# SEDIMENT SOURCE ANALYSIS AND PRELIMINARY SEDIMENT BUDGET FOR THE NOYO RIVER

Prepared for:

**Tetra Tech, Inc.**
**Under Contract 68-C7-0018**
**Work Assignment # 0-18**

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**May 1999**

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## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

***** Figures Located at the End of the Document

# SEDIMENT SOURCE ANALYSIS AND PRELIMINARY SEDIMENT BUDGET FOR THE NOYO RIVER

## INTRODUCTION

The Noyo River watershed (Figure 1) has been listed as a sediment impaired waterbody and included in California's 1995 CWA 303(d) list as adopted by the State of California North Coast Regional Water Quality Control Board (NCRWQCB). This sediment impairment has resulted in non-attainment of designated beneficial uses, including salmonid habitat and recreation.

In April 1999, Graham Matthews & Associates was requested by the U.S. Environmental Protection Agency (EPA), State of California Water Quality Control Board (RWQCB) and Tetra Tech, Inc., to prepare a sediment source analysis and preliminary sediment budget for the Noyo River watershed. The purpose of the sediment budget is to assist the EPA in establishing Total Maximum Daily Load (TMDL) standards for sediment in the Noyo River watershed.

The Noyo River watershed has been divided into five planning areas with 17 sub-watersheds for general planning purposes for this TMDL (Figure 2). For each of these sub-watersheds, we have been asked to determine past sediment production and delivery, by erosional process.

The purpose of report is to compile, summarize, and analyze sediment production data for the Noyo River watershed that could be used for TMDL development. The sediment production data is then integrated with other geomorphic information to develop a preliminary sediment budget for the Noyo River watershed. This study is primarily based on analysis of aerial photographs and analysis of GIS coverages, with only very limited field reconnaissance.

### Previous Work

As a result of the study methods and timing, existing information from a variety of sources was used to supplement our remotely gathered data, often providing critical field-verified values. Other planning efforts are underway in both the Jackson State Demonstration Forest (JDSF HCP/SYP) and Mendocino Redwoods Company (MRC), and Georgia-Pacific Corporation completed a sustained yield plan for the Fort Bragg Timberlands in 1997. Extensive research into the effects of timber harvest on sediment production, delivery and yield has been under taken on Caspar Creek over the past 30 years.

# FIGURE 1
# NOYO RIVER WATERSHED LOCATION MAP

## STUDY AREA

### Sub-Watershed Areas

The Noyo River watershed has been subdivided into 5 planning areas: the Headwaters, North Fork Noyo, Middle Noyo, South Fork Noyo, and Lower Noyo. The first four are very similar in drainage area, ranging from 25.46 square miles ($mi^2$) to 27.46 $mi^2$, while the Lower Noyo is much smaller, with an area of only 7.84 $mi^2$. The Lower Noyo was broken out because of its topographic differences, being largely on coastal terraces, and a relatively low level of land management activities. In addition, the confluence of the South Fork and the nearby location of the USGS gage make for a logical separation point. The four large planning areas have been divided again into 15 sub-watersheds. This sub-division does not match the CALWAA divisions and instead reflects analysis units from previous work (MRC 1999) combined with obvious tributary drainage patterns. Table 1 presents the Planning Areas and sub-watersheds along with their drainage areas. These areas are shown graphically in Figure 2.

### Watershed Characteristics and Overview

The Noyo River drains a 113 $mi^2$ watershed located in the northern California Coast Range in Mendocino County (Figures 1 and 2). The only city in the watershed is Fort Bragg, located near the mouth of the watershed. Elevations within the Noyo River watershed range from sea level at the basin outlet to 3207 feet at Sherwood Peak.

Annual precipitation averages 38 inches near Fort Bragg to over 50 inches at Willetts just east of the watershed, although precipitation maps indicate that annual rainfall may be in excess of 70 inches at the northern edge of the watershed at Sherwood Peak. Snowfall occurs occasionally in the higher elevations of the watershed, but rarely accumulates and typically melts within a short period. Large flood events are thus generally associated with intense periods of rainfall rather rain-on-snow events. Stream gaging records for the Noyo River watershed have been collected by the US Geological Survey from 1952 to the present.

### History

The history of the Noyo River watershed is dominated by logging and railroads, with the railroads original purpose to allow economical timber harvest which has since evolved into a significant passenger carrying enterprise.

Logging

The Noyo Lumber Company operated a sawmill constructed on the Noyo River in 1858. In 1891 the Noyo Lumber Company and the Fort Bragg Redwood Company merged to form

Union Lumber Company, which constructed a railroad tunnel through the ridge between Pudding Creek and the Noyo River for access to the vast timber resources in the Noyo basin. Significant damage in the San Francisco Bay area during the San Andreas earthquake of 1906 and the associated large fires kept the demand for lumber strong, and the Mendocino area mills supplied a large share. The new company was the major producer of lumber in Mendocino County for more than 50 years.

Methods of hauling lumber evolved over time from utilizing jackscrews, horses, bull teams, log flumes, splash dams, logging inclines, Dolbeer donkey, railroads, to trucking on haul and skid roads; with each of these having varying levels of impact on the watershed. 3 wooden piers, constructed just upstream from the harbor in the middle of the channel, were used to corral logs floated downstream. Remains of the crib structure of these piers can still be seen in the lower river.

Since 1940, tractor yarding and the construction of roads, skid trails and landings were the primary types of logging practices. Until the Forest Practices Act was passed in 1973, logging practices were unregulated. This Act required road construction and timber harvesting practices intended to improve aquatic habitat and watershed resource protection. During the past twenty years the use of cable yarding on steeper slopes has increased substantially, and beginning in 1995 helicopter logging has been used for a small portion of the harvest (<2%). These most recent changes in practice create far less ground disturbance than tractor yarding, although tractor yarding is still responsible for 40-80% of the harvest, depending upon ownership. Harvesting of second growth forests started during the 1960s. The practice of extensive large woody debris removal from streams was significant in the 1950s and continued to occur through the 1980s and early 1990s and resulted in reduced fishery habitat.

### Railroads

Railroads were used in the California Redwoods as early as 1852 to speed logging operations. In the Noyo River the *Fort Bragg Railroad* started operations in 1886 with the line helping to pay its way as it was constructed. The tunnel connecting rail lines along Pudding Creek with the Noyo River was completed in 1893, opening up substantial new territory for economical logging. By 1898, the railroad tracks had been extended as far east as the Little North Fork of the Noyo. The railroad from Fort Bragg to Willits was completed in 1911 allowing lumber shipments to go anywhere in the country by rail, rather than depending solely on shipping by sea. This railroad was only 42 miles long, but rises 1750 feet in elevation with very rugged terrain making construction difficult. Operation and maintenance of the railroad was high due to the mountainous terrain and that the track followed the inner gorge of the Noyo river, either crossing it repeatedly with bridges, or hanging on the steep valley walls, suffering extensive damage during large storm years. The railroad originally had 115 bridges, but has been reduced to 32 with various improvements made to the railroad over the years. Union Lumber Co. has operated the Willits "Express" train for more than 50 years but was utilized by many other mills in the surrounding area. Spur tracks were developed up both the North and South Fork Noyo drainage's to allow for further expansion of logging activities. Beginning in the 1940s, most of the railroad grades were converted to roads.

## Ownership

Detailed ownership maps have not been compiled for the entire watershed in a readily accessible, GIS-based format. Viewed simply, there are three major land owners in the watershed, (1) the State of California in the Jackson State Demonstration Forest (mainly in the South Fork Planning Area), (2) Mendocino Redwoods Company (mainly in the North Fork and Headwaters Planning Areas, and (3) Georgia-Pacific Corporation, mainly in the Middle Noyo Planning Area. Overall, 80.6% of the watershed is in private ownership, and 19.4% is in public ownership (Figure 3). Essentially all of the public ownership is concentrated in the South Fork Noyo Planning Area, where 78.4% is publicly owned, while the remaining 21.6% is privately held.

## Topography

The topography of the Noyo River watershed is quite diverse along the length of the watershed. The terrain varies from essentially flat to rugged mountainous topography with high relief.

The western end of the watershed along the coast is distinguished by relatively flat marine terraces. The Noyo River occupies a narrow deeply-incised channel. This topography quickly rises to the mountainous terrain that makes up the great majority of the watershed.

The area between the coastal margin and the headwaters is characterized by narrow incised drainages. The drainages are bordered by steep slopes and narrow summits and ridge lines to about Northspur. Subdued topography and relatively low relief characterize the headwaters of the South Fork.

The Noyo mainstream and major tributaries in the upper reaches (headwaters) of the watershed are situated in relatively broad alluviated valleys with entrenched meanders. Locally slopes vary from steep to locally subdued and low relief. Locally slopes in the southeast area of the headwaters area quite subdued due to the relatively soft bedrock in contrast to the relatively more competent bedrock that underlies the remainder of the watershed.

## Slope Analysis

A slope analysis was conducted using GIS data by CDF. Figure 5 graphically presents the results of this analysis by color coded slope class. Table 2 summarizes the areas of the various planning and sub-watersheds by slope class. The significant differences between the

Lower Noyo and the other planning watersheds is readily apparent, with 62% of the land in that planning area having slopes of less than 20%, compared to 10-15% for the other 4 basins. For those basins, typically 60-70% of the area of each falls with the 30%-65% slope class range, reflecting the rugged terrain characterizing much of basin. The 4 basins also have 20-30% of their area at slopes greater than 50%. Several sub-watersheds stand out in terms of unusually steep slopes: McMullen Creek and Redwood Creek, both in the Headwaters Planning Watershed, have 17.3 and 19.6% area greater than 65% slope.

The low gradient valley floors of the Upper Noyo, Olds Creek, Redwood Creek and the Lower North Fork Noyo visually stand out in Figure 5, with the blue color coding. What is not evident at this scale, is that much of the channel through these reaches is incised into the valley floor to such an extent that these surfaces do not function as floodplains, but instead act to store hillslope generated sediments.

## Geology

The geology of watershed is represented by the bedrock and overlying surficial deposits. The watershed bedrock geology is dominated by rocks of the Franciscan complex and locally some Mesozoic age volcanic rocks (Figure 4). These bedrock units are in turn overlain locally by surficial materials of either marine terrace deposits, dune sand, landslide debris, or alluvium. These earth materials are briefly described below. The following descriptions are derived from Blake and others (1985), Jayko and others (1989), Jennings (1977), Kilbourne (1982; 1983a, b, c; and 1984 a, b), Kilbourne and Mata-Sol (1983), and Kramer (1976).

### Bedrock

The entire watershed is underlain by rocks of the Franciscan Complex except for some volcanic rocks that are mapped to underlie Riley Ridge. Within the watershed, the Franciscan occurs as two distinct bedrock units: the relatively coherent Tertiary to Cretaceous age Coastal Belt terrane and the relatively incoherent Tertiary to Jurassic age Central Belt terrane.

### Coastal Belt Terrane

Coastal Belt rocks underlie the entire watershed except for the southeastern area of the headwaters. On Riley Ridge they are mapped in association with volcanic rocks.

Franciscan Coastal Belt terrane is characterized by sandstone and interbedded siltstone and shale, with locally minor amounts of conglomerate present. Elsewhere chert, limestone, and greenstone are found.

Coastal Belt rocks have been deformed by past tectonic activity. This has created a body of rock that has been broken up into coherent bedrock blocks of varying size (up to city blocks or larger) separated by shear zones and faulting; locally the bedrock is tightly folded.

### Central Belt Terrane

Central Belt rocks crop out in the southeastern area of the headwaters. They underlie the subdued topography of that area.

The Central Belt is a melange characterized by blocks of bedrock, varying in size from fist size pieces to blocks up to city blocks or larger in size, in a highly sheared, mashed, and mangled clayey matrix. The blocks of bedrock can include sandstone, conglomerate, chert, greenstone, blueschist, limestone, eclogite, serpentine, amphibole, and ultramafic rocks. The subdued nature of the hillside topography overlying the central belt is a result of the weak nature of the sheared melange matrix.

### Volcanic Rocks

A large lens of Tertiary to Cretaceous age volcanic rocks underlies Riley Ridge in the west central area of the watershed. They are mapped to crop out along the ridge top and other nearby ridges. The volcanic rocks are reportedly composed of greenstone, metatuffaceous sandstone, volcanic breccia, diabase, and pillow basalt may also be present.

### Surficial Deposits

Locally overlying the bedrock are a variety of surficial deposits that include marine terrace deposits, dune sands, landslide debris, and alluvium.

### Marine Terrace and Dune Sand Deposits

These deposits underlie and are essentially confined to the relatively flat areas between the coastal cliffs and the base of the hills. Some terrace deposits may be present on the west-facing slope of the range front. Dune deposits are mapped to locally overlie the terrace deposits.

The terrace deposits are composed of interbedded quartz sand and minor amounts of gravel. Along the eastern margins, these deposits interfinger with sediments shed from the range front. The overlying dune deposits are composed of fine to medium grained quartz sand.

### Landslide debris

Landslide deposits occur everywhere thoughout the watershed. They vary from small creek side failures to large slides involving hundreds of acres.

The slides are composed of a heterogeneous mixture of soil, colluvium, and bedrock debris carried down slope as either intact masses or heterogeneous flows or avalanches.

Alluvium

Alluvial deposits occur along the drainages of the watershed. They are found in the channels of the rivers and creeks and as thick accumulations filling drainages in the upper reaches of the watershed. Near the mouth of the Noyo River alluvial deposits are mapped to interfinger with estuarine deposits.

The alluvial deposits are composed of poorly consolidated interbedded gravel, sand, silt, and clay. Estuarine deposits are composed of unconsolidated dark gray silt and fine sand.

### Time Period of Analysis

The time period for the sediment source analysis and preliminary sediment budget includes a 67 years period extending from 1933 to 1999. The period was dictated by available aerial photography coverage in the years 1942, 1952, 1957, 1963, 1965, 1978, 1988, 1996, and 1999. We assumed that features observed in the 1942 photographs covered a +/- 10 year period generally similar to the length of the subsequent study periods. Sediment source data has been developed for all nine of these time intervals and capturing different periods of sediment producing events, including both storm history periods (1938, 1956, 1965, 1974, 1993 high flows) and changes in land management practices. Thus, a combination of changing harvest and road building techniques, with most of the largest storms this century provide the framework for evaluating changes in sediment production and delivery within the watershed.

## METHODS

### Available Data

Existing data were compiled from a variety of sources including the Mendocino Redwoods Company Draft Watershed Assessment (MRC 1999), the Georgia Pacific Fort Bragg Timberlands Sustained Yield Plan (Jones & Stokes Associates, Inc. 1997), preliminary results of the Jackson Demonstration State Forest HCP/SYP Watershed Assessment (Cafferata/Stillwater Sciences, pers. comm. 1999), and TMDL and/or sediment source analyses for similar basins such as the Navarro (Entrix et al. 1997) and the Garcia (PWA, 1997).

### Hydrology

Existing precipitation data were collected from the National Weather Service NCDC database on CD-ROM and from James Goodridge, former state climatologist and now consultant to the California Department of Water Resources. Streamflow records were obtained from USGS publications and on CD-ROM, while provisional streamflow records were obtained directly from the USGS Sacramento office. These data were analyzed for magnitude, frequency, and duration.

## Geomorphology

Gaging station records were obtained from the USGS Sacramento office consisting of complete 9-207 forms for the period 1952-1999. These records were used to evaluate changes in mean streambed elevation (MBE) at the gage. Historic aerial photographs were used to evaluate changes in sediment storage. Historic records of timber harvest, railroad construction, and early photographs from a variety of sources were examined to provide a glimpse of conditions in the watershed from 1860-1940. Several rapid field reconnaissance visits to portions of the watershed were made, as well as an overflight by light aircraft. Selected portions of the mainstem and tributary channels were floated using an inflatable kayak to assess changes in channel stored sediment and bank erosion.

## Sediment Source Analysis

### Mass Wasting

Landslide mapping of the watershed was accomplished by review of sequential years of vertical stereoscopic aerial photographs. Methodology followed was modified from Washington TFW protocols and CDMG landslide mapping methods. An Abrams 2 and 4 power Model CB-1 stereoscope was used during review of aerial photographs.

For the most part, the air photos were reviewed sequentially from oldest to youngest. However, two years were review out of order. The order of review was, from initial set of photo to the last set reviewed: 1988, 1963, 1941/42, 1952, 1957, 1965, 1978, 1996, and 1999.

The majority of coverage varied from a scale of 1:20,000 to 1:24,000; however, three sets were not of these scales, they ranged from 1:12,000 (1996) to about 1:31,000 (1988) to 1:53,000 (1957). The earliest coverages available (1942 and 1952) were confined primarily to the South Fork drainage and areas south of the mainstream. The 1957 coverage included almost all the basin except about the eastern boundary, and northern one-quarter. The 1999 coverage was limited to the southern half of the watershed. Other years had complete coverage of the watershed.

Landslides observed an the aerial photographs were plotted on acetate overlays placed on 7½ minute topographic maps. They were classified as either rotational/translational, earthflow, debris slide, or debris flow/torrent. Rotational/translational and earthflow slides are characterized as relatively deep-seated slow moving or static slides and it is generally assumed that such failures are contributing little sediment except that derived from sheetwash or gullying processes. Debris slides, however, are judged to be short-term active failures that contribute relatively modest to large volumes of sediment to the drainage. However, over time they revegetate and eventually heal so that, in many cases, sediment input is reduced to similar levels as adjacent undisturbed areas. Debris flows/torrents are fast-moving, relatively shallow (in most, but not all) failures. For this study, cutslope and fillslope failures and rock avalanches are also included in this classification.

In an attempt to maintain uniformity in the size of debris flows mapped from photo set to photo set, only those failures with estimated dimensions of about 75 to 100 feet or more in width or length were mapped. This included almost all failures observed.

As mapping progressed, slides mapped from earlier photos were searched for in later photos. If they were observed, it was appropriately recorded. Unfortunately some slides that were observed over a long period of time were not noted on all sequences of photos. This may have been due to being overlooked during review, camera angle, shadows, partial revegetation, or the slide may have healed and failed again. It was noted if a debris slide occurred along a road, the railroad, in a recently cut harvest unit, or in a natural or essentially revegetated area. It was also noted whether sediment was likely delivered to the adjacent drainage and whether the feature occurred on an inner gorge slope position.

### Surface Erosion

Surface erosion from roads and skid roads was estimated by developing a road construction history prior to 1985 and a harvest history prior to 1988. Both of these mapping efforts were shown on overlays and essentially record road or harvest activity during the period between years of photographs reviewed. For roads, only main roads or haul roads were mapped. Because of revegetation over time, probably not all haul roads were mapped, their importance could be misled by lack of use, being overgrown, or being incorporated into harvest units and lost in a maze of skid trails. In tractor logged harvest units, road and skid trail density was characterized as either low, moderate, or high. Data from the overlays was digitized into the GIS database for subsequent mapping and analysis.

## HYDROLOGY

### Precipitation

Precipitation in the Noyo Watershed, as is typical of California, is highly seasonal, with 90 percent falling between October and April. A small portion of the annual precipitation falls as snow at the higher elevations, although it rarely remains long, and snowmelt or even rain-on-snow events are not important hydrologic functions. Annual precipitation ranges from about 38 inches in Fort Bragg to over 50 inches in Willetts just east of the watershed. The isohyetal map for the watershed (Figure 6) indicates that annual precipitation likely exceeds

70 inches at the highest elevations in the far northern portion of the watershed near Sherwood Peak.

There are relatively few precipitation stations in or near the basin. The longest is that of Willetts, with a period of record of 1879-1998. Figures 7 and 8 show the annual precipitation at Fort Bragg and Willetts, respectively and the computed cumulative departure, while Table 3 presents the annual totals. At the Willetts station, the wettest year on record was 1958 when 92.82 inches of precipitation were recorded, while the driest was only 16.88 inches in 1977. The mean for the 120-year period is 50.35 inches. For Fort Bragg, the wettest year contained in its record (1896-1998) is 1998 when precipitation totals reached 77.31 inches, dramatically wetter than 1983 the next highest, when 62.47 inches were recorded. The driest year at Fort Bragg was also 1977, when only 16.56 inches of precipitation were recorded. The mean for the 102-year record in 38.74 inches.

It is interesting to note that the relationship between precipitation at Fort Bragg and at Willetts is highly variable. In some of the drier years, Fort Bragg actually recorded more precipitation than Willetts, while in wetter years, Willetts averages about 150% of the Fort Bragg amounts. 1998 was a highly anomalous year, as more rain fell at the coast than at Willetts, despite being a very wet year. Review of the ranked annual precipitation totals indicates that none of the years are in the same order as at the other station, thereby complicating the task of determining the most significant events from a geomorphic perspective.

Cumulative departure from the mean is a measure of the consecutive and cumulative relationship of each year's rainfall to the long-term mean. When the cumulative departure line is descending (left to right), there is a dryer than normal period, while an ascending line denotes wetter then normal. The relatively long-term record at Willetts provides an excellent basis for evaluating wet and dry periods in the last 125 years. At Willetts, 1881-1889 was a dry period, followed by a long, very wet period extending from 1890 through 1909, just the period when the railroad was being built up the Noyo River. A prolonged drought period followed from 1910-1937. 1928-1935 was particularly dry with 8 consecutive years below the long-term. 1938-1942 was a wet period, followed by another 8 year dry period between 1943 and 1950. Between 1950 and 1986 was a slightly wetter than normal period, with a number of wet years alternating with slightly below average years. The 1976-1977 drought was intense, but short-lived. The worst drought in the 120-year record occurred from 1987-1992, when 6 consecutive years barely averaged over 50% of the long-term mean. 6 years stand out from the perspective of total annual runoff: 1879, 1890, 1904, 1938, 1958, and 1983. The pattern at Fort Bragg is generally similar, although the 1987-1992 drought did not appear as severe.

Table 4 shows ranked 1-day (24-hour) precipitation intensities (only the top 75 entries) for both the Willetts and Fort Bragg stations. The maximum 1-day precipitation at Willetts is 8.8 inches in 1965, while at Fort Bragg it is 4.15 inches in 1953. The differences between storms is even more surprising when daily totals are considered. The Dec 1964 event was the largest at Willetts by a significant margin, but only ends up 11th on the ranked list for Fort Bragg.

The 1953 event, the largest at Fort Bragg, is far down the list for Willetts (#31). In fact, in the top ten for each station, there is only one match, 1938. Other large years based on intensity records at Willetts are 1938, 1906, 1914, 1947, 1960 and 1974. Comparison of the 1-day intensities with peak discharge reveals a poor relationship, indicating that 1-day precipitation (at Willetts) is not the driving force in peak flows experienced by the Noyo.

## Streamflow

Streamflow records have been collected at one gage in the basin by the USGS, located 0.6 miles downstream from the South Fork confluence. The gage measures streamflow from 106 of the 113 square miles of the watershed. The Noyo, like most of coastal California, is a flashy basin, one that rises very quickly in response to precipitation inputs, and drops back down to base flow levels nearly as quickly.

### Peak Discharge

The largest peak discharge for the Noyo River occurred in January 1974, when the river crested at 26,600 cfs according to USGS records, as shown in Figure 9. Table 5 lists the annual peaks for the 47-year record, ranks them and computes recurrence intervals based on the Weibull formula. Other significant storms occurred in December 1955 (WY1956), December 1964 (WY1965), January 1993, January 1956, and December 1951(WY1952). The peak discharge is typically 1.5 times the mean daily discharge on the day of the peak flow, indicating how sharp the peak flow hydrographs are.

### Flood Frequency

Flood frequency analysis is a method used to predict the magnitude of a flood that would be expected to occur, on average, in a given number of years (recurrence interval) or to have a specific probability of occurrence in any one year (1% chance event, for example). Typically, the observed annual maximum peak discharges are fitted to the log-Pearson Type III distribution using a generalized or station skew coefficient. When long records are available, the station skew is used exclusively. The results of a the log-Pearson Type III analysis for the 1952-1998 period of record is shown in Figure 10 and summarized in Table 6 below. This analysis indicates that the 1974 flood would be between a 60-70-year event, while flows

**TABLE 6**

**NOYO RIVER FLOOD FREQUENCY ANALYSIS**

| PROBABILITY | RECURRENCE INTERVAL (years) | DISCHARGE (cfs) |
|---|---|---|
| 0.5 | 2 | 7000 |
| 0.2 | 5 | 13000 |
| 0.1 | 10 | 16900 |
| 0.05 | 20 | 20700 |
| 0.04 | 25 | 21900 |
| 0.02 | 50 | 25400 |
| 0.01 | 100 | 28900 |
| 0.005 | 200 | 32300 |

similar to December 1955 would be about a 25-year event. The 2-year event is about 7000 cfs.

## Historic Floods

Although the Noyo has a relatively short period of streamflow records, many of the largest floods in the past 150 years have occurred since 1950. Known large flood events in the region or the watershed have occurred in 1861, 1881, 1890, 1906, 1914, 1938, 1956, 1965, 1966, 1974, and 1993. The largest of these were likely to have been the 1861 and 1890 events, followed by the 1914, 1938, and 1974 events.

Storm events have resulted in significant damage to the railroad over the years. In 1906-07 floods took out “immense sections” of the tracks and “it took three months of hard work in the mud and steep slopes to get the Iron Horse operating again” (Crump 1998). In 1914, 9” of rain was reported to have fallen in 36 hours resulting in high flows which took out bridges, a trestle, and caused a 150’ landslide (Crump 1998). These reports of high flows and damage correspond to years in which the 3rd and 4th largest 1-day precipitation events occurred.

Table 7 presents information that may be used to assess the magnitude of storm events and their geomorphic significance includes ranked data for the top 20 events in each type. During the period of streamflow records, 1974 stands out well above other years, not only because of the highest peak flow, but also its duration, several subsidiary peaks flows, and the total annual runoff. 1-day intensity values would suggest that the December 1964 event should have produced the largest peak discharge this century, but USGS streamflow data indicate that 1974 event was larger. It is possible, that 1974 was anomalously high due to a rain-on-snow event, as was experienced farther north such as in Shasta and Trinity Counties.

## Mean Daily Discharge

The USGS publishes mean daily discharge records for each of its gages on an annual basis. These values are typically used to construct annual streamflow hydrographs and perform flow duration analyses. A water year type analysis was made on the Noyo River, ranking years in terms of annual runoff and stratifying them into water year types (normal, wet, dry, etc.). This analysis is shown in Table 8. Figure 11 shows the annual mean daily streamflow hydrographs for 3 water year types. Peak discharges during storms are of very short duration, one to 2 days at most generally, and flows rapidly return to typical winter base flow of 200-300 cfs within one week after the peak. Almost all significant runoff events occur between December and March.

## Flow Duration

A flow duration analysis was performed using mean daily discharge for the USGS gage. The

results are presented in Figure 12. The analysis indicates that the Noyo only exceeds 500 cfs 10% of the time, or 36 days per year on average. 50% of the time flows are below 32 cfs. Flows exceed 2590 cfs only 1% of the time, or 3.6 days per year on average, while flows exceed 5000 cfs on average 1 day per year. Relatively little sediment transport probably occurs below 1000 cfs, thus all of the geomorphic work accomplished by the river occurs in less than 5% of the time, with most concentrated in the top 1% of the flows.

### Annual Runoff

Annual runoff has been measured in the Noyo River watershed with the USGS streamflow gage. The mean annual runoff for the 1952-1997 period is 151,900 acre-feet. The annual runoff data are shown in Table 9, and plotted in Figure 13. Large volumes of runoff are often associated with both large flood years and years with high annual precipitation. The two largest annual runoff years were 1983 and 1974, almost 20% larger than the 3rd largest runoff year, 1958. Three particular dry periods stand out of the cumulative departure analysis, 1959-1964, 1976-1981, and 1987-1992.

## SEDIMENT TRANSPORT

### Sediment Transport for the Noyo River (Estimate of Suspended Sediment and Bedload Discharge)

No sediment transport data exist for the Noyo River. To approximate sediment transport for the Noyo River, regional sediment rating curves were developed and utilized to estimate suspended sediment and bedload discharge. The following sections describe the general approach, data, analysis and results.

### General Approach and Data

Regional sediment rating curves were developed from sediment data for various streams located in the North Coast Hydrologic Basin Planning Area, as delineated by the State of California Regional Water Quality Control Board. Only sediment data from watersheds ranging in size from 50 to 250 mi$^2$ was utilized. This seemed a reasonable screening criterion, as the Noyo Watershed is 106 mi$^2$ in size. Sediment data (discharge, suspended sediment concentration, suspended sediment discharge, and bedload discharge) was collected for 14 streams located in six (6) different hydrologic unit codes (HUC), from the USGS Quality of Water data base. Table 10 lists the station number, station name, drainage area, HUC, and type of data utilized. Data ranged from water year (WY) 1953 through 1995, with most stations containing only a few years or intermittent data. No station contained a complete sediment record for WY 1953-95. All 14 stations contained suspended sediment

data which resulted in a large sample size (n=1439) for developing the suspended sediment rating curve. However, only 5 stations contained bedload data, resulting in a smaller sample size (n=57) for the bedload rating curve.

The regional suspended sediment rating curve (Figure 14a) found stream discharge to be a strong predictor of suspended sediment discharge for the regression model ($R^2=0.91$, $P<0.0001$), with 91% of the observed variation in suspended sediment discharge explained by stream discharge. For the regional bedload rating curve (Figure 14b), stream discharge explained 62% of the variation in bedload discharge. The bedload regression model ($R^2=0.62$, $P<0.0001$) was determined to be an adequate predictor of bedload discharge. Due to seasonal variance, extreme values and the use of regional sediment data, both rating curves were log-log transformed.

To provide a visual assessment of the regression models, the 95% confidence intervals about the regression line, and the 90% prediction intervals on future observed responses are also shown on Figures 14a and 14b. The width of the confidence intervals measures the overall quality of the mean response of the regression equation. Prediction intervals represent the interval with a specified probability of containing a future observed value. The 90% prediction intervals were used to provide a range of estimated sediment transport rates for the Noyo River based on the regional sediment rating curves.

## TABLE 10

**Gaging station information and data utilized**

| Station No. | Station Name | Drainage Area ($mi^2$) | Hydrologic Unit Code | Data Utilized |
|---|---|---|---|---|
| 11472200 | Outlet Creek near Longvale | 161 | 18010103 | D, SSC, SSD |
| 11472800 | MF Eel River above Black Butte River | 204 | 18010104 | D, SSC, SSD |
| 11472900 | Black Butte River near Covelo | 162 | 18010104 | D, SSC, SSD |
| 11473700 | Mill Creek near Covelo | 95.6 | 18010104 | D, SSC, SSD |
| 11473800 | Elk Creek near Hearst | 84.1 | 18010104 | D, SSC, SSD |
| 11474500 | NF Eel River near Mina | 248 | 18010105 | D, SSC, SSD, BD |
| 11475100 | Dobbyn Creek near Fort Seward | 61.4 | 18010105 | D, SSC, SSD, BD |
| 11475500 | SF Eel River near Brans | 43.9 | 18010106 | D, SSC, SSD |
| 11467590 | Garcia River at Eureka Hill Rd | 98.5 | 18010108 | D, SSC, SSD, BD |
| 11468500 | Noyo River near Fort Bragg | 106 | 18010108 | D |
| F8310000 | Noyo River near Fort Bragg | 106 | 18010108 | D, T |
| 11461000 | Russian River near Ukiah | 100 | 18010110 | D, SSC, SSD, BD |
| 11461500 | EF Russian River near Calpella | 92.2 | 18010110 | D, SSC, SSD |
| 11462000 | EF Russian River near Ukiah | 105 | 18010110 | D, SSC, SSD |
| 11463200 | Big Sulphur Creek near Cloverdale | 85.5 | 18010110 | D, SSC, SSD |
| 11465200 | Dry Creek near Geyserville | 162 | 18010110 | D, SSC, SSD, BD |

D = Discharge (cfs)
SSC = Suspended sediment concentration (mg/l)
SSD = Suspended sediment discharge (ton/day)
BD = Bedload discharge (ton/day)
T = Turbidity (FTU)

## Analysis and Results

To provide an estimate of average suspended sediment and bedload discharge for the Noyo River, the regression equations from the regional rating curves (Figures 14a and 14b) where applied to the entire discharge record (water year 1951-97) for the Noyo River near Fort Bragg gaging station (Station No. 11468500). The daily sediment rates were then summed to provide an estimate of annual sediment discharge for each water year. Table 11 summarizes the estimated sediment and bedload discharge rates, and sediment yields for the Noyo River watershed. Based on this approach, the average annual sediment discharge rate for the Noyo River is approximately 133,600 tons/yr, which corresponds to a watershed sediment yield of 1,254 tons/mi$^2$/year.

As an estimate of the potential upper and lower range of the estimated annual average sediment discharge and yield for the Noyo River (Table 11), the 90% prediction intervals for the developed sediment rating curves (Figures 14a and 14b) where applied to the Noyo River discharge record. Results of this analysis indicate an interval with a 90% probability of containing a future response of sediment discharge for the Noyo River. Table 3 lists results of the prediction interval analysis for annual average sediment transport and yield estimates. As an example of this analysis, the annual average sediment yield (1,254 ton/mi$^2$/yr) has a 90% probability of being located in the range from 135 to 12,570 ton/mi$^2$/yr. It should be noted that this range was determined using the 90% prediction interval lines, and therefore represent extreme estimates of the upper and lower range for the annual average values. To further clarify, in order to obtain an annual average sediment yield at the lower range (135 ton/mi$^2$/yr) all estimates of daily sediment discharge would have to occur on the lower 90% prediction interval lines shown on Figures 14a and 14b. This wide range is indicative of using regionally based equations.

### TABLE 11

**Summary of estimated annual suspended sediment discharge, bedload discharge, sediment discharge, and sediment Yield for the Noyo River for Water Year 1951-97 using the regional regression equations.**

| Value | SSD (ton/yr) | BD (ton/yr) | SD (ton/yr) | SY (ton/mi2/yr) |
|---|---|---|---|---|
| Average value (WY 1951-97) | 113,000 | 20,600 | 133,600 | 1,254 |
| Minimum value (WY 1974) | 78 | 41 | 119 | 1.1 |
| Maximum value (WY 1977) | 621,000 | 92,700 | 713,700 | 6,735 |

SSD = suspended sediment discharge
BD = bedload discharge
SD = total sediment discharge
SY = total sediment yield

## TABLE 12

### Range of annual suspended sediment discharge, bedload discharge, sediment discharge, and sediment yield for the Noyo River for Water Year 1951-97 using 90% prediction intervals.

| Item | Units | Value |
|---|---|---|
| SSD - lower 90% prediction interval | ton/yr | 13,100 |
| SSD - average value (regression eq.) | ton/yr | 113,000 |
| SSD - upper 90% prediction interval | ton/yr | 968,000 |
| BD - lower 90% prediction interval | ton/yr | 1,170 |
| BD - average value (regression eq.) | ton/yr | 20,600 |
| BD - upper 90% prediction interval | ton/yr | 363,000 |
| SD - lower 90% prediction interval | ton/yr | 14,300 |
| SD - average value (regression eq.) | ton/yr | 133,600 |
| SD - upper 90% prediction interval | ton/yr | 1,331,000 |
| SY - lower 90% prediction interval | ton/mi$^2$/yr | 135 |
| SY - average value (regression eq.) | ton/mi$^2$/yr | 1,254 |
| SY - upper 90% prediction interval. | ton/mi$^2$/yr | 12,570 |

SSD = suspended sediment discharge
BD = bedload discharge
SD = total sediment discharge
SY = total sediment yield

## Total Sediment Load and Sediment Yields

Using the mean regional equation developed in the preceding section, total sediment loads (the sum of suspended load and bedload) was computed for each year in the Noyo River streamflow record (1952-1997). These data are shown in Table 13. Annual sediment yields were calculated from these computed annual loads, and the mean value is 1,257 tons/mi$^2$/yr. Over the 47-year period, an estimated 6,129,000 tons of sediment have been transported at the USGS gage. Of this total amount 11.6% was computed to have been transported in 1974 alone, while the top 10 years accounted for 57.8% of the total sediment load.

One available source of information that may be used to validate the computed sediment discharge is dredging data from the Noyo Harbor for the period 1933 to 1995 compiled by the U.S Army Corps of Engineers (L. Graham, pers. comm. 1999). We made assumptions that 80% of the bedload and 20% of the suspended load would remain in the harbor area, while the balance would be discharged into the ocean. Figure 16 is a plot of estimated sediment accumulation in the harbor versus dredged volumes from 1952 to 1995. From the 1950s through 1974, dredging occurred on an irregular basis, which sometimes coincided with our estimates of significant accumulated sediment load, and often did not. However beginning in 1974, dredging amounts closely correspond with our estimates. In years with small estimated transport amounts, only small volumes of dredging occurred, while in years with calculated greater loads, much larger volumes of sediment were dredged. This comparison suggests that our estimates have a reasonable validity.

### Turbidity

Turbidity data has been collected by the City of Fort Bragg at their instream diversion at Madsen Hole (river mile 4.0). In certain years, depending upon the type of diversion (which has varied from direct diversions to Rainey-type gallery intakes), the turbidity samples may not be representative of conditions in the channel. Since 1990, a direct diversion has been operated with the turbidity being measured from the raw water prior to any modification, and therefore probably accurately represents the turbidity in the channel.

Relating turbidity data to USGS mean daily streamflow records was completed using portions of the available data. Figure 17a shows turbidity and streamflow data for a 6 month period in 1995. The turbidity data track well with streamflow hydrographs in terms of event timing, although there is considerable divergence between the streamflow/turbidity relationship between storm events. Figure 17b examines the relationship between streamflow and turbidity. For this small sample, variation in streamflow is able to explain about 70% of the variability in turbidity values, although the range of values may cover almost an order of magnitude. Figure 17c examines the relationship between streamflow and turbidity over time, comparing the April-May period for 4 different water years. The April-May period was selected in an effort to minimize the effects of larger storms for which there is greater variability, and instead focus on a comparable period of time between years. The results show that turbidity values have increased steeply between 1993 and 1997. 1995 and 1996 data occupy a central position between 1993 and 1997 suggesting that a trend over time has occurred. Since 1993 was the 3rd highest peak flow since 1952, these data could suggest a lag in the downstream transport of sediment that was produced in 1993. On the other hand, 1995 and 1997 were also wet years, and it could also reflect an actual increase in sediment production and delivery.

Comparison to other historic turbidity data, as it becomes available, could provide additional insight in changes in turbidity values over time and how this relates to land management changes in the watershed.

## CHANNEL GEOMETRY

Trend monitoring of channel geometry can provide insight into changes to the river channel, due to specific events (typically large floods) and to longer-term adjustments and recovery from these floods events. Channel geometry is most often monitored through cross section and profile surveys, both of which are two-dimensional representations of channel shape, with the cross section perpendicular to the flow direction, and the longitudinal profile parallel. Unfortunately, few projects have a long-term perspective, and one of the most useful (and often only) sources of historic channel information can be obtained from USGS stream gaging station records.

## Analysis of Gaging Station Data

Overview:

Gaging station records used to develop a stream channel history include the station description, level notes, and discharge measurement records. Discharge measurements collected at the same location allow development of the most definitive record of change. Since the location of low-flow (wading) measurements depends on the selection of the best measurement site and may vary over a reach up to 1000 feet upstream or downstream from the gage, analysis is often limited to high-flow discharge measurements taken at a cableway or bridge. Data obtained include the thalweg (or minimum streambed elevation) and mean streambed elevation over the period of record of the gage.

The procedure involves computing average channel depth (area/width or discharge/(width)(velocity)) and then subtracting this value and the maximum channel depth from the gage height at the time of the streamflow measurement. Any changes in gage datum during the period of record must be carefully taken into account. Care must be taken in interpreting upward (e.g. channel fill) spikes of the mean bed elevation plot, as very high discharge measurements have a greater top width, which may artificially create the appearance of fill. If the cross section has very steep banks, such as in bedrock canyon reaches, these upward spikes may in fact reflect channel aggradation. Plotting the mean and minimum bed elevations provides a check for this effect. Selected discharge measurements can also be plotted as cross sections to compare channel shape changes over time.

Changes in hydraulic geometry relationships may also be used to define changes in channel geometry and specifically in the rate of adjustment of the various hydraulic variables.

Noyo River near Fort Bragg:

For the Noyo River, the relatively long period of record at the mainstem gage provides the basis for a reasonable trend analysis. The 9-207 records from the USGS gage were analyzed for Mean Bed Elevation (MBE) and the results are shown in Figures 18 a and 18b. Figure 18a provides calculations from all of the discharge measurements in the USGS records, a total of 474 streamflow measurements from 1951 through January 1999. A 5 period moving average is also plotted to assist in data interpretation. The data indicate that the mean streambed elevation was declining from 1951-1957, perhaps with a foot of change over this period. Beginning in 1958, the mean elevations rose slowly through 1963 and then sharply through about 1970. The total increase in mean bed elevation is about 2 feet over this period. From 1970 through 1992, there was a slight downward trend, resulting in somewhat less than 1 foot drop over this 22 year period. Beginning in 1993, there was an increasing trend through 1998. The most recent data may suggest another period of bed degradation is starting.

Figure 18b is a plot of only cableway measurements, those made from the exact same location over time. Unfortunately, due to the generally low flows on the Noyo, not that many cableway measurements have been made over the years. This figure is interpreted to show that the total aggradation from 1958 to 1970 may be on the order of almost 4 feet, with only a slight recovery since then. The period from 1951-1958 is interpreted to reflect a period of rapidly changing bed topography, as significant sediment is being moved through the system. The large spikes seen do not necessarily reflect bed elevation changes and are often found to be artifacts of the computational process. For example, if the channel width increases significantly at a higher flow, such that the margins of the channel are not carrying much flow, then the MBE can be biased upward due to the width increase. As a result, some analysts (Hickey 1969) only use low-water measurements, where width changes with discharge are generally not an appreciable effect. As a result, the trend over time is a more important indicator than one or several measurements.

Figure 18c is a plot of the stage-discharge relationships for the annual peak discharges. It should be noted that the curves shown are not USGS data and probably do not exactly reflect the curves used to compute their discharges. We merely grouped data together that seemed to fit. The analysis shows that the streambed aggraded about 2 feet for the period 1957-1973, then dropped back down to its previous relationship, but showed greater aggradation from 1992-present of 3-4 feet. Again, there are limitations to use of stage-discharge relationships to analyze channel bed trends, as other changes in the shape of the channel can effect the discharge rating while the streambed remains constant. The solution is to graph the actual depth readings from the various measurements and evaluate channel change using the entire cross section.

Streambed elevations generally reflect the overall balance of sediment transport at their location. If sediment delivered to the channel is greater than the transport capacity of the channel (which is a combination of flow and channel geometry), then the channel will aggrade or rise in elevation. When sediment loads are less than transport capacity, the channel will degrade or scour as along as suitably-sized (i.e. capable of being mobilized) alluvial deposits are present on the channel bed. Dramatic channel adjustments have been observed to occur in watersheds with very high sediment production and delivery, particularly when delivered catastrophically, such as in the December 1964 flood in many northern California basins.

The Noyo reflects far less dramatic changes, which is in character with its more stable geology (Franciscan Coastal Belt vs. the melange of the Central Belt), generally dense vegetation coverage, and lower precipitation rates. However, the changes observed do appear to correlate well with changes in sediment production and delivery over time as discussed in the next section.

## SEDIMENT SOURCE ANALYSIS

This section describes the process used to evaluate possible sources of sediment within the Noyo Watershed and presents the results of these analyses. The sediment source analysis encompasses three primary components: (1) evaluation of the dominant geomorphic processes that deliver sediment to the various stream channels in the Noyo River watershed through limited field reconnaissance, review of pertinent documents, and discussions with those involved with current studies in the basin; (2) measurement of various parameters, such as landslide size/type/associated land use, road length, and harvest areas from sequential aerial photography; and (3) selection of factors to modify and or extend the photo-based measurements, thus allowing computation of results.

Since this analysis is based on an in-direct, office approach, data collection was limited to parameters discernible on aerial photography, thus eliminating identification or mapping of many small-scale features (such as gullies, streamside landsliding, and bank erosion, all of which would be generally hidden beneath the canopy). Given the scale of the photography that was available for this analysis and given the need for consistency between photo sets of differing scales and print qualities, only mass movement features with a minimum dimension exceeding 75 feet could be identified. Various studies have shown that for many areas of Northern California, sediment delivery to channels is dominated by the contributions of the largest slides (Pitlick 1995, Kelsey et al. 1995, Raines 1998, PWA 1998 a,b).

Sources of sediment in the Noyo watershed include mass wasting (deep-seated landslides, shallow-seated landslides or debris slides, and debris flows or torrents), surface erosion (hillslope erosion and road erosion), and fluvial erosion (gullying and streambank erosion). This sediment source investigation included photo-based measurements to address mass wasting and surface erosion. Estimates of fluvial erosion were based on published values and ongoing research by MRC.

### Mass wasting

Nine sets of aerial photographs were examined in this investigation. Unfortunately, several of the years did not cover the entire basin and measured values thus represent minimum rates.

A total of 1781 features (slides) were mapped during this study. Features were given a certainty rating of definite, probable, or questionable. The first screening of the project database eliminated all questionable features from further consideration. Mass wasting features were also coded based on sediment delivery. The second screening step eliminated all features that were judged to be non-delivering, leaving those considered to be delivering, potentially delivering, or unknown. These two datasets (all mapped slides and delivering slides only) are shown in Figure 21a and 21b using output from the GIS digital files. After the delivery screening, only 973 remained. This screening step eliminated virtually all of the large, apparently inactive landslides that were found on the CDMG base maps and also mapped in this study. This included many deep-seated rotational/translational slides throughout the watershed, and a number of slow-moving earthflows identified in the eastern portion of the basin underlain by the Franciscan Melange Terrane.

Since the 1999 photos did not cover the northern half of the watershed and the 1996 photos , we added all slides mapped by MRC and determined to be delivering in 1998 in their holdings in the North Fork and Headwaters sub-basins. This added 117 slides to the database. Again, since MRC only mapped slides within their ownership, these values represent minimums for those sub-basins and planning areas. At the same time, a comparison was made between the 1978 features mapped by MRC and this study. Table 14 presents the results of this comparison. The numbers refer to the number of features mapped on the 1978 photo set by MRC, or on a series of photo sets depending on the age of the feature. Since all of these features were available as GIS coverage's, the two datasets were overlaid digitally, and each numbered feature from the MRC database was examined. When features mapped by both projects either directly overlaid each other, or were slightly divergent but of the same general size and shape (due to distortions usually encountered in the digitizing process), a match was assumed. The difference between the two datasets is primarily related to small landslides, which were not visible to such an extent on the 1:24000 photos used in this study compared to the 1:12000 photos used by MRC. Review of estimated slide volumes indicates that these slides were typically 200-2000 $ft^3$ or roughly 10-75 $yd^3$ features. It should be noted that MRC also field visited over 30% of their mapped features for verification of dimensions and delivery attributes.

**Table 14. Comparison of features mapped from aerial photography.**

| **PLANNING WATERSHED**<br>Sub-Watershed | (This Study)<br>**COYLE** | (C. Surfleet, pers. comm. 1999)<br>**MRC** |
|---|---|---|
| **HEADWATERS** | | |
| Noyo River Headwaters | | |
| McMullen Creek | **10** | **16** |
| Redwood Creek | **2** | **3** |
| Olds Creek | **3** | **7** |
| Upper Noyo River | | |
| **NORTH FORK** | | |
| Hayworth Creek | **14** | **27** |
| Upper North Fork Noyo | **7** | **17** |
| Lower North Fork Noyo | | |
| **MIDDLE NOYO** | | |
| Little North Fork Noyo | | |
| Mainstem Noyo | **7** | **22** |

The remaining dataset was queried by landslide type, year, number of slides, and area. Summary tables for the Planning Watersheds and each sub-watershed were prepared for use in interpreting the data and performing volume calculations. The distribution of sediment delivering landslides by type for each sub-watershed is shown in Table 15. Of the 1090 slides mapped over the 57 year period, 1030 or 94.5% were debris slides, 5% were debris flows/torrents, and 0.6% were earthflows. The 1090 slides gives a watershed averaged rate of 9.65 slides/mi$^2$ for the period. Landslide frequency for each of the photo periods in shown in Figure 27. Landslide frequencies were highest in the 1988, 1963, and 1942 photo years. Surprisingly, none of these periods contained the largest known storm events (Jan 1974, Dec 1964, Jan 1993, and Dec 1955), in terms of peak discharge, although the Dec 1937 storm had the second highest 1-day precipitation intensity at Willetts in an 88-year record, only behind Dec 1964.

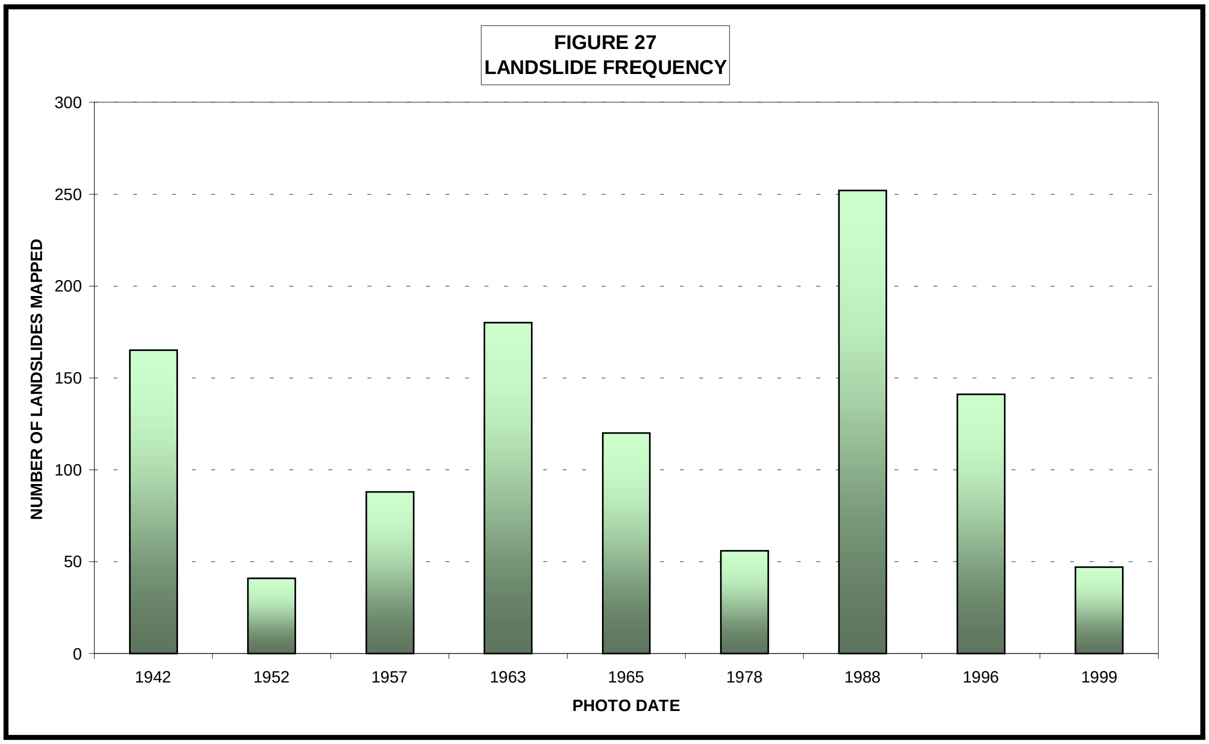


FIGURE 27
LANDSLIDE FREQUENCY

However, when the landslide rate (#/year) for each of the periods represented by the aerial photos is calculated, the 1963-1965 period stands out (Figure 28). Only 120 “new” slides were identified on the 1965 photos, however, because this represents only a two year period, the rate is 60 slides/year. Undoubtedly almost all of these slides actually occurred in 1965, centered around the Dec 1964 event, as 1964 was a below normal precipitation year (38” at Willetts, well below the mean of 50”).

It is surprising how few landslides were mapped in the 1978 photo set, considering that event probably produced the largest peak discharge this century. Although the precipitation intensity of the 1974 event was only the 7th highest at Willetts and the 23rd highest at Fort Bragg, it produced the highest flow recorded at the USGS gage, and 1974 was the second highest in terms of annual runoff. It is possible, that since this storm may have included a

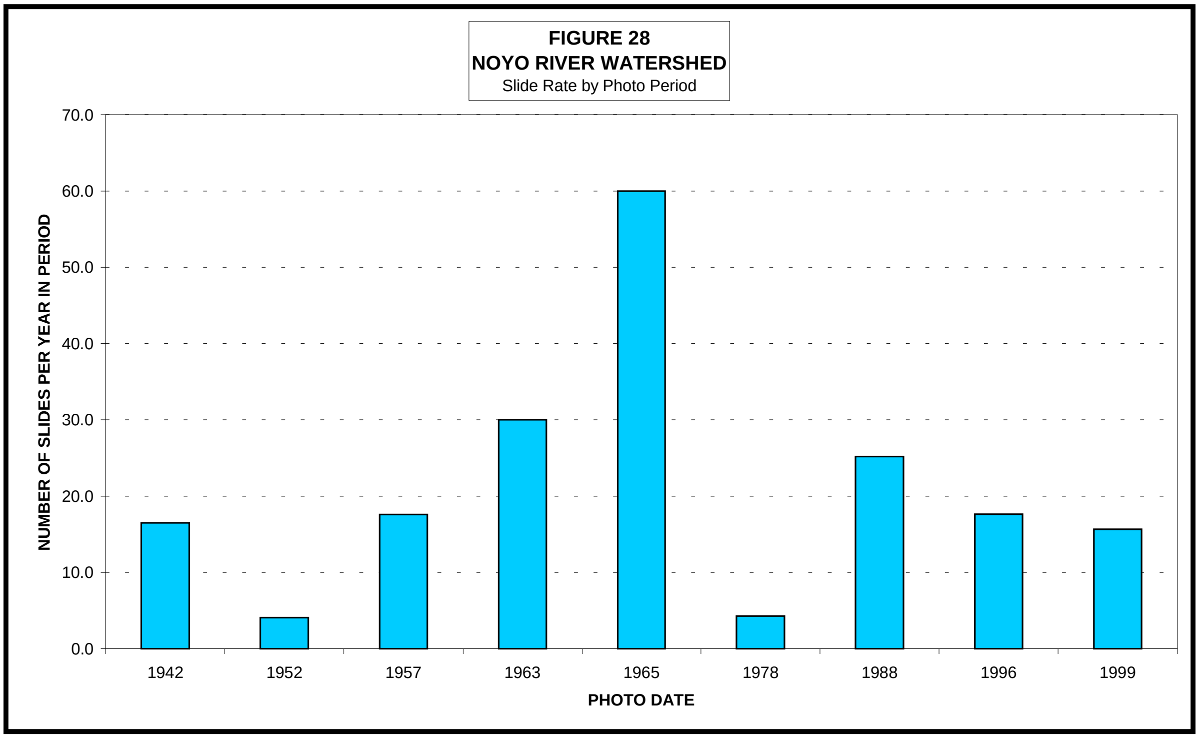


FIGURE 28
NOYO RIVER WATERSHED
Slide Rate by Photo Period

significant rain-on-snow component (it did in basins further north), intensity threshholds were not exceeded while creating high runoff.

The 1952 photo set occurred at the end of a relatively dry period, between 1943 and 1951, and a period of lesser land use activity, so fewer slides is to be expected. The general trend in landslide rates appears to be increasing from 1952 through 1965, and declining since then. This period of increased slide frequency would appear to correlate well with periods of relatively intense land use activity in the form of both harvest and road construction in a period when these activities were much less regulated.

Review of landslide distribution by the various sub-watersheds (Table 16), shows that three areas stand out for the number of slides (Mainstem Noyo, North Fork South Fork Noyo, and Hayworth Creek), with 195, 173, and 115 slides respectively. However, when viewed on a unit area basis, a number of other sub-watersheds stand out, (North Fork South Fork Noyo, McMullen Creek, Parlin Creek, Kass Creek, Olds Creek and Hayworth are the top 6). Notable sub-watersheds with fewer slides per area include the Upper Noyo, Little North Fork Noyo, Upper South Fork Noyo, and Noyo Headwaters.

## Landform Association with Mass Wasting

In contrast to many other studies, inner gorge slopes do not appear to be the most common origin for landslides in the Noyo Watershed. Figure 25a-e depicts delivering slide locations

over the GIS slope coverage. Clearly, most landslides occur on slopes exceeding 50%, but the majority of these appear to be mid-slope locations rather than below the lowest significant slope break, with slopes greater than 65%, next to a stream channel, as inner gorges are commonly defined as. Inner gorge slides are most important along the Mainstem Noyo between Northspur and the mouth. Over 50% of the slides in the Mainstem Noyo sub-watershed are considered inner gorge, and almost 60% of all mapped inner gorge slides occurred in this sub-watershed (Table 17). Figure 26 shows the locations of inner gorge landslides in the Middle Noyo Planning Watershed, and most of these slides can be examined in the series of enlarged aerial photographs contained in Figure 20.

**TABLE 17**

**DISTRIBUTION OF INNER GORGE SLIDES IN NOYO WATERSHED, 1942-1999**

| PLANNING WATERSHED | # of Inner Gorge Slides | % of Total | Total Area (acres) | Acres/slide | Slides/mi$^2$ |
|---|---|---|---|---|---|
| **HEADWATERS** | **2** | **1.2%** | **0.80** | **0.40** | **0.07** |
| **NORTH FORK** | **0** | **0.0%** | **0** | **0** | **0** |
| **MIDDLE NOYO** | **98** | **58.3%** | **144.10** | **1.47** | **3.85** |
| **SOUTH FORK** | **40** | **23.8%** | **95.54** | **2.39** | **1.46** |
| **LOWER NOYO** | **28** | **16.7%** | **61.51** | **2.20** | **3.57** |
| **TOTAL** | **168** | | | | |

## Land Use Associations with Mass Wasting

The inventory of mass wasting included a parameter which distributed the observed features into one of four categories based on associated land use interpreted from the aerial photography. The categories included occurrence in harvest units, “natural” forest units, railroad-related, and road related. Table 18 presents the distribution of land use types for all mapped features screened for certainty and delivery, as previously described. Of the 117 slides added from the MRC database, their indication of whether the feature was road-related (37) or not was used. The remaining non road-related slides (80) were then equally distributed between the harvest and forest categories within the appropriate sub-watershed.

Of the 1090 mapped mass wasting features, 668 or 61.3% were identified as occurring in forested areas. Although virtually all of the Noyo Watershed has been harvested at least once, the term forested was used to describe hillslopes covered with trees that were difficult

to distinguish from undisturbed, but still second growth, conditions. Due to the photo scale and vegetation growth rates, this implies that there had not been harvesting in the area for at least 15-20 years. 259 slides or 23.8% were judged to be road-related, 116 or 10.6% were found to be associated with recently harvested areas, and 47 or 4.3% were found to be associated with the railroad. Table 19 expresses the distribution of slides type by percentage in each Planning Watershed and sub-watershed as a function of the total number of slides in the entire watershed.

**TABLE 19**

**DISTRIBUTION OF SLIDES BY ASSOCIATED LAND USE TYPE**
**AND EXPRESSED AS PERCENTAGE OF TOTAL WATERSHED SLIDES IN EACH CATEGORY**

| **PLANNING WATERSHED**<br>Sub-Watershed | Harvest Unit<br>(# of Slides) | Natural Forest<br>(# of Slides) | Railroad<br>(# of Slides) | Road<br>(# of Slides) |
|---|---|---|---|---|
| **HEADWATERS** | **25.9%** | **19.6%** | **12.8%** | **30.1%** |
| Noyo River Headwaters | 2.6% | 4.6% | 8.5% | 6.9% |
| McMullen Creek | 10.3% | 2.5% | 0.0% | 8.1% |
| Redwood Creek | 4.3% | 3.9% | 0.0% | 6.9% |
| Olds Creek | 6.9% | 5.4% | 4.3% | 6.9% |
| Upper Noyo River | 1.7% | 3.1% | 0.0% | 1.2% |
| **NORTH FORK** | **21.6%** | **20.2%** | **0.0%** | **31.3%** |
| Hayworth Creek | 10.3% | 9.4% | 0.0% | 17.8% |
| Upper North Fork Noyo | 6.0% | 5.2% | 0.0% | 5.4% |
| Lower North Fork Noyo | 5.2% | 5.5% | 0.0% | 8.1% |
| **MIDDLE NOYO** | **37.9%** | **15.6%** | **61.7%** | **21.6%** |
| Little North Fork Noyo | 3.4% | 2.2% | 0.0% | 1.2% |
| Mainstem Noyo | 34.5% | 13.3% | 61.7% | 20.5% |
| **SOUTH FORK** | **12.9%** | **43.4%** | **23.4%** | **11.2%** |
| Upper South Fork Noyo River | 3.4% | 5.8% | 0.0% | 0.0% |
| Parlin Creek | 0.0% | 9.7% | 2.1% | 0.0% |
| North Fork South Fork Noyo River | 2.6% | 24.7% | 21.3% | 1.5% |
| Kass Creek | 6.9% | 1.9% | 0.0% | 2.3% |
| Lower South Fork Noyo River | 0.0% | 1.2% | 0.0% | 7.3% |
| **LOWER NOYO** | **1.7%** | **1.2%** | **2.1%** | **5.8%** |

Thus, we see that the Middle Noyo has 37.9% of the harvest unit slides and 61.7% of the railroad-related slides, and lesser amounts of the other categories. 61.4% of the road-related slides occurred either in the Headwaters or North Fork Planning Watersheds, while at the sub-watershed level, Hayworth Creek produced 17.8% of all road-related slides for the entire Noyo Watershed.

### Mass Wasting Area and Volume

Although comparisons between the number of slides is useful at one level, it is the comparison between delivered sediment volumes by type, period, and watershed location that are of primary importance in evaluating both high risk areas for certain slide types and also changes in sediment delivery over time. The first step in determining slides volumes was to query slide areas from the database. Since each slide had been digitized into the database as a polygon in the GIS coverage, geometric characteristics are simply determined. There was no need to measure average slide width and length, and compute area in that manner, but rather the true area as mapped is defined. This provides an improved estimate of area compared to other methods. Table 20 provides the average slide areas by type across the entire watershed, while Table 21 presents the areas on a planning watershed and sub-watershed level.

The average size of slides by type reveals some interesting results: average railroad slides are almost three times the size of slides from road-related or forest locations, while the average for harvest related slides fell in between. The higher average area for railroad-related slides is attributable to a number of large, inner gorge failures along the mainstem Noyo in the Middle Noyo Planning Watershed.

## TABLE 20

### AVERAGE SLIDE SIZE BY TYPE

| Type | # | Area (acres) | Avg Size (acres) |
|---|---|---|---|
| Harvest | 116 | 66.01 | 0.57 |
| Forest | 668 | 220.33 | 0.33 |
| Railroad | 47 | 42.28 | 0.90 |
| Road | 259 | 79.46 | 0.31 |

Factoring in the area of the slide, changed the watershed distribution of slide types by area, with the harvest and railroad related slides increasing from 10.6% and 4.3% by number to 16.2% and 10.4% by area, respectively. The percentage of forest and road-related types declined by similar amounts. The distribution of slide areas within the Planning Watershed level also changed. For example, the Middle Noyo increased from 21.4% of the slides by number to 34.6% of the slides by area. Again, this reflects the importance of large, inner gorge slides often associated with the railroad.

To compute sediment delivery from slide area requires the application of a slide thickness and a delivery ratio, and then conversion of volume ($yd^3$) to tons. Without field studies to assess slide thickness, we relied on published values and more importantly, the mean values

for all slides field verified by MRC in their Level 2 Watershed Assessment. With similar geology throughout the watershed, it appears reasonable to use mean values based on watershed field investigations. We used preliminary data from MRC to distinguish road-related slides with a mean thickness of 3.5 feet, from forest or harvest non road- related slides, which were found to have a mean thickness of 3.0 feet (MRC, 1999). Since no MRC field investigations examined railroad-related inner gorge slides, we selected a mean thickness of 5 feet, to reflect the large size of many of these slides, which was readily apparent on the aerial photographs. Many of these slides can be seen on the Figure 20 photo enlargements. Sediment delivery factors vary considerably in the literature, from 40-100% depending upon slide type and position. MRC developed a mean delivery ratio of 81% for deliverable slides in close proximity to a watercourse. Other studies have used 80% for riparian roads and 50% for shallow landslides (Cafferata/Stillwater Sciences, pers. comm. 1999). PWA selected 40% for both road and hillslope landslides in the North Fork Elk River watershed. For the purposes of this analysis, a mean rate of 50% was selected for all slide types and locations. Conversion of computed volumes (area x thickness, in $yd^3$) to weight used a factor of 110 $pounds/ft^3$, or 1.36 $tons/yd^3$.

Volumes for delivering landslides by Planning Watershed and sub-watershed are shown in Table 22. Table 23 presents these results in terms of percentages by PW/SW as a function of the entire volume in a given year for the Noyo Watershed. The results by PW are summarized below:

## TABLE 24

## PERCENT VOLUME OF DELIVERING LANDSLIDES MAPPED BY PERIOD BY PW

| PLANNING WATERSHED | AERIAL PHOTO YEAR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sub-Watershed | 1942 | 1952 | 1957 | 1963 | 1965 | 1978 | 1988 | 1996 | 1999 |
| HEADWATERS | -NA- | -NA- | 4.9% | 25.4% | 32.3% | 6.9% | 32.6% | 22.8% | 38.6% |
| NORTH FORK | -NA- | -NA- | 4.7% | 27.8% | 23.1% | 55.9% | 32.2% | 18.7% | 19.9% |
| MIDDLE NOYO | -NA- | -NA- | 70.4% | 27.0% | 17.6% | 34.8% | 17.2% | 40.3% | 27.3% |
| SOUTH FORK | 75.4% | 70.63% | 20.0% | 16.9% | 23.2% | 2.4% | 15.0% | 13.3% | 14.3% |
| LOWER NOYO | 0.94% | 0.00% | 0.0% | 3.0% | 3.7% | 0.0% | 3.0% | 4.9% | 0.0% |

Review of the data from the aerial photograph analysis can provide insights to particular sub-watersheds that are producing and delivering sediment volumes at greater or lesser rates then the mean. In addition, time trends of sub-watershed response can be attributed to either susceptibility to a given type of failure location or the effects of the various land management practices. For example, the trends over time for percentage contribution by the various

planning watersheds are significantly different. The headwaters has a definite increasing trend through the period, while the North Fork increases to a peak in 1978 and then declines noticeably. The Middle Noyo has an early peak in 1957 associated with railroad-related mass wasting, then declines, but increases again in 1996. The South Fork has a slight declining trend over time. These relationships are depicted graphically in Figure 29.

## TABLE 25

### DELIVERED SEDIMENT FROM MASS WASTING

Percentage by Type and Period

| PERIOD YEARS | DELIVERED SEDIMENT FROM MASS WASTING | | | |
|---|---|---|---|---|
| | Harvest (tons) | Forest (tons) | Railroad (tons) | Road (tons) |
| 1933-1942 | 1.8% | 86.3% | 11.8% | 0.0% |
| 1943-1952 | 2.4% | 58.5% | 39.1% | 0.0% |
| 1953-1957 | 1.5% | 29.5% | 62.6% | 6.3% |
| 1958-1963 | 4.6% | 48.4% | 24.9% | 22.1% |
| 1964-1965 | 5.0% | 51.8% | 12.3% | 30.9% |
| 1966-1978 | 28.1% | 31.5% | 6.8% | 33.6% |
| 1979-1988 | 8.7% | 54.6% | 3.9% | 32.8% |
| 1989-1996 | 23.4% | 51.3% | 0.0% | 25.2% |
| 1997-1999 | 14.1% | 47.4% | 0.0% | 38.5% |

Table 25 summarizes delivered sediment by period and land use as a percentage of each budget period, while Table 26 compares sediment delivery from mass wasting by period and type, and also provides the overall sediment delivery by period in tons/mi$^2$/yr. Estimated sediment delivery by period has ranged from 46 tons/mi$^2$/yr to 514 tons/mi$^2$/yr. The early budget periods are a minimum due to lack of coverage by the air photographs in the North Fork PW and northern portions of the Headwaters PW as well as northern portions of the Middle Noyo PW.

The trends of mass wasting by associated land use are quite clear: a decline in the percentage of forest, compared to an increase in the role of roads and harvest. Railroad-related mass wasting peaked in 50’s and early 60’s and has declined to zero in the last ten years. Figure 30 clearly depicts these time trends.

Figure 31 tracks the sediment delivery rate of mass wasting in terms of a watershed wide yield in tons/mi$^2$/yr. There is a clear peak associated with the 1964 flood, and a sharp decline in mass wasting sediment delivery in recent times. It could be inferred that improved management practices post 1974 change in the forest practice rules has dramatically reduced the amount of mass wasting in this watershed, despite a sequence of wet years from 1993-1999. The overall sediment yield from mass wasting for the period of 1933-1999, is estimated at 168 tons/mi$^2$/yr.

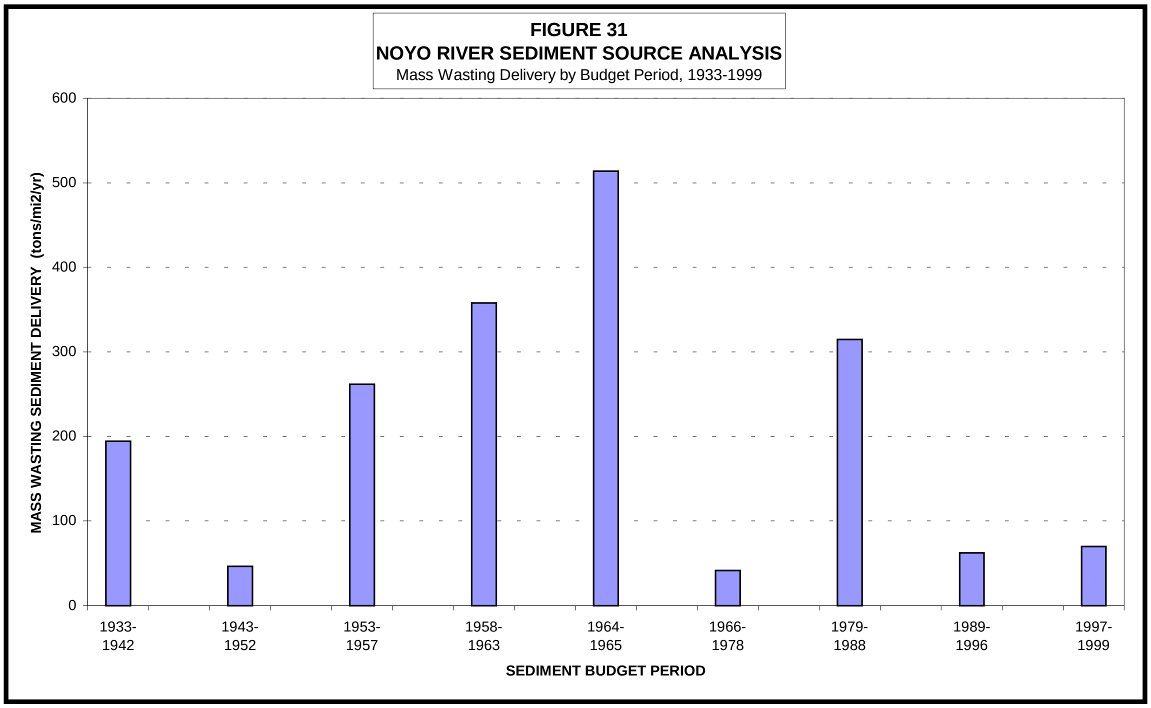


**FIGURE 31**
**NOYO RIVER SEDIMENT SOURCE ANALYSIS**
Mass Wasting Delivery by Budget Period, 1933-1999

## Limitations of Mass Wasting Analysis

The mass wasting analysis presented here is considered to underestimate the role of mass wasting in sediment for several reasons: (1) lack of data regarding small slides which were smaller than the resolution of the aerial photographs used; (2) the continuing sediment delivery from old slides was ignored, due to lack of data supporting any chronic contributions; (3) the subsequent reactivation of healed slides, although noted in our database, was ignored again due to lack of information on potential slide thickness; and (4) assumption that all slides delivered at a rate of 50%, when inner gorge slides probably deliver at greater rates.

Comparison to other mass wasting rates developed in other north coast California watersheds with similar geology also indicate that these rates are likely somewhat underestimated. Recent work within the watershed provides the best basis for comparison. MRC (1999), in their Level 2 Watershed Analysis, estimated rates of mass wasting for their holdings in the Noyo River watershed at between 67-611 tons/mi$^2$/yr for a 40-year period between 1958 and

1998. These results were averages which included much higher rates for the pre-1978 period reflecting differing forest practice rules. The 1978-1998 rates were from 47-310 tons/mi$^2$/yr, which end up being fairly similar to the results of this study. Studies underway in the Jackson State Demonstration Forest (JDSF) in support of their HCP/SYP Watershed Assessment indicate a rate of delivered sediment to stream channels of 265 tons/mi$^2$/yr.

Numerous other studies from north coastal California have developed mass wasting yields of between 192 tons/mi$^2$/yr (OCEI, 1997) for portions of the Garcia River watershed to 566 tons/mi$^2$/yr in the Navarro River watershed (Entrix et al., 1998), to 2400 tons/mi$^2$/yr in Redwood Creek (Madej et al., unpublished). Revisions to the Garcia River rates based on new information developed in a Level 2 Watershed Assessment by LP, increased the rate to 462 tons/mi$^2$/yr (PWA, 1997).

## SURFACE EROSION

Accelerated surface erosion from land management activities is well recognized. Erosion from road surfaces is a persistent source of sediment in logged basins due to the large network of dirt roads associated with harvest activities. Numerous studies have documented the role of road construction in increased sediment yields (Reid and Dunne 1984, Rice et al. 1979). The surface erosion section of the source analysis includes 2 primary components: (1) road surface erosion; and (2) hillslope erosion from skid roads and harvest areas. Given the constraints of the project such that no field work was possible, the standard procedure emphasizing road evaluation and inventory was not possible. Indirect methods were employed involving development of road and harvest history from aerial photographs, querying of GIS database, and selection of factors for computation of rates.

### Road Surface Erosion

#### Road History

According to the GIS road coverage developed by CDF from various sources including the USGS topographic maps and submitted timber harvest plans, there are currently 754 miles of roads in the Noyo Watershed, which indicates a basin wide road density of 6.67 mi/mi$^2$. Table 27 shows the existing road network distributed by Planning Watershed and sub-watershed. The highest road density in the basin is in the Lower South Fork Noyo, with a density of 10.04 mi/mi$^2$, followed closely by the Little North Fork Noyo at 9.97 mi/mi$^2$. The 10 classes contained proposed roads (64 mi) as well as abandoned roads (only 1.8 miles). These 10 classes were combined into 4 categories for simplicity: highway, paved, rocked, and dirt. Not surprisingly, seasonal (dirt) roads were 83.7% of the total, followed by rocked road at 13.2%, paved at 1.9%, and highway at 1.2%. The paved and highway road types were only a significant component in the South Fork Noyo and Lower Noyo Planning Watersheds with

a combined 6.5% and 18.3% respectively. The Middle Noyo Planning Watershed has the highest road density (8.22 mi/mi$^2$) of the 5 planning watersheds (Figures 32 and 33).

FIGURE 32
EXISTING ROAD NETWORK BY SUB-WATERSHED

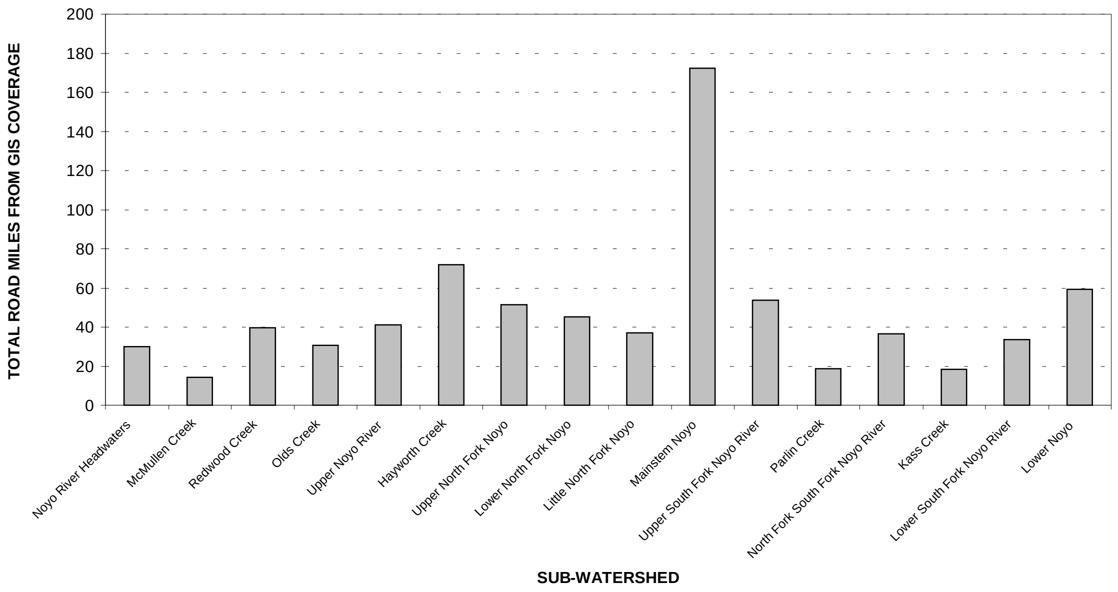


FIGURE 33
EXISTING ROAD DENSITY BY SUB-WATERSHED

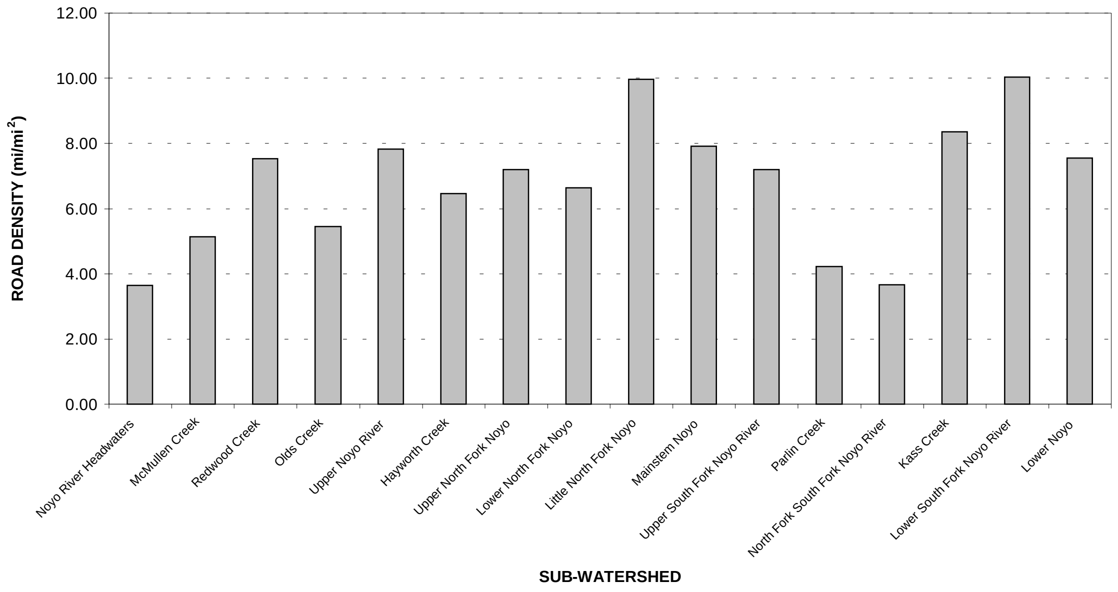


Table 28 presents the results of our mapping of the road network over time on the sequential aerial photographs, defining the miles of roads added by period. It should be noted that mapping of roads from aerial photographs with a scale of 1:20,000 or 1:24,000 and

significant forest canopy is not an easy task. We focussed on main roads and haul roads, and either missed or ignored smaller roads in some years, resulting in larger construction totals for the 1999 period, as these numbers were obtained by subtraction of the cumulative total by years through 1985 from the existing GIS total. This also presumes that roads proposed on the THP's were constructed. Also, just as for landslides, the aerial photos available did not cover the entire basin in 1942 (very little North Fork or Middle Noyo north of the mainstem), 1952 (very little except South Fork, although enlarged 1952 photos show few roads), and 1957 (was almost entire basin, except far northern end of North Fork), however, any roads not observed in these early years were probably picked up in the 1957 or 1965 photos. The road construction history is depicted in Figure 23, which contains enlargements of each planning watershed with the roads mapped by photo year.

Table 29 converts the observed road mileage by year into cumulative road miles by period to allow for road surface erosion calculations. Figure 34 graphically presents both the incremental road miles constructed and cumulative total for the entire watershed.

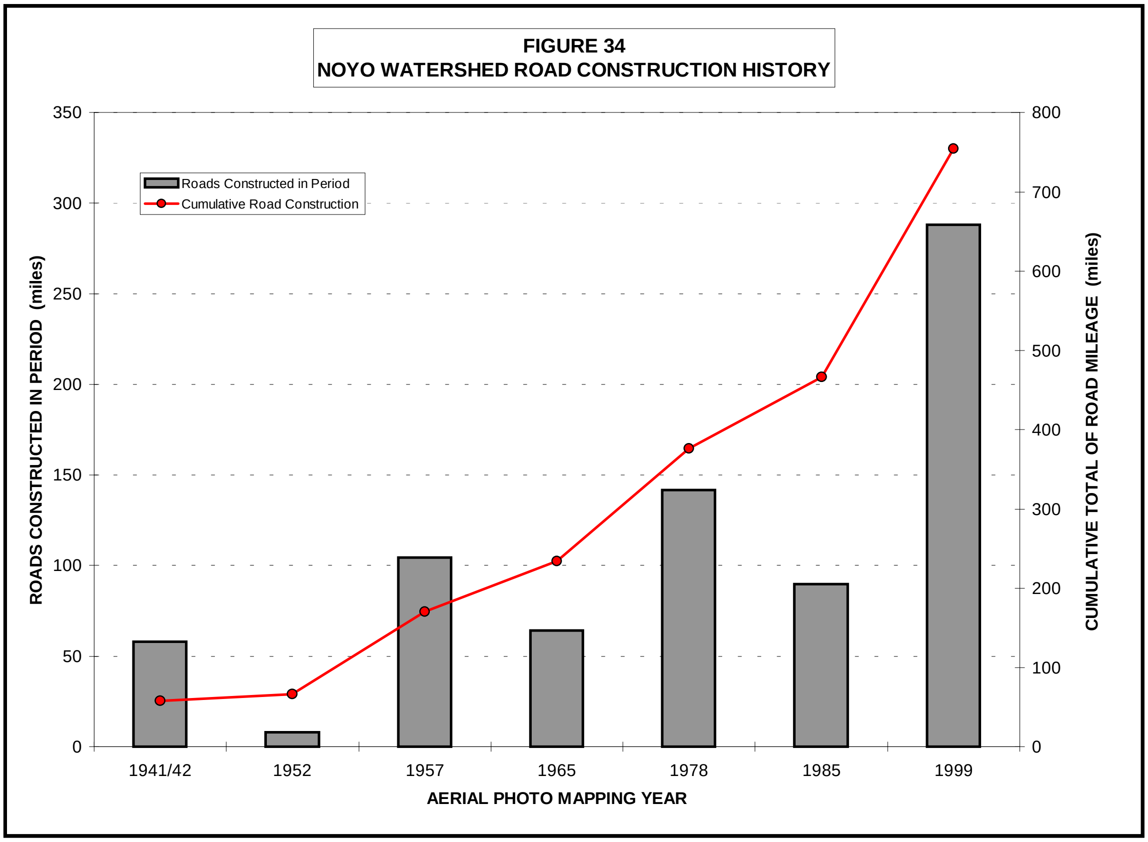


FIGURE 34
NOYO WATERSHED ROAD CONSTRUCTION HISTORY

The method used to estimate sediment production from roads is based on characterization of road use (application of a use function) and then calculation of road sediment production by such use (application of a yield function). Any other method would require detailed information on road characteristics and use that can only be developed through a detailed road inventory. This procedure was developed by Reid (1981) based on studies of industrial timber roads and associated use and sediment production in the Clearwater basin. A similar

application of this method was recently undertaken on the Navarro River watershed. The total road mileage in a given sub-watershed is stratified into use categories by application of a "use function" which computes the road miles of four use categories (high, moderate, low, none) based on fixed percentages (high use -5%, moderate use – 5%, low use – 40%, and no use – 50%). These percentages are based on the patterns of log-truck usage observed by Reid (1981), slightly modified to round the percentages (high from 6% to 5%, low from 39% to 40%). The next step involves application of the sediment production rates for each use class. Reid (1981) found that sediment production rates for each use class decline by approximately an order of magnitude (i.e. 800 tons/mi for high, 80 tons/mi for moderate, 8 tons/mi for low, and 0.8 tons/mi for no use). The product of each use class by the applicable sediment rate gives annual sediment yield by class. The classes are then summed to obtain sub-watershed production from roads. This procedure was followed for all years with road mileage data. There was one significant and one minor modification to this computation process: (1) to account for improved road practices in recent years, overall factors of 0.8 and 0.6 were applied to the total computed sediment yield by sub-watershed for the 1985 and 1998 periods, respectively; and (2) road sediment production in the Lower Noyo planning watershed was adjusted by a factor of 0.5 to account for the much higher percentage of paved roads, and the lower slope for most of the basin. Table 30 shows the results of this method for existing road conditions (1998). Table 31 summarizes the average road sediment production from the entire watershed by period and Figure 35 displays those results.

**TABLE 31**

| YEAR | ROAD SEDIMENT PRODUCTION (tons/mi$^2$/yr) |
|---|---|
| 1942 | 24.3 |
| 1952 | 27.7 |
| 1957 | 71.7 |
| 1965 | 98.7 |
| 1978 | 158.4 |
| 1985 | 157.0 |
| 1998 | 183.1 |

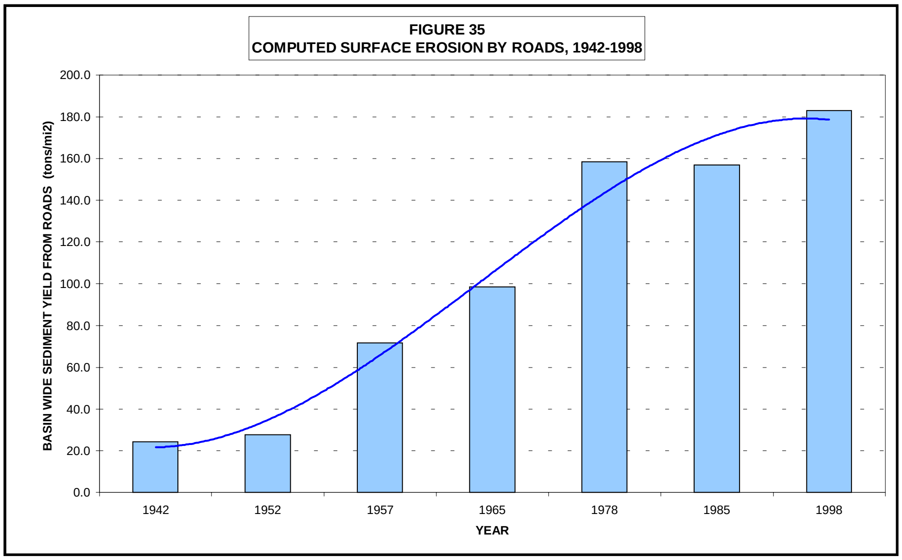


FIGURE 35
COMPUTED SURFACE EROSION BY ROADS, 1942-1998

The analysis indicates that sediment production from roads has increased significantly over the study period, obviously tracking cumulative road construction. Providing the assumptions regarding improved road construction and maintenance practices are correct, the rate of increase has slowed considerably, though the amount of road construction in the past 20 years has still led to small increases in the overall load. Existing conditions are estimated to produce an overall average yield of 183 tons/mi$^2$/yr, which is estimated to be an almost 8-fold increase over 1942 rates.

## Hillslope Erosion (Skid Roads)

There is considerable variation in estimates in the role of skid roads in sediment production and delivery to stream channels. Since skid roads are generally not linked as directly to stream channels as roads typically are, drainage practices (proper installation of water bars) are of primary importance in determining whether significant sediment production and delivery will occur. Properly drained skid roads will revegetate within 5 years (Cafferata/Stillwater Sciences, pers. comm. 1999), leading to relatively minor and short-lived sediment production. In contrast, roads produce sediment every year, even without large storm events. On the other hand, recent research (Ramos 1995, unpublished, cited by Cafferata/Stillwater Sciences, pers. comm. 1999) in nearby Juan Creek, indicates that skid roads in intensively harvested areas may produce as much sediment as roads. As a result of these site specific characteristics that control sediment generation, extensive direct field observations would be the only way to obtain reliable information on the role of skid roads.

Evaluation of sediment production and delivery from skid trails has also been undertaken in this study using indirect methods. In this case, harvest areas were identified on the historic aerial photographs and given a high, medium, or low rating regarding the density of skid roads. The area of the different types was computed by GIS methods for each sub-watershed. Table 32 summarizes the harvest area by photo date, while Figure 36 graphically depicts the variation in harvest through time. Harvest rates in the modern period increased at a steady rate between 1942 and 1988, and then jumped dramatically in the 1987-1996 period.

TABLE 32

**SUMMARY OF TIMBER HARVEST BY STUDY PERIOD**

| YEAR | TIMBER HARVEST (acres) |
|---|---|
| 1942 | 366 |
| 1957 | 3136 |
| 1965 | 6684 |
| 1978 | 7952 |
| 1988 | 11887 |
| 1996 | 28498 |
| 1999 | 4791 |

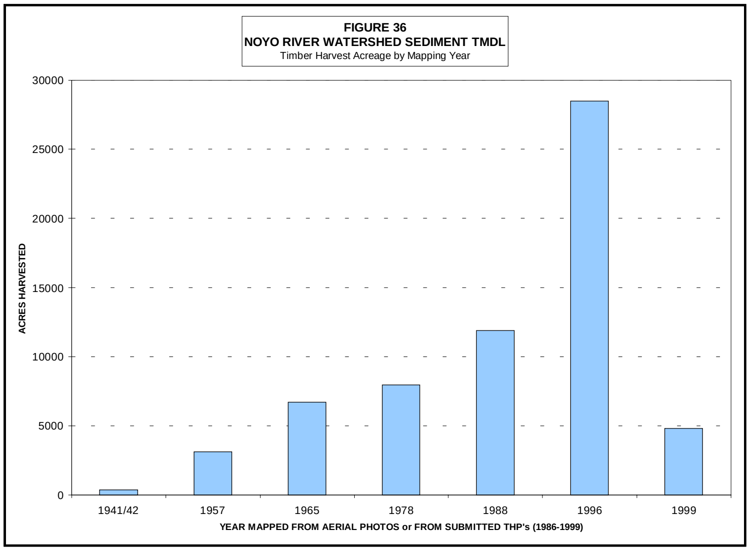


**FIGURE 36**
**NOYO RIVER WATERSHED SEDIMENT TMDL**
Timber Harvest Acreage by Mapping Year

Most of these areas had been cut in the 1800s, and by shortly after the turn of the century, most of the accessible old growth redwood had been cut. Difficult to reach areas might not have been cut until 1910-1930. Harvest of second growth began in small amounts in the 40s and in significantly increasing amounts since the mid-1950s.

Table 33 provides the detailed harvest areas by sub-watershed for the various sediment analysis periods. The total harvest in the watershed for the 34 year period from 1957 to 1999

(period with generally complete photo coverage) was 63314 acres or 87.5 % of the total watershed area. In actuality, a number of areas have been harvested several times. Figure 24a-e shows the various harvest areas by year overlaid on the GIS Planning Watershed base maps. For the 1988 and 1996 budget periods, harvest areas were not mapped, but rather computed from the GIS database based on annual THP's submitted to CDF. The annual values were simply summed for the period of interest. Table 34 shows the annual harvest acreage for 1986-1998 based on submitted THP's. The areas are broken down by planning watershed and sub-watershed for use in calculating various parameters based on the area of harvest within each sub-watershed. The table also contains the % of each sub-watershed or planning watershed harvested in the period. Figure 37 shows the annual harvest for the entire watershed along with the cumulative acreage for the period.

**FIGURE 37**
**NOYO RIVER SEDIMENT TMDL**
Acreage of Submitted THP, 1986-1999, with Cumulative Acreage

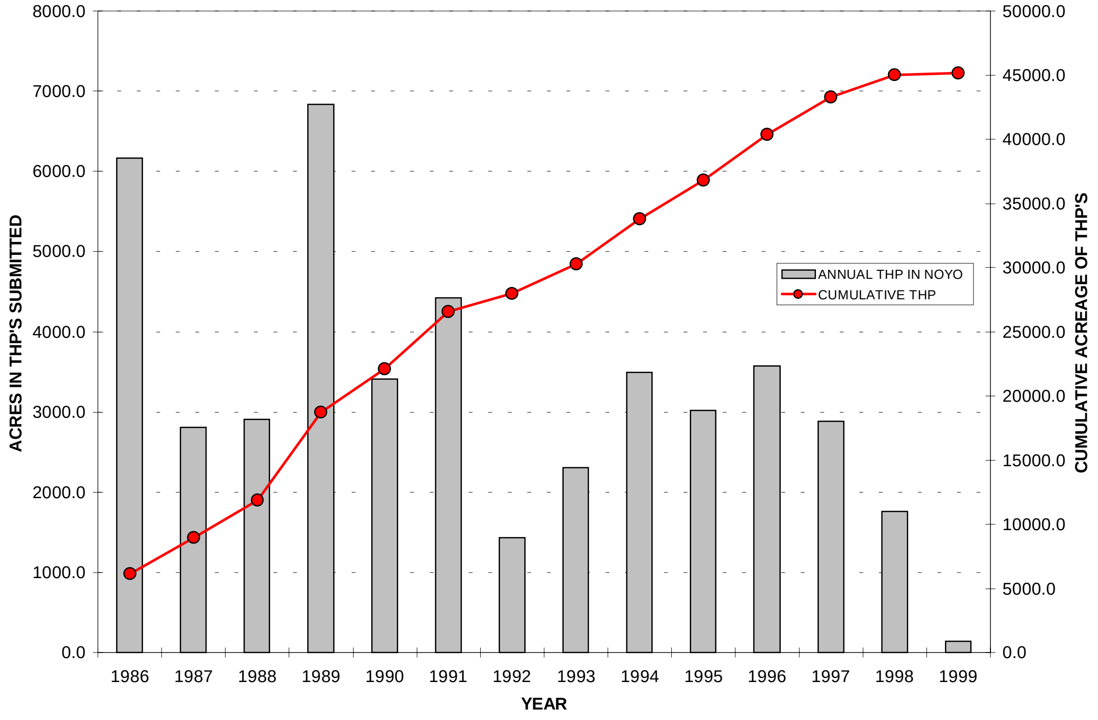
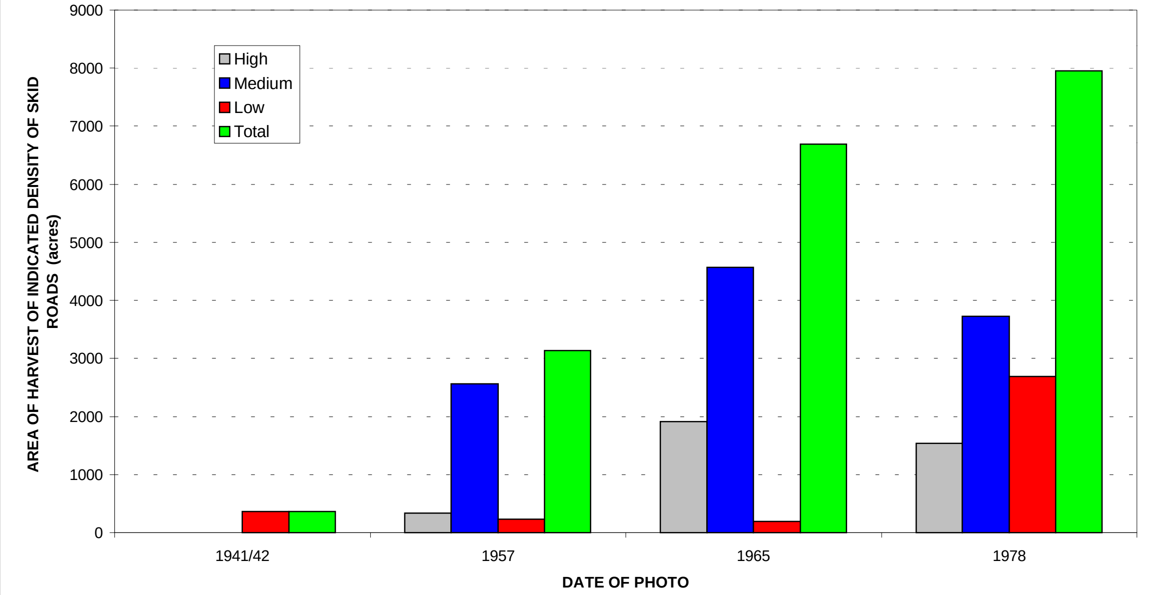


Table 35 presents the area of various density skid roads in harvest areas based on the mapping from aerial photography using the 1942, 1957, 1965, and 1978 photo sets. The 1942 photos only covered the South Fork Noyo Planning Watershed, and only a small amount of recent harvest was visible. The total harvest area increased sharply between 1957 and 1965 for an average harvest rate of 835 acres/yr. The total harvest acreage increased to 7952 acres in 1978, but the annual rate of harvest declined to 612 acres/yr due to the longer period. Figure 38 shows the distribution of the three classes and the total area of harvest by photo year. It is apparent that the harvest area with high and medium densities of skid roads peaked in 1965, declining somewhat by 1978, when more acreage was harvested using low density skid roads.

FIGURE 38
NOYO RIVER WATERSHED SEDIMENT SOURCE ANALYSIS
Summary of Harvest Areas by Year with Given Density of Skid Roads



To compute hillslope surface erosion rates from the harvest acreage data requires selection of a yield function for each class and selection of a time function to characterize the change in sediment yield over time, as revegetation occurs and the site stabilizes. Without the benefit of field work, we were limited to the use of previously developed yield and time functions (MRC 1999). Based on a review of the literature, MRC selected 450 tons/mi$^2$/yr as a mean rate for skid road sediment production. They applied these rates over a 12 year period, with 2 years at the initial high rate, and 10 years thereafter at a reduced, or base rate (C. Surfleet, pers. comm. 1999). To extrapolate their method to the various density classes that we mapped, we used 600 tons/mi$^2$/yr for high densities, 450 tons/mi$^2$/yr for medium densities, and 300 tons/mi$^2$/yr for low densities. We also used a 12 year period, with the first two years at the rates listed above, and then reduced to 25% of that rate for the remaining 10 years. For years 1988, 1996, and 1999, the rate was adjusted downward to an average of 100 tons/yr to reflect the combination of improved management practices post-1974 FPR, and the advent of cable skyline yarding. Based on review of preliminary revegetation data on skid roads observed in the JDSF (Cafferata/Stillwater Sciences, pers. comm. 1999), this time function may somewhat underestimate sediment production. They found an average value of about 75% revegetation cover within 5 years after use ended.

Table 36 shows the computed surface erosion from skid roads in harvest units for the various sediment budget periods. The results suggest a peak in surface erosion coinciding with high harvest rates pre-FPR during the period of 1958-1978. Declines in surface erosion totals in recent years would reflect changes in harvest techniques, drainage practices on skid roads, and reduced harvest rates in general.

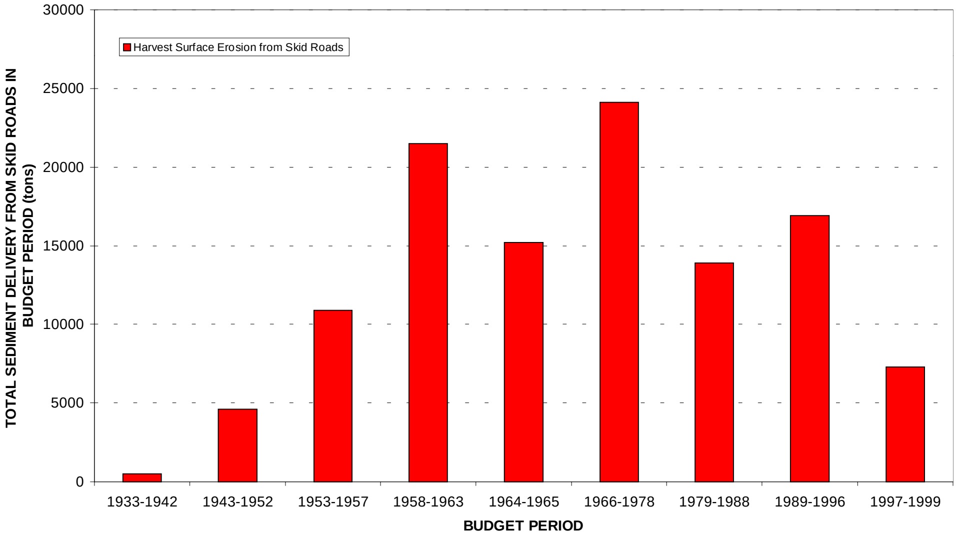
## TABLE 36

### SUMMARY OF HARVEST SURFACE EROSION ESTIMATES

| Period | Harvest Surface Erosion from Skid Roads |
|---|---|
| 1933-1942 | 500 |
| 1943-1952 | 4600 |
| 1953-1957 | 10900 |
| 1958-1963 | 21500 |
| 1964-1965 | 15200 |
| 1966-1978 | 24100 |
| 1979-1988 | 13900 |
| 1989-1996 | 16900 |
| 1997-1999 | 7300 |

Figure 39 displays the total estimated harvest area surface erosion by period. Estimated amounts peaked between 1958 and 1978 as a function of the number of acres of medium and high density skid roads in harvest areas. Levels are still elevated over the 1940s and early 1950s simply due to the annual number of acres being harvested, even with improved tecnhiques.

FIGURE 39
NOYO RIVER SEDIMENT SOURCE ANALYSIS
Total Sediment Delivery by Period from Harvest Area Surface Erosion



## Fluvial Erosion

Numerous studies have indicated that fluvial erosion, whether from road diversions and washouts, road drainage-induced gullies, natural gullies, bank erosion and small streamside landslides can be a major component of the watershed sediment sources. Unfortunately, these components require considerably field investigations, mostly as part of the comprehensive road inventory process, in order to develop any quantitative information. As a result, we were limited to application of a selected fluvial erosion rate simply on a per mi$^2$ basis. We extrapolated preliminary data from MRC (C. Surfleet, pers. comm. 1999) of 0.023 tons/ft/yr for small streamside landsliding along stream channels mapped as MWMU1, and 0.002 tons/ft/yr for MWMU2, and bank erosion values from USDA (1972) to arrive at a value of 200 tons/mi$^2$/yr. This value was then multiplied by the drainage area and the period length in years to obtain the period fluvial erosion total.

We factored in our observed bank erosion rates from a 4.5 mile float of the mainstem Noyo between Olds Creek and the North Fork Noyo confluence. Virtually no bank erosion was found (on the order of 10-20 tons per stream mile per year), due to the incised nature of the channel into very stable deposits with numerous bedrock outcrops and dense vegetation. There was no evidence that this reach of the river had changed appreciably in many years.

## Changes in Alluvial Storage

Due to the entrenched nature of most of the Noyo mainstem, and much of its major tributaries, fluvial-induced change in alluvial storage is considered a relatively minor term in the sediment budget. There are few locations with even modest active alluvial features, except for a reach of the Noyo mainstem between Redwood Creek and upstream of McMullen Creek. This was the only reach where even small amounts of active bank erosion was visible during our fly-over reconnaissance. A more significant effect on alluvial storage occurred from extensive instream large woody debris (LWD) removal program conducted in the 1950s-1980s. During that time period, most of the Noyo tributaries had extensive amounts of LWD removed out of the floodplain. MRC (1999) documented the removal of some 4,661,000 board feet of LWD were removed between 1959 and 1964. Additional removal programs have been identified in the South Fork Noyo at later dates (Cafferata/Stillwater Sciences, pers. comm. 1999).

Lacking quantitative data, only qualitative descriptions of changes in alluvial storage are possible. In comparing the enlarged 1952 and 1996 aerial photographs (Figure 20), it is apparent that the number and size of active gravel bars along the mainstem Noyo below the confluence of the North Fork has substantially declined. It appears that much of this change is related to vegetation encroachment and stabilization of what were seen as open, active gravel bars in 1952. This change may not, therefore, involve appreciable change in volumes of stored sediment and instead reflect a change in residence time. Even so, the amount of alluvial storage in the Noyo watershed is small. Non-alluvial channel boundaries in the steep valleys combined with the entrenched channel geometry and bank stabilization by dense streamside forest cover greatly reduces the opportunity for sediment storage. It appears that much of the sediment that reaches these entrenched channels is flushed through the system into low gradient areas of the lower river in relatively short periods of time.

Data from the USGS gage developed in previous sections, suggests that up to several feet of aggradation may have occurred in the lower reaches of the river over the past 40 years. However, since the USGS gage is considered to be at the downstream end of the study area, any channel aggradation in this area would be downstream of the outflow term in the budget, and thus of no importance in the budget itself.

## SEDIMENT BUDGET

### Overview

Typically, a sediment budget quantifies sediment sources (inputs), by each erosional process, as well as changes in the amount of channel stored sediment, and sediment outputs as measured at a gaging station over a designated time frame or several time periods (Reid and Dunne, 1996). Quantifying sediment sources involves determining the volume of sediment delivered to stream channels by the variety of erosional processes operating within the watershed. For the Noyo River watershed, these can be divided into four primary processes or sediment delivery mechanisms: 1) mass movement (landslides), 2) fluvial erosion (gullies, road and skid trail crossing failures, and stream bank erosion), 3) surface erosion (rills and sheetwash) and 4) land management activities which directly place sediment in stream channels.

The first three processes can deliver sediment to stream channels both naturally and as a result of land use activities. Sediment production by mass movement processes occurs commonly during large, infrequent storm events, whereas fluvial and surface erosional processes can occur during storms that in virtually every water year or as a result of large storms. Direct sedimentation into stream channels by heavy equipment involved with road/railroad construction and timber harvest was commonplace in the Noyo River watershed prior to 1975. After passage of the California Forest Practices Act in 1975, the practice of yarding logs down stream channels which resulted in direct sedimentation into stream channels has been prohibited. However, many areas are still experiencing elevated sediment yields as a legacy of the former practices. The residence time of such introduced sediments is highly variable, but on the order of years to decades.

Changes in the amount of sediment stored in stream channels is usually measured in the field by analyzing surveyed channel cross sections or by field surveys which estimate the amount of past channel filling and subsequent downcutting that has occurred. Analyzing changes in channel stored sediment can answer questions such as how much of what type of sediment is transported and where is it deposited, how does introduced sediment interact with sediment which was already in storage in the channel, and how does the transport affect overall stream morphology (Reid and Dunne, 1996).

Quantifying sediment outputs requires determining annual transport rates of bedload and suspended sediment past a given point in the watershed, which is typically measured at a gaging station. Few sites have sufficient data to establish a meaningful record, although use of regional values can provide reconnaissance-level information.

Reid and Dunne (1996) discuss the seven steps involved in the construction of a reconnaissance-level sediment budget. Such a budget uses rapid measurements and estimates of physical processes based on air photo analysis, field evidence and published information and should use the following process:

1. Careful definition of the problem,
2. Collection of background information and data,
3. Subdivision of the watershed an project area into uniform or representative sub-areas,
4. Analysis and interpretation of aerial photography,
5. Field inventory, analysis, and calibration,
6. Data analysis,
7. Checking and verification of results through regional comparisons

In this analysis, step 5 was unable to be undertaken due to time and budgetary constraints, and data from other studies which incorporated field inventory and verification was used.

The development of a sediment budget for a large watershed area, such as the Noyo River watershed, can best be accomplished by stratifying the area into sub-watershed units of similar characteristics. A sediment budget is developed for each sub-watershed and these values are combined to provide an estimate of the overall sediment budget for the watershed. In this reconnaissance-level sediment budget, the Noyo watershed is considered to be quite homogeneous in terms of soil, bedrock, vegetation, and topography. Land use is the major variable.

In developing a sediment budget, the magnitude of each major hillslope and channel erosion process operating in the watershed should be evaluated through a combination of (1) field sampling and verification, (2) analysis of aerial photography, (3) GIS-based computer analysis, and (4) an analysis of existing data and literature, generally from regional sources. We accomplished steps 2-4 in developing this preliminary sediment budget for the Noyo River watershed.

## Inputs

Inputs, by process, time period, and sub-watershed were compiled by combining information from several different sources. The source analysis section of this document describes the development of the various input sources. Table 37 summarizes the sediment budget inputs, computes percentages by process, and computes unit rates for the entire watershed.

## TABLE 37

### SEDIMENT BUDGET INPUTS

| | | TOTAL ESTIMATE (tons) | PROCESS % OF TOTAL (%) | UNIT RATE (67-year Period) (tons/mi2/yr) |
|---|---|---|---|---|
| MASS WASTING | | 1276800 | 28.6% | 169 |
| BACKGROUND | | 567900 | 12.7% | 75 |
| SURFACE EROSION | SKID ROADS | 114900 | 2.6% | 15 |
| | ROADS | 836100 | 18.7% | 110 |
| FLUVIAL EROSION | BANK EROSION | 1515000 | 33.9% | 200 |
| CHANGE IN STORAGE | | 146,000 | 3.3% | 19 |
| TOTAL INPUTS | | 4465000 | 99.8% | 590 |

Of these inputs, previous analyses in the source analysis indicate that about 50% of the mass wasting is management-related under current conditions (or about 14% of the input total). Combining management-related mass wasting with surface erosion which is almost entirely management-related, indicates that about 35% of the sediment inputs for which estimates were developed are management-related. Lack of data on several potentially important contributing processes (gullying from stream diversions due to road and skid roads, for example) probably keeps this percentage somewhat low. Various other studies have arrived at similar percentages for management-related sediment generation, including the Garcia River with an estimated 40-60% management-related (PWA 1997).

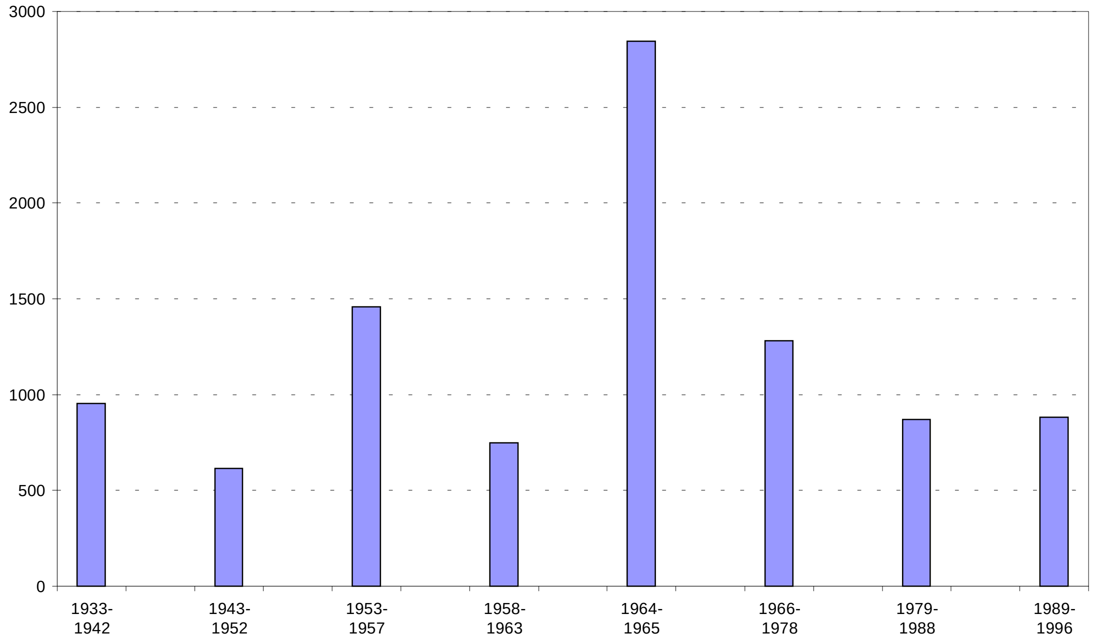
### Outputs

The output side of the sediment budget has been developed based on regional sediment transport equations, which were developed in this study through evaluation of other basins in the general area of roughly similar characteristics. We expect use of this regional equation process to provide data only slightly better than an order of magnitude estimate. Available evidence suggests that our sediment yields may be somewhat high, but well within the likely range.

Computed sediment yields for the 67-year study period average 979 tons/mi$^2$/yr. In general, yields of this magnitude would be considered low in northern California. Data from Caspar Creek, with very similar characteristics, fall in the same range, with adjusted estimates of 793 tons/mi$^2$/yr (Cafferata/Stillwater Sciences, pers. comm. 1999). It is quite likely that regional sediment transport somewhat overestimates the sediment transport characteristics of the Noyo watershed.

Figure 40 shows the computed sediment yield in tons/mi$^2$/yr for the various budget periods. The short 2-year period that contains the Dec 1964 flood appears to have the highest rate, but that is due to the 1974 yield being averaged into a longer budget period. Figure 15 is a more accurate representation of annual loads.

**FIGURE 40**
**NOYO RIVER SEDIMENT SOURCE ANALYSIS**
Computed Sediment Yield of Noyo River for Sediment Budget Periods



## Sediment Budget

The preliminary sediment budget for the Noyo River watershed between 1933 and 1999 is shown in Table 38. Explanations for the various input and output elements have been developed in previous sections of this document. Estimated inputs total 4,465,000 tons over the 67-year period, while computed outflow is 7,411,000 tons. Evidence suggests that the sediment outflow is over estimated somewhat by the regional approach due to a number of factors which lead to lower sediment yields in the Noyo watershed. At the same time, various input sources are likely to be underestimated, both because of information available and the limitations of the analytic techniques.

## CONCLUSIONS

This study has developed estimates of sediment production and delivery by process for the entire Noyo River watershed using exclusively indirect techniques, involving aerial photo and GIS-based analyses. Sources were stratified by time period, land use type, and dominant process, in order to assess management and non-management related sediment sources and their relative contributions. Significant changes through time and by land use were found in the mass wasting category. Improvements in management practices since 1974 have resulted in decreases in road-related mass wasting and harvest related surface erosion. Significant construction of new roads has led to increasing sediment yields from road surface erosion, despite improved practices. Overall, management-related sediment delivery is estimated at 35% of the total.

## REPORT LIMITATIONS

This report is a reconnaissance-level sediment source analysis and preliminary sediment budget. The constraints under which this work was completed have been well described. Graham Matthews provides his findings, conclusions, and recommendations after preparing such information in a manner consistent with that level of care and skill ordinarily exercised by members of the profession practicing under similar conditions in the fields of hydrology and fluvial geomorphology. John Coyle provides his mapping products, findings, conclusions, and recommendations after preparing such information in a manner consistent with that level of care and skill ordinarily exercised by members of the profession practicing under similar conditions in the field of geology.

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# APPENDIX A
# AERIAL PHOTOGRAPHY USED

| | | |
|---|---|---|
| 1941/1942 | 1:20,000 | B/W (On file at CDR Ft. Bragg) |
| 9/28/41 | CVN 4B -59 to -61 | |
| 1/6/41 | CVN 5B -114 to -116 | |
| 10/6/41 | CVN 5B -129 to -130 | |
| 2/8/41 | CVN 13B -54 to 55 | |
| 2/8/42 | CVN 13B -75 to -77 | |
| 2/9/42 | CVN 15B -185 to -186 | |
| 2/10/42 | CVN 14B -111 to -115 | |
| 2/11/42 | CVN 14B -184 to -186 | |
| 2/15/42 | CVN 15B -101 to -102 | |
| 8/25/42 | CVN 18B -96 to -101 | |
| 9/14/42 | CVN 19B -35 to -36 | |
| 8/15/52 | 1:20,000 | B/W (On file at CDF Ft. Bragg) |
| | CVN 5K -36 to -37 | |
| | CVN 6K -77 to -82 | |
| | CVN 6K -172 to -176 | |
| 7/4/57 | 1:52,000 | B/W (On file at CDF Ft. Bragg) |
| | GS-VQV 2-16 to -18 | |
| | GS-VQV 3-45 to -50 | |
| 8/5/63 | 1:30,000 | B/W (On file w/G. Matthews) |
| | Men 1-166 to -173 | |
| | Men 4-31 to -38 | |
| | Men 4-1-2 to -109 | |
| | Men 4-174 to -182 | |
| | Men 4-213 to -220 | |
| | Men 6-34 to -37 | |
| | Men 6-44 to -52 | |
| | Men 6-126 to -130 | |
| | Men 8-34 to -39 | |
| | Men 8-106 to -114 | |
| | Men 8-184 to -191 | |
| 7/21/65 | 1:20,000 | B/W (On file CDF Ft. Bragg) |
| | AJN 5-FF 39-46 | |
| | AJN 5-FF 66-70 | |
| | AJN 5-FF 106-109 | |
| | AJN 5 FF 121-122 | |
| | AJN 6 FF 32-39 | |

| | | |
|---|---|---|
| | AJN 6FF 55-63<br>AJN 6FF 133-139<br>AJN 6FF 151-157<br>AJN 6FF 234-242<br>AJN 7FF 48-56<br>AJN 7FF 70-75<br>AJN 10FF 220-225 | |
| 1978<br>(Month/day unknown) | 1:24,000<br>02607-20 to 26<br>02607-020A to 026A<br>02607-72 to 74<br>02607-106 to 112<br>02607-107A to 112A<br>02607-363 to 366<br>02607-363A to 366A | B/W (On file at NRCS Ukiah) |
| 8/19/88 | 1:31,680<br>WAC-88CA 15-148 to -155<br>WAC-88CA 15-207 to -215<br>WAC-88CA 27-50 to -58<br>WAC-88CA 27-86 to -95<br>WAC-88CA 27-123 to -130<br>WAC-88CA 27-153 to -161<br>WAC-88CA 27-180 to –283 | B/W (On file at CDF Santa Rosa) |
| 3/26/96 | 1:12,000<br>WAC Mendocino - 96 1-10 to 1-18<br>WAC Mendocino - 96 1-81 to 1-93<br>WAC Mendocino - 96 1-148 to 1-159<br>WAC Mendocino - 96 1-205 to 1-212<br>WAC Mendocino - 96 2-1 to 2-9<br>WAC Mendocino - 96 2-117 to 2-121<br>WAC Mendocino - 96 2-185 to 2-190<br>WAC Mendocino - 96 6-170 to 6-176<br>WAC Mendocino - 96 9-224 to 9-226<br>WAC Mendocino - 96 12-34 to 12-44<br>WAC Mendocino - 96 12-96 to 12-101<br>WAC Mendocino - 96 12-148 to 12-152<br>WAC Mendocino - 96 12-197 to 12-200<br>WAC Mendocino - 96 12-246 to 12-257<br>WAC Mendocino - 96 13-41 to 13-52<br>WAC Mendocino - 96 13-111 to 13-123<br>WAC Mendocino - 96 13-108 to 13-201 | B/W (On file at CDF Santa Rosa) |

| | |
|---|---|
| | WAC Mendocino - 96 13-273 to 13-283<br>WAC Mendocino - 96 14-54 to 14-65 |
| 4/25/99 | WAC |