MONITORING THE EFFECTS OF INTERIM FLOWS FROM GLEN CANYON DAM ON SAND BARS IN THE COLORADO RIVER CORRIDOR, GRAND CANYON NATIONAL PARK, ARIZONA

FINAL REPORT: 30 June, 1995

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CONTENTS

ABSTRACT iii

ACKNOWLEDGEMENTS iv

LIST OF FIGURES v

LIST OF TABLES vi

INTRODUCTION 1
- Project Overview 1
- Objectives 2
- Previous Work 4
- Modern Alluvial Deposits of the Colorado River 6
- Flow Regimes During Study 8

METHODS 10
- Study Sites 10
- Data Collection 10
- Data Processing and Analysis 12
  - Topographic Model Formation 12
  - The "Hydrologically Active Zone" (HAZ) 12
  - Hypsometry 14
  - Stage-Discharge Ratings 15

RESULTS AND DISCUSSION 17
- Sediment Volume 17
  - HAZ Analysis 17
  - Hypsometric Analysis 21
- Geomorphic Adjustment of sandbars 22
  - Interim Flows 22
  - Rapid Erosion Events 31
  - The 1993 LCR Tributary Floods 34
    - Sand bar deposition and erosion 34
    - Rates of deposition and erosion 38
    - Main channel transport and storage 43
  - Smaller Tributary Impacts 43

SUMMARY 49
- Sand Bar and Recirculation Zone Adjustment to Interim Flows 49
- Evaluation of Interim Flows and Alternatives 51

Management Implications 54

CONCLUSIONS 56

REFERENCES 57

ABSTRACT

Grand Canyon sand bars are a primary resource of Grand Canyon National Park and the effects of Interim Flows on sand bars is of particular concern to river managers. We assessed whether Interim Flows have minimized sand bar erosion by comparing biannual topographic and bathymetric surveys at 32 study sites along the Colorado River through Grand Canyon National Park.

Erosion of sand bars exposed above the surface of the river is a ubiquitous process that occurs by river-related mechanisms (tractive and seepage erosion), surface runoff, wind, and human impact. Lower ranges of flow fluctuations during Interim Flows increased the amount of sand bar area exposed above the surface of the river. Our measurements indicate that the exposed areas of sand bars have significantly eroded during the Interim Flow period. Sand has been eroded from the upper, subaerially exposed elevations of sand bars and displaced to lower elevations of recirculation zones and the main channel, within and below the flow fluctuation zone. The majority of erosion was typically caused by the development and shoreward migration of cutbanks. Tractive force erosion caused cutbanks to develop at the maximum elevation of flow fluctuations. Reduced down-ramp rates and restricted flow fluctuations during Interim Flows appear to have minimized seepage-driven erosion. With seepage forces minimized, tractive force erosion was the dominant erosional mechanism at the study sand bars. Deposition of sand occurred in recirculation zones within and below the range of Interim Flow stage elevations, but a trend of decreasing sediment volume within the smaller recirculation zones indicates that more sediment is eventually removed from the recirculation zones than deposited. Former high-discharge return channels were disconnected from the river by low-elevation deposition and have filled in with sand, silt, and vegetation. Lower elevation Interim Flow return channels are narrower and shallower due to bankward migration of bar platforms. The decrease in return channel area is limiting native fish habitat because these "backwaters" are only viable at certain stage elevations not well represented by Interim Flows.

Three floods from the Little Colorado River during the winter of 1993 provided an unexpected test case of a bar-building event by elevating Colorado river stages to slightly higher than powerplant capacity. These floods demonstrated that sediment accumulated on the river bottom can be redistributed to sand bars during a high flow release. Downstream of the LCR, a significant amount of flood-related deposition raised the tops of bar platforms by 1-2 meters and in-filled high-discharge return current channels. High erosion rates following the floods significantly eroded 84% of the sites downstream of the LCR. Newly aggraded bars eroded to pre-flood size within 6 months, but high elevation flood-deposition remained in areas not reached by Interim Flow stage elevations and retreating cutbanks.

These results support the need for cyclic rebuilding of sand bars with annual Bar-Building/Habitat Maintenance flows, as recommended in each of the Restricted Fluctuating and Steady Flow alternatives in the Glen Canyon Dam Environmental Impact Statement. Sediment redistributed and stored in sand bars is removed from downstream transport and becomes available for riparian habitat development and recreational camping area. However, maintenance of sand bars depends on determining the duration and discharge which will build bars and restructure habitats without causing a net depletion of sand. The continued monitoring and research is needed to determine the effects of these, and future dam management strategies.

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LIST OF FIGURES

Figure 1. Location map showing study locations 2

Figure 2. Schematic diagram showing flow patterns and configuration of bed deposits in a typical recirculation zone 6

Figure 3. Daily minimum and maximum discharge hydrograph from Colorado River gage near Grand Canyon 8

Figure 4. Daily minimum and maximum discharge hydrograph from Colorado River gage near Grand Canyon for the interval between February 1993 and March 1993 9

Figure 5. Topographic maps from RM122 showing HAZ boundary 13

Figure 6. Plot of HAZ volume summed column ranks used in Friedman Analysis as a function of time 17

Figure 7. HAZ volume histograms. 18

Figure 8. Plot of hypsometric integral summed column ranks used in Friedman Analysis as a function of time 21

Figure 9. Photograph showing a large cutbank developed after 1993 LCR floods at RM62 22

Figure 10 Photographs showing armoring of the upstream areas of RM45 separation bar 23

Figure 11. Topographic maps from the RM22 reattachment bar. 25

Figure 12 Topographic profiles from RM22.8 26

Figure 13. Photographs taken on 11/3/91 and 10/18/93 respectively, showing the return channel area at RM122 27

Figure 14. Photograph taken October 27, 1991 of the reattachment deposit at RM50 28

Figure 15. Topographic maps from the reattachment bar at RM119 29

Figure 16. Photograph taken on 10/17/93 of RM 119 reattachment bar showing the eroded area downstream of the reattachment point 30

Figure 17. Topographic profiles from RM119 30

Figure 18. Topographic maps from the RM3 reattachment bar 32

Figure 19. Topographic profiles from RM3 reattachment bar 33

Figure 20. Area distribution histograms from surveys surrounding bar failure events at RM3 and RM16 33

Figure 21. Hypsometric change diagrams showing area change due to bar failure events and subsequent bar rebuilding at RM3 and RM16 34

Figure 22. Topographic maps from the RM183 reattachment bar 35

Figure 23. Topographic profiles from RM183 36

Figure 24. Photograph of the RM202 separation bar taken on 4/13/93 showing cutbank erosion following the winter 1993 floods 36

Figure 25. RM68 surface comparison of the topographic surfaces generated from the 10/22/92 and 4/06/93 surveys 37

Figure 26. Topographic maps of the recirculation zone at RM62 38

Figure 27. Photographs of the emergent reattachment bar at RM62 40

Figure 28. Comparison map of RM62 with one meter contour 42

Figure 29. Cross-channel profiles from selected sites that show channel bed elevation change 44

Figure 30. Stage Discharge relationships for the RM68 study site 45

Figure 31. Hypsometric curves from the RM68 study site 46

Figure 32. Photographs from RM123 study site 47

Figure 33. Topographic maps of the RM123 upper pool/reattachment deposit 48

Figure 34. Schematic diagram of a reattachment bar at low discharge 50

Figure 35. Schematic cross sections of the active width and height of a typical sand bar. A) no action alternative, B) restricted fluctuation and steady flow alternatives, and C) Interim Flows 52

Figure 36. Schematic cross sections of the active width and height of a hypothetical sand bar. A) Interim Flows, B) after a beach/habitat building flow, and C) after a habitat maintenance flow. 54

Figure 37. Schematic diagram of volume changes within recirculation zones over time with and without dam-release floods. 55

LIST OF TABLES

Table 1. Sand Bar Survey Sites 3

Table 2. Interim Flow Sand Bar Surveys 11

Table 3. Hypsometric Integrals 16

Table 4. HAZ Volume Changes 20

Table 5. Deposition rate at RM 62.4 during January 12-16, 1993 flood 41

Table 6. Average study site sand bar height and active width 53

INTRODUCTION

Project Overview

Glen Canyon Dam (GCD) operations completely control the flow of the Colorado River through Grand Canyon and as a result downstream sediment resources are impacted (Water Science and Technology Board, 1991). Operational effects of GCD include: 1) a reduction in sediment supply because the dam traps nearly all incoming sediment, 2) extremely reduced flows as compared to historic peak flows which in turn has reduced the capacity of the river to transport sediment, and 3) fluctuating flows that affect sand bar stability and limit the height of annual deposition and erosion to the range of powerplant releases. Sand bars form the foundation on which the fluvial ecosystem is structured, and therefore sediment resources below GCD are a management priority of Grand Canyon National Park.

Specific objectives for sediment management in the Grand Canyon National Park River Management Plan are: 1) to maintain the various morphologic components of temporary sand storage (e.g., sand bar deposits), and 2) to maintain a positive sand balance (U.S. National Park Service, 1989). Starting in August of 1991, a program of restricted maximum flow and reduced fluctuation from GCD, termed Interim Flows, has been implemented. This operating strategy was designed to limit 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-Environmental Impact Statement (GCD-EIS), (U.S. Bureau of Reclamation, 1994). Implementation of Interim Flows for GCD during the EIS preparation period requires that sediment resource conditions be monitored.

Sand bar stability and sand storage varies with changes in discharge, size and dimensions of debris fans, and tributary sand input. The effects of dam operations on the morphology of sand bar deposits is closely linked to how recirculation zones respond to alternative water release patterns (Beus et al., 1992). Depending on the operating regime for GCD the balance between sand supply and main channel transport can be positive or negative (Smillie, et al., 1992). Because much of the remaining sediment in the Colorado River below GCD is stored in recirculation zones as sand bars (Schmidt, 1992) it is critical that this resource be monitored. The stability of sand bar deposits and changes in sand storage in recirculation zones are used in this study as an indicator of the impacts of Interim Flows. Short-term changes in sand bars are monitored so that impacts related to changes in water release patterns are documented and long-term sand storage trends can be detected.

This report presents the results from survey studies designed to monitor the effects of Interim Flows on Colorado River sand bar dynamics in Grand Canyon. These surveys allow us to test the hypothesis that Interim Flows maintain a positive mass sediment balance and minimize sand bar erosion. The study of this discharge strategy for GCD during the period of EIS review is important because the EIS-Preferred Alternative (EIS-PA) closely resembles Interim Flows, but also includes yearly bar-building/habitat maintenance flows and endangered aquatic species research flows (U.S. Bureau of Reclamation, 1994). This sand bar study involves the comparison of topographic and bathymetric surveys at 32 sites located in each of the 11

geomorphic reaches of the Colorado River corridor that were defined by Schmidt and Graf (1990). A campsite inventory, included separately in an additional report, addresses the carrying capacity of the river corridor by quantifying Interim Flow impacts on the size of campsites used by river rafting trips and hikers (Kearsley, 1995). To determine the effects of Interim Flows on the sediment and recreational resources within Grand Canyon National Park, the following objectives were established:

Objectives

A. Assess whether erosion of sand bar deposits has been minimized by Interim Flow criteria and if Grand Canyon National Park management objectives for the Colorado River sand bars in Grand Canyon are being achieved.

B. Monitor subaerial and subaqueous sand bar topography on an annual to biannual basis at 32 sand bars in the Colorado River corridor downstream from GCD during the Interim Flow period (Figure 1).

C. Determine how natural floods and sediment input from the Little Colorado River (LCR) tributary during the winter of 1993 affected sand bar size and morphology.

E. Assist in compilation of the above data for the Glen Canyon Environmental Studies/National Park Service Geographic Information System (GIS).

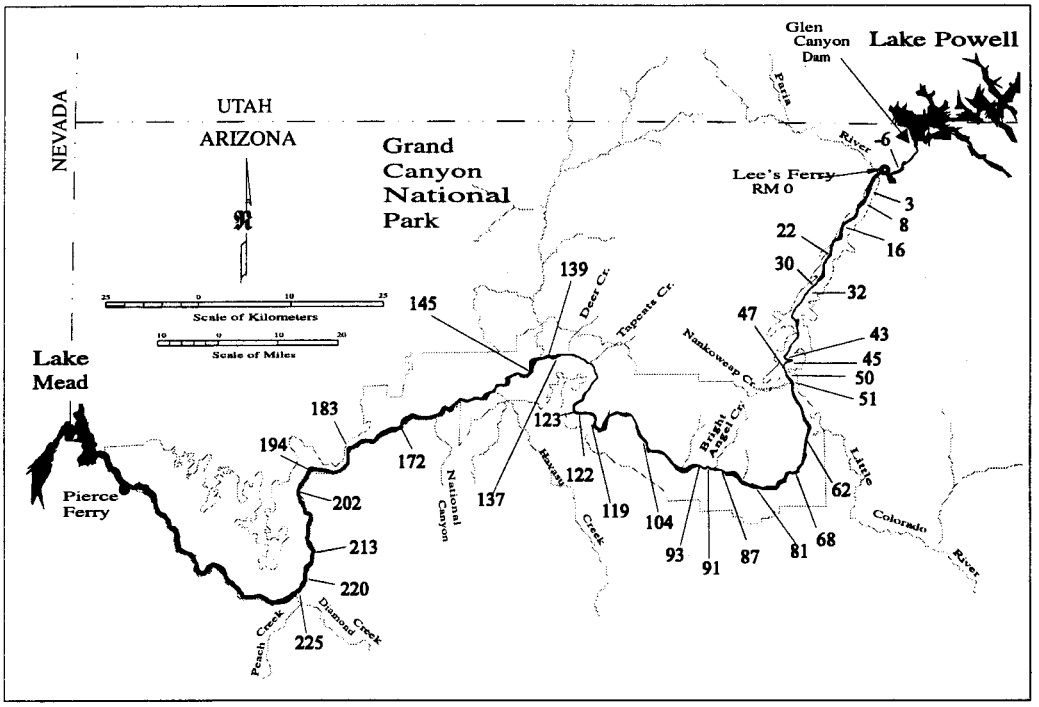


Figure 1. Location map showing study locations.

Table 1. Sand Bar Survey Sites

Site Ref.#	River Mile (RM)*	River Side	Site #	Site Name	Deposit Type	Reach/ Relative Width
-6	-6.5	Right	2	Hidden Sloughs	R	0W
3	2.6	Left	3	Cathedral Wash	R	1W
8	7.9	Left	4	Lower Jackass	S	1W
16	16.4	Left	5	Hot Na Na	S	2N
22	21.8	Right	6		R	2N
30	30	Right	7	Fence Fault	R	3N
31	31.6	Right	8	South Canyon	S	3N
43	43.1	Left	10	Anasazi Bridge	R/UP	4W
45	45.6	Left	11	Eminence Break	S	4W
47	47.1	Right	12	Lower Saddle	R	4W
50	50	Right	13	Dino	R/S	4W
51	51.2	Left	14		R	4W
62	62.4	Right	34	Crash Canyon	R	5W
68	68.2	Right	15	Upper Tanner	R/UP	5W
81	81.1	Left	16	Grapevine	R/S	6N
87	87.5	Left	17	Cremation	R/UP	6N
91	91.1	Right	18	Upper Trinity	S	6N
93	93.3	Left	19	Upper Granite	R/UP	6N
104	103.9	Right	20		R/UP	6N
119	119.1	Right	21		R	7N
122	122.2	Right	22		R	7N
123	122.7	Left	23	Upper Forster	R/UP	7N
137	136.7	Left	24	Middle Ponchos	R	8N
139	139	Right	25	Upper Fishtail	R/UP	8N
145	145	Left	26	Above Olo	R	9N
172	172.2	Left	27		R	10W
183	182.8	Right	28		R	10W
194	194.1	Left	29		R	10W
202	202	Right	30		S	10W
213	212.9	Left	31	Pumpkin Spring	R/UP	10W
220	219.9	Right	32	Middle Gorilla	R/UP	11N
225	225.3	Right	33		R	11N

* Distance downstream from Lees Ferry in Stevens (1983) river miles (RM). Deposit type from Schmidt and Graf (1990): R- reattachment deposit, S - separation deposit, UP - upper pool deposit. Reaches (0-11) and channel width (W-wide, N-narrow) from Schmidt and Graf (1990).

Previous Work

Historical and concurrent studies of sand bar dynamics, morphology, and sedimentology that pertain to this study can be separated into research conducted prior to initiation of the Bureau of Reclamation's Glen Canyon Environmental Studies (GCES) program in 1982 (National Resource Council, 1987), publications from GCES Phase I and II investigations, the latter of which was intended to be used for the GCD-EIS (Bureau of Reclamation, 1994), and ongoing monitoring during the Interim Flow period.

Adverse downstream impacts from GCD were first recognized by Dolan et al. (1974) and early work that first quantified dam induced changes on sand deposits was based on analysis of aerial and ground photography since 1965 (Laursen and Silverston, 1976; Turner and Karpiscak, 1980) and topographic profile surveys of about 20 sand bars since 1973 (Howard, 1975; Howard and Dolan, 1981; Beus et al., 1985). These studies documented slight to insignificant instability and erosion of sand bars under the post-dam fluctuating flow regimes, with bar building and rapid erosion observed during the high flows of 1983-1986. Erosional patterns were described as being obscured by variability in reach characteristics, local channel geometry, poorly developed stage/discharge relationships, unknown antecedent conditions, and survey accuracy.

Public concern over dam operations culminated with the proposal by the Bureau of Reclamation in the early 1980's to revise and possibly increase the peaking power generation at GCD. This led the Department of the Interior, under pressure from the concerns of the public and other government agencies, to direct the Bureau of Reclamation to initiate the GCES Phase I program, the results of which are included in the GCES Final Report (U.S. Department of Interior, 1988) which was subsequently reviewed by the Water Science and Technology Board (1987). Several studies that were part of the Phase I program were the first to carefully describe the general hydraulic and sedimentologic characteristics of recirculation zones and associated bars. Schmidt and Graf (1990) developed a classification and description of alluvial sand deposits in Grand Canyon, a reach-length classification of the river corridor, and documented the history of bar aggradation and degradation at several study sites. Schmidt (1990) described the general association of sand bars with recirculating flow. Bar sedimentology and morphology were examined by Rubin et al. (1990). These studies greatly increased our understanding of the effects of fluctuating flows on sand bar stability and many of the concepts and processes discussed in this investigation were anticipated by them.

Increased public environmental concern initiated another phase of multidisciplinary research (GCES Phase II) in 1990 (Water Science and Technology Board, 1991) to provide information for the GCD-EIS. As part of this research, the Bureau of Reclamation conducted a series of discrete research flows from June 1990 through July 1991 to determine the impacts of specific flow regimes on sand bar stability (Beus and Avery, 1992). The test flows lasted a minimum of 11 days and included a variety of both steady and fluctuating releases. Fluctuating releases were either uniform (same daily pattern) or varied in response to changes in electrical load (normal releases). Each flow was preceded by 3 days of 142 m^3/s (5,000 ft^3/s). Important studies contained within Beus and Avery (1992) and other investigations conducted as part of the GCES Phase II program that are relevant to this report include bank stability changes related to

groundwater fluctuations (Carpenter et al., 1991; Budhu, 1992; Werrel et al., 1993), the importance of surface-gravity waves on sand bar stability (Bauer and Schmidt, 1993), modeling of recirculating flow (Nelson, 1991), daily photography detailing short-term topographic changes (Cluer, 1992), repeated surveying of topographic changes (Beus et al., 1992), and analysis of long-term trends in sediment storage (Clark et al., 1991; Schmidt, 1992; Webb et al., 1991).

In their evaluation of how alternative discharge regimes affect the stability of sand bars, 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, bars in wide reaches aggraded and 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 (Schmidt, 1992).

3) The total amount of sand bar instability during test flows, 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 (Beus et al., 1992).

4) Major periods of erosion followed periods of aggradation suggesting that antecedent conditions influenced subsequent changes in sand bar topography (Beus et al., 1992).

5) Periods of aggradation were associated with large-fluctuation flows, especially after tributary sediment input. However, high-fluctuating flows were also associated with degradation or little net change (Beus et al., 1992).

6) Net erosion or negligible change characterized the three constant flows and the low-fluctuation test flows (Beus et al., 1992).

7) Bank failure correlates with change from one flow regime to another. Consequently, ramping rate, in particular down-ramping, was suspected to be the most destructive component of flow under normal dam operations. This is, in part, correlated to river stage dropping faster than bank-stored groundwater can drain from the sand bars, leaving a perched water table in the bars. As the water drains, it causes rilling and ultimately mass wasting of oversteepened banks at the water's edge (Budhu, 1992; Werril, 1992).

8). Both short- and long-term discharge patterns from Glen Canyon Dam affect the stability of sand bars (Beus and Avery, 1992).

The results from the GCES Phase II research flows, and in lieu of a Record of Decision for the GCD-EIS, led the Bureau of Reclamation to examine the effectiveness of the Interim Operating Criteria. Ongoing monitoring studies related to this investigation during the Interim Flow period are repeated inventories of campsite size (Kearsley et al., 1994; Kearsley, 1995), sedimentologic investigations (Rubin et al., 1994), the importance of seepage erosion (Budhu and Gobin, 1994), daily eddy dynamics (Dexter et al., 1994), and long-term history of sediment storage change (Schmidt, 1994; 1995).

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 constrictions and expansions in the main river channel (Figure 2; Webb et al., 1989). These channel irregularities produce a recirculation zone (eddy) where flow separates from and then reattaches to the bank (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 et al., 1993). Deposition is typically localized near the separation point, reattachment point, and eddy center.

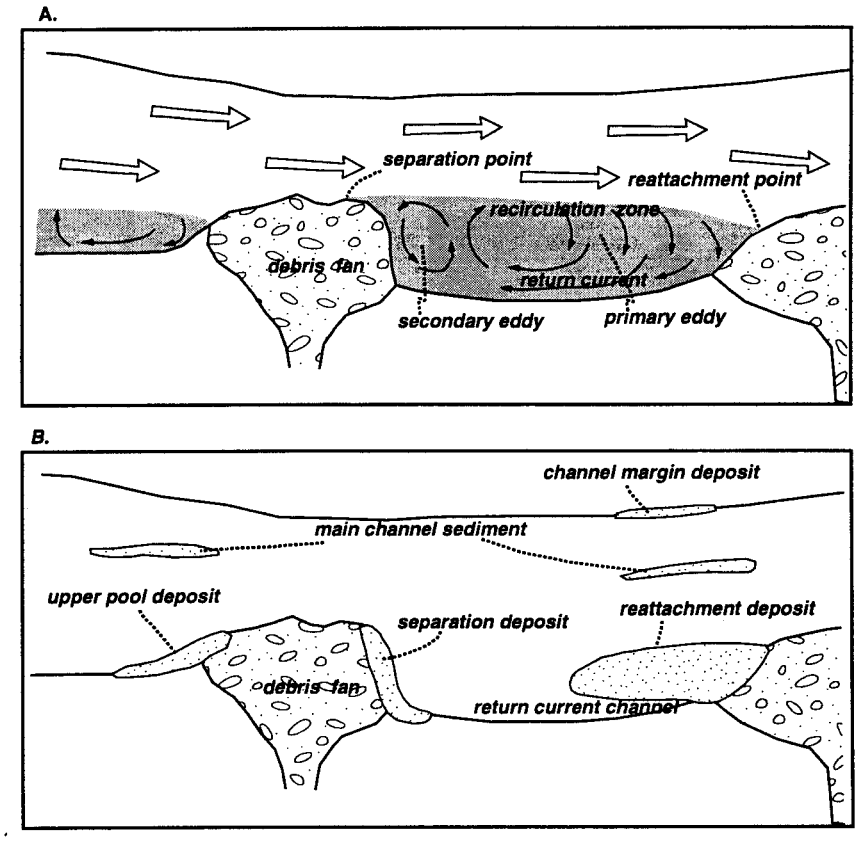


Figure 2. Schematic diagram showing flow patterns and configuration of bed deposits in a typical recirculation zone. A) flow patterns. B) configuration of bed deposits. Modified from Schmidt and Graf (1990).

Schmidt and Graf (1990) recognized several different types of alluvial sand deposits in Grand Canyon. These are:

Reattachment deposits form near the reattachment point of large primary eddies (Rubin et al., 1990). These bars are typically deposited along the downstream regions of the eddy by currents sweeping across the eddy toward the shore, 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. When a recirculation zone is present in the pool above the constriction an *upper pool deposit* is typically deposited that is similar to reattachment bar morphology or exists as a linear deposit along and parallel to the shoreline.

Separation deposits typically form immediately downstream of debris fan 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.

Channel margin deposits are those that parallel the shoreline in areas not specifically related to recirculation zones or separation points. This type of deposit was not examined in this study.

In addition to the above, *main-channel sediments* are transported and locally deposited along the channel bottom and in pools above constrictions.

The morphology and sedimentology of sand bars in recirculation zones is closely associated with changing flow patterns in the recirculating eddy (Rubin et al., 1990; Schmidt, 1990). During increasing discharge, recirculation zones expand as more bar area is inundated, and secondary eddies or low velocity zones develop upstream of the return current channel. This results in downstream migration of the reattachment point and upstream migration of the separation point onto the debris fan (Schmidt, 1990). Deposition rates also increase (Andrews, 1991a). The reattachment deposit may fill much of the recirculation zone beneath the primary eddy. During periods of low discharge recirculation zones generally consist of a smaller, primary eddy and large areas where both the reattachment and separation bars are exposed (Schmidt and Graf, 1990).

Flow Regimes During Study

The discharge of the Colorado River in Grand Canyon has been regulated by GCD since its completion in 1963. GCD has substantially reduced the sediment load, sediment concentration, duration of high flows, and peak-flow rates compared to the unregulated streamflow of the pre-dam era. The annual flood from spring runoff is contained by Lake Powell. Only under extreme circumstances such as the extended periods during 1983-86 when spillway releases were necessary, has discharge exceeded maximum powerplant capacity of 940 m^3/s (33,200 ft^3/s). The other important flow exception during the post-dam era occurred in 1965 and 1980 for reservoir balancing and spillway tests, respectively, and when discrete research flows were conducted from June 1990 through July 1991 to provide data for the GCD-EIS. Prior to these test flows and until Interim Flows were implemented, the previous range of discharge fluctuation was 85 m^3/s (3,000 ft^3/s) to 892 m^3/s (31,500 ft^3/s), with no limitations on maximum daily change and the rate of change in powerplant output discharge (ramp rate).

Interim Flows limit the maximum discharge to 566 m^3/s (20,000 ft^3/s), the minimum discharge to 142 m^3/s (5,000 ft^3/s), with up- and down-ramp rates of 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. In addition, normal dam operations that have continued during the Interim Flow period are 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 (Figure 3). Interim Flow criteria specify that daily change cannot exceed 142 m^3/s (5,000 ft^3/s) during low volume months, 170 m^3/s (6,000 ft^3/s) during medium volume months, and 227 m^3/s (8,000 ft^3/s) during high volume months. Normal operations still include reduced flows on weekends as electrical demand decreases.

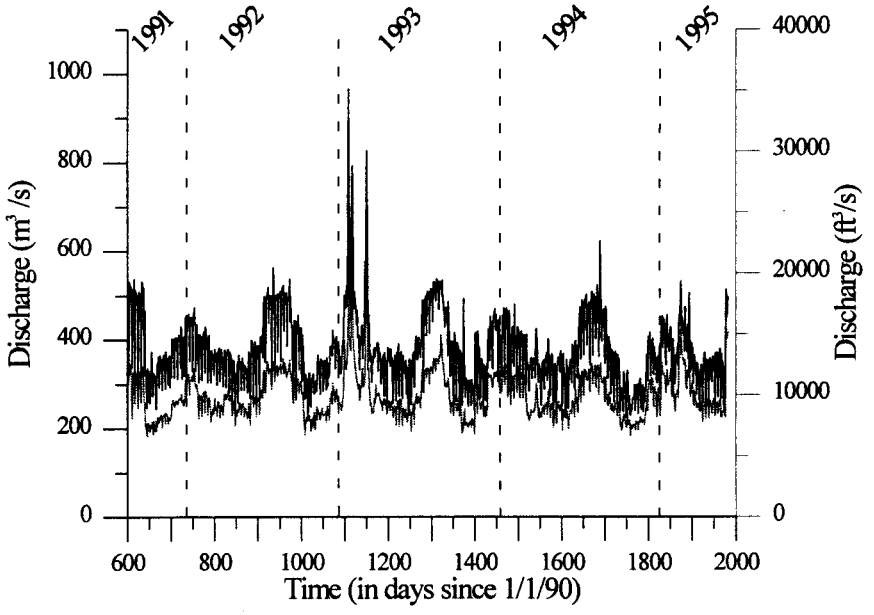


Figure 3. Daily minimum and maximum discharge hydrograph from Colorado River gage near Grand Canyon (RM 88) for the interval between September 1991 and June 1995. Note seasonal variation in flows. Provisional USGS gage data.

Natural flood events on the LCR during January and February, 1993, caused a significant deviation from the lower-volume Interim Flows on the mainstem Colorado River (Figures 3 and 4). Three separate floods, January 12-16, January 19-23, and February, 23-26, 1993, raised flows that peaked at Phantom Ranch (RM88) to approximately 966 m^3/s (34,120 ft^3/s), 793 m^3/s (28,016 ft^3/s), and 824 m^3/s (29,100 ft^3/s), respectively. It is important to note that the EIS-Preferred Alternative (EIS-PA) is essentially the same as Interim Flows with the exception of an additional, annual or biannual bar-building/habitat maintenance flows and experimental steady flows for endangered aquatic species (U.S. Bureau of Reclamation, 1994). By raising mainstem flows to slightly above powerplant capacity and delivering a significant amount of sediment, the 1993 winter floods provided an unexpected test-case of a bar-building flow event (Hazel et al., 1993). Therefore, results from this study are directly applicable to a critical evaluation of the success of the EIS-PA scenario and proposed flow exceptions.

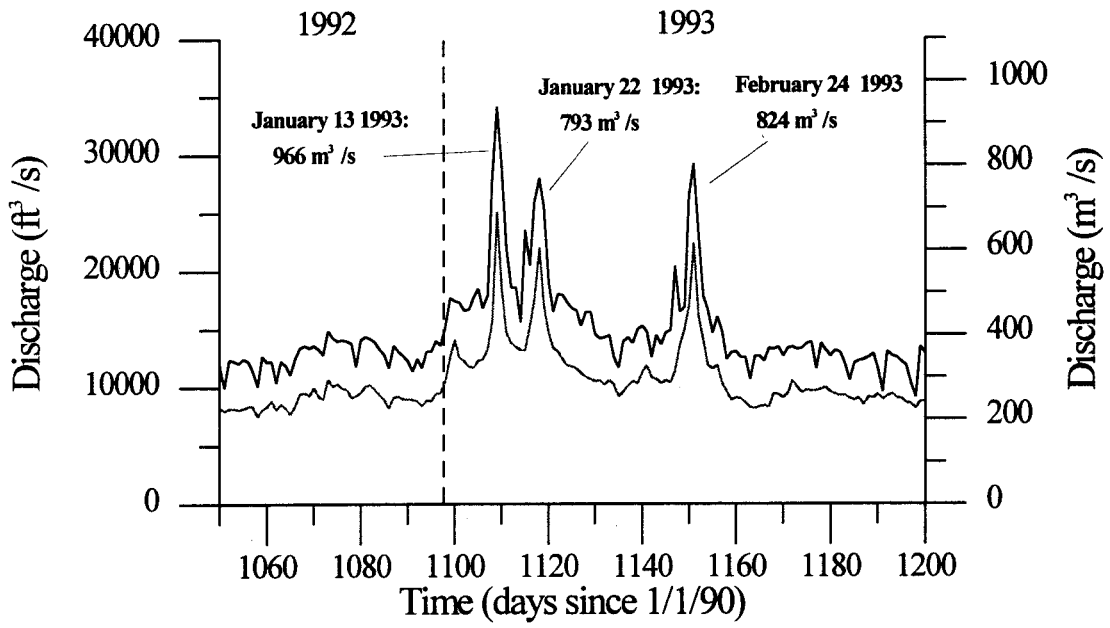


Figure 4. Daily minimum and maximum discharge hydrograph from the Colorado River gage near Grand Canyon (RM88) for the interval between February 1993 and March 1993. Provisional USGS gage data.

METHODS

Study Sites

We collected topographic and bathymetric measurements from thirty-two sand bar study sites along the Colorado River corridor during five river survey expeditions: October 15-November 3, 1992, April 1-15, 1993, October 7-28, 1993, April 7-18, 1994, and November 20-December 5, 1994 (Figure 1; Table 1; Appendix A). However, not all sites were sampled during every research trip (Table 2). Our data set also includes surveys conducted after 1 to 2 months of Interim Flow operations, during October and November, 1991 (Table 2). In addition to topographic surveying, sedimentologic data was acquired from trenching 1993 winter flood and pre-flood deposits.

Study sites (sand bars) were named on the basis of river mile (RM) and located within each of the geomorphic reaches defined by Schmidt and Graf (1990). Twelve sites are located between the Paria and LCR confluences, a reach supplied with sand primarily from the Paria River (RM1). Eighteen sites are situated between the LCR and Diamond Creek, and receive sediment from the Paria, LCR, and other tributaries. One site, RM-6, is located 6.5 miles upstream from Lees Ferry (RM0) in the tailwaters reach below GCD, which has no regular tributary contribution of sediments.

Data Collection

Field surveys during the Interim Flow period were conducted bi-annually during low-discharge months in the spring and fall on 15-20 day river trips. The trips typically 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 total stations equipped with digital data collectors. Site size and topographic complexity determine the point density needed to form proper topographic models. Smaller sites (~2000 m^2) typically require 200-400 points and larger sites (~10,000 m^2) require 750-1000 points. Points are also collected offshore to depths of approximately 1 m to provide overlapping coverage with the bathymetry survey and extend the ground-based coverage across the entire HAZ region (see discussion of HAZ later in the Methods section). Survey protocol was developed during the GCES Phase II test flows (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. Priority was placed on completing surveys within the zone of dam fluctuation, then expanding coverage to the higher elevations. Survey coverage typically extended from the 142 m^3/s (5,000 ft^3/s) stage elevation to slightly above the 850 m^3/s (30,000 ft^3/s) stage elevation contour. Upon completion of each survey, field data were transferred to micro-computers and edited.

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

Table 2. Interim Flow Sand Bar Surveys

		July 1991		September 1991		October 1991		October 1992		April 1993		October 1993		April 1994	
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	Vol m^3	Area m^2
-6R	R	3388	3523					3331	3645	3370	3516	3338	3470	3276	3585
3L	R	3564	3016			2640	2467	4052	3601	3995	3448	3249	2774	3417	3130
8L	S	1351	1482			1316	1524	1354	1729	1408	1788	1301	1440	1286	1403
16L	S	1726	1284					2103	1549			1316	981	1386	1122
22R	R	3578	1727			3197	1474	3276	1593	3532	1819	2012	4008	3930	1994
30R	R	7366	3656							5662	3377	3708	2379	3969	2922
31R	S	2055	2407	2013	2400	1936	2298	2033	2884	2124	3333	1740	2130	1806	2315
43L	R/UP	3661	2107	3629	1903	3610	1959	3453	1844	3285	1723	3380	1744	3616	1974
45L	S	3456	2585	3549	2656			3119	2479			3121	2498	3133	2550
47R	R	7647	7180					5790	5923			5761	6078	5313	5273
50R	S/R	3921	2452					2390	1952	2394	2099	2782	2475	2732	2547
51L	R	6441	5939	6422	5830	6463	5789	6109	5519	6029	5596	4511	4093	5136	4981
68R	S/R/UP	3723	3077	3410	2658	3426	2818	3171	2979	2390	2102	6341	4828	5496	4106
81L	R/S/UP	2811	1334	2520	1184	2515	1154	2391	1170	2766	1249	2567	1198	2485	1180
87L	UP	492	317	521	323			607	395	596	571	593	414	605	414
91R	S	241	223	169	139	171	135	189	208	216	155	171	126	180	161
93L	UP/R	1634	1401	1256	1021			1888	1690	2145	1717	2057	1590	2224	1878
104R	UP/R	526	364					504	360			428	289	426	311
119R	R	4825	2792	3645	2291			2481	1724	3952	2360	3192	2011	2767	2252
122R	R	4928	3622			4900	3568	4435	3134	5666	2990	5120	2860	4908	3004
123L	R/UP	1310	1280					1223	1317			1160	1118	825	954
137L	R	4989	2924	4116	3018	4189	2965	3965	2994	4074	2879	3712	2976	3761	3074
139R	R/UP	3768	1896					3252	1989			1867	1113	2701	2079
145L	R	928	582	833	540	838	510	756	496	1046	570	933	549	916	544
172L	R/UP	2448	2254	1327	1068	1340	1120	1719	1415	1535	1105	1043	878	1367	1591
183R	R/UP	2670	2077	2694	2152			2905	2237	4723	2710	4180	2436	4023	2476
194L	R/UP	4357	3284	4263	3296	4388	3234	4464	3377	4823	3287	5005	3451	4765	3363
202R	S	3710	2230					3075	1981	2991	1768	2295	1611	2133	1617
213L	R/UP	2772	1334					3625	1693	3781	1520	2802	1398	2814	1514
220R	S/UP	1190	717			1069	719	1035	719	1266	742	953	665	1032	712
225R	R	4695	2822					5440	3286			3975	1860	4588	2646

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

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. 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, the GCES survey division purchased the "Hydrographics Survey Package" (HSP) that consists of a shore-based total station, a boat-mounted transducer, a digital/analog receiving unit, and a computer that controls the digital data collection process. The shore station data is radio-telemetered to the boat computer where depth-position data is calculated and automatically stored. Starting in April, 1993, and continuing to the present, the HSP has been used by bathymetry crews to survey two sites per day.

Data Processing and Analysis

Topographic Model Formation

The ground-based and bathymetric survey points were combined and used to form a Triangulated Irregular Network (TIN) model of the sand bar surface using Sokkia Mapping Software (Datacom Software Research Limited, 1992). Breaklines were coded during ground-based data collection along lines known to have a constant grade, such as cutbanks, water surface lines, slope breaks, etc. Breaklines are used in TIN model formation to force individual prism sides along the proper grade breaks and stop the program from making incorrect interpolations across the surface (Datacom Software Research Limited, 1992). Topographic maps of the sites were prepared with a 0.2 m contour interval to insure proper model formation. The surface model, not the topographic map, is used to generate profiles at predetermined locations (appendix A), and determine volumes and areas within what we term the "hydrologically active zone" (HAZ) (Table 2).

The "Hydrologically Active Zone" (HAZ)

The HAZ is a boundary formed around a subset of the survey area that encompasses the elevation range of dam operations (142-850 m^3/s). The concept of the HAZ boundary was developed during the GCES Phase II test flows to provide a consistent, repeatable region, within which to quantify changes in sand bar volume and area due to dam operations (Beus et al., 1992). The HAZ is used in this study to examine changes in sediment storage, recreational use, and riparian habitat areas, resources which are recognized management priorities for Grand Canyon National Park. A limitation of this analysis is that it does not detect changes outside the range of the HAZ boundary. However, the improvements in bathymetric survey techniques

described earlier allow us to compare changes in the sandbar surface throughout the eddy complex.

The HAZ boundary consists of two sections: a fixed upper and side section, and a mobile front section. Figure 5 shows an example HAZ zone constructed at RM122 for two different surveys. These segments are formed using the following general guidelines. The upper, or back HAZ boundary is placed at or slightly above (~0.5 m) the 850 m^3/s stage elevation. While the survey coverage typically extends beyond this stage elevation, placing the HAZ boundary at this level isolates the region directly affected by dam operations. The side sections of the fixed boundary at reattachment bars were placed along the center of the return channel. In addition, the HAZ boundary typically excludes large boulders, armored areas, large groves of vegetation, and regions of poor survey accuracy. The fixed section of the HAZ boundary in Figure 5 (solid black line) follows the approximate level of the 850 m^3/s stage elevation (93-93.4 m) along the rear of the bar, excludes a large boulder and tamarisk trees (the large indentation), and follows the return channel. The lower HAZ boundary is defined by the 142 m^3/s stage elevation contour in between the intersection with the fixed segment (Figure 5). HAZ volumes and areas are determined by calculating the volume above the 142 m^3/s stage elevation contour within the boundary (Table 3, Figure 5).

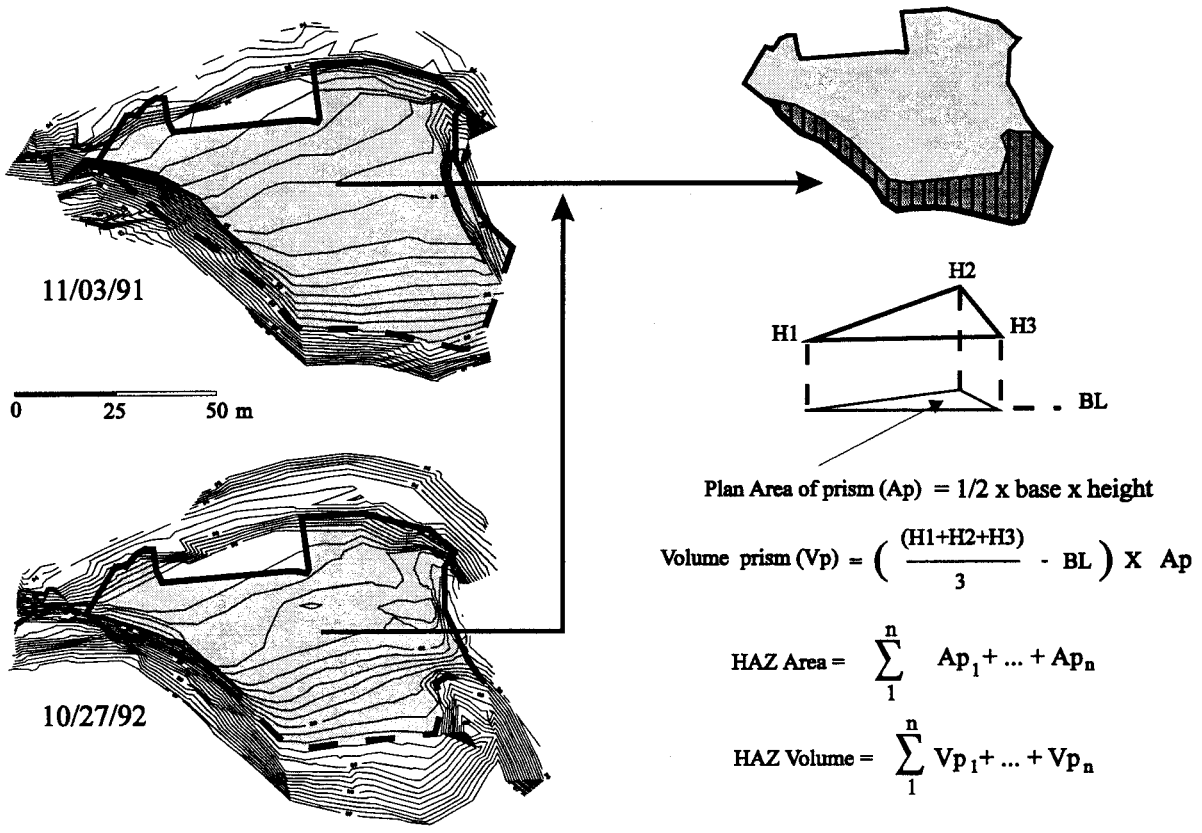


Figure 5. Topographic maps from RM122 showing HAZ boundary and area and volume calculations.

We tested the HAZ volume dataset using two standard nonparametric statistical methods; Friedman two-way analysis of variance by ranks and Wilcoxan paired sample test (Zar, 1974, Daniel, 1990). The Friedman analysis tests the null hypothesis (H_o) that there is no difference in HAZ volume between survey runs. This test ranks the HAZ volume values from lowest to highest for each block (site), then sums the ranks down each column, or survey run. If H_o is true, the column rank sums will be fairly close in size. If the H_o is false, we would expect a lack of randomness in this distribution. In this example, large or small ranks would indicate a systematic gain or loss of HAZ volume between survey runs. The Friedman test detects departures from the expectation under H_o on the basis of the magnitudes of the sums of the ranks by columns. If the Friedman test leads to rejection of H_o, an additional multiple-comparison procedure was applied to determine where the differences are located (Daniel, 1990). In the discussion of test results that follows, we present the Friedman test statistic (F), the number of number of cases (n), and the significance value (p) to describe the test results in the following format: (F(n)=###, p= ###).

The Wilcoxan paired-sample test by ranks (Zar, 1974) tests the H_o that there is no significant difference between the number of sites eroding versus the number of sites that aggraded in each category (5% confidence interval). Based on daily repeated surveys at RM45 (Figure 1), Beus et al. (1992) determined that the survey techniques used in this study have a survey precision of plus or minus 3%. Volume changes are considered increases or decreases if the volume change exceeded 3% of the starting HAZ volume, and the same if changes did not exceed three percent. Rejection of H_o indicates that a significant *number* of sites either gained or lost volume within the HAZ between survey runs. Because multiple comparisons were made based upon the same dataset, we also employed the sequential Bonferoni technique to adjust the significance values (p) accordingly (Holm, 1979). In our discussion of the results from this test we present the Wilcoxan test statistic (T), number of blocks (n), and significance level (p) in the following format: (T(n)=###, p=###, p<>###), where the second p value is the level needed to achieve significance, as determined from the sequential Bonferoni procedure.

Hypsometry

Hypsometry is the distribution of area with respect to elevation for a topographic surface (Strahler, 1952; Schumm, 1956; Bloom, 1991). By using dimensionless parameters, hypsometric curves can be used to compare different regions, irrespective of true scale. Hypsometric analysis has previously been applied to Grand Canyon sand bars by Kyle (1992) and Schmidt (1992). These studies derived hypsometric relationships for topographic profiles to estimate volume changes at several Grand Canyon sand bars. Improvements in bathymetric survey techniques have allowed us to define the hypsometric relationship within the entire recirculation zone at each of our study sand bars. Comparing hypsometric relationships of repeated surveys at individual sandbars can describe the change in sediment distribution within the eddy system. Comparison of all study sites can be used to determine whether dam operating strategies have led to system-wide changes in the distribution of sediment within recirculation zones.

The hypsometric curve data were derived from 0.5 meter contour maps of the study sites (Appendix A). The contour maps were generated from TIN models that combined topographic and bathymetric data. TIN models for this analysis were created with ARC/INFO software following transfer of the survey information to the GCES Geographic information system (Kaplinski et al., 1994a). Results from the GIS-based analysis were exported to DOS-based machines for analysis.
The hypsometric data are calculated from within a boundary that was constructed to approximate the size and shape of the recirculation zone at 30,000 ft^3 /s and excluded the main channel. The areas enclosed by each contour line within the boundary were summed to generate the area distribution with elevation histograms and hypsometric curves. To convert the recirculation zone areas and elevations to dimensionless parameters which are comparable irrespective of individual eddy shape or size, the area values were divided by the total recirculation zone area and the height values were divided by the total recirculation zone height.

We used the Friedman analysis to test the null hypothesis that no significant difference in the hypsometric curve integrals between survey runs. The hypsometric integral, calculated for each curve (Table 3), is defined as the ratio between the volume of the recirculation zone surface above the base elevation and the volume of the rectangular figure defined by the height difference multiplied by the maximum area of the hypsometric boundary. Changes of the hypsometric integral over time would indicate GCD-flow induced, system-wide sediment storage changes within recirculation zones. The Friedman test results are presented as discussed in the HAZ volume analysis section above.

Stage-Discharge Ratings

Stage-discharge relationships were empirically developed for each site (Appendix A) by compiling daily high and low water surface elevations collected during the GCES Phase II test flow and Interim Flow periods. Discharges were assigned to each elevation by comparing the daily high and low discharges from the nearest U.S. Geological Survey gaging station above and below each site. Data were plotted and a best-fit line (in most cases a 2nd order polynomial) was calculated at each site to determine the stage discharge relationship. Local changes in the stage discharge relationship can be caused by changes in the channel constriction due to debris flows and, to a lesser degree, by changes in sandbar topography. Over the period of study only debris flow-induced changes in the channel constriction caused significant changes in the local stage discharge relationship. These relationships were derived to define the upper and lower HAZ boundary and to quantify changes in specific stage elevation ranges.

Table 3. Hypsometric Integrals

Site	7/91	10/92	4/93	10/93	4/94	10/94
-6	0.493	0.497	0.499	0.528	0.498	0.521
3			0.745	0.677	0.728	0.693
16		0.631		0.535	0.574	
22			0.474		0.485	0.473
30			0.566	0.532	0.543	0.547
32		0.695		0.647		0.651
43		0.492	0.507	0.515	0.470	0.502
45				0.633	0.618	0.625
47		0.617		0.602	0.598	0.548
50		0.497		0.500	0.476	0.487
51		0.715		0.713	0.725	0.723
62			0.827	0.633	0.542	0.498
68		0.566		0.679	0.686	
81				0.647	0.615	0.580
87		0.439		0.423	0.412	0.404
91		0.572	0.533	0.538	0.552	0.552
93		0.630		0.628	0.623	0.600
104					0.576	0.565
119		0.531		0.537	0.538	0.534
122		0.700	0.695	0.690	0.696	0.685
123		0.567		0.564	0.543	0.574
137		0.432	0.429	0.438	0.415	0.428
139		0.501		0.482	0.508	0.482
145	0.510	0.470	0.514	0.502	0.492	0.477
172		0.505		0.490	0.507	0.507
183		0.489	0.512	0.506	0.504	0.497
194		0.727	0.724	0.742	0.734	0.734
202		0.620	0.598	0.549	0.589	0.553
213		0.567	0.568	0.548	0.561	0.555
220		0.649	0.664	0.654	0.690	0.650
225		0.603		0.556	0.611	0.588

RESULTS AND DISCUSSION

Sediment Volume

HAZ Analysis

Grand Canyon sandbars were significantly impacted by Interim Flows and tributary interactions during this study. We use sand volume fluctuation within the HAZ to quantify these impacts (Table 3 and 4). The general pattern of HAZ volume adjustment to the varying flow regimes of the past three years is highlighted by the Friedman analysis (Figure 6). The pattern is characterized by an overall decrease in volume that is interrupted by a substantial increase as a result of the winter 1993 LCR floods. The Friedman test shows that there is a significant difference between survey runs ($F(22)=21.506$, $p = 0.001$) and that HAZ volumes from surveys conducted in July, 1991 and April, 1993 are significantly lower than the November, 1994 surveys (difference in Rank sums > 36, p(0.05)). Subtracting volumes measured at the beginning of Interim Flows (7/91) from surveys conducted nearly three years later (4/94) demonstrated that a significant number of sites (65%; Wilcoxan $T(31) = 128$, $p=0.009$, $p< 0.0125$) have decreased in sand volume during the period of study (Figure 6a and Table 4). Subdividing the dataset into sites above and below the LCR showed that an even greater percentage (83%; $T(12)=6$, $p=0.007$, $p<0.0125$) of sandbars above the LCR have decreased in sand volume, while the amount of volume loss below the LCR was not significant (32%; $T(19)=67$, $p=0.13$, $p>0.025$) during the period from 7/91 to 4/94. The largest volume losses occurred between the 7/91 and 10/92 surveys (Figure 6b; 67%, $T(30)=147$ $p=0.042$, $p>0.025$) as well as between the 4/93 and 10/93 surveys (Figure 6d; 84% below the LCR, $T(19)= 47$ $p=0.029$, $p>0.025$). Comparison of the latest survey runs showed no significant difference between sites that had eroded and those that had gained sediment (Figure 6e; $T(31)=236$, $p=0.27$, $p>0.05$). This shows that erosion rates are high following a change in dam operations and then decrease with time, as reported by Schmidt and Graf (1990) and Schmidt (1992). These analyses show that erosion during the Interim Flows period significantly decreased the amount of sand volume between the 850m^3/s (30,000 ft^3/s) and 142m^3/s (5,000ft^3/s) stage elevations.

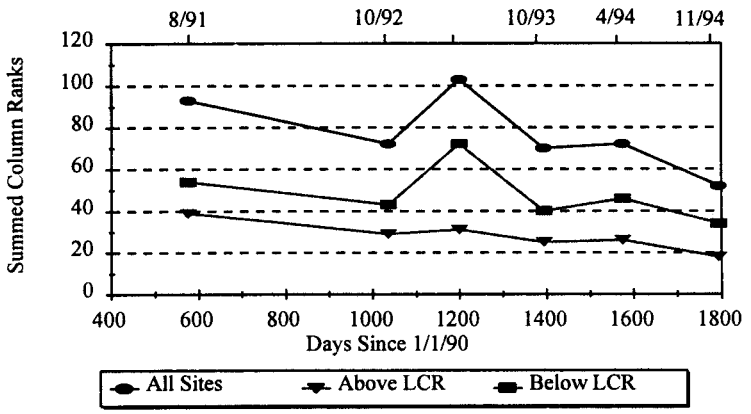


Figure 6. Plot of HAZ volume summed columns ranks used in the Friedman Analysis as a function of time.

Tributary flood events have also had a significant impact on Grand Canyon sand bars. Deposition during flood events temporarily replaces sediment lost from the bars during low-volume flow periods such as Interim Flows. A significant change in volume occurred ($F(14)=17.143$, $p=.004$) and a significant number of sites aggraded (65%, $T(15)=20$ $p=0.0003$, $p<0.01$) between the 10/92 and 4/93 surveys at sites below LCR (Figures 6 and 7c). Above the LCR and tributary sand input sites showed a general trend of decreasing volume but no significant difference between surveys (Figure 6; $F(8)=8.714$, $p = .121$). The subset of sites below the LCR increased significantly in volume between the surveys surrounding the winter 1993 flood events (10/92 to 4/93, 4/93 to 10/93) as well as a significant decrease in volume between the 4/93 and 11/94 surveys (difference in Rank sums > 28, p(0.05)). Sand bars that aggraded below the LCR were quickly destabilized to pre-flood conditions within one year (Figure 7d). Comparison of surveys over the entire Interim Flow period (Figure 7a) showed that there was not a significant number of sites eroded below the LCR, while a significant number of sites above the LCR eroded (above the LCR $T(12)=6$ $p=0.007$, p; sites below the LCR $T(19)=67$ $p=0.13$, $p>0.025$). We attribute this difference in erosional patterns above and below the LCR to tributary sediment supply and flood-related deposition.

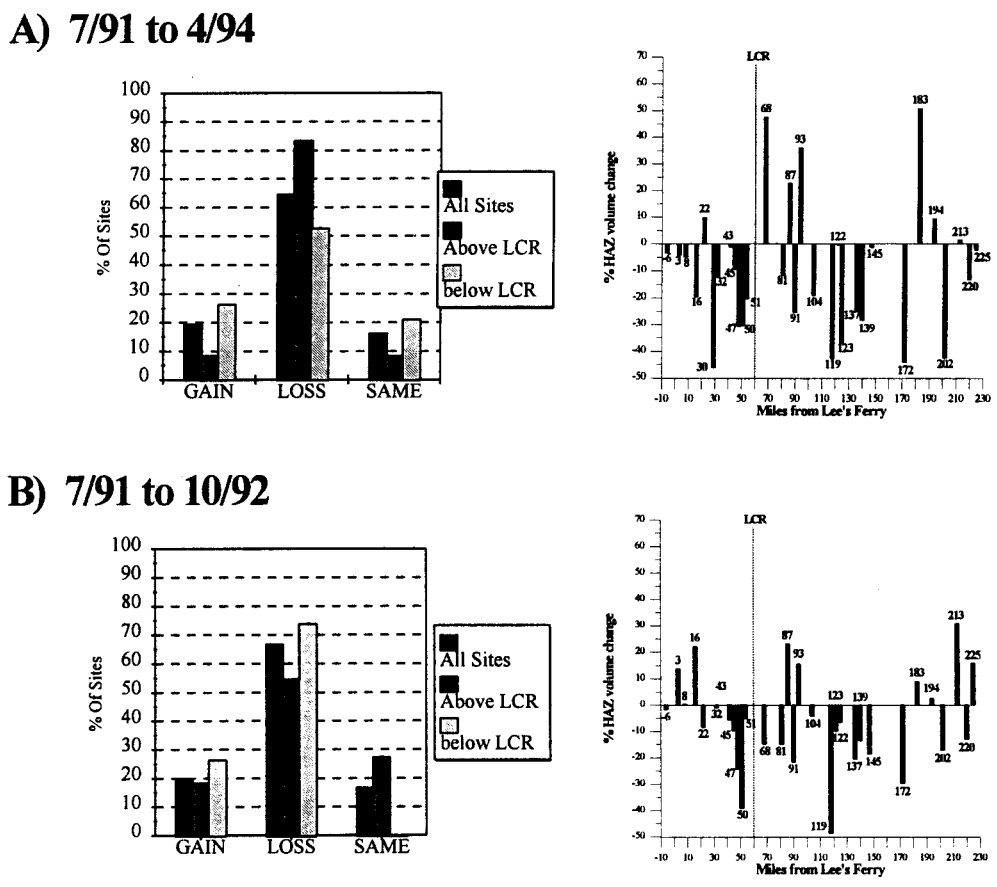
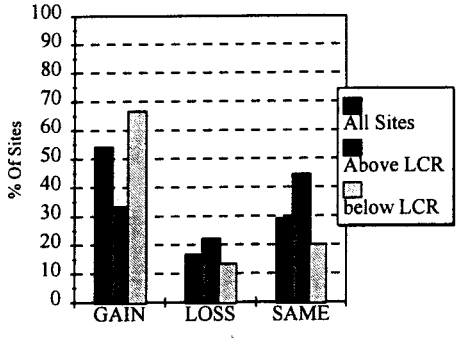
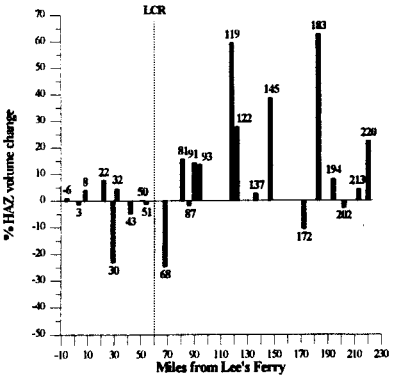


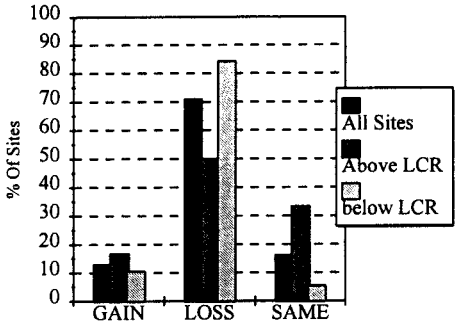
Figure 7. HAZ volume histograms. The volume change comparisons are shown as percentages of the site categories, and as a function of distance downstream from Lee's Ferry.

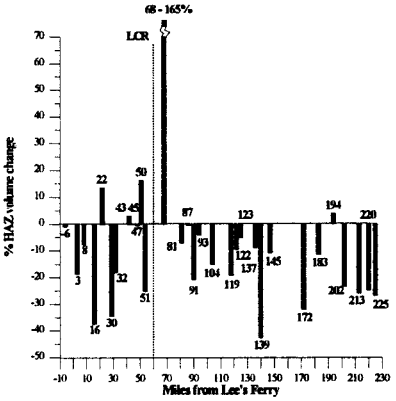
C) 10/92 to 4/93



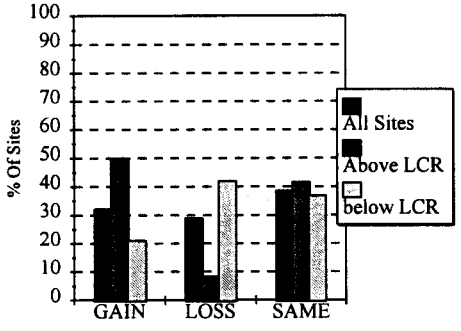


D) 4/93 to 10/93





E) 10/93 to 4/94



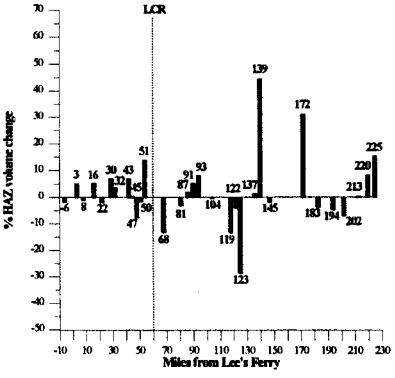


Figure 7. continued

Table 4. HAZ Volume Changes

8/91 to 4/94	INCREASE	DECREASE	SAME
All Sites Percent (number) n=31	19% (6)	65% (20)	16% (5)
Sites Above the LCR n=12	8% (1)	83% (10)	8% (1)
Sites Below the LCR n=19	26% (5)	32% (10)	21% (4)
8/91 to 10/92			
All Sites n=30	20% (6)	67% (20)	10% (3)
Sites Above the LCR n=11	18% (2)	55% (6)	27% (3)
Sites Below the LCR n=19	26% (5)	74% (14)	0% (0)
10/92 to 4/93			
All Sites n=24	54% (13)	17% (4)	29% (7)
Sites Above the LCR n=9	33% (3)	22% (2)	44% (4)
Sites Below the LCR n=15	73% (10)	13% (2)	20% (3)
10/92 vs 10/93			
All Sites n= 31	32% (10)	52% (16)	16% (5)
Sites Above the LCR n=12	17% (2)	50% (6)	33% (4)
Sites Below the LCR n=19	42% (8)	53% (10)	5% (1)
4/93* to 10/93			
All Sites n=31	13% (4)	71% (22)	16% (5)
Sites Above the LCR n=12	17% (2)	50% (6)	33% (4)
Sites Below the LCR n=19	11% (2)	84% (16)	5% (1)
10/93 to 4/94			
All Sites n=31	32% (10)	29% (9)	39% (12)
Sites Above the LCR n=12	50% (6)	8% (1)	42% (5)
Sites Below the LCR n=19	21% (4)	42% (8)	37% (7)

*most recent survey was used for comparison where 4/93 survey was not available.

Hypsometric Analysis

Analysis of hypsometric integrals from a subset of the surveys conducted indicates that there was no significant difference in total sediment volume within recirculation zones during Interim Flows. We find no significant difference in hypsometric integrals during Interim Flows. Friedman analysis of the hypsometric integral dataset from 4/93 to 11/94 leads to acceptance of the null hypothesis that there is no significant difference in hypsometric integrals between survey runs ($F(14)=5.98$, $p=0.113$). However, while not a statistically significant difference, the hypsometric integrals showed a decreasing trend with time (Figure 8). This observation suggests the possibility that Interim Flows have led to a net loss of sediment storage within the recirculation zones. If Interim Flows were achieving the objectives of maintaining a positive mass balance of sediments and minimizing sand bar erosion, the expected result would be a measurable increase of sediment volume within eddy systems. We have observed that the lower elevation areas of sand bars have aggraded during Interim Flows. We suggest that smaller Interim Flow recirculation zones cannot store the quantity of sediment needed to show a net increase in sediment volume.

A major disadvantage of the Friedman analysis is that null values are not tolerated (Daniel, 1990). Less than half of the sites were included in the analysis because of missing values due to logistical constraints and failure of the bathymetric data collection system (Table 3). Many sites that were excluded had changed notably during our monitoring, but are not represented in the analysis. With additional surveys, however, this analysis does show promise as a tool for the measurement of sediment storage in eddies.

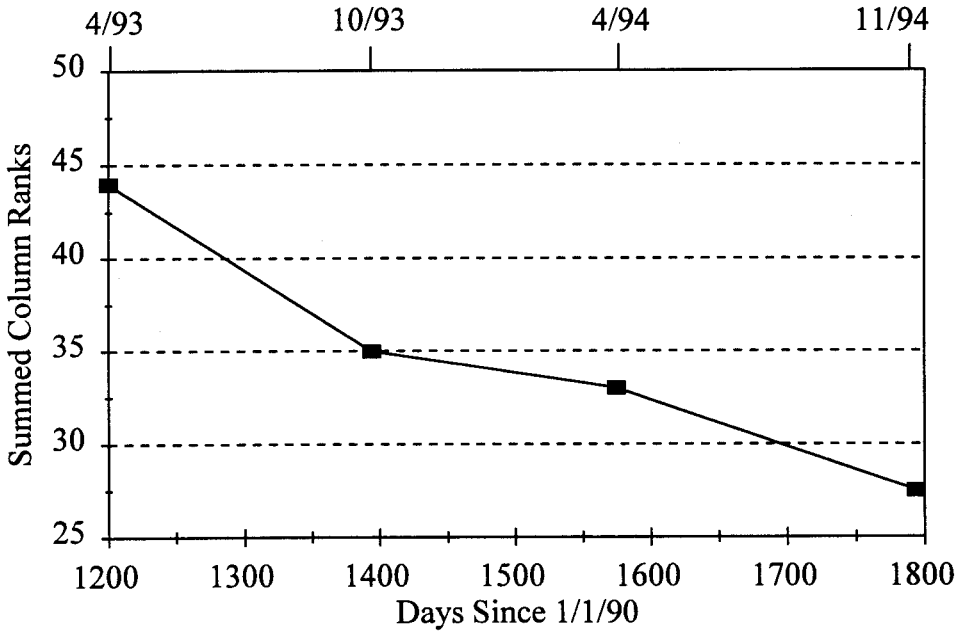


Figure 8. Plot of hypsometric integral summed columns ranks used in the Friedman Analysis as a function of time.

Geomorphic Adjustment of Sand Bars

The HAZ volume analysis discussed in the previous section clearly demonstrates that Interim Flows and large tributary floods have had a major impact on Grand Canyon sandbars. In general, within recirculation zones, erosion dominated above the water level of the maximum fluctuation, while deposition occurred below. In addition large-scale adjustments of sand bar morphology have occurred because of local tributary flash floods and debris flows. This section describes the general impacts to sand bars and the processes of geomorphic adjustment based on qualitative comparison of topographic and bathymetric surveys, field observations, and photographic data.

Interim Flows

Interim Flows generally eroded the upper, exposed portion of bars. The bulk of this erosion occurred as cutbanks developed and migrated into the sand bar (e.g. Appendix A: RM50, profiles 7 and 9; RM81, profile 5). Cutbanks developed at the upper limit of flow fluctuations and caused progressive erosion (Figure 9). This has lowered the tops of the majority of reattachment bars platforms under study by 0.5 to 1.5 m. Separation bars were also eroded and several sites became increasingly armored by rocks (Figure 10).

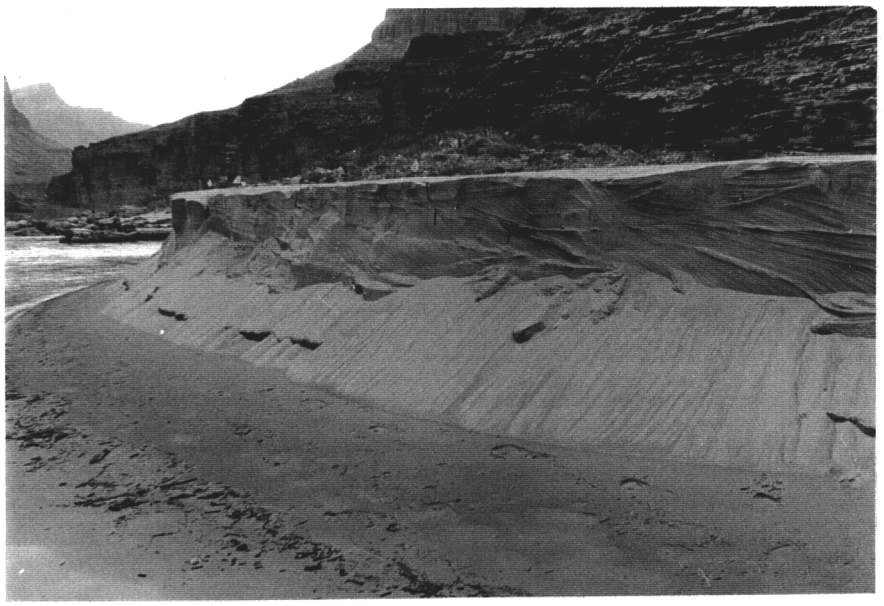
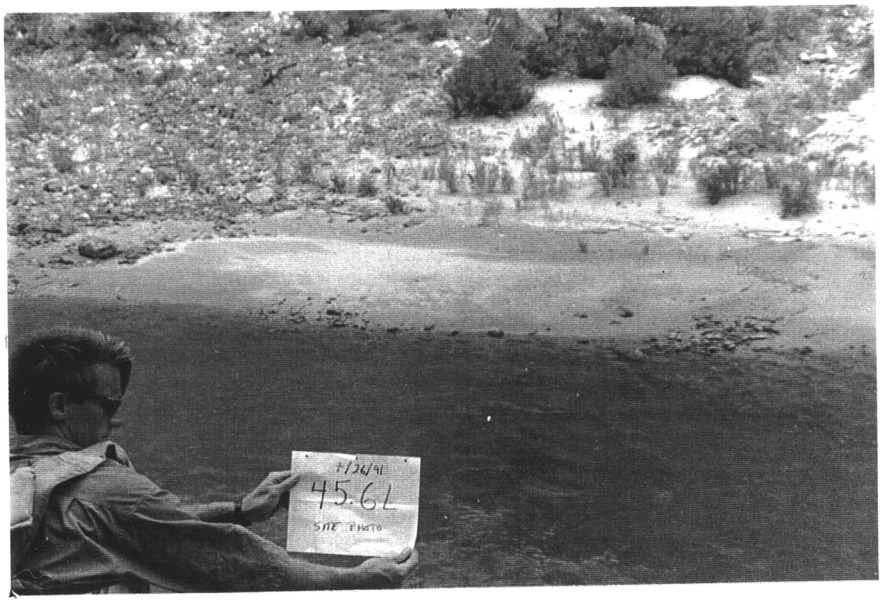


Figure 9. Large cutbank developed after 1993 LCR floods at RM62. Photograph taken on 4/5/93.

A.



B.

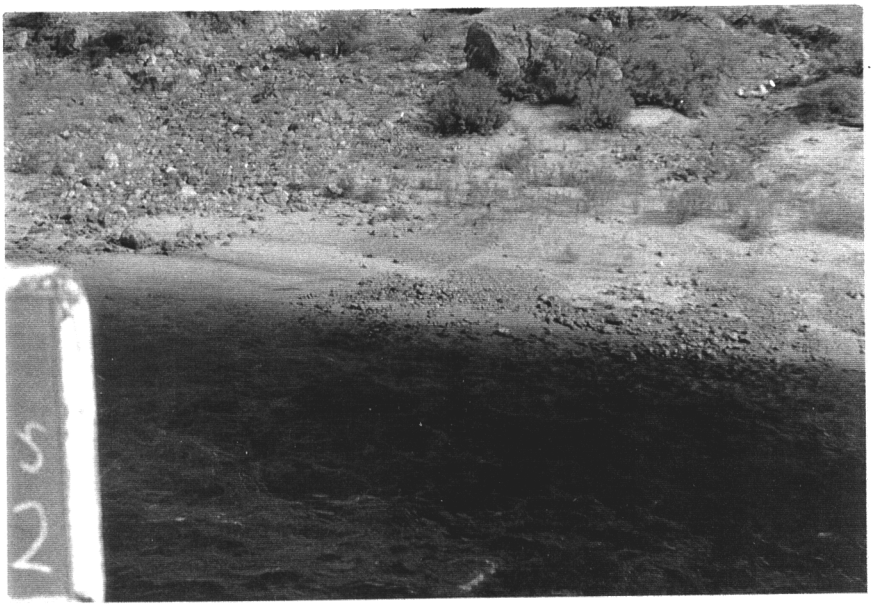


Figure 10. Photographs showing armoring of the upstream areas of the RM45 separation bar by progressive erosion during Interim Flows. A) 7/26/91, B) 10/19/92.

While the subaerially exposed sections of sand bars were being eroded, deposition occurred within and below the range of flow fluctuations. This deposition took place mainly on the upstream end of reattachment bar platforms (Figure 11). Schmidt and Graf (1990; Figure 20) showed that when decreasing discharge shortens the dimensions of the eddy, bank retreat within the recirculation zone redistributes sand within the recirculation zone. The example shown in Figure 11, RM22, increased in HAZ volume from 3197 m^3 to 3930 m^3, a positive gain of 733 m^3 of sand. The time-series volume plots (Appendix A: RM22) and profiles across the deposit (Figure 12) suggest that this gain accumulated gradually during the 30 months in between the two surveys. Over the same time interval, the plan area of the HAZ boundary increased from 1474 to 1994 m^2, a gain of 520 m^2. Bankward migration of the bar platform forms a narrower and shallower return-current channel (Figure 12a; for other examples of slipface migration into recirculation zones, see Appendix A: RM3, profiles 5 and 6; RM 122, profile 2; RM137, profiles 1 and 3; RM183, profiles 1 and 2). In the upper elevation/high discharge part of this and other reattachment deposits, 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 and have aggraded with sand and silt (Figures 12b and 13).

At several sites the amount of sand lost to bank retreat was greater than the amounts redistributed to lower levels. For example, at RM50 the HAZ area under study encompasses both the separation and the reattachment bar. Profiles across the separation bar show that it has remained stable during Interim Flows (Appendix A: RM50. profiles 1-4). However, by the October, 1991 survey, a large 2 m high cutbank had developed along the bank of the reattachment bar. One year later (October 10, 1992) the HAZ volume was 1531 m^3 less than the 3921 m^3 of sand that existed at both bars during the last GCES Phase II test flow survey (July 27, 1991; Table 2). Profiles across the reattachment bar show that a large part of the bar-front had been eroded, the result of large-scale cutbank retreat or a rapid erosion event. A low elevation bar was then rebuilt in front of the stable, remaining portion of the previous deposit (Figure 14; Appendix A: RM50, profiles 6-9). The low-elevation gains in HAZ area at this site were not greater than the amount of volume lost. This implys that the smaller Interim Flow recirculation zones cannot store as much sediment as larger, higher discharge regime eddies (compare recirculation zone size in the aerial photo of the RM50 and RM22 study sites in Appendix A).

The hypsometric integral of most eddies (26 of 32, 81%) remained within 5% of their starting sand volume. However, 5 of 32 (16%) lost sand volume and 1 of 32 (3%) gained sand volume between the first and last surveys during Interim Flows. This flow alternative reduced overall eddy size, thus reducing the potential amount of sand storage. From these data it is apparent that loss of sediment will continue under Interim Flows. The net effect of this erosion will be greatest in upstream reaches (above the LCR) because of a limited mainstem sediment supply, and also to a lesser degree at sites below the LCR.

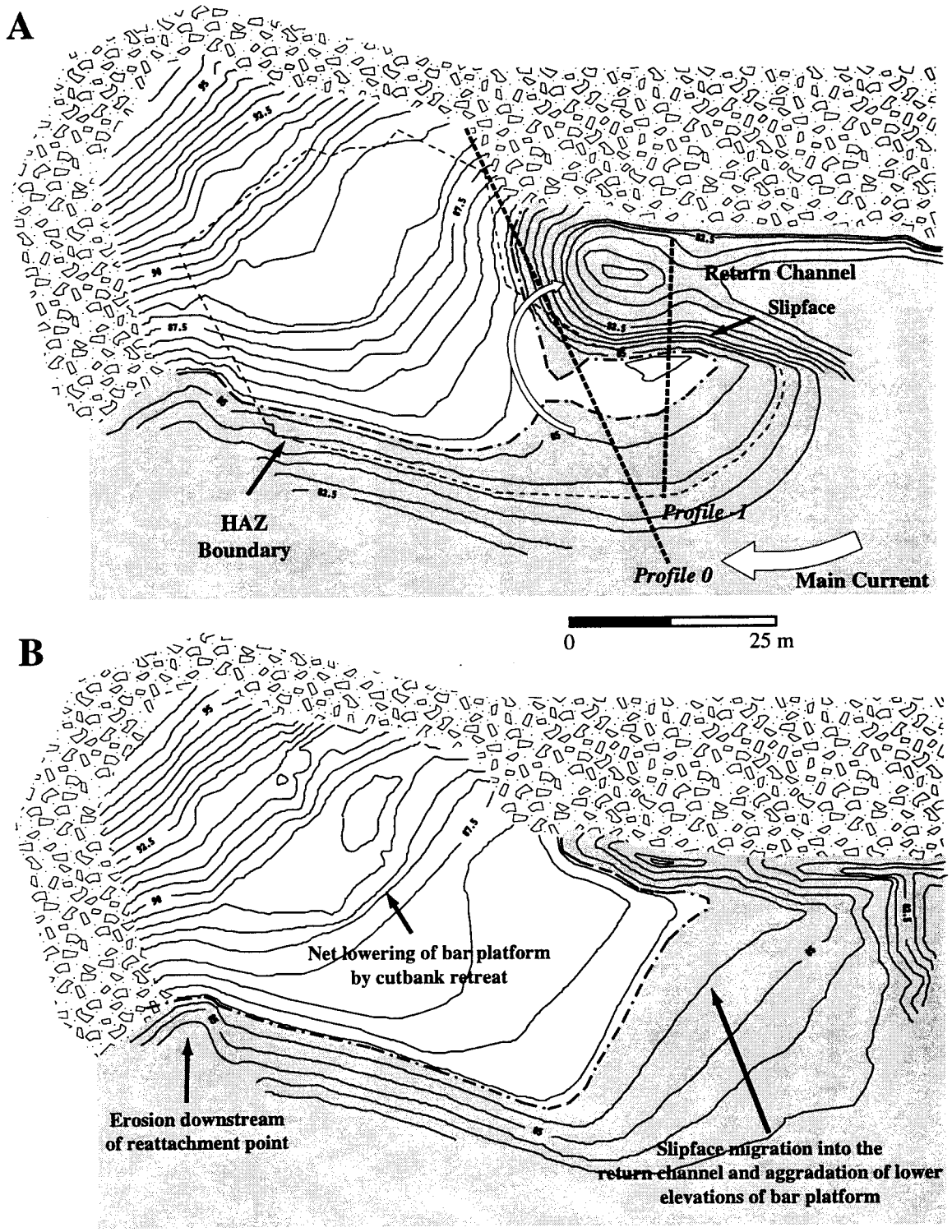
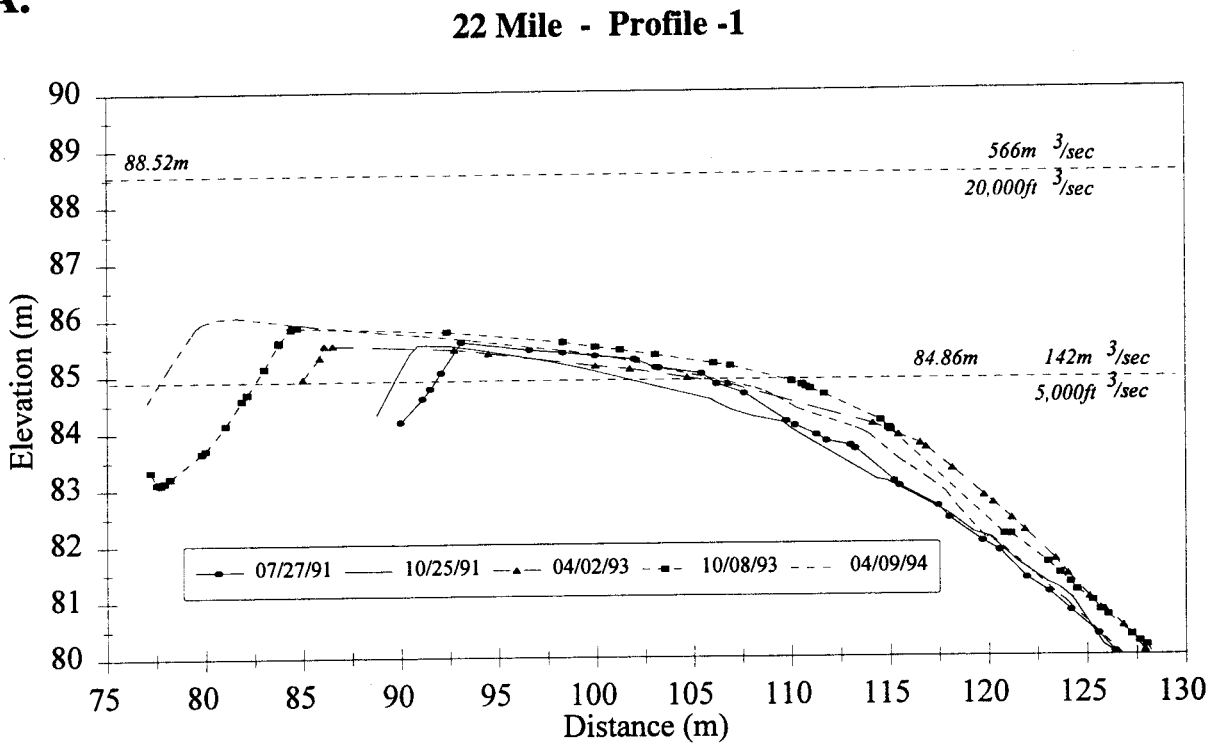


Figure 11. Topographic maps from the RM22 reattachment bar. A, October 25, 1991, discharge 181 m^3/s (6,380 ft^3/s). B, April 9, 1994, discharge 240 m^3/s (8,475 ft^3/s). Note that although discharge is higher in B more area of the reattachment platform is subaerially exposed.

A.



B.

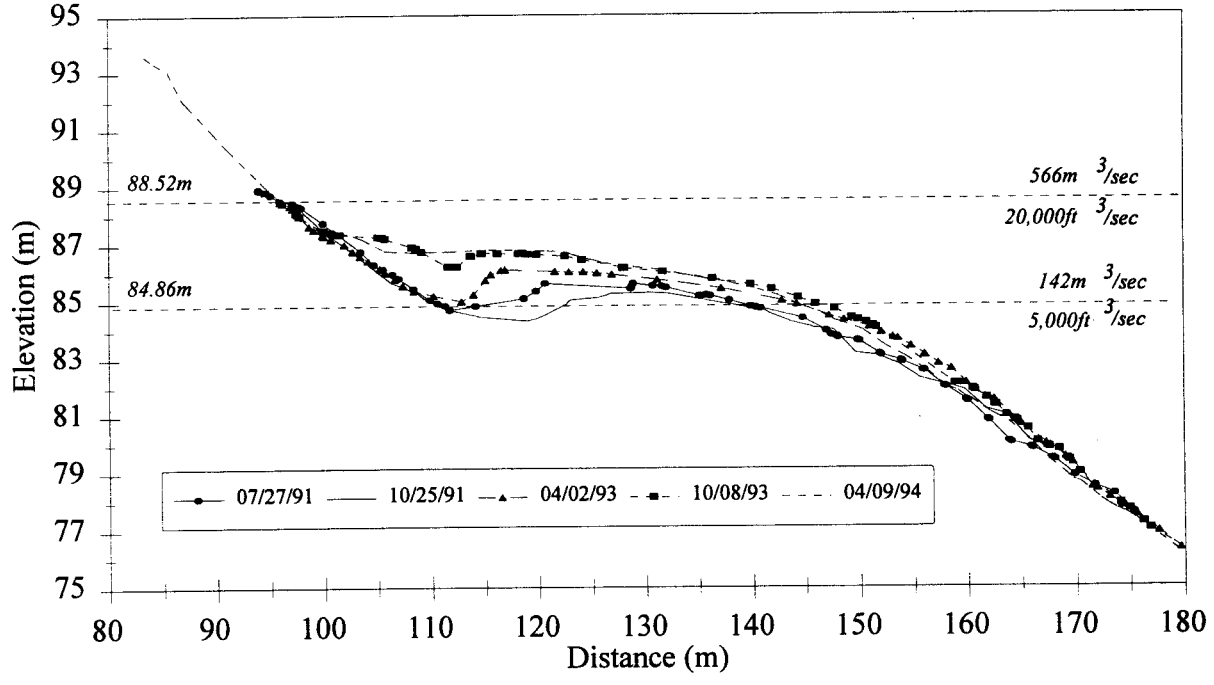
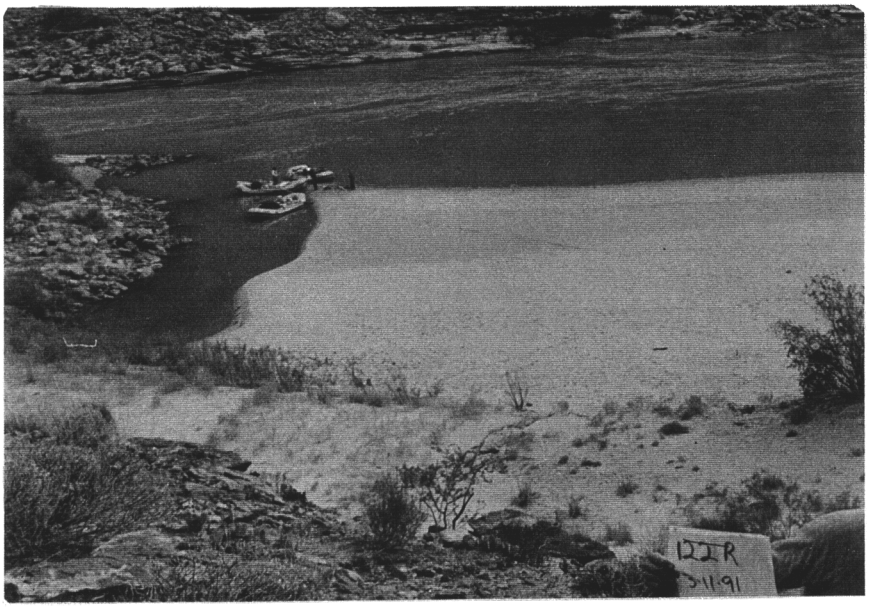


Figure 12. Topographic profiles from RM22. See Figure 11 for location. The main channel is to the right. A) Note the progradation of the bar platform by slipface migration to the left into the return channel. B) A minimum of 1m was deposited on the platform and the return channel.

A.



B.

Figure 13. Photographs taken on 11/3/91 and 10/18/93 respectively, showing the return current channel area at RM122. Notice in A the large return channel that existed prior to and during the early part Interim Flows, and in B how the same area (in the vicinity of where the trenchs are being dug) has been filled in between the reattachment bar platform and the constricting debris fan.

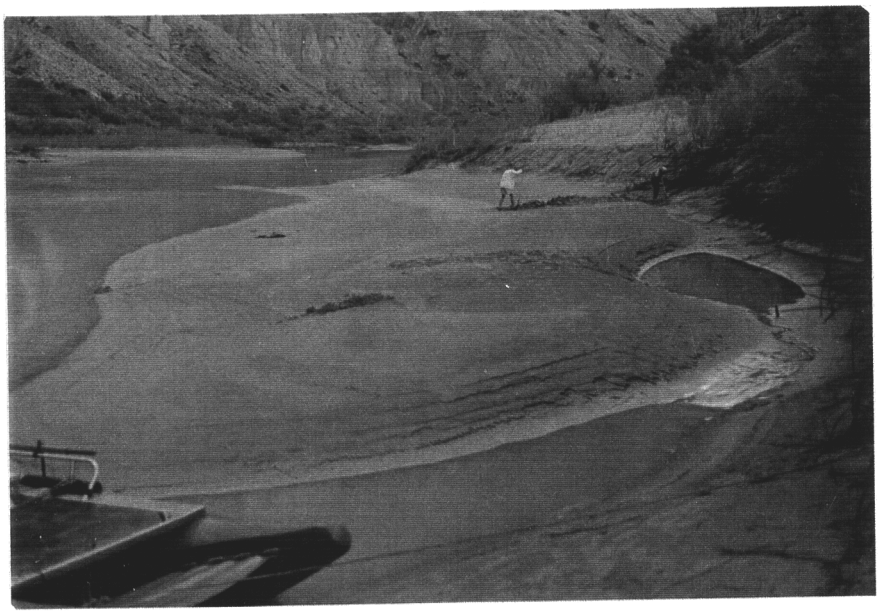


Figure 14. Photograph taken October 10, 1993 of the reattachment deposit at RM50 showing the lower elevation bar rebuilt in front of the large 2 m cutbank that developed shortly after the onset of Interim Flows.

Significant erosion is also occurring in areas downstream of the reattachment point (Figures 15, 16, and 17). The erosional feature at RM119 and highlighted in Figure 15 developed shortly after the onset of Interim Flows. A profile across this area shows a distinct progression of erosion (Figure 17). Initially, erosion was moderate between the July 28, 1991 and October 26, 1992 surveys, with a maximum of 3 m of bank retreat. The April 10, 1993 profile shows that although nearly 1 m of sediment was deposited during the winter 1993 floods, in as little as 2 months, approximately 7.5 m of bank retreat had occurred along two distinct topographic levels. A vertical, 2 m cutbank developed at the 92.6 m stage elevation and a smaller one at the 91 m stage elevation that correspond with discharge levels of 382 m^3/s (13,500 ft^3/s) and 665 m^3/s (23,500 ft^3/s), respectively (Figure 16). Apparently, some of the retreat at the upper level occurred during one of the 1993 LCR flood events. By the October 18, 1993 survey the cutbank had retreated an additional 3 m at the 92 m stage elevation. There was little or no retreat evident in the April 17, 1994 survey. Cumulatively, the area within the box shown in Figure 15a had decreased 85 m^2 in area and 386 m^3 in volume since the start of Interim Flows.

This type of erosion is ubiquitous at nearly all reattachment bars in this study (for other examples, see Appendix A: RM3, profile 2; RM47, profiles 1 and 3; RM122, profile 6; RM 137, profile 6; RM 183, profile 8). When recirculation zones contract during lower flows, areas downstream of the reattachment point are exposed to erosion by the mainstem current. Sand eroded from these areas is deposited directly into the main channel. These observations confirm the observations and model of this process proposed by Schmidt and Graf (1990; Figure 20).

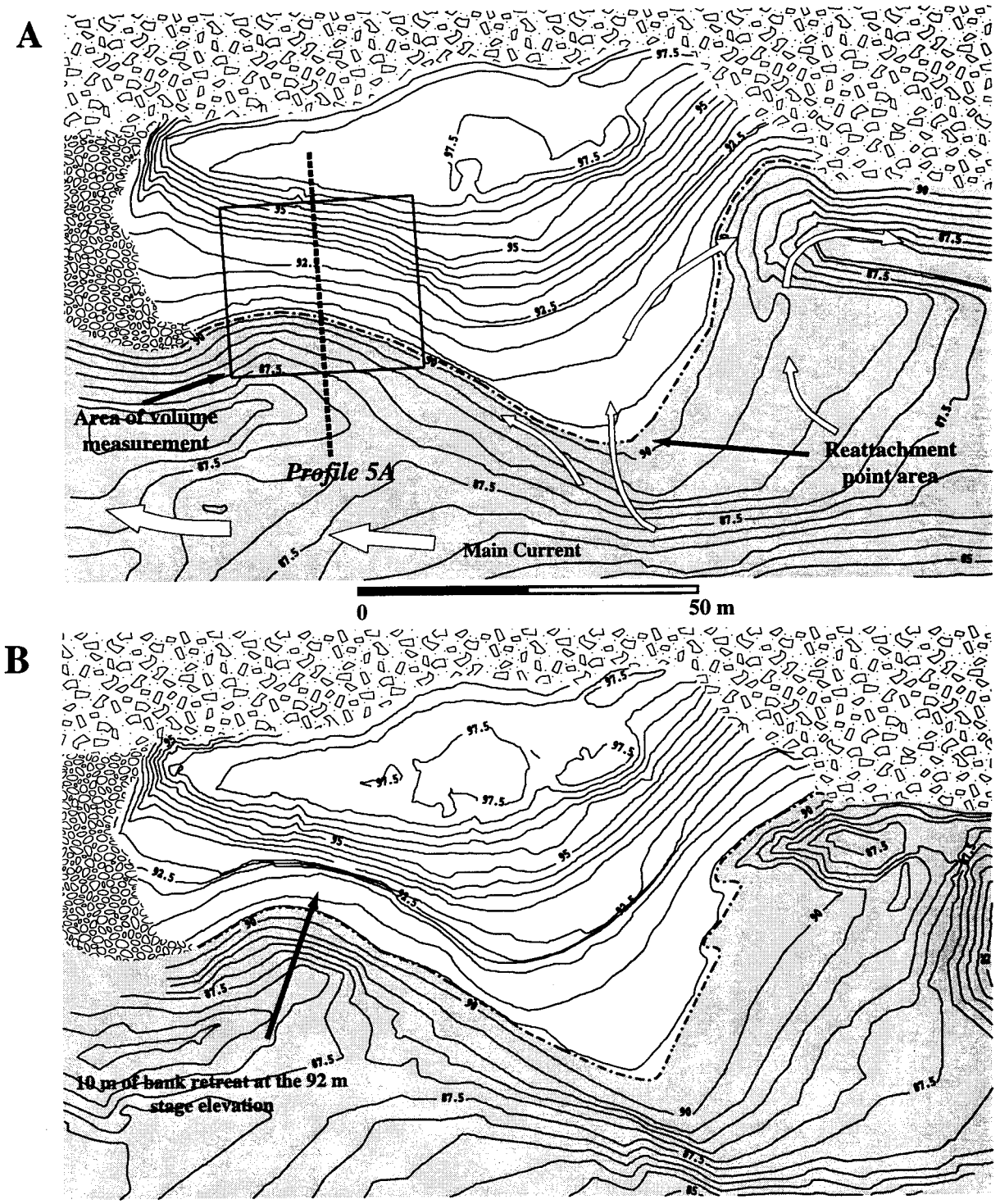


Figure 15. Topographic maps from a reattachment bar at RM119. A, October 26, 1992, discharge 251 m^3/s (8,864 ft^3/s). B, April 17, 1994, discharge 285 m^3/s (10,064 ft^3/s). The box in A is the area from which volumes of eroded sediment were calculated.

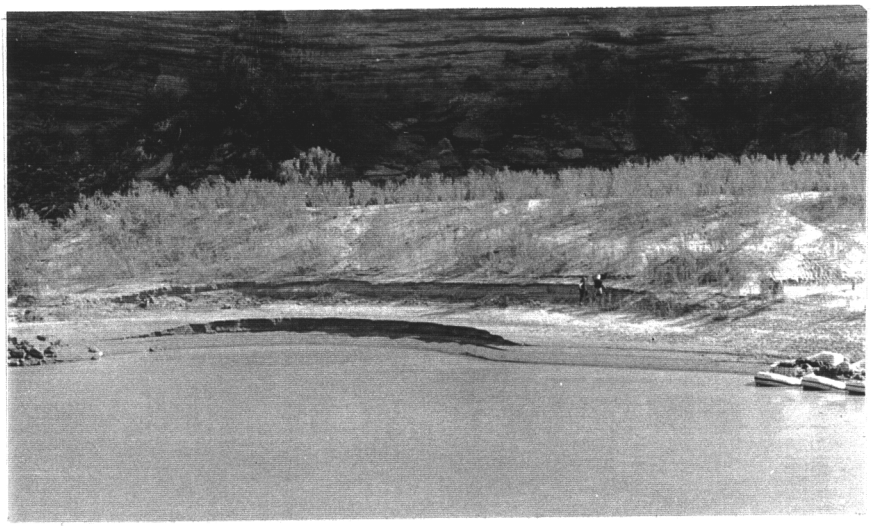


Figure 16. Photograph taken on 10/17/93 of RM119 reattachment bar showing the eroded area downstream of the reattachment point.

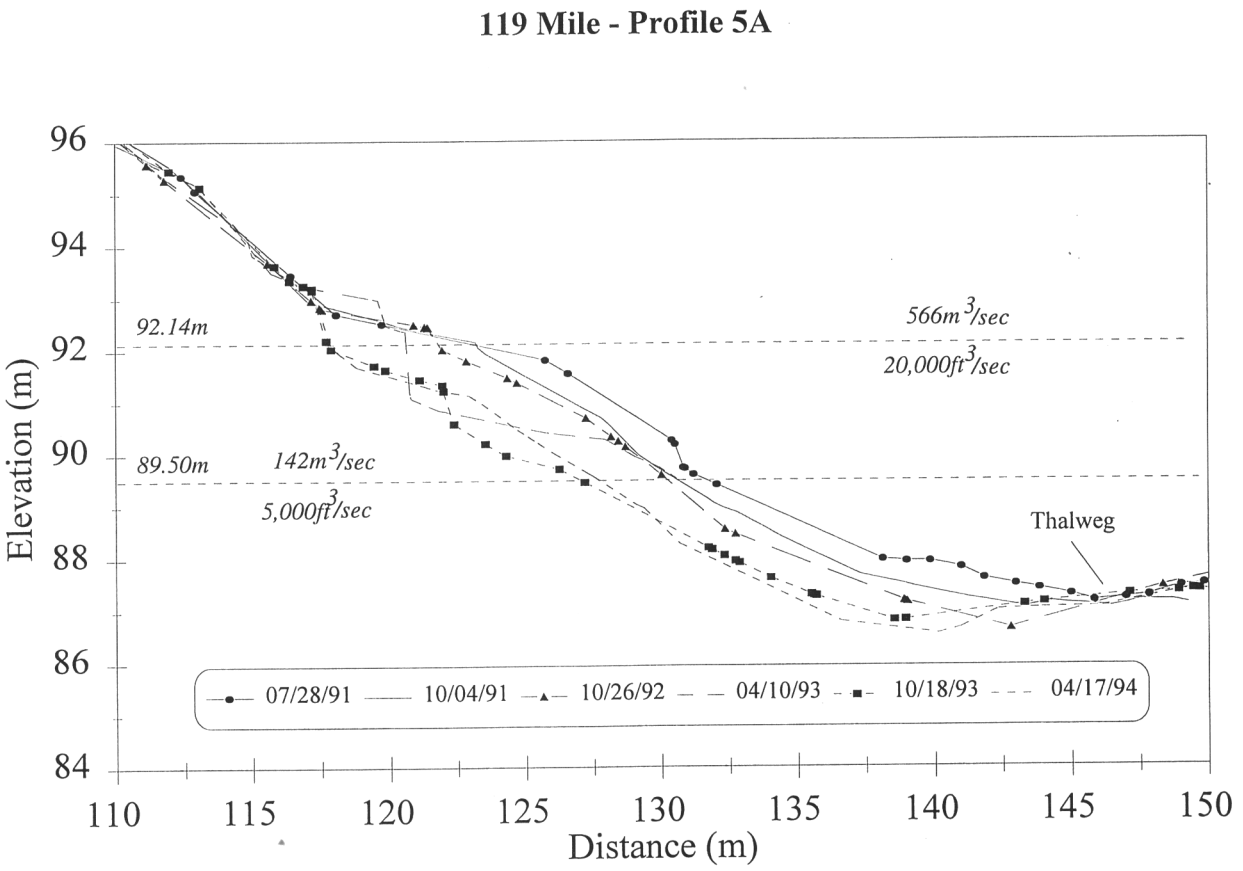


Figure 17. Profile 5A from RM 119. This is a profile across the eroded area downstream of the reattachment point shown in Figure 15. Note that the base of cutbanks are developed at similar, distinct topographic levels that correspond with the upper range of Interim Flow fluctuation levels.

Rapid Erosion Events

Daily, oblique photography of sand bars (Cluer, 1991; 1992; Cluer and Carpenter, 1993; Dexter et al., 1994) has shown that rapid erosion (bar-failure) events occur and that many of their study sites follow a pattern of rapid erosion followed by aggradation. Topographic changes observed by this study show that during bar-failure events, large areas of the bar platforms collapse and then gradually rebuild and onlap the remaining portion of the deposit (Figures 18 and 19).

Our survey data identified bar failure events at RM3 and RM16 (Figure 19 and Appendix A). At the RM3 reattachment bar, a minimum of 934 m^3 (1,048 m^2) of sand was eroded from the HAZ between April 1, 1993 and November 17, 1993 (Figure 18 and Table 2). Hypsometric data reveal that, while the upper section of the bar eroded, the lower elevations within the eddy gained area (Figure 20a). The bar rebuilt during the moderate to high winter flows and by the April 7, 1994 survey had regained 729 m^3 in volume, but did not completely rebuild to its previous size (Figures 18c, 19, 20a, and Table 2). The failure event evident during the October 8, 1993 survey at the RM16 separation bar displayed the same characteristics as the RM3 failure. The loss of area at the upper sections was coincident with area gains at lower elevations in the eddy (Figures 20b and 21b). The pattern of area change within the RM3 and RM16 eddies suggests that a large percentage of the sediment eroded during bar failure events is stored within the same eddy, but at lower elevations. Dexter et al. (1994) showed that these erosional events can occur over very short time periods, typically less than 24 hours, and that aggradation is greatest immediately following erosional events and then decreases with time. Apparently, failure areas as large as that in Figure 18b can be rebuilt in as little as two weeks (Dexter et al., 1994). Following a bar failure, sediment is transferred back to the bar top from lower elevations and the bar platform is rebuilt, but not to its original size (Figures 20 and 21).

These observations suggest that sand bars aggrade and degrade in cycles of platform buildup followed by erosion. The erosional phase of the cycle sometimes occurs as a rapid erosion events (Dexter et al., 1994). It is difficult to discern the erosional mechanism (rapid versus gradual bank retreat) on a biannual time step because the bar morphology resulting from each is similar. Rapid erosion events can only be identified if biannual surveys fall within several days of the failure events. The aggradational phase of the bar building cycle, in the absence of flood flows, never replaces the total amount of sand eroded during the erosional phase. Hypsometric data from the two sites discussed previously suggest that the upper bar platform aggrades to a maximum size limit before failure (Figure 20). Other large-scale failures have been identified at RM8, RM51, RM68, RM122, RM123, and RM225. Regardless of which erosional mechanism (progressive or rapid) predominates, the cumulative effect is that the upper parts of sand bars are not being replenished with sand.

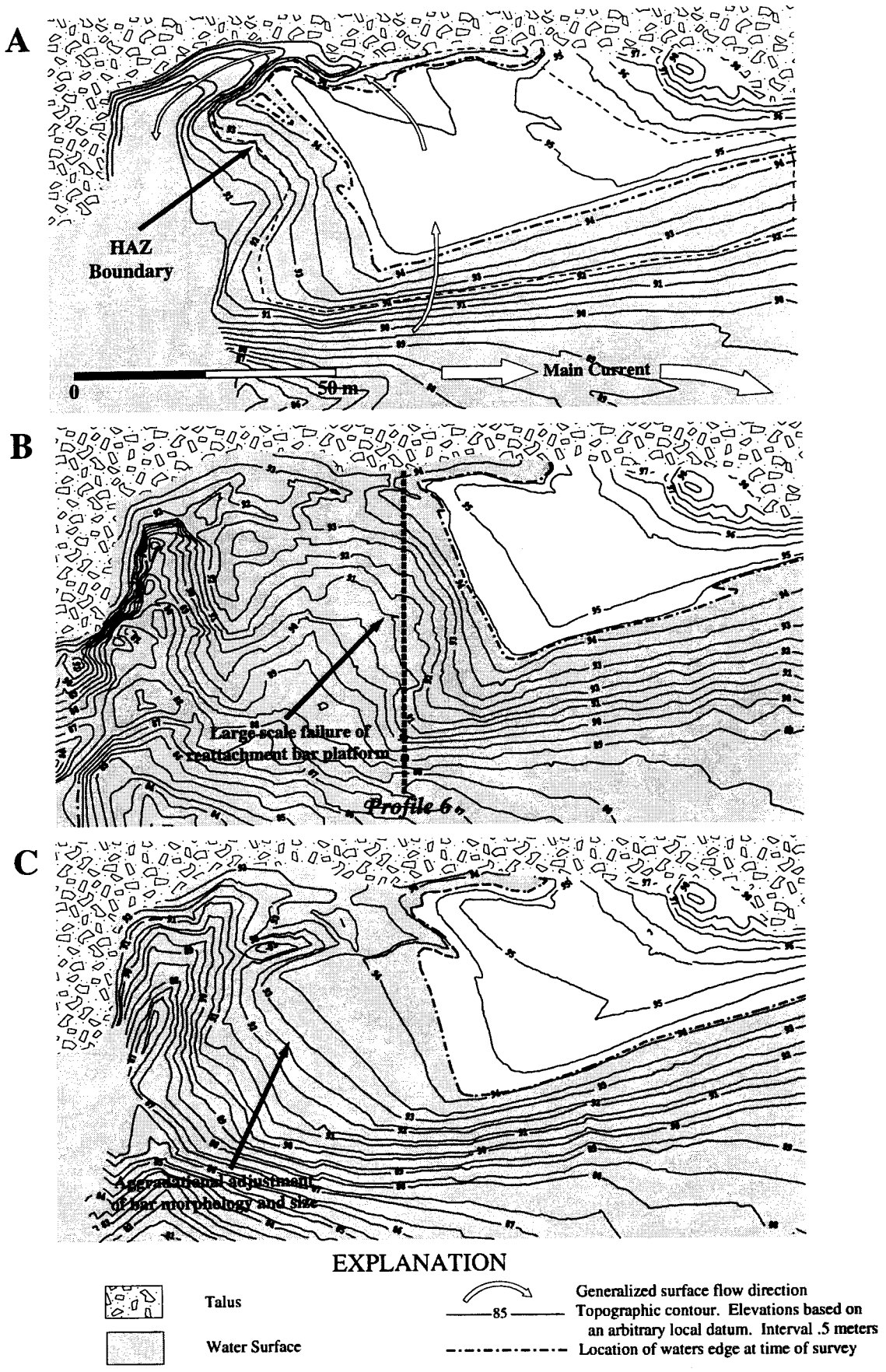


Figure 18. Topographic maps from the RM3 reattachment bar. A, April 1, 1993, discharge 300 m^3/s (10,595 ft^3/s). B, November 17, 1993, discharge 328 m^3/s (11,583 ft^3/s). C, April 7, 1994, discharge 286 m^3/s (10,100 ft^3/s).

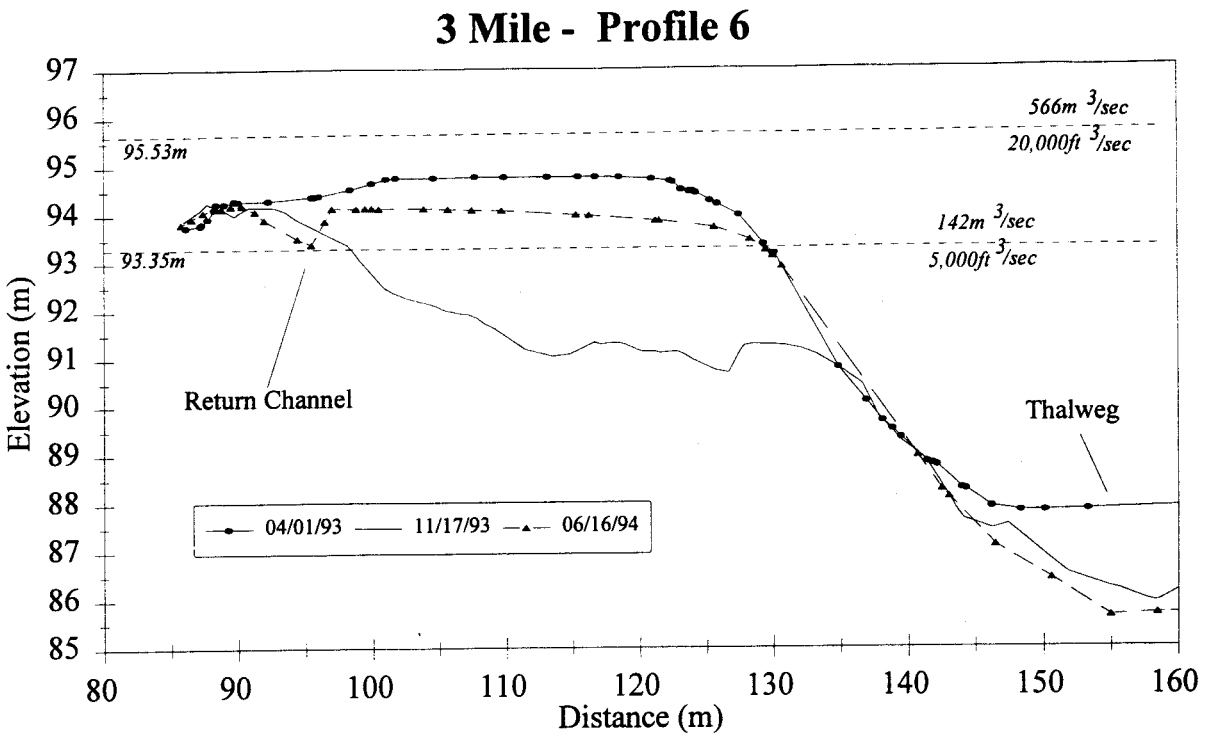


Figure 19. Profile 6 from RM3. Note the large-scale collapse of the platform between the April 1, 1993 and November 17, 1993 surveys. Location of profile is shown in Figure 18.

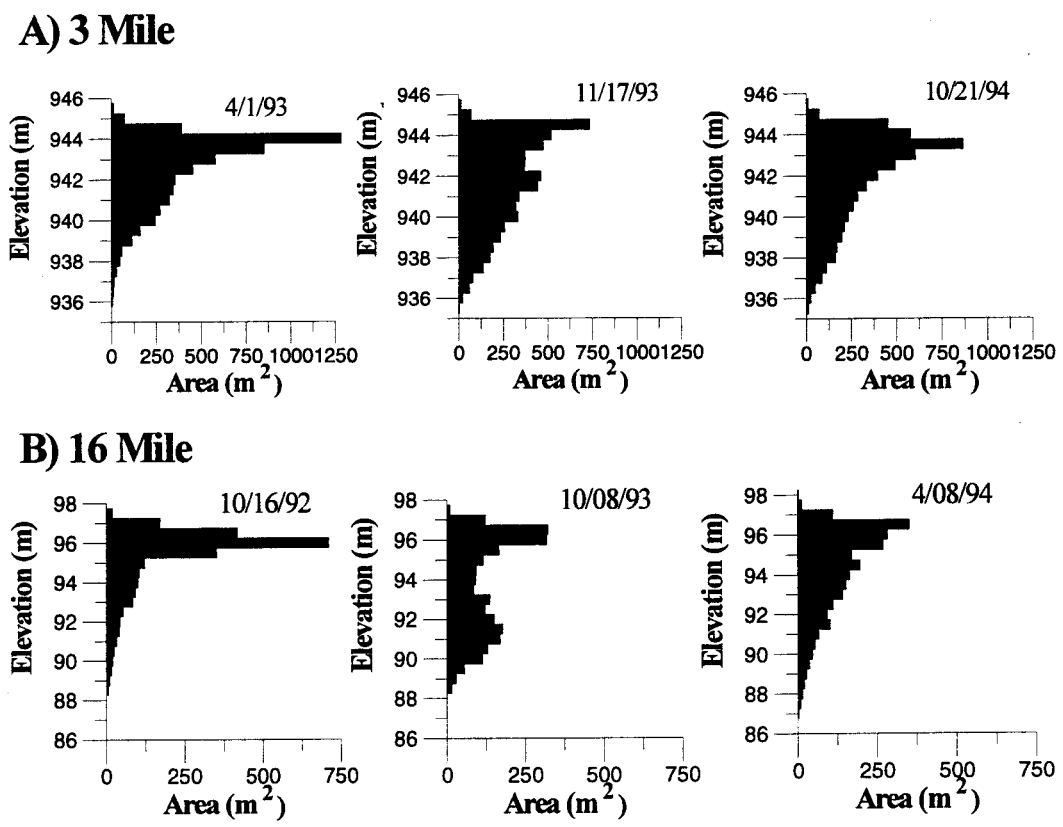


Figure 20. Area distribution hystograms from surveys surrounding bar failure events at RM3 and RM16.

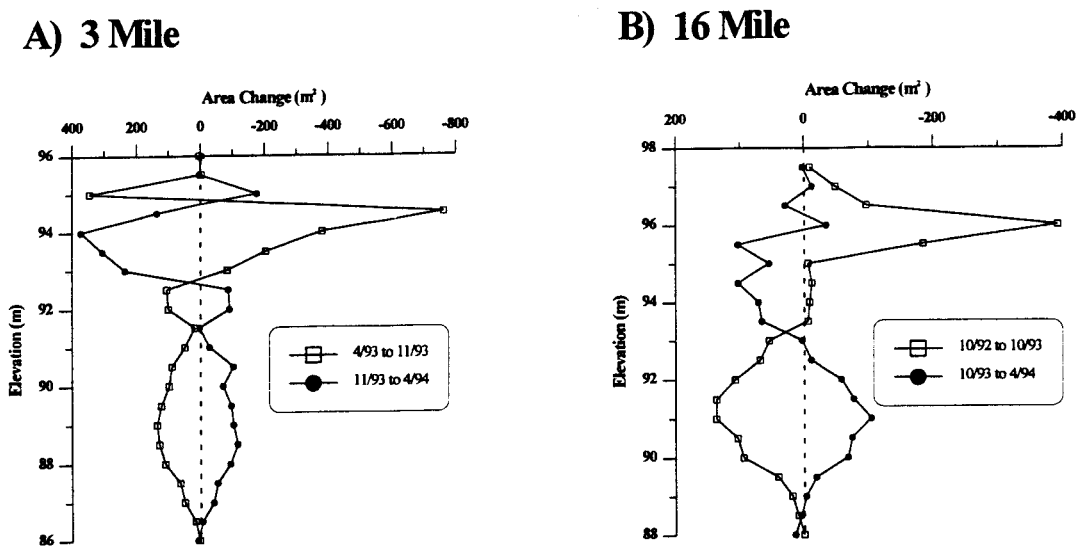


Figure 21. Hypsometric change diagrams showing area change due to bar failure events and subsequent bar re-building at RM3 and RM16.

The 1993 Little Colorado River Tributary Floods

Impacts by tributary events such as those that occurred from the LCR tributary (RM60) during the winter of 1993 are significant perturbations to the system (Figures 6 and 7). With the reduction in the amount of sediment input to the Grand Canyon in the post-dam era, the Paria River and the LCR are now the main suppliers of sediment to the Colorado River downstream from GCD (Randle and Pemberton, 1987; Smillie et al., 1993). The capacity of the river to transport sediment (especially larger than sand-size) has also been reduced. The sediment-rich 1993 winter floods have important implications for increasing the sediment budget of the river and sandbar deposition. By increasing mainstem flows to slightly above powerplant capacity and delivering a significant amount of sediment, the floods provided an unexpected test-case of a bar-building flow event. This section discusses the deposition of sandbars during high mainstem flows, the longevity of rebuilt bars, rates of deposition and erosion, and changes in channel sand storage from the LCR sediment input.

Sand bar deposition and erosion. The winter 1993 floods deposited large amounts of sediment on both reattachment and separation bars downstream from the LCR (Figure 22; see also Appendix A: RM119; RM122; RM 137; RM145; RM202). Analysis of the HAZ shows that a significant amount of aggradation occurred downstream of the LCR during the floods (Figures 6 and 7c; Table 3 and Table 4). Sand bars were aggraded up to 1.0 - 2.5 meters above the maximum Interim Flow stage elevation (Figures 22 and 23). The newly aggraded sand bars were quickly eroded after the return to normal GCD operations and large-scale cutbanks were observed at virtually every study site downstream of the LCR-Colorado River confluence (Figures 9, 23 and 24).

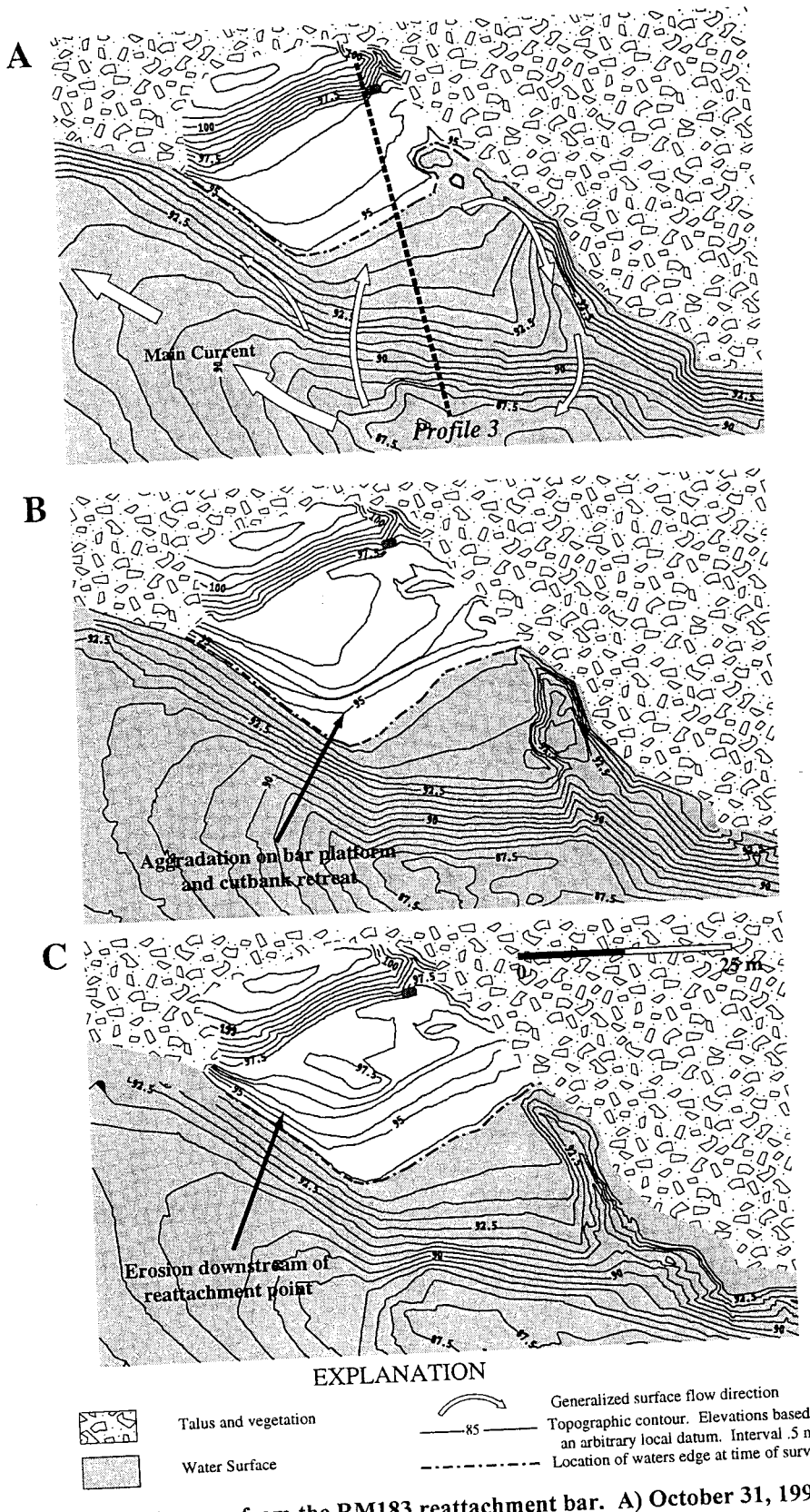


Figure 22. Topographic maps from the RM183 reattachment bar. A) October 31, 1992, discharge 299 m^3/s (10,559 ft^3/s). B) April 12, 1993, discharge 280 m^3/s (9,888 ft^3/s). C) October 23, 1993, discharge 246 m^3/s (8,687 ft^3/s). Notice in C that the bar configuration is nearly identical to B suggesting that much of the erosion of this bar following the flood deposition took place in as little as 2 months.

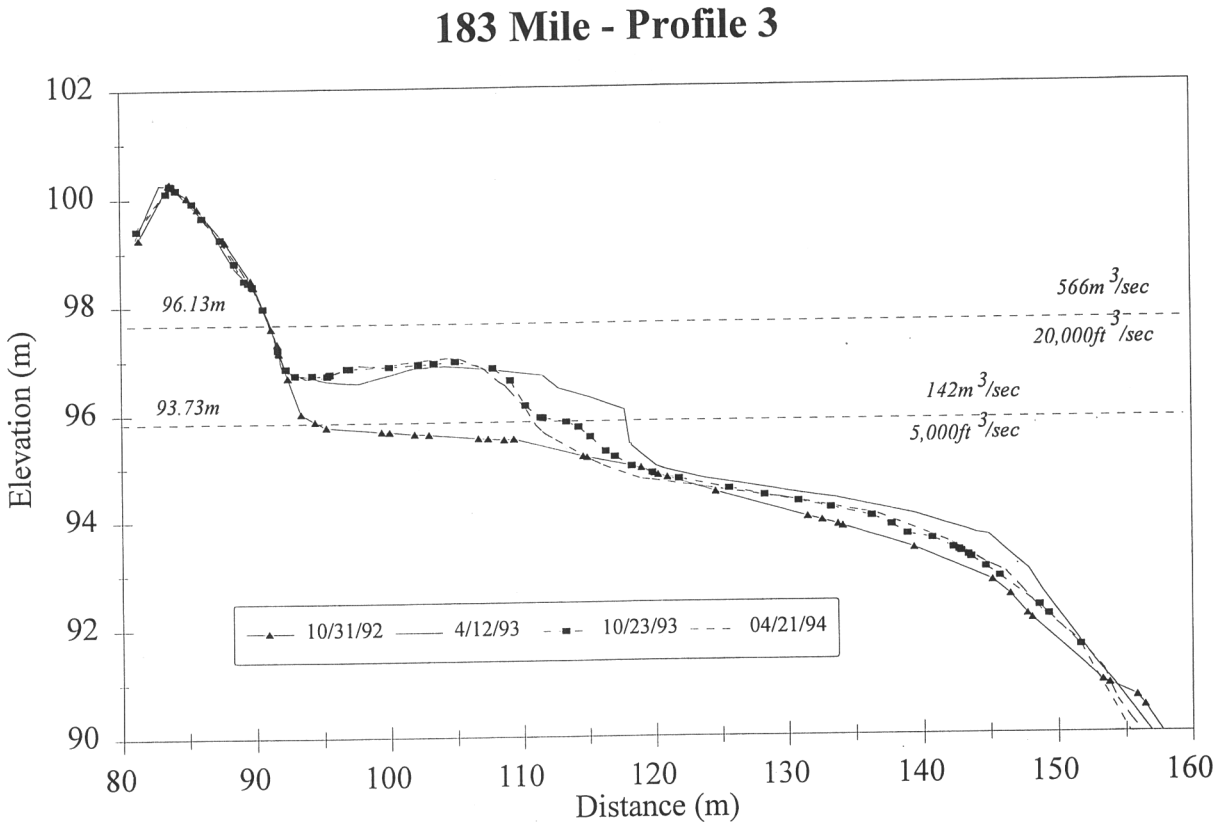


Figure 23. Topographic profile from RM183. Nearly 2 m of sand was deposited on the bar platform and there was 7.5 m of bank retreat by the October 1993 survey. The bank retreat did not progress any further by the April 1994 survey. Location is shown on Figure 22.

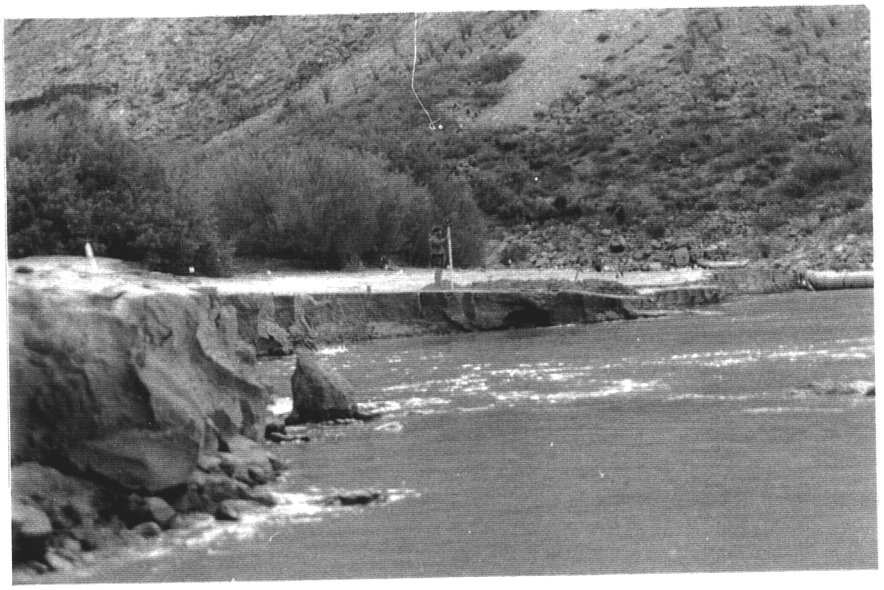


Figure 24. Photograph of the RM202 separation bar taken on 4/13/93 showing cutbank erosion following the winter 1993 floods.

Bank retreat rapidly reduced the HAZ area and volume (Figure 7d). This observation is consistent with previous work that reported erosion rates increased dramatically after the 1983 spill then gradually decreased with time (Brian and Thomas, 1984; Beus et al., 1985; Schmidt and Graf, 1990; Kearsley et al., 1994). The largest HAZ volume loss following the flood was measured at RM68 and is attributed to a bank failure that occurred on the waning limb of the first flood (Figures 7 and 25; Mark Manone, personal communication, 1994). In Figure 25, note the difference in the location of water's edge. These lines were surveyed at similar stage elevations and show how extensive the bar failure event was. However, while the higher elevations of the bar lost sediment, the channel bed elevation increased by up to 5 meters in the channel adjacent to the bar.

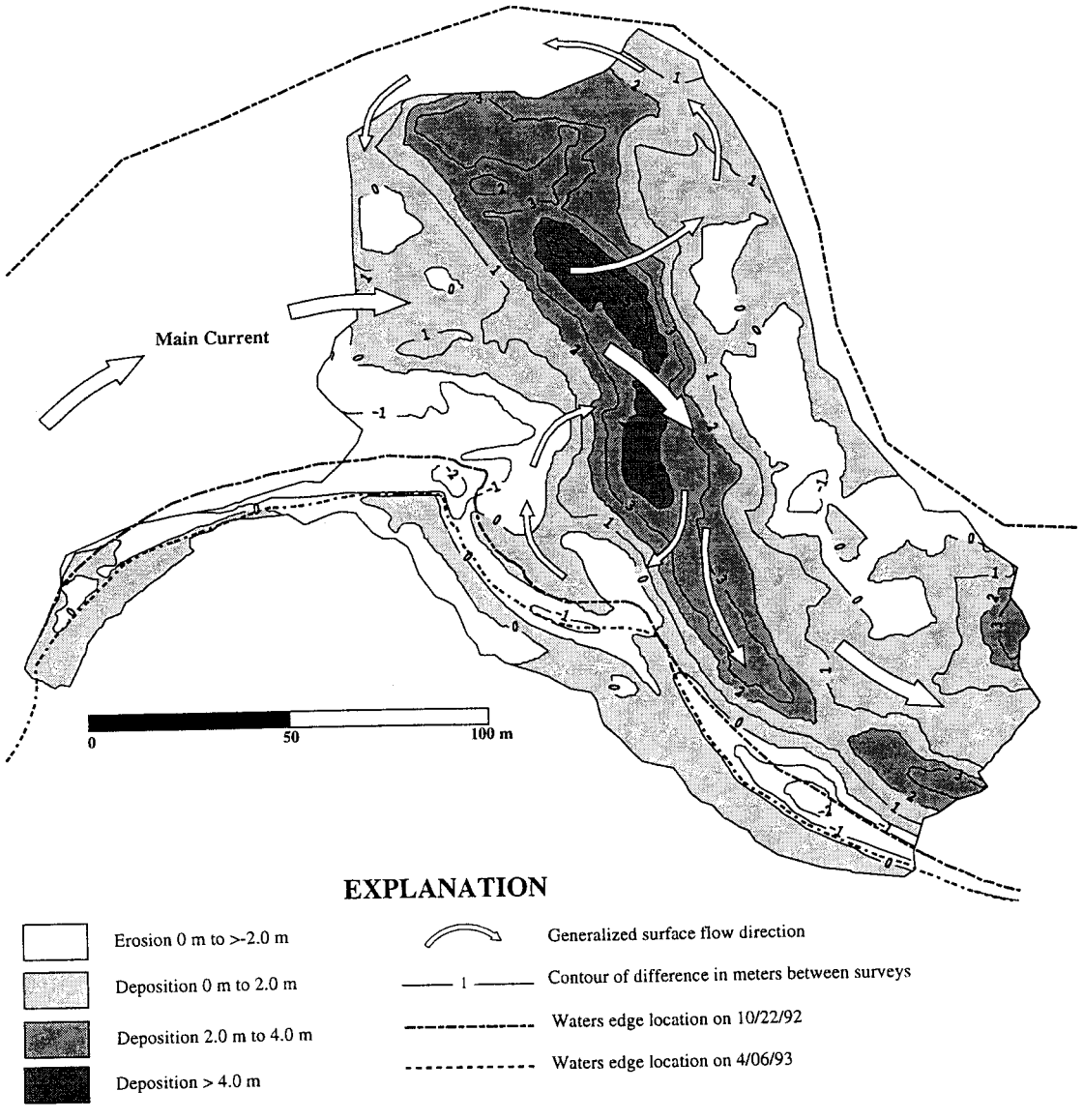


Figure 25. RM68 surface comparison of the topographic maps generated from the 10/22/92 and 4/06/93 surveys.

Return current channels associated with reattachment bars were in-filled with sediment during the floods. The short-duration flood peaks of the LCR events apparently were not of sufficient duration to scour return channels. Upon the return to Interim Flows, the aggraded return channel areas were cut off from the river by the lower range of fluctuations. Smaller return channels, located at and below the Interim Flow stage elevations developed in front of the aggraded bar tops (Figure 13).

One year after the floods most of the flood-related deposition had been eroded. The Friedman analysis of HAZ volume show that the 1993 flood events significantly increased HAZ volumes downstream of the LCR (Figure 6). During the two years following the floods, years without significant flood-related deposition, HAZ volumes decreased to levels lower than the pre-flood condition. These results suggests that a return interval of once every year, as suggested in the GCD-EIS, is needed to replenish the sandbars. These observations demonstrate the benefits of main channel flooding and how an intentional bar-building or habitat-maintenance release might modify sandbars.

Rates of deposition and erosion. A reattachment bar at Crash Canyon (RM62) that was deposited during the LCR flood events provided a unique opportunity to examine rates and style of bar development (Kaplinski et al., 1994b). Subsequent surveys allowed us to determine the rate at which sand was removed from this eddy and transported downstream. The bar formed in a channel expansion approximately two kilometers downstream of the confluence of the Colorado and the LCR (Figure 25; Appendix A: RM62). The eddy was previously devoid of a subaerially exposed sand deposit. After the floods receded, a steep, 1.5-m high cutbank developed across the face of the bar, exposing the internal structure along the entire 120-meter face of the bar platform (Figure 9). A line drawing of the observed stratigraphic relationships was made from a photomosaic along the face of the cutbank and an interpretive model of bar evolution was constructed (Kaplinski et al., 1994b; Rubin et al., 1994).

Deposition at this site was consistent with published descriptions of depositional patterns at other Grand Canyon sand bars (Rubin et al., 1990; Schmidt et al., 1993). Photographs taken on January 15, 1993and sedimentary structures observed along the front of the bar indicate that the majority of bar-building occurred during the first flood event (Figure 27), (Rubin et al., 1994). Deposition began near the center of the eddy and as the flood elevated the river stage and delivered large amounts of sediment, large-scale bedforms migrated into and across the empty eddy system. Continued deposition caused the bar to expand until it approached the water surface throughout most of the eddy (Dave Rubin, written communication, 1994).

Observations of the site in mid-June, 1993, during low-volume, Interim Flow operations (230 to 340 m^3/s [8,000 to 13,000 ft^3/s]) showed that only about 5-10% of the deposit we measured in April had been eroded. We estimate that, from April to June, erosion rates ranged from 50 to 100 m^3/day. Dam operation changed from low volume to high-volume (340 to 540 m^3/day [12,000 to 18,000 ft^3/s]) Interim Flows on July 1, 1993. Observations of the site in late-July 1993 indicated that there was no longer a subaerially exposed deposit. Interviews with commercial rafting guides indicate that much of the subaerially exposed section of the bar,

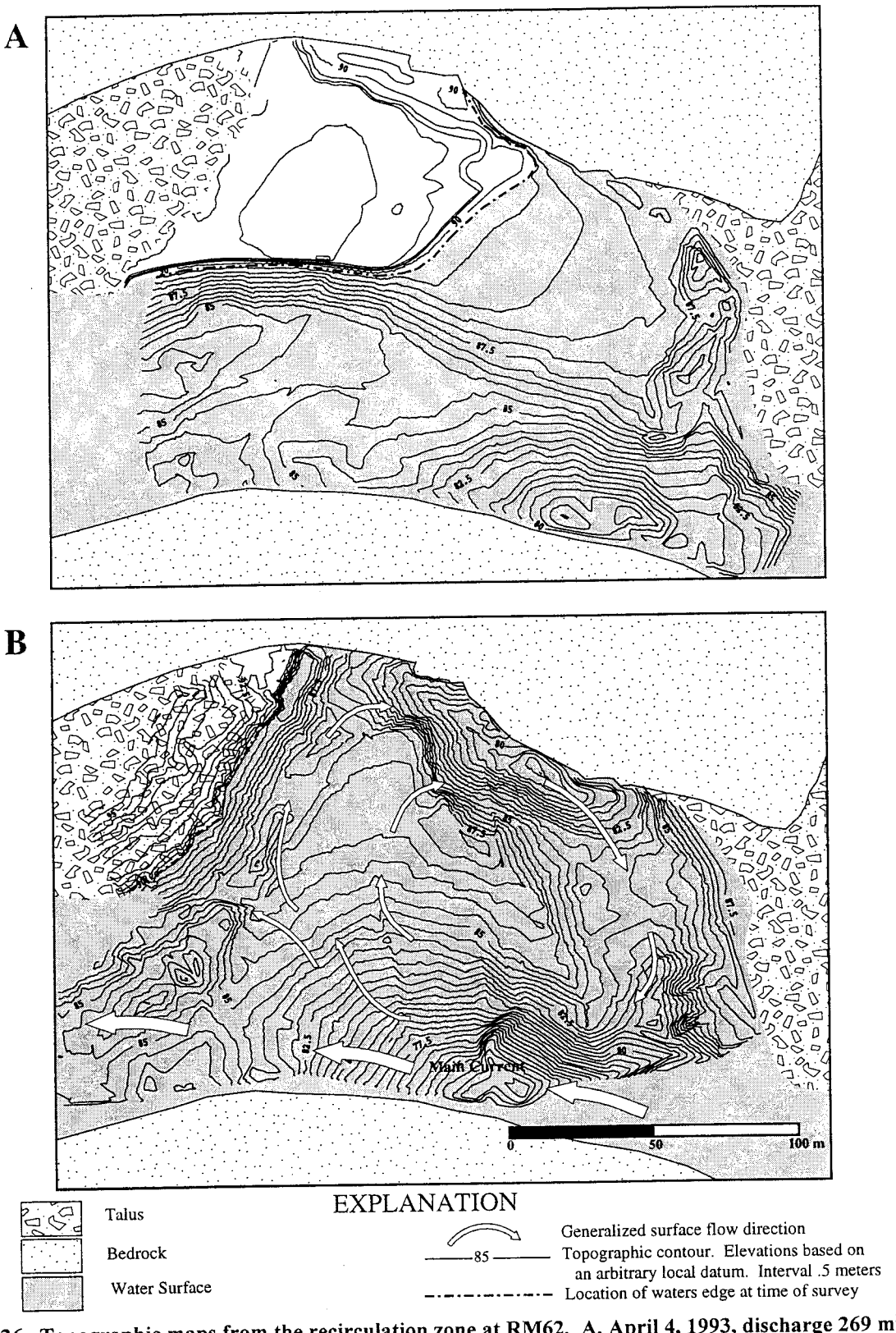


Figure 26. Topographic maps from the recirculation zone at RM62. A, April 4, 1993, discharge 269 m^3/s (9,500 ft^3/s). B, April 13, 1994, discharge 260 m^3/s (9,200 ft^3/s). Note the large subaerially exposed reattachment bar in A and in B a lower elevation, submerged reattachment deposit. Much of the sand captured by this zone during the winter 1993 floods has been exchanged back to the main channel.

Figure 27. Photographs of the emergent reattachment bar at RM62 taken during recession of the first flood on January 15, 1993. Flow level in the photographs is approximately 651 m^3/s (23,000 ft^3/s).

approximately above the 283 m^3/s (10,000 ft^3/s) stage elevation, had completely eroded within a two to three week period. Based on this assumption, erosion rate during this period ranged from 2,000 to 2,500 m^3/day. At this site, it appears that the change in dam release schedules possibly triggered an order of magnitude increase in erosion rate.

Contouring the elevation difference between surveys conducted in April, 1993 and April, 1994 shows that in both the recirculation zone and the channel, up to 10 m of sediment was removed and transported downstream (Figure 28). 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. Table 5 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 calculations. These rates are at least an order of magnitude higher than the range of rates determined from flume experiments of recirculation zone sedimentation (0.22 to 0.05 kg/s) and field estimates of deposition rates at Grand Canyon sandbars (4.5 to 7.8 kg/s) (Schmidt et al., 1993). However, due to the close proximity to the sediment source, these rates are not unreasonable. Deposition rates during clear-water floods from GCD would most likely be much lower. Because of the 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 RM62 site are similar to conceptual models of bar-building in Grand Canyon recirculation zones (Rubin et al., 1990; Schmidt, 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 5. Deposition rates at RM62 during the January 12-16 flood.

Duration (hours)	12	24	36	48	60	72
Deposition rate (m^3/hour)	5.387	2,693	1,795	1,346	1,077	898
Deposition Rate (kg/s)	3,965	1,983	1,322	991	793	660

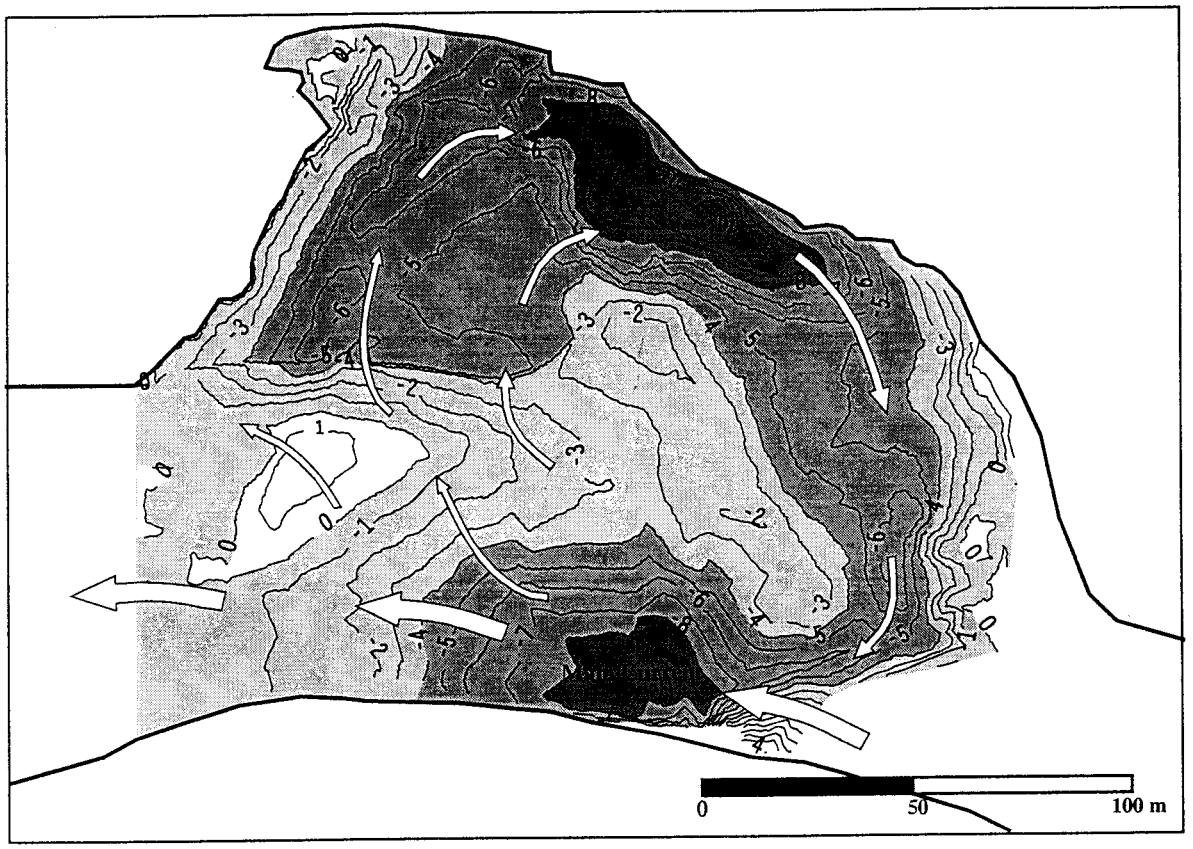


Figure 28. Comparison map of RM62 with one meter contours of the difference between surveys conducted on 4/5/93 and 4/13/94. The largest amounts of sediment were removed from the downstream portion of the eddy near the debris fan, the return current channel, and the scour hole immediately downstream from the debris fan constriction on river right.

Main channel transport and storage. The mainstem Colorado continually transports sediment downstream, even during the lower sediment transport capacities that exist during Interim Flows. Cumulatively the three floods delivered an estimated 4,600,000 tons of sand into the Colorado River (Jansen et al., 1995). Two months after the flood events a bathymetric survey at RM68 showed at least a 5 m change in channel bed elevation (Figure 25). Surveys at this site prior to the flood events showed little change in channel bed elevation (Appendix A: RM68). The elevation change at this site was likely sand deposited by the floods on the channel floor (Figures 25 and 29). Similar aggradation was apparent as far downstream as RM93 (Figure 29; Appendix A: RM93). Burkham (1987) reported that bed elevation in the pool at the USGS gauging station near Phantom Ranch changed as much as 2.5 m 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 present on the bed 9 months after the LCR flood events (Figure 28; Appendix A: 87L). Sites farther downstream (Appendix A: 119R and on), however, showed little change or a slight decrease in channel sand elevation. These observations imply that sediment input from the LCR was transported up to 49km (30mi) downstream of the LCR-Colorado River confluence by the relatively short duration floods. Downstream of the 49km (30mi) zone below the LCR, sand was deposited from the redistribution of sediment that had accumulated in recirculation zones or on the channel bottom.

Cross-channel profiles constructed from subsequent bathymetric surveying (April, 1994; November/December, 1994) show a slight to moderate increase in bed elevation (1-2 m) adjacent to recirculation zones at several study sites downstream of RM93 (Figure 29; Appendix A: RM 123; RM137; RM139; RM194; RM220). The increase in bed elevation had decreased somewhat by the November 1994 survey but the quantity of sand stored downstream of RM93 appears to be greater than that measured shortly after or before the floods (Figure 29). This is not surprising as progressively more sediment accumulates in the channel in the downstream direction (Randle et al., 1993). These observations and similar cross-section monitoring by the USGS (Graf, et al., 1993; Jansen, et al., 1995) indicate that even during the reduced flows of the Interim period, main channel sediment transport is occurring and sediments are being stored on the river bed as well as in eddy zones.

Smaller Tributary Impacts

Other geomorphically significant drainages besides the Paria River and LCR can have significant impacts to Grand Canyon sand bars. These are typically ephemeral streams that deliver sediment to the river by debris flows and flash floods (Webb et al., 1989). Debris flows create and maintain the rapids that are the hydraulic controls of the Colorado River (Kieffer, 1985; Webb et al., 1989). The size and extent of resulting debris fans control the size and locations of eddies (Webb et al., 1991; Melis and Webb, 1993). Side canyon flash floods, including debris flows, can erode sand bars that reside in these areas or change the geometry of the debris fans and flow patterns within the eddy. Although the potential for sediment delivery to the Colorado River is highly variable throughout Grand Canyon, there are, nonetheless, about 525 tributaries that periodically have had flash floods or debris flows (Melis and Webb, 1993).

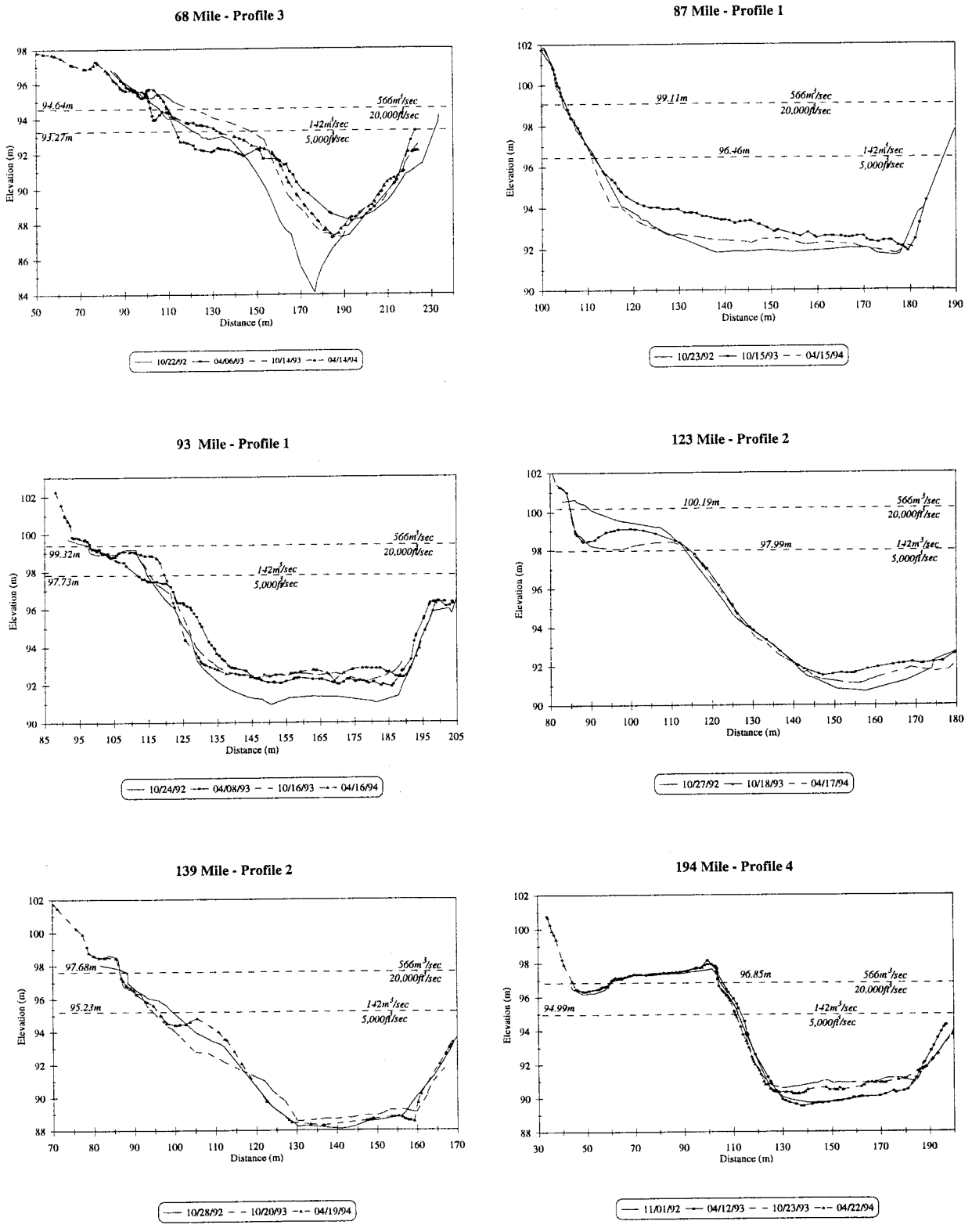


Figure 29. Cross-channel profiles from selected sites that show channel bed elevation change, some of which we attribute to sediment input from the LCR.

During the Interim Flow period debris flows occurred in Jackass and Tanner canyons, affecting sand bars under study by changing the eddy hydraulics in which the bars reside. A small debris flow in Jackass Creek in August 1994 modified the debris fan at the Colorado River. Historical photographs show that no debris flows have occurred at Badger Rapid after 1890 (Webb et al., 1991). The RM8 separation bar that mantles the downstream portion of the debris fan was surveyed in November 1994, less than 3 months after the event. It is important to note that the biggest change in 25 surveys dating back to June 1990 had been 19% in area and 8% in volume within the HAZ boundary (Appendix A: RM8 volume plots) and thus the site was considered relatively stable during and prior to Interim Flows. However, the November 1994 survey showed a 49% decrease in area and a 58% decrease in HAZ volume (Appendix A: RM8). We hypothesize that changes to the constricting debris flow at this site caused significant changes to the sand bar.

The Tanner debris flow in August, 1993 altered Tanner rapid (RM68.5) and modified the constricting debris fan. The pool configuration above the rapid was significantly changed and a different local stage discharge relationship developed (Figure 30). Hypsometric data from the upper pool reattachment bar at the RM68 study site show a shift in the area distribution at this site (Figure 31). Profiles show a progressive building of a reattachment bar downstream of the area in which the reattachment bar typically resided prior to the upper pool change (Appendix A: RM68; profile 8). The reworked debris fan at this site has affected both the location of sand bar deposition and shape of the flow separation zone that exists in the upper pool.

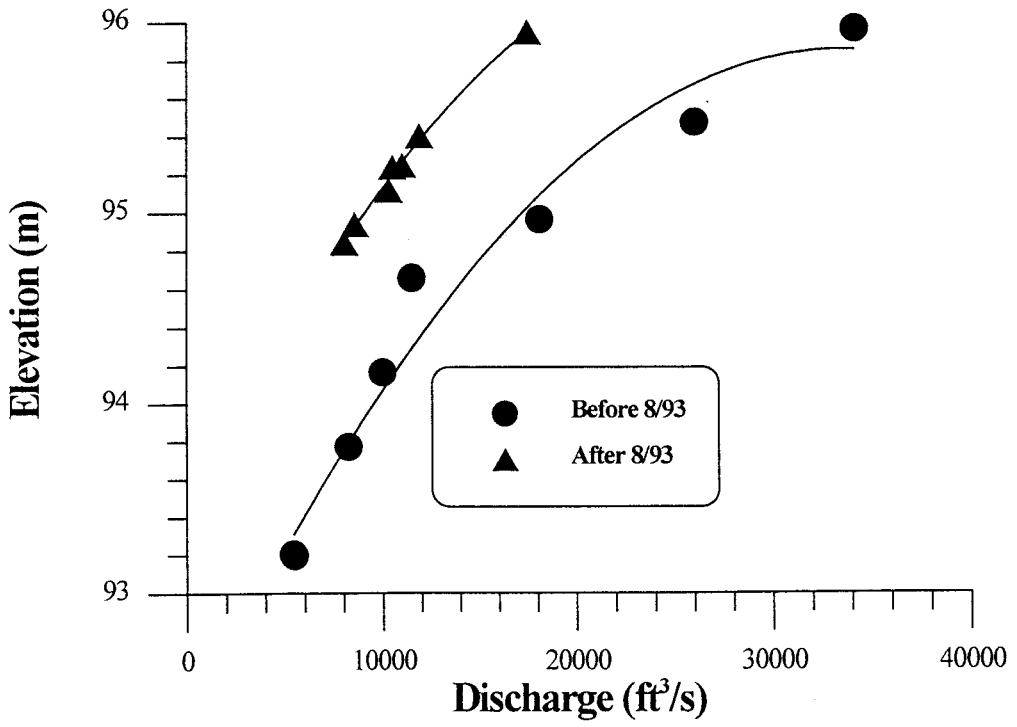


Figure 30. Stage discharge relationships for the RM68 study site showing the change in specific stage elevations before and after the debris flow induced changes in the channel constriction (Tanner Rapid).

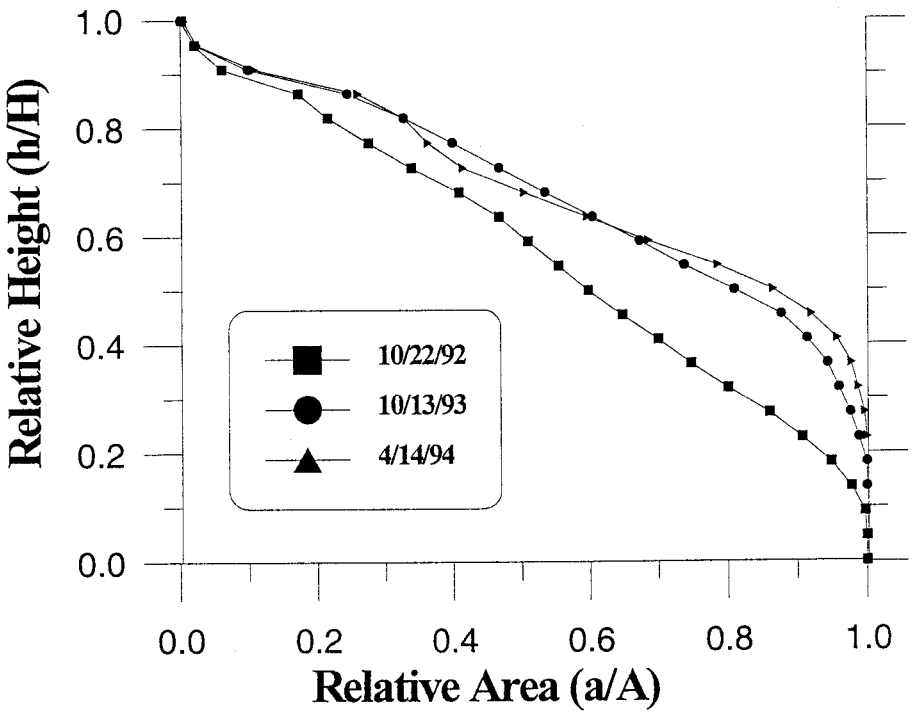
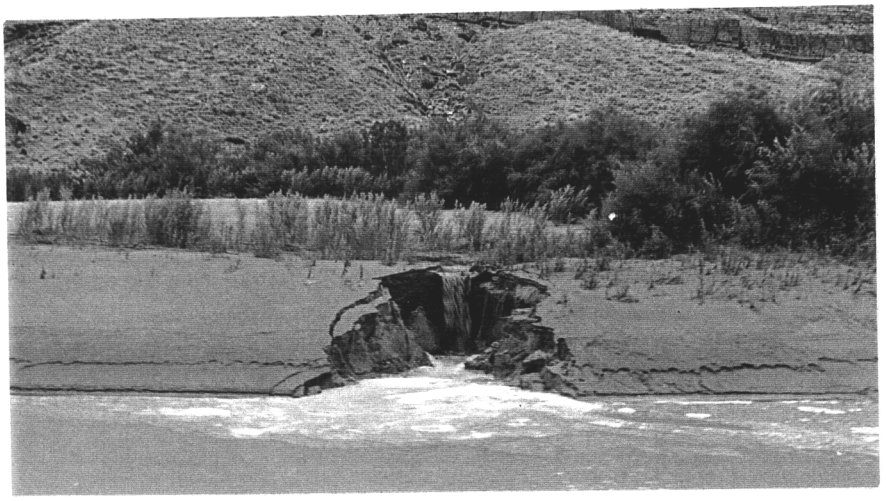


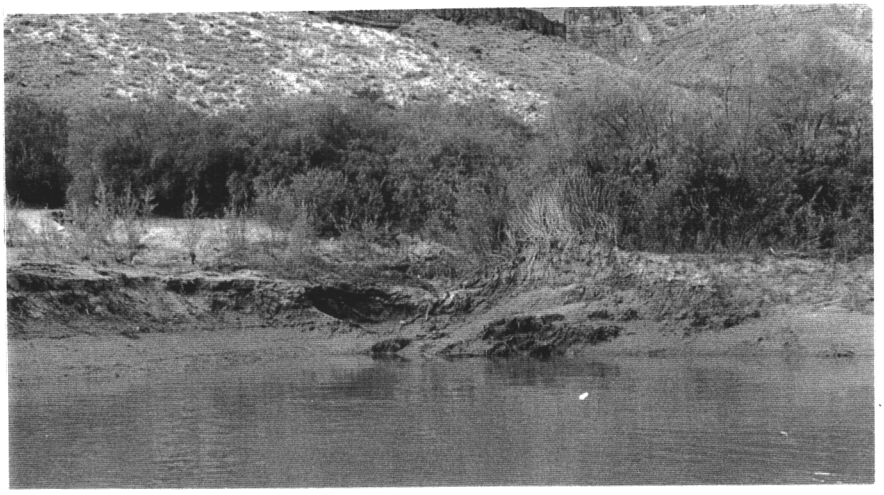
Figure 31. Hypsometric curves from the RM68 study site showing the increase in sediment volume at higher elevations.

Flash floods that have eroded bars or covered them with gravel have occurred at RM-6, RM45, and RM123. At RM123 a flash flood from Forster Canyon eroded the downstream portion of the sandbar (Figure 32a and 33a). Fluctuating flows then enlarged this area (Figure 32a and 33a). However, at this site deposition from the LCR winter floods was successful in rebuilding this bar (Figure 32c and 33c). Tributary impacts will become more important because Interim Flows are no longer high enough to aggrade damaged areas or flush out rapids that have had post-dam debris flows. Kearsley (1995) documented the destruction of two campsites (RM 157.7R and 160.9R) by localized debris flows and flooding from one storm event on August 20, 1993. In addition to tributary flash floods, direct surface runoff can channelize through the exposed areas of sand bars and cause extensive erosion. Surficial erosion of the exposed sand bars is an ubiquitous process that can only be offset by rebuilding sand bars through planned dam-release floods.

A.



B.



C.

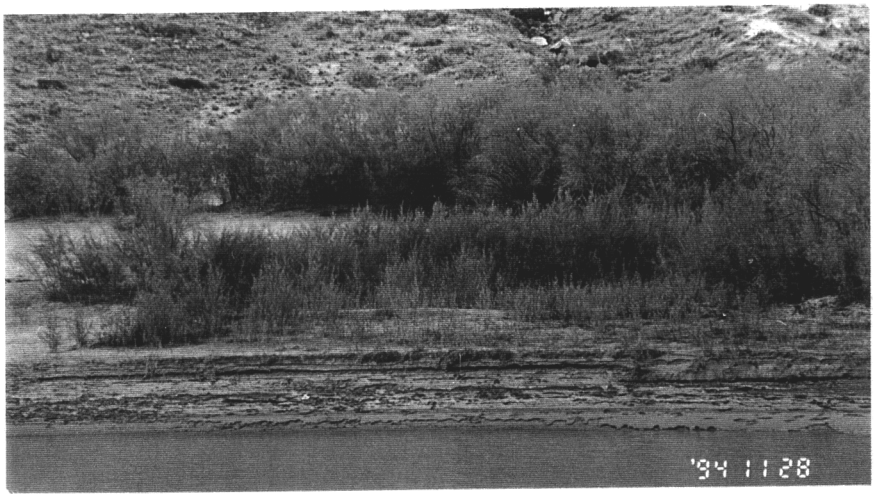
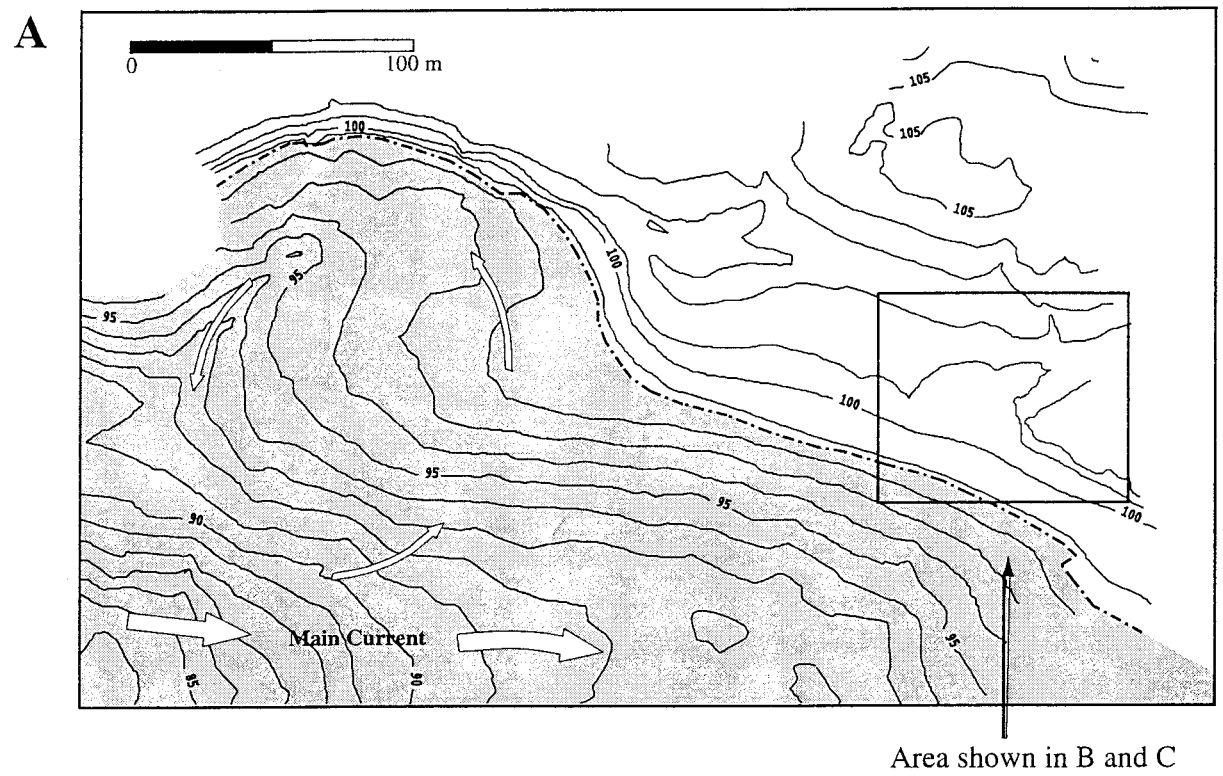


Figure 32. Photographs from RM123 showing A) the August 1990 flash flood that scoured the downstream portion of the bar, B) enlargement of the area by fluctuating flows, and C) deposition of sand in the degraded area after the LCR floods.



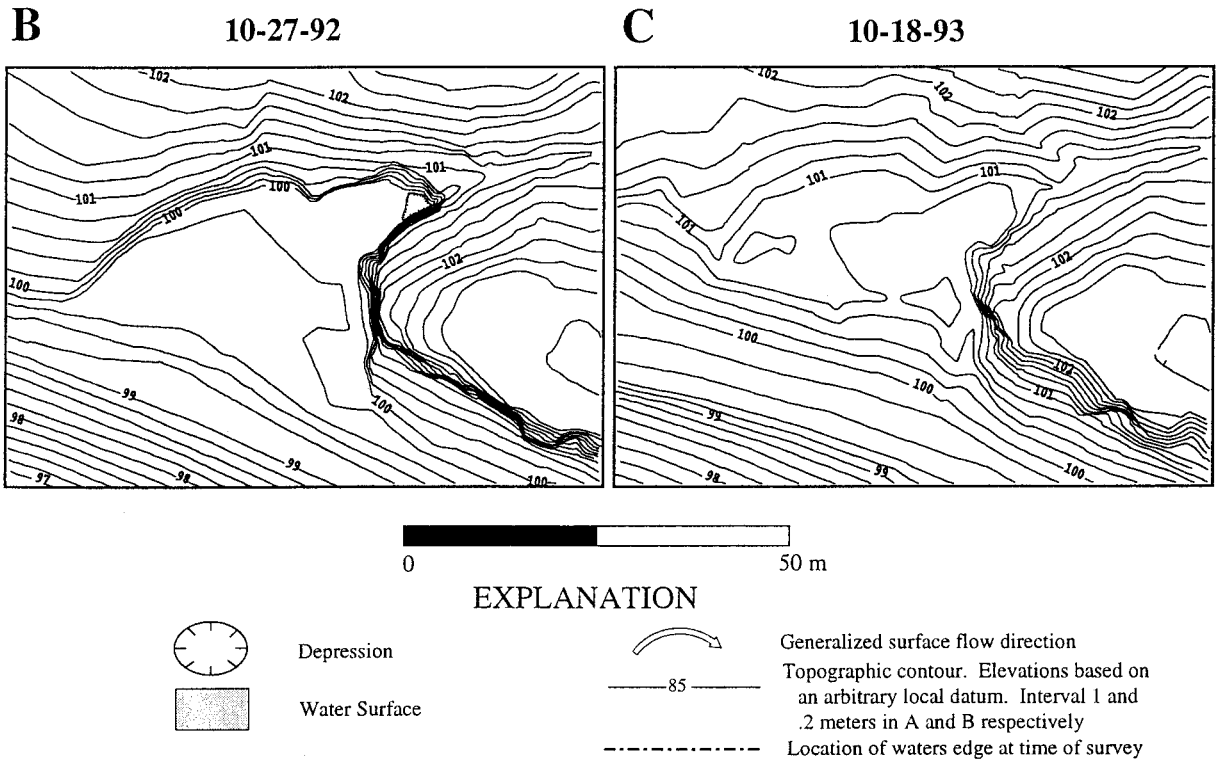


Figure 33. Topographic map of the upper pool/reattachment deposit at RM123 in A showing the location of the area eroded by a flash flood from Forster Canyon in B. This area was subsequently filled in the LCR winter floods in 1993. Over 1 m of deposition filled in the scoured area as indicated by the 100 m contour in C.

SUMMARY

Sand Bar and Recirculation Zone Adjustment to Interim Flows

Grand Canyon sand bars have adjusted significantly to changes in the local eddy geometry and restricted flow fluctuations during Interim Flow monitoring. Changes in eddy geometry occur due to a combination of varying mainstem flow regimes, sand accumulation within the eddy, and changes in the local geomorphic control. Previous investigations have shown that, due to the variability in local geomorphology and local reach sediment budget, sand bars respond differently to varying flow regimes (Schmidt and Graf, 1990; Webb et al., 1991; Andrews, 1991b; Schmidt, 1992; 1995). Our results indicate that a consistent, measurable pattern of sand bar change has occurred during Interim Flows and that our measurements are indicative of system-wide behavior of alluvial deposits along the Colorado River.

Interim Flows were implemented to reduce daily flow fluctuations and minimize impacts to downstream resources, while allowing limited flexibility for power operations (Bureau of Reclamation, 1994). Many of the adjustments to Interim Flows, such as subaerial sand bar erosion, deposition at lower bar elevations, sediment storage within smaller eddies, and encroachment of vegetation were anticipated by research conducted during GCES Phase II. Our results confirm that the pattern of change has been as predicted. The exposed areas of both reattachment and separation bars have been eroded (Figure 34). Sediment was transferred from high (emergent) to low elevations (submergent or daily inundated). Sediment eroded from high-elevation locations was deposited either in the main channel and transported downstream or within smaller recirculation zones along the lower portion of the bars below the water level of the maximum fluctuation (Figure 34b). Seasonal variations in daily minimum and maximum flows (Figure 3) creates cutbank terraces across the bar platform (Figure 34c). The downstream areas of reattachment bars became exposed to main-current erosion due to contraction of the recirculation zones (Figure 34c). Return-current channels associated with reattachment bars that occupied the area inundated by 566-793 m^3/s (20,000-28,000 ft^3/s) flows have aggraded with sand and silt and are no longer connected to the river (Figure 35b). Return channels that are still open to the river are narrower and shallower because of bankward migration of bar platforms (Figure 34b). This limits the size and extent of possible native fish backwater habitat since the bar platform is daily inundated and the return channel has little chance for warming.

Cutbank development was typically observed at the maximum stage of the Interim Flow fluctuation range. Numerical models of seepage erosion by Budhu (1992) and Budhu and Gobin (1994) predict that the minimum stage determines the zone between stable and unstable sediments. It is likely that the Interim criteria of lessened down-ramp rates and restricted flow fluctuations successfully minimized seepage erosion and that tractive forces were the dominant erosional mechanism during the Interim Flow period.

Interim Flows have stored sand in recirculation zones, but the smaller size of the eddies prohibits a system-wide increase in the overall volume of eddy-stored sediment. The depletion of eddy-stored sand will continue during Interim Flows or similiar flow alternatives, especially in the sediment-starved reaches above the LCR.

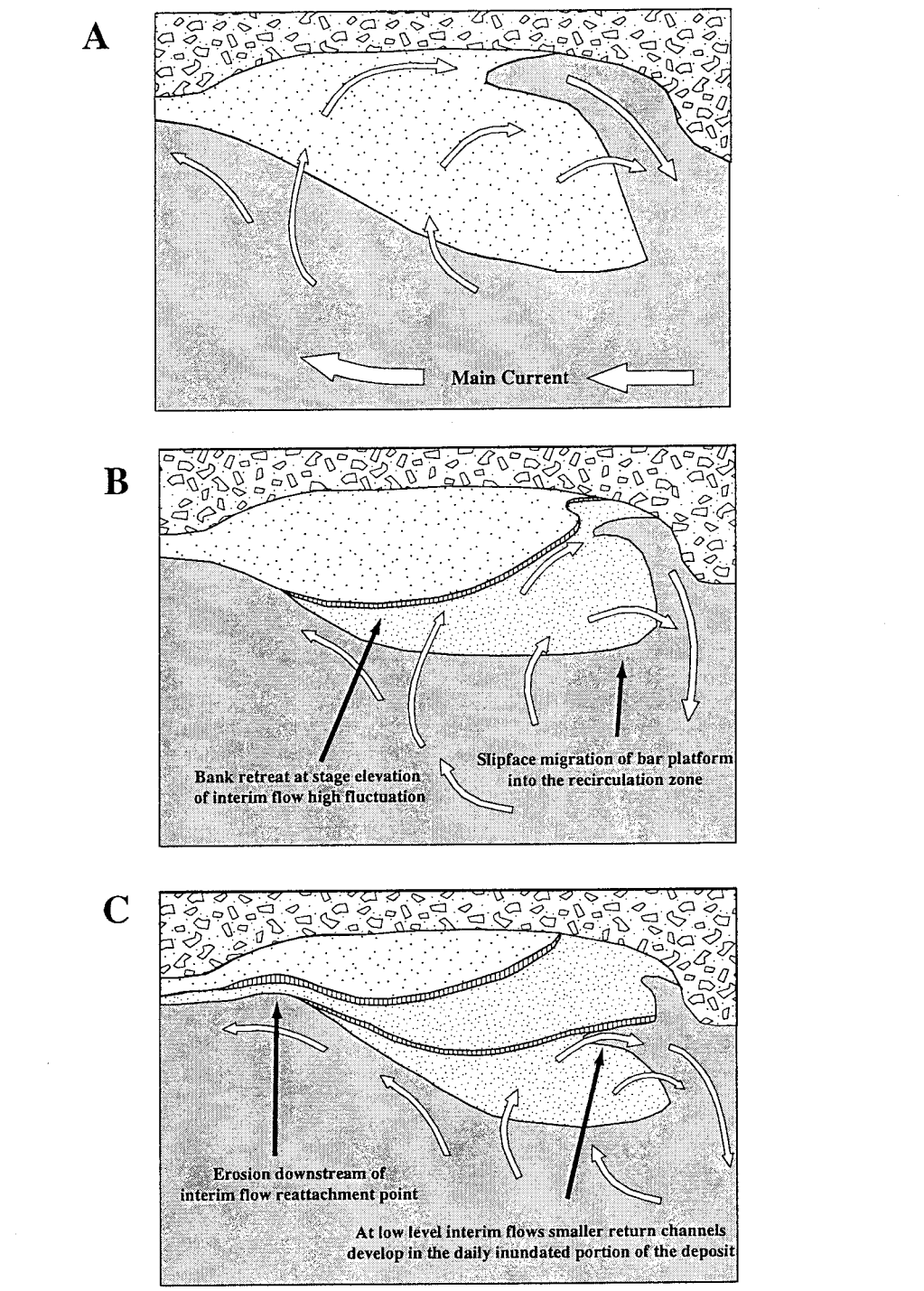


Figure 34. Schematic diagram of a reattachment bar at low discharge. A) bar morphology prior to Interim Flows. B) Erosion of bar platform by cutbank migration at lower Interim Flow stage elevations. C) Typical bar morphology after three years of Interim Flows.

The process of sand bar adjustment and redistribution of sediments involves the entire eddy and much of the sand in storage, especially during Interim Flows, is subaqueous. An important question to consider is whether sand eroded from sand bars during Interim Flows remains within the recirculation zone and fuels changes within that eddy, as proposed by Budhu and Gobin (1994), or do these processes strip large quantities of sand from the eddy and result in downstream transport (Dexter et al., 1994). Although the scope of our study does not allow a definitive answer to this question, at several sites we have observed that a large percentage of the sediments eroded from the sand bars are not transported out of the recirculation zone (Figure 21). This sediment becomes available to rebuild the bar that resides in the same recirculation zone (Schmidt, 1990).

In the simulations used in the GCD-EIS sediment transport model developed by Bennett (1993), the amount of sand stored in the eddies is relatively small, seldom exceeding more than 30% of the total in the reach. Our results indicate that the smaller Interim Flow recirculation zones have accumulated sediments and that deposition has been primarily from redistribution of sediments eroded upstream from the reattachment point. If sediment storage has been primarily in recirculation zones then the duration of proposed bar-building and habitat maintenance flows that are included in the GCD-EIS must be carefully planned so that sustained sediment transport rates do not result in net erosion of recirculation zones, particularly in upstream sediment deficient reaches such as the lower Glen Canyon and Marble Canyon reaches (Schmidt et al., 1993).

Evaluation of Interim Flows and Alternatives

In the GCD-EIS the active width and height of sand bars is used as an indicator of the effects of flow alternatives (Bureau of Reclamation, 1994). The GCD-EIS impact analysis is based on the sand bar slope stability model developed by Budhu (1992) and Budhu and Gobin (1994). According to this model, sand bars are initially deposited at a slope angle between 30 and 32 degrees. As the river stage recedes slope failure occurs due to seepage, high velocities, or wave action and will progress until an equilibrium profile of about 11 degrees is reached. Reach-averaged stage discharge relationship and an assumed slope angle of 11 degrees were used to define the active width and height of a hypothetical bar. In the GCD-EIS evaluation of the various alternatives, reduced ranges of fluctuations reduce the active width of the sandbars (Figure 35b). We determined the active width at our study sites by measuring the width of the sand bar slope between the zone inundated by the range of daily and annual flow fluctuations (Figure 35 and Table 6). The measured active width and height of the sand bars monitored during this study are shown in Table 6 to compare with the hypothetical impacts of the Interim Low and Modified Low Fluctuating Flow Alternatives summarized in Table IV-6 of the GCD-EIS (Bureau of Reclamation, 1994) to changes measured at individual sand bars during Interim Flows.

Our measurements show that the active width of sand bars was not reduced during Interim Flows. Restrictions in flow fluctuation will result in a smaller active width of the sand bar only immediately following a change to lower flows, such as Interim Flows (Figure 35b). We

observed that, in as little as 2 months, cut bank retreat had progressively widened the active width of the sand bars (Figure 35c). For these alternatives the annual discharge range is 142 m^3/s to 566 m^3/s (5,000 ft^3/s to 20,000 ft^3/s) and reach averaged active sand bar width was calculated to range between 7 and 13 m (24 and 41ft). Our measurements (Table 6) show that although the potential sand bar heights fall within the estimated range in Table IV-6 (GCD-EIS), the active width as of April 1994 averaged nearly 21 m (68 ft), approximately 7 to 14 m (23 to 46 ft) wider than suggested in the GCD-EIS. These values are similiar (slightly greater than 1 m) to those measured just prior to the start of Interim Flows (Table 6). Because the active sand bar width did not decrease during Interim Flows as predicted, some uncertainty exists in the use of this analysis as an indicator of alternative flow impacts. Analyses based on seepage-driven erosion models may not be appropriate for evaluating low fluctuatin flow alternatives because during Interim Flows seepage-driven erosion was minimized and tractive force erosion appeared to be the dominant erosional mechanism. Future evaluation of flow effects should be based on results from the long-term monitoring of sand bars.

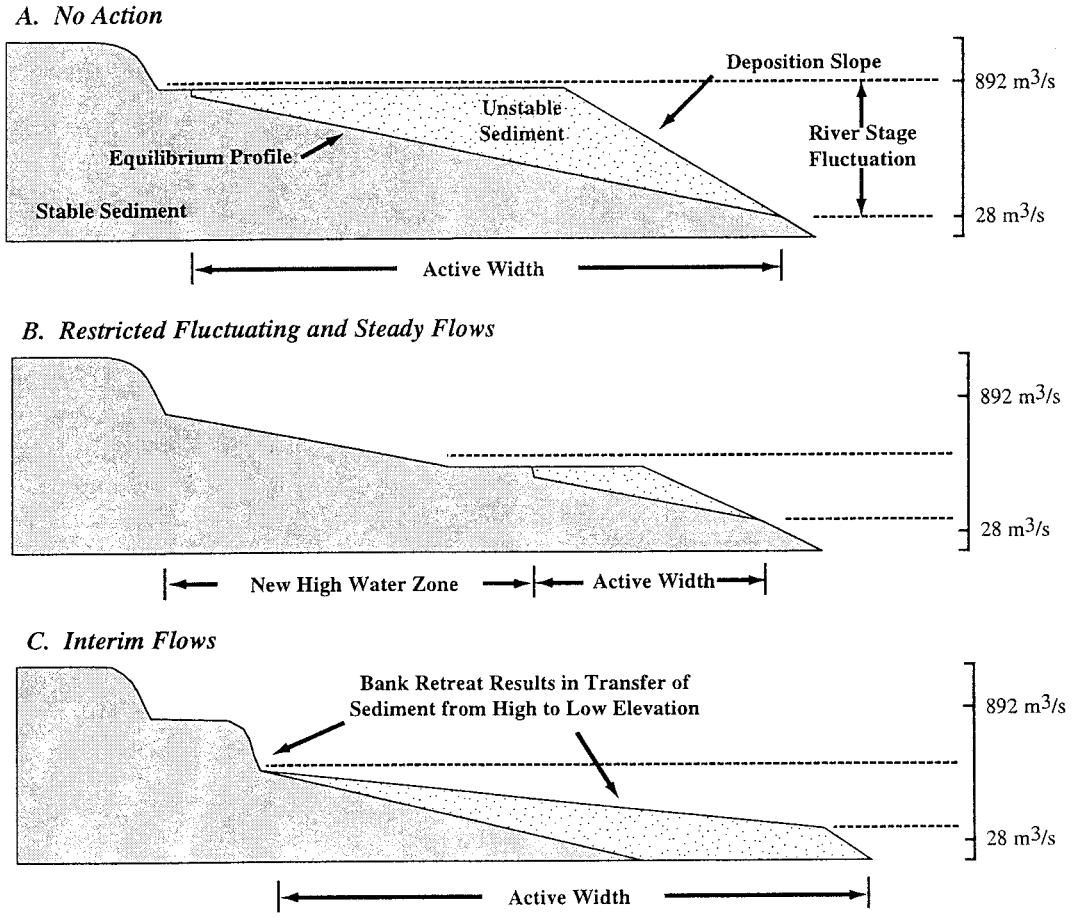


Figure 35. Schematic cross sections of the active width and height of a typical sand bar used in the GCD-EIS for impact analysis of the A) No Action Alternative, and B) Restricted Fluctuating and Steady Flow Alternatives. Modified from Bureau of Reclamation (1994). The GCD-EIS implies that as the fluctuating zone is reduced, so too is the zone of unstable sediment and sandbar heights. However, our results C) show that the Interim Low Fluctuating Flow Alternative leads to a progressively wider active width as cutbanks migrate across the bar and sand is transferred to low-elevation locations.

Table 6. Average study site sand bar height and active width

Site[a]	Height m(ft)[b]		Active Width m(ft)[c] 07/91		Active Width m(ft)[c] 04/94	
-6R	1.63	(5.35)	23.60	(77.43)	24.40	(80.05)
3L	2.18	(7.15)	27.9	(91.54)	33.80	(110.89)
8L	1.67	(5.48)	15.40	(50.52)	15.60	(51.18)
16L	2.27	(7.45)	20.75	(68.08)	23.33	(76.55)
22R	3.66	(12.01)	22.50	(73.82)	30.67	(100.61)
30R	3.13	(10.27)	18.80	(61.68)	23.40	(76.77)
31R	1.85	(6.07)	24.00	(78.74)	25.00	(82.02)
43L	2.19	(7.19)	11.40	(37.40)	10.08	(32.43)
45L	2.44	(8.01)	14.40	(47.24)	15.40	(50.52)
47R	1.76	(5.77)	38.40	(125.98)	32.40	(106.30)
50R	2.24	(7.35)	12.80	(41.99)	17.00	(55.77)
51L	1.93	(6.33)	23.83	(78.19)	21.33	(69.99)
81L	2.69	(8.83)	10.30	(33.79)	8.20	(26.90)
87l	2.65	(8.69)	5.63	(18.45)	7.75	(25.43)
91R	2.51	(8.23)	10.50	(34.45)	8.50	(27.89)
93L	1.59	(5.22)	7.60	(24.93)	9.80	(32.15)
104R	2.76	(9.06)	12.30	(40.35)	10.40	(34.12)
119R	2.64	(8.66)	19.80	(64.96)	15.40	(50.52)
122R	2.69	(8.83)	38.40	(125.98)	20.00	(65.62)
123L	2.20	(7.22)	13.63	(44.70)	14.00	(45.93)
137L	2.61	(8.56)	30.50	(100.07)	31.00	(101.71)
139R	2.45	(8.04)	11.17	(36.64)	12.83	(42.10)
145L	3.01	(9.88)	8.88	(29.12)	9.75	(31.99)
172L	2.04	(6.69)	33.25	(109.09)	34.50	(113.19)
183R	2.40	(7.87)	37.00	(121.39)	27.40	(89.90)
194L	1.86	(6.10)	62.00	(203.41)	13.67	(44.84)
202R	2.03	(6.66)	15.10	(49.54)	12.80	(41.99)
213L	1.86	(6.10)	9.80	(32.15)	11.00	(36.09)
220R	1.96	(6.43)	8.20	(26.90)	10.00	(32.81)
225R	2.13	(6.99)	4.13	(13.53)	6.75	(22.15)
Average	**2.29**	**(7.52)**	**19.73**	**(64.74)**	**20.83**	**(68.35)**
Std. Dev.	**.47**	**(1.56)**	**12.48**	**(40.94)**	**12.77**	**(41.91)**

[a]RM68 excluded from this analysis because of the upper pool change upstream of Tanner Rapid.
[b]Sand bar height derived from difference in water-surface elevations between 142 m^3/s and 566 m^3/s in the stage-discharge relationship developed for each site in Appendix A.
[c]Active sand bar widths derived from the profiles in Appendix A for each site and are calculated from the differences in river stage corresponding to the 142 m^3/s and 566 m^3/s discharge elevations.

Management Implications

The system wide changes we have described in this report indicate that Interim Flows did little to decrease erosion of sand bars and we conclude that Interim Flow objectives are only partially being met. Sediment accumulated in smaller recirculation zones but erosion of sediment at higher bar elevations was not being replaced (Figure 36). Sand bars should be considered the preferred location for storing sediment because sediment stored in bars is removed from downstream mainstem transport and becomes available for riparian habitat development and recreational camping area. Removing sediment from mainstem transport maximizes the residence time of sediment at a particular site and minimizes the eventual transport of sediment

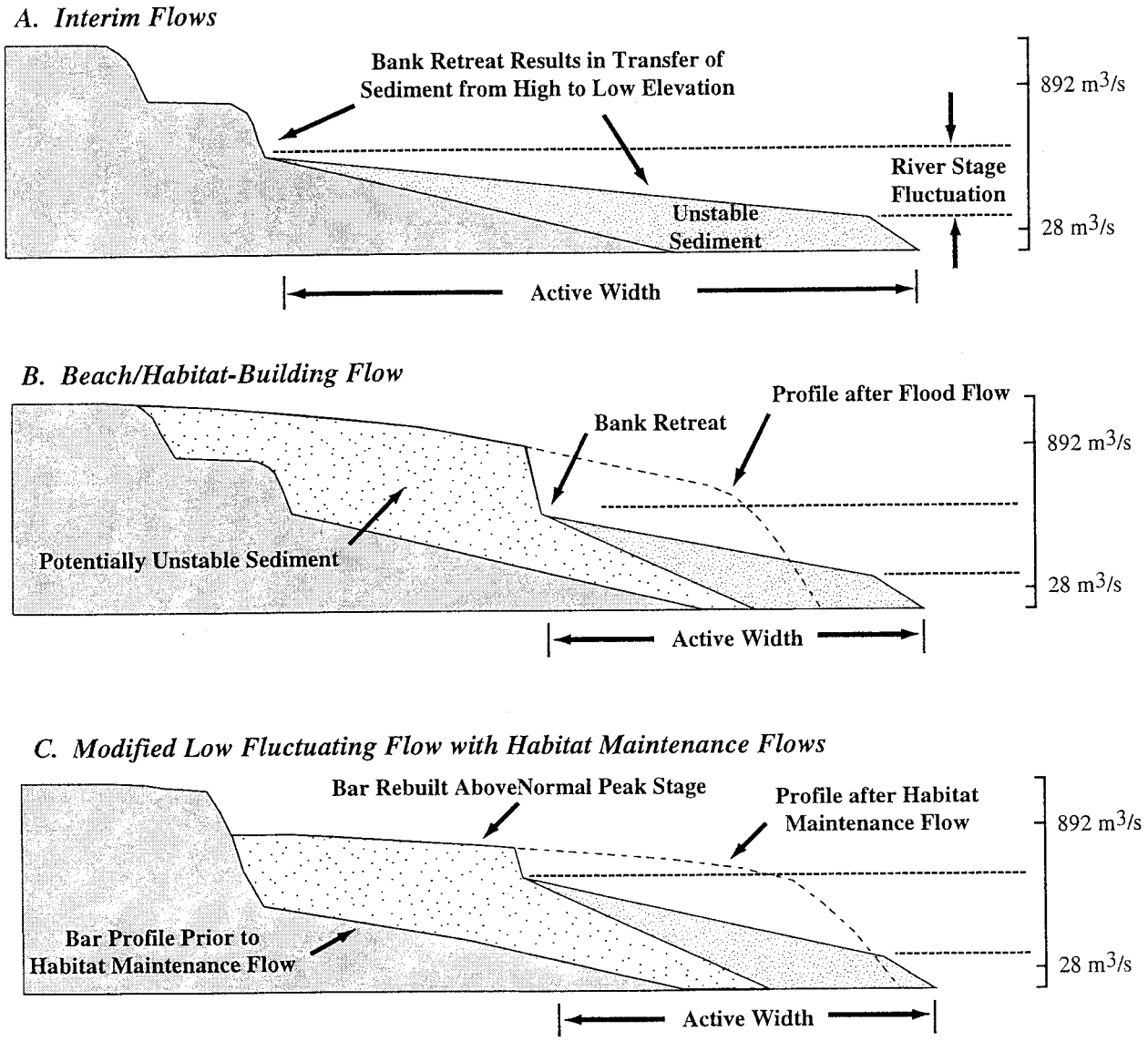


Figure 36. Schematic cross sections of the active width and height of a hypothetical sand bar. In A) Interim Flows, B) after a Beach Habitat-Building Flow, and C) after a Habitat Maintenance Flow. Both B and C are shown following the return to the Modified Low Fluctuating Flow Alternative.

downstream. Erosion is a ubiquitous process that continually decreases the size of sand bars. We have observed a trend of decreasing sediment volume within recirculation zones during Interim Flows (Figure 37). Sediment stored as sand bars can be maintained by raising mainstem flows and depositing sand at higher elevations (Figures 36 and 37).

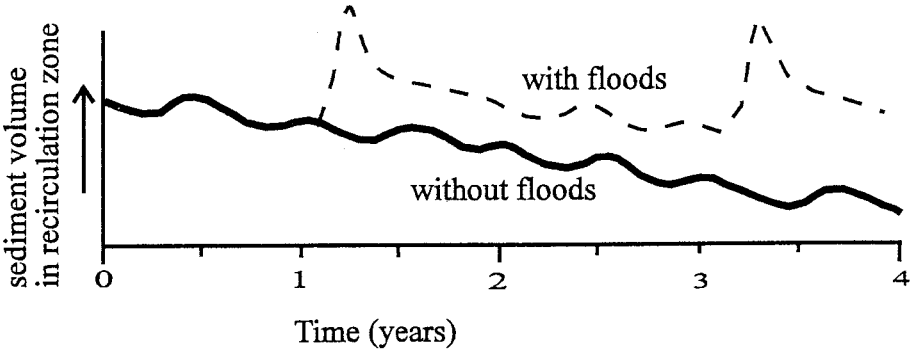


Figure 37. Schematic diagram of volume changes within recirculation zones over time with and without dam-release floods

If return channels are a desirable feature to resource managers, floods are needed to restructure return channels and increase the number of backwaters. Floods supposedly increase the number of backwaters by scouring the return-current channels and removing vegetation (Bureau of Reclamation, 1994). Our observations of natural, sediment-rich, short duration floods from the LCR reveal that return channels actually aggraded with sediment. A clear-water, dam-release flood needs to be of sufficient duration to achieve the desired return-channel restructuring without degrading the deposit. High flow releases are included in both the Moderate and Modified Low Fluctuating Flow Alternatives. Habitat Maintenance Flows are high, steady releases within powerplant capacity that would occur nearly every year in the spring. Beach/Habitat-Building Floods might be as high as 1,274 m^3/s to 1,472 m^3/s (45,000 to 52,000 ft^3/s) but the optimum duration has not been decided (Bureau of Reclamation, 1994). Maintenance of sand bars depends on determining the duration and discharge which will build bars and restructure habitats without causing a net depletion of sand (Andrews, 1991b)

Based on existing data, we support the EIS Preferred Alternative, which combines periodic dam-release flood flows from GCD, the reduced sediment transport rates of Interim Flows, and the opportunity to determine the effects of seasonally adjusted steady flows. Although the reduction in the daily fluctuations of discharge represented by Interim Flows did not eliminate or even possibly reduce the erosion of sand bars, this type of flow restriction does, however, decrease the frequency and duration of bar submergence (Rubin, et al., 1995) and increases the net sediment budget in the canyon (Smith et al., 1993; Randle et al., 1993; Bennet, 1993). The Modified Low Fluctating Flow Alternative may be preferable as it will result in bars that are emergent for longer time periods during the year. This will increase camping area, riparian habitat, and backwaters. The most critical aspect of this and other alternatives is a yearly high-water release from GCD to replace sediment eroded during the remainder of the year. Continued monitoring and research is needed to determine the effects of this, and future dam management strategies.

CONCLUSIONS

Interim Flows have significantly eroded Colorado River sand bars.

Interim Flow operations from GCD have resulted in deposition within smaller recirculation zones below the maximum Interim Flow stage elevation along the lower portions of many sand bars

Sand bars were eroded by tractive forces (cutbank erosion and/or rapid erosion events).

Seepage erosion was minimized during Interim Flows.

Interim Flows have led to a trend of decreasing sediment volume contained within recirculation zones.

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 and maintain sand bar volume.

"Bar-building flows" at or near powerplant capacity do redistribute sediment to higher elevations.

Natural, short-duration floods from the LCR aggraded sand bars and in-filled return current channels.

Smaller return current channels developed during Interim Flows and higher discharge return channel areas were stranded above Interim Flow levels and/or filled with sediment.

Biannual sand bar surveys can detect system-wide changes in sedment storage.

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MONITORING THE EFFECTS OF INTERIM FLOWS FROM GLEN CANYON DAM ON SAND BARS IN THE COLORADO RIVER CORRIDOR, GRAND CANYON NATIONAL PARK, ARIZONA

APPENDIX A: Atlas of Sand Bar Survey Sites

MONITORING THE EFFECTS OF INTERIM FLOWS FROM GLEN CANYON DAM ON SAND BARS IN THE COLORADO RIVER CORRIDOR, GRAND CANYON NATIONAL PARK, ARIZONA

APPENDIX A: Atlas of Sand Bar Survey Sites

Atlas information available at WWW sandbar survey home page:
http://vishnu.glg.nau.edu/gces/sbar.html

GLEN CANYON ENVIRONMENTAL STUDIES OFFICE

AUG 2 8 1995

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Co./Dept. GCES | Co. NAU Geology
Phone # | Phone # 523 9145
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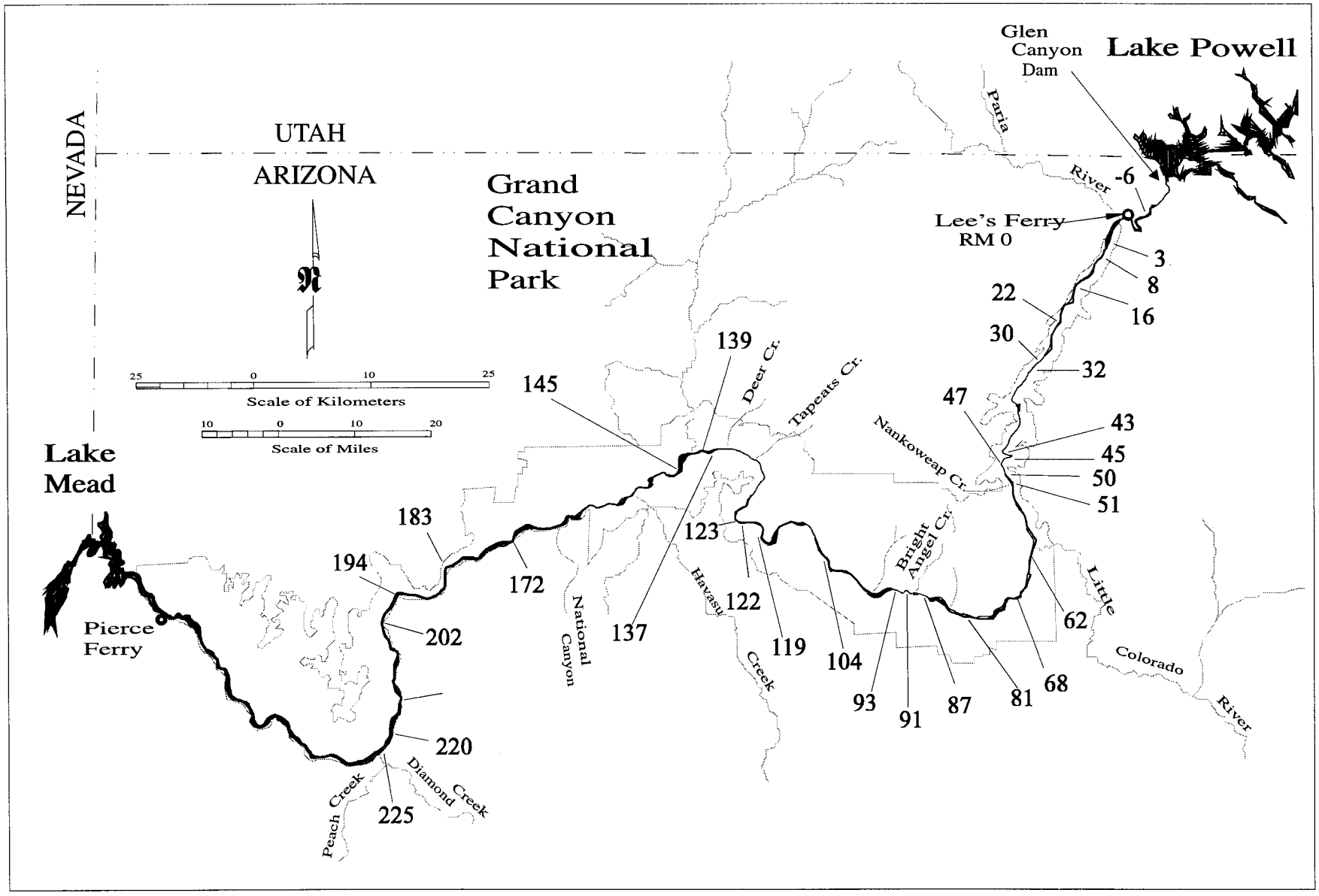
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Tapeats Cr.
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Bright Angel Cr.
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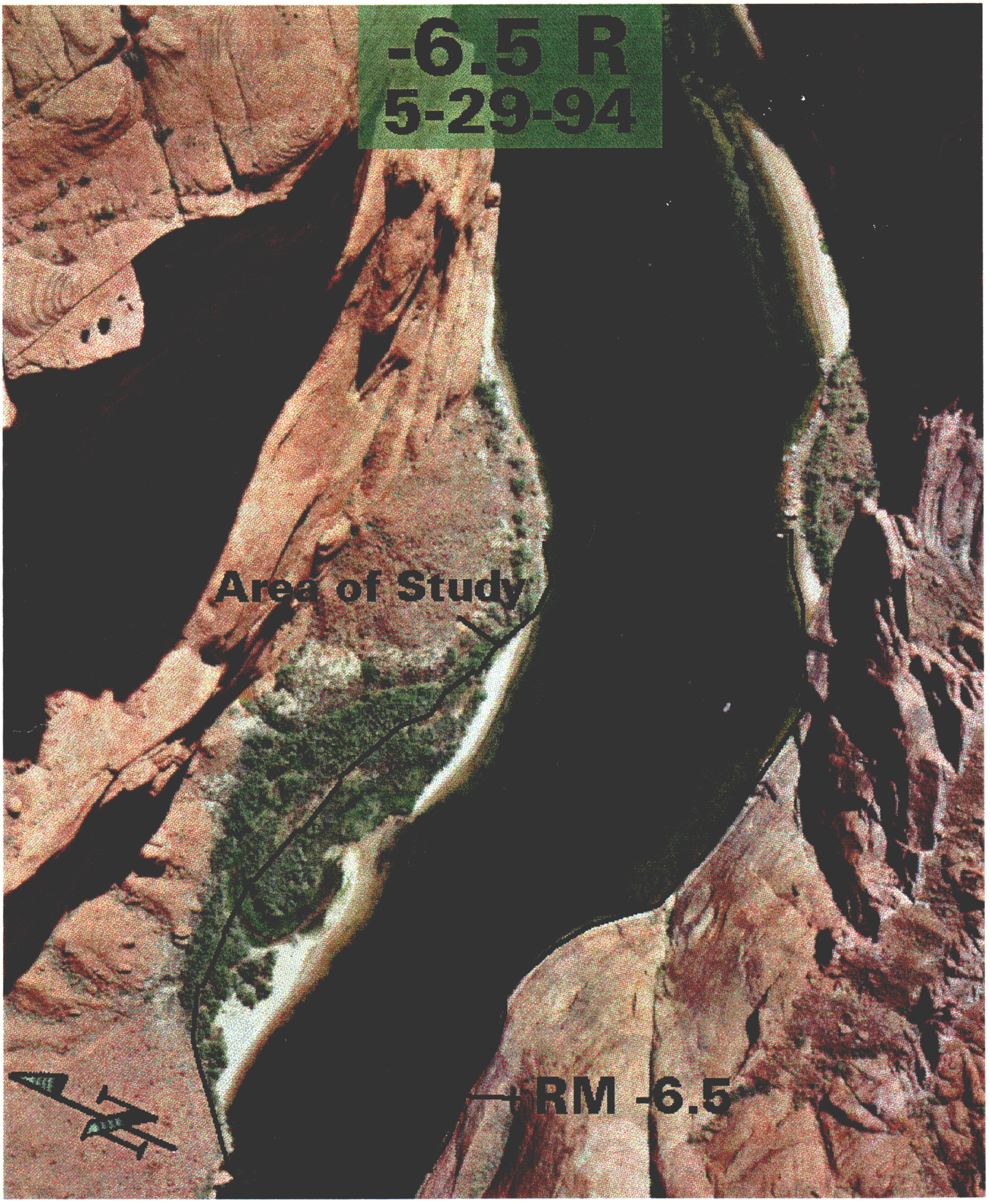
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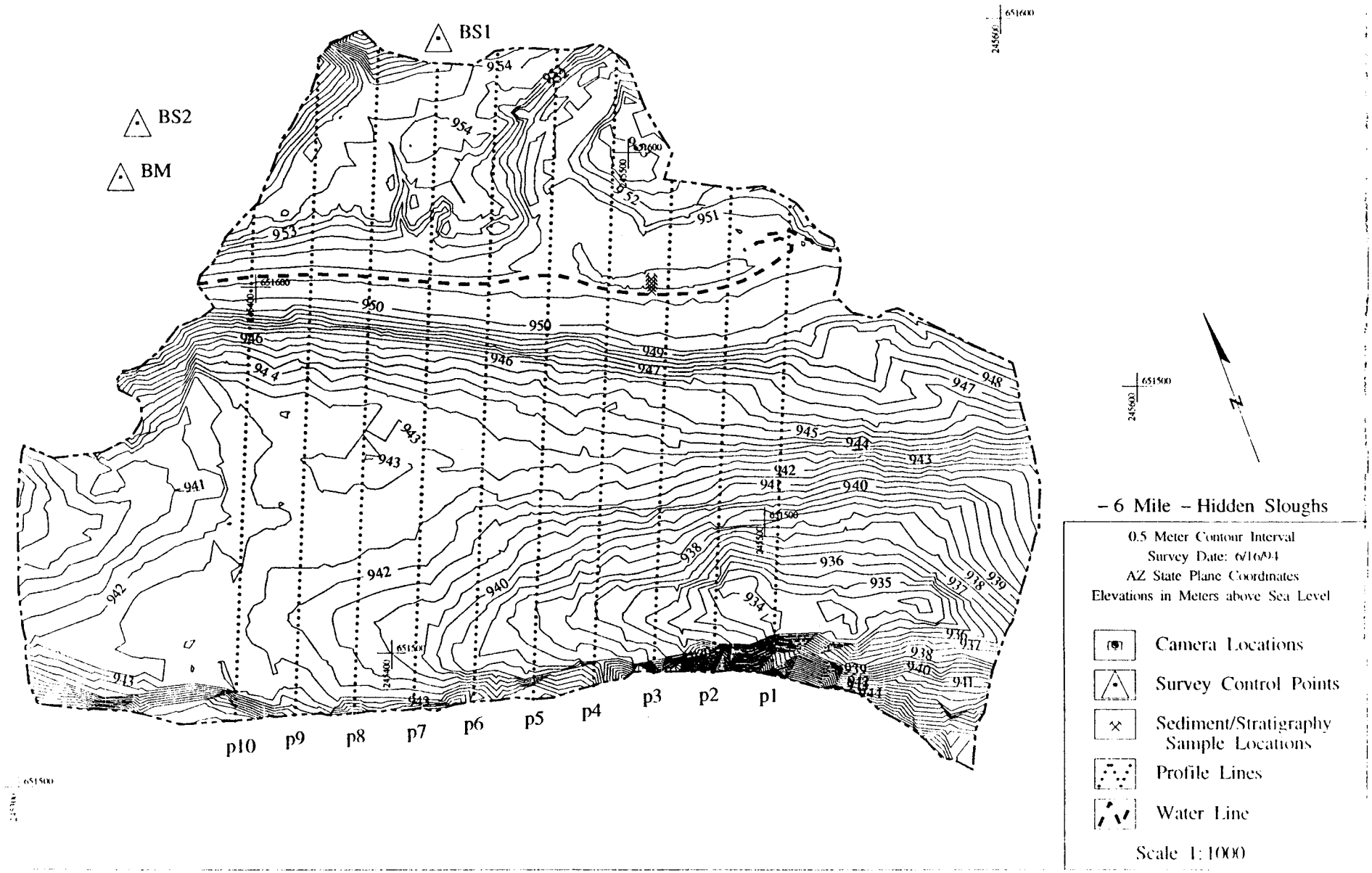
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N
- 6 Mile - Hidden Sloughs
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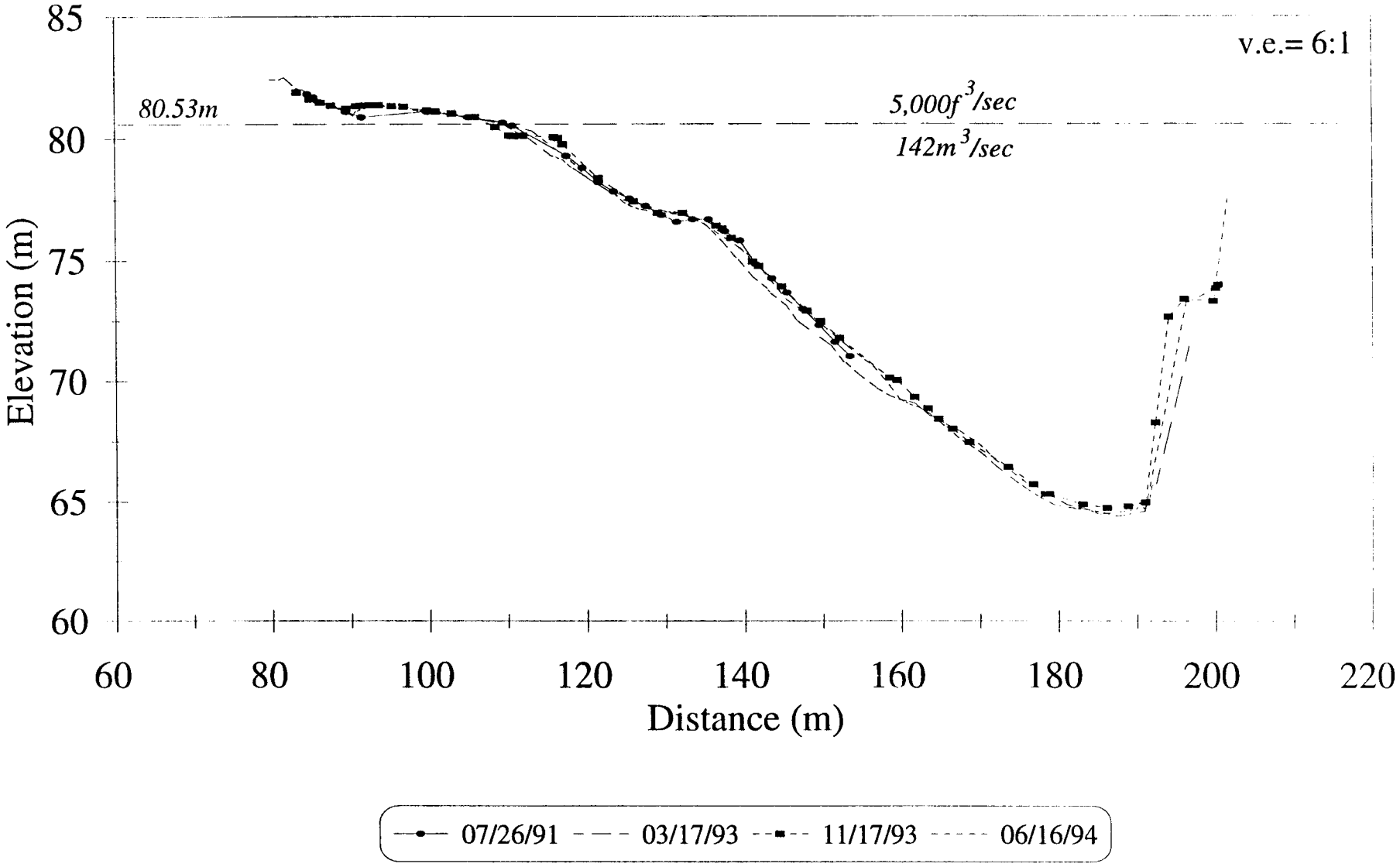
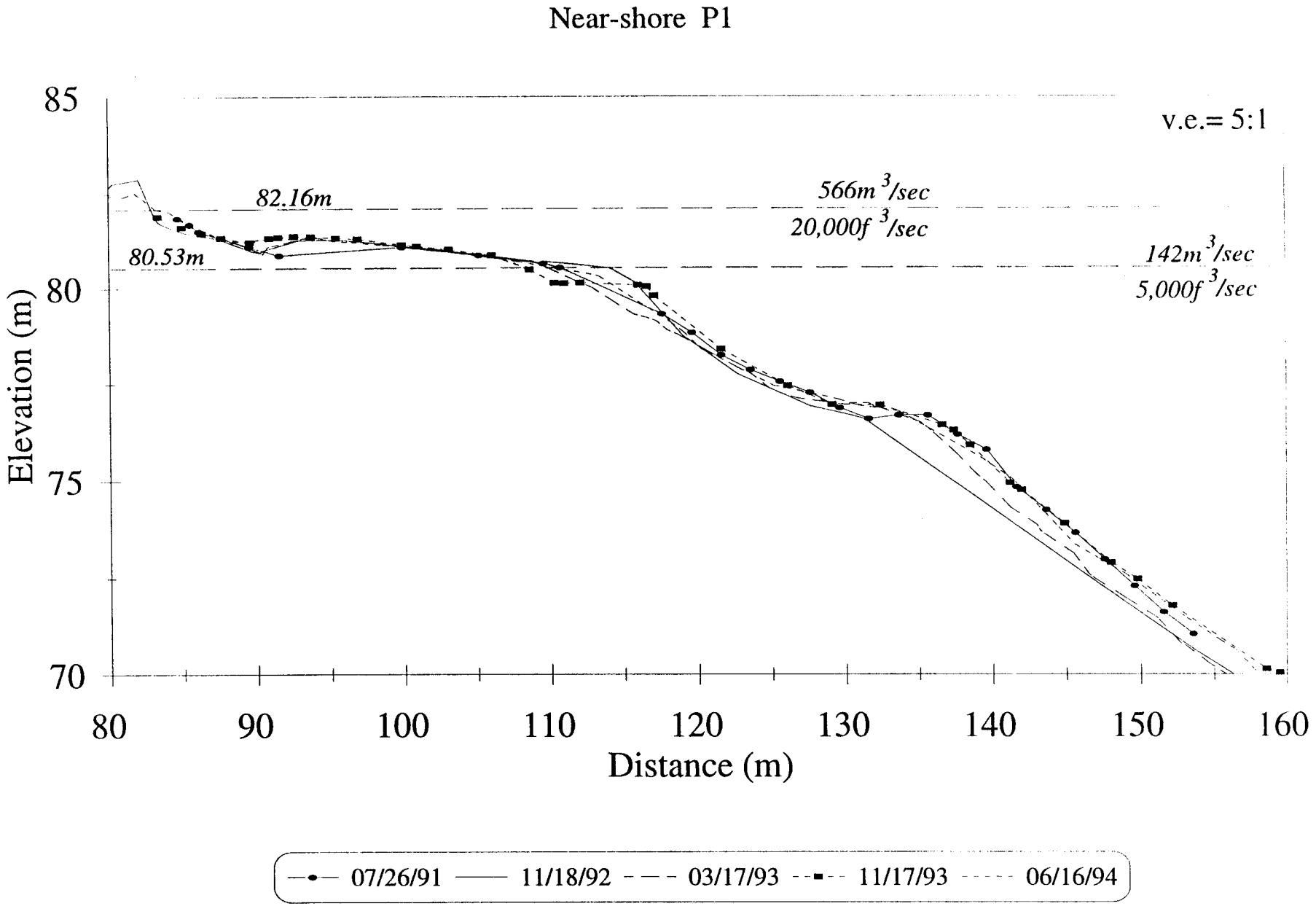
Survey Date: 6/16/94
AZ State Plane Coordinates
Elevations in Meters above Sea Level
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:1000

-6 Mile

Cross-channel P1




Near-shore P1
v.e.= 5:1
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80.53m
566m 3/sec
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142m 3/sec
5,000f 3/sec
Elevation (m)
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80
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Distance (m)
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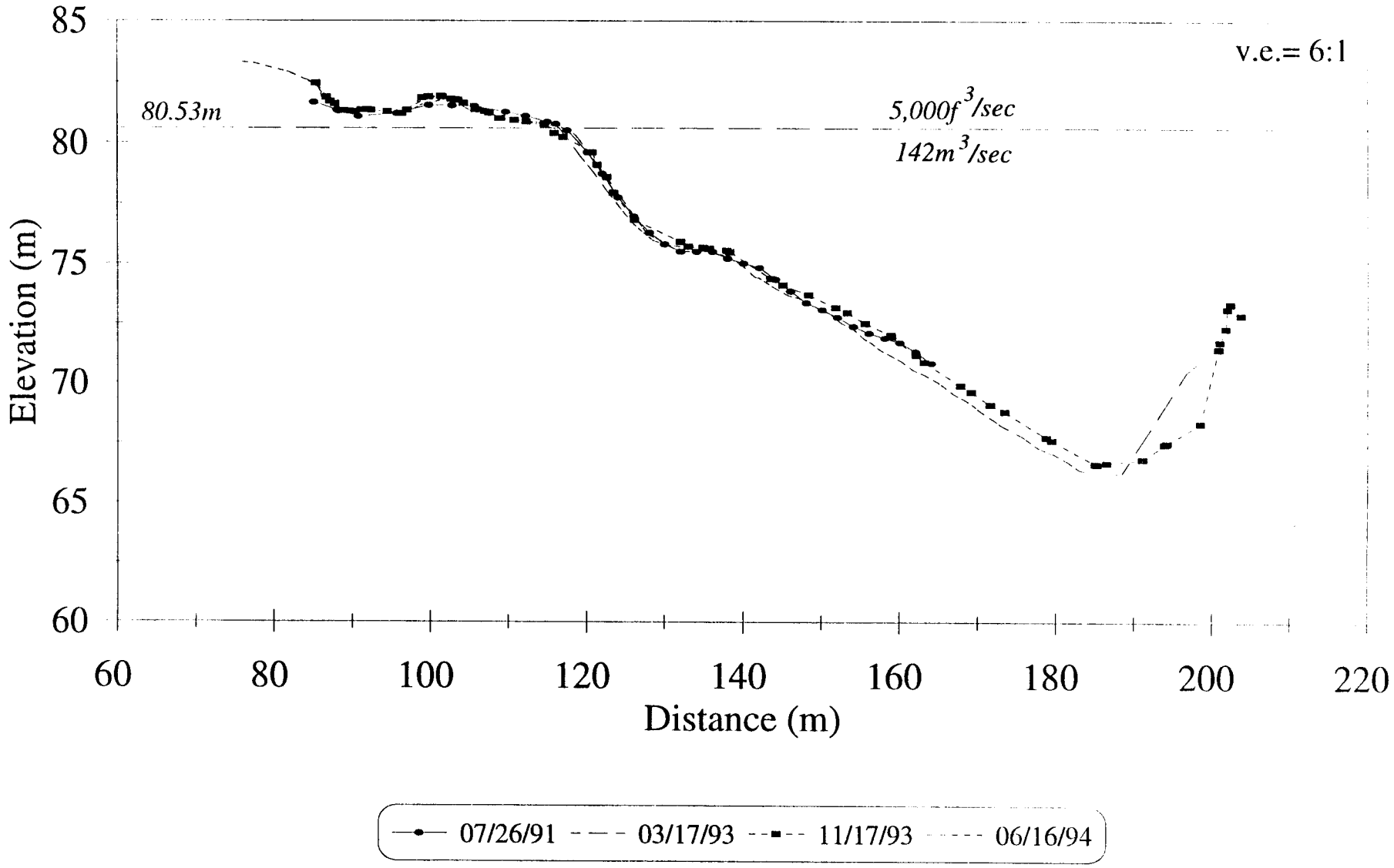
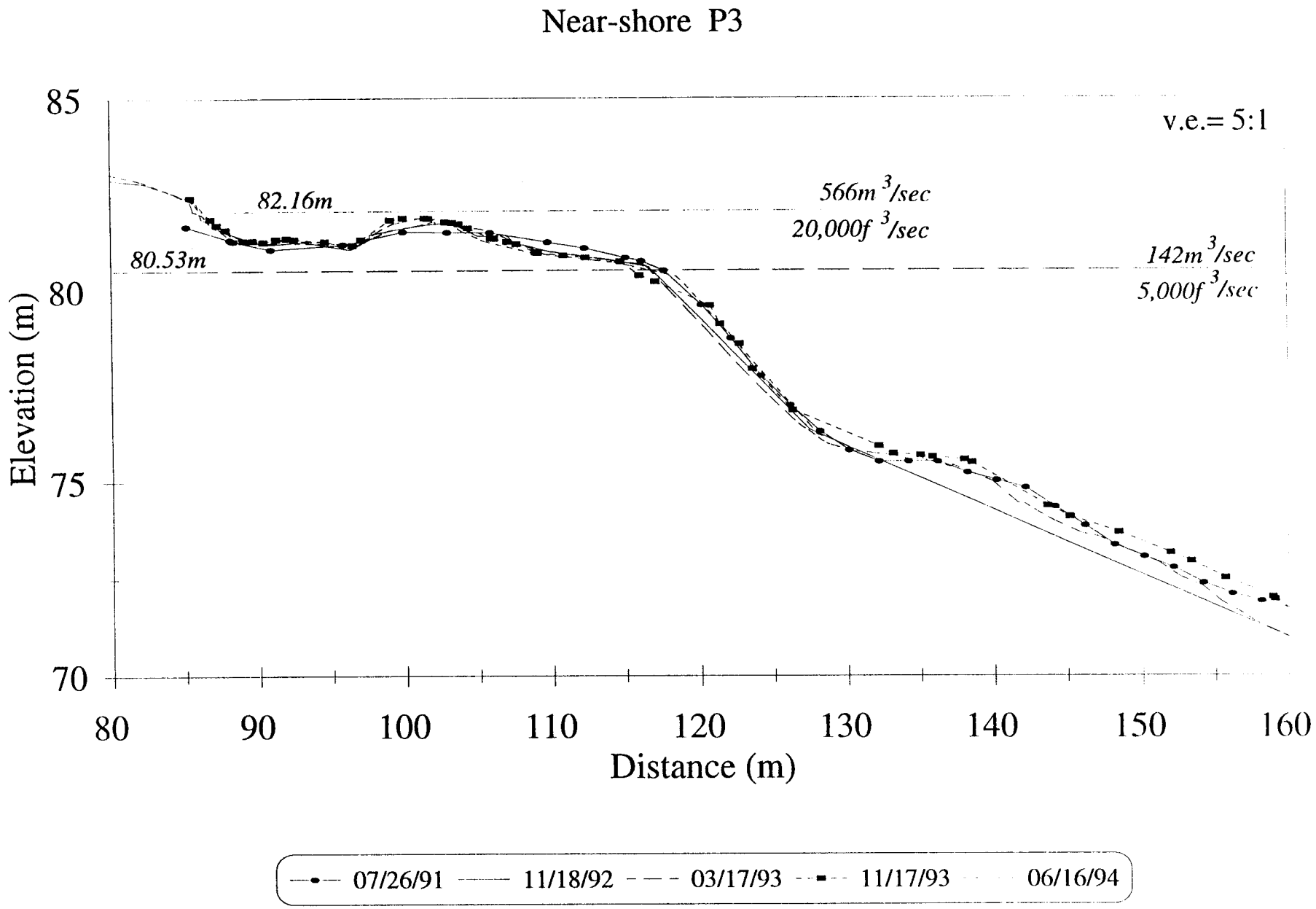
-6 Mile

Cross-channel P3

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20,000f 3/sec
142m 3/sec
5,000f 3/sec
Elevation (m)
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Distance (m)
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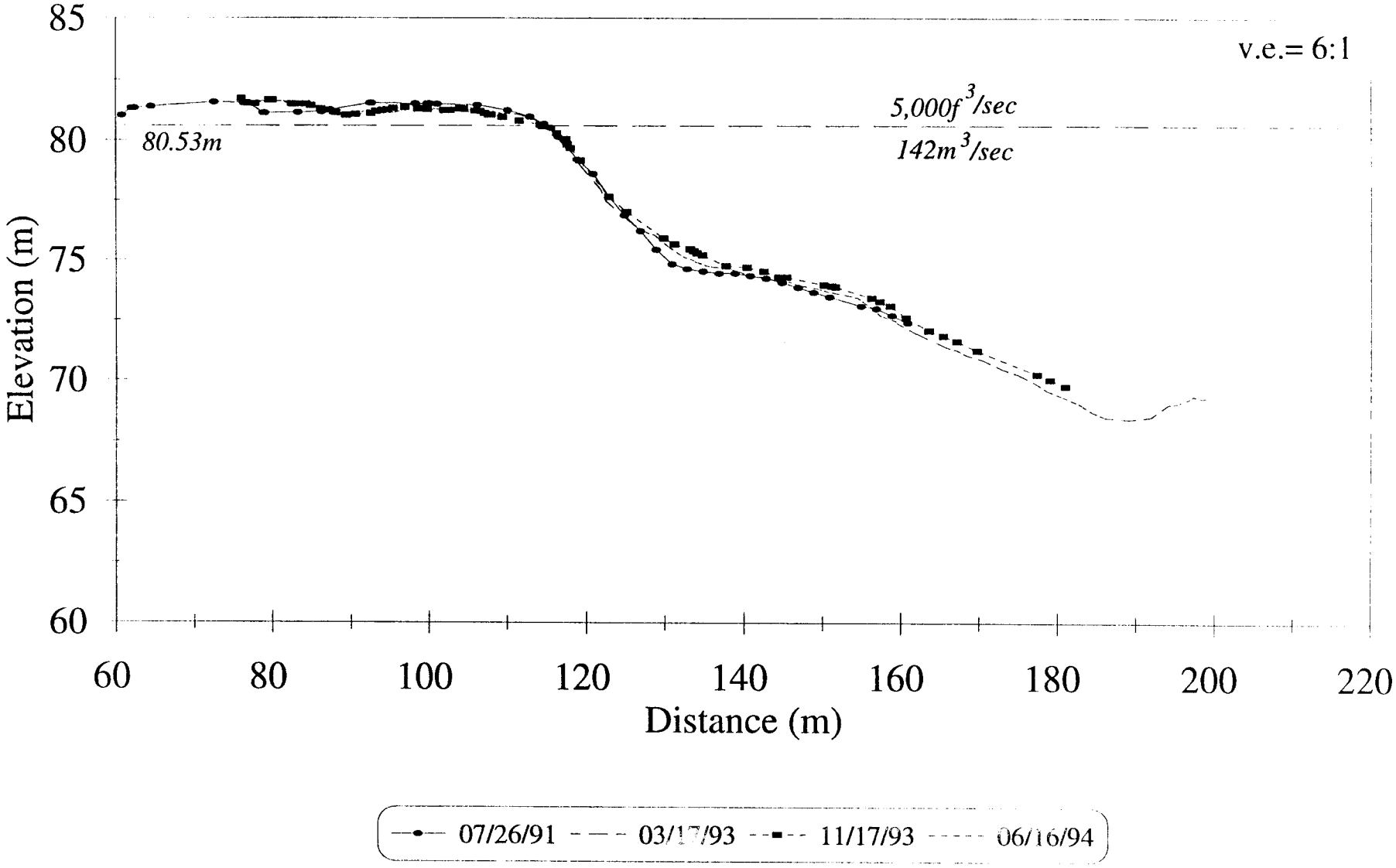
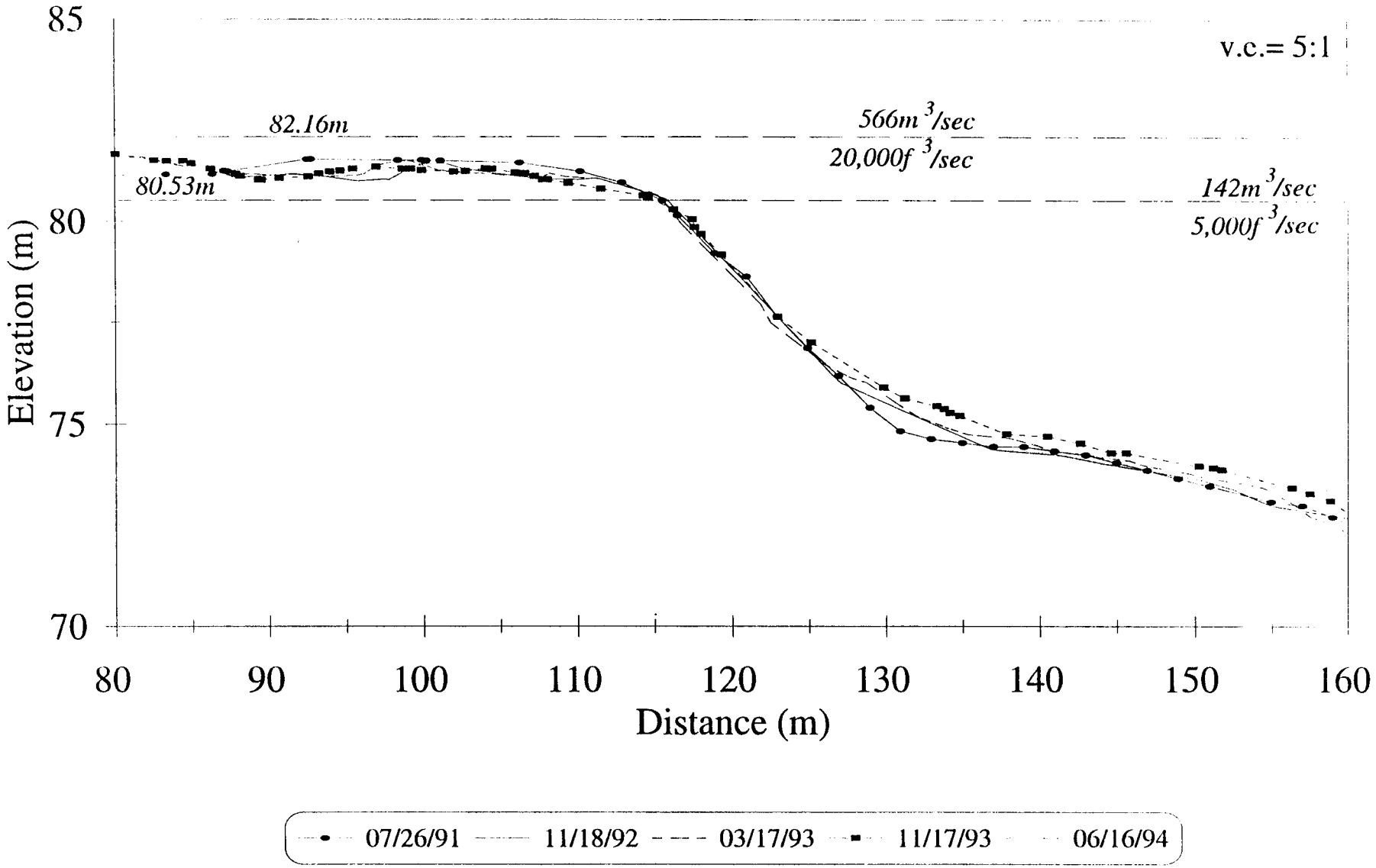
06/16/94

-6 Mile

Cross-channel P5

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80.53m
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20,000f 3/sec
142m 3/sec
5,000f 3/sec
Elevation (m)
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80
75
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Distance (m)
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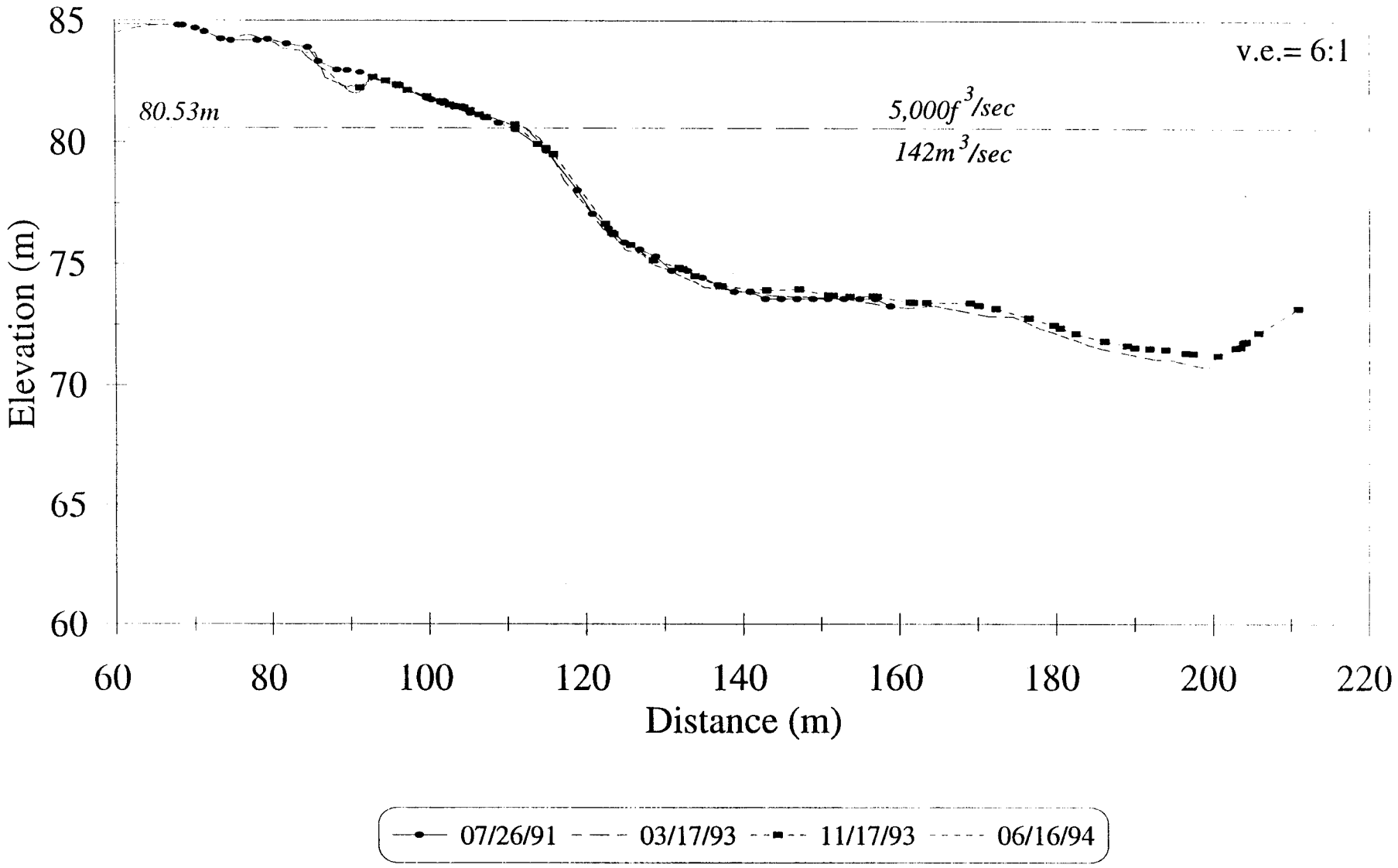
06/16/94

-6 Mile

Cross-channel P7



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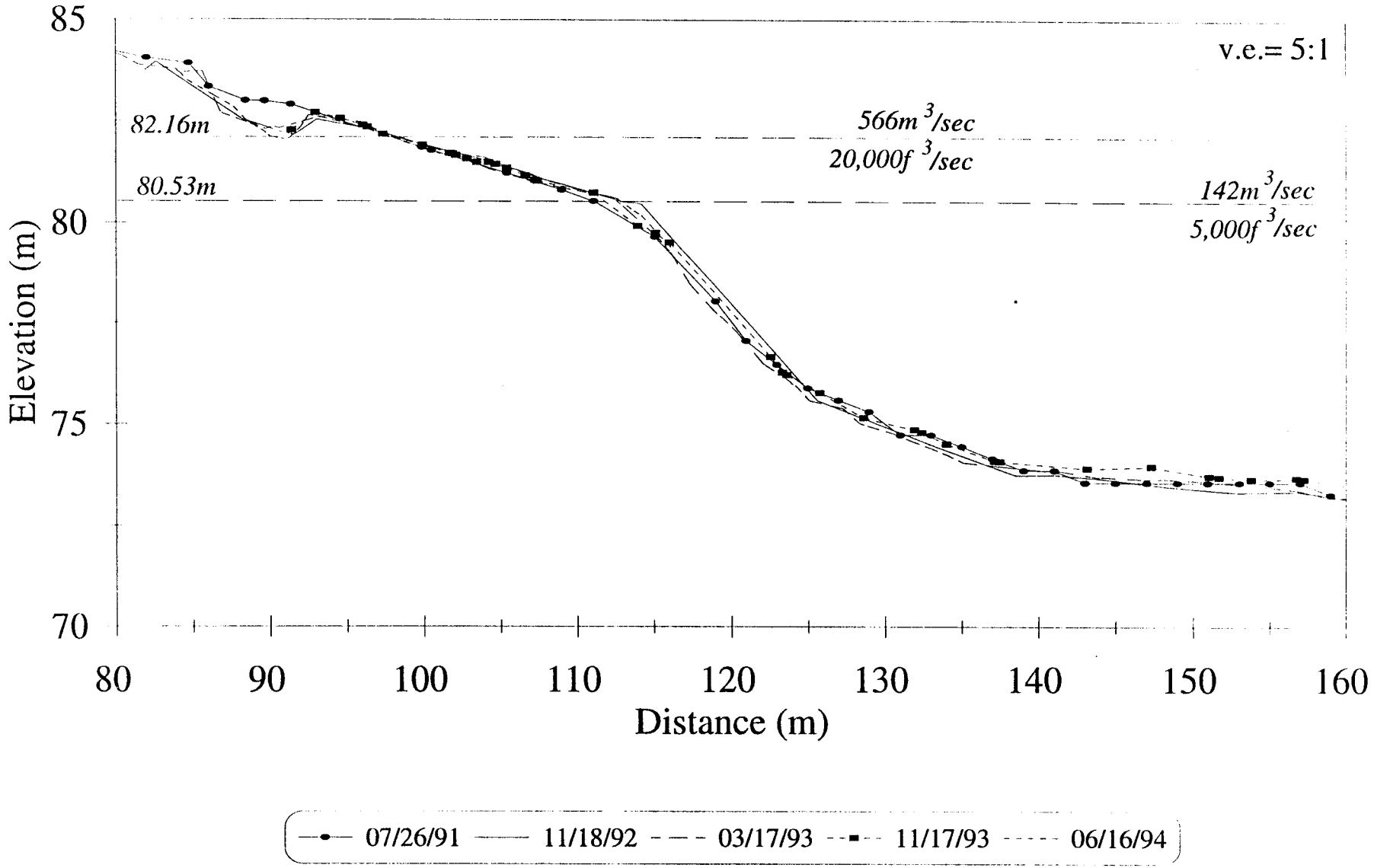
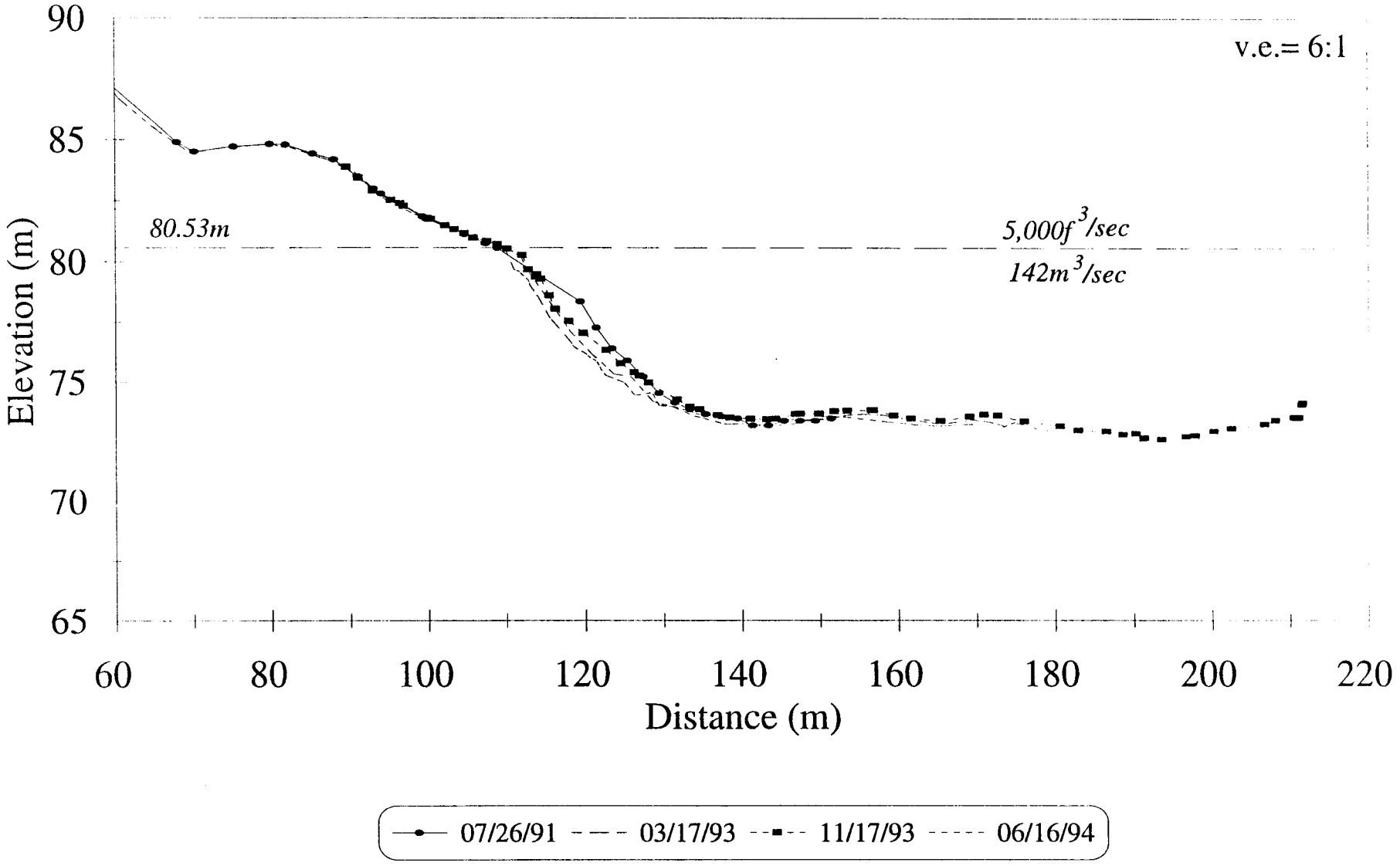
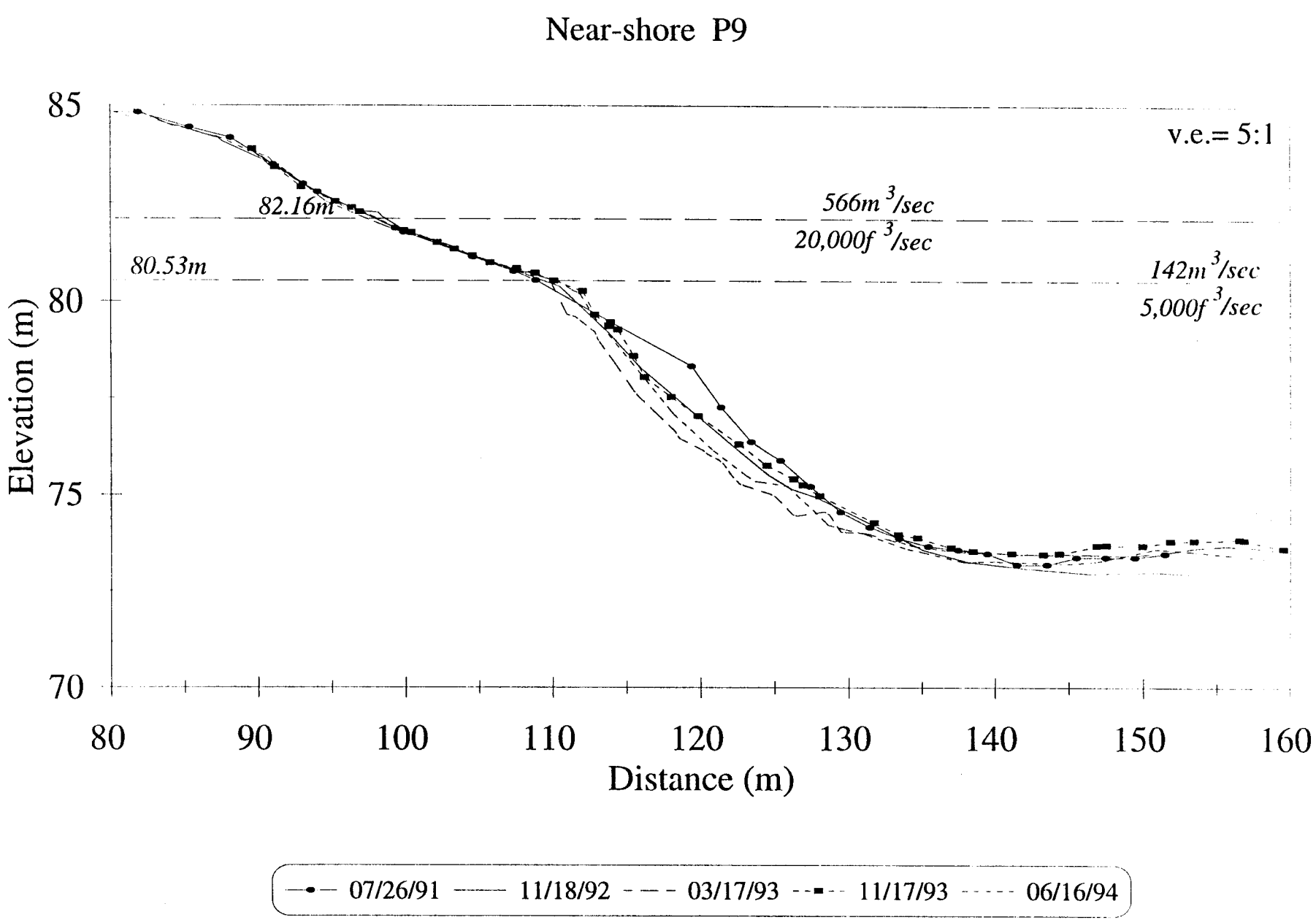


-6 Mile

Cross-channel P9




Near-shore P9
v.e.= 5:1
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20,000f 3/sec
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142m 3/sec
5,000f 3/sec
Elevation (m)
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Distance (m)
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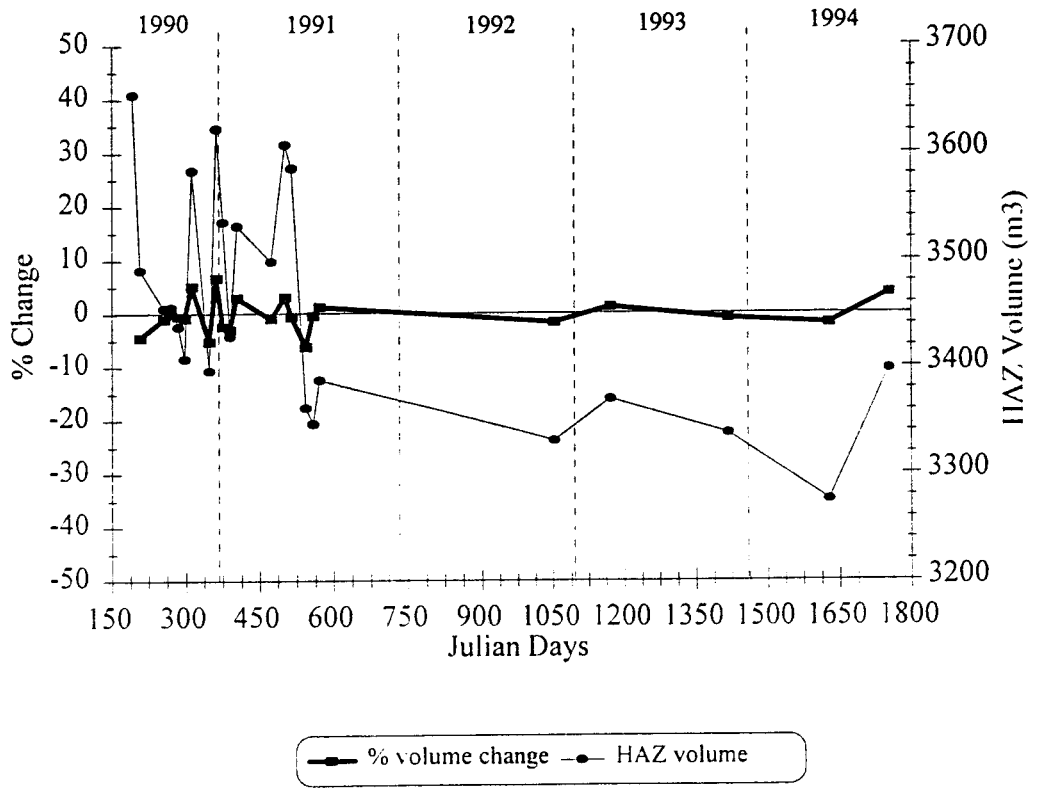
-6 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C	900712	G	193	3441	3655	3441			
D	900727	F	208	3417	3491	-24	-164	-0.70	-4.49
E		NORM							
F	900914	NORM	257	3383	3455	-34	-36	-1.00	-1.03
G	900928	E	271	3440	3456	57	1	1.68	0.03
H	901012	A	285	3407	3438	24	-17	0.71	-0.49
I	901026	8000 CFS	299	3419	3408	12	-30	0.35	-0.87
J	901109	NORM	313	3426	3584	7	176	0.20	5.16
K	901214	NORM	348	3399	3397	-27	-187	-0.79	-5.22
L	901228	11000 CFS	362	3425	3623	26	226	0.76	6.65
M	910111	C	376	3429	3536	4	-87	0.12	-2.40
N	910125	NORM	390	3412	3429	-17	-107	-0.50	-3.03
O	910208	B	404	3441	3532	29	103	0.85	3.00
P	910419	NORM	474	3446	3499	5	-33	0.15	-0.93
Q		NORM							
R	910517	D	502	3474	3608	28	109	0.81	3.12
S	910531	15000 CFS	516	3540	3586	66	-22	1.90	-0.61
T	910628	NORM	544	3543	3362	3	-224	0.08	-6.25
U	910712	G	558	3537	3347	-6	-15	-0.17	-0.45
V	910726	F	572	3523	3388	-14	41	-0.40	1.22
Y	921118	INT	1053	3645	3331	122	-57	3.46	-1.68
Z	930317	INT	1172	3516	3370	-129	39	-3.54	1.17
B02	931117	INT	1417	3470	3338	-46	-32	-1.31	-0.95
CO2	940616	INT	1628	3585	3276	115	-62	3.31	-1.86
D02	941020	INT	1754	3570	3398	-15	122	-0.42	3.72



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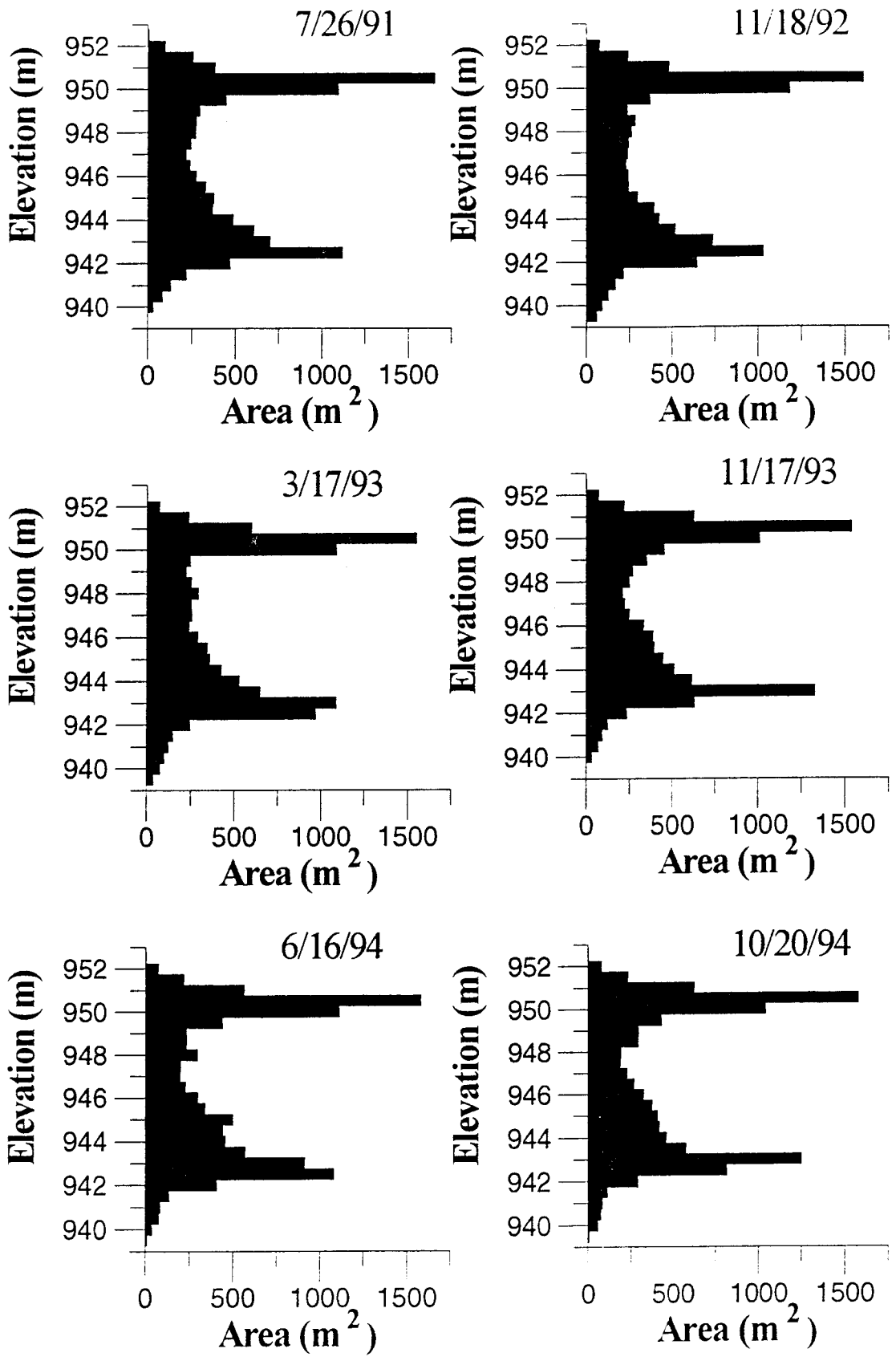
Area Distribution Histograms



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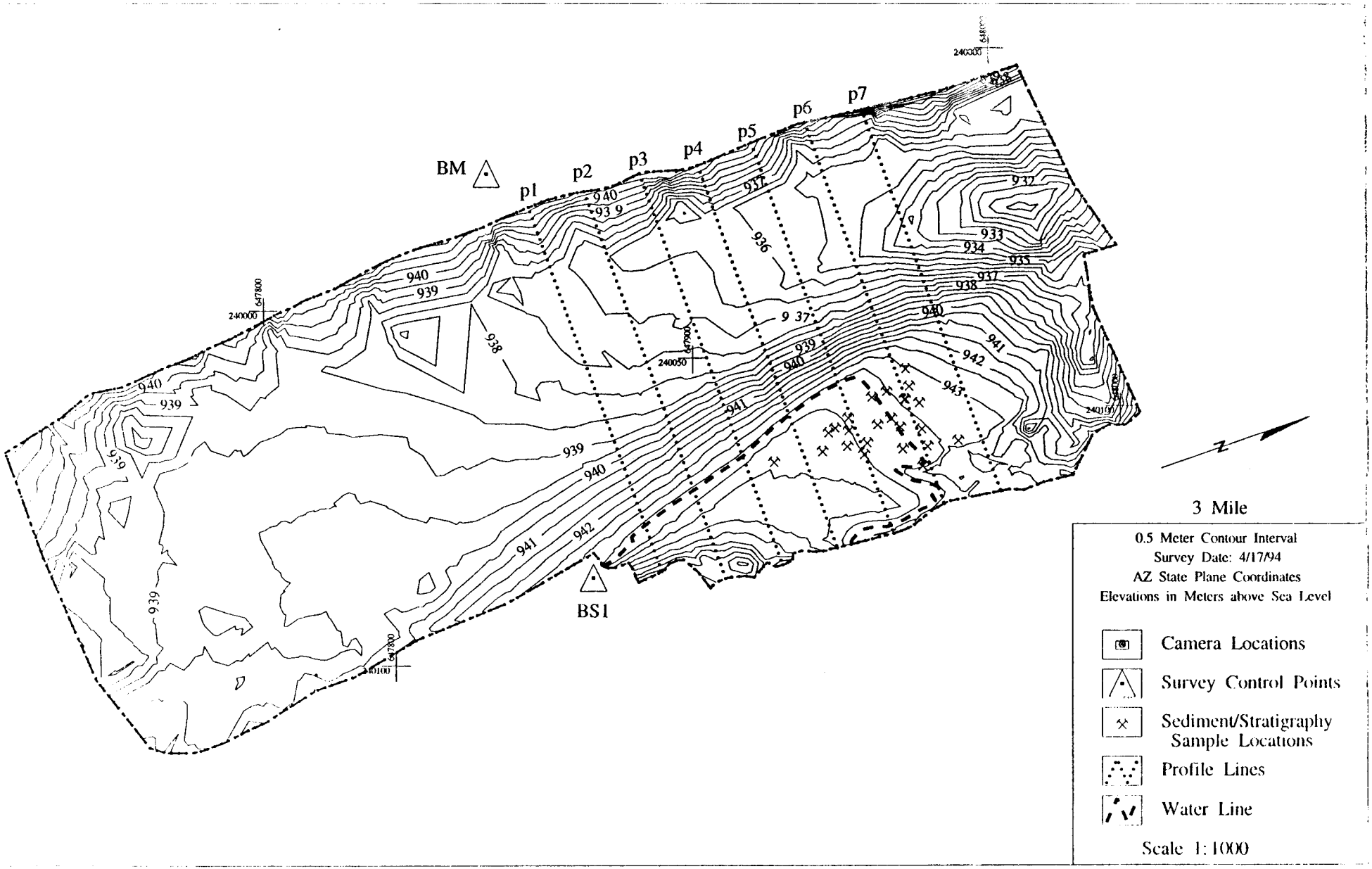
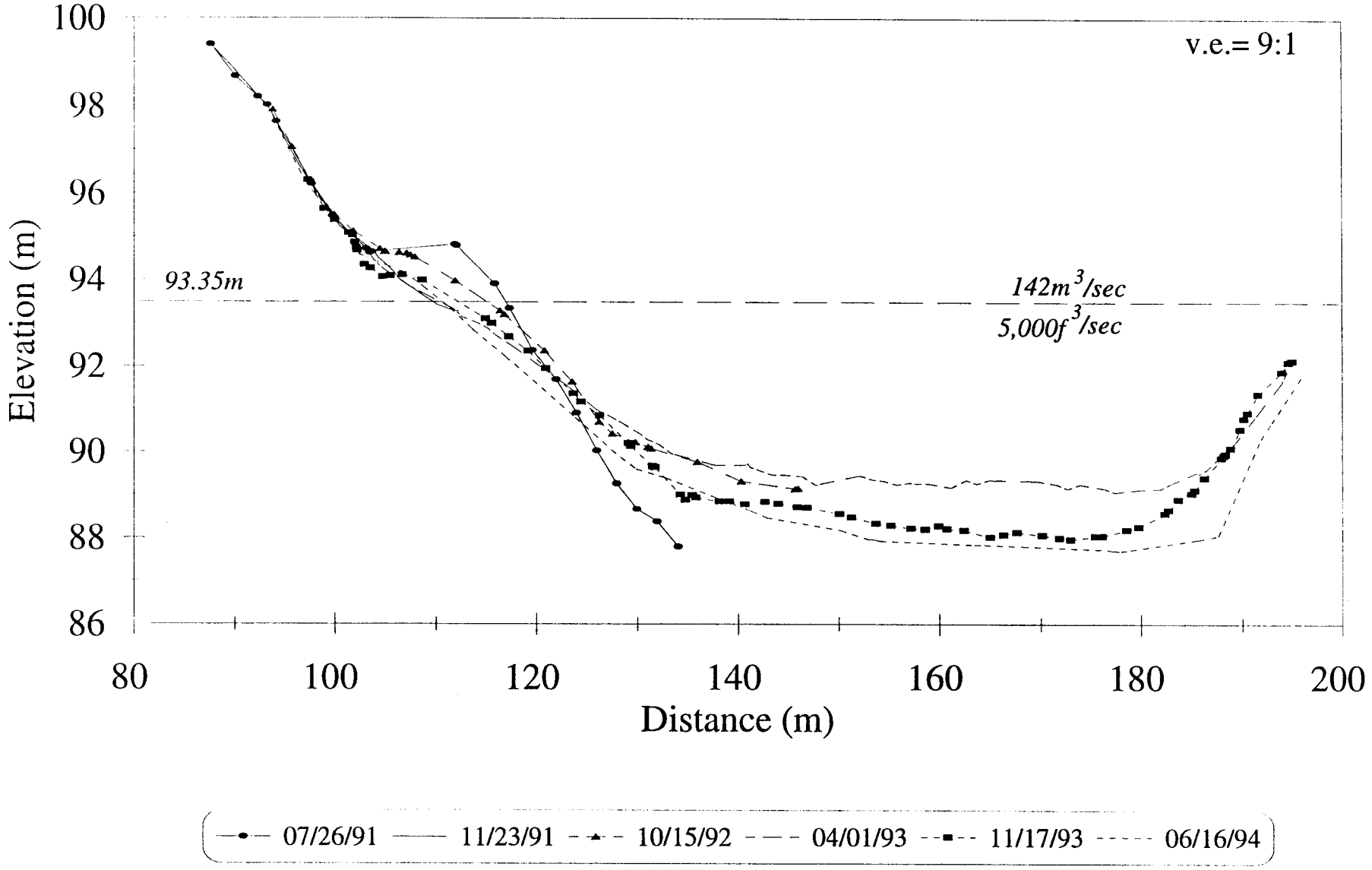
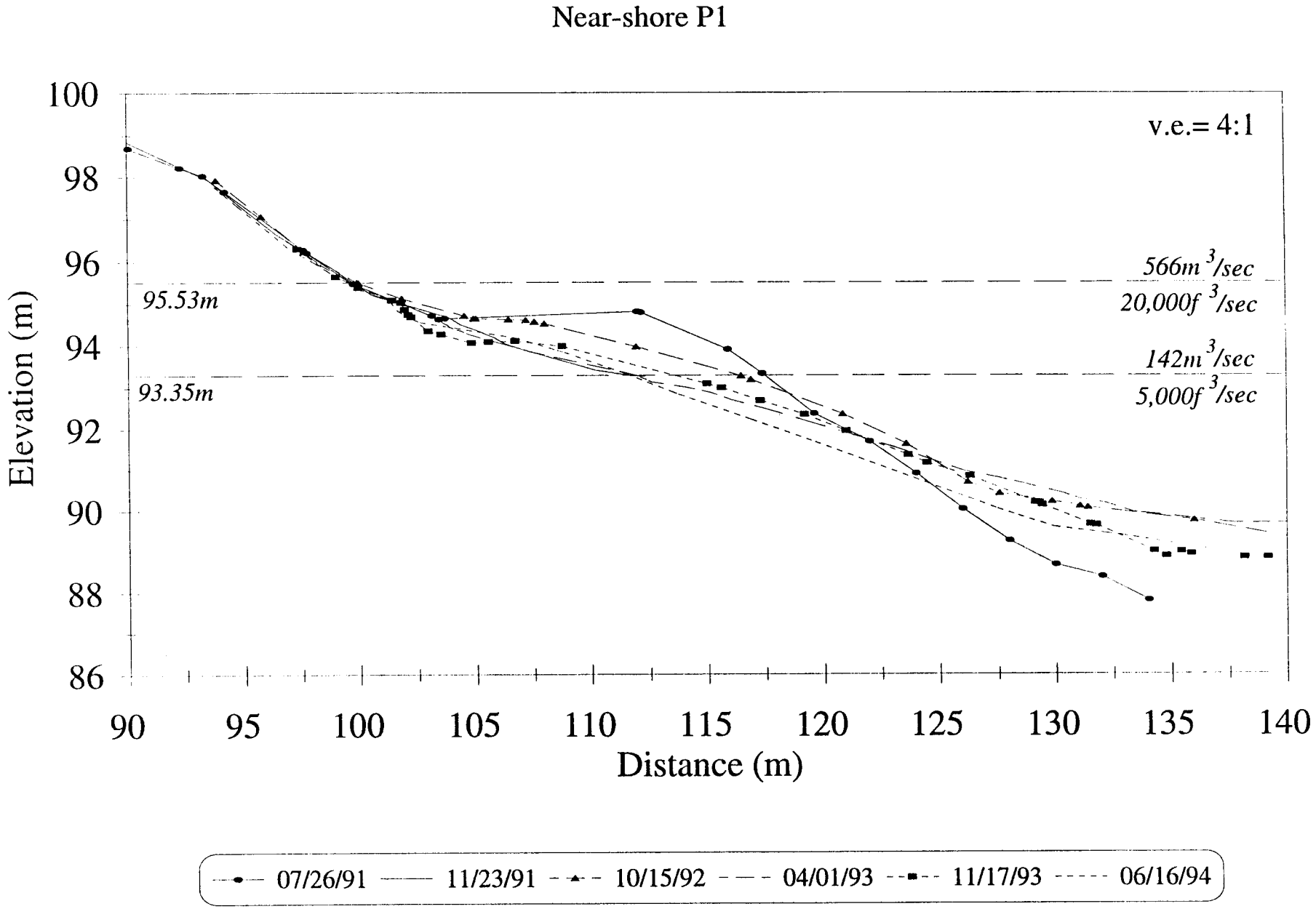
Area of Study
RM 2.5


BM
BS1
p1
p2
p3
p4
p5
p6
p7
240000
240050
240100
647800
647900
938
939
940
941
942
943
944
945
936
937
933
934
935
932
3 Mile
0.5 Meter Contour Interval
Survey Date: 4/17/94
AZ State Plane Coordinates
Elevations in Meters above Sea Level
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:1000

3 Mile

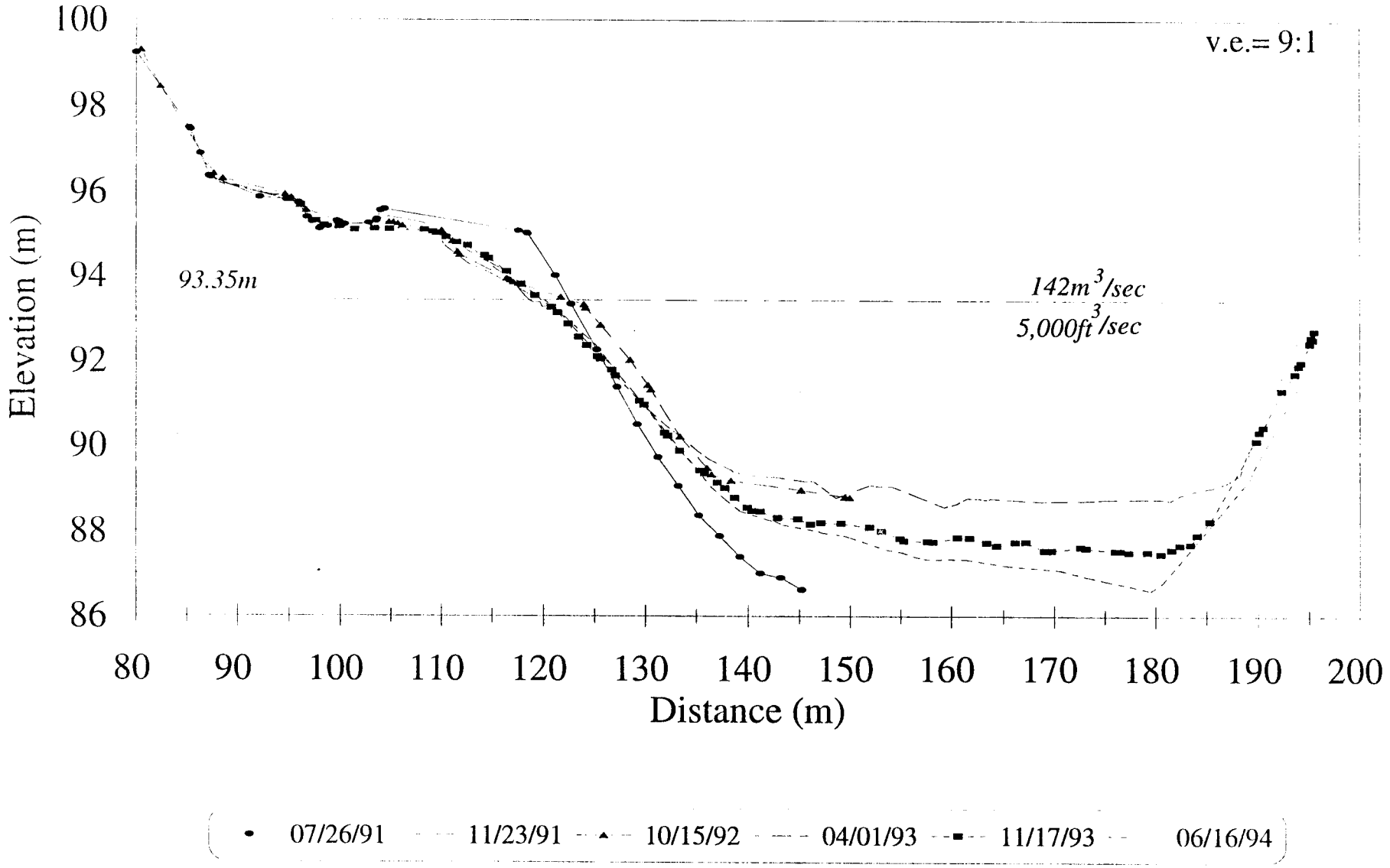
Cross-channel P1



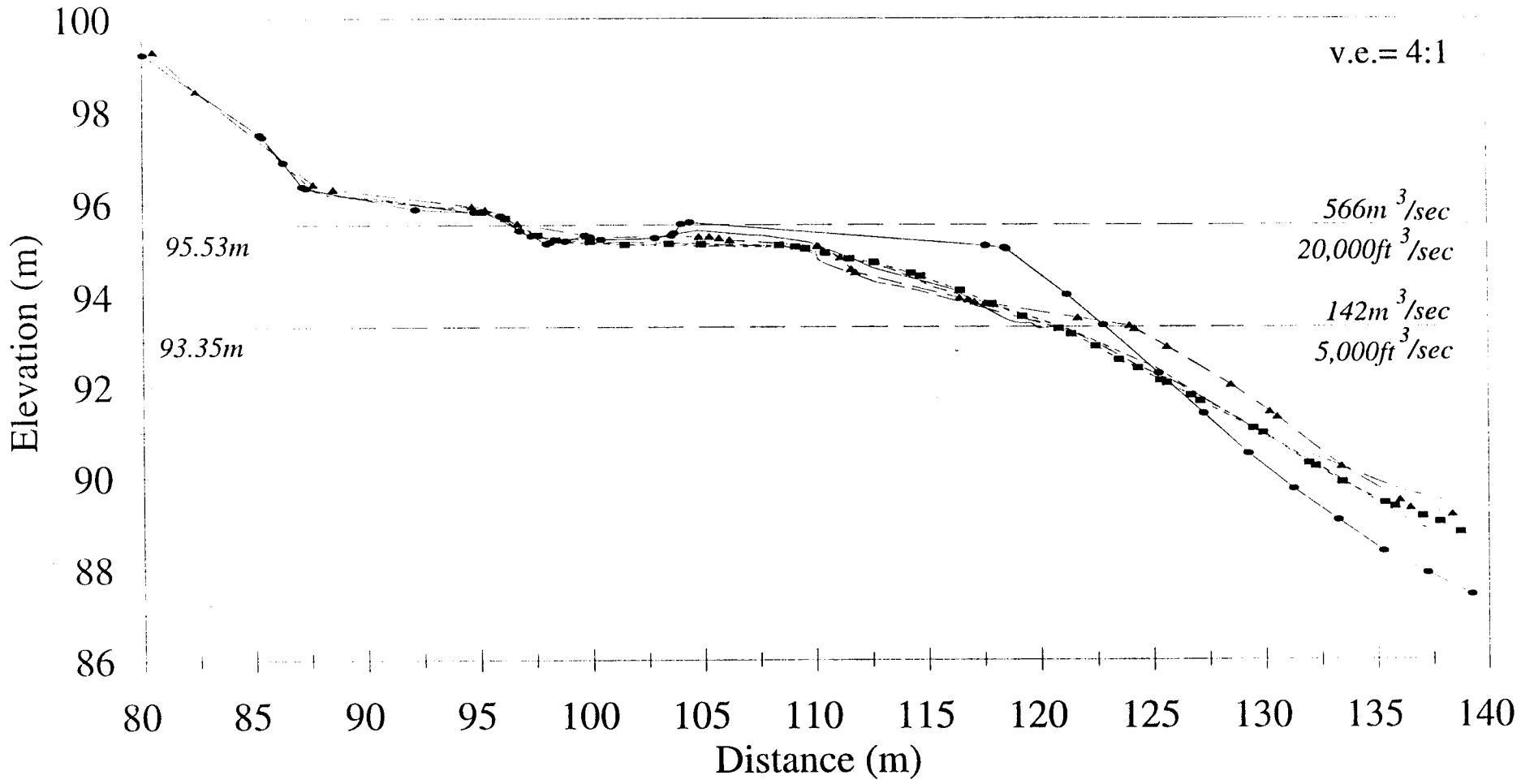

Near-shore P1
v.e.= 4:1
566m 3/sec
20,000f 3/sec
142m 3/sec
5,000f 3/sec
95.53m
93.35m
Elevation (m)
100
98
96
94
92
90
88
86
90
95
100
105
110
115
120
125
130
135
140
Distance (m)
07/26/91
11/23/91
10/15/92
04/01/93
11/17/93
06/16/94

3 Mile

Cross-channel P3

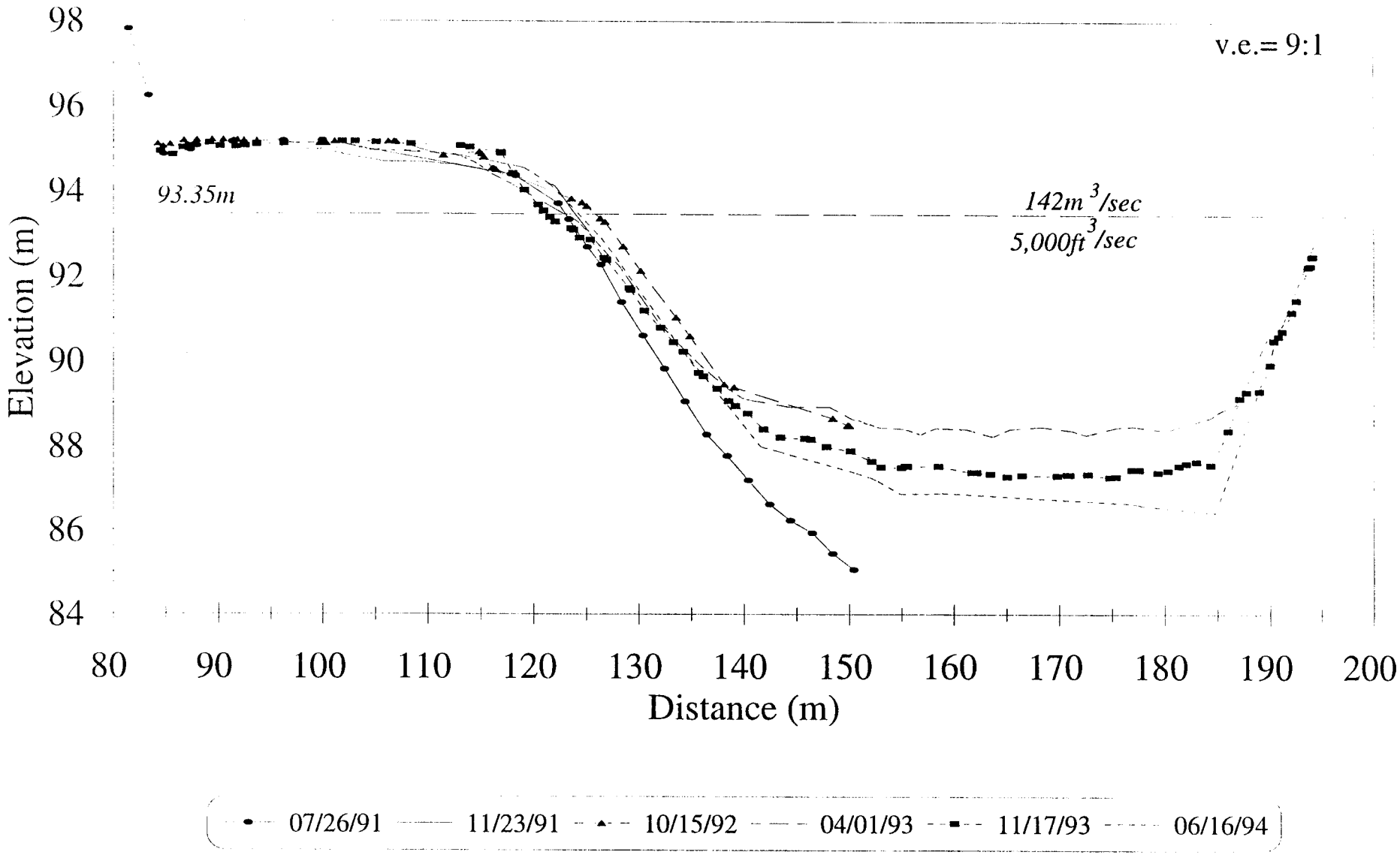


Near-shore P3

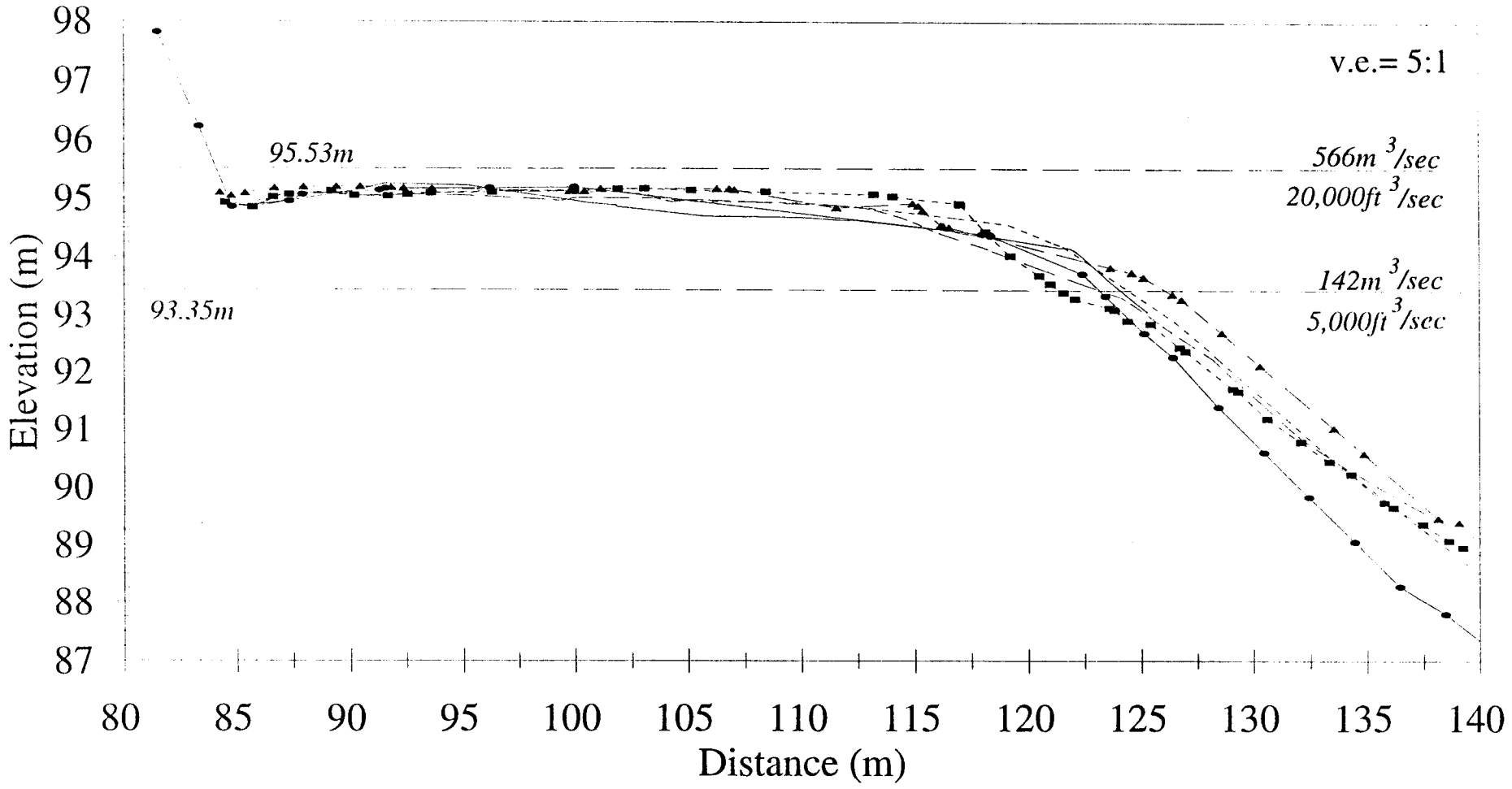


3 Mile

Cross-channel P4

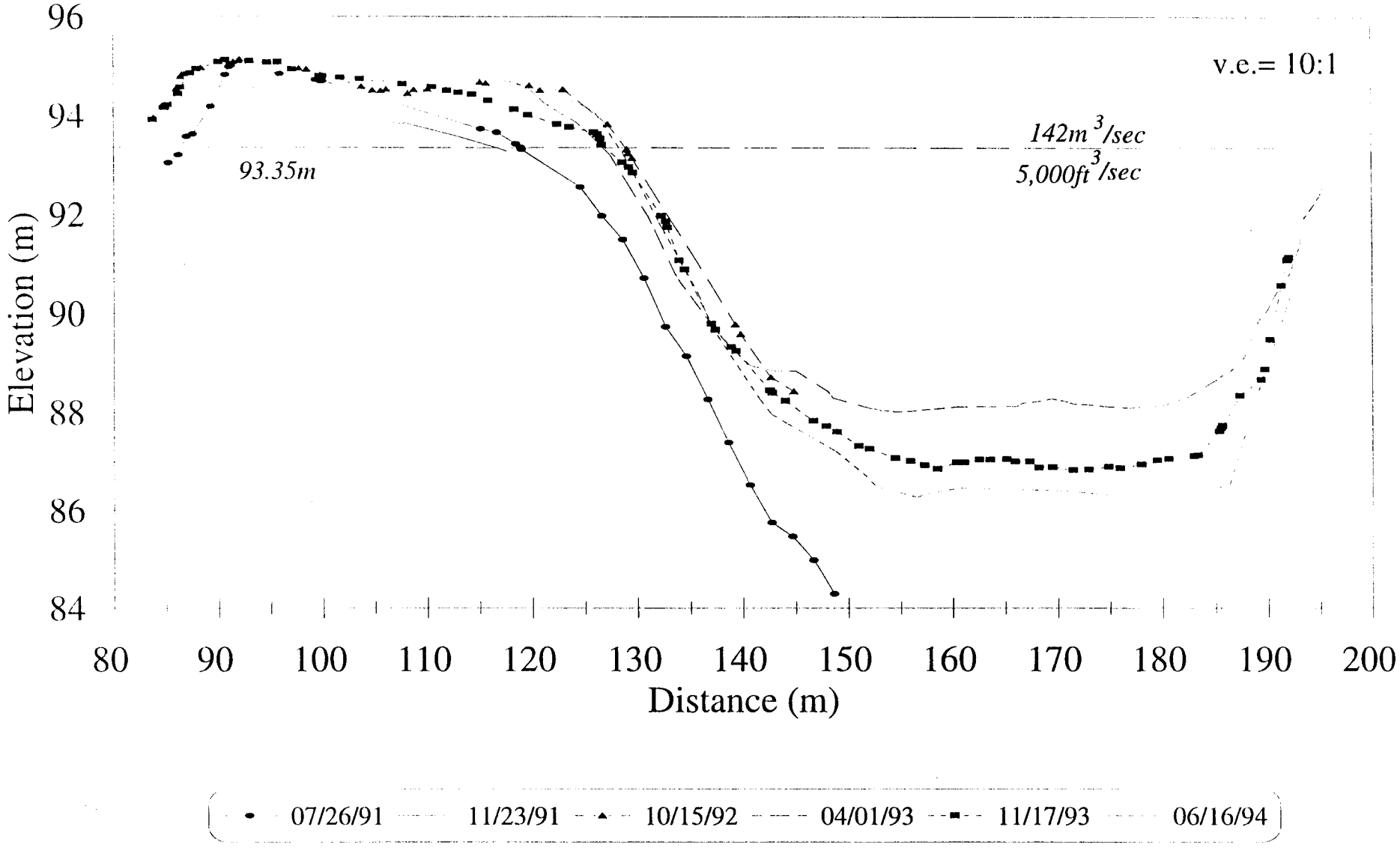


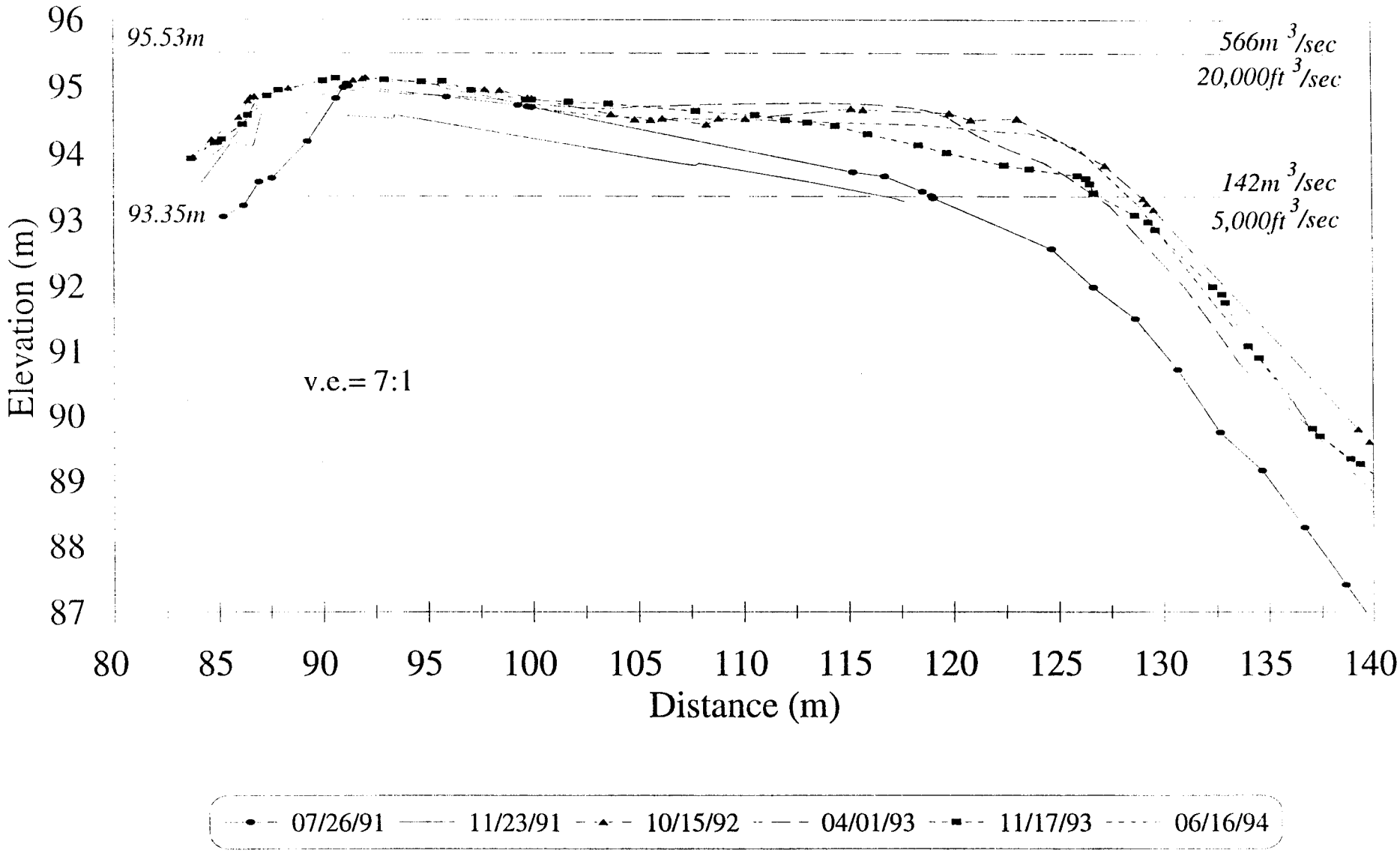
Near-shore P4



3 Mile

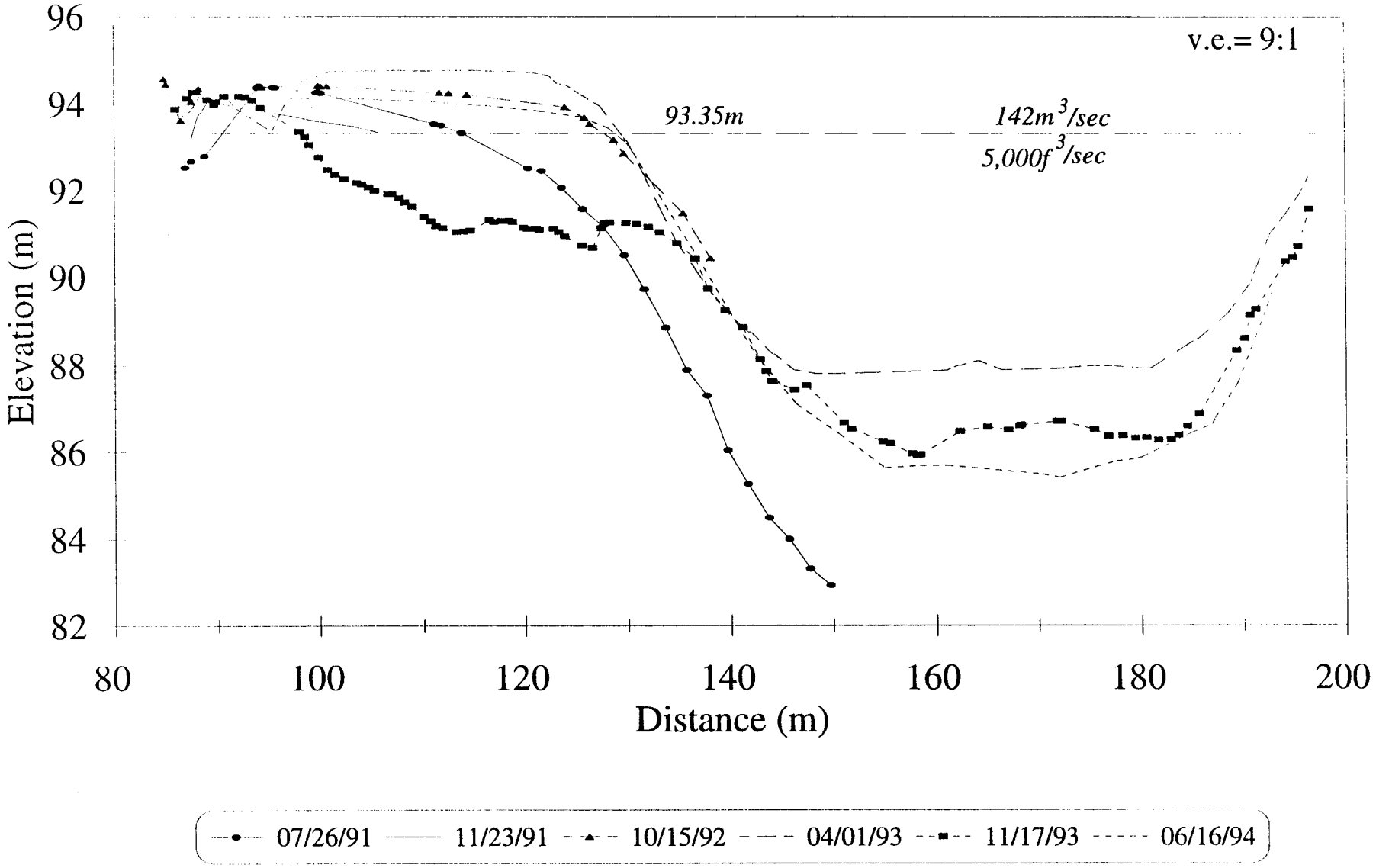
Cross-channel P5



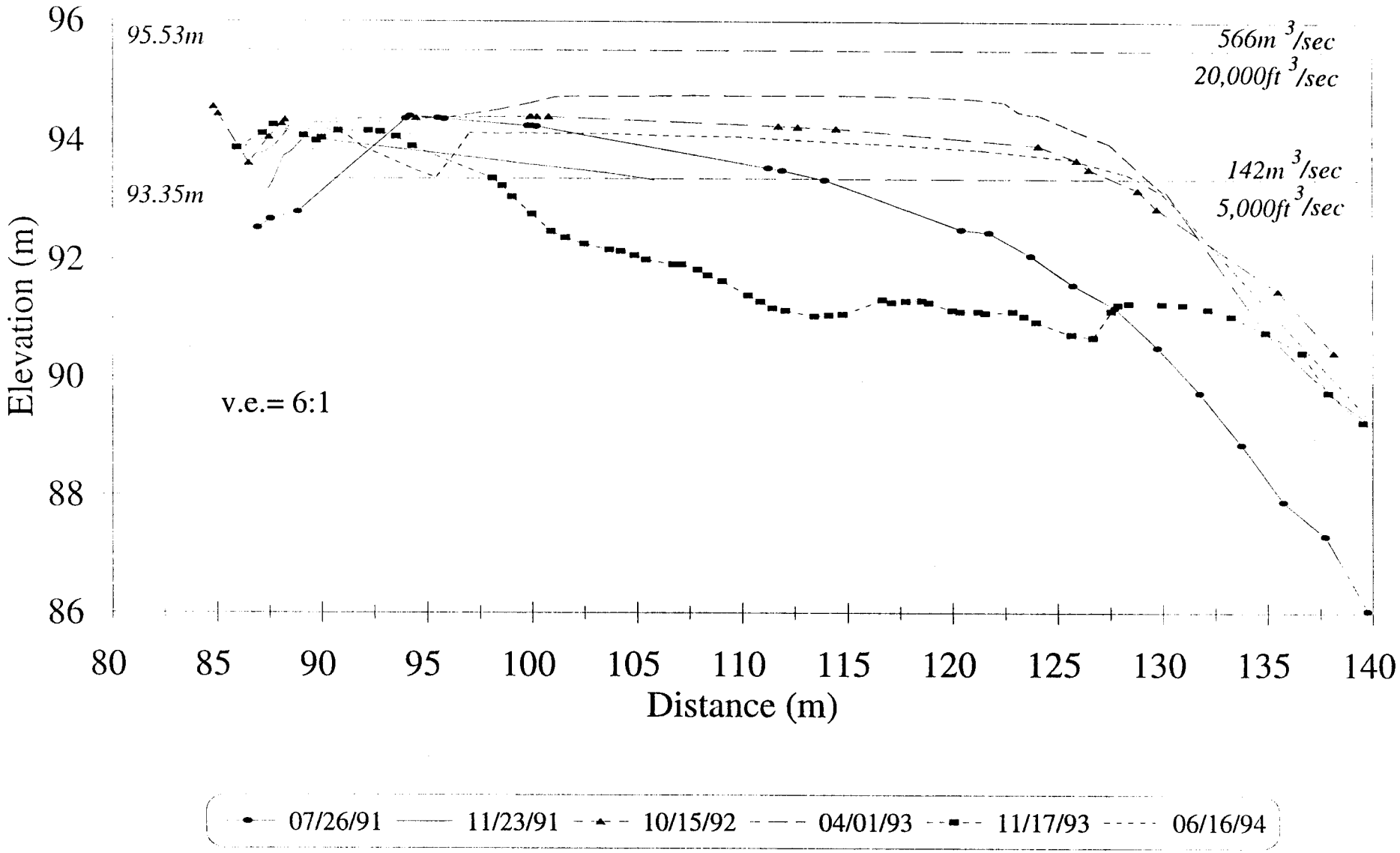

Near-shore P5
95.53m
93.35m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
v.e.= 7:1
Elevation (m)
96
95
94
93
92
91
90
89
88
87
80
85
90
95
100
105
110
115
120
125
130
135
140
Distance (m)
07/26/91
11/23/91
10/15/92
04/01/93
11/17/93
06/16/94

3 Mile

Cross-channel P6

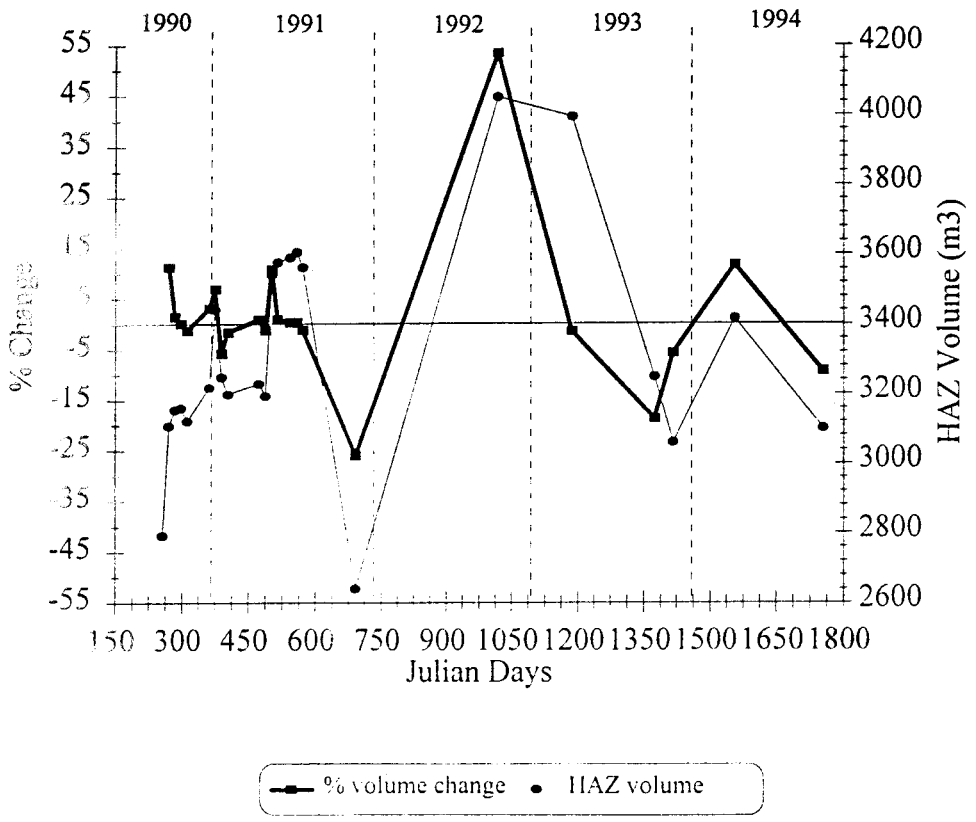


Near-shore P6



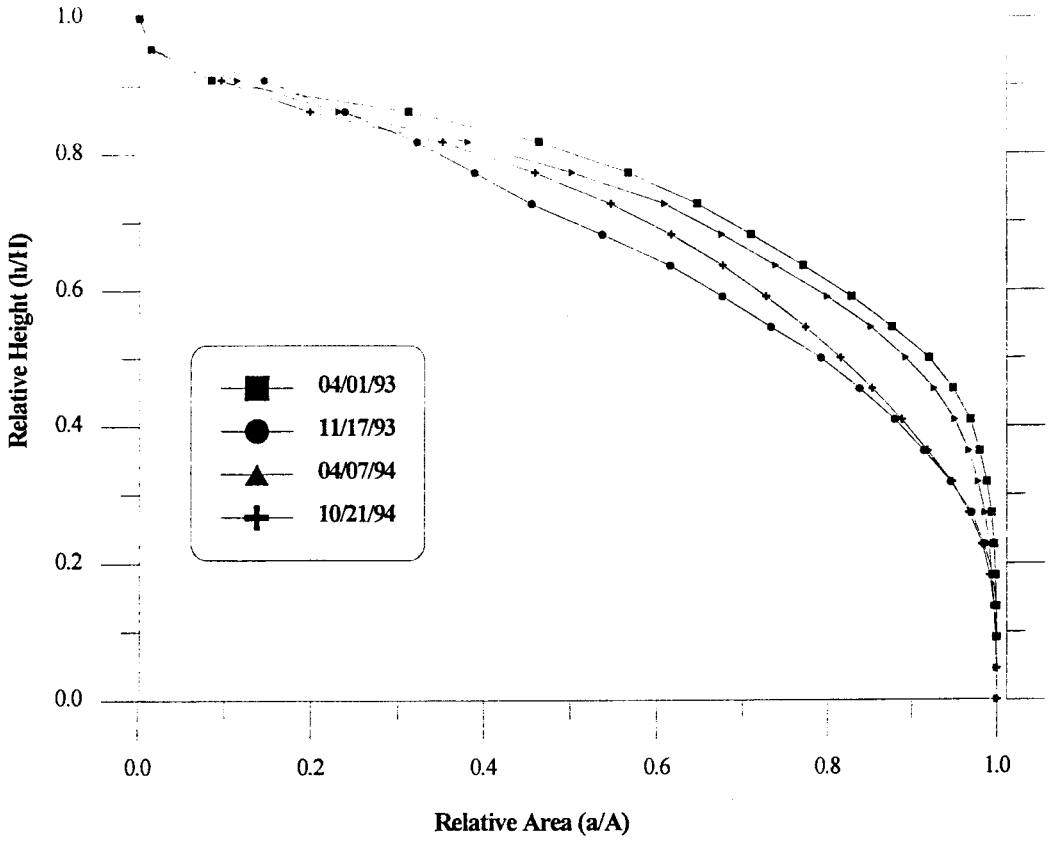
3 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F	900914	NORM	257	2487	2793				
G	900928	E	271	2723	3109	236	316	9.49	11.31
H	901012	A	285	2670	3155	-53	46	-1.95	1.48
I	901026	8000 CFS	299	2722	3161	52	6	1.95	0.19
J	901109	NORM	313	2754	3122	32	-39	1.18	-1.23
K		NORM							
L	911228	11000 CFS	362	2897	3219	143	97	5.19	3.11
M	910111	C	376	2989	3444	92	225	3.18	6.99
N	910125	NORM	390	2861	3250	-128	-194	-4.28	-5.63
O	910208	B	404	2866	3200	5	-50	0.17	-1.54
P	910419	NORM	474	2769	3230	-97	30	-3.38	0.94
Q	910503	NORM	488	2826	3195	57	-35	2.06	-1.08
R	910517	D	502	2874	3542	48	347	1.70	10.86
S	910531	15000 CFS	516	2835	3578	-39	36	-1.36	1.02
T	910628	NORM	544	2726	3591	-109	13	-3.84	0.36
U	910712	G	558	2950	3606	224	15	8.22	0.42
V	910726	F	572	3016	3564	66	-42	2.24	-1.16
X	911123	INT	692	2467	2640	-549	-924	-18.20	-25.93
Y	921015	INT	1019	3601	4052	1134	1412	45.97	53.48
Z	930401	INT	1187	3448	3995	-153	-57	-4.25	-1.41
A03	931007	INT	1376	2774	3249	-674	-746	-19.55	-18.67
B03	931117	INT	1417	2401	3061	-373	-188	-13.45	-5.79
C04	940407	INT	1558	3130	3417	729	356	30.36	11.63
D04	941021	INT	1755	2864	3100	-266	-317	-8.50	-9.28

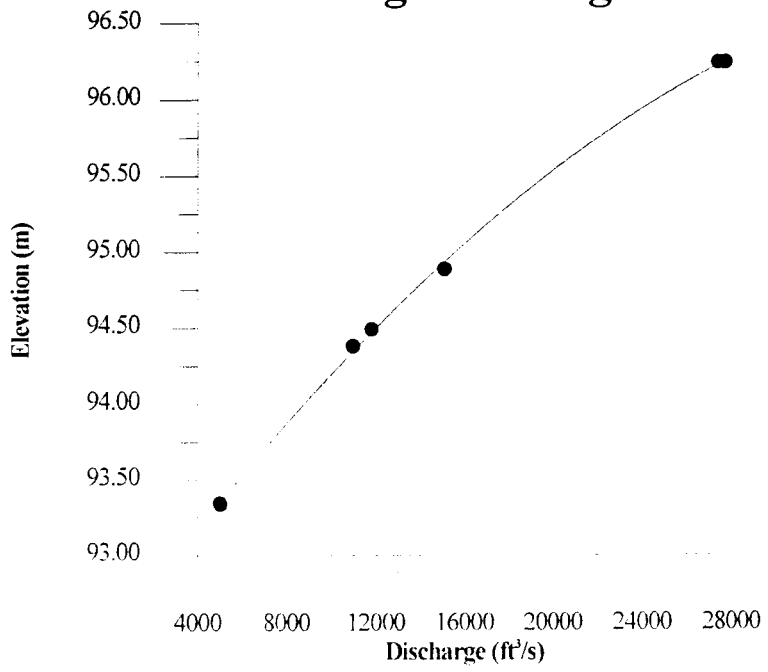


3 Mile

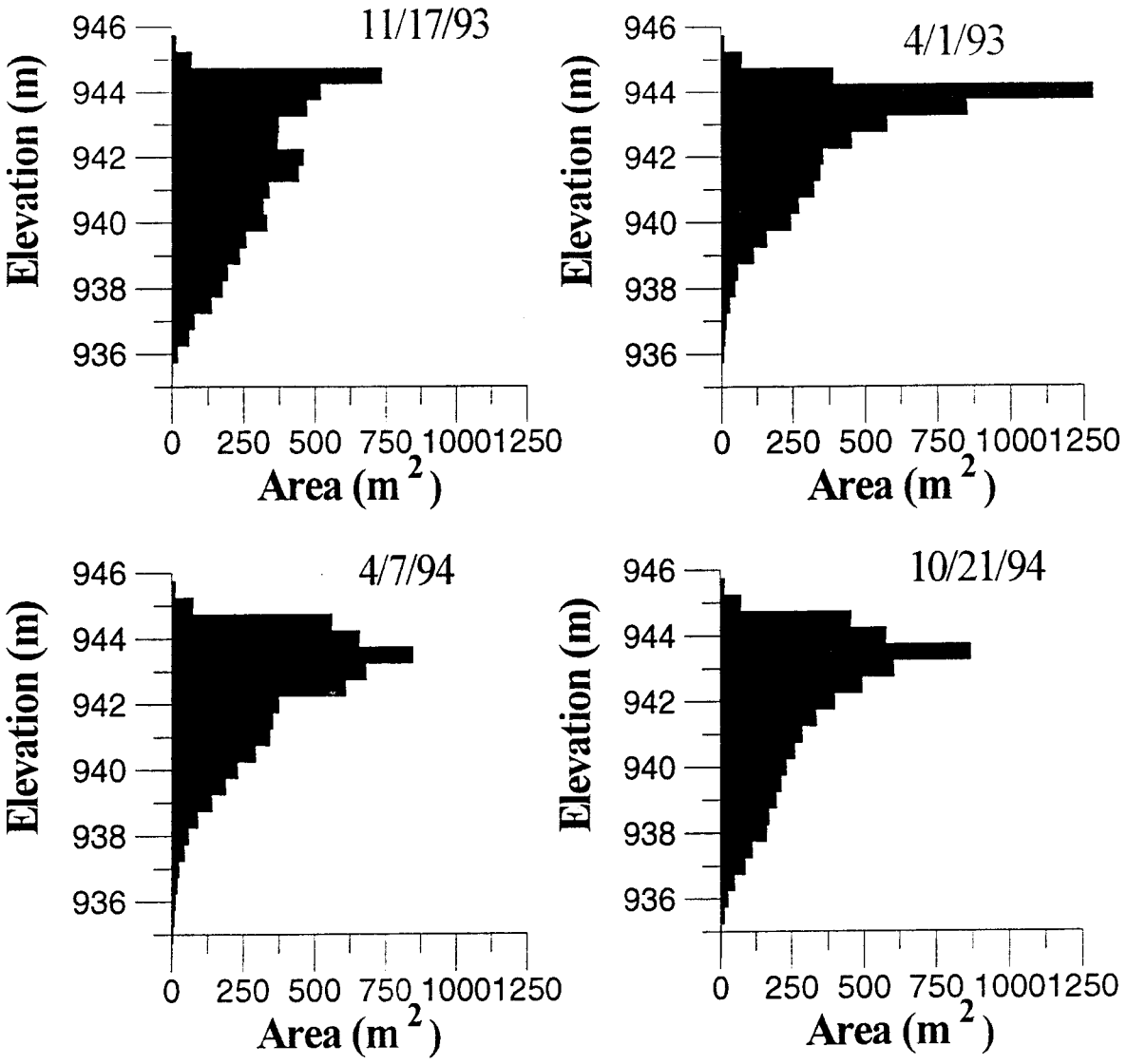
Hypsometric Curves

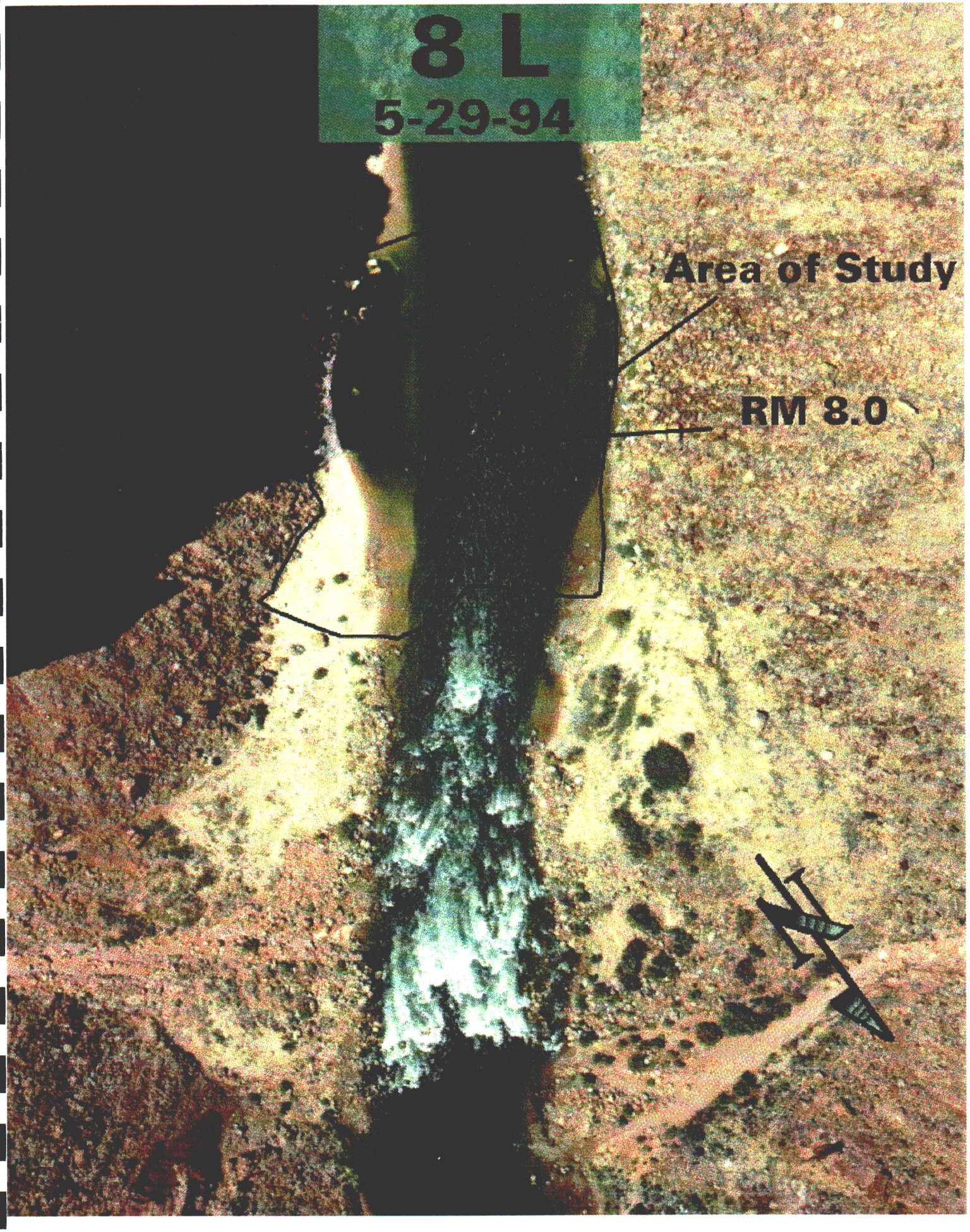


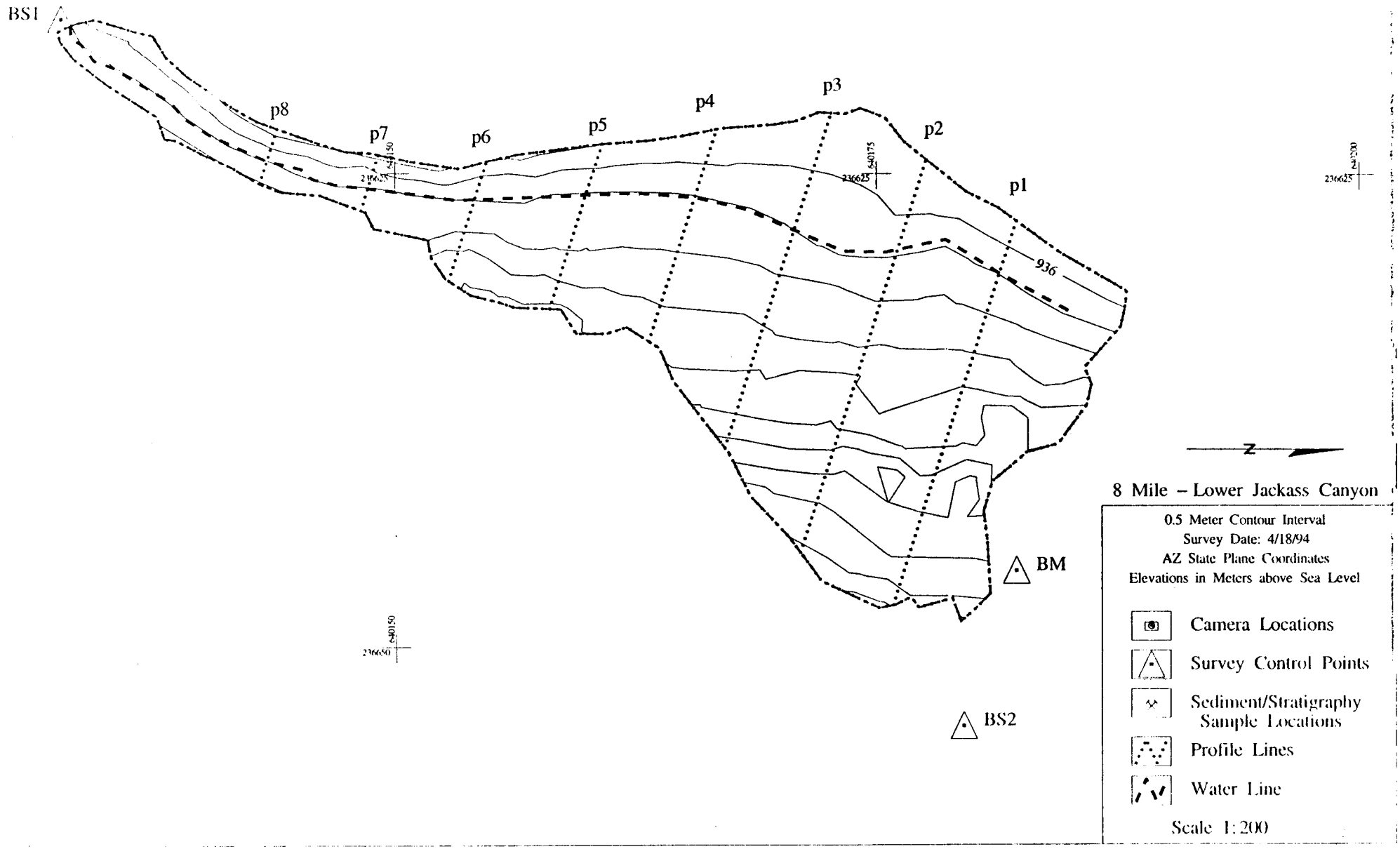
Stage Discharge



3 MILE
Area Distribution Histograms

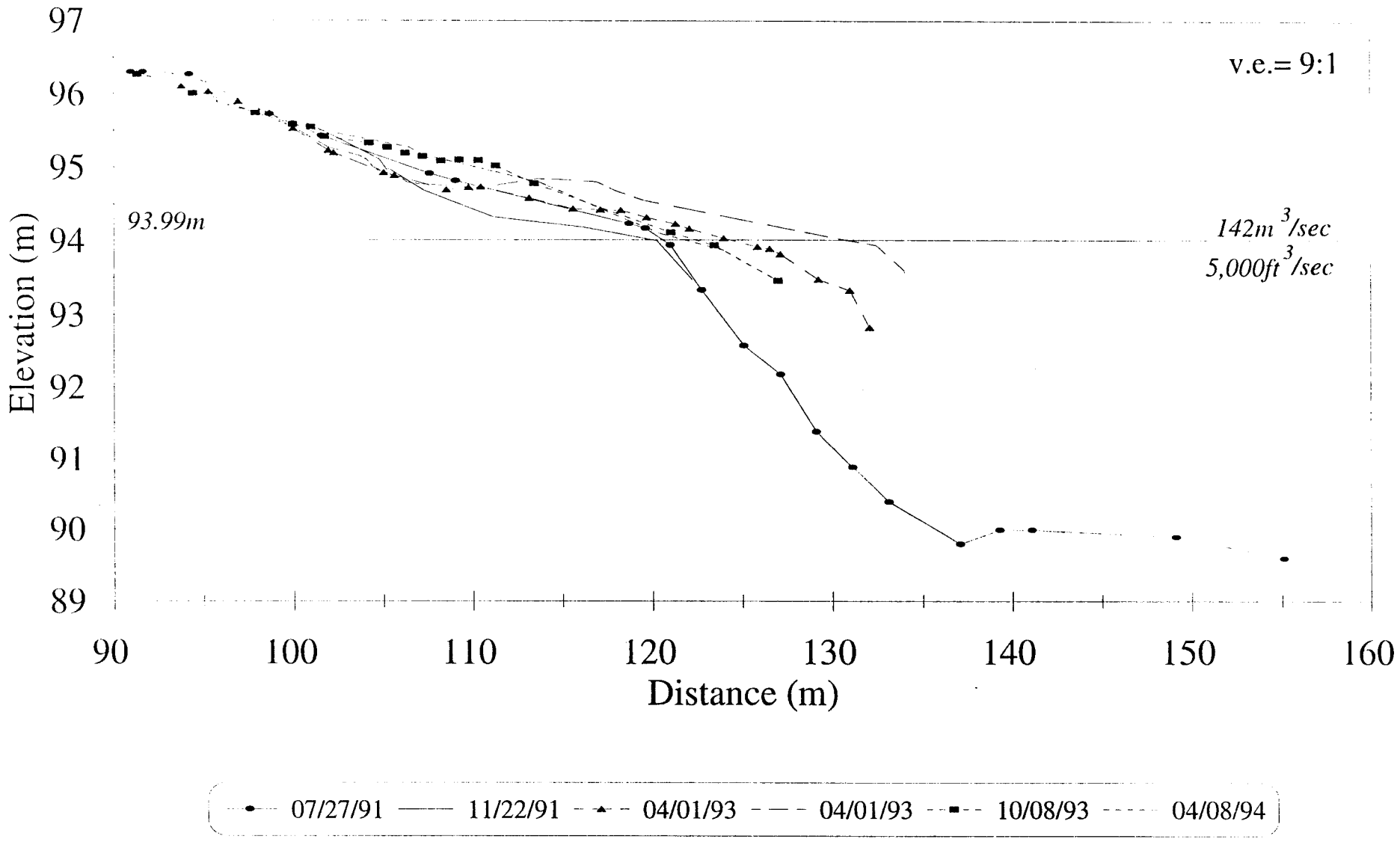


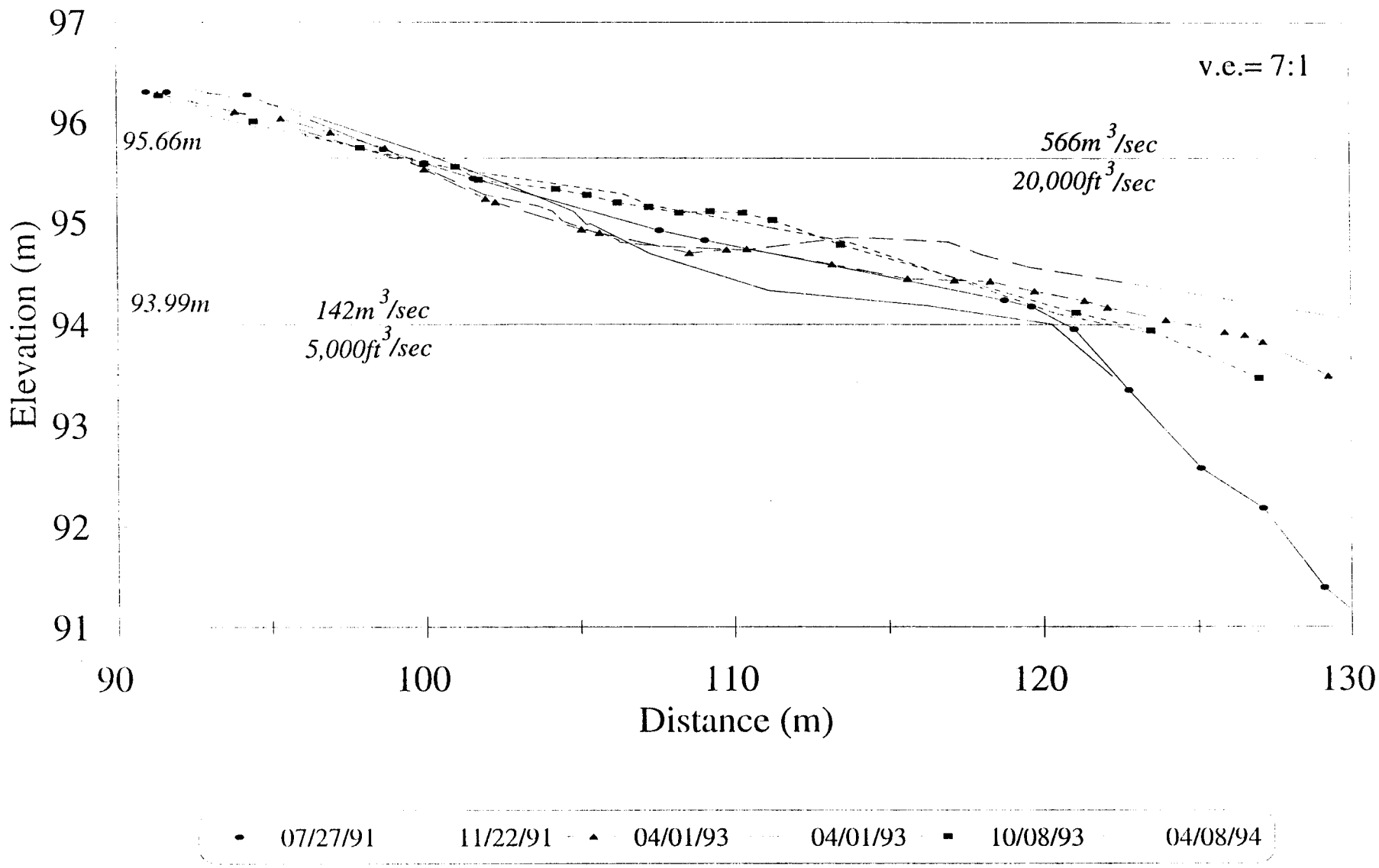

8 L
5-29-94
Area of Study
RM 8.0
N


BS1
p8
p7
p6
p5
p4
p3
p2
p1
936
BM
BS2
N
8 Mile – Lower Jackass Canyon
0.5 Meter Contour Interval
Survey Date: 4/18/94
AZ State Plane Coordinates
Elevations in Meters above Sea Level
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:200

8 Mile

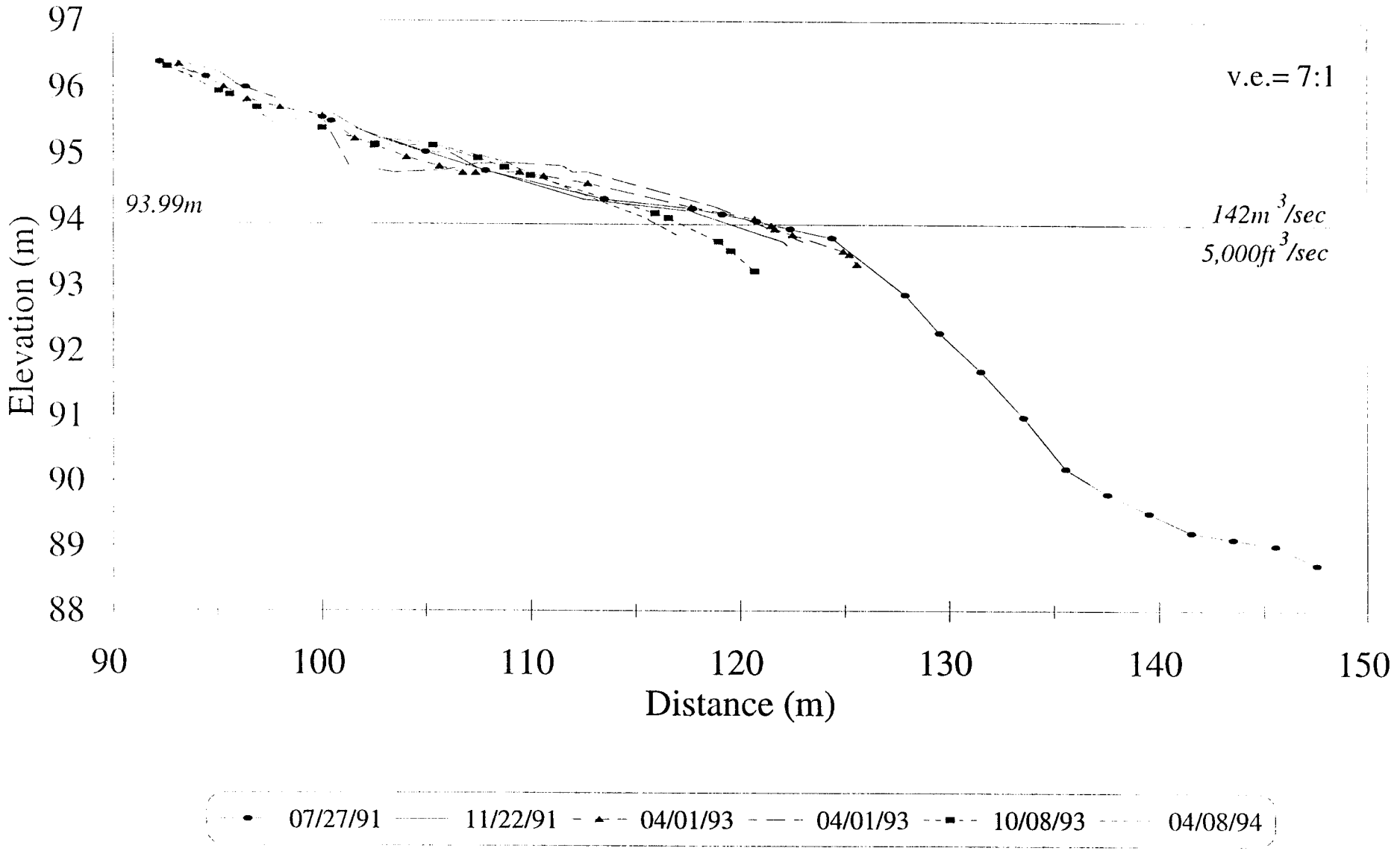
Cross-channel P4



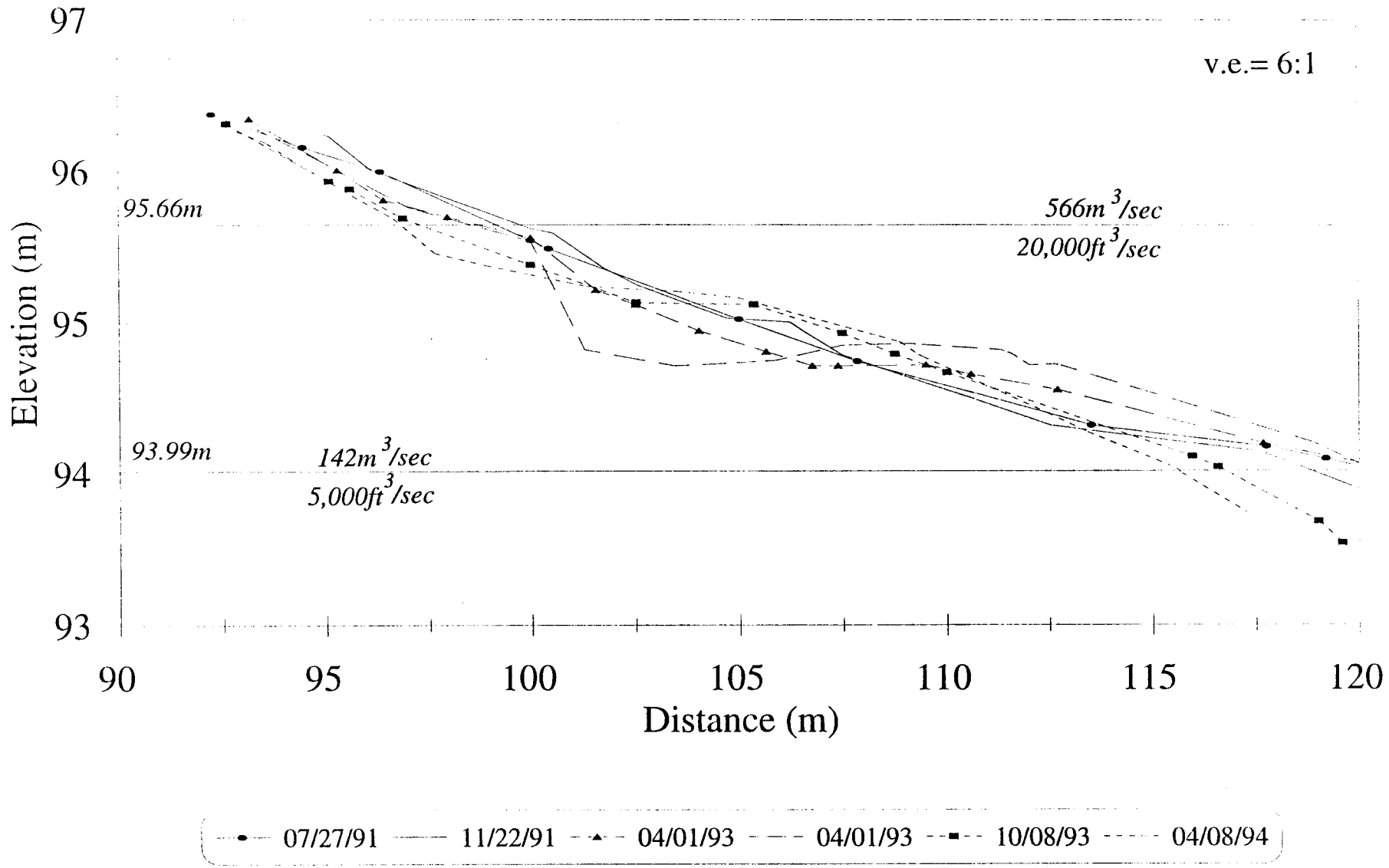

Near-shore P4
v.e.= 7:1
95.66m
93.99m
142m 3/sec
5,000ft 3/sec
566m 3/sec
20,000ft 3/sec
Elevation (m)
97
96
95
94
93
92
91
90
100
110
120
130
Distance (m)
07/27/91
11/22/91
04/01/93
04/01/93
10/08/93
04/08/94

8 Mile

Cross-channel P5

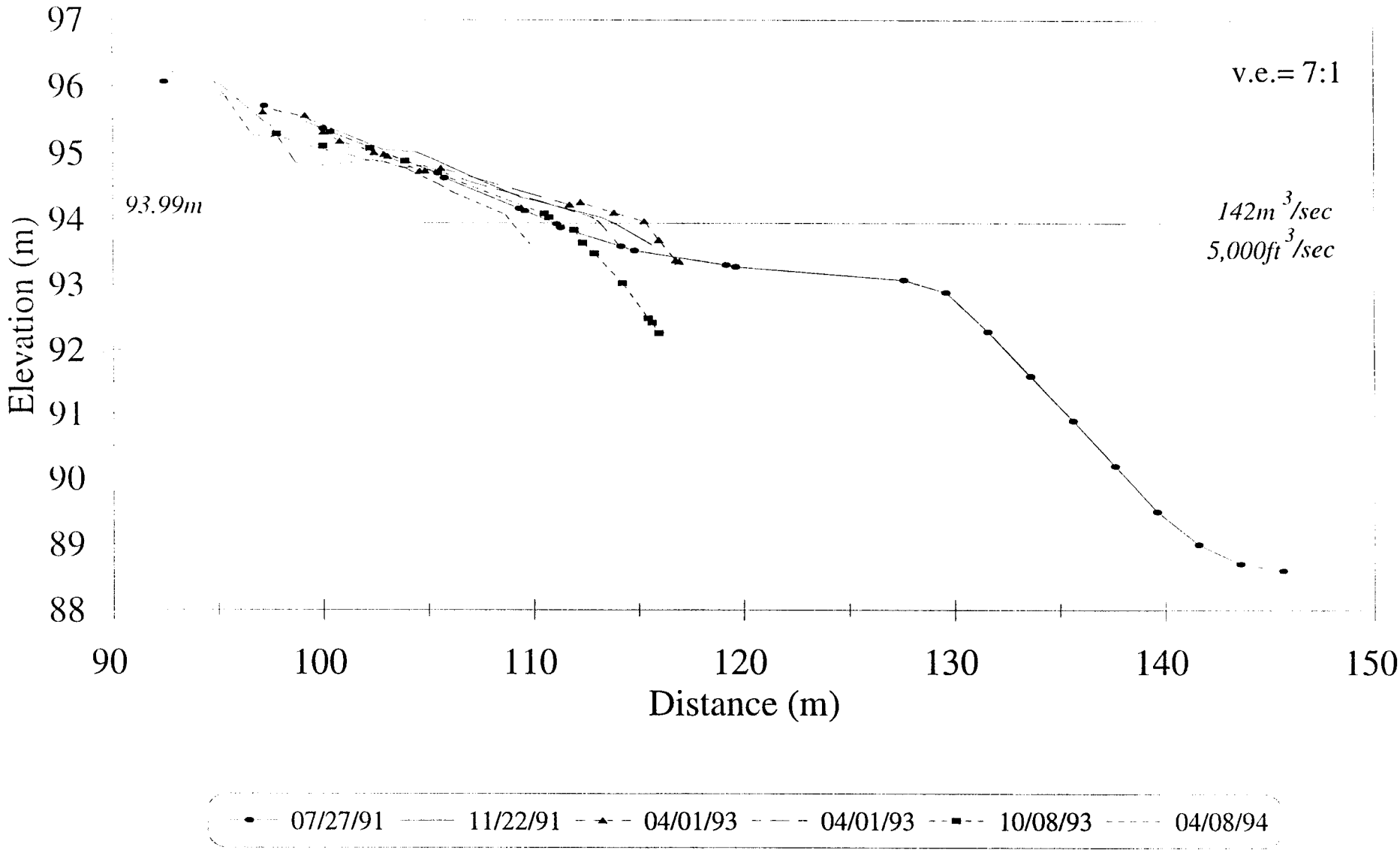


Near-shore P5

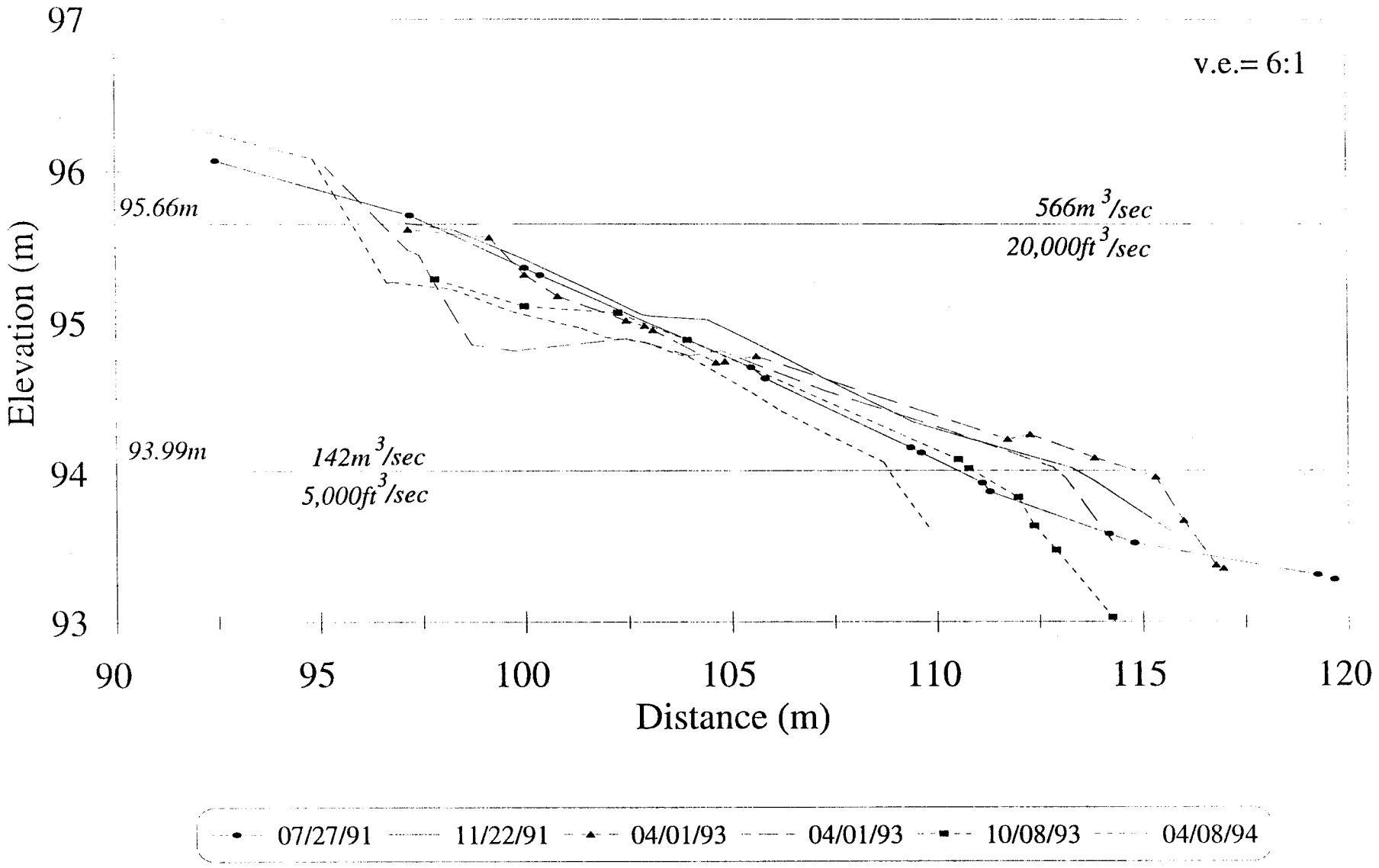


8 Mile

Cross-channel P6

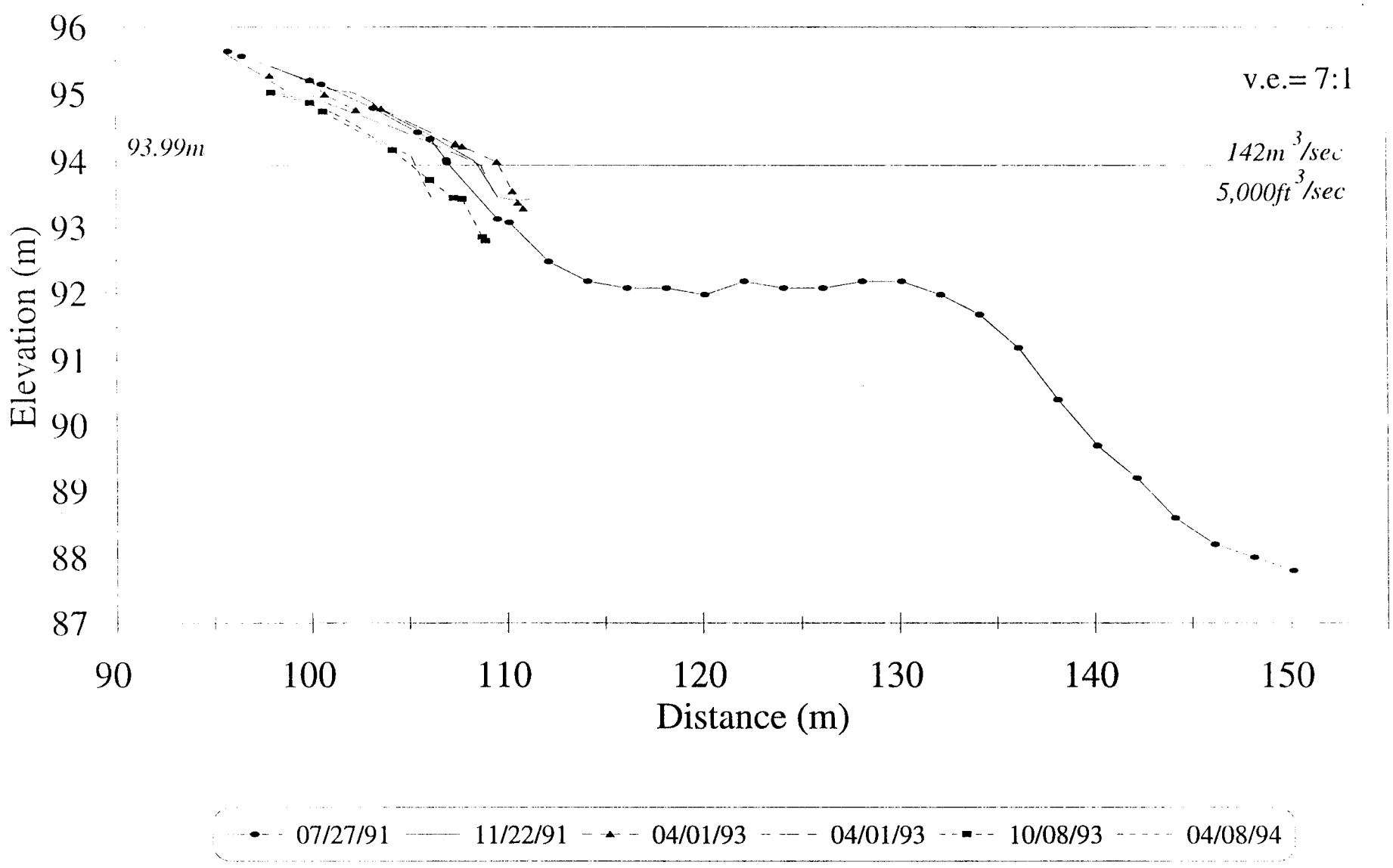


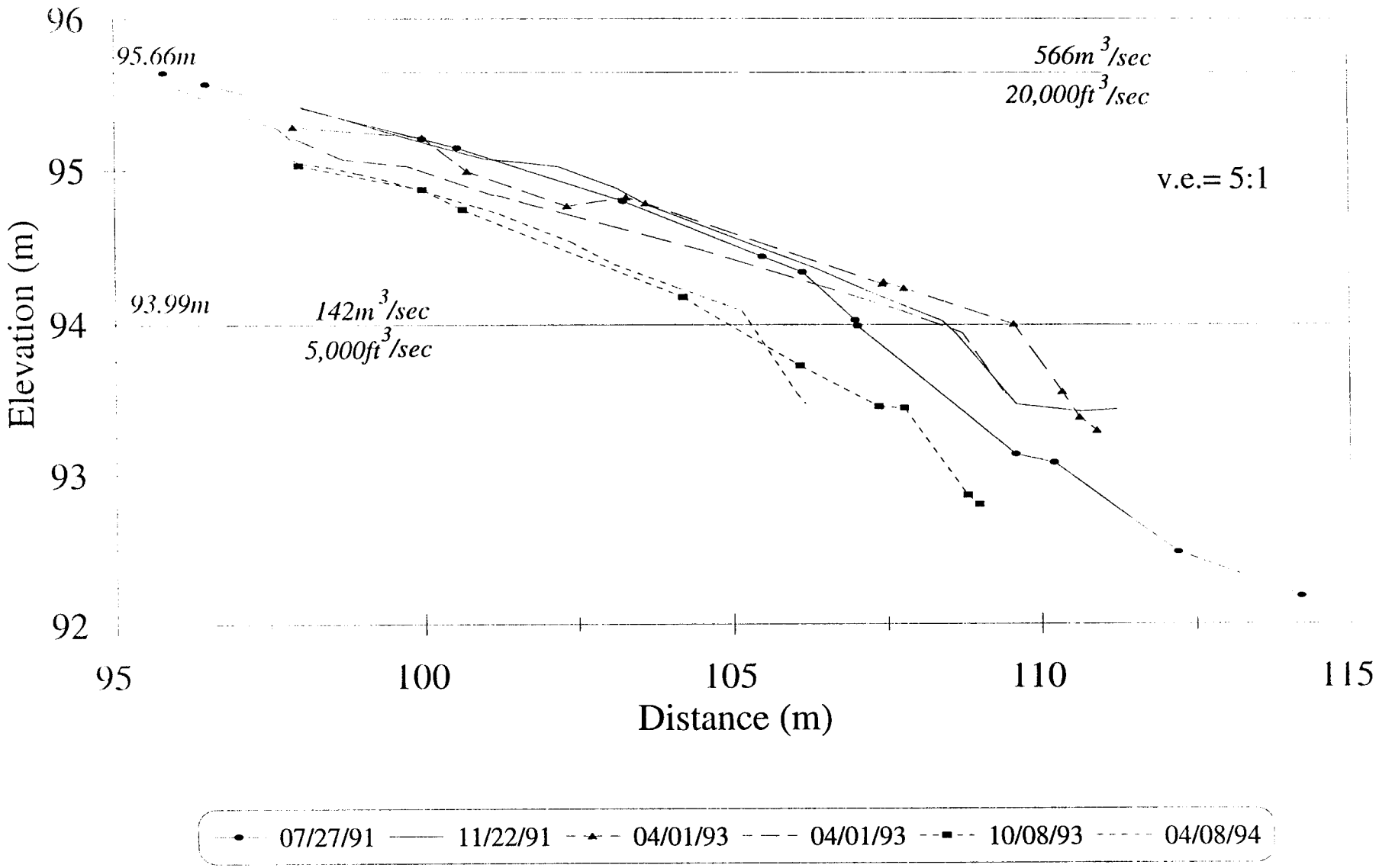
Near-shore P6



8 Mile

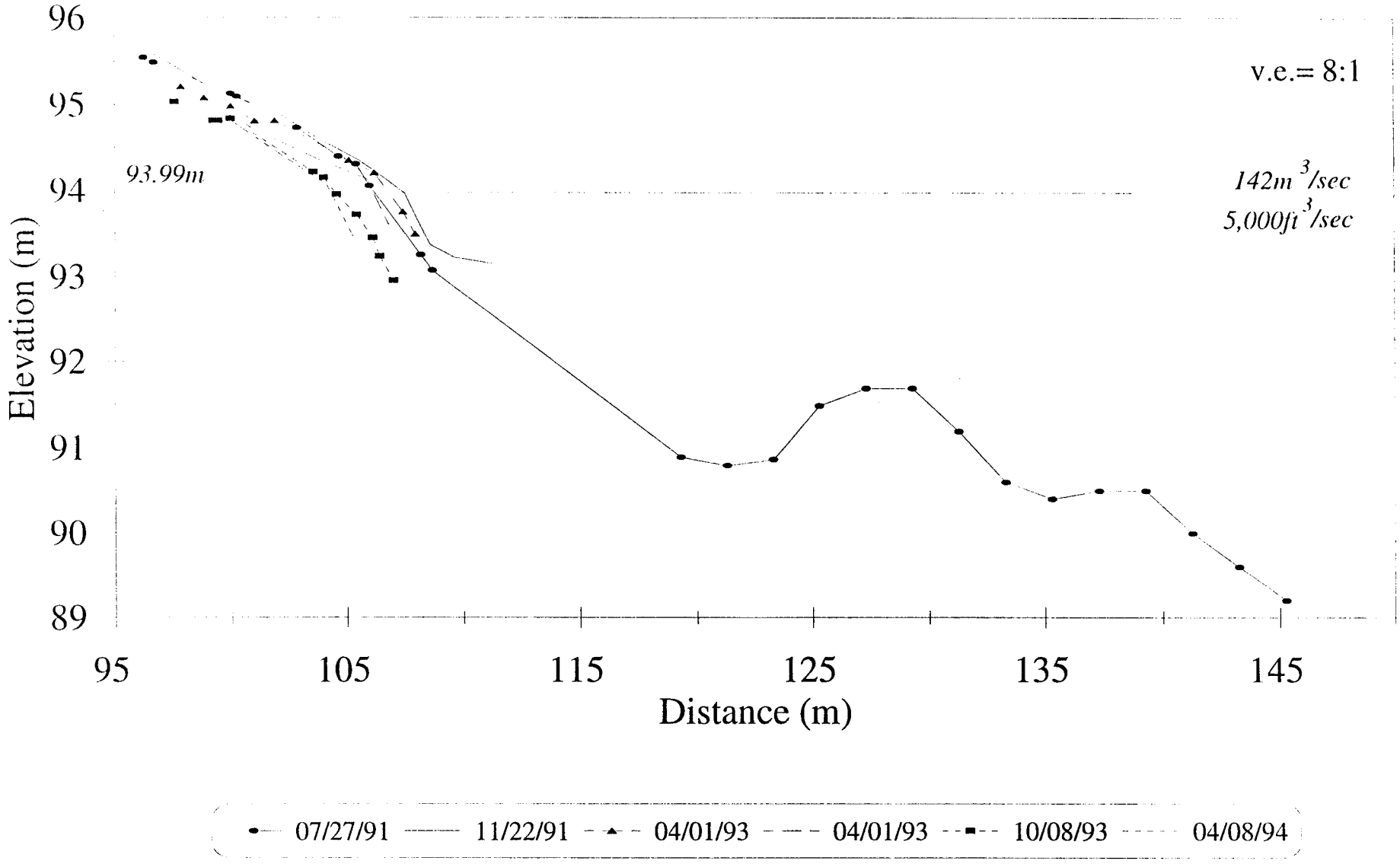
Cross-channel P7



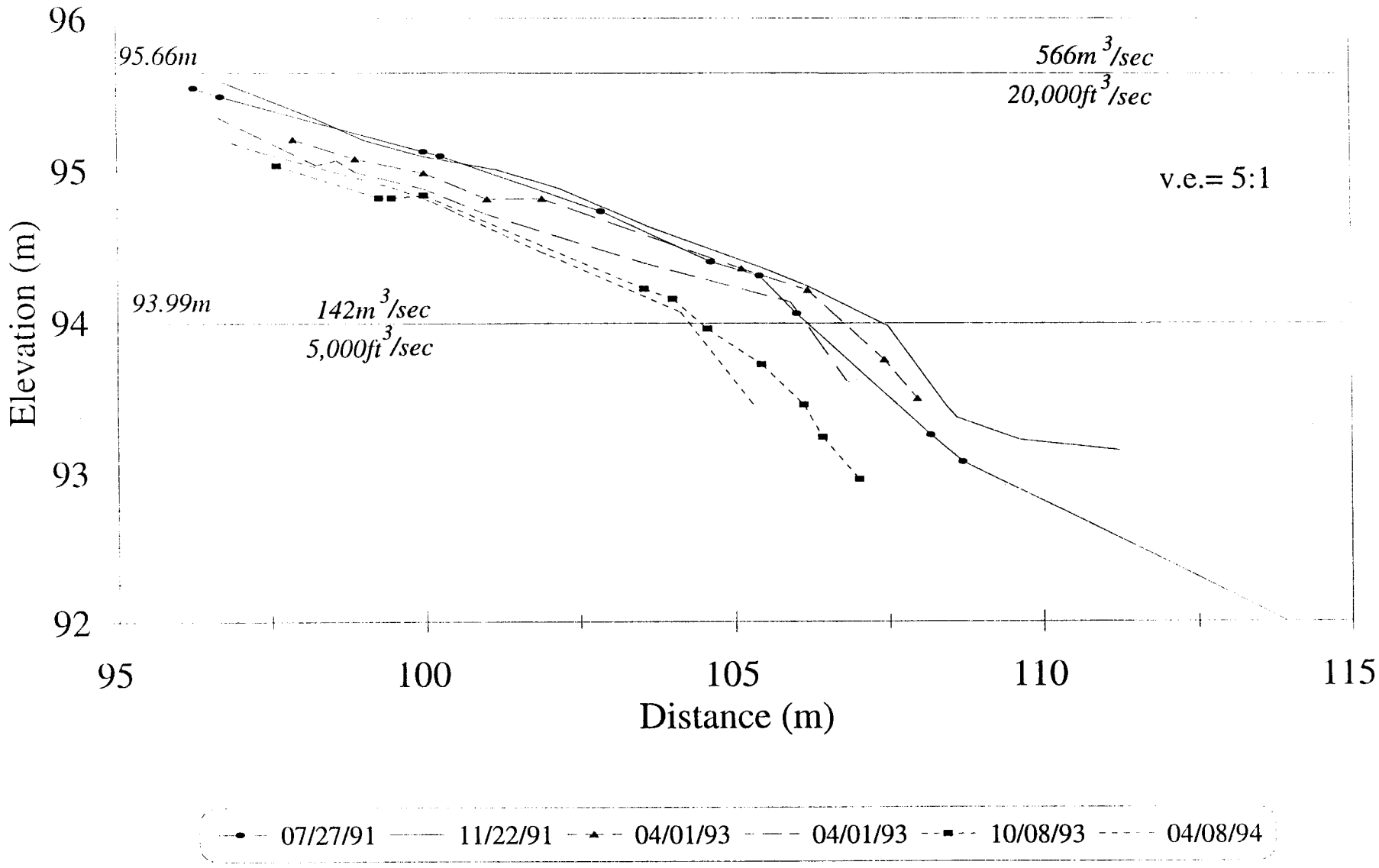

Near-shore P7
96
95
94
93
92
Elevation (m)
95.66m
566m 3/sec
20,000ft 3/sec
v.e.= 5:1
93.99m
142m 3/sec
5,000ft 3/sec
95
100
105
110
115
Distance (m)
07/27/91
11/22/91
04/01/93
04/01/93
10/08/93
04/08/94

8 Mile

Cross-channel P8

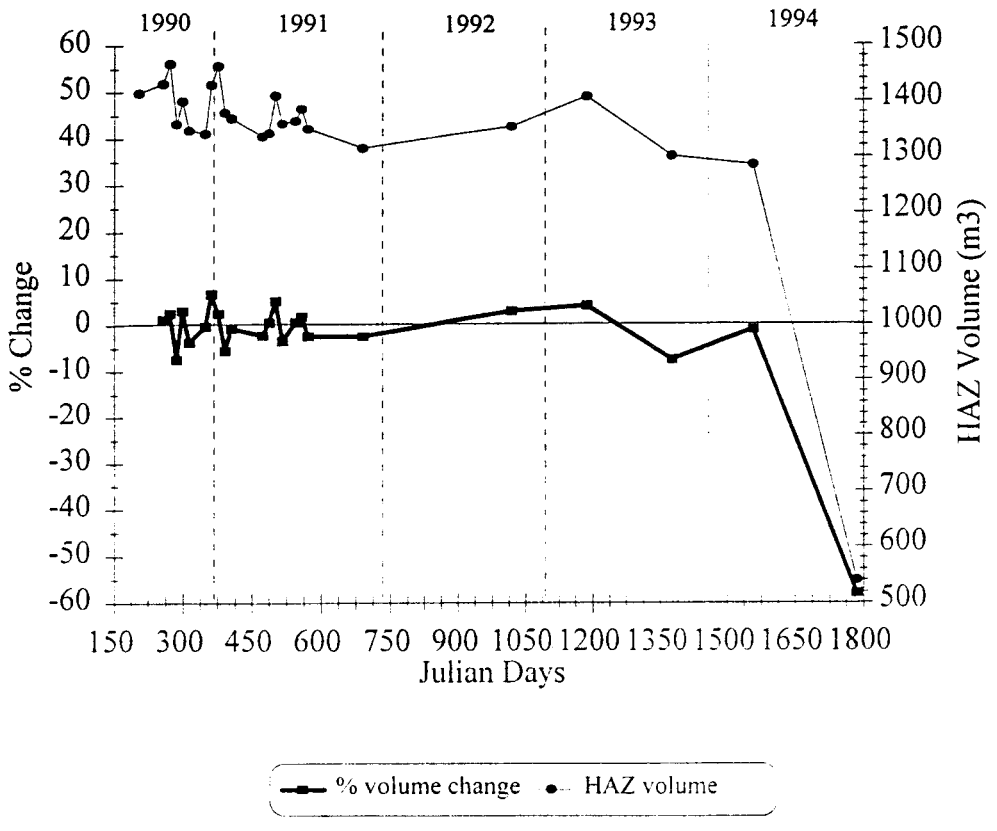


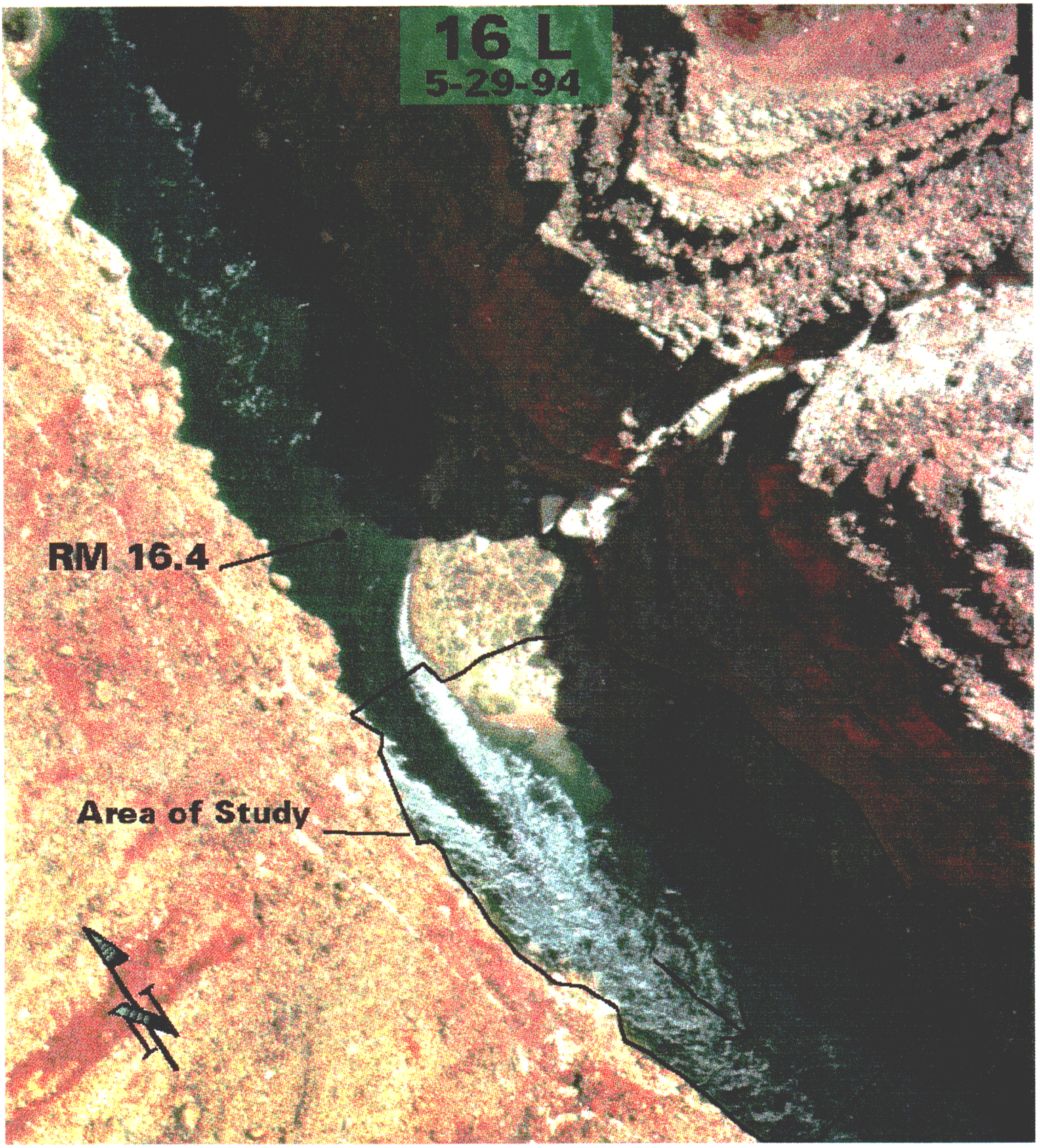
Near-shore P8

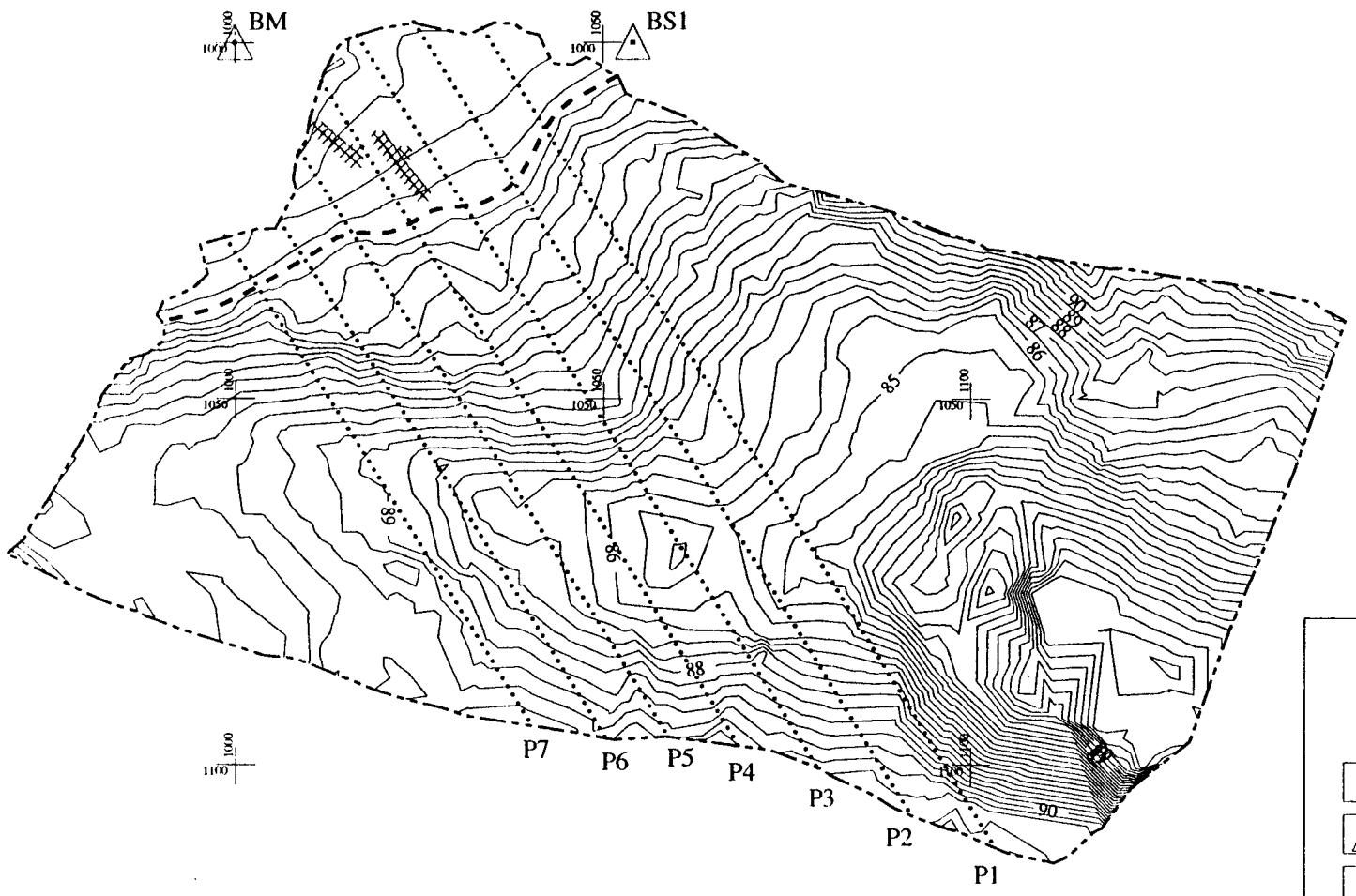


8 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D	900725	F	206	1630	1416				
E		NORM							
F	900915	NORM	258	1559	1432	-71	16	-4.36	1.13
G	900929	E	272	1573	1468	14	36	0.90	2.51
H	901013	A	286	1558	1360	-15	-108	-0.95	-7.36
I	901027	8000 CFS	300	1605	1401	47	41	3.02	3.01
J	901110	NORM	314	1585	1348	-20	-53	-1.25	-3.78
K	901215	NORM	349	1587	1342	2	-6	0.13	-0.45
L	901229	11000 CFS	363	1574	1430	-13	88	-0.82	6.56
M	910112	C	377	1611	1464	37	34	2.35	2.38
N	910126	NORM	391	1591	1381	-20	-83	-1.24	-5.67
O	910209	B	405	1511	1370	-80	-11	-5.03	-0.80
P	910419	NORM	474	1502	1337	-9	-33	-0.60	-2.41
Q	910503	NORM	488	1506	1343	4	6	0.27	0.45
R	910518	D	503	1643	1411	137	68	9.10	5.06
S	910601	15000 CFS	517	1571	1360	-72	-51	-4.38	-3.61
T	910629	NORM	545	1534	1365	-37	5	-2.36	0.37
U	910713	G	559	1496	1387	-38	22	-2.48	1.61
V	910727	F	573	1482	1351	-14	-36	-0.94	-2.60
X	911122	INT	691	1524	1316	42	-35	2.83	-2.59
Y	921015	INT	1019	1729	1354	205	38	13.45	2.89
Z	930401	INT	1187	1788	1408	59	54	3.41	3.99
B04	931008	INT	1377	1440	1301	-348	-107	-19.46	-7.60
C04	940408	INT	1559	1403	1286	-37	-15	-2.57	-1.15
D04	941120	INT	1785	720	541	-683	-745	-48.68	-57.93

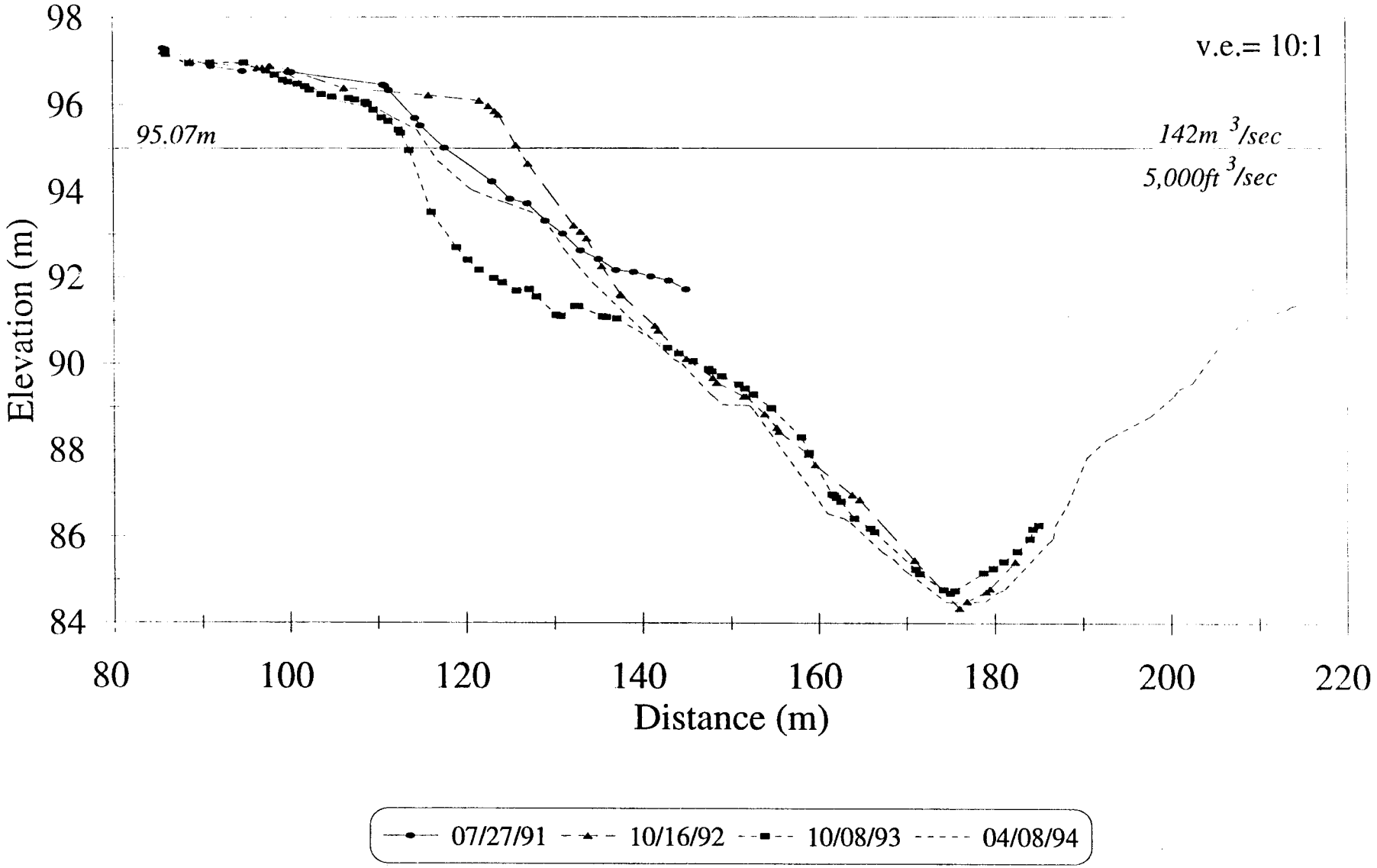


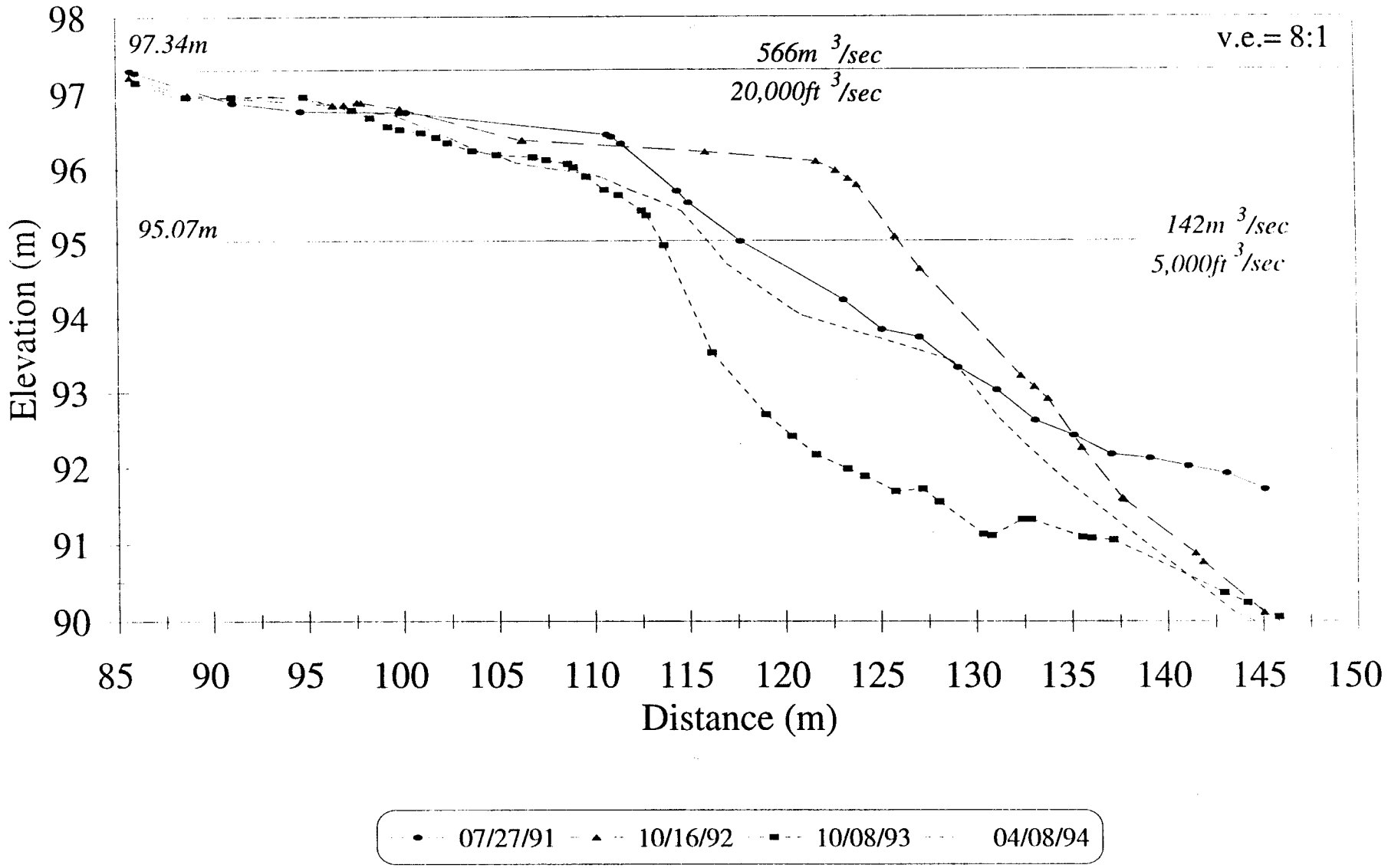

16 L
5-29-94
RM 16.4
Area of Study
N


BM
BS1
P7
P6
P5
P4
P3
P2
P1
N
16 Mile – Hot Na Na
0.5 Meter Contour Interval
Survey Date: 4/8/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:700

16 Mile

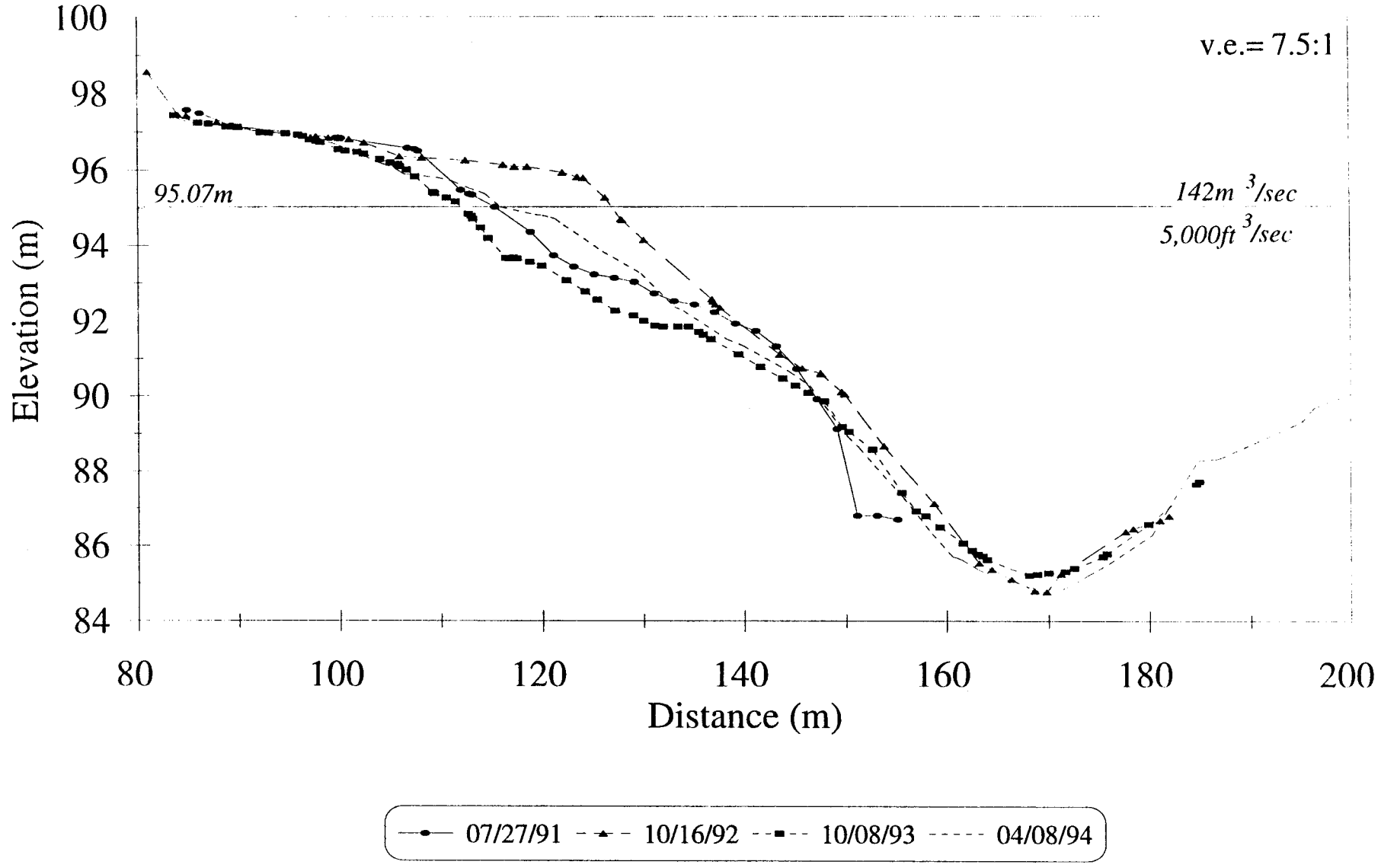
Cross-channel P2



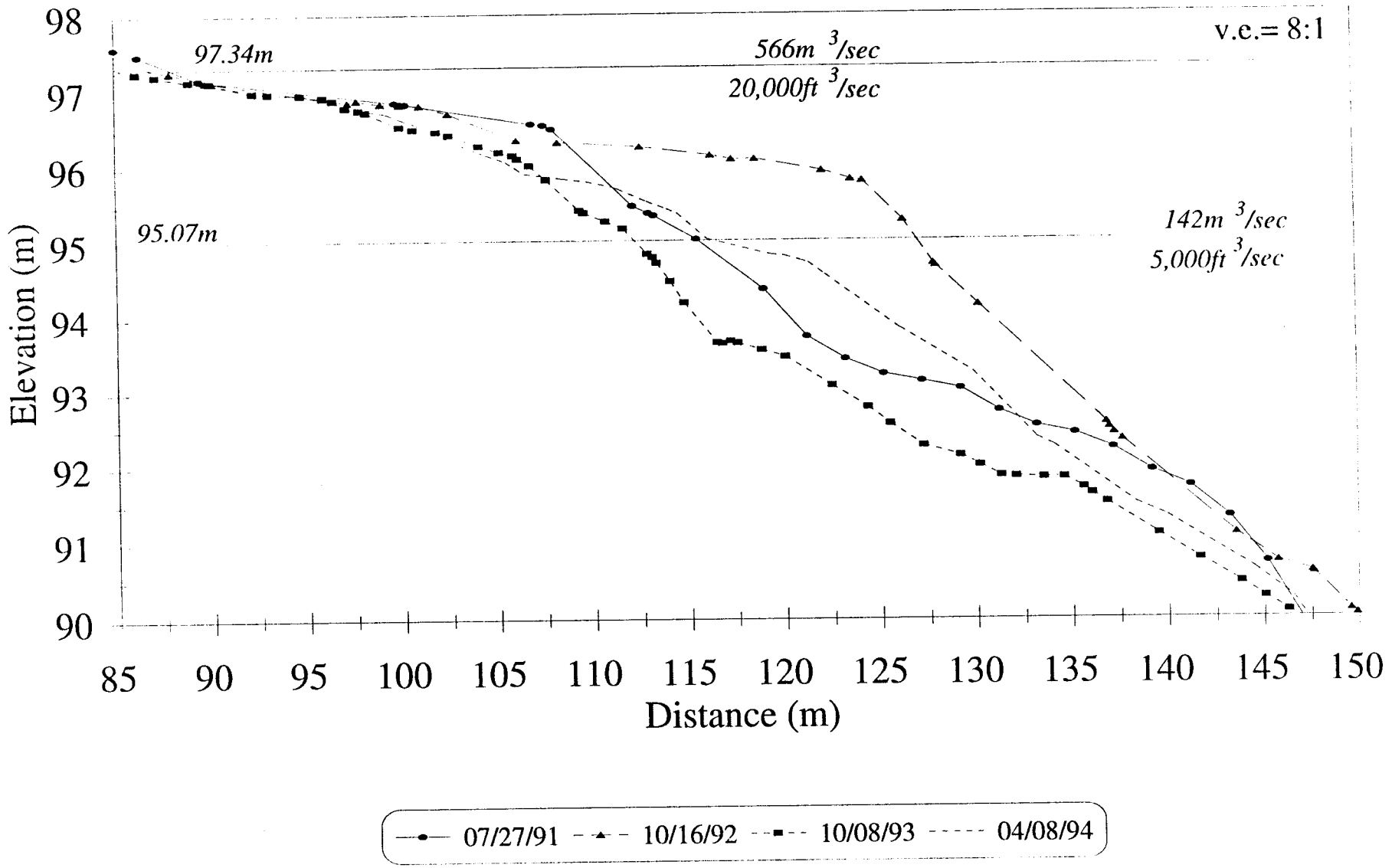

Near-shore P2
98
97
96
95
94
93
92
91
90
Elevation (m)
97.34m
95.07m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
v.e.= 8:1
85
90
95
100
105
110
115
120
125
130
135
140
145
150
Distance (m)
07/27/91
10/16/92
10/08/93
04/08/94

16 Mile

Cross-channel P3

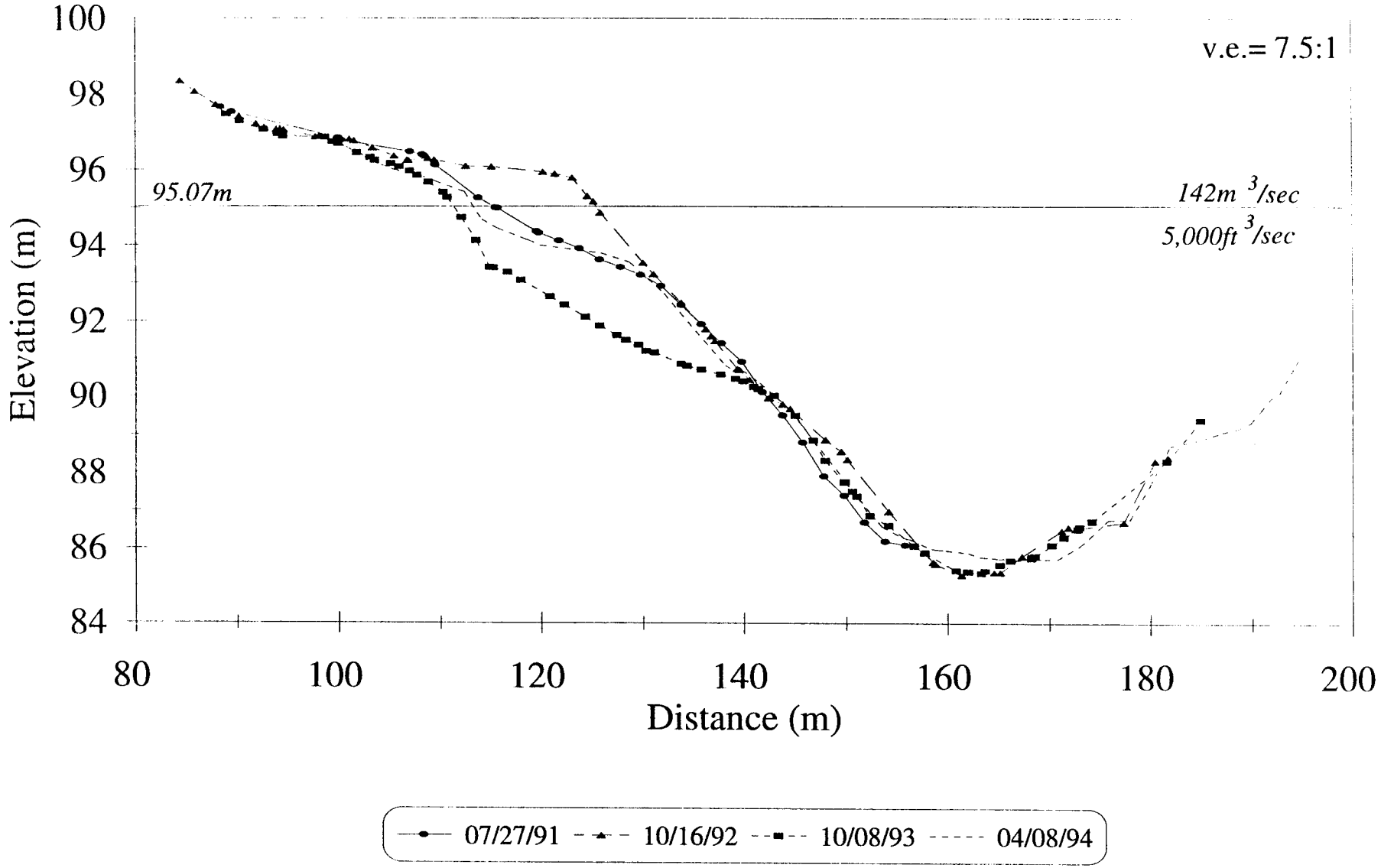


Near-shore P3

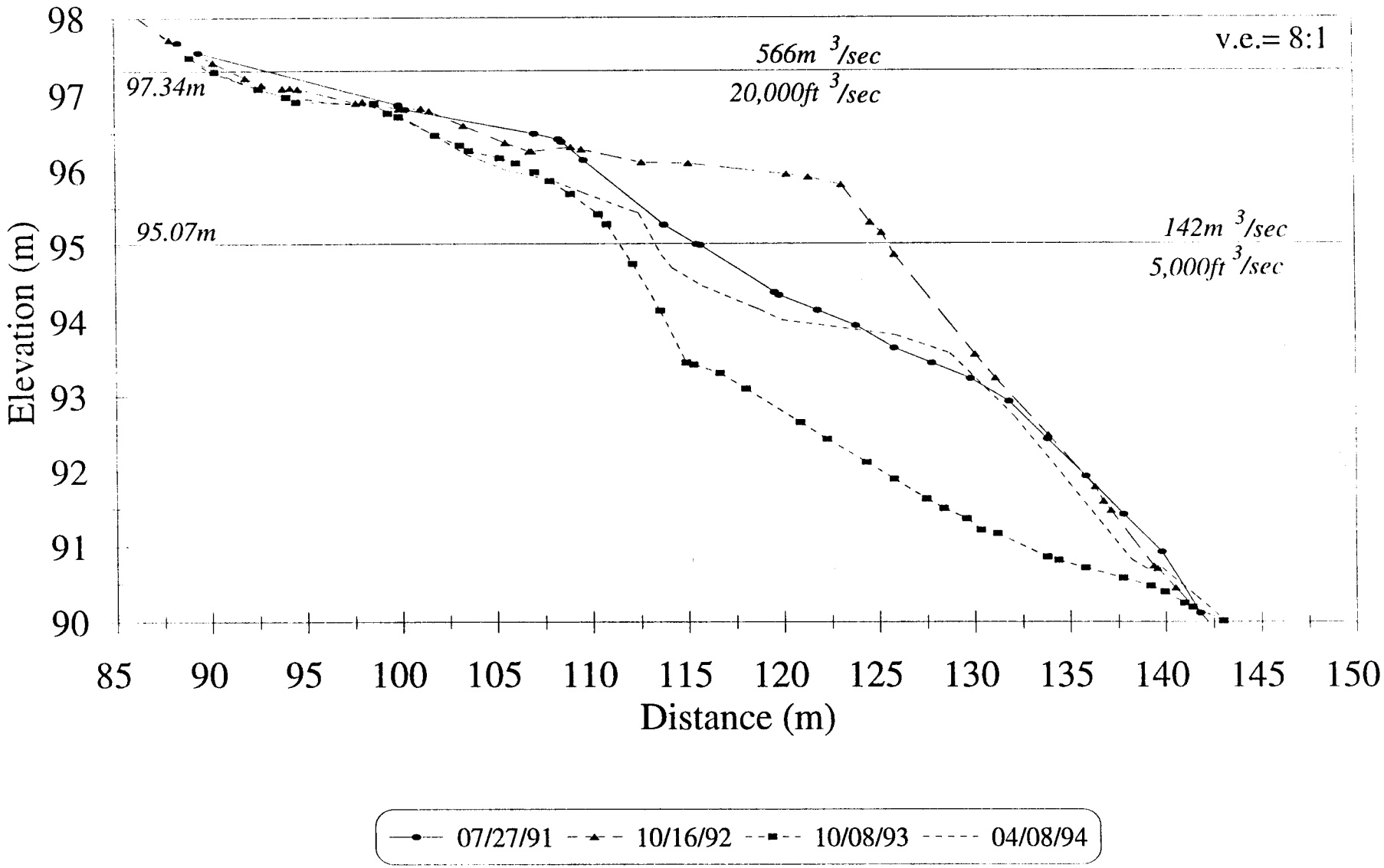


16 Mile

Cross-channel P4

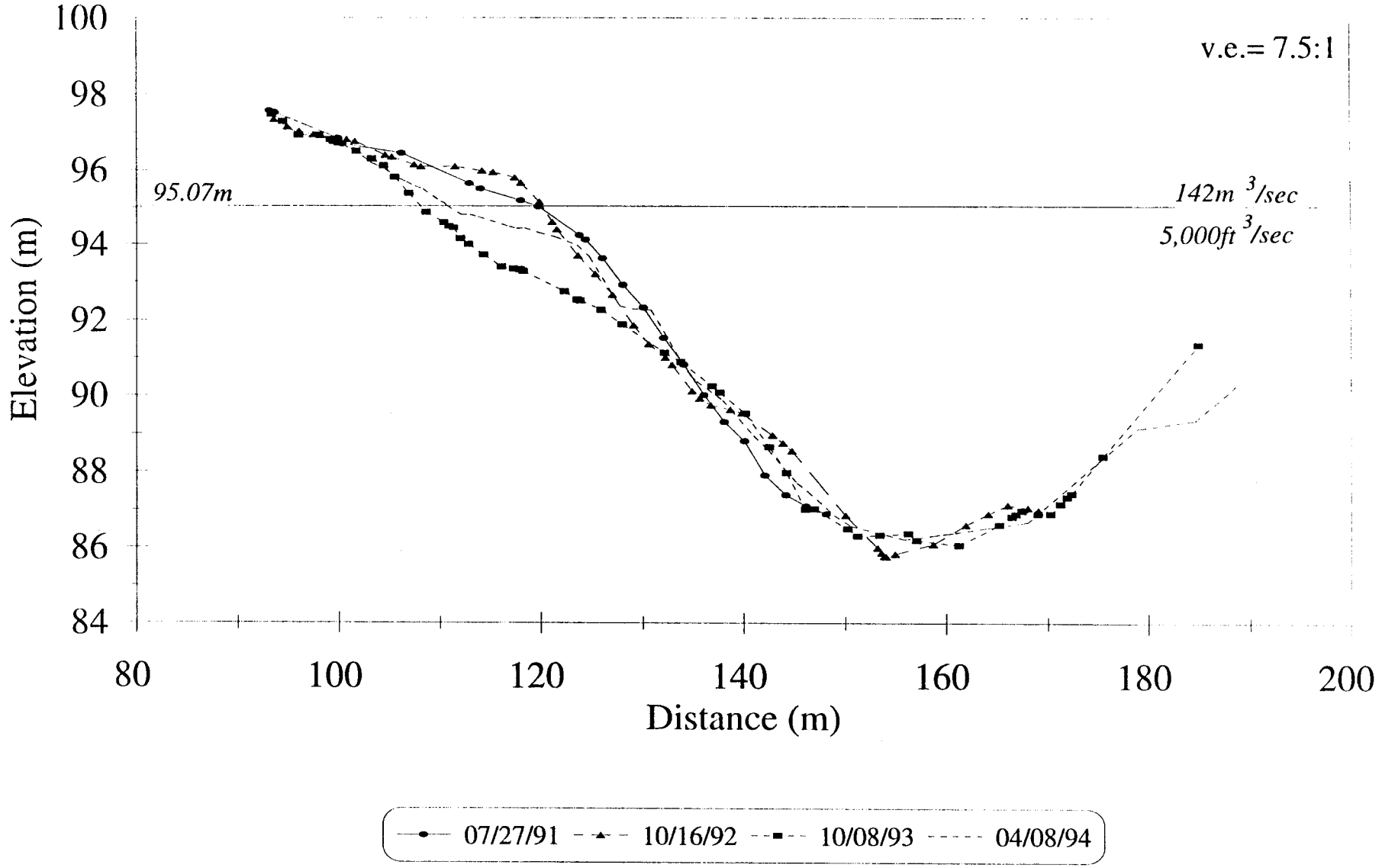


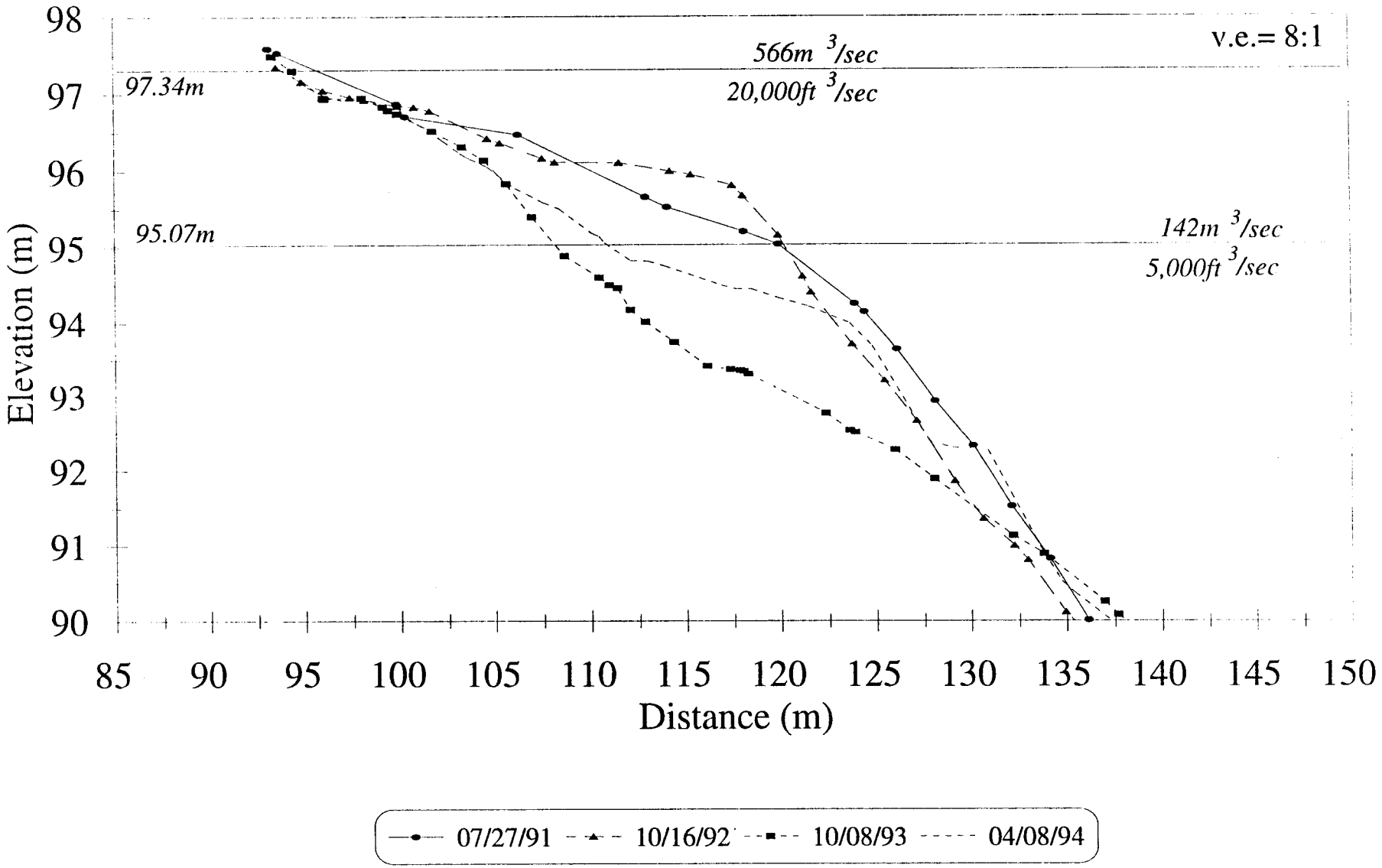
Near-shore P4



16 Mile

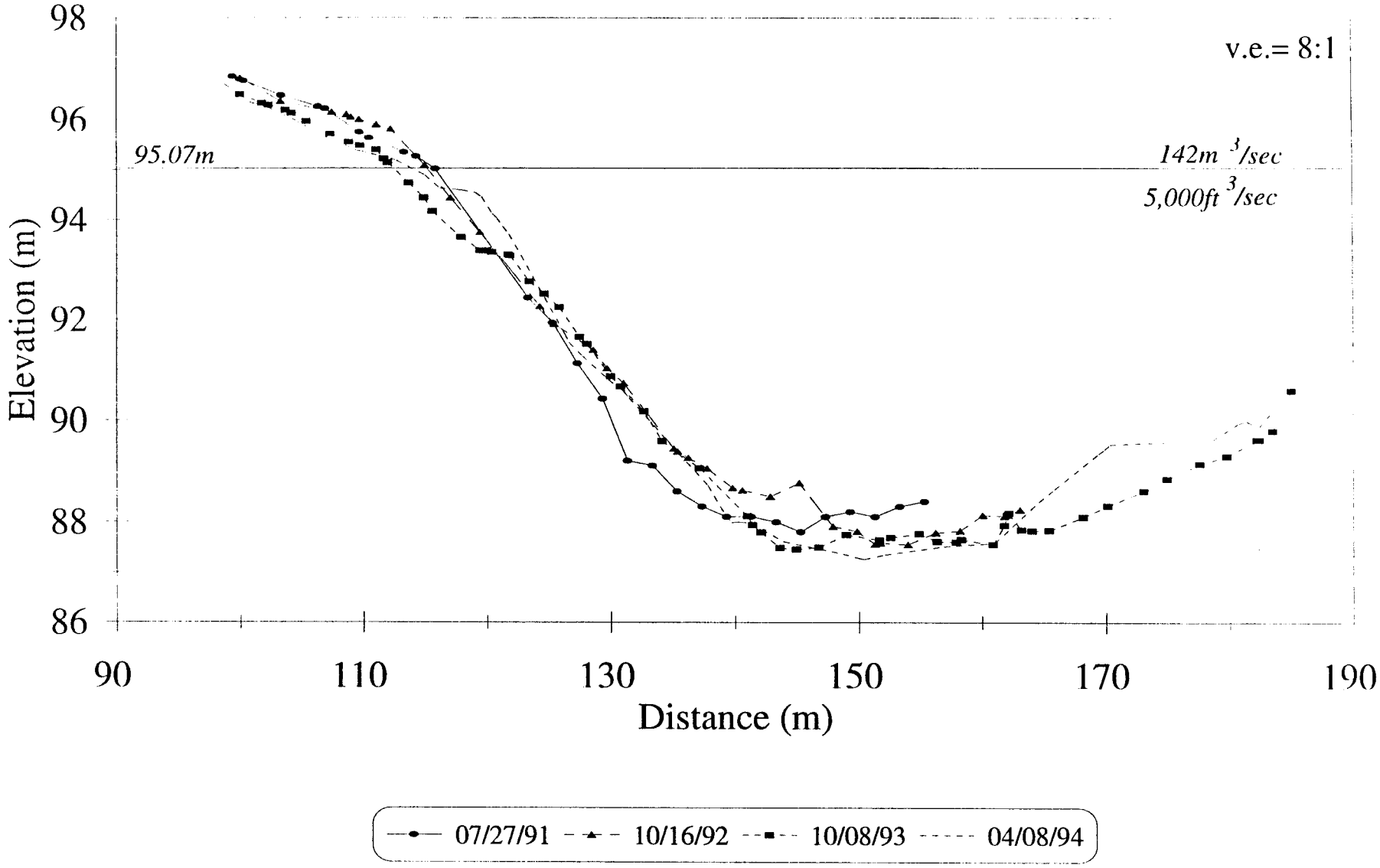
Cross-channel P5

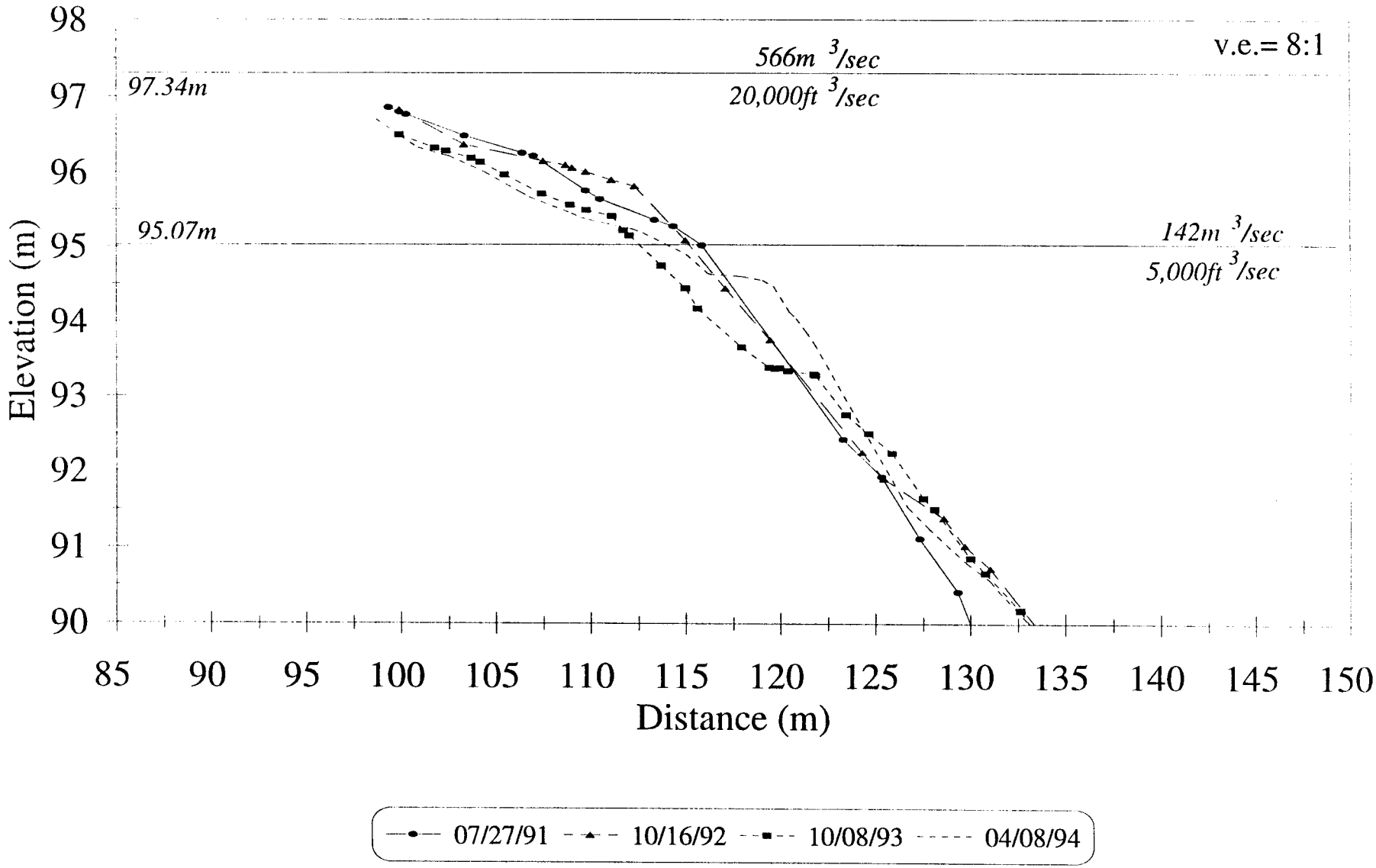



Near-shore P5
v.e.= 8:1
566m 3/sec
20,000ft 3/sec
97.34m
95.07m
142m 3/sec
5,000ft 3/sec
Elevation (m)
98
97
96
95
94
93
92
91
90
85
90
95
100
105
110
115
120
125
130
135
140
145
150
Distance (m)
07/27/91
10/16/92
10/08/93
04/08/94

16 Mile

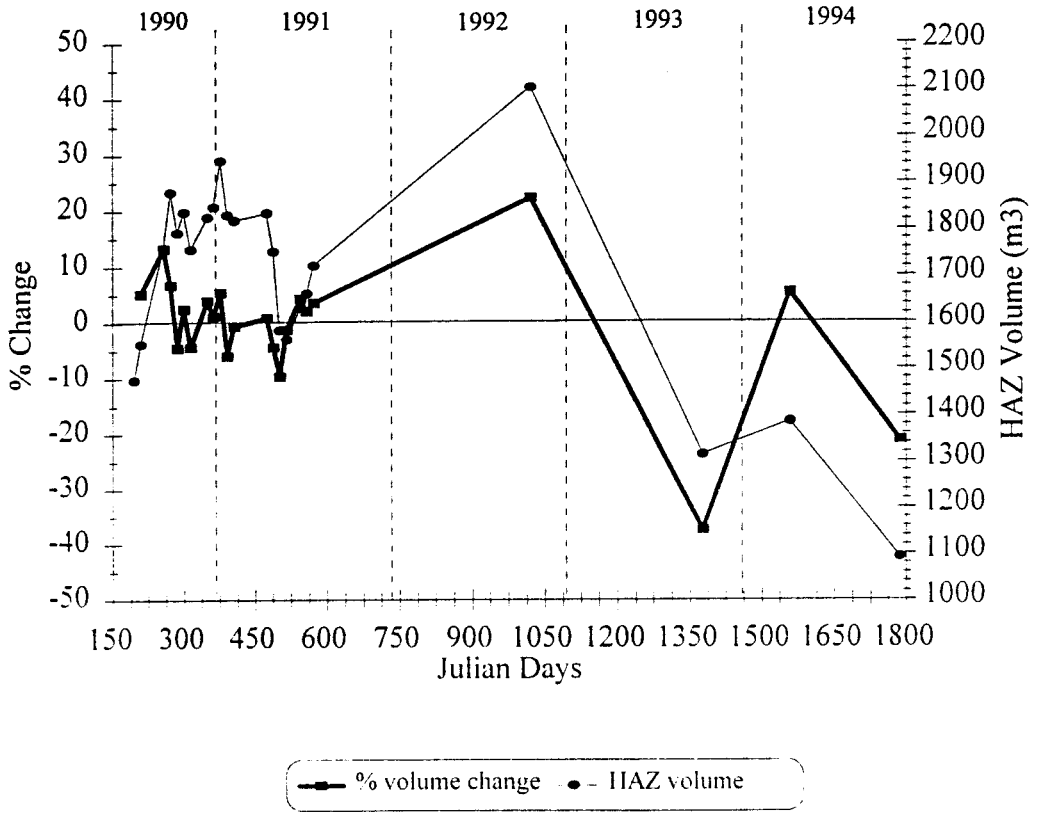
Cross-channel P6




Near-shore P6
v.e.= 8:1
566m 3/sec
20,000ft 3/sec
97.34m
95.07m
142m 3/sec
5,000ft 3/sec
Elevation (m)
98
97
96
95
94
93
92
91
90
85
90
95
100
105
110
115
120
125
130
135
140
145
150
Distance (m)
07/27/91
10/16/92
10/08/93
04/08/94

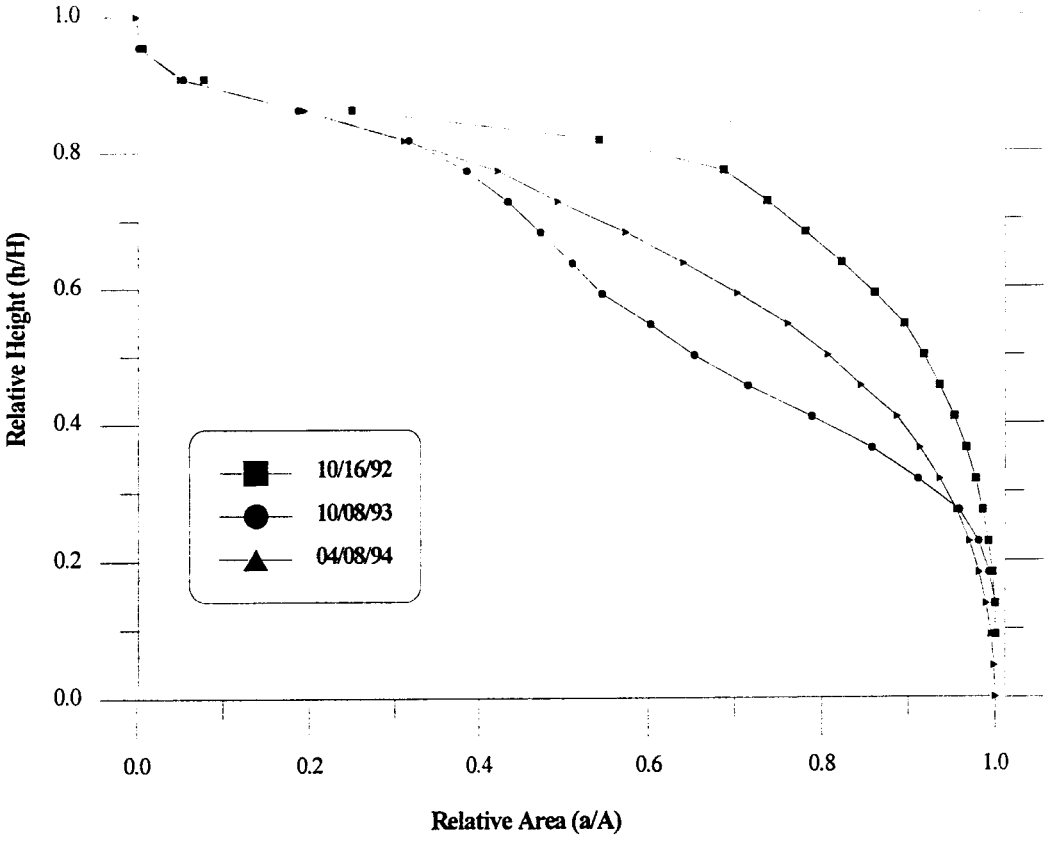
16 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C	900714	G	195	1047	1478				
D	900728	F	209	1115	1555	68	77	6.49	5.21
E	910517	NORM							
F	900915	NORM	258	1207	1761	1207	1761	8.25	13.25
G	900929	E	272	1294	1880	87	119	7.21	6.76
H	901013	A	286	1288	1794	-6	-86	-0.46	-4.57
I	901027	8000 CFS	300	1298	1838	10	44	0.78	2.45
J	901110	NORM	314	1292	1758	-6	-80	-0.46	-4.35
K	901215	NORM	349	1328	1827	36	69	2.79	3.92
L	911229	11000 CFS	363	1338	1848	10	21	0.75	1.15
M	910112	C	377	1368	1948	30	100	2.24	5.41
N	910126	NORM	391	1343	1832	-25	-116	-1.83	-5.95
O	910209	B	405	1346	1820	3	-12	0.22	-0.66
P	910420	NORM	475	1379	1835	33	15	2.45	0.82
Q	910504	NORM	489	1362	1753	-17	-82	-1.23	-4.47
R	910518	D	503	1083	1584	-279	-169	-20.48	-9.64
S	910601	15000 CFS	517	1110	1564	27	-20	2.49	-1.26
T	910629	NORM	545	1207	1631	97	67	8.74	4.28
U	910713	G	559	1248	1663	41	32	3.40	1.96
V	910727	F	573	1280	1722	32	59	2.56	3.55
Y	921016	INT	1020	1549	2103	269	381	21.02	22.13
B05	931008	INT	1377	981	1316	-568	-787	-36.67	-37.42
C05	940408	INT	1559	1122	1386	141	70	14.37	5.32
D05	941120	INT	1786	864	1093	-258	-293	-22.99	-21.14

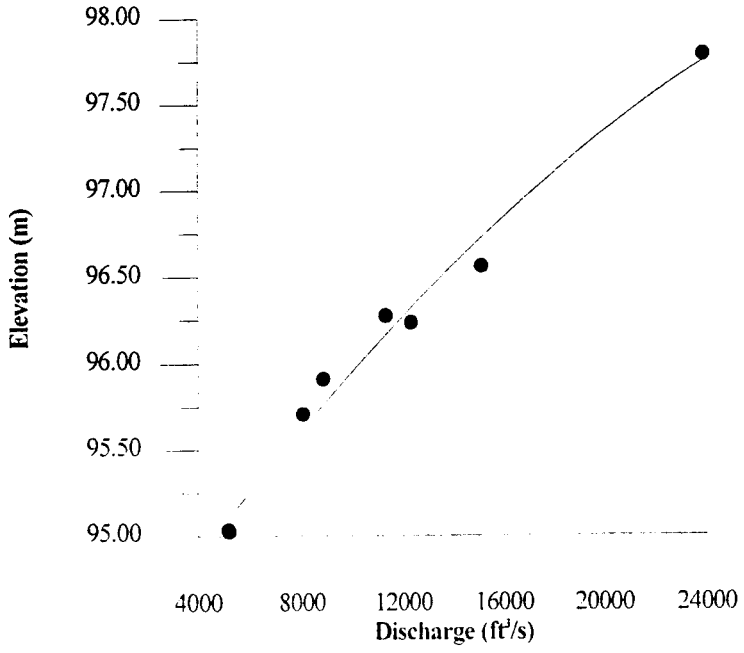


16 Mile

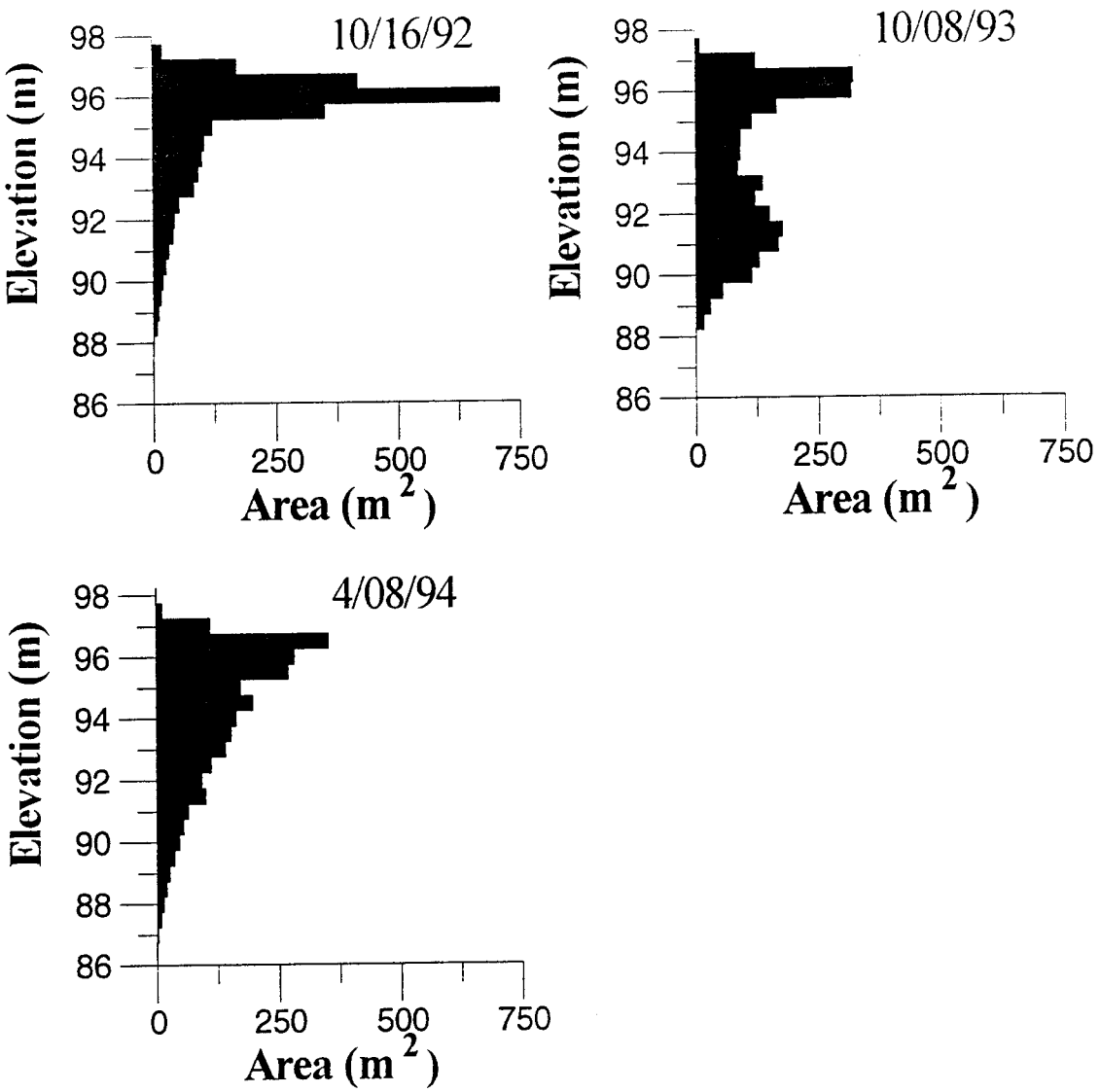
Hypsometric Curves



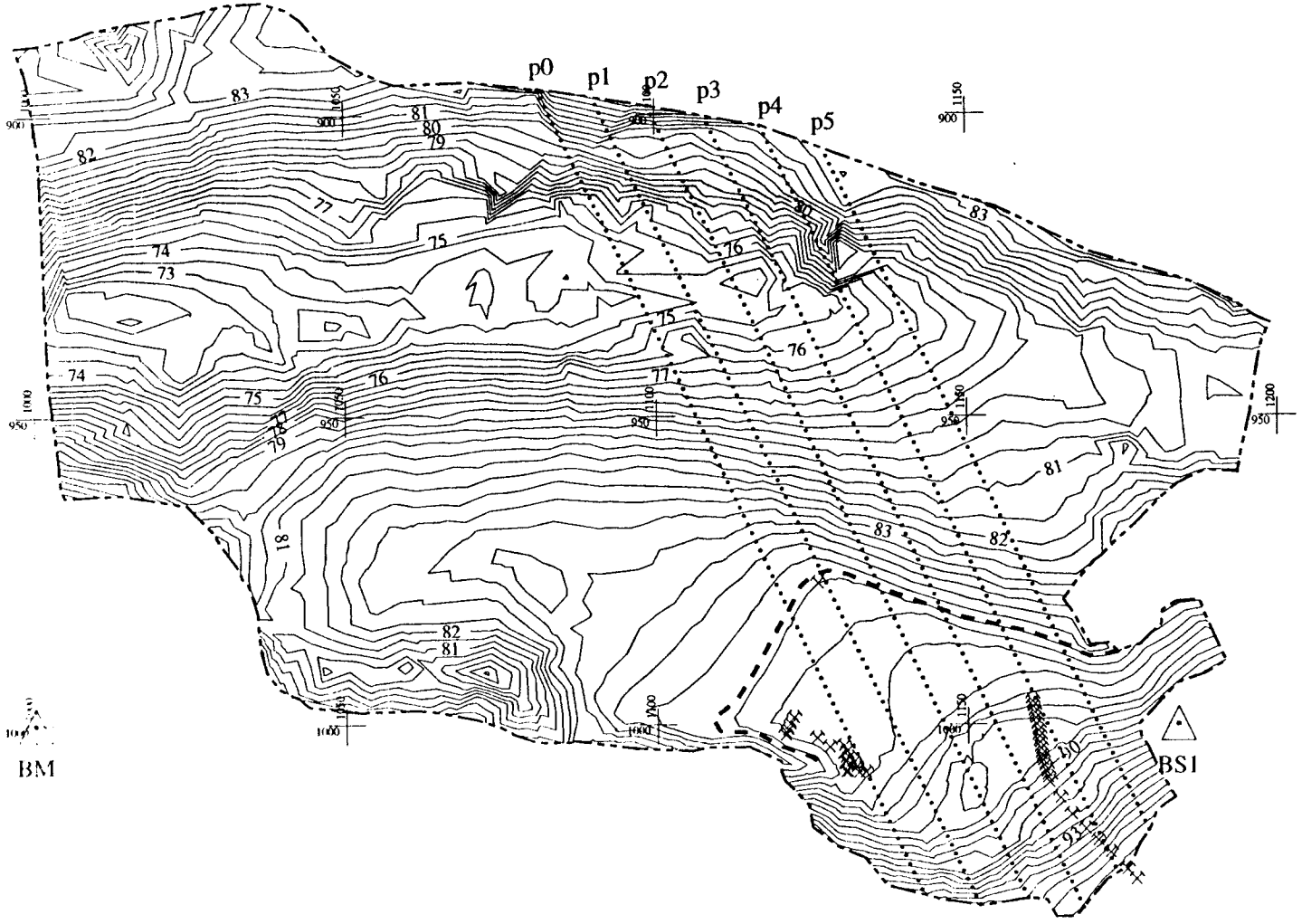
Stage Discharge



16 MILE
Area Distribution Histograms



22 R
5-29-94
Area of Study
RM 21.8



N

22 Mile

0.5 Meter Contour Interval
Survey Date: 4/9/04
Local Control Coordinates
Elevations in Meters

Camera Locations

Survey Control Points

Sediment/Stratigraphy Sample Locations

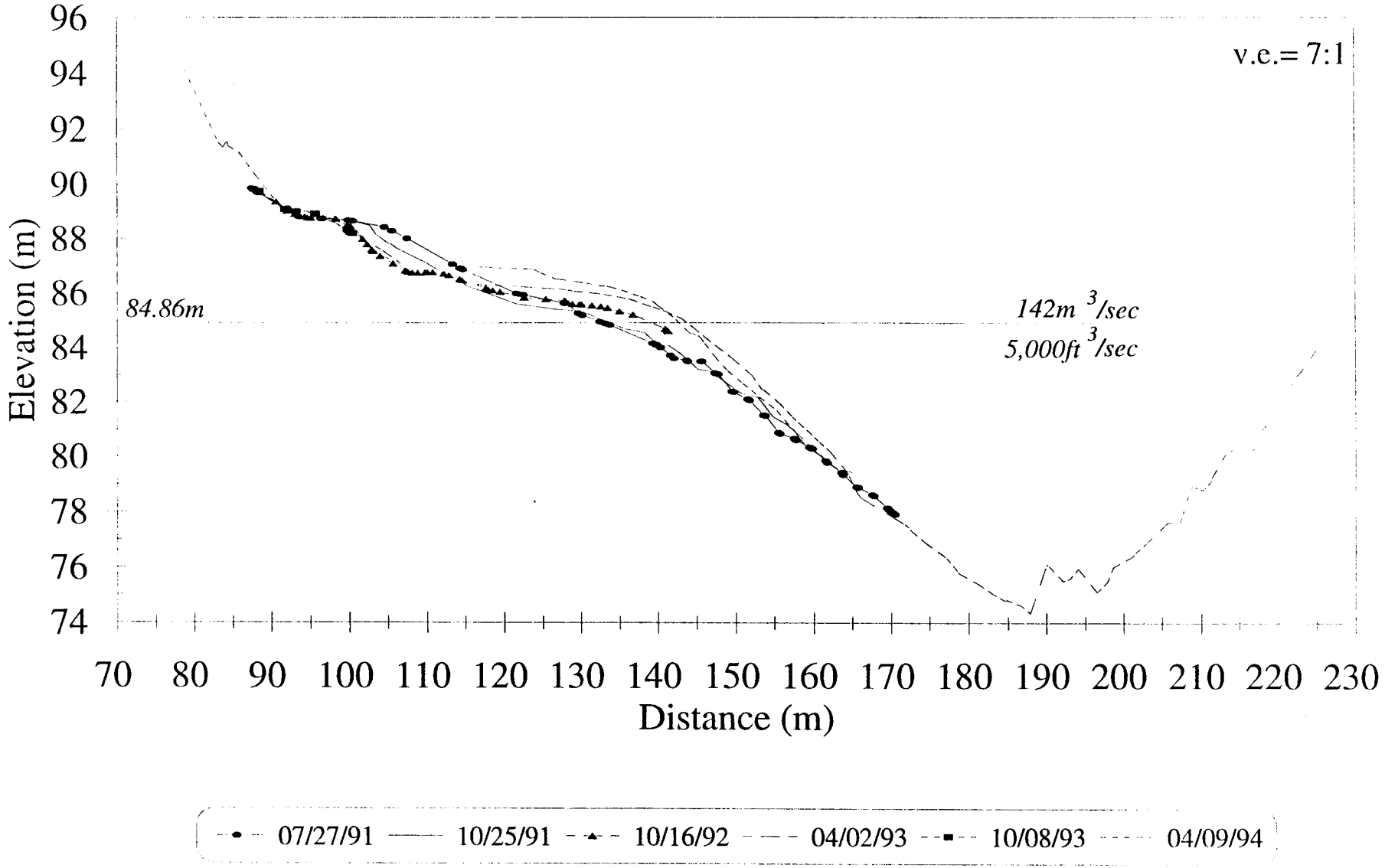
Profile Lines

Water Line

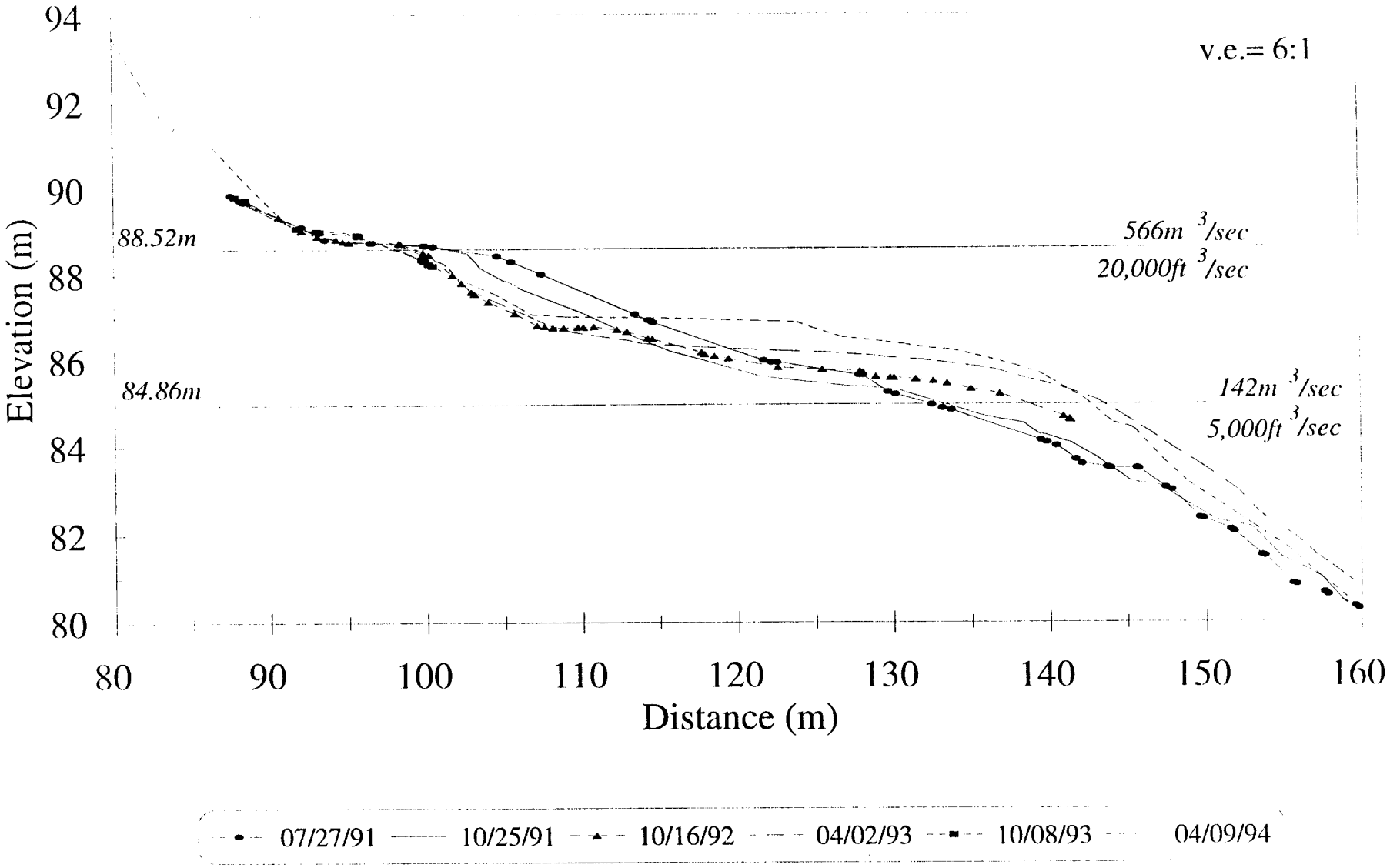
Scale 1:800

22 Mile

Cross-channel P1

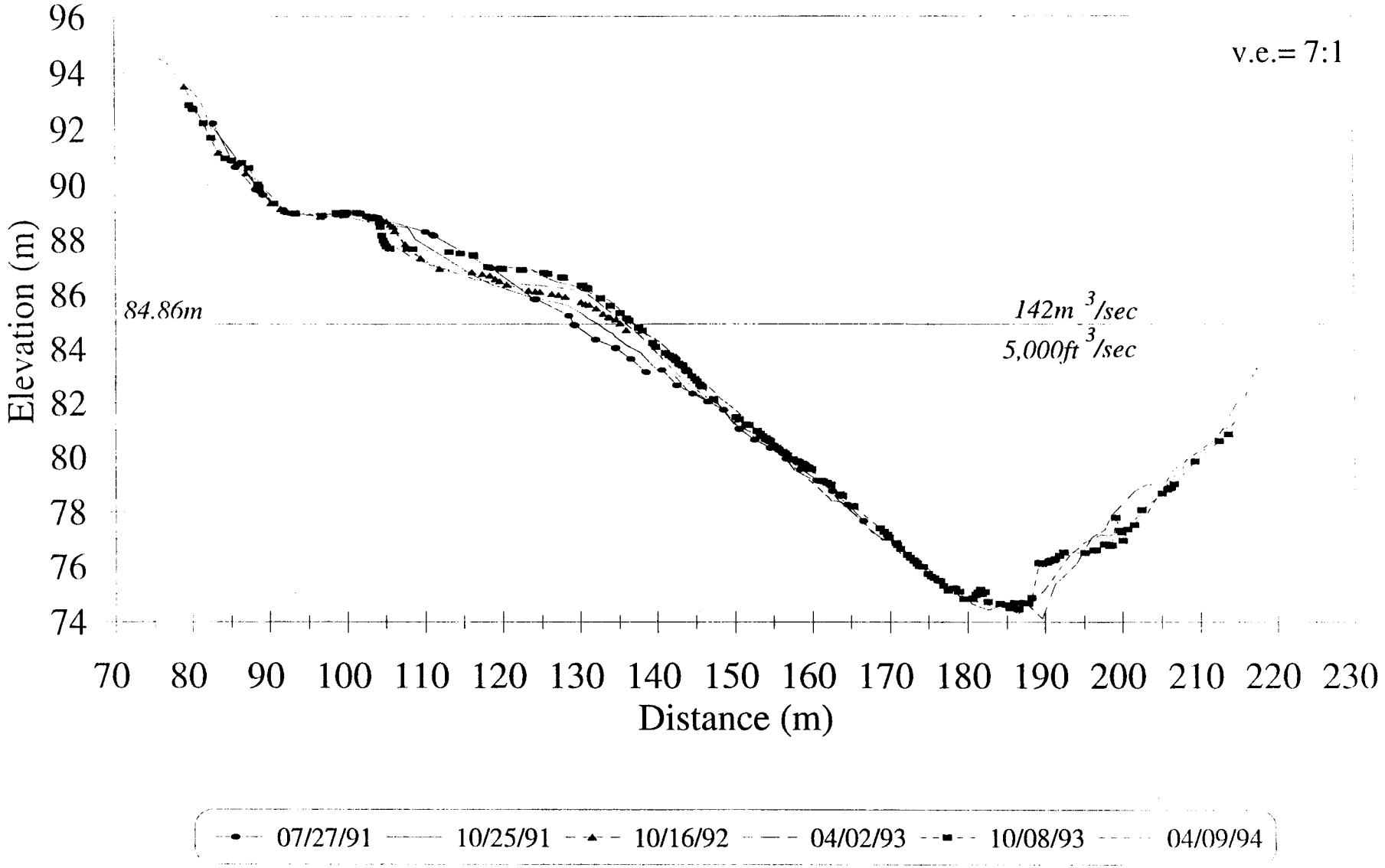


Near-shore P1

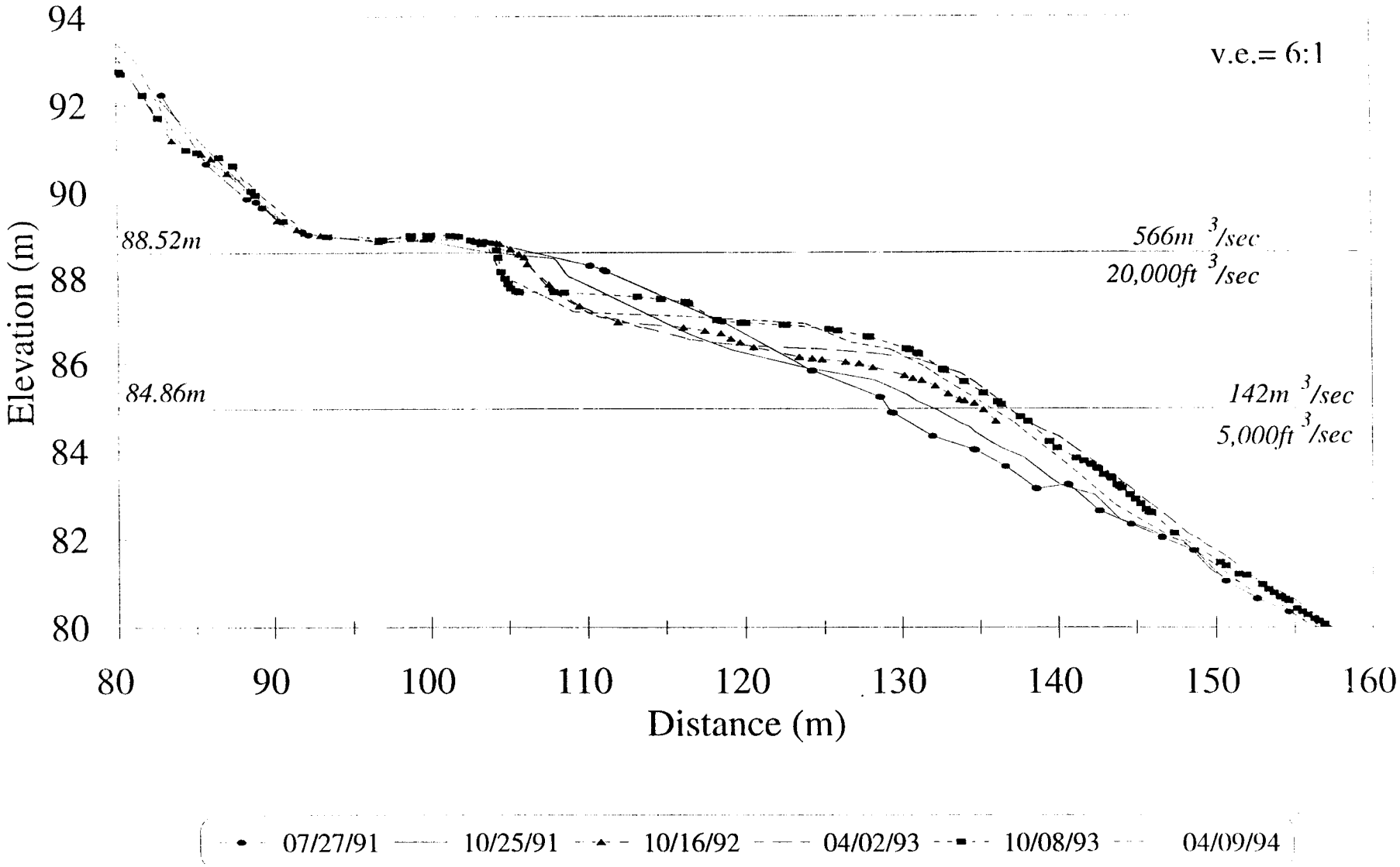


22 Mile

Cross-channel P2

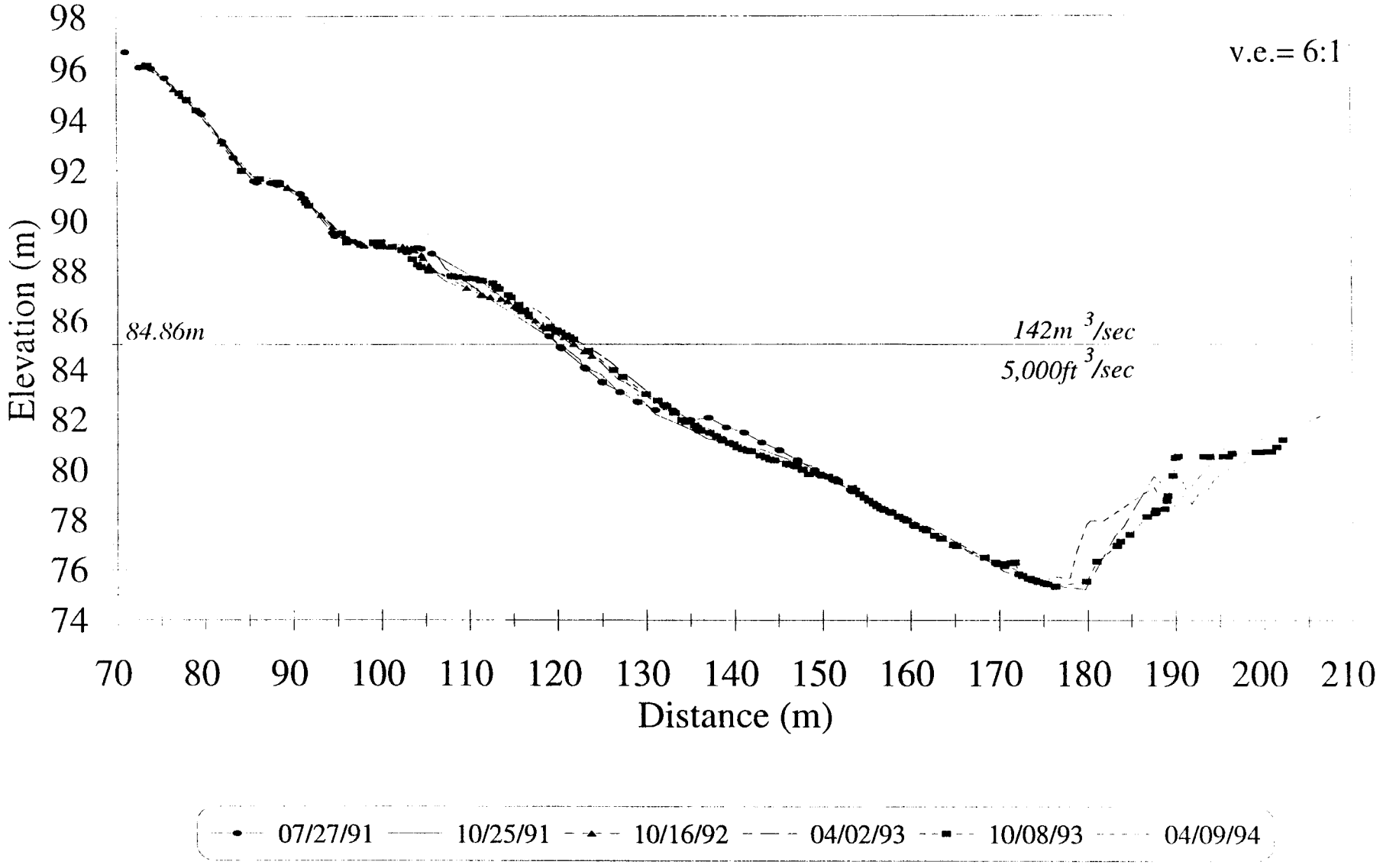


Near-shore P2

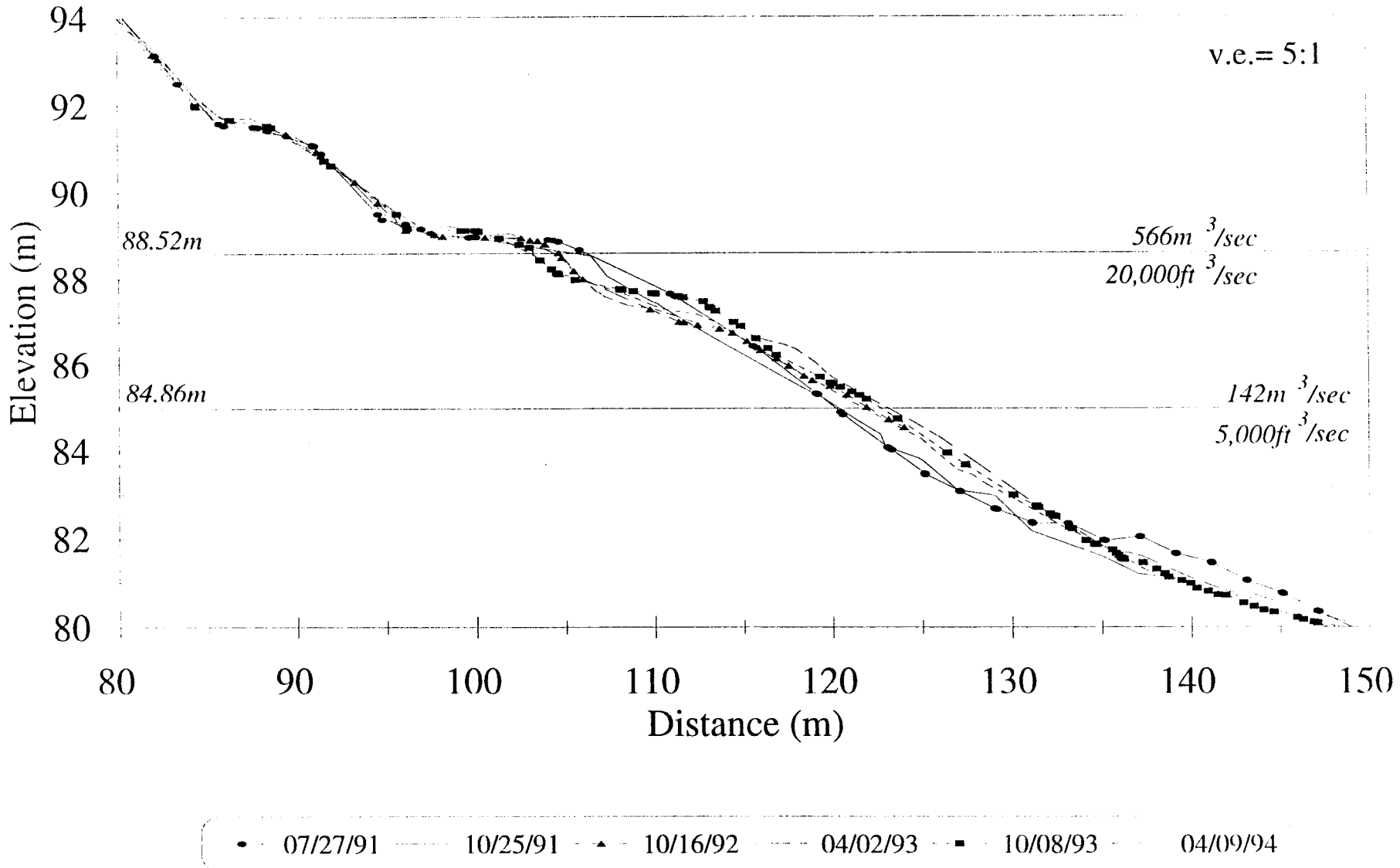


22 Mile

Cross-channel P4

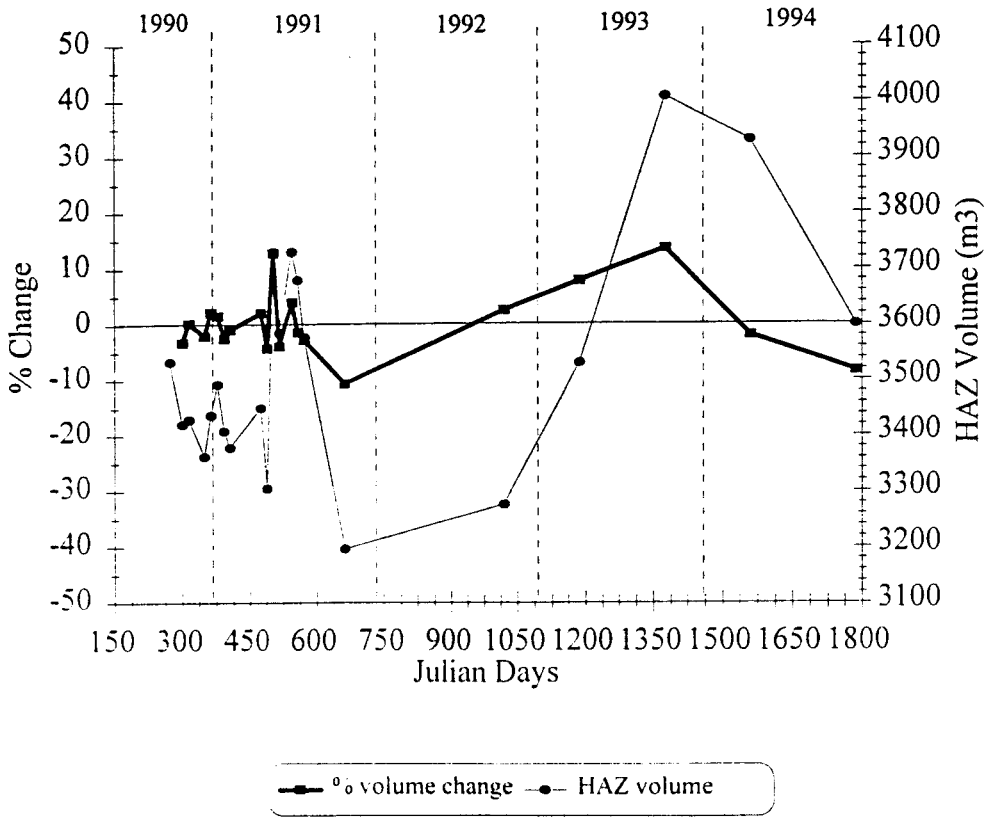


Near-shore P4



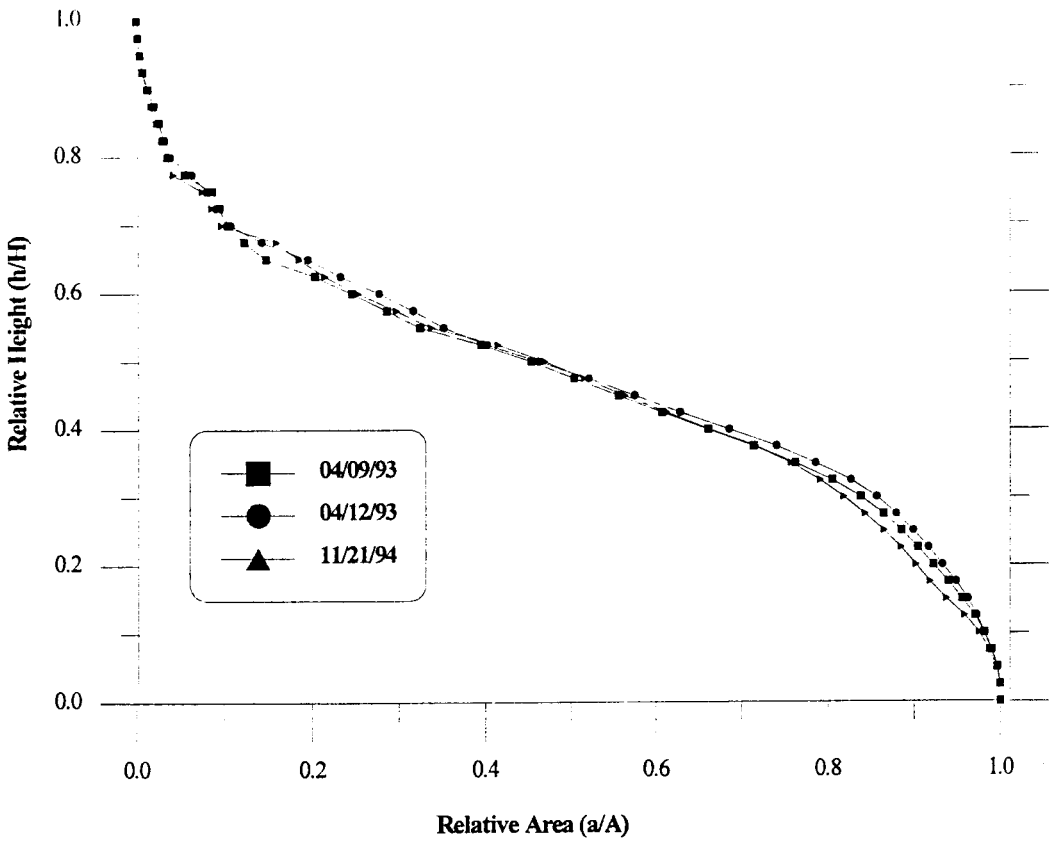
22 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F		NORM							
G	900930	E	273	1703	3534				
H		A							
I	901028	8000 CFS	301	1660	3421	-43	-113	-2.52	-3.20
J	901111	NORM	315	1694	3430	34	9	2.05	0.26
K	901216	NORM	350	1658	3363	-36	-67	-2.13	-1.95
L	901230	11000 CFS	364	1625	3438	-33	75	-1.99	2.23
M	910113	C	378	1685	3494	60	56	3.69	1.63
N	910127	NORM	392	1636	3409	-49	-85	-2.91	-2.43
O	910209	B	405	1624	3379	-12	-30	-0.73	-0.88
P	910420	NORM	475	1633	3451	9	72	0.55	2.13
Q	910504	NORM	489	1550	3306	-83	-145	-5.08	-4.20
R	910519	D	504	1908	3731	358	425	23.10	12.86
S	910601	15000 CFS	517	1787	3586	-121	-145	-6.34	-3.89
T	910629	NORM	545	1866	3731	79	145	4.42	4.04
U	910713	G	559	1777	3680	-89	-51	-4.77	-1.37
V	910727	F	573	1727	3578	-50	-102	-2.81	-2.77
X	911025	INT	663	1474	3197	-253	-381	-14.65	-10.65
Y	921016	INT	1020	1593	3276	119	79	8.07	2.47
Z	930402	INT	1188	1819	3531	226	255	14.19	7.78
B06	931008	INT	1377	2012	4008	193	477	10.61	13.51
C06	940409	INT	1560	1994	3930	-18	-78	-0.89	-1.95
D06	941121	INT	1786	1843	3600	-151	-330	-7.57	-8.40

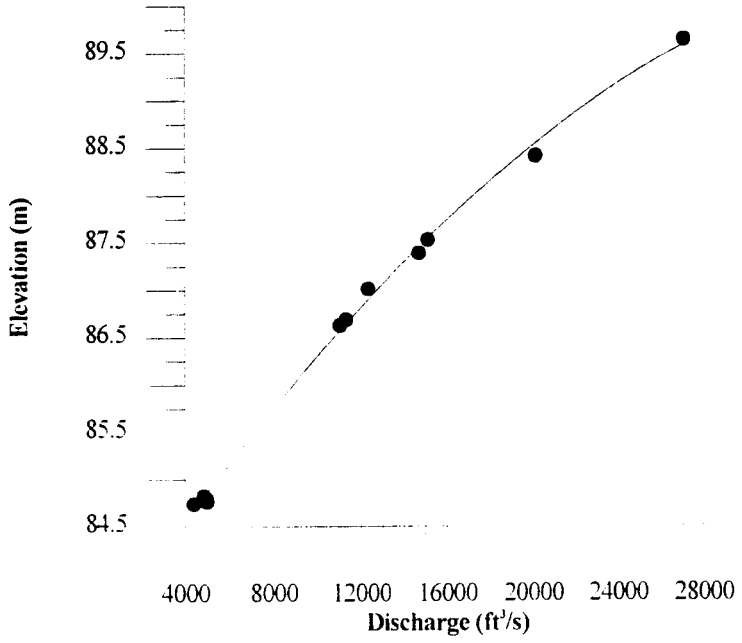


22 Mile

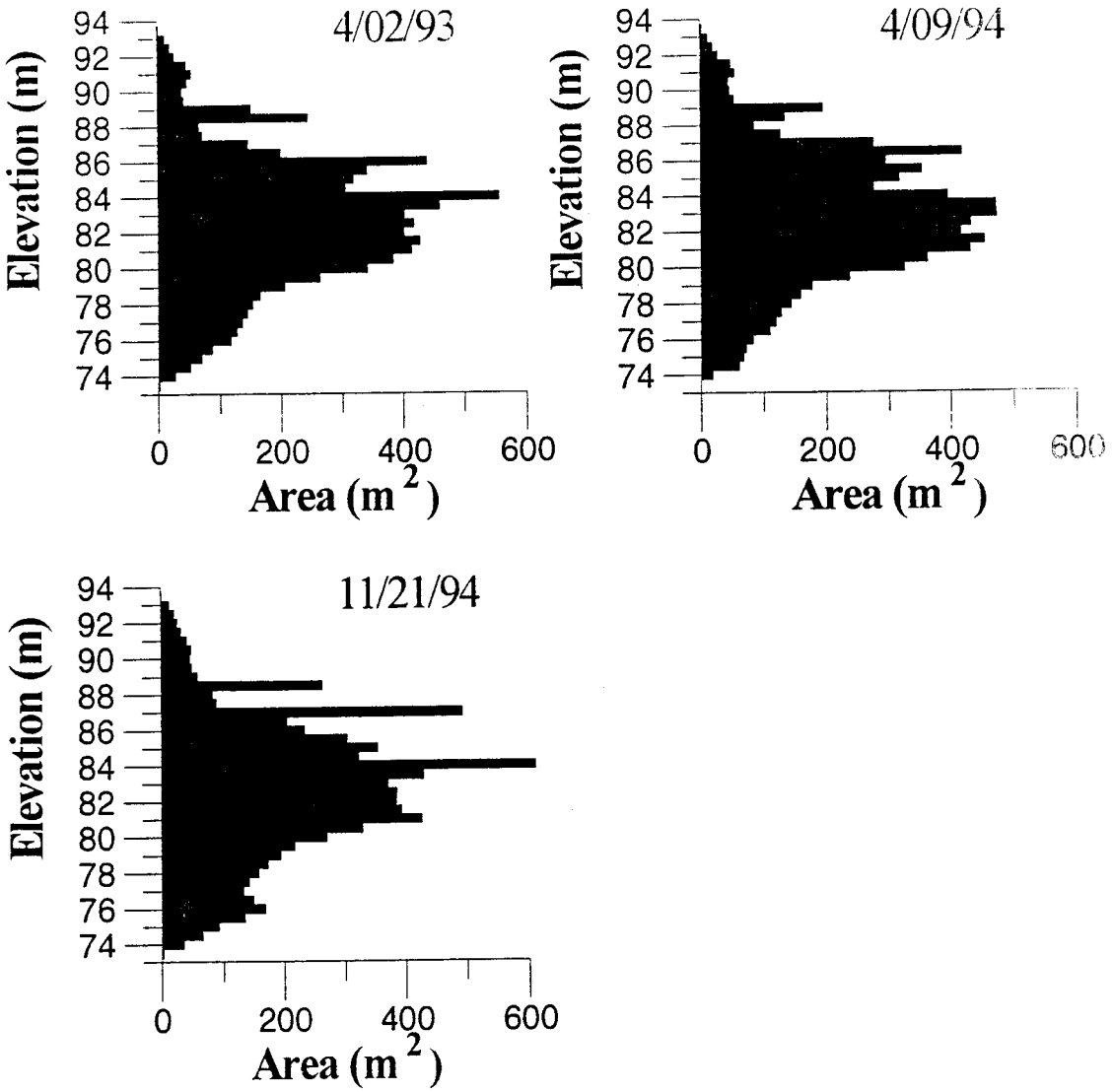
Hypsometric Curves

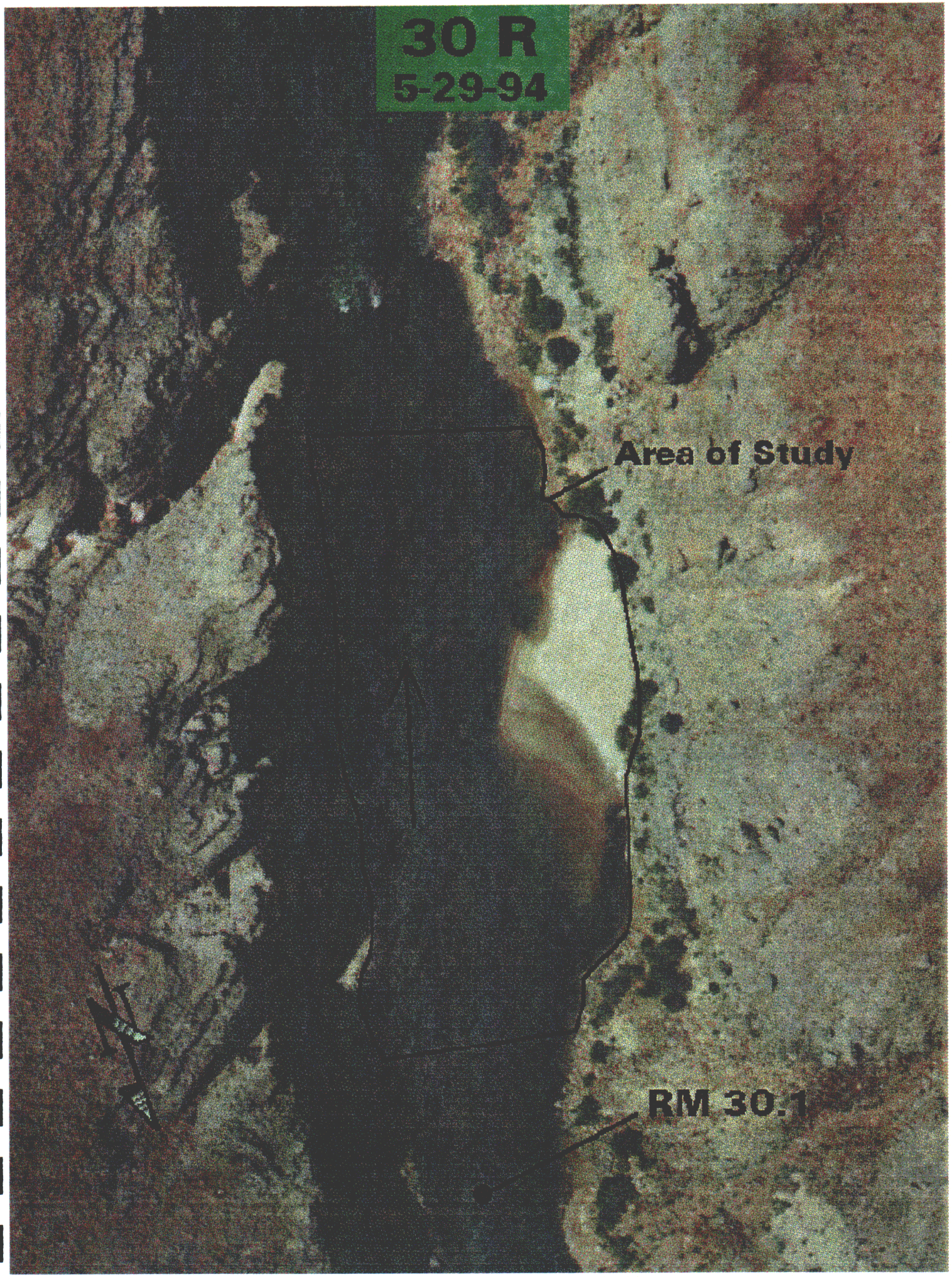


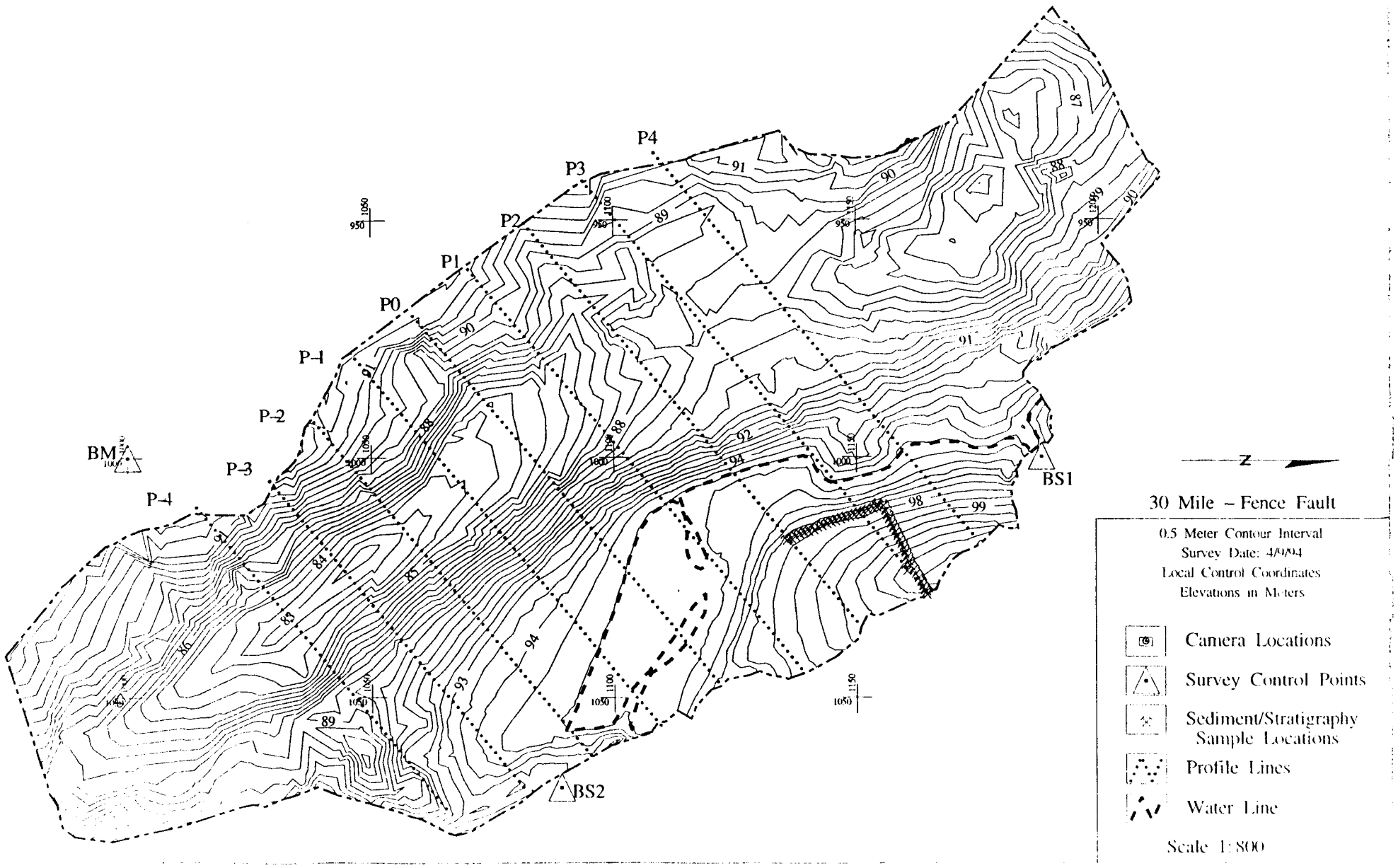
Stage Discharge



22 MILE
Area Distribution Histogams

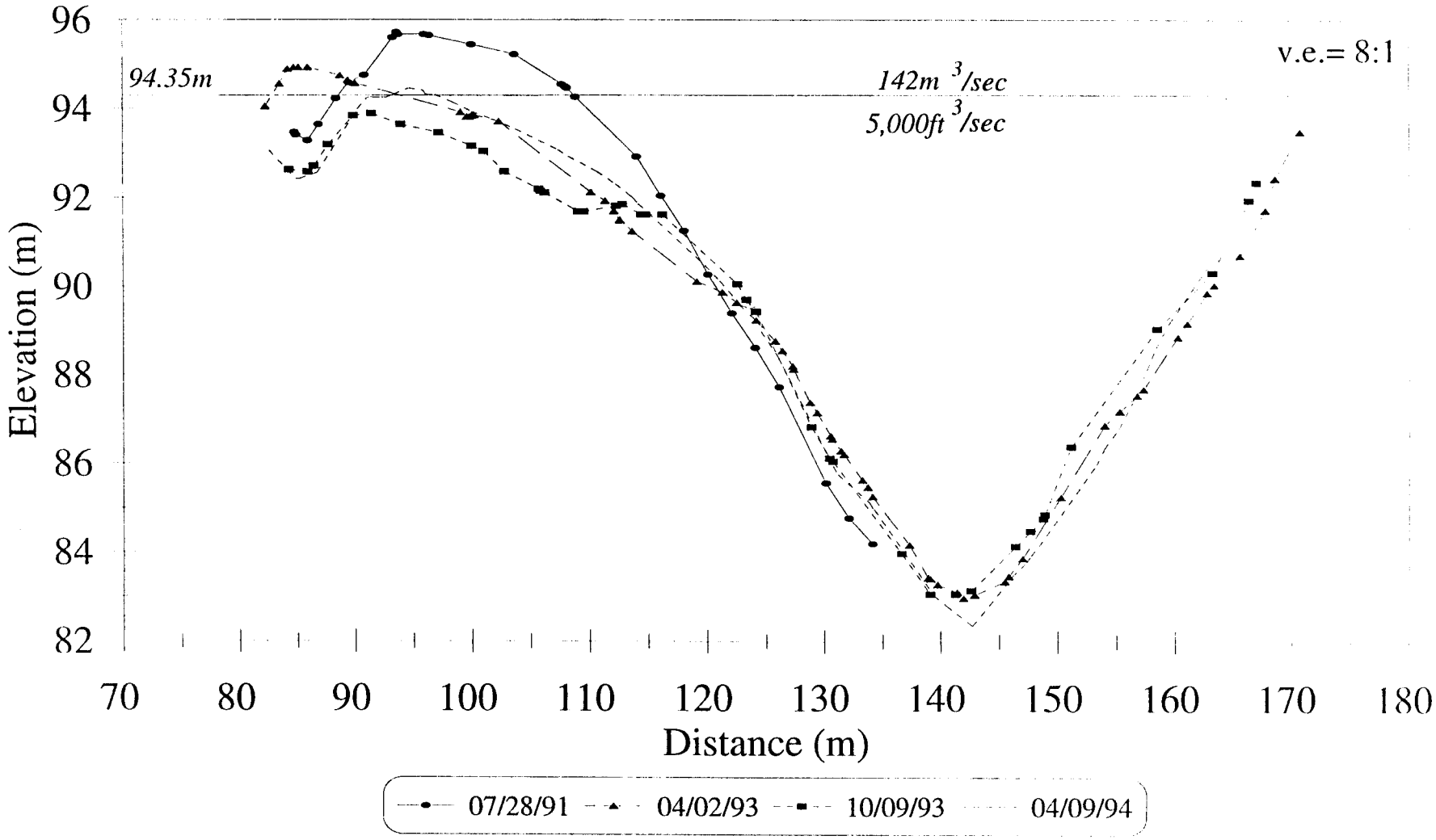



30 R
5-29-94
Area of Study
RM 30.1

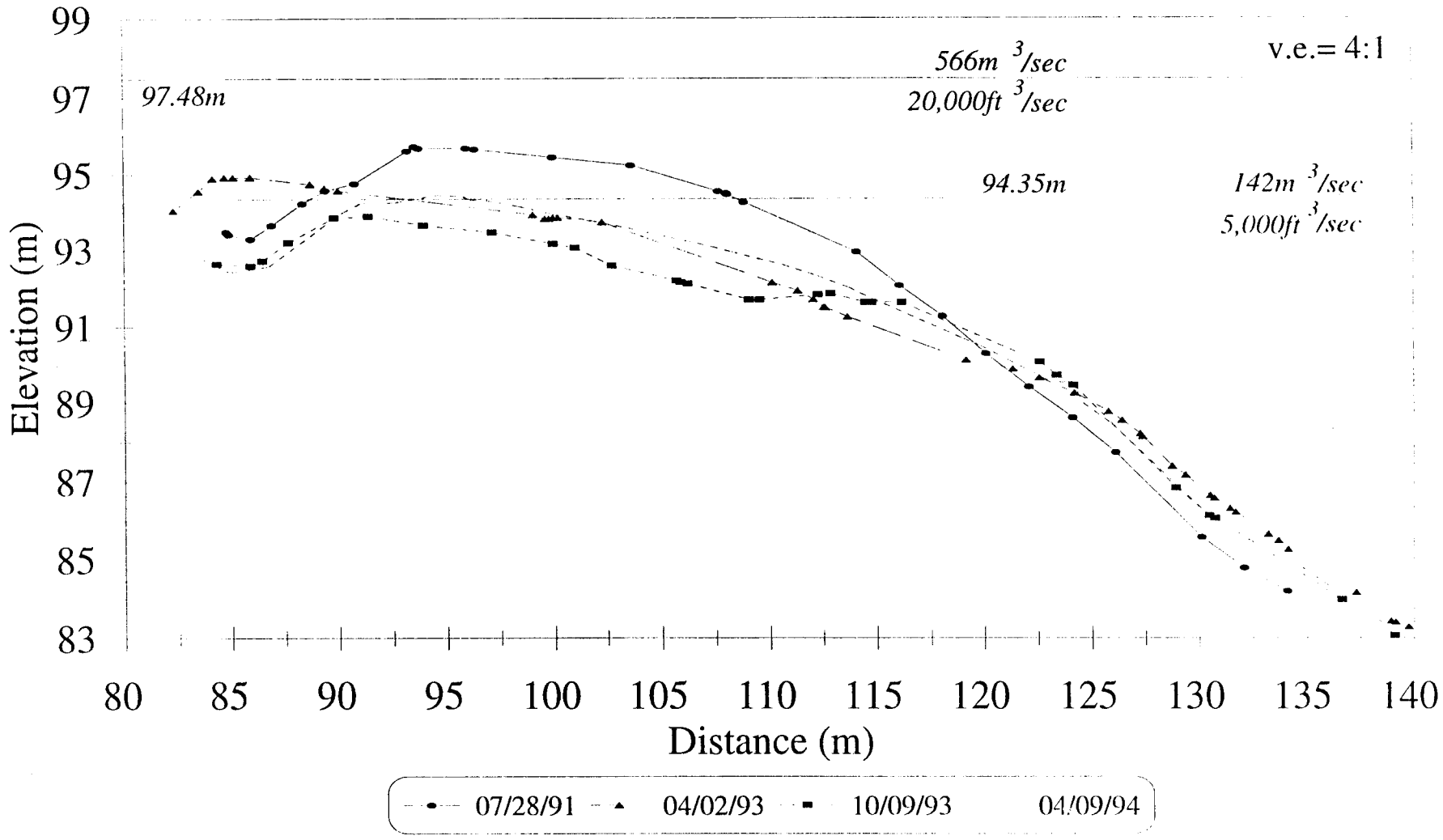

P4
P3
P2
P1
P0
P-1
P-2
P-3
P-4
BM
BS1
BS2
N
30 Mile – Fence Fault
0.5 Meter Contour Interval
Survey Date: 4/0/04
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:800

30 Mile

Cross-channel P-3

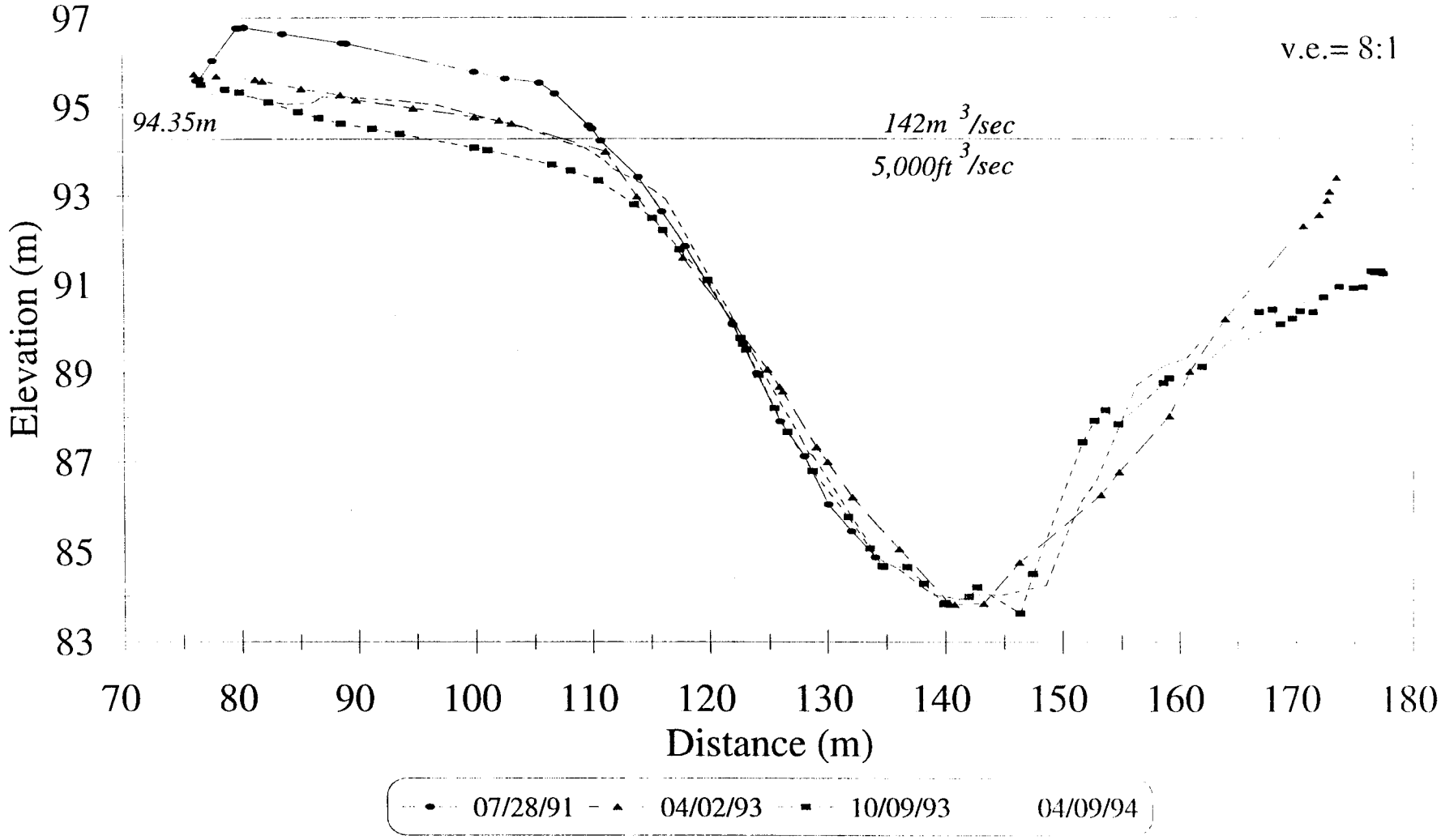


Near-shore P-3

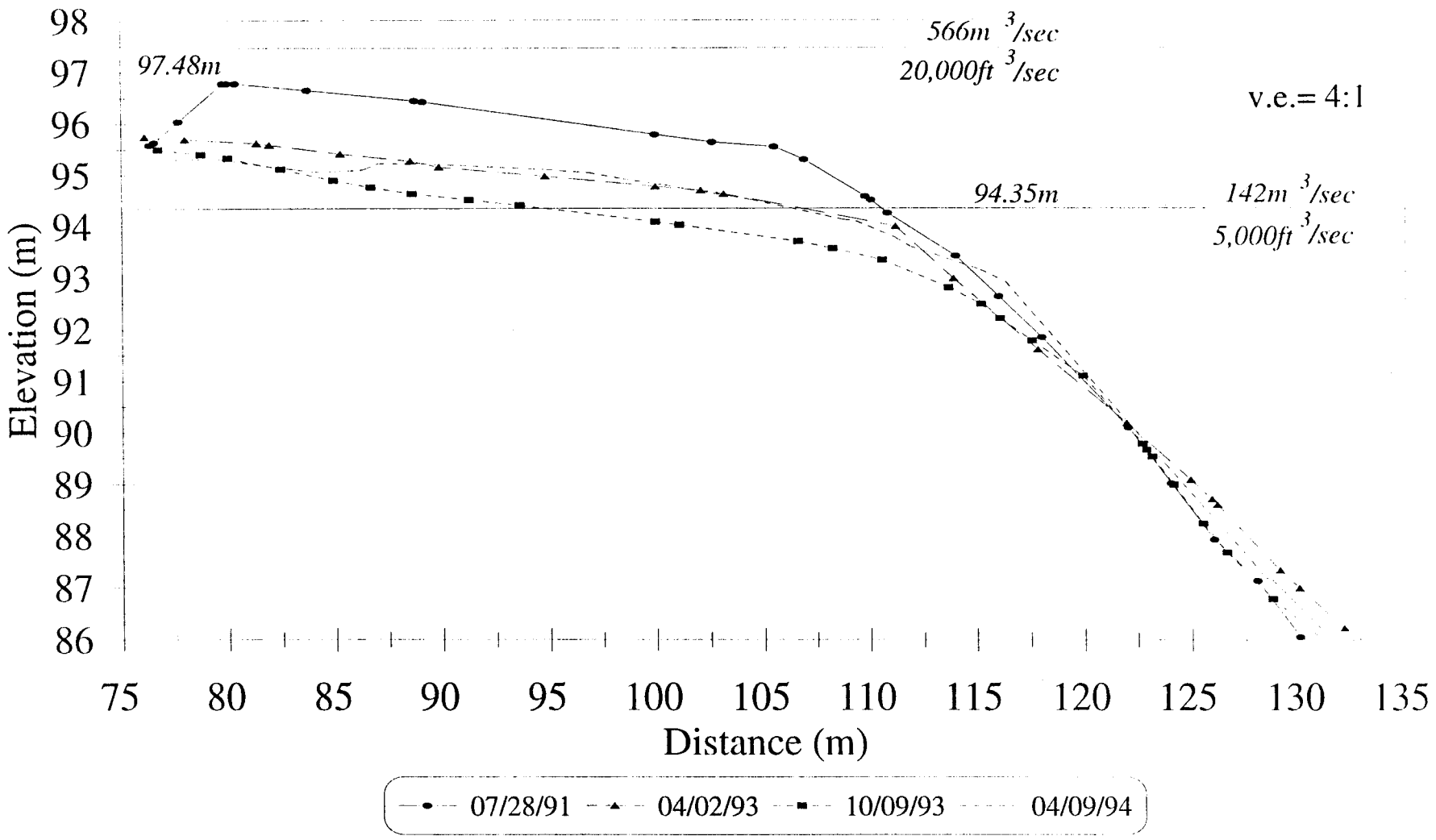


30 Mile

Cross-channel P-1

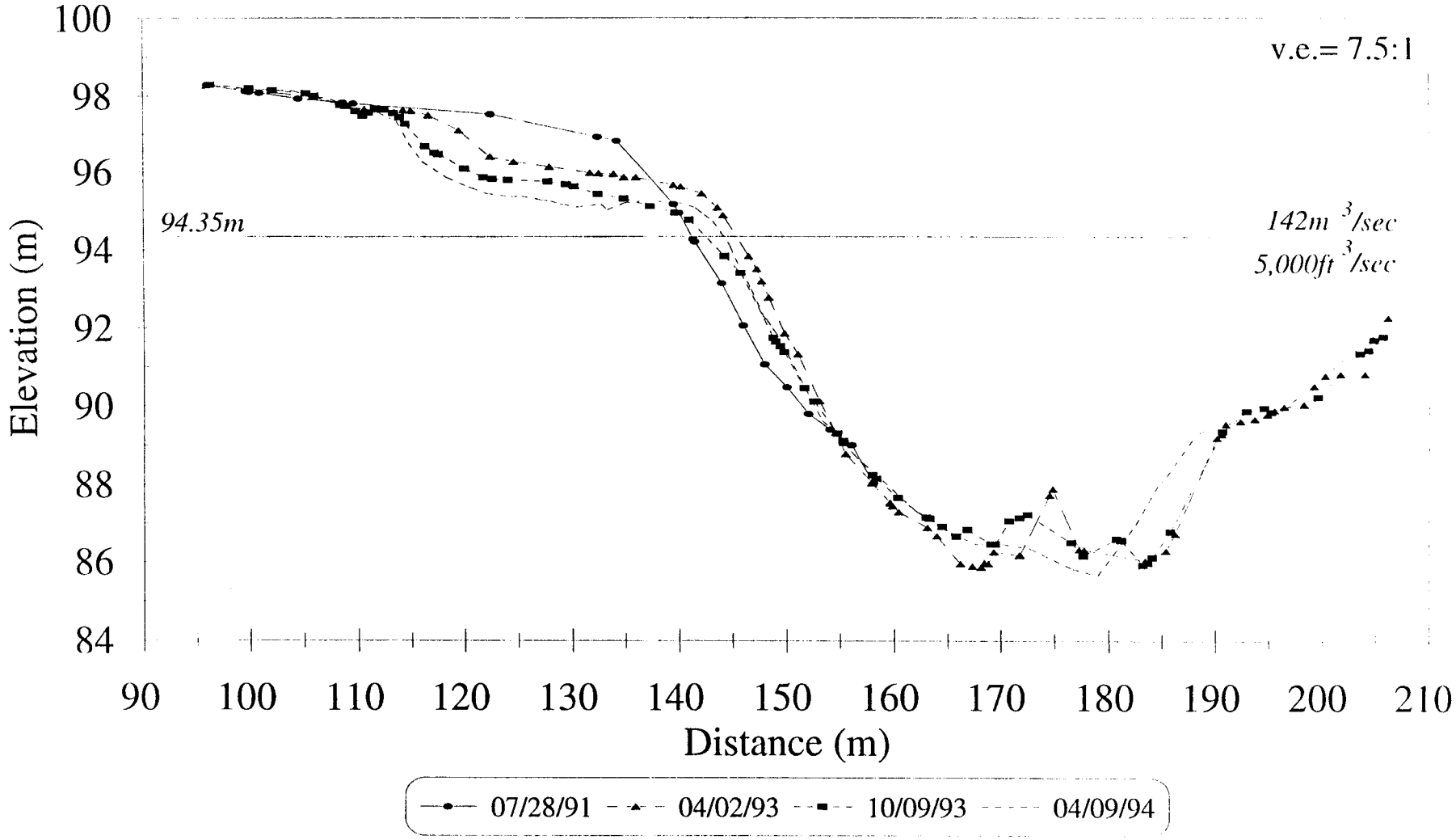


Near-shore P-1

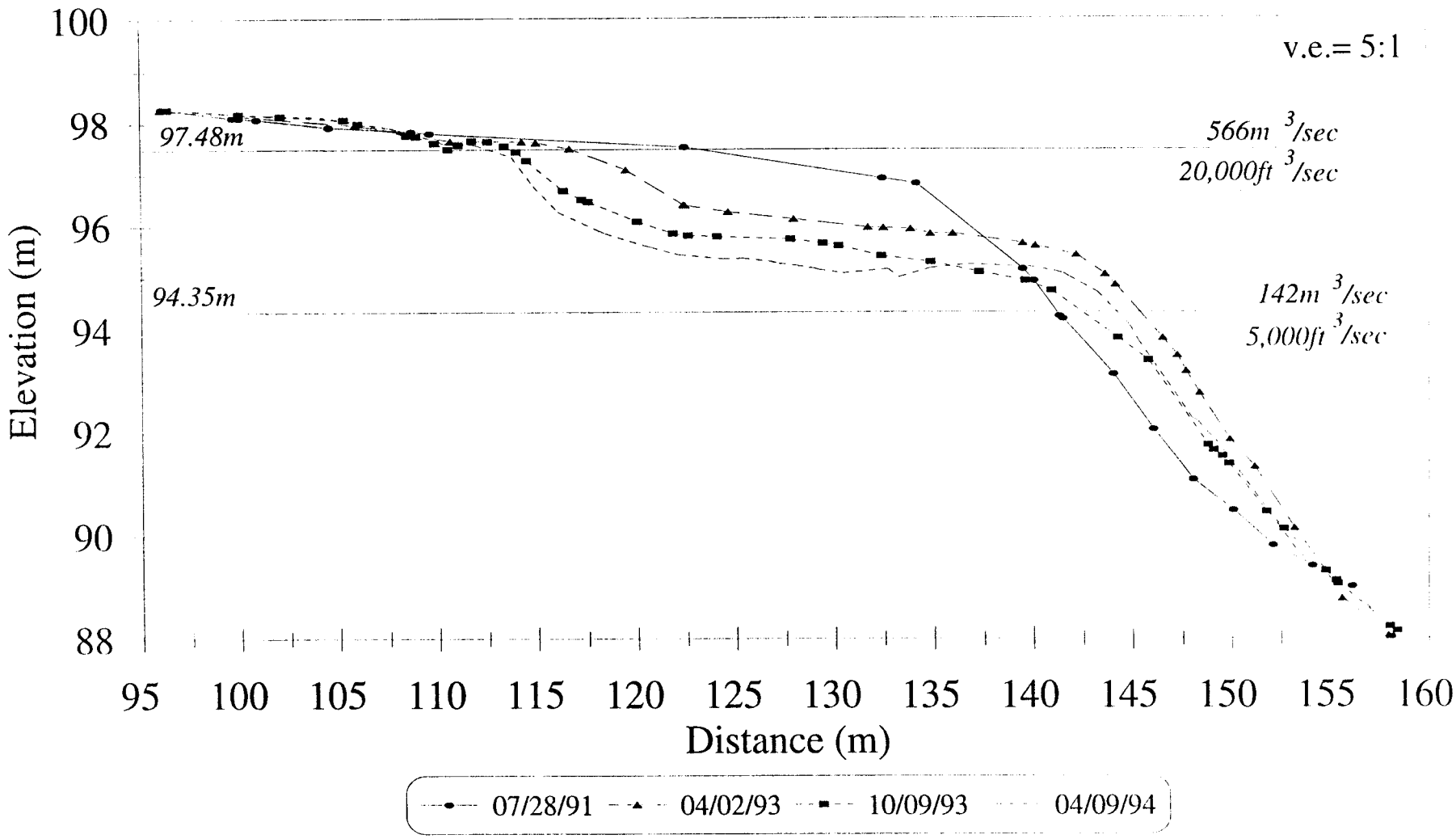


30 Mile

Cross-channel P1

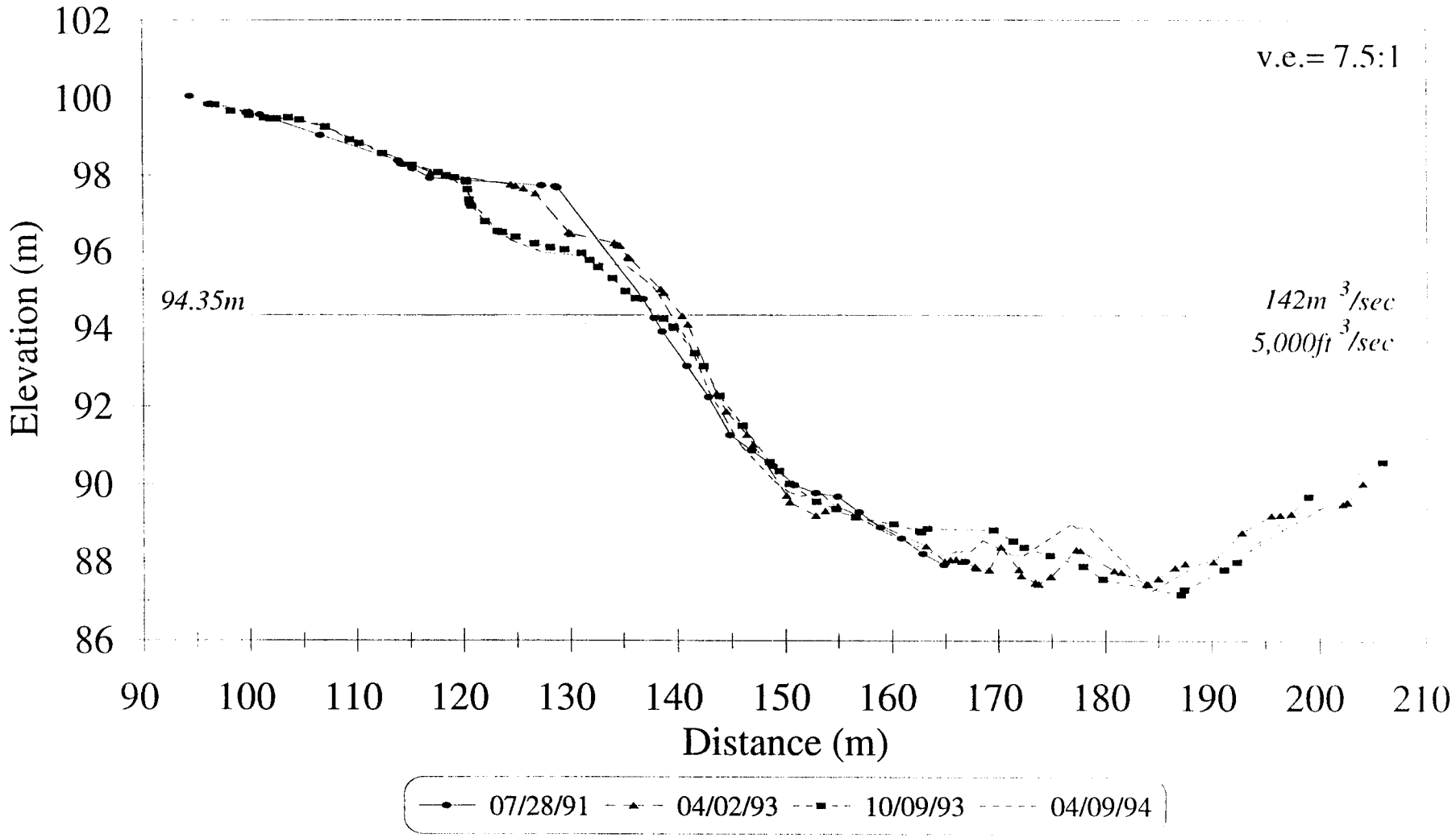


Near-shore P1

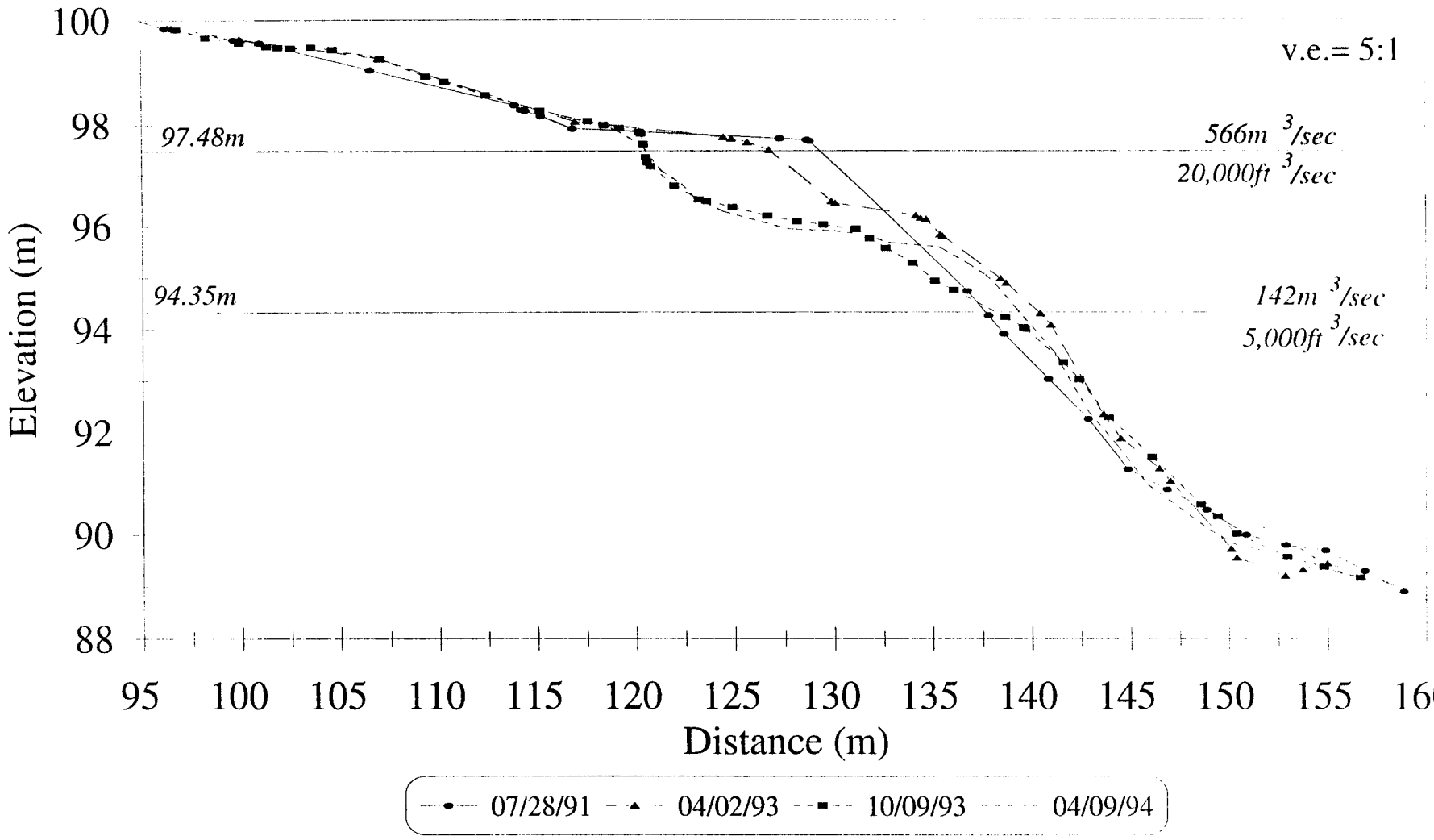


30 Mile

Cross-channel P2

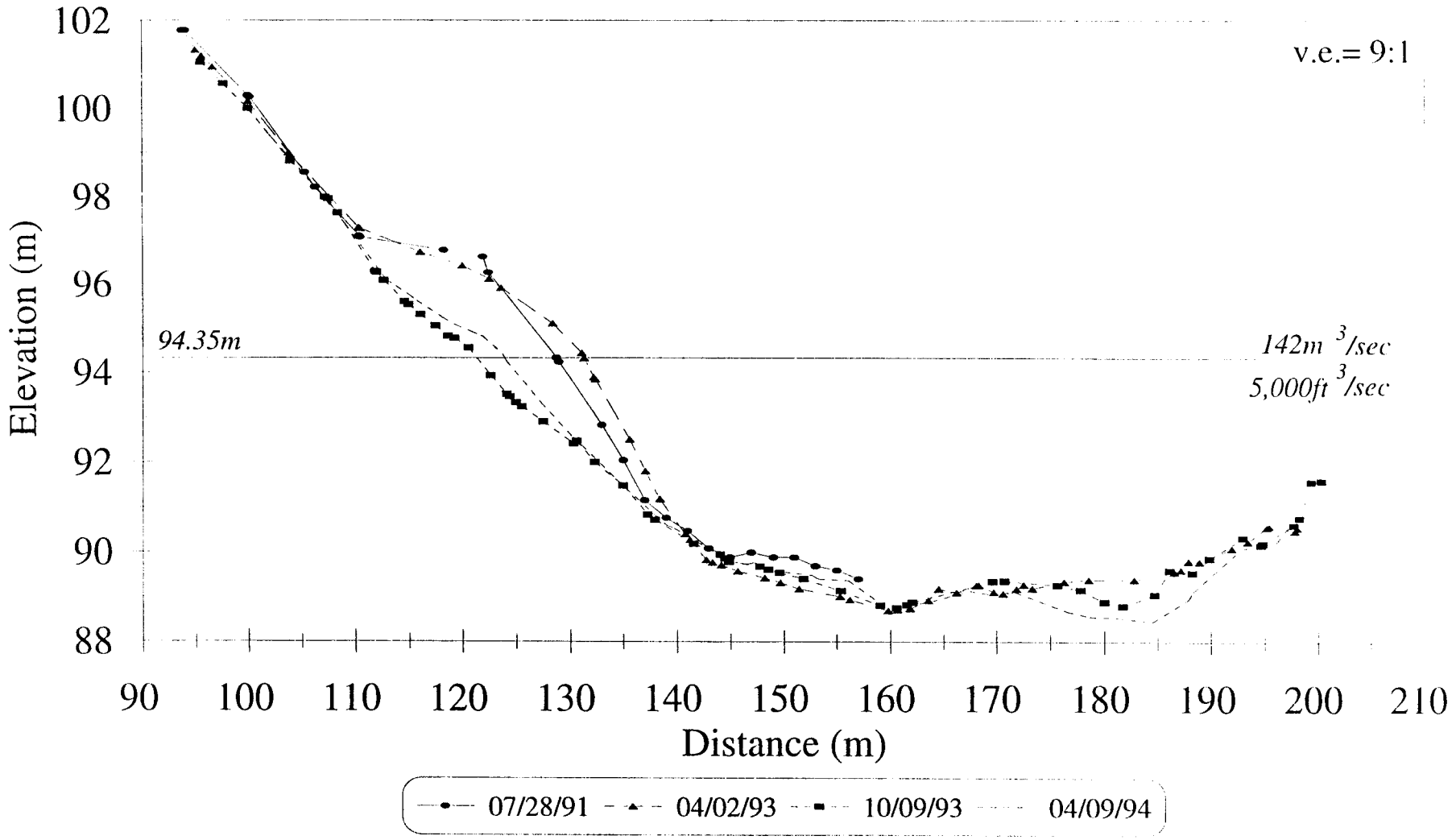


Near-shore P2

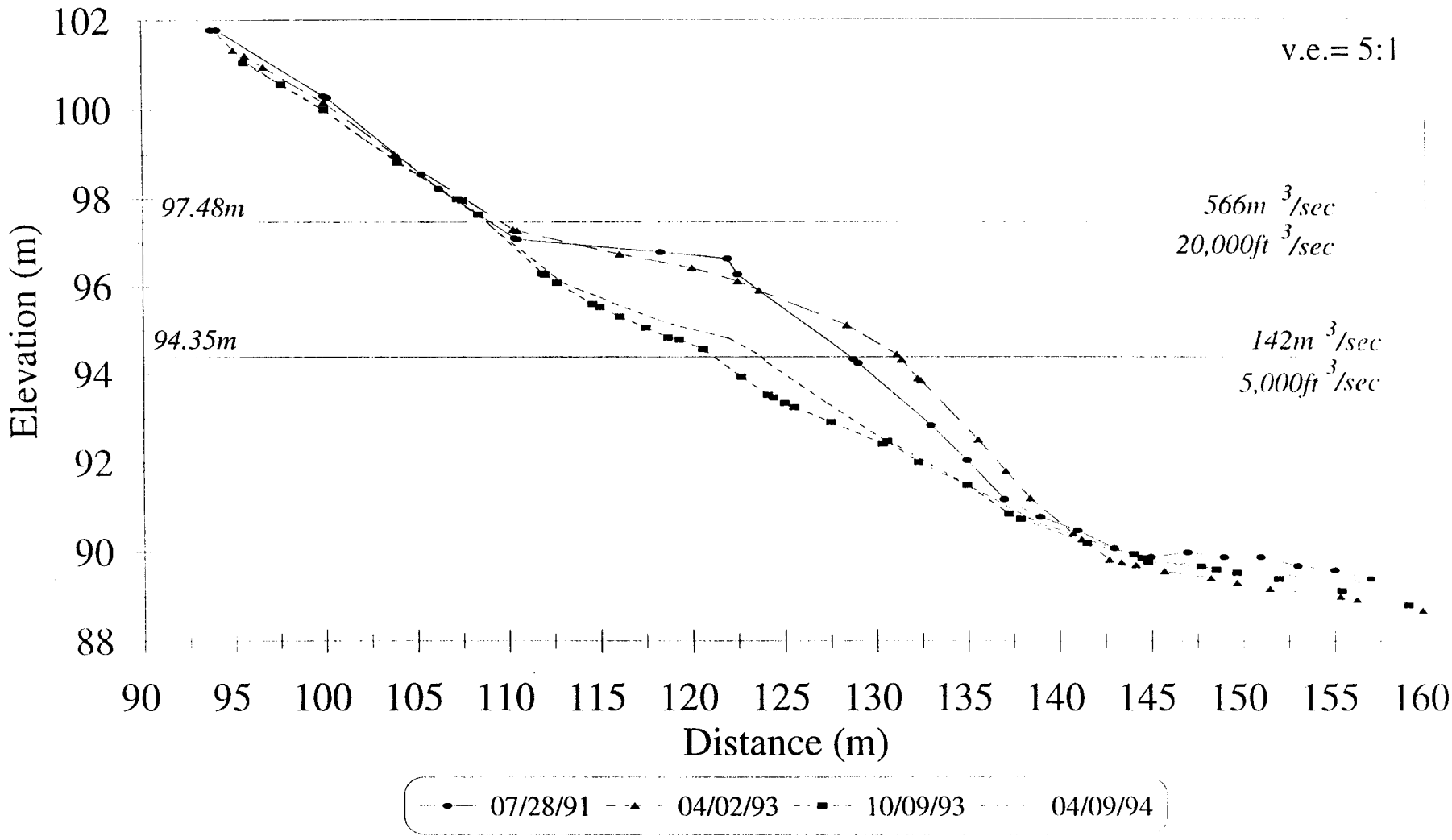


30 Mile

Cross-channel P4

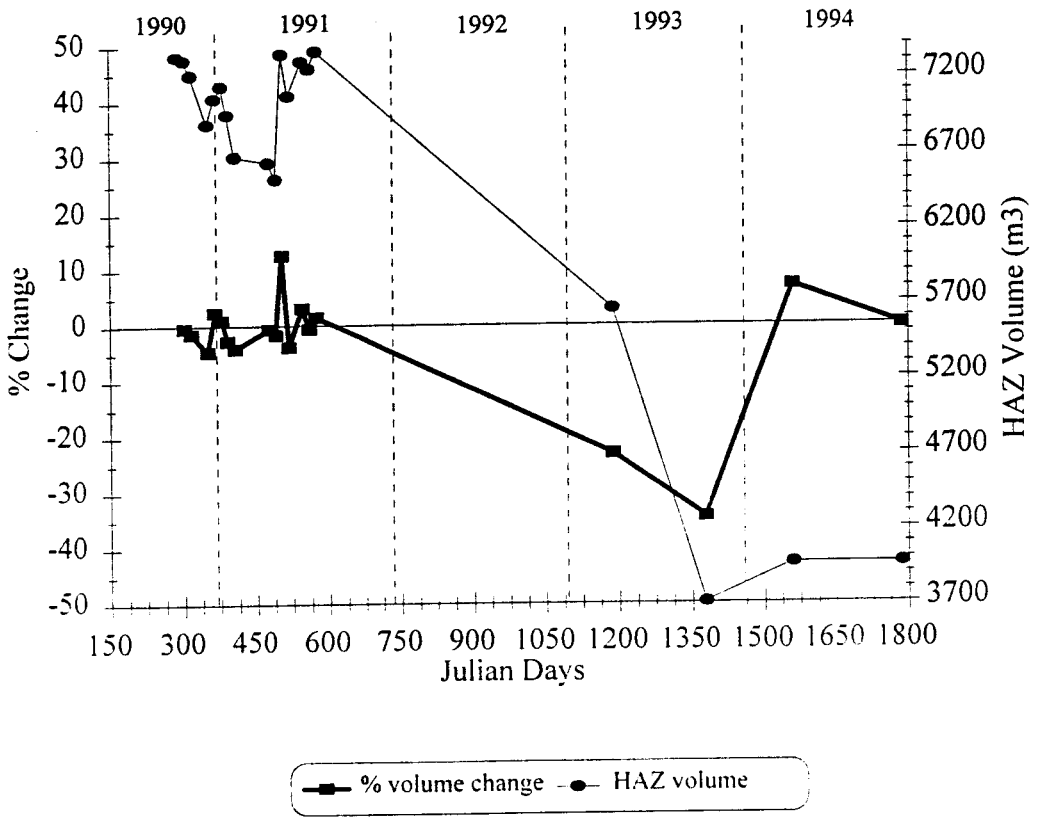


Near-shore P4



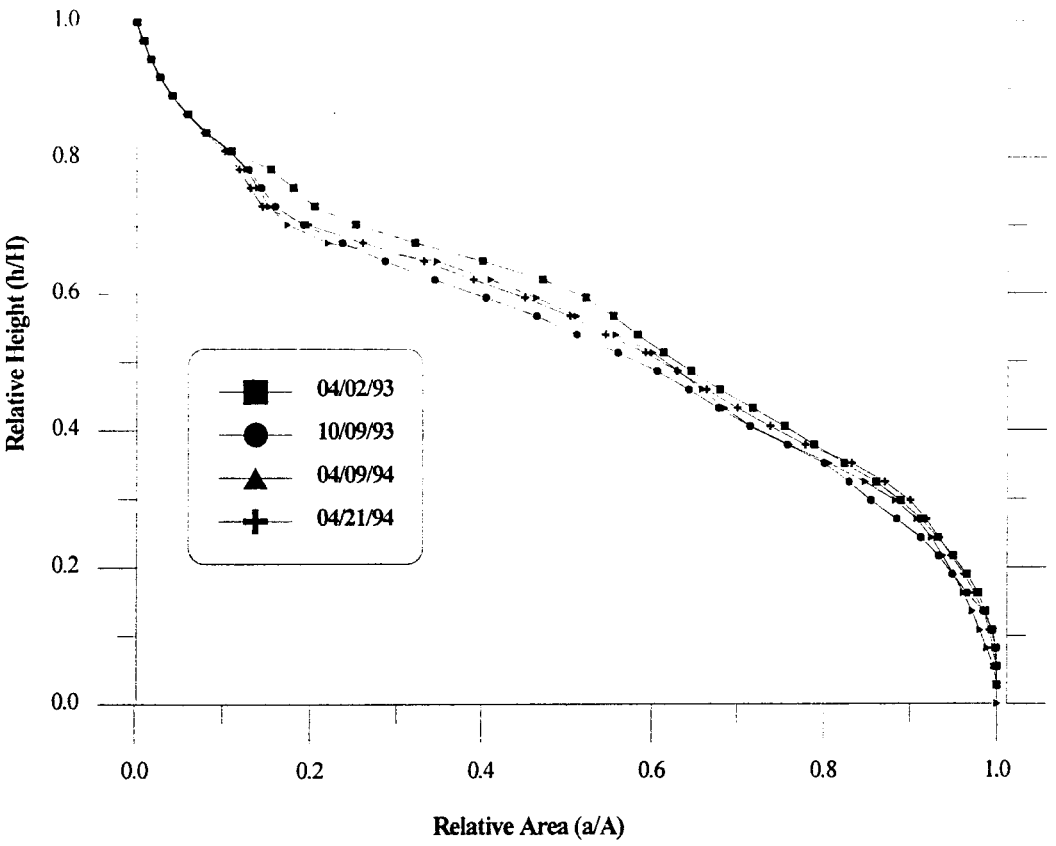
30 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS VOL CH	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F		NORM							
G		E							
H	901014	A	287	3732	7336				
I	901028	8000 CFS	301	3672	7314	-60	-22	-1.61	-0.30
J	901111	NORM	315	3655	7216	-17	-98	-0.46	-1.34
K	901216	NORM	350	3705	6889	50	-327	1.37	-4.53
L	901230	11000 CFS	364	3686	7061	-19	172	-0.51	2.50
M	910113	C	378	3813	7140	127	79	3.45	1.12
N	910125	NORM	390	3812	6953	-1	-187	-0.03	-2.62
O	910210	B	406	3762	6673	-50	-280	-1.31	-4.03
P	910420	NORM	475	3741	6631	-21	-42	-0.56	-0.63
Q	910506	NORM	491	3752	6525	11	-106	0.29	-1.60
R	910519	D	504	3794	7352	42	827	1.12	12.67
S	910602	15000 CFS	518	3765	7076	-29	-276	-0.76	-3.75
T	910630	NORM	546	3444	7299	-321	223	-8.53	3.15
U	910714	G	560	3569	7254	125	-45	3.63	-0.62
V	910728	F	574	3656	7366	87	112	2.44	1.54
Z	930402	INT	1188	3377	5662	-279	-1704	-7.63	-23.13
B07	931009	INT	1378	2379	3708	-998	-1954	-29.55	-34.51
C07	940409	INT	1560	2922	3969	543	261	22.82	7.04
D07	941121	INT	1786	2747	3967	-175	-2	-5.99	-0.05

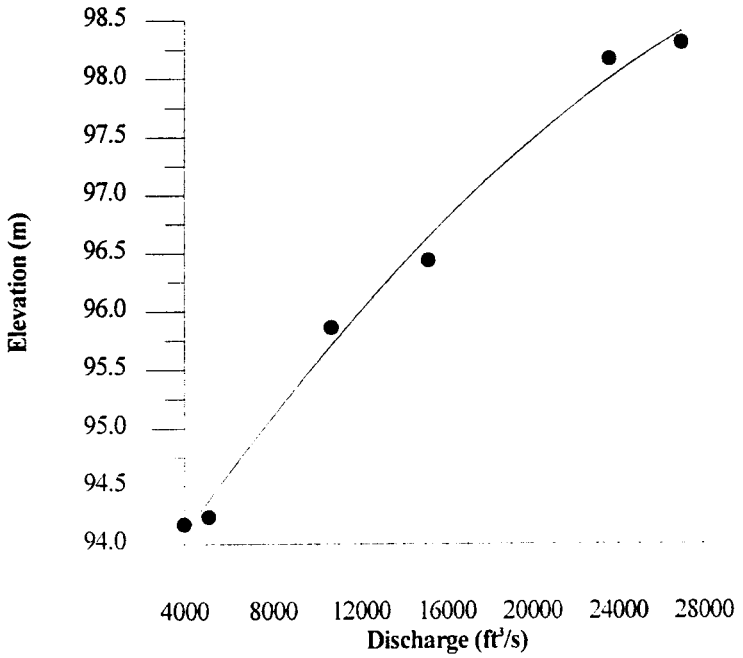


30 Mile

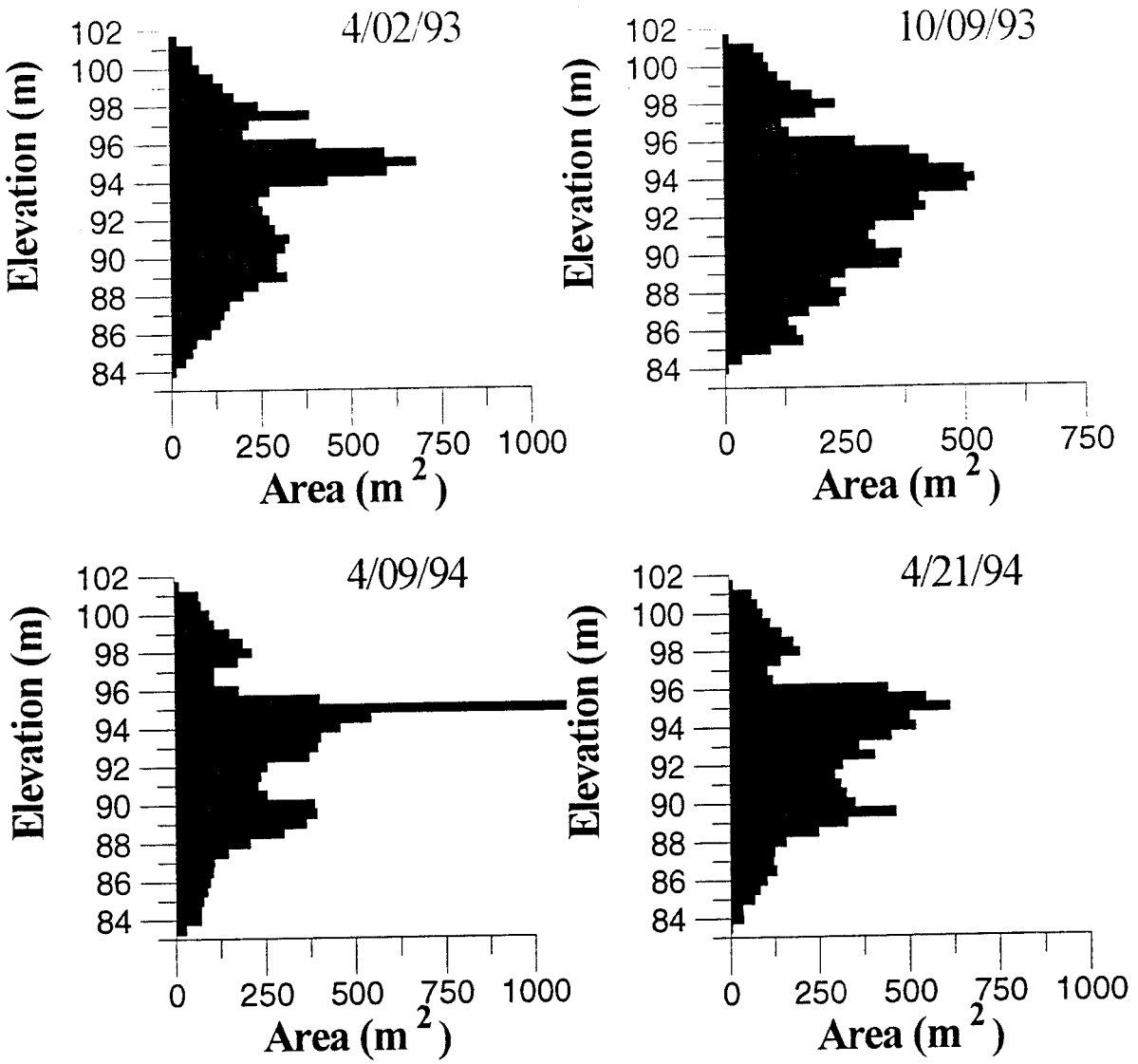
Hypsometric Curves



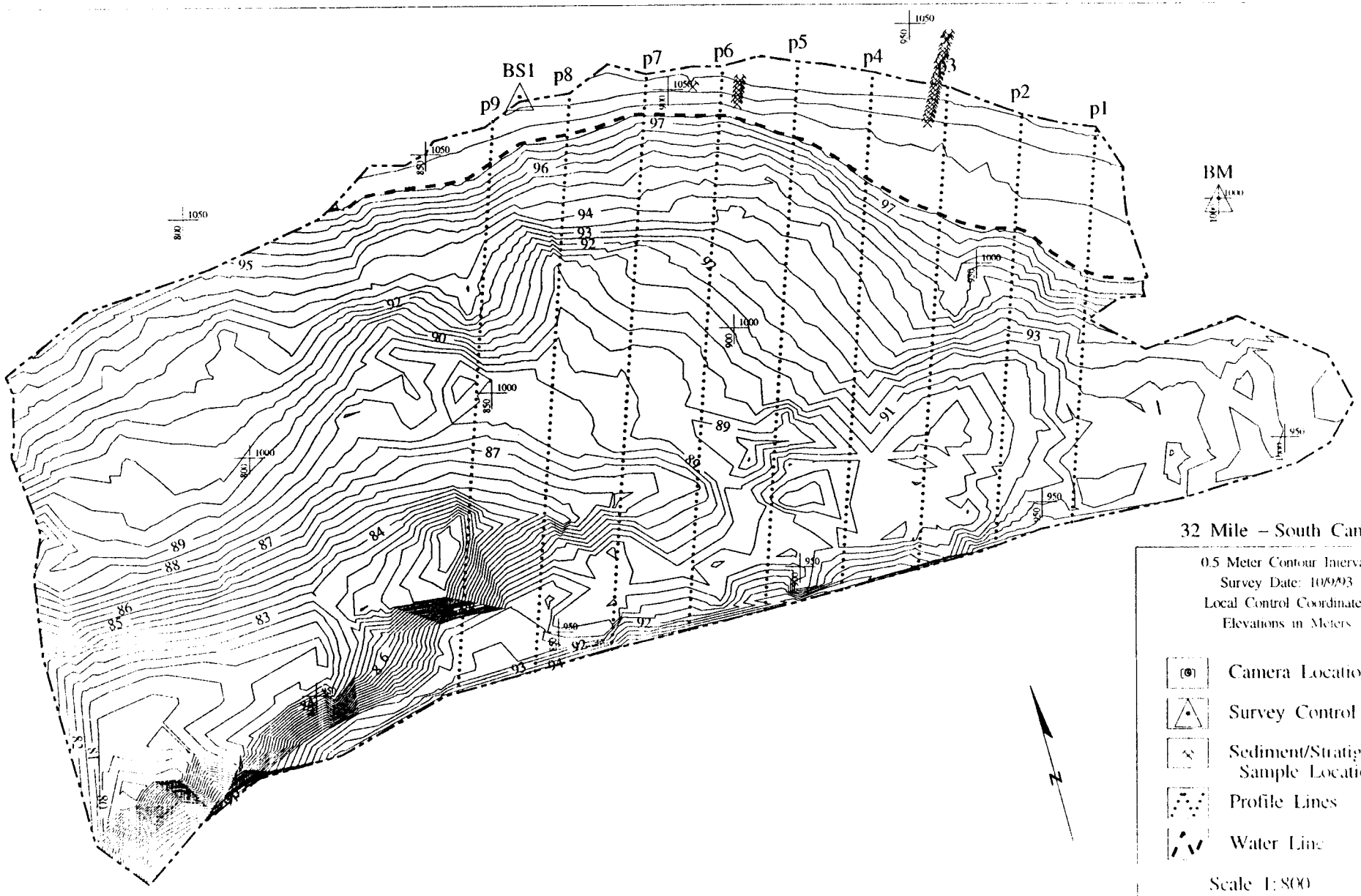
Stage Discharge



30 MILE
Area Distribution Diagrams

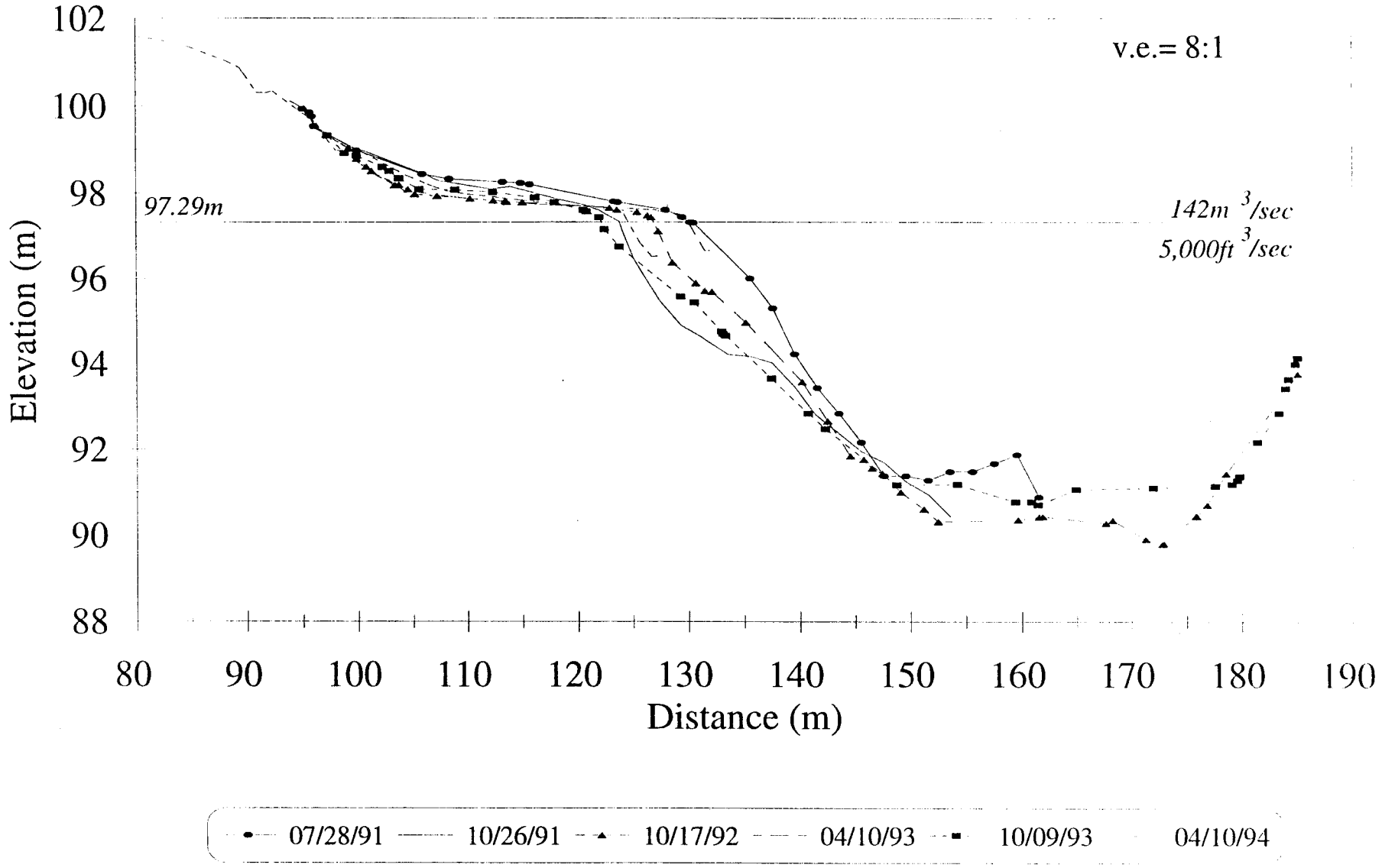


31 R
5-29-94
Area of Study
RM 31.5

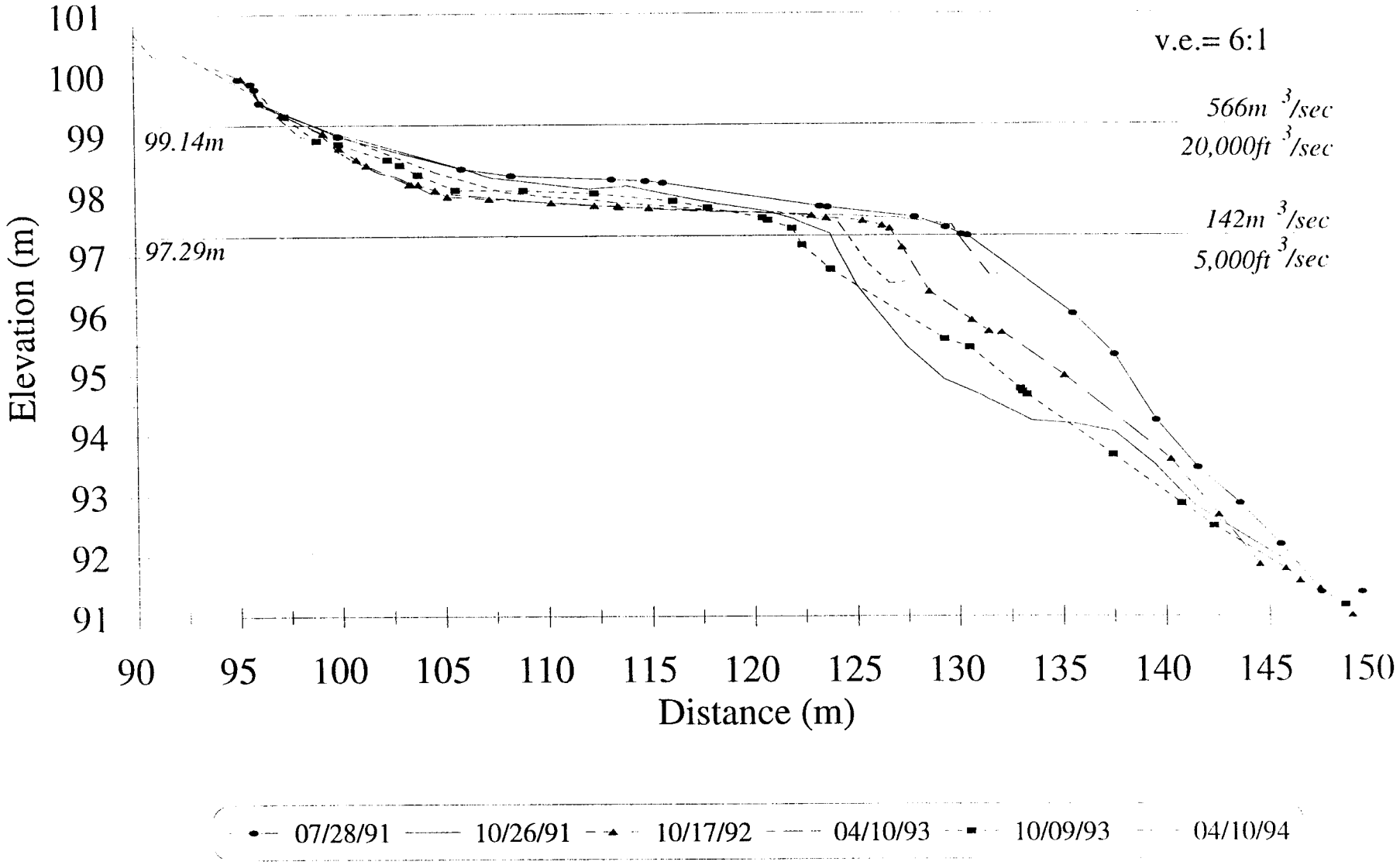

BS1
p9
p8
p7
p6
p5
p4
p3
p2
p1
BM
32 Mile – South Canyon
0.5 Meter Contour Interval
Survey Date: 10/9/03
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:800
N

31 Mile

Cross-channel P2

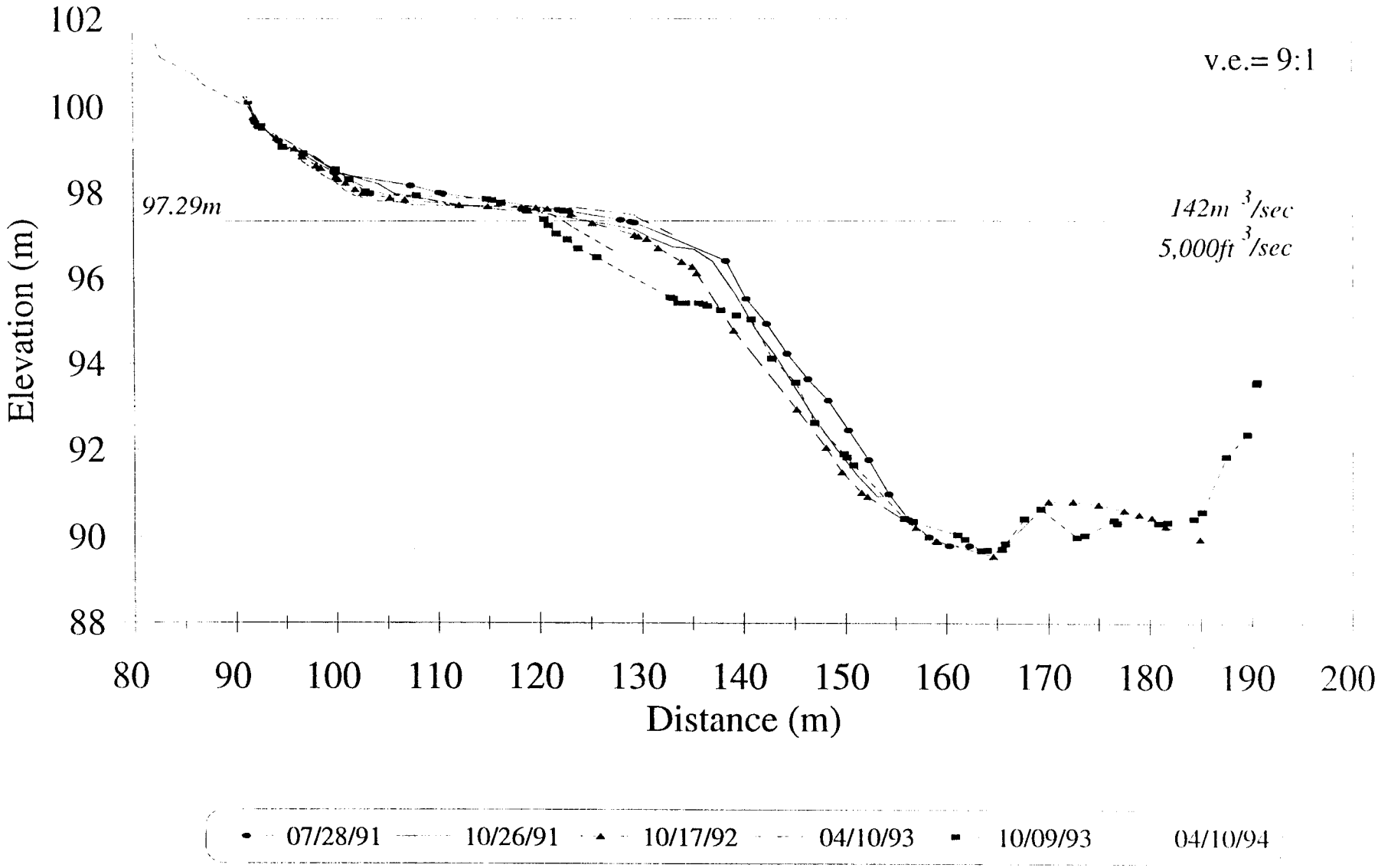


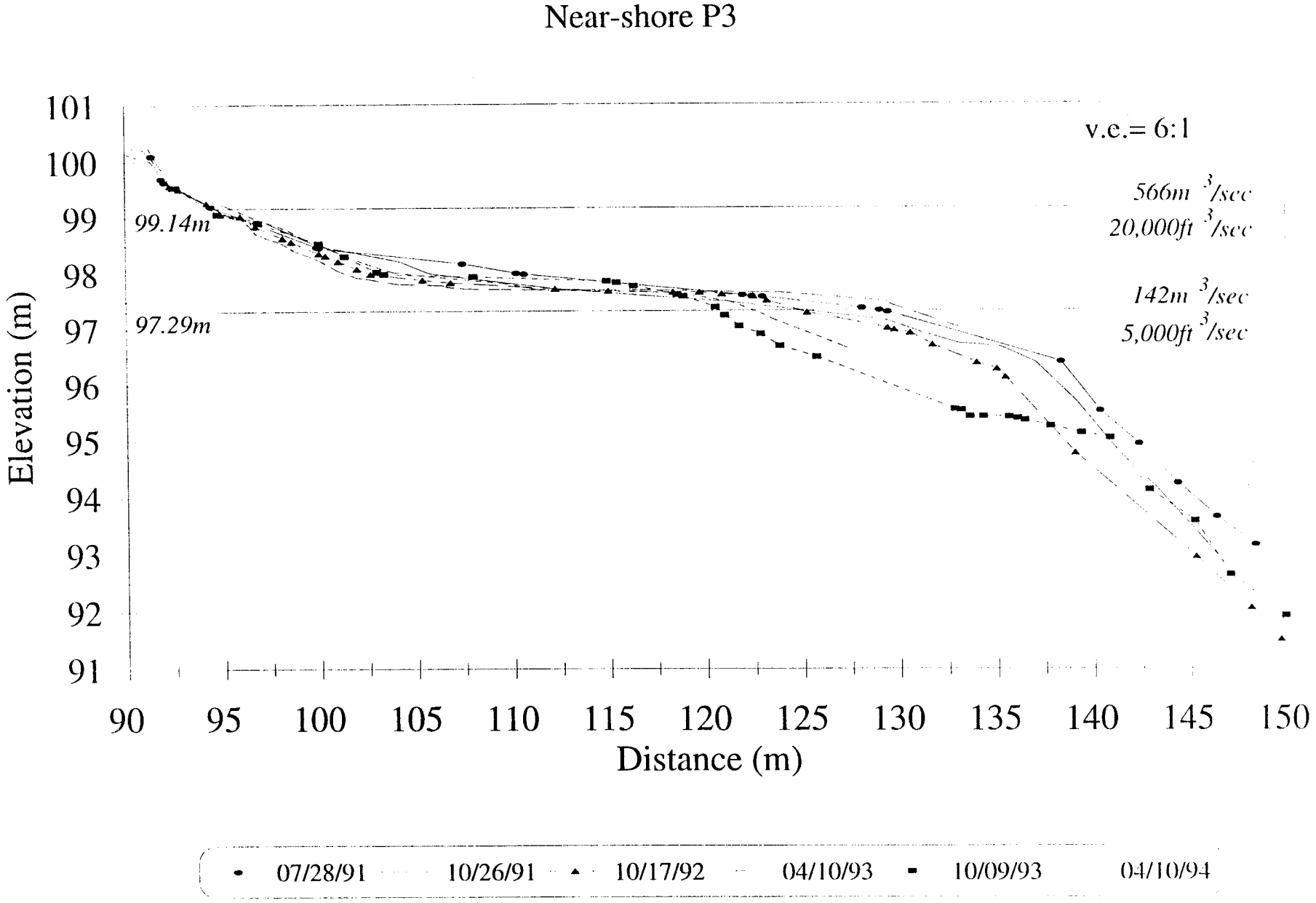
Near-shore P2



31 Mile

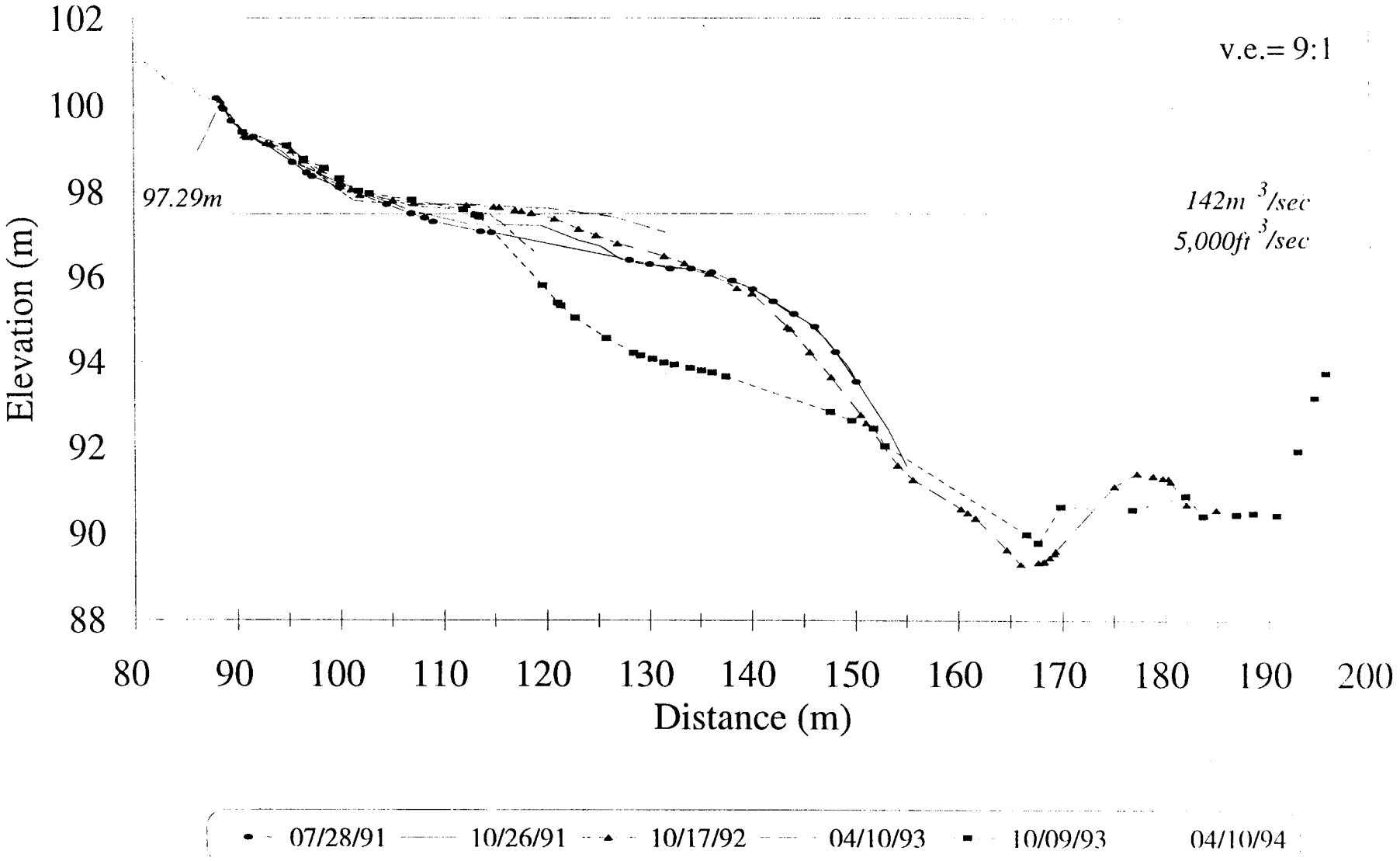
Cross-channel P3



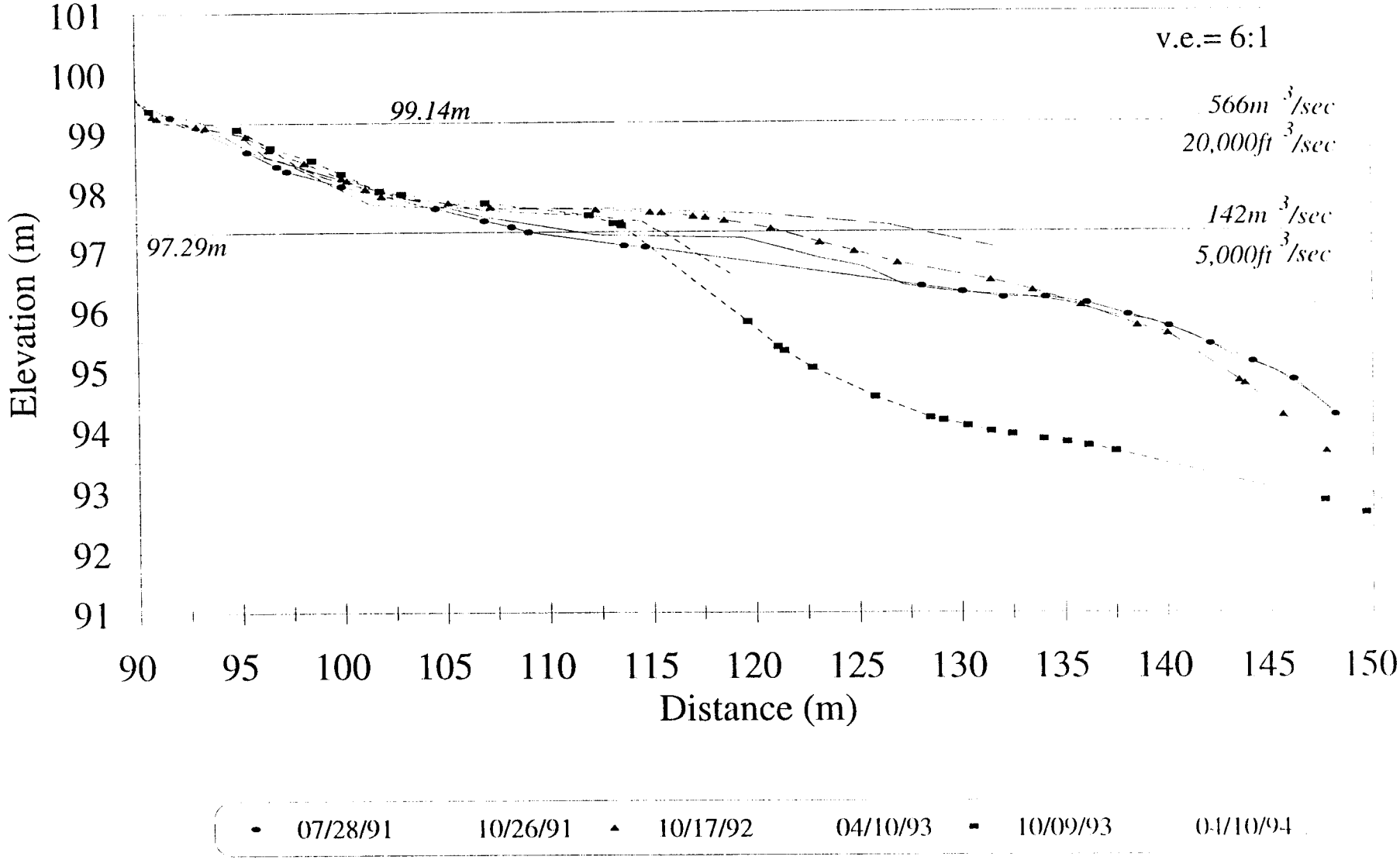

Near-shore P3
v.e.= 6:1
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
99.14m
97.29m
Elevation (m)
101
100
99
98
97
96
95
94
93
92
91
90
95
100
105
110
115
120
125
130
135
140
145
150
Distance (m)
07/28/91
10/26/91
10/17/92
04/10/93
10/09/93
04/10/94

31 Mile

Cross-channel P4

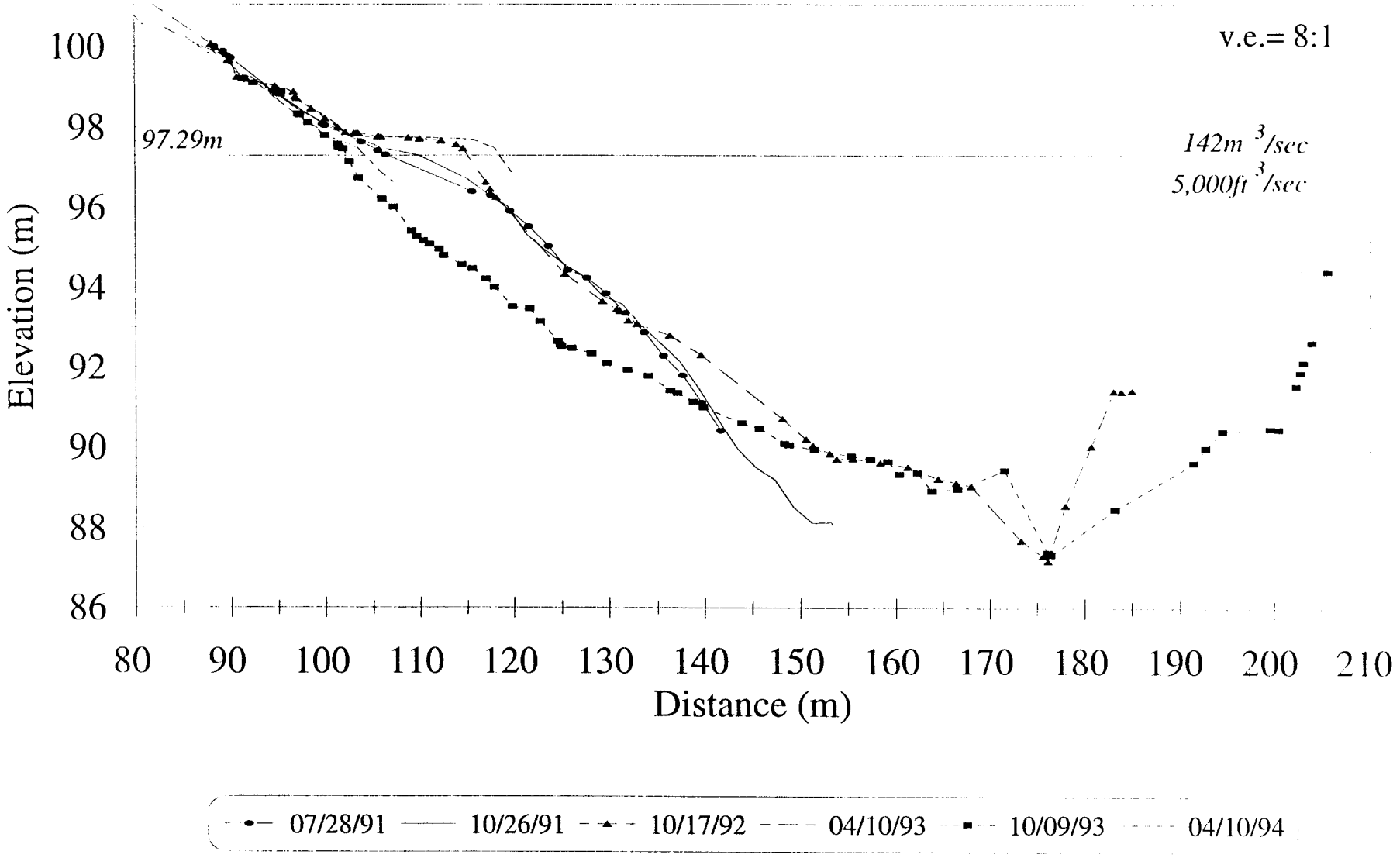


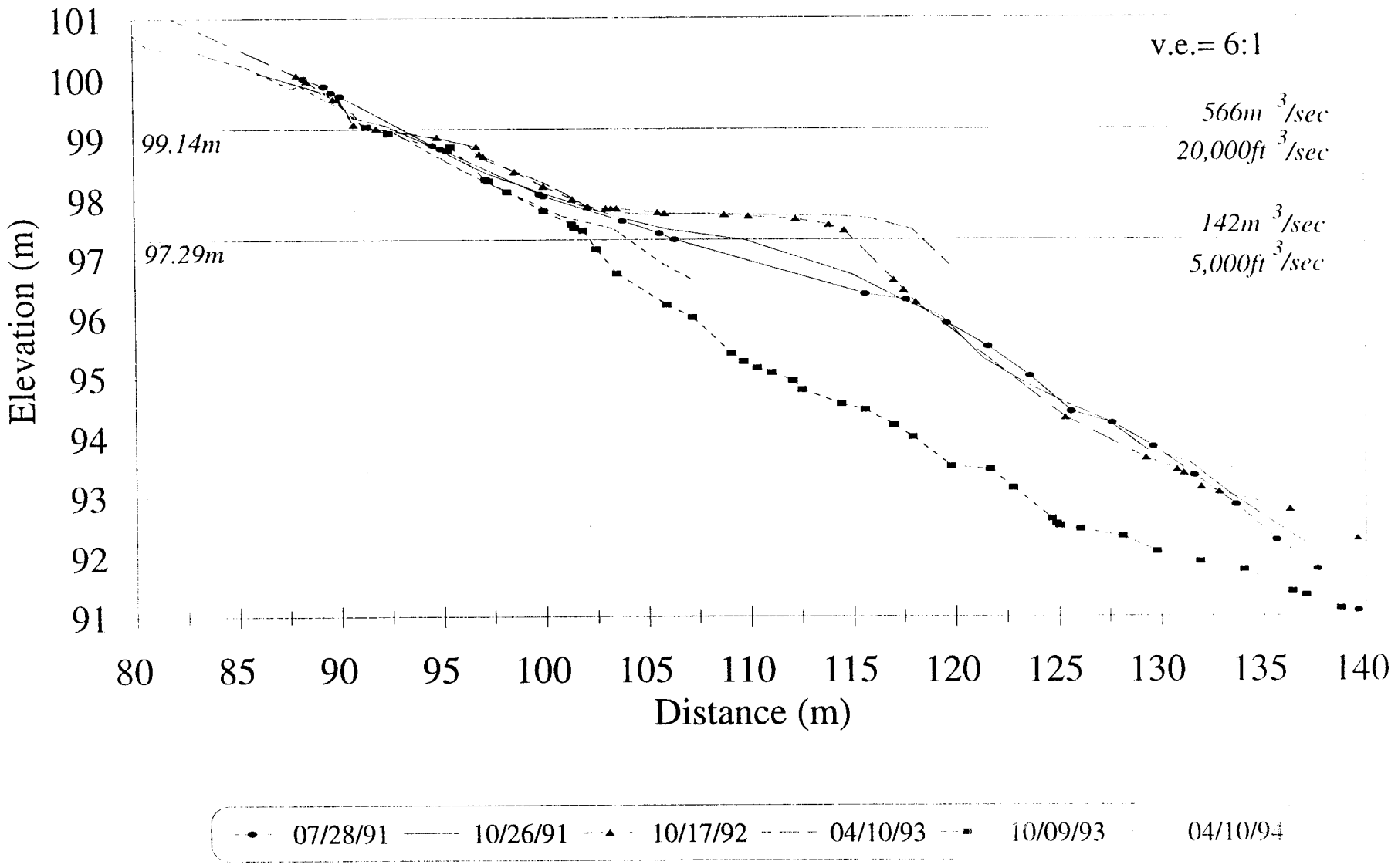
Near-shore P4



31 Mile

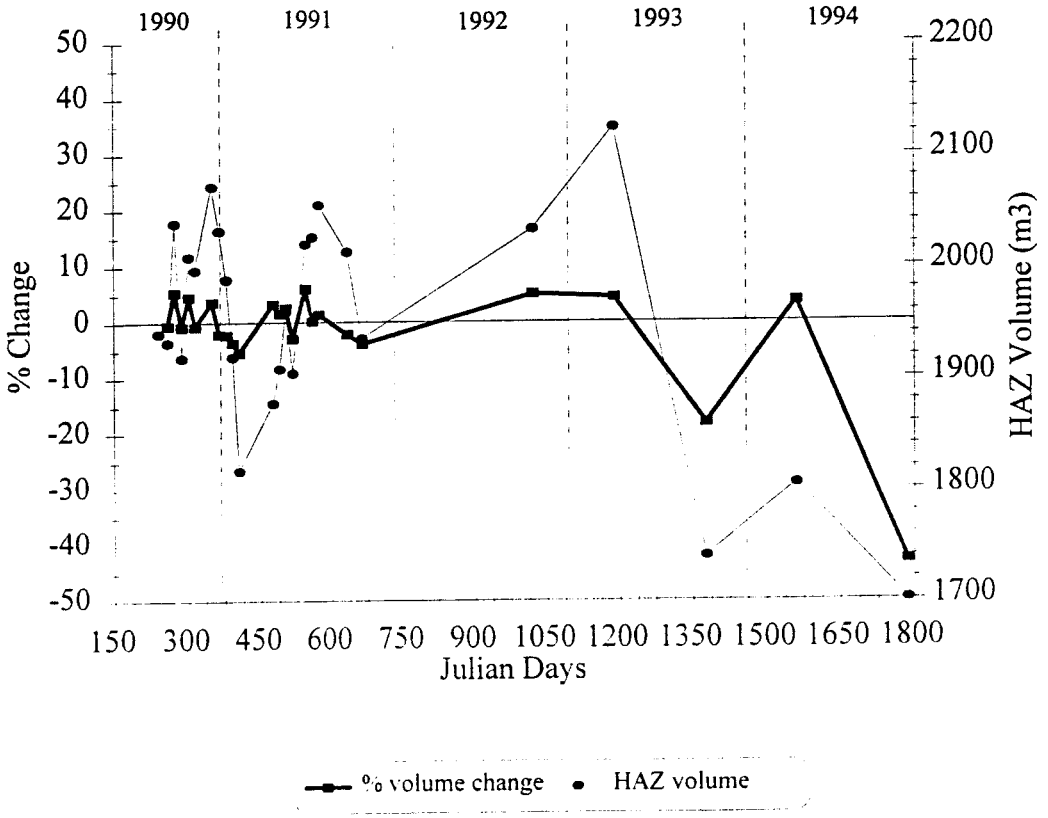
Cross-channel P6




Near-shore P6
v.e.= 6:1
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
99.14m
97.29m
Elevation (m)
101
100
99
98
97
96
95
94
93
92
91
80
85
90
95
100
105
110
115
120
125
130
135
140
Distance (m)
07/28/91
10/26/91
10/17/92
04/10/93
10/09/93
04/10/94

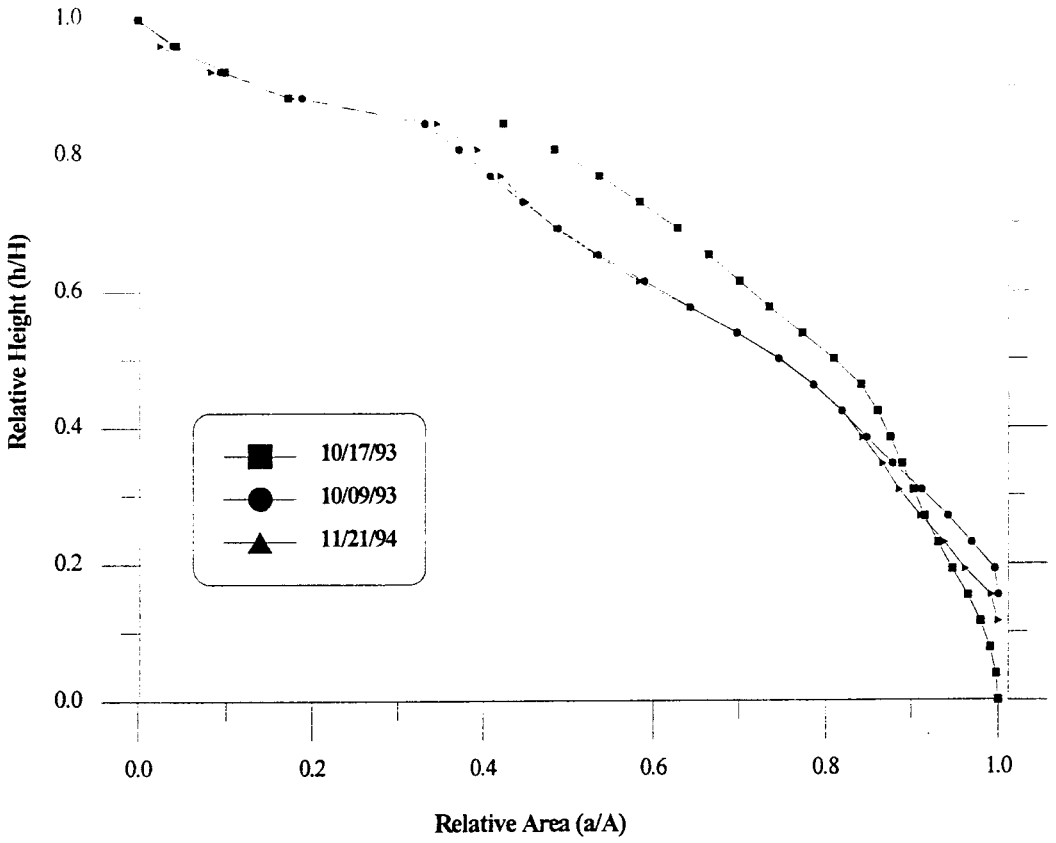
32 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	V=100%	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH	% VOL CH
A		NORM								
B		NORM								
C		G								
D		F								
E	900829	NORM	241	1924	1941	94.5				
F	900916	NORM	259	1972	1933	94.1	-8	-0.3892944039	-0.41	-0.41
G	900930	E	273	1997	2039	99.2	106	5.1581508516	5.48	5.48
H	901015	A	288	2032	1919	93.4	-14	-0.6812652068	-0.72	-0.72
I	901029	8000 CFS	302	2053	2009	97.8	90	4.3795620438	4.69	4.69
J	901112	NORM	316	2048	1997	97.2	-12	-0.5839416058	-0.60	-0.60
K	901217	NORM	351	2066	2072	100.8	75	3.6496350365	3.76	3.76
L	901231	11000 CFS	365	2054	2032	98.9	-40	-1.9464720195	-1.93	-1.93
M	910114	C	379	2111	1989	96.8	-43	-2.0924574209	-2.12	-2.12
N	910128	NORM	393	2048	1920	93.4	-69	-3.3576642336	-3.47	-3.47
O	910210	B	406	2035	1818	88.5	-102	-4.9635036496	-5.31	-5.31
P	910421	NORM	476	2084	1878	91.4	60	2.9197080292	3.30	3.30
Q	910505	NORM	490	2071	1909	92.9	31	1.5085158151	1.65	1.65
R	910519	D	504	2173	1960	95.4	51	2.4817518248	2.67	2.67
S	910602	15000 CFS	518	2185	1905	92.7	-55	-2.6763990268	-2.81	-2.81
T	910630	NORM	546	2289	2020	98.3	115	5.596107056	6.04	6.04
U	910714	G	560	2343	2026	98.6	6	0.2919708029	0.30	0.30
V	910728	F	574	2407	2055	100.0	29	1.4111922141	1.43	1.43
W	910925	INT	633	2400	2013	98.0	-42	-2.0437956204	-2.04	-2.04
X	911026	INT	664	2298	1936	94.2	-77	-3.7469586375	-3.83	-3.83
Y	921017	INT	1021	2884	2033	98.9	97	4.7201946472	5.01	5.01
Z	930403	INT	1189	3333	2124	103.4	91	4.4282238443	4.48	4.48
B08	931009	INT	1379	2130	1740	84.7	-384	-18.686131387	-18.08	-18.08
C08	940410	INT	1561	2315	1806	87.9	66	3.2116788321	3.79	3.79
D08	941121	INT	1786	2299	1701	50.2	-105	-37.676600109	-5.81	-42.87

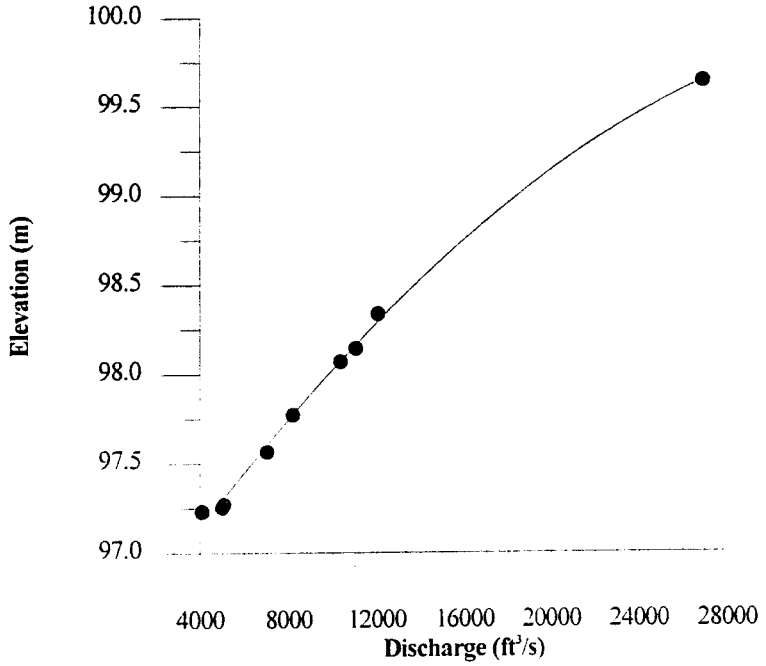


32 Mile

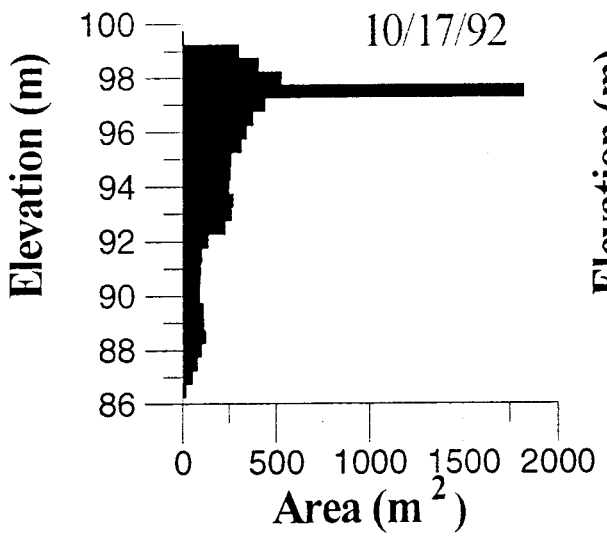
Hypsometric Curves

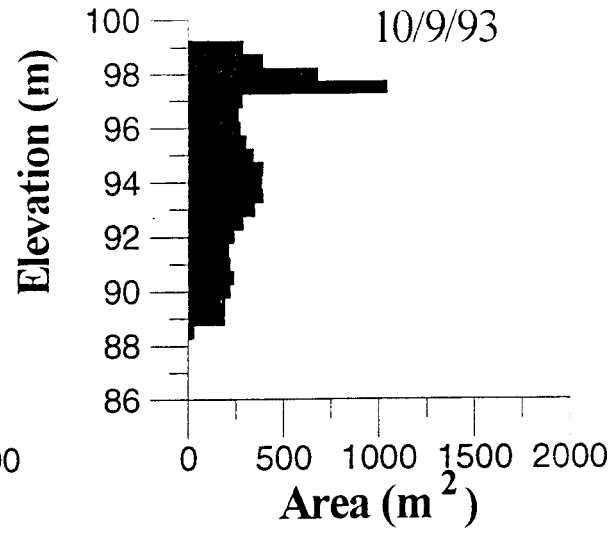


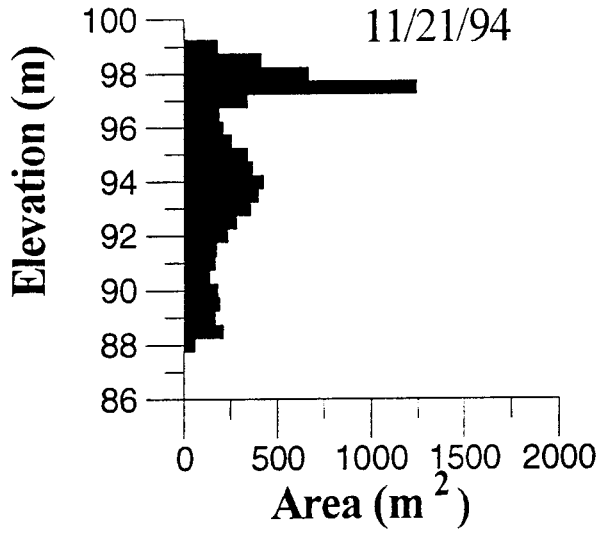
Stage Discharge



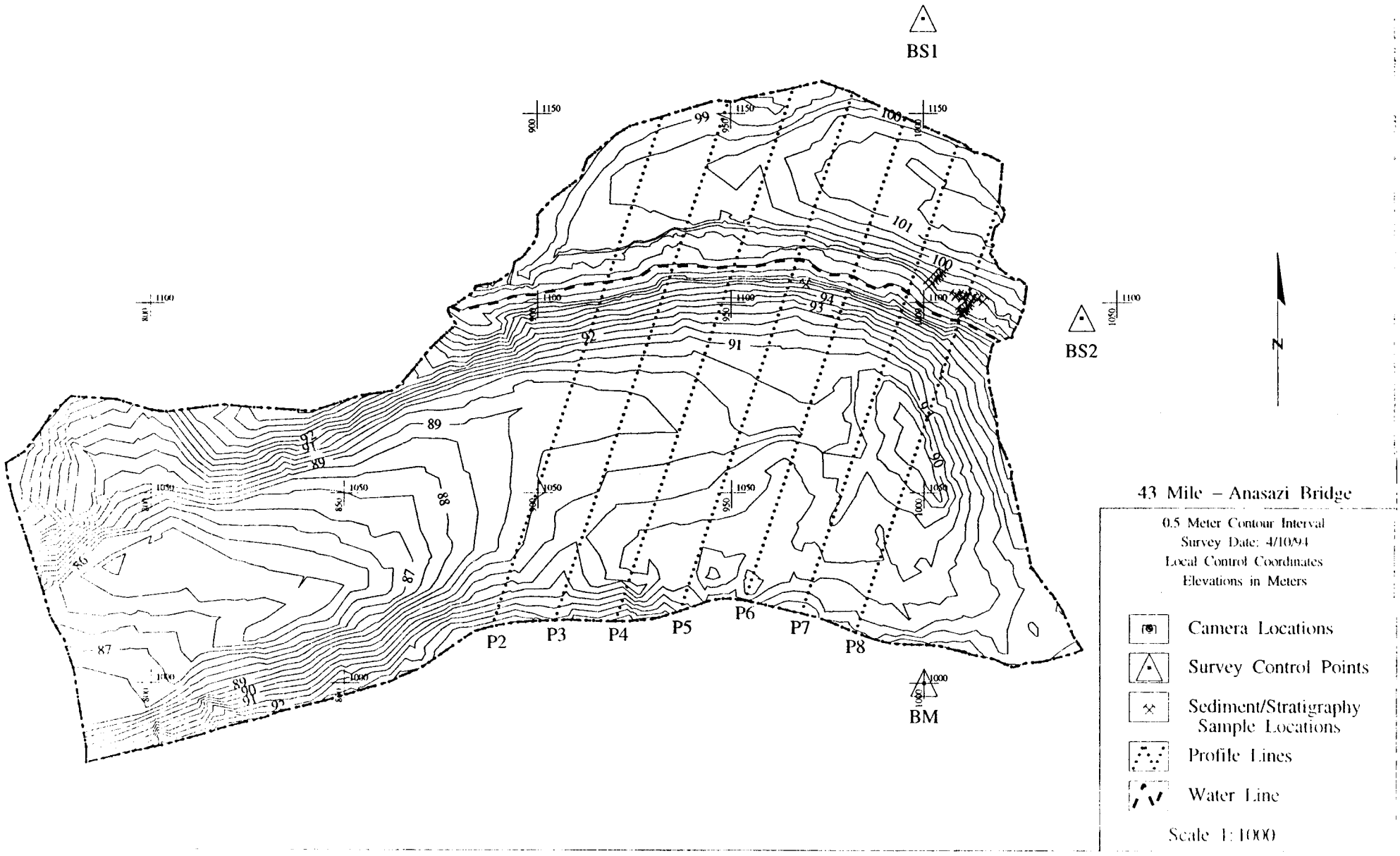
32 MILE
Area Distribution Histograms





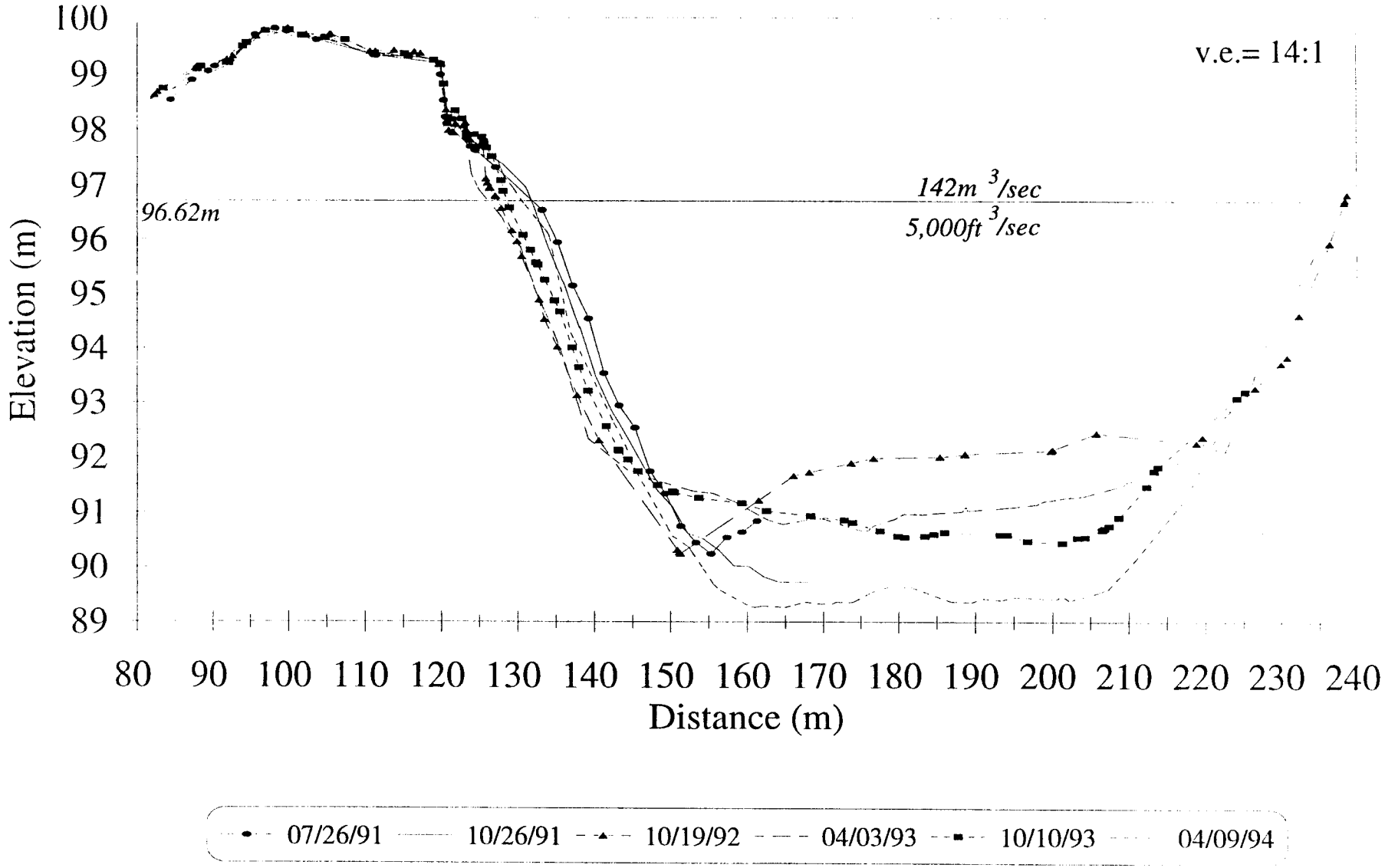


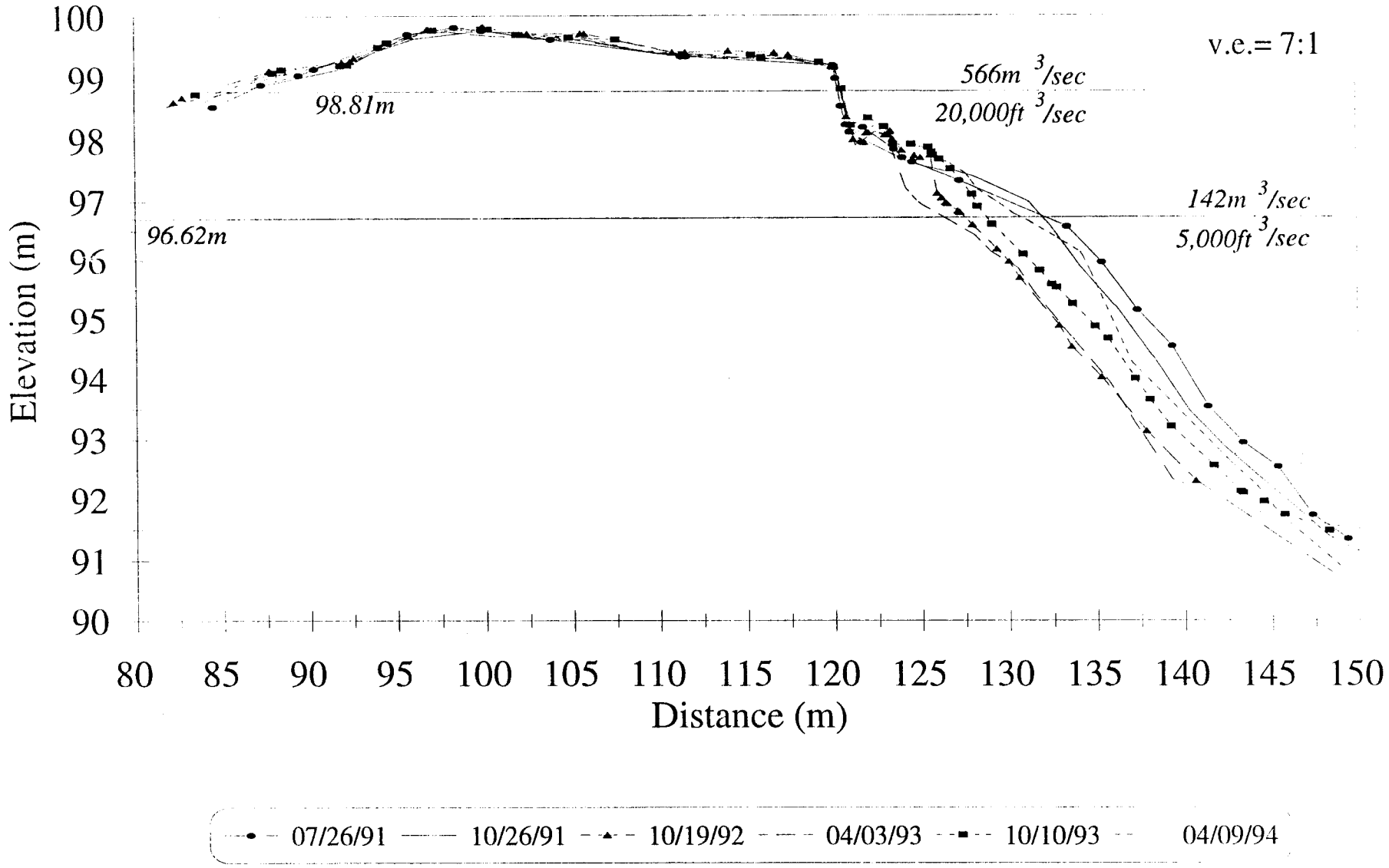
43 L
5-29-94
Area of Study


BS1
BS2
BM
P2
P3
P4
P5
P6
P7
P8
N
43 Mile – Anasazi Bridge
0.5 Meter Contour Interval
Survey Date: 4/10/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:1000

43 Mile

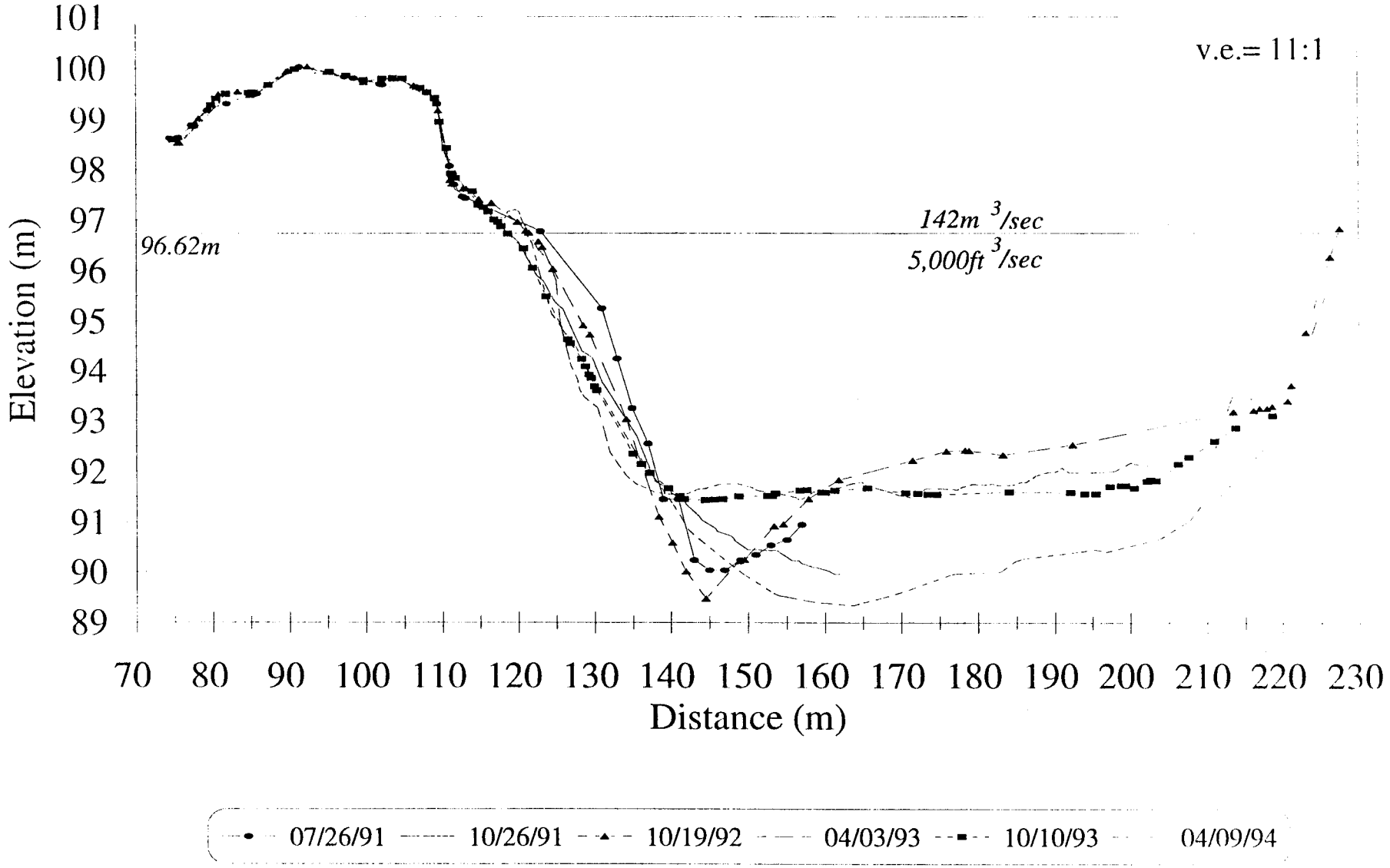
Cross-channel P2



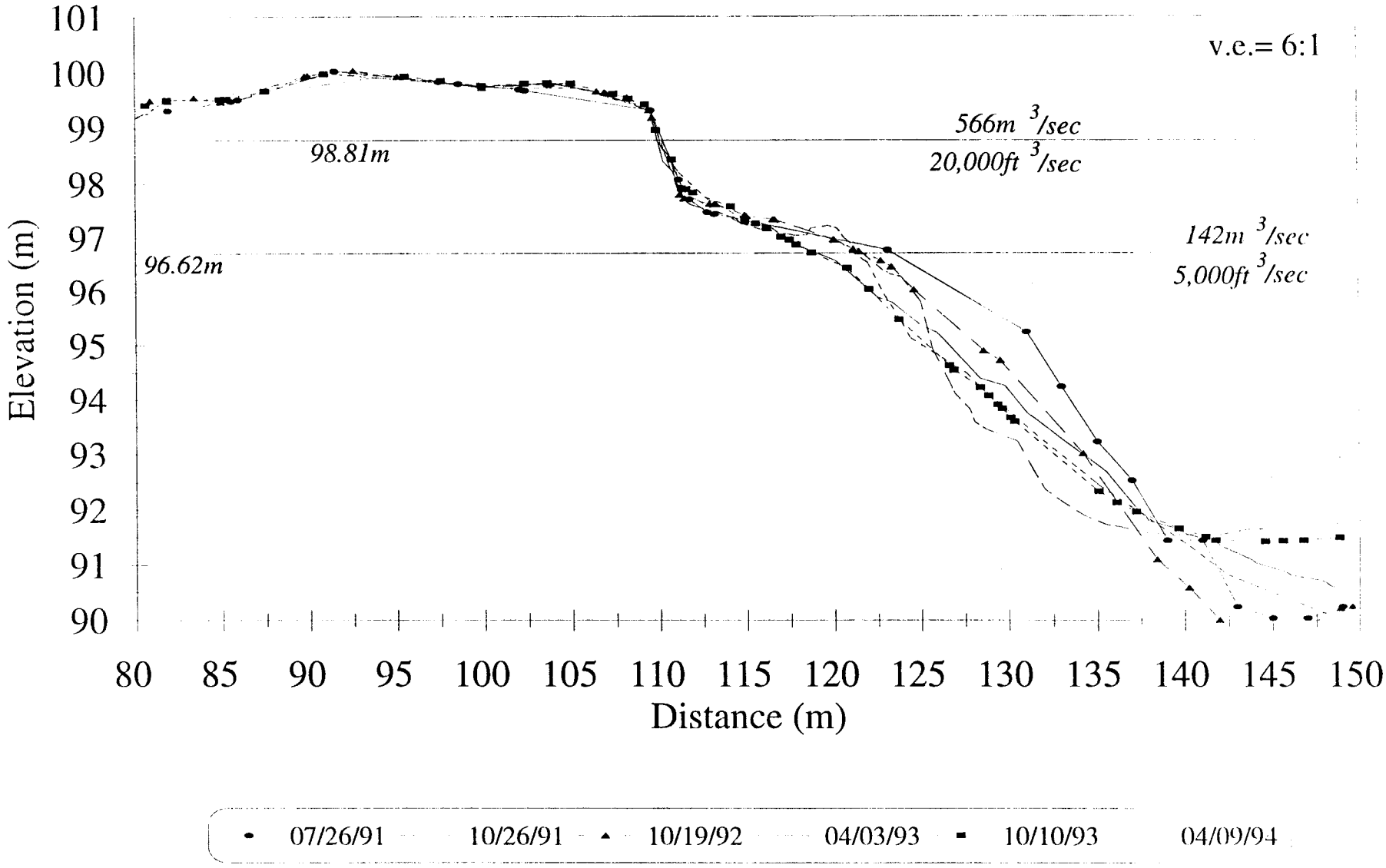

Near-shore P2
v.e.= 7:1
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
98.81m
96.62m
Elevation (m)
100
99
98
97
96
95
94
93
92
91
90
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
Distance (m)
07/26/91
10/26/91
10/19/92
04/03/93
10/10/93
04/09/94

43 Mile

Cross-channel P3

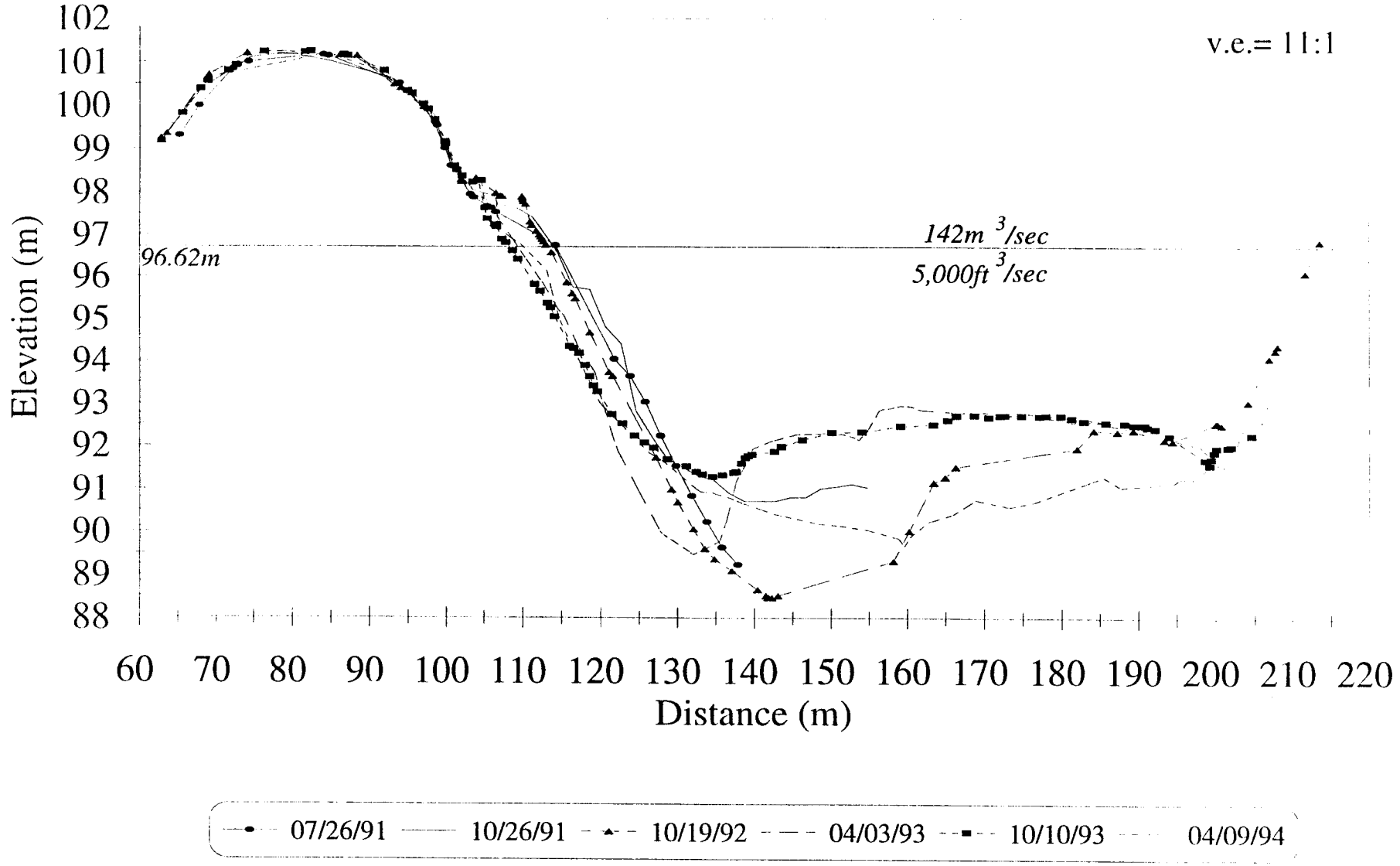


Near-shore P3

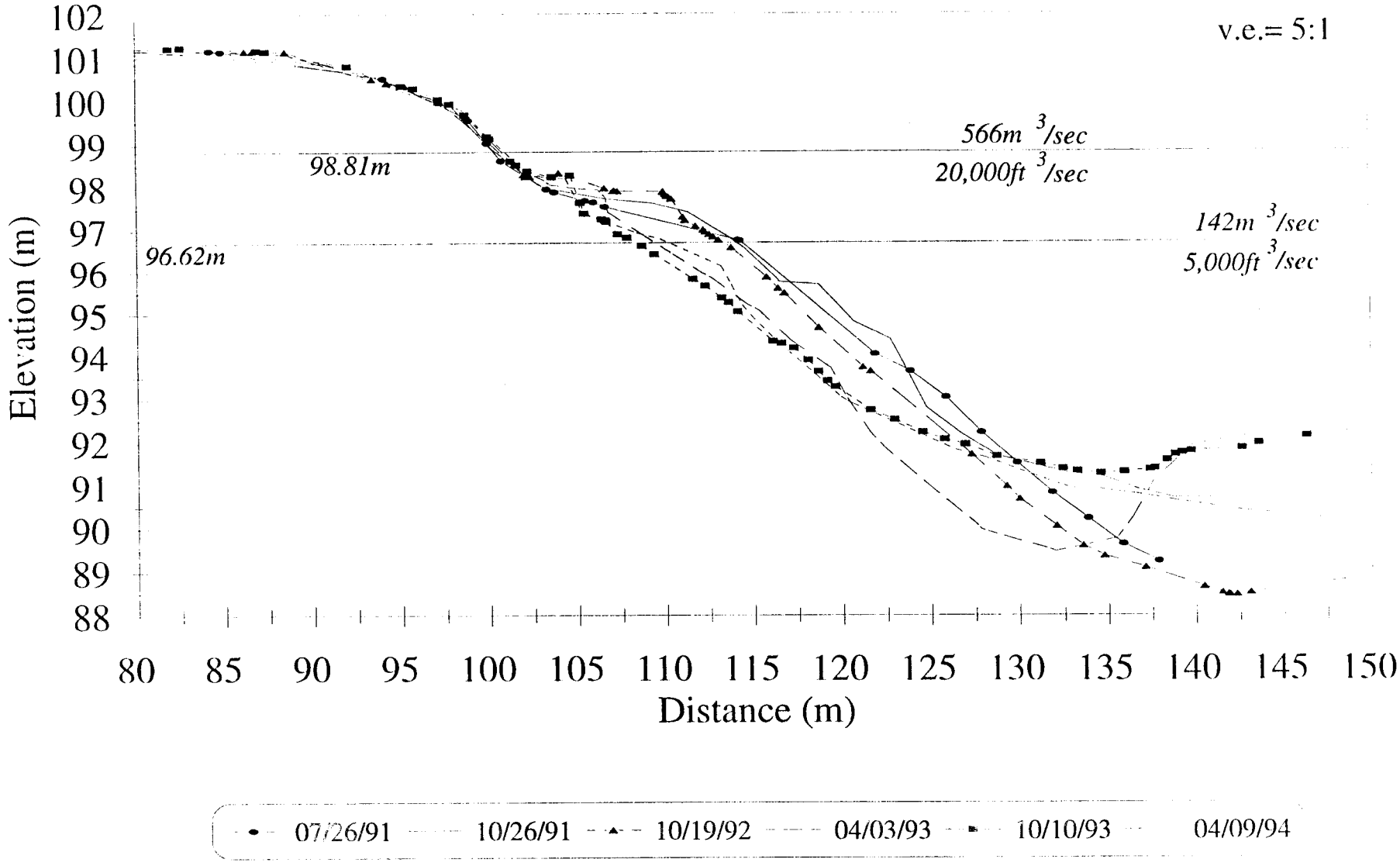


43 Mile

Cross-channel P5

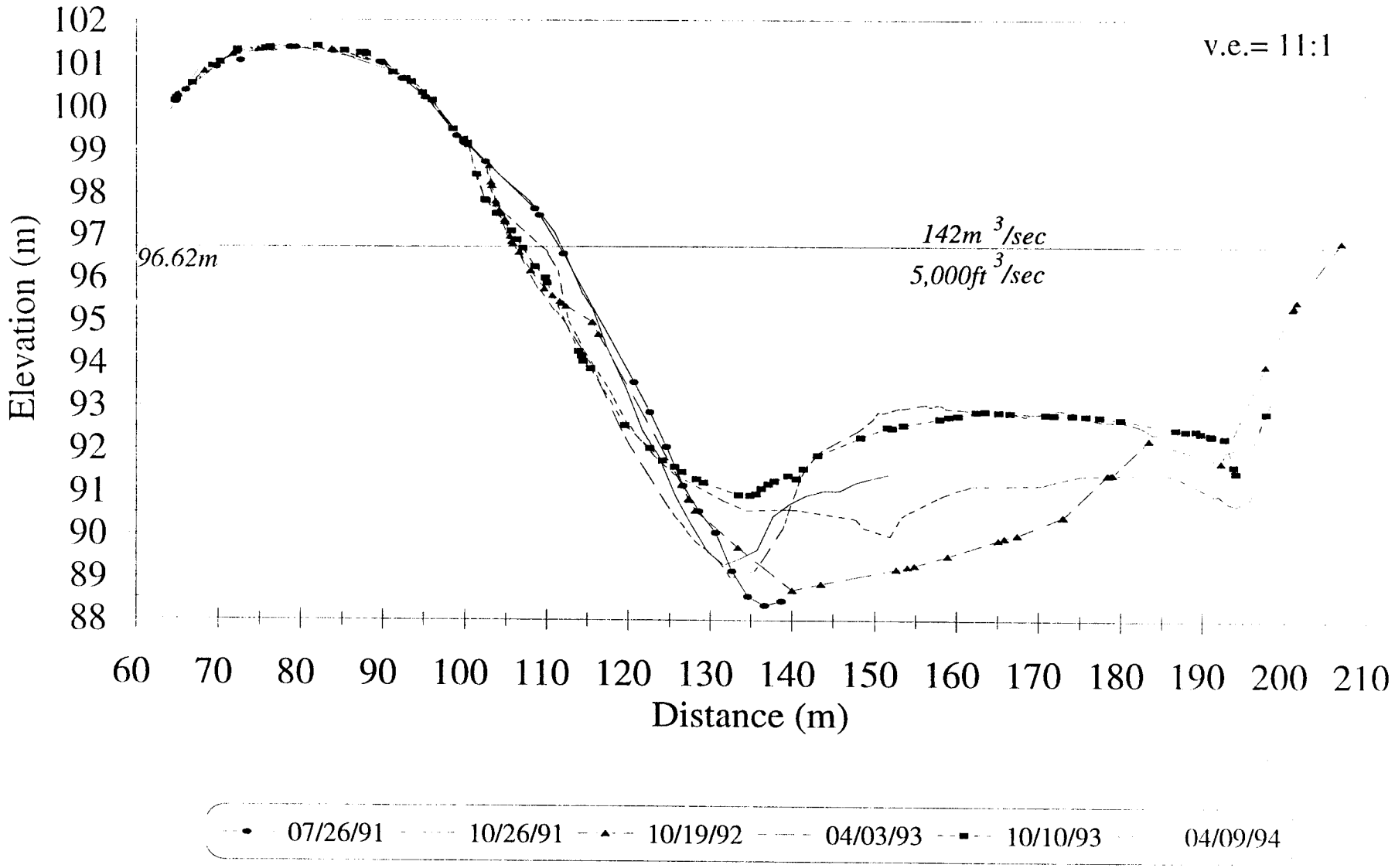


Near-shore P5

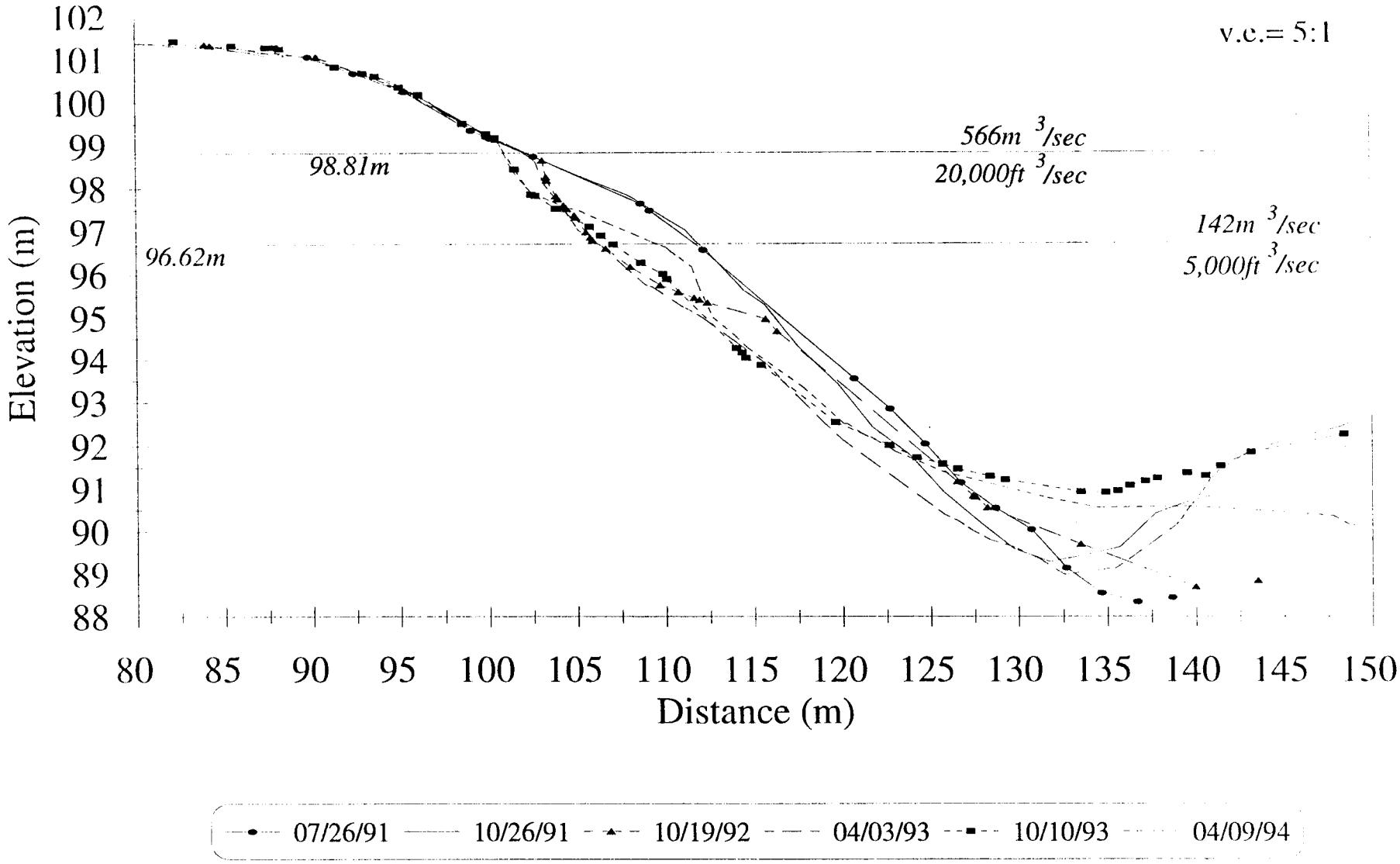


43 Mile

Cross-channel P6

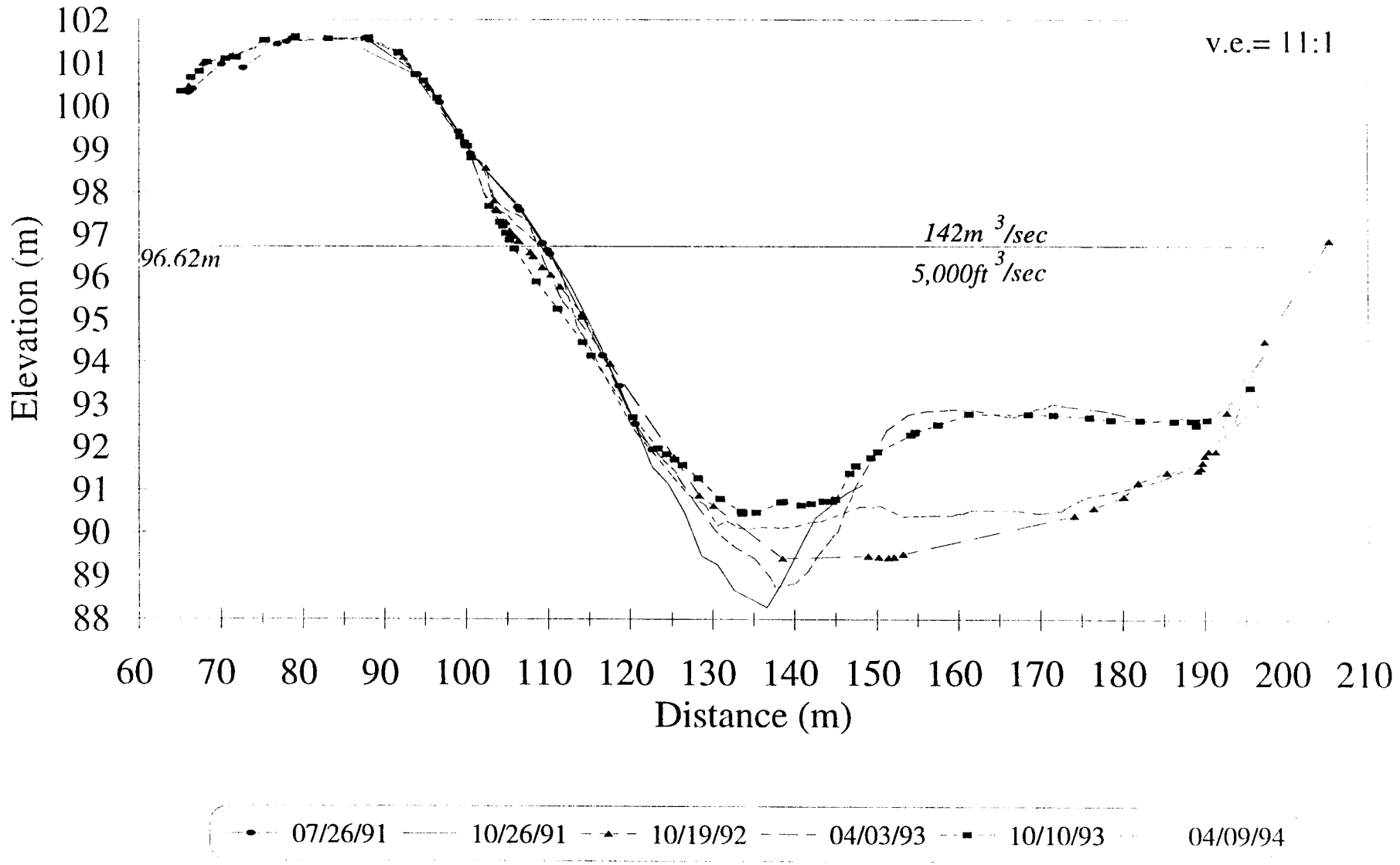


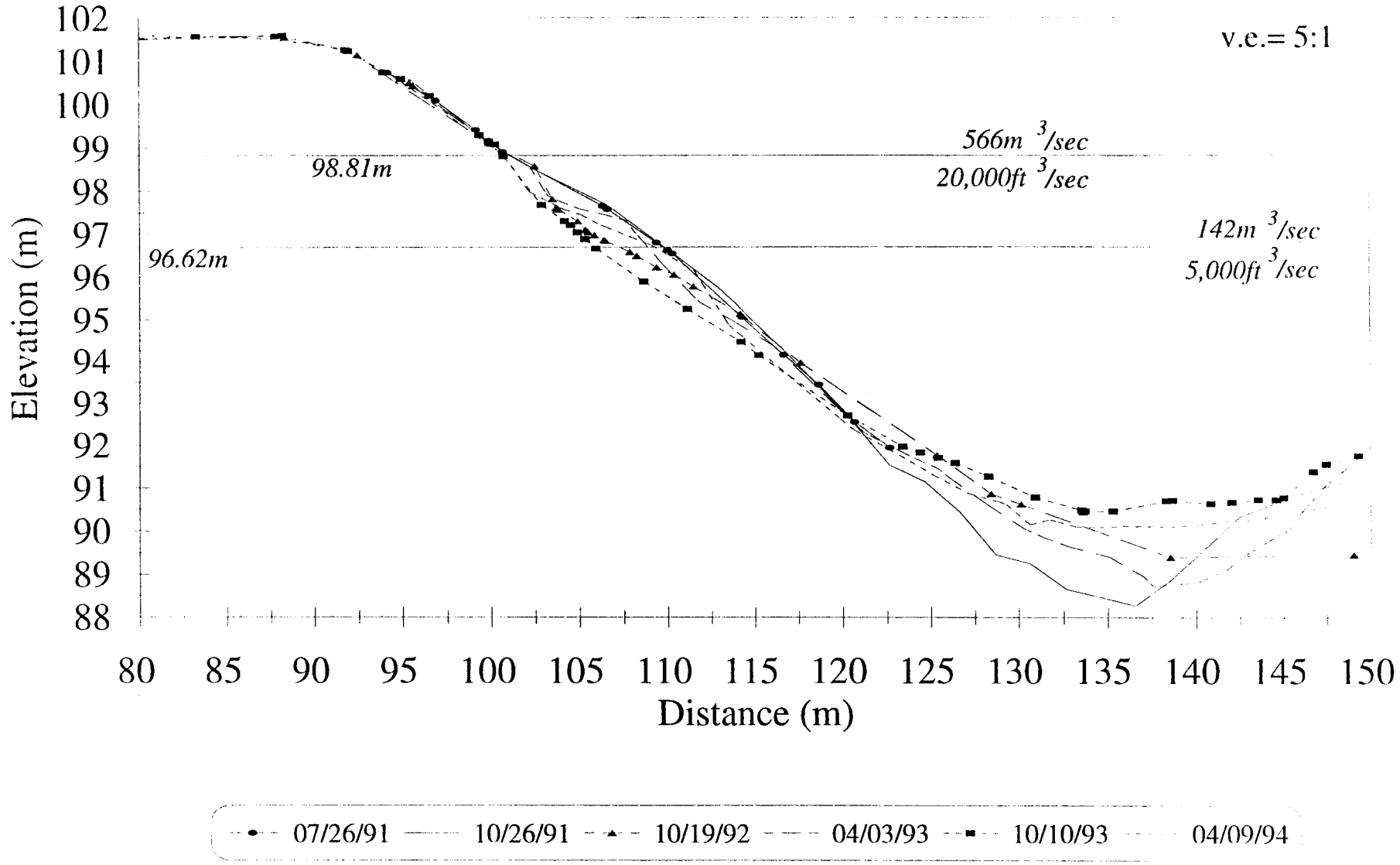
Near-shore P6



43 Mile

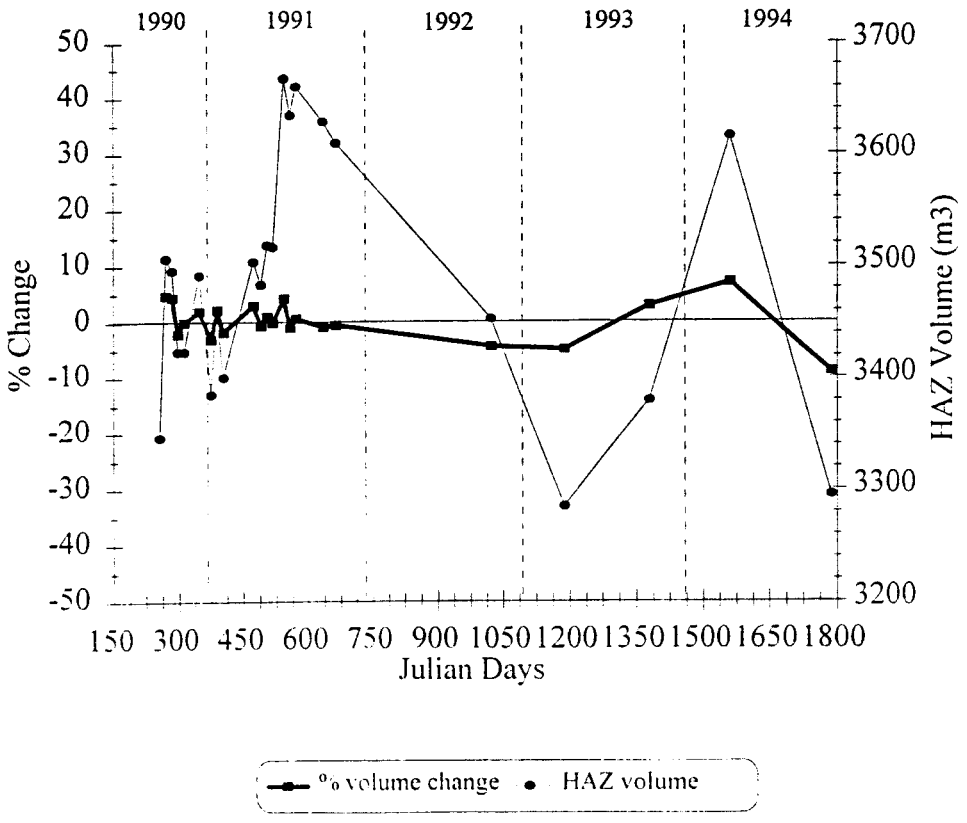
Cross-channel P7




Near-shore P7
v.e.= 5:1
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
98.81m
96.62m
Elevation (m)
102
101
100
99
98
97
96
95
94
93
92
91
90
89
88
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
Distance (m)
07/26/91
10/26/91
10/19/92
04/03/93
10/10/93
04/09/94

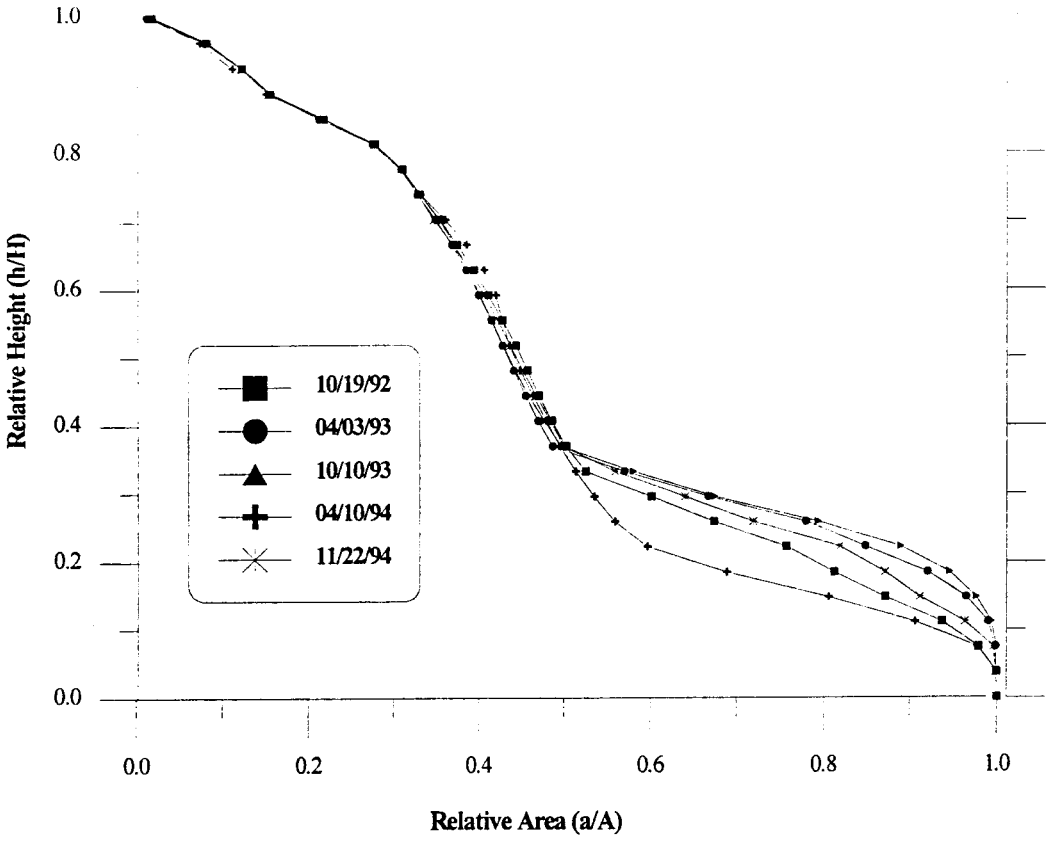
43 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F	900914	NORM	257	1736	3347				
G	900928	E	271	1849	3507	113	160	6.51	4.78
H	901012	A	285	1906	3496	170	149	9.79	4.45
I	901026	8000 CFS	299	1882	3424	-24	-72	-1.26	-2.06
J	901109	NORM	313	1858	3424	-24	0	-1.28	0.00
K	901214	NORM	348	1967	3492	109	68	5.67	1.99
L		11000 CFS							
M	910111	C	376	1934	3388	-33	-106	-1.68	-3.04
N	910125	NORM	390	1955	3460	21	74	1.09	2.19
O	910208	B	404	1872	3401	-83	-59	-4.25	-1.71
P	910419	NORM	474	2069	3504	197	103	10.52	3.03
Q	910505	NORM	490	2003	3484	-66	-20	-3.19	-0.57
R	910520	D	505	2036	3519	33	35	1.65	1.00
S	910602	15000 CFS	518	2069	3517	33	-2	1.62	-0.06
T	910628	NORM	544	2118	3668	49	151	2.37	4.29
U	910712	G	558	2100	3635	-18	-33	-0.85	-0.90
V	910726	F	572	2107	3661	7	26	0.33	0.72
W	910926	INT	634	1903	3629	-204	-32	-9.68	-0.87
X	911026	INT	664	1959	3610	56	-19	2.94	-0.52
Y	921019	INT	1023	1844	3453	-115	-157	-5.87	-4.35
Z	930403	INT	1189	1723	3285	-121	-168	-6.56	-4.87
B10	931010	INT	1380	1744	3380	21	95	1.22	2.89
C10	940410	INT	1561	1974	3616	230	236	13.19	6.98
D10	941122	INT	1787	1794	3295	-180	-321	-9.12	-8.88

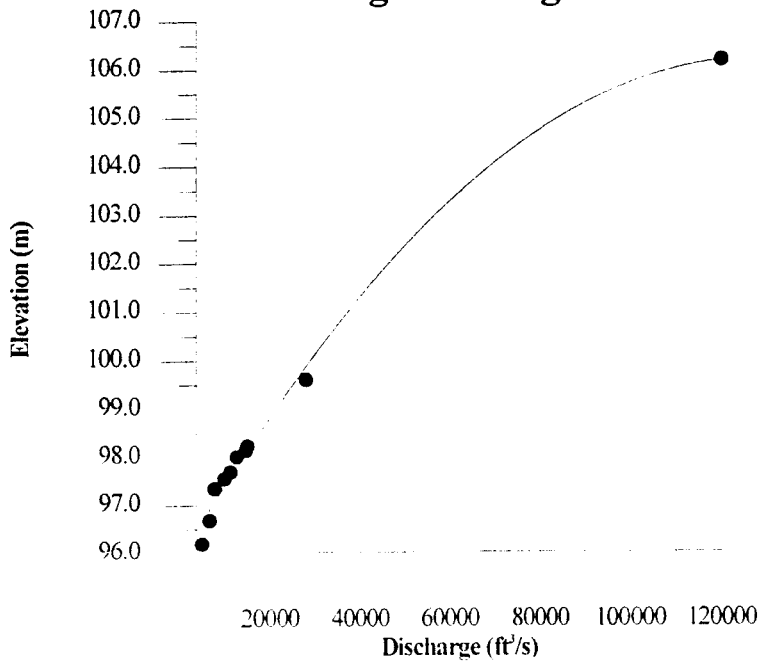


43 Mile

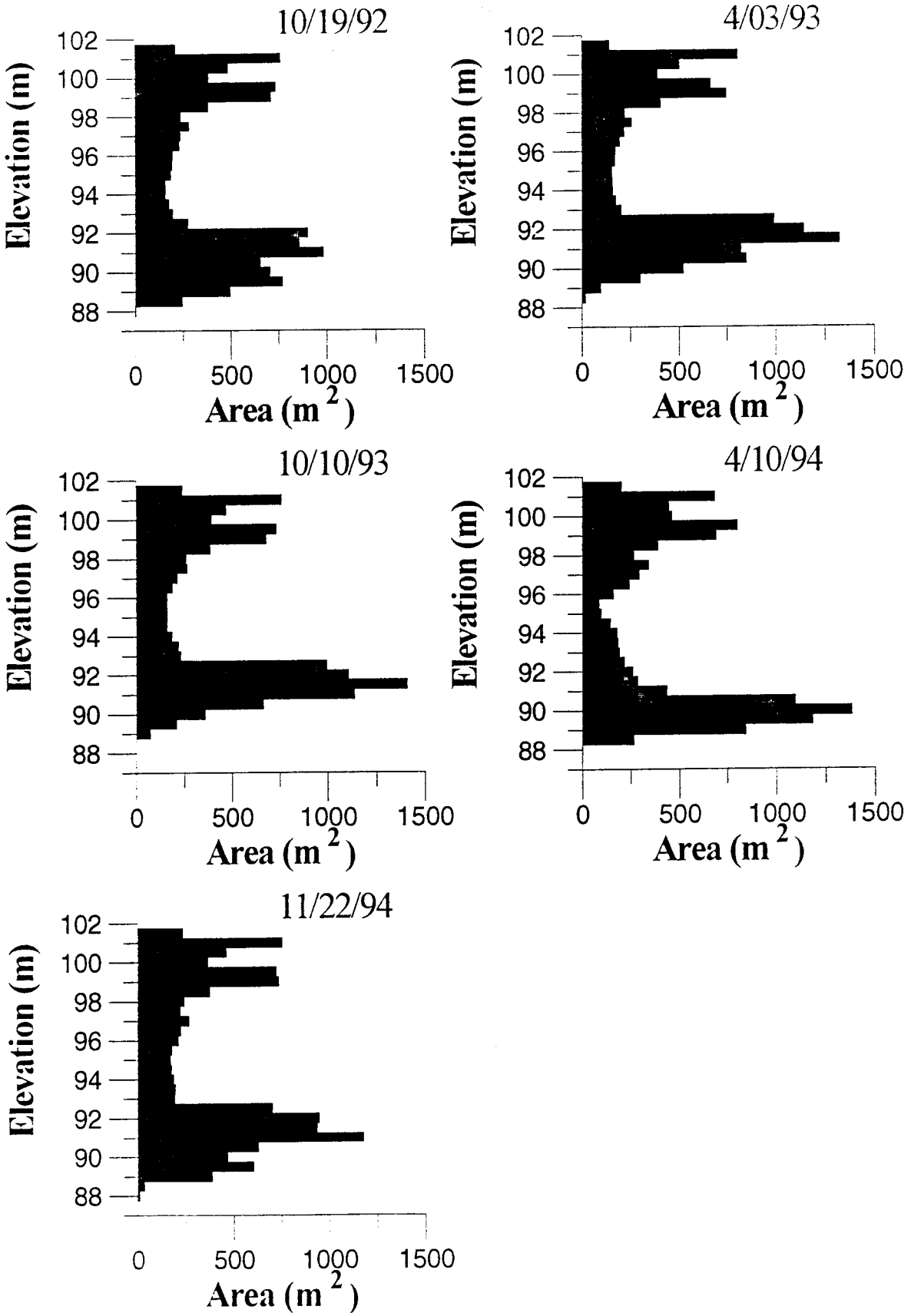
Hypsometric Curves

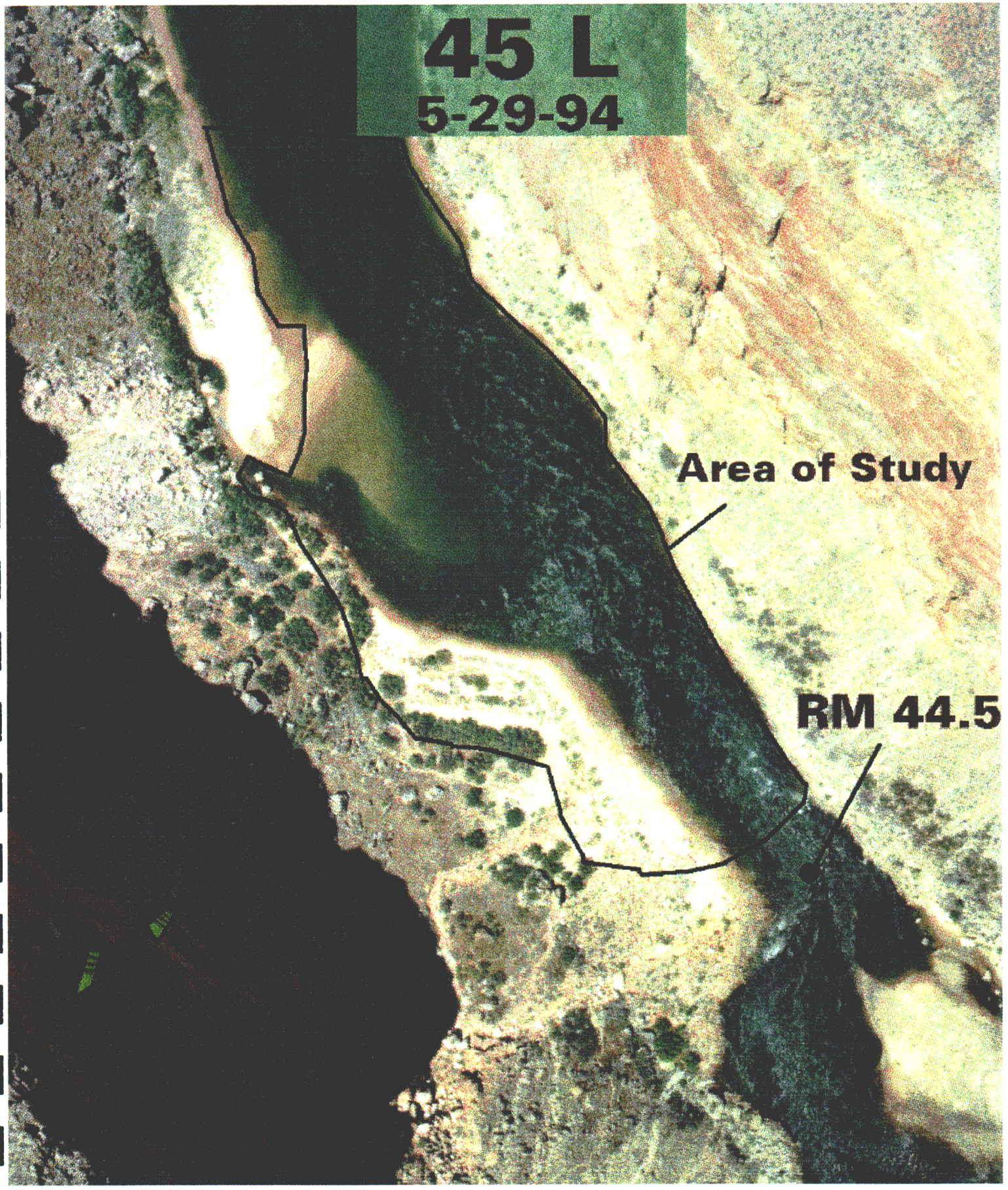


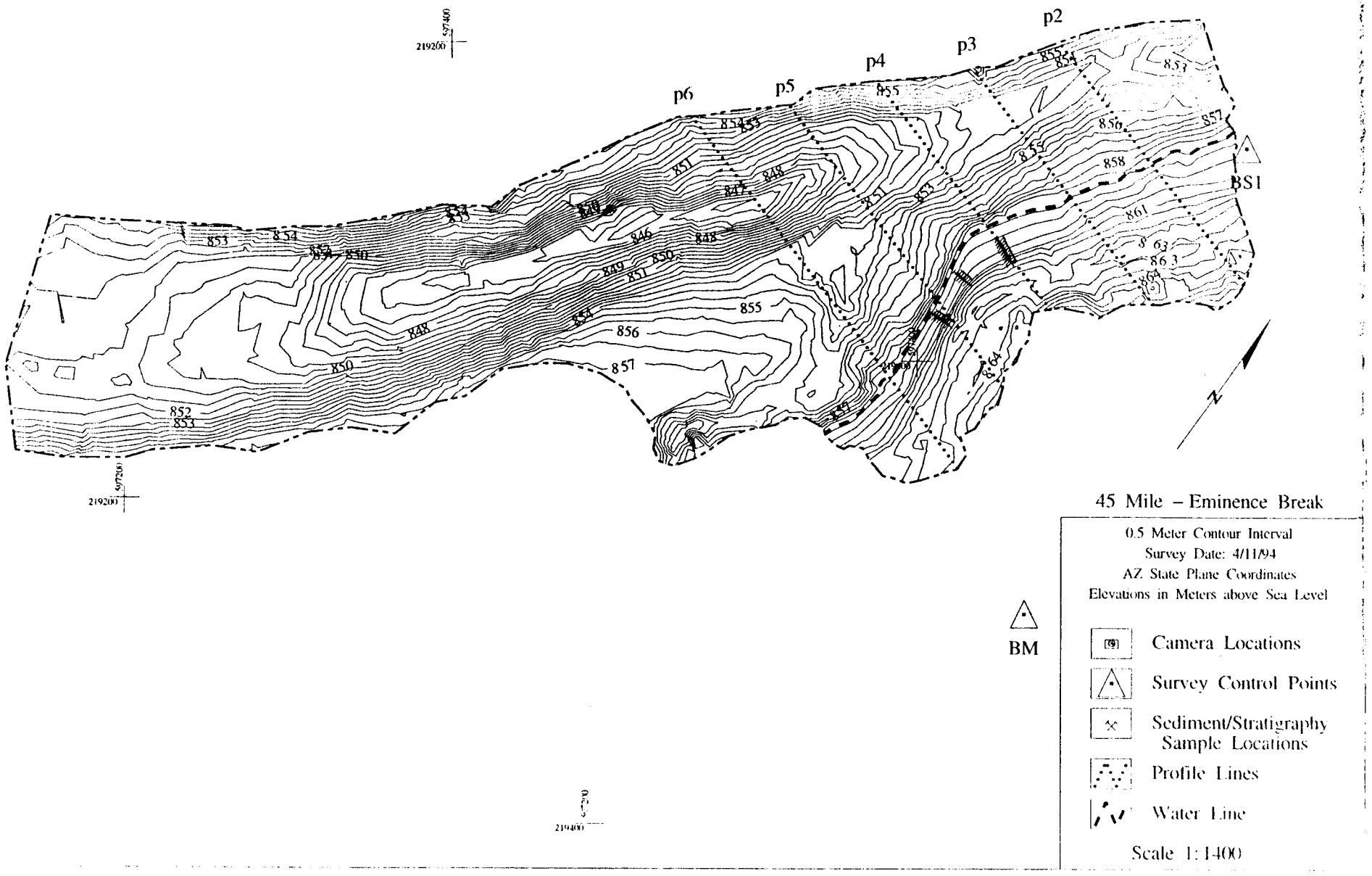
Stage Discharge



43 MILE
Area Distribution Histograms

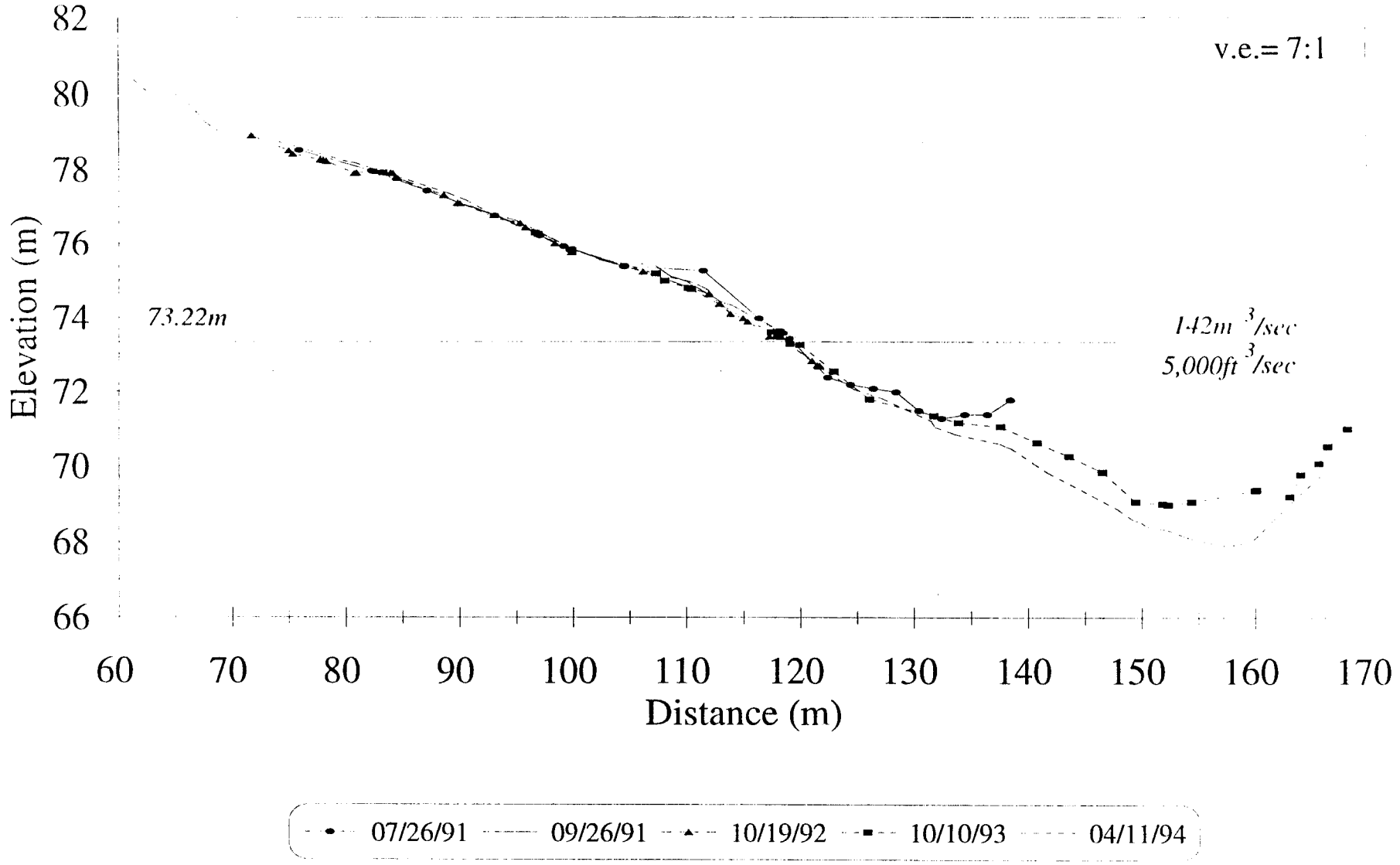



45 L
5-29-94
Area of Study
RM 44.5

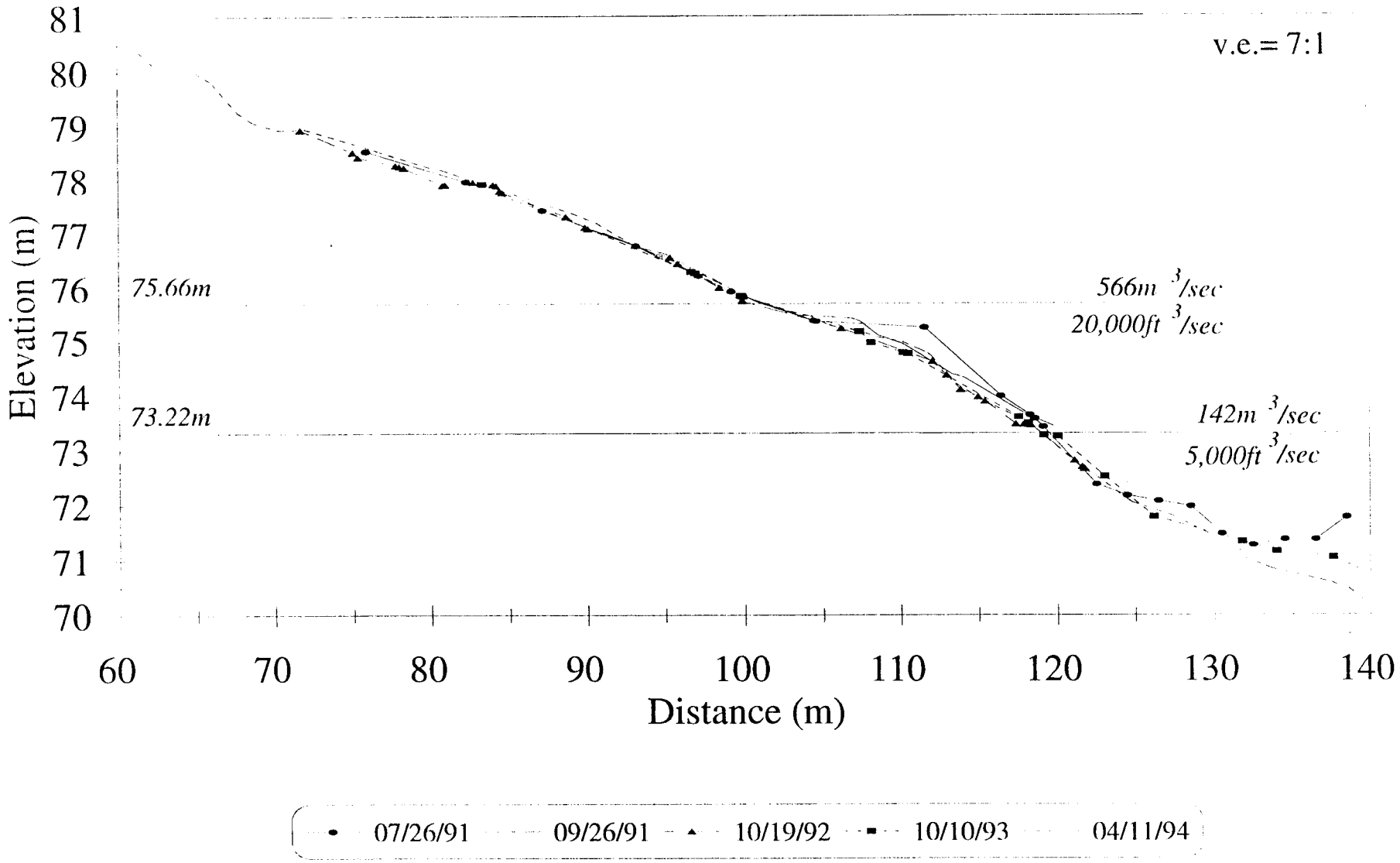

597400
219200
p6
p5
p4
p3
p2
BS1
BM
597200
219200
219400
45 Mile – Eminence Break
0.5 Meter Contour Interval
Survey Date: 4/11/94
AZ State Plane Coordinates
Elevations in Meters above Sea Level
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:1400

45 Mile

Cross-channel P2

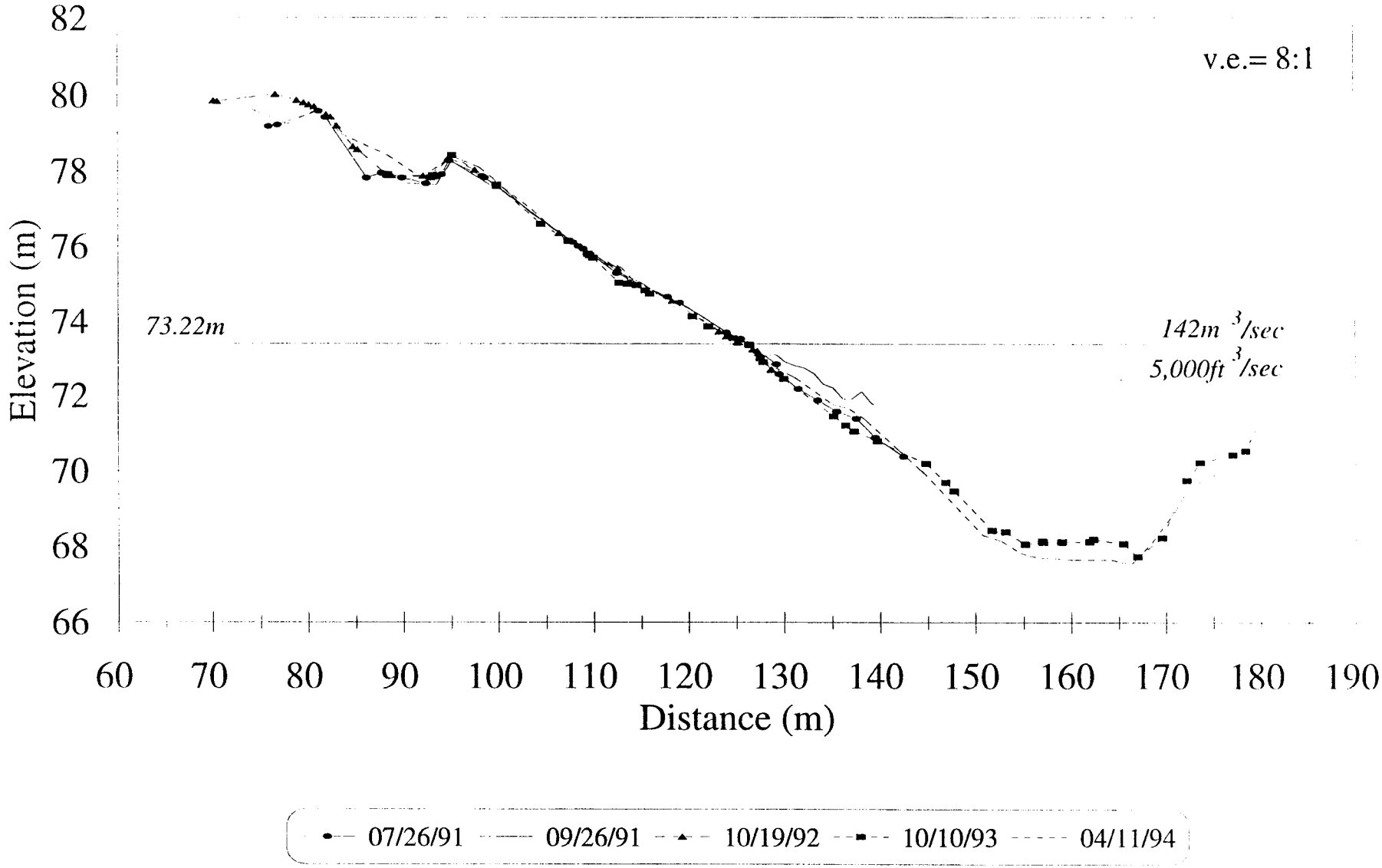


Near-shore P2

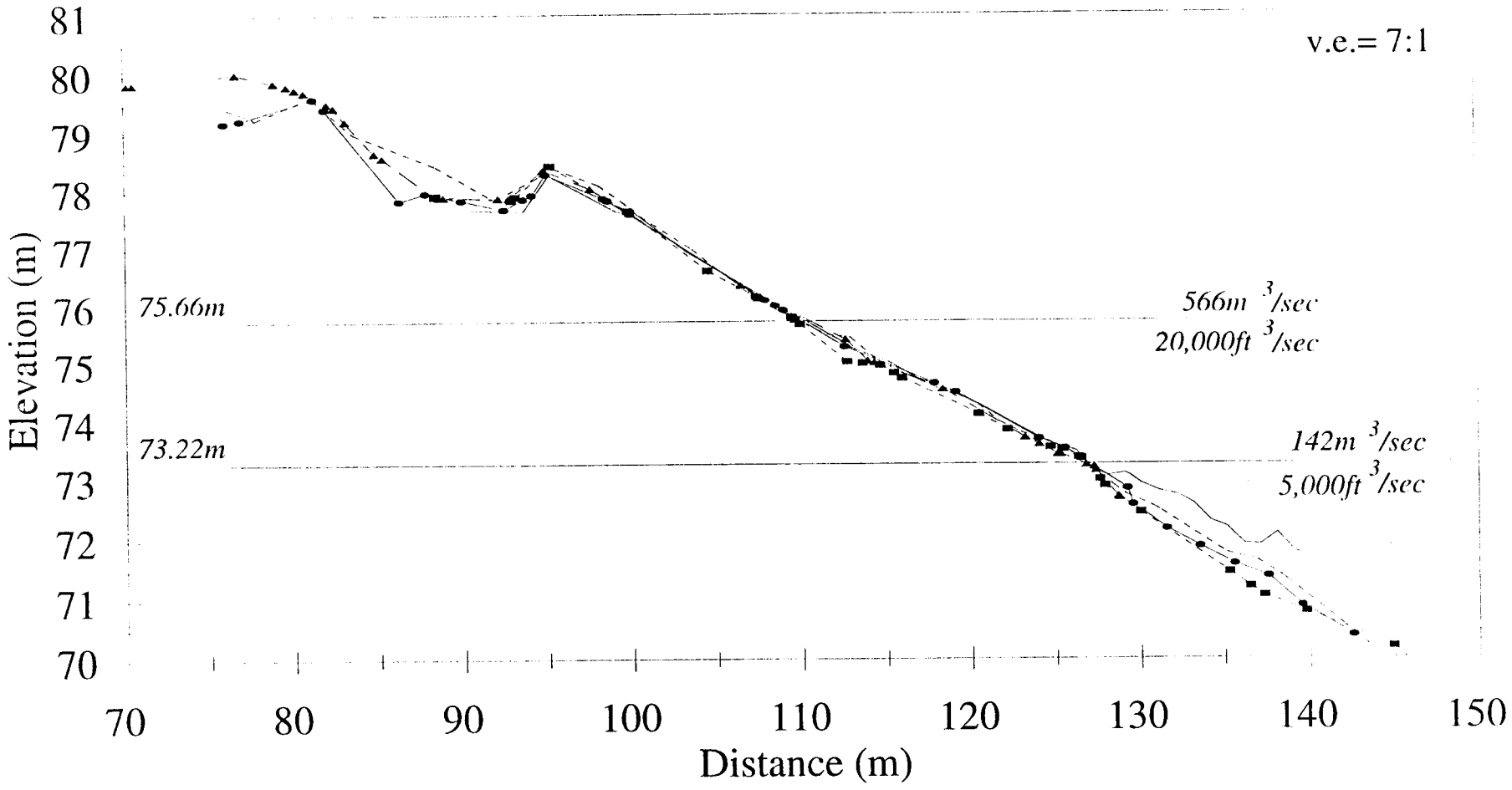


45 Mile

Cross-channel P3

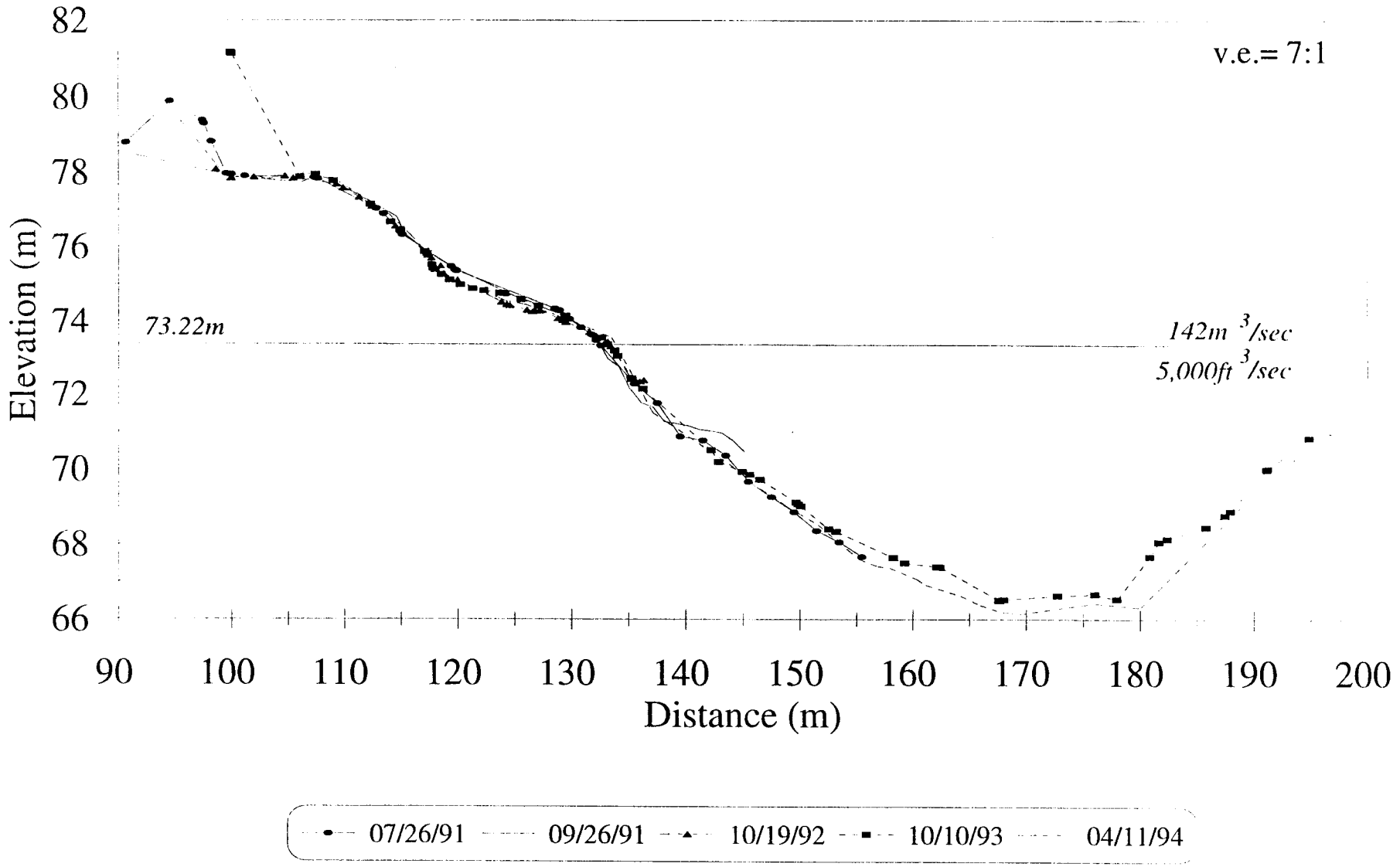


Near-shore P3

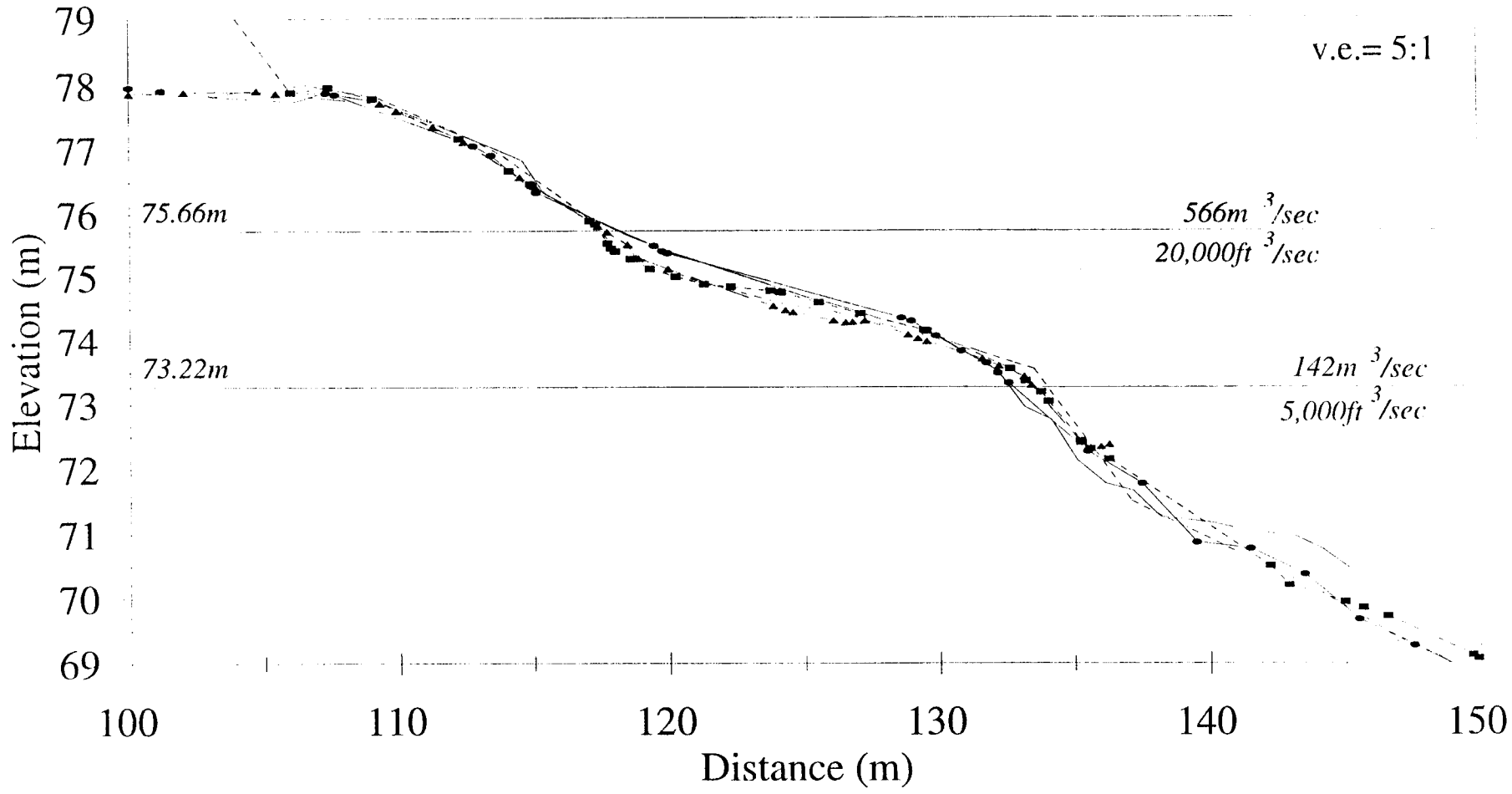


45 Mile

Cross-channel P4

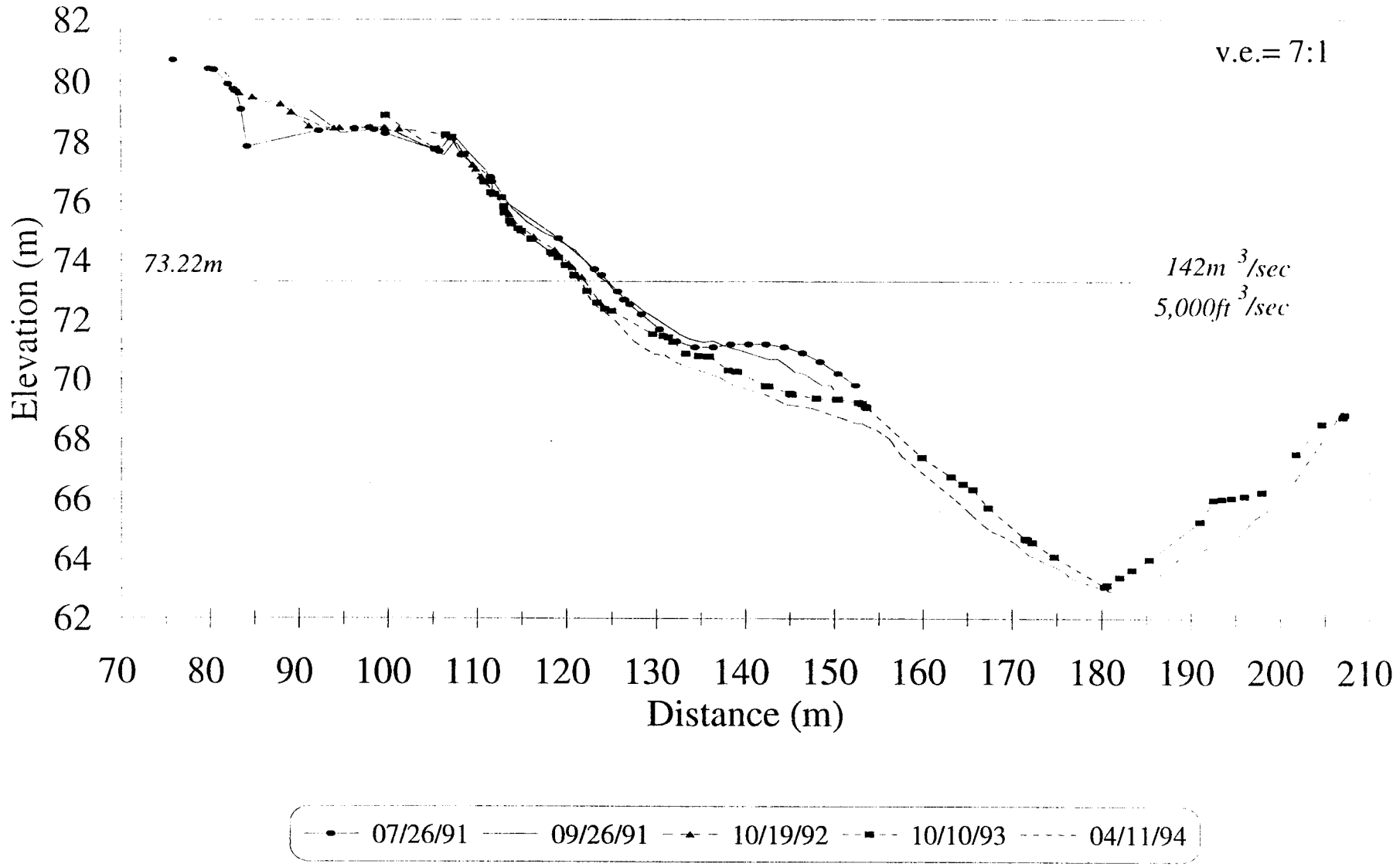


Near-shore P4

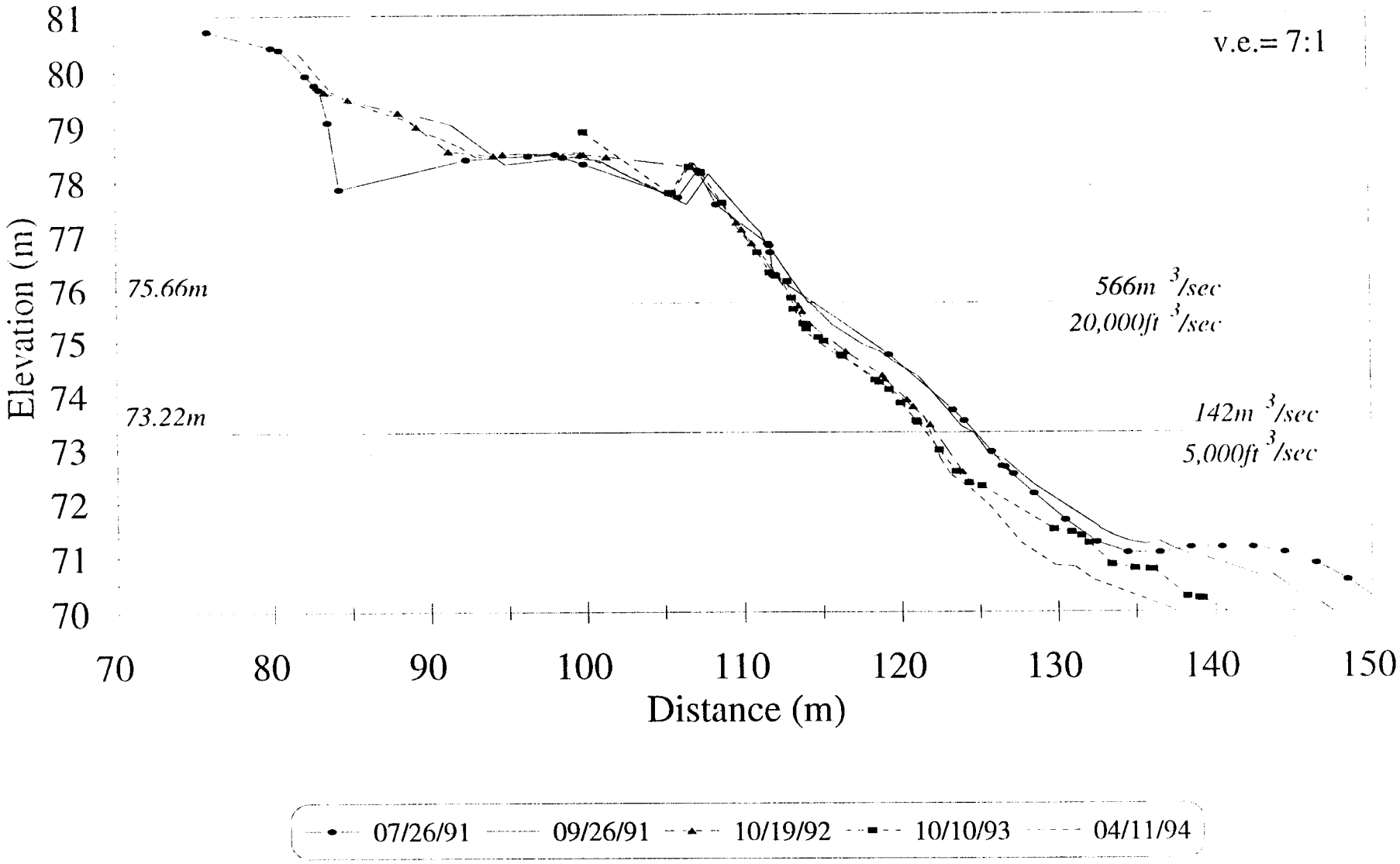


45 Mile

Cross-channel P5

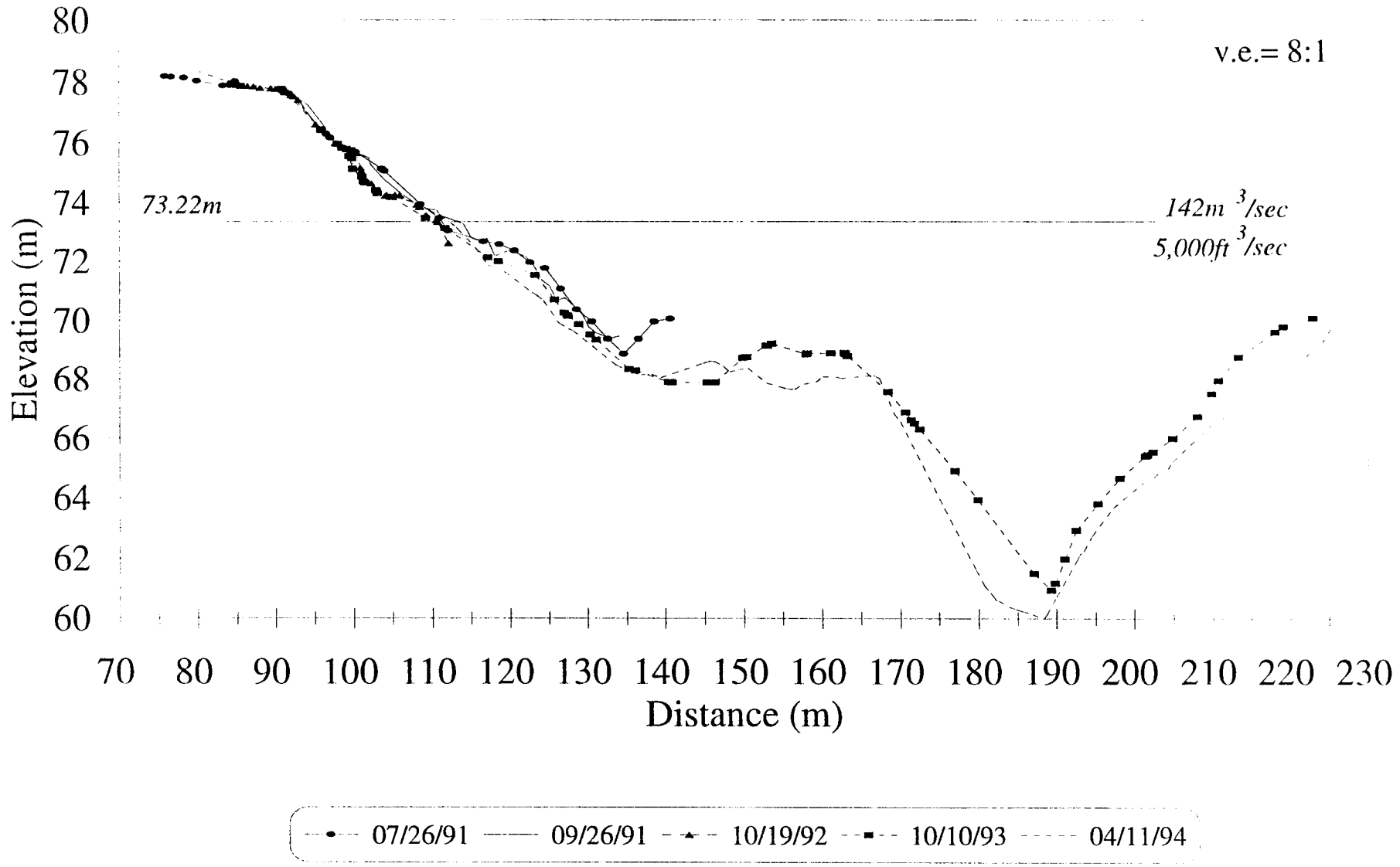


Near-shore P5

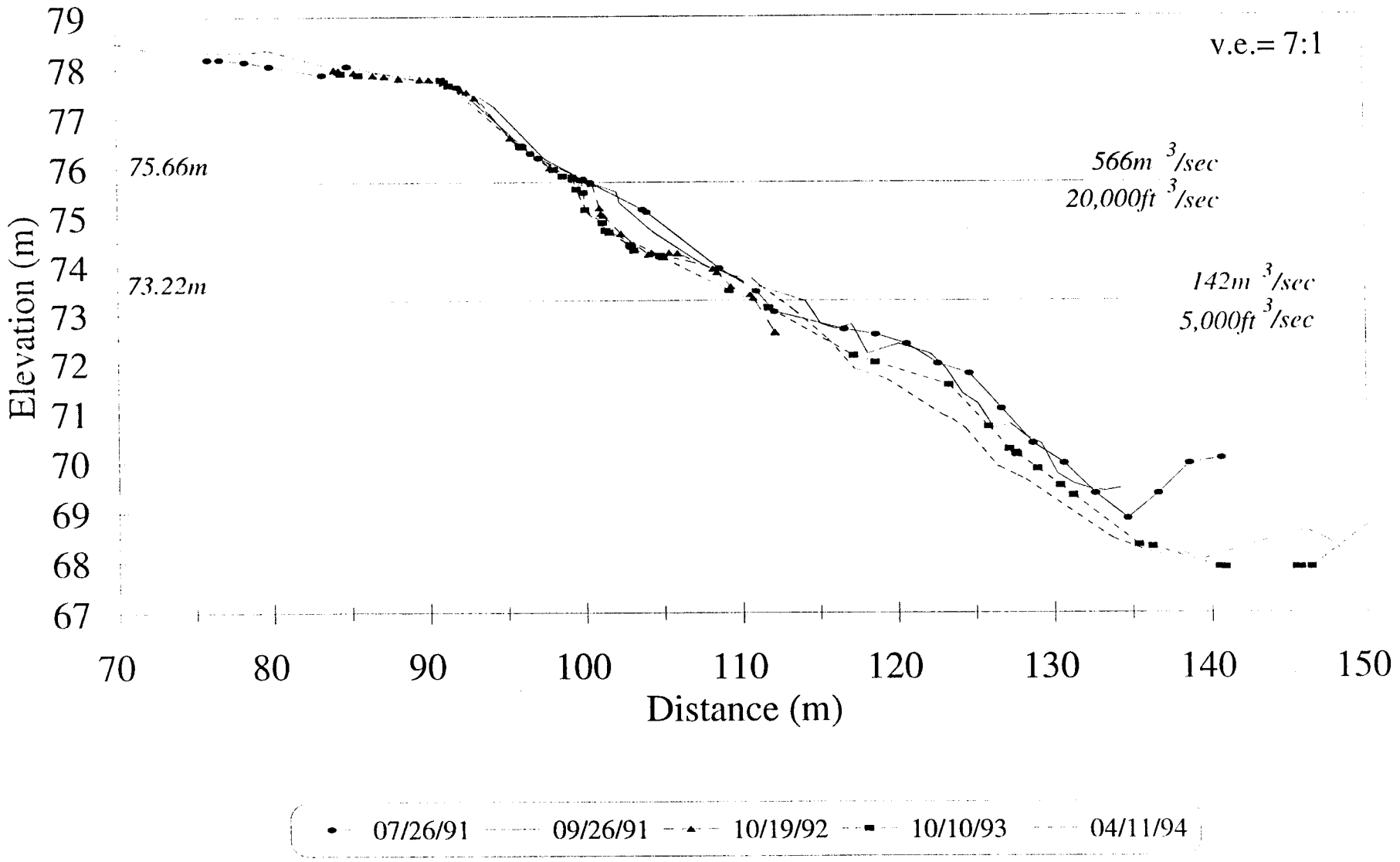


45 Mile

Cross-channel P6

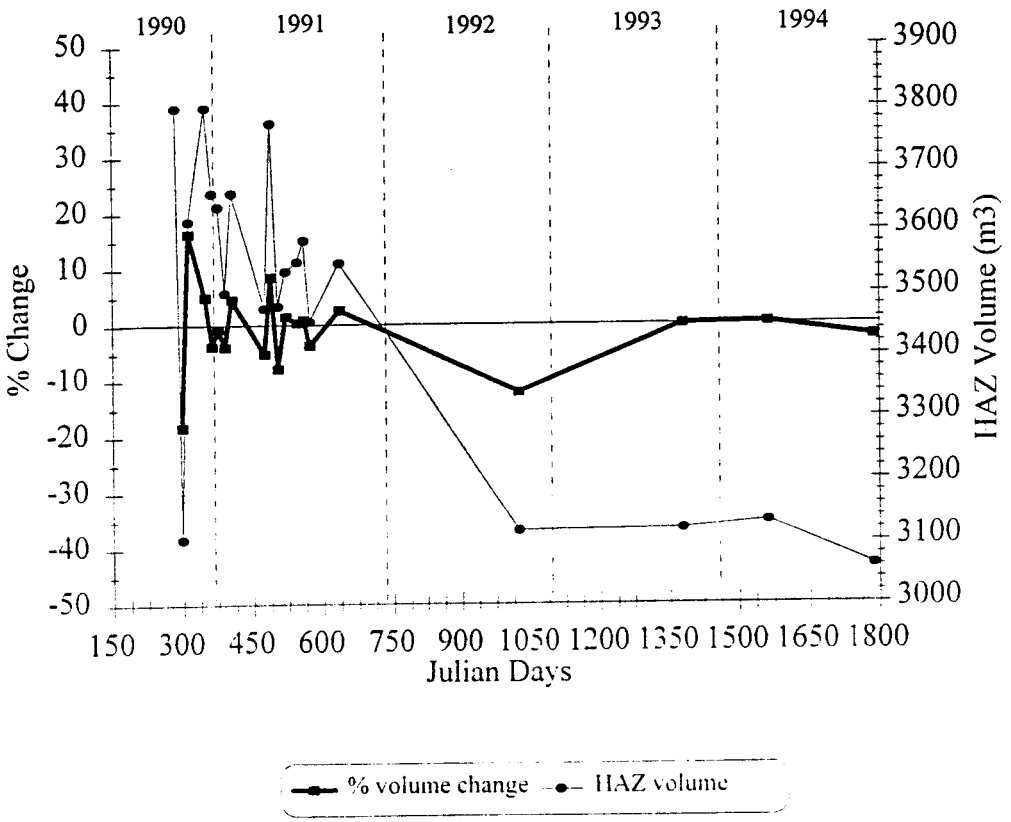


Near-shore P6



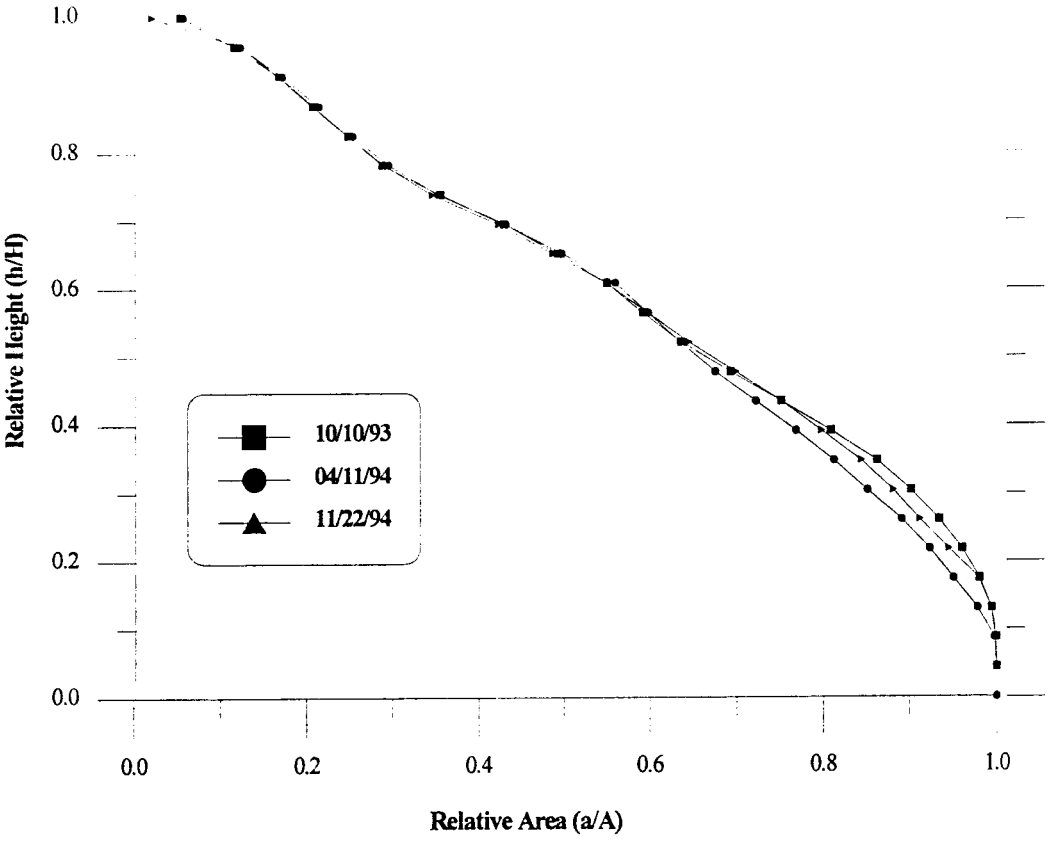
45 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F		NORM							
G		E							
H	901012	A	285	2578	3801				
I	901026	8000 CFS	299	2417	3107	-161	-694	-6.25	-18.26
J	901109	NORM	313	2551	3618	134	511	5.54	16.45
K	901214	NORM	348	2611	3802	60	184	2.35	5.09
L	901228	11000 CFS	362	2722	3663	111	-139	4.25	-3.66
M	910111	C	376	2688	3642	-34	-21	-1.25	-0.57
N	910125	NORM	390	2577	3502	-111	-140	-4.13	-3.84
O	910208	B	404	2604	3663	27	161	1.05	4.60
P	910419	NORM	474	2623	3478	19	-185	0.73	-5.05
Q	910502	NORM	487	2633	3776	10	298	0.38	8.57
R	910517	D	502	2632	3481	-1	-295	-0.04	-7.81
S	910603	15000 CFS	519	2674	3536	42	55	1.60	1.58
T	910628	NORM	544	2646	3552	-28	16	-1.05	0.45
U	910712	G	558	2675	3586	29	34	1.10	0.96
V	910726	F	572	2585	3456	-90	-130	-3.36	-3.63
W	910926	INT	634	2656	3549	71	93	2.75	2.69
Y	921019	INT	1023	2479	3119	-177	-430	-6.66	-12.12
B11	931010	INT	1379	2498	3121	19	2	0.77	0.06
C11	940411	INT	1562	2550	3133	52	12	2.08	0.38
D11	941122	INT	1787	2485	3062	-65	-71	-2.55	-2.27

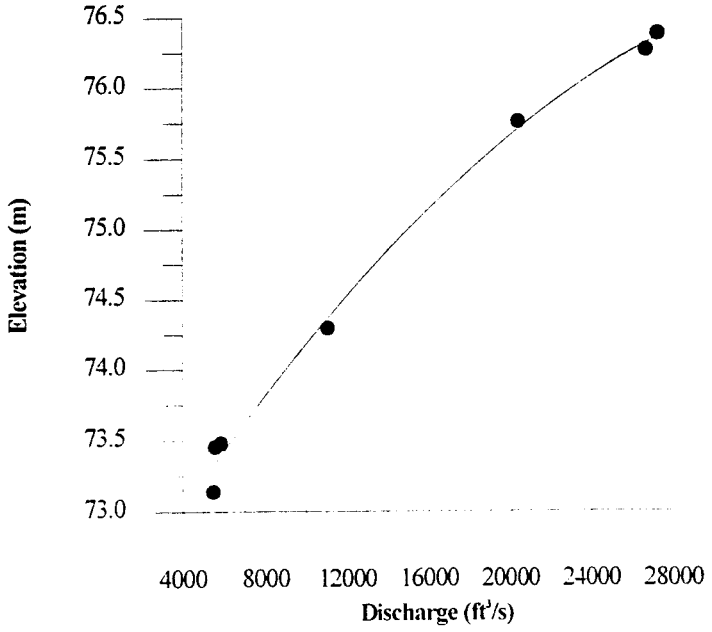


45 Mile

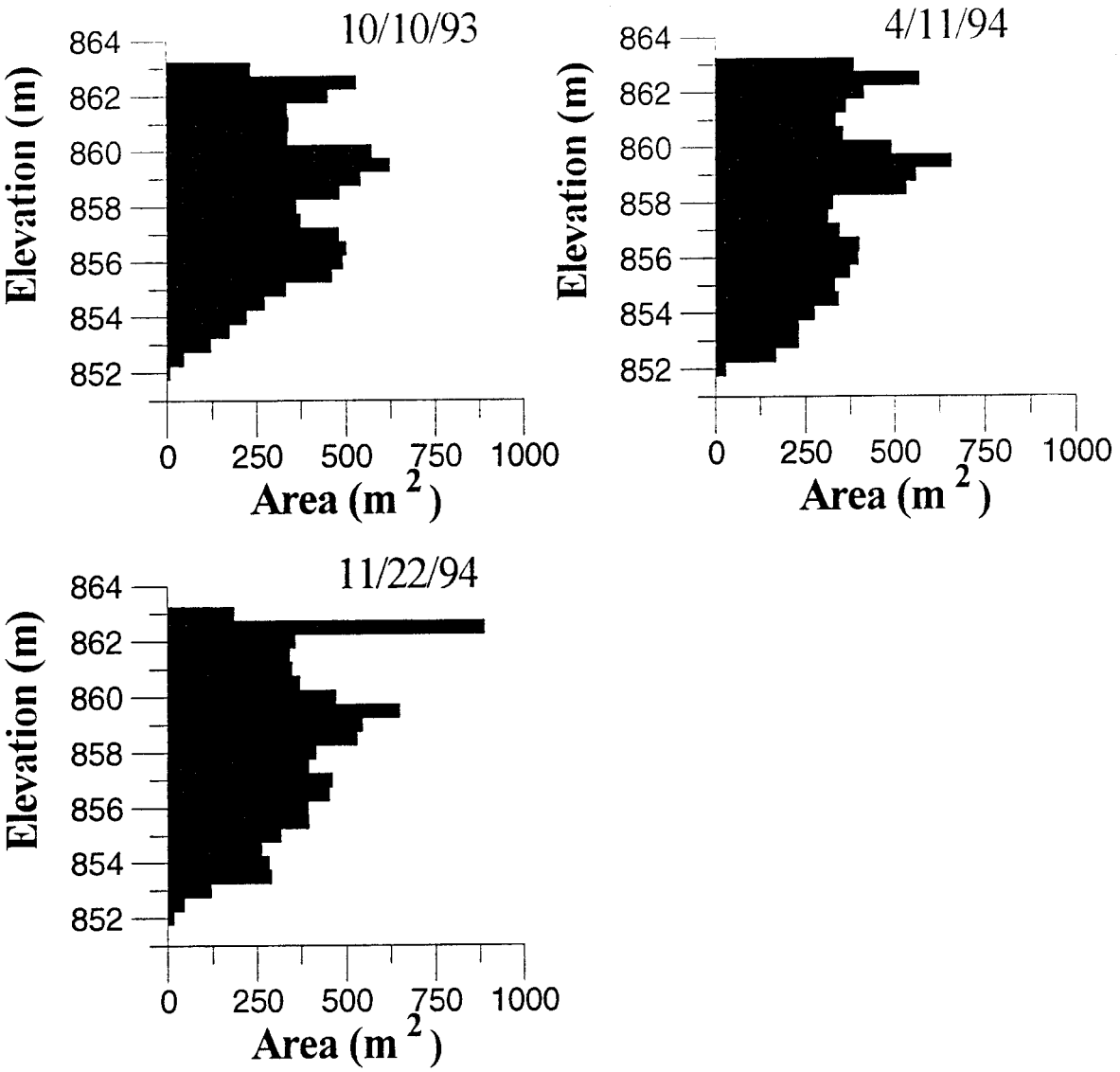
Hypsometric Curves

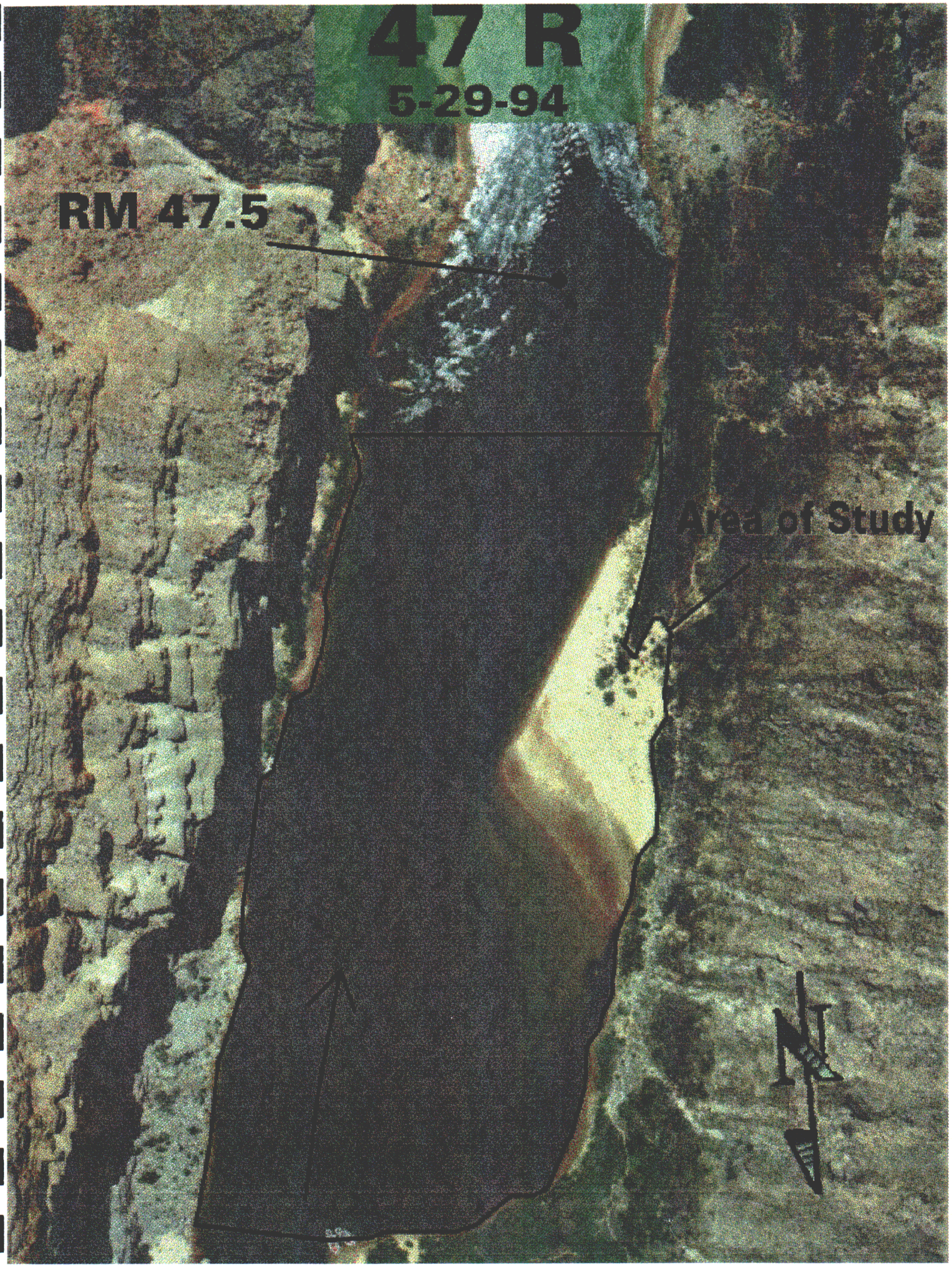


Stage Discharge



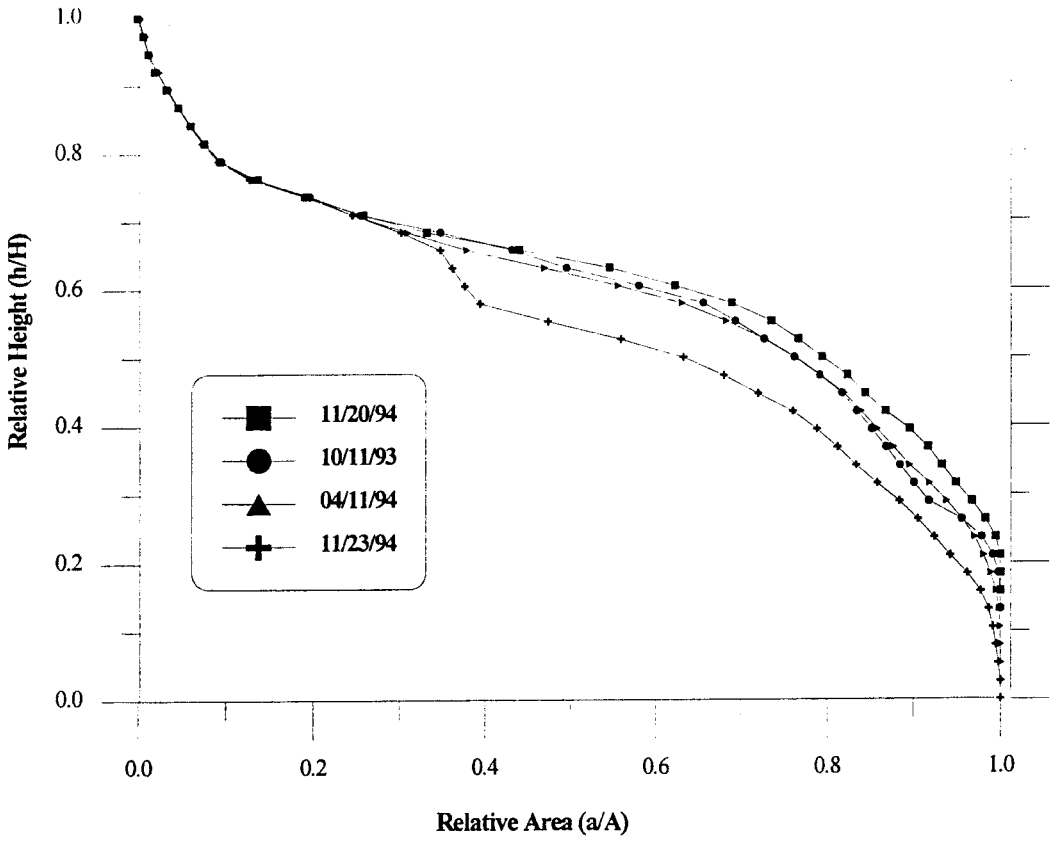
45 MILE
Area Distribution Histograms



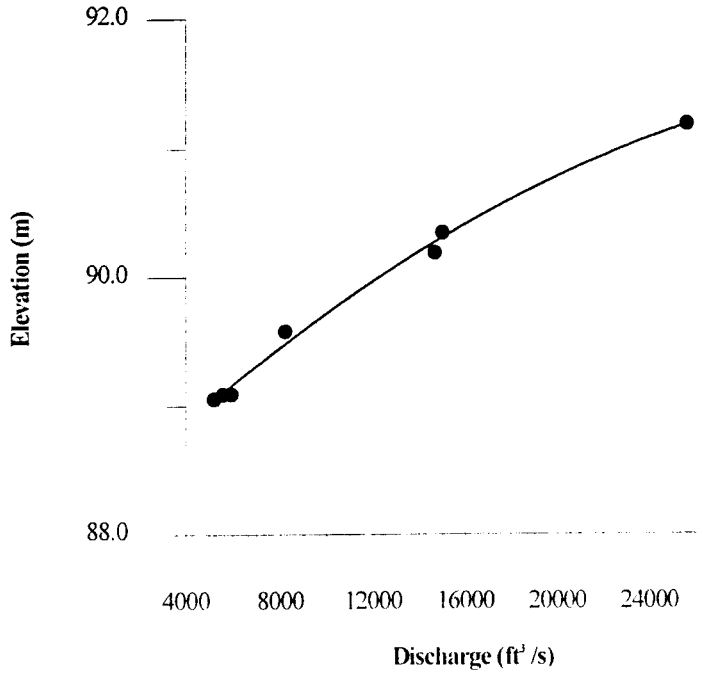

47 R
5-29-94
RM 47.5
Area of Study
N

47 Mile

Hypsometric Curves

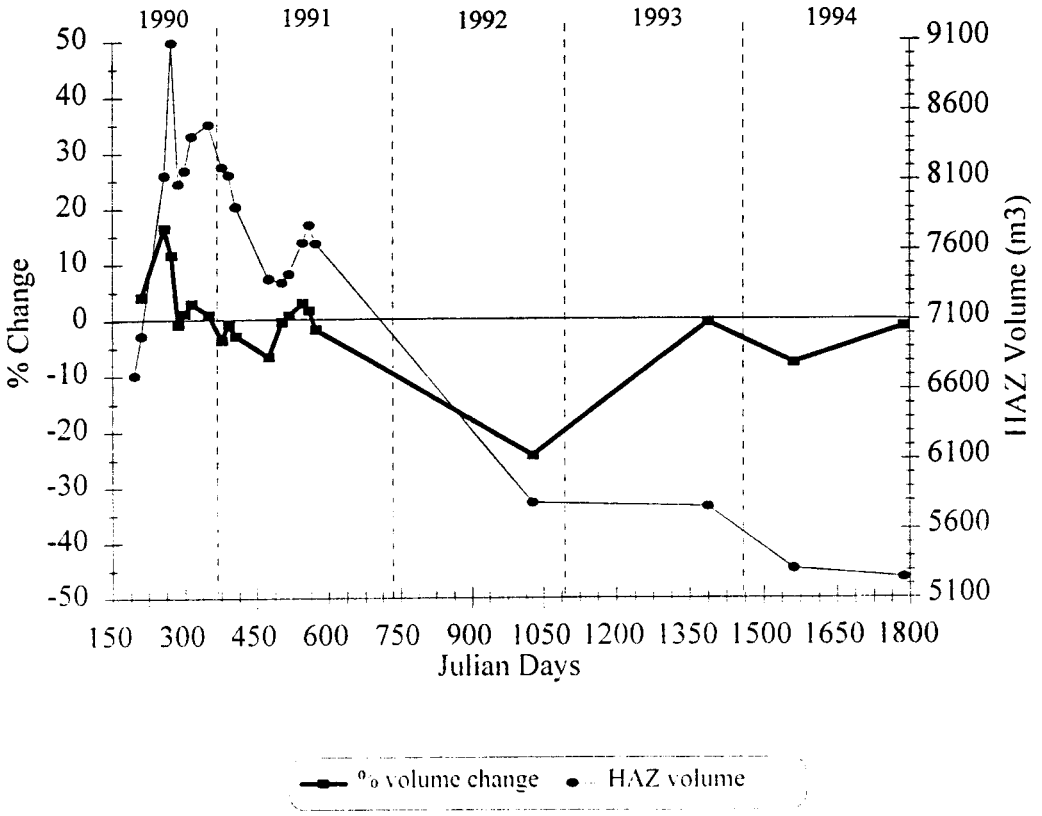


Stage Discharge

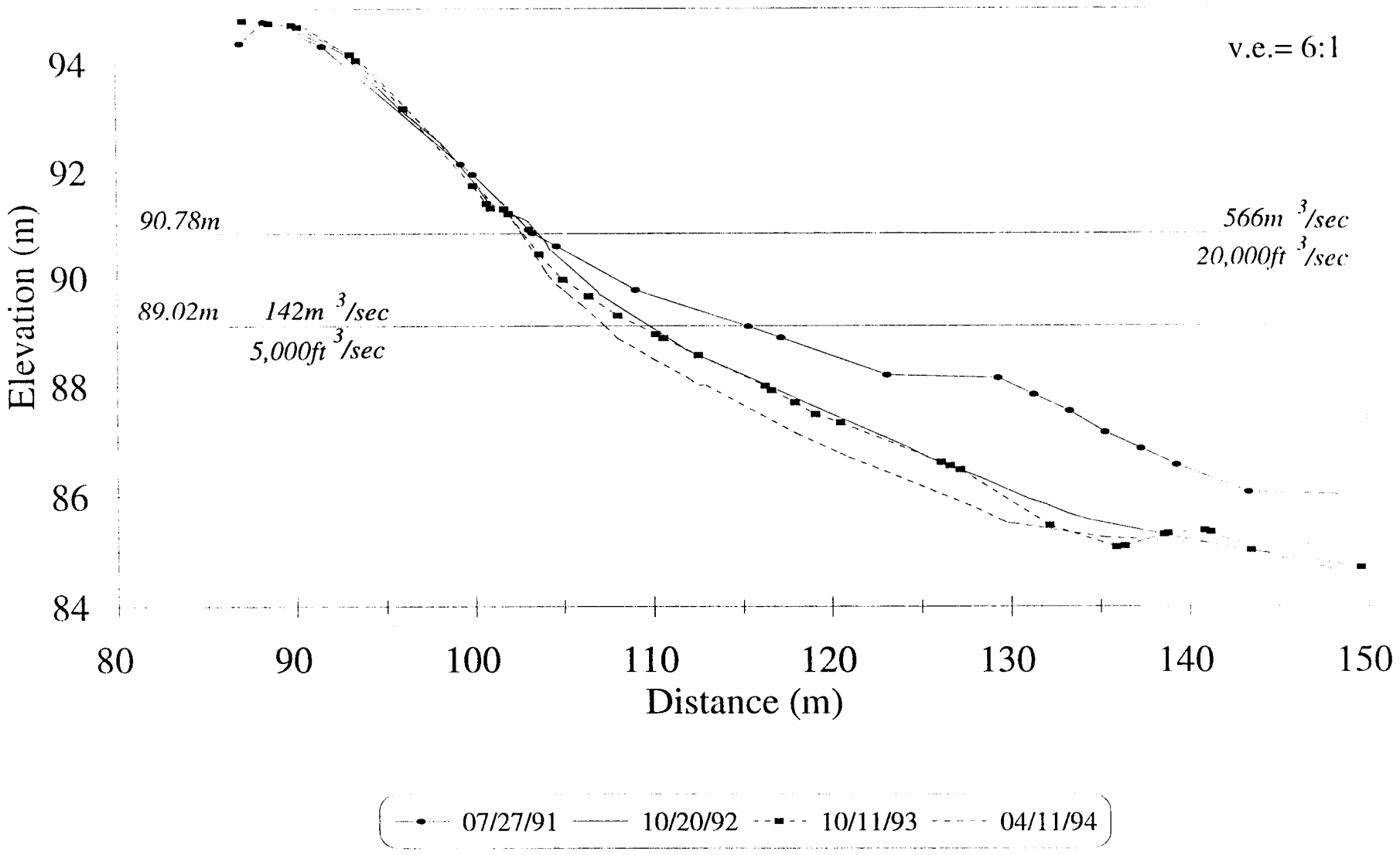


47 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C	907014	G	195	6575	6708				
D	900728	F	209	6914	6989	339	281	5.16	4.19
E		NORM							
F	900915	NORM	258	7555	8141	641	1152	9.27	16.48
G	900929	E	272	7829	9090	274	949	3.63	11.66
H	901013	A	286	7693	8077	138	-64	1.83	-0.79
I	901027	8000 CFS	300	7728	8173	35	96	0.45	1.19
J	901110	NORM	314	7615	8421	-113	248	-1.46	3.03
K	901215	NORM	349	7628	8507	13	86	0.17	1.02
L		11000 CFS							
M	910112	C	377	7298	8200	-330	-307	-4.33	-3.61
N	910126	NORM	391	7216	8144	-82	-56	-1.12	-0.68
O	910209	B	405	7083	7915	-133	-229	-1.84	-2.81
P	910420	NORM	475	6796	7393	-287	-522	-4.05	-6.60
Q	910503	NORM	488						
R	910518	D	503	6801	7366	5	-27	0.07	-0.37
S	900601	15000 CFS	517	6643	7428	-158	62	-2.32	0.84
T	910629	NORM	545	6951	7653	308	225	4.64	3.03
U	910713	G	559	7105	7781	154	128	2.22	1.67
V	910727	F	573	7180	7647	75	-134	1.06	-1.72
Y	921020	INT	1026	5923	5790	-1257	-1857	-17.51	-24.28
B12	931011	INT	1388	6078	5761	155	-29	2.62	-0.50
C12	940411	INT	1562	5273	5313	-805	-448	-13.24	-7.78
D12	941123	INT	1788	5028	5248	-245	-65	-4.65	-1.22

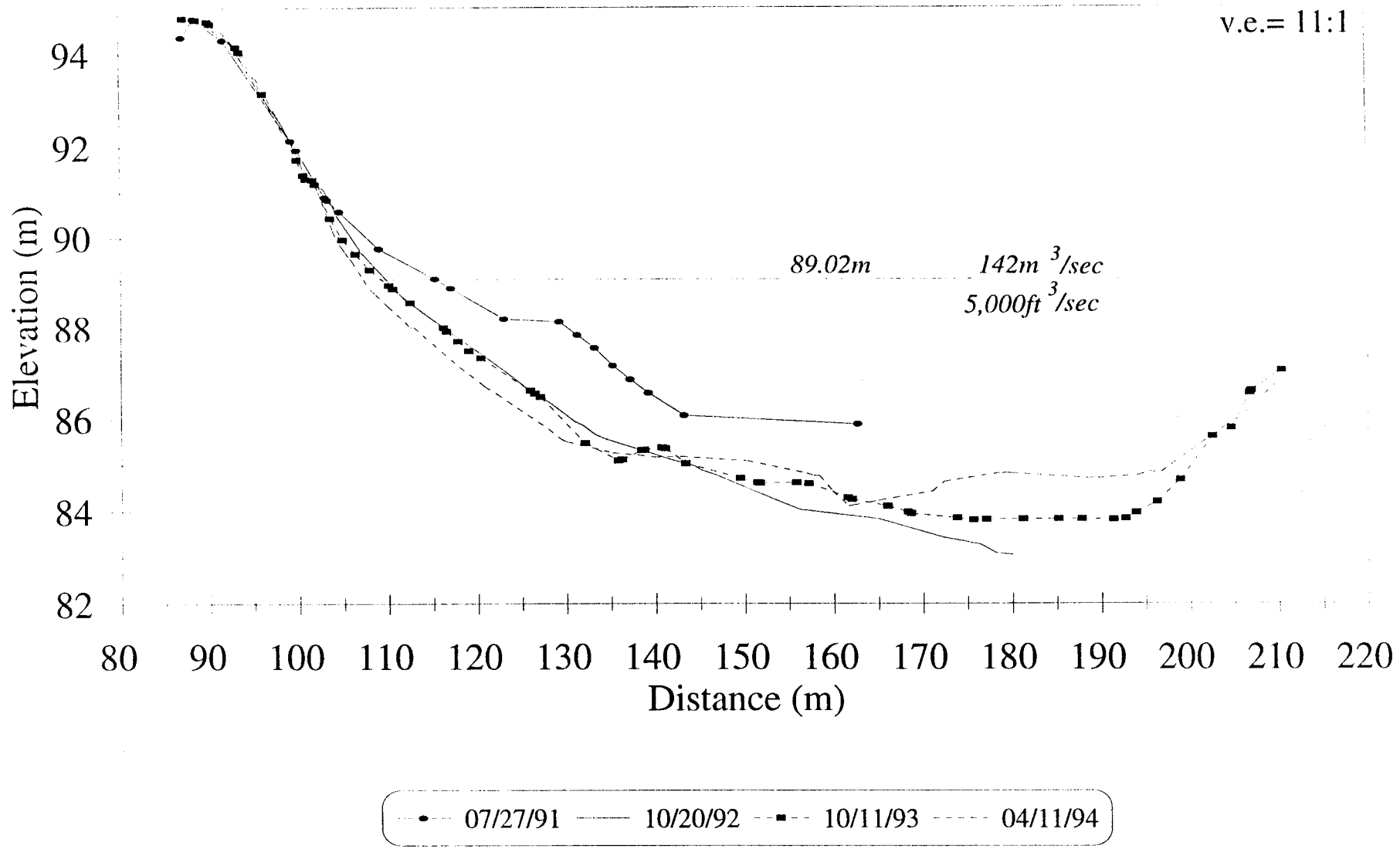


Near-shore P7

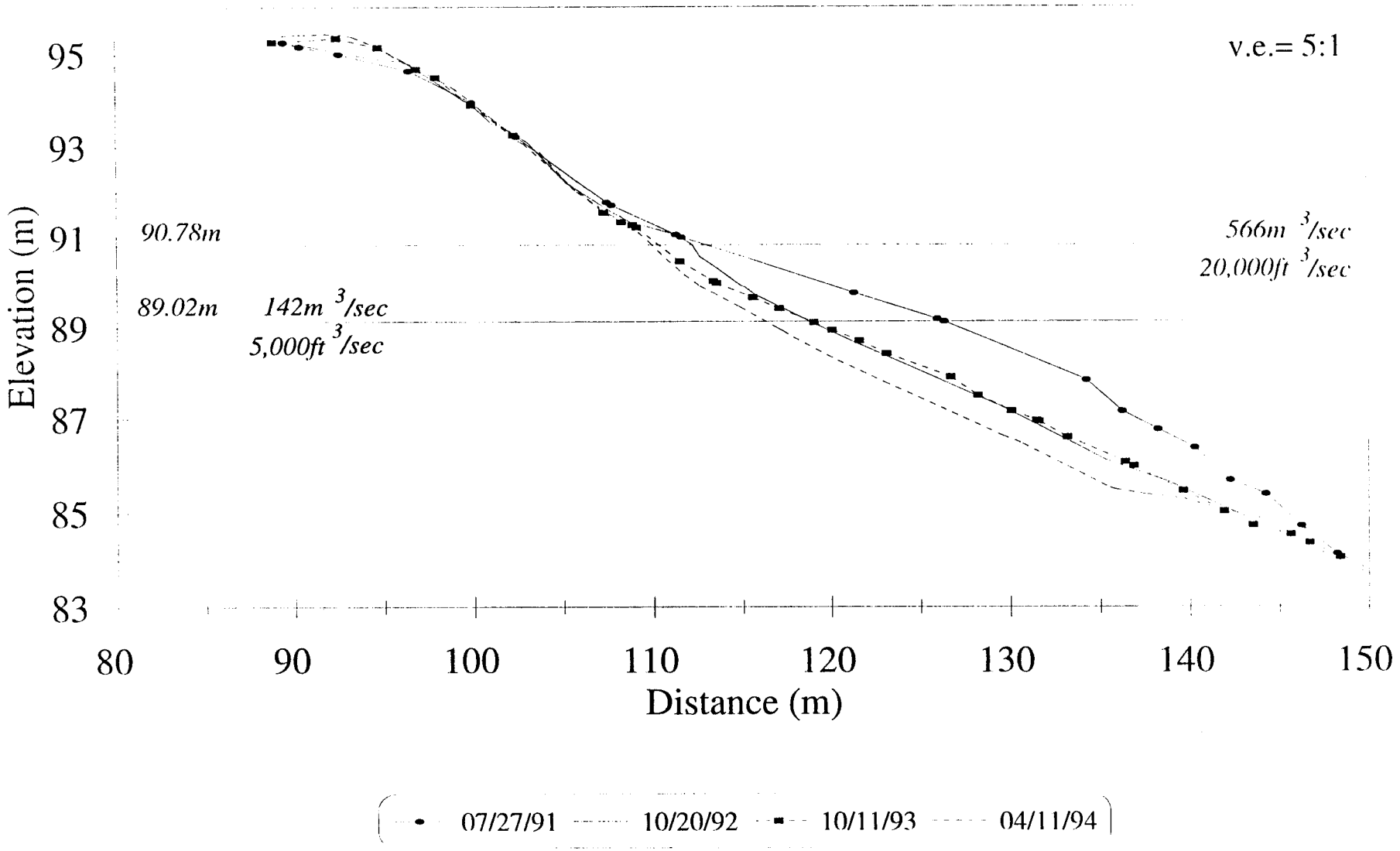


47 Mile

Cross-channel P7

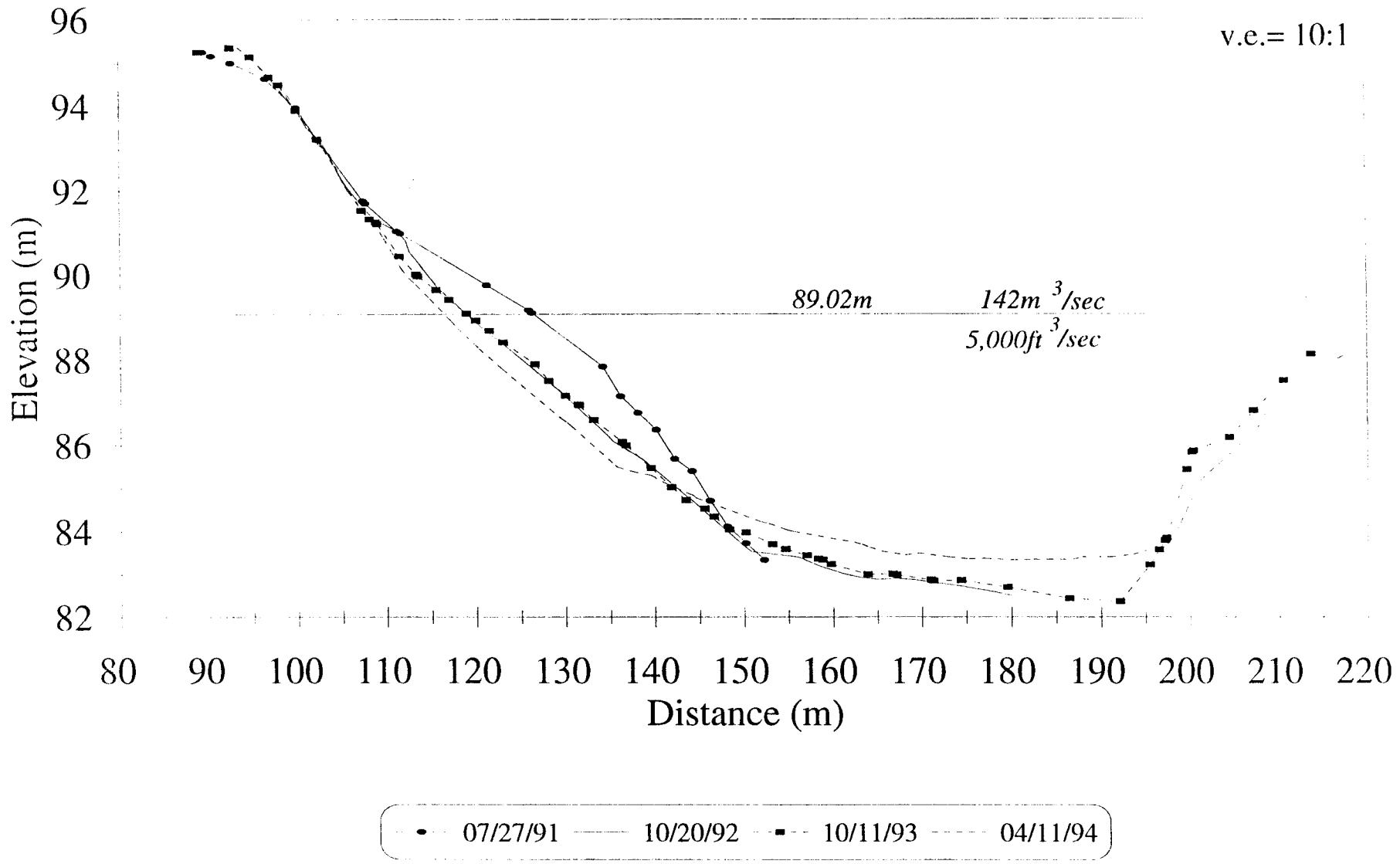


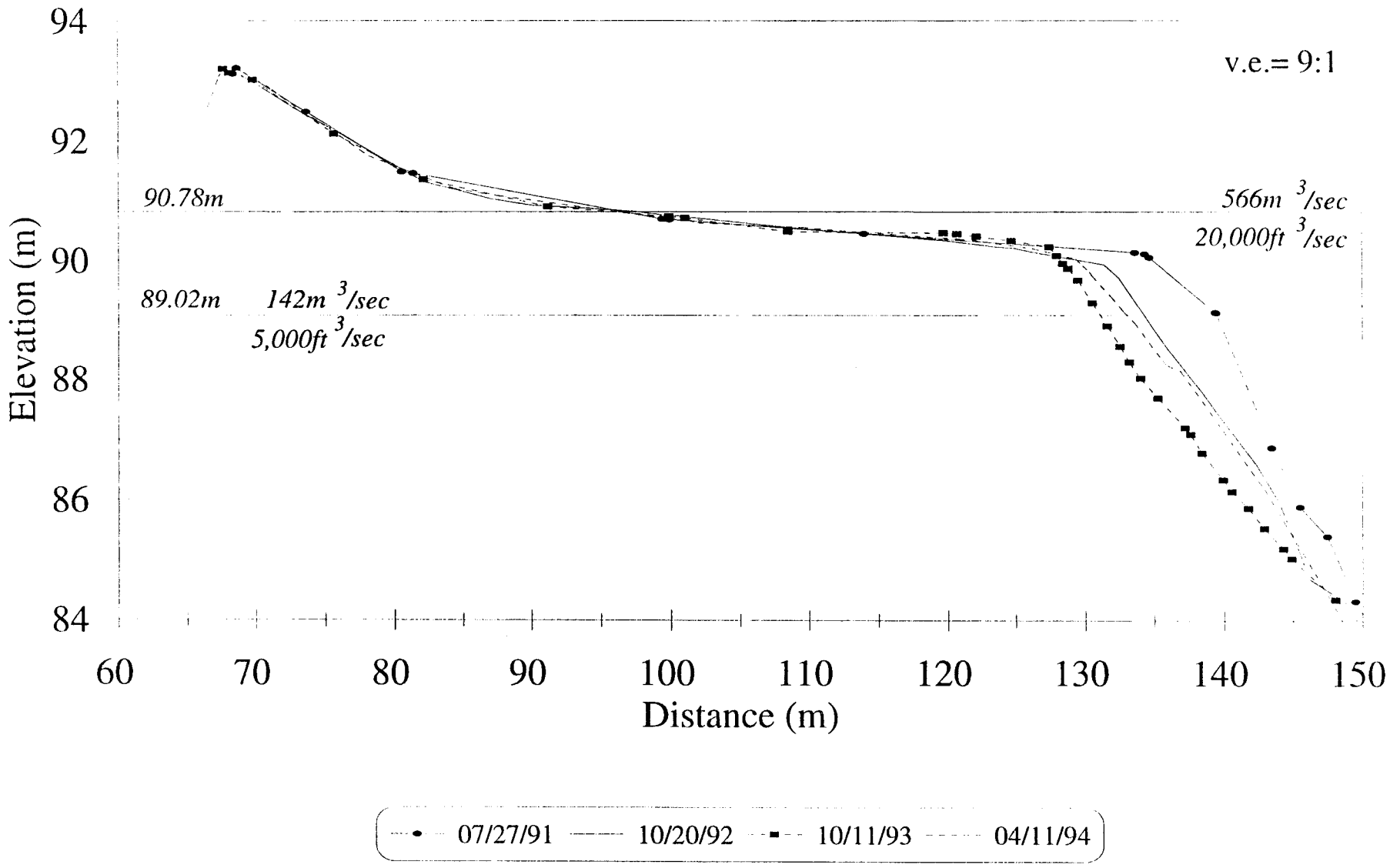
Near-shore P6



47 Mile

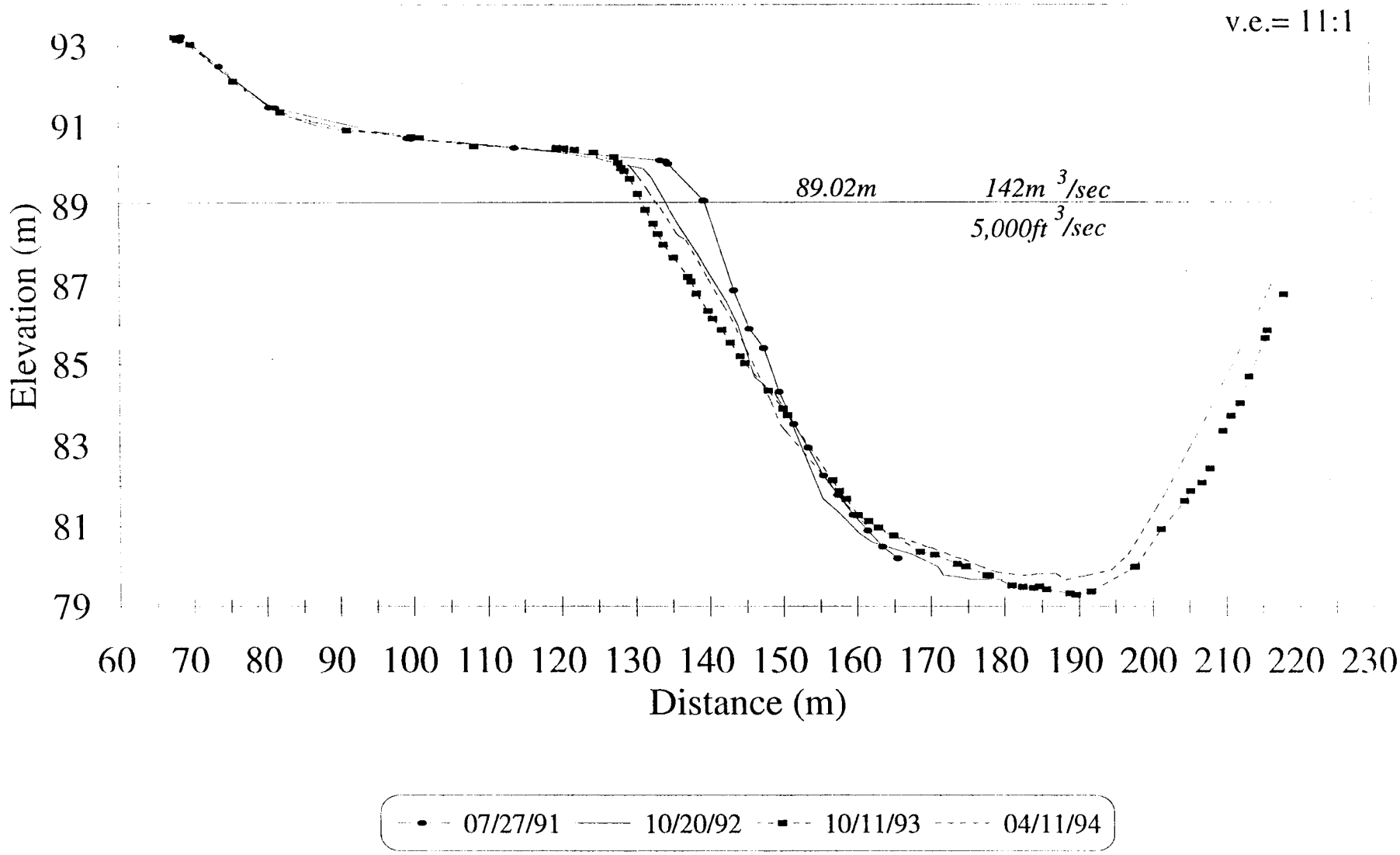
Cross-channel P6

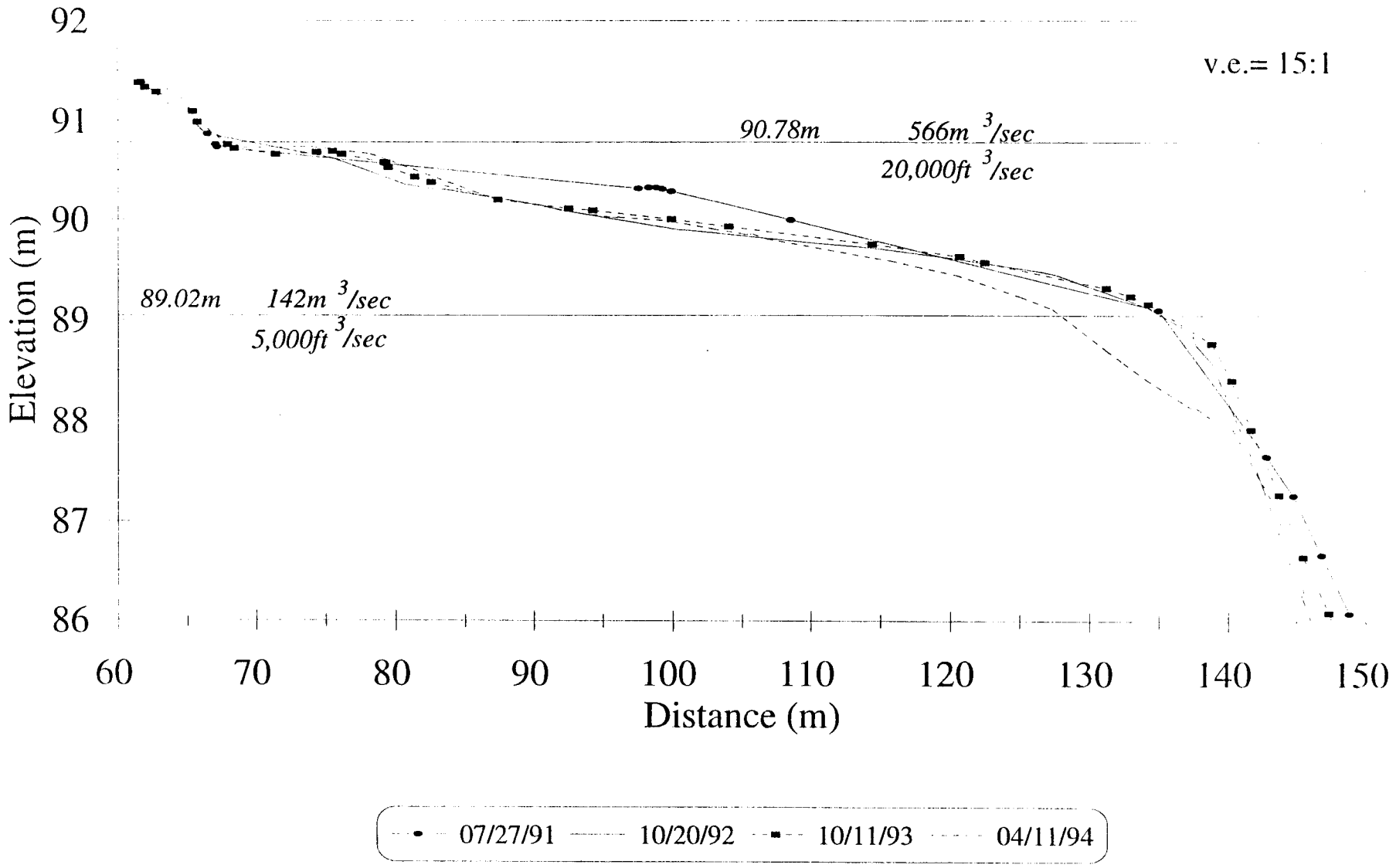



Near-shore P4
v.e.= 9:1
90.78m
566m 3/sec
20,000ft 3/sec
89.02m
142m 3/sec
5,000ft 3/sec
Elevation (m)
94
92
90
88
86
84
60
70
80
90
100
110
120
130
140
150
Distance (m)
07/27/91
10/20/92
10/11/93
04/11/94

47 Mile

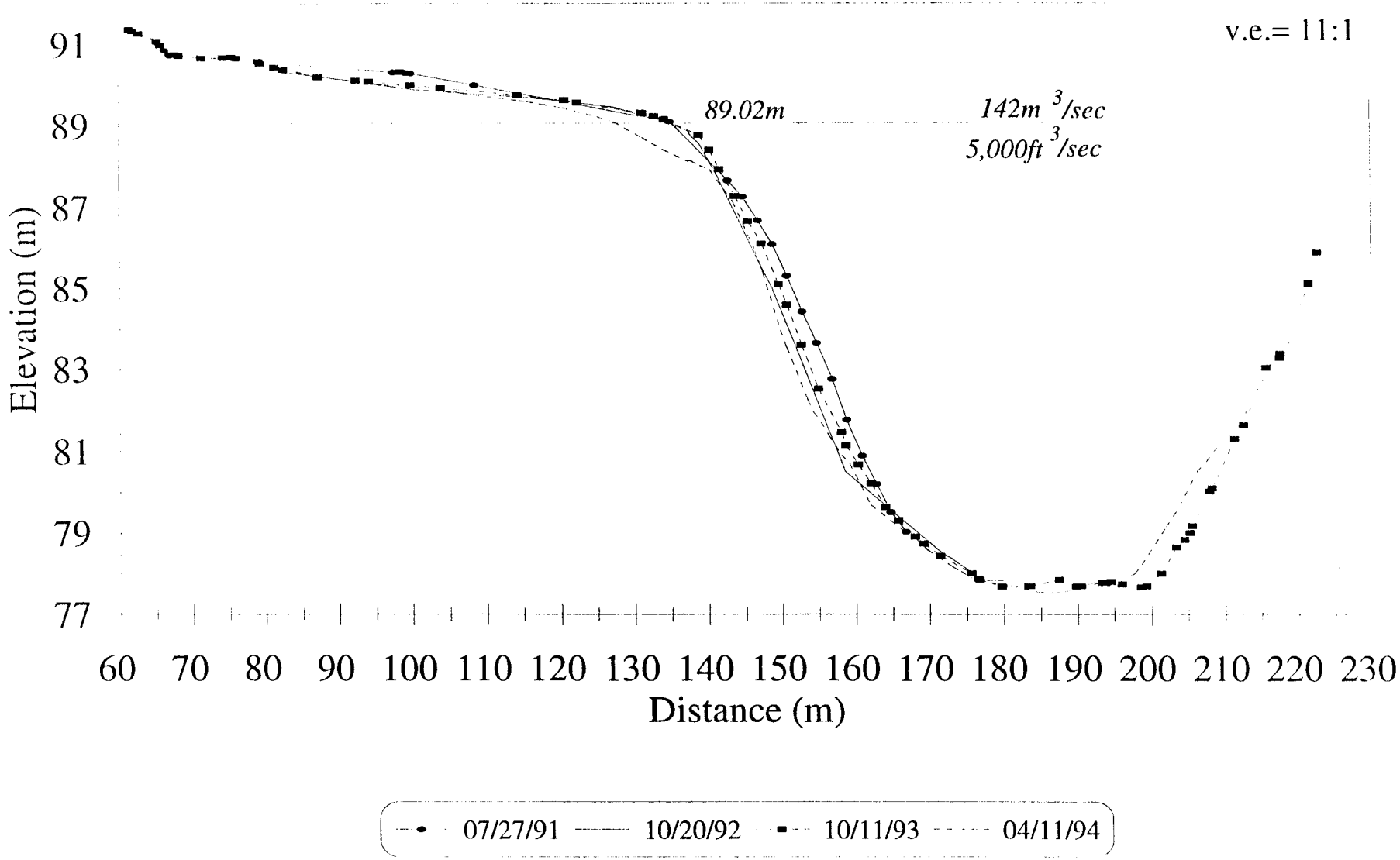
Cross-channel P4

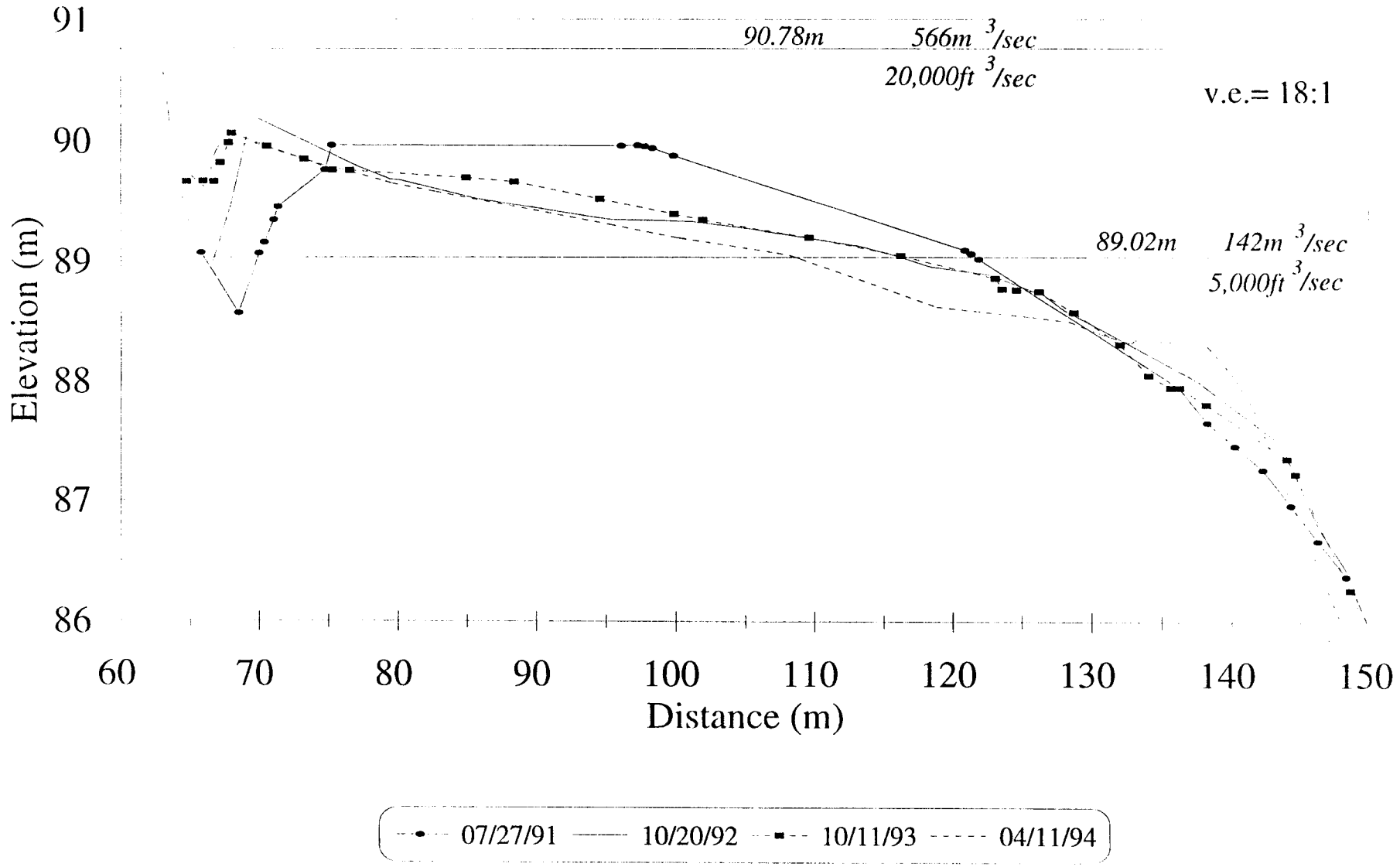



Near-shore P3
v.e.= 15:1
90.78m
566m 3/sec
20,000ft 3/sec
89.02m
142m 3/sec
5,000ft 3/sec
Elevation (m)
92
91
90
89
88
87
86
60
70
80
90
100
110
120
130
140
150
Distance (m)
07/27/91
10/20/92
10/11/93
04/11/94

47 Mile

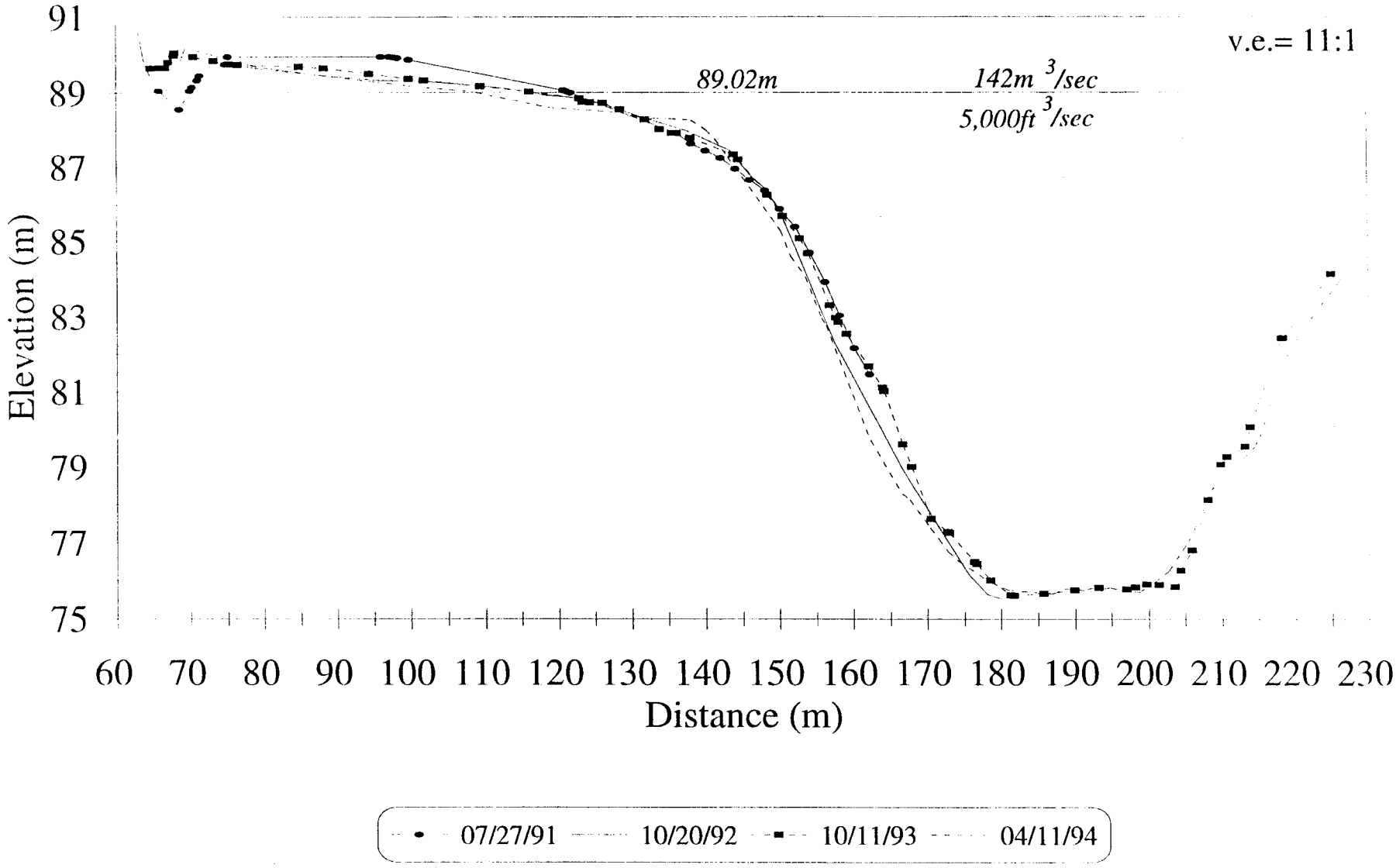
Cross-channel P3

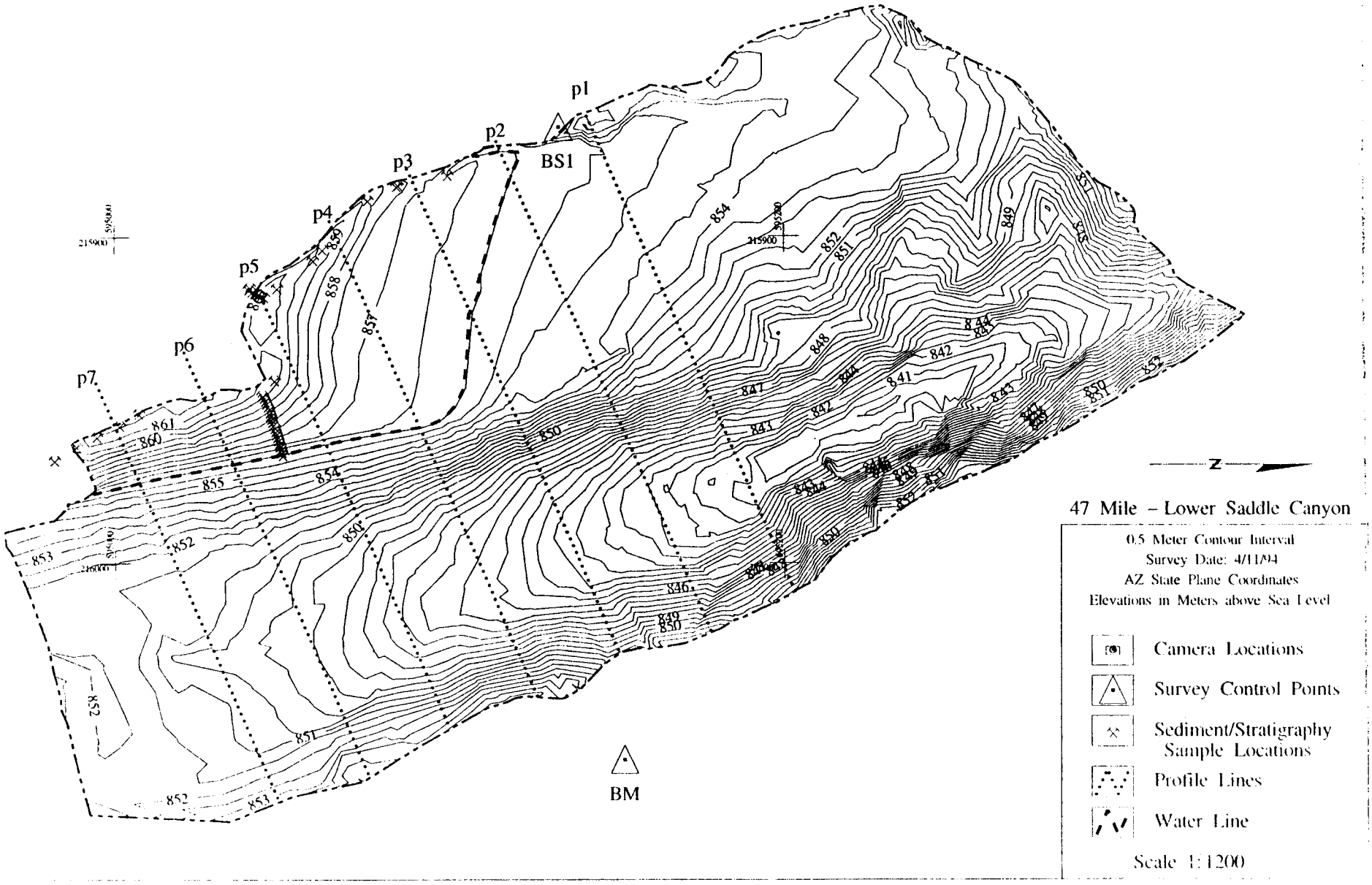



Near-shore P2
91
90
89
88
87
86
Elevation (m)
90.78m
566m 3/sec
20,000ft 3/sec
v.e.= 18:1
89.02m
142m 3/sec
5,000ft 3/sec
60
70
80
90
100
110
120
130
140
150
Distance (m)
07/27/91
10/20/92
10/11/93
04/11/94

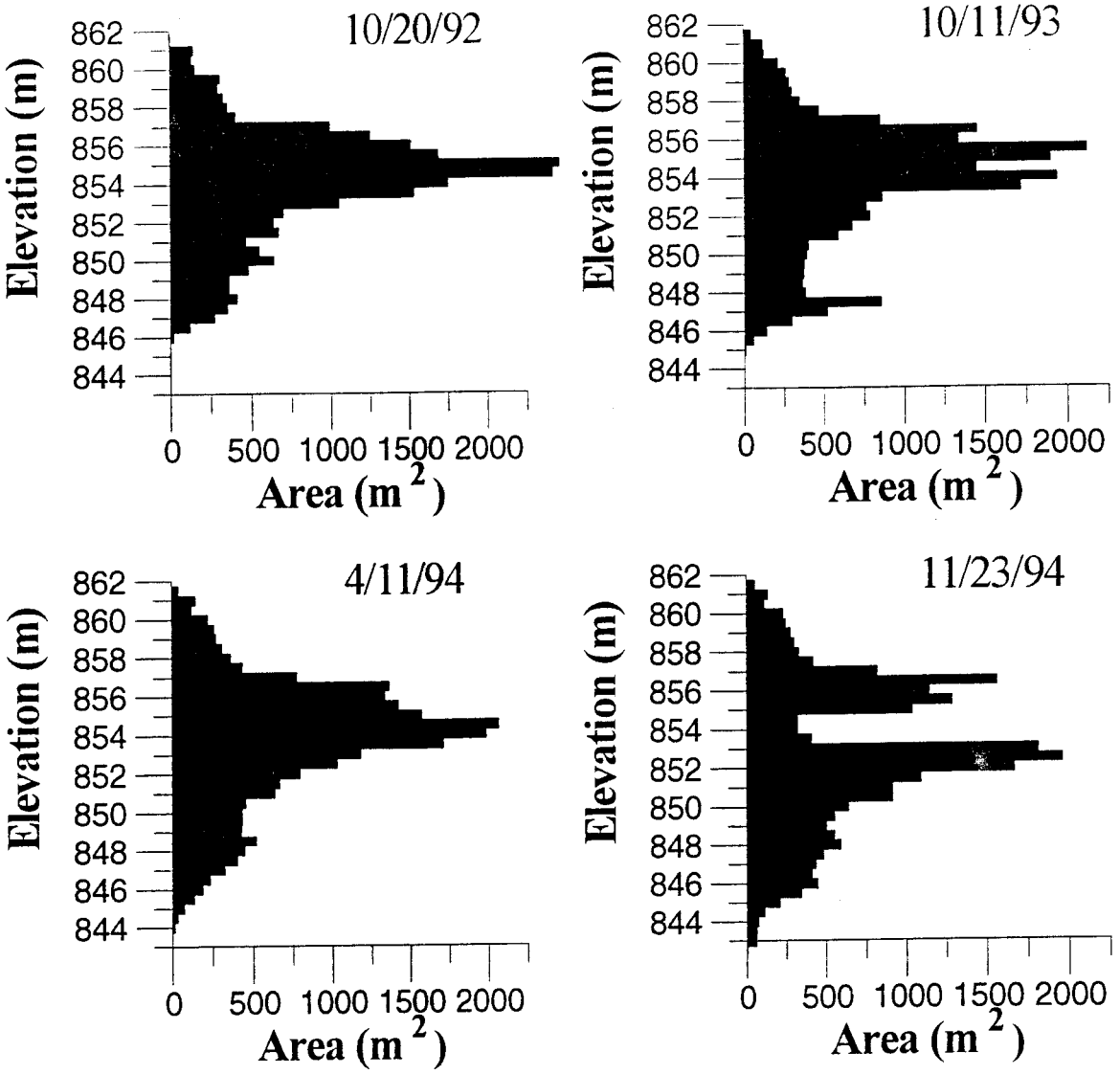
47 Mile

Cross-channel P2

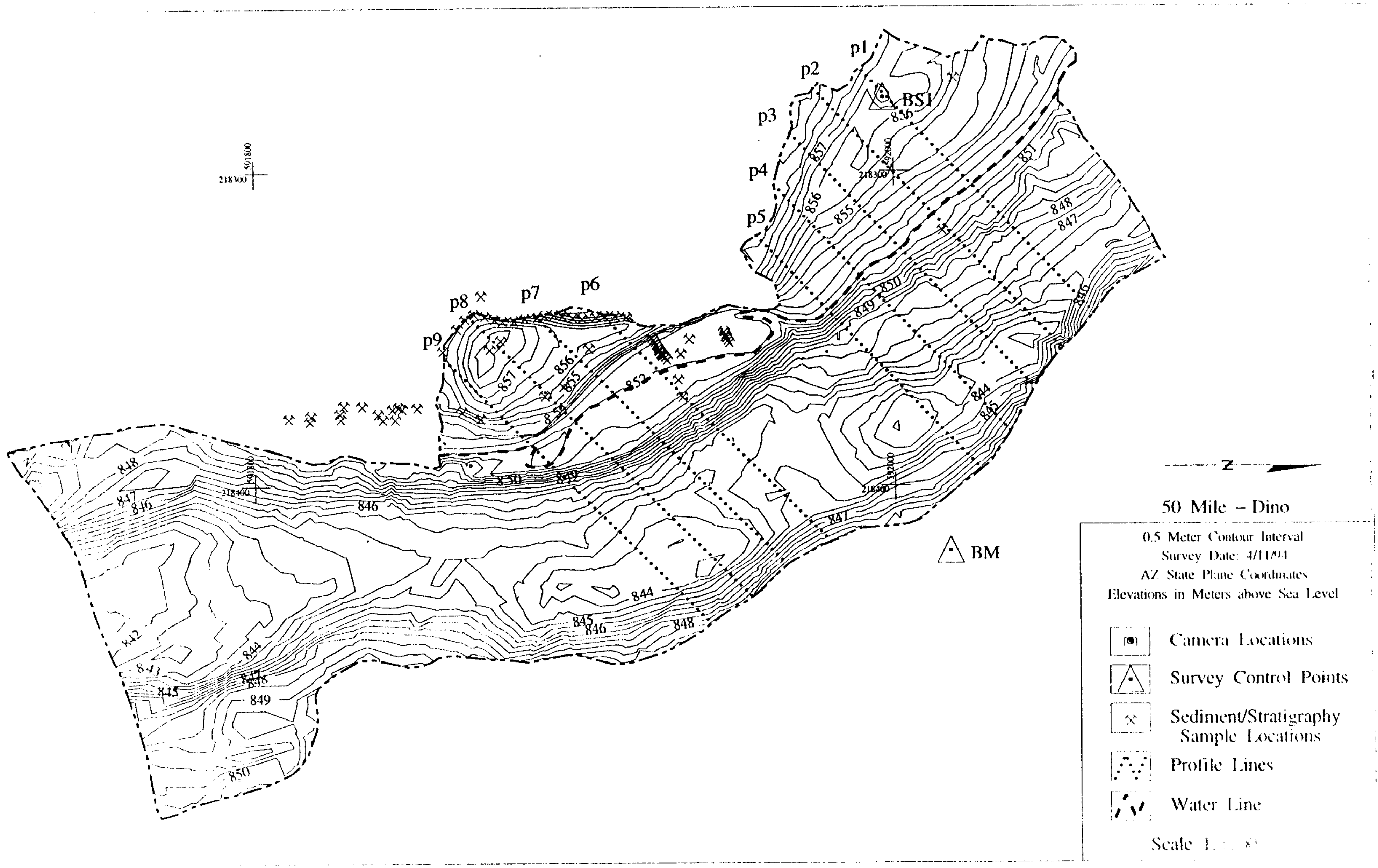



p1
p2
BS1
p3
p4
p5
p6
p7
BM
N
47 Mile – Lower Saddle Canyon
0.5 Meter Contour Interval
Survey Date: 4/11/04
AZ State Plane Coordinates
Elevations in Meters above Sea Level
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:1200

47 MILE
Area Distribution Histograms

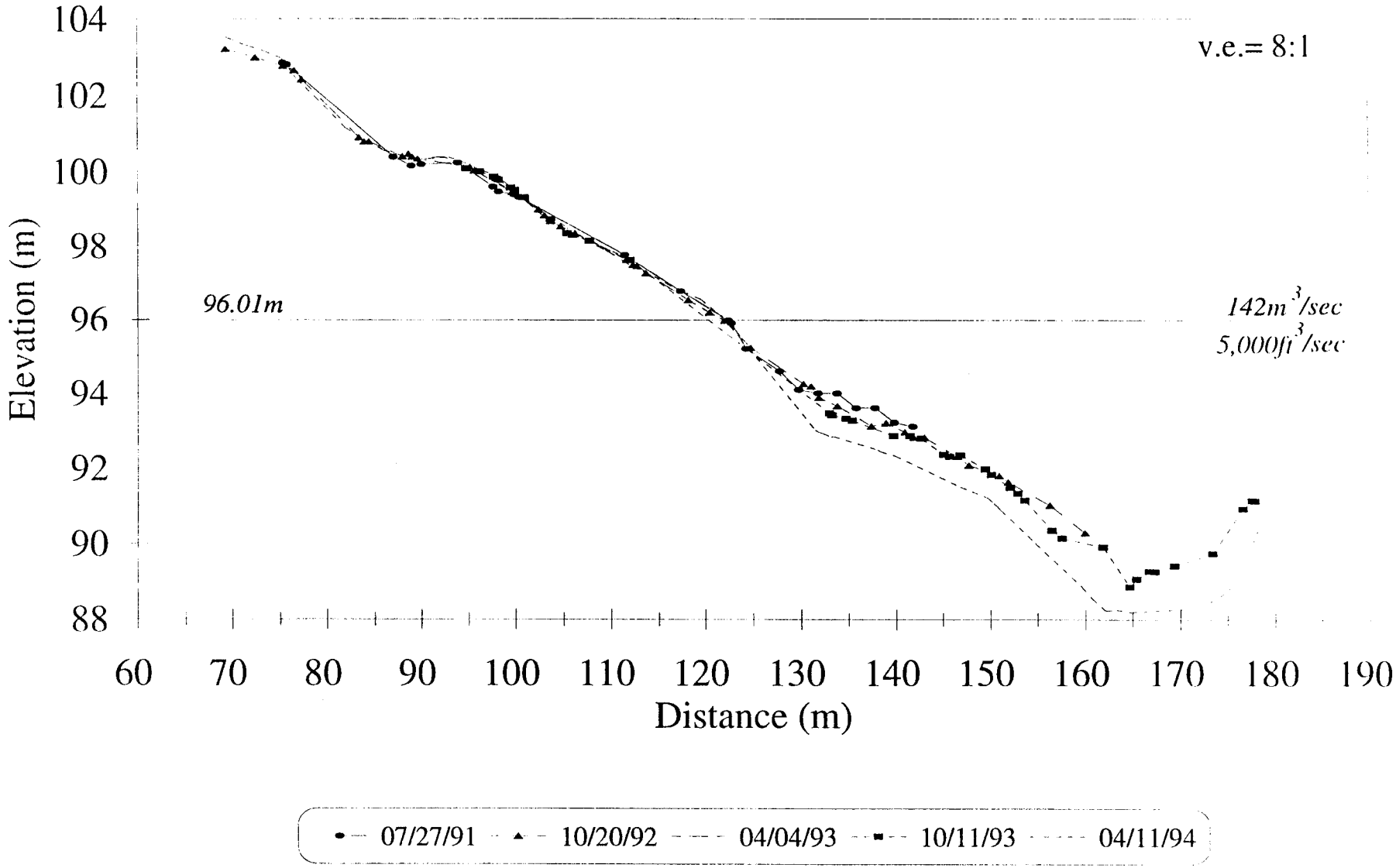


50 R
5-29-94
RM 50.0
Area of Study
N


N
50 Mile – Dino
0.5 Meter Contour Interval
Survey Date: 4/11/94
AZ State Plane Coordinates
Elevations in Meters above Sea Level
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
BM
BS1
p1
p2
p3
p4
p5
p6
p7
p8
p9
218300
591800
592000
218400

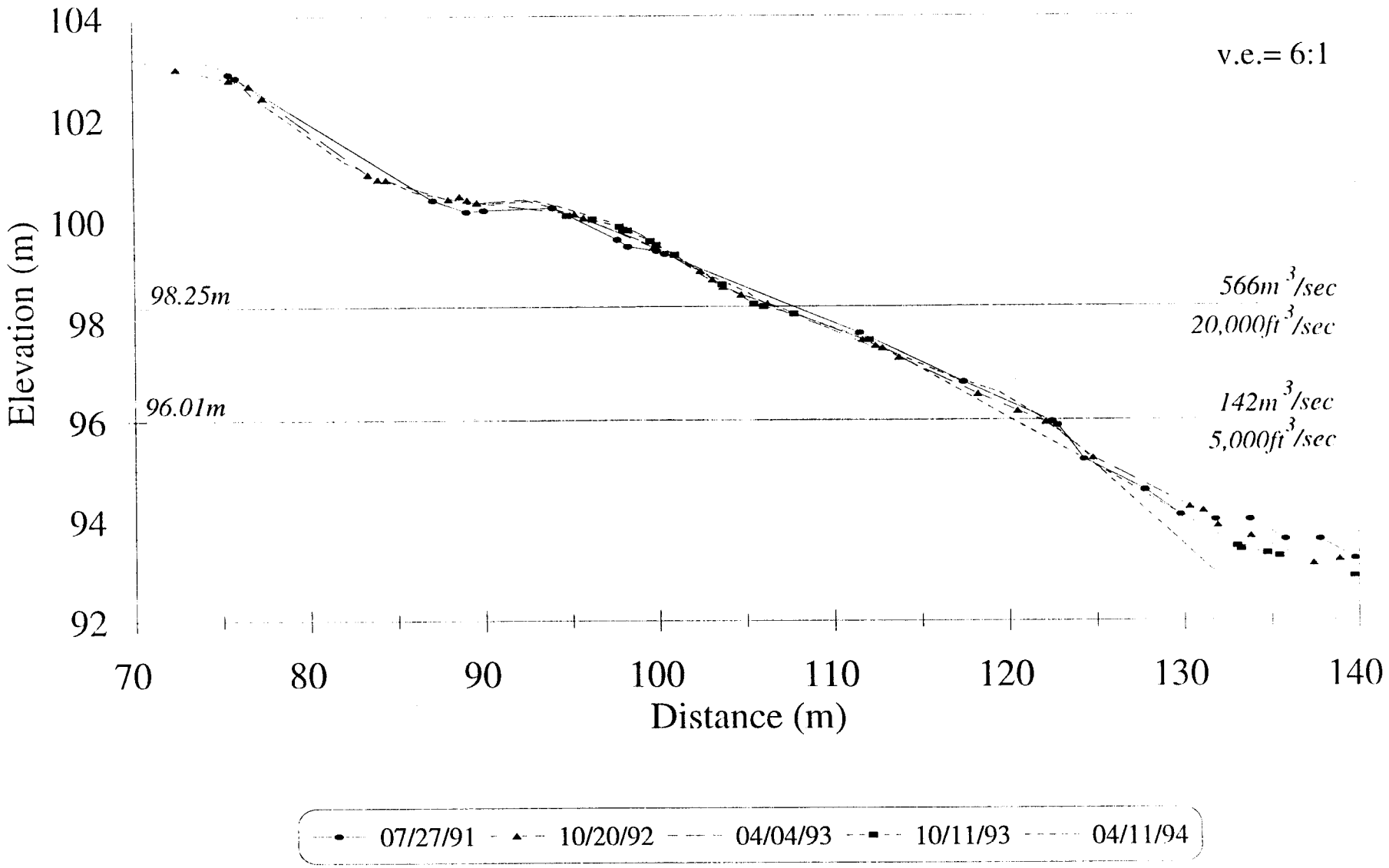
50 Mile

Cross-channel P3



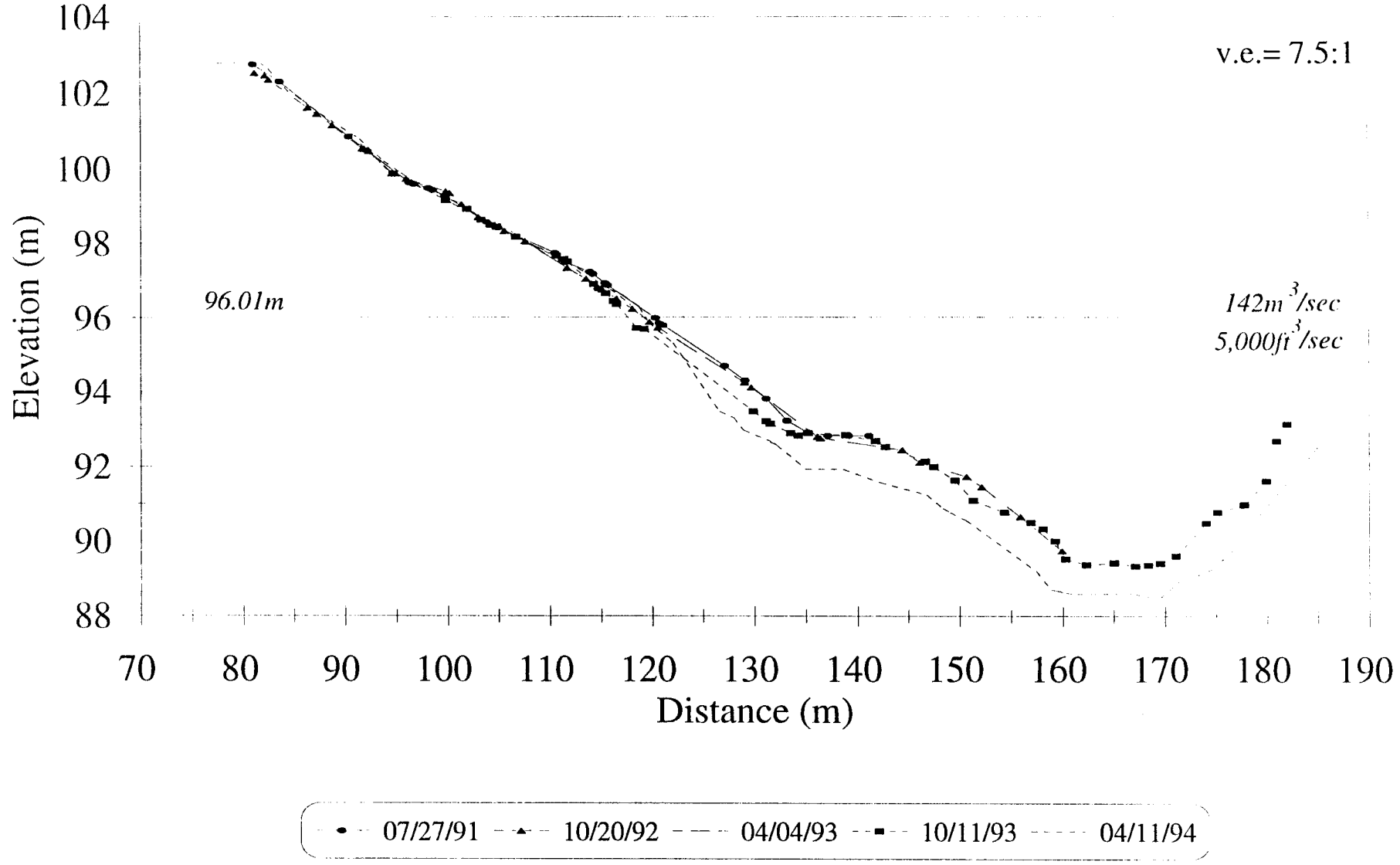
50 Mile

Near-shore P3



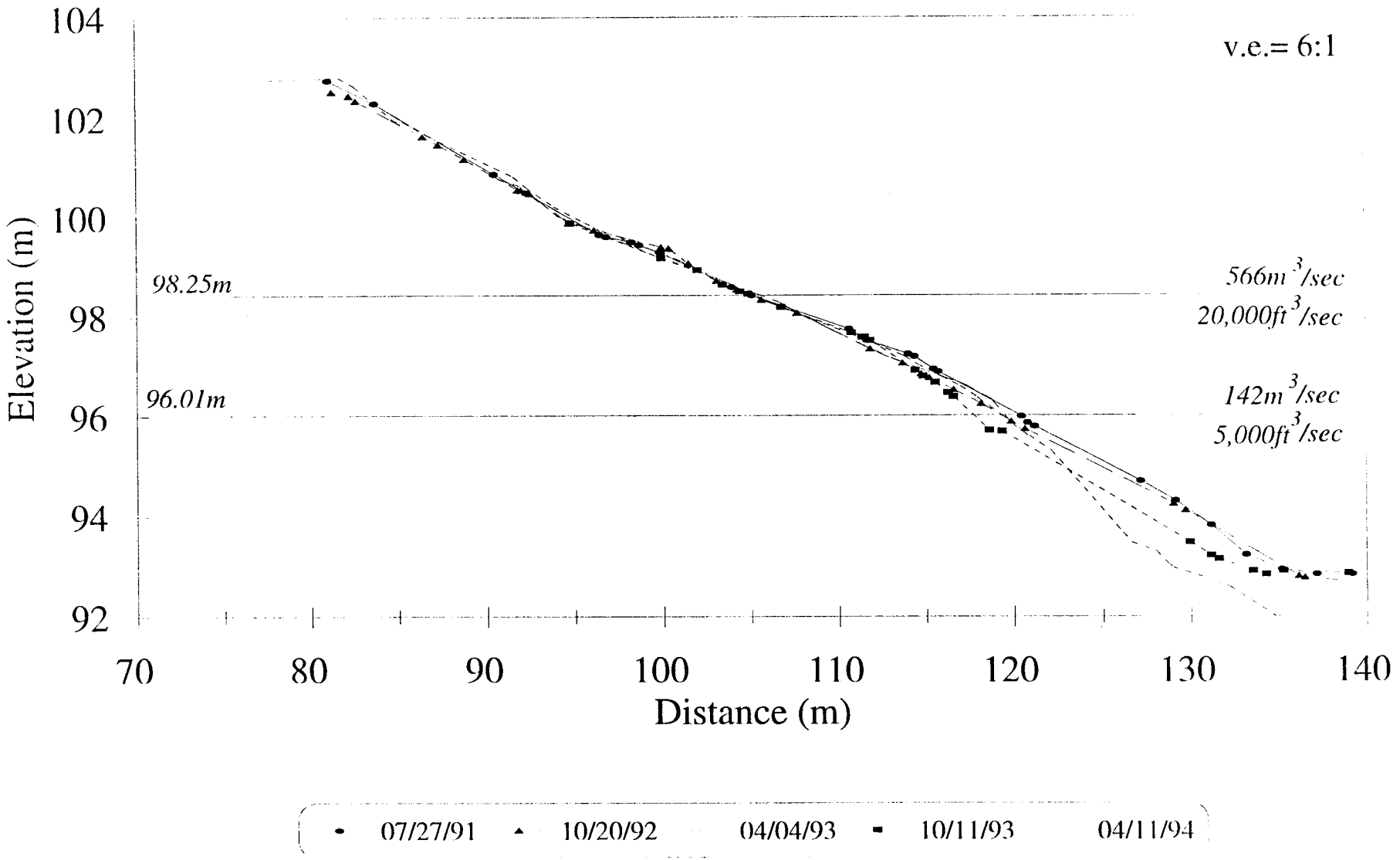
50 Mile

Cross-channel P4



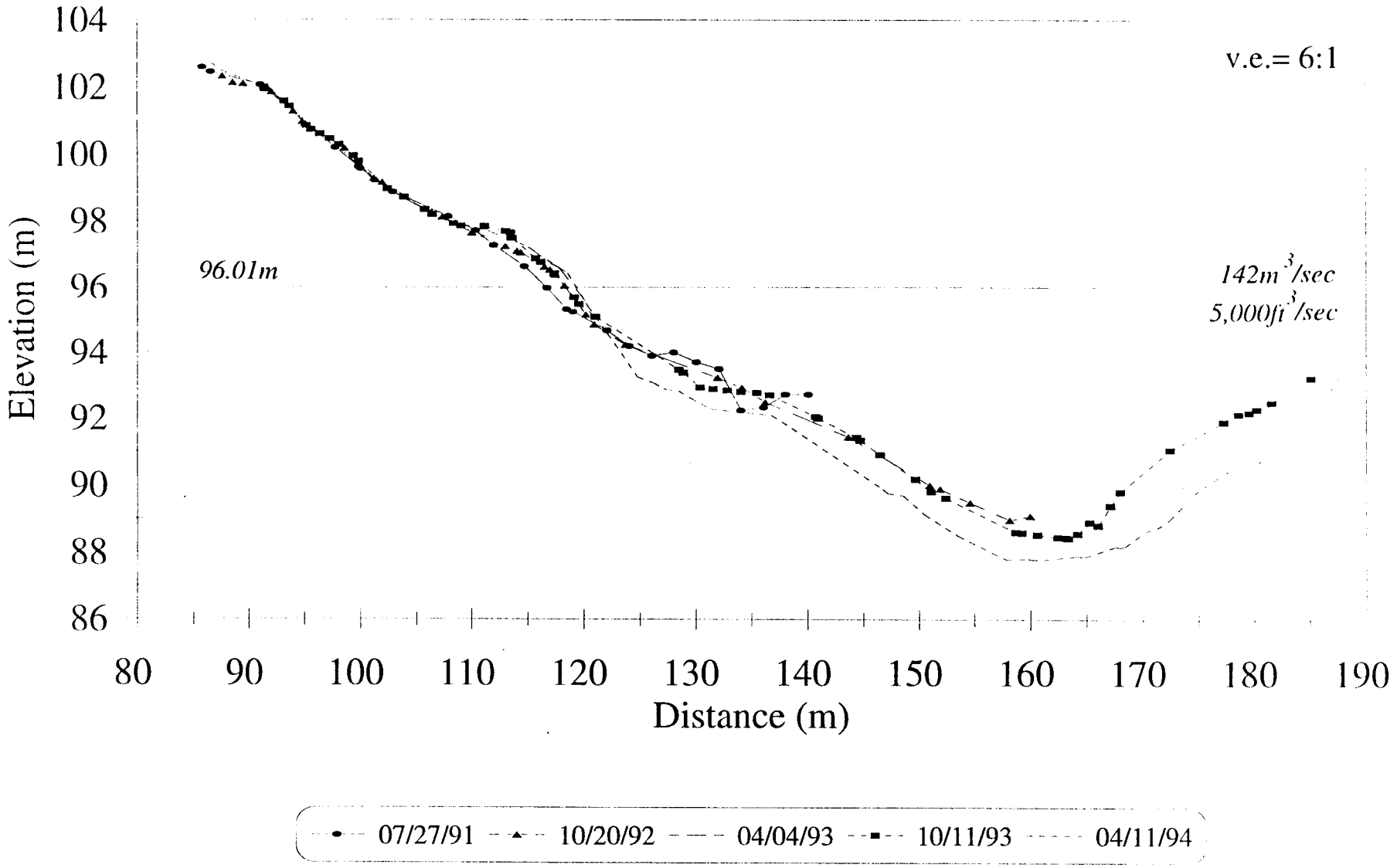
50 Mile

Near-shore P4



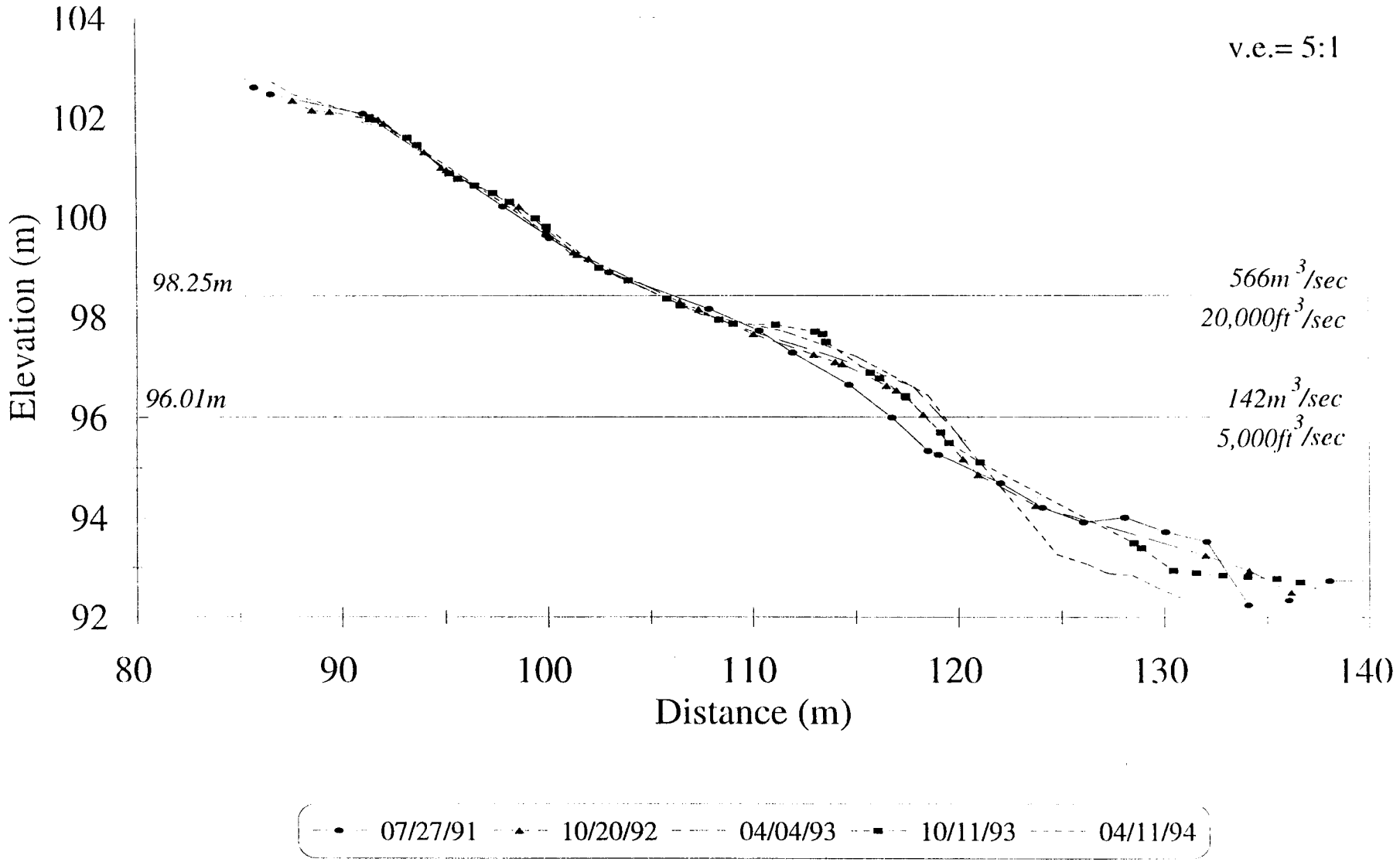
50 Mile

Cross-channel P5



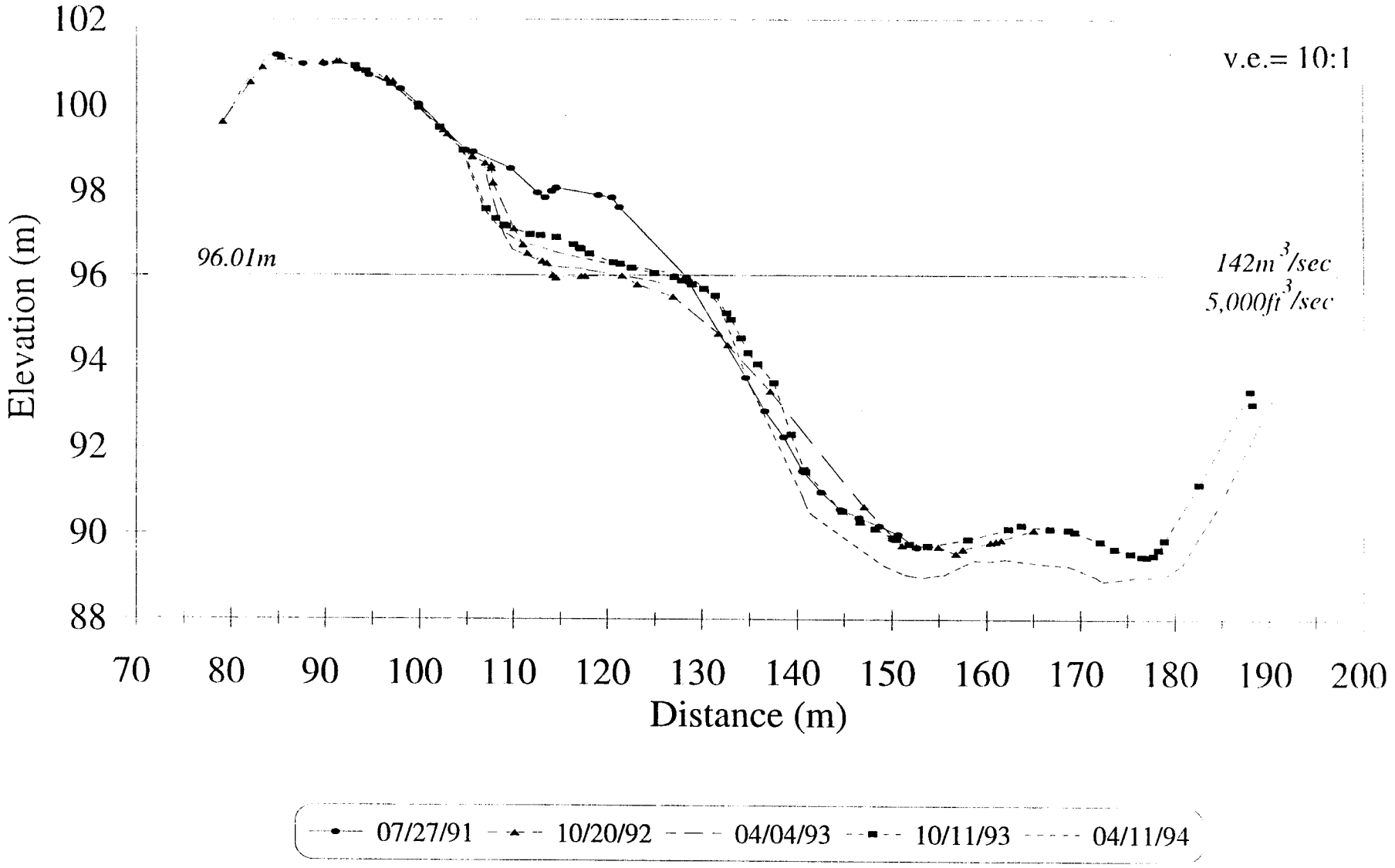
50 Mile

Near-shore P5



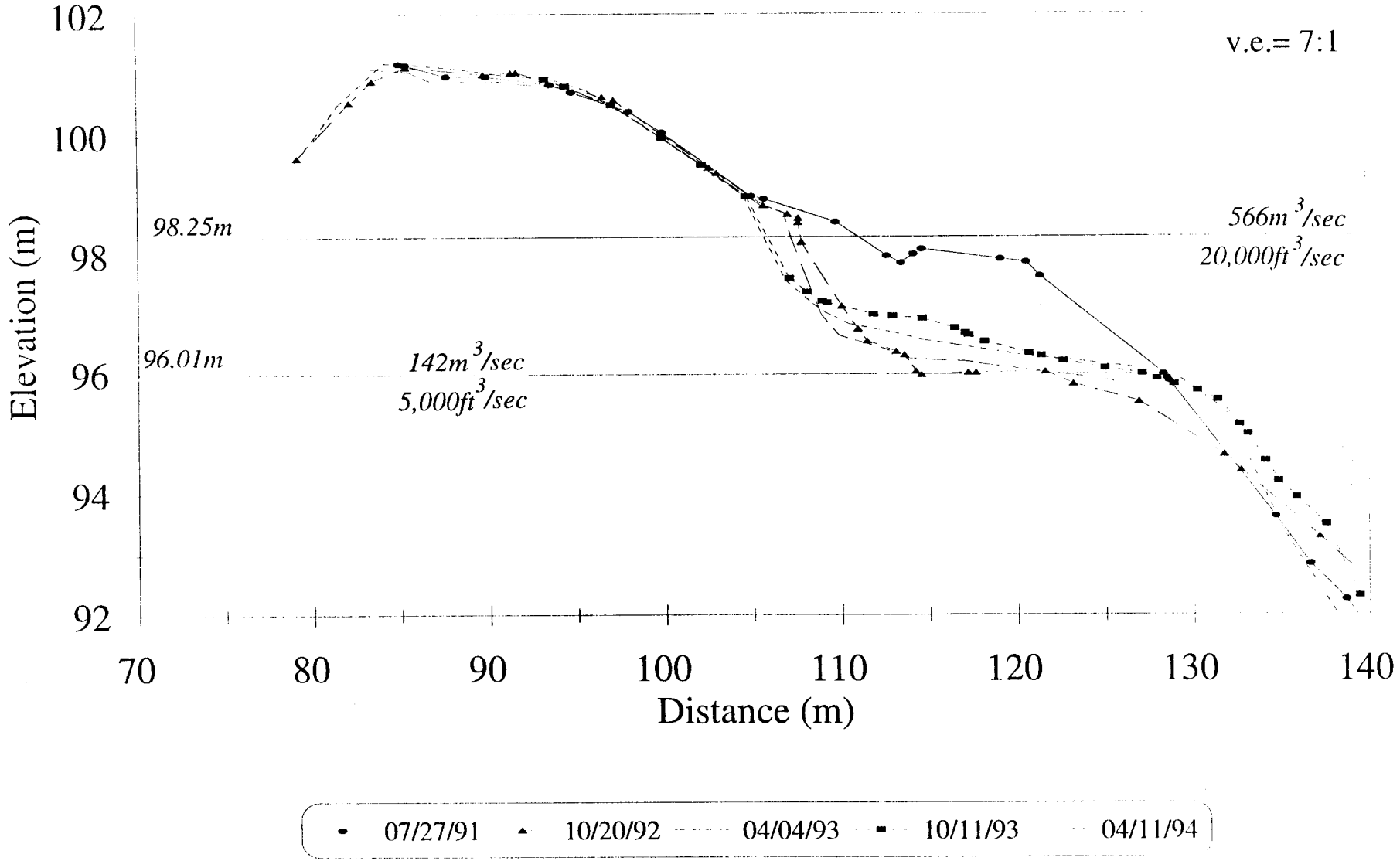
50 Mile

Cross-channel P7



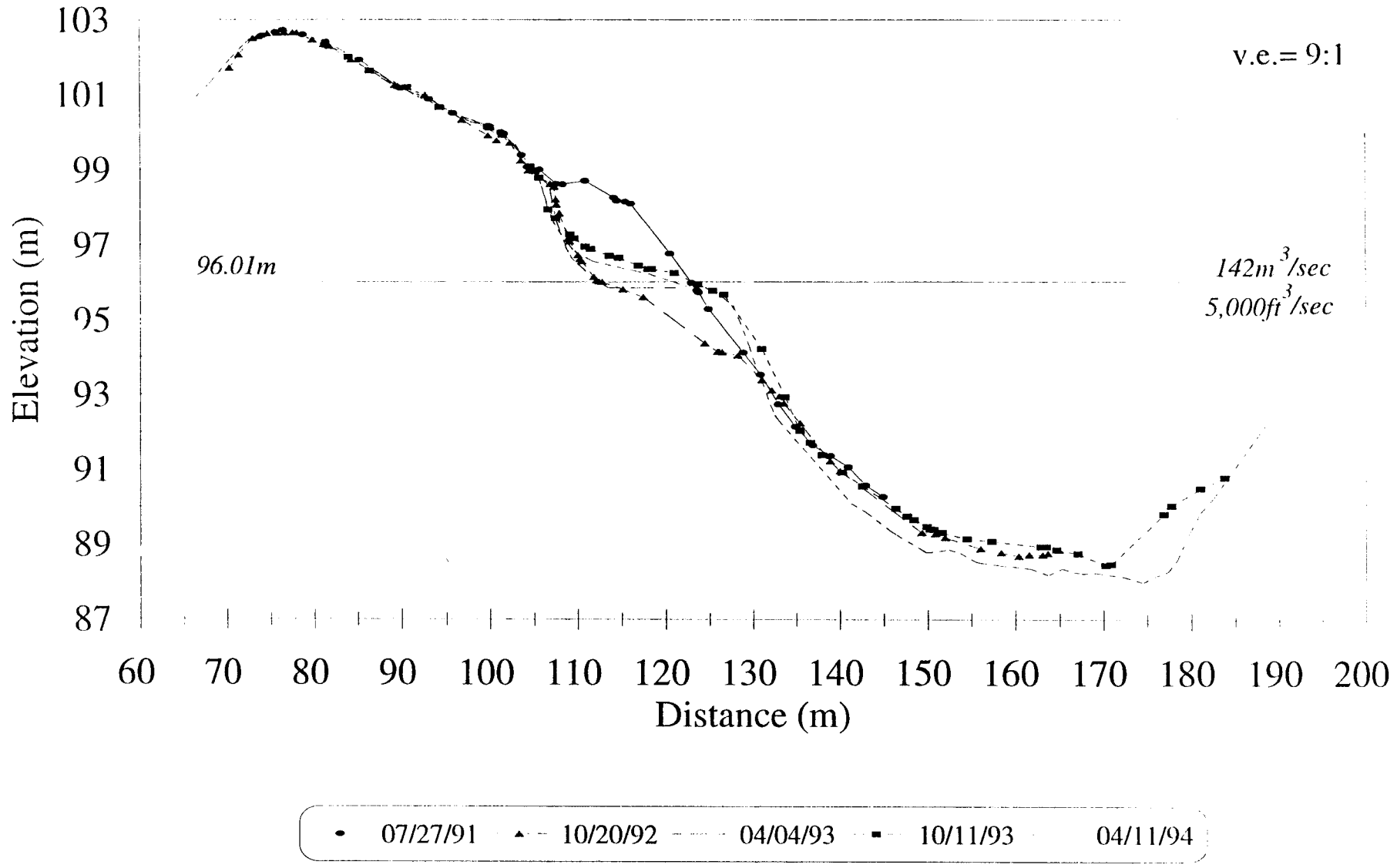
50 Mile

Near-shore P7



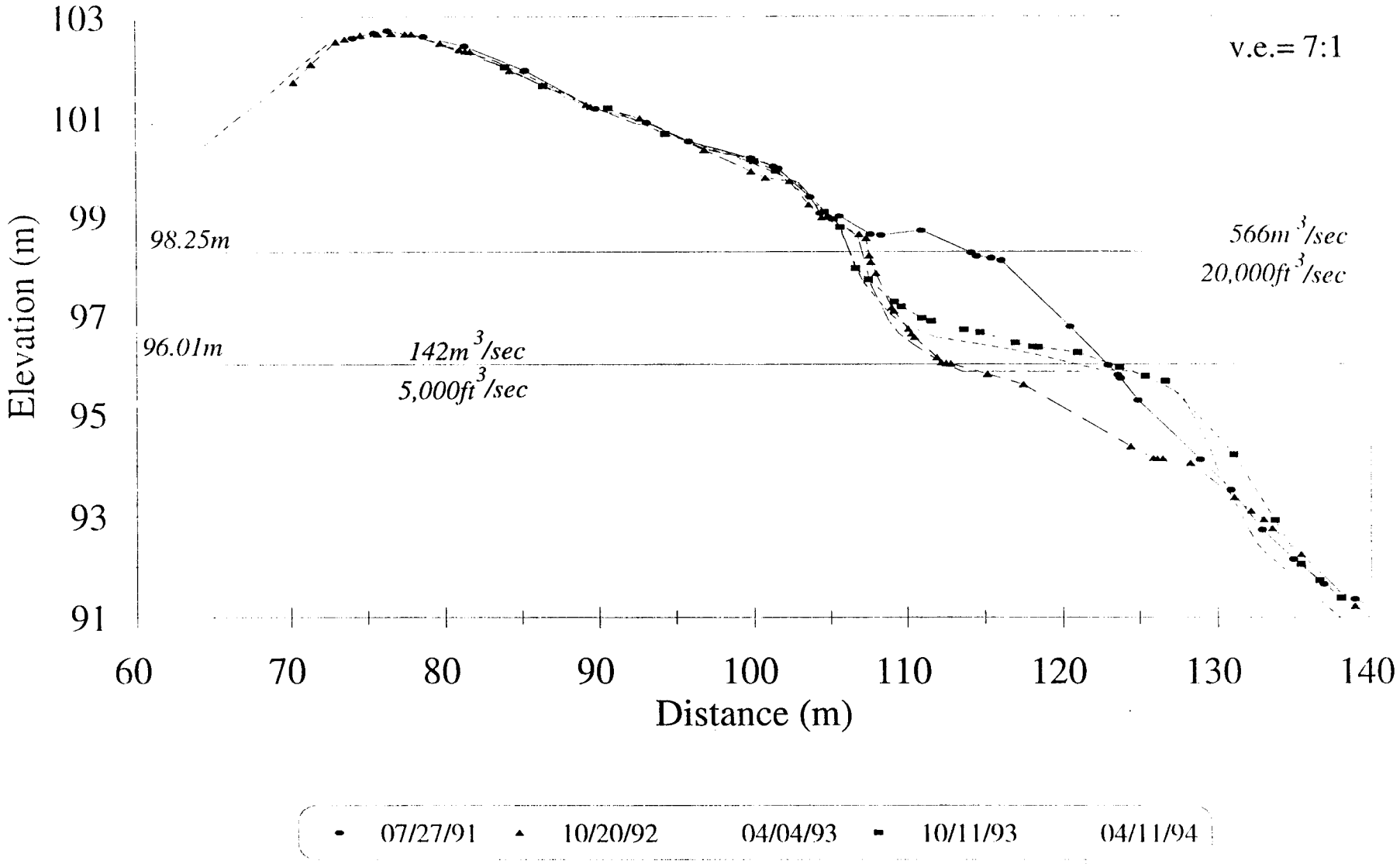
50 Mile

Cross-channel P8



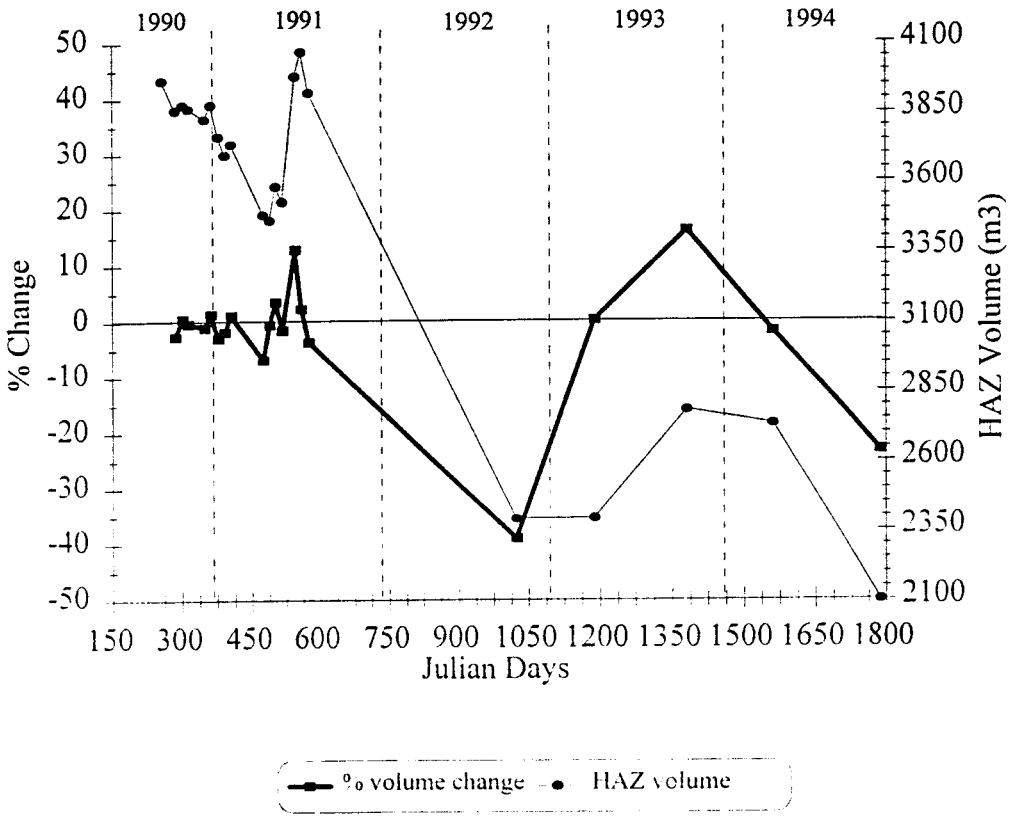
50 Mile

Near-shore P8



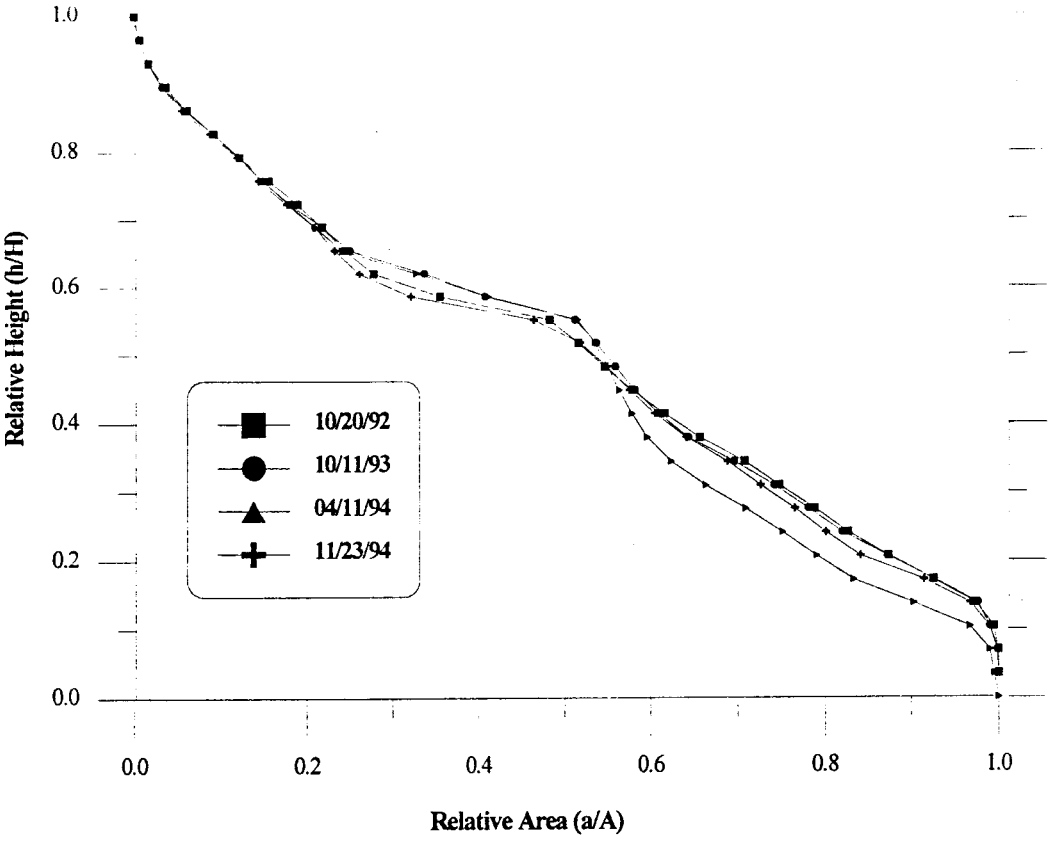
50 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F	900915	NORM	258	2417	3968				
G		E							
H	901013	A	286	2391	3862	-26	-106	-1.08	-2.67
I	901029	8000 CFS	302	2377	3881	-14	19	-0.59	0.49
J	901110	NORM	314	2331	3867	-46	-14	-1.94	-0.36
K	901215	NORM	349	2351	3828	20	-39	0.86	-1.01
L	901229	11000 CFS	363	2359	3880	8	52	0.34	1.36
M	910113	C	378	2369	3765	10	-115	0.42	-2.96
N	910127	NORM	392	2350	3698	-19	-67	-0.80	-1.78
O	910209	B	405	2363	3739	13	41	0.55	1.11
P	910420	NORM	475	2340	3484	-23	-255	-0.97	-6.82
Q	910504	NORM	489	2341	3462	1	-22	0.04	-0.63
R	910518	D	503	2385	3584	44	122	1.88	3.52
S	910601	15000 CFS	517	2369	3529	-16	-55	-0.67	-1.53
T	910629	NORM	545	2500	3981	131	452	5.53	12.81
U	910713	G	559	2507	4069	7	88	0.28	2.21
V	910730	F	576	2452	3921	-55	-148	-2.19	-3.64
Y	921020	INT	1024	1952	2390	-500	-1531	-20.39	-39.05
Z	930404	INT	1189	2099	2394	147	4	7.53	0.17
B13	931011	INT	1381	2475	2782	376	388	17.91	16.21
C13	940411	INT	1562	2547	2732	72	-50	2.91	-1.80
D13	941123	INT	1788	1648	2101	-899	-631	-35.30	-23.10

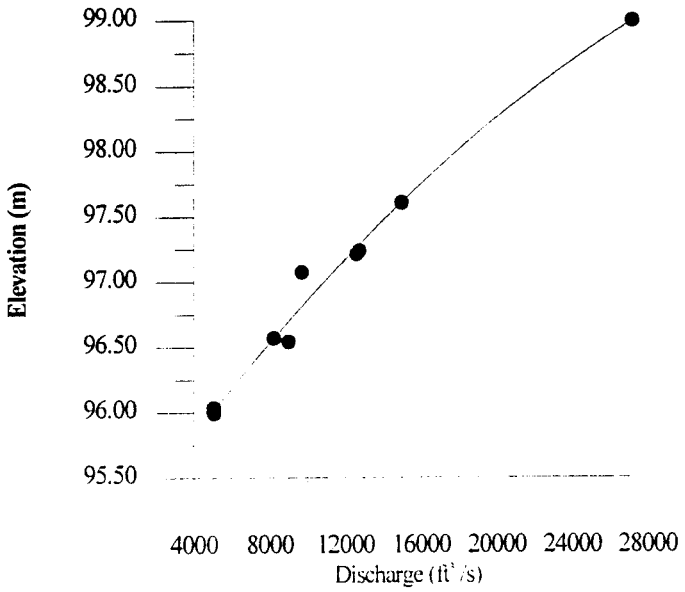


50 Mile

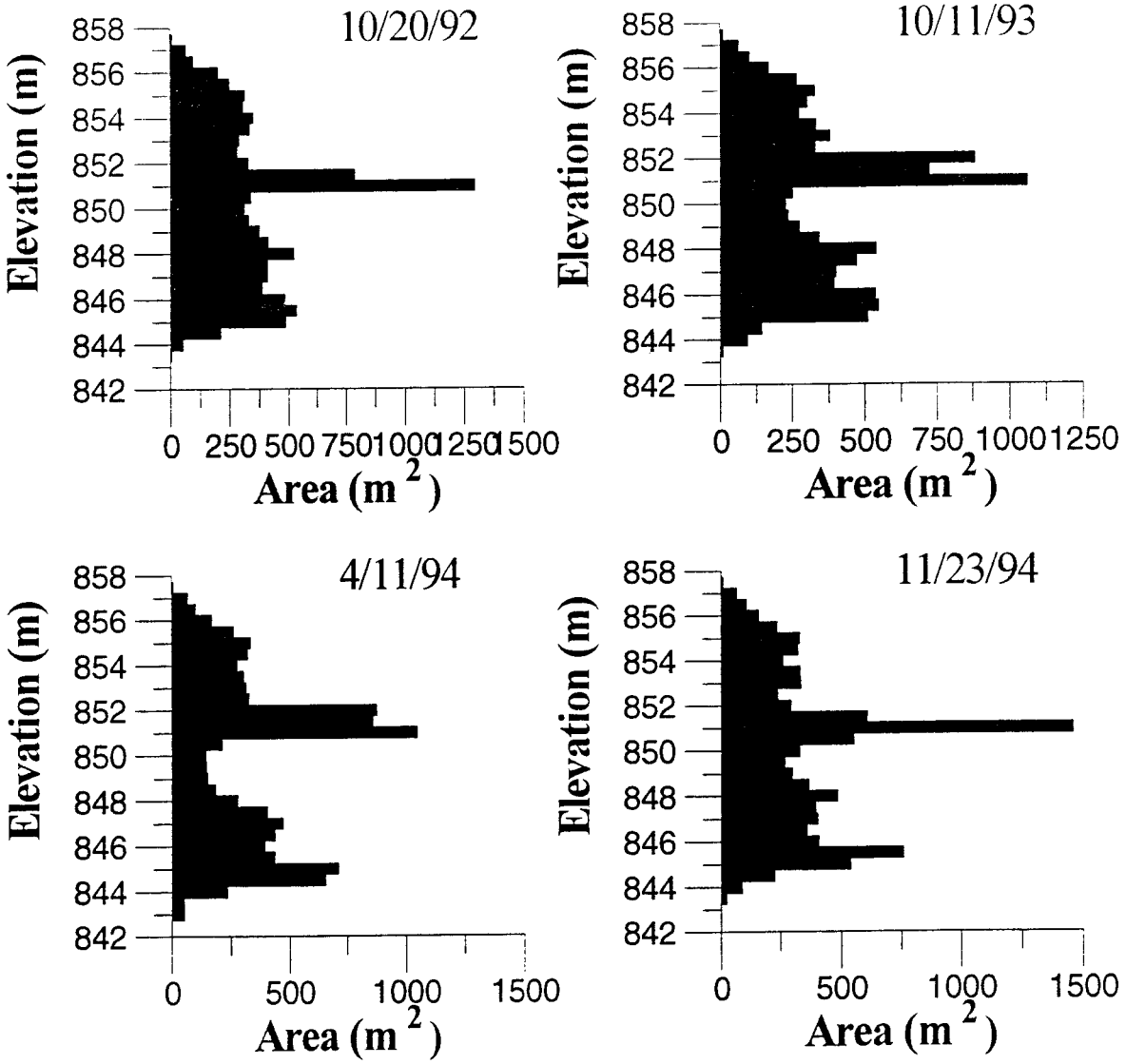
Hypsometric Curves

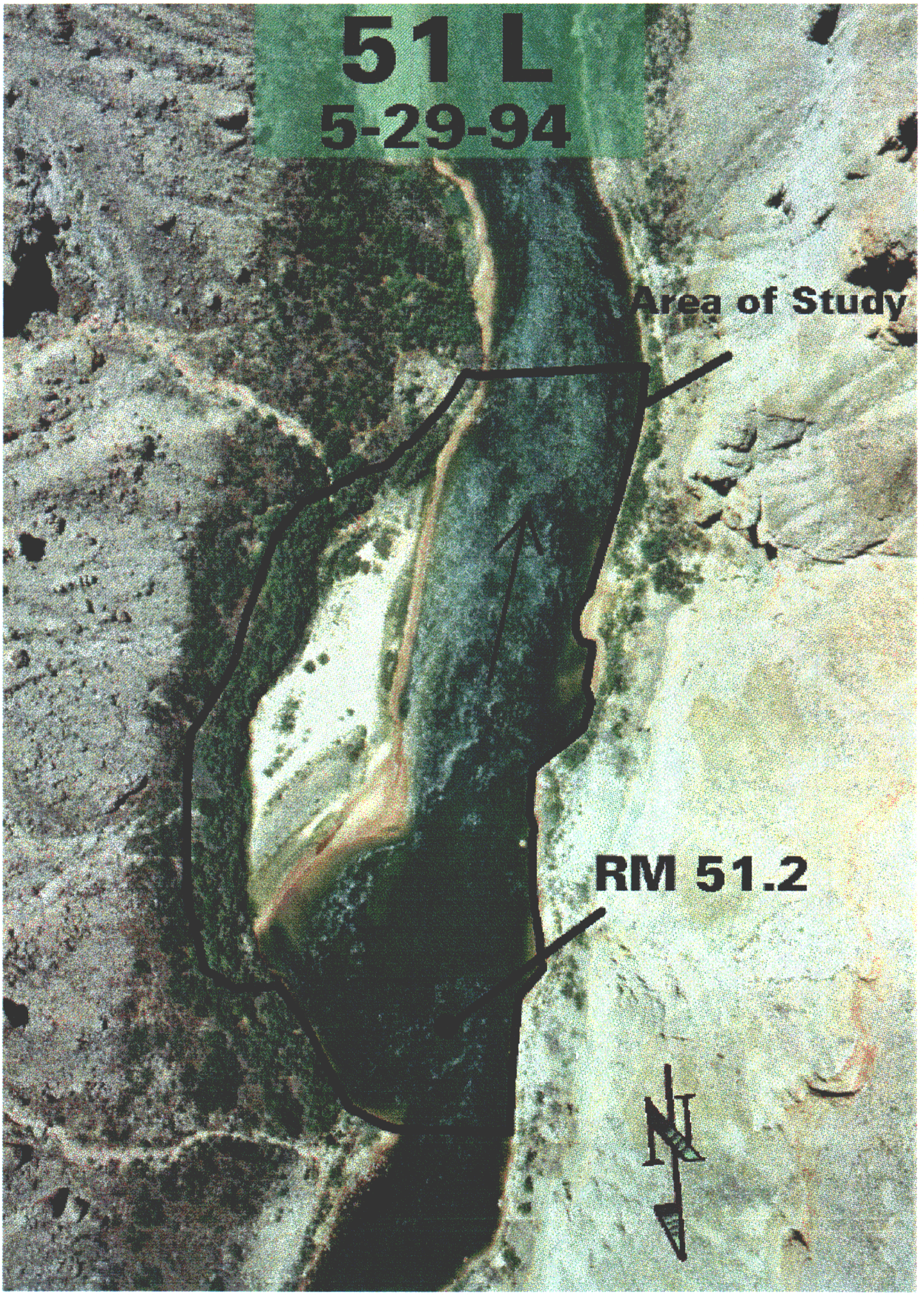


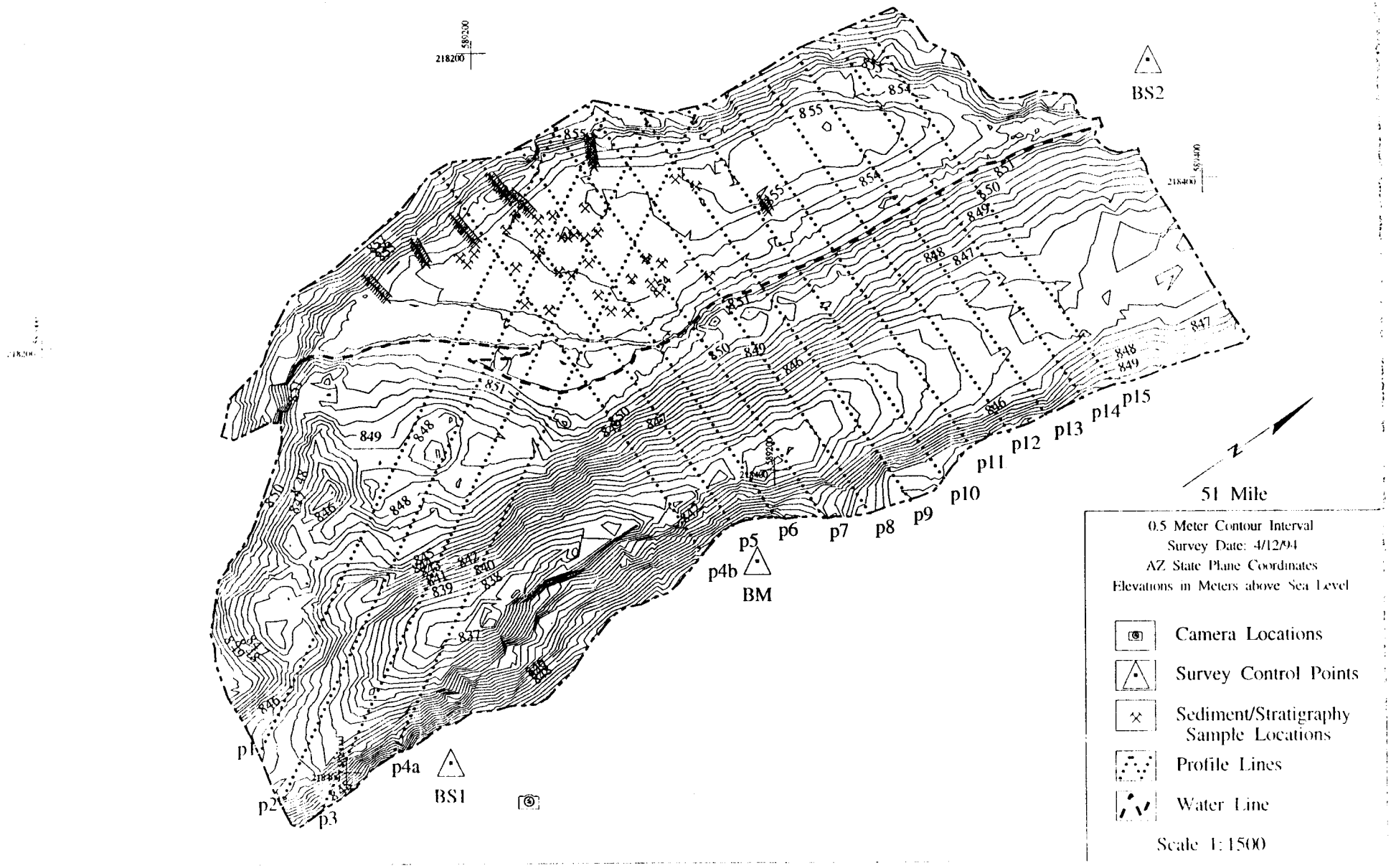
Stage Discharge



50 MILE
Area Distribution Histograms

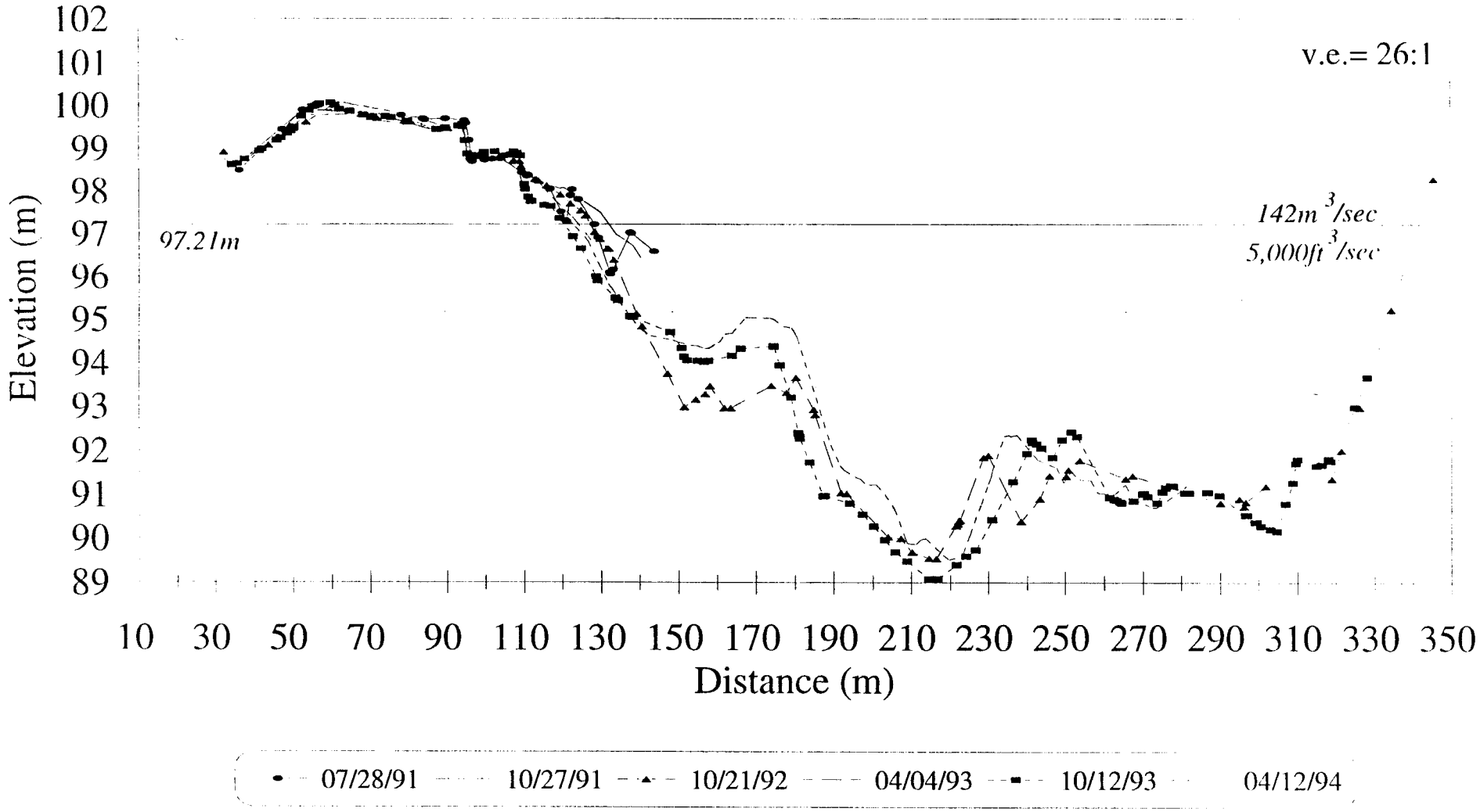



51 L
5-29-94
Area of Study
RM 51.2
N

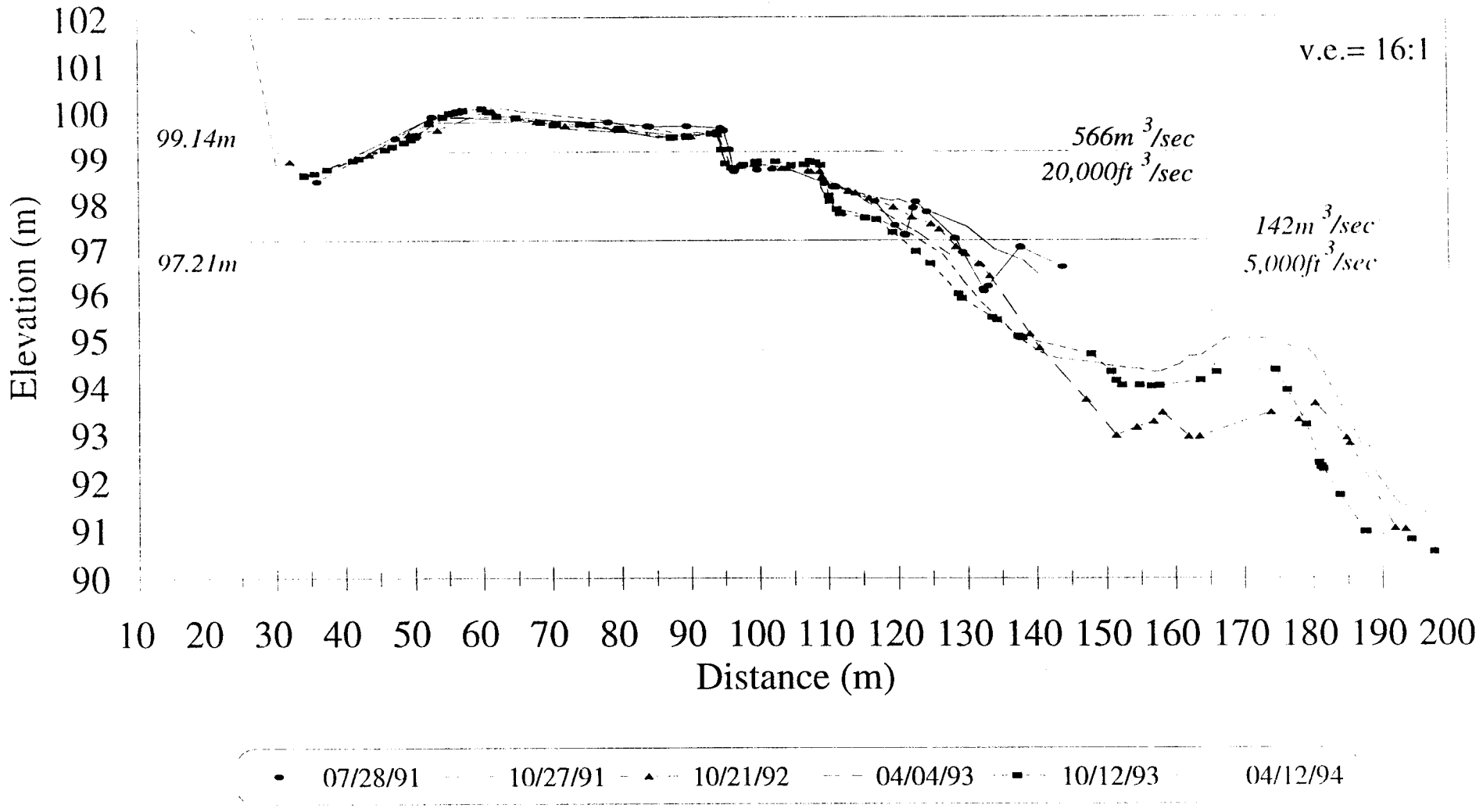

218200
589200
BS2
218400
589400
854
855
851
850
849
848
847
846
840
839
837
838
p15
p14
p13
p12
p11
p10
p9
p8
p7
p6
p5
p4b
BM
p4a
BS1
p1
p2
p3
N
51 Mile
0.5 Meter Contour Interval
Survey Date: 4/12/94
AZ State Plane Coordinates
Elevations in Meters above Sea Level
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:1500

51 Mile

Cross-channel P1

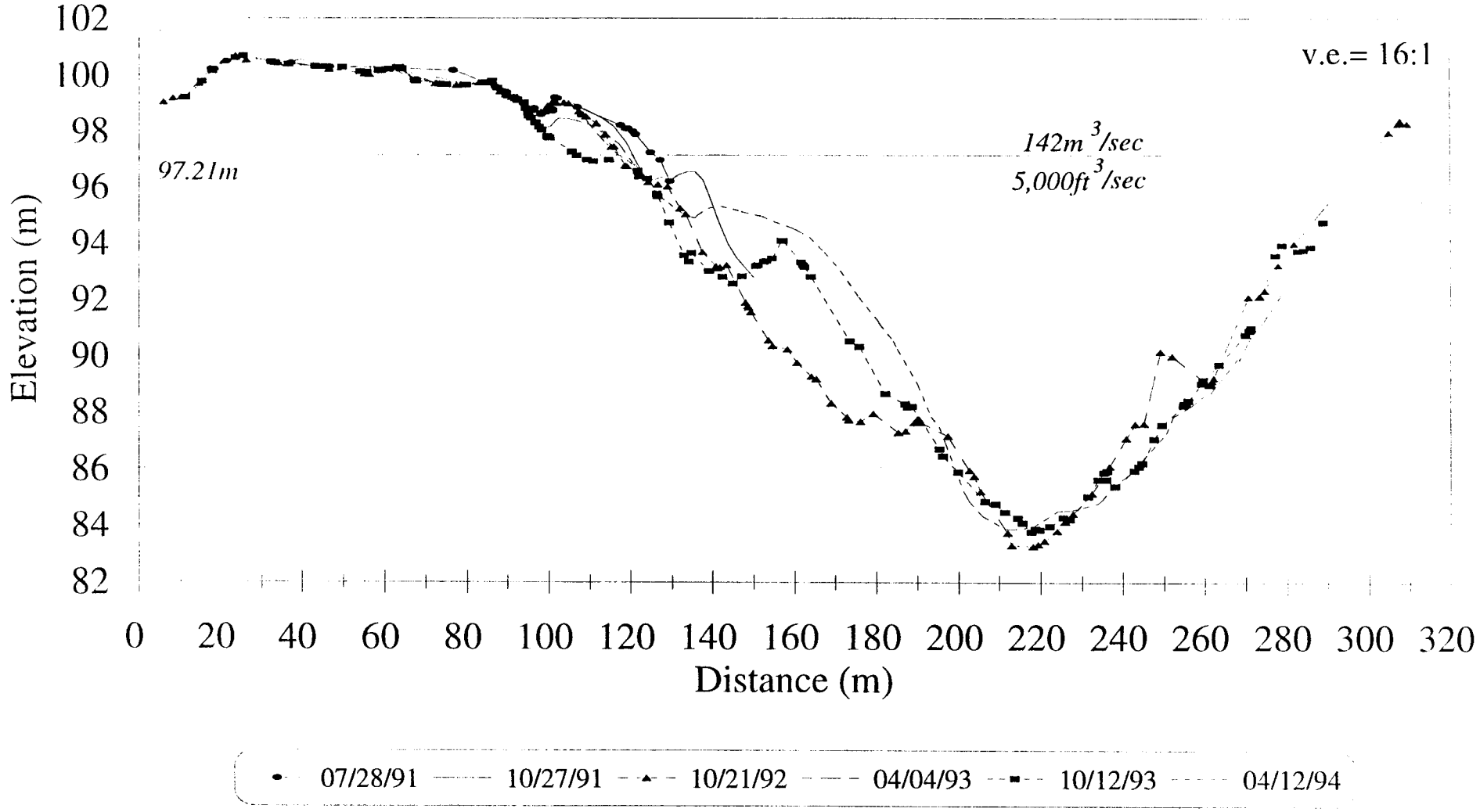


Near-shore P1

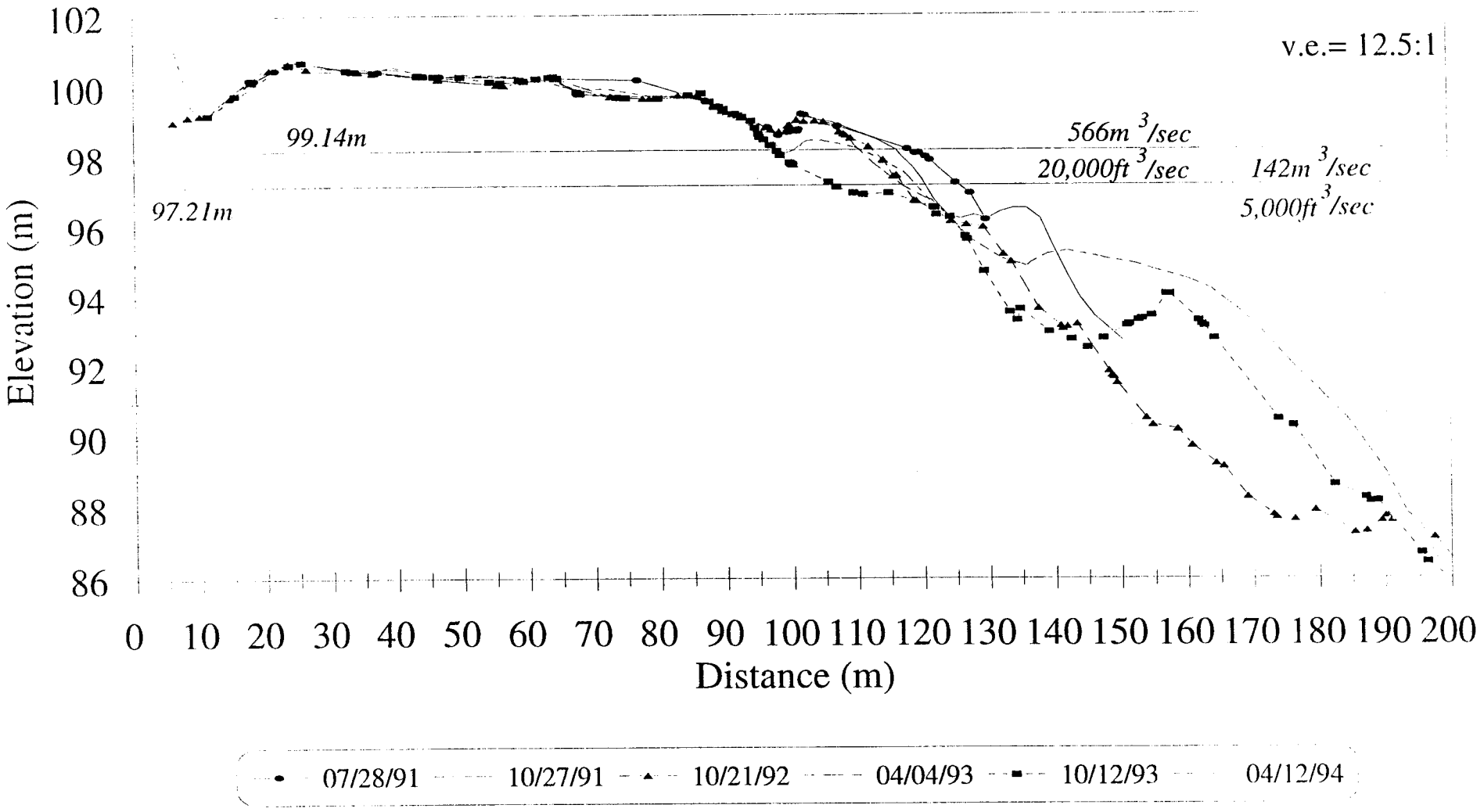


51 Mile

Cross-channel P3

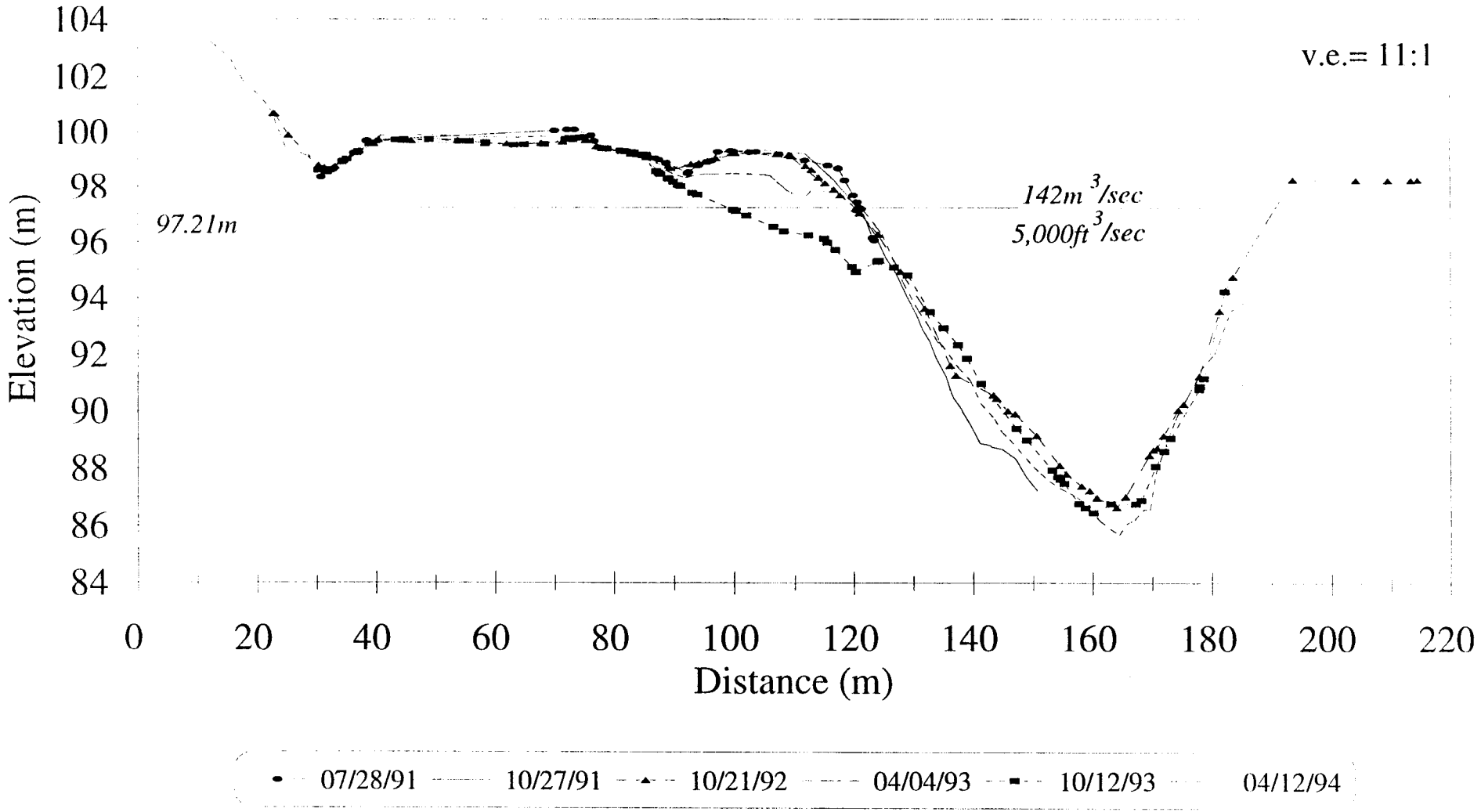


Near-shore P3

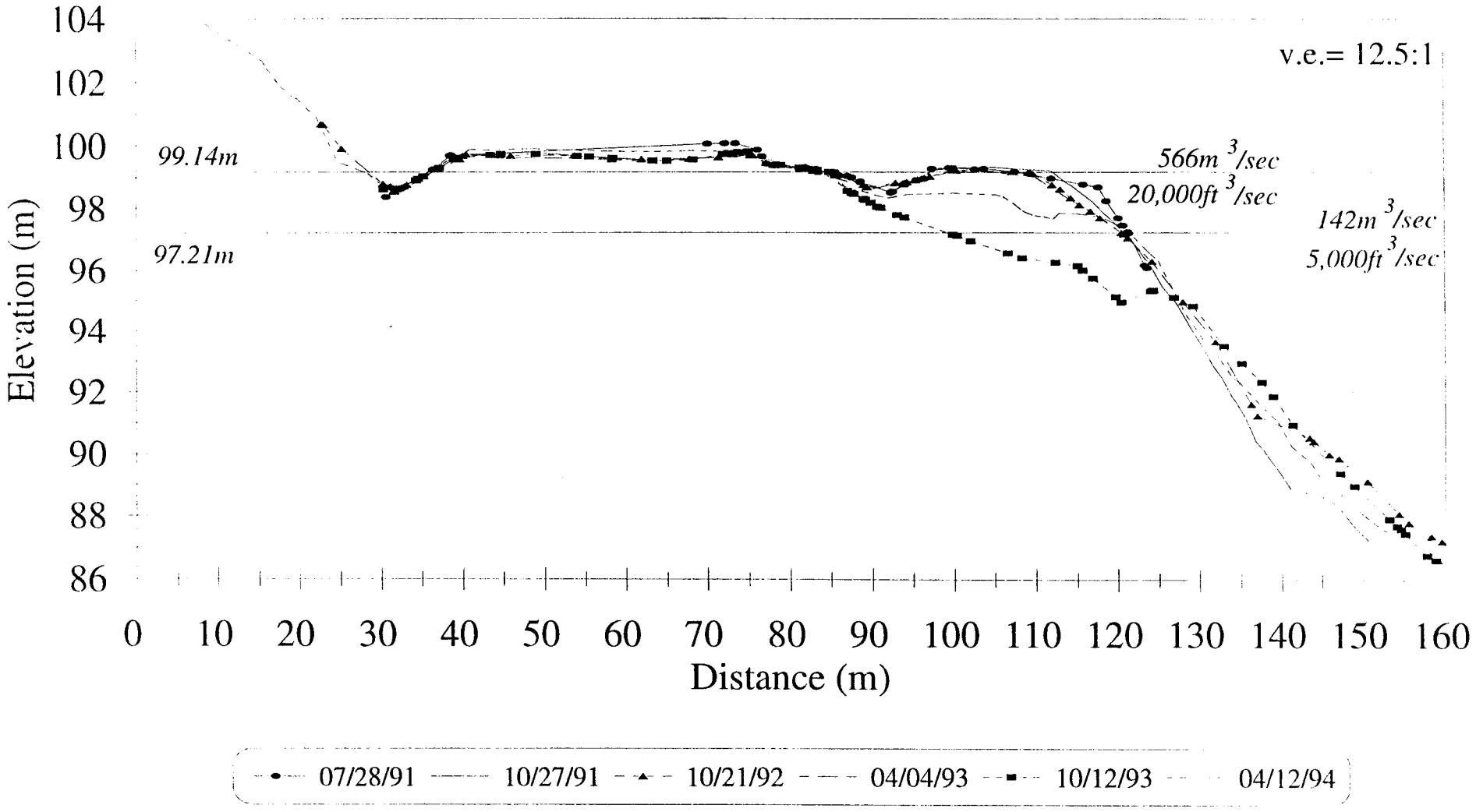


51 Mile

Cross-channel P4b

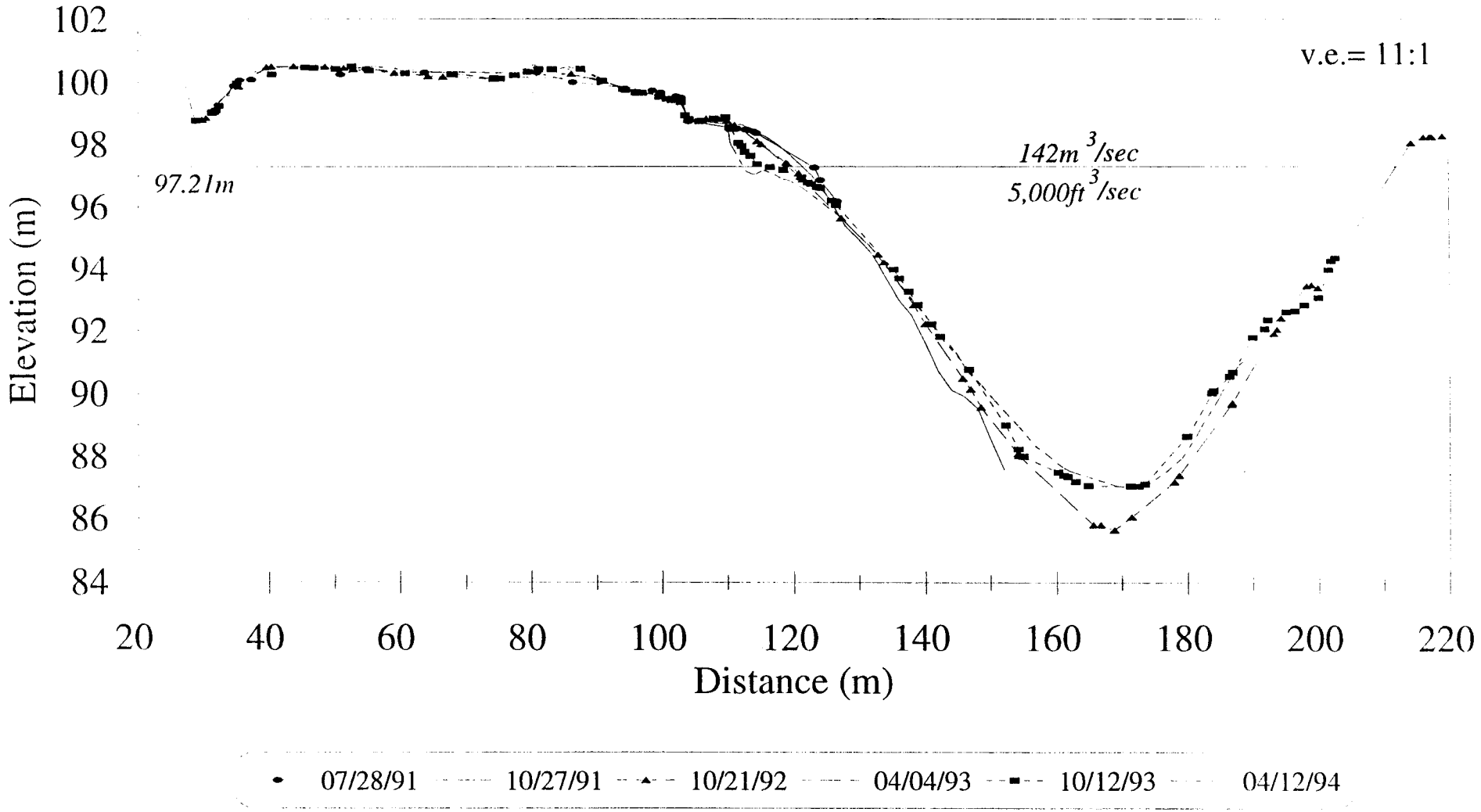


Near-shore P4b

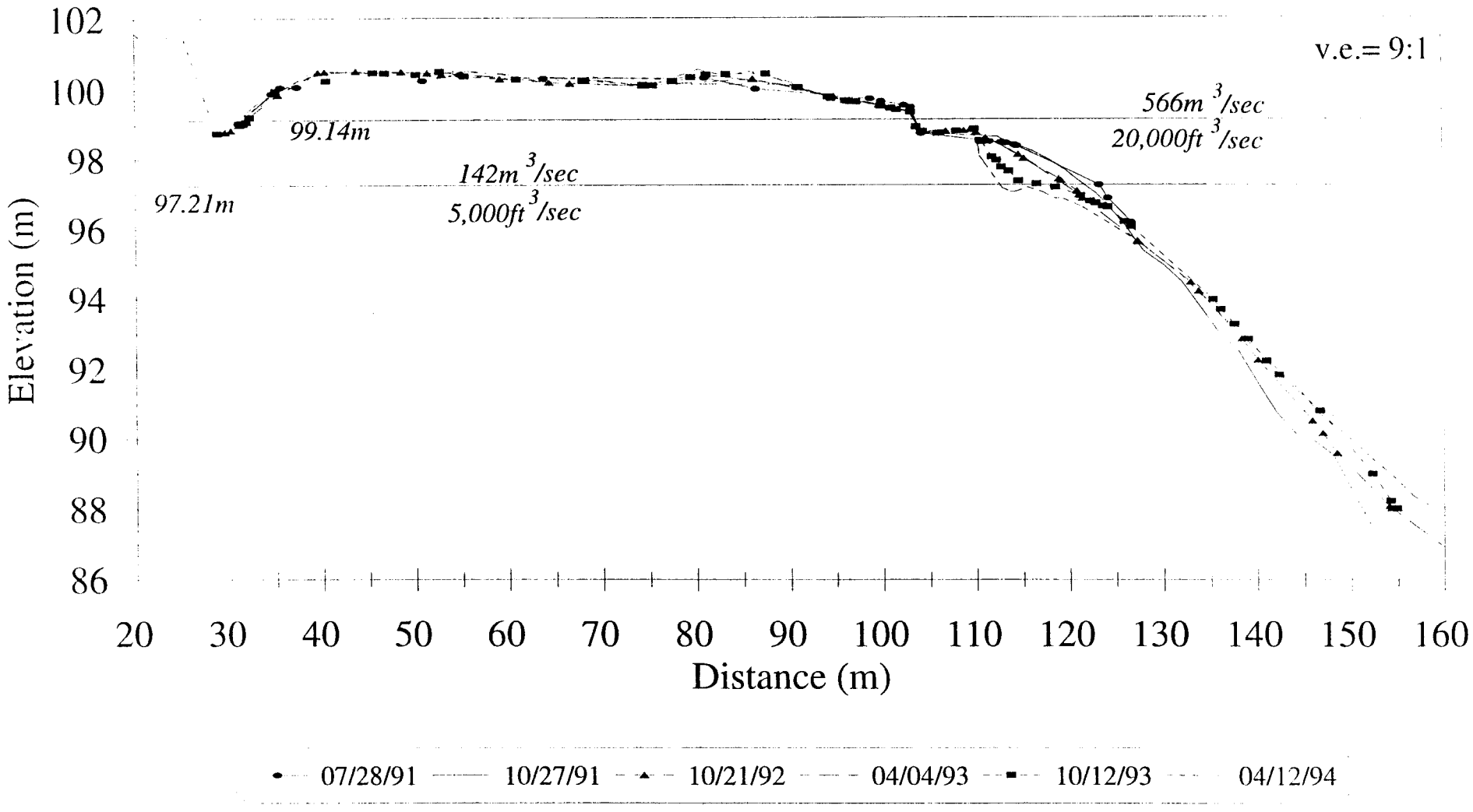


51 Mile

Cross-channel P7

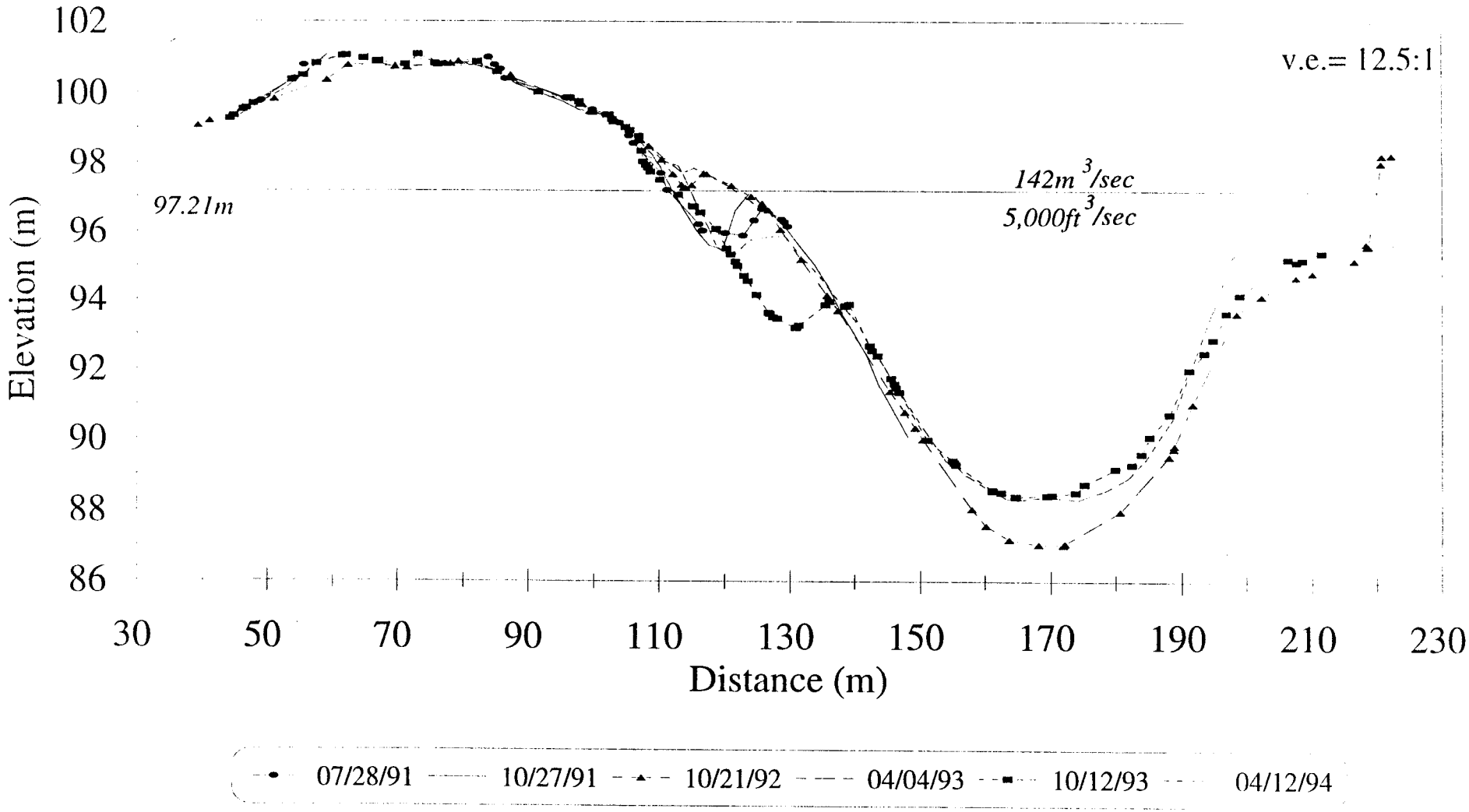


Near-shore P7

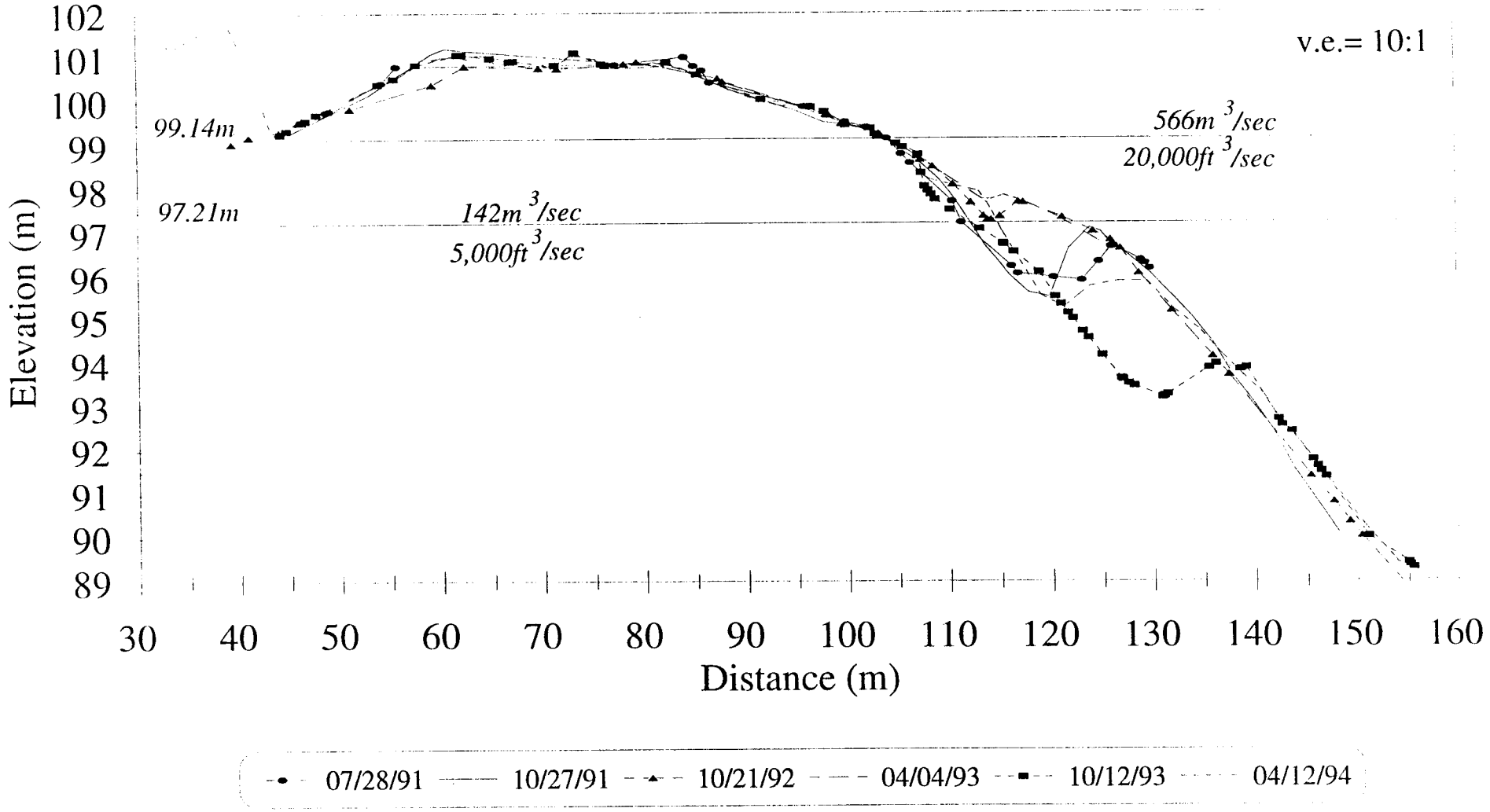


51 Mile

Cross-channel P9

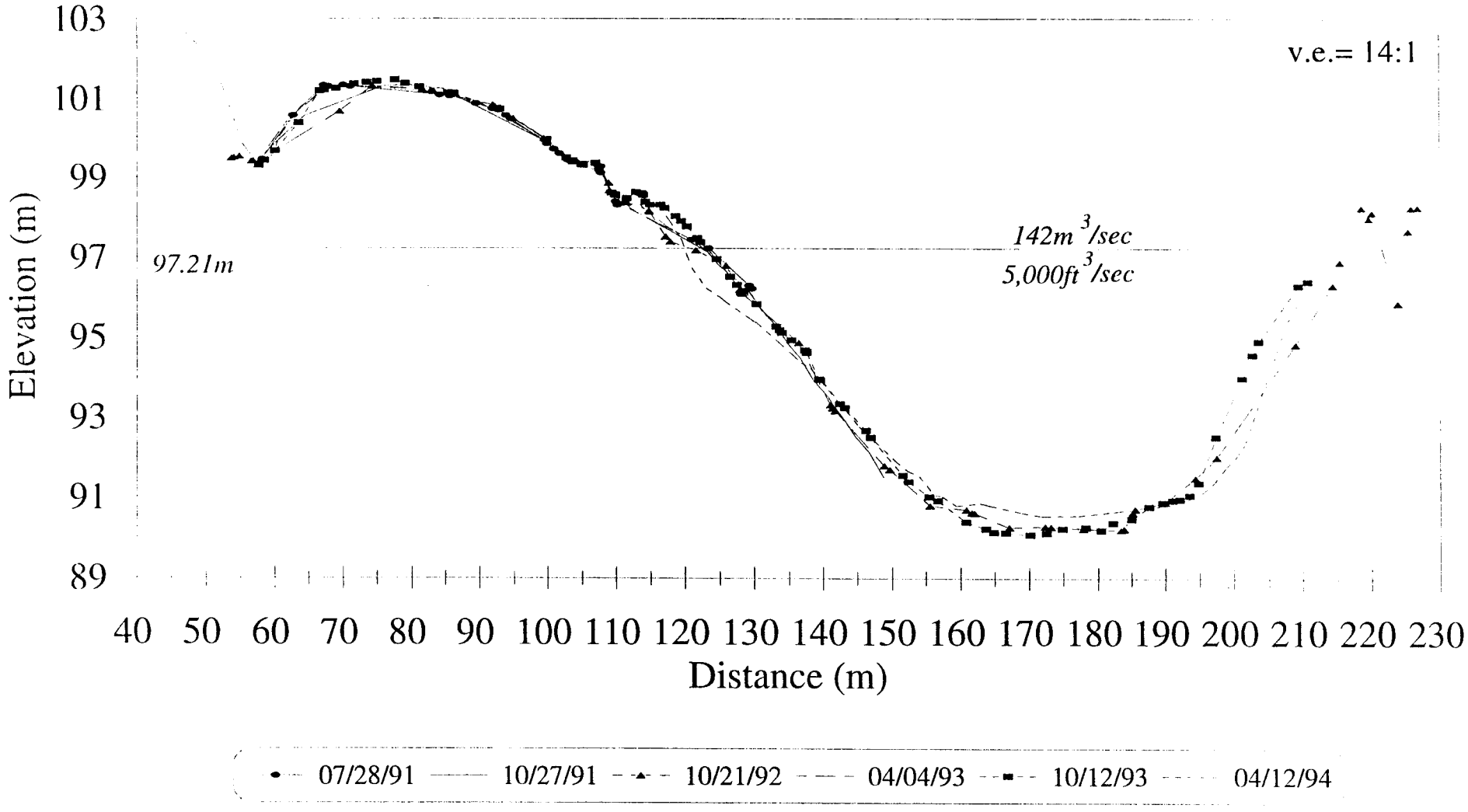


Near-shore P9

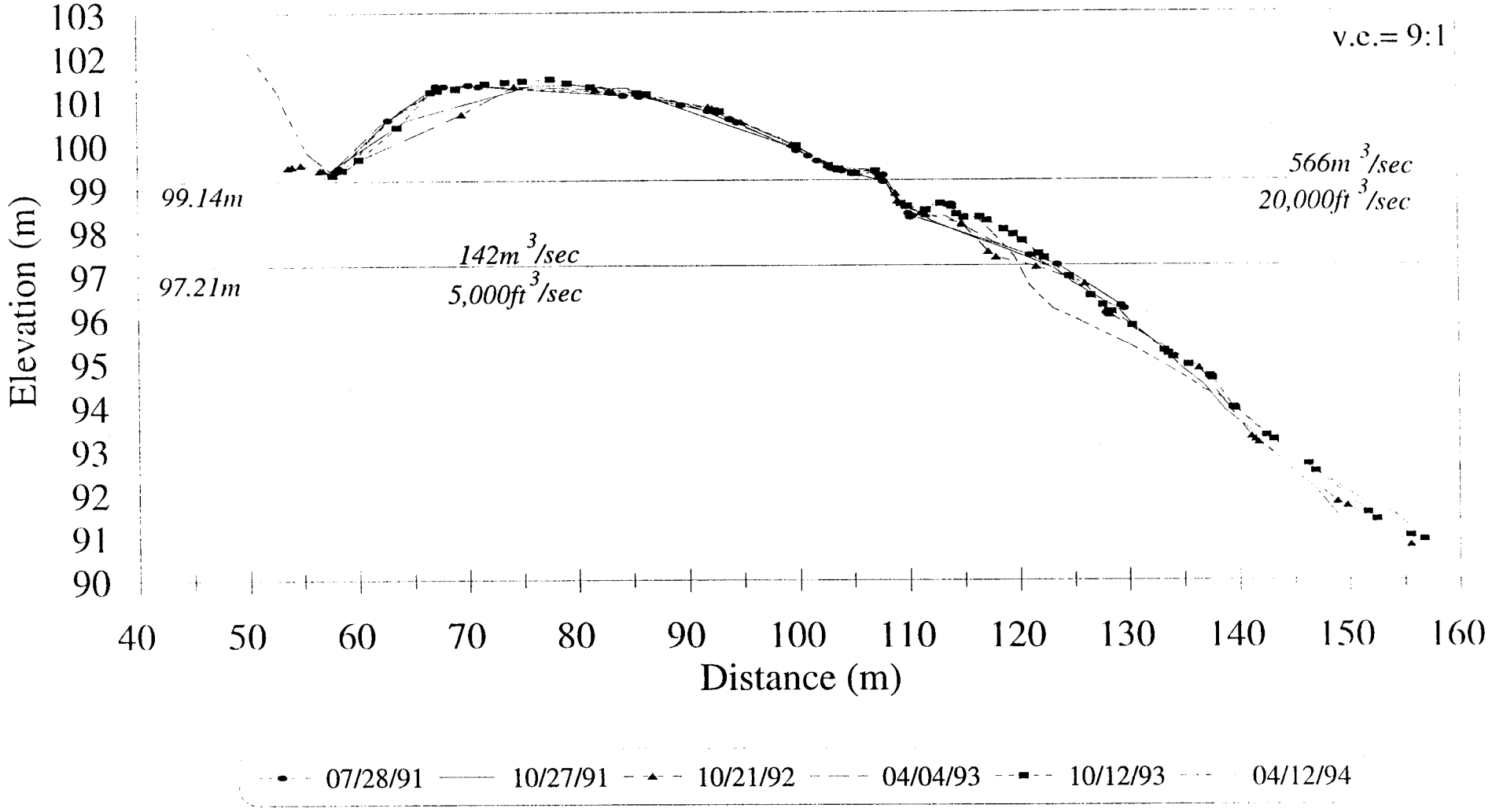


51 Mile

Cross-channel P12

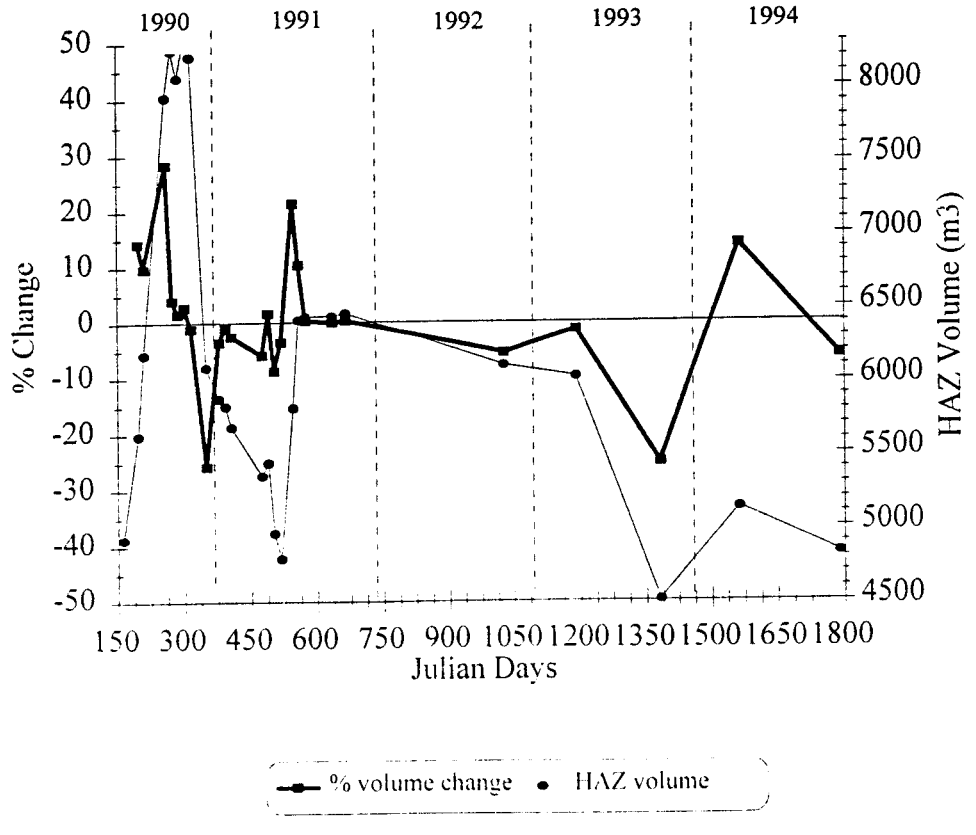


Near-shore P12



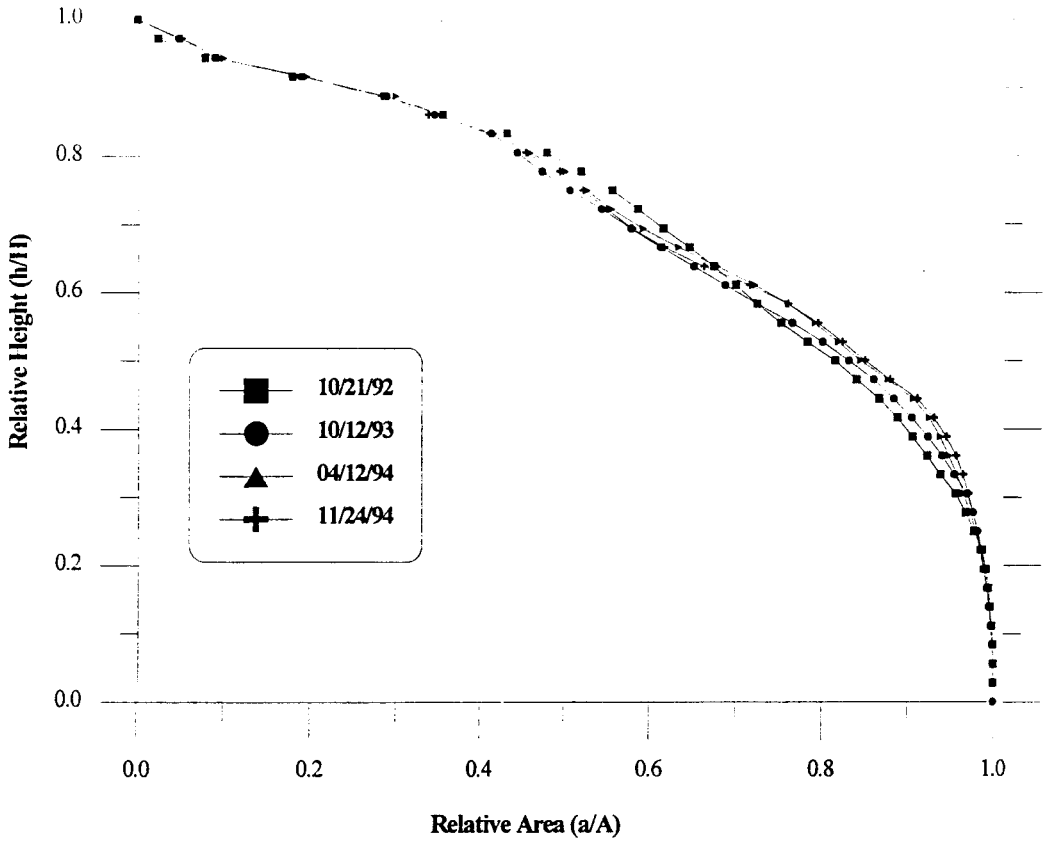
51 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A	900611	NORM	162	5370	4930				
B		NORM							
C	900715	G	196	6058	5634	688	704	12.81	14.28
D	900729	F	210	6272	6184	214	550	3.53	9.76
E		NORM							
F	900916	NORM	259	7177	7938	905	1754	14.43	28.36
G	900930	E	273	7944	8257	767	319	10.69	4.02
H	901014	A	287	7781	8068	604	130	8.42	1.64
I	901028	8000 CFS	301	7869	8294	88	226	1.13	2.80
J	901111	NORM	315	7955	8211	86	-83	1.09	-1.00
K	901216	NORM	350	5955	6095	-2000	-2116	-25.14	-25.77
L		11000 CFS							
M	910113	C	378	6009	5883	54	-212	0.91	-3.48
N	910127	NORM	392	5693	5831	-316	-52	-5.26	-0.88
O	910210	B	406	5436	5687	-257	-144	-4.51	-2.47
P	910420	NORM	475	5085	5355	-351	-332	-6.46	-5.84
Q	910504	NORM	489	5126	5443	41	88	0.81	1.64
R	910518	D	503	4904	4968	-222	-475	-4.33	-8.73
S	910602	15000 CFS	518	4852	4795	-52	-173	-1.06	-3.48
T	910630	NORM	546	5645	5819	793	1024	16.34	21.36
U	910713	G	559	5869	6421	224	602	3.97	10.35
V	910728	F	574	5939	6441	70	20	1.19	0.31
W	910927	INT	635	5830	6442	-109	1	-1.84	0.02
X	911027	INT	665	5789	6463	-41	21	-0.70	0.33
Y	921021	INT	1025	5519	6109	-270	-354	-4.66	-5.48
Z	930404	INT	1190	5596	6029	77	-80	1.40	-1.31
B14	931012	INT	1382	4093	4511	-1503	-1518	-26.86	-25.18
C14	940412	INT	1563	4981	5136	888	625	21.70	13.86
D14	941124	INT	1789	4741	4830	-240	-306	-4.82	-5.96

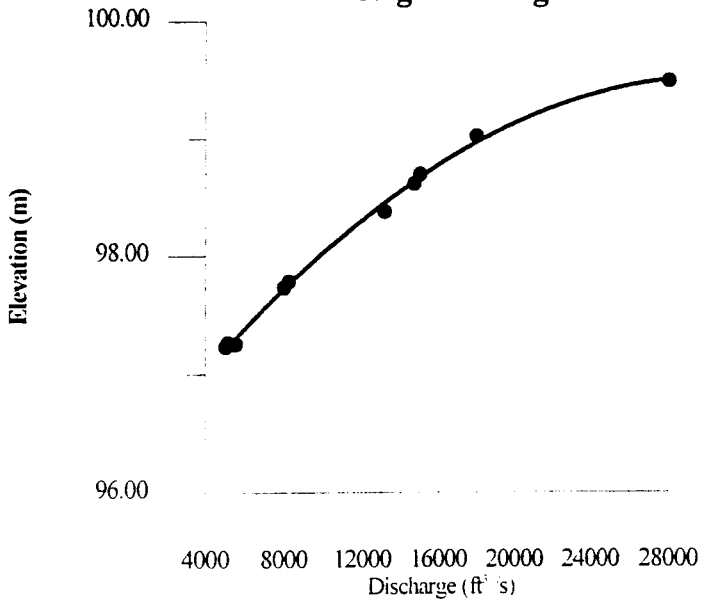


51 Mile

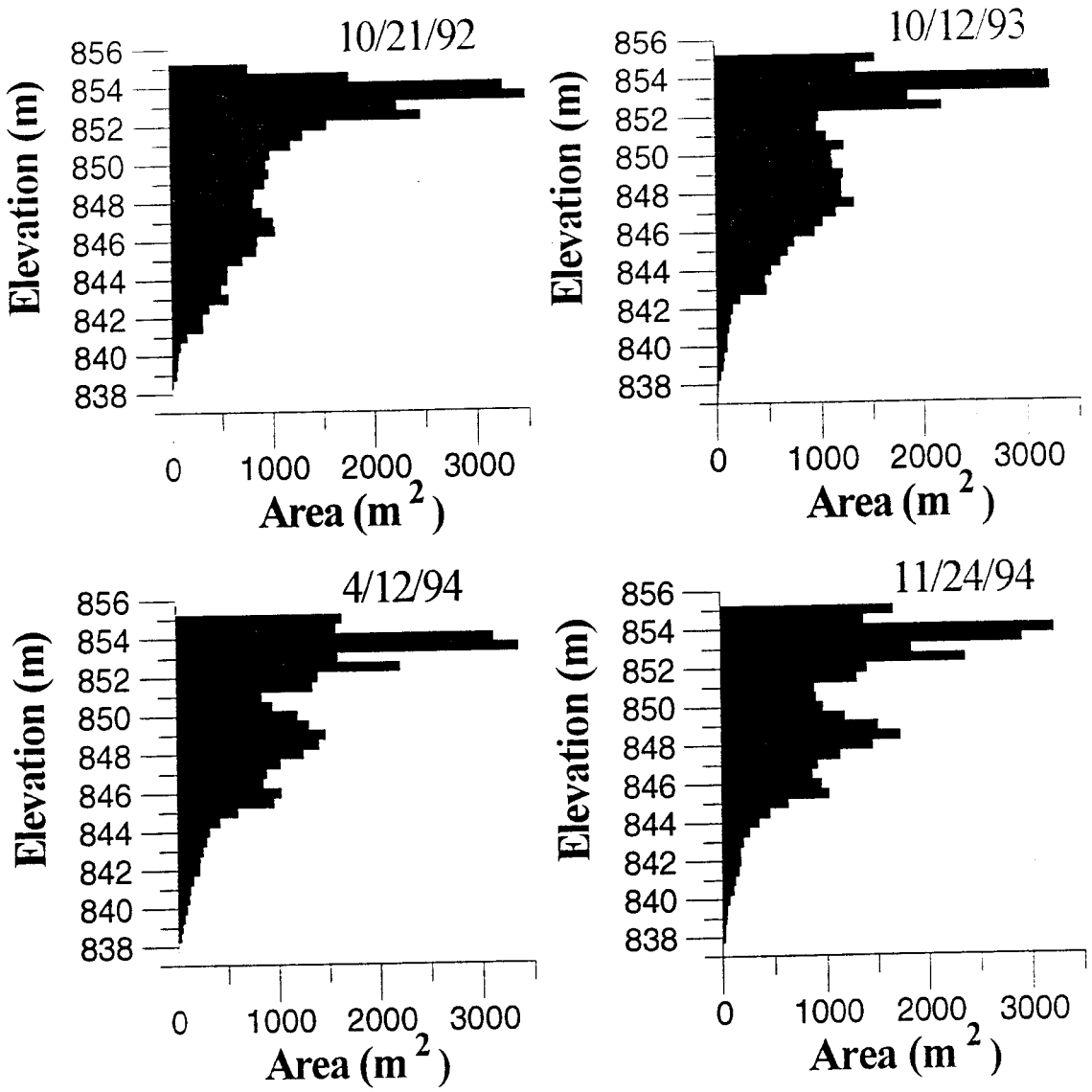
Hypsometric Curves

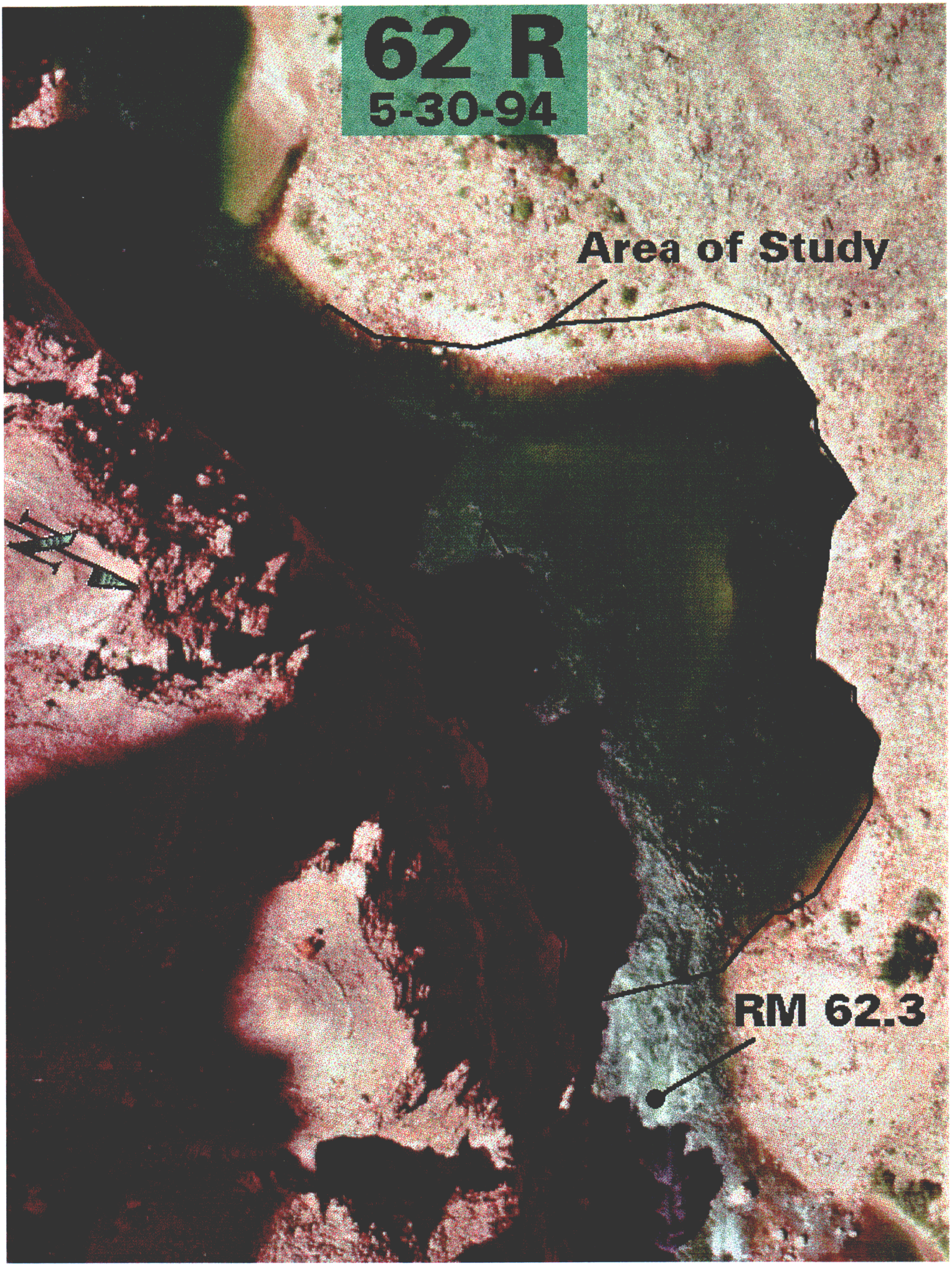


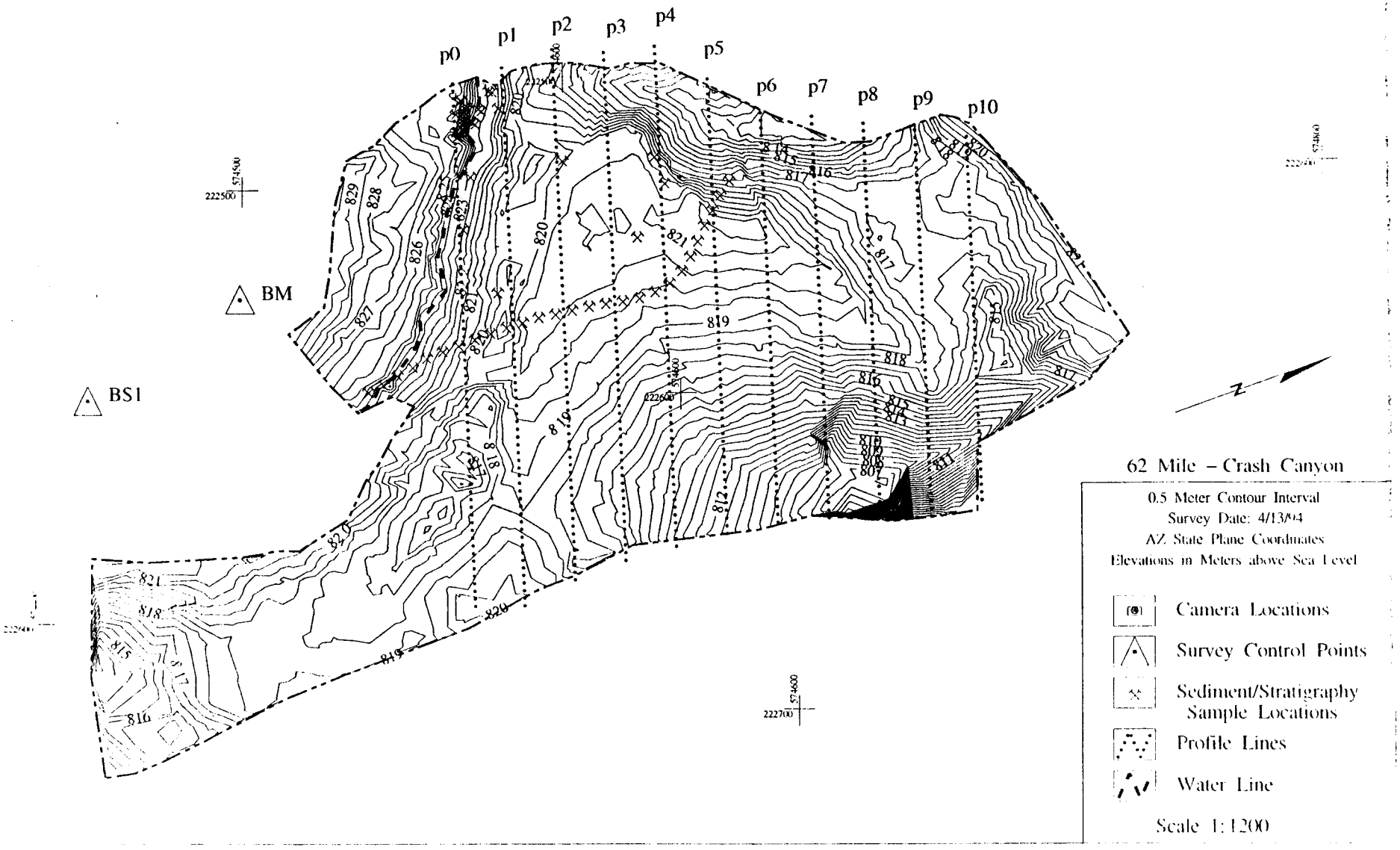
Stage Discharge



51 MILE
Area Distribution Histograms

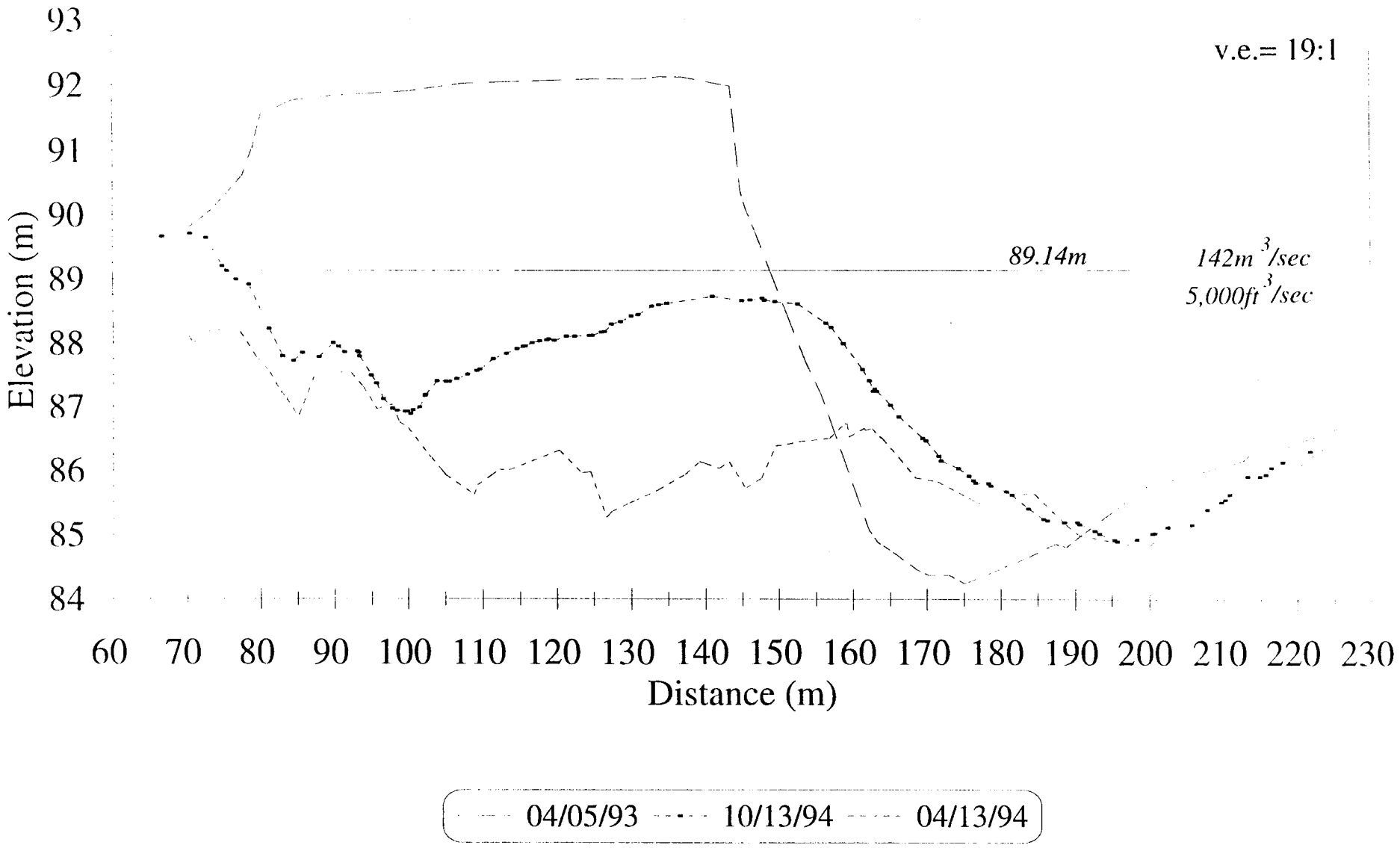



62 R
5-30-94
Area of Study
N
RM 62.3

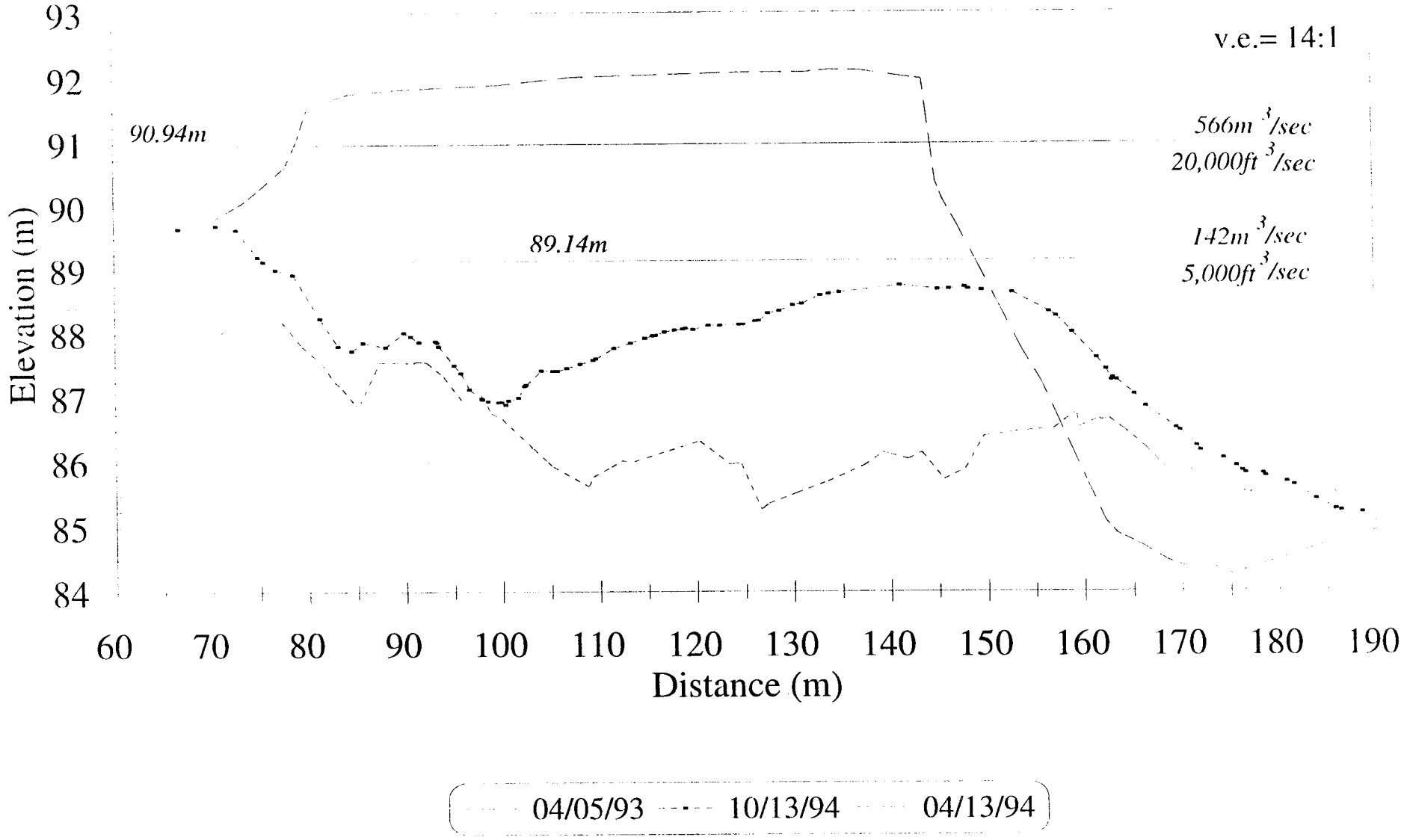

p0
p1
p2
p3
p4
p5
p6
p7
p8
p9
p10
BM
BS1
574500
222500
574600
222600
222700
62 Mile – Crash Canyon
0.5 Meter Contour Interval
Survey Date: 4/13/04
AZ State Plane Coordinates
Elevations in Meters above Sea Level
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:1200

62 Mile

Cross-channel P1

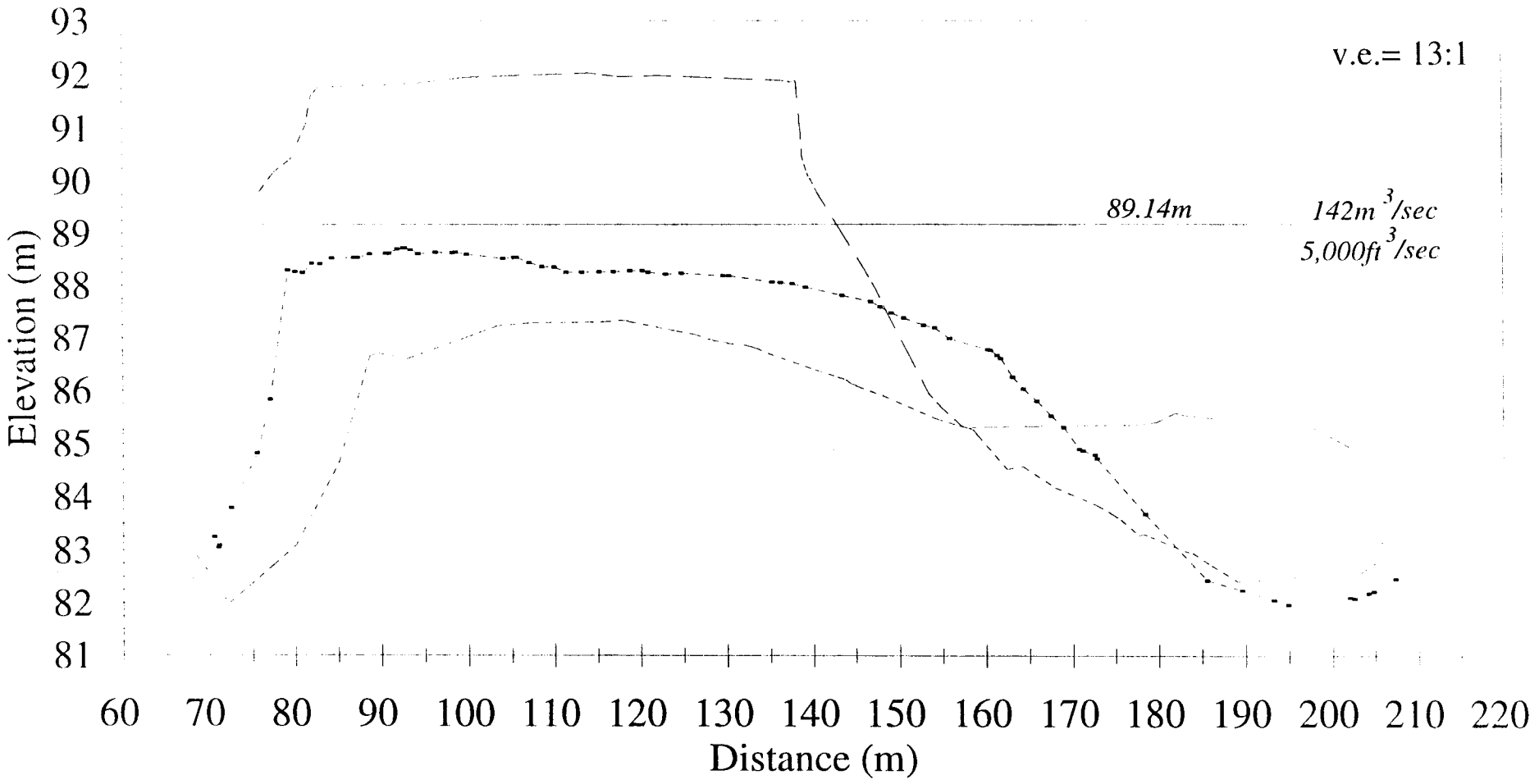


Near-shore P1

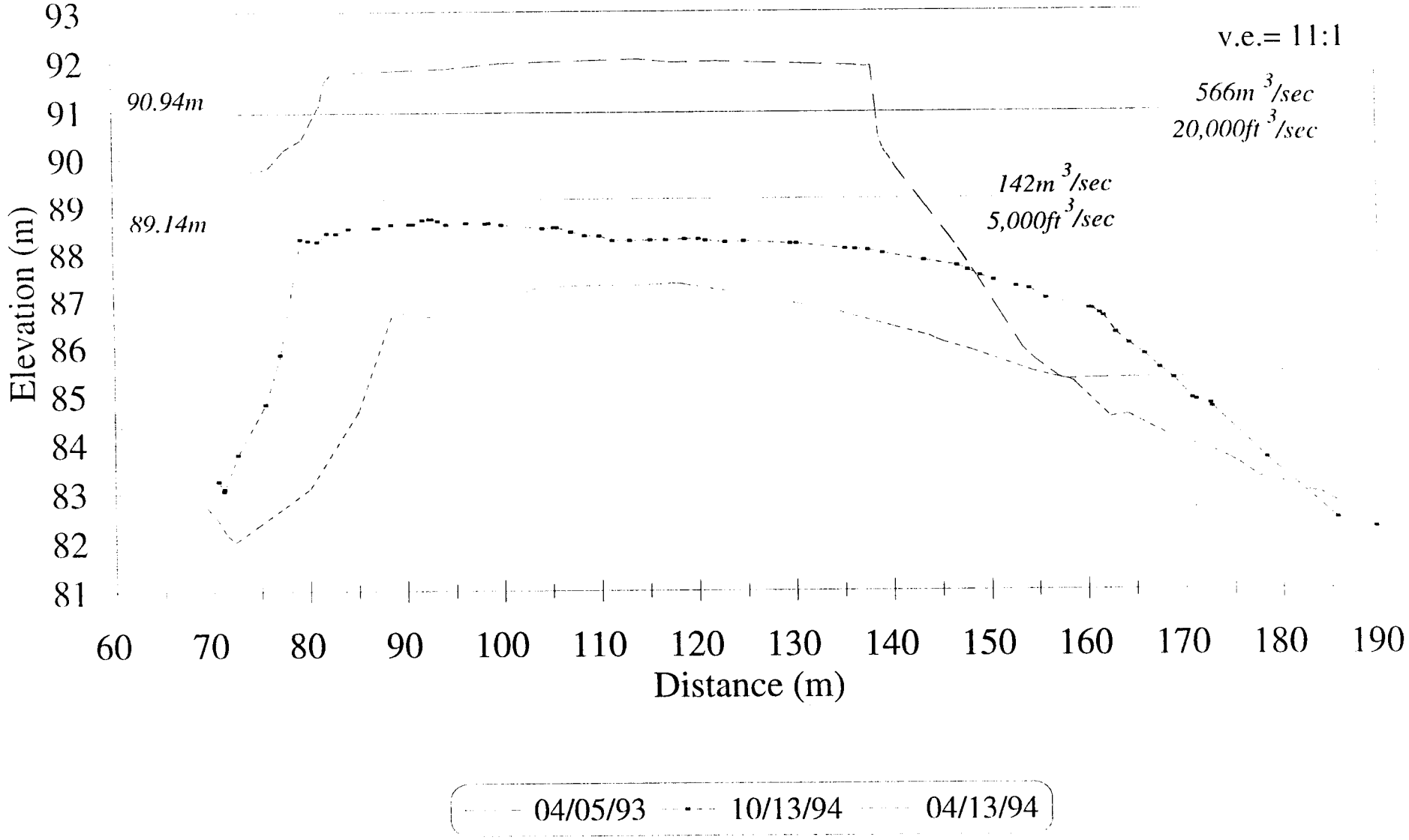


62 Mile

Cross-channel P3

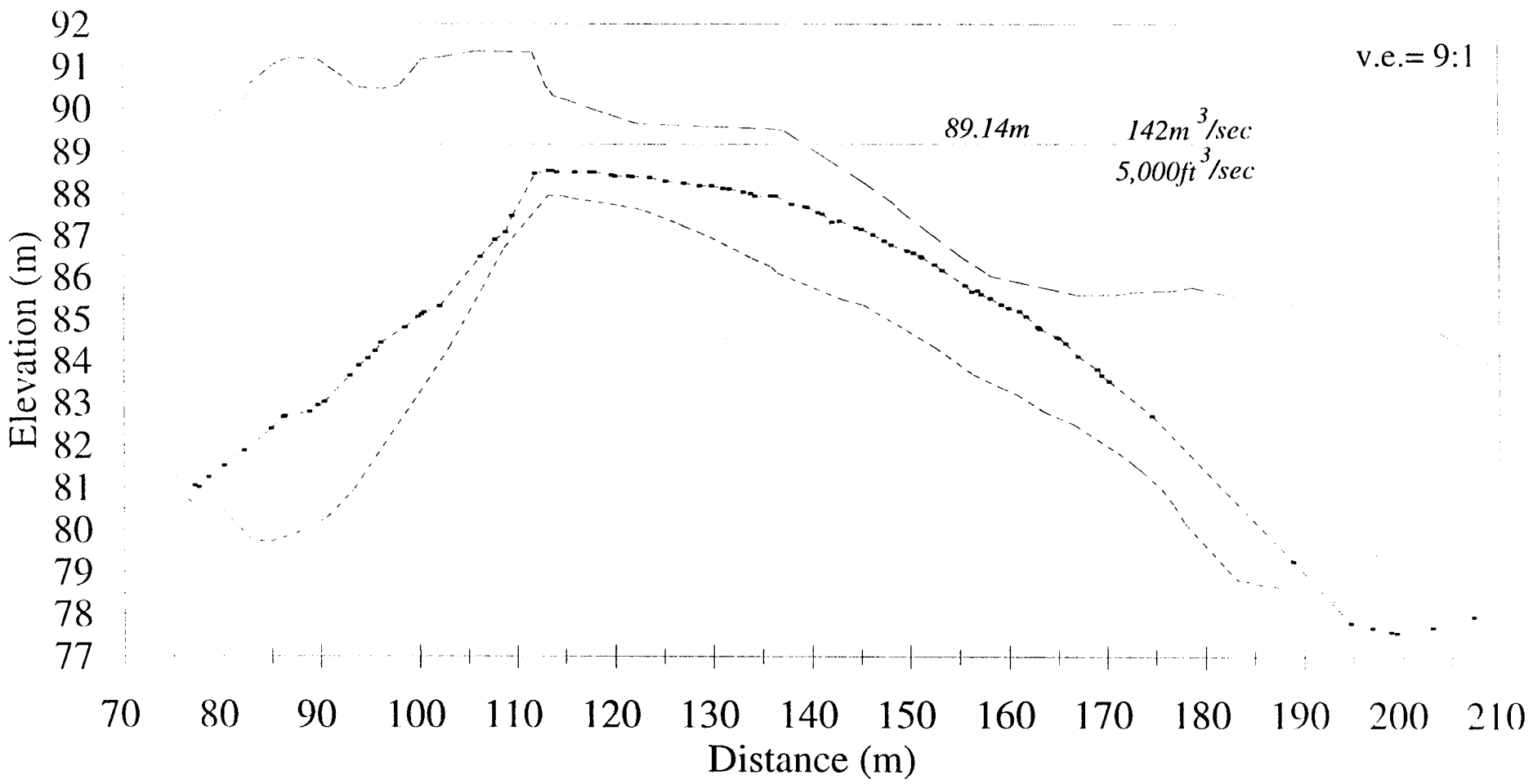


Near-shore P3

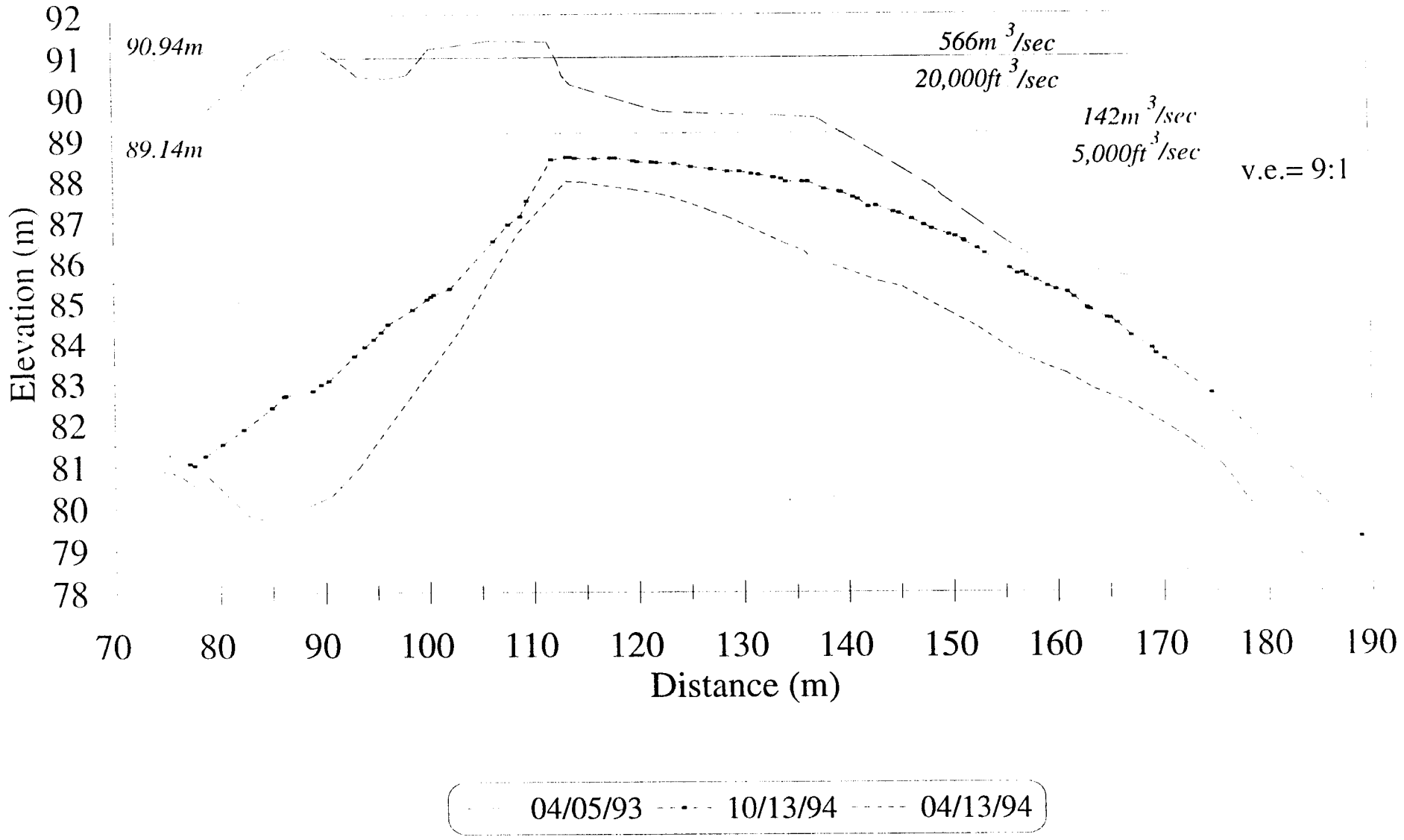


62 Mile

Cross-channel P5

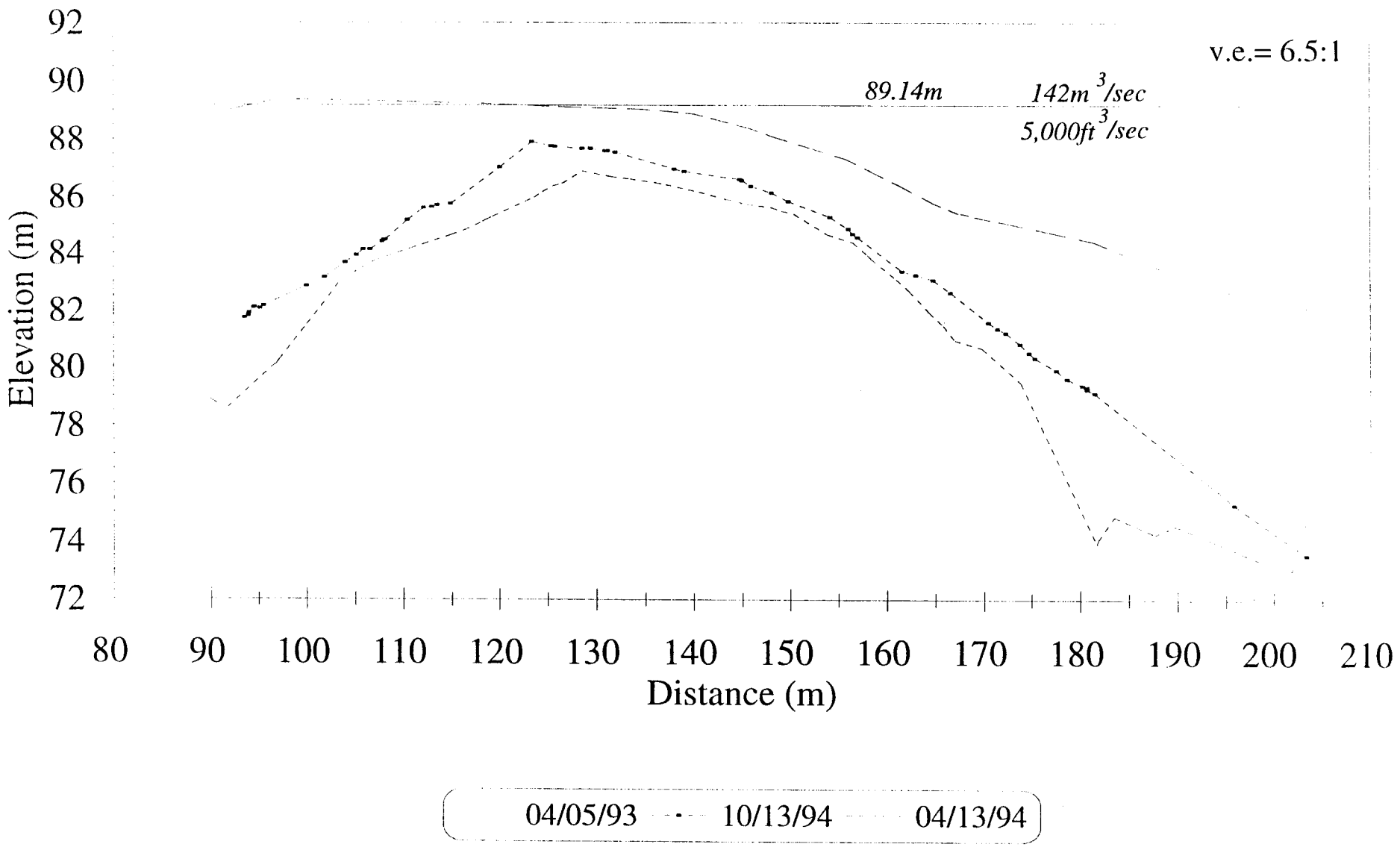


Near-shore P5

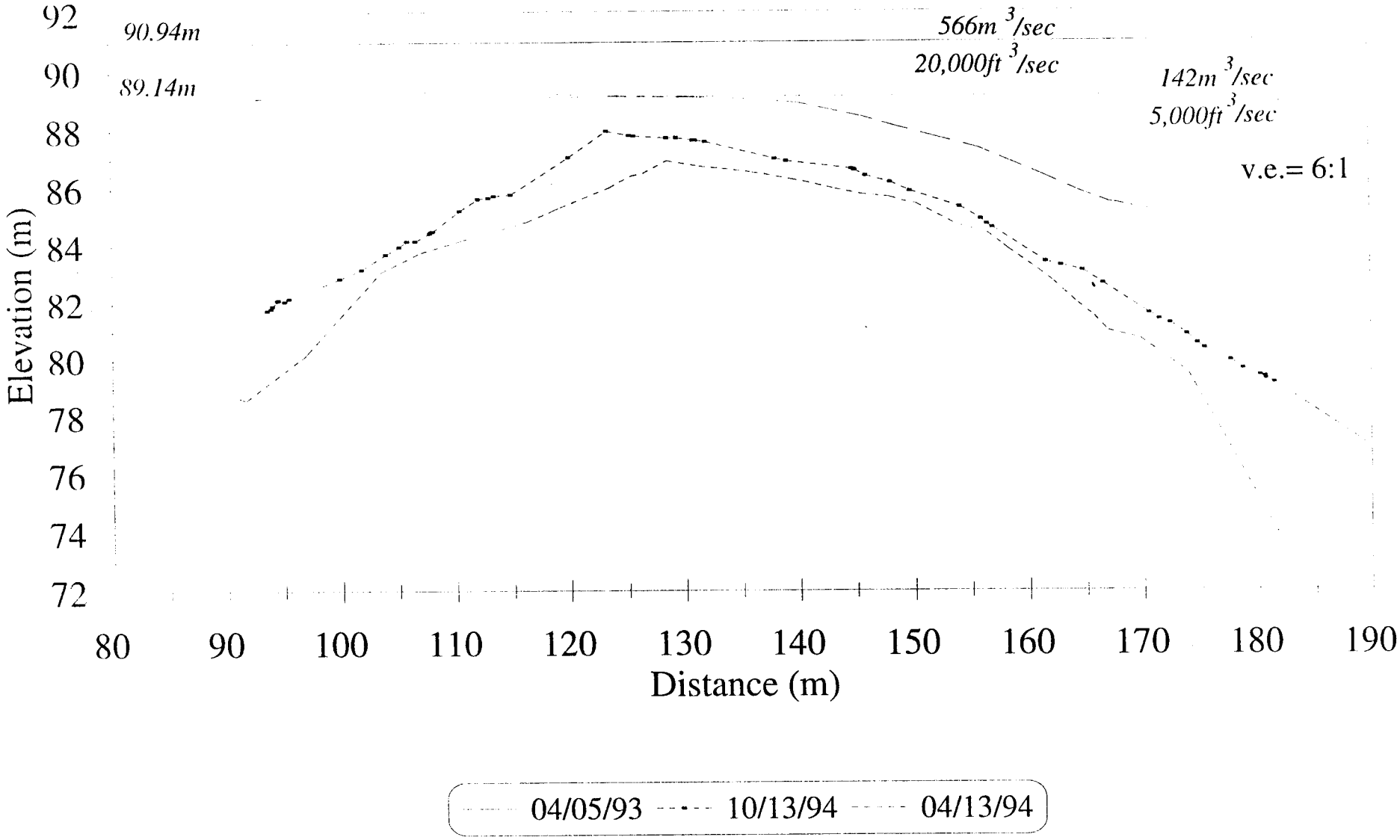


62 Mile

Cross-channel P7

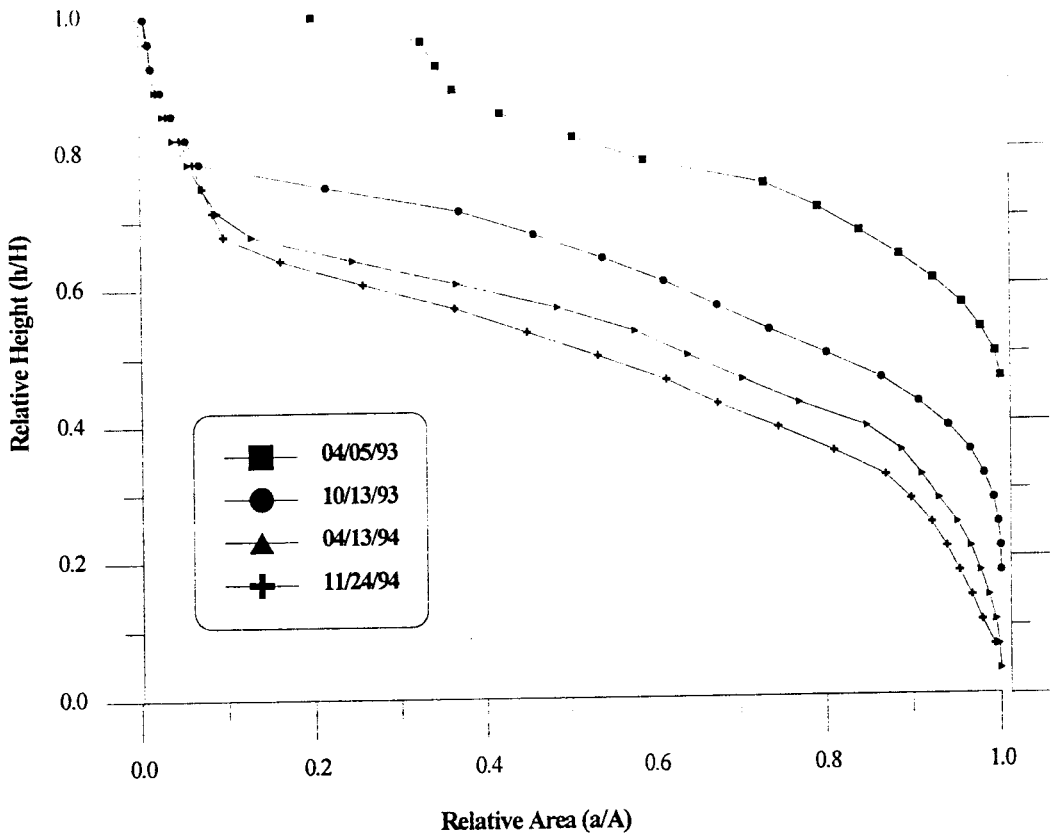


Near-shore P7

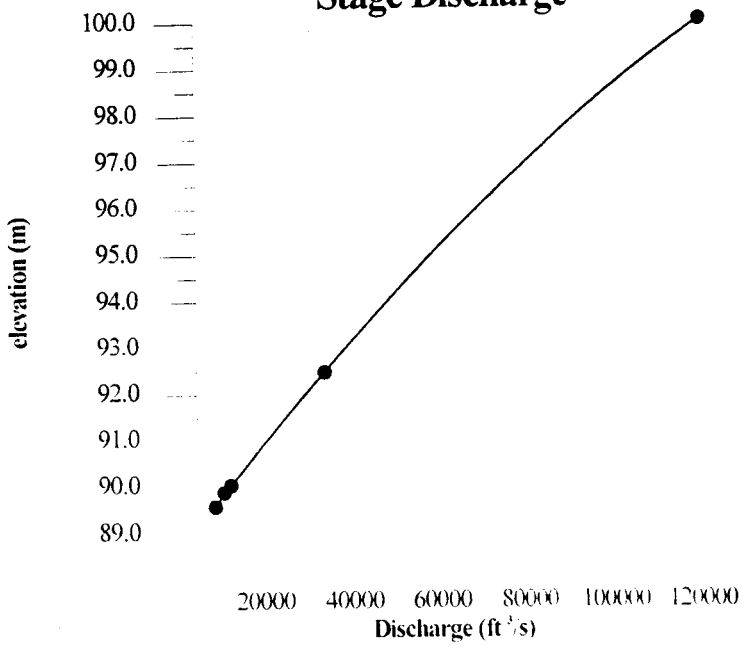


62 Mile

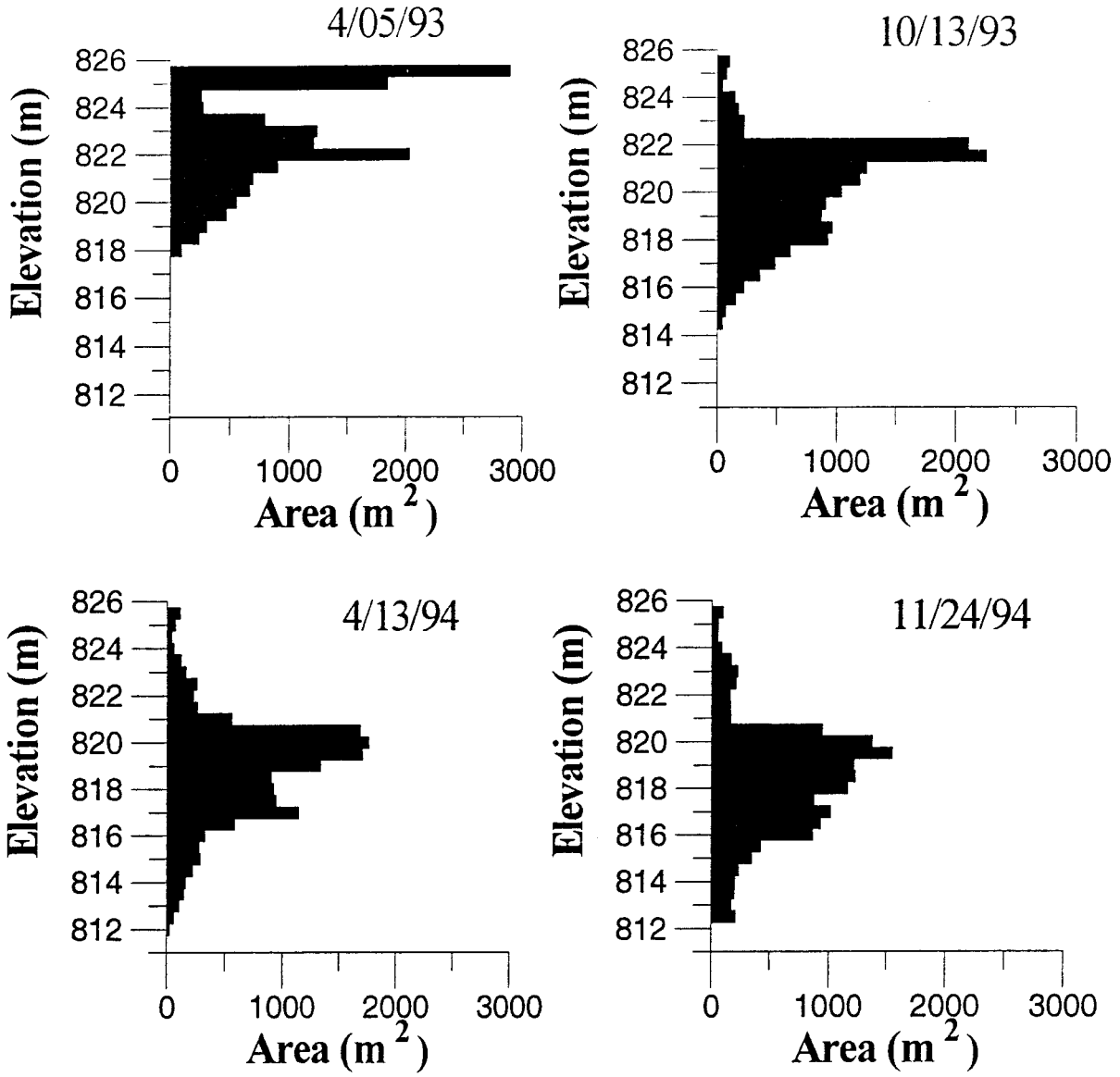
Hypsometric Curves



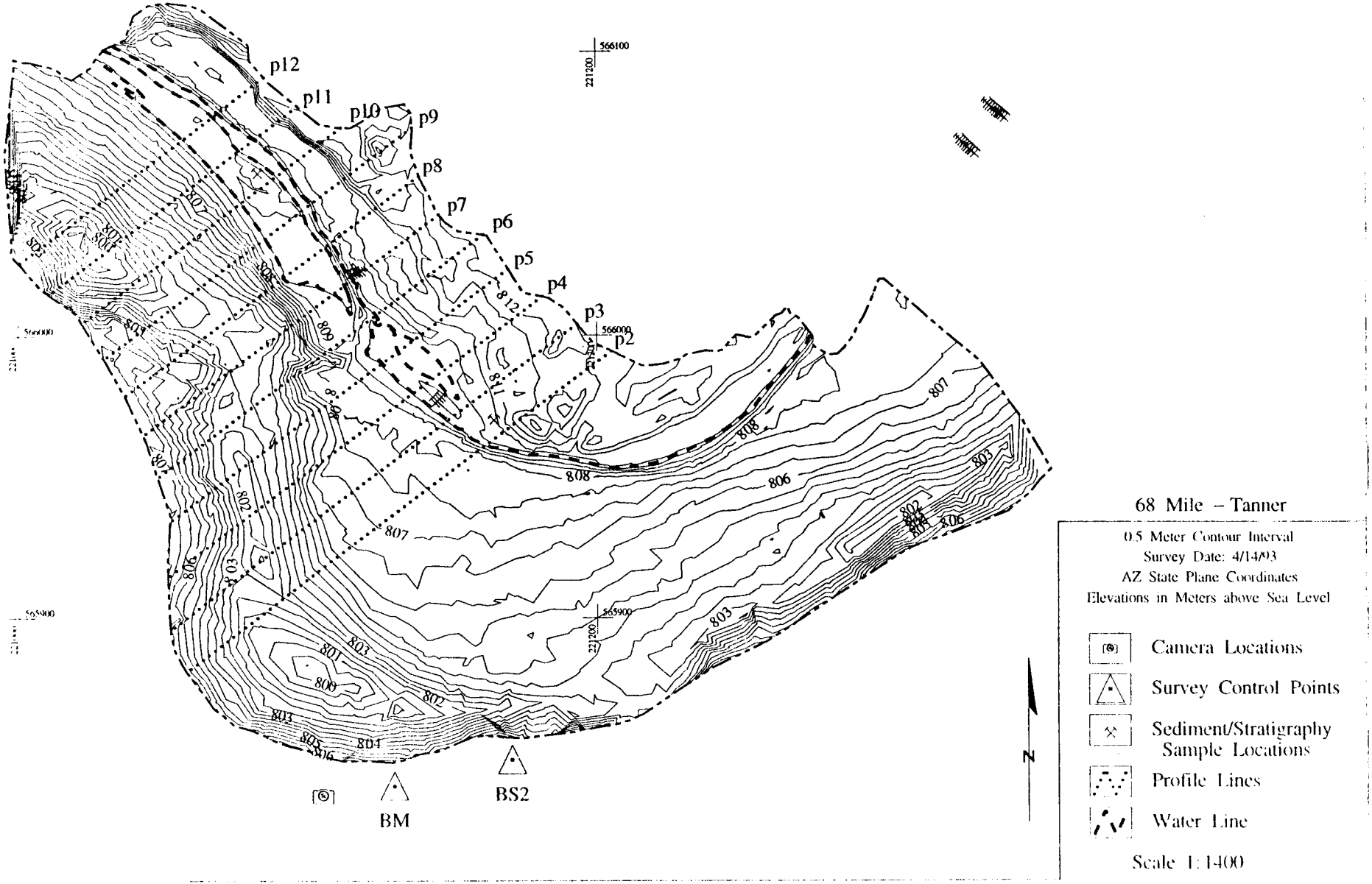
Stage Discharge



62 MILE
Area Distribution Histograms

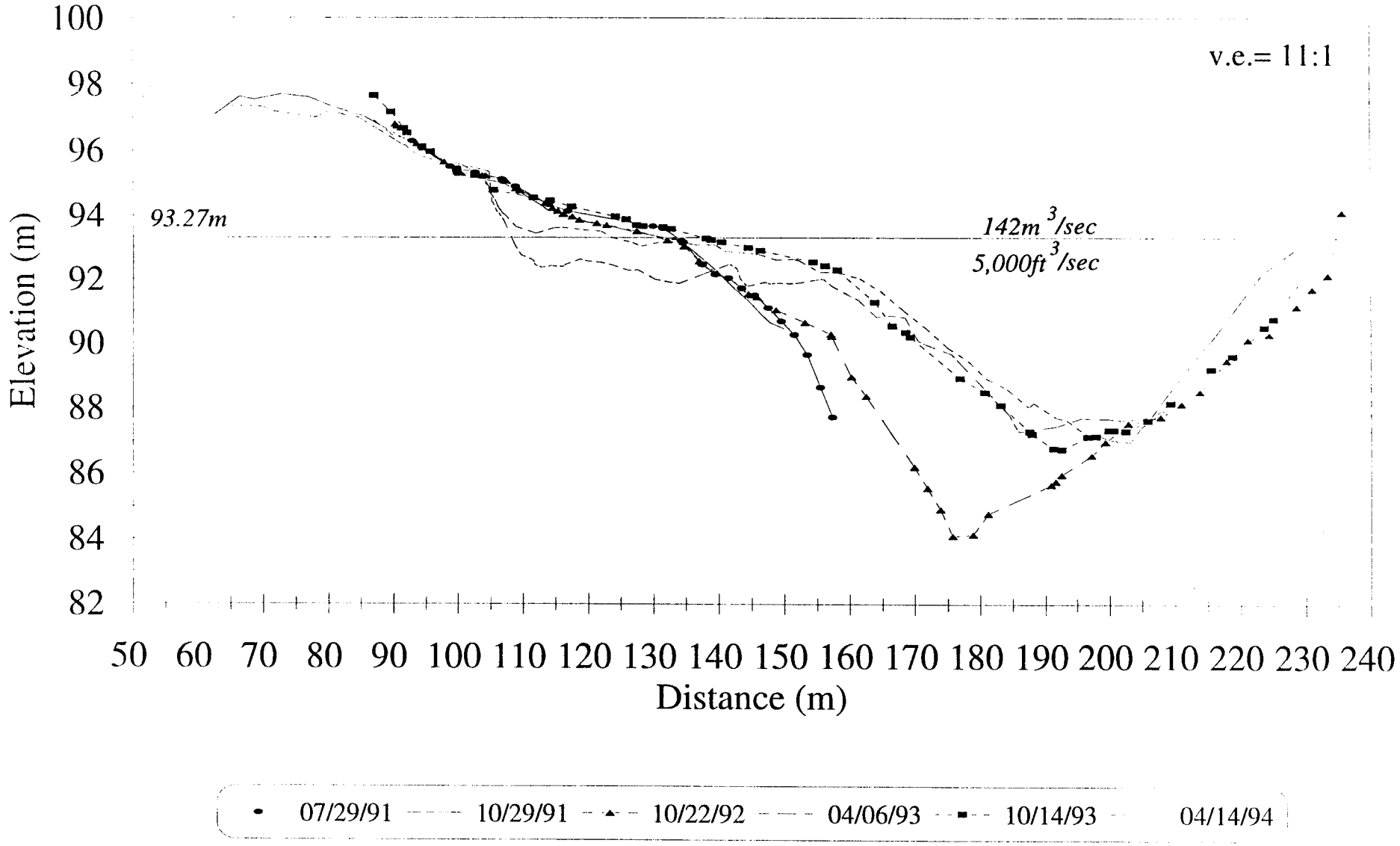


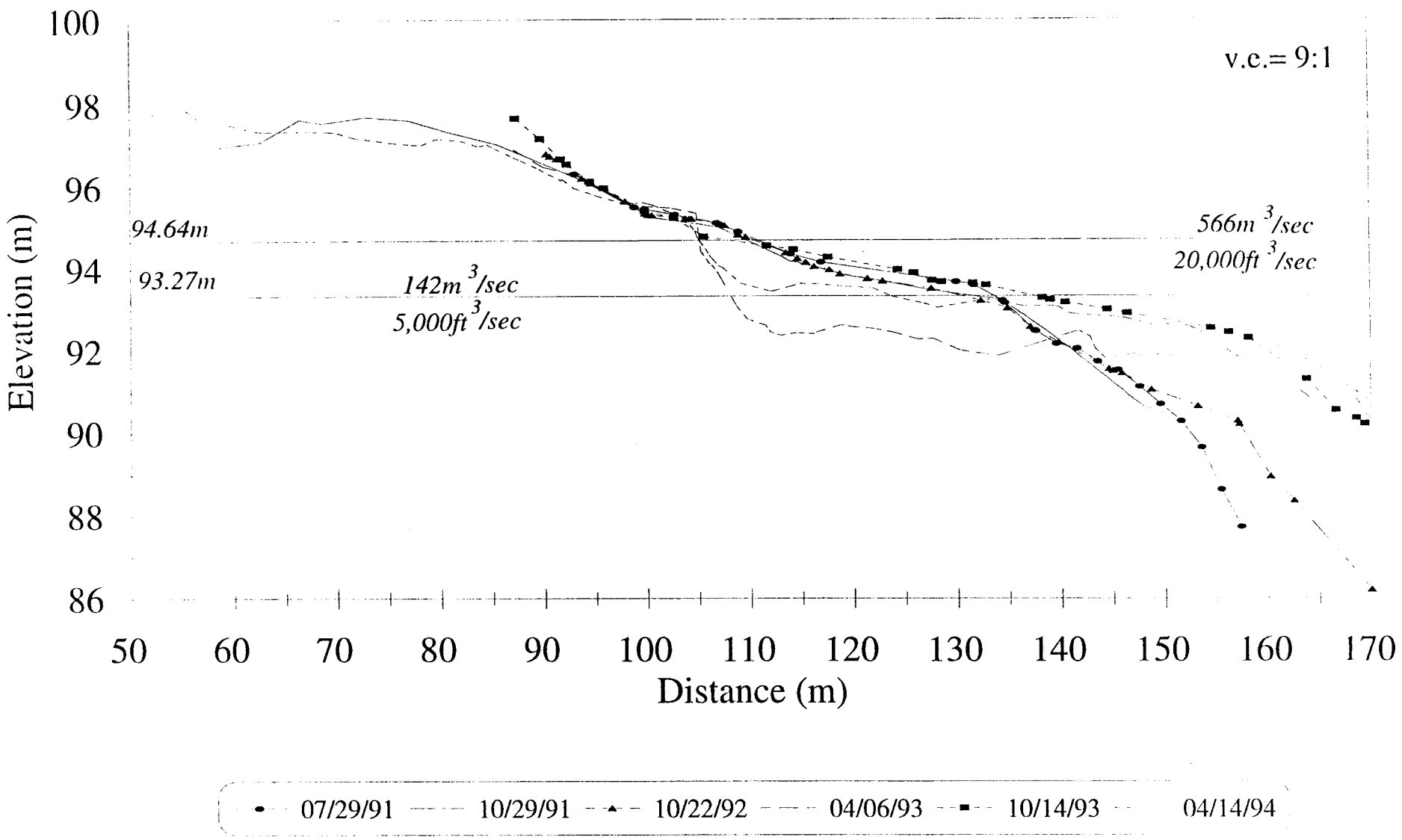
68 R
5-30-94
Area of Study
RM 68.5


p12
p11
p10
p9
p8
p7
p6
p5
p4
p3
p2
566100
221200
566000
221100
565900
221200
BM
BS2
N
68 Mile – Tanner
0.5 Meter Contour Interval
Survey Date: 4/14/93
AZ State Plane Coordinates
Elevations in Meters above Sea Level
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:1400

68 Mile

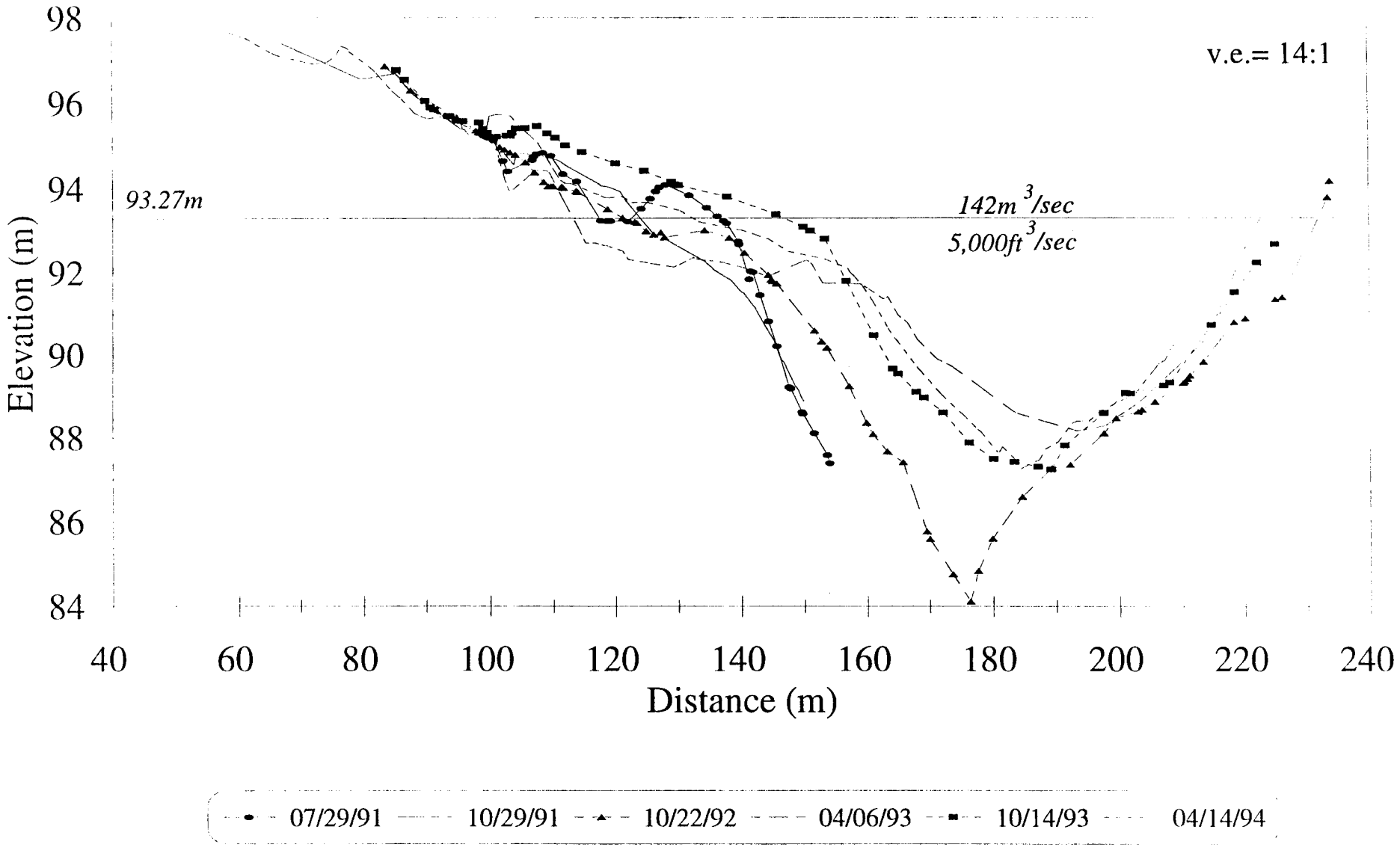
Cross-channel P2



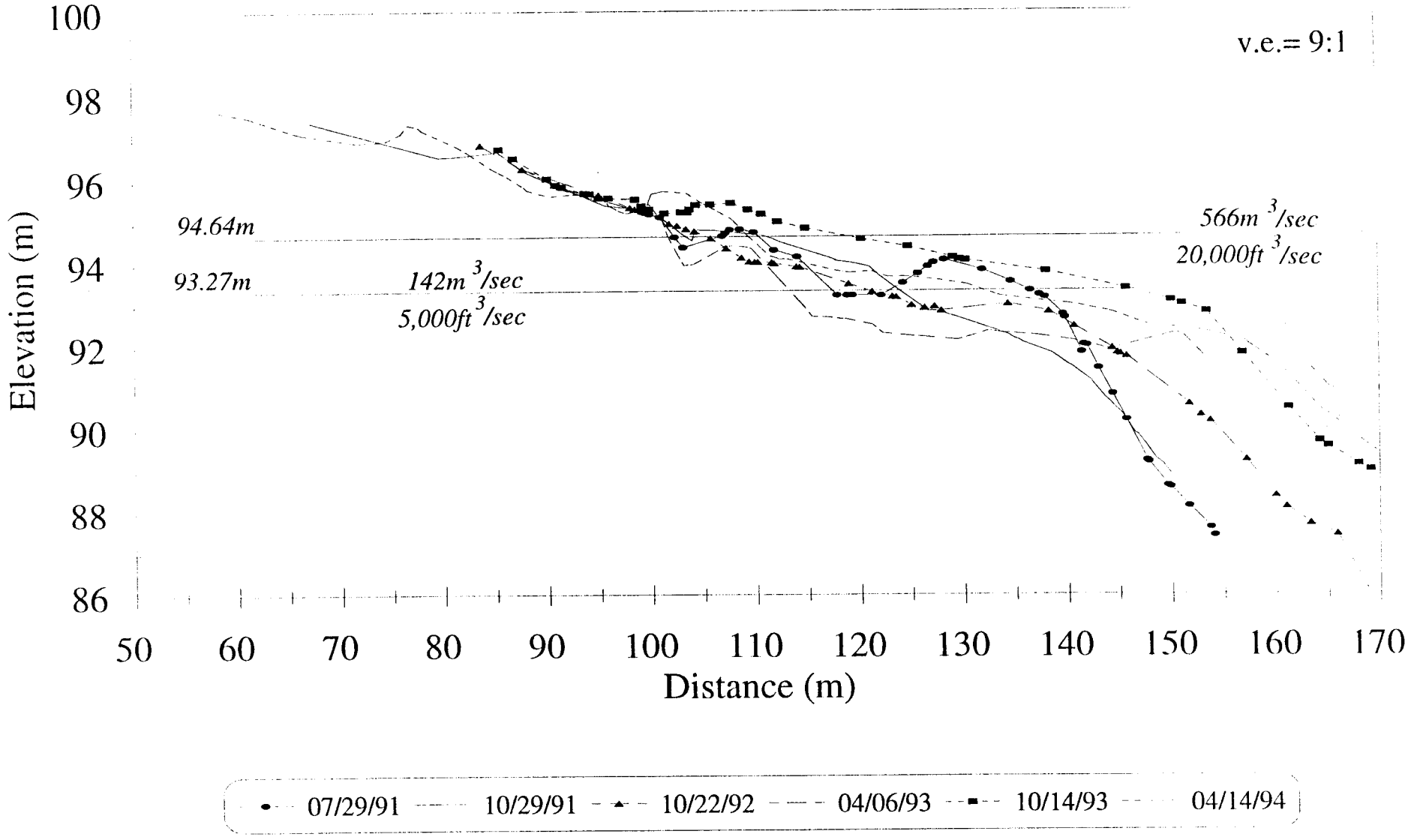

Near-shore P2
v.c.= 9:1
94.64m
93.27m
142m 3/sec
5,000ft 3/sec
566m 3/sec
20,000ft 3/sec
Elevation (m)
100
98
96
94
92
90
88
86
50
60
70
80
90
100
110
120
130
140
150
160
170
Distance (m)
07/29/91
10/29/91
10/22/92
04/06/93
10/14/93
04/14/94

68 Mile

Cross-channel P3

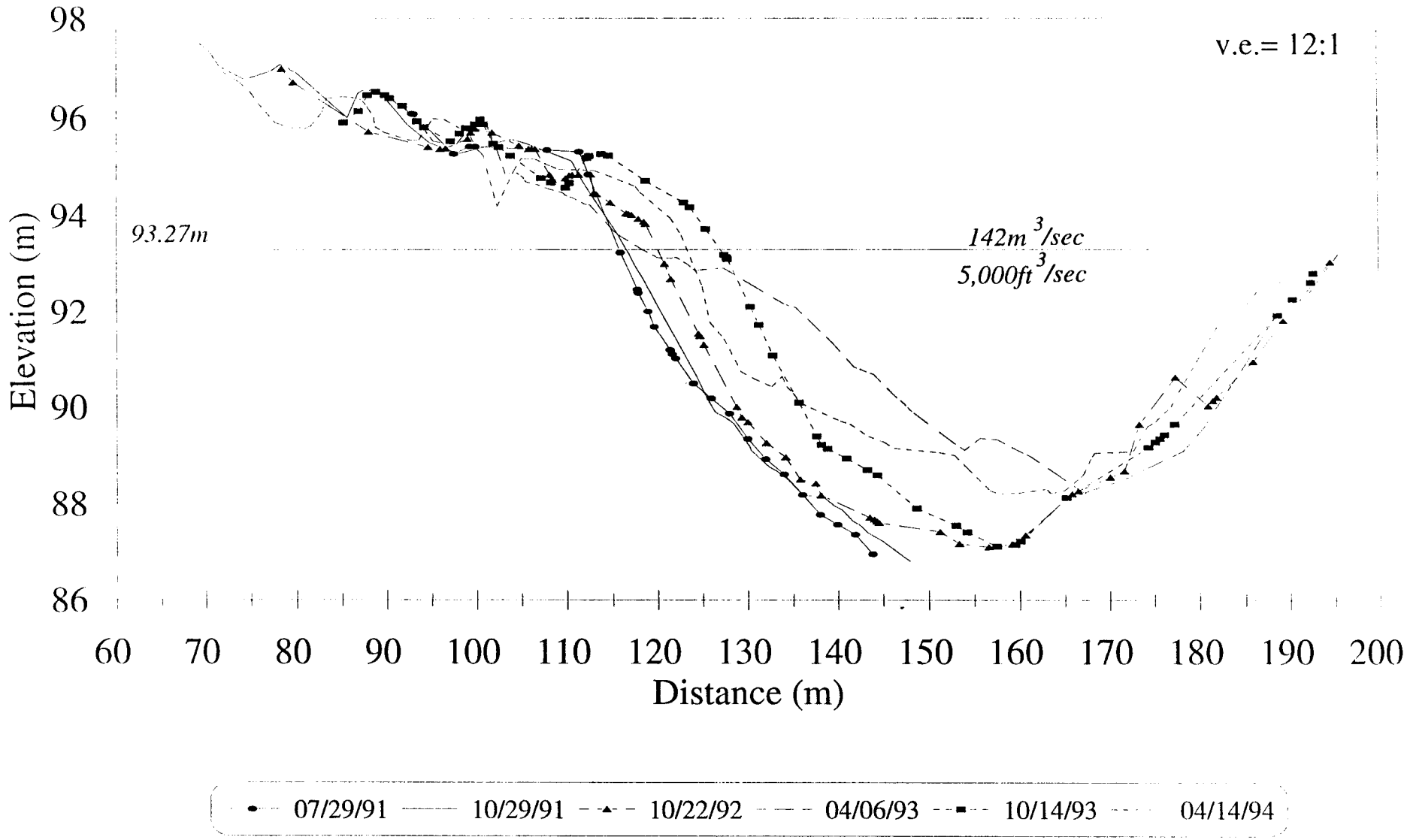


Near-shore P3

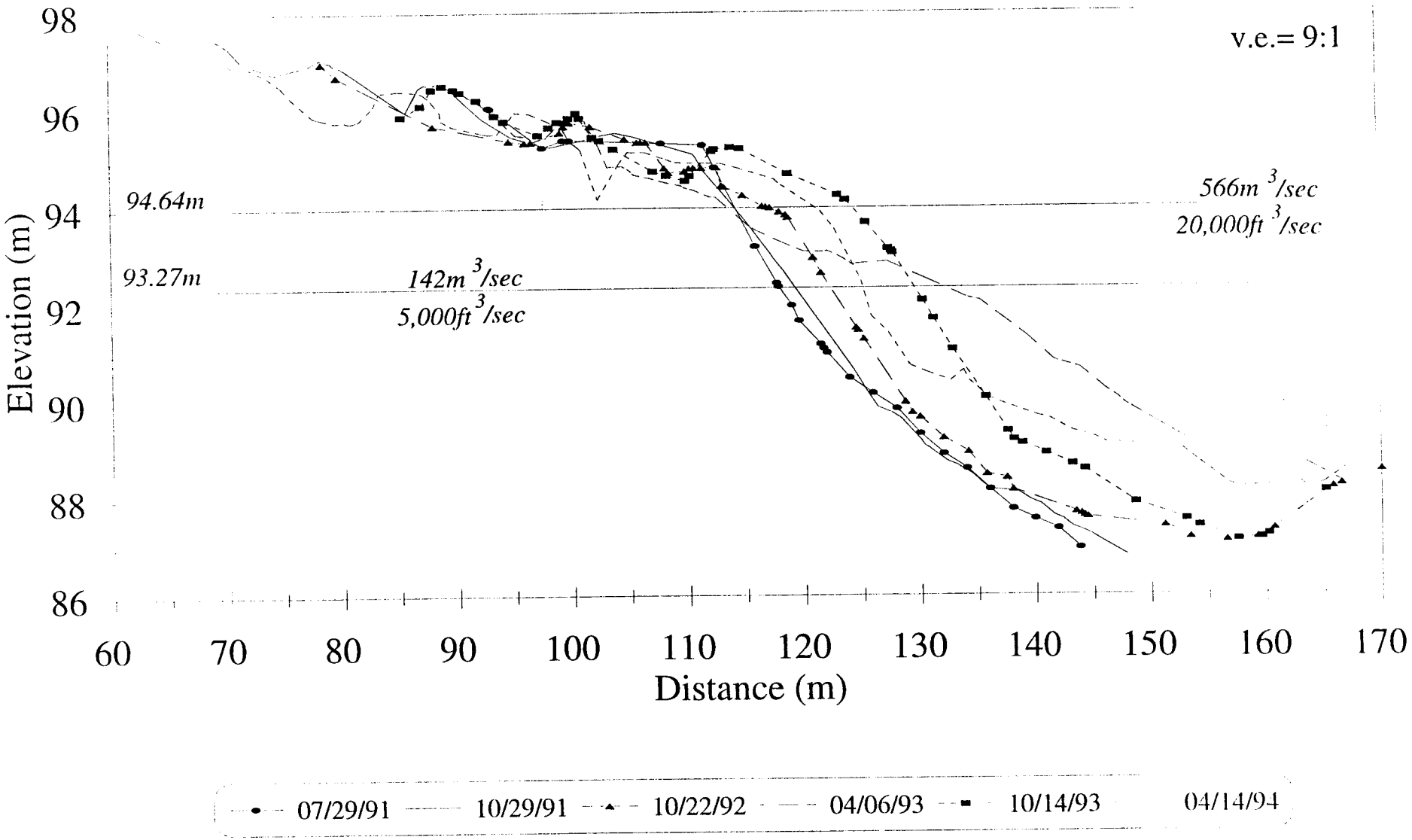


68 Mile

Cross-channel P6

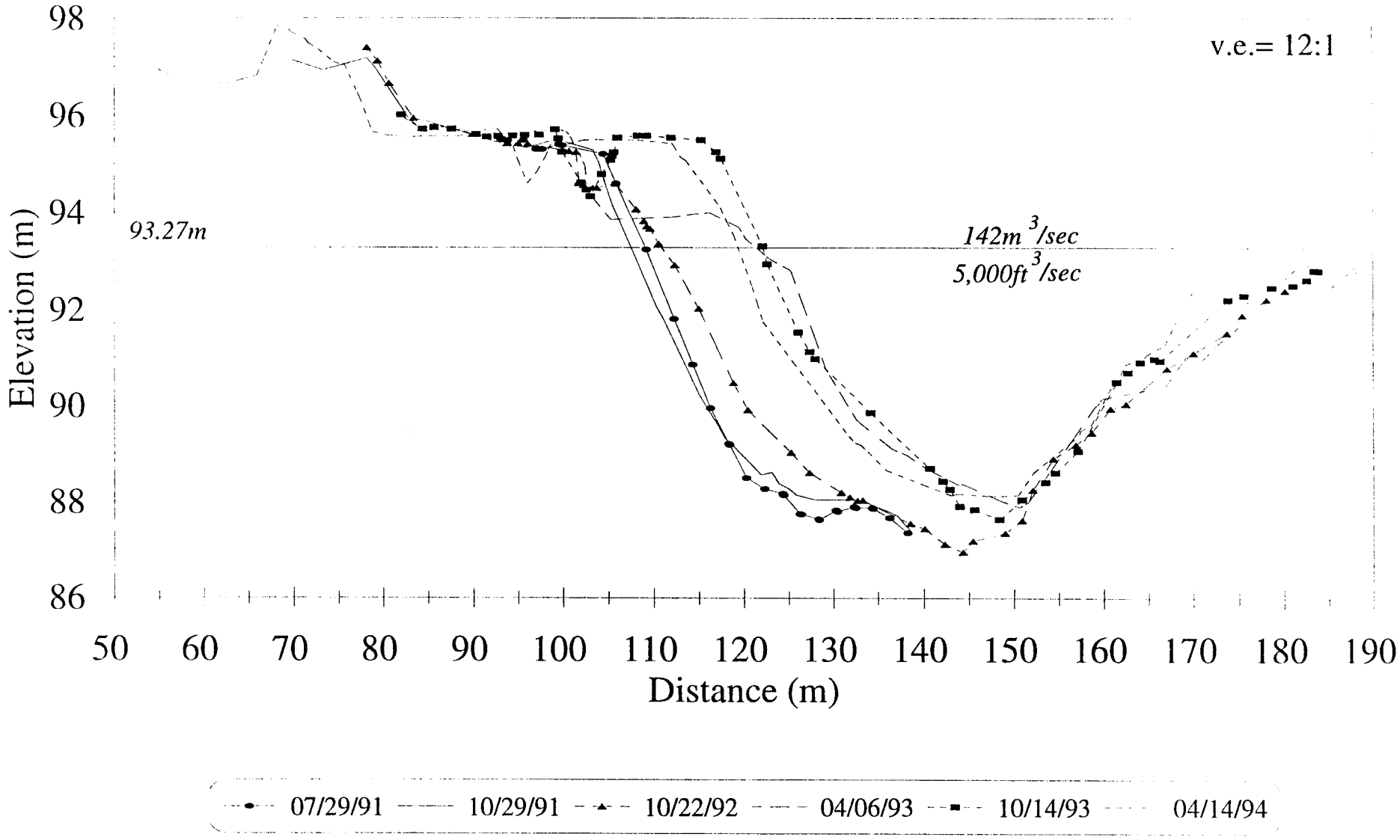


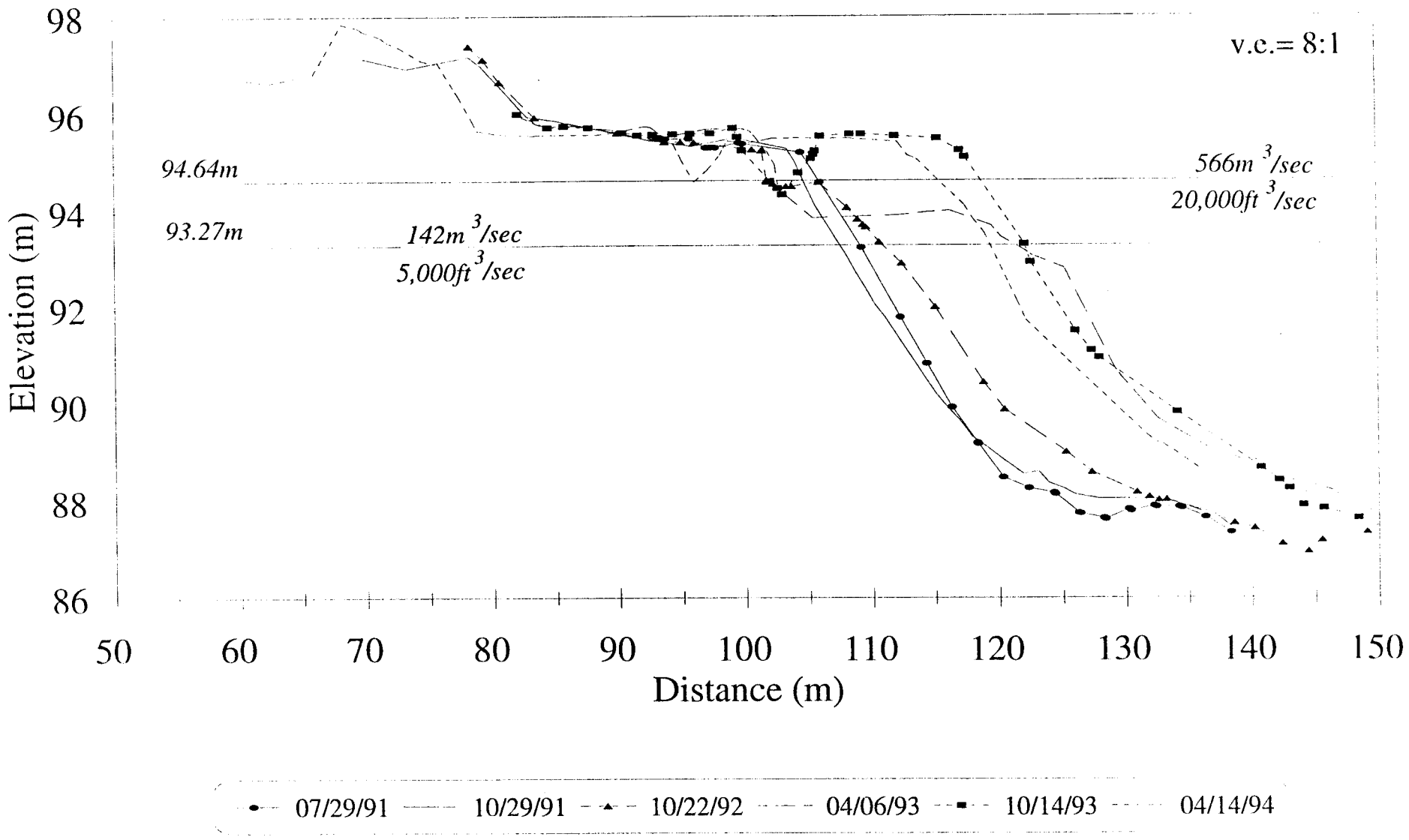
Near-shore P6



68 Mile

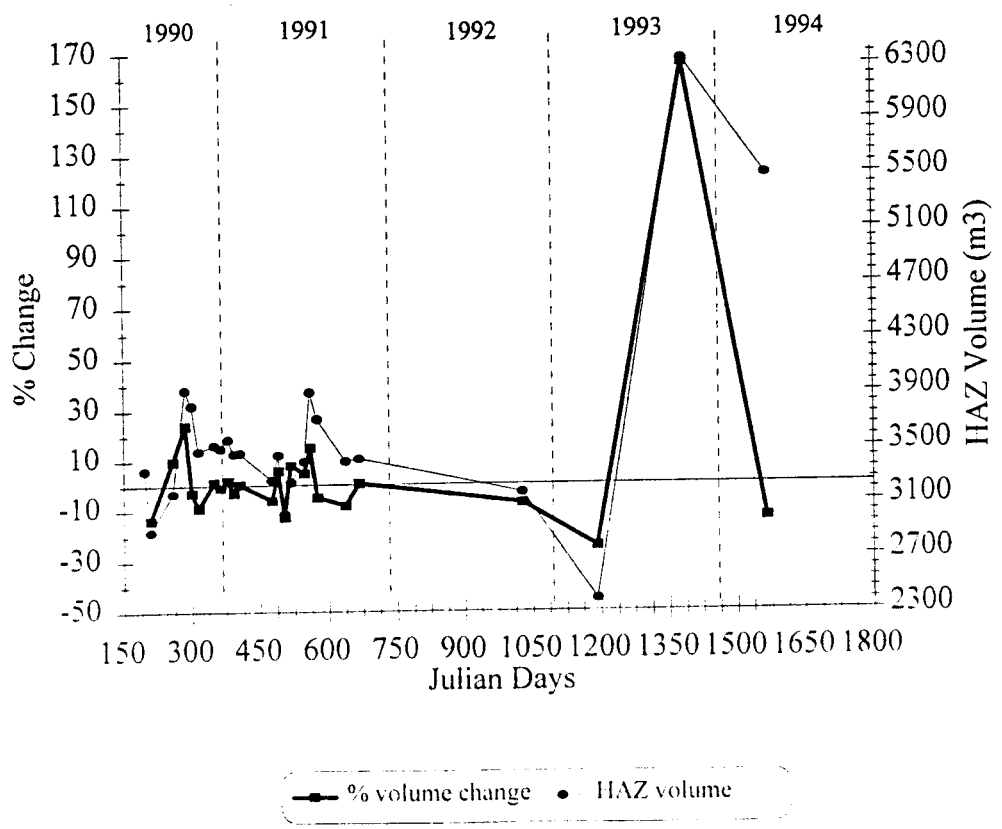
Cross-channel P8




Near-shore P8
v.e.= 8:1
94.64m
93.27m
142m 3/sec
5,000ft 3/sec
566m 3/sec
20,000ft 3/sec
Elevation (m)
98
96
94
92
90
88
86
50
60
70
80
90
100
110
120
130
140
150
Distance (m)
07/29/91
10/29/91
10/22/92
04/06/93
10/14/93
04/14/94

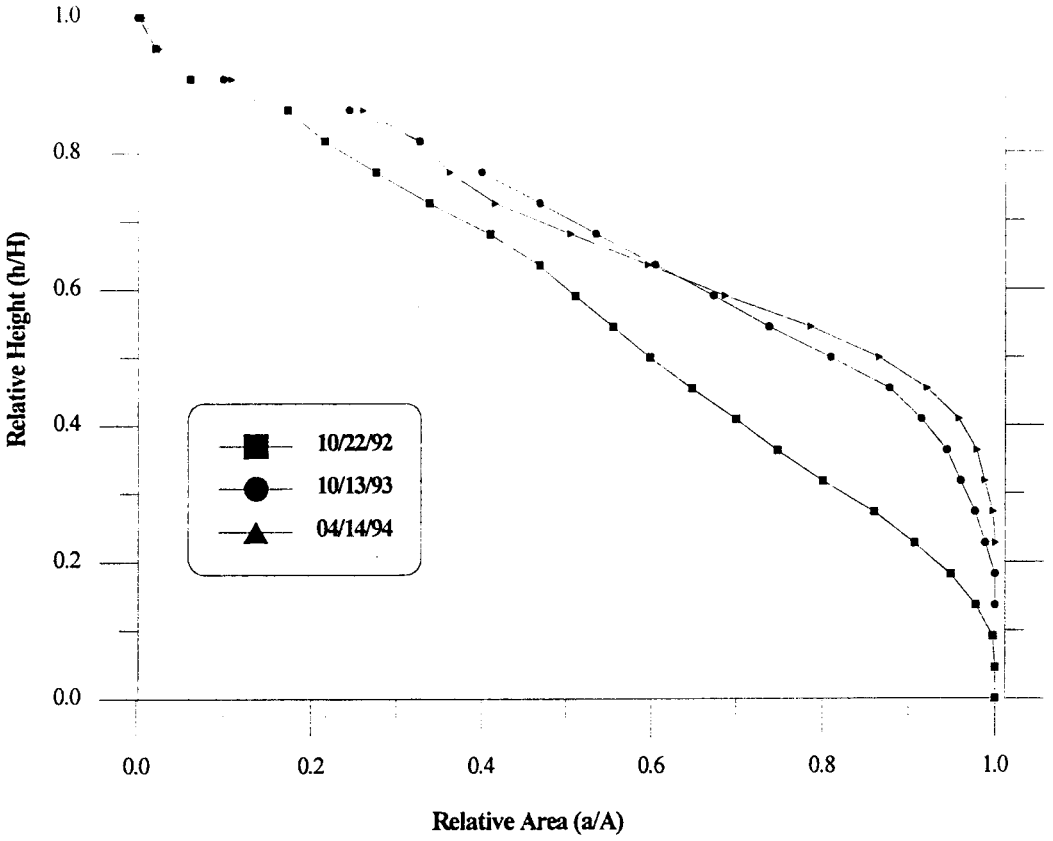
68 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C	900715	G	196	2990	3348				
D	900729	F	210	2649	2894	-341	-454	-11.40	-13.56
E		NORM							
F	900916	NORM	259	2764	3174	115	280	4.34	9.68
G		E							
H	901014	A	287	3163	3940	399	766	14.44	24.13
I	901028	8000 CFS	301	3155	3827	-8	-113	-0.25	-2.87
J	901112	NORM	316	3116	3490	-39	-337	-1.24	-8.81
K	901216	NORM	350	2943	3536	-173	46	-5.55	1.32
L	901230	11000 CFS	364	2940	3511	-3	-25	-0.10	-0.71
M	910114	C	379	2971	3579	31	68	1.05	1.94
N	910128	NORM	393	2963	3469	-8	-110	-0.27	-3.07
O	910210	B	406	3063	3478	100	9	3.37	0.26
P	910421	NORM	476	2954	3269	-109	-209	-3.56	-6.01
Q	910505	NORM	490	3288	3459	334	190	11.31	5.81
R	910519	D	504	2808	3020	-480	-439	-14.60	-12.69
S	910602	15000 CFS	518	3019	3256	211	236	7.51	7.81
T	910701	NORM	547	2998	3409	-21	153	-0.70	4.70
U	910714	G	560	3162	3919	164	510	5.47	14.96
V	910729	F	575	3077	3723	-85	-196	-2.69	-5.00
W	910929	INT	637	2659	3410	-418	-313	-13.58	-8.41
X	911029	INT	667	2818	3426	159	16	5.98	0.47
Y	921022	INT	1026	2979	3171	161	-255	5.71	-7.44
Z	930406	INT	1192	2102	2389	-877	-782	-29.44	-24.66
B15	931013	INT	1382	4828	6341	2726	3952	129.69	165.42
C15	940414	INT	1565	4106	5496	-722	-845	-14.95	-13.33

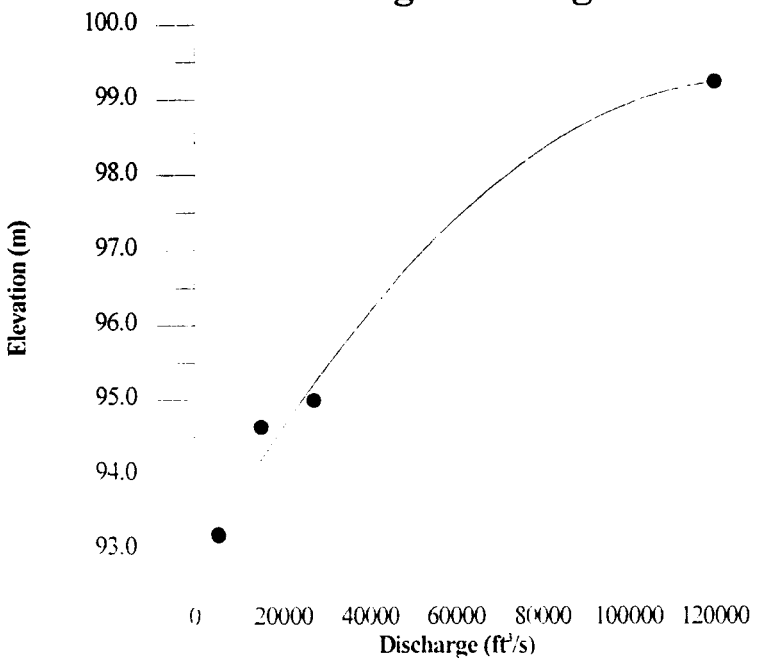


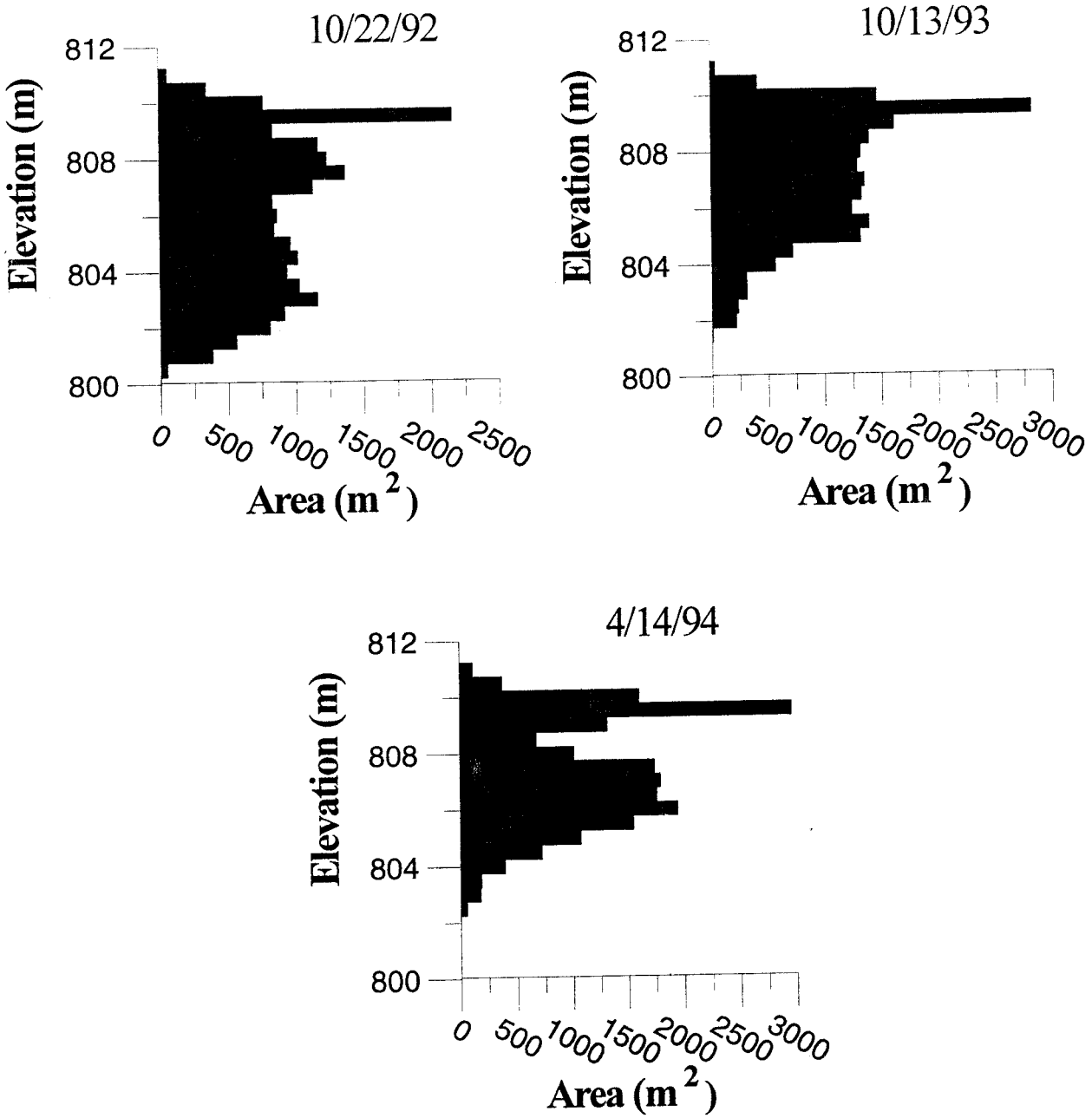
68 Mile

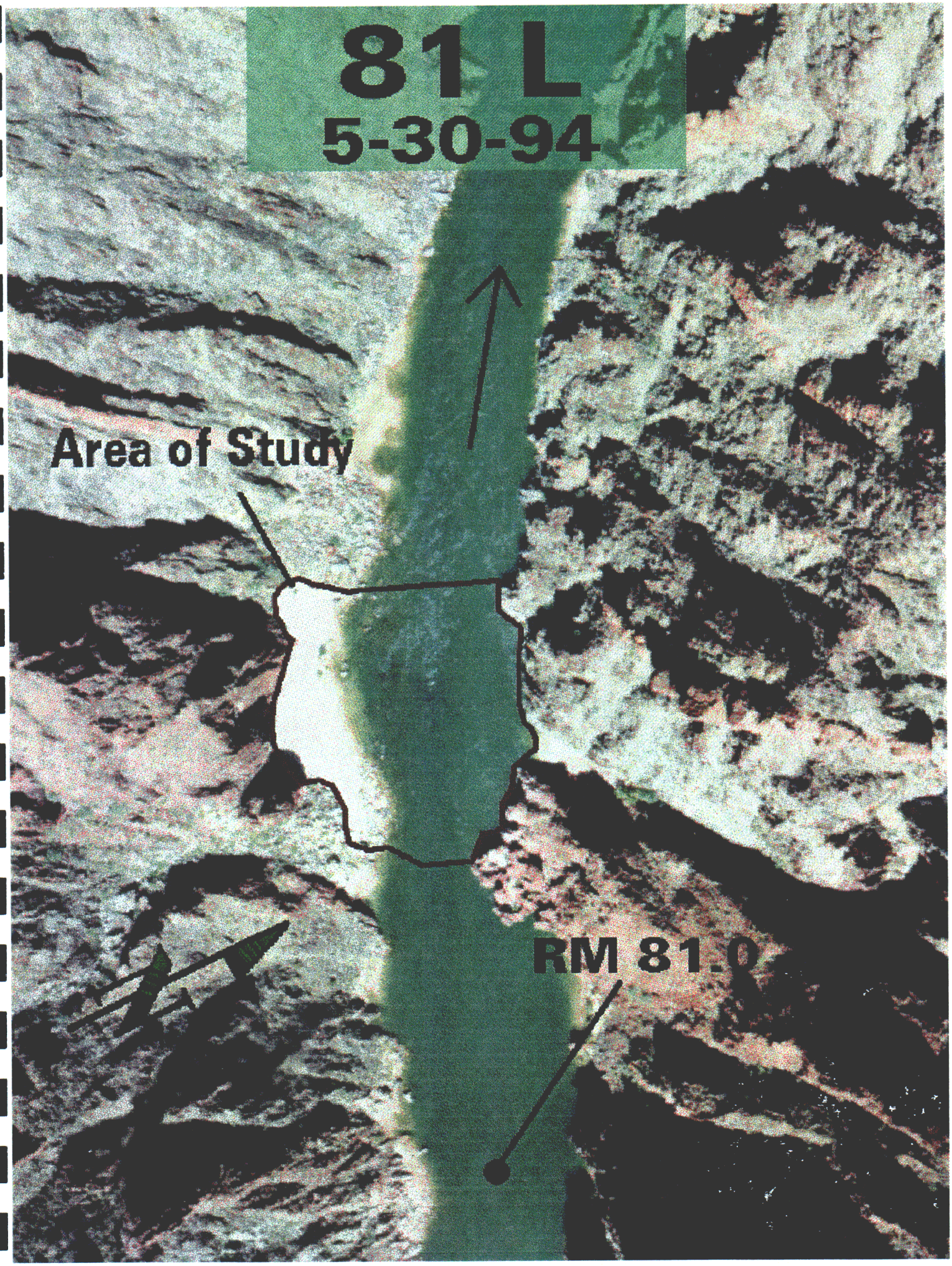
Hypsometric Curves

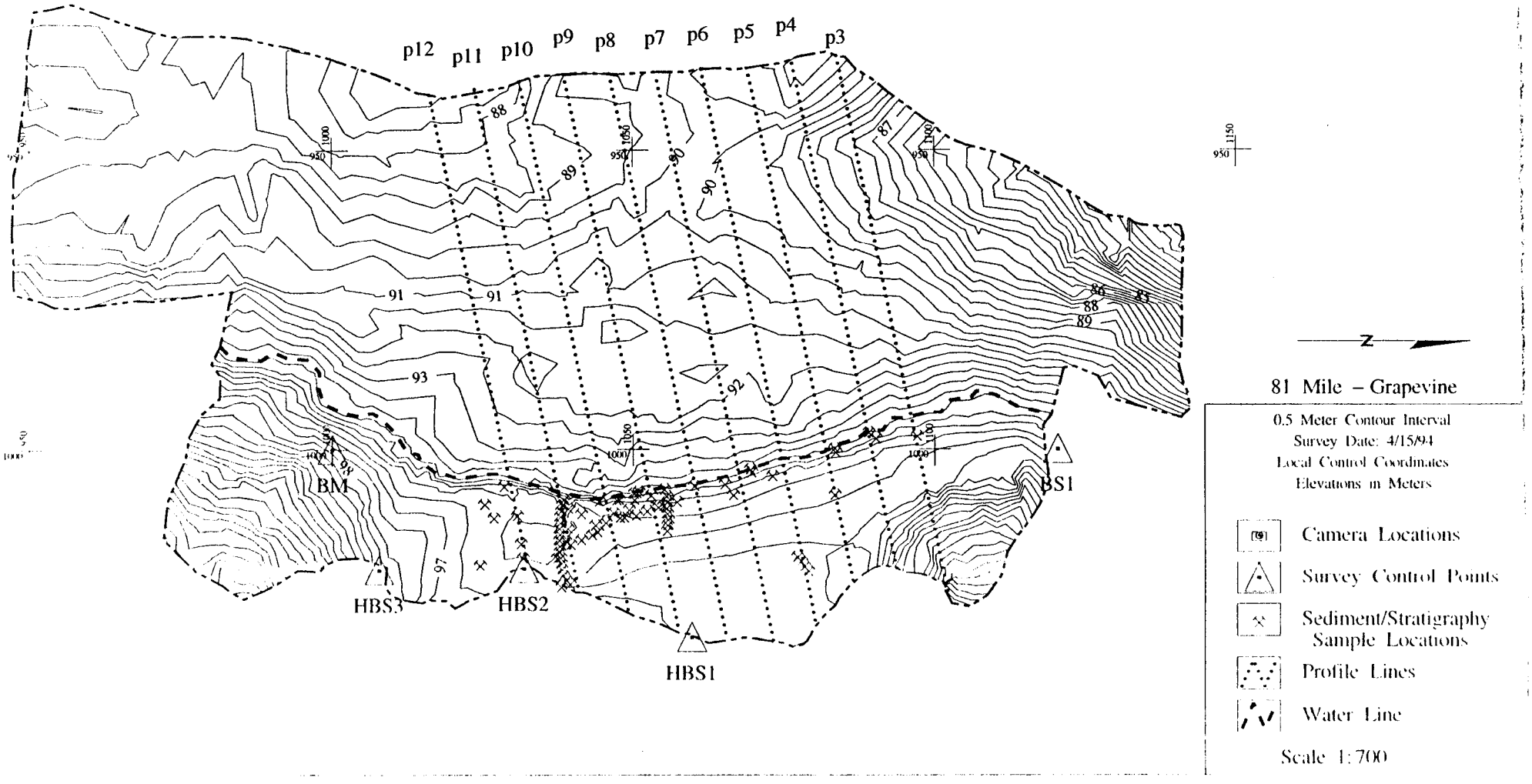


Stage Discharge



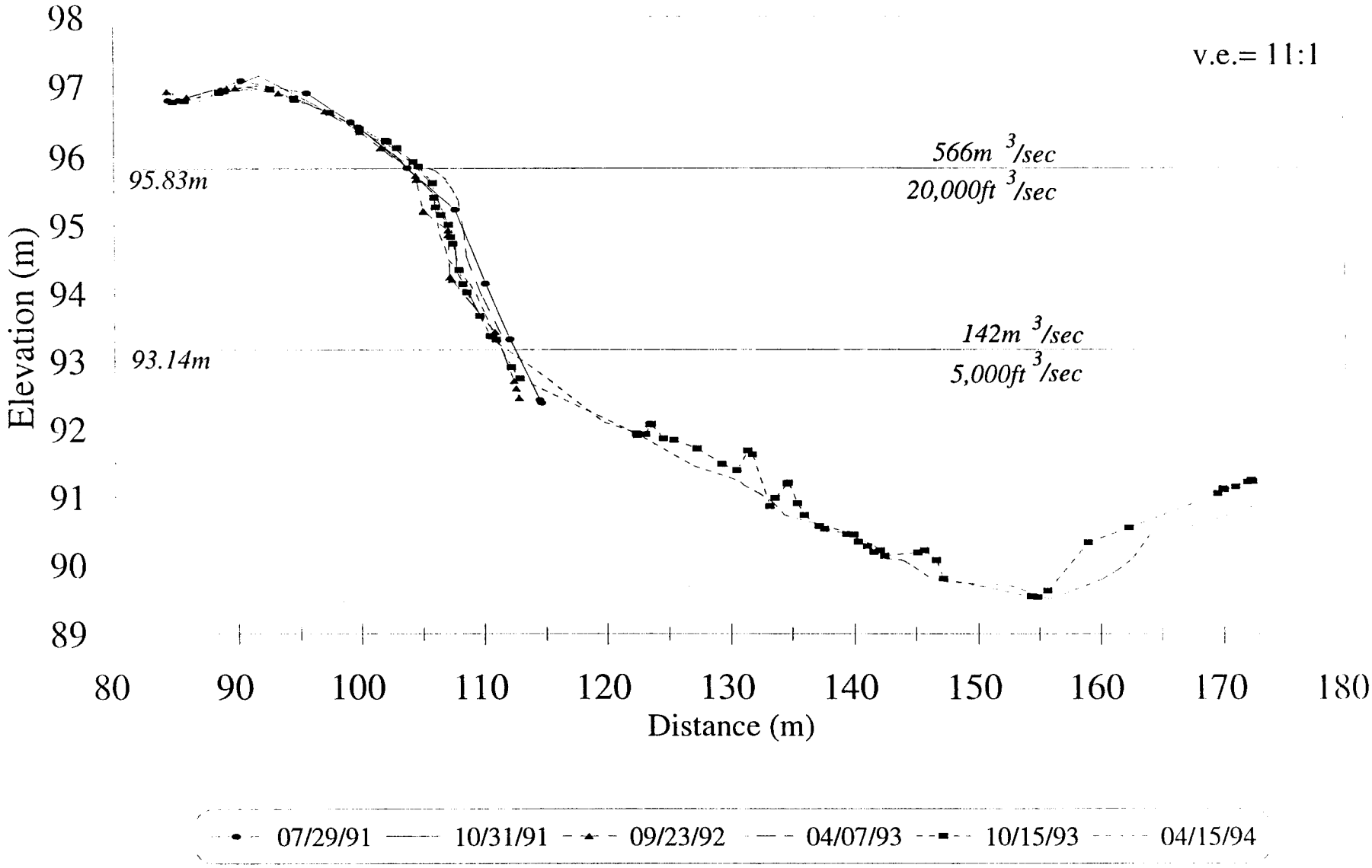

10/22/92
812
808
804
800
Elevation (m)
0
500
1000
1500
2000
2500
Area (m 2)
10/13/93
812
808
804
800
Elevation (m)
0
500
1000
1500
2000
2500
3000
Area (m 2)
4/14/94
812
808
804
800
Elevation (m)
0
500
1000
1500
2000
2500
3000
Area (m 2)


81 L
5-30-94
Area of Study
RM 81.0

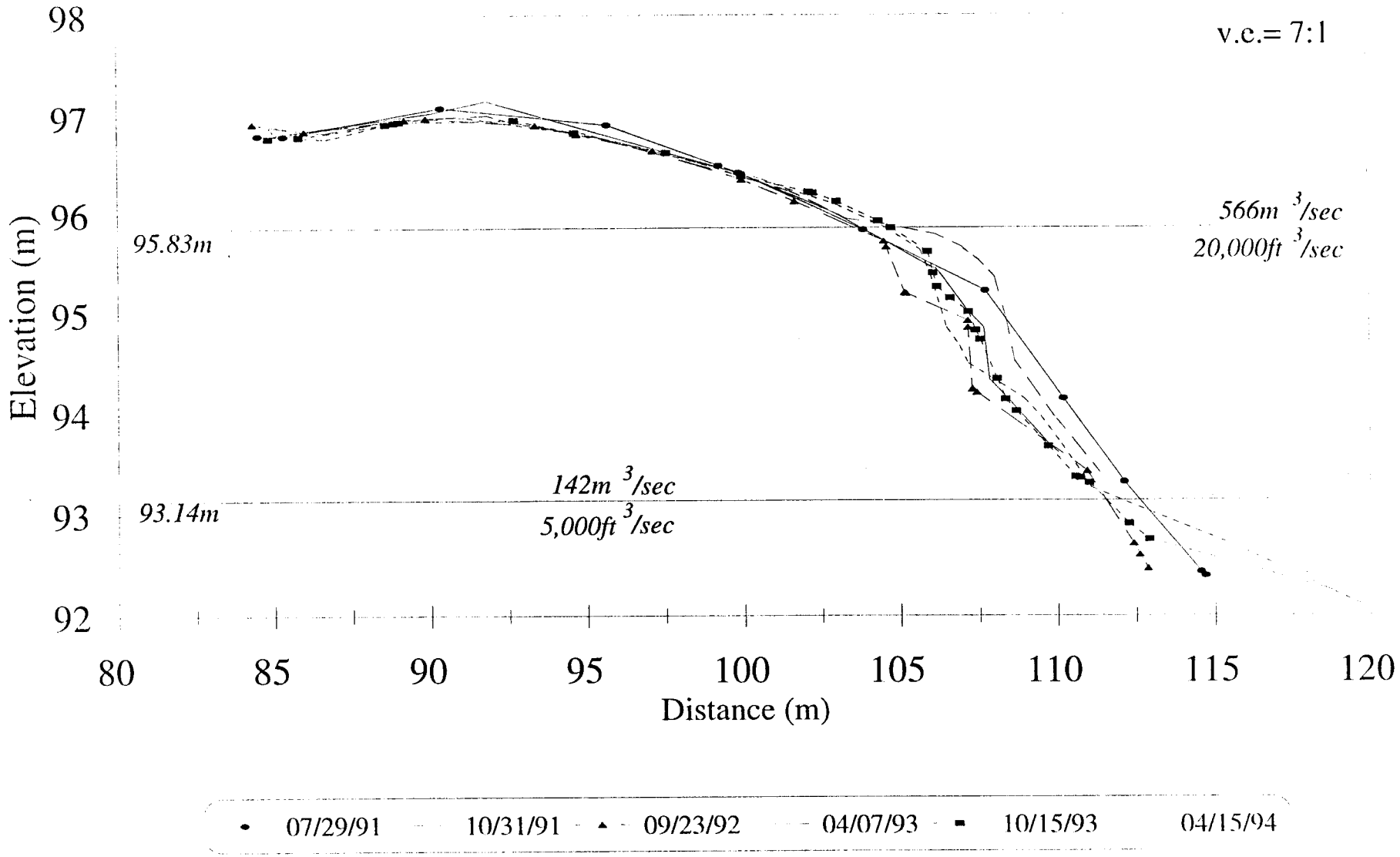

p12
p11
p10
p9
p8
p7
p6
p5
p4
p3
88
89
90
90
87
91
91
93
92
86
88
89
BM
HBS3
HBS2
HBS1
BS1
N
81 Mile – Grapevine
0.5 Meter Contour Interval
Survey Date: 4/15/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:700

81 Mile

Cross-channel P5

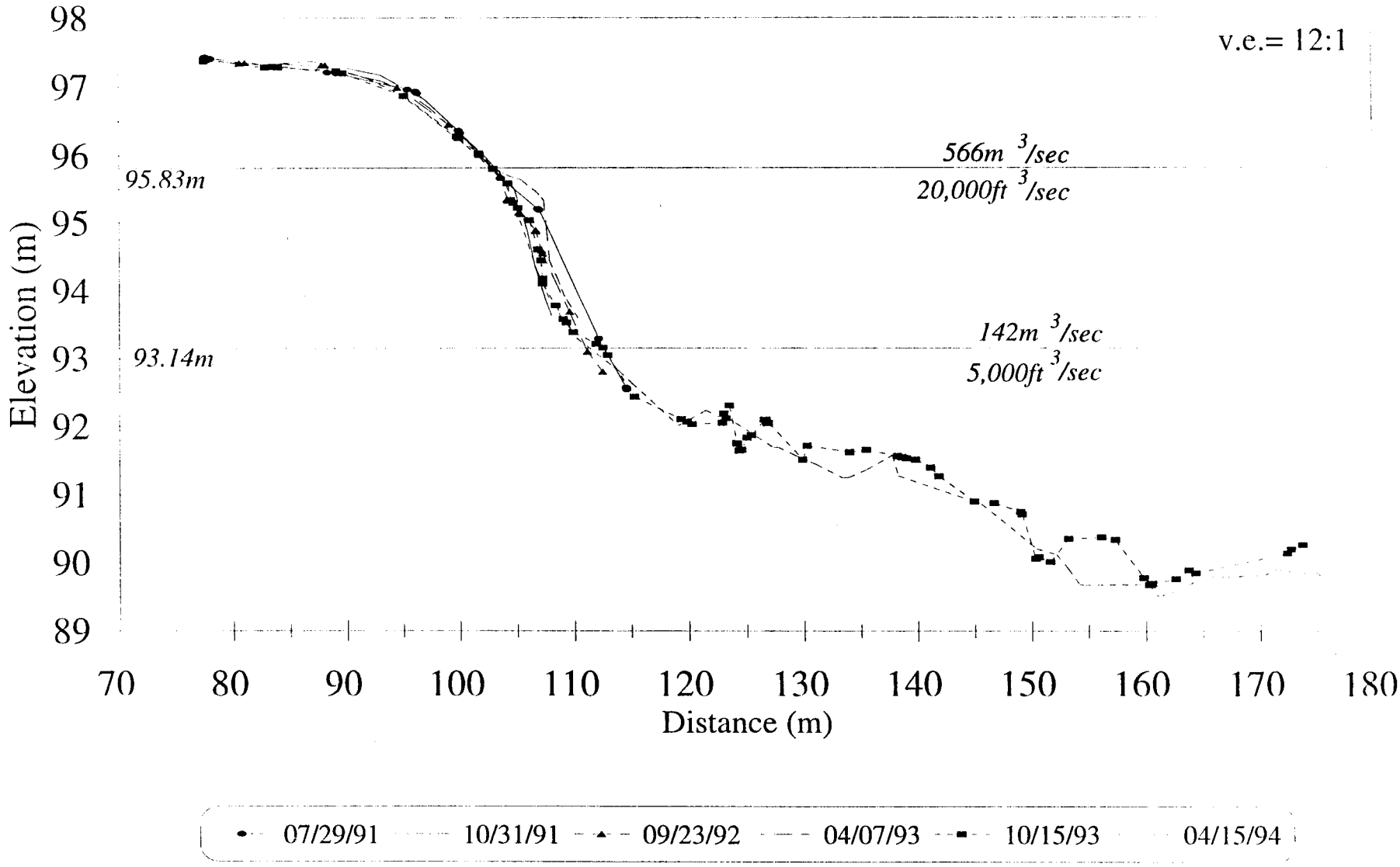


Near-shore P5

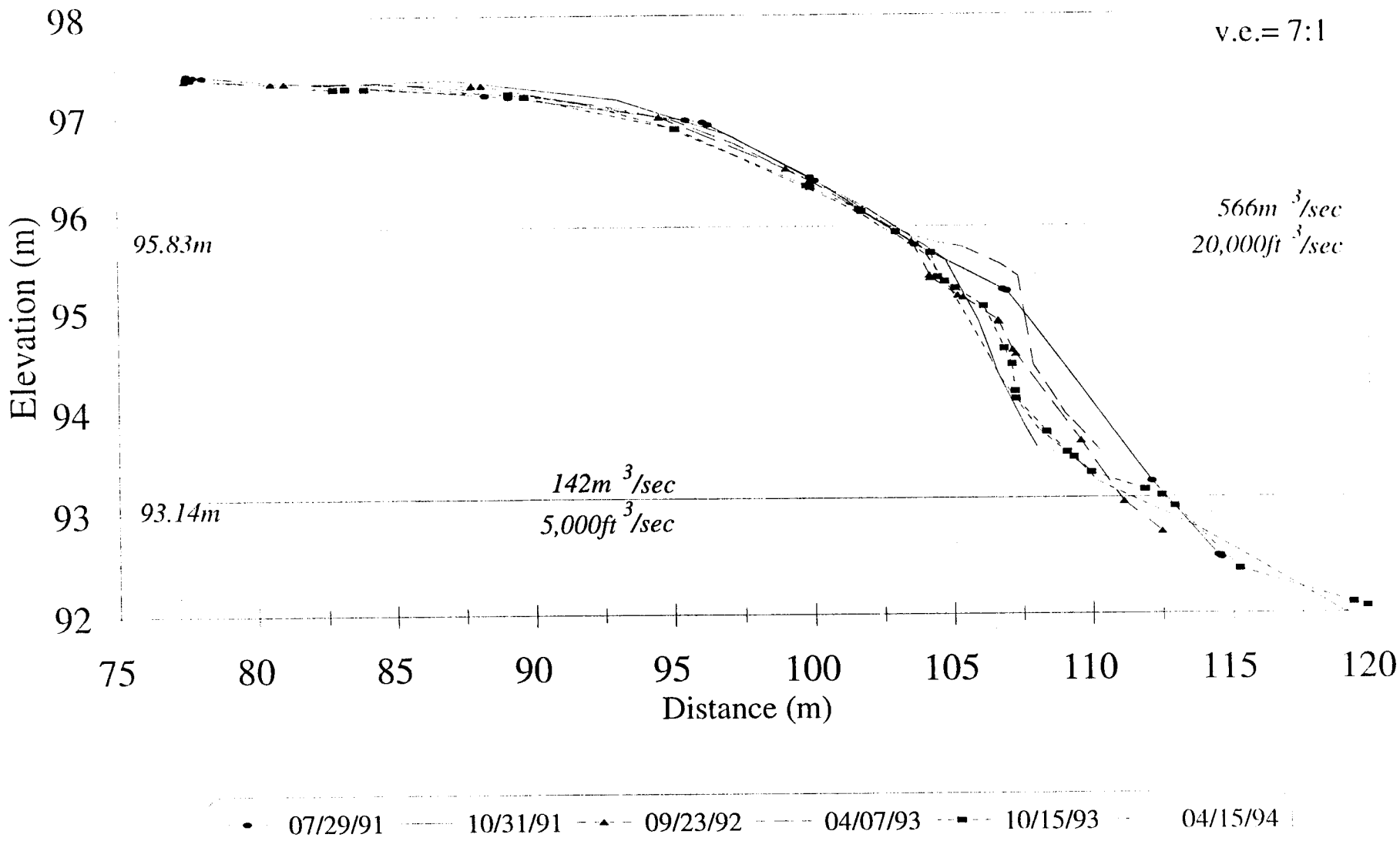


81 Mile

Cross-channel P7

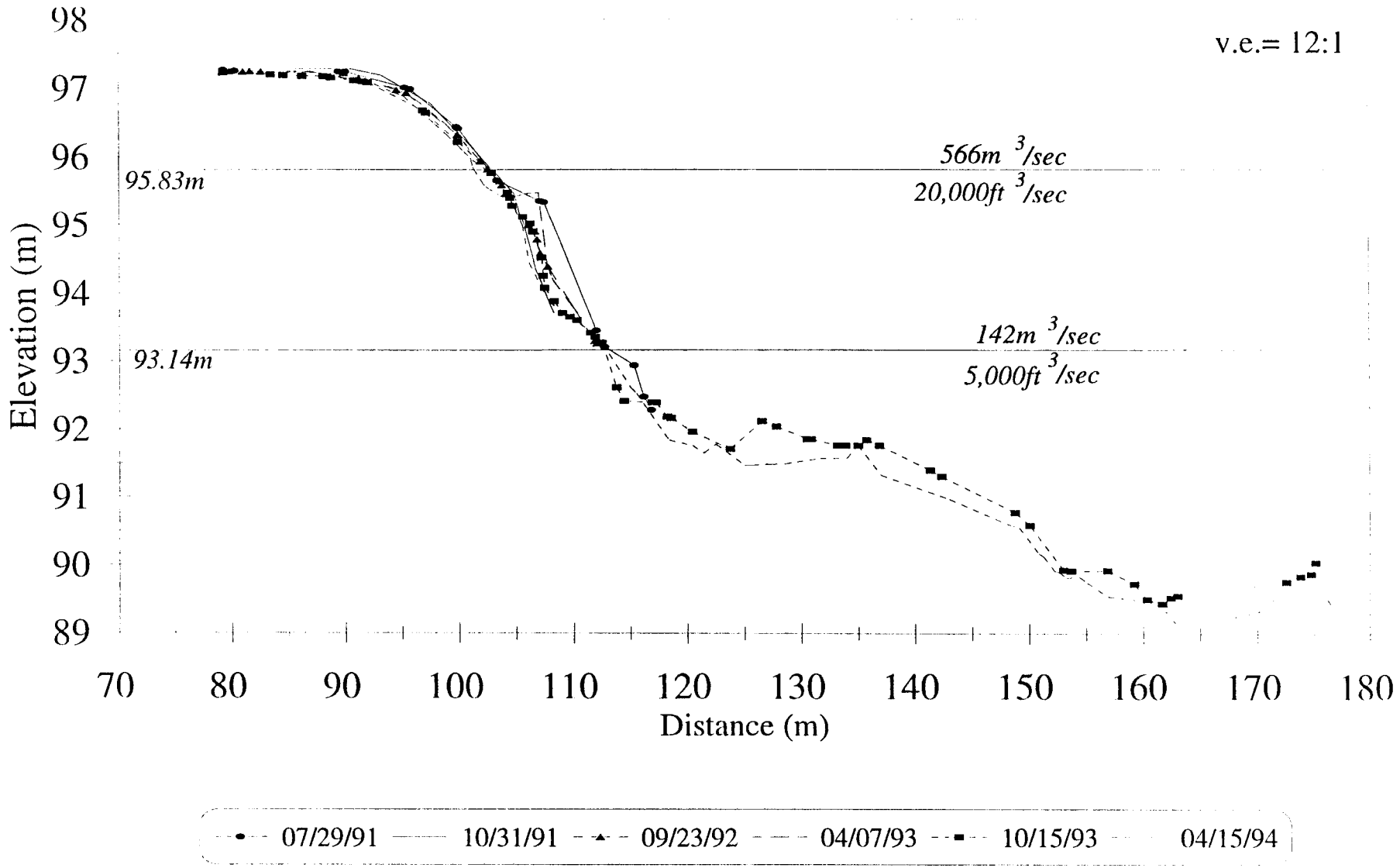


Near-shore P7

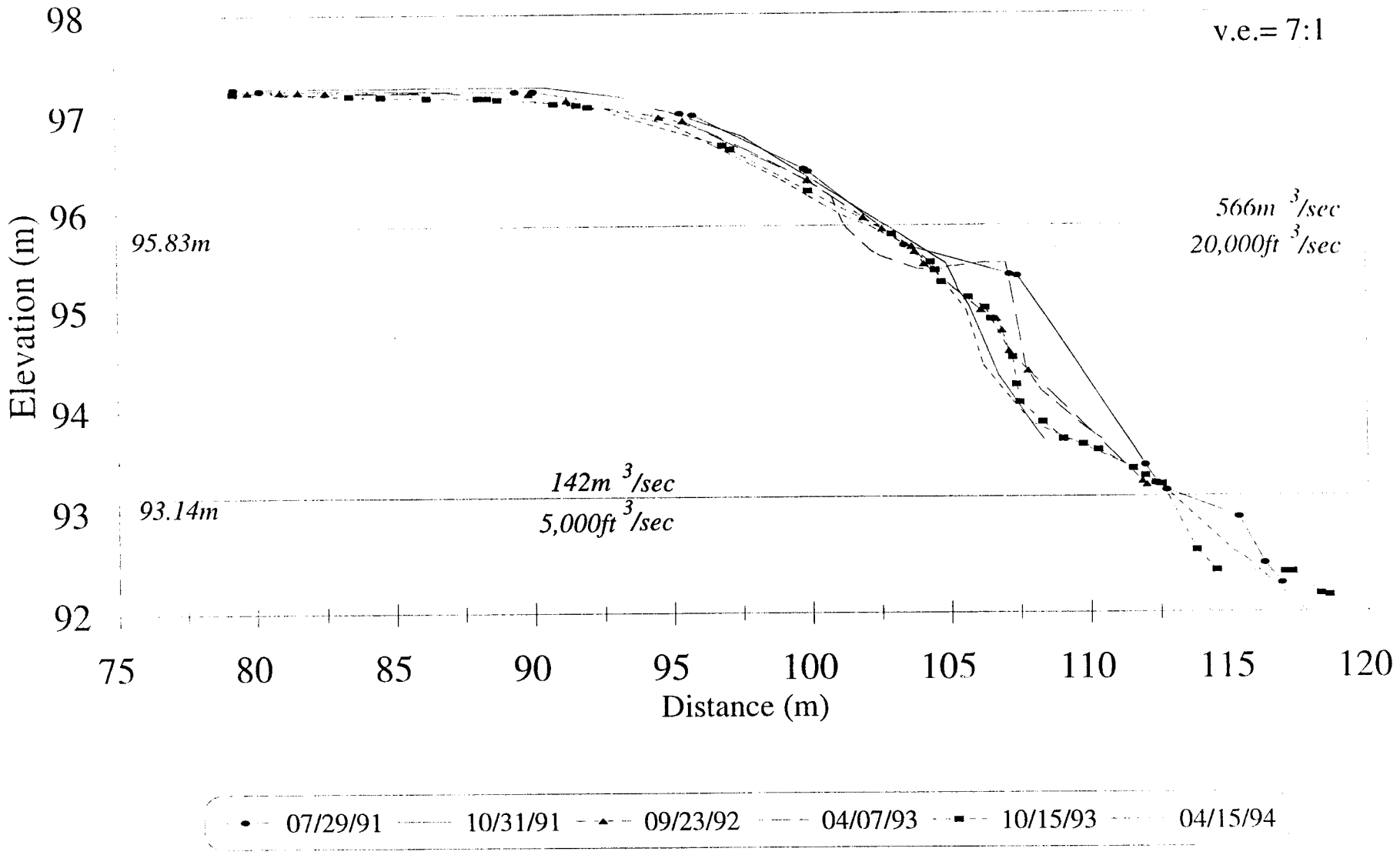


81 Mile

Cross-channel P8

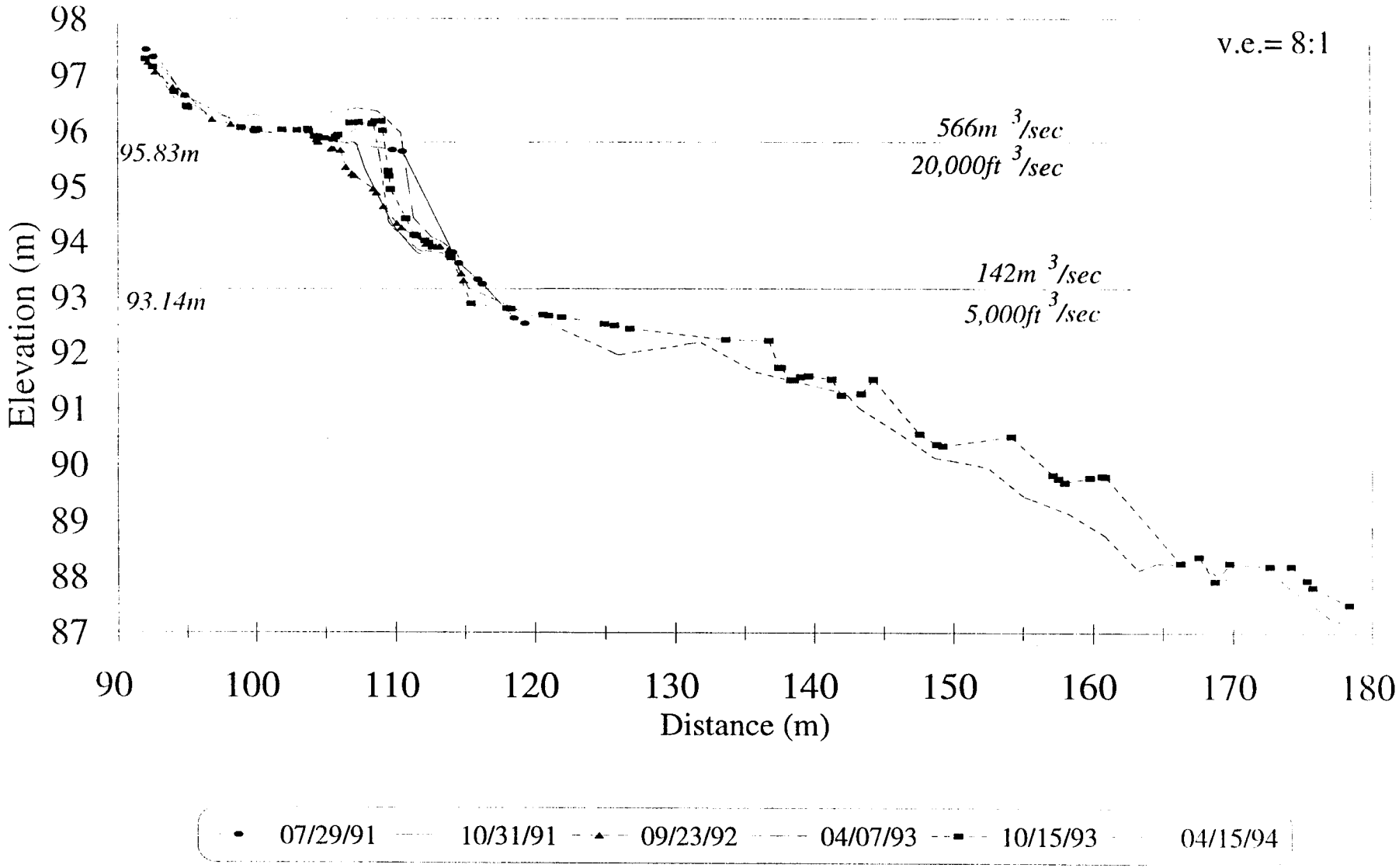


Near-shore P8

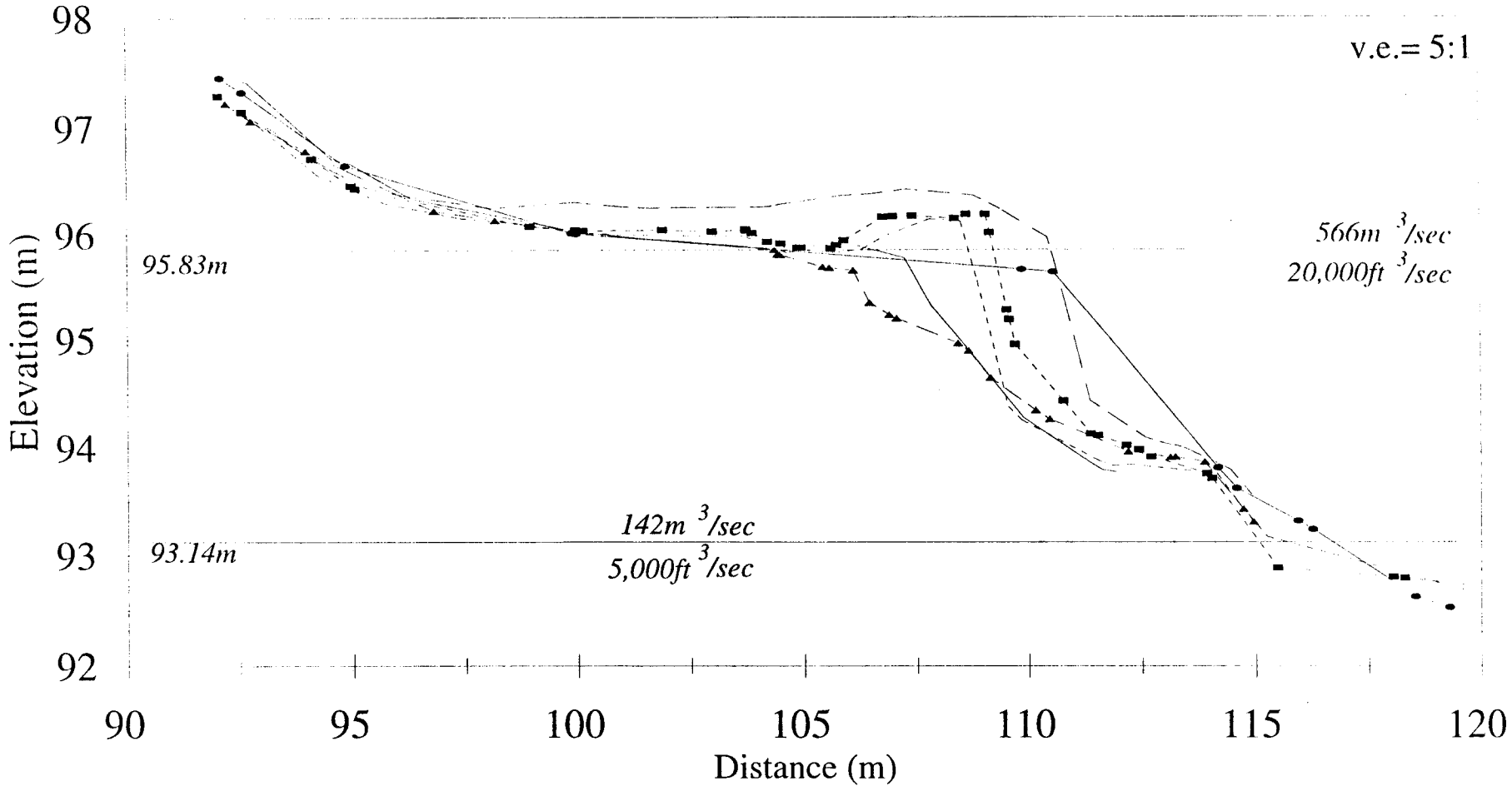


81 Mile

Cross-channel P11

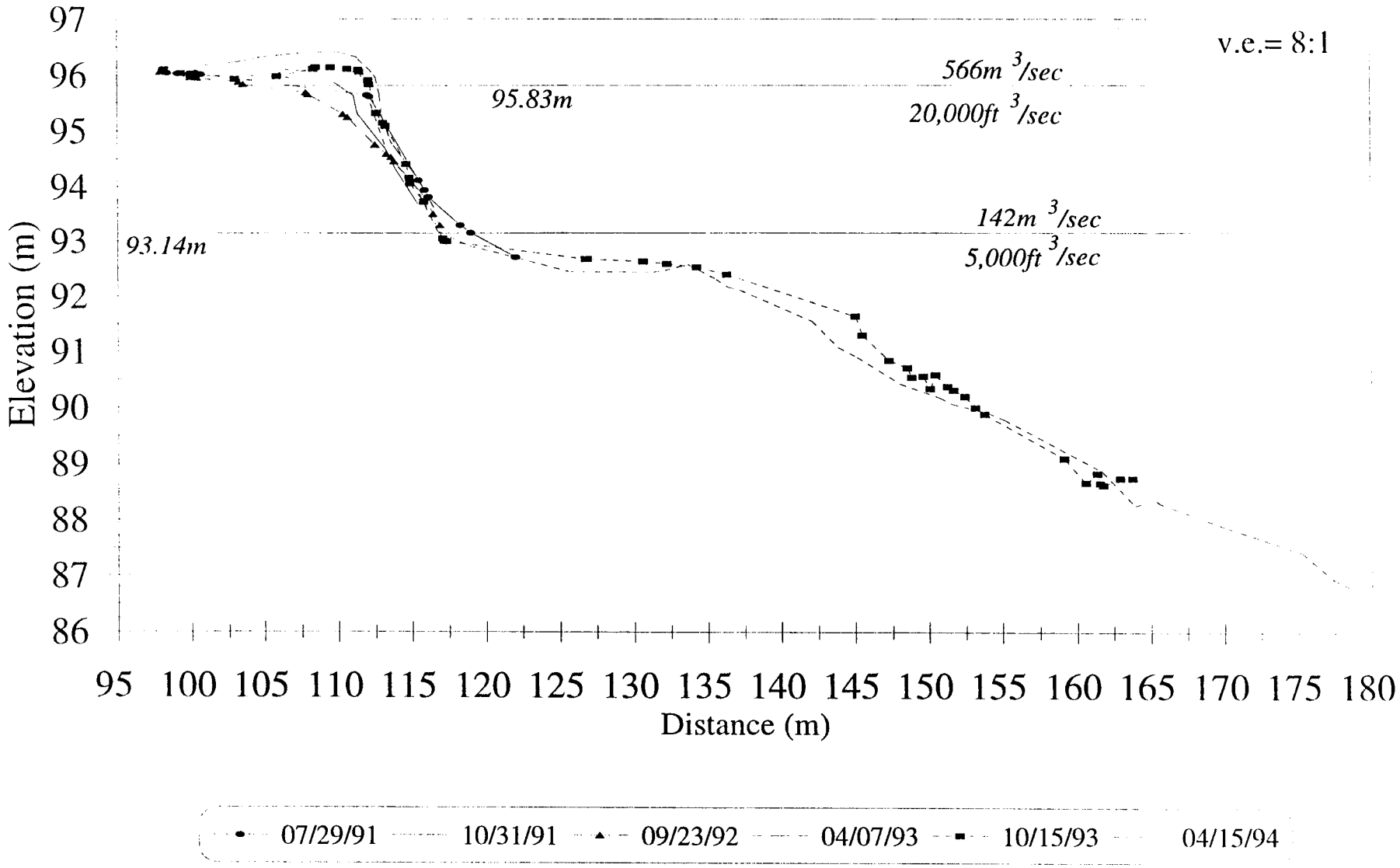


Near-shore P11

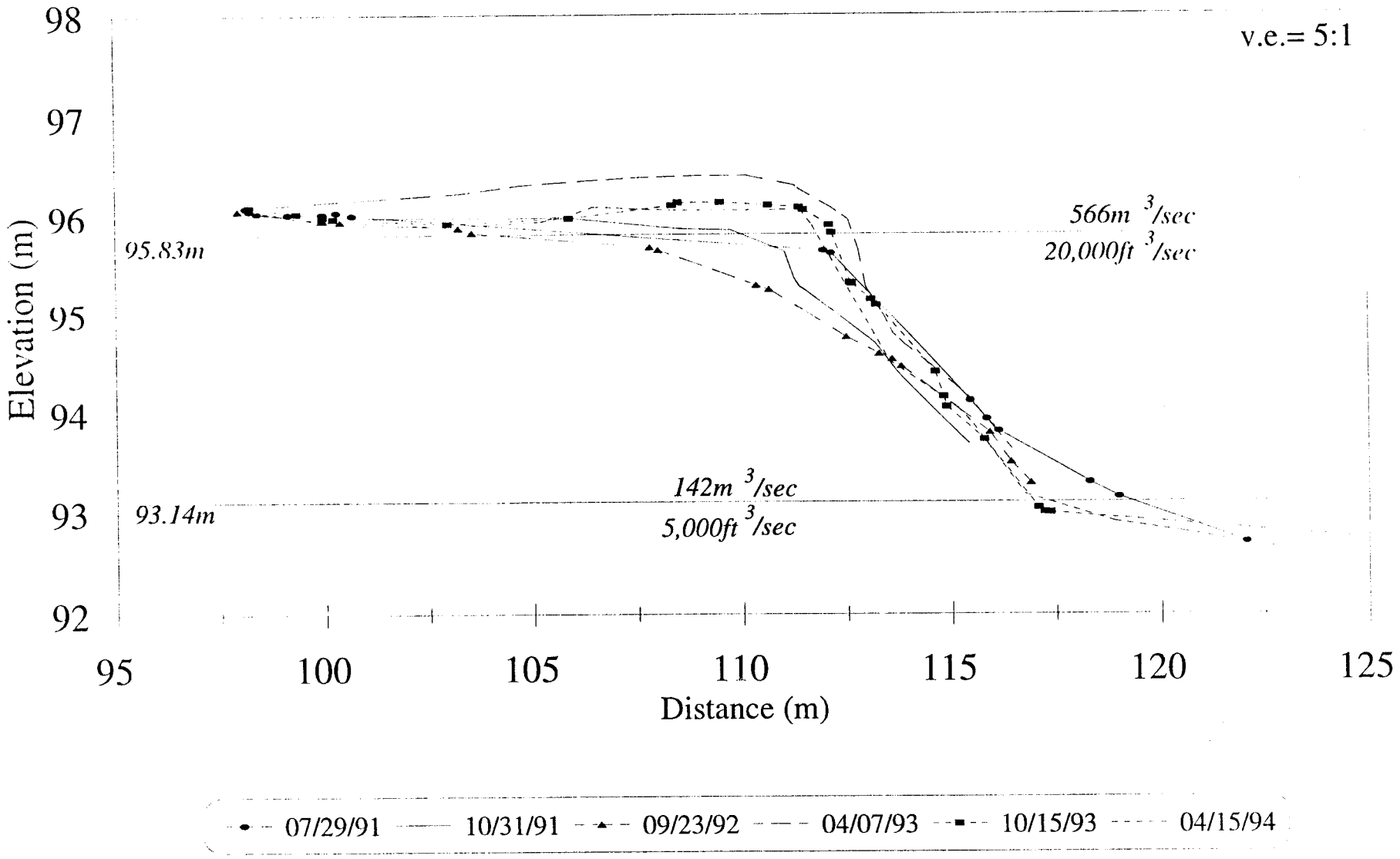


81 Mile

Cross-channel P12

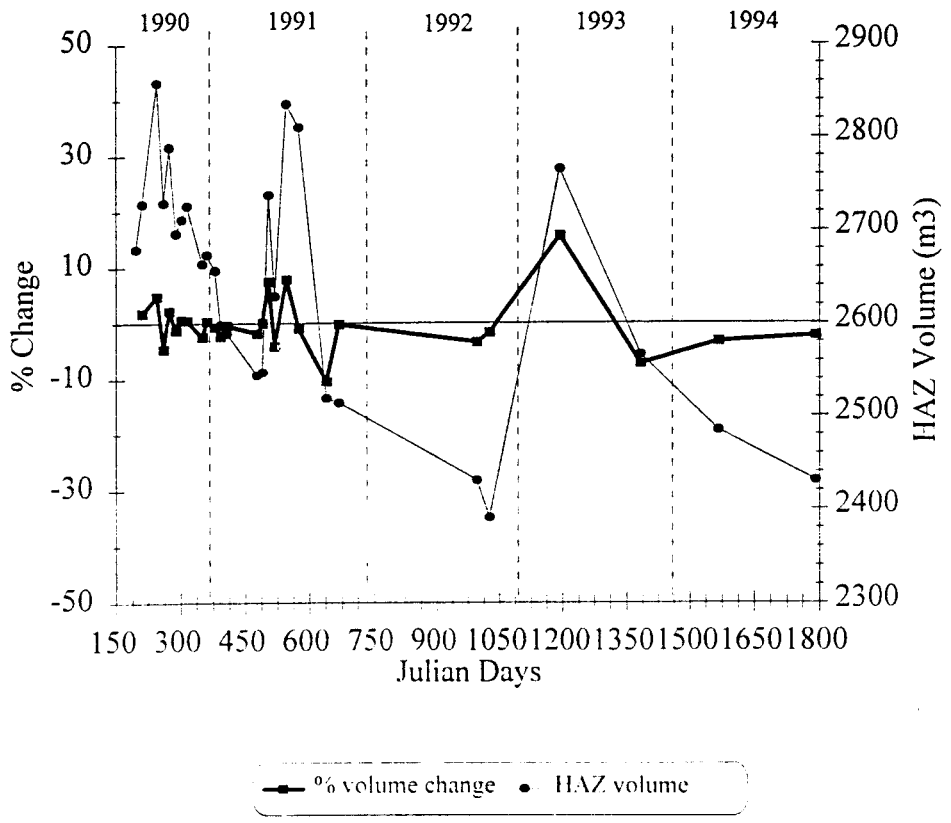


Near-shore P12



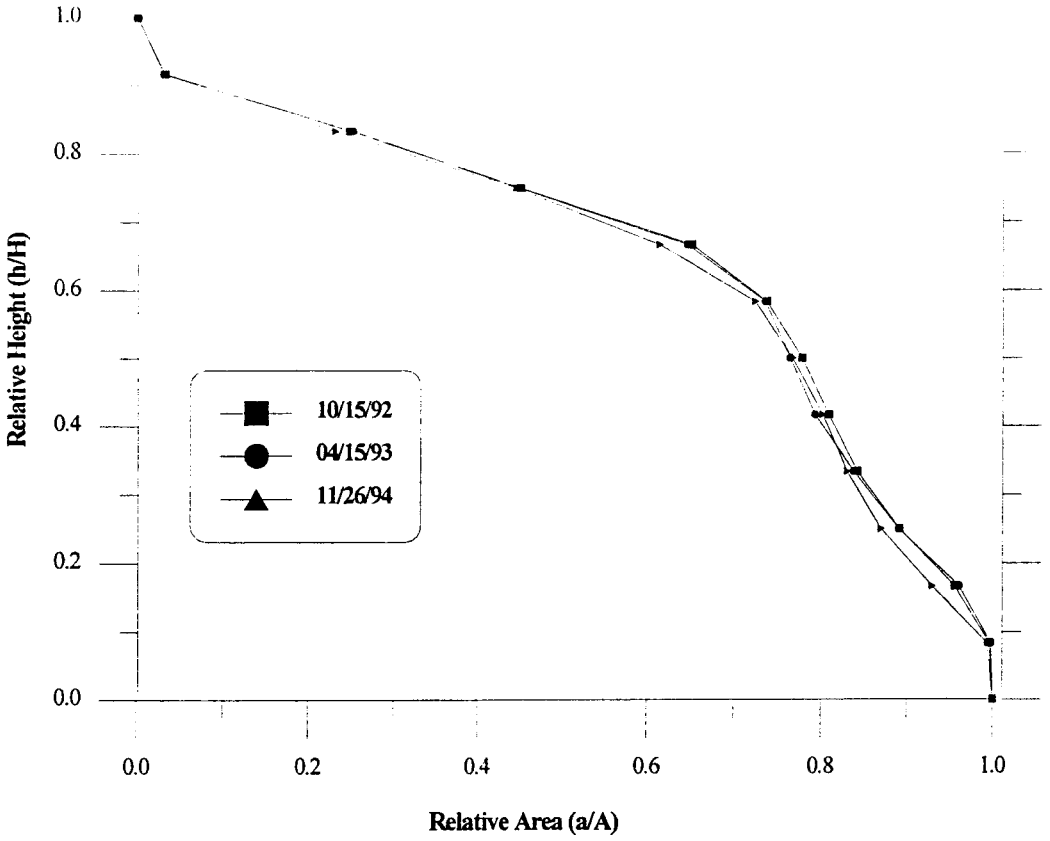
81 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C	900716	G	197	1308	2680				
D	900730	F	211	1300	2729	-8	49	-0.61	1.83
E	900902	NORM	245	1334	2659	34	130	2.62	4.76
F	900917	NORM	260	1296	2730	-38	-129	-2.85	-4.51
G	901001	E	274	1314	2790	18	60	1.39	2.20
H	901016	A	289	1255	2697	-41	-33	-3.16	-1.21
I	901029	8000 CFS	302	1223	2712	-32	15	-2.55	0.55
J	901112	NORM	316	1236	2727	13	15	1.06	0.55
K	901217	NORM	351	1218	2664	-18	-63	-1.46	-2.31
L	901227	11000 CFS	361	1189	2674	-29	10	-2.38	0.38
M	910114	C	379	1280	2657	91	-17	7.65	-0.64
N	910128	NORM	393	1211	2599	-69	-58	-5.39	-2.18
O	910211	B	407	1201	2590	-10	-9	-0.83	-0.35
P	910422	NORM	477	1198	2545	-3	-45	-0.25	-1.74
Q	910506	NORM	491	1201	2548	3	3	0.25	0.12
R	910520	D	505	1328	2738	127	190	10.57	7.46
S	910603	15000 CFS	519	1230	2629	-98	-109	-7.38	-3.98
T	910701	NORM	547	1350	2836	120	207	9.76	7.87
U		G							
V	910729	F	575	1334	2811	-16	-25	-1.19	-0.88
W	911001	INT	639	1184	2520	-150	-291	-11.24	-10.35
X	911031	INT	669	1154	2515	-30	-5	-2.53	-0.20
Y	920923	INT	996	1223	2431	69	-84	5.98	-3.34
&	921023	INT	1027	1170	2391	-53	-40	-4.33	-1.65
Z	930407	INT	1194	1249	2766	79	375	6.75	15.68
B16	931015	INT	1384	1197	2567	-52	-199	-4.16	-7.19
C16	940415	INT	1566	1180	2485	-17	-82	-1.42	-3.19
D16	941126	INT	1791	1147	2431	-33	-54	-2.80	-2.17

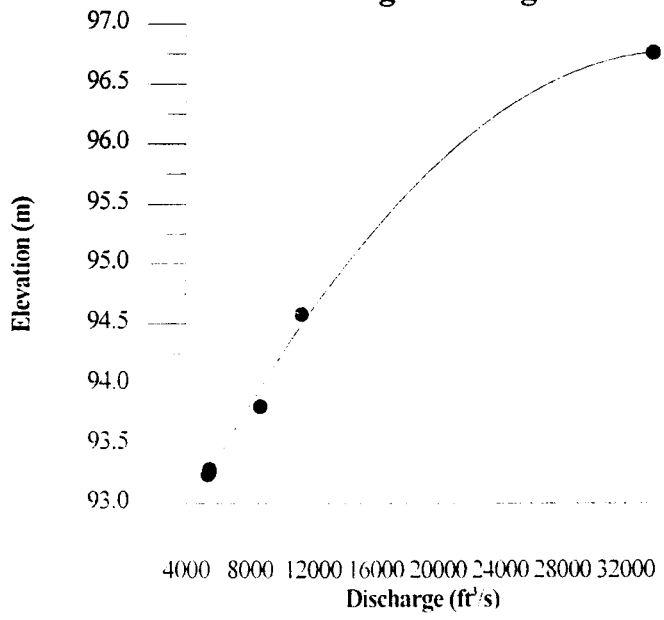


81 Mile

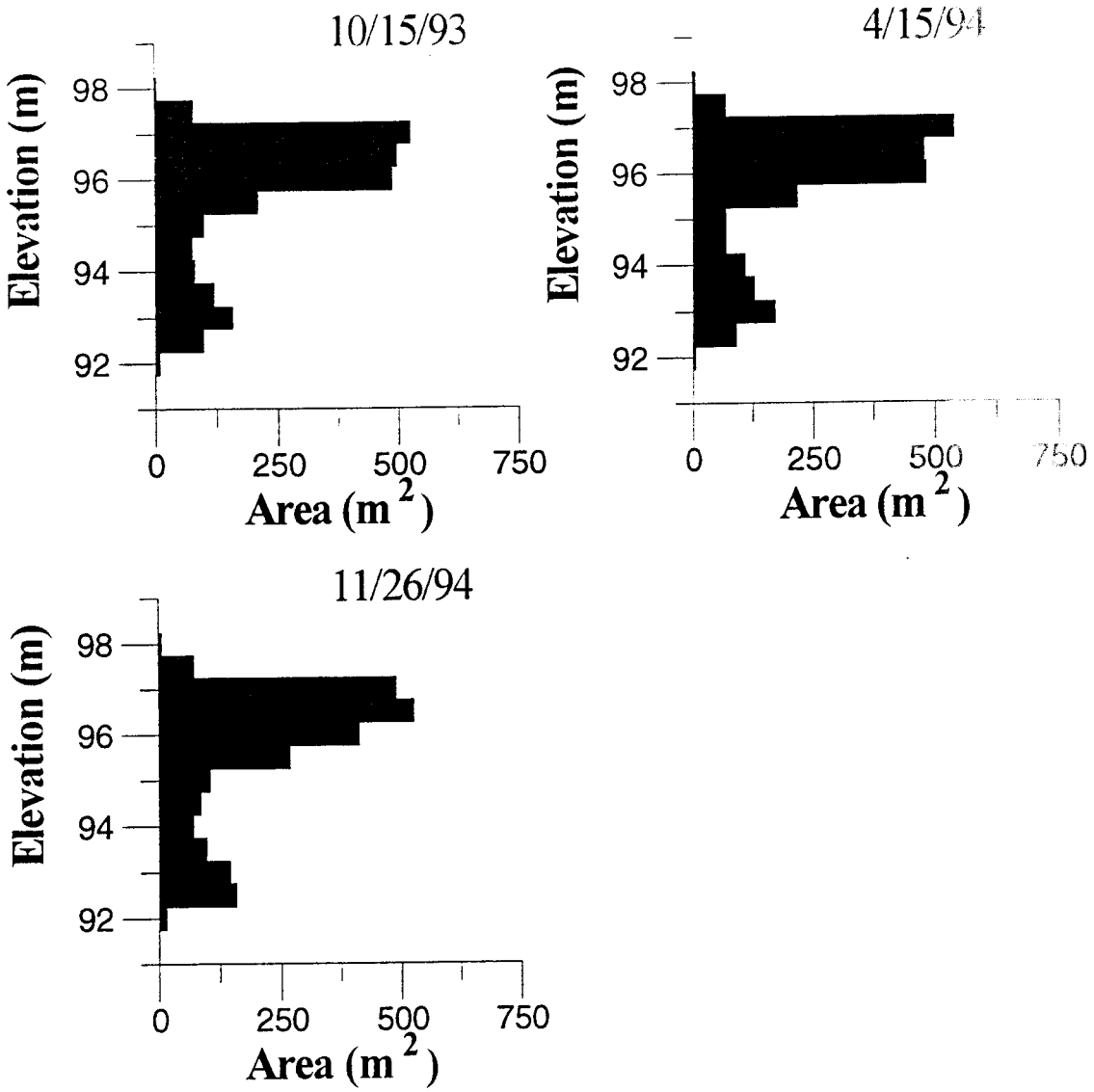
Hypsometric Curves

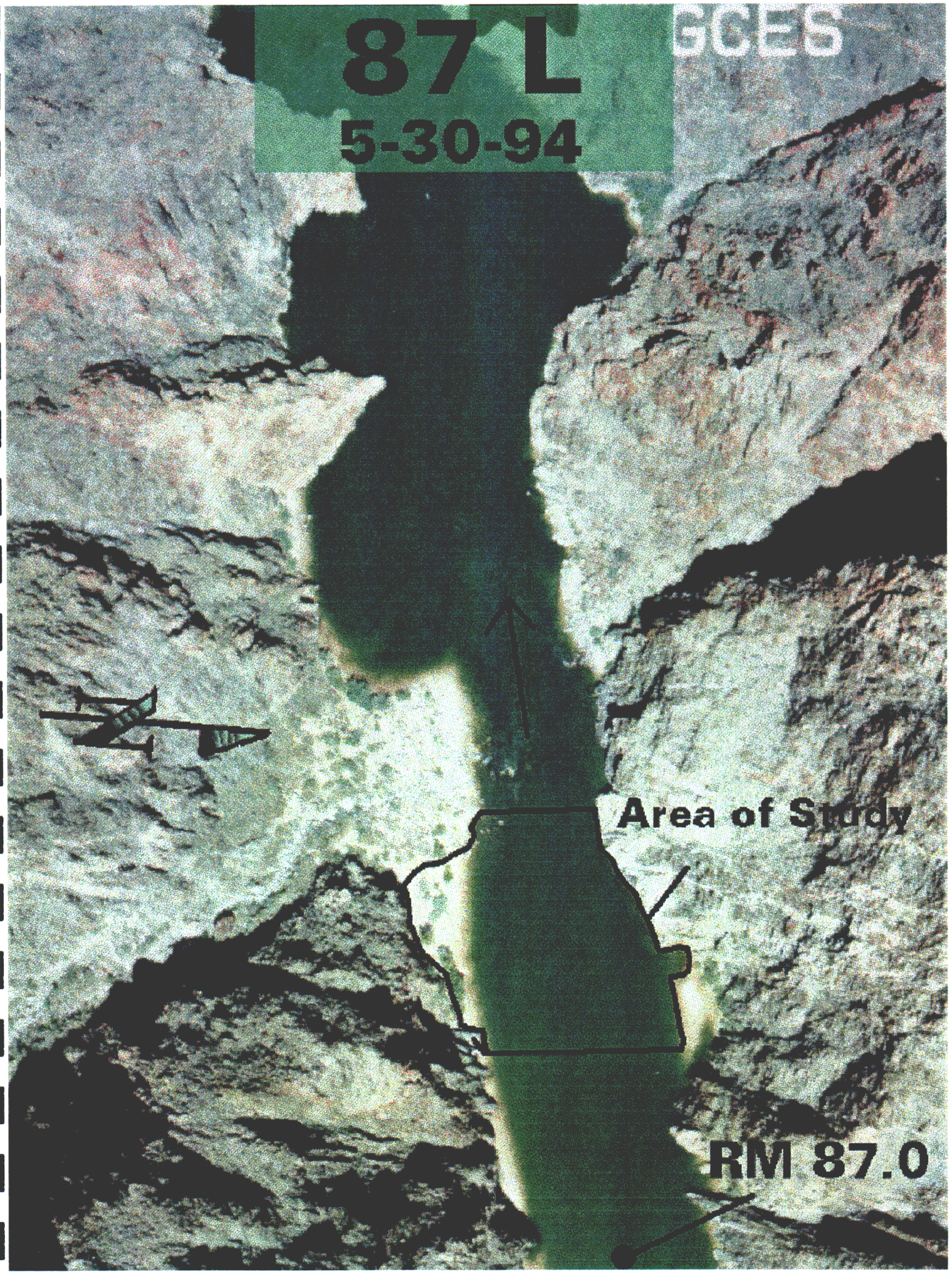


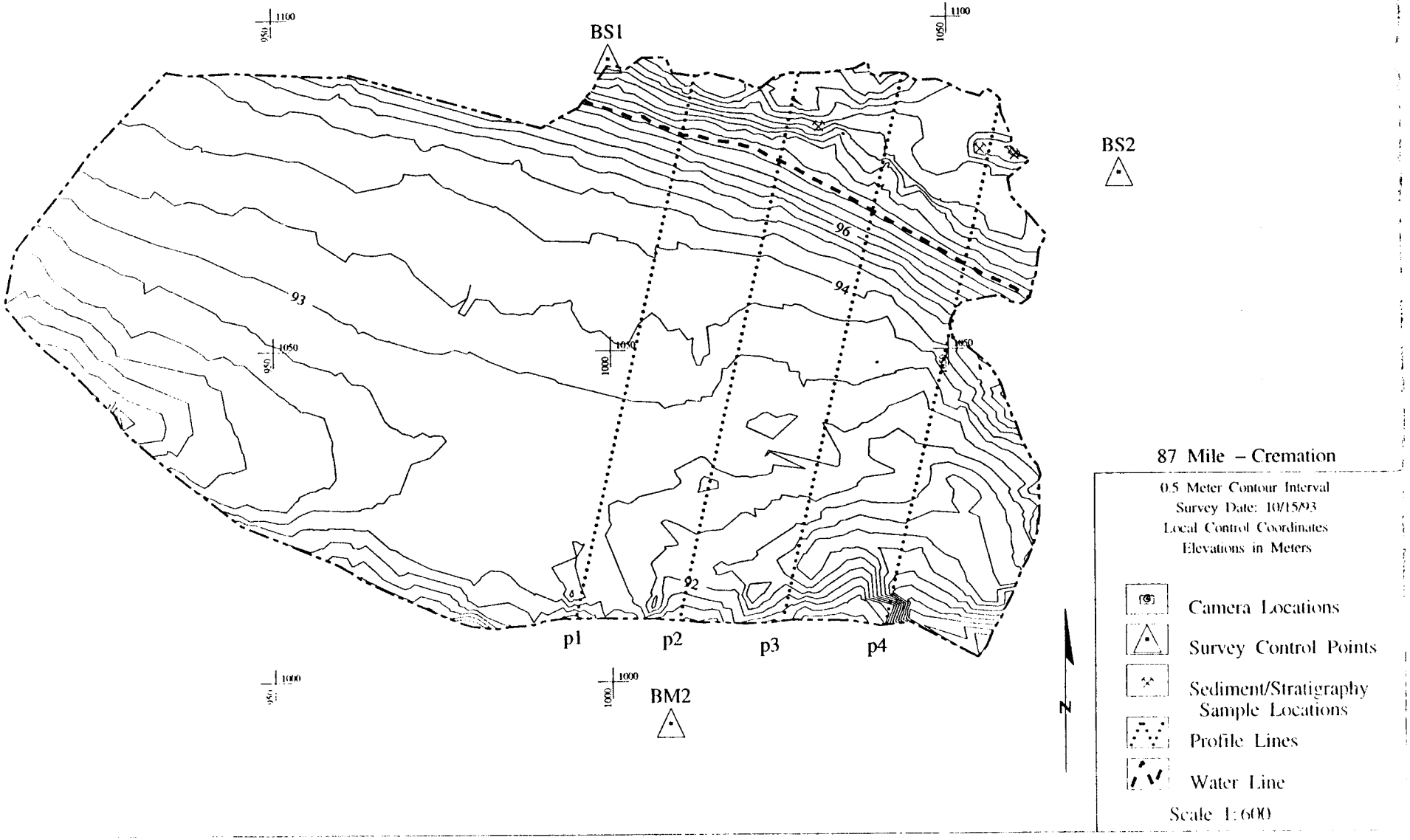
Stage Discharge



81 MILE
Area Distribution Curves

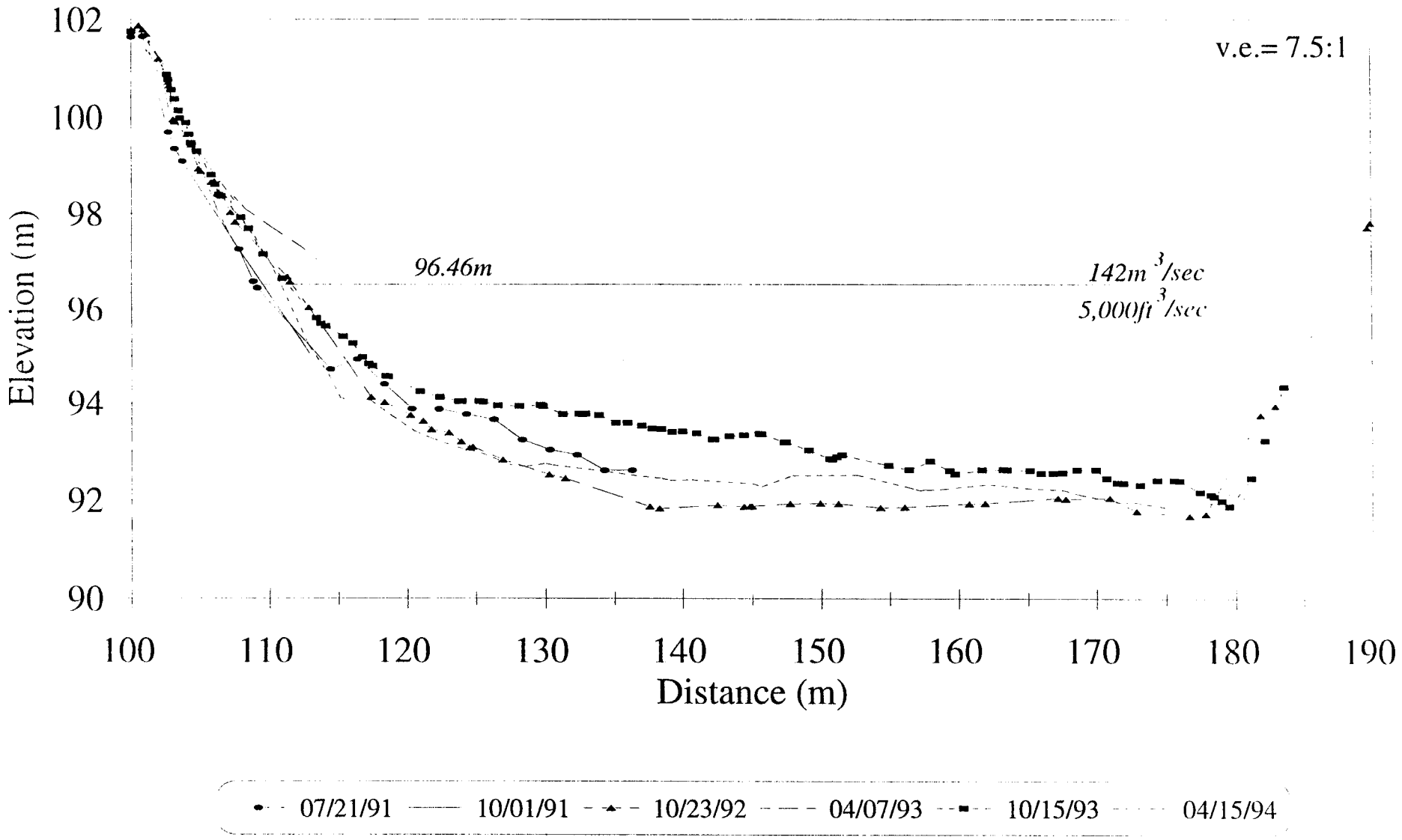



87 L
5-30-94
GCES
Area of Study
RM 87.0

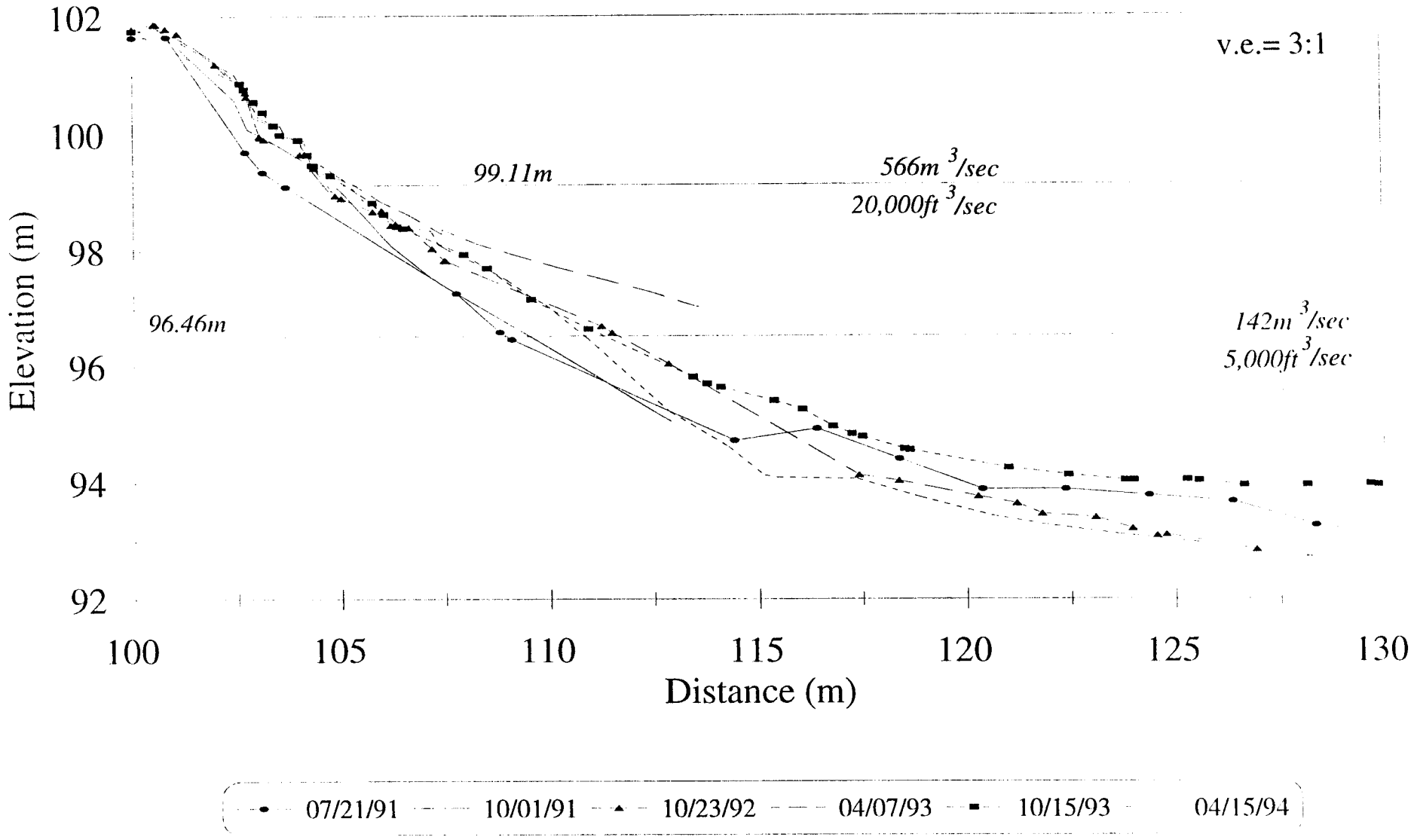

BS1
BS2
BM2
p1
p2
p3
p4
96
94
93
92
N
87 Mile – Cremation
0.5 Meter Contour Interval
Survey Date: 10/15/93
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:600

87 Mile

Cross-channel P1

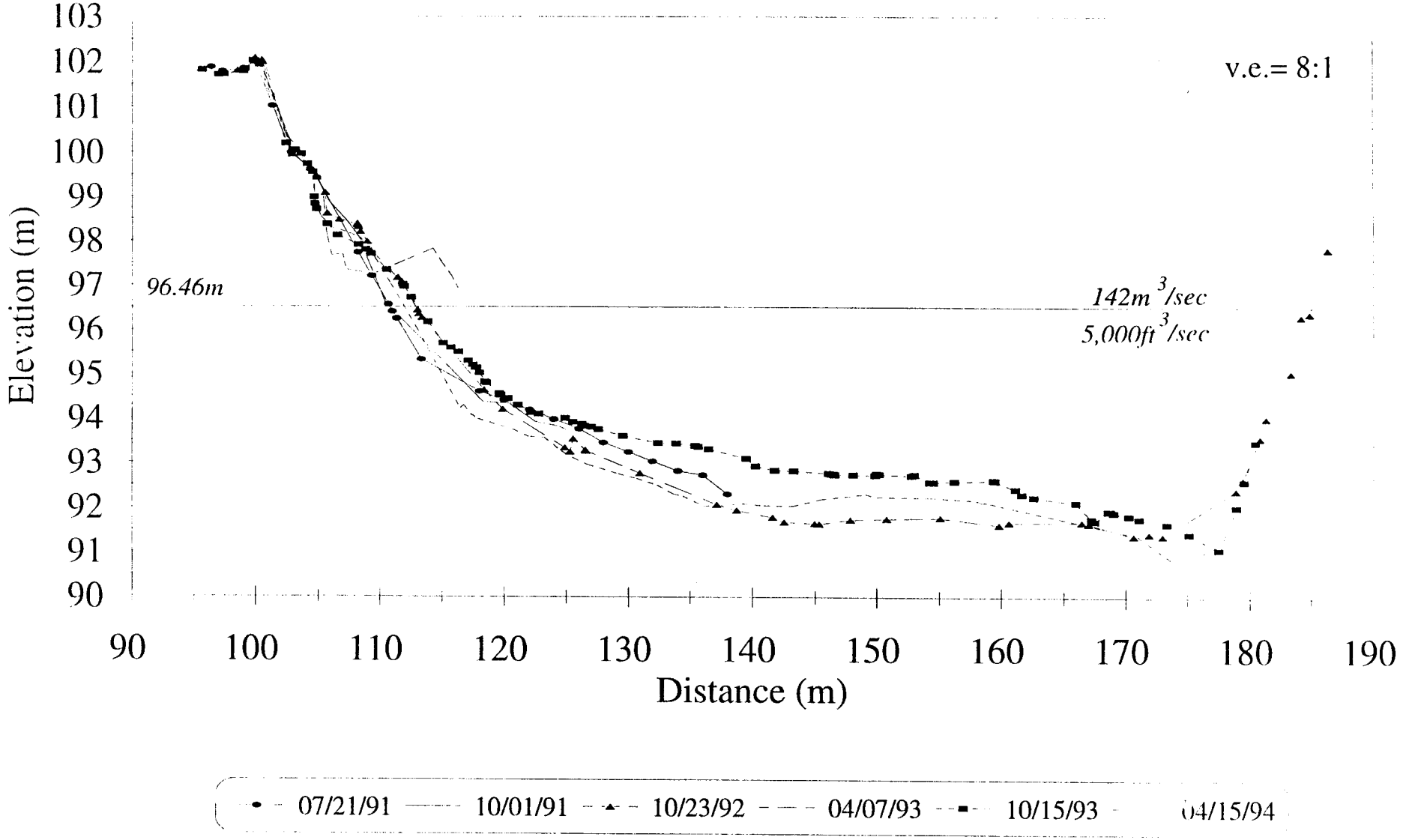


Near-shore P1

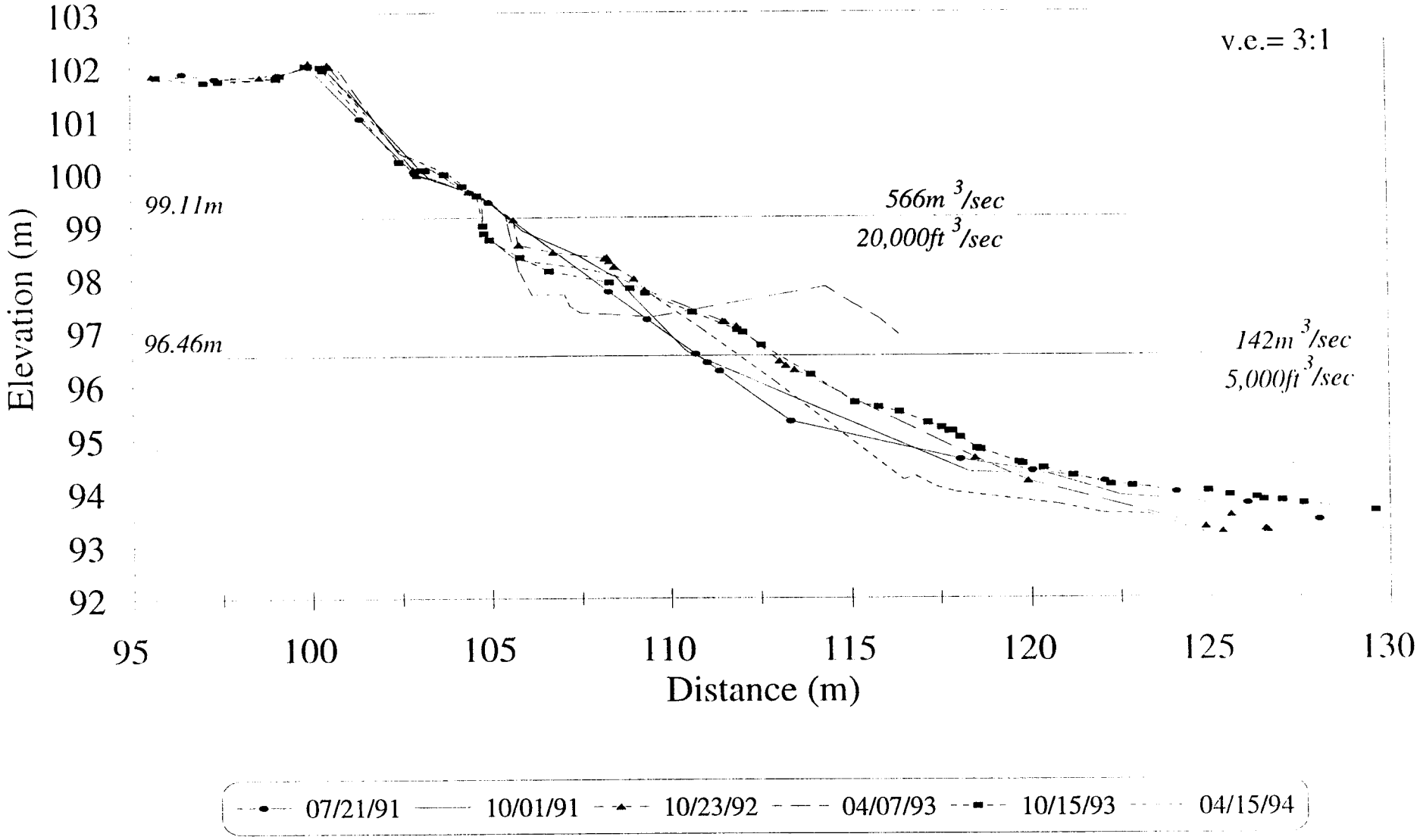


87 Mile

Cross-channel P2

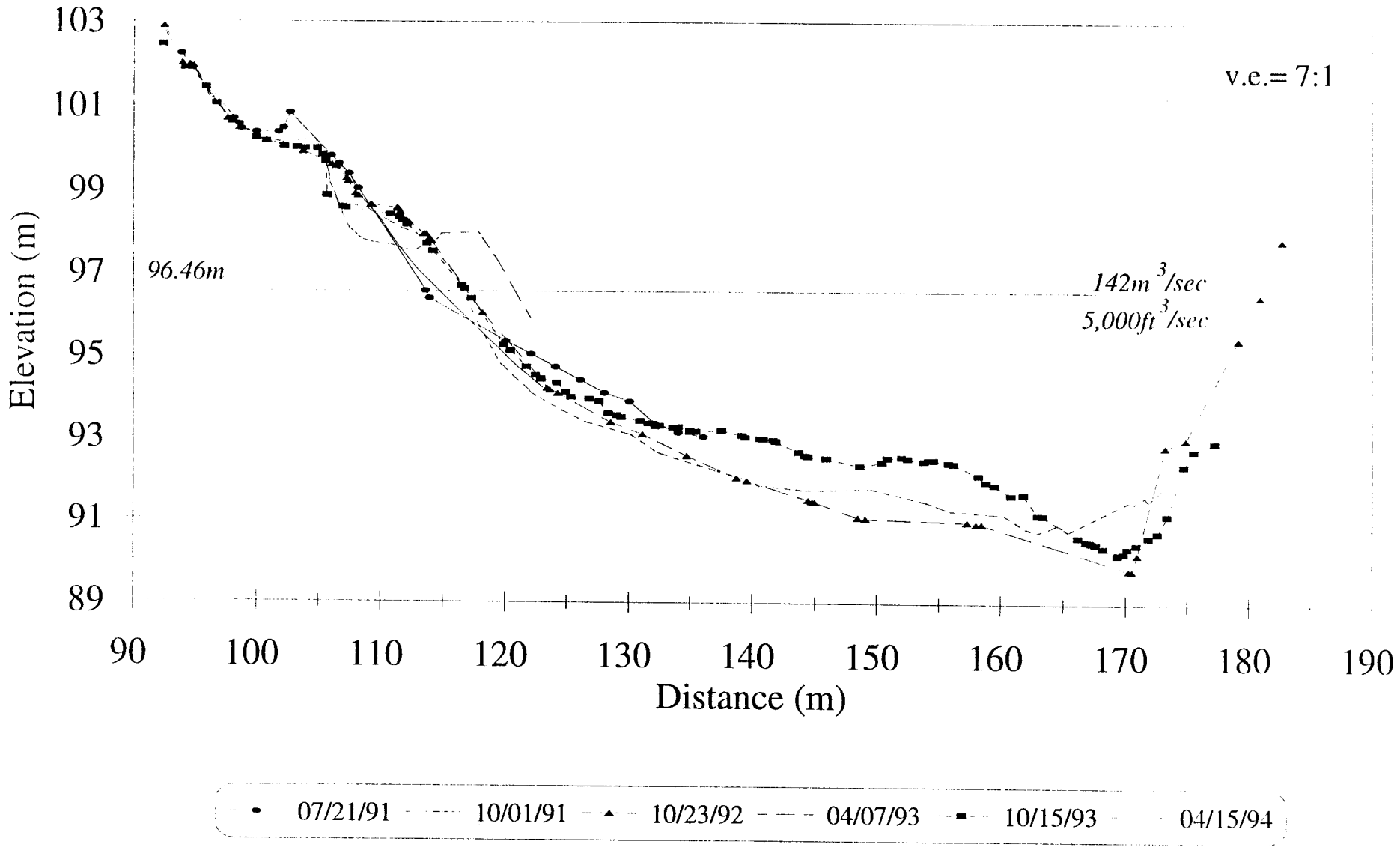


Near-shore P2

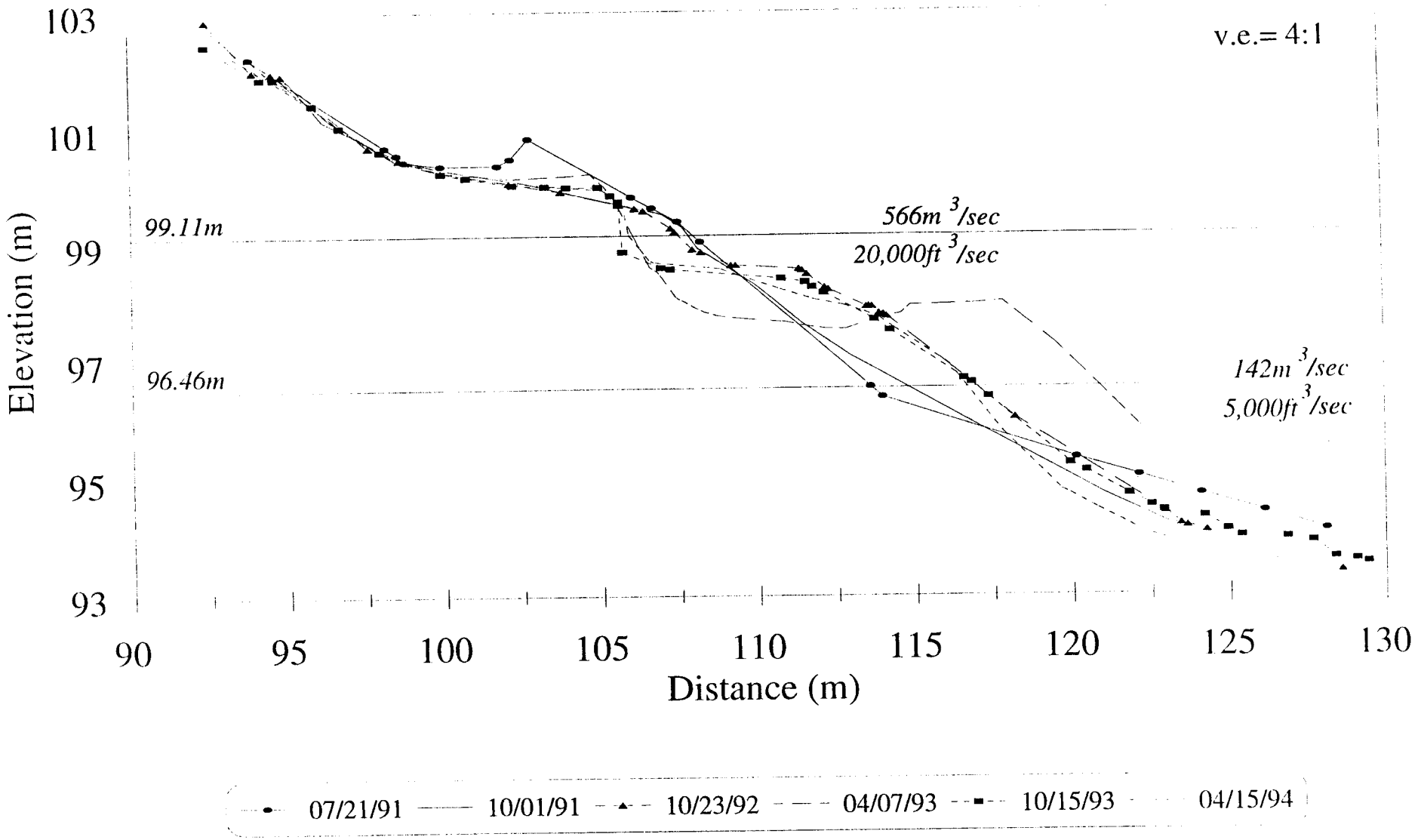


87 Mile

Cross-channel P3

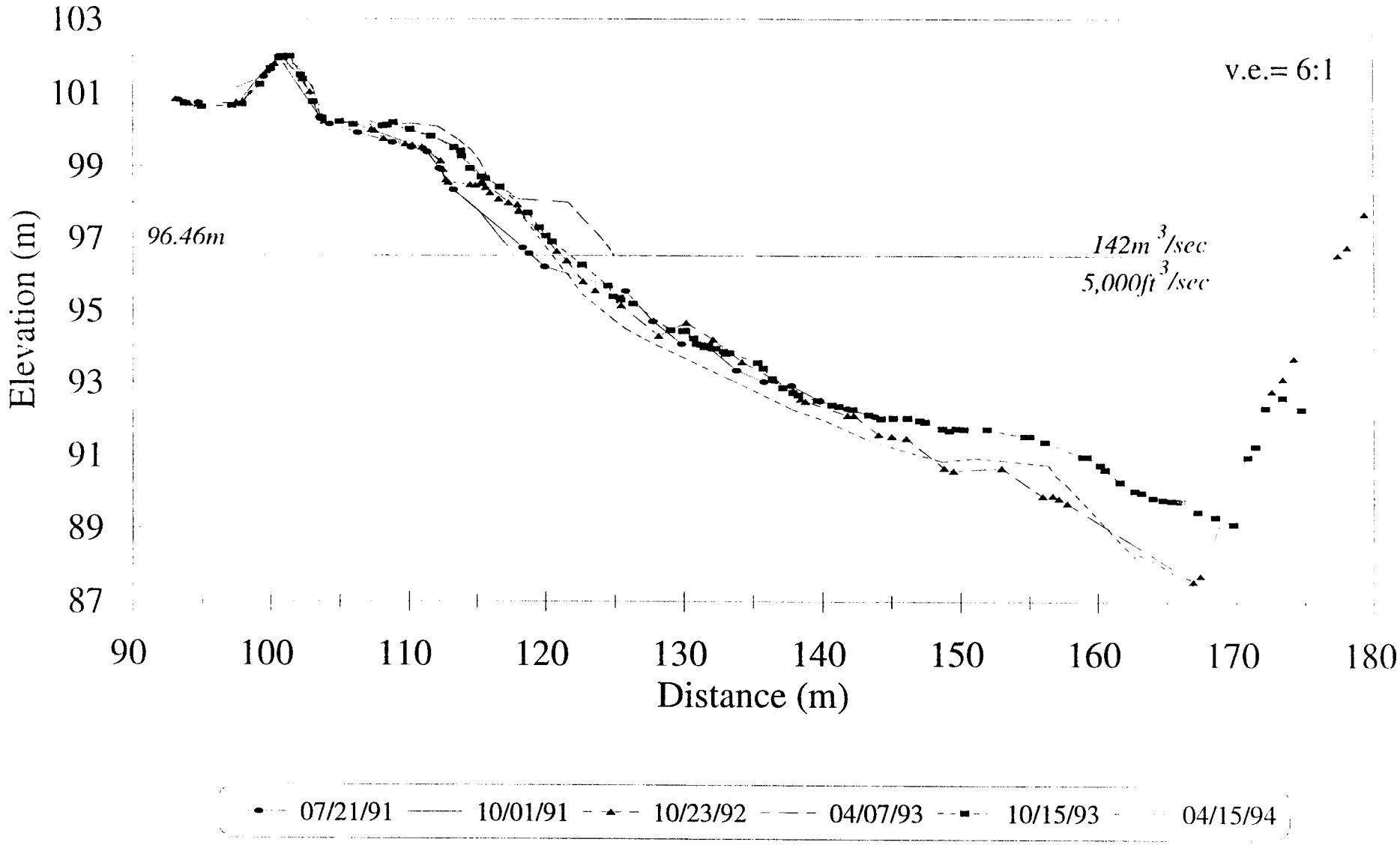


Near-shore P3

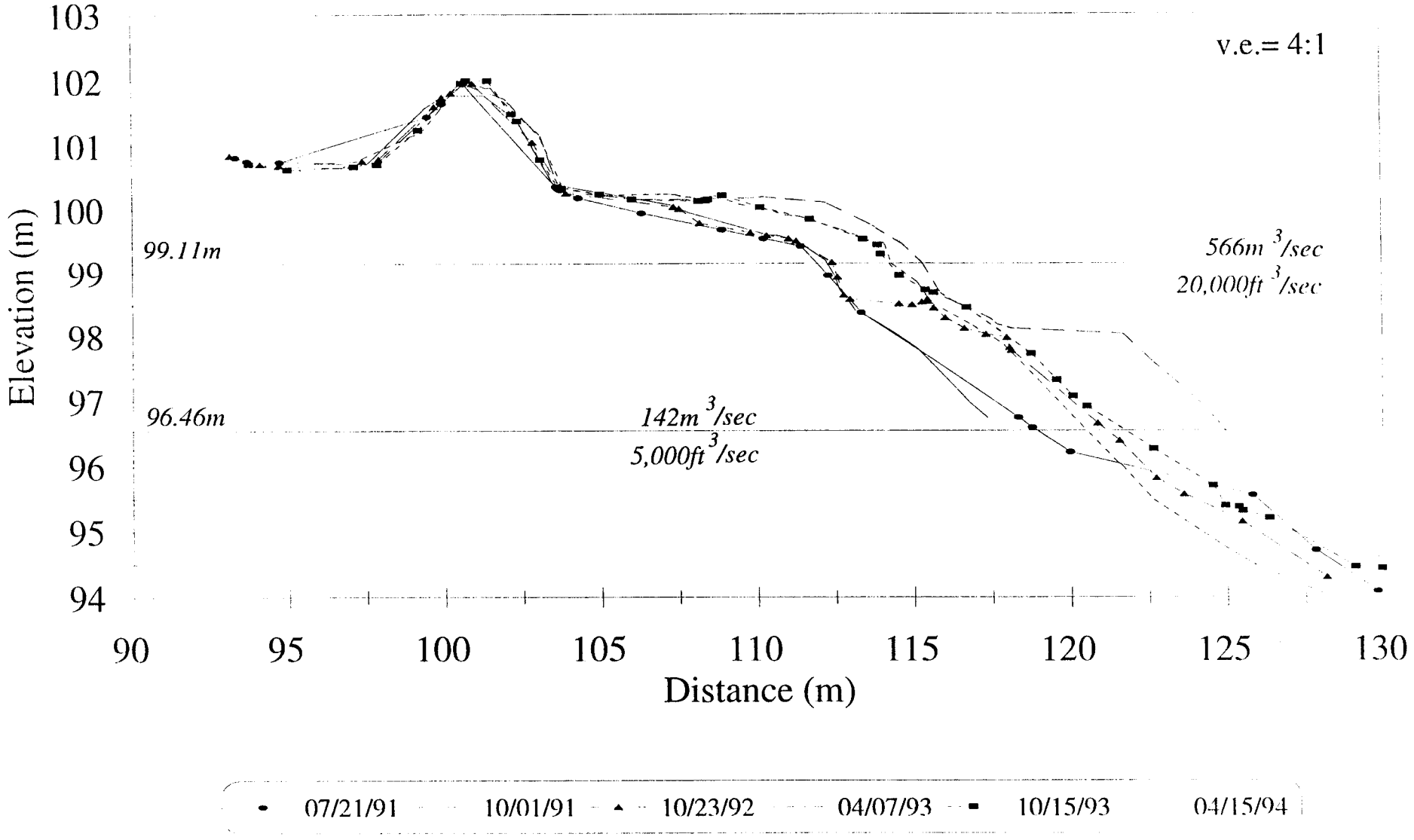


87 Mile

Cross-channel P4

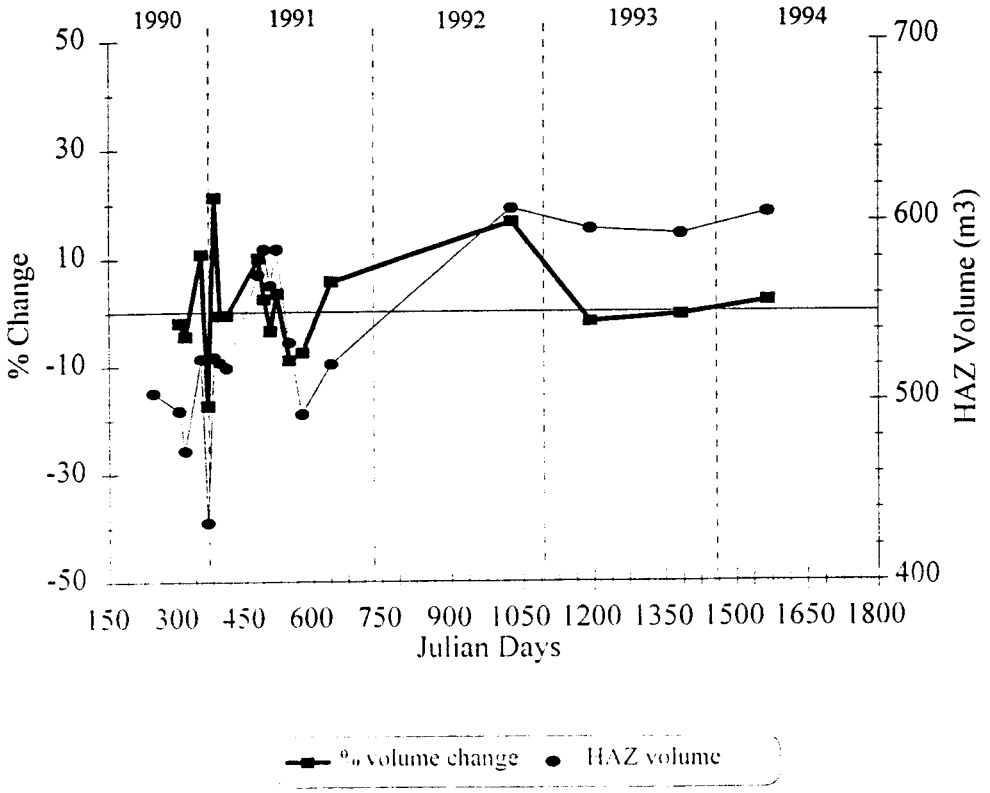


Near-shore P4

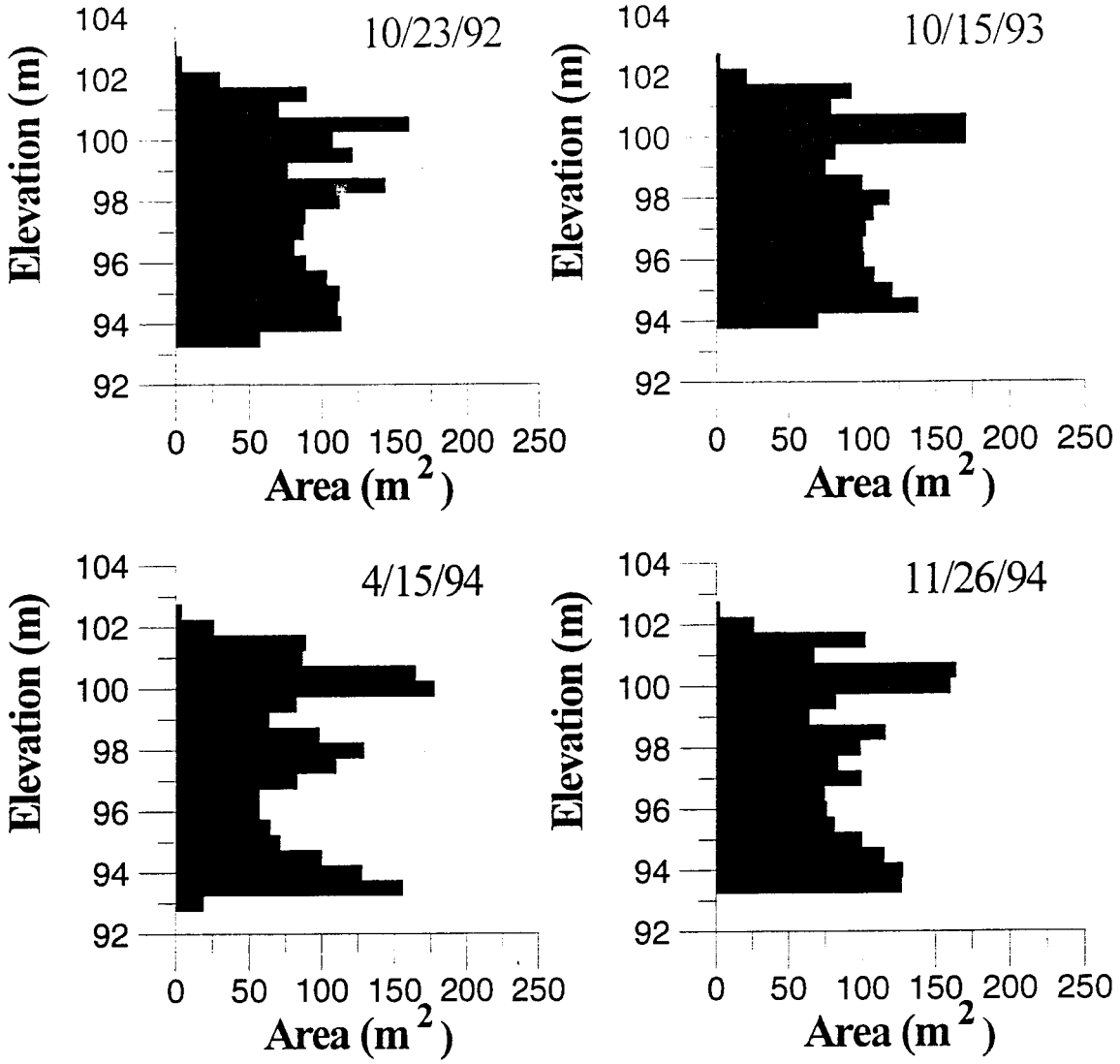


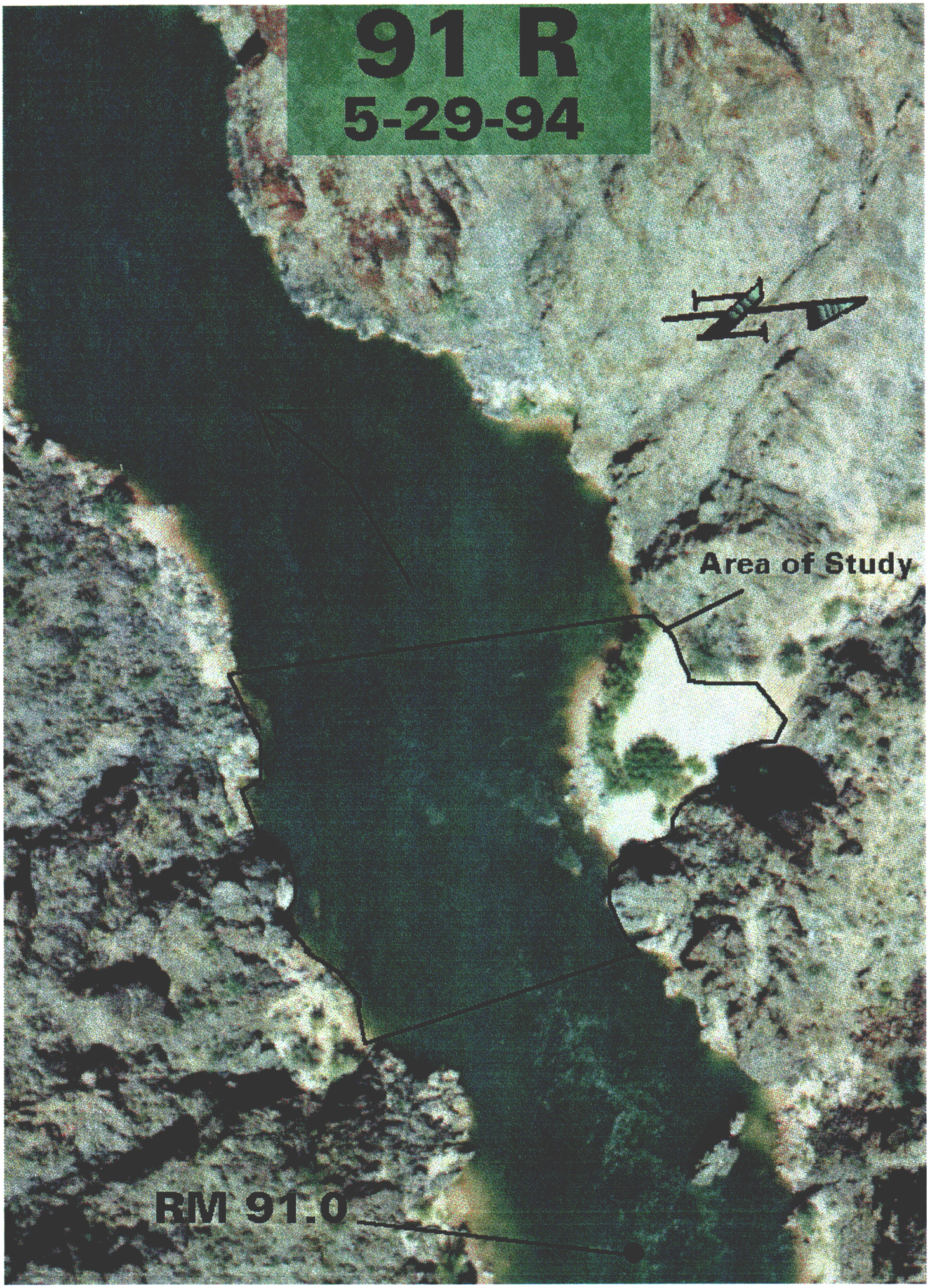
87 Mile

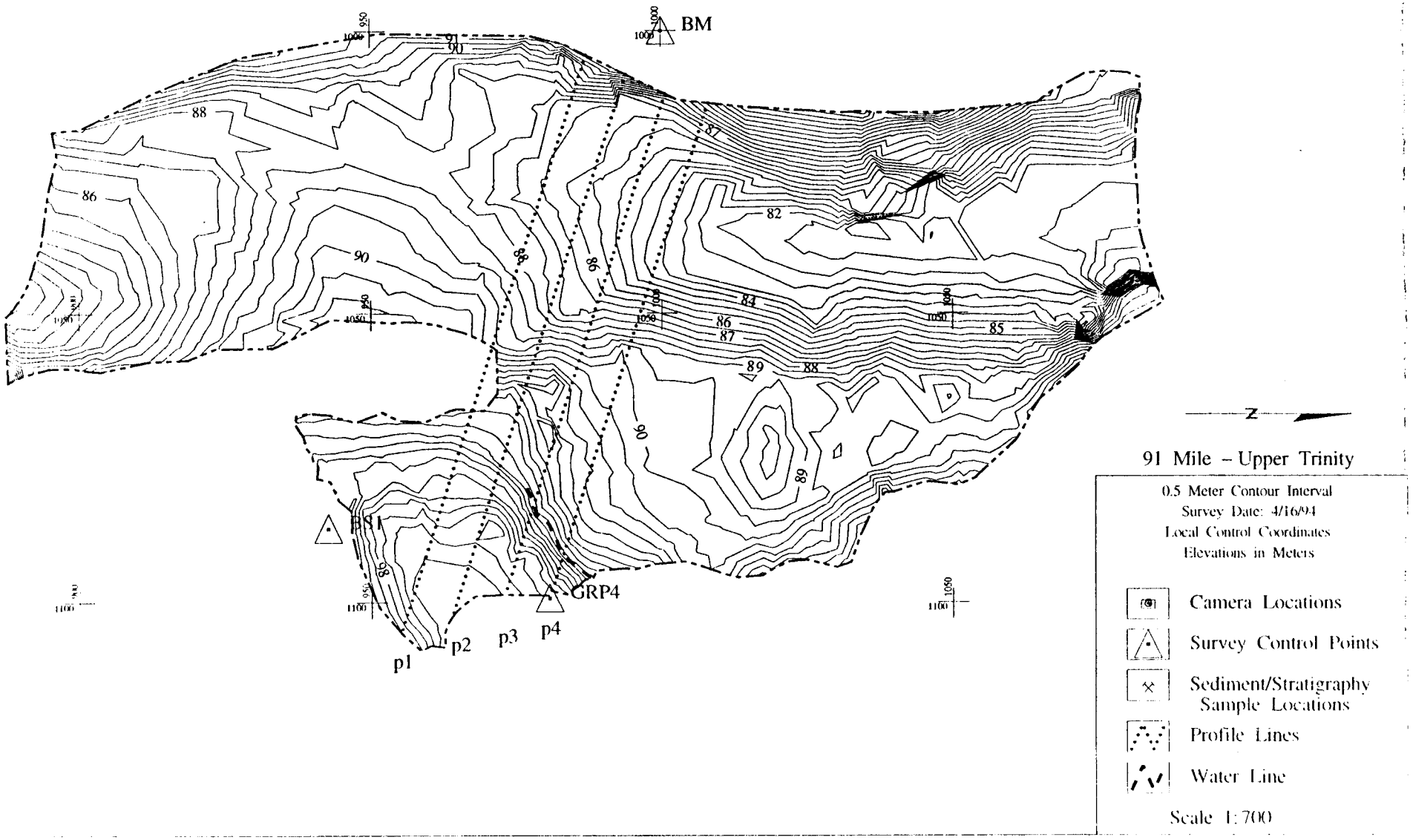
RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E	900903	NORM	246	307	505				
F		NORM							
G		E							
H		A							
I	901029	8000 CFS	302	305	495	-2	-10	-0.65	-1.98
J	901112	NORM	316	315	473	10	-22	3.28	-4.44
K	901217	NORM	351	334	524	19	51	6.03	10.78
L	901231	11000 CFS	365	310	433	-24	-91	-7.19	-17.37
M	910114	C	379	347	525	37	92	11.94	21.25
N	910128	NORM	393	340	522	-7	-3	-2.02	-0.57
O	910211	B	407	351	519	11	-3	3.24	-0.57
P	910422	NORM	477	387	571	36	52	10.26	10.02
Q	910506	NORM	491	404	585	17	14	4.39	2.45
R	910520	D	505	340	565	-64	-20	-15.84	-3.42
S	910603	15000 CFS	519	351	585	11	20	3.24	3.54
T	910701	NORM	547	321	533	-30	-52	-8.55	-8.89
U		G							
V	910729	F	575	317	493	-4	-40	-1.25	-7.50
W	911001	INT	639	323	521	6	28	1.89	5.68
Y	921023	INT	1027	395	607	72	86	22.29	16.51
Z	930407	INT	1193	571	596	176	-11	44.56	-1.81
B17	931015	INT	1384	414	593	-157	-3	-27.50	-0.50
C17	940415	INT	1566	414	605	0	12	0.00	2.02



87 MILE
Area Distribution Histograms

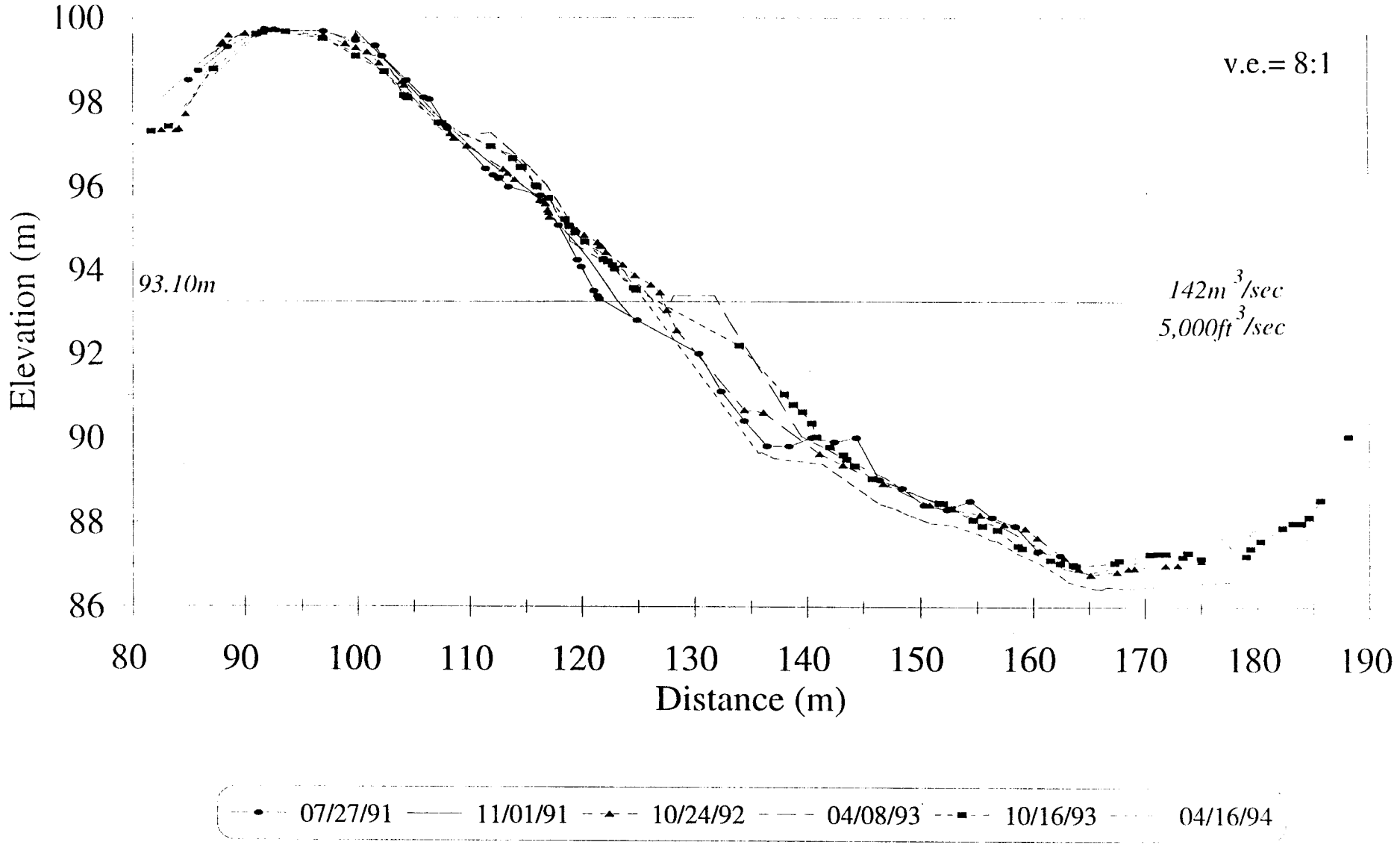


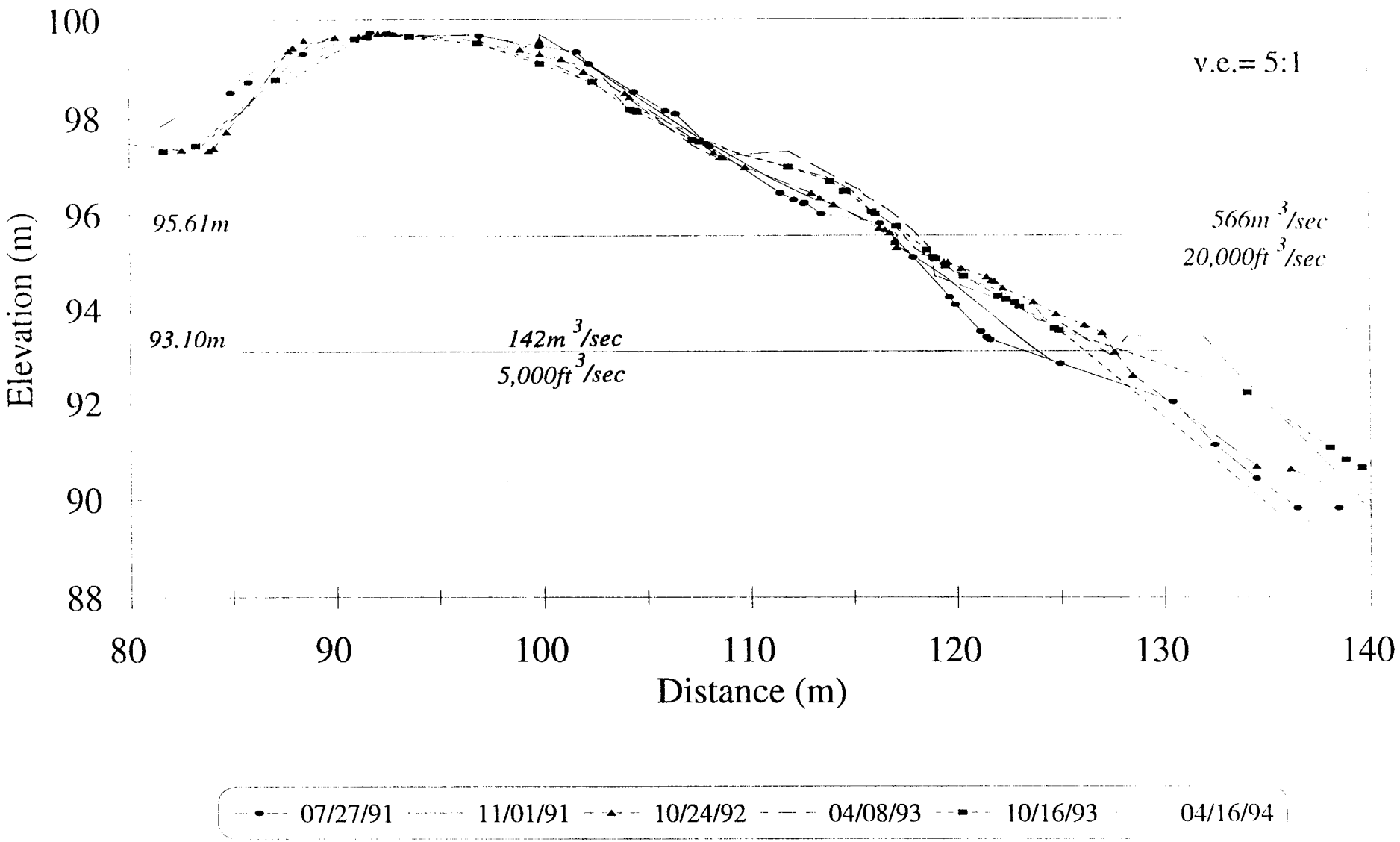

91 R
5-29-94
Area of Study
RM 91.0


BM
BS1
GRP4
p1
p2
p3
p4
88
86
90
87
82
84
85
89
N
91 Mile – Upper Trinity
0.5 Meter Contour Interval
Survey Date: 4/16/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:700

91 Mile

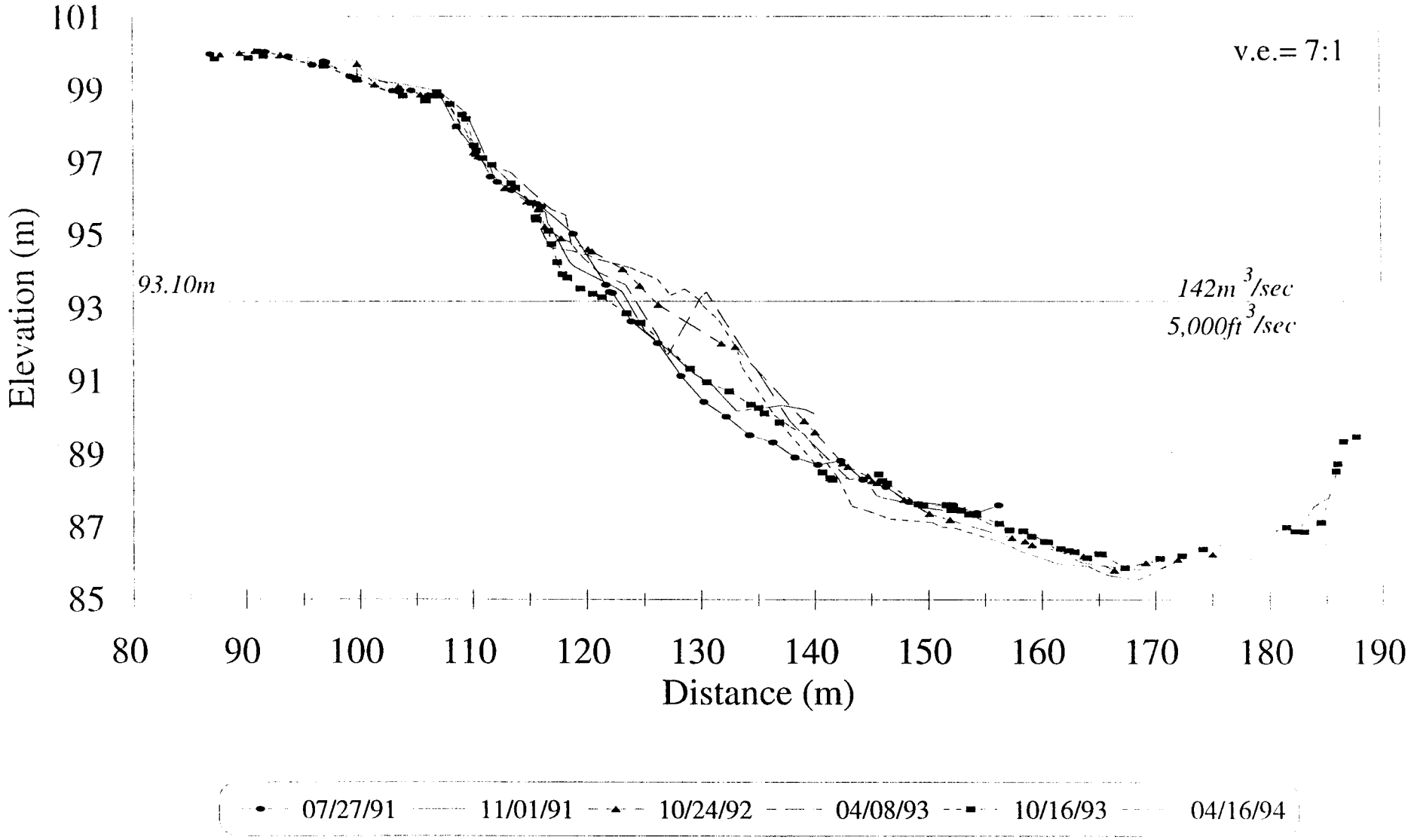
Cross-channel P1



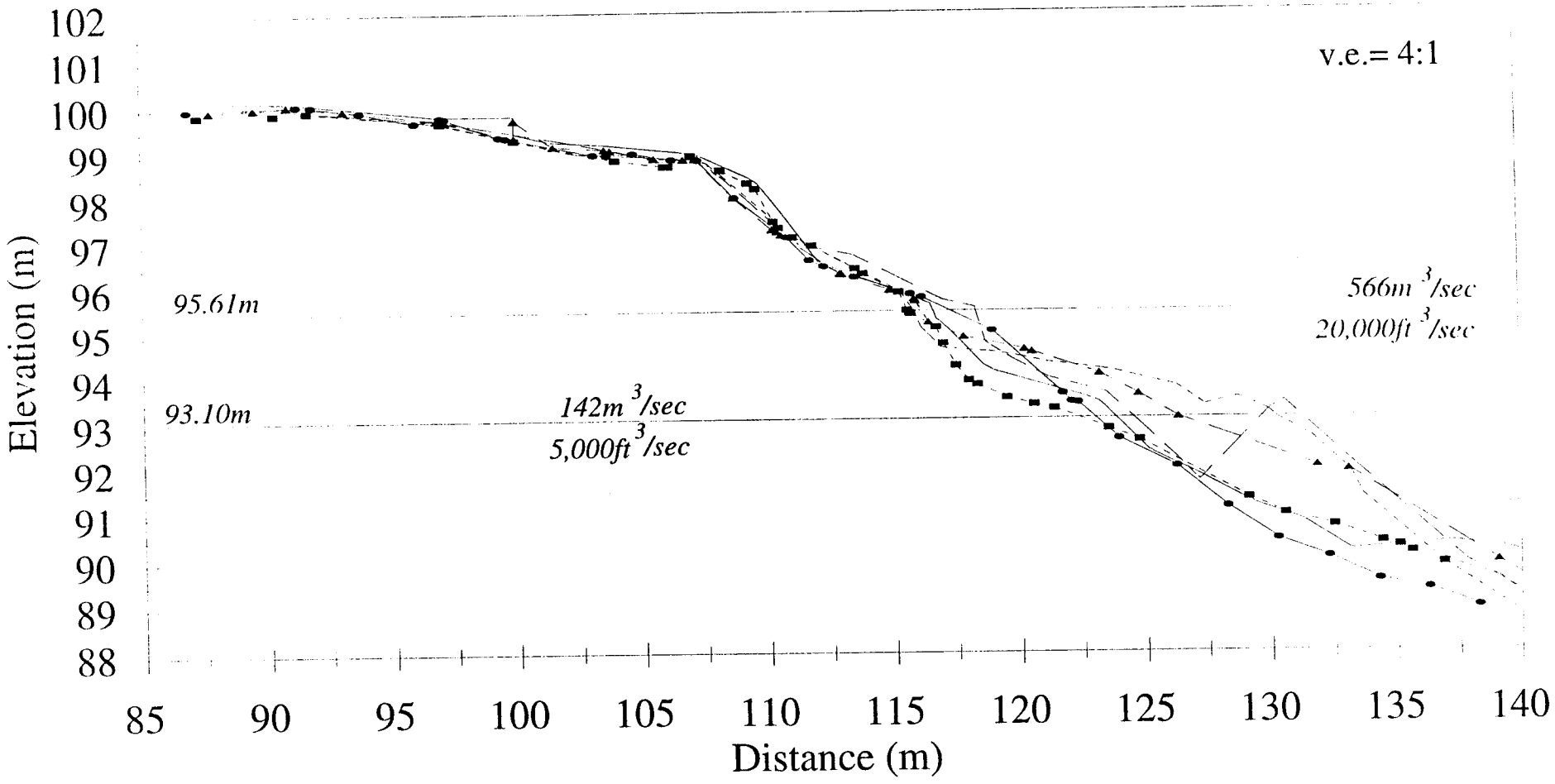

Near-shore P1
100
98
96
94
92
90
88
Elevation (m)
v.e.= 5:1
95.61m
93.10m
142m 3/sec
5,000ft 3/sec
566m 3/sec
20,000ft 3/sec
80
90
100
110
120
130
140
Distance (m)
07/27/91
11/01/91
10/24/92
04/08/93
10/16/93
04/16/94

91 Mile

Cross-channel P2

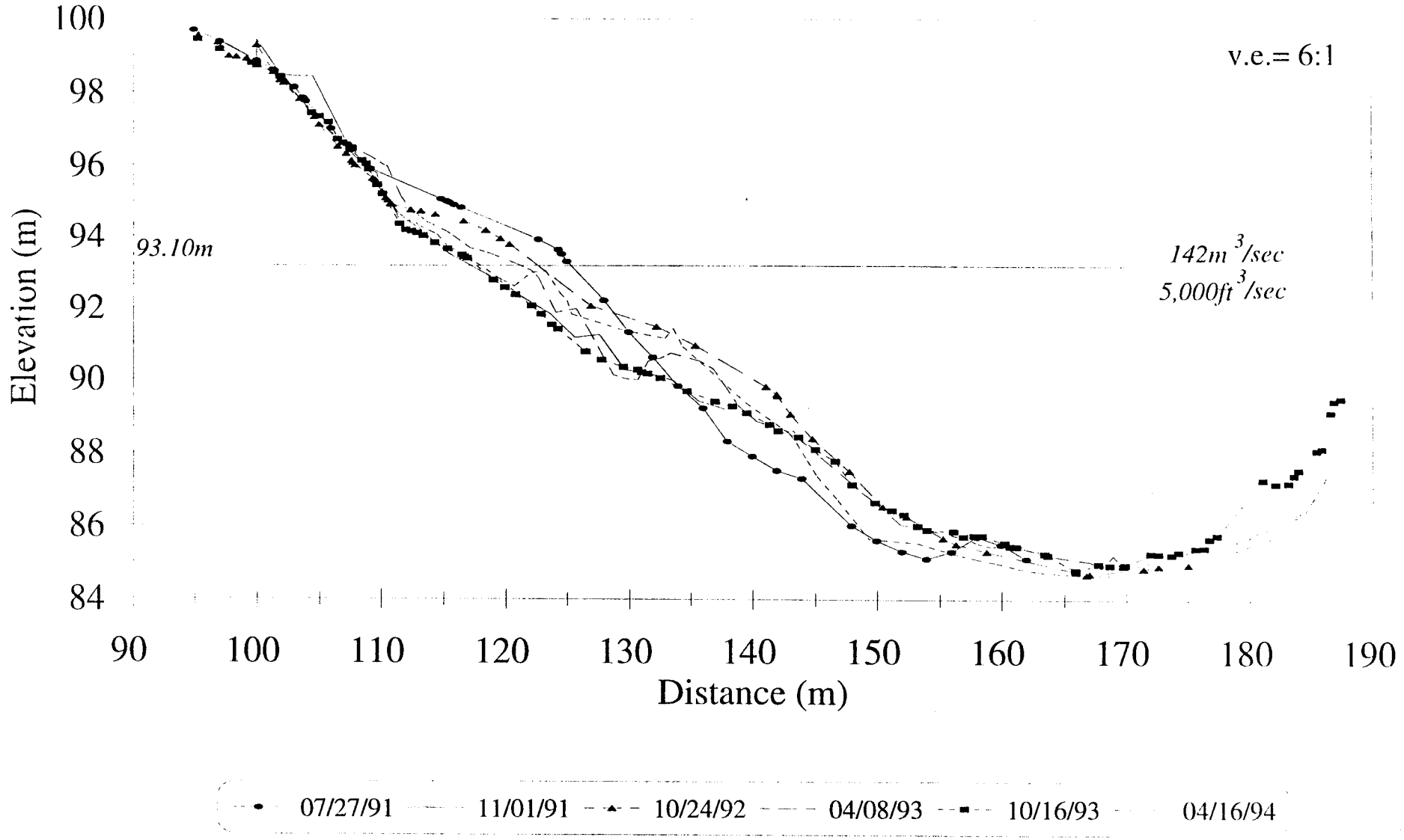


Near-shore P2

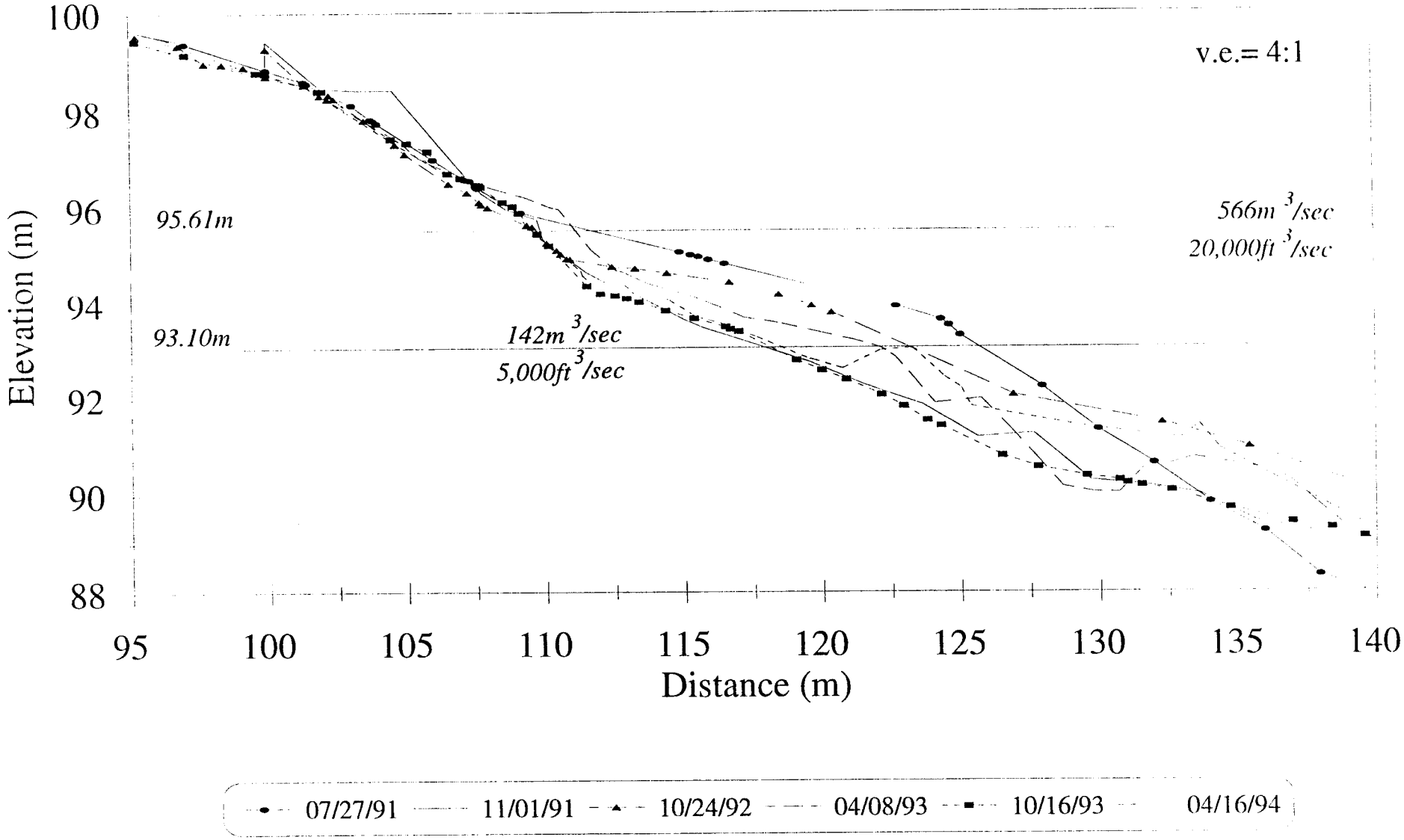


91 Mile

Cross-channel P3

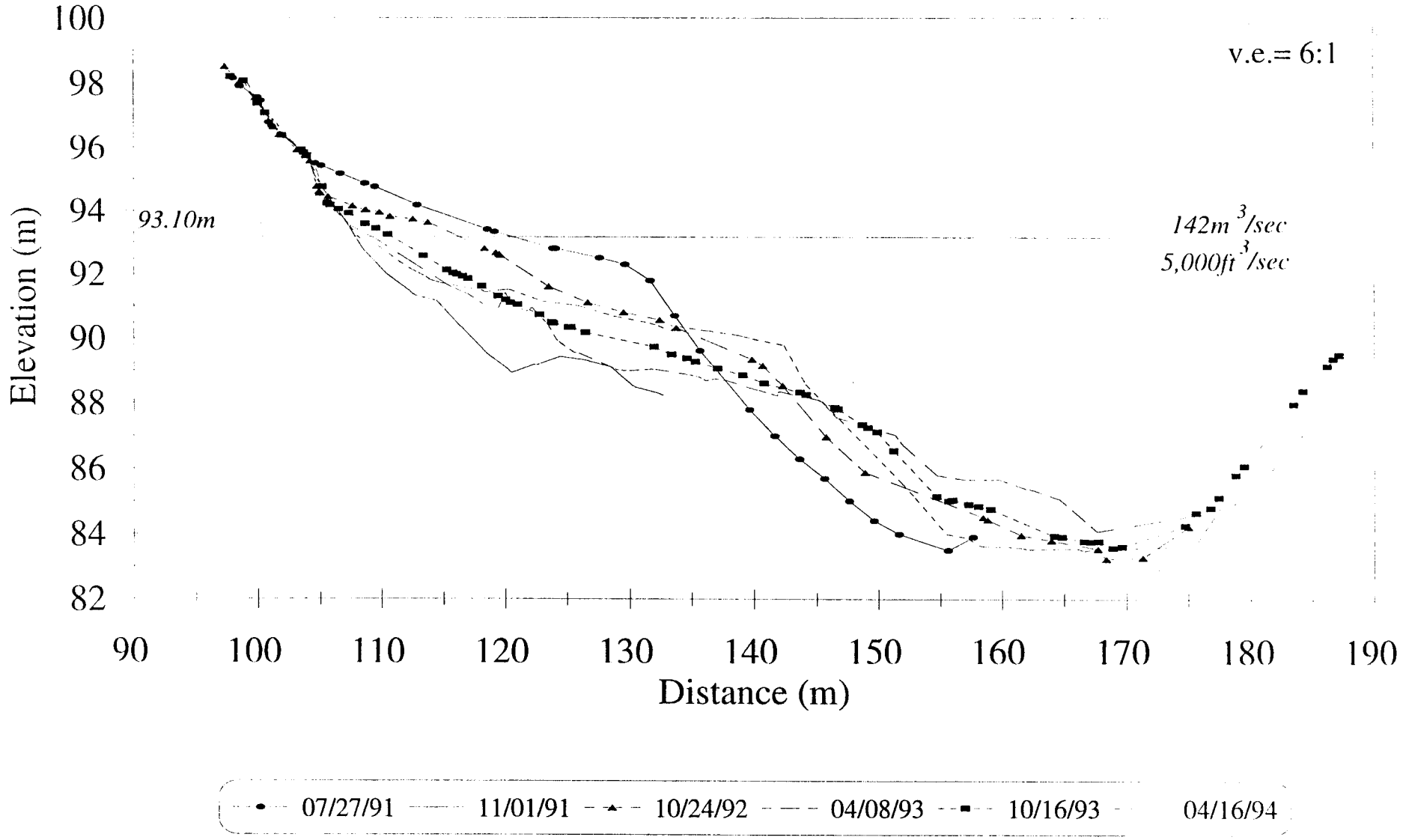


Near-shore P3

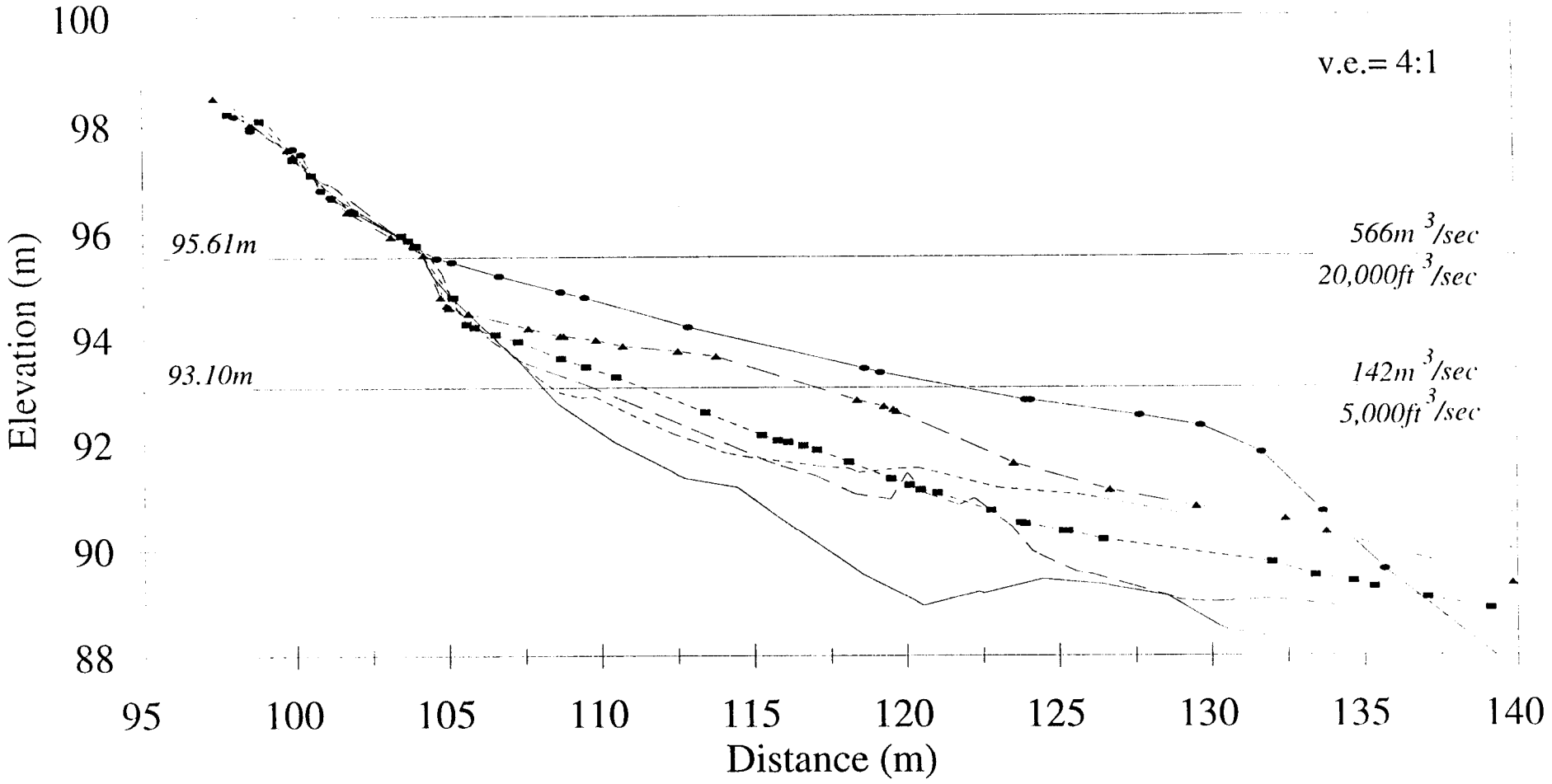


91 Mile

Cross-channel P4

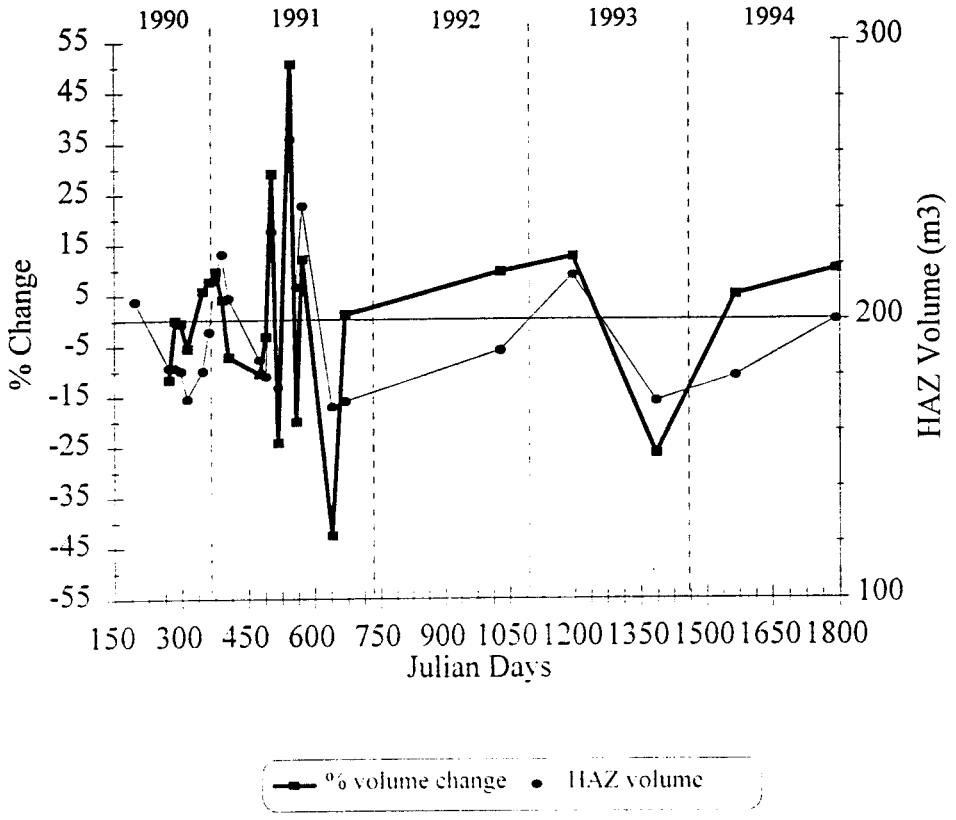


Near-shore P4



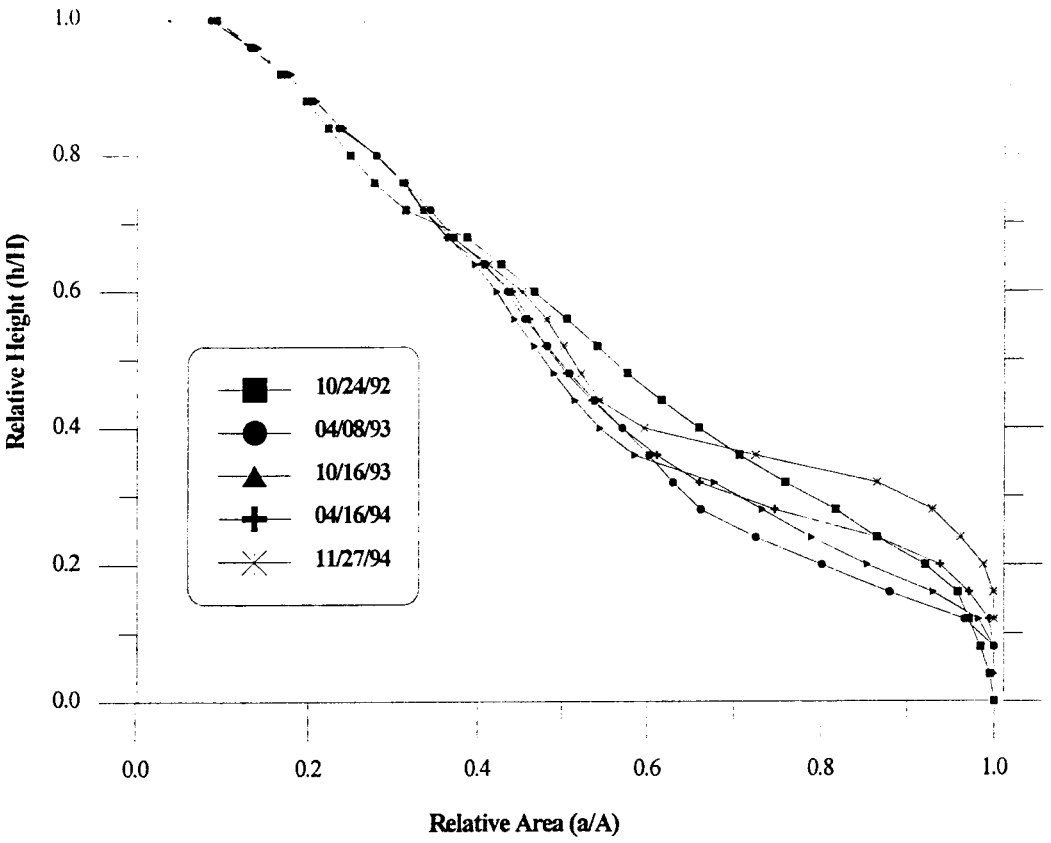
91 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C	900714	G	195	215	207				
D		F							
E		NORM							
F		NORM							
G	900928	E	271	177	183	-38	-24	-17.67	-11.59
H	901012	A	285	176	183	-1	0	-0.56	0.00
I	901026	8000 CFS	299	178	182	2	-1	1.14	-0.55
J	901109	NORM	313	159	172	-19	-10	-10.67	-5.49
K	901214	NORM	348	174	182	15	10	9.43	5.81
L	911228	11000 CFS	362	177	196	3	14	1.72	7.69
M	910112	C	377	223	215	46	19	25.99	9.69
N	910126	NORM	391	238	224	15	9	6.73	4.19
O	910209	B	405	235	208	-3	-16	-1.26	-7.14
P	910420	NORM	475	182	186	-53	-22	-22.55	-10.58
Q	910504	NORM	489	189	180	7	-6	3.85	-3.23
R	910518	D	503	225	232	36	52	19.05	28.89
S	910601	15000 CFS	517	142	176	-83	-56	-36.89	-24.14
T	910702	NORM	545	217	265	75	89	52.82	50.57
U	910712	G	558	198	212	-19	-53	-8.76	-20.00
V	910727	F	573	223	241	25	29	12.63	12.03
W	911002	INT	640	139	169	-84	-72	-37.67	-42.60
X	910001	INT	670	135	171	-4	2	-2.88	1.17
Y	921024	INT	1028	208	189	73	18	54.07	9.52
Z	930408	INT	1195	155	216	-53	27	-25.48	12.50
B18	931016	INT	1385	126	171	-29	-45	-18.71	-26.32
C18	940416	INT	1567	161	180	35	9	27.78	5.00
D18	941127	INT	1792	177	200	16	20	9.94	10.00

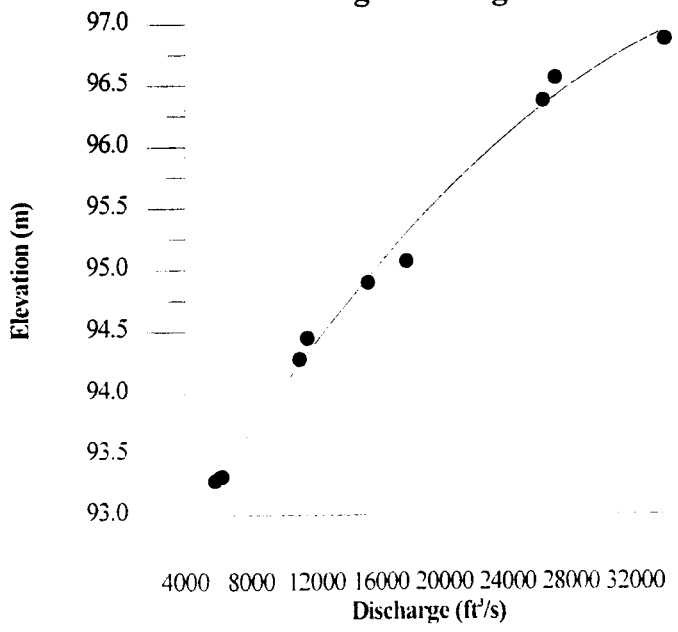


91 Mile

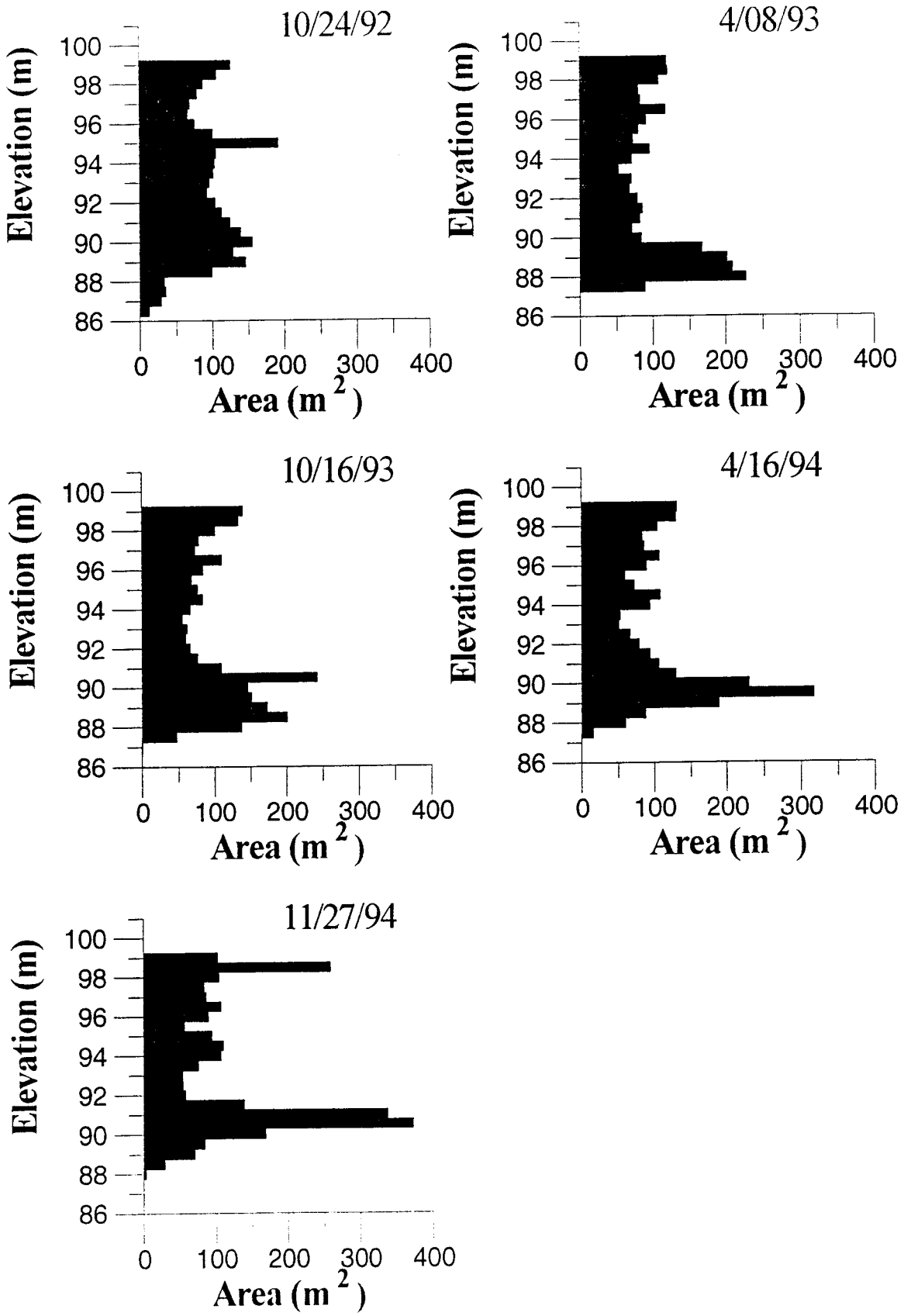
Hypsometric Curves



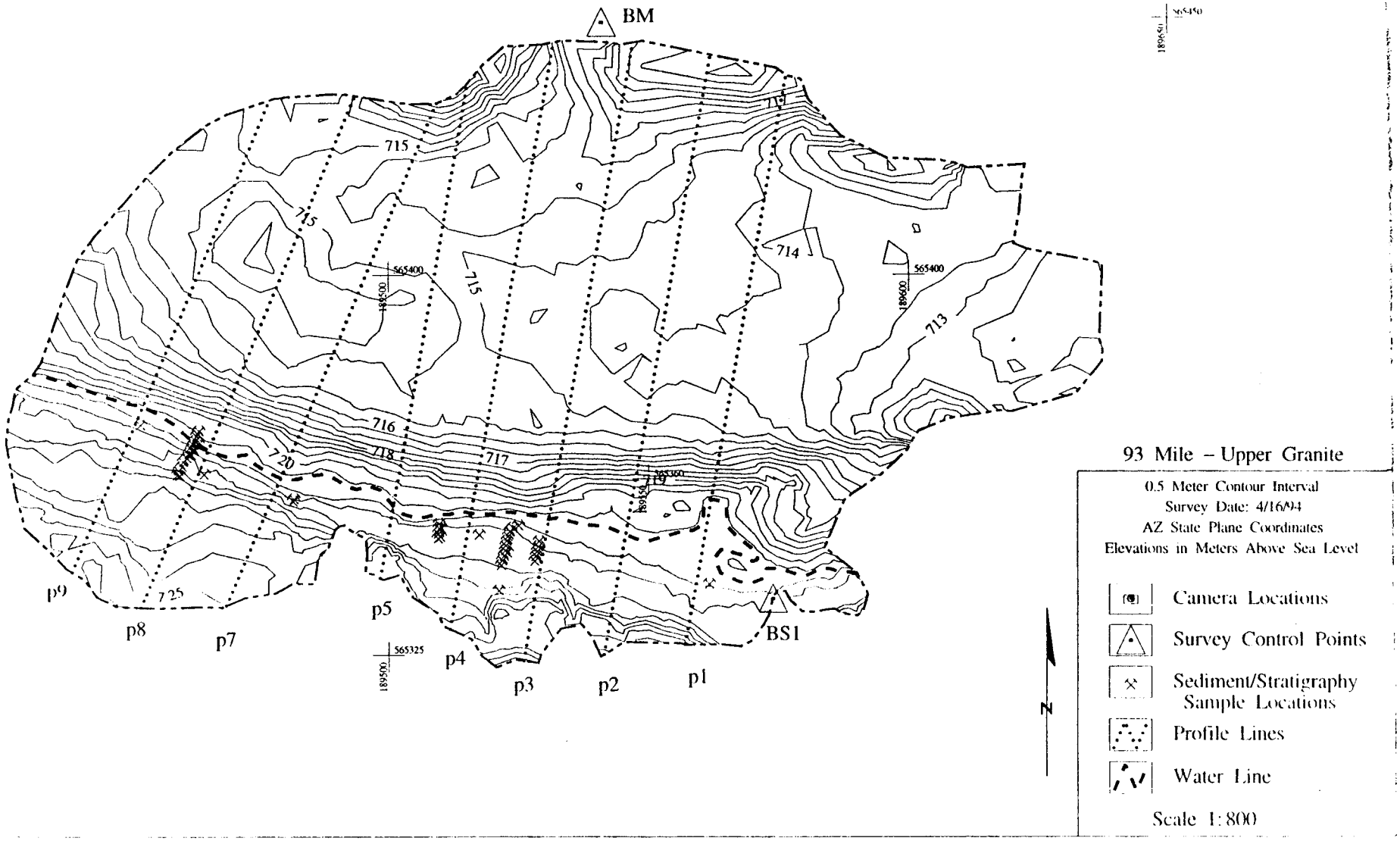
Stage Discharge



91 MILE
Area Distribution Curves

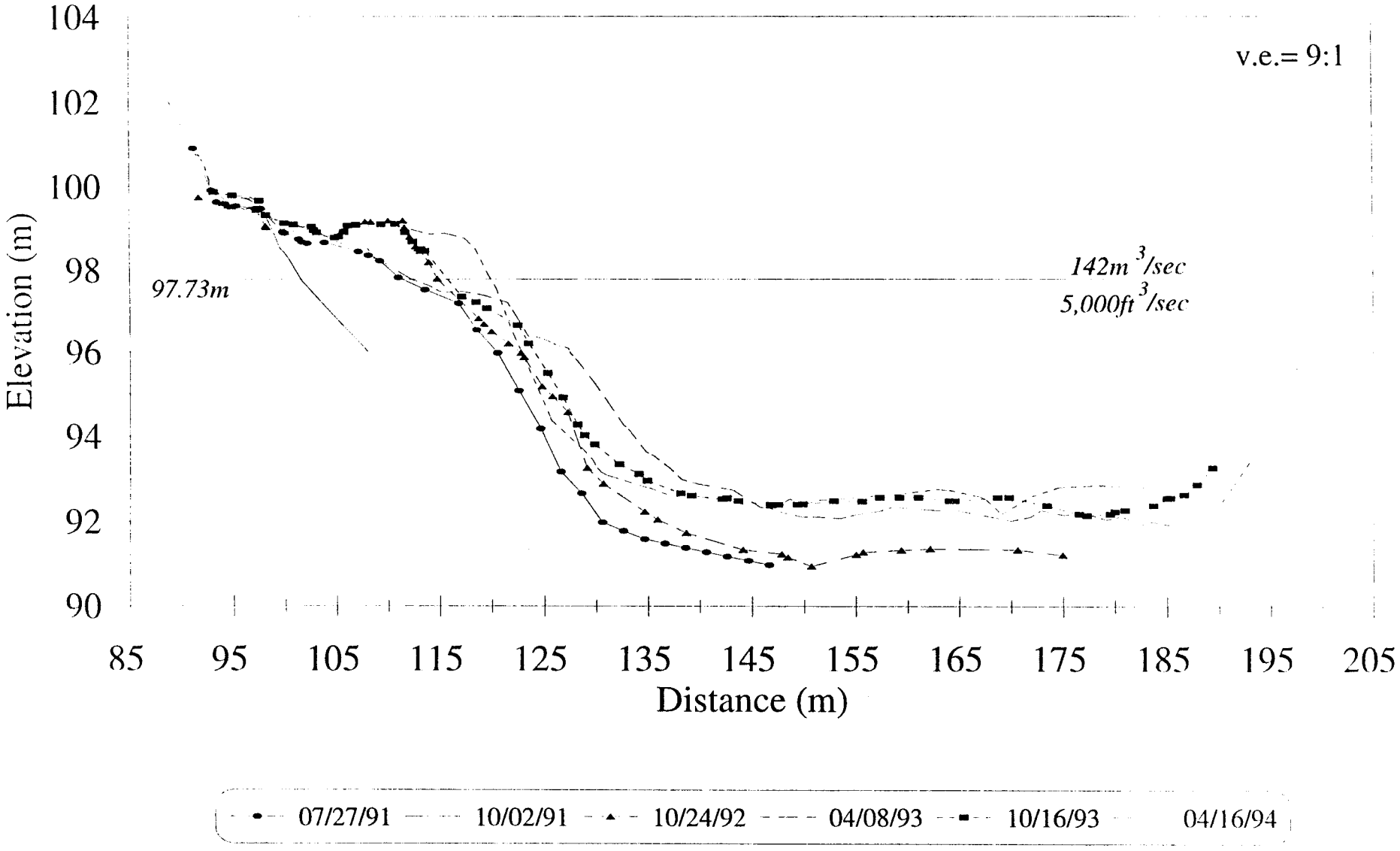


93 L
5-29-94
Area of Study
RM 93.4

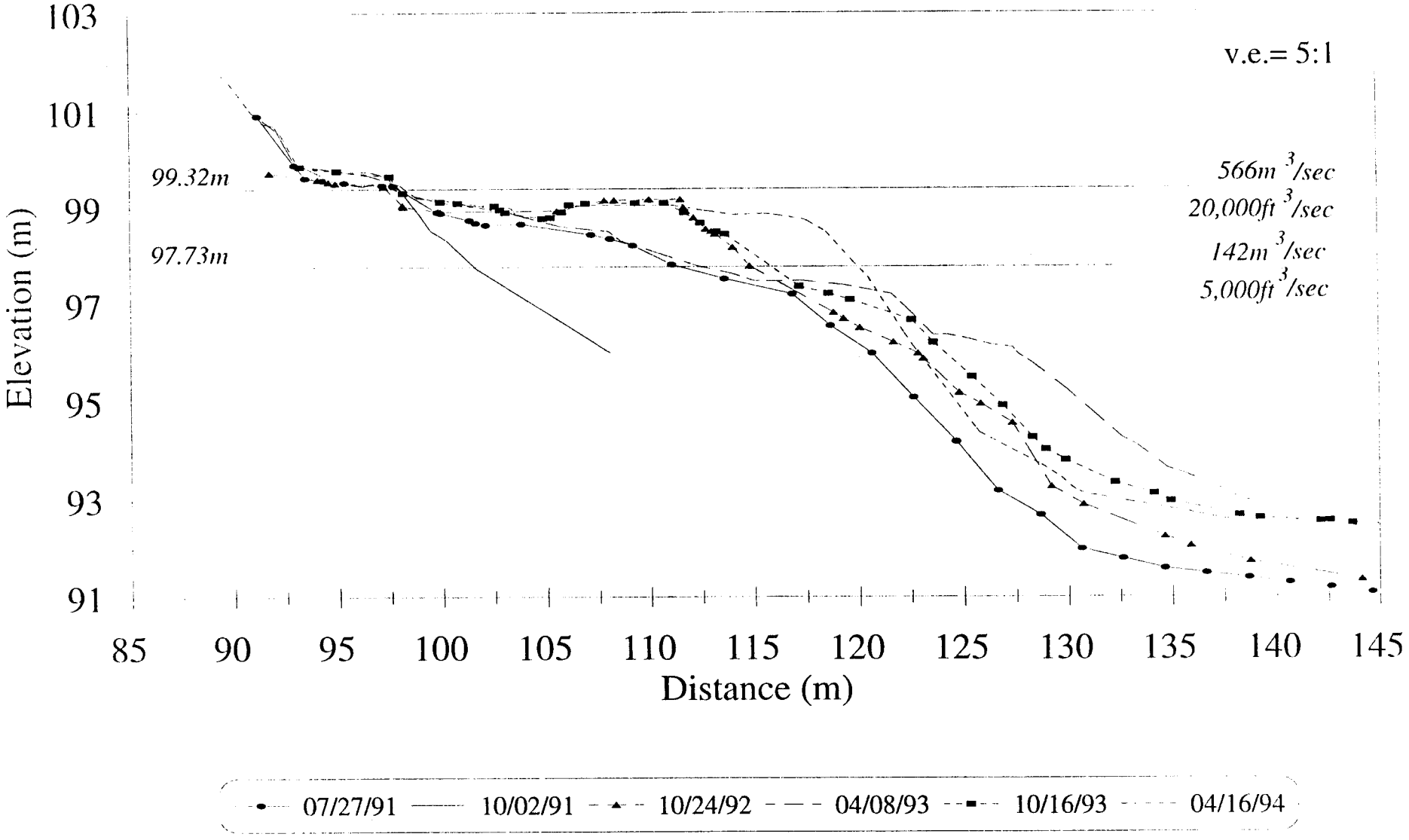

BM
715
715
714
715
713
716
720
718
717
565400
565400
565325
565360
p9
p8
p7
p5
p4
p3
p2
p1
BS1
725
N
93 Mile – Upper Granite
0.5 Meter Contour Interval
Survey Date: 4/16/94
AZ State Plane Coordinates
Elevations in Meters Above Sea Level
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:800

93 Mile

Cross-channel P1

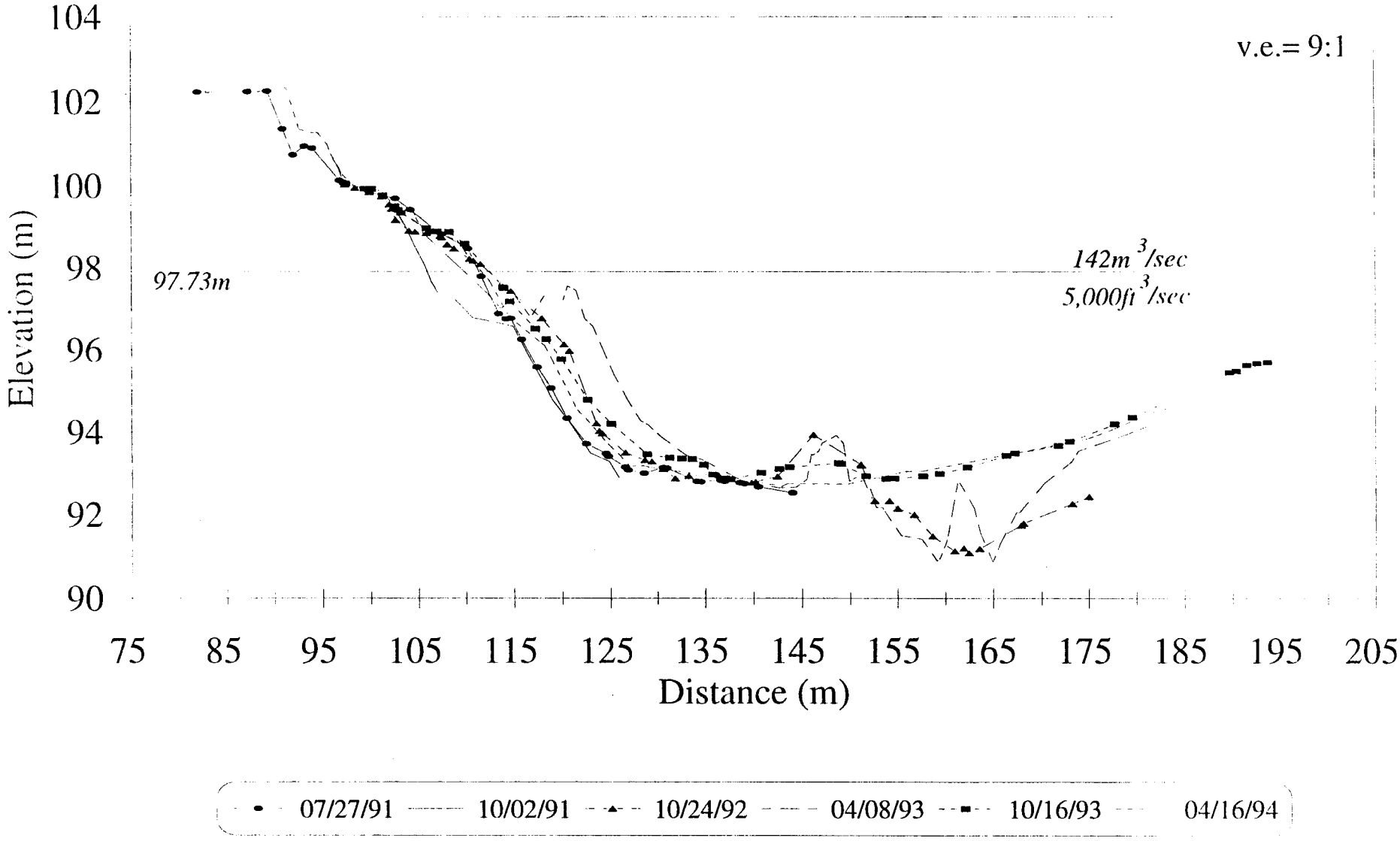


Near-shore P1

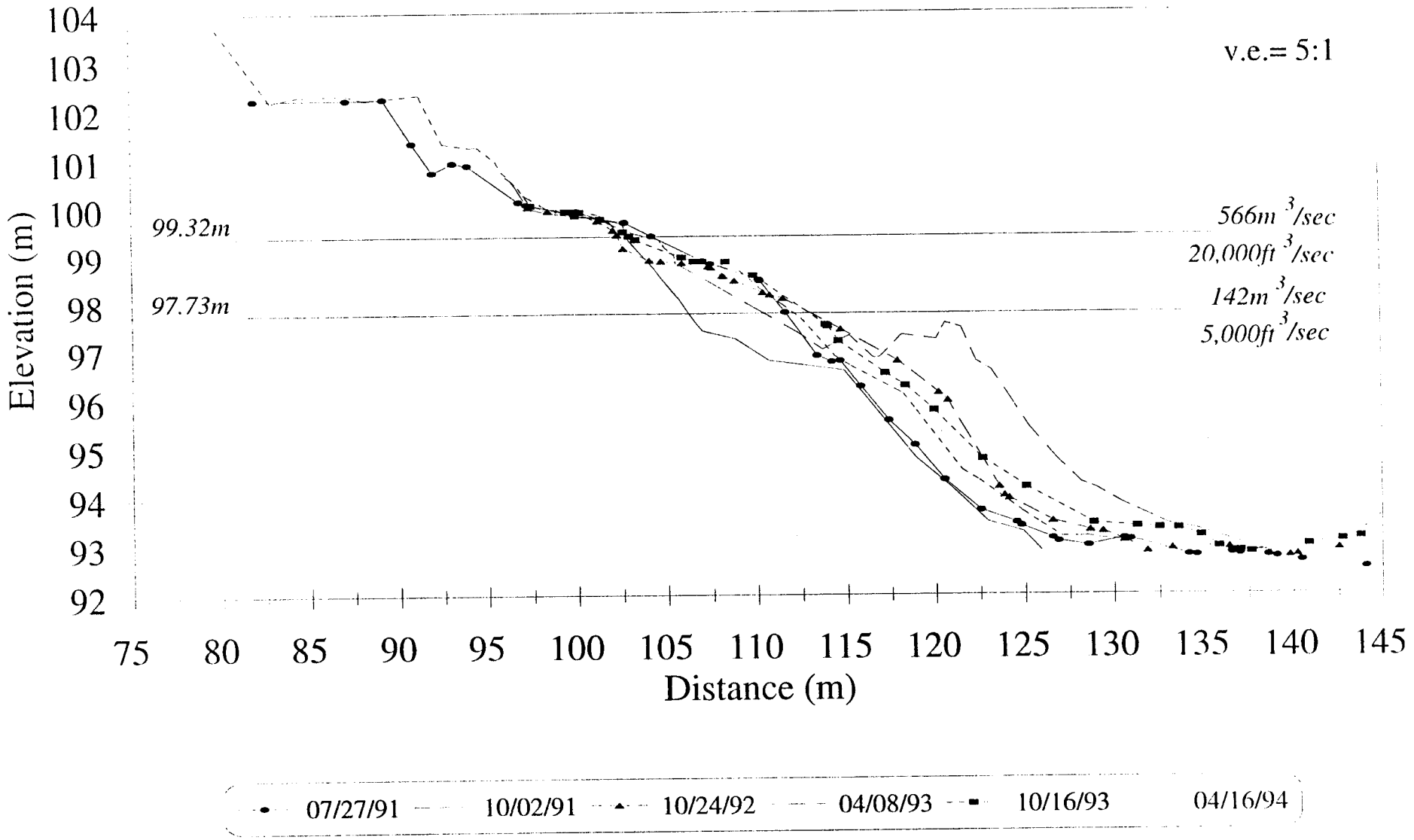


93 Mile

Cross-channel P3

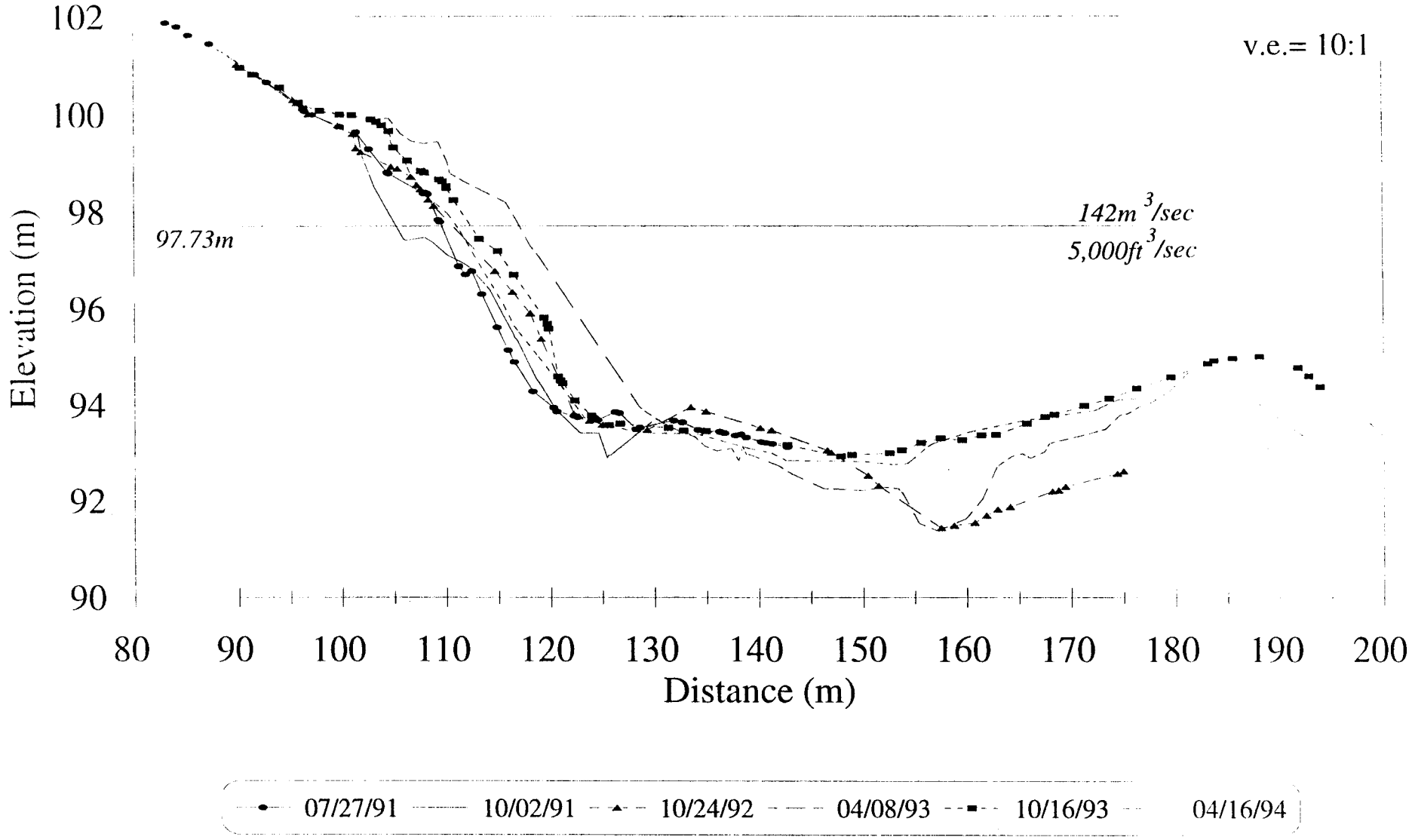


Near-shore P3

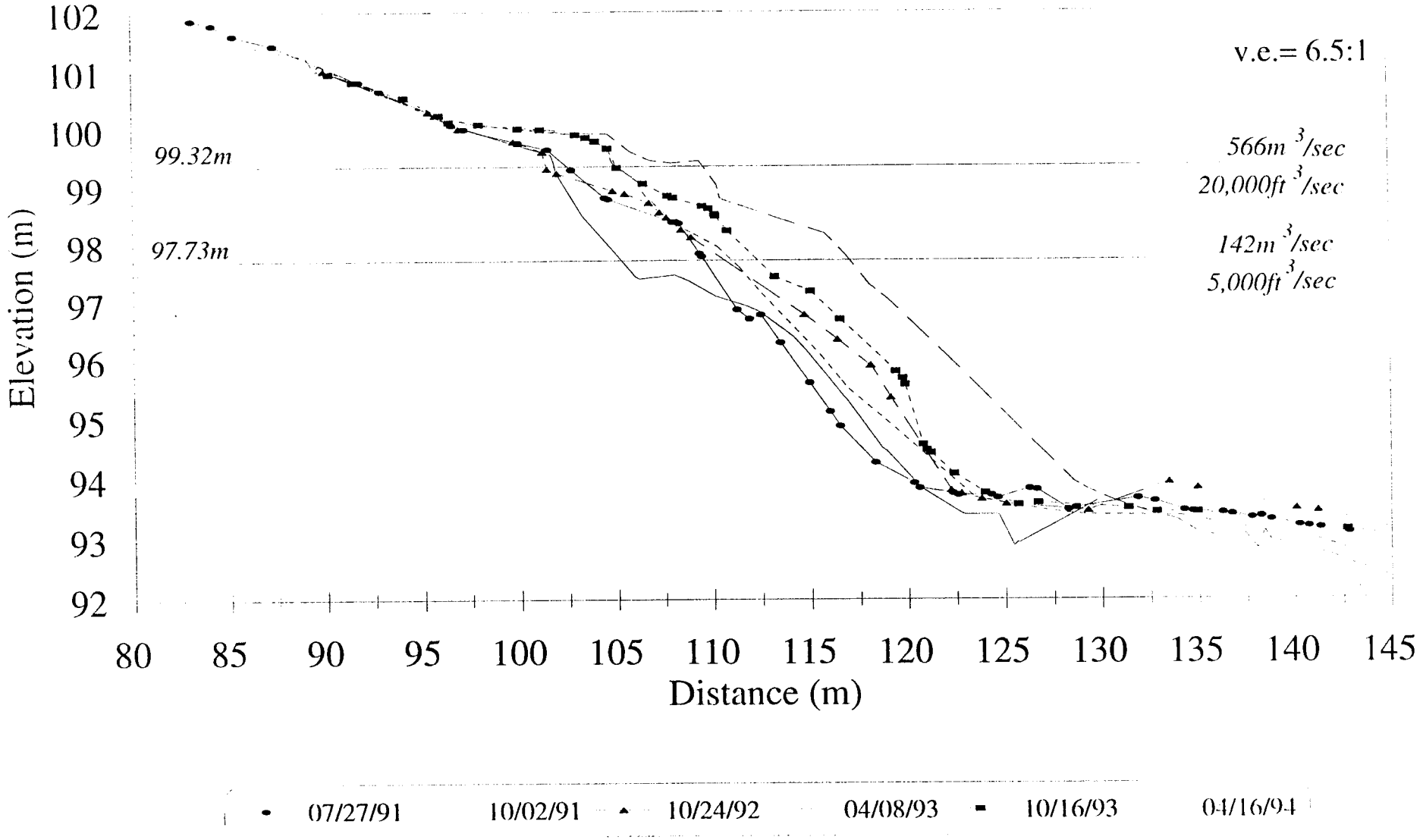


93 Mile

Cross-channel P4

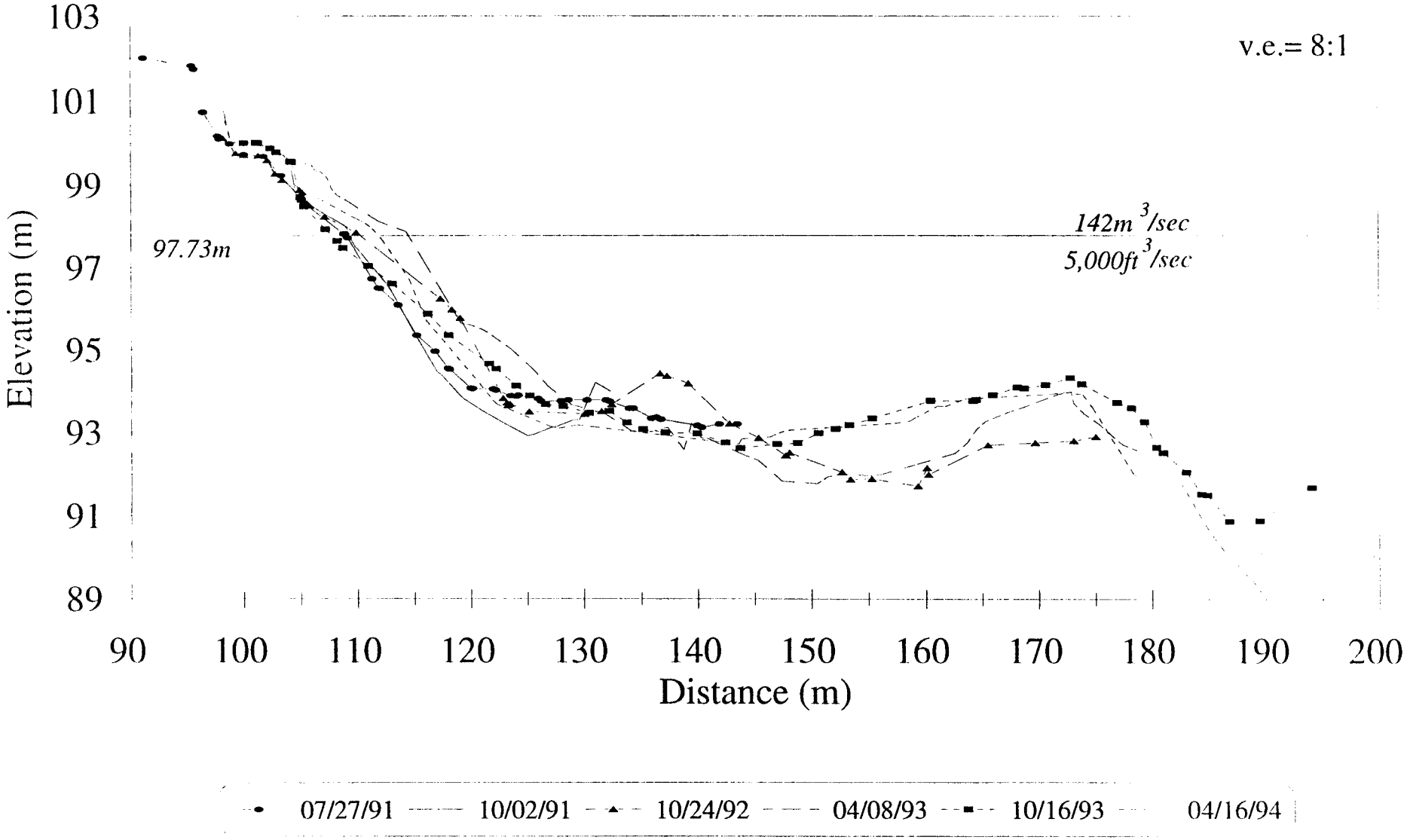


Near-shore P4

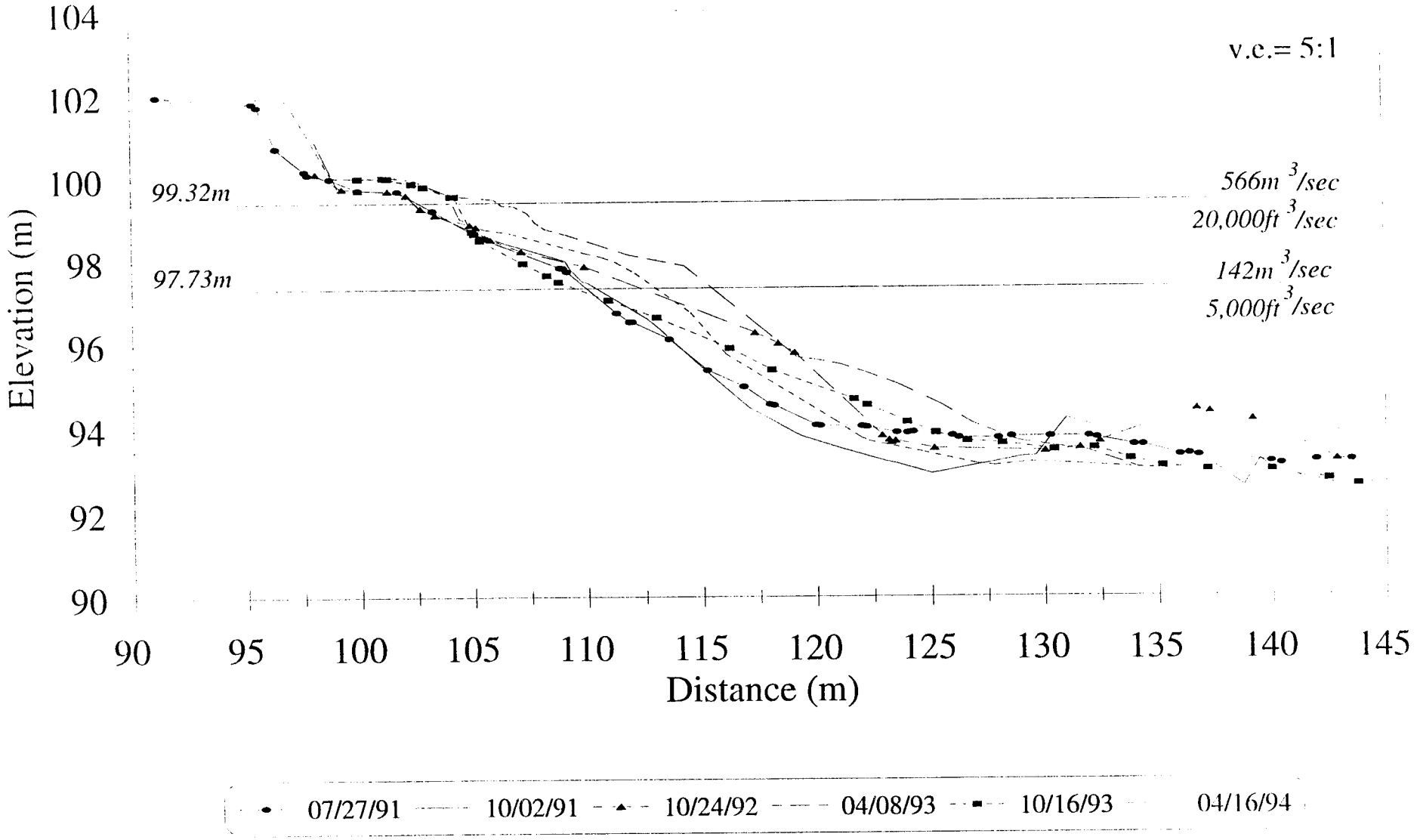


93 Mile

Cross-channel P5

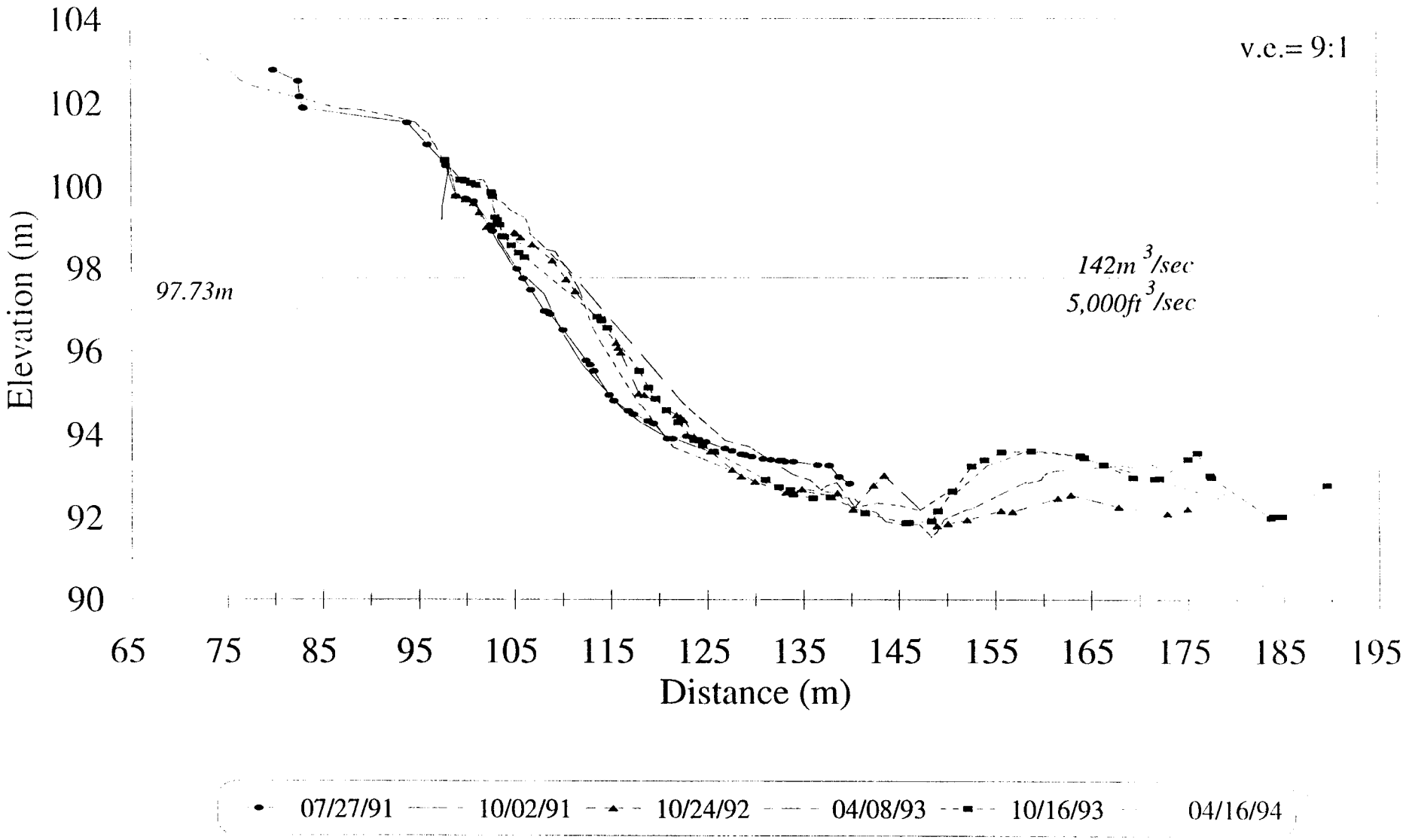


Near-shore P5

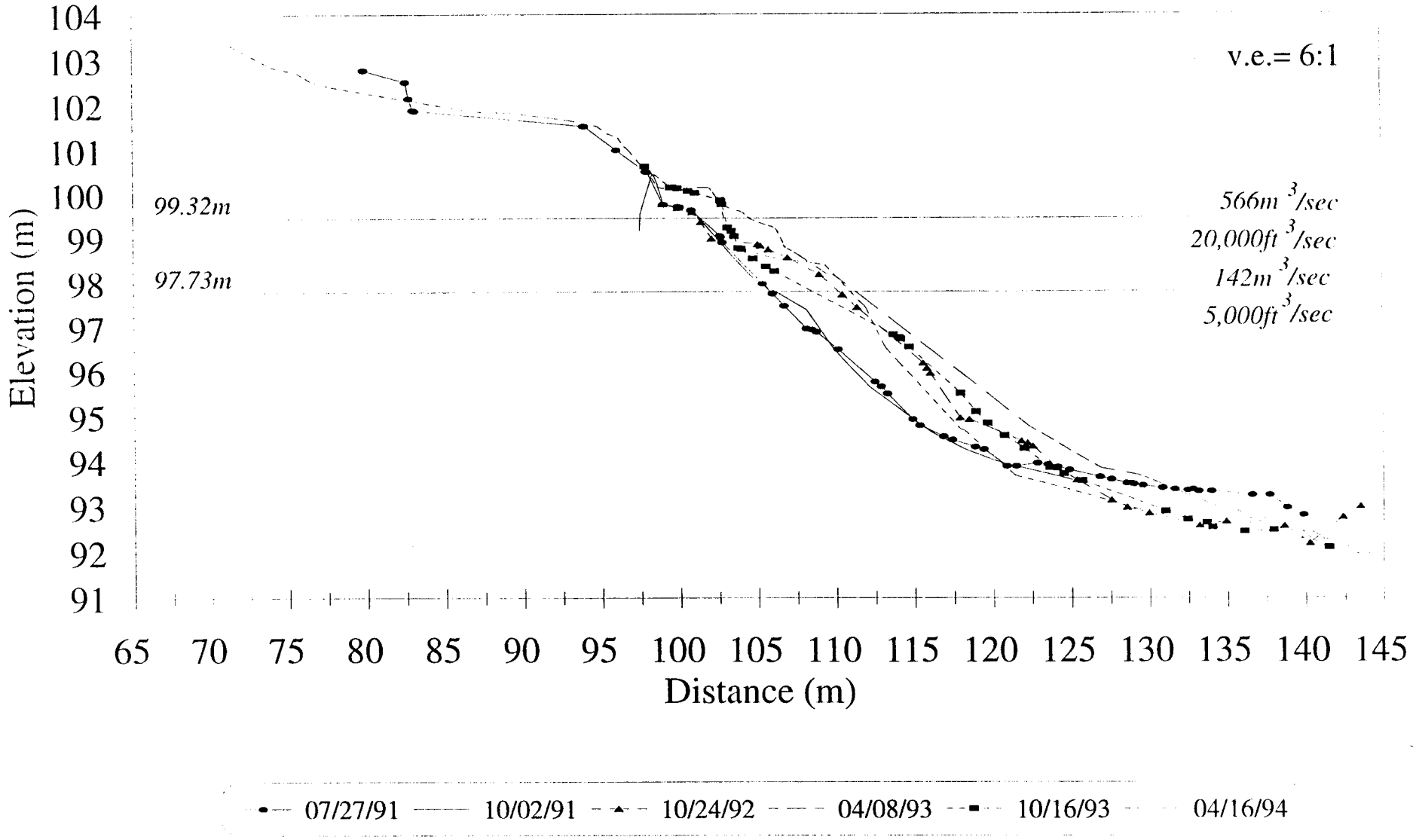


93 Mile

Cross-channel P8

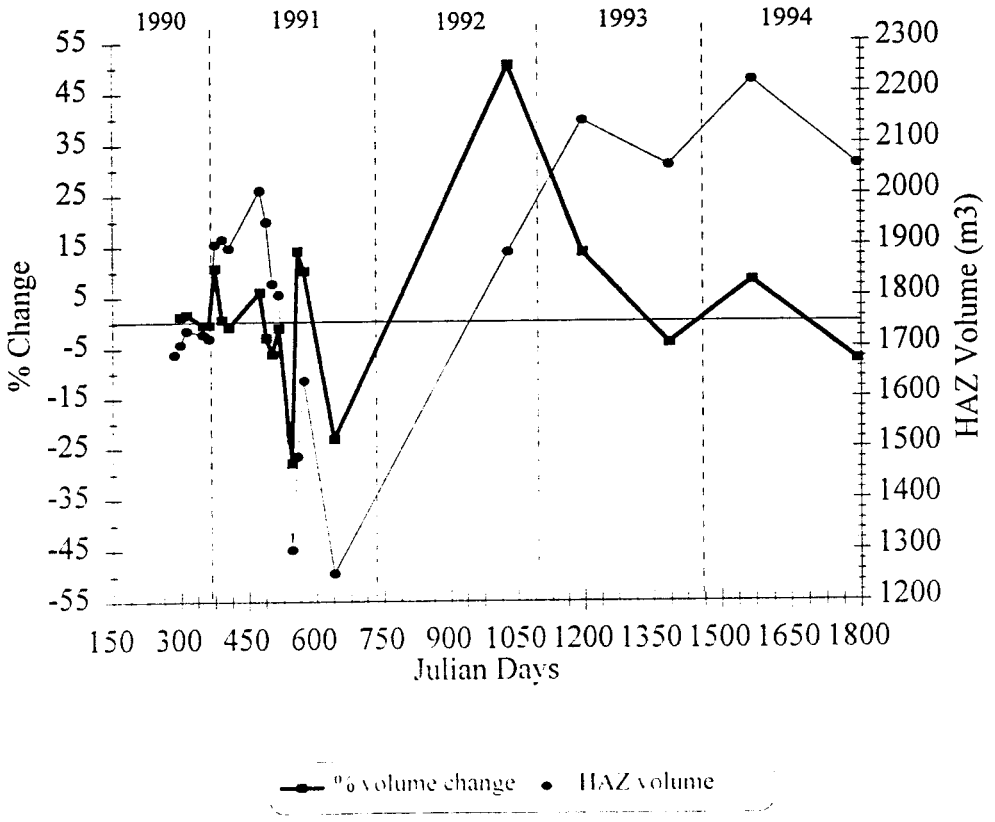


Near-shore P8



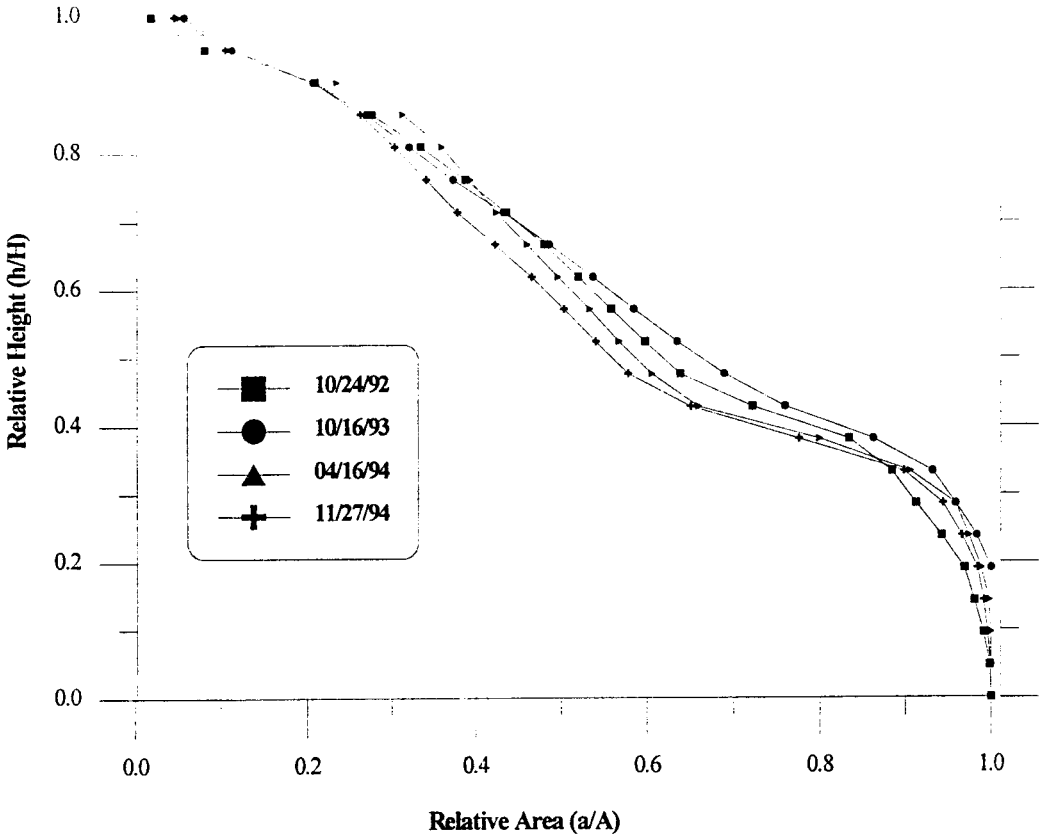
93 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F		NORM							
G		E							
H	901013	A	286	1394	1688				
I	901027	8000 CFS	300	1390	1708	-4	20	-0.29	1.18
J	901110	NORM	314	1397	1735	7	27	0.50	1.58
K	901215	NORM	349	1433	1727	36	-8	2.58	-0.46
L	901229	11000 CFS	363	1417	1719	-16	-8	-1.12	-0.46
M	910112	C	376	1631	1904	214	185	15.10	10.76
N	910126	NORM	391	1598	1915	-33	11	-2.02	0.58
O	910209	B	405	1601	1897	3	-18	0.19	-0.94
P	910420	NORM	475	1574	2010	-27	113	-1.69	5.96
Q	910504	NORM	489	1637	1949	63	-61	4.00	-3.03
R	910518	D	503	1380	1826	-257	-123	-15.70	-6.31
S	910601	15000 CFS	517	1418	1805	38	-21	2.75	-1.15
T	910629	NORM	545	1001	1302	-417	-503	-29.41	-27.87
U	910713	G	559	1231	1485	230	183	22.98	14.06
V	910727	F	573	1401	1634	170	149	13.81	10.03
W	911002	INT	640	1021	1256	-380	-378	-27.12	-23.13
Y	921024	INT	1028	1690	1888	669	632	65.52	50.32
Z	930408	INT	1195	1717	2145	27	257	1.60	13.61
B19	931016	INT	1385	1590	2057	-127	-88	-7.40	-4.10
C19	940416	INT	1567	1878	2224	288	167	18.11	8.12
D19	941127	INT	1792	1628	2059	-250	-165	-13.31	-7.42

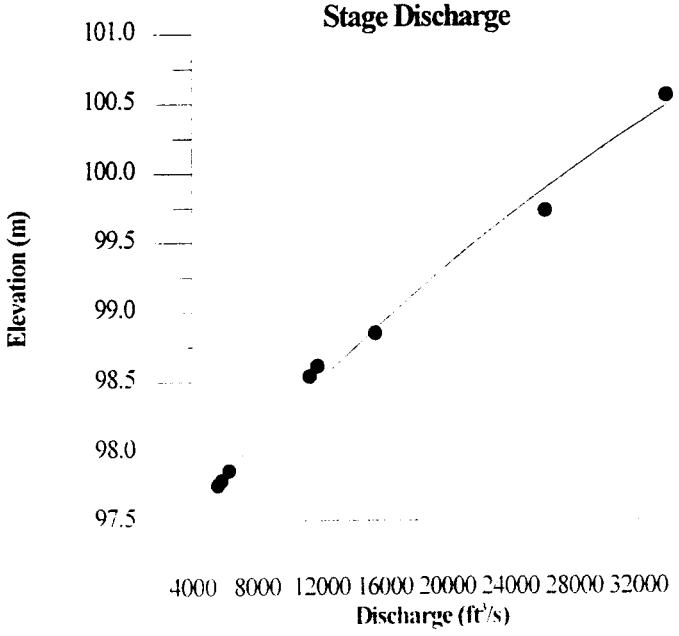


93 Mile

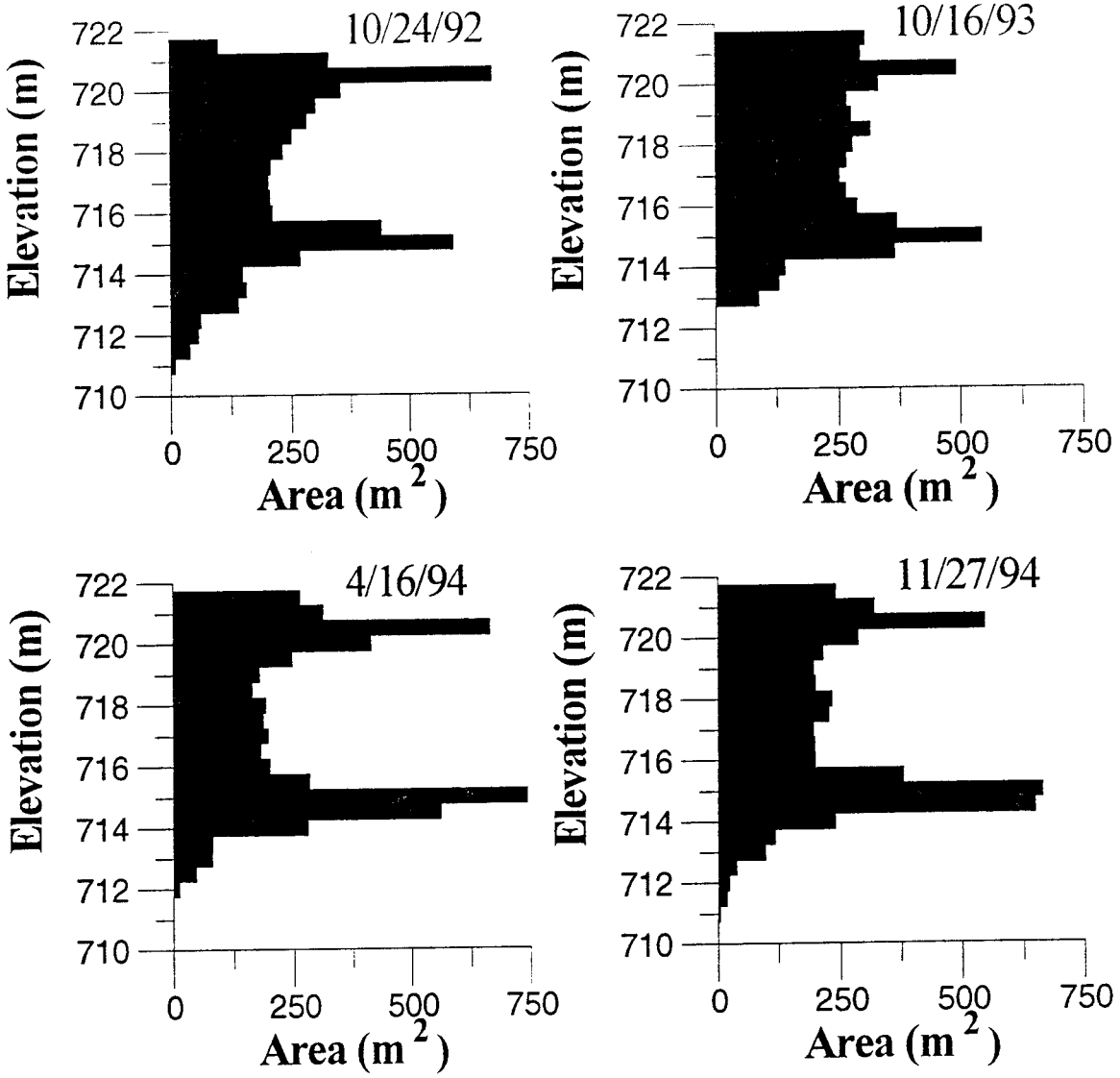
Hypsometric Curves

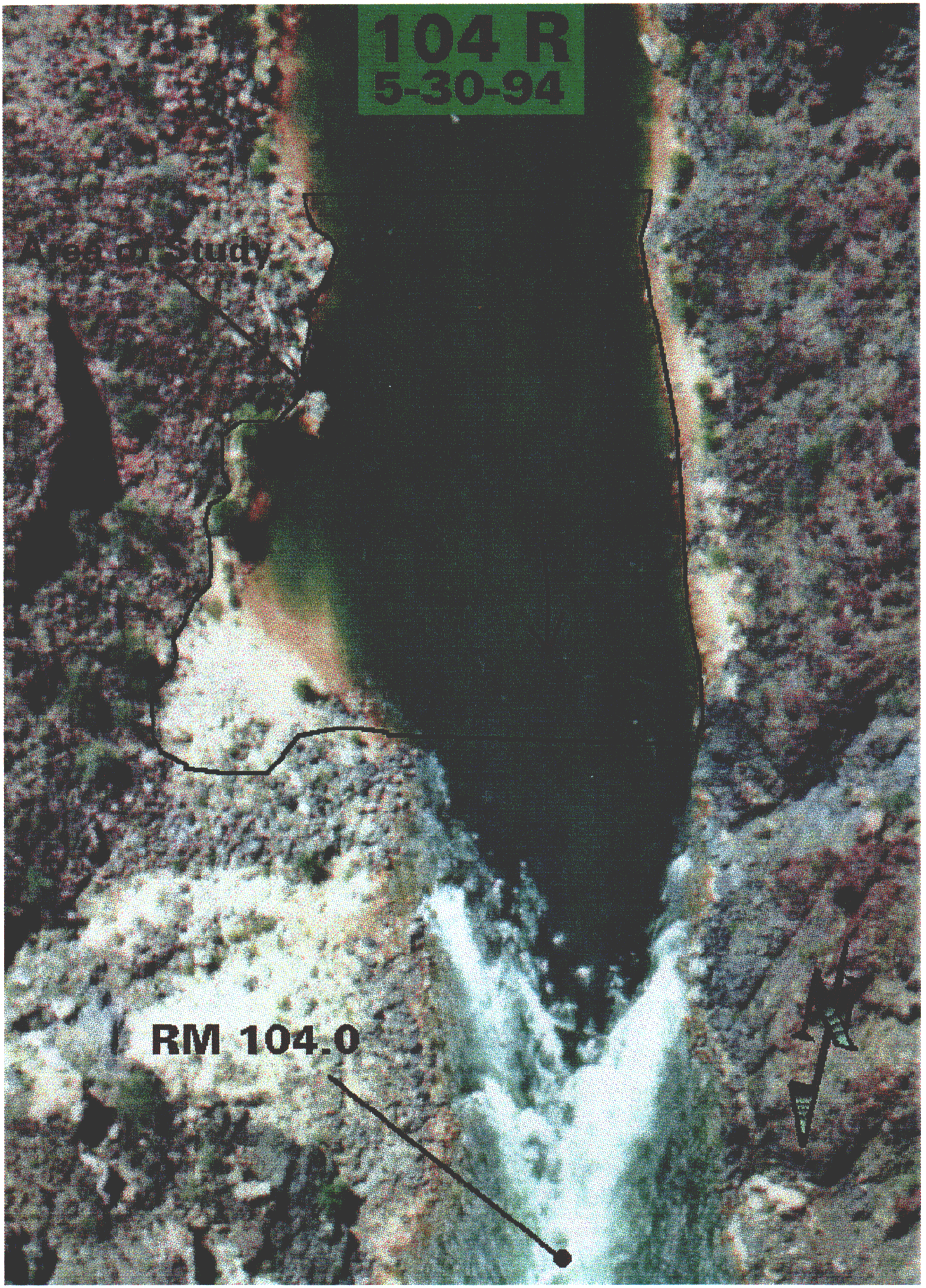


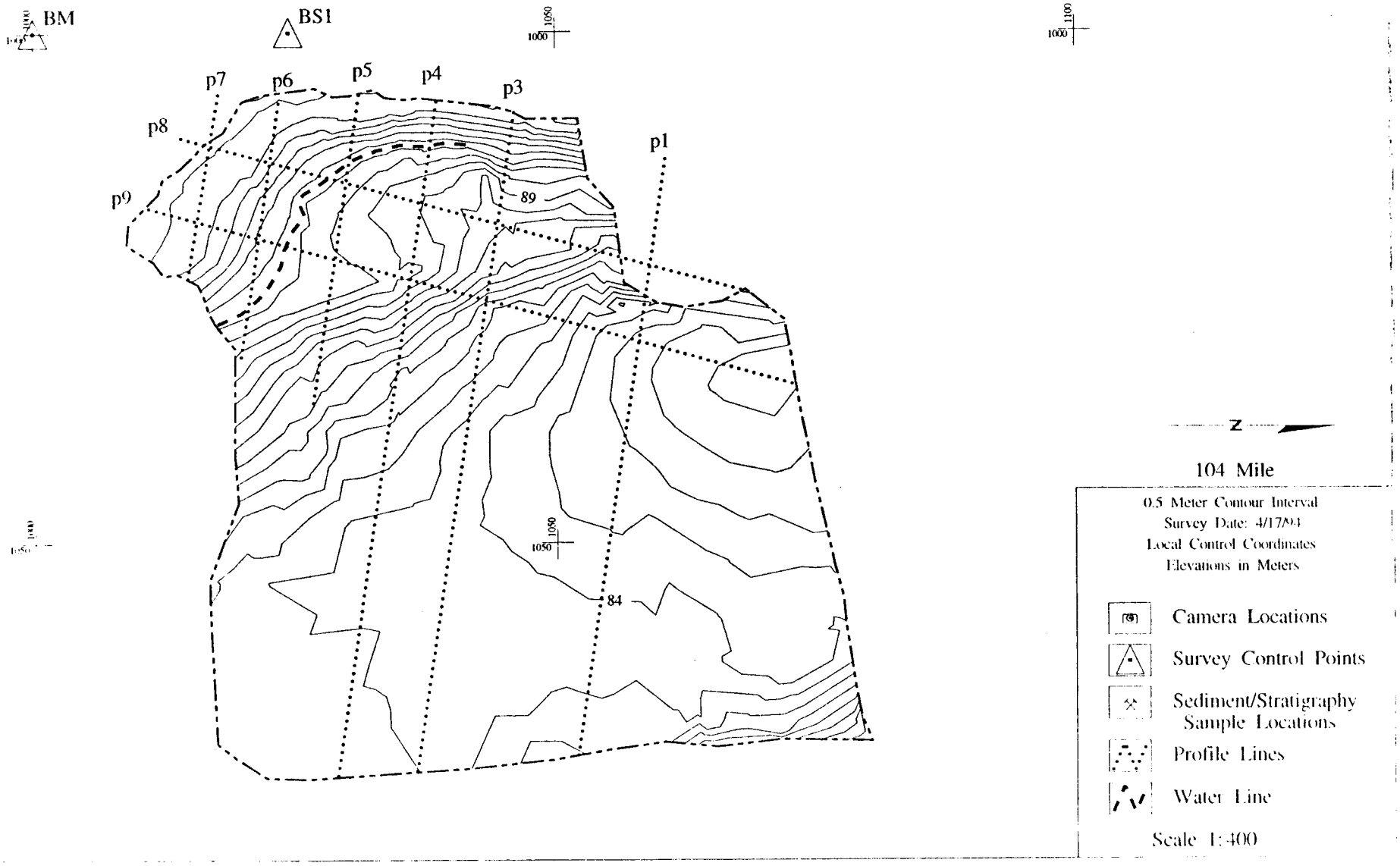
Stage Discharge



93 MILE
Area Distribution Histograms

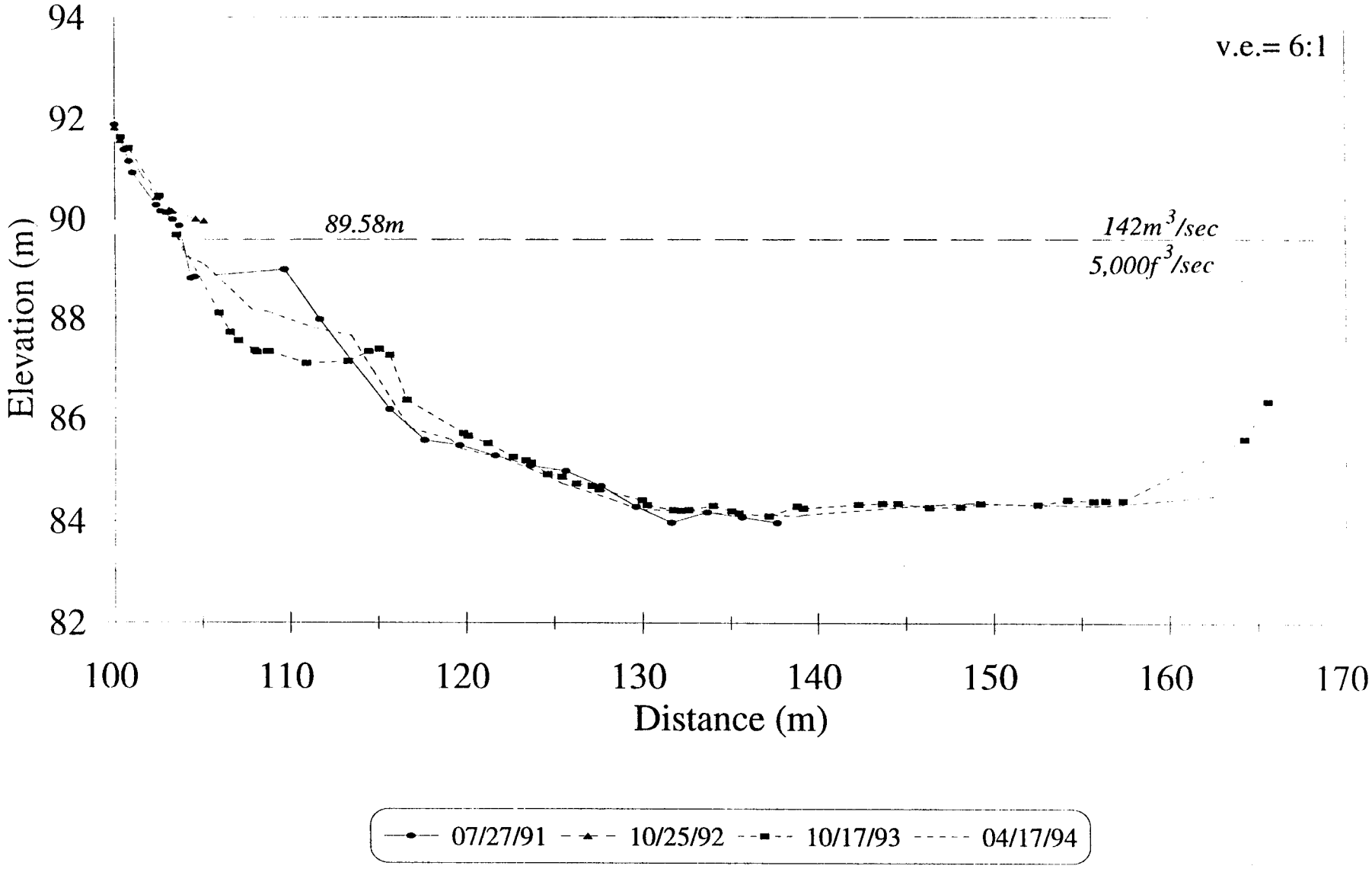


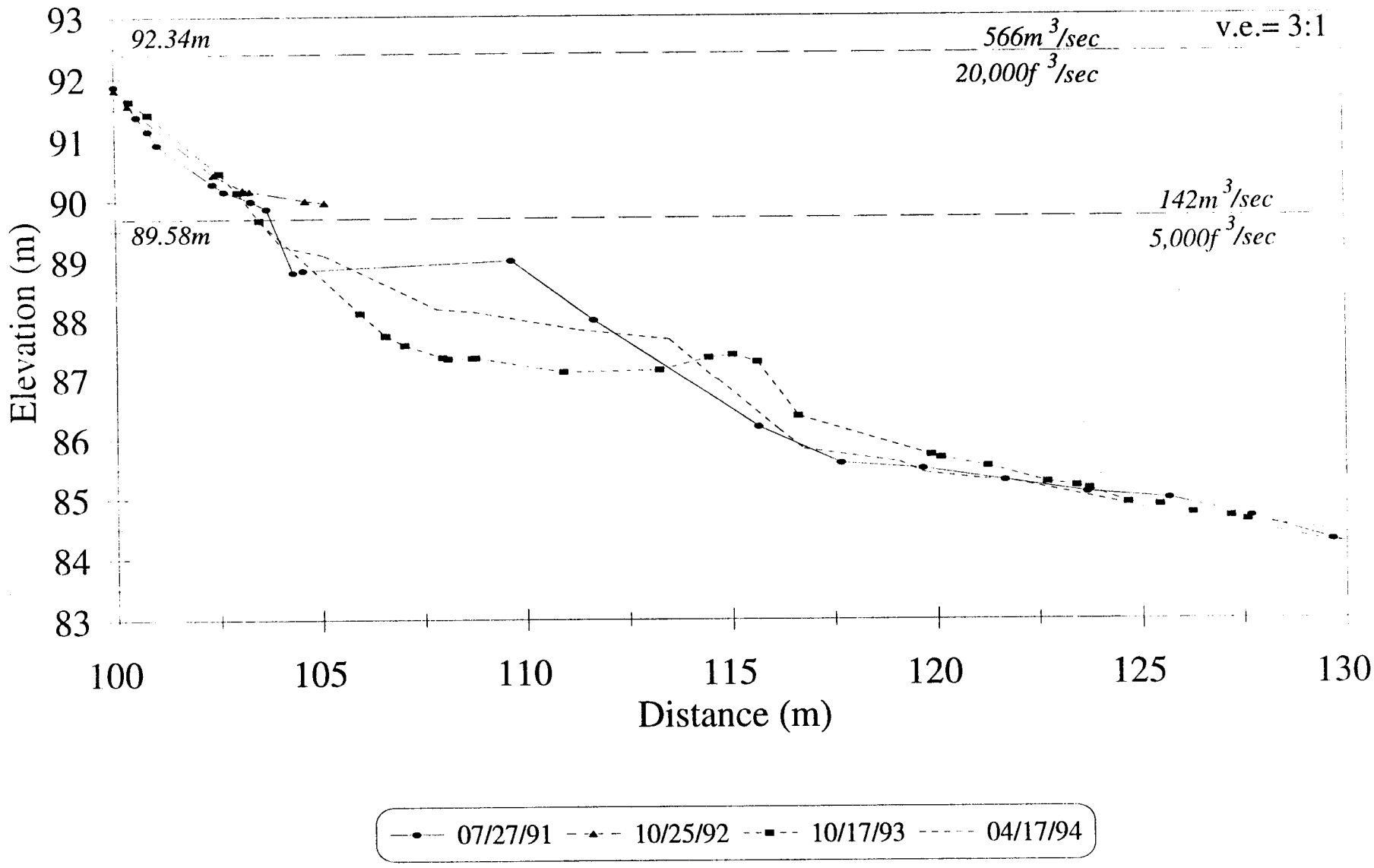

104 R
5-30-94
Area of Study
RM 104.0


BM
BS1
1000
1050
1100
p7
p6
p5
p4
p3
p8
p1
p9
89
84
N
104 Mile
0.5 Meter Contour Interval
Survey Date: 4/17/03
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:400

104 Mile

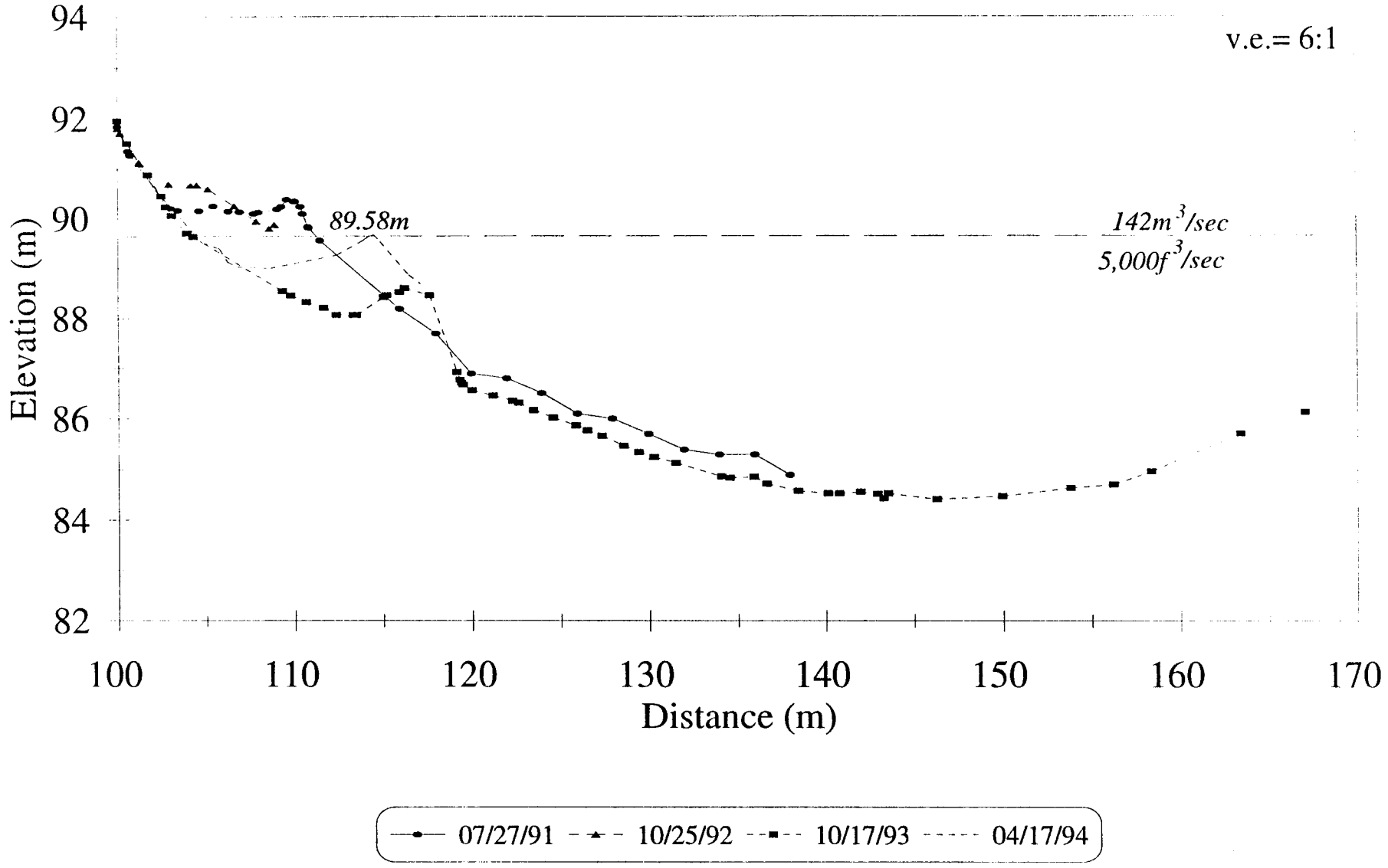
Cross-channel P3

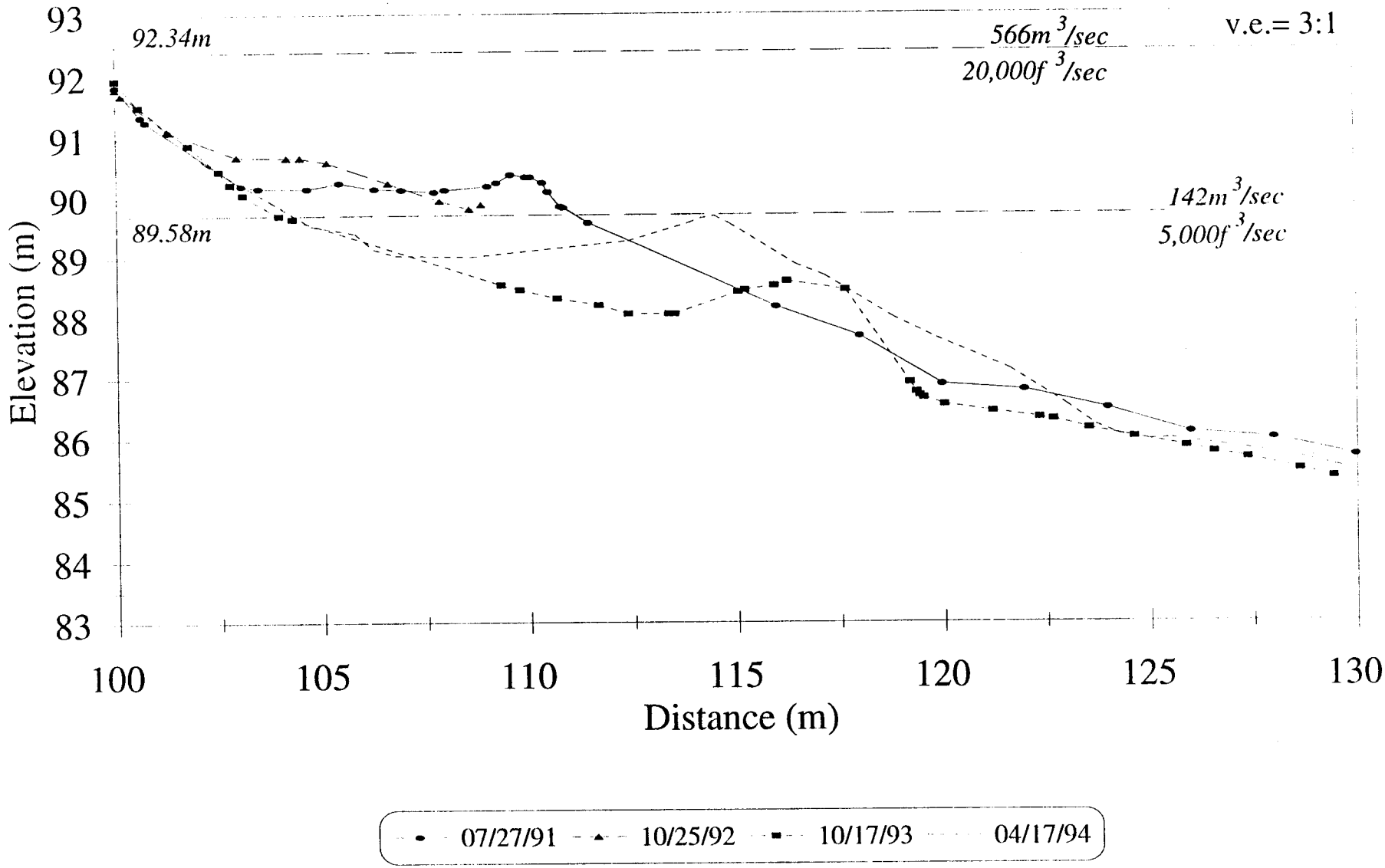



Near-shore P3
93
92
91
90
89
88
87
86
85
84
83
Elevation (m)
92.34m
89.58m
566m 3/sec
20,000f 3/sec
142m 3/sec
5,000f 3/sec
v.e.= 3:1
100
105
110
115
120
125
130
Distance (m)
07/27/91
10/25/92
10/17/93
04/17/94

104 Mile

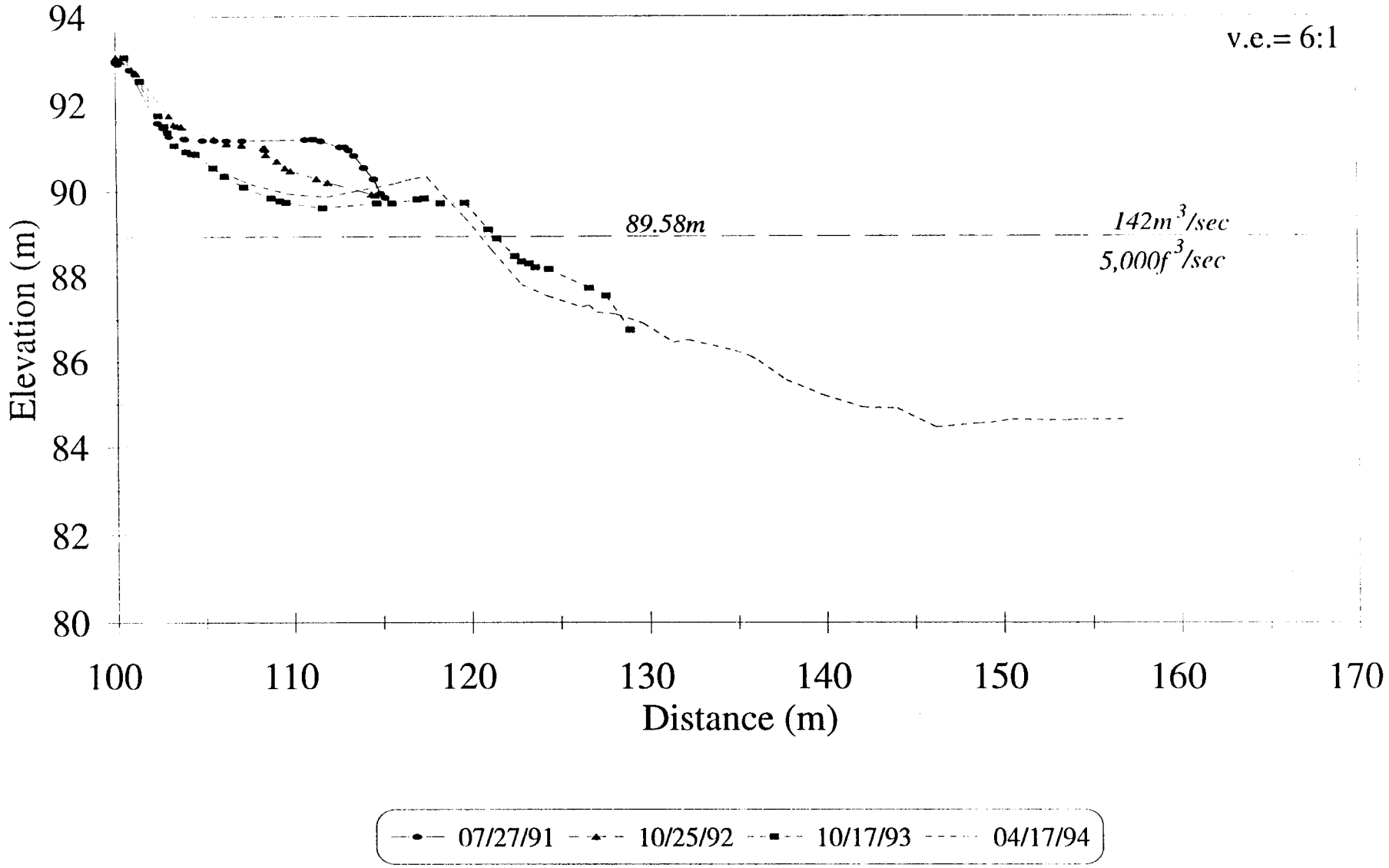
Cross-channel P4

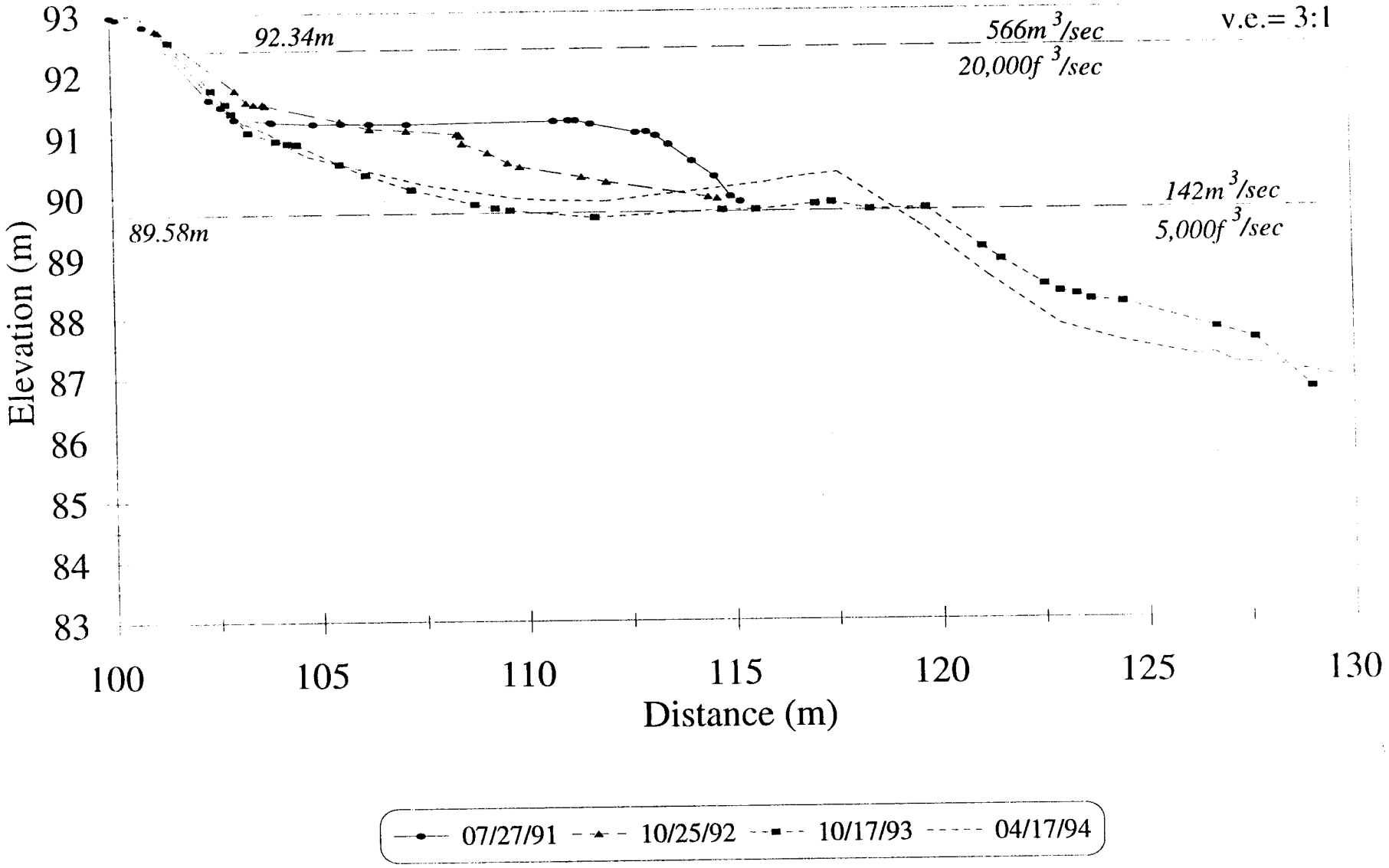



Near-shore P4
93
92
91
90
89
88
87
86
85
84
83
Elevation (m)
92.34m
89.58m
566m 3/sec
20,000f 3/sec
142m 3/sec
5,000f 3/sec
v.e.= 3:1
100
105
110
115
120
125
130
Distance (m)
07/27/91
10/25/92
10/17/93
04/17/94

104 Mile

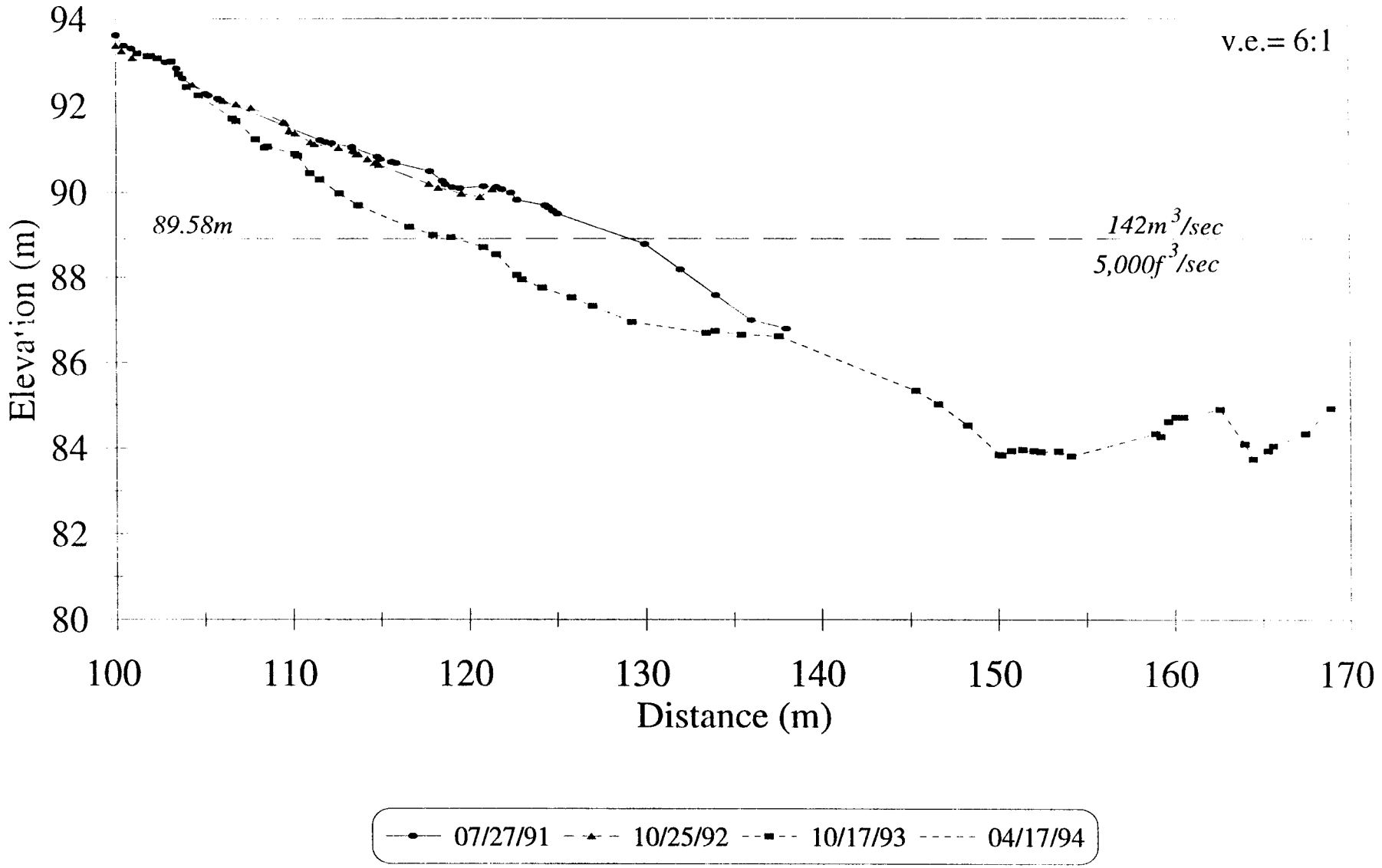
Cross-channel P5

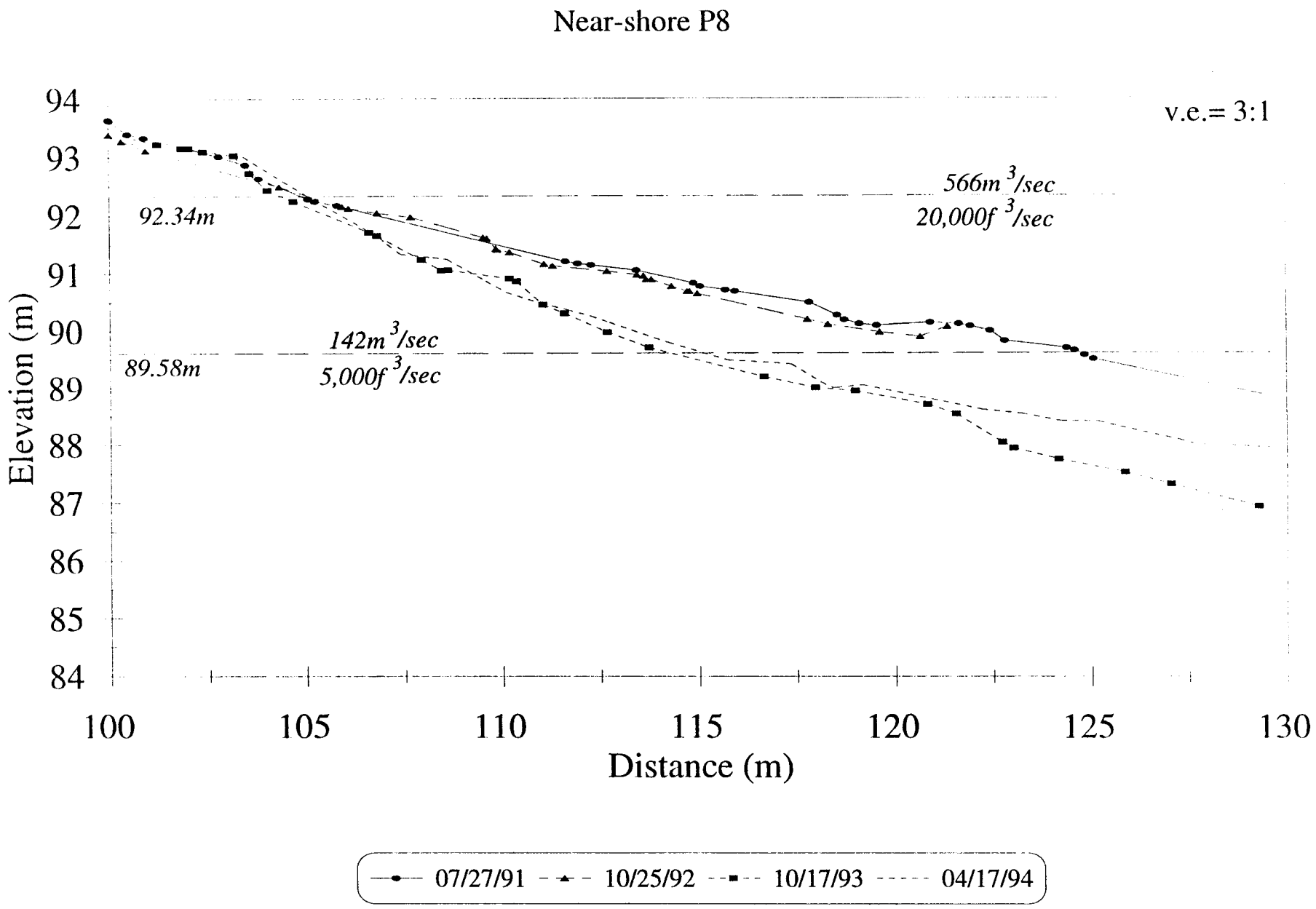



Near-shore P5
v.e.= 3:1
92.34m
566m 3/sec
20,000f 3/sec
142m 3/sec
5,000f 3/sec
89.58m
Elevation (m)
93
92
91
90
89
88
87
86
85
84
83
100
105
110
115
120
125
130
Distance (m)
07/27/91
10/25/92
10/17/93
04/17/94

104 Mile

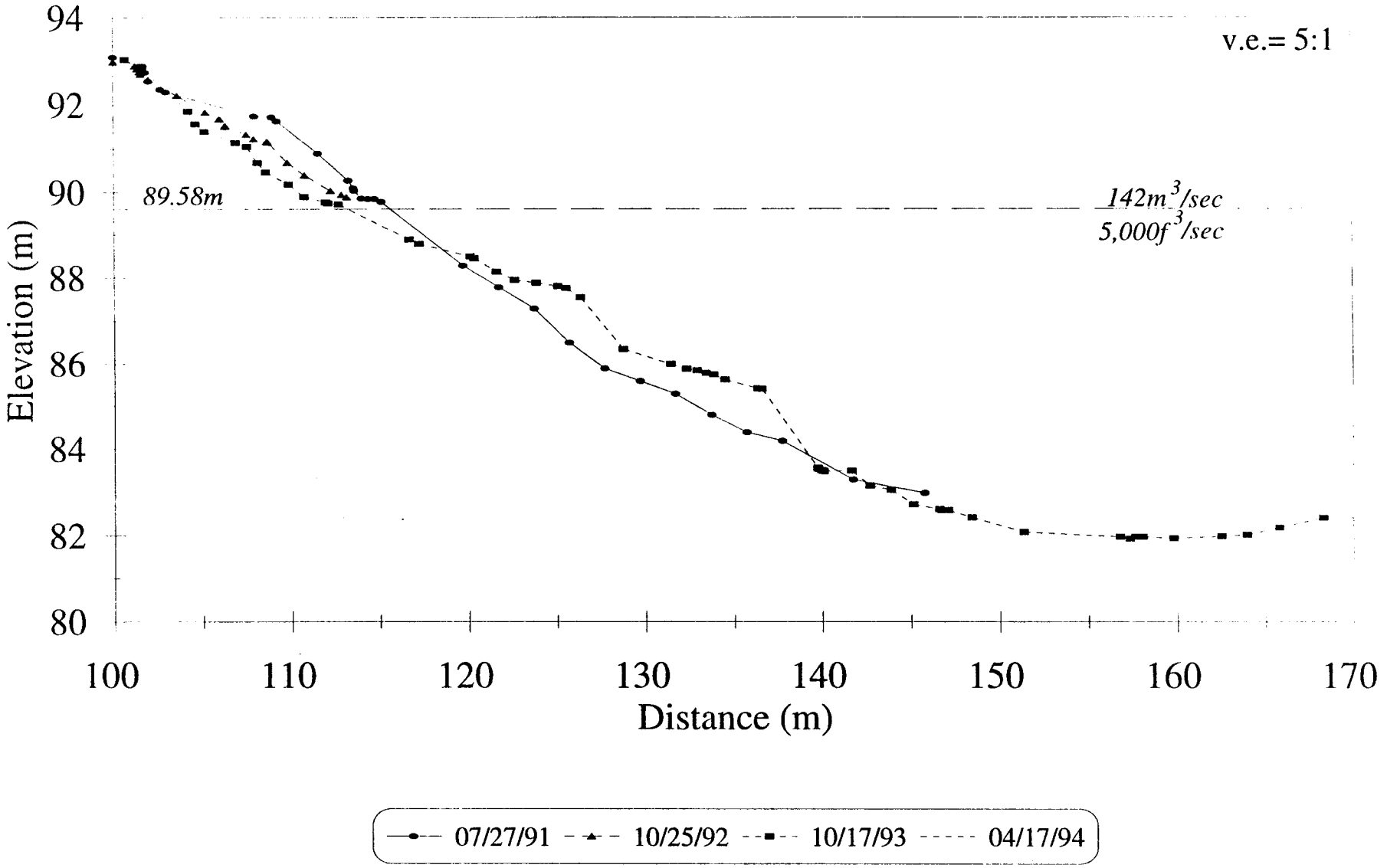
Cross-channel P8

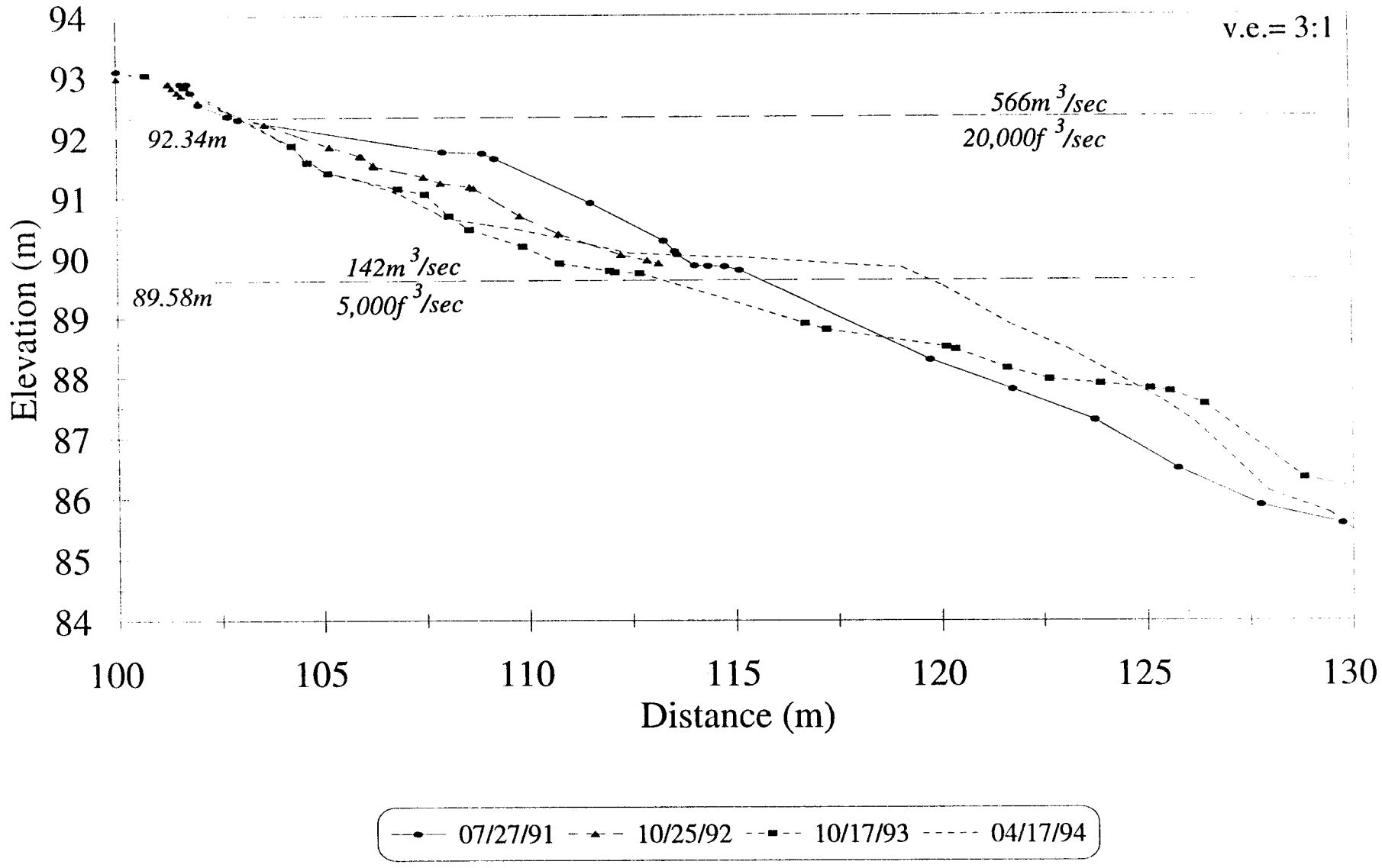



Near-shore P8
v.e.= 3:1
566m 3/sec
20,000f 3/sec
92.34m
142m 3/sec
5,000f 3/sec
89.58m
Elevation (m)
94
93
92
91
90
89
88
87
86
85
84
100
105
110
115
120
125
130
Distance (m)
07/27/91
10/25/92
10/17/93
04/17/94

104 Mile

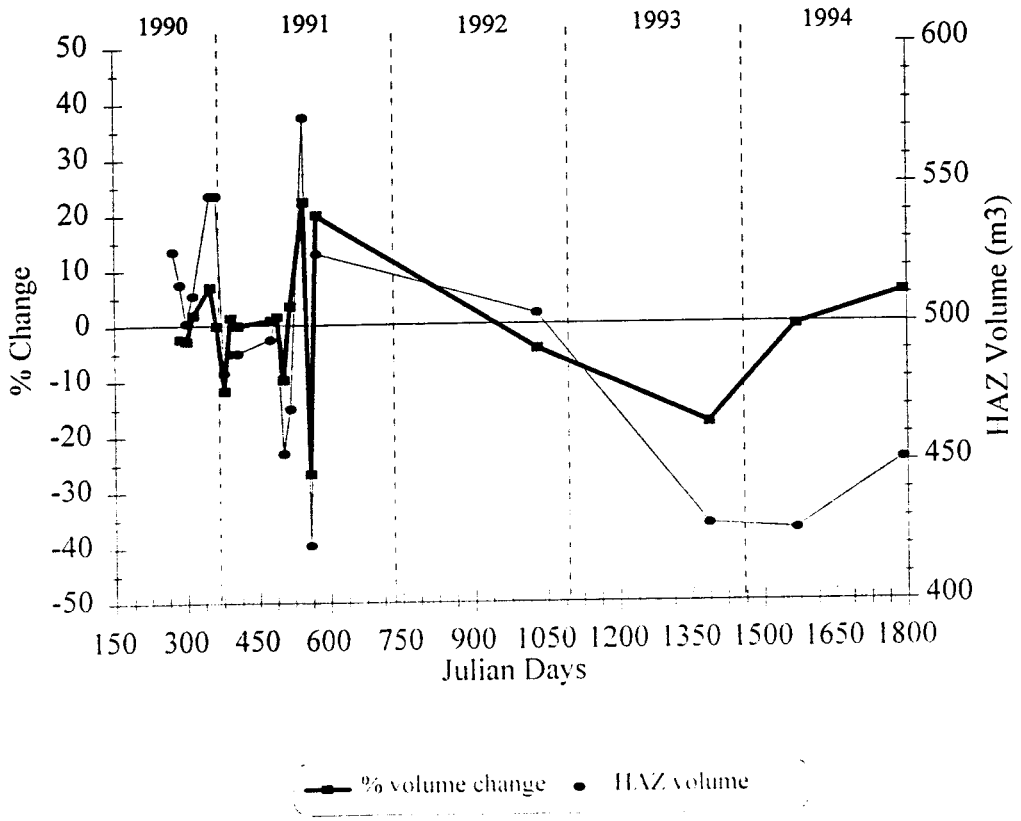
Cross-channel P9




Near-shore P9
v.e.= 3:1
566m 3/sec
20,000f 3/sec
92.34m
142m 3/sec
5,000f 3/sec
89.58m
Elevation (m)
94
93
92
91
90
89
88
87
86
85
84
100
105
110
115
120
125
130
Distance (m)
07/27/91
10/25/92
10/17/93
04/17/94

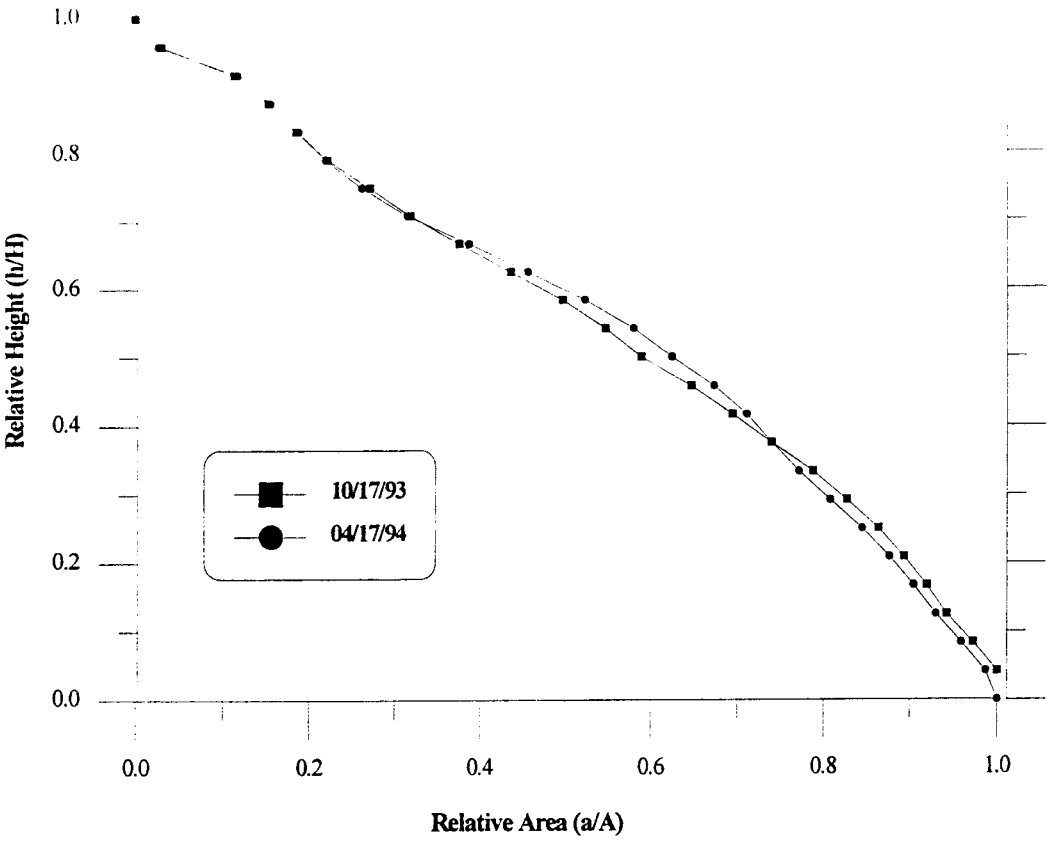
104 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F		NORM							
G	900929	E	272	324	527				
H	901013	A	286	330	515	6	-12	1.85	-2.28
I	901027	8000 CFS	300	330	501	0	-14	0.00	-2.72
J	901110	NORM	314	326	511	-4	10	-1.21	2.00
K	901215	NORM	349	333	547	7	36	2.15	7.05
L	901229	11000 CFS	363	358	547	25	0	7.51	0.00
M	910113	C	378	308	483	-50	-64	-13.97	-11.70
N	910126	NORM	391	335	490	27	7	8.77	1.45
O	910209	B	405	333	490	-2	0	-0.60	0.00
P	910420	NORM	475	319	495	-14	5	-4.20	1.02
Q	910504	NORM	489	315	503	-4	8	-1.25	1.62
R	910518	D	503	288	454	-27	-49	-8.57	-9.74
S	910601	15000 CFS	517	315	470	27	16	9.38	3.52
T	910629	NORM	545	364	575	49	105	15.56	22.34
U	910713	G	559	278	421	-86	-154	-23.63	-26.78
V	910727	F	573	364	526	86	105	30.94	19.96
Y	921025	INT	1029	360	504	-4	-22	-1.10	-4.37
B20	931017	INT	1386	289	428	-71	-76	-19.72	-17.76
C20	940417	INT	1568	311	426	22	-2	7.61	-0.47
D20	941127	INT	1792	312	451	1	25	0.32	5.54

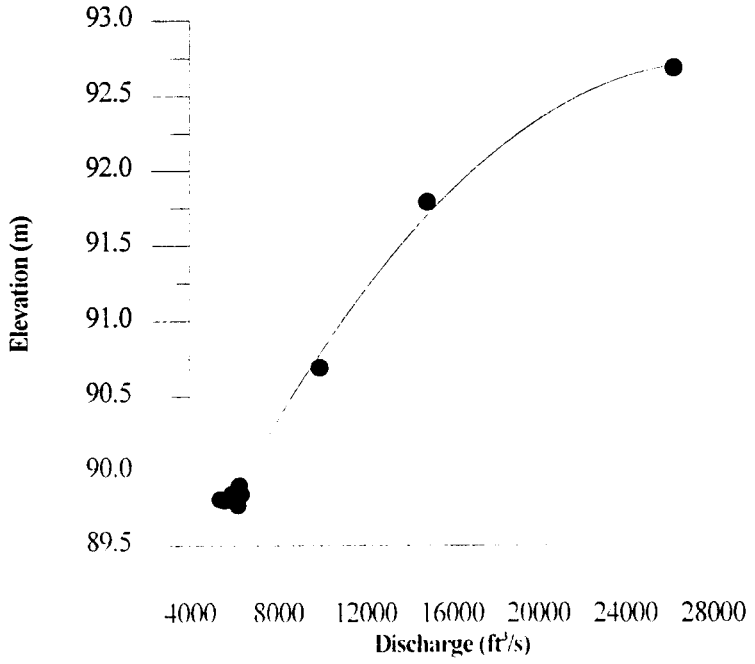


104 Mile

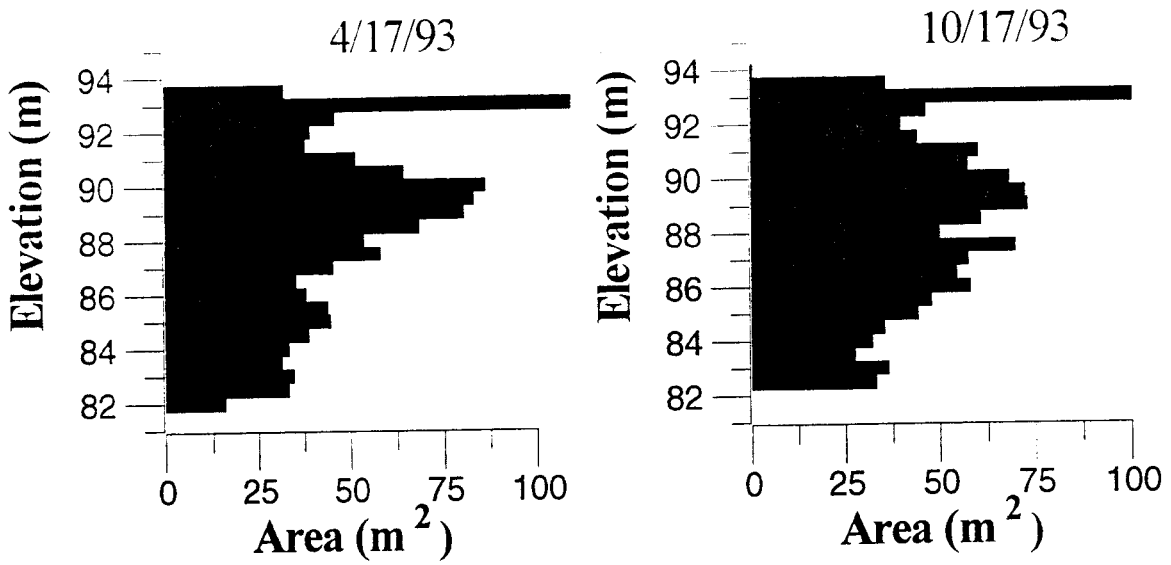
Hypsometric Curves

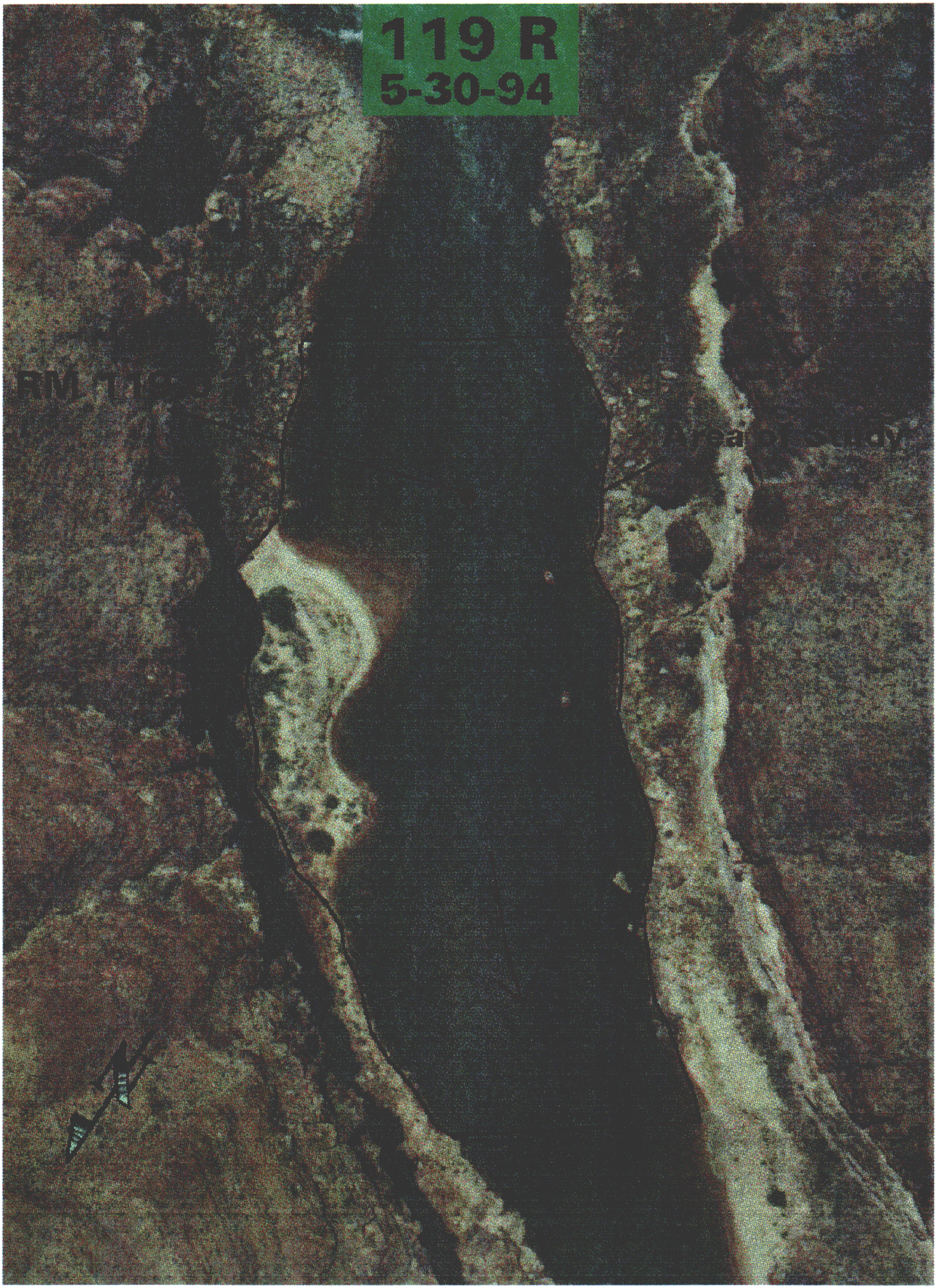


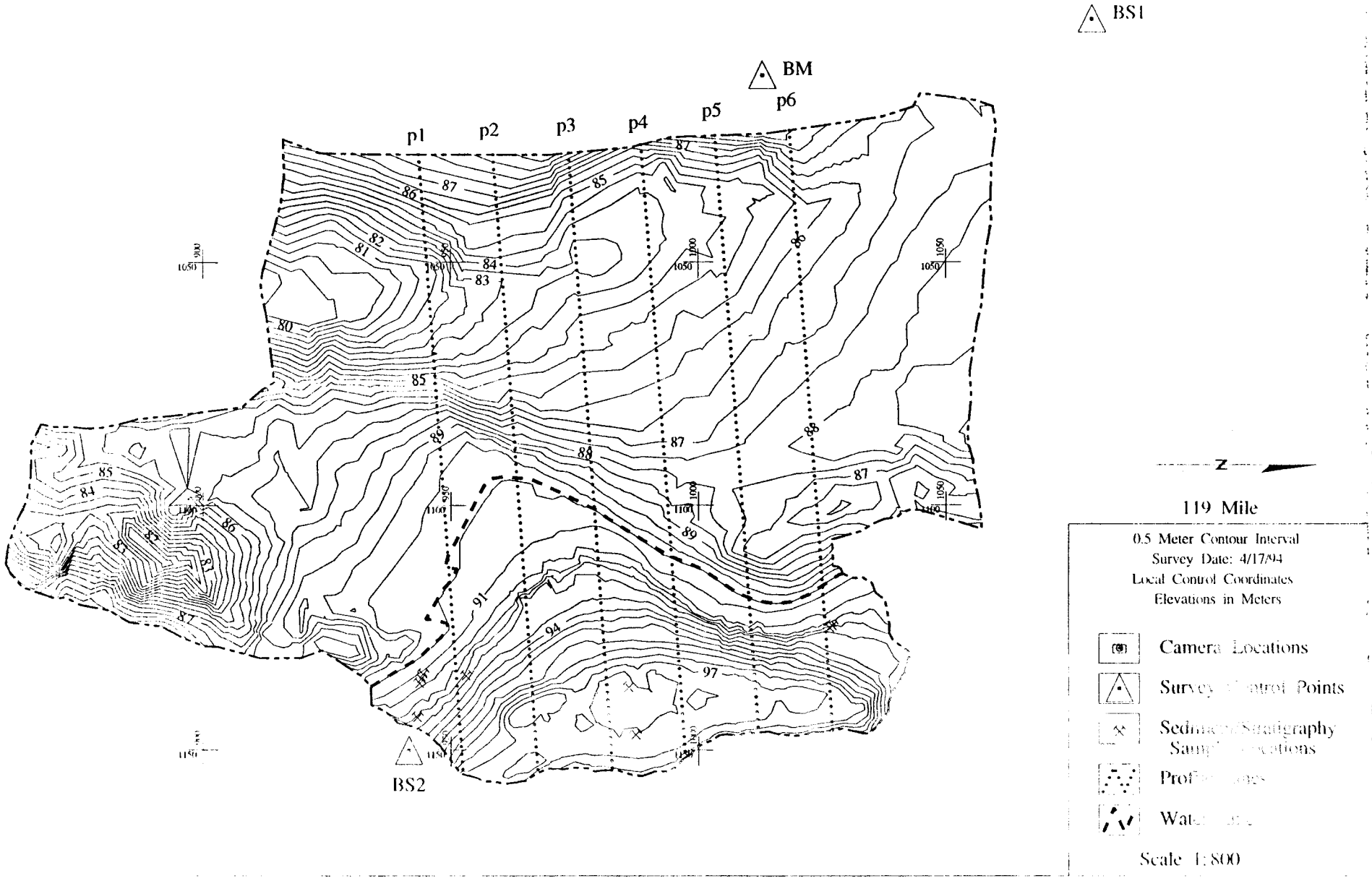
Stage Discharge



104 MILE
Area Distribution Histograms

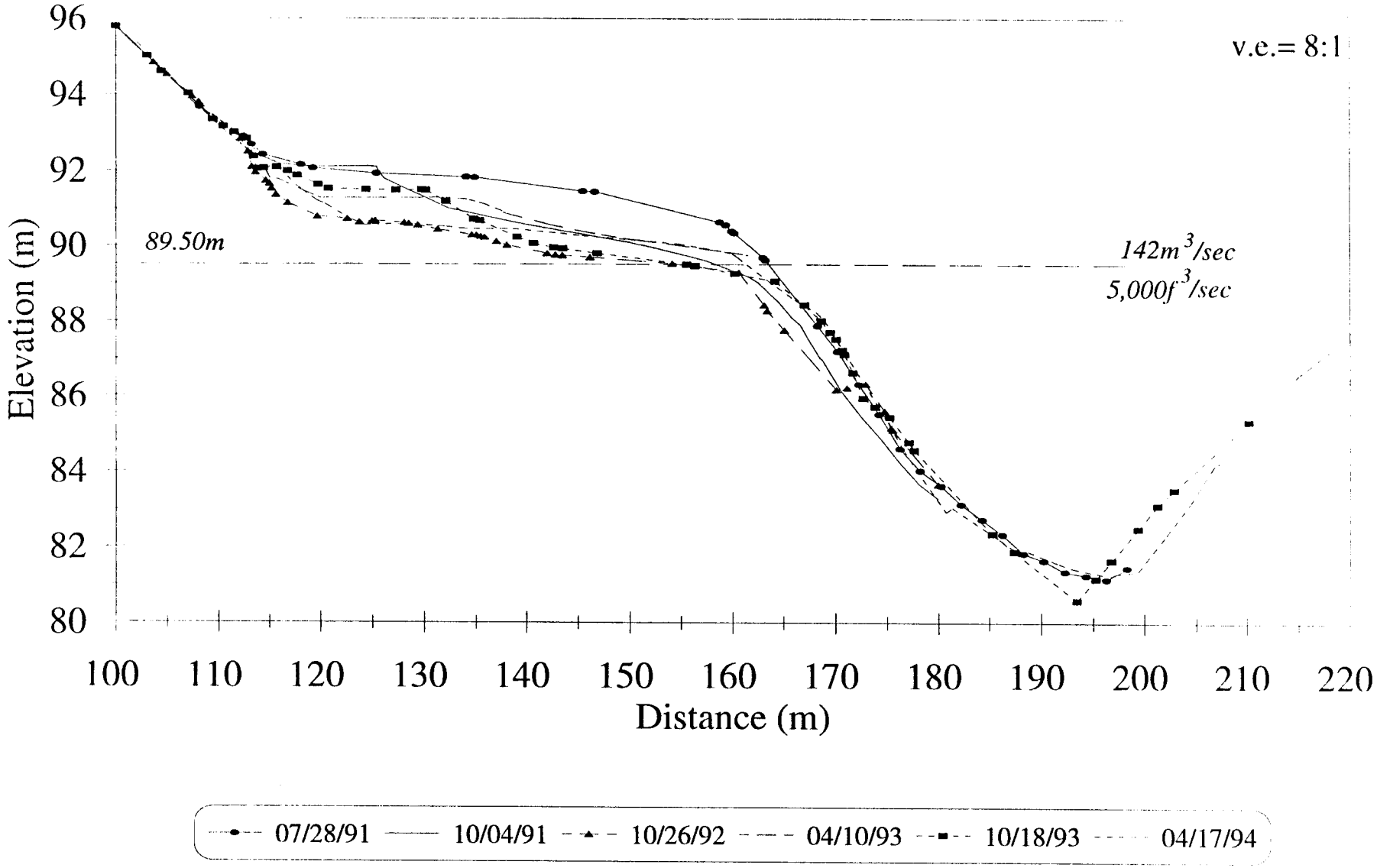


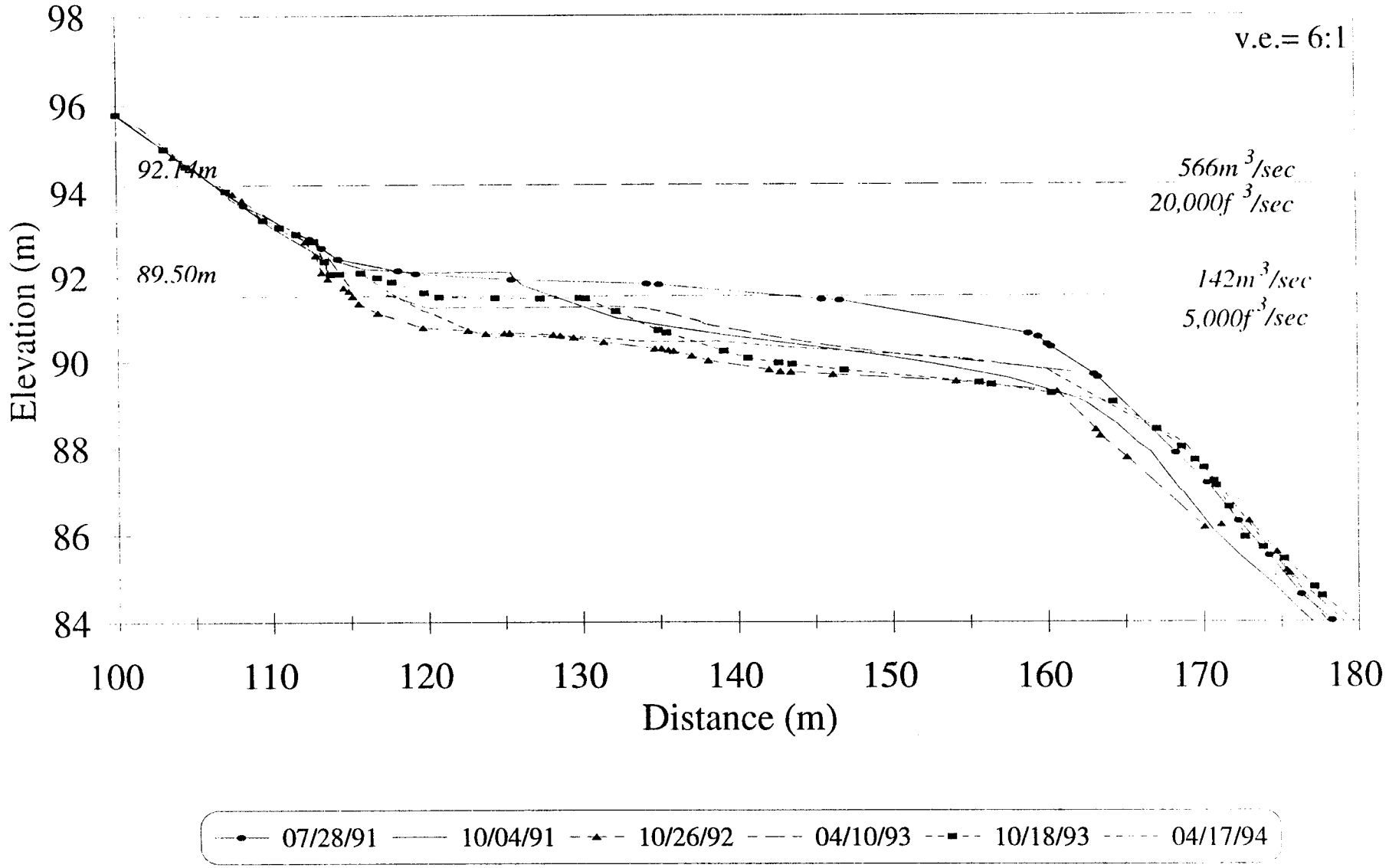

119 R
5-30-94


BS1
BM
p6
p5
p4
p3
p2
p1
BS2
N
119 Mile
0.5 Meter Contour Interval
Survey Date: 4/17/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Scale 1:800

119 Mile

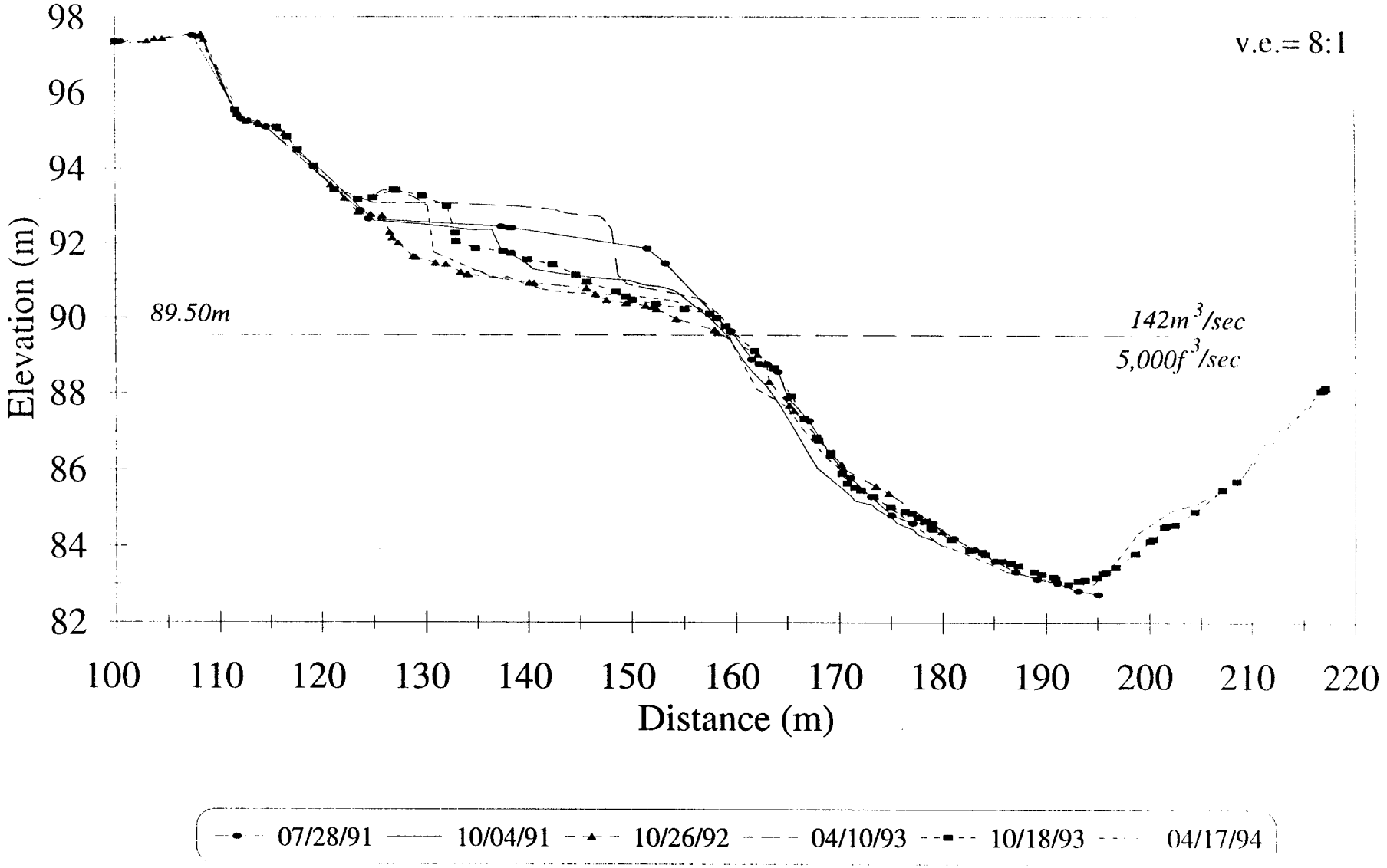
Cross-channel P1



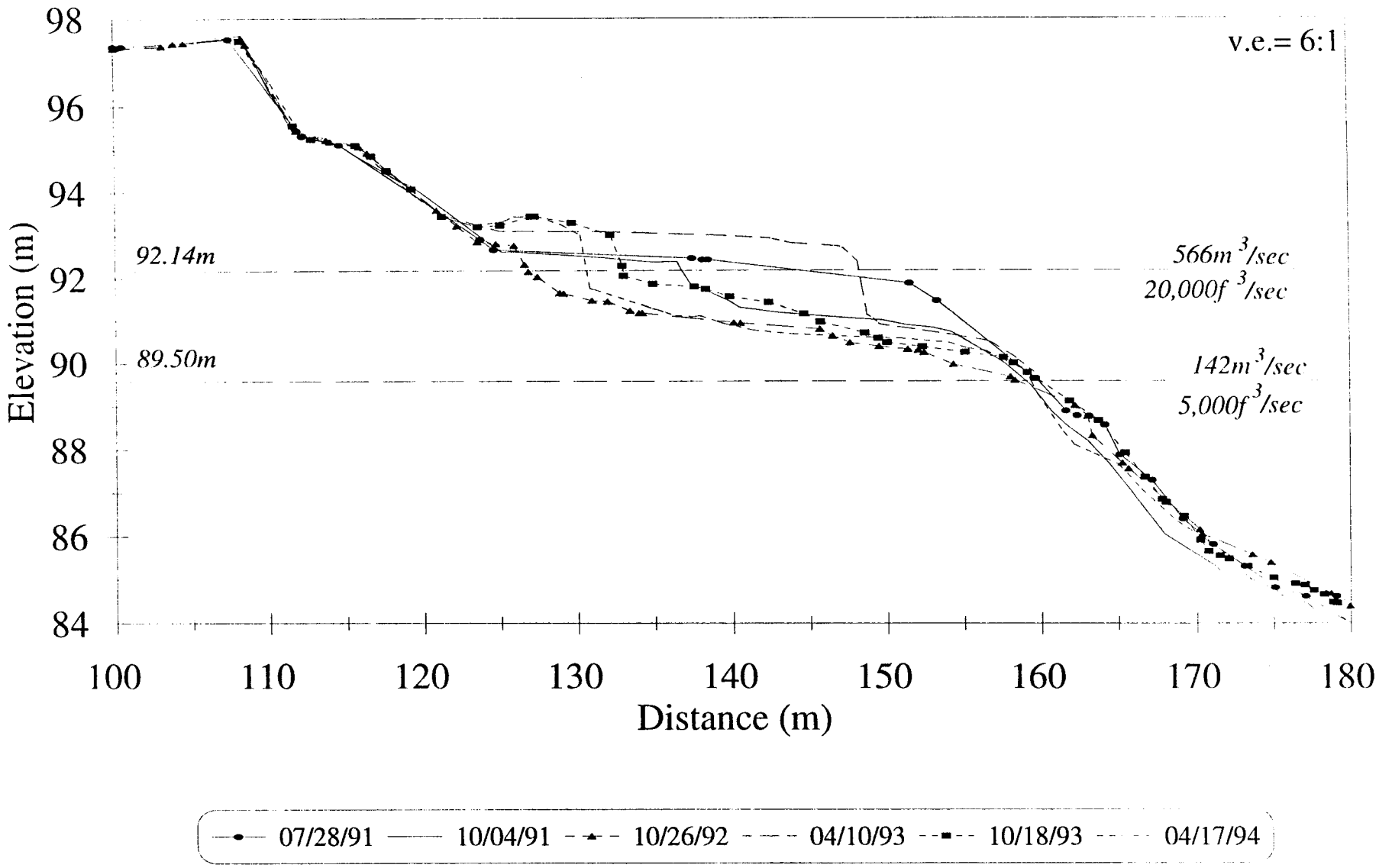

Near-shore P1
v.e.= 6:1
92.14m
89.50m
566m 3/sec
20,000f 3/sec
142m 3/sec
5,000f 3/sec
Elevation (m)
98
96
94
92
90
88
86
84
100
110
120
130
140
150
160
170
180
Distance (m)
07/28/91
10/04/91
10/26/92
04/10/93
10/18/93
04/17/94

119 Mile

Cross-channel P2

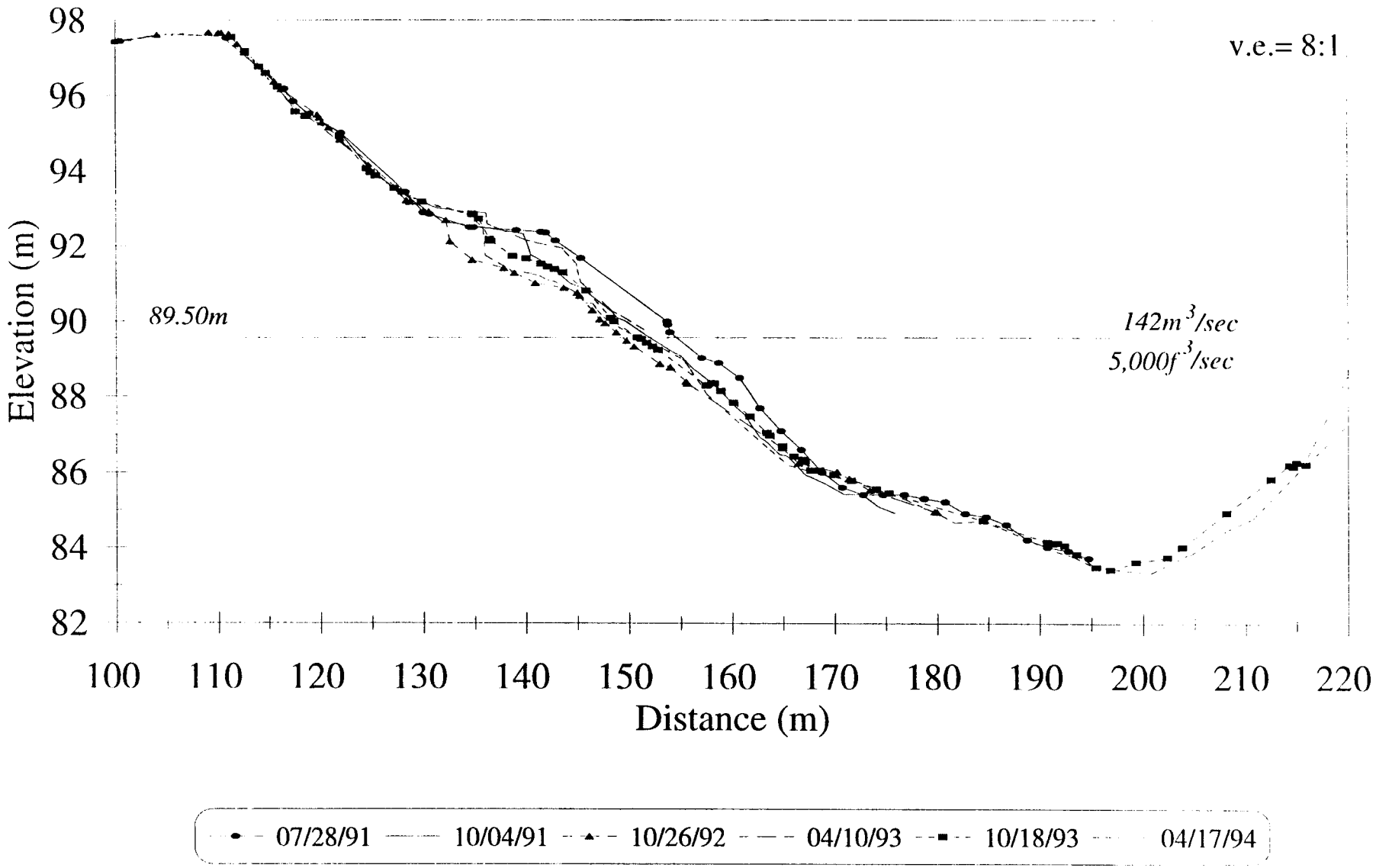


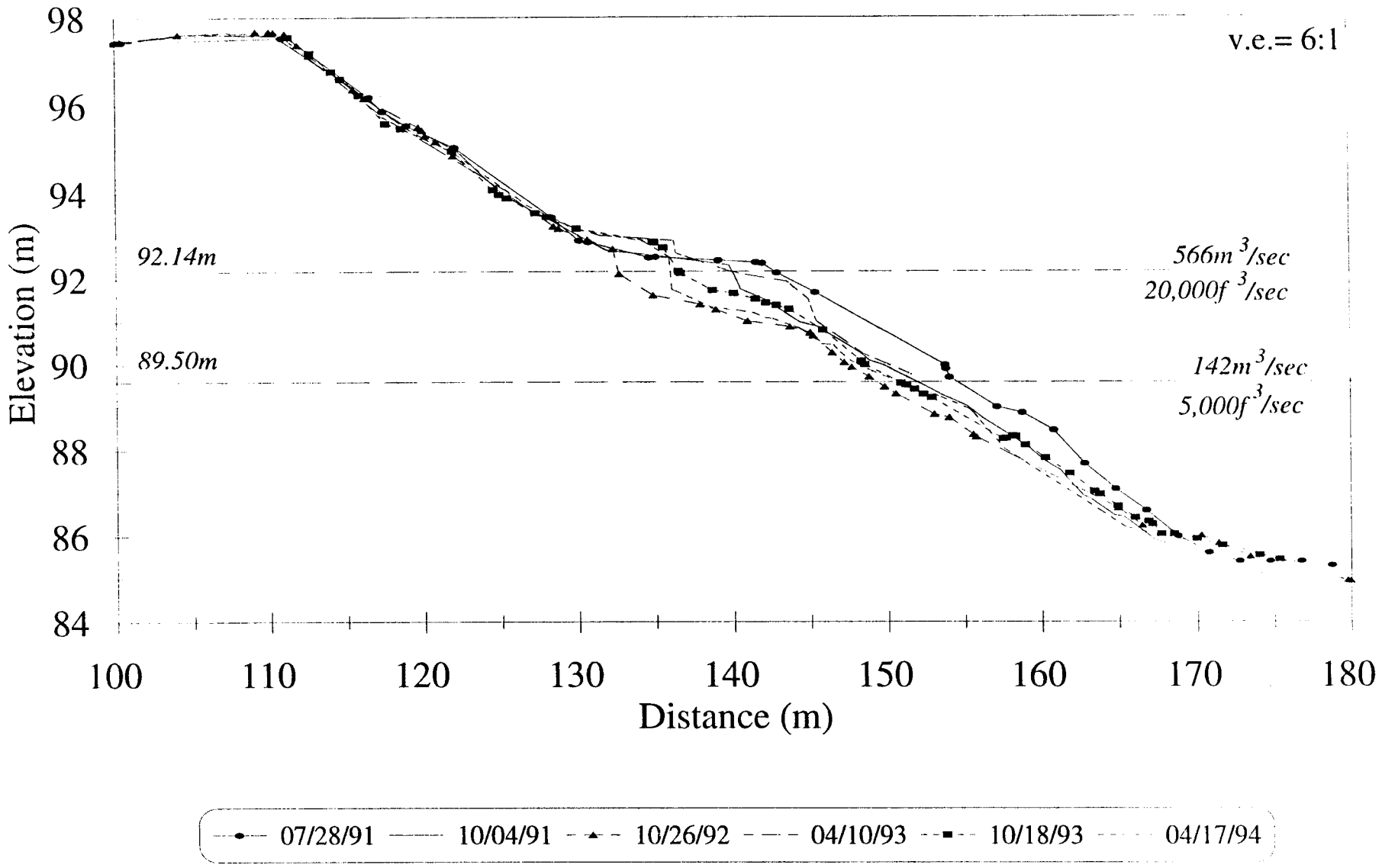
Near-shore P2



119 Mile

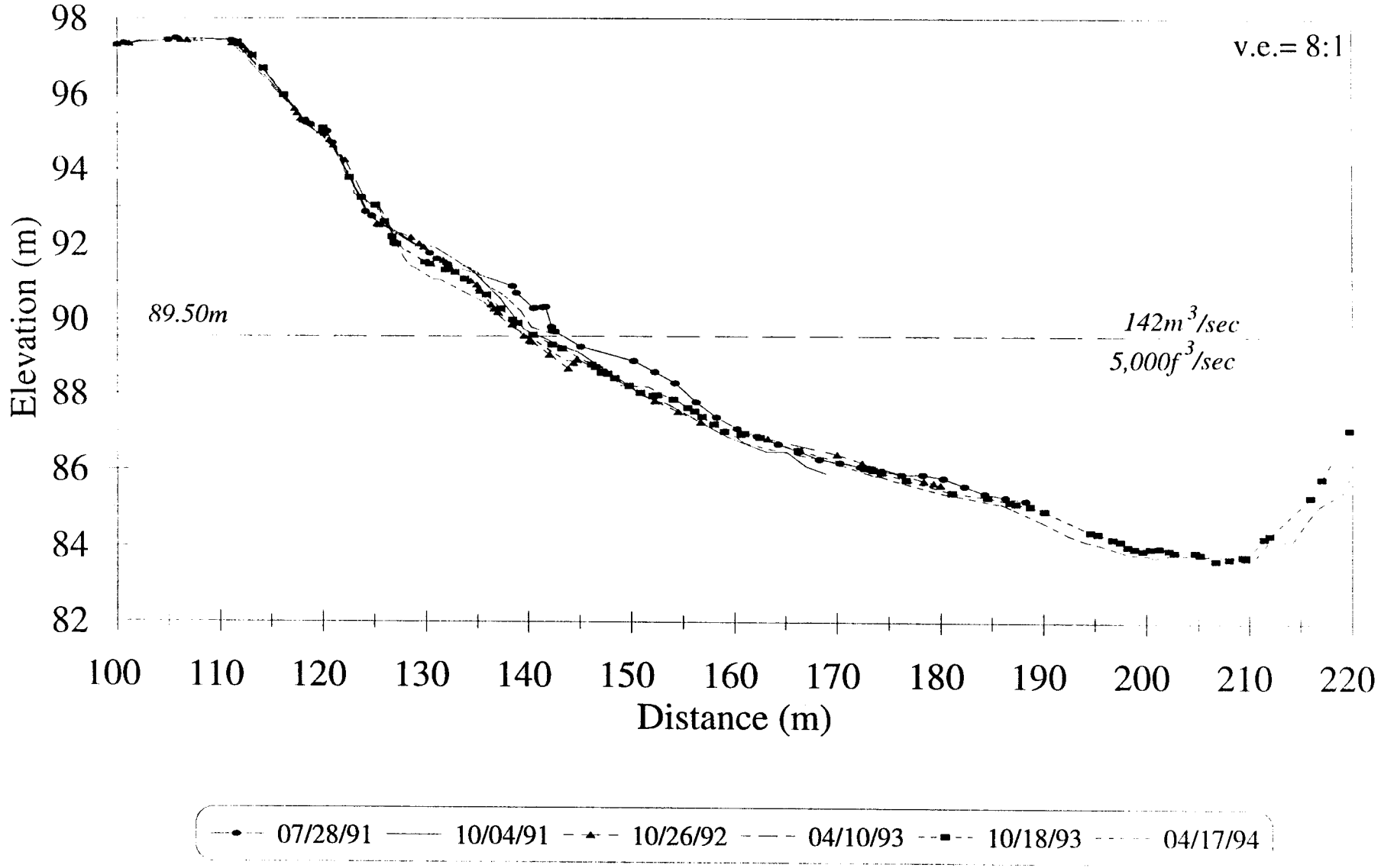
Cross-channel P3



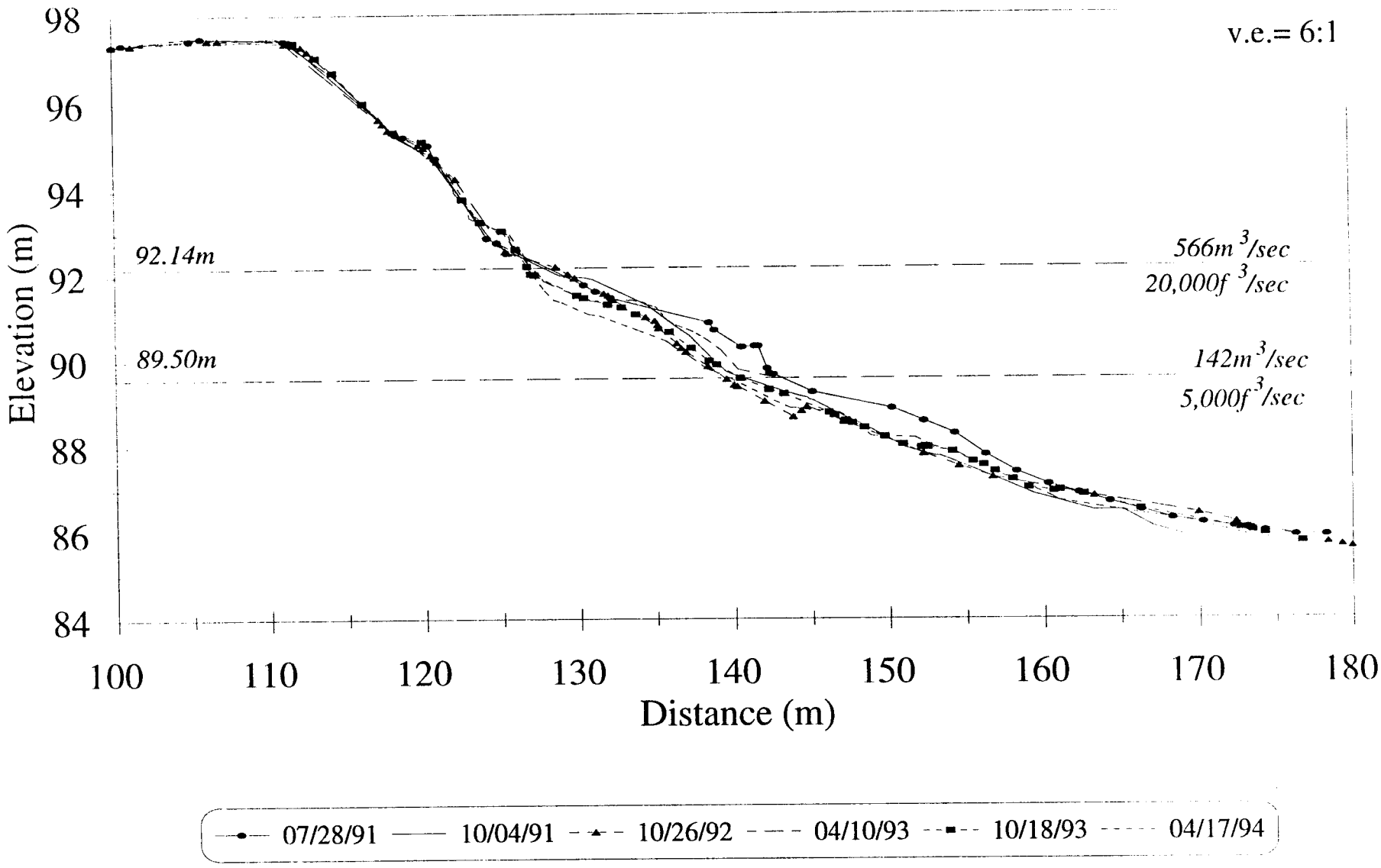

Near-shore P3
v.e.= 6:1
Elevation (m)
98
96
94
92
90
88
86
84
92.14m
89.50m
566m 3/sec
20,000f 3/sec
142m 3/sec
5,000f 3/sec
100
110
120
130
140
150
160
170
180
Distance (m)
07/28/91
10/04/91
10/26/92
04/10/93
10/18/93
04/17/94

119 Mile

Cross-channel P4

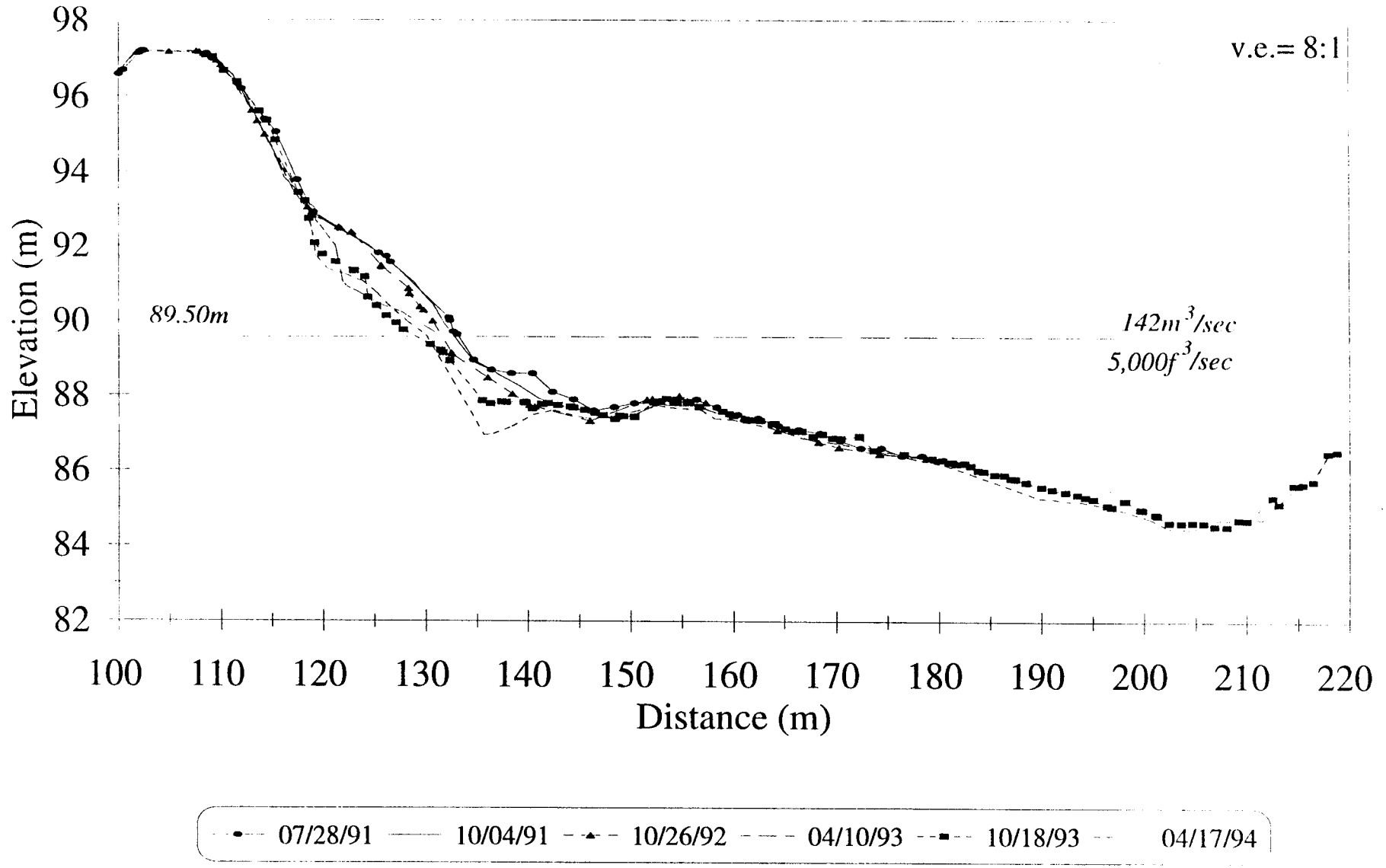


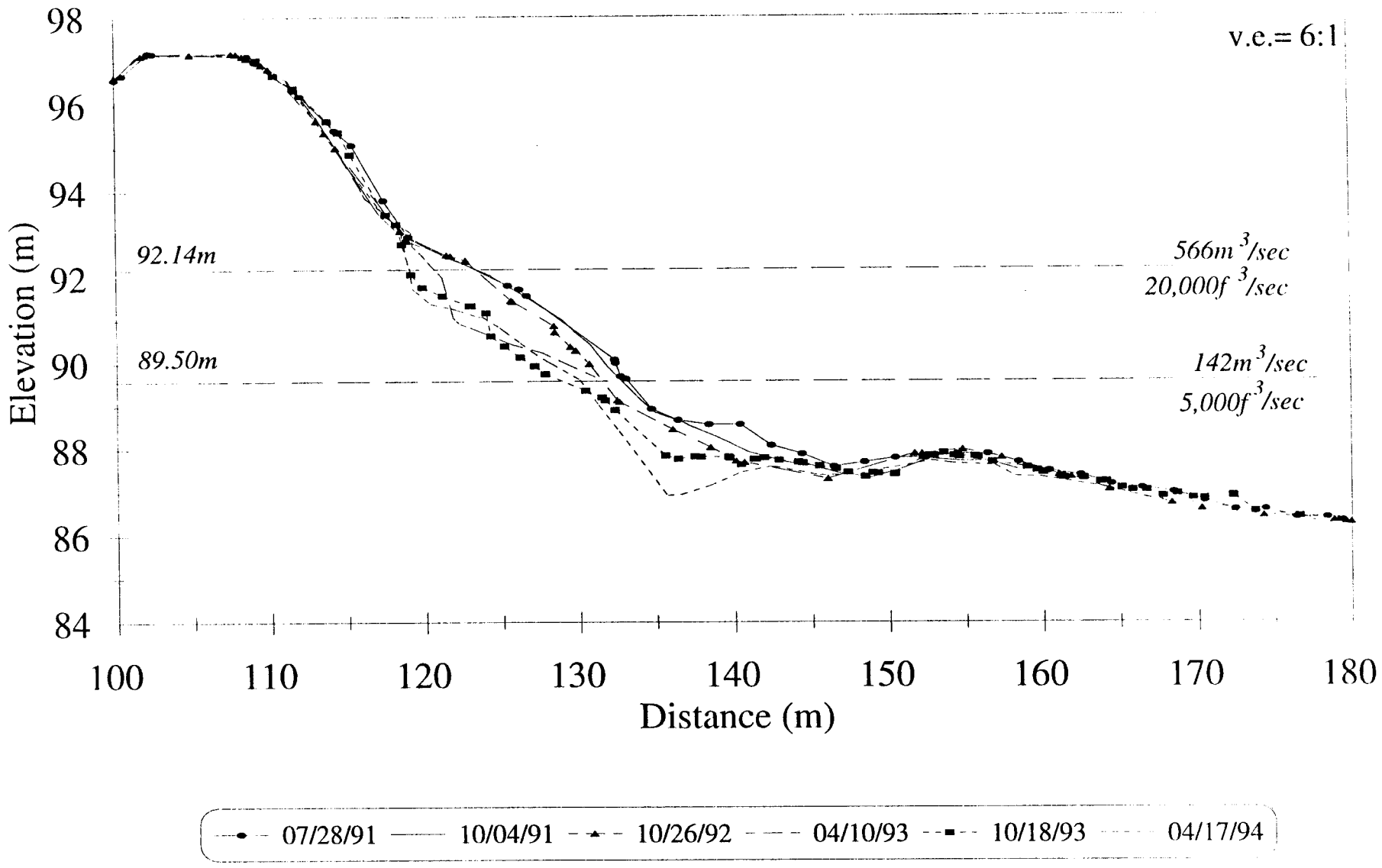
Near-shore P4



119 Mile

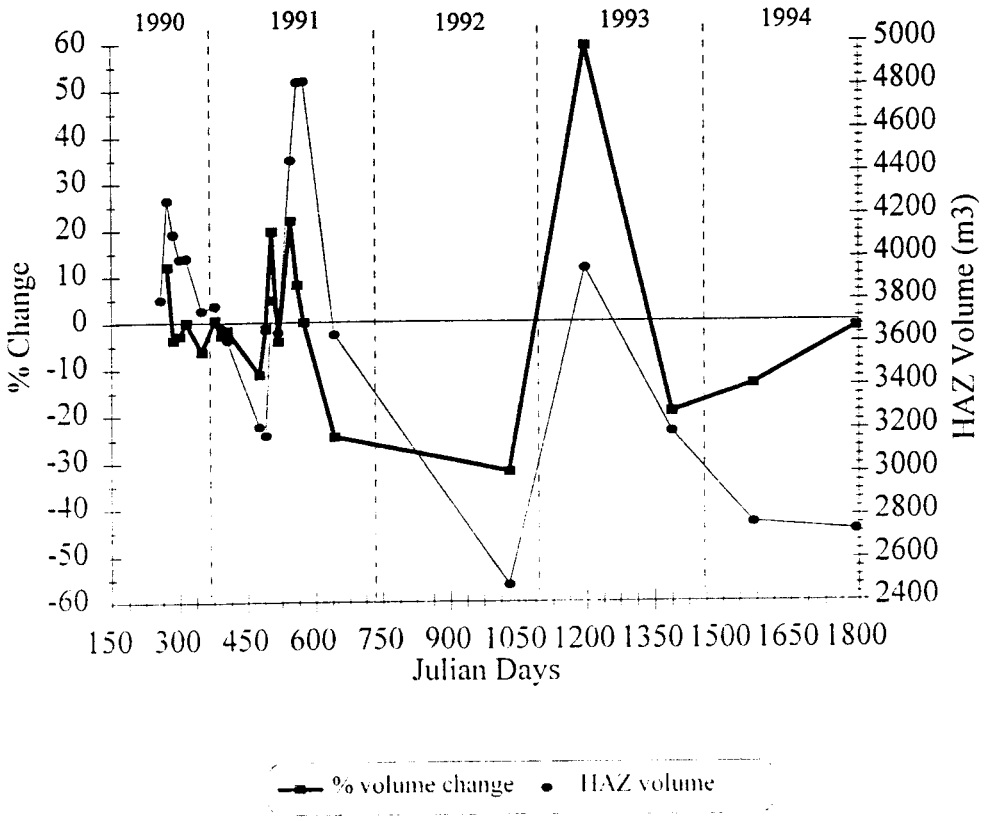
Cross-channel P5




Near-shore P5
v.e.= 6:1
Elevation (m)
98
96
94
92
90
88
86
84
92.14m
89.50m
566m 3/sec
20,000f 3/sec
142m 3/sec
5,000f 3/sec
100
110
120
130
140
150
160
170
180
Distance (m)
07/28/91
10/04/91
10/26/92
04/10/93
10/18/93
04/17/94

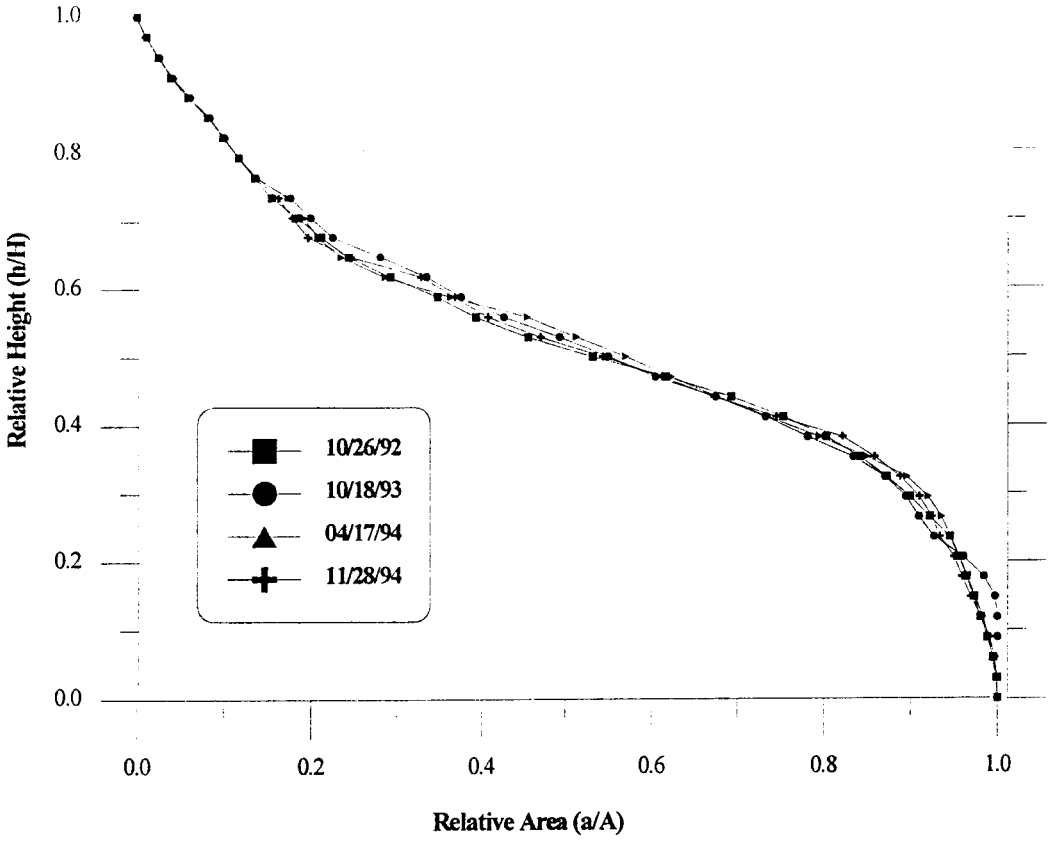
119 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D	900729	F							
E		NORM							
F	900916	NORM	259	2586	3809				
G	900930	E	273	2725	4273	139	464	5.38	12.18
H	901014	A	287	2556	4116	-169	-157	-6.20	-3.67
I	901028	8000 CFS	301	2454	4000	-102	-116	-3.99	-2.82
J	901111	NORM	315	2352	4005	-102	5	-4.16	0.13
K	901216	NORM	350	2260	3757	-92	-248	-3.91	-6.19
L		11000 CFS							
M	910113	C	378	2326	3780	66	23	2.92	0.61
N	910127	NORM	392	2252	3677	-74	-103	-3.18	-2.72
O	910210	B	406	2205	3619	-47	-58	-2.09	-1.58
P	910421	NORM	476	2093	3219	-112	-400	-5.08	-11.05
Q	910505	NORM	490	2036	3180	-57	-39	-2.72	-1.21
R	910519	D	504	2465	3807	429	627	21.07	19.72
S	910602	15000 CFS	518	2312	3655	-153	-152	-6.21	-3.99
T	910630	NORM	546	2709	4459	397	804	17.17	22.00
U	910714	G	560	2814	4822	105	363	3.88	8.14
V	910728	F	574	2792	4825	-22	3	-0.78	0.06
W	911004	INT	642	2290	3645	-502	-1180	-17.98	-24.46
Y	921026	INT	1030	1724	2481	-566	-1164	-24.72	-31.93
Z	930410	INT	1196	2360	3952	636	1471	36.89	59.29
B21	931018	INT	1387	2011	3192	-349	-760	-14.79	-19.23
C21	940417	INT	1568	2252	2767	241	-425	11.98	-13.31
D21	941128	INT	1793	1884	2732	-368	-35	-16.34	-1.26

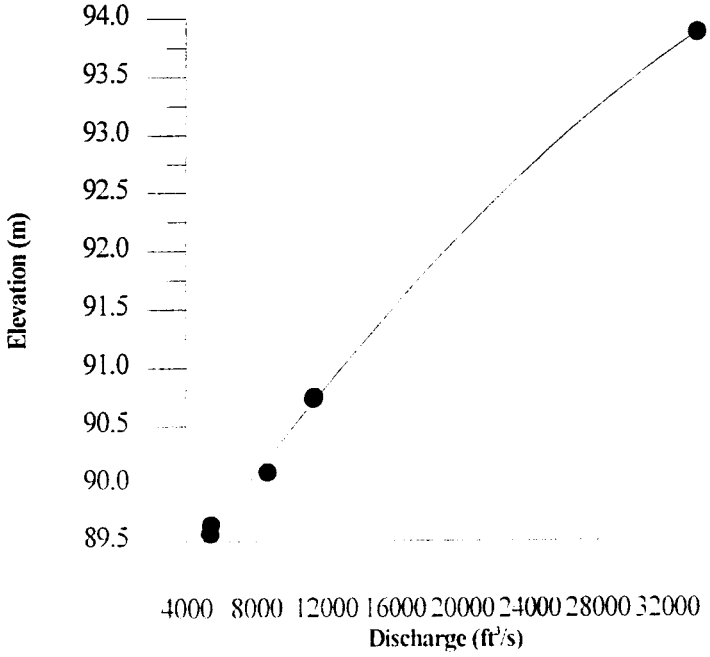


119 Mile

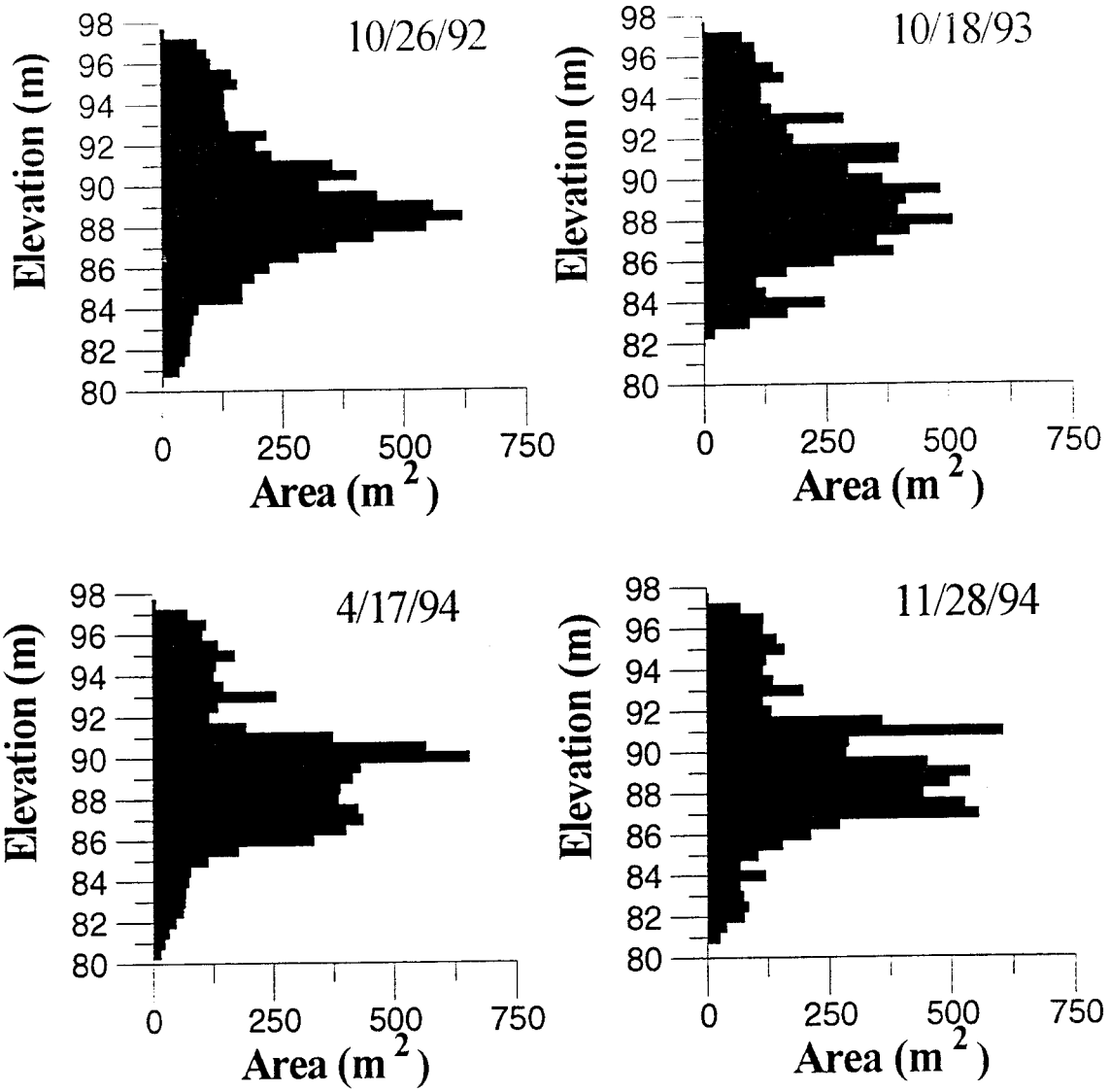
Hypsometric Curves



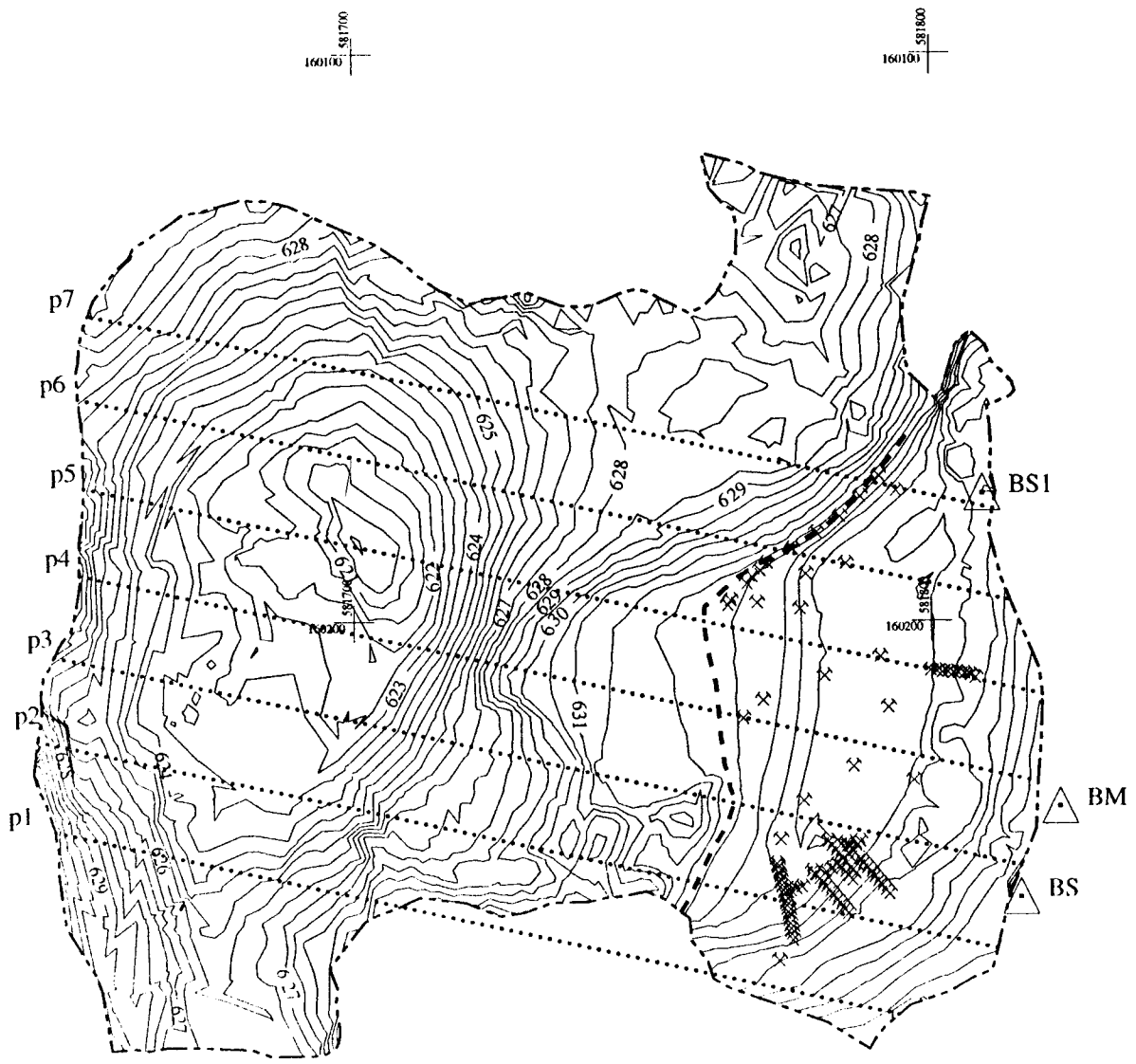
Stage Discharge



119 MILE
Area Distribution Curves



122 R
5-30-94
Area of Study
RM 122.0



N

122 Mile

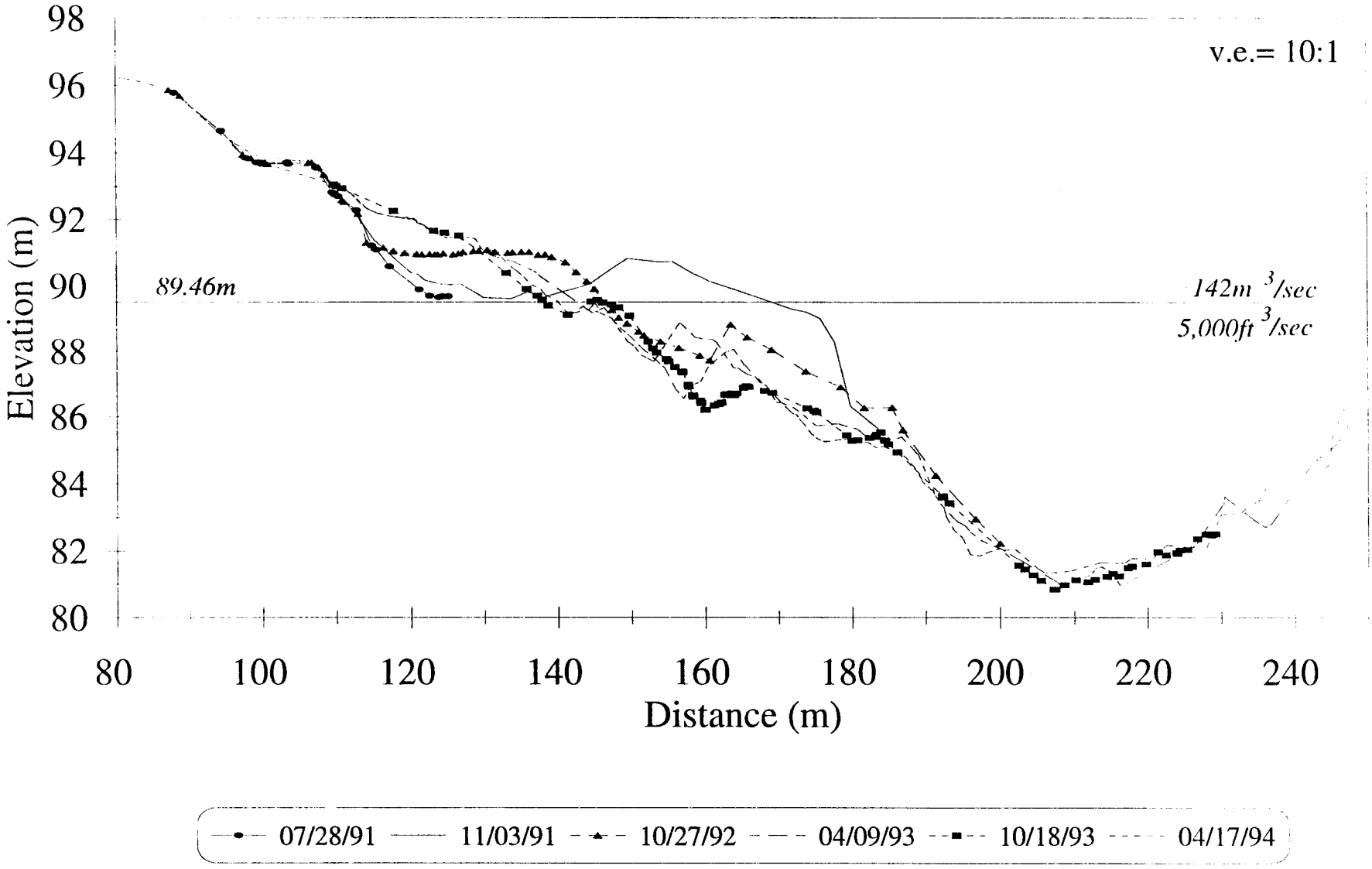
0.5 Meter Contour Interval
Survey Date: 4/17/94
AZ State Plane Coordinates
Elevations in Meters above Sea Level

- Camera Locations
- Survey Control Points
- Sediment/Stratigraphy Sample Locations
- Profile Lines
- Water Line

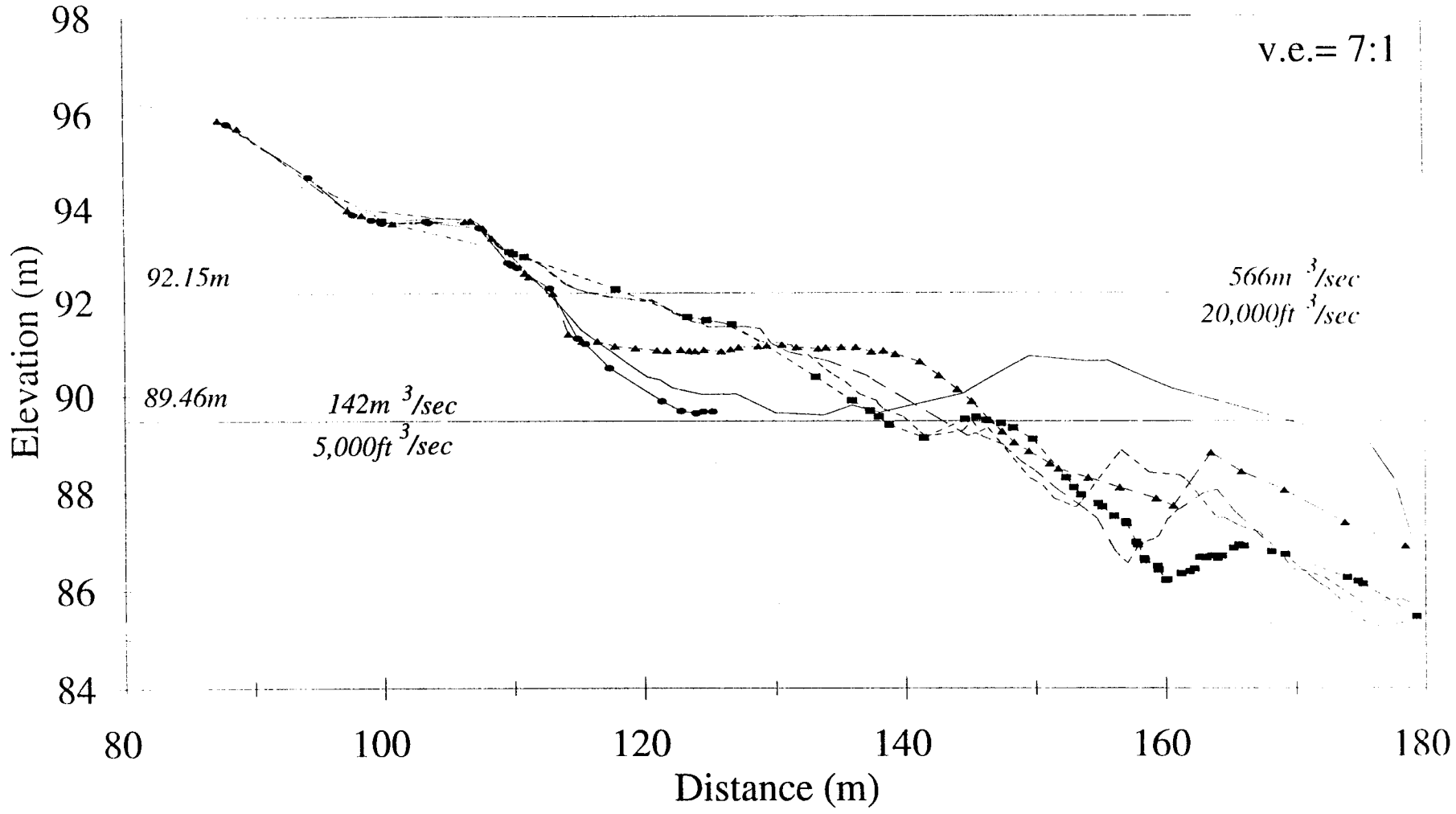
Scale 1:900

122 Mile

Cross-channel P2

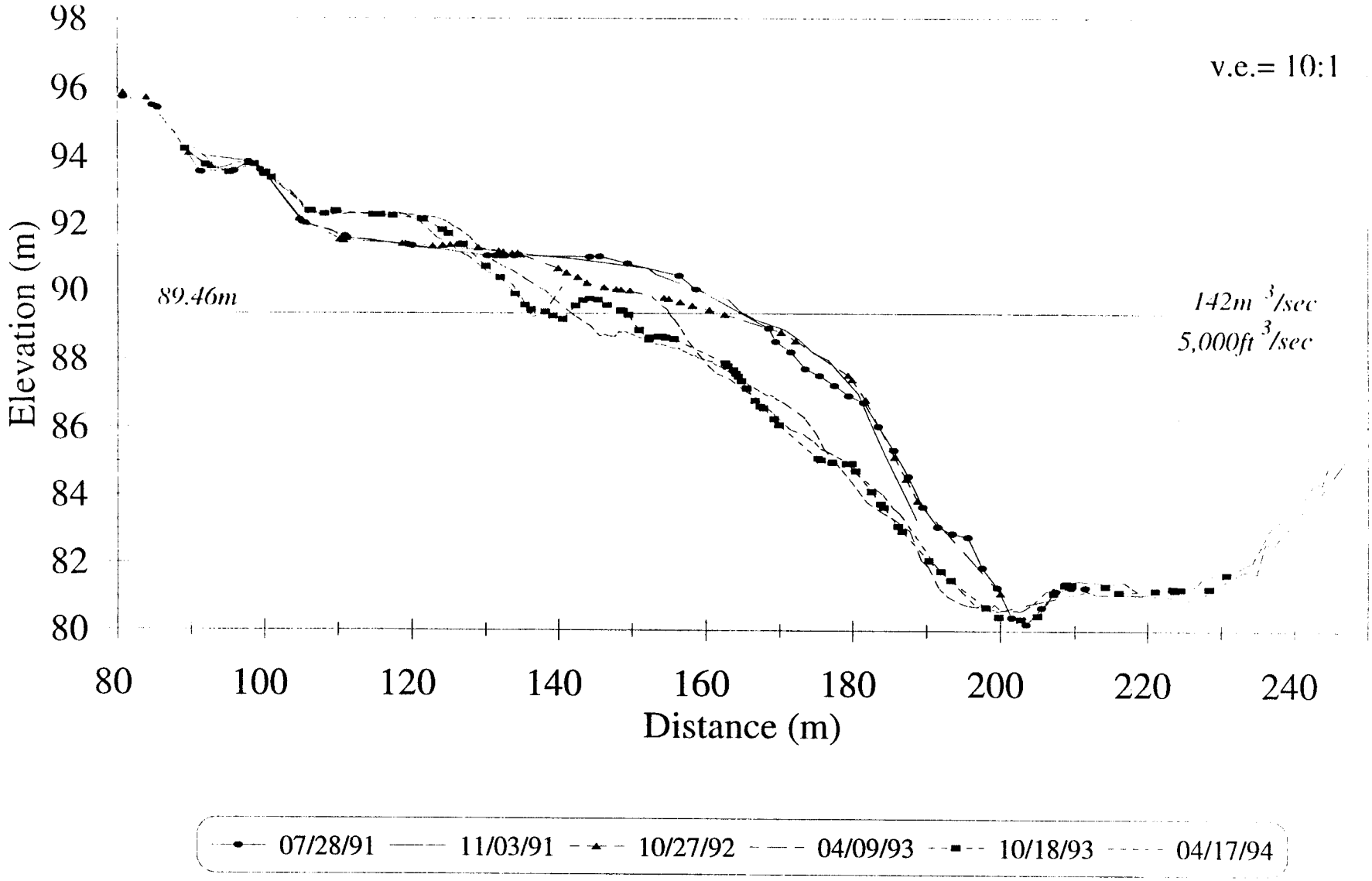


Near-shore P2

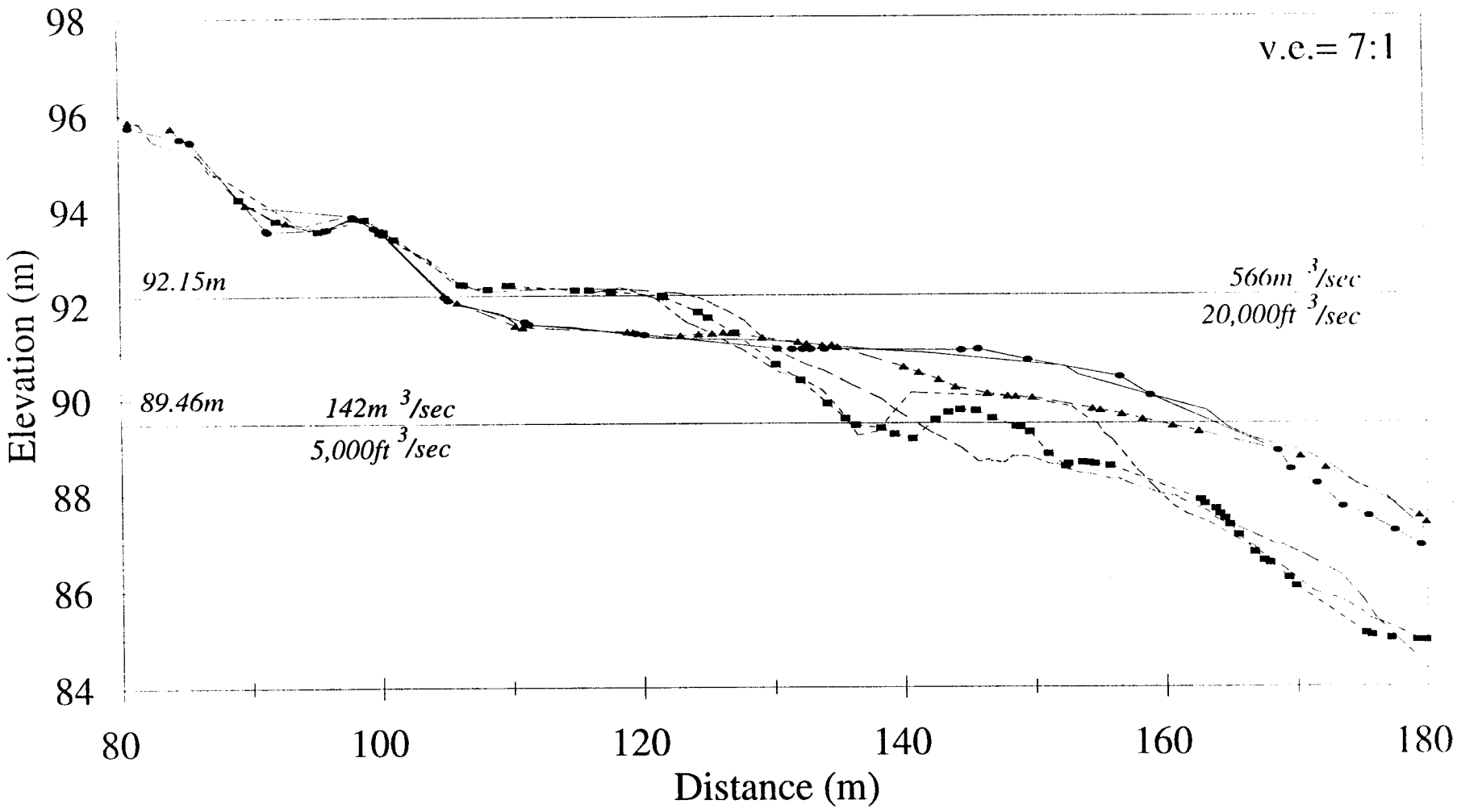


122 Mile

Cross-channel P3

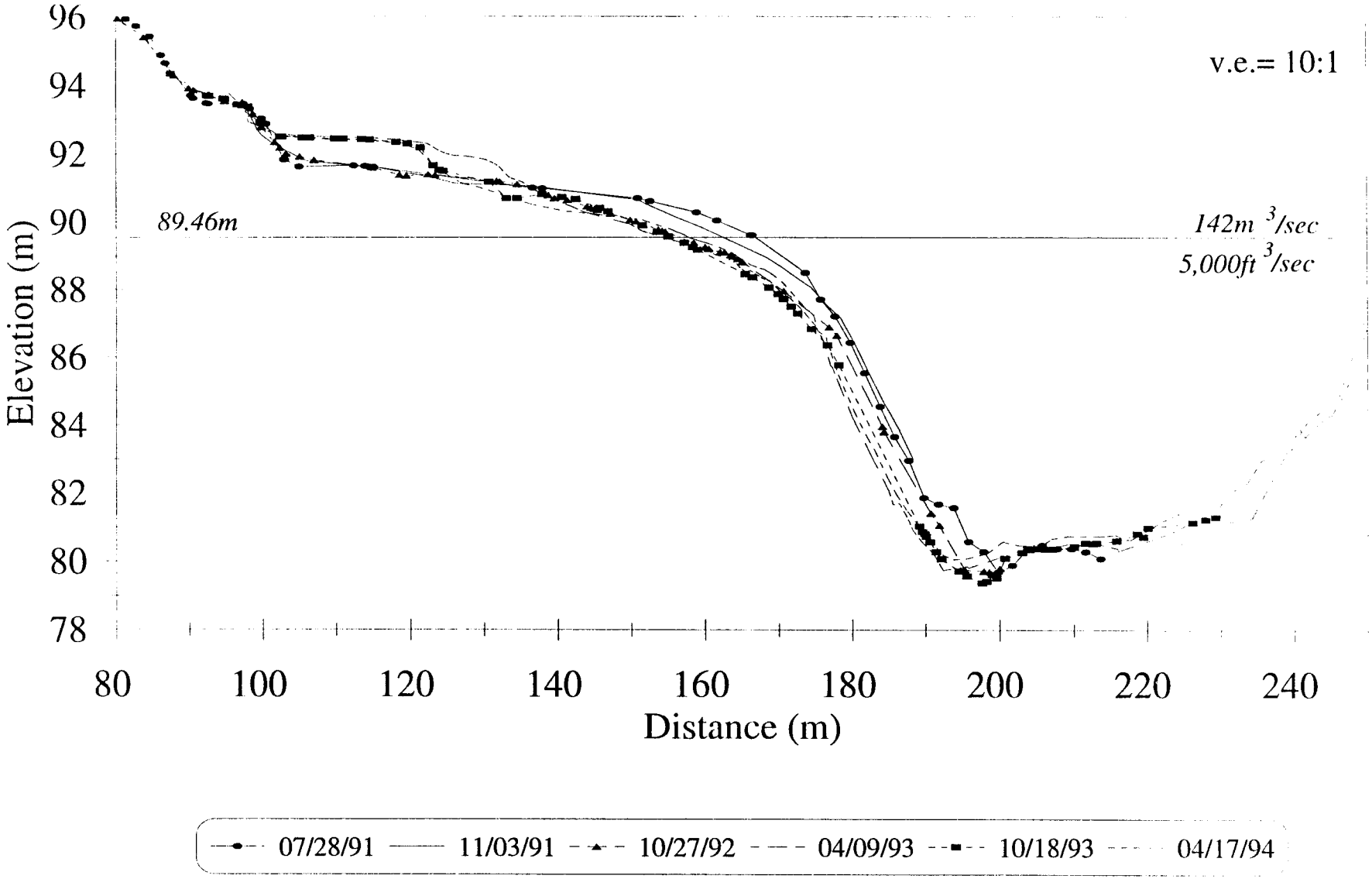


Near-shore P3

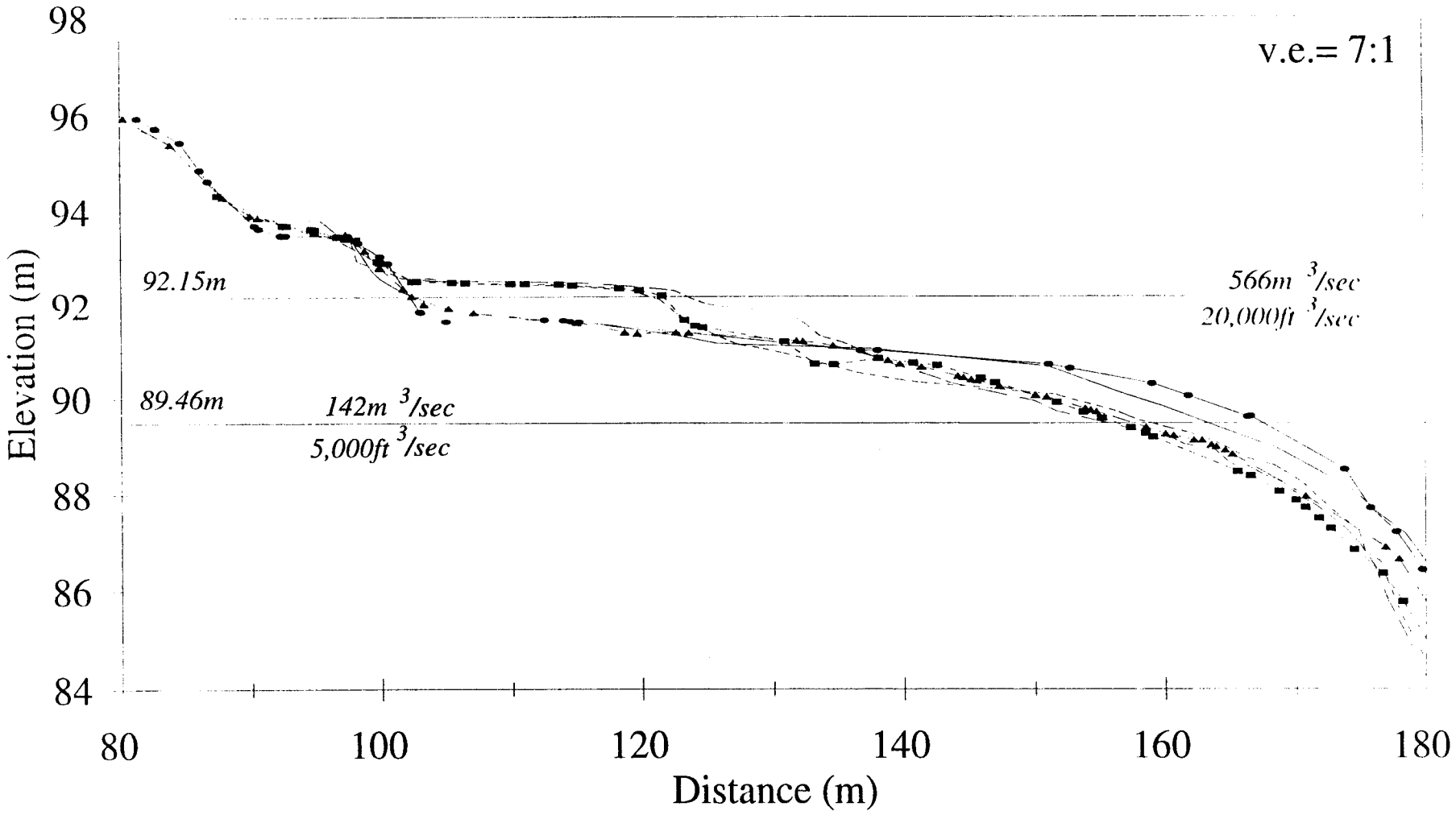


122 Mile

Cross-channel P4

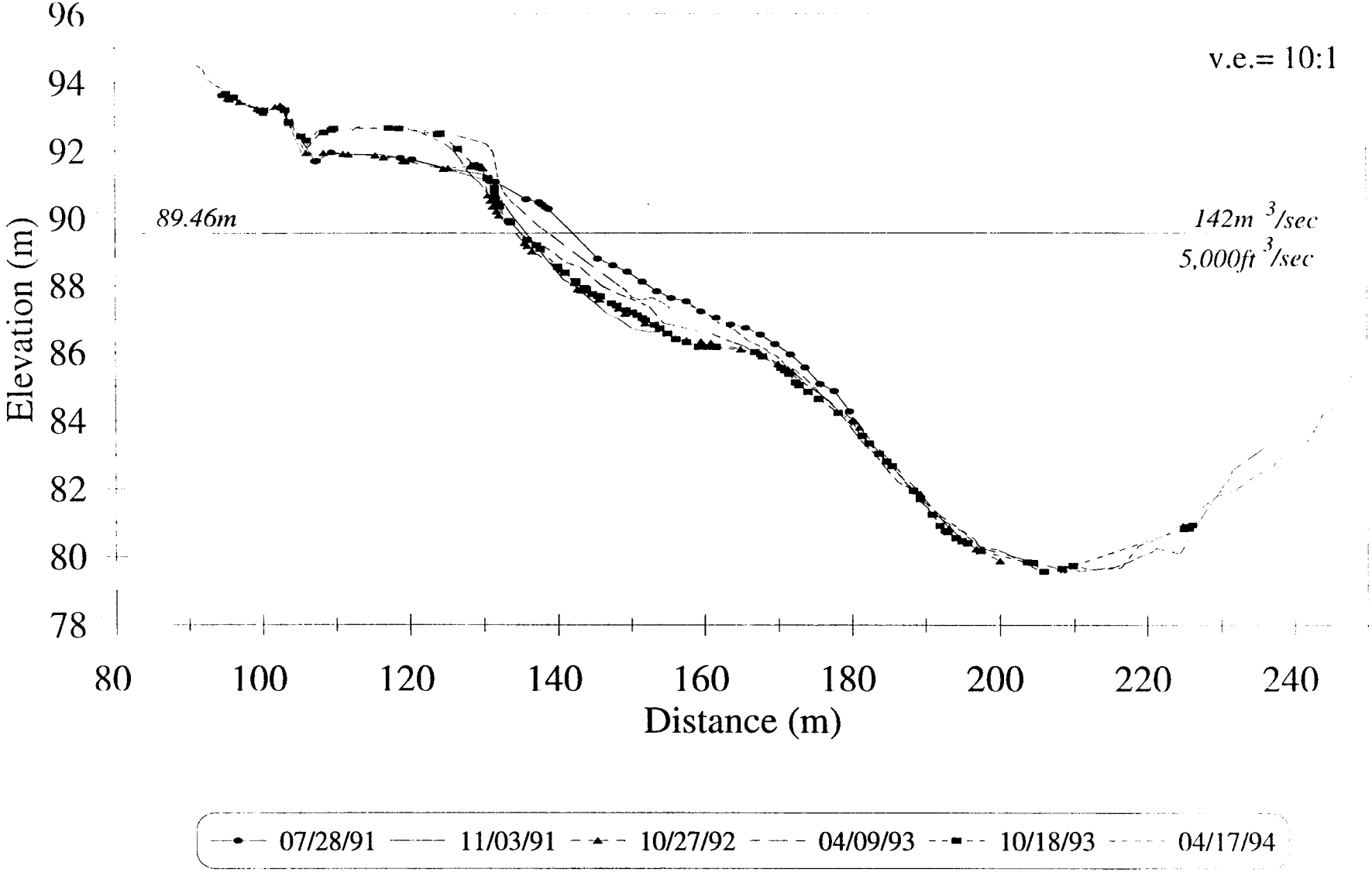


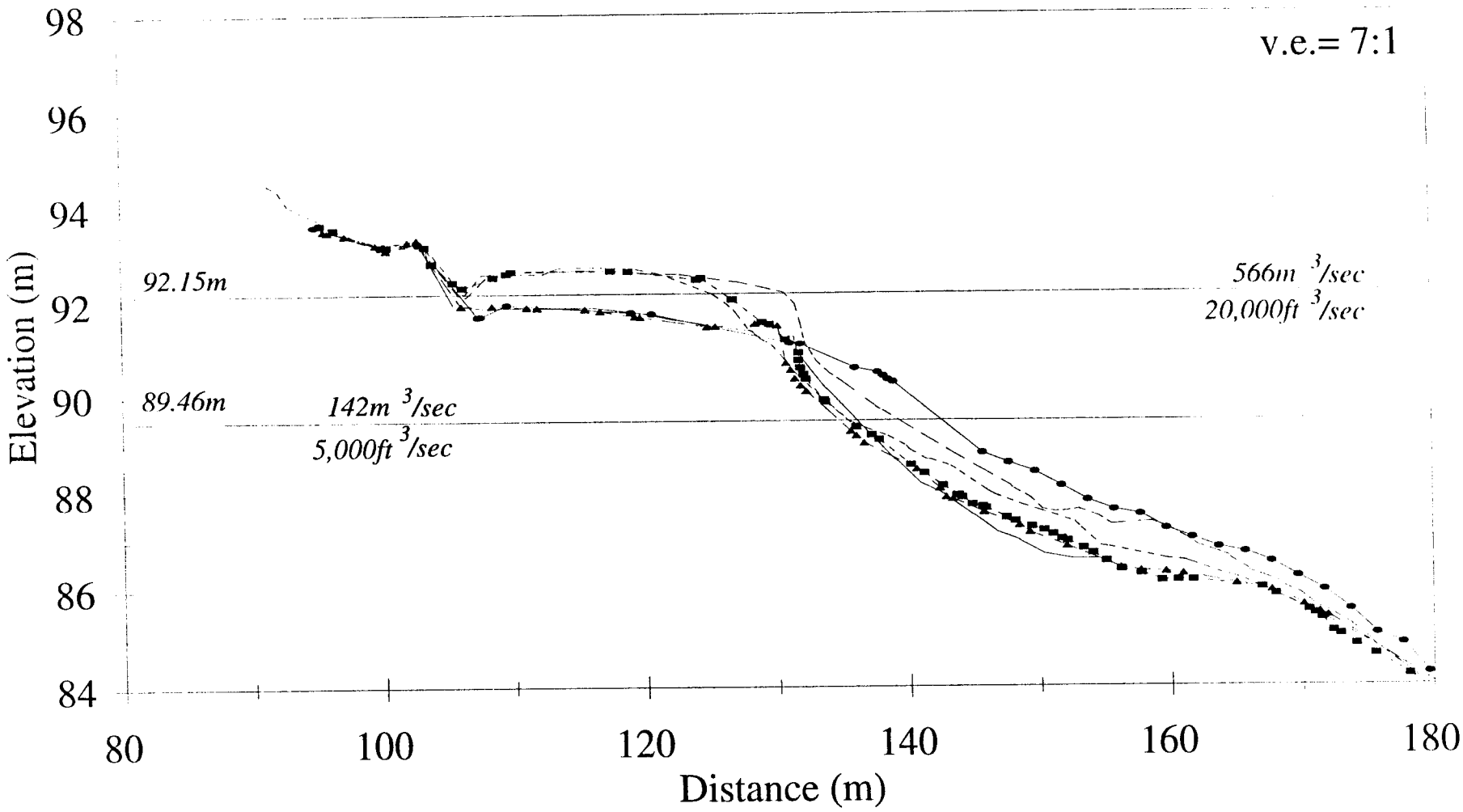
Near-shore P4



122 Mile

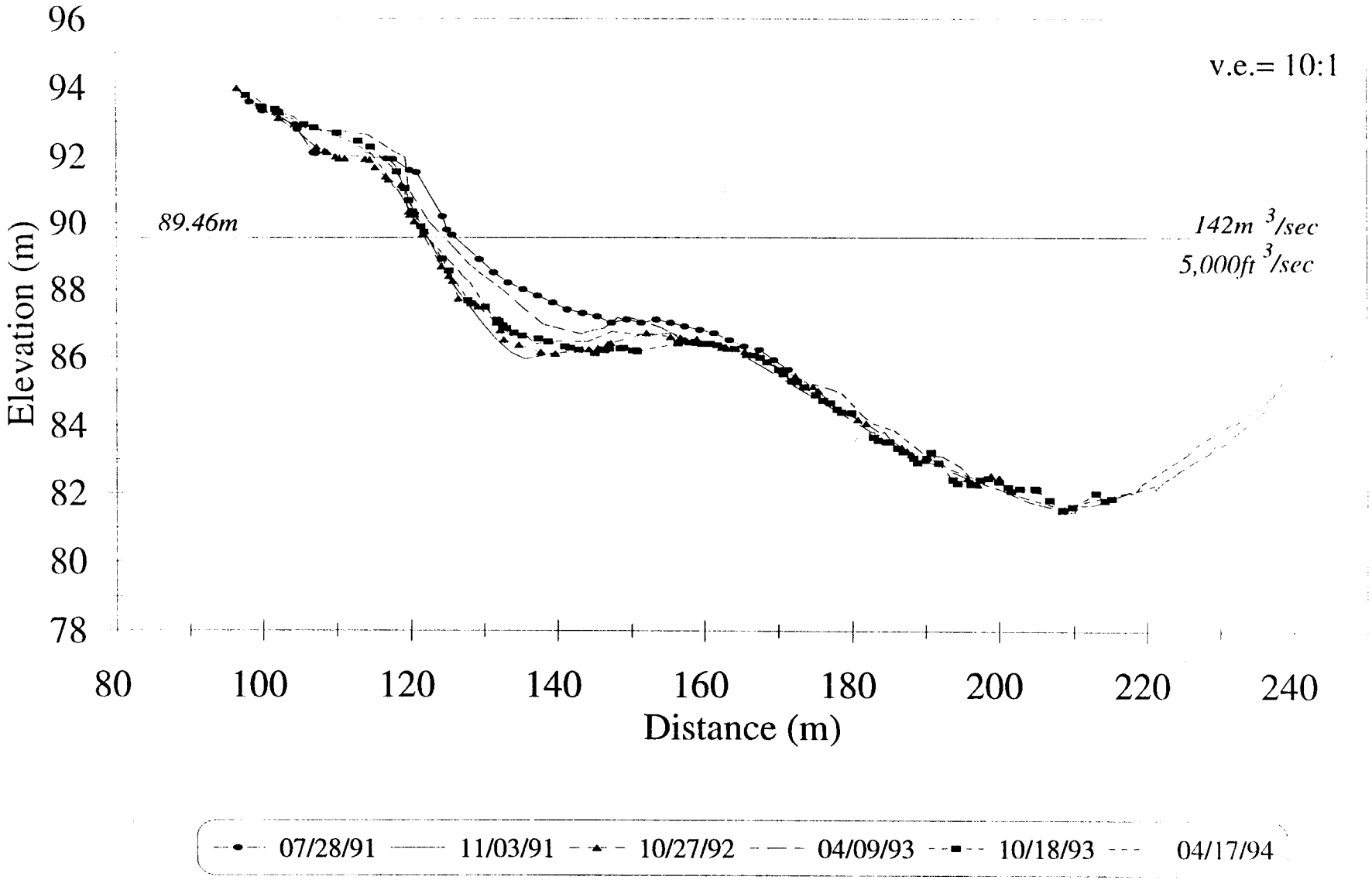
Cross-channel P6

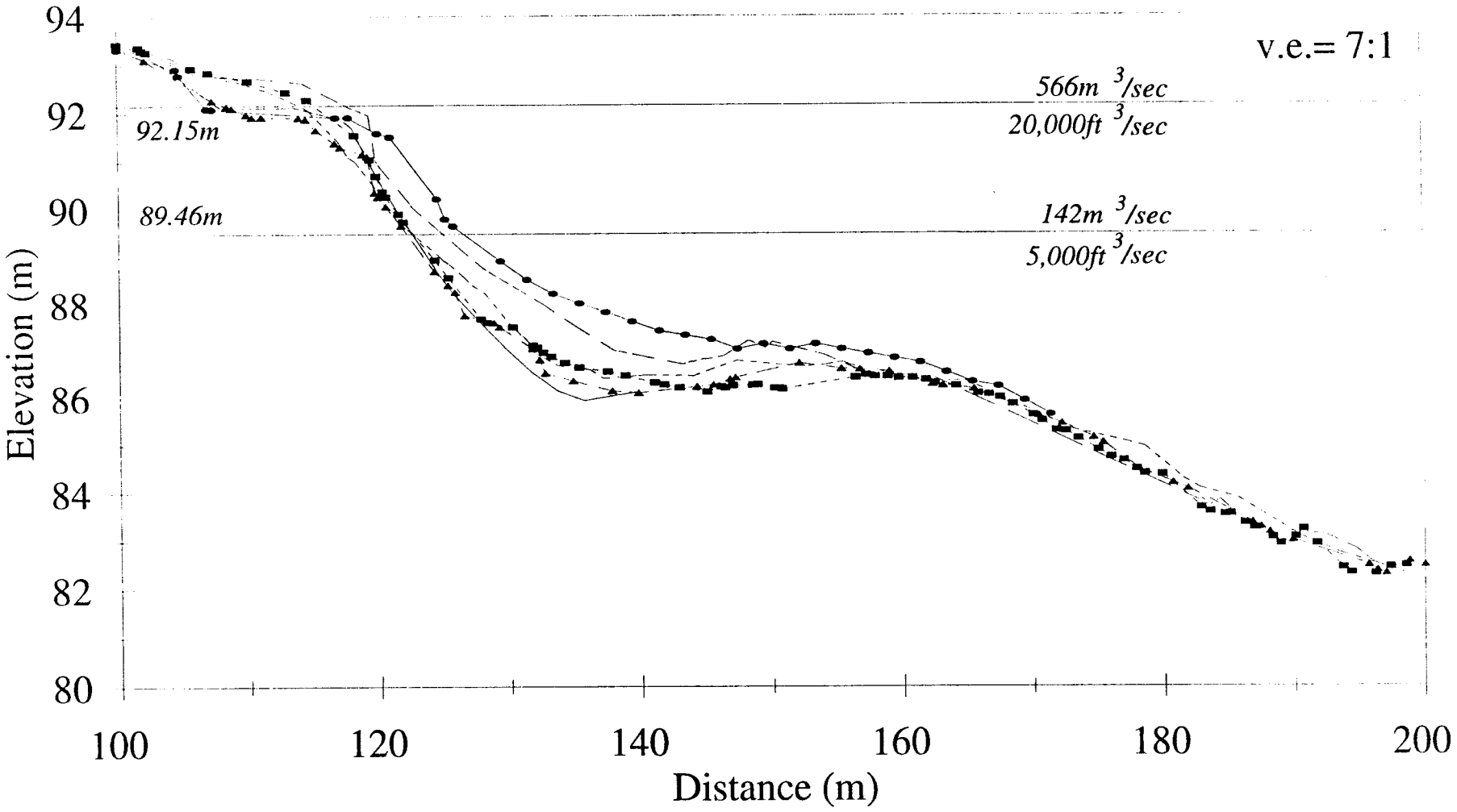



Near-shore P6
v.e.= 7:1
98
96
94
92
90
88
86
84
Elevation (m)
92.15m
89.46m
142m 3/sec
5,000ft 3/sec
566m 3/sec
20,000ft 3/sec
80
100
120
140
160
180
Distance (m)

122 Mile

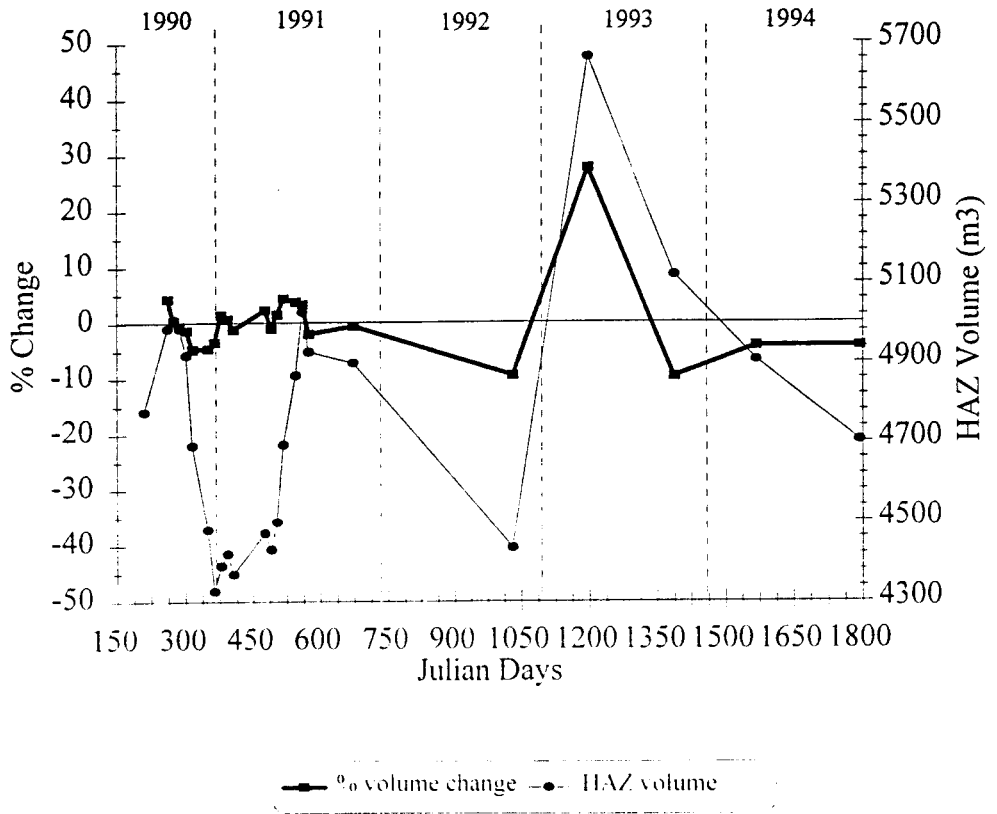
Cross-channel P7




Near-shore P7
v.e.= 7:1
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
92.15m
89.46m
Elevation (m)
94
92
90
88
86
84
82
80
100
120
140
160
180
200
Distance (m)

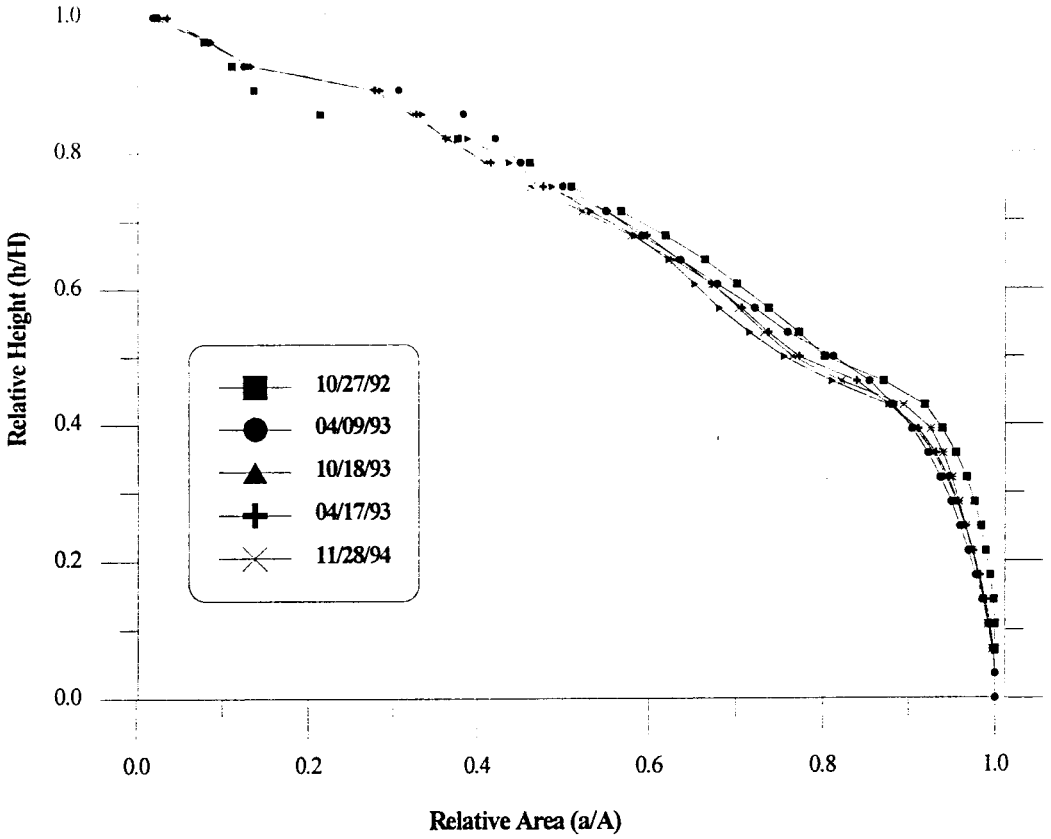
122 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D	900729	F	210	3642	4778				
E		NORM							
F	900917	NORM	260	3785	4988	143	210	3.93	4.40
G	901001	E	274	3779	5011	-6	23	-0.16	0.46
H	901014	A	287	3428	4987	-351	-24	-9.29	-0.48
I	901029	8000 CFS	302	3293	4921	-135	-66	-3.94	-1.32
J	901111	NORM	315	3215	4694	-78	-227	-2.37	-4.61
K	901216	NORM	350	3183	4480	-32	-214	-1.00	-4.56
L	901230	11000 CFS	364	3126	4327	-57	-153	-1.79	-3.42
M	910113	C	378	3332	4391	206	64	6.59	1.48
N	910127	NORM	392	3518	4420	186	29	5.58	0.66
O	910210	B	406	3491	4370	-27	-50	-0.77	-1.13
P	910421	NORM	476	3522	4472	31	102	0.89	2.33
Q	910505	NORM	490	3524	4431	2	-41	0.06	-0.92
R	910519	D	504	3645	4500	121	69	3.43	1.56
S	910602	15000 CFS	518	3895	4695	250	195	6.86	4.33
T	910630	NORM	546	3585	4870	-310	175	-7.96	3.73
U	910714	G	560	3498	5028	-87	158	-2.43	3.24
V	910728	F	574	3622	4928	124	-100	3.54	-1.99
X	911103	INT	672	3568	4900	-54	-28	-1.49	-0.57
Y	921027	INT	1031	3134	4435	-434	-465	-12.16	-9.49
Z	930409	INT	1196	2991	5666	-143	1231	-4.56	27.76
B22	931018	INT	1387	2860	5120	-131	-546	-4.38	-9.64
C22	940417	INT	1568	3004	4908	144	-212	5.03	-4.14
D22	941128	INT	1793	2760	4704	-244	-204	-8.12	-4.16

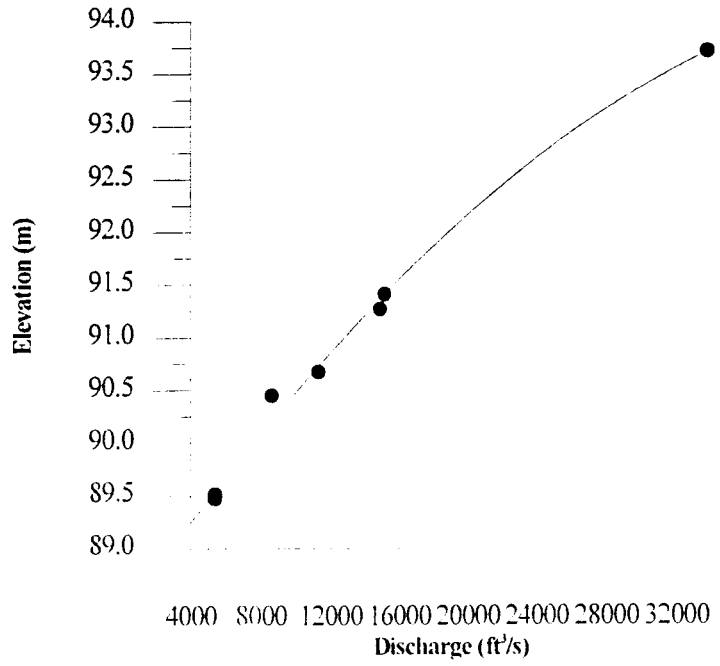


122 Mile

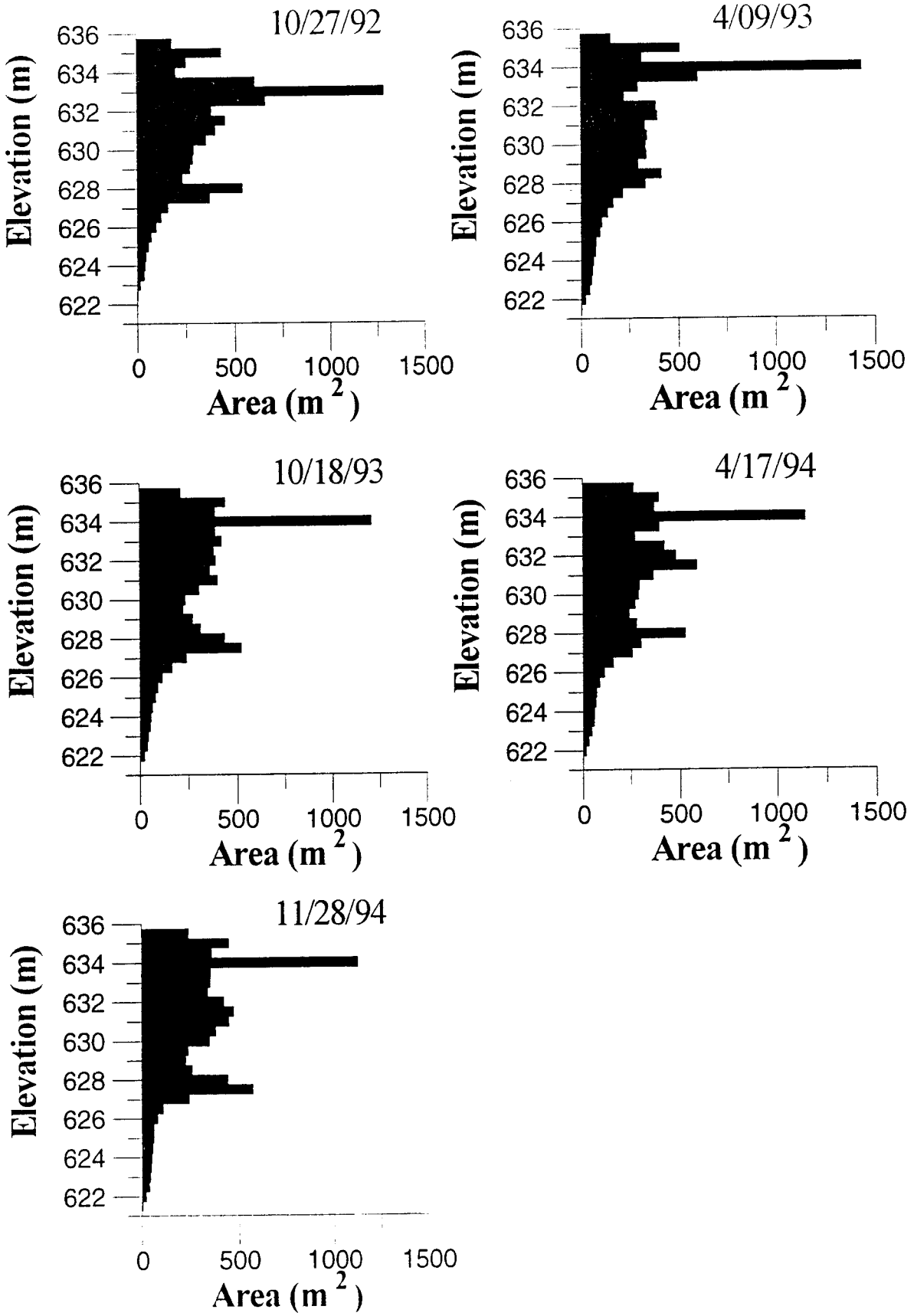
Hypsometric Curves



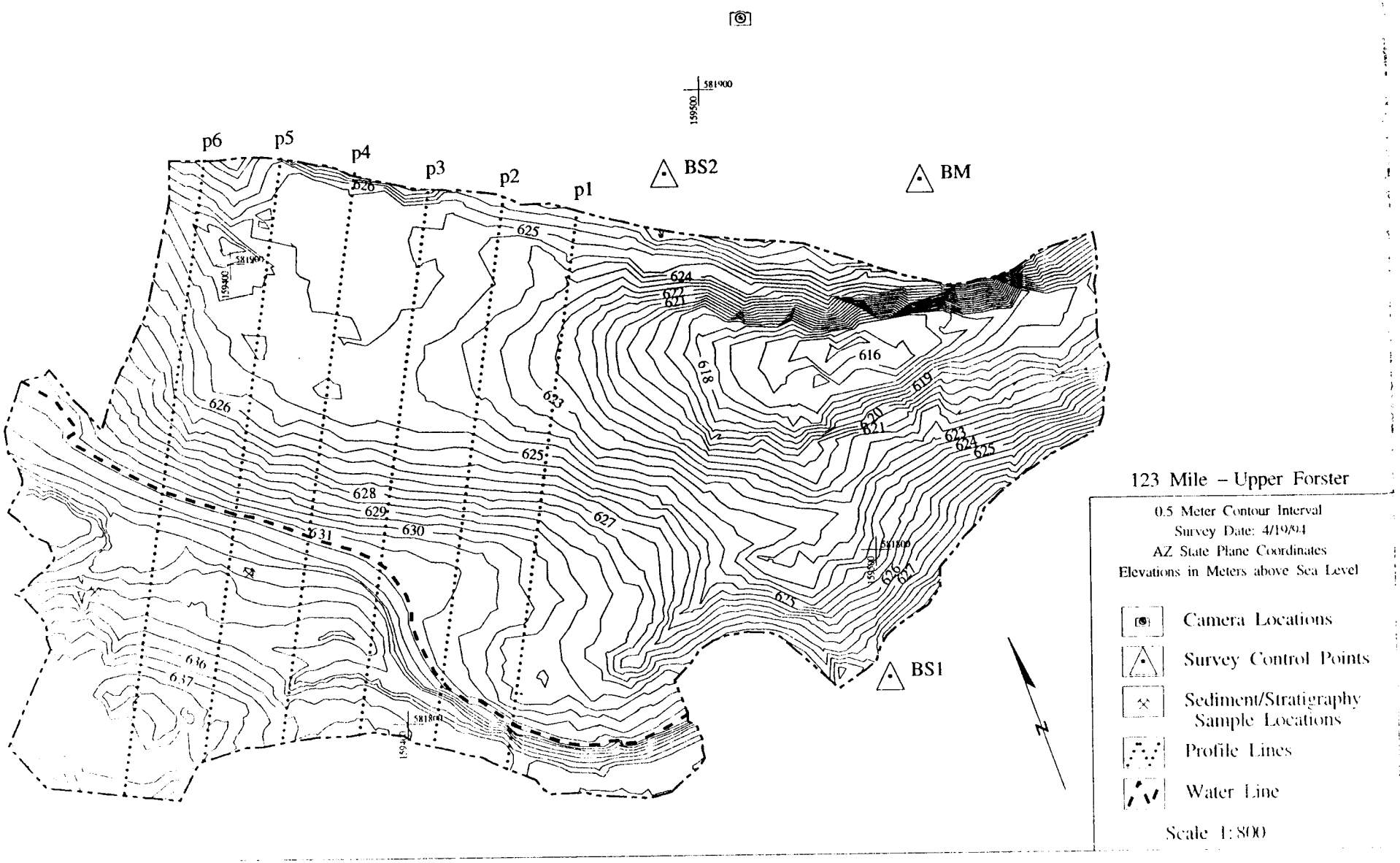
Stage Discharge



122 MILE
Area Distribution Histograms

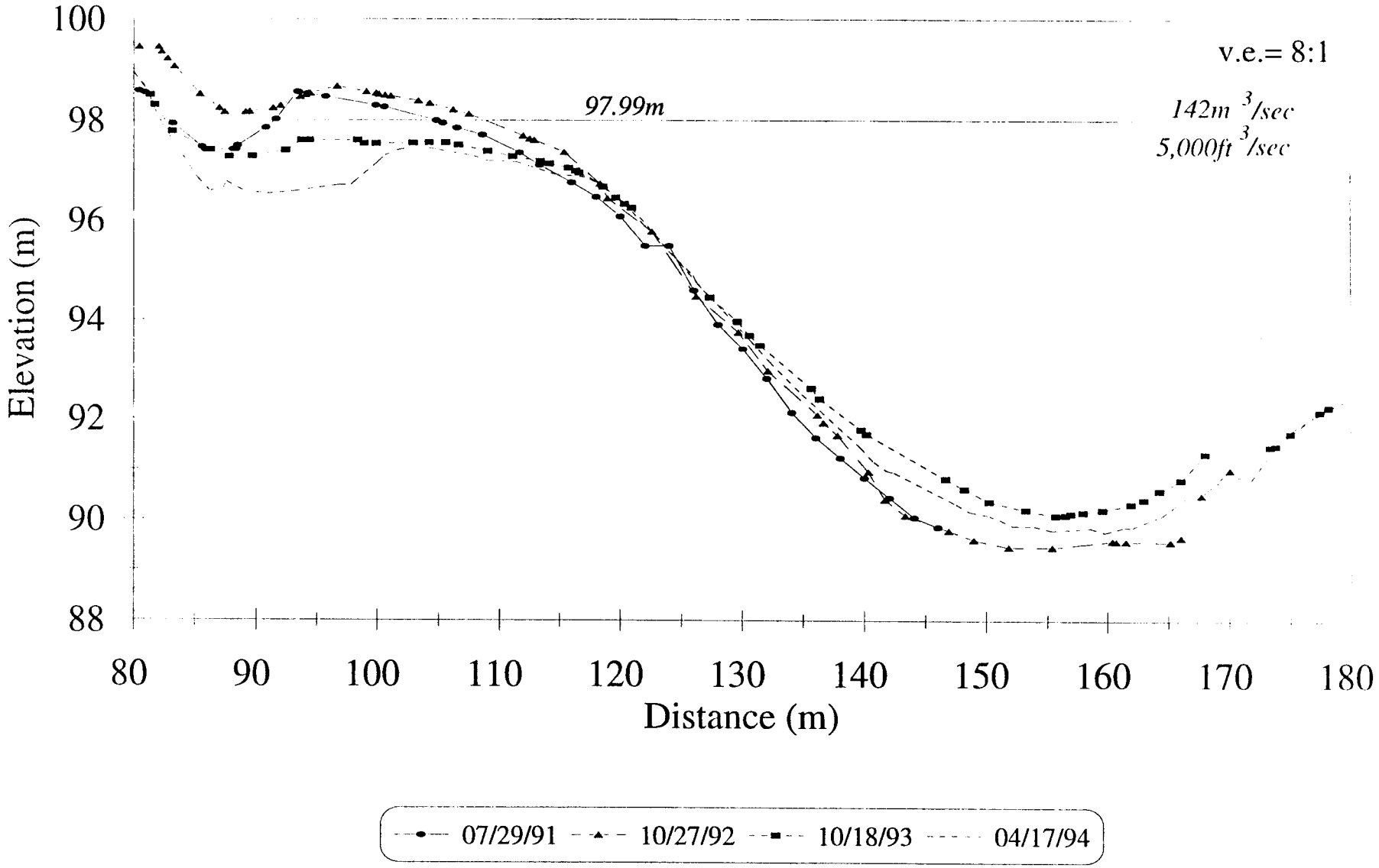


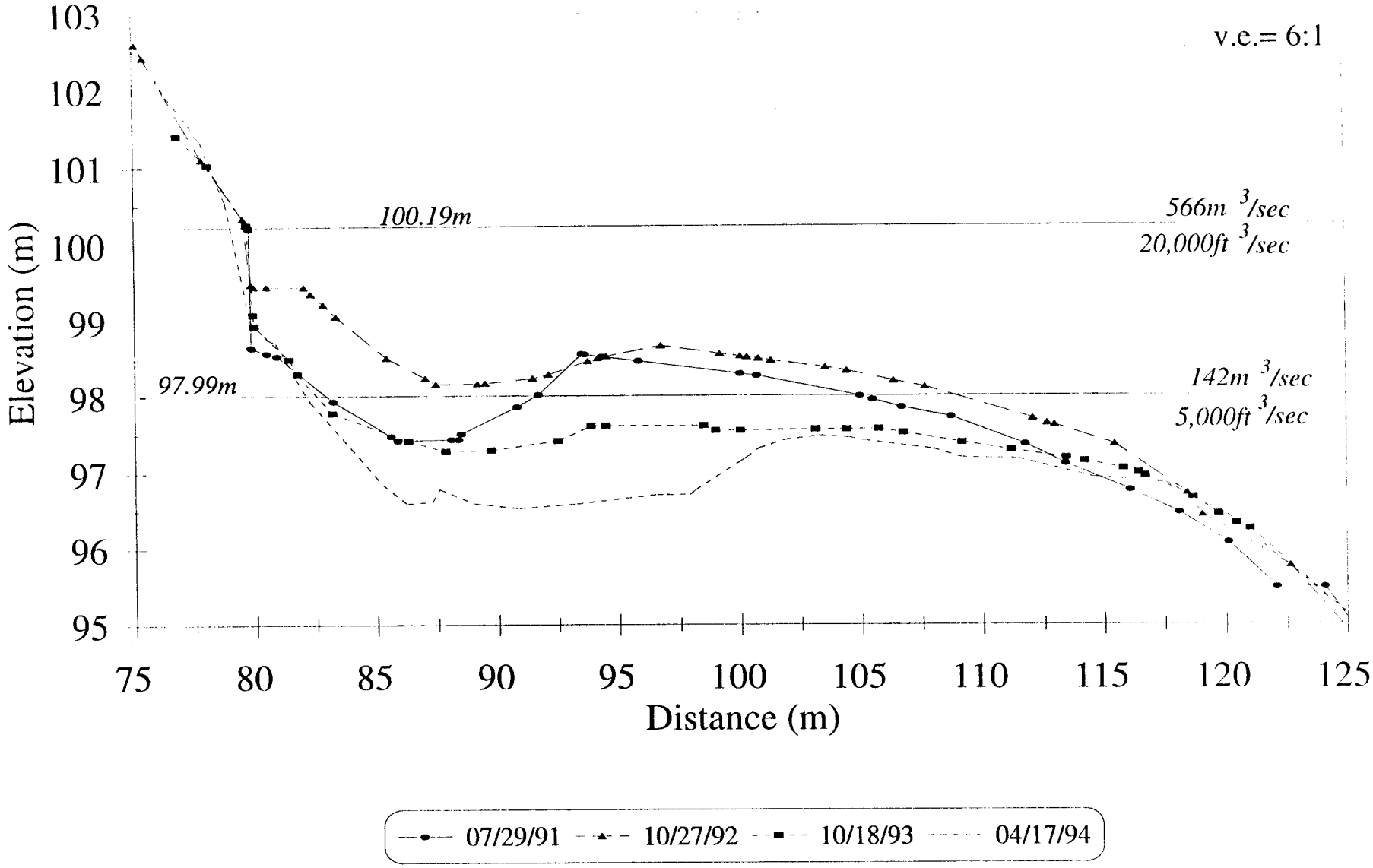
123 L
5-30-94
Area of Study
RM 122.5


581900
159500
p6
p5
p4
p3
p2
p1
BS2
BM
BS1
626
625
624
627
621
616
618
619
620
622
623
628
629
630
631
636
637
581800
159400
N
123 Mile – Upper Forster
0.5 Meter Contour Interval
Survey Date: 4/19/94
AZ State Plane Coordinates
Elevations in Meters above Sea Level
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:800

123 Mile

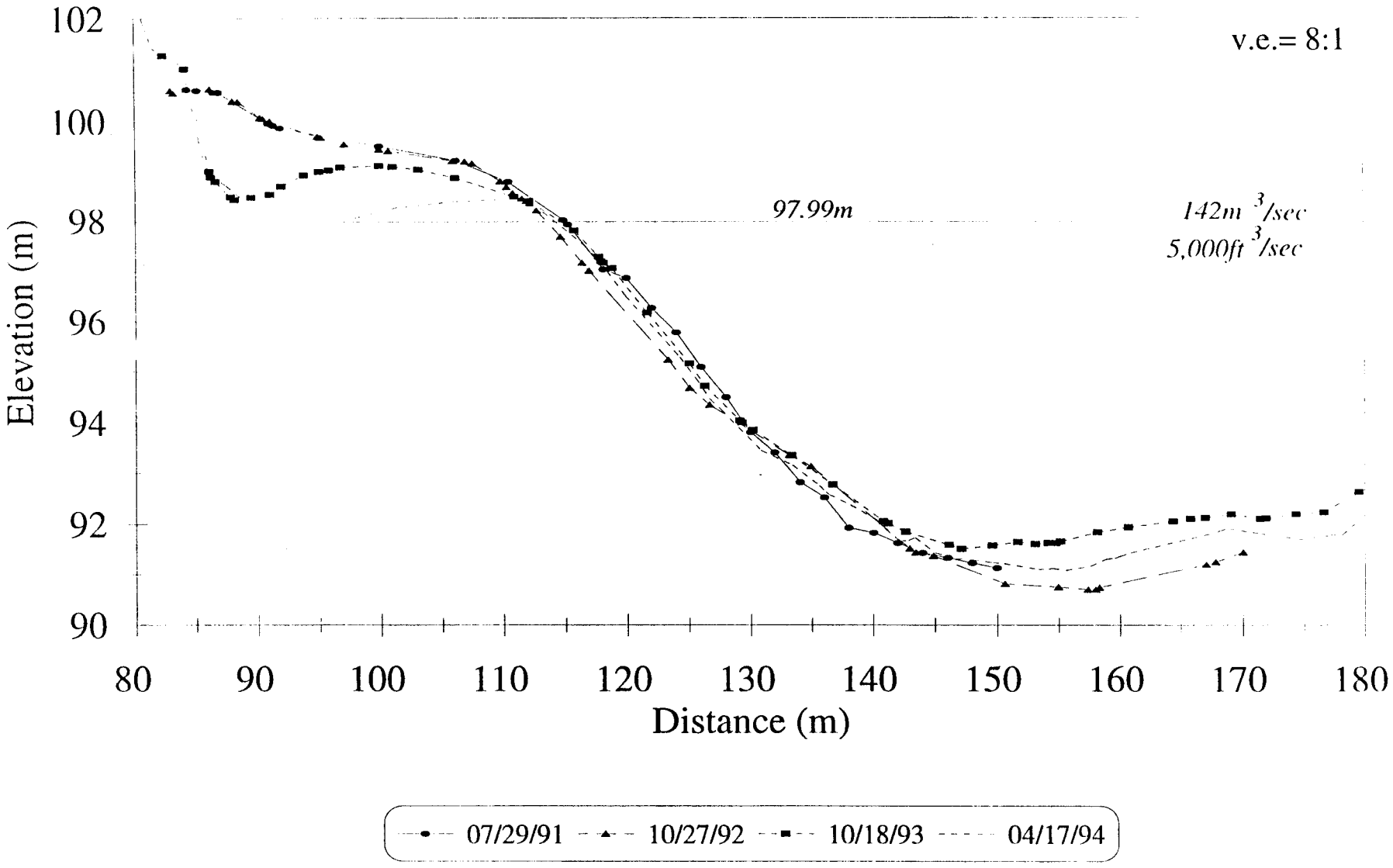
Cross-channel P1

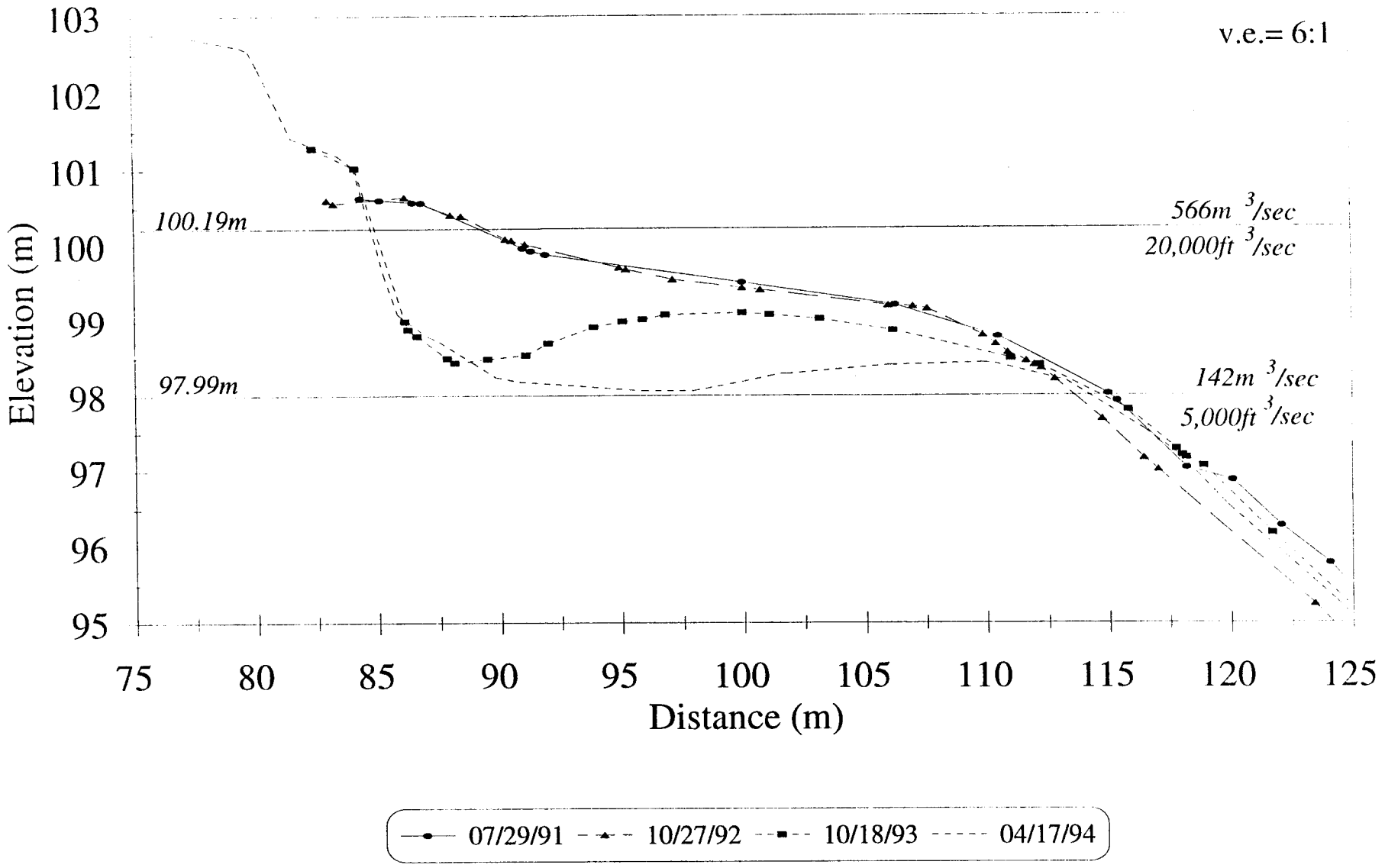



Near-shore P1
v.e.= 6:1
Elevation (m)
103
102
101
100
99
98
97
96
95
100.19m
97.99m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
75
80
85
90
95
100
105
110
115
120
125
Distance (m)
07/29/91
10/27/92
10/18/93
04/17/94

123 Mile

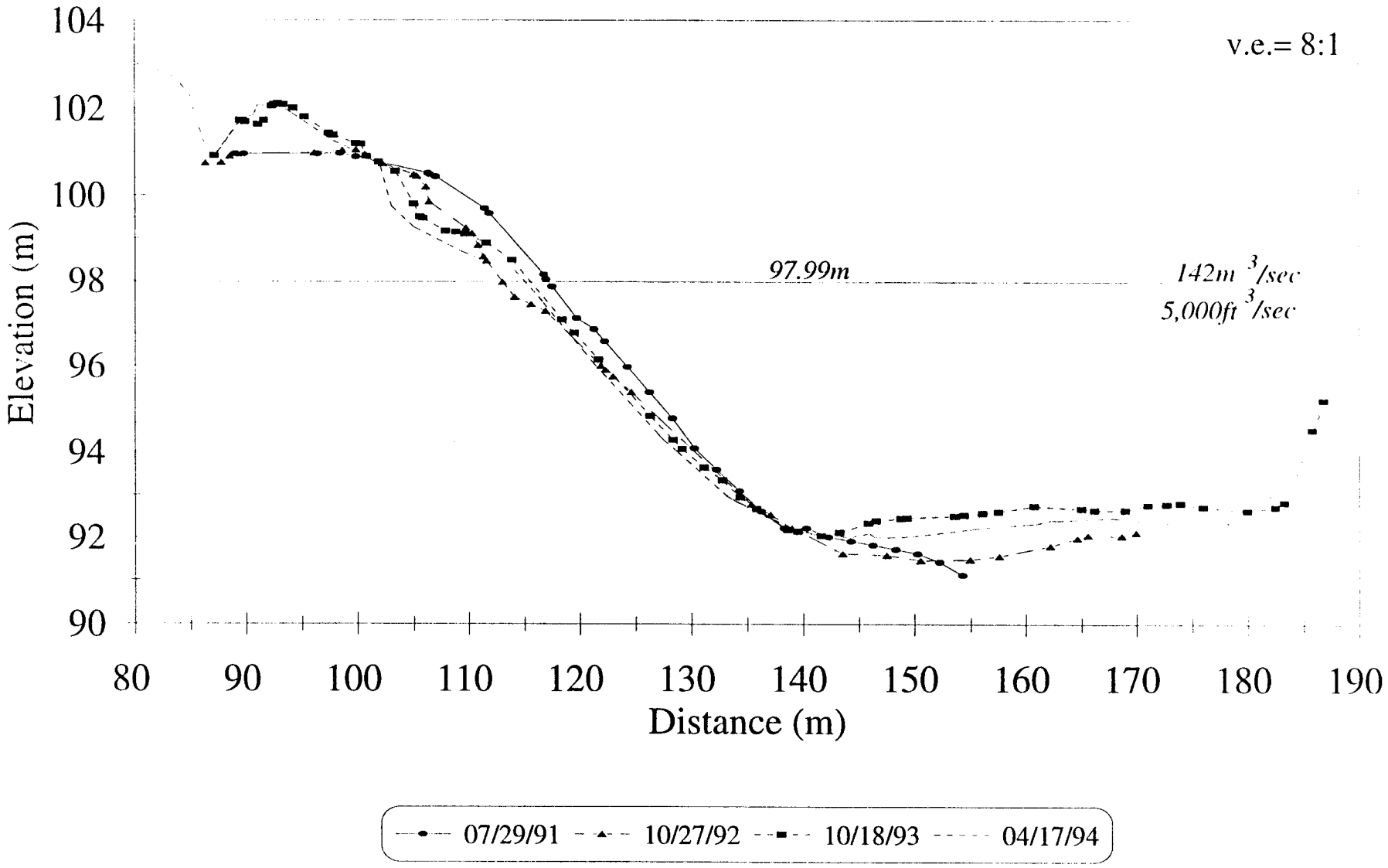
Cross-channel P2

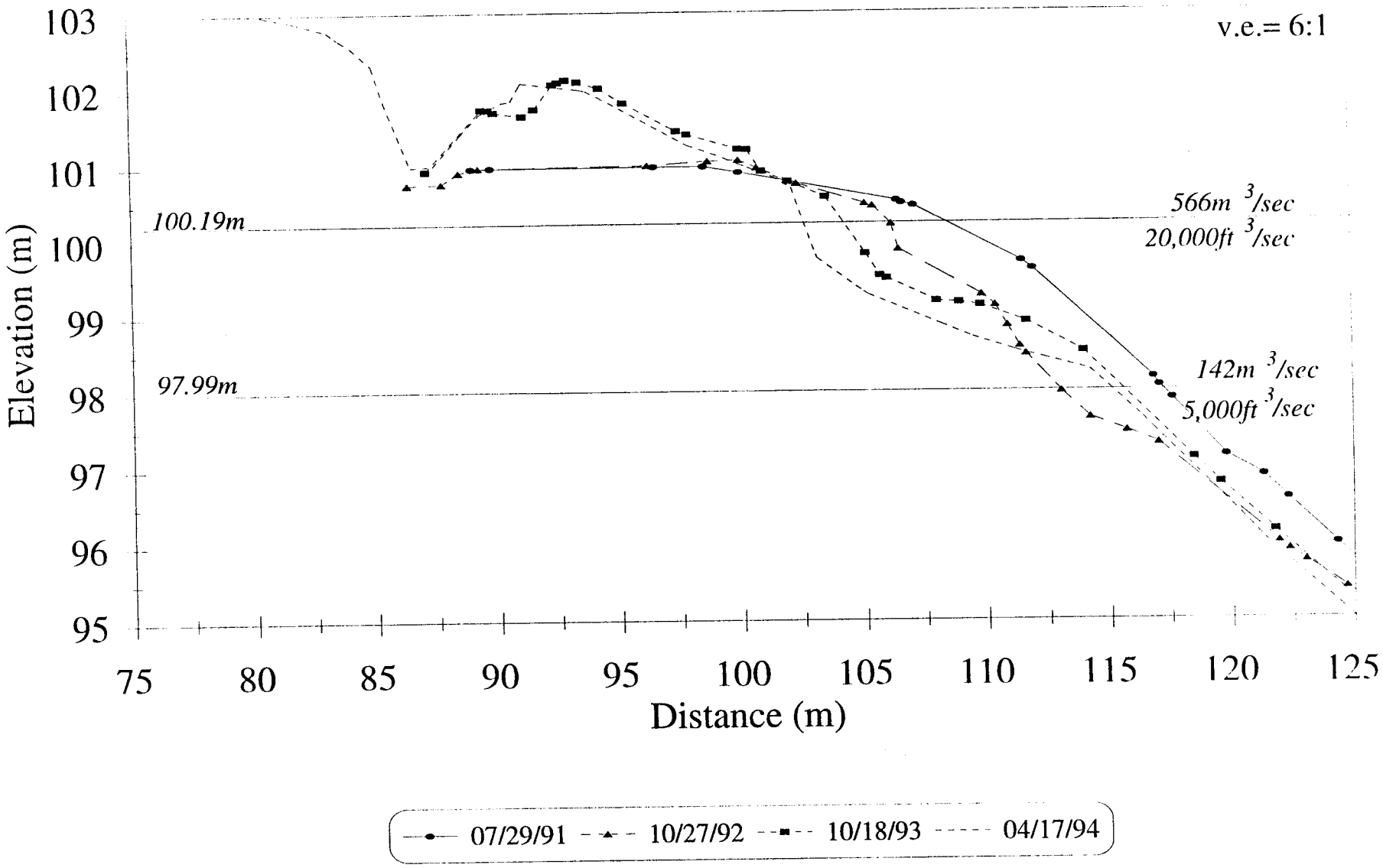



Near-shore P2
v.e.= 6:1
Elevation (m)
103
102
101
100
99
98
97
96
95
100.19m
97.99m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
75
80
85
90
95
100
105
110
115
120
125
Distance (m)
07/29/91
10/27/92
10/18/93
04/17/94

123 Mile

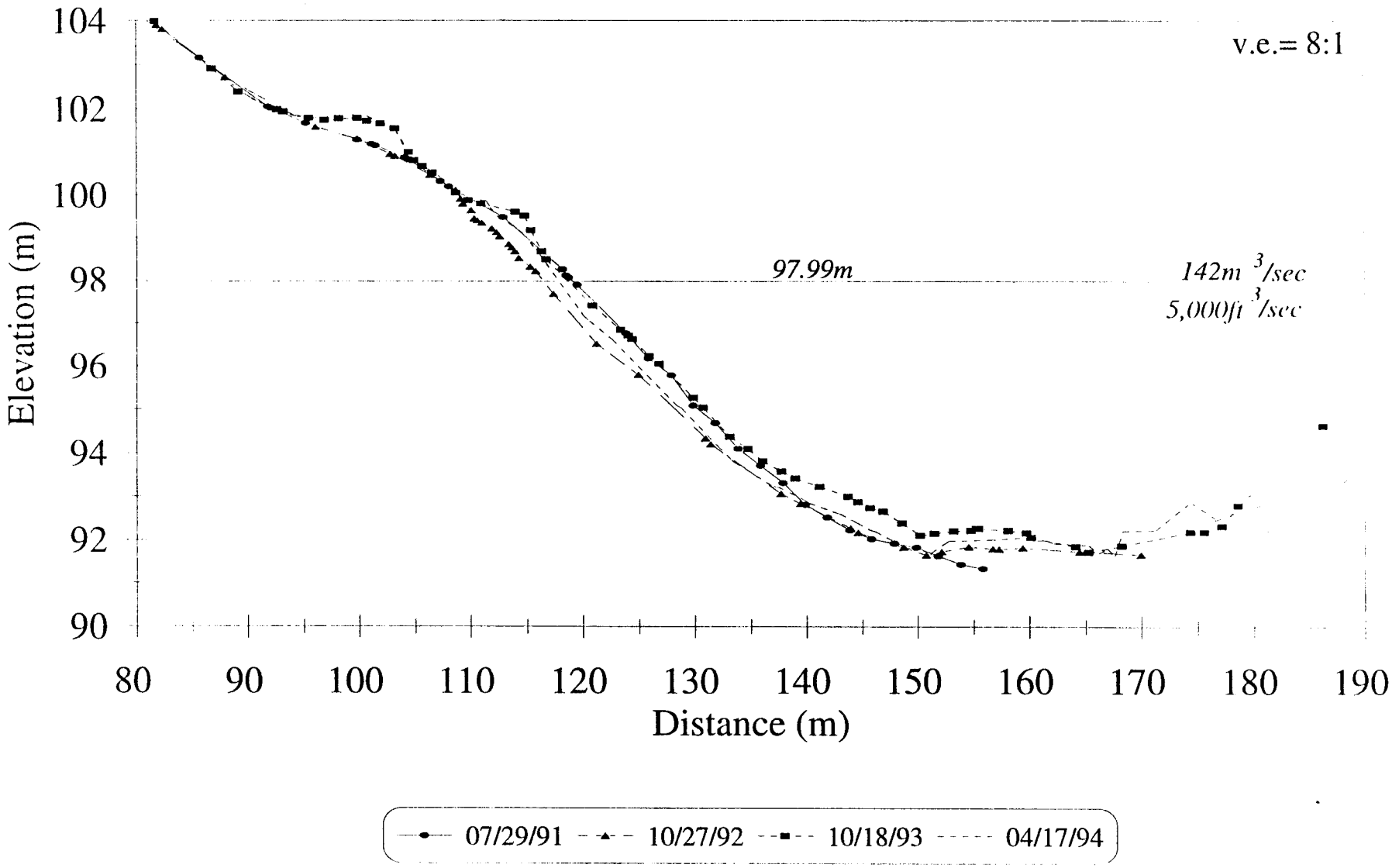
Cross-channel P3

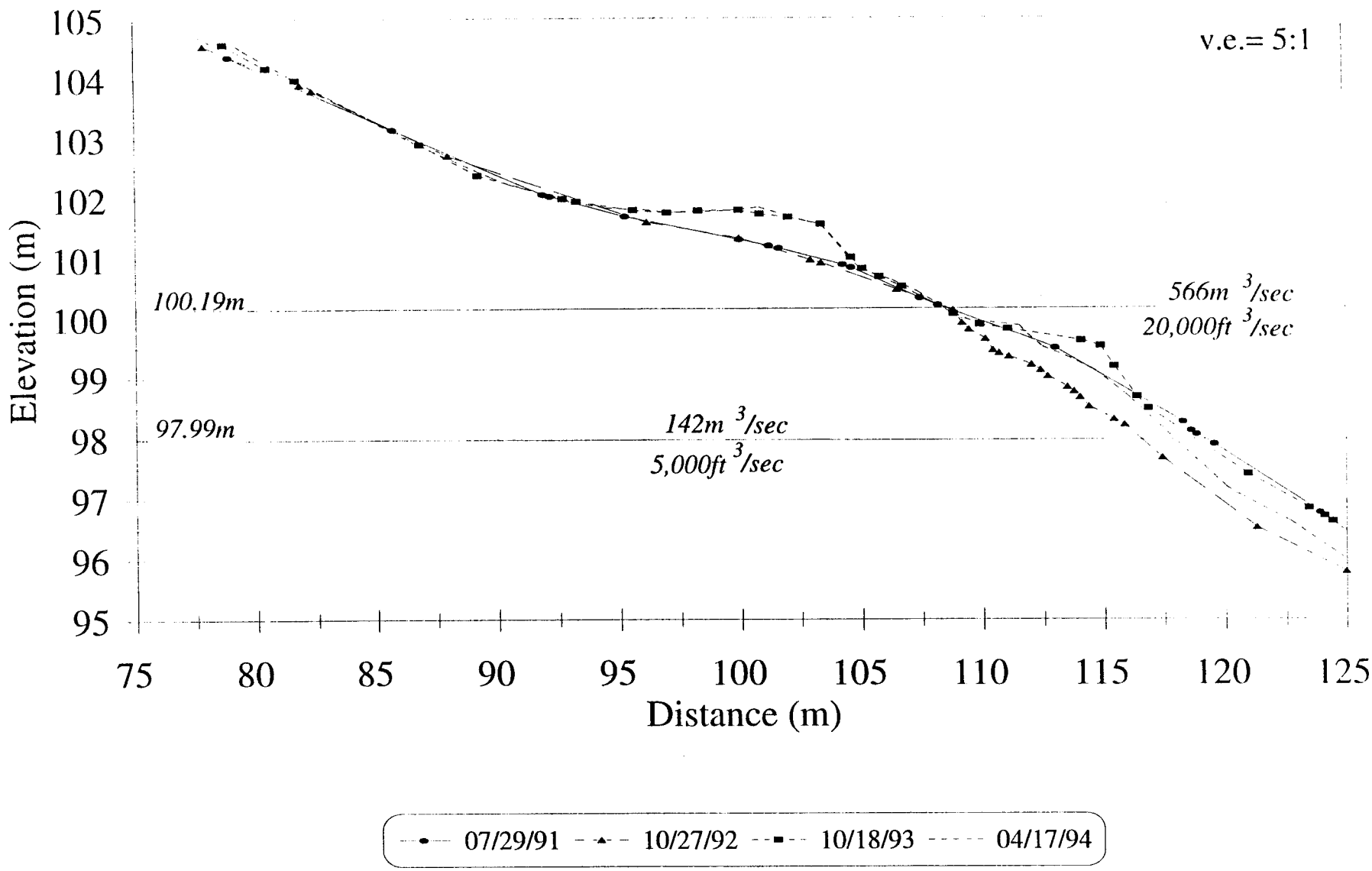



Near-shore P3
v.e.= 6:1
Elevation (m)
103
102
101
100
99
98
97
96
95
100.19m
97.99m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
75
80
85
90
95
100
105
110
115
120
125
Distance (m)
07/29/91
10/27/92
10/18/93
04/17/94

123 Mile

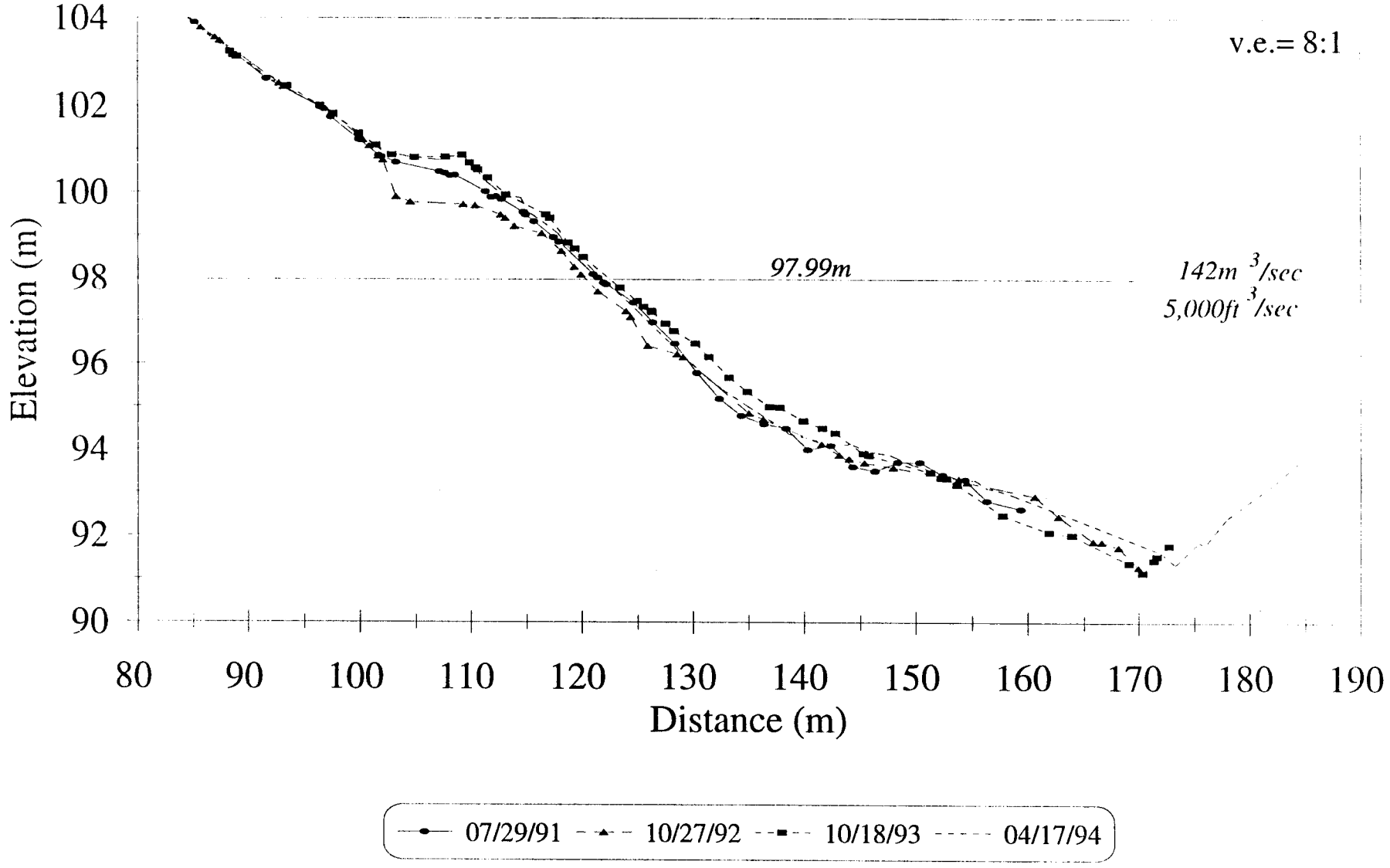
Cross-channel P5



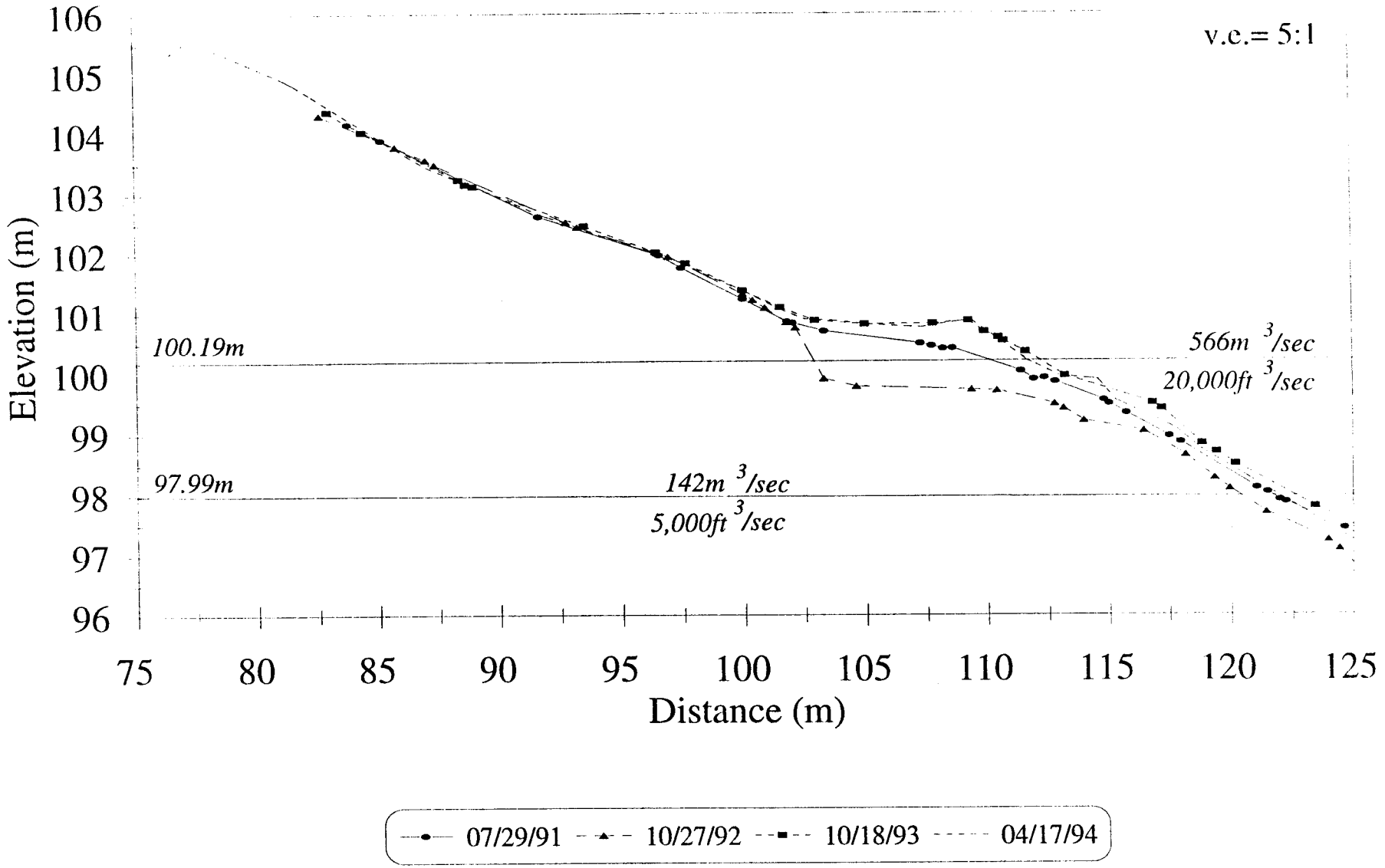

Near-shore P5
v.e.= 5:1
Elevation (m)
105
104
103
102
101
100
99
98
97
96
95
100.19m
97.99m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
75
80
85
90
95
100
105
110
115
120
125
Distance (m)
07/29/91
10/27/92
10/18/93
04/17/94

123 Mile

Cross-channel P6

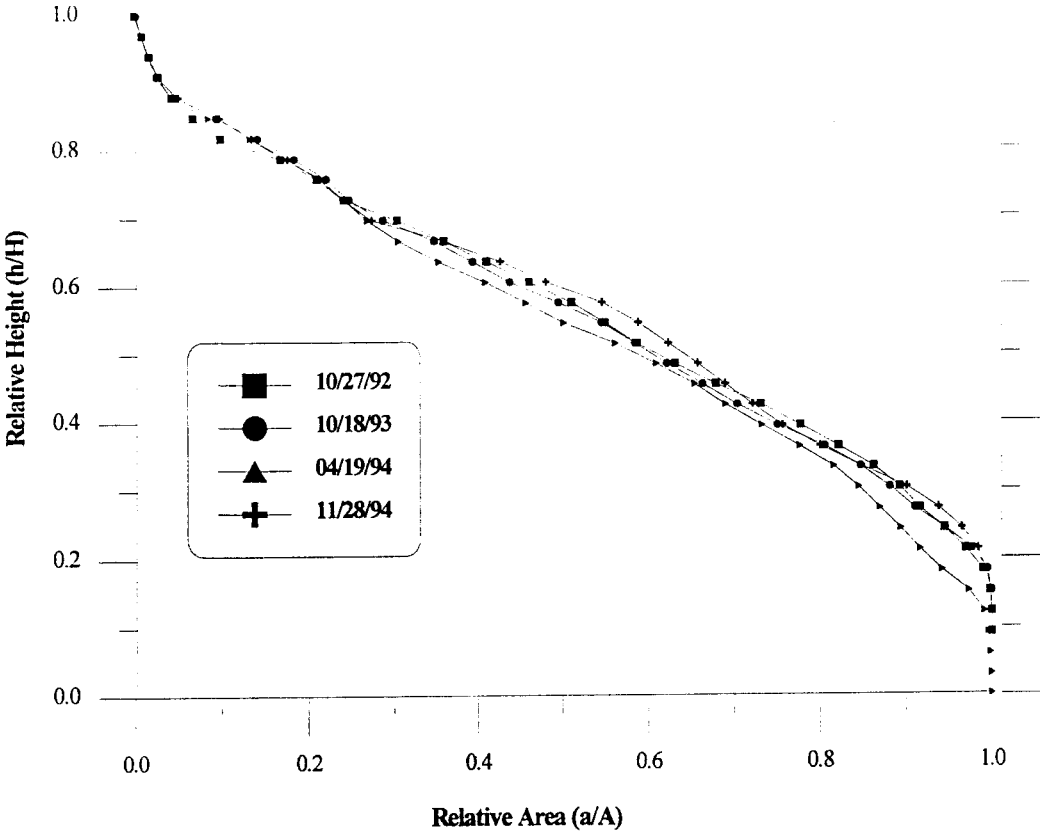


Near-shore P6

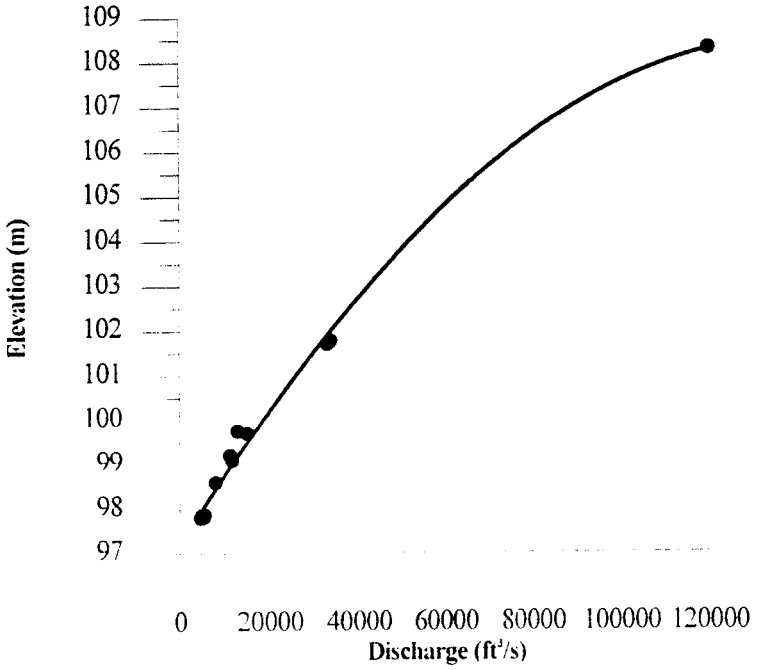


123 Mile

Hypsometric Curves

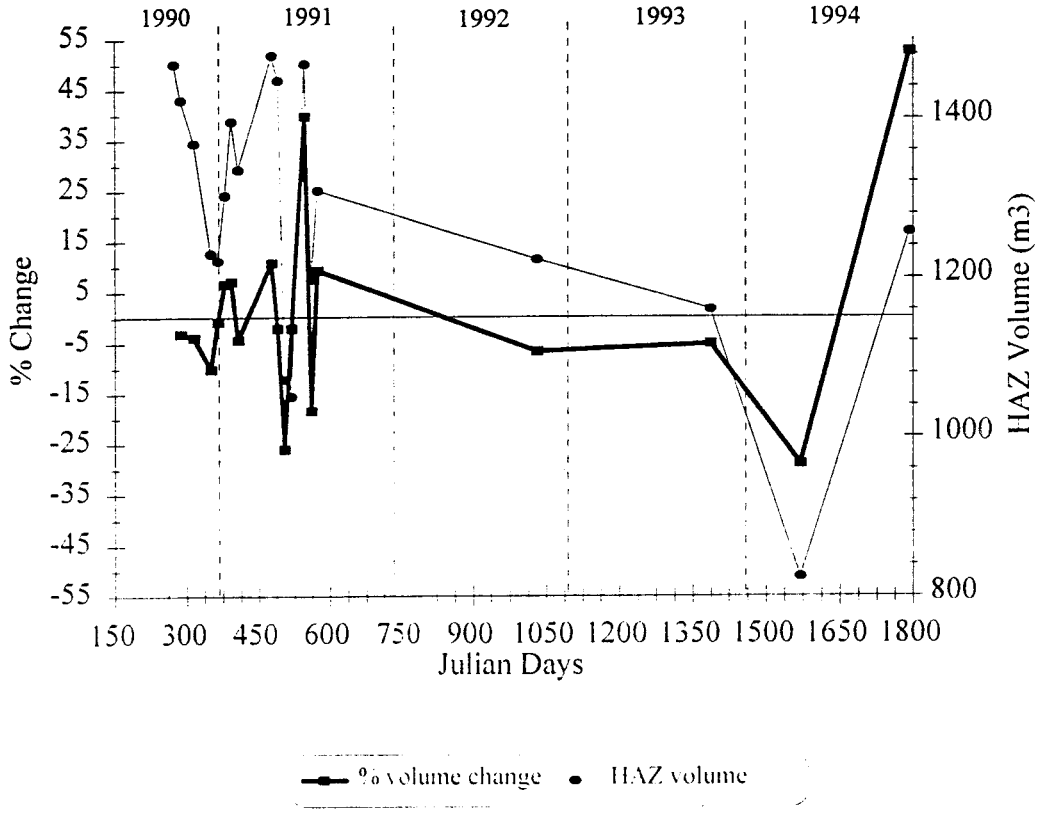


Stage Discharge

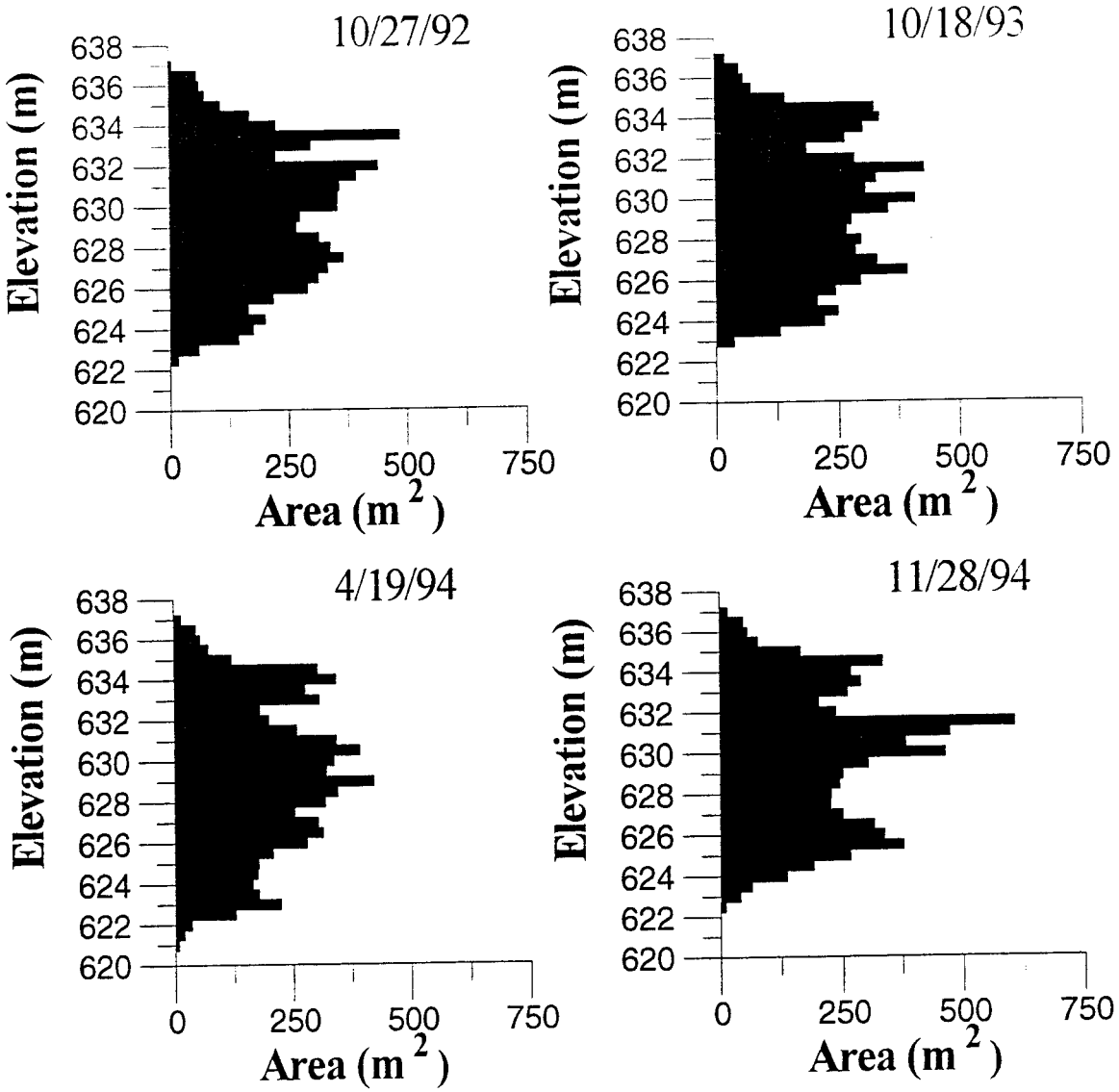


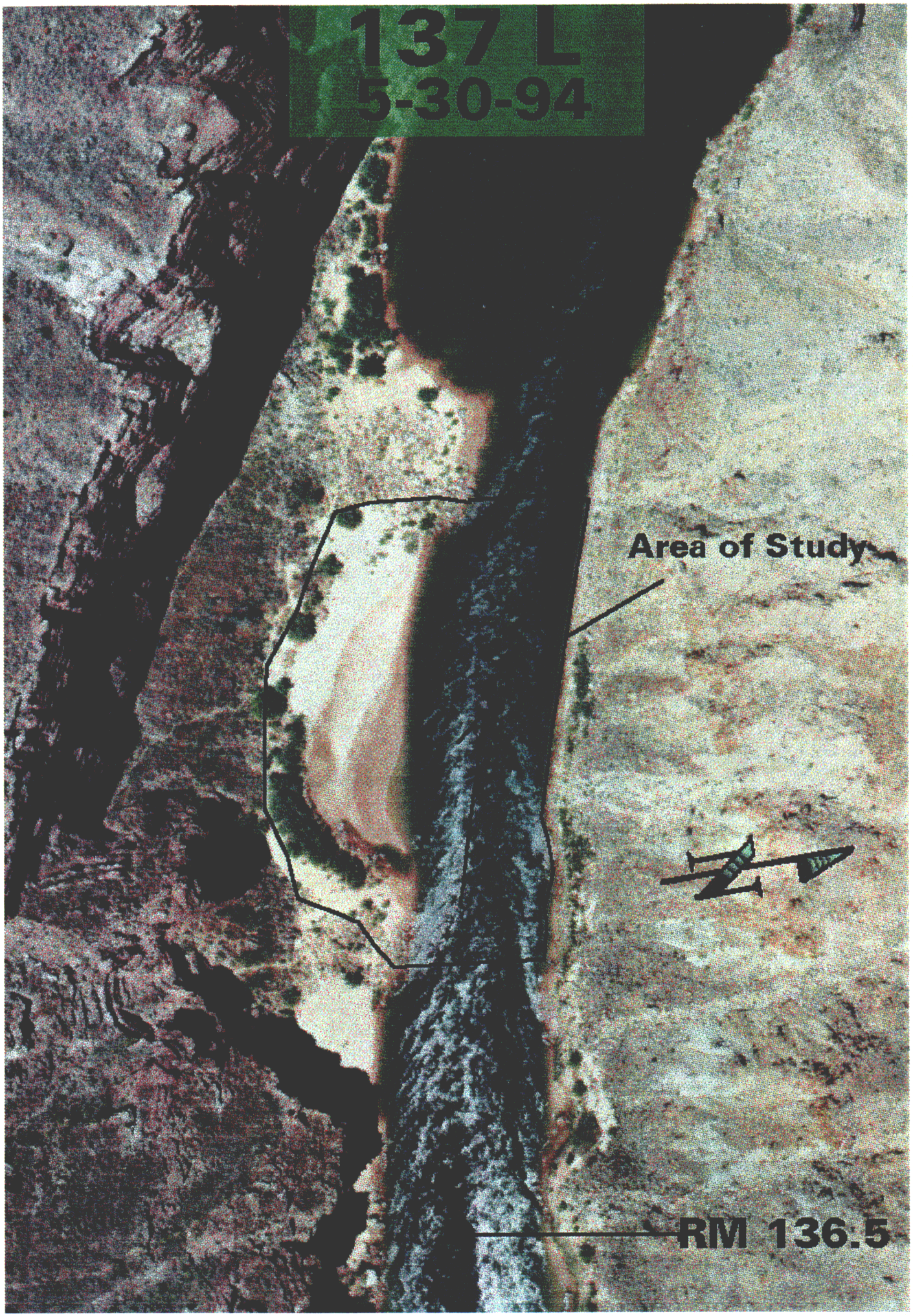
123 Mile

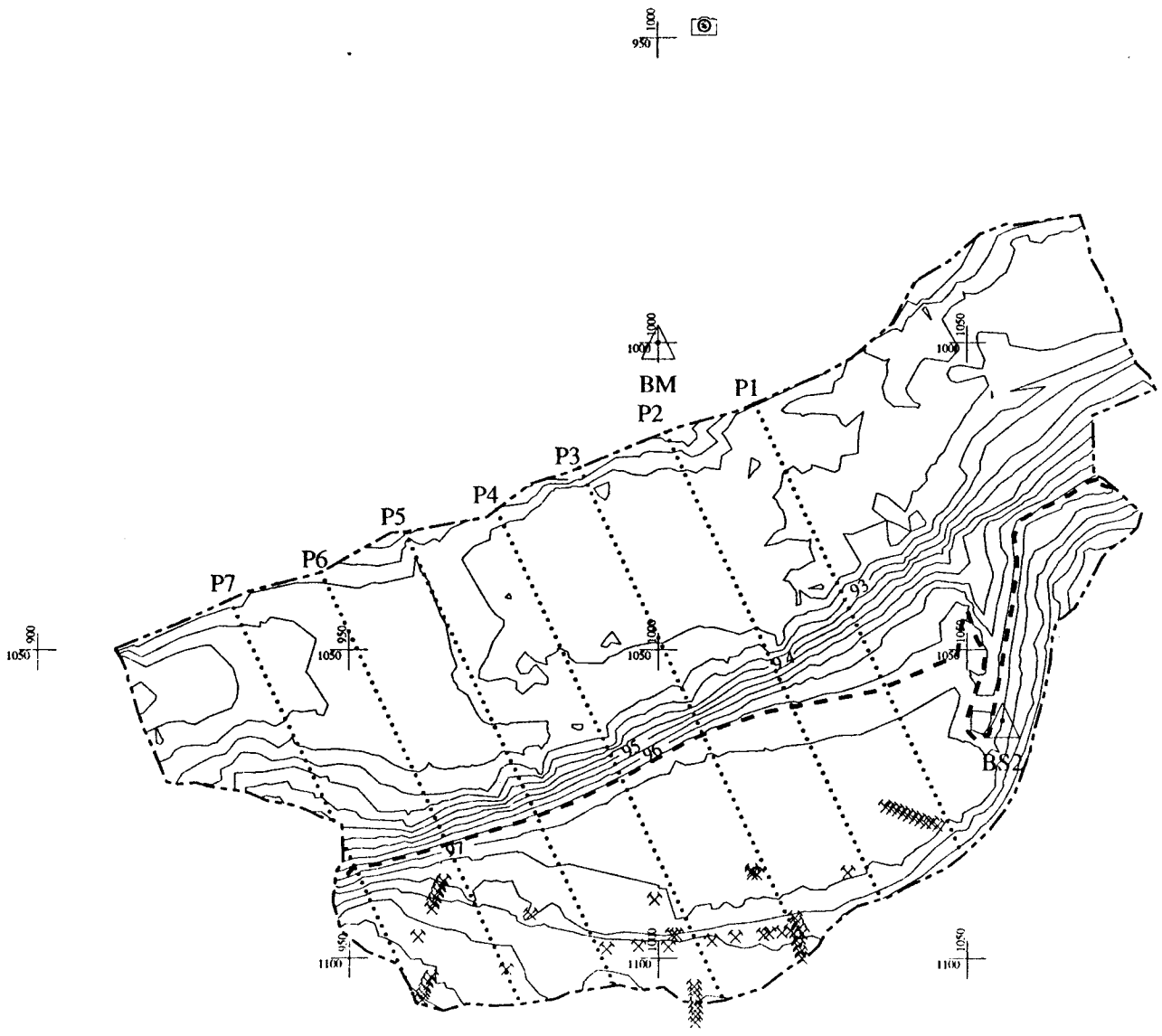
RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F	900917	NORM	260						
G	901001	E	274	1453	1469				
H	901015	A	288	1423	1424	-30	-45	-2.06	-3.06
I		8000 CFS							
J	901112	NORM	316	1383	1369	-40	-55	-2.81	-3.86
K	901217	NORM	351	1300	1231	-83	-138	-6.00	-10.08
L	901231	11000 CFS	365	1322	1222	22	-9	1.69	-0.73
M	910114	C	379	1481	1304	159	82	12.03	6.71
N	910128	NORM	393	1477	1397	-4	93	-0.27	7.13
O	910211	B	407	1450	1336	-27	-61	-1.83	-4.37
P	910422	NORM	477	1495	1480	45	144	3.10	10.78
Q	910506	NORM	491	1475	1449	-20	-31	-1.34	-2.09
R	910520	D	505	1097	1073	-378	-376	-25.63	-25.95
S	910603	15000 CFS	519	1084	1051	-13	-22	-1.19	-2.05
T	910701	NORM	547	1501	1469	417	418	38.47	39.77
U	910715	G	561	1181	1198	-320	-271	-21.32	-18.45
V	910728	F	574	1280	1310	99	112	8.38	9.35
Y	921027	INT	1031	1317	1223	37	-87	2.89	-6.64
B23	931018	INT	1387	1118	1160	-199	-63	-15.11	-5.15
C23	940419	INT	1570	954	825	-164	-335	-14.67	-28.88
D23	941128	INT	1793	1402	1258	448	433	46.96	52.48



123 MILE
Area Distribution Histograms

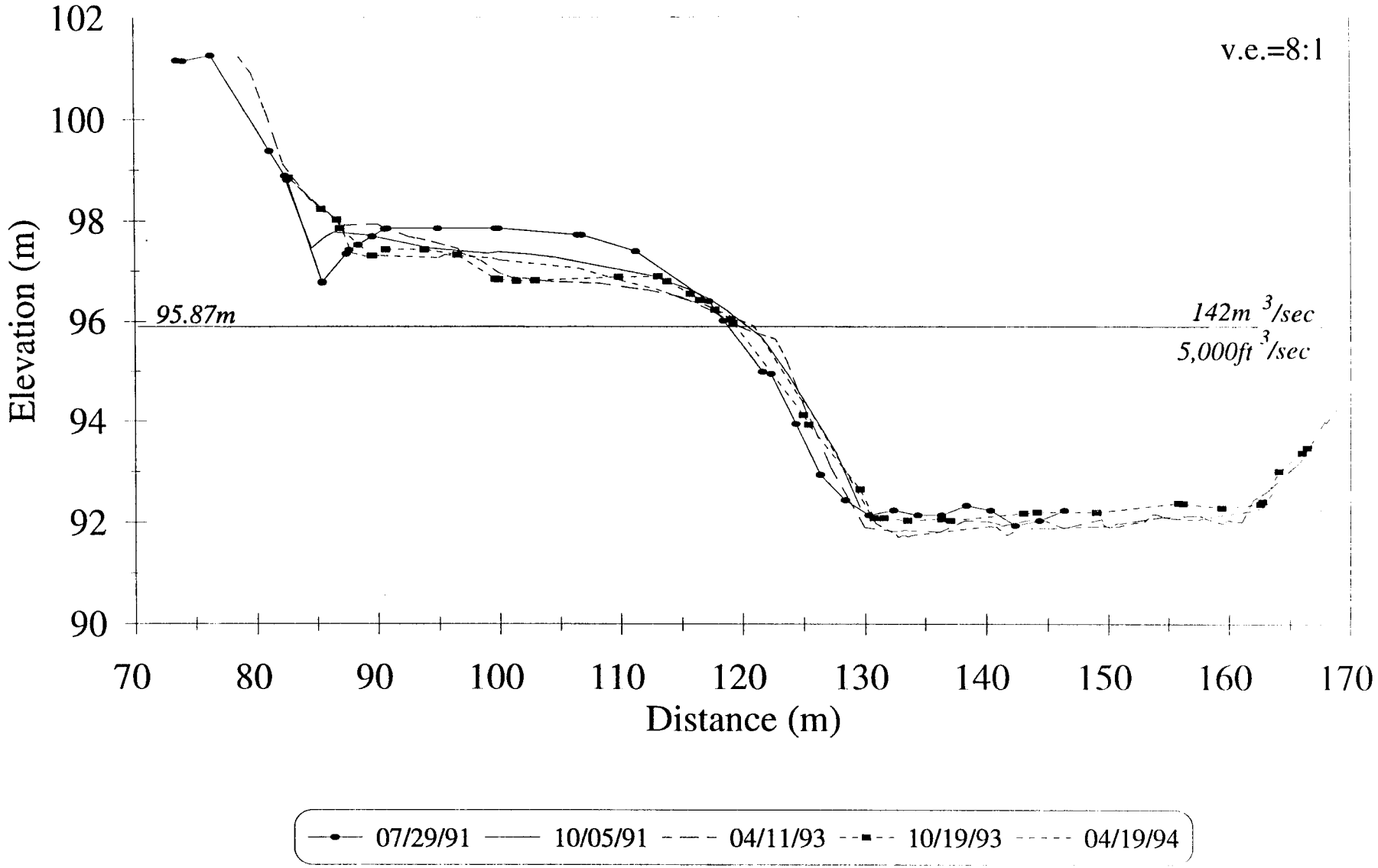



137 L
5-30-94
Area of Study
N
RM 136.5

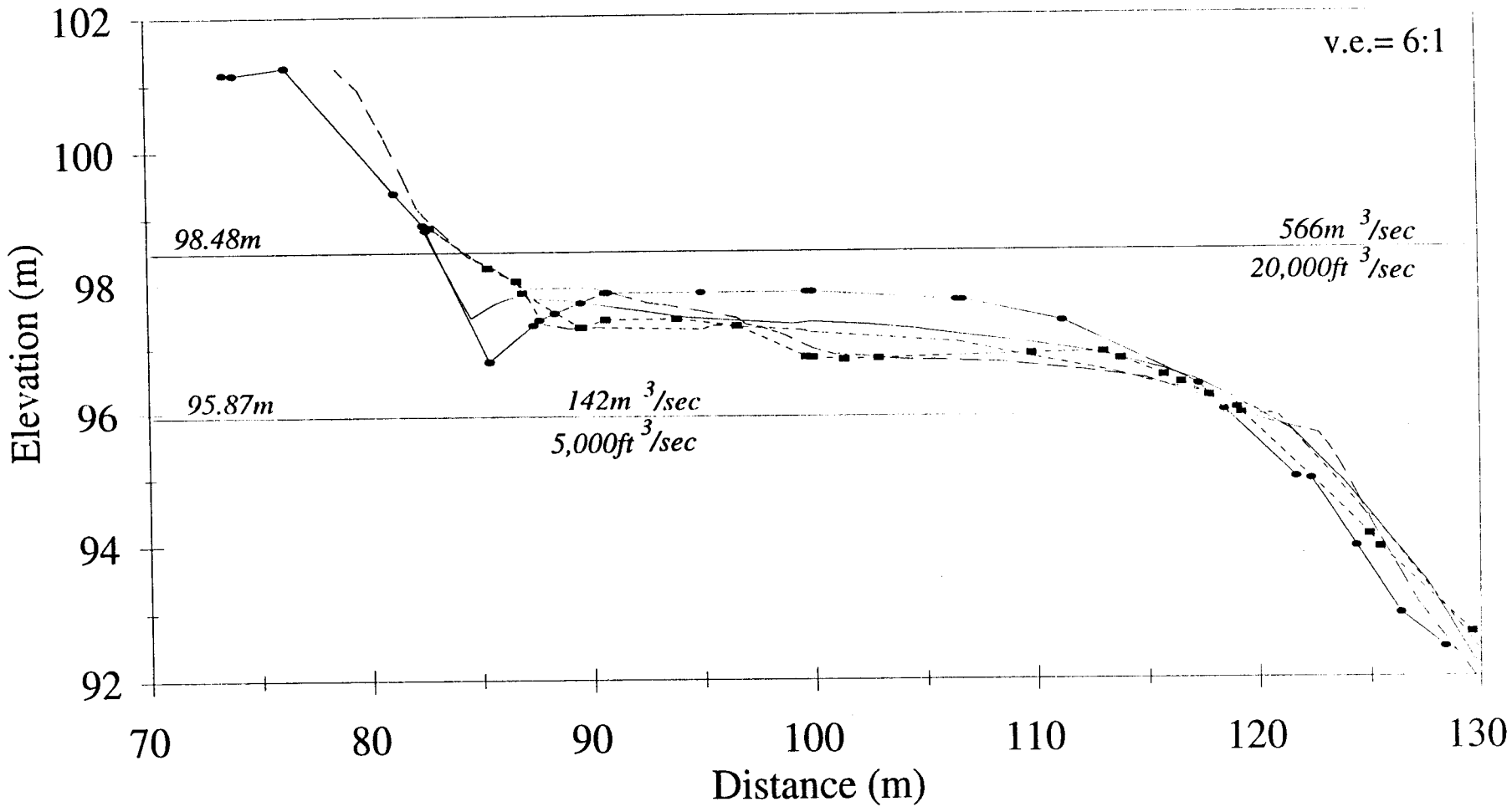

BM
P1
P2
P3
P4
P5
P6
P7
BS1
BS2
N
137 Mile – Middle Ponchos
0.5 Meter Contour Interval
Survey Date: 4/18/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:800

137 Mile

Cross-channel P1

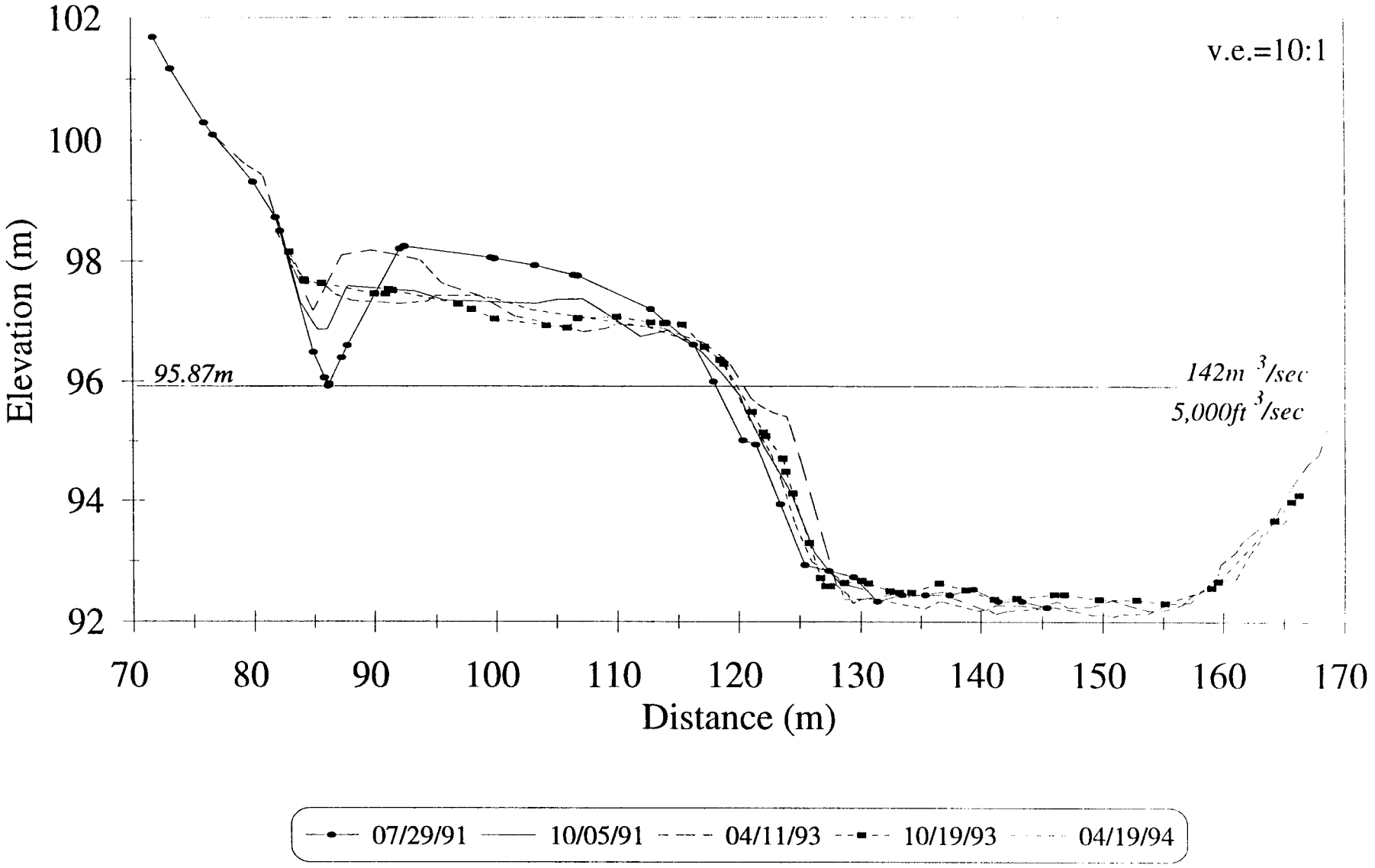


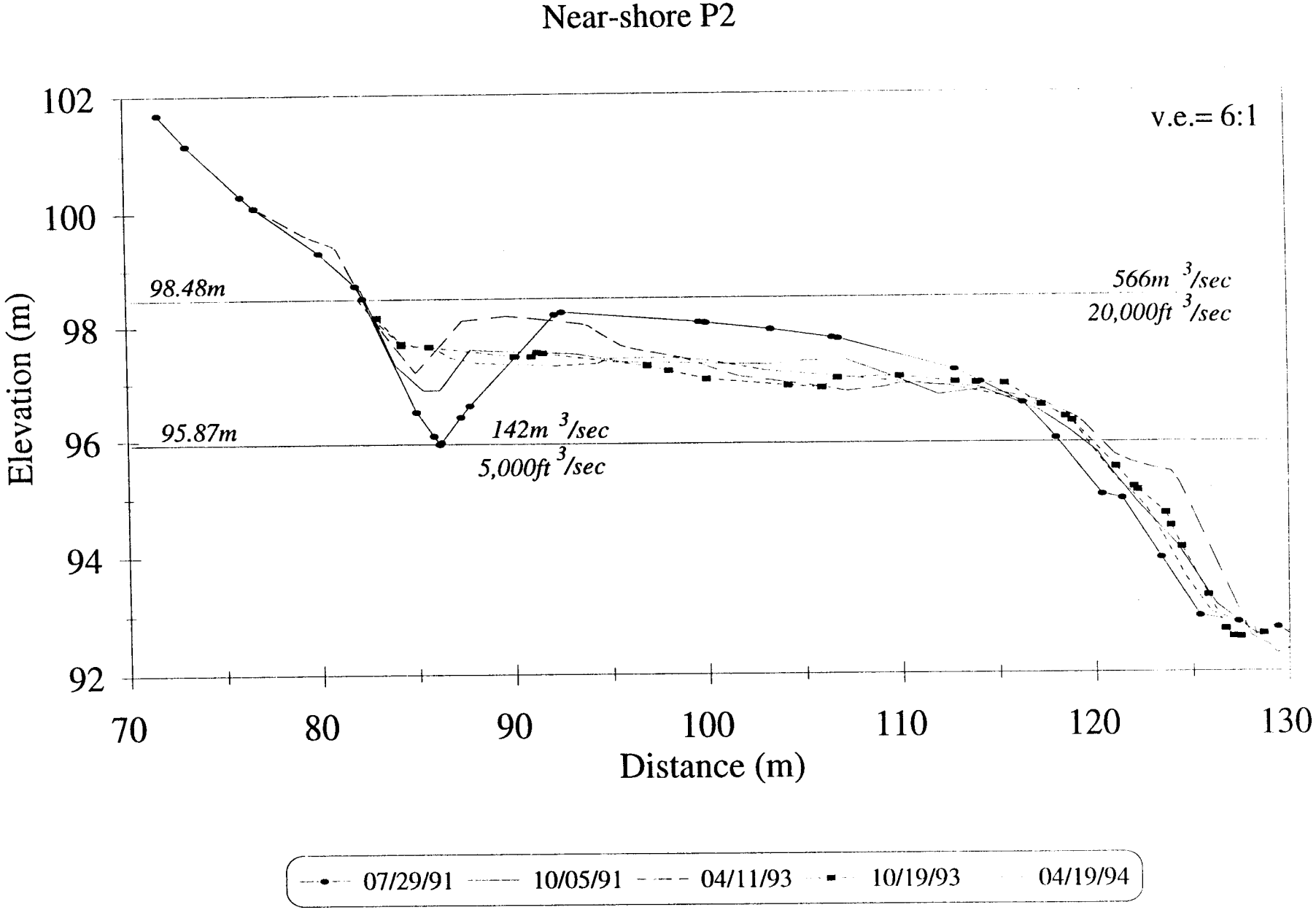
Near-shore P1



137 Mile

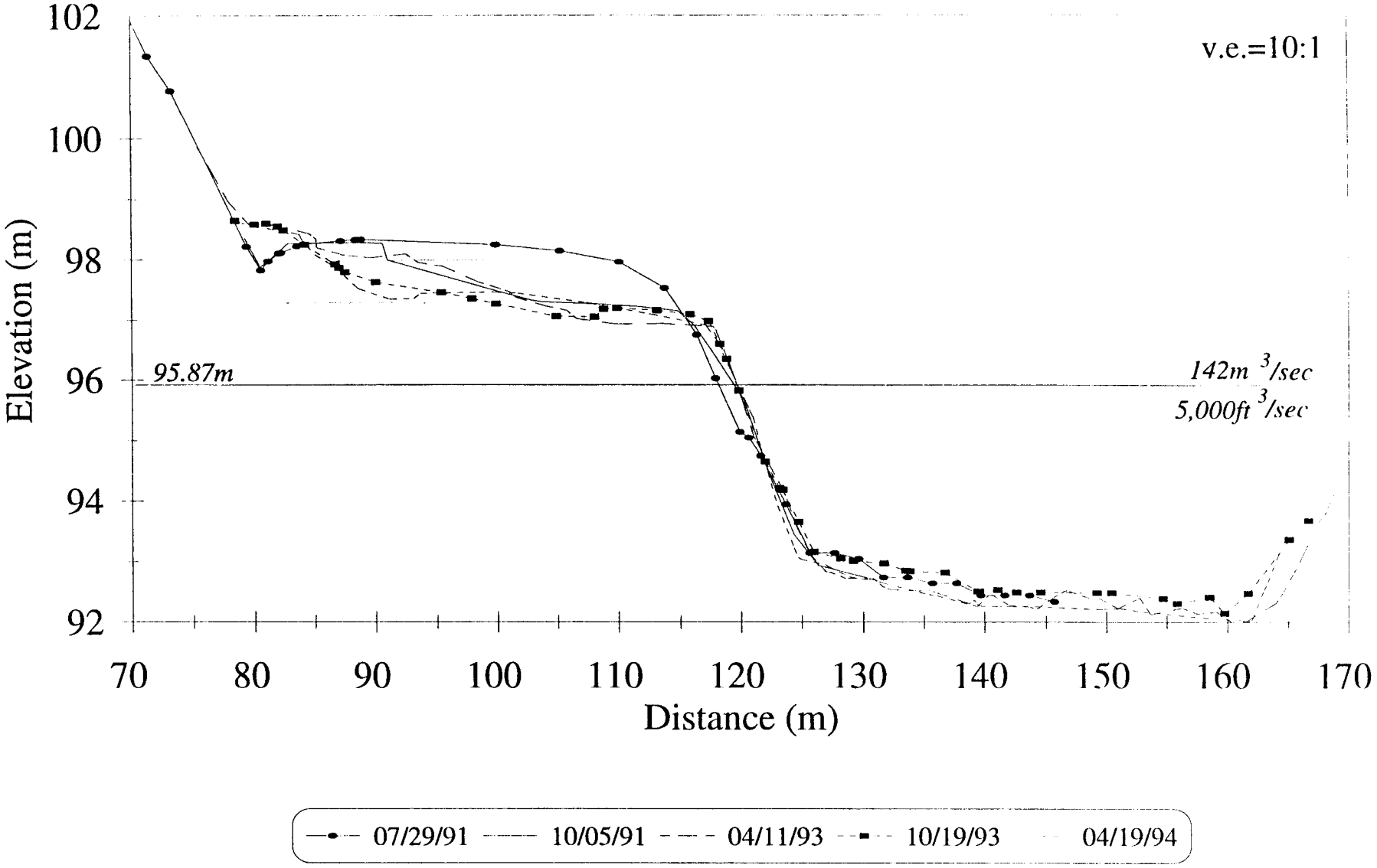
Cross-channel P2

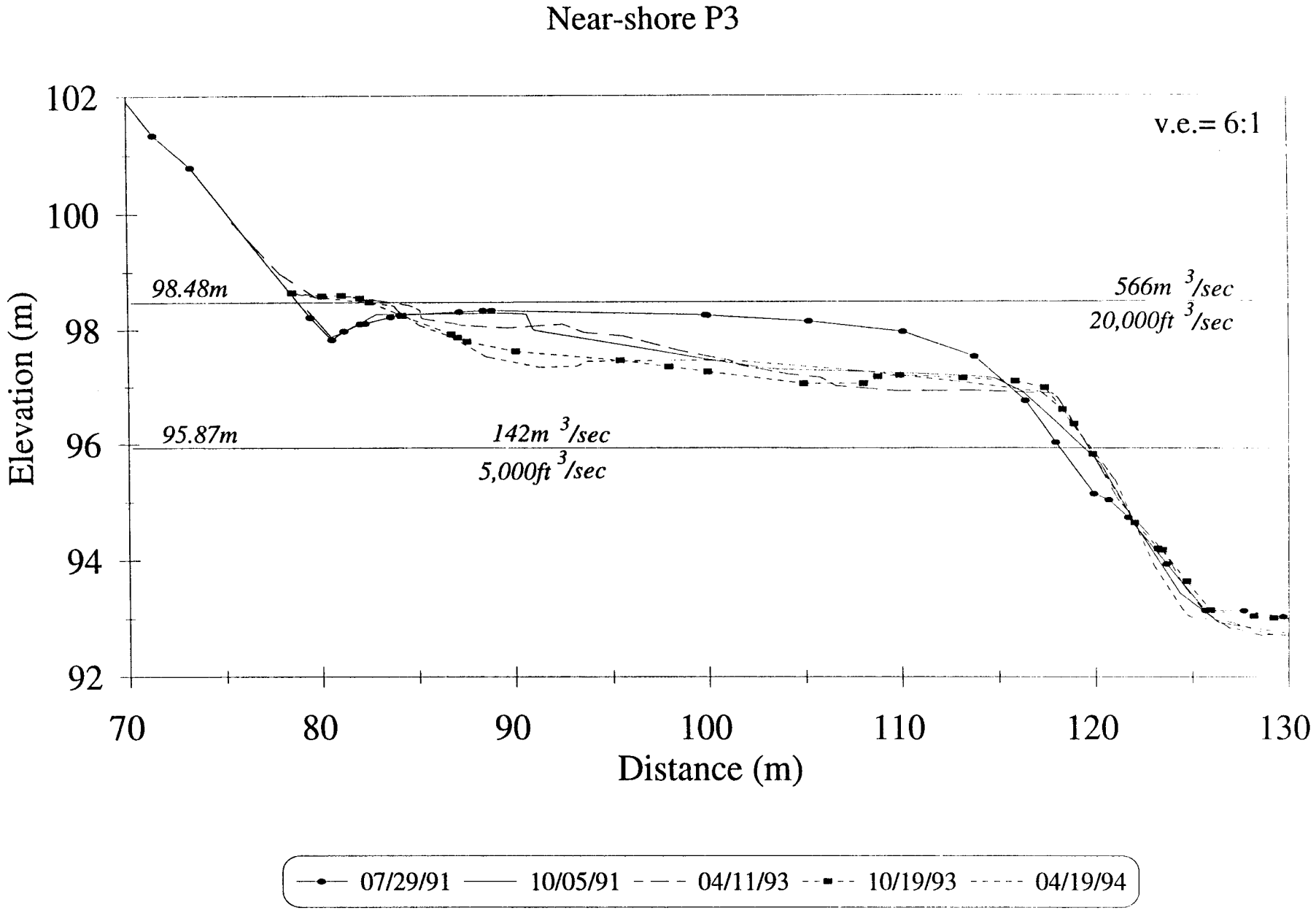



Near-shore P2
v.e.= 6:1
102
100
98
96
94
92
Elevation (m)
98.48m
95.87m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
70
80
90
100
110
120
130
Distance (m)
07/29/91
10/05/91
04/11/93
10/19/93
04/19/94

137 Mile

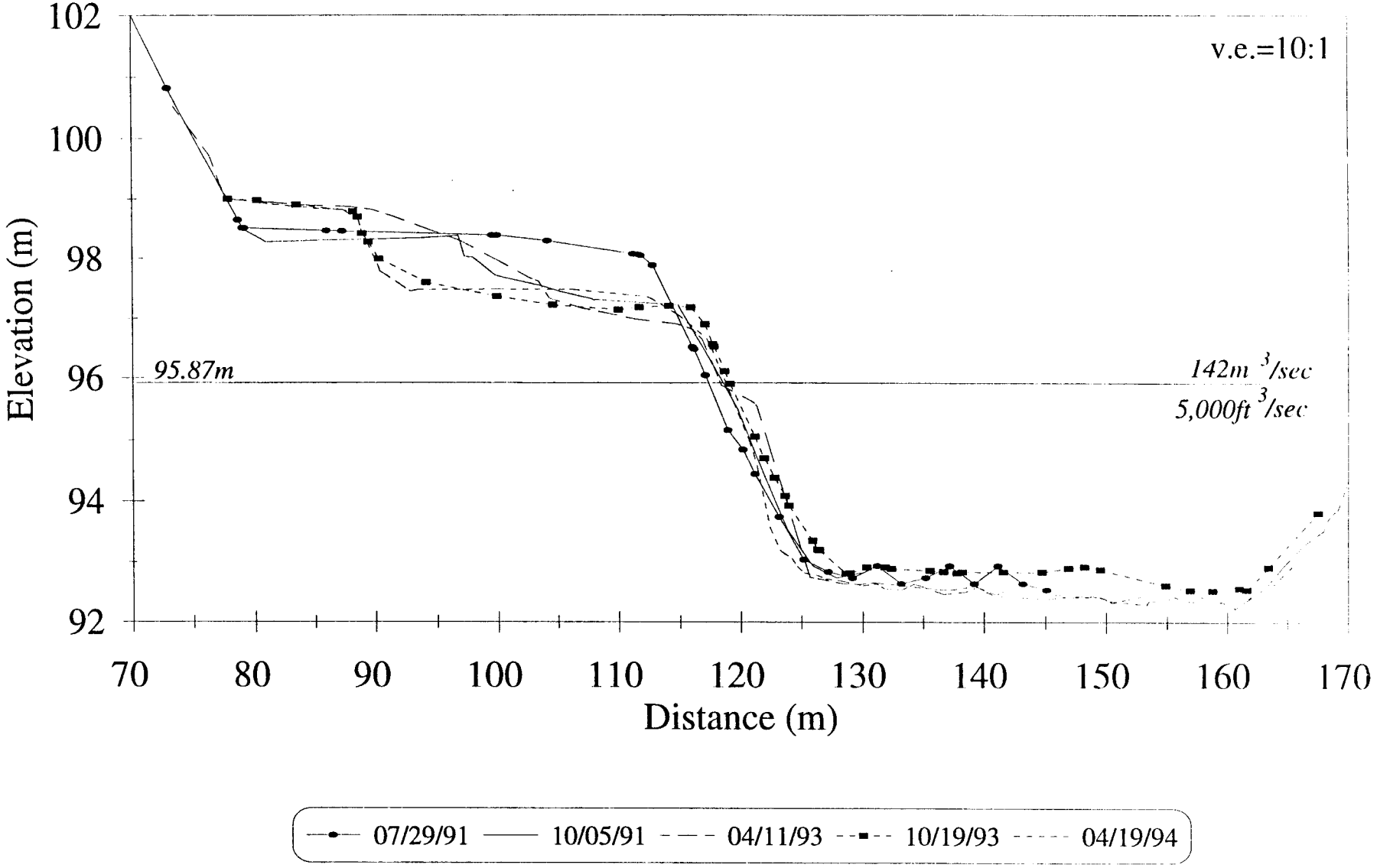
Cross-channel P3



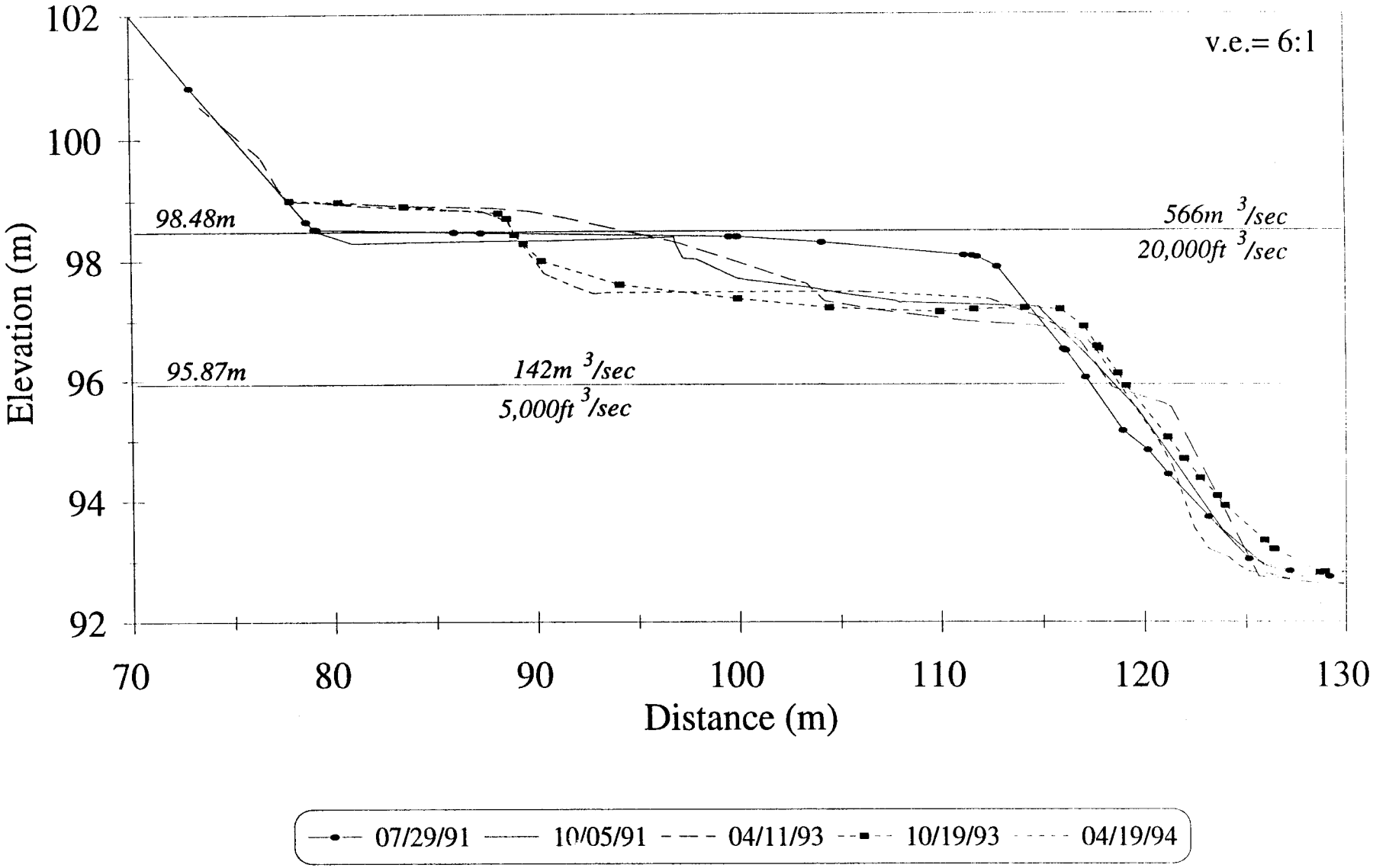

Near-shore P3
v.e.= 6:1
Elevation (m)
102
100
98
96
94
92
98.48m
566m 3/sec
20,000ft 3/sec
95.87m
142m 3/sec
5,000ft 3/sec
70
80
90
100
110
120
130
Distance (m)
07/29/91
10/05/91
04/11/93
10/19/93
04/19/94

137 Mile

Cross-channel P4

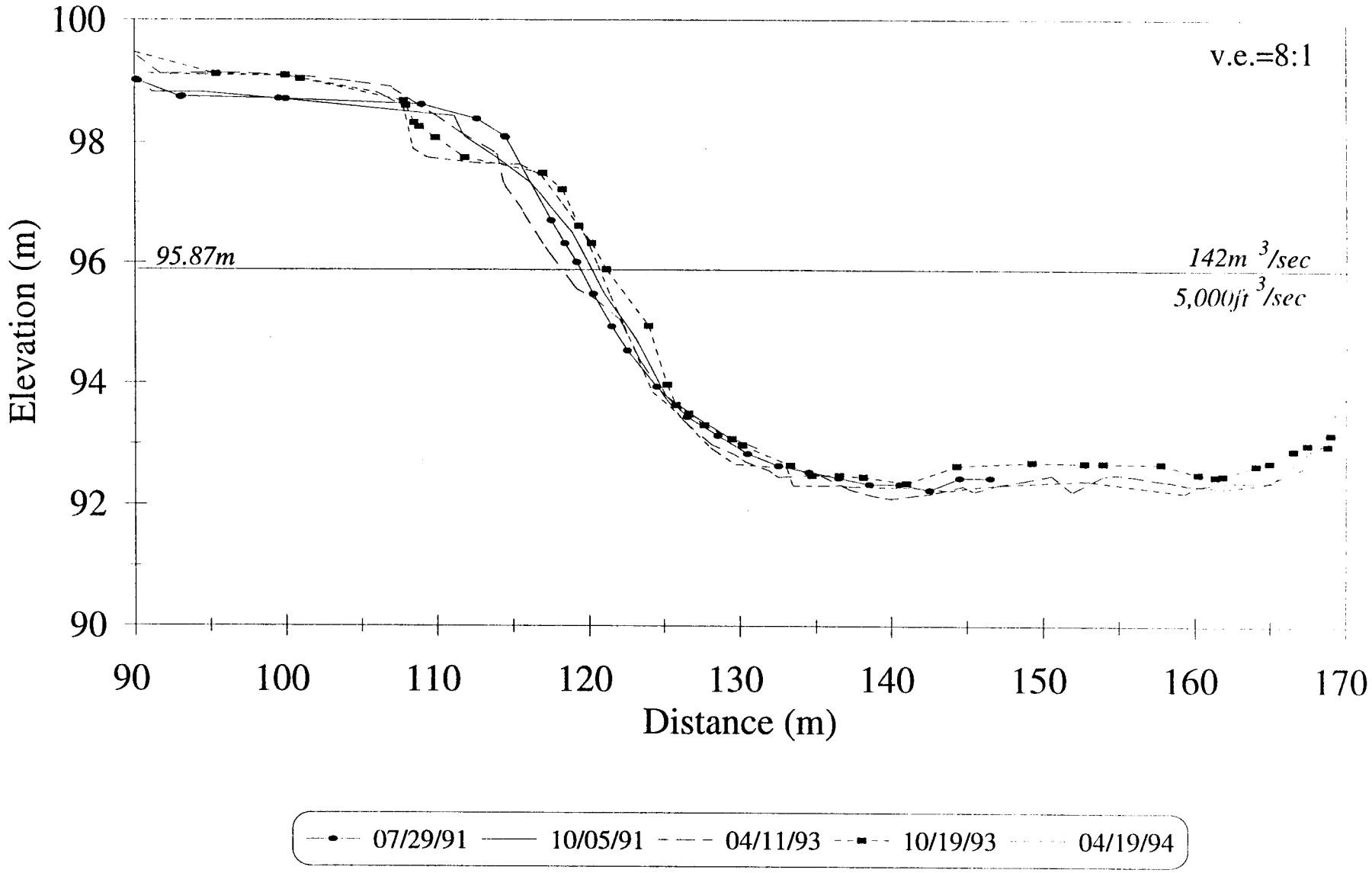


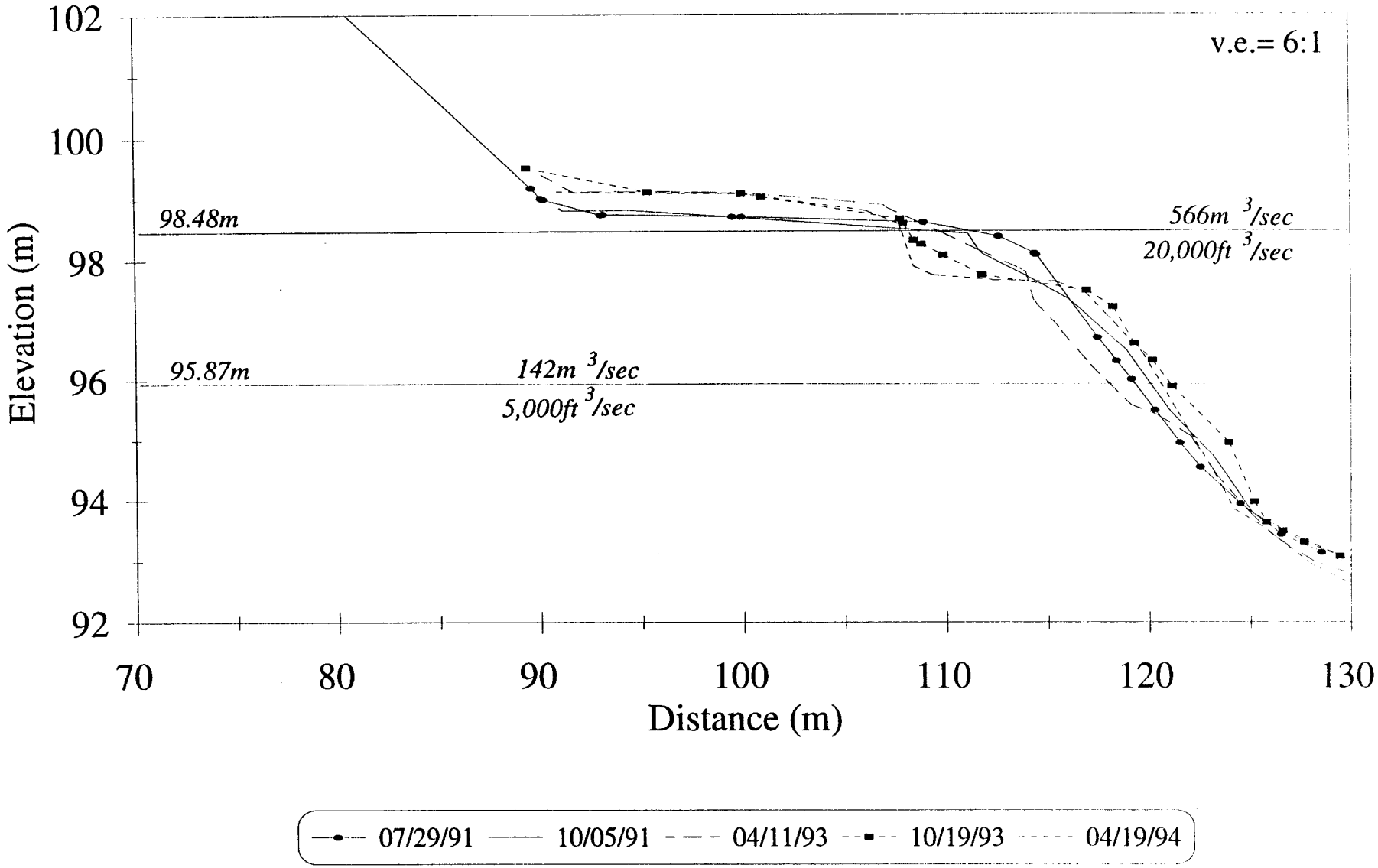
Near-shore P4



137 Mile

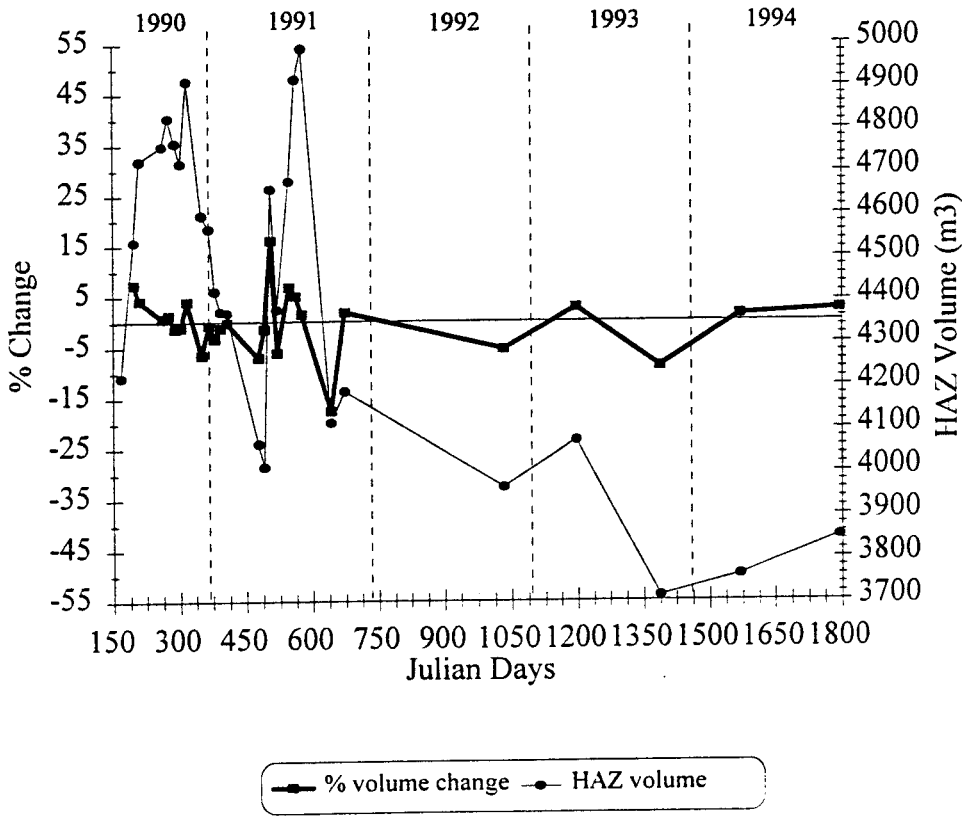
Cross-channel P6




Near-shore P6
v.e.= 6:1
Elevation (m)
102
100
98
96
94
92
98.48m
566m 3/sec
20,000ft 3/sec
95.87m
142m 3/sec
5,000ft 3/sec
70
80
90
100
110
120
130
Distance (m)
07/29/91
10/05/91
04/11/93
10/19/93
04/19/94

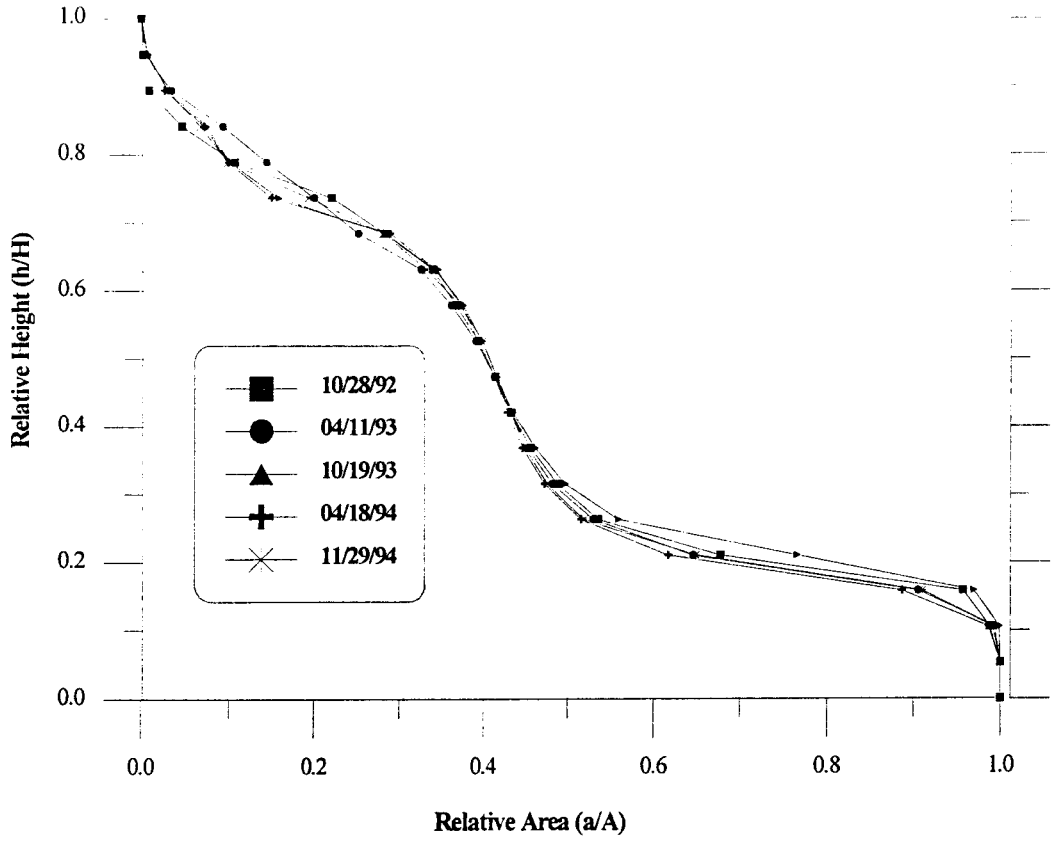
137 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A	900617	NORM	168	3025	4222				
B		NORM							
C	900716	G	197	2953	4537	-72	315	-2.38	7.46
D	900729	F	210	2957	4727	4	190	0.14	4.19
E		NORM							
F	900918	NORM	261	2976	4762	19	35	0.64	0.74
G	901002	E	275	2943	4827	-33	65	-1.11	1.36
H	901016	A	289	2923	4769	-20	-58	-0.68	-1.20
I	901029	8000 CFS	302	2905	4721	-18	-48	-0.62	-1.01
J	901113	NORM	317	2933	4914	28	193	0.96	4.09
K	901217	NORM	351	3012	4599	79	-315	2.69	-6.41
L	910101	11000 CFS	366	2989	4568	-23	-31	-0.76	-0.67
M	910114	C	379	3009	4422	20	-146	0.67	-3.20
N	910128	NORM	393	3016	4374	7	-48	0.23	-1.09
O	910211	B	407	3018	4371	2	-3	0.07	-0.07
P	910422	NORM	477	2943	4067	-75	-304	-2.49	-6.95
Q	910506	NORM	491	2953	4014	10	-53	0.34	-1.30
R	910520	D	505	2854	4661	-99	647	-3.35	16.12
S	910603	15000 CFS	519	2946	4379	92	-282	3.22	-6.05
T	910701	NORM	547	2831	4679	-115	300	-3.90	6.85
U	910715	G	561	2864	4917	33	238	1.17	5.09
V	910729	F	575	2924	4989	60	72	2.09	1.46
W	911005	INT	642	3018	4116	94	-873	3.21	-17.50
X	911104	INT	673	2965	4189	-53	73	-1.76	1.77
Y	921028	INT	1032	2995	3965	30	-224	1.01	-5.35
Z	930411	INT	1197	2880	4074	-115	109	-3.84	2.75
B24	931019	INT	1388	2976	3712	96	-362	3.33	-8.89
C24	940418	INT	1569	3074	3761	98	49	3.29	1.32
D24	941129	INT	1794	2991	3851	-83	90	-2.70	2.39

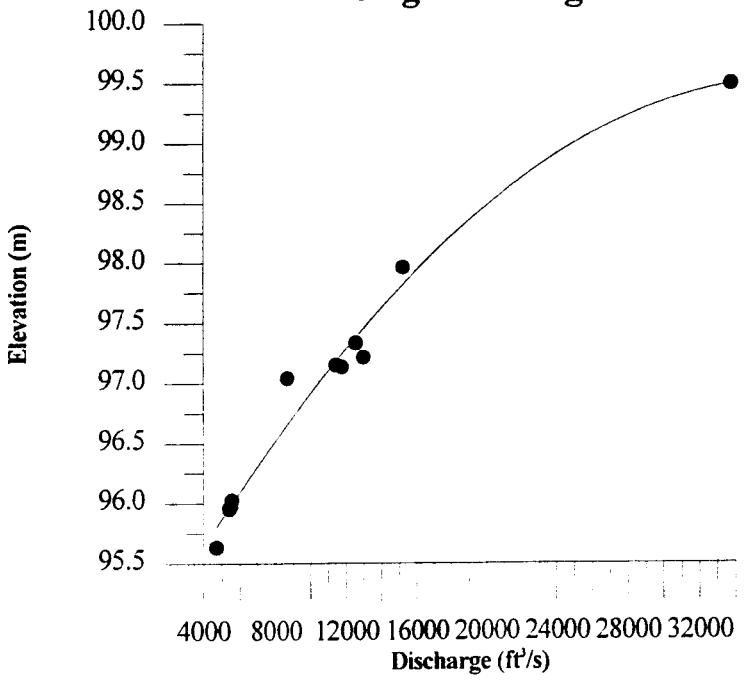


137 Mile

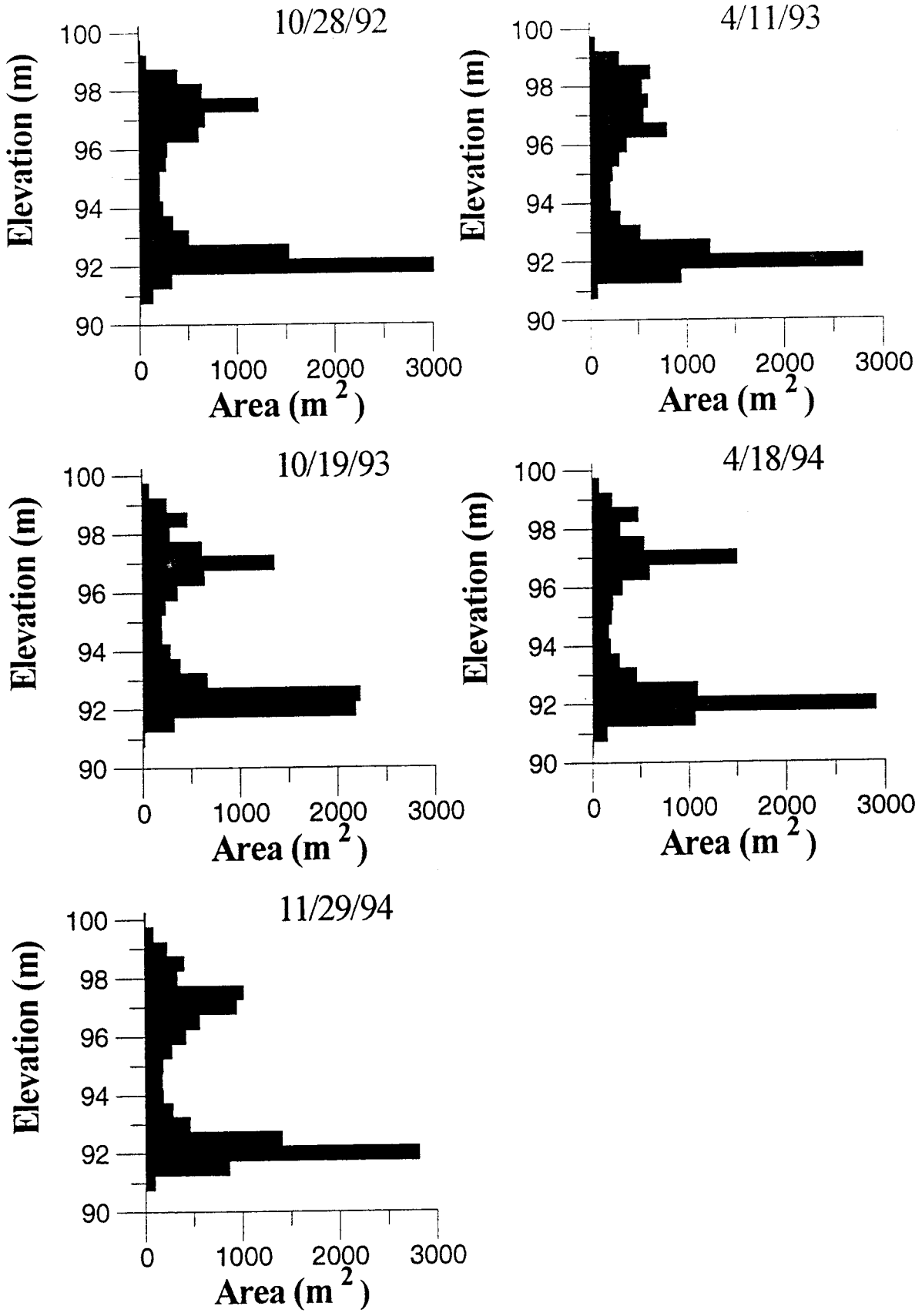
Hypsometric Curves

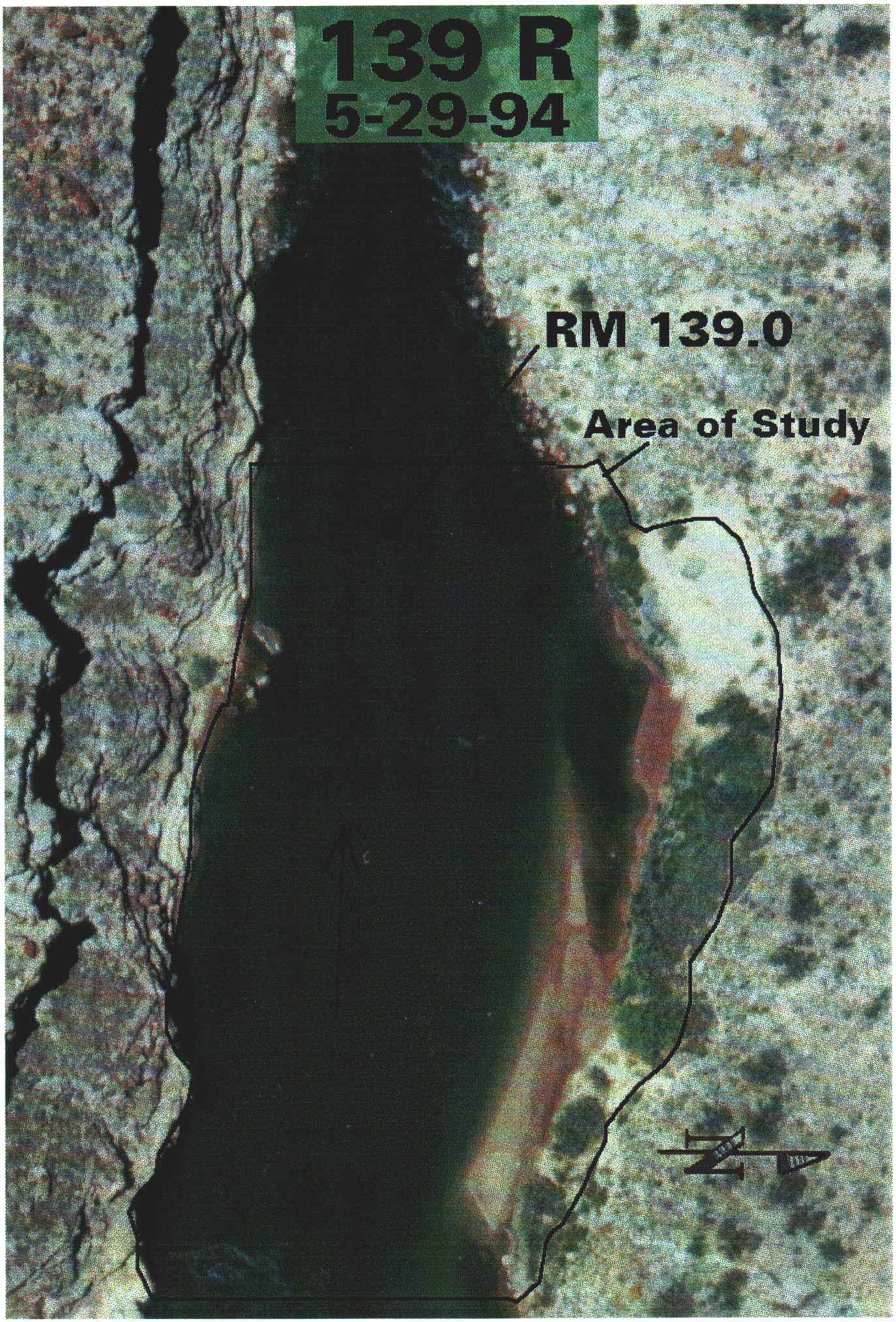


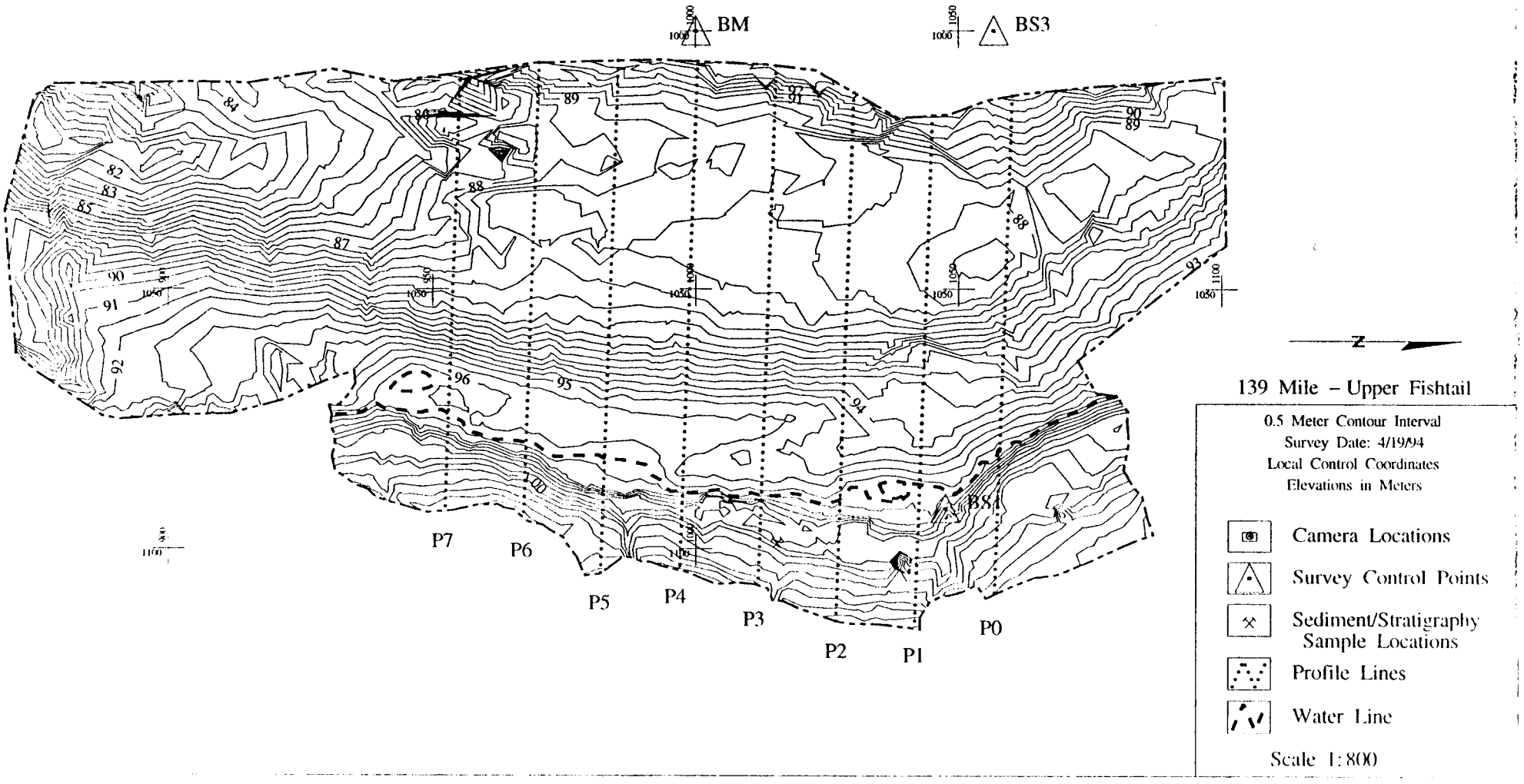
Stage Discharge



137 MILE
Area Distribution Histograms

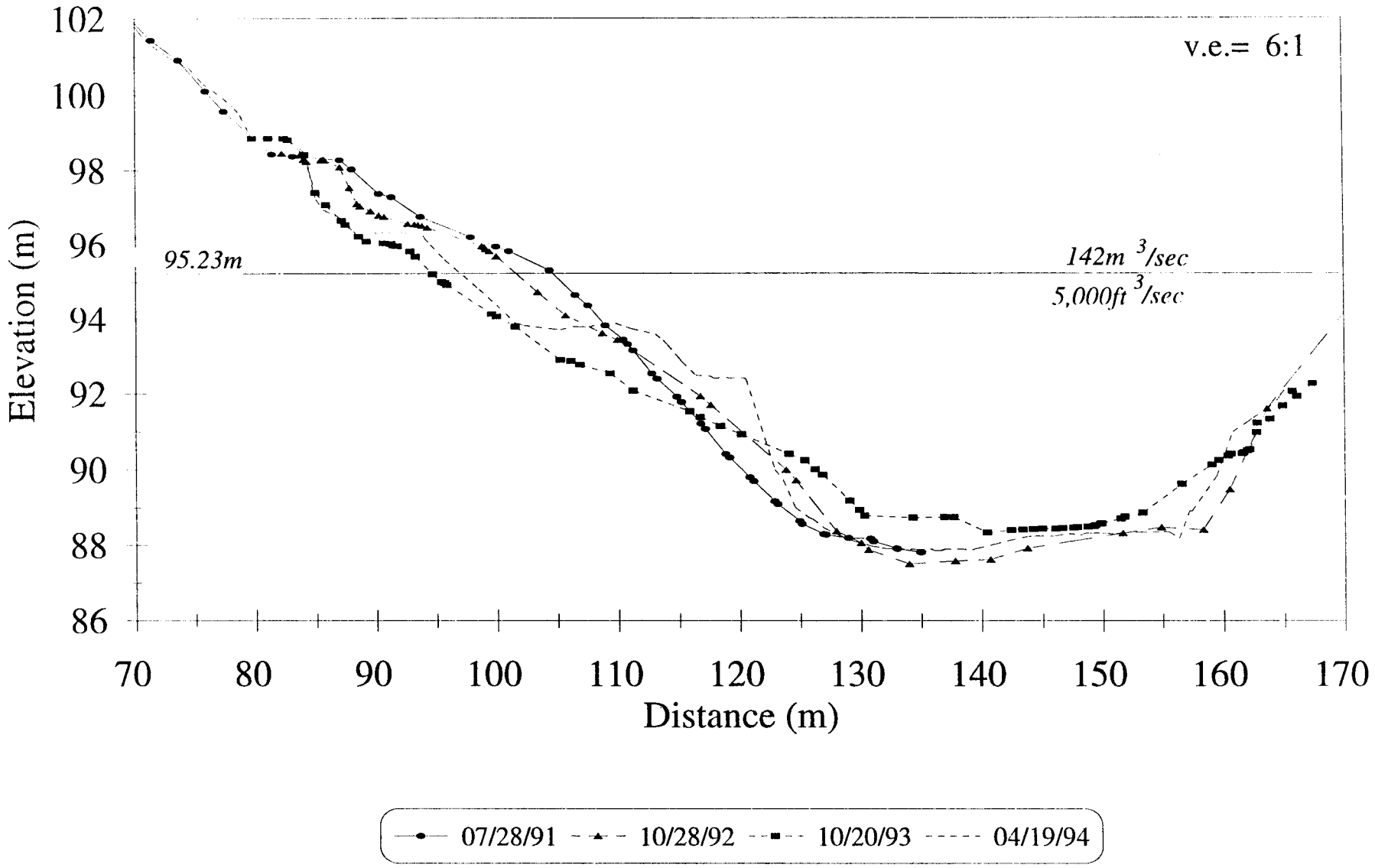


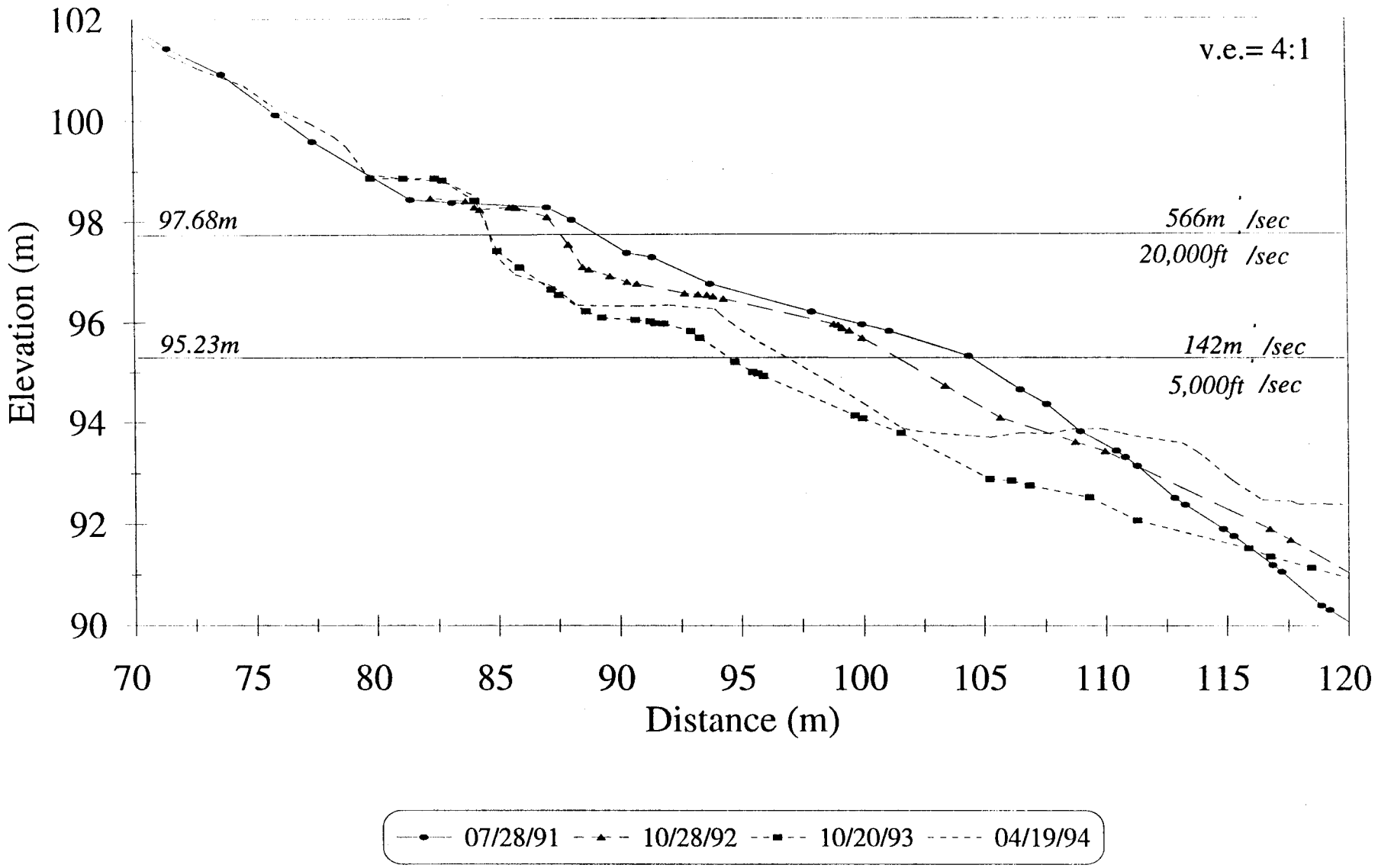

139 R
5-29-94
RM 139.0
Area of Study


BM
BS3
BS1
P7
P6
P5
P4
P3
P2
P1
P0
N
139 Mile – Upper Fishtail
0.5 Meter Contour Interval
Survey Date: 4/19/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:800

139 Mile

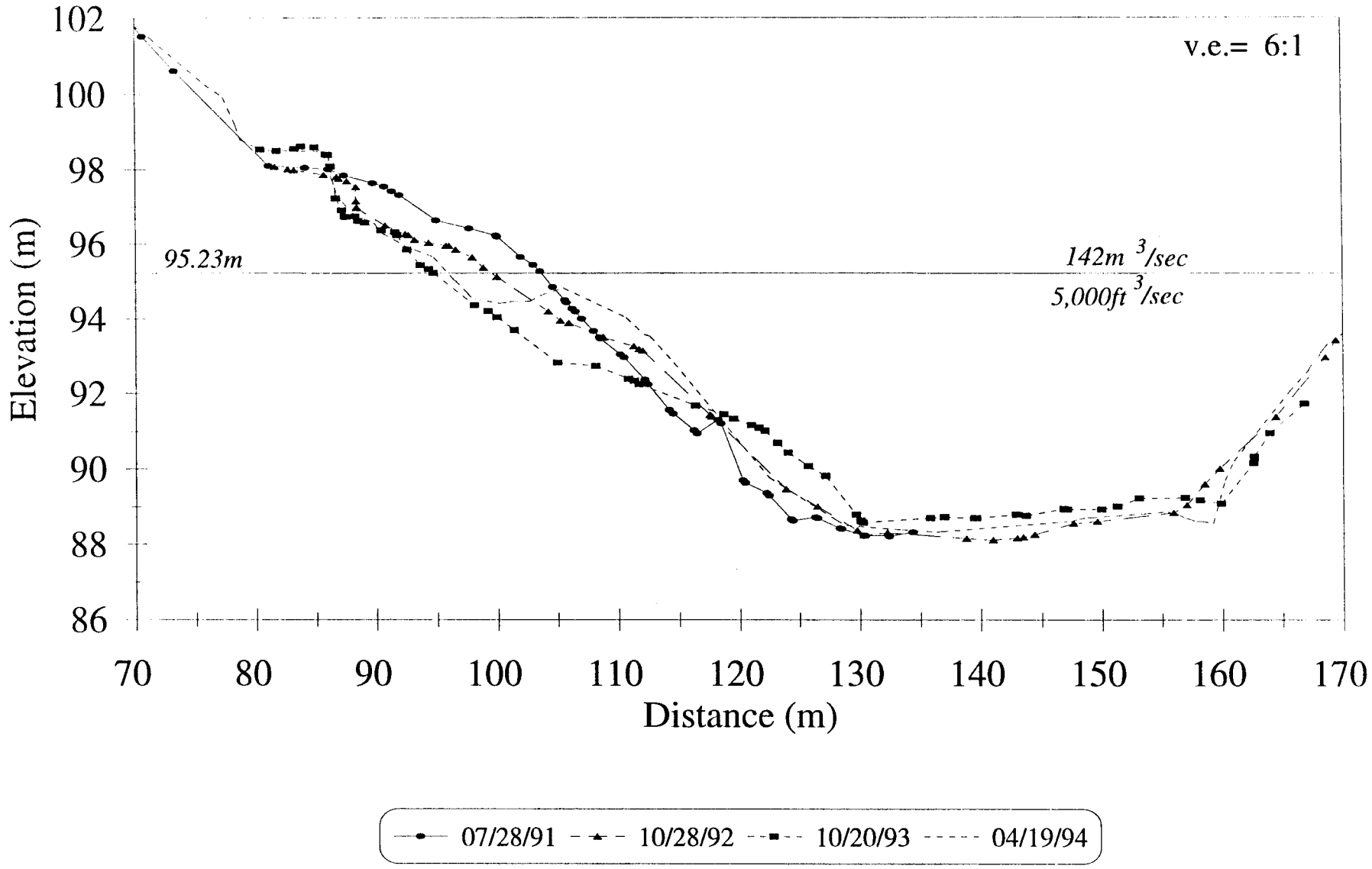
Cross-channel P1

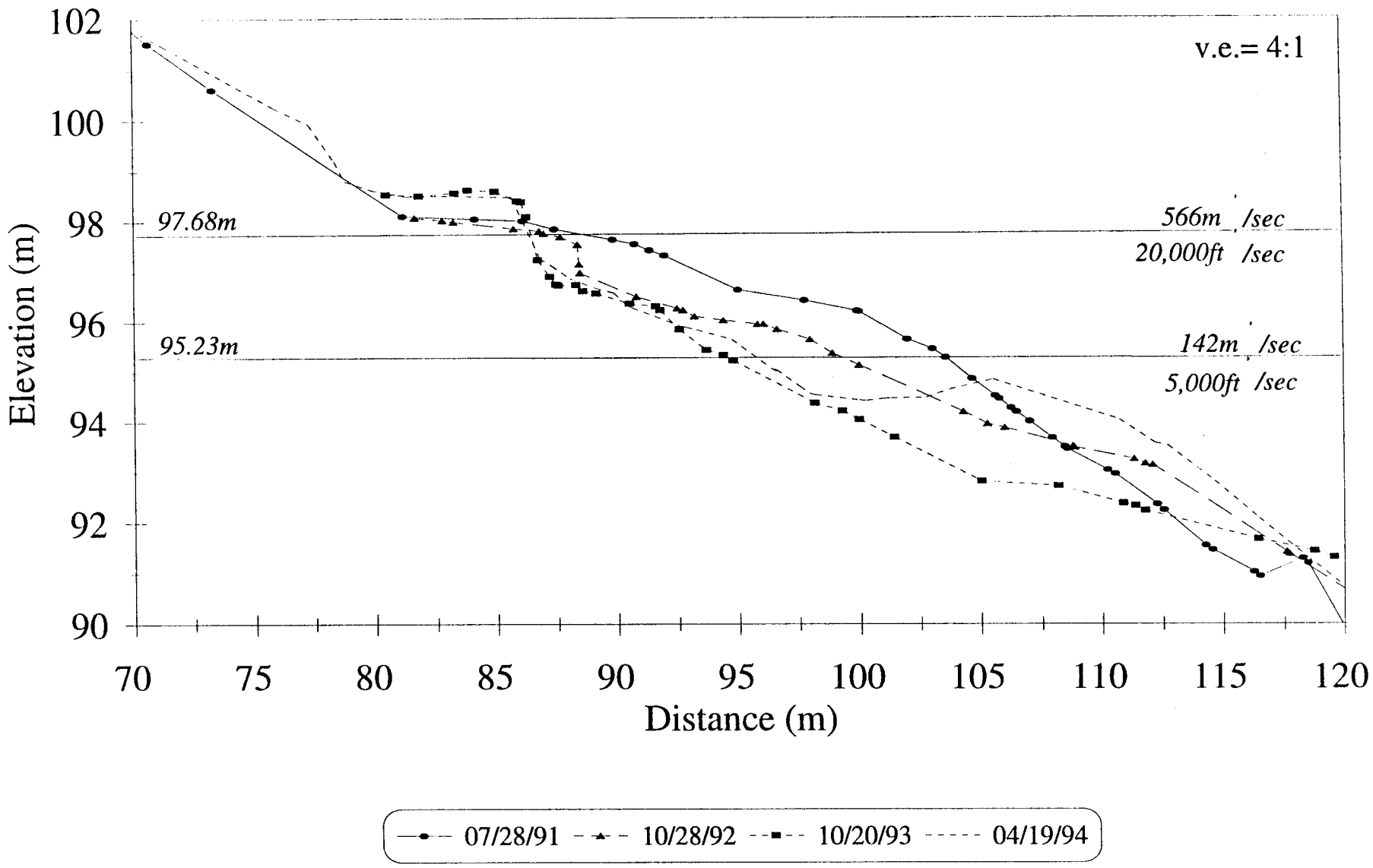



Near-shore P1
v.e.= 4:1
Elevation (m)
102
100
98
96
94
92
90
97.68m
95.23m
566m /sec
20,000ft /sec
142m /sec
5,000ft /sec
70
75
80
85
90
95
100
105
110
115
120
Distance (m)
07/28/91
10/28/92
10/20/93
04/19/94

139 Mile

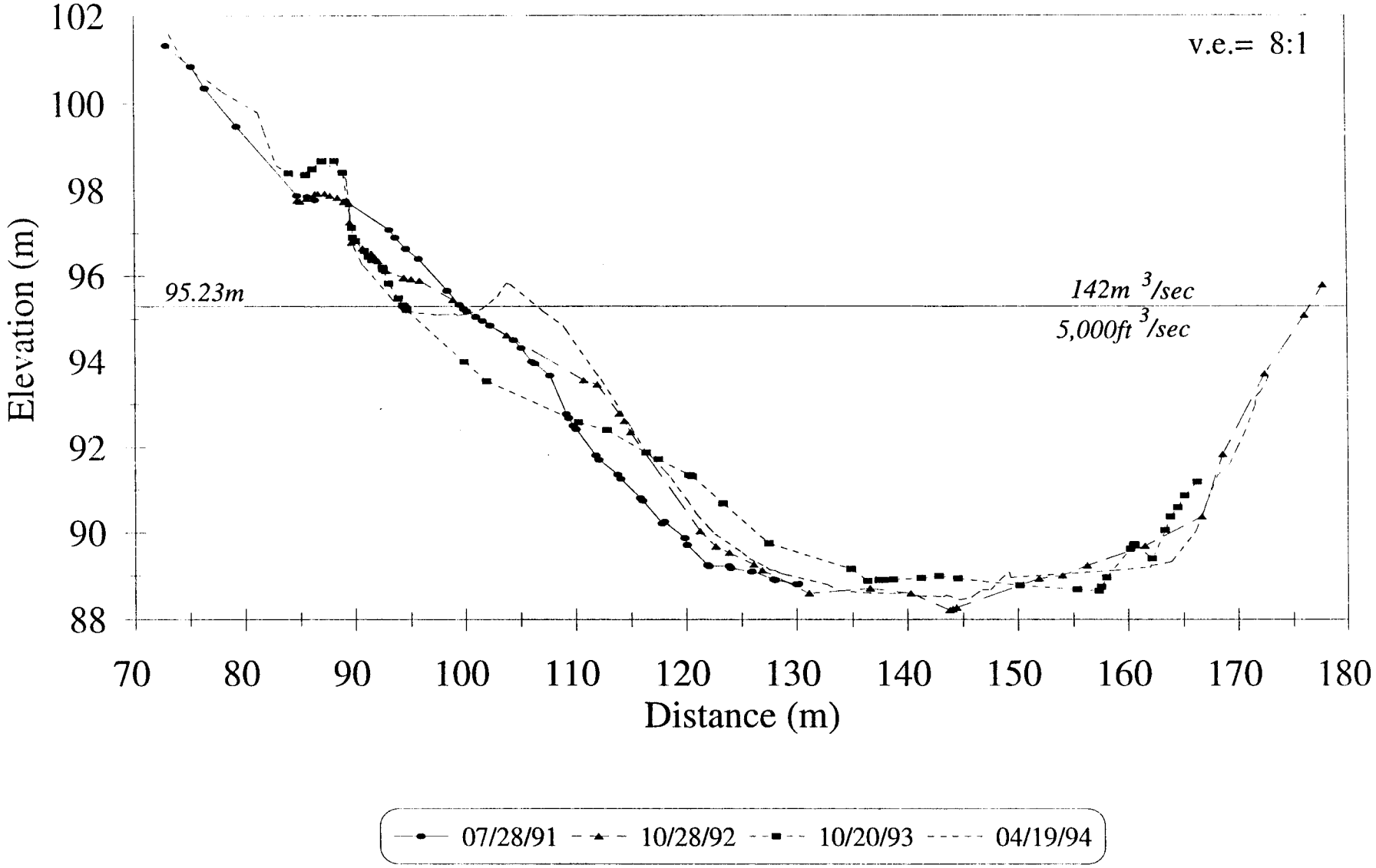
Cross-channel P2



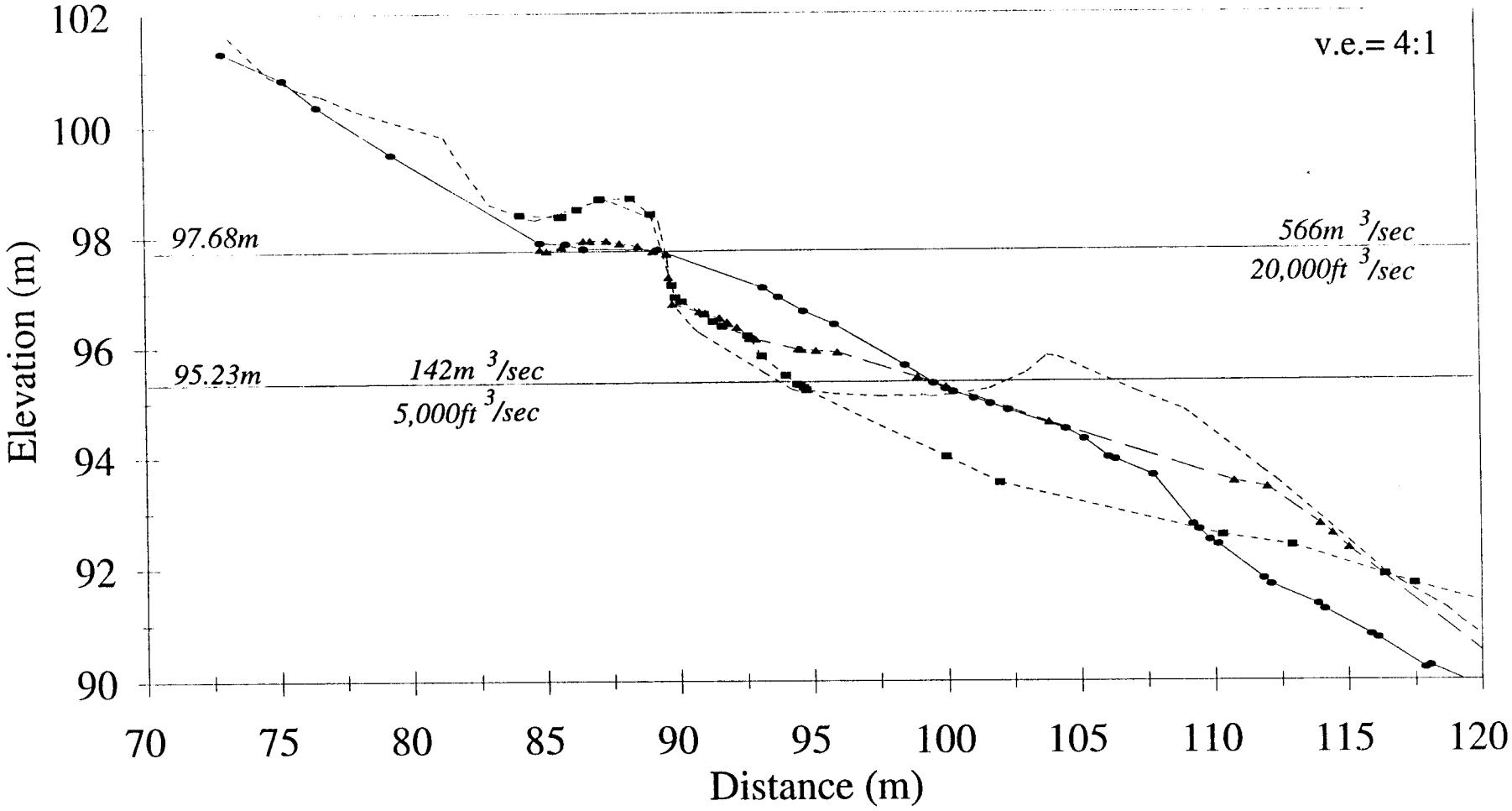

Near-shore P2
v.e.= 4:1
Elevation (m)
102
100
98
96
94
92
90
97.68m
95.23m
566m /sec
20,000ft /sec
142m /sec
5,000ft /sec
70
75
80
85
90
95
100
105
110
115
120
Distance (m)
07/28/91
10/28/92
10/20/93
04/19/94

139 Mile

Cross-channel P3

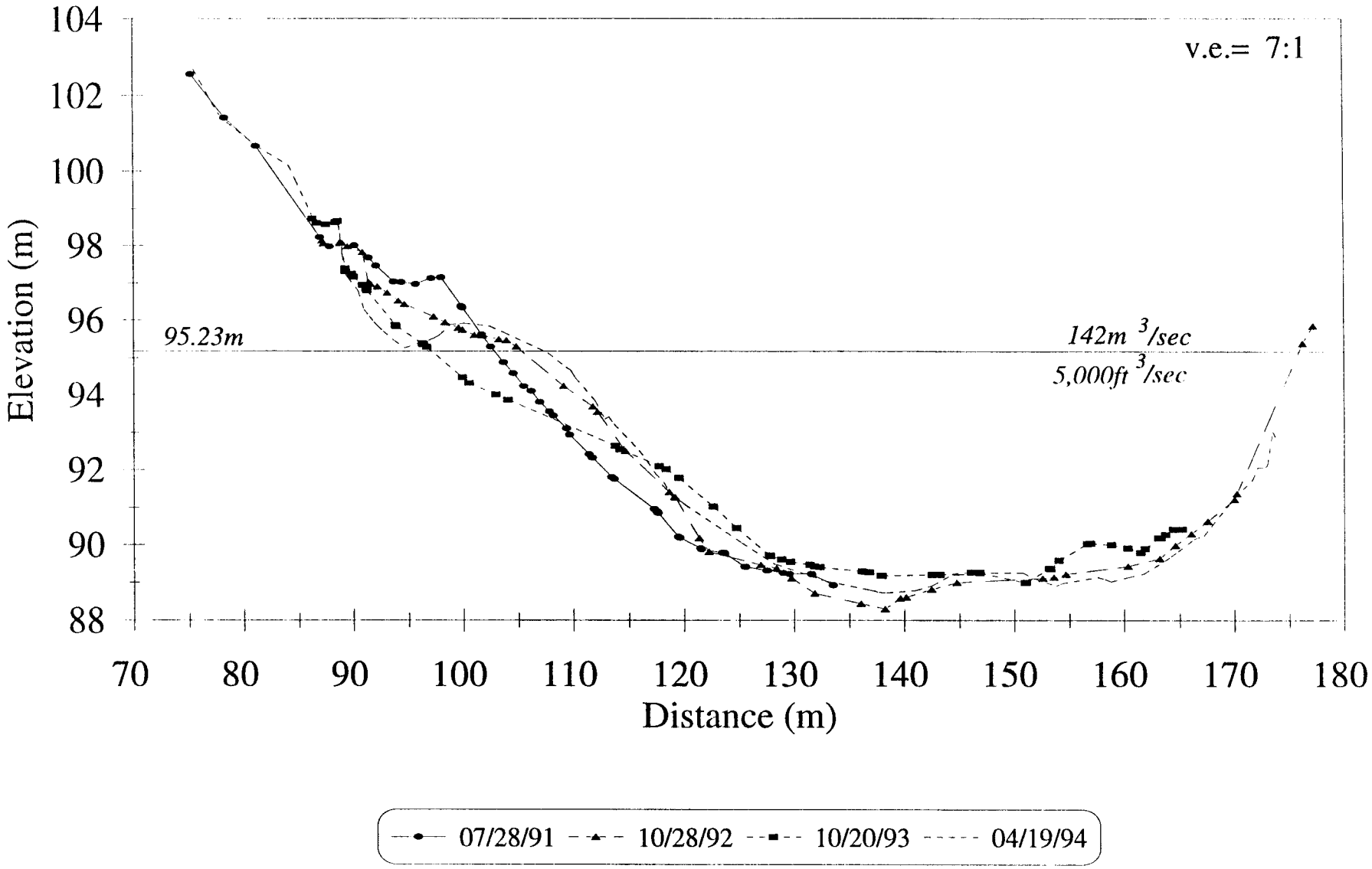


Near-shore P3

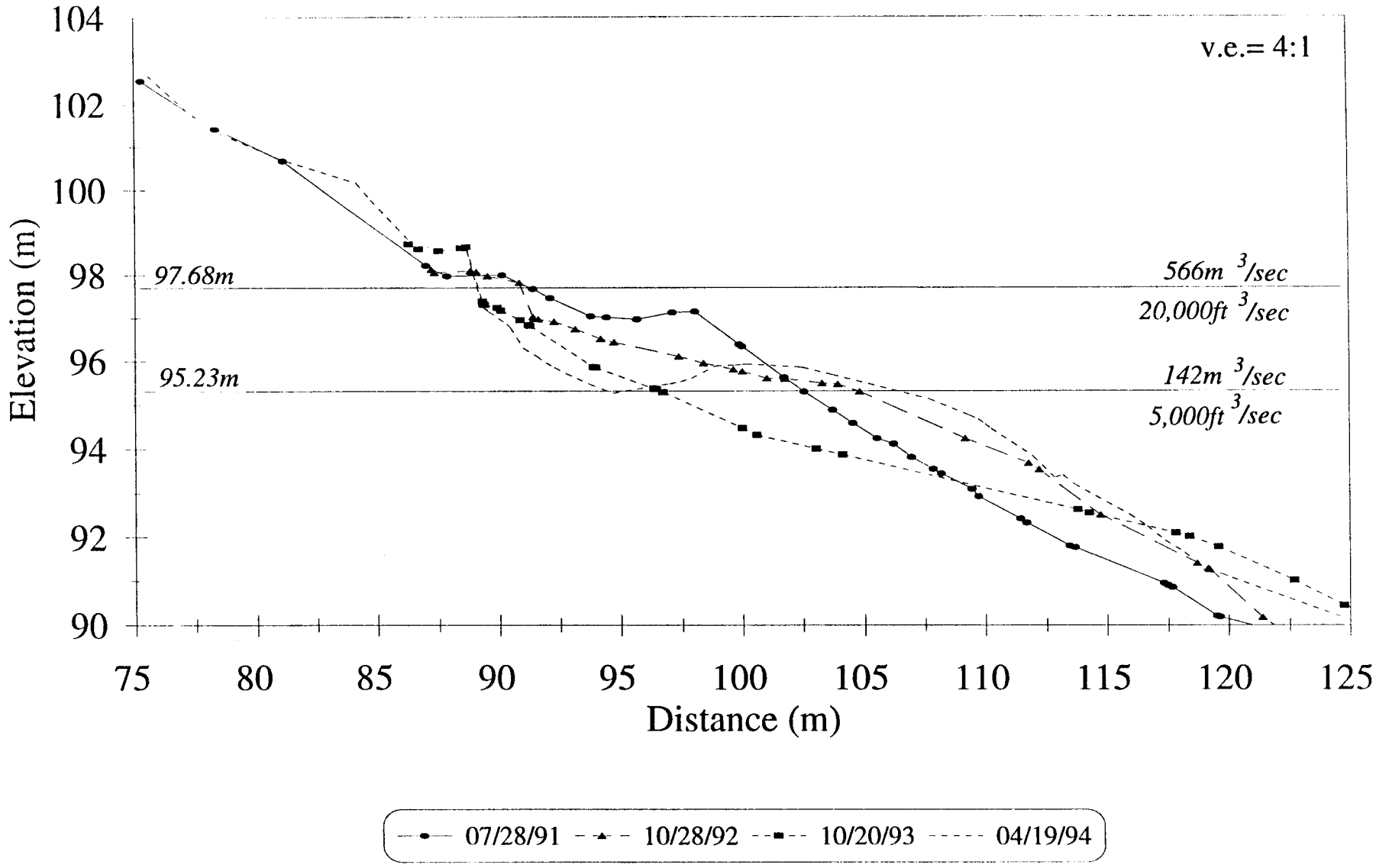


139 Mile

Cross-channel P4

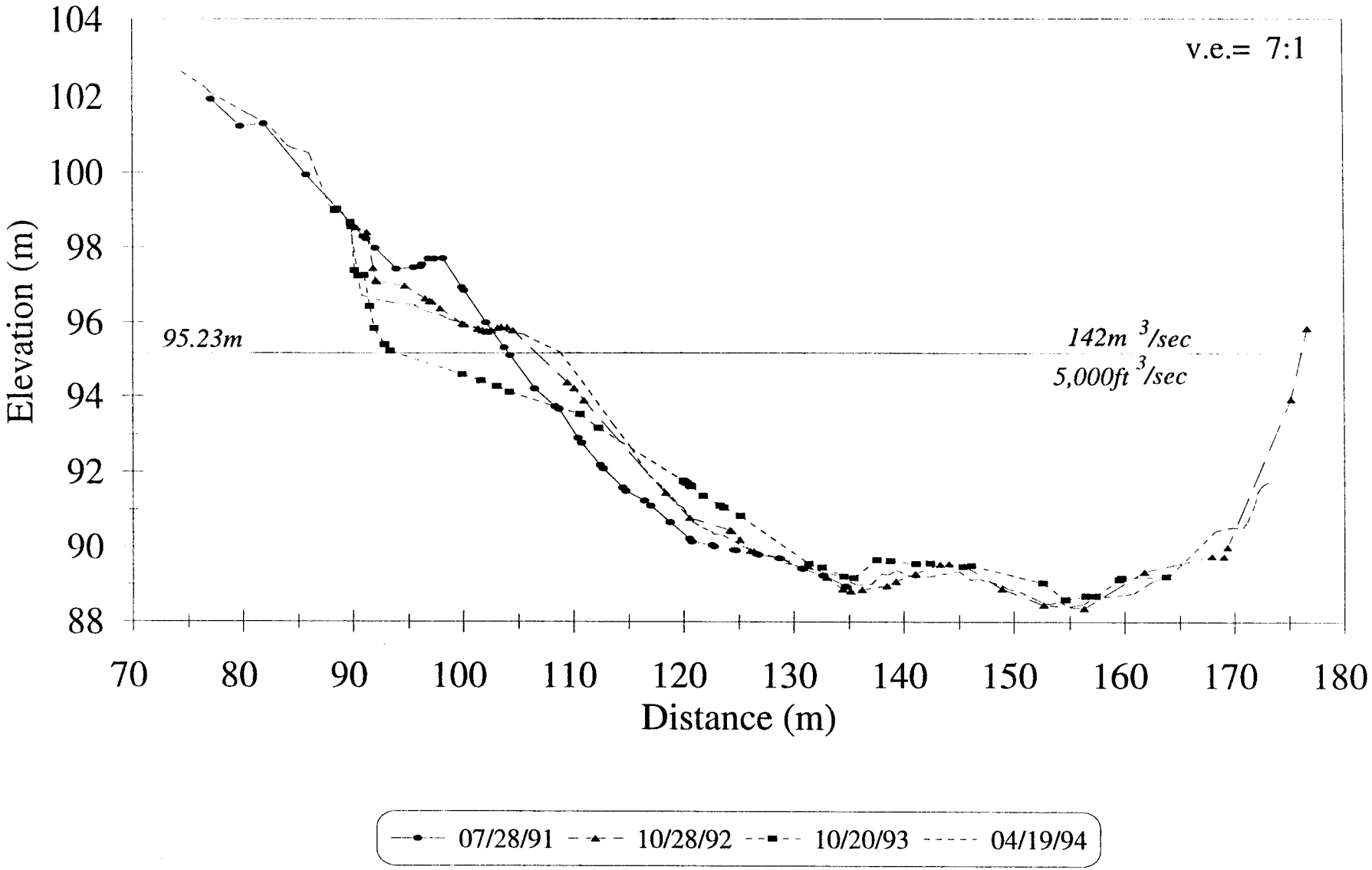


Near-shore P4

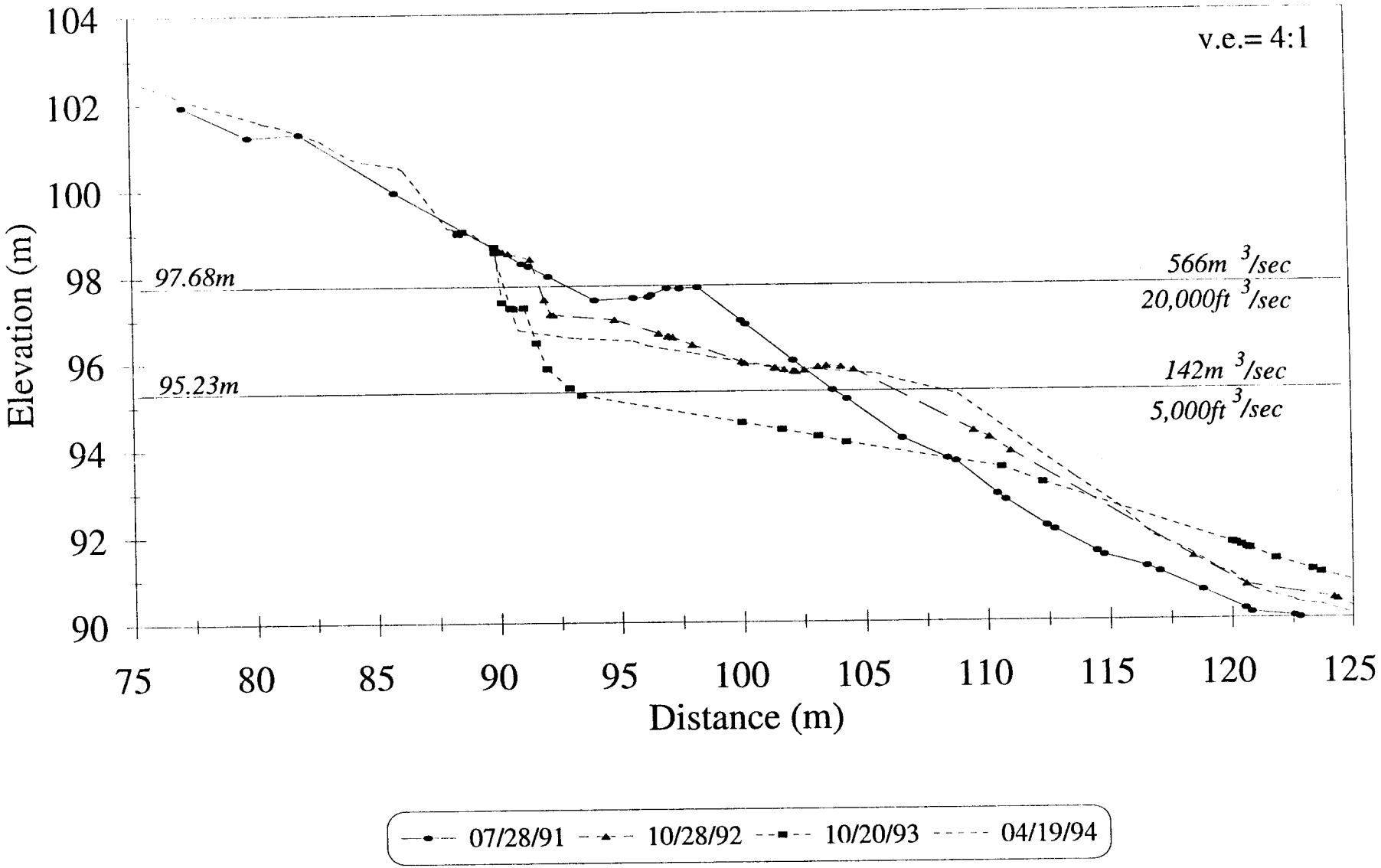


139 Mile

Cross-channel P5

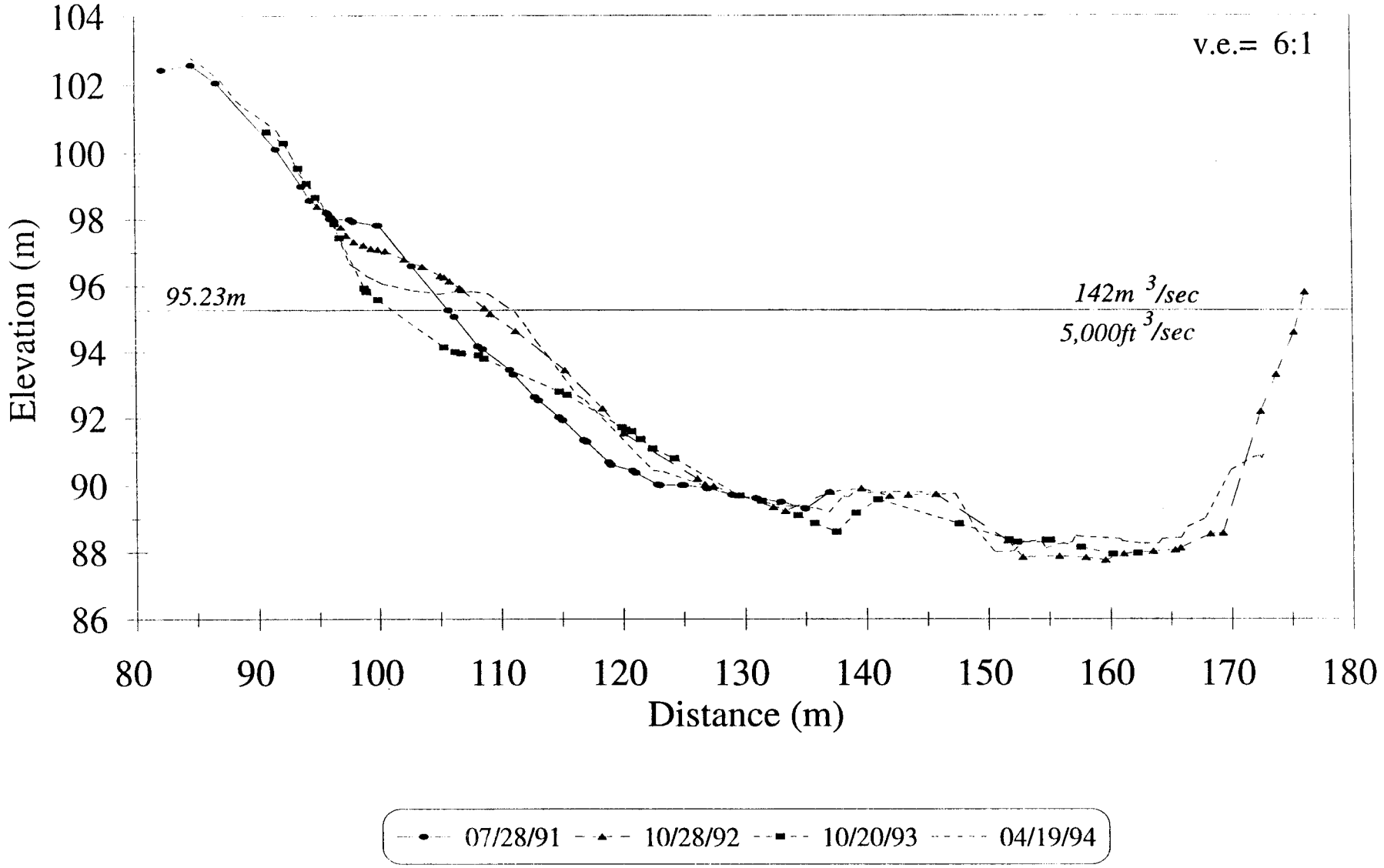


Near-shore P5

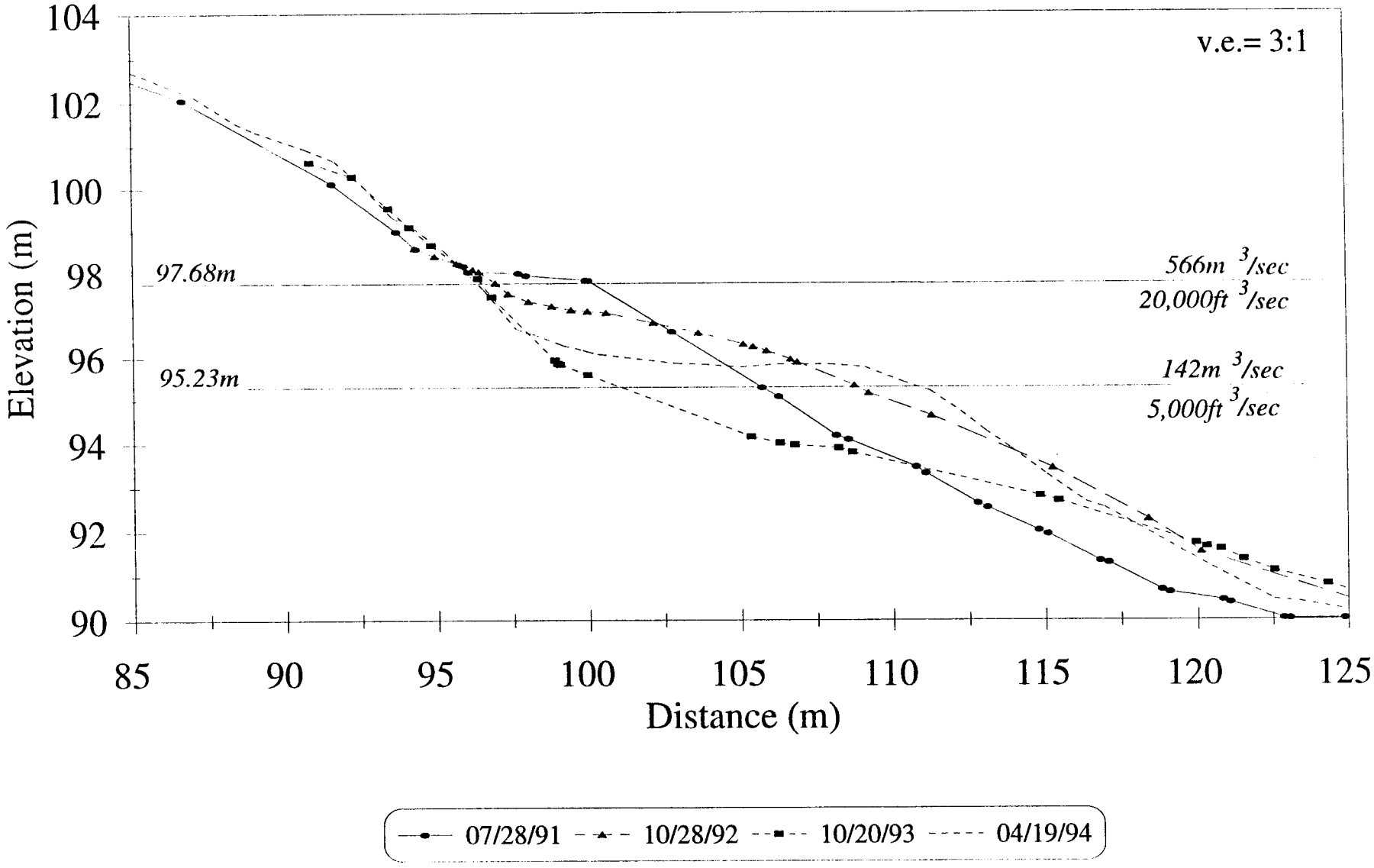


139 Mile

Cross-channel P6

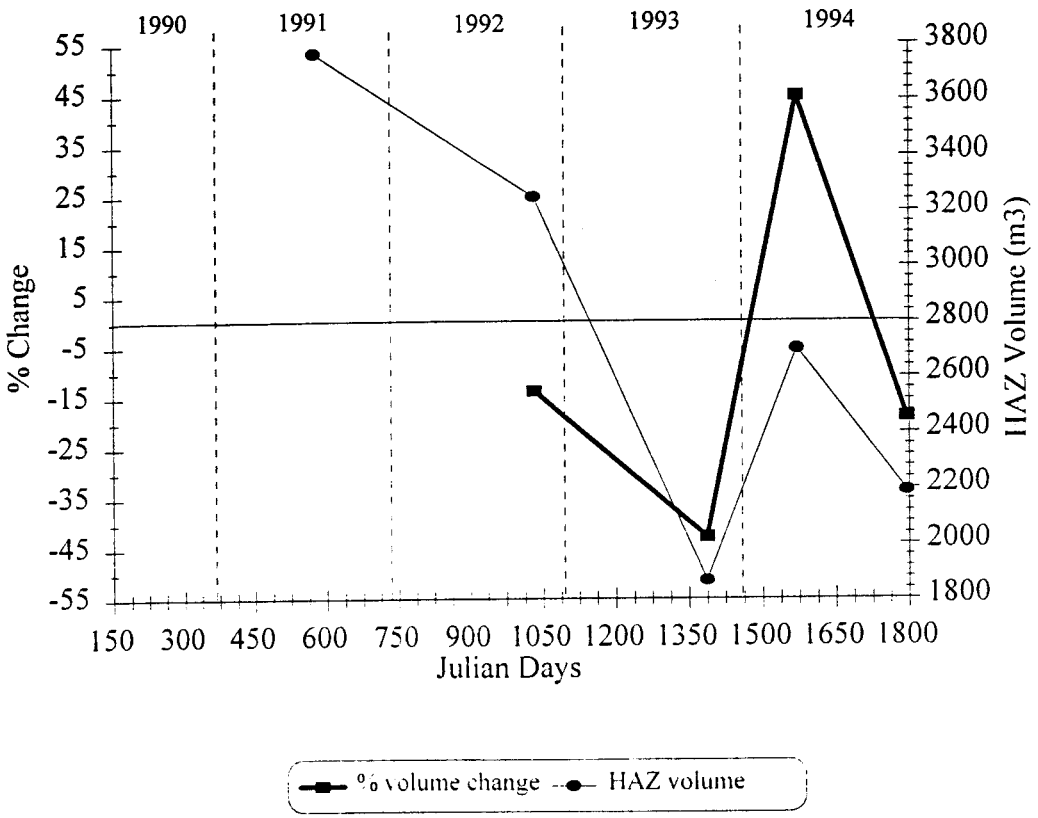


Near-shore P6



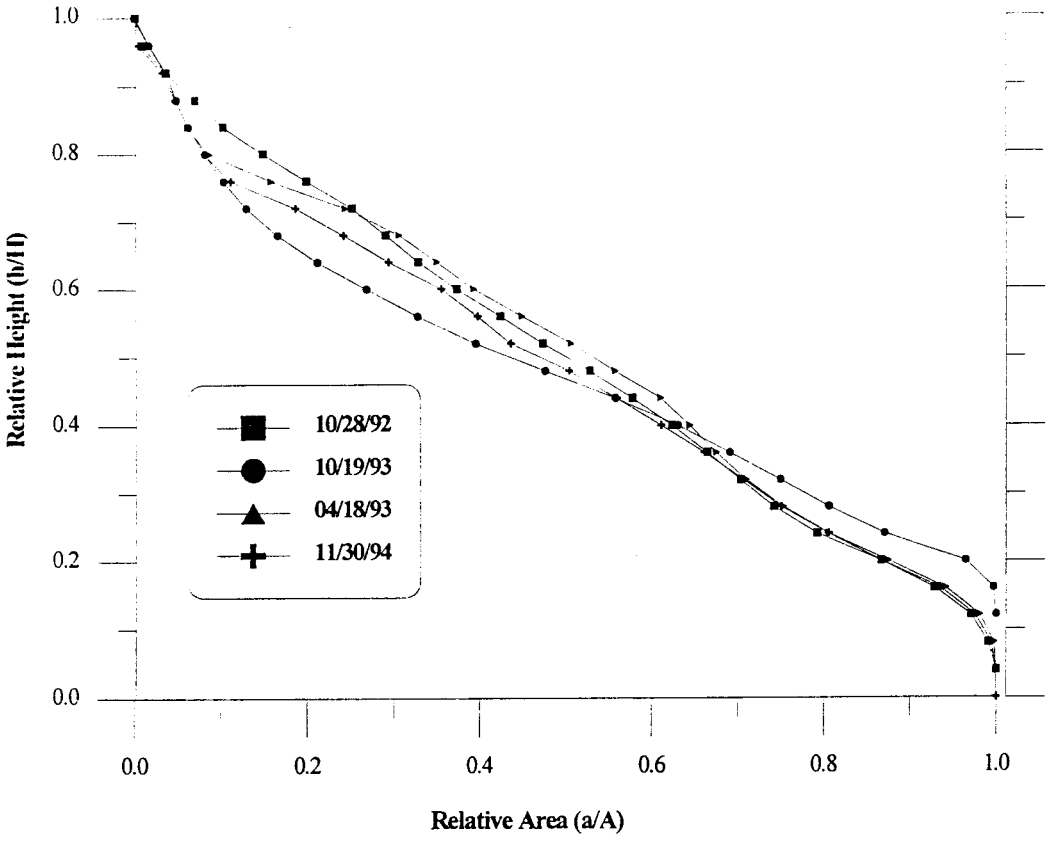
139 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F		NORM							
G		E							
H		A							
I		8000 CFS							
J		NORM							
K		NORM							
L		11000 CFS							
M		C							
N		NORM							
O		B							
P		NORM							
Q		NORM							
R		D							
S		15000 CFS							
T		NORM							
U		G							
V	910729	F	575	1896	3768				
Y	921028	INT	1032	1989	3252	93	-516	4.91	-13.69
B25	931019	INT	1388	1113	1867	-876	-1385	-44.04	-42.59
C25	940418	INT	1570	2079	2701	966	834	86.79	44.67
D25	941130	INT	1795	1642	2191	-437	-510	-21.02	-18.88

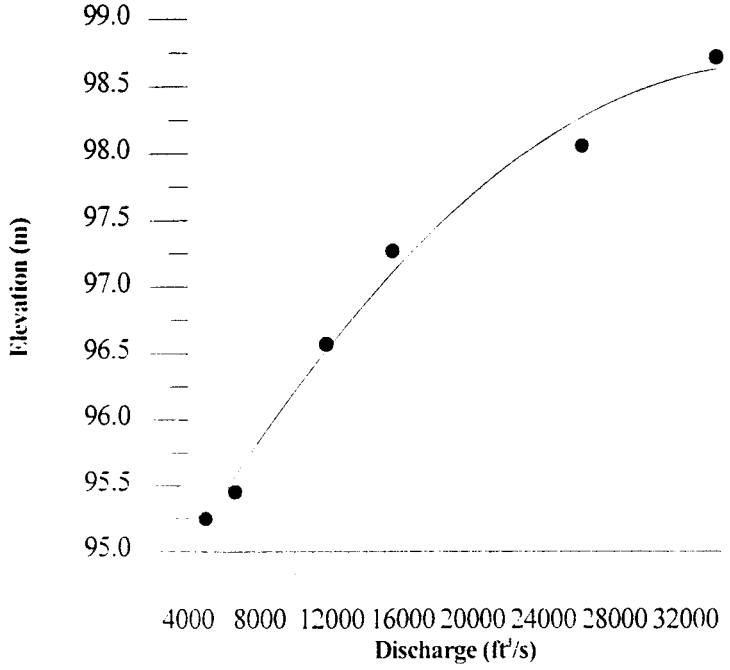


139 Mile

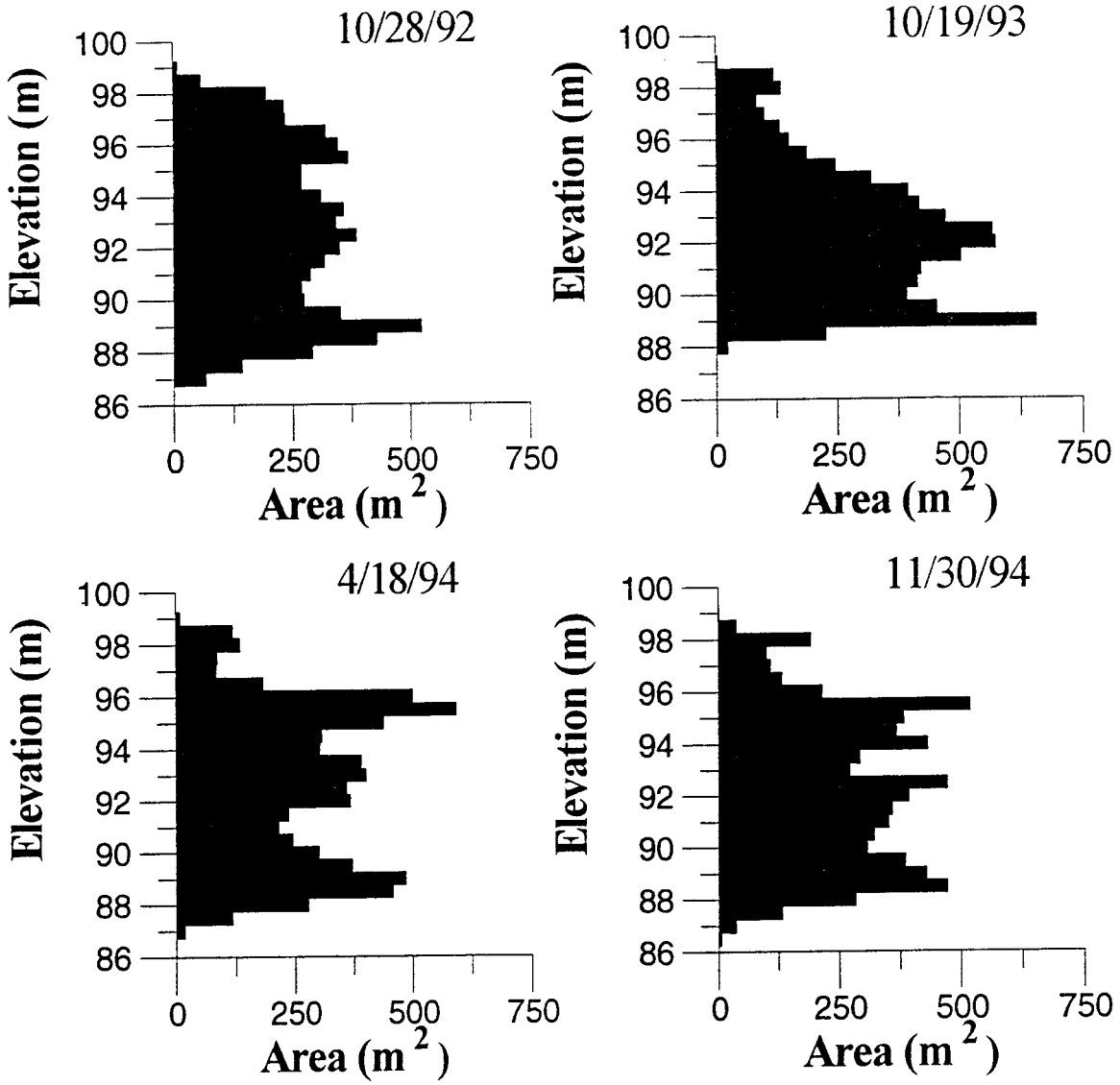
Hypsometric Curves

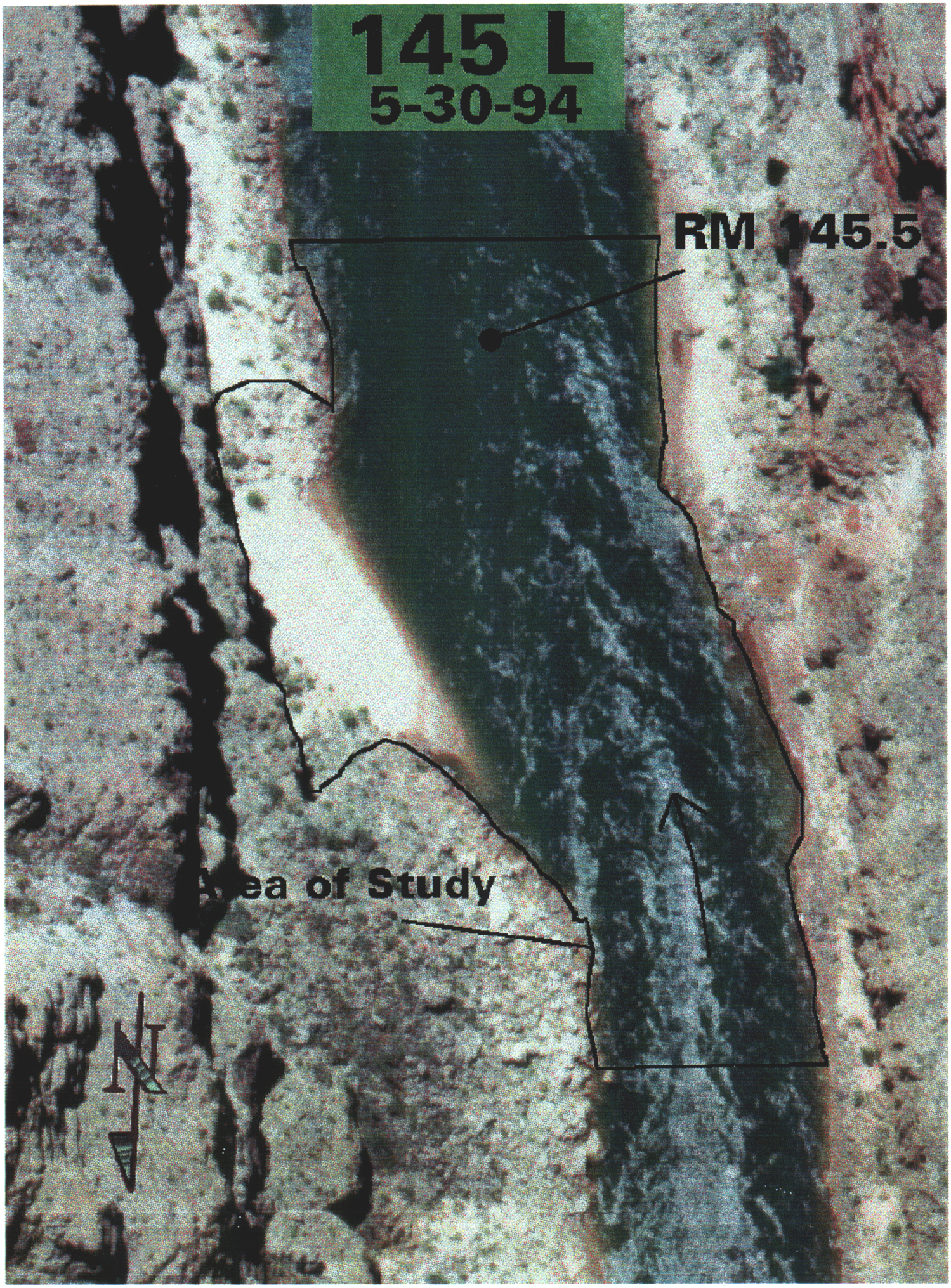


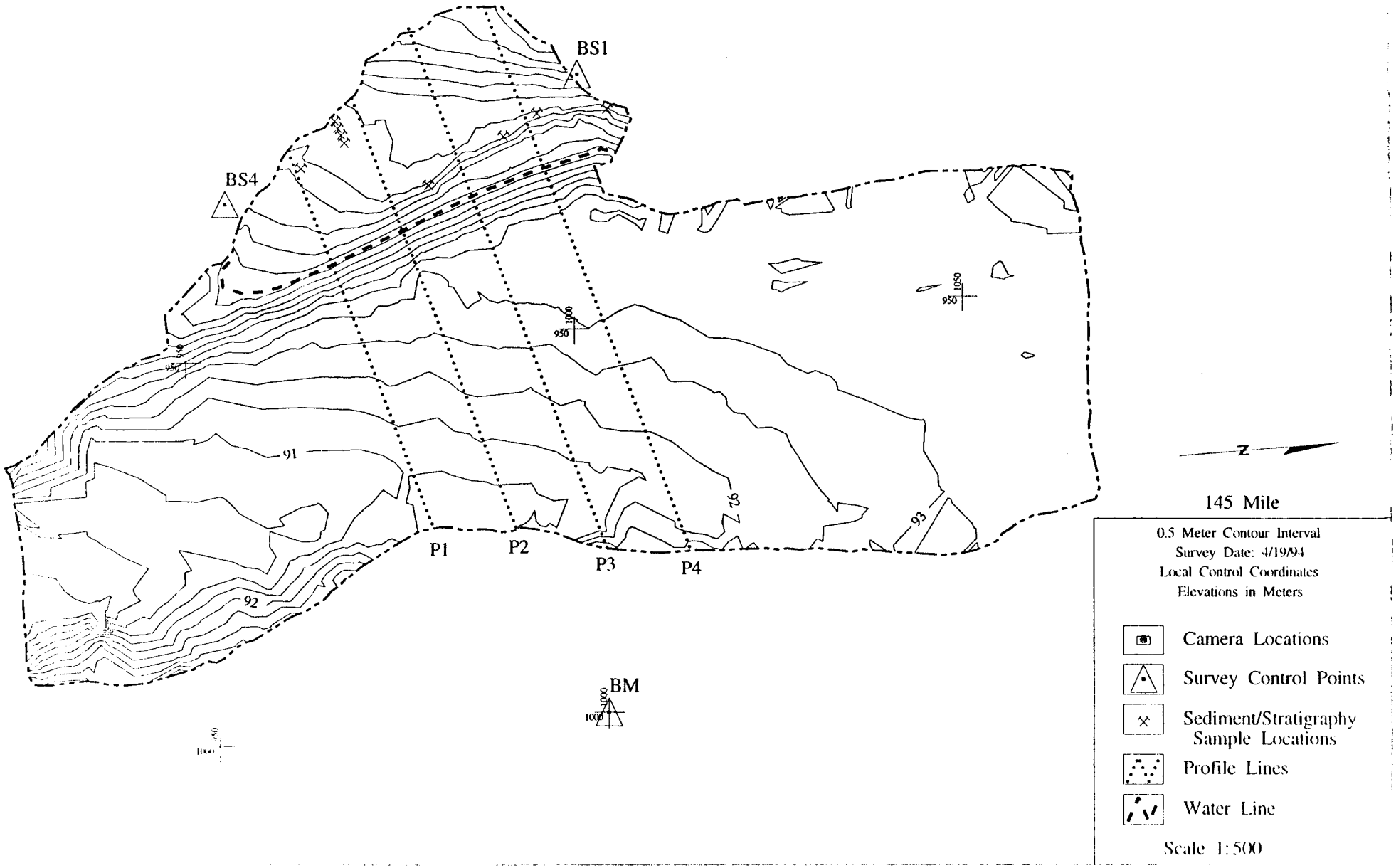
Stage Discharge



139 MILE
Area Distribution Histograms

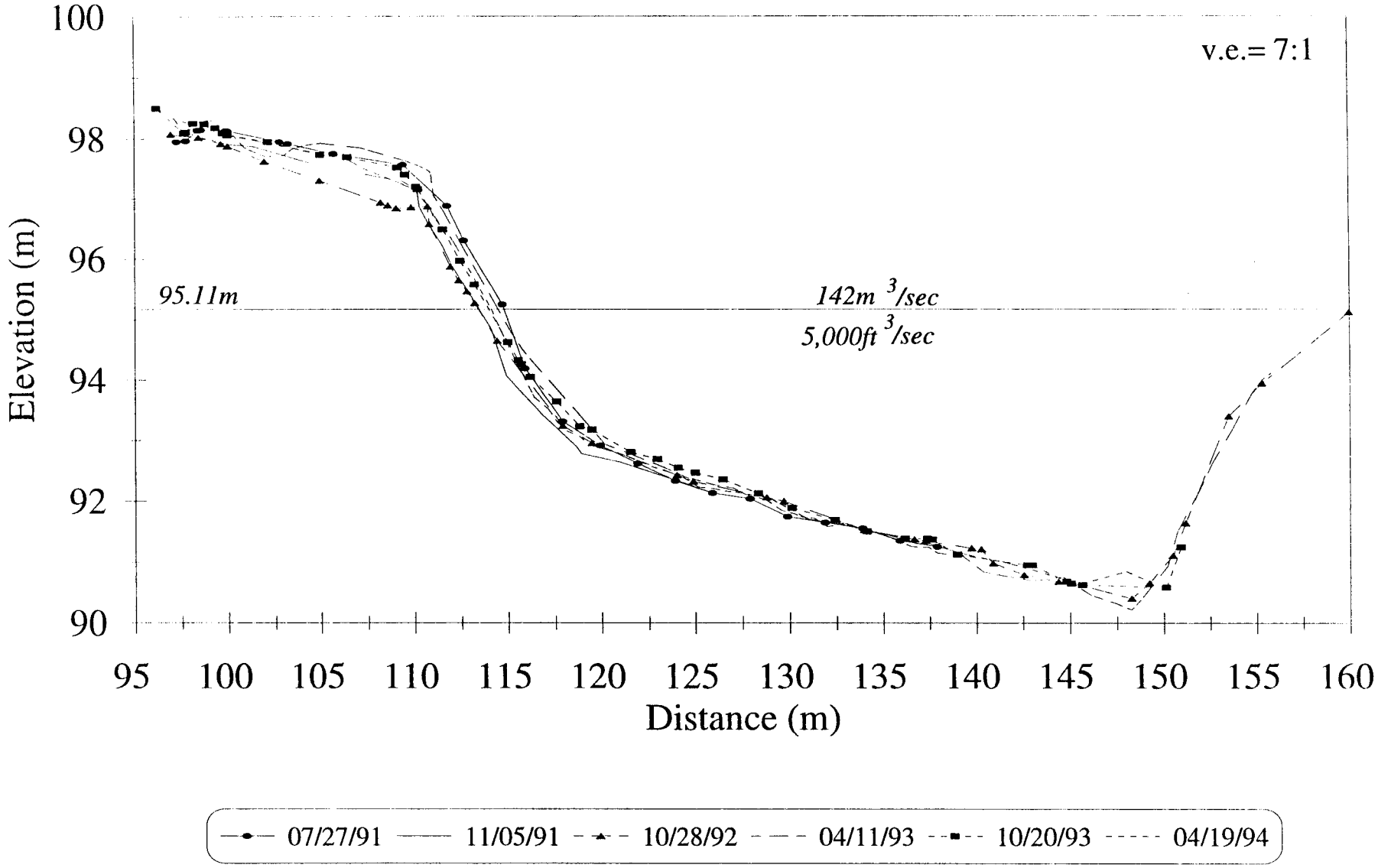



145 L
5-30-94
RM 145.5
Area of Study
N

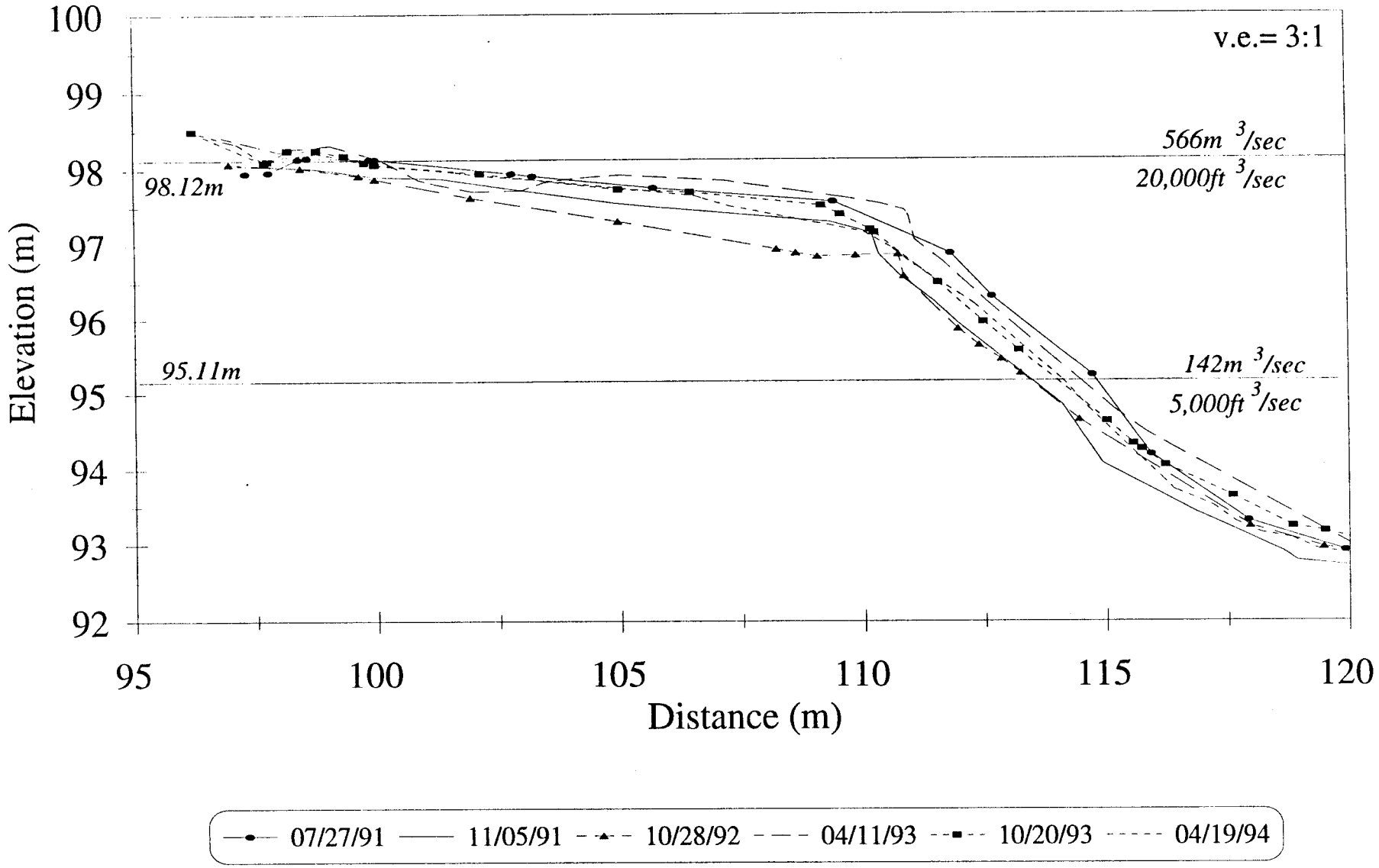

BS1
BS4
BM
P1
P2
P3
P4
91
92
93
950
1050
1000
N
145 Mile
0.5 Meter Contour Interval
Survey Date: 4/19/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:500

145 Mile

Cross-channel P1

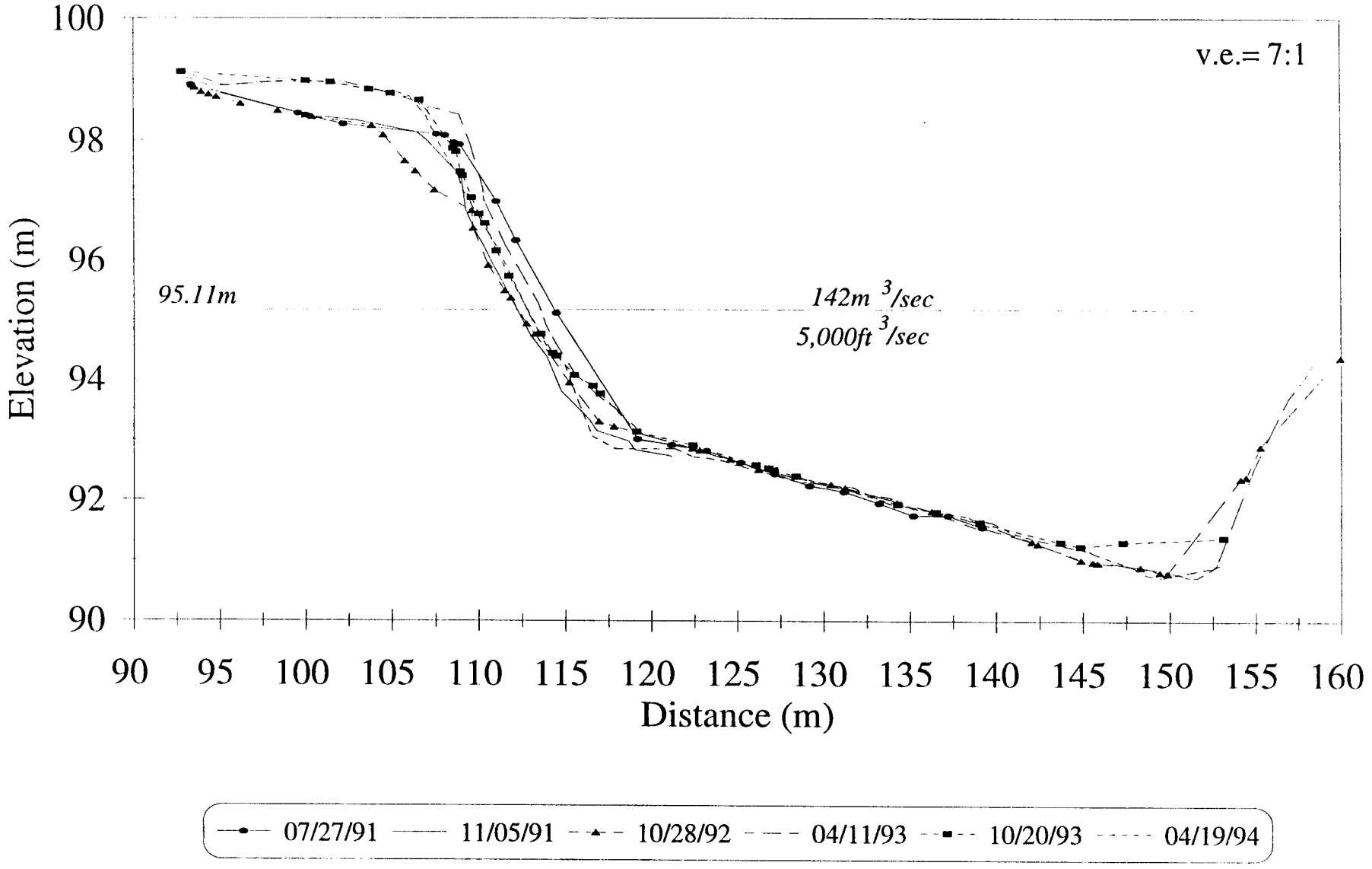


Near-shore P1

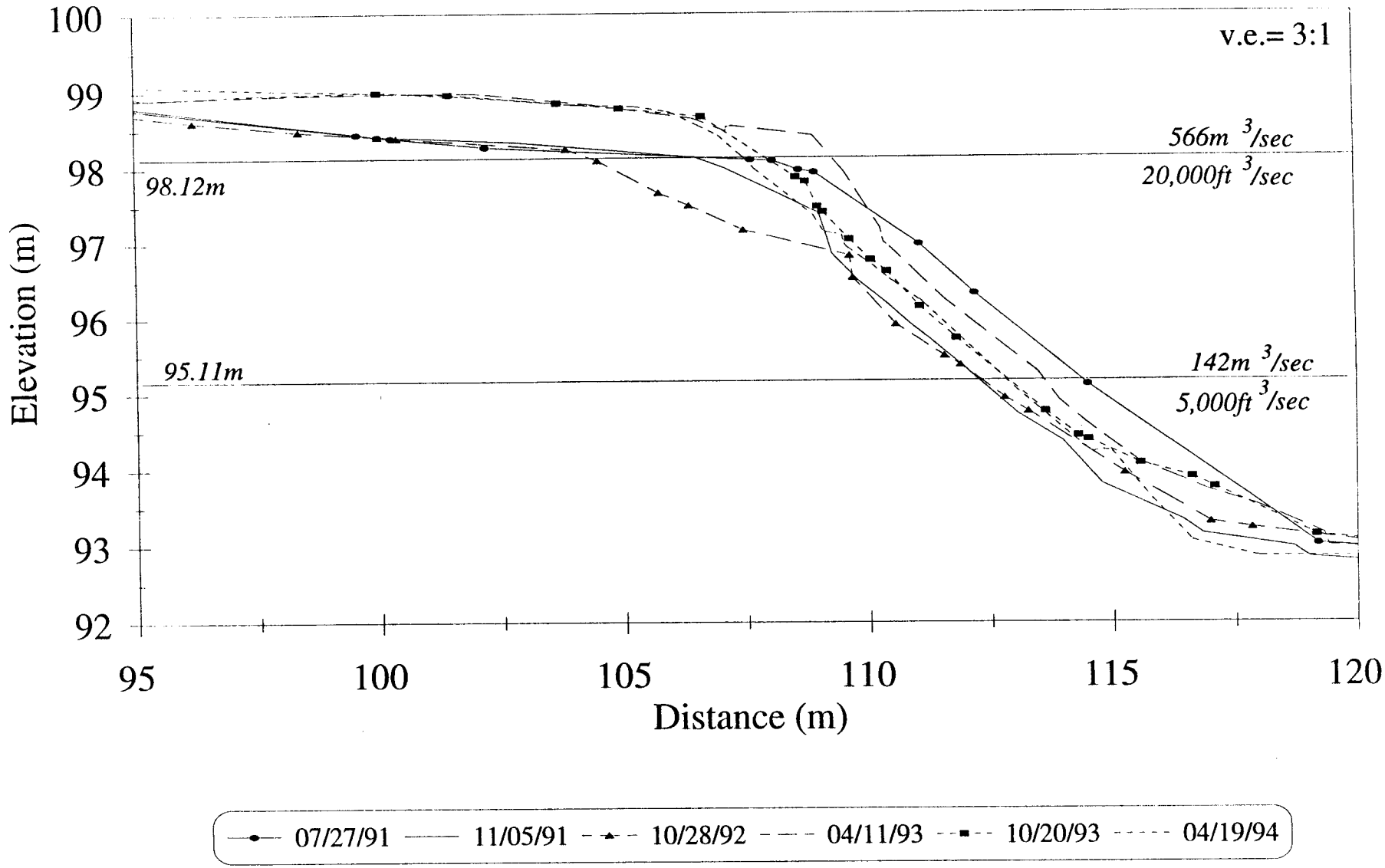


145 Mile

Cross-channel P2

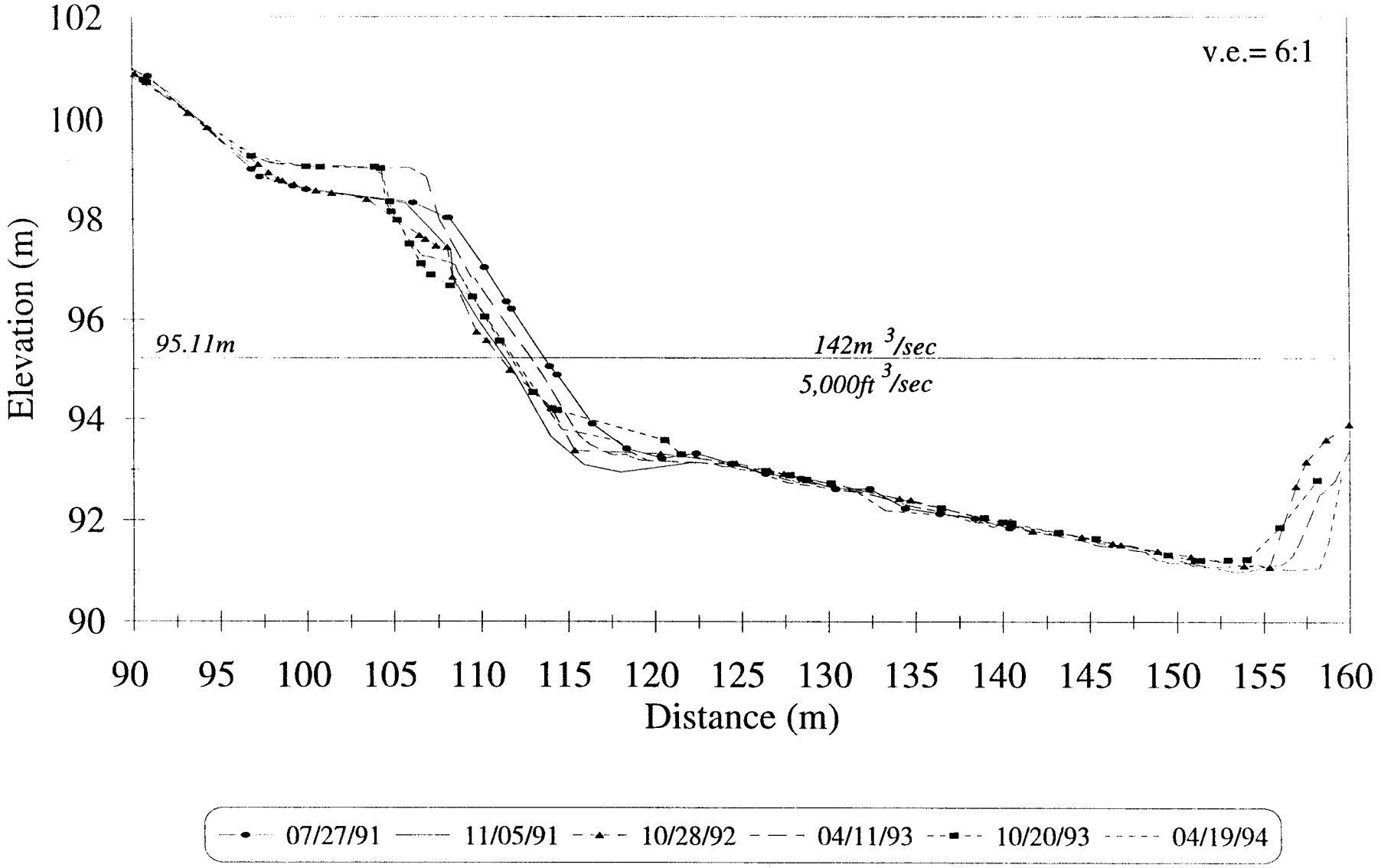


Near-shore P2

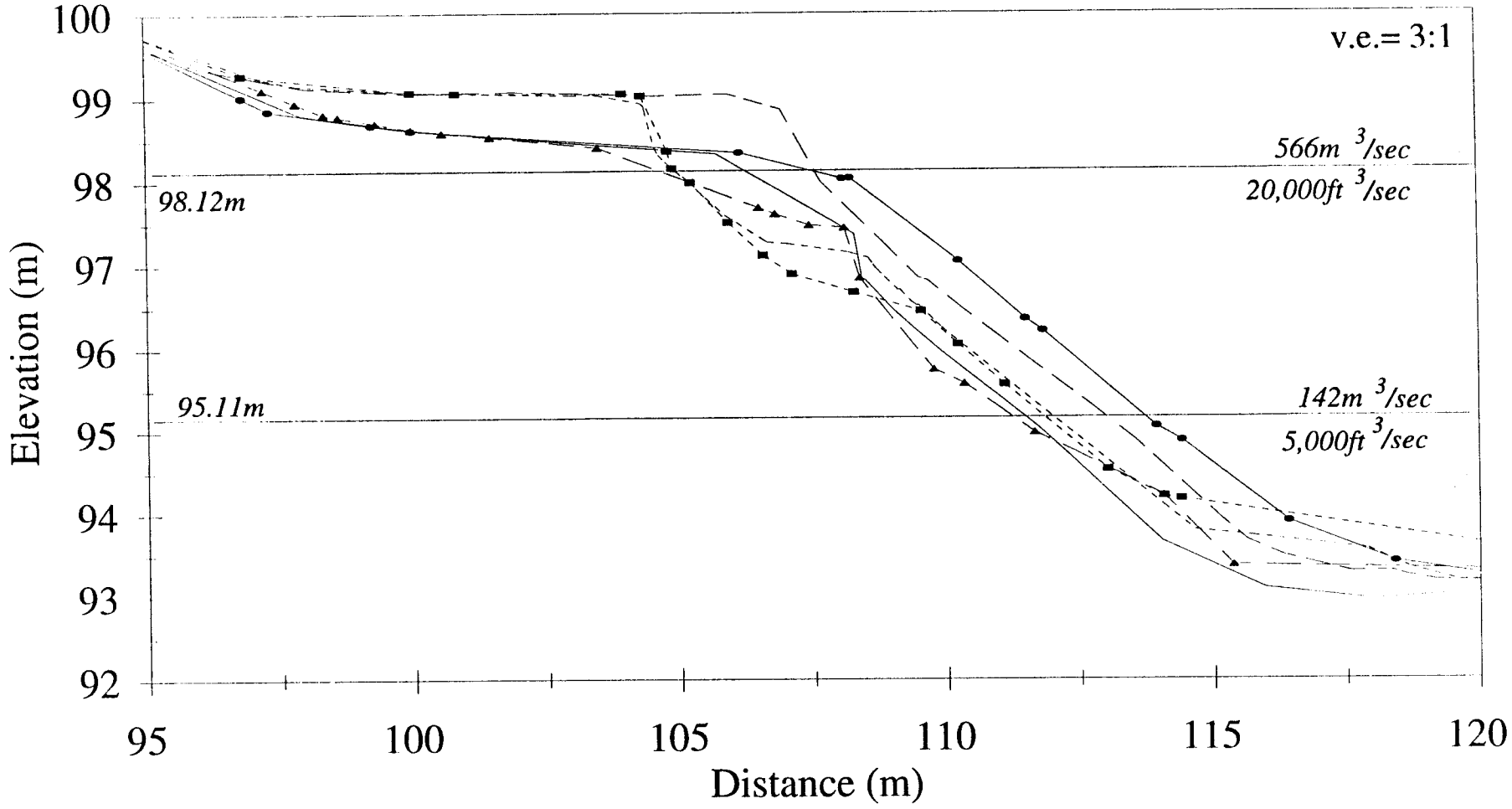


145 Mile

Cross-channel P3

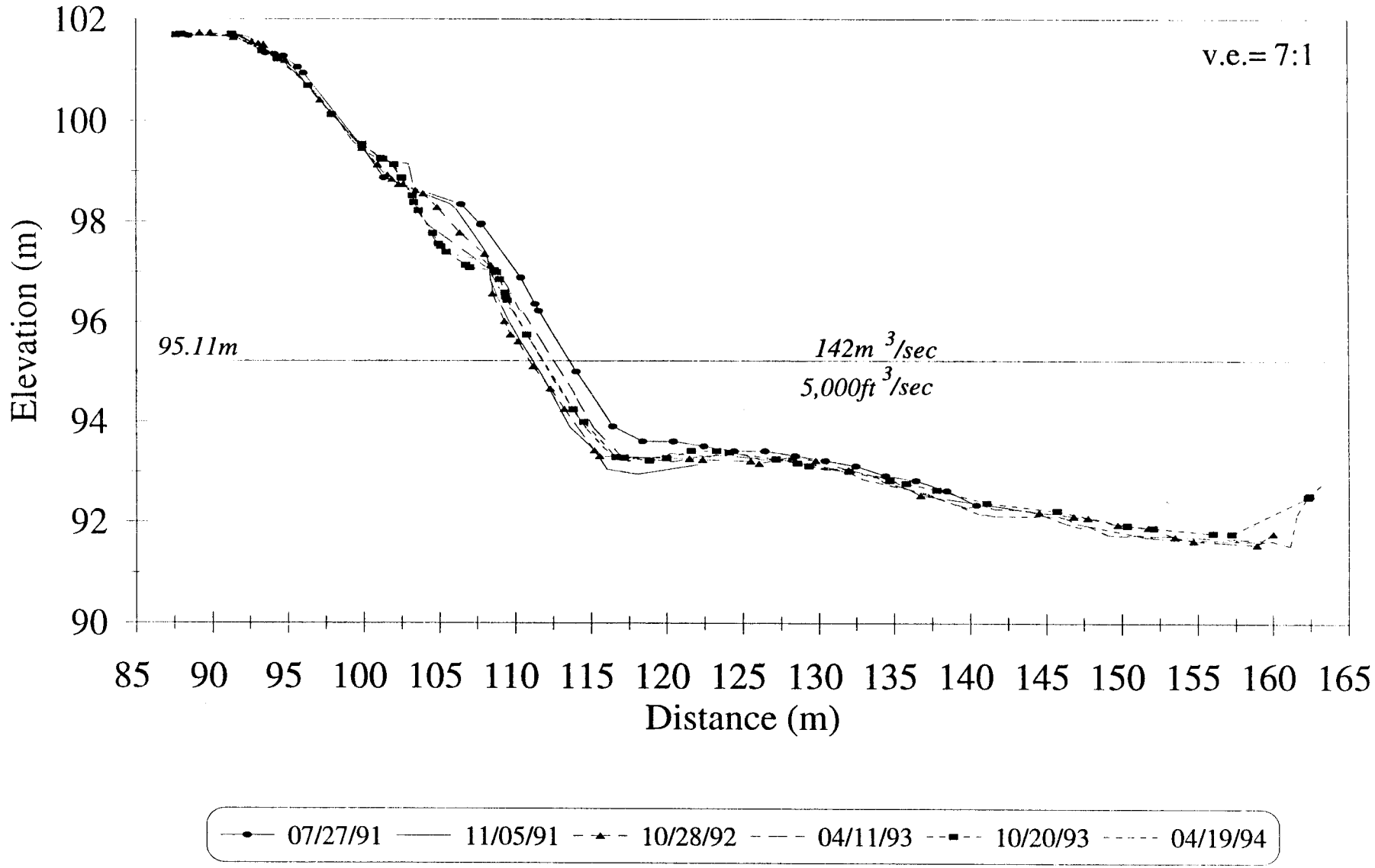


Near-shore P3

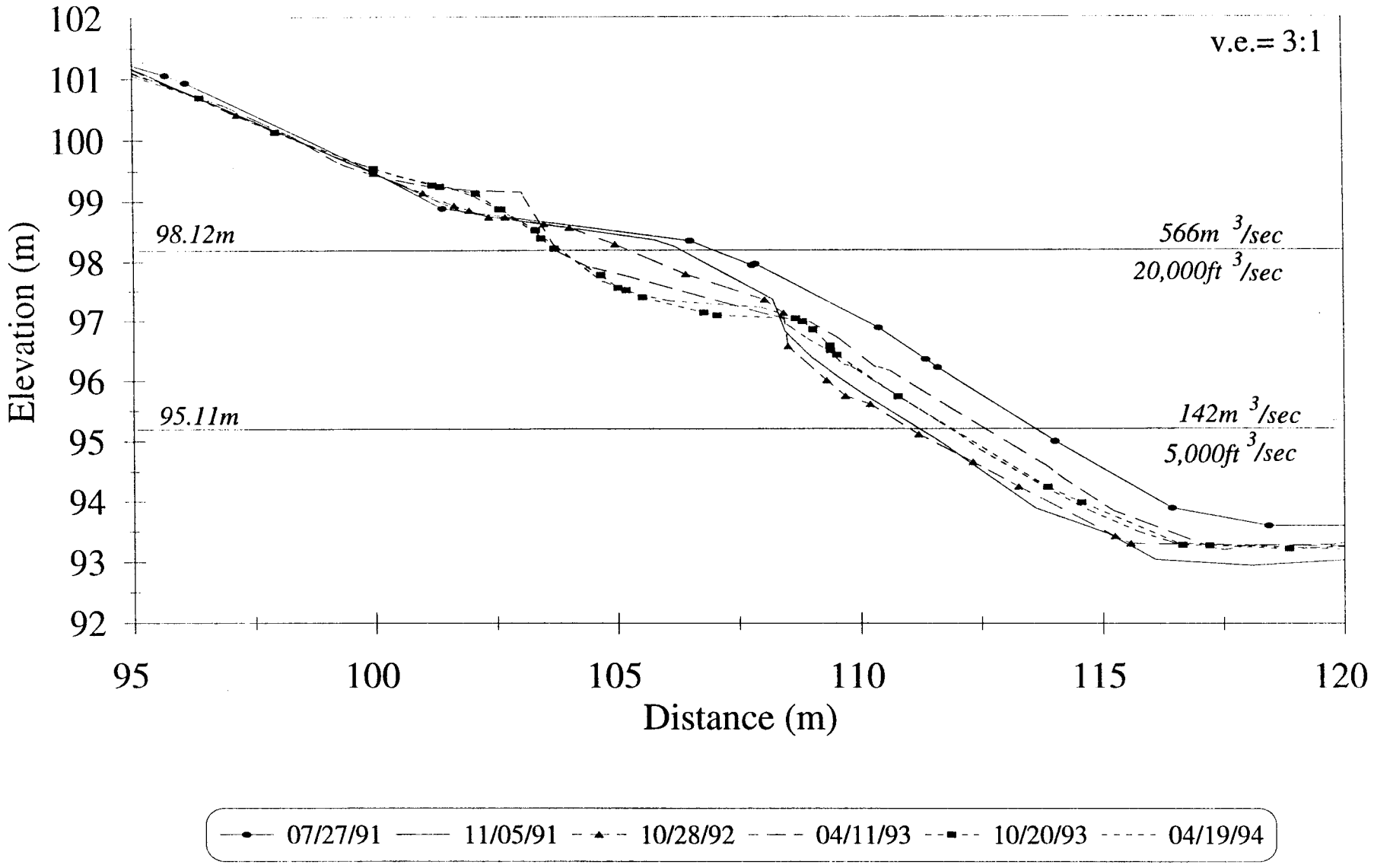


145 Mile

Cross-channel P4

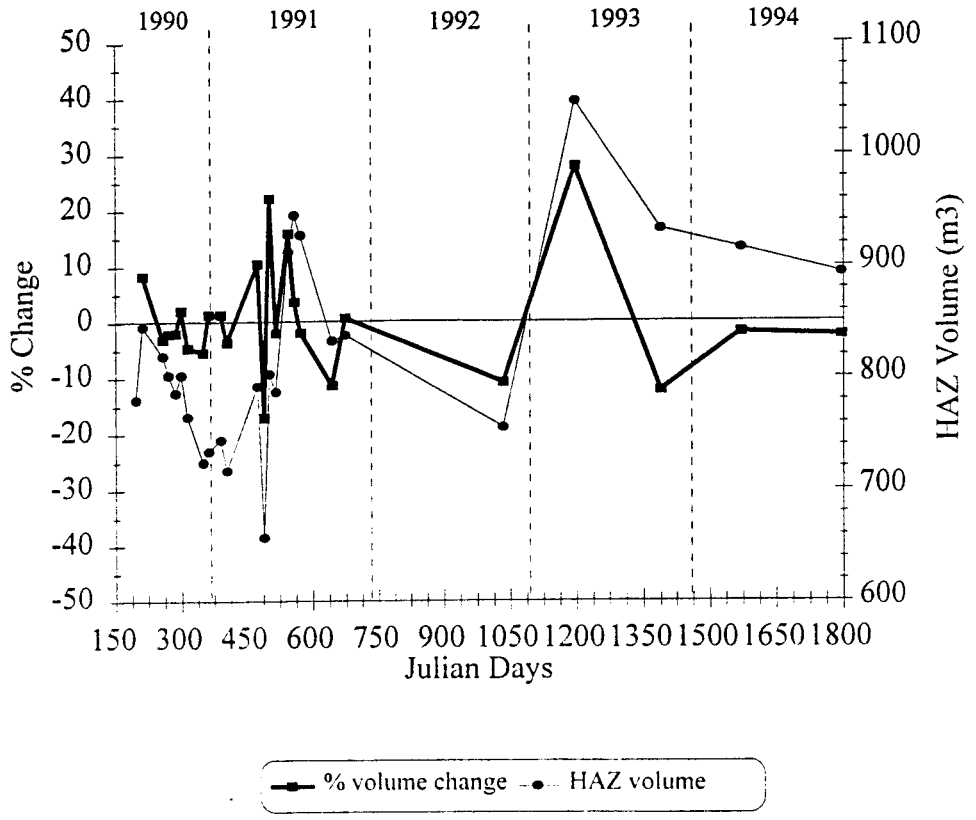


Near-shore P4



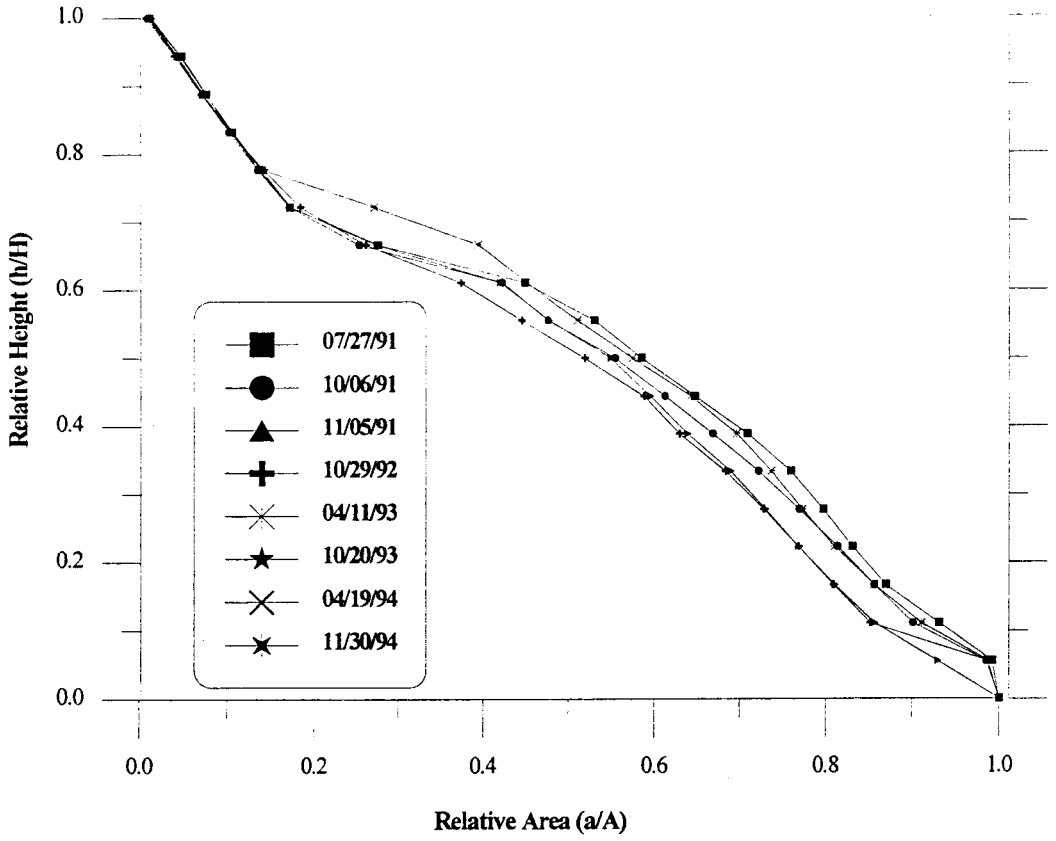
145 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C	900716	G	197	531	781				
D	900730	F	212	536	846	5	65	0.94	8.32
E		NORM							
F	900915	NORM	258	540	820	4	-26	0.75	-3.07
G	900928	E	271	544	803	4	-17	0.74	-2.07
H	901013	A	286	520	787	-24	-16	-4.41	-1.99
I	901027	8000 CFS	300	515	803	-5	16	-0.96	2.03
J	901110	NORM	314	482	766	-33	-37	-6.41	-4.61
K	901215	NORM	349	491	725	9	-41	1.87	-5.35
L	901229	11000 CFS	363	482	735	-9	10	-1.83	1.38
M		C							
N	910125	NORM	390	528	745	46	10	9.54	1.36
O	910208	B	404	505	718	-23	-27	-4.36	-3.62
P	910420	NORM	475	535	793	30	75	5.94	10.45
Q	910504	NORM	489	481	658	-54	-135	-10.09	-17.02
R	910518	D	503	545	804	64	146	13.31	22.19
S	910601	15000 CFS	517	549	788	4	-16	0.73	-1.99
T	910629	NORM	545	566	913	17	125	3.10	15.86
U	910713	G	559	576	946	10	33	1.77	3.61
V	910727	F	573	581	928	5	-18	0.87	-1.94
W	911006	INT	644	540	833	-41	-95	-7.06	-11.40
X	911105	INT	674	510	838	-30	5	-5.56	0.60
Y	921029	INT	1033	497	756	-13	-82	-2.55	-10.85
Z	930411	INT	1197	570	1047	73	291	14.69	27.79
B26	931020	INT	1389	549	933	-21	-114	-3.68	-12.22
C26	940419	INT	1570	544	916	-5	-17	-0.91	-1.86
D26	941130	INT	1795	500	894	-44	-22	-8.09	-2.46

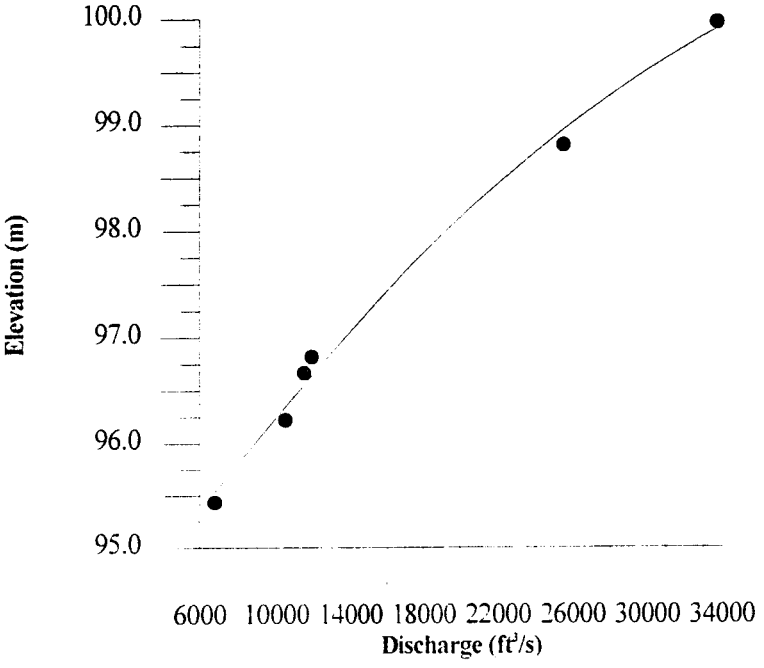


145 Mile

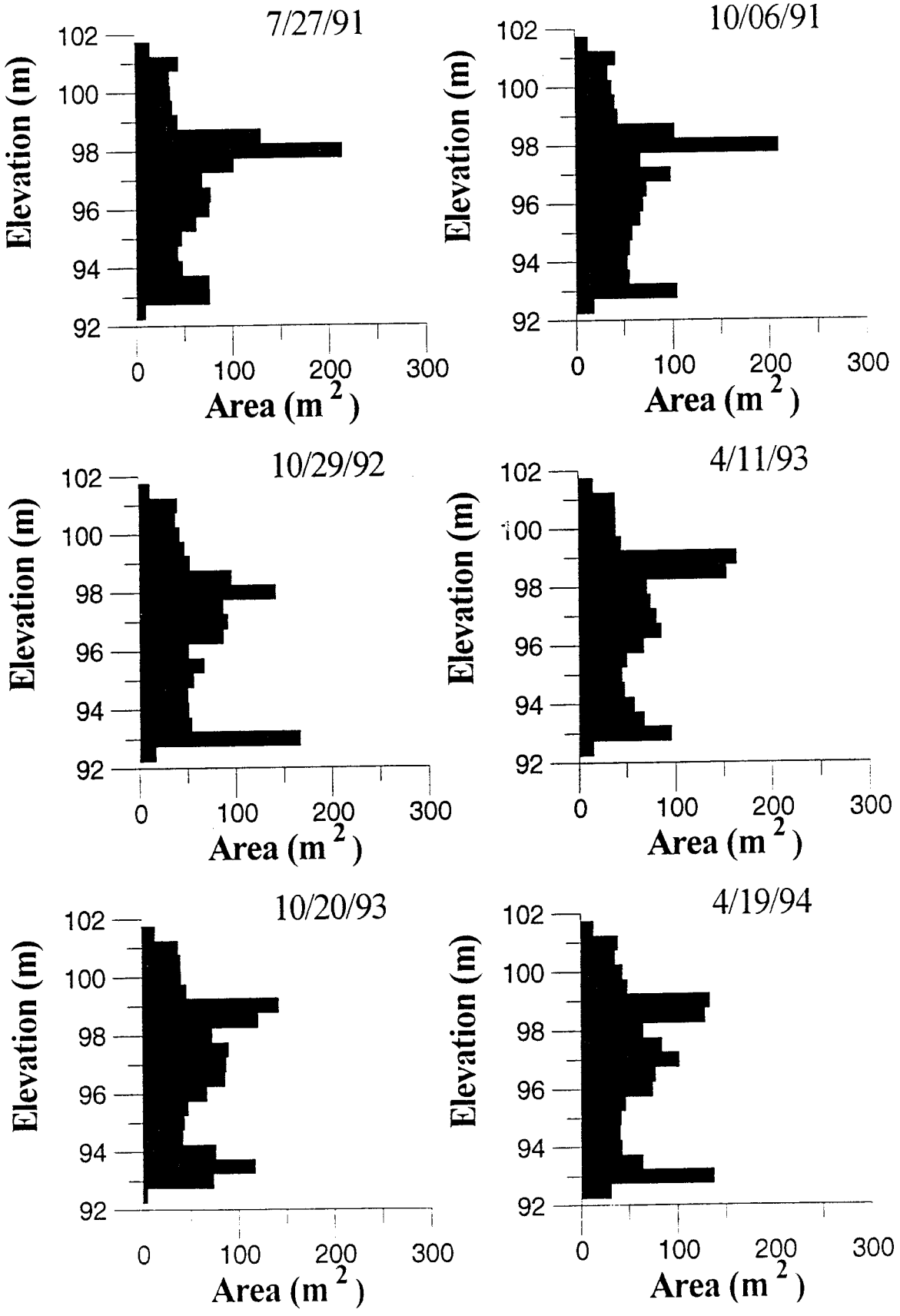
Hypsometric Curves



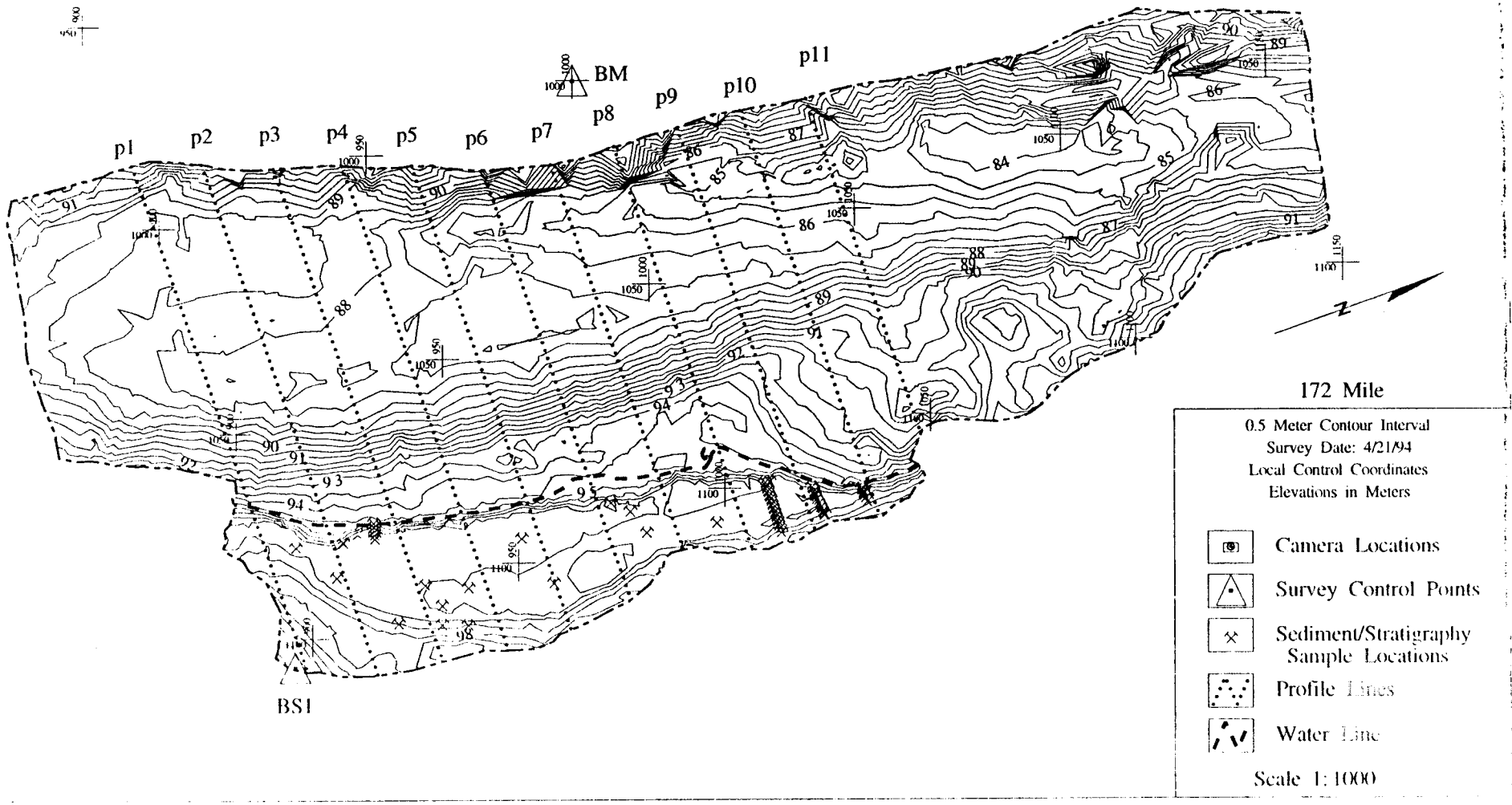
Stage Discharge



145 MILE
Area Distribution Histograms

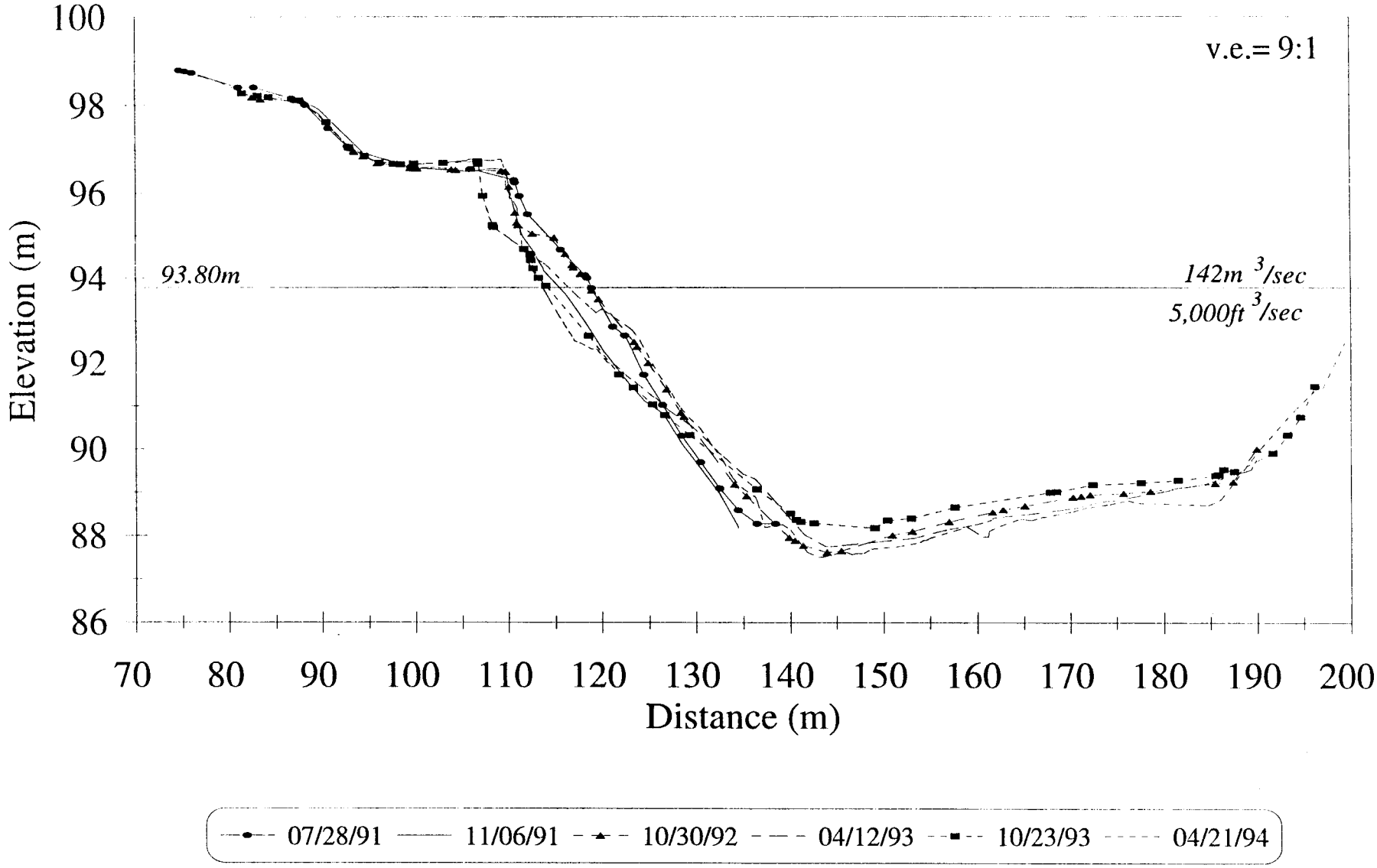


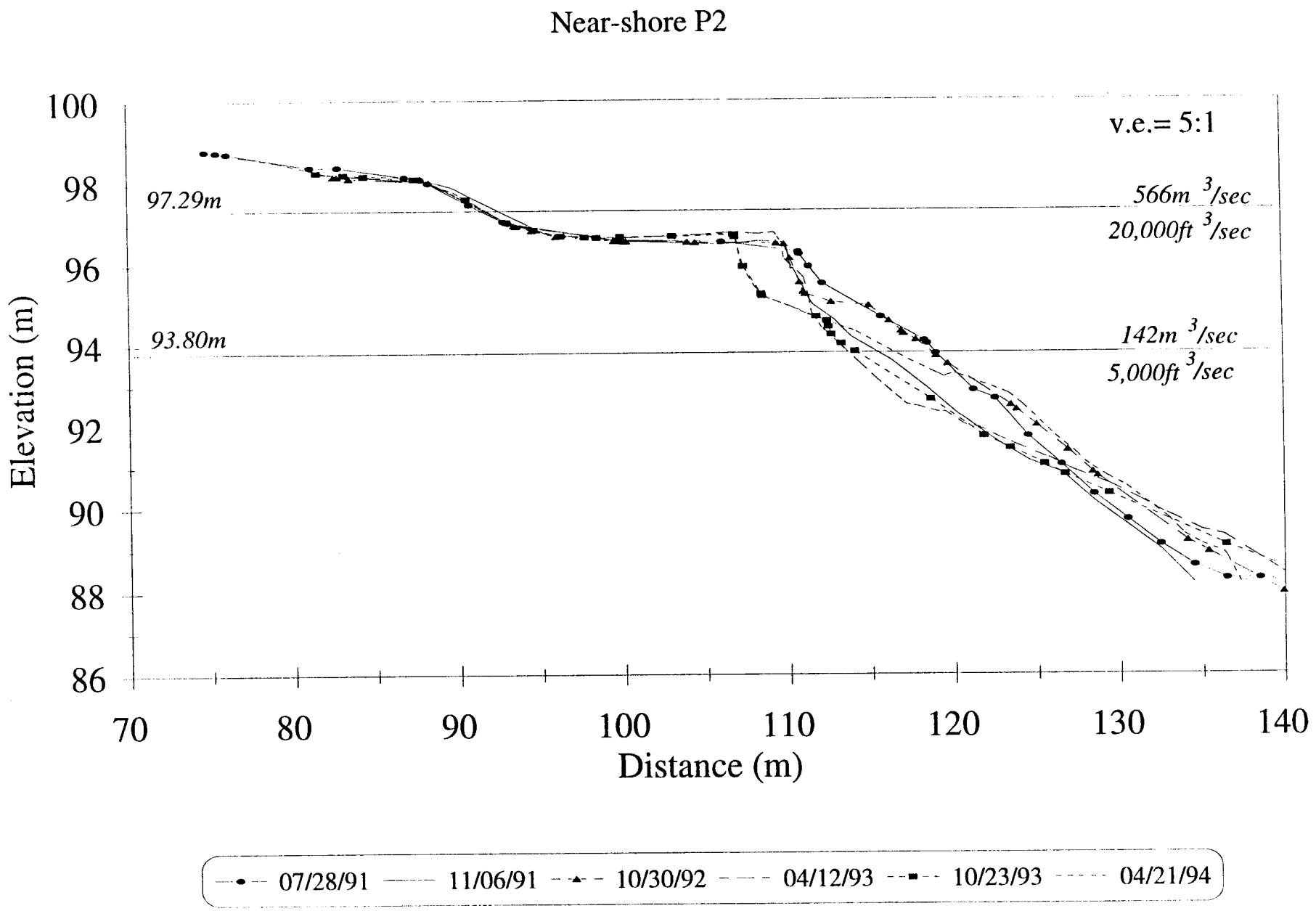
172 L
5-30-94
Area of Study
RM 172.0


p1
p2
p3
p4
p5
p6
p7
p8
p9
p10
p11
BM
BS1
172 Mile
0.5 Meter Contour Interval
Survey Date: 4/21/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:1000

172 Mile

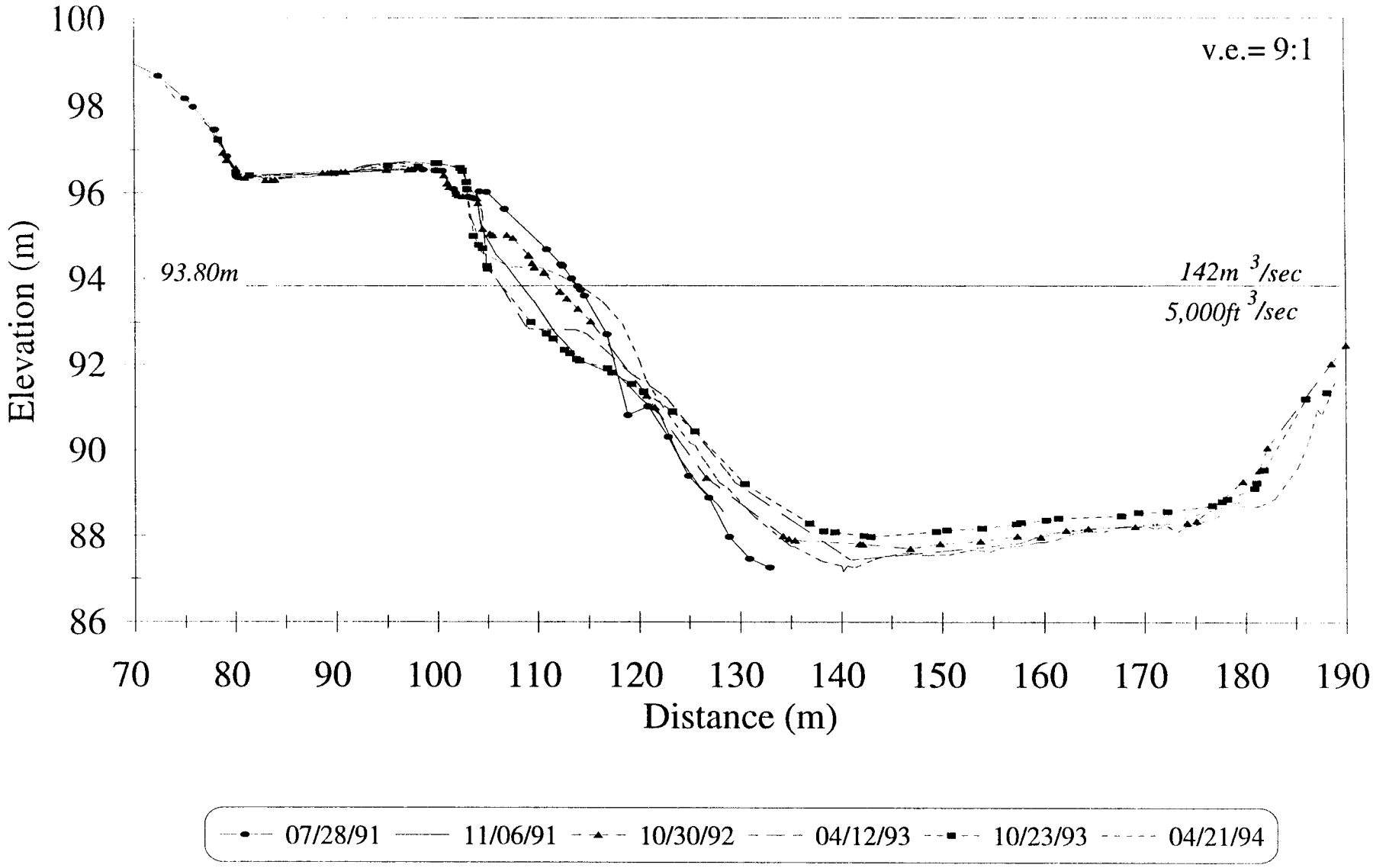
Cross-channel P2



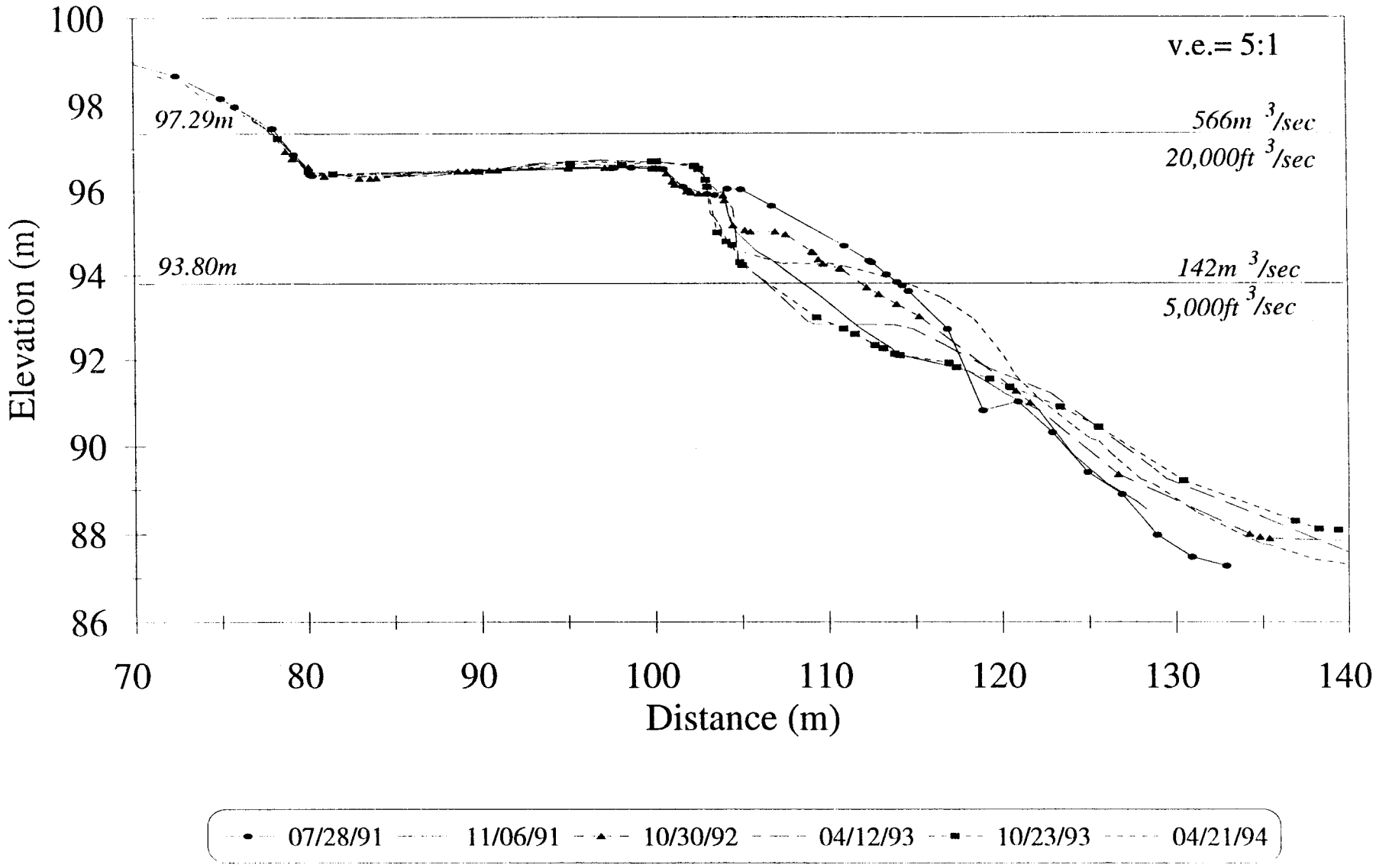

Near-shore P2
v.e.= 5:1
97.29m
566m 3/sec
20,000ft 3/sec
93.80m
142m 3/sec
5,000ft 3/sec
Elevation (m)
100
98
96
94
92
90
88
86
70
80
90
100
110
120
130
140
Distance (m)
07/28/91
11/06/91
10/30/92
04/12/93
10/23/93
04/21/94

172 Mile

Cross-channel P4

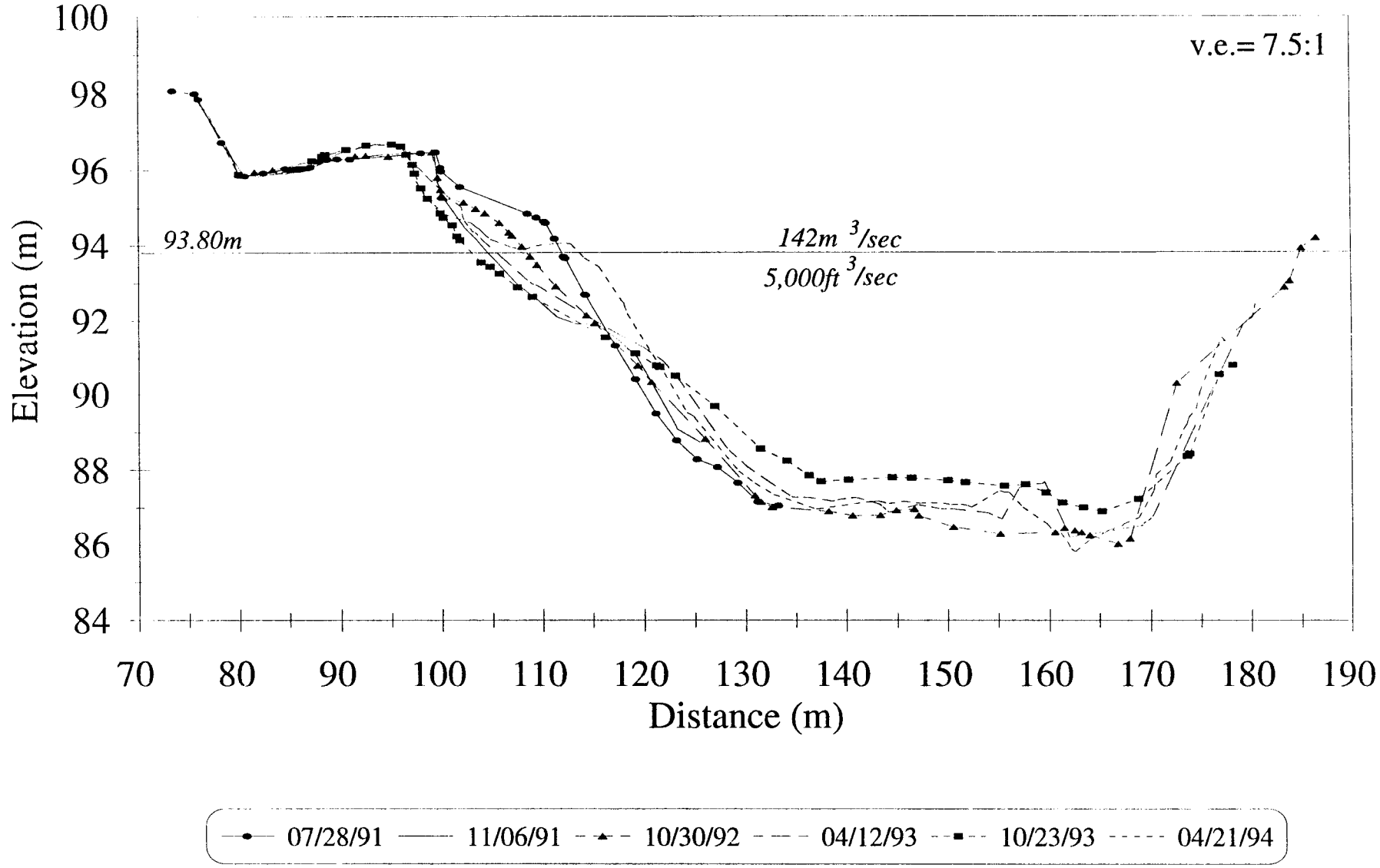


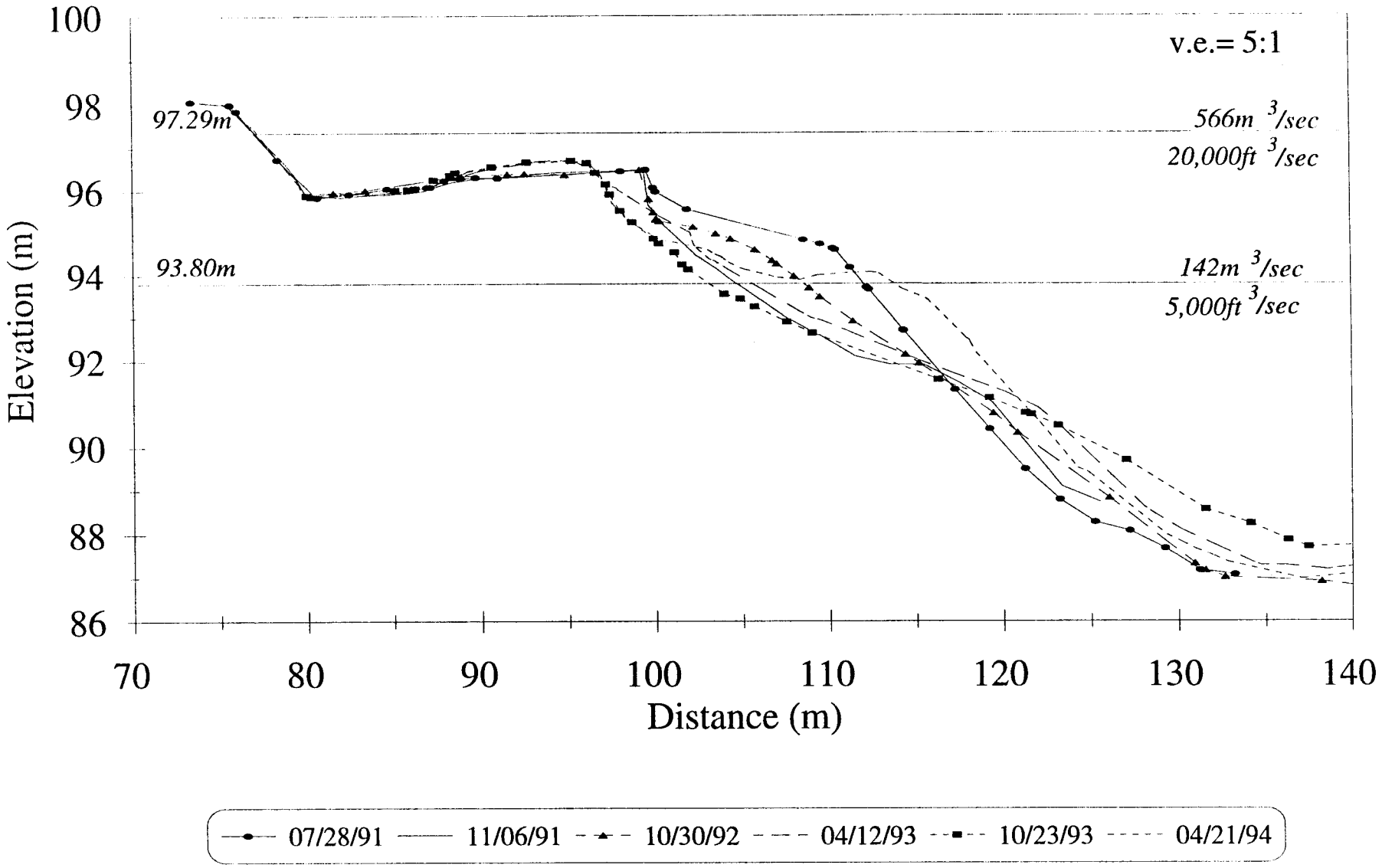
Near-shore P4



172 Mile

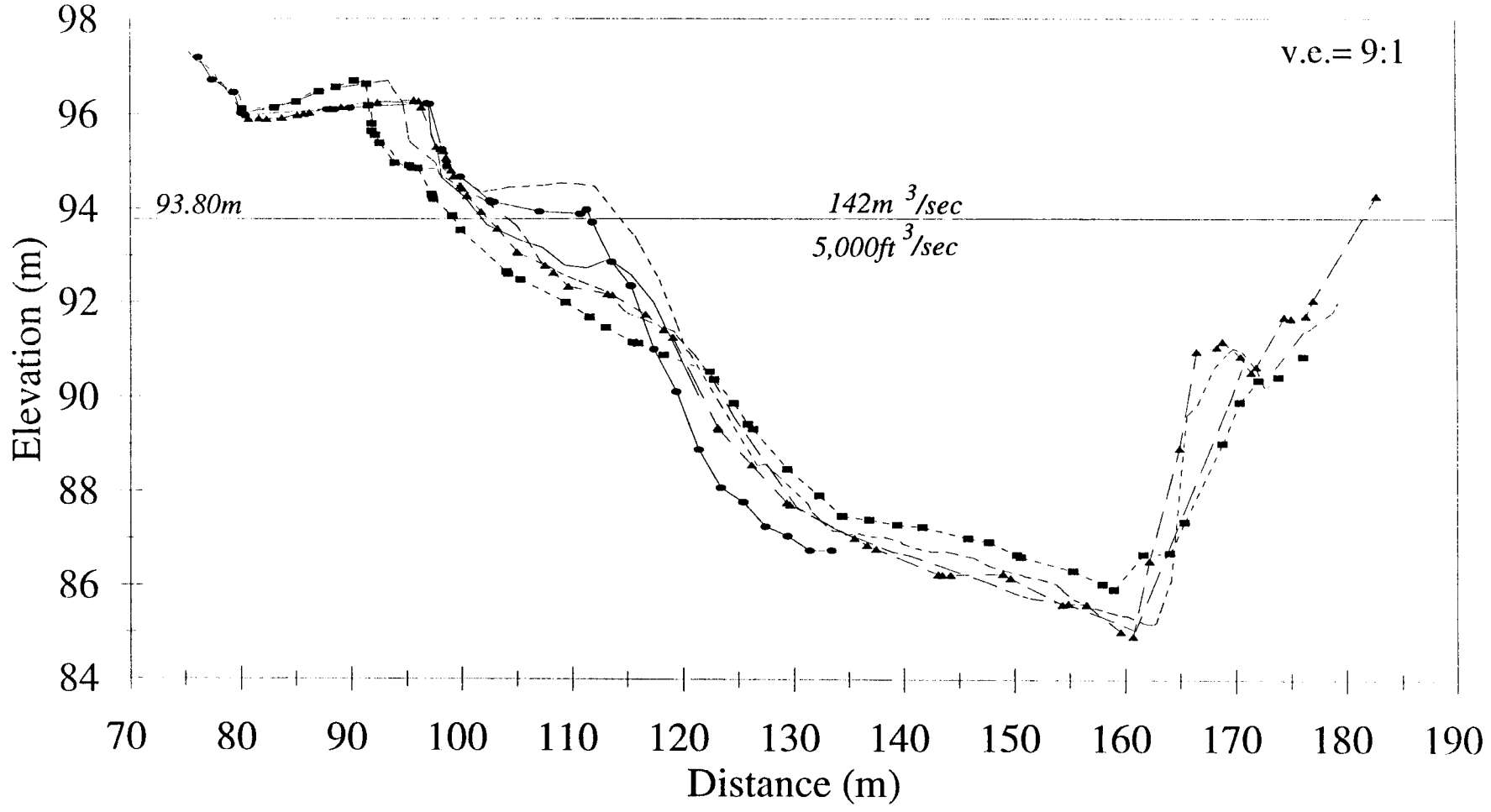
Cross-channel P6

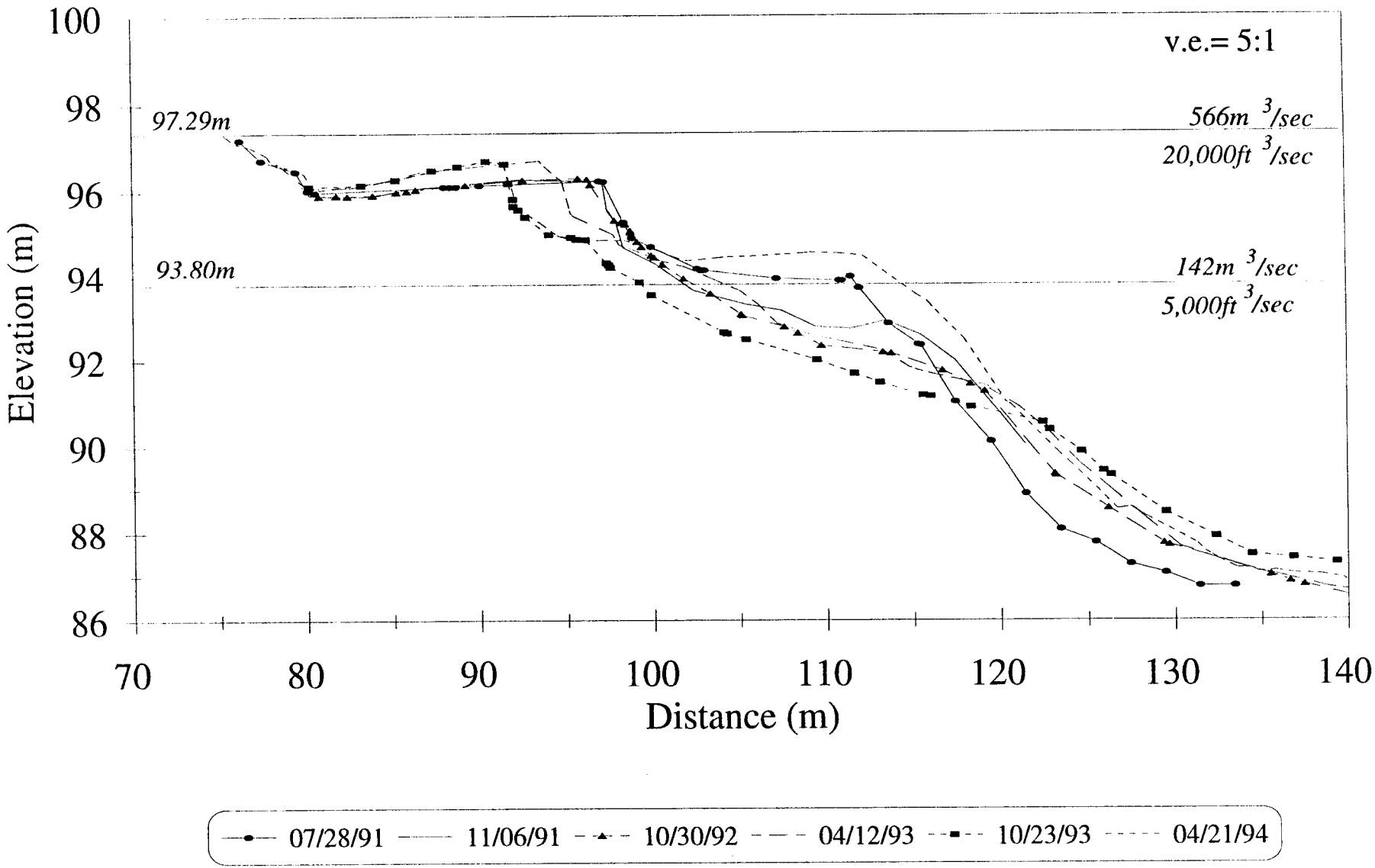



Near-shore P6
v.e.= 5:1
97.29m
93.80m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
Elevation (m)
100
98
96
94
92
90
88
86
70
80
90
100
110
120
130
140
Distance (m)
07/28/91
11/06/91
10/30/92
04/12/93
10/23/93
04/21/94

172 Mile

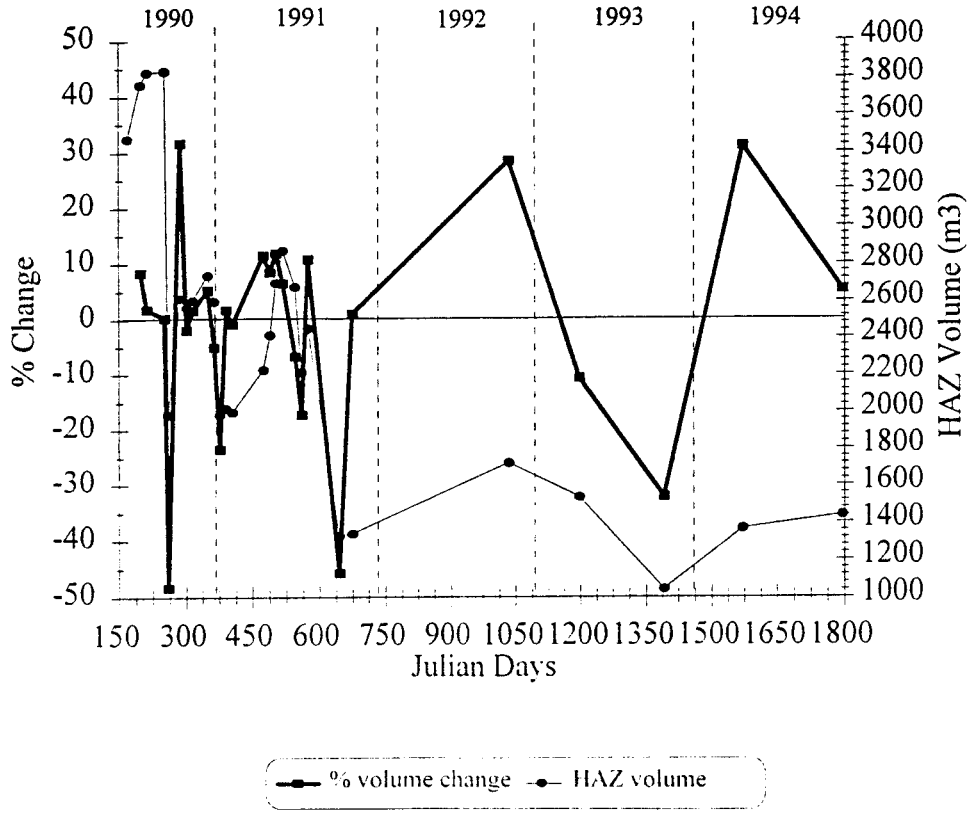
Cross-channel P8




Near-shore P8
v.e.= 5:1
97.29m
566m 3/sec
20,000ft 3/sec
93.80m
142m 3/sec
5,000ft 3/sec
Elevation (m)
100
98
96
94
92
90
88
86
70
80
90
100
110
120
130
140
Distance (m)
07/28/91
11/06/91
10/30/92
04/12/93
10/23/93
04/21/94

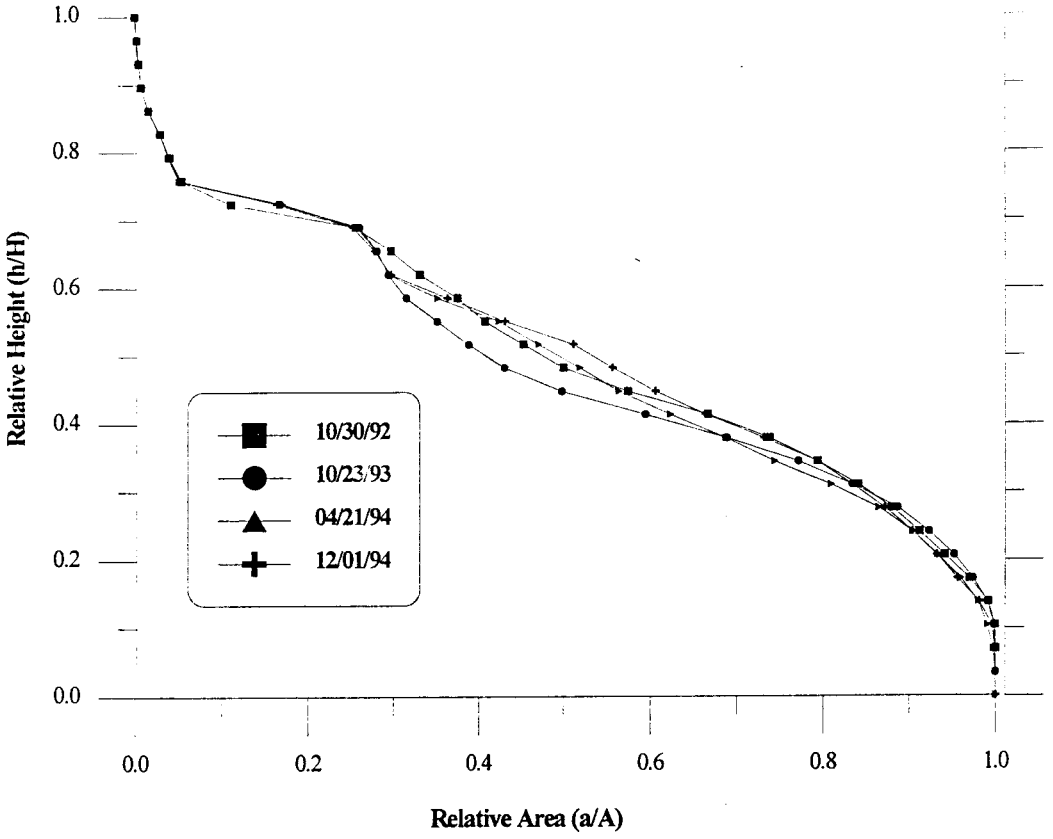
172 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A	900618	NORM	169	2769	3476				
B		NORM							
C	900717	G	198	2804	3766	35	290	1.26	8.34
D	900731	F	212	2747	3833	-57	67	-2.03	1.78
E	900908	NORM	251	2747	3839	0	6	0.00	0.16
F	900916	NORM	259	1757	1985	-990	-1854	-36.04	-48.29
G	900930	E							
H	901014	A	287	2162	2614	405	629	23.05	31.69
I	901028	8000 CFS	301	2177	2563	15	-51	0.69	-1.95
J	901111	NORM	315	2197	2602	20	39	0.92	1.52
K	901216	NORM	350	2276	2737	79	135	3.60	5.19
L	901230	11000 CFS	364	2234	2597	-42	-140	-1.85	-5.12
M	910112	C	377	1517	1985	-717	-612	-32.09	-23.57
N	910126	NORM	391	1600	2017	83	32	5.47	1.61
O	910209	B	405	1594	1998	-6	-19	-0.38	-0.94
P	910420	NORM	475	1925	2225	331	227	20.77	11.36
Q	910504	NORM	489	2024	2412	99	187	5.14	8.40
R	910518	D	503	2006	2696	-18	284	-0.89	11.77
S	910602	15000 CFS	518	2147	2869	141	173	7.03	6.42
T	910629	NORM	545	2146	2674	-1	-195	-0.05	-6.80
U	910714	G	560	1864	2212	-282	-462	-13.14	-17.28
V	910728	F	574	2254	2448	390	236	20.92	10.67
W	911007	INT	645	1068	1327	-1186	-1121	-52.62	-45.79
X	911106	INT	675	1119	1340	51	13	4.78	0.98
Y	921030	INT	1034	1416	1719	297	379	26.54	28.28
Z	930412	INT	1198	1105	1535	-311	-184	-21.96	-10.70
B27	941023	INT	1392	878	1043	-227	-492	-20.54	-32.05
C27	940421	INT	1572	1591	1367	713	324	81.21	31.06
D27	941201	INT	1796	1649	1439	58	72	3.65	5.27

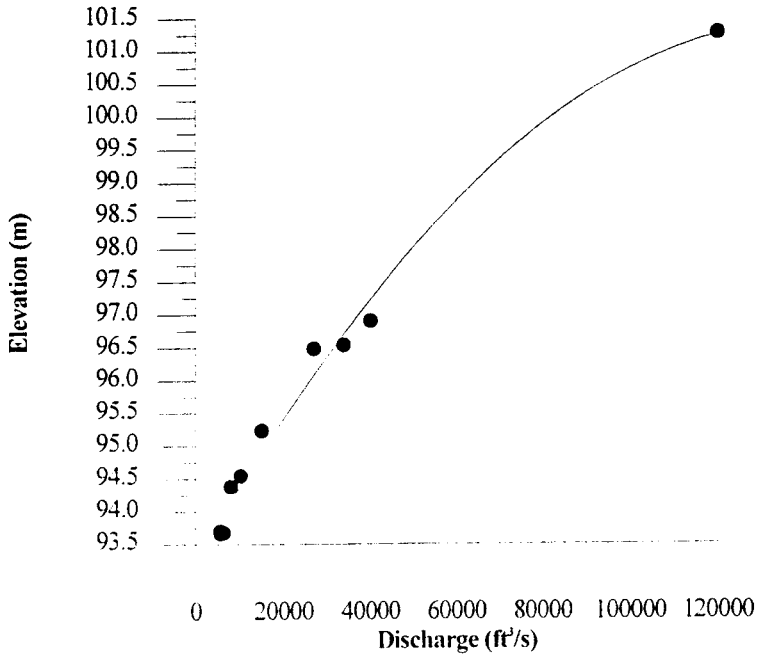


172 Mile

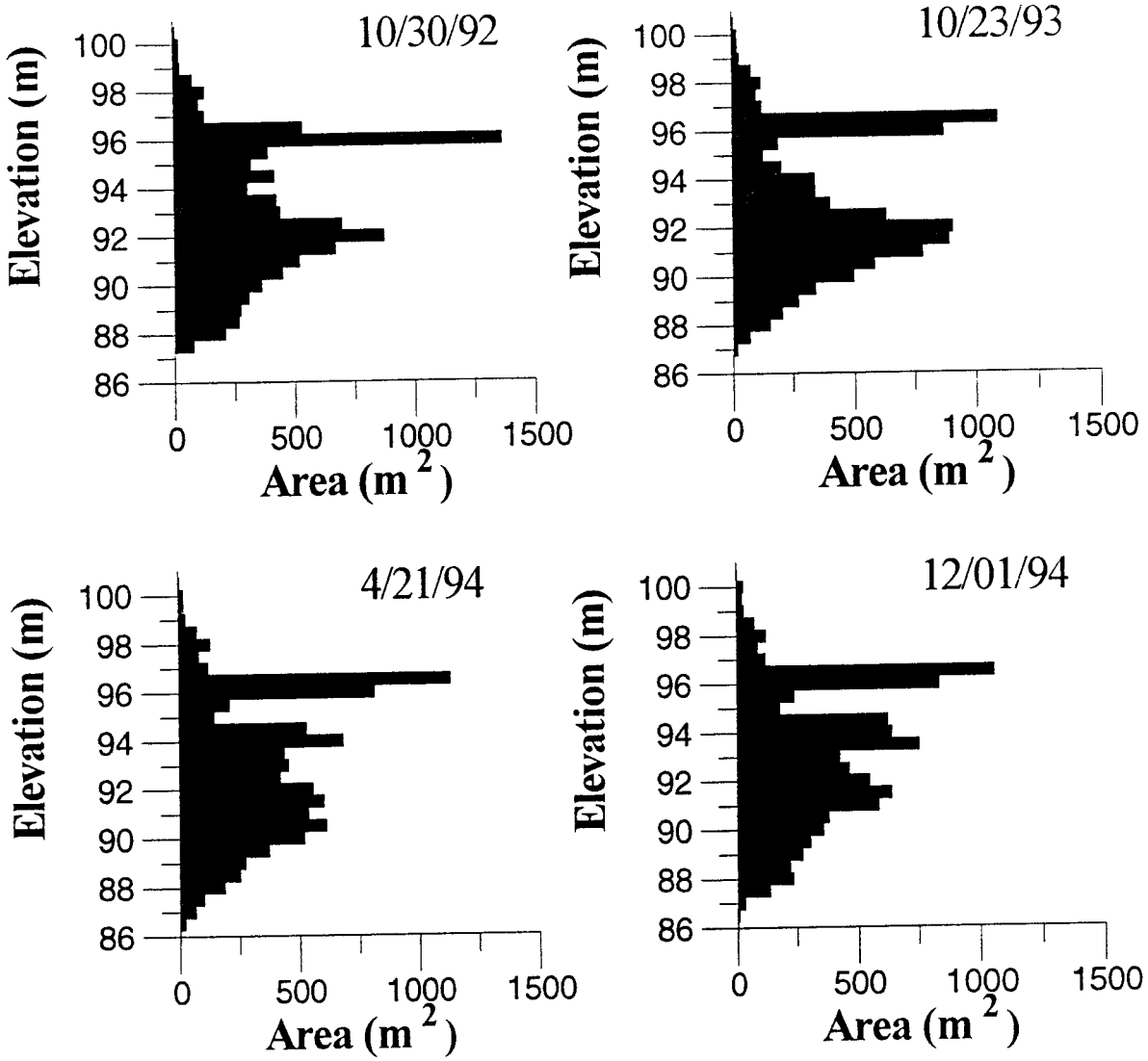
Hypsometric Curves



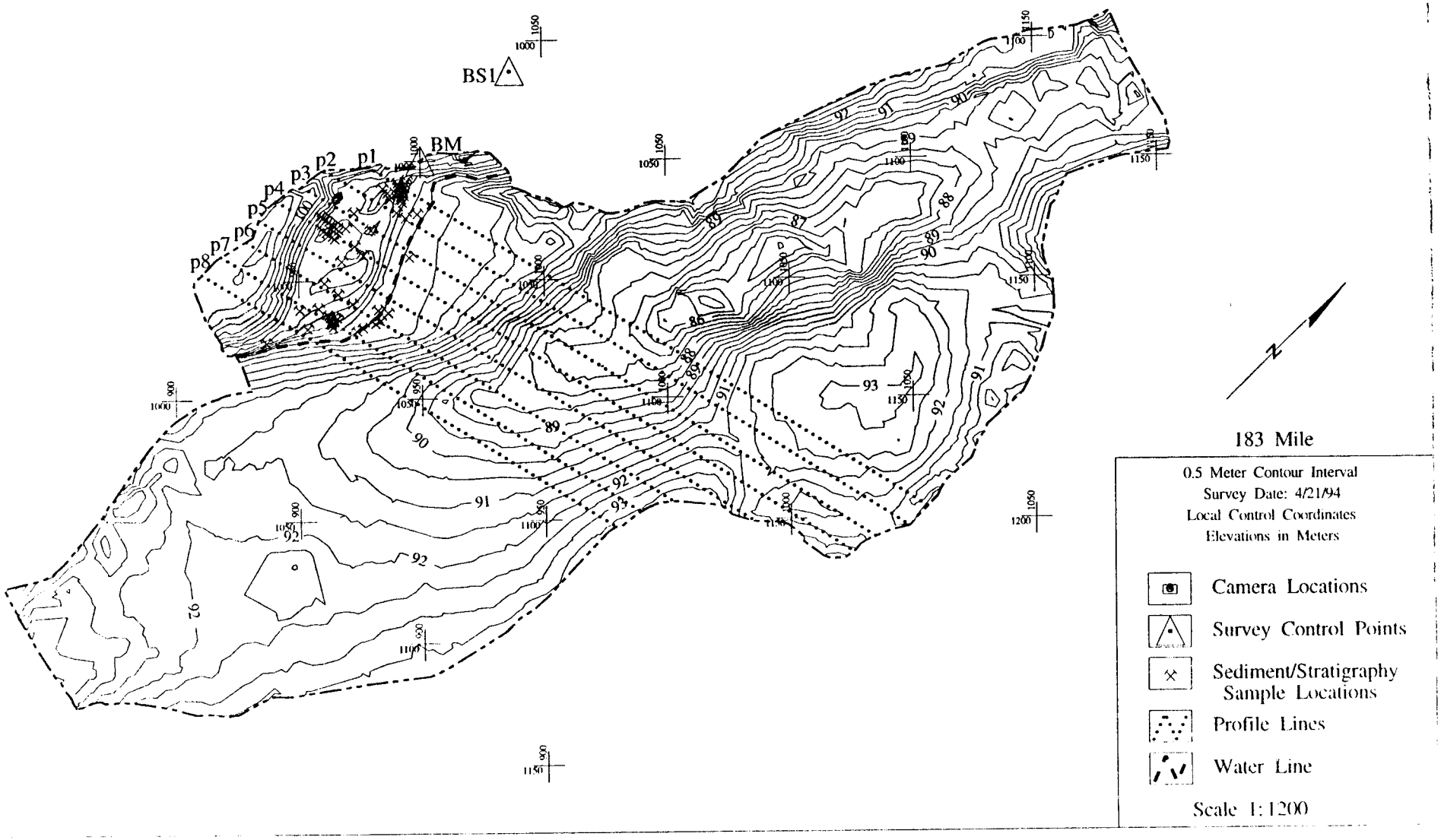
Stage Discharge



172 MILE
Area Distribution Histograms

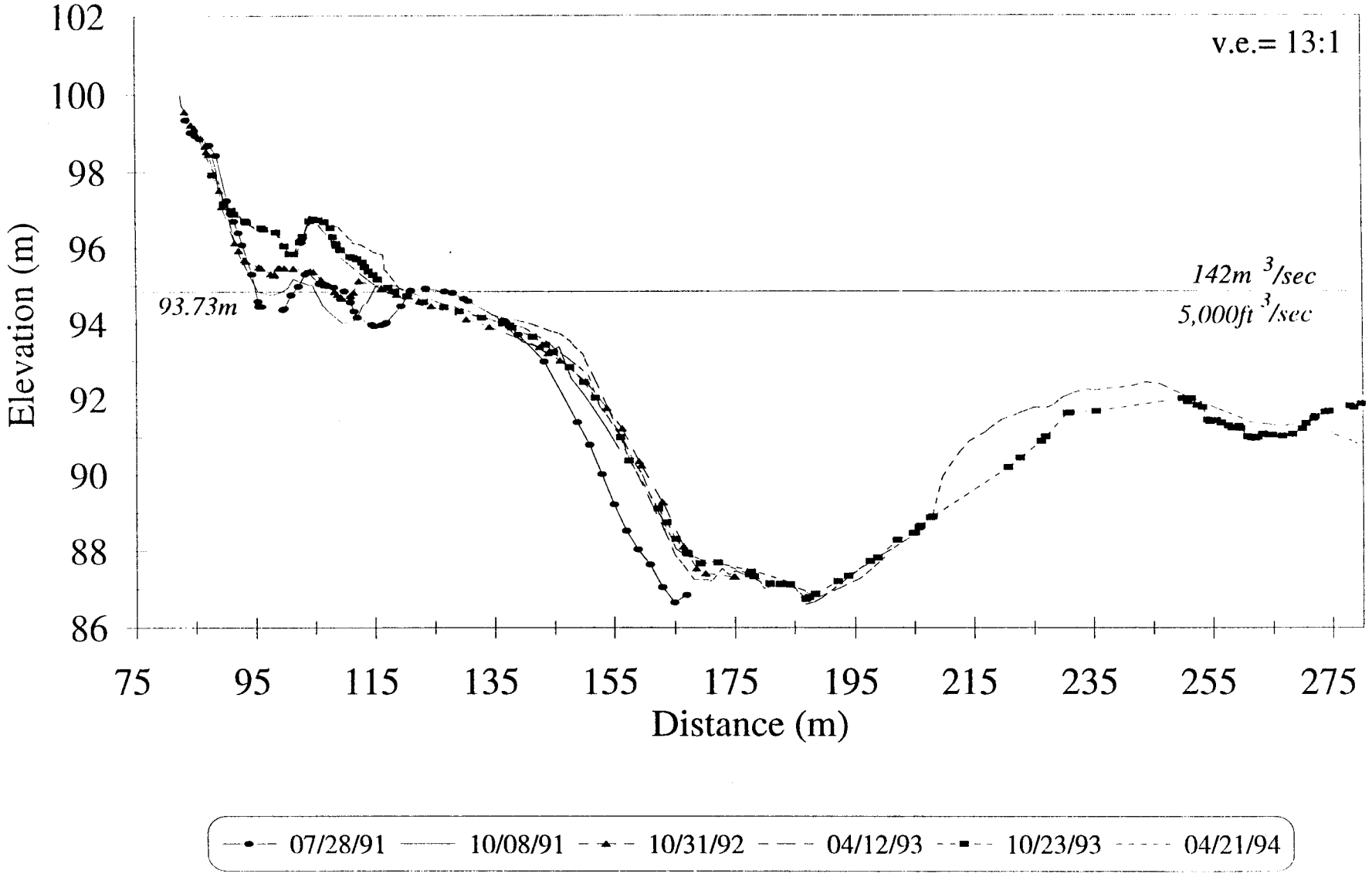


183 R
5-31-94
Area of Study
RM 182.7

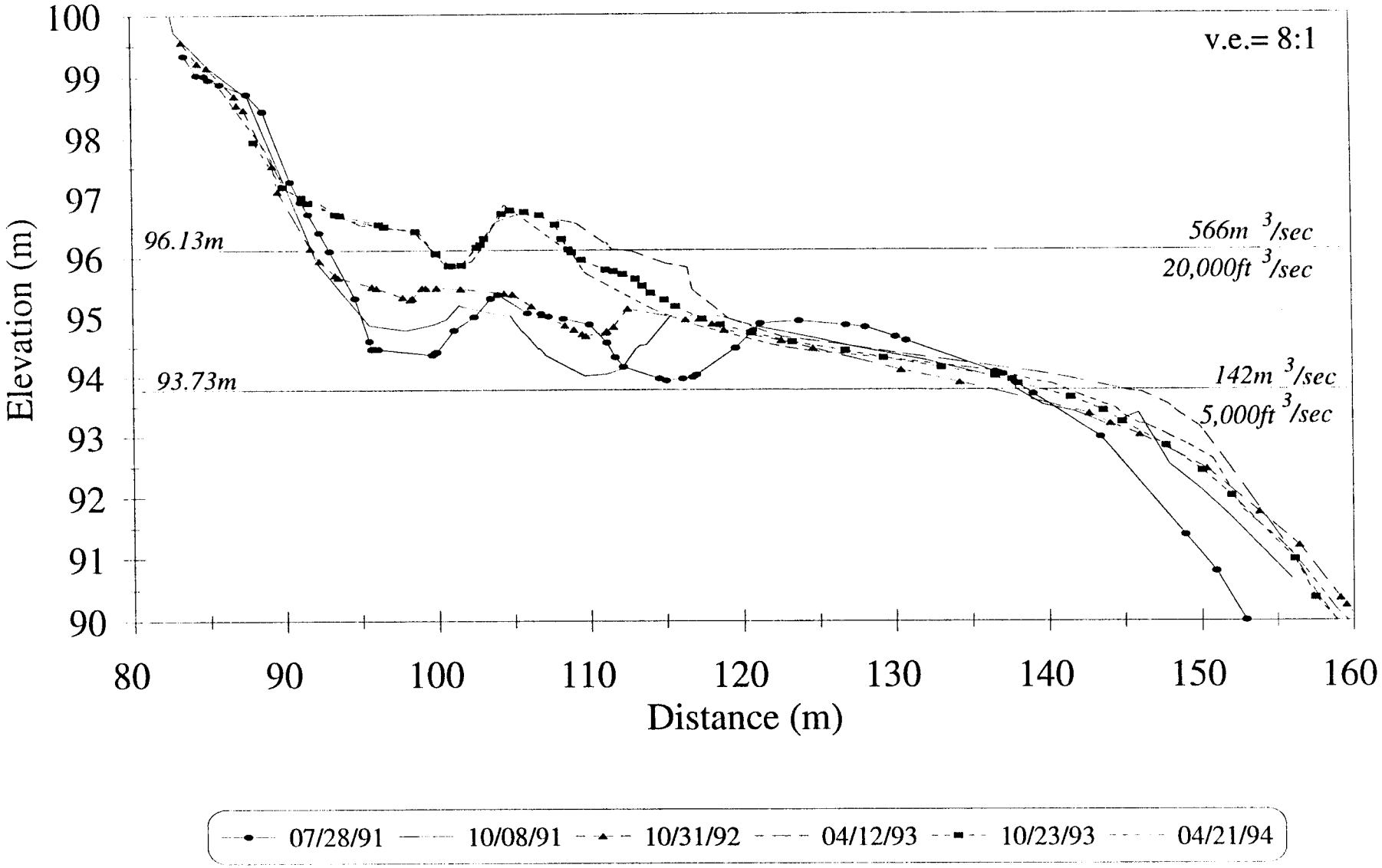

BS1
BM
p1
p2
p3
p4
p5
p6
p7
p8
183 Mile
0.5 Meter Contour Interval
Survey Date: 4/21/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:1200

183 Mile

Cross-channel P2

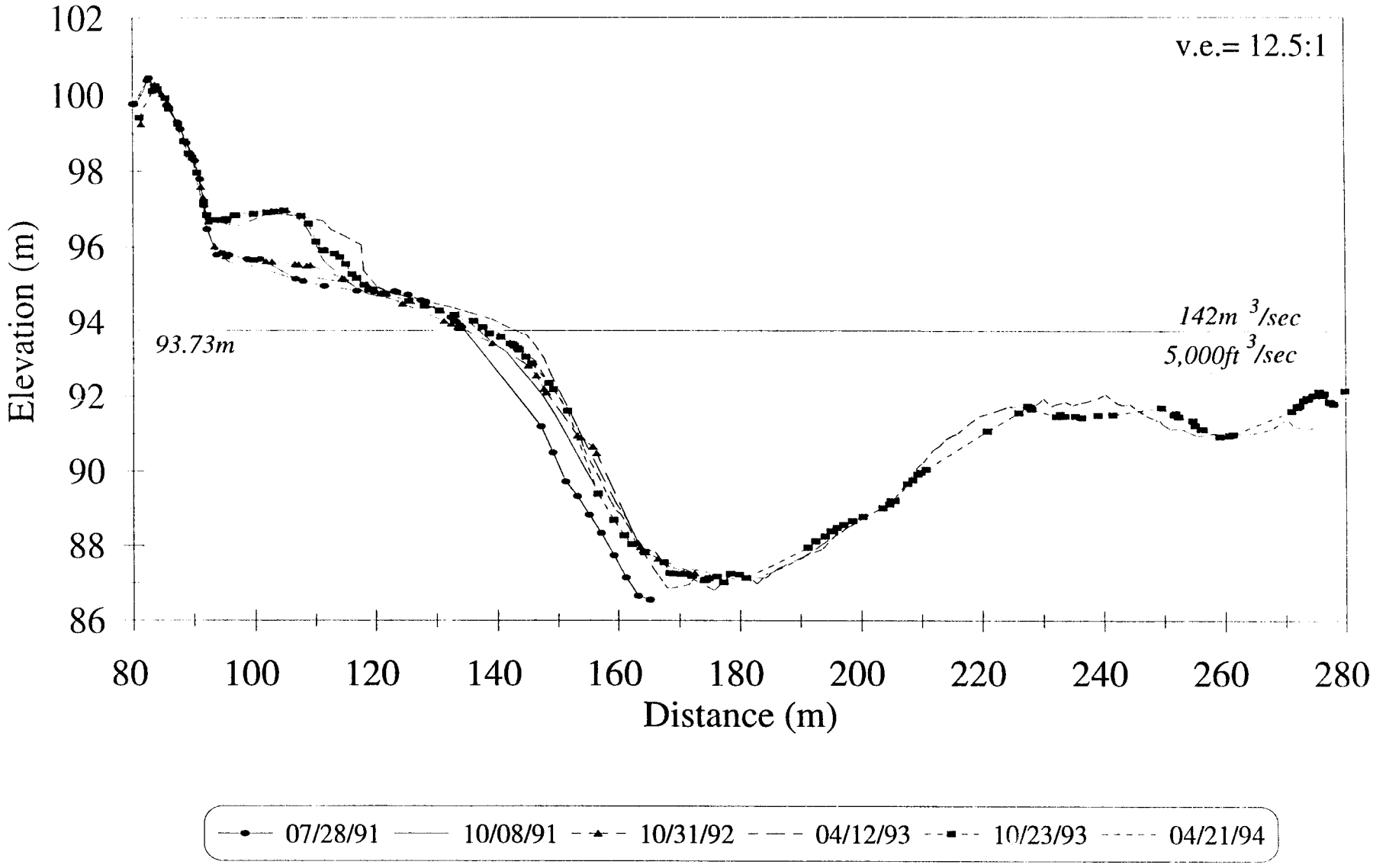


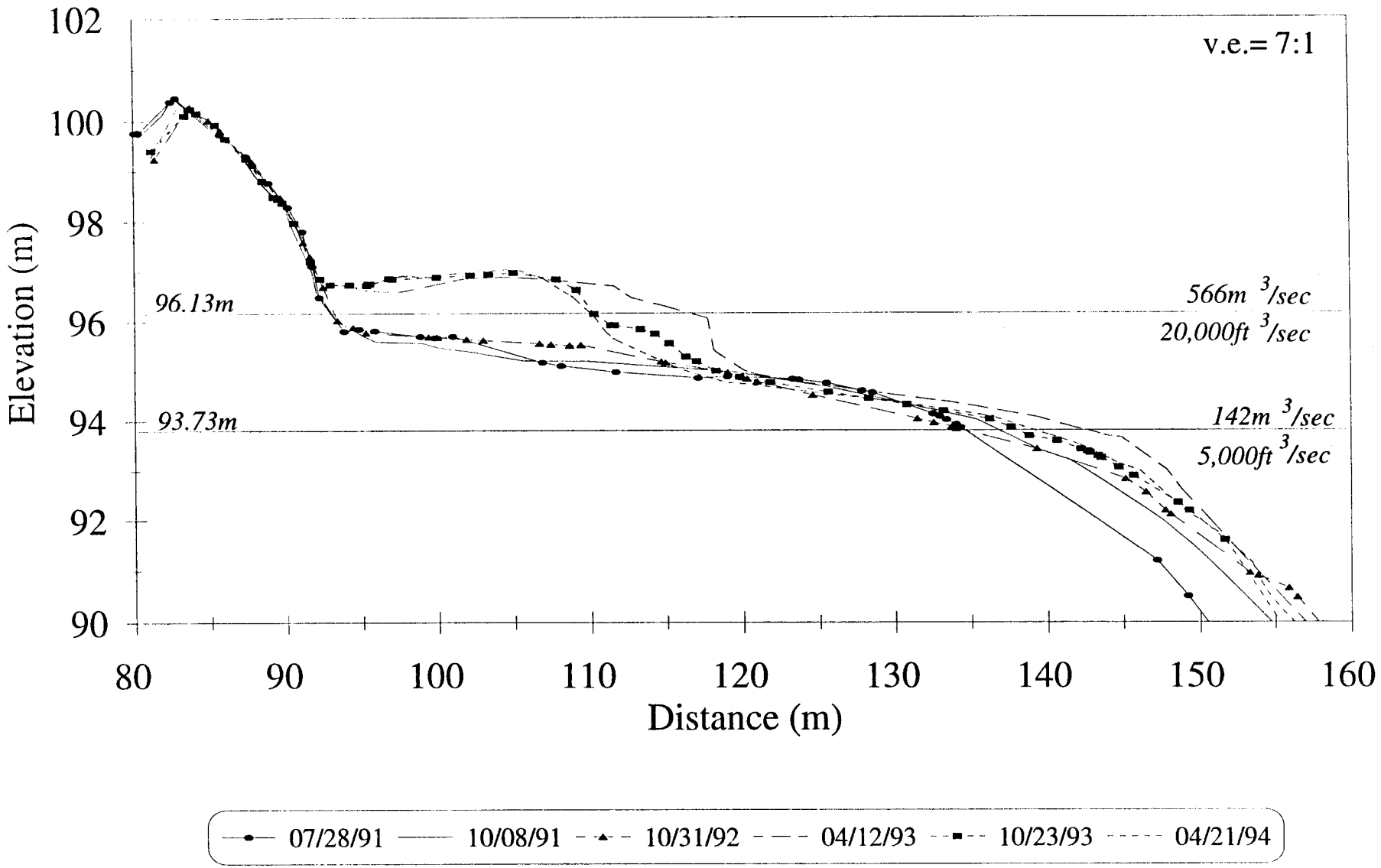
Near-shore P2



183 Mile

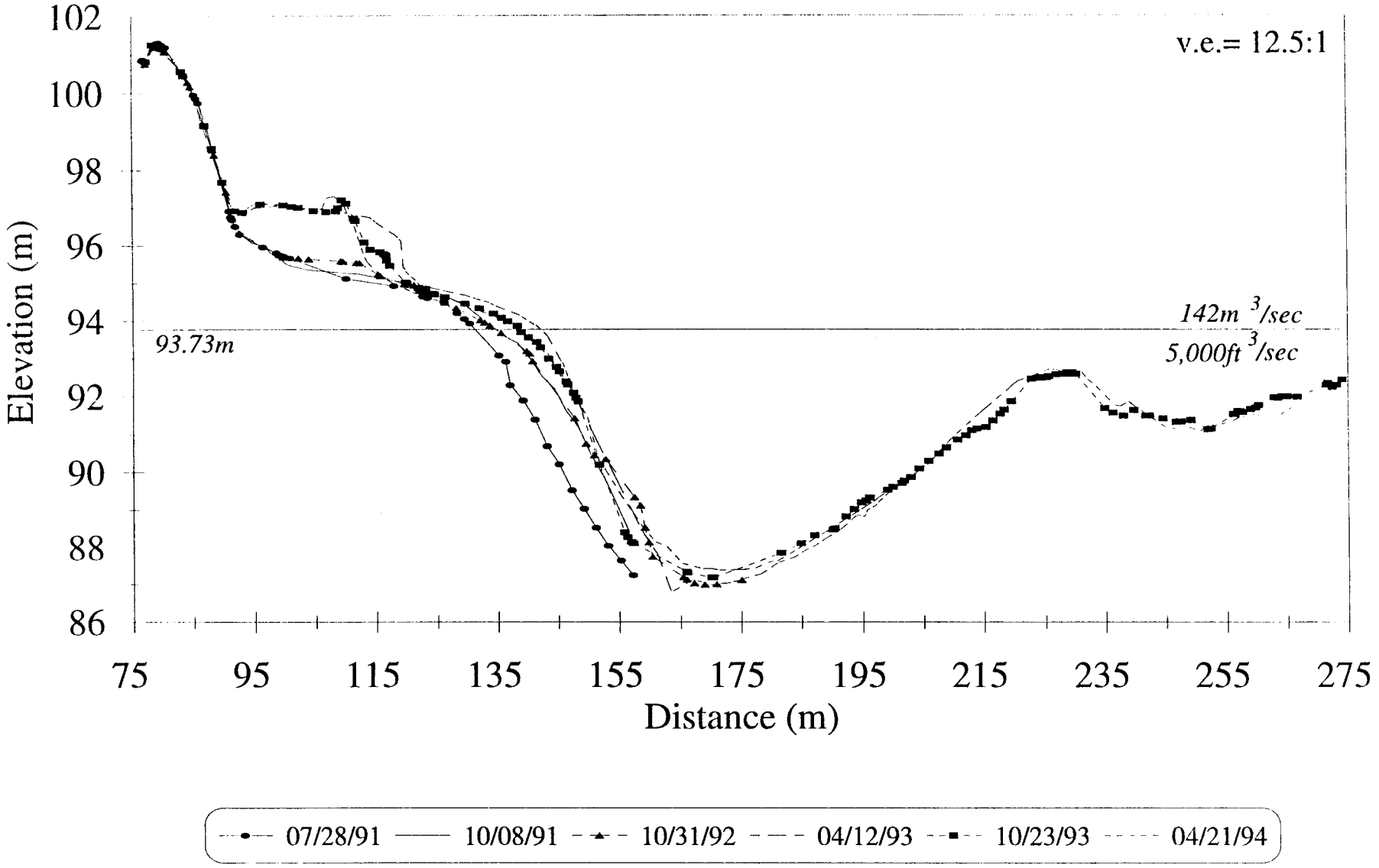
Cross-channel P3



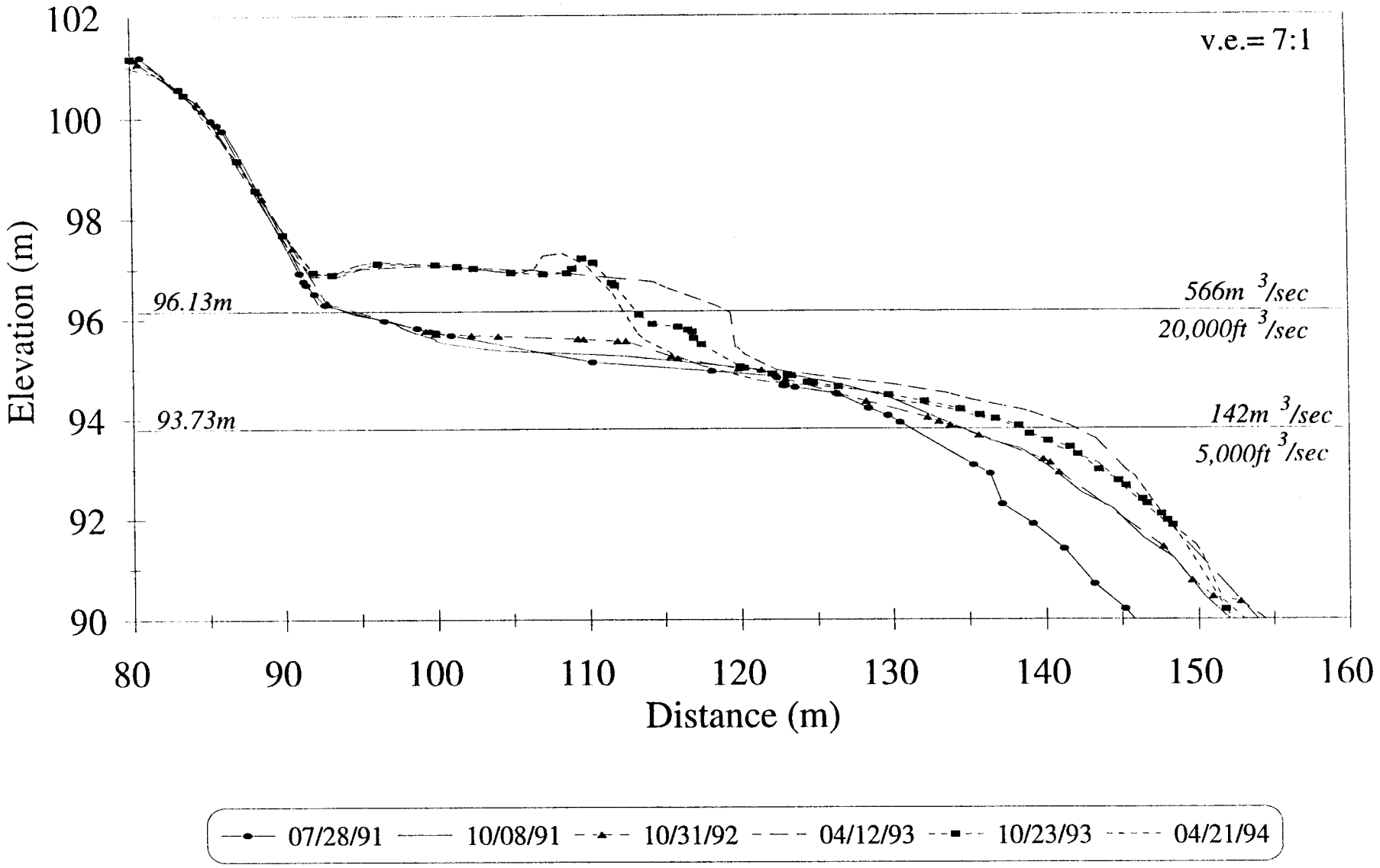

Near-shore P3
v.e.= 7:1
Elevation (m)
102
100
98
96
94
92
90
96.13m
93.73m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
80
90
100
110
120
130
140
150
160
Distance (m)
07/28/91
10/08/91
10/31/92
04/12/93
10/23/93
04/21/94

183 Mile

Cross-channel P4

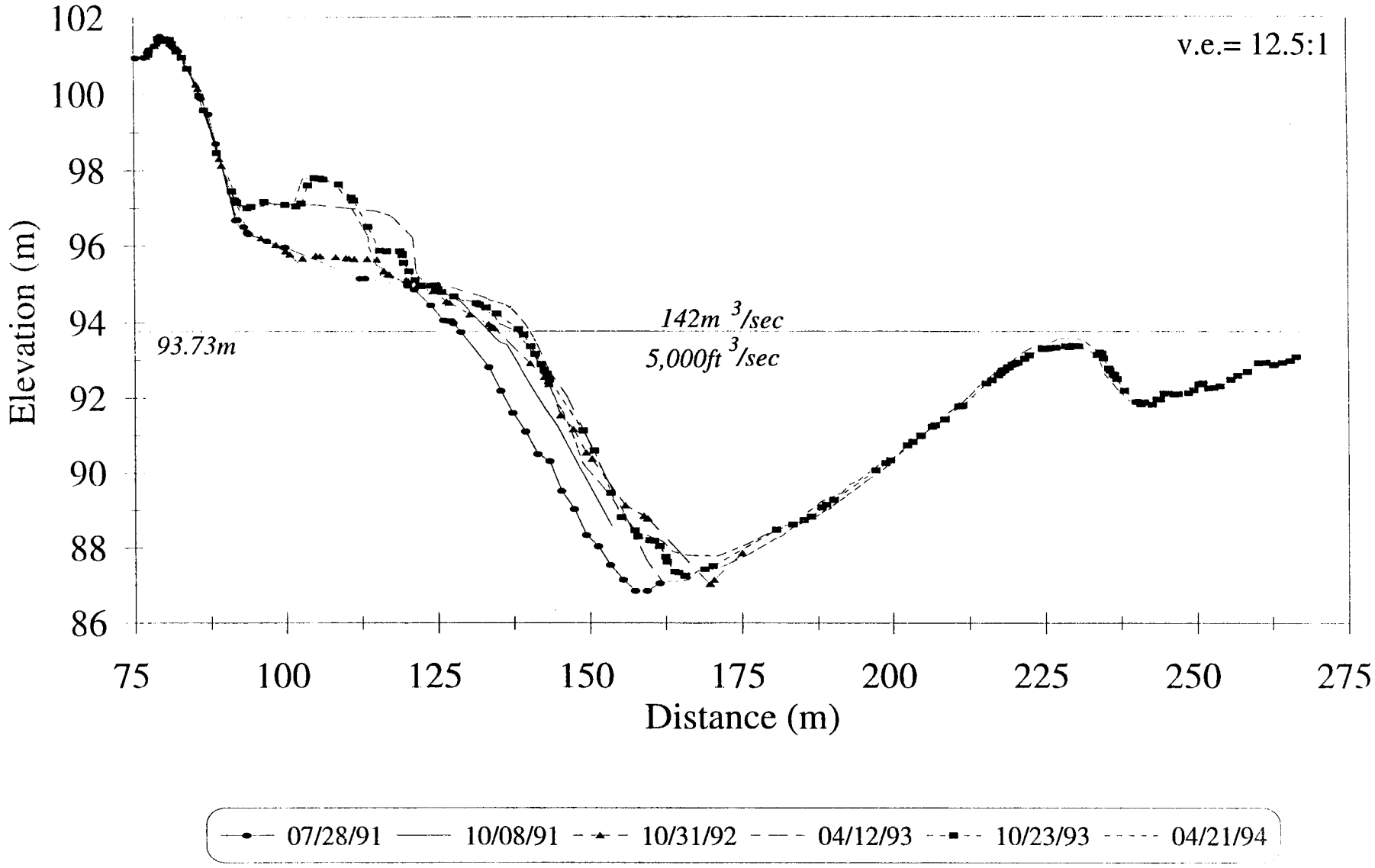


Near-shore P4

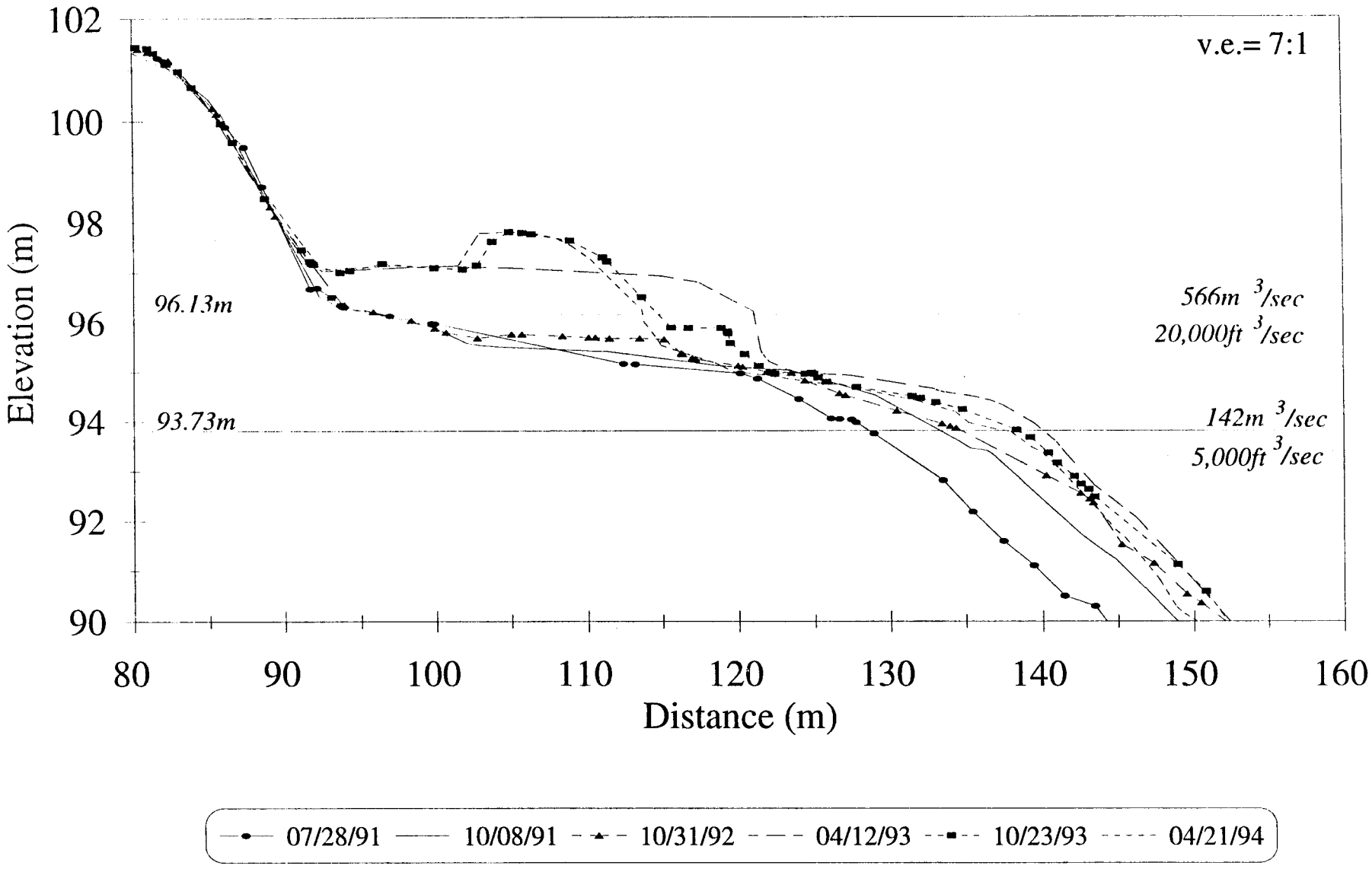


183 Mile

Cross-channel P5

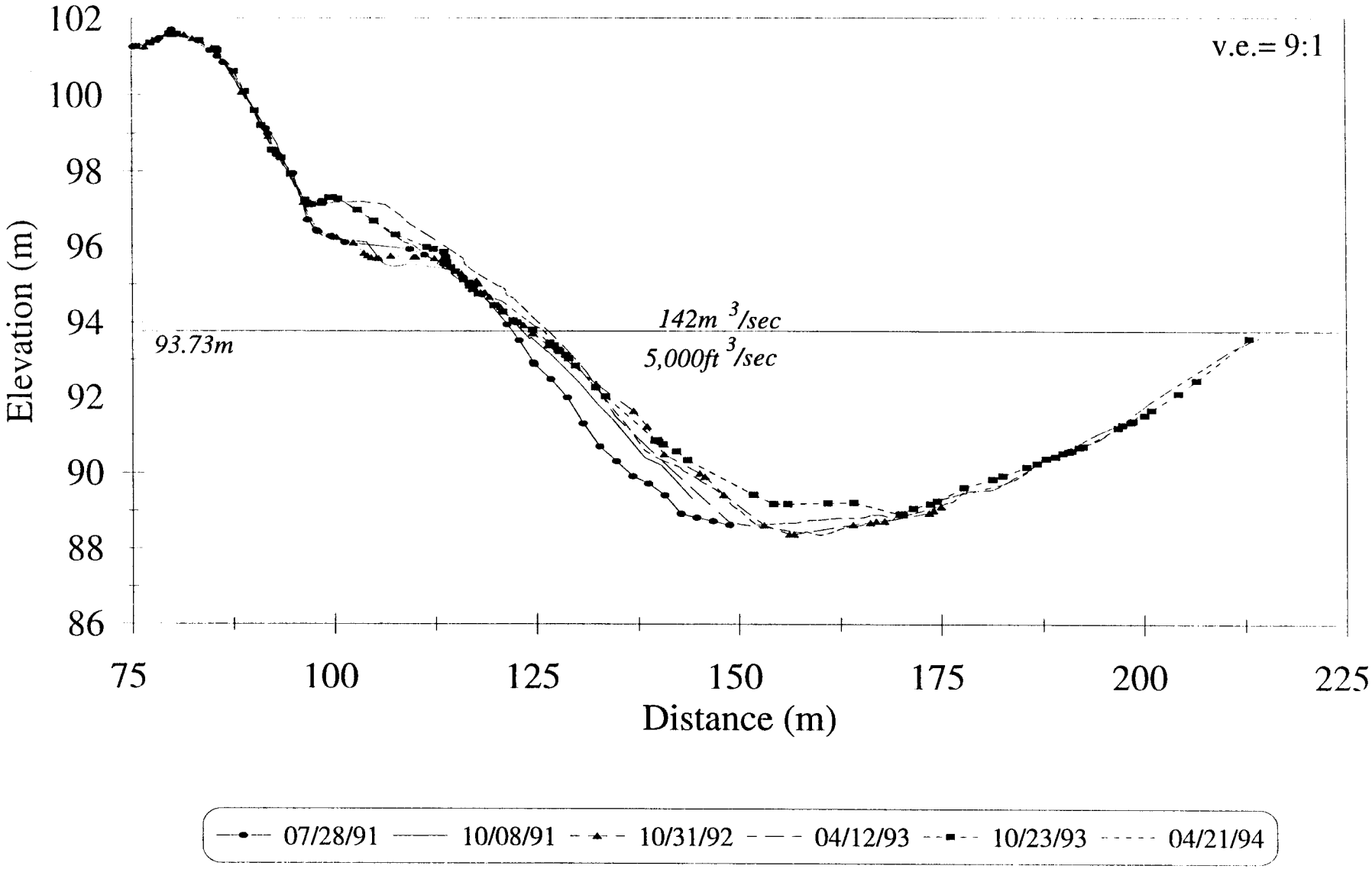


Near-shore P5

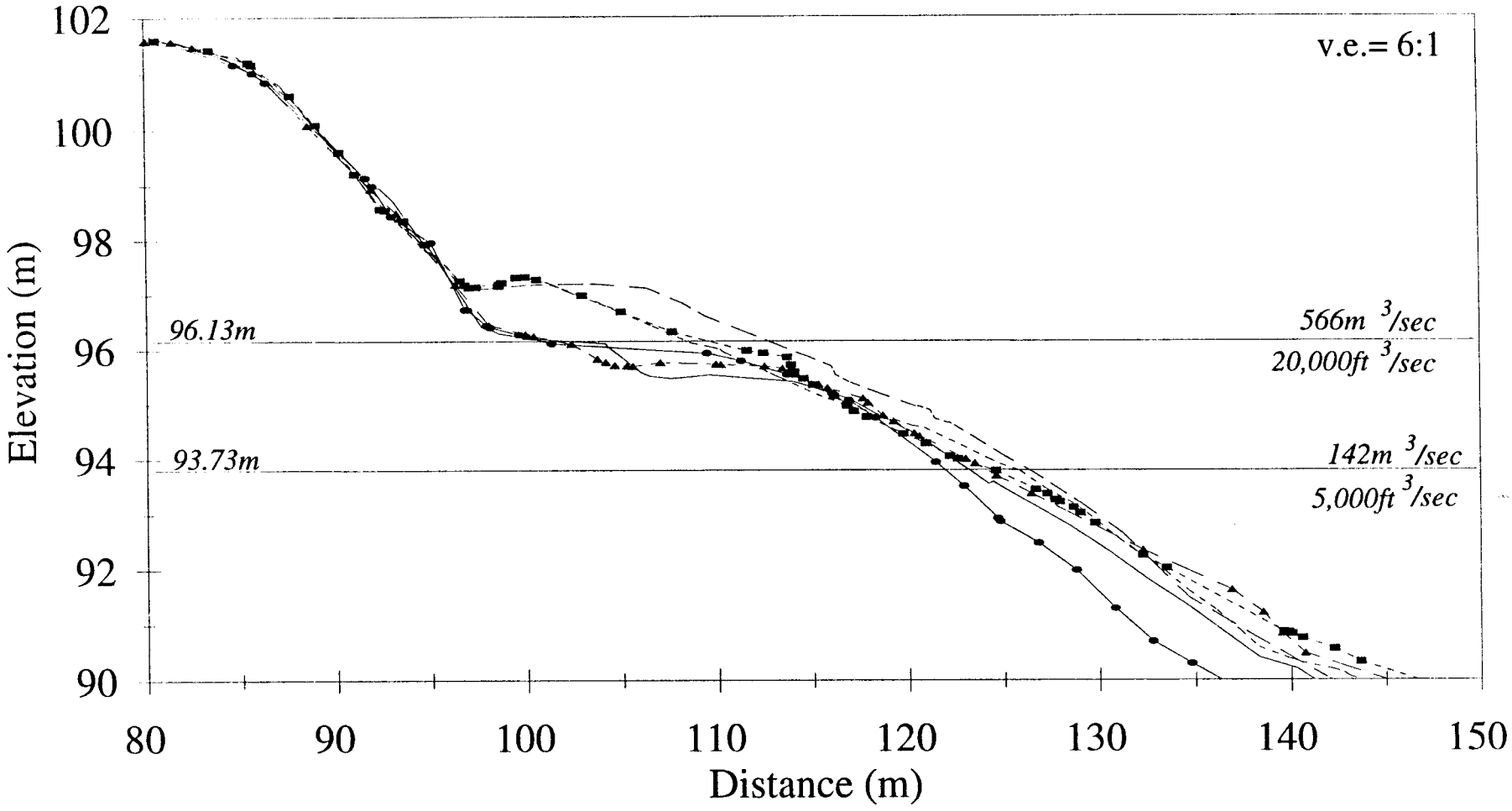


183 Mile

Cross-channel P7

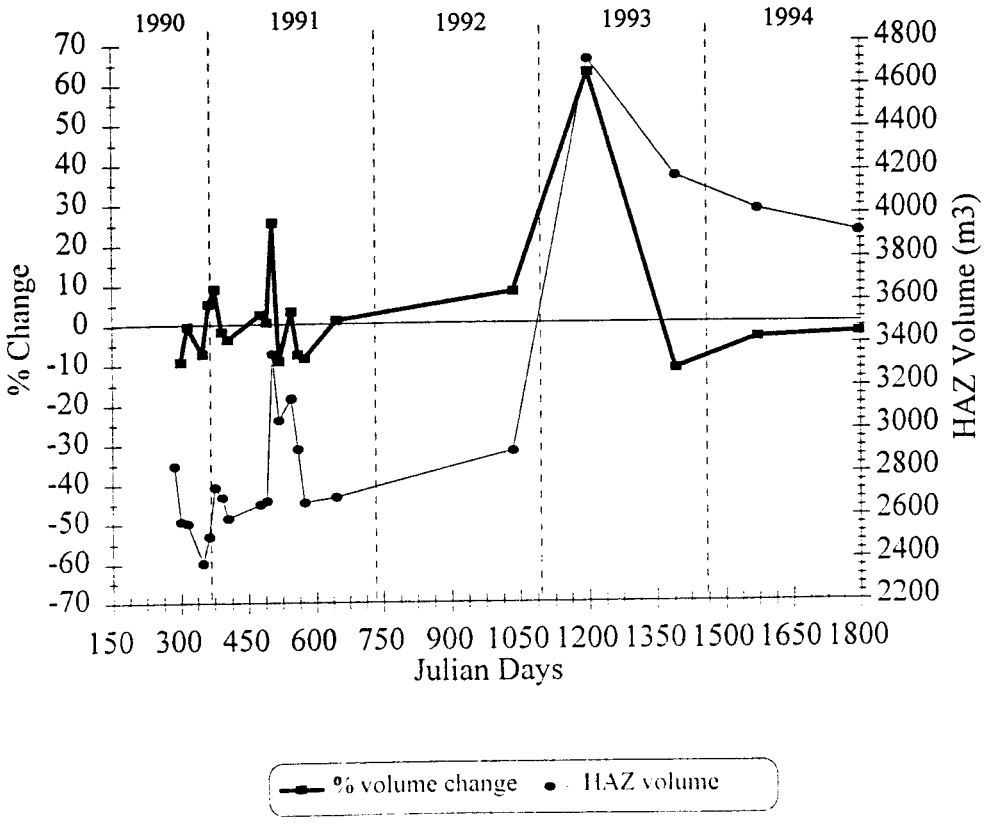


Near-shore P7



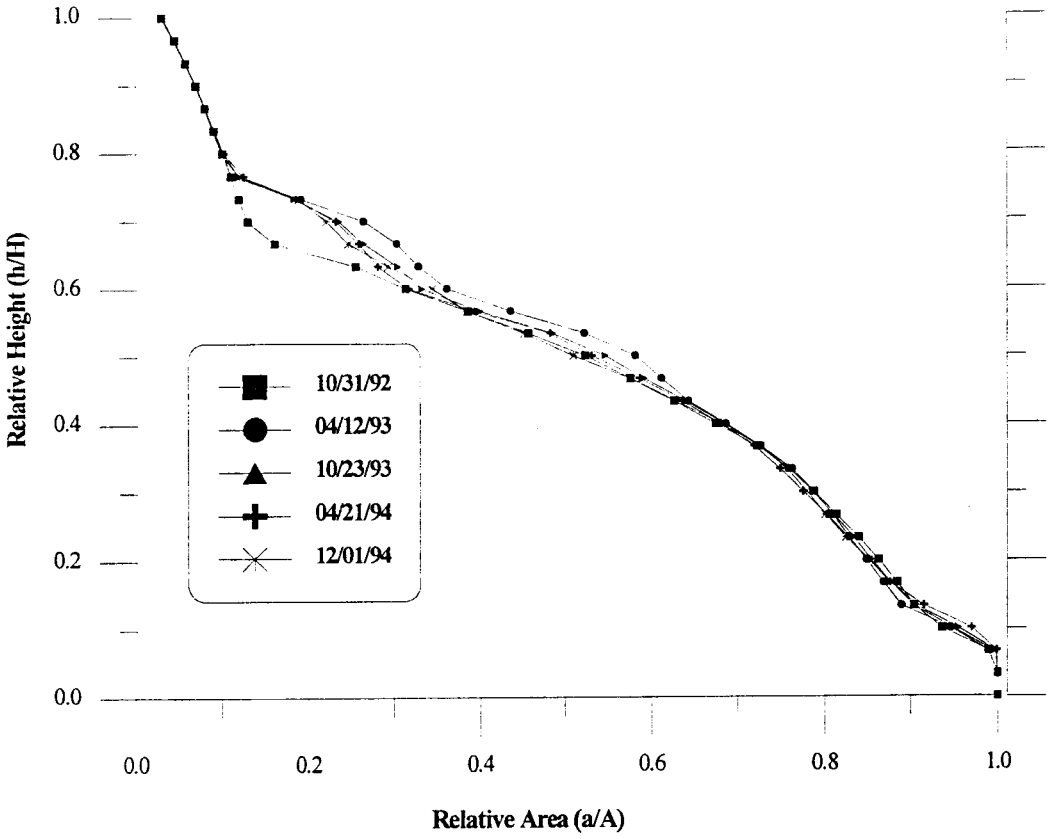
183 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F		NORM							
G		E							
H	901014	A	287	2041	2844				
I	901028	8000 CFS	301	1831	2583	-210	-261	-10.29	-9.18
J	901111	NORM	315	1790	2575	-41	-8	-2.24	-0.31
K	901216	NORM	350	1865	2390	75	-185	4.19	-7.18
L	901230	11000 CFS	364	1921	2515	56	125	3.00	5.23
M	910112	C	377	2073	2744	152	229	7.91	9.11
N	910128	NORM	393	2044	2697	-29	-47	-1.40	-1.71
O	910210	B	406	2027	2599	-17	-98	-0.83	-3.63
P	910421	NORM	476	2112	2663	85	64	4.19	2.46
Q	910506	NORM	491	2123	2680	11	17	0.52	0.64
R	910519	D	504	2242	3364	119	684	5.61	25.52
S	910602	15000 CFS	518	2215	3056	-27	-308	-1.20	-9.16
T	910630	NORM	546	2144	3156	-71	100	-3.21	3.27
U	910714	G	560	2087	2919	-57	-237	-2.66	-7.51
V	910728	F	574	2078	2670	-9	-249	-0.43	-8.53
W	911008	INT	646	2152	2694	74	24	3.56	0.90
Y	921031	INT	1035	2237	2906	85	212	3.95	7.87
Z	930412	INT	1198	2710	4723	473	1817	21.14	62.53
B28	931023	INT	1392	2436	4179	-274	-544	-10.11	-11.52
C28	940422	INT	1572	2476	4023	40	-156	1.64	-3.73
D28	941201	INT	1796	2232	3921	-244	-102	-9.85	-2.54

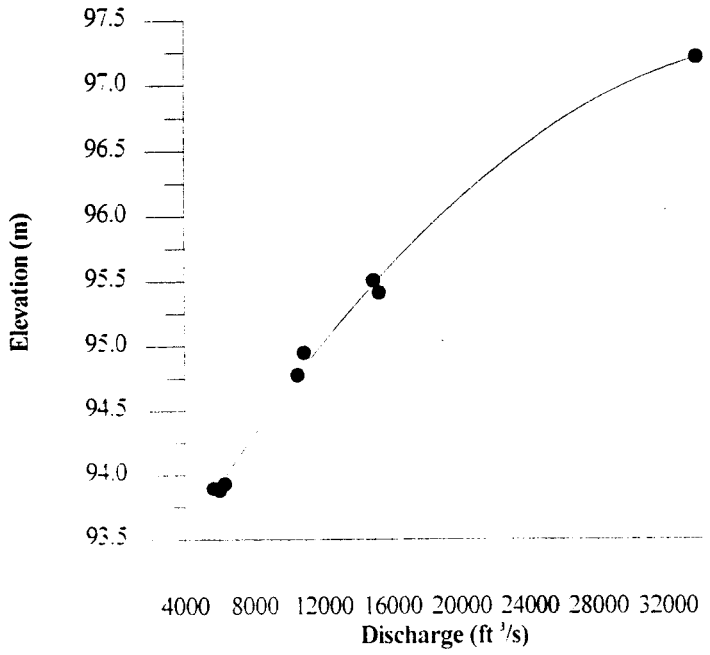


183 Mile

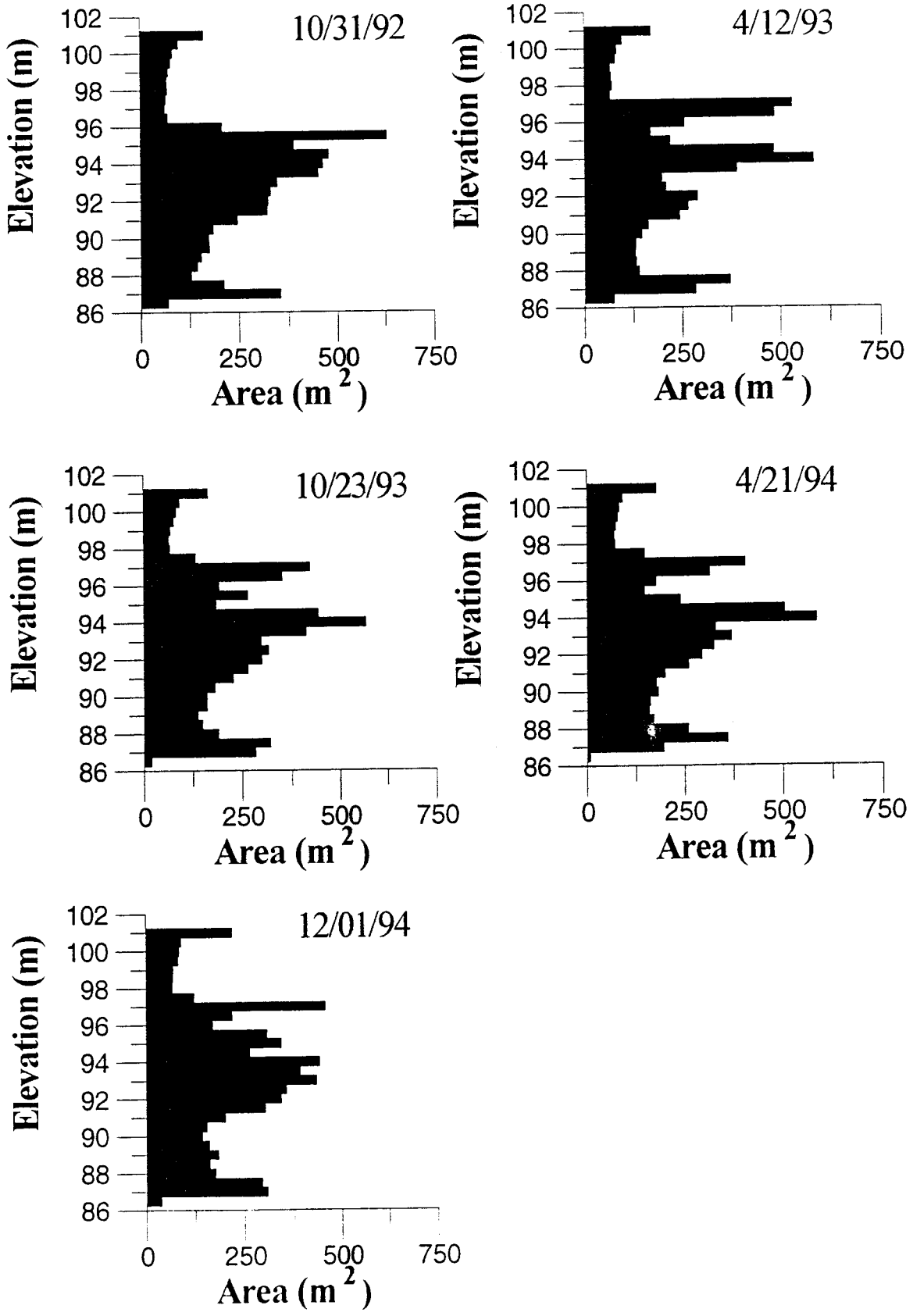
Hypsometric Curves

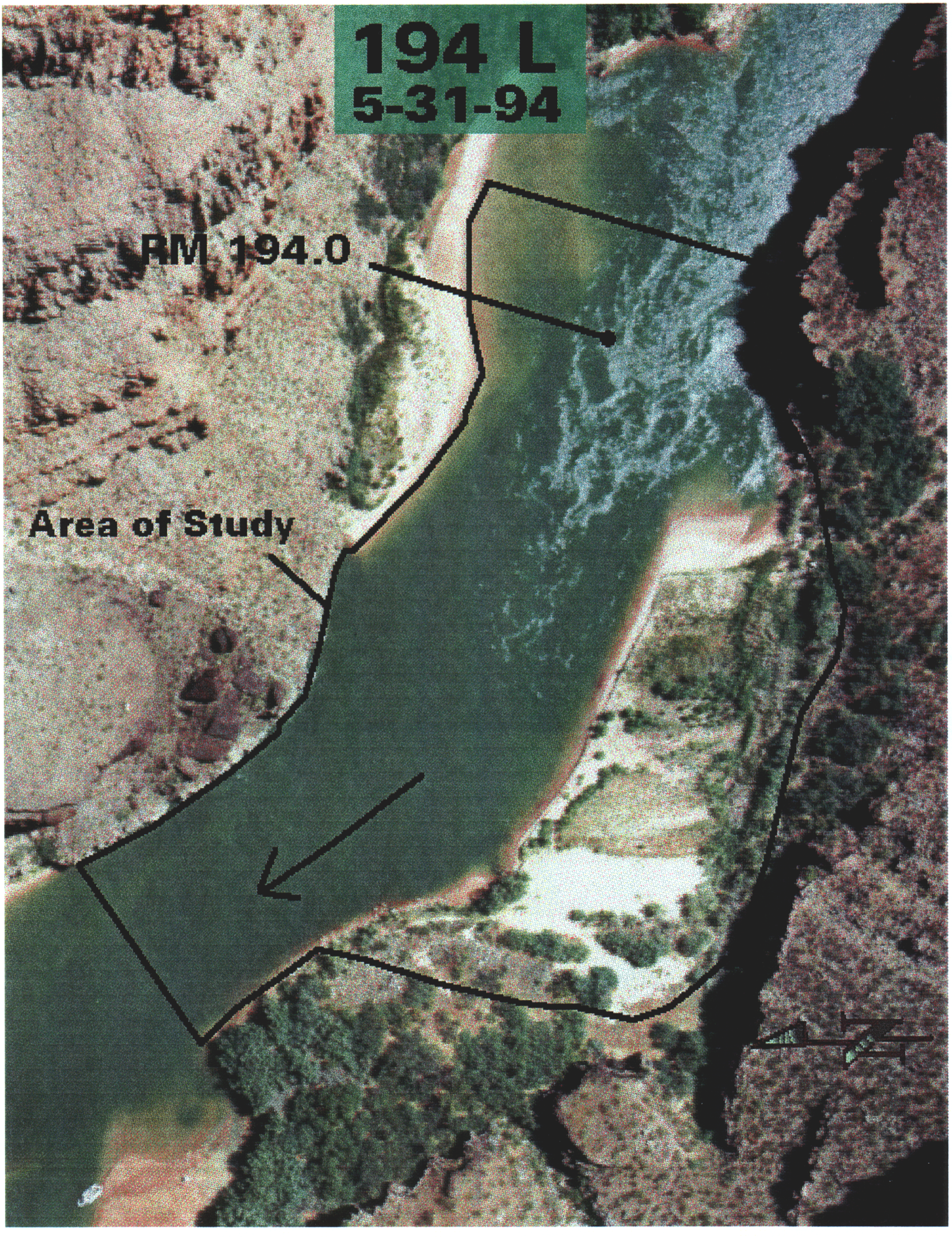


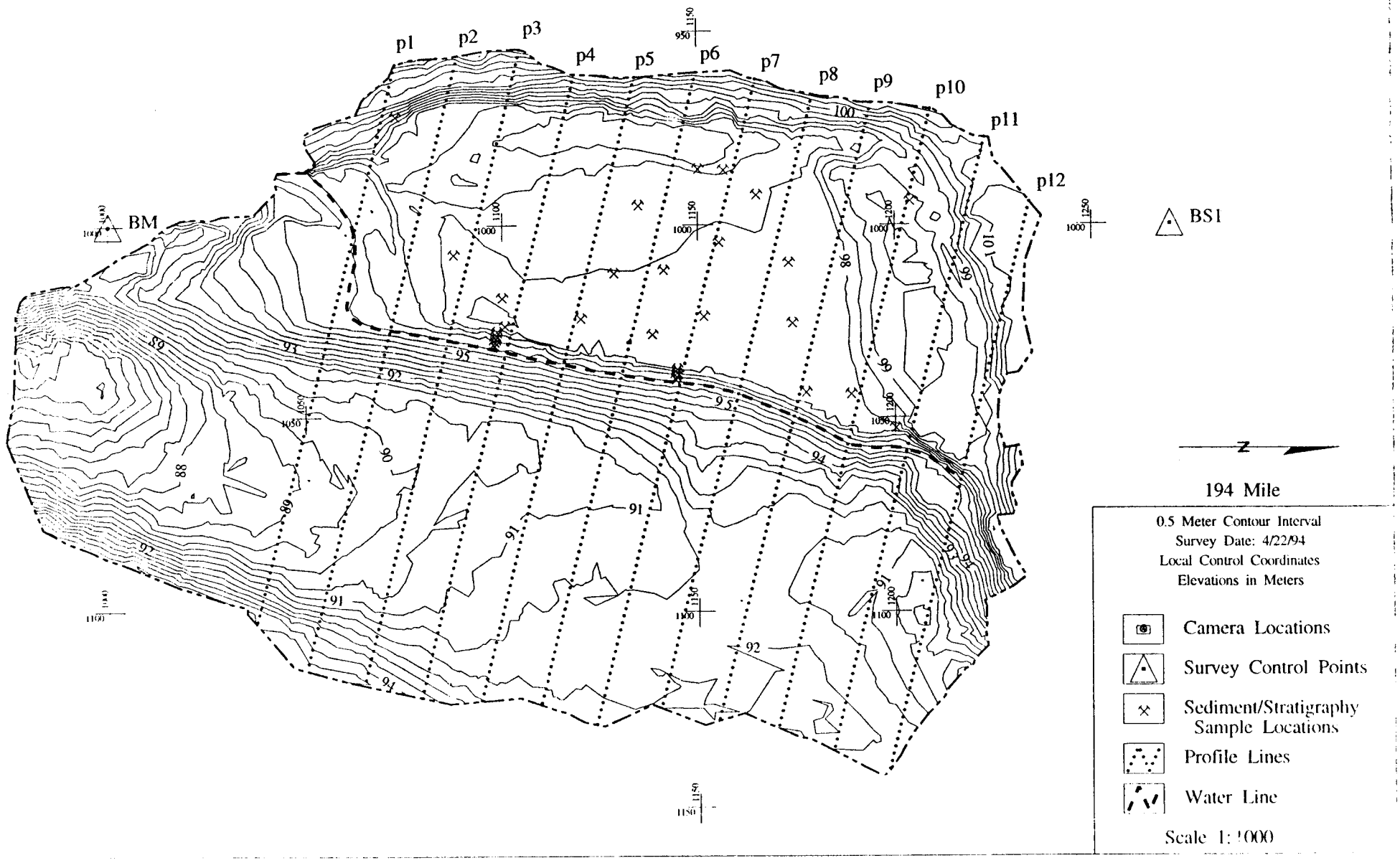
Stage Discharge



183 MILE
Area Distribution Histograms

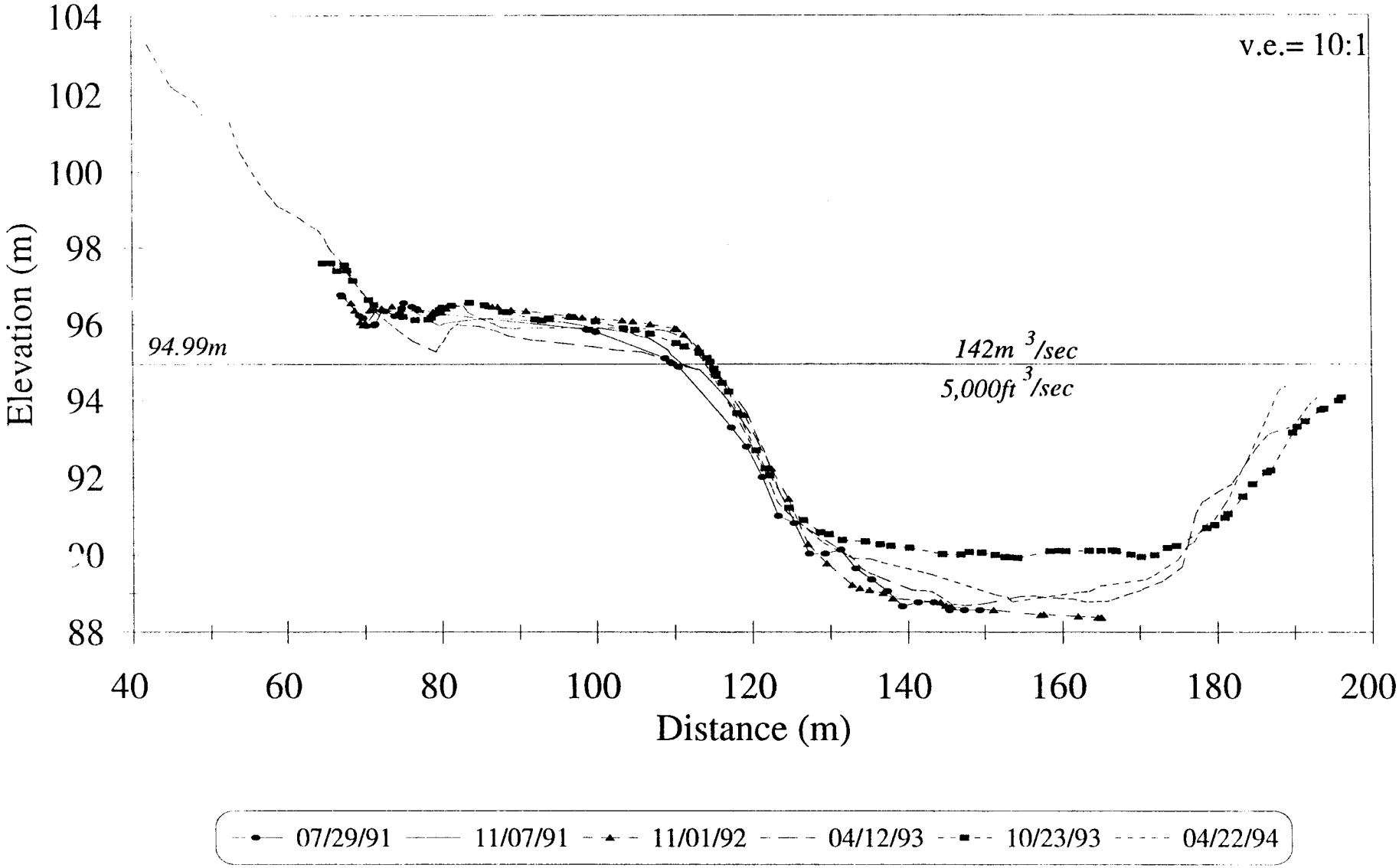



194 L
5-31-94
RM 194.0
Area of Study

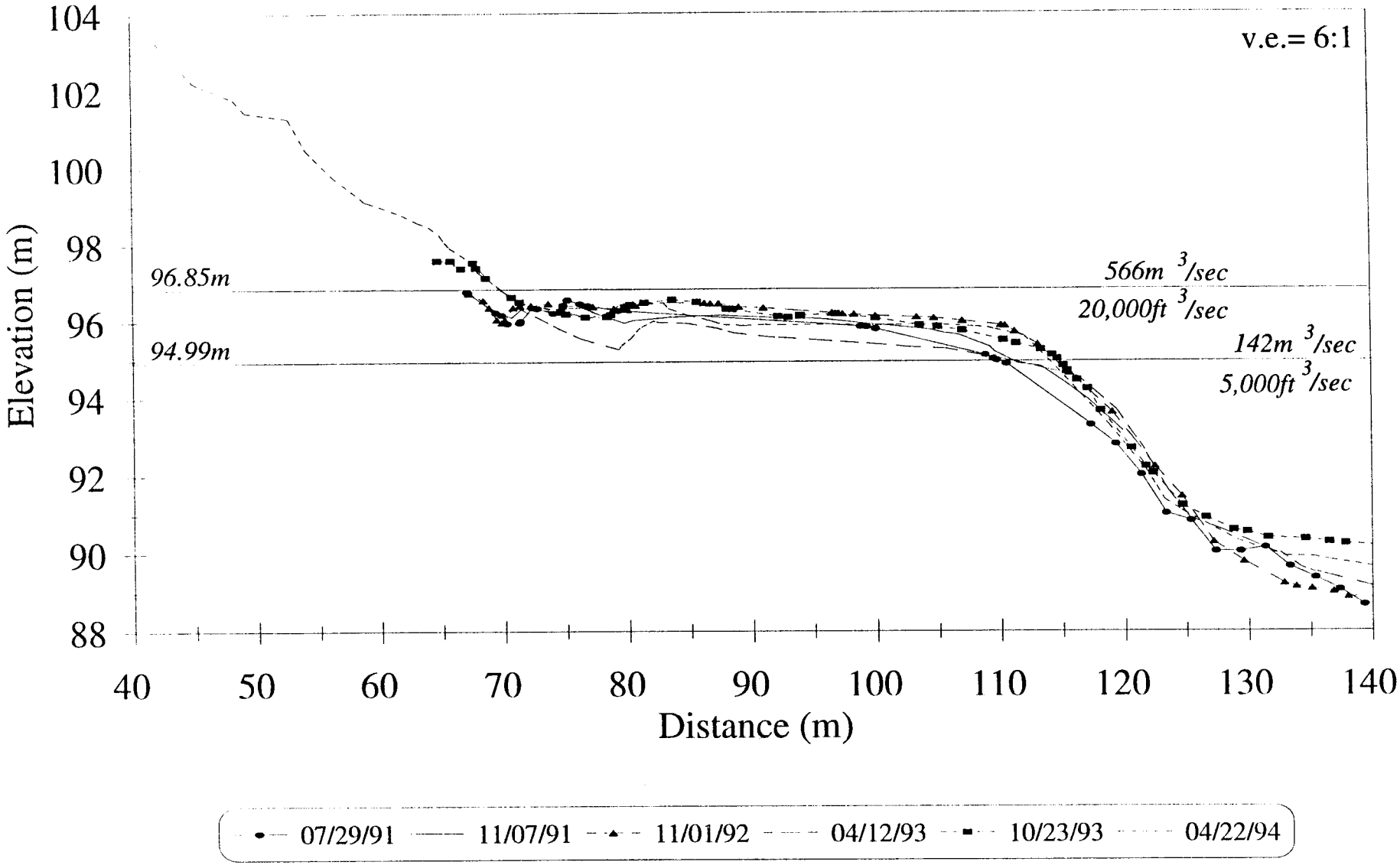

p1
p2
p3
p4
p5
p6
p7
p8
p9
p10
p11
p12
BM
BS1
194 Mile
0.5 Meter Contour Interval
Survey Date: 4/22/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:1000

194 Mile

Cross-channel P1

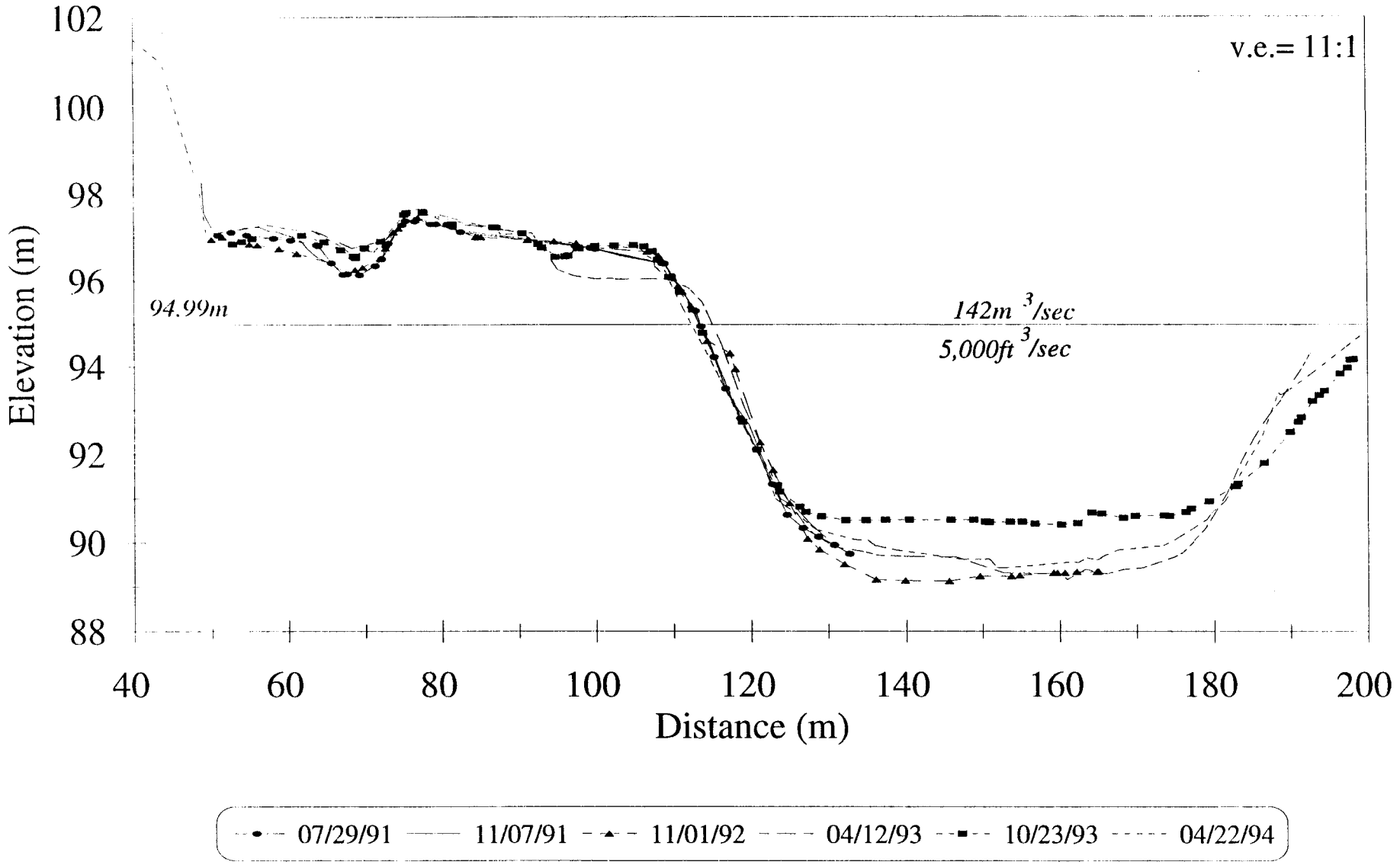


Near-shore P1

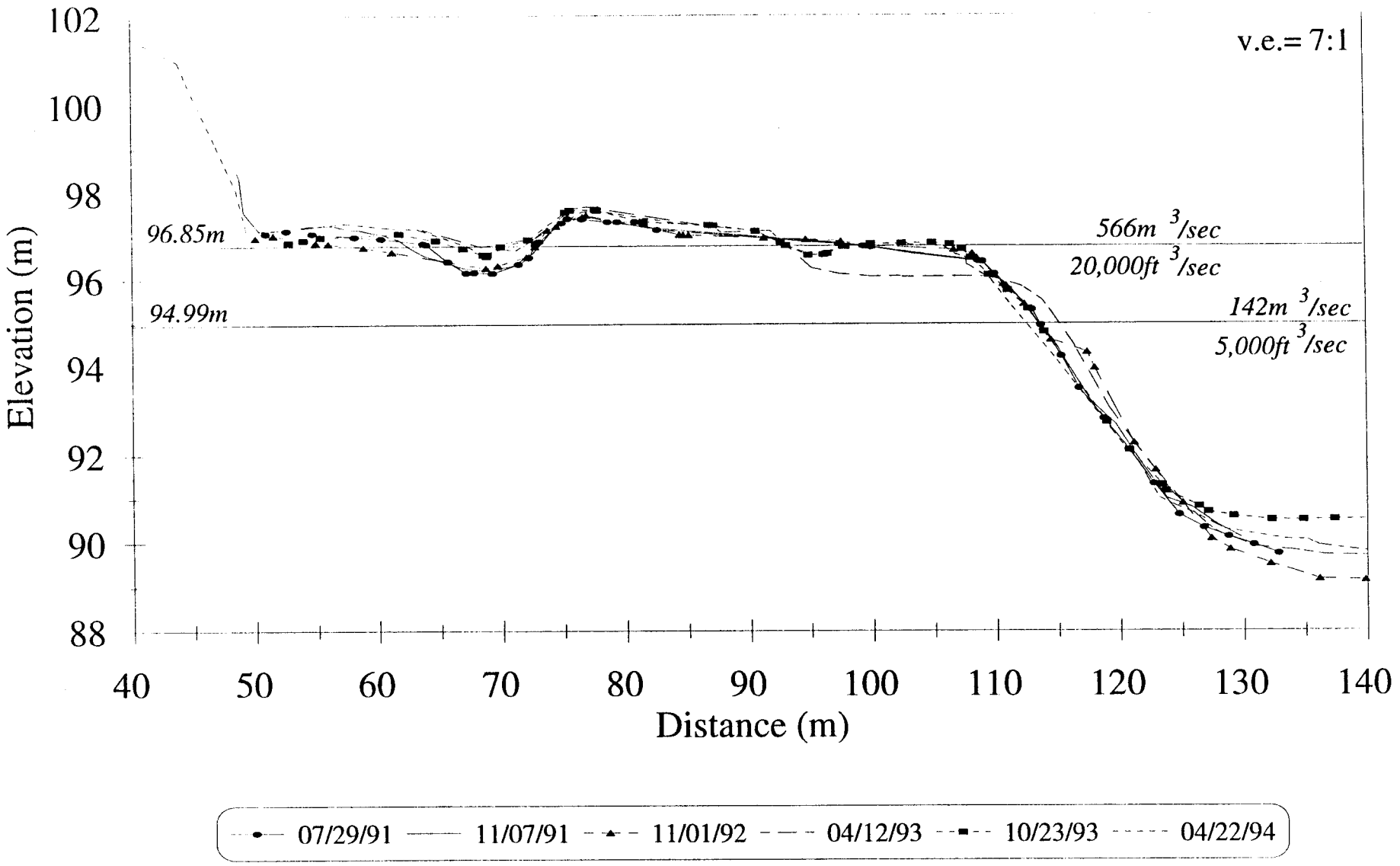


194 Mile

Cross-channel P2

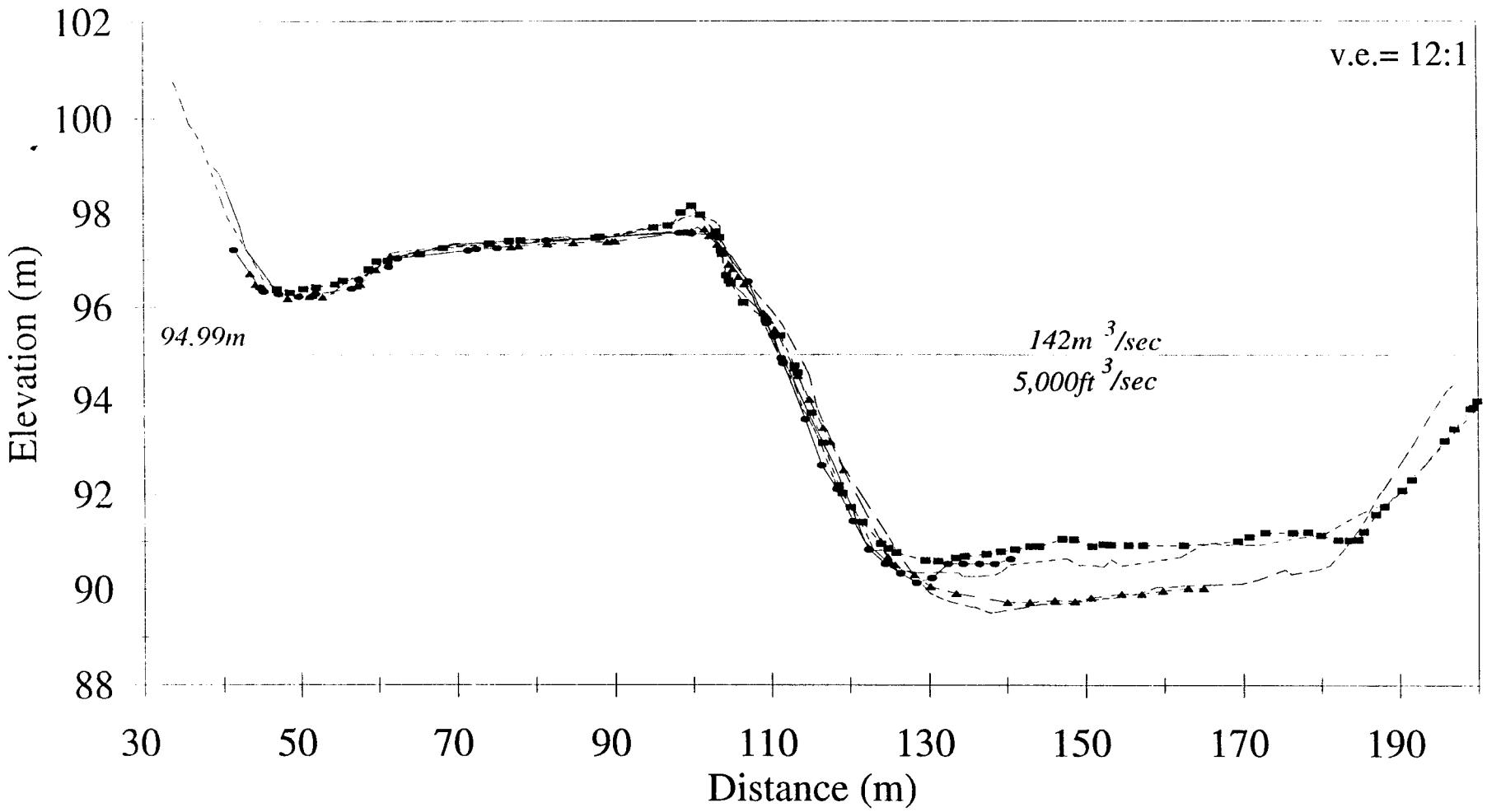


Near-shore P2

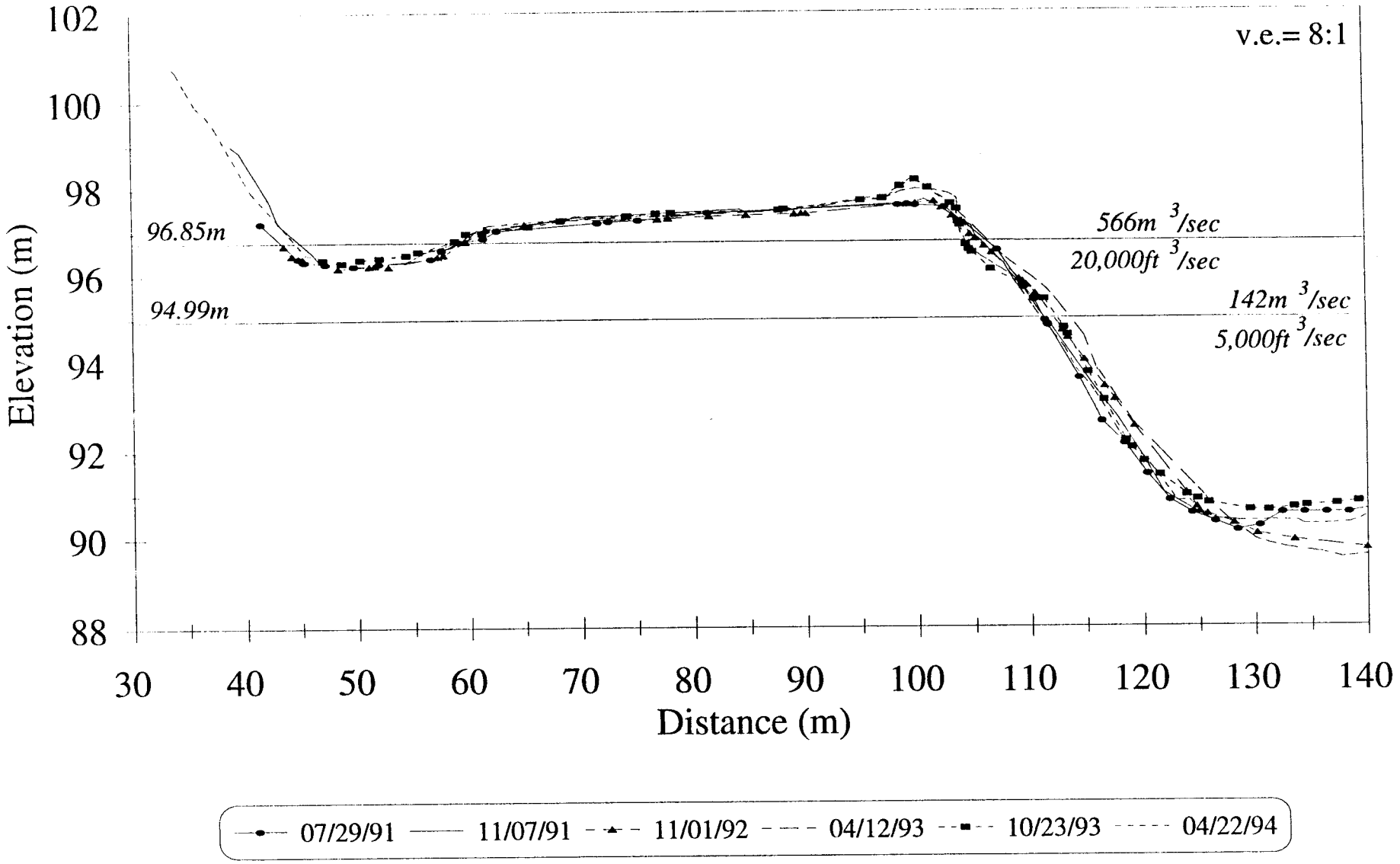


194 Mile

Cross-channel P4

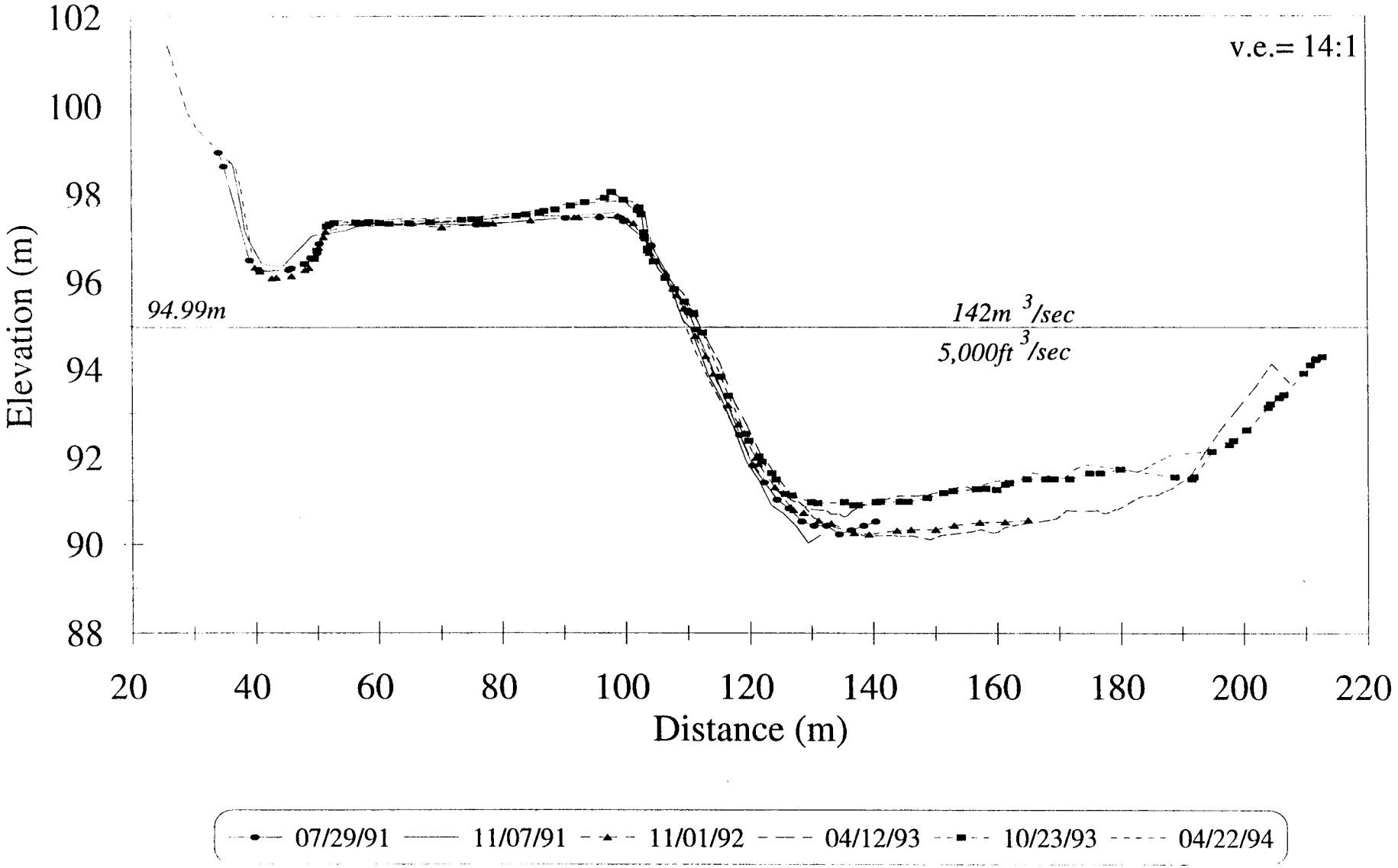


Near-shore P4

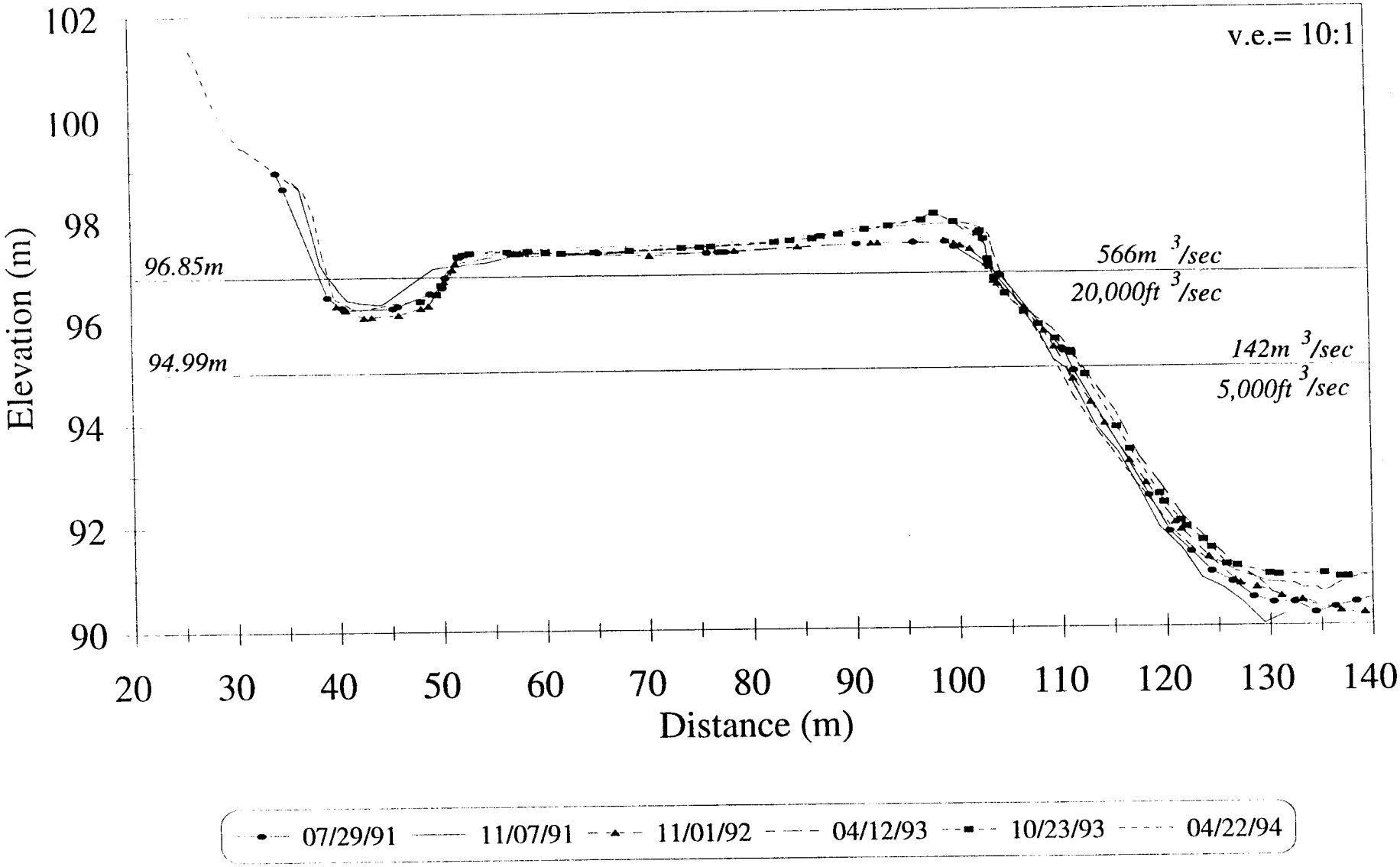


194 Mile

Cross-channel P6

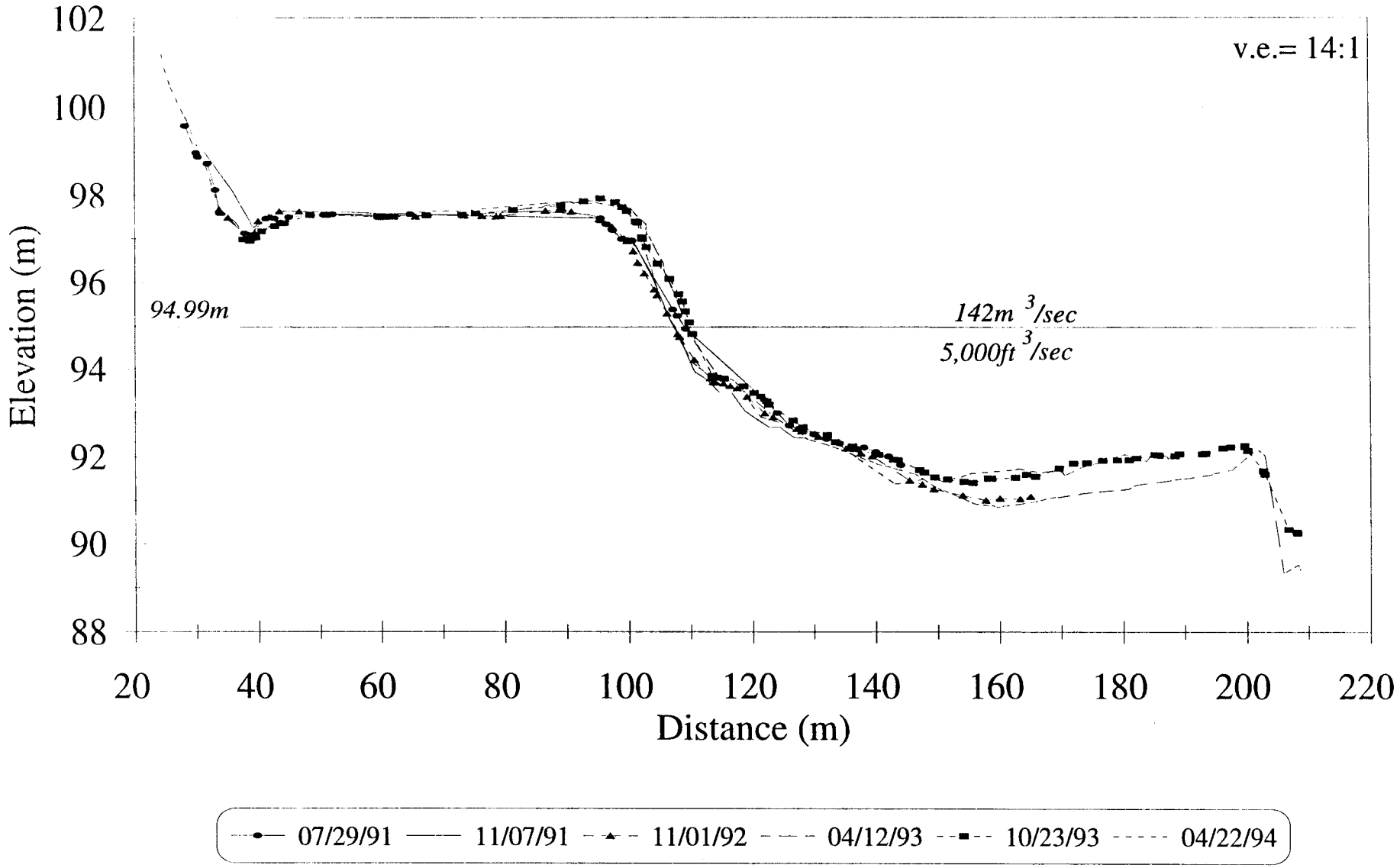


Near-shore P6

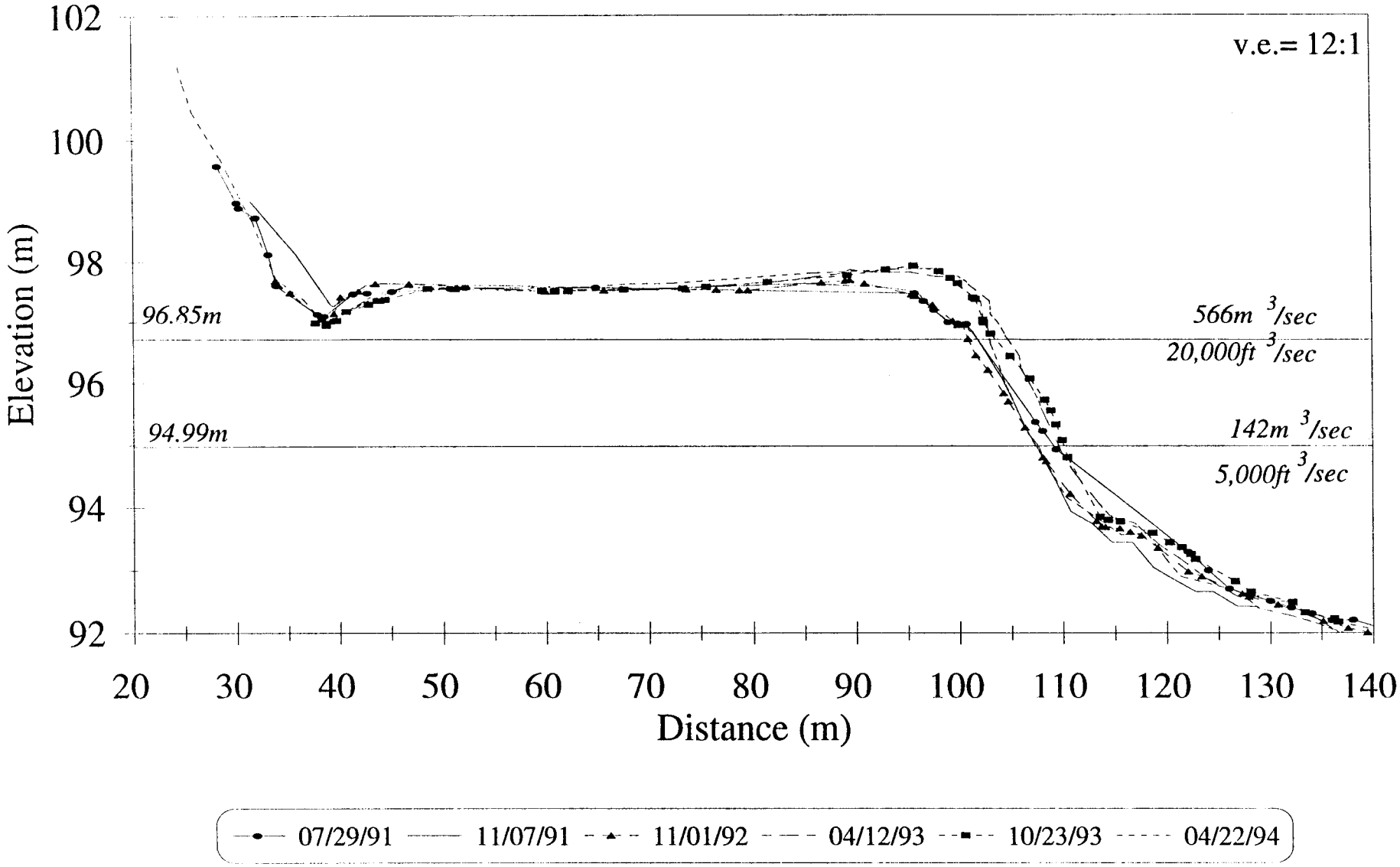


194 Mile

Cross-channel P8

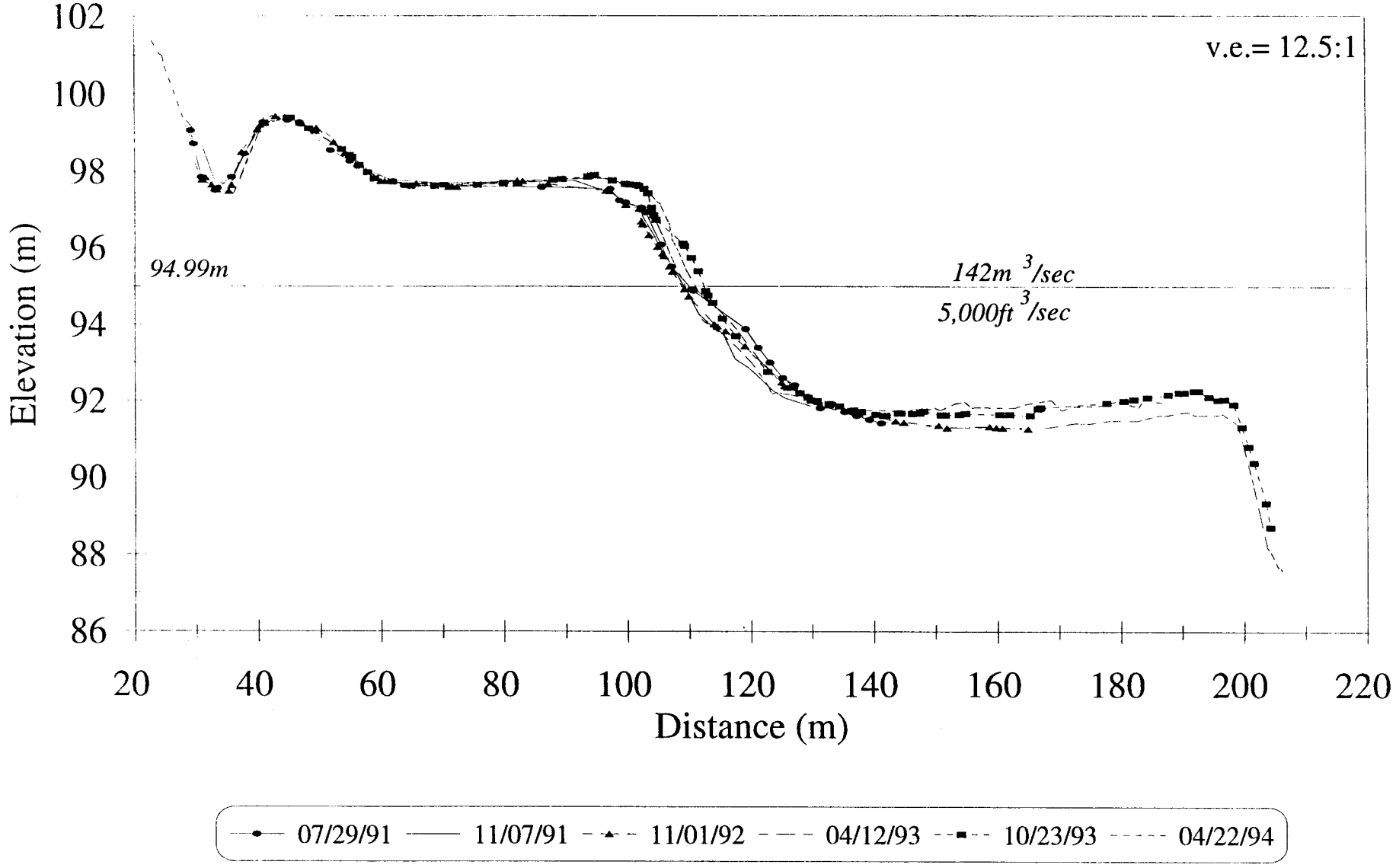


Near-shore P8

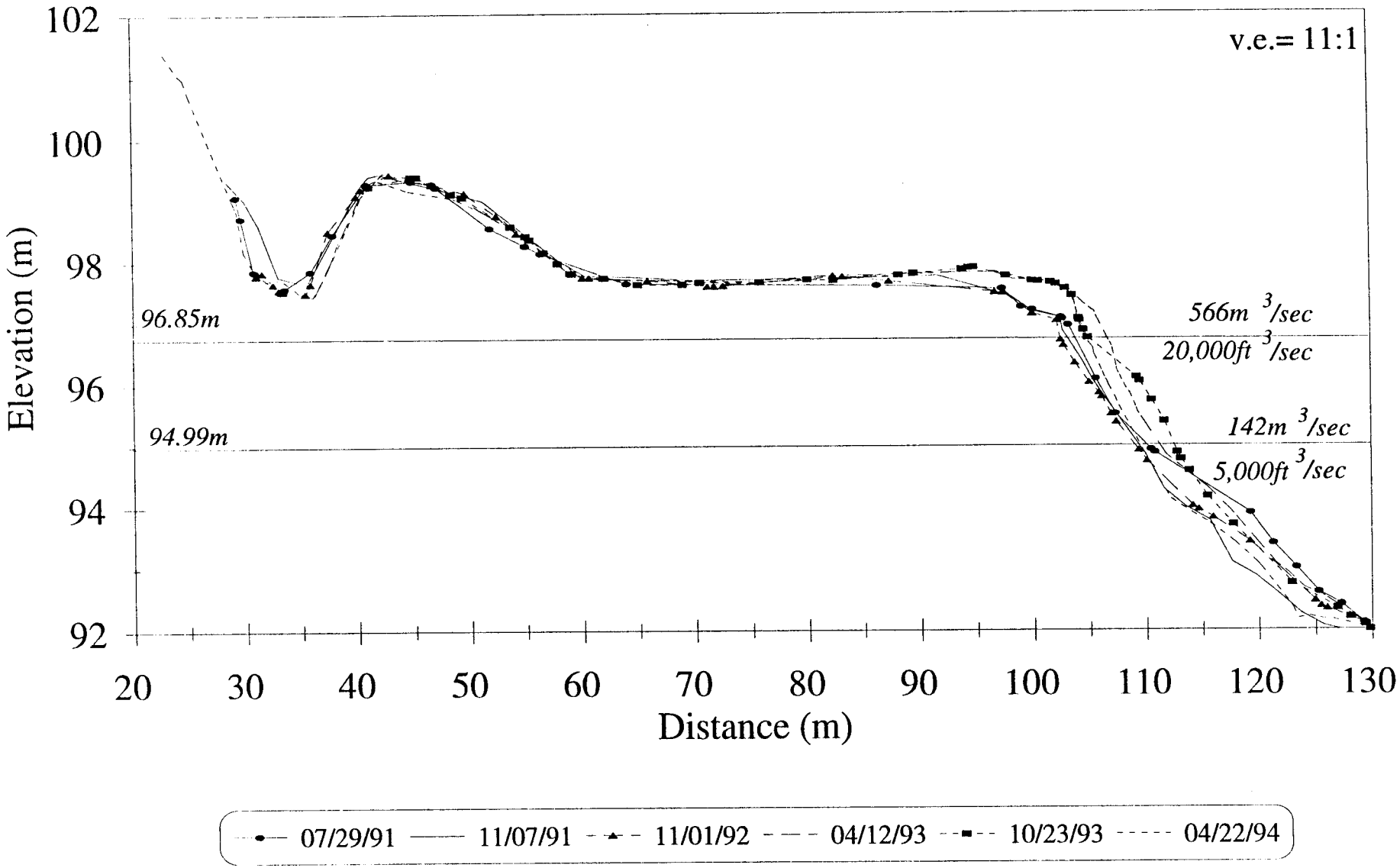


194 Mile

Cross-channel P9

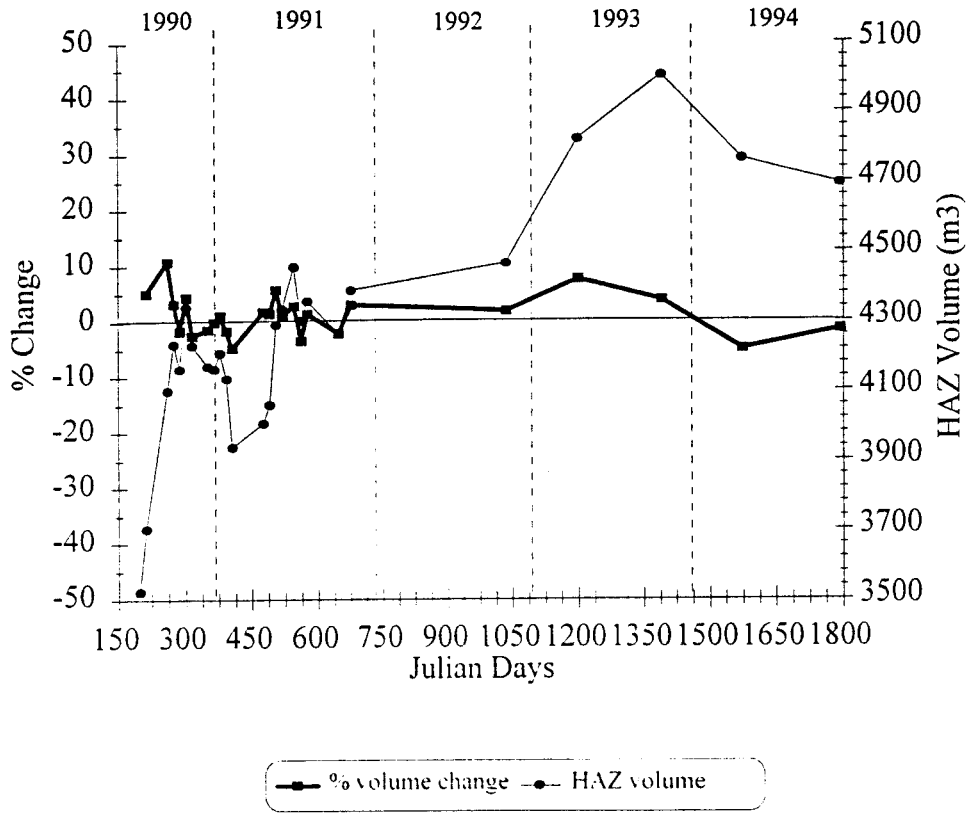


Near-shore P9



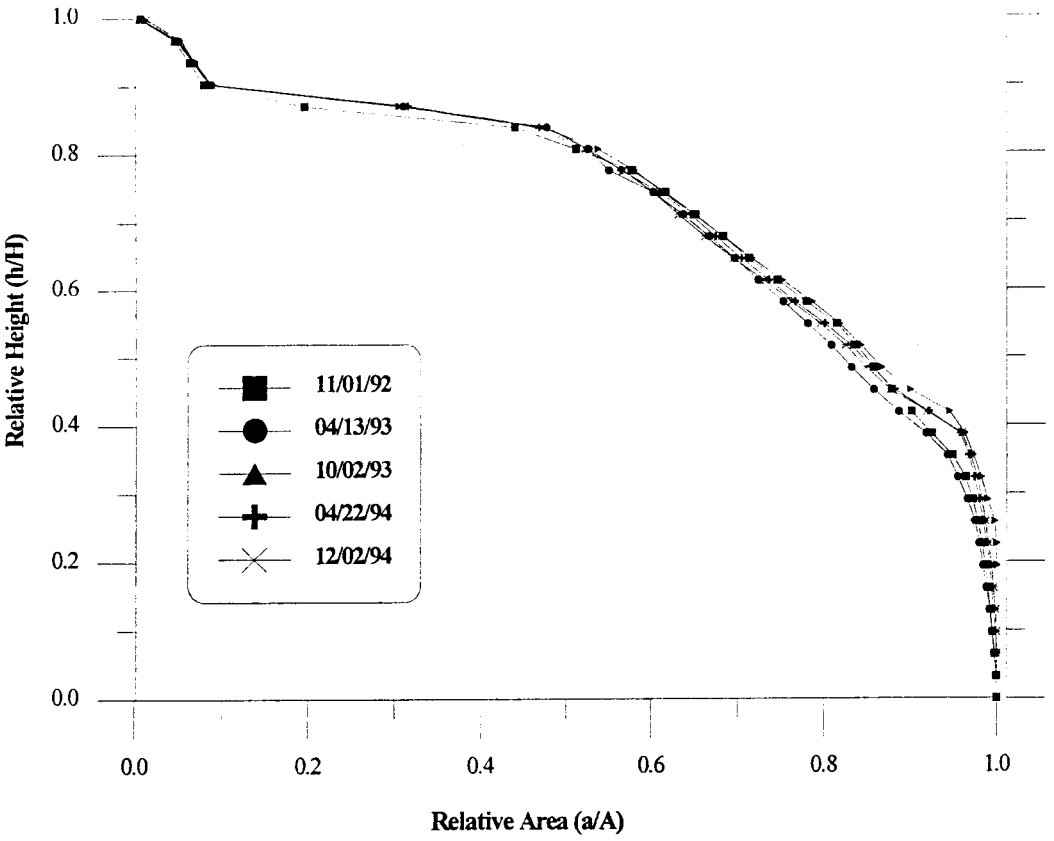
194 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G	198	3025	3524				
D		F	212	3049	3704	24	180	0.79	5.11
E		NORM							
F		NORM	260	3245	4102	196	398	6.43	10.75
G		E	275	3384	4235	139	133	4.28	3.24
H	901015	A	288	3392	4163	8	-72	0.24	-1.70
I	901029	8000 CFS	302	3379	4343	-13	180	-0.38	4.32
J	901112	NORM	316	3303	4231	-76	-112	-2.25	-2.58
K	901217	NORM	351	3154	4171	-149	-60	-4.51	-1.42
L	901231	11000 CFS	365	3075	4163	-79	-8	-2.50	-0.19
M	910113	C	378	3245	4209	170	46	5.53	1.10
N	910128	NORM	392	3228	4136	-17	-73	-0.52	-1.73
O	910210	B	406	3156	3938	-72	-198	-2.23	-4.79
P	910421	NORM	476	3122	4007	-34	69	-1.08	1.75
Q	910506	NORM	491	3120	4061	-2	54	-0.06	1.35
R	910520	D	505	3221	4291	101	230	3.24	5.66
S	910603	15000 CFS	519	3353	4336	132	45	4.10	1.05
T	910630	NORM	546	3344	4456	-9	120	-0.27	2.77
U	910715	G	561	3210	4301	-134	-155	-4.01	-3.48
V	910729	F	575	3284	4357	74	56	2.31	1.29
W	911008	INT	646	3296	4263	12	-94	0.37	-2.21
X	911107	INT	676	3234	4388	-62	125	-1.88	2.85
Y	921101	INT	1036	3377	4464	143	76	4.42	1.70
Z	930413	INT	1199	3288	4823	-89	359	-2.64	7.44
B29	931023	INT	1392	3451	5005	163	182	4.96	3.64
C29	940422	INT	1573	3363	4765	-88	-240	-2.55	-5.04
D29	941202	INT	1793	3159	4694	-204	-71	-6.07	-1.51

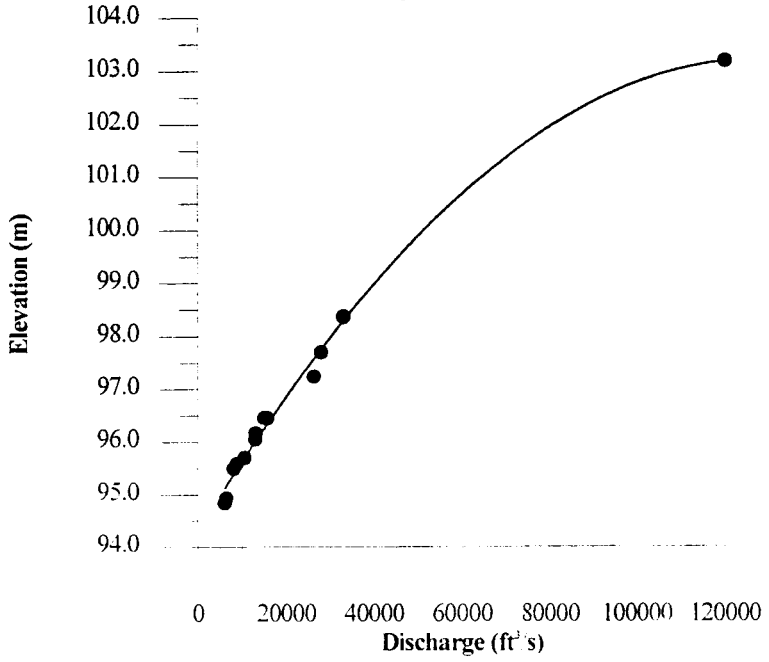


194 Mile

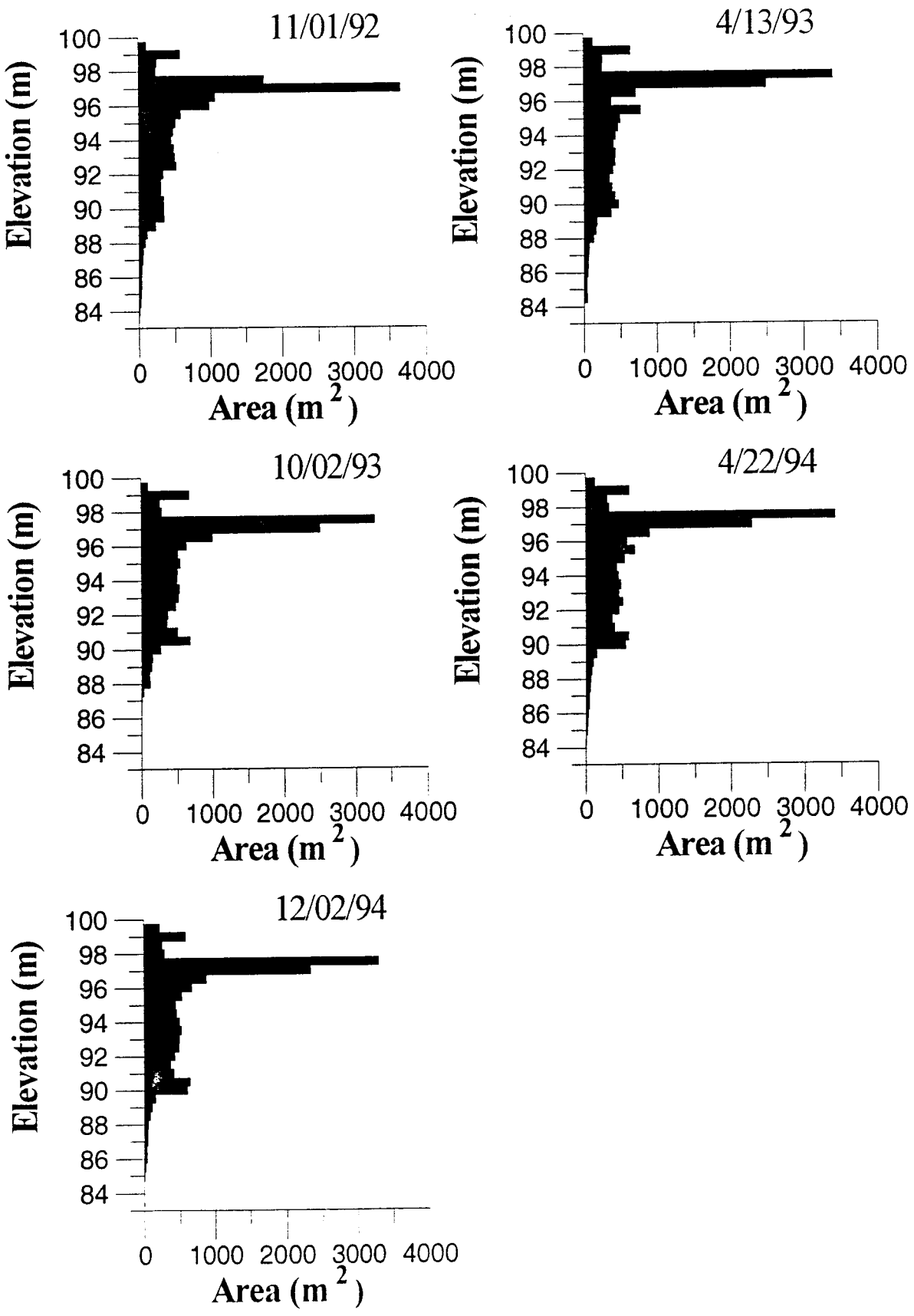
Hypsometric Curves

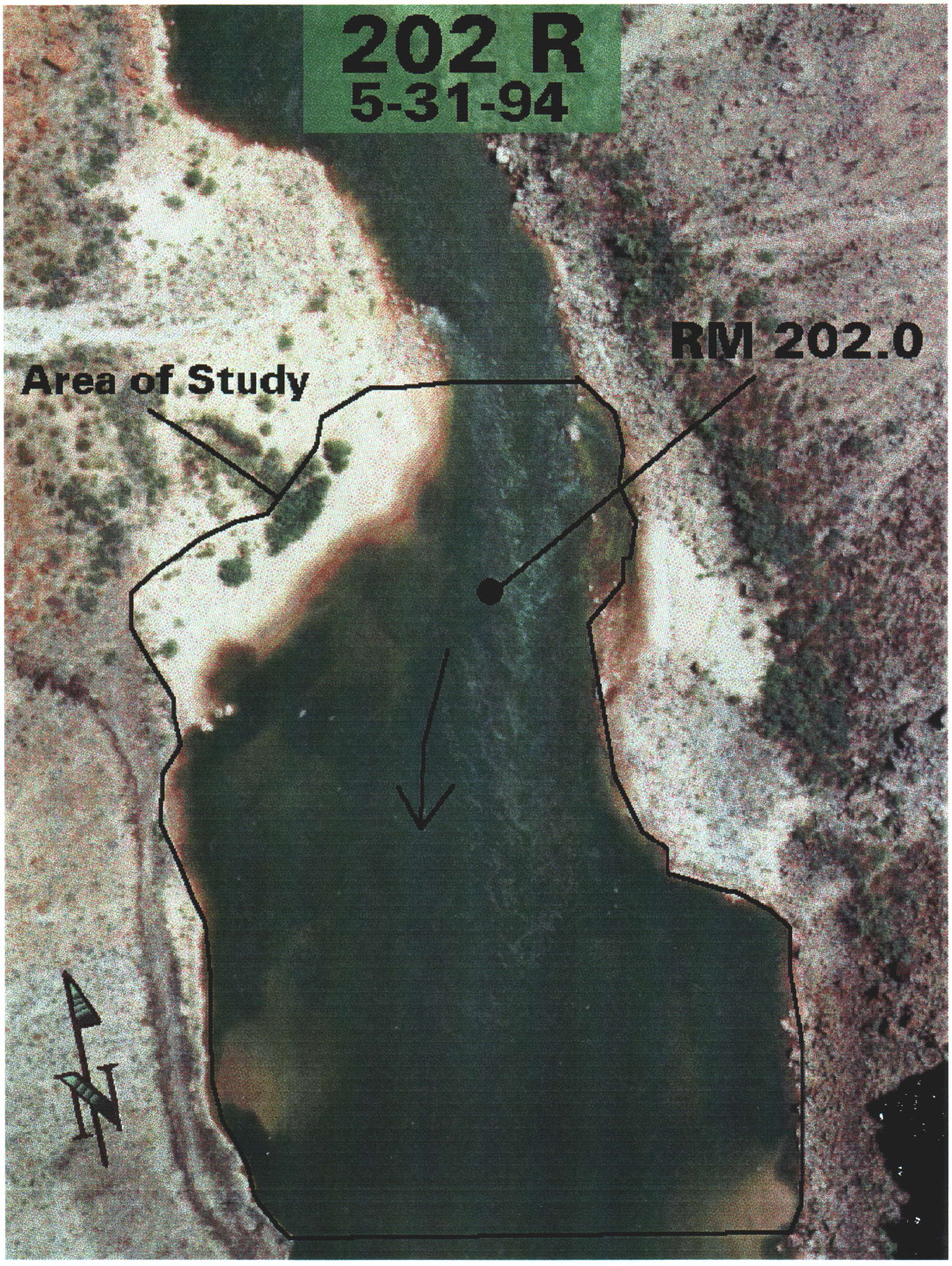


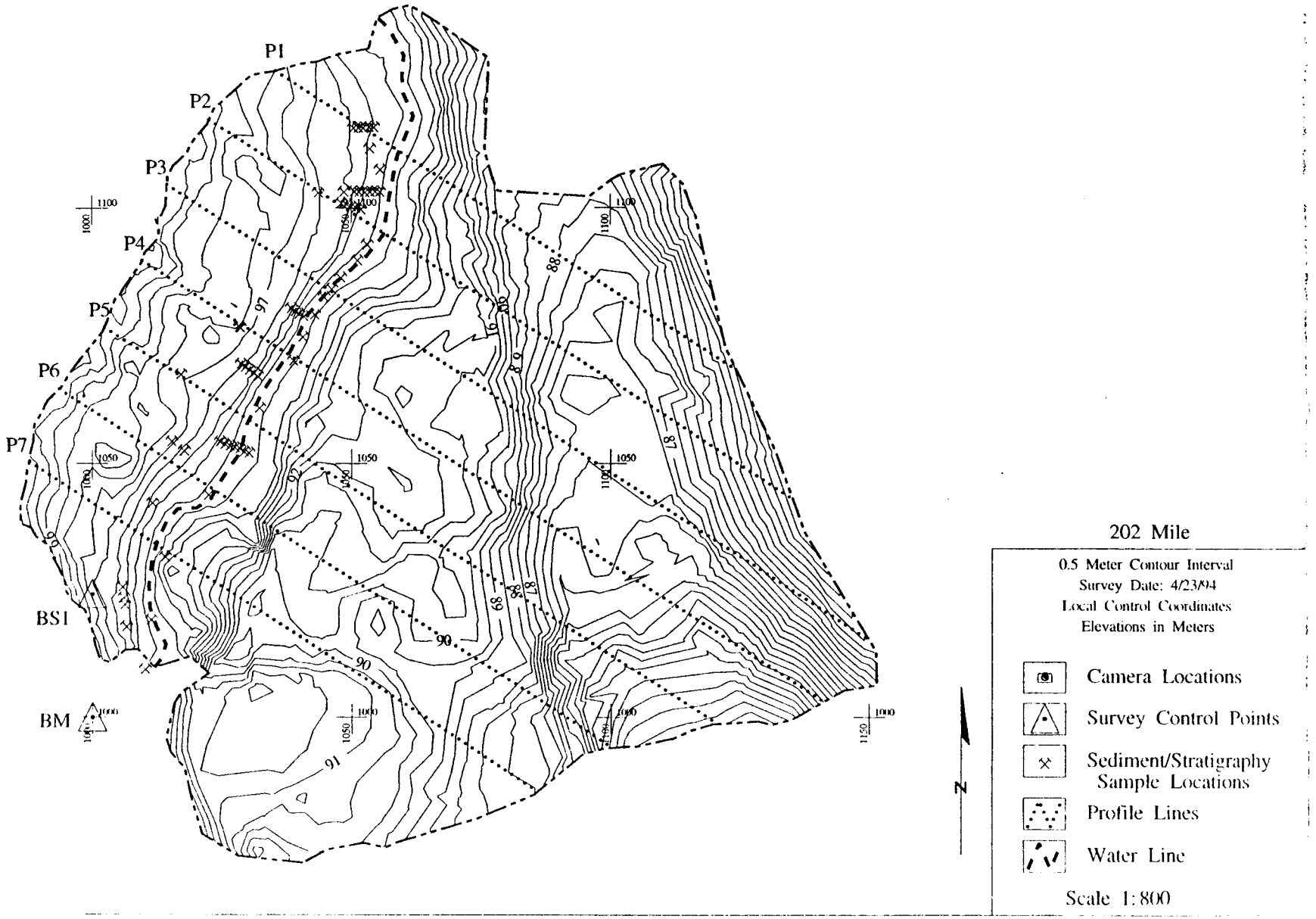
Stage Discharge



194 MILE
Area Distribution Histograms

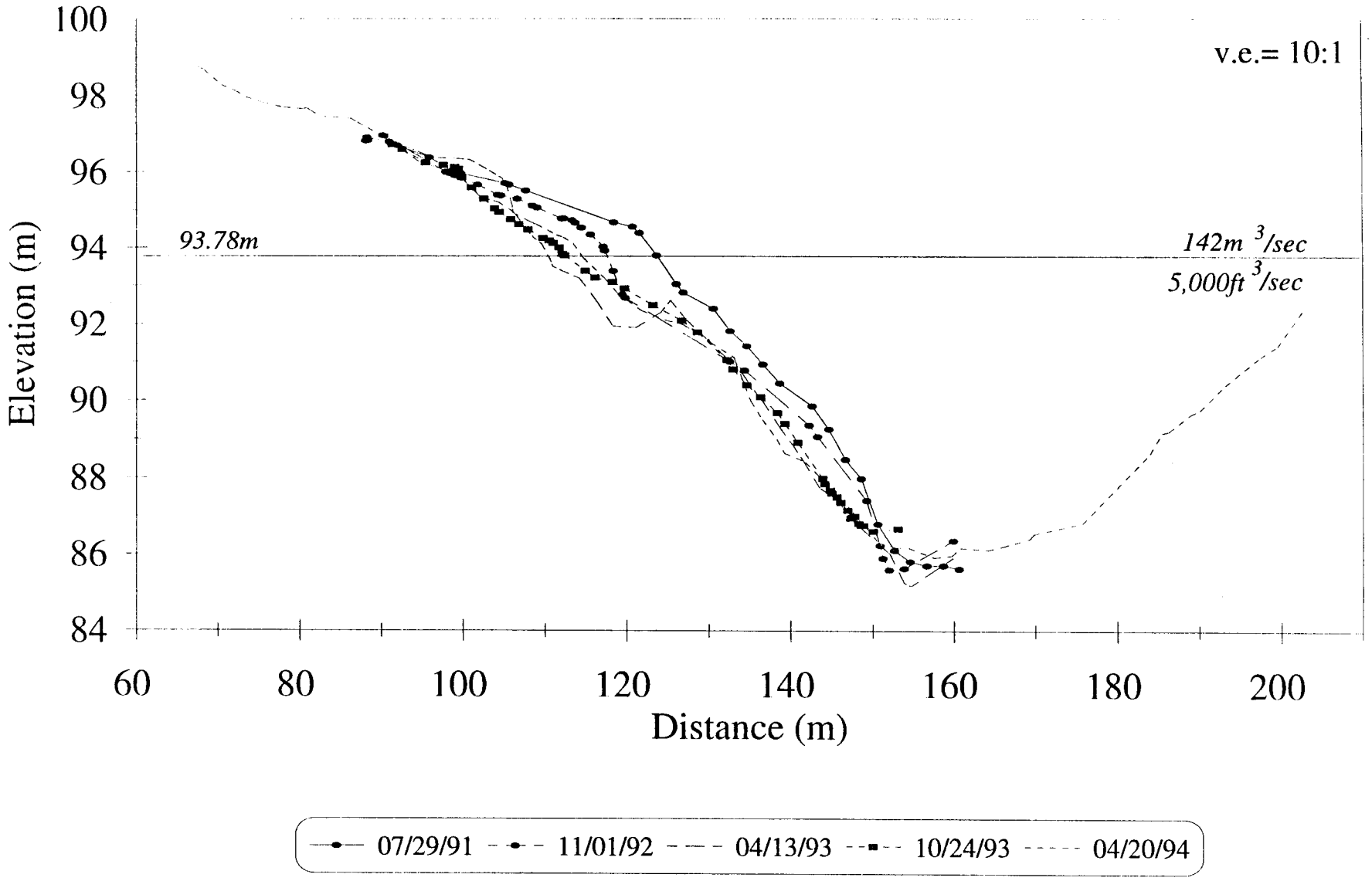



202 R
5-31-94
RM 202.0
Area of Study
N

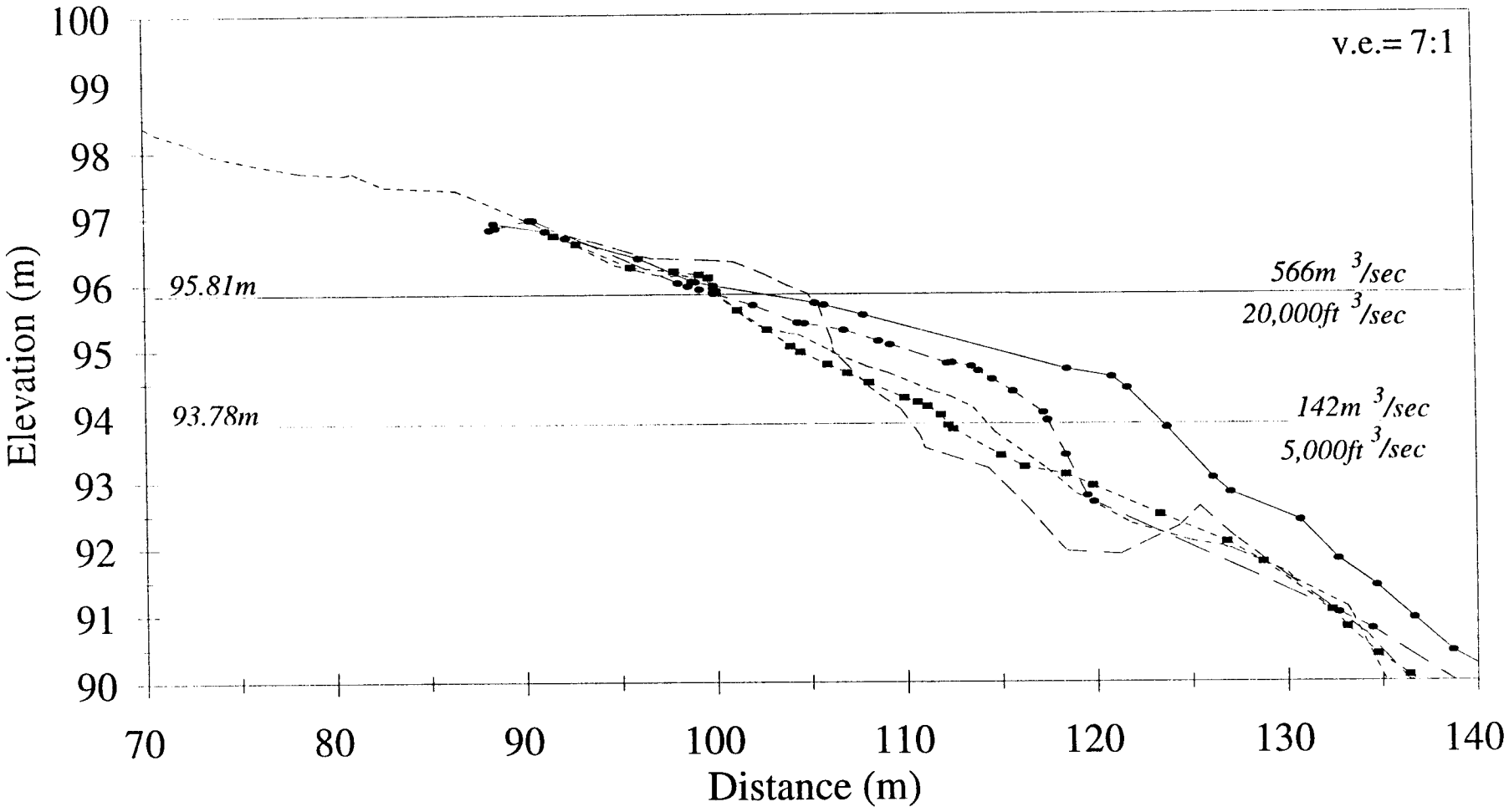

P1
P2
P3
P4
P5
P6
P7
BS1
BM
202 Mile
0.5 Meter Contour Interval
Survey Date: 4/23/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:800
N

202 Mile

Cross-channel P2

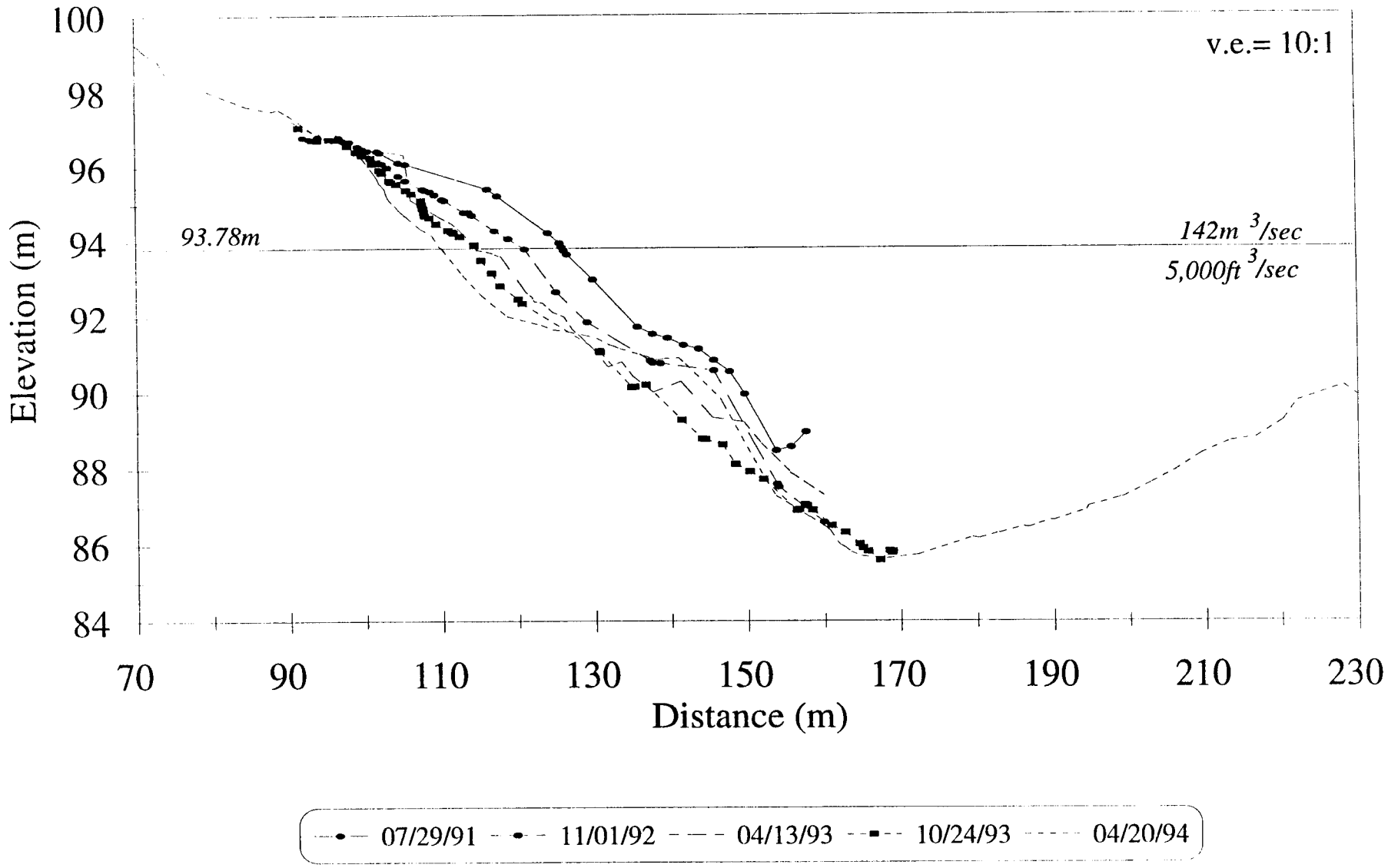


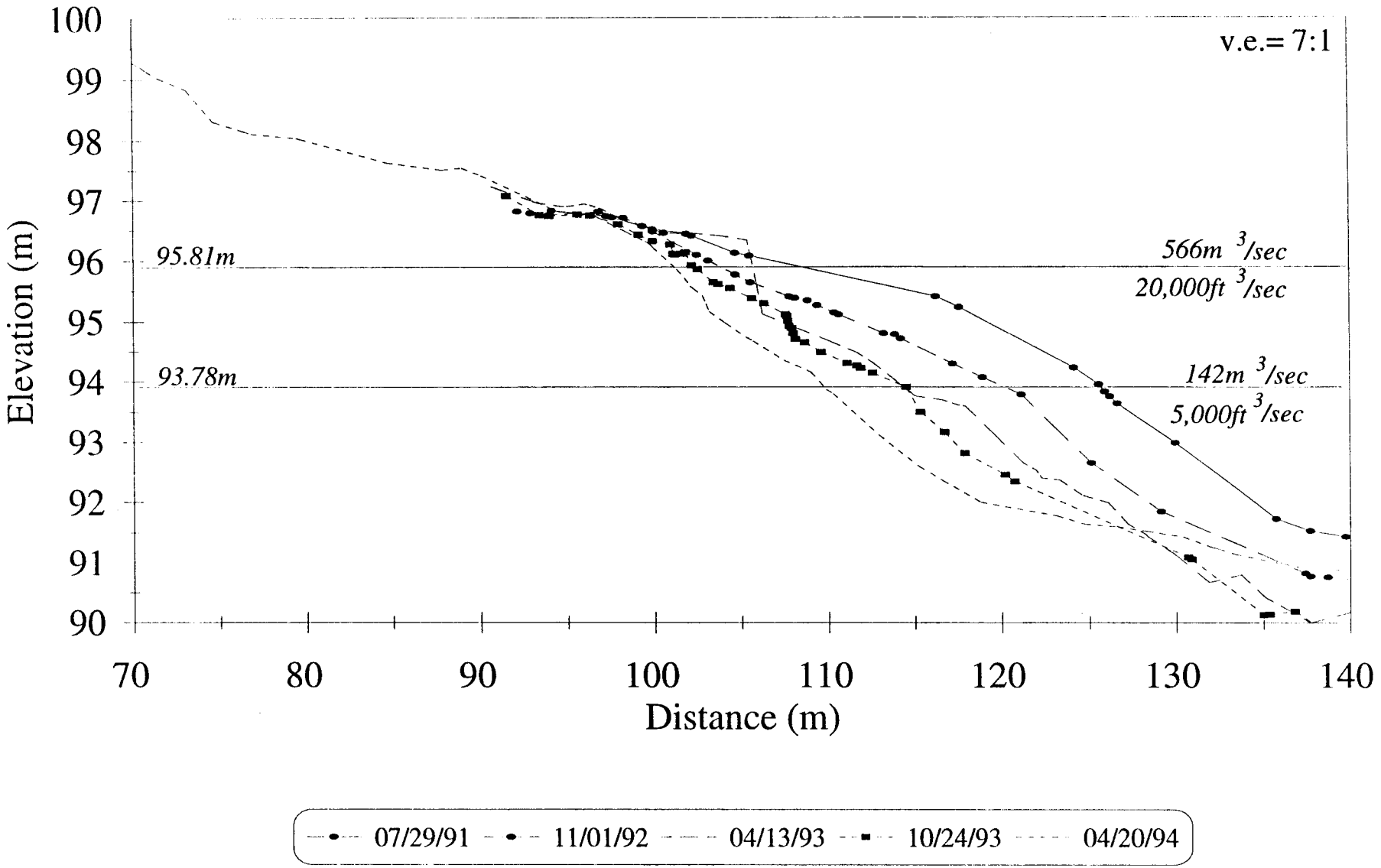
Near-shore P2



202 Mile

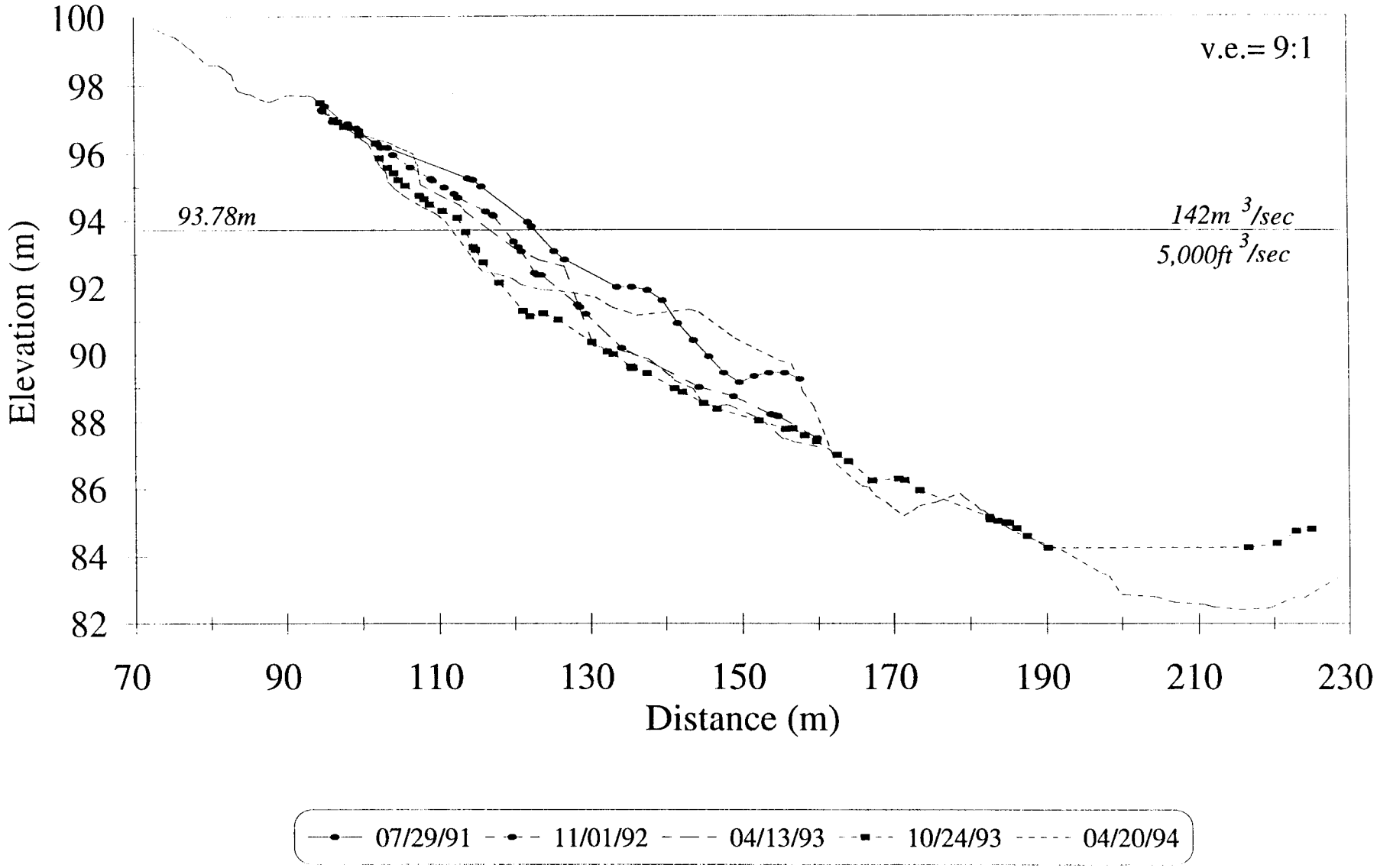
Cross-channel P3

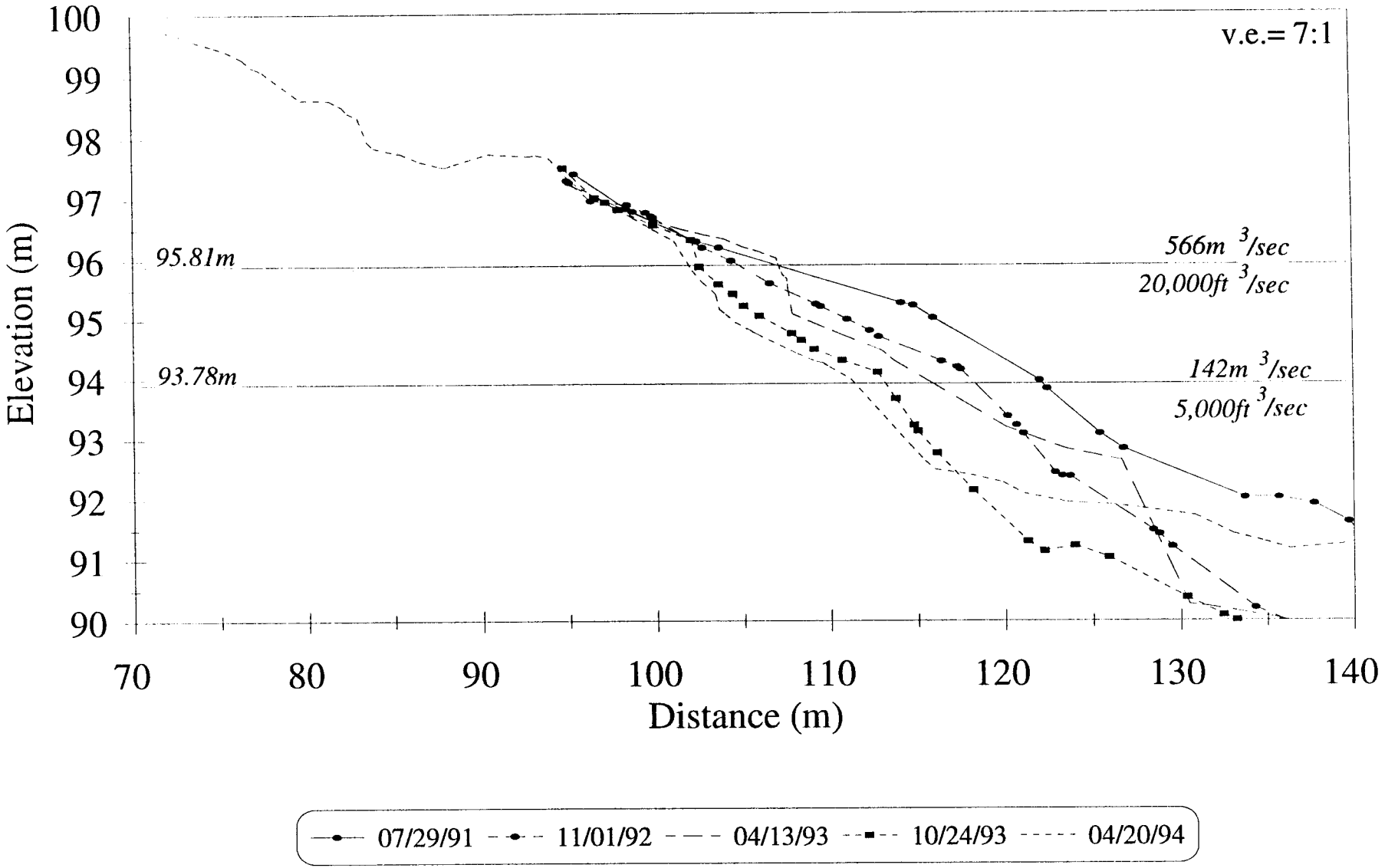



Near-shore P3
v.e.= 7:1
Elevation (m)
100
99
98
97
96
95
94
93
92
91
90
95.81m
93.78m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
70
80
90
100
110
120
130
140
Distance (m)
07/29/91
11/01/92
04/13/93
10/24/93
04/20/94

202 Mile

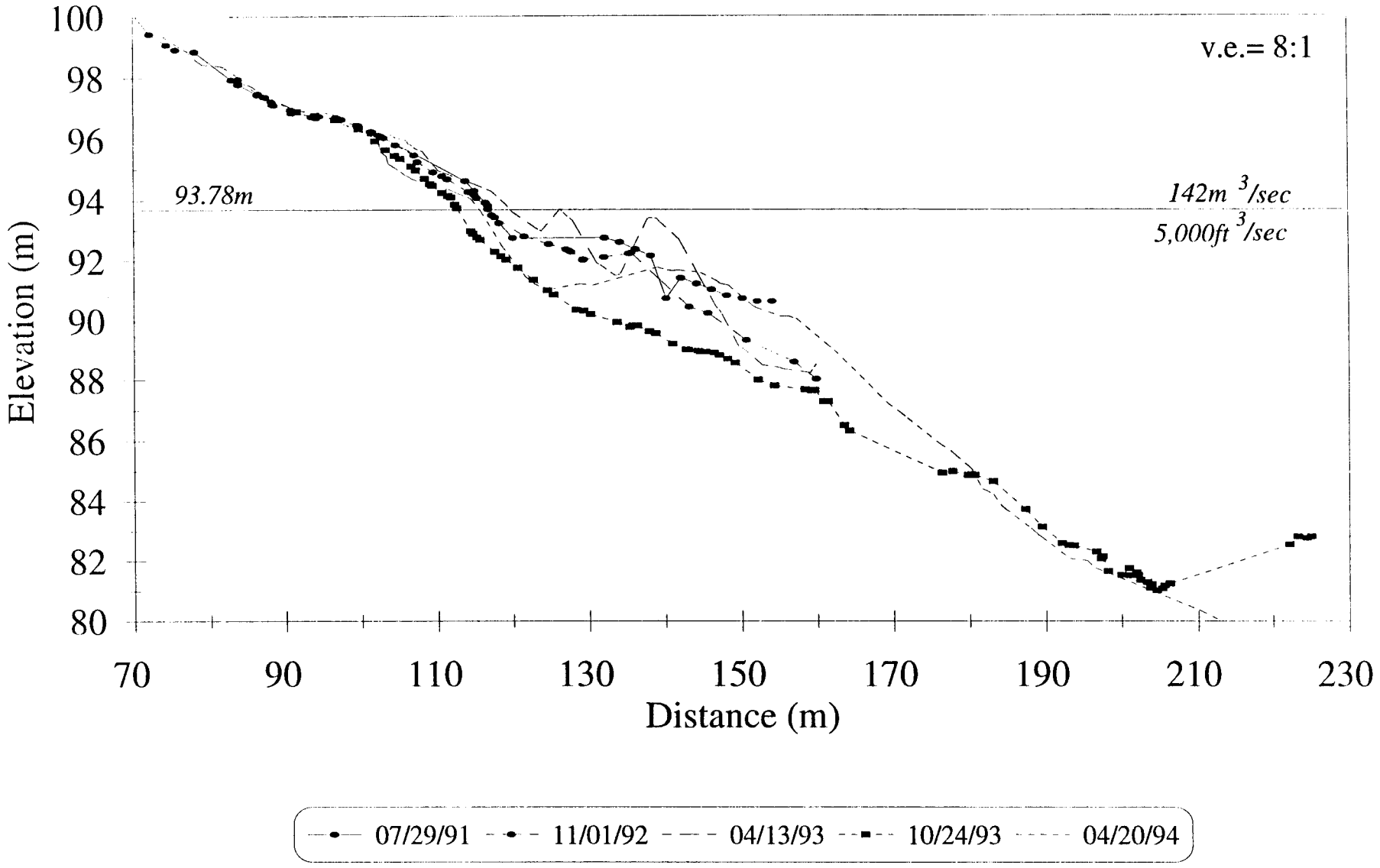
Cross-channel P4



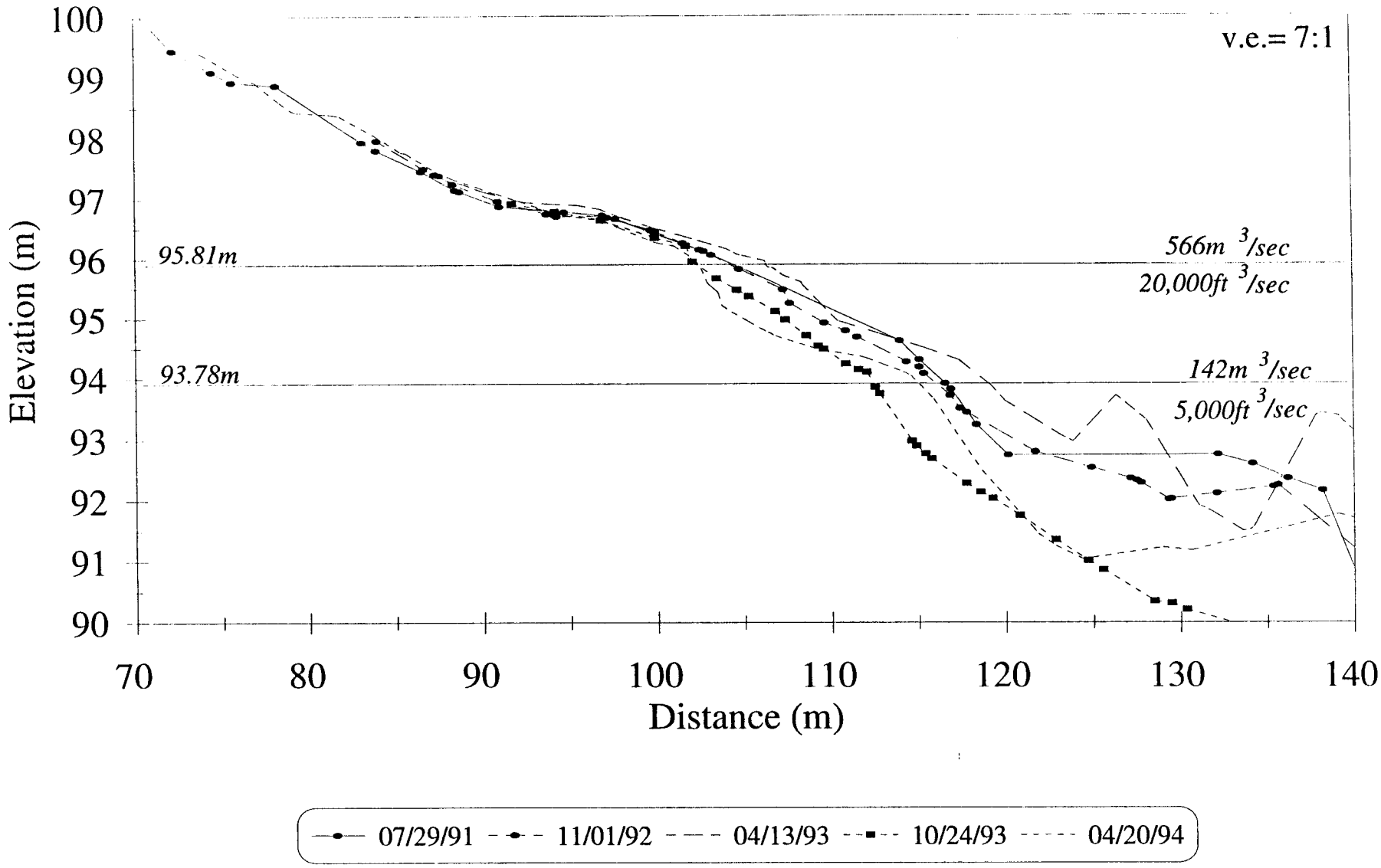

Near-shore P4
v.e.= 7:1
Elevation (m)
100
99
98
97
96
95
94
93
92
91
90
95.81m
93.78m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
70
80
90
100
110
120
130
140
Distance (m)
07/29/91
11/01/92
04/13/93
10/24/93
04/20/94

202 Mile

Cross-channel P5

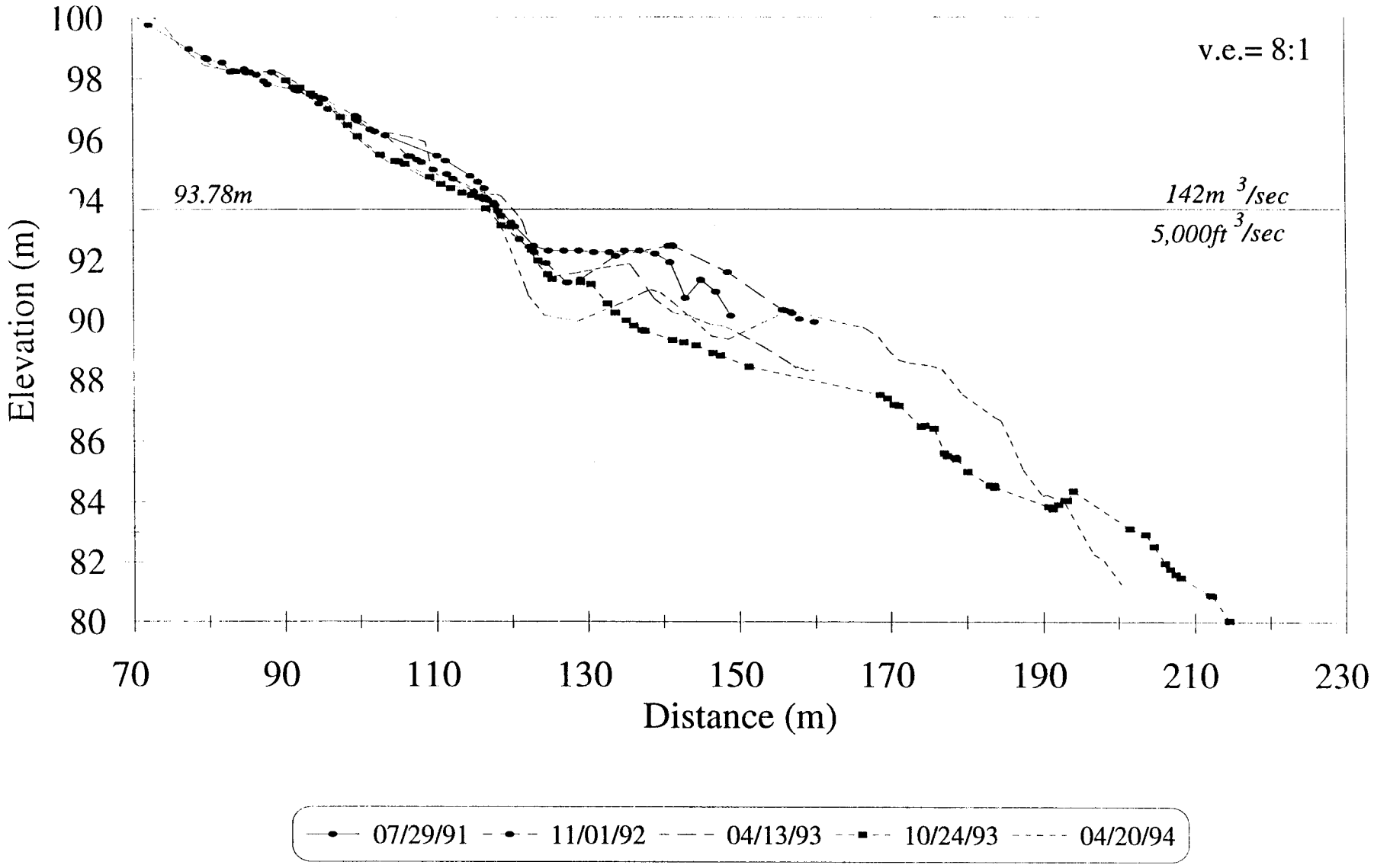


Near-shore P5

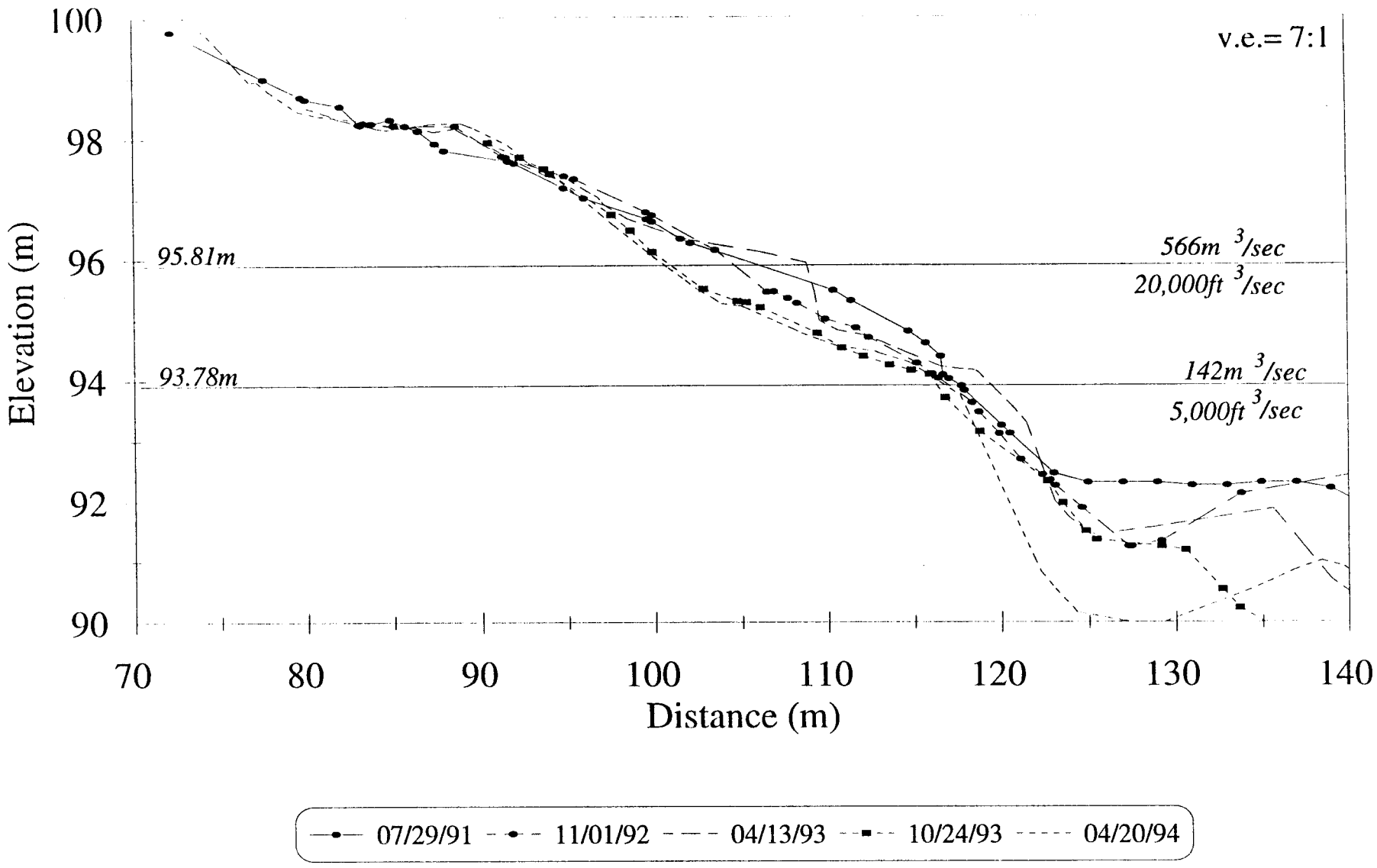


202 Mile

Cross-channel P6

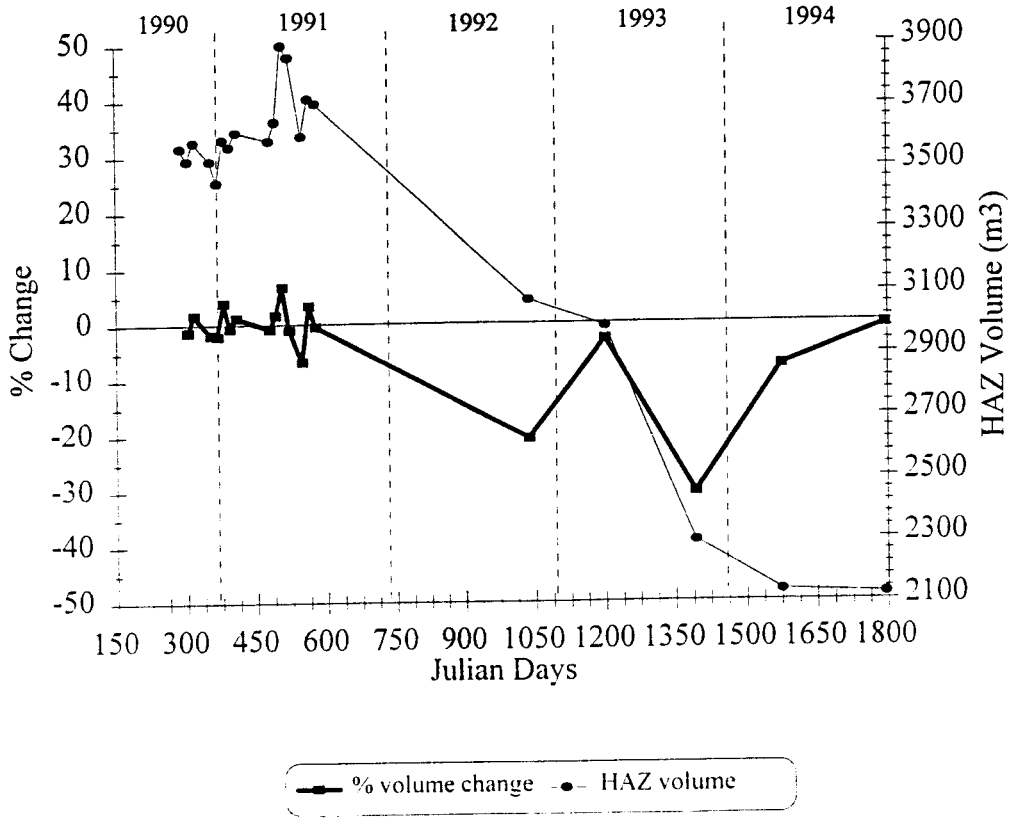


Near-shore P6



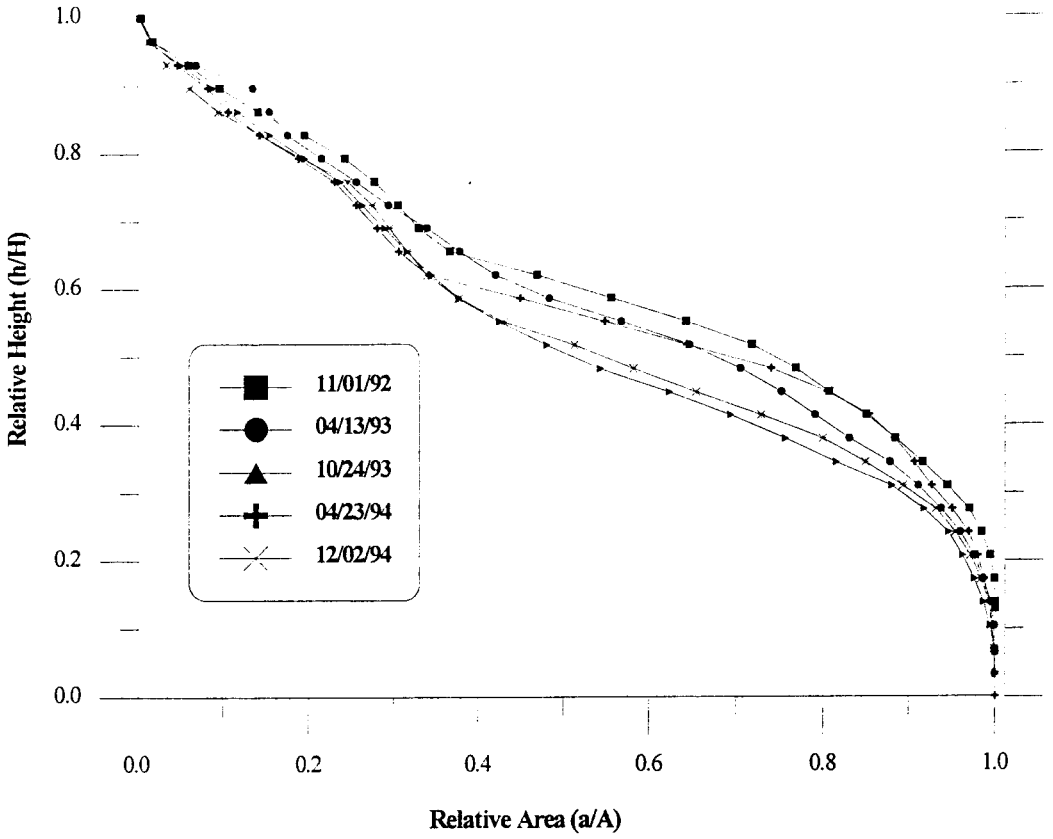
202 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F		NORM							
G		E							
H	901016	A	289	2089	3570				
I	901030	8000 CFS	303	2060	3528	-29	-42	-1.39	-1.18
J	901113	NORM	317	2131	3588	71	60	3.45	1.70
K	901218	NORM	352	2142	3527	11	-61	0.52	-1.70
L	910101	11000 CFS	366	2158	3458	16	-69	0.75	-1.96
M	910114	C	379	2213	3596	55	138	2.55	3.99
N	910128	NORM	393	2246	3573	33	-23	1.49	-0.64
O	910211	B	407	2263	3619	17	46	0.76	1.29
P	910422	NORM	477	2328	3591	65	-28	2.87	-0.77
Q	910506	NORM	491	2328	3653	0	62	0.00	1.73
R	910520	D	505	2445	3899	117	246	5.03	6.73
S	910603	15000 CFS	519	2410	3861	-35	-38	-1.43	-0.97
T	910701	NORM	547	2132	3605	-278	-256	-11.54	-6.63
U	910715	G	561	2224	3726	92	121	4.32	3.36
V	910729	F	575	2230	3710	6	-16	0.27	-0.43
Y	921101	INT	1036	1981	3075	-249	-635	-11.17	-20.65
Z	930413	INT	1199	1768	2991	-213	-84	-10.75	-2.81
B30	931024	INT	1393	1611	2295	-157	-696	-8.88	-30.33
C30	940423	INT	1574	1617	2133	6	-162	0.37	-7.59
D30	941202	INT	1794	1783	2122	166	-11	10.27	-0.52

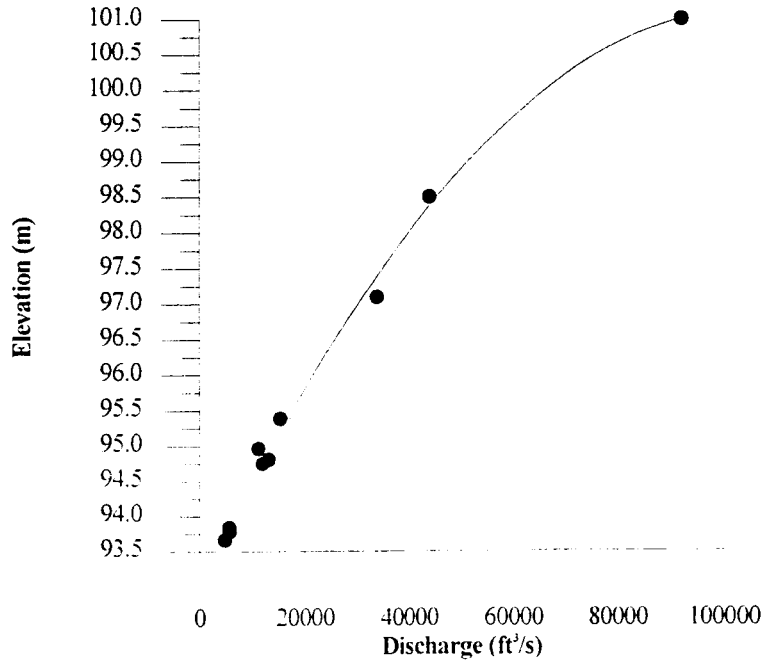


202 Mile

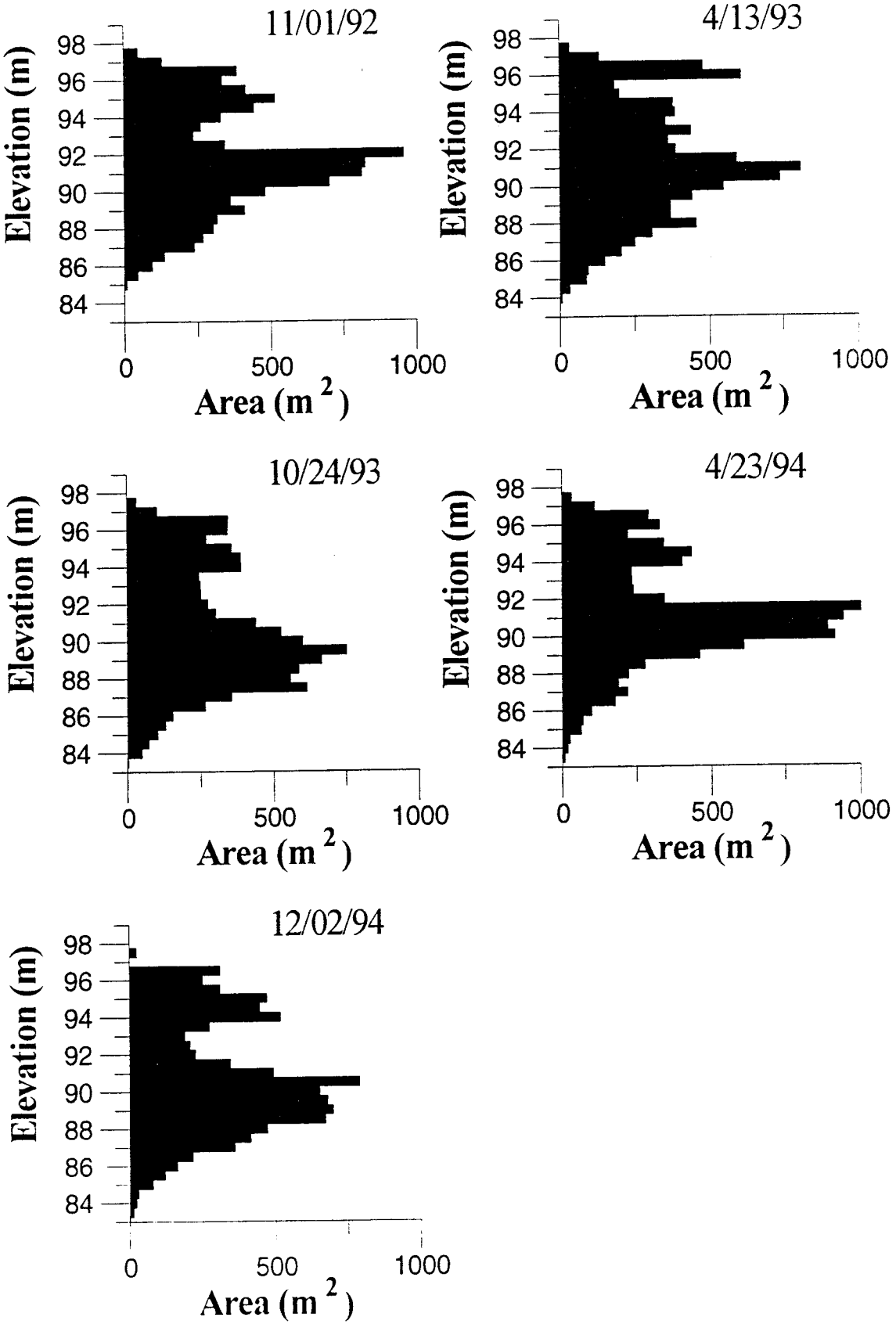
Hypsometric Curves



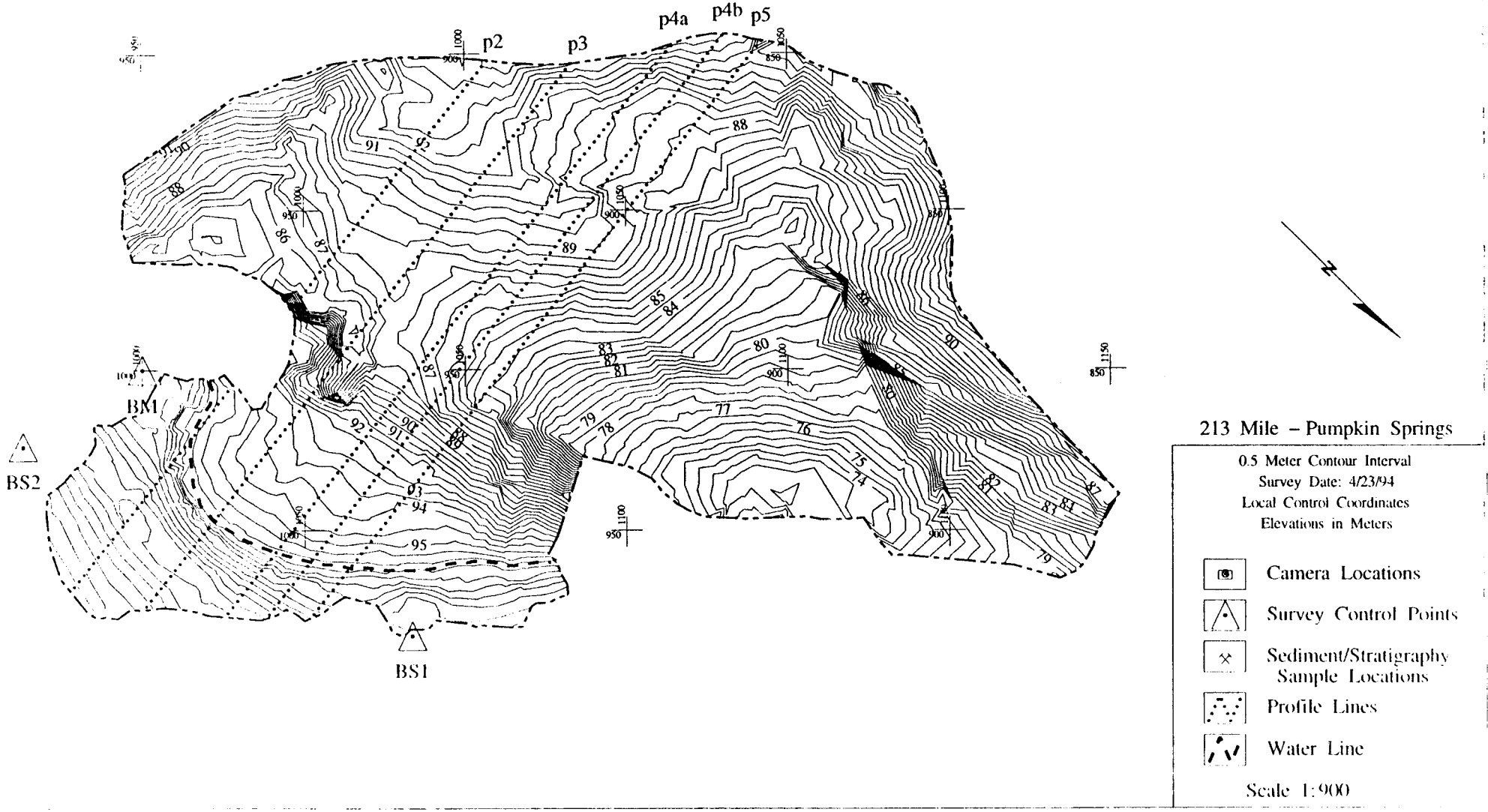
Stage Discharge



202 MILE
Area Distribution Histograms

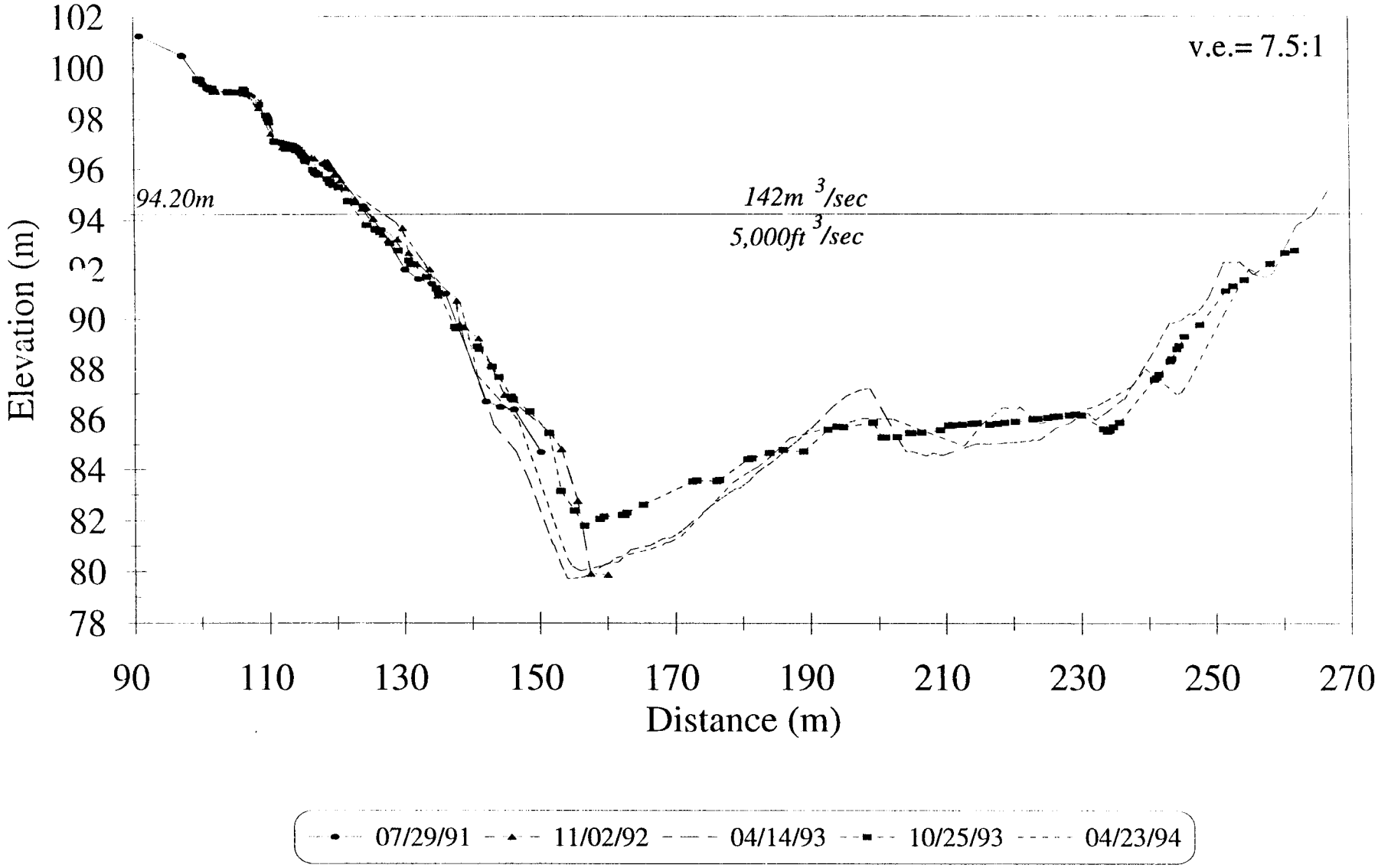


213 L
5-31-94
M 213.0
Area of Study
N

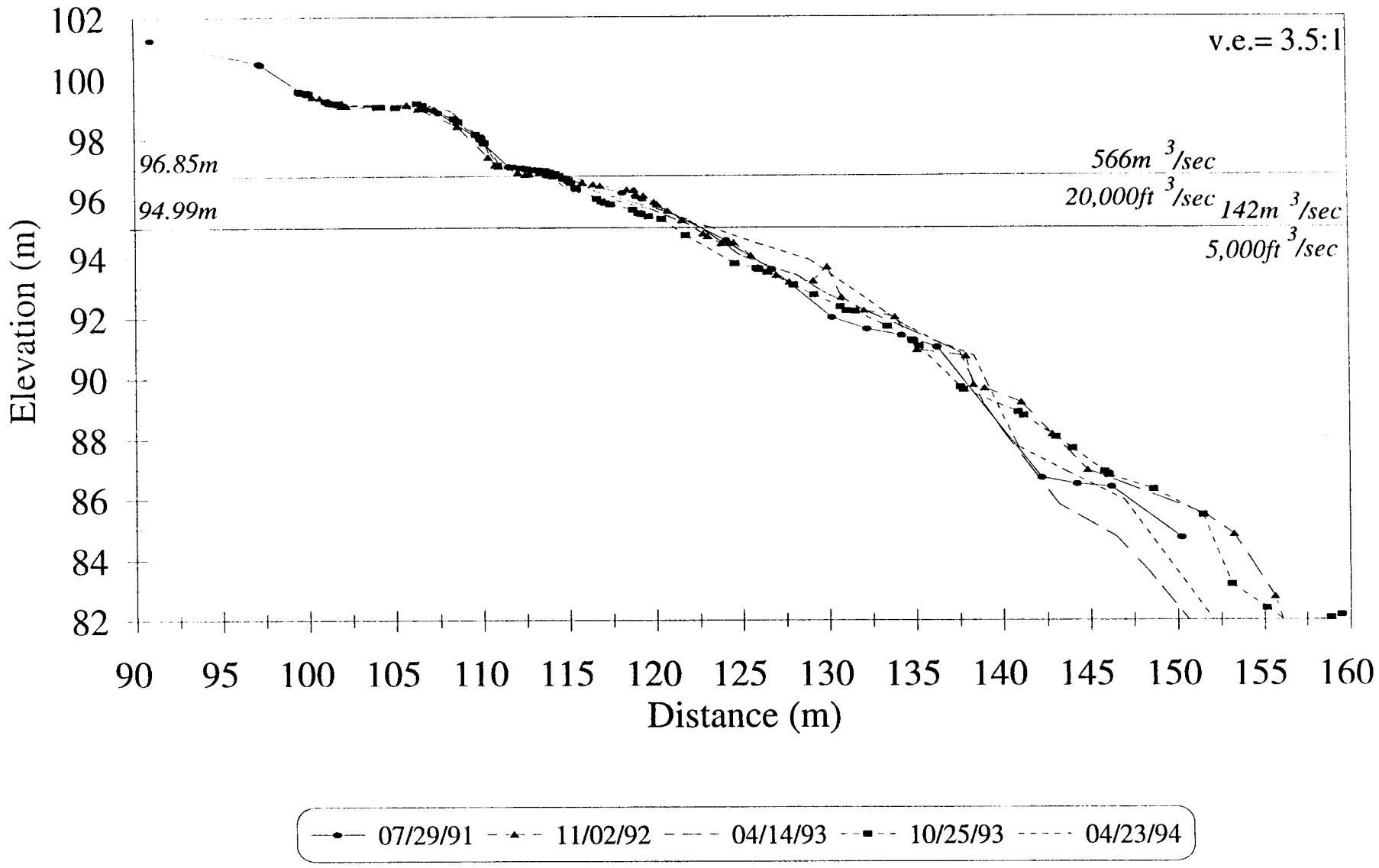

p2
p3
p4a
p4b
p5
BM1
BS2
BS1
213 Mile – Pumpkin Springs
0.5 Meter Contour Interval
Survey Date: 4/23/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:900

213 Mile

Cross-channel P2

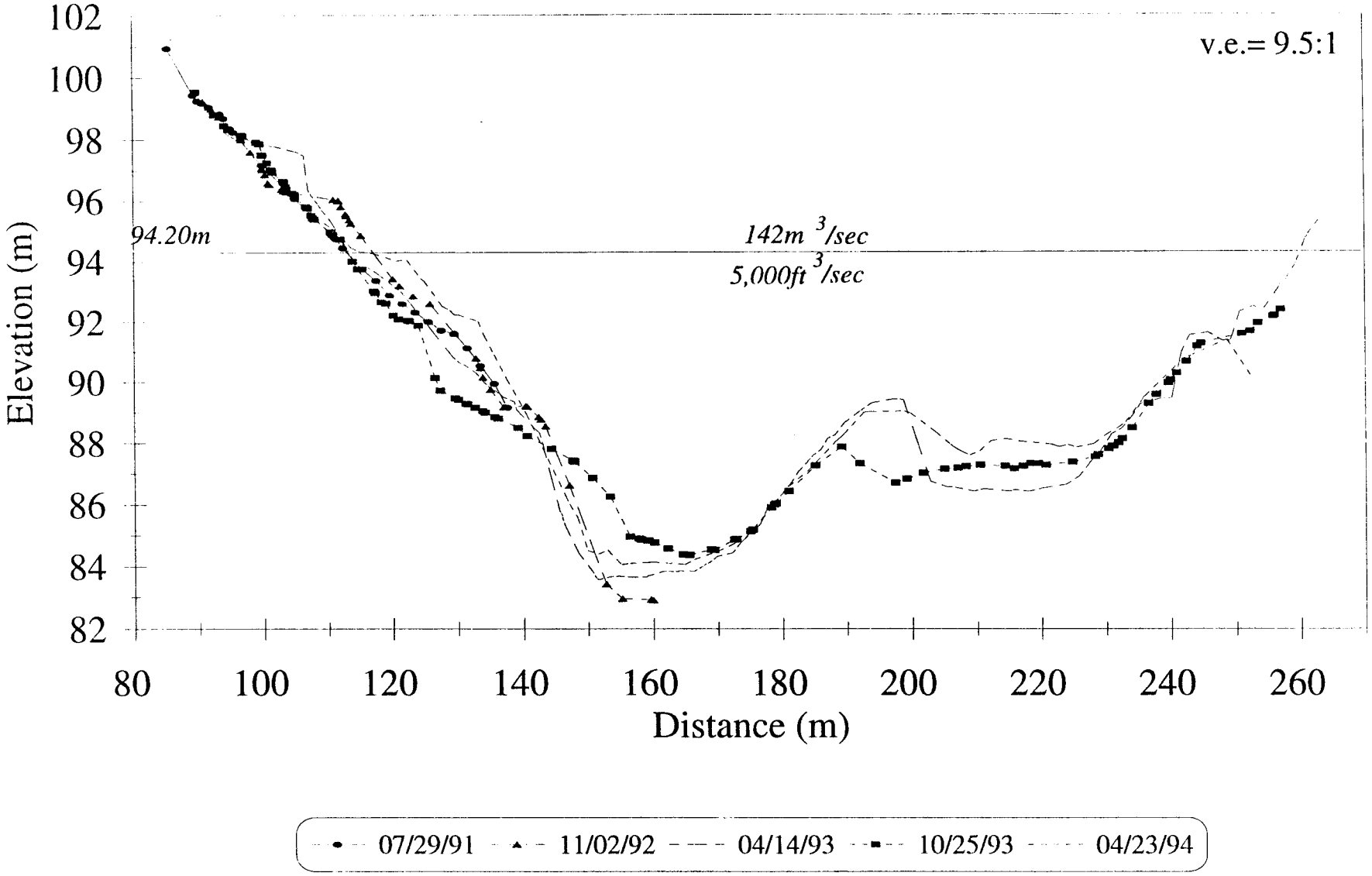


Near-shore P2

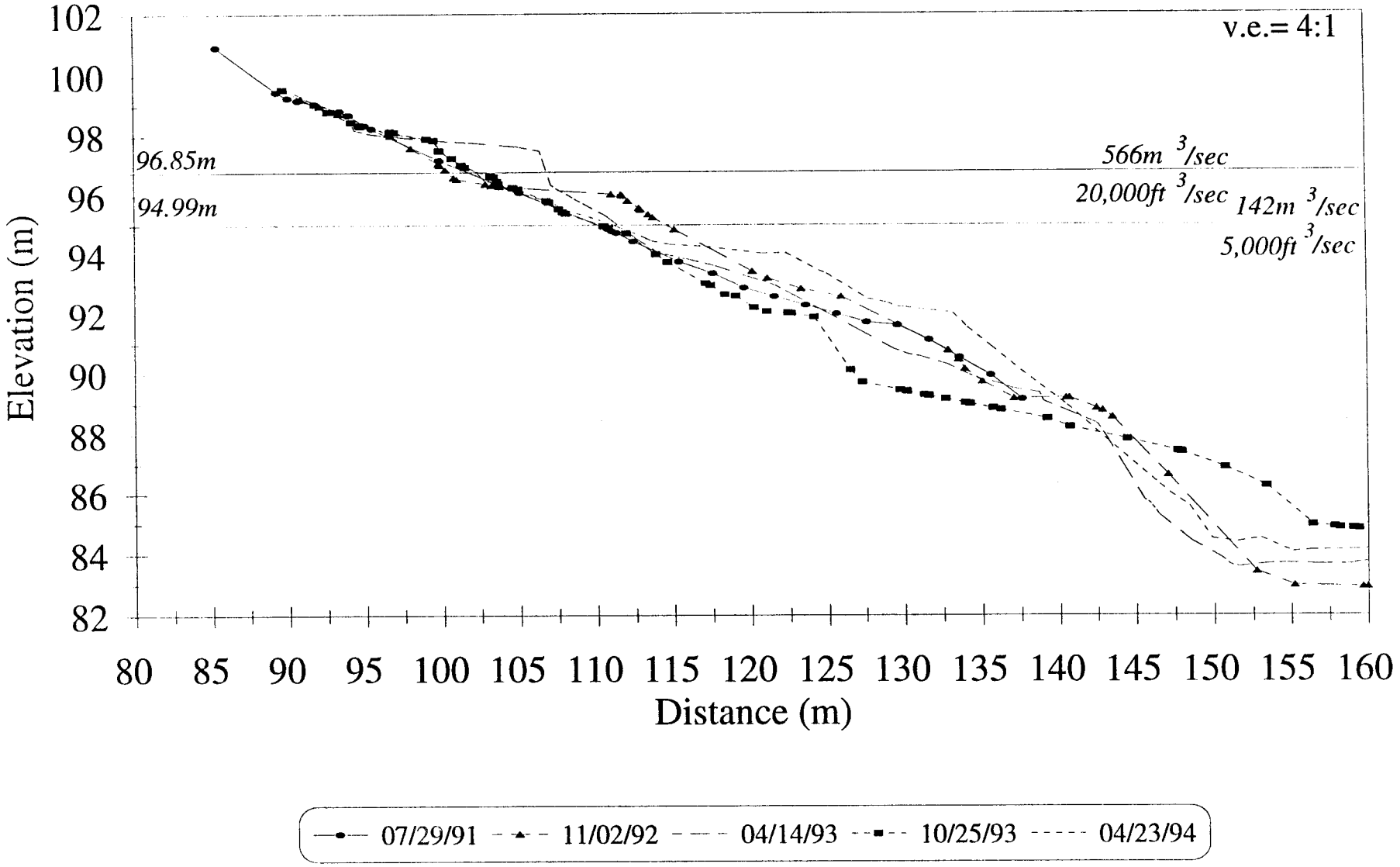


213 Mile

Cross-channel P3

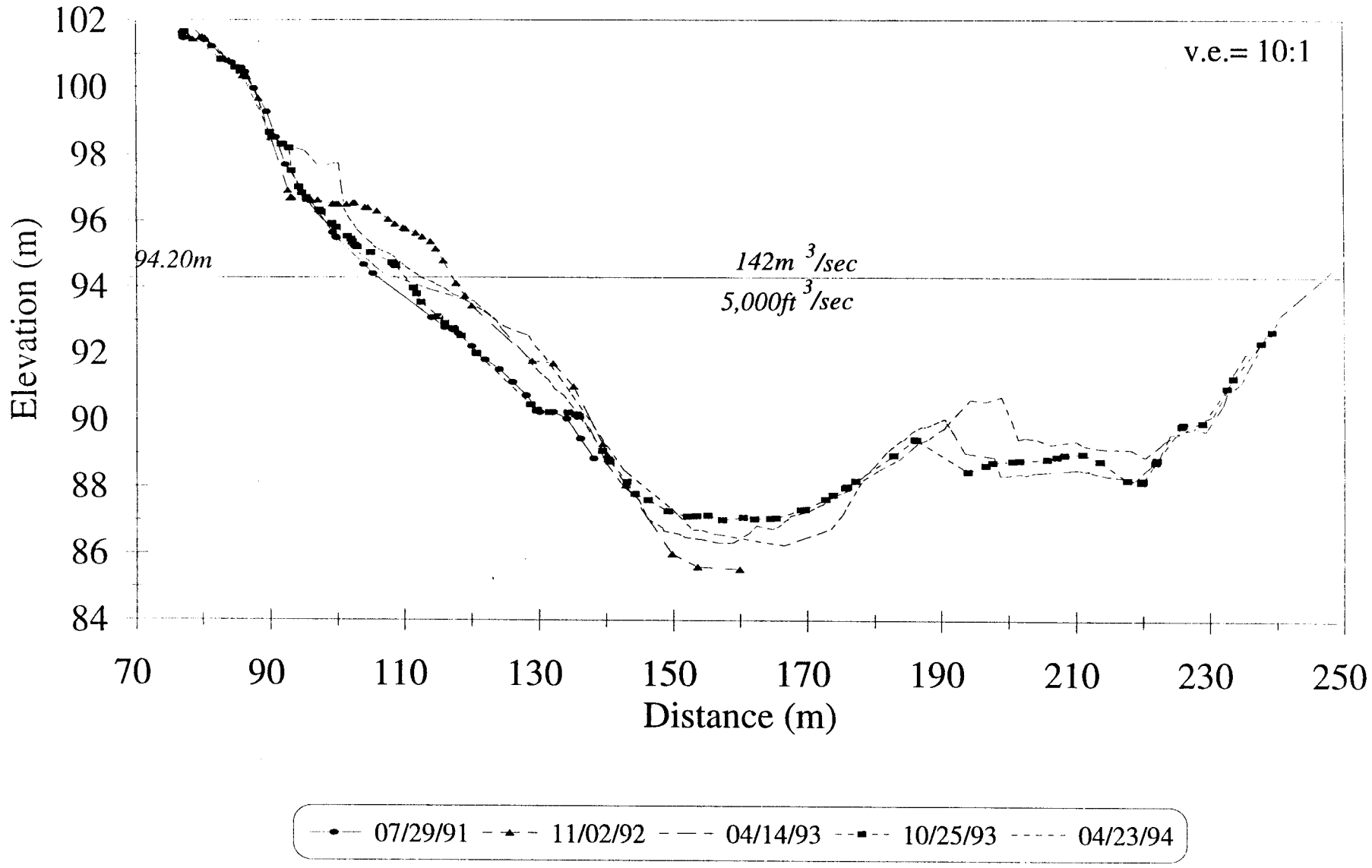


Near-shore P3

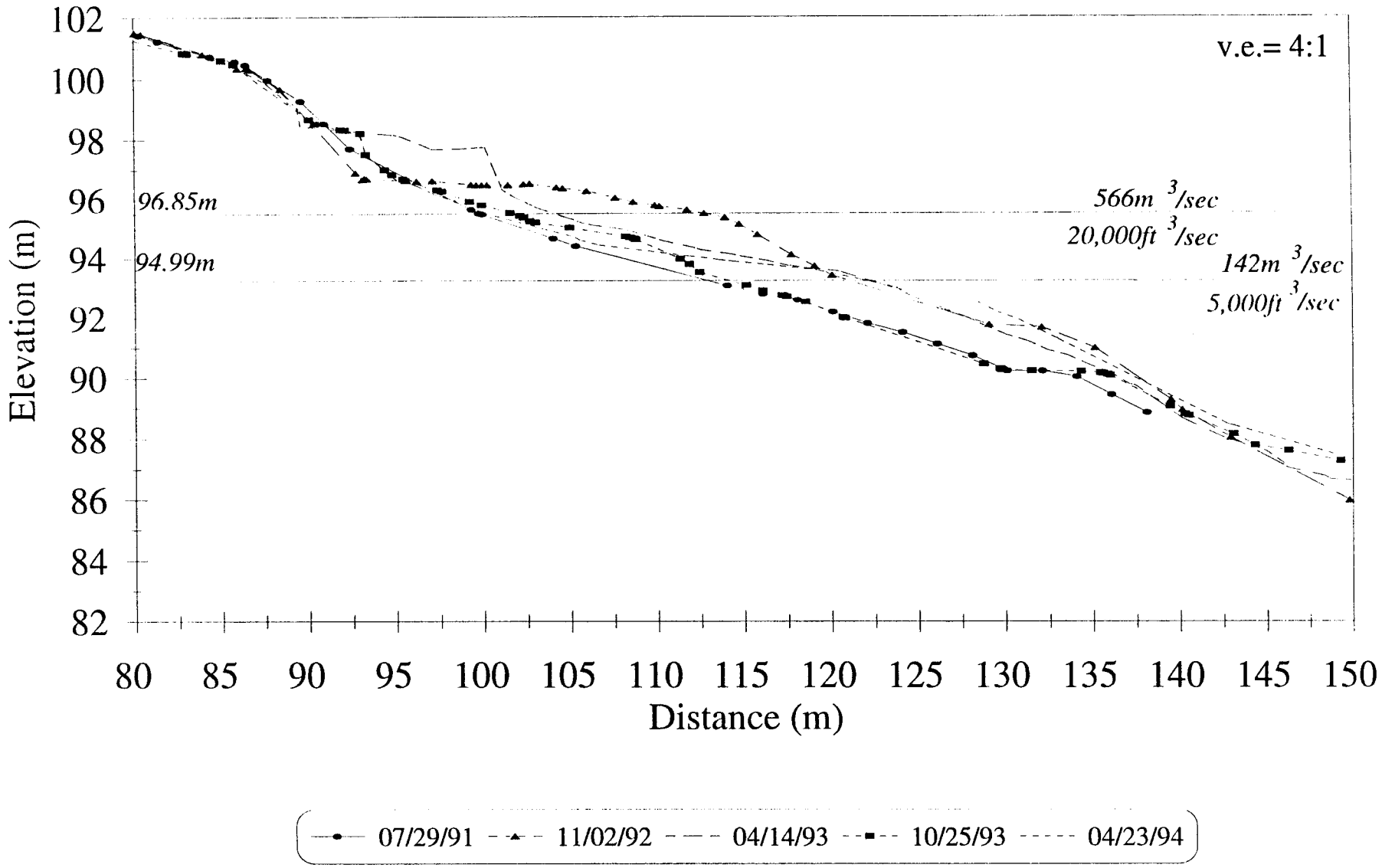


213 Mile

Cross-channel P4a

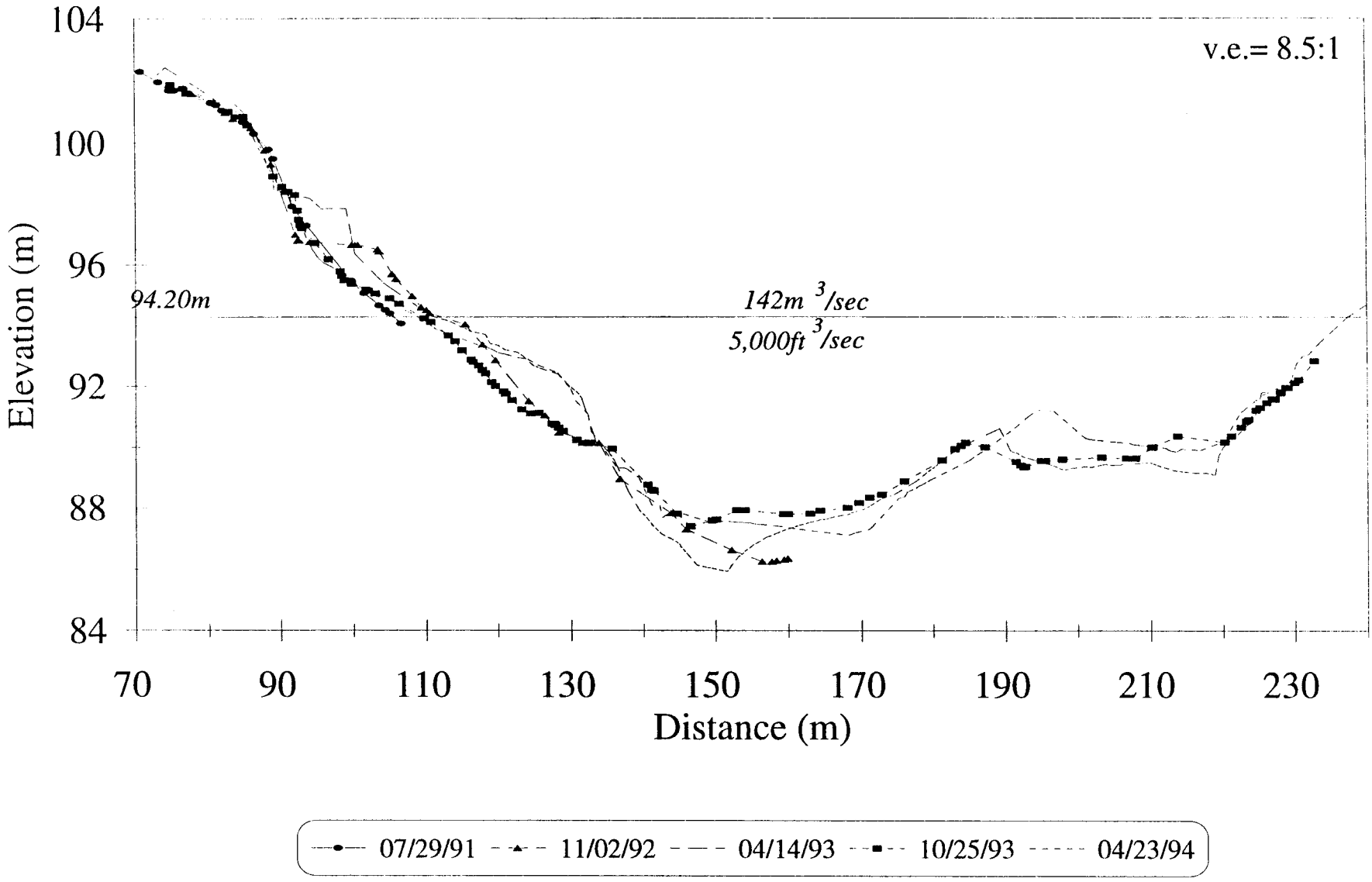


Near-shore P4a

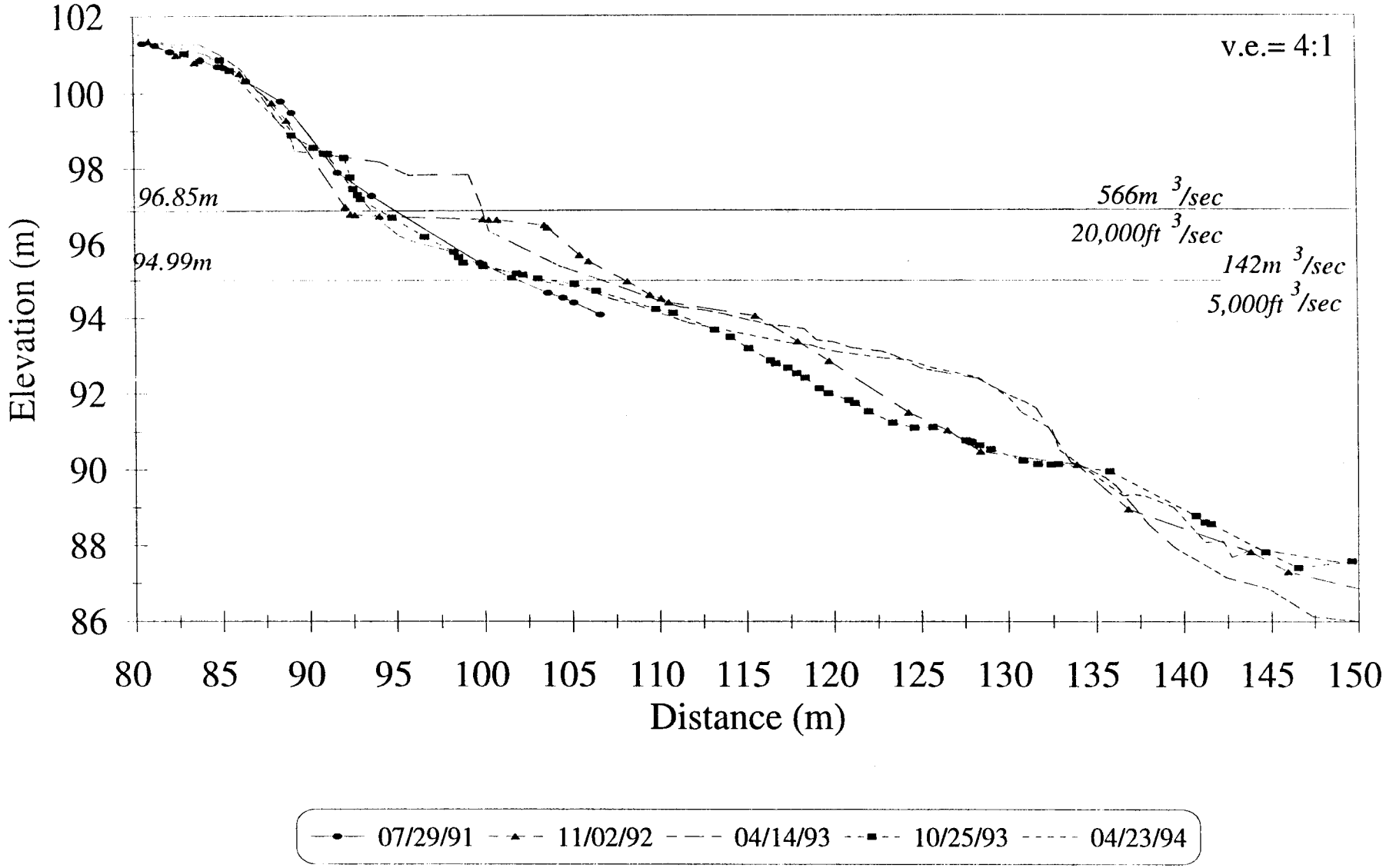


213 Mile

Cross-channel P4b

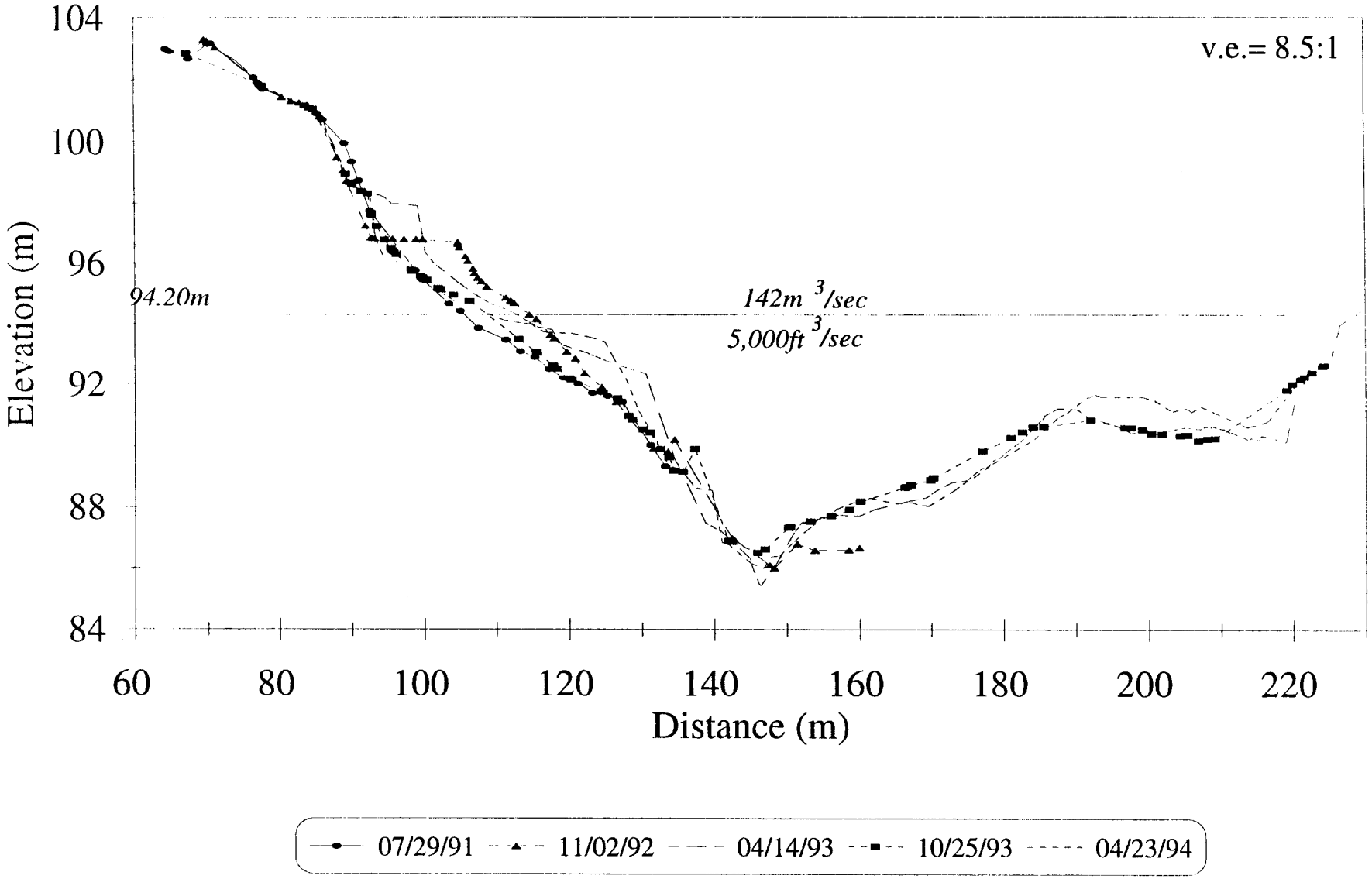


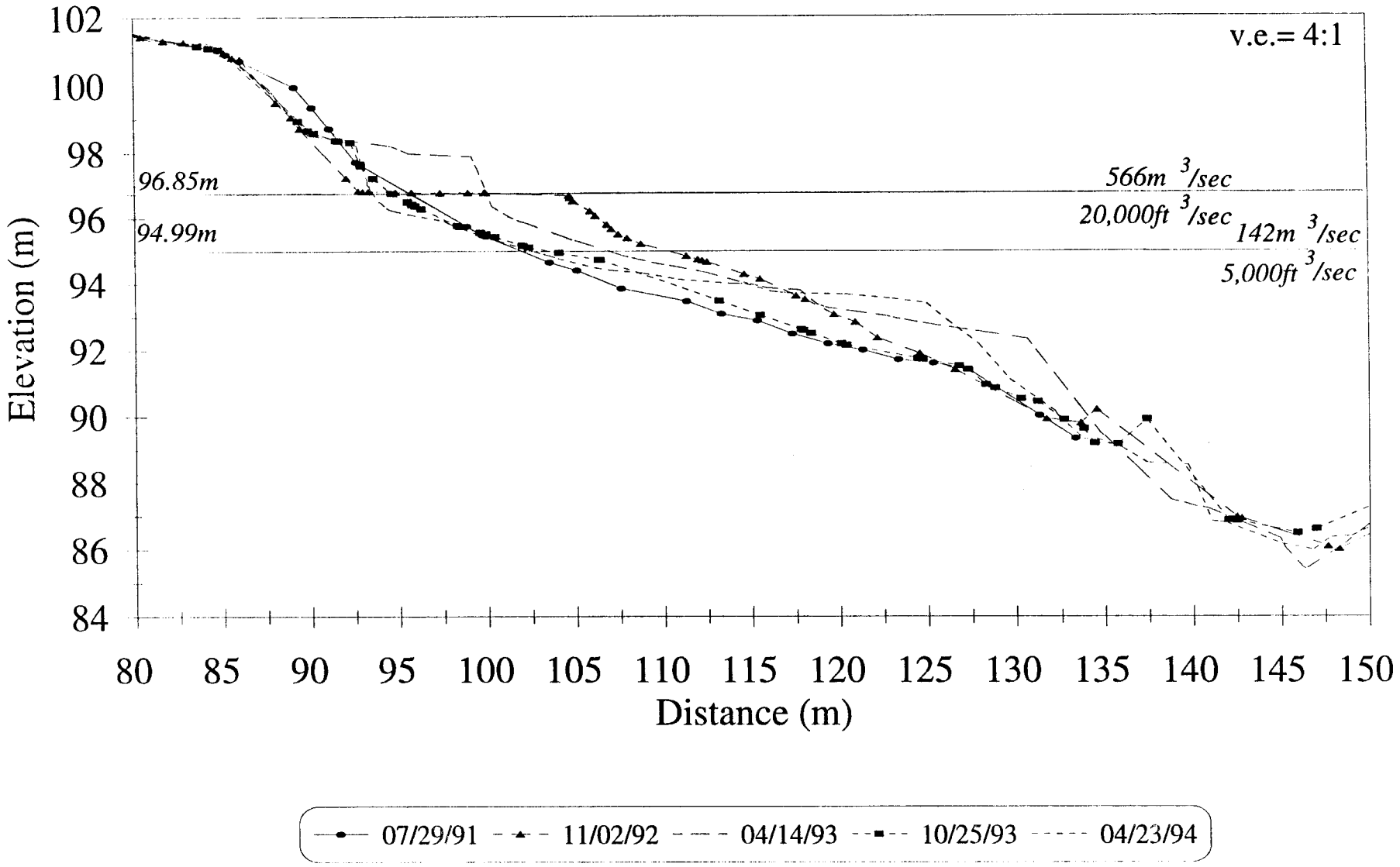
Near-shore P4b



213 Mile

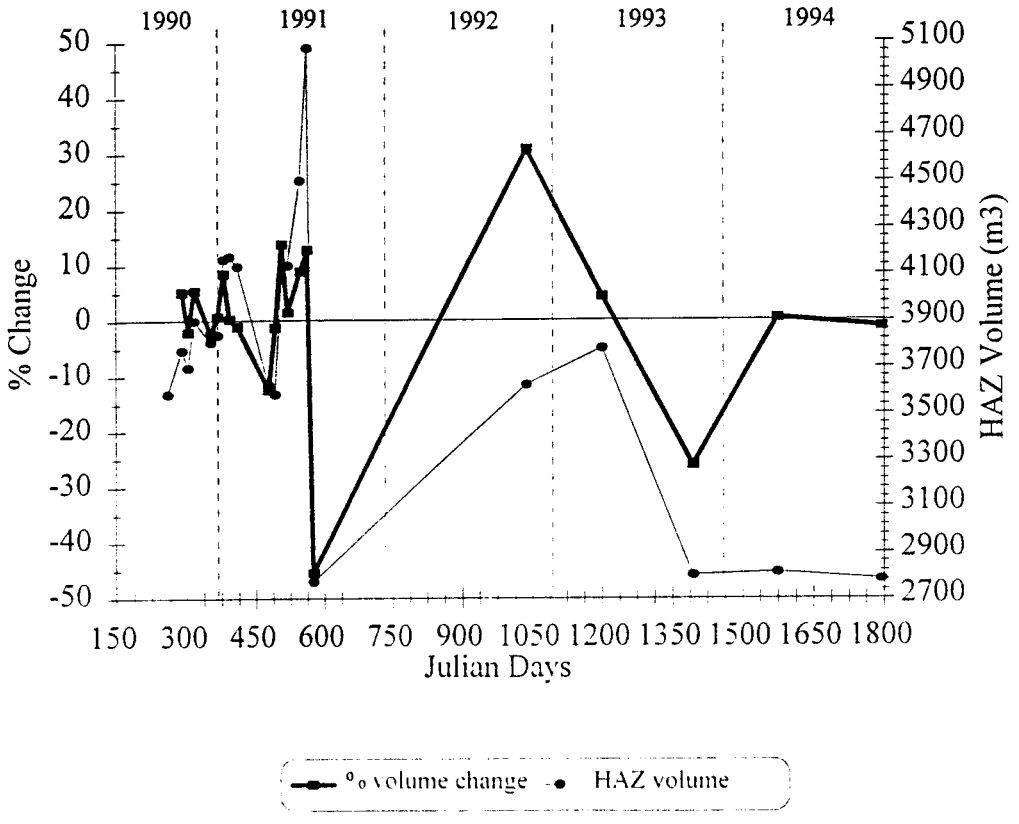
Cross-channel P5




Near-shore P5
v.e.= 4:1
96.85m
94.99m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
Elevation (m)
102
100
98
96
94
92
90
88
86
84
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
Distance (m)
07/29/91
11/02/92
04/14/93
10/25/93
04/23/94

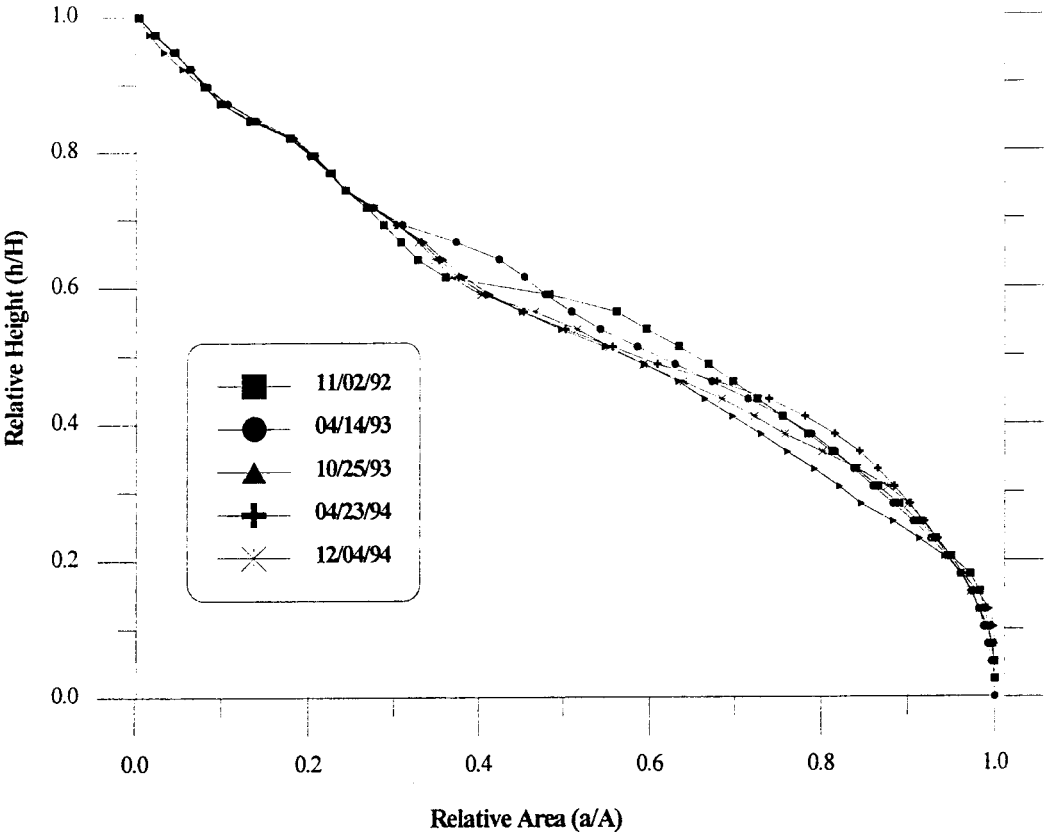
213 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F	900918	NORM	261	1600	3587				
G		E							
H	901017	A	290	1859	3775	259	188	16.19	5.24
I	901031	8000 CFS	304	1736	3701	-123	-74	-6.62	-1.96
J	901113	NORM	317	1789	3903	53	202	3.05	5.46
K	901218	NORM	352	1820	3810	31	-93	1.73	-2.38
L	910101	11000 CFS	366	1823	3840	3	30	0.16	0.79
M	910114	C	379	1887	4166	64	326	3.51	8.49
N	910128	NORM	393	1904	4179	17	13	0.90	0.31
O	910211	B	409	1911	4137	7	-42	0.37	-1.01
P	910422	NORM	477	1588	3627	-323	-510	-16.90	-12.33
Q	910507	NORM	492	1622	3585	34	-42	2.14	-1.16
R	910521	D	506	1774	4080	152	495	9.37	13.81
S	910604	15000 CFS	520	1805	4138	31	58	1.75	1.42
T	910701	NORM	547	1842	4504	37	366	2.05	8.84
U	910716	G	562	1987	5077	145	573	7.87	12.72
V	910729	F	575	1334	2772	-653	-2305	-32.86	-45.40
Y	921102	INT	1037	1693	3625	359	853	26.91	30.77
Z	930414	INT	1200	1520	3781	-173	156	-10.22	4.30
B31	931025	INT	1394	1398	2802	-122	-979	-8.03	-25.89
C31	940423	INT	1575	1514	2814	116	12	8.30	0.43
D31	941204	INT	1794	1395	2783	-119	-31	-7.86	-1.10

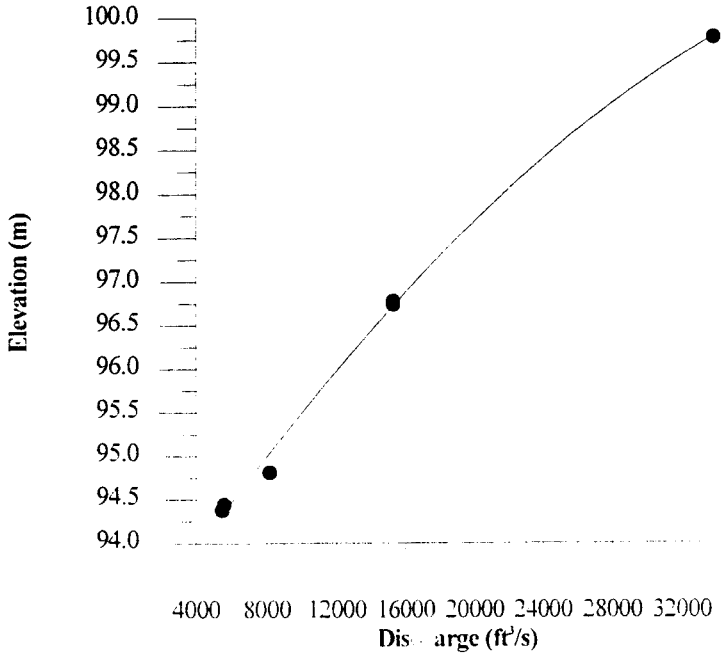


213 Mile

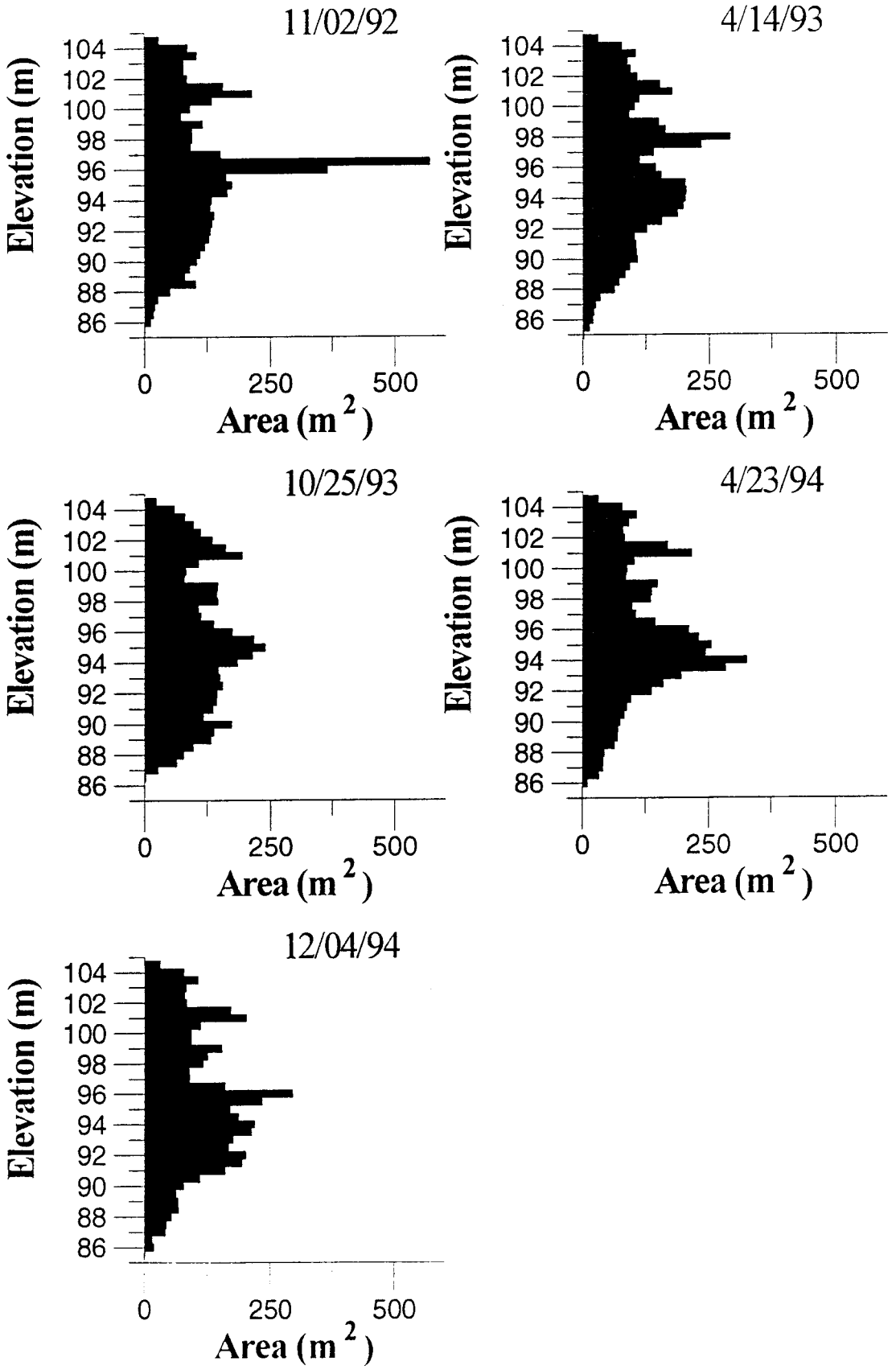
Hypsometric Curves

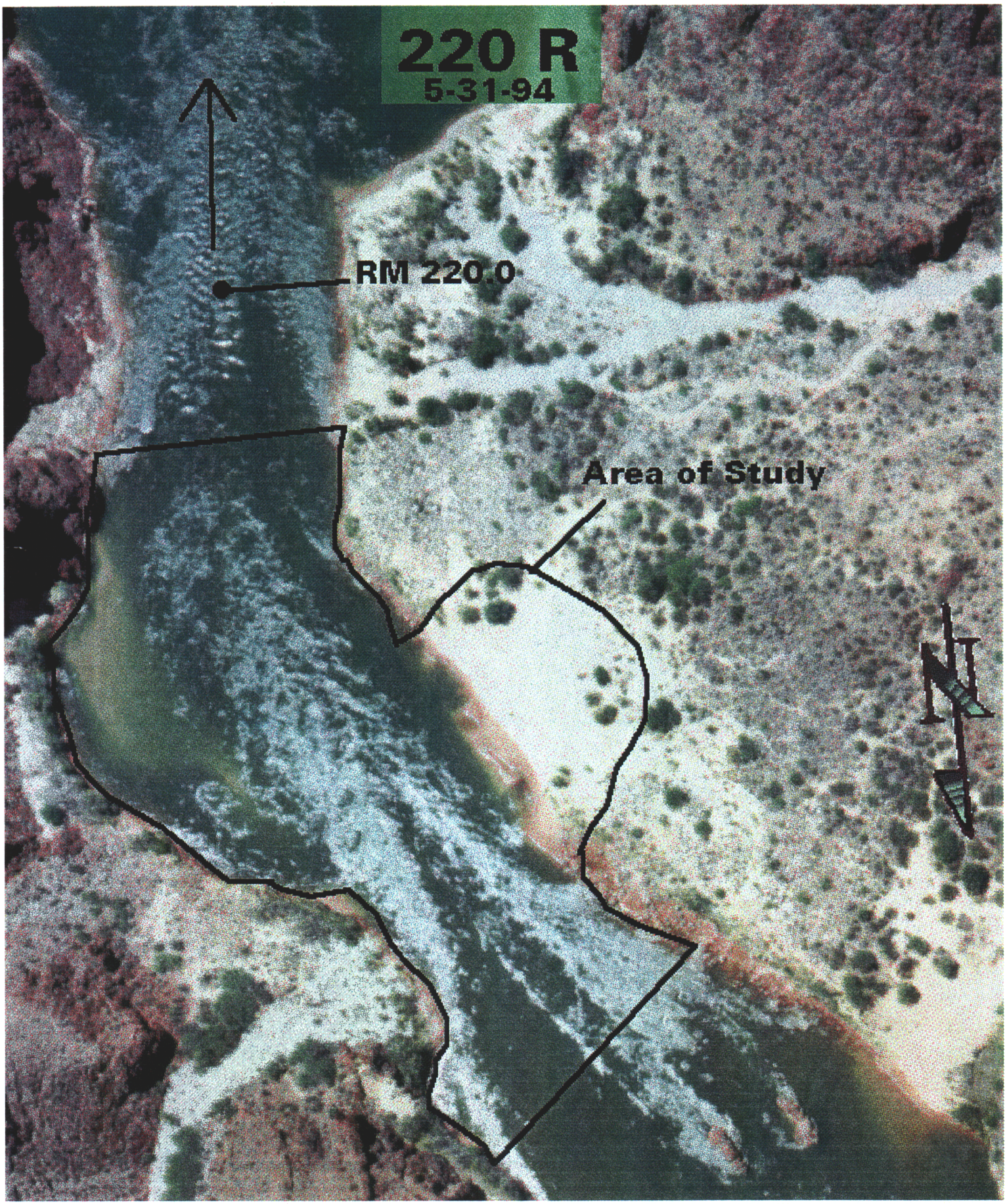


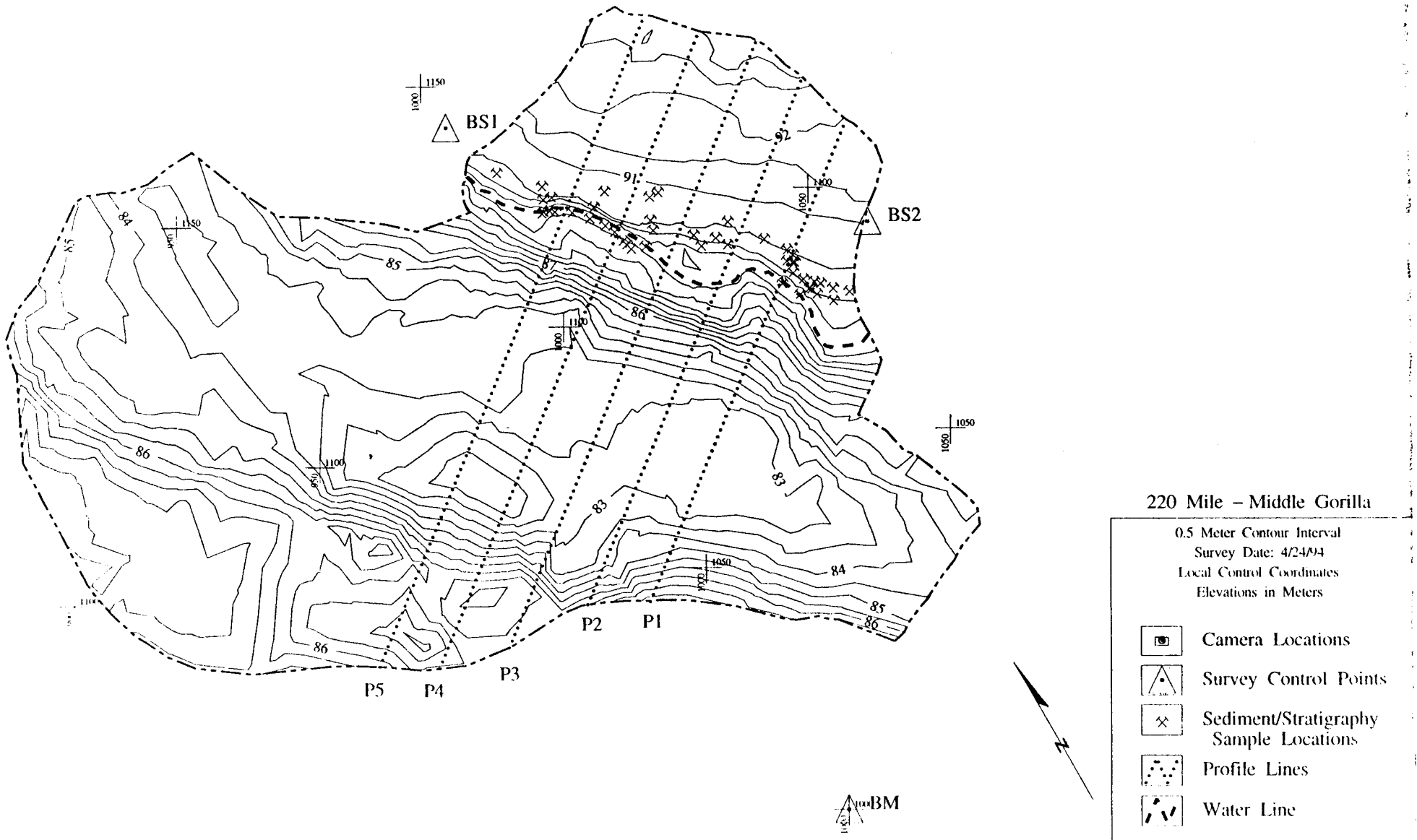
Stage Discharge



213 MILE
Area Distribution Histograms

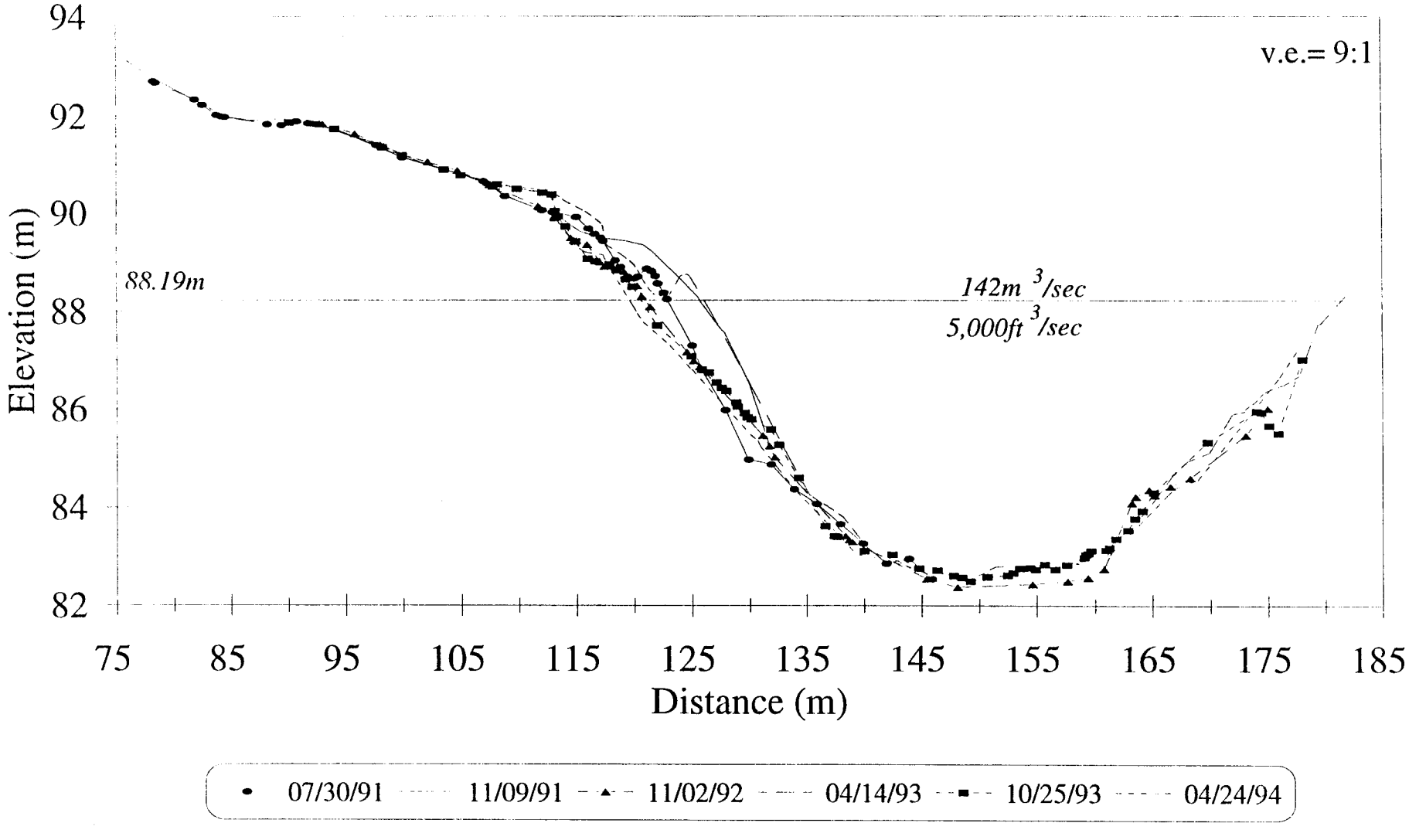



220 R
5-31-94
RM 220.0
Area of Study
N

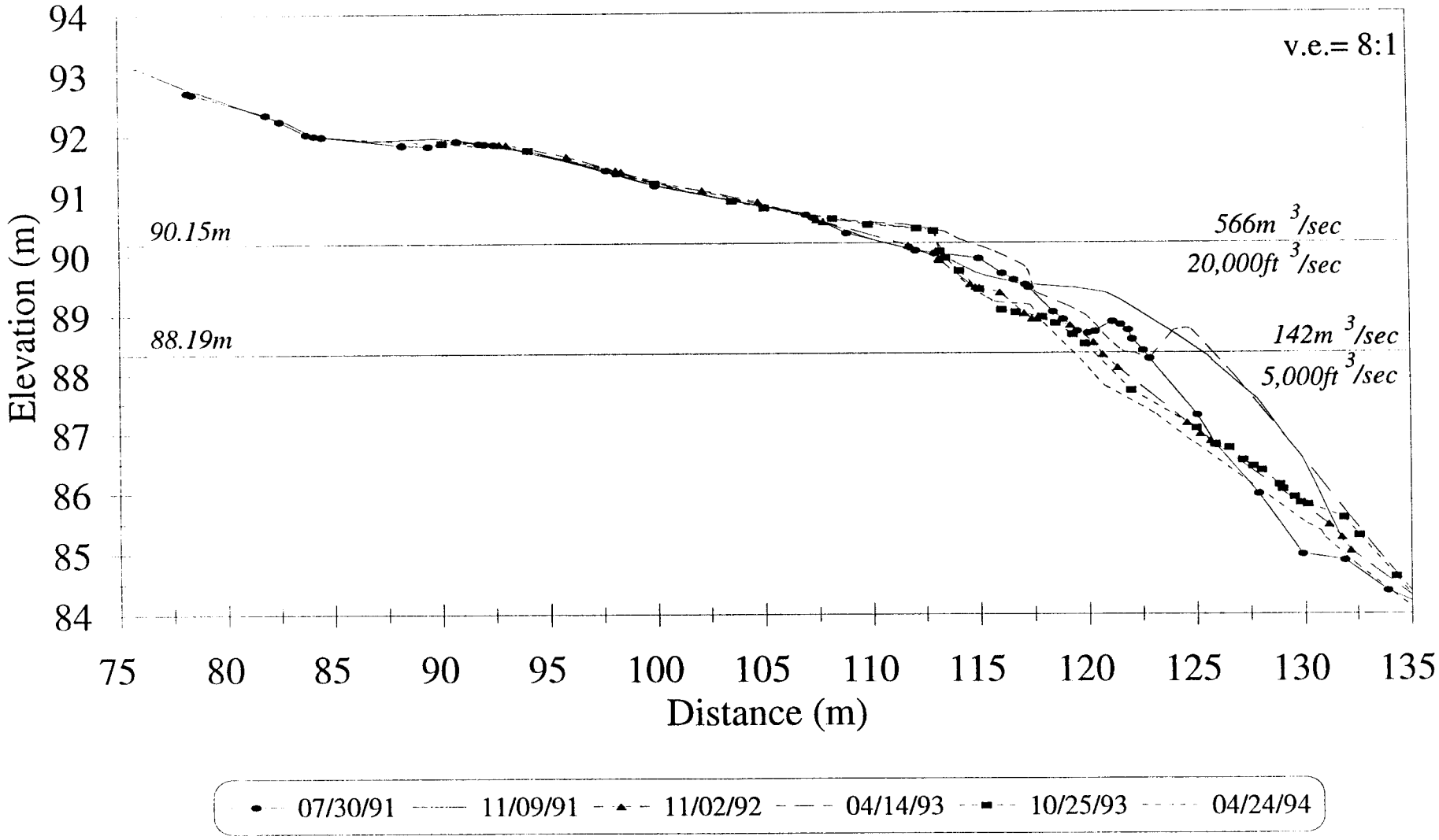

BS1
BS2
P1
P2
P3
P4
P5
100BM
N
220 Mile – Middle Gorilla
0.5 Meter Contour Interval
Survey Date: 4/24/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:700

220 Mile

Cross-channel P1

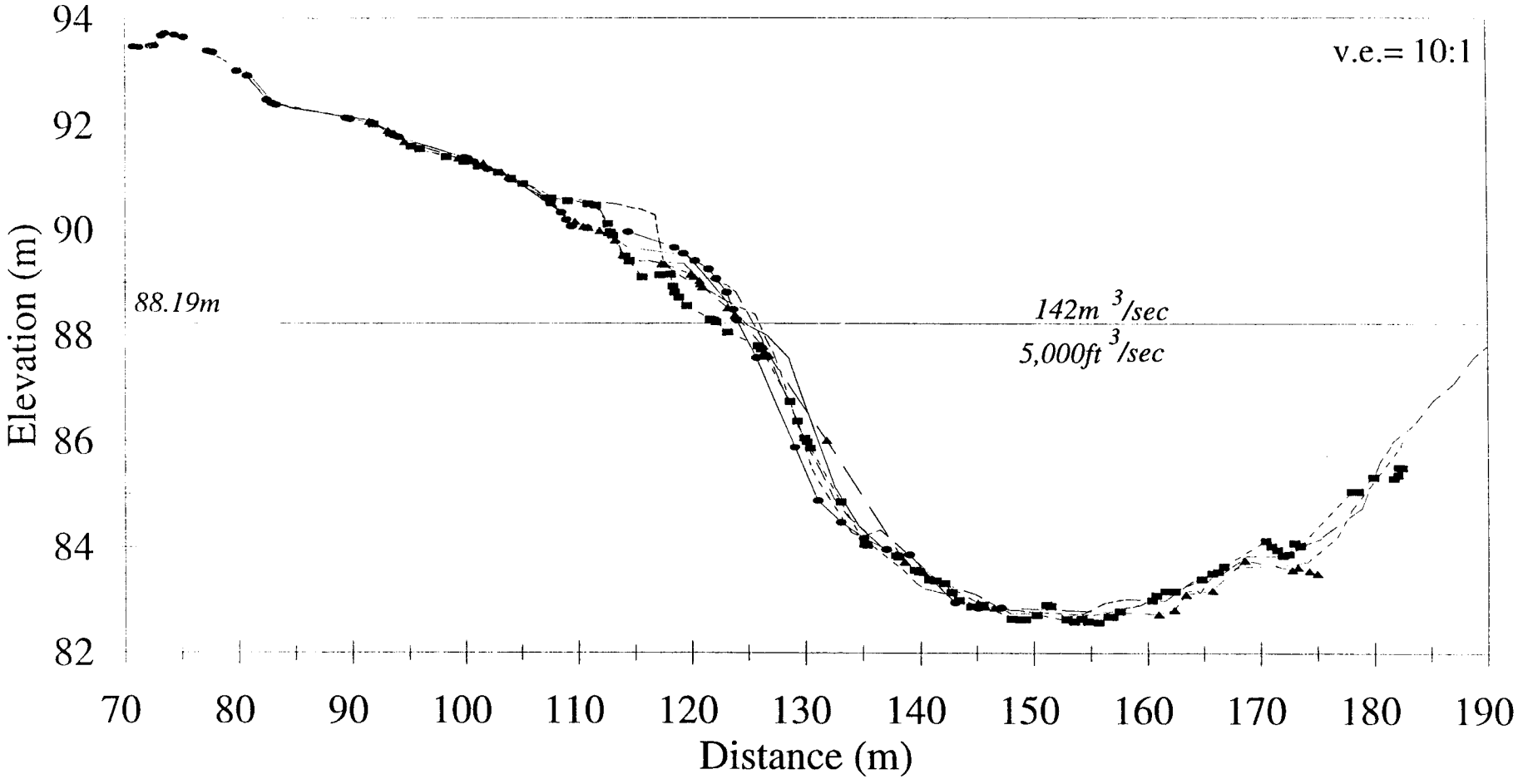


Near-shore P1

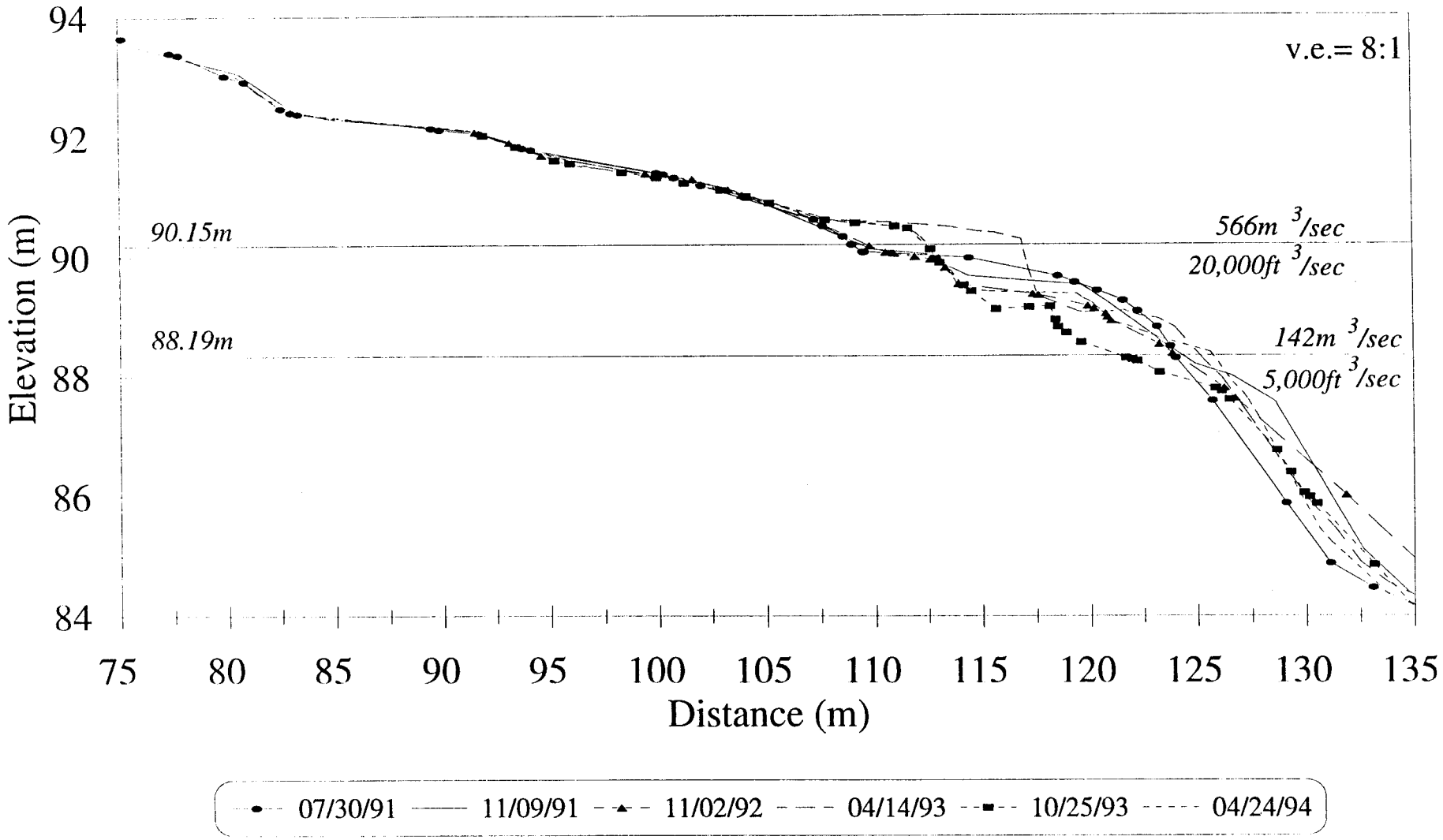


220 Mile

Cross-channel P2

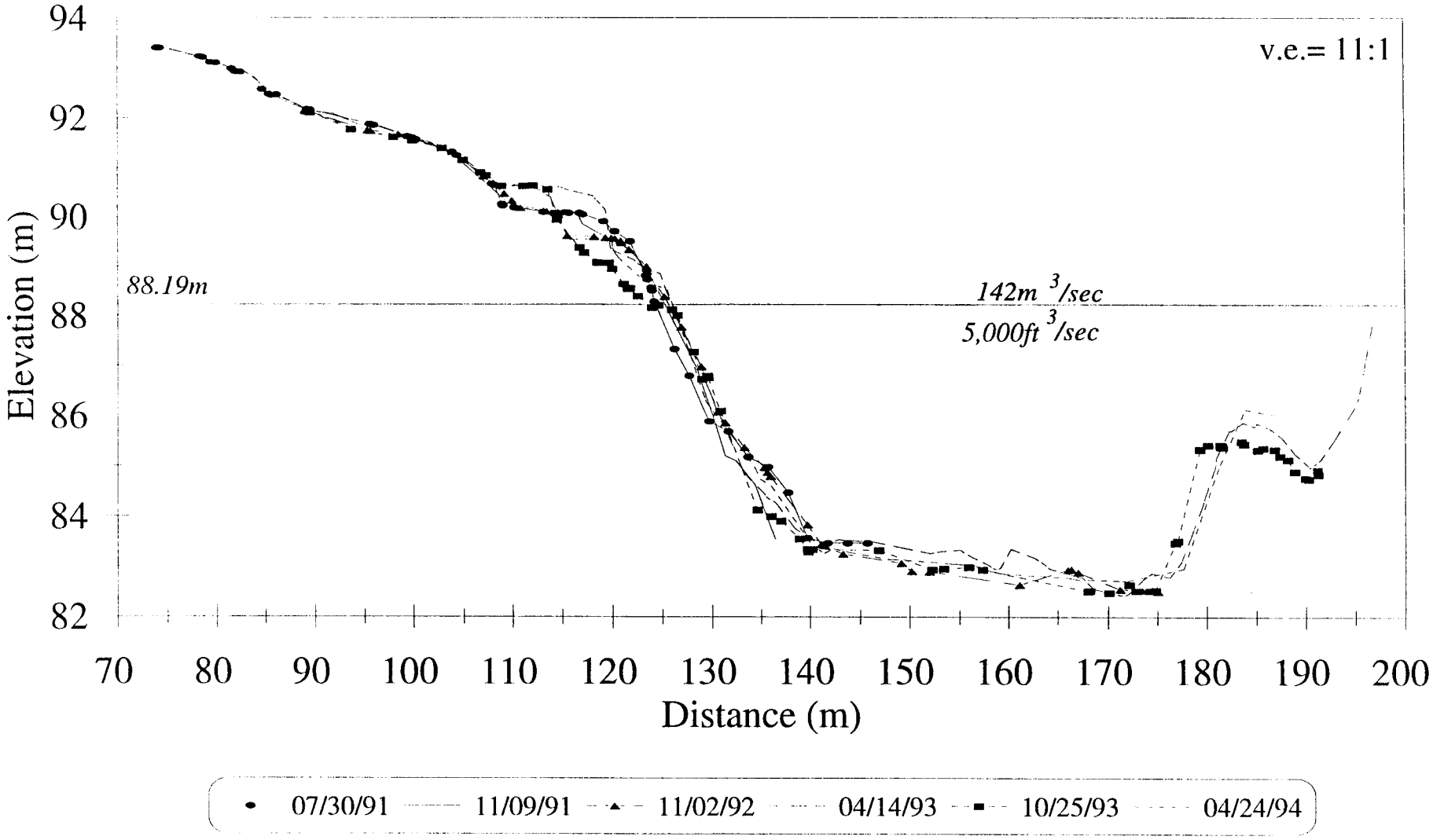


Near-shore P2

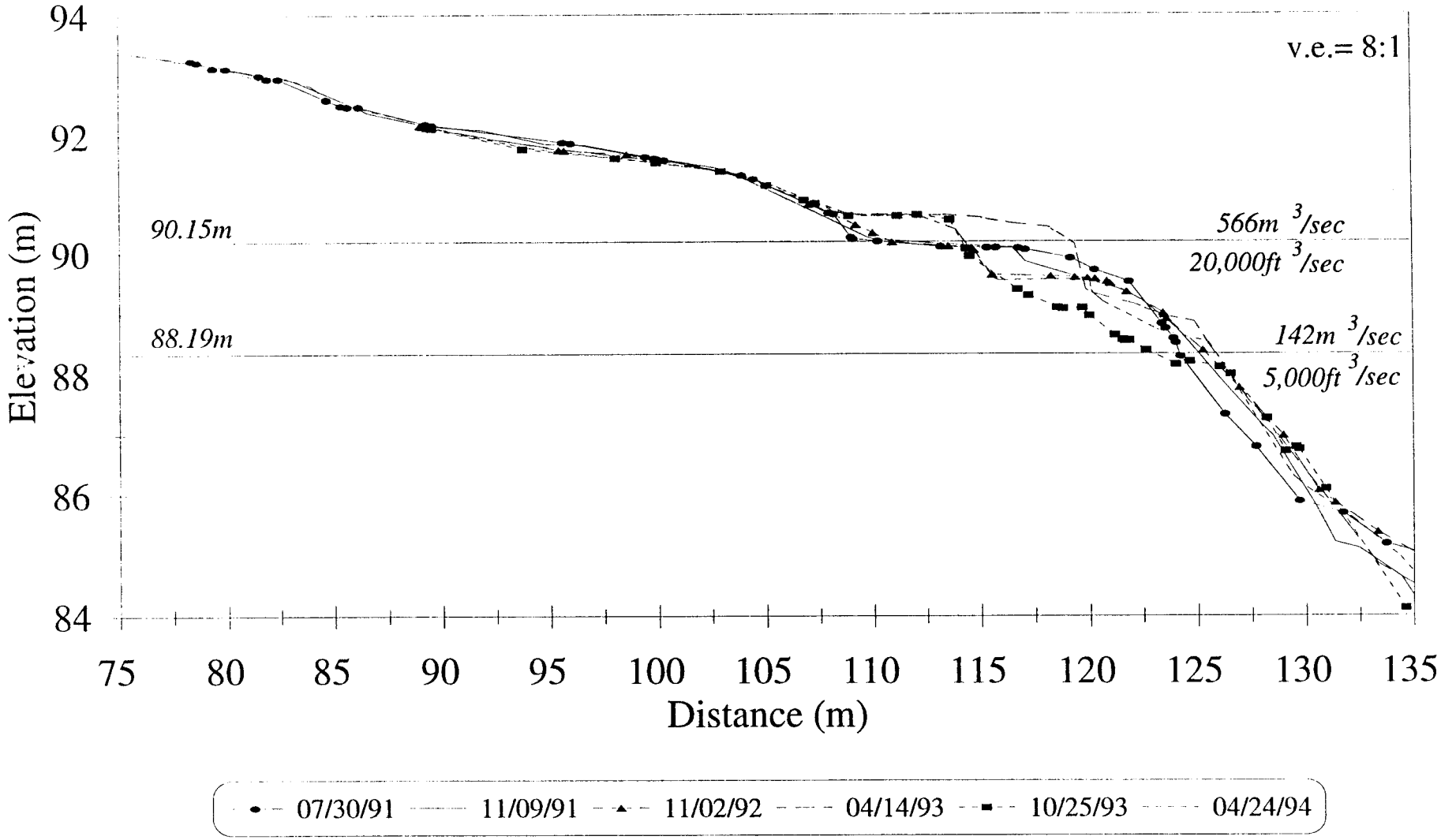


220 Mile

Cross-channel P3

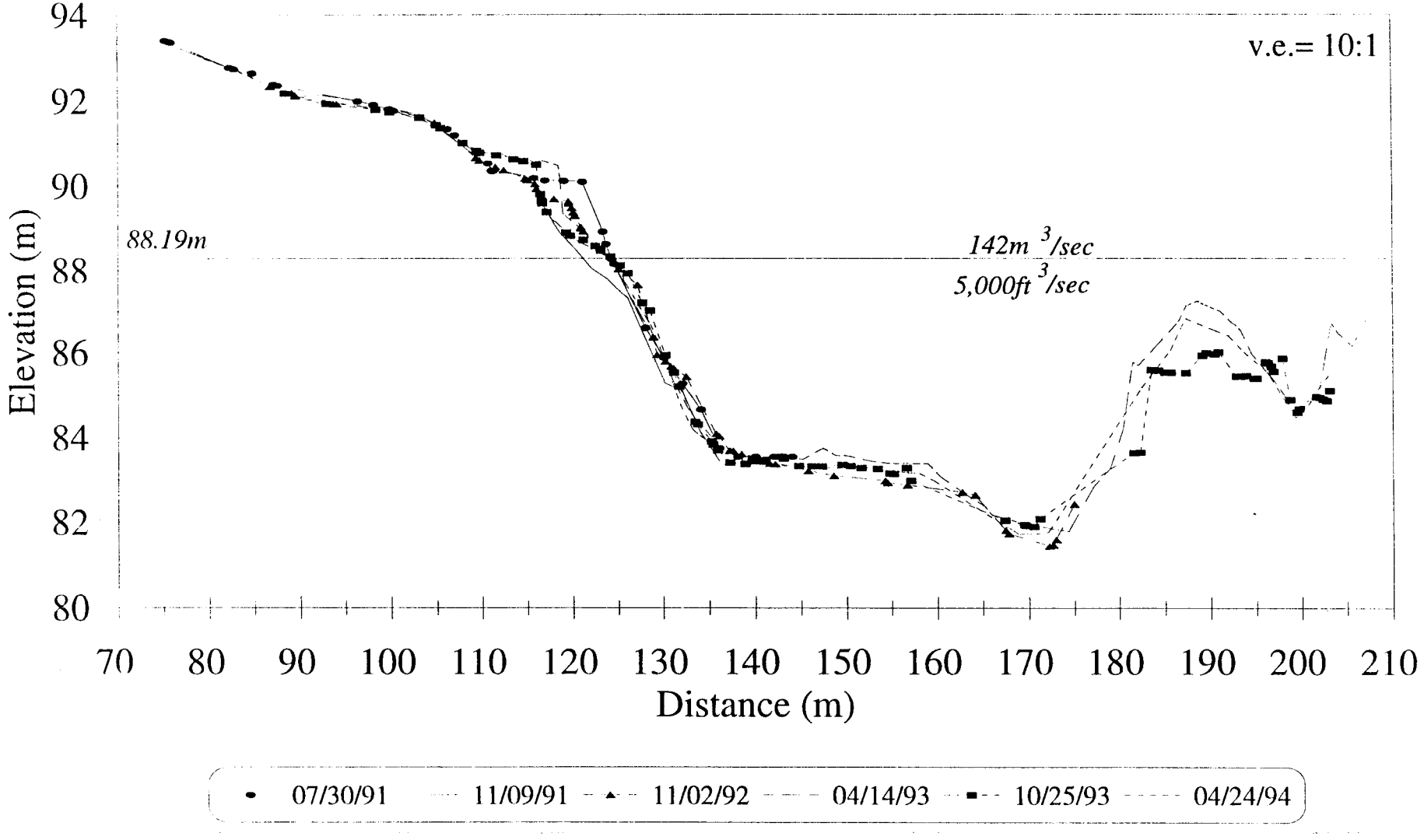


Near-shore P3

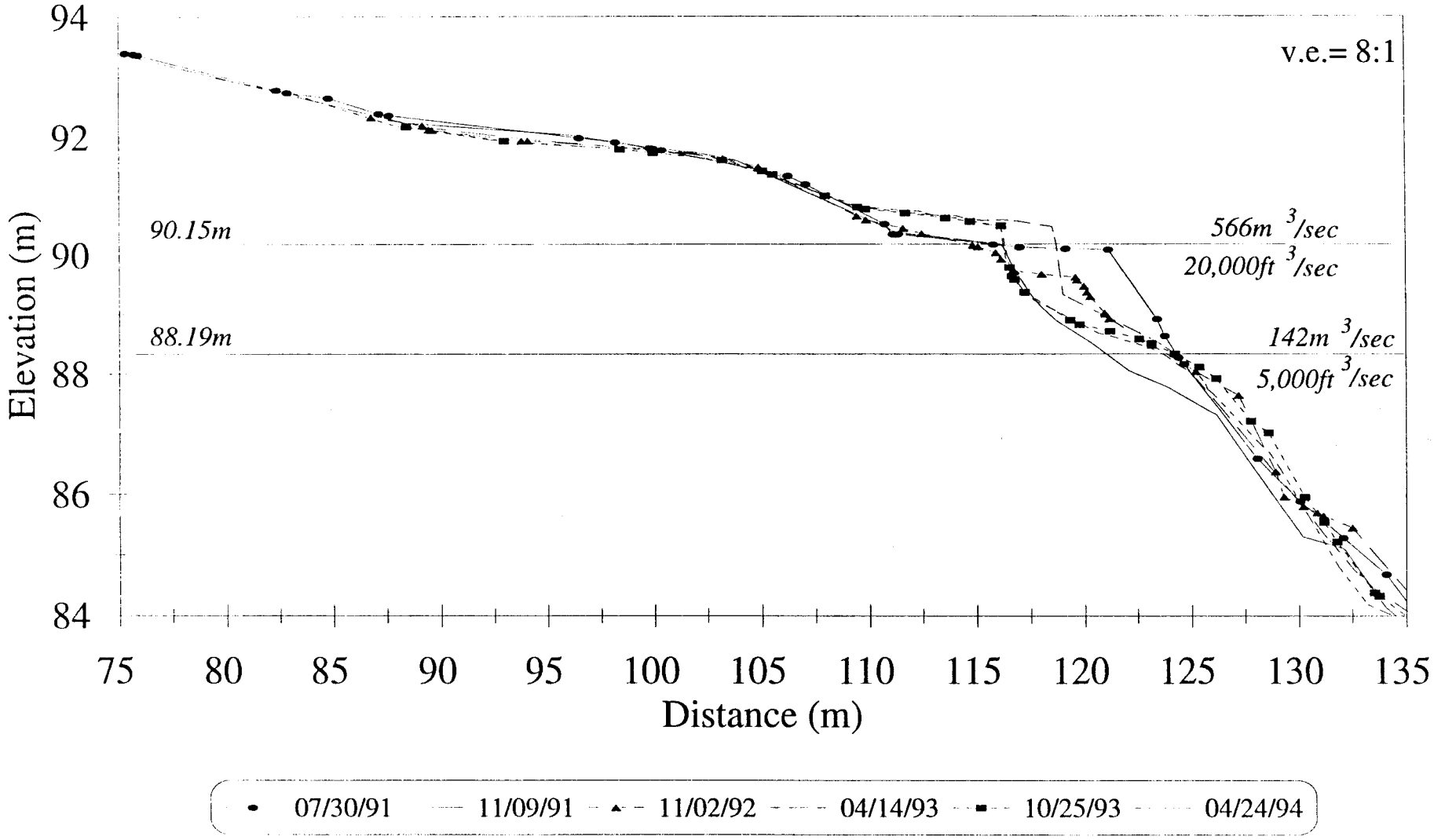


220 Mile

Cross-channel P4

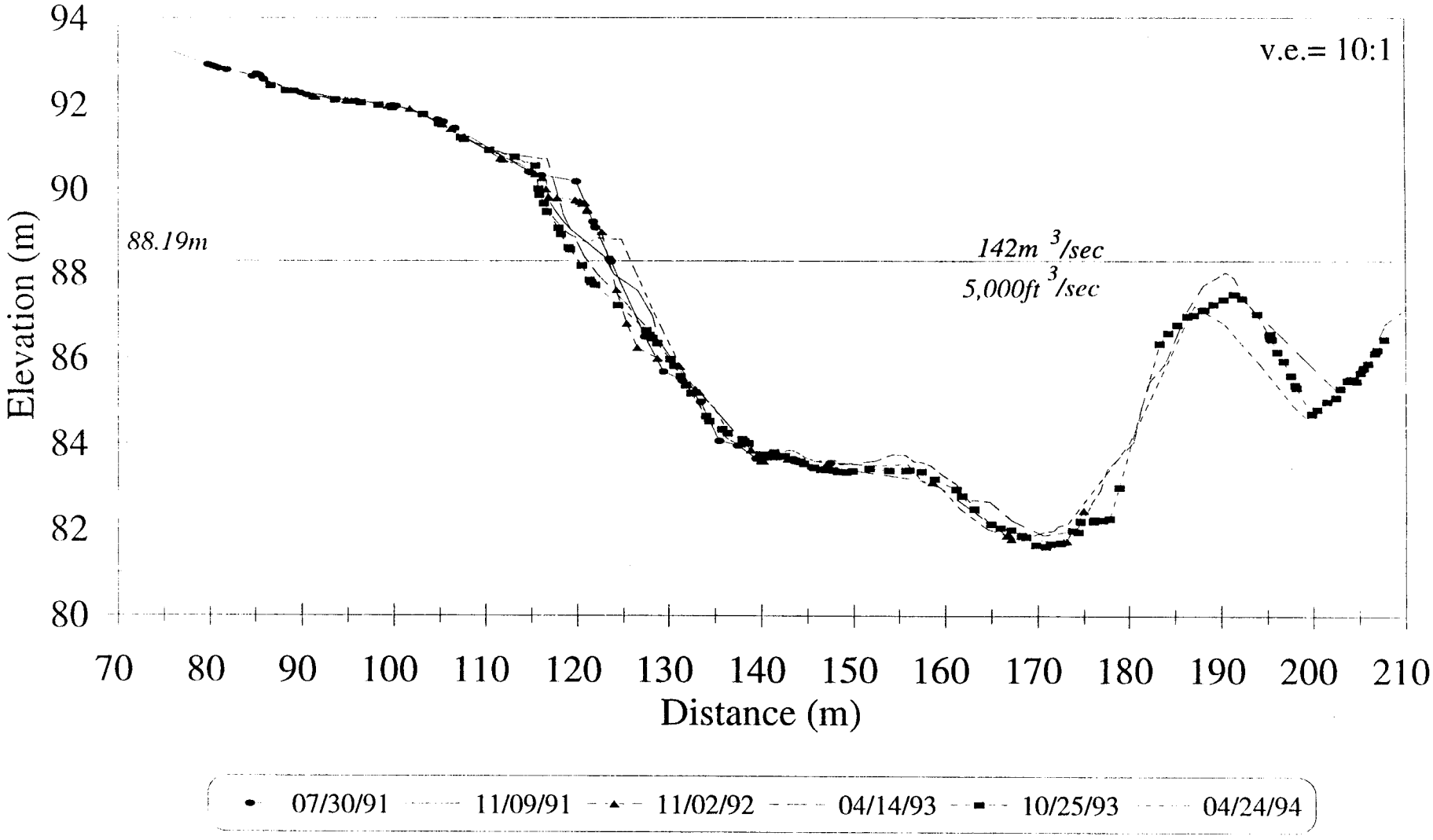


Near-shore P4

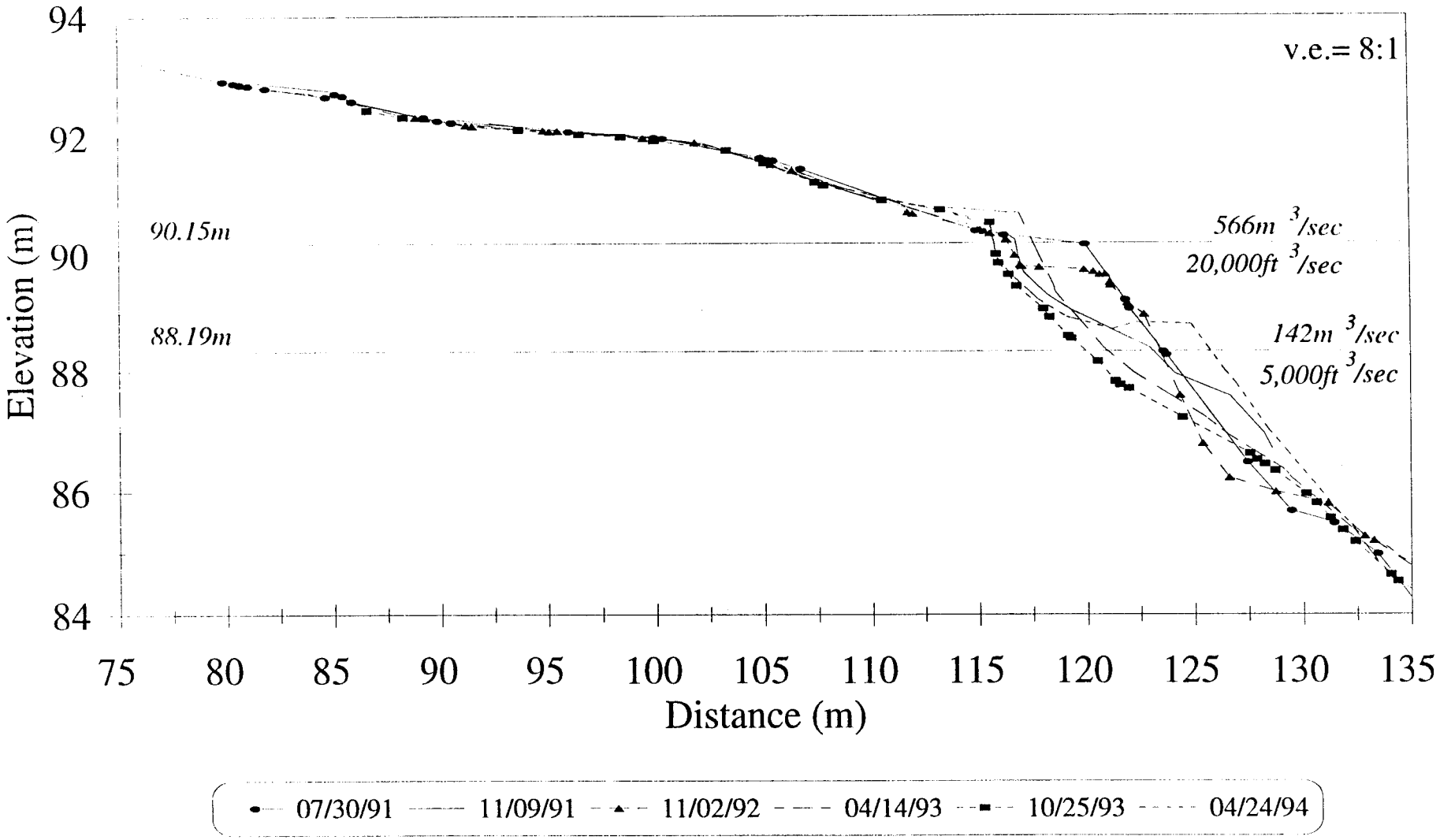


220 Mile

Cross-channel P5

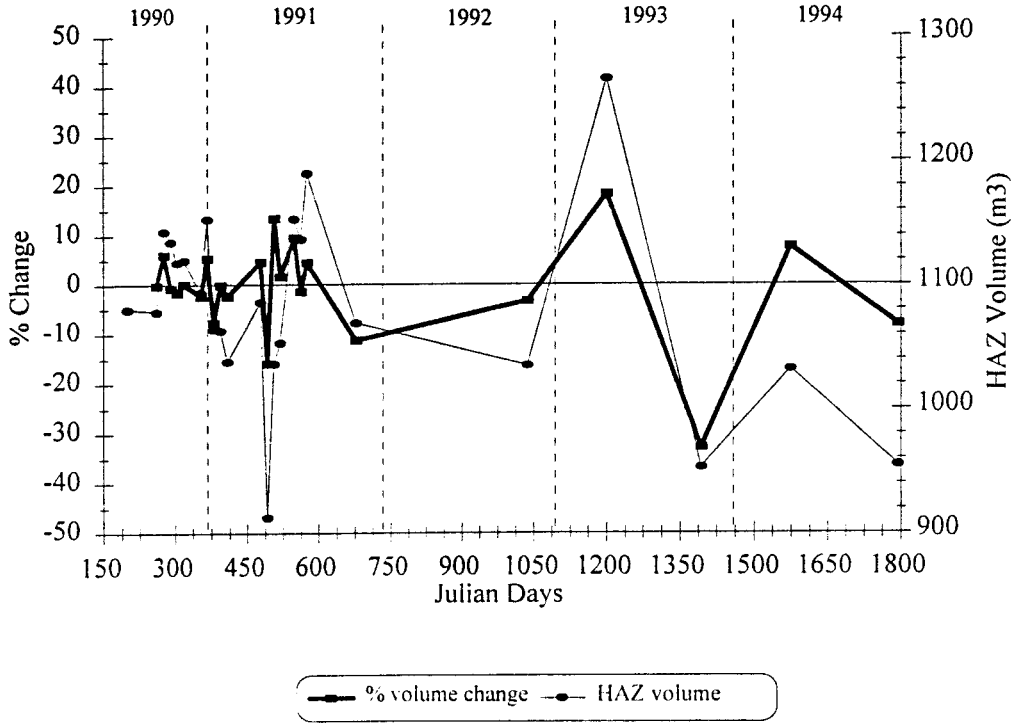


Near-shore P5



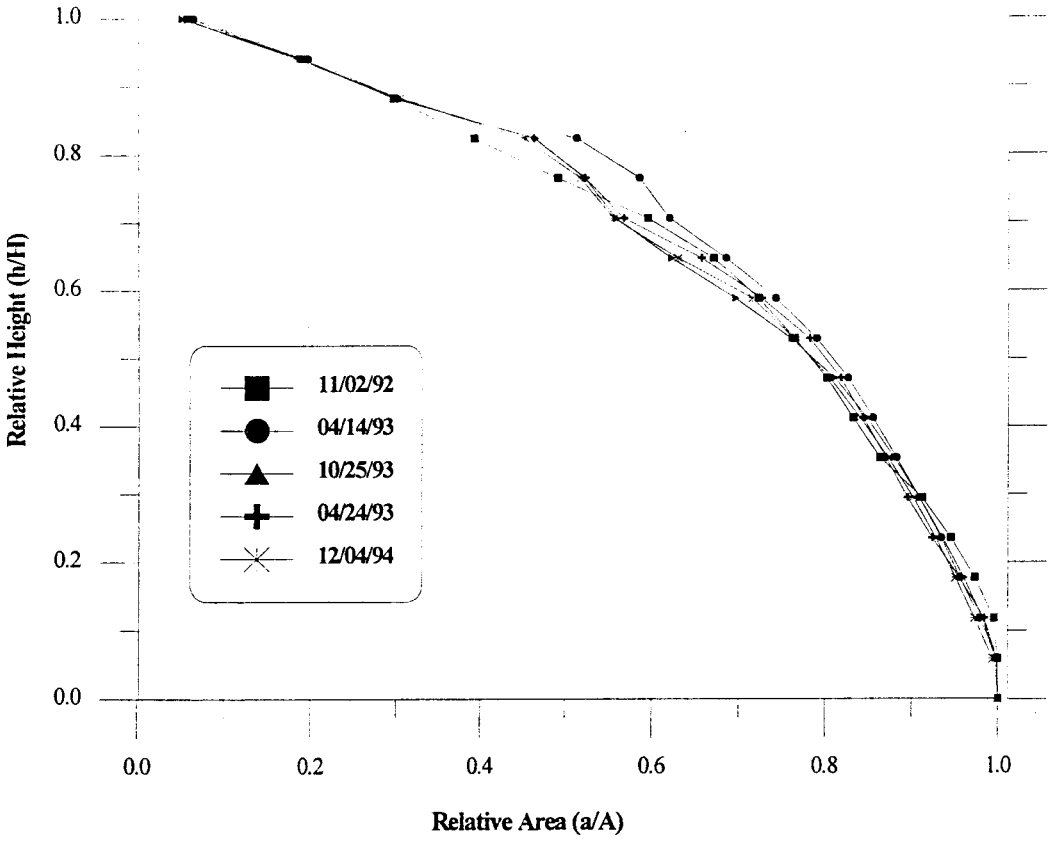
220 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C	900718	G	199	726	1080				
D		F							
E		NORM							
F	900918	NORM	261	696	1078	-30	-2	-4.13	-0.19
G	901003	E	276	715	1143	19	65	2.73	6.03
H	901017	A	290	711	1135	-4	-8	-0.56	-0.70
I	901031	8000 CFS	304	726	1118	15	-17	2.11	-1.50
J	901114	NORM	318	715	1120	-11	2	-1.52	0.18
K	901219	NORM	353	741	1094	26	-26	3.64	-2.32
L	910102	11000 CFS	367	776	1153	35	59	4.72	5.39
M	910115	C	380	721	1064	-55	-89	-7.09	-7.72
N	910129	NORM	394	737	1063	16	-1	2.22	-0.09
O	910212	B	408	749	1038	12	-25	1.63	-2.35
P	910423	NORM	478	732	1086	-17	48	-2.27	4.62
Q	910507	NORM	492	666	913	-66	-173	-9.02	-15.93
R	910521	D	506	714	1036	48	123	7.21	13.47
S	910604	15000 CFS	520	735	1053	21	17	2.94	1.64
T	910702	NORM	548	721	1153	-14	100	-1.90	9.50
U	910716	G	562	706	1137	-15	-16	-2.08	-1.39
V	910730	F	576	718	1190	12	53	1.70	4.45
X	911109	INT	678	719	1069	1	-121	0.14	-11.32
Y	921102	INT	1037	719	1035	0	-34	0.00	-3.29
Z	930414	INT	1200	742	1266	23	231	3.20	18.25
B32	931025	INT	1394	665	953	-77	-313	-10.38	-32.84
C32	940424	INT	1575	712	1032	47	79	7.07	7.66
D32	941204	INT	1794	666	955	-46	-77	-6.46	-8.06

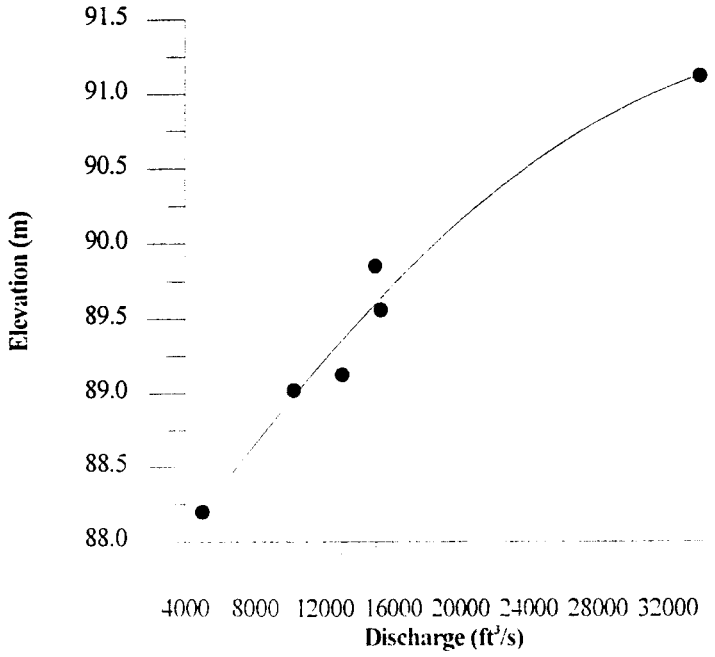


220 Mile

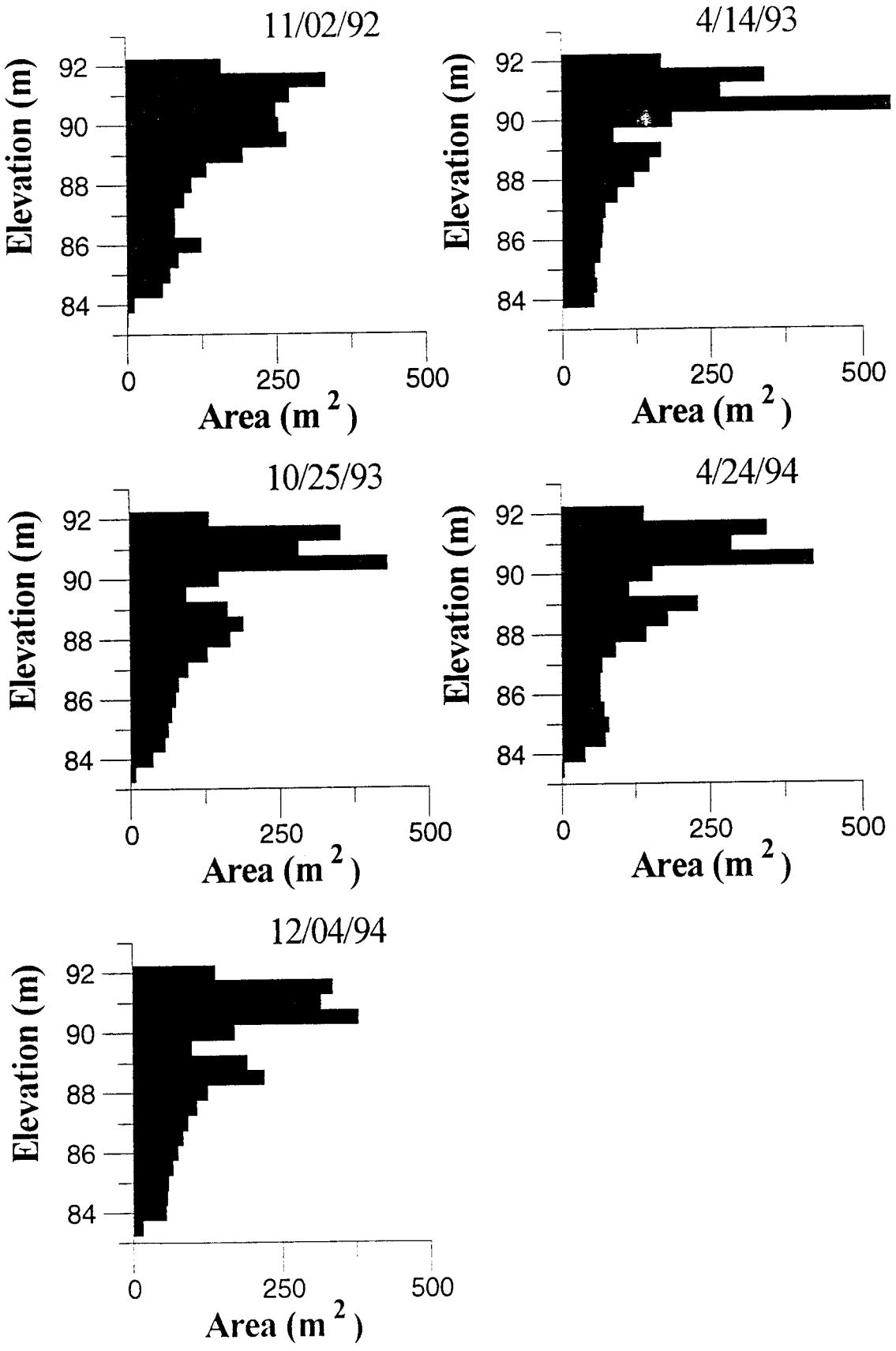
Hypsometric Curves

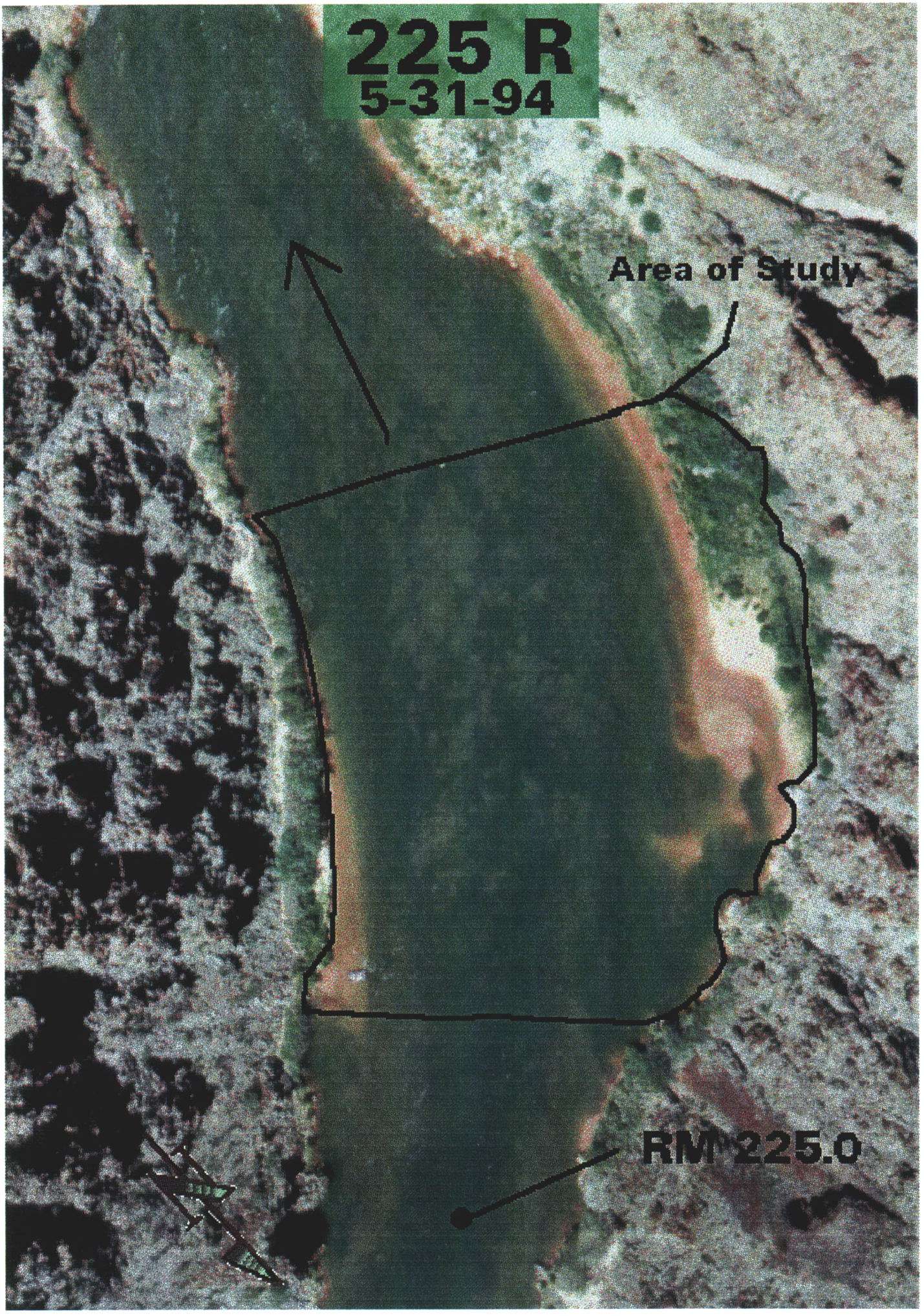


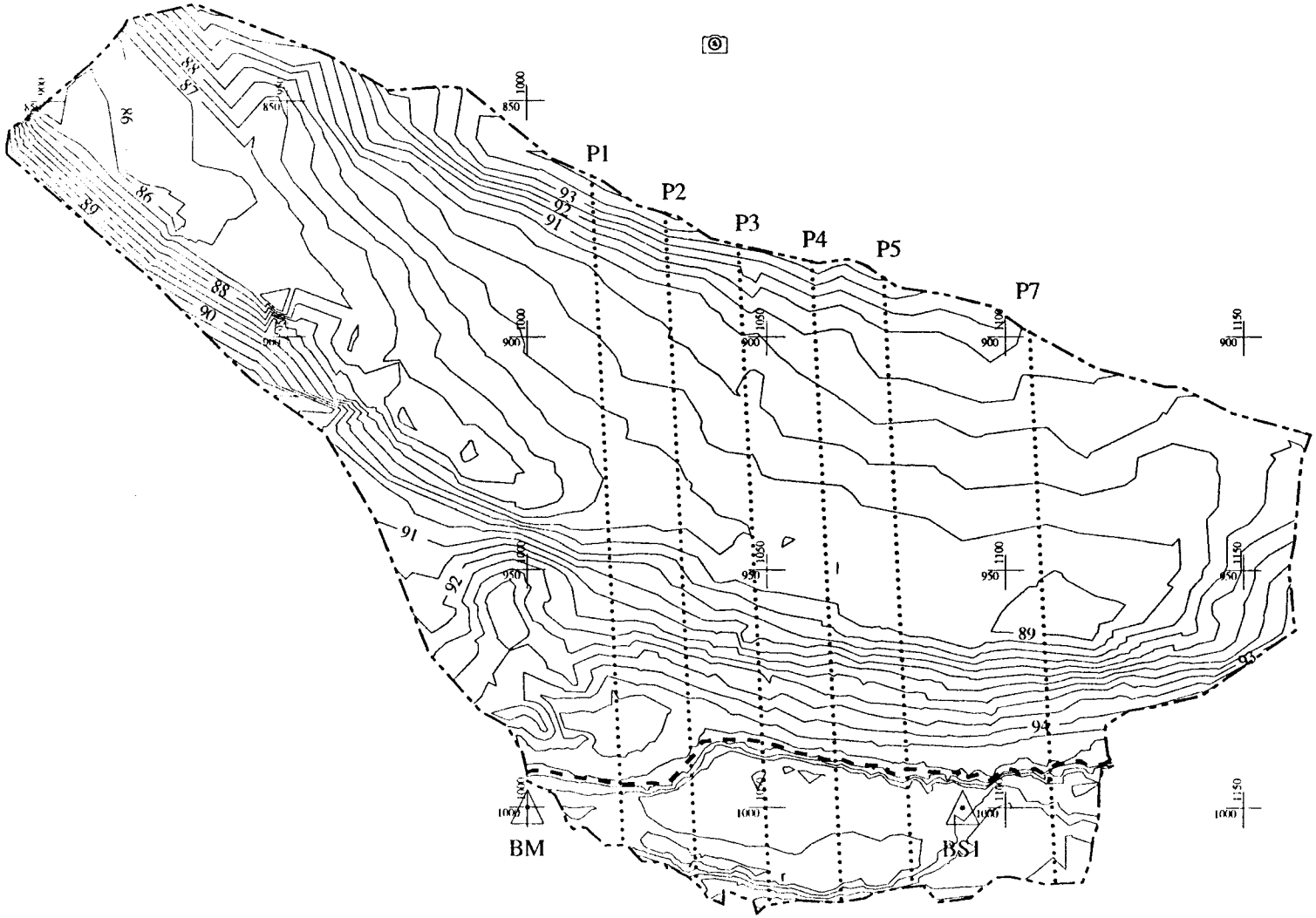
Stage Discharge



220 MILE
Area Distribution Histograms

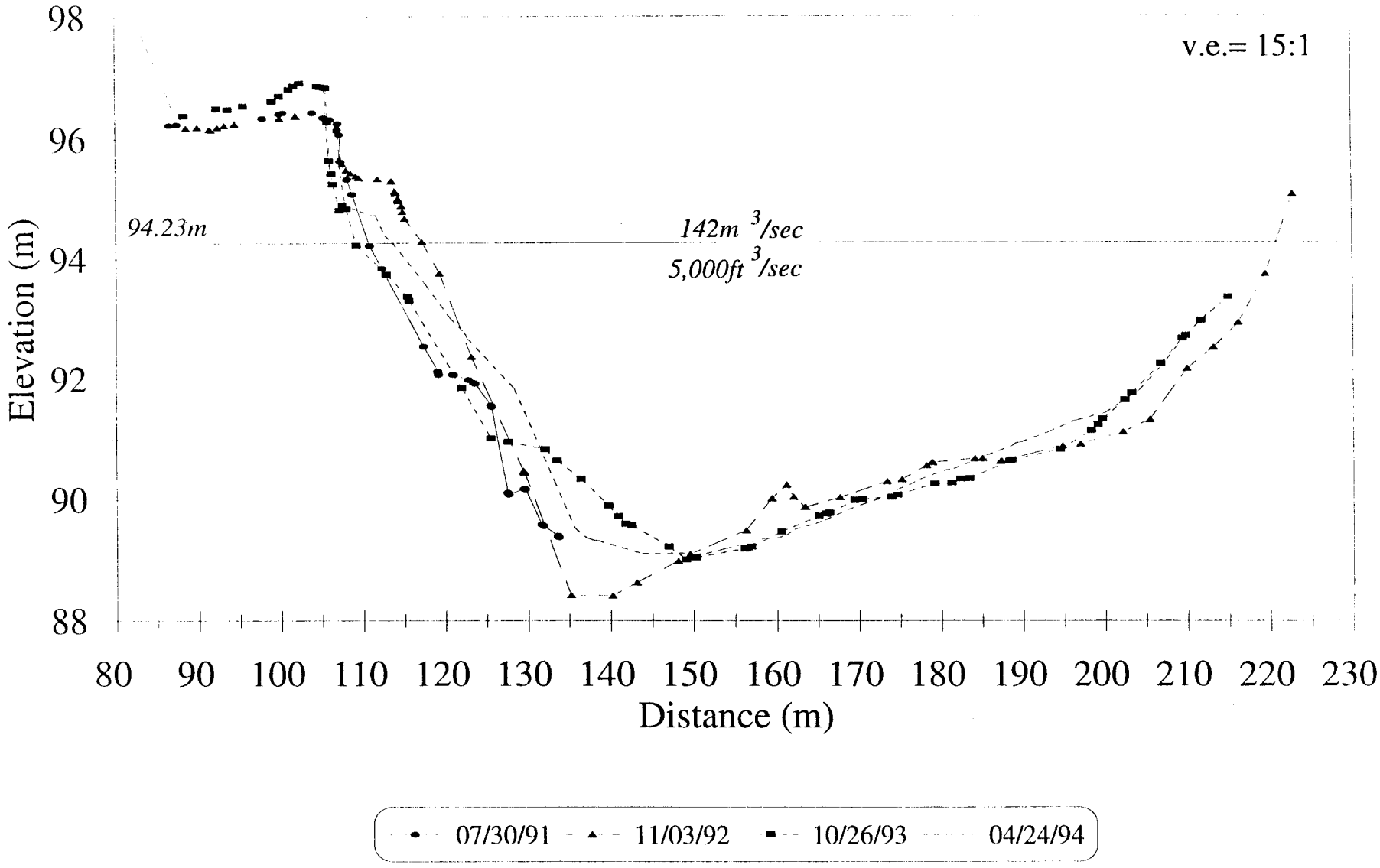



225 R
5-31-94
Area of Study
RM 225.0

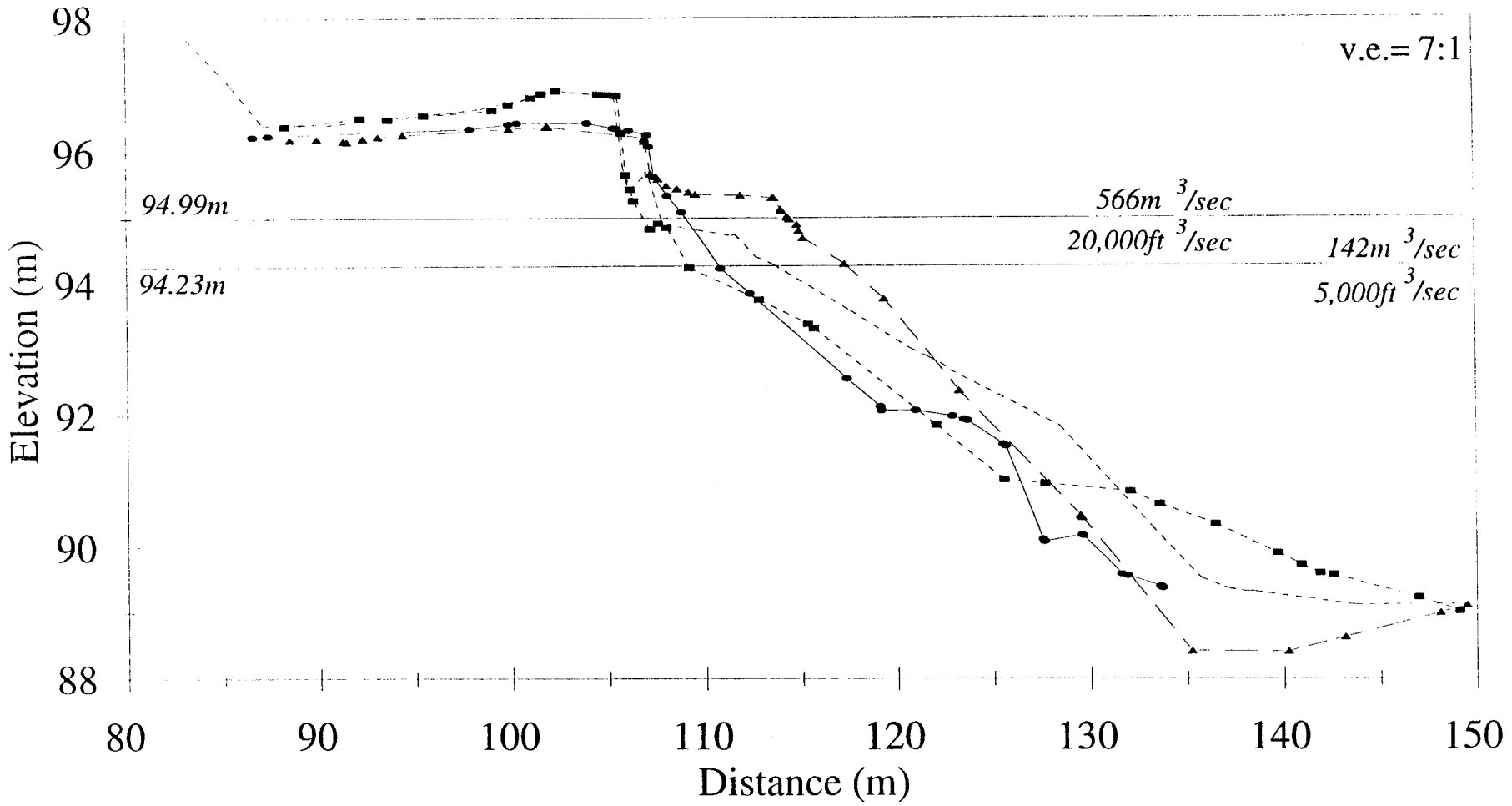

P1
P2
P3
P4
P5
P7
BM
BS1
N
225 Mile
0.5 Meter Contour Interval
Survey Date: 4/24/94
Local Control Coordinates
Elevations in Meters
Camera Locations
Survey Control Points
Sediment/Stratigraphy Sample Locations
Profile Lines
Water Line
Scale 1:1000

225 Mile

Cross-channel P3

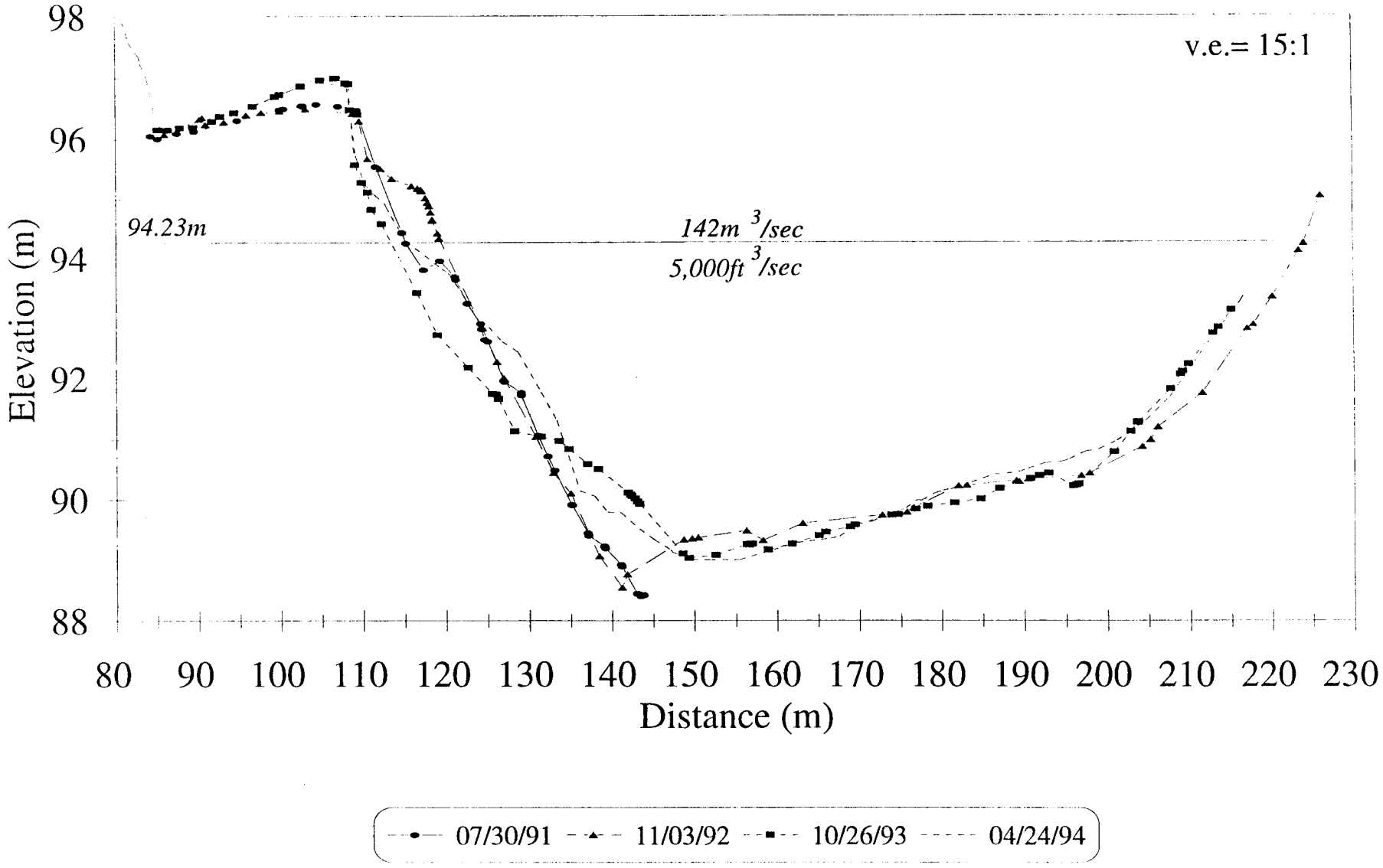


Near-shore P3

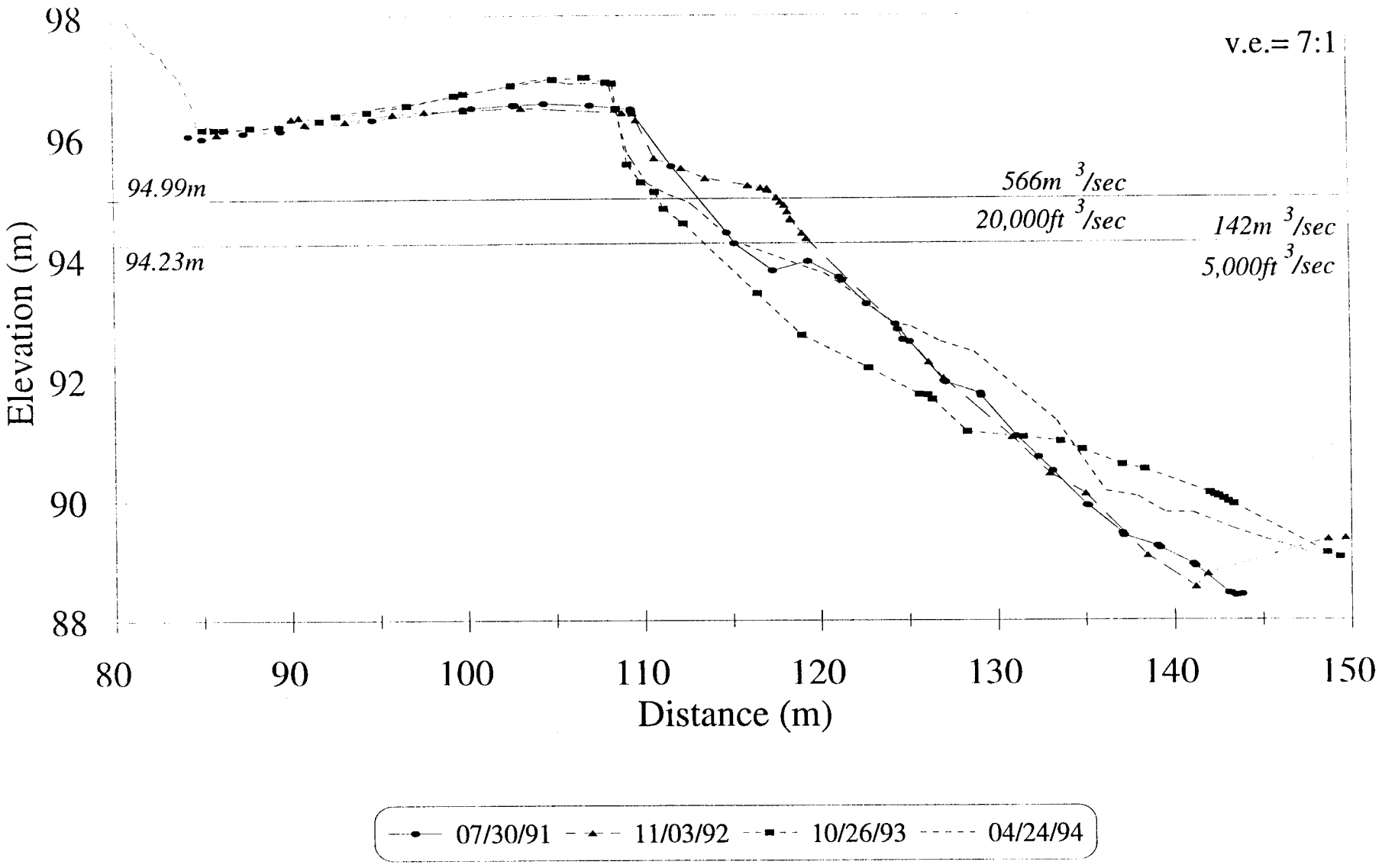


225 Mile

Cross-channel P4

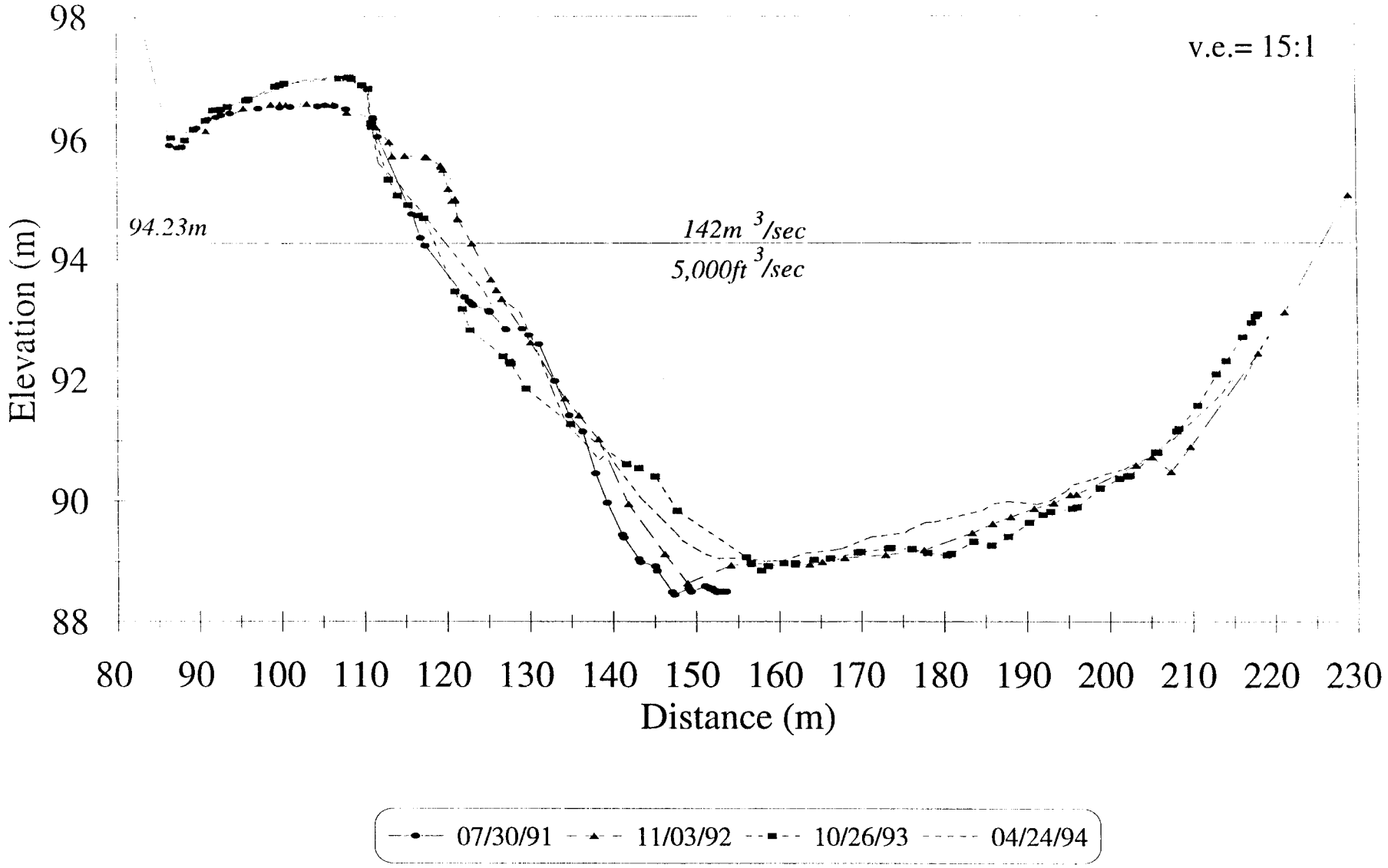


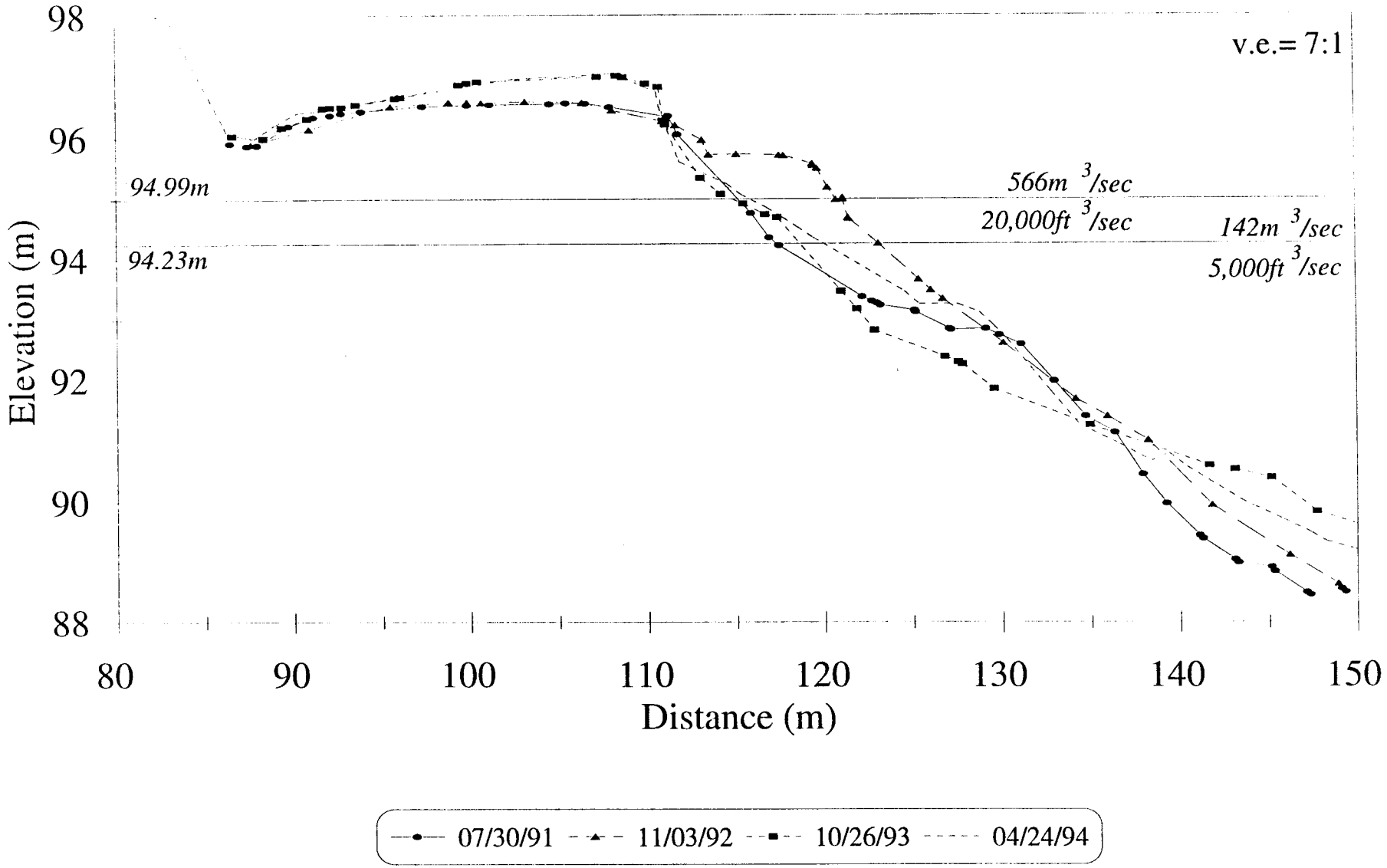
Near-shore P4



225 Mile

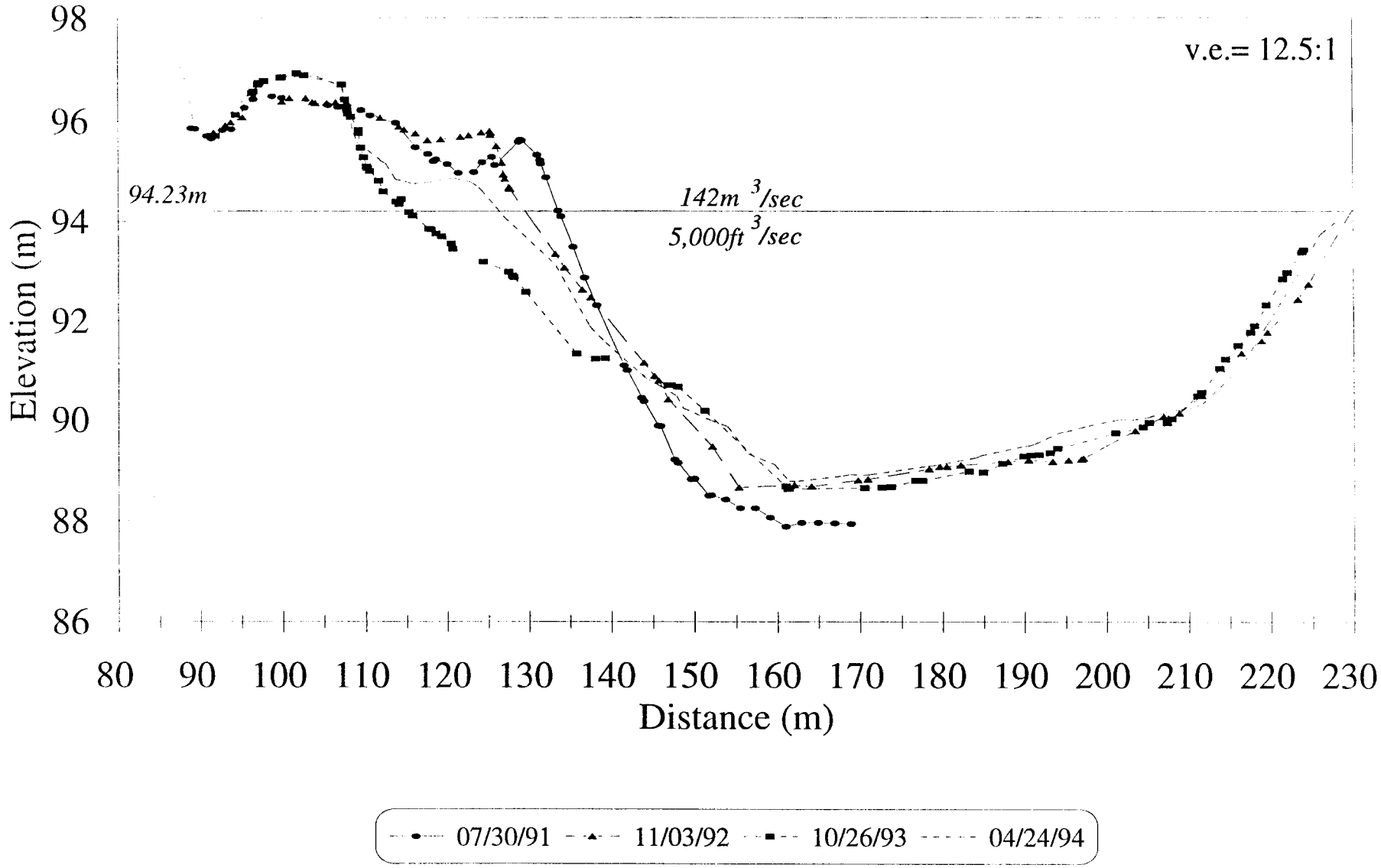
Cross-channel P5



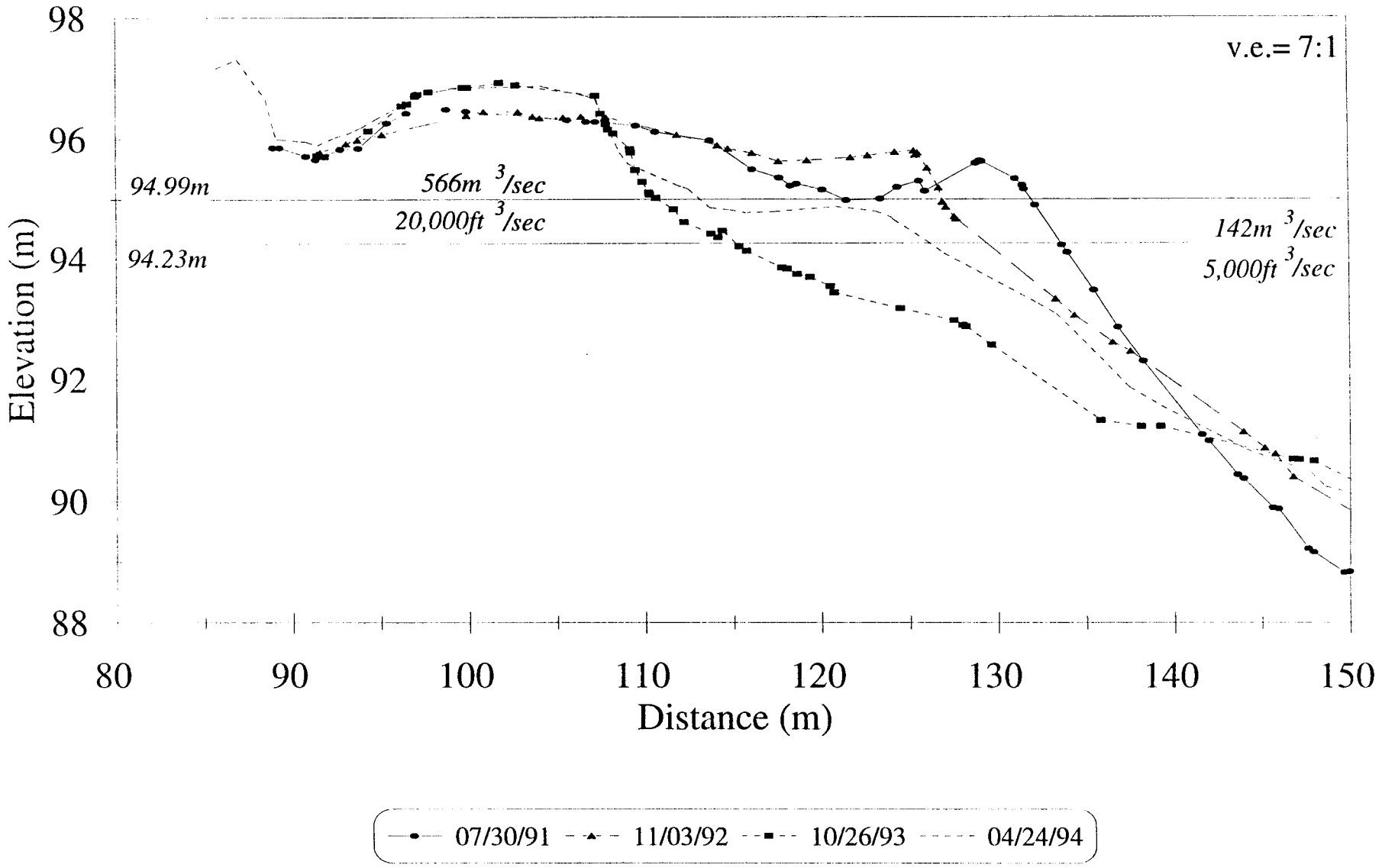

Near-shore P5
v.e.= 7:1
94.99m
94.23m
566m 3/sec
20,000ft 3/sec
142m 3/sec
5,000ft 3/sec
Elevation (m)
98
96
94
92
90
88
80
90
100
110
120
130
140
150
Distance (m)
07/30/91
11/03/92
10/26/93
04/24/94

225 Mile

Cross-channel P6

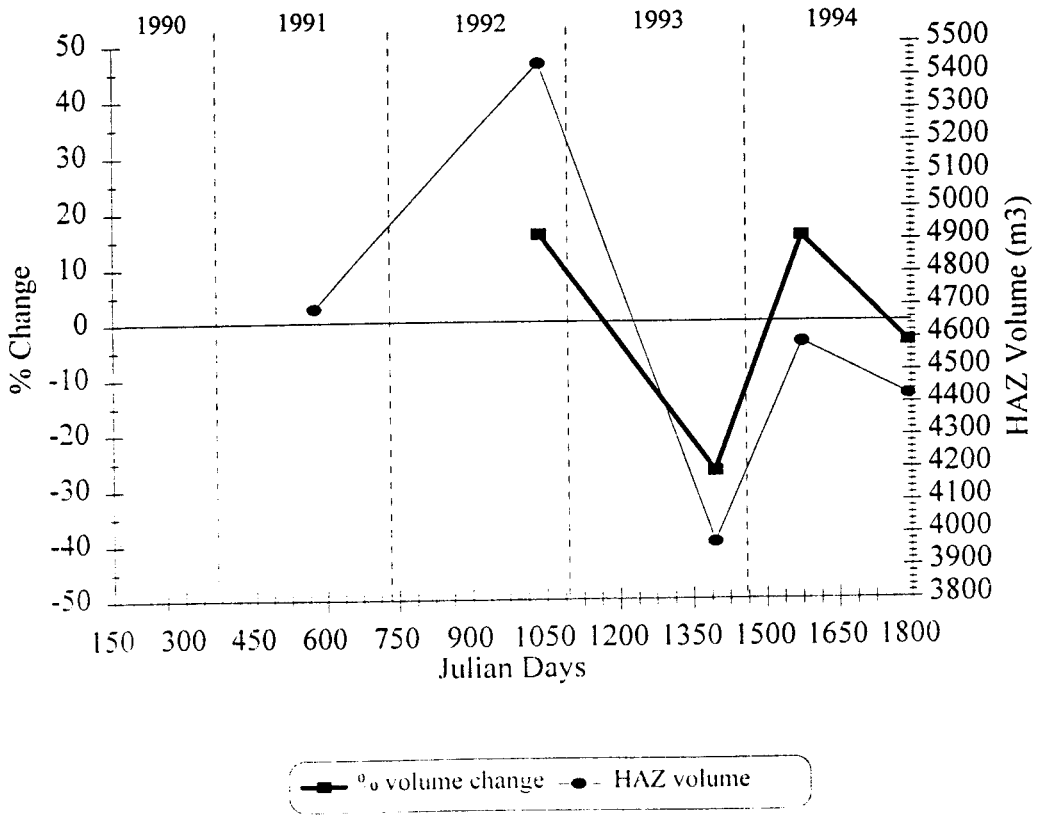


Near-shore P6



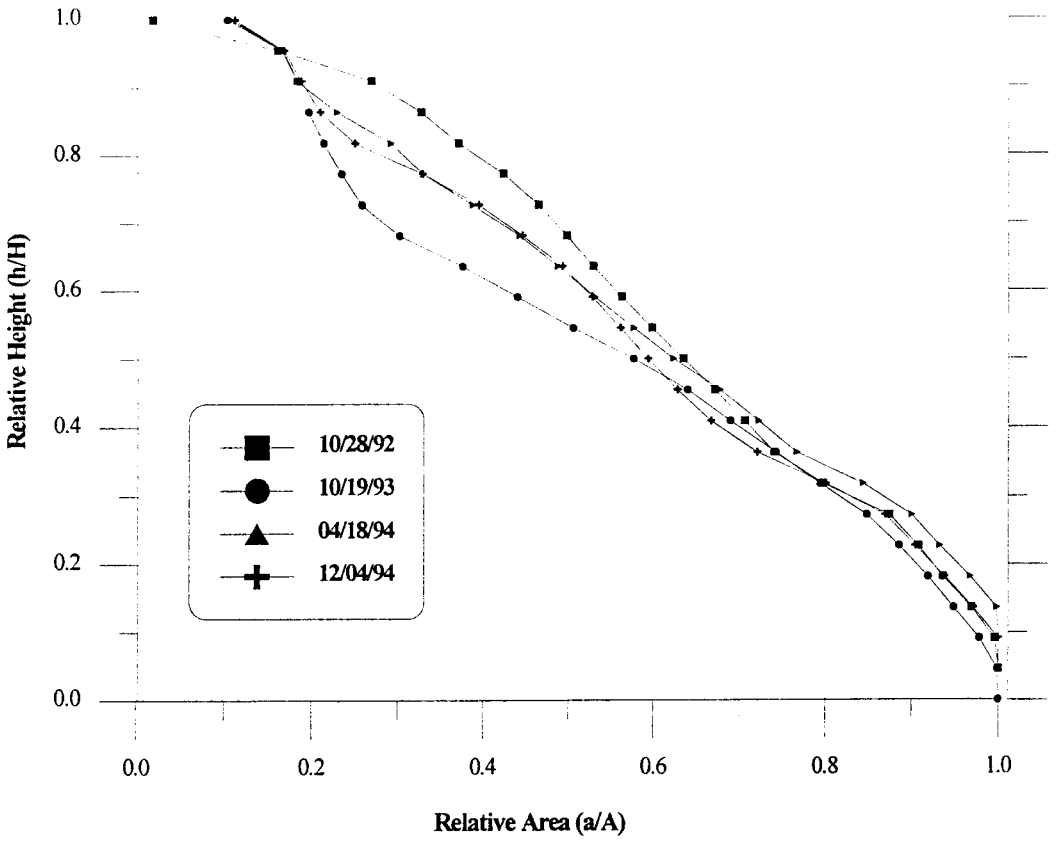
225 Mile

RUN ID	SURVEY DATE	FLOW EVALUATED	JULIAN DAYS	HAZ AREA	HAZ VOLUME	% VOL. AREA CH.	ABS. VOL CH.	% AREA CH.	% VOL CH.
A		NORM							
B		NORM							
C		G							
D		F							
E		NORM							
F		NORM							
G		E							
H		A							
I		8000 CFS							
J		NORM							
K		NORM							
L		11000 CFS							
M		C							
N		NORM							
O		B							
P		NORM							
Q		NORM							
R		D							
S		15000 CFS							
T		NORM							
U		G							
V	910729	F	576	2822	4695				
Y	921103	INT	1037	3286	5440	464	745	16.44	15.87
B33	931019	INT	1395	1860	3975	-1426	-1465	-43.40	-26.93
C33	940418	INT	1575	2646	4588	786	613	42.26	15.42
D33	941204	INT	1794	2713	4426	67	-162	2.53	-3.53

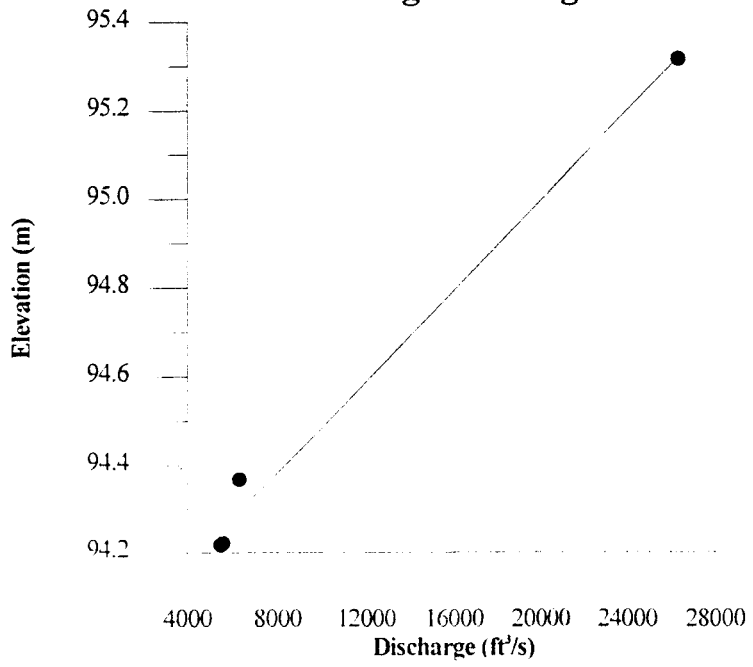
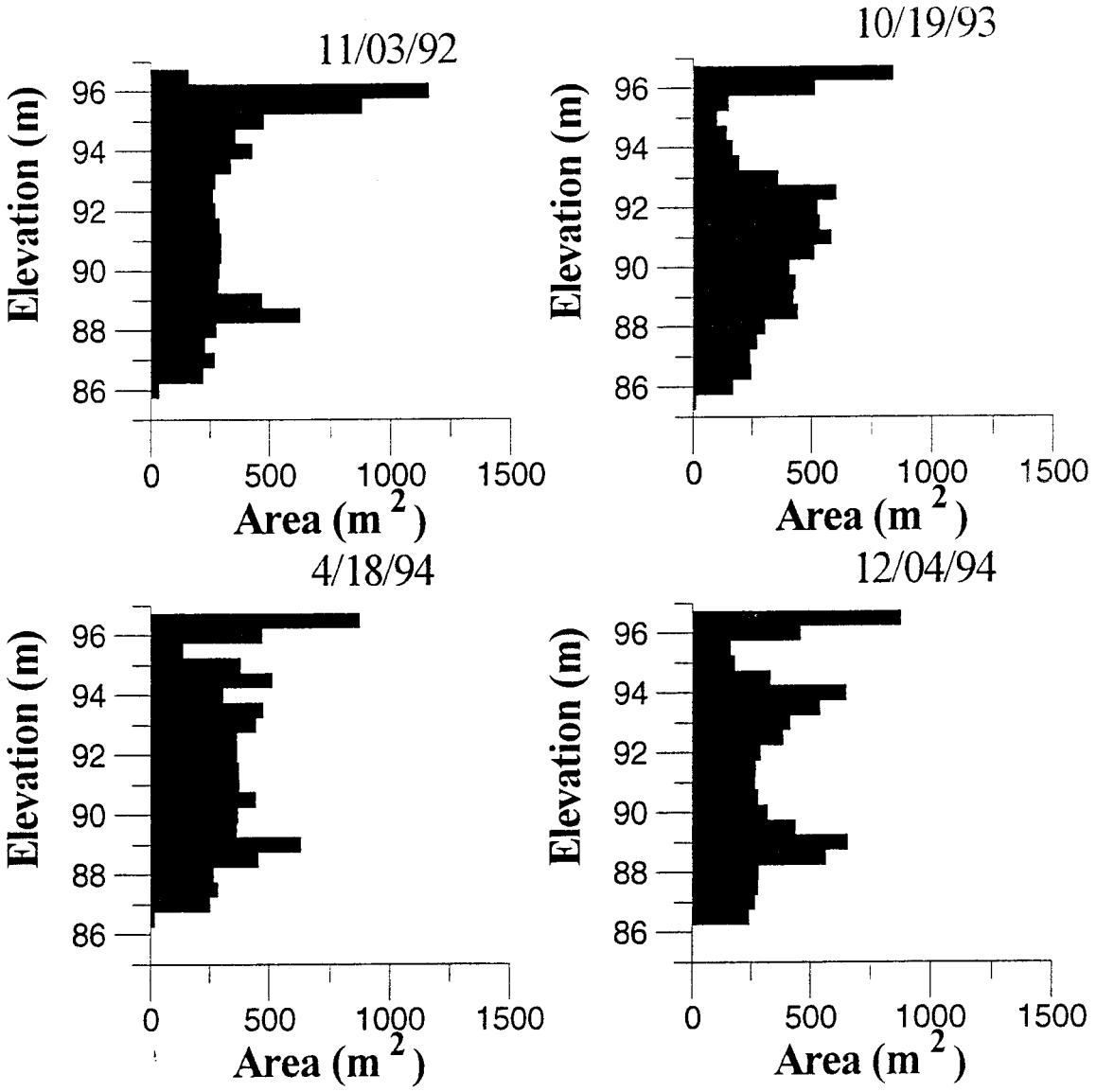


225 Mile

Hypsometric Curves



Stage Discharge



225 MILE
Area Distribution Histograms