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PHYSICAL MONITORING OF THE REDWOOD CREEK ESTUARY
1991 Progress Report
Submitted by:
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Introduction

The physical condition of the Redwood Creek estuary, as with all river mouth estuaries, is the result of complex interactions between nearshore marine and terrestrial geomorphic processes. Effects from human activities can dramatically alter these processes and thus impair the crucial functions which are necessary to support native ecologic communities. Three classes of functional values for wetlands have been identified (Adamus and Stockwell 1983):

1. hydrologic functions

2. water quality improvement functions

3. food chain support functions

Because of their complex interactions and high degree of temporal and spatial variability, the processes which drive these functions cannot be well understood unless they are quantitatively monitored over a period of several years or more (Zedler and others 1988). Understanding these driving processes is essential for developing sound preservation, mitigation, restoration, and management strategies.

Past studies have documented several aspects of the estuary and its inhabitants: 1) historical changes and modern-day physical processes at work in the Redwood Creek estuary (Ricks 1985; Klein and Weaver 1989), 2) biological communities (Larson and others 1982), 3) interrelationships between physical and biological processes (Larson and others 1981), and 4) past and present management policies and implications (Hofstra and Sacklin 1987).

Physical monitoring (which has been ongoing for over ten years) has helped us to understand the geomorphic processes which shape the estuary: an understanding which is crucial for planning restoration activities aimed at altering these processes to improve aquatic habitat. The following report summarizes results of monitoring physical processes in the Redwood Creek estuary conducted by the Geomorphology Branch.

Study Objectives

The objectives of physical monitoring and experimentation in the estuary are: 1) to document temporal changes in the estuary's physical structure and processes (mainly water and sediment

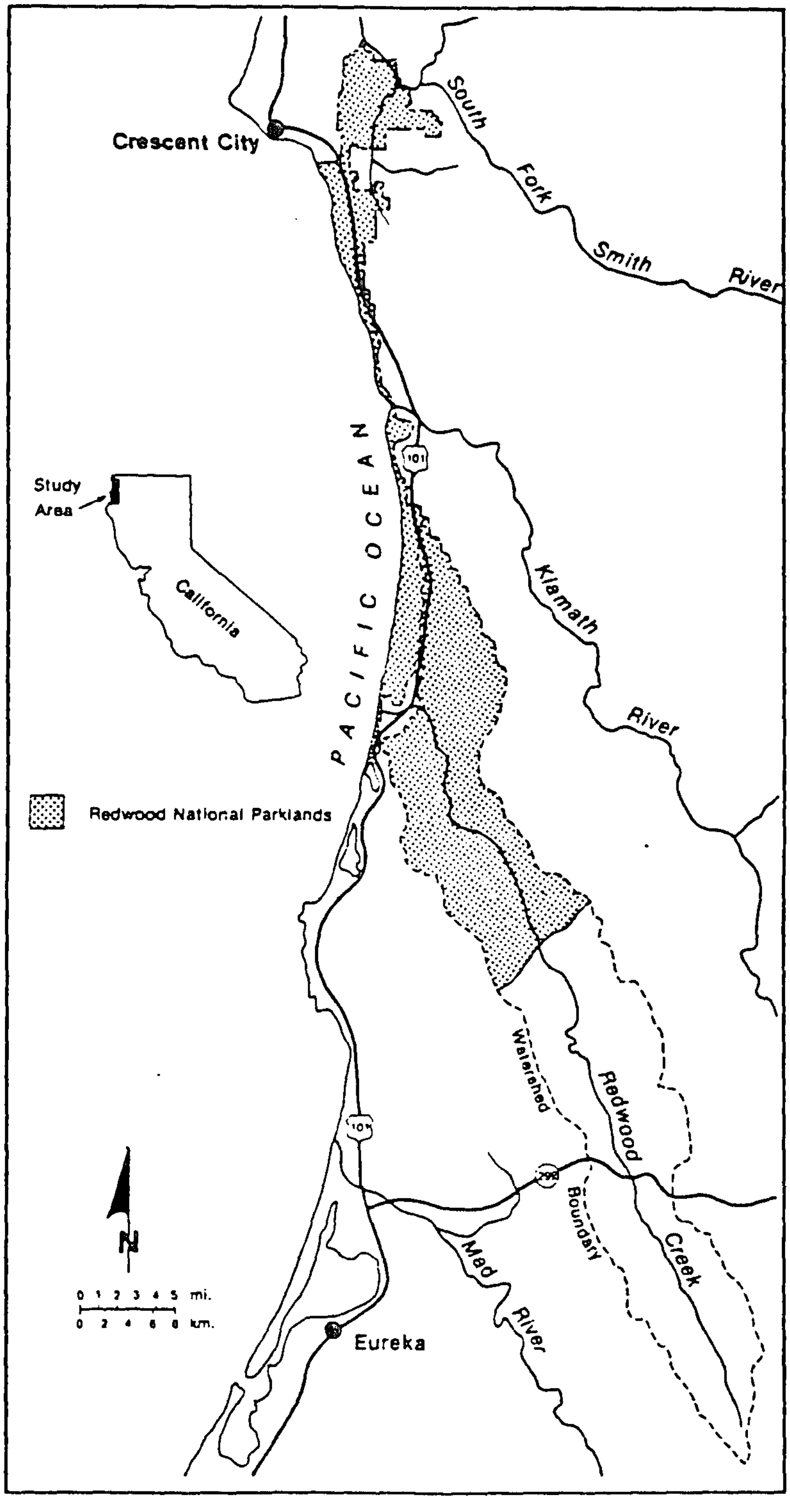

Figure 1. Location map of Redwood Creek basin in northwestern California.

movement), 2) to examine causal relationships between human influences and degradation of the physical habitat, 3) to guide the conceptualization and development of restoration measures, and 4) to test the effectiveness of restoration measures implemented.

Study Area

The estuary of Redwood Creek is located on the northern California coast about sixty miles south of the Oregon border and 340 miles north of San Francisco (Figure 1). Redwood Creek drains a long, narrow basin of about 280 square miles in size. It has an average discharge rate of 1062 cfs for a 31-year record, ranging from a winter flood peak of over 50,000 cfs to under 10 cfs minimum summer flow.

The hydrology of the lower four kilometers of Redwood Creek is affected by tidal action (Figure 2). Local tides range to about two meters in amplitude, with a mean of 1.4 meters, and are mixed semidiurnal (two cycles per day of alternating magnitude). Because of its proximity to the surf zone of the Pacific Ocean, wave action has a strong influence in the estuary.

The combined effects of rapid tectonic uplift, highly erodible terrain, and intense winter rainstorms are responsible for the naturally high rates of erosion and sedimentation in the region (Janda and others 1975). Land use (primarily timber harvest and associated road building) has accelerated erosion and sedimentation rates to significantly above background levels (Janda and others 1975).

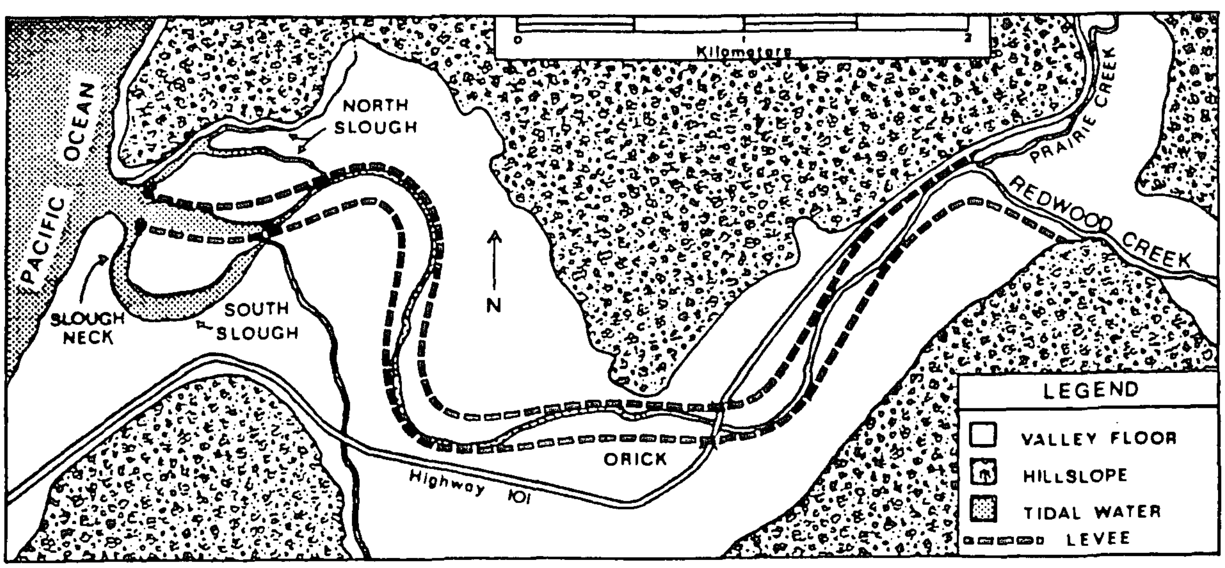

Figure 2. Lower 5 kilometers of Redwood Creek in the Orick valley.

Flood control levees completed in 1968 totally confine the lowest 5 km of Redwood Creek (Figure 2). These levees have had a dramatic effect on the hydrologic and geomorphic functions of the estuary. By eliminating the scouring action of high streamflows passing through the north and south sloughs, the levees have caused the westward ends of both sloughs (necks) to become filled with marine-derived sand, reducing the tidal prism and available habitat for aquatic species (Ricks 1985). Hydrologic isolation of the sloughs from the main estuary also causes seasonal water quality degradation (Larson and others 1982).

In an attempt to alleviate sedimentation and water quality problems in the south slough, a large, gated culvert was installed through the south levee at the east end of the slough in 1988 (Figure 3). The culvert establishes limited hydrologic communication between the south slough and Redwood Creek. Much of the monitoring and experimentation focuses on evaluating the performance of this structure.

Monitoring Methods

Physical monitoring in the estuary consists of the following:

1) annual topographic and cross section surveys,

2) several years of continuously recording water levels,

3) aerial photography.

In addition to these activities, several experiments have been conducted to examine short-term processes driven by tidal or high streamflow events:

1) circulation experiments (conducted jointly by Humboldt State University and RNP staff) following tracer movement in the South Slough with the diversion culverts both open and closed,

2) measurement of tidal flow rates and sediment transport in the South Slough during two complete tide cycles; once with the culverts open and once closed,

3) operation of the South Levee diversion culverts to attempt to cause the slough neck to scour during a high flow event on Redwood Creek.

Topographic and cross section surveys

Annual surveys are performed on 12 cross sections in the estuary (Figure 3). Most of these are located in the North and South Slough necks. These are supplemented by topographic surveys of important geomorphic features, such as the mouth configuration, sand bars, and the flood-tidal delta in the South Slough neck. Additionally, ten cross sections located in less active areas are surveyed on a less frequent basis.

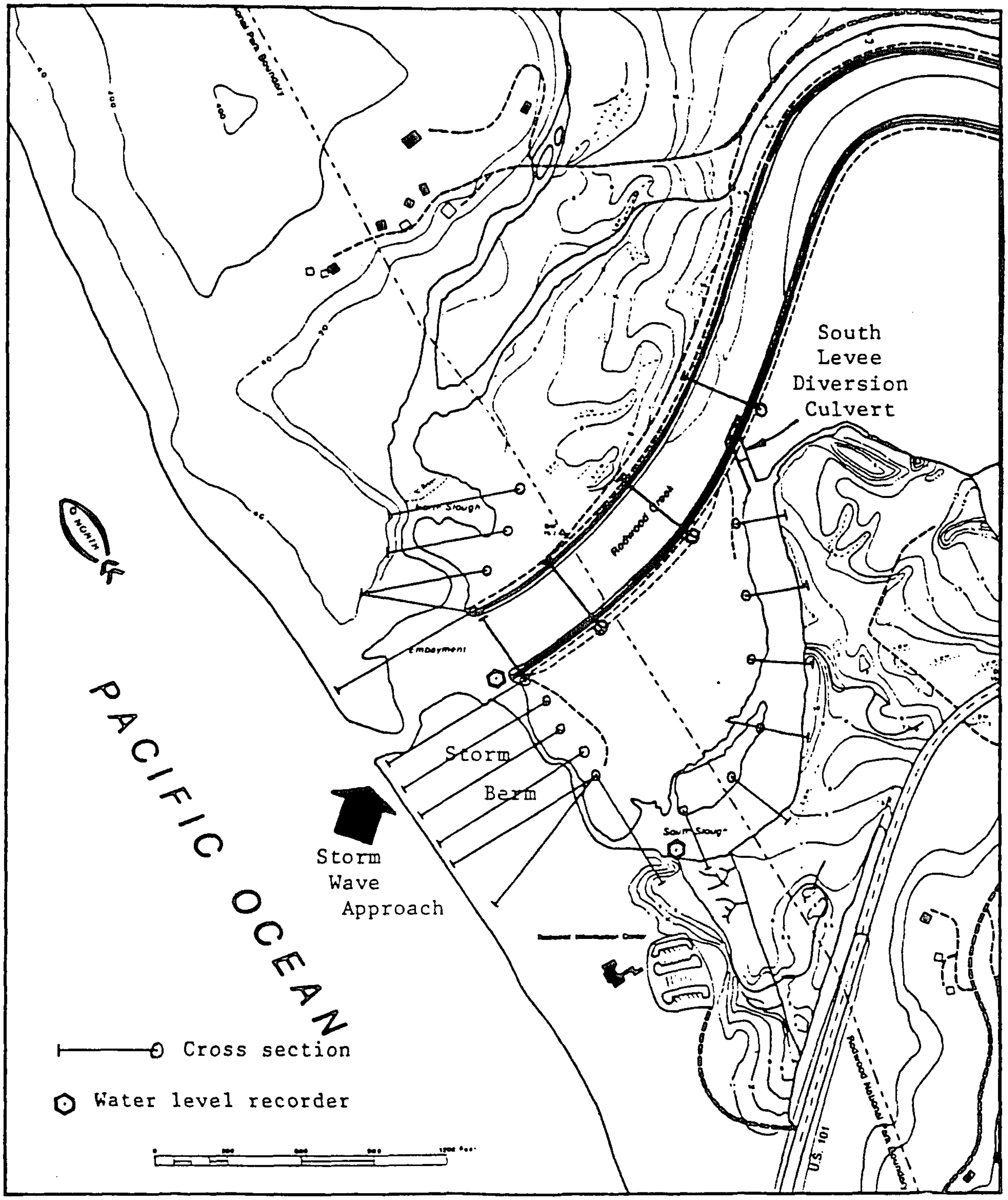

Figure 3. Locations of cross sections and water level recorders in the Redwood Creek estuary. Also shown are the location of the winter storm berm which separates the south slough from the ocean and the storm wave approach direction.

Water level recording

Water level recorders have been operated for several years to monitor water level fluctuations in both the South Slough and the main estuary (Figure 3). These data have been invaluable for documenting hydrologic processes that would otherwise have gone unobserved or unquantified (see Klein and Weaver 1989), such as:

1) response of water levels in the estuary to both artificial and natural breaching

2) truncated tidal response in the South Slough due to increasing aggradation in the slough neck

3) muted tidal response in the estuary when the mouth is closed

4) interaction between high tides and high streamflows

5) tidal response in the groundwater levels in the surrounding land, and

6) documentation of maintenance of estuary water levels below five feet MSL, as per our agreeement with adjacent landowners.

Summary of Results to Date

Cross section surveys

Results of the annual cross section surveys from previous years were presented in the form of graphic plots with earlier surveys overlaid onto recent surveys in order to show topographic changes. In addition, areas of scour and fill (aggradation) were computed for sequential surveys. These are maintained in files at SOC. Annual reports were prepared on cross section surveys and estuary geomorphology from 1982 through 1987. At this writing, current plots of cross sections and scour/fill calculations were unavailable for the most recent surveys (1990).

From these surveys, we have documented the following: 1) the rate of aggradation of sand in the slough necks following their excavation in 1983, 2) the horizontal advance of the flood-tidal delta in the South Slough neck, 3) scour and fill occurring between the lower levees, and 4) absence of scour occurring in the South Slough neck due to operation of the South Levee diversion culvert.

The lowest elevation on a channel cross section is referred to as the thalweg. In the slough necks, the highest thalweg elevations represent the vertical limit for hydrologic communication between the sloughs and the main estuary. When water levels in the main estuary fall below the limiting elevation, the sloughs become hydrologically isolated from the main estuary. Table 1 lists the limiting elevations for North and South Sloughs for 1983 through 1990, encompassing the 1983 excavation of the slough necks.

Table 1. Limiting elevations for the North and South sloughs, 1983-1990.

	Limiting Elevations (feet above MSL)[1]								
Slough	1983[2]	1983[3]	1984	1985	1986	1987	1988	1989	1990
North	7.18	2.70	2.77	2.96	4.28	4.41	4.70	4.70	11.90
South	3.45	0.67	1.84	1.84	2.57	2.47	2.84	2.46	2.79

[1] earlier estimates for 1983-86 were raised by 0.6 feet due to survey error
[2] immediately before excavation
[3] immediately after excavation

As shown above, limiting elevations for both sloughs have risen since the 1983 excavation. In both the sloughs, elevations had risen by about two feet since excavation, and had not changed much from 1986-89. In the winter of 1989-90, a large marine storm caused massive sand deposition in the north slough neck. This single event raised the limiting elevation by nearly seven feet (from 4.70 to 11.90 feet) in the north slough, while very little aggradation occurred in the south slough. This difference between processes in the two sloughs is due to their geographic orientation.

Large ocean storm waves (commonly reaching heights in excess of 20 feet) approach the estuary from the southwest, which subjects the north slough neck to direct wave attack (Figure 3). To reach the south slough, waves must either refract around or overtop the storm berm which separates the south slough from the ocean (Figure 3). In doing so, the waves lose much of their energy to transport sand to the south slough neck. Occasionally, large waves do overtop the berm and may move significant quantities of sand into the south slough. While wave overwash has occurred twice since the 1983 excavation, a low berm constructed by the heavy equipment work along the western edge of the slough neck has prevented overwashed sand from reaching the south slough.

The following generalized results are based on integration of various elements of the monitoring and experiments:

1) sand has aggraded in the South Slough neck to nearly the same elevation as before the 1983 excavation,

2) nearly all of this sand has been brought in by flood-tidal currents enhanced by wave bores propagating upstream from the creek mouth (as evidenced by the absence of recent storm berm overwash features),

3) since the 1983 excavation, sand volume in the slough neck has increased through landward advancement of a flood tidal delta (Figure 4), which has migrated horizontally about 30 m per year,

4) sand is transported by both flood and ebb tidal currents, but more is transported into the slough on the flood tide than leaves the slough on the subsequent ebb tide, resulting in a net increase in sand volume stored in the slough neck,

5) when streamflow is low and the mouth of the creek is open, opening of the culverts splits the flood tidal volume entering the south slough nearly evenly between the neck and the culverts. However, because of its lower elevation, a greater proportion of the ebb flow volume leaves the slough via the culvert,

6) operation of the culverts during high flow conditions on Redwood Creek has not resulted in any scour of sediment from the slough neck. This observation is based on operation of the culverts during a relatively small flood event (1.5 years return period).

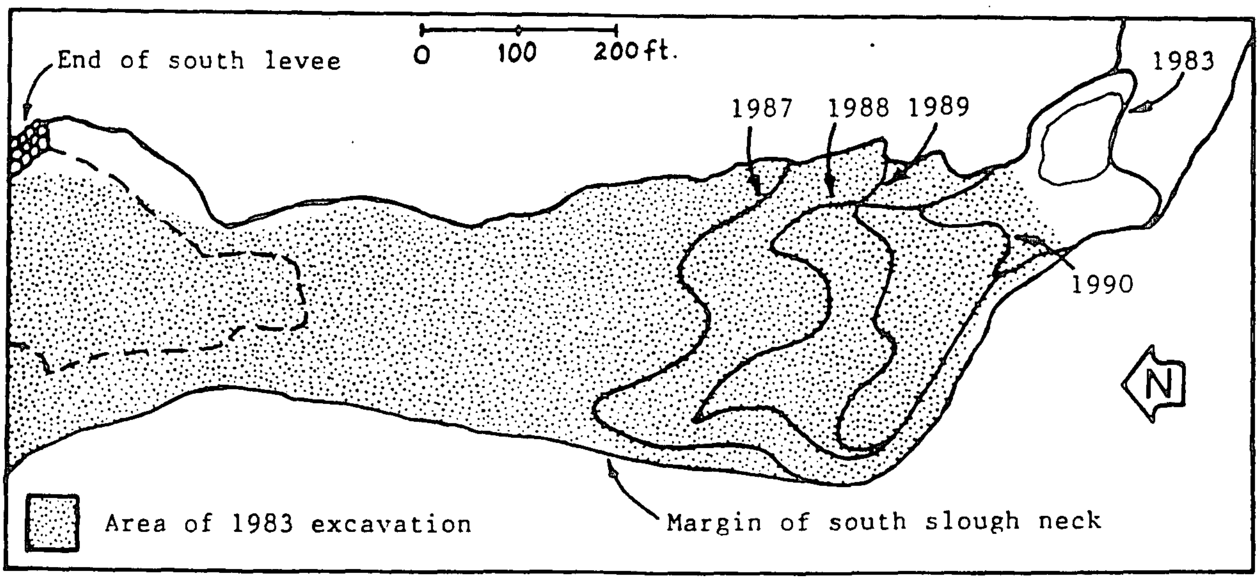

Figure 4. South slough neck showing position of the flood tidal delta front before the 1983 excavation, and its migration back up into the slough in recent years.

Preliminary Conclusions and Recommendations

The following presents interpretations of study results and ideas for restoration alternatives in the South Slough, and offers recommendations for important points of consideration for restoration alternatives which are being considered for the estuary. In particular, discussion of a proposed North Levee diversion culvert is presented in light of what has been learned from experiments and observations of the South Levee culvert. This project would be funded primarily by the Army Corps of Engineers with cost-sharing provided by a non-federal sponsor.

Sedimentation

Although the lack of high flow events has limited opportunities to conduct trials, results from trials that have been conducted so far cast some doubts as to the effectiveness of the culvert for scouring sand from the South Slough neck. A basic problem with trying to scour sand at the slough neck is that even when the tide is low, high stages on Redwood Creek limit the energy gradient (and thus the streampower) of flows through the neck.

Even during recessional flows on Redwood Creek (recommended condition for culvert operation), a large amount of suspended sediment may still be transported. Because of the large and abrupt increase in channel width as the flow proceeds from the culverts into the slough, velocity also decreases abruptly. The sediments which moved as suspended load through the culverts quickly settle out as they enter the head of the slough. Should this prove to be an inevitable process resulting from operation of the culverts during high flow conditions, it may offset the benefits of any scouring of sand that might be achieved in the slough neck.

A possibly more promising method for scouring sand from the South Slough neck might be to use them to manipulate tidal flows. By opening the culverts during the flood tide, the flow volume entering the slough via the neck is diminished. An inferrence from this is that the volume of sand transported up into the slough neck on the flood tide is also diminished by splitting the flow volume between the two locations. If the flood tidal flows through the slough neck were diminished without subsequently diminishing the ebb tidal flows, it might be possible to change the tidal sediment transport regime from one of flood tide dominance to ebb tide dominance. Tidal flap gates, which are commonly used to prevent flood tidal waters from inundating low lying coastal areas, could accomplish this. It is likely that retrofitting tide gates onto the slough side of the culverts might be a cost effective means to either slow or reverse the trend of aggradation which has filled the slough neck.

While tide gates might slow or reverse aggradation in the South Slough neck, they are not likely to be very effective at removing the large volume of sediment that presently resides there. The most reliable method for this is by heavy equipment excavation, as was done in 1983. The cost for excavating this today would likely be much greater than in 1983 for two reasons: 1) equipment rental rates have risen substantially since then, and 2) unlike in 1983, when much of the material excavated from the slough was used to landscape around the RIC and to build a berm adjacent to the slough, the excavated material will have to be moved some distance to a suitable fillsite. This may involve endhauling by dumptruck.

Another possible way to move significant quantities of sediment out of the slough neck is to delay the ebb flow from the slough until the tide has dropped in the main estuary. This would do two things: 1) the ebb flow hydrograph would be of shorter duration but greater magnitude, thereby increasing ebb flow discharge rates, and 2) the energy slope of of the ebb flow would be much steeper. Since streampower (the ability of a stream of water to do work) is the product of these two quantities, delaying the ebb flow might be capable of greatly increasing ebb tidal sediment transport. Delaying the ebb flow could be accomplished by use of temporary, water-filled dams which could be placed across the slough neck at the upstream end of the aggraded reach (near the observation deck) at high tide and deflated to release the slough water at low tide. These dams are inexpensive, very low impact, easily removed when not in use, and re-useable. A local supplier has offered to let us try them out at no charge.

While these recommendations may help alleviate sedimentation in the South Slough neck, several important differences exist in the North Slough which are likely to render similar approaches (except heavy equipment excavation) less effective. First, the potential tidal prism of the North Slough is much less than the South Slough because of its smaller surface area. This would preclude use of tide gates or ebb flow retention dams from having the volume of tidal water necessary to generate much sediment transport.

Second, nearly all of the sediment which has filled the North Slough neck has done so from storm wave action as opposed to tidal transport. This is why the elevation of sand in the North Slough has built up to well above the elevation of the high tide range. Storm waves usually approach the mouth of Redwood Creek from the southwest, which gives them a straight, unobstructed pathway to the North Slough neck. To reach the South Slough neck, waves must refract around the storm berm or reflect off the North levee, losing much of their energy before reaching the slough neck. Because large magnitude, non-tidal processes have deposited the sediment in the North Slough neck, it is unlikely that tidal forces can be manipulated to effectively remove it.

Third, the tidal elevation range for a diversion culvert through the north levee would be smaller than that for the south levee. This is because the location would have to be farther upstream at a higher elevation. Subsequently, the volume of tide water moving into an out of a north levee culvert would likely only be a small fraction of that which occurs in the south levee culvert, especially if the structure is narrower.

Water quality

The Fish and Wildlife Branch has water quality measurements (dissolved oxygen and temperature) which have shown improvements due to tidal circulation through summer operation of the culverts. A similar structure presently being considered for the North Slough would be subject to the same limitations mentioned earlier because of the smaller potential tidal prism of the North Slough compared to that of the South Slough.

While construction of another diversion culvert may be appealing from the standpoint that it could be funded from sources outside RNP, it would do little to help achieve our long term goals for restoring the estuary. It may, in fact, work against these goals by establishing a durable, expensive (three-quarters of a million dollars, as estimated by the Corps of Engineers) structure which would be hard to justify demolishing several years after its construction. In addition, the structure could be viewed as restoration, when in reality, it would simply be a high maintenance, temporary fix. This would diminish the impetus for pursuing a true, permanent restoration plan for the estuary. The only restoration alternative which furthers our goal of creating a "self-sustaining ecosystem" is the removal of the lower levees and re-establishment of historic hydrologic functions and vegetative conditions in the estuary.

Plans for Future Work

Annual surveys of cross sections and topography will continue. Water level recorders, which were discontinued in 1989 because of equipment malfunctions, will be re-installed. Monthly plots of water levels will be produced and distributed to interested staff. Two experiments are planned for 1991: 1) tidal sediment transport in the South Slough using the culverts to simulate tide gate operation, and 2) use of a water-filled dam to delay the ebb tidal flow to scour sand from the South Slough neck. Finally, experimentation with use of the South Levee diversion culvert to induce scouring of sand from the South Slough neck will continue as the occurrence of high flow events permits.

References Cited

Adamus, P.R., and L.T. Stockwell. 1983. A method for wetland functional assessment. Vol. 1. Federal Highway Administration Report No. FHWA-IP-82-23. U.S. Dept. of Transportation, Washington, D.C.

Hofstra, T.D., and J.A.Sacklin. 1987. Restoring the Redwood Creek estuary. In: Coastal Zone '87. WW Div., ASCE. Seattle, Washington. pp 812-825.

Janda, R.J., K.M. Nolan, D.R. Harden, and S.M. Coleman. 1975. Watershed conditions in the drainage basin of Redwood Creek, Humboldt County, California, as of 1973. U.S. Geological Survey Open-File Report 75-568. 266 pp.

Klein, R.D., and W.E. Weaver. 1989. Hydrologic restoration of the Redwood Creek estuary. In: Proceedings of the First Annual Conference. Society for Ecological Restoration. Oakland, California. pp 433-445.

Larson, J.P., C.L. Ricks, and T.J. Salamunovich. 1981. Alternatives for restoration of estuarine habitat at the mouth of Redwood Creek, Humboldt County, California. In: Proceedings of a Symposium on Watershed Rehabilitation in Redwood National Park and Other Pacific Coastal Areas. Arcata, California. R.N. Coats, ed.pp 236-245.

Larson, J.P., J. McKeon, T.J. Salamunovich, and T.D. Hofstra. 1982. Water quality and productivity of the Redwood Creek estuary. In: Proceedings of the First Biennial Conference of Research in California's National Parks. Davis, California. C. van Riper III, L.D. Whittig, and M.L. Murphy, eds. pp 190-199.

Ricks, C.L. 1985. Flood history and sedimentation at the mouth of Redwood Creek, Humboldt County, California. Redwood National Park Technical Report No. 15. 154 pp.

Zedler, J.B., R. Langis, J. Cantilli, M. Zalejko, K. Swift, and S. Rutherford. 1988. Assessing the functions of mitigation marshes in southern California. In: Proceedings of the National Wetlands Symposium. Urban Wetlands. J.A. Kusler, S. Daly, and G. Brooks, eds. Oakland, California. pp 323-330.