MANAGEMENT ALTERNATIVES FOR THE REDWOOD CREEK ESTUARY

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I. INTRODUCTION

Redwood National Park's Watershed Rehabilitation Plan (United States Department of the Interior [USDI], National Park Service [NPS], Denver Service Center [DSC] 1981) and Resources Management Plan (USDI, NPS, Redwood National Park [RNP], 1982) recognized that the embayment at the mouth of Redwood Creek was an extremely important and potentially very productive part of the watershed. Both plans also recognized that the morphology and productivity of the estuary had been impaired by construction of a flood control project on the lower 3.2 miles of Redwood Creek. In order to understand the nature and extent of the problem and to determine the feasiblity of restoring the estuary, a research project was initiated in 1980.

The research was designed to: (1) determine seasonal patterns in changes of water quality; (2) determine and compare present patterns of inundation, seasonal morphological changes, and sediment sources with historic information, and; (3) determine abundance, distribution and seasonal timing of use of the estuary by fish species.

The purposes of this document are: (1) to summarize the research results relating to the physical and biological functioning of the estuary; (2) to present and analyze interim and long-term management alternatives for the estuary, and; (3) to facilitate obtaining public input on the estuary management/rehabilitation issue.

A more detailed technical discussion of research results will be presented in a forthcoming technical report.

II. AFFECTED AREA

The mouth of Redwood Creek is located approximately 2.5 river miles west of Orick, California (see Figure 1). Orick, along with adjacent ranches, mills, and farms was settled and developed within the Redwood Creek floodplain. Removal of spruce trees and other vegetation allowed farming and grazing of the rich alluvial soils and intermixed wetland area. The relatively narrow floodplain was periodically flooded due to steep basin gradients, intense storms, and rapid runoff characteristics of the region.

A series of severe floods occurred in 1953, 1955 and 1964. The flood of December 18 - 24, 1964 was the most damaging event of the century in the north coast region (Harden, Janda, and Nolan 1978). The peak discharge of this flood was only slightly larger than the 1953 and 1955 floods (Table 1), but the total flood volume and damage to streambanks and hillslopes was much greater (Janda and others 1975). Orick was inundated by five feet of water. Thick silt deposits, logs, and debris covered pastures in the valley (California Department of Water Resources 1966).

Following the 1964 storm, local residents requested the U.S. Army Corps of Engineers (COE) implement previously planned flood control measures (U.S. Army Corps of Engineers 1961) in the valley. In 1968, the Corps completed a flood control project on the lower 3.2 miles of Redwood Creek which consisted of levees and creek channelization. Prior to the flood control levees, the embayment formed a relatively deep, broad pool just landward from the beach (Figure 2 and Figure 3). Water levels fluctuated with river discharge, tides, sediment deposition, and shape of the outlet. Sediment deposition from ocean processes and river transport, and sediment removal through flooding, shaped the estuary on a year-to-year basis. Sediment along the west side of the embayment was deposited seasonally through ocean processes and represented the variability of wave transport and outlet location.

River deposition of sediment varied yearly with rainfall intensity. Climate, geology, and soil characteristics combine in rivers draining northern California to result in sediment yields that are among the highest in North America for basins of comparable size (Table 2). Sediment deposited along the east side of the embayment, adjacent to the middle island, middle slough, and north slough, seemed to be a permanent feature. This deposit was modified by interaction of eddies against the north cliffs, currents in the mainstem and middle slough, as well as tidal height and wave energy. Nevertheless there was a noticeable trend toward accumulation of sediment in the area between the middle and north sloughs which probably resulted from increased sediment carried from upstream during floods. Significant deposition in this part of the embayment is apparent on aerial photos taken three weeks after the flood of record on January 13, 1965. Slow recession of the 1964 flood waters contributed to extensive sediment deposition across the entire floodplain (Ricks 1983).

Before channelization, floods scoured the channel adjacent to the north cliffs and removed beach deposits which were laid down each winter at the

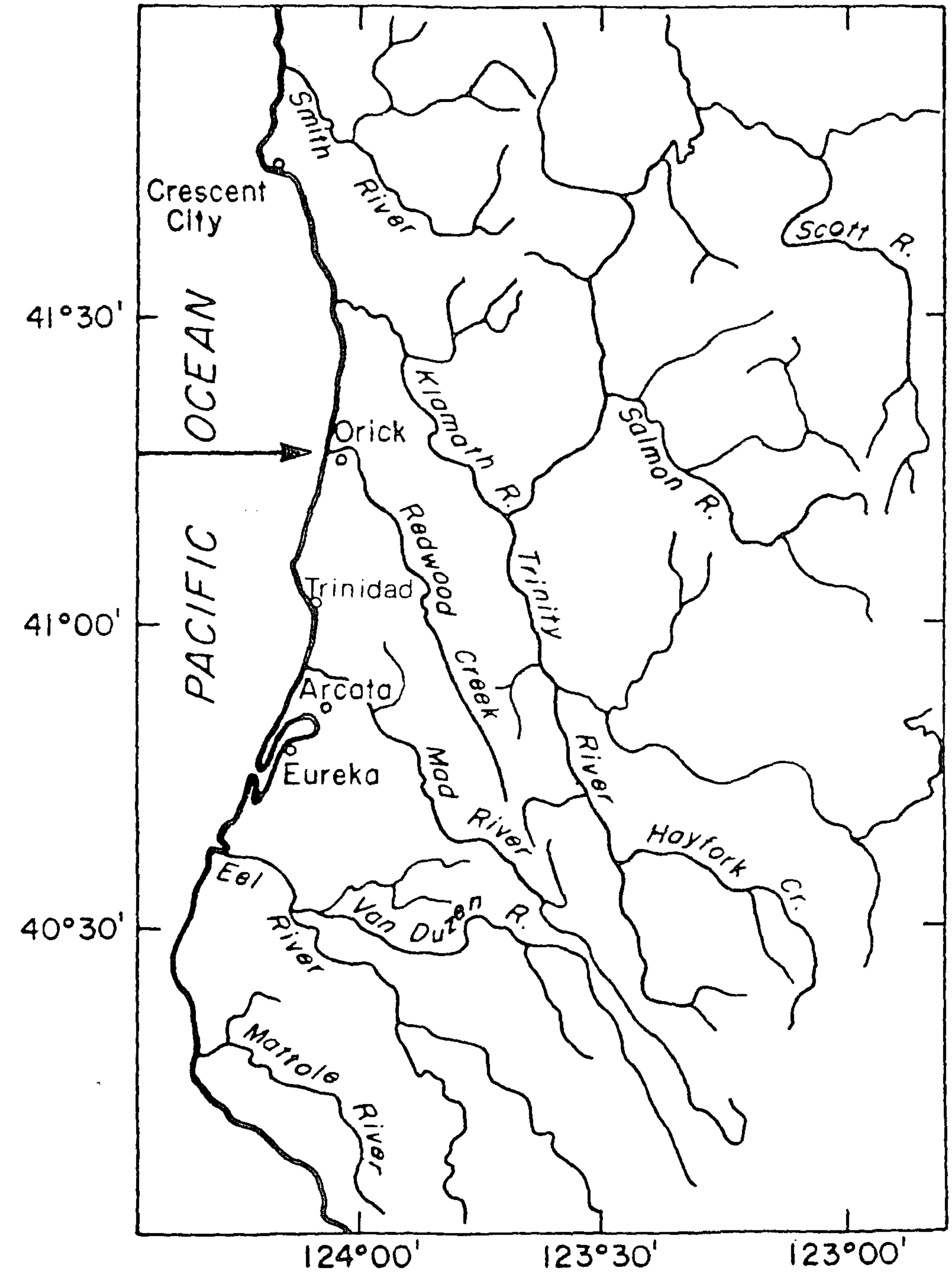


Figure 1: Northern California location map.

TABLE 1: Instantaneous Peak Discharge, Total Runoff and Antecedent Precipitation Index at Orick for Recent Major Floods on Redwood Creek (revised from Harden, Janda and Nolan, 1978).

Storm Dates	Instantaneous Peak Discharge m^3/sec (CFS)	Instantaneous Peak Discharge $m^3/sec/km^2$ (CFS/mi^2)	Storm Runoff cm (in)	Antecedent Precipitation Index[1] cm (in)
January 16-20, 1953 (peak @ ----, January 18)	1,415 (50,000)	1.97 (180)	- -	22.48 (8.85)
December 15-23, 1955 (peak @ 0600, December 22)	1,415 (50,000)	1.97 (180)	32.5 (12.8)	17.12 (6.74)
December 18-24, 1964 (peak @ 2100, December 22)	1,430 (50,500)	1.99 (182)	41.4[2] (16.3)	17.42 (6.86)
January 19-24, 1972 (peak @ 1430, January 22)	1,285 (45,300)	1.78 (163)	28.7 (11.3)	11.38 (4.48)
March 1-4, 1972 (peak @ 0045, March 3)	1,410 (49,700)	1.96 (179)	18.0 (7.1)	21.84 (8.60)
March 15-24, 1975 (peak @ 1300, March 18)	1,420 (50,200)	1.98 (181)	28.2 (11.1)	12.55 (4.94)

1 API indicates the effect of previous rainfall in wetting the soil and of natural drainage and evapotranspiration in reducing the soil moisture.

2 Total runoff at Orick for the extended storm period December 18-30, 1964, was 64.0 cm (25.2 in).

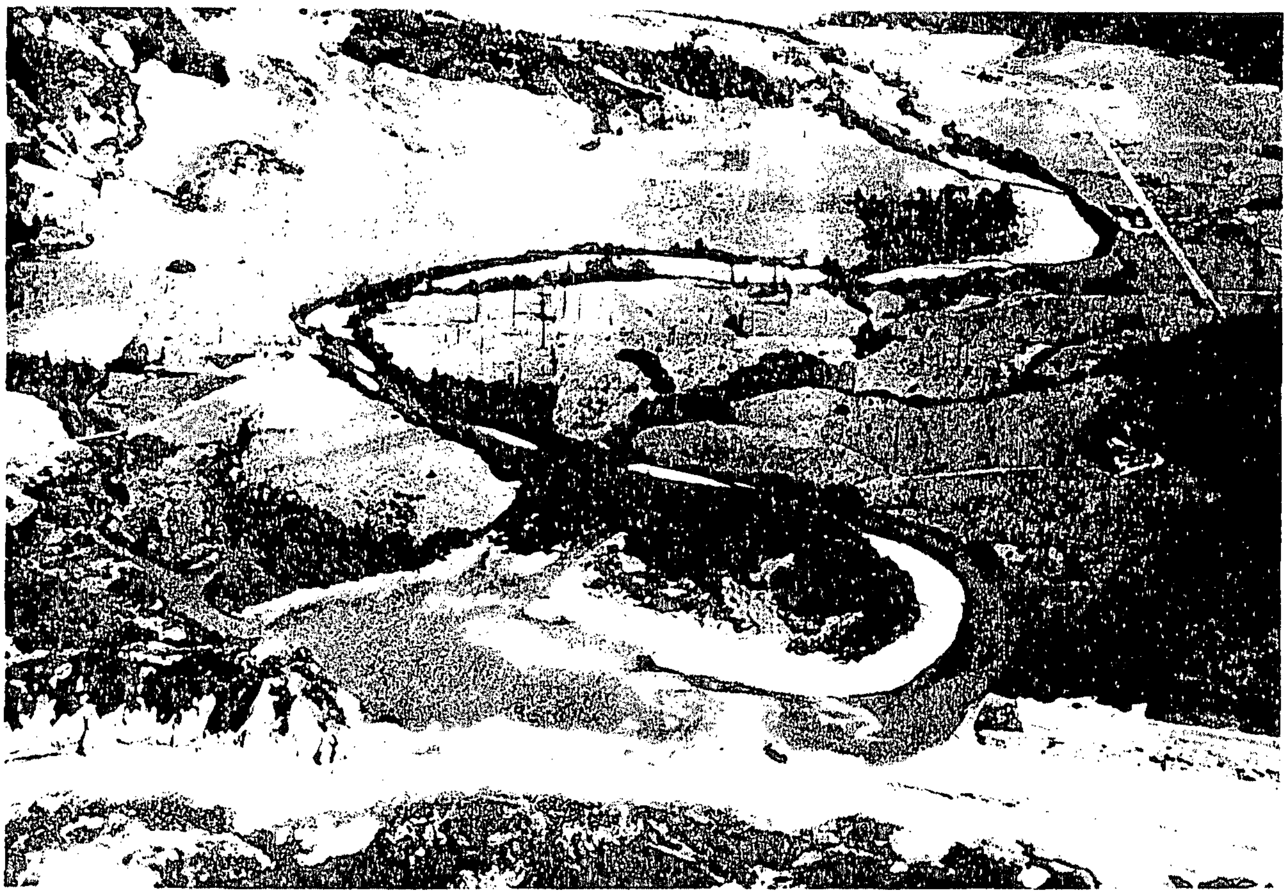


Figure 2: Mouth of Redwood Creek, September 7, 1948. (COE photo).

Figure 3: Historic estuarine features. (COE photo, June 30, 1966).

TABLE 2: Suspended Sediment Yield for Northern California and Other North American Rivers. Northern California Rivers Ranked by Average Annual Sediment Load (data assembed by Ricks 1983).

STREAM/STATION	DRAINAGE AREA (KM²)	PERIOD OF RECORD (WATER YEARS)	AVERAGE ANNUAL SEDIMENT YIELD TONNES/KM²/YR
Eel River @ Scotia	8,063	1958 - 1977	2,760
Van Duzen River near Bridgeville (Tributary of Eel River)	575	1956 - 1967 1975	3,000
	8,638		2,776
Klamath River @ Orleans	21,950	1968 - 1977	162
Trinity River @ Hoopa (Tributary of Klamath River)	7,389	1957 - 1977	630
	29,339		280
Mad River @ Arcata	1,256	1958 - 1974	2,000
Sacramento River @ Sacramento	60,943	1957 - 1969	40
Russian River near Guerneville	3,465	1965 - 1977	676
Redwood Creek @ Orick	720	1971 - 1977	2,250
Mattole River near Petrolia	622	1967	5,730
Colorado	356,900	1926 - 1957	380
Mississippi	3,222,000	1952 - 1965	97
Columbia	265,700	1950 - 1952	35
Saskatchewan	323,900	1954 - 1960 1962 - 1964	13
Rio San Juan	31,080	1934 - 1941	156
Average, North America			86

mouth. Along the north cliffs from Dorrence Creek to the west (Figure 3) the water was always at least 20 feet deep (Ricks and Feranna, unpublished report). The December 1964 flood removed the entire beach berm from the north cliffs to the California-Pacific Mill site (Figure 4).

Redwood Creek was well known for its salmon and steelhead runs and for the large size of fish produced. According to local residents who were interviewed to gather information regarding the historic fishery (Ricks and Feranna, ibid.; Feranna, unpublished report). From the earliest accounts (circa 1890) Redwood Creek was said to have supported a substantial salmonid fishery. Although coho salmon (*Oncorhyncus kisutch*), and cutthroat (*Salmo clarki*) and steelhead trout (*Salmo gairdneri*) were present, king salmon (*Oncorhynchus tshawytscha*) was the most sought after fish because of its size and numbers. Fifty pound king salmon were not uncommon, and when fish were in, people would come from miles around to harvest this resource.

Local Indians used spears to catch fish on lower portions of the creek in shallow areas, usually at a riffle where fish were easily seen or heard. They also used more efficient gill nets where the water was deeper. One account (1897-1898) recalls 40 salmon netted near Strawberry Creek.

Spear and net fishing continued by both Indians and settlers, but the use of nets by settlers became common as early settlers acquired the Indians' fishing skills. Commercial fishing was also occurring at the mouth of the creek (circa 1920) to supply Eureka fish markets. Sport fishing gained attention as the magnitude of Redwood Creek's resource became known. King salmon to 65 pounds became part of the sport catch and large fish were seen throughout the watershed. Local residents recall "a dozen hookbills (coho salmon) were trying to spawn on most every riffle on Strelow Creek near Gold Bluff Road on Thanksgiving 1911," or "so many salmon carcasses were along Boyes Creek and Lost Man Creek in the early 1920's, you couldn't stand to walk along the creeks for the smell" (Feranna ibid.). The north slough area was a favorite fishing spot.

Actual counts of the historic spawning run of anadromous fish in Redwood Creek do not exist. However, in 1965 the California Fish and Wildlife Plan (California Department of Fish and Game 1965) listed Redwood Creek as a major stream and while "representing a drastic decline from former years" estimated spawning populations of 2,000 coho and 5,000 chinook salmon, and 10,000 steelhead trout. These figures were extrapolated from data relating to other streams and then applied to Redwood Creek.

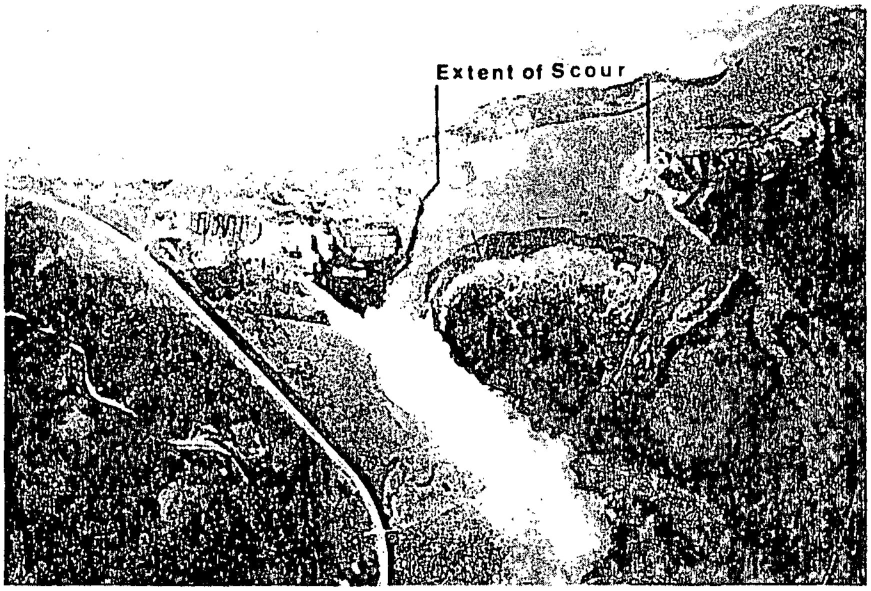


Figure 4: Mouth of Redwood Creek, January 13, 1965, three weeks after the flood of record (50,500 cfs). The entire beach from the mill site to the north cliffs has been removed. (COE photo).

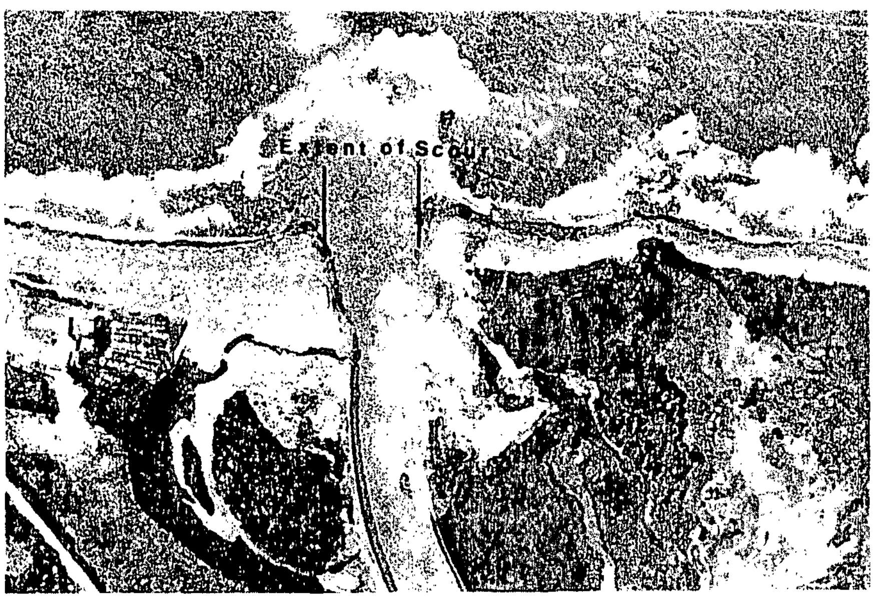


Figure 6: Mouth of Redwood Creek, March 7, 1972, four days after flow of 49,700 cfs. Scouring is now limited to only about 30% of the beach area that was removed by floods before construction of the levees.

III. CURRENT CONDITIONS

A. Present Estuarine Configuration and Morphologic Characteristics

The Corps of Engineers flood protection project on Redwood Creek extended from the confluence of Prairie Creek to the mouth of Redwood Creek. The resulting channel was designed to contain a peak discharge of 77,000 cubic feet per second (cfs), which is about 50 percent larger than the flood of record (U.S. Army Corps of Engineers 1961, 1966).

Bulldozers were used to remove riparian vegetation, loosen gravel bars, and reshape the channel. Excess dredge material was deposited at designated sites next to the levees. Levee construction resulted in the loss of diverse habitats associated with stream pool and riffle structure, and the riparian zone.

The lowermost section of the levee bypassed the last downstream meander, leaving north and south sloughs with little circulation (see Figure 5). Smoothing the channel bottom and increasing the channel gradient by removing the downstream meander combined to increase average stream velocity. More sediment may now be transported and a more mobile stream bottom now exists between the levees as compared to the natural channel.

Ocean sand accumulated rapidly in the neck of the south slough. By March, 1972 (Figure 6) wave overwash had filled in the old channel east of the berm. Mouth Profile Z (Figures 7 and 8) illustrate the amount of sediment accumulation across the berm and in the south slough neck since the 1966 Corps survey (U.S. Army Corps of Engineers 1966). The small outlet from the south slough established its present position between June 1976 and May 1978. However, more recent aerial photos (September 1981) show continued deposition in the south slough neck. Sediment accumulation in the channel bed and erosion of both banks during 1980 - 1981 are evident in south slough Profile A (Figure 9).

Prior to channelization, 20-foot water depths along the north cliffs apparently prevented the Corps from surveying the neck of the north slough. Aerial photos indicate that most of the sediment accumulation in the north slough neck occurred between March 1972 and September 1974. Between September 1974 and May 1978, the north slough outlet channel across the neck had assumed its present (1982) position. Sand has accumulated from 2 to 6 feet across mouth profile X (Figure 10) since 1964, although the elevation of the deposit varies from year to year from exposure to direct wave action.

Since the Corps of Engineers 1964 - 1966 surveys, 47 to 54 percent of the lower estuary between zero and four feet above mean sea level (msl) has filled with sediment (Ricks 1982). Presently, the volume of the lower estuary or embayment at the end of each rainy season varies in response to the amount of sediment removed by the year's peak flow.

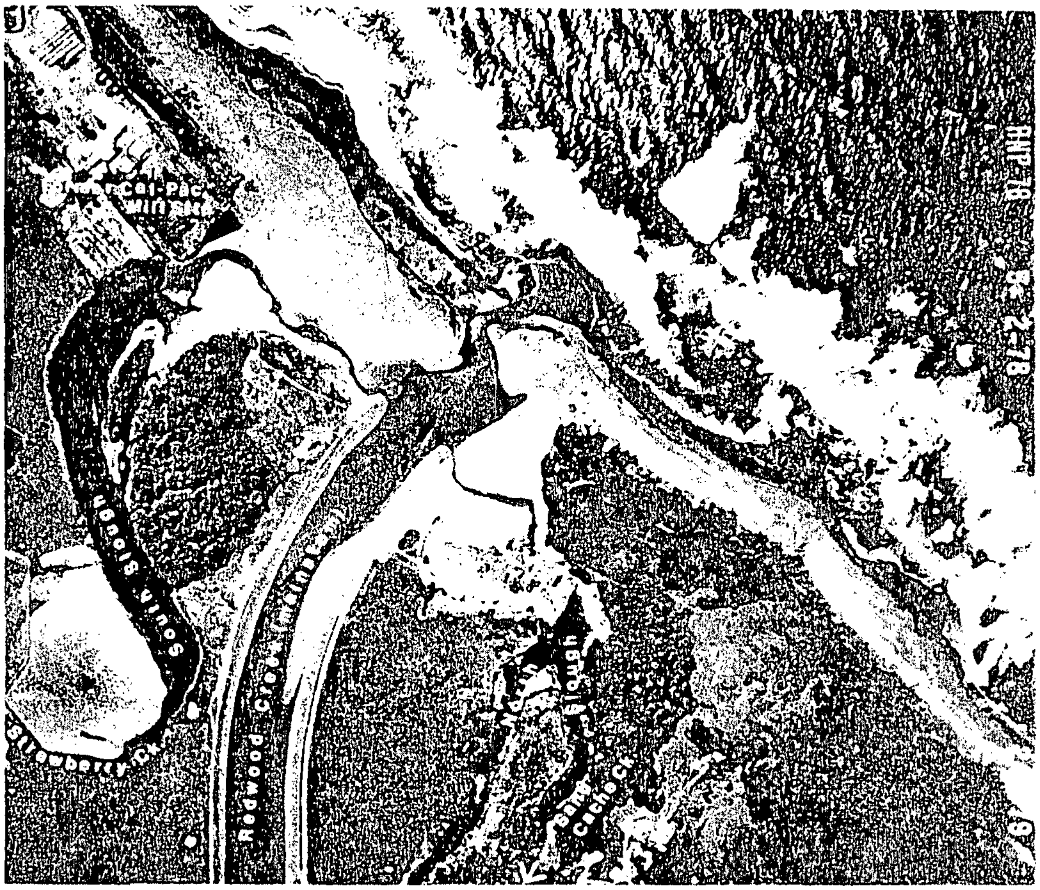


Figure 5: Present estuarine configuration. (RNP photo, May 2, 1978).

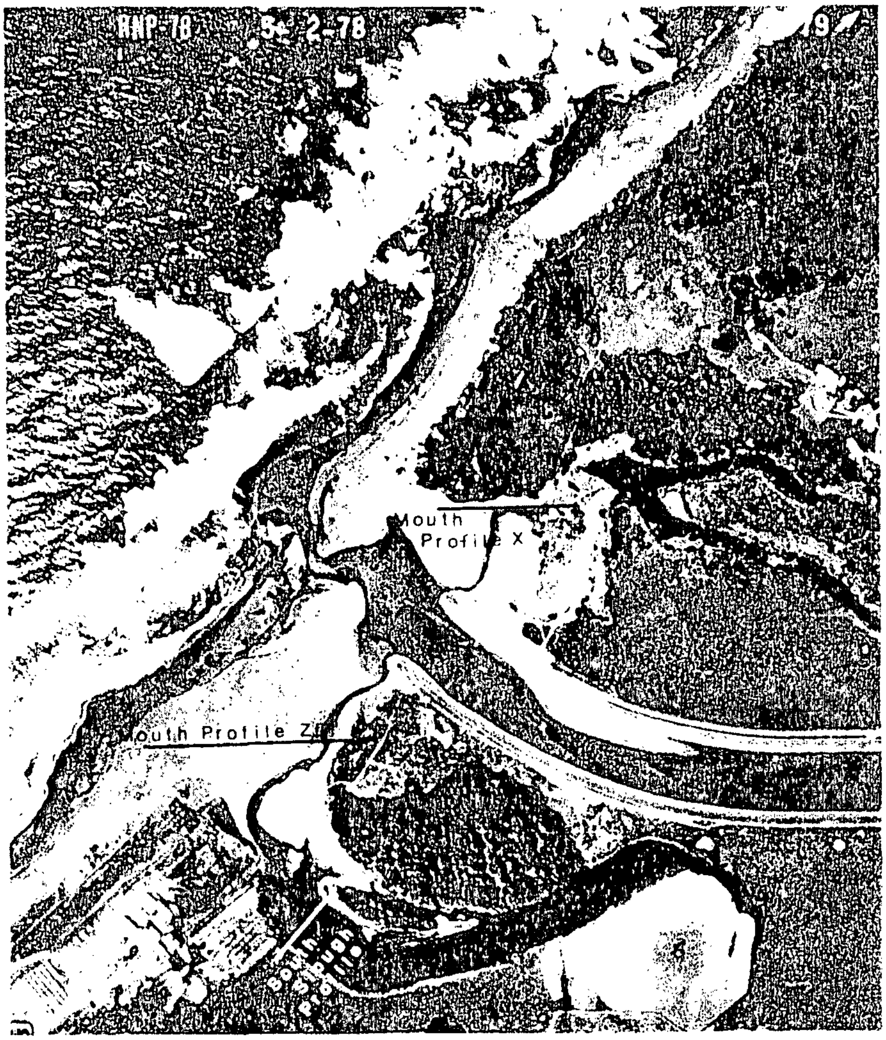


Figure 7: Location of topographic profiles of channel characteristics, mouth of Redwood Creek. (RNP photo, May 2, 1978).

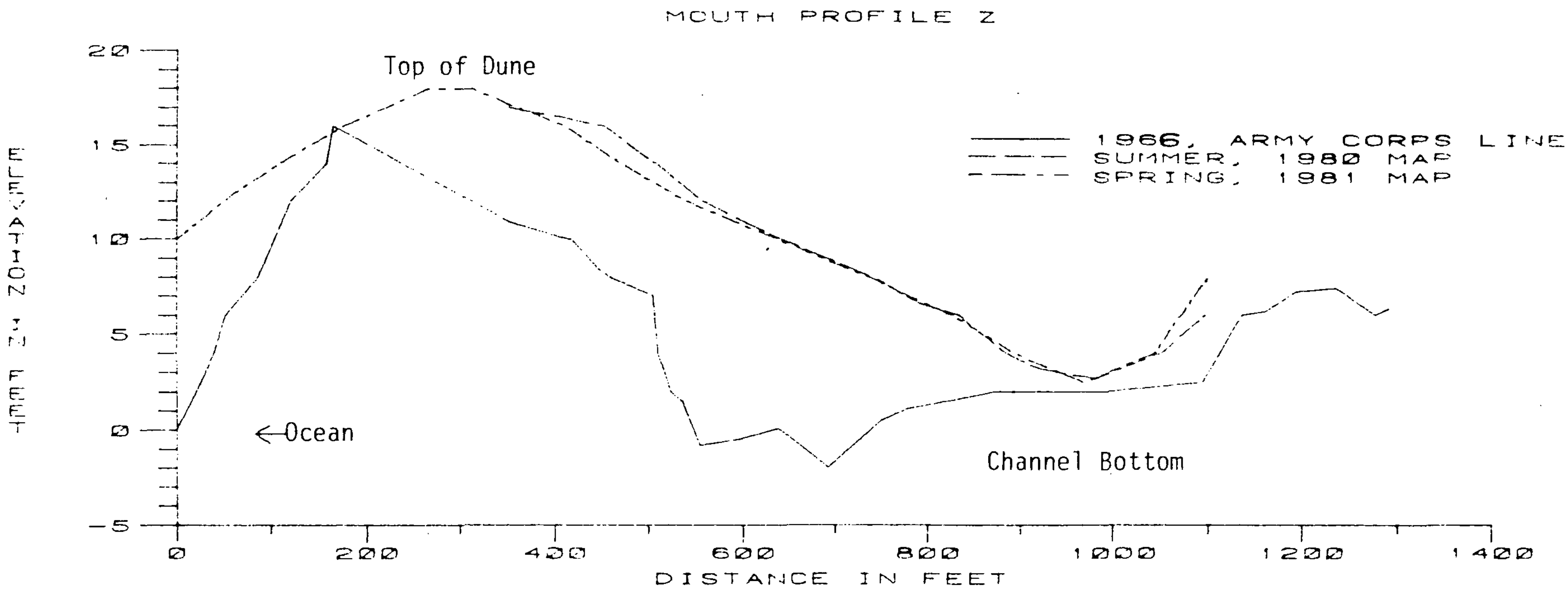


Figure 8: Topographic profile Z illustrating degree of sediment accumulation in the neck of the south slough (old stream channel) from 1966 through 1981.

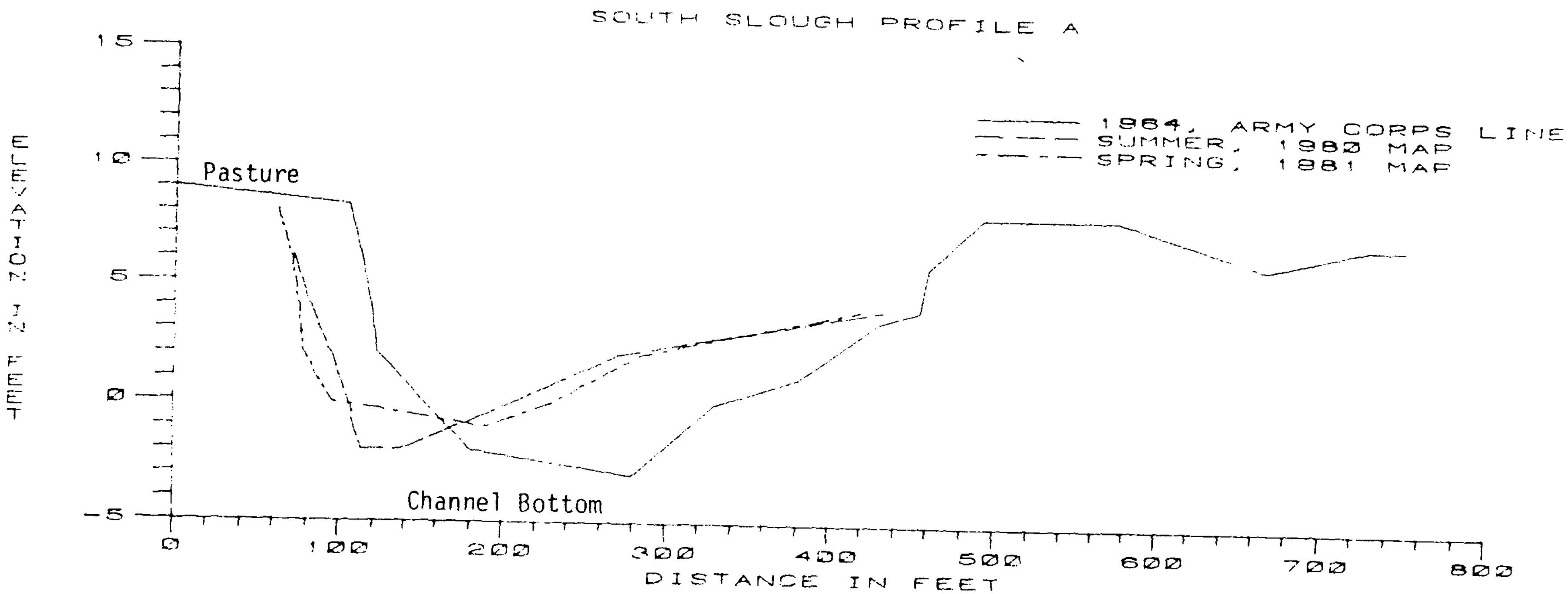


Figure 9: Topographic profile A showing channel changes in the south slough for the period 1964 through 1981.

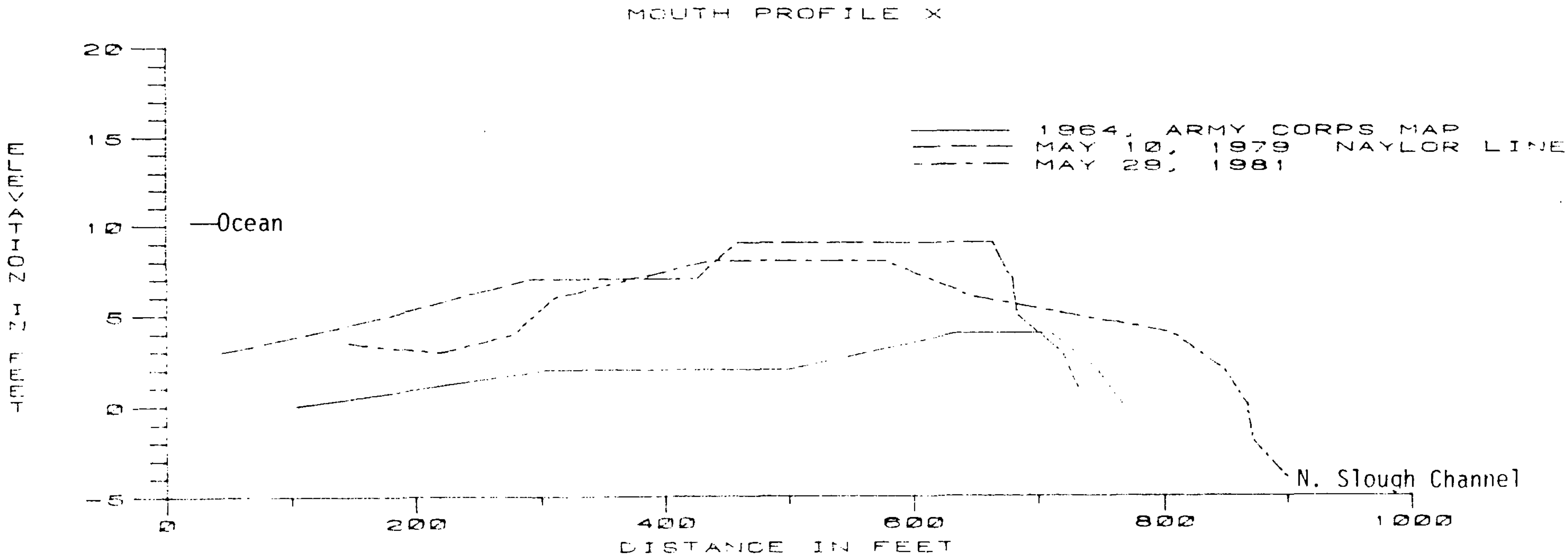


Figure 10: Topographic profile X showing sediment accumulation near the neck of the north slough from 1964 through 1981.

The levee constricts streamflow so efficiently that a very limited section of the berm is scoured by floods. Steep banks in the berm mark the limits of scour, particularly on the south side. Comparing the aerial photo taken after the December 1964 flood (50,500 cfs, Figure 4) with the aerial view of the berm taken 4 days after the March 3, 1972 flood (49,700 cfs, Figure 6) shows that only about 30 percent of the berm is now scoured by flood flows.

By confining the Redwood Creek flow between levees, a sediment trap was created in the backwater areas at the ends of the levees. Flows from Strawberry and Sand Cache Creeks now provide the only through-going circulation and are not sufficient at any time of the year to flush accumulated sediment from the necks of the sloughs. The north and south sloughs are therefore isolated from the mainstem of the creek except during periods of high water.

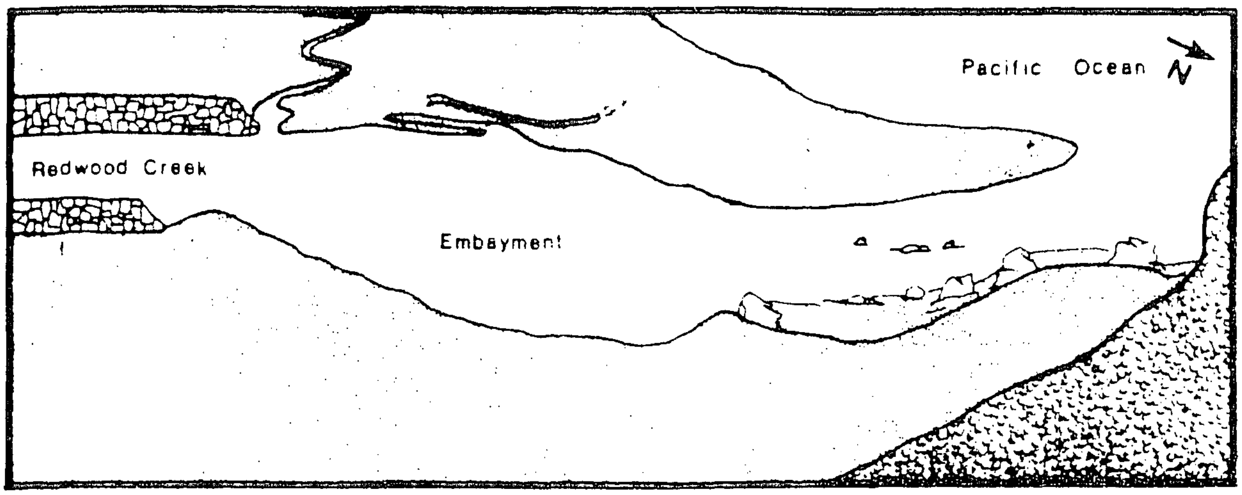
B. Embayment Formation

As stream discharge decreases through the spring months, the straight outflow channel is modified by incoming waves and tidal currents. Diffraction of waves around the berm results in deposition of a lobe of sand into the deep water embayment (Figure 11, views a and b). When prevailing north-northwest winds and high seas occur concurrently with high tides, the outflow channel migrates rapidly to the south. However the sheltering effect of the adjacent headland to the north may prevent southward migration if the channel outflow develops at the extreme north end of the beach. When the channel does migrate south, waves deflect the flow against the shoreward channel bank, eroding the bank while depositing a berm on the seaward side (see Figure 11, view c). Sediment deposited by overwash raises the channel bed. The height of the outflow channel restricts the rate of outflow, causing expansion of the embayment when rates of outflow, seepage, and evaporation are less than inflow from stream discharge. Continued onshore sediment transport may cause the outflow channel to completely close.

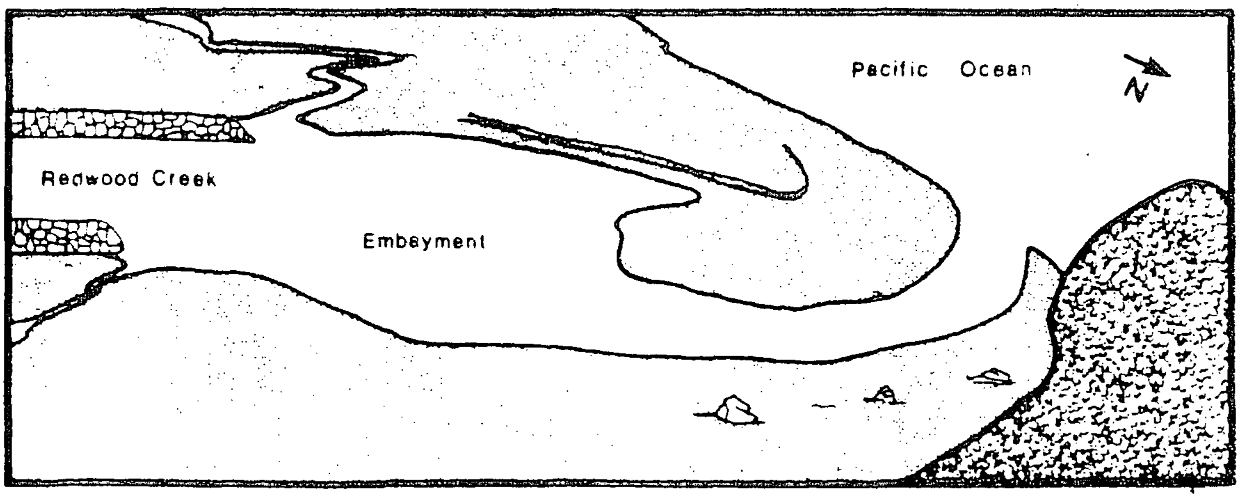
According to coastal engineering criteria, when the cross-sectional area of a tidal inlet exists below mean sea level, the mouth of the stream is functionally open (Rice 1974; Johnson 1974). The ratio of wave energy (wave height and period) to tidal energy per tidal cycle determines whether the mouth will close (O'Brien 1971). Tidal energy depends on both the amplitude of the tide and the tidal prism in the estuary. The ebb (outflowing) current velocity of a large tidal prism (i.e. a large volume of water in the estuary) can effectively erode a tidal inlet, keeping the mouth open.

Stream discharge increases the ebb current velocity and enhances erosion of the outflow channel. With decreasing stream flows in the spring, the berm may build above mean sea level and functionally close the mouth. Several factors may cause functional closure to occur more rapidly and/or earlier in the year now than in the past. The increase in stream gradient from channelization and sediment accumulation in the sloughs, has

View a: Winter - Early Spring - High stream discharge causes the creek to flow straight out from the levees, scouring to expose large rocks.



View b: Spring - As discharge recedes, ocean sand begin to accumulate in the mouth. Offshore processes begin to cause the outflow channel to shift southward. Embayment forms as elevation of outflow channel rises.



View c: Late Spring - Early Summer - Offshore processes have caused the outflow channel to shift far to the south with a progressive increase in elevation, and embayment volume. The north and south sloughs are now connected to the mainstem.

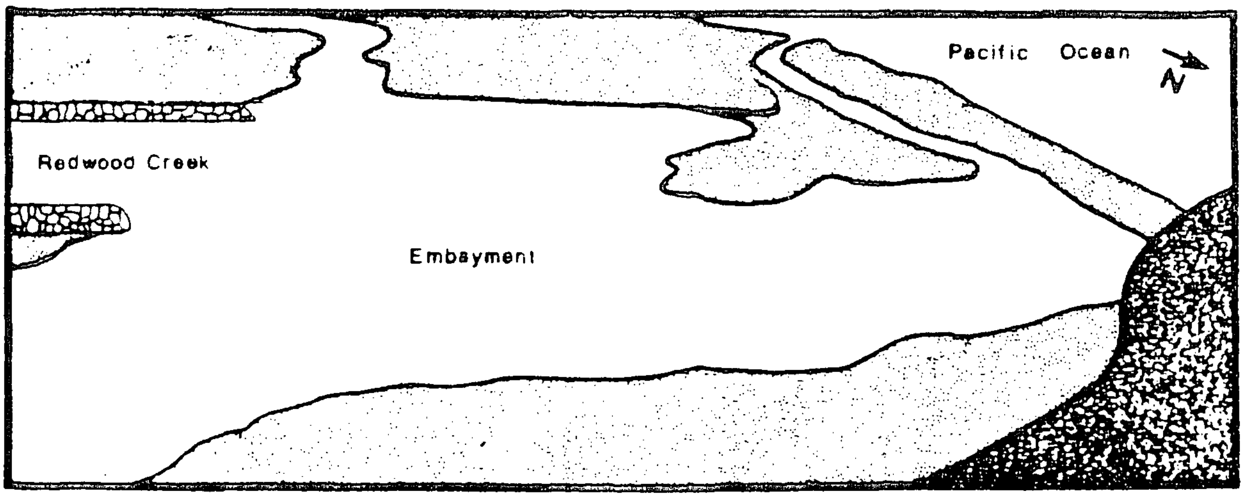


FIGURE 11: Process of Embayment Formation, Mouth of Redwood Creek

decreased the tidal prism. Additionally, flow duration curves indicate a slight, long-term decrease in stream discharge during the summer months since the advent of widespread timber harvest (Janda et al. 1975).

As the sill builds up to and above mean sea level, the effective tidal range is decreased. As the ebb current velocity decreases, the berm and outflow channel build higher and the rate of outflow decreases. Expansion of the embayment results when stream discharge is greater than rates of outflow, seepage, and evaporation. The relative water levels of the ocean and embayment, quality of sand, and area of embayment in contact with the berm determine seepage rates (Clifton, Phillips, and Hunter 1973). Presently, water may seep more slowly (than in pre-levee times) across the gentle gradient through the wide storm berm (Figure 12). The narrow portion of the swell berm, where seepage would be more rapid, is limited in length.

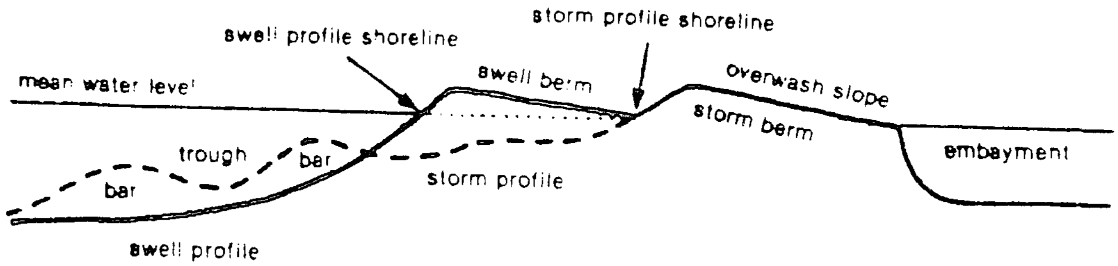
The shape and length of the outflow channel determines the degree of saltwater intrusion and the distance upstream that sediment is transported by high tide currents. Boggs and Jones (1976) examined upstream tidal current transport by releasing dyed grains in the lower part of the outflow channel of the Sixes River, Oregon. During a single flood tide, sediment was transported 0.5 miles with a straight outflow channel (e.g. Figure 11, view a). Tidal currents were dissipated more rapidly through a meandering channel (e.g. Figure 11, view c) where sediment of the same size and density was transported only 0.2 miles.

Sediment is transported further into the embayment if the outflow channel is straight (due to a recent breach and/or lack of migration). Increased sedimentation occurring through a straight outflow channel reduces the available aquatic habitat. While the outflow channel is straight and open, marine sands are transported and deposited in the embayment. Migration of the outflow channel reduces the tidal range in the embayment, resulting in less bottom disturbance and sand deposition by tidal currents. Several inches of mud, fine sand and marine organic detritus, may seasonally accumulate in the embayment following outlet migration.

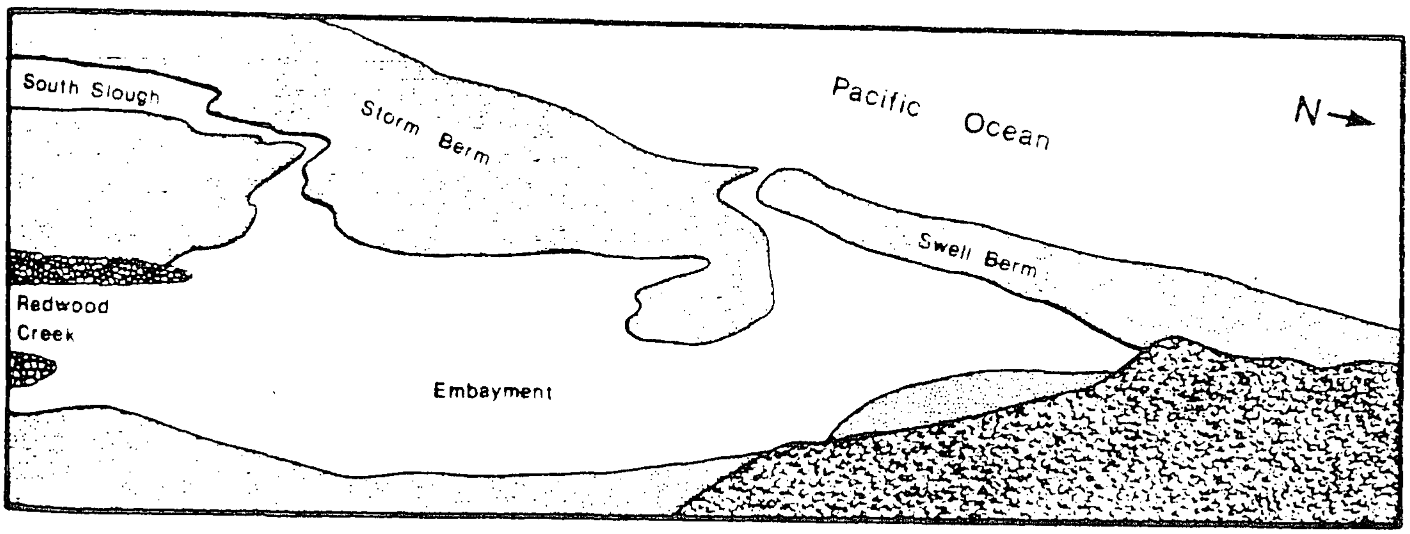
C. Existing Fish Resources

The anadromous fishery of Redwood Creek has experienced a substantial reduction during the last 20 years. Intense landuse and severe flooding have contributed to increased degradation of salmon and steelhead spawning and rearing habitat. The California Department of Fish and Game and National Park Service conducted a survey of Redwood Creek in 1972 (on file, Department of Fish and Game, Eureka, California). They reached the following conclusions:

> "Redwood Creek is not suitable as a trout stream. Steelhead production is severely limited and salmon production is reduced. The upper 10 miles is choked with logging debris, collapsed bridges, and sediment....About 60 percent of the adjacent slopes are unstable or sliding. Approximately 80 percent of the



a. Cross-sectional view of beach for storm (winter) conditions and swell (summer) conditions (from Ricks 1983). During winter there is a narrow berm with sand shifted into offshore bars. In summer the berm is wider with less sand offshore in bars.



b. Visible, summertime characteristics of features illustrated in a. above.

Figure 12: Seasonal changes of beach profiles, mouth of Redwood Creek.

immediate watershed has been logged in a manner detrimental to the stream.

The production of fish and fish food organisms is extremely limited by the lack of pools and shelter, the great amount of fine sediments in the stream bottom and by the unstable nature of the streambed."

In 1975, the U.S. Fish and Wildlife Service, Division of Ecological Services, stated that "in spite of the lack of reliable definitive data, it is safe to assume that current fish runs are far below those which occurred 70 - 80 years ago." (USDI, Fish and Wildlife Services [FWS], Division of Ecological Services 1975).

The only quantitative evidence of the fishery decline comes from Humboldt County Prairie Creek Fish Hatchery records. These records show the greatest fishery decline during the last 15 years. An estimated 70 percent to 80 percent decline in the chinook salmon fishery and a 60 percent decline in the coho fishery has occurred. Even though extensively supported by hatchery programs, the comparably more resilient steelhead fishery has realized a 50 percent reduction. The relatively recent reduction in quality of the fishery is also supported by reports of local fishermen.

No definitive data are available regarding current total numbers of returning adult salmon and steelhead. Accurate information of this type is extremely difficult and costly to obtain. However, Redwood National Park has begun conducting adult spawner surveys on Redwood Creek tributary streams within park boundaries. This information will allow development of an index of species and relative abundance.

In 1965, the California Fish and Wildlife Plan (California Department of Fish and Game 1965) estimated sport fishing pressure as 700 angler-days per year for salmon and 1,300 angler-days per year for steelhead. They estimated that sport fishing yielded 150 salmon and 500 steelhead per year based upon 0.2 fish/angler-day and 0.4 fish/angler-day for salmon and steelhead respectively. The U.S. Fish and Wildlife Service (USDI 1975) estimated fishing pressure from 2,000 to 4,000 angler-days for salmon and steelhead combined yielding from 650 to 6,250 fish annually. No other information is available regarding present day sport fishing on Redwood Creek.

D. Importance of Estuary to Anadromous Salmonids

The estuary serves as the passageway to the sea for downstream migrating juvenile salmonids and to spawning grounds for upstream migrating adults. It also serves as an area for acclimation from freshwater to saltwater, and for feeding and growth of juvenile fish.

Reimers (1973) documented the role that estuaries play in fall chinook salmon production. From scale analysis of spawning fall chinook, he determined that the majority of returning adults spend June, July, and August as juveniles within the estuary before completing their seaward migration. His investigations determined that juvenile chinook spending less than three months in the estuary seldom returned to spawn in the natal stream. Reimers concluded that these fish did not survive as well as the fish that had spent three months in the estuary. Apparently a survival advantage was conferred upon these fish which remained in the estuary and grew to a larger size before entering the ocean. Recent literature emphasizes the importance of the estuary to juvenile and adult salmon (Healey 1980, 1982; Cannon 1982; Kjelson, Raquel and Fisher 1982; Myers and Horton 1982: Pearce, Meyer and Boomer 1982; Simenstad, Fresh and Salo 1982).

Although not as well documented, it has been shown that juvenile steelhead will spend rearing time in an estuary (Amend _et al_. 1980) while coho salmon appear to move into the sea almost immediately.

E. Biological Productivity of the Redwood Creek Estuary

1. Invertebrate Productivity

The productivity of aquatic invertebrates is important because they serve as the main food resource for juvenile salmonids. Studies begun in 1980 show the lower 2.5 miles of Redwood Creek as characterized by low productivity of aquatic invertebrates. In contrast, the sloughs appear to support a more stable invertebrate production throughout the year. This production, which can result in large biomasses, is primarily limited to the margins and shallow portions of the sloughs. The south slough supports a higher density of invertebrates than the main channel during spring and winter. One exception to the poor production of the main channel was observed during the sampling period. This was the appearance of an extensive population of two species of the amphipod _Corophium_ (Larson, Ricks, and Salamunovich 1981). These animals, which build tubes on the substrate and feed on decaying aquatic vegetation, attained an exceptionally large biomass per unit area in the embayment. Because these animals build tubes on and from bottom materials, a stable environment is required. High winter and spring flows, and periods when the mouth of the creek is open directly to the ocean (see Section III.A.) keep the bottom in constant motion. Not until the outlet begins to migrate and an embayment begins to form is the bottom material stable enough to allow _Corophium_ populations to develop.

2. Salmon and Steelhead Productivity

All anadromous salmonids utilize the ocean for the majority of their growth but require a freshwater environment for reproduction. Eggs are deposited in gravels in an excavation called a redd. The eggs develop in the redd until hatching. After hatching, the young fish, called alevins, remain in the gravel until the yolk sac is absorbed. When young fish emerge they are called fry. The total period of development depends upon water temperature, but averages 60 to 90 days.

Young fish spend a variable amount of time (depending upon species) in freshwater before heading for the ocean. Just prior to entering the ocean, young fish undergo a series of physiological adaptations which will allow them to survive in seawater. This process is called smoltification, and after undergoing these changes fish are referred to as smolts. Coho (or silver) salmon generally spend one full year rearing in freshwater before entering the ocean. Downmigration of coho to the ocean from upstream Redwood Creek rearing areas occurs in early spring (March-April). Our data indicate that these young salmon now move directly into the ocean, spending a minimal amount of time in the estuary (Larson, unpublished data). However, juvenile coho salmon may have at one time utilized the south slough. Young coho were observed in the early 1970's at the U.S. 101 bridge crossing of Strawberry Creek (Steve Sanders, Prairie Creek Fish Hatchery Manager, personal communication).

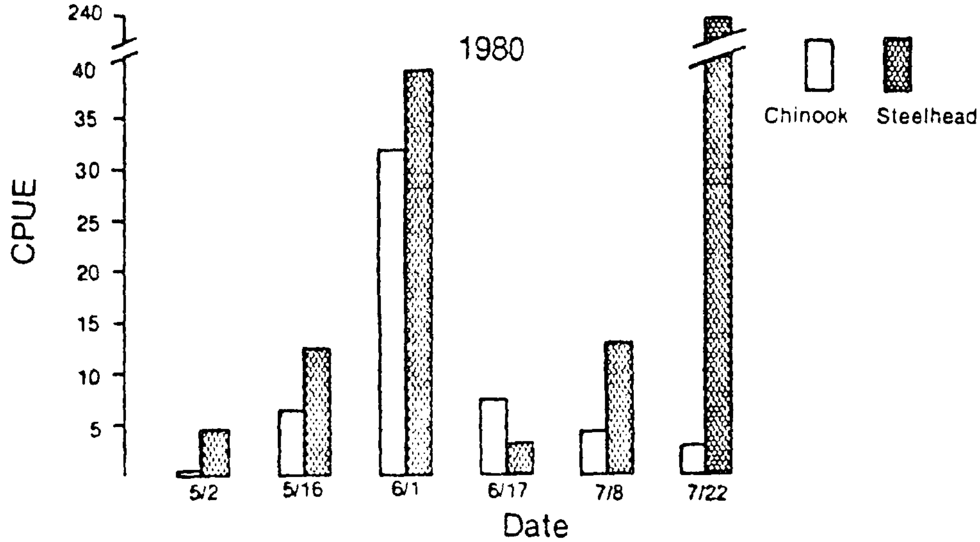
Steelhead trout spend an average of two years rearing in freshwater before entering the ocean. The majority of young steelhead in Redwood Creek spend their second year in the estuary and lower part of the creek (Larson, unpublished data; Hofstra, unpublished data). Young chinook salmon in Redwood Creek, on the other hand, do not spend rearing time in upstream areas (Anderson and Brown 1982). Shortly after emerging from the gravels the chinook fry begin to move downstream. Our research shows that if given the opportunity they will spend an extended period rearing in the estuary before entering the ocean. Seasonal migration patterns for chinook salmon and steelhead trout in Redwood Creek for 1980 through 1982 are shown in Figure 13. Mean length and size range of these fish before entering the estuary is shown in Table 3 (Larson, Salamunovich, McKeon, and Hofstra 1982).

Table 3. Mean length (mm) and size range (mm) of downstream migrant chinook salmon in Redwood Creek for 1980, 1981, and 1982.

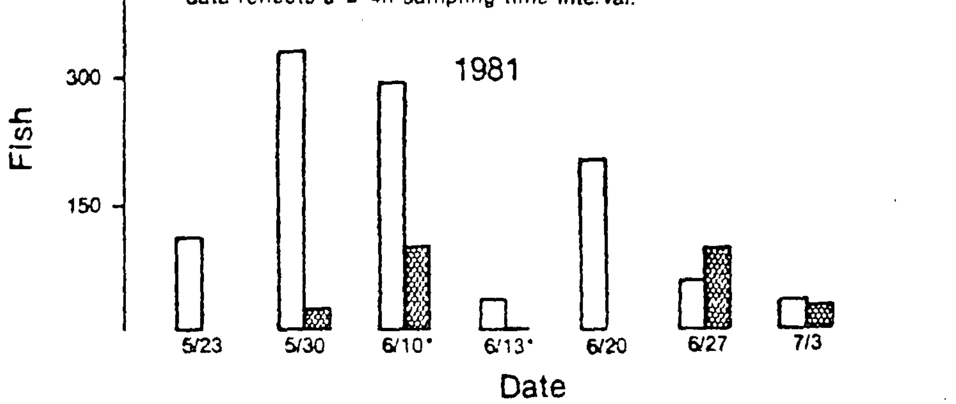
YEAR	MEAN LENGTH (mm)	RANGE (mm)
1980	73.5 (FL)	53 - 97 (FL)
1981	65 (TL)	41 - 86 (TL)
1982	66 (TL)	51 - 105 (TL)

FL - Fork Length TL - Total Length

A. Catch per unit effort (CPUE) illustrating the peak seasonal downstream migration period of juvenile chinook salmon and steelhead trout in 1980.



B. Number of fish captured within a 6h sampling time interval illustrating the peak seasonal downstream migration period of juvenile chinook salmon and steelhead trout in 1981.
*data reflects a ≈ 4h sampling time interval.



C. Number of fish captured within a 6h sampling time interval illustrating the peak seasonal downstream migration period of juvenile chinook salmon and steelhead trout in 1982.

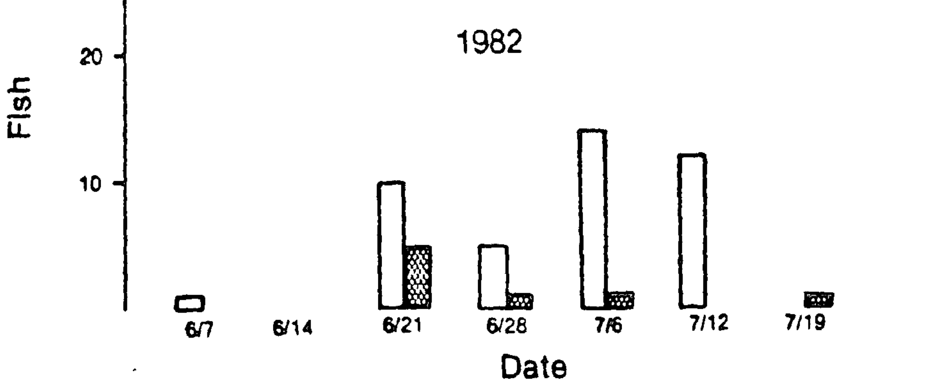


Figure 13: Peak seasonal downstream migration of juvenile salmonids for 1980, 1981, and 1982 in Redwood Creek.

IV. THE PROBLEM

A. Spring/Summer Flooding and Draining of Embayment

As the mouth of the creek begins to migrate southward (Section III, and Figure 11) the berm is also building higher. If instream flows are greater than rates of outflow, seepage, and evaporation, water levels will rise in the embayment and local adjacent private properties may begin to flood. Saturated soils may affect growth of crops or prevent use of farm equipment in the fields. Woody debris that is deposited in the fields when waters recede can interfere with cultivation and mowing. Additionally, Hufford Road may be flooded, inhibiting or preventing access to the homes adjacent to the north slough. Typically landowners have dealt with flooding problems by breaching the berm to drain the embayment and their fields. To accomplish this a trench is dug in the sill at its narrowest point. This is the shortest distance between the embayment and the ocean and allows for the steepest gradient to be achieved. Erosion proceeds rapidly and the trench deepens and widens. Within a short period of time (4 - 6 hours) the embayment can be drained to near sea level (Delbert Rocha, personal communication).

B. Physical and Biological Impacts of Embayment Draining

If an embayment forms and is maintained during the peak downstream migration of juvenile chinook salmon and steelhead, they may reside in the estuary for an extended period before entering the ocean. In 1980 the embayment formed in early June which coincided with peak downstream migration of salmonids. The numbers of fish began to increase indicating extended preferential utilization of the area since the mouth of the creek had not closed, hence fish were free to migrate into the ocean. During this period, embayment water levels increased and the embayment became connected with the productive south slough. Sampling showed juvenile salmonids utilized the expanded habitat provided by the south slough (Larson *et al*. 1981).

On June 24, 1980 the salmonid population was estimated as 20,000 fish and the catch per unit effort (CPUE) was 200 fish per seine haul. On July 2, the berm was breached by local ranchers because of the threat of flooding. This breaching released 75 percent of the water in the embayment. The volume of water was released so rapidly (4 - 6 hours) that the fish were entrained in the discharge and involuntarily flushed into the ocean. The remaining fish habitat was drastically reduced in size. Sampling efforts following breaching showed a CPUE near zero making a population estimate impossible. The fish did appear to be smolting before being flushed into the ocean, as indicated by their silver appearance, but to what degree the smoltification process was complete is not known. Reduced survival and growth has been documented for salmonids involuntarily inducted into seawater before smolting (e.g. Saunders and Henderson 1970; Adams *et al*. 1973; and Wagner 1974). Nevertheless, these fish were not of a size that would maximize their chances of survival in the ocean (see Section III. D.).

As the embayment first developed and the bottom became more stable, suitable habitat for an expanded *Corophium* population became available (see Section III. C.). The breaching occurred before the full food production potential was realized. It was not until after the embayment again formed that the highly productive *Corophium* population became established. Young steelhead entering the embayment from upstream after its re-establishment fed predominately upon *Corophium* (Larson *et al*. 1981).

In 1981 the berm was artificially breached in April. This was prior to peak downmigration of salmonids (see Table 3). The embayment did not re-establish and as a result the productive south slough remained inaccessible to fish throughout the summer. As a consequence, no rearing area was available to juvenile salmonids. Had the berm not been breached an embayment would have been available as nursery habitat for these young fish.

Man-induced breaching of the berm and the lack of adequate water depth within Redwood Creek also affects returning adult salmon and steelhead. Breaching the berm before the first fall rains may induce adult fish to enter the creek. Insufficient instream flows prevent them from continuing their upstream migration. In the shallow estuarine and upstream areas, the fish are extremely vulnerable to predators and illegal fishing practices, which have been substantial in some years according to local accounts (Times-Standard November 29, 1978).

When breaching of the berm occurred prior to construction of the flood control levels it was not as devastating to the salmonid population. The north slough and the deep water area next to the rock headland provided a rearing area for juvenile fish that was not as greatly reduced in volume by breaching. The north slough also would have remained connected to the mainstem because the sand deposit that now separates the two did not begin to accumulate until after levee construction. Prior to levee construction the last meander of the creek (south slough) was probably the same productive summertime environment that it is today. Even if the sill were breached this area would still be available to juvenile fish.

Deepwater areas that existed in the pre-levee estuary provided protection for adult salmon and steelhead when the berm was breached in the fall. While these fish could still become stranded in shallower areas upstream, they were not as vulnerable to poaching as they are today. Historically fishermen would open the embayment to stimulate migration of adults. The resource was heavily utilized (see Section II). More recently opening the embayment in the fall has resulted, by local accounts, in widespread illegal fish taking activities. Such poaching of adult fish is especially severe considering the presently reduced run (see Section III. C.).

V. WHAT HAS BEEN DONE

A. Department of Fish and Game Activities

The State of California Fish and Game Code, Chapter 6, Sections 1600-1606, recognizes that alteration of a lake, or stream channel may negatively affect fish and wildlife resources. Therefore, these types of activities are regulated. Breaching the berm that forms at the mouth of Redwood Creek is an activity that requires, under this Chapter of the Code, an agreement with the Department of Fish and Game. Violations are considered a misdemeanor, punishable by either a $500.00 fine, 30 days in jail or both. Some individuals who have wanted to breach the berm in the past have notified the Department of their intentions and some have not. The Department of Fish and Game has concurred with some proposals but not others. Concurrence with a proposal is based upon the need for protection of fish and wildlife resources.

If activities described in a notification are inconsistent with resource protection and if they cannot be modified to ensure resource protection, then the Department will not concur with the proposal. Some interested individuals have indicated to park staff that they would breach the berm regardless of whether they have Fish and Game concurence. Because it is so easy to breach the berm, and because 24-hour surveillance of the area is impractical, the existing regulatory process may not always be effective in protecting fishery resources.

Most recently (May, 1982) individuals were stopped from attempting to dig open the mouth of the creek. No formal notification of this activity had been made; however, no citations were issued. Based upon protection of the fishery resource and in recognition of Redwood National Park's desire to try to alleviate pasture flooding by water level manipulation (see following section) the Department of Fish and Game did not concur with a subsequent landowner request. Fish and Game did, however, concur with the Park's proposal to manipulate embayment water levels.

In the fall of 1982, the Wildlife Conservation Board of the Department of Fish and Game proposed acquisition of 130 acres of land along the lower floodplain of Redwood Creek. The management objectives for the area would be the restoration and protection of fishery habitat and wetlands. It was recognized that restoration and management would be most easily accomplished if conflicting land uses were eliminated.

Affected landowners were notified of the proposal and asked if they would be willing to sell their property. The Wildlife Conservation Board has condemnation rights but has never exercised them in acquiring property, purchasing only from willing sellers. None of the landowners contacted indicated a willingness to sell.

B. Humboldt County Prairie Creek Fish Hatchery Management

Prior to 1978 most young chinook salmon were released from Prairie Creek Fish Hatchery in the early spring. These were fish that were hatched from eggs taken only four or five months earlier. The fish were released with the expectation that they would spend a period rearing in the estuary before entering the sea. However, because of degraded conditions and pasture flooding problems, it was recognized that the needed summer rearing habitat was not available. In 1978 - 1979 the hatchery began to release only yearling-size king salmon. That is, the young salmon are now reared at the hatchery for a full year before being released. The 1981 -1982 season would have been the first year returning adults would be expected from the yearling release program. Figure 14 illustrates run size and percent composition of returning king salmon that were of hatchery origin from 1976 - 1977 through 1982 - 1983. In 1981 - 1982 and 1982 - 1983 fish of hatchery origin made up 47 percent and 56 percent of the run respectively. This is a significant increase over previous years, implies the yearling program is a success, and that the negative effects of the present estuary situation on success of chinook salmon is substantial.

While seemingly successful the hatchery yearling program is more costly. Providing ponding environments and feeding for a full year increases production costs considerably, requiring seven additional months labor expense and predator control (Steve Sanders, personal communication).

C. National Park Service Activities

1. Removal of Woody Debris and Log Boom Installation

The park's research indicated that it might be possible to control the opening of the estuary. This would theoretically involve lowering embayment water levels so that pastures are no longer flooded while still retaining sufficient water to provide adequate habitat for juvenile salmonids. It appeared such an opening would require the proper combination of tides, ocean conditions, and berm configuration. It was recognized that some short-term flooding might be unavoidable while waiting for these optimal conditions. Interviews with local residents in the fall of 1980 indicated that the main concern with flooding was not water on the fields so much as it was the woody debris that was carried in and deposited as the water receded (Delbert Rocha, personal communication). This problem occurred on property adjacent to both sloughs but was more serious in the north slough. Because of the sediment accumulation in the neck of the north slough, logs and other debris that washed in during winter storms was trapped in the slough (see Figure 15). This material was then deposited in the fields during subsequent winter and/or summer flooding. In January 1981 a storm raised water levels, flooded the pastures, and deposited most of this floating debris on the adjacent pasture. A few months later, Redwood National Park laborers removed woody debris from the pastures adjacent to the north and south sloughs in a good faith effort. It was hoped the park could gain the trust, confidence, and flexibility that might be needed in controlling water levels. Through the joint efforts of Redwood National Park, the Department of Fish and Game, and the California Conservation Corps, a log boom was constructed in the north

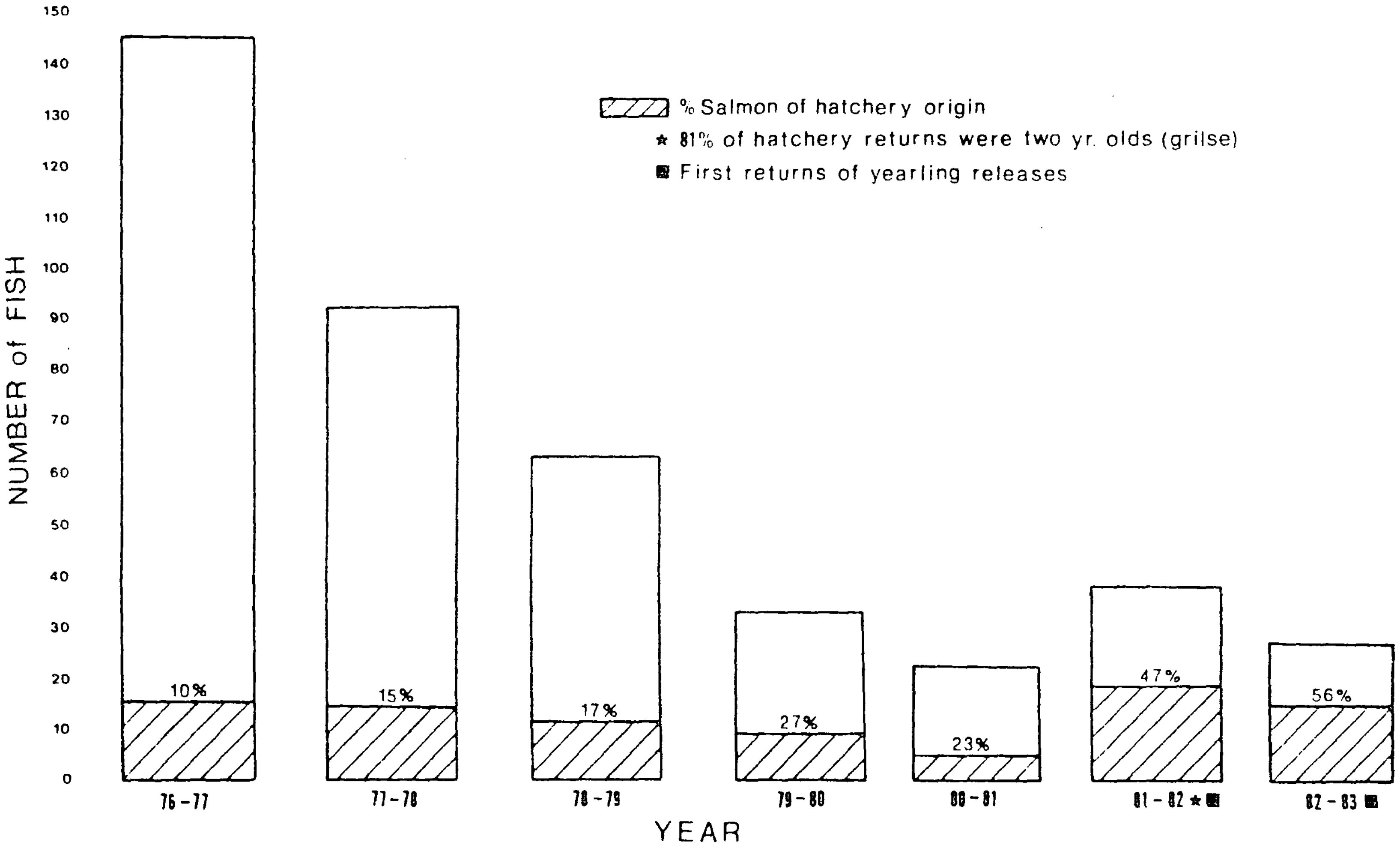


Figure 14 : Chinook salmon trapped at Prairie Creek Fish Hatchery, Fall 1976 through Spring, 1983.

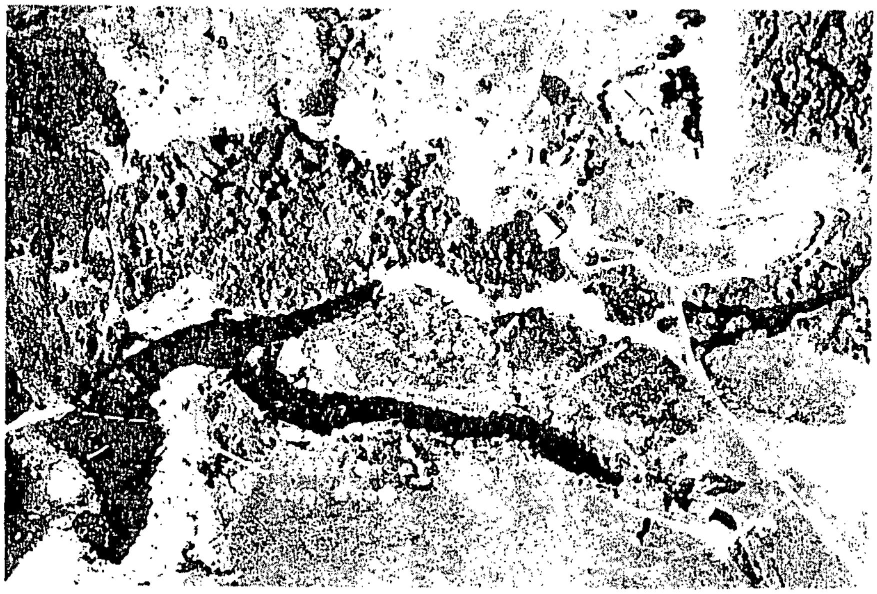


Figure 15 : Logs and woody debris floating on the surface of the north slough. This material was deposited on adjacent pastures by high water in January, 1981. Subsequently, a log boom was installed to prevent further debris accumulation. (RNP photo, August 16,1978).

slough to prevent more logs from entering the area. The log boom has been effective in preventing more woody debris from accumulating in the north slough.

2. Embayment Water Level Regulation

a. Methods of Regulation

No embayment water level control activities were undertaken in 1981 because the berm was artificially breached very early in the year (April) and an embayment therefore was not allowed to form (see Section IV. B.).

In 1982, the pasture adjacent to the south slough was cultivated and planted with oats. Unlike pasture land, an oat hay crop is reportedly unable to withstand flooding even for short periods. On May 25 and 26 the field flooded. An attempt was made to open the estuary but the individuals were stopped from digging since they had not obtained the proper approvals (see Section V. A.). At a subsequent meeting with the concerned parties, Redwood National Park agreed to try to control the water level within the estuary. Fish and Game concurred with the park's proposal.

The goal of a controlled breach is to release water at a rate that results in fewer fish being entrained in the discharge while still maintaining the integrity (water level, bottom stability) of the embayment. An artificial breach can only be controlled if the gradient of the outflow channel is kept low. A steep gradient results in rapid erosion of the berm and widening of the channel such that water is released too rapidly. Controlled breaching releases water more slowly than digging through the berm directly out from the center of the levees (Figure 16). Digging near the center releases water so rapidly the entire embayment drains before offshore physical processes close the breach.

As the mouth migrates farther south and the length of the outlet increases, the berm gets higher and the water level in the embayment rises (Section III. A.). This southward migration reduces the flow gradient, decreases water velocity and amount of downcutting, and allows the berm to build higher. Conversely, reducing the length of the outlet increases channel gradient and water velocity, and results in downcutting through the berm and a reduction of water level in the embayment.

The outflow channel is shortened by capturing the flow in a new channel dug through the berm (see Figure 16). The closer to the embayment the new channel is dug, the steeper the gradient achieved, and the lower the resultant embayment water level. The higher the ocean swells and rougher the seas, the faster a new channel will begin to migrate southward, again decreasing outflow.

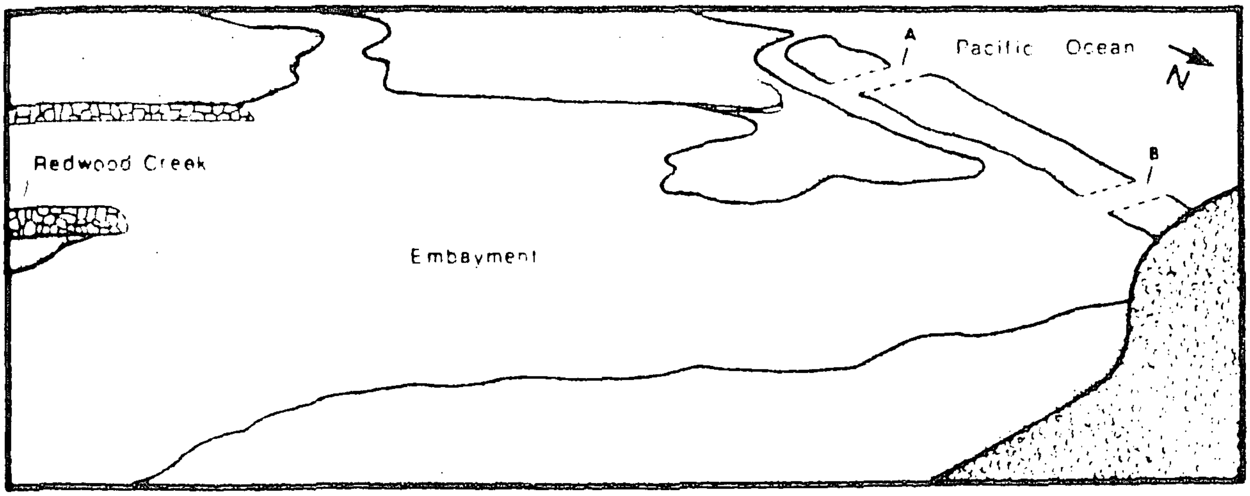


Figure 16: Mouth of Redwood Creek showing locations where channels should be dug in the berm for: A, a controlled breach; and B, an uncontrolled breach.

b. Results of Regulation

Between May 22 and October 25, 1982, Redwood National Park staff artificially manipulated the embayment water level a total of 20 times. The oat crop was flooded three times during this period. The first time for one day when artificial breaching was delayed one tidal cycle. The second flooding occurred when the southward flowing outlet had filled in with sand from overwash and it was feared that a breach could not be controlled. A preliminary decision was made not to dig because of the increased chance of draining the entire embayment and losing the fish. Finally, however, it was decided to try to excavate a new southward flowing channel utilizing a large crawler tractor. Although expensive, the procedure worked and the embayment water level was lowered but the field had been flooded for 4.5 days in the interim. Because the third flooding occurred after the oat crop had been harvested negative effects resulting from three days of flooding were minimal. Following one of the first fall rains flooding again occurred and Hufford Road was inundated. In order to drain the road the park opened the estuary which remained open through the winter. A claim was filed and paid for damages to the oat hay crop resulting from summer flooding. On two occasions, embayment water levels fell below the level that maintained a connection which the sloughs.

The fish population was monitored to see if the park's efforts were successful in providing habitat that would be used by juvenile salmonids during the summer. Population estimates for juvenile chinook salmon and steelhead trout for the summer of 1982 are shown in Table 4.

Table 4. Population estimates for chinook salmon and steelhead trout in the Redwood Creek estuary in 1982.*

POPULATION ESTIMATES

Date (1982)	Species: Chinook	Steelhead
1 July	17,342	17,685
21 July	17,112	18,229
3 August	8,118	17,937
20 August	12,699	25,900
2 September	11,992	19,950

*Does not include Prairie Creek Hatchery (see section V.B.)

Growth of juvenile chinook during this same period is shown in Figure 17. Population estimates reveal substantial numbers of chinook and steelhead even though the berm had been artificially breached by the National Park Service a total of 20 times throughout the summer. These data indicate that when habitat is available juvenile salmonids will spend an extended rearing time in the estuary. Even though water levels occassionally fell below the desirable minimum elevation, the fish remained. This underscores the importance of maintaining a slow release of water when lowering the embayment. In addition, comparing the length data in Table 3 with those in Figure 17 demonstrates that extended rearing periods allow for increased growth. The larger the juvenile fish upon entering the ocean, the greater the chances of returning as an adult spawer.

When evaporative and seepage losses from the embayment exceed input, water levels in the embayment begin to fall. For the period August 12 through September 7, 1982 embayment water levels fell from 4.52 feet above mean sea level (msl) to 3.0 msl, a vertical loss of over 1.5 feet of water. Below about 3 feet msl the south slough is effectively isolated from the mainstem. Habitat for fish becomes more and more limiting with decreasing water levels.

Redwood National Park's efforts to control embayment water levels were successful. Except for the instances mentioned, flooding of pastures was prevented and at the same time summer estuarine habitat was provided for juvenile salmon and steelhead.

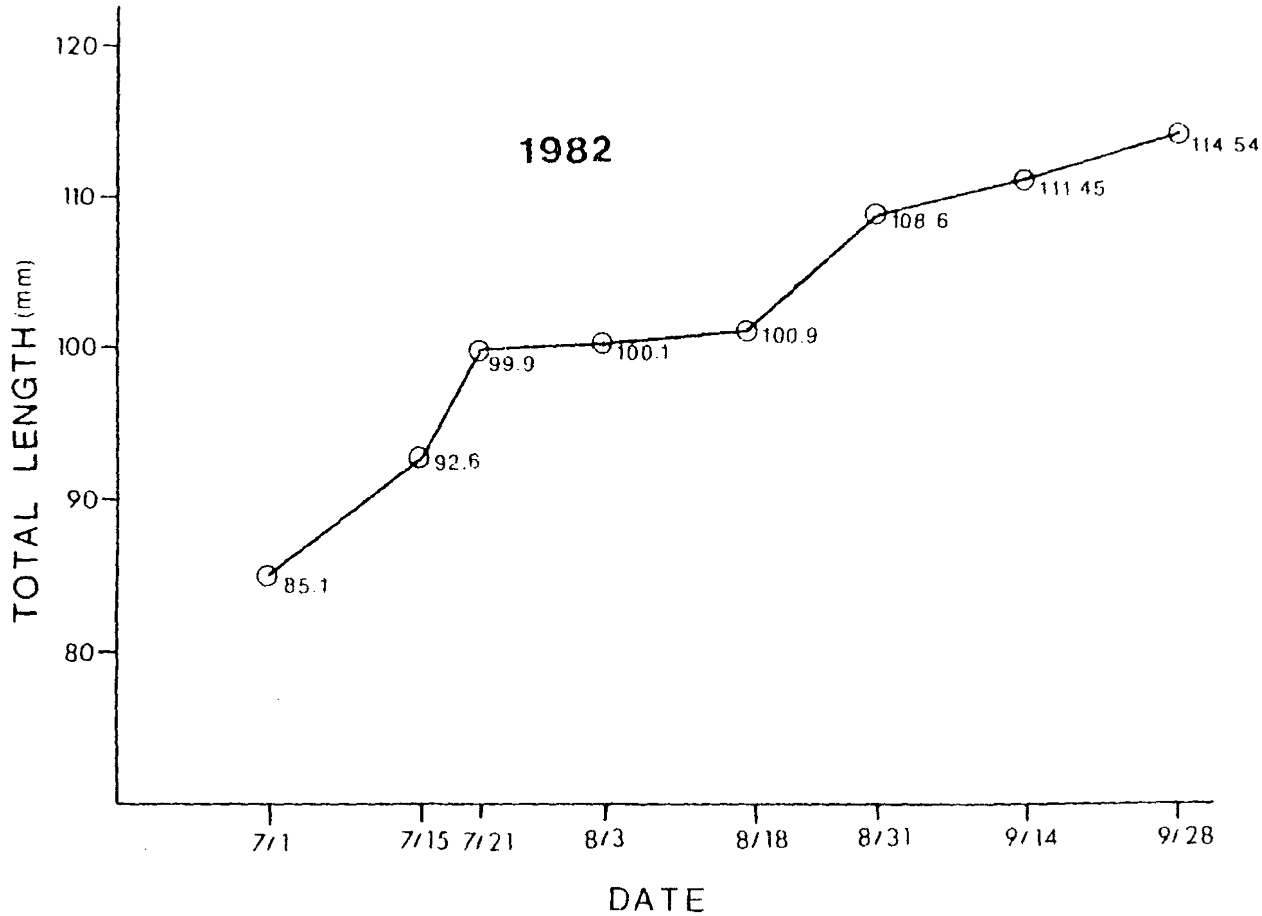


Figure 17 : Growth of juvenile chinook salmon residing in the Redwood Creek estuary during summer, 1982.

VI. WHAT CAN BE DONE

A. Management Objectives

The objective of the alternatives presented here are to ensure that estuarine management is consistent with legislation and with existing management policies and planning documents.

Redwood National Park's enabling legislation (P.L. 90-545) states "...That, in order to preserve significant examples of primeval coastal redwood forests and the streams and seashores with which they are associated for the purpose of public inspiration, enjoyment, and scientific study, there is hereby established a Redwood National Park..." National Park Service Management Policies (USDI, NPS, 1978) state, "The National Park Service will manage the natural resources of the National Park System to maintain and perpetuate their inherent integrity."

The General Management Plan (GMP)(USDI, NPS, DSC, 1980) identifies the lower portion of Redwood Creek as a natural zone. In natural zones, "shoreline processes...erosion, deposition, dune formation, etc....will be allowed to take place naturally, except where control measures, required by law or Service commitment, are necessary to protect life and property in neighboring areas" and "fisheries management shall be specifically aimed towards preservation or restoration of the full spectrum of native species" (USDI, NPS, 1978).

Recent park planning documents have outlined considerations for management at the mouth of Redwood Creek. The ultimate goal identified in the Watershed Rehabilitation Plan (1981) is "the restoration of natural ecosystems to a condition similar to what would have existed without disturbance by man." Furthermore, it was emphasized that the estuary required research to "identify existing estuarine productivity and to propose restoration activities."

Two management objectives presented in the Resources Management Plan (USDI 1982) are to "restore and maintain the natural ecosystems of the park as they would have evolved without disturbance by human technology" and "minimize the impacts of park resources resulting from current human activity outside the park." More specifically, flooding associated with embayment formation was identified as well as the need to develop alternative measures for dealing with this problem.

B. Goals

The goal of rehabilitation and management actions at the mouth of Redwood Creek is to restore natural processes and the quality of aquatic habitat. These alternatives may be relatively inexpensive or costly, temporary or permanent. In any case, political and legal concerns complicate many of the alternatives. There are both long-term major rehabilitation as well as interim management alternatives. The long-term alternatives would require restructuring of the lower portion of the flood control project to re-establish circulation in the sloughs for improvement of water quality and to provide a means for removing the sediment that settles in the necks of the sloughs. Such measures would provide increased fish habitat and ensure that the sloughs would be connected to the mainstem and accessible to fish even at low embayment water levels. Major restructuring of the levees would require careful design, additional research, and a substantial commitment of funds. Research on the feasibility of such an effort may take several more years to complete.

Meanwhile, additional impacts to the fishery resources may be expected if active management is not undetaken. While other alternatives are available, this management primarily involves regulation of embayment water levels during spring and summer months. Summer 1982's program indicates that water level management can effectively provide summertime rearing habitat for juvenile salmonids.

Keeping as much water in the embayment as possible during summer to provide important salmonid rearing habitat is the goal of water level management. This ensures a connection, albeit a shallow one, between the productive south slough and the mainstem of the creek and provides maximum habitat for juvenile fish.

C. Short Term Alternatives

1. No Action

Under this alternative, the park would not undertake any management actions at the estuary in the short term. Breaching of the berm would be regulated under the existing Fish and Game agreement process (see Section V.A.). Applications would be denied if necessary to protect fishery resources but it is likely that attempts would still be made to breach the berm.

This alternative would likely result in continuing impacts and depressed fish runs. It would not achieve total protection of pasture land from flooding, and only if the existing regulatory process is adhered to would there be any protection of fishery resources. Selection of the no-action alternative in the short-term would likely result in further reduced runs of fish prior to implementation of a major long-term alternative. The no-action alternative would be inconsistent with the long-term goals of the park's Watershed Rehabilitation Plan and proposed management addressed in the Natural Resources Management Plan.

2. Strict Enforcement of Management Policies

This alternative would preclude manipulation at the mouth of Redwood Creek and follow National Park Service Management Policies (USDI 1978) which indicate that natural shoreline processes will continue unimpeded unless required by law or legislation.

The embayment water level would rise unimpeded resulting in flooded pastures, and occasionally innundation of Hufford Road adjacent to the estuary. This alternative would achieve protection of fishery resources by allowing natural processes (albeit a modified system) to determine water levels but would also result in alienation and economic loss to landowners. Illegal attempts to open the estuary would likely increase leading to confrontations between enforcement personnel and landowners. This alternative seems extreme now because recent studies showed embayment water levels can be controlled to protect both fishery and farmland resources (Section V.C.2.b).

3. Dredging

This alternative would involve dredging the embayment and necks of the north and south sloughs to historical depths. The amount of habitat available for juvenile and adult salmonids would thereby be increased. For example, if the neck of the south slough were dredged, the slough itself would then be connected to the mainstem even in late summer when seepage and evaporation reduce embayment water levels. Sand deposits would no longer displace as much of the estuary volume, and summertime flooding would not be as severe. Dredging would only be a temporary solution, however, as overwash and aggradation would continue. A single severe winter storm could quickly fill this area again. Also, when an embayment is not forming, lower south slough water levels could result. If the elevation of the channel within the levees is below that adjacent to it in the south slough, water would drain from the slough to the lower main channel. However, when used in conjunction with long-term rehabilitation efforts designed to re-establish historic patterns of circulation, dredging would be an important first step in removing accumulated sand from the necks of the sloughs.

4. Diking Pastures

This alternative requires diking pastures which are subject to summertime flooding. Water level control would be facilitated by increasing the maximum allowable water level and a larger volume of habitat could be achieved and maintained throughout the summer. This is especially important in late summer when significant evaporative losses begin to occur. Dikes would have to be well planned to ensure all points are blocked where water might enter adjacent fields. Consideration must also be given to field drainage problems as dikes would restrict drainage from the fields after rains. If properly constructed, dikes would last many years but would require regular inspection and maintenance. Benefits to the fishery would result due to a less restrictive water level regime. No estimates are available but expenses would likely be substantial due to hauling and grading. Implementing this alternative would result in an area more artificially modified than at present.

5. Controlled Breaching

a. Goal

The goal of a controlled breach is to release water at a rate that results in the maintenance of embayment integrity and a minimum number of fish being entrained in the discharge (see Section V. C. 2. a. for a description of the method used in controlled breaching).

The period this manipulation would remain effective depends on flow within Redwood Creek and ocean conditions. The higher the ocean swells and rougher the seas, the faster this new channel will begin to migrate southward, lowering the outflow channel gradient and decreasing estuary discharge. Breaching would be accomplished immediately after high tide with a falling water level to allow sufficient time for the embayment to drain before offshore processes begin to close the new channel. Depending upon flows within Redwood Creek, the embayment can quickly rise to a level that will again require manipulation. For example, on June 15, 1982 the estuary was opened at 2:30 p.m. By 10:00 p.m. that same day, manipulation was again required.

In early summer when instream flows are high, constant monitoring of the water level is required (including weekends and holidays) and artificial breaching may be required at least once daily. The berm can be breached manually or with the use of heavy equipment. The benefits and costs of controlled breaching are discussed in Section V.C.2.b.

b. Manual Manipulation

This involves manually digging the new channel through the berm. It is a labor-intensive method and usually requires two or more individuals. As berm height increases through the summer, progressively more time and/or labor is required to effectively dig the new channel.

c. Mechanical Manipulation

Overwash of the berm deposits sand in the outflow channel. As instream flows recede, the volume of water in the outflow channel becomes insufficient to carry this sand away. The result is a slow filling-in of the channel. Eventually the channel will completely fill in and the mouth of the creek will be closed (Figure 18).

Once this occurs, a southward migrating channel is no longer available through which a controlled breach could be accomplished. Excavation of a new channel to the south through which water can be released, is necessary and requires the use of heavy earth-moving equipment. In the summer of 1982, Caterpillar tractors were used on three separate occasions to effect a controlled breach.

Figure 18: Mouth of Redwood Creek completely closed by overwash. Points A and B are where the levees could be breached, culverts or controlled flood gates installed. (RNP photo, 1974).

The length of the newly excavated channel depends on embayment water level. A higher water level requires a longer channel so the gradient is not too steep and water is not released too rapidly.

Heavy equipment costs vary from approximately $75.00 to $150.00 per hour. While this method of manipulation is relatively more expensive, it is the only feasible means of water level control once the embayment has closed. Controlled breaching can be very effective in controlling water levels but requires a substantial commitment of personnel, time, and money. The costs of the 1982 efforts are shown in Table 5.

6. Temporary Installation of Drainage Structure

Embayment water levels could possibly be controlled by temporarily installing a drainage structure in the berm . This structure would probably consist of a culvert placed relative to the berm as shown in Figure 19a. A structure able to accommodate the entire volume of streamflow early in the season would be prohibitively large and expensive. For example, the average maximum instream flow for the month of May during the period 1969 through 1981 was 1,127 cubic feet per second (cfs). This flow was calculated require a 180-inch pipe and could cost (depending upon length) as much as $25,000 (if structural steel is used). Using a larger number of smaller pipes to carry the maximum flow was also considered. Four 144-inch pipes would be needed to carry the same flow as the one 180-inch pipe as simple straight-line relationship between pipe diameter and flow volume does not exist.

Maximum and minimum, June through September, flows are 300 cfs and 17 cfs respectively. To maintain water levels at a five foot msl elevation (above this fields begin to flood) at 17 cfs requires a 28-inch culvert pipe placed on a five percent grade. A headgate is required if flows fall below 17 cfs and to prevent water levels from falling below 3.5 msl, the elevation which maintains a south slough connection. The maximum flow of 300 cfs would require nine 36-inch culvert pipes (possibly with headgates) placed at the same channel elevation and grade as the 28-inch pipe (Figure 19b). Constant monitoring of stream flow would be necessary. Additionally, the inlet of the culvert would have to be submerged at least 28 inches below the water surface to function properly. The length of the drain would at least partially be dependent upon this requirement as it may be necessary to "string" the pipe some distance into the embayment to achieve this depth.

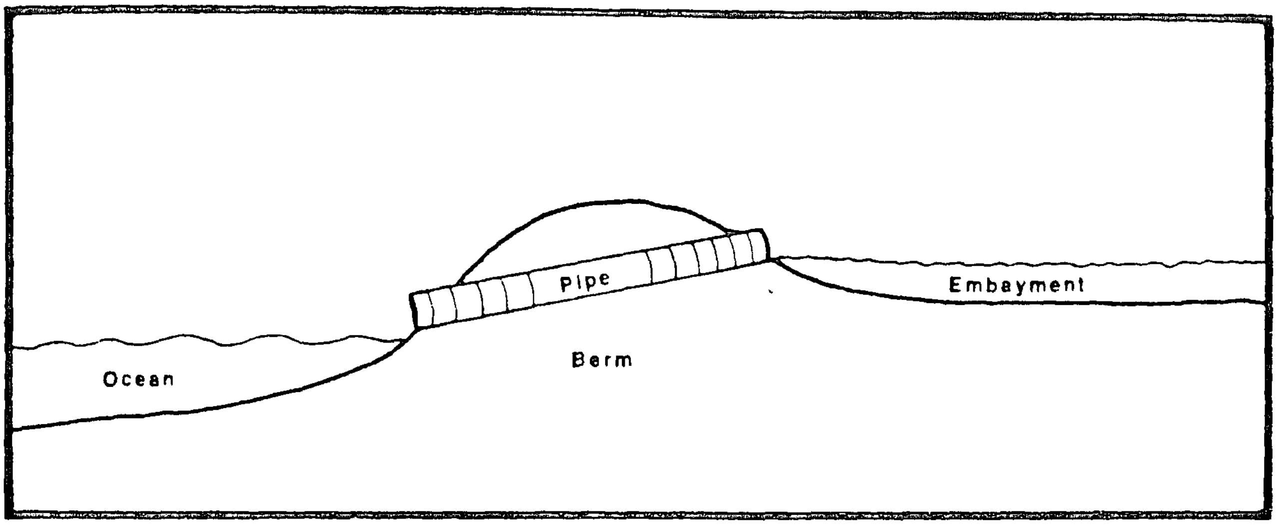
To eliminate the need for constant monitoring a 28-inch culvert could be used to accommodate the minimum flow and twenty 18-inch culvert pipes could be placed at the top of the 28-inch pipe. These would accommodate maximum flows of 300 cfs without close monitoring. Estimated costs are:

Table 5: Redwood Creek Estuary Level Maintenance Project: May 27, 1982 - December 31, 1982: Resource Management Division.

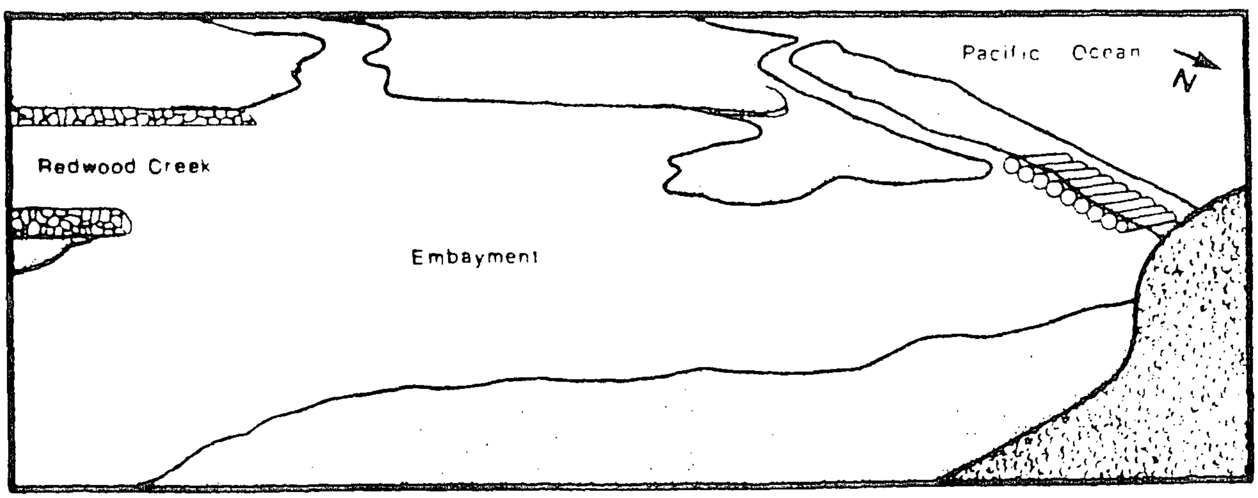
Date	Person Hours* Regular Time	Overtime	Equipment Rental		Totals
June 3	4				
June 8	4				
June 10	4				
June 15/16		9			
June 18	16				
June 20		4			
June 22	24				
June 23		7			
July 7	33	4			
July 11			$ 250.00	Bulldozer	
July 12	29				
July 17		14			
July 21	5				
July 23	10				
July 31			$ 488.00	Bulldozer	
August 1			$ 150.00	Front-End Loader	
August 3	3				
October 13	10	2	$ 1,220.00	Bulldozer	
October 14	9				
October 25	30	5	$ 262.50	Front-End Loader	
HOURS	241	60			301
	81** (Monitoring not included in above total)				
COSTS	$ 2,486.00	$ 816.50	$ 2,370.50		$ 5,673.00
	$ 850.50**(Monitoring costs not included in above total)				

* Person hours include: Park Laborers, Resource Management Technician, Redwoods United Personnel, CETA Employees, and Resource Management Specialist time. Does not inlcude Division Chiefs' nor Fish and Wildlife Ecologist's time, which was considerable but not recorded.

** These hours spent on monitoring estuary levels, checking mouth of Redwood Creek for closure, etc., during the period of May 26 through December 31, 1982.



a. Cross-sectional view of temporary drain(s) installed in swell berm. Pipe would be installed on a five percent grade. The lip of the pipe(s) on the embayment side would be placed at the minimum desirable water level elevation.



b. Location of drains that would accomodate the maximum (300 cfs) and minimum (17 cfs) June through September flows. One 28 inch and nine 36 inch pipes would be required.

Figure 19: Illustration showing placement of temporary drain(s) to control embayment water levels.

140 feet of 28-inch culvert	@ $ 22/linear foot	=	$ 3,080
2,800 feet of 18-inch culvert	@ $ 9/linear foot	=	25,200
40 hours of loader or dozer work	@ $100/hr	=	4,000
	Labor	=	2,500
	Total	=	$ 34,780
	If 36-inch culvert is used, total costs are:		$ 29,100

The costs for new culvert could be reduced or eliminated by using used culvert that is removed from road crossings as part of the Watershed Rehabilitation Program. Labor costs would increase, but a substantial savings would result. Eliminating culvert costs would result in expenses exceeding $6,500. If a coffer dam is required during culvert installation the overall costs would make this alternative totally unfeasible.

Besides costs, there are several other constraints to installing temporary drains. These include a restrictive water level range (3.5 feet to 5.0 feet msl), berm height and width during installation, and depth of embayment. Additionally, this type of activity is untested in an ocean environment. Constant monitoring of the drains themselves (separate from streamflow monitoring) is necessary to guard against undercutting of sand at the discharge end, erosion next to and around the culvert, and plugging of the culvert(s) with sand and woody debris, and to operate headgates if such a system is selected. Ideally a culvert should be installed in the summer before large numbers of juvenile fish begin to populate the embayment. If water drawdown is required, the potential for severe impacts to fish resources would be less during this period. To prevent loss from high flows the culvert(s) would be removed before fall rains. At this time of the year, the embayment would probably be closed and due to evaporative losses the water level would be below the level of the culvert. Risk of draining the embayment would be minimal at this time.

7. Drainage Structure(s) and Controlled Breaching

This alternative combines controlled breaching with a temporary drain. Breaching would be required whenever stream flows exceeded the capacity of the drain. Berm height and width or embayment depth in any given year may be such that the diameters or numbers of culverts required to accommodate downstream flows (see previous section) could not be used. Smaller and/or fewer drains might be installed, but they would be unable to independently transport flows required to control the embayment water level.

Flows within the stream recede rapidly as the summer progresses. For example, the average maximum flows that might be expected for June and July are 281 cfs and 108 cfs respectively. Controlled breaching, if required in conjunction with the drain, would be necessary for only a short period of time. If water levels are efficiently controlled the fishery benefits are the same as for controlled breaching and pasture flooding would be prevented. Costs of this alternative would vary from year to year and would probably exceed those associated with culvert installation alone.

8. Flood Easements

Under this alternative, landowners would receive compensation for the possibility of their property being flooded, which may or may not happen, depending upon circumstances varying from year to year. Landowners could manage their property as they wish but must understand that their activities could be interrupted at any time due to flooding. It is this potential interruption of activities for which they are compensated.

Acquiring flood easements on private properties adjacent to the estuary would eliminate the need for embayment water level manipulation almost entirely. The one exception would be flooding of Hufford Road. The park would not allow summer embayment water levels to rise so that access across this road is precluded. Elevating the road would reduce frequency of flooding.

Also, even with a flood easement, embayment water levels could be lowered so as not to interfere with landowner activities if maintaining higher water levels is not considered necessary to protect fishery resources. This would require a year-to-year determination.

In the summer of 1982, a formal claim for damages from flooding to an oat crop was filed by a landowner and paid by the National Park Service. This can be a lengthy and troublesome process for all parties involved. Flood easements provide compensation before damage occurs.

The costs of providing easements would likely vary between areas, but would probably not exceed those associated with controlled breaching or culvert installation. Loss of production and perhaps value of the fishery would provide the basis for determining payments. In 1982 it was estimated that oat hay production was four tons per acre and was valued at $108.00 per ton.

The value of the fishery resouces utilizing the estuary in September, 1982 if conservatively assigned a value of $1.00 each, was approximately $32,000. If the embayment had been allowed to form naturally without concern for flooding (as could be expected with flood easements) it is probable that even a larger number of fish would have been in the estuary in September. Near maximum protection could be provided to the fishery resource as water level manipulation would not be required (with the exception of Hufford Road flooding).

Flood easements could alleviate the problems associated with conflicting land uses without the expense and problems of land acquisition.

9. Land Acquisition

This alternative involves placing in public ownership those private properties now affected by summertime flooding. By eliminating the conflicting land uses the major management consideration would be the fisheries resource. The one exception would be preventing flooding of Hufford Road. If the road were elevated, maximum fisheries protection would be achieved. In addition, substantial benefits to wildlife would also occur by allowing the acquired properties to become naturally vegetated and inhabited by native wildlife.

Acquiring land that might be affected by estuarine management would leave landowners with a much reduced land base. In some cases the size of the remaining farm might be insufficient to provide a major source of income to landowners. Such effects must be carefully considered. Likewise, the cost of land acquisition would be substantial.

D. <u>Long-Term Alternatives</u>

1. No Action

This alternative would result in no attempt to restore natural estuarine processes and quality of aquatic habitat. The present status of fish runs, especially chinook salmon and steelhead, would likely stay at their present, depressed levels. The adult king salmon population could even fall to a level that would no longer support a viable run of fish. Because of its importance to all species of anadromous fish, a compromising situation at the estuary would decrease the overall effectiveness of other fisheries and erosion-control rehabilitation efforts occurring further upstream. Restoration of the fishery resources of Redwood Creek and its tributaries, an ultimate objective of the Watershed Rehabilitation Program and a desired outcome of the combined efforts of each specific rehabilitation project, could probably never be fully achieved.

2. Levee Removal

If restoration of natural circulation in the estuary is a critical step toward achieving restoration goals then the first alternative to consider is removal of the levees. Levee removal back to the first bend in the creek east of the estuary would restore flows to the original last meander of the creek (south slough) and would allow for some additional circulation in the north slough during higher flows. Winter flows could again erode away sand that had been deposited in the estuary over the summer and the deep hole adjacent to the rocks on the north side of the estuary could reappear. Initial dredging in the necks of the north and south sloughs would facilitate return to historic depths in those areas. The result would be improved summertime water quality and increased habitat for fish.

The stream now presently carries an increased bedload compared to historical characteristics. Consideration must be given to the patterns of sedimentation that may occur in the estuary as a result of this increased bedload. It is possible that severe aggradation could occur in the presently "deep" south slough area as winter flows recede.

Increased flooding of pastures might also be expected during winter months as storm flows would no longer be confined between levees. Normally such flooding is beneficial to affected areas depositing a layer of nutrient rich silt. However, crop and livestock losses could also occur. Additionally, without revetments or other protection erosion should also be expected on the south bank of the south slough.

Additional hydrologic research including modeling is required before the feasibility of this alternative can be realistically evaluated.

3. Partial Levee Removal

This would involve removing only the southern levee back to the first bend in the creek east of the estuary. The same positive effects might be expected in the south slough and embayment but no benefits to the north slough from increased circulation would be realized. The same potential negative effects of flooding, erosion, and aggradation from increased bedload would have to be examined as with removal of both levees.

4. Breaching the Levees/Culvert Installation

This would involve removal of only a relatively small portion of the levees at the upstream point where the south and north sloughs are closest to the mainstem (Figure 18). The levees (south and/or north) would be removed down to a pre-determined elevation or a culvert could be installed in the levees at this elevation. Higher flows could then enter the sloughs and scour accumulated sediment where it had been deposited by winter wave action. This alternative could allow for increased circulation in the sloughs without concern for aggradation from increased bedload. As flows receeded to levels that were below the elevation of the breached portion of the levee, they would again be totally confined within the levees. Bedload would settle within the levees or be carried directly through the mouth avoiding aggradation in the sloughs. Additional research would be required as for complete levee removal.

5. Installation of Controlled Flood Gates

Controlled flood gates could be installed in the levees at the points where the north and south slough historically connected with the mainstem (Figure 18). Controlled gates would allow only the desired flows to circulate through the sloughs and could be closed when aggradation from bedload is a threat. Additionally, during the summer low flow period, the gates could again be opened so fish passage to the sloughs would be facilitated and so there would be circulation in the sloughs during this period. Additional research is required.

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