Estuary Subbasin

The Redwood Creek estuary is located approximately three miles west of the town of Orick. The Estuary Subbasin is within the CalWater 2.2.1 Skunk Cabbage Creek Planning Watershed (Figure IV- 1). Main features of the Estuary Subbasin are the estuary/lagoon, the town of Orick, rural residential developments, agricultural and pasture lands, and flood control levees (Table IV- 1). The mainstem Redwood Creek channel of the Estuary Subbasin extends inland approximately 3.0 miles to the confluence with Prairie Creek, but salt water intrusion only extends 1.6 miles upstream from the ocean. Tributary channels to the estuary are Strawberry Creek, and Sand Cache and Dorrance creeks. The lower reaches of Sand Cache and Dorrance creeks from the North Slough channels.

The Redwood Creek estuary seasonally alternates between an open estuary and a closed coastal lagoon. The estuary usually remains open from the first substantial rains in the fall until the early summer season when a sand bar forms across the estuary mouth creating a coastal lagoon. Like many estuaries and lagoons along California's coast, the Redwood Creek estuary/lagoon plays an important role as anadromous salmonid habitat.

Table IV- 1. Estuary Subbasin summary, Redwood Creek.

Square Miles	5.4
Total Acreage	3,430
Private Acres	2,010
Federal Acres	1,420
State Acres	0
Principal Communities	Orick
Predominant Land Use	Livestock grazing
Predominant Vegetation Type	Pasture/Ag Land
Miles of Anadromous Stream	~5
Low Elevation (feet)	0
High Elevation (feet)	1,243

Geology

The Estuary Subbasin consists of a broad flood-plane valley surrounded by steep hillsides. The hillsides are underlain by Redwood Creek schist and remnants of uplifted marine terraces from flat-topped ridge crests. Slopes north of the estuary are mantled with several earthflow complexes. Several rotational landslides as well as large areas of disrupted ground and debris-slide slopes are found on the south side of the estuary. Several small alluvial fans have built out upon the valley floor.

The Estuary Subbasin is unique to the Redwood Creek basin in that the dominant landslide potential classes are either very low or high and very high (Table IV- 2). This condition exists because of the contrasting topography of flood plain and the relatively unstable hillsides of this subbasin. Historically active features account for less than 1% of the total subbasin area.

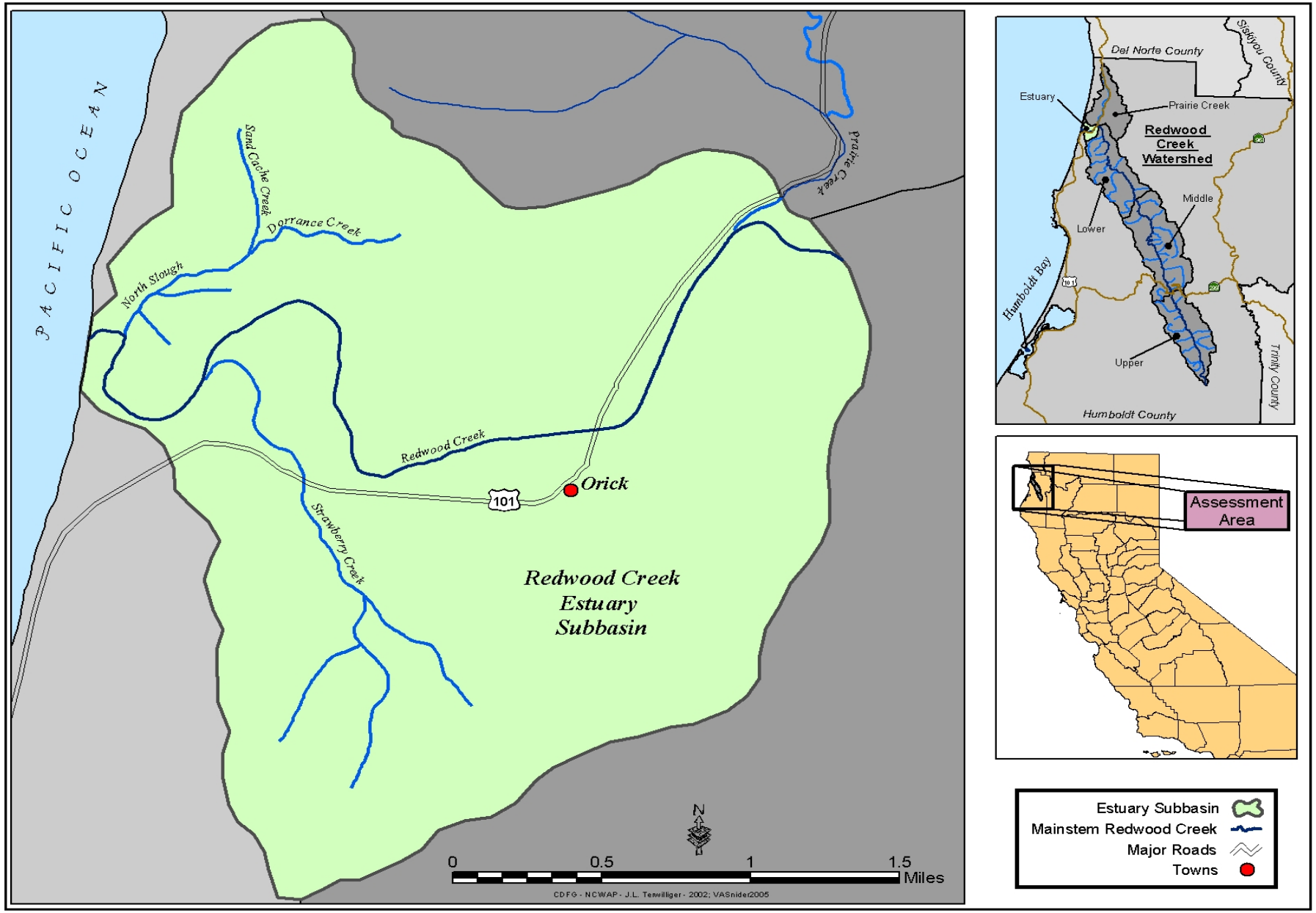

Figure IV- 1. Estuary Subbasin.

Table IV- 2. Estuary Subbasin summary of relative landslide potential and landslide features.

Relative Landslide Potential	Acres	% Area
Very Low	1,457	42.4%
Low	67	2.0%
Moderate	216	6.3%
High	1,200	35.0%
Very High	486	14.2%
High/Very High Subtotal	1,686	49%
Total of Above Features	**3,426**	**100%**
Landslide and Selected Geomorphic Features	**acres**	**% area**
Historically Active Landslide Features Total	2	0.0%
Earthflow	0	0.0%
Rock Slide	1	0.0%
Debris Slide	0	0.0%
Debris Flow	1	0%
Dormant Landslide Features Total	700	20%
Selected Geomorphic Features Total	617	18%
Disrupted Ground	277	8%
Debris Slide Slope	337	10%
Inner Gorge (area)	3	0%
Total of All Above Features	**1,320**	**39%**

Streamside Landslides

Table IV- 3 shows the number of small streamside landslides located on slopes adjacent to tributary streams in the subbasin. From 1984 to 2000, the number of active streamside landslides decreased 50%, from 26 to 13.

Table IV- 3. Estuary Subbasin number and indices of streamside slides.

Subbasin Unit of Analysis	Analysis Unit Area (sq. km.)	1984 # of Active** Slides Along Streams	2000 # of Active** Slides Along Streams	1984 Indexed** Active Slides	2000 Indexed** Active Slides	% Change 1984-2000
Estuary Subbasin	19.6	26	13	133	66	-50

**Index = (# slides/analysis unit area) X 100

Vegetation

Redwood (310 acres or 9% of the subbasin) and Sitka spruce-redwood (640 acres or 20% of the subbasin) compose most of the conifer cover type in the Estuary Subbasin (Table IV- 4 and Figure IV- 2). Old growth redwood is found within the subbasin, along with previously harvested areas that now support second growth trees. Red alder (770 acres or 24% of the subbasin) occupies a relatively extensive area within this subbasin. Grass lands used as pasture, and agricultural land comprise approximately 35% of the subbasin.

Historic forest condition of the areas were much different than today. By inspection of historic photographs, it is clear that there was once considerably more redwood, Sitka spruce, and red alder forests and sedges surrounding the estuary.

Table IV- 4. Estuary Subbasin generalized vegetation cover type.

Subbasin or Planning Watershed	Cover Type (estimated acres)								
	Agriculture	Barren	Conifer	Hardwood	Grassland	Shrub	Developed	Water	Total
Estuary	350	110	1,075	770	800	30	80	65	3,300

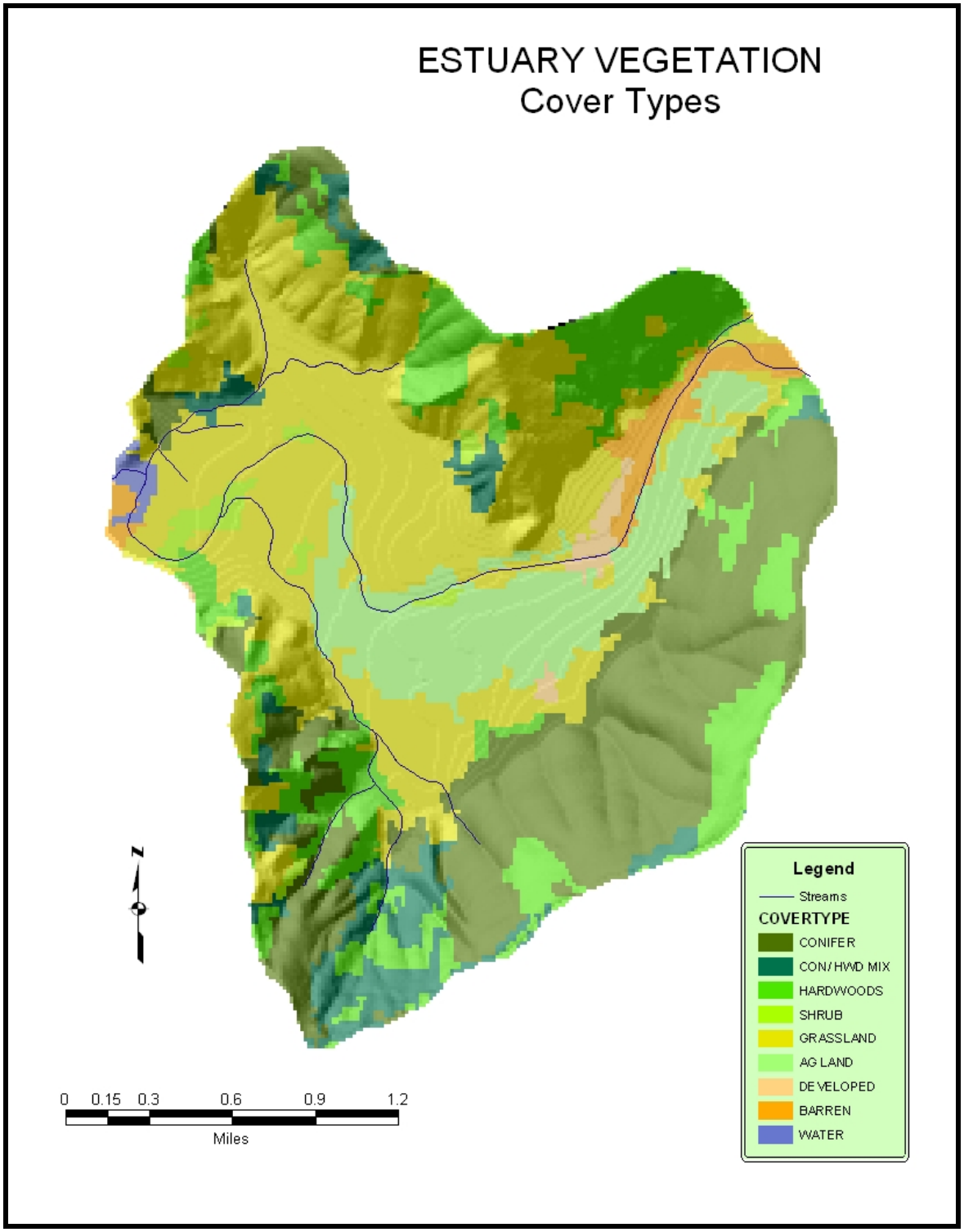

Figure IV- 2. Estuary vegetation map showing cover types.

Land Use

Native Americans were the first people to utilize the Redwood Creek estuary. They built villages located near the ocean along Redwood Creek, but no notable change to the estuarine area can be detected from the Native American presence.

The lands surrounding the estuary were the first areas in the Redwood Creek basin to be modified by western settlers. Land use in the Estuary Subbasin, including farming, grazing, and development, began in the 1850s.

By the early 1900s, much of the present grasslands within the delta area were converted from redwood, Sitka spruce, and red alder forests, and sedges. The estuary subbasin has the largest amount of agricultural land (350 acres or 10% of the subbasin) within the Redwood Creek basin (Table IV- 4). Most of this vegetative cover type is in permanent grazing land and pasture. The town of Orick is located in the Estuary Subbasin and with a population of approximately 500 is the largest settlement in the Redwood Creek Basin. Approximately 80 acres have been developed in and around the town of Orick.

The most significant land use impact to the estuary came from the construction of flood control levees. In response to the 1964 flood, earthen levees were built in 1968 by the Army Corps of Engineers along the lower 3.4 miles of Redwood Creek to protect the town of Orick and agricultural lands located in the valley flood plain. The flood control project included removal of all riparian vegetation growing between the levees; the main channel was also straightened, shortened, and modified to form a 250 foot wide trapezoidal shape. The levee system has had a profound effect on the estuary, including reducing the estuarine area and changing ecosystem processes. Further effects from the levees are discussed in the following sections.

Timber Harvest

Timber harvest operations within the Estuary Subbasin began in the mid 1800s. By 1942, most of the area had been converted to other land uses, such as pastureland and development. Table IV- 5 and Figure IV-3 summarize the timber harvest history for the Estuary Subbasin since 1950. Table IV- 5 and Figure IV-3 do not show acres in the flood plain converted from forest to agricultural land. About 1,470 acres have been harvested in the subbasin during this period, an area equivalent to 42.8% of the total subbasin area. There has been no timber harvest activity in the subbasin since the 1970s.

Table IV- 5. Estuary Subbasin timber harvest history 1950-2000.

Subbasin	Harvest Acres by Period							
	1950 to 1964	1965 to 1974	1975 to 1983	1984 to 1992	1992 to 2000	Total Harvested	Total Subbasin Acres	Percent Harvested
Estuary	1,249	84	137	0	0	1,470	3,433	42.8

Roads

The Estuary Subbasin has approximately 16 miles of roads. Most of the roads are paved. The road density is about 3.3 road miles per square mile. About 32% of the road miles are on areas of high or very high relative landslide potential.

Fire and Fuels

The Estuary Subbasin has 27% of its area in the moderate fuel rank, 49% of its area in the high fuel rank, and 11% in the very high fuel rank (Table IV- 6 and Figure IV- 4). Fourteen percent of the area is in agricultural and developed areas which are not considered in the fuel ranking process. The areas of very high rank are relatively large and contiguous in this subbasin as compared to the other subbasins. Given the relatively cool, damp, marine-influenced weather of the Estuary Subbasin, the fuel rankings alone overstate the fire risk found in the subbasin.

Table IV- 6. Estuary Subbasin fuel ranks summary.

Area of Analysis	Fuel Rank								Total Acres
	Moderate		High		Very High		Not Mapped		
	Acres	%	Acres	%	Acres	%	Acres	%	
Estuary	920	27	1,670	49	378	11	467	14	3,435

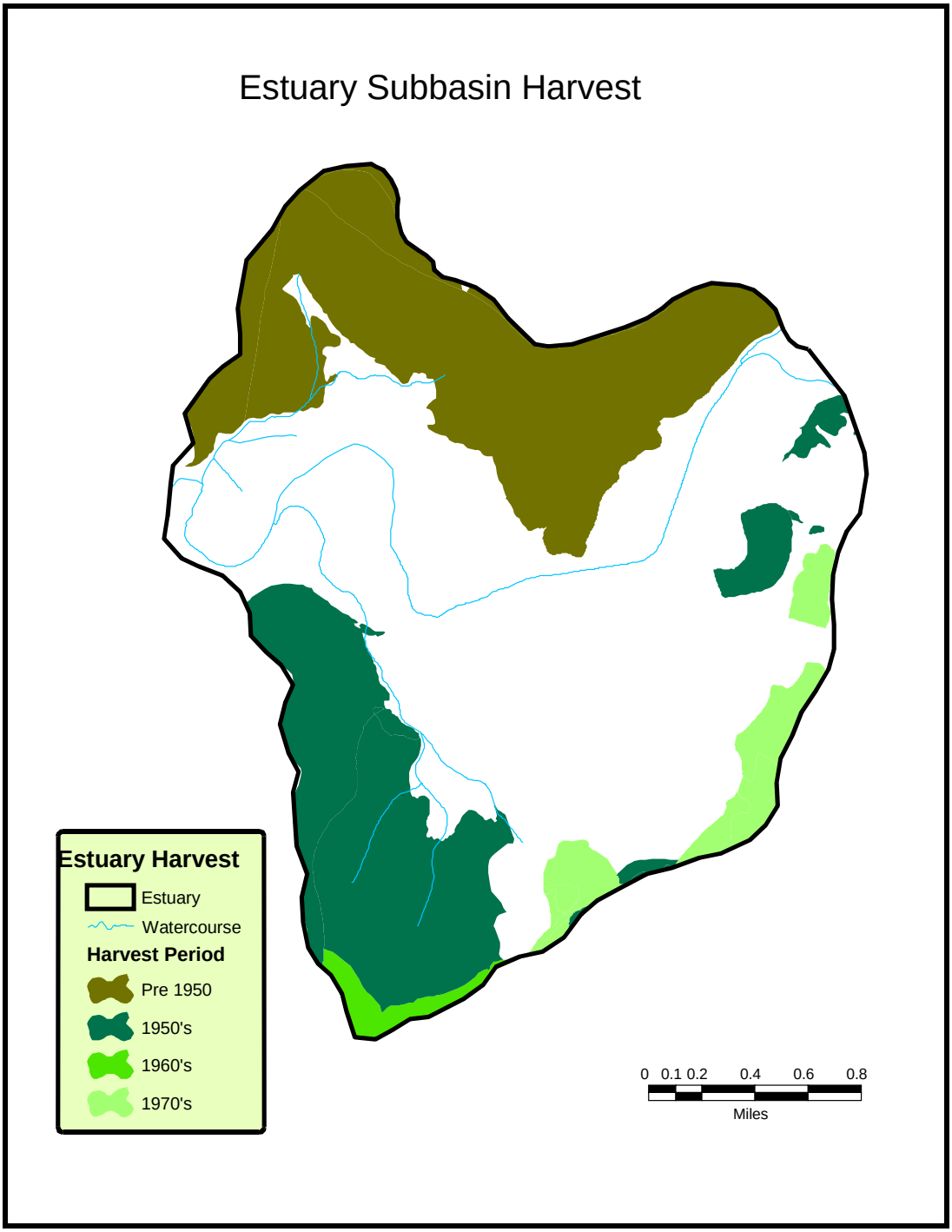

Figure IV-3. Estuary Subbasin timber harvest.

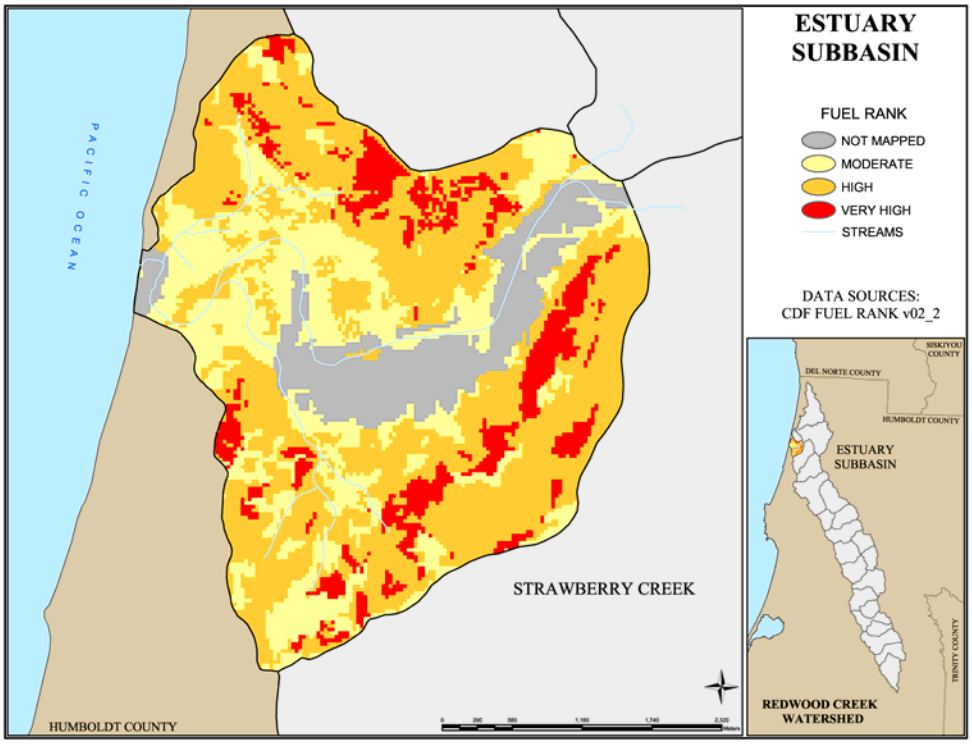

Figure IV- 4. Estuary Subbasin fuel ranking map.

Fluvial Geomorphology

Janda and others (1975) described the estuary at the mouth of Redwood Creek and observed that in the early 1970s, the tidal influence extended 1.6 miles upstream. The subbasin contains 10 blue-line tributaries, four of which have names: Johnson Creek, Skunk Cabbage Creek, Sand Cache Creek, North Sough, and Strawberry Creek.

Aerial photographs taken from 1936 through 1965 (Figures IV-5 through IV-7) show the estuary was significantly larger before flood control levees were built in 1968 (Appendix E includes photos from 1905-2000). Aerial photographs taken in 1988 and 2000 show a remnant embayment at the mouth of Redwood Creek and a constricted estuarine channel at the beach (Figures IV-8 and IV-9).

The levee system was designed to contain a storm runoff of approximately 77,000 cubic feet per second (cfs), a flow frequency recurrence interval of once in more than 200 years (COE 1998). The maximum peak flows on record are 50,500 and 50,200 for the water years 1965 and 1975 respectively.

Recent studies suggest that the levees will begin to overtop at flows of 65,200 cfs (estimated 100 year flood recurrence interval) rather than the design runoff of 77,000 cfs (COE 1998). The reduction in flow capacity of the project is caused by the combination of channel aggradation, subsidence (1 to 2 feet) along the upper and lower reach of the levee system, and vegetation growth on the levees (COE 1998). Hydraulic analysis revealed that 75% of the loss in flow capacity (approximately 9,000 cfs) is from channel aggradation (COE 1998).

The aggradation is partially in response to the presence of flood control levees. The levees form a semi-canal which encourages the deposition of sediment load brought from the sea and from the land. The levees make it impossible for sediment to be dispersed over the sides of the main channel. The overall effect is to encourage sedimentation in the estuarine channel.

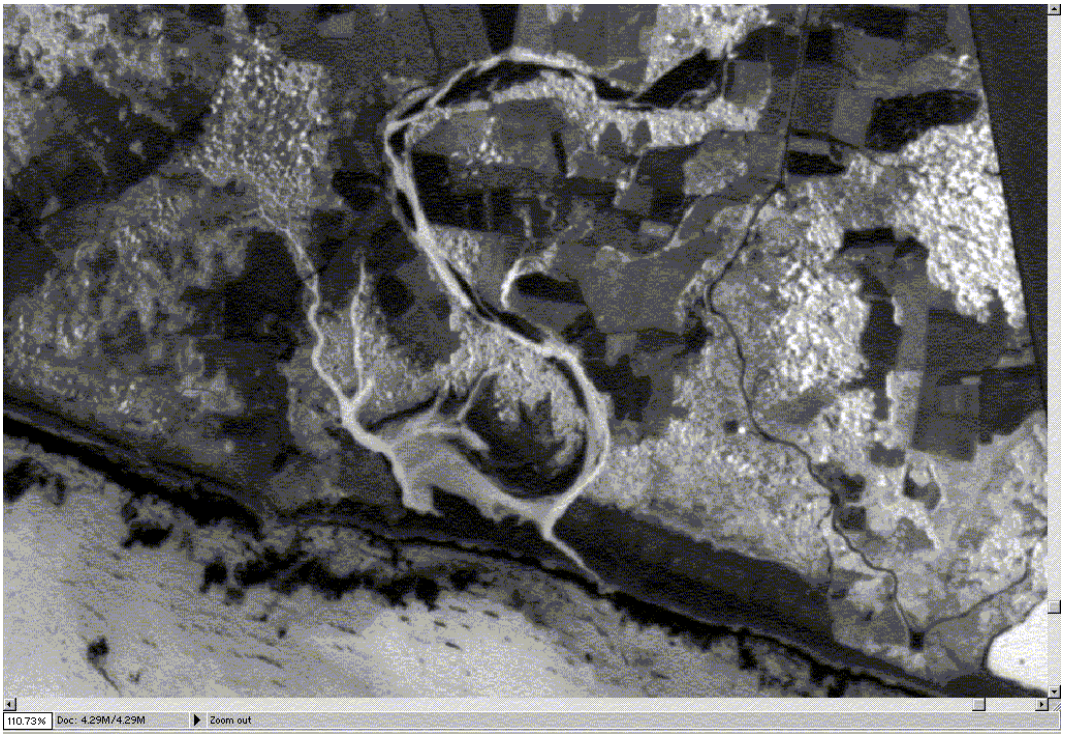

Figure IV- 5. Redwood Creek estuary in 1936.

North is to the left. Note the size and continuity of the water in the estuary and the amount of water in the tidal inlets to northeast. Aerial photography was provided by Redwood National Park.

Figure IV- 6. Redwood Creek estuary in 1948.

North is toward the top of the photograph. Source of aerial photographs is U.S. Forest Service, flight CDF2, 1:26,400.

Figure IV- 7. Redwood Creek estuary in 1965, after the flood of 1964.

There is a great deal of water in the creek and estuary, and the lateral gravel bars are probably submerged. However, the flood did not significantly change the shape or location or area of the estuary or the lower meanders of Redwood Creek. Source: U.S. Department of Agriculture, Soil Conservation Service, flight CVL, 1:20,000.

Figure IV- 8. Redwood Creek estuary in 1988.

Construction of levees in the late 1960s confined lower Redwood Creek to a smaller channel and the size of the estuary diminished Used with permission from W.A.C. Corp., Eugene OR.

Figure IV- 9. Redwood Creek mouth, 2000.

The area of the former estuary is filled with beach sand. The tidal inlets, called the North Slough, are nearly dry. The south meander of the creek is a backwater slough. The estuary is a constriction of Redwood Creek at its mouth. Levee construction did more damage to the estuary than the storm of 1964, because the size of the estuary has been reduced dramatically. The alternating lateral bars in lower Redwood Creek represent an attempt by the stream to form meanders and to dissipate energy. Aerial photography, 1:24,000, used with permission from W.A.C. Corp., Eugene, OR.

Approximately 210,000 cubic yards of gravel was removed from the estuary channel in 1987 and1988. The gravel was used to construct the Highway 101 bypass. Approximately 33% of the gravel was replenished by the following year and 44% had returned within three years (Moffatt and Nichol 2003). The vast majority of bedload measured near Orick was deposited between the levees over those three years (Moffatt and Nichol 2003), indicating the short term effects from removing gravel as a potential solution to the channel aggradation problem.

According to Janda and others (1975), the estuary covered twice its size before the levees were built. The lower two meanders were once active parts of the mainstem of lower Redwood Creek (Baine's Bend and the meander south of Middle Island) and carried the main flow. This part of the channel became a backwater slough after the creek was confined between levees (Janda and others 1975). Slough inlets extended inland from the north side of the estuary to the northeast and east. After the construction of the levees, these inlets were constricted by sediment and largely disappeared from aerial view. Presently, the slough inlets are plugged by marine beach sediment rather than fluvial sediment. Ricks (1985) showed that there was an increase in marine sediment in the estuary following construction of the levees. Sediment samples from well within the estuary showed an increase in blue-green hornblende, which is a mineral carried southward by longshore currents from the Klamath River. Thus, the proportion of marine sediment increased within the estuary after levee construction and contributed to the loss of estuarine habitat area, a loss of slough channel connectivity, and a reduction of the tidal prism.

An important feature of Redwood Creek's estuary is that it forms a lagoon depending on the status of the Redwood Creek mouth. During late spring and early summer, tidal flow through the mouth of the Redwood Creek estuary is restricted by the presence of a sill as longshore transport of sand begins to close the mouth and the lagoon begins to form. The restriction of the tidal flow may result in shorter flood tides, which are characterized by higher velocities, in the presence of low river flow, and a greater transport of marine sediments into the estuary (Larguer et al. 1992). Excessive accumulation of sediments and reduction of tidal prism may

contribute to closing the mouth earlier than it did historically. Early closure of the mouth decreases the window of time available for juvenile salmonids to migrate to sea and may alter physical elements of channel morphology and water quality.

Sediment Storage and Transport

Sediment storage and transport through the estuary are influenced by the amount and rate and size of sediment delivered from upstream sources, stream flows, channel gradient, confinement of the channel from levees, and tidal action. The great majority of sediment stored or transported through the estuarine channel is derived from hillslopes located in the Lower, Middle and Upper subbasins. The fluvial sediment supply was enhanced by major floods during the last 50 years in 1955, 1964, 1972, 1975, and a moderate flood in 1996-1997 (RNSP 1999). CGS/NCWAP observed gravel bars in lowermost Redwood Creek aerial photographs from 1936, 1948, 1965, 1984, 1988 and the spring of 2000. The gravel bars vary in size and shape from decade to decade, reflecting storage and transport of sediment. Channel cross sections monitored by RNSP and COE show irregular, net accumulations of sediments throughout the estuarine channel (COE 1998, Moffatt and Nichol 2003). The channel will likely continue to aggrade until the levees are modified and the sediment supply from upstream adjusts with the transport rate of the estuary channel.

Table IV- 7 summarizes findings from examination of aerial photos for negative stream features. CGS found that negative stream features, mostly consisting of elevated sediment, increased 95% by length in the estuary subbasin between 1984 and 2000. This is largely due to the downstream transport and subsequent deposition of sediment originating from the Upper, Middle, and Lower subbasins.

Table IV- 7. Estuary Subbasin length of negative stream features, negative stream feature index, and percent change 1984 to 2000.

Subbasin Unit of Analysis	Analysis Unit Area (sq. km.)	Negative Features 1984 (m)	Negative Features 2000 (m)	Indexed Negative Features 1984*	Indexed Negative Features 2000*	% Change 1984-2000
Estuary	19.6	2,936	5,734	150	293	95

* Index = (length of negative features in meters/area of unit of analysis in square kilometers)

Water Quality

The Estuary Subbasin consists of two distinct water quality zones: an estuarine/lagoon zone and freshwater, riverine zone. The water quality of the Redwood Creek estuary/lagoon is influenced by complex relationships between seasonal changes in freshwater flows, ocean tides, the coastal fog climate, channel morphology, and lagoon conditions. The influence of the estuary/lagoon extends approximately 1.5 miles up the Redwood Creek channel and also for some distance up Strawberry Creek, Dorrance Creek, and Sand Cache Creek. Approximately two miles of Redwood Creek riverine channel extends between the upper limit of the estuary/lagoon and the confluence with Prairie Creek. This reach is somewhat cooled by water coming from Prairie Creek and cool air temperature provided by the coastal climate.

Temperature, Salinity and Dissolved Oxygen

RNSP biologists have studied water quality of the estuary/lagoon and sloughs during the summer months for several years, monitoring vertical profiles of conductivity, salinity, dissolved oxygen, and temperature. Information retrieved from annual estuary monitoring reports (Anderson 1983-87 an d1997-2000) indicate that under lagoon conditions, unfavorable water temperature and dissolved oxygen levels have been limiting factors for salmonids in the lower embayment and slough channels. These conditions begin by mid July of most years, when a sand bar closes the creek mouth and the estuary converts to a lagoon.

In general, the water column develops a salinity gradient or stratifies with freshwater on the surface and saline water in the middle and bottom waters (RNSP 2000). Water temperatures in the lagoon generally raise, dissolved oxygen levels fall, forming conditions can become stressful or lethal to salmonids especially in the slough channels where circulation is minimal (Larson et al. 1982, RNSP 2000). For example, an MWAT in the lagoon of 68°F was recorded in 1997. Maximum daily temperatures recorded during the summers of 1997 and

1998 for sites in the estuary/lagoon were 70 and 68ºF, respectively. These data indicate that during the hottest part of the year, temperatures in the estuary are below the lethal limit of 75ºF but may still cause stress to salmonids. Dissolved oxygen (DO) measurements collected during fish sampling in the early 1990s varied among sites. Adequate levels of DO were observed in the lower embayment, but levels approaching 0 ppm were recorded in the slough channels (RNSP 2000). Cumulative effects from elevated nutrient delivery from livestock grazing lands and dairies, algal growth and decomposition, and lack of water circulation have likely contributed to low (at times lethal to fish) dissolved oxygen levels in the sloughs.

Water Column Chemistry

A monitoring site for water chemistry data near the town of Orick has been sampled quarterly for approximately 30 years. The Orick site is upstream of saline influence from tidal action. Data from this site indicate a slight increasing trend for DO and pH, however both parameters fall within Basin Plan water quality objective goals. There are a few additional monitoring sites closer to the mouth of Redwood Creek in the estuary. The data are scattered and scarce, but can be obtained at the USGS NWIS web website http://waterdata.usgs.gov/ca/nwis. (USGS 2001). Since chemical analysis of the water is performed above the estuarine channel there is no data to determine if waste products from cattle grazing are affecting the water quality of the estuary/lagoon.

The Surface Water Ambient Monitoring Program (SWAMP) sampled a site near the town of Orick thirteen times during 2001-2003. This site samples fresh water upstream from tidal influence. Data showed mainstem waters having mean dissolved oxygen of 10.7mg/L (water quality objective >8mg/L), pH at 7.7 (water quality objective 6.5-8.5), and conductance of 101umhos (water quality objective <220umhos). Samples for nutrients were within normal limits. Low-level metals testing showed presence in small non-threatening amounts. Results from this sampling effort can be found in Appendix B. Organic pesticide and herbicide sampling results were not available at the time of this report. However they will be made available on the following website: http://www.swrcb.ca.gov/swamp. Future sampling efforts from the SWAMP program will extend trend lines for pH, dissolved oxygen, and conductivity, as well as maintain a watch on water quality.

In-Channel Sediment

In-channel sediment was sampled in the estuary subbasin at mainstem Redwood Creek near the town of Orick by USGS. Redwood Creek at Orick was sampled every two years from 1983 to 1995 for percent of fine materials using McNeil cores and sieved dry. See Appendix C for a display of the data. No distinct trends in the gravimetrically measured samples are noticeable. TMDL targets do not apply to estuarine areas under tidal influence due to the natural breakdown of substrate materials and the possible influx of oceanic sediments resulting from wave action. Due to the method of analysis, these streambed data are not comparable to TMDL targets because the samples were not analyzed volumetrically. No D_{50} data exist for this subbasin or the data were not assessed in this report.

Salmonid Habitat Assessment

The estuarine environment provides a transition area between fresh water and marine environments where ocean tides, river flows, sediments, plants, and animals interact to form a dynamic ecosystem. Due to the highly variable measures of salinity and temperature found in estuaries, most fish find estuaries a harsh environment. However, fish that tolerate estuarine conditions benefit from abundant planktonic and macroinvertebrate food supplies and obtain a degree of protection from most predatory fish. The abundance of low trophic level food supplies and the sheltered environment makes estuaries important nursery and rearing areas for juvenile fish including anadromous salmonids. Anadromous salmonids also use the estuarine environment as a transition area to undergo critical physiologic adaptations as they acclimate to changes in salinity and water temperature during downstream seaward migrations as juveniles and upstream spawning migrations as adults. Fish, including salmonids that utilize estuaries and lagoons for juvenile rearing or other important parts of their life cycle may be referred to as estuarine-dependant. Because of this value as nursery grounds and adult holding habitat, the Redwood Creek estuary and lagoon are critical habitat areas for anadromous salmonids. Table IV- 8 presents a list of fish species found in the Redwood Creek estuary/lagoon and length of channels accessible to anadromous salmonids in the Estuary Subbasin.

The Redwood Creek estuary provides juvenile salmonids essential rearing habitat needed to achieve important growth before entering the ocean. Juveniles that rear in estuaries and lagoons for extended periods usually increase in size, giving them a survival advantage upon the onset of their ocean life. It is believed that the larger juveniles are less likely to be preyed upon by other fish and they may also have a wider food base to feed upon during critical first weeks at sea. The estuary/lagoon rearing may be especially beneficial for Chinook salmon and steelhead originating from streams like Redwood Creek where warm summer water temperature or low flows may limit instream rearing in much of the mainstem during the summer and fall seasons. They arrive to the estuary at a relatively small size where they can reside and continue to grow before migrating to the sea.

An estuarine rearing strategy is an important component of behavioral diversity within juvenile salmonid life history strategies. Producing juveniles that successfully rear in both stream and estuarine habitats for variable time periods before they enter the ocean may also promote genetic diversity. This is important as genetic and behavioral diversity helps ensure survival for fish that encounter a wide range of environmental conditions in both the freshwater and marine environments.

Table IV- 8. Estuary Subbasin species present, and number of stream miles accessible to anadromous salmonids.

Stream	Species Observed	Anadromous Length (mi.)	References
Redwood Creek estuarine channel	coho salmon Chinook salmon steelhead coastal cutthroat trout Pacific herring staghorn sculpin prickly sculpin saddleback gunnel Pacific lamprey brook lamprey three-spine stickleback starry flounder eulachon surf smelt night smelt shiner surfperch tidewater goby	3.5	Fish species of Redwood National Park (1992)
Strawberry Creek	coho salmon steelhead coastal cutthroat trout Pacific lamprey	1	RNSP 2000, Draft Strawberry Creek 1994
Sand Cache Creek/North Slough channel	Chinook salmon coastal cutthroat coho salmon steelhead tidewater goby	.5	D. Anderson, RNSP, Personal communications
Dorrance Creek	*na	na	

*not available

During the mid-1800s to the mid-1900s the estuary/lagoon was a popular area for sport fishing on Redwood Creek. Fishers used to troll for salmon in rowboats and also fished from the shore. Frequent articles printed in local newspapers in the early 1900s told of Chinook weighing sixty pounds or more and numerous other salmon that were caught in the estuary, the tidal channel of Strawberry Creek, and North Slough channel (Van Kirk 1994). Coastal cutthroats also were often taken in the four to six pound range. The current effort and catch from sport fishing in the estuary is greatly reduced compared to the past accounts. Presently, much of the fishing effort is focused along the reach above tidewater (~1.5 miles upstream of the mouth) to the confluence of Prairie Creek (Tom Weseloh, California Trout, personal communication). Naturally produced anadromous salmonids are managed as a catch and release fishery.

Over the past 125 years, the estuary area has been altered by conversion of forest and wetland areas to pasture land, and by channel modifications and levee construction in 1968. Flood control levees built in 1968 account

for the largest change to the estuarine ecosystem. As a result of modifications, the fish rearing area of the Redwood Creek estuary/lagoon has been reduced by 50 to 75% (Ricks 1983). These changes have impaired the physical and biologic function and reduced the capacity of the estuary/lagoon to support salmonids.

A fundamental study conducted in the Redwood Creek estuary by Larson et al. (1981) noted the importance of the estuary/lagoon as juvenile salmonid rearing habitat. They also identified opportunities for habitat improvements. The years of studies and management recommendations that followed also prompted RNSP and others to develop a series of alternatives to improve conditions in the estuary. Some of the ideas can be found in the *General Management Plan for Redwood National and State Parks* (RNSP 2000) and *Hydraulic Analysis of Alternative Levee Configurations for Lower Redwood Creek* (Moffatt and Nichol 2003). The studies have shown a high potential to improve the estuary/lagoon condition by increasing the channel width while maintaining protection of Highway 101 and the town of Orick, and addressing needs and concerns of landowners of the estuary project area. Alternatives also include efforts to purchase land within the project area and should consider conservation easement strategies. The goals of any estuarine restoration project should promote improvement of estuarine ecosystem integrity by increasing the area of the lower embayment and lower river channel while also increasing depths, shelter, and connectivity and circulation between the main channel and slough channels, and re-establishing riparian forests.

Salmonid Fishery Resources

Chinook Salmon

Juvenile Chinook salmon of the Redwood Creek Basin rear in the estuary/lagoon before entering the sea. The estuarine rearing strategy is important because juvenile Chinook salmon are typically less than 70 mm fork length (FL) when they arrive to the estuary in May, June, and July (Anderson 2000 and 2001, Wilzbach 2001). The average size of these fish is below the optimal size of more than 100 mm FL noted for high survival rates upon ocean entry (Nicholas and Hankin 1989). Rearing in the estuary/lagoon allows Chinook to obtain larger size, but the creek mouth typically closes before Chinook reach 100 mm FL. Thousands of juvenile Chinook remain to rear and grow in the lagoon over the summer season. However, a review of population estimates provided by RNSP studies shows that only 7 to 15% of the Chinook populations survived from July to September in the lagoon during 2000 and 2001(Anderson 2000 and 2001) (Table IV- 9). The impaired condition of the estuary/lagoon likely contributes to the low over summer survival rate of juvenile Chinook and is a factor limiting Chinook production in the basin. Additional information about Chinook use of the estuary can be found in the Anadromous Salmonids Status and Life History in Section III of this report.

Table IV- 9. Juvenile steelhead and Chinook population estimates.

Redwood Creek Estuary Fish Sampling - Summer/Fall 2000						
Date	**Mouth**	**Steelhead Population Estimate**	**Ave FL**	**Chinook Population Estimate**	**95% CI**	**Ave FL**
5-Jun	Open	12,780	126	55,640	± 17,710	72
July 17,18,20	Closed	8,950	202	18,350	± 20,490	74
Sept 11,12	Closed	4,270	220	2,910	± 1,900	94
26-Oct	Closed	na*	na	na	na	111
4-Jun	Open	38,456	113	58,633	± 19,531	62
16-Jul	Closed	34,259	89	34,259	± 27,032	71
13-Aug	Closed	4,612	81	3,616	± 3,035	77
10-Sep	Closed	9,348	126	2,288	± 2,485	86
2-Oct	Closed	na	118	na	na	91
23-Oct	Closed	na	147	na	na	102

*na: population estimate not determined
95% confidence interval (CI), and average fork lengths (FL) collected from Redwood Creek Estuary/Lagoon 2000 and 2001 (Anderson 2000 and 2001).

Steelhead

Steelhead may rear in estuaries/lagoons including the Redwood Creek estuary/lagoon for several months to one year or more before entering the ocean (Anderson 1988, Ridenhour and Hofstra 1994, Cannata 1998, RNSP 2000). The additional growth added in the estuary/lagoon is believed to increase steelhead survival rates upon

ocean entry. Steelhead size and growth in the Redwood Creek estuary/lagoon appears highly variable between years. As with Chinook, a large percentage of steelhead residing in the Redwood Creek lagoon do not survive over the summer months (Table IV- 9). However, steelhead seem to survive at a higher rate than Chinook. Additional information about steelhead use of the estuary can be found in the Anadromous Salmonids Status and Life History in Section III of this report.

Coastal Cutthroat

The Redwood Creek estuary once supported a large population of coastal cutthroat trout (Van Kirk 1994). Presently, small numbers of coastal cutthroat trout reside in the estuary and some may stay there year-round (Dave Anderson, RNSP, personal communication). Sport catches of coastal cutthroats in the 3 to 4 pound range were common from the estuary in the late 1800s and early 1900s (Van Kirk 1994). It is thought that some coastal cutthroats use the estuary for adult habitat much like the salmon use the ocean for growing and then return to small streams to spawn. Others use the estuary for juvenile rearing grounds as a transition zone before seaward migrations. Catches of coastal cutthroats are reported in annual RNSP beach seine surveys of the estuary, but their numbers are relatively low. Additional information about coastal cutthroat use of the estuary can be found in Anadromous Salmonids Status and Life History in Section III of this report.

Coho Salmon

Juvenile coho rely on the estuary for feeding, rearing, and for acclimating to changes in salinity before entering the ocean. They tend to be most abundant in June when the mouth is still open, but some have been caught after the mouth has closed (Dave Anderson, RNSP, and personal communication).Several juvenile coho have been collected in the estuary (1,390 ± 630 in year 2000) and a few have resided in the lagoon over the summer (Anderson 2000). Small numbers (<50) of juvenile coho are usually captured in the lagoon during annual (June through October) fish sampling. Some coho may reside in the estuary/lagoon by their own volition as they were not ready for life at sea before the mouth closed. Little is known of juvenile coho use of the estuary/lagoon for winter or spring residence. Additional information about coho salmon use of the estuary can be found in Anadromous Salmonids Status and Life History in Section III of this report.

Estuary Subbasin General Issues

Key salmonid fishery issues of concern identified for the Redwood Creek estuary include:

Channel modifications from the flood control levee system have likely had the most impacts to the physical form and alterations of natural processes that drive the estuarine ecosystem:

- The affects of levees exacerbate sediment accumulations and a contribute to the loss of tidal connectivity to slough channels and a reduction in tidal prism;
- Removal of riparian trees for pasture development and levee construction caused the loss of benefits from the riparian forests;
- Riparian vegetation is periodically removed from the estuary channel as part of a levee maintenance procedure.

Since it is located at the bottom of the basin, the estuary is particularly susceptible to watershed cumulative effects:

- Juvenile salmonids that reside and pass through the estuary during spring and early summer during seaward migrations find favorable water quality conditions for rearing and may acclimate to changes in salinity and temperature;
- Much of the water quality and sediment characteristics of the estuary are related to upstream watershed conditions.

The low gradient, depositional reach of Redwood Creek in the Estuary Subbasin accumulates sediments delivered from upstream source and transport reaches:

- These include relatively warm water inputs and high levels of sediment delivery.

Juvenile salmonid rearing success is impaired by estuarine habitat conditions:

- The fish rearing area of the Redwood Creek estuary/lagoon has been reduced by 50 to 75%;
- Survivorship is very low (estimates of 7-15%) for juvenile Chinook and steelhead that rear in the lagoon through the summer;
- The estuary/lagoon once supported an abundant, year round population of coastal cutthroat trout. At present, only a few coastal cutthroat are found during fish surveys;
- The estuarine channels are shallower compared to historic conditions;
- Habitat shelter complexity is low due to a lack of riparian vegetation and LWD;
- Dissolved oxygen levels can be at stressful or lethal levels in the slough channels.

Estuary habitat improvement projects have been proposed:

- A large amount of work has been done by RNSP, private landowners, public agencies, and interested parties to develop alternatives to improve habitat conditions in the estuary/lagoon, while protecting Highway 101 and the Town of Orick. These include various levee setback alternatives and shortening the extent of the levees to exclude the lowermost channel reach;
- A properly functioning riparian zone is needed to improve the estuarine ecosystem and increase the estuary's value as salmonid habitat.

Integrated Analysis and Cumulative Effects

The Redwood Creek estuary/lagoon receives water and sediment originating from the entire drainage basin. As such, much of the water quality and sediment characteristics of the estuary are related to upstream watershed conditions. These include relatively warm water inputs and high levels of sediment delivery. However, modifications from land development surrounding the estuary and the flood control levee system have likely had the greatest effects to the physical form and alteration of natural processes that drive the estuarine ecosystem. Flood control levees built in 1968 account for the largest change to the estuarine ecosystem. As a result of modifications, the fish rearing area of the Redwood Creek estuary/lagoon has been reduced by 50 to 75%. Cumulatively, these changes to the channels and surrounding delta ecosystem have impaired the physical and biologic function and reduced the capacity of the estuary/lagoon to support salmonids.

Most of the subbasin is located within three miles of the ocean so the local climate is strongly influenced by cool, marine air masses and coastal fog. The marine climate helps to somewhat cool the warm water coming from the much warmer inland areas during the summer months.

The estuarine channel typically maintains an open connection with the sea from the onset of fall rains until the following June or July. While the mouth is open, cool flows of mid-fall to spring seasons conveyed by the creek and cold water delivered by ocean tides mix together to make favorable water temperature and dissolved oxygen levels. Variable salinities in the channel gradually decrease with distance upstream from the mouth. The cool water is important because adult salmon that enter the creek in fall occasionally must hold in the estuary until rains increase stream flows to allow passage upstream to spawning habitat. Juvenile salmonids that reside and pass through the estuary during spring and early summer during seaward migrations find favorable water quality conditions for rearing and may acclimate to changes in salinity and temperature.

The low gradient, depositional reach of Redwood Creek in the Estuary Subbasin accumulates sediments delivered from upstream source and transport reaches. The affects of levees may exacerbate this net sediment accumulation. Because, coarse sediment moving events are of limited duration, it may take several large high flow events to transport coarse gravels and cobbles through the estuary. During coarse sediment transport events, instead of spreading across a wide flood plane, coarse sediments accumulate into tall bars within the confined levee channel (Randy Kline, RNSP, personal communication). The bars also function as large roughness elements and are associated with deep pool habitats needed for fish. However, the aggraded gravel

bars reduce channel capacity and the effectiveness of the levees to prevent flooding. At times the channel gravels bars are excavated to remove gravel accumulations. Removing these bars diminishes the pools associated with them.

The estuary flood plain and riparian zone was once dominated by redwoods, Sitka spruce forest and adjacent wetlands were forested with red alder, spruce, and sedge (Ricks 1983). Removal of riparian trees for pasture development and levee construction caused the loss of benefits from the riparian forests. These include a loss of shade to help cool water and elimination of a source of important overhanging and instream vegetation that provides shelter for fish. The loss of riparian vegetation also reduces the amount of terrestrial insect food supplies and stops local delivery of nutrients in the form of leaf litter and wood. To preserve channel capacity, any growing riparian vegetation is periodically removed from the estuary channel as part of a levee maintenance procedure. A properly functioning riparian zone is needed to improve the estuarine ecosystem and increase the estuary's value as salmonid habitat.

There are few historically active landslides in the estuary subbasin (Table IV- 10). Looking at relative landslide potential and land use or land type, about 32% of the road length is found on areas with high or very high relative landslide potential (Table IV- 10). This is the lowest percentage for all of the subbasins.

Timberland comprises the largest land type in the subbasin. Forty-five percent of the Estuary Subbasin area (1,546 acres) consists of timberland on areas of high or very high landslide potential (Table IV-11). The bulk of the woodland and grassland in the subbasin (641 of 800 acres or 80%) is found on very low relative landslide potential. Table IV- 10 does not show areas that do not fit into any of the three area-based land types or land uses in the subbasin including 663 acres or 19% of the subbasin area predominantly in agriculture and developed areas on relatively flat and stable ground.

Table IV- 10. Historically active landslide features and relative landslide potential by land type or land use.

Unit of Analysis	Historically Active Landslide Feature[1]	Entire Unit of Analysis		Woodland and Grassland[2]		THPs 1991 – 2000[3]		Timberland, No Recent Harvest[4]		Roads	
		Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Area (acres)	% of Area	Length (miles)	% of Total Length
Estuary Subbasin (3,433 acres) (15.9 road miles)	Earthflow										
	Rock Slide	1	0.0%					1	0.0%		
	Debris Slide										
	Debris Flow	1	0.0%								
	All Features	2	0.1%	0	0.0%	0	0.0%	1	0.0%	0	0.0%
	Relative Landslide Potential										
	Very Low	1,457	42.4%	641	18.7%			223	6.5%	8.1	50.9%
	Low	67	2.0%	7	0.2%			57	1.7%	1.0	6.3%
	Moderate	216	6.3%	55	1.6%			136	4.0%	1.7	10.7%
	High	1,200	35.0%	76	2.2%			1,095	31.9%	4.0	25.2%
	Very High	486	14.2%	21	0.6%			451	13.1%	1.1	6.9%
	High/Very High Subtotal	1,686	49.1%	97	2.8%			1,546	45.0%	5	32.1%
	TOTAL	**3,426**	**100%**	**800**	**23%**	**0**	**0%**	**1,963**	**57%**	**16**	**100%**

[1] Refer to Plate 2 and California Geological Survey appendix. Areas of disrupted ground are not included as active landslide features in this analysis. These areas are likely underlain by earthflow or rockslide complexes. If so, this would substantially increase the miles of roads and area of land type and land use on active landslide features.
[2] Woodland and grassland category includes areas mapped in 1998 as grassland and non-productive hardwood.
[3] THPs are complete or active between the 1991 and 2000 timeframe.
[4] Area of timberlands that were not contained in a THP during the 1991 to 2000 period; includes parklands with timberland characteristics. Percent of area is based on the unit of analysis: watershed or subbasin.

Table IV- 11. Estuary Subbasin integrated information summary.

Relative Landslide Potential	Acres	% Area
Very Low	1,457	42.4%
Low	67	2.0%
Moderate	216	6.3%
High	1,200	35.0%
Very High	486	14.2%
High/Very High Subtotal	1,686	49%
GRAND TOTAL	**3,426**	**100%**
Landslide and Selected Geomorphic Features	**acres**	**% area**
Historically Active Landslide Features Total	2	
Earthflow	1	0.0%
Rock Slide	0	0.0%
Debris Slide	0	0.0%
Debris Flow	1	0%
Dormant Landslide Features Total	**700**	**20%**
Selected Geomorphic Features Total	**617**	**18%**
Disrupted Ground	277	8%
Debris Slide Slope	337	10%
Inner Gorge (area)[2]	3	0%
Total of All Above Features	**1320**	**39%**
Other Land Uses	**acres**	**% area**
Grazing	113	3.3%
Agriculture	1	0.0%
Development	0	0.0%
Timberland, No Recent Harvest	1,963	57.3%
TOTAL	**2,077**	**60.6%**
Roads		
Road Density (miles/sq. mile)	3.0	
Density of Road Crossings (#/stream mile)	0.2	
Roads within 200' of Stream (miles/stream mile)	0.1	
Streams	**% stream length**	
% Stream by Gradient		
< 1% (Response Reach)		77.4%
1-4% (Response Reach)		6.8%
4-20% (Transport Reach)		11.6%
>20% (Source Reach)		4.3%
Historically Active and Dormant Landslide and Selected Geomorphic Features[4]	**% area**	**% stream length**
Within 180' of Blue Line Stream	1.2%	2.5%

[1] Refer to California Geological Survey appendix for landslide map (Plate 1), relative landslide potential map (Plate 2), and description. Areas of disrupted ground are not included as active landslide features in this analysis. These areas are likely underlain by earthflow or rockslide complexes. If so, this would substantially increase the miles of roads and area of land type and land use on active landslide features.

[2] Area based on inner gorges captured as polygons plus inner gorges captured as linear features, which are treated as having an average width of 100 feet.

[3] Category 1 includes clearcut, rehab, seed tree step, and shelterwood seed step prescriptions; Category 2 includes shelterwood prep step, shelterwood removal step, and alternative prescriptions; Category 3 includes selection, commercial thin, sanitation salvage, transition, and seed tree removal step prescriptions.

[4] Landslide features and selected geomorphic features include earth flow, rock slide, debris slide, debris flow, debris slide slopes, disrupted ground, eroding banks and inner gorges.

There was no timber harvest activities in the 1990–2003 period.

EMDS Stream Reach Condition and Limiting Factors Analysis

No stream surveys were performed in the Estuary Subbasin so there are no data to evaluate with the EMDS stream reach model. A list of factors limiting salmonid production in the estuary is provided as a response to the assessment questions below.

Refugia Areas

The channels within the Estuary Subbasin are considered high potential refugia habitat.

Responses to Assessment Questions

What are the history and trends of the size, distribution, and relative health and diversity of salmonid populations?

- The Redwood Creek estuary/lagoon supports populations of Chinook and coho salmon and steelhead and coastal cutthroat trout;
- Juvenile salmonids use an estuarine rearing strategy to increase in size before entering the sea;
- Survivorship is very low (estimates of 7-15%) for juvenile Chinook and steelhead that rear in the lagoon through the summer;
- The estuary/lagoon once supported an abundant, year round population of coastal cutthroat trout. At present, only a few coastal cutthroat are found during fish surveys;
- Small numbers of coho salmon are captured during fish surveys in the lagoon in most years;
- Coho may have used the estuary/lagoon to a greater extent in the past;
- The numbers of adult salmonids returning to the Redwood Creek Basin of any brood year or stock may depend on their numbers and condition when they leave the estuary/lagoon environment as juveniles;
- The estuary once provided a popular and productive sport fishery, but the salmon fishery has drastically declined in angler effort and catch.

What are the current salmonid habitat conditions? How do these conditions compare to desired conditions?

- The estuary/lagoon provides critical year-round juvenile rearing habitat for all salmonids of Redwood Creek;
- Under present conditions the estuary/lagoon is much less suitable for supporting salmonids compared to historic conditions;
- The estuary provides a migration pathway and transitional habitat needed by anadromous salmonids as they migrate to and from the freshwater and marine environments;
- The fish holding and rearing area of the Redwood Creek estuary/lagoon has been reduced by 50 to 75 percent;
- The impaired condition of the estuary/lagoon likely contributes to the low over summer survival rate of juvenile Chinook and steelhead;
- Levees prevent connectivity and change the natural circulation patterns between the main channel, slough channels, and surrounding wetlands;
- The reduction in tidal connectivity and loss of area due to sedimentation has contributed to an overall loss in the estuary tidal prism;
- The estuarine channels are shallower compared to historic conditions;
- Water temperatures raise above desirable levels in the lagoon;
- Low dissolved oxygen levels likely contribute to high mortality rates for juvenile salmonids rearing in the lagoon over the summer and early fall seasons;
- Riparian vegetation is lacking along the Redwood Creek estuary channel. Therefore there is no shade, or nutrient inputs, drifts insect inputs, or shelter provided by overhanging and instream vegetation;
- Habitat shelter complexity is low due to a lack of riparian vegetation and LWD;
- Dissolved oxygen levels can be at stressful or lethal levels in the slough channels;
- Large amounts of blue-green algae cover portions of the north slough channel bottom;

- The lower reach of Strawberry Creek lacks channel complexity and lacks functional riparian vegetation;
- A properly functioning riparian zone is needed to improve the estuarine ecosystem and increase the estuary's value as salmonid habitat.

What are the past and present relationships of geologic, vegetative, and fluvial processes to stream habitat conditions?

- The relatively flat delta area surrounding the estuary was formed from fluvial deposits;
- The delta area is naturally prone to flooding during high winter flows and to a lesser extent under lagoon conditions;
- The area of the embayment near the mouth has accumulated excessive sediments delivered by ocean tides. Sediment accumulations derived from both terrestrial and marine origins have become excessive in the estuary and have contributed to reduction of estuarine area, channel diversity, and channel depth;
- In the past, the estuarine channels were deeper, more diverse, and more complex. At present, the channel is straightened, shallow, and less diverse. Connectivity between the North slough channels is greatly reduced;
- Excessive amounts of accumulated sediment has reduced tidal flows into the north slough channel and contributes to more than a 50% reduction in area and a loss of depth of the lower estuary;
- The North slough channels (Dorrance and Sand Cache creeks) were historically maintained by tidal currents and the flushing of sediments by the tidal prism. The accumulation of marine sediments at the mouth of the North Slough has reduced the connectivity with the main channel and contributed to the loss of tidal prism;
- Algal decomposition may increase the biological oxygen demand, which may contribute to low dissolved oxygen levels observed in the North Slough channel;
- Channel aggradation has been exacerbated by severe erosion in the upstream subbasins and by levee configuration;
- Warm water inflows from Redwood Creek help sustain high water temperatures in the lagoon;
- Intermittent surface flow between the Redwood Creek and the estuary/lagoon in 2001 and 2002 is linked to the aggraded channel, increased bed elevation, and widened lower, mainstem reach in the Lower Subbasin;
- Due to excessive sediment accumulations and reduction of the tidal prism, the estuary mouth may close earlier in the year than it did historically;
- Riparian forests are no longer present to provide a shade canopy, nutrient inputs, or shelter from woody debris.

How has land use affected these natural processes?

- Over the past 125 years, the physical structure and natural processes of the estuary have been altered by conversion of riparian forest and wetlands to pasture lands, and by the impacts from the flood control levee system;
- The removal of riparian vegetation for pasture development and levee construction and maintenance has disrupted the natural processes of trees providing shade to help cool water temperatures. Loss of riparian forests also prevent inputs of woody debris, instream vegetation and overhanging vegetation for fish shelter, and nutrient inputs from terrestrial insects, leaf litter, and wood materials;
- The main estuarine channel is narrowed, confined and straightened by the levees which have altered intrinsic estuarine fluvial processes that transport and store sediments;
- Excessive sediment inputs related to upstream land use have contributed to sediment accumulations in the estuary and associated loss of channel depth and habitat diversity;

- After levee construction, large amounts of marine sediments have accumulated in the lower embayment and at the mouth of the North Slough channel;
- The present levee system has simplified the estuary channel by reducing sinuosity and channel diversity and contributed to aggradation and a loss of channel area and depth;
- Much of the historic connectivity between freshwater and tidal flow is blocked by the levees;
- The Strawberry Creek channel has been ditched, re-routed, and riparian vegetation has been removed. Cattle have free range to graze along the banks of the stream zone contributing to bank instability, fine sediment, and nutrient delivery to the creek. Some vegetation grows in the creek channel, which impedes the transport of sediment downstream;
- Waste from cattle likely enters into the Strawberry Creek and slough channels which may fuel algal growth.

Based upon these conditions, trends, and relationships, are there elements that could be considered to be limiting factors for salmon and steelhead production?

- The present condition of the estuary/lagoon is considered a significant factor limiting anadromous the production of anadromous salmonids of the Redwood Creek basin;
- High over summer juvenile mortality rates in the lagoon are likely linked to present habitat conditions;
- Limiting factors that impair the ability of the estuary/lagoon to support salmonids include:
  - A reduction in size of the estuarine channel area, restricting rearing area available to salmonids
  - A loss of channel connectivity with adjacent wetlands and sloughs, restricting rearing area available to salmonids;
  - A loss of channel depth, diversity, and complexity, rearing escape/ambush cover, and territorial space;
  - A loss of riparian vegetation function, reducing shade, land, and nutrients for rearing fish;
  - Stressful water temperatures and low dissolved oxygen levels;
  - The lack of instream shelter elements;
  - Predation on salmonids;
  - Intermittent flow delivery from Redwood Creek during dry summer months.

What watershed and habitat improvement activities would most likely lead toward more desirable conditions in a timely, cost effective manner?

- A great amount of work has been done by RNSP, private landowners, public agencies, and interested parties to develop alternatives to improve habitat conditions in the estuary/lagoon, while protecting Highway 101 and the Town of Orick. These include widening the levees and shortening the extent of the levees to exclude the lowermost channel reach;
- The use of levee set backs, reconfiguration, or levee removal strategies to develop a wider flood plain that restores natural sinuosity, improves connectivity with sloughs and adjacent wetlands, and the allows the development of an effective zone of riparian vegetation will contribute to a large improvement to the estuarine ecosystem. The following recommendations are provided to help guide the goals and objectives of a project to benefit the estuarine ecosystem and in turn increase the production and carrying capacity of anadromous salmonids in the estuary/lagoon.

Flow and Water Quality Improvement Activities:

- Increase tidal prism by restoring tidal and riverine flow and connectivity between the main channel and slough channels;
- Increase depth and tidal exchange at the confluence of North Slough channel;
- Increase circulation between the lagoon, Strawberry Creek and sloughs to help mix water and increase dissolved oxygen levels;

- Prevent or reduce cattle waste from entering stream and slough channels;
- Develop a shade corridor of riparian trees along main channel to help cool water;
- Land managers should work to maintain and/or establish adequate streamside protection zones to reduce solar radiation and moderate air temperatures into Redwood Creek and its tributaries throughout the Redwood Creek basin;
- The goal of any controlled breech project must be to maintain the volume in the lagoon to best support the anadromous fisheries;
- Digging of any artificial channel through the beach sand berm that would result in an uncontrolled breech should be discouraged;
- Any controlled breech should be performed as an option and in coordination with the expert judgment of RNSP staff and CDFG to preserve natural resources.

Erosion and Sediment Delivery Reduction Activities:

- Reduce inputs of sands by tidal currents to the embayment and North Slough by modifying levee configuration or removing levees altogether;
- Use levee set back, reconfiguration or removal strategies to achieve more natural flood plain characteristics;
- Land managers should continue their efforts such as road improvements, good maintenance, and decommissioning and other erosion control practices associated with all land use activities throughout the basin to reduce sediment delivery to lowermost Redwood Creek and the estuary.

Riparian and Instream Habitat Improvement Activities:

- A properly functioning riparian zone is needed to improve the estuarine ecosystem and increase the estuary's value as salmonid habitat;
- Where feasible, develop or improve riparian vegetation function along the banks of Redwood Creek, Strawberry Creek, and slough channels;
- Work to restore natural drainage patterns within adjacent wetlands and the subbasin;
- Increase off-channel and rearing habitat by improving conditions of sloughs and tributaries (Strawberry, Dorrance and Sand Cache creeks);
- Increase depth and complexity in the main channel and slough channels;
- Where feasible add LWD to increase salmonid shelter complexity;
- Leave large wood in estuarine channels, on the beach, and on stream banks for potential recruitment into the estuary;
- Relocate drift logs that block tidal connectivity between the embayment and the North Slough channels; logs could be assembled into minimum logjams and anchored into appropriate areas in the main channel;
- Re-establish a corridor of riparian vegetation to lower Strawberry Creek and restore riparian function in areas where vegetation removal or significant cattle impacts have been noted. This may require temporary fencing the riparian zone to prevent cattle and deer from grazing on seedlings and trampling growing trees.

Education, Research, and Monitoring Activities:

- Work should continue by Redwood National and State Parks (RNSP), private landowners, agencies, and interested parties to improve habitat conditions of the estuary by modifying the levee system while protecting Highway 101 and the town of Orick;

- RNSP, CDFG, RWQCB should continue existing monitoring of anadromous salmonid populations and expand to include some winter and early spring sampling;
- Water temperature and dissolved oxygen monitoring in the lagoon and sloughs should continue. Some dissolved oxygen measurements should be collected just before sunrise to capture lowest diurnal levels;
- Monitoring water quality in the lagoon should be expanded to include nutrient levels (ammonia, nitrates, nitrates) that may be elevated from runoff from cattle pastures;
- Work with USACE, Redwood National and State Parks, and Humboldt County Department of Public Works to modify levees and levee maintenance manuals to be consistent with habitat requirements of salmonids and a properly functioning estuarine ecosystem.

Subbasin Conclusions

The Redwood Creek estuary/lagoon plays a vital role as habitat for juvenile and adult anadromous salmonids. The estuary/lagoon once had all of the characteristics of excellent anadromous salmonid habitat, but its present value as fisheries habitat is greatly reduced compared to the historic condition. Over the past 125 years, the estuary area was altered by conversion of forest, riparian and wetland areas to pasture land, and by channel modifications and levee construction. These changes combined with sediment accumulations have impaired the physical and biologic function and capacity of the estuary/lagoon to support salmonids. The present estuary condition limits salmonid production.

The Redwood Creek estuary is an excellent candidate area for channel and riparian improvement projects that benefit for anadromous salmonids. RNSP and others have developed management alternatives to improve the estuarine habitat while offering flood control protection to the town of Orick and pasturelands surround the estuary. The recent project alternatives involve levee removal, relocation, and re-configuration. A restoration project should benefit fish production by increasing the depth and area of the lower embayment while increasing depth, shelter, connectivity, and circulation between the main channel and slough channels. Projects that increase the estuary/lagoon's juvenile salmonid carrying capacity and survival rate during the summer months should receive high priority. Restoration efforts that move conditions and processes towards historic status also will benefit other fish and wildlife resources of Redwood Creek.