Wegner

MONITORING THE EFFECTS OF INTERIM FLOWS FROM GLEN CANYON DAM ON SAND BAR DYNAMICS AND CAMPSITE SIZE IN THE COLORADO RIVER CORRIDOR, GRAND CANYON NATIONAL PARK, ARIZONA

QUARTERLY REPORT: 1 October, 1993

Stanley S. Beus, Matthew A. Kaplinski,
Joseph E. Hazel Jr., Linda A. Tedrow
Geology Department
Northern Arizona University, Campus Box 4099
Flagstaff, AZ 86011

Lisa Kearsley
National Park Service, Recources Management Division
Grand Canyon National Park
Grand Canyon, AZ

Cooperative Agreement: CA8022-8-0002

Project Name: INTERIM FLOW SAND BAR SURVEY

Principal Investigator: Dr. Stanley S. Beus

Government Technical representative: Dr. Peter G. Rowlands

Short Title of Work: INTERIM FLOW SAND BAR SURVEY: Quarterly Report

Effective Date of Cooperative Agreement: 9-1-92

Cooperative Agreement Expiration Date: 1-31-95

Funded by: The U.S. Department of Interior
Bureau of Reclamation
Glen Canyon Environmental Studies

Sponsored by: The U.S. Department of Interior
National Park Service
Cooperative Parks Studies Unit
Northern Arizona University, Campus Box 5614
Flagstaff, AZ 86011

National Park Service Cooperative Agreement: CA8022-8-0002

INTERIM FLOW SAND BAR
QUARTERLY REPORT: 1 OCTOBER, 1993

A. MAJOR ACCOMPLISHMENTS

1. *Overview of Project*

The Bureau of Reclamation is the lead agency charged with preparing an Environmental Impact Statement on the impacts of Glen Canyon Dam operations on resources downstream in Glen and Grand canyons. Implementation of Interim Flow criteria for Glen Canyon Dam during the EIS preparation period requires that sand bar and campsite conditions be monitored to assess whether degradation of those sediment resources has been stabilized by this action. The present research is a monitoring study designed to evaluate the effectiveness of interim flows in reducing sand bar degradation and camp site loss as a result of dam operations. This project is being coordinated by the Bureau of Reclamation Glen Canyon Environmental Studies office (GCES) and conducted through the National Park Service Cooperative Parks Studies Unit at Northern Arizona University geology department in Flagstaff, Arizona, with Dr. Stanley S. Beus as principal investigator, Mr. Matthew Kaplinski and Joseph E. Hazel Jr. as research associates, Linda A. Tedrow as a graduate research technician, Lisa Kearsley as campsite size investigator, and Dr. Peter G. Rowlands as government contracting officer.

2. *Objectives*

A. Monitor subaerial and subaqueous sand bar topography on an annual to biannual basis on 30 representative sand bars in the Colorado River corridor downstream from Glen Canyon Dam during the interim flow period.

B. Compare topographic change on sand bars from July, 1991 to September, 1991, October/November, 1991, October, 1992, April, 1993, and October, 1993.

C. Determine how interim flows are affecting beach size, morphology, and camping area. This objective has been modified to include analysis of unexpected flood flows from the Little Colorado River tributary during the winter of 1993.

D. Assist in compilation of the above data for the GCES/NPS Geographic Information System (GIS).

E. Compare topographic change on sand bars from October, 1992 to April, 1993 and assess the sand bar dynamics due to large flooding events that ocurred in the river corridor during Jan. and Feb., 1993.

3. *Accomplishments*

We have collected topographic and bathymetric measurements from up to 30 sand bar study sites along the Colorado River corridor during two river survey expeditions: from October 15 to November 3, 1992, and from April 1 to 15, 1993 (Table 1, Table 2, Figure 1). The April trip was initiated to examine sand bar response to the Little Colorado River (LCR) tributary winter flood events and resulting sand input. In addition to topographic surveying, sedimentologic data was aquired from trenching flood and pre-flood deposits. Our data set also includes surveys conducted after 1 to 2 months of interim flow operations, during September and October, 1991 (Table 2).

Data collection for the campsite size portion of this study has consisted of two river trips: September, 1992 and May, 1993. During the first trip, 111 campsites were examined; 77 of which were in critical reaches (as defined by

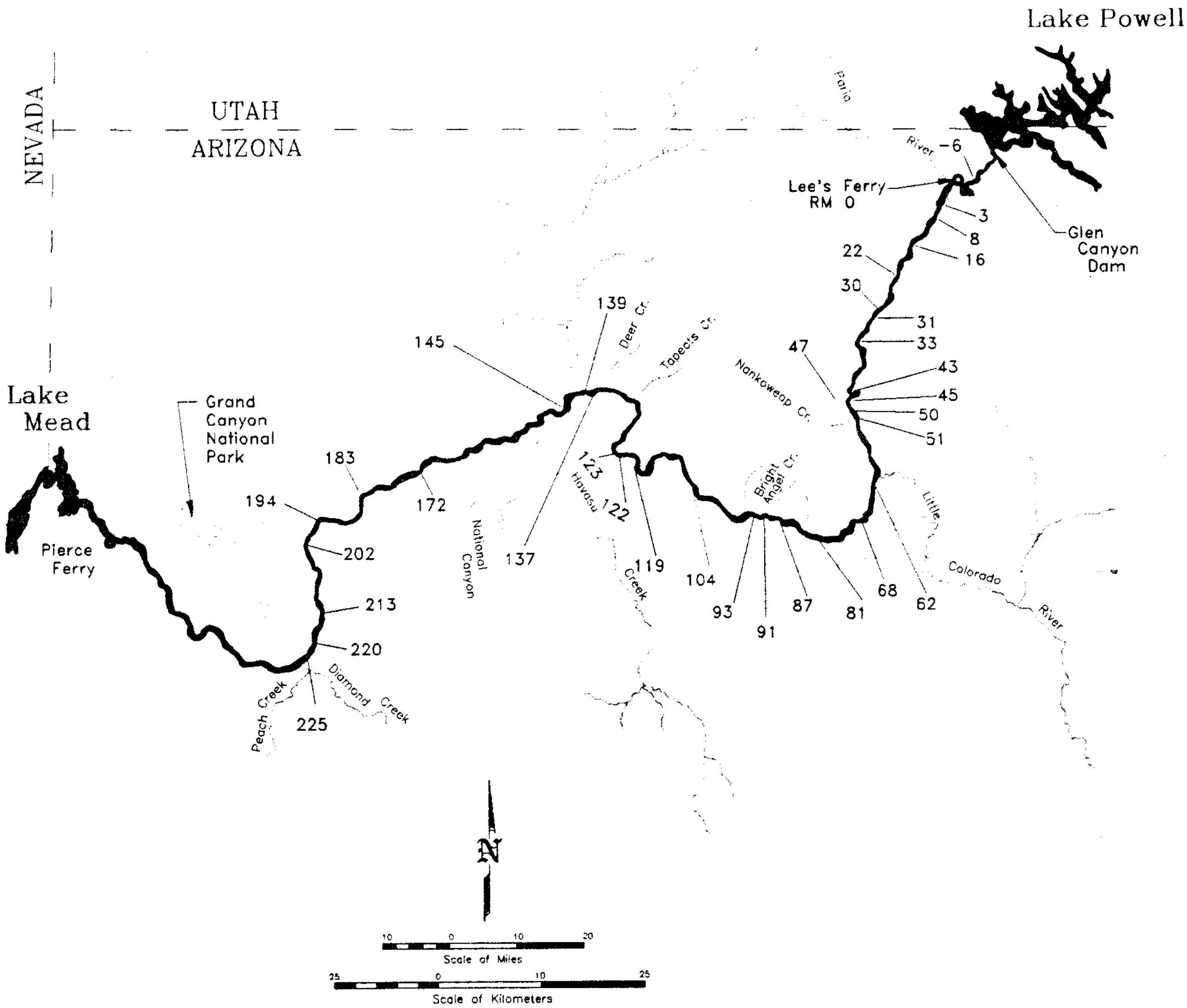


Figure 1. Location map showing study locations

post-flood effects; nearly all campsites were remeasured. Gross changes in campsite size area were assessed and tallied to prepare a descriptive analysis of changes in campsite area since implementation of interim flows.

B. PROBLEMS ENCOUNTERED

Several problems were encountered with the new GCES Hydrographics Survey Package (HSP) during the April, 1993 trip, primarily as this was the systems first sortie into the harsh environment of the Grand Canyon. Several sites did not receive bathymetric coverage when the HSP was periodically inoperative and processing time of bathymetric data that was collected was delayed until the manufacturer solved a software problem. Those that did have been analyzed and are incorporated with the subaerial surveys included in this report.

C. FISCAL STATUS

1. Cooperative Agreement Amount: $293,769
2. Expenditures and Commitments to Date: $192,434
3. Estimated Funds Required to Complete Work: $101,335
4. Estimated Date of Completion of Work: 1-1-95

   Final report, final management report,
   final oral report .... 1 January, 1995

D. ACTION REQUESTED OF NPS

1. Continued support of this project during the analysis and report preparation phases is requested of the NPS.

E. FUTURE PLANS

1. We are presently on schedule with this project and will be following the timetable for completion of tasks and deliverables.

Table 1: Schedule for completion of tasks and deliverables for sand bar studies in the Grand Canyon.

DELIVERABLE(S)	DUE DATE
Pre-study Oral Presentation, secure equipment, conduct crew training for field data collection	1 August,1992
First quarterly report (QR)	1 October, 1992
First sampling trip	1-18 October, 1992
Annual progress report, annual management report	31 January 1993
Second sampling trip	1-15 April, 1993
QR	1 April, 1993
QR	1 August, 1993
QR	1 October, 1993
Third sampling trip	7-27 October, 1993
Annual progress report, annual management report	31 January 1994
QR	1 April, 1994
QR	1 August, 1994
Draft final technical and management reports	**1 October, 1994**
Final report, final management report, final oral report	**1 January, 1995**

F. PRELIMINARY RESULTS

1. *SAND BAR SURVEYS*

We have collected topographic and bathymetric data from 30 sand bars during survey river trips in September, 1991, November, 1991, October, 1992, and April, 1993, in order to compare changes in sand bar morphology due to GCD interim flow operations (Figure 1; Table 2). This report presents comparisons of these surveys with the 1991 interim flow surveys (aquired during vegetation monitoring) and the surveys of Beus et al. (1992). Thus, the surveys provide useful comparitive information on a 20 month period of interim flow operation, including the onset (August 1, 1991). Following the methods of Beus et al. (1992), we have prepared topographic maps of the sites with a 0.2 m contour interval, constructed profiles across the deposits, and calculated the sediment volume within what we term the "hydrologically active zone" (HAZ), that portion of the sand bar exposed to the range of dam operations (142-850 m^3/s).

Table 2. Interim Flow Sand Bar Surveys

		July 1991		Sept. 1991		October 1991		Nov. 1992		April 1993	
Site (Mile)	Deposit Type	Vol m^3	Area m^2	Vol m^3	Area m^2	Vol m^3	Area m^2	Vol m^3	Area m^2	Vol m^3	Area m^2
-6R	R	3388	3523					3314	3570	3370	3516
3L	R	3564	3016			2640	2500	4052	3601	3995	3448
8L	S	1351	1481			1316	1523	1354	1729	1375	1631
16L	S	1726	1284					2103	1549		
22R	R	3578	1727	3197		3197	1474	3276	1593	3532	1819
30R	R	7366	3651							5562	3377
31R	R	2055	2407	2013	2400	1936	2298	2033	2884	2124	3333
43L	R/UP	3661	2107	3629	1903	3610	1959	3453	1844	3285	1723
45L	S	3456	2585	3549	3119	2479		3119	2479		
47R	S	7647	7180					5790	5923		
50R	S	4234	2813					2390	1952	2393	2099
51L	R	6441	5939	6422	5830	6463	5789	6109	5519	6029	5596
68R	S/R	3723	3077	3410	2658	3426	2818	3171	2979	2390	2102
81L	UP	2811	1334	2520	1184	2515	1154	2431	1223	2766	1249
87L	UP	492	317	521	323			607	395	596	571
91R	S	241	223					189	208	216	155
93L	UP	1634	1401	1256	1021			1888	1690	2145	1716
119R	R	4825	2792	3645	2291			2481	1724	3952	2360
122R	R	4928	3622			4900	3568	4435	3134	5666	2990
123L	R/UP	1310	1280					1223	1317		
137L	R	4989	2924	4116	3018	4189	2965	3965	2994	4074	2879
145L	R	928	582	833	540	838	510	756	496	1046	570
172L	R/UP	2448	2254	1327	1068	1340	1120	1719	1415	1535	1105
183R	R/UP	2670	2077	2694	2152			2905	2237	4723	2710
194L	R/UP	4357	3284	4387	4262	3296	4388	4464	3377	4823	3287
202R	S	3710	2230					3075	1981	2991	1768
213L	R/UP	2772	1334					3625	1693	3781	1520
220R	S/UP	1190	717	1069	719			1035	719	1266	742

* R-Reattachment Bar; S-Separation Bar; UP-Upper Pool (from Beus et al., 1992).

Sediment Volume Within the HAZ

Surveys conducted shortly after the onset of interim flows show a system-wide negative response of sandbar HAZ to the new discharge pattern (Table 3; Figure 2). After 14 months of low and high volume interim flows the response was as follows: of the 29 beaches evaluated, 66 % (19) have lost sediment volume within the HAZ, 17% (5) have gained volume, and 17% (5) have remained the same as compared to volumes calculated from the survey previous to the onset of interim flows (Table 3; Figure 2). Among the different deposit types sampled, reattachment bars showed the most significant HAZ volume increases (Figure 2; 2.6, 87, 93 mile), while separation deposits showed the most volume loss (Figure 2; 45, 50, 202 mile). HAZ volume was increased in reattachment bars by deposition below the maximum interim flow stage elevation, particularly along the upstream portion of the bar platform.

During January/February, 1993, unusually heavy precipitation throughout the Southwest sent floods ranging from 500 to 566 m^3/s (18,000 to 20,000 ft^3/s) down the LCR and increased the Colorado River mainstem flows downstream from the LCR confluence in excess of 850 m^3/s (30,000 ft^3/s) (Figure 3). The surveys conducted in April, 1993 included 24 of the 30 sand bars (Table 2, Figure 4) and examined the effects of these natural, sediment-laden flood events from the LCR (RM 61) drainage on the sand bars. Not suprisingly, we measured a significant increase in the movement and volume of sand bars downstream of the LCR (Figure 2, Figure 4). Eight sand bars were examined above the confluence of the Colorado and LCR to examine changes in the more sediment-starved portion of the Colorado River and the possible influence of sediment input from the Paria River (RM 0.5);(Figure 4). 63% (5) remained relatively unchanged between October, 1992 and April, 1993, 25% (2) had a large volume gain (22, 31 mile), and 13% (1), 43 mile, sustained a significant net loss of HAZ sand (Table 3; Figure 4). Downstream from the LCR and Colorado River confluence, 16 sand bars were examined, including a new reattachment deposit at mile 62.4 in a recirculation zone previously devoid of a significant subaerial deposit. 73% (11) showed large volume increases (e.g., 81, 183 mile), 20% (3) remained relatively unchanged (87, 137, 202 mile), and 2 (17%) lost HAZ volume (68, 172 mile) as compared to the October, 1992 surveys (Table 3; Figure 4). The response of sand bars above the LCR was similiar to the aforementioned sand bar response to interim flow operations between August 1, 1991 and October, 1992. Sand bars below the LCR showed large volume gains. Post-flood erosion, however, was quickly destabilizing the bars to pre-flood volumes (Figure 2, 202 mile). Although erosion rates will likely decrease, several of the bars can be expected to lose much of the sediment gain reported here.

Table 3. HAZ Volume Changes

8/91 to 10/92	INCREASE	DECREASE	SAME
ALL SITES Percent (number) n=29	17% (5)	66% (19)	17% (5)
SITES ABOVE THE LCR n=12	17% (2)	58% (7)	25% (3)
SITES BELOW THE LCR n=17	18% (3)	70% (12)	12% (2)

10/92 to 4/93			
ALL SITES n=23	52% (12)	13% (3)	35% (8)
SITES ABOVE THE LCR n=8	25% (2)	12% (1)	63% (5)
SITES BELOW THE LCR n=15	73% (10)	13% (2)	20% (3)

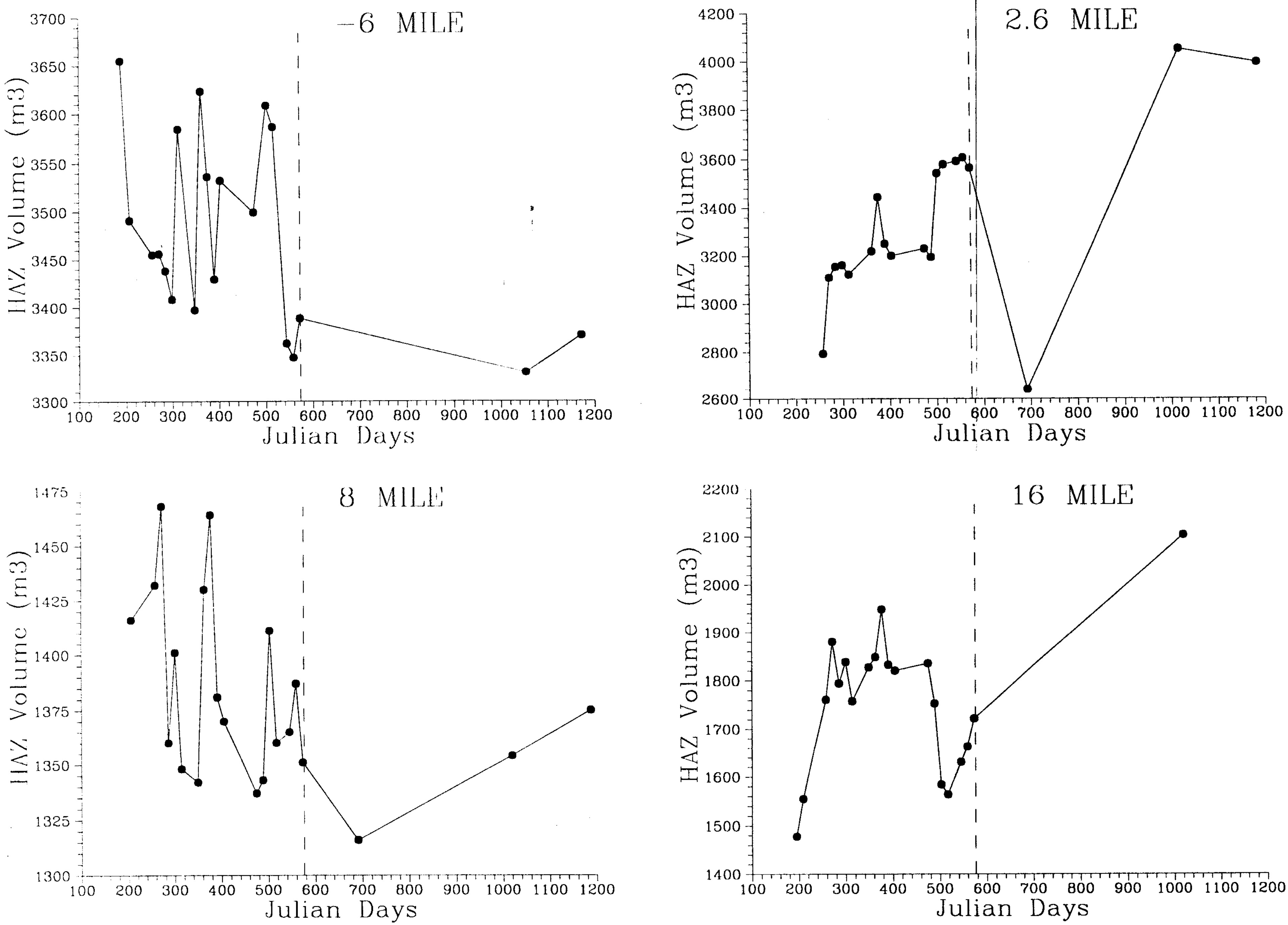


Figure 2. Volume vs. Time plots for 29 sand bars. Vertical dashed line represents the beginning of interim flow operations on August 1, 1991.

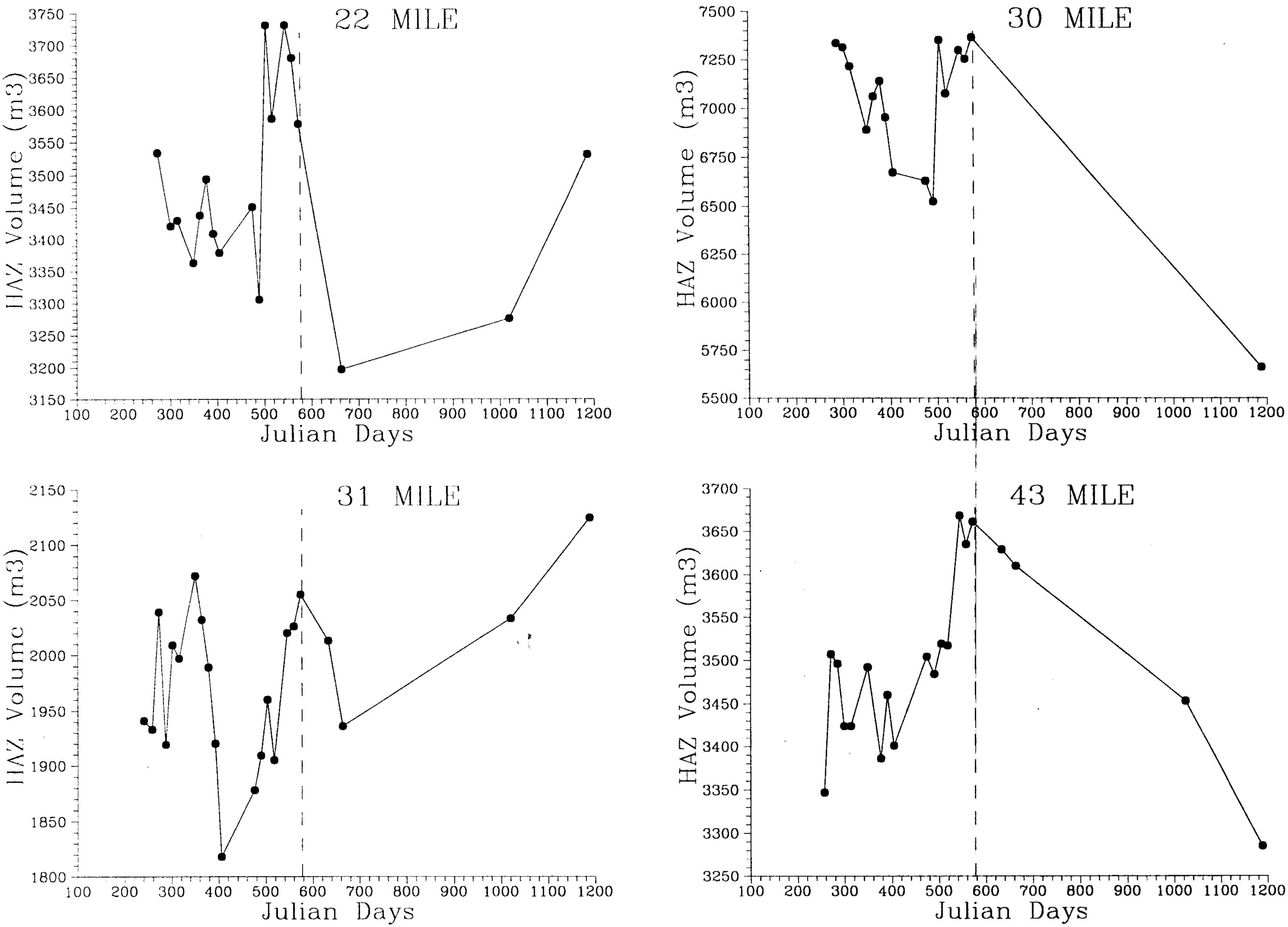


Figure 2. (continued)

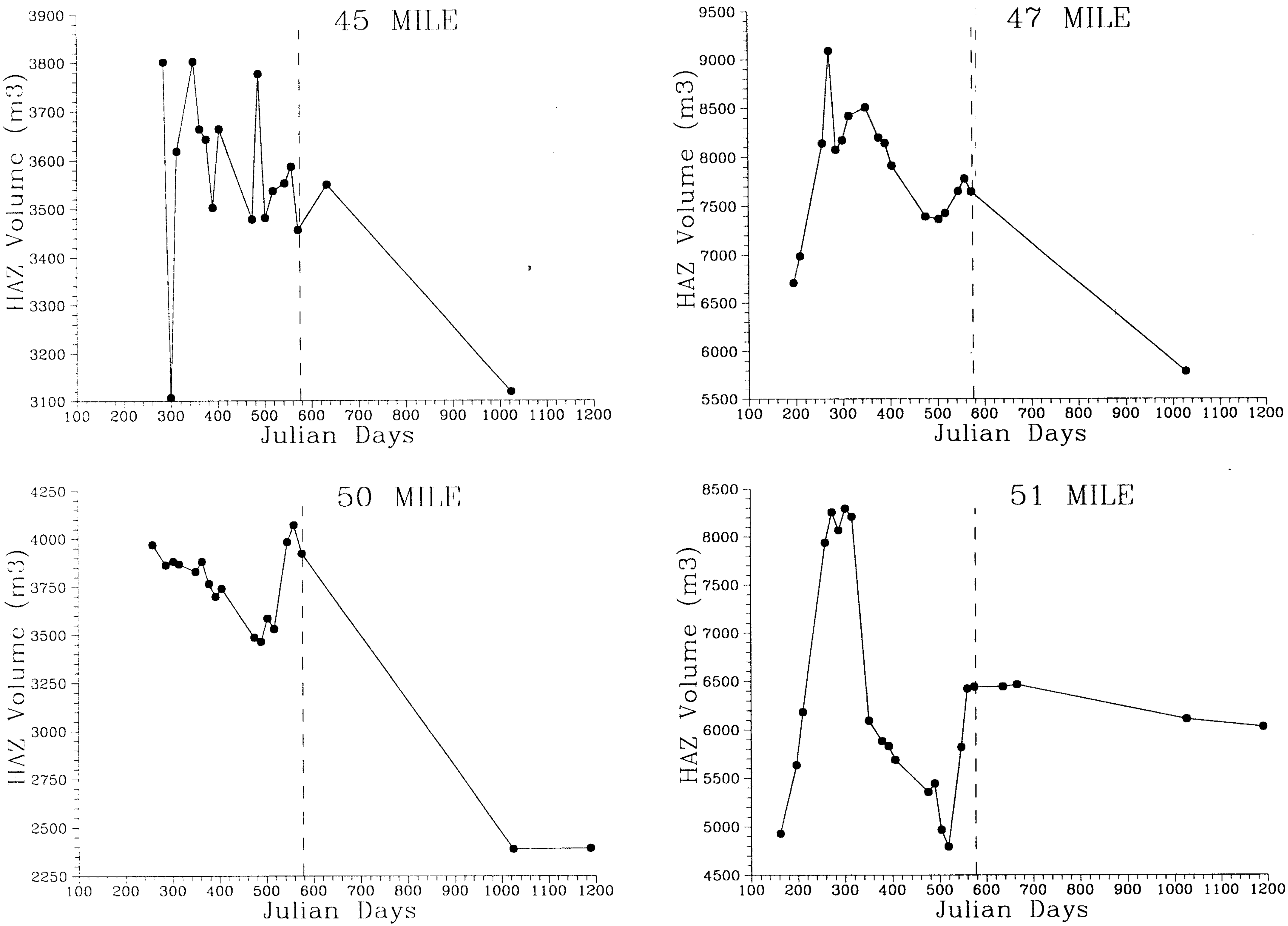


Figure 2. (continued)

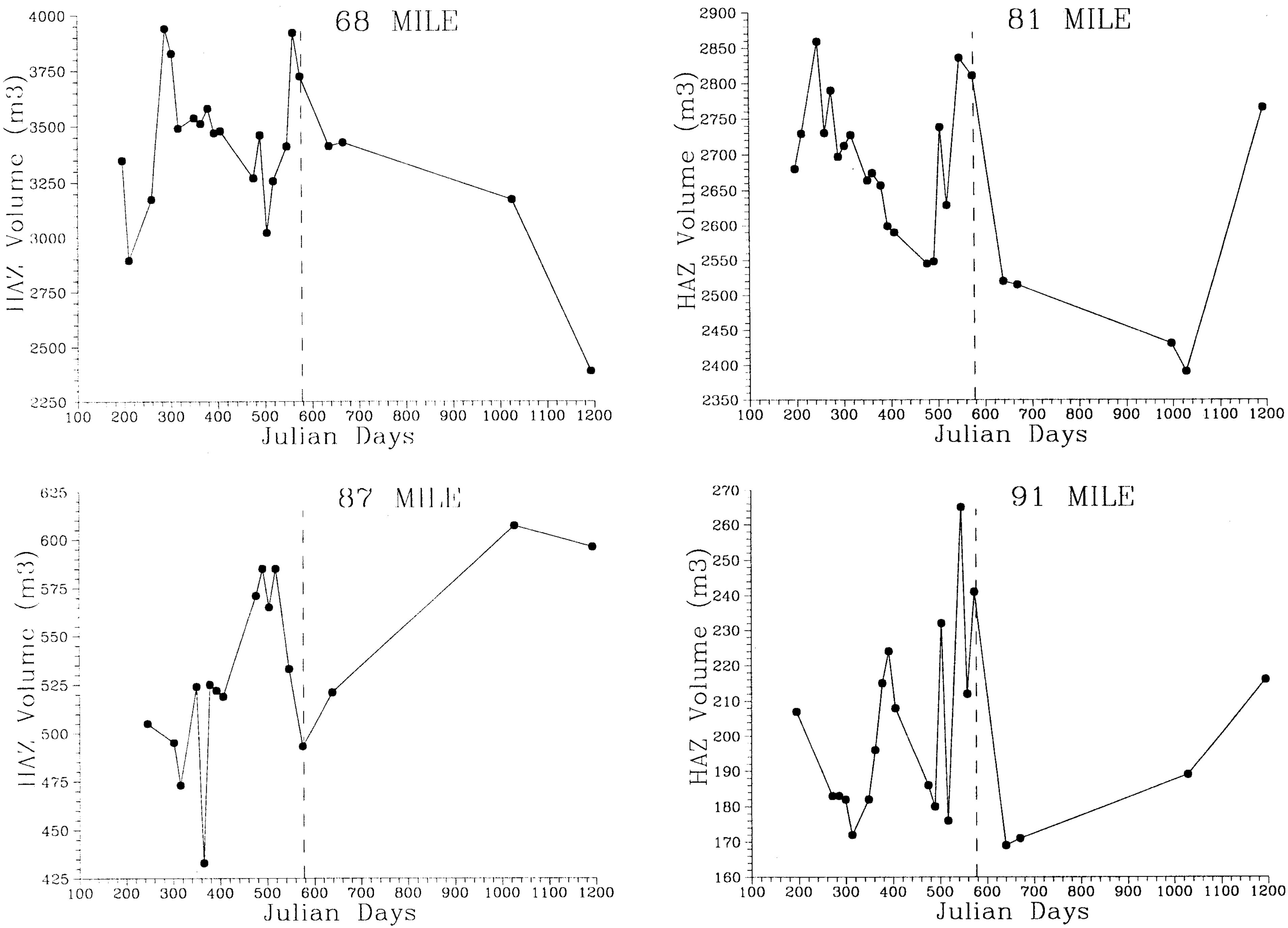


Figure 2. (continued)

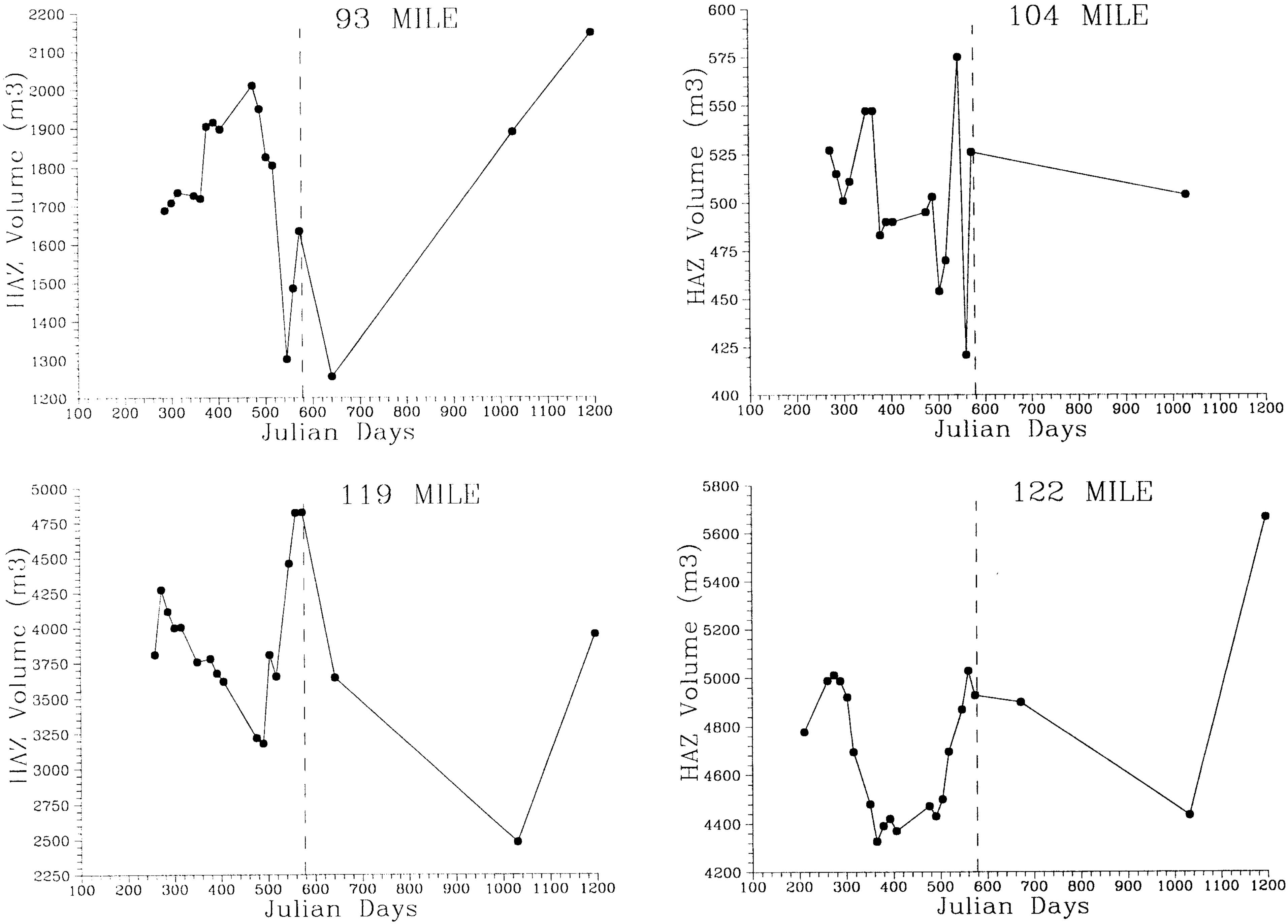


Figure 2. (continued)

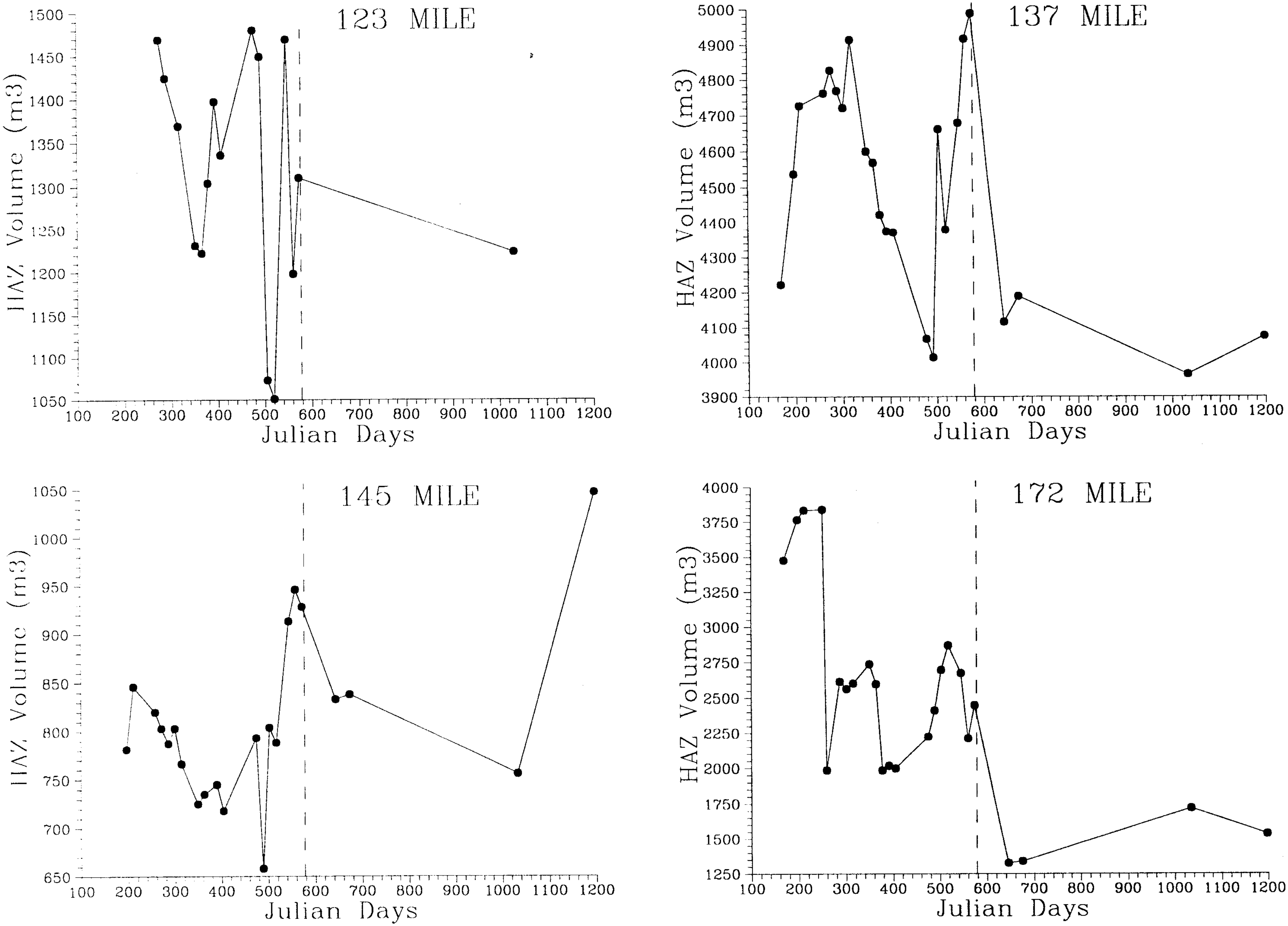


Figure 2. (continued)

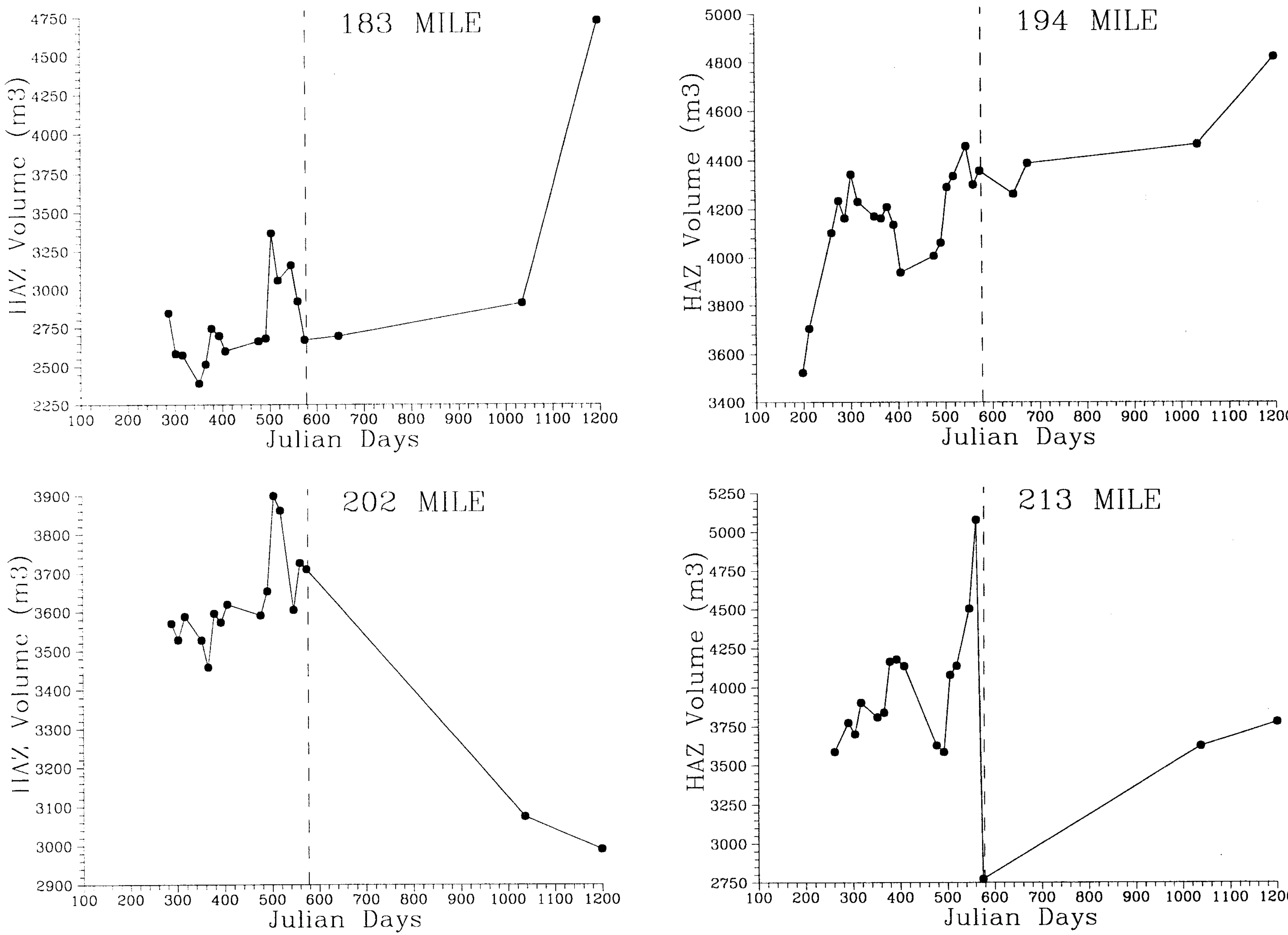


Figure 2. (continued)

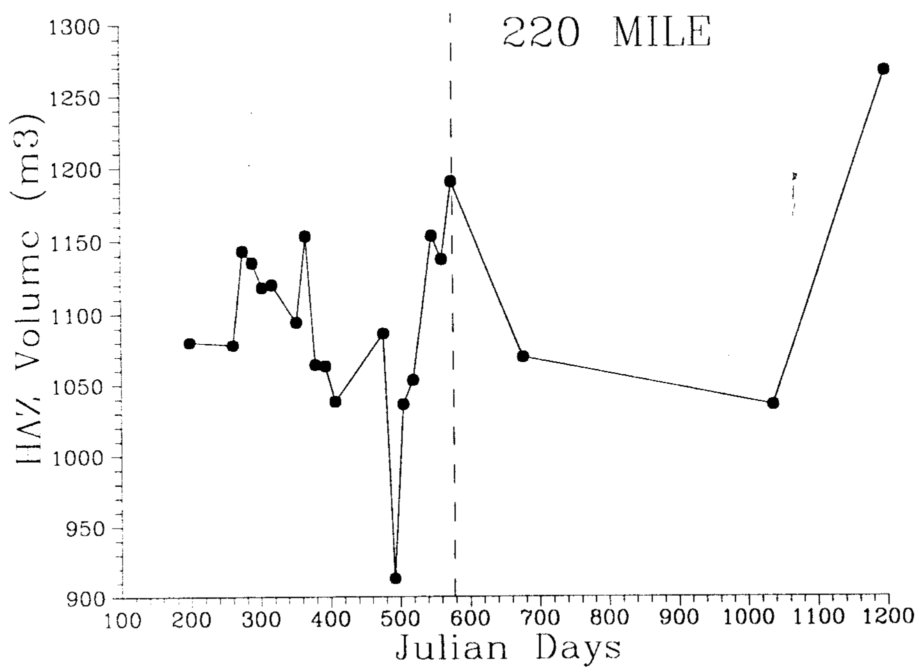


Figure 2. (continued)

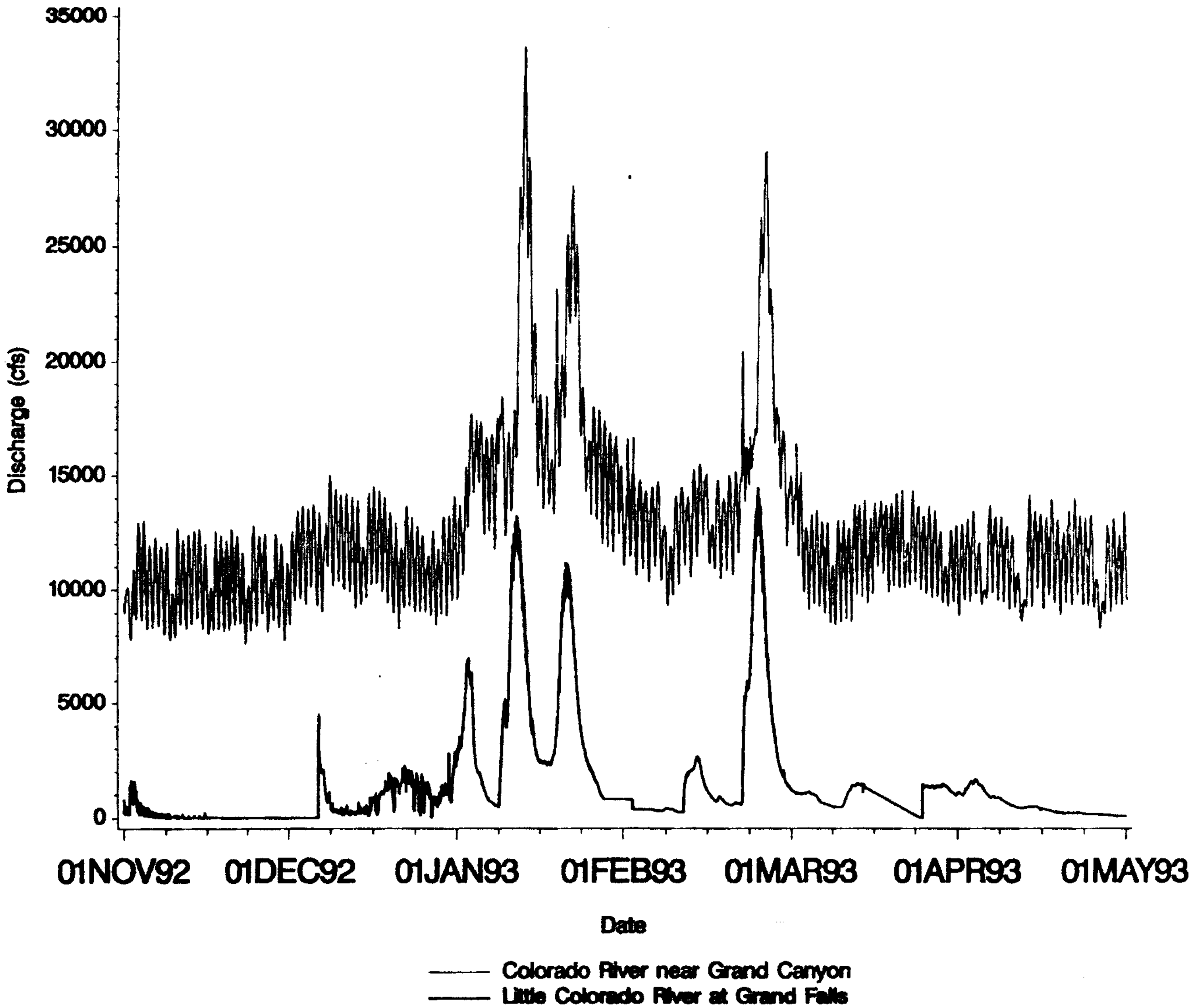


Figure 3. Colorado river hydrograph for the interval between the October, 1992 and April, 1993 survey trips. Provisional data from USGS gaged discharge.

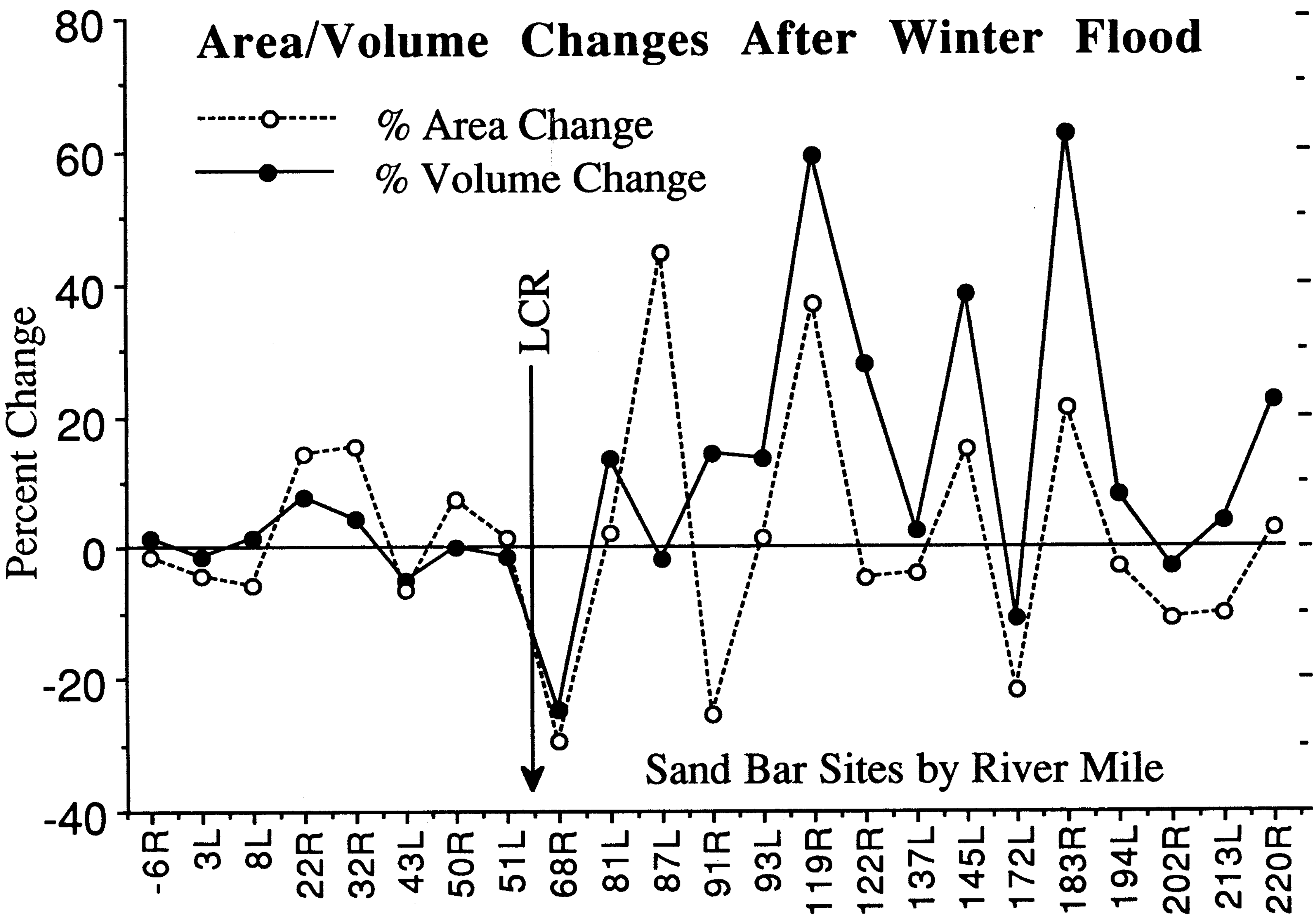


Figure 4. Net HAZ volume and area change for 23 sand bars between the October, 1992 and April, 1993 surveys. Note the dynamic sand bar response to the floods downstream from the LCR.

Sand Bar Profiles

Figures 5 to 12 present profiles from several of the study sand bars and demonstrate several relationships inferred from the HAZ volume analysis. Low-level flow fluctuations have resulted in erosion of the upper portion of nearly all bars by the development and subsequent shoreward migration of cut banks (e.g. Figure 5, profile 5; Figure 6, profile 3). Deposition is occurring along reattachment bar platforms within and below the range of interim flow stage elevations (Figure 6, profiles 0 & 1; Figure 7) that is resulting in significant HAZ volume increases. Deposition within recirculation zones also includes sediment in-filling of eddy return channels (Figure 6, profile 0; Figure 7, profiles 5 & 6). Obviously, sediment lost from higher elevations cannot be replaced by interim flows because of their lower stage elevations.

The winter floods, however, deposited large amounts of high-elevation sediment (Figure 8; Figure 9). Large-scale cut bank retreat began shortly after the flooding events receded and the newly reformed bars were exposed to fluctuating flows (Figure 5, Figure 8, profile 6; Figure 9, profiles 3 & 5; Figure 10). Notice that the sediment-laden floods did not deflate in-filled return channels (Figure 9, profile 2). Subaqueous to low-elevation subaerial sediment storage in both recirculation zones and channel areas was substantially increased immediately downstream from the LCR (Figures 11 & 12). However, there was a trend of sand depletion from river-storage downstream of 119 Mile (Figure 8, profile 3; Figure 9). It appears that much of the high-elevation sand bar aggradation was at the expense of the modest sand accumulations that had been increasing as a result of interim flows (Compare surveys prior to flood in Figures 8 & 9). Although eddy scour occurred at several of the study bars (68, 119, 122), high-elevation aggradation was substantial enough to offset a volume loss that would be reflected in our HAZ analysis. Large-scale cut bank retreat, however, was resulting in a rapid reduction in HAZ area (Figure 4; 68, 91, 122, 172 miles).

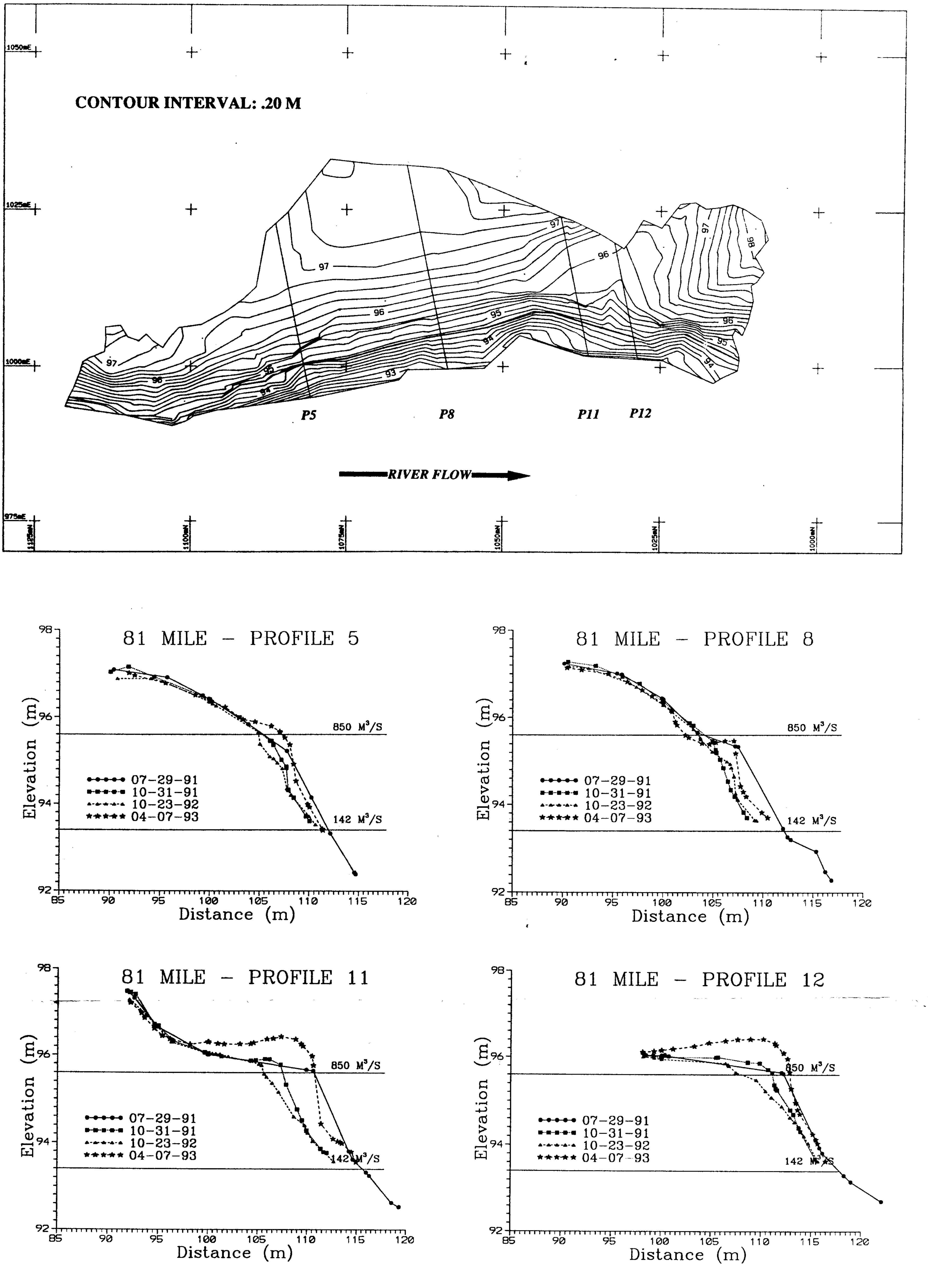


Figure 5. Site map and selected profiles from 81 mile "grapevine camp".

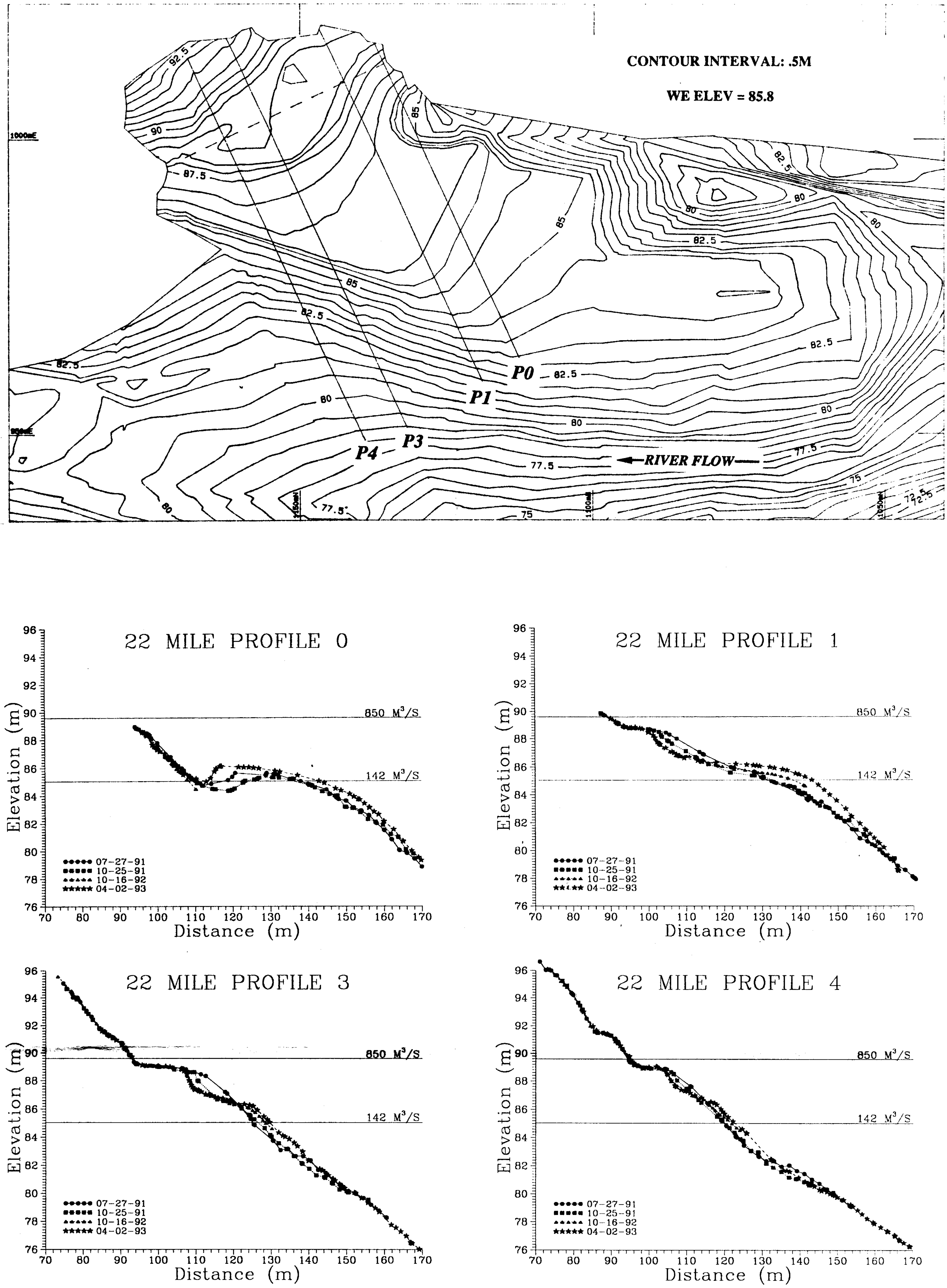


Figure 6. Site map and selected profiles from 22 mile.

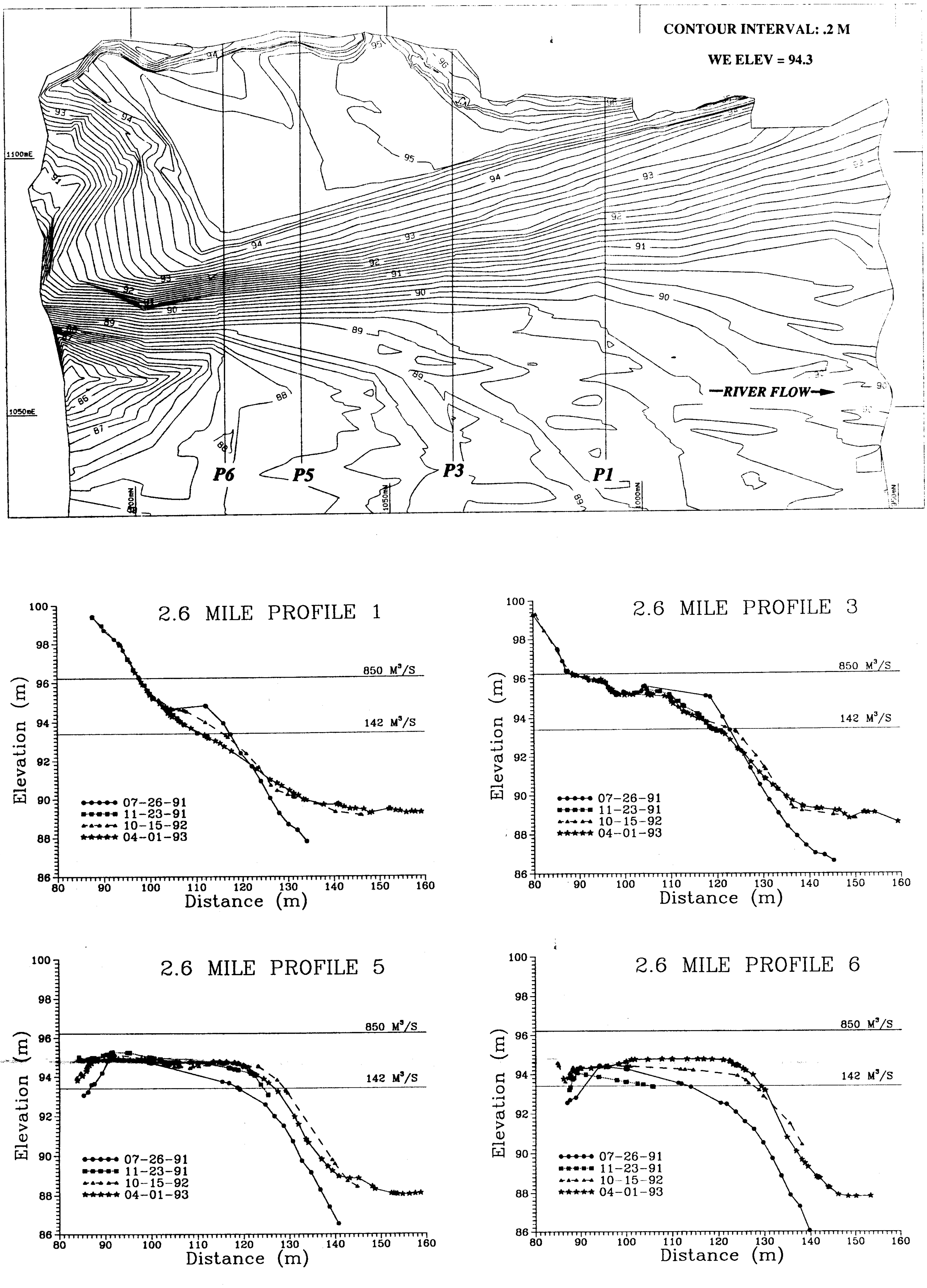


Figure 7. Site map and selected profiles from 2.6 mile.

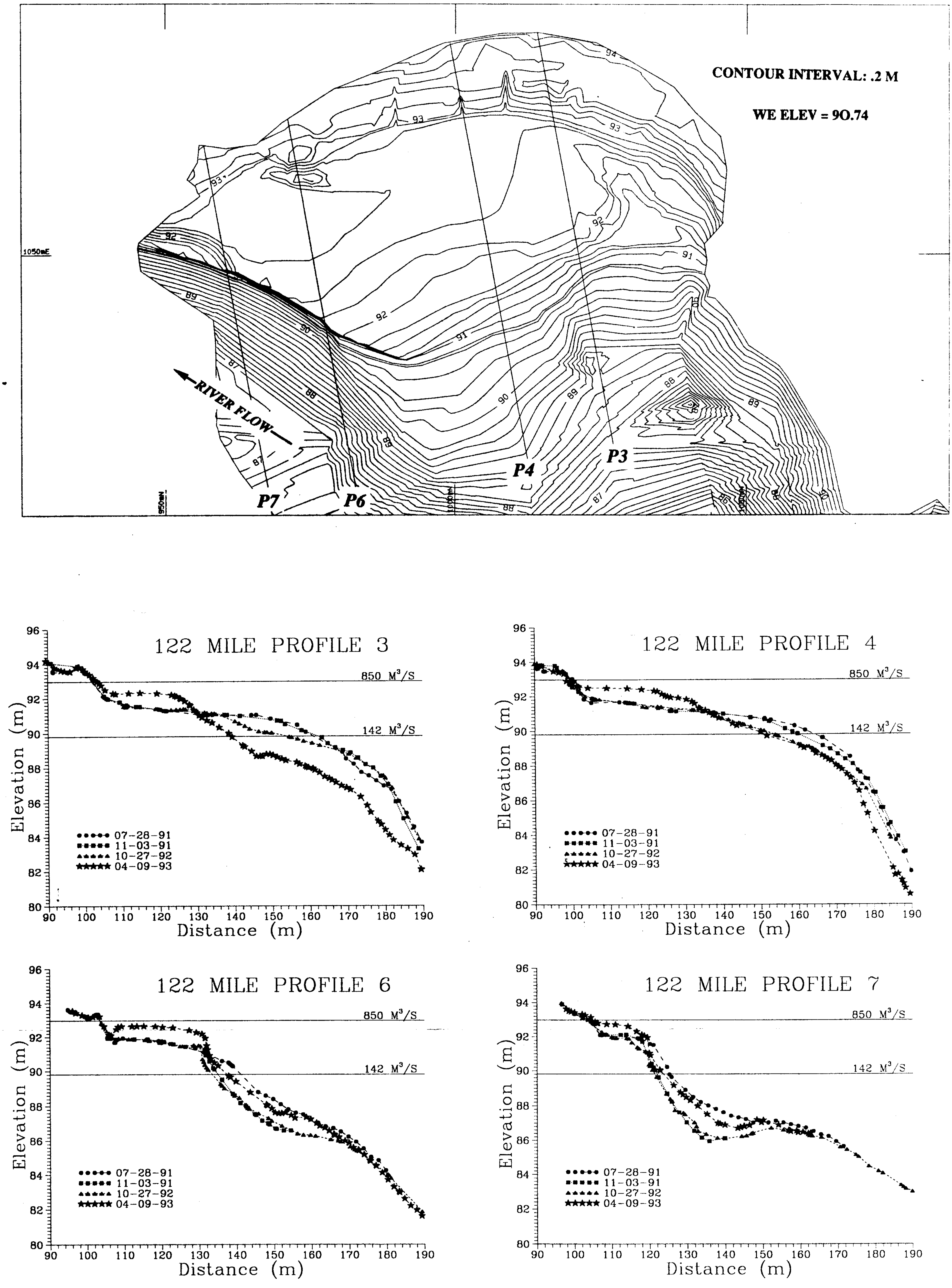


Figure 8. Site Map and selected profiles from 122 mile.

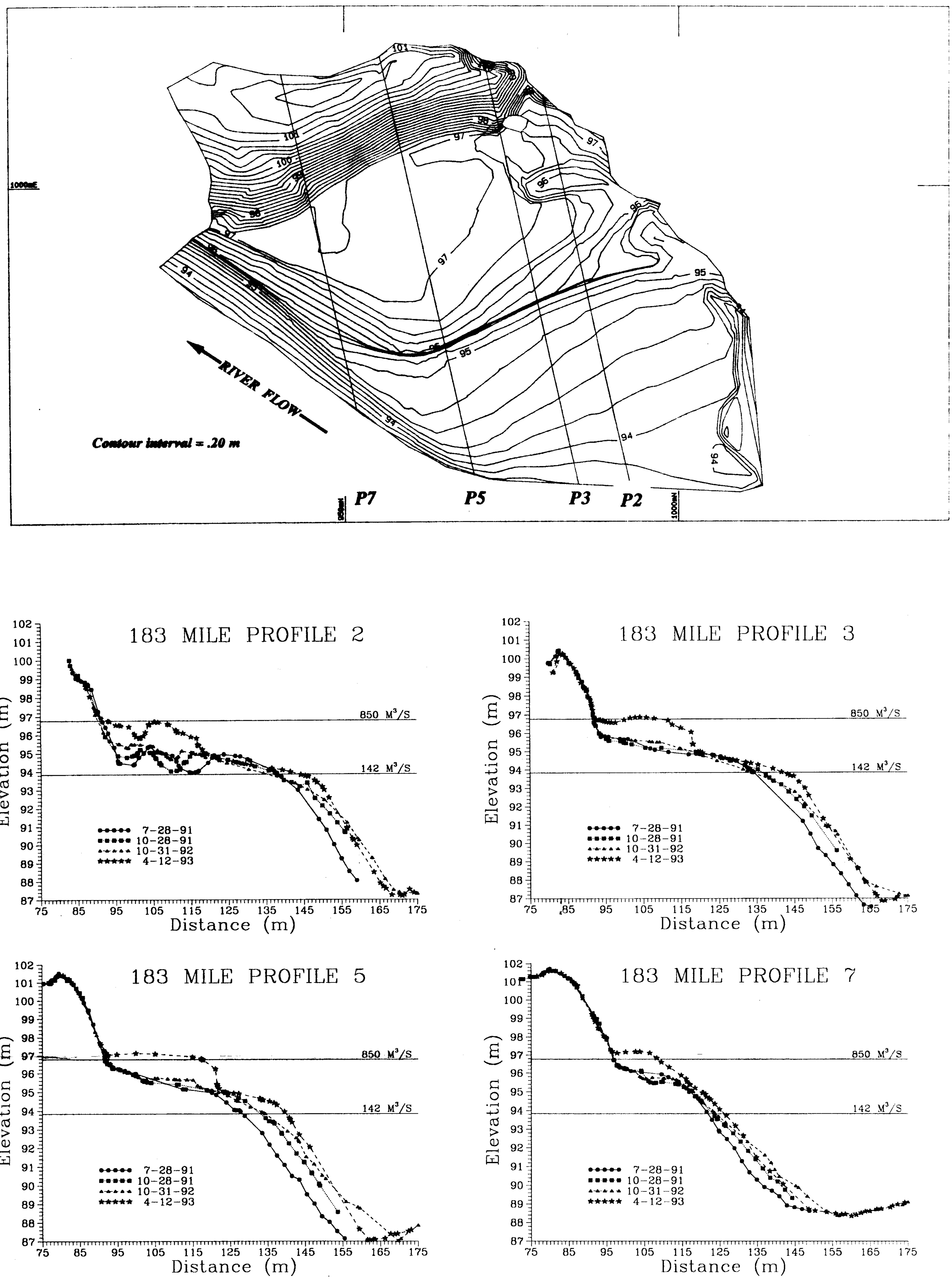


Figure 9. Site Map and selected profiles from 183 mile.

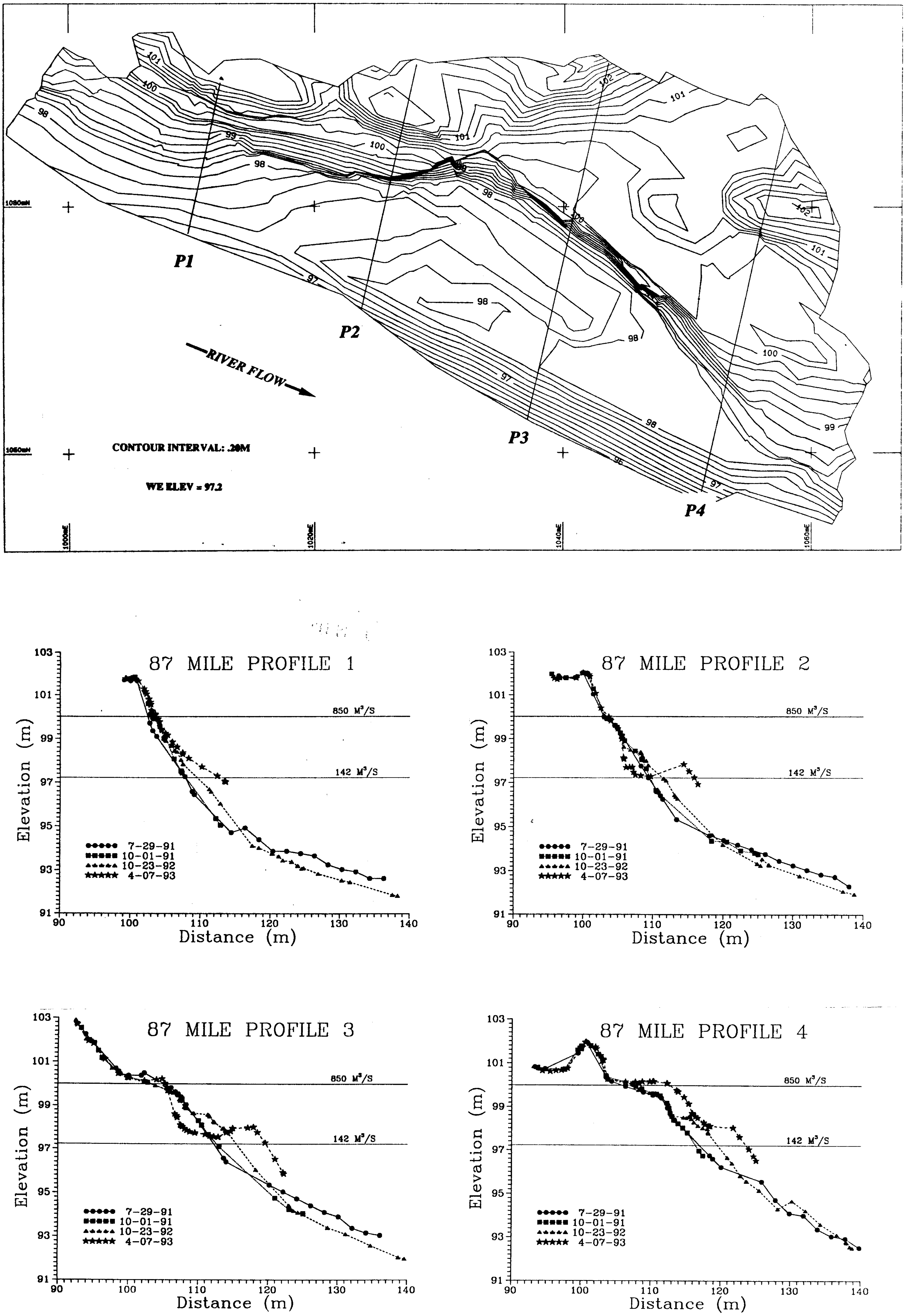


Figure 10. Site map and selected profiles from 87 mile.

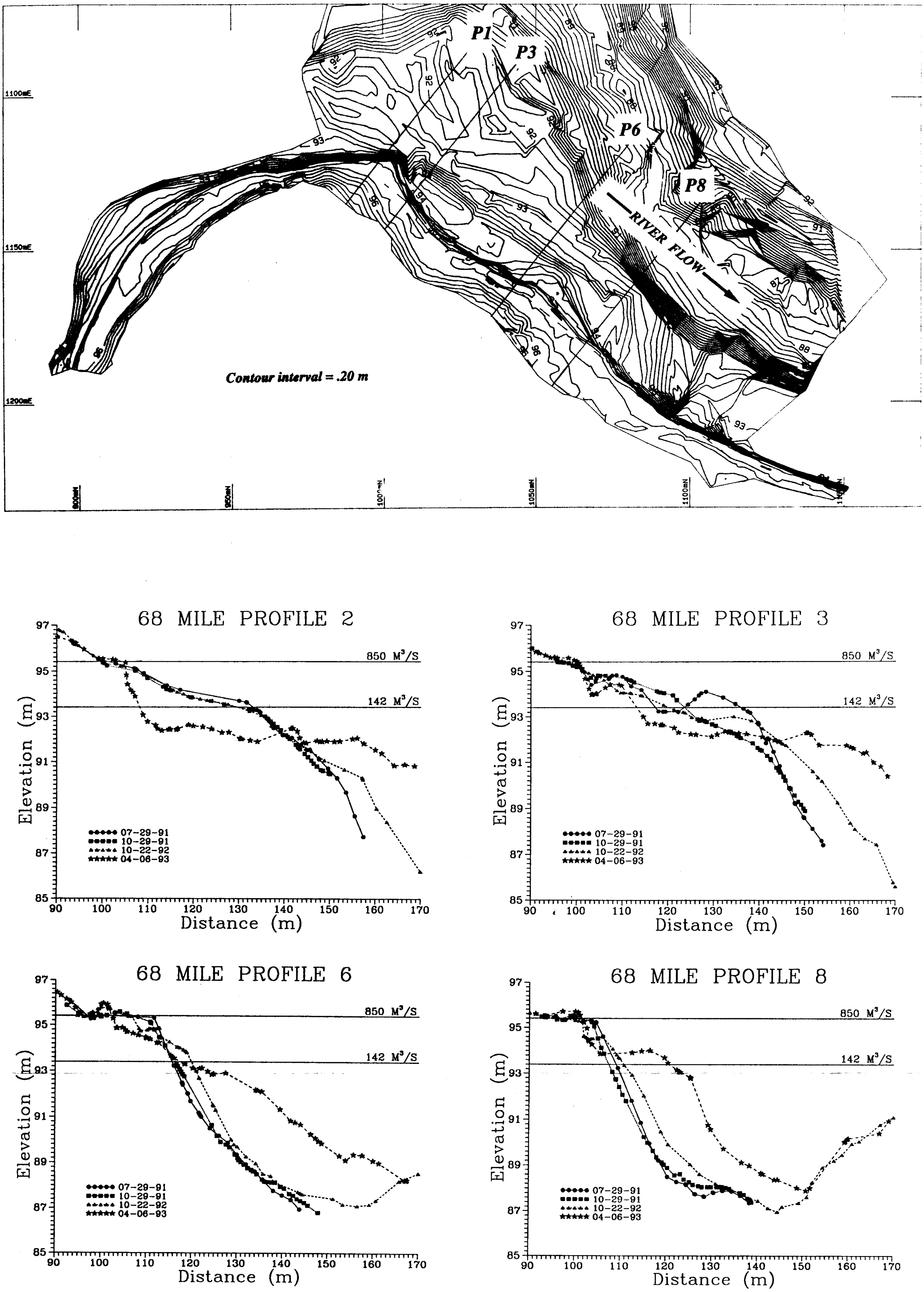
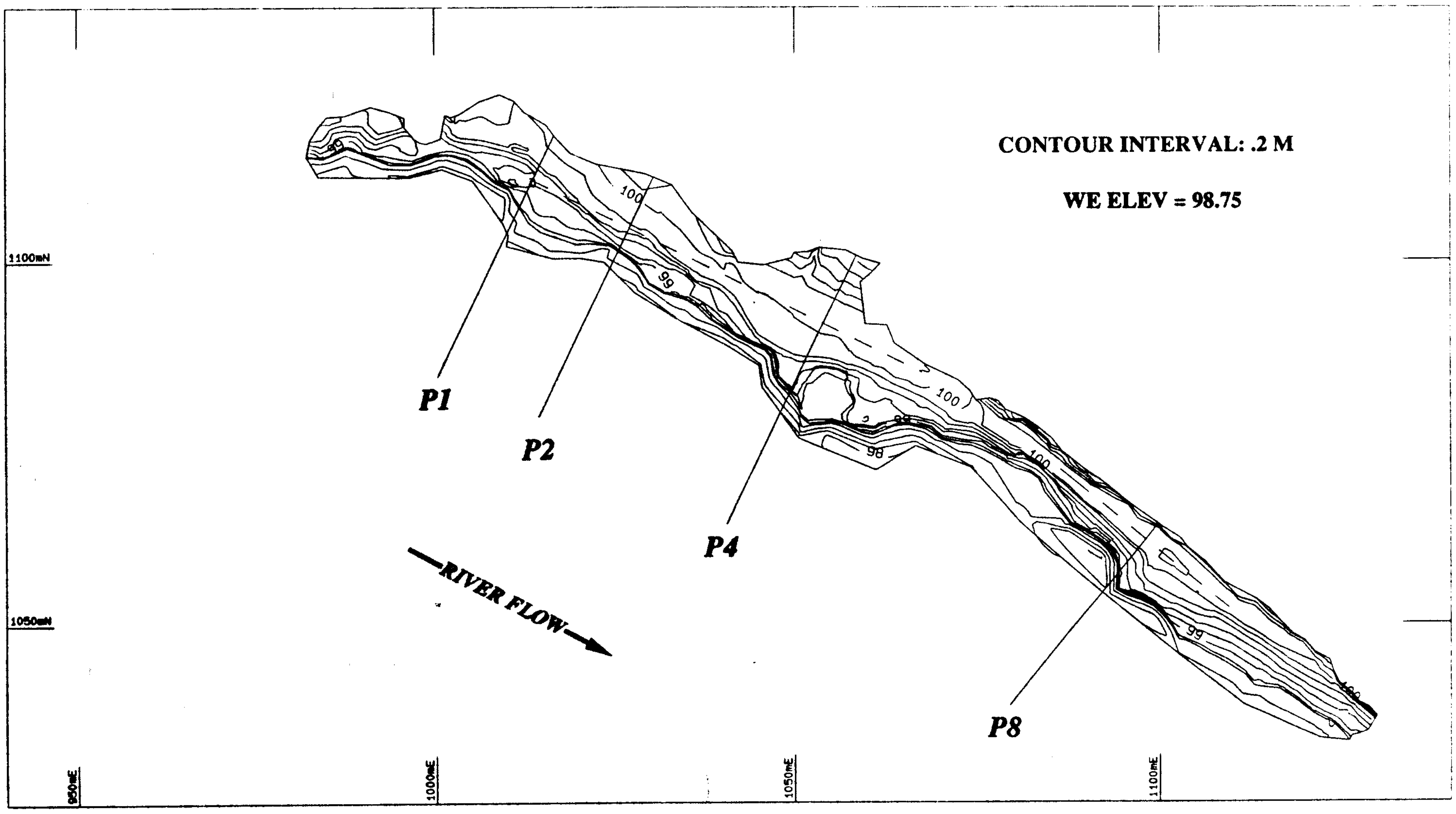


Figure 11. Site map and selected profiles from 68 mile.



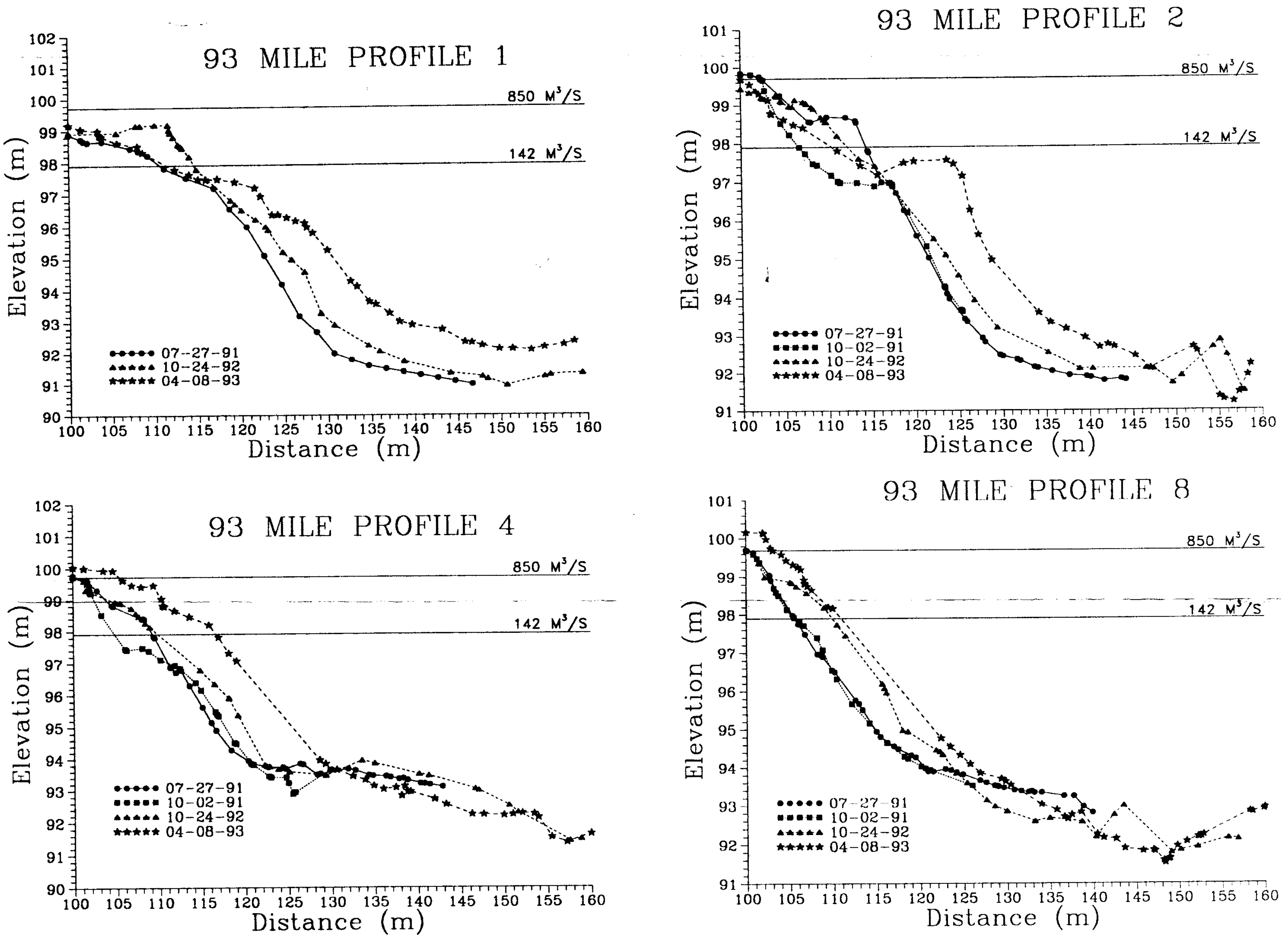


Figure 12. Site map and selected profiles from 93 mile.

2. *CAMPSITE SIZE STUDY*

Fall 1992 Results

Of the 111 campsites evaluated prior to the winter flood events, 15 camps, all in critical reaches, consist entirely of campsite area which is well above 850 m^3/s. Since these camps are above the HAZ during interim flows and during non-flood years of fluctuating flows, they were not directly influenced by interim flows and will not be evaluated with the rest of the campsites. Ninety-six campsites, 63 in critical reaches, and 33 in non-critical reaches have campsite area below 850 m^3/s and their condition prior to the winter floods is presented here. Of these sites, 13 have increased in size, 44 have decreased in size, and 39 have remained the same size (Table 3). These results are based on a minimum campsite stage elevation of 226 m^3/s whereas the Sand Bar Survey volumetric analysis is taken from a 142 m^3/s minimum.

Table 4. Campsite Area Changes

	INCREASE	DECREASE	SAME
ALL CAMPS Percent (number) n=96	13% (13)	46% (44)	41% (39)
CRITICAL REACHES Percent (number) n=63	11% (7)	54% (34)	35% (22)
NON-CRITICAL REACHES Percent (number) n=33	18% (6)	30% (10)	52% (17)

Decrease in Size

Nearly half (46%) of the camps decreased in size. A higher percentage of these camps occur in critical reaches (54%) than non-critical reaches (30%); however, these and other differences in number between critical and non-critical reaches are not significant (X^2_{2df} = 4.86, X>0.05).

The campsites which decreased in size were broken down into several categories, which are as follows:

Gone	3
Large decrease	4
Moderate decrease	22
Slight decrease	8
Still very large camps	7
Total	44

Campsites which are "gone" are those which have lost sufficient sediment so that they no longer fit the 1992 campsite definition; the definition states that there needs to be space sufficient for 10 or more people plus a standard kitchen and toilet in a non-emergency situation (Kearsley and Warren 1993). All three campsites categorized as "gone" were in critical reaches where campsites are scarce. Campsites categorized as "large decrease" have lost approximately one half of the campable area measured in 1991. All four campsites with this categorization are also in critical reaches. Campsites categorized as "slight decrease" have lost small portions of campable area and have not decreased in carrying capacity. Often, the areas which have eroded were suboptimal and had little recreational value. Campsites which are "still very large camps" are those which have capacity far exceeding the maximum allowable group size of 36 people; decreased area in these campsites does not affect the sites' carrying capacity, as they can still accommodate more than 36 people. These campsites are in both critical reaches and non-critical reaches.

In addition to the above 44 campsites which have decreased in size, 14 sites have also decreased in size from flash floods. In these sites, gullies or drainages have formed since 1991 in what had been campable areas. These sites were not included with the others that have decreased in size because their loss of sediment was not directly related to interim flows.

Increase in Size

Thirteen percent of the campsites increased in size (Table 4). There is a trend for a greater percentage of camps in non-critical reaches to increase in size than critical reaches; however, as with the decreased sized camps, this difference is not significant.

The campsites which increased in size can be broken down into the following categories:

Slight increase	4
Moderate increase	3
Low water increase	6
Total	13

Campsites categorized as "slight increase" have slight increases in the amount of campable area; these increases, however, are too small to increase the carrying capacity of these camps. Campsites categorized as "low water increase" have new campable area available only below 425 m^3/s. These areas would not be useable unless flows remained well below 425 m^3/s.

May 1993 Results

During May 1993, 88 campsites with camp area below 850m^3/s were reevaluated and are summarized here. Campsite size change above versus below the LCR was very different in response to the winter flooding event. Campsite size change in critical versus non-critical reaches was not different, so data will be separated only into sites above versus below the LCR (Table 5). In general, a higher percentage of sites have increased and a lower percentage have decreased in size since Fall 1992. Most of the increase occurred in sites below the LCR, and most of the decrease occurred in sites above the LCR.

Table 5. Campsite Size Changes

	CAMPSITE AREA		
	INCREASE	DECREASE	SAME
ALL CAMPS '92 n=96 Percent (number)	13% (13)	46% (44)	39% (41)
ALL CAMPS '93 n=88 Percent (number)	57% (50)	11% (10)	32% (28)
ABOVE THE LCR '93 n=23 Percent (number)	35% (8)	35% (8)	30% (7)
BELOW THE LCR '93 n=65 Percent (number)	65% (42)	3% (2)	32% (21)

Above the LCR

Roughly equal percentages of sites above the LCR have increased, decreased, and remained the same size. However, most of the sites which increased in size were what we term "low water increase," meaning that increased area was at very low water levels, approximately below $435m^2/s$. Also, the increased area in 5 of the 8 sites was minimal. Of the 8 sites which decreased in size, 4 sites had very slight decreases, and one degraded to the condition that it can no longer be considered a camp. The decreased size in two of the camps resulted from tributary flash flood damage.

Below the LCR

A large percentage of campsites below the LCR increased in size. Of the 42 which increased, 8 had very large increases in size (one of which regained status as a campsite since Fall 92), 25 had moderate increases, 6 had slight increases, and 3 had low water increases. Half of the camps which increased in size increased to the extent that they were larger in May 1993 than when they were first measured in Spring 1991.

Only two campsites decreased in size since fall 92, and 21 remained the same size. Some of the camps that remained the same size actually had accumulated sand so that the campsite area was at a higher elevation and could be used at higher water levels than in previous assessments; however, since they did not increase in useable camp area, the campsites did not increase in size.

3. *DISCUSSION*

Prior to the natural sediment-laden winter floods, interim flow operations resulted in subaerial sand bar erosion, deposition at lower bar elevations, and increased sediment storage in recirculation zones as well as the main channel proximal to the sand bar (Figure 13A). Preliminary results indicate that, in general, this was again the observed pattern for sand bars above the LCR in April, 1993. Both the amount of sediment within the HAZ and the area available for camping was continuing to decrease as a result of interim flow operations from GCD. Our observation was that sediments were being eroded from high-elevation sand bar locations and that deposition, not necessarily of the same sediment, was occurring in a smaller recirculation zone along the lower portion of the sand bars below the maximum elevation of interim flows (Figure 13A). Downstream from the confluence of the LCR and Colorado River, however, the three winter flood events augmented the sediment budget and increased main stem transport rates. There was a considerable increase in both erosion and deposition at sites below the LCR (Figure 4).

Downstream of the LCR, sand bars aggraded considerably in size with deposition of up to 1-2 meters of sediment at elevations well above current interim flow fluctuations (Figure 13B). Subaqueous sediment storage within both the main channel and eddy systems was substantial. Up to four meters of aggradation occurrred along the channel floor and recirculation zones at 68 Mile (Figure 11). Similiar aggradation was apparent as far downstream as 93 Mile (Figure 12). Several sites farther downstream (119 Mile and on), however, show a decrease in sediment storage in recirculation zones and the main channel. These observations imply that sediment input from the LCR was transported and redistributed up to 30 miles downstream of the LCR-Colorado River confluence. Below this zone high-elevation sand bar aggradation resulted from redistribution of pre-existing sediment in river-storage.

Destablization of the newly aggraded bars began soon after the return to normal GCD interim flow operations. Large-scale cutbanks, up to 2.5 m high, developed and retreated in response to the rapid return to seepage and tractive force erosion associated with fluctuating flows (Figure 13B). Sand bars erode rather quickly after a bar-building event, as was reported after the 1983 flooding event (Brian and Thomas, 1984; Schmidt and Graf, 1990). Two months after the 1993 winter flood events the same response of sand bars to interim flows began to be re-established (Figure 13B); these are erosion by cutbank retreat and aggradation along the lower portions of sand bars within the interim flow tidal range and subaqueously as well. Although the post-flood erosion rates are likely to diminish, continued interim flow operations can be expected to result in continued erosion of the upper portions of the sand bars resulting in a loss of both camping area, and riparian/wildlife habitat.

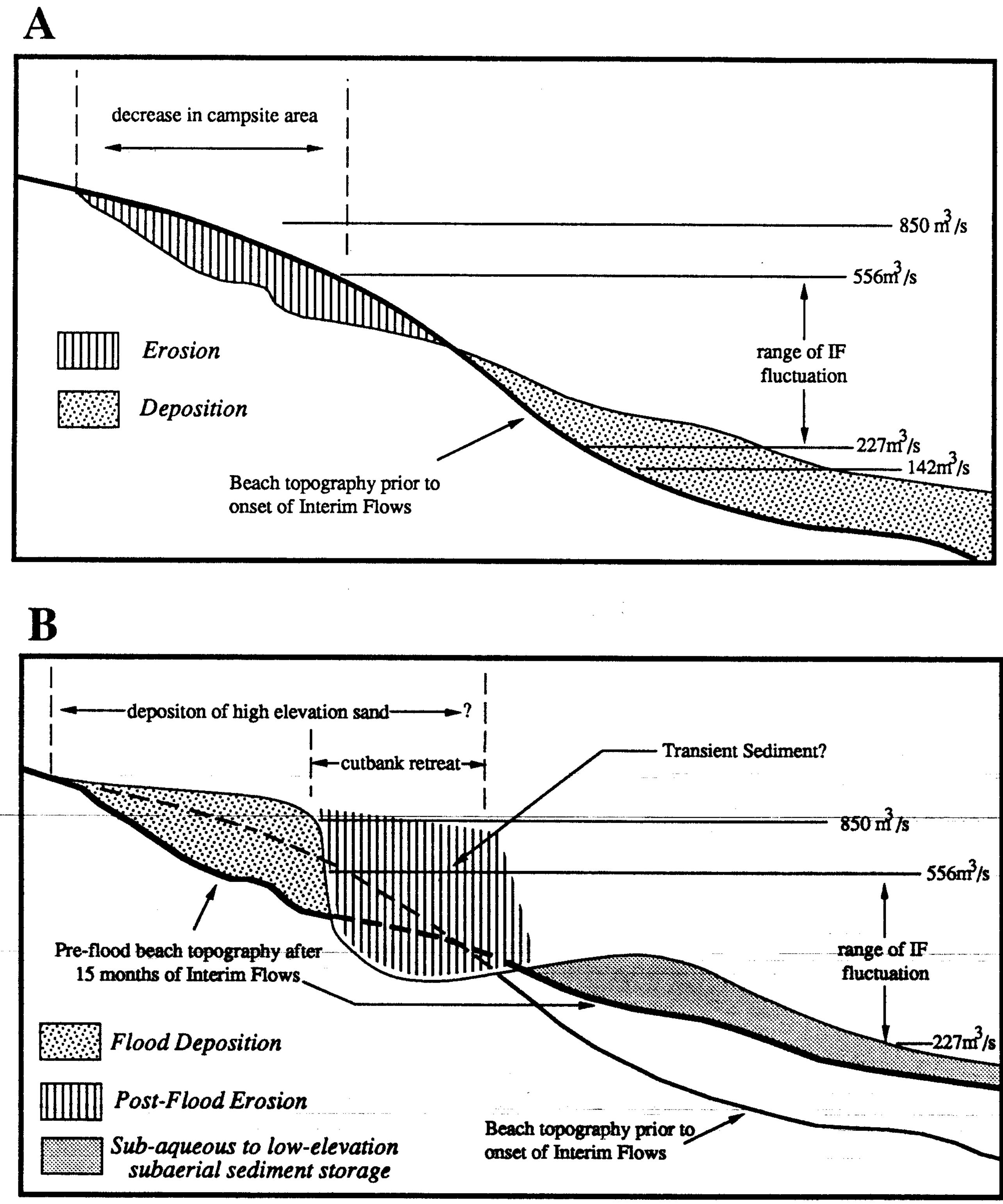


Figure 13. Schematic cartoon diagrams (not to scale) illustrating, A) erosional and depositional relationships during interim flows prior to the winter 1993 floods, and B) Flood deposition, post-flood cutbank retreat, and low-elevation subaerial and subaqueous deposition.

The primary goal of interim flow criteria was to promote sediment storage in the river system; however, we observed that interim flow objectives were only partially being met. Sediment accumulated in recirculation zones and the main channel proximal to the sand bars, but erosion of sediment at higher bar elevations was not being replaced. Aggradation is also occurring within the return current channels of reattachment bars that limits native fish habitat. Schmidt and Graf (1990) observed a similiar response of sand bars to the 1985-86 fluctuating flow period. Periodic high-flow releases from GCD are needed to redistribute sediment to higher sand bar elevation and increase the erosive power of recirculation currents in an attempt to deflate infilled return current channels. A clear-water, experimental flow, near or greater than GCD power plant capacity, is being planned for March/April, 1994. The 1993 winter floods provided an unexpected test case of a bar-building flow event. Significant deposition has occurred as a result of these floods and suggests that a bar-building flow at or near powerplant capacity is feasible. However, in order to minimize the development of large-scale cuttbanks, such as those observed following the winter 1993 floods, we suggest that the experimental flow include an extended period of draw-down (Figure 14a). An extended draw-down would decrease the slope angle along the frontal portions of the sand bars and lead to more stable conditions when the sandbars are exposed to interim flows (Budhu, 1992)(Figure 14B).

Conclusions

1. Interim flow operations from GCD have led to erosion of the higher elevation portions of sand bars.

2. Interim flow operations from GCD have resulted in deposition below the maximum interim flow stage elevation along the lower portions of many sand bars, including the return current channnels of reattachment bars.

3. Preliminary results from the flood deposits indicate that, in general, sand bars aggraded 1-2 meters, but the volume gain was destabilized upon the rapid return low-volume interim flow operations from GCD.

4. Occasional "bar-building flows" near, or in excess of GCD power-plant capacity are necessary to redistribute sediment from river-storage to bar elevations not reached by GCD interim flows.

5. "Bar-building flows" at or near powerplant capacity are feasible.

6. The longevity of newly re-formed sand bars is dependent on a dam operation strategy that limits bank erosion processes.

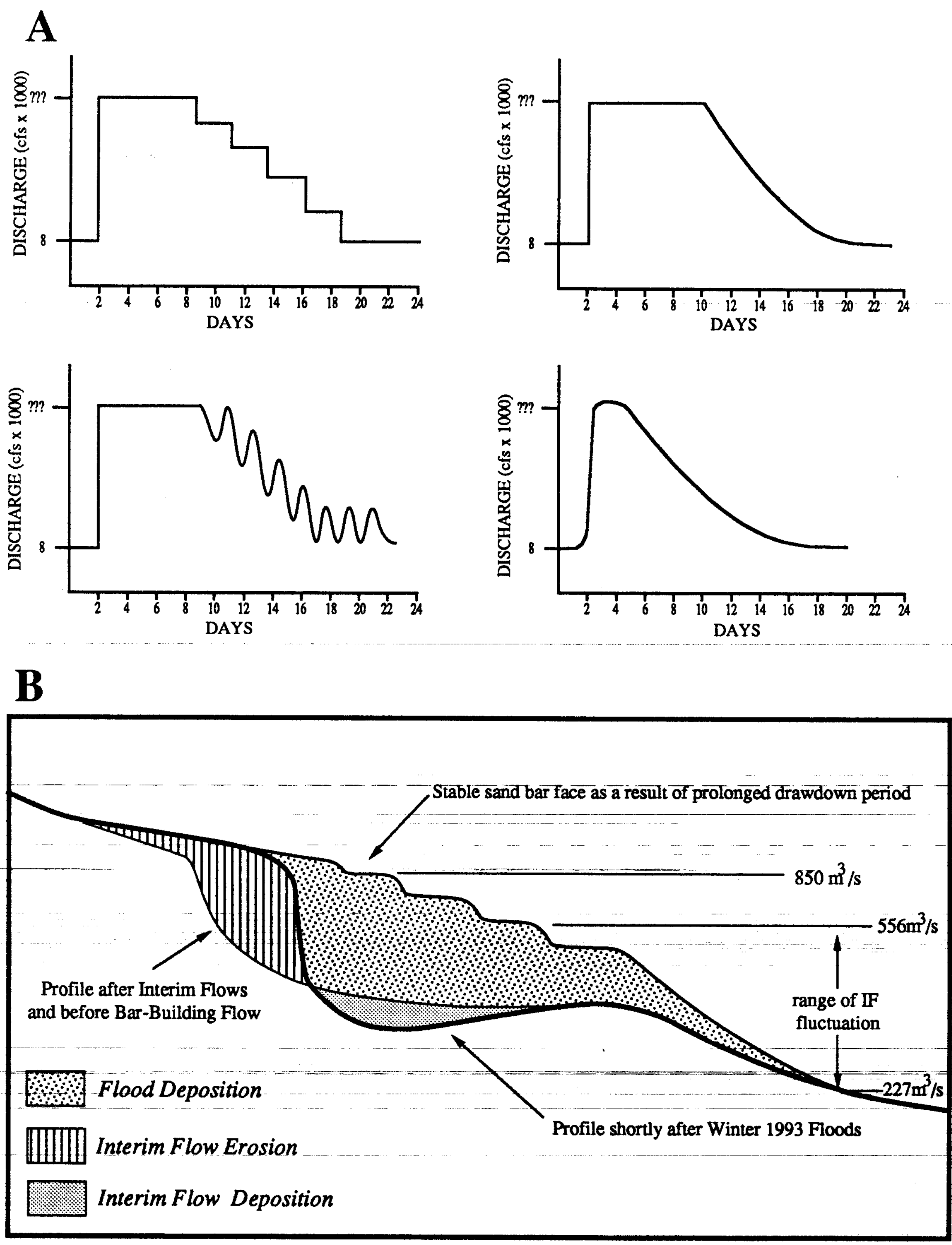


Figure 14. A) Various hypothetical flood hydrographs with an extended drawdown period; and B) schematic cartoon diagram illustrating the depositional relationship that might result from the experimental bar-building flow with an extended drawdown period.

4. REFERENCES

Beus, S.S., Avery, C.C., Stevens, L.E, Kaplinski, M.A., and Cluer, B.L., 1992, The influence of variable discharge regimes on Colorado River sand bars below Glen Canyon Dam, in S.S. Beus and C.C. Avery (eds.), The Influence of Variable Discharge Regimes on Colorado River Sand Bars below Glen Canyon Dam: Final Report to the National Park Service.

Brian, N.J., and Thomas, J.R., 1984, 1983 Colorado River beach campsite inventory, Grand Canyon National Park, Arizona: Division of Resources Management, Grand Canyon National Park report, 56 p.

Budhu, M. 1992, Mechanisms of erosion and a model to predict seepage-driven erosion due to transient flow, in S.S. Beus and C.C. Avery (eds.), The Influence of Variable Discharge Regimes on Colorado River Sand Bars Below Glen Canyon Dam: Final Report to the National Park Service.

Kearsley, L.H., and Warren, K., 1993, River Campsites in Grand Canyon National Park: Inventory and Effects of Discharge on Campsite Size and Availability: Division of Resources Management, National Park Service, Grand Canyon National Park, Arizona, 65 p.

Schmidt, J.C., and Graf, J.B., 1990, Aggradation and degradation of alluvial sand deposits, 1965 to 1986, Colorado River, Grand Canyon National Park, Arizona, U.S. Geological Survey Professional Paper, 1493

G. INVENTORY OF PROPERTY ACQUIRED DURING THE REPORT PERIOD

QUANT.	DESCRIPTION
2	notebook microcomputer P.C.'s
2	Math Co-processor chips
1	Color Monitor
2	extra notebook microcomputer batteries
1	microcomputer battery charger
1	port replicator
1	101 keyboard
220	3.5" 1.4Mb computer diskettes
1	Hewlett Packard 42S scientific calculator
2	notebook keyboard covers
1	optical cartridge
1	word 5.1 update
1	Sokia software upgrade 4.02-5.0
1	logitech mouse
1	battery charger
3	marine batteries