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LONG-TERM CHANNEL RESPONSE TO LARGE FLOODS AND SEDIMENTATION

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Introduction

Redwood Creek, like many streams in north coastal California, has experienced dramatic changes in channel configuration and sediment load since the mid-1950s. During the last four decades, a series of large floods, combined with the advent of widespread timber harvesting and road building, caused extensive erosion which contributed high volumes of sediment (silt, sand and gravel) to Redwood Creek and its tributaries. Channel changes caused by this increase of sediment include channel widening, increased stored sediment in the channel, increased streambed elevation, decreased number of pools and riparian vegetation, and decreased streambed material size (Janda 1977).

Concern about the effects of channel changes on the riparian and aquatic resources of Redwood National Park prompted the initiation of many studies to document the magnitude and cause of change in the Redwood Creek basin (Nolan and Marron 1995). In 1973, monitoring of long-term channel stability in Redwood Creek was initiated by the U.S. Geological Survey in cooperation with the National Park Service. The purpose of the study was to document channel response to large storms and land use in the Redwood Creek basin.

Channel cross-sectional and longitudinal profile surveys are used to document and quantify changes in channel geometry (width, bed elevation), pool frequency and depth, net changes in channel area (scour and fill) and long-term channel trends. Twenty-three years of data currently: 1) quantify channel response since 1973, 2) describe the movement of streambed sediment through the channel and, 3) provide baseline data for the next large flood.

Study Area

Redwood Creek drains a 720 km² basin in north coastal California. The main channel is 108 km long and roughly bisects the basin. Channel gradient decreases from 12 percent in the headwaters to 0.10 percent near the mouth. Total basin relief is 1615 m and the average hill slope gradient is 26 percent. The basin receives 2000 mm of rainfall annually, most of which falls as rain between October and March.

As a result of periodic large floods and highly fractured bedrock, the landscape is highly susceptible to landslides and gullyng. Annual suspended sediment discharge (fine sand, silt, and clay) of Redwood Creek (1000 to 2500 Mg/km²/yr) is among the highest measured in the United States for basins of this size, outside of rivers draining active glaciers or volcanoes.

Aerial photographs from 1936 and 1947 show that prior to the advent of commercial timber harvesting, 82 percent of the basin was covered with old-growth redwood and Douglas-fir forest, and the remaining acreage was oak woodlands and prairie grasslands (Best 1984). Redwood Creek was narrow and sinuous in most reaches, with a thick canopy of coniferous trees over much of its length. Large-scale timber harvesting began in the early 1950s. By 1966, 55 percent of the coniferous forest had been logged, and by 1992, about 80 percent of the forest was logged, largely by clearcutting. Thousands of kilometers of logging roads were built during the last forty years, and the vast majority were built prior to any forest practice rules dealing with road standards.

Large floods in 1955, 1964, 1972, and 1975 (recurrence interval of 20 to 50 years [Coghlan 1984]) initiated widespread road failures, gullyng, and streamside landsliding in the basin. These floods caused extensive sedimentation and bank erosion in Redwood Creek. Channel changes were most extensive in the upstream half of the basin, where both the storms and previous logging activity had been most intense. Aerial photographs, field observations, and accounts by local residents documented that the channel widened, pools filled in, channel bed material became finer, and the channel bed aggraded (filled with sediment) up to nine meters at some sites (Madej 1992).

Methods

Since initiation of the monitoring program in 1973, a network of 58 channel cross sections has been established on Redwood Creek. Channel cross sections are located from the headwaters to the mouth of Redwood Creek and have been surveyed annually or after major flows. Cross sections were monumented with 1.2 m lengths of steel rebar reinforced by concrete and referenced to at least two

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other triangulation points. Relative elevations between end points were established by leveling (Emmett 1974). Cross sections were surveyed during the summer months with either an automatic level, stadia rod, and tape or a theodolite and electronic distance meter. Longitudinal streambed profiles in lower Redwood Creek were surveyed in 1977, 1983, 1986, and 1995. Profiles followed the deepest point of the channel. Relative elevations were surveyed with an automatic level and stadia rod, and distances were measured with a tape.

Results

In the upstream 70 km of Redwood Creek, the channel initially aggraded after the 1964 floods. Subsequent floods in 1972 and 1975 flushed much of the sediment downstream. Cross section surveys show the channel scoured from 1973 to 1985. Since 1985, the channel has reached a stable bed elevation.

In contrast, surveys in the lower 38 km of Redwood Creek document more complex channel response and recovery. The most dramatic channel changes were observed in the downstream portion of this reach where the channel widens abruptly and was the site of massive deposition of sediment in the early 1970s. Cross section monitoring quantified the movement of a "sediment wave" which was best documented in the downstream most 26 km of Redwood Creek (Madej and Ozaki, in press). As the wave moved downstream, it spread out in both space and time resulting in both slower travel rates and lower wave heights the farther it moved downstream. As the wave traveled downstream: 1) transit rates decreased from 1700 to 700 m/yr (about a half-mile per year). 2) peak sedimentation at downstream cross sections lagged at least 18 years behind upstream sites. 3) the height of the sediment wave attenuated more than a meter as it moved downstream. 4) average bed elevations at cross sections increased up to 1.6 m as the wave passed. For the first time in more than 20 years, cross-sections surveys in 1995 document some channel bed scouring in the downstream-most 15 km of Redwood Creek. This may indicate the beginning of channel recovery and passage of the sediment wave through this lower-most reach.

Longitudinal streambed profiles document recovery of pool and riffle sequences in the sections of the creek where the sediment wave has passed. Longitudinal profiles and field observations showed that after the initial deposition of sediment in lower Redwood Creek, the channel was flat and featureless. The average pool depth was only 0.4 m, and pool frequency was less than one pool/km of river channel (based on the 1977 survey). As the sediment wave passed, channel bed elevation dropped, and pools and riffles developed. Pool frequency increased to 5 pools/km in 1986 and has remained the same as of 1995. In addition, pools deepened to an average depth of 1.8 m in 1986 and

2.3 m in 1995. Average pool depths in 1995 were nearly six times the depths observed in 1977.

Discussion and Conclusions

Climatic conditions in north coastal California result in periodic, large, flood-producing storms and in the past have been accompanied by accelerated erosion from logged lands and road networks. Large storms have occurred in the past and will continue to be a process which shapes and influences Redwood Creek. The last large flood occurred in 1975 (recurrence interval = 25-30 years [Coghlan 1984]), and flows since then have all been less than the five-year recurrence interval. Consequently, the cross-section network has been in operation during relatively low to moderately-low flow years.

Channel cross sections document how high influxes of sediment from hill slopes and stream channels during large storm events in the upper and middle Redwood Creek basin can persist for decades. After more than 30 years, the effects of the 1964 flood event are still impacting the main channel on park lands in lower Redwood Creek. As sediment is transported through the system, from the headwaters to the mouth, the sediment wave diminishes in both time and space. As the wave moves downstream, the height of the wave decreases and the wave spreads out, resulting in slower movement of the sediment wave. The persistence of the sediment wave in Redwood Creek (>18 years) has impacted several life cycles of steelhead and salmon.

While the channel bed has returned to a probable pre-disturbance elevation in the upper reaches, bed elevation is just one measure of channel recovery. For most of its length, the channel still remains wider than pre-1964 conditions. In addition, the original characteristics of the riparian vegetation (old-growth coniferous forest) have not been reestablished. Instead, current riparian forests consist mostly of alders.

Cross-sections surveys are presently documenting channel recovery. If there are no large influxes of sediment to Redwood Creek in the next decade or two, we expect to see continued flushing of stored channel sediment and channel recovery. Most changes will probably occur in lower Redwood Creek, as the sediment wave continues to move out of the Redwood Creek system.

The effects of another large flood on the Redwood Creek channel are unknown. While the upper and middle basin appear to have recovered to a pre-disturbance bed-elevation, studies indicate that potential sites of in-channel sediment storage are still partially full from the last series of large floods (Madej 1982). This legacy suggests that the channel will have less ability to store sediment and that we might see a repeat of the 1964 flood effects. Without an ability to store or transport excess sediment, the channel

bed will respond by filling with sediment and widening and potentially repeating impacts observed in earlier floods.

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