

# 1998 Redwood Creek Estuary Annual Monitoring Report

Redwood National and State Parks  
Division of Resource Management and Science  
Fish and Wildlife Branch

This is a summary of Redwood National and State Parks Fish and Wildlife Branch monitoring activities in the Redwood Creek estuary for the calendar year 1998. The purpose of the study is to determine utilization of the estuary by fish, monitor estuary water and sand berm elevations, and document breaching incidents. This report serves as the annual report for the Division of Resource Management and Science and the U.S. Army Corps of Engineers (Corps). An annual report is specified by special condition seven of Corps permit No. 21881N. The permit authorizes breaching of the mouth of Redwood Creek. The eight special conditions of the permit are addressed in this report. A copy of the permit is in Appendix I.

## Study Location

The Redwood Creek estuary is located 2.5 miles west of Orick, California at the mouth of Redwood Creek at the Pacific Ocean (Figure 1). Redwood Creek is 108 km long and the basin is 720 km<sup>2</sup> in area. U.S. Army Corps of Engineers constructed 3.4 miles of flood control levees in 1968 on lower Redwood Creek, which bisect and terminate in the estuary. The estuary consists of the north and south sloughs, and the embayment. The south slough was the last oxbow of the river bypassed by the south levee.

## Methods

### Fish Monitoring

Population Estimates - The Peterson mark and recapture method (Youngs and Robson 1978) was used to estimate numbers of juvenile salmonid fish in the Redwood Creek embayment. Fish were seined with a 150-long, 15-foot wide, ¼ inch mesh beach seine net deployed off the bow of a 16-foot motor boat. A blue mark was applied to the upper or lower caudal fin or anal fin of captured fish using a Panjet needleless injector and Alcian Blue dye. Captured fish were marked the first two days, allowed to mix the third day, and seined on the fourth day to determine the ratio of marked to unmarked fish. Population estimates were rounded off to the nearest 10.

Growth Estimates - Fork length (mm) measurements were obtained from 200 each of chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*O. mykiss*), and weight (g) measurements were taken from 30 juveniles of each species. Measurements were done in conjunction with the population estimate fish marking. Other salmonid species, coastal cutthroat trout (*O. clarki*) and coho salmon (*O. kisutch*), though not as numerous as chinook or steelhead, are also measured.

### Water Quality Monitoring

Water temperature (°C) was measured in the Redwood Creek embayment. A HOBOTM temperature logger was located in the middle of the Redwood Creek channel between the ends of the north and

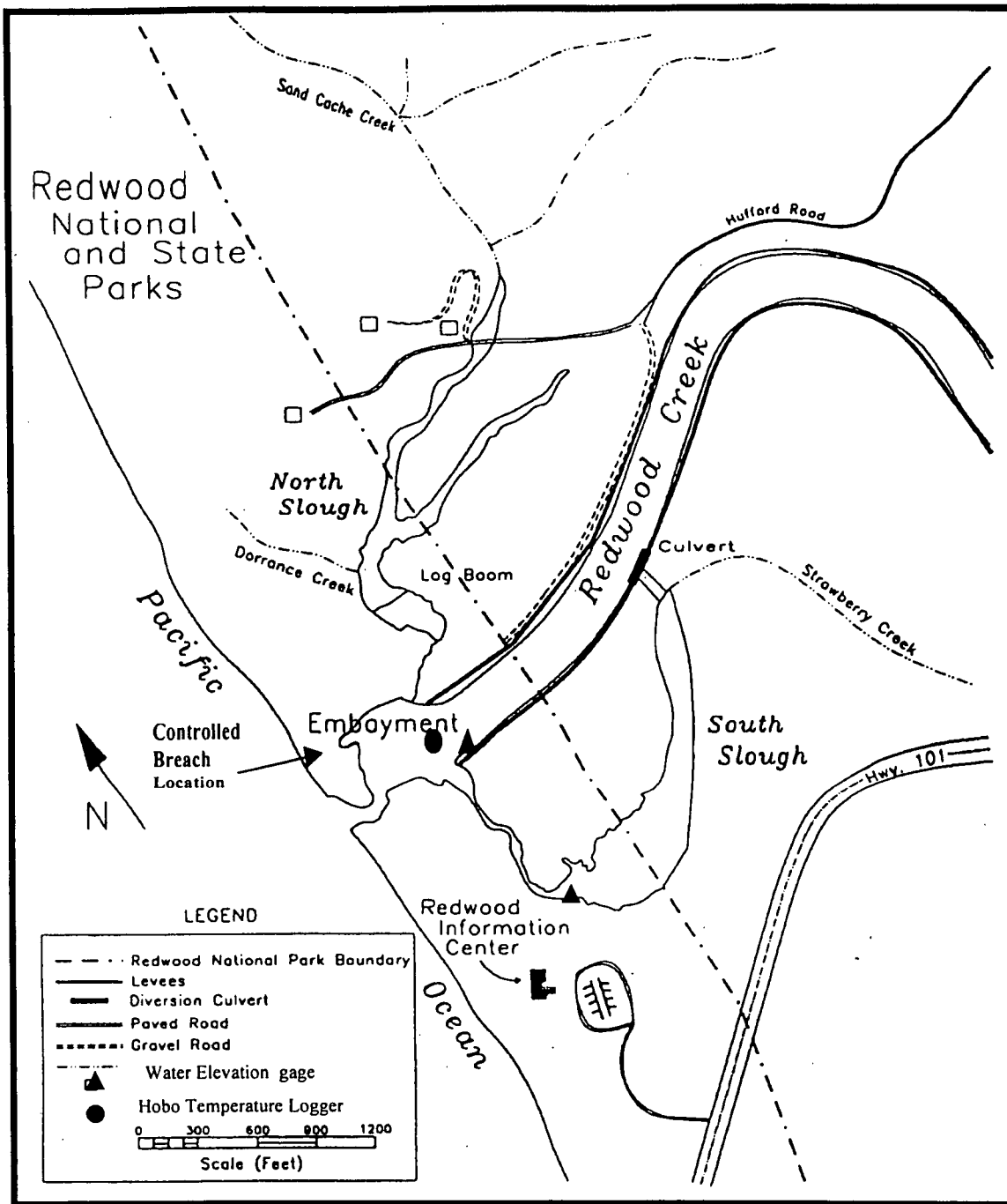


Figure 1. Map of the Redwood Creek Estuary, Humboldt County, California, including the embayment, north and south sloughs, and location of water elevation gages, temperature logger, and controlled breach.

south flood control levees at one foot or less from the bottom (Figure 1). It recorded water temperature every 48 minutes. Temperature monitoring is a special condition (# 8) of the Corps permit.

### **Tide and Stream Flow Data**

Tide Data: Calendar year 1998 tide data for the mouth of Redwood Creek was compiled from Crescent City Harbor, California tide data. It was corrected for the locality of the mouth of Redwood Creek [CC tide x 0.98] and transformed to feet Mean Sea Level (MSL) [tide - 3.65 = ft MSL].

Stream Flow Data: Hourly Redwood Creek flow data for calendar year 1998 was downloaded off the Department of Water Resources, Division of Flood Management website (<http://cdec.water.ca.gov>). The Orick gaging station (ORK) is located on Redwood Creek downstream of the confluence of Prairie Creek just north of the community of Orick. Maintaining daily records of water flows in Redwood Creek is special condition (# 3) of the Corps permit.

### **Estuary Water Levels**

South slough water elevations (feet MSL) were recorded at 30-minute intervals by a continuous recording gage using a pressure transducer and ENMOS logger. The gage site is located at the end of the Redwood Information Center boardwalk trail (Figure 1). A seasonal gage site was established on June 9 at the end of the south slough levee to measure the water elevation in the estuary embayment. The south levee gage had the capability to measure lower water elevations (to approximately 0 ft MSL) than the gage in the south slough. The low water level in the south slough is limited by the invert of south slough culvert gates and sand deposited in the south slough outlet channel. Water elevation monitoring is a special condition (# 3) of the Corps permit.

### **Estuary Cross Sections**

As a special condition of the Corps permit (# 6), permanent cross-sections of the estuary perpendicular to the flow were established through the main embayment. The northside cross section endpoints, located along the base of the hill, were monumented with 8 ft t-bar fence posts, or natural endpoints used such as large partially buried sea-stacks. Each cross section was shot at a bearing of 169° using a Sokkisha Set 4 Total Station. A wetsuited person holding a rod with prism took measurements in the embayment at breaks in slope. The permanent endpoints were surveyed and referenced to a BLM benchmark located at the park boundary fence separating the pasture from the parking area adjacent to the north levee.

### **Sand Berm Elevation Monitoring**

A special condition (#4) of the Corps permit specified a survey of sand berm elevations parallel to the shore, once per month from May to September, along the highest ridge of the sand dunes. The survey extended from a minimum of 100 feet north of the estuary to 100 feet south of the Redwood Information Center (RIC), approximately 3,000 feet. Surveys were conducted with a Sokkisha Set 4 Total Station and rod with prism. Measurements were taken at breaks in slope along the sand berm. The elevation of the surveys were referenced in the south to a permanent NOAA benchmark referred to as Melch 3 located west of RIC, to the end of the RIC west boardwalk, and in the north to the BLM benchmark, and the western most estuary cross-section endpoint, RM2 (a.k.a. E-5).

## **Corophium Monitoring**

A special condition (#8) of the Corps permit specified *Corophium* abundance be documented prior to and one week after a breaching event. Two measured transects in the embayment were snorkeled and *Corophium* presence or absence was noted and recorded along each transect.

## **Results**

### **Fish Monitoring**

Presence – During the summer and fall of 1998, four salmonid species were seined in the Redwood Creek embayment; chinook and coho salmon, and steelhead and coastal cutthroat trout. No half-pounder or adult sized steelhead were captured. Five other fish species were captured, and 15 bird species observed. A complete list of all fish and other species captured or observed in and around the Redwood Creek estuary is presented in Table 1. No tidewater gobies were found in the estuary (Anderson 1999).

Population Estimates -Three population estimates were conducted during the summer and fall of 1998 on the weeks of June 15, July 13, and September 14 (Table 2).

The initial chinook salmon estimate was the week of June 15. On the final day of the population estimate, no marked fish were recaptured. Only 342 chinook salmon juveniles were caught all week. Based on one recapture the second day of the estimate, the population estimate was 13,390, but the 95% confidence interval (CI) was poor, 237 to 39,410. On July 13, the estimate was 12,030, but again the 95% CI was poor, 331 to 28,470. Only 2 marked fish were recaptured on the final day, and 331 chinook captured all week. By September 14, the population had declined to 1,590 chinook, and the 95% CI was tight, 1,370 to 1,810.

The initial steelhead trout estimate of the week of June 15 was 6,510 (95% CI 5,380 to 7,630). The population increased to 7,990 (95% CI 5,600 to 9,990) on July 13, and decreased to 2,200 (95% CI 201 to 4,250) on September 14.

Thirty-three coho salmon smolts were captured the first sample week of June 15 and one each on the remaining sample weeks in July and September, for a total of 35 fish. Two hundred and thirty coho were estimated to be in the embayment on June 15. A total of 41 coastal cutthroat trout were captured, 30 in June, 16 in July, and 5 in September. A cutthroat population estimate was possible on June 15, 56 individuals, and on September 14, 9 individuals.

Growth Estimates - Three growth estimates were done in conjunction with the population estimates during the weeks of June 15, July 13, and September 14, 1998 (Table 3). Chinook salmon mean fork length increased from 80 to 107 mm, an increase of 27 mm, between the June and September sample dates. Mean weight rose from 6.3 to 13.6 g, and increase of 7.3g. Steelhead trout mean fork length decreased from 131 to 125 mm, a 6 mm decrease between June and September. Mean weight decreased from 24.6 to 26.6 g, a decrease of 2.0 g.

Table 1. List of salmonid and non-salmonid fish and aquatic species seined; and birds, mammals, and sensitive plants observed in the Redwood Creek estuary, Redwood National and State Parks, Humboldt County, California during the summer/fall 1998 sampling.

	1998 Date (Week of)		
	June 15	July 13	September 14
<b>Salmonid Fish</b>			
Coastal Cutthroat Trout	X	X	X
Steelhead Trout	X	X	X
Chinook Salmon	X	X	X
Coho Salmon	X	X	X
<b>Non-Salmonid Fish</b>			
Three Spine Stickleback	X		
Staghorn Sculpin		X	X
Prickly Sculpin	X	X	X
Shiner Surfperch		X	
Starry Flounder	X	X	
<b>Sensitive Plants</b>			
Pink Sand Verbena		X	
<b>Birds</b>			
Brown Pelican	X	X	X
Double Crested Cormorant	X	X	
Turkey Vulture	X	X	
Osprey	X		
American Widgeon			X
Aleutian Goose			X
Killdeer	X		
Gulls	X	X	X
Caspian Tern	X	X	X
Violet Green Swallow	X	X	
Barn Swallow		X	
Corvids (Crows and Ravens)	X	X	
Surf Scoter	X		
Merganser		X	
<b>Mammals</b>			
Harbor Seal	X		

Table 2. Population estimates and 95 percent confidence intervals for chinook salmon, steelhead trout, coastal cutthroat trout, and coho salmon seined in the Redwood Creek estuary embayment, Humboldt County, California. Mouth of creek denotes if Redwood Creek mouth was open or closed to the Pacific Ocean.

DATE (1998)	Mouth of Creek (Open or Closed)	Chinook Salmon		Steelhead Trout	
		Population Estimate	95% Confidence Interval	Population Estimate	95% Confidence Interval
6/15,16,18	OPEN	342 <sup>a c</sup>	----	6,510	5,380 – 7,630
7/13,14,16	OPEN	12,030	331 <sup>b</sup> – 28,470	7,990	5,600 – 9,990
9/14,15,17	CLOSED	1,590	1,370 – 1,810	2,200 <sup>b</sup>	201 <sup>b</sup> – 4,250
		Cutthroat Trout		Coho Salmon	
6/15,16,18	OPEN	56	30 <sup>b</sup> – 90	230	33 <sup>b</sup> – 650
7/13,14,16	OPEN	16 <sup>a</sup>	---	1 <sup>a</sup>	---
9/14,15,17	CLOSED	9	5 <sup>b</sup> – 21	1 <sup>a</sup>	---
<p>a. Actual count of fish captured in seine net hauls. No marked fish were recaptured.</p> <p>b. Actual minimum count, calculated 95% lower interval was below what was actually caught</p> <p>c. Based on one recapture the second day, and using only two days of data, a population estimate for chinook can be estimated at 13,390 and 95% CI of 237<sup>b</sup> – 39,410</p>					

Table 3. Mean fork length (mm) and weight (g), standard deviation, range, and numbers sampled of juvenile chinook and coho salmon and steelhead and coastal cutthroat trout seined in the Redwood Creek estuary embayment, Humboldt County, California, during summer and fall sample dates of 1998. Mouth denotes if Redwood Creek mouth was open or closed to the ocean.

Redwood Creek Estuary Summer/Fall 1998							
1998 DATE	MOUTH	Mean Fork Length (mm) (No. Sampled)	Std. Dev. (mm)	Range (mm)	Mean Weight (g) (No. Sampled)	Std Dev. (g)	Range (g)
<b>CHINOOK SALMON</b>							
6/15,16	OPEN	80 (200)	7	53 – 99	6.3 (30)	1.5	3.9 – 10.0
7/13,14	OPEN	83 (200)	6	67 – 102	6.6 (30)	1.3	4.1 – 10.6
9/14,15	CLOSED	107 (234)	5	93 – 120	13.6 (30)	2.2	9.1 – 18.1
<b>COHO SALMON</b>							
6/15,16,18	OPEN	109 (32)	7	90 – 123	---	---	---
7/14	OPEN	125 (1)	---	---	---	---	---
9/14	CLOSED	126 (1)	---	---	---	---	---
<b>STEELHEAD TROUT</b>							
6/15	OPEN	131 (205)	16	99 – 185	24.6 (30)	9.8	10.1 – 60.2
7/13	OPEN	129 (203)	15	88 – 175	24.0 (30)	8.8	5.9 – 44.3
9/14,15,17	CLOSED	125 (201)	32	77 – 207	26.6 (30)	20.7	4.9 – 83.1
<b>CUTTHROAT TROUT</b>							
6/15,16,18	OPEN	224 (30)	72	115 – 380	---	---	---
7/13,14,16	OPEN	228 (16)	40	161 – 327	---	---	---
9/14,15,17	CLOSED	236 (5)	13	222 – 257	---	---	---

Coho salmon smolt mean fork length the week of June 15 was 109 mm (n = 32). The two singular coho caught in July and September were 125 mm and 126 mm, respectively. Cutthroat trout mean fork length increased from 224 to 228 to 236 mm from June to July to September. Throughout the summer and fall, cutthroat trout fork length ranged from 115 to 380 mm.

### **Water Quality Monitoring**

In 1998, water temperature (°C) was the only water quality parameter monitored in the Redwood Creek estuary. The HOBO temperature logger recorded water temperature every 48 minutes from July 20 through September 18, 1998 (Figure 2). The maximum and minimum water temperature were 20.2 and 13.7 °C. The average water temperature for the period of 60 days was 17.9°C. Though a logger was placed in the estuary on May 28, a laptop computer failure prevented the retrieval of the early data stored on the hard disk. It will be downloaded later and incorporated in a later report.

### **Tide and Stream Flow**

Tides at the Mouth of Redwood Creek - The maximum and minimum calculated tide at the mouth was 4.9 ft MSL and -5.6 ft MSL, respectively, a range of 10.5 feet. Tidal data is included in Figure 3 and 4).

Stream Flow: Calendar year 1998 stream flow data, January 1 through December 31, is presented in Appendix II. The maximum flow was 35,495 cfs on November 21, 1998. The gage was only able to measure a minimum flow of 16.5 cfs. Summer flow declined below 16.5 cfs. No streamflow events occurred between June 16 and October 8.

### **Estuary Water Levels**

South Slough and South Levee Water Level Gaging - South slough water elevations (feet MSL) were recorded for the period January 1 to December 31, 1998, excluding February 5 through 24, March 3 through 18, and April 1 through 7 (Figure 3). A bad chip caused the latter two data lapses.

The south levee gage measured embayment water elevations from June 17 to November 23, 1998 (Figure 4). Gaging was stopped after the November 21 35,500 cfs flow event to retrieve the ENMOS recording equipment before high flows, ocean waves, and driftwood being thrown on the south levee would damage it.

The mouth of the creek partially closed on July 23 at midnight at approximately 4 ft MSL (Figure 5). It occurred at the peak of high tide, the wave overwash most likely filling in more of the small channel with sand. Tidal influence ended in the estuary, except from wave overwash over the berm.

During the August 3 berm survey little flow was entering the ocean. On August 18, water was observed flowing slowly in the channel, but filtering into the sand at the end and not reaching the ocean at the surface.

After the July 23 partial closure, the water level quickly rose to 5 ft MSL and maintained that elevation for 14 days, wherein the level rose to 6 ft MSL over 2 days. It maintained that level until September 14 when it started to decline and hover around 5.5 ft MSL (Figure 4).



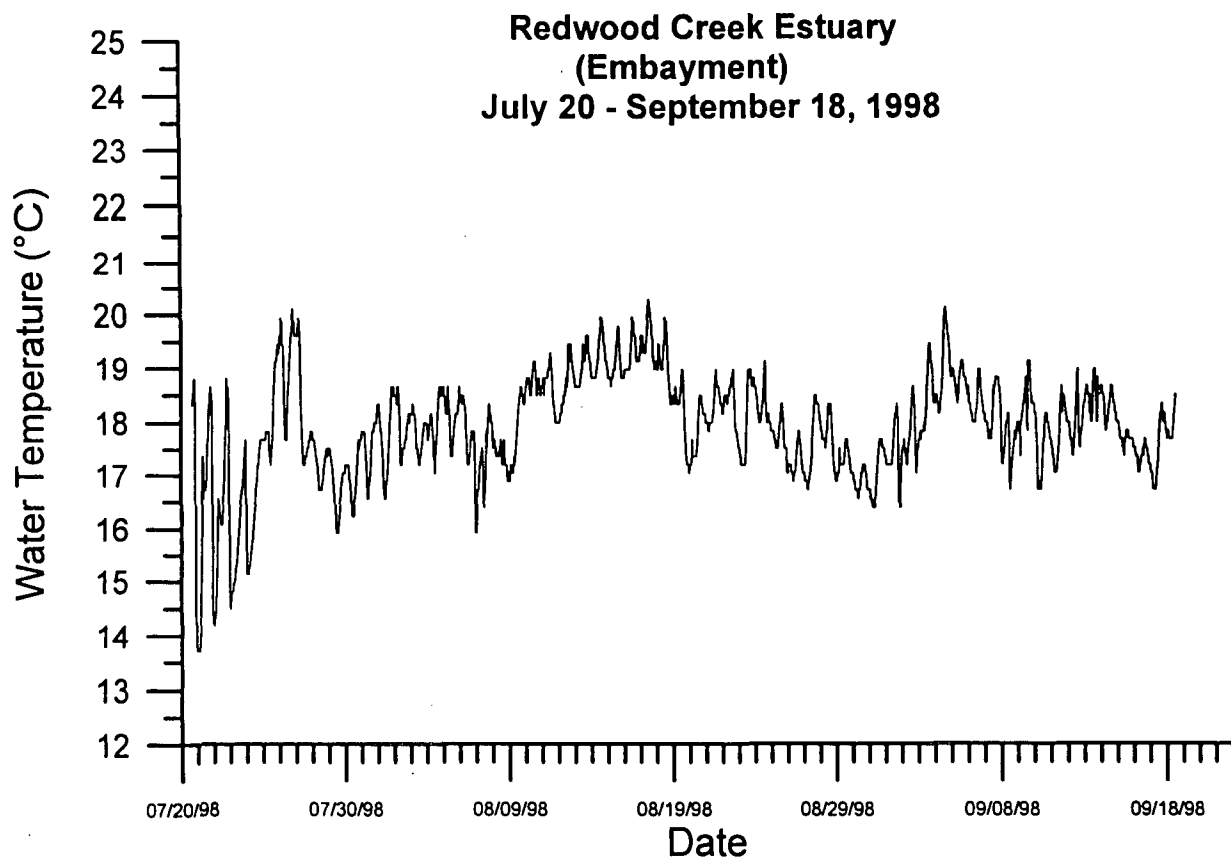


Figure 2. Redwood Creek estuary water temperatures (°C) measured by a HOBO temperature logger located in the middle of the Redwood Creek channel between the ends of the north and south flood control levees in the embayment. The temperature logger, located one foot from the bottom, recorded water temperature every 48 minutes from July 20 through September 18, 1998.

## South Slough Water Level Record and Tide 01/01/98 - 12/31/98

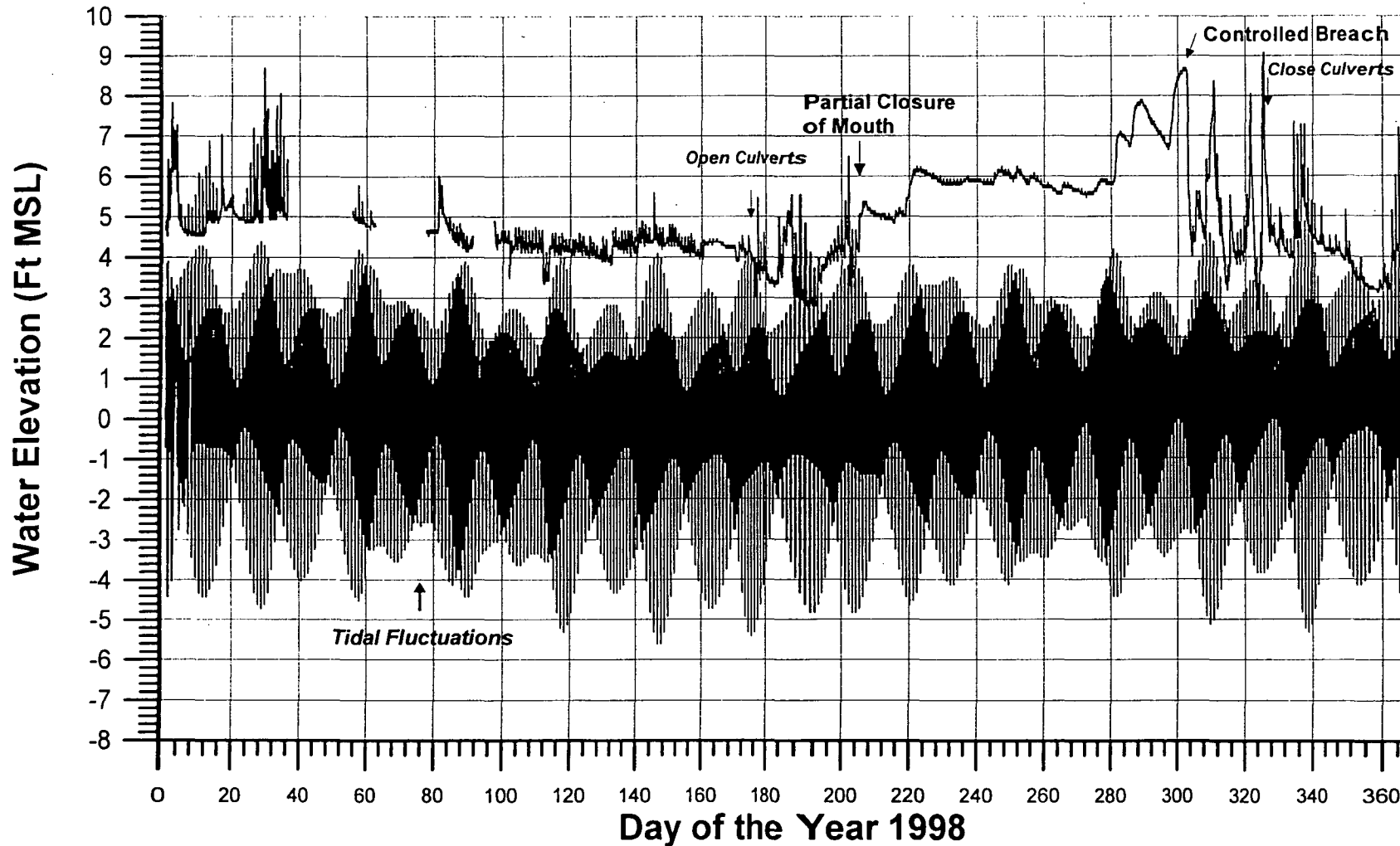


Figure 3. South slough water elevations (feet Mean Sea Level [MSL]) of the Redwood Creek estuary, Humboldt County for the period January 1 to December 31, 1998, excluding February 5 through 24, March 3 through 18, and April 1 through 7, 1998. Estimated tidal elevations are corrected for the coastal locality at the mouth of Redwood Creek and adjusted to feet MSL. A controlled breach occurred on October 29, 1998.

**Embayment Water Level  
Tides at Mouth of Redwood Creek  
06/17/98 - 11/23/98**

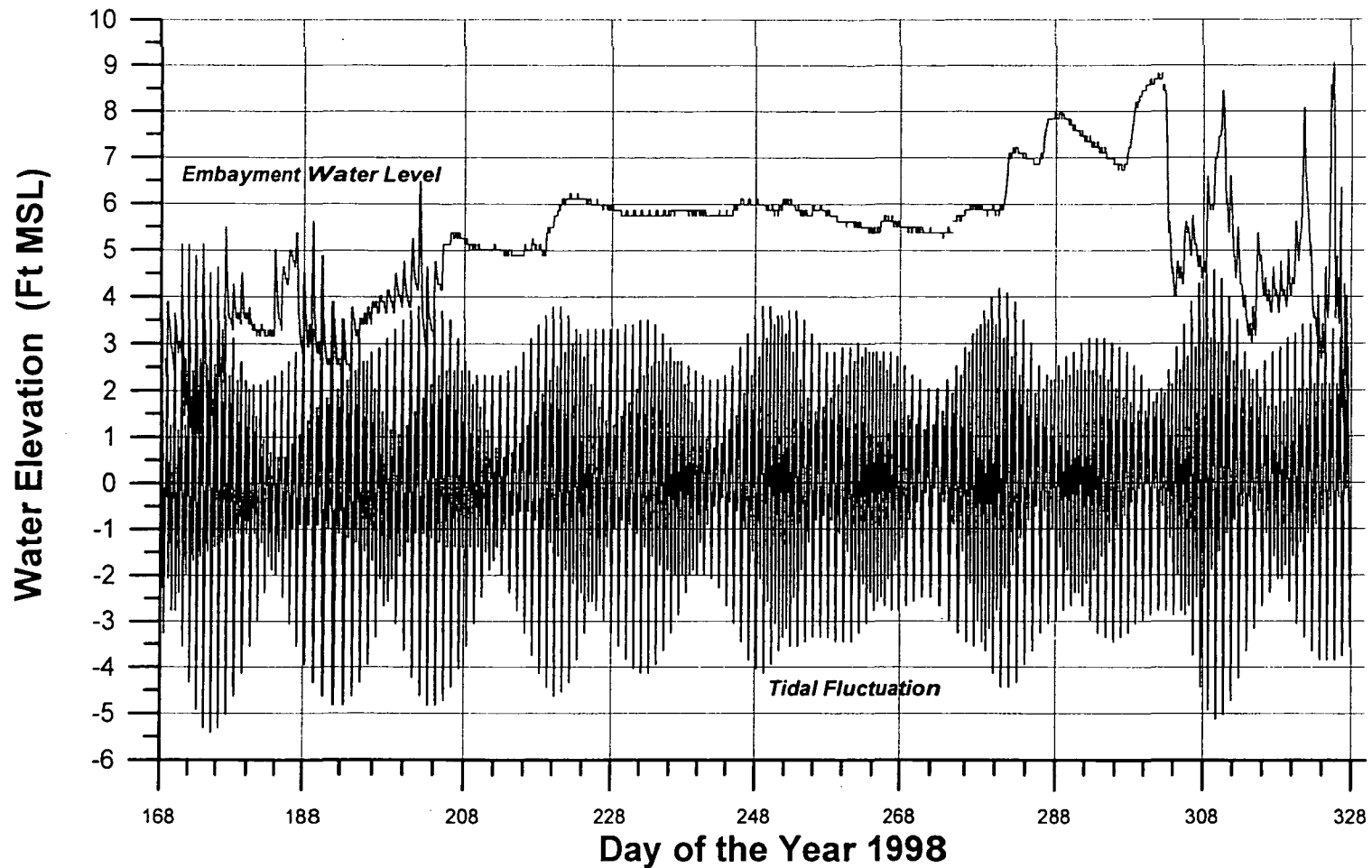


Figure 4. Embayment water elevations (feet Mean Sea Level [MSL]) of the Redwood Creek estuary, Humboldt County for the period the seasonal gage was in operation, June 12 through November 23, 1998. Estimated tidal elevations are corrected for the coastal locality at the mouth of Redwood Creek and adjusted to feet MSL. A controlled breach occurred on October 29, 1998.

Embayment Water Level  
Tides at Mouth of Redwood Creek  
07/14/98 - 08/03/98

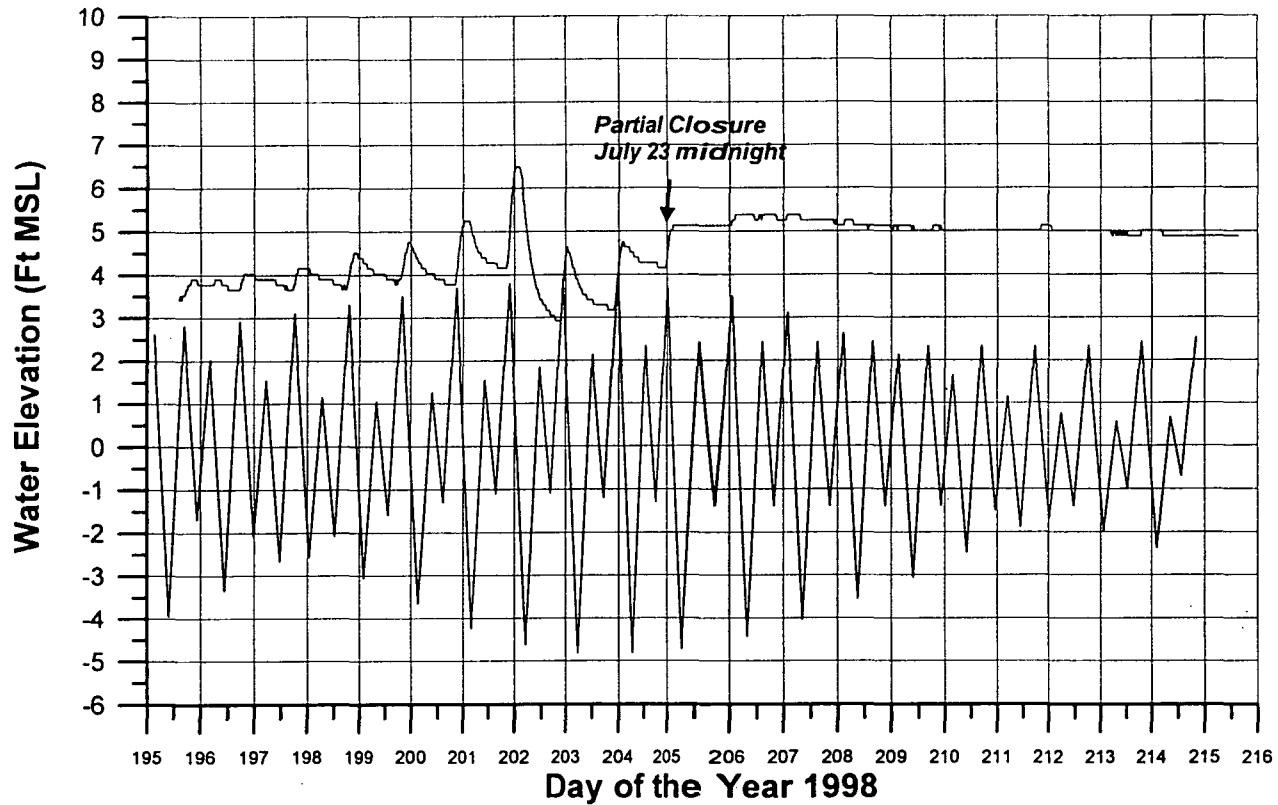


Figure 5. Partial closure of the channel of Redwood Creek estuary on July 23, 1998 at midnight.

Beginning on October 8, and responding to two small peak flow events of 245 cfs and 340 cfs (Figures 6), the water level peaked at 7.96 ft MSL on October 14, but again decreased to 6.73 ft MSL on October 23, 1998 (Figure 7). A peak flow event of 430 cfs on October 25 caused the water level to increase to 8.8 ft MSL on October 29 at which time a controlled breach was completed.

Overall, the Redwood Creek was closed for 97.4 days, from July 23 until it was control breached on October 29, 1998.

#### Controlled Breaching Activities and Estuary Response

Section 7 consultation with the National Marine Fisheries Service was completed and a biological opinion and conference opinion, *Redwood Creek Estuary Management Activities: Sand Bar Breaching at the Mouth of Redwood Creek*, issued to Redwood National and State Parks on June 16, 1998. Once received, breaching activities were permitted. Completing section 7 consultation was a special condition (# 1) of the Corps permit.

Based on recent storms, their flows increasing estuary water levels, weather reports and satellite photos predicting storms, and the height of the berm, a decision was made to breach the berm on October 27. The decision to excavate a channel at the north side of the embayment between the two sea stacks was based on channel observations made in previous winters. The channel was observed to migrate to the north and lengthen, thus preventing a catastrophic drop in water level. Also, the two rocks and underlying rock substrate acted as a hydraulic invert and prevented channel downcutting.

On October 27, 1998, Redwood National Park attempted a controlled breach of the sand berm at the north side of the embayment. A special condition (#2) of the Corps permit specified that breaching could not occur until the embayment water level reached 8.0 ft National Geodetic Vertical Datum (NGVD). The south slough gage read 8.48 ft MSL at 0910 that morning. (The difference between NGVD and MSL is 0.05 ft.) A 16 man California Department of Forestry Alder Camp conservation crew and 4 RNP personnel dug using shovels, a channel approximately 1 m wide and 48 m long. The excavated channel, approximately 4 feet deep at the berm crest, began between the two seastack rocks and proceeded in a northerly direction to the ocean. Digging began at 0950 and the channel plug was removed at 1327 to start the breach. However, because it was opened prior to the 1528 high tide, and not after, as it should have been, incoming ocean waves transported sand into the channel and closed the channel at 1400. Flow was again established at 1640 but it must have closed again because the next morning water only flowed two-thirds of the way down the channel before it percolated into the aggradated channel.

On October 29, 1998, a second controlled breaching attempt was made and was successful. The south slough gage read 8.7 ft MSL at 0800. Based on hand level/stadia rod measurements, the difference between the lowest berm crest depression and the water elevation of the embayment was 0.6 ft, a berm height of 9.3 ft. At 0837, Tom Dore started widening and deepening the existing hand-dug channel, particularly the lower portion of the channel, with a John Deere 410C 4X4 backhoe with front bucket. At 0950, the plug in the middle was removed and water flowed into the ocean. Low tide was at 1228, and high tide was not until 1801. Conditions at the time of both breaches are

**Redwood Creek Flow at Orick (ORK)  
10/07/98 - 11/25/98**

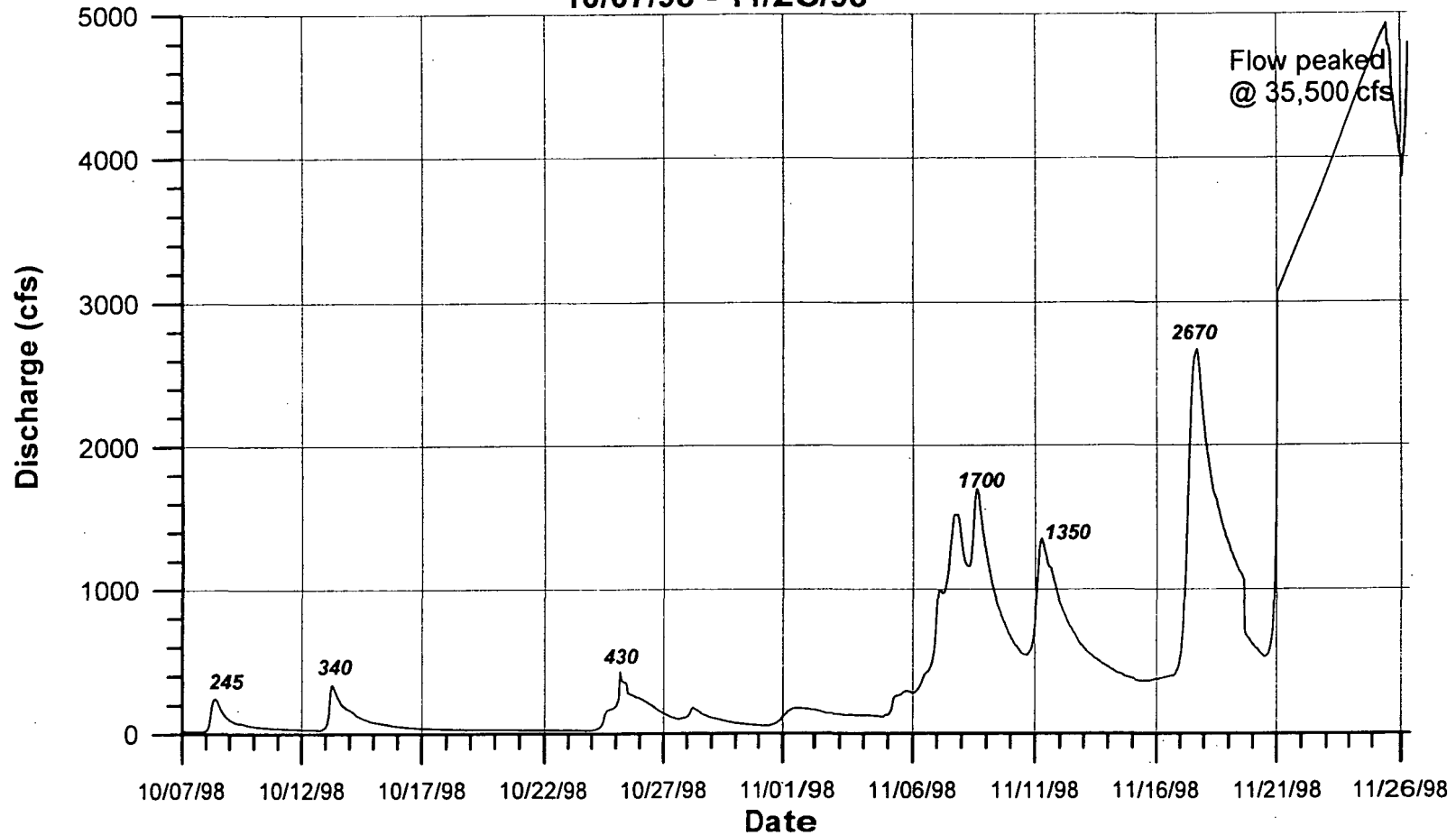


Figure 6. Redwood Creek flow (cfs) at Orick (ORK) stream flow gage for the period October 7 to November 25, 1998. Data is clipped at 5,000 cfs. Peak flow on November 21, was 35,500 cfs.

### Embayment Water Level and Tides at Mouth of Redwood Creek 10/08/98 - 11/23/98

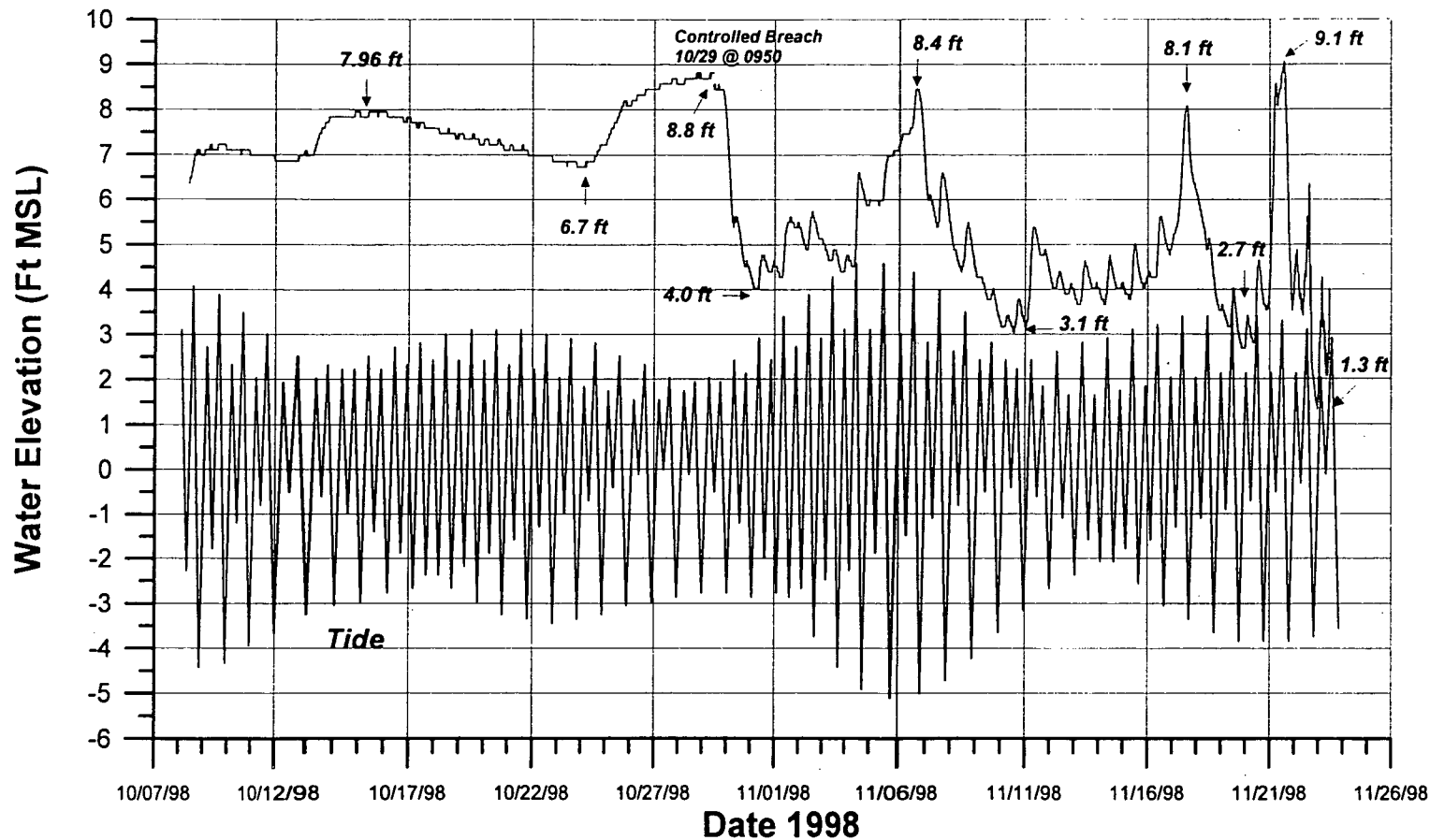


Figure 7. Redwood Creek embayment water elevations and tides at the mouth of Redwood Creek in feet Mean Sea Level (MSL) before and after the controlled breach on October 29, 1998.

presented in Table 4. Within one hour, flow in the excavated channel was estimated to be 5 cfs and by late afternoon, flow was 90 cfs. Throughout the day, increasing flow and erosion continued to widen and deepen the channel. The right channel bank and mouth migrated up the beach to the north.

Table 4. High and low tides, tide and embayment water level, and flow at time of attempted October 27 breach and successful October 29, 1998 breach.

Breach Date and Time	Tide (ft MSL)			Tide at Breach (ft MSL)	Embayment Water Level (ft MSL)	Flow (cfs)
	Low	High	Low			
10/27/98 @ 1327	0.0 @ 0953	2.0 @ 1528	-2.9 @ 2245	1.5 @ 1330	8.69 @ 1319	102 @ 1300
	High	Low	High			
10/29/98 0950	2.0 @ 0648	-0.5 @ 1228	1.9 @ 1801	0.5 @ 1000	8.82 @ 0948	90 @ 1000

After the breach, the water level of the embayment decreased to 4.0 ft MSL on October 31, a decrease of 4.8 ft over 1.7 days (Figure 7). Based on embayment volume estimations, a 61% loss in volume (2,240,000 ft<sup>3</sup>) occurred. On November 6, the water level peaked at 8.4 ft, appearing to close briefly at the peak of a series of high tides. However a bimodal storm event peaking at 1,700 cfs naturally opened the mouth and the water level fell to 3.1 ft over 3.9 days.

On November 17, the water level peaked at 8.1 ft. Given the amount of rain that had fallen previously, I was surprised at the height of the estuary and went out to the mouth to observe what was happening. The south slough gage read 7.86 ft at 1508. There were two channels present. The older longer low gradient channel that extended to the north was being de-watered as a new shorter but smaller channel adjacent to the sea stacks was deepening and widening as more and more water flowed into it. Over the course of an hour, as flow increased in the new channel, it deepened until its channel bottom was lower than the old channel. The old channel was de-watered except for a few small pools. A stranded fish, most likely a salmonid about 1.5 ft in length, was observed in the old channel flopping on the bank and attracting the attention of gulls and crows. It could not be rescued because high flow prevented crossing the new channel. At 1608, the south slough gage read 7.3 ft, a decrease of 0.56 ft in one hour. The water level fell to 2.7 ft over 2.2 days, a decrease of 5.4 ft.

On November 21 the estuary peaked at 9.1 ft as a result of the storm flows that peaked at 35,500 cfs. The following day, the water level decreased to 1.3 ft, a drop of 7.7 ft over 1.4 days. The channel was no longer to the north, but located south opposite the levees. Flow was going straight out to the ocean.



### Stranded Fish Survey

On November 2, four days after the controlled breach, four RNSP biologists conducted a stranded fish survey. The private pasture adjacent to the south slough, Zuber's field, was searched for stranded fish. Four sumps remained, no greater than 1 ft deep, filled with manure tainted water and covered with a iridescent sheen. They had no fish in them. The water quality in the sumps was very poor. One dead eviscerated grebe was found in the field.

On the south side of the embayment, a small isolated pond about 40 ft in diameter and 3.5 to 4 ft deep was seined with a 10' long 1/8" mesh beach seine. Three spined stickleback and juvenile staghorn sculpin were captured. A 5" long salmonid was seen swimming along the surface but could not be captured. Subsurface flow was entering into the pool at the embayment side lessening the chances of the pool drying up. The south slough was still connected by its outlet channel to the embayment.

### South Slough Culvert Gates

The culvert gates were opened to increase circulation between the south slough and the embayment after the last storms of spring. The three south slough culvert gates were cracked open several inches on June 18 at 1530 to attenuate any change in water level. They were completely opened on June 25 at 0900. The water that entered the embayment from the south slough was very turbid. The gates were closed on November 23, 1998 to prevent sedimentation in the slough.

### *Corophium* Survey

Two transects were qualitatively snorkel surveyed for *Corophium* abundance before the breach on October 26 and a week later on November 5, 1998.

The first transect, 100 m in length, was the entire river channel between the ends of the north and south levees. The entire transect substrate was covered with billowy algae about a foot high. When the algae was fanned away, only silt covered substrate was observed, no tubes. At 56 m, *Corophium* tubes were seen. A few tubes were seen in the algae. The top of the water column was turbid. On November 5, at 86.5 m a sandy spot was seen, but algae still covered the substrate along the transect. A saltwater layer covering the bottom of the channel obstructed diver vision. Algae samples brought to the surface for inspection had a few *Corophium* tubes. Except for the existence of a saltwater lens that entered the estuary after the breach, the transect was the same as before. Flow, a result of the breach, had not disturbed the substrate or algae where *Corophium* lived.

The second transect, 63.4 m in length, was located on the northwest side of the embayment. It started at a partially submerged boulder and extended west to the sand berm separating the embayment from the ocean. It was in the area upstream of where the excavated channel would be dug for the controlled breach. Starting at the rock, the first 10.1 m had no sign of *Corophium*. In the next 31.2 m, 49% of the transect, *Corophium* tubes were numerous. The last 22.1 m to the water's edge at the berm was clean sand deposited by waves washing over the berm and not colonized. Where the *Corophium* tubes were seen, the substrate was not covered by billowy algae, but a thin "crust" of algae. The substrate was predominately sand, not silt. On November 5, 16.2 m (26%) of the transect was out of the water, 1.5 m adjacent to the rock and 14.7 m of the uncolonized berm

deposited sand. In the other 47.2 m, *Corophium* could not be found. The original substrate was disturbed and covered with sediment waves from a sand delta that had formed at the upstream end of the excavated channel and extended into the embayment. Ocean waves traveling up the channel at high tides deposited the delta and caused the sediment waves.

### **Estuary Cross Sections**

Five permanent parallel cross sections perpendicular to the flow of the embayment were surveyed on June 24 and June 29, 1998. Starting at the ends of the levees with E-1 and ending to the west with E-5 at the sea stack adjacent to the berm, they extended through the embayment to the sand dunes to the south. Estuary cross sections are presented in Appendix III. They will be surveyed annually as specified by the Corps permit. The lowest elevation (ft MSL) at E-1 was -1.5 ft, at E-2 it was -1.7 ft, at E-3 it was -1.9 ft, at E-4 it was -2.1, and at E-5 it was -4.3 ft.

Also calculated for the embayment only (excluding the north and south sloughs and the area of the embayment/channel east of the ends of the levees) is the embayment volume (ft<sup>3</sup>) and wetted width of the cross sections for varying water elevations (Appendix IV). The embayment volume ranged from 53,794 ft<sup>3</sup> at -1 ft MSL to 10,441,569 ft<sup>3</sup> at 11 ft MSL.

### **Sand Berm Elevation Monitoring**

The longitudinal profile of sand berm parallel to the ocean shore and separating the estuary from the ocean was surveyed five times during the summer and fall of 1998, on May 27, June 24, August 3, August 26, and September 21. The permit specified monthly surveys. A late July survey was attempted but fog prevented surveying the long distances. The survey was scheduled the following week, the first week of August. The longitudinal surveys, profiles 1 through 5, are presented in Appendix V. Initially, the winter storm berm was surveyed and is denoted as the high berm. Later in the summer, a summer swell berm formed to the west of the winter storm berm. It too was surveyed on August 3 and 26, and September 21 and is denoted as the low berm.

Between May 27 and September 21 most of the winter storm berm (high berm) did not change in elevation (see combined profiles 1 - 5). Because of the depth of the channel and flow, it was not possible to wade into and survey the channel. However, changes occurred at the channel banks of the mouth as the water elevation increased over time. The rising water levels was indicative of the channel filling in with sand and a building berm (see profiles 1-5). On May 27 and June 24 the mouth was open to the ocean. The water elevation (ft MSL) at the channel bank, denoted as water's edge, was 0.02 ft for the left edge water (LEW) and 0.04 ft for the right edge water (REW) on May 27 (see profile 1). On June 24, it was 1.17 ft LEW and 1.22 ft REW (see profile 2). On August 3, with low flow through the mouth and the mouth partially closed, tidal influenced fluctuations within the estuary were small. The water's edge at the high berm was 5.05 ft LEW and 5.03 ft REW, and at the low berm it was 1.27 ft LEW and 0.94 ft REW (see Profile 3). The channel was at such a low gradient and long, 1,445 ft, and the flow so low, 35 cfs at ORK, that stream flow erosional forces were not causing channel adjustments that would lower the estuary water level.

On August 26, with the mouth completely closed, the water elevation at the high berm at the channel was 5.88 ft MSL at LEW (see Profile 4). The lowest depression on low berm crest was 6.19 ft MSL, the height at which the estuary would naturally breach on its own. That day the flow station was not registering flow (<16.5 cfs). Even with the mouth closed, seepage through the berm into the ocean was occurring. At low tides, flow emerging from the sand/gravel layers along the beach opposite the embayment was observed.

On September 21 and the mouth closed, the water elevation at the high berm at the channel was 5.50 ft MSL at REW (see Profile 5). The lowest depression on the low berm crest was 8.3 ft MSL. The estuary water level would have had to rise 2.8 ft to naturally breach.

On October 29, the day of the controlled breach, the lowest point of the berm was estimated at 9.3 ft MSL based on calculations using a hand level and stadia rod. Evidently since the last survey on September 21, wave action had deposited sand increasing the height of the berm. It appeared to be wider too. Previous visits during the second week of October when the water approached 8 ft, the distance between the water's edge the crest of the berm was much smaller than at the time of the breach.

The survey points plotted on 1 : 6000 aerial photos for each survey are presented in Appendix VI.

## **Discussion**

The mean length of salmonid fish residing in the estuary increased during the summer indicating the estuary provided rearing habitat. The small increase of steelhead length is most likely due to the presence of several age classes which affected the mean. The larger standard deviation of 32 mm and range, 77 to 207 mm, in September indicates this. The large size and appearance of the coho captured were indicative of smolts migrating downstream. Their absence the rest of the summer indicates we must have intercepted the last portion of the downstream coho smolt migration. All the populations decreased. Fish might have migrated out the estuary prior to its closure and/or died while residing the rest of the summer in the lagoon.

Water temperatures in the Redwood Creek estuary were warm. Water temperatures which ranged between 13.7 and 20.2°C, were not optimum for rearing salmonids. After the partial closure of the mouth on July 23, temperatures were not in the preferred range for rearing salmonids. Preferred water temperatures for rearing steelhead trout and chinook salmon are 7.8 to 14.6°C (optimum 10.1°C) and 7.3 to 14.6°C (optimum 12.2°C), respectively (Reiser and Bjorn 1979). During the period when the estuary was closed, fish could not migrate to the cooler ocean waters, nor would there have been much input of cooler ocean water into the estuary, except by wave overwash across the berm. Upstream, water entering the estuary was warm too. Water temperatures measured in the mainstem, upstream of Tall Trees Grove reached 24.4°C (Anderson 1999). The high temperatures may have contributed to the decline in the chinook and steelhead populations when the mouth was closed.

Fish stranding surveys found no fish on the surrounding fields. The isolated pool in the sand adjacent to the embayment had sufficient depth and subsurface inflow to still provide habitat for any stranded juveniles. *Corophium* surveys determined the effect to the benthic gammarid was localized in the general location of the outlet. Dewatering ends of the northwest and levee transects did not affect the *Corophium*. Based on the cross section of E-2, E-3, and E-4, a water elevation decrease from 9 to 4 feet would have decreased the average wetted width of the embayment by half, from around 1,350 ft to 650 ft (Appendix IV). However, because the water levels rose to 8.8 ft in such a short time, *Corophium* probably had not colonized the newly wetted areas, and the effects of breaching were not as great. In future *Corophium* surveys, additional transects will be chosen.

The northern location we chose to breach was not where a natural uncontrolled breach would have occurred. It would have breached further to the south on the berm. Breaching at and to the north prevented an uncontrolled breach that would have decreased the water level even lower than a controlled breach. By breaching at and to the north, the mouth stayed in that area for three weeks until the large 35,500 cfs storm event. It caused higher water levels than if an uncontrolled breach had been allowed to occur.

## References

- Anderson, D.G. 1999. 1998 Tidewater goby annual report. Fish and Wildlife Branch, Redwood National and State Parks, Orick, California. 8 pp.
- Anderson, D.G. 1999. 1999 RNSP Redwood Creek summer steelhead trout survey. Fish and Wildlife Branch, Redwood National and State Parks, Orick, California. 12 pp.
- Reiser, D.W., and T.C. Bjorn. 1979. Influence of forest and rangeland management on anadromous fish habitat in Western Northern America: Habitat requirements of anadromous salmonids. Pacific Northwest Forest and Range Experimental Station. USDA Forest Service General Technical Report PNW-96. 54 pp.
- Youngs, W.D., and D.S. Robson. 1978. Estimation of population number and mortality rates. PP 137 - 164. In: Methods of assessment of fish production in fresh waters. Third Edition. T. Bagenal (ed.) Blackwell Scientific Publications, London. 365 pp.

Prepared by: David G. Anderson – REDW Fishery Biologist (707) 464-6101 x 5271  
[3/99]

Appendix I. U.S. Army Corps of Engineers permit No. 21881N, effective until December 31, 2002. The permit authorizes the Redwood National and State Parks to breach the mouth of Redwood Creek. It includes eight special conditions.

DEPARTMENT OF THE ARMY PERMIT

Permittee: Redwood National and State Parks

Permit No . 21881N

Issuing Office: San Francisco District

NOTE: The term "you" and its derivatives, as used in this permit, means the permittee or any future transferee. The term "this office" refers to the appropriate district or division office of the Corps of Engineers having jurisdiction over the permitted activity or the appropriate official of that office acting under the authority of the commanding officer.

You are authorized to perform work in accordance with the terms and conditions specified below.

**Project Description:** Excavation of approximately 1,250 cubic yards of sand, at the mouth of Redwood Creek, a water of the United States, as described in the attached drawings entitled "Purpose: Breaching of Mouth of Redwood Creek", Sheets 1 and 2 of 4

**Project Location:** Redwood Creek Estuary, west of the community of Orick, Humboldt County, California

**Permit Conditions:**

**General Conditions:**

1. The time limit for completing the work authorized ends on **December 31, 2002**. If you find that you need more time to complete the authorized activity, submit your request for a time extension to this office for consideration at least one month before the above date is reached.
2. You must maintain the activity authorized by this permit in good condition and in conformance with the terms and conditions of this permit. You are not relieved of this requirement if you abandon the permitted activity, although you may make a good faith transfer to a third party in compliance with General Condition 4 below. Should you wish to cease to maintain the authorized activity or should you desire to abandon it without a good faith transfer, you must obtain a modification of this permit from this office, which may require restoration of the area.
3. If you discover any previously unknown historic or archeological remains while accomplishing the activity authorized by this permit, you must immediately notify this office of what you have found. We will initiate the Federal and state coordination required to determine if the remains warrant a recovery effort or if the site is eligible for listing in the National Register of Historic Places.
4. If you sell the property associated with this permit, you must obtain the signature of the new owner in the space provided and forward a copy of the permit to this office to validate the transfer of this authorization.
5. If a conditioned water quality certification has been issued for your project, you must comply with the conditions specified in the certification as special conditions to this permit. For your convenience, a copy of the certification is attached if it contains such conditions.
6. You must allow representatives from this office to inspect the authorized activity at any time deemed necessary to ensure that it is being or has been accomplished in accordance with the terms and conditions of your permit.

**Special Conditions:**

1. Before work commences, the permittee shall complete Section 7 consultation with the National Marine Fisheries Service. All relevant special conditions of the Biological Opinion shall become part of this permit. The

permittee shall notify the Corps of any conflicts between the biological opinion and this permit, and shall apply to the Corps for an amendment to resolve the conflicts.

2. The permittee shall not breach the mouth of Redwood Creek until the estuary waterlevel elevation has reached 8.0 feet National Geodetic Vertical Datum (NGVD).

3. The permittee shall maintain daily records of water elevation in Redwood Creek estuary (main embayment) and water flows in Redwood Creek.

4. The permittee shall survey sand berm elevations parallel to the shore, once per month from May to September, along the highest ridge of the sand dunes, from a minimum of 100 feet north of the estuary to 100 feet south of the information center. Surveys shall note the lowest elevation of the sand berm where breaching may occur and any changes in elevations from previous survey. Surveys shall map ridge line locations on an aerial plan of the estuary.

5. In the event of any type of breach, the permittee shall submit to the Corps the following information: estuary water elevation at time of breach, water flow in Redwood Creek at time of breach, last survey of sand berm elevations, indications of type of breach (man induced or natural) and tide height at time of breach.

6. The permittee shall survey, on a yearly basis, permanent cross-sections of the estuary perpendicular to flow, with a minimum of three cross-sections through the main embayment. Cross-sections shall be monumented to ensure subsequent remeasurement in the following years. The permittee shall submit cross sections to the Corps each year by December 31, with the first set of cross-sections due in 1998.

7. The permittee shall submit to the Corps, on a yearly basis, all information gathered, an analysis of the information, and a summary of the estuary response to any action or no action taken by the National Park Service during the year. Reports shall be due December 31.

8. In the event of a planned breach by the permittee, the permittee shall document *Corophium* abundance, by utilizing transects, prior to the breach and one week after the breaching event. The permittee shall also maintain temperature recordings on a continuous reading hobotemp until September 1 of the year in which breaching occurred.

Further Information:

1. Congressional Authorities: You have been authorized to undertake the activity described above pursuant to:

- (X) Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. 403).
- (X) Section 404 of the Clean Water Act (33 U.S.C. 1344).

2. Limits of this authorization.

- a. This permit does not obviate the need to obtain other Federal, state, or local authorizations required by law.
- b. This permit does not grant any property rights or exclusive privileges.
- c. This permit does not authorize any injury to the property or rights of others.
- d. This permit does not authorize interference with any existing or proposed Federal project.

3. Limits of Federal Liability. In issuing this permit, the Federal Government does not assume any liability for the following:

- a. Damages to the permitted project or uses thereof as a result of other permitted or unpermitted activities or from natural causes

- b. Damages to the permitted project or uses thereof as a result of current or future activities undertaken by or on behalf of the United States in the public interest.
  - c. Damages to persons, property, or to other permitted or unpermitted activities or structures caused by the activity authorized by this permit.
  - d. Design or construction deficiencies associated with the permitted work.
  - e. Damage claims associated with any future modification, suspension, or revocation of this permit.
4. **Reliance on Applicant's Data:** The determination of this office that issuance of this permit is not contrary to the public interest was made in reliance on the information you provided.
5. **Reevaluation of Permit Decision.** This office may reevaluate its decision on this permit at any time the circumstances warrant. Circumstances that could require a reevaluation include, but are not limited to, the following:
- a. You fail to comply with the terms and conditions of this permit.
  - b. The information provided by you in support of your permit application proves to have been false, incomplete, or inaccurate (See 4 above).
  - c. Significant new information surfaces which this office did not consider in reaching the original public interest decision.

Such a reevaluation may result in a determination that it is appropriate to use the suspension, modification, and revocation procedures contained in 33 CFR 325.7 or enforcement procedures such as those contained in 33 CFR 326.4 and 326.5. The referenced enforcement procedures provide for the issuance of an administrative order requiring you to comply with the terms and conditions of your permit and for the initiation of legal action where appropriate. You will be required to pay for any corrective measures ordered by this office, and if you fail to comply with such directive, this office may in certain situations (such as those specified in 33 CFR 209.170) accomplish the corrective measures by contract or otherwise and bill you for the cost.

6. **Extensions.** General condition I establishes a time limit for the completion of the activity authorized by this permit. Unless there are circumstances requiring either a prompt completion of the authorized activity or a reevaluation of the public interest decision, the Corps will normally give favorable consideration to a request for an extension of this time limit.

Your signature below, as permittee, indicates that you accept and agree to comply with the terms and conditions of this permit.

Andrew T. R-sold 1/13/98  
 (PERMITTEE) (DATE)

This permit becomes effective when the Federal official, designated to act for the Secretary of the Army, has signed below.

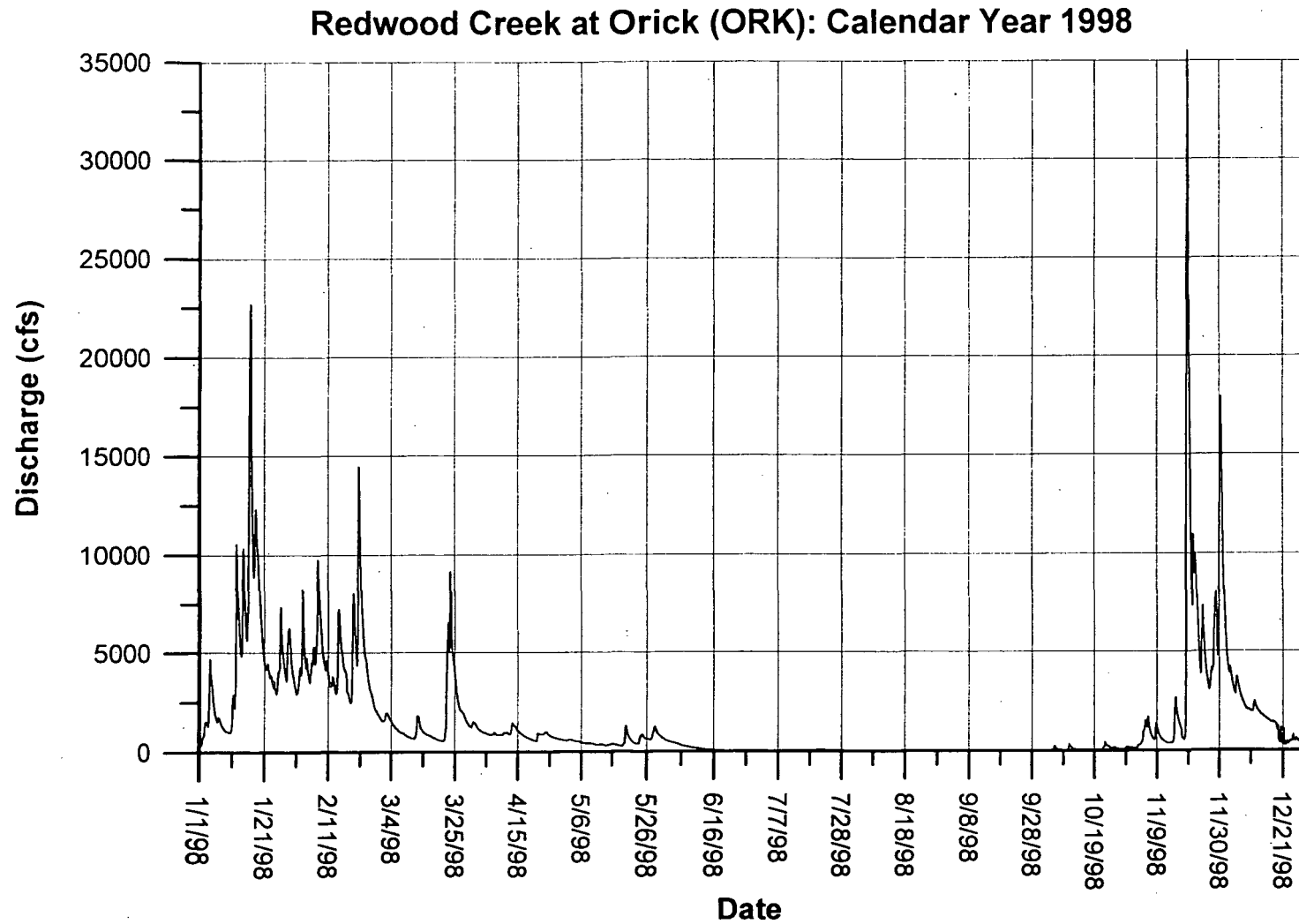
Richard G. Thompson 1-27-98  
 (DISTRICT ENGINEER) RICHARD G. THOMPSON (DATE)  
 LTC, EN

When the structures or work authorized by this permit are still in existence at the time the property is transferred, the terms and conditions of this permit will continue to be binding on the new owner(s) of the property. To validate the transfer of this permit and the associated liabilities associated with compliance with its terms and conditions, have the transferee sign and date below.

\_\_\_\_\_  
 (TRANSFEREE) (DATE)

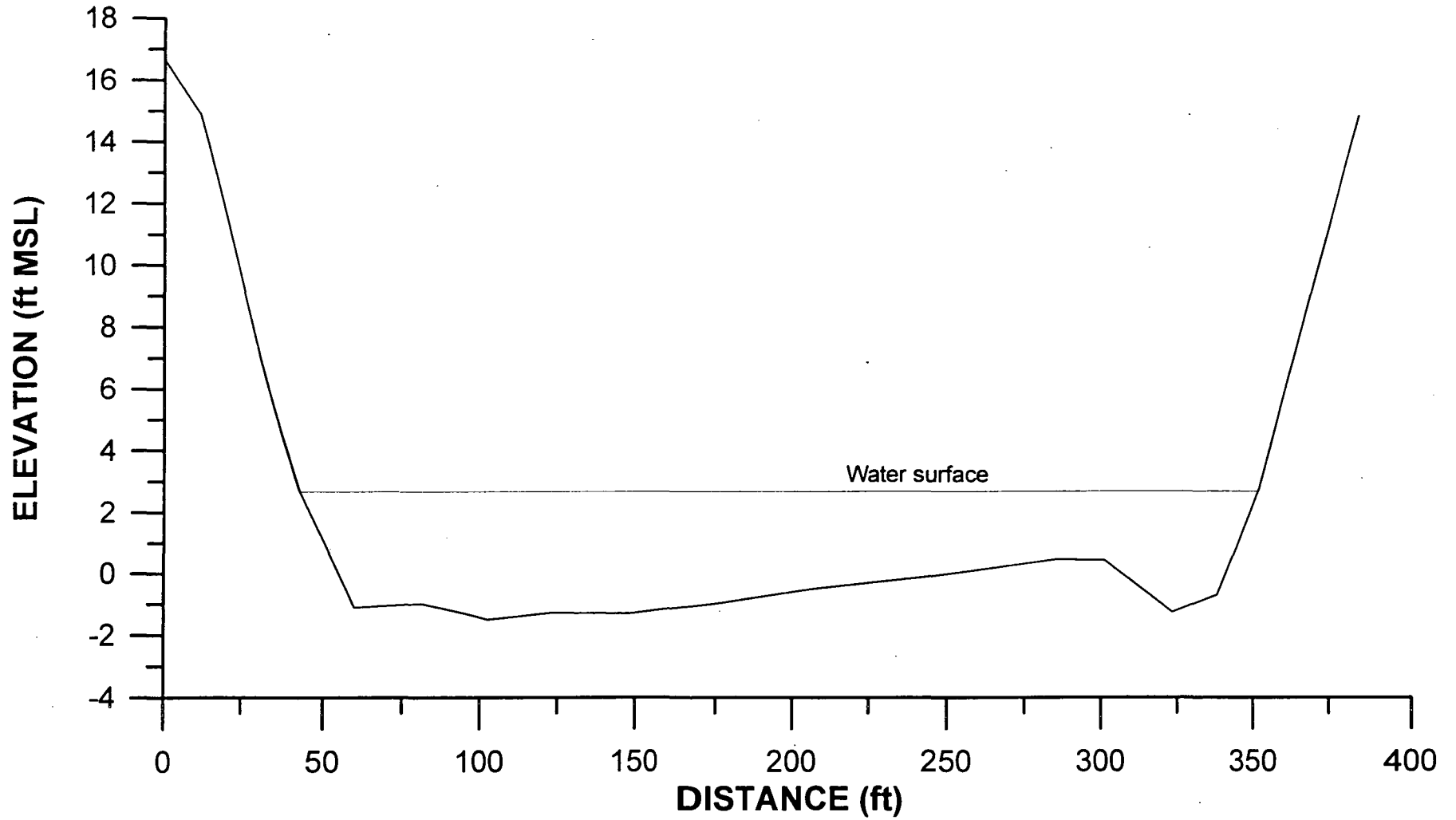


Appendix II. Hourly Redwood Creek flow data for calendar year 1998, January 1 through December 31, 1998. Data is from the California Department of Water Resources Orick (ORK) gaging station located on Redwood Creek downstream of the confluence of Prairie Creek and north of the community of Orick, California.

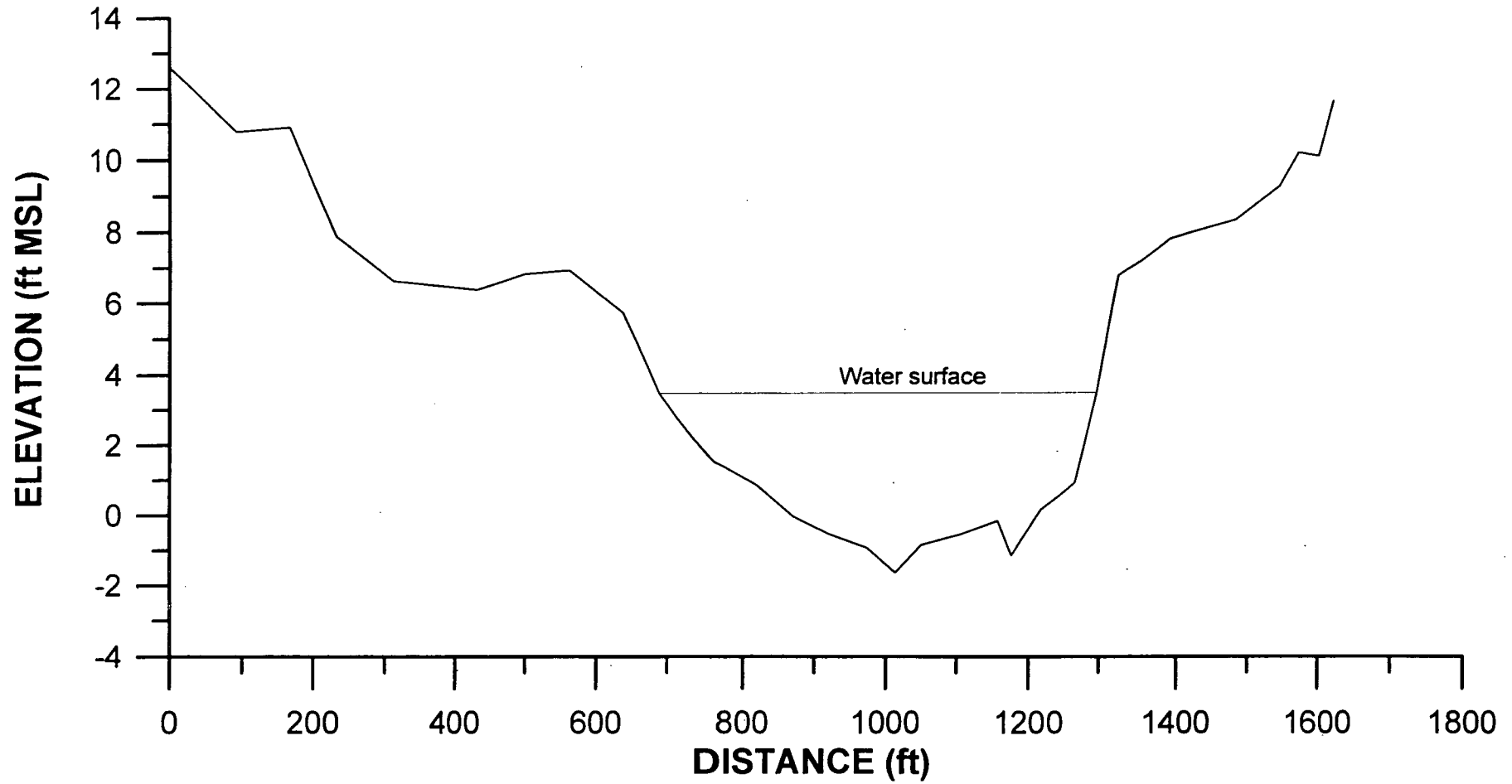


Appendix III . The five permanent cross-sections in the estuary embayment perpendicular to the flow. Established and surveyed in June of 1998, each cross section was shot at a bearing of 169° from the north endpoints through the embayment to the sand dunes on the south. The parallel cross sections start between the ends of the levees with E-1 and end to the west with E-5 at the seawall adjacent to the berm. Zero on the x-axis of each graph represents the northside endpoint. The water surface was that at the time of the June 24 or 29, 1998 survey.

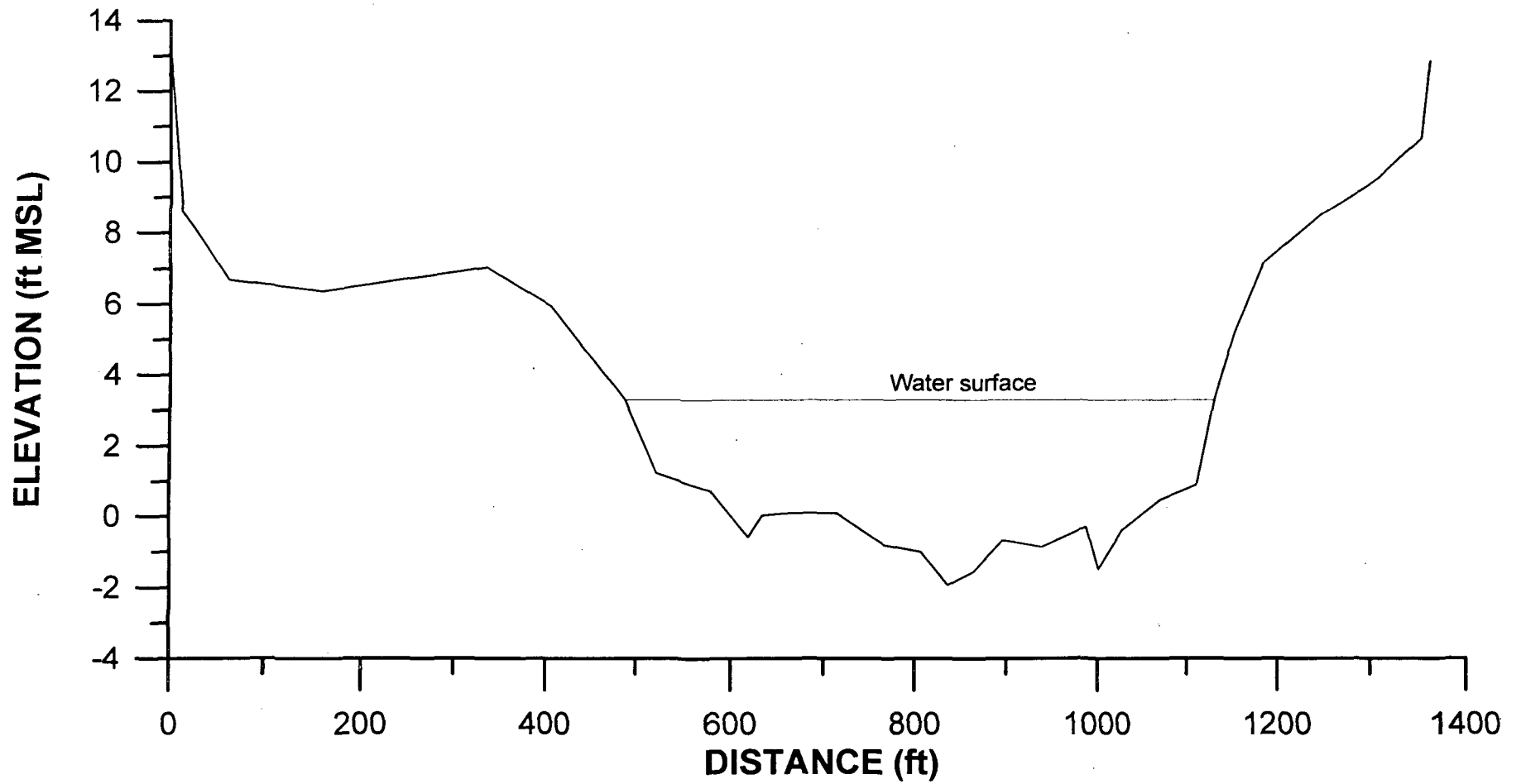
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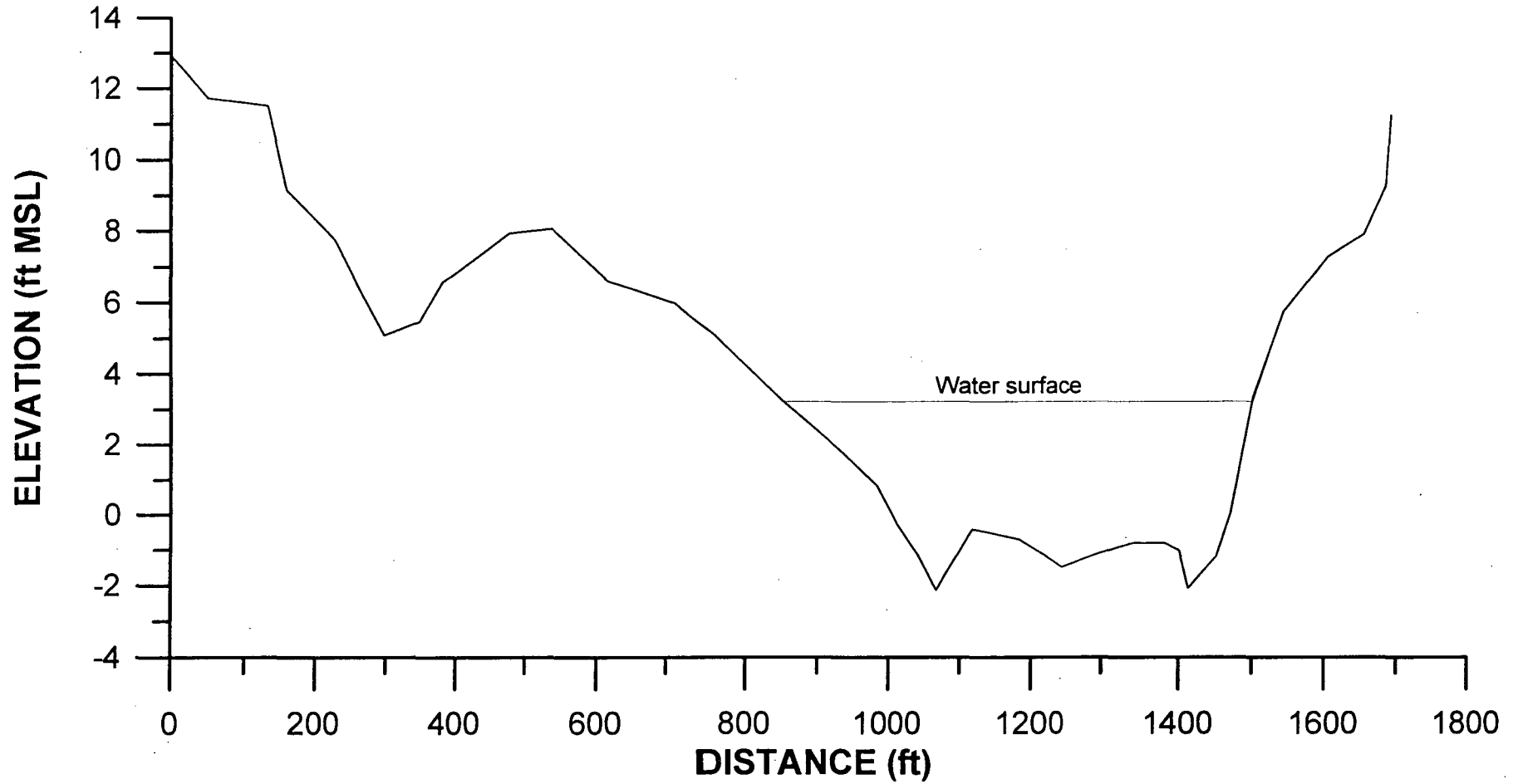
# ESTUARY CROSS SECTION E-2



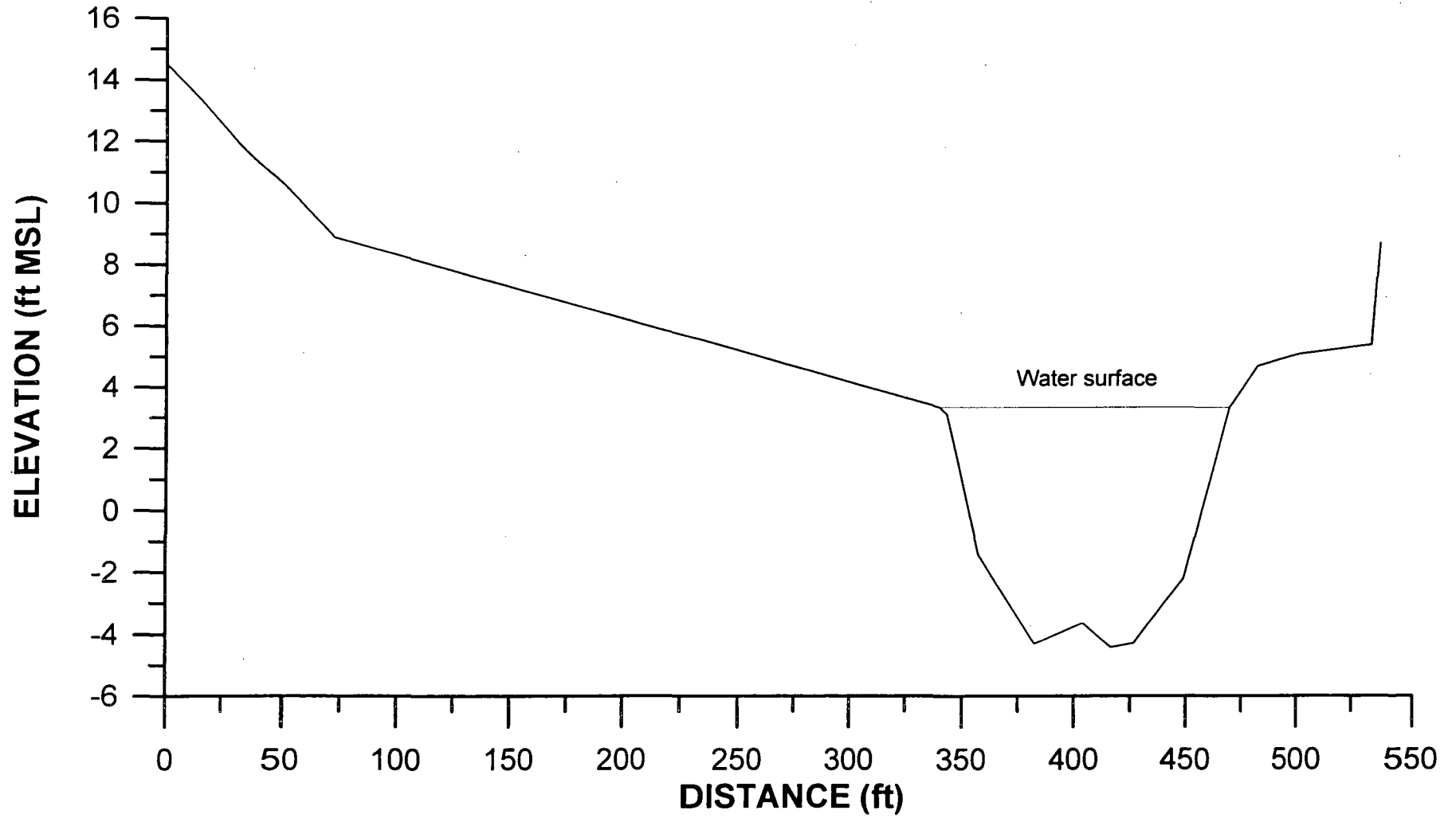
# ESTUARY CROSS SECTION E-3



# ESTUARY CROSS SECTION E-4



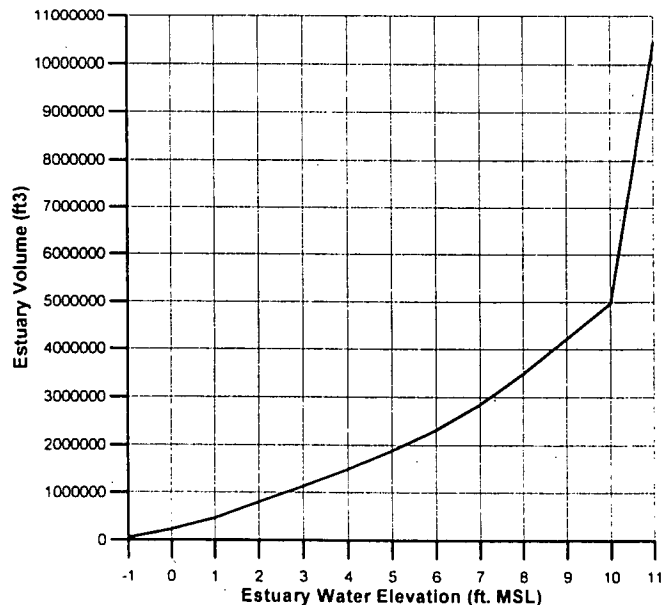
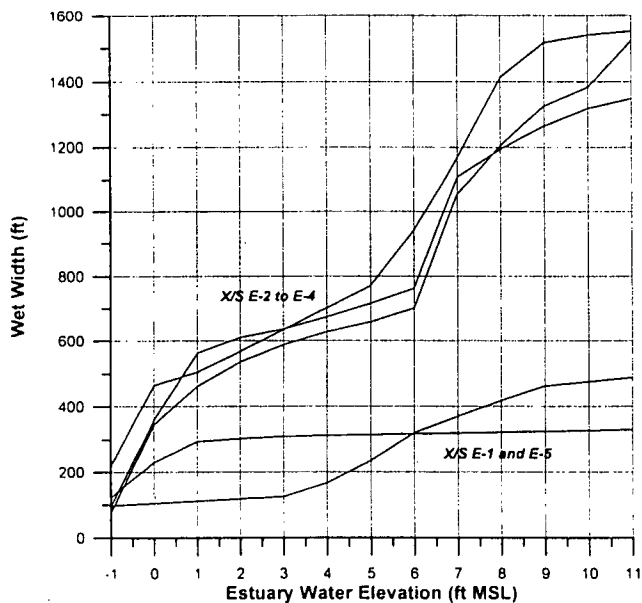
# ESTUARY CROSS SECTION E-5



Appendix IV. Calculated volume (ft<sup>3</sup> and yd<sup>3</sup>) and width (ft) of the Redwood Creek embayment at water elevations of -1 to 11 ft MSL based on the five cross sections E-1 through E-5. Volume of embayment is the area west of the ends of the north and south levee and not including the north or slough outlet channels or sloughs.

Volume for Varying Water Elevations in the Redwood Creek Embayment – 1998							
Water Elev. (ft MSL)	X/S E-1 Wet Width (ft)	X/S E-2 Wet Width (ft)	X/S E-3 Wet Width (ft)	X/S E-4 Wet Width (ft)	X/S E-5 Wet Width (ft)	Embayment Volume (ft <sup>3</sup> )	Embayment Volume (yd <sup>3</sup> )
11	330.6	1521.9	1348.4	1549.3	489.0	10,441,569	386,725
10	328.1	1383.7	1317.6	1537.6	476.1	4,976,663	184,321
9	325.5	1325.2	1263.2	1515.2	463.2	4,216,846	156,179
8	323.0	1204.8	1193.9	1413.2	418.4	3,491,578	129,318
7	320.5	1055.8	1109.2	1167.5	370.0	2,843,996	105,333
6	318.0	701.2	763.1	941.3	321.6	2,320,103	85,930
5	315.4	658.4	716.2	771.1	235.7	1,886,777	69,881
4	312.9	627.7	673.7	702.0	166.9	1,495,882	55,403
3	310.4	587.5	636.3	634.6	124.9	1,134,128	42,005
2	303.4	536.3	610.3	567.9	118.0	798,888	29,588
1	294.7	461.7	562.5	505.2	111.2	464,790	17,214
0	230.6	345.1	359.4	465.1	104.3	226,903	8,404
-1	122.9	75.3	95.2	219.2	97.5	53,794	1,992

Note: Water Elevations of 5' and lower on X/S e5 are accurate.  
 For Reference: X/S E-1 @ end of Redwood Creek levees and X/S E-5 near large sea stack on beach, X/S closest to ocean

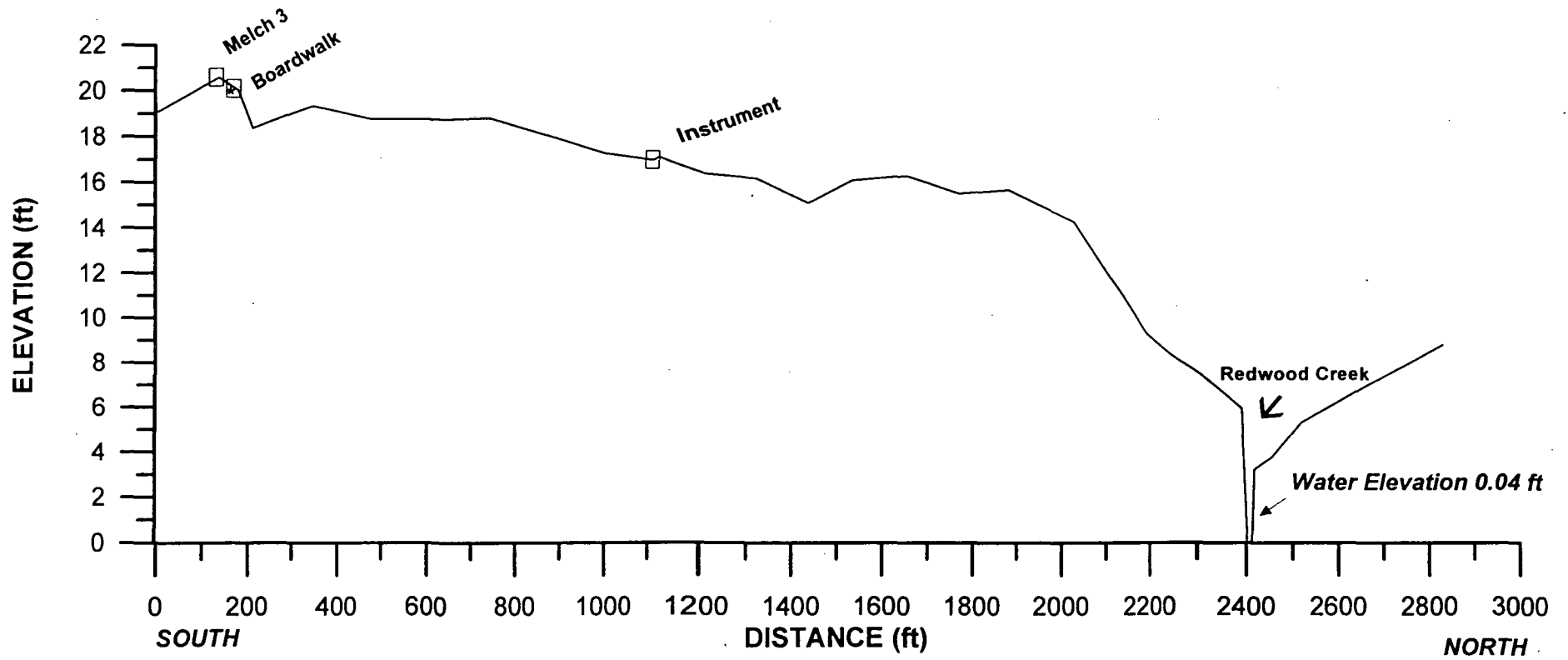




Appendix V. Longitudinal profiles of the sand berm along the highest ridge parallel to the shore and separating the estuary from the ocean for May 27, June 24, August 3, August 26, and September 21, 1998 (Profiles 1 through 5 respectively). The profiles extended from a minimum of 100 feet north of the estuary to 100 feet south of the Redwood Information Center (RIC). . Measurements were taken at breaks in slope along the sand berm. The elevations in feet MSL were referenced in the south to a permanent NOAA benchmark referred to as Melch 3 located west of RIC and to the end of the RIC boardwalk. In the north, they were referenced to a BLM benchmark, and the western most estuary cross section endpoint of E-5, RM2, a rock seastack. The winter storm berm, denoted as the high berm, and later in the summer, the summer swell berm, denoted as the low berm, were surveyed. The mouth was completely closed to the ocean on August 26 and September 21 surveys.

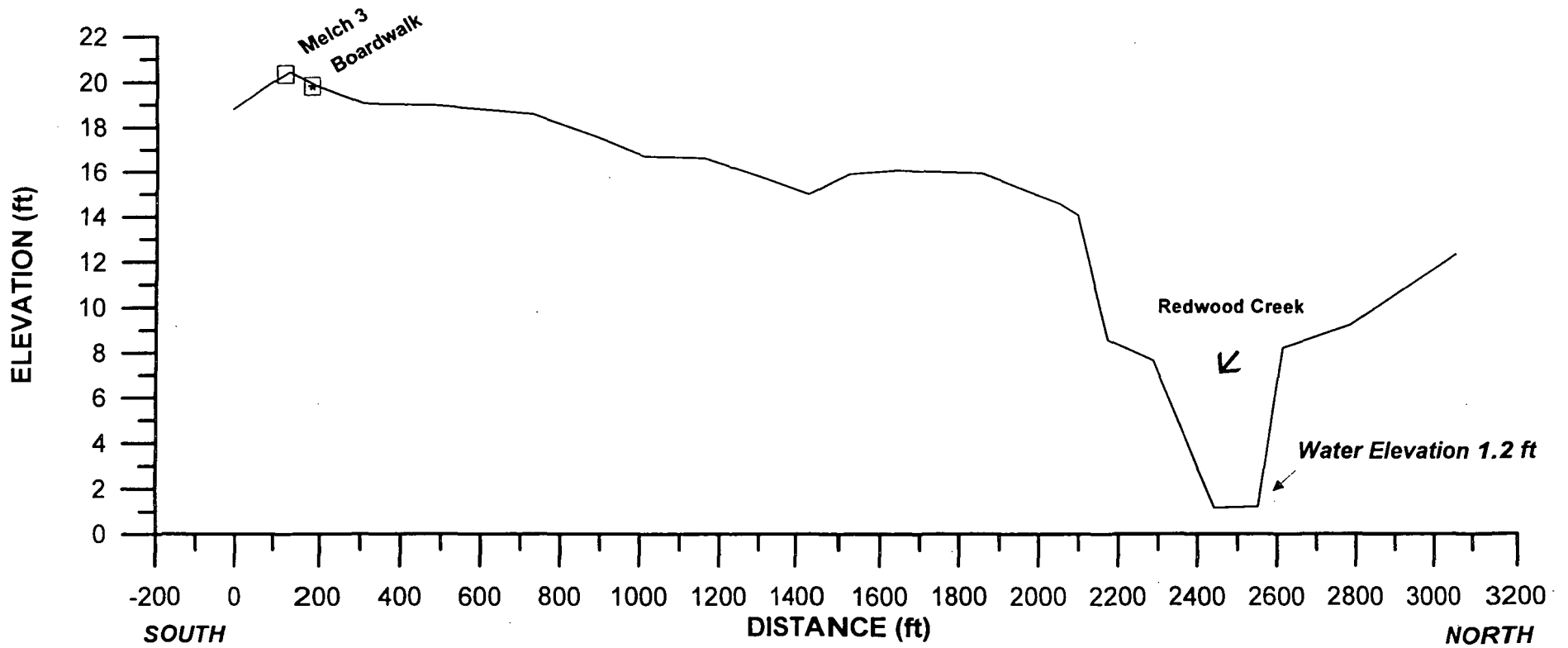
# RWC ESTUARY DUNE PROFILE 1

5/27/98



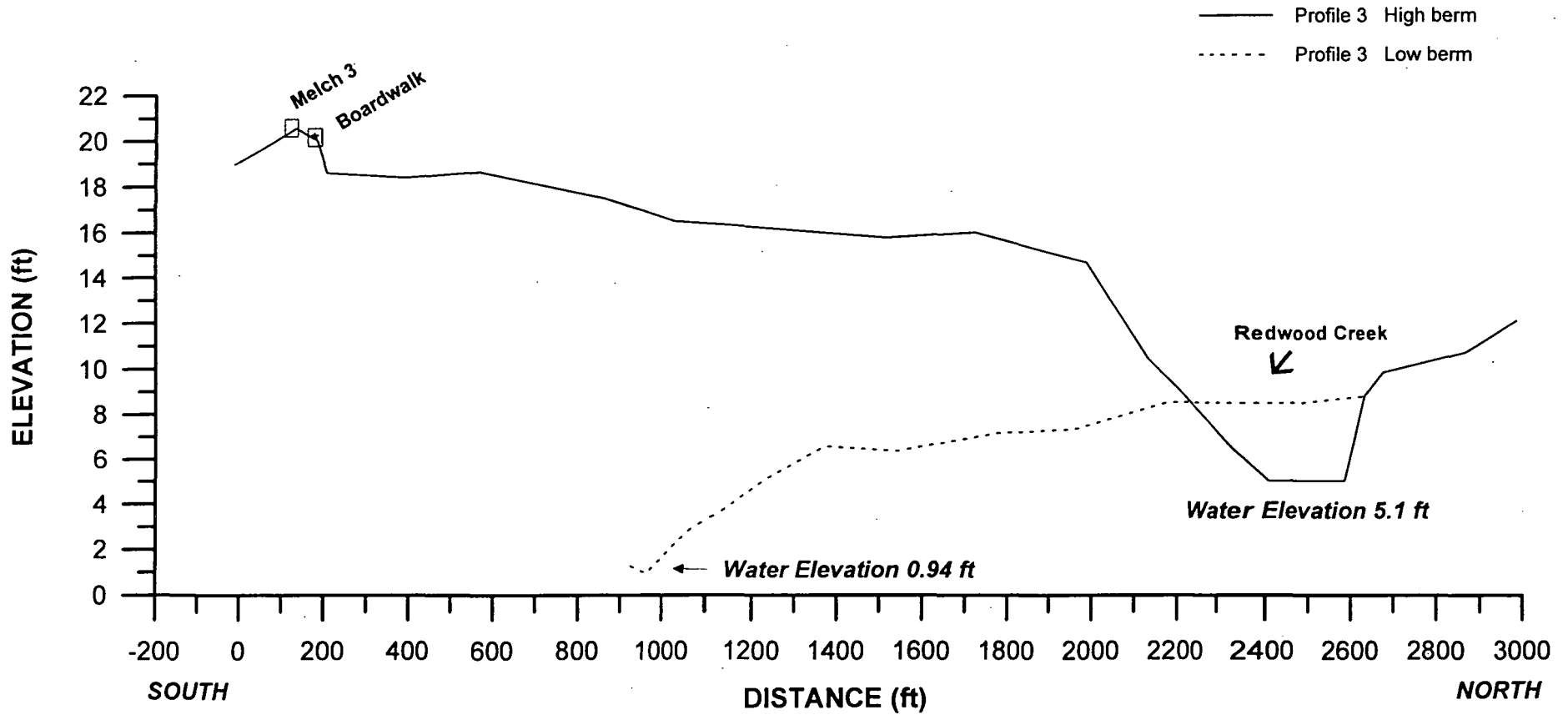
# RWC ESTUARY DUNE PROFILE 2

6/24/98



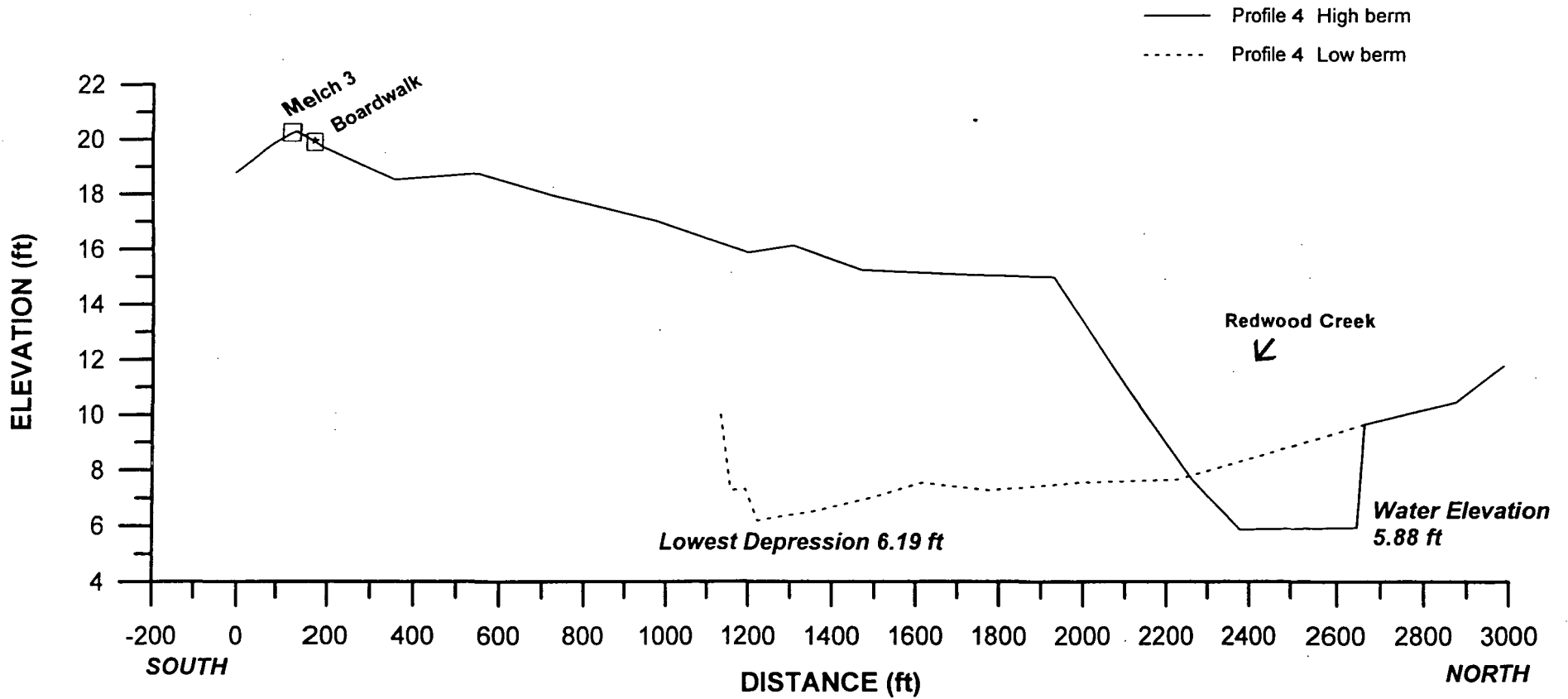
# RWC ESTUARY DUNE PROFILE 3

8/03/98



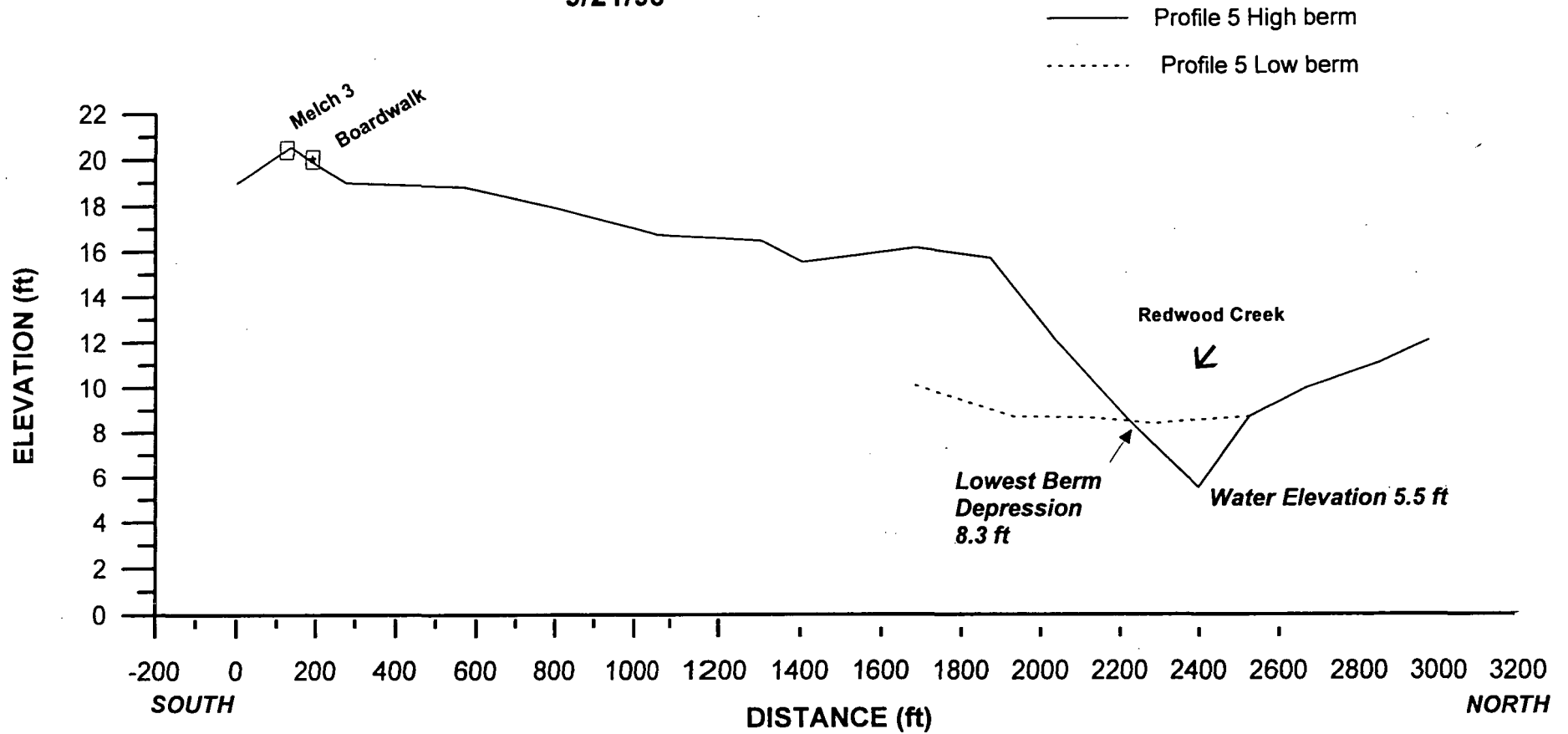
# RWC ESTUARY DUNE PROFILE 4

8/26/98

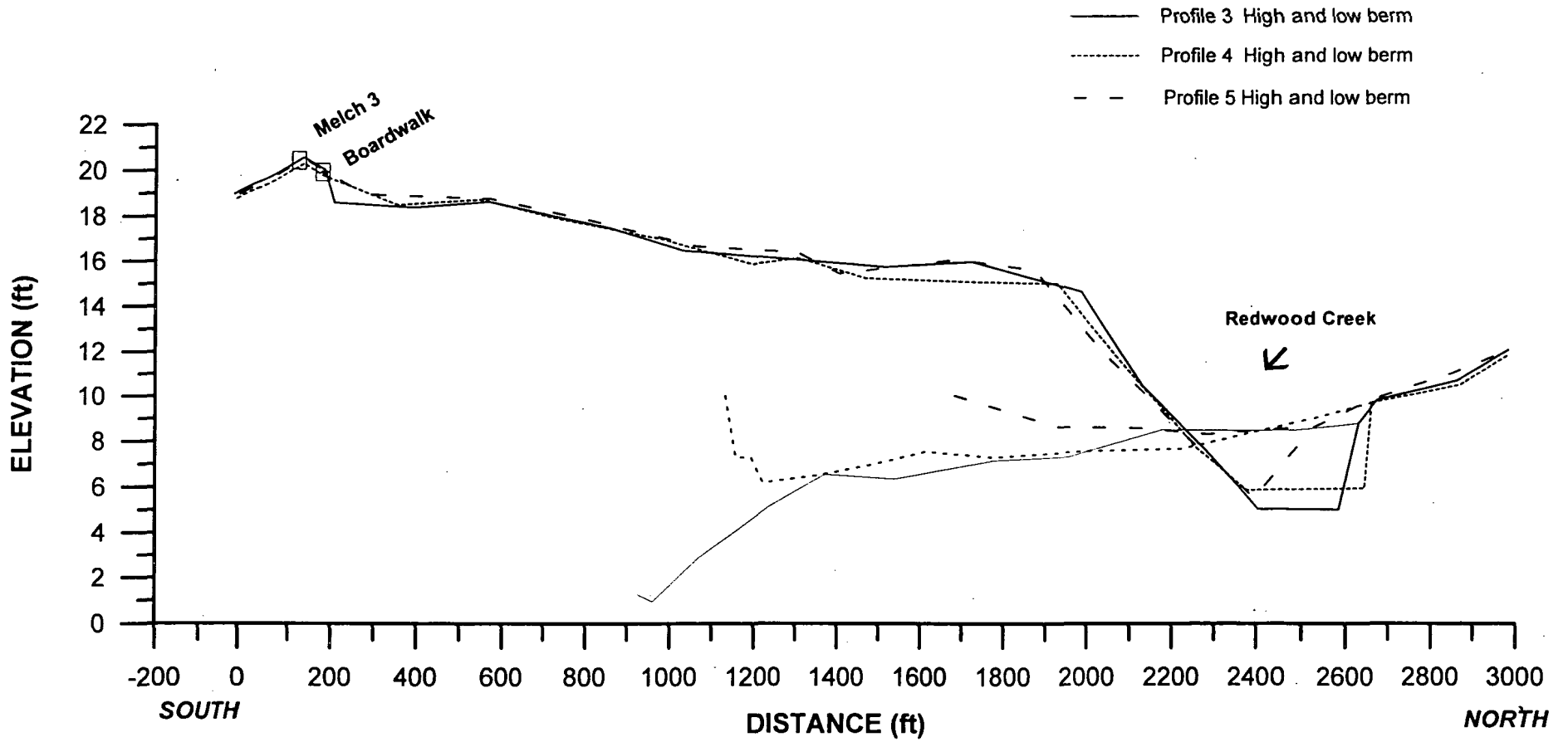


# RWC ESTUARY DUNE PROFILE 5

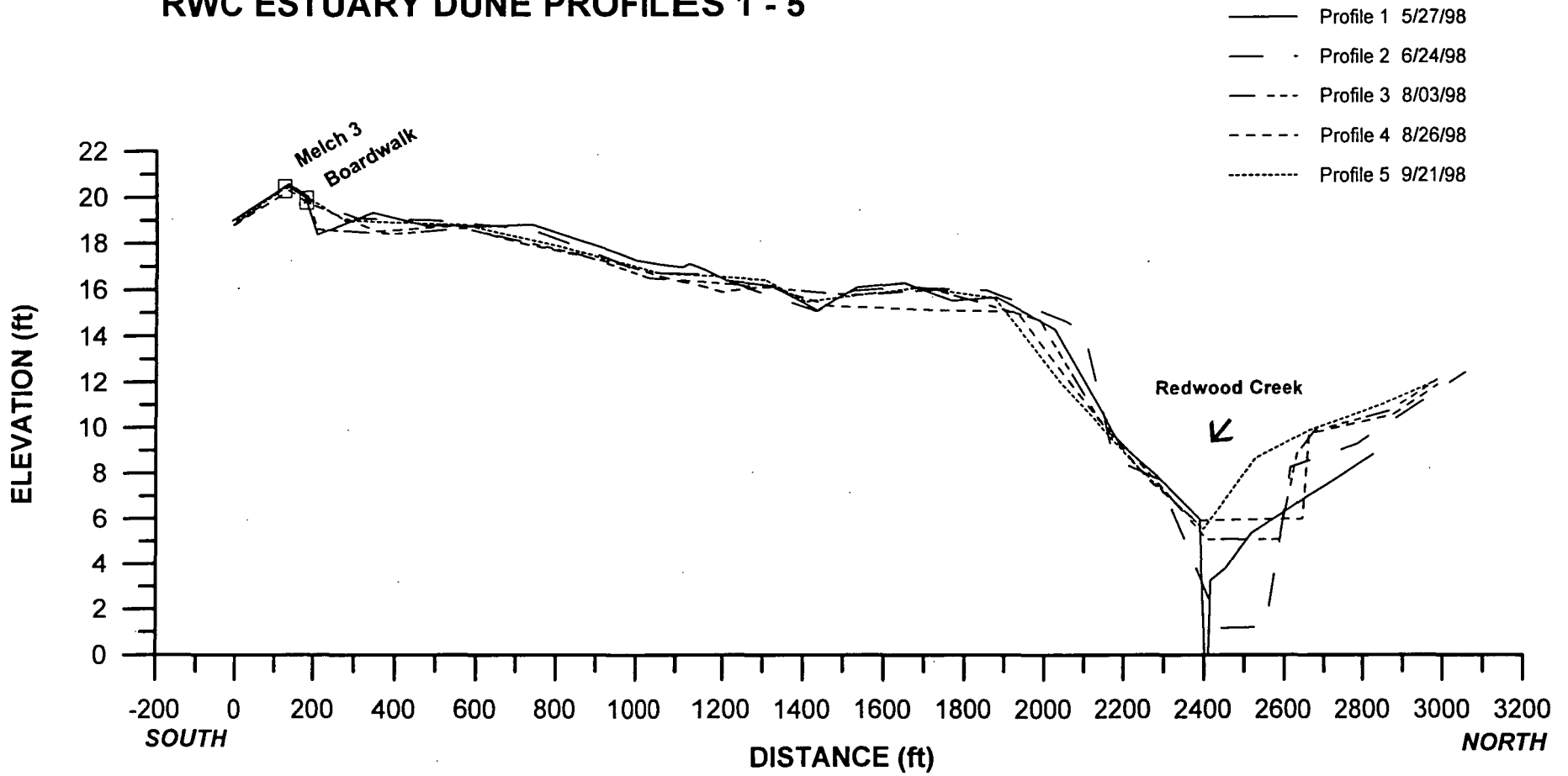
9/21/98



# RWC ESTUARY DUNE PROFILES 3 - 5



# RWC ESTUARY DUNE PROFILES 1 - 5

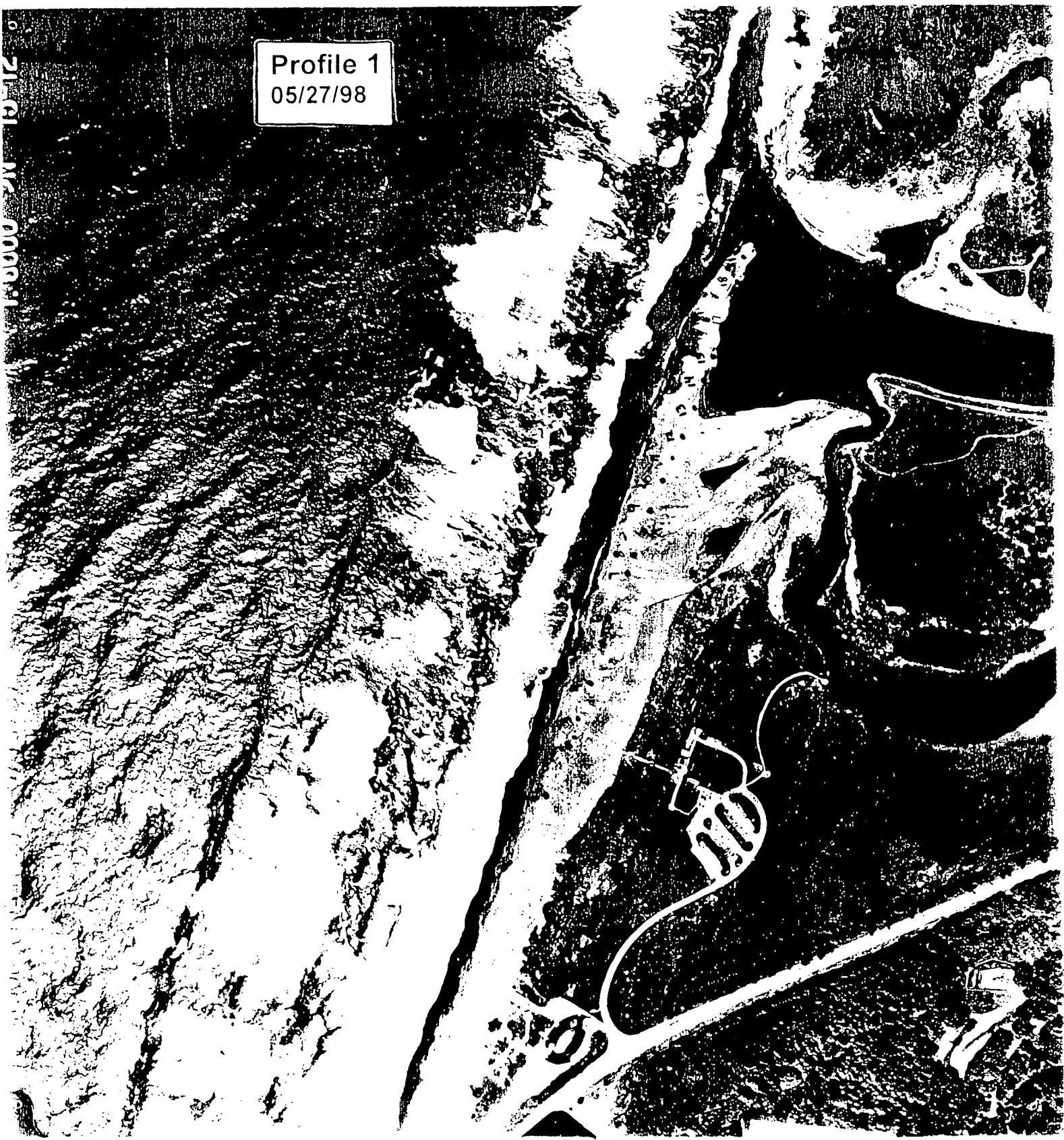






oints of the longitudinal sand berm profiles plotted on 1:6000 aerial  
r each of the five profiles. (Redwood National and State Parks photo no.  
edwood Creek 97 dated 6/19/97).

Profile 1  
05/27/98

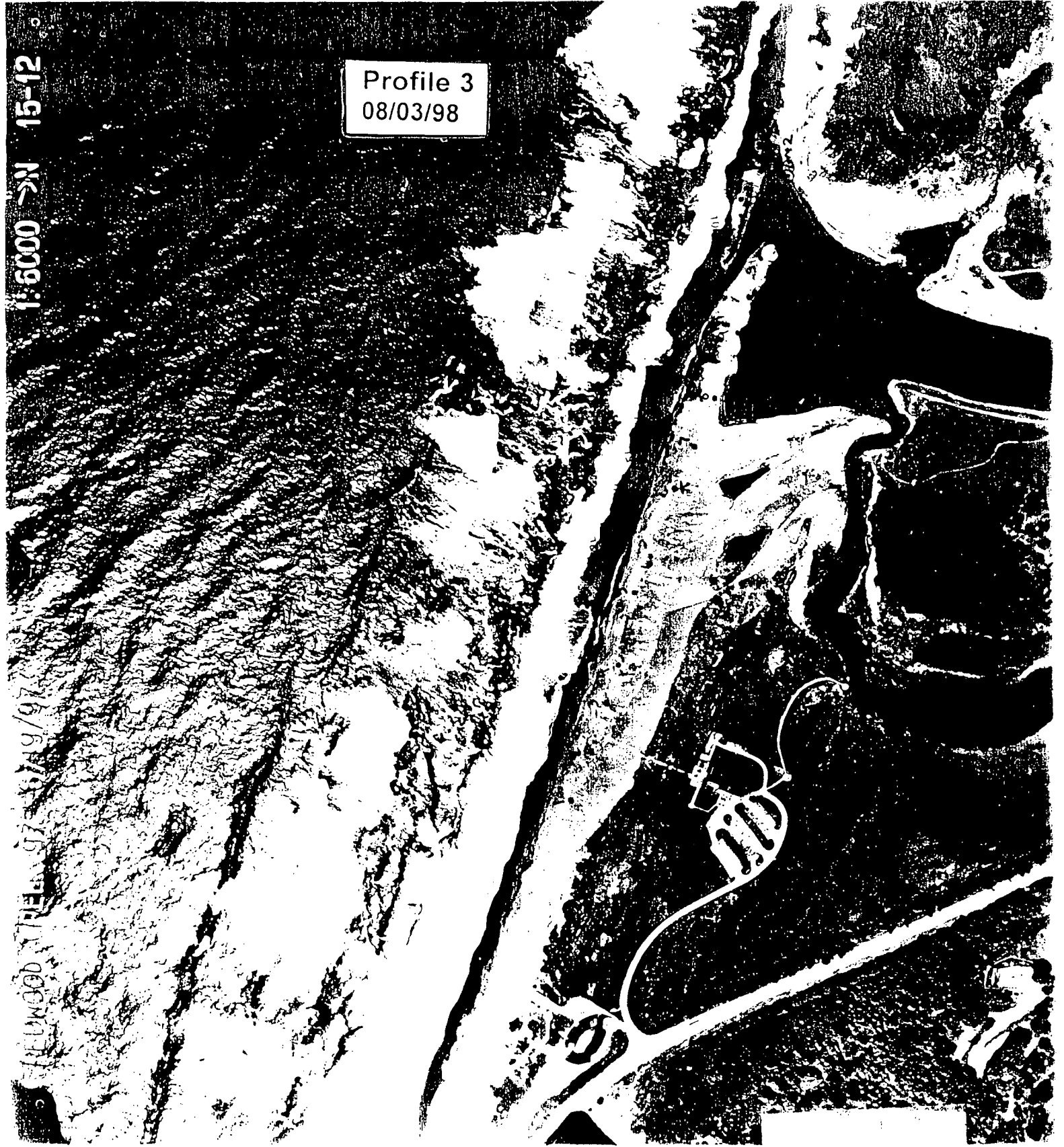


05/27/98 00001

1:6000 →N 15-12

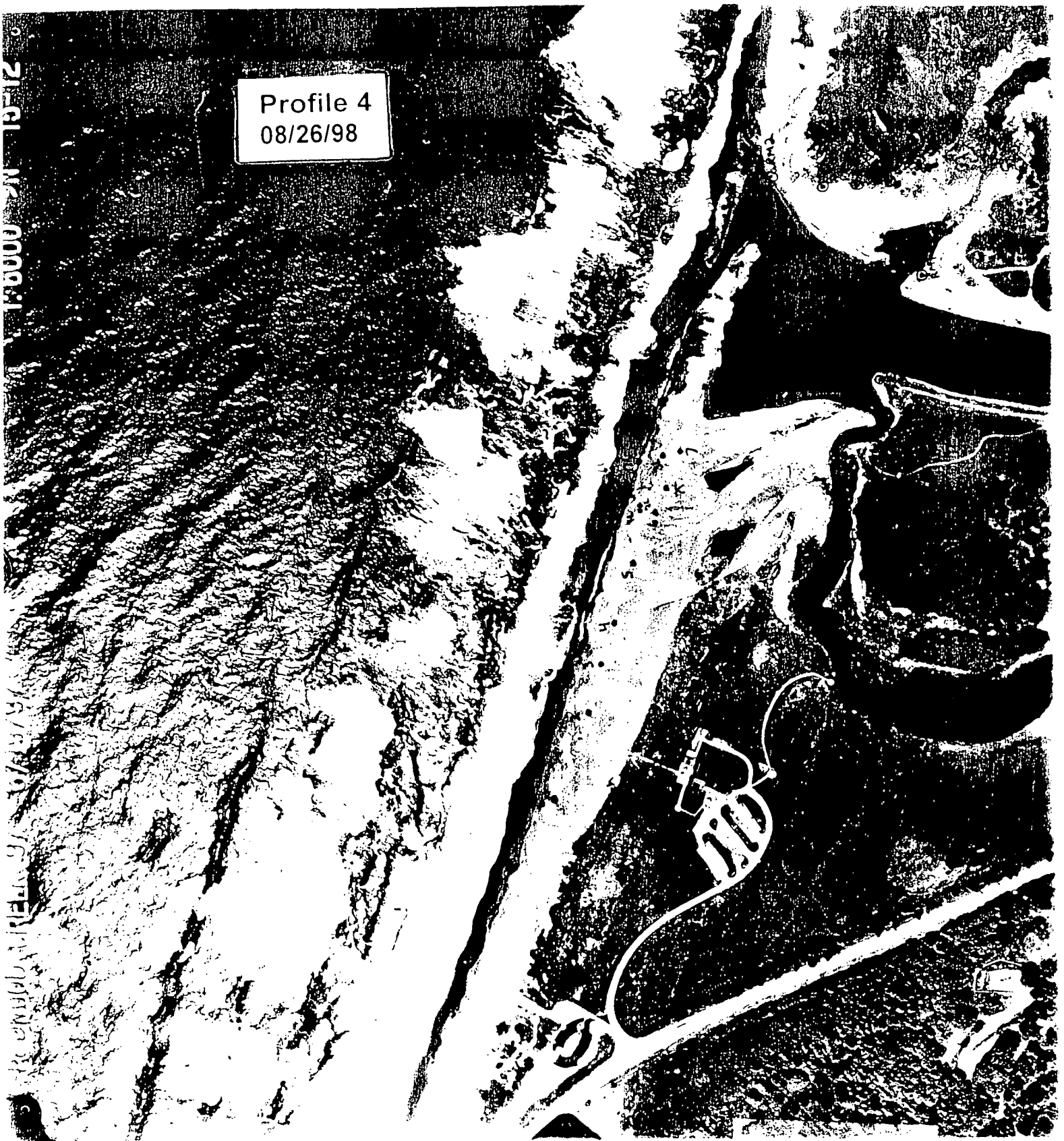
Profile 3  
08/03/98

RECORDED AT FIELD 97-8719/97

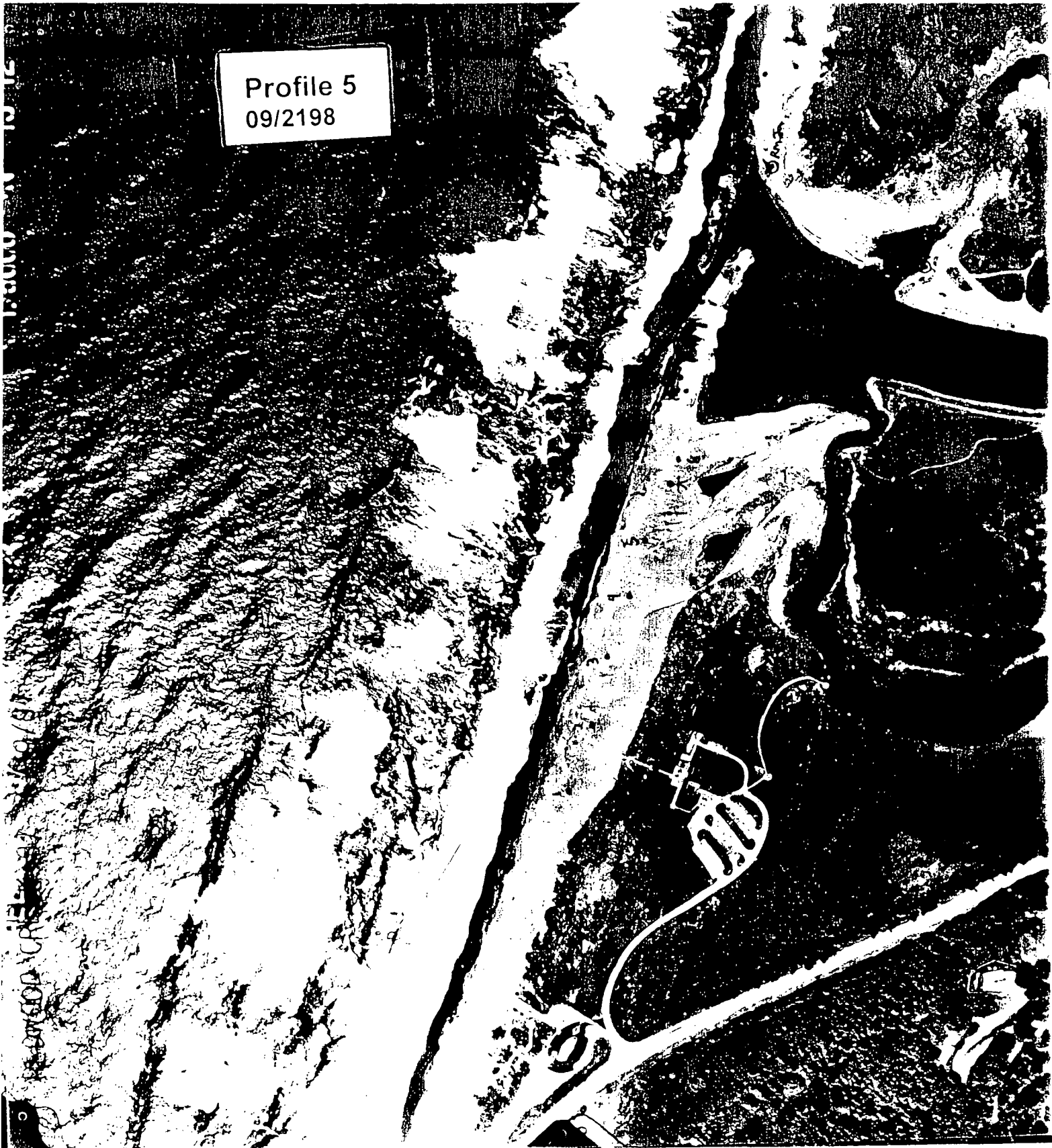


Profile 4  
08/26/98

00001 19512



Profile 5  
09/2198



## **Acknowledgements**

David Anderson, RNSP fishery biologist, supervised all estuary monitoring in the field. The following people assisted, worked on, or contributed to the various estuary monitoring projects.

### Estuary Biological Monitoring

Fish and Wildlife Branch: David Anderson, Cara Arguello, Bill Falvey, Eddie Childers, Shirley Bartz, Jim Long, Judi Friedman, Don Baldwin

Resource Management Labor Support Crew: Joel Gordon, Darlene Buckskin, Keith Richey, Doug Smith, and Rodney Yandell

YCC: Jonathan Irish, Samantha Hunt

VIP: NSF Science Teachers – Rand Hall, Kevin Lane

Interpretation Interns: Steve Kanoza, Tara Markley, Melanie Dunbar, and Daniel Matthews

### Estuary Water Level Monitoring

Geological Services: Carrie Jones (Data Collection and synthesis)

### Installation of South Levee Water Elevation Recording Gage

Geological Services: Carrie Jones, Tom Marquette

Fish and Wildlife Branch: David Anderson, Jim Long

Resource Management Labor Support Crew: Rodney Poole (fabrication)

### Estuary Surveying of Berm and Embayment Cross Sections

Geological Services: Vicki Ozaki, Carrie Jones, and Dawn McGuire

Fish and Wildlife Branch: David Anderson

Resource Management Labor Support Crew: Darlene Buckskin

VIP: NSF Science Teachers – Rand Hall, Kevin Lane, and Elliot Dabill

### Culverts Opening and Closing

Resource Management Labor Support Crew: Rodney Poole

Fish and Wildlife Branch: David Anderson

### Estuary Breaching

Fish and Wildlife Branch: David Anderson, Howard Sakai, Rick Wallen, and Bill Falvey

Resource Management Labor Support Crew: Tim Tanno, Darlene Buckskin, and Keith Richey

Roads and Trails: Tom Dore (backhoe operator)

California Department of Forestry: Alder Camp Crew -16 people (hand labor), Captain Johnson

Vegetation Management: Diona Roja (convict crew liaison)

### Breaching Documentation (Photos)

Geological Services: Vicki Ozaki (aerials), Jim Howard, and Meredith Howard

### Stranded Fish Survey

Fish and Wildlife Branch: David Anderson, Howard Sakai, Bill Falvey, and Eddie Childers

