

1999 Redwood Creek Estuary Annual Monitoring Report

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

This report summarizes Redwood National and State Parks' Fish and Wildlife Branch monitoring activities in the Redwood Creek estuary for the calendar year 1999. Monitoring activities have occurred in the Redwood Creek estuary since 1980. The purpose of the study is to determine fish utilization of the estuary, 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 km² 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 and 95 percent confidence interval (95% CI) estimates are rounded off to the nearest 10.

Growth Estimates - Fork lengths (mm) were measured 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.

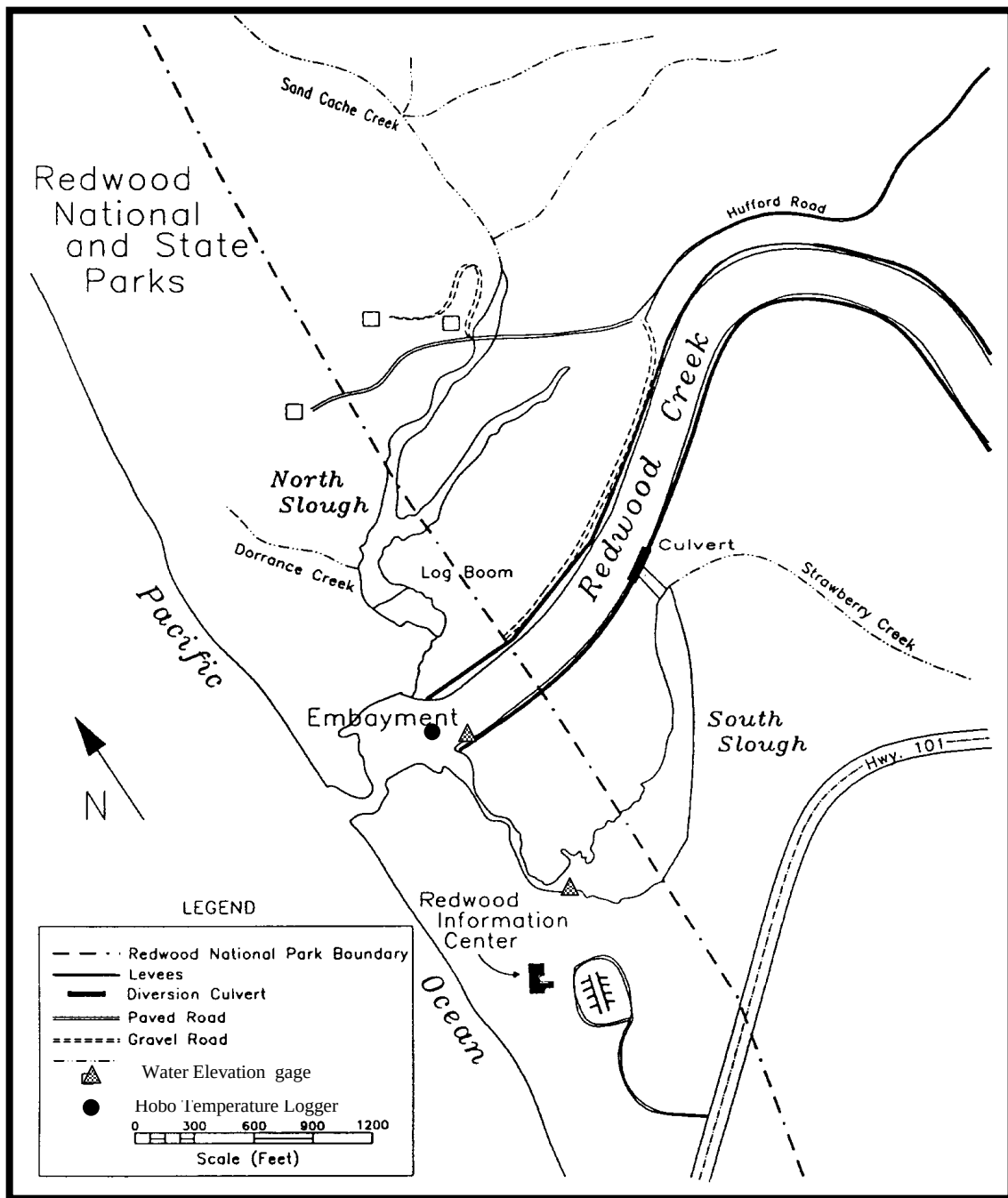


Figure 1. Map of the Redwood Creek Estuary, Humboldt County, California, including the embayment, north and south sloughs, and location of water elevation gages and temperature logger.

Water Quality Monitoring

Water temperature (°C) was measured in the Redwood Creek embayment. A HOBO™ temperature logger was located in the middle of the Redwood Creek channel between the ends of the north and south flood control levees at one foot or less from the bottom (Figure 1). It recorded water temperature every one hour. Temperature monitoring is special condition # 8 of the Corps permit.

Tide and Stream Flow Data

Tide Data: Calendar year 1999 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 [$CC\ tide \times 0.98$] and transformed to feet Mean Sea Level (MSL) [$tide - 3.65 = ft\ MSL$].

Stream Flow Data: Hourly Redwood Creek flow data for calendar year 1999 was downloaded off the Department of Water Resources, Division of Flood Management website (<http://cdec.water.ca.gov>). Water Resources has not yet reviewed the preliminary flow data for accuracy. 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 installed on July 12 at the end of the south slough levee to measure the water elevation in the estuary embayment. The south levee gage measured embayment water levels every 10-minutes using a Global Water WL-14 Water Level Logger. The embayment site could measure lower water elevations (to approximately 0 ft MSL) than the gage in the south slough. Low water levels in the south slough are limited by the invert of the south slough culvert gates and sand deposited in the south slough outlet channel. Water elevation monitoring is special condition # 3 of the Corps permit.

Estuary Cross Sections

As a special condition # 6 of the Corps permit, permanent cross-sections of the main embayment of the estuary perpendicular to the flow were surveyed. Established in 1998, the northside cross section endpoints located along the base of the hill are 8 ft t-bar fence posts, or natural endpoints such as large partially buried sea-stacks. Each cross section was shot at a bearing of 170° using a Sokkisha Set 4 Total Station. A person in a boat with a rod and prism took measurements in the embayment at breaks in slope. The transects were measured to at least 11ft MSL in elevation. The permanent endpoints are 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

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 ft in length. 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. Survey elevations were referenced in the south to *Melch 3* the permanent NOAA benchmark 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**

Special condition #8 of the Corps permit specified *Corophium* abundance be documented prior to and one week after a planned breaching event. No diver transects were conducted in 1999 as the mouth unexpectedly breached naturally.

Other Activities

Pit-tagged Coho - During the week of the June 7th population estimate, HSU Fisheries graduate student Ethan Bell assisted us. He was looking for pit-tagged coho smolts that had been tagged as juveniles the previous fall in Prairie Creek. Approximately 1,000 coho had been tagged.

Estuary Snorkeling

On June 3, 1999, USFS Redwood Sciences Laboratory personnel (Rod Nakamoto and Heather Hendrixon) with assistance from David Anderson and Kyle Max of RNSP, snorkeled the Redwood Creek channel within the levees from the first upstream bend to its terminus at the ocean, a distance of 1900m. They were classifying cover and observing fish. On June 7th, Rod and Heather snorkeled the embayment in conjunction with four RNSP beach seine hauls; two at the berm, one opposite the berm in the channel, and one at the south levee. They would dive a seine haul sampling site before we seined the location. They were trying to correlate what they observed with what was captured in the seine at a site.

Results

Fish Monitoring

Presence – During the summer and fall of 1999, four salmonid species were seined in the Redwood Creek embayment; chinook and coho salmon, and steelhead and coastal cutthroat trout. No half-pounder and one adult sized steelhead were captured. Six other fish species were captured, and 12 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 in the embayment the summer of 1999 during the weeks of June 7, July 19, and September 13, 1999 (Table 2).

The initial juvenile chinook salmon estimate the week of June 7 was 20,740 (95% CI 16,190 to 25,280). By July 19, the population had increased to 31,170 (95% CI 27,020 to 35,320). By September 13, the population had declined to 3,670 (95% CI 540 to 6,200).

Table 1. List of salmonid and non-salmonid fish seined, and birds observed in the Redwood Creek estuary, Redwood National and State Parks, Humboldt County, California during summer 1998 sampling.

	1999 Date (Week of)		
	June 07	July 19	Sept 13
Salmonid Fish			
Coastal Cutthroat Trout	X	X	X
Steelhead Trout	X	X	X
Chinook Salmon	X	X	X
Coho Salmon	X	X	
Non-Salmonid Fish			
Three Spine Stickleback	X	X	X
Night Smelt		X	
Staghorn Sculpin		X	
Prickly Sculpin	X	X	X
Sucker			X
Starry Flounder	X		
Birds			
Brown Pelican		X	
Double Crested Cormorant	X		X
Turkey Vulture	X		X
Osprey	X	X	
Semipalmated Sandpiper			X
Killdeer	X		X
Gulls			X
Caspian Tern		X	X
Violet Green Swallow	X		
Bank Swallow	X		
Corvids (Crows and Ravens)	X		X
Merganser		X	X

Table 2. Population estimates and 95 percent confidence intervals for juvenile chinook and coho salmon, juvenile steelhead trout, and coastal cutthroat trout seined in the Redwood Creek estuary embayment, Humboldt County, California, summer 1999. Mouth of creek denotes if Redwood Creek mouth was open or closed to the Pacific Ocean.

1999 DATE	Mouth of Creek (Open or Closed)	Chinook Salmon		Coho Salmon	
		Population Estimate	95% Confidence Interval	Population Estimate	95% Confidence Interval
6/07, 08, 10	OPEN	20,740	16,190 – 25,280	1,660	1,080 – 2,250
7/19, 20, 22	CLOSED	31,170	27,020 – 35,320	6	4 ^b - 13
9/13, 14, 16	CLOSED	3,670	540 – 6,200	0	---
		Steelhead Trout		Cutthroat Trout	
6/07, 08, 10 ^d	OPEN	13,620	257 ^b – 40,050	29 ^a	---
7/19, 20, 22	CLOSED	9,060	6,060 – 12,060	7 ^a	---
9/13, 14, 16	CLOSED	2,080	1,640 – 2,530	45 ^{a c}	---
<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 two recaptures the second day, and using the first two days of data, a population estimate for cutthroat trout Can be estimated at 190 and 95%CI of 46^b – 430.</p> <p>d. One adult steelhead was caught the week of June 7, 1999.</p>					

The initial juvenile steelhead trout estimate the week of June 7 was 13,620 (95% CI 257 to 40,050). The CI was poor because only one marked fish was recaptured. The population decreased to 9,060 (95% CI 6,060 to 12,060) on July 19, and decreased further to 2,080 (95% CI 1,640 to 2,530) on September 13.

The initial juvenile steelhead trout estimate the week of June 7 was 13,620 (95% CI 257 to 40,050). The CI was poor because only one marked fish was recaptured. The population decreased to 9,060 (95% CI 6,060 to 12,060) on July 19, and decreased further to 2,080 (95% CI 1,640 to 2,530) on September 13.

A large number of coho salmon smolt, over 525, were captured the first sample week of June 7. Four were captured the week of July 19, and none were captured the week of September 13. A population of 1,660 coho (95% CI 1,080 to 2,250) were estimated to be in the embayment on June 7, and 6 coho (95% CI 4 to 13) were estimated to be in the embayment on July 19. A total of 81 coastal cutthroat trout were captured; 29 in June, 7 in July, and 45 in September. A cutthroat population estimate for September 13 of 190 cutthroat (95% CI of 46 to 430) can be calculated using the first two days of data and two recaptures. On the two earlier dates, no marked cutthroat were recaptured.

Growth Estimates - Three growth estimates were done in conjunction with the population estimates during the weeks of June 7, July 19, and September 13, 1999 (Table 3). Chinook salmon mean fork length increased from 60 to 91 mm, an increase of 31 mm, between the June and September sample dates. Minimum and maximum chinook fork lengths ranged between 44 and 100 mm during summer. Mean weight rose from 2.2 to 8.3 g, an increase of 5.1g between June and September. Minimum and maximum chinook weights ranged between 0.8 to 10.7 g during summer.

Coho salmon smolt mean fork length on June 7 was 114 mm (n = 231). During the week of July 20, mean fork length was 110 mm, but sample size was only four coho. Minimum and maximum fork length ranged between 90 and 131 mm. Mean weight on June 7 was 15.1 g, and on the week of July 20, 12.6 g. Minimum and maximum weights ranged between 9.6 and 24.5 g.

Steelhead trout mean fork length increased from 123 to 147 mm, a 24 mm increase between June and September. Minimum and maximum fork length ranged between 47 and 204 mm during the summer. Mean weight increased from 19.4 to 32.6 g, an increase of 13.2 g. Minimum and maximum weights ranged between 8.5 and 71.8 g.

Cutthroat trout mean fork length increased from 180 to 227 to 268 mm from June to July to September, and increase of 88 mm. Throughout the summer and fall, cutthroat trout fork length ranged from 119 to 374 mm.

Table 3. Mean fork length (mm), mean weight (g), standard deviation, range, and dates 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 1999. Mouth denotes if Redwood Creek mouth was open or closed to the ocean.

Redwood Creek Estuary Summer 1999							
1999 DATE	MOUTH	Mean Fork Length (mm) (No. Sampled)	Std. Dev. (mm)	Range (mm)	Mean Weight (g) (No. Sampled)	Std Dev. (g)	Range (g)
JUVENILE CHINOOK SALMON							
6/7	OPEN	60 (201)	8	44 - 82	2.2 (30)	0.9	0.8 - 4.3
7/19, 20	CLOSED	80 (230)	6	62 - 97	5.7 (30)	1.0	3.7 - 7.8
9/13, 14, 16	CLOSED	91 (213)	4	80 - 100	8.3 (30)	1.2	6.5 - 10.7
JUVENILE COHO SALMON							
6/7	OPEN	114 (231)	7	90 - 131	15.1 (44)	3.1	9.6 - 24.5
7/20, 22	CLOSED	110 (4)	9	97 - 117	12.6 (3)	1.9	10.4 - 13.8
9/13, 14, 16	CLOSED	(0)	---	---	---	---	---
JUVENILE STEELHEAD TROUT							
6/7, 8, 10	OPEN	123 (217)	20	47 - 181	19.4 (25)	8.9	8.5 - 42.6
7/19, 20	CLOSED	120 (202)	18	63 - 164	18.9 (32)	6.1	5.9 - 32.4
9/13, 14	CLOSED	147 (206)	24	70 - 204	32.6 (30)	12.6	5.7 - 71.8
ADULT STEELHEAD TROUT							
6/7	OPEN	550 (1)	---	---	---	---	---
CUTTHROAT TROUT							
6/7, 8, 10	OPEN	180 (27)	51	119 - 330	---	---	---
7/19, 20, 22	CLOSED	227 (7)	32	183 - 286	---	---	---
9/13, 14, 16	CLOSED	268 (45)	37	212 - 374	---	---	---

Water Quality Monitoring

In 1999, water temperature (°C) was the only water quality parameter monitored in the Redwood Creek estuary. The HOBO temperature logger recorded water temperature every 1-hour from June 3 through October 27, 1999 (Figure 2). The maximum and minimum water temperatures were 21.1 (on June 22) and 8.9°C (on June 26), respectively. The average water temperature for the period of was 16.0°C. For the period June 3 through July 14, when the estuary was open, the maximum and minimum water temperatures were 21.1 and 8.9°C, respectively. The average water temperature was 15.7°C. For the period July 15 through October 27, when the estuary was closed, the maximum and minimum water temperatures were 20.1 and 10.6°C, respectively. The average water temperature was 16.0°C. During the period the mouth was open, water temperature extremes were larger, up to 11 degrees in a 24-hr period (a low of 9° to a high of 20°C).

Tide and Stream Flow

Tides at the Mouth of Redwood Creek - The maximum and minimum calculated tide at the mouth was 5.1 ft MSL and -5.9 ft MSL, respectively, a range of 11 feet. Tidal data is included in Figure 3).

Stream Flow - Calendar year 1999 stream flow data, January 1 through December 31, is presented in Appendix II. The maximum flow was 10,900 cfs on February 28, 1999. The gage measured a minimum flow of 11 cfs during the summer, but was unable to measure lower flows. No streamflow events occurred between June and late October.

Estuary Water Level

South Slough and South Levee/Embayment Water Level Gaging

South slough water elevations (feet MSL) were recorded for the period January 1 to December 31, 1999, excluding March 10 through 23, and September 30 through October 18, 1999 (Figure 3).

The south levee gage recorded embayment water elevations from July 12 to October 29, excluding August 12 through 26 (Figure 4). We attempted to download the gage on November 9, but it was dead. The battery terminals were corroded, probably a result of large ocean waves that propagated into the estuary and onto the levee ends and recorder box on October 28. The equipment was removed on November 18 before additional high flows, ocean waves, and driftwood being thrown on the south levee would damage it. Again, like 1998, the staff plate was missing. The October 7 through 29, 1999 south levee/embayment file was recovered, corrupted data edited out, and graphed.

On May 18 and June 14, the water level in the estuary dropped quickly (Figure 3). In both instances the mouth/channel was to the south, and a new mouth had formed upstream of the old mouth shortening the channel and causing a drop in estuary water elevation. We observed the newly dewatered channel on May 18 and surveyed the old and new mouth during the May 26, 1999 dune profile survey. The old mouth was 1,290 ft to the south of the new mouth (Appendix V profile 1).

The estuary was open till July 14, 1999. Based on south slough water level records, the embayment started to close on July 10 when at 3.6 ft MSL, the water elevation rose to 7.6 ft MSL on July 14, and the estuary completely closed (Figure 3). This corresponds to the 1999 embayment water

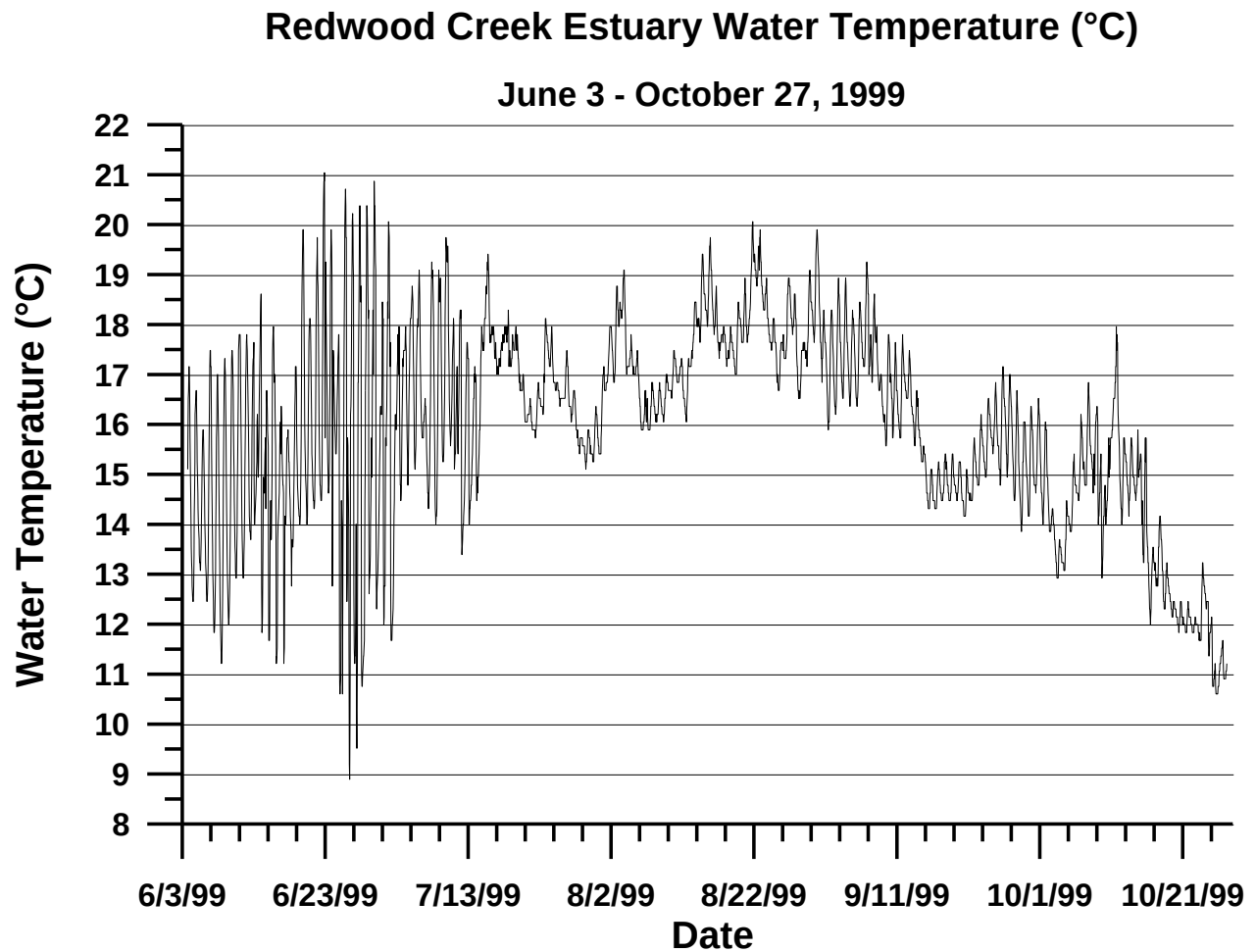


Figure 2. Redwood Creek estuary water temperatures (°C) measured by a HOBO temperature logger located in the middle of the Redwood Creek channel between the ends of the north and south flood control levees in the embayment. The temperature logger, located one foot from the bottom, recorded water temperature every 1-hour from June 3 through October 27, 1999.

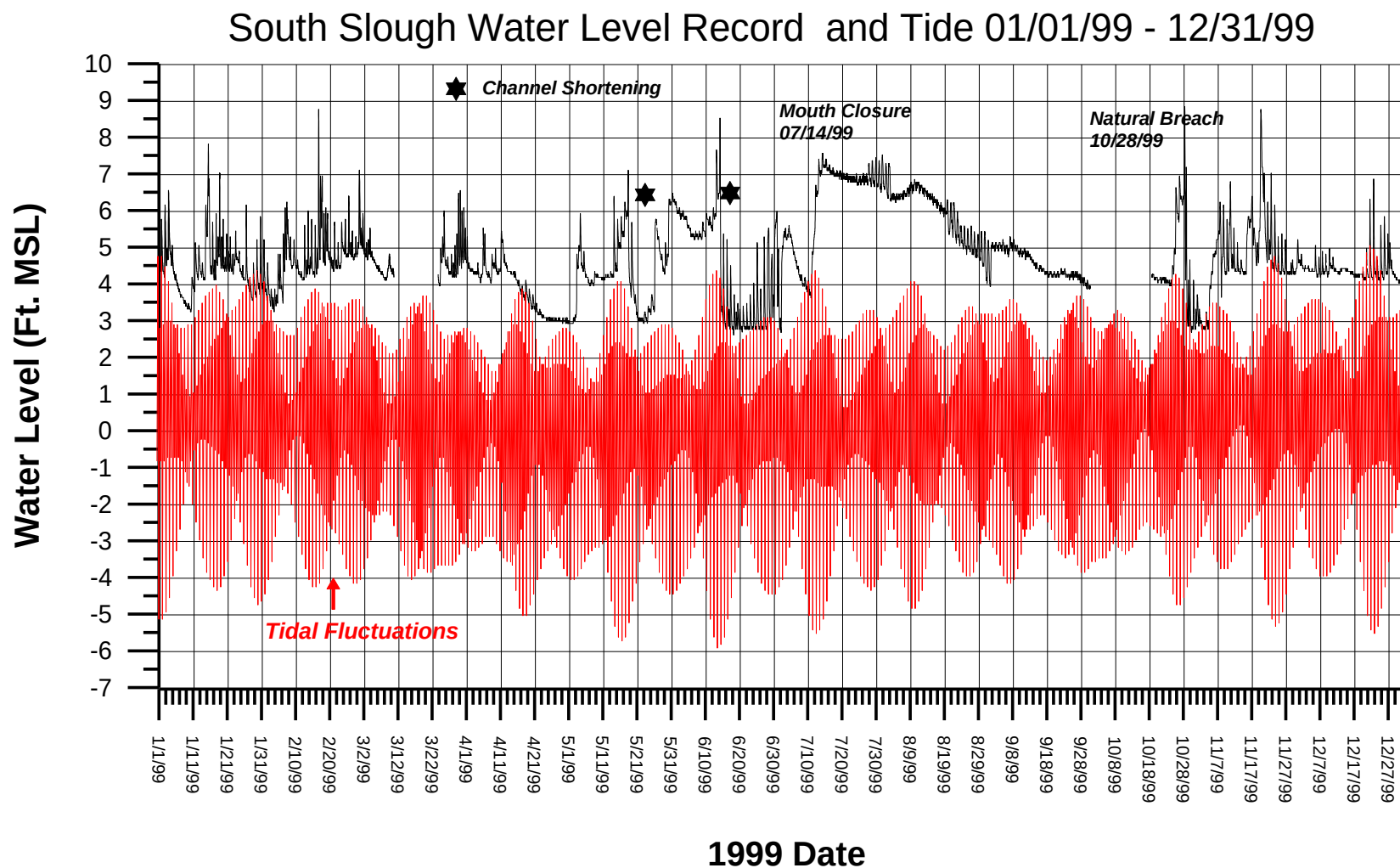


Figure 3. South slough water elevations (feet Mean Sea Level [MSL]) of the Redwood Creek estuary, Humboldt County for the period January 1 to December 31, 1999, excluding March 10 through 23, and September 30 through October 18, 1999. Estimated tidal elevations are corrected for the coastal locality at the mouth of Redwood Creek and adjusted to feet MSL

Embayment Water Level Tides at Mouth of Redwood Creek 07/12/99 - 10/29/99

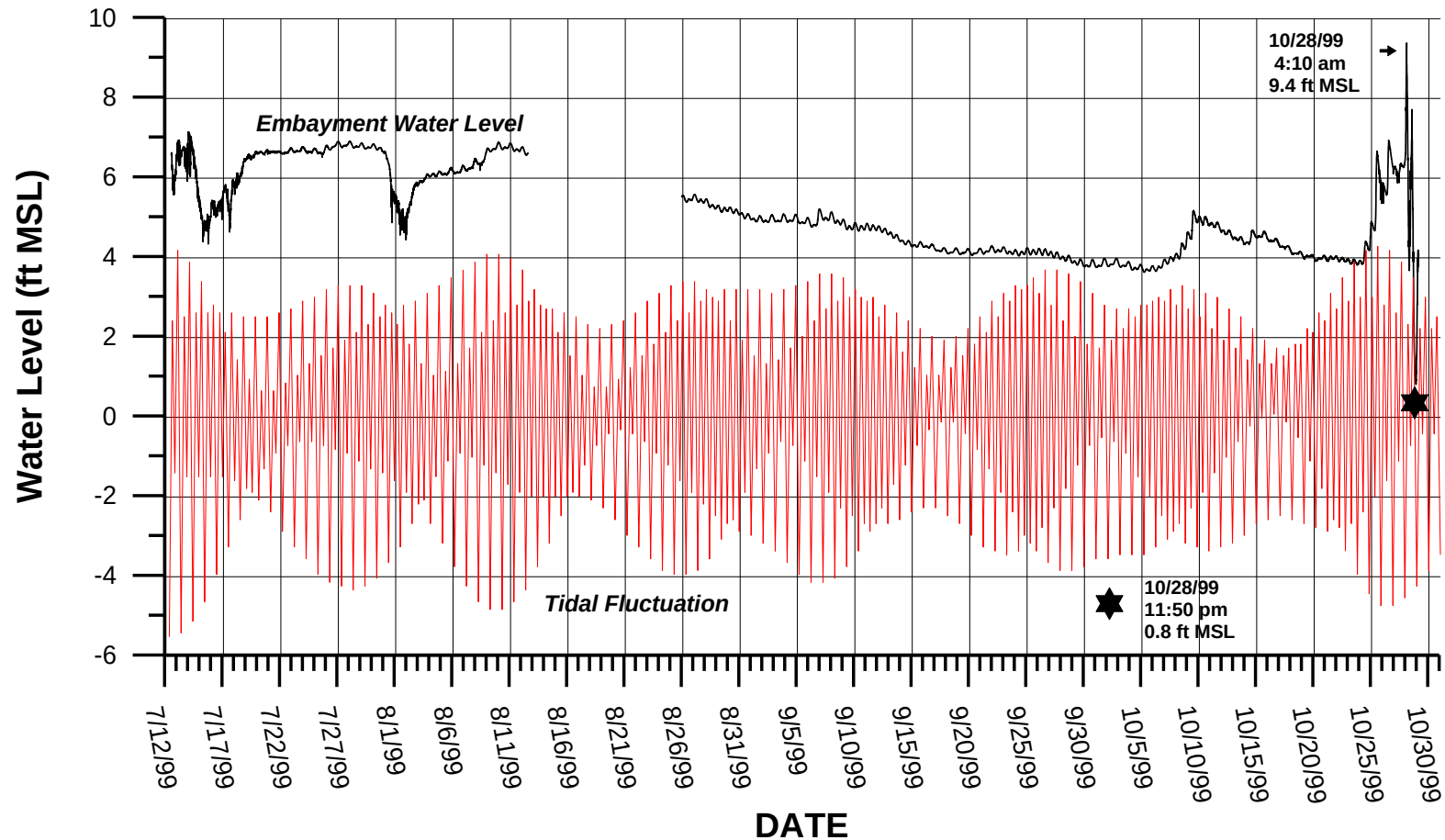


Figure 4. Embayment water elevations (feet Mean Sea Level [MSL]) of the Redwood Creek estuary, Humboldt County for the period the seasonal gage was in operation, July 12 to October 29, excluding August 12 through 26, 1999. Estimated tidal elevations are corrected for the coastal locality at the mouth of Redwood Creek and adjusted to feet MSL. A natural breach occurred on October 28, 1999.

temperature records that indicate tidal action influencing water temperature ended between July 14 and 15 (Figure 2). The embayment remained closed for 106 days, from July 14 until its natural breach on October 28. Between July 10 and October 25 (when the water level began to rise precipitously), the water elevation gradually dropped from 7.6 to 3.8 ft MSL, a decline of 3.8 ft.

Breaching and Estuary Response

The estuary breached naturally on October 28, 1999. It was not predicted. High seas played a major part in the natural breach. A small flow event, the first of the season, that peaked at 276 cfs on the morning of October 28 (Appendix II), coupled with an afternoon high tide of 7.5 ft (3.89 ft MSL) and very high seas filled the embayment causing water to top, scour, and breach the berm. Combined seas on October 28 were forecast at 31-37 ft during the day, 27 to 33 ft in the evening and 16 to 20 ft at night. We observed large waves washing over the entire berm and propagating into the embayment that afternoon. The embayment water level was observed even with the berm height. At the south levee gage, the embayment water level peaked at 9.4 ft MSL at 4 a.m. on October 28. By 11:50 p.m. that night the mouth was open as the water level had decreased to 0.8 ft MSL (Figure 4). The last berm survey on October 18 had the lowest elevation on the low berm at 7.6 ft MSL and on October 24, the embayment water level had decreased to 3.8 ft MSL. An increase of 3.8 ft would have been necessary to breach the berm then, but based on the maximum water elevation recorded, 9.4 ft MSL, the berm must have aggraded another 1.8 ft from 7.6 to 9.4 ft MSL. Before it breached, a 5.6 ft water elevation increase occurred. After the natural breach the estuary stayed open the rest of the season, aided by five small flow events, the largest peaking at 3,034 cfs on December 1, 1999 (Figure 3 and Appendix II).

South Slough Culvert Gates

The culvert gates are 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 from 0.5 to 1 ft on May 27, 1999. Unlike other years, the embayment and slough were at the same level as no water flowed through the culverts when the gates were opened. They were completely opened on June 17 at 1530. The gates were closed on November 8, 1999 to prevent sedimentation in the slough.

Estuary Cross Sections

Five permanent parallel cross-sections perpendicular to flow in the embayment were surveyed on July 21, 1999. 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 south through the embayment to the sand dunes. They are surveyed annually as specified by the Corps permit. Estuary cross sections are presented in Appendix III. The lowest elevation (ft MSL) at E-1 was -1.12 ft, at E-2 -1.17 ft, at E-3 -1.76 ft, at E-4 -4.04, and at E-5 0.76 ft. The net change (scour or fill) from 1998 cross sections were as follows: E-1 +65.1 ft², E-2 +47.5 ft², E-3 +2,606.1 ft², E-4 +5,737.5 ft², and E-5 +3,008.1 ft².

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 (ft³) and wetted width of the cross sections for varying water elevations (Appendix IV). The embayment volume ranged from 5,733 ft³ at -3 ft MSL to 3,872,874 ft³ at 11 ft MSL.

Sand Berm Elevation Monitoring

A longitudinal profile of the sand berm parallel to the ocean shore separating the estuary from the ocean was surveyed six times (instead of the required five) during the summer and fall of 1999, on May 26, June 28, July 29, August 30, September 15, and October 18, 1999. The longitudinal berm surveys, profiles 1 through 6, are presented in Appendix V. Both the winter storm berm, denoted as the high berm, and summer swell berm, denoted as the low berm, were surveyed. Because of the depth of the channel and flow, it was not always possible to wade into and survey the channel bottom.

On May 26 and June 28 surveys, the mouth was open to the ocean. The water elevation (ft MSL) at the low berm was 0.94 ft MSL and 5.4 ft MSL at the edge of the high berm on May 26 (see profile 1). The channel was 1,500 ft long between the high and low berms. On June 28, at the low berm the water was 2.56 ft MSL at right edge of channel, -0.52 ft MSL on the thalweg bottom, and 2.66 ft MSL at the edge of the high berm (see profile 2). The channel was 600 ft long between the high and low berms.

On July 29, with the mouth completely closed, the water elevation at the high berm was 6.6 ft MSL and the lowest depression on the low berm was 7.4 ft MSL (see profile 3). On August 30 and the mouth closed, the water elevation at the high berm was 5.28 ft MSL and the lowest depression on the low berm was 8.7 ft MSL (see profile 4). On September 15 and the mouth closed, the water elevation at the high berm was 4.6 ft MSL and the lowest depression on the low berm was 9.6 ft MSL (see profile 5). On October 18 and the mouth closed, the water elevation at the high berm was 4.3 ft MSL and the lowest depression on the low berm was 7.6 ft MSL (see profile 6). The lowest depression on the low berm represents the height at which the estuary would naturally breach on its own. Even with the mouth closed, seepage through the berm into the ocean occurred.

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

Other Activities

Pit-tagged Coho – During the week of June 7th, we captured 10 pit-tagged coho smolts that were read by Ethan Bell. During the week of July 19th, one of the four coho smolts caught had an adipose fin clip, indicating it was a pit-tagged fish.

Estuary Snorkeling – Initial observations of snorkeling between the levees are that there was not much large woody debris for cover. Most of the cover was at the levee toe where riprap, algae, and grass provided cover. Very few fish were observed over the 1900 m reach, 3 sculpin, 7 threespine stickleback, 2 salmonids, and 12 young-of-the-year steelhead. In the embayment west of the slough outlets, only the 3 sculpin were observed.

Of the snorkel observations in conjunction with the four seine hauls, only six prickly sculpins were observed at the south levee location, but 180 fish were captured in the seine net. No fish were observed at the other three berm/channel sites, but seine hauls caught from 140 to 230 fish including cutthroat and steelhead trout, coho and chinook salmon, threespine stickleback, starry flounder, and prickly sculpins.

Discussion

The mean lengths and weights of salmonid fish residing in the estuary increased during the summer

indicating the estuary provided rearing habitat. Length and weight ranges continued to increase during the summer indicating the entire estuary population was growing. Those fish that resided in the estuary during the summer and migrated to the ocean in the fall were larger than those that emigrated prior to the closure of the mouth. Their larger size would confer an increased chance of survival in the ocean (Reimers 1973).

Coho salmon were the exception. Their large size and early capture were indicative of smolts migrating downstream to the ocean. The large number caught during the week of June 7th, over 525 coho, was the most ever caught in the Redwood Creek estuary for the period 1988 to 1995, 1997, and 1998 (Anderson 1995, 1997, 1998). Their relative absence the rest of the summer indicates we intercepted the last segment of the downstream coho smolt migration.

All estuary population estimates decreased over time. Some fish might have migrated out the estuary prior to its closure, but many died while residing in the closed embayment the rest of the summer. Contributing factors could have been decreased estuary volume (Table 4), disease, and high water temperatures. A low incidence of popeye was seen in chinook juveniles. Popeye is when one or both eyes protrude from the eye socket.

Table 4. Calculated 1998 and 1999 volume (ft³) of the Redwood Creek embayment at water elevations -3 to 11 ft MSL. Volume of the embayment is the area west of the ends of the north and south levee and not including the north or south sloughs.

Water Elevation (ft MSL)	1998 Volume (ft ³)	1999 Volume (ft ³)
11	10,441,569	3,872,874
10	4,976,663	3,809,759
9	4,216,846	3,059,301
8	3,491,578	2,450,967
7	2,843,996	1,981,568
6	2,320,103	1,617,018
5	1,886,777	1,296,799
4	1,495,882	1,014,197
3	1,134,128	760,089
2	798,888	527,405
1	464,790	332,726
0	226,903	171,681
-1	53,794	63,343
-2		22,052
-3		5,733

Water temperatures in the Redwood Creek estuary were warm. Water temperatures, which ranged between 8.9 and 21.1°C, were not always optimum for rearing salmonids. After the closure of the

mouth on July 15, temperatures during July through September 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 that period water temperatures did not fall below 14°C and at times were above 15 and 16°C. This was a period when the estuary was closed and fish could not migrate to cooler ocean waters, nor would there have been much input of cooler ocean water into the estuary, except by wave overwash across the berm.

One 320-mm cutthroat was captured with fishing line in its mouth indicating some fishing pressure occurs in the estuary.

The berm profile surveys determined the high berm (winter berm) did not change between May and October. However, the low berm (summer berm) profiles changed. Locations of the mouth changed as the channel migrated and shortened. Portions of the low berm increased in height after closure of the mouth. It remained relatively unchanged between July 29 and September 15, and lowered by October 18. Also, survey points plotted on the aerial photo indicate the winter berm has moved over the years.

Snorkeling in the estuary, direct observation, to observe fish does not seem to be an effective technique. The deep water depth, from 2-3 m, lack of habitat complexity, no flow, wide expanses, and limited horizontal visibility allow the fish to evade visual detection. In all cases we seined many more fish than were observed.

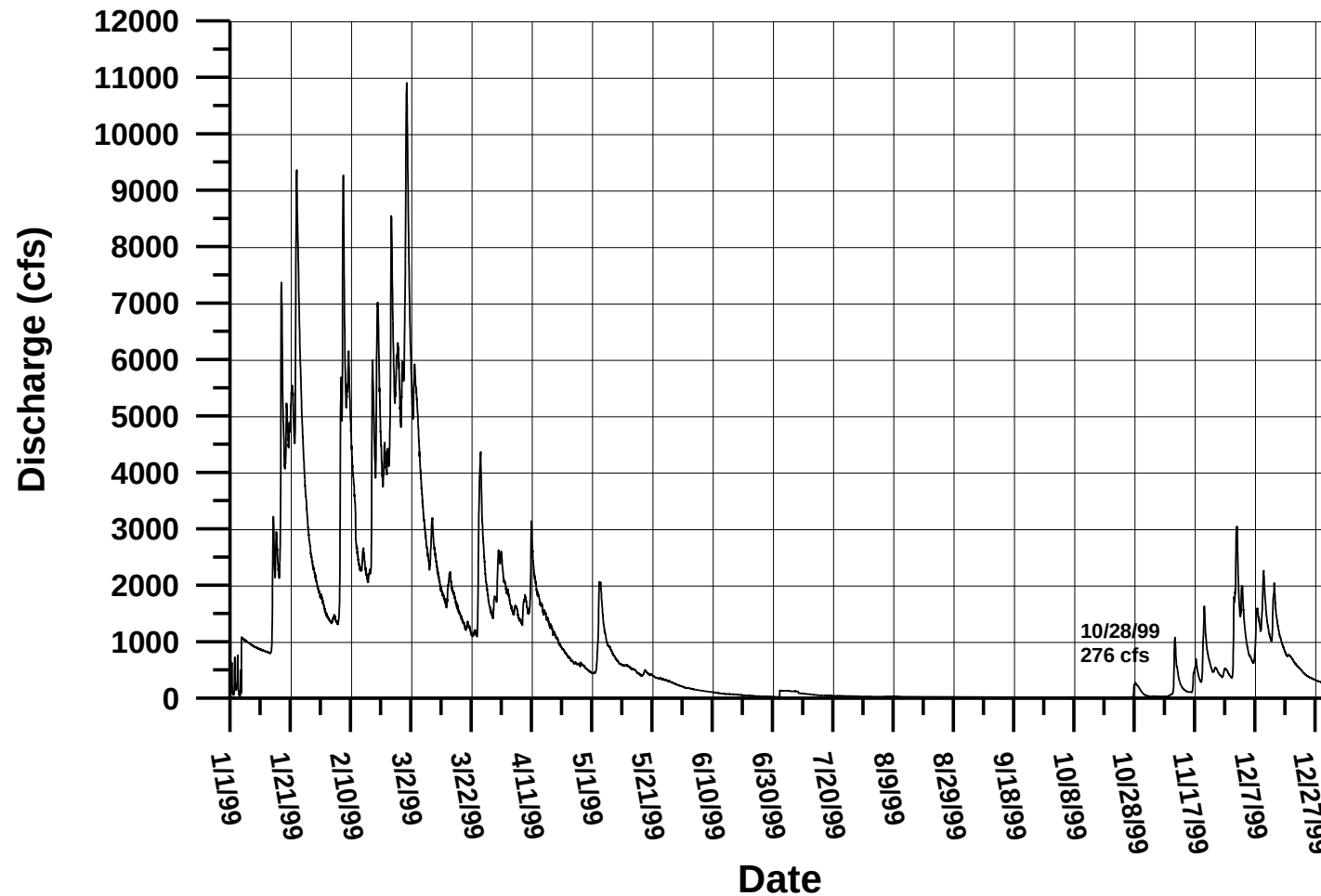
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- Prepared by: David G. Anderson – REDW Fishery Biologist, Redwood National and State Parks, P.O. Box 7, Orick, California. 95555 (707) 464-6101 x 5271
[2/2000]

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.

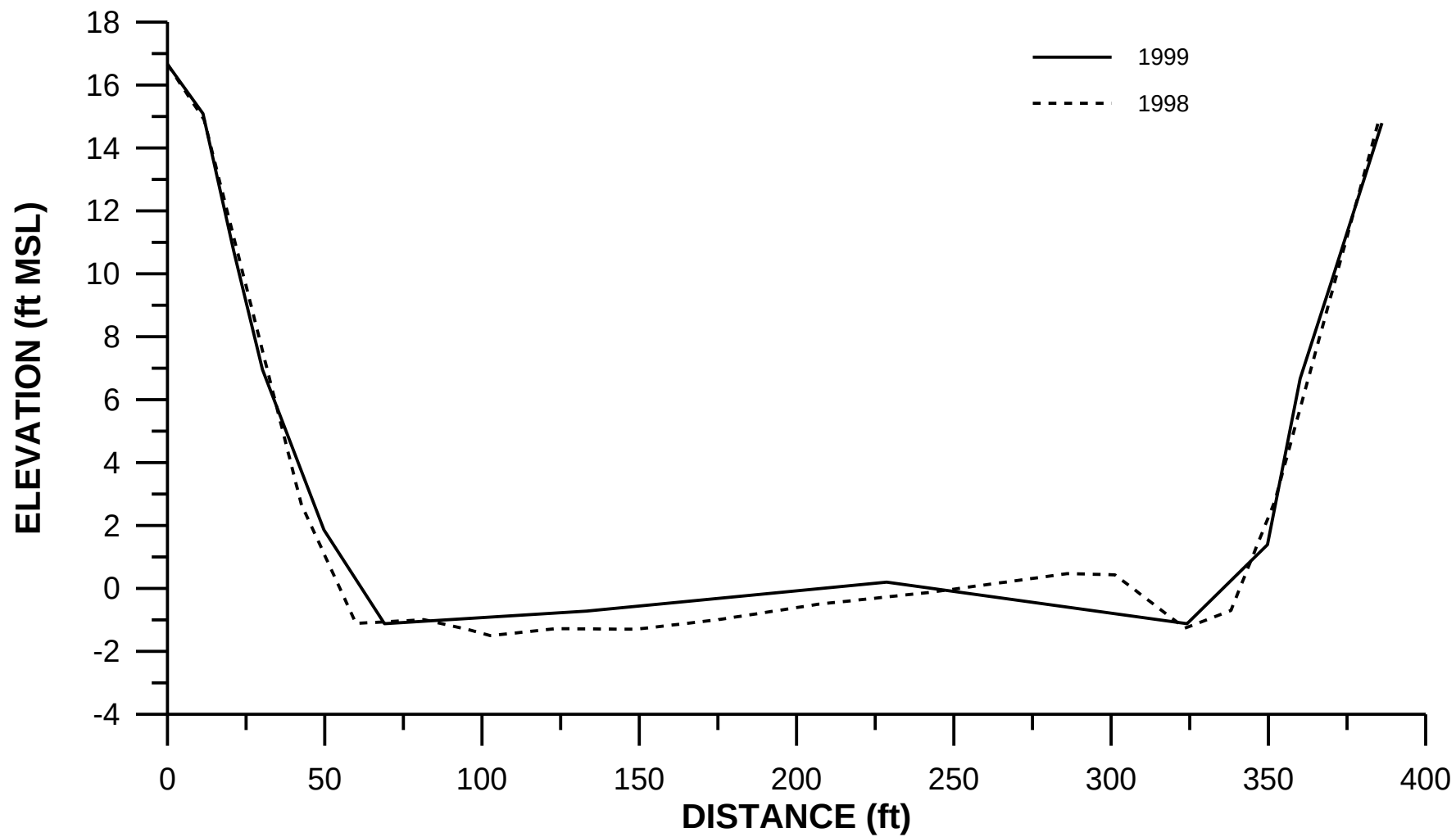
Appendix II. Hourly Redwood Creek flow data for calendar year 1999, January 1 through December 31, 1999. Data is from the California Department of Water Resources Orick (ORK) gaging station located on Redwood Creek downstream of the confluence of Prairie Creek and north of the community of Orick, California.

Redwood Creek at Orick (ORK): Calendar Year 1999

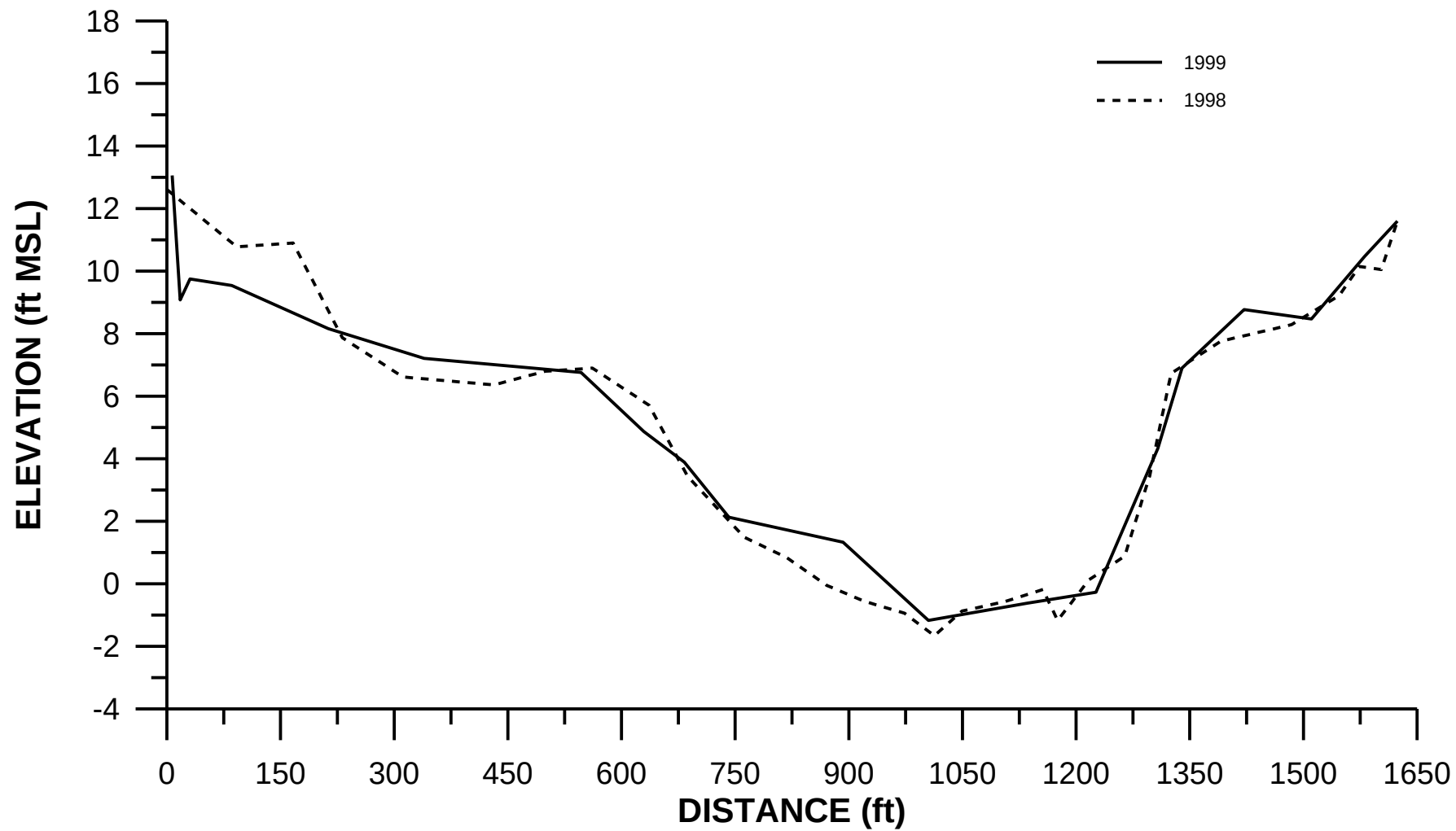


Appendix III. The five permanent cross-sections surveyed on July 21, 1999 in the estuary embayment perpendicular to the flow. Established in June of 1998, each cross section was shot at a bearing of 170° from the north endpoints through the embayment to the sand dunes on the south. The parallel cross sections start between the ends of the levees with E-1 and end to the west with E-5 at the seastack adjacent to the berm. Zero on the x-axis of each graph represents the northside endpoint.

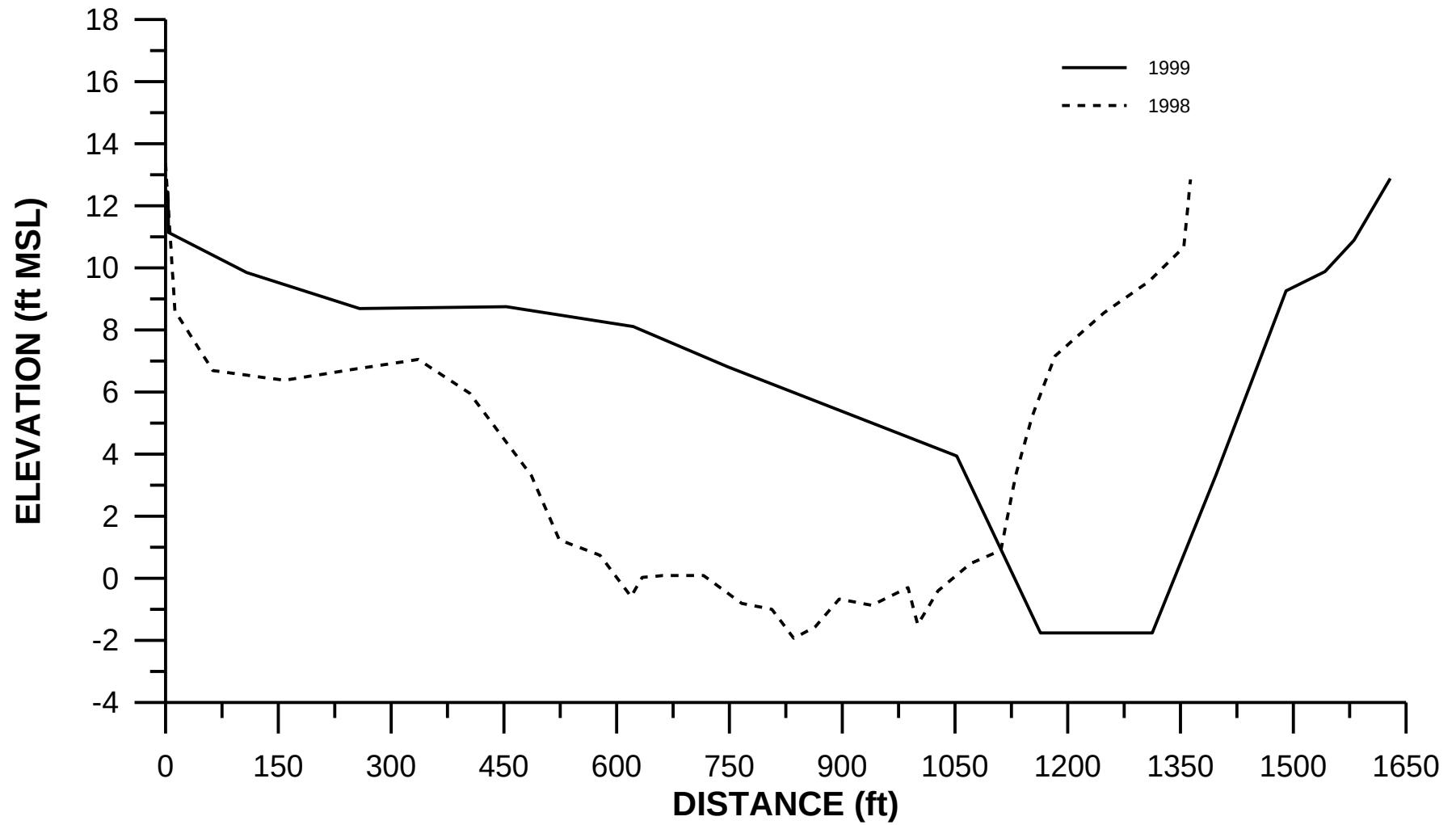
ESTUARY CROSS SECTION E-1



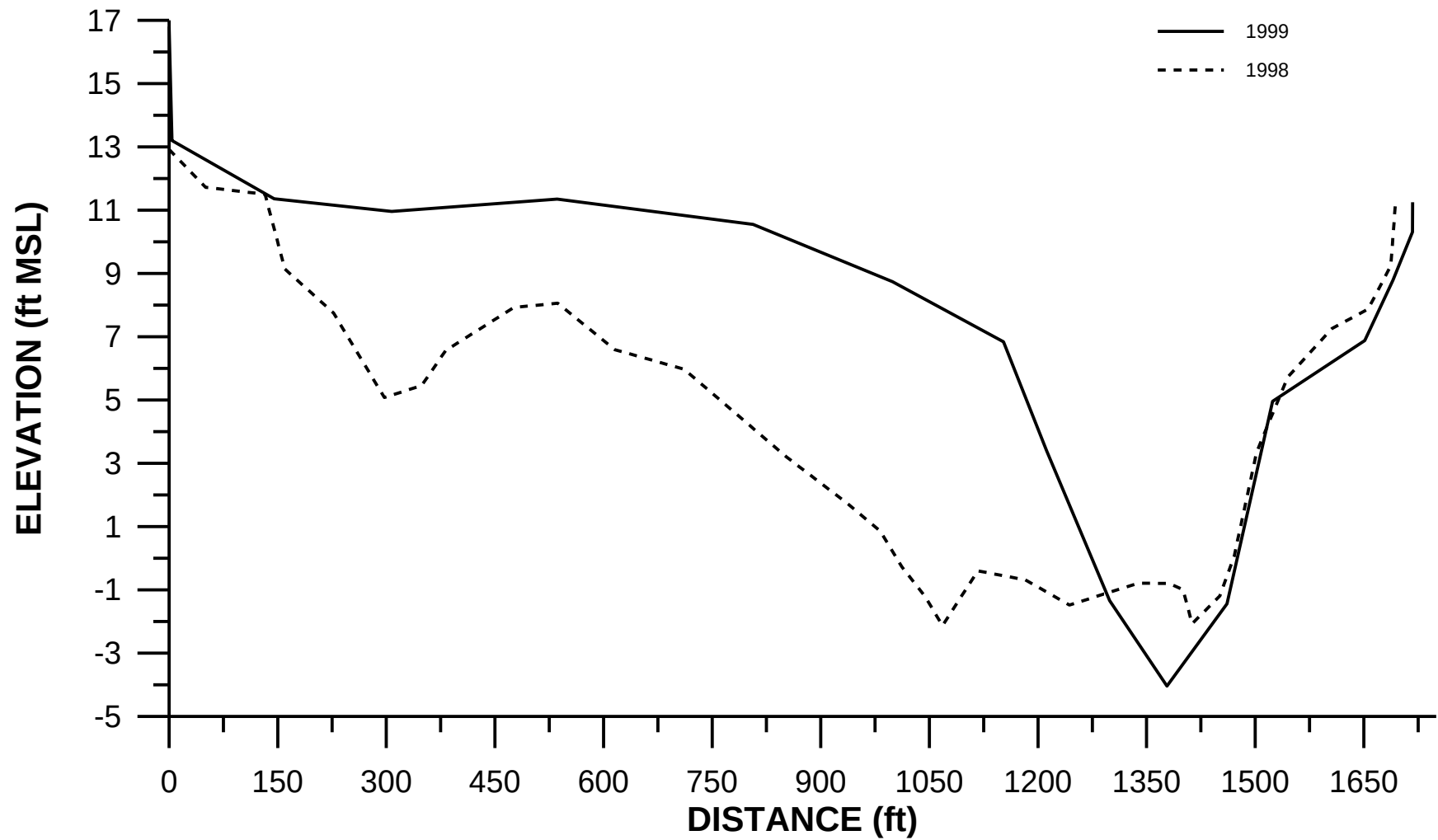
ESTUARY CROSS SECTION E-2



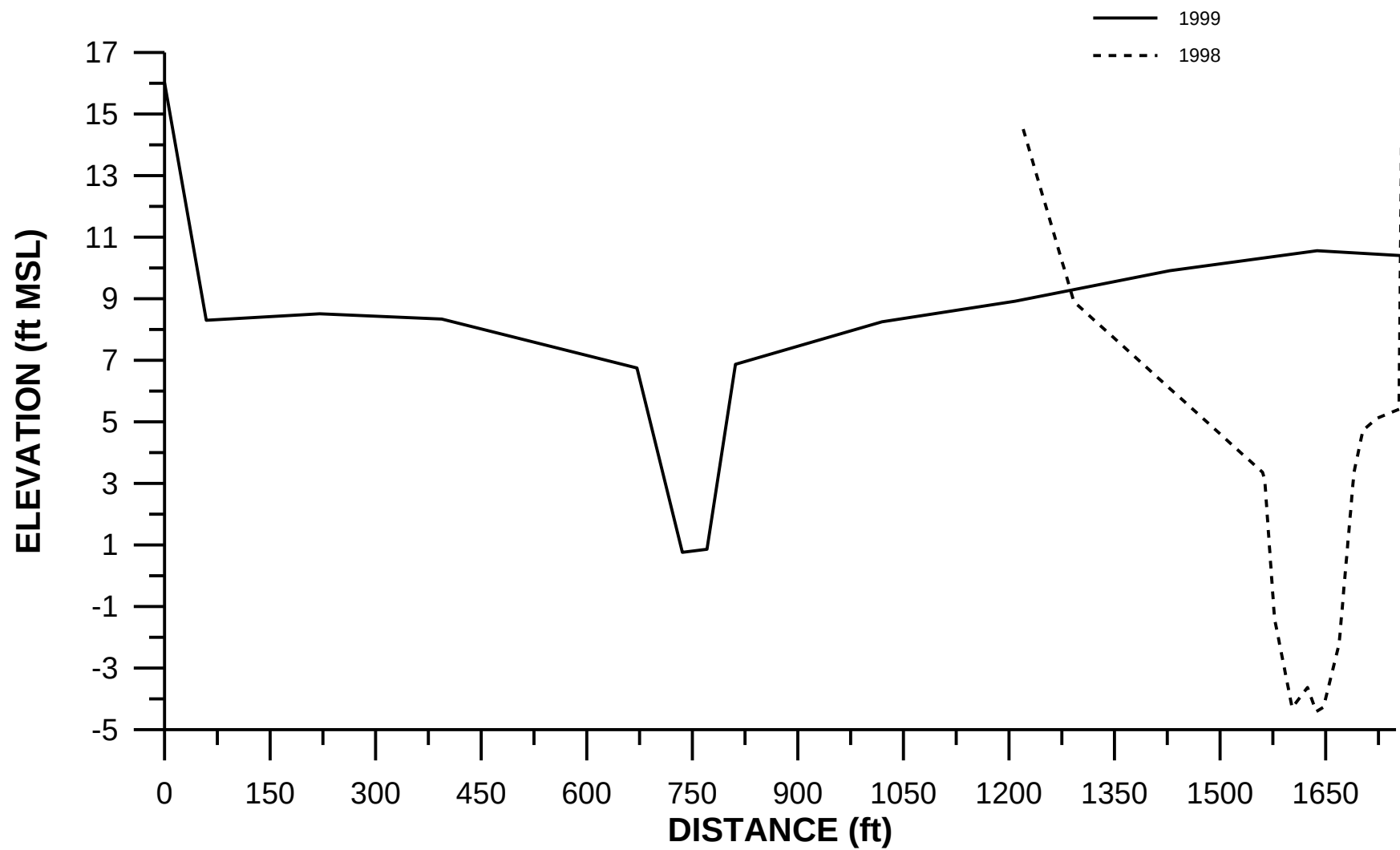
ESTUARY CROSS SECTION E-3



ESTUARY CROSS SECTION E-4



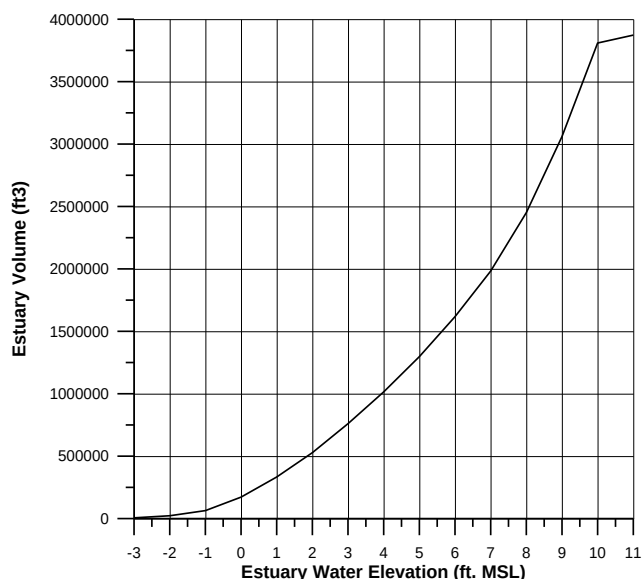
ESTUARY CROSS SECTION E-5



Appendix IV. Calculated volume (ft³ and yd³) and wet width (ft) of the Redwood Creek embayment at water elevations of -1 to 11 ft MSL based of the five cross sections E-1 through E-5 surveyed on July 21, 1999. Volume of embayment is the area west of the ends of the north and south levee and not including the north or south outlet channels or sloughs.

Volume for Varying Water Elevations in the Redwood Creek Estuary – 1999							
Water Elev. (ft MSL)	X/S E1 Wet Area (ft)	X/S E2 Wet Area (ft)	X/S E3 Wet Area (ft)	X/S E4 Wet Area (ft)	X/S E5 Wet Area (ft)	Estuary Volume (ft ³)	Estuary Volume (yd ³)
11	3668.17	9584.27	7755.21	1102.85	4710.53	3,872,874	143,440
10	3317.35	8015.65	6244.69	4691.77	3102.85	3,809,759	141,102
9	2972.15	6539.59	4885.78	3907.14	1814.78	3,059,301	113,307
8	2632.61	5274.16	3872.68	3240.38	926.87	2,450,967	90,777
7	2298.71	4216.06	3090.97	2675.52	560.68	1,981,568	73,391
6	1970.84	3426.9	2424.97	2207.17	419.27	1,617,018	59,890
5	1648.83	2706.14	1880.51	1822.91	301.73	1,296,799	48,030
4	1332.62	2045.98	1457.73	1496.23	201.74	1,014,197	37,563
3	1022.21	1448.47	1118.55	1196.83	119.29	760,089	28,151
2	717.61	903.6	815.49	925.4	54.39	527,405	19,534
1	420.39	498.59	548.64	682.16	7.04	332,726	12,323
0	141.78	188.57	318	467.12	0.0	171,681	6,359
-1	1.8	4.08	123.57	280.27	0.0	63,343	2,346
-2	0	0	0	127.47	0.0	22,052	817
-3	0	0	0	33.14	0.0	5,733	212

For Reference:
X/S e1 @ end of Redwood Creek levees
X/S e5 near large sea stack on beach, X/S closest to ocean

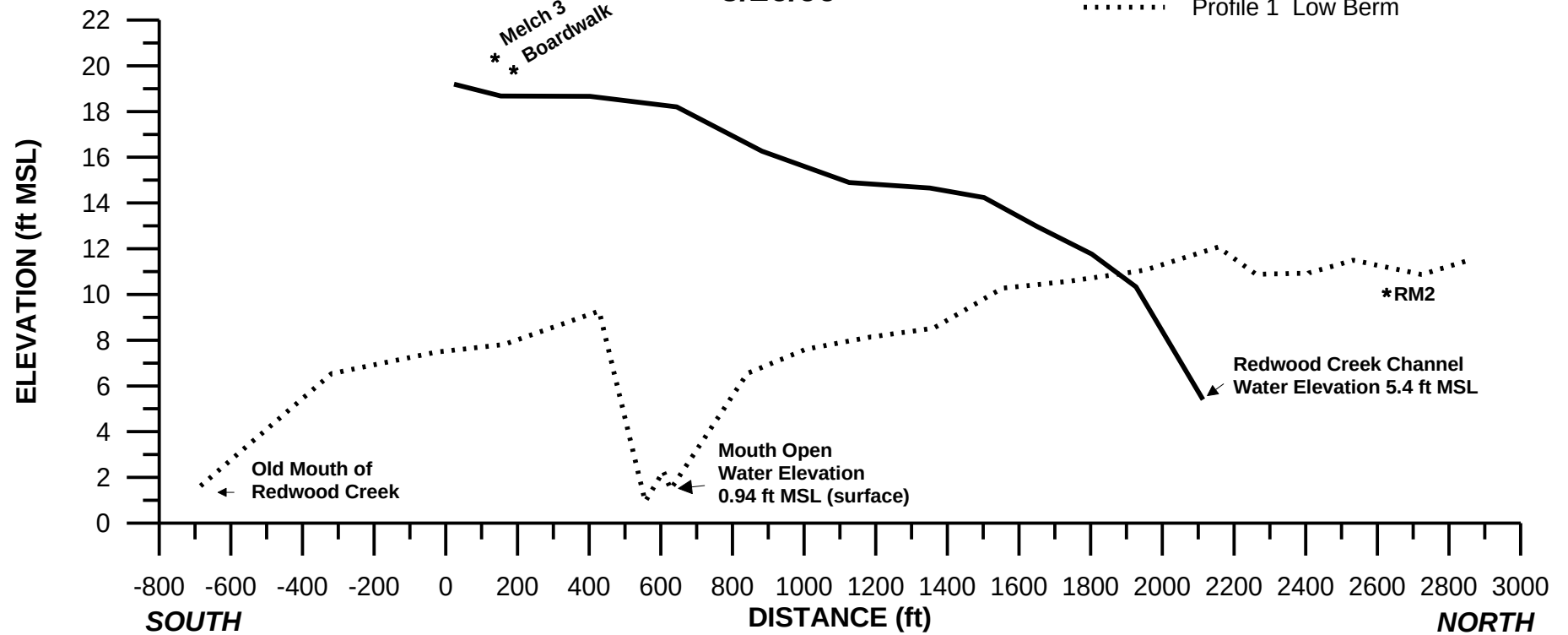


Appendix V. Longitudinal profiles of the sand berm along the highest ridge parallel to the shore and separating the estuary from the ocean for May 26, June 28, July 29, August 30, September 15, and October 18, 1999 (Profiles 1 through 6 respectively). The profiles extended from a minimum of 100 feet 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 the summer swell berm, denoted as the low berm, were surveyed. The mouth was completely closed to the ocean on July 29, August 30, September 15, and October 18 surveys.

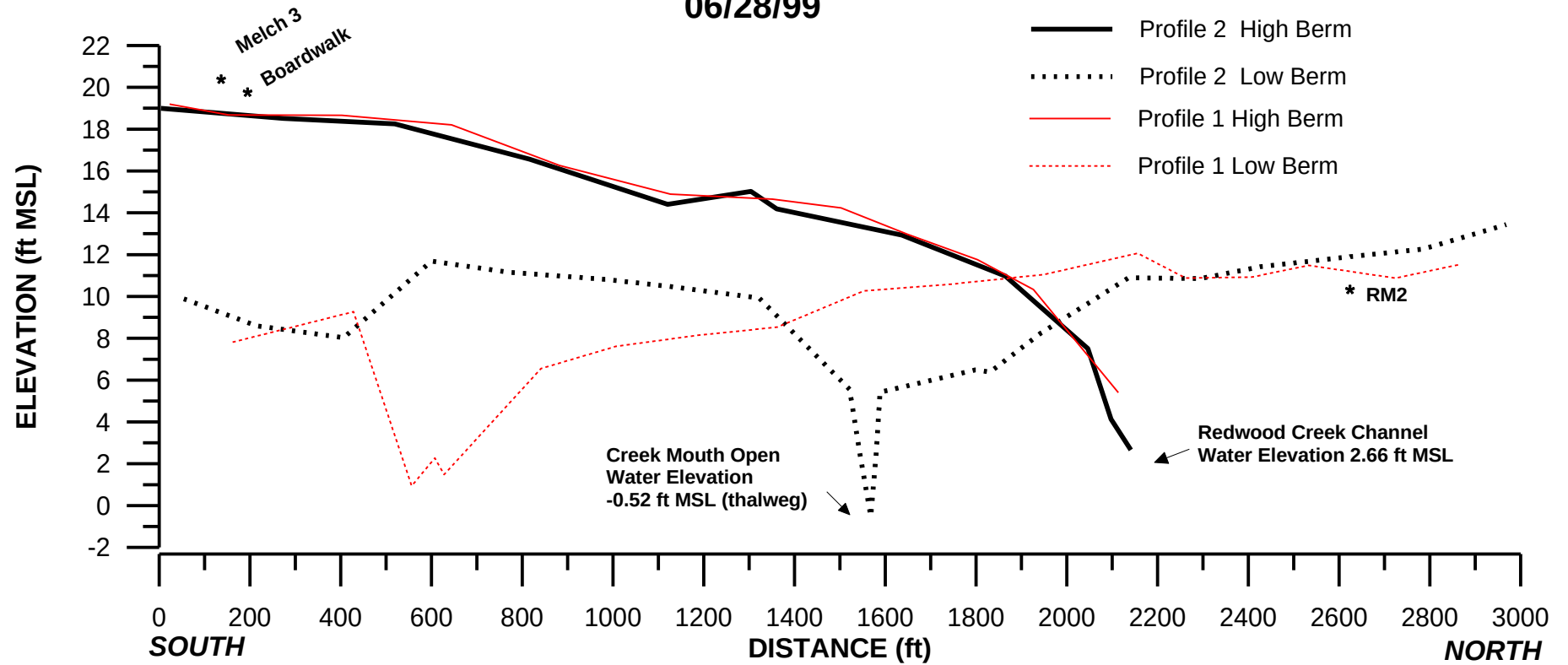
1999 RWC ESTUARY DUNE PROFILE 1

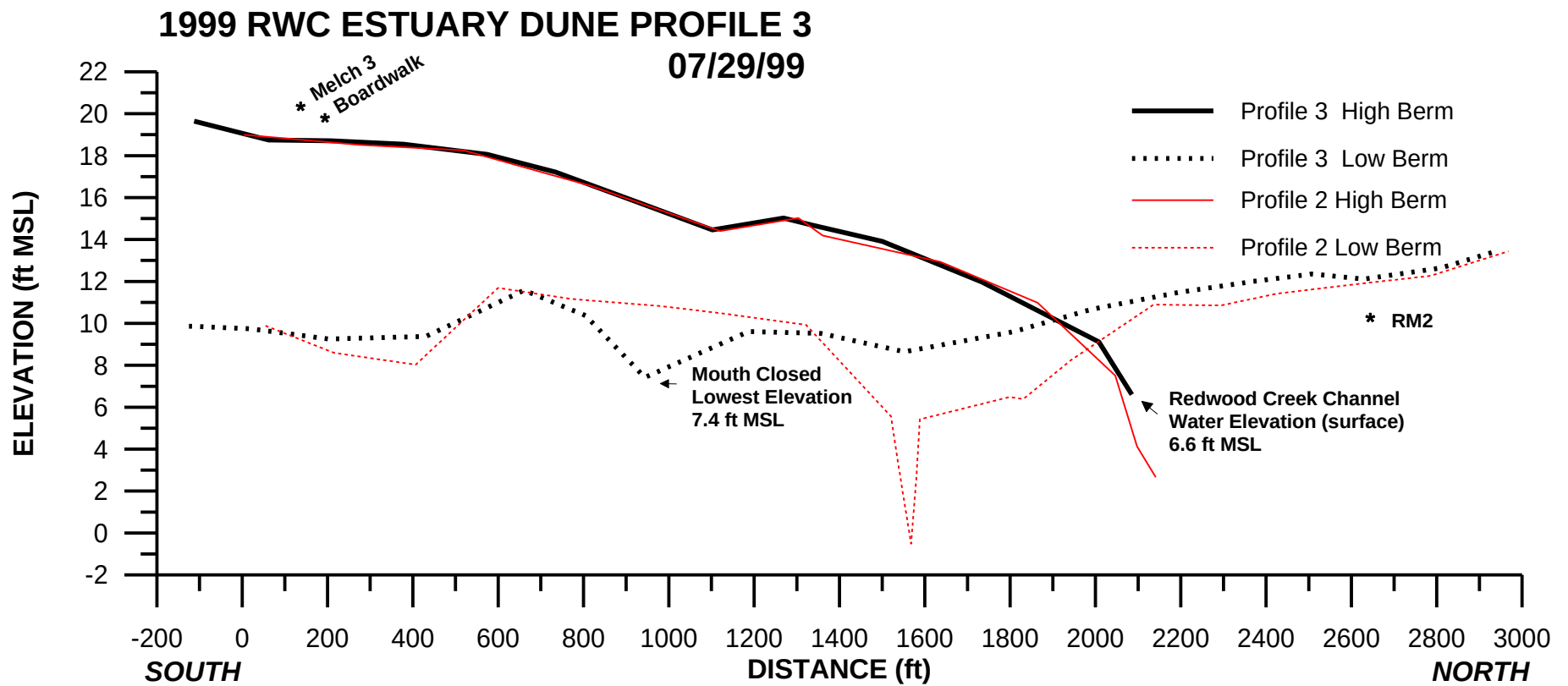
5/26/99

— Profile 1 High Berm
..... Profile 1 Low Berm

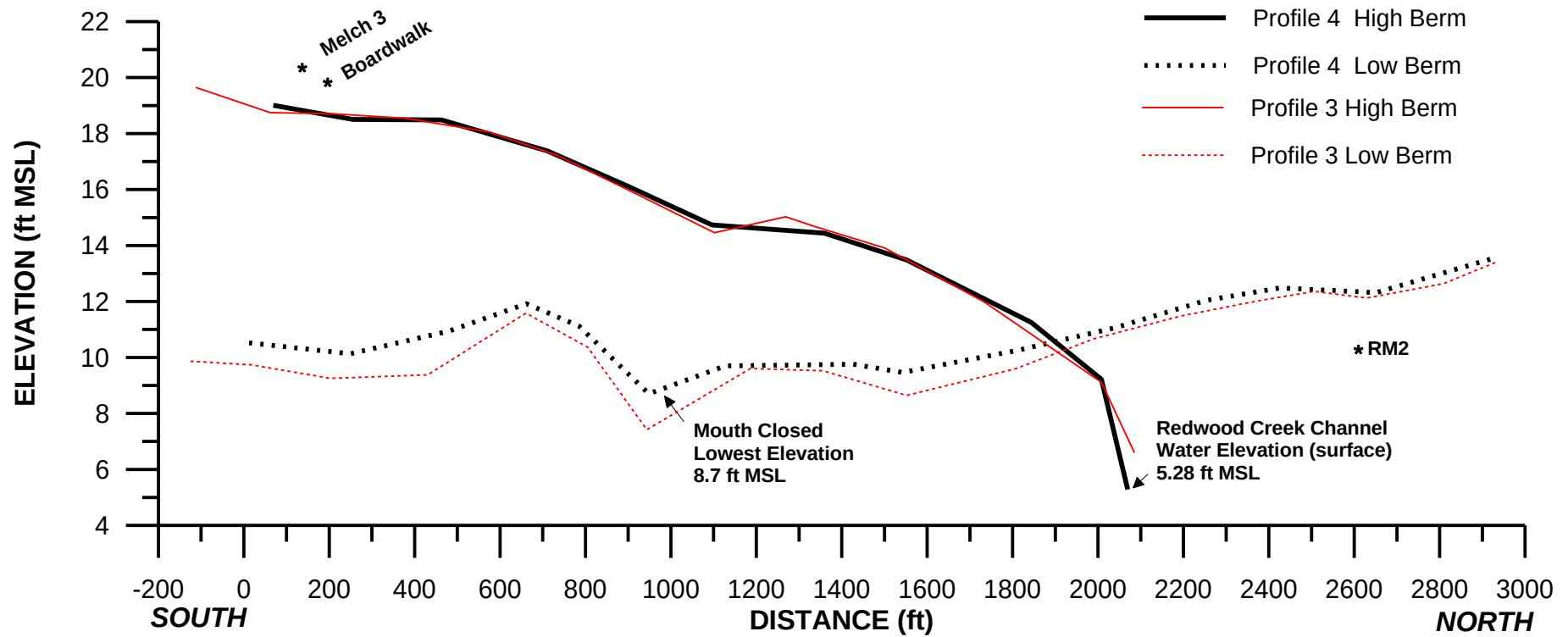


1999 RWC ESTUARY DUNE PROFILE 2 **06/28/99**



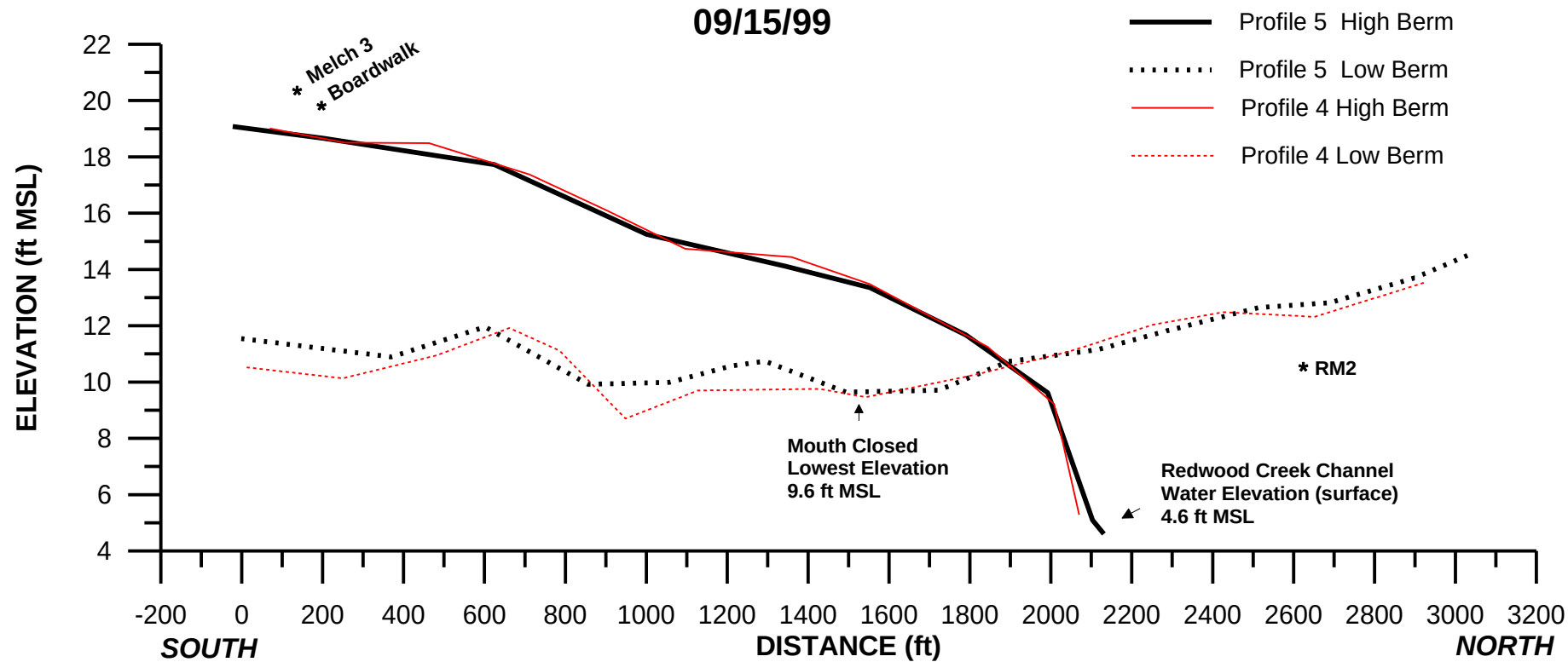


1999 RWC ESTUARY DUNE PROFILE 4 **08/30/99**

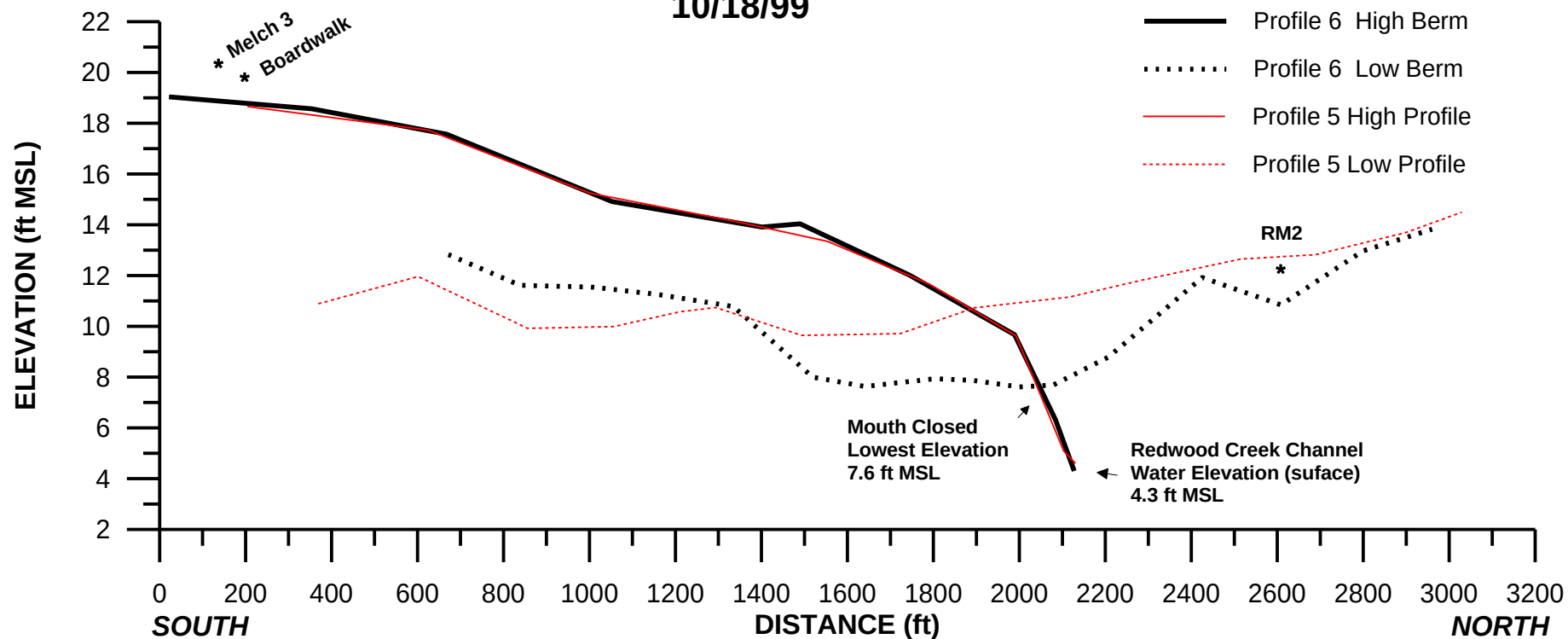


1999 RWC ESTUARY DUNE PROFILE 5

09/15/99



1999 RWC ESTUARY DUNE PROFILE 6 **10/18/99**



Appendix VI. Survey points of the longitudinal sand berm profiles plotted on 1:6000 aerial photo for each of the six profiles (2 cm = 407 ft). (Redwood National and State Parks photo no. 15-12 Redwood Creek 97 dated 6/19/97).

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 components.

Estuary Biological Monitoring

Fish and Wildlife Branch: David Anderson, Eddie Childers, Howard Sakai, Bill Falvey, Baker Holden III, and Kyle Max

Resource Management Labor Support Crew: Tim Tanno, Darlene Buckskin, Keith Richey, Doug Smith, and Robert Hurst

VIP: Trevor Parker, NSF Forest Science Teachers – Kevin Lane and Greg Stackhouse, Heidi Jandro and Karen Shay

Agency: Rod Nakamoto and Heather Hendrixon of Redwood Sciences Laboratory- USFS, Ethan Bell and Steve Tussing of Fish Coop Unit-HSU

Estuary Water Level Monitoring

Geological Services: Carrie Jones (Data Collection and synthesis) and Tom Marquette (Equipment Repair)

Installation and Removal of South Levee Water Elevation Recording Gage

Geological Services: Carrie Jones

Fish and Wildlife Branch: David Anderson, Kyle Max, and Baker Holden III.

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

Estuary Surveying of Berm and Embayment Cross Sections

Geological Services: Vicki Ozaki, Carrie Jones, and Sherry Romanini

Fish and Wildlife Branch: David Anderson

VIP: Keenan Hinz

Culverts Opening and Closing

Fish and Wildlife Branch: David Anderson and Baker Holden III.