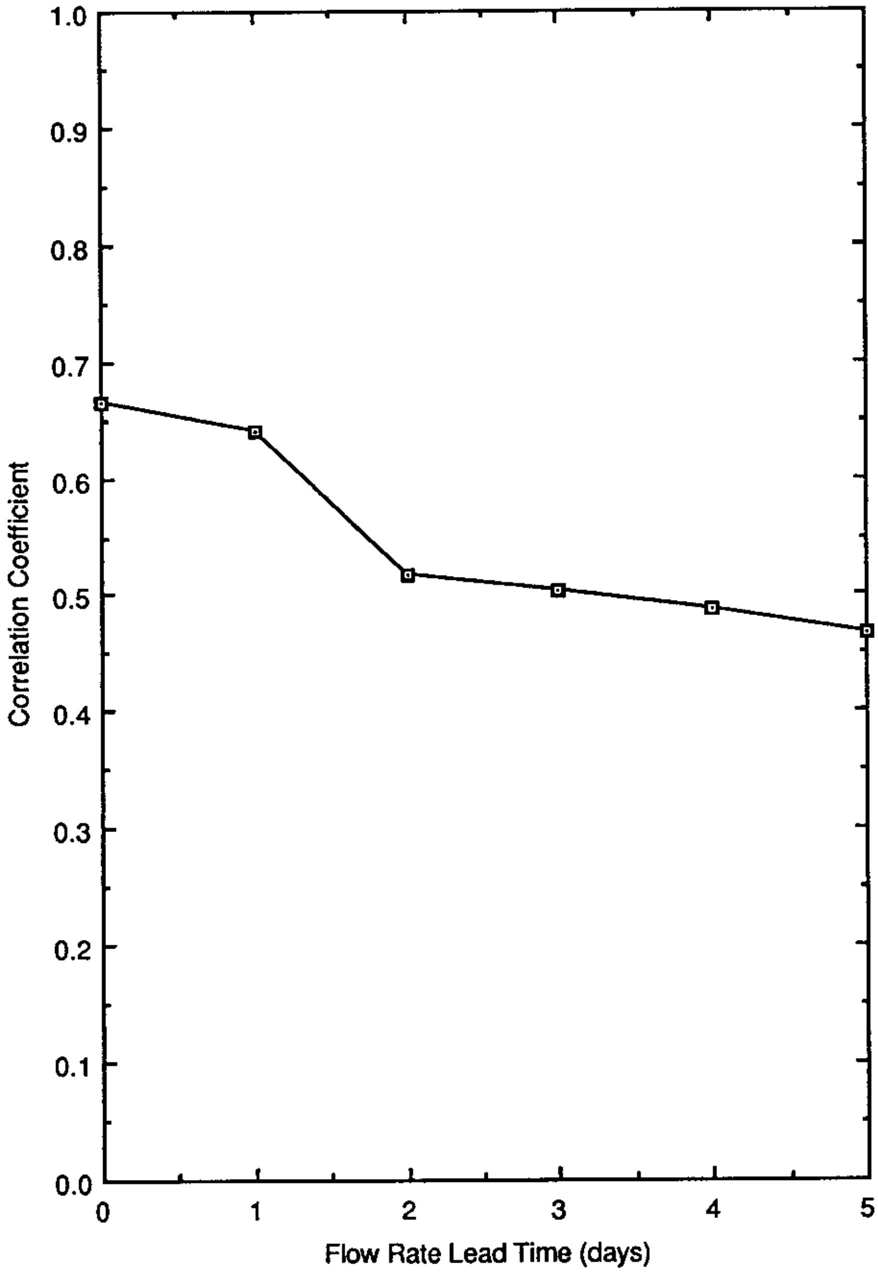

Fig. 2.4.1 - Correlation of Suspended Sediment Concentration with Leading Flow Rate for Guadalupe River at Victoria (1973-1988)

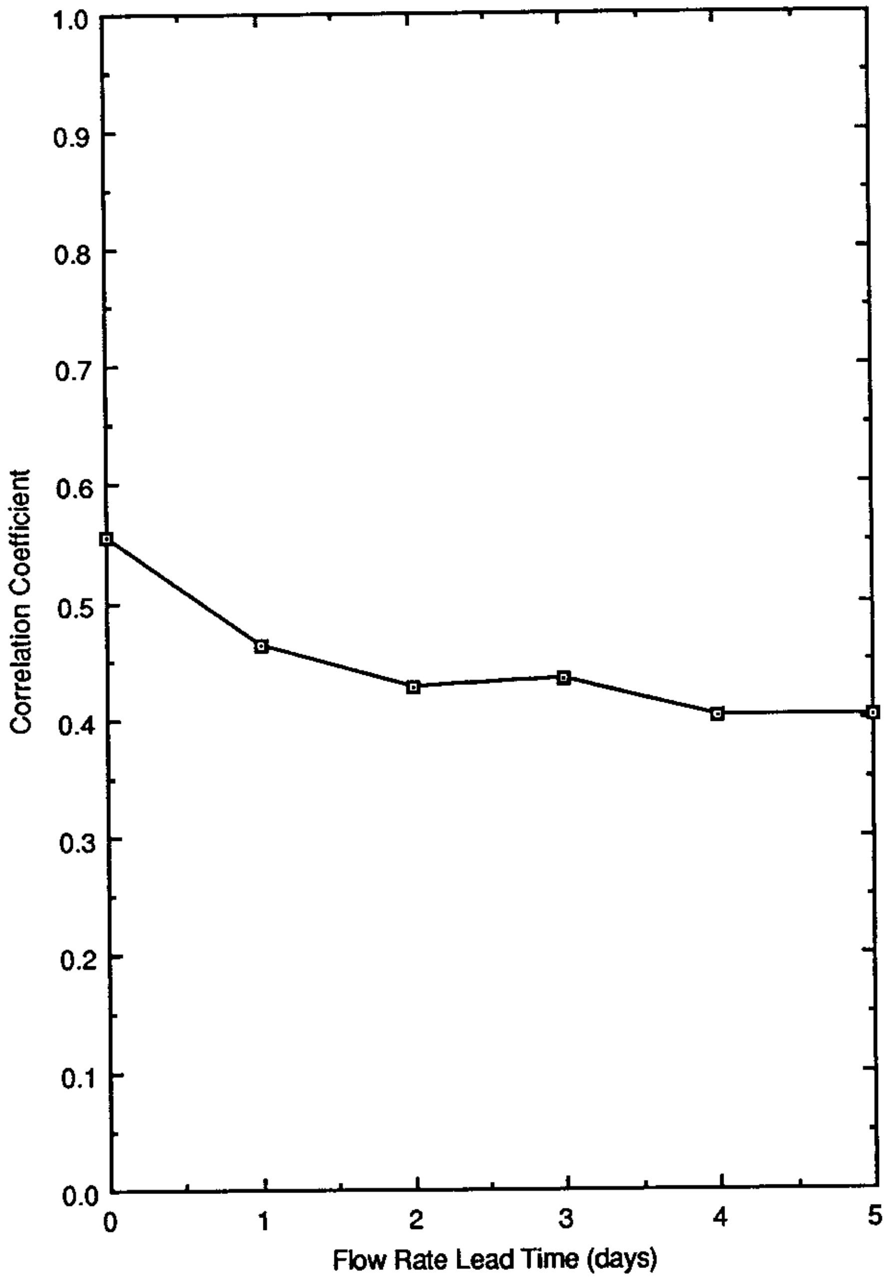

Fig. 2.4.2 - Correlation of Suspended Sediment Concentration with Leading Flow Rate for San Antonio River at Goliad (1973-1988)

For some of the runoffs which came from far upstream, there might be a lag between the flow and the concentration (e.g., Section 3.9), but the scope of this project did not allow for investigating spatial and temporal distributions of rainfall events which generated the flows in order to separate the runoff far upstream from the local runoff. Nevertheless, the very slow decrease in the correlation coefficient with increasing lead time, especially for the San Antonio, may be an indirect indication that this type of dependence of the present sediment concentration on the previous flow existed for some of the data.

2.5 EFFECT OF SEDIMENT FALL VELOCITY

A given flow rate presumably could carry a larger concentration of suspended sediments if the sediments had a smaller fall velocity. In order to investigate whether this possibility might account for part of the scatter in Figs. 2.3.1 and 2.3.2, the grain sizes and water viscosity were used as indicators of fall velocity.

The only information which was available on grain sizes was the percentage of the sediments which were smaller than 0.062 mm (Tables 2.2.1 and 2.2.2). A multiple regression analysis of the concentration data against both river flow rate and percent of sediment finer than 0.062 mm showed that the percent finer was not a statistically significant variable for either river. Perhaps Figs. 2.5.1 - 2.5.4 help to give a visual impression of the reason for this lack of correlation. The general impression from the figures is probably that there is no significant correlation of percent finer with either the flow rate or the concentration. Even though the multiple regression analysis showed no statistically significant correlation, a closer inspection of the figures perhaps gives a slight visual impression that there might be a tendency of the percent finer than 0.062 mm to increase as Q and C increase, particularly for the Guadalupe which has a larger range of "percent finer" than the San Antonio. If this is indeed the case, this would be a curious result, since the normal expectation would be that larger flows could carry larger grain sizes in suspension. These figures definitely show that the sediment sizes for the San Antonio River are smaller on the average than for the Guadalupe River. For the Guadalupe, the average value of the percent finer is 83% while it is 92% for the San Antonio.

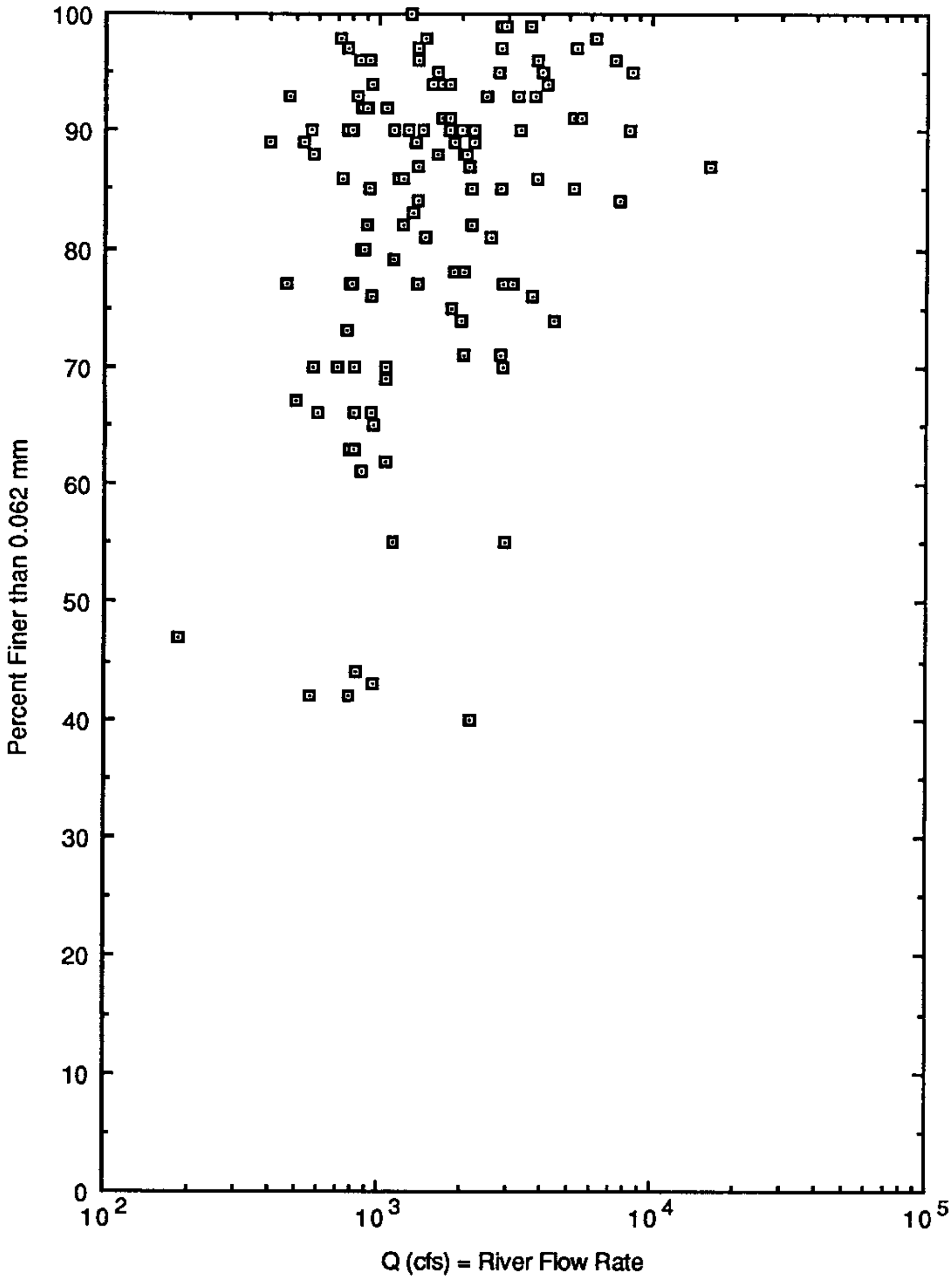

Fig. 2.5.1 - Correlation of Suspended Grain Size with Flow Rate for Guadalupe River at Victoria (1973-1988)

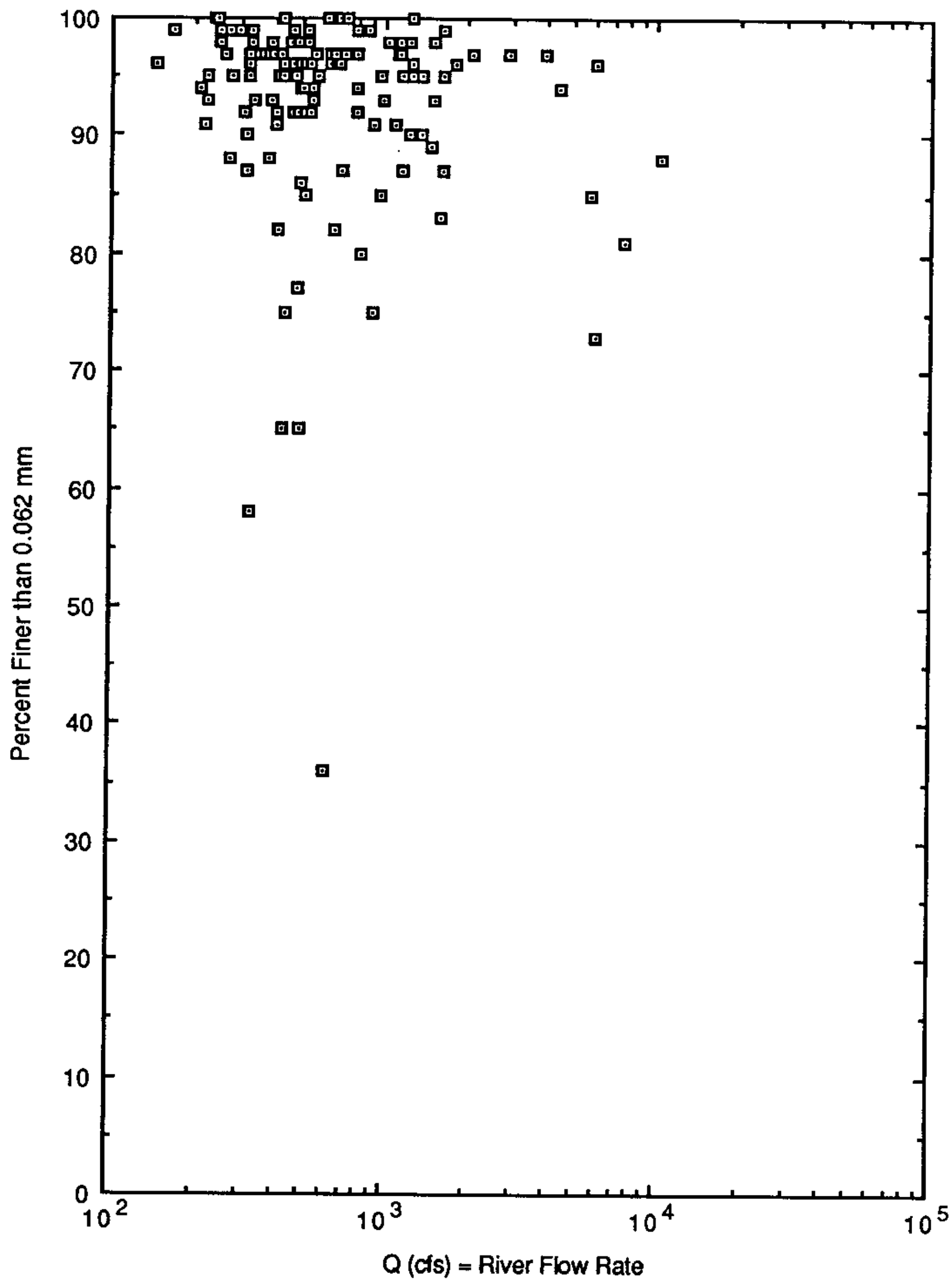

Fig. 2.5.2 - Correlation of Suspended Grain Size
with Flow Rate for San Antonio River at Goliad (1973-1988)

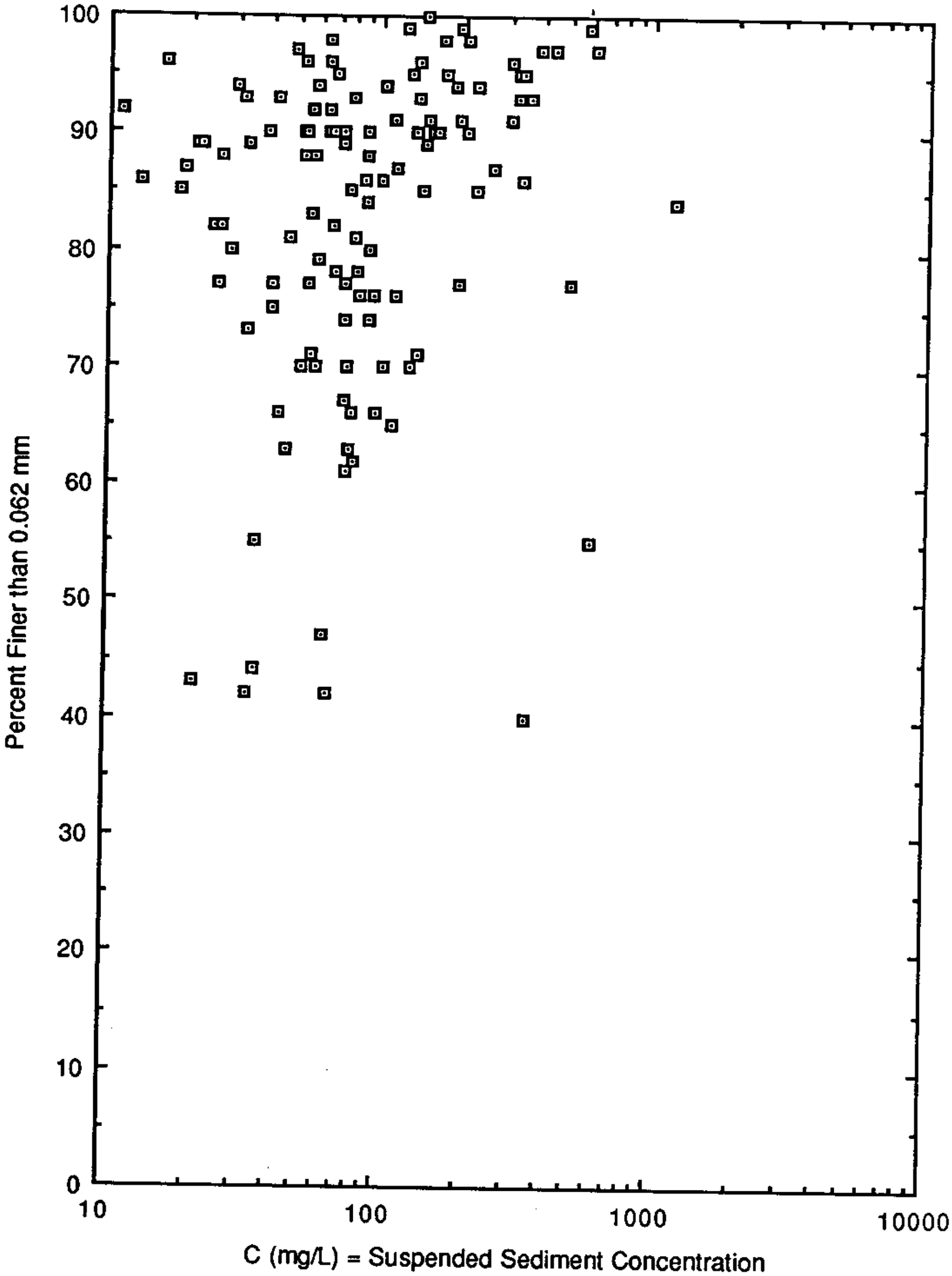

Fig. 2.5.3 - Correlation of Suspended Grain Size with Concentration for Guadalupe River at Victoria (1973-1988)

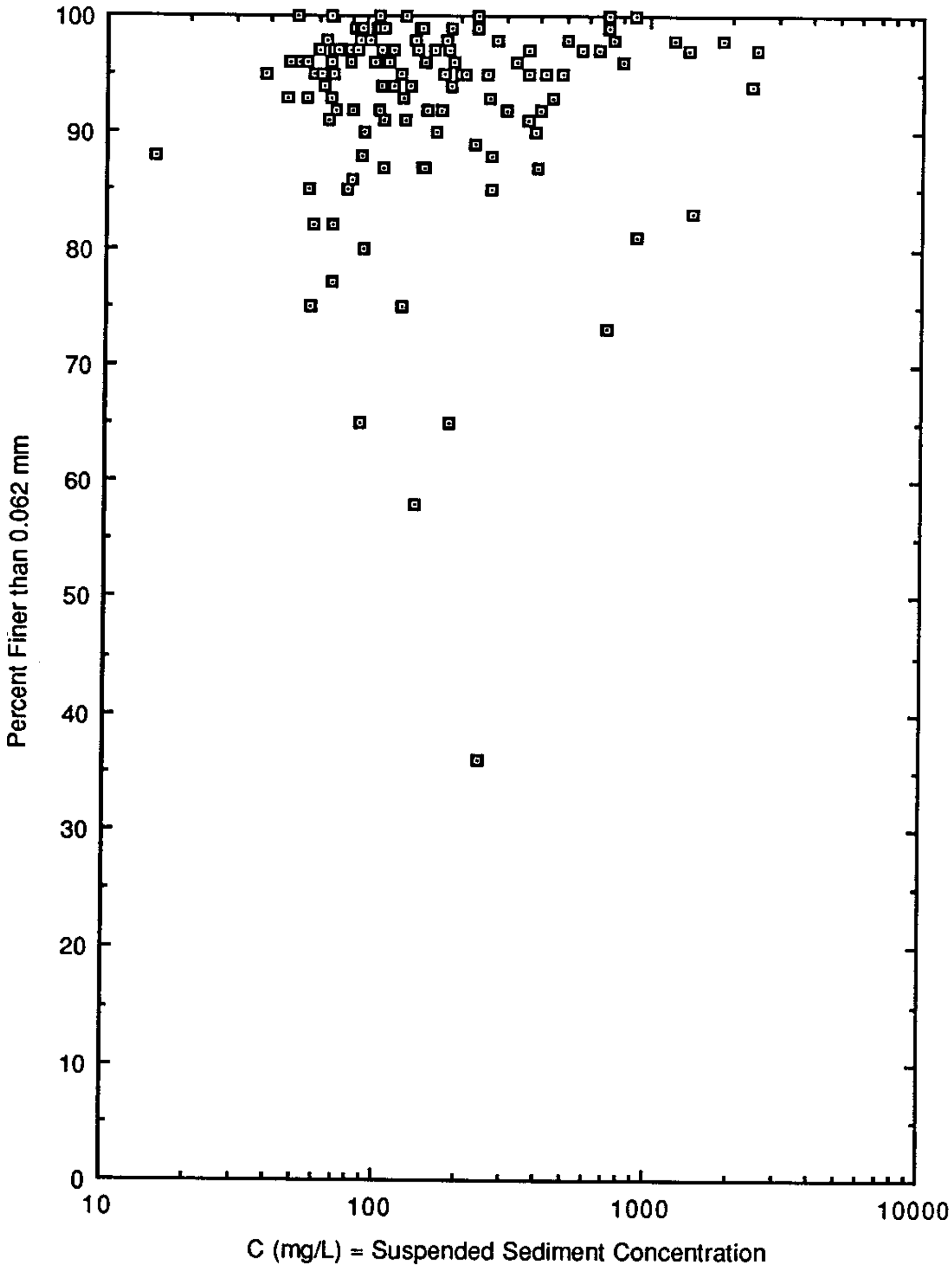

Fig. 2.5.4 - Correlation of Suspended Grain Size
with Concentration for San Antonio River at Goliad (1973-1988)

The potential effect of fluid viscosity was investigated by using the water temperatures to obtain the water viscosity and then performing a multiple regression analysis of the sediment concentrations against river flow rate and viscosity. As for the size analysis, there was no statistically significant correlation of the suspended sediment concentration with the viscosity.

2.6 EFFECT OF PHASE OF THE FLOW HYDROGRAPH

For some runoff events, e.g., runoffs resulting from long duration rainfall, it might be expected that the sediment concentration for a given flow rate on the rising limb of the hydrograph would be larger than for the same flow rate on the falling limb if the sediment is primarily from wash load from near the measurement site. To investigate this possibility, graphs were made for the daily average flows for the entire period of the available sediment data. The days on which sediment samples were collected were marked on these plots, and the hydrographs at the time of sediment sampling were classified as steady, rising, falling, trough (between a falling limb and an adjacent rising limb), and peak. The sediment data were then separated into the various classifications to determine if the data for a single classification had a better correlation with the flow rate than all of the data grouped together as in Figs. 2.3.1 and 2.3.2. The numbers of points in each classification were as follows:

River	Total Number	Steady	Rising	Falling	Trough	Peak
Guadalupe	130	67	6	36	8	7
San Antonio	129	52	16	37	8	3

The classification was admittedly somewhat subjective. Nevertheless, for each river there were a few sampling times which could not reasonably be fitted into any of the classifications (six for the Guadalupe and thirteen for the San Antonio).

For each river, only the steady and falling classifications have enough points to investigate possible effects of the phase of the hydrograph. It might be argued that the data collected at peaks should be associated with the rising limb and that the data for troughs should be associated with the falling limb. However, the numbers of data points for each of these two classifications is too small to have a significant influence on the correlation. The graphs comparing the steady and falling classifications are shown in Figs. 2.6.1 and 2.6.2. Even though the number of points for the rising classification for the San Antonio River is rather small, these points are also shown on Fig. 2.6.2.

Figs. 2.6.1 and 2.6.2 certainly do not give any clear indication that any of the scatter of the data in Figs. 2.3.1 and 2.3.2 is associated with the phase of the hydrograph during which the samples were collected. It is interesting that the highest frequency of occurrence of a flow classified as steady is about 80% for the San Antonio River, which has no upstream reservoirs on the main stem. (Medina Lake is on a tributary upstream of the city of San Antonio. Braunig and Calaveras Reservoirs are on tributaries southeast of the city of San Antonio.) The highest frequency for the Guadalupe is about 93%, apparently corresponding to a large sustained release rate from Canyon Dam.

2.7 DISCUSSION OF VARIOUS EFFECTS

In Section 2.1 and Figs. 2.3.1 and 2.3.2, it was seen that the suspended sediment concentration has a strong dependence on the river flow rate but that there must also be some other significant variables affecting the concentration since the graphs of C versus Q have a scatter of a factor of about ten for each river. Sections 2.4 through 2.6 were concerned with analyses for some of the most apparent additional variables which might be influencing the concentrations. None of these analyses produced a meaningful reduction in the scatter of the data. However, these results do not necessarily mean that none of these additional variables are important. Rather, the conclusion should probably be that none of the additional variables is important enough for *all* of the data to reduce the scatter. For example, the lag between the concentration and the river flow rate may be important for flows coming from runoff far upstream of the gaging station but not for the same magnitude runoff near the gaging station. The same kinds of distinctions might need to be made for some of the other variables also. Thus, it seems that the next most logical place to look for an explanation of the scatter in the graph of C versus Q might be the location of the rainfall and runoff producing the flow that is carrying the sediment.

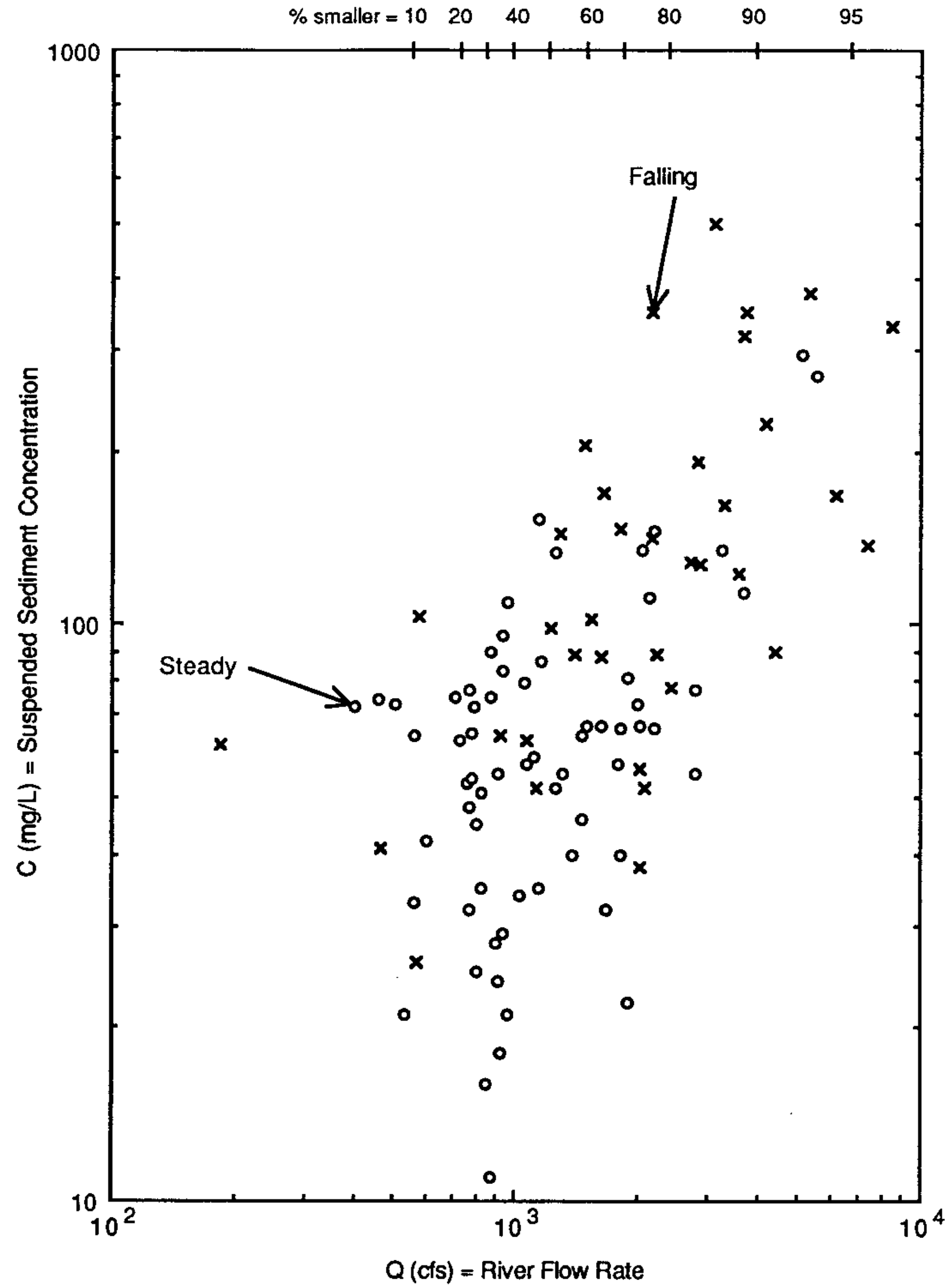

Fig. 2.6.1 - Effect of Hydrograph Phase
for Guadalupe River at Victoria (1973-1988)

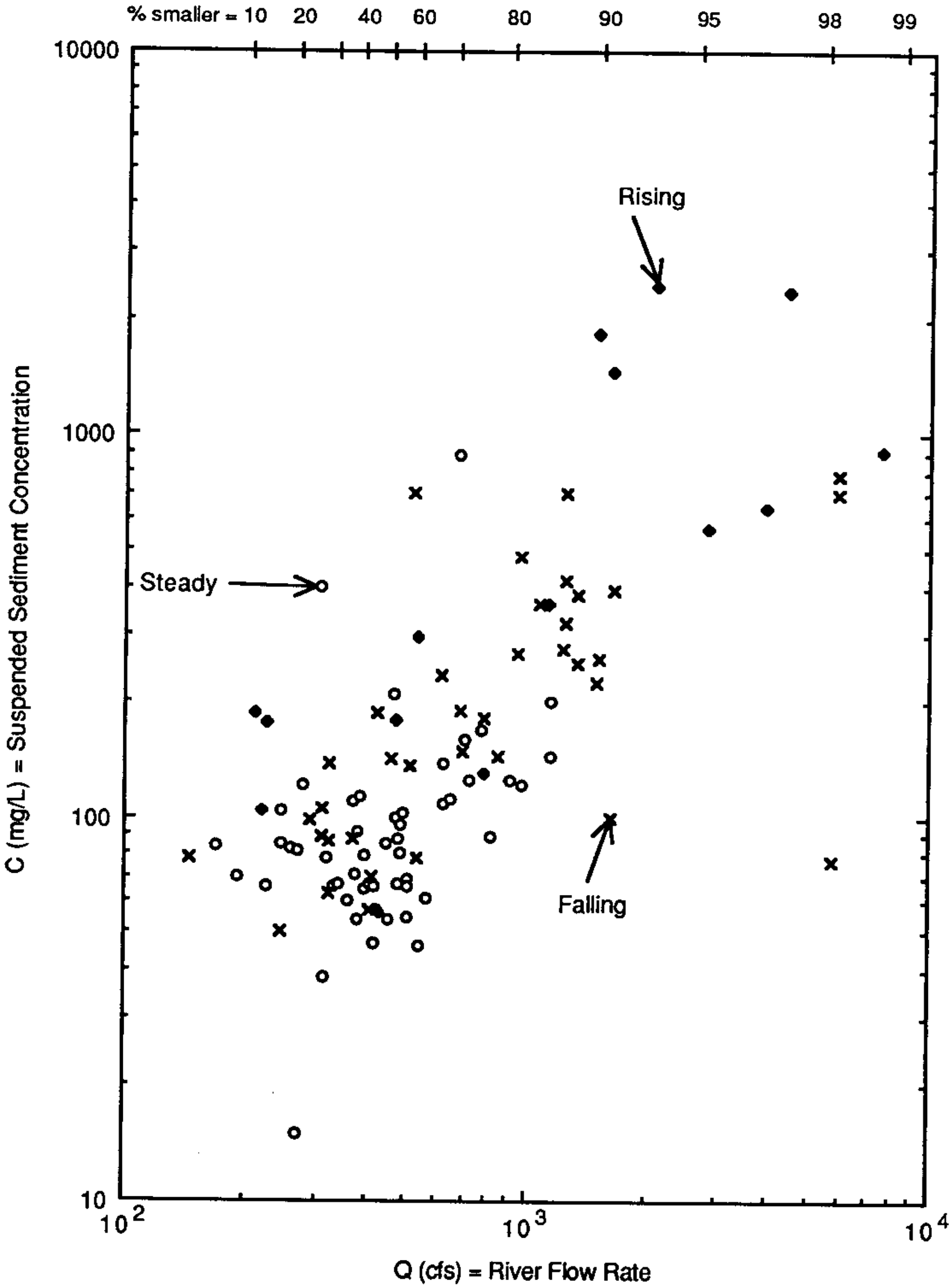

Fig. 2.6.2 - Effect of Hydrograph Phase
for San Antonio River at Goliad (1973-1988)

2.8 TOTAL SEDIMENT LOAD

When considering the impact of possible future impoundments on sediment transport in the lower parts of the river on which the impoundment is to be placed, there are at least two possible effects. One is that the impoundment becomes a settling basin for upstream sediments so that most of these sediments can reach neither the lower parts of the river nor the coastal waters into which the river flows. Since the scope of this project did not include identification of the sources of the sediments, it is not possible to investigate this possible impact.

A second effect of an impoundment is in changing the time distribution of flows in the river and in reducing or eliminating the very large flows and the associated sediment transport. Some insight into this point can be gained by considering which percentage of the flows carry which percentage of the sediment. For this purpose, the daily average flows from 1966 to 1989 were used. First, the flows were rank ordered by magnitude from the smallest to the largest. Next, it was assumed that the concentration for each flow would be given by the regression equations on Figs. 2.3.1 and 2.3.2. The product of the flow rate and the concentration gave the sediment load for each day. These loads were summed from the smallest flow rate to each ranked flow rate to give the amount of sediment and then the fraction of the total sediment carried by flows smaller than and equal to each entry in the rank ordered flow rates. The results are shown in Figs. 2.8.1 and 2.8.2. These curves need to be viewed with some caution because of the scatter in Figs. 2.3.1 and 2.3.2 and because the regression equations in those two figures have been extrapolated beyond the highest flow rate for which data are available. Nevertheless, even considering the possible uncertainty in Figs. 2.8.1 and 2.8.2, these figures definitely support the conventional wisdom that the large flows carry the majority of the sediment. The largest 10% of the flows carry more than 80% of the sediment for the Guadalupe and more than 90% for the San Antonio. This value for the San Antonio may be somewhat distorted by the very large daily flow of 121,000 cfs which is included in the period being analyzed. The next two largest daily flows for the San Antonio River during 1966 to 1989 were 84,200 cfs and 42,900 cfs, and these two flows were part of the same runoff event as the 121,000 cfs flow. These three daily flows account for almost 30% of the total calculated sediment load for the 1966-1989 period. The next largest flow for a different runoff event was 32,800 cfs or approximately

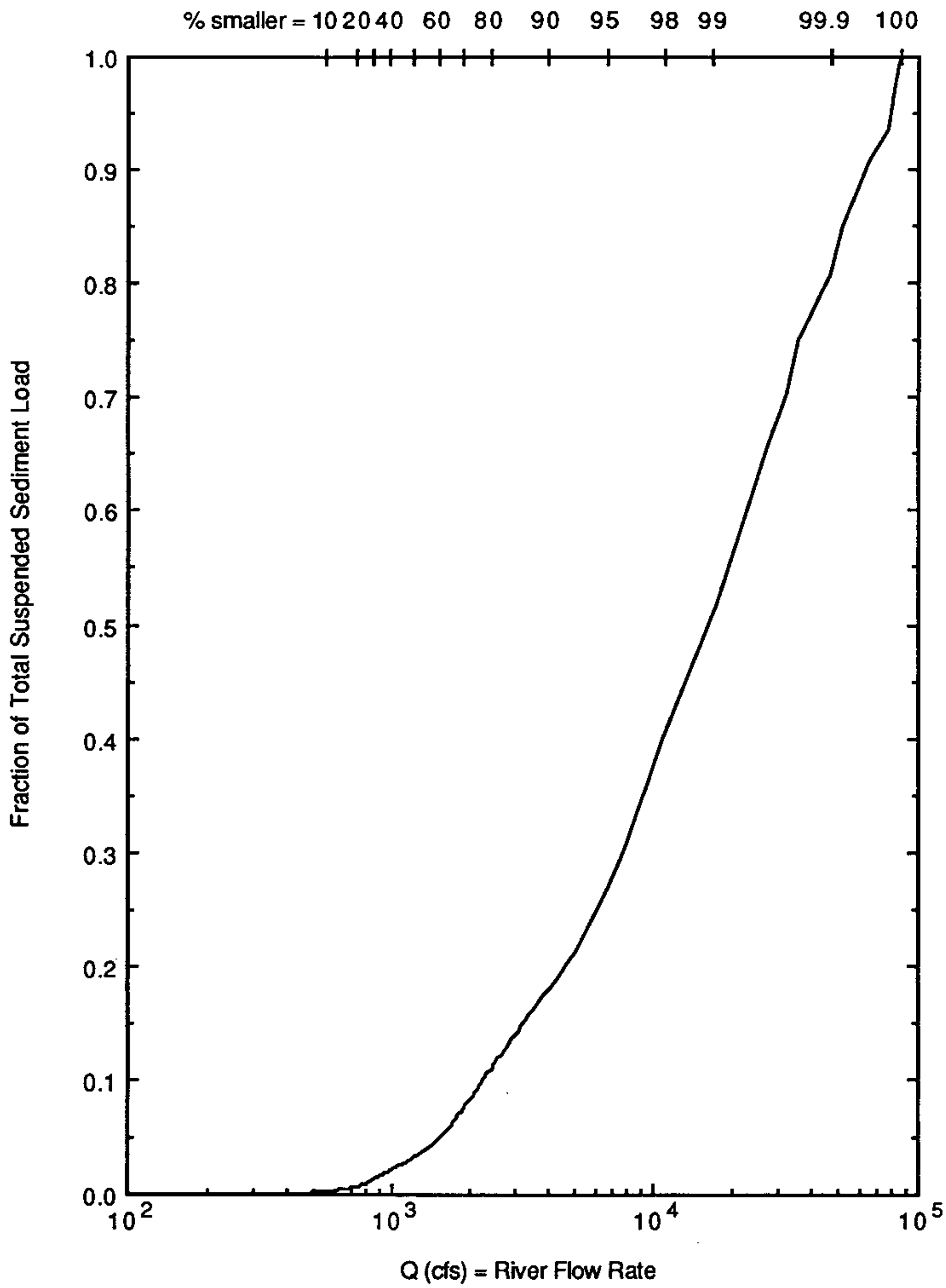

Fig. 2.8.1 - Calculated Relation of Total Suspended Load to Flow Rate for Guadalupe River at Victoria (1966-1989)

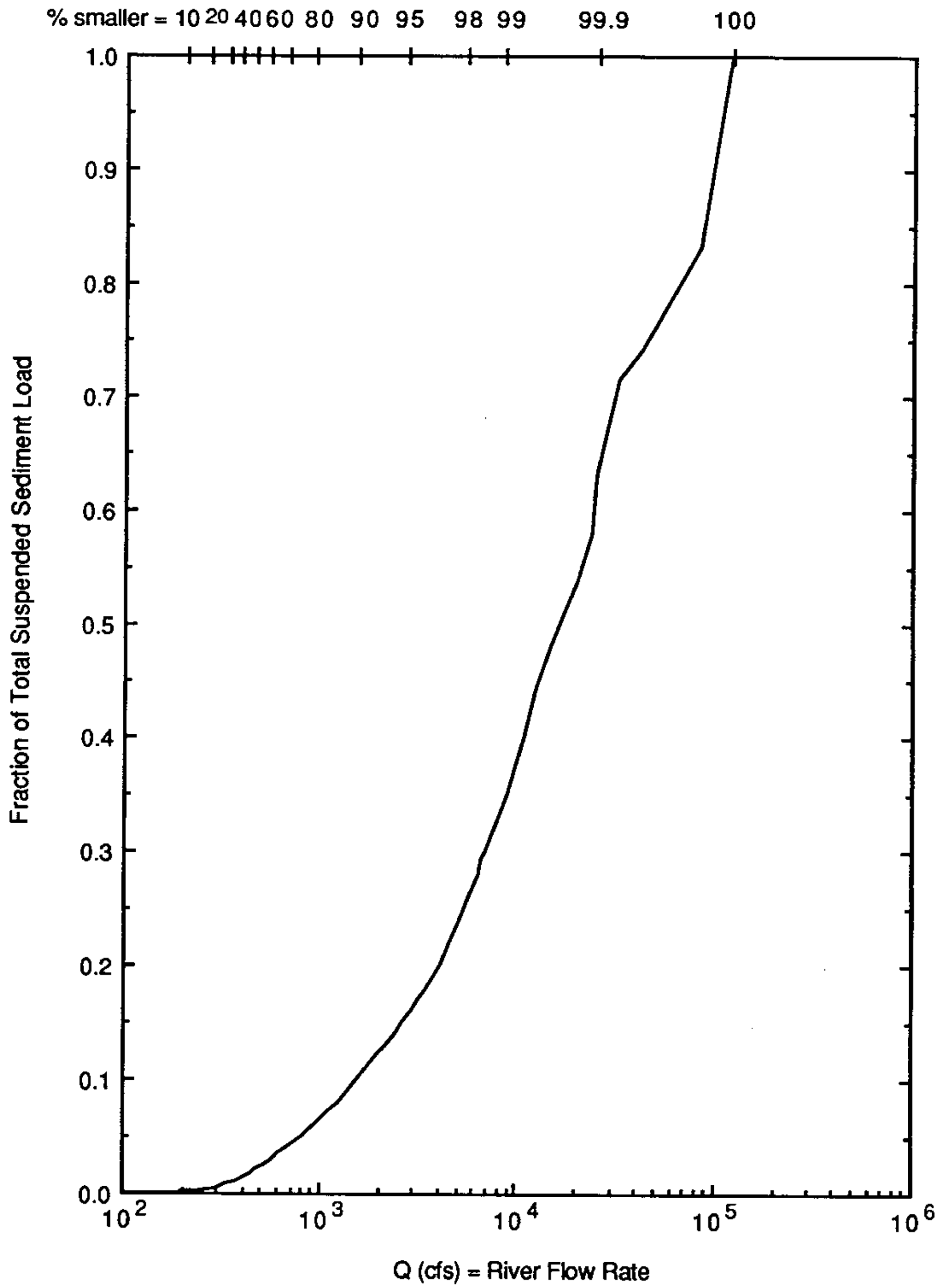

Fig. 2.8.2 - Calculated Relation of Total Suspended Load to Flow Rate for San Antonio River at Goliad (1966-1989)

one quarter of the largest recorded flow. Nevertheless, this analysis definitely shows that impoundments which reduce the peak flows have the potential of significantly reducing the amount of sediment carried to the coast.

The calculated average amounts of sediment carried by the Guadalupe and San Antonio Rivers were respectively 630,000 tons/year and 700,000 tons/yr. Because of the uncertainty associated with the equations on Figs. 2.3.1 and 2.3.2 and because of the occurrence of statistically larger flows in the San Antonio watershed than in the Guadalupe watershed, it probably should be concluded only that the amount of sediment is about the same for the San Antonio and Guadalupe Rivers. However, even this conclusion means that the San Antonio is much more efficient as regards sediment transport since its flows are smaller than in the Guadalupe on the average. The effect ofCanyon Lake on the Guadalupe River on this higher efficiency for the San Antonio River is unknown.

3. FIELD MEASUREMENTS

3.1 RECONNAISSANCE TRIPS

The first field trip was on October 22-23, 1988. The objective of this trip was to evaluate possible data collection sites and procedures. In order to have the maximum flexibility in sampling, the original plan was to collect sediment samples and to make depth and velocity measurements from a boat, probably just upstream of the confluence of the San Antonio and Guadalupe Rivers in order to collect data from the two rivers separately. Thus this first trip involved putting a boat in the rivers and investigating the rivers in the vicinity of their confluence. The first thing that became obvious was that there is not a boat ramp which allows reliable access to this section of the river. The nearest one which can be used on a regular and reliable basis is at State Highway 35 (Fig. 1.3.1), downstream of the inflatable dam which controls salinity intrusion. Although local sportsmen in small boats regularly jump the dam when it is inflated, this procedure was not deemed to be feasible in the research boat loaded with equipment. The next thing that became obvious was that trees overhanging the rivers would make it very hazardous to try to maneuver a boat during high flows. Thus, it was concluded that operating from a boat was not feasible. The hazard associated with the overhanging trees during high flows is so great that the decision not to sample from a boat would have been made even if there had been no inflatable dam and a good ramp. The decision was strengthened when it was later learned that large amounts of floating debris (including large logs and occasionally nearly a whole tree) come down the rivers during high flows.

After rejecting the use of a boat, it was then necessary to evaluate the most appropriate bridge crossings for measurements and sampling. On December 2-3, 1988, a field trip was made for this purpose. The sites that were investigated were as follows:

(1) Guadalupe River bridge on State Highway 35 northeast of Tivoli.

This bridge is downstream of the confluence of the San Antonio River with the Guadalupe River. It is the only readily accessible location for making measurements for the combined flows. There is a USGS gage at this location, but it is only for determining stage because of the frequent tidal influence. During the early part of the project, an attempt was made to measure velocities, but the flow was sluggish, at best, and was sometimes in the upstream direction. It was also felt that the upstream inflatable dam would provide a settling basin so that the sediment which reached this site might not be representative of the undisturbed river flow. Thus, because of the upstream inflatable dam and the tidal influence, this site was abandoned as a measurement point.

(2) Guadalupe River bridge on the FM 175 by-pass road south of Victoria.

This is the next upstream highway bridge crossing on the Guadalupe River above the Highway 35 bridge. While it would be a possible measurement site, it offered no compelling advantage over the next site.

(3) Guadalupe River bridge on U. S. Highway 59 on the west side of Victoria.

This site is only about 4 to 5 miles farther upstream than the FM 175 bridge. It has a USGS gaging station. There is a sidewalk on the bridge so that measurements can be made without having to close a lane of traffic. There is essentially no pedestrian traffic on the side of the bridge used for gaging. Even though this location is farther upstream than had been originally desired, it was accepted as the best available site for measurements on the Guadalupe River. Unfortunately, this location is upstream of the confluence of the Guadalupe River and Coleta Creek, but there is no bridge crossing downstream of the confluence.

(4) San Antonio River bridge on U. S. Highway 77 between Victoria and Refugio.

This is the next upstream highway bridge crossing on the San Antonio River above the Highway 35 bridge. It has the advantage of being 25 to 30 miles farther downstream than the next site. Nevertheless, it was decided that it was more advantageous to make measurements at an established USGS gaging site than to be somewhat farther downstream.

(5) San Antonio River bridge on U. S. Highway 59 west of Goliad.

This is a two-lane, heavily-travelled, steel-truss bridge. Measurements from the bridge itself are not feasible both because of the traffic and because the bridge trusses prevent ease of movement of instruments lowered over the side of the bridge. However, the USGS has a cableway just upstream of the bridge, and permission was obtained to use this cableway for the measurements and sampling. As with the Guadalupe River, this location is farther upstream than had originally been desired, but this location was selected as the most feasible site for the San Antonio River.

(6) San Antonio River Bridge on U. S. Highway 183 south of Goliad.

Even though this bridge was considered as a possible measurement site, it is very close to the USGS gaging station on Highway 59 west of Goliad and it offered no compelling advantage over the Highway 59 bridge location.

(7) Miscellaneous other locations.

USGS quadrangle maps and county maps were used to try to locate any bridges on local roads, abandoned or active railway bridges, or any other possible sites for access to the river. Based on the maps, several sites were visited, but no suitable sites downstream of the chosen sites were found.

3.2 FIELD EQUIPMENT AND PROCEDURES

The primary purpose of the field work was to measure the suspended and bedload sediment transport. In support of this objective and to help in understanding the flows in the rivers, it was also desired to perform traditional stream gaging, i.e. to measure water depths and velocities across the cross sections. The pieces of equipment chosen for the field work were a P-61 suspended sediment sampler (Fig. 3.2.1) obtained from the Federal Interagency Sedimentation Project (FIASP) in Minneapolis, Minnesota; a Model #65-1.4 Helley-Smith bedload sampler (Fig. 3.2.2) with a 250 micron mesh bag obtained from GBC, Inc. (190 South Union, Lakewood, Colorado 80228); and a standard Price current meter with a 15 pound weight (Fig. 3.2.3) and with headphones for counting clicks or rotations of the meter.

For the depth and velocity measurements, the width of the stream was typically divided into 11 subareas of equal width and the velocities were normally measured at the 0.2 and 0.8 depths at the centers of the subareas. It is recognized that 11 subareas is fewer than is normally recommended for accurate measurement of the flow rate. However, the purpose of the measurements in this project was to obtain a general indication of the depths and velocities rather than to determine the river flow rate with the normally required accuracy.

The P-61 sampler has an electrical valve so that the sampler can be lowered to the desired sampling point and then the valve can be opened for the necessary time to obtain a sample at that location. The sampler was used with quart plastic bottles which were also obtained from the Federal Interagency Sedimentation Project. The Texas District Office of the USGS loaned a four-wheel trolley for the bridge measurements. A battery-operated winch was modified to use for the P-61 sampler, which weighs about 100 lb. This winch was adapted for both the four-wheel trolley and the stand-up cable car on the cableway at Goliad.

The P-61 sampler provides enough sediment for determination of concentration, but not enough for size distribution analysis. Thus, some sediment samples were obtained by pumping in order to obtain larger volumes and thus larger amounts of sediment. An available 110-volt well pump was

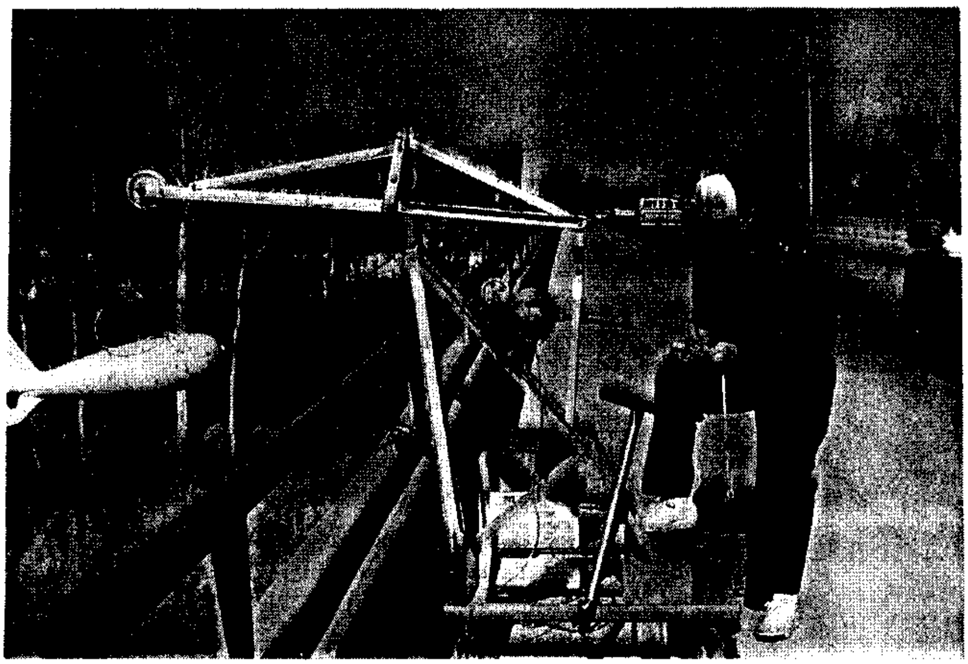

Fig. 3.2.1 - P-61 Point Sampler at U.S. Highway 90 Bridge Over Brazos River in Richmond

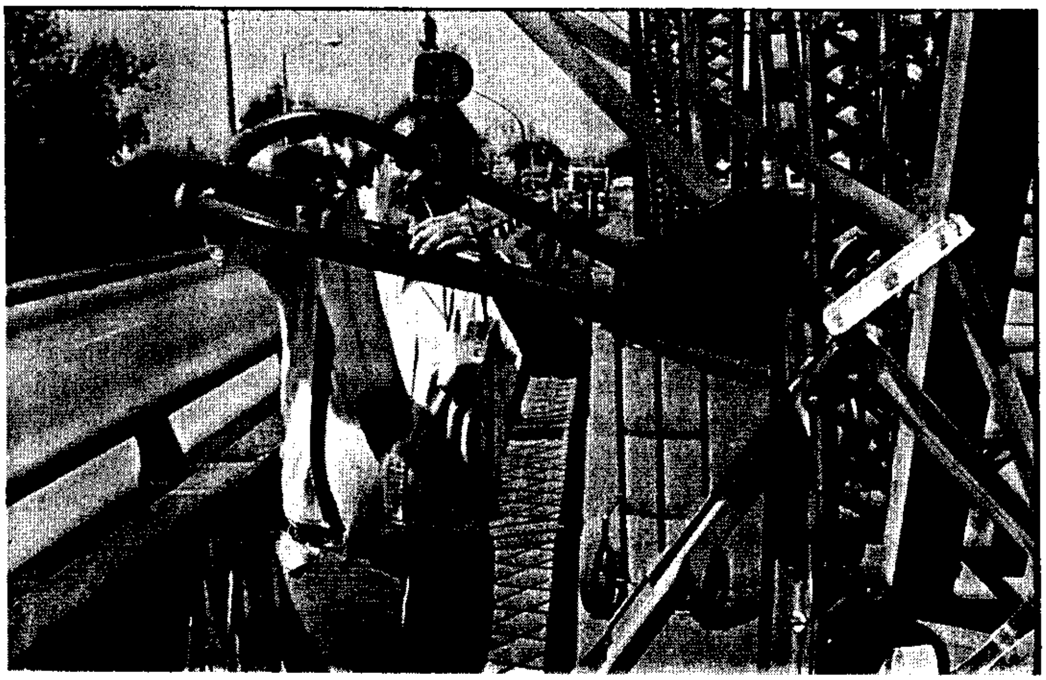

Fig. 3.2.2 - Helley-Smith Bedload Sampler on U.S. Highway 59 Bridge Over Guadalupe River at Victoria

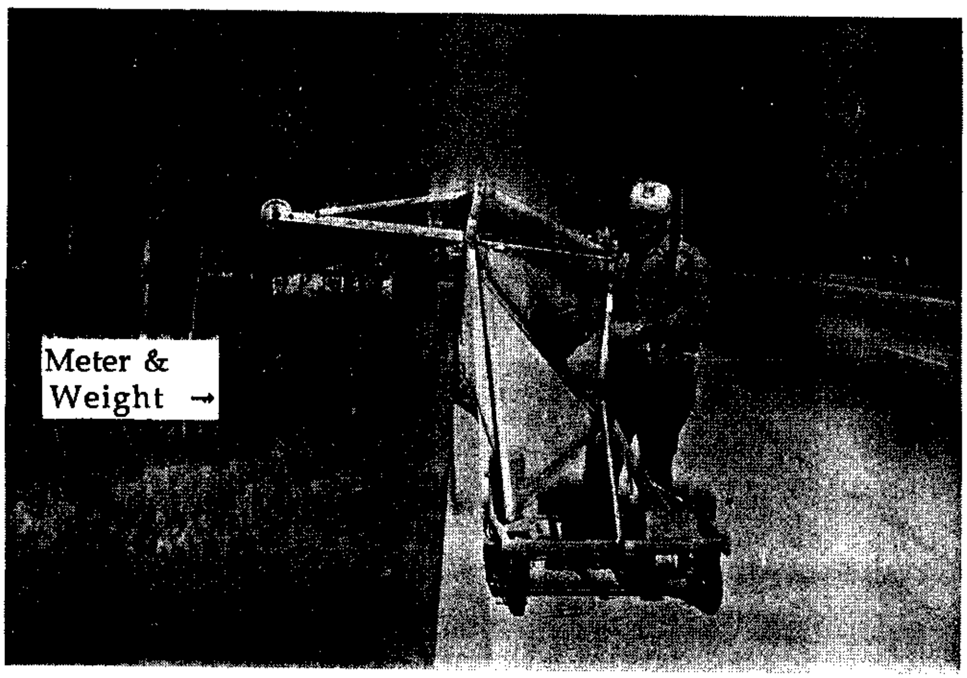

Fig. 3.2.3 - Price Meter and Weight at U.S. Highway 90 Bridge
Over Brazos River at Richmond

modified for the pumped samples. The modifications included closing most of the screened area so that the intake velocity would be approximately equal to the river flow velocity and adding fins so that the remaining open part of the intake would always be on the upstream side of the pump (Fig. 3.2.4). A garden hose was used to convey the water to the sample bottles (Figs. 3.2.5). Another potential concern with pumped samples is the differential settling of different size grains in the vertical hose as the sample is being pumped up from the river (Fig. 3.2.6). The larger grains settle faster relative to the flow than the smaller grains. However, this behavior did not have an adverse effect on the sampling for at least two reasons. The most important reason is that this behavior affects the concentration in the hose from the pump only during the start of pumping. The sediment in the hose soon reaches an equilibrium with the concentration equal to the original concentration. If this were not true, then the sediment flux out the top of the hose would be different from the sediment flux into the pump so that sediment would need to be continually either created or stored inside the hose. The creation of sediment obviously is not possible, and it was also obvious from using the pumping system continuously for long periods of time that sediment did not continually collect in the hose. The second reason is that the settling velocities are very small relative to the flow velocity in the hose. With a typical flow rate of 1.7 gpm in the 1/2-in. hose, the flow velocity was 2.8 fps. On the other hand, the settling velocity of a 0.062 mm sand grain, which is a typical large grain for suspended sediment, is only 0.05 fps. Thus, the differential settling of the various size grains is very small. In travelling vertically for 50 ft through the hose, a 0.062 mm grain would settle only 0.9 ft relative to the flow.

Based on the amount of sediment needed for grain size analysis, it was decided that 5 gal samples would be needed. For the first tests, 5 gal jugs were used. These bottles proved to be so unwieldy in the laboratory when trying to separate the sediment and the water that there was concern over the accuracy of the resulting analysis. Thus, it was then decided to use five one-gallon plastic milk jugs (Fig. 3.2.7). These bottles were much easier to handle in the laboratory analysis. Also, being able to use from one to five of the bottles for a given set of five sample bottles, depending on the required amount of sediment, is an advantage. This system worked well if reasonable care was taken to keep the garden hose and the electric lines from becoming entangled

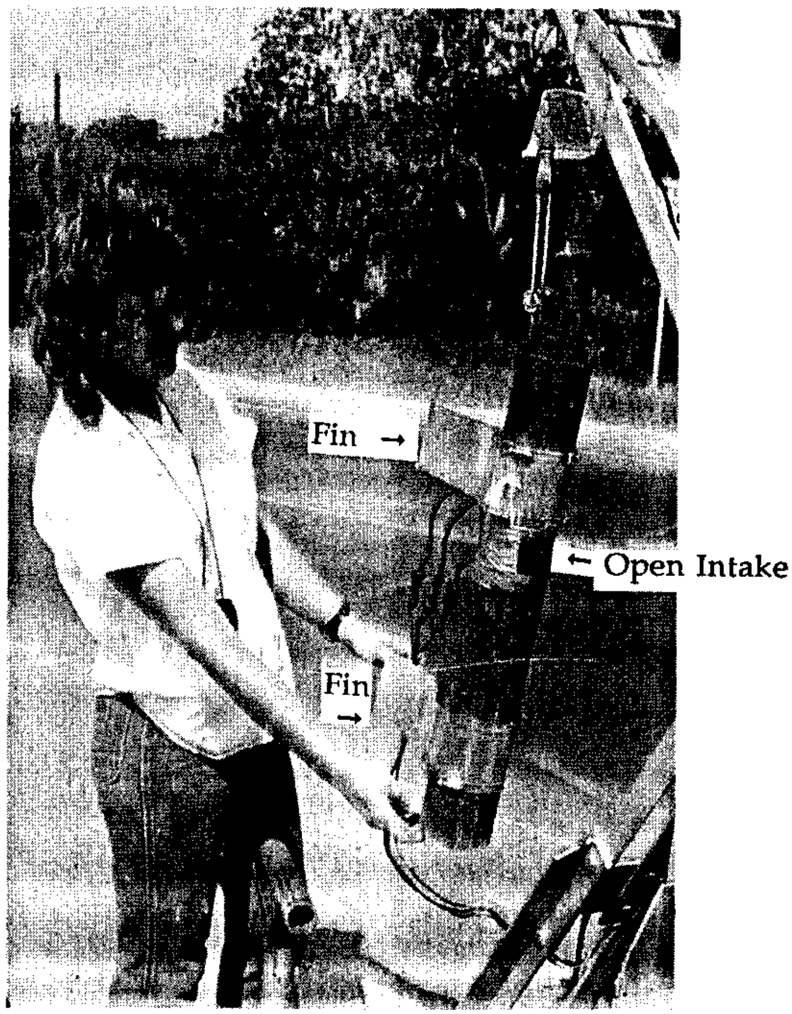

Fig. 3.2.4 - Well Pump with Fins and Partially Closed Screen

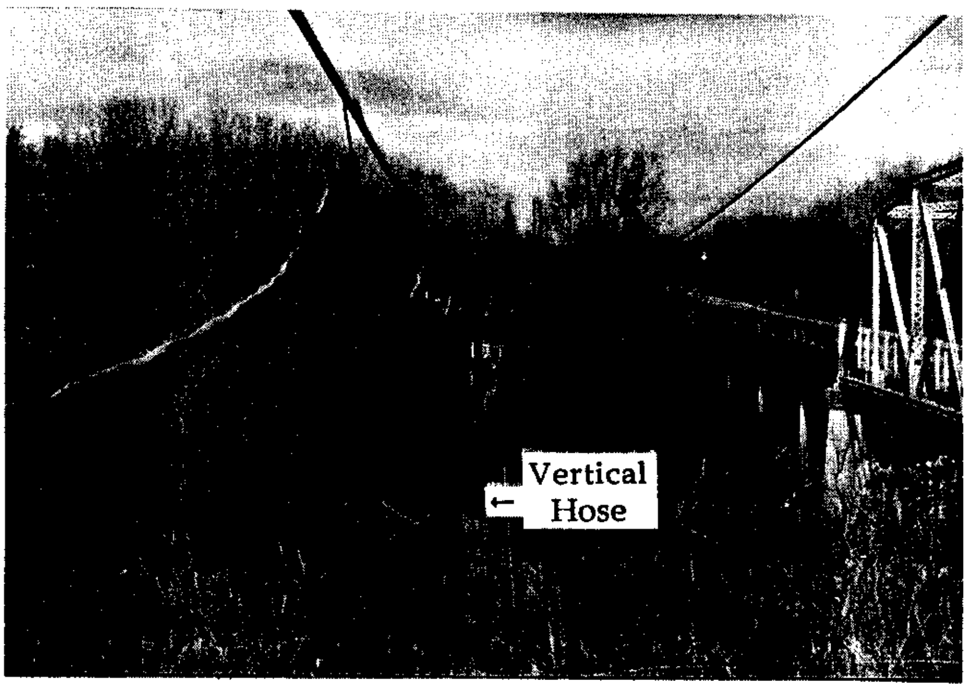

Fig. 3.2.5 - Hose and Extension Cord Strung Along Cable
Over San Antonio River at Goliad

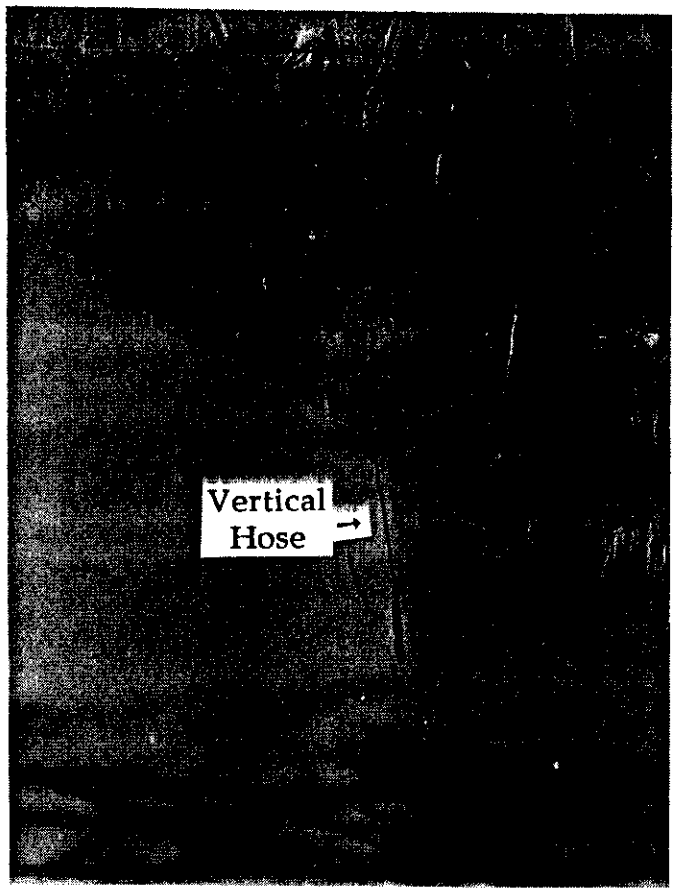

Fig. 3.2.6 - Pump Being Lowered Into San Antonio River at Goliad

Fig. 3.2.7 - Filling One-Gallon Milk Jugs On U.S. Highway 59 Bridge Over the Guadalupe River at Victoria

with each other or with the pump. Each time that the pump was set at a new location, adequate time was allowed (based on the flow rate in the hose) to purge the hose. A gasoline-powered electric generator was used to operate the pump.

3.3 LABORATORY EQUIPMENT AND PROCEDURES

The samples from the quart bottles were analyzed only for concentration since the amount of sediment was too small for the method adopted for size distribution analysis. The entire sample was vacuum filtered using double Whatman 934-AH filters. Then using standard drying and weighing procedures, the concentration was determined. For filtering the sediments from the quart bottles, 11-cm diameter filters were used. For the pipet samples discussed later, 5.5-cm diameter filters were used.

The primary procedures considered for the size distribution analysis for suspended sediments were the pipet method, the Visual Accumulation Tube, the Coulter counter, and laser doppler techniques. Laser doppler techniques were eliminated because of the very high cost of the equipment and the fact that the techniques have not been shown to given reliable results for any shaped particles except spheres. Some preliminary tests were made with an available Coulter Counter. Although this technique is not a commonly used method for analysis of suspended sediments from rivers, it seemed to have the possibility of being a viable method. A strong advantage is that the amount of sediment needed can be very small, so that size distribution analyses could be done with the amount of sediment typically collected in the quart bottles in the P-61 sampler. In spite of this advantage of the Coulter Counter, the preliminary tests indicated that most, if not all, of the duration of the project would be required to learn to operate and properly calibrate the instrument and to interpret the results. Thus, the possibility of using the Coulter Counter was eliminated. Nevertheless, the preliminary investigation of this method led to the conclusion that it deserves consideration for size distribution analysis for riverine sediments, particularly if an experienced operator is available. The typical sizes of the suspended sediments were too small for the Visual Accumulation Tube, so it was eliminated. The elimination of the other possible methods and the fact that the pipet method is essentially the standard method for size distribution analysis for suspended sediments led to the decision to use the pipet method.

The pipet method which was used was basically the standard method as described by Guy (1969). The modifications which were introduced were mostly for the purpose of checking the mass balance of the sediments and for making the procedures somewhat easier. A 25-mL pipet was used. It was found by trial and error that the tip of the pipet had to be removed to provide a larger opening. Although this part of the technique was not mentioned by Guy (1969), it was later learned that removing the tip is a procedure followed by many persons performing pipet tests. For these tests, the entire tip was removed, leaving an opening of about 3 mm at the end of the tube. The original opening in the end of a 25-mL pipet is too small to obtain a representative sample in the early part of the method when the larger sediments need to be drawn into the pipet. Removing the tip meant that the pipet had to be recalibrated. To make the procedure somewhat easier, the upper stem of the pipet was calibrated in 0.1 mL increments rather than having only one mark for 25 mL. This series of marks meant that it was not necessary to fill the pipet to exactly 25 mL. By interpolation between the marks, it was possible to determine the volume of the sample to approximately 0.01 mL. This accuracy is more than sufficient for sediment analysis.

Guy (1969) gives the major aspects of the pipet technique. However, it was felt that the techniques could have been implemented more quickly and the procedures could have been checked more easily if some additional information had been given. For this reason plus the fact that the use of gallon and five-gallon samples is not discussed explicitly by Guy, the procedures used in this analysis are summarized below. These procedures should be read in the context of the description given by Guy.

(1) Weigh the gallon (or five gallon) jugs containing the pumped samples. This weight and the subsequent empty weight of the jugs were used to determine the total weight of the water and sediments. This weight was needed for evaluating the concentration of sediments in the jugs.

(2) Allow the sediments in the jugs to settle for several weeks (until the supernatant appears to be essentially clear).

(3) Siphon as much of the supernatant as possible from the jugs being careful not to disturb the settled sediments. During the development of the laboratory procedures, an alloquot of the

supernatant from each jug was evaporated to determine the amount of fine sediment which had not settled. It was soon determined that the settling was essentially complete and that the very small amounts of sediment in the supernatant were negligible.

(4) Flush the sediments from the bottom of the jugs into a beaker using the smallest possible amount of distilled water. For the gallon jugs, the required number of samples was composited to obtain the appropriate total weight of sediment. After running a few samples, the laboratory technician was able to determine by visual inspection the number of samples to composite. Typically, the sediments from two to five gallons were needed to obtain the required 2 to 5 grams for the analysis. It was primarily this step which showed that the use of 5 gal jugs was not feasible.

(5) Wet sieve the sediments using a 0.063 mm sieve.

(6) Dry and weigh the sediments on the sieve. This weight gives the sand fraction, i.e., the fraction larger than 0.063 mm.

(7) Resettle the sediments smaller than 0.063 mm, preferably in a 2L Ehrlenmeyer flask.

(8) Siphon the water in the flask down to about 700 mL.

(9) Resuspend sediments in the flask. Add 10 mL of 44 g/L Calgon solution, and stir on a magnetic stirrer for about 5 minutes.

(10) Pour water and sediments into 1000 mL graduated cylinder if the amount of sediment was judged to be greater than 2 g or into a 500 mL graduated cylinder, if less than 2 g. Although the nominal range of 2 to 5 g is given for the pipet method with a 1000 mL graduated cylinder, reliable results were obtained for as much as 20 g. It was concluded that it was definitely preferable to use a sample with more than 5 g of sediment than to try to split the sample to reduce the amount of sediment being analyzed.

(11) Measure temperature of the water in the graduated cylinder for determining appropriate pipet withdrawal times.

(12) Using a thin perforated plate on the end of a rod, very thoroughly stir the sample in the graduated cylinder, being certain that the heavier and more rapidly settling particles are uniformly mixed over the height of the graduate. Be careful not to introduce air bubbles into the water. If air bubbles are introduced, stop stirring until the air bubbles escape and then restart this step.

(13) Start timing for the sampling immediately upon stopping the mixing and withdrawing the mixing rod.

(14) Take pipet samples at the specified time and depth below the current water surface. Record the volume for each sample. Withdraw samples to determine the amount of sediment smaller than 0.062 mm, 0.031 mm, 0.016 mm, 0.008 mm, 0.004 mm, and 0.002 mm.

(15) If multiple tests (graduated cylinders) are to be conducted at the same time, it is best to prepare all tests to the point of having the water and sediments in the graduated cylinders before any test is started. Then start one test. After collecting the first three pipet samples, the water in the second cylinder can be mixed and the second test started, and so on. Care should be taken to plan the starting times so that samples from different cylinders do not need to be taken at the same time or at nearly the same time.

(16) If a sampling time is missed for any reason, the test can be salvaged by restarting the test but omitting the samples already collected. Remix the sediments remaining in the graduated cylinder. Restart timing the test at the end of the mixing. The first sample to be collected is the one previously missed. The remaining samples are collected at the appropriate times for the restarted test.

(17) Flush the pipet samples into beakers and allow them to settle overnight. With the minimum possible disturbance of the settled sediments, put most of the water through the filters and then use only the last few milliliters to resuspend the sediments for filtering. Use the minimum possible amount of distilled

water to flush all of the sediments onto the filter. Use doubled 5.5-cm diameter filter papers.

(18) Filter papers should be prewashed, dried for one hour, and preweighed after cooling in a dessicator for one hour or more.

(19) After withdrawing all of the pipet samples, allow the sediment remaining in the graduated cylinder to settle. Filter the entire sample (approximately 850 mL) as in (17) but using doubled 11 cm filter papers. Dry and weigh the sediment.

(20) Even with the doubled filter papers, a significant amount of fine sediment may pass through the filter papers when filtering the approximately 850 mL remaining in the graduated cylinder. To determine the total amount of sediment in the original sample,

(a) Collect the filtrate from (19) and determine the volume.

(b) Thoroughly mix this filtrate and withdraw 25 mL to a predried, preweighed evaporating dish.

(c) Withdraw 50 mL from the filtrate in 19 and place in a 50 mL centrifuge tube. Cap and spin at 1500 rpm for 30 minutes. Put 25 mL of the supernate into another predried, preweighed evaporating dish to determine the dissolved solids.

(d) Evaporate both dishes. Subtract the net weight of (c) from the net weight of (b) to obtain the weight of the suspended solids.

(e) Scale this weight to the original volume in the graduated cylinder (1000 or 500 mL).

In principle, part of the sediment from each pipet sample also passed through the filter papers. However, since this sediment is a small fraction of a small amount of sediment in the 25 mL pipet samples, the sediment passing the filters for the pipet samples was neglected.

(21) Add the weights from (6), (19) and (20e) to the accumulated weight from all of the pipet samples. Use this total weight to determine the concentration of the original sample.

With appropriate scaling, the first pipet sample for sediments smaller than 0.062 mm should match the total amount of sediment used in the pipet method (neglecting the small difference between the 0.063 mm sieve and the sampling time in the pipet method for 0.062 mm). As mentioned above, these two values did not agree with each other until the tip of the pipet was removed. After this modification, the deviation between the two values was typically less than 5%. The concentration of the original samples in the jugs was then determined from the combined weight of the sediments in the pipet method and the sediments larger than 0.062 mm.

3.4 FIELD TRIP ON APRIL 13-14, 1989

Even though the flows were known to be very low and the suspended sediment sampler for this project had not yet been obtained, this trip was made to test the equipment and procedures for stream gaging. Because of ease of access, it was decided that the first measurements should be made at the Guadalupe River bridge in Victoria and then at the Guadalupe bridge near Tivoli. It was felt that it was unwise to venture onto the cableway at Goliad on the first field trip. Even though the equipment had been checked before going to the field, there were naturally several "bugs" to be worked out of both the equipment and the procedures.

For the measurements at Victoria on April 13, 1989, the width of the river was divided into 11 segments of equal width, as stated previously, but five to six velocity measurements were taken along each vertical line at 0.2, 0.4, 0.6, and 0.8 depth and at 0.5 ft above the bed, if this point was below the 0.8 depth point. The closest that the Price meter could get to the bed was 0.5 ft due to the weight below the Price meter. For the low flow condition which existed, the width of the water surface was 126 ft and the maximum depth was 6.2 ft. The maximum measured velocity was 1.50 fps. Because of equipment breakdown, it was not possible to complete the cross section. The USGS records give a daily average flow of 555 cfs.

After repairing the equipment, gaging was done at the Guadalupe River bridge on State Highway 35 east of Tivoli on April 14, 1989, which was before the decision was made not to use this station as one of the regular sampling stations. The same general procedures were used as on the previous day. However, the measurements had to be abandoned because of heavy rain.

In spite of equipment problems and bad weather, this field trip provided a good check of the procedures for stream gaging. The procedures were modified somewhat during the two days of measurements. The resulting procedures were considered to be generally satisfactory. However, it was decided that there would not be enough time to make six velocity readings along each vertical and that future measurements should be made at only the standard 0.2 and 0.8 depths.

3.5 FIELD TRIPS ON AUGUST 18, 24-25, 1989

After finally receiving the P-61 suspended sediment sampler and testing it in the laboratory, it was decided to make a field trip to test the field operation of the P-61 and the associated procedures and to collect data for low flow conditions at both Victoria and Goliad. On August 18, 1989, a test for stream gaging and suspended sediment sampling was initiated at the Guadalupe River bridge in Victoria. However, the P-61 sampler failed to operate even though it was new and had been thoroughly checked before going to the field. Repeated attempts to get it to operate and various modifications in procedures were all unsuccessful. The reason for the failure of the P-61 is discussed below. While one person was working with the P-61, another person was proceeding with the stream gaging. The river width was 120 ft with a maximum depth of 4.5 ft. The maximum measured velocity was 0.66 fps. Because of the difficulties with the P-61 sampler, it was decided to abandon this field activity and the gaging was stopped before the velocities were measured in the last three subareas. For the part of the cross section which was gaged, a partial flow rate of 169 cfs was obtained. The USGS records show an average daily flow rate of 184 cfs. This is generally acceptable accuracy since the remaining three subareas appeared to be in a separation zone, so that the amount of additional flow was probably rather low. The daily average flows in the USGS records were very stable for August 13-20, 1989, with variations of about ±10 cfs. Before leaving the site, "grab" suspended sediment samples were obtained at the surface by lowering a weighted line with a quart sampling bottle attached. Samples were collected 28 ft, 60 ft, and 93 ft from the left bank. The corresponding concentrations were respectively 27 mg/L, 16 mg/L, and 12 mg/L. Both the river flow rate and suspended sediment concentrations were very low on this date.

After dismantling the P-61 sampler in the laboratory, thoroughly cleaning and lubricating all internal moving parts, and again checking the operation, the field trip was resumed on August 24, 1989. The first test was at the Guadalupe River bridge on State Highway 35 east of Tivoli. The stream gaging revealed that the flow was very sluggish and was upstream in some parts of the cross section. These measurements played a major role in the decision which was made after this field trip not to make any further measurements at this location. Before leaving the site, three suspended sediment samples were collected at midstream at 0.3 ft, 3.0 ft, and 7.5 ft below the surface. The total water depth was 14.6 ft at the sampling location. The sediment concentrations were respectively 29 mg/L, 14 mg/L, and 32 mg/L.

On August 25, 1989, measurements were made at Goliad and at Victoria. At Goliad, the San Antonio River was so low that stream gaging was done with a wading rod and a tag line. The river width was 77 ft, the area was 118 ft^2, the maximum depth was 2.1 ft, the average depth was 1.5 ft, the maximum measured velocity was 1.5 fps, the average velocity was 1.2 fps, and the flow rate was 139 cfs. The USGS records give a daily average flow of 140 cfs for August 25, 1989, and 144 cfs for August 24. The P-61 sampler was used successfully to collect a set of suspended sediment samples 1 ft below the water surface. The results are given in Table 3.5.1. The concentrations are essentially uniform across the channel width. These results provided some encouragement that the P-61 sampler was working properly and was being used properly. The concentrations are also very low, as might be expected for the very low river flow rate.

On August 25, 1989, the Guadalupe River at Victoria was also very low, but the stream gaging was done from the bridge. The river width was 118 ft, the area was 427 ft^2, the maximum depth was 4.5 ft, the average depth was 3.6 ft, the maximum measured velocity was 0.66 fps, the average velocity was 0.26 fps, and the measured flow rate was 110 cfs. The USGS records give a daily average flow of 152 cfs for August 25, 1989. The lack of agreement between the measured flow and the flow given by the USGS gaging station is not too

Table 3.5.1 - Suspended Sediment Data from August 1989 Measurements in San Antonio River at Goliad

Date	Time	Concentration mg/L	Station ft	Total Depth ft	Sample Depth ft
8/25	11:00	54	14	2.0	1.0
	10:43	56	28	2.0	1.0
	10:20	51	42	2.0	1.0
	10:25	66	42	2.0	1.0
	11:36	50	42	2.0	1.0
	11:42	52	42	2.0	1.0
	11:11	52	54	1.8	1.0
	11:15	56	54	1.8	1.0
	11:27	50	70	1.3	1.0

Left bank station = 4 ft
Right bank station = 81 ft

surprising for two reasons. One is that four of the eleven subareas used in the gaging had essentially zero velocity. Thus, the measured flow actually came from measurements in only seven subareas. The other reason is that the flow in the river was in recession at the time of the measurements. The flows from the USGS gaging station were 223 cfs on August 24, 152 cfs on August 25, and 105 cfs on August 26. The measurements giving the flow of 110 cfs were made late in the afternoon (4:00 to 5:00) on August 25. While the stream gaging was being done, attempts were being made to collect suspended sediment samples with the P-61 sampler. Only one sample was successfully collected. This sample was 32 ft from the left bank at a depth of 4.1 ft in water 4.6 ft deep and was in a region where the velocity was less than 0.2 fps. The concentration was 13 mg/L. Repeated attempts were made, as on August 18, to collect other samples, but the sampler would not work although it had worked satisfactorily during the morning of the same day. Before leaving the site, a grab sample was collected by lowering a weighted quart sample bottle 70 ft from the left bank. This surface sample had a concentration of 179 mg/L. After the field trip, it was learned from personnel at the Federal Interagency Sedimentation Project that the water was too warm for the sampler to work. The water temperature was 32.5°C or 90.5°F, presumably due to the time of the year and the low flow conditions. Although no specific maximum operating temperature was quoted for the sampler, the indications were that various parts in the valve mechanism undergo differential thermal expansion at these relatively high temperatures for river water, resulting in binding so that the valve will not operate. This problem with thermal expansion was apparently the reason that the valve worked in the air-conditioned laboratory when it was checked before the field trip but frequently did not work in the field.

3.6 FIELD TRIP ON FEBRUARY 10-11, 1990

During the previous field trips, the river flows were very low (near their historic lows). After the fall season of 1989 and the first part of the winter of 1989-1990 produced no significant rainfall in the watersheds of interest, it was decided that some sites other than the lower parts of the Guadalupe and San Antonio Rivers should be investigated, at least for further development of field techniques and procedures and possibly for changing the major locations for data collection. Thus, on February 10-11, 1990, a reconnaissance trip was made to investigate the bridge crossings on the Colorado, Brazos, and Trinity Rivers. The evaluation focused on features such as accessibility for instruments and measurements, presence of a USGS gaging station, flow conditions, highway traffic conditions, and safety. The locations investigated on the Colorado River were the U. S. Highway 59 bridge south of Wharton, the State Highway 35 bridge west of Bay City, and the inflatable dam downstream of the Highway 35 bridge. The FM 521 bridge southwest of Wadsworth was not investigated because of the probability of being in a tidally influenced region for low flows and because of the inflatable dam just downstream of Highway 35. The sites investigated on the Brazos River were the State Highway 332 and 35 bridges east of Brazoria and east of Columbia, respectively, the FM 1462 bridge west of Rosharon, and the U. S. Highway 59 and 90 bridges south of Richmond and in Richmond, respectively. The lowest part of the Trinity River was not considered because the distance from Lake Livingston to Trinity Bay is only about 65 to 70 miles. The sites investigated above Lake Livingston were the State Highway 21 and 7 bridges northeast of Midway and west of Crockett, respectively, the U. S. Highway 79/84 and 287 bridges northeast of Oakwood and west of Cayuga, respectively, and the State Highway 31 bridge in Trinidad. From all of these locations, only the U. S. Highway 90 bridge in Richmond emerged as a clear possibility for an alternate site. It is far downstream relative to the size of the watershed and relative to upstream reservoirs; it is essentially assured of having significant flows at all times because of the size of the watershed and the typical amounts of rainfall in the watershed; the bridge for the east-bound lanes has a wide sidewalk for good accessibility; and the traffic on the bridge normally is travelling at city speeds rather than open-highway speeds. This location is also a USGS gaging station. However, the USGS measurements are made from the downstream side of the west-bound lanes, where there is not a sidewalk. The upstream side of the east-bound lanes was selected for this project for accessibility and safety reasons.

3.7 FIELD TRIP ON MARCH 2-3, 1990

The field trip started by going to the Guadalupe River bridge in Victoria and the San Antonio River bridge in Goliad on March 2. The stages and flows in both rivers were still very low. The daily average flows for the Guadalupe and San Antonio Rivers at these two sites were respectively 446 cfs and 345 cfs. Both flows had been nearly constant for several preceding days. Because of the low flows, no stream gaging was done. Nevertheless, to test the operation of the pumped sampling technique described in Section 3.2, one 5 gallon sample was obtained at Victoria and two 5 gallon samples were obtained at Goliad. At Victoria, the sample was collected at USGS station 205 ft, which is near the center of the river. The left bank was at station 147 ft. The intake on the pump was 1.3 ft above the bed. After starting the pump, about 3 minutes were allowed to flush the 1/2-in. garden hose coming from the pump to the sample bottle. The internal volume of the hose was about 0.5 gal, and the pumping rate was typically 1.7 gpm. Thus, 3 minutes were required to fill the 5 gal sample bottle. The concentration was 23 mg/L. At Goliad, the sample bottles and the electric generator were kept at the base of the tower supporting the cable for the cart used for measurements and sampling. The 1/2-in. garden hose and a 100 volt extension cord were strung along the cable (Fig. 3.2.5). The pump was lowered into the river (Fig. 3.2.6) at midstream. The water was so shallow that the pump had to be inclined relative to vertical to get the intake to about middepth. Two 5 gal samples were collected. The concentrations were 109 mg/L and 116 mg/L. The size distributions are shown in Table 3.7.1 and in Fig. 3.7.1. The results for the San Antonio River may not be very reliable. The fraction of the sample larger than 0.062 mm and the amount of difference between the two samples for the San Antonio River are both reasons to view the results for the San Antonio River with some skepticism. The water was so shallow that setting the base of the pump on the stream bed and then inclining it may have caused a disturbance of the bed sediments and caused sand from the bed to have been collected along with the suspended sediment. Nevertheless, these tests helped to establish the procedures to be used for pumped samples and gave some additional data on the sediments for low flow conditions.

Because of the continued low flows in the Guadalupe and San Antonio Rivers, it was decided to shift to the alternate site at the Brazos River bridge on U. S. Highway 90 at Richmond for the testing on March 3, 1990. The primary purposes of the work at Richmond were to further develop techniques for measuring and sampling in a larger flow than had existed for many months at the two primary sites, to collect samples for comparison of the pumping technique and the P-61 sampler, and to obtain a larger number of sediment samples for developing and testing the laboratory analysis

Table 3.7.1 - Suspended Grain Size Distributions from March 2, 1990 Measurements in Guadalupe River at Victoria and San Antonio River at Goliad

River	Guadalupe	San Antonio	San Antonio
Concentration (mg/L)	23	109	116
Size (mm)		Percent	
>0.062	1	5	10
<0.062	97	88	90
<0.031	93	93	90
<0.016	94	88	84
<0.008	81	83	70
<0.004	60	62	62
<0.002	30	42	35

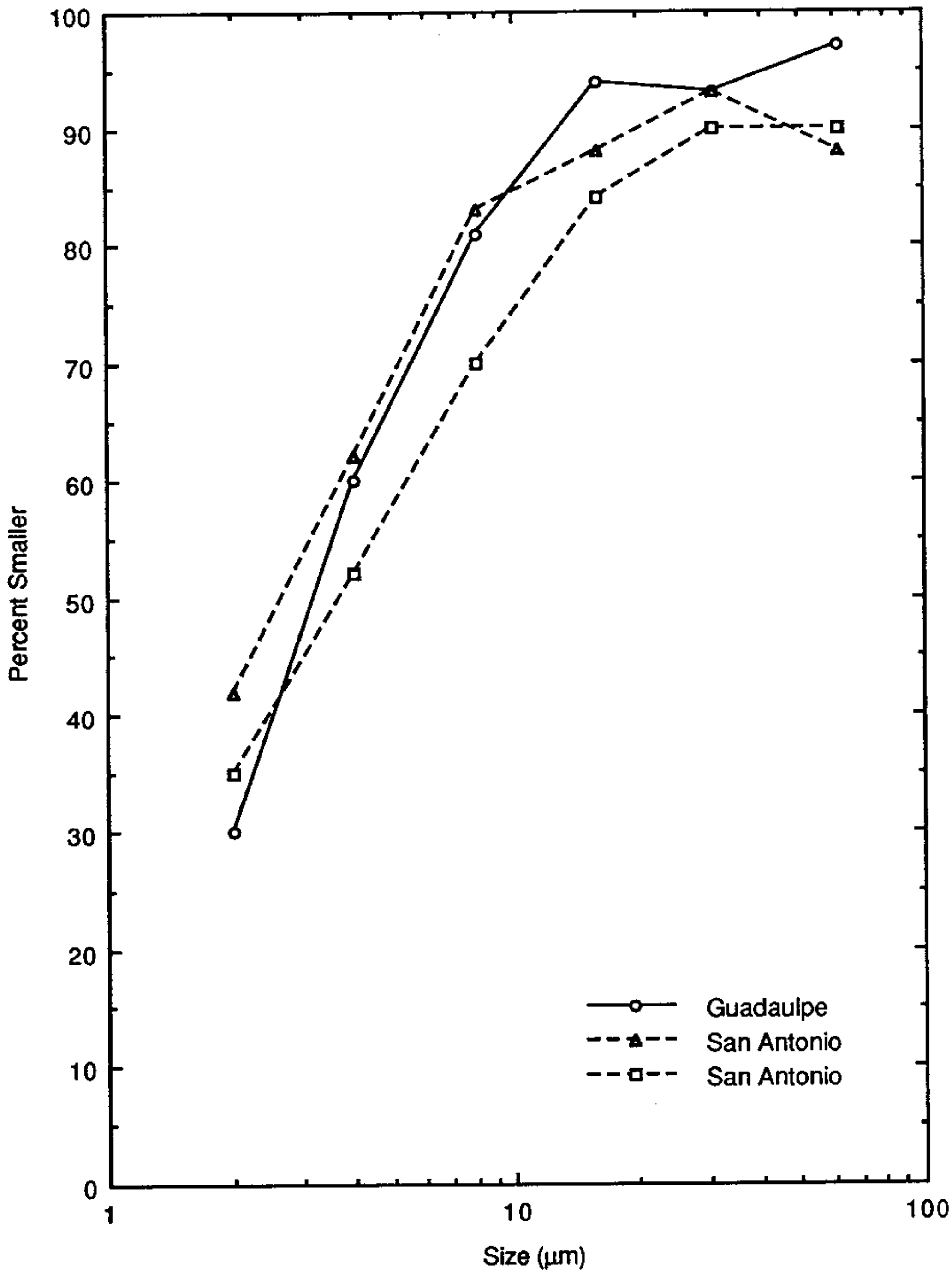

Fig. 3.7.1 - Suspended Grain Size Distributions for Guadalupe and San Antonio Rivers on March 2, 1990

techniques. Stream gaging was done from about 1:00 PM to 3:00 PM. The longer-than-normal time was required for training some new personnel. A set of stations was established for this set of measurements. Relative to these stations, the left bank was at 165 ft and the river width was 230 ft. The area was 2880 ft^2, the maximum depth was 18.9 ft, the average depth was 12.5 ft, the maximum measured velocity was 2.0 fps, the average velocity was 1.5 fps, and the measured flow rate was 4310 cfs. The USGS records give a daily average flow of 4390 cfs for March 3, 1990.

Sediment samples were collected only at the thalweg, which was at station 343 ft or 178 ft from the left bank. Samples were collected by several different methods to determine the sensitivity of the results to the sampling method. The results are summarized in Table 3.7.2. From left to right across the table, the sampling methods were as follows: (1) using the P-61 sampler with a 100 second sampling time, (2) using the full flow of the pump (approximately 4 gpm on this day only) to fill the quart sample bottle in about 4 seconds, (3) splitting the flow from the pump over the lip of the quart bottle so that most of the flow was wasted and the remaining flow filled the bottle in about 40 seconds, (4) intermittently, but with a regular timing pattern, letting the flow from the hose go into the quart sample bottle for less than a second so that a total of about 40 seconds was needed to fill the quart bottle, and (5) filling the 5 gal bottles with the full flow from the pump so that about 75 seconds were needed to fill the bottles. The conclusions were that there were no discernable trends in the concentrations for the various methods of filling the quart sample bottles with the pump, that the pumped quart samples had essentially the same concentrations at the P-61 samples, and that the concentrations in the 5 gallon samples were consistently a few percent (5% to 7%) too low. From these comparisons, it was further concluded that the pumped samples were essentially the same as the P-61 samples, but that there were apparently some problems with the sampling or the handling of the samples for the 5 gallon bottles. The indications from the results in Table 3.7.2 are that some of the sediment in the 5 gallon jugs was not extracted from the jugs during the analysis in the laboratory. There are also indications of difficulties in handling the 5 gallon samples in the grain size analysis mentioned below. Both because of these results and because of the difficulties of handling the 5 gallon bottles in the laboratory, the use of the 5 gallon bottles was discontinued in favor of five one-gallon plastic milk jugs for future tests.

Table 3.7.2 - Comparison of Suspended Sediment Sampling Techniques in the Brazos River at Richmond on March 3, 1990

Depth ft		Sediment Concentrations mg/L					Ratios	
	Size Method	1 qt P-61	1 qt pumped full flow	1 qt pumped split flow	1 qt pumped intermittent	5 gal pumped full flow	1 qt (all pumped) +P-61	5 gal +P-61
3.8		384	371	369		359	1.00	0.93
		367	383	372		340		
		381						
avg		375	378	370		349		
9.5		368	383	376	374	354	1.03	0.95
		381		348				
		386						
avg		368	383	376	374	351		
15.1		397	375	393	386	365	0.99	0.95
		373	377	368				
avg		385	376	393	377	365		

The grain size distributions are shown in Table 3.7.3 and Fig. 3.7.2. The grain sizes for the 3.8-ft depth are somewhat smaller than for the larger depths. The fact that some of the samples, particularly the last two in the table, have a sum of sizes greater and less than 0.062 mm which is significantly greater than 100% is another indication of difficulties with handling the 5 gallon samples.

3.8 FIELD TRIP ON APRIL 27-30, 1990

Near the end of April 1990, the weather conditions were such that there appeared to have been enough rain to have increased flows in the Guadalupe and San Antonio River basins and to allow enough time to get to the sites and collect data and samples for higher flows than had been existing. For example, at some of the rainfall gages in the Guadalupe watershed below Canyon Dam and upstream of Victoria, the rainfall amounts were as given in Table 3.8.1 (National Climatic Data Center, 1990a). Similar data for the San Antonio watershed above Goliad, from the same reference, are given in Table 3.8.2. The eight daily average flows from April 25 through May 2 for the Guadalupe River at Victoria (Fig. 1.3.4b) were 636 cfs, 903 cfs, 2220 cfs, 2060 cfs, 2900 cfs, 2070 cfs, 1440 cfs, and 996 cfs. Similar values for the San Antonio River at Goliad (Fig. 1.3.5b) were 252 cfs, 261 cfs, 1630 cfs, 2420 cfs, 3790 cfs, 2590 cfs, 954 cfs, and 716 cfs.

Since there was a significant amount of rainfall in both watersheds, the original plan was to alternate between the two primary sampling sites. An attempt was made to do stream gaging and to collect sediment samples on April 27 at Goliad, but the large number of large log rafts (ranging from large logs to nearly entire trees) made it unsafe to have a Price meter or a sampler in the water for more that a few seconds between rafts of the debris. This condition did not allow enough time to take velocity readings nor to collect sediment samples with either the P-61 sampler or the bedload sampler. (Fig. 3.8.1 shows log rafts from July 1990. The ones during this test in April 1990 were somewhat less frequent and somewhat smaller, but still they prohibited normal measurements and sampling.) Thus, the site at Goliad was abandoned in favor of Victoria. There were occasionally floating logs that passed the measurement station at Victoria, but they were much less frequent and the measurements were being made from a bridge instead of a cableway. Thus, it was considered to be safe to work at Victoria. Stream gaging was

Table 3.7.3 - Suspended Grain Size Distributions from March 3, 1990
Measurements in Brazos River at Richmond

Concentration (mg/L)	359	340	354	348	365
Sample Depth (ft)	3.8	3.8	9.5	9.5	15.1
Size (mm)	Percent				
> 0.062	2	2	3	3	5
< 0.062	101	103	102	103	105
< 0.031	103	101	95	96	96
< 0.016	94	89	83	85	82
< 0.008	78	--	74	74	76
< 0.004	63	66	65	59	60
< 0.002	48	45	49	48	45

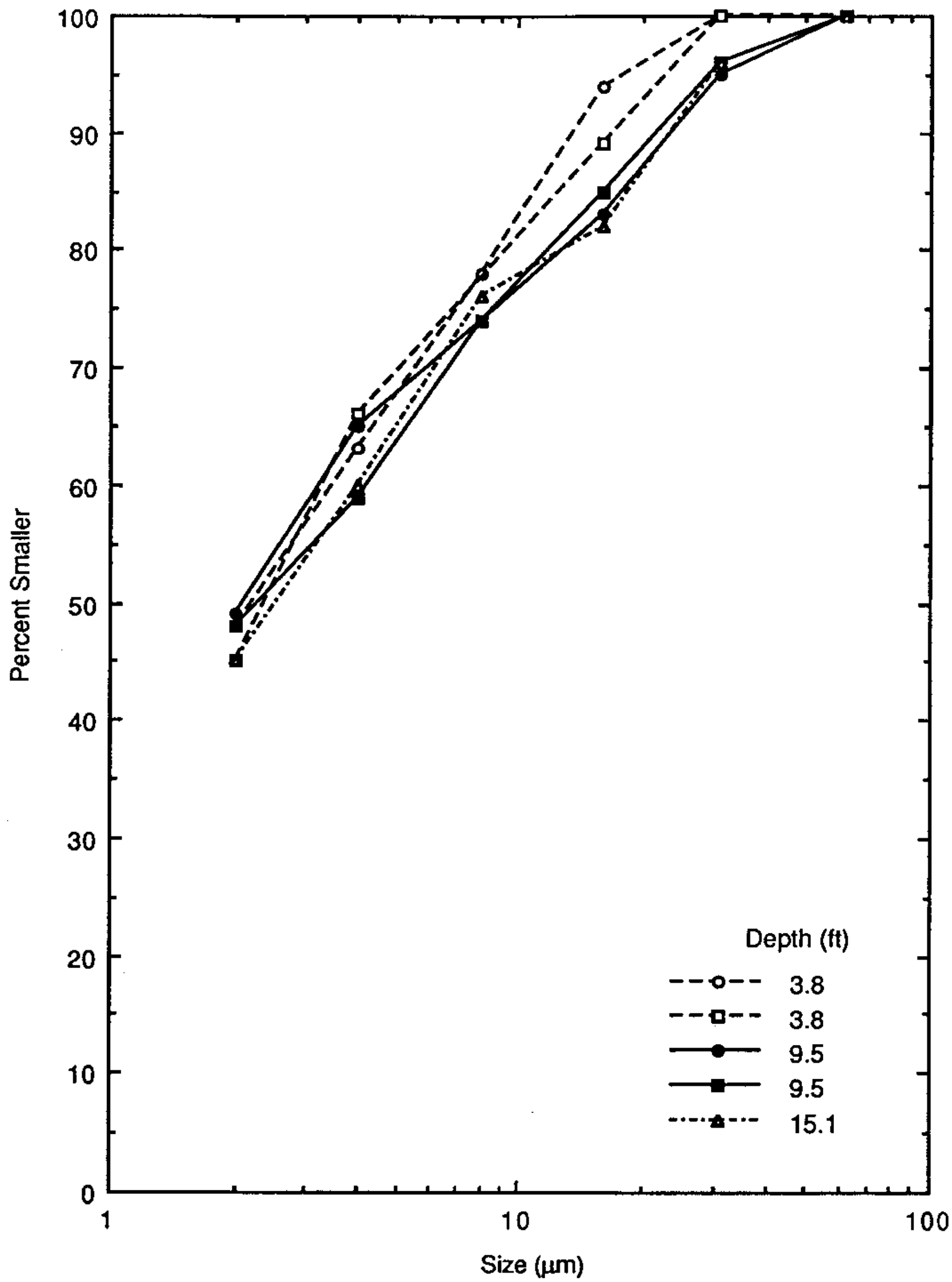

Fig. 3.7.2 - Suspended Grain Size Distributions for Brazos River at Richmond on March 3, 1990

Table 3.8.1 - Rainfall in Guadalupe River Watershed on April 25-27, 1990*

Gage	Amount (in.)		
	April 25	April 26	April 27
Cuero	0.05	0.04	2.30
Gonzales	--	0.51	2.76
Jeddo 1 SW	0.30	1.82	1.10
Lockhart	1.19	1.14	--
Luling	0.02	0.79	2.26
New Braunfels	1.50	1.57	--
Nixon	--	1.97	0.01
Victoria WSO	--	2.64	--
Waelder 7 S	--	--	2.05
Wimberly 2	--	1.65	1.05
Yorktown	0.01	2.95	--

*National Climatic Data Center, 1990a

Table 3.8.2 - Rainfall in San Antonio River Watershed on April 25-27, 1990*

Gage	Amount (in.)		
	April 25	April 26	April 27
Boerne	0.06	2.89	0.82
Bulverde	2.22	0.35	--
Falls City 4 WSW	--	0.16	2.24
Goliad	--	2.08	--
Medina	0.03	1.80	0.02
Riomedina 2 N	--	1.76	--
Runge	--	--	--
San Antonio WSFO	0.01	3.60	--
San Antonio Sea World	0.02	1.56	0.28
Stockdale 4 N	--	1.66	--

(No reports from Goliad 1SE)

*National Climatic Data Center, 1990a

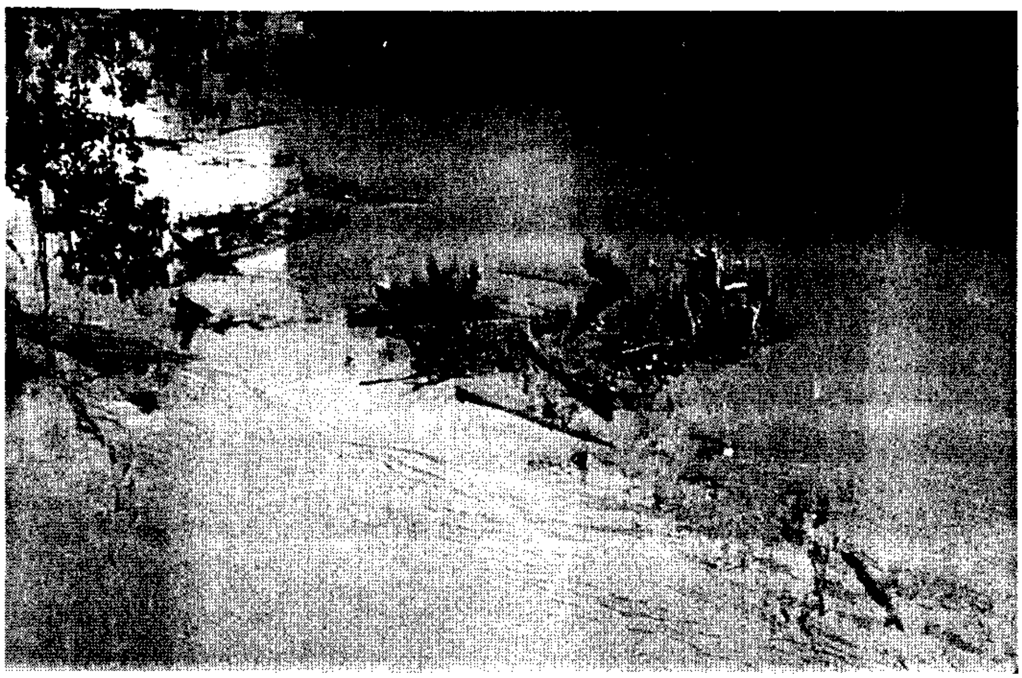

Fig. 3.8.1 - Frequent Large Log Rafts on San Antonio River at Goliad in July 1990

done each day while suspended sediment samples were being collected. The results for the gaging are summarized in Table 3.8.3. The relatively long time for the stream gaging measurements was due to almost continual training of new students and other personnel for the different measurements and to occasionally needing to interrupt the gaging to do or to assist with sediment sampling. The measured flow rates all agree to within about 15% with the daily average flow rates. This degree of agreement is considered to be acceptable since the measured flow rates were obtained using only 11 subareas and since they were each obtained over a 2 to 3 hour time period during a period with significant changes in flow rate from one day to the next, while the daily flow rates are the daily averages.

Suspended sediment samples were collected with the P-61 sampler and with the pump and five one-gallon jugs. The data are summarized in Table 3.8.4 and are shown in Fig. 3.8.2. The flow rates in Fig. 3.8.2 were obtained from hourly stages and a polynomial approximation for the rating curve. Thus, the flows are not exactly the same as would be obtained from the more detailed tabulated rating "curve." The table shows the time and location of each sample. In the figure, time is measured in days since midnight (0:00) at the beginning of April 25, 1990. The figure shows that there is a general correlation between flow rate and suspended sediment concentration. There is no consistent trend for variations of concentrations with depth of the sample. Also, except for April 27, there are no consistent differences between the pumped samples and the P-61 samples.

The grain size distributions for the pumped suspended sediment samples are given in Table 3.8.5 and are shown in Figs 3.8.3 through 3.8.7a. Fig. 3.8.7a is a composite of all of the distributions from the individual days, except that the data from April 27 are omitted because of the differences in the P-61 and pumped samples (Fig. 3.8.2). For the data in Fig. 3.8.7a, the standard deviation for each grain size is 3% or less even though samples were collected during different phases of the flow hydrograph. A variation of 3% could easily be attributed to random sampling and measurement errors.

Fig. 3.8.7b shows the only known previous data for grain size distributions (Welborn, 1967). The trend of the data is significantly different from the trend in Fig. 3.8.7a. The reason for the difference is unknown. The only obvious difference in procedures is that Welborn's data are for samples collected using a depth-integrating sampler, while the samples in this study

Table 3.8.3 - Stream Gaging Results for Guadalupe River at Victoria for April 27-30, 1990

Date	Time	Left Bank Station ft	Width ft	Area ft^2	Max Depth ft	Avg Depth ft	Max Vel fps	Avg Vel fps	Measured Flow Rate cfs	Daily Flow Rate cfs
April 27	8:51-12:29	138	142	1320	11.5	9.3	2.9	1.9	2440	2220
April 28	9:05-11:47	138	141	1155	9.8	8.2	2.7	1.8	2060	2060
April 29	12:51-15:54	138	145	1560	13.0	10.8	3.2	2.1	3290	2900
April 30	16:08-18:18	138	140	1075	9.4	7.7	2.7	1.6	1745	2070

Table 3.8.4 - Suspended Sediment Concentrations from April 1990 Measurements in Guadalupe River at Victoria

Date	Time	Concentration P-61 mg/L	Concentration p-gal mg/L	Stage ft	Station ft	Total Depth ft	Sample Depth ft
4/27	11:07	443			210	10.9	2.2
	10:50	477					5.5
	11:15	430					8.8
	12:20		405		210	10.9	2.2
	12:15		289				5.5
	12:30		321				8.8
4/28	9:32	375			234	8.6	1.7
	9:26	384					4.3
	9:20	395					6.9
	9:55	371			209	9.7	2.0
	10:02	385					5.0
	10:15	377					8.0
	10:30	383			183	9.8	2.0
	10:40	404					5.0
	10:45	381					8.0
	17:45			9.60			
	17:28		391		175		2.0
	17:21		397				5.0
	17:15		408				8.0
	17:15	421					8.0
	18:43		386				???
	18:43	383					???
4/29	16:22	778			211	12.5	3.1
	16:28	766					6.2
	16:40	756					9.4
	16:48	758			211	12.5	3.1
	16:55	743					6.4
	17:20	780					11.4
	18:25		723		211	12.5	3.1
	18:35		754				6.2
	18:46		782				9.4
	18:53		756				11.4
	19:10			11.22			
4/30	11:20			9.21			
	11:30	456			209	9.3	2.4
	11:55	437					2.4
	12:27		432				2.4
	12:05	433					4.8
	12:36		420				4.8
	12:11	426					7.2
	12:40		418				7.2
	13:11	383					8.0
	12:30	392					8.5
	12:40	457					8.5
	14:30			8.90			
	17:45			8.62			

Left bank station = 138 ft (all days)
Right bank station = 280 ft (4/27), 279 (4/28), 283 (4/29), 278 (4.30)

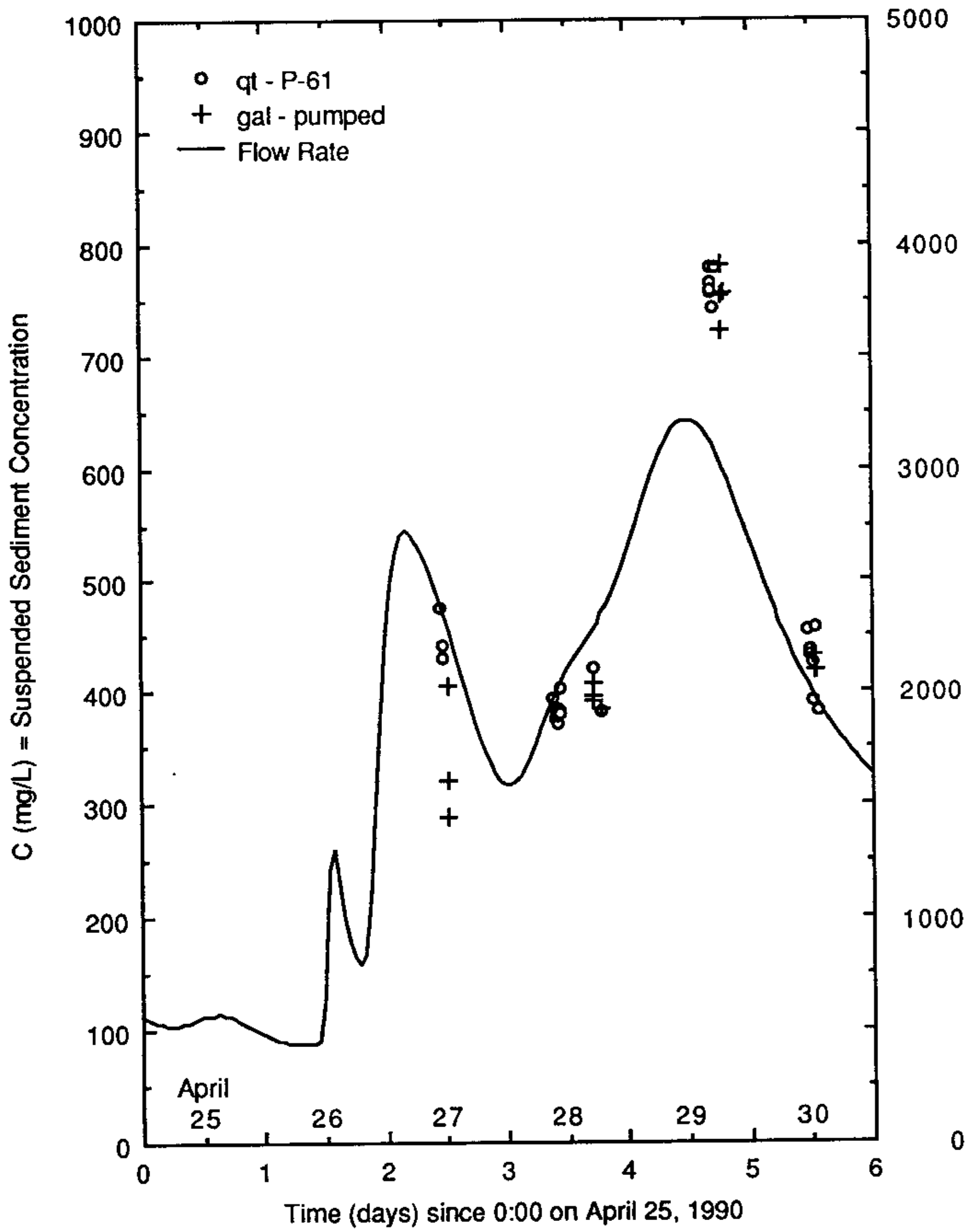

Fig. 3.8.2 - Suspended Sediment Concentrations and Flow Hydrographs for Guadalupe River at Victoria for April 1990

Table 3.8.5 - Suspended Grain Size Distributions from April 1990
Measurements in Guadalupe River at Victoria

Date	4/27	4/27	4/27	4/28	4/28	4/28	4/28	4/29	4/29	4/29	4/29	4/30	4/30	4/30	
Concen-tration (mg/L)	405	289	321	391	397	408	386	723	754	782	756	432	420	418	
Sample Depth (ft)	2.2	5.5	8.8	2	5	8	??	3.1	6.2	9.4	11.4	2.4	4.8	7.2	avg
Size (mm)	Percent														
> 0.062	2	3	2	2	3	3	5	2	2	4	3	3	2	3	3
< 0.062	94	97	97	100	99	90	95	97	97	94	95	93	97	98	96
< 0.031	93	97	98	98	97	90	94	93	94	91	94	93	95	95	94
< 0.016	85	95	89	86	84	81	81	84	82	79	81	83	78	81	82
< 0.008	69	80	78	71	67	66	65	68	64	63	65	66	61	67	66
< 0.004	54	67	69	56	51	53	52	51	50	47	47	50	47	46	50
< 0.002	35	37	47	36	32	34	33	33	30	29	30	29	35	31	32

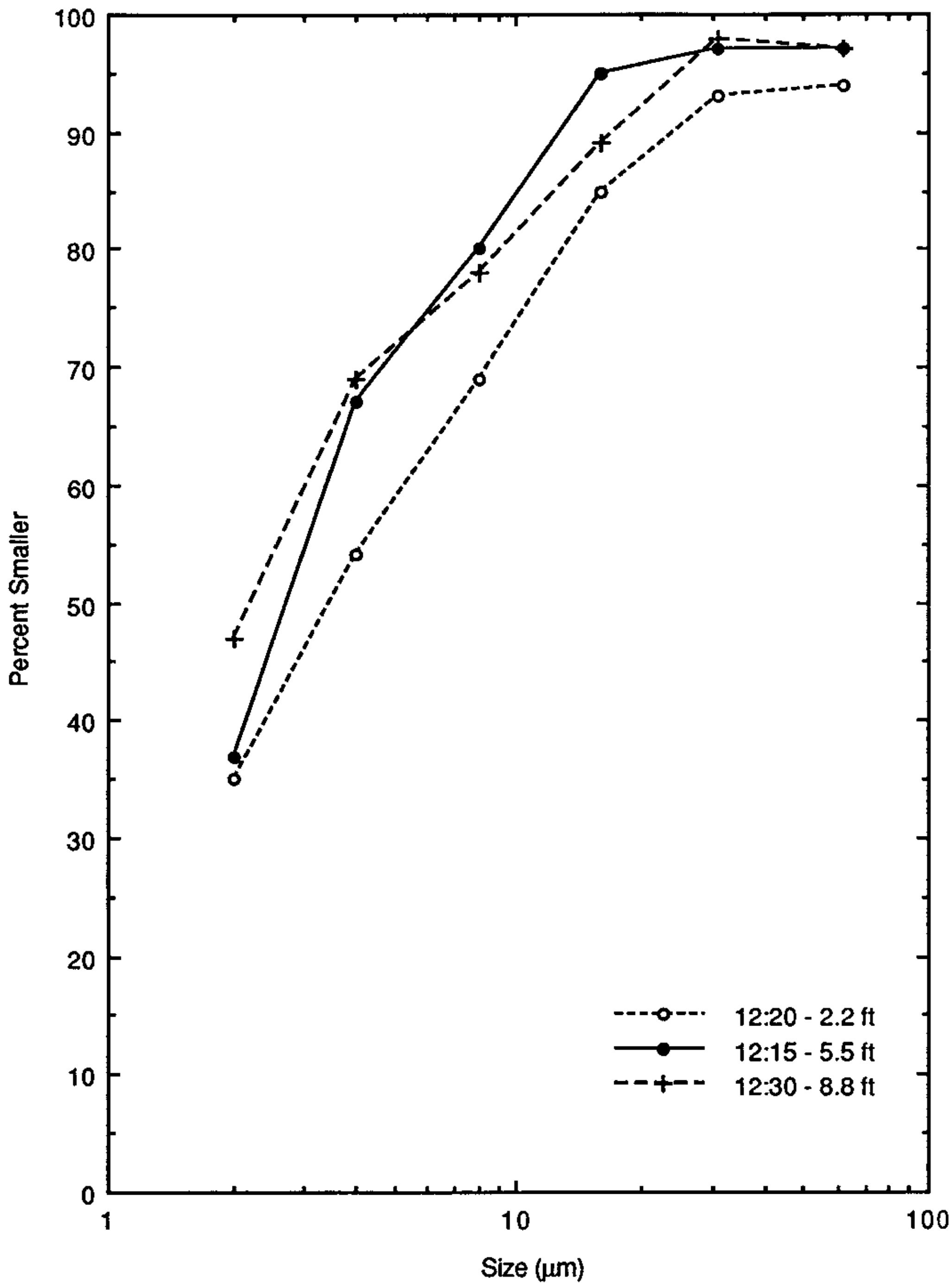

Fig. 3.8.3 - Suspended Grain Size Distributions for Guadalupe River at Victoria on April 27, 1990

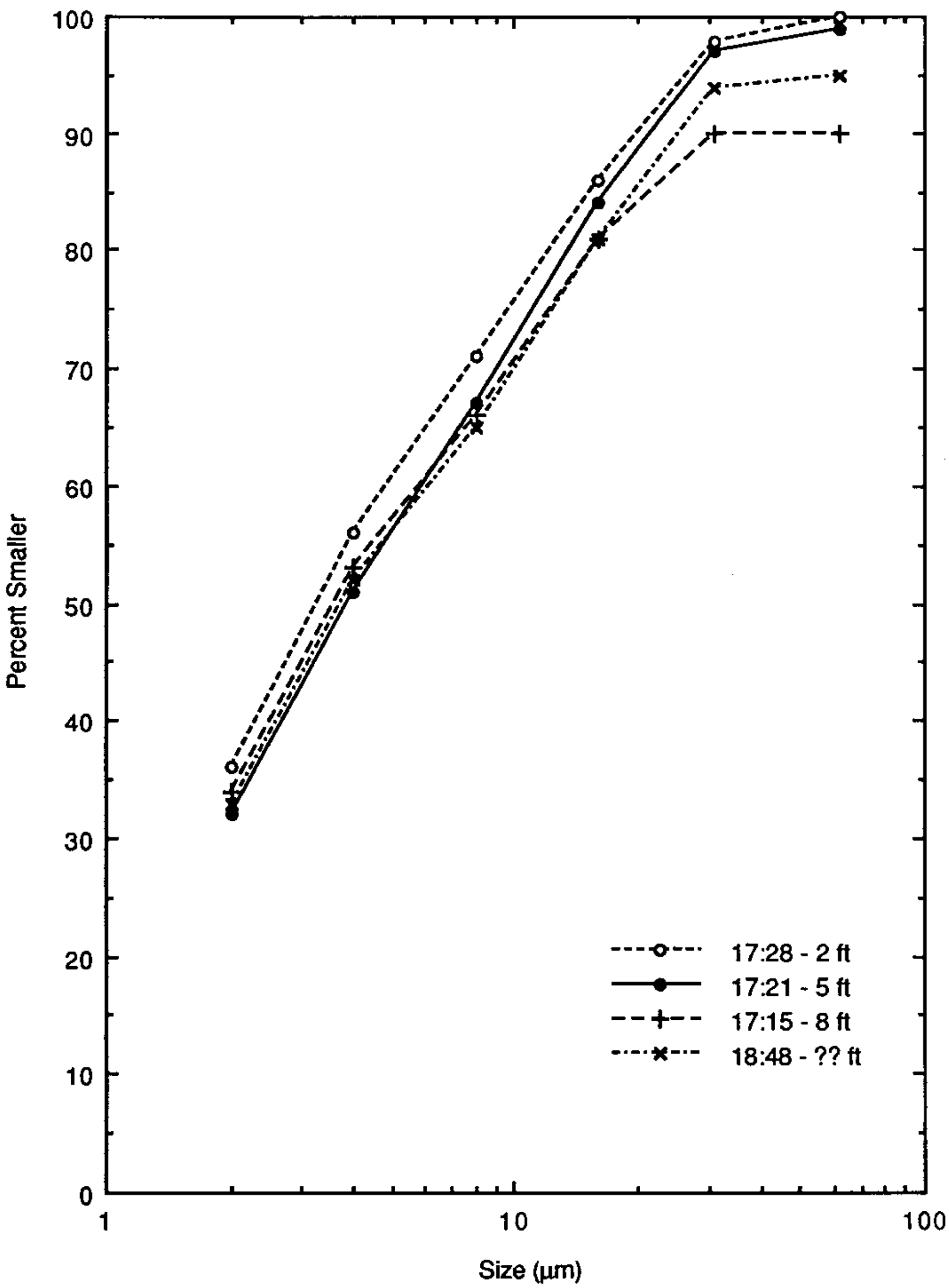

Fig. 3.8.4 - Suspended Grain Size Distributions for Guadalupe River at Victoria on April 28, 1990

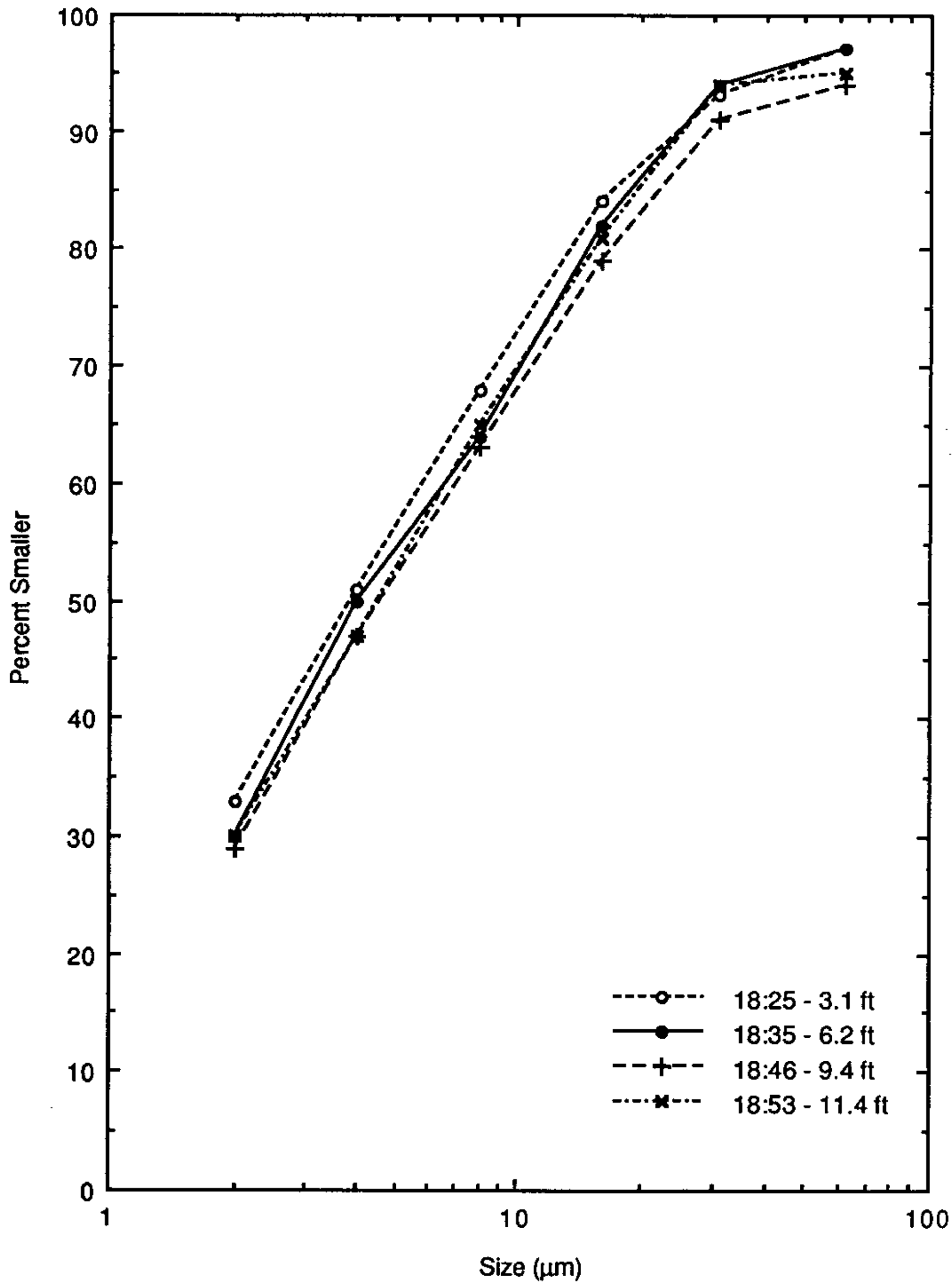

Fig. 3.8.5 - Suspended Grain Size Distributions for Guadalupe River at Victoria on April 29, 1990

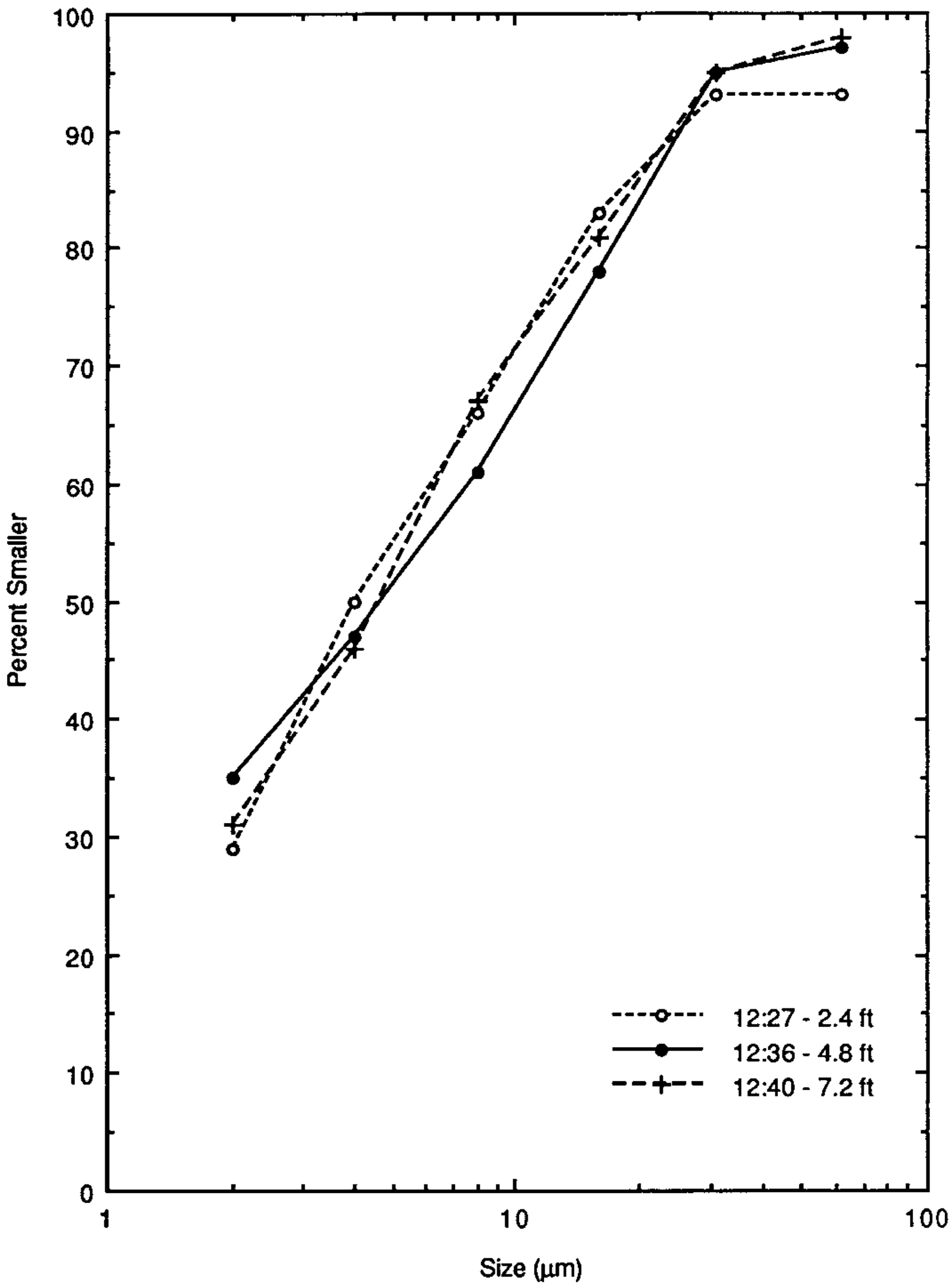

Fig. 3.8.6 - Suspended Grain Size Distributions for Guadalupe River at Victoria on April 30, 1990

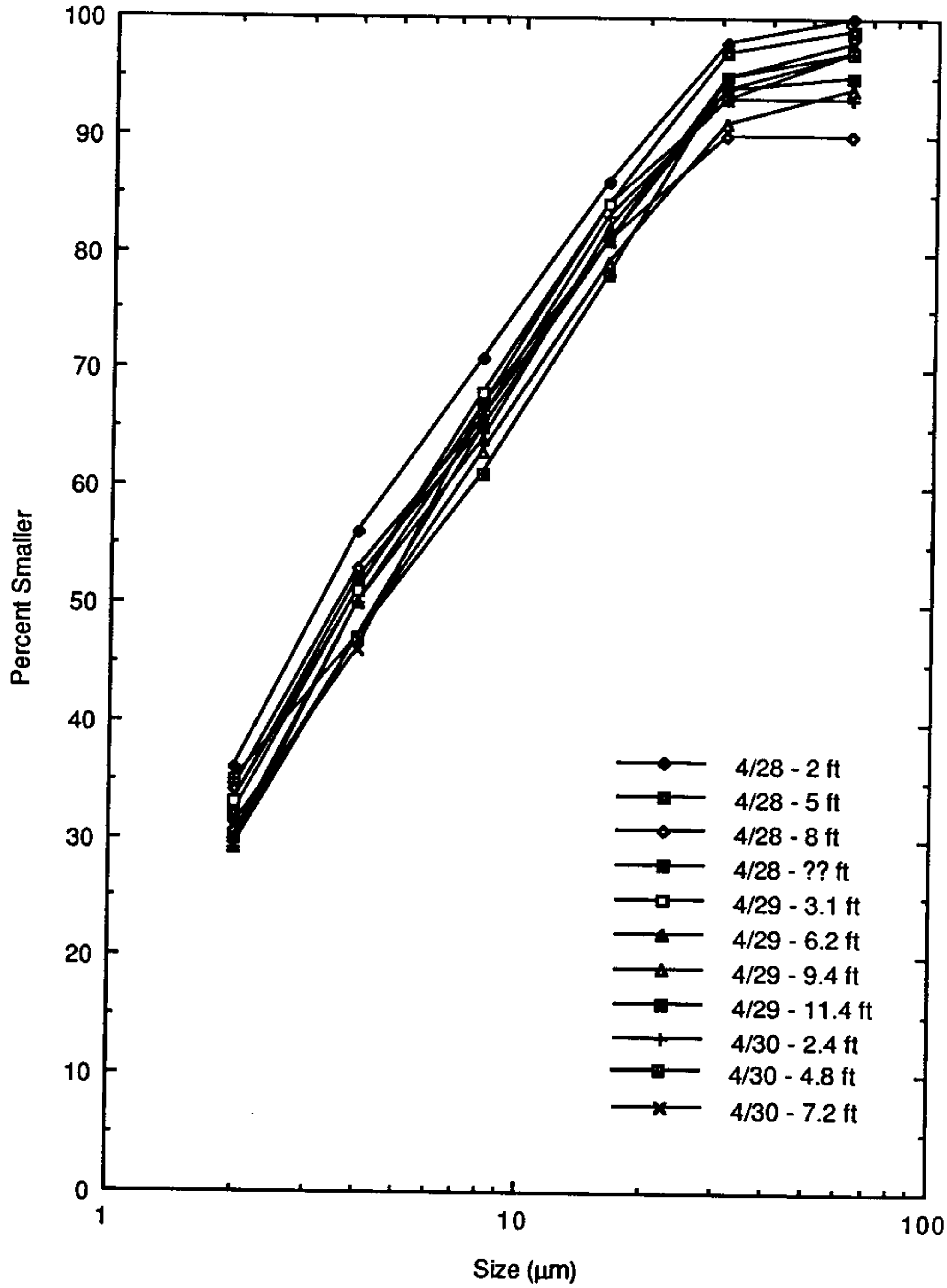

Fig. 3.8.7a - Suspended Grain Size Distributions for Guadalupe River at Victoria on April 28-30, 1990

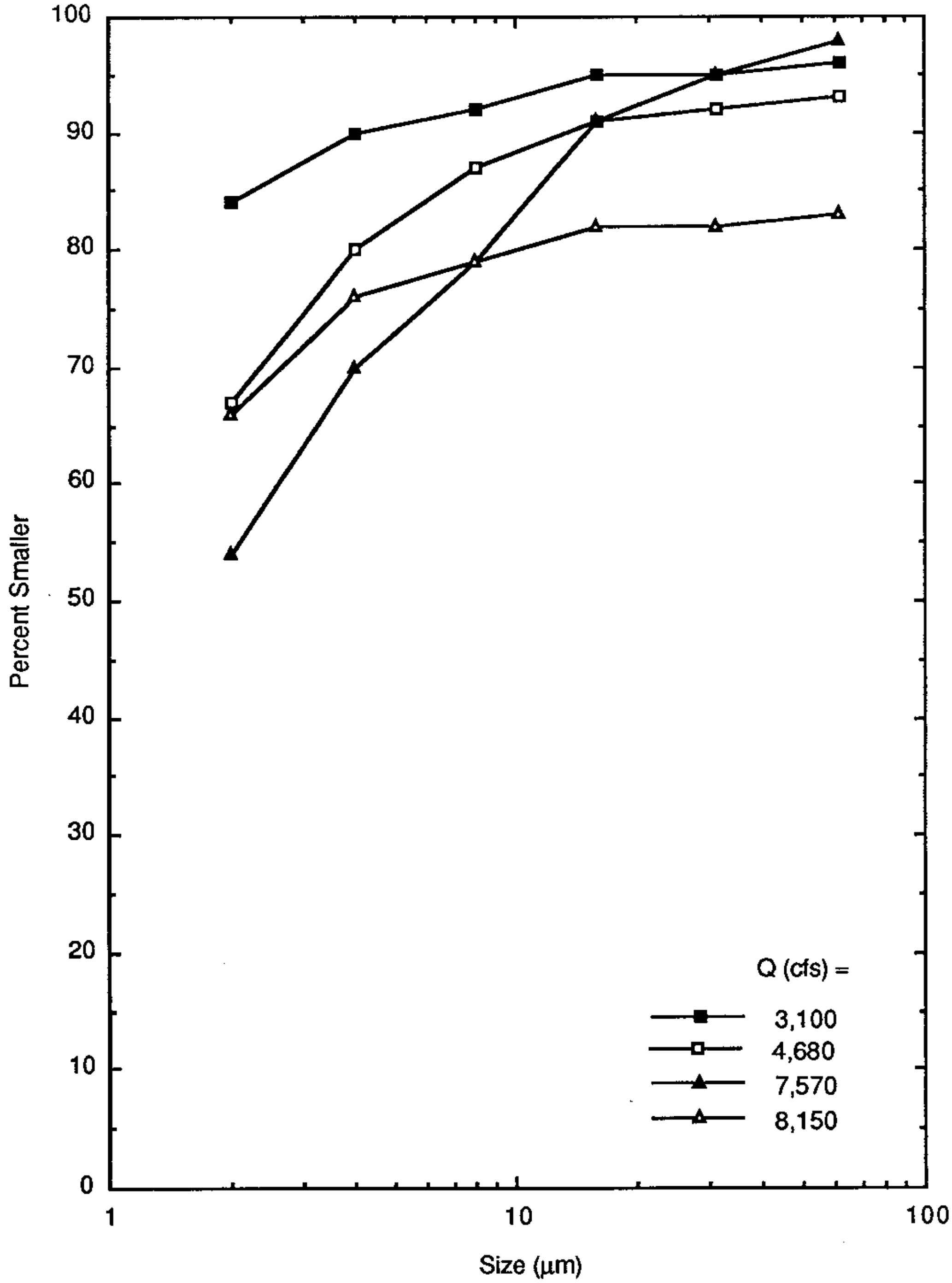

Fig. 3.8.7b - Suspended Grain Size Distributions for Guadalupe River at Victoria in 1958-61 (Welborn, 1967)

were collected with a point sampler, but these point samples indicate no consistent variation of grain size with depth.

For the bedload, the amounts of sediment collected and the grain size distributions are given in Tables 3.8.6 and 3.8.7 and in Figs. 3.8.8 through 3.8.10. Ten of the samples have very similar grain size distributions. The other five distributions are significantly different. At least part of the reason for these differences is that a few large grains collected in the sampler can make a very significant difference in the grain size distribution since the distribution is based on weight and the weight of individual grains increases as the cube of the size of the grains. In Table 3.8.6, an attempt is made to estimate the total bedload transport rate even though there really were not enough samples across the width of the river to make this estimate as accurate as would be desirable. For estimating the bedload transport rate, first it was assumed that half of the width of the river had active bedload transport. It was clear from observations during the testing and from the samples that part of the river on each side did not have any active bedload transport, but the actual fraction of the width with transport is unknown. Based on the samples collected within the central one half of the width, the average rate of collection of sediment was calculated for each day. Using the 3 in. size of the opening on the Helley-Smith sampler and half of the width of the river, the average rate of collection of bedload sediments was extrapolated to a total load. Even with all of the uncertainty concerning the estimation of the bedload transport rates, those rates are a couple of orders of magnitude smaller than the suspended load transport rates based on the average concentration from all of the measurements for each day and the daily average flow from the USGS (Table 3.8.6).

3.9 FIELD TRIP ON JULY 17-23, 1990

The last field trip of this project was conducted on July 17-23, 1990, near the end of the project duration. It was reported in the local news media that more than 12 in. of rain had fallen in some parts of the city of San Antonio within less than a 24 hour period. At the time, a record was not made of the reported rainfall amounts and locations since it was assumed that this type of information could be obtained later from the official rainfall records. The information is undoubtedly in some type of rainfall records, but it is not in the climatological data summary (National Climatic Data Center, 1990b). The

Table 3.8.6 - Bedload Data from April 1990 Measurements in Guadalupe River at Victoria

Date	Time	Station ft	Weight g	Δt min	Sampler g/min	Width ft	Bedload tons/day	Suspended load Conc. mg/L	Suspended load Flow cfs	Suspended load Load tons/day
4/27/90	13:09	184	29	5	6	142				
	13:22	210	325	5	65	142				
	13:35	235	463	5	93	142				
		avg			54	142	25	394	2220	2400
4/28/90	11:15	183	304	5	61	141				
	11:30	209	93	5	19	141				
	11:50	234	267	5	53	141				
	15:20	183	10	5	2	141				
	13:55	209	56	5	11	141				
	13:46	234	91	5	18	141				
		avg			27	141	12	389	2060	2200
4/30/90	17:30	*164	3	15	0	141				
	17:07	183	258	10	26	141				
	18:05	183	115	10	12	141				
	16:00	209	344	5.5	63	141				
	16:30	209	903	10	90	141				
	18:30	*234	12	11	1	141				
		avg			48	141	21	425	2070	2400

* excluded from average.

Table 3.8.7 - Bedload Grain Size Distributions from April 1990 Measurements in Guadalupe River at Victoria

Date	4/27	4/27	4/27	4/28	4/28	4/28	4/28	4/28	4/28	4/30	4/30	4/30	4/30	4/30	4/30
Wt (g)	29	325	463	304	93	267	10	56	91	3	258	115	344	903	12
Size (mm)	Percent														
< 8	33.0	99.5	99.6	97.8	97.5	99.9	90.1	87.4	99.0	100.0	97.4	95.0	97.3	99.7	83.5
< 4	25.8	98.7	99.1	96.8	95.9	99.7	80.7	82.7	98.1	100.0	96.9	94.1	97.1	99.5	77.4
< 2	22.2	97.3	98.3	94.9	92.9	98.9	73.9	78.9	96.7	87.5	96.6	92.7	96.4	98.8	72.3
< 1.4	21.2	96.3	97.7	93.8	91.9	97.8	71.1	77.4	95.9	86.1	96.2	91.5	95.7	97.8	69.3
< 1	20.6	94.5	96.2	91.9	90.1	94.9	68.2	75.9	94.3	82.9	95.4	90.9	93.7	95.0	66.8
< 0.71	19.5	91.1	91.9	87.0	87.5	87.7	66.0	73.4	89.8	79.8	92.2	86.9	85.3	86.7	64.6
< 0.5	16.1	83.0	77.1	70.0	80.8	70.2	60.3	68.7	77.4	68.5	70.9	67.4	56.3	60.1	57.3
< 0.25	0.6	15.9	12.4	9.4	15.2	10.6	7.4	12.5	11.4	4.4	3.3	3.5	5.3	8.4	10.7
< 0.125	0.1	1.0	0.5	0.7	1.4	0.4	1.5	1.2	0.8	1.3	0.3	0.3	0.2	0.3	1.7

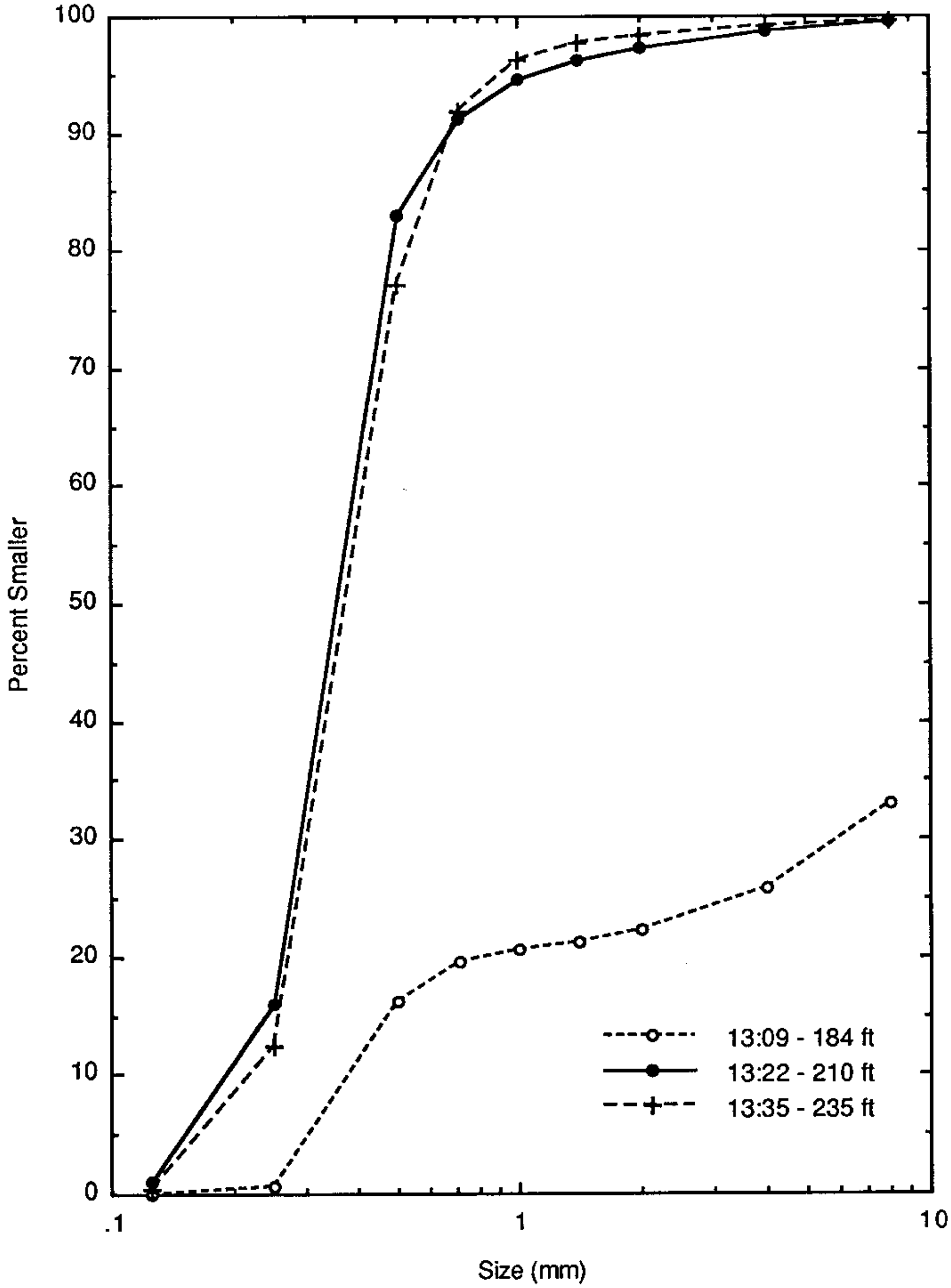

Fig. 3.8.8 - Grain Size Distributions for Bedload for Guadalupe River at Victoria on April 27, 1990

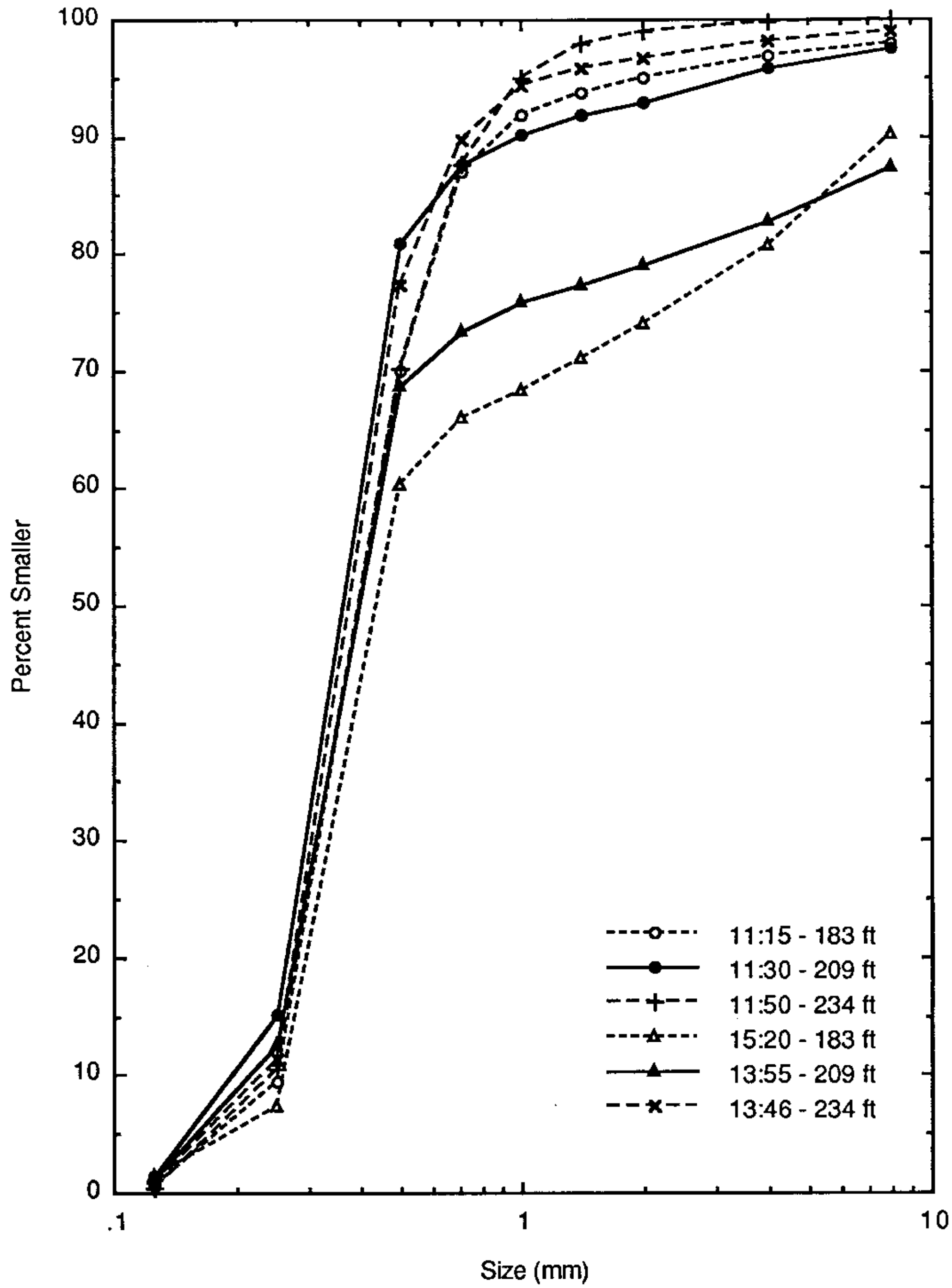

Fig. 3.8.9 - Grain Size Distributions for Bedload for Guadalupe River at Victoria on April 28, 1990

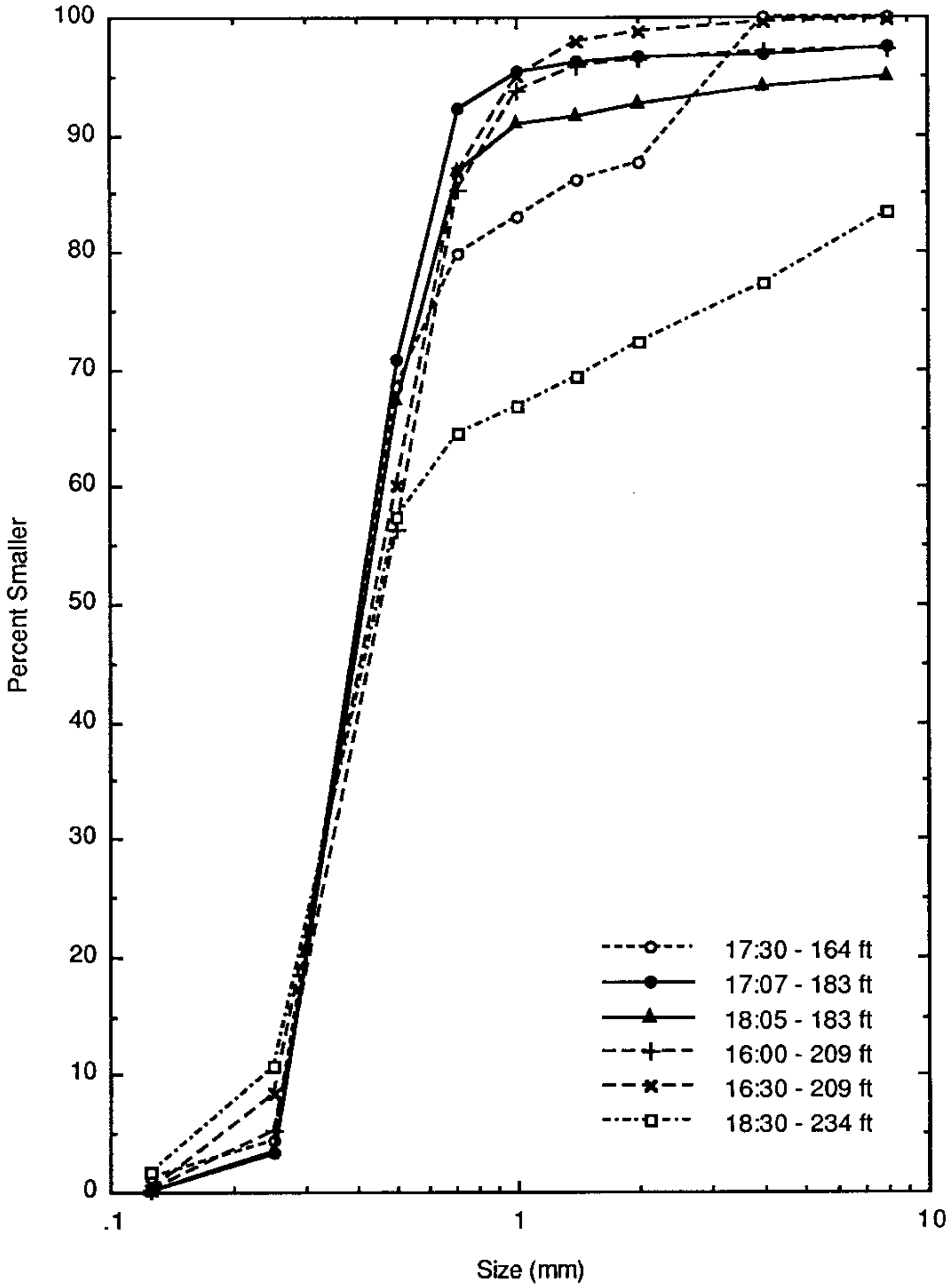

Fig. 3.8.10 - Grain Size Distributions for Bedload for Guadalupe River at Victoria on April 30, 1990

relevant rainfall data are in Tables 3.9.1 and 3.9.2. From these data, it seems that the reported rainfall of more than 12 in. in San Antonio was probably on July 15. None of the gages had any significant amount of rain on July 14. From the local news and personal contacts in different towns in the watersheds, it was concluded that the San Antonio watershed had received much more rainfall than the Guadalupe watershed and that the rain had fallen far enough upstream that there should be time to prepare for the field trip and get to Goliad before the flow from the heavy rain in the city of San Antonio reached the measurement point at Goliad. Based on the preliminary information available at the time of the field trip on the relative amounts of rainfall in the two watersheds and based on the observations of the two rivers during the first part of the field trip, it was also decided to place the primary emphasis for this trip on measurements in the San Antonio River at Goliad. The flow hydrographs in Figs. 3.9.7 and 3.9.8 confirm this decision since the maximum flow rate in the San Antonio River during the sampling period was more than three times greater than the maximum flow rate in the Guadalupe River. Nevertheless, a few sediment samples were collected in the Guadalupe River and are discussed at the end of this section.

Because of the prior experience with the log rafts on the San Antonio River, it was decided that the primary sampling during the rising part of the hydrograph would have to be by grab samples collected with the quart sample bottles attached to a weighted rope. Even though this is certainly not the most desirable method of obtaining suspended sediment samples, safety considerations eliminated both pumped samples and the P-61 sampler because of the log rafts (Fig. 3.8.1) during the rising part of the hydrograph. Because of the reported amount of rainfall, the indications were that the flows should be rather large in the San Antonio River. Thus, it was considered to be important to obtain samples by whatever means were possible. This decision was apparently justified since the maximum daily flow of 9290 cfs on July 21, 1990, was larger than 99% of the flow which occurred during 1966-89 (Table 1.3.1). As the peak of the hydrograph approached, the number of log rafts decreased significantly and there were essentially no rafts during the falling stages. For these conditions, it was possible to obtain some pumped samples. The P-61 sampler was not used because prior experience had shown that there were negligible differences between the pumped samples and the P-61 sampler (Table 3.7.2) and because it

Table 3.9.1 - Rainfall in Guadalupe River Watershed on July 15-23, 1990

	Amount (in.)								
Gage	July 15	July 16	July 17	July 18	July 19	July 20	July 21	July 22	July 23
Cuero	--	1.46	2.23	0.03	0.08	0.23	--	--	--
Gonzales	--	1.12	0.72	0.07	0.08	1.13	1.30	--	--
Jeddo 1 SW	--	0.49	0.67	--	0.02	0.89	0.02	--	--
Lockhart	4.66	0.28	0.04	0.20	0.74	--	--	--	0.02
Luling	--	2.77	0.40	0.02	0.10	1.23	0.04	--	--
New Braunfels	2.69	1.32	1.59	0.10	--	--	--	--	--
Nixon	0.75	1.60	0.60	0.10	0.09	0.01	--	--	--
Victoria WSO	0.46	7.58	2.59	0.06	0.22	1.44	--	0.01	--
Waelder 7 S	--	0.39	0.98	--	--	0.08	0.01	--	--
Wimberly 2	--	3.30	0.90	0.02	--	0.63	--	--	--
Yorktown	2.05	3.50	0.03	0.12	0.97	0.05	--	--	--

Table 3.9.2 - Rainfall in San Antonio River Watershed on July 15-23, 1990

	Amount (in.)								
Gage	July 15	July 16	July 17	July 18	July 19	July 20	July 21	July 22	July 23
Boerne	--	5.27	1.30	0.86	2.06	0.35	--	--	--
Bulverde	2.55	2.47	0.17	0.70	--	--	--	--	--
Falls City 4 WSW	--	1.29	2.23	0.03	--	2.28	--	--	--
Goliad	0.20	5.25	5.63	1.91	0.49	--	--	--	0.23
Goliad 1 SE	0.50	12.15	4.55	2.00	--	--	--	--	--
Medina	--	2.34	1.45	2.01	1.00	.25	--	--	0.65
Riomedina 2 N	2.00	2.30	1.91	0.28	0.11	--	--	--	--
Runge	--	0.81	1.66	0.02	0.40	0.39	--	--	--
San Antonio WSFO	4.09	1.85	1.32	0.16	0.29	--	--	--	0.02
San Antonio Sea World	--	2.50	2.35	0.15	0.02	0.39	0.01	--	0.09
Stockdale 4 N	2.43	1.51	--	0.20	0.22	0.01	--	--	0.03

is much easier to use the pump than the P-61 sampler from the cableway. The results for the San Antonio River are summarized in Table 3.9.3. No stream gaging was done.

The size distributions from the five one-gallon pumped samples are in Table 3.9.4 and in Figs. 3.9.1-3.9.5a. The summary graph (Fig. 3.9.5a) has a little more scatter than the similar graph for the Guadalupe River at Victoria (Fig. 3.8.7a). The standard deviation for all grain sizes except 8 μm is 4% or less. (The standard deviation for 8 μm is 5.7%.)

Welborn's (1967) data for the San Antonio River are shown in Figs. 3.9.5b and 3.9.5c. As was the case for the Guadalupe River (Figs. 3.8.7a and 3.8.7b), there is a significant but unexplained difference in the trends of Welborn's data and the data from this study. Welborn's data for the San Antonio River in Fig. 3.9.5c show an irregular but definite trend for a decrease in grain sizes with an increase in flow rate, for flow rates above about 750 cfs. (The decrease in grain sizes is indicated by an increase in the percentage smaller than each size in the figure.)

The average grain sizes for the Brazos, Guadalupe, and San Antonio Rivers from this research (Figs. 3.7.2, 3.8.7a, and 3.9.5a) are compared in Fig. 3.9.6. The average sizes for the San Antonio and Guadalupe Rivers are essentially the same, with the sizes for the Brazos being smaller. Recall that this comparison is based on only one day's sampling at the Brazos and measurements for only a few days for the Guadalupe and the San Antonio Rivers. An analysis of the variance and an F-test were used to determine whether there is any statistical significance to the difference in the means for the percent smaller than each grain size in Fig. 3.8.7a for the Guadalupe River and in Fig. 3.9.5a for the San Antonio River. At the 95% confidence level, there is no statistically significant difference for all of the grain sizes except 8 μm. The F-test showed only slightly more variation than allowed at the 95% confidence level for 8 μm. Thus, on the average, it can be concluded that the distributions of suspended sediment sizes were the same for the Guadalupe and San Antonio Rivers for the samples collected during this research.

The suspended sediment concentrations are shown in relation to the flow hydrograph in Fig. 3.9.7 for the San Antonio River and in Fig. 3.9.8 for the Guadalupe. The flows were obtained as discussed for Fig. 3.8.2. There were no significant increases in flow rates for several weeks after July 23 for either river. The sediment data were collected by a two-man crew. Since two

Table 3.9.3 - Suspended Sediment Concentrations from July 1990 Measurements in San Antonio River at Goliad

Date	Time	Concentration (mg/L) grab	Concentration (mg/L) p-qt	Concentration (mg/L) p-gal	Stage ft	Sample Depth ft
7/17/90	??	759				surface
	??	755				surface
	??	743				surface
7/18/90	14:10				13.65	
	14:45	2435				surface
	14:51	2493				surface
	15:07				14.24	
	15:17				14.37	
	15:52	2794				surface
	15:58	2724				surface
	16:03	2676			14.80	surface
	16:53				16.53	
	17:05	3120				surface
	18:33	3687			16.08	surface
	19:33	3990			16.52	surface
7/19/90	8:20	2569			20.63	surface
	9:28				20.93	
	10:10	2461			21.07	surface
	12:20	2114			21.63	surface
	14:25	1999			22.05	surface
	16:25	1906			22.40	surface
	18:30	1778			22.76	surface
7/20/90	7:15	1268			24.72	surface
	12:00				25.42	
	12:10			1067		3.0
	12:26	1106				surface
	16:29	1026			25.97	surface
	20:13	927			26.43	surface
7/21/90	6:44	726			27.29	surface
	11:40		658		27.50	5.0
	11:45			596		5.0
	11:50		635			5.0
	11:50		652			12.0
	11:50		669			12.0
	11:55			628		12.0
	12:06	677				surface
	12:13				27.59	
	17:56	597			27.63	surface
	20:54	585			27.51	surface

Date	Time	Concentration (mg/L) grab	Concentration (mg/L) p-qt	Concentration (mg/L) p-gal	Stage ft	Sample Depth ft
7/22/90	6:34	644			25.20	surface
	10:30				23.12	
	11:30		1034			4.5
	11:30		1024			4.5
	11:30			1007		4.5
	11:36		1040			11.5
	11:36		1033			11.5
	11:36			1013		11.5
	11:42		1080			18.5
	11:42		1075			18.5
	11:42			1043		18.5
	11:53	1122			22.25	surface
	15:42	1494			19.96	surface
	19:59	1899			17.49	surface
7/23/90	7:03	1818			12.96	surface
	10:56				11.94	
	11:32		1698			2.3
	11:32		1698			2.3
	11:32			1646		2.3
	11:50		1720			5.8
	11:50		1737			5.8
	11:50			1667		5.8
	11:50		1825			9.2
	11:50		1821			9.2
	11:50			1794		9.2
	12:37		1643			1.0
	12:47	1649			11.54	surface
	16:00	1484			10.95	surface

Table 3.9.4 - Suspended Grain Size Distributions from July 1990 Measurements in San Antonio River at Goliad

Date	7/20/90	7/21/90	7/21/90	7/22/90	7/22/90	7/22/90	7/23/90	7/23/90	7/23/90
Concentration (mg/L)	1067	596	628	1007	1013	1043	1646	1667	1794
Sample Depth (ft)	3.0	5.0	12.0	4.5	11.5	18.5	2.3	5.8	9.2
Size (mm)									
> 0.062	4	6	6	1	2	1	3	4	9
< 0.062	88	94	91	97	100	97	96	95	89
< 0.031	89	91	88	95	97	95	92	90	86
< 0.016	84	85	81	85	88	85	82	81	75
< 0.008	71	81	72	70	74	68	67	67	60
< 0.004	55	59	56	50	52	53	48	47	46
< 0.002	37	37	36	31	33	32	31	29	27

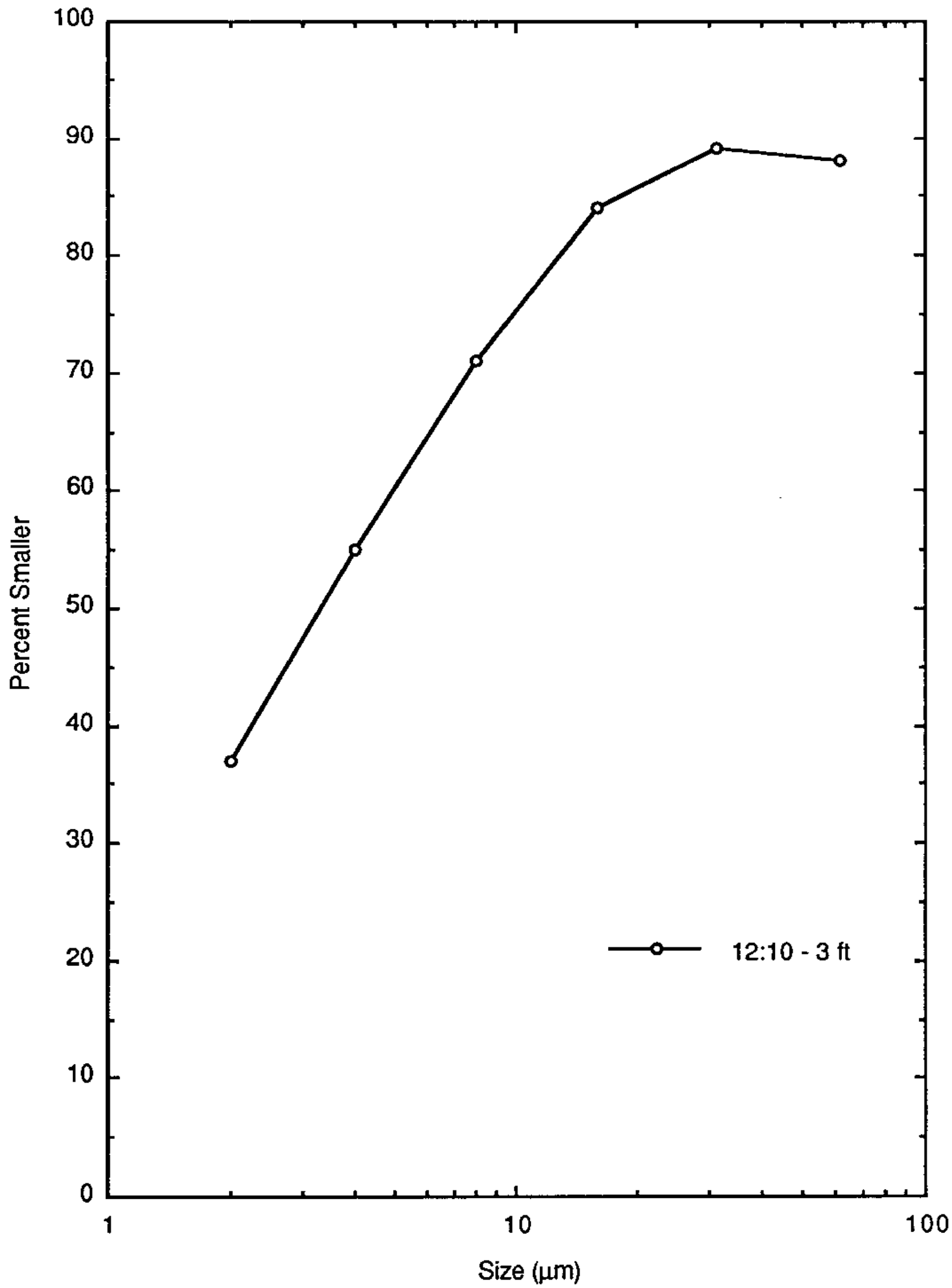

Fig. 3.9.1 - Suspended Grain Size Distributions
for San Antonio River at Goliad on July 20, 1990

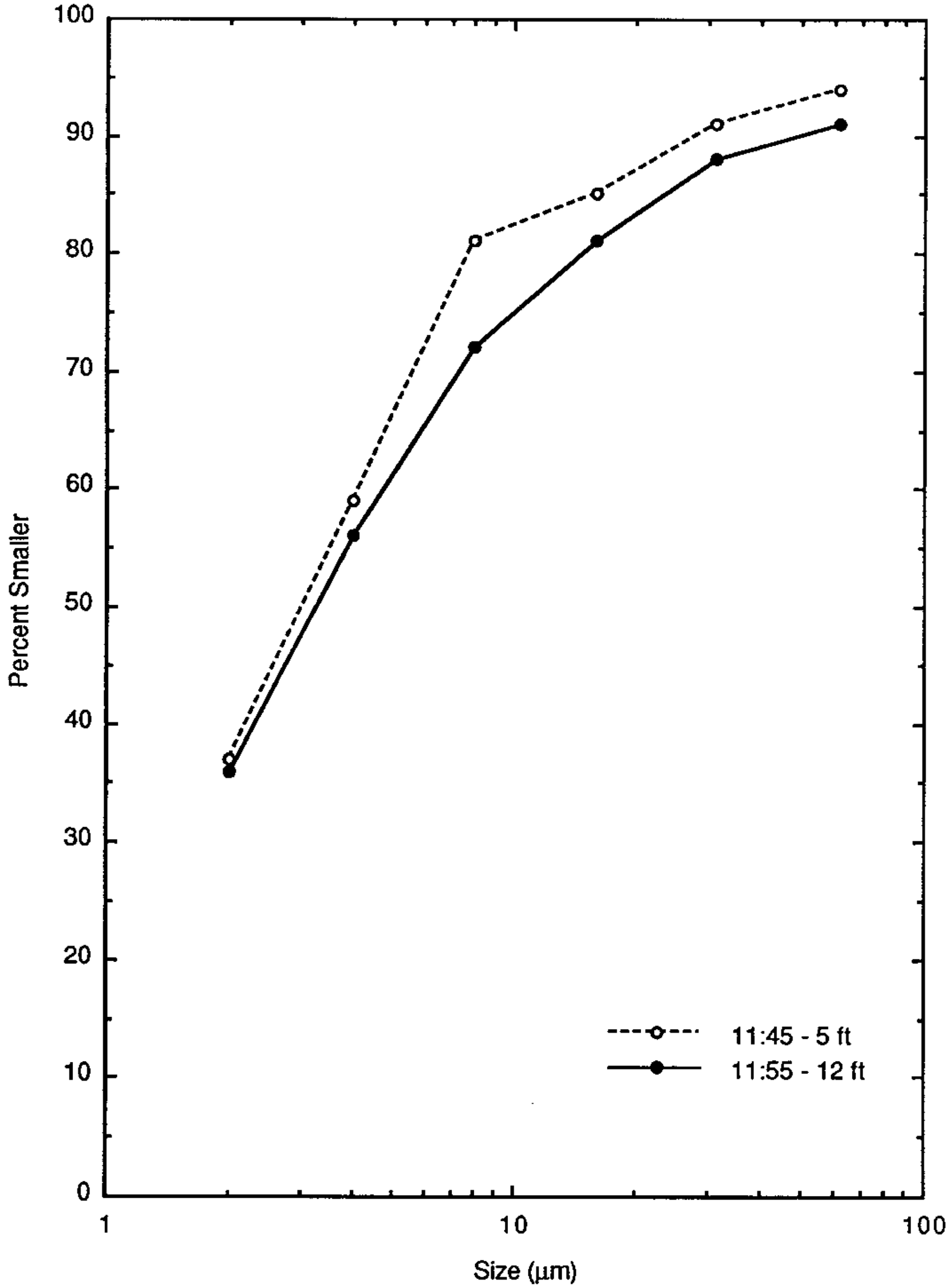

Fig. 3.9.2 - Suspended Grain Size Distributions
for San Antonio River at Goliad on July 21, 1990

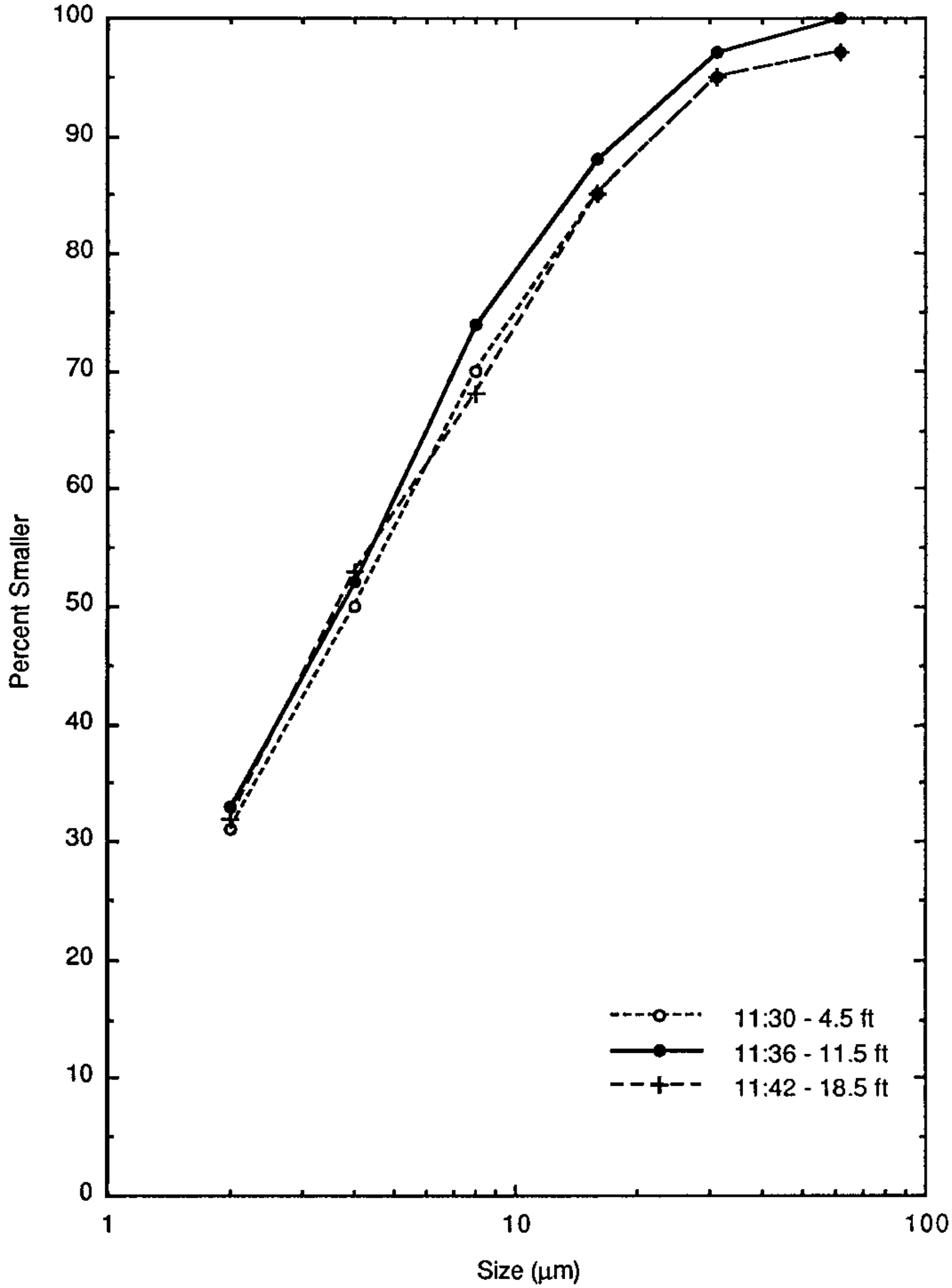

Fig. 3.9.3 - Suspended Grain Size Distributions
for San Antonio River at Goliad on July 22, 1990

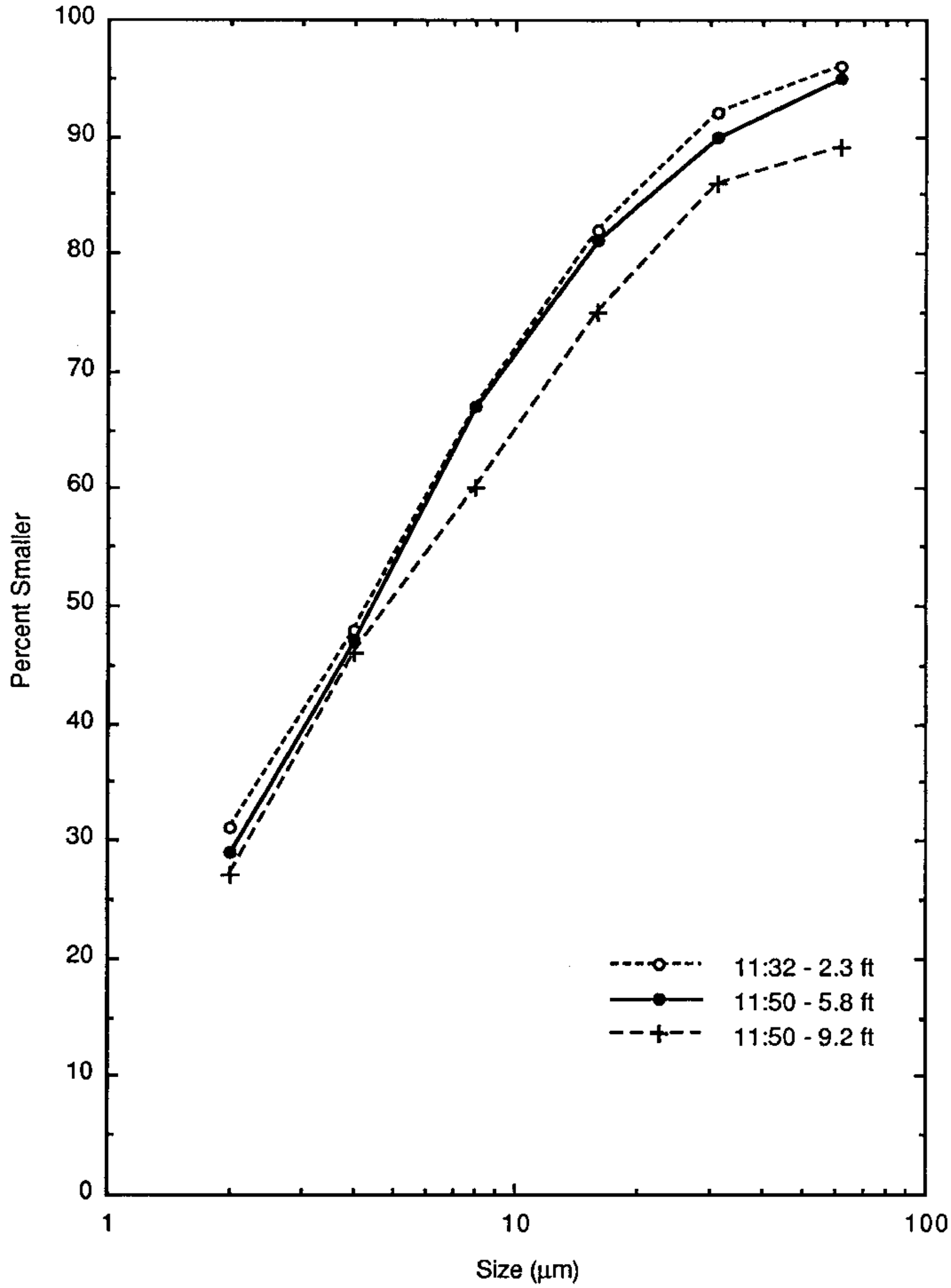

Fig. 3.9.4 - Suspended Grain Size Distributions
for San Antonio River at Goliad on July 23, 1990

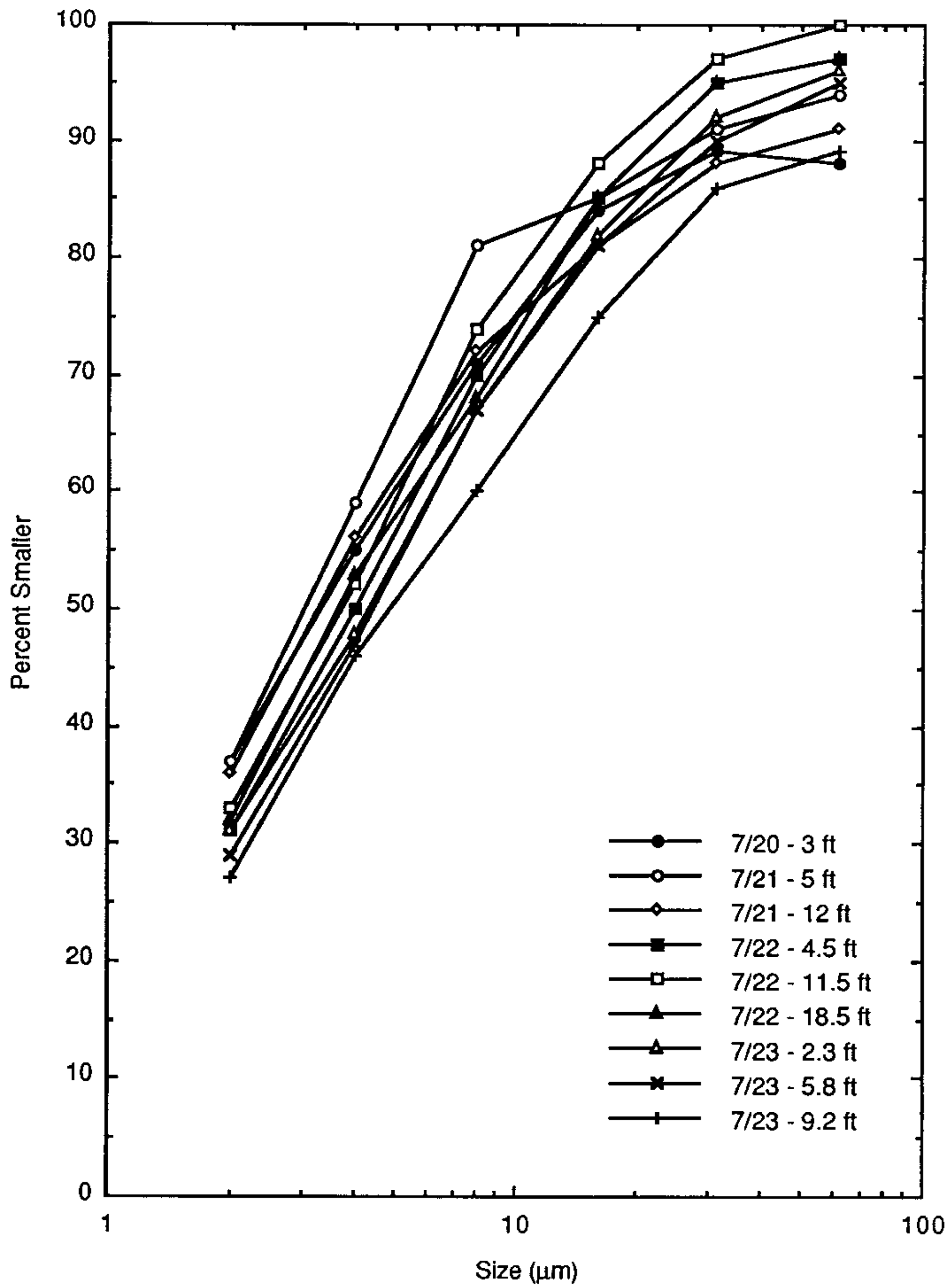

Fig. 3.9.5a - Suspended Grain Size Distributions for San Antonio River at Goliad on July 20-23, 1990

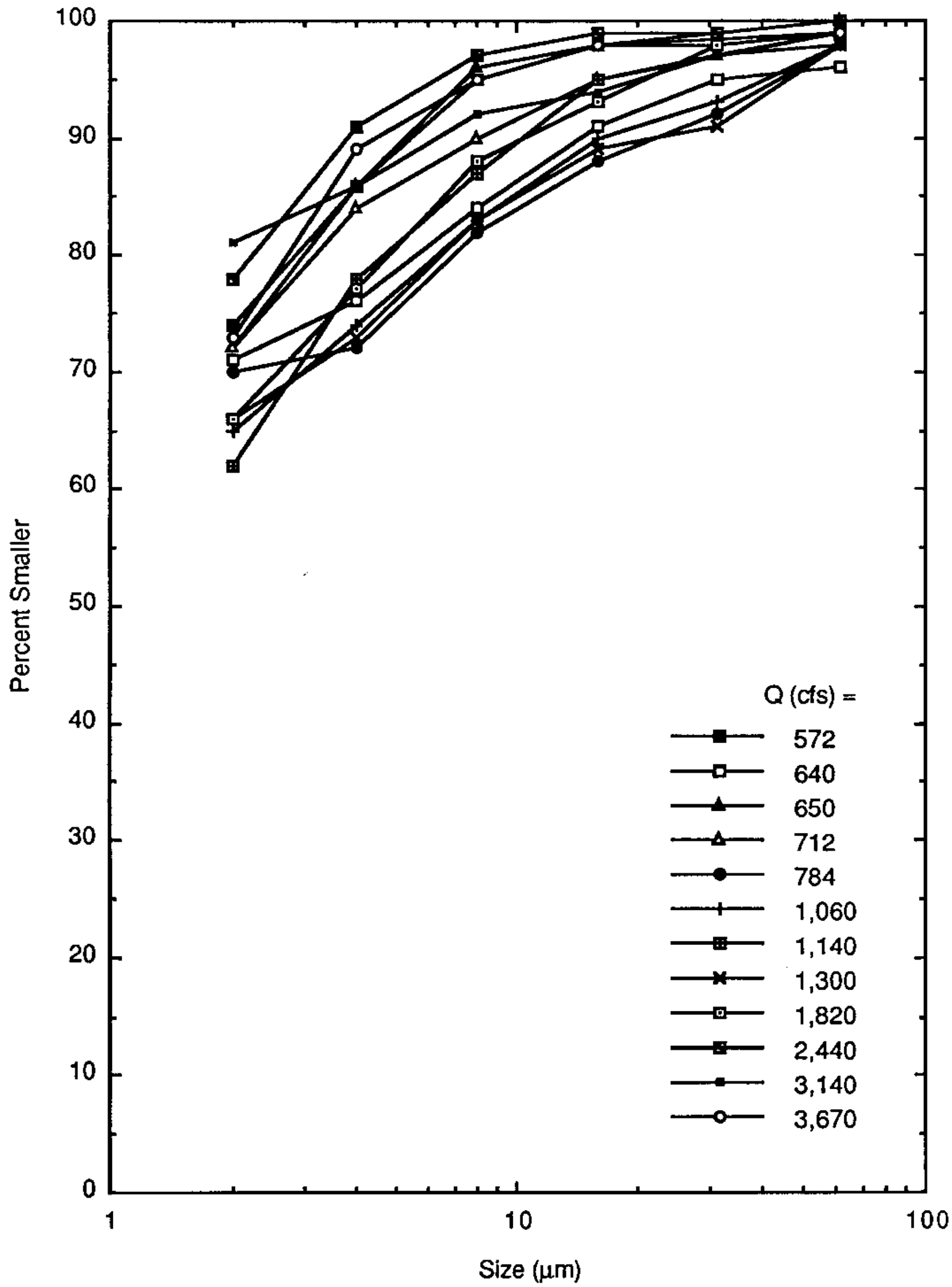

Fig. 3.9.5b - Suspended Grain Size Distributions for San Antonio River at Goliad in 1958-62 (Welborn, 1967)

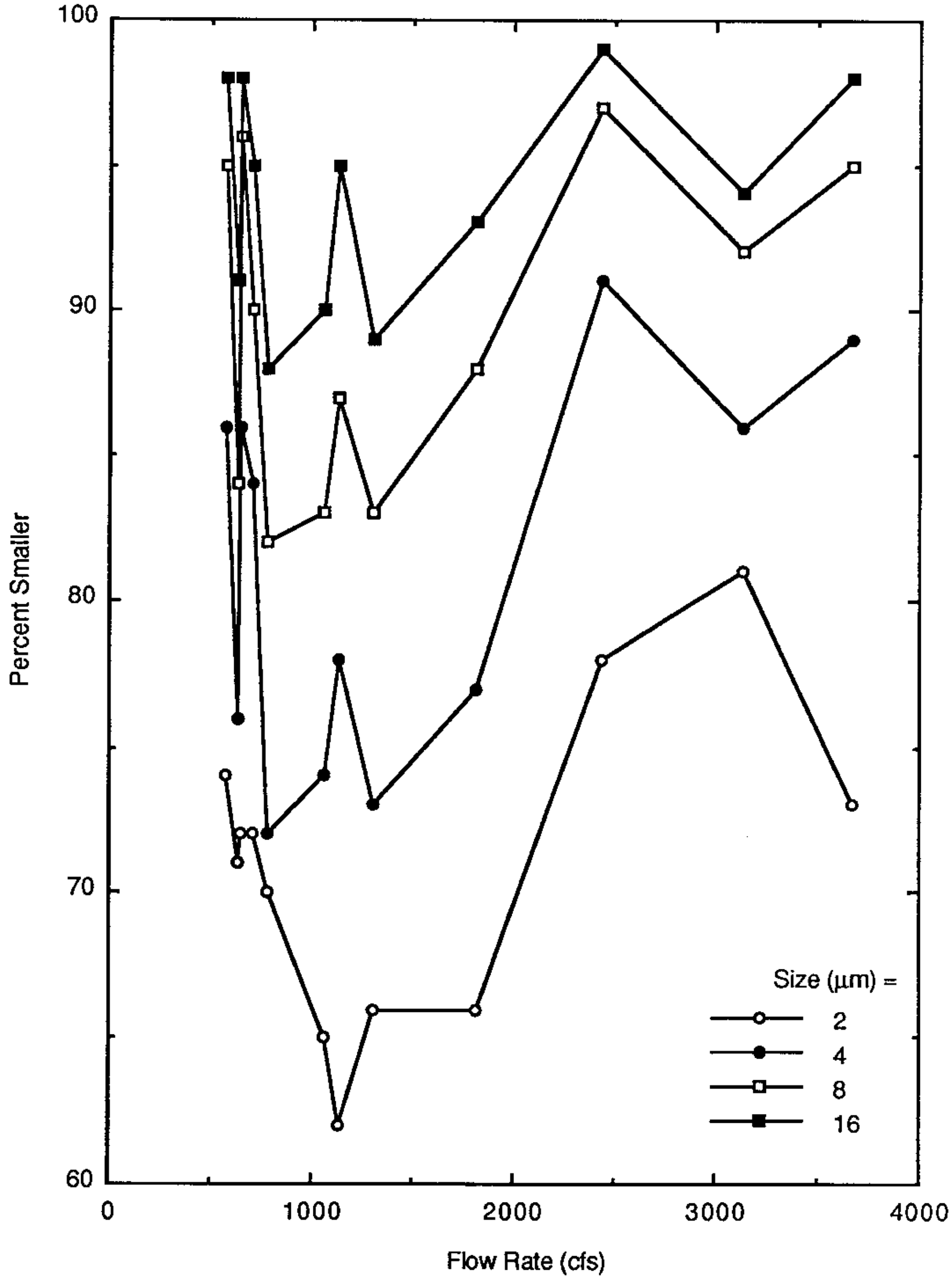

Fig. 3.9.5c - Variations of Suspended Grain Size Fractions with Flow Rate for San Antonio River at Goliad in 1958-62 (Welborn, 1967)

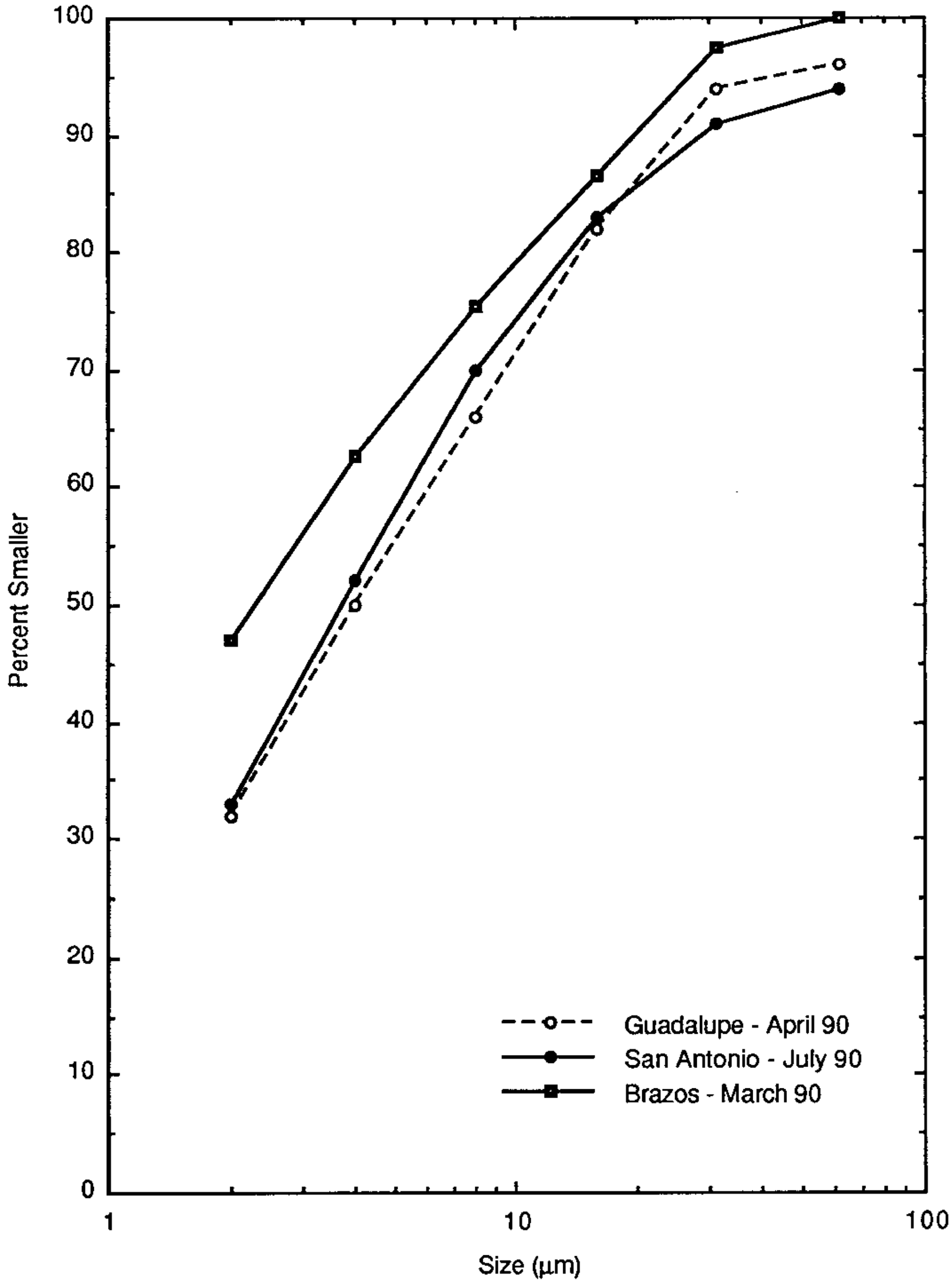

Fig. 3.9.6 - Average Suspended Grain Size Distributions
for Guadalupe, San Antonio, and Brazos Rivers

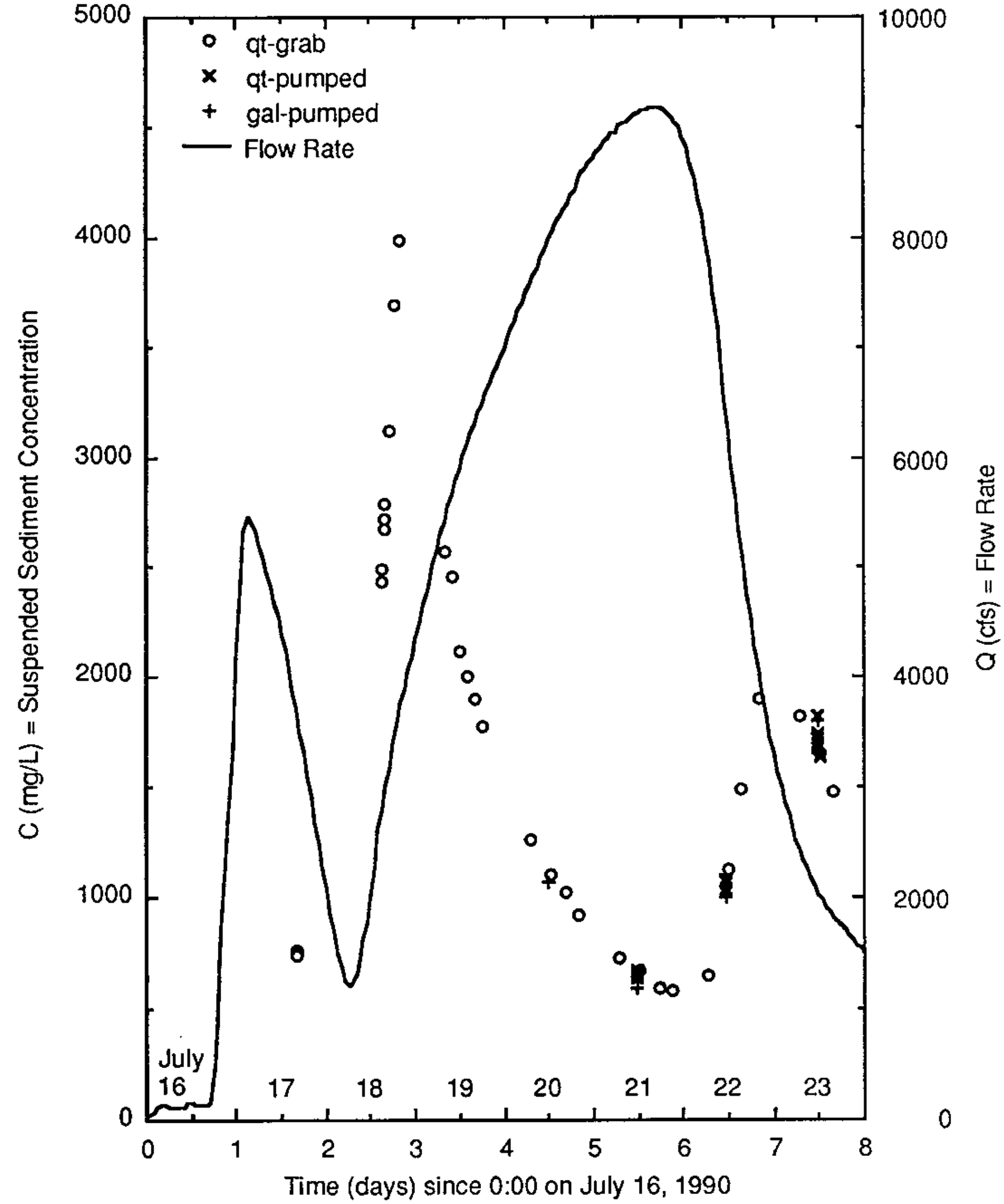

Fig. 3.9.7 - Suspended Sediment Concentrations and Flow Hydrographs for San Antonio River at Goliad for July 1990

persons were needed for the sampling, it was not possible to collect samples 24 hours per day. The gaps in the sediment samples were primarily associated with the crew's periods of sleep each day during the sampling period and with the occasional trips between Goliad and Victoria.

The following discussion is related to the measurements in the San Antonio River at Goliad. The measurements at Victoria are discussed at the end of this section.

The first peak in the flow hydrograph was apparently due to local rainfall on July 16 and 17. Much of the 12.15 in. of rainfall in Goliad on July 16 was apparently downstream of the gaging station. The second peak in the flow was apparently associated with the large rainfall in the city of San Antonio. There is a very well defined variation in the concentrations of suspended sediment, but the sediment hydrograph is out of phase with the flow hydrograph. Due to the double peaks of the flow and sediment hydrographs, the interpretation of Fig. 3.9.7 is some what subjective. The problems with interpretation of the data are compounded by not having sediment data on July 16 and 17. When planning the field trip, news of the large rainfall in Goliad had not been received, so the plan was to start sampling well before the flow peak from the rainfall in the vicinity of San Antonio. Thus, the equipment was loaded on July 16 and travel to the site was on July 17. The few sediment samples on July 17 were collected without knowing about the previous peak in the flow hydrograph.

The first part of the sediment hydrograph (July 18-21) was apparently associated with the first flow hydrograph (July 16-17) and with additional runoff from rainfall between Goliad and the city of San Antonio. The second part of the sediment hydrograph (July 22-23) was apparently associated with the large rainfall in the vicinity of San Antonio and lagged behind the flow hydrograph (July 18-23). With the available data, no other interpretation seems possible. However, there are several aspects of this interpretation which deserve further consideration:

(1) No sediment data are available for July 16 and most of July 17 to investigate the immediate sediment response.
(2) Most of the rainfall producing the first flow hydrograph was very near the measurement location. If all of the runoff except that from the large rainfall near San Antonio were in the first flow hydrograph, it would be difficult to understand why the

peak of the first sediment hydrograph is about a day and a half after the peak of the flow hydrograph. An additional possibility is that the second flow hydrograph, especially the rising limb, is actually a superposition of the flow hydrograph from the city of San Antonio and later rainfall (July 16-18) between Goliad and San Antonio. This possibility can be given some credence because of the rainfall (Table 3.9.2) and because of the shape of the second flow hydrograph which does not follow the classical shape of the hydrograph for a single rainfall event, especially since the rising limb is more gradual than the falling limb.

(3) Without this superposition, it would also be difficult to understand why the recession limb following the first peak of the sediment hydrograph lasted for more than three days. It does not seem reasonable to expect a three-day recession if the sediment did come from only near the measurement location.

(4) There is apparently no reason to expect that the sediment hydrograph from the rainfall in the vicinity of city of San Antonio would outrun the flow hydrograph and reach Goliad before the flow. That is, there appears to be no reason to expect that the first part of the sediment hydrograph is from the large rainfall near San Antonio. If that were the case, there would be no way to explain the second sediment hydrograph since there was no significant increase in the flow rate for several weeks following the data collection.

(5) If the previous considerations are correct, then the peak of the sediment hydrograph from the rainfall near San Antonio reached Goliad about one and a half days after the peak of the flow hydrograph, and the maximum sediment concentration was much lower relative to the maximum flow for the second part of the hydrograph than for the first one.

Even though the interpretation of the flow and sediment hydrographs in Fig. 3.9.7 may be somewhat subjective, it is certain for both peaks of the hydrographs that there is a considerable time shift between the flow and the sediment concentrations. Fig. 3.9.7 illustrates the difficulty of trying to correlate individual sediment concentrations with the flow existing at the time when the sediment sample is collected.

The few sediment samples which were collected in the Guadalupe River at Victoria during this field trip are summarized in Table 3.9.5 and shown graphical in relation to the flow hydrograph in Fig. 3.9.8. Unfortunately, the samples were too sparse to be able to draw any meaningful conclusions about the sediment hydrographs. The sediment concentrations were lower than for the samples collected on April 27-30, 1990. No samples were collected for analysis of grain size distributions.

4. CONCLUSIONS

The first four conclusions are based on the analysis of data collected prior to this study (Chapter 2). The other conclusions are from the data collected during this study (Chapter 3).

(1) For a given frequency of occurrence, the flows in the Guadalupe River at Victoria are about twice as large as the flows in the San Antonio River at Goliad.

(2) For a given flow rate, the suspended sediment concentration at Goliad is about five times larger than at Victoria.

(3) The primary correlation of suspended sediment concentration is with the simultaneous river flow rate. However, this correlation has a large amount of scatter. Other variables such as a possible lag between the suspended sediment concentration and the flow rate, the fall velocity of the particles, and the phase of the hydrograph were not important enough for all of the data to give any significant reduction in the scatter.

(4) The infrequent large flows carry the majority of the suspended sediment. An extrapolation of existing data indicates that the largest 10% of the daily flows carried more than 80% of the suspended sediment for the Guadalupe and more than 90% for the San Antonio for 1966-1989. Thus, it is extremely important to have sediment data for large flows when trying to consider the possible effects of altering fresh water inflows. However, there is very little data for large flows. There appears to be a need for a concerted effort to collect sediment data for large flows in the downstream reaches of Texas rivers.

(5) Very limited data collected during this study indicated that the bedload transport is much smaller than the suspended load transport. Much more

Table 3.9.5 - Suspended Sediment Concentrations from July 1990 Measurements in Guadalupe River at Victoria

Date	Time	Concentration grab (mg/L)	Concentration p-qt (mg/L)	Stage ft	Sample Depth ft
7/18/90	9:05			6.86	
	9:26		*212		5.8
	9:26		*309		5.8
	9.34		94		3.7
	9:35		89		3.7
	9:38		93		1.5
	10:17		89		1.5
	10:17	92			surface
	10:21		87		1.5
	10:21	105			surface
	10:26		90		1.5
	10:26	98			surface
	10:59			6.43	
	20:25	114		6.21	surface
	20:25	117			surface
7/19/90	7:34	101		6.96	surface
	7:36	112			surface
	12:58	119			surface
	19:10	112			surface
	19:10	109			surface
7/20/90	14:13	225		8.25	surface
	14:13	88			surface
7/21/90	17:24	85		5.60	surface
	17:24	84			surface
7/22/90	13:05	93		6.32	surface
	13:05	87			surface

*Sand in sample, apparently from disturbing sand on the bed.

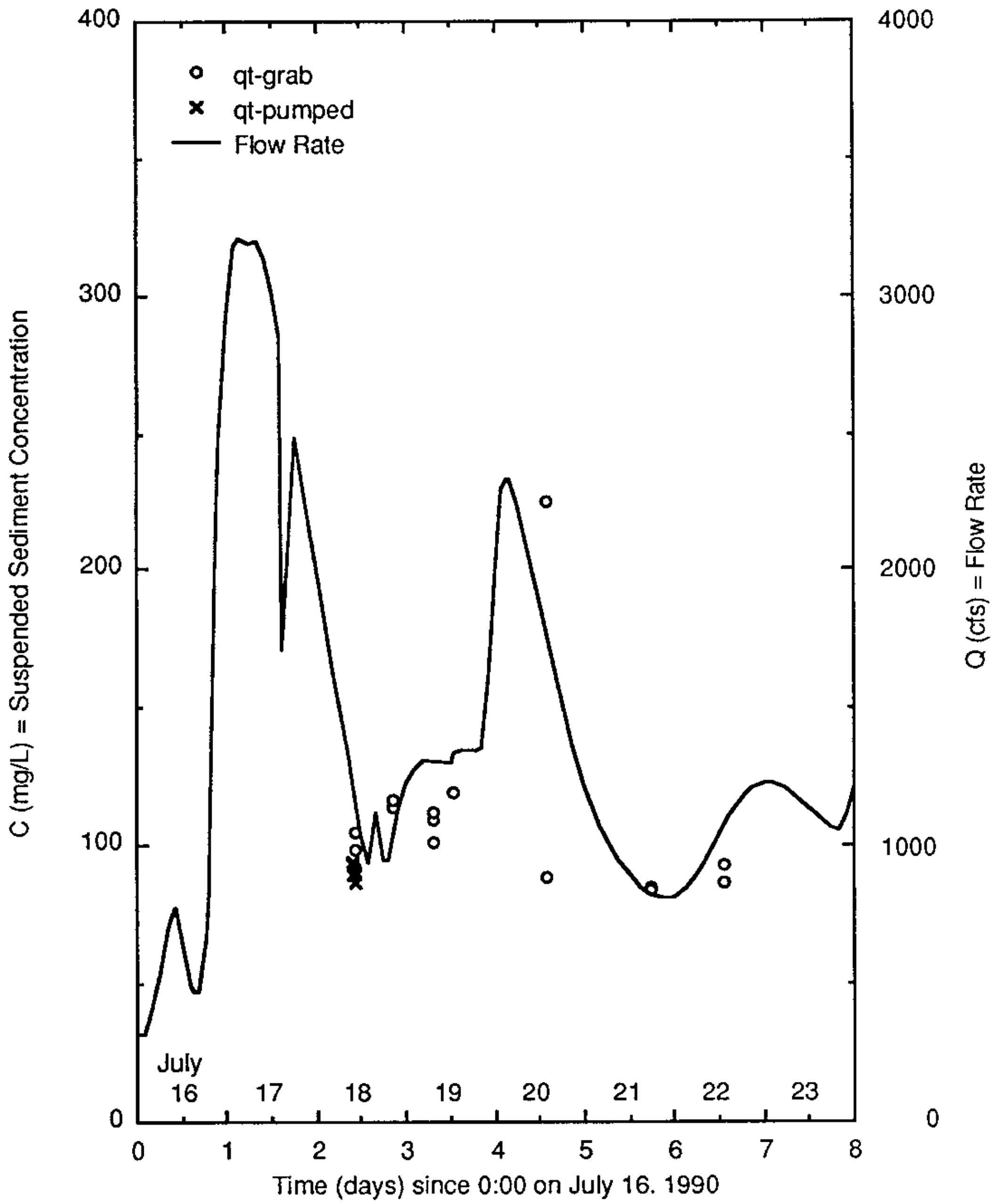

Fig. 3.9.8 - Suspended Sediment Concentrations and Flow Hydrographs for Guadalupe River at Victoria for July 1990

bedload data is needed before the amount and significance of bedload transport can be accurately assessed.

(6) With appropriate care and adjustment of the pumping system, pumped samples can be used to obtain larger quantities of suspended sediment than are obtained from the P-61 sampler. These larger quantities are needed for grain size analysis. The pump intake should be on the upstream side of the pump and aligned with the flow so that the streamlines into the intake will be straight. Also, the pump flow rate should be adjusted so that the intake velocity is approximately equal to the local river flow velocity. Adequate time must be allowed for flushing the tube between the pump and the sample bottles. Use of multiple (up to five) one-gallon plastic milk jugs proved to be a feasible method of collecting large samples.

(7) For the field trips to the Guadalupe River at Victoria in April 1990 and the San Antonio River at Goliad in July 1990, the grain size distributions for various phases of the hydrographs showed very little variations. There were also very small differences in the suspended grain sizes for the Guadalupe and San Antonio Rivers.

(8) For the particular events sampled during these two field trips, there appeared to be a good correlation between the flow rate and the sediment concentration for one test on the Guadalupe River while there was clearly a significant lag between the flow hydrograph and the suspended sediment hydrograph for the San Antonio River. The data for the San Antonio River illustrated the difficulty of trying to correlate suspended sediment concentrations with simultaneous flow rates.

REFERENCES

Buckner, H. D., Carrillo, E. R. and Davidson, H. J., (1989) *Water Resources Data Texas Water Year 1989*, vol. 3, U. S. Geological Survey, Austin, TX

Colby, R. B. (1963) "Fluvial sediments - A summary of source, transportation, deposition, and measurement of sediment discharge," Bulletin 1181-A, U. S. Geological Survey, Washington, 47 pp.

Dougherty, J. P. (1979) "Suspended-sediment load of Texas streams, October 1971-September 1975," Report 233, Texas Department of Water Resources

Guy, H. P. (1969) "Laboratory theory and methods for sediment analysis," Book 5, Chap. C1, Techniques of Water-Resources Investigations, U. S. Geological Survey, Washington, DC, 58 p.

Heidel, S. G. (1956) "The progressive lag of sediment concentration with flood waves," *Transactions*, American Geophysical Union, vol. 37, part 1, pp. 56-66.

Mirabal, J. (1974) "Suspended-sediment load of Texas Streams, October 1965-September 1971," Report 184, Texas Water Development Board

National Climatic Data Center (1990a) "Climatological Data Texas," vol. 95, no. 4, April, Asheville, NC

National Climatic Data Center (1990b) "Climatological Data Texas," vol. 95, no. 7, July, Asheville, NC

Wellborn, C. T. (1967) "Comparative Results of Sediment Sampling with the Texas Sampler and the Depth-Integrating Sampler, and Specific Weight of Fluvial Sediment Deposits in Texas," Report 36, Texas Water Development Board.