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 August, 1994

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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: Annual Report

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A. MAJOR ACCOMPLISHMENTS

1. *Overview of Project*

The Bureau of Reclamation was the lead agency charged with preparation of the Environmental Impact Statement (EIS) on the impacts of Glen Canyon Dam (GCD) operations on resources downstream in Glen and Grand Canyons. Implementation of Interim Flow (IF) criteria for GCD during the EIS preparation period requires that sediment resource conditions be monitored. The present research is a monitoring study designed to evaluate the effectiveness of IF in reducing sand bar degradation and camp site loss. 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 specialists, 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 at 30 representative sand bars in the Colorado River corridor downstream from Glen Canyon Dam during the interim flow period (FIgure 1; Table 1).

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 and sediment input from the Little Colorado River (LCR) 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 occurred in the river corridor during January and February, 1993.

3. *Accomplishments*

We have collected topographic and bathymetric measurements from up to 34 sand bar study sites along the Colorado River corridor during four river survey expeditions: October 15-November 3, 1992, April 1-15, 1993, October 7-28, 1993 and April 7-18, 1994 (Figure 1; Table 1). The April, 1993 trip was initiated to examine sand bar response to the LCR tributary, river mile (RM) 61, 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 October and November, 1991 (Table 2). Sedimentologic data (Hurlburt, et al., 1994; Pederson, et al., 1994) will be presented this October at the Annual meeting of the Geological Society of America at Seattle, Washington.

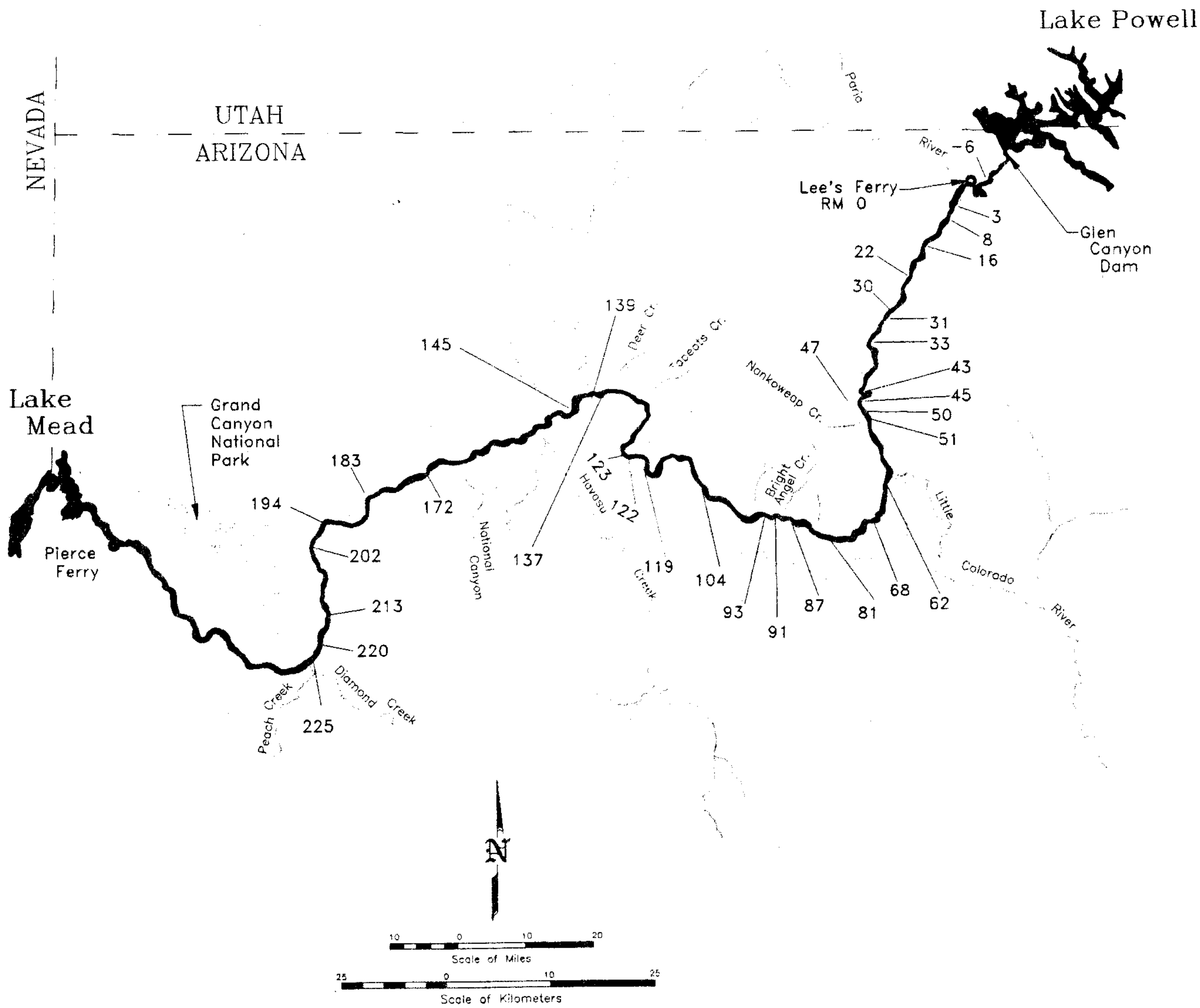


Figure 1. Location Map showing sand bar survey study sites.

Table 1. Sand Bar Survey Sites*

Site Ref.#	River Mile (RM)	River Side	#	Site Name	Deposit Type
-6	-6.5	Right	2	Hidden Sloughs	R
3	2.6	Left	3		R
8	8	Left	4	Lower Jackass	S
16	16.4	Left	5	Hot Na Na	S
22	21.8	Right	6		R
30	30	Right	7	Fence Fault	R
31	31.6	Right	8	South Canyon	S
43	43.1	Left	10	Anasazi Bridge	R/UP
45	45.6	Left	11	Eminence Break	S
47	47.1	Right	12	Lower Saddle	R
50	50	Right	13	Dino	R/S
51	51.2	Left	14		R
62	62.4	Right	34	Dead Chub Eddy	R
68	68.2	Right	15	Upper Tanner	R/UP
81	81.1	Left	16	Grapevine	R/S
87	87.5	Left	17	Cremation	R/UP
91	91.1	Right	18	Upper Trinity	S
93	93.3	Left	19	Upper Granite	R/UP
104	103.9	Right	20	Wanna-be-Ruby	R/UP
119	119.1	Right	21		R
122	122.1	Right	22		R
123	122.7	Left	23	Upper Forster	R/UP
137	136.7	Left	24	Middle Ponchos	R
139	139	Right	25	Upper Fishtail	R/UP
145	145	Left	26		R
172	172.2	Left	27		R
183	182.8	Right	28		R
194	194.1	Left	29		R
202	202	Right	30	202 Mile Cave	S
213	212.9	Left	31	Pumkin Spring	R/UP
220	219.9	Right	32	Middle Gorilla	R/UP
225	225.3	Right	33	Hell Beach	R

* River Mile #'s after Stevens (1983). Deposit type after Schmidt and Graf (1990): R - reattachment deposit, S - separation deposit, UP - upper pool deposit

Sand bars that have recreational value are called "beaches" and are commonly used as campsites (U.S. National Park Service, 1989). Data collection for the campsite size portion of this study has consisted of three river trips: September, 1992, May, 1993, and April, 1994. During these trips, 111 campsites were examined; 77 of which were in critical reaches (as defined by Kearsley and Warren, 1993), and 34 of which were in non-critical reaches. 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. A quantitative analysis is currently being performed and the results will be included in the final report.

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. Post-trip data processing time of bathymetric data was also delayed until the manufacturer solved a software problem. The system performed flawlessly on subsequent trips and those data have been analyzed and are incorporated with the subaerial surveys included in this report.

C. FISCAL STATUS

1. Cooperative Agreement Amount: $295,041
2. Expenditures and Commitments to Date: $250,664
3. Estimated Funds Required to Complete Work: .... $ 44,377
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. In addition, all study sites will be included in an appendix. This will contain site maps, aerial photographs, surface comparisons, profiles, volume and area plots, and a hypsographic analysis. Each sand bar will also have a short summary of the history of aggradation and degradation during IF.

Table 2: 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

INTRODUCTION

The Colorado River is the most highly-regulated river system in North America (Stanford and Ward, 1979) and has the highest proportion of its annual flow stored in reservoirs of any major North American watershed (Hirsch et al., 1990). GCD operations completely control its flow through Grand Canyon (Water Science and Technology Board, 1991). The operational effects of GCD include hydraulic erosion and aggradation and thus affect the stability of fluvial sediment deposits in Lower Glen, Marble, and Grand Canyons (Howard and Dolan, 1981; Beus et al., 1985; Water Science Technology Board, 1987; U.S. Department of the Interior, 1988; Schmidt and Graf, 1990; Rubin et al., 1990; Beus and Avery, 1992). The National Park Service recognizes these sand bars as a primary natural and recreational resource because the sand bars form the foundation on which the fluvial ecosystem is structured. Starting in August of 1991, a program of reduced maximum flows and reduced fluctuation from GCD, termed Interim Flows (IF), has been implemented. The IF were designed to mitigate the impacts of dam operations on downstream river resources until a Record of Decision is delivered by the Secretary of the Interior for the GCD EIS (U.S. Bureau of Reclamation, 1994). This report presents the preliminary results from two surveying studies that were designed to monitor the effects of IF on sand bars and campsite size along the Colorado River through the Grand Canyon. The sand bar study involves the comparison of topographic and bathymetric surveys at 30 sites located in each of the 11 geomorphic reaches of the Colorado River corridor (as defined by Schmidt and Graf, 1990). The campsite size study addresses IF impacts on the size of campsites used by river trips and hikers.

SAND BAR SURVEYS

Background

Modern Alluvial Deposits Of The Colorado River

Alluvial sand deposits along the Colorado River corridor in Grand Canyon are generally associated with tributary debris fans that form local restrictions and expansions in the main river channel (Figure 2; Webb et al., 1989). Typically these channel irregularities produce a recirculation zone (eddy) where flow separates from and then reattaches to the bank (Schmidt, 1990). Deposits that form in recirculation zones or similiar low-velocity areas in bedrock channel gorges have been described from this and other similiar settings (McKee, 1938; Howard and Dolan, 1981; Baker et al. 1983; Baker, 1984; Schmidt, 1990). Water velocities in recirculation zones are much lower than velocities in the main channel and therefore are sites of potential sand deposition by a variety of bar forms (Schmidt, 1990). Deposition is typically localized near the separation point, reattachment point, and eddy center. Schmidt and Graf (1990) recognized four major types of alluvial sand deposits in Grand Canyon:

reattachment deposits form upstream of the reattachment point of large primary eddies. They are typically formed along the lower, downstream regions of the eddy by currents sweeping across the eddy toward the shore and perpendicular to the main river current. This type of bar is characterized by a broad platform that extends upstream into the eddy. Return current channels form along the shoreward side of the reattachment bar platform where the eddy current is redirected along the shoreline.

separation deposits typically form immediately downstream of debris fans which produce constrictions in the main river channel. They commonly mantle the downstream portion of the debris fan and are deposited in secondary eddies upstream of the larger primary eddy associated with the debris fan. This type of bar is typically steeper and of higher elevation than reattachment bars.

upper pool deposits typically form upstream from debris fans or other constrictions in the main channel within minor recirculation zones. They commonly occur as linear deposits along and parallel to the shoreline.

channel margin deposits are those that parallel the shoreline in areas not specifically related to recirculation zones or separation points.

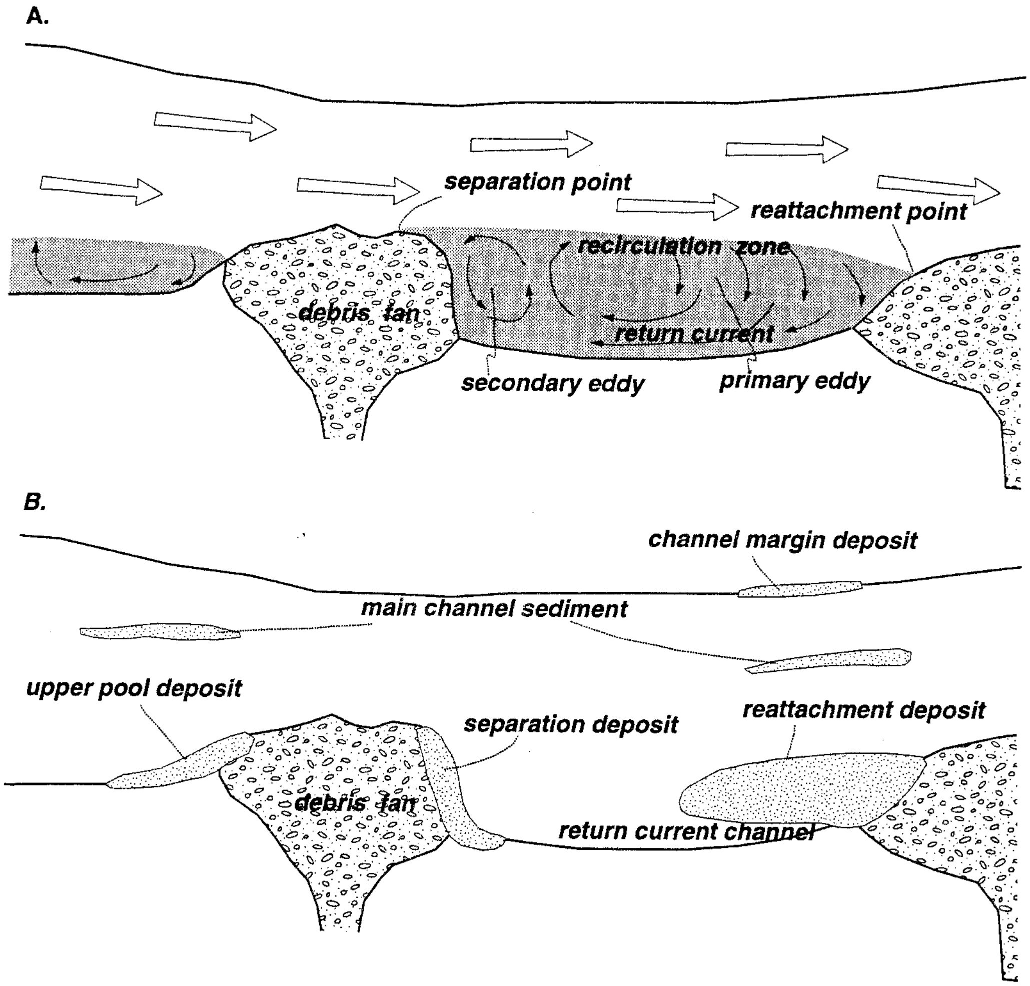


Figure 2. Schematic diagram showing flow patterns and configuration of bed deposits in a typical recirculation zone. A) flow patterns. B) Configuration of bed deposits. After Schmidt and Graf (1990).

In addition to the above, *main-channel sediments* are transported and locally deposited along the channel bottom as discontinuous stringers of sand.

Sand storage in recirculation zones varies with changes in discharge, size and dimensions of debris fans, and tributary sand input. Important contributions to our understanding of recirculation zone sedimentation in Grand Canyon have been made by Rubin et al. (1990), Schmidt (1990), Schmidt and Graf (1990), and Schmidt et al. (1993). During lower discharge flow regimes such as IF, recirculation zones generally consist of a primary eddy and large areas of both the reattachment and separation bars are exposed. The reattachment deposit may fill much of the recirculation zone beneath the primary eddy. Return-current channels are excavated by the increase in current velocity as flow across the bar converges with the upstream flow along the channel bank (Rubin et al., 1990). As discharge increases and recirculation zones expand, more area is inundated, and secondary eddies or low velocity zones develop upstream of the return current channel. Expansion of the recirculation zone causes the reattachment point to migrate downstream and the separation point to migrate upstream and onto the debris fan. Sediments deposited within the expanded, higher-discharge eddy system are exposed to a very different flow pattern when decreasing discharge shortens the dimensions of the eddy. For example, deposits which were within the high-discharge recirculation zone become subjected to downstream flow as the reattachment point migrates upstream along the main-channel margin of the bar, and sand is lost to the main channel.

Flow Regimes During Time of Study

The IF have been in effect since August, 1991 (Figure 3) and will continue until a Record of Decision is reached for the GCD EIS. The IF limit the maximum discharge to 566 m^3/s (20,000 ft^3/s), the minimum to 142 m^3/s (5,000 ft^3/s), with rates of up- and downramp to 57 $m^3/s/hr$ (2,000 $ft^3/s/hr$) and 42.5 $m^3/s/hr$ (1,500 $ft^3/s/hr$), respectively. Daily change cannot exceed 142 m^3/s (5,000 ft^3/s). These IF consist of low-, medium-, and high-volume months, with low flows during the late Spring and late Fall, moderate flows in May and September, and high flows during mid-Summer and mid-Winter.

A major change in the IF flow regulated release patterns occurred downstream of the LCR during January and February, 1993 (Figure 3). Three flood events occurred on the LCR on January 12-16, January 19-23, and February, 23-26, 1993, that raised flows in the mainstem Colorado to 960 m^3/s (34,000 ft^3/s) , 764 m^3/s (27,000 ft^3/s), and 849 m^3/s (30,000 ft^3/s) respectively. Sand was deposited in nearly every eddy downstream of the LCR-Colorado confluence for at least 30 miles, either adding to existing deposits or filling empty eddies. (Hazel et al., 1993).

The study of IF during the period of EIS review is extremely important because the EIS Preferred Alternative (EIS-PA) essentially is IF with an additional, yearly bar-building/habitat maintenance flow and endangered aquatic species research flows (U.S. Bureau of Reclamation, 1994). The winter floods of 1993 provided an unexpected test-case of a bar-building flow event. Therefore, results from research conducted during IF are directly applicable to the EIS-PA scenario.

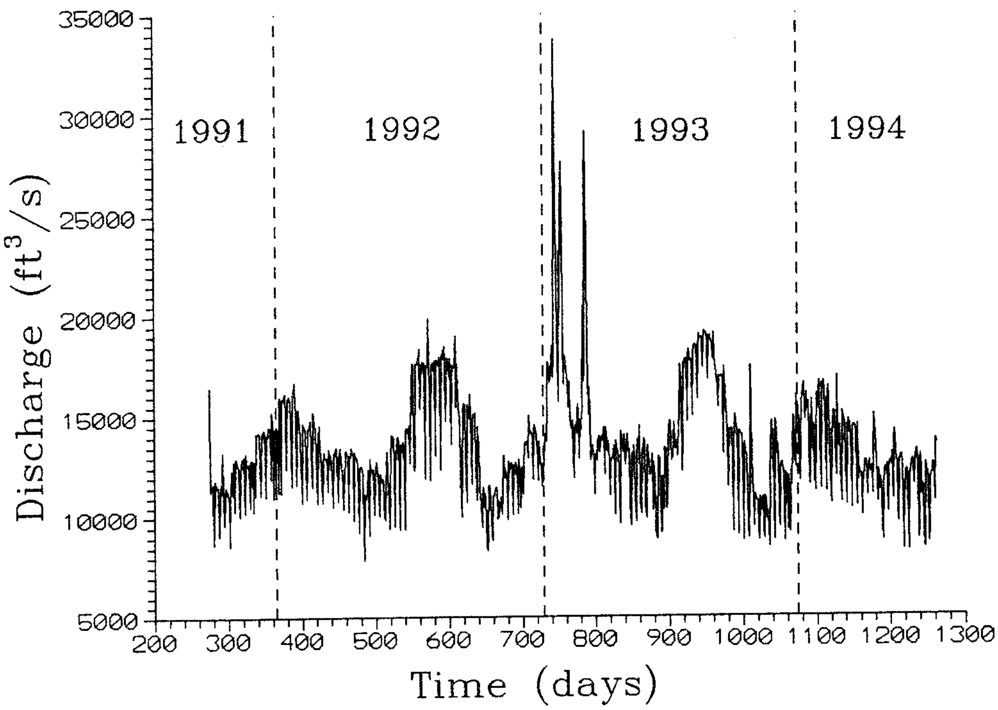


Figure 3. Daily maximum discharge from Colorado River guage near Grand Canyon (RM 88) hydrograph for the interval between October 1991 and June 1994.

Previous Work

Prior to GCES Phase II studies, knowledge of the stability (aggradation, degradation, and rates of change) of fluvial deposits in the Colorado River downstream from Glen Canyon Dam was based on sporadic profile surveys of about 30 sand bars since 1973, and occasional aerial photography since 1965 (Howard, 1975; Howard and Dolan, 1981; Beus et al., 1985; Schmidt, 1990; Schmidt and Graf, 1990; and Schmidt et al., 1992. These studies documented slight to insignificant instability of sand bars under the post-dam fluctuating flow regimes, with bar building reported under the high flows of 1983-1986, and both prior and subsequent erosion. Erosional patterns are obscured by variability in reach characteristics, local channel geometry, poorly developed stage/discharge relationships, unknown antecedent conditions, and survey accuracy. Schmidt and Graf (1990) determined that sand bars typically used as campsites (and topographic study sites) were an unusually stable subset of the entire population of sand bars.

Budhu (1992) and Werrel et al. (1993) studied seepage erosion, an important erosional mechanism operating in systems with rapid changes in stage (Howard and McLane, 1988). Seepage-driven erosion occurs when rapid decreases in water level leave perched water tables in cohesionless sediment deposits, such as sand bars along the Colorado River. As the bankstored groundwater drains, it causes rilling and ultimately mass wasting at the water's edge. In Grand Canyon, discharge from GCD may very up to an order of magnitude during a day. This fluctuating regime creates a "daily tide" from the dam to Lake Mead, Arizona. Under normal dam operations river stage typically drops faster than bank-stored groundwater can drain from the sand bars, leaving a perched water table in the bars, resulting in seepage-driven rilling and mass wasting of over-steepened banks.

Under the auspices of the GCES Phase II program and the Glen Canyon Dam Environmental Impact Statement, the National Park Service, Northern Arizona University and the U.S. Geological Survey undertook a study of sand bar stability in the Grand Canyon (Beus and Avery, 1992). The Bureau of Reclamation conducted a series of 11-day test flows in 1990-1991 to determine the impacts of specific flow regimes and model the effects of dam operations on seepage driven erosion groundwater data from three validation sites.

Beus and Avery (1992) concluded the following:

1) Sand bar topography was affected by discharge, local geomorphology, sediment supply, and antecedent conditions.

2) The temporal and spatial record of sandbar change must be considered to fully interpret short term measurements of sand bar responses to flow regimes. Periods of low discharge (1966-1982 and 1987-1990) were characterized by aggradation of low elevation sand bars, while high elevation sand bars degraded. Between 1983 and 1986, when annual peak discharges were more than twice the low discharge periods, sand bars in wide reaches aggraded and sand bars in narrow, critical reaches were eroded. Erosion rates change through time as a function of changing sediment storage: aggradation rates in 1987-1990 were equivalent to those of 1966-1982, but degradation rates were about twice as great.

3) The total amount of sand bar instability, both aggradational and degradational, was positively correlated with increasing distance downstream from GCD. Bar instability was slightly but not significantly positively correlated with mean discharge, increasing daily fluctuation, and increasing ramping rate.

3) Major periods of erosion followed periods of aggradation suggesting that antecedent conditions influenced subsequent changes in sand bar topography.

4) Periods of aggradation were associated with large-fluctuation flows. However, high-fluctuating flows were also associated with degradation or little net change.

5) Little change or slight net erosion characterized the three constant flows and the low-fluctuation test flows.

6) Bank failure correlates with change from one flow regime to another. Consequently, ramping rate, in particular down-ramping, is suspected as the most destructive component of flow under normal dam operations.

7). Both short- and long-term discharge patterns from Glen Canyon Dam affect the stability of sand bars.

Methods

Field surveys during IF were conducted bi-annually during low-discharge months in the Spring and Fall on 15-20 day river trips. The trips consisted of two ground-based survey teams, a bathymetry team, and a sedimentology/stratigraphy team. Each ground-based team completed one survey per day using Leitz Set4c and Set3c instruments equipped with data collectors. Bathymetry crews collected data at two sites each day. A total of thirty sites are included in our database, however, not all sites were sampled during every research trip (Table 3).

A variety of bathymetric survey techniques were used during the course of this study. Initially (1991), bathymetric surveys were conducted using a Lowrance X-16 depthfinder mounted on the raft. Sonar profiles were located by attaching one end of a metered cable to the transducer mount on the boat and locating a survey assistant with a cable/reel system on the sand bar at a surveyed point. Two points along the beach were marked and used to guide the boat along the proper azimuth. Distances from the cable operators location to the boat were recorded every two meters and corresponded to fiducial marks on the analog sonar recording. Coordinates of individual depth and distance were obtained by calculating the offsets along the azimuth of the profile based on the surveyed location of the cable reel operator. Elevations of the bathymetry points were calculated by subtracting the sonar depths from the surveyed water's edge elevation. The sonar equipment was calibrated daily to control changes in the travel time of the signal due to suspended sediment load. The extent of areal coverage generated from this technique was limited to the region directly in front of the sand bar face and to the 45m length of the metered cable. On the October, 1992 survey trip we employed a different bathymetric survey system that allowed us to expand our coverage to include the entire river channel surrounding the sand bar. This system consisted of the Lowrance depthfinder mounted on the boat and a total station located at a known shore location and is referred to by the nickname "hardly-hydro". The location of the boat was determined by targeting a reflective prism mounted directly above the transducer. The analog sonar recording was marked each time a position was aquired, typically every 7-10 seconds. The sonar records were then digitized at every mark and the elevation of the bathymetry points were obtained by subtracting the digitized depths and distance between the target and the transducer from the elevation collected by the total station. Following the October, 1992 survey trip using the "hardly-hydro" system, the GCES survey division purchased the "hydrographics Survey Package" (HSP) that automates the entire data collection process and collects highly accurate digital data. The HSP has been utilized on every trip since then and consists of a shore total station and a boat-mounted transducer and computer to control the data collection. The shore station data is radio-telemmetred to the boat computer where depth-position data is calculated and automatically stored. A comparison of the different methods is planned for September, 1994 in order to determine the relative differences between the methods.

Survey protocol was developed during the GCES Phase II test flows (see Beus et al., 1992) and documented according to standard survey practices for ground surveying. Benchmark and backsight relationships were verified at all sites during March, 1991. Upon completion of each survey, field data were transferred to micro-computers and edited.

The ground-based and bathymetric survey points are then combined and used to form a Triangulated Irregular Network (TIN) model of the surface. 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 and area 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). In addition, area beneath selected cross-sections will be calculated for the hydrologically inactive zone (HIZ) outside the range of dam operations, the HAZ, and the bathymetric zone. The percent change in volumes and areas will be analyzed using a multivariate analysis of variance against the last pre-interim flow survey data. We are currently waiting for flow model output data from the US Geological Survey in order to complete the analysis.

Results

The following results are from survey collection trips during September, 1991; November, 1991; October, 1992; April, 1993; and October, 1993 (Table 3; Figure 4).

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 4; Figure 4). After 14 months of low and high volume interim flows the response was as follows: of the 29 sand bars evaluated, 66 % (19) lost sediment volume within the HAZ, 17% (5) gained volume, and 17% (5) remained the same as compared to volumes calculated from the survey previous to the onset of interim flows (Table 4; Figure 4). Among the different deposit types sampled, reattachment bars showed the most significant HAZ volume increases (Figure 4; RM 2.6, 87, 93), while separation deposits showed the most volume loss (Figure 4; RM 45, 50, 202). 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.

Table 3. Interim Flow Sand Bar Surveys

		July 1991		September 1991		October 1991		October 1992		April 1993		October 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	Vol m^3	Area m^2
-6R	R	3388	3523	3470	3338			3314	3570	3370	3516	3470	3338
3L	R	3564	3016	2401	3061	2640	2500	4052	3601	3995	3448	2401	3061
8L	S	1351	1481	1440	1450	1316	1523	1354	1729	1375	1631	1440	1450
16L	S	1726	1284	981	1316			2103	1549			981	1316
22R	R	3578	1727	3197		3197	1474	3276	1593	3532	1819	2012	4008
30R	R	7366	3651							5562	3377	2379	3709
31R	S	2055	2407	2013	2400	1936	2298	2033	2884	2124	3333	2130	1740
43L	R/UP	3661	2107	3629	1903	3610	1959	3453	1844	3285	1723	1744	3380
45L	S	3456	2585	3549	3119	2479		3119	2479			2498	3121
47R	R	7647	7180					5790	5923			6078	5761
50R	S/R	4234	2813					2390	1952	2393	2099	2475	2782
51L	R	6441	5939	6422	5830	6463	5789	6109	5519	6029	5596	4093	4511
68R	S/R/UP	3723	3077	3410	2658	3426	2818	3171	2979	2390	2102	4828	6341
81L	R/S/UP	2811	1334	2520	1184	2515	1154	2431	1223	2766	1249	1198	2567
87L	UP	492	317	521	323			607	395	596	571	414	893
91R	S	241	223					189	208	216	155	126	171
93L	UP/R	1634	1401	1256	1021			1888	1690	2145	1716	1590	2057
119R	R	4825	2792	3645	2291			2481	1724	3952	2360	289	428
122R	R	4928	3622			4900	3568	4435	3134	5666	2990	2011	3192
123L	R/UP	1310	1280					1223	1317			2860	5120
137L	R	4989	2924	4116	3018	4189	2965	3965	2994	4074	2879	1118	1160
145L	R	928	582	833	540	838	510	756	496	1046	570	2976	3712
172L	R/UP	2448	2254	1327	1068	1340	1120	1719	1415	1535	1105	549	933
183R	R/UP	2670	2077	2694	2152			2905	2237	4723	2710	2436	4180
194L	R/UP	4357	3284	4387	4262	3296	4388	4464	3377	4823	3287	3451	5005
202R	S	3710	2230					3075	1981	2991	1768	1611	2295
213L	R/UP	2772	1334					3625	1693	3781	1520	1398	2802
220R	S/UP	1190	717	1069	719			1035	719	1266	742	665	953

* R-Reattachment Bar; S-Separation Bar; UP-Upper Pool (after Schmidt and Graf, 1990).

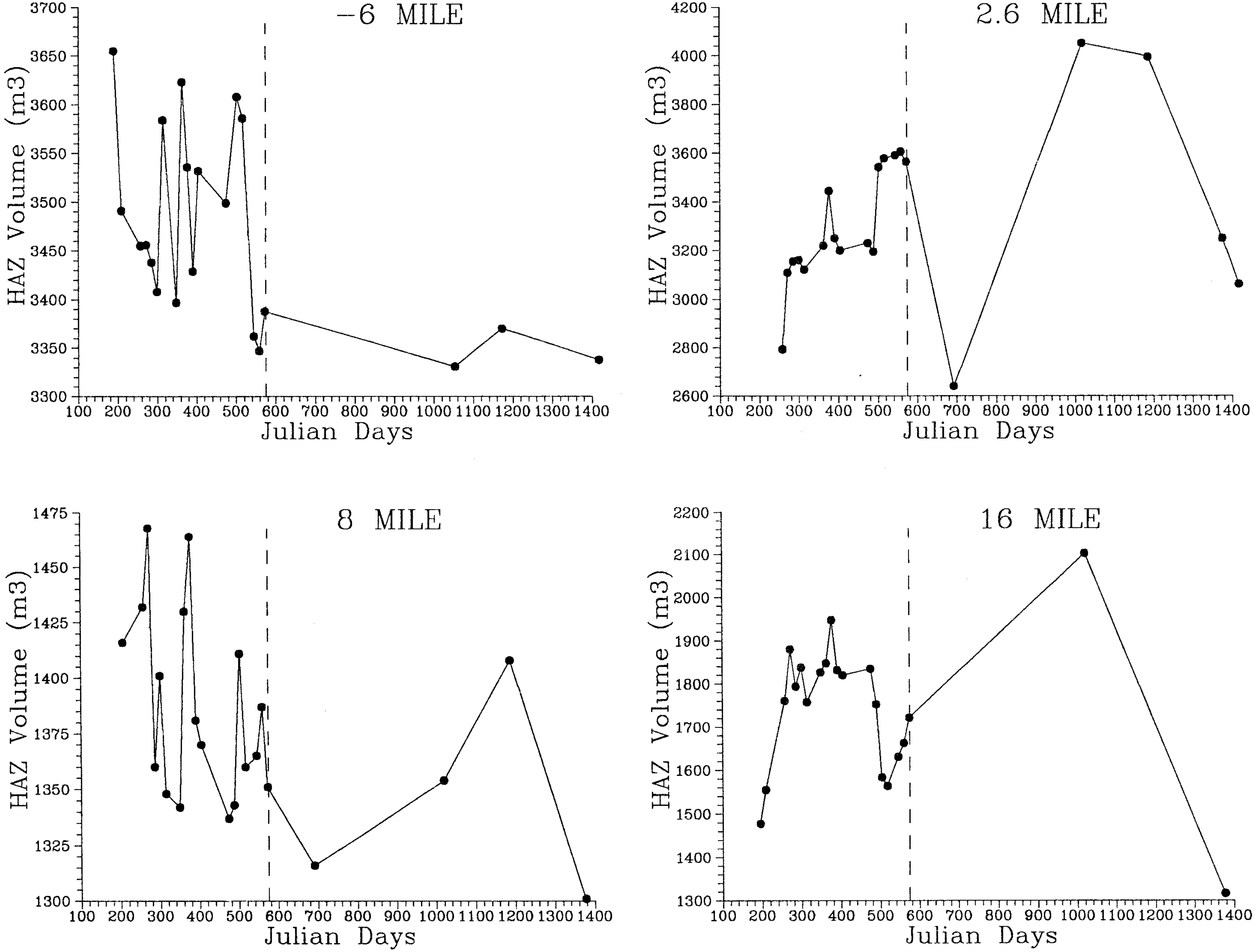


Figure 4. Volume vs. Time plots for 29 sand bars. Vertical dashed line represents the beginning of interim flow operations on August 1, 1991.

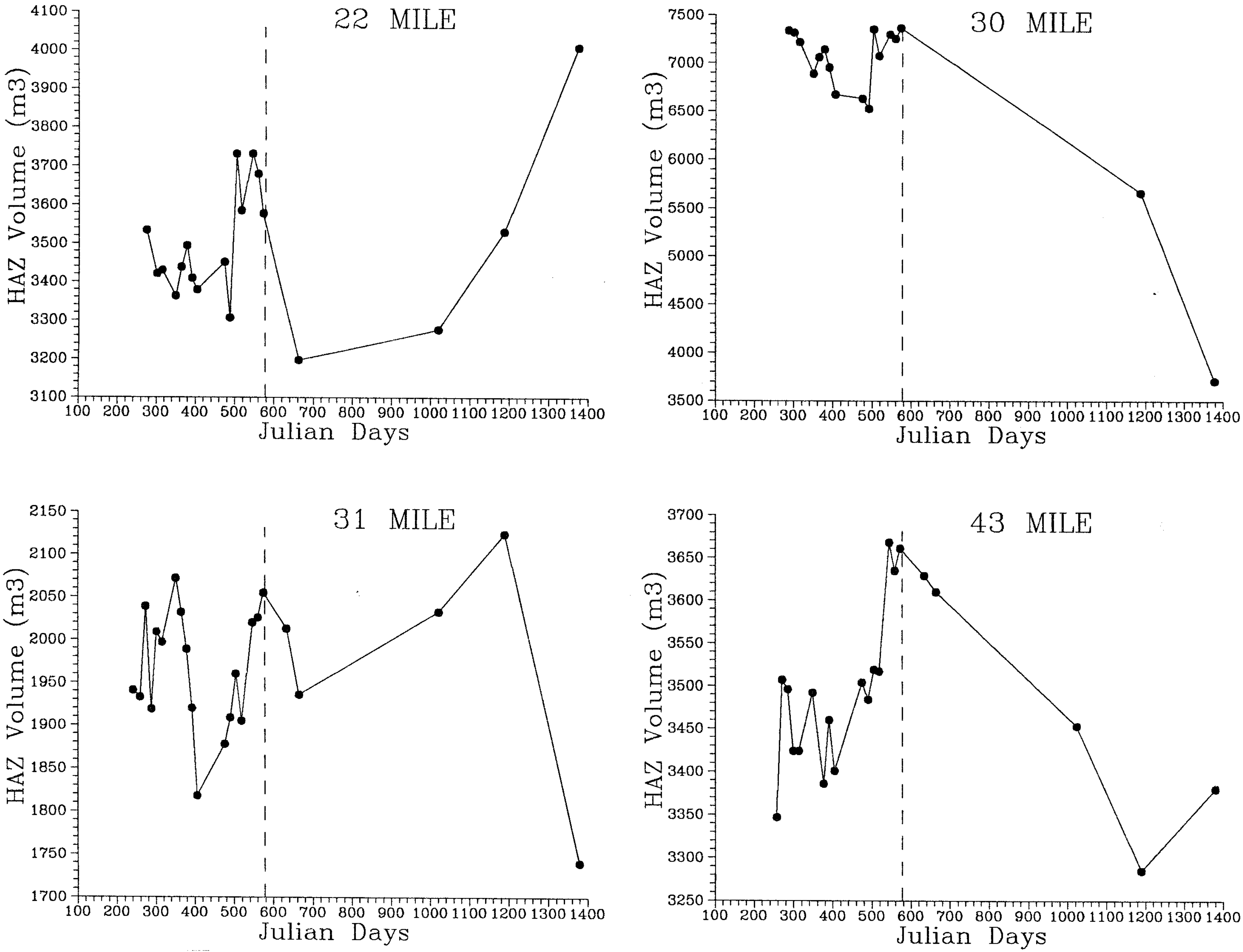


Figure 4. (continued)

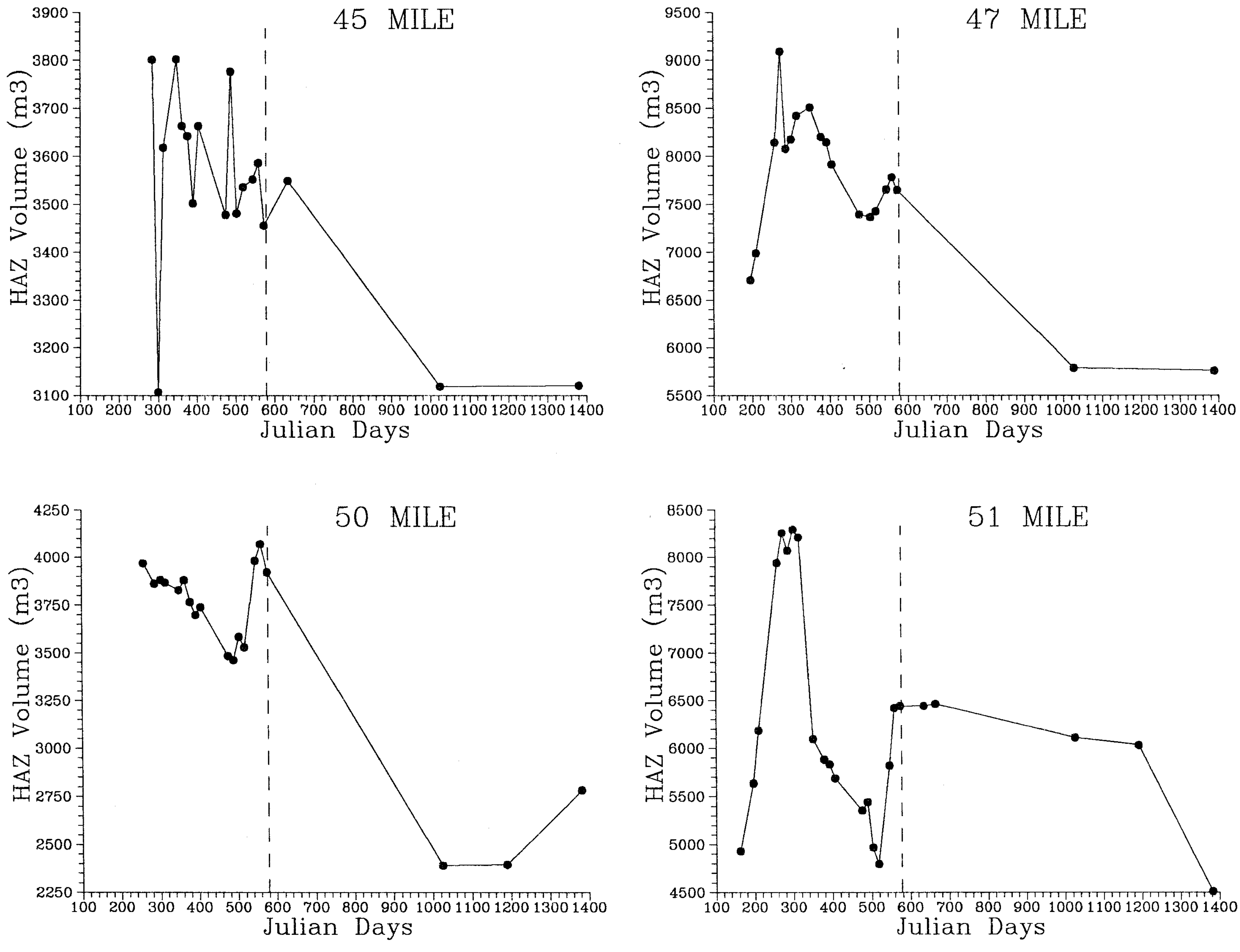


Figure 4. (continued)

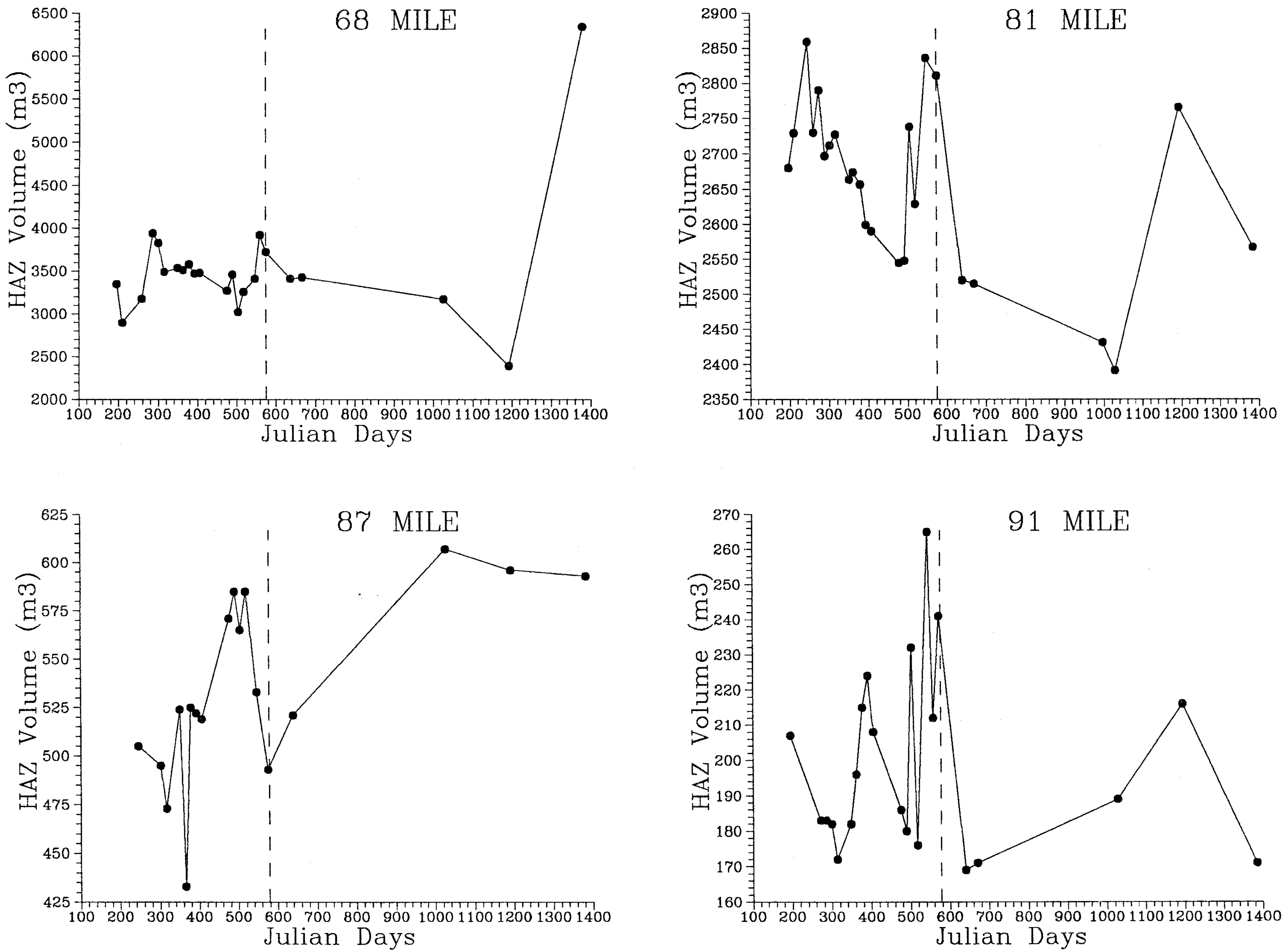
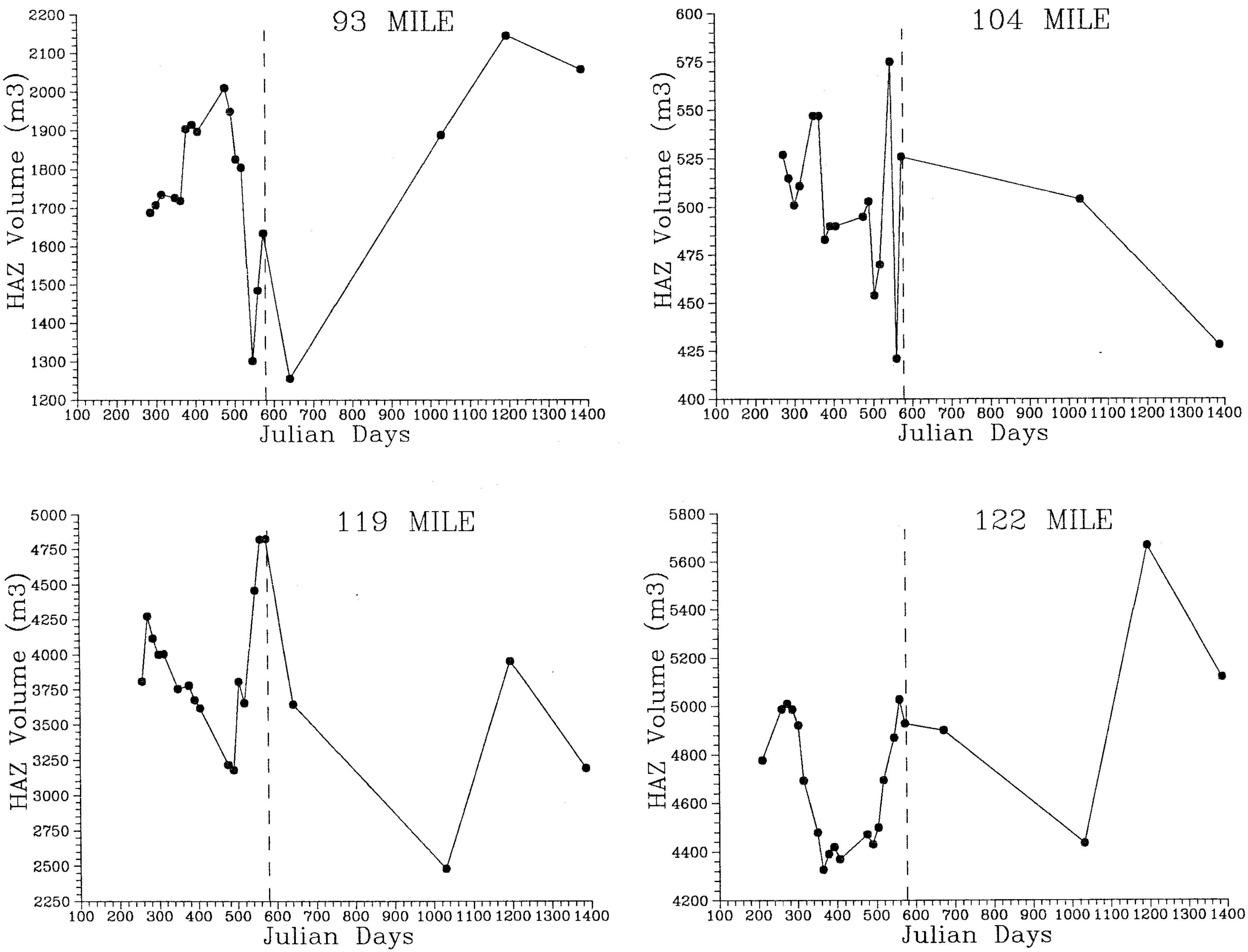


Figure 4. (continued)



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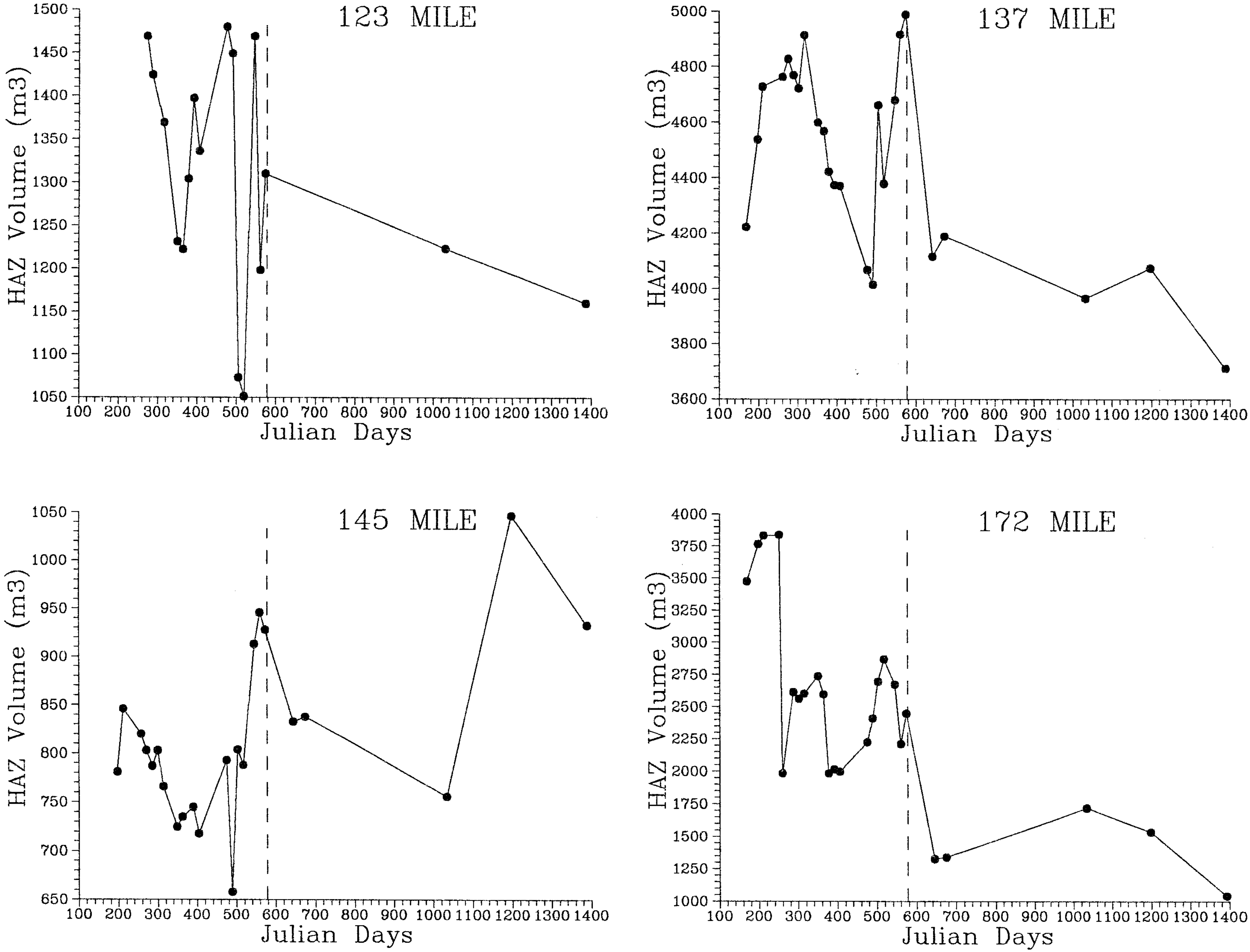

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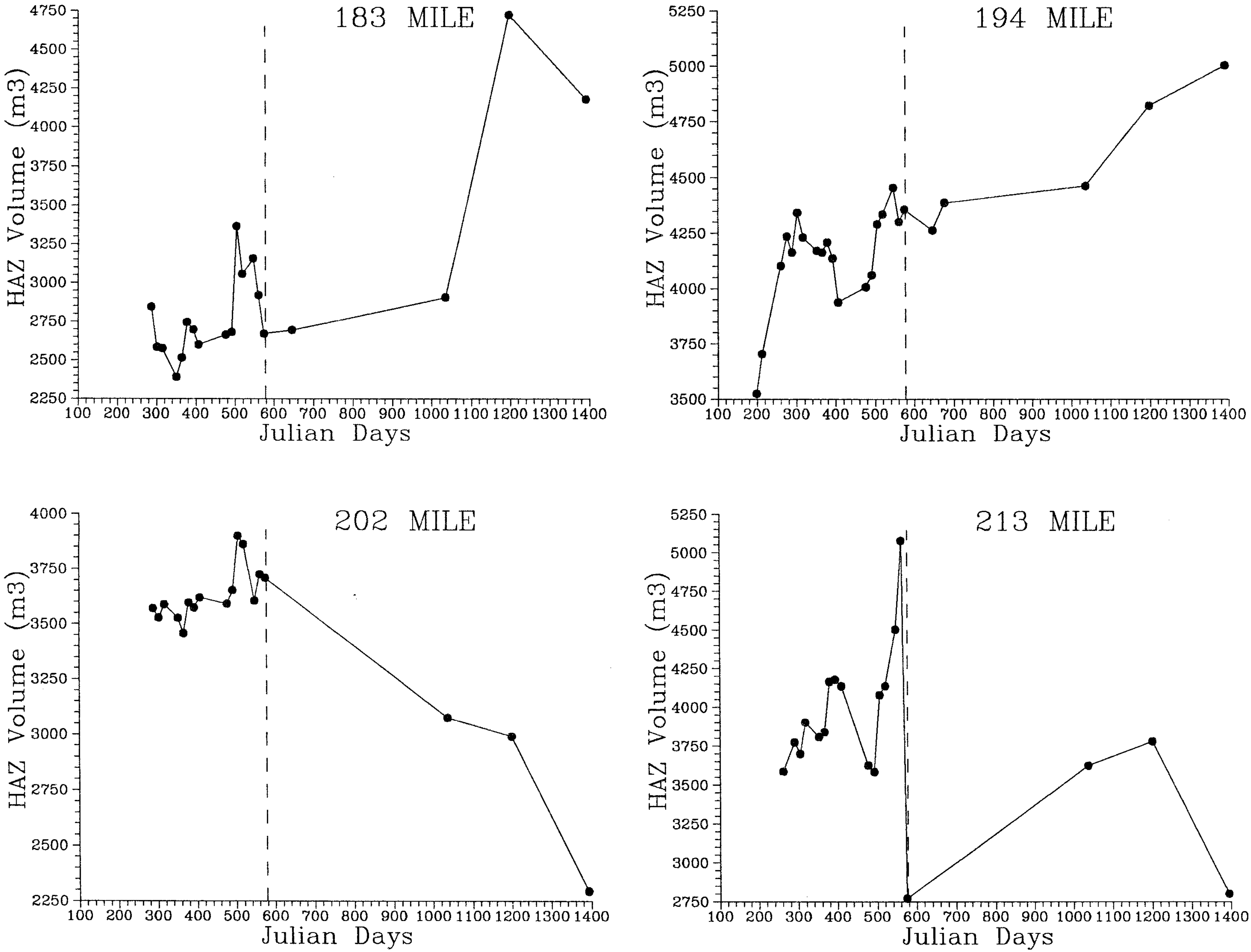

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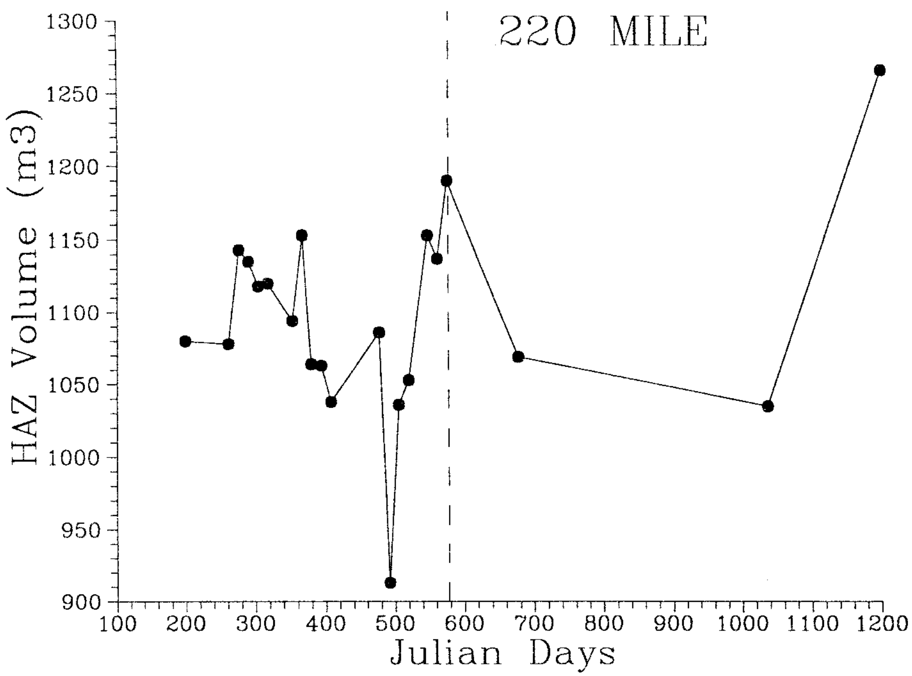


Figure 4. (continued)

The surveys conducted in April, 1993 included 24 of the 30 sand bars (Table 3) and examined the effects of the Jan/Feb 1993 flood events from the LCR 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 5, Table 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). 63% (5) remained relatively unchanged between October, 1992 and April, 1993, 25% (2) had a large volume gain (RM 22, 31), and 13% (1), RM 43, sustained a significant net loss of HAZ sand (Table 4; Figure 5). Downstream from the LCR and Colorado River confluence, 16 sand bars were examined, including a new reattachment deposit at RM 62.4 in a recirculation zone previously devoid of a significant subaerial deposit. 73% (11) showed large volume increases (e.g., RM 81, 183), 20% (3) remained relatively unchanged (RM 87, 137, 202), and 2 (17%) lost HAZ volume (RM 68, 172) as compared to the October, 1992 surveys (Table 4; Figure 5). 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 4, RM 202).

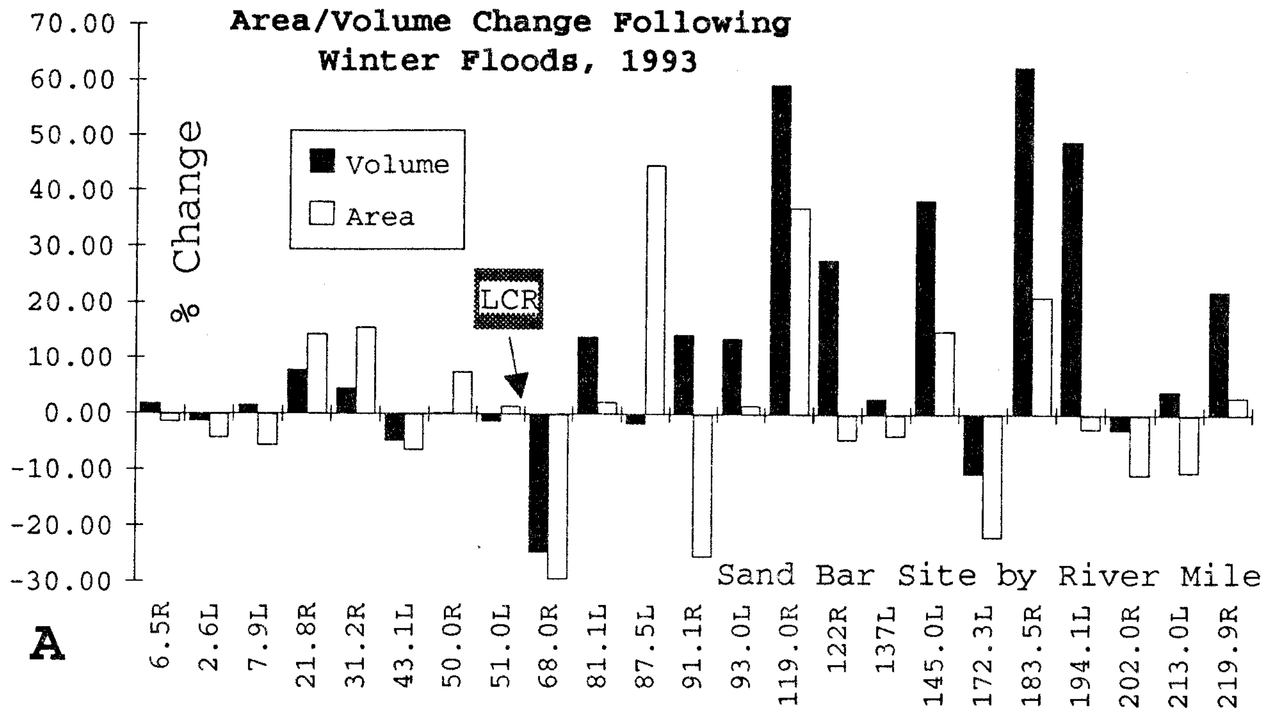
Table 4. HAZ Volume Changes

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)

4/93* to 10/93			
ALL SITES n=29	17% (5)	66% (19)	17% (5)
SITES ABOVE THE LCR n=12	25% (3)	50% (6)	25% (3)
SITES BELOW THE LCR n=17	12% (2)	77% (13)	12% (2)

*10/92 used for comparison on sites that were not surveyed on the April trip



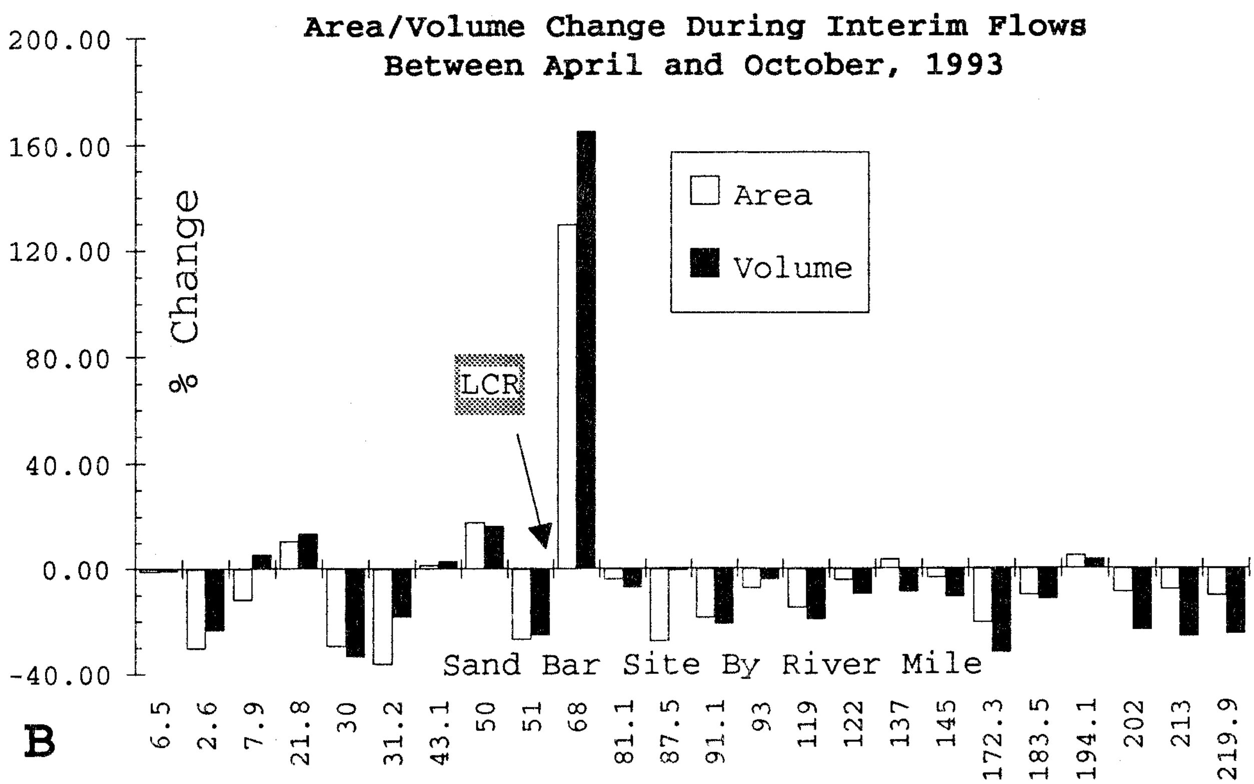


Figure 5. Net HAZ volume and area change for A) 23 sand bars between the October 1992 and April 1993 surveys; and B) sand bar volume and area change between April and October 1993. Note the dynamic sand bar response to the floods downstream from the LCR in A and loss of HAZ volume in these same bars in B.

Although erosion rates decreased between April, 1993 and October, 1993 many of the bars have degraded to pre-flood volumes and several still appeared to be unstable. 77% (13) of the bars below the LCR decreased in HAZ volume (Table 4; Figure 5). This is not surprising as newly aggraded bars are expected to erode, however, 50% (6) of the bars between GCD and the LCR continued to erode or lost the moderate low-elevation volume increase gained since the onset of interim flows (Tables 3, 4). In the 25 month period between the start of interim flows and the October, 1993 survey 62% (18) of the sand bars continued net degradation, while 24% (7) aggraded and 14% (4) remained the same (14%).

Sand Bar Profiles

Figures 6 to 13 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 6, profile 5; Figure 6, profile 3). The bases of nearly all cutbanks examined were developed at the discharge elevation of the interim flow high fluctuation. As a result, several of the reattachment bars examined in this report decreased in platform elevation by .5 to 1.5 m, prior to the January and February, 1993 winter floods. However, aggradation is occurring along reattachment bar platforms within and below the range of interim flow stage elevations (Figure 7, profiles 0 & 1; Figure 8) that is resulting in significant HAZ volume increases. This aggradation is occurring on the slope into the main channel on the upstream end of reattachment bar platforms. Deposition within recirculation zones also includes sediment in-filling of eddy return channels (Figure 7, profile 0; Figure 8, profiles 5 & 6) as aggradation on the platform side of the return-current channel causing the channels to become narrower and shallower. In addition, return-current channels that occupied the area inundated by 566-793 m^3/s (20,000-28,000 ft^3/s) flows have been abandoned by the smaller interim flow recirculation zones and have been plugged with sand and silt. 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 9; Figure 10). Large-scale cut bank retreat began shortly after the flooding events receded and the newly reformed bars were exposed to fluctuating flows (Figure 6, Figure 9, profile 6; Figure 10, profiles 3 & 5; Figure 11). Notice that the sediment-laden floods did not restructure or deflate in-filled return channels (Figure 10, 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 12 & 13). However, there was a trend of sand depletion from river-storage downstream of RM 119 (Figure 9, profile 3; Figure 10). 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 9 & 10). Although eddy scour, typically at lower sand bar elevations, occurred at several of the study bars (RM 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 5a; RM 68, 91, 122, 172.

Preliminary analyses of the bathymetric data from the October 1993 survey provide insights as to the status of sand that was dumped into the mainstem by the LCR. It appears that much of the sand mass is still stored in the 30 mile zone downstream from the LCR (Figures 11, 12, 13). Slight to moderate increase in bed elevation (1-2 m) in the channel adjacent to recirculation zones at several sites occurred during this period, downstream from this zone (Figure 10; profile 7; 123 Mile; 137 Mile; 194 Mile). This relatively rapid short term sediment storage increase on the riverbed was coincident with HAZ depletion in recirculation zones (Figure 5b). In addition, two large HAZ volume losses (2.6 MILE; 51 Mile) are probably the result of bar failure (Figure 8; profile 6).

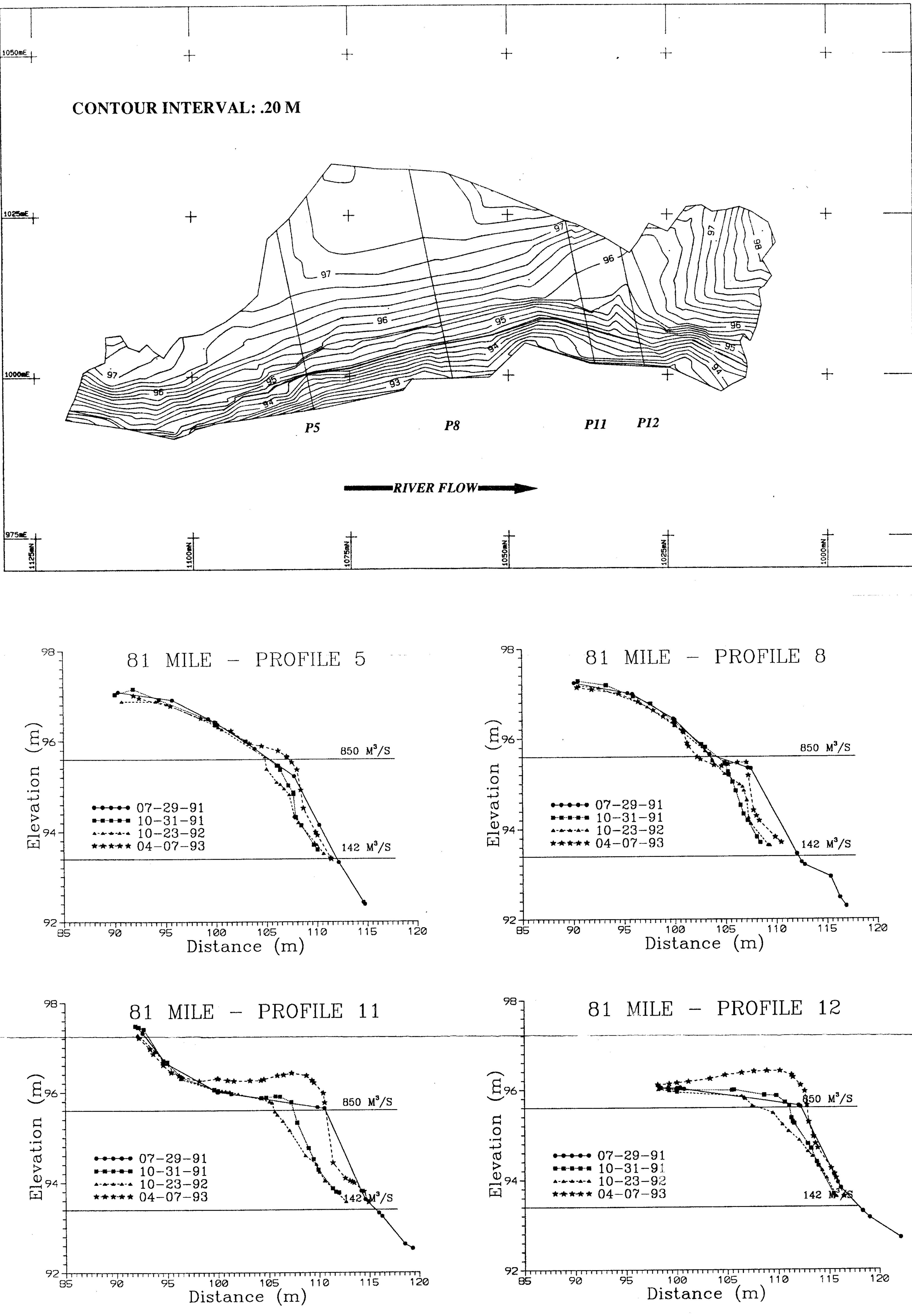


Figure 6. Site map and selected profiles from 81 mile "grapevine camp".

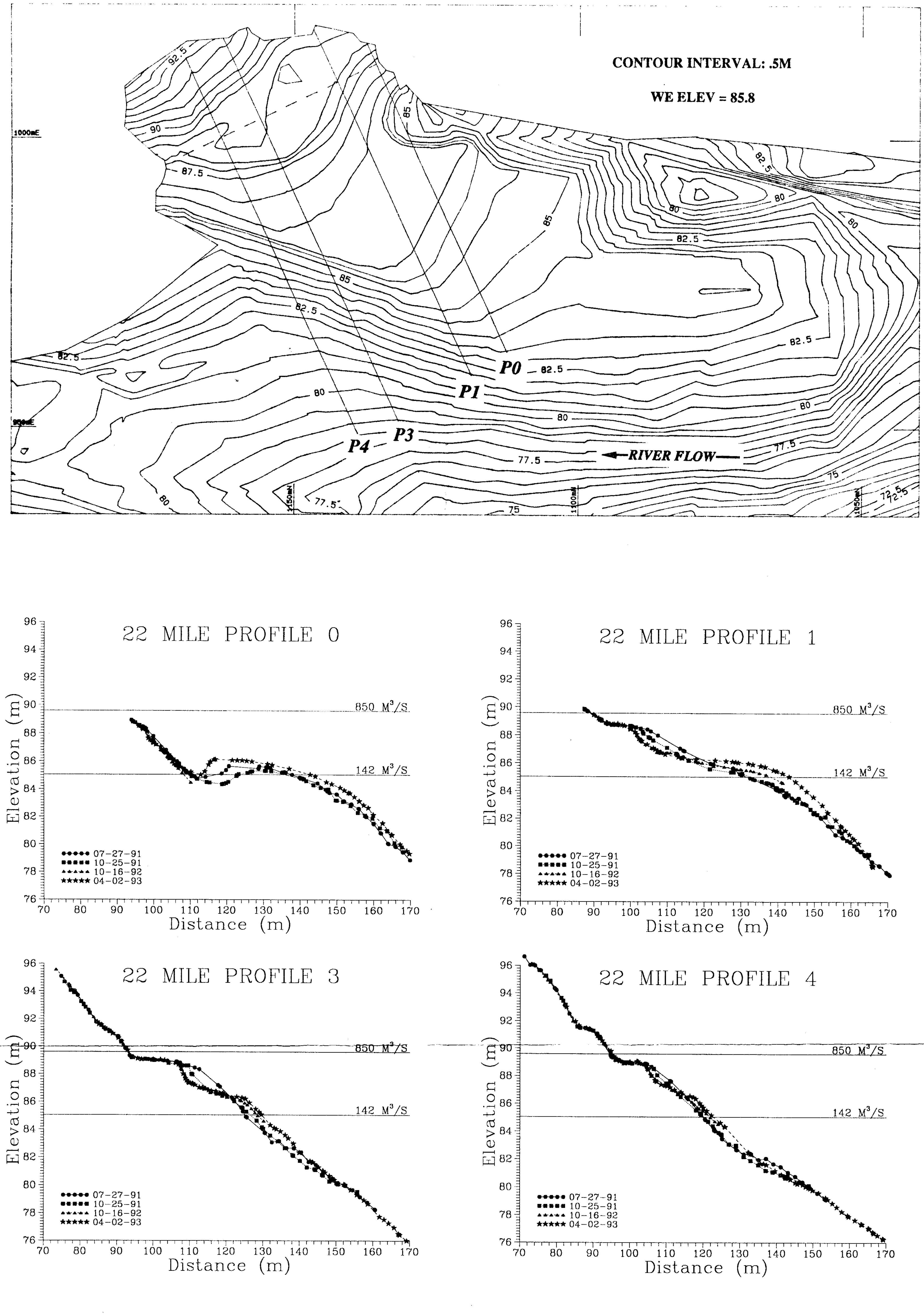


Figure 7. Site map and selected profiles from 22 mile.

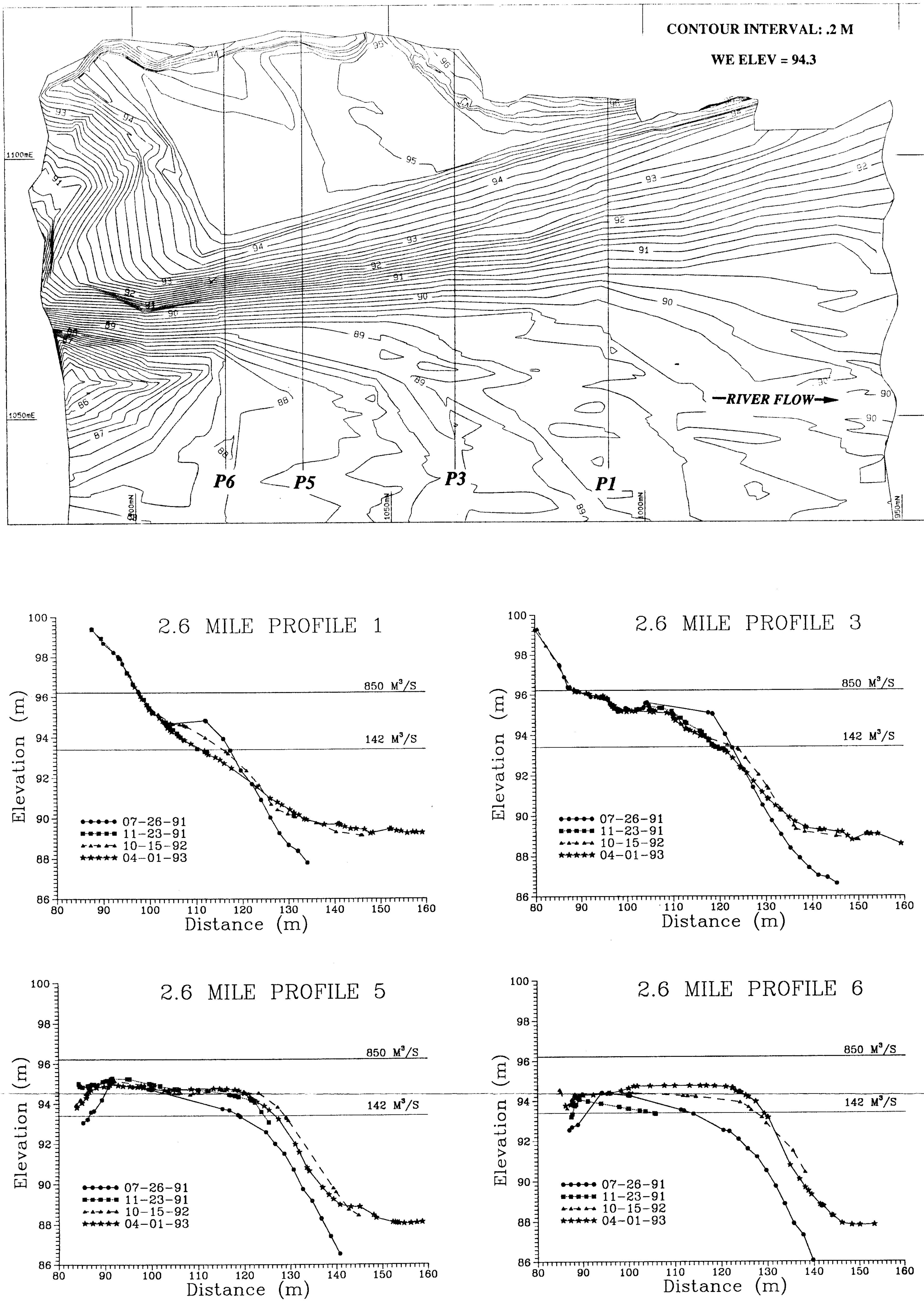


Figure 8. Site map and selected profiles from 2.6 mile.

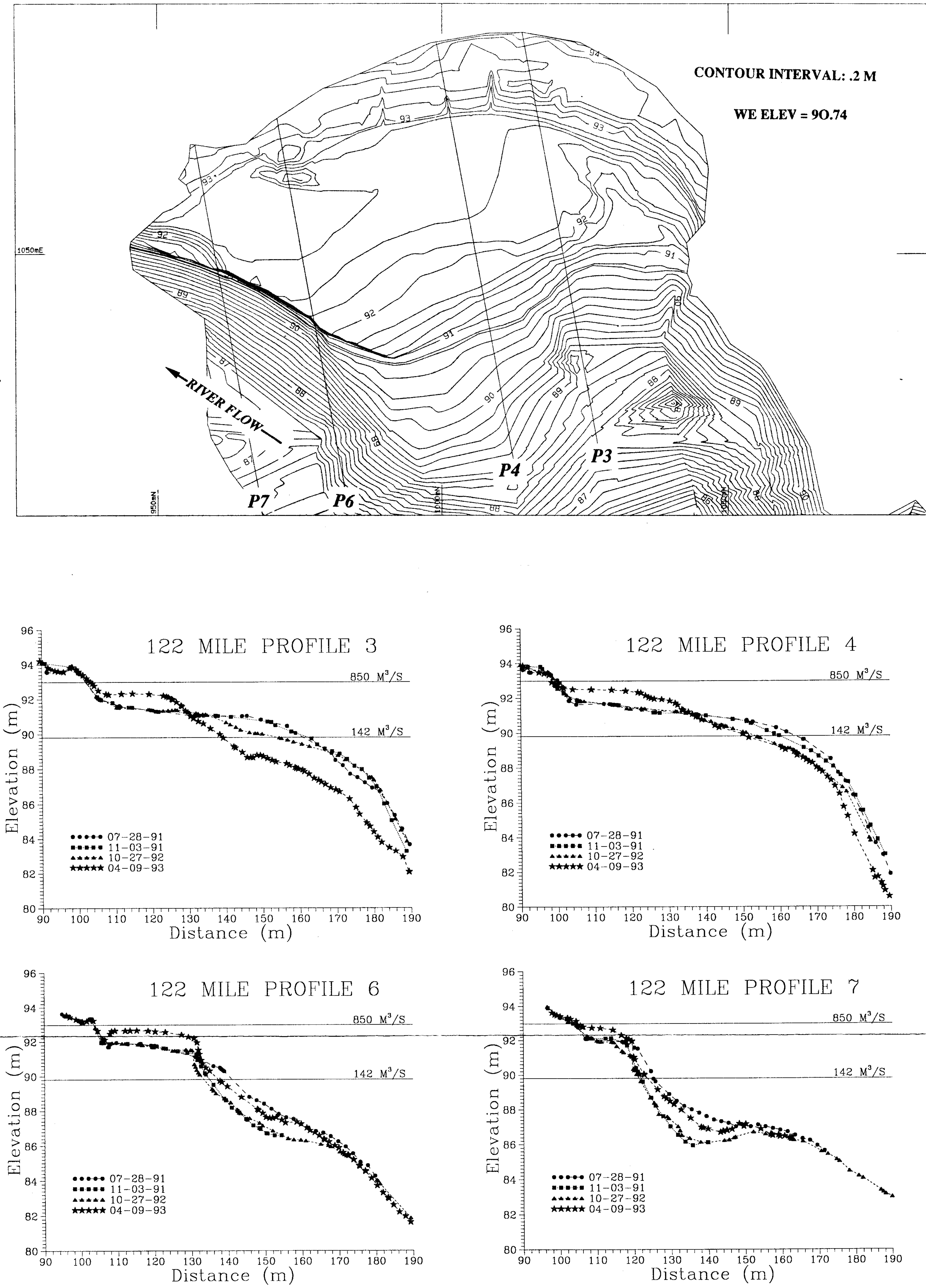


Figure 9. Site Map and selected profiles from 122 mile.

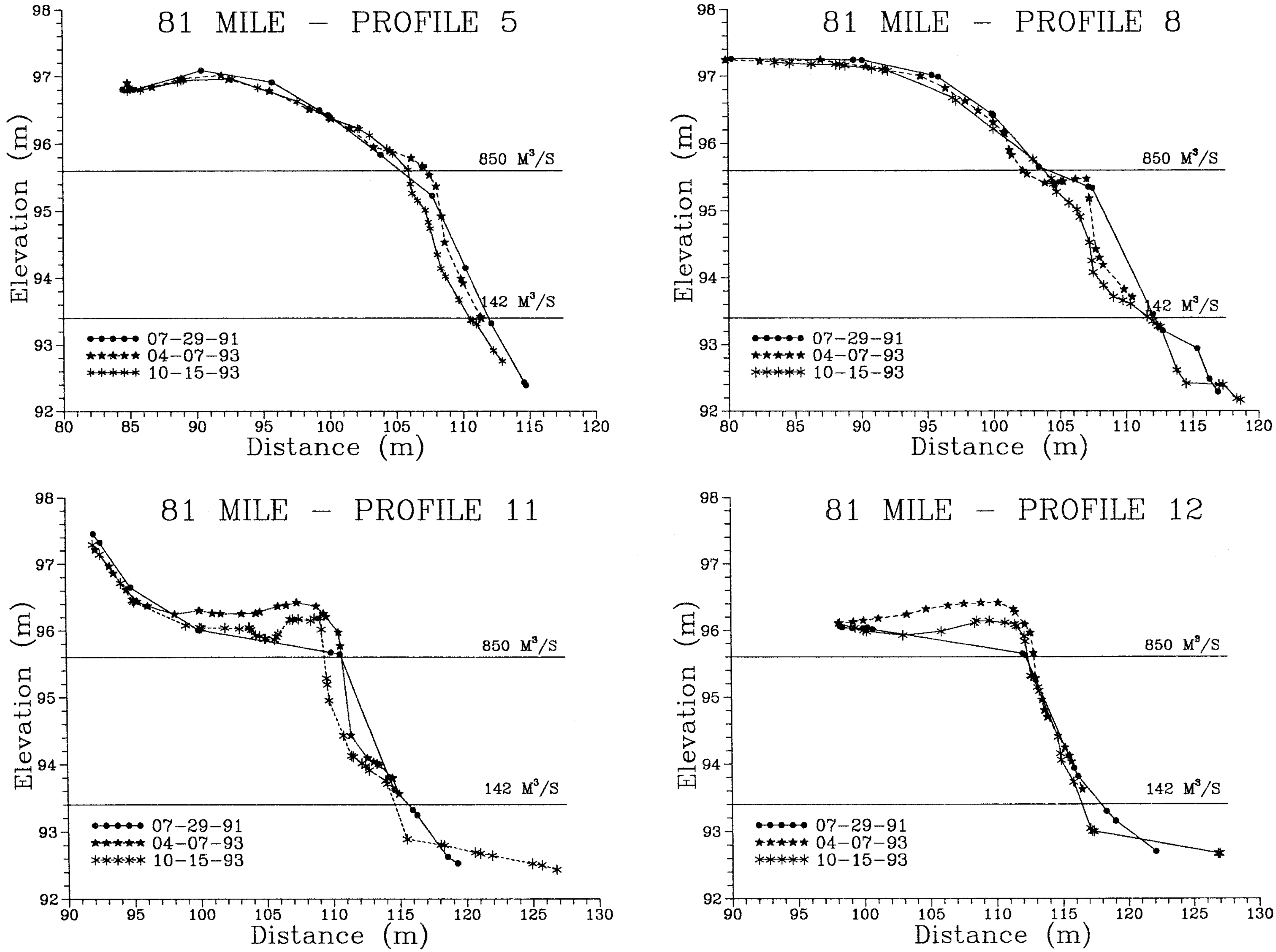
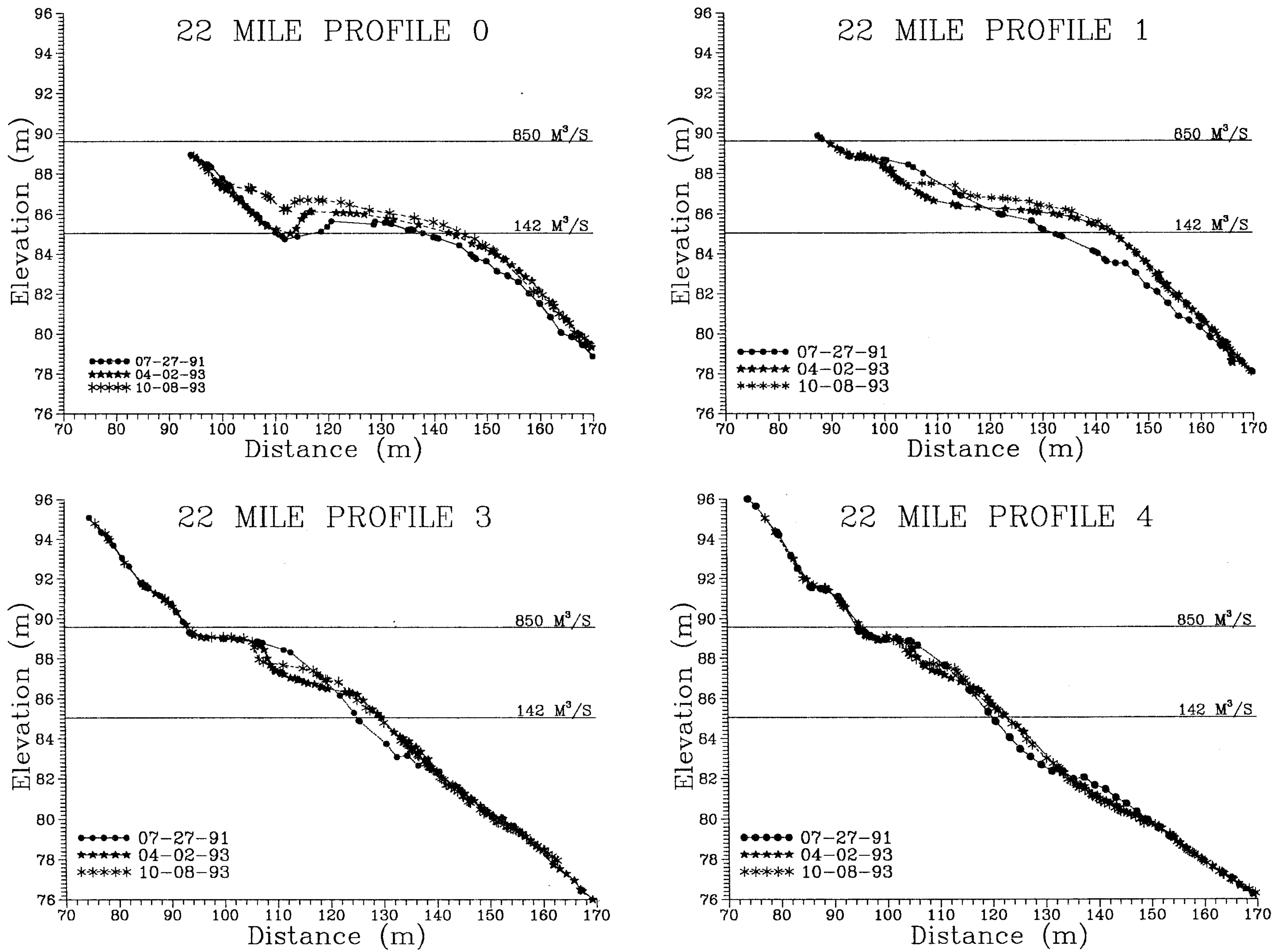


Figure 6. Cont.



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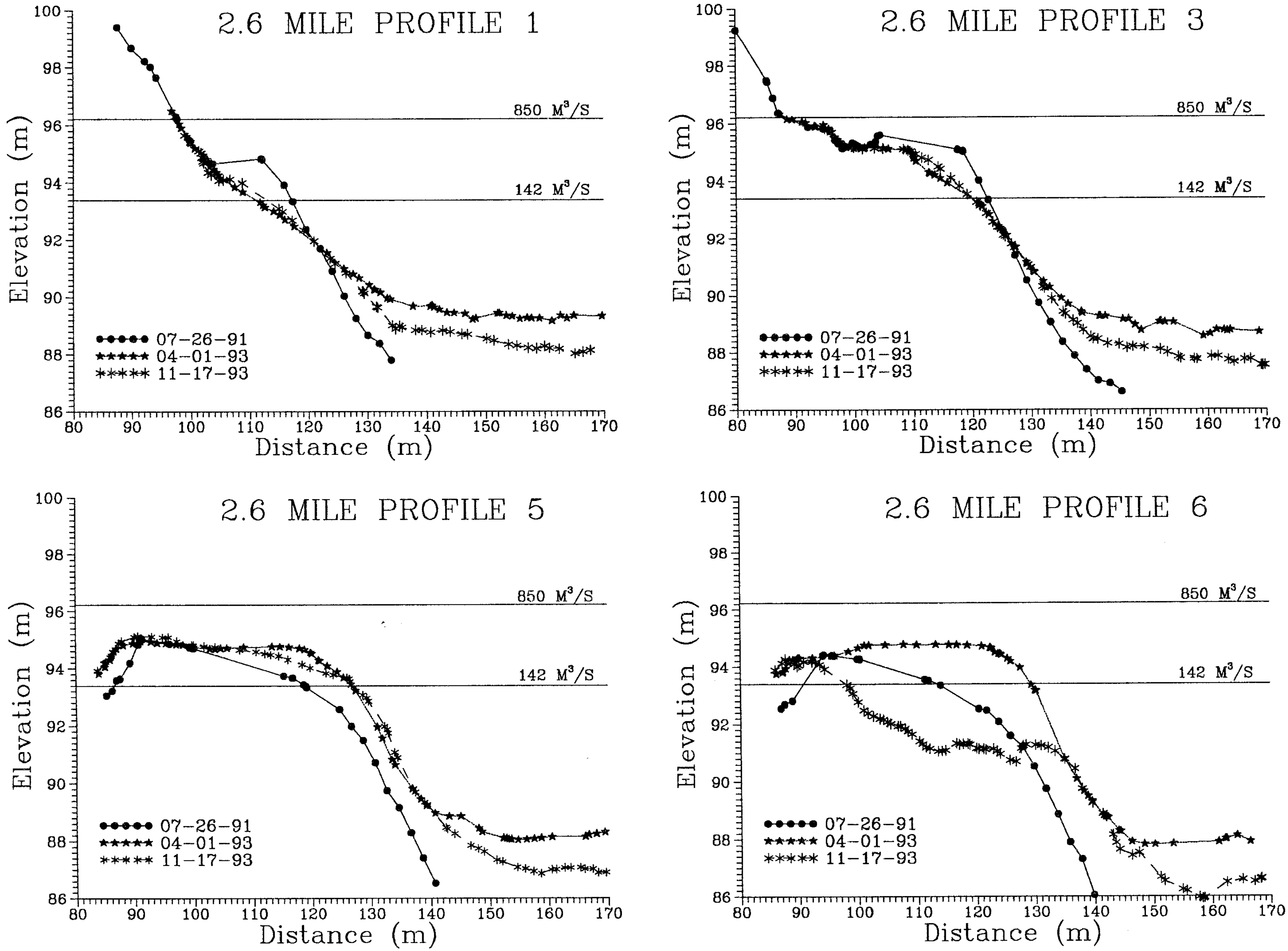

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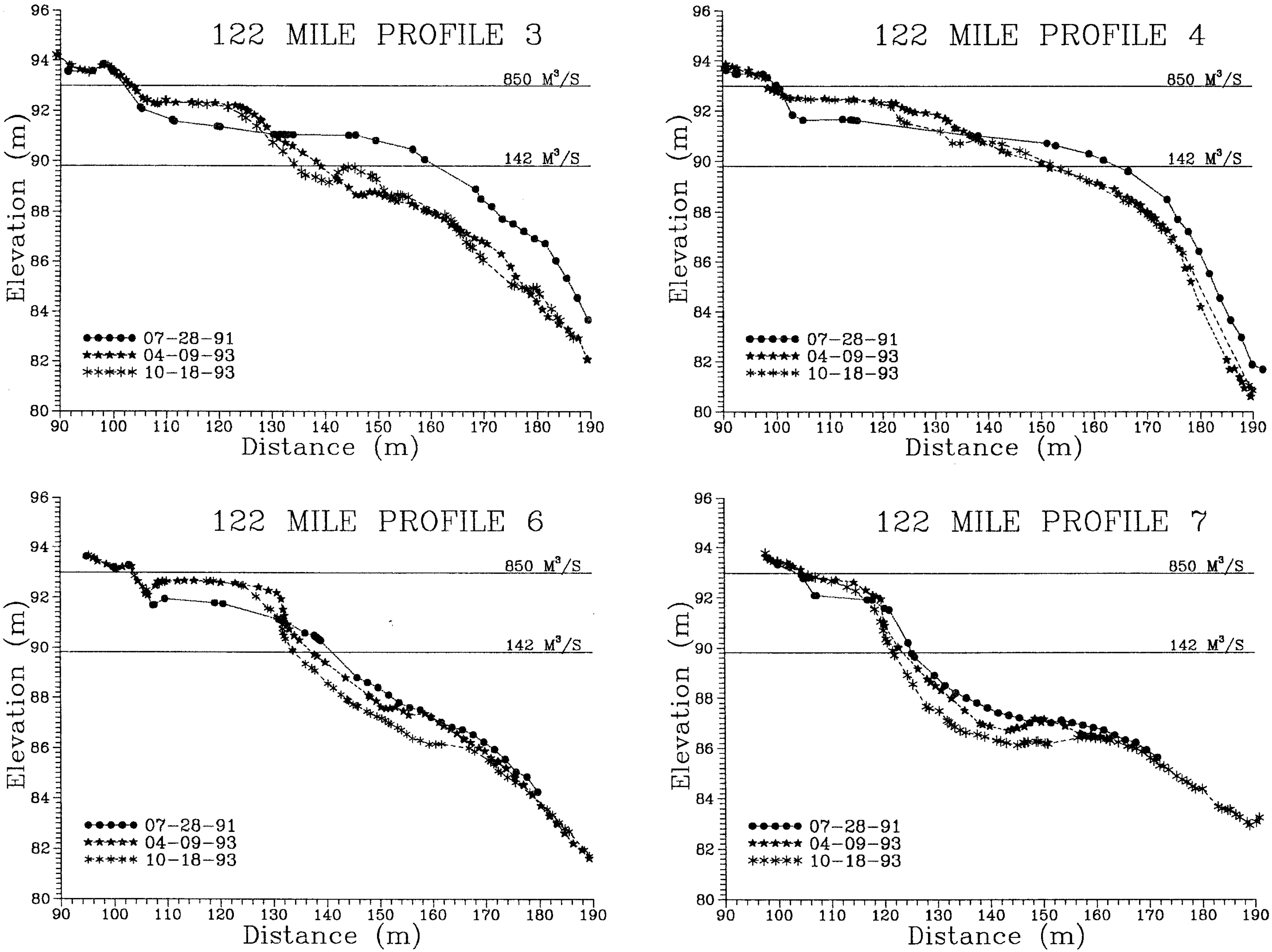

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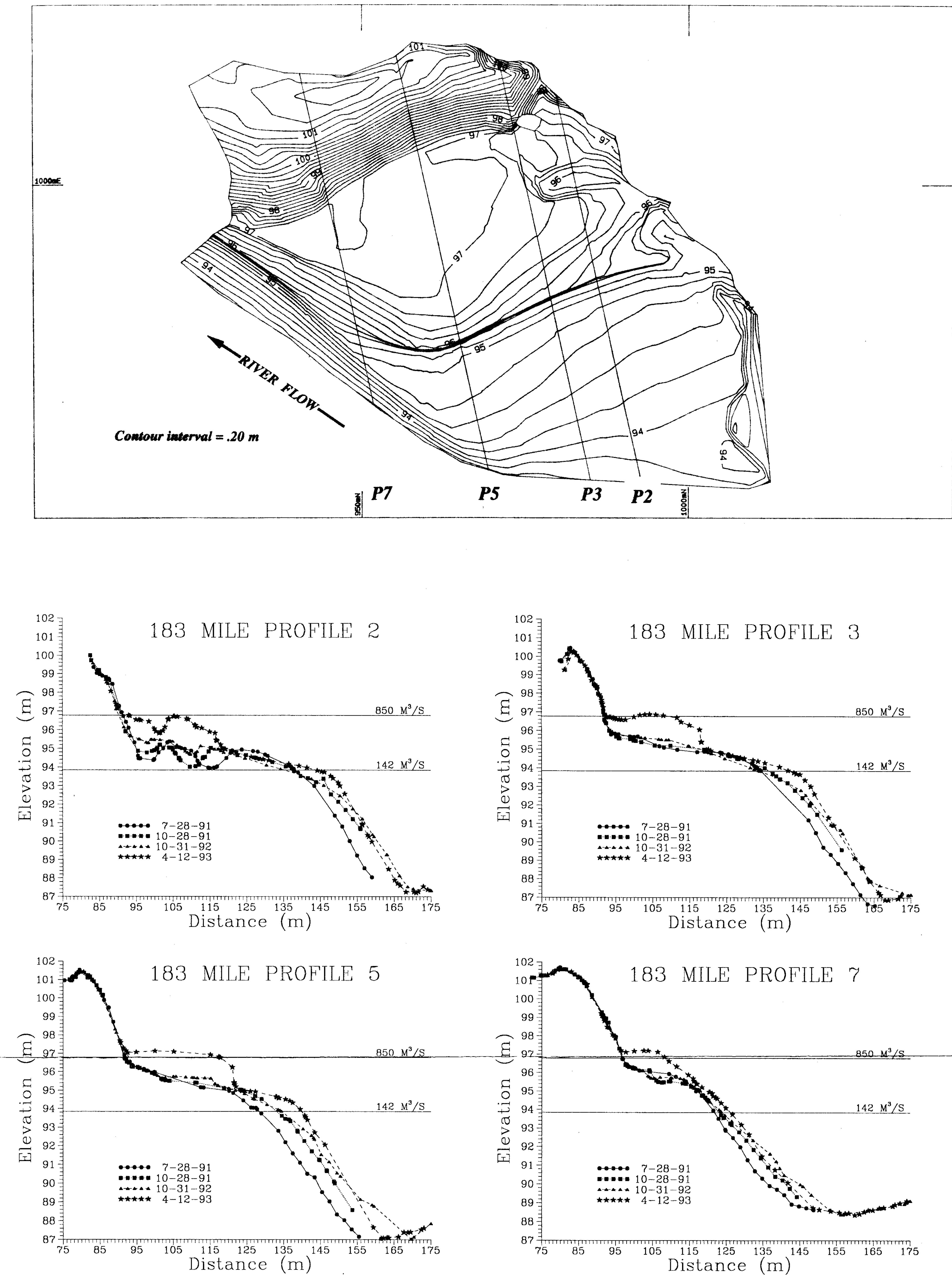


Figure 10. Site Map and selected profiles from 183 mile.

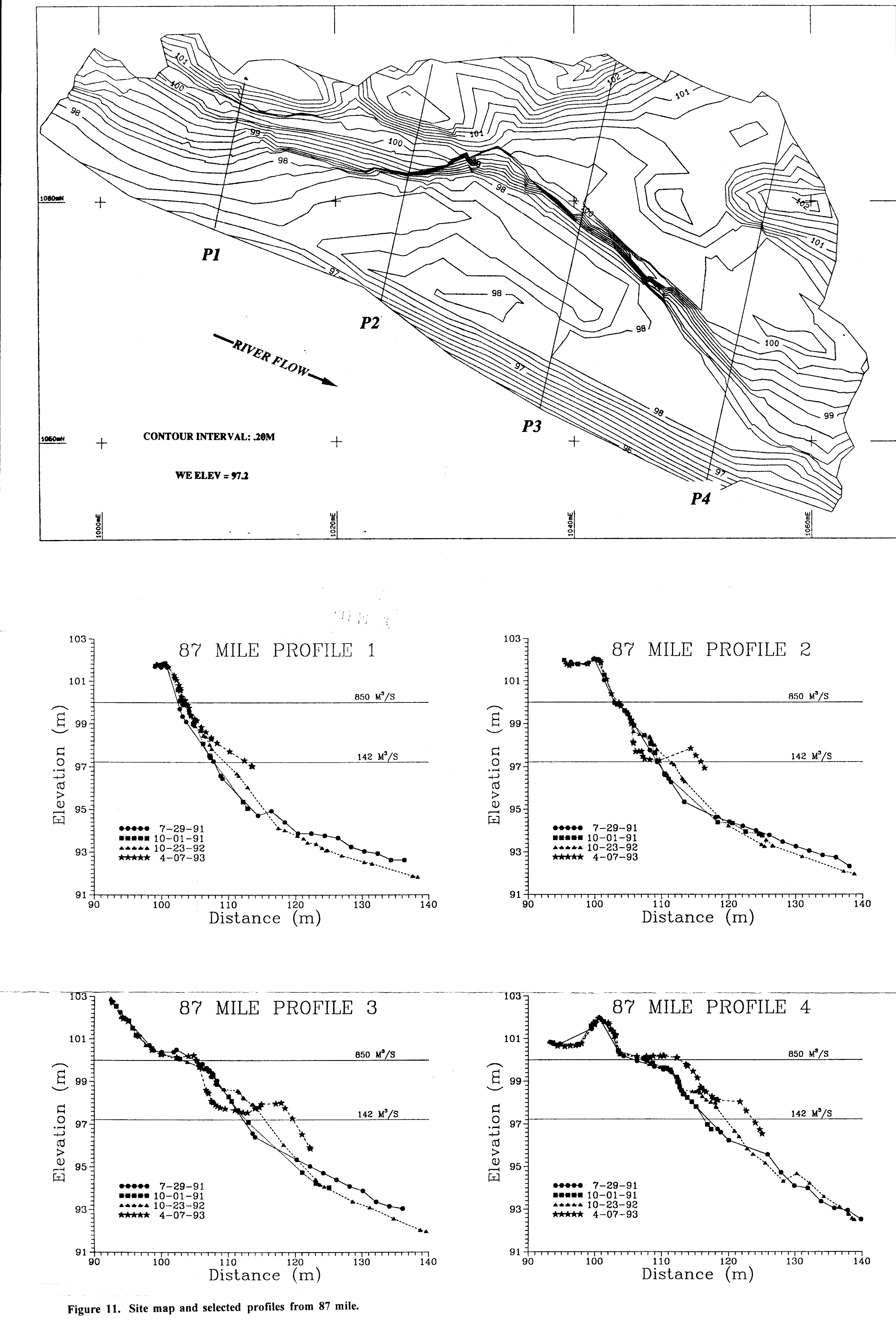


Figure 11. Site map and selected profiles from 87 mile.

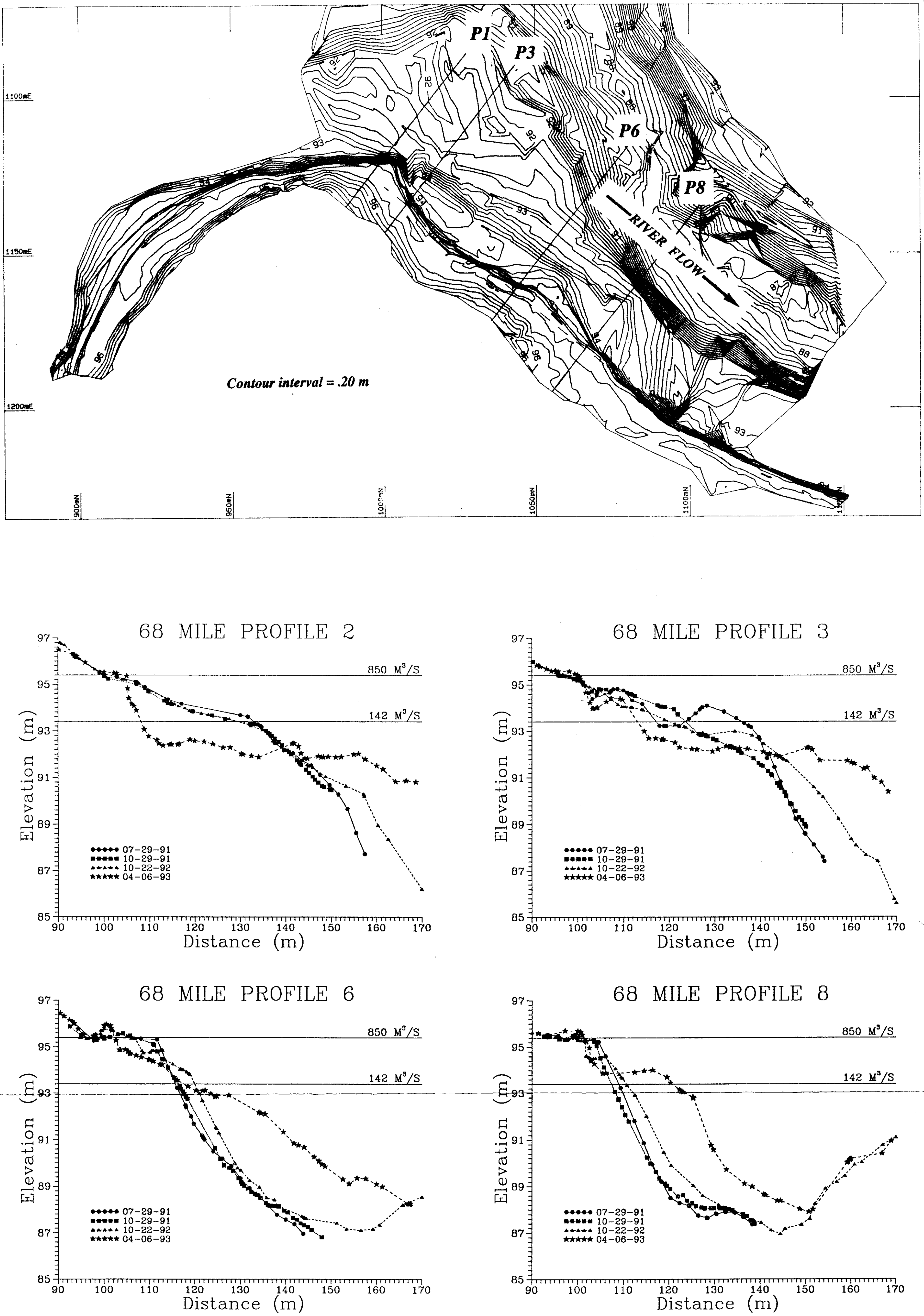


Figure 12. Site map and selected profiles from 68 mile.

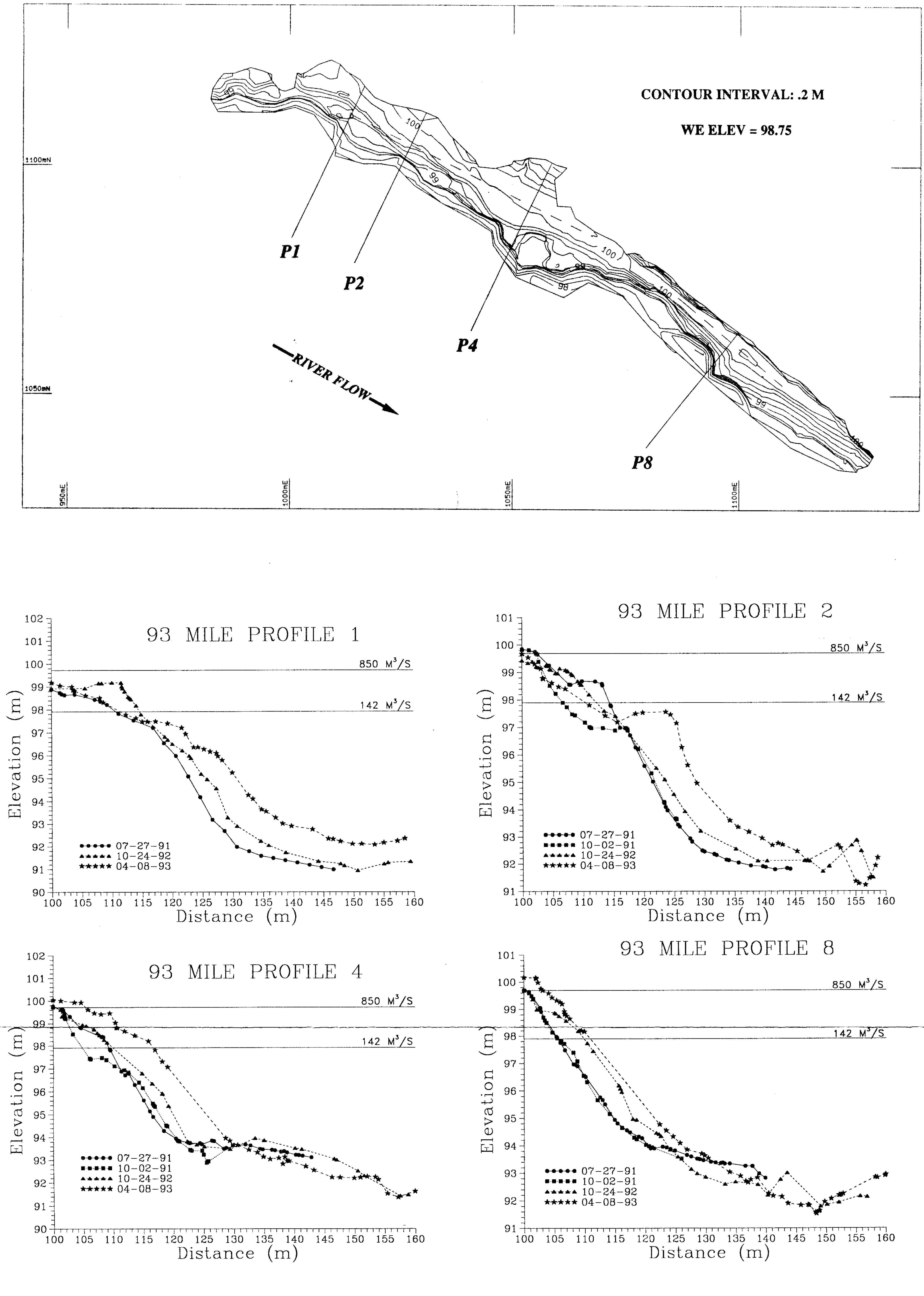
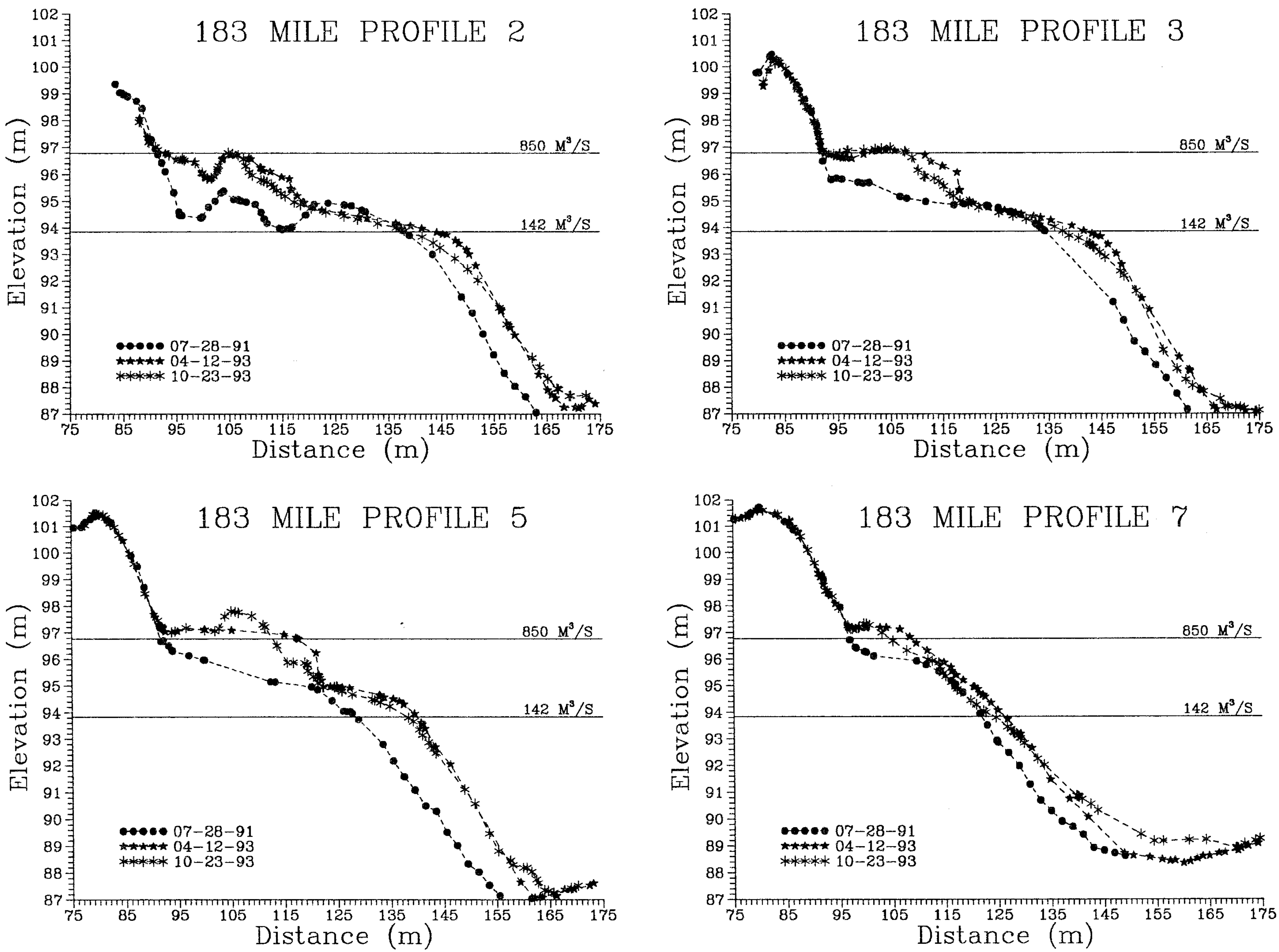


Figure 13. Site map and selected profiles from 93 mile.



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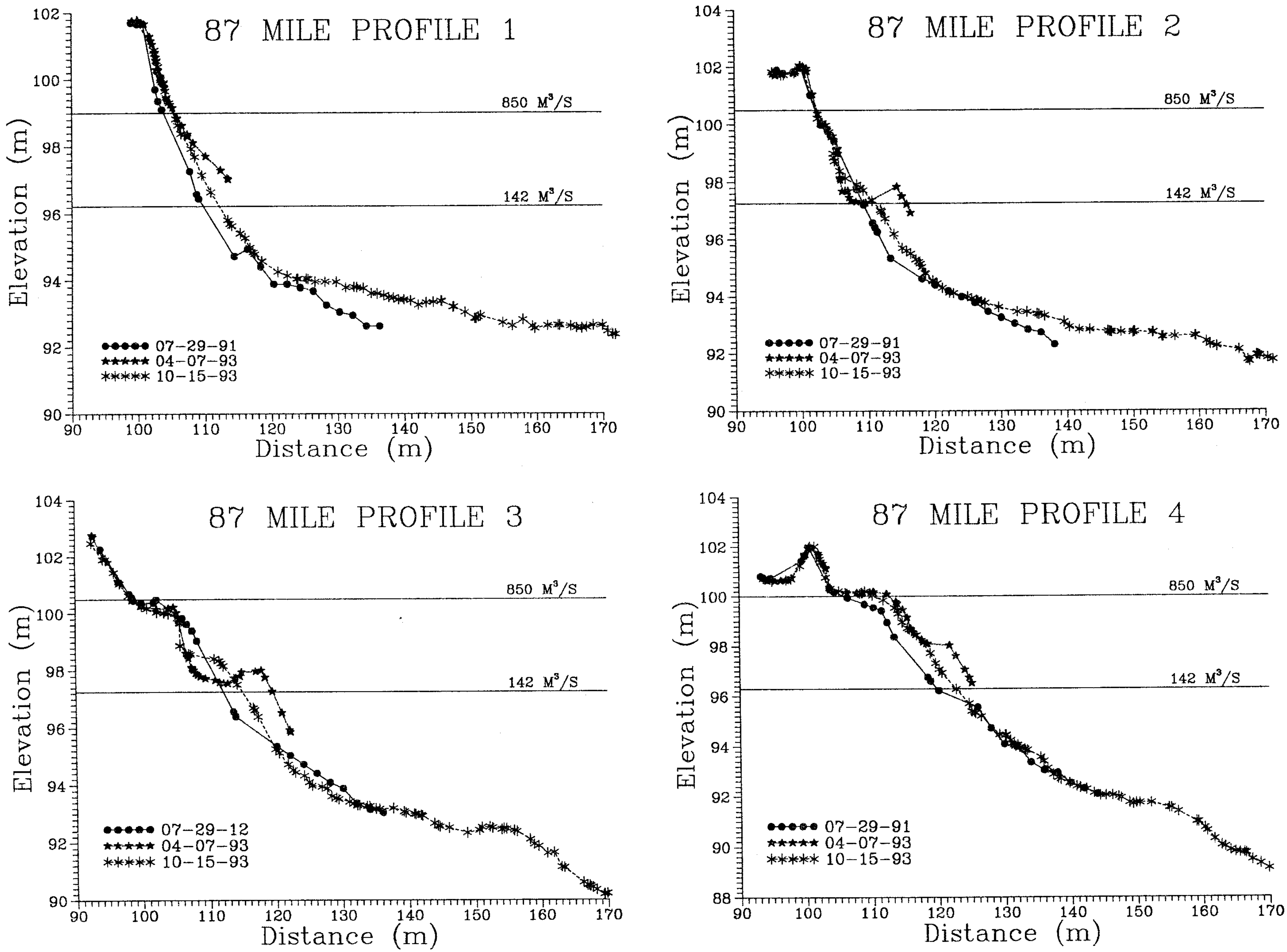

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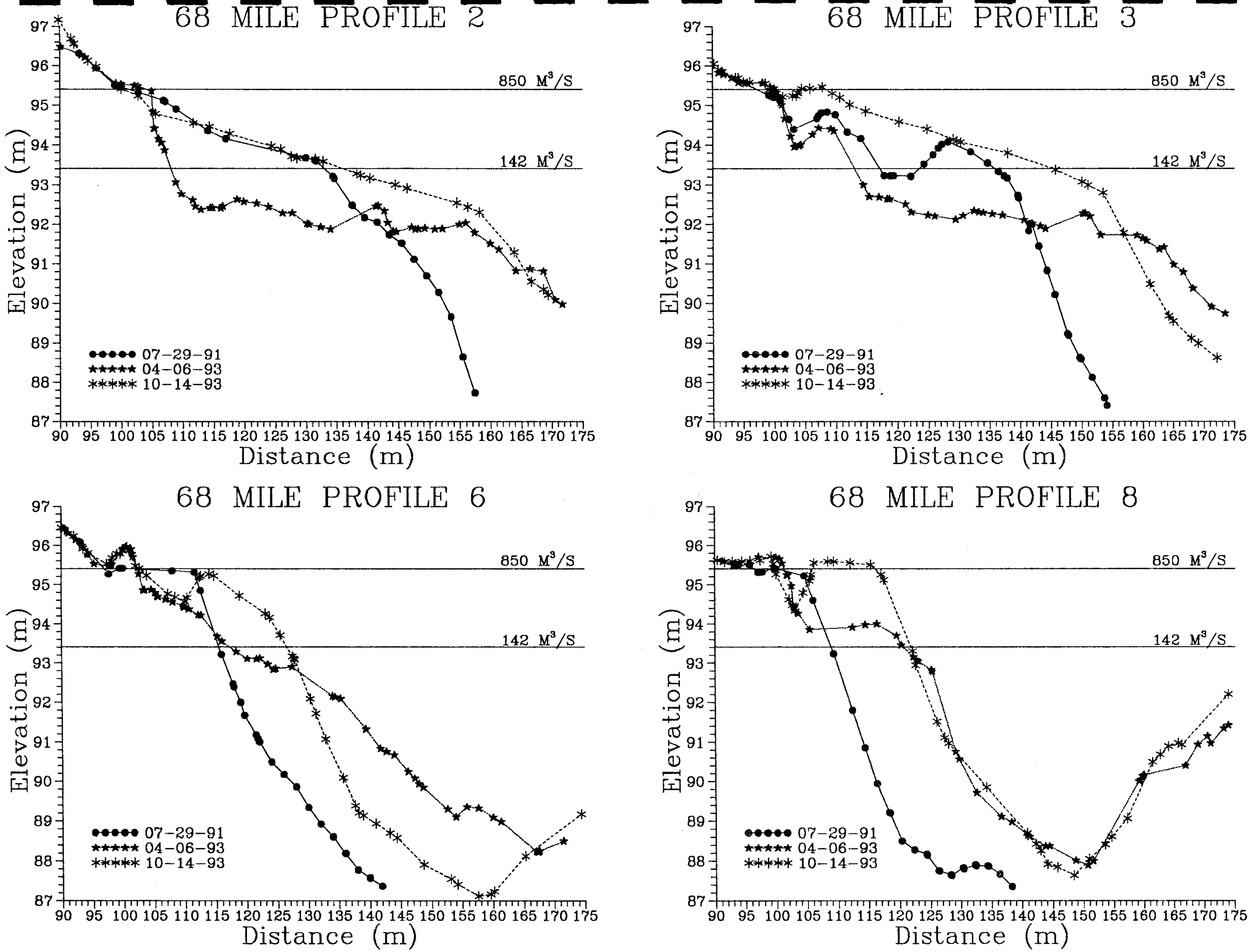

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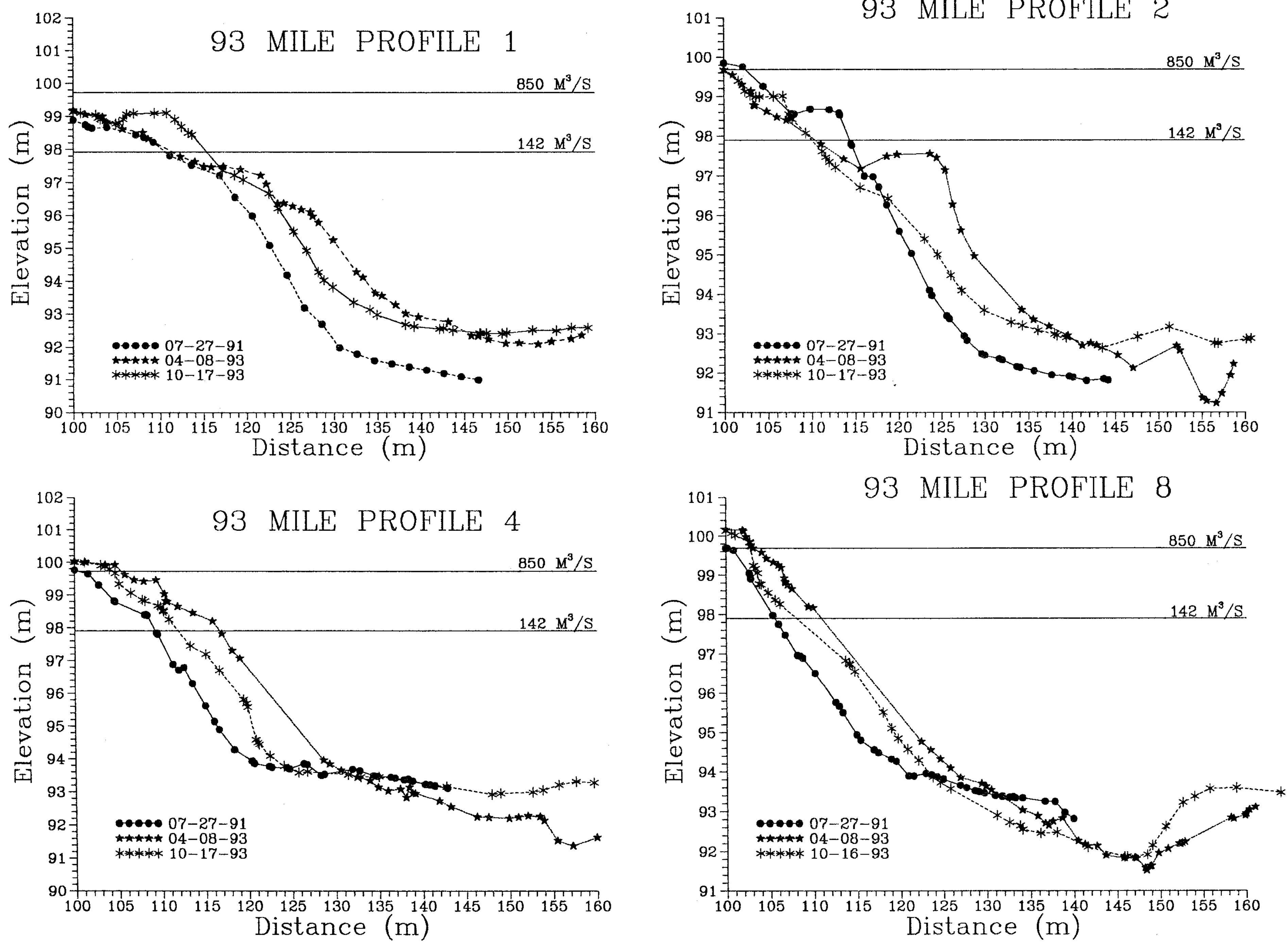

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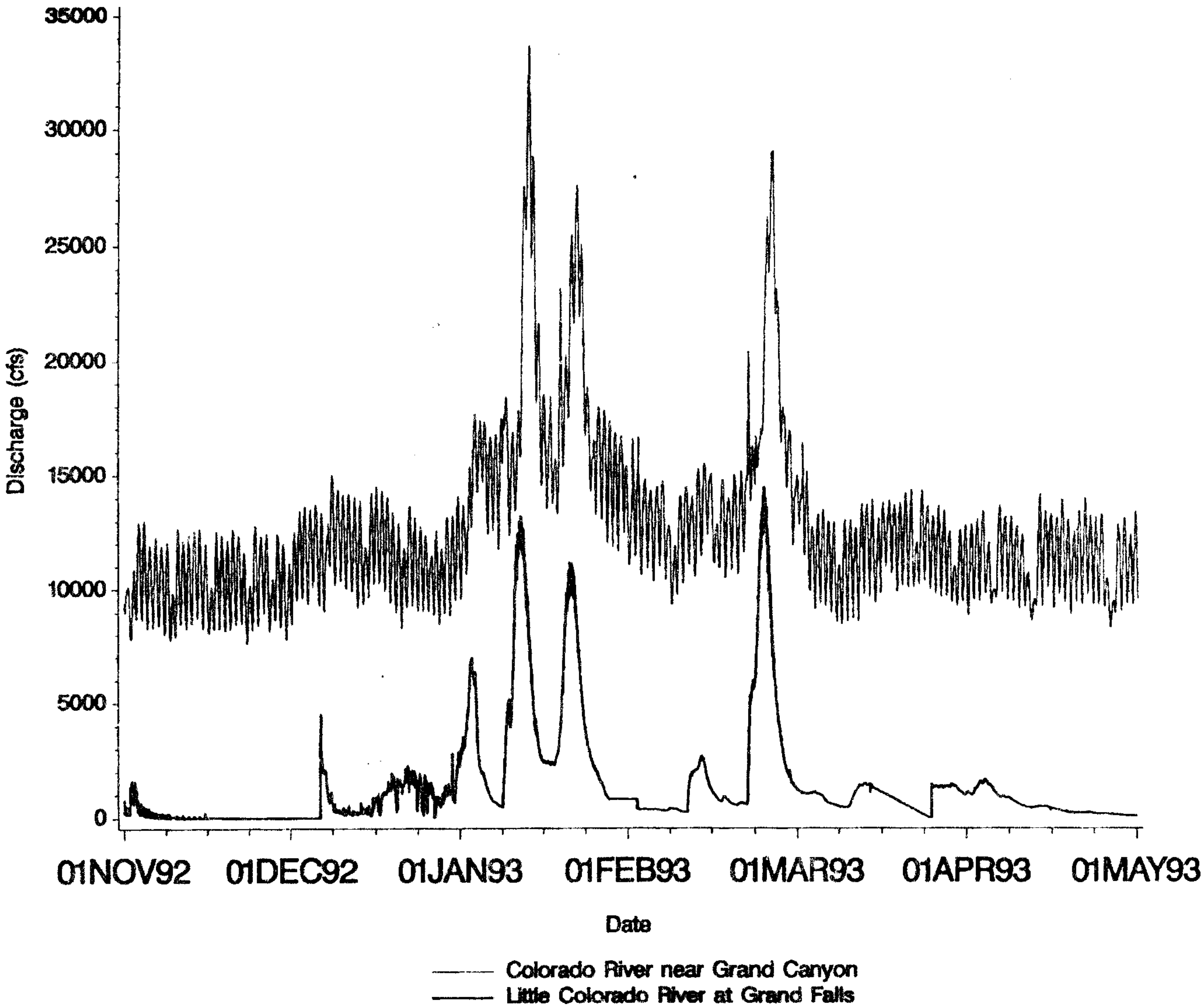

Figure 14. Hydrograph from the Colorado River (RM88) and the Little Colorado River at Grand Falls for the interval between the October, 1992 and April, 1993.

Structure and Evolution of the "Dead Chub Eddy" (RM 62.4) Sand Bar

A sand bar deposited during the January and February 1993 flood events provided a unique opportunity to examine the rate and style of sand bar development (Kaplinski et al., 1994). The sand bar formed in a channel expansion approximately two kilometers downstream of the confluence of the Colorado and the LCR (RM 62.4; Figure 1). This eddy was devoid of a subaerially exposed sand deposit before the flood events. River stages were elevated up to 2 meters above typical fluctuating-flow regime levels at the peak of the flood (Figure 14). After the floods receded, a steep, 1.5-meter high cutbank developed across the face of the bar, exposing the internal structure along the entire 120-meter face of the bar platform.

sand bar evolution

Sedimentary structures exposed along this cutbank suggest that deposition began near the center of the eddy. The structures during this first stage are mainly overlapping scour pits filled with trough-shaped sets of cross-beds caused by subaqueous dunes migrating onshore. Continued deposition, accompanied by migration of ripples, caused the bar to expand until it approached the water surface throughout most of the eddy.

The portion of the 62 Mile bar that we examined was deposited entirely during the three flood events. The majority of the bar was deposited during the first, and largest of the three floods. The bar is comprised of three main stratigraphic units (Kaplinski et al., 1994). Initial deposition began during the first tributary flood event on January 12, 1993. As the flood elevated river stage and delivered large amounts of sediment, large-scale bedforms migrated into and across the empty eddy system accompanied by climbing ripple structures adjacent to the debris fan. The migration of the large-scale bedforms deposited an overlapping sequence of scour pits (Rubin, 1987; fig 34) filled with trough-shaped sets of cross-beds. This style of deposition continued until dune height approached the water surface. The majority of these bedforms were located near the center of the eddy and underly the topographically highest portion of the bar (Kaplinski et al., 1994). The second unit was comprised mainly of climbing ripple structures that migrated onshore and onlap the upstream portion of the central core (unit 1) of the bar. Both units 1 and 2 were overlain by unit 3. Unit 3 was characterized by horizontal plane beds at the downstream end of the bar that changed laterally into small-scale trough cross beds at the upstream portion of the bar platform. Unit 3 represented the final phase of deposition within the eddy and was the result of bedforms migrating bankward into the the eddy return current channel (Rubin et al., 1990). Units 2 and 3 could either be the product of the second or third flood events or the result of changes in flow regime due to daily dam fluctuations. Although inconclusive, we prefer the latter explanation, especially in reference to unit 2, because of the lack of clearly defined erosional scour surfaces. In addition, stage elevations during the second and third flood events were not as high and may have only slightly overtopped the first flood bar platform but appear to have aggraded the lower-elevation, upstream portion of the bar platform.

style and rates of aggradation and degradation

Following the winter floods and the return to "normal" low-volume interim flow regimes (227-350 m^3/s), erosion rates at the bar increased as the unstable cutbank retreated. This was likely due to migration of the reattachment point upstream because of the lower discharge. The downstream ends of reattachment bars are then subjected to erosive downstream flow (Schmidt and Graf, 1990). An additional increase in erosion rate was observed in June, upon the increase to high-volume interim flow operations (400-556 m^3/s). By mid-July, 1993, the subaerial portion of the deposit that we examined was almost entirely removed. Topographic and bathymetric surveys were conducted in May, 1993 and October, 1993 (Figure 15). Comparison of the surveys provides an estimate of the minimum amount of sediment delivered to the recirculation zone during the sediment-laden floods.

The comparison shows that in the recirculation zone, sediment was removed from the downstream portion of the eddy near the debris fan and from the return current channel. Observations of the site in mid-June, 1993, during low-volume, interim flow operations (230 to 340 m^3/s [8,000 to 12,000 ft^3/s]) showed that only about 5-10% of the deposit we measured in April had been eroded and erosion rates ranged from 50 to 100 m^3/day. An order of magnitude increase in the erosion rates took place on July 1, when dam operation changed to high-volume, interim flow operations (340 to 540 m^3/day [12,000 to 19,000 ft^3/s]). After the change in dam operations we observed that the portion of the bar above the 142 m^3/s (5,000 ft^3/s) stage elevation had completely eroded within a two to three week period. Our calculations indicate that erosion rates reached 2,000 to 2,500 m^3/day during this period of time. Therefore, at this site in particular, changes in dam release schedules had a dramatic effect on erosion rate. The differences in erosion rates due to various dam operating scenarios should be considered in the design of the flows that follow proposed, dam-controlled habitat restoration floods. Priority should be placed on strategies that minimize erosion rates following large flood events.

A)

B)

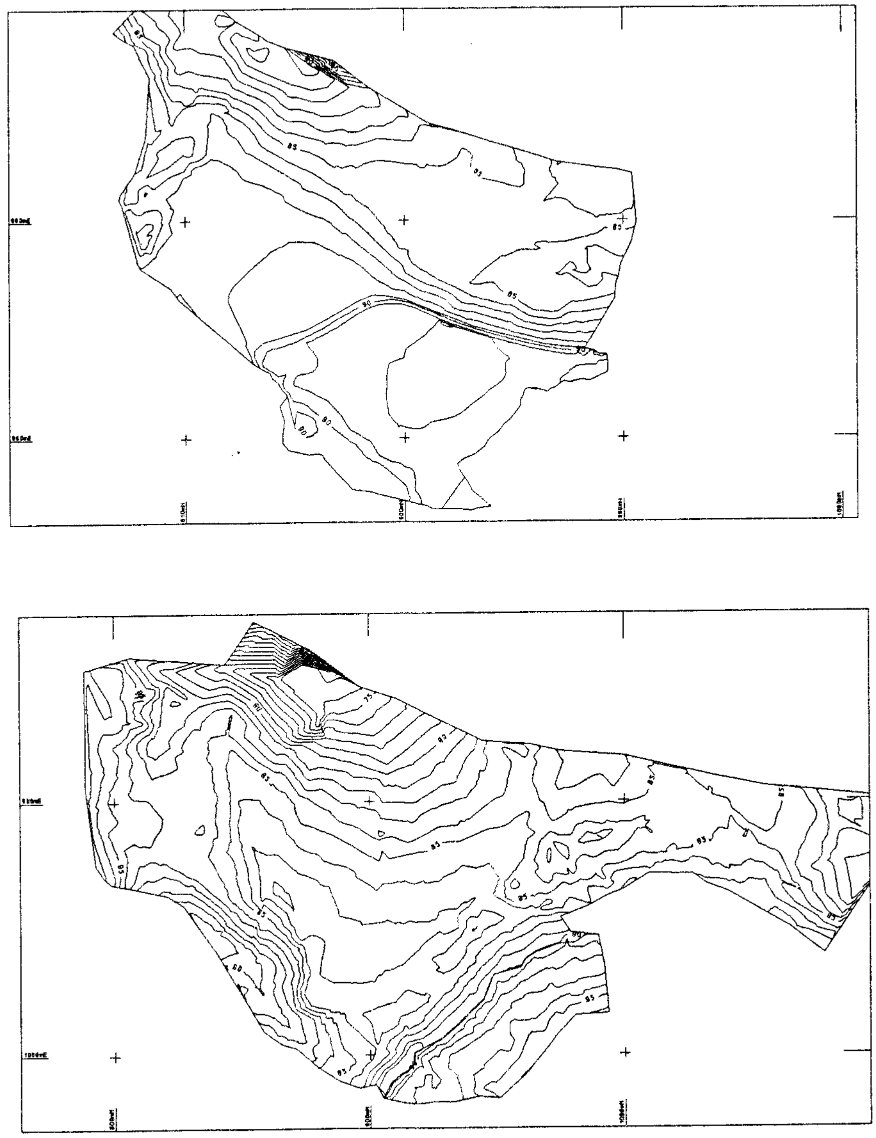

Figure 15. topographic maps of RM 62.4. Contour interval 1 meter. A) 4-05-93 B) 4-14-94.

The volume of sediment removed from the eddy during this period can also be used to estimate an accurate, minimum volume and rate of sediment accumulation in the recirculation zone during the January, 1993 flood. The actual volume of sediment was probably greater because the eddy system was devoid of a significant deposit prior to the flood event. Sedimentary structures observed along the front of the bar and photographs taken on January 13th indicate that the majority of bar-building occurred during the first flood event, possibly within the several hour period of peak discharge (Kaplinski et al., 1994; Figure 14). Table 6 contains deposition rates calculated for several different periods of time. A total volume of 64,644 m^3 and a sediment density of 2.65 g/cm^3 was assumed in the calcualtions. Assuming that the majority of deposition occurred during the first 12 hours of the flood, our rates are slightly higher than the range of rates (0.22 to 0.05 kg/s) determined from flume experiments of recirculation zone sedimentation (Schmidt et al., 1993). Because of close proximity to the sediment source (LCR), observed high current velocities within the recirculation zone, and the lack of a significant deposit before the flood, this bar may not be representative of eddy dynamics at other sand bars along the river corridor during similar flood events. However, the topographic changes and sedimentologic characteristics at the RM 62.4 site are similar to conceptual models of bar-building in Grand Canyon recirculation zones (Rubin et al., 1990; Schmidt and Graf, 1990; Schmidt et al., 1993). Similar studies should be conducted at other sites with varying geomorphic controls in order to gain a more complete understanding of the response of Colorado River sand bars to flood events.

Table 6. Deposition rates at RM 62.4 during January 12-16 flood

Duration (Hours)	6	12	24	48
Deposition Rate (m^3/s)	10,774	5,387	2,694	1,347
(kg/s)	0.79	0.40	0.20	0.10

Discussion

Sand Bar and Recirculation Zone Adjustment to Interim Flows

Our biannual surveys of sand bars along the Colorado River in Grand Canyon indicate that both the amount of sediment within the HAZ and the area available for camping was continuing to decrease as a result of IF operations from GCD. Nearly three years of interim flows from GCD have 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 16A). Sediment is being eroded from high-elevation sand bar locations and deposition, not necessarily of the same sediment, is occurring in a smaller recirculation zone along the lower portion of the sand bars below the maximum elevation of interim flows (Figure 16A). The downstream portions of reattachment bars are now exposed to main-current erosion due to contraction of the recirculation zones during the low discharge months of interim flow operations. The increase in channel-bed elevation at several sites between Lees Ferry and the LCR is likely sand eroded from these areas that is being deposited in the main channel. Within the recirculation zones, repeated topographic profiles show that the main platform of reattachment bars are being planed off and reduced 1-2 m in elevation. This is due in part to the seepage-erosion processes described by Budhu (1991) that occur as water circulates bankward over the bar surface in a broad, non-channelized, shallow flow (Rubin et al., 1990). This results in cutbank development and retreat and slope failures, thereby lowering the bar in elevation and increasing the area that is daily inundated by fluctuating flows and thus decreasing the area available for recreational use. These erosive mechanisms are not reflected in the HAZ volume analysis at many of our study sites, however, as net sand bar erosion is being offset by deposition of sand at lower elevations on the main platform, upstream of the reattachment point.

Reattachment bars and the return-current channels directly associated with them are important for backwaters and are an important component of the riparian ecosystem (Turner and Karpiscak, 1980; Stevens and Waring, 1986). Open return-current channels, or backwaters, are important rearing habitat for endangered native fish because they are warmed by the sun and have little or no velocity (Valdez et al., 1992). Since implementation of IF, backwater habitats have filled with sediment (Beus et al., 1994) and consequently the number of suitable backwater habitats are decreasing (Bureau of Reclamation, 1994). According to Schmidt (written communication in draft EIS (U.S. Bureau of Reclamation, 1994)) floods increase the number of backwaters by scouring the return-current channels and removing vegetation; between floods backwaters decrease in size and number as they fill with sediment and become vegetated. The response of reattachment bars to IF is the development of a smaller reattachment bar platform and return current channel that projects upstream into the eddy. This perches the former high-discharge return channel beyond the influence of IF. These perched channels are now disconnected from the river and have filled in with sand, silt, and vegetation. Our preliminary analysis of the sedimentology from trenching these areas indicate flows that infill the return channels are characterized by relatively short-lived eddy activation or low discharge within the return channels and low flow depths over the return channel platform (Hurlburt et al., 1994).

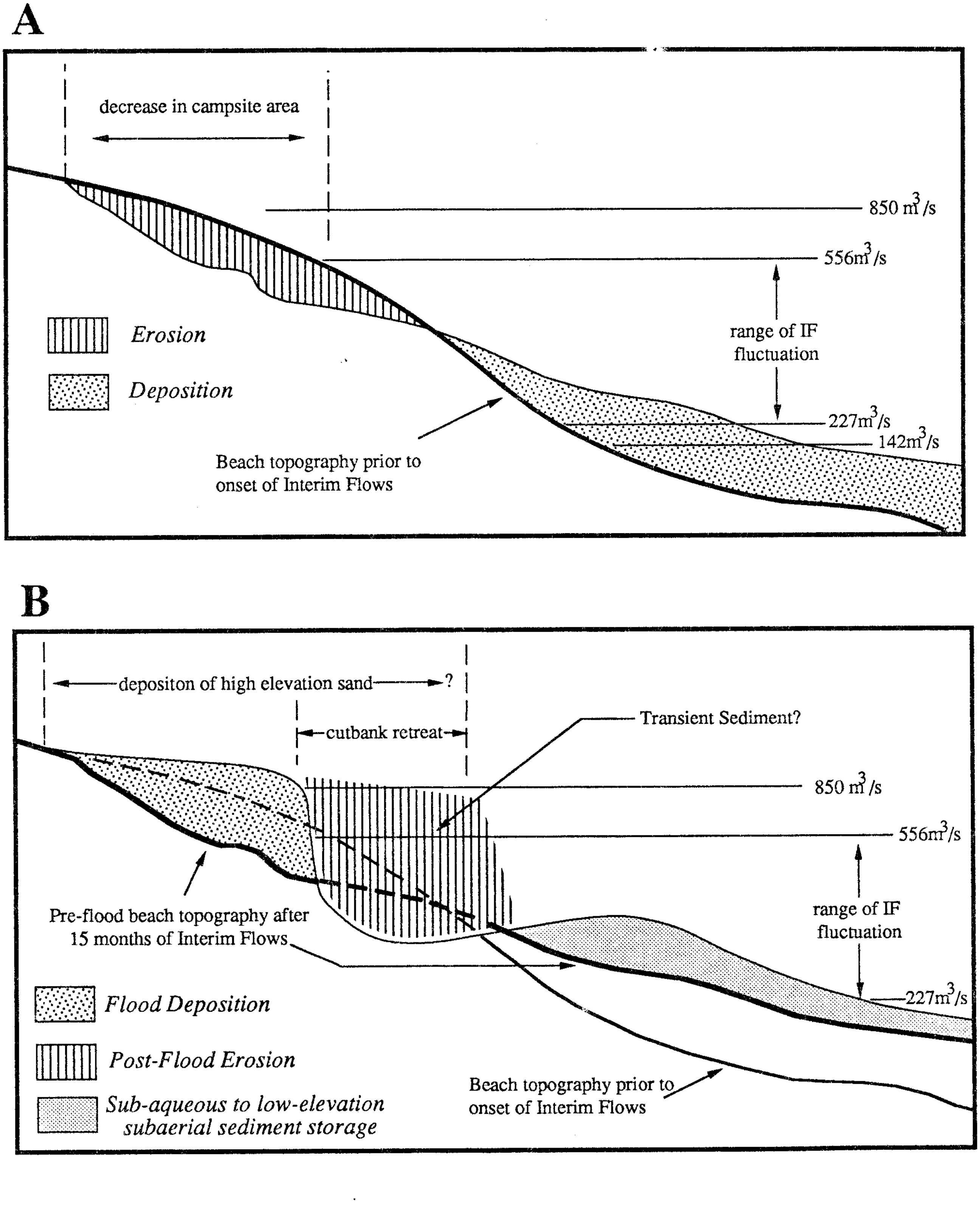

Figure 16. Schematic cartoon diagrams (not to scale) illustrating, A) erosional and depostional relationships during IF prior to the winter 1993 floods, and B) flood deposition, post-flood cutbank retreat, and low-elevation subaerial and subaqueous deposition.

Responses to a Tributary Sediment Input

Downstream from the confluence of the LCR and Colorado River, the three 1993 winter flood events augmented the sediment budget and increased main stem transport rates. 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 16B). Subaqueous sediment aggradation 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 12). Burkham (1987) reported that bed elevation in the pool at the USGS gauging station near Phantom Ranch changed as much as 2.5 meters annually before the construction of GCD and subsequent flow regulation. Just upstream from this gauge at 87 Mile, cross-channel profiles show that up to 2 m of sand was still stored on the bed 9 months after the LCR flood events. Similiar aggradation was apparent as far downstream as RM 93 (Figure 13). Several sites farther downstream (RM 119 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 stored on the riverbed.

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 16B). Sand bars erode rather quickly after a bar-building event, as was reported after the 1983 "spill" (Brian and Thomas, 1984; Beus et al., 1985; 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 16B); 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. Bathymetric data from the October, 1993 survey show that much of the sand mass is still retained in the 30 mile zone downstream from the LCR. Computations of sand transport (Randle and Pemberton, 1987) and measurements of bed elevation change (Burkham, 1987) indicate that sand is not transported through most channel pools and bed degradation initiated until flows exceed 15,000-20,000 ft^3/s. Discharge in this range was only reached for short periods in July and August, 1993. There has been a moderate increase in sediment storage at most channel expansion areas associated with study sites downstream from this zone, however, this is probably sediment that is being lost from sand bar areas that are now exposed to downstream current under interim flow size recirculation zones. Although the post-flood erosion rates diminished, 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.

Management Implications and Bar-building Flows

The primary goal of the IF was to promote sediment storage in the river system. 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. Because of reduced capacity to transport sand, the Colorado River is now storing more sand in low velocity areas such as recirculation zones and upper pools above constrictions. This gain is sand storage, especially between the Paria and LCR, is potentially the principal sediment source for rebuilding dans bars.

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 order to restructure infilled return current channels. A clear-water, experimental flow, near or greater than GCD power plant capacity, is being planned for March/April, 1995. The 1993 winter floods provided an unexpected test case of a bar-building flow event. Significant deposition occurred as a result of these floods. Similiarly, our preliminary analysis suggest that riverbed sand accumulated during the interim flow period could be successfully redistributed during a high-flow GCD release. Such a release, at or greater than powerplant capacity, would probably cause net system-wide aggradation at high-elevation sand bar locations.

Conclusions

1. Interim flow operations from GCD have led to erosion of the higher elevation portions of sand bars, typically between the 20,000- and 30,000 cfs levels.

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. Data 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 majority of bar-building at 62.4 Mile bar occured during the 72 hour duration of the first January flood.

7. A minimum of 64,644 m^3 of sediment accumulated in the 62.4 Mile recirculation zone during the floods at a rate between 0.79 and 0.2 kg/s.

8. The longevity of newly re-formed sand bars is dependent on a dam operation strategy that limits bank erosion processes. Changes in dam-release patterns following flood deposition at 62.4 Mile had a pronounced effect on erosion rates at the site. An order of magnitude change in erosion rates at the site was observed after dam operations changed to high volume interim flows on July 1, 1993.

CAMPSITE SIZE STUDY

Introduction

A primary influence of GCD on downstream recreation in Grand Canyon National Park has been its effect on sand deposits (described in the previous section), many of which are used as campsites. The size and abundance of these sand deposits limit the river's recreational carrying capacity. Campsites are an integral part of all raft trips because trips are multi-day expeditions. Without open sand deposits, river trips could not be conducted because the remainder of the shoreline is too rocky or too densely vegetated to be used as campsites except under extreme circumstances. Development of dam operating criteria must be based on sound understanding of how dams affect downstream resources and activities, including recreation.

Campsite carrying capacity is of concern due to Grand Canyon National Park's popularity. The annual number of people traveling downstream on the river through the park increased from 547 in 1965 to 16,428 in 1973 (Shelby, 1981). As of 1993, the U.S. National Park Service limits use to approximately 22,000 people per year. Even with this limitation, many campsites are used nearly every night during the summer and sometimes, for lack of alternative camps, by two river parties on the same night.

The primary purpose of this study is to determine changes in campsite area since the initiation in August 1991 of IF. Dam managers and citizens alike require a clear picture of the pattern of historical campsite change if the imposition of new rules intended to restore campsite size and number is to be justified.

Background

Three campsite inventories conducted between Lees Ferry and Diamond Creek show a decrease in the number of campsites between 1973 and 1991. The first inventory, in 1973, documented 333 campsites above the new high water zone (25,000-28,000 cfs) (Weeden et al., 1975). The second inventory was conducted in 1983 after flood level flows were discharged from the Glen Canyon Dam; it documented 438 campsites. The increased number of campsites since 1973 were primarily attributed to the previous year's flood releases (Brian and Thomas 1984). The most recent survey, which was not preceded by flood conditions, was conducted in 1991. This inventory documented 226 campsites, a 32% reduction in campsite number since 1973, and a 48% reduction since 1983 (Kearsley and Warren, 1993).

A comparison of the three inventories also shows an overall decrease in size of campsites. Size class comparison of 133 campsites documented in all three inventories shows that 41% of the campsites have decreased in size between 1973 and 1991, while only 5% have increased in size.

Certain reaches of the river are limited in the number of available campsites, and competition for sites in these "critical reaches" is greater than for sites on other stretches of the river (Kearsley and Warren 1993). Because of their importance to the overall carrying capacity of the river, campsites in critical reaches received primary focus in the 1991 study.

Data collection of measured campsites consisted of the following: in March and May 1991, 89% (89/94) of the campsites in critical reaches were measured, and 24% (41/169) of the campsites in non-critical reaches were measured. Maps were drawn of all measured sites, and areas suitable for camping were measured in m^2 at 5,000 cfs, 8,000 cfs, 15,000 cfs, and 25,000 cfs. Measured areas of campsites provided baseline information for monitoring studies and showed trends in the effects of river discharge on available campsite area.

Methods

The area of campsites during different interim flow years was determined by the following methods: Laser xerox copies of aerial photographs taken in October 1992, May 1993, and May 1994 at 8,000 cfs were made for each campsite to be measured. While visiting each site, useable area was assessed and outlined on the laser copies. Useable area includes any area that is relatively flat (less than 9 degree slope), non-cobbled, and non-vegetated. While some of these spaces may be "used" for purposes of sitting, playing, or other recreation, they are not considered useable space because they do not contribute to the overnight carrying capacity of the site.

These laser copies were then scanned into a map and image processing computer (MIPS) to compute campable area below the 25,000 cfs zone as well as total campable area for each year. Each image was calibrated while visiting the site by measuring the distance between two fixed points visible in the laser xerox, usually two large trees or shrubs, then entering these distances into the computer. The planimeter tool was used to outline the perimeter of each useable area. For areas that are not visible from the air, such as space under overhangs, beneath vegetation, or space that is too small to be discerned on the video images (i.e. small separated sleeping areas). Measurements were made in the field by taking the length and width of the area to the nearest half meter. Data will be analyzed as follows: Percent changes in campable area due to interim flows wil be ananlzed from surveys conducted from air photos collected in May 1991, October 1992, May 1993, and May 1994. will be arcsine square root transformed and analyzed with a repeated measure analysis of variance (Sokal and Rohlf 1981).

Results

Fall 1992

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 6. 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

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 7. 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.

Campsite Size Trip Report: April 15 to May 1, 1994

The following is a list of 96 campsites to be remeasured during the April 15-May 1, 1994 river trip. Total camspite area was reevaluated on all camspites labeled "Y" in the "Total Area" column. Campsite area only at and below the 30,000 cfs zone was evaluated in the remaining sites. A general trend noted on this trip was that much of the aggraded sand resulting from the 1993 winter flood has since eroded. Data will be quantified and analyzed this summer.

94 camps		Name	Total Area
8.0	R	Badger	Y
8.0	L	Jackass	Y
11.0	R	Soap Creek	Y
12.2	L	Below Salt Water	Y
16.4	L	Hot Na Na Wash	Y
17.0	R	Lower House Rock	
18.0	L	Upper 18-mile	Y
19.0	R	Upper 19-mile	Y
19.1	L	Lower 19-mile	
19.9	L	Twenty mile	
20.4	R	Upper North Canyon	
21.5	L	Twenty-two mile Wash	Y
21.9	R	Twentytwo-mile	Y
23.0	L	Twentythree mile	Y
23.7	L	Lone Cedar	Y
26.3	L	Above Tiger Wash	Y
29.3	L	Shinumo Wash	Y
30.4	R	Below Thirty mile	Y
31.6	R	South Canyon	Y
33.6	L	Below Redwall	Y
37.7	L	Tatahatso	Y
39.0	R	Redbud Alcove	Y
44.2	L	Eminence	Y
47.2	R	Lower Saddle	Y
53.0	R	Main Nankoweap	Y
56.2	R	Kwagunt	Y
59.8	R	Sixty mile Canyon	Y
61.7	R	Below LC Island	Y
66.8	L	Espejo	Y
74.1	R	Upper Rattlesnake	Y
74.3	R	Lower Rattlesnake	Y
75.6	L	Neville's	
75.8	R	Papago	Y
76.6	L	Hance	Y
81.3	L	Grapevine	Y
84.0	R	Clear Creek	Y
84.4	L	Above Zoroaster	Y
91.1	R	Lower 91-mile	Y
92.3	L	92-mile	Y
93.4	L	Granite	Y
94.3	R	Ninetyfour Mile	Y
94.9	L	Hermit	Y
96.0	R	Ninetysix-mile	Y
96.1	L	Schist	Y
98.0	R	Upper Crystal	Y
102.8	R	New Shady Grove	Y
103.8	R	Emerald	Y
107.8	L	Ross Wheeler	Y
108.0	R	Parkins' Inscr.	Y
114.3	R	Upper Garnet	Y
114.5	R	Lower Garnet	Y
119.2	R	No Name	Y
119.8	L	Onetwenty mile	Y

120.0	R	Upper Blacktail	Y
122.2	R	Onetwentytwo mile	Y
122.7	L	Upper Forester	Y
125.4	L	Below Fossil	Y
126.2	R	Randy's Rock	Y
131.1	R	Below Bedrock	Y
131.8	R	Galloway	Y
132.0	R	Stone Creek	
133.0	L	Onethirtythree mile	Y
133.5	R	Racetrack	Y
134.6	L	Owl Eyes	Y
136.0	L	Junebug	Y
136.2	L	Opp. Deer Creek	Y
136.3	L	Below Deer Creek	Y
136.9	L	Football Field	Y
137.0	L	Backeddy	Y
137.9	L	Doris	Y
139.0	R	Fishtail	Y
139.8	L	Oneforty-mile	Y
145.1	L	Above Olo	Y
145.6	L	Olo Canyon	Y
148.4	L	Lower MatKat	Y
148.5	L	Below Matkat	Y
155.7	R	Last Chance	Y
157.7	R	First Chance	Y
158.5	R	Second Chance	Y
160.0	L	Onesixty-mile	Y
160.7	R	Onesixtyone mile	Y
164.5	R	Tuckup Canyon	Y
166.6	L	Lower National	
168.0	R	Fern Glen	Y
174.3	R	Upper Cove	Y
174.4	R	Lower Cove	Y
177.7	L	Vulcan's Anvil	Y
184.5	L	No Name	Y
188.0	R	Upper Whitmore	
188.4	R	Lower Whitmore	Y
202.0	R	Two-o-two mile	Y
211.7	R	Fall Canyon	Y
212.9	L	Pumpkin Springs	Y
219.8	L	Upper Twotwenty	Y
219.9	R	Middle Twotwenty	Y
220.0	R	Lower Twotwenty	Y
222.0	L	Twotwentytwo-mile	Y

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G. INVENTORY OF PROPERTY ACQUIRED

QUANT.	DESCRIPTION
2	notebook microcomputer P.C.'s
2	Math Co-processor chips
2	Color Monitors
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
2	surge protectors
1	camera tripod
1	flashlight
1	Gateway 2000 computer
1	1 HP laserjet printer
1	simms chips

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