SEDIMENT SOURCE ANALYSIS AND PRELIMINARY SEDIMENT BUDGET FOR THE TEN MILE RIVER, MENDOCINO COUNTY, CA

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SEDIMENT SOURCE ANALYSIS AND PRELIMINARY SEDIMENT BUDGET FOR THE TEN MILE RIVER

INTRODUCTION

The Ten Mile River watershed (Figure 1) has been listed as a sediment impaired waterbody in California's 1995 CWA 303(d) list, 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, primarily salmonid habitat.

In October 1999, Graham Matthews & Associates was requested by the U.S. Environmental Protection Agency (EPA) and Tetra Tech, Inc., to prepare a sediment source analysis and preliminary sediment budget for the Ten Mile River watershed. The purpose of the sediment budget is to assist the EPA in establishing a Total Maximum Daily Load (TMDL) for sediment in the Ten Mile River watershed.

The Ten Mile River watershed has been divided into four planning areas with a total of 20 sub-watersheds for general planning purposes for this TMDL (Figure 1). For each of these sub-watersheds, past sediment production and delivery, by erosional process, will be determined.

The purpose of this report is to compile, summarize, and analyze sediment production data for the Ten Mile 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 Ten Mile River watershed. This study is primarily based on analysis of aerial photographs and analysis of GIS coverages, with limited field reconnaissance and verification surveys.

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. Georgia-Pacific West, Inc., the major property owner in the watershed at that time, completed a sustained yield plan for the Fort Bragg Timberlands in 1997, which provides considerable background information on the watershed and its resources. Georgia-Pacific West, Inc. and its successor in ownership, Campbell Timberland Management, Inc., have been monitoring instream conditions since 1993.

A similar sediment source analysis for the next significant watershed to the south, the Noyo River, was completed by Graham Matthews & Associates in May 1999. Hydrology and sediment transport relationships developed in that report have been modified for use in the

Ten Mile River watershed as data from the Noyo Watershed provides the best available information, due to similar hydrologic conditions.

STUDY AREA

Sub-Watershed Areas

The Ten Mile River watershed has been subdivided into 4 planning watersheds (PW): North Fork Ten Mile, Middle Fork Ten Mile, South Fork Ten Mile, and the Mainstem Ten Mile. The three main forks are quite similar in drainage area, ranging from 33.45 square miles (mi^2) to 38.97 mi^2, while the Lower Ten Mile is much smaller, with an area of only 8.83 mi^2. The obvious and logical separation of the three main forks left the lower portions of the Mainstem Ten Mile in a separate planning watershed. The four planning watersheds have been divided again into a total of 20 Sub-Watersheds (SW). This sub-division does not entirely match the CALWAA divisions and instead reflects analysis units that allow more separation of significant tributaries from the main channel watersheds of the three forks. Table 1 presents the Planning Watersheds and Sub-Watersheds along with their drainage areas. These areas are shown graphically in Figure 1.

Watershed Characteristics and Overview

The Ten Mile River drains a 119.6 mi^2 watershed located in the northern California Coast Range in Mendocino County (Figures 1 and 2), entering the Pacific Ocean about 10 miles north of Fort Bragg, the nearest significant population center. There is little human occupation in the watershed, with only scattered ranches and residences. Elevations within the Ten Mile River watershed range from sea level at the basin outlet to 3240 feet at Strong Peak. The basin is remote, rugged, and entirely privately owned, with Campbell Timberland Management, Inc. owning about 85% of the watershed.

Annual precipitation averages 38 inches near Fort Bragg, south of the watershed, to over 50 inches at Willits, to the southeast of the watershed, although precipitation maps indicate that annual rainfall is in excess of 70 inches at the higher elevations in the northern and eastern portions of the watershed. 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. Only limited stream gaging records exist for the Ten Mile River watershed, having been collected by the US Geological Survey from 1965 to 1973 on the Middle Fork only (Figure 1).

History

The history of the Ten Mile River watershed is dominated by timber harvest. The following information is summarized from the history section of the Georgia-Pacific West, Inc. SYP

(Jones & Stokes Associates 1997). Logging began in the lower basin about 1870 using hand methods and teams of oxen. The logs were hauled to the mill in Fort Bragg. The first railroad in the area connecting the South Fork with Fort Bragg was developed in the 1910s. The South Fork was the major log supply to the Fort Bragg mill between about 1920 and 1940. Railroads were extended into the Middle and North Forks by the early 1920s and railroad logging was the primary method of removing timber through the 1930s, when it was generally replaced with tractor logging and most of the railroad grades were converted to roads.

Methods of hauling lumber evolved over time from utilizing jackscrews, horses, bull teams, logging inclines, Dolbeer donkey, railroads, to trucking on haul and skid roads: each of these methods had varying levels of impact on the watershed. There is no information indicating that splash dams were used in the Ten Mile River watershed as they were in the Noyo and Big River watersheds to the south.

Since 1940, tractor yarding and the construction of roads, skid trails and landings were the primary types of logging practices. Major portions of the watershed were harvested using tractor logging between the mid 1940s and mid 1960s. Until the Forest Practices Act was passed in 1973, logging practices were unregulated. This Act required road construction and timber harvesting practices intended to protect aquatic habitat and watershed resources. During the past twenty years the use of cable yarding on steeper slopes has increased substantially, and tractor logging is generally restricted to gentler slopes. 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. Relative to the 1940-1960 period, harvest levels were apparently far lower between the late 1960s and the mid 1980s, because the forest was fairly well depleted and was left to regenerate. Current harvest levels have increased with the maturity of second growth forests, and most of the watershed is managed using about a 60-year average rotation age.

Ownership

Detailed ownership maps have not been compiled for the entire watershed in a readily accessible, GIS-based format. However, Georgia-Pacific Corporation owns about 85% of the watershed, with 4 smaller industrial timberland owners, a few ranches, and a handful of private residences making up the balance.

Topography

The topographic setting of the Ten-Mile River watershed is quite diverse. The terrain varies from flat estuarine environments to rugged mountainous topography with high relief (Figures 2 and 3).

The western end of the watershed is distinguished by a wide, drowned and filled estuary flanked by slopes of relatively low relief. However, this topography quickly gives way to higher relief terrain that borders a modestly wide (typically about 1000 feet on the mainstem) alluvial valley floor that extends from about 3 to 6 miles upstream along the South Fork and Mainstem respectively.

Most of the watershed, aside from the northeast grasslands area, is characterized by narrow drainages. The drainages are in turn bordered by steep to moderately steep slopes and narrow to gentle summits and ridgelines up to the headwaters of the Middle Fork and South Fork. Similar conditions exist along the North Fork except in the headwaters area where the topography is subdued and of generally low to moderate relief. Inner gorge topography locally characterizes portions of the North, Middle, and South Forks of Ten Mile River up to the their middle reaches. Fluvial cut terraces are also present locally, except along the Middle Fork, where they are generally not present.

The Ten Mile Mainstem 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 subdued with low relief. Locally, slopes in the eastern portion of the headwaters area are 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 provided by the California Department of Forestry and Fire Protection, Coast-Cascade GIS Department (CDF). Figure 4 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 Ten Mile and the other planning watersheds are readily apparent, with 18% of the land in that planning area having slopes of less than 10%, compared to 5-10% for the other three planning watersheds. The estuary sub-watershed has 44% of its area in slopes less than 10%. In all the Planning Watersheds, typically 60-80% of the area of each falls with the 15%-35% slope class range, reflecting the moderately rugged terrain characterizing much of basin. All of the basins also have less than 3% of their area at slopes greater than 40%. There are really no sub-watersheds that stand out in terms of having unusually steep slopes.

The low gradient valley floors of the Mainstem Ten Mile, Lower North Fork, Upper North Fork, Upper Middle Fork, and Lower and Middle South Fork stand out visually in Figure 4, with the blue color coding of the GIS slope classes. 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 the watershed is represented by the bedrock and overlying surficial deposits. The bedrock geology is dominated by rocks of the Franciscan Complex. These bedrock materials are in turn overlain by a veneer of a variety of surficial deposits. These surficial deposits include soil and colluvium and locally landslide debris, alluvium, estuarine sediments, and minor occurrences of marine terrace deposits, beach sand, and dune sand. These earth materials are briefly described below, using definitions derived from Blake and others, (1985), Jayko and others (1989), Jennings (1977), Kelly (1983a, b and 1984), and Kilbourne, 1982a,b and 1983a,b).

Bedrock

Rocks of the Franciscan Complex underlie the entire watershed. Within the watershed, the Franciscan occurs as two distinct bedrock units: the relatively coherent (stable) Tertiary to Cretaceous age Coastal Belt terrane and the relatively incoherent (easily eroded) Tertiary to Jurassic age Central Belt terrane.

Coastal Belt Terrane

Coastal Belt rocks underlie the entire watershed except for the northeastern area of the headwaters of the North Fork. Though they have not been recognized, minor occurrences of Mesozoic volcanic rocks could be present.

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 northeastern area in the headwaters of the North Fork. 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.

Surficial Deposits

Locally overlying the bedrock are a variety of surficial earth materials deposits that include beach sand, marine terrace deposits, dune sands, estuary deposits, landslide debris, alluvium, and soil and colluvium.

Beach Sand, Marine Terrace, and Sand Dune Deposits

These deposits occur in a very small area at the mouth of Ten Mile River. It is likely that the beach sand and sand dune deposits interfinger along the back of the beach.

The beach sands are composed of fine to coarse sand with local pebble and cobble gravel lenses. The terrace deposits are represented by poorly consolidated sand and minor amounts of gravel. The overlying dune deposits are composed of fine- to medium-grained sand.

Estuary Deposits

Estuary deposits occur in the very lower reaches of Ten Mile River. They are found on both sides of the river from near the mouth to about two to three miles up river. They likely interfinger with alluvial deposits in the lower reaches.

Estuary deposits are composed of unconsolidated muds, silts, and fine-grained sands. They are locally rich in organic debris.

Landslide debris

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

The slides are composed of a mixture of soil, colluvium, and bedrock debris carried down-slope as either intact masses or heterogeneous flows or avalanches. Locally overlying the bedrock is a variety of surficial deposits that include marine terrace deposits, dune sands, landslide debris, and alluvium.

Alluvium

Alluvium deposits occur along the watercourses of the watershed. They are found in the channels of the river and tributary creeks. The deposits vary in size from thin veneers too small to map in the upper reaches of the watershed to thick, wide accumulations found along and beneath the lower reaches of the mainstem. Alluvial deposits interfinger with the estuarine deposits and soil/colluvial deposits mantling the lowest portions of the hillslopes.

Alluvial deposits are composed of a variety of poorly consolidated to loose sediments. These sediments vary from coarse gravel on down in size to interbedded sand, silt, and clay.

Soil and Colluvium

Except for very steep to precipitous slopes, soil and colluvial deposits mantle the hillsides. They also occur on ridge tops and valley bottoms. Soils are derived from the mechanical and chemical weathering of the underlying rock or surficial deposits. The materials that make up colluvial deposits are derived by the same weathering processes that make up soils. However, colluvial deposits are characterized by being accumulations of these weathering products that have moved down slope by raindrop impact, sheetwash, and other gravity-driven processes, other than mass wasting (landsliding), to collect at the lower reaches and bottoms of hillsides. Generally deposits of soil materials thicker than about 3 to 4 feet thick are judged to be colluvial deposits.

Soil and colluvial deposits are composed of a heterogeneous and poorly consolidated mixture of rock debris, sand, silt, and clay. These materials can be present in varying amounts along with organic debris.

Time Period of Analysis

The time period for the sediment source analysis includes a 67-year period extending from 1933 to 1999. The period was dictated by available aerial photography coverage in the years 1942, 1952, 1965, 1978, 1988, 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. Therefore, we assigned 1933 as the beginning of the sediment budget period. Sediment source data have been developed for all six of these time intervals. These intervals capture different periods of sediment-producing events, including both storm history periods (1938, 1956, 1965, 1974, 1993 water years contained notable high flows) and changes in timber harvest practices. Thus, a combination of changing harvest and road building techniques, together 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 Georgia-Pacific Fort Bragg Timberlands Sustained Yield Plan (Jones & Stokes Associates, Inc. 1997), and TMDL and/or sediment source analyses for similar basins such as the Noyo (Matthews & Associates 1999), the Navarro (Entrix et al. 1998) and the Garcia Rivers (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. The limited streamflow records available were obtained from USGS publications and on CD-ROM, while other historic periodic streamflow records were obtained directly from the USGS Sacramento office. A correlation process was used to extend the short record available on the Middle Fork Ten Mile using the longer record from the Noyo River. Synthetic streamflow records were developed for the North, Middle, and South Forks independently. These data were analyzed for magnitude, frequency, and duration.

Geomorphology

Gaging station records, consisting of complete 9-207 forms for the period 1965-1973 for the Middle Fork Ten Mile Gaging Station, were obtained from the USGS Sacramento office. 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 1870-1940. Field reconnaissance visits to limited portions of the lower watershed were made to assess changes in channel stored sediment and bank erosion. The cross section at the cableway of the former USGS gaging station was resurveyed to evaluate bed elevation changes since 1973.

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, CDMG landslide mapping methods, and nomenclature put forth by Cruden and Varnes (1998). An Abrams 2 and 4 power Model CB-1 stereoscope was used to review aerial photographs.

We tried to map the air photos sequentially from oldest to youngest to facilitate consistency and efficiency in the analysis. However, several years were reviewed out of order due to time constraints in photo availability. The order of review was, from initial set of photos to the last set reviewed: 1941/42, 1965, 1978, 1952, 1988 and 1999. The majority of coverage varied from a scale of 1:20,000 to 1:24, 000; although the scale of the 1988 coverage was about 1:31,680. The earliest coverage available (1941/42) was confined primarily to the western half of the watershed; however, the northwestern corner area of the watershed was also missing. These photos are available at National Archives, but could not be received in the time constraints of this study. Other years had complete coverage of the watershed.

Landslides observed on the aerial photographs were plotted on acetate overlays placed on 7½ -minute topographic maps. They were classified as 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 and 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 failures 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 slide occurred along a road, skid road or railroad, on a cutslope or fillslope. Other aspects also noted included if a slide occurred in a forested area or a partial cut or clear-cut. An attempt was also made to relate occurrence to historic harvest activity. A judgment call was made in revegetating areas as to whether a slide occurred in an area harvested in the past 20 years or if the historic harvest appeared to be more than 20 years old.

A three-tier system of sediment delivery (<33%, 34%-66%, >66% delivery) was assigned to estimate the amount of sediment delivered to a watercourse. Slope morphology and slope position were also recorded, including if the slide occurred in an inner gorge. Certainty of identification was noted as either definite, probable, or questionable.

Large, deep-seated landslides were identified as either active, dormant, or relic. Those considered dormant are judged to be relatively stable but could be partially or wholly reactivated under current climatic environmental conditions. Relic means it was judged unlikely to become reactivated under current climatic/environmental conditions. Very few deep-seated landslides were identified as active.

Mass Wasting Field Reconnaissance

In mid June 2000 a limited field reconnaissance of portions of the watershed was conducted. The purpose was to calibrate some aspects of the aerial photograph landslide interpretation to site conditions. Of special concern were slides observed along the main roads parallel to Mainstem, and North, Middle, and South Forks of Ten Mile River. Other slides on slopes that could be reached in a timely manner were observed, along with areas of subdued topography in the headwaters areas of the North Fork. Over two dozen sites or slides were observed.

The reconnaissance confirmed our assumptions from the aerial photos that in the case of fill failures mapped along roads (and former railroads) that were immediately adjacent to stream channels, sediment delivery was essentially 100%. However, cutslope failures had a different history of delivery. Based on discussions with a long-time Georgia-Pacific employee, it was determined that prior to the mid 1970s most cutslope features along the roads and railroads parallel to the stream channels were usually cleared up by pushing or side-casting the slide debris over the edge and into the adjacent watercourse. This resulted in a very high delivery of sediment from cutslope failures to the stream. Since the mid 1970s, cutslope failures have either been spread out along the roadway or are end-hauled to an appropriate disposal site. Thus, current practices for cutslope failure result in very little, if any, delivery of debris from cutslope failures to watercourses, although delivery was very high prior to the mid-1970s.

The thickness of failures and slides visited in the field was also estimated. For the most part, thicknesses of about 3 to 4 feet appeared to characterize many of the road failures visited. Non-road related slides appeared somewhat more variable, possibly due in part to our selecting larger failures to visit. The areas of initiation were thicker, often up to 6 feet, but the average over the entire area from which sediment was derived appeared to be less than 3 feet, with an average of again about 3 feet.

Two of the more than two-dozen features visited in the field turned out not to be slides. These had been mapped as slides based on interpretation of aerial photographs. In one case, the features that led to an initial interpretation as a slide appeared upon field observation to be related to the layout of skid roads. The other feature that turned out not to be a slide appeared to be due to tonal contrast on the aerial photographs related to grassy vegetation. These slides were removed from the database. It is likely that a small percentage of other features mapped are not actually slides, but our sample size was too small to simply use as a percentage for adjusting other slides. Instead, the database was not adjusted and we acknowledge that our estimates are probably conservative as a result, although complete exclusion of the questionable category (of which several probably were slides) may balance this out.

Two narrow cable harvest units were visited in the Middle Fork drainage. These units had been recently cut (probably in the last 2 years). They were observed for evidence of erosion and sediment delivery. Gullying and rilling was not observed within the units, likely because of the protection provided by the abundant slash left behind. In addition, at the bottom of the units, no sediment was observed moving from the harvest unit into the buffer zone and thus into the adjacent watercourse. Finally, though we could not get directly on the ground in the melange terrane (Central Belt of the Franciscan Formation) in the headwaters of the North Fork due to private property constraints, we did observe this area from a modest distance. Overall, this terrane is inherently unstable, with higher than usual soil creep rates. However, our observations suggest that it is not all, at the same time, so mobile that the entire area is undergoing higher than usual rates of delivery due to accelerated soil creep, compared with the other areas of the watershed. Our observations suggest that perhaps only one-quarter to one-half of the hillside areas in the melange terrain are experiencing sediment delivery rates that are higher than background soil creep rates for the melange terrane or elsewhere in the watershed.

Surface Erosion

Surface erosion from roads and skid roads was estimated by developing a road construction history and a harvest history. Prior to 1988, the history was developed primarily from interpretation of aerial photography. From 1988 to present, road and harvest history was obtained from CDF GIS coverage's which had been developed by directly inputting information provided as part of submitted Timber Harvest Plans (THPs). Data from the pre-1988 mapping efforts were shown on overlays and simply 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. Furthermore, their importance could be misinterpreted because of 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 low, moderate, or high. Data from the overlays was digitized into the GIS database for subsequent mapping and analysis.

HYDROLOGY

Precipitation

Precipitation in the Ten Mile 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 Willits to the southeast of the watershed. The isohyetal map for the watershed (Figure 5) indicates that annual precipitation likely exceeds 70 inches at the highest elevations in the far northern portion of the watershed near Strong Peak.

There are relatively few precipitation stations near the basin and none located within the watershed. The longest is that of Willits, with a period of record of 1879-1998. Figures 6 and 7 show the annual precipitation at Willits and Fort Bragg, respectively and the computed cumulative departure, while Table 3 presents the annual totals. At the Willits 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 is 38.74 inches.

It is interesting to note that the relationship between precipitation at Fort Bragg and at Willits is highly variable. In some of the drier years, Fort Bragg actually recorded more precipitation than Willits, while in wetter years, Willits averages about 150% of the Fort Bragg amounts. 1998 was a highly anomalous year, as more rain fell at the coast than at Willits, 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. Furthermore, much of the watershed averages higher precipitation than either of the two nearby stations (Figure 5), and the accuracy of the available isohyetal maps is unknown. Computation of mean annual precipitation for the three main forks of the Ten Mile River was undertaken based on areas within each average precipitation band in Figure 5, weighted for the relative proportion of the area compared to the entire area of the tributary. The South Fork has a mean annual precipitation of 48.3 inches, while the Middle Fork is 53.8, and the North Fork is 57.4. Thus, we see that the North Fork is about 20% wetter on average than the South Fork, which has implications for both total runoff and peak stormflows.

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 Willits provides an excellent basis for evaluating wet and dry periods in the last 125 years. At Willits, 1881-1889 was a dry period, followed by a long, very wet period extending from 1890 through 1909, just prior to the period when the railroad was being built up to the South Fork Ten Mile 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 multi-year drought in the 120-year record occurred from 1987-1992, when 6 consecutive years barely averaged over 50% of the long-term mean. Six years stand out from the perspective of total annual precipitation and thus 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 Willits and Fort Bragg stations. The maximum 1-day precipitation at Willits 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 Willits 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 Willits (#31). In fact, in the top ten for each station, there is only one match, 1938. Other large years based on intensity records at Willits 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 Willits) is not the driving force in Ten Mile River peak flows.

Streamflow

Streamflow data collected in the basin by the USGS are limited to a single gage: #11468600, located about 0.9 miles upstream on the Middle Fork from its confluence with the North Fork. The gage measures streamflow from 32.9 of the 119.6 mi^2 of the watershed. The period of record for the USGS gage extends from 9/1/64 to 10/25/73, when the gage was discontinued. In addition, some instantaneous summer low-flow discharge measurements were made on all three forks by the USGS between 1951 and 1954, but these data have proven to be of little value. Due to the relatively short stream flow record on the Middle Fork and the unavailability of continuous streamflow records for the North and South Forks, it was necessary to develop synthetic streamflow records for the watershed. Once synthetic data were developed, they were used to perform the necessary hydrologic and sediment transport analysis. The Ten Mile River, like most of coastal California, is a flashy basin, one that rises very quickly in response to precipitation inputs, and drops back to base flow levels nearly as quickly.

Peak Discharge

Middle Fork

The largest recorded peak discharge for the Middle Fork Ten Mile River occurred in December 1964, when the river crested at 5,670 cubic feet per second (cfs), according to USGS records, as shown in Figure 8. Synthetic peak discharge for the Middle Fork Ten Mile River was developed using peak correlation analysis. Peak discharges were correlated between the Noyo River Watershed and the Ten Mile River Watershed in order to extend the record. Peak discharges were forecast back to 1952 and forward to 1998. Table 5 lists the annual peaks for the 10- year historic record as well as synthetic data, ranks them and computes recurrence intervals based on the Weibull formula. Other significant storms occurred in December 1951(WY1952), December 1955 (WY1956), December 1965 (WY1966), January 1974 (WY1974) and January 1993 (WY1993). 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.

North and South Forks

No peak flow analysis was performed on the North or South Forks of the Ten Mile River Watershed since data for correlation were not available. Peaks flows would have been higher in the North Fork and lower in the South Fork based on average precipitation differences and likely orographic effects during large storms.

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.

Middle Fork

The results of a the log-Pearson Type III analysis for the combined historic and synthetic 1952-1998 period of record is shown in Figure 10 and summarized in Table 6 below. This analysis indicates that the 1964 (WY 1965) flood would be between a 60-70-year event, while flows similar to December 1955 would be about a 25-year event. The 2-year event is about 2000 cfs.

North and South Forks

Due to the lack of streamflow records on the North and South Forks of the Ten Mile River, flood frequency was accomplished through modeling. A regional model for flood magnitude estimates in North Coastal California was used (Waananen and Crippen 1977). This method produces flood frequency estimates based upon drainage area, mean annual precipitation and an altitude index. The results are shown in Figure 11.

Historic Floods

Although the Ten Mile River has a relatively short period of streamflow records, the dates of significant floods years are generally known, due to regional data. Known large flood events in the region or the watershed have occurred in Water Years 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, 1965 and 1974 events (not necessarily in that order by magnitude).

Table 7 presents information that may be used to assess the magnitude of storm events and their geomorphic significance, and includes ranked data for annual streamflow, peak discharge, a magnitude-duration product, annual precipitation, and 1-day precipitation intensity. The top 20 events in each type are included. During the period of available historic and synthetic streamflow records, 1965 and 1974 stand out well above other years, not only because of their high peak flows, but also their duration. In contrast to the Noyo watershed data where the 1974 event was far more significant (Matthews & Associates 1999), in the Ten Mile River watershed the December 1964 event appears to have been somewhat larger, and the most significant in the past 50 years.

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. Due to the extremely short period of record for the Middle Fork Ten Mile River (10 years) and the lack of stream flow records on the North and South Forks, modeling was employed to extend or create a mean daily discharge record for each fork. Mean daily discharge measurements were scaled from the Noyo Watershed using watershed area and mean annual precipitation as the scaling factors. Figure 11 shows a typical annual mean daily streamflow hydrograph for the Middle Fork Ten Mile River. High flows during storms are of very short duration, one to two days at most generally, and flows rapidly return to typical winter base flow 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 a combination of historic and mean daily discharge for the USGS gage on the Middle Fork Ten Mile River as well as for the synthetic records developed for the ungaged North and South Forks of Ten Mile River. The results are presented in Figure 12. The analysis indicates that the Middle Fork only exceeds 173 cfs 10% of the time, or 36 days per year on average, while the North and South Forks only exceed 209 cfs and 119 cfs 10% of the time respectively. 50% of the time flows are below 13 cfs, 11 cfs, and 7.3 cfs in the North, Middle, and South Forks respectively. Flows exceed 1045 cfs, 854 cfs, and 596 cfs in the North, Middle, and South Forks respectively only 1% of the time, or 3.6 days per year on average. Relatively little sediment transport probably occurs below 400 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

Middle Fork

Annual runoff has been measured in the Middle Fork Ten Mile River watershed with the USGS streamflow gage and computed from the synthetic data generated for the watershed. The mean annual runoff for the 1952-1997 period is 50,300 acre-feet. The annual runoff data are shown in Table 8, 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.

North and South Forks

Annual runoff was not computed for the North or South Forks.

SEDIMENT TRANSPORT

Sediment Transport for the Ten Mile River (Estimate of Suspended Sediment and Bedload Discharge)

No sediment transport data exist for the Ten Mile River watershed. It was originally intended for a modest amount of sediment transport data collection to occur in the Ten Mile watershed during the winter of WY2000; however, access could not be obtained from Campbell Timberlands, Inc. in a timely enough fashion to allow sampling in WY2000. The purpose of such data collection was to allow calibration and verification of regional datasets with site-specific sediment transport data. Instead, we were limited to application of regional sediment rating curves to approximate sediment transport for the Ten Mile River. Regional relationships had been developed for the Noyo River (Matthews & Associates 1999) and the same relationships were utilized to estimate suspended sediment and bedload discharge in the Ten Mile River. 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 Ten Mile Watershed is 119.6 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 9 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.

In addition, unpublished data collected by Matthews & Associates during the winter of Water Year 2000 in the Big and Albion River watersheds are also shown. These data represent suspended sediment discharge from basins considerably closer to the Ten Mile watershed than the other basins included in the regional analysis. Although these points are within the general scatter of the regional curve data, they mostly plot below the regression line, possibly indicating lower suspended sediment transport rates in coastal areas. However, there were not sufficient data to justify using this relationship exclusively, and the regional equation was still used.

The regional suspended sediment rating curve (Figure 14) 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 15), stream discharge explained 64% of the variation in bedload discharge. The bedload regression model (r^2=0.64, 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 14 and 15. 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.

TABLE 9

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
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)

Analysis and Results

To provide an estimate of average suspended sediment and bedload discharge for the Ten Mile River, the regression equations from the regional rating curves (Figures 14 and 15) where applied to the entire discharge record (water year 1952-97) for the synthetic data developed for the three forks of the Ten Mile River. The flow data for the three forks were combined and an adjustment (5% was added) was made for contributions of flow and therefore sediment transport for the lower 8.8 mi^2 of the watershed in the Lower Ten Mile Planning Watershed. The Lower Ten Mile Planning Watershed is 7.4% of the drainage area, but has lower slopes, flat alluvial valley floors, and lower precipitation than other parts of the watershed, so the 7.4% was arbitrarily reduced to 5%. Using this streamflow dataset for the entire watershed, the daily sediment rates were then summed to provide an estimate of annual sediment discharge for each water year. Table 11 summarizes the estimated suspended sediment and bedload discharge rates, and sediment yields for the three forks of the Ten Mile River and for the entire watershed. The annual yields for the three forks and entire watershed are shown in Figure 16. Based on this approach, the average annual sediment discharge rate for the Ten Mile River is approximately 135,700 tons/yr, which corresponds to a watershed sediment yield of 1,135 tons/mi^2/year for the 1952-1997 period of synthetic streamflow records.

The transport rates predicted for the individual forks are probably underestimated, in part because the regional relationships were developed for basins with larger drainage areas. Typically, unit rates for both flow and sediment transport increase with a decrease in drainage area. Since sediment transport is approximated by a power function with an exponent of greater than 2, combining the flows from the three forks also results in a far greater rate of transport. Given that the regional equations were developed from watersheds with drainage areas from 44-248 mi^2, it is most appropriate to use the combined flows and the regional equations, rather than attempting to compute sediment loads for each Planning Watershed. The local sediment transport relationships for the three forks would probably have greater unit values than that for the watershed as a whole.

Total sediment load for the three forks computed separately results in a combined load of 2,050,000 tons in the 1952-1997 period, while the combined flows, when computed with the same equations, transports 6,245,700 tons. This difference highlights the role of the power function when applied to streamflow records. We used the larger amount as the most appropriate based on basin size, as described in the previous paragraph.

Of this total amount (6,245,700 tons) for the combined flow, 11.6% was computed to have been transported in 1974 alone, while the top 10 sediment transport years (1974, 1965, 1956, 1993, 1995, 1983, 1952, 1986, 1953, 1958) accounted for 57.8% of the total sediment load.

TABLE 10

Summary of estimated annual suspended sediment discharge, bedload discharge, sediment discharge, and sediment yield for the Ten Mile River for Water Year 1952-97 using the regional regression equations.

Value	SSD (ton/yr)	BD (ton/yr)	SD (ton/yr)	SY (ton/mi2/yr)
Average value (WY 1952-97)	114,100	21,600	135,700	1135
Minimum value (WY 1977)	122	43	165	1.37
Maximum value (WY 1965)	632,000	96,700	728,500	6091

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

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 flood 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 monitoring projects have had a long-term perspective, and often one of the only sources of historic channel information is that which 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 (Smelser and Schmidt 1998). 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 analysis provides values for the thalweg (or minimum streambed elevation) and mean streambed elevation (MBE) over the period of record of the gage. Trend analysis for these variables may provide considerable insight into channel changes.

The MBE 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 may 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. 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.

Mean Streambed Elevation for Middle Fork Ten Mile River near Fort Bragg:

For the Ten Mile River, the relatively short period of record at the Middle Fork gage provides only limited data for a trend analysis. The 9-207 records from the USGS gage were analyzed for Mean Bed Elevation (MBE) and the results are shown in Figure 17, which includes data from all of the wading discharge measurements in the USGS records, a total of 86 streamflow measurements from 1964 through 1973. A 5-period moving average is also plotted to assist in data interpretation. The data indicate that the mean streambed elevation was essentially stable during this period, with no large changes despite the occurrence of the large December 1964 flood in the period. Frequently, large sediment pulses occur during and after significant storm events as large volumes of sediment delivered into the stream system during the peak of the storm are flushed through the channel network.

Cross Section Changes at Former USGS Cableway

We also relocated and resurveyed the channel cross section at the site of the cableway at the former USGS gage site on the Middle Fork Ten Mile River, and compared this to surveys and cableway streamflow measurement data to evaluate changes. We were able to find the large concrete anchor block at the cableway used as the right bank anchor and the large redwood tree that had been used for the left bank anchor. Cross sections at four dates are shown in Figure 18, one in the summer of 1964, one from a discharge measurement taken at the cableway during the December 1964 storm hydrograph, one in 1970, and the 2000 resurvey. The data indicate that a small amount of aggradation occurred between 1964 and 1970, presumably the result of the December 1964 and the January 1966 high flows, and that significant downcutting has occurred in the 30 years between 1970 and 2000. The obvious interpretation is that significant amounts of sediment that were stored in the channel due to upstream harvest activities in the 1940s to late 1970s eventually flushed through the system.

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 long 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 Ten Mile River watershed 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 than most of the watersheds further north. In general, areas on the Mendocino Coast experienced lesser effects from the December 1964 flood, compared to the unprecedented flood magnitudes experienced in the Eel and Klamath basins (Waananen et. al. 1971). However, the changes observed since 1970 do appear to correlate well with changes in sediment production and delivery over time, as discussed in the next section.

Channel Planform Changes

Alluvial valley reaches in river systems often act as "response reaches", since they are areas of temporary (in a time frame of 10s to 100s of years) sediment storage that adjust their storage and the stream channel geometry traversing these areas in response to changes in streamflow and sediment discharge. Thus, episodic events such as large floods may cause the channel location to change, sometimes dramatically, in response to the energy of these high flows which exceeds the resisting forces of the stream channel banks and riparian vegetation. In a similar manner, large influxes of sediment, whether derived in a single large storm event or delivered chronically over a longer time period, may cause changes in channel form in these response reaches as sediment deposition locally overwhelms the capacity of the channel to transport it. Braided and rapidly laterally migrating channels are often the result.

Lower Ten Mile Mainstem Planform Analysis, 1942-1999

We examined sequential aerial photographs for a portion of the lower mainstem Ten Mile River (below the Middle Fork Confluence) in 1942, 1952, 1965, and 1999. This reach is clearly alluvial, so the probability of channel change during significant flood events is high. Once the North Fork and Middle Fork join farther downstream, there is an even greater probability of channel response. Significant changes to channel geometry would be readily apparent in these areas. The aerial photos are shown in Figures 19 and 20.

In 1942, the channel was considerably wider than it is presently, with large open gravel bars evident in a number of locations. The riparian corridor was large in places, but almost non-existent in others, perhaps due to recent channel migration in the December 1937 flood. By 1952, although a few places showed an increase in riparian cover, the majority of the river corridor had noticeably less riparian vegetation. Only small changes in the channel location had occurred. Additional areas of riparian vegetation on the floodplain had been cleared by 1952, apparently for agricultural purposes. In 1965, shortly after the large December 1964 flood, even lesser amounts of riparian vegetation remained, the channel had changed locations in a few areas, and it had developed a braided form in several locations. Although these changes are indications of the passage of a significant flood event, the scale of these changes is relatively minor compared to those experienced in watersheds farther north.

Dramatic changes occurred along this reach of Lower Ten Mile River between 1965 and 1999, primarily related to the recovery of riparian vegetation. Certain bends have continued to migrate, which is not surprising given the magnitude of the 1974, 1983, and 1993 floods, but overall the channel is now bordered by a dense, continuous riparian corridor. In many areas shown, the width of the corridor is limited by agricultural operations on adjacent floodplains. The corridor is substantially wider in the upper one-third of the channel shown in Figure 20, and also in the westernmost portion of the figure, where significant floodplain areas are now densely covered by riparian species.

Lower Mainstem Channel Centerlines, 1942-1999

Figures 21 and 22 present the sequential channel centerlines for the six sets of aerial photographs (1942-1999) for a slightly longer reach of the Ten Mile River than that shown in Figures 19 and 20. This reach of the mainstem Ten Mile River extends from the confluence of the Middle Fork to the confluence of the South Fork and the start of the estuary. Figure 21 is overlain on the 1999 aerial photograph of this area, while Figure 22 is overlain on a GIS-based shaded relief map. Locations of channel migration are evident with the color-coding of the different years. Given the flood history of the past 60 years, the amount of channel migration is surprisingly small. The recovery of the riparian corridor over the past 30 years is a dramatic improvement, probably reflecting lower overall sediment delivery, recovery from past practices, and improved current management practices.

The reaches within lower portions of the major sub-watersheds show similar patterns from the 1940s to present. The potential for channel migration is considerably more limited in these tributary areas due to the confined nature of the valleys (with the exception of the South Fork). Presently, the channel is often difficult to observe on aerial photographs due to the dense riparian corridor, which has complete canopy closure in many locations.

Lower Tributary Channel Changes, 1942-1999

Figures 23-25 show comparisons between 1942 and 1999 aerial photographs in lower reaches of the North Fork, Middle Fork, and South Fork Ten Mile River, respectively. In Figure 23, harvests along the North Fork upstream and downstream of the confluence of the Little North Fork are readily apparent in the 1942 photo. A maze of skid trails have been constructed mostly along the north or west side of the river. Numerous slope failures along the path of the railroad can be seen, and there is very little riparian vegetation along much of the river. The 1942 conditions sharply contrast with those seen in the 1999 photo. The forest has regrown dramatically, and few bare areas are visible. Roads can be seen, but are much less obtrusive and appear to follow the topography better rather than running straight down slopes. The riparian corridor has become reestablished to the point that it is difficult to see the channel, and canopy coverage appears complete in most areas.

Figure 24 shows a portion of the Middle Fork between river mile 3.0 and 5.0, mostly upstream of the confluence of Bear Haven Creek, which is visible in the upper left portion of the photos. In 1942, the extent of harvesting on the Middle Fork is readily apparent, with areas of untouched old growth generally seen above river mile 4.5. Railroad access was developed to the confluence of Bear Haven Creek, and these areas were the most accessible at that time. A road had been constructed along the Middle Fork upstream of Bear Haven and numerous slope failures are evident. Again, there was little riparian vegetation present in 1942. The changes between 1942 and 1999 are similar to the North Fork with regrowth of the forest and development of a dense riparian corridor. More roads are present in 1999 than in 1942 since the eastern portion of this watershed was undisturbed in the earlier period. Several narrow clear cuts are visible, a relatively recent type of timber harvest, in the 1999 photos. Few slope failures are apparent in 1999, nor were any slope failures evident in that portion of the old growth forest in the 1942 photo.

In contrast to Figures 23 and 24, where the change between 1942 and 1999 were dramatic, there are few differences apparent in the Lower South Fork for the same period (Figure 25). The reach shown extends from river mile 1.5 to 3.2, and includes the confluence of Smith Creek, visible in the center of the photo. Harvest occurred much earlier here than in the other forks, so in places regrowth was already well underway in 1942. The Lower South Fork also has a significant amount of agricultural operations using the relatively wide floodplain. There were efforts to convert this land entirely to grazing in the late1940s and 1950s through repeated burning (Jones & Stokes 1997). These efforts were unsuccessful and the land was re-purchased by Georgia-Pacific and returned to timberlands.

The riparian corridor along the South Fork was largely intact in 1942, although bare stretches along the lower 0.5 mile of Smith Creek are evident, possibly related to agricultural operations. By 1999, riparian vegetation had developed along parts of this reach, but continuing agriculture may have prevented complete recovery. There are several possible reasons for the intact condition of the Lower South Fork riparian corridor in 1942: (1) the valley floor was sufficiently wide that the railroad did not need to encroach on the corridor directly, and (2) without steep inner gorge type slopes, large amounts of sediment did not need to be pushed directly into the river in order to construct the railroad grade. It is hypothesized that the generation of large volumes of sediment during railroad construction as seen in the North and Middle Forks, which when combined with harvesting of the corridor and the geomorphic effects of a few significant storms, could have led to the observed devastation of the riparian corridor. This was not the case in the Lower South Fork. Surprisingly, there does not appear to have been any appreciable change in position of the river channel in this area between 1942 and 1999. A few new roads can be seen in the 1999 photo, and some areas with recent harvests of second growth from the 1980s and 1990s are also apparent. A significant portion of the floodplain appears to have a tree farm growing on it in 1999.

One additional small source of information regarding channel changes is documented at the former USGS gage on the lower Middle Fork Ten Mile River. The gage was installed in 1964, along the right bank of the channel 0.9 miles upstream from the confluence with the North Fork. The gage consisted of a 48” CMP with several intakes that were described in the original gage description as being 10 feet long, indicating that the stream channel was immediately adjacent to the gage. When the gage was found in 2000, the channel had migrated towards the south away from the gage, which is now located some 45 feet from the new top of the right bank of the active channel. A new floodplain surface had been formed by deposition of sediment, and the banks and floodplain were stabilized by willow and alders up to 12” in diameter. Clearly, even in these relatively confined valleys, the channel may be quite dynamic. It may be inferred from these findings that significant amounts of sediment may have been stored along the sub-watershed channels since the 1960s, as the channels narrowed and the riparian corridor was reestablished.

SEDIMENT SOURCE ANALYSIS

This section describes the process used to evaluate possible sources of sediment within the Ten Mile River 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 Ten Mile River watershed through limited field reconnaissance, review of pertinent documents, and discussions with those involved with current studies in the basin or other nearby basins; (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 complement, modify, and/or extend the photo-based measurements, thus allowing computation of results.

Since this analysis is primarily an indirect, office-based 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 dimensions (length and width) 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).

Sources of sediment in the Ten Mile watershed include landsliding (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 landsliding and surface erosion, with limited field verification surveys of these features. Estimates of fluvial erosion were based on published values, field work completed by Georgia-Pacific Corporation, and results from similar, nearby watersheds.

Landsliding

Six sets of aerial photographs were examined in this investigation. Unfortunately, the earliest set (1941-42) did not contain coverage for much of the eastern half of the basin; thus measured values for this year represent minimum rates. Much of this eastern portion of the basin (particularly in the Middle and North Forks) still contained old growth forest in 1942 and had yet to be harvested. For areas of old growth forest covered by the available photos, very few slides seen in the dense tree cover, which we interpret to infer that few large slides had occurred. Thus, despite a lack of photos for the eastern portions of the watershed, we suspect that our estimates are probably similar to what we would have seen had complete coverage been available.

A total of 2,724 features (slides) were mapped during this study, which includes some slides mapped in different time periods due to continuing delivery, reactivation, or expansion. There were 2,373 unique landsliding features mapped and 351 judged to be delivering in more than one time period. Slides which were observed to have healed with vegetation were not counted as delivering sediment in future time periods. 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, and resulted in a database of 2,272 definite or probable unique landslide features with a total (including repeats) of 2,562 slides. The distribution of landslides by type for each period is shown in Table 12.

The second screening step involved separation of landslide features into two categories based on assessment of sediment delivery: either delivering or non-delivering. Delivering slides are those whose sediment directly enters a watercourse. Non-delivering slides are those whose sediment generation only reaches a watercourse at a rate comparable to background hillslope creep. Features mapped as non-delivering were eliminated from all future analyses. Determination of sediment delivery status is based on the judgment of the geologist performing the mapping and takes into account slide position relative to the adjacent watercourse, slope at terminus of slide or run-out area, and other factors. These two datasets (all mapped slides and delivering slides only) are shown in Figure 26 and 27 using output from the GIS digital files. After the delivery screening, 1,649 unique features remained, with a total of 2,008 including slides mapped as delivering in multiple periods. 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, since these were judged to not be delivering sediment in excess of background rates. This included many deep-seated rotational/translational slides (only 3 out of 392 were mapped as delivering sediment) throughout the watershed, and a number of very slow-moving earthflows (only 5 of 157 were mapped as delivering) identified in the eastern portion of the basin underlain by the Franciscan Melange Terrane. Of the 1,649 delivering slides, 1,320 or 80% were considered “definite” and the remaining 329 or 20% were considered “probable.”

The remaining dataset was queried by landslide type, year, number of slides and area, and the locations were separated into sub-watershed areas for evaluation at that level. Summary tables for the Planning Watersheds and each sub-watershed were prepared for use in interpreting the data and performing volume calculations.

Of the 1,649 unique slides mapped over the 57-year period (1942-1999), 1,527 or 92.6% were debris slides, 110 or 6.7% were debris flows/torrents, 5 or 0.3% were earthflows, 4 or 0.2 % were gullies, and 3 or 0.2% were Rotational/Translational slides. The 1,649 slides gives a watershed averaged rate of 13.79 delivering slides/mi^2 for the entire period. Landslide frequencies were highest in the 1965, followed by the 1952 and 1942 photo years. The number of slides in 1942 may have been higher as previously discussed, but we did not have photo coverage for the entire watershed. Not surprisingly, these periods contained several of the largest known storm events, in terms of peak discharge (Dec 1964, Dec 1955, and Dec 1937), and the Dec 1937 and Dec 1964 storms had the two highest 1-day precipitation intensities at Willits in an 88-year record. The large number of slides from the 1952 photo set seems anomalously high, given the absence of large floods in the 1942-1952 period, and must be attributed to the high level of disturbance in this period.

There is a clear trend of substantially decreasing numbers of slides since the peak number in 1965. Only 26.6% of the slides that were mapped occurred in the 1965-1978, 1979-1988, and 1989-1999 periods, combined, and only 6.1% of the slides occurred in the 1989-1999 period. Higher slide frequency appears to correlate well with known periods of relatively intense land use activity in the form of both harvest and road construction, while far fewer slides were found in recent times, when both harvest quantities had been reduced and new forest management practices were implemented.

Landslide Distribution by Sub-Watershed

Review of landslide distribution within the various planning watersheds (PW) and sub-watersheds (SW) (Table 13), shows a relatively smooth distribution of total slides for the entire period (i.e. no major outliers), ranging from 198 slides in Smith Creek to 25 slides in the Ten Mile River Estuary. The highest numbers were found in Smith Creek, Lower Middle Fork Ten Mile River, and Lower North Fork Ten Mile, with 198, 175 and 170 slides respectively. Notable sub-watersheds with fewer slides include the Upper North Fork Ten Mile River, Little Bear Haven and Bear Haven Creeks, and the Lower South Fork Ten Mile River.

The number of slides initiated by period was also examined to determine the "legacy" effects, since a considerable number of slides are either reactivated, enlarged, or simply continue to deliver in more than one period. Table 14 shows the total number of delivering slides by period as well as the total number of slides initiated only in that period (i.e. not reactivated or enlarged). In 1988, only 59.7% of the slides mapped as delivering were initiated in that period, and by 1999 the percentage had dropped to 52.5%. In contrast, over 70% of the slides were initiated in the 1952 and 1965 periods, and 95% of the slides mapped in 1978 were initiated in that period. The reason for the higher initiation percentage in 1978 compared to 1965 is unknown, given that flow records indicate that peak discharges were greater in the

Dec 1964 event compared to the Jan 1974 event, and thus was likely the more geomorphically significant event. One would have expected some level of reactivation or enlargement in response to the 1974 event, but little was seen. We hypothesize that since there was a very high delivery percentage of slides in 1964, relatively little sediment remained at these sites to be reactivated in 1974, and thus most of the slides that occurred in 1974 were new slides. In addition, those 1964 slides with lower delivery percentages may have quickly stabilized since they had a high threshold of initiation, which was not matched in the 1974 event. The lower initiation percentages in the recent periods probably results from a combination of smaller storms (there were no large events in the 1978-1988 period) and improved management practices. There are no percentages expressed in the 1942 period, since we did not have any information to determine whether any of these slides had been initiated in earlier periods, and thus we assumed that all were initiated in that period.

TABLE 14

PERCENT DELIVERING SLIDES INITIATED BY PERIOD

Total	1942	1952		1965		1978		1988		1999		
Slides	(#)	(#)	(%)	(#)	(%)	(#)	(%)	(#)	(%)	(#)	(%)	NOTES
2,008	449	451		575		230		181		122		All Delivering Slides
1,649	449	350	77.4%	458	79.3%	219	95.2%	109	59.7%	64	52.5%	Initiated by Period

Slide Delivery Percentage Category over Time

Analysis of the nature of the delivering slides in relation to the estimated percent delivery was also examined by time period. Delivering slides were placed into three categories based on estimated percent delivery: <33%, 33%-66%, and >66%. These categories are based on the judgment of the geologist mapping the features and reflects his opinion of the probable delivery percentage. Factors such as type of slide, location relative to adjacent watercourse, and slide appearance were used to estimate the delivery category of each slide. The analysis was intended to investigate whether changes in Forest Practice Rules have resulted in slides that have lower delivery percentages. Table 15 presents the results of this analysis. In 1942, 68.8% of the slides mapped were considered to have a delivery percentage of 66% or greater, while by 1978, this percentage had dropped to 53%, and by 1999 had dropped to 27%. Similarly, the percentage of slides estimated to deliver less than 33% increased, from 16.3% in 1942, to 23.8% in 1965, and to 49.2 % in 1999. The most significant shift occurred after the 1978 photo period, and, although there may be other factors as well, it appears to correlate well with changes in Forest Practice Rules following the Z'Berg-Nejedly Forest Practice Act of 1973.

TABLE 15
NUMBER AND PERCENTAGE OF SLIDES BY DELIVERY PERCENTAGE CATEGORY

% Delivery	1942		1952		1965		1978		1988		1999	
Category	(#)	(%)	(#)	(%)	(#)	(%)	(#)	(%)	(#)	(%)	(#)	(%)
< 33%	73	16.3%	115	25.5%	137	23.8%	49	21.3%	74	40.9%	60	49.2%
33 - 66%	67	14.9%	116	25.7%	115	20.0%	59	25.7%	55	30.4%	29	23.8%
> 66%	309	68.8%	220	48.8%	323	56.2%	122	53.0%	52	28.7%	33	27.0%
TOTAL	449		451		575		230		181		122	

Landform Association with Landsliding

In contrast to many other studies, but similar to the recent Sediment Source Analysis on the Noyo River, inner gorge slopes are not the most common origin for landslides at most locations in the Ten Mile Watershed. Inner gorge slides are particularly important because of their high delivery rate, often directly into the stream channel. Overall, 347, or 21%, of the 1,649 unique slides mapped were found to be inner gorge slides, with the determination of inner gorge status based on the judgment of the analyst. Of the 2,008 slides delivering by period, 464 were inner gorge slides. Inner gorge slides are the most dominant type along the main channels of the three forks and the Lower Mainstem Ten Mile River. In the Lower North and Middle Forks, almost 50% of the slides are considered inner gorge, whereas for the rest of the basin, the percentages are almost all less than 25%, with many less than 20%. In part, this is because a small proportion of the basin area is occupied by inner gorge slopes, as reflected in the slope analysis, which revealed that only 1.5% of the watershed has slopes exceeding 40%. Figure 32 shows the locations of inner gorge landslides in the Middle Fork Ten Mile River Planning Watershed.

Land Use Associations with Landsliding

The inventory of landsliding included a land use parameter. This parameter distributed the observed features into a number of categories based on associated land use interpreted from the aerial photography. The categories included occurrence in forested units or harvest units, and occurrence judged to be related to railroads, roads, or agriculture. Although virtually all of the Ten Mile River 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 30-40 years. Features mapped in harvest units were further subdivided into clear cuts, partial cuts, harvested areas less than 20 years old with method uncertain, harvested areas more than 20 years old with method uncertain, and skid trails. Features mapped in roads and railroads were further subdivided into cut or fill failures.

Table 17 presents the distribution of land use types for all mapped features in the debris torrents and slides categories, which encompassed virtually all of the delivering landslides. Of the mapped debris torrents, only 1 in 148 occurred in the forested category. This may be related to the fact that significant portions of the watershed were not mapped in 1942, although few slides of any type were found in those areas of old growth that were mapped in 1942. In contrast, virtually the entire watershed had been harvested by the time of the large December 1964 storm, thus most features occurred on managed lands. It is also possible that few debris torrents actually occur in old growth forests, when sufficient canopy exists on colluvial hollows (frequently the source of debris torrents) to alter the geomorphic response. Of the slides, only 36 of 1,861 features or 1.9%, were identified as occurring in unmanaged forested areas. 21 debris torrents (14.2%) and 515 slides (27.7%) were judged to be road-related, while 126 debris torrents (85.2%) and 1,222 slides (65.7%) were found to be associated with harvested areas, which includes skid trails. 28 slides (1.5%) were associated with agricultural operations in the Upper North Fork sub-watershed or in the Lower South Fork sub-watershed. 43 slides (2.3%) were found to be related to the railroads located along the main channels of the North, Middle, and South Forks. No debris torrents were related to railroads, probably because few rail lines would have been built on mid to upper slopes, where torrents generally initiate.

Of the slides occurring in harvested areas, 35.5% were found in those areas harvested over 20 years prior, while 20.9% were in harvest areas considered to be less than 20 years old. 3.1% of the slides were identified to have occurred in recent clear cut areas, while recent partial cut areas only had 1.6%. For the vast majority of harvest areas, however, the method of harvest could not be clearly determined.

Table 18 divides delivering slides by land use type by Planning Watershed (PW) and sub-watershed. A number of interesting observations can be made, including:

- Slides related to roads and railroads are very limited in the South Fork Planning Watershed, with about 90% related to harvest areas and only 9% related to roads or railroads. Numbers of slides related to skid trails (included in harvest land use category) were also very low. This may reflect the fact that the majority of first entry harvest in the South Fork was completed in the 1910-1940 period, prior to much road construction. Although significant road construction has occurred in the last decade, improved construction and maintenance practices in recent years are known to reduce the frequency of road-related failures.

- 59% of the slides in the North Fork Planning Watershed are road, skid trail or railroad related.
- 56% of the slides in the Middle Fork Planning Watershed are road, skid trail or railroad related.
- 49% of the slides in the Lower Mainstem Planning Watershed are road, skid trail or railroad related.
- Slides related to road fills are 2-3 times more common than those related to road cuts.
- 72 of the 90 (80%) slides in the Middle North Fork sub-watershed (SW) are related to roads or skid trails.
- 12 of 40 (30%) slides in the Upper North Fork SW are related to grazing, only slightly less than those road-related in this SW.
- 56 of 91 (62%) slides in the Little North Fork SW occur in harvest areas, while only 35% are road, skid trail, or railroad related.
- Roads are particularly significant (30-50%) in all of the sub-watersheds within the Middle Fork PW except for Bear Haven Creek.
- Slides related to skid trails are more significant in the Middle Fork PW than the others, frequently being 10-20% of the total slides.
- Of all the SW in the South Fork PW, Churchman Creek SW has the most road and skid trail-related slides (32 of 88, or 36%), while only the Campbell Creek SW had no road or skid trail-related slides.
- For the Mill Creek SW in the Lower Mainstem PW, roads and skid trails are related to 58 of the 91 slides (63.7%).

Landslide 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; instead, the true area as mapped is defined. This provides an improved estimate of area compared to other methods.

<u>Determining Slide Thickness</u>
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. With only limited field studies to assess slide thickness, we relied on a combination of published values and our field verified values. Since the Ten Mile River watershed has similar geology to that of the Noyo River throughout the watershed, it appears reasonable to use mean values based on Noyo River watershed field investigations by Mendocino Redwoods Company (MRC 1999), who found that forest or harvest non road-related slides had a mean thickness of 3.0 feet. Stillwater Sciences (1999) used 1.3 m (4 feet) for shallow landsliding in the South Fork Eel

Basin, based on average thicknesses from Kelsey et al. (1995) in the Redwood Creek Basin, and Kelsey (1977) from the Van Duzen basin.

Although MRC found that road-related slides had a mean thickness of 3.5 feet, our field verification efforts in the Ten Mile River watershed did not find evidence for such a distinction between harvest-related and road-related slides. As a result, we used a thickness of 3 feet for both types of slides. Earthflows were assigned a thickness of 10 feet, and rotational/translational slides were assumed to average 25 feet thick. A few larger slides were assigned thicknesses greater than 3 feet, but only when large scarps were clearly visible.

Sediment Delivery Ratios and Volume-to-Weight Conversions

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. In this study, delivering slides were placed into three categories based on estimated percent delivery: <33%, 33%-66%, and >66%. Volume calculations used the midpoint of each of these percent delivery classes (.166, .50, and .833, respectively) as factors to adjust slide volumes. We converted volumes (area x thickness, in yd^3) to weight using a factor of 110 pounds/ft^3, or 1.48 tons/yd^3.

Landslide Delivery Adjustment Factors

In addition, adjustment factors were developed where judged necessary to account for various unique elements of the different slide types. Debris torrents were assigned an adjustment factor of 0.50 to account for mapping that included track lengths and run-out areas, and recognition that portions of run-out areas are probably not delivering sediment to the watercourse. Earthflows were assigned a factor of .02 to account for the slow rate of movement of these features, while deep-seated rotational/translational slides were given an adjustment factor of 0.005 to account for even slower movement and thus delivery. These factors were developed based on the experience and judgment of the geologist mapping the features, as we are unaware of any published rates for these features, although it is readily apparent that they behave far differently than debris slides or torrents.

Results of Volume Analysis

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 relative sediment contribution from different Planning Watersheds or sub-watersheds during the various study periods are significantly different. Table 19 shows the computed delivered sediment from all types of slides by PW and SW for the study period in both tons and as a percent of the entire watershed delivery. Notable highlights include:

- 61% of the sediment delivery in the 1933-1942 period occurred in the South Fork PW, which is in line with the extent of disturbance in that SW during that period. 40% of the entire amount from the PW came from the Smith and Campbell Creek SW.
- 26% of the total volume of sediment for the study period (1942-1999) is computed to have occurred in the 1933-1942 period, and 36% in the 1953-1965 period.
- By 1952, sediment sources were much more evenly distributed throughout the watershed, though the South Fork PW still produced 35% of the computed volume. Largest sources on a SW basis in the 1943-1952 period were in the Lower North Fork and Lower Middle Fork SW at 10 and 11% of the yearly total, respectively. Despite the greater area of harvest in the 1943-1952 period, only 16% of the total volume of sediment for the study period is computed to have occurred in the 1943-1952 period, probably mostly reflecting the relatively dry nature (no large storms) of the period.
- Sediment contributions during the 1953-1965 period are significant: 36% of the total sediment delivery from 1933-1999 occurred in this 13-year period. Of that 36%, 49% was from the North Fork PW, 31% from the Middle Fork PW, and only 16% from the South Fork PW.
- 34% of the entire watershed sediment delivery in the 1953-1965 period came from the Middle North Fork SW alone. The Upper Middle Fork and Middle Middle Fork SW were also significant sediment producers with 10% each.
- The 1978 period produced only 8% of the 1942-1999 period total, despite one of the larger storms (1974) in the period. Of the 8%, 29% was from the North Fork PW, 36% was from the Middle Fork PW, 20% was from the South Fork PW, and 15% was from the Lower Ten Mile PW. SW producing significant sediment were Bald Hill Creek, the Lower and Upper Middle Forks, and Mill Creek, with 14%, 14%, 10%, and 10% of the 1966-1978 period total, respectively.
- Mostly as a result of one large slide (reactivated and enlarged from 1965) in the Middle North Fork SW, the 1979-1988 period delivered 11% of the total 1942-1999 sediment delivery. Without that slide of 298,000 tons, the 1979-1988 contribution for the entire watershed would have been 5.8%. Due to this large slide, 63% of the computed 1979-1988 sediment delivery occurred in the Middle North Fork SW, with the next largest SW being Mill Creek at 6% of the annual total.
- By 1999, the volume of slides had been reduced to only 3% of the 1942-1999 period total, apparently reflecting the cumulative effect of improved practices in the last 25 years, and perhaps the sediment delivery savings from improvement works on roads, etc., performed by property owners, primarily Georgia-Pacific West, Inc. since the early 1990s.
- Significant SW contributors in the 1989-1999 period include the Middle North Fork (27%), the Lower Middle Fork (17%), and the Middle Middle Fork (7%). The same large slide in the Middle North Fork continued to delivery substantial amounts, again resulting in a disproportionate amount of the total volume.

There is a trend toward significantly reduced volumes of sediment delivered from landslide sources during the last decade compared to historical periods, in spite of the fact that the middle 1990s have been one of the wetter periods this century, with significant events occurring in 1993, 1995, 1997, and 1998. The percentage of volume reduction is even greater than that previously discussed for the number of slides during the study period. This is a result of a reduction in both the average size and average delivery percentage as we approach the present. Table 20 computes the average volume per slide for the various time periods. A noticeable downward trend since 1965 is interrupted by the influence of one very large slide in the 1979-1988 period. If that one slide was excluded, the average volume per slide in the 1979-1988 period would have been 1606 tons.

Overall, notable SW with lower than average sediment delivery from landsliding include: Ten Mile Estuary (0.38% of total sediment delivery for entire watershed), Lower South Fork (0.80%), Upper North Fork (1.46%), Little Bear Haven Creek (1.62%), Mill Creek (2.26%), Bear Haven Creek (2.76%), and Redwood Creek (2.78%).

TABLE 20

NUMBER, TOTAL VOLUME, AND AVERAGE VOLUME OF SLIDES BY PERIOD

	1933-1942		1943-1952		1953-1965		1966-1978		1979-1988		1989-1999		TOTAL
Category	(#)	(%)	(#)	(%)	(#)	(%)	(#)	(%)	(#)	(%)	(#)	(%)	
Number of Slides	449	22.4%	451	22.5%	575	28.6%	230	11.5%	181	9.0%	122	6.1%	2008
Total Volume (tons)	1,368,600	26.1%	822,700	15.7%	1,883,700	36.0%	423,400	8.1%	588,800	11.2%	149,300	2.9%	5236500
Average Volume (tons)	3048		1824		3276		1841		3253		1224		2608

<u>Volume by Land Use Type</u>

Table 21 presents slide volume data by land use type and sub-watershed lumped for the entire study period, thus providing the ability to evaluate the relative contributions of various types of sources within the PW and SW. Table 22 presents these same values as percentages of total sediment delivery. Overall, 65% of the sediment delivery from mass movement occurred in areas affected by timber harvest (including skid trails), while 32.5% was related to roads and railroads. Sediment delivery from landsliding related to apparently undisturbed forest and grazing is very small at 2.2% and 0.3%, respectively.

The North Fork, Middle Fork, and Lower Mainstem have generally similar proportions of sediment delivery by land use type (50.2%, 56.7%, and 60.6% harvest-related, respectively and 46.5%, 39.6%, and 35.5% road-related, respectively), which contrasts with that of the South Fork (91.5% harvest-related and 8.2% road-related).

Within the harvest-related land use type, the majority of landsliding occurs in harvest units greater than 20 years old, which overall represented 38% of the total sediment delivery from the watershed. Harvest units less than 20 years old produced 19.6% of the total, of which 4.3% came from clear cuts and 2% came from partial cuts. In the remaining 13.3%, the method of harvest could not be clearly defined. Skid trails were locally significant (6.5%, 17%, 0.6%, and 8.3% for the NF, MF, SF and Lower Mainstem PW, respectively), but only 7.4% overall.

Road-related mass wasting was sub-divided into cut and fill categories. Fill-related failures were more significant, producing 21.9% of the overall sediment, while cut-related failures totalled 7.3%. Railroad-related failures, mostly from the 1943-1952 period, totaled only 3.3% of the overall sediment delivery.

Review of the sediment delivery volumes by land use type on a SW basis (Table 21) produced the following highlights:

- Road-related sediment is most significant in terms of overall volumes from the Middle North Fork, Lower Middle Fork, Lower North Fork, and Upper Middle Fork, with the Middle North Fork over double the volume of the next SW.
- Harvest-related sediment volumes are largest in the Middle North Fork, Smith Creek, Campbell Creek, Middle South Fork, and Lower Middle Fork SW. Again, the Middle North Fork is almost double the next largest SW volume.
- Skid trail sediment volumes are most significant (though relatively small compared to road or other harvest-related volumes) in the Lower Middle Fork, Upper Middle Fork, Little North Fork, and Bald Hill Creek.
- Road Cut volumes are most significant in the Lower Middle Fork, Lower North Fork, and Middle North Fork.

As a percentage of the sediment volumes delivered by each SW by land use (Table 22), the following observations are made:

- Road-related sediment delivery is most significant in the Ten Mile River Estuary (73.4%), Upper North Fork (57.8%), Lower Middle Fork (55.5%), Lower North Fork (52.8%), Mill Creek (51.4%), and Middle North Fork (49.3%) sub-watersheds.
- The lowest percentages of road-related sediment delivery are found in South Fork SW, namely Campbell Creek (0.0%), Redwood Creek (3.7%), and Smith Creek (4.4%). The highest percent road-related sediment delivery in the South Fork is Churchman Creek SW at 26.9%.
- Grazing-related sediment delivery was only found in three SW: Upper North Fork (14.4%), Lower South Fork (4.3%), and Ten Mile River Estuary (11.5%). These percentages are in relation to the total sediment delivery from the respective SW over the study period.
- Significant amounts of forest-related sediment delivery only occurred in two sub-watersheds: Upper Middle Fork (11.2%) and Bald Hill Creek (10.2%), both of which were unharvested prior to 1942.

- Harvest-related sediment delivery as a percentage of SW total for period was found to be most significant in the essentially all of the SW, particularly in the South Fork where all of the SW were 73-100%. SW where harvest-related sediment delivery percentages were less significant include Ten Mile River Estuary (15.2%), Upper North Fork (21.4%), Lower North Fork (41.3%), Lower Middle Fork (44.1%), and Mill Creek (44.9%).
- Within the harvest-related land use type, skid roads were most significant in Little Bear Haven Creek (32.8%), Little North Fork (26.7%), Bald Hill Creek (23.1%), Lower Middle Fork (22.2%), and Upper Middle Fork (16.6%). For most of the other SW, skid trails were very minor sediment producers, typically 2% or less.
- Particularly relative to the size of the PW, the Lower Ten Mile produces considerable sediment from clear cut harvesting (27% of the overall volume and 41% of the Mainstem SW).

Unit Area Relationships

In Table 23, unit area volumes for each study period are shown. These values are computed from the mass wasting sediment delivering volumes divided by the drainage area of each PW and SW, thus providing a rate per unit area (tons/mi^2). Computed rates for differing time periods and the various SW range from 102 tons/mi^2 to 71,963 tons/mi^2, reflecting the enormous range of response between SW due to varying geologic, slope, precipitation, and land use parameters both within a given year and between periods. A number of SW had no observed mass wasting features, and thus zero delivery volumes, in certain periods.

The highest unit rate for the 1933-1942 period was in Campbell Creek, followed by Smith Creek and Lower North Fork. The unit rate for the South Fork was much greater than the other PW in the 1933-1942 period, reflecting the intensity of land use up to that time.

Unit rates for PW in the 1943-1952 period are much closer in value, reflecting the more even distribution of forest management in that time period. All PW unit area volumes were between 4,200 and 8,360 tons/mi^2 for the 1943-1952 period, with lower values mainly due to a lack of large storm events in that 10-year period.

Unit area volumes increased dramatically in the 1953-1965 period due to the two large storm events in December 1955 and December 1964. Unit area volumes ranged from 7,600 to 23,540 tons/mi^2, for the four PW. In the 1953-1965 period, the individual unit areas rates were dominated by the Middle North Fork SW (71,963 tons/mi^2) and the Middle Middle Fork SW (28,718 tons/mi^2). Since 1965, the unit area volumes have been sharply lowered from 3,539 tons/mi^2 in the 1966-1978 period, to 1,248 tons/mi^2 in 1989-1999 period for the entire watershed.

In the 1966-1978 period, unit area volumes were highest in Mill Creek (16,104 tons/mi^2), Bald Hill Creek (11,148 tons/mi^2), and Lower Middle Fork (10,152 tons/mi^2). In 1988, unit area volumes were dominated by the Middle North Fork SW (41,288 tons/mi^2) and Mill

Creek SW (12,210 tons/mi^2) with almost all of the other SW having values less than 4,000 tons/mi^2. In the most recent period (1989-1999), only two SW stand out, Lower Middle Fork (4,498 tons/mi^2) and Middle North Fork (4,521 tons/mi^2).

Overall unit area sediment production by mass wasting for the entire study period was highest in the Middle North Fork, followed by Campbell Creek, Lower Middle Fork, Smith Creek, and Lower North Fork. SW with the lowest overall rates are Upper North Fork, Ten Mile River Estuary, and Lower South Fork.

Average Annual Unit Area Volumes

One final way of evaluating mass wasting sediment production involves calculation of average annual unit area volumes by study period. These data are shown in Table 24 and are simply the unit area rates divided by the number of years in each study period. Although we know that most sediment production from mass wasting actually occurs during years with a combination of high annual precipitation and intense storms, we have no quantitative way to assign volumes to a specific year, and it is useful from a planning perspective to look at average annual rates within the selected study periods.

The overall sediment delivery from landsliding for the period of 1933-1999 is estimated at 644 tons/mi^2/yr, with individual periods ranging from 1,211 tons/mi^2/yr (1965) to 113 tons/mi^2/yr (1999). For the entire watershed, the highest delivery is associated with the 1964 flood, followed by a sharp decline in landslide sediment delivery in recent times, probably largely the result of improved management practices. The highest average annual rates for individual SW in a study period were found to be Campbell Creek in the 1933-1942 period at 6,300 tons/mi^2/yr, followed by the Middle NF at 5,536 tons and Smith Creek at 4,905 tons. By the 1989-1999 period, Campbell Creek was only delivering sediment from landsliding at a rate of 31 tons/mi^2/yr, the Middle NF at 411 tons/mi^2/yr, and Smith Creek at 109 tons/mi^2/yr.

Limitations of Mass Wasting Analysis

The mass wasting analysis presented here most likely underestimates the role of mass wasting in sediment delivery due to lack of data regarding small slides which were smaller than the resolution of the aerial photographs used, as well as the lack of comprehensive field verification. It has also been suggested that small slides not seen beneath the canopy in old growth areas could also substantially increase the background or non-management related landslide volumes. Without any data on small slides and gullies, we have no way to determine the magnitude of these features, and whether they are significant.

Comparison to mass wasting rates developed in other north coast California watersheds with similar geology suggests that the results of this study are reasonable. Recent work within the adjacent Noyo 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 that included much higher rates for the pre-1978 period reflecting differing forest practice rules. The 1978-1998 rates developed by MRC were from 47-310 tons/mi^2/yr, which are 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 (Cafferata/Stillwater Sciences, pers. comm. 1999).

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., 1999). Revisions to the Garcia River rates based on new information developed in a Level 2 Watershed Assessment by Louisiana Pacific, 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 often 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 (e.g. 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 only a small amount of field reconnaissance 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 the GIS database, and selection of factors for computation of rates.

Road Surface Erosion

Methods

Road data were developed from various sources and compiled into the GIS. CDF provided much of the base data, which had been obtained from the USGS topographic maps (2 of the 7.5' quads were done in the 1960s and 2 in 1991) which were amended to include data from submitted timber harvest plans since 1988. Unfortunately, the THP data did not include existing roads outside of the harvest area boundaries, and thus new road segments were not always shown connected to other roads. In places, road locations were only roughly defined, and we corrected roads based on our aerial photo mosaic for the watershed. This correction process also connected isolated road segments into the road network.

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 always straightforward. We focused on main roads and haul roads, and likely either missed or ignored smaller roads in some years. This likely resulted in an under-estimate of roads for years prior to 1999, and an over-estimate of construction totals for the 1989-1999 period, as the 1989-1999 period estimate was obtained by subtraction of the cumulative total by years through 1988 from the existing GIS total, which was based on CDF's data derived from THP's. In addition, road segments that had not been coded as a specific year in the CDF data were also assigned to the 1989-1999 period. Furthermore, just as for landslides, the aerial photos available did not cover the entire basin in 1942 (eastern portions of the North Fork and a portion of the Middle Fork). This probably resulted in a minor underestimate of roads for that period, since very little timber harvest activity took place in that portion of the watershed by 1942.

The road construction history for the entire watershed is depicted in Figure 30, while individual sub-watersheds are shown in Appendix B. We were unable to determine the extent that roads had been abandoned and either put to bed, or simply allowed to revegetetate, as is clearly the case in parts of the watershed. Figure 23 provides an indication that this process has occurred based on the density of roads near the Little North Fork in 1942 compared to that currently visible in 1999. This process would be most common where very dense road networks were developed in early harvest periods, and many of these roads were subsequently re-worked or totally abandoned. However, unless properly storm-proofed, even abandoned roads may contribute sediment, though likely at a declining rate with time as vegetation coverage develops. Harvest areas with very dense road networks were not that common except in the 1933-1942 period.

Current Road Conditions and Types

According to the GIS road coverage developed in this study, there are currently 940 miles of roads in the Ten Mile Watershed, which translates to a basinwide road density of 7.86 mi/mi^2. Table 25 shows the existing road network distributed by Planning Watershed and sub-watershed. The highest road density in the basin is in the Little North Fork SW, with a density of 11.61 mi/mi^2, followed closely by the Bear Haven Creek SW (10.99 mi/mi^2), Lower North Fork SW (10.98 mi/mi^2), and Middle South Fork SW (10.23 mi/mi^2). The various CDF GIS classes were combined into 4 categories for simplicity: highway (paved), permanent (rocked but not paved), seasonal (native surface), and temporary. Not surprisingly, seasonal roads were 87.7% of the total, followed by permanent road at 8.5%, temporary (4WD) at 3.6%, and highway at 0.1%. Only a very small portion of Highway 1 is contained in the watershed. The Lower Ten Mile Planning Watershed has the highest road density (8.46 mi/mi^2) of the 4 planning watersheds. The South Fork PW has the largest amount of road miles at 318, followed by the North Fork PW at 291 miles. There is a higher percentage of permanent roads in the Lower Ten Mile PW (16.2%) and South Fork (13%) than in the North Fork (5.9%) or Middle Fork (3.7%).

Railroads

As previously discussed in the brief history of the watershed, railroads played an important role in the transportation of harvested timber between about 1910 and 1950. Figure 29 shows the extent of the railroad network based on the 1942 aerial photographs. Main tracks extended far up the South Fork, with spur lines up Smith Creek, Campbell Creek and Redwood Creek. Tracks were extended a much shorter distance up the Middle and North Forks. Table 26 provides the length of the railroad network in 1942. Beginning in the 1940s, railroads were replaced by trucks and the railroad grades were converted to road beds. This conversion appears to have been complete by the early 1950s. Railroad trestles are still visible at a number of sites thoughout the watershed, particularly at abandoned river crossings.

TABLE 26

LENGTH OF RAILROADS IN THE TEN MILE WATERSHED 1942

PLANNING WATERSHED	Length (miles)
North Fork Ten Mile River	5.96
Middle Fork Ten Mile River	2.60
South Fork Ten Mile River	25.84
Lower Mainstem Ten Mile River	5.93

Road History

Table 27 presents the results of our mapping of the road network over time based on the sequential aerial photographs. The miles of roads constructed by period for each PW and SW is shown. Of the current total of 940 miles of roads, 10% were existing in 1942, 21.5% were added in the 1943-1952 period, 13.1% were constructed in the 1953-1965 period, another 11.6% were built in the 1966-1978 period, only 5.4% were added in the 1979-1988 period, while 37.9% were created in the most recent 1989-1999 period, although the latter period probably includes some roads that were actually constructed earlier, as discussed previously. The road construction mirrors the progress of timber harvest through the watershed, with most concentrated in the South Fork and lower Middle and North Forks in the 1940s. Major road construction in the 1952 period occurred in Middle South Fork (11.2 miles), Redwood Creek (12.0 miles), Bear Haven Creek (20.7 miles), Middle Middle Fork (15.2 miles), Upper Middle Fork (34.6 miles), and all through the North Fork PW. In the 1965 period, most road construction occurred in the North Fork PW with 65 miles of roads built between 1953 and 1965. In the 1978 period, major road construction occurred in Campbell Creek, Mill Creek, Bear Haven Creek, Lower North Fork, and Upper North Fork SW, with only small amounts in the remaining areas. Relatively little construction occurred in the 1988 period, with most of that in the South Fork PW and the Upper Middle and Upper North Forks. Widespread construction occurred in the 1989-1999 period, as harvest rates rose considerably.

As noted earlier, some of the roads attributed to 1999 probably were constructed in prior periods, mainly in 1979-1988, but it is still evident that many miles of roads were recently built. 170 miles or 58.5% of the total in the South Fork PW were considered built in the 1999 period, while the Middle and North Forks each had 30% of their total roads constructed in the period (88 miles each). Despite the significant increase in road density, the advantage of recently constructed roads over earlier roads is that construction standards have markedly improved in the past 25 years, thereby reducing the impact of these features. In addition, many of these recent roads are ridgetop roads, providing access for cable-yarding harvest techniques. Ridgetop roads generally deliver less sediment to watercourses than roads near stream courses or mid-slope roads. Unfortunately, the scope of this road investigation could not take the location of the road into account for computation of sediment delivery and it remains for development of a detailed road inventory to accurately characterize the road network.

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 sediment delivery 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 (Washington State). Similar applications of this method have been recently undertaken on the Navarro River and Noyo River watersheds.

The first step involves converting the observed road mileage by year into cumulative road miles by period to allow for road surface erosion calculations (Table 28). The total road mileage in a given sub-watershed is then stratified into use categories by application of a "use function" which proportions the road miles into 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), with the percentages rounded to the nearest 5 or 10% to simplify computation (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 in the Clearwater Basin declined 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 yields in the various 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 modification to this computation process: 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 1988 and 1999 periods, respectively. Table 29 shows the results of this method for estimating road surface erosion for the Ten Mile River watershed.

The analysis indicates that sediment production from roads has increased significantly over the study period, tracking cumulative road construction. However, the adjustment factors in recent years, predicated on substantially improved practices, result in a much lower rate of increase overall in recent years and in decreases for certain sub-watersheds. 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 225 tons/mi^2/yr, which is estimated to be an almost 6-fold increase over 1942 rates, though with almost a 10-fold increase in the mileage of roads during the period.

Current road surface erosion rates are computed to vary between 117 tons/mi^2/yr for the Middle North Fork to 331 tons/mi^2/yr for the Little North Fork. The eastern (upper watershed) portions of the North Fork and Middle Fork PW typically had rates below the watershed average, while the lower portions of all three forks and all of the South Fork and Lower Mainstem had rates greater than the watershed average.

Limitations of Roads Analysis

The method of characterizing sediment delivery from roads used in this sediment source analysis has a number of limitations, and is only considered a “first-cut” based on the presently available information. Substantial refinement of these values could occur during implementation phases when detailed road inventories are developed. As noted previously, we had no way of quantifying the extent of abandoned roads, although we estimate that this is probably well less than 10% of the existing total miles. This study lacked precise information on actual type of roads, actual use rates, and typical sediment loading and we were forced to rely on previously published factors. We were not able to quantitatively determine the relative locations of roads and the effect of this on sediment delivery.

Hillslope Erosion (Skid Roads)

There is considerable variation in estimates from the literature 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, etc.) are of primary importance in determining whether significant sediment production and delivery will occur. Properly drained skid roads will probably revegetate within 5-10 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 Juan Creek, also located in Mendocino County, 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.

Given the limitations of this study, evaluation of sediment production and delivery from skid trails has been undertaken 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 30 summarizes the harvest area by photo date, broken down by PW and SW. The largest harvest rate occurred in the 1942 period, when 35,030 acres or 46% of the watershed area was cut. Since then, harvest rates declined steadily between 1942 and 1988, and then jumped dramatically in the 1989-1999 period.

The total harvest in the watershed for the 58 year period from 1942 to 1999 was 106,154 acres or 139% of the total watershed area, reflecting that a number of areas have been harvested several times. Figure 31 summarizes the harvest history for the entire watershed, while individual sub-watersheds are plotted in Appendix C. For the 1999 budget period, harvest areas were not mapped, but rather computed from the GIS database based on annual THP's submitted to CDF. The annual values from the database were simply summed to obtain a single value for the 1989-1999 period. 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.

Table 31 presents the area in acres of harvested areas containing skid roads of high, medium, or low densities based on the mapping from aerial photography using the 1942, 1952, 1965, 1978, 1988, and 1999 photo sets. The 1942 photos only covered the western half of the watershed except for the South Fork where the entire Planning Watershed was covered, but at least in the Middle and North Forks, little harvest had occurred in the upper watershed areas by 1942. All harvest areas in the 1942 photos were considered to have a high density of skid roads. In 1952 and 1965 the majority of harvesting still used a high density of skid trails. Harvest rates were very low in 1978 and 1988, and by 1988 there were not any harvest areas mapped as high density. In 1999, areas that were mapped all had a low density of skid roads, along with a number of new categories from the CDF GIS database, including clear cuts, narrow clear cuts, and cable-yarded areas. Typically, few, if any, skid roads were seen on these areas, as much effort was apparently spent to obliterate the skid trails developed during harvest operations.

To compute surface erosion rates from the harvest acreage data requires selection of a yield or sediment delivery function for each class and selection of a time function to characterize the change in sediment delivery 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 developed by Mendocino Redwoods Company (MRC 1999) for their holdings in the Noyo River Watershed. Based on a review of the literature, MRC selected 50 tons/mi^2/yr as a mean rate for skid road sediment production for current management methods. They applied these rates over a 12 year period for each harvest area, 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. These higher values were estimated to reflect earlier, pre-Forest Practice Rules operations. We used a 10 year period to simplify the calculations, since a 12-year period would have overlapped many of the period lengths, necessitating more complex calculations. The first two years were at the rates listed above, and then reduced to 25% of that rate for the remaining 8 years. For periods 1979-1988 and 1989-1999, the rate was adjusted downward to an average of 100 tons/mi^2/yr to reflect the combination of improved management practices post-1974 FPR, and the advent of cable skyline yarding and greatly improved buffering practices. 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 only about 75% revegetation cover within 5 years after use ended. Unfortunately, we had no site-specific information on vegetation cover establishment in the Ten Mile watershed with which to adjust our calculations, and therefore no adjustments were made.

Table 32 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 in the 1942 period, with declining amounts since then. Very little surface erosion was generated in the 1988 period (1,927 tons), but the amount increased in the 1989-1999 period to 16,439 tons due to the major increase in harvest rates.

Fluvial Erosion

Numerous studies have indicated that fluvial erosion, whether from road diversions and washouts, road drainage-induced gullies, natural gullies, bank erosion or small streamside landslides, can be a major component of the watershed sediment sources. Unfortunately, quantification of these components requires considerable field investigation, typically as part of a comprehensive road inventory process, in order to develop reliable information.

The first step in our indirect approach involved use of unit area values of fluvial erosion rates developed for the Noyo River, which had been extrapolated from preliminary data from Mendocino Redwoods Company (C. Surfleet, pers. comm. 1999) of 0.023 tons/ft/yr for small streamside landsliding along stream channels mapped as Mass Wasting Map Unit 1 (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. In the Noyo sediment source analysis, these values were then multiplied by the drainage area and the period length in years to obtain an estimate of the period fluvial erosion total.

To cross check these estimates, we also evaluated descriptions (which included rough dimensions of length and height) from the 1994 habitat surveys made by Georgia-Pacific West, Inc. (GP) as reported in their 1995 instream monitoring report. 59 sites of bank erosion and streamside landsliding were specifically identified with dimensions from the 105.6 miles of channel walked during the surveys. An additional 38 sites were noted, but no dimensions were estimated. We assumed an average thickness of 1.5 feet (one-half of the average used for landslides, due to generally smaller sizes) for these streamside erosion and landsliding features, and then computed volumes. The average volume per feature was then multiplied by the number of features without dimensions and the two categories (features with dimensions and those without) were summed to reach a total for the watershed of 207 tons/stream mile. While the majority of channels in the watershed were walked during the inventory process (those considered suitable or accessible to anadromous fisheries), we did not have the data needed to extrapolate these measured values to the remainder of each portion of the watershed. Instead, we decided to use the unit area values developed for the Noyo. A significantly complicating factor in the analysis is the frequency of occurrence for these streamside slides and areas of bank erosion. We had no information on the actual age of the erosion sites mapped by GP, that is, whether they corresponded to one or several years of erosion. Despite the inability to convert the tons/stream mile into tons/mi^2/yr, we believe that the actual value is probably in the same general range, since most of the channels in the watershed were inventoried, and the relative agreement of these two approaches provides a measure of confidence in the relative magnitude of this sediment source and the reasonableness of our selected unit rate.

The results of our analysis of bank erosion from the GP surveys are shown in Table 34. We used the 200 tons/mi^2/yr rate from the Noyo in our sediment budget computations. Actual computations are developed in the following sediment budget section and are shown in Tables 35 and 36.

Changes in Alluvial Storage

Due to the confined nature of most of the main channels of the three forks of the Ten Mile River, fluvial-induced change in alluvial storage in these areas is considered a relatively small term in the sediment budget for these portions of the watershed. This is not the case for the lower reaches of the North Fork, South Fork, and the entire mainstem, where much more extensive alluvial deposits are present. Little change in the position or vegetation characteristics of the South Fork were seen between 1942 and 1999, suggesting that lower precipitation and lower slopes combine in a more stable floodplain setting. This may also have resulted from less intensive activities right in or adjacent to the channel, as was clearly the case in the North and Middle Forks. Along much of the Lower South Fork, the valley floodplain was wide enough for the early railroads to be set well back from the channel on relatively gentle land and materials excavated in construction of the grades were not dumped directly into the channel.

Lacking quantitative data, only order-of-magnitude estimates of changes in alluvial storage are possible. In comparing various aerial photographs of the lower alluvial reaches for the years used in this study (Figures 19-20, 23-25), it is apparent that the active width of the channel has decreased markedly between the 1965 and 1978 photos. Noticeable change had occurred by 1978, although much of this may have taken place after the significant flood event in 1974. It appears that much of this change is related to vegetation encroachment and stabilization of what were seen as open, active gravel bars in the 1942-1965 period. It is likely that this condition persisted through the 1974 high flows also, and then, with lower harvest and a number of low precipitation years, vegetation was able to rapidly encroach. Vegetation in this setting typically acts to trap sediment, creating new floodplain surfaces, which in turn allows more vegetation to become established. Even so, the amount of alluvial storage in the Ten Mile 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.

We infer that due to management practices and high flow years between 1938 and 1974, a substantial amount of alluvial storage was lost as the channel widened. We approximate this change by estimating that the channel widened by an average 50 feet over a 10.5 mile reach including 4.5 miles of the Mainstem Ten Mile above the estuary, the lower 3 miles of the Middle Fork, and the lower 3 miles of the North Fork. We furthermore assume that the average height of floodplain lost was 5 feet. This calculation results in a volume of about 760,000 tons. If we assume that most of this floodplain has been recreated since 1974, as suggested by the dense riparian corridor currently existing along almost the entire channel, then storage increased by an equal amount during the period 1975-1999. Still, compared to landsliding volumes, change in storage volumes are likely to be rather small. For the purposes of the sediment budget, the change in storage was distributed between the periods as follows: (1) periods of decreasing storage: 1933-1942 (40%), 1943-1952 (20%), and 1953-1965 (40%), and (2) periods of increasing storage: 1966-1978 (20%), 1979-1988 (60%), and 1989-1999 (20%). The distribution of the change in storage volumes to these periods is highly speculative and subjective, but is proportioned based on relative changes seen on sequential aerial photographs and magnitude and duration of storm flows within each period. The 1979-1988 period was given a greater percentage because of the large landslide observed which delivered a tremendous amount of sediment into the system that was likely rapidly stabilized.

Calculation of Relative Disturbance Index

One parameter of in-channel physical habitat data in the Ten Mile watershed that should be directly related to upslope sediment delivery is the percent of fine sediment (%<0.85mm) found in spawning gravel substrate in the various watershed areas. Since the early 1990s, GP, and now Campbell Timberland, have annually collected bulk samples of substrate quality at over 20 sites throughout the watershed. In an effort to see how the findings of our primarily office-based approach for this sediment source analysis correspond to measured instream values, we developed a simplistic relative disturbance index and compared that to recent (1996) instream data.

The relative disturbance index for current conditions was defined as the product of SW road density, the percent of SW area harvested in the 1989-1999 period, and the unit area volume (tons/mi^2) of landslides mapped in the 1989-1999 period. The simple product of these three variables equally weights all three metrics of potential or actual delivery (Table 33). The results ranged from 0 in the Ten Mile River Estuary SW, due to an absence of slides in the period, to 1248 for the Middle South Fork SW, which combined a high road density with a high percent of harvest, and a moderately high unit area slide volume. Figure 47 shows the relationship between relative disturbance index and substrate quality for 17 of the 20 SW. There were no comparable substrate sampling sites for three of the SW. Although there is a considerable amount of scatter in this relationship, it is also reasonably apparent that there is a general relationship between the index and the % fines < 0.85mm. Further review of the relationship indicated that two distinct groupings of SW appeared to exist. Figure 48 subdivides the SW into these two groupings. We hypothesize that these groups represent watershed areas that have different sensitivities to disturbance. Thus, the analysis suggests that certain sub-watershed areas may be less sensitive to disturbance than others.

Development of a more sophisticated disturbance index utilizing improved road and fluvial erosion sediment delivery values could well lead to an improved relationship. A stronger relationship could provide the basis for prioritization of sediment reduction efforts throughout the watershed.

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 Ten Mile 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 small storms 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 Ten Mile River watershed prior to 1974. After passage of the California Forest Practices Act in 1973, the practice of yarding logs down stream channels, which resulted in direct sedimentation into stream channels, was 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 could not be undertaken due to time and budgetary constraints, so 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 Ten Mile River watershed, can best be accomplished by stratifying the area into sub-watershed units of similar characteristics. A sediment budget would be 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 Ten Mile watershed is considered generally homogeneous in terms of soil, bedrock, vegetation, and topography, and is, as a result, treated as a whole. Land use remains 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 Ten Mile

River watershed, with a modest amount of field verification of landslides. Budgetary and timing constraints (most of the work was completed during winter months when roads are often closed to minimize disturbance) precluded any additional field investigations.

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 35 summarizes the sediment budget inputs, computes percentages by process, and computes unit rates for the entire watershed.

Landsliding has ranged from 18-73% of the total inputs, with road inputs ranging from 2.5-35.7%, harvest-related surface erosion (skid trails) ranging from 0.2-7%, background rates ranged from 4.5-11.9%, and fluvial erosion from 11.9-31.8%. The general trend has been a decrease in landsliding inputs over time, and an increase in road-related sediment delivery over time. Surface erosion related to harvest activities was very high in early periods, dropped to very low levels in the 1980s when very little harvest occurred, and has increased in the current period based on a sharp increase in the number of acres harvested. Since background and fluvial erosion rates are computed based on a simple tons/mi^2/yr value, their relative contribution by period is a function of the number of years in the period and the overall total inputs. For example, as the input from landsliding decreases, background and fluvial erosion will have a higher percent input. Total inputs by period are shown in Figure 49, which shows generally decreasing inputs over time, with the exception of a large spike in the 1953-1965 period related to the known large hydrologic events.

Under current conditions, roads are estimated to provide 35.7% of the inputs, while fluvial erosion is 31.8% of the total, landslides are responsible for 18.1%, background for 11.9%, and skid trails for 2.4%.

Of these inputs, previous analyses in the source analysis section indicate that about 98% of the landsliding is management-related. Sediment delivery from skid roads and roads is essentially 100% management-related. Thus, combining these management-related terms (98% of 18.1%, 2.4%, and 35.7%), indicates that about 56% of the sediment inputs for which estimates were developed are management-related under current conditions. Roads are computed to have almost double the sediment input of landsliding (35.7% vs. 18.1%) under current conditions. Lack of data on several potentially important contributing processes (gullying from stream diversions due to road and skid roads, for example) may result in an underestimation of road sediment delivery. Various other studies have arrived at generally lower percentages for management-related sediment generation, including the Noyo River at 35% (Matthews & Associates 1999), and the Garcia River estimated at 40-60% management-related (PWA 1997).

Outputs

The output side of the sediment budget has been developed based on regional sediment transport equations and streamflow records. The regional sediment equations were developed through evaluation of other basins in the general area of roughly similar characteristics. This process provides data only slightly better than an order of magnitude estimate. Available evidence suggests that our sediment yields may be somewhat low, but well within the likely range. Outputs were computed for the 1952-1999 period using historic and synthetic mean daily streamflow data. Outputs for the 1933-1951 period were estimated based on a relationship developed between annual precipitation and total sediment discharge.

Computed sediment yields for the entire 67-year study period average 1,135 tons/mi^2/yr. In general, yields of this magnitude would be considered low in northern California, compared to values from the Eel, Mad, or Redwood Creek basins. However, available information on sediment yields for watersheds in the Mendocino coast suggests that these values are reasonable and perhaps slightly higher than nearby basins. Long-term yields for the Noyo River, with very similar characteristics, were 979 tons/mi^2/yr (Matthews & Associates 1999) while for those for Caspar Creek fall in the same general range, with adjusted estimates of 793 tons/mi^2/yr (Cafferata/Stillwater Sciences, pers. comm. 1999). While it is possible that regional sediment transport data somewhat overestimate the sediment transport characteristics of the Ten Mile watershed, it is probable that the method used underestimates sediment transport (see pages 16-18).

Sediment Budget

The preliminary sediment budget for the Ten Mile River watershed between 1933 and 1999 is shown in Table 36. Explanations for the various input and output elements have been developed in previous sections of this document. Estimated inputs total 9,007,000 tons over the 67-year period, while computed outflow is 8,093,000 tons. Although these values are reasonably similar, evidence suggests that the sediment outflow may be over-estimated by the regional approach and underestimated by the computational method, with a net result to the output calculations that is unknown. At the same time, various input sources are likely to be underestimated, both because of information available and the limitations of the analytic techniques. Assigning a great deal of confidence to the sediment budget numbers because they are quite similar, would a mistake given the uncertainties in certain methods and assumptions used. What the sediment budget does suggest, is that much of the sediment generated during the 1940s-1970s pre-forest practice rules period, has likely flushed through the system.

CONCLUSIONS

This study has developed estimates of sediment production and delivery by process for the entire Ten Mile 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. Under current conditions (1989-1999 period), management-related sediment delivery is estimated to be 56% of the total input.

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 & Associates provide their 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 & Associates provide their 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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TABLE 1
TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
PLANNING WATERSHED AND SUB-WATERSHED CHARACTERISTICS

PLANNING WATERSHED Sub-Watershed	Drainage Area (mi^2)	Stream Miles (mi)	Main Channel Relief Upstream Elev (ft)	Main Channel Relief Downstream Elev (ft)	Main Channel Gradient (ft/ft)	Topographic High (ft)	Basin Relief (ft)
NORTH FORK TEN MILE	**38.97**	**23.2**					
Upper North Fork Ten Mile River	10.40	4.3	2380	460	0.0846	3240	2780
Middle North Fork Ten Mile River	8.98	5.0	460	230	0.0087	2845	2615
Bald Hill Creek	5.14	2.7	1100	230	0.0610	2680	2450
Lower North Fork Ten Mile River	6.70	7.6	230	40	0.0047	1980	1940
Little North Fork Ten Mile River	7.75	3.6	450	40	0.0216	1720	1680
MIDDLE FORK TEN MILE	**33.45**	**24.9**					
Upper Middle Fork Ten Mile River	11.64	6.0	1760	420	0.0423	3240	2820
Middle Middle Fork Ten Mile River	6.45	4.1	420	190	0.0106	2260	2070
Little Bear Haven Creek	3.00	2.7	530	190	0.0238	1623	1433
Bear Haven Creek	6.60	5.3	150	100	0.0018	1662	1562
Lower Middle Fork Ten Mile River	5.76	6.8	190	40	0.0042	1700	1660
SOUTH FORK TEN MILE	**38.39**	**39.6**					
Upper South Fork Ten Mile River	8.18	6.8	1230	300	0.0259	3200	2900
Redwood Creek	7.87	5.4	1200	300	0.0316	2988	2688
Churchman Creek	3.96	4.0	620	140	0.0227	1288	1148
Middle South Fork Ten Mile River	5.52	6.5	300	140	0.0047	1360	1220
Campbell Creek	4.25	4.6	680	40	0.0264	1700	1660
Smith Creek	5.49	6.2	440	35	0.0124	1700	1665
Lower South Fork Ten Mile River	3.12	6.1					
LOWER TEN MILE	**8.83**	**10.0**					
Mainstem Ten Mile River	4.28	3.8	40	10	0.0015	1400	1390
Mill Creek	2.71	3.15	280	10	0.0162	1460	1450
Ten Mile River Estuary	1.84	3.05	10	0	N/A	640	640
TOTAL	**119.64**	**97.7**					

Notes: Main channel determined by upstream extent of solid USGS Blueline. Elevations approximated from USGS 40' contour interval.

TABLE 2

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Slope Analysis by Planning Watershed and Sub-Watershed

PLANNING WATERSHED	DRAINAGE AREA OF GIVEN SLOPE CLASS (square miles and %)																	
Sub-Watershed	0-5%		5-10%		10-15%		15-20%		20-25%		25-30%		30-35%		35-40%		>40%	
NORTH FORK TEN MILE	**0.608**	1.6%	**1.928**	4.9%	**5.109**	13.1%	**8.143**	20.9%	**8.654**	22.2%	**7.172**	18.4%	**4.685**	12.0%	**2.008**	5.2%	**0.548**	1.4%
Upper North Fork Ten Mile River	0.174	1.7%	0.779	7.5%	2.519	24.3%	3.235	31.2%	2.038	19.7%	1.022	9.9%	0.436	4.2%	0.136	1.3%	0.030	0.3%
Middle North Fork Ten Mile River	0.094	1.0%	0.385	4.3%	1.003	11.2%	1.910	21.3%	2.267	25.3%	1.782	19.9%	1.030	11.5%	0.400	4.5%	0.098	1.1%
Bald Hill Creek	0.045	0.9%	0.130	2.5%	0.364	7.1%	0.791	15.5%	1.276	25.0%	1.272	24.9%	0.847	16.6%	0.320	6.3%	0.065	1.3%
Lower North Fork Ten Mile River	0.162	2.4%	0.325	4.9%	0.448	6.7%	0.845	12.6%	1.327	19.8%	1.511	22.6%	1.308	19.5%	0.603	9.0%	0.165	2.5%
Little North Fork Ten Mile River	0.133	1.7%	0.309	4.0%	0.775	10.0%	1.362	17.7%	1.746	22.6%	1.585	20.5%	1.064	13.8%	0.549	7.1%	0.190	2.5%
MIDDLE FORK TEN MILE	**0.396**	1.2%	**1.396**	4.2%	**3.475**	10.4%	**5.966**	17.8%	**7.544**	22.6%	**7.402**	22.1%	**5.021**	15.0%	**1.855**	5.5%	**0.393**	1.2%
Upper Middle Fork Ten Mile River	0.116	1.0%	0.631	5.4%	1.832	15.7%	2.676	23.0%	2.779	23.9%	2.116	18.2%	1.128	9.7%	0.312	2.7%	0.045	0.4%
Middle Middle Fork Ten Mile River	0.098	1.5%	0.291	4.5%	0.573	8.9%	1.124	17.4%	1.576	24.4%	1.579	24.5%	0.943	14.6%	0.238	3.7%	0.026	0.4%
Little Bear Haven Creek	0.026	0.9%	0.085	2.8%	0.184	6.1%	0.344	11.5%	0.583	19.4%	0.858	28.6%	0.683	22.8%	0.217	7.2%	0.022	0.7%
Bear Haven Creek	0.077	1.2%	0.193	2.9%	0.353	5.4%	0.850	12.9%	1.512	22.9%	1.723	26.1%	1.254	19.0%	0.521	7.9%	0.115	1.7%
Lower Middle Fork Ten Mile River	0.079	1.4%	0.196	3.4%	0.533	9.2%	0.972	16.9%	1.094	19.0%	1.126	19.5%	1.013	17.6%	0.567	9.8%	0.185	3.2%
SOUTH FORK TEN MILE	**0.982**	2.6%	**2.004**	5.2%	**4.262**	11.1%	**7.655**	19.9%	**9.258**	24.1%	**7.313**	19.0%	**4.437**	11.6%	**1.859**	4.8%	**0.605**	1.6%
Upper South Fork Ten Mile River	0.102	1.2%	0.361	4.4%	1.016	12.4%	1.906	23.3%	2.397	29.3%	1.584	19.4%	0.632	7.7%	0.150	1.8%	0.028	0.3%
Redwood Creek	0.130	1.7%	0.400	5.1%	1.067	13.6%	1.981	25.2%	2.081	26.4%	1.384	17.6%	0.641	8.1%	0.164	2.1%	0.026	0.3%
Churchman Creek	0.060	1.5%	0.178	4.5%	0.352	8.9%	0.592	14.9%	0.755	19.1%	0.809	20.4%	0.696	17.6%	0.349	8.8%	0.170	4.3%
Middle South Fork Ten Mile River	0.119	2.2%	0.292	5.3%	0.595	10.8%	0.979	17.7%	1.226	22.2%	1.110	20.1%	0.762	13.8%	0.312	5.7%	0.121	2.2%
Campbell Creek	0.092	2.2%	0.216	5.1%	0.371	8.7%	0.665	15.6%	0.906	21.3%	0.845	19.9%	0.666	15.7%	0.369	8.7%	0.122	2.9%
Smith Creek	0.131	2.4%	0.244	4.4%	0.487	8.9%	0.976	17.8%	1.256	22.9%	1.078	19.6%	0.778	14.2%	0.427	7.8%	0.110	2.0%
Lower South Fork Ten Mile River	0.348	11.2%	0.313	10.1%	0.374	12.0%	0.556	17.9%	0.637	20.5%	0.503	16.2%	0.262	8.4%	0.088	2.8%	0.028	0.9%
LOWER TEN MILE	**0.952**	10.8%	**0.632**	7.2%	**0.728**	8.2%	**1.093**	12.4%	**1.459**	16.5%	**1.489**	16.9%	**1.357**	15.4%	**0.828**	9.4%	**0.264**	3.0%
Mainstem Ten Mile River	0.333	7.8%	0.282	6.6%	0.326	7.7%	0.493	11.6%	0.710	16.7%	0.837	19.6%	0.722	16.9%	0.401	9.4%	0.156	3.7%
Mill Creek	0.056	2.1%	0.103	3.8%	0.199	7.3%	0.307	11.3%	0.460	16.9%	0.509	18.8%	0.569	21.0%	0.406	15.0%	0.105	3.9%
Ten Mile River Estuary	0.563	30.8%	0.247	13.5%	0.203	11.1%	0.293	16.0%	0.289	15.8%	0.143	7.8%	0.066	3.6%	0.021	1.1%	0.003	0.2%
TEN MILE RIVER WATERSHED	**2.94**	2.5%	**5.96**	5.0%	**13.57**	11.4%	**22.86**	19.1%	**26.92**	22.5%	**23.38**	19.6%	**15.50**	13.0%	**6.55**	5.5%	**1.81**	1.5%

Data Source: Converted 30m DEM to 10m grid. Base data from CDF

TABLE 3

ANNUAL PRECIPITATION DATA FOR TEN MILE RIVER WATERSHED AREA

ORDERED

Water Year	Willits (inches)	Fort Bragg (inches)	Water Year	Willits (inches)	Fort Bragg (inches)
1879	85.46		1940	63.78	41.18
1880	63.98		1941	71.88	60.32
1881	54.97		1942	65.99	50.53
1882	44.59		1943	47.85	39.11
1883	37.20		1944	35.22	28.73
1884	34.74		1945	48.30	37.95
1885	31.23		1946	50.98	45.33
1886	63.96		1947	36.74	23.95
1887	38.96		1948	49.81	38.47
1888	39.84		1949	36.98	35.17
1889	38.63		1950	39.86	30.49
1890	84.51		1951	55.80	41.55
1891	38.61		1952	63.05	47.27
1892	49.44		1953	60.32	48.36
1893	64.83		1954	50.72	42.32
1894	68.57		1955	31.86	32.00
1895	70.28		1956	72.71	47.41
1896	63.13	36.90	1957	51.96	33.45
1897	47.73	41.98	1958	92.82	58.02
1898	45.98	24.85	1959	40.24	29.44
1899	43.23	28.61	1960	44.45	30.72
1900	56.85	40.39	1961	48.92	39.20
1901	63.05		1962	42.01	34.04
1902	62.89	45.21	1963	58.03	38.43
1903	55.48	37.92	1964	38.30	32.78
1904	89.30	50.43	1965	64.46	41.70
1905	55.80	36.75	1966	44.52	35.10
1906	64.83	39.46	1967	54.40	46.47
1907	61.63	44.04	1968	43.59	34.48
1908	45.25	32.69	1969	65.69	50.62
1909	71.13	58.52	1970	56.46	41.26
1910	41.71	42.63	1971	59.10	46.24
1911	41.47	32.85	1972	40.64	31.57
1912	36.28	37.69	1973	53.83	44.62
1913	37.47	27.17	1974	76.39	54.84
1914	64.15	52.61	1975	57.00	40.98
1915	57.93	55.85	1976	33.28	28.79
1916	49.15	40.08	1977	16.88	16.56
1917	39.60	31.51	1978	65.56	47.95
1918	29.63	23.89	1979	33.51	31.87
1919	42.25	40.79	1980	53.86	41.17
1920	21.94	20.76	1981	37.31	30.25
1921	54.66	50.52	1982	72.33	43.67
1922	31.10	30.08	1983	86.48	62.47
1923	34.17	31.41	1984	54.42	39.56
1924	17.16	16.56	1985	38.13	33.06
1925	66.23	49.78	1986	65.61	42.41
1926	30.41	28.22	1987	33.14	31.46
1927	61.67	47.22	1988	31.88	29.02
1928	46.34	36.36	1989	18.13	42.25
1929	29.18	29.54	1990	22.48	35.56
1930	43.63	26.63	1991	27.75	24.47
1931	32.74	19.85	1992	36.75	32.70
1932	46.58	30.62	1993	57.44	51.54
1933	41.70	32.53	1994	29.98	30.81
1934	38.71	26.03	1995	74.44	58.61
1935	47.47	39.45	1996	63.41	46.64
1936	60.08	39.26	1997	58.03	49.71
1937	36.31	33.05	1998	75.93	77.31
1938	87.62	53.29			
1939	37.30	25.74			

LARGEST 50 YEARS

SORTED

Rank	Water Year	Willits (inches)	Water Year	Fort Bragg (inches)
1	1958	92.82	1998	77.31
2	1904	89.30	1983	62.47
3	1938	87.62	1941	60.32
4	1983	86.48	1995	58.61
5	1879	85.46	1909	58.52
6	1890	84.51	1958	58.02
7	1974	76.39	1915	55.85
8	1998	75.93	1974	54.84
9	1995	74.44	1938	53.29
10	1956	72.71	1914	52.61
11	1982	72.33	1993	51.54
12	1941	71.88	1969	50.62
13	1909	71.13	1942	50.53
14	1895	70.28	1921	50.52
15	1894	68.57	1904	50.43
16	1925	66.23	1925	49.78
17	1942	65.99	1997	49.71
18	1969	65.69	1953	48.36
19	1986	65.61	1978	47.95
20	1978	65.56	1956	47.41
21	1893	64.83	1952	47.27
22	1906	64.83	1927	47.22
23	1965	64.46	1996	46.64
24	1914	64.15	1967	46.47
25	1880	63.98	1971	46.24
26	1886	63.96	1946	45.33
27	1940	63.78	1902	45.21
28	1996	63.41	1973	44.62
29	1896	63.13	1907	44.04
30	1901	63.05	1982	43.67
31	1952	63.05	1910	42.63
32	1902	62.89	1986	42.41
33	1927	61.67	1954	42.32
34	1907	61.63	1989	42.25
35	1953	60.32	1897	41.98
36	1936	60.08	1965	41.70
37	1971	59.1	1951	41.55
38	1963	58.03	1970	41.26
39	1997	58.03	1940	41.18
40	1915	57.93	1980	41.17
41	1993	57.44	1975	40.98
42	1975	57.00	1919	40.79
43	1900	56.85	1900	40.39
44	1970	56.46	1916	40.08
45	1905	55.8	1984	39.56
46	1951	55.8	1906	39.46
47	1903	55.48	1935	39.45
48	1881	54.97	1936	39.26
49	1921	54.66	1961	39.20
50	1984	54.42	1943	39.11

Source: Goodridge (1999)

TABLE 4
PRECIPITATION INTENSITY DATA FOR WILLITS AND FORT BRAGG

	Willits		Fort Bragg		GREATEST MONTHLY PRECIPITATION WILLITS		
RANK	Water Year	Ranked 1-Day	Water Year	Ranked 1-Day	Water Year	Month	Monthly Precip (inches)
1	1965	8.80	1953	4.15	1902	Feb	29.21
2	1938	7.61	1939	4.05	1958	Feb	29.10
3	1906	7.07	1995	3.84	1965	Dec	28.65
4	1914	6.50	1979	3.78	1995	Jan	28.36
5	1947	6.50	1990	3.78	1879	Feb	27.17
6	1960	6.46	1938	3.70	1904	Feb	26.56
7	1974	5.90	1937	3.62	1886	Nov	26.17
8	1952	5.87	1969	3.58	1970	Jan	26.05
9	1943	5.78	1958	3.52	1956	Dec	25.76
10	1951	5.50	1966	3.52	1896	Jan	25.29
11	1986	5.50	1965	3.49	1997	Dec	25.17
12	1963	5.40	1915	3.42	1879	Jan	24.60
13	1956	5.33	1996	3.30	1906	Jan	24.05
14	1969	5.21	1998	3.30	1998	Jan	23.83
15	1940	5.20	1971	3.23	1895	Jan	23.18
16	1990	5.20	1993	3.23	1936	Jan	23.17
17	1913	5.13	1913	3.10	1914	Jan	23.07
18	1966	5.10	1956	3.07	1969	Jan	22.70
19	1979	5.06	1994	3.06	1940	Feb	21.64
20	1932	5.05	1997	3.06	1986	Feb	21.62
21	1939	4.92	1921	3.03	1894	Jan	21.52
22	1942	4.87	1949	3.00	1890	Jan	21.22
23	1954	4.69	1974	2.99	1908	Dec	21.20
24	1996	4.66	1967	2.97	1904	Nov	20.72
25	1915	4.65	1952	2.92	1904	Mar	20.36
26	1921	4.65	1960	2.81			
27	1989	4.50	1925	2.79			
28	1995	4.42	1951	2.77			
29	1970	4.36	1968	2.76			
30	1993	4.33	1980	2.65			
31	1953	4.23	1955	2.62			
32	1958	4.23	1916	2.61			
33	1937	4.15	1981	2.60			
34	1971	4.05	1989	2.56			
35	1997	4.02	1983	2.55			
36	1957	4.00	1963	2.54			
37	1941	3.97	1985	2.49			
38	1916	3.80	1927	2.48			
39	1917	3.80	1986	2.44			
40	1930	3.75	1930	2.43			
41	1981	3.75	1910	2.40			
42	1980	3.74	1948	2.40			
43	1985	3.65	1970	2.40			
44	1936	3.60	1926	2.37			
45	1919	3.59	1928	2.37			
46	1925	3.53	1919	2.30			
47	1946	3.53	1991	2.29			
48	1927	3.51	1964	2.21			
49	1962	3.44	1975	2.20			
50	1983	3.39	1954	2.17			

Source: Goodridge (1999)

TABLE 5

USGS Gage Middle Fork Ten Mile River near Fort Bragg, #11468600

Peak Discharge, Annual Maximum (Historic and Synthetic Data)

Water Year	Peak Discharge (cfs)	Rank	Water Year	Peak Discharge (cfs)	Probability	Recurrence Interval (years)
1952	3570	1	1965	5670	0.021	48.00
1953	3110	2	1993	4650	0.042	24.00
1954	2910	3	1956	4490	0.063	16.00
1955	1680	4	1974	4340	0.083	12.00
1956	4490	5	1966	4160	0.104	9.60
1957	1690	6	1952	3570	0.125	8.00
1958	2380	7	1986	3510	0.146	6.86
1959	1770	8	1953	3110	0.167	6.00
1960	2960	9	1970	3100	0.188	5.33
1961	1730	10	1995	2990	0.208	4.80
1962	2260	11	1960	2960	0.229	4.36
1963	1890	12	1954	2910	0.250	4.00
1964	2130	13	1971	2870	0.271	3.69
1965	5670	14	1983	2800	0.292	3.43
1966	4160	15	1997	2800	0.313	3.20
1967	1520	16	1982	2700	0.333	3.00
1968	1100	17	1996	2420	0.354	2.82
1969	2330	18	1958	2380	0.375	2.67
1970	3100	19	1972	2370	0.396	2.53
1971	2870	20	1980	2360	0.417	2.40
1972	2370	21	1969	2330	0.438	2.29
1973	1860	22	1962	2260	0.458	2.18
1974	4340	23	1975	2240	0.479	2.09
1975	2240	24	1964	2130	0.500	2.00
1976	1660	25	1998	2030	0.521	1.92
1977	1140	26	1963	1890	0.542	1.85
1978	1810	27	1990	1890	0.563	1.78
1979	1490	28	1973	1860	0.583	1.71
1980	2360	29	1985	1850	0.604	1.66
1981	1580	30	1978	1810	0.625	1.60
1982	2700	31	1959	1770	0.646	1.55
1983	2800	32	1989	1760	0.667	1.50
1984	1720	33	1961	1730	0.688	1.45
1985	1850	34	1984	1720	0.708	1.41
1986	3510	35	1957	1690	0.729	1.37
1987	1490	36	1955	1680	0.750	1.33
1988	1660	37	1976	1660	0.771	1.30
1989	1760	38	1988	1660	0.792	1.26
1990	1890	39	1981	1580	0.813	1.23
1991	1360	40	1967	1520	0.833	1.20
1992	1440	41	1994	1500	0.854	1.17
1993	4650	42	1979	1490	0.875	1.14
1994	1500	43	1987	1490	0.896	1.12
1995	2990	44	1992	1440	0.917	1.09
1996	2420	45	1991	1360	0.938	1.07
1997	2800	46	1977	1140	0.958	1.04
1998	2030	47	1968	1100	0.979	1.02

XXXX = Historic USGS Data

XXXX = Synthetic data from peak correlation with Noyo River

TABLE 6

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

FLOOD FREQUENCY DATA

PROBABILITY	RECURRENCE INTERVAL (YEARS)	SOUTH FORK	MIDDLE FORK	NORTH FORK
		DISCHARGE (CFS)		
0.5	2	2120	2700	3510
0.2	5	3170	4240	5250
0.1	10	4090	5270	6770
0.04	25	5060	6590	8360
0.02	50	6140	7550	10160
0.01	100	6870	8510	11400

Middle Fork Data: Historic and Synthetic Data, Log Pearson Type III Analysis
South and North Fork Data: From Regional Equations of Waananen and Crippen (1977)

TABLE 7
MIDDLE FORK TEN MILE RIVER WATERSHED
DATA FOR ASSESSING EVENT MAGNITUDE

Data Sources Sorted and Ranked, with Top 20 Values Listed

ANNUAL RUNOFF Middle Fork Ten Mile River near Fort Bragg Rank	Water Year	Annual Runoff (ac-ft)	PEAK DISCHARGE Middle Fork Ten Mile River near Fort Bragg Rank	Water Year	Peak Discharge (cfs)	MAGNITUDE/DURATION PRODUCT Water Year	AR*PQ Product	ANNUAL PRECIPITATION Willits Water Year	Annual Precip (inches)	Fort Bragg 5N Water Year	Annual Precip (inches)	1-DAY PRECIPITATION INTENSITY Rank	Willits Water Year	1-Day Precip (inches)	Fort Bragg Water Year	1-Day Precip (inches)
1	1974	112010	1	1965	5670	1965	502220672	1958	92.82	1998	77.31	1	1965	8.80	1953	4.15
2	1983	110937	2	1993	4650	1974	486121473	1904	89.30	1983	62.47	2	1938	7.61	1939	4.05
3	1958	90871	3	1956	4490	1956	358279853	1938	87.62	1941	60.32	3	1906	7.07	1995	3.84
4	1965	88575	4	1974	4340	1993	342098435	1983	86.48	1995	58.61	4	1914	6.50	1979	3.78
5	1982	80915	5	1966	4160	1983	310943916	1879	85.46	1909	58.52	5	1947	6.50	1990	3.78
6	1995	80250	6	1952	3570	1952	269082751	1890	84.51	1958	58.02	6	1960	6.46	1938	3.70
7	1956	79868	7	1986	3510	1995	239666167	1974	76.39	1915	55.85	7	1974	5.90	1937	3.62
8	1969	77197	8	1953	3110	1953	227248971	1998	75.93	1974	54.84	8	1952	5.87	1969	3.58
9	1952	75418	9	1970	3100	1986	222977136	1995	74.44	1938	53.29	9	1943	5.78	1958	3.52
10	1971	73744	10	1995	2990	1982	218129357	1956	72.71	1914	52.61	10	1951	5.50	1966	3.52
11	1993	73503	11	1960	2960	1958	216190943	1982	72.33	1993	51.54	11	1986	5.50	1965	3.49
12	1953	73096	12	1954	2910	1970	211790975	1941	71.88	1969	50.62	12	1963	5.40	1915	3.42
13	1970	68320	13	1971	2870	1971	211645470	1909	71.13	1942	50.53	13	1956	5.33	1996	3.30
14	19	65158	14	1983	2800	1966	190036776	1895	70.28	1921	50.52	14	1969	5.21	1998	3.30
15	1986	63586	15	1997	2800	1969	179869222	1894	68.57	1904	50.43	15	1940	5.20	1971	3.23
16	1996	60796	16	1982	2700	1997	169029054	1925	66.23	1925	49.78	16	1990	5.20	1993	3.23
17	1997	60305	17	1996	2420	1954	161699493	1942	65.99	1997	49.71	17	1913	5.13	1913	3.10
18	1967	60051	18	1958	2400	1996	147336782	1969	65.69	1953	48.36	18	1966	5.10	1956	3.07
19	1975	59014	19	1972	2370	1975	132454585	1986	65.61	1978	47.95	19	1979	5.06	1994	3.06
20	1954	55567	20	1980	2360	1973	121193542	1978	65.56	1956	47.41	20	1932	5.05	1997	3.06

Notes: Annual Runoff Data is Synthetic for all Years Except Wy 1965-1973

Peak Discharge was Obtained by Correlation Analysis Except WY 1965-1974

Annual Precipitation and Intensity Data from Goodridge (1999)

TABLE 8
MIDDLE FORK TEN MILE RIVER
Annual Runoff and Cumulative Departure

Water Year	Annual Runoff (ac-ft)	Cumulative Departure (ac-ft)
1952	75418	25042
1953	73096	47762
1954	55567	52953
1955	22802	25379
1956	79868	54871
1957	33004	37498
1958	90871	77994
1959	28822	56440
1960	34890	40954
1961	38569	29147
1962	30882	9653
1963	47511	6788
1964	26384	-17203
1965	88575	20996
1966	45682	16302
1967	60051	25976
1968	37550	13151
1969	77197	39972
1970	68320	57916
1971	73744	81284
1972	44928	75836
1973	65158	90618
1974	112010	152252
1975	59014	160890
1976	19793	130307
1977	2508	82439
1978	54743	86806
1979	24534	60965
1980	46983	57572
1981	21314	28509
1982	80915	59048
1983	110937	119608
1984	50738	119970
1985	31765	101360
1986	63586	114570
1987	25762	89956
1988	24810	64390
1989	39597	53611
1990	26579	29814
1991	13754	-6808
1992	18139	-39045
1993	73503	-15918
1994	16062	-50231
1995	80250	-20358
1996	60796	-9937
1997	60305	-8
Mean	50376	
Max	112010	
Min	2508	

RANKED ANNUAL RUNOFF

Rank	Water Year	(ac-ft)
1	1974	112010
2	1983	110937
3	1958	90871
4	1965	88575
5	1982	80915
6	1995	80250
7	1956	79868
8	1969	77197
9	1952	75418
10	1971	73744
11	1993	73503
12	1953	73096
13	1970	68320
14	1973	65158
15	1986	63586
16	1996	60796
17	1997	60305
18	1967	60051
19	1975	59014
20	1954	55567
21	1978	54743
22	1984	50738
23	1963	47511
24	1980	46983
25	1966	45682
26	1972	44928
27	1989	39597
28	1961	38569
29	1968	37550
30	1960	34890
31	1957	33004
32	1985	31765
33	1962	30882
34	1959	28822
35	1990	26579
36	1964	26384
37	1987	25762
38	1988	24810
39	1979	24534
40	1955	22802
41	1981	21314
42	1976	19793
43	1992	18139
44	1994	16062
45	1991	13754
46	1977	2508

Notes: Annual Runoff Data Derived from Synthetic Data except for WY 1961-1974

TABLE 11

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Computed Sediment Loads for North, Middle, and South Forks

Water Year	COMPUTED ANNUAL SS LOAD North Fork	Middle Fork	South Fork	COMPUTED ANNUAL BEDLOAD North Fork	Middle Fork	South Fork	COMPUTED ANNUAL TOTAL LOAD North Fork	Middle Fork	South Fork
1952	38100	23600	12400	8400	5500	3100	46500	29100	15500
1953	32600	20200	10600	7700	5000	2800	40300	25200	13400
1954	18200	11300	5900	4500	2900	1700	22700	14200	7600
1955	2200	1400	700	700	500	300	3000	1900	1000
1956	56900	35200	18500	11700	7700	4300	68500	42900	22800
1957	5900	3600	1900	1700	1100	600	7600	4800	2500
1958	30200	18700	9800	7900	5200	2900	38100	23900	12700
1959	6300	3900	2000	1800	1200	700	8100	5100	2700
1960	13300	8200	4300	3100	2100	1200	16400	10300	5500
1961	5900	3700	1900	1800	1200	700	7700	4800	2600
1962	4900	3000	1600	1500	1000	500	6400	4000	2100
1963	8800	5500	2900	2600	1700	1000	11400	7200	3800
1964	5200	3200	1700	1400	900	500	6600	4200	2200
1965	87800	41000	28500	15900	8900	5900	103700	49900	34400
1966	23800	12900	7700	4800	3000	1800	28600	15900	9500
1967	7800	7300	2500	2400	2200	900	10100	9600	3400
1968	3700	3500	1200	1200	1100	400	4900	4600	1700
1969	26700	17900	8700	6500	4700	2400	33100	22600	11100
1970	29300	21100	9500	6800	5200	2500	36100	26200	12000
1971	20900	15800	6800	5100	4200	1900	26000	20000	8700
1972	3100	6200	1000	1000	1800	400	4100	8000	1400
1973	11400	9700	3700	3200	2800	1200	14600	12500	4900
1974	103000	63900	33500	19500	12800	7200	122500	76700	40700
1975	21500	13300	7000	5400	3500	2000	26900	16900	9000
1976	2500	1600	800	800	500	300	3300	2100	1100
1977	0	0	0	0	0	0	0	0	0
1978	11400	7100	3700	3300	2100	1200	14700	9200	4900
1979	2800	1800	900	900	600	300	3800	2400	1300
1980	10400	6400	3400	2800	1900	1000	13200	8300	4400
1981	2300	1400	800	800	500	300	3100	1900	1000
1982	25900	16100	8400	6600	4400	2500	32500	20400	10900
1983	37100	23000	12100	9700	6300	3600	46800	29300	15600
1984	8900	5500	2900	2600	1700	1000	11600	7300	3900
1985	4800	3000	1600	1400	900	500	6200	3900	2100
1986	36800	22800	12000	8000	5200	3000	44800	28000	14900
1987	2900	1800	900	1000	600	400	3800	2400	1300
1988	3700	2300	1200	1200	800	400	4900	3100	1600
1989	6400	4000	2100	2000	1300	700	8400	5300	2800
1990	4300	2700	1400	1300	800	500	5600	3500	1900
1991	1200	800	400	400	300	200	1600	1000	600
1992	2000	1200	600	700	400	200	2600	1700	900
1993	41900	26000	13600	8900	5800	3300	50800	31800	16900
1994	1900	1100	600	600	400	200	2400	1500	800
1995	39400	24400	12800	9100	6000	3400	48500	30400	16200
1996	13900	8600	4500	3900	2600	1400	17800	11200	6000
1997	31000	19200	10100	6800	4500	2500	37800	23700	12600
Total	**859000**	**534900**	**279100**	**199400**	**133800**	**73800**	**1058100**	**668900**	**352900**
Max	**103000**	**63900**	**33500**	**19500**	**12800**	**7200**	**122500**	**76700**	**40700**
Min	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Average	**18674**	**11628**	**6067**	**4335**	**2909**	**1604**	**23002**	**14541**	**7672**

Flow Records and Regional Sediment Transport Relationships

TABLE 12

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

All Landsliding Features Mapped: Delivering and Non-Delivering by Type and Period

		1942		1952		1965		1978		1988		1999	
TYPE	**Total**	**(#)**	**(%)**	**(#)**	**(%)**	**(#)**	**(%)**	**(#)**	**(%)**	**(#)**	**(%)**	**(#)**	**(%)**
Debris Torrent	148	35	4.8%	36	7.2%	42	5.4%	18	6.4%	10	6.4%	7	5.7%
Earthflows	157	40	5.5%	3	0.6%	96	12.3%	17	6.0%	0		1	0.8%
Gully	4	4	0.6%	0		0		0		0		0	
Rotational/Translational	392	233	32.3%	20	4.0%	100	12.8%	37	13.2%	1	0.6%	1	0.8%
Slides	1861	410	56.8%	440	88.2%	542	69.5%	209	74.4%	146	93.0%	114	92.7%
TOTALS:	**2562**	**722**		**499**		**780**		**281**		**157**		**123**	
% of Total		28.2%		19.5%		30.4%		11.0%		6.1%		4.8%	

Source: Aerial Photography Analysis by John Coyle & Associates

TABLE 13

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Number of Delivering Slides by Study Period and Watershed

PLANNING WATERSHED	Drainage Area	1942		1952		1965		1978		1988		1999		TOTAL ALL PERIODS	
Sub-Watershed	(mi^2)	(#)	(%)	(#)	(%)	(#)	(%)	(#)	(%)	(#)	(%)	(#)	(%)	(#)	(%)
NORTH FORK TEN MILE	**38.97**	74	16.5%	110	24.4%	149	25.9%	74	32.2%	45	24.9%	35	28.7%	487	24.3%
Upper North Fork Ten Mile River	10.40	0	0.0%	14	3.1%	17	3.0%	5	2.2%	2	1.1%	2	1.6%	40	2.0%
Middle North Fork Ten Mile River	8.98	0	0.0%	17	3.8%	43	7.5%	9	3.9%	11	6.1%	10	8.2%	90	4.5%
Bald Hill Creek	5.14	1	0.2%	18	4.0%	25	4.3%	31	13.5%	14	7.7%	7	5.7%	96	4.8%
Lower North Fork Ten Mile River	6.70	58	12.9%	45	10.0%	33	5.7%	15	6.5%	13	7.2%	6	4.9%	170	8.5%
Little North Fork Ten Mile River	7.75	15	3.3%	16	3.5%	31	5.4%	14	6.1%	5	2.8%	10	8.2%	91	4.5%
MIDDLE FORK TEN MILE	**33.45**	**41**	**9.1%**	**109**	**24.2%**	**213**	**37.0%**	**76**	**33.0%**	**62**	**34.3%**	**38**	**31.1%**	**539**	**26.8%**
Upper Middle Fork Ten Mile River	11.64	0	0.0%	33	7.3%	64	11.1%	16	7.0%	10	5.5%	8	6.6%	131	6.5%
Middle Middle Fork Ten Mile River	6.45	3	0.7%	22	4.9%	64	11.1%	12	5.2%	14	7.7%	5	4.1%	120	6.0%
Little Bear Haven Creek	3.00	0	0.0%	13	2.9%	16	2.8%	12	5.2%	8	4.4%	1	0.8%	50	2.5%
Bear Haven Creek	6.60	8	1.8%	15	3.3%	29	5.0%	4	1.7%	5	2.8%	2	1.6%	63	3.1%
Lower Middle Fork Ten Mile River	5.76	30	6.7%	26	5.8%	40	7.0%	32	13.9%	25	13.8%	22	18.0%	175	8.7%
SOUTH FORK TEN MILE	**38.39**	**289**	**64.4%**	**204**	**45.2%**	**174**	**30.3%**	**44**	**19.1%**	**38**	**21.0%**	**31**	**25.4%**	**780**	**38.8%**
Upper South Fork Ten Mile River	8.18	9	2%	23	5.1%	65	11.3%	20	8.7%	14	7.7%	4	3.3%	135	6.7%
Redwood Creek	7.87	43	9.6%	17	3.8%	25	4.3%	5	2.2%	2	1.1%	2	1.6%	94	4.7%
Churchman Creek	3.96	6	1.3%	37	8.2%	31	5.4%	6	2.6%	5	2.8%	3	2.5%	88	4.4%
Middle South Fork Ten Mile River	5.52	55	12.2%	33	7.3%	26	4.5%	3	1.3%	5	2.8%	7	5.7%	129	6.4%
Campbell Creek	4.25	61	13.6%	23	5.1%	16	2.8%	2	0.9%	3	1.7%	3	2.5%	108	5.4%
Smith Creek	5.49	100	22.3%	66	14.6%	9	1.6%	7	3.0%	9	5.0%	7	5.7%	198	9.9%
Lower South Fork Ten Mile River	3.12	15	3.3%	5	1.1%	2	0.3%	1	0.4%	0	0.0%	5	4.1%	28	1.4%
LOWER TEN MILE	**8.83**	**45**	**10.0%**	**28**	**6.2%**	**39**	**6.8%**	**36**	**15.7%**	**36**	**19.9%**	**18**	**14.8%**	**202**	**10.1%**
Mainstem Ten Mile River	4.28	26	5.8%	15	3.3%	22	3.8%	11	4.8%	4	2.2%	8	6.6%	86	4.3%
Mill Creek	2.71	2	0.4%	9	2.0%	17	3.0%	22	9.6%	31	17.1%	10	8.2%	91	4.5%
Ten Mile River Estuary	1.84	17	3.8%	4	0.9%	0	0.0%	3	1.3%	1	0.6%	0	0.0%	25	1.2%
TEN MILE RIVER WATERSHED	**119.6**	**449**	**22.4%**	**451**	**22.5%**	**575**	**28.6%**	**230**	**11.5%**	**181**	**9.0%**	**122**	**6.1%**	**2008**	**100%**

TABLE 14

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

NUMBER AND VOLUME OF INNER GORGE LANDSLIDES BY SUB-WATERSHED AND STUDY PERIOD

PLANNING WATERSHED	1942		1952		1965		1978		1988		1999		TOTAL	
Sub-Watershed	#	(tons)	#	(tons)	#	(tons)	#	(tons)	#	(tons)	#	(tons)	#	(tons)
NORTH FORK TEN MILE	**39**	**121194**	**48**	**120891**	**57**	**421498**	**3**	**6366**	**4**	**57762**	**7**	**6967**	**158**	**734678**
													34.1%	**46.9%**
Upper North Fork Ten Mile River					7	24406	2	2795	0		1	699	10	27899
Middle North Fork Ten Mile River			8	37350	14	311041	0		1	55370	4	4121	27	407883
Bald Hill Creek	0		11	15836	11	21555	0		0		0		22	37391
Lower North Fork Ten Mile River	31	94529	27	66769	16	42450	1	3571	3	2392	2	2147	80	211859
Little North Fork Ten Mile River	8	26665	2	936	9	22047	0		0		0		19	49647
MIDDLE FORK TEN MILE	**25**	**95074**	**48**	**141230**	**49**	**175536**	**3**	**1282**	**18**	**18837**	**14**	**12713**	**157**	**444673**
													33.8%	**28.4%**
Upper Middle Fork Ten Mile River			8	24108	18	74396	0		4	6448	1	539	31	105492
Middle Middle Fork Ten Mile River	3	5597	10	25195	14	36362	0		1	655	2	363	30	68171
Little Bear Haven Creek			2	2716	1	334	0		0		0		3	3050
Bear Haven Creek	3	4781	5	9869	0		0		0		0		8	14650
Lower Middle Fork Ten Mile River	19	84696	23	79343	16	64444	3	1282	13	11733	11	11811	85	253310
SOUTH FORK TEN MILE	**47**	**179849**	**29**	**56915**	**31**	**86317**	**2**	**5243**	**9**	**7816**	**3**	**1363**	**121**	**337503**
													26.1%	**21.6%**
Upper South Fork Ten Mile River	2	5674	2	3586	14	27409	1	1710	1	570			20	38949
Redwood Creek	2	8106	1	1726	1	2489	0		1	0			5	12321
Churchman Creek	4	8626	1	1916					1	665			6	11208
Middle South Fork Ten Mile River	14	29389	6	13907	10	50136	1	3532	4	4097	2	1113	37	102175
Campbell Creek	6	18960	1	2027	2	3182	0		1	1734			10	25902
Smith Creek	19	109093	18	33754	2	2560			1	750	1	250	41	146407
Lower South Fork Ten Mile River	0		0		2	541	0		0		0		2	541
LOWER TEN MILE	**8**	**15119**	**8**	**18556**	**7**	**8775**	**0**	**0**	**4**	**5704**	**1**	**450**	**28**	**48602**
													6.0%	**3.1%**
Mainstem Ten Mile River	7	13708	7	17073	1	147	0		0		0		15	30928
Mill Creek	1	1410	1	1483	6	8627	0		4	5704	1	450	13	17674
Ten Mile River Estuary	0		0		0		0		0		0		0	0
TEN MILE RIVER WATERSHED	**119**	**411236**	**133**	**337592**	**144**	**692126**	**8**	**12891**	**35**	**90118**	**25**	**21493**	**464**	**1565456**
	25.6%	26.3%	28.7%	21.6%	31.0%	44.2%	1.7%	0.8%	7.5%	5.8%	5.4%	1.4%		

TABLE 15

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

OCCURRENCE OF DEBRIS TORRENTS AND SLIDES BY LAND USE, 1941-1999

DEBRIS TORRENTS

Land Use	1941	1952	1965	1978	1988	1999	TOTAL BY LAND USE	%
Clear Cut	5		1	1			7	4.7%
Partial Cut	2	2	2				6	4.1%
Forested			1				1	0.7%
Harvested in last 20yr	12	10	3	2	1	1	29	19.6%
Harvest older than 20yr	16	20	25	7	7	3	78	52.7%
Road Cut			2				2	1.4%
Road Fill		4	8	4	1	2	19	12.8%
Skid Trail				4	1	1	6	4.1%
Grazing/AG								
Railroad Cut								
Railroad Fill								
Undetermined								
TOTAL BY PERIOD	35	36	42	18	10	7	148	100%
% of TOTAL	23.6%	24.3%	28.4%	12.2%	6.8%	4.7%		

SLIDES

Land Use	1941	1952	1965	1978	1988	1999	TOTAL BY LAND USE	%
Clear Cut	38	6	6		1	7	58	3.1%
Partial Cut	10	8	9	1	1		29	1.6%
Forested	11	16	7	1	1		36	1.9%
Harvested in last 20yr	112	106	42	19	10	11	300	16.1%
Harvest older than 20yr	152	129	243	44	50	42	660	35.5%
Road Cut	22	61	46	14	17	15	175	9.4%
Road Fill	26	66	142	49	35	22	340	18.3%
Skid Trail	6	21	29	78	29	12	175	9.4%
Grazing/AG	6	14	2	3	1	2	28	1.5%
Railroad Cut	22	11	3				36	1.9%
Railroad Fill	4	1	1			1	7	0.4%
Undetermined	1	1	12		1	2	17	0.9%
TOTAL BY PERIOD	410	440	542	209	146	114	1861	100%
% of TOTAL	22.0%	23.6%	29.1%	11.2%	7.8%	6.1%		

TABLE 16

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

NUMBER AND VOLUME OF INNER GORGE LANDSLIDES BY SUB-WATERSHED AND STUDY PERIOD

PLANNING WATERSHED	1942		1952		1965		1978		1988		1999		TOTAL	
Sub-Watershed	(#)	(tons)	(#)	(tons)	(#)	(tons)	(#)	(tons)	(#)	(tons)	(#)	(tons)	(#)	(tons)
NORTH FORK TEN MILE	**39**	**121,194**	**48**	**120,891**	**57**	**421,498**	**3**	**6,366**	**4**	**57,762**	**7**	**6,967**	**158**	**734,678**
													34.1%	**46.9%**
Upper North Fork Ten Mile River					7	24,406	2	2,795	0		1	699	10	27,899
Middle North Fork Ten Mile River			8	37,350	14	311,041	0		1	55,370	4	4,121	27	407,883
Bald Hill Creek	0		11	15,836	11	21,555	0		0		0		22	37,391
Lower North Fork Ten Mile River	31	94,529	27	66,769	16	42,450	1	3,571	3	2,392	2	2,147	80	211,859
Little North Fork Ten Mile River	8	26,665	2	936	9	22,047	0		0		0		19	49,647
MIDDLE FORK TEN MILE	**25**	**95,074**	**48**	**141,230**	**49**	**175,536**	**3**	**1,282**	**18**	**18,837**	**14**	**12,713**	**157**	**444,673**
													33.8%	**28.4%**
Upper Middle Fork Ten Mile River			8	24,108	18	74,396	0		4	6,448	1	539	31	105,492
Middle Middle Fork Ten Mile River	3	5,597	10	25,195	14	36,362	0		1	655	2	363	30	68,171
Little Bear Haven Creek			2	2,716	1	334	0		0		0		3	3,050
Bear Haven Creek	3	4,781	5	9,869	0		0		0		0		8	14,650
Lower Middle Fork Ten Mile River	19	84,696	23	79,343	16	64,444	3	1,282	13	11,733	11	11,811	85	253,310
SOUTH FORK TEN MILE	**47**	**179,849**	**29**	**56,915**	**31**	**86,317**	**2**	**5,243**	**9**	**7,816**	**3**	**1,363**	**121**	**337,503**
													26.1%	**21.6%**
Upper South Fork Ten Mile River	2	5,674	2	3,586	14	27,409	1	1,710	1	570			20	38,949
Redwood Creek	2	8,106	1	1,726	1	2,489	0		1	-			5	12,321
Churchman Creek	4	8,626	1	1,916					1	665			6	11,208
Middle South Fork Ten Mile River	14	29,389	6	13,907	10	50,136	1	3,532	4	4,097	2	1,113	37	102,175
Campbell Creek	6	18,960	1	2,027	2	3,182	0		1	1,734			10	25,902
Smith Creek	19	109,093	18	33,754	2	2,560			1	750	1	250	41	146,407
Lower South Fork Ten Mile River	0		0		2	541	0		0		0		2	541
LOWER TEN MILE	**8**	**15,119**	**8**	**18,556**	**7**	**8,775**	**0**	**-**	**4**	**5,704**	**1**	**450**	**28**	**48,602**
													6.0%	**3.1%**
Mainstem Ten Mile River	7	13,708	7	17,073	1	147	0		0		0		15	30,928
Mill Creek	1	1,410	1	1,483	6	8,627	0		4	5,704	1	450	13	17,674
Ten Mile River Estuary	0		0		0		0		0		0		0	0
TEN MILE RIVER WATERSHED	**119**	**411,236**	**133**	**337,592**	**144**	**692,126**	**8**	**12,891**	**35**	**90,118**	**25**	**21,493**	**464**	**1,565,456**
	25.6%	26.3%	28.7%	21.6%	31.0%	44.2%	1.7%	0.8%	7.5%	5.8%	5.4%	1.4%		

NOTE: All Inner Gorge Slides are considered delivering

TABLE 17

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

OCCURRENCE OF DELIVERING DEBRIS TORRENTS AND SLIDES BY LAND USE, 1942-1999

DEBRIS TORRENTS

LAND USE / Sub-Type	1942	1952	1965	1978	1988	1999	TOTAL BY LAND USE	%
FOREST			1				1	0.7%
HARVEST-RELATED								
Clear Cut	5		1	1			7	4.7%
Partial Cut	2	2	2				6	4.1%
Harvested in last 20yr	12	10	3	2	1	1	29	19.6%
Harvest older than 20yr	16	20	25	7	7	3	78	52.7%
Skid Trail				4	1	1	6	4.1%
TOTAL:	35	32	31	14	9	5	126	85.1%
ROAD-RELATED								
Road Cut			2				2	1.4%
Road Fill		4	8	4	1	2	19	12.8%
Railroad Cut								
Railroad Fill								
TOTAL:	0	4	10	4	1	2	21	14.2%
GRAZING								
TOTAL BY PERIOD	35	36	42	18	10	7	148	100%
% of TOTAL	23.6%	24.3%	28.4%	12.2%	6.8%	4.7%	100.0%	

SLIDES

LAND USE / Sub-Type	1942	1952	1965	1978	1988	1999	TOTAL BY LAND USE	%
FOREST	11	16	7	1	1		36	1.9%
HARVEST-RELATED								
Clear Cut	38	6	6		1	7	58	3.1%
Partial Cut	10	8	9	1	1		29	1.6%
Harvested in last 20yr	112	106	42	19	10	11	300	16.1%
Harvest older than 20yr	152	129	243	44	50	42	660	35.5%
Skid Trail	6	21	29	78	29	12	175	9.4%
TOTAL:	318	270	329	142	91	72	1222	65.7%
ROAD-RELATED								
Road Cut	22	61	46	14	17	15	175	9.4%
Road Fill	26	66	142	49	35	22	340	18.3%
Railroad Cut	22	11	3				36	1.9%
Railroad Fill	4	1	1			1	7	0.4%
TOTAL:	74	139	192	63	52	38	558	30.0%
GRAZING	6	14	2	3	1	2	28	1.5%
Undetermined	1	1	12		1	2	17	0.9%
TOTAL BY PERIOD	410	440	542	209	146	114	1861	100%
% of TOTAL	22.0%	23.6%	29.1%	11.2%	7.8%	6.1%	100.0%	

TABLE 18

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

NUMBER OF DELIVERING SLIDES BY LAND USE BY WATERSHED FOR ENTIRE STUDY PERIOD

PLANNING WATERSHED	FOREST		HARVEST							ROADS						GRAZING		TOTAL
Sub-Watershed	(#)	(%)	Clear Cut	Partial Cut	Harvest (<20 yrs)	Harvest (>20 yrs)	Skid Trails	HARVEST TOTAL #	(%)	Road Cut	Road Fill	RR Cut	RR Fill	ROADS TOTAL #	(%)	(#)	(%)	(Number)
NORTH FORK TEN MILE	14	2.9%	22	16	58	75	58	229	47.0%	57	151	20	3	232	47.6%	12	2.5%	487
Upper North Fork Ten Mile River	2	5.0%	0	0	7	3	3	13	32.5%	2	11	0	0	13	32.5%	12	30.0%	40
Middle North Fork Ten Mile River	2	2.2%	0	3	6	7	7	23	25.6%	13	52	0	0	65	72.2%	0	0.0%	90
Bald Hill Creek	2	2.1%	0	2	15	9	19	45	46.9%	11	38	0	0	49	51.0%	0	0.0%	96
Lower North Fork Ten Mile River	4	2.4%	16	5	16	26	17	80	47.1%	26	43	14	3	86	50.6%	0	0.0%	170
Little North Fork Ten Mile River	4	4.4%	6	6	14	30	12	68	74.7%	5	8	6	0	19	20.9%	0	0.0%	91
MIDDLE FORK TEN MILE	21	3.9%	14	15	60	127	96	312	57.9%	74	114	14	4	206	38.2%	0	0.0%	539
Upper Middle Fork Ten Mile River	13	9.9%	1	0	17	29	22	69	52.7%	8	39	0	2	49	37.4%	0	0.0%	131
Middle Middle Fork Ten Mile River	5	4.2%	2	1	0	54	17	74	61.7%	11	30	0	0	41	34.2%	0	0.0%	120
Little Bear Haven Creek	0	0.0%	0	0	3	19	14	36	72.0%	1	13	0	0	14	28.0%	0	0.0%	50
Bear Haven Creek	2	3.2%	1	4	30	9	3	47	74.6%	8	3	1	2	14	22.2%	0	0.0%	63
Lower Middle Fork Ten Mile River	1	0.6%	10	10	10	16	40	86	49.1%	46	29	13	0	88	50.3%	0	0.0%	175
SOUTH FORK TEN MILE	2	0.3%	12	3	215	464	7	701	89.9%	28	40	2	0	70	9.0%	7	0.9%	780
Upper South Fork Ten Mile River	0	0.0%	1	0	6	115	2	124	91.9%	1	10	0	0	11	8.1%	0	0.0%	135
Redwood Creek	0	0.0%	0	0	38	52	0	90	95.7%	1	3	0	0	4	4.3%	0	0.0%	94
Churchman Creek	0	0.0%	3	2	15	36	3	59	67.0%	9	20	0	0	29	33.0%	0	0.0%	88
Middle South Fork Ten Mile River	0	0.0%	3	0	32	76	1	112	86.8%	12	5	0	0	17	13.2%	0	0.0%	129
Campbell Creek	0	0.0%	1	0	22	85	0	108	100.0%	0	0	0	0	0	0.0%	0	0.0%	108
Smith Creek	1	0.5%	3	0	94	93	1	191	96.5%	5	1	0	0	6	3.0%	0	0.0%	198
Lower South Fork Ten Mile River	1	3.6%	1	1	8	7	0	17	60.7%	0	1	2	0	3	10.7%	7	25.0%	28
LOWER TEN MILE	5	2.5%	17	0	27	41	19	104	51.5%	21	53	7	0	81	40.1%	12	5.9%	202
Mainstem Ten Mile River	2	2.3%	16	0	10	24	6	56	65.1%	10	13	4	0	27	31.4%	1	1.2%	86
Mill Creek	3	3.3%	1	0	17	12	13	43	47.3%	6	39	0	0	45	49.5%	0	0.0%	91
Ten Mile River Estuary	0	0.0%	0	0	0	5	0	5	20.0%	5	1	3	0	9	36.0%	11	44.0%	25
TEN MILE RIVER WATERSHED	42	2.1%	65	34	360	707	180	1346	67.0%	180	358	43	7	589	29.3%	31	1.5%	2008

TABLE 19

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

VOLUME OF DELIVERING SLIDES BY STUDY PERIOD BY WATERSHED

PLANNING WATERSHED	Drainage Area	1942		1952		1965		1978		1988		1999		TOTAL		
Sub-Watershed	(mi^2)	(tons)	(%)	(tons)	(%)	(tons)	(%)	(tons)	(%)	(tons)	(%)	(tons)	(%)	(tons)	(% of Total for Entire Watershed for Entire Period)	(% of PW or SW)
NORTH FORK TEN MILE	**38.97**	268,792	20%	220,139	27%	917,343	49%	123,857	29%	413,805	70%	61,574	41%	2,005,511		38.3%
Percent of Total for SW 1942-1999			13%		11%		46%		6%		21%		3%			
Upper North Fork Ten Mile River	10.40	-	0%	15,895	2%	53,410	3%	3,624	1%	2,235	0%	1,064	1%	76,227	1.46%	3.8%
Middle North Fork Ten Mile River	8.98	3,909	0%	46,928	6%	646,227	34%	13,445	3%	370,765	63%	40,602	27%	1,121,876	21.42%	55.9%
Bald Hill Creek	5.14	715	0%	56,223	7%	66,039	4%	57,299	14%	22,580	4%	3,732	2%	206,588	3.95%	10.3%
Lower North Fork Ten Mile River	6.70	191,848	14%	83,321	10%	100,085	5%	24,753	6%	10,793	2%	6,811	5%	417,611	7.97%	20.8%
Little North Fork Ten Mile River	7.75	72,321	5%	17,772	2%	51,583	3%	24,737	6%	7,433	1%	9,364	6%	183,209	3.50%	9.1%
MIDDLE FORK TEN MILE	**33.45**	140,186	10%	279,598	34%	580,636	31%	152,565	36%	89,354	15%	46,310	31%	1,288,649		24.6%
Percent of Total for SW 1942-1999			11%		22%		45%		12%		7%		4%			
Upper Middle Fork Ten Mile River	11.64	-	0%	67,804	8%	190,321	10%	42,435	10%	21,941	4%	6,771	5%	329,272	6.29%	25.6%
Middle Middle Fork Ten Mile River	6.45	5,597	0%	46,690	6%	185,228	10%	20,550	5%	27,212	5%	9,831	7%	295,108	5.64%	22.9%
Little Bear Haven Creek	3.00	-	0%	26,500	3%	28,256	2%	21,476	5%	7,427	1%	1,369	1%	85,028	1.62%	6.6%
Bear Haven Creek	6.60	14,905	1%	48,462	6%	63,237	3%	9,628	2%	5,820	1%	2,430	2%	144,483	2.76%	11.2%
Lower Middle Fork Ten Mile River	5.76	119,685	9%	90,142	11%	113,593	6%	58,476	14%	26,952	5%	25,909	17%	434,758	8.30%	33.7%
SOUTH FORK TEN MILE	**38.39**	831,991	61%	285,893	35%	293,594	16%	85,400	20%	50,476	9%	32,634	22%	1,579,988		30.2%
Percent of Total for SW 1942-1999			53%		18%		19%		5%		3%		2%			
Upper South Fork Ten Mile River	8.18	18,445	1%	29,179	4%	107,335	6%	32,111	8%	16,966	3%	1,959	1%	205,995	3.93%	13.0%
Redwood Creek	7.87	94,948	7%	17,884	2%	20,762	1%	8,353	2%	1,615	0%	2,152	1%	145,714	2.78%	9.2%
Churchman Creek	3.96	16,458	1%	70,080	9%	47,661	3%	27,400	6%	13,398	2%	9,026	6%	184,023	3.51%	11.6%
Middle South Fork Ten Mile River	5.52	129,156	9%	42,443	5%	79,197	4%	4,099	1%	7,579	1%	8,993	6%	271,467	5.18%	17.2%
Campbell Creek	4.25	267,734	20%	54,794	7%	20,456	1%	5,472	1%	3,146	1%	1,440	1%	353,043	6.74%	22.3%
Smith Creek	5.49	269,308	20%	69,340	8%	17,641	1%	7,431	2%	7,772	1%	6,598	4%	378,092	7.22%	23.9%
Lower South Fork Ten Mile River	3.12	35,941	3%	2,173	0%	541	0%	534	0%		0%	2,466	2%	41,654	0.80%	2.6%
LOWER TEN MILE	**8.83**	127,615	9%	37,100	5%	92,103	5%	61,577	15%	35,154	6%	8,808	6%	362,357		6.9%
Percent of Total for SW 1942-1999			35%		10%		25%		17%		10%		2%			
Mainstem Ten Mile River	4.28	104,074	8%	27,157	3%	70,591	4%	17,141	4%	1,738	0%	3,420	2%	224,122	4.28%	61.9%
Mill Creek	2.71	6,338	0%	8,336	1%	21,512	1%	43,642	10%	33,088	6%	5,388	4%	118,304	2.26%	32.6%
Ten Mile River Estuary	1.84	17,202	1%	1,607	0%	-	0%	794	0%	328	0%	-	0%	19,931	0.38%	5.5%
TEN MILE RIVER WATERSHED	**119.64**	1,368,585	100%	822,730	100%	1,883,676	100%	423,400	100%	588,789	100%	149,326	100%	5,236,505	100%	100%
% of Total for Entire Period 1942-1999			26%		16%		36%		8%		11%		3%	100%		

TABLE 20

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

UNIT AREA VOLUMES OF SLIDES BY STUDY PERIOD BY WATERSHED

PLANNING WATERSHED Sub-Watershed	Drainage Area (mi^2)	1942 (Tons/mi^2 for Period)	1952 (Tons/mi^2 for Period)	1965 (Tons/mi^2 for Period)	1978 (Tons/mi^2 for Period)	1988 (Tons/mi^2 for Period)	1999 (Tons/mi^2 for Period)	TOTAL (Tons/mi^2 for Period)
NORTH FORK TEN MILE	**38.97**	6897	5649	23540	3178	10619	1580	63521
Upper North Fork Ten Mile River	10.40	0	1528	5136	348	215	102	7327
Middle North Fork Ten Mile River	8.98	435	5226	71963	1497	41288	4521	177261
Bald Hill Creek	5.14	139	10938	12848	11148	4393	726	40195
Lower North Fork Ten Mile River	6.70	28634	12436	14938	3695	1611	1017	62328
Little North Fork Ten Mile River	7.75	9332	2293	6656	3192	959	1208	23639
MIDDLE FORK TEN MILE	**33.45**	4191	8359	17358	4561	2671	1384	38526
Upper Middle Fork Ten Mile River	11.64	0	5825	16351	3646	1885	582	28290
Middle Middle Fork Ten Mile River	6.45	868	7239	28718	3186	4219	1524	45752
Little Bear Haven Creek	3.00	0	8833	9419	7159	2476	456	28333
Bear Haven Creek	6.60	2258	7343	9581	1459	882	368	21894
Lower Middle Fork Ten Mile River	5.76	20779	15650	19721	10152	4679	4498	75486
SOUTH FORK TEN MILE	**38.39**	21672	7447	7648	2225	1315	850	41157
Upper South Fork Ten Mile River	8.18	2255	3567	13122	3926	2074	239	25183
Redwood Creek	7.87	12065	2272	2638	1061	205	273	18513
Churchman Creek	3.96	4156	17697	12036	6919	3383	2279	46465
Middle South Fork Ten Mile River	5.52	23398	7689	14347	742	1373	1629	49185
Campbell Creek	4.25	62996	12893	4813	1288	740	339	83059
Smith Creek	5.49	49054	12630	3213	1354	1416	1202	68871
Lower South Fork Ten Mile River	3.12	11519	696	173	171	0	790	13365
LOWER TEN MILE	**8.83**	14452	4202	10431	6974	3981	998	41031
Mainstem Ten Mile River	4.28	24316	6345	16493	4005	406	799	52360
Mill Creek	2.71	2339	3076	7938	16104	12210	1988	43653
Ten Mile River Estuary	1.84	9349	873	0	431	178	0	10815
TEN MILE RIVER WATERSHED	**119.64**	11,439	6877	15745	3539	4921	1248	47696

TABLE 21

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

VOLUMES OF DELIVERING SLIDES BY LAND USE BY WATERSHED FOR ENTIRE STUDY PERIOD

(ALL VALUES IN TONS)

PLANNING WATERSHED	Drainage Area	FOREST	HARVEST						ROADS					GRAZING	TOTAL
Sub-Watershed	(mi^2)		Clear Cut	Partial Cut	Harvest (<20 yrs)	Harvest (>20 yrs)	Skid Trails	TOTAL	Road Cut	Road Fill	RR Cut	RR Fill	TOTAL		(Tons for Period)
NORTH FORK TEN MILE	**38.97**	56,576	53,529	45,578	135,147	641,468	130,763	1,006,485	125,656	749,962	49,055	6,824	931,496	10,954	2,005,511
Upper North Fork Ten Mile River	10.40	4,941	-	-	12,325	2,890	1,060	16,275	2,232	41,825	-	-	44,057	10,954	76,227
Middle North Fork Ten Mile River	8.98	3,441	-	24,578	3,244	530,814	6,358	564,994	34,824	518,615	-	-	553,440	-	1,121,876
Bald Hill Creek	5.14	21,024	-	4,728	47,818	10,928	47,765	111,239	16,398	57,926	-	-	74,325	-	206,588
Lower North Fork Ten Mile River	6.70	24,706	26,734	7,460	58,860	52,888	26,686	172,629	69,877	118,083	25,492	6,824	220,276	-	417,611
Little North Fork Ten Mile River	7.75	2,463	26,795	8,811	12,899	43,948	48,895	141,348	2,324	13,512	23,563	-	39,398	-	183,209
MIDDLE FORK TEN MILE	**33.45**	46,825	67,191	37,103	128,521	278,888	218,750	730,453	169,912	248,415	49,839	42,271	510,436	-	1,287,713
Upper Middle Fork Ten Mile River	11.64	36,977	525	-	37,354	74,907	54,559	167,345	3,057	82,878	-	39,017	124,951	-	329,272
Middle Middle Fork Ten Mile Rive	6.45	7,645	15,324	3,709	-	134,392	37,653	191,077	7,653	88,732	-	-	96,385	-	295,108
Little Bear Haven Creek	3.00	-	-	-	7,661	32,525	27,849	68,035	258	16,736	-	-	16,994	-	85,028
Bear Haven Creek	6.60	217	681	17,715	72,202	19,489	2,287	112,375	23,644	2,529	1,527	3,254	30,954	-	143,547
Lower Middle Fork Ten Mile River	5.76	1,986	50,661	15,678	11,304	17,576	96,401	191,620	135,301	57,539	48,311	-	241,151	-	434,758
SOUTH FORK TEN MILE	**38.39**	2,345	10,092	21,325	399,041	1,005,749	9,880	1,446,087	46,111	79,773	4,120	-	130,004	1,791	1,580,227
Upper South Fork Ten Mile River	8.18	-	239	-	9,833	171,434	2,443	183,949	2,897	19,387	-	-	22,285	-	206,234
Redwood Creek	7.87	-	-	-	81,421	58,848	-	140,269	421	5,023	-	-	5,445	-	145,714
Churchman Creek	3.96	-	2,723	21,072	22,007	84,732	4,043	134,578	11,131	38,314	-	-	49,445	-	184,023
Middle South Fork Ten Mile River	5.52	-	5,551	-	58,180	174,557	2,601	240,890	15,456	15,121	-	-	30,577	-	271,467
Campbell Creek	4.25	-	272	-	47,188	305,582	-	353,043	-	-	-	-	-	-	353,043
Smith Creek	5.49	1,478	1,008	-	151,896	206,368	793	360,066	16,205	343	-	-	16,548	-	378,092
Lower South Fork Ten Mile River	3.12	867	298	253	28,515	4,226	-	33,291	-	1,585	4,120	-	5,705	1,791	41,654
LOWER TEN MILE	**8.83**	11,607	96,817	-	31,476	61,235	30,185	219,712	39,962	68,359	20,271	-	128,593	2,445	362,357
Mainstem Ten Mile River	4.28	7,231	91,889	-	10,404	46,437	14,846	163,577	20,502	24,203	8,452	-	53,157	158	224,122
Mill Creek	2.71	4,376	4,928	-	21,071	11,777	15,339	53,115	17,182	43,631	-	-	60,813	-	118,304
Ten Mile River Estuary	1.84	-	-	-	-	3,021	-	3,021	2,278	525	11,820	-	14,623	2,287	19,931
TEN MILE RIVER WATERSHED	**119.64**	117,352	227,629	104,006	694,185	1,987,340	389,578	3,402,737	381,641	1,146,509	123,285	49,094	1,700,529	15,190	5,235,808

TABLE 22

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

VOLUMES OF DELIVERING SLIDES BY LAND USE BY WATERSHED AS PERCENTAGE OF PW OR SW TOTAL

(ALL VALUES IN TONS)

PLANNING WATERSHED	Drainage Area	FOREST	HARVEST						ROADS					GRAZING	TOTAL
Sub-Watershed	(mi^2)		Clear Cut	Partial Cut	Harvest (<20 yrs)	Harvest (>20 yrs)	Skid Trails	TOTAL	Road Cut	Road Fill	RR Cut	RR Fill	TOTAL		
NORTH FORK TEN MILE	**38.97**	2.8%	2.7%	2.3%	6.7%	32.0%	6.5%	50.2%	6.3%	37.4%	2.4%	0.3%	46.4%	0.5%	38.3%
Upper North Fork Ten Mile River	10.40	6.5%	0%	0%	16.2%	3.8%	1.4%	21.4%	2.9%	54.9%	0%	0%	57.8%	14.4%	1.5%
Middle North Fork Ten Mile River	8.98	0.3%	0%	2.2%	0.3%	47.3%	0.6%	50.4%	3.1%	46.2%	0%	0%	49.3%	0%	21.4%
Bald Hill Creek	5.14	10.2%	0%	2.3%	23.1%	5.3%	23.1%	53.8%	7.9%	28.0%	0%	0%	36.0%	0%	3.9%
Lower North Fork Ten Mile River	6.70	5.9%	6.4%	1.8%	14.1%	12.7%	6.4%	41.3%	16.7%	28.3%	6.1%	1.6%	52.7%	0%	8.0%
Little North Fork Ten Mile River	7.75	1.3%	14.6%	4.8%	7.0%	24.0%	26.7%	77.2%	1.3%	7.4%	12.9%	0%	21.5%	0%	3.5%
MIDDLE FORK TEN MILE	**33.45**	3.6%	5.2%	2.9%	10.0%	21.7%	17.0%	56.7%	13.2%	19.3%	3.9%	3.3%	39.6%	0.0%	24.6%
Upper Middle Fork Ten Mile River	11.64	11.2%	0.2%	0%	11.3%	22.7%	16.6%	50.8%	0.9%	25.2%	0%	11.8%	37.9%	0%	6.3%
Middle Middle Fork Ten Mile River	6.45	2.6%	5.2%	1.3%	0%	45.5%	12.8%	64.7%	2.6%	30.1%	0%	0%	32.7%	0%	5.6%
Little Bear Haven Creek	3.00	0%	0%	0%	9.0%	38.3%	32.8%	80.0%	0.3%	19.7%	0%	0%	20.0%	0%	1.6%
Bear Haven Creek	6.60	0.2%	0.5%	12.3%	50.3%	13.6%	1.6%	78.3%	16.5%	1.8%	1.1%	2.3%	21.6%	0%	2.7%
Lower Middle Fork Ten Mile River	5.76	0.5%	11.7%	3.6%	2.6%	4.0%	22.2%	44.1%	31.1%	13.2%	11.1%	0%	55.5%	0%	8.3%
SOUTH FORK TEN MILE	**38.39**	0.1%	0.6%	1.3%	25.3%	63.6%	0.6%	91.5%	2.9%	5.0%	0.3%	0.0%	8.2%	0.1%	30.2%
Upper South Fork Ten Mile River	8.18	0%	0.1%	0%	4.8%	83.1%	1.2%	89.2%	1.4%	9.4%	0%	0%	10.8%	0%	3.9%
Redwood Creek	7.87	0%	0%	0%	55.9%	40.4%	0%	96.3%	0.3%	3.4%	0%	0%	3.7%	0%	2.8%
Churchman Creek	3.96	0%	1.5%	11.5%	12.0%	46.0%	2.2%	73.1%	6.0%	20.8%	0%	0%	26.9%	0%	3.5%
Middle South Fork Ten Mile River	5.52	0%	2.0%	0%	21.4%	64.3%	1.0%	88.7%	5.7%	5.6%	0%	0%	11.3%	0%	5.2%
Campbell Creek	4.25	0%	0.1%	0%	13.4%	86.6%	0%	100.0%	0%	0%	0%	0%	0.0%	0%	6.7%
Smith Creek	5.49	0.4%	0.3%	0%	40.2%	54.6%	0.2%	95.2%	4.3%	0.1%	0%	0%	4.4%	0%	7.2%
Lower South Fork Ten Mile River	3.12	2.1%	0.7%	0.6%	68.5%	10.1%	0%	79.9%	0%	3.8%	9.9%	0%	13.7%	4.3%	0.8%
LOWER TEN MILE	**8.83**	3.2%	26.7%	0.0%	8.7%	16.9%	8.3%	60.6%	11.0%	18.9%	5.6%	0.0%	35.5%	0.7%	6.9%
Mainstem Ten Mile River	4.28	3.2%	41.0%	0%	4.6%	20.7%	6.6%	73.0%	9.1%	10.8%	3.8%	0%	23.7%	0.1%	4.3%
Mill Creek	2.71	3.7%	4.2%	0%	17.8%	10.0%	13.0%	44.9%	14.5%	36.9%	0%	0%	51.4%	0%	2.3%
Ten Mile River Estuary	1.84	0%	0%	0%	0%	15.2%	0%	15.2%	11.4%	2.6%	59.3%	0%	73.4%	11.5%	0.4%
TEN MILE RIVER WATERSHED	**119.64**	2.2%	4.3%	2.0%	13.3%	38.0%	7.4%	65.0%	7.3%	21.9%	2.4%	0.9%	32.5%	0.3%	100%

TABLE 23

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

UNIT AREA VOLUMES OF SLIDES BY STUDY PERIOD BY WATERSHED

PLANNING WATERSHED	Drainage Area	1933-1942	1943-1952	1953-1965	1966-1978	1979-1988	1989-1999	TOTAL
Sub-Watershed	(mi^2)	(Tons/mi^2 for Period)	(Tons/mi^2 for Period)	(Tons/mi^2 for Period)	(Tons/mi^2 for Period)	(Tons/mi^2 for Period)	(Tons/mi^2 for Period)	(Tons/mi^2 for Period)
NORTH FORK TEN MILE	**38.97**	**6,897**	**5,649**	**23,540**	**3,178**	**10,619**	**1,580**	**51,463**
Upper North Fork Ten Mile River	10.40	-	1,528	5,136	348	215	102	7,330
Middle North Fork Ten Mile River	8.98	435	5,226	71,963	1,497	41,288	4,521	124,930
Bald Hill Creek	5.14	139	10,938	12,848	11,148	4,393	726	40,192
Lower North Fork Ten Mile River	6.70	28,634	12,436	14,938	3,695	1,611	1,017	62,330
Little North Fork Ten Mile River	7.75	9,332	2,293	6,656	3,192	959	1,208	23,640
MIDDLE FORK TEN MILE	**33.45**	**4,191**	**8,359**	**17,358**	**4,561**	**2,671**	**1,384**	**38,525**
Upper Middle Fork Ten Mile River	11.64	-	5,825	16,351	3,646	1,885	582	28,288
Middle Middle Fork Ten Mile River	6.45	868	7,239	28,718	3,186	4,219	1,524	45,753
Little Bear Haven Creek	3.00	-	8,833	9,419	7,159	2,476	456	28,343
Bear Haven Creek	6.60	2,258	7,343	9,581	1,459	882	368	21,891
Lower Middle Fork Ten Mile River	5.76	20,779	15,650	19,721	10,152	4,679	4,498	75,479
SOUTH FORK TEN MILE	**38.39**	**21,672**	**7,447**	**7,648**	**2,225**	**1,315**	**850**	**41,156**
Upper South Fork Ten Mile River	8.18	2,255	3,567	13,122	3,926	2,074	239	25,183
Redwood Creek	7.87	12,065	2,272	2,638	1,061	205	273	18,515
Churchman Creek	3.96	4,156	17,697	12,036	6,919	3,383	2,279	46,470
Middle South Fork Ten Mile River	5.52	23,398	7,689	14,347	742	1,373	1,629	49,179
Campbell Creek	4.25	62,996	12,893	4,813	1,288	740	339	83,069
Smith Creek	5.49	49,054	12,630	3,213	1,354	1,416	1,202	68,869
Lower South Fork Ten Mile River	3.12	11,519	696	173	171	-	790	13,351
LOWER TEN MILE	**8.83**	**14,452**	**4,202**	**10,431**	**6,974**	**3,981**	**998**	**41,037**
Mainstem Ten Mile River	4.28	24,316	6,345	16,493	4,005	406	799	52,365
Mill Creek	2.71	2,339	3,076	7,938	16,104	12,210	1,988	43,655
Ten Mile River Estuary	1.84	9,349	873	-	431	178	-	10,832
TEN MILE RIVER WATERSHED	**119.64**	**11,439**	**6,877**	**15,745**	**3,539**	**4,921**	**1,248**	**43,769**

TABLE 24

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

AVERAGE ANNUAL UNIT AREA VOLUMES OF SLIDES BY STUDY PERIOD BY WATERSHED

PLANNING WATERSHED / Sub-Watershed	Drainage Area (mi^2)	1942 (10 years, 1933-1942) ($t/mi^2/yr$)	1952 (10 years, 1943-1952) ($t/mi^2/yr$)	1965 (13 years, 1953-1965) ($t/mi^2/yr$)	1978 (13 years, 1966-1978) ($t/mi^2/yr$)	1988 (10 years, 1979-1988) ($t/mi^2/yr$)	1999 (11 years, 1989-1999) ($t/mi^2/yr$)	TOTAL ($t/mi^2/yr$)
NORTH FORK TEN MILE	**38.97**	**690**	**565**	**1,811**	**244**	**1,062**	**144**	**757**
Upper North Fork Ten Mile River	10.40	0	153	395	27	21	9	108
Middle North Fork Ten Mile River	8.98	44	523	5536	115	4129	411	1837
Bald Hill Creek	5.14	14	1094	988	858	439	66	591
Lower North Fork Ten Mile River	6.70	2863	1244	1149	284	161	92	917
Little North Fork Ten Mile River	7.75	933	229	512	246	96	110	348
MIDDLE FORK TEN MILE	**33.45**	**419**	**836**	**1,335**	**351**	**267**	**126**	**567**
Upper Middle Fork Ten Mile River	11.64	0	583	1258	280	188	53	416
Middle Middle Fork Ten Mile River	6.45	87	724	2209	245	422	139	673
Little Bear Haven Creek	3.00	0	883	725	551	248	41	417
Bear Haven Creek	6.60	226	734	737	112	88	33	322
Lower Middle Fork Ten Mile River	5.76	2078	1565	1517	781	468	409	1110
SOUTH FORK TEN MILE	**38.39**	**2,167**	**745**	**588**	**171**	**131**	**77**	**605**
Upper South Fork Ten Mile River	8.18	225	357	1009	302	207	22	370
Redwood Creek	7.87	1206	227	203	82	21	25	272
Churchman Creek	3.96	416	1770	926	532	338	207	683
Middle South Fork Ten Mile River	5.52	2340	769	1104	57	137	148	723
Campbell Creek	4.25	6300	1289	370	99	74	31	1222
Smith Creek	5.49	4905	1263	247	104	142	109	1013
Lower South Fork Ten Mile River	3.12	1152	70	13	13	0	72	196
LOWER TEN MILE	**8.83**	**1,445**	**420**	**802**	**536**	**398**	**91**	**603**
Mainstem Ten Mile River	4.28	2432	635	1269	308	41	73	770
Mill Creek	2.71	234	308	611	1239	1221	181	642
Ten Mile River Estuary	1.84	935	87	0	33	18	0	159
TEN MILE RIVER WATERSHED	**119.64**	**1,144**	**688**	**1,211**	**272**	**492**	**113**	**644**

TABLE 25

EXISTING ROAD TYPES BY PLANNING WATERSHED AND AND SUB-WATERSHED

PLANNING WATERSHED Sub-Watershed	Drainage Area	MILES OF INDICATED ROAD TYPE Highway	Permanent	Seasonal	Temporary	TOTAL BY PW (mi)	TOTAL BY SW (mi)	ROAD DENSITY (mi/mi^2)
NORTH FORK TEN MILE	**38.97**	**0**	**17.17**	**257.77**	**16.70**	**291.63**		**7.48**
Upper North Fork Ten Mile River	10.40	0	0	55.40	6.67		62.07	5.97
Middle North Fork Ten Mile River	8.98	0	0	34.27	2.64		36.91	4.11
Bald Hill Creek	5.14	0	2.04	25.99	1.06		29.09	5.66
Lower North Fork Ten Mile River	6.70	0	5.78	63.23	4.54		73.54	10.98
Little North Fork Ten Mile River	7.75	0	9.35	78.88	1.79		90.01	11.61
MIDDLE FORK TEN MILE	**33.45**	**0**	**9.53**	**243.50**	**2.80**	**255.83**		**7.65**
Upper Middle Fork Ten Mile River	11.64	0	0	84.90	1.24		86.14	7.40
Middle Middle Fork Ten Mile River	6.45	0	1.76	31.28	0.79		33.83	5.24
Little Bear Haven Creek	3.00	0	0.06	19.31	0		19.37	6.46
Bear Haven Creek	6.60	0	0.04	72.32	0.16		72.52	10.99
Lower Middle Fork Ten Mile River	5.76	0	7.66	35.70	0.61		43.96	7.63
SOUTH FORK TEN MILE	**38.39**	**0**	**41.53**	**266.79**	**9.90**	**318.21**		**8.29**
Upper South Fork Ten Mile River	8.18	0	4.00	50.87	1.38		56.2	6.88
Redwood Creek	7.87	0	4.30	59.68	3.78		67.8	8.61
Churchman Creek	3.96	0	1.96	27.35	0		29.3	7.40
Middle South Fork Ten Mile River	5.52	0	13.65	42.14	0.70		56.5	10.23
Campbell Creek	4.25	0	4.87	32.54	2.88		40.3	9.48
Smith Creek	5.49	0	4.82	36.92	0.59		42.3	7.71
Lower South Fork Ten Mile River	3.12	0	7.93	17.29	0.57		25.8	8.26
LOWER TEN MILE	**8.83**	**0.96**	**12.07**	**57.06**	**4.62**	**74.70**		**8.46**
Mainstem Ten Mile River	4.28	0	6.19	28.88	2.88		37.96	8.87
Mill Creek	2.71	0	0.59	21.44	1.74		23.78	8.77
Ten Mile River Estuary	1.84	0.96	5.28	6.73	0		12.97	7.05
TOTAL TEN MILE WATERSHED	**119.64**	**0.96**	**80.29**	**825.11**	**34.02**	**940.38**		**7.86**
% of Total Roads		**0.10%**	**8.54%**	**87.74%**	**3.62%**	**100.00%**		

Notes: Base road data from CDF, substantially added to and corrected to aerial mosaic by GMA.

TABLE 27

ROAD CONSTRUCTION HISTORY BY PLANNING WATERSHED AND AND SUB-WATERSHED

PLANNING WATERSHED Sub-Watershed	Drainage Area	MILES OF ROAD CONSTRUCTED IN PERIOD 1942	1952	1965	1978	1988	1999	TOTAL BY PW OR SW (mi)	% TOTAL WATERSHED ROAD MILES (mi)	PW or SW Road Density (mi/mi2)
NORTH FORK TEN MILE	**38.97**	**34.47**	**59.58**	**65.20**	**35.24**	**8.75**	**88.40**	**291.63**	**31.0%**	**7.48**
	% of PW Total	**11.8%**	**20.4%**	**22.4%**	**12.1%**	**3.0%**	**30.3%**			
Upper North Fork Ten Mile River	10.40	0	10.58	23.50	12.10	7.05	8.83	62.07	6.60%	5.97
Middle North Fork Ten Mile River	8.98	1.30	13.77	16.47	1.38	0.84	3.16	36.91	3.93%	4.11
Bald Hill Creek	5.14	0	15.10	3.36	1.70	0.39	8.53	29.09	3.09%	5.66
Lower North Fork Ten Mile River	6.70	3.10	11.91	8.73	17.07	0.03	32.70	73.54	7.82%	10.98
Little North Fork Ten Mile River	7.75	30.06	8.21	13.15	2.99	0.43	35.17	90.01	9.57%	11.61
MIDDLE FORK TEN MILE	**33.45**	**11.85**	**85.36**	**28.03**	**33.97**	**9.25**	**87.37**	**255.83**	**27.2%**	**7.65**
	% of PW Total	**4.6%**	**33.4%**	**11.0%**	**13.3%**	**3.6%**	**34.2%**			
Upper Middle Fork Ten Mile River	11.64	0	34.60	8.98	4.22	9.25	29.10	86.14	9.16%	7.40
Middle Middle Fork Ten Mile River	6.45	0.39	15.17	4.40	2.72	0	11.15	33.83	3.60%	5.24
Little Bear Haven Creek	3.00	0.52	5.89	0	6.40	0	6.55	19.37	2.06%	6.46
Bear Haven Creek	6.60	3.22	20.69	5.50	16.17	0	26.95	72.52	7.71%	10.99
Lower Middle Fork Ten Mile River	5.76	7.72	9.01	9.15	4.46	0	13.62	43.96	4.67%	7.63
SOUTH FORK TEN MILE	**38.39**	**30.31**	**42.19**	**16.80**	**31.74**	**26.54**	**170.64**	**318.21**	**33.8%**	**8.29**
	% of PW Total	**9.5%**	**13.3%**	**5.3%**	**10.0%**	**8.3%**	**53.6%**			
Upper South Fork Ten Mile River	8.18	1.82	7.61	0.78	7.29	0.16	38.59	56.2	5.98%	6.88
Redwood Creek	7.87	3.97	12.03	3.67	0	7.94	40.16	67.8	7.21%	8.61
Churchman Creek	3.96	0.34	7.20	2.92	0	0	18.84	29.3	3.12%	7.40
Middle South Fork Ten Mile River	5.52	7.46	11.15	2.27	0.25	6.20	29.16	56.5	6.01%	10.23
Campbell Creek	4.25	4.29	1.00	0	16.97	1.48	16.57	40.3	4.28%	9.48
Smith Creek	5.49	5.18	1.84	4.84	1.34	8.77	20.35	42.3	4.50%	7.71
Lower South Fork Ten Mile River	3.12	7.23	1.36	2.32	5.89	2.00	6.98	25.8	2.74%	8.26
LOWER TEN MILE	**8.83**	**21.53**	**14.72**	**13.02**	**8.52**	**6.56**	**10.36**	**74.70**	**7.9%**	**8.46**
	% of PW Total	**28.8%**	**19.7%**	**17.4%**	**11.4%**	**8.8%**	**13.9%**			
Mainstem Ten Mile River	4.28	11.61	8.98	5.65	0.80	6.22	4.69	37.96	4.04%	8.87
Mill Creek	2.71	0.77	5.74	4.89	7.59	0.34	4.45	23.78	2.53%	8.77
Ten Mile River Estuary	1.84	9.15	0	2.48	0.12	0	1.22	12.97	1.38%	7.05
TOTAL TEN MILE WATERSHED	**119.64**	**98.15**	**201.84**	**123.05**	**109.47**	**51.10**	**356.76**	**940.38**	**100.0%**	**7.86**
% of Total Roads		**10.44%**	**21.46%**	**13.08%**	**11.64%**	**5.43%**	**37.94%**	**100.00%**		

Notes: Base road data from CDF, substantially added to and corrected to aerial mosaic by GMA.
Eastern portion of watershed not covered by 1942 aerial photographs.
Road segments not codified by year by CDF or mapped into specific period by John Coyle are all included in 1999 period.

TABLE 28

CUMULATIVE MILES OF ROADS BY PLANNING WATERSHED AND AND SUB-WATERSHED

PLANNING WATERSHED		CUMULATIVE MILES OF ROADS BY PERIOD					
Sub-Watershed	Drainage Area	1942	1952	1965	1978	1988	1999
NORTH FORK TEN MILE	**38.97**	**34.5**	**94.0**	**159.2**	**194.5**	**203.2**	**291.6**
	% of PW Total	**11.8%**	**32.2%**	**54.6%**	**66.7%**	**69.7%**	**100.0%**
Upper North Fork Ten Mile River	10.40	0	10.6	34.1	46.2	53.2	62.1
Middle North Fork Ten Mile River	8.98	1.3	15.1	31.5	32.9	33.8	36.9
Bald Hill Creek	5.14	0.0	15.1	18.5	20.2	20.6	29.1
Lower North Fork Ten Mile River	6.70	3.1	15.0	23.7	40.8	40.8	73.5
Little North Fork Ten Mile River	7.75	30.1	38.3	51.4	54.4	54.8	90.0
MIDDLE FORK TEN MILE	**33.45**	**11.9**	**97.2**	**125.2**	**159.2**	**168.5**	**255.8**
	% of PW Total	**4.6%**	**38.0%**	**49.0%**	**62.2%**	**65.8%**	**100.0%**
Upper Middle Fork Ten Mile River	11.64	0	34.6	43.6	47.8	57.0	86.1
Middle Middle Fork Ten Mile River	6.45	0.4	15.6	20.0	22.7	22.7	33.8
Little Bear Haven Creek	3.00	0.5	6.4	6.4	12.8	12.8	19.4
Bear Haven Creek	6.60	3.2	23.9	29.4	45.6	45.6	72.5
Lower Middle Fork Ten Mile River	5.76	7.7	16.7	25.9	30.3	30.3	44.0
SOUTH FORK TEN MILE	**38.39**	**30.3**	**72.5**	**89.3**	**121.0**	**147.6**	**318.2**
	% of PW Total	**9.5%**	**22.8%**	**28.1%**	**38.0%**	**46.4%**	**100.0%**
Upper South Fork Ten Mile River	8.18	1.8	9.4	10.2	17.5	17.7	56.2
Redwood Creek	7.87	4.0	16.0	19.7	19.7	27.6	67.8
Churchman Creek	3.96	0.3	7.5	10.5	10.5	10.5	29.3
Middle South Fork Ten Mile River	5.52	7.5	18.6	20.9	21.1	27.3	56.5
Campbell Creek	4.25	4.3	5.3	5.3	22.3	23.7	40.3
Smith Creek	5.49	5.2	7.0	11.9	13.2	22.0	42.3
Lower South Fork Ten Mile River	3.12	7.2	8.6	10.9	16.8	18.8	25.8
LOWER TEN MILE	**8.83**	**21.5**	**36.2**	**49.3**	**57.8**	**64.3**	**74.7**
	% of PW Total	**28.8%**	**48.5%**	**66.0%**	**77.4%**	**86.1%**	**100.0%**
Mainstem Ten Mile River	4.28	11.6	20.6	26.2	27.0	33.3	38.0
Mill Creek	2.71	0.8	6.5	11.4	19.0	19.3	23.8
Ten Mile River Estuary	1.84	9.1	9.1	11.6	11.8	11.8	13.0
TOTAL TEN MILE WATERSHED	**119.64**	**98.15**	**300.00**	**423.04**	**532.51**	**583.61**	**940.38**
% of Total Roads		**10.44%**	**31.90%**	**44.99%**	**56.63%**	**62.06%**	**100.00%**

Notes: Base road data from CDF, substantially added to and corrected to aerial mosaic by GMA.
Eastern portion of watershed not covered by 1942 aerial photographs.
Road segments not codified by year by CDF or mapped into specific period by John Coyle are all included in 1999 period.

TABLE 29

ROAD CONSTRUCTION HISTORY BY PLANNING WATERSHED AND AND SUB-WATERSHED

PLANNING WATERSHED		COMPUTED SURFACE EROSION FROM ROADS BY PERIOD (tons/yr)						TOTAL BY PW OR SW	% TOTAL WATERSHED ROAD SURFACE EROSION	1999 UNIT AREA ROAD SURFACE EROSION
Sub-Watershed	Drainage Area	1942	1952	1965	1978	1988	1999	(mi)	(mi)	(tons/mi^2/yr)
NORTH FORK TEN MILE	38.97	1,641	4,477	7,580	9,258	7,739	8,329	39,023	34.4%	213.7
	% of PW Total	4.2%	11.5%	19.4%	23.7%	19.8%	21.3%			
Upper North Fork Ten Mile River	10.40	-	504	1,622	2,198	2,027	1,773	8,125	7.2%	170.5
Middle North Fork Ten Mile River	8.98	62	717	1,501	1,567	1,285	1,054	6,187	5.5%	117.4
Bald Hill Creek	5.14	-	719	879	960	783	831	4,171	3.7%	161.6
Lower North Fork Ten Mile River	6.70	148	714	1,130	1,943	1,555	2,100	7,590	6.7%	313.5
Little North Fork Ten Mile River	7.75	1,431	1,822	2,448	2,590	2,088	2,571	12,950	11.4%	331.7
MIDDLE FORK TEN MILE	33.45	564	4,627	5,961	7,578	6,415	7,306	32,452	28.6%	218.4
	% of PW Total	1.7%	14.3%	18.4%	23.4%	19.8%	22.5%			
Upper Middle Fork Ten Mile River	11.64	-	1,647	2,074	2,275	2,172	2,460	10,629	9.4%	211.4
Middle Middle Fork Ten Mile River	6.45	19	741	950	1,080	864	966	4,619	4.1%	149.8
Little Bear Haven Creek	3.00	25	305	305	610	488	553	2,287	2.0%	184.4
Bear Haven Creek	6.60	153	1,138	1,400	2,169	1,735	2,071	8,667	7.6%	313.8
Lower Middle Fork Ten Mile River	5.76	367	796	1,232	1,444	1,155	1,256	6,250	5.5%	218.0
SOUTH FORK TEN MILE	38.39	1,443	3,451	4,250	5,761	5,620	9,088	29,613	26.1%	236.7
	% of PW Total	4.9%	11.7%	14.4%	19.5%	19.0%	30.7%			
Upper South Fork Ten Mile River	8.18	87	449	486	833	672	1,606	4,134	3.6%	196.4
Redwood Creek	7.87	189	762	937	937	1,052	1,936	5,812	5.1%	245.9
Churchman Creek	3.96	16	359	498	498	399	837	2,608	2.3%	211.3
Middle South Fork Ten Mile River	5.52	355	886	994	1,006	1,040	1,613	5,894	5.2%	292.3
Campbell Creek	4.25	204	251	251	1,059	904	1,151	3,821	3.4%	270.8
Smith Creek	5.49	247	334	565	629	837	1,209	3,820	3.4%	220.2
Lower South Fork Ten Mile River	3.12	344	409	519	800	716	736	3,525	3.1%	236.0
LOWER TEN MILE	8.83	1,025	1,725	2,345	2,751	2,450	2,134	12,430	10.9%	241.6
	% of PW Total	8.2%	13.9%	18.9%	22.1%	19.7%	17.2%			
Mainstem Ten Mile River	4.28	552	980	1,249	1,287	1,267	1,084	6,420	5.7%	253.3
Mill Creek	2.71	37	310	543	904	736	679	3,208	2.8%	250.6
Ten Mile River Estuary	1.84	436	436	554	559	448	371	2,802	2.5%	201.4
TOTAL TEN MILE WATERSHED	119.64	4,672	14,280	20,137	25,348	22,224	26,857	113,518	100.0%	224.5
% of Total Roads		4.1%	12.6%	17.7%	22.3%	19.6%	23.7%	100%		

Notes: Base road data from CDF, substantially added to and corrected to aerial mosaic by GMA.
Eastern portion of watershed not covered by 1942 aerial photographs.
Road segments not codified by year by CDF or mapped into specific period by John Coyle are all included in 1999 period.
Surface erosion computed using method of Reid (1981) based on use function analysis (High, Moderate, Low, None) and application of sediment production rate (800, 80, 8, 0.8 tons/yr) modified by factors of 0.8 in 1988 and 0.6 in 1999.

TABLE 30

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

HARVEST ACRES BY STUDY PERIOD BY WATERSHED

PLANNING WATERSHED	Drainage Area		1942		1952		1965		1978		1988		1999		TOTAL	
Sub-Watershed	(mi^2)	(acres)	(acres)	(%)	(acres)	(%)	(acres)	(%)	(acres)	(%)	(acres)	(%)	(acres)	(%)	(acres)	(%)
NORTH FORK TEN MILE	**38.97**	**24941**	**6062**	**24%**	**5670**	**23%**	**6484**	**26%**	**2188**	**9%**	**114**	**0%**	**5519**	**22%**	**26,035**	
Upper North Fork Ten Mile River	10.40	6656	0	0%	32	0%	2671	40%	40	1%	62	1%	428	6%	3,233	49%
Middle North Fork Ten Mile River	8.98	5747	2	0%	1927	34%	3302	57%	273	5%	51	1%	213	4%	5,768	100%
Bald Hill Creek	5.14	3290	60	2%	2657	81%	0	0%	1437	44%	0	0%	479	15%	4,633	141%
Lower North Fork Ten Mile River	6.70	4288	3183	74%	454	11%	243	6%	80	2%	0	0%	2527	59%	6,487	151%
Little North Fork Ten Mile River	7.75	4960	2817	57%	600	12%	267	5%	359	7%	0	0%	1872	38%	5,914	119%
MIDDLE FORK TEN MILE	**33.45**	**21408**	**5240**	**24%**	**9682**	**45%**	**5272**	**25%**	**700**	**3%**	**0**	**0%**	**7320**	**34%**	**28,214**	
Upper Middle Fork Ten Mile River	11.64	7450	2958	40%	1343	18%	2037	27%	142	2%	0	0%	2789	37%	9,269	124%
Middle Middle Fork Ten Mile River	6.45	4128	2	0%	3111	75%	1130	27%	0	0%	0	0%	574	14%	4,817	117%
Little Bear Haven Creek	3.00	1920	0	0%	1918	100%	2	0%	2	0%	0	0%	542	28%	2,465	128%
Bear Haven Creek	6.60	4224	835	20%	2935	69%	293	7%	211	5%	0	0%	2393	57%	6,667	158%
Lower Middle Fork Ten Mile River	5.76	3686	1445	39%	375	10%	1809	49%	344	9%	0	0%	1022	28%	4,996	136%
SOUTH FORK TEN MILE	**38.39**	**24570**	**21341**	**87%**	**2474**	**10%**	**740**	**3%**	**897**	**4%**	**1233**	**5%**	**18738**	**76%**	**45,424**	
Upper South Fork Ten Mile River	8.18	5235	4987	95%	6	0%	124	2%	897	17%	25	0%	3363	64%	9,402	180%
Redwood Creek	7.87	5037	4617	92%	272	5%	122	2%	0	0%	363	7%	4107	82%	9,480	188%
Churchman Creek	3.96	2534	763	30%	1755	69%	179	7%	0	0%	0	0%	1670	66%	4,366	172%
Middle South Fork Ten Mile River	5.52	3533	3519	100%	12	0%	0	0%	0	0%	190	5%	2909	82%	6,630	188%
Campbell Creek	4.25	2720	2720	100%	0	0%	0	0%	0	0%	52	2%	3002	110%	5,774	212%
Smith Creek	5.49	3514	3187	91%	27	1%	296	8%	0	0%	512	15%	2828	80%	6,850	195%
Lower South Fork Ten Mile River	3.12	1997	1548	78%	402	20%	19	1%	0	0%	93	5%	859	43%	2,921	146%
LOWER TEN MILE	**8.83**	**5651**	**2386**	**42%**	**2745**	**49%**	**516**	**9%**	**62**	**1%**	**140**	**2%**	**632**	**11%**	**6,481**	
Mainstem Ten Mile River	4.28	2739	1840	67%	620	23%	265	10%	1	0%	0	0%	225	8%	2,951	108%
Mill Creek	2.71	1734	546	31%	945	54%	231	13%	61	4%	140	8%	399	23%	2,323	134%
Ten Mile River Estuary	1.84	1178	0	0%	1179	100%	20	2%	0	0%	0	0%	8	1%	1,208	103%
TEN MILE RIVER WATERSHED	**119.64**	**76570**	**35030**	**46%**	**20570**	**27%**	**13011**	**17%**	**3847**	**5%**	**1487**	**2%**	**32209**	**42%**	**106,154**	**139%**

NOTES: Base data for 1999 period from CDF; All other data from aerial photo mapping. Values in excess of 100% indicate multiple harvest entries in that period.

TABLE 31

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

SUMMARY OF HARVEST AREAS BY SKID TRAIL DENSITY BY STUDY PERIOD BY WATERSHED

PLANNING WATERSHED			1942	1952				1965				1978				1988				1999							TOTAL	
	Drainage Area		HIGH	HIGH	MEDIUM	LOW	TOTAL	HIGH	MEDIUM	LOW	TOTAL	HIGH	MEDIUM	LOW	TOTAL	MEDIUM	LOW	CLEAR CUT	TOTAL	MEDIUM	LOW	CLEAR CUT	CABLE	NARROW CLEAR CUT	PARTIAL CUT	TOTAL	TOTAL HARVEST BY PW OR SW	PERCENT OF PW OR SW HARVESTED ENTIRE PERIOD
Sub-Watershed	(mi^2)	(acres)	(acres)	(acres)				(acres)				(acres)				(acres)				(acres)							(acres)	(%)
NORTH FORK TEN MILE	38.97	24941	6062	1754	687	3228	5670	5338	1141	5	6484	2034	24	131	2188	0	114	0	114	0	20	714	21	0	4763	5519	26,035	104%
Upper North Fork Ten Mile River	10.40	6656	0	28	0	5	32	2666	0	5	2671	0	0	40	40	0	62	0	62	0	0	109	0	0	319	428	3,233	49%
Middle North Fork Ten Mile River	8.98	5747	2	835	88	1003	1927	2473	829	0	3302	273	0	0	273	0	51	0	51	0	0	0	0	0	213	213	5,768	100%
Bald Hill Creek	5.14	3290	60	784	138	1734	2657	0	0	0	0	1437	0	0	1437	0	0	0	0	0	7	68	1	0	402	479	4,633	141%
Lower North Fork Ten Mile River	6.70	4288	3183	108	0	346	454	135	108	0	243	80	0	0	80	0	0	0	0	0	13	219	20	0	2275	2527	6,487	151%
Little North Fork Ten Mile River	7.75	4960	2817	0	461	139	600	63	204	0	267	244	24	91	359	0	0	0	0	0	0	318	0	0	1554	1872	5,914	119%
MIDDLE FORK TEN MILE	33.45	21408	5240	4833	390	4458	9682	3709	850	713	5272	558	0	142	700	0	0	0	0	0	0	1006	42	10	6262	7320	28,214	132%
Upper Middle Fork Ten Mile River	11.64	7450	2958	1171	8	165	1343	887	437	713	2037	0	0	142	142	0	0	0	0	0	0	885	0	0	1904	2789	9,269	124%
Middle Middle Fork Ten Mile River	6.45	4128	2	2077	150	883	3111	923	207	0	1130	0	0	0	0	0	0	0	0	0	0	84	0	0	490	574	4,817	117%
Little Bear Haven Creek	3.00	1920	0	1480	46	392	1918	2	0	0	2	2	0	0	2	0	0	0	0	0	0	0	0	2	540	542	2,465	128%
Bear Haven Creek	6.60	4224	835	43	105	2787	2935	87	206	0	293	211	0	0	211	0	0	0	0	0	0	26	42	0	2325	2393	6,667	158%
Lower Middle Fork Ten Mile River	5.76	3686	1445	63	82	230	375	1809	0	0	1809	344	0	0	344	0	0	0	0	0	0	11	0	8	1003	1022	4,996	136%
SOUTH FORK TEN MILE	38.39	24570	21341	1885	281	308	2474	327	166	247	740	443	0	454	897	166	393	674	1233	0	48	3938	46	3	14704	18738	45,424	185%
Upper South Fork Ten Mile River	8.18	5235	4987	6	0	0	6	0	75	49	124	443	0	454	897	0	25	0	25	0	0	666	7	0	2689	3363	9,402	180%
Redwood Creek	7.87	5037	4617	4	195	73	272	30	91	0	122	0	0	0	0	112	250	0	363	0	0	909	21	1	3175	4107	9,480	188%
Churchman Creek	3.96	2534	763	1541	0	213	1755	0	0	179	179	0	0	0	0	0	0	0	0	0	3	52	0	2	1613	1670	4,366	172%
Middle South Fork Ten Mile River	5.52	3533	3519	3	0	9	12	0	0	0	0	0	0	0	0	53	75	62	190	0	0	716	15	0	2179	2909	6,630	188%
Campbell Creek	4.25	2720	2720	0	0	0	0	0	0	0	0	0	0	0	0	1	1	49	52	0	0	692	1	0	2309	3002	5,774	212%
Smith Creek	5.49	3514	3187	14	0	12	27	296	0	0	296	0	0	0	0	0	41	471	512	0	45	769	0	0	2014	2828	6,850	195%
Lower South Fork Ten Mile River	3.12	1997	1548	316	85	0	402	0	0	19	19	0	0	0	0	0	0	93	93	0	0	134	1	0	725	859	2,921	146%
LOWER TEN MILE	8.83	5651	2386	2745	0	0	2745	332	0	184	516	1	61	0	62	0	0	140	140	0	0	58	1	0	573	632	6,481	115%
Mainstem Ten Mile River	4.28	2739	1840	620	0	0	620	137	0	127	265	1	0	0	1	0	0	0	0	0	0	1	0	0	224	225	2,951	108%
Mill Creek	2.71	1734	546	945	0	0	945	195	0	37	231	0	61	0	61	0	0	140	140	0	0	58	1	0	340	399	2,323	134%
Ten Mile River Estuary	1.84	1178	0	1179	0	0	1179	0	0	20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8	1,208	103%
TEN MILE RIVER WATERSHED	119.64	76570	35030	11218	1358	7994	20570	9705	2157	1150	13011	3035	85	727	3847	166	507	814	1487	0	68	5716	110	13	26302	32209	106,154	139%

NOTES: Base data for 1999 period from CDF; All other data from aerial photo mapping. Values in excess of 100% indicate multiple harvest entries in that period.

TABLE 32

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

SUMMARY OF SURFACE EROSION ESTIMATES FROM HARVEST AREAS BY SKID TRAIL DENSITY BY STUDY PERIOD BY WATERSHED

PLANNING WATERSHED	Drainage Area		1933-1942	1943-1952				1953-1965				1966-1978				1979-1988				1989-1999							TOTAL	
Sub-Watershed	(mi^2)	(acres)	HIGH (tons)	HIGH	MEDIUM (tons)	LOW	TOTAL	HIGH	MEDIUM (tons)	LOW	TOTAL	HIGH	MEDIUM (tons)	LOW	TOTAL	MEDIUM	LOW (tons)	CLEAR CUT	TOTAL	MEDIUM	LOW	CLEAR CUT	CABLE (tons)	NARROW CLEAR CUT	PARTIAL CUT	TOTAL	TOTAL EROSION BY PW OR SW (tons)	PERCENT OF PW OR SW HARVESTED ENTIRE PERIOD (%)
NORTH FORK TEN MILE	38.97	24941	22732	6578	1933	6053	14564	20017	3208	10	23235	7626	67	245	7938	0	213	0	213	0	37	446	13	0	2977	3474	72,155	27%
Upper North Fork Ten Mile River	10.40	6656	0	103	0	9	113	9997	0	10	10007	0	0	74	74	0	117	0	117	0	0	68	0	0	199	268	10,578	3.9%
Middle North Fork Ten Mile River	8.98	5747	9	3129	249	1882	5260	9275	2331	0	11606	1023	0	0	1023	0	96	0	96	0	0	0	0	0	133	133	18,127	6.7%
Bald Hill Creek	5.14	3290	225	2941	388	3252	6581	0	0	0	0	5388	0	0	5388	0	0	0	0	0	13	43	1	0	251	308	12,503	4.6%
Lower North Fork Ten Mile River	6.70	4288	11936	404	0	649	1052	506	304	0	811	300	0	1	301	0	0	0	0	0	24	137	13	0	1422	1595	15,694	5.8%
Little North Fork Ten Mile River	7.75	4960	10562	0	1296	262	1557	238	573	0	811	915	67	170	1152	0	0	0	0	0	0	199	0	0	971	1170	15,253	5.6%
MIDDLE FORK TEN MILE	33.45	21408	19652	18125	1098	8359	27583	13908	2390	1338	17635	2092	0	266	2358	0	0	0	0	0	0	629	26	6	3914	4575	71,802	27%
Upper Middle Fork Ten Mile River	11.64	7450	11092	4390	23	308	4721	3326	1228	1338	5892	0	0	266	266	0	0	0	0	0	0	553	0	0	1190	1743	23,714	8.8%
Middle Middle Fork Ten Mile River	6.45	4128	9	7791	421	1656	9868	3461	583	0	4044	0	0	0	0	0	0	0	0	0	0	53	0	0	306	359	14,280	5.3%
Little Bear Haven Creek	3.00	1920	0	5550	128	736	6414	9	0	0	9	9	0	0	9	0	0	0	0	0	0	0	0	1	338	339	6,771	2.5%
Bear Haven Creek	6.60	4224	3132	161	295	5226	5683	327	579	0	906	791	0	0	791	0	0	0	0	0	0	16	26	0	1453	1496	12,007	4.4%
Lower Middle Fork Ten Mile River	5.76	3686	5419	235	231	432	898	6784	0	0	6784	1292	0	0	1292	0	0	0	0	0	0	7	0	5	627	639	15,031	5.6%
SOUTH FORK TEN MILE	38.39	24570	80030	7070	790	577	8437	1225	468	463	2155	1660	0	852	2512	468	737	421	1626	0	90	2461	28	2	9190	11772	106,532	39%
Upper South Fork Ten Mile River	8.18	5235	18701	24	0	0	24	0	211	92	303	1660	0	852	2512	0	47	0	47	0	0	416	5	0	1681	2102	23,689	8.8%
Redwood Creek	7.87	5037	17313	15	549	137	701	114	257	0	370	0	0	0	0	316	469	0	785	0	0	568	13	1	1984	2567	21,737	8.0%
Churchman Creek	3.96	2534	2860	5781	0	400	6181	0	0	335	335	0	0	0	0	0	0	0	0	0	5	32	0	1	1008	1047	10,423	3.9%
Middle South Fork Ten Mile River	5.52	3533	13198	11	0	17	28	0	0	0	0	0	0	0	0	148	141	39	328	0	0	447	9	0	1362	1818	15,372	5.7%
Campbell Creek	4.25	2720	10201	0	0	0	0	0	0	0	0	0	0	0	0	4	3	31	37	0	0	433	1	0	1443	1877	12,115	4.5%
Smith Creek	5.49	3514	11951	54	0	23	77	1111	0	0	1111	0	0	0	0	0	77	294	371	0	84	480	0	0	1259	1824	15,334	5.7%
Lower South Fork Ten Mile River	3.12	1997	5805	1186	240	0	1427	0	0	36	36	0	0	0	0	0	0	58	58	0	0	84	1	0	453	537	7,863	2.9%
LOWER TEN MILE	8.83	5651	8948	10292	0	0	10292	0	0	0	0	4	171	0	175	0	0	88	88	0	0	37	1	0	358	395	19,898	7%
Mainstem Ten Mile River	4.28	2739	6898	2327	0	0	2327				0	4	0	0	4	0	0	0	0	0	0	0	0	0	140	141	9,370	3.5%
Mill Creek	2.71	1734	2049	3543	0	0	3543				0	0	171	0	171	0	0	88	88	0	0	36	1	0	213	249	6,100	2.3%
Ten Mile River Estuary	1.84	1178	1	4422	0	0	4422				0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	4,428	1.6%
TEN MILE RIVER WATERSHED	119.64	76570	131361 48.6%	42066	3821	14990	60876 22.5%	35149	6066	1810	43025 15.9%	11381	238	1363	12983 4.8%	468	950	509	1927 0.7%	0	127	3573	69	8	16439	20215 7.5%	270,387	100%

NOTES: Base data for 1999 period from CDF; All other data from aerial photo mapping. Values in excess of 100% indicate multiple harvest entries in that period.

TABLE 33

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

CALCULATION OF RELATIVE DISTURBANCE INDEX

Sub-Watershed	ROADS Road Density (RD, mi/mi2)	HARVEST % Harvested in 89-99 Period (HD, ac/ac)	LANDSLIDES Unit Slide Vol for 1989-1999 Period (delivering only) (DSV, tons/mi^2)	Relative Disturbance Index (RD*HD*DSV)	1996 Substrate Quality (% <0.85 mm)
Upper North Fork Ten Mile River	5.97	0.06	9.30	4	18.4
Middle North Fork Ten Mile River	4.11	0.04	2148.49	327	20.7
Bald Hill Creek	5.66	0.15	66.01	54	13.7
Lower North Fork Ten Mile River	10.98	0.59	92.41	598	15.5
Little North Fork Ten Mile River	11.61	0.38	109.85	481	17.3
Upper Middle Fork Ten Mile River	7.40	0.37	52.88	147	15.1
Middle Middle Fork Ten Mile River	5.24	0.14	138.56	101	19.7
Little Bear Haven Creek	6.46	0.28	41.50	76	17.4
Bear Haven Creek	10.99	0.57	33.47	208	12.9
Lower Middle Fork Ten Mile River	7.63	0.28	408.92	865	16.9
Upper South Fork Ten Mile River	6.88	0.64	21.77	96	16.2
Redwood Creek	8.61	0.82	24.86	175	16.0
Churchman Creek	7.40	0.66	207.20	1010	19.2
Middle South Fork Ten Mile River	10.23	0.82	148.11	1248	21.8
Campbell Creek	9.48	1.10	30.81	322	22.8
Smith Creek	7.71	0.80	109.26	678	17.2
Lower South Fork Ten Mile River	8.26	0.43	71.84	256	
Mainstem Ten Mile River	8.87	0.08	72.65	53	
Mill Creek	8.77	0.23	180.74	365	23.7
Ten Mile River Estuary	7.05	0.01	0.00	0	

NOTES: All data from previous analyses this study except substrate quality
Substrate quality from Georgia-Pacific West, Inc. Ten Mile River Watershed Instream Monitoring Report (1996).

TABLE 34

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Calculation of Bank Erosion Volumes from Notes contained in1994-1995 Georgia-Pacific Habitat Surveys

	Area Estimated			No Area Estimated	Total Watershed	Total	Total Length Surveyed	
	Number of Sites	Total Area (sq. ft)	Average (cubic yards)	Number of Sites	Sites	Tons	(feet)	(miles)
NORTH FORK	35	5,816	166.2	16			196,271	37.2
MIDDLE FORK	10	2,071	207.1	10			153,507	29.1
SOUTH FORK	14	1,129	80.6	13			207,854	39.4
TOTAL WATERSHED	59	9,016	152.8	39	98	21,864	557,632	105.6

Total Watershed Area = 119.6 mi^2

AVERAGE RATE PER MILE OF STREAM CHANNEL FOR ENTIRE WATERSHED: 207 tons/mile

Notes: All areas based on reported size estimates of bank erosion observed during course of 1994-1995 Georgia-Pacific habitat surveys.
Thickness of failures assumed to be 3 feet, same as debris slides in landslide analysis.
Conversion from cubic yards to tons using factor of 1.46 tons/cubic yard.
Total watershed tons of bank erosion computed by taking total number of sites and multiplying by average developed from 59 sites.

TABLE 35

TEN MILE RIVER WATERSHED SEDIMENT SOURCE ANALYSIS

Preliminary Sediment Budget: Sediment Budget Inputs as Percent of Total Inputs

PERIOD YEAR	INPUTS: LANDSLIDING	INPUTS: SURFACE EROSION – BACKGROUND	INPUTS: SURFACE EROSION – SKID TRAILS	INPUTS: SURFACE EROSION – ROAD	INPUTS: FLUVIAL EROSION – BANK EROSION		INPUTS: TOTAL INPUTS	OUTPUTS: OUTFLOW SSL AND BL (tons)	OUTPUTS: % of INPUTS (tons/mi2/yr)
1933-1942	73.0%	4.8%	7.0%	2.5%	12.8%		100%	1,360,000	65.3%
1943-1952	60.7%	6.6%	4.5%	10.5%	17.7%		100%	600,000	42.5%
1953-1965	72.0%	4.5%	1.6%	10.0%	11.9%		100%	1,956,000	70.0%
1966-1978	35.5%	9.8%	1.1%	27.6%	26.1%		100%	1,970,000	214.8%
1979-1988	51.6%	7.9%	0.2%	19.3%	21.0%		100%	1,007,000	171.2%
1989-1999	18.1%	11.9%	2.4%	35.7%	31.8%		100%	1,200,000	210.7%

Notes:
- -- All values rounded to four significant figures
- -- Mass Wasting derived from landslides mapped from aerial photographs taken at the end of each budget period
  Eastern portions of the watershed were not covered by the photographs in 1942, though the area was relatively undisturbed. See text for details.
- -- Background rates (containing creep, surface erosion by sheetwash and rilling, and deep-seated landslide components) based on work of Roberts and
  Church (1986) and Cafferata/Stillwater Sciences (pers. Comm. 1999). Rate used is 75 tons/mi2/yr.
- -- Skid roads based on measured harvest areas on the 1942, 1952, 1965, 1978, 1988 and 1999 aerial photographs, delineated into 3 classes of skid road density.
  Harvest areas after 1988 are computed from GIS coverages developed by CDF.
- -- Road erosion computed from measured road miles in 1942, 1952, 1965, 1978, 1988, and 1999 aerial photographs. Roads after
  1988 are based on GIS coverage developed from THPs submitted to CDF, corrected to 1999 aerial mosaic developed by GMA.
- -- Bank erosion is based on a rate of 200 tons/mi/yr, based on rates developed in the Noyo watershed (Matthews & Associates 1999). This category
  includes bank erosion and smaller streamside mass movements under the canopy and generally not visible on aerial photography.
- -- Sediment Outflow computed from regional suspended sediment and bedload transport equations developed as described in the text and applied to
  combined synthetic flow records for the period 1952-1997. Pre-1952 values based on correlation with annual precipitation.

TABLE 36

TEN MILE RIVER WATERSHED SEDIMENT SOURCE ANALYSIS

Preliminary Sediment Budget

PERIOD YEAR	INPUTS: LANDSLIDING (tons)	INPUTS: SURFACE EROSION: BACKGROUND (tons)	INPUTS: SURFACE EROSION: SKID TRAILS (tons)	INPUTS: SURFACE EROSION: ROAD (tons)	INPUTS: FLUVIAL EROSION: BANK EROSION (tons)	TOTAL INPUTS (tons)	TOTAL INPUTS (tons/mi^2/yr)	CHANGE IN STORAGE (tons)	OUTPUTS: OUTFLOW SSL AND BL (tons)	OUTPUTS: YIELD (tons/mi^2/yr)
1933-1942	1,368,000	89,700	131,400	46,720	239,200	1,875,000	1,568	304,000	1,360,000	1137
1943-1952	822,700	89,700	60,900	142,800	239,200	1,355,000	1,133	152,000	600,000	502
1953-1965	1,884,000	116,600	43,000	261,800	311,000	2,616,000	1,683	304,000	1,956,000	1258
1966-1978	423,400	116,600	12,980	329,500	311,000	1,193,000	767	(152,000)	1,970,000	1267
1979-1988	588,800	89,700	1,930	220,200	239,200	1,140,000	953	(456,000)	1,007,000	842
1989-1999	149,300	98,670	20,200	295,400	263,100	827,000	629	(152,000)	1,200,000	912
										Mean Yield
TOTAL	5,236,000	601,000	270,400	1,296,000	1,603,000	9,007,000	1,124	--	8,093,000	1015
(% of Total Inputs)	58%	7%	3%	14%	18%					

Notes:

-- All values rounded to four significant figures
-- Mass Wasting derived from landslides mapped from aerial photographs taken at the end of each budget period
Eastern portions of the watershed were not covered by the photographs in 1942, though the area was relatively undisturbed. See text for details.
-- Background rates (containing creep, surface erosion by sheetwash and rilling, and deep-seated landslide components) based on work of Roberts and Church (1986) and Cafferata/Stillwater Sciences (pers. Comm. 1999). Rate used is 75 tons/mi2/yr.
-- Skid roads based on measured harvest areas on the 1942, 1952, 1965, 1978, 1988 and 1999 aerial photographs, delineated into 3 classes of skid road density.
Harvest areas after 1988 are computed from GIS coverages developed by CDF.
-- Road erosion computed from measured road miles in 1942, 1952, 1965, 1978, 1988, and 1999 aerial photographs. Roads after 1988 are based on GIS coverage developed from THPs submitted to CDF, corrected to 1999 aerial mosaic developed by GMA.
-- Bank erosion is based on a rate of 200 tons/mi/yr, based on rates developed in the Noyo River watershed. This category includes bank erosion and smaller streamside mass movements under the canopy and generally not visible on aerial photography.
-- Change in storage represents estimates of net change in channel dimensions based on aerial photographs, multiplied by length of alluvial reach
-- Sediment Outflow computed from regional suspended sediment and bedload transport equations developed as described in the text and applied to combined synthetic flow records for the period 1952-1997. Pre-1952 values based on correlation with annual precipitation.

FIGURE 1

TEN MILE RIVER WATERSHED

TMDL Planning Areas and Sub-Watersheds

TMDL Planning Area Sub-Watershed	Acres	Sq. Miles
North Fork	**24,943**	**38.97**
Upper North Fork Ten Mile River	6,655	10.40
Middle North Fork Ten Mile River	5,748	8.98
Bald Hill Creek	3,289	5.14
Little North Fork Ten Mile River	4,960	7.75
Lower North Fork Ten Mile River	4,291	6.70
Middle Fork	**21,414**	**33.45**
Upper Mdl. Fork Ten Mile River	7,452	11.64
Middle Mdl. Fork Ten Mile River	4,126	6.45
Little Bear Haven Creek	1,922	3.00
Bear Haven Creek	4,224	6.60
Lower Mdl. Fork Ten Mile River	3,689	5.76
South Fork	**24,567**	**38.39**
Upper South Fork Ten Mile River	5,236	8.18
Redwood Creek	5,038	7.87
Churchman Creek	2,537	3.96
Middle South Fork Ten Mile River	3,531	5.52
Campbell Creek	2,720	4.25
Smith Creek	3,511	5.49
Lower South Fork Ten Mile River	1,994	3.12
Mainstem	**5,653**	**8.83**
Mainstem Ten Mile River	2,737	4.28
Mill Creek	1,737	2.71
Ten Mile River Estuary	1,179	1.84

Watershed Boundary

Planning Watersheds

North Fork

Middle Fork

South Fork

Mainstem

Streams

Perennial

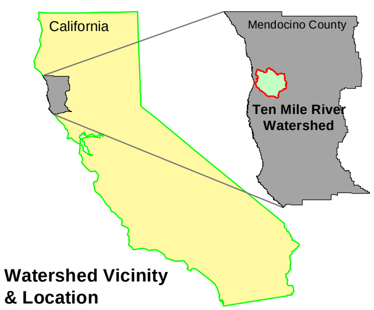
Intermittent

Ephemeral

Sub-Watersheds

8 **Former USGS Gauge**

Basemap Data Source: Calif. Dept. of Forestry



Watershed Vicinity & Location

4

Scale: 1 = 130,000

1 0 1 2 3 Miles

1 0 1 2 3 4 Kilometers

Presented By

Graham Matthews & Associates

Prepared By

Trinity County Resource Conservation District

August 3, 2000

K D S

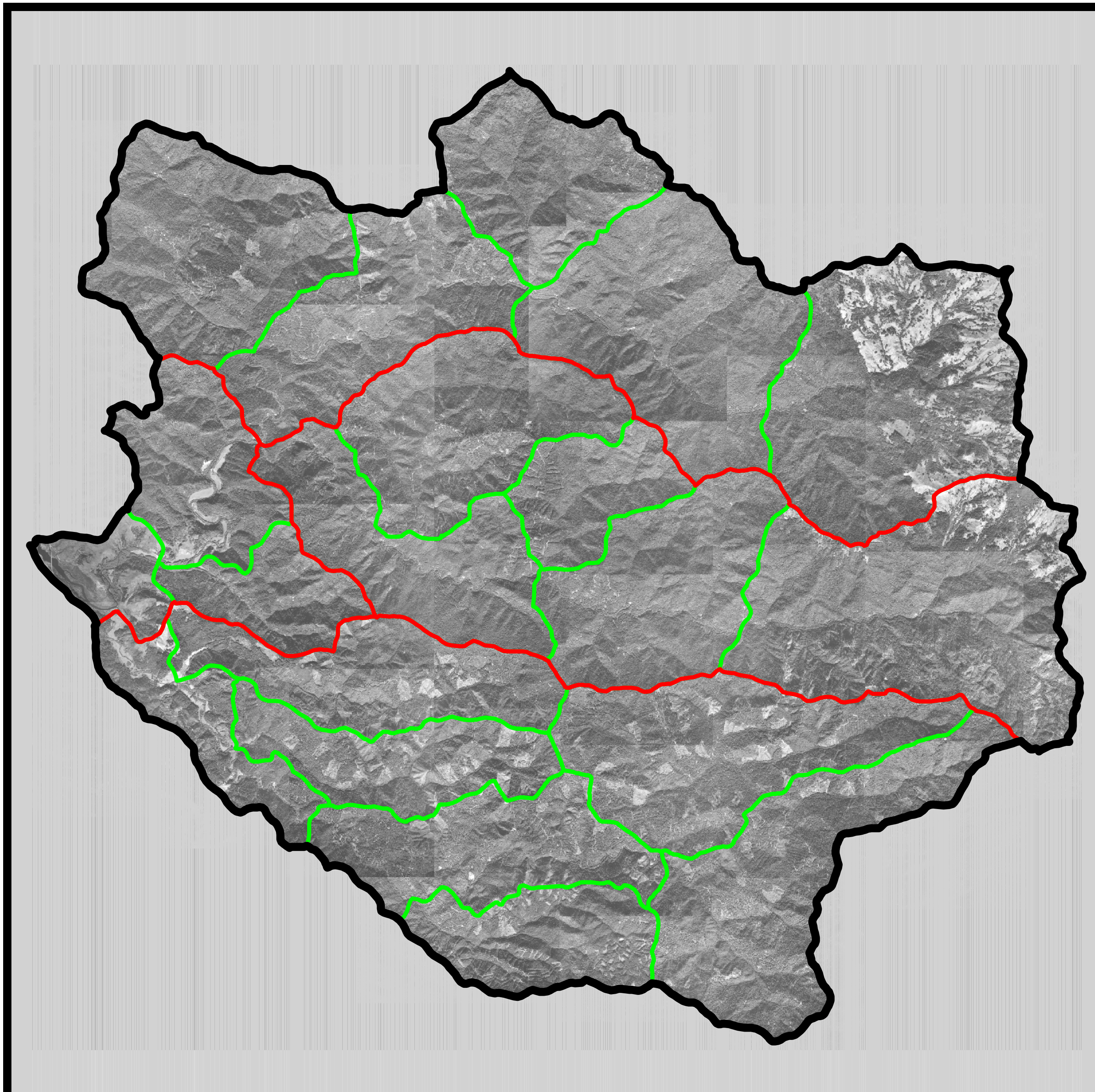


FIGURE 2

TEN MILE RIVER WATERSHED

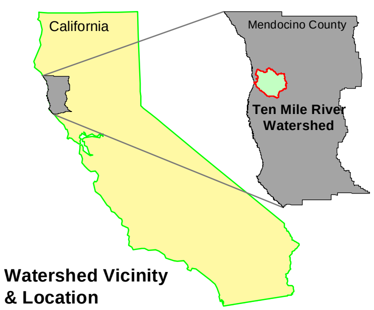
1999 Aerial Photography of Watershed

Watershed Boundary

Planning Watersheds

Sub-Watersheds

Basemap Data Source: Calif. Dept. of Forestry



Watershed Vicinity & Location

4

Presented By

Graham Matthews & Associates

Prepared By

Trinity County Resource Conservation District

August 3, 2000

Scale: 1 = 130,000

1 0 1 2 3 Miles

1 0 1 2 3 4 Kilometers

K D S

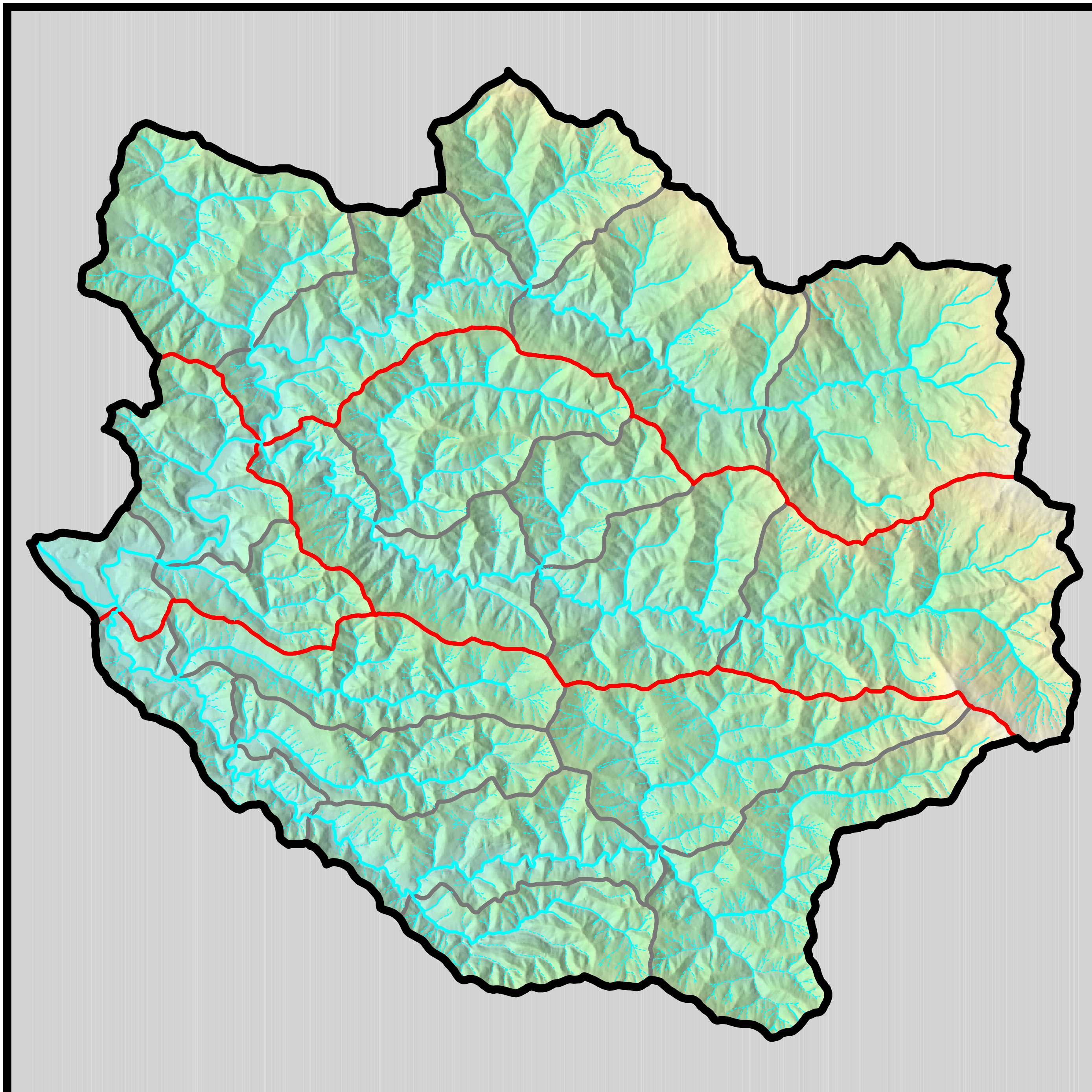


FIGURE 3

TEN MILE RIVER WATERSHED

Shaded Relief Map of Watershed

Watershed Boundary

Planning Watersheds

Sub-Watersheds

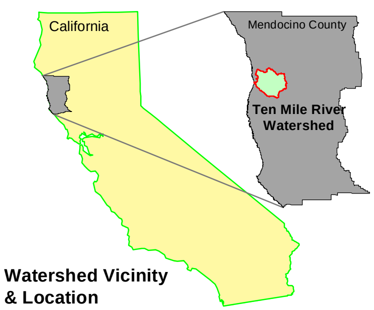
Streams

Perennial

Intermittent

Ephemeral

Basemap Data Source: Calif. Dept. of Forestry



Watershed Vicinity & Location

4

Scale: 1 = 130,000

Presented By

Graham Matthews & Associates

Prepared By

Trinity County Resource Conservation District

August 3, 2000

1 0 1 2 3 Miles

1 0 1 2 3 4 Kilometers

KDS

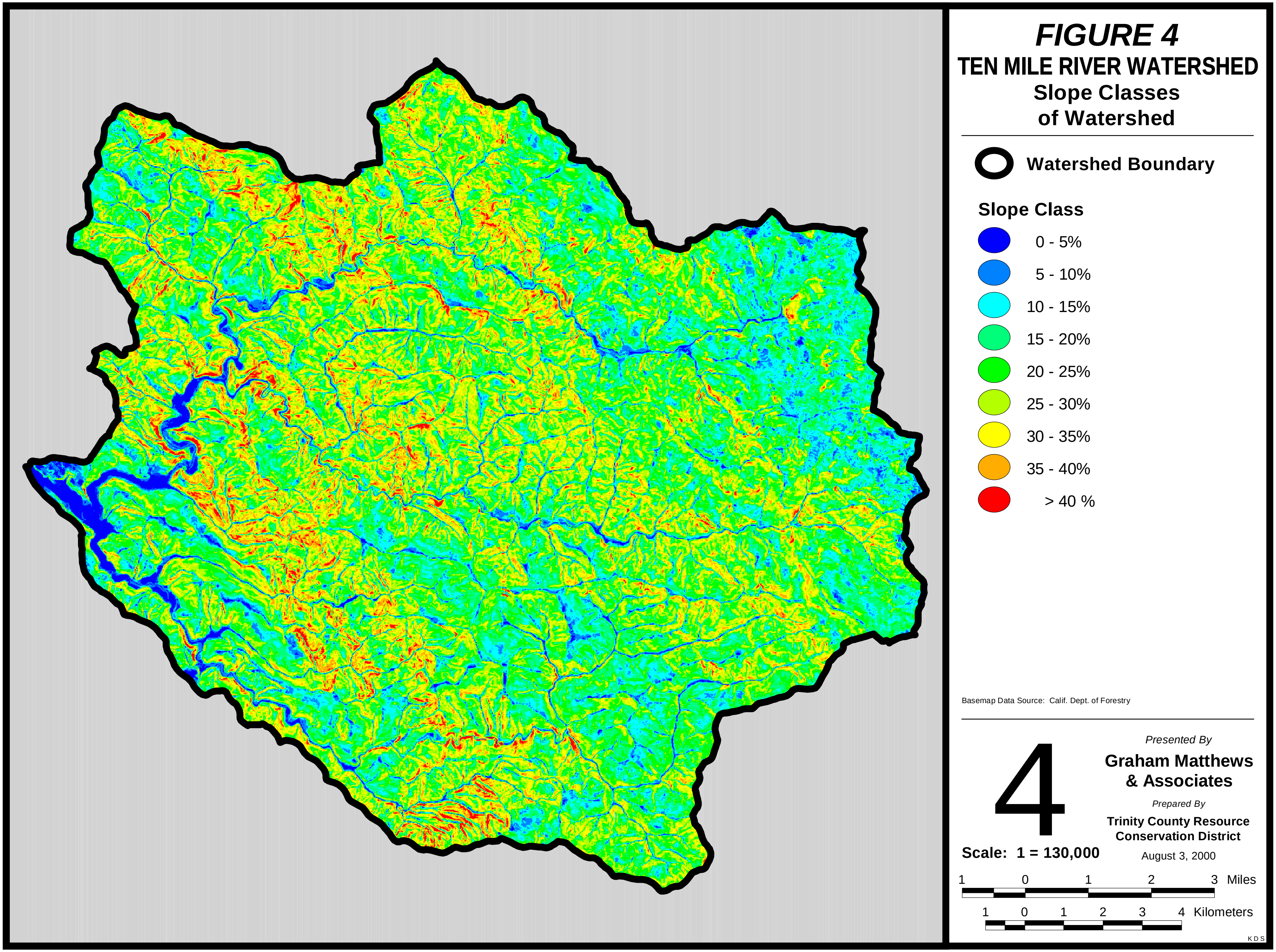


FIGURE 4
TEN MILE RIVER WATERSHED
Slope Classes
of Watershed
Watershed Boundary
Slope Class
0 - 5%
5 - 10%
10 - 15%
15 - 20%
20 - 25%
25 - 30%
30 - 35%
35 - 40%
> 40 %
Basemap Data Source: Calif. Dept. of Forestry
4
Presented By
Graham Matthews
& Associates
Prepared By
Trinity County Resource
Conservation District
August 3, 2000
Scale: 1 = 130,000
1 0 1 2 3 Miles
1 0 1 2 3 4 Kilometers
K D S

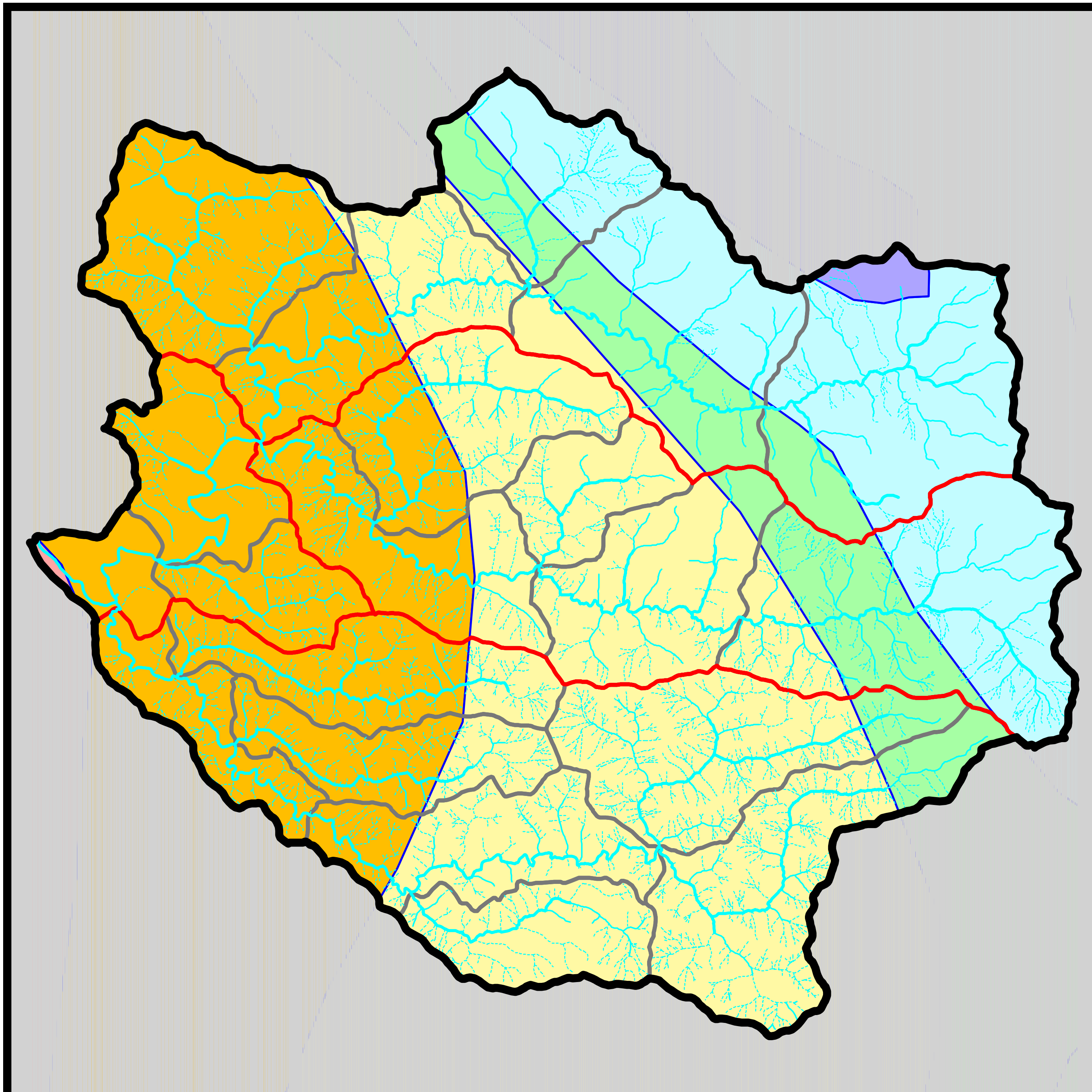


FIGURE 5

TEN MILE RIVER WATERSHED

Isohyetal Map of Watershed

Watershed Boundary

Planning Watersheds

Sub-Watersheds

Average Precipitation

40

45

55

65

75

85

Streams

Perennial

Intermittent

Ephemeral

Basemap Data Source: Calif. Dept. of Forestry

4

Scale: 1 = 130,000

Presented By

Graham Matthews & Associates

Prepared By

Trinity County Resource Conservation District

August 3, 2000

1 0 1 2 3 Miles

1 0 1 2 3 4 Kilometers

KDS

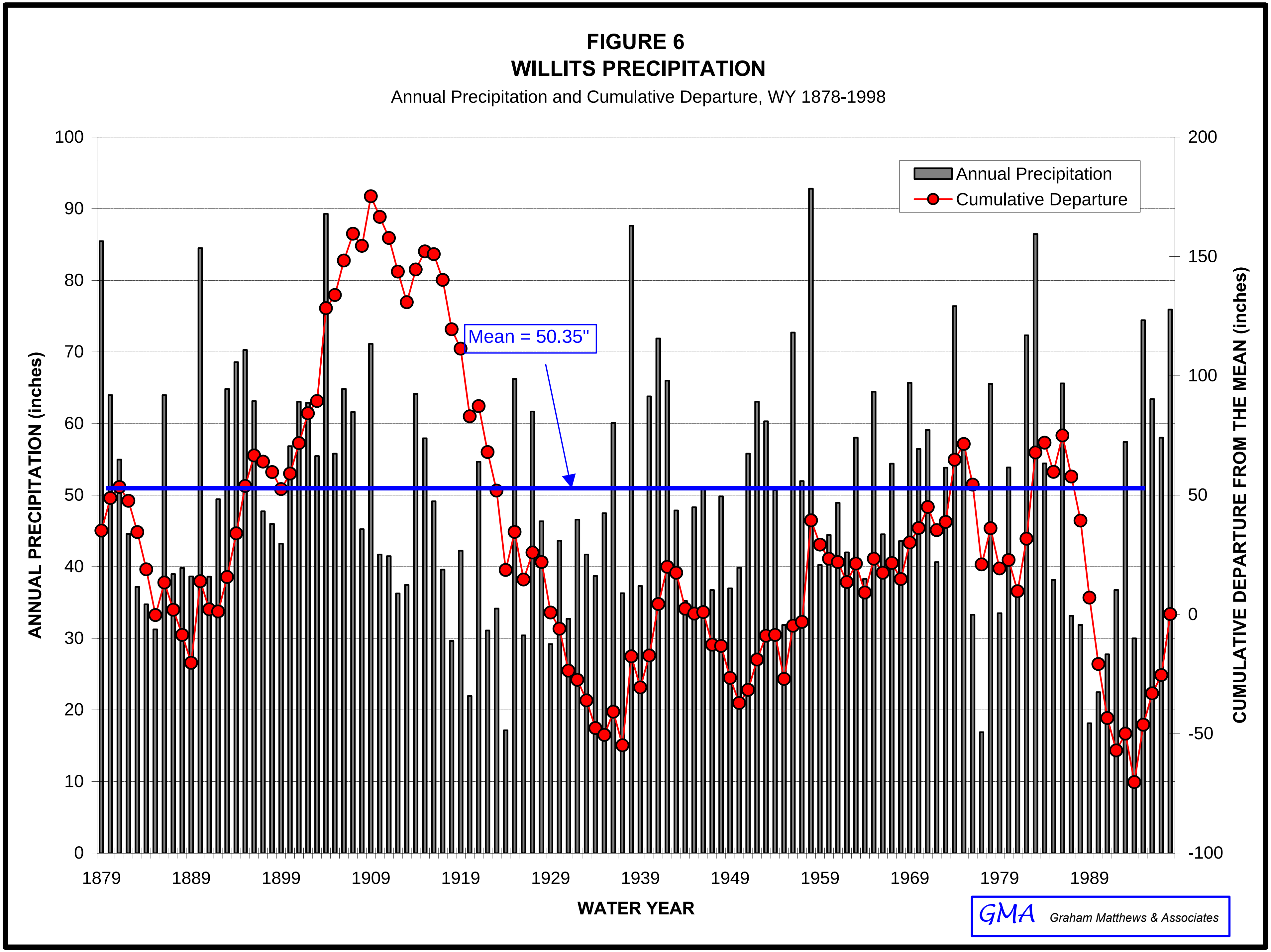


FIGURE 6
WILLITS PRECIPITATION
Annual Precipitation and Cumulative Departure, WY 1878-1998
ANNUAL PRECIPITATION (inches)
CUMULATIVE DEPARTURE FROM THE MEAN (inches)
WATER YEAR
Annual Precipitation
Cumulative Departure
Mean = 50.35"
0
10
20
30
40
50
60
70
80
90
100
-100
-50
0
50
100
150
200
1879
1889
1899
1909
1919
1929
1939
1949
1959
1969
1979
1989
GMA Graham Matthews & Associates

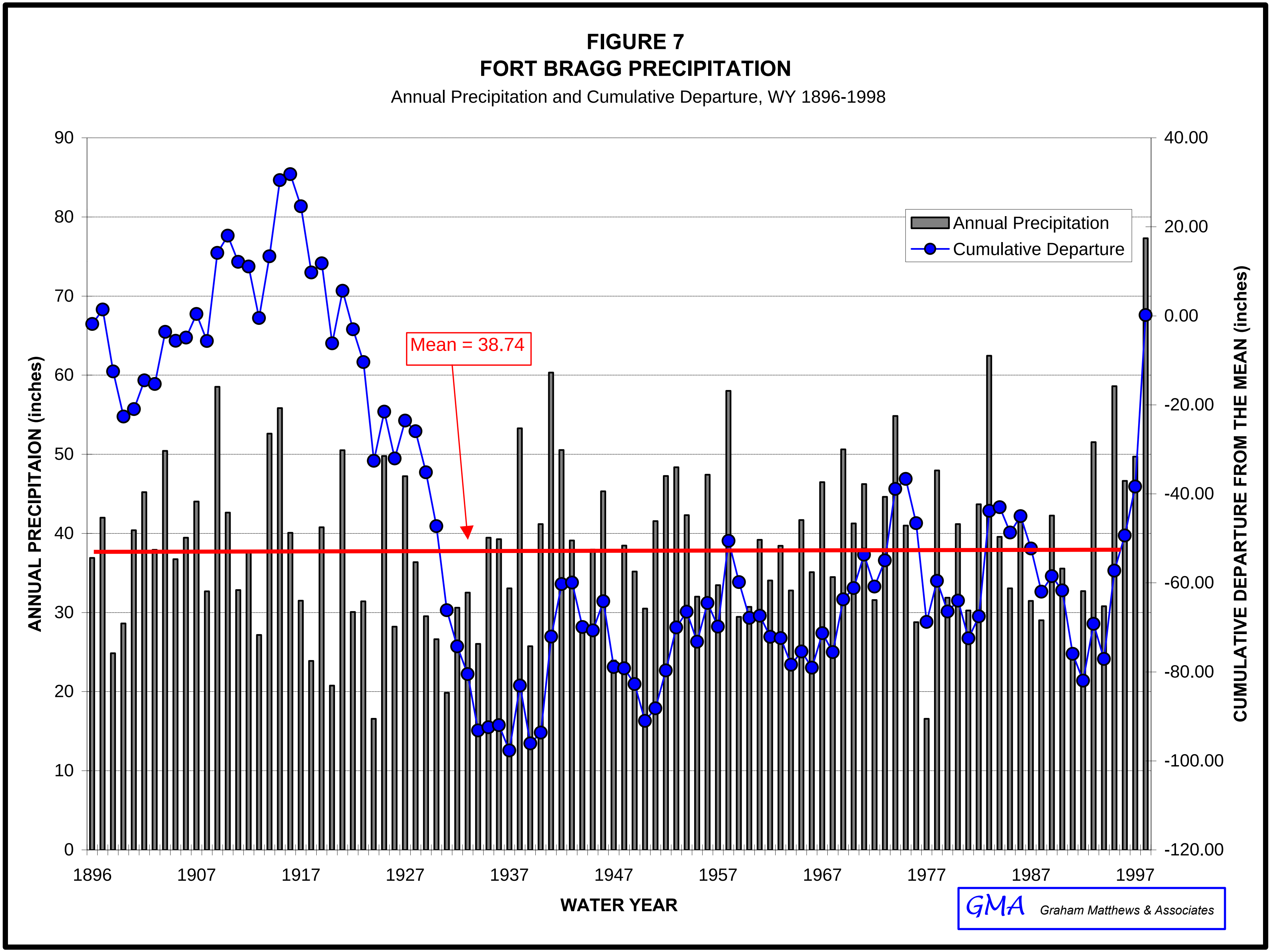


FIGURE 7
FORT BRAGG PRECIPITATION
Annual Precipitation and Cumulative Departure, WY 1896-1998
ANNUAL PRECIPITAION (inches)
CUMULATIVE DEPARTURE FROM THE MEAN (inches)
WATER YEAR
Annual Precipitation
Cumulative Departure
Mean = 38.74
0
10
20
30
40
50
60
70
80
90
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
1896
1907
1917
1927
1937
1947
1957
1967
1977
1987
1997
GMA
Graham Matthews & Associates

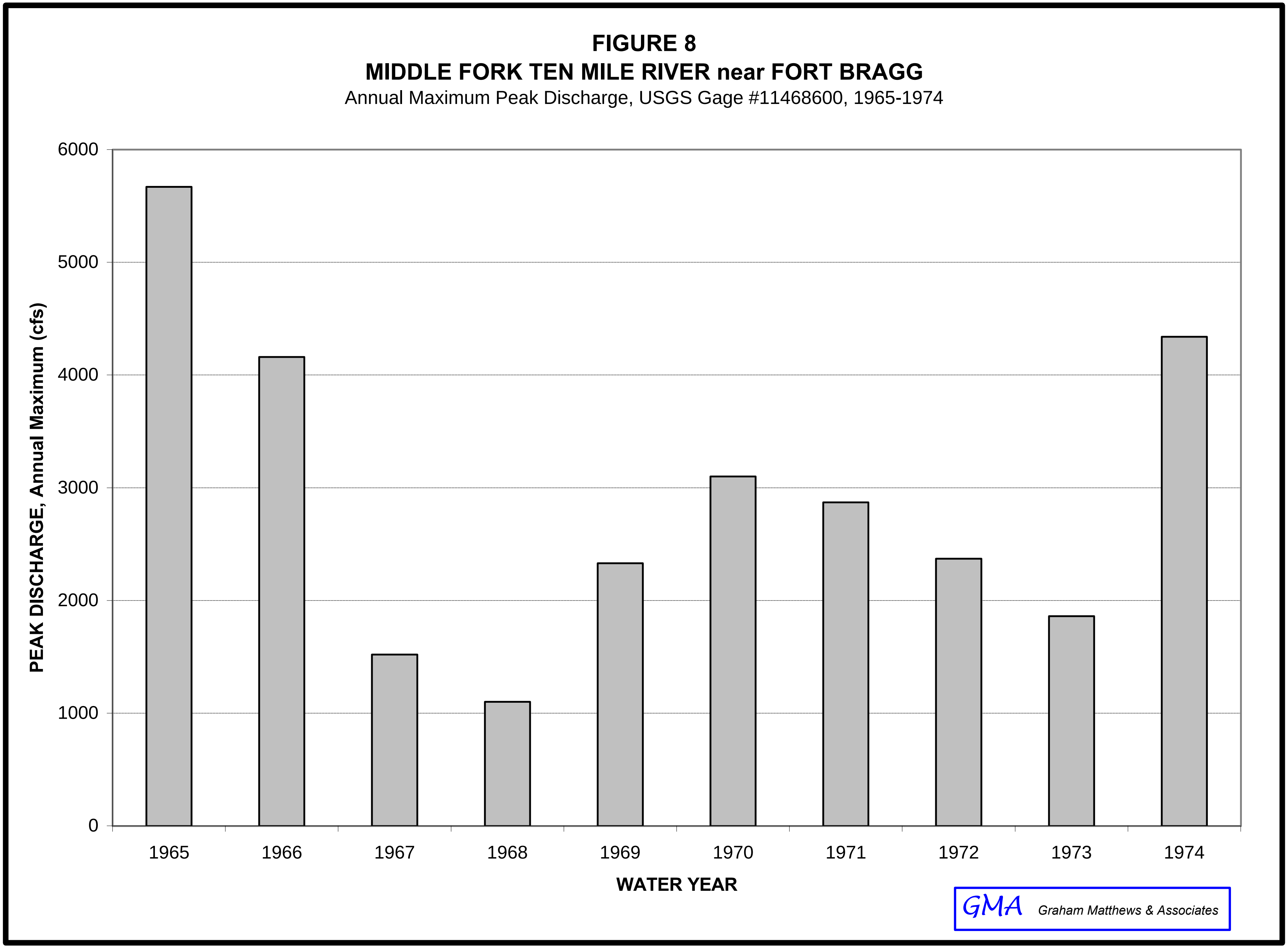


FIGURE 8
MIDDLE FORK TEN MILE RIVER near FORT BRAGG
Annual Maximum Peak Discharge, USGS Gage #11468600, 1965-1974
PEAK DISCHARGE, Annual Maximum (cfs)
0
1000
2000
3000
4000
5000
6000
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
WATER YEAR
GMA
Graham Matthews & Associates

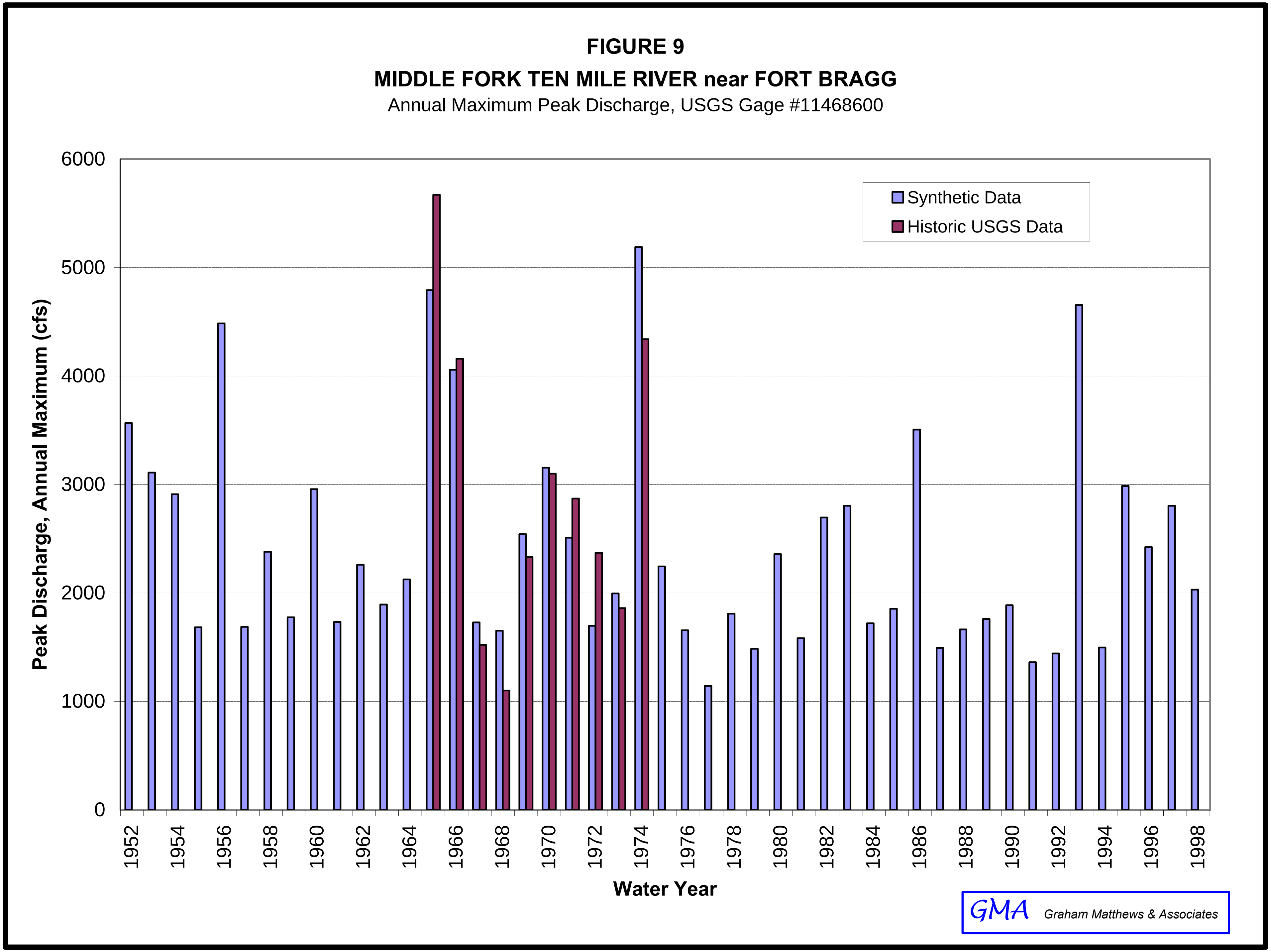


FIGURE 9
MIDDLE FORK TEN MILE RIVER near FORT BRAGG
Annual Maximum Peak Discharge, USGS Gage #11468600
Peak Discharge, Annual Maximum (cfs)
0
1000
2000
3000
4000
5000
6000
Synthetic Data
Historic USGS Data
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Water Year
GMA Graham Matthews & Associates

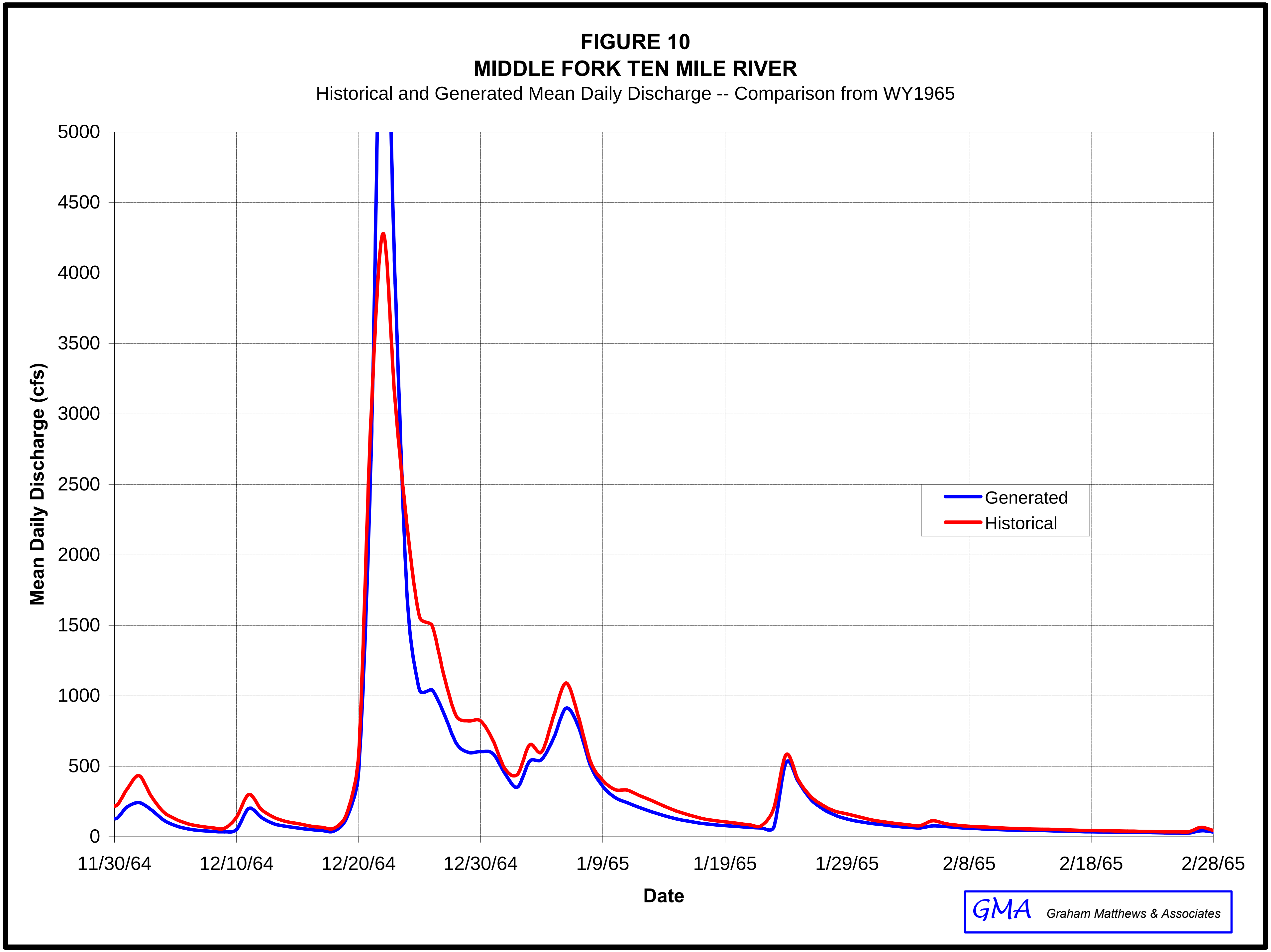


FIGURE 10
MIDDLE FORK TEN MILE RIVER
Historical and Generated Mean Daily Discharge -- Comparison from WY1965
Mean Daily Discharge (cfs)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
11/30/64
12/10/64
12/20/64
12/30/64
1/9/65
1/19/65
1/29/65
2/8/65
2/18/65
2/28/65
Date
Generated
Historical
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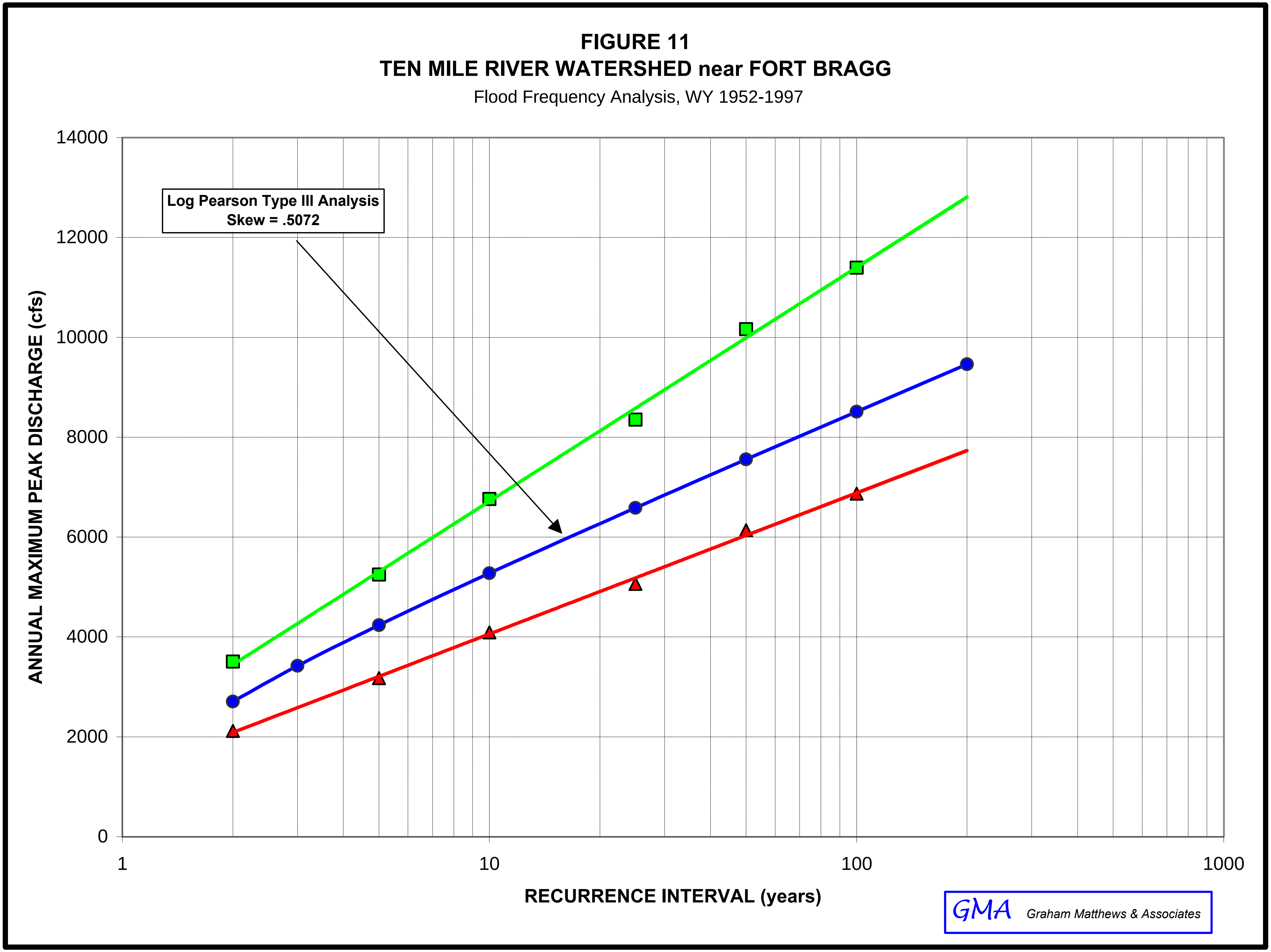
FIGURE 11
TEN MILE RIVER WATERSHED near FORT BRAGG
Flood Frequency Analysis, WY 1952-1997
Log Pearson Type III Analysis
Skew = .5072
ANNUAL MAXIMUM PEAK DISCHARGE (cfs)
0
2000
4000
6000
8000
10000
12000
14000
1
10
100
1000
RECURRENCE INTERVAL (years)
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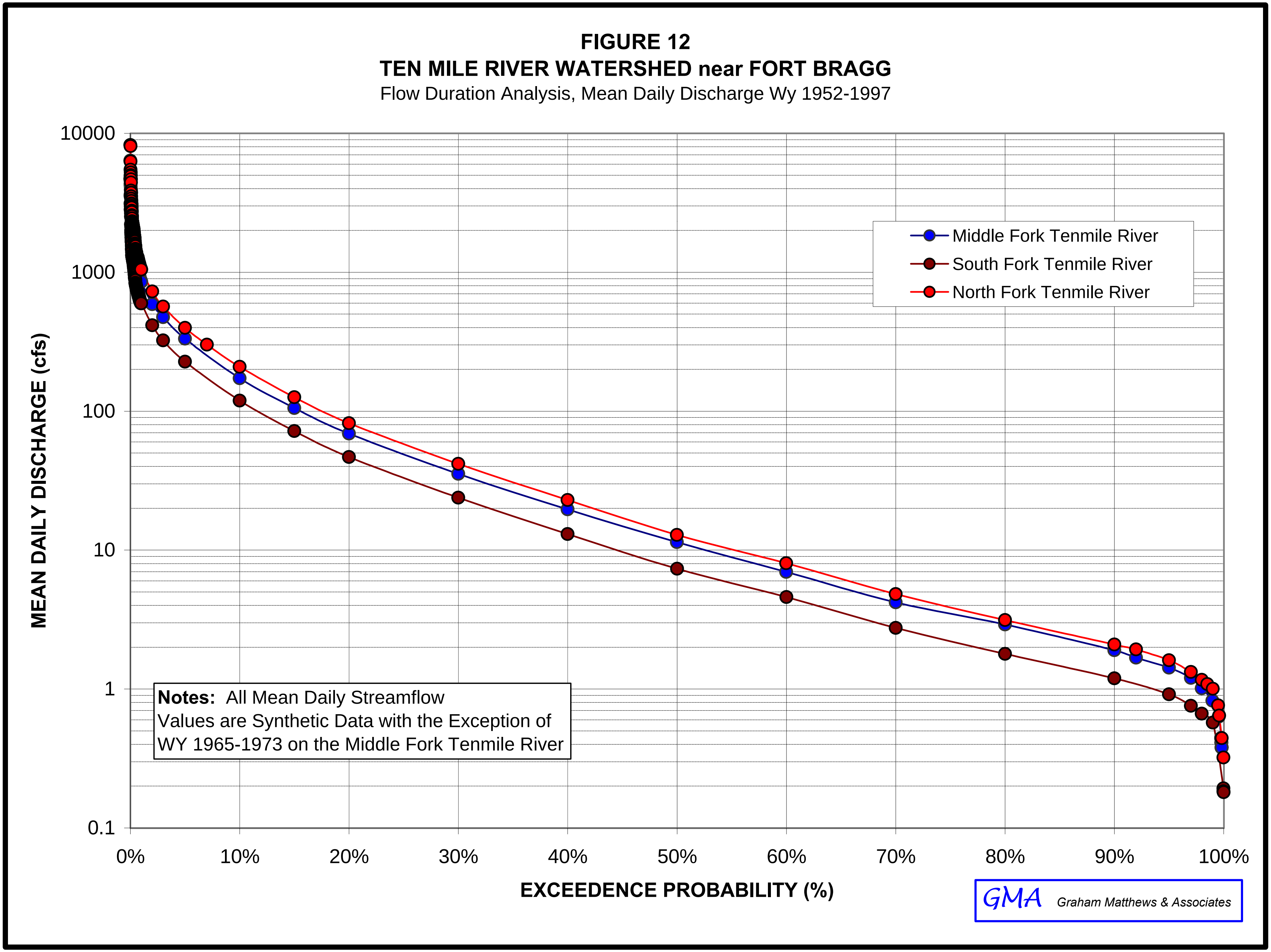
FIGURE 12
TEN MILE RIVER WATERSHED near FORT BRAGG
Flow Duration Analysis, Mean Daily Discharge Wy 1952-1997
MEAN DAILY DISCHARGE (cfs)
10000
1000
100
10
1
0.1
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
EXCEEDENCE PROBABILITY (%)
Middle Fork Tenmile River
South Fork Tenmile River
North Fork Tenmile River
Notes: All Mean Daily Streamflow
Values are Synthetic Data with the Exception of
WY 1965-1973 on the Middle Fork Tenmile River
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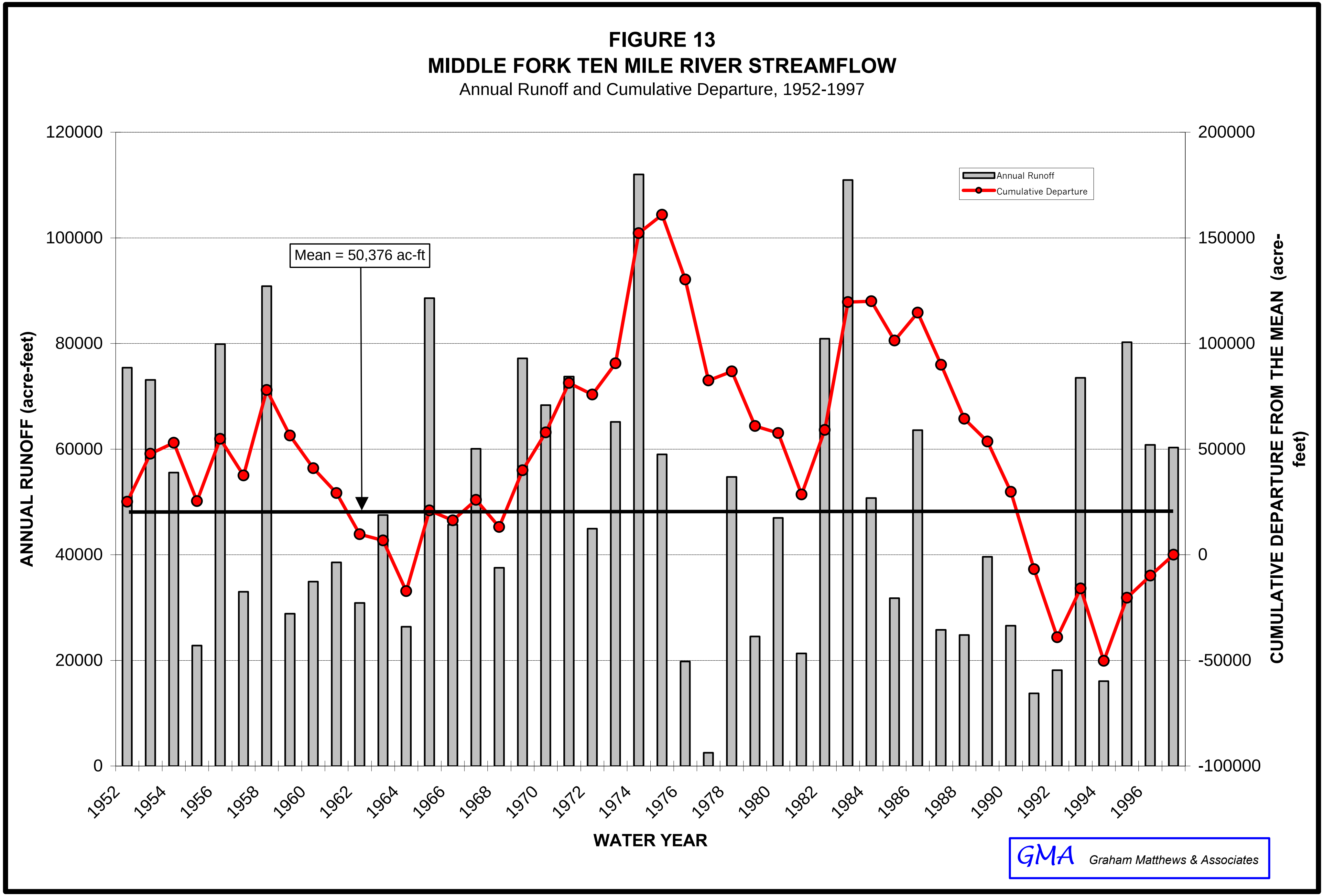

FIGURE 13
MIDDLE FORK TEN MILE RIVER STREAMFLOW
Annual Runoff and Cumulative Departure, 1952-1997
Annual Runoff
Cumulative Departure
Mean = 50,376 ac-ft
ANNUAL RUNOFF (acre-feet)
CUMULATIVE DEPARTURE FROM THE MEAN (acre-feet)
WATER YEAR
120000
100000
80000
60000
40000
20000
0
200000
150000
100000
50000
0
-50000
-100000
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
GMA Graham Matthews & Associates

FIGURE 14
TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
Regional Data used to Develop Suspended Sediment Equation

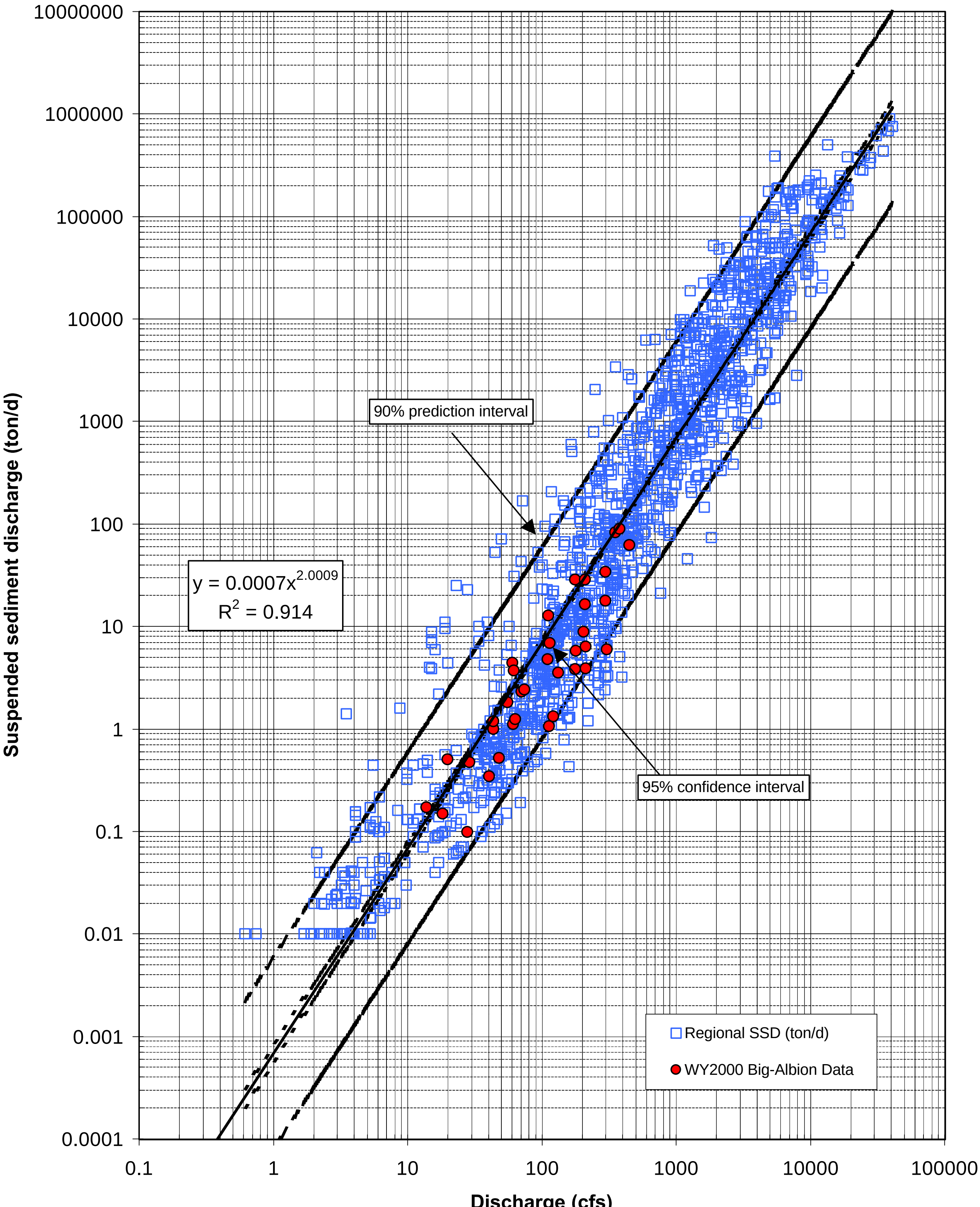

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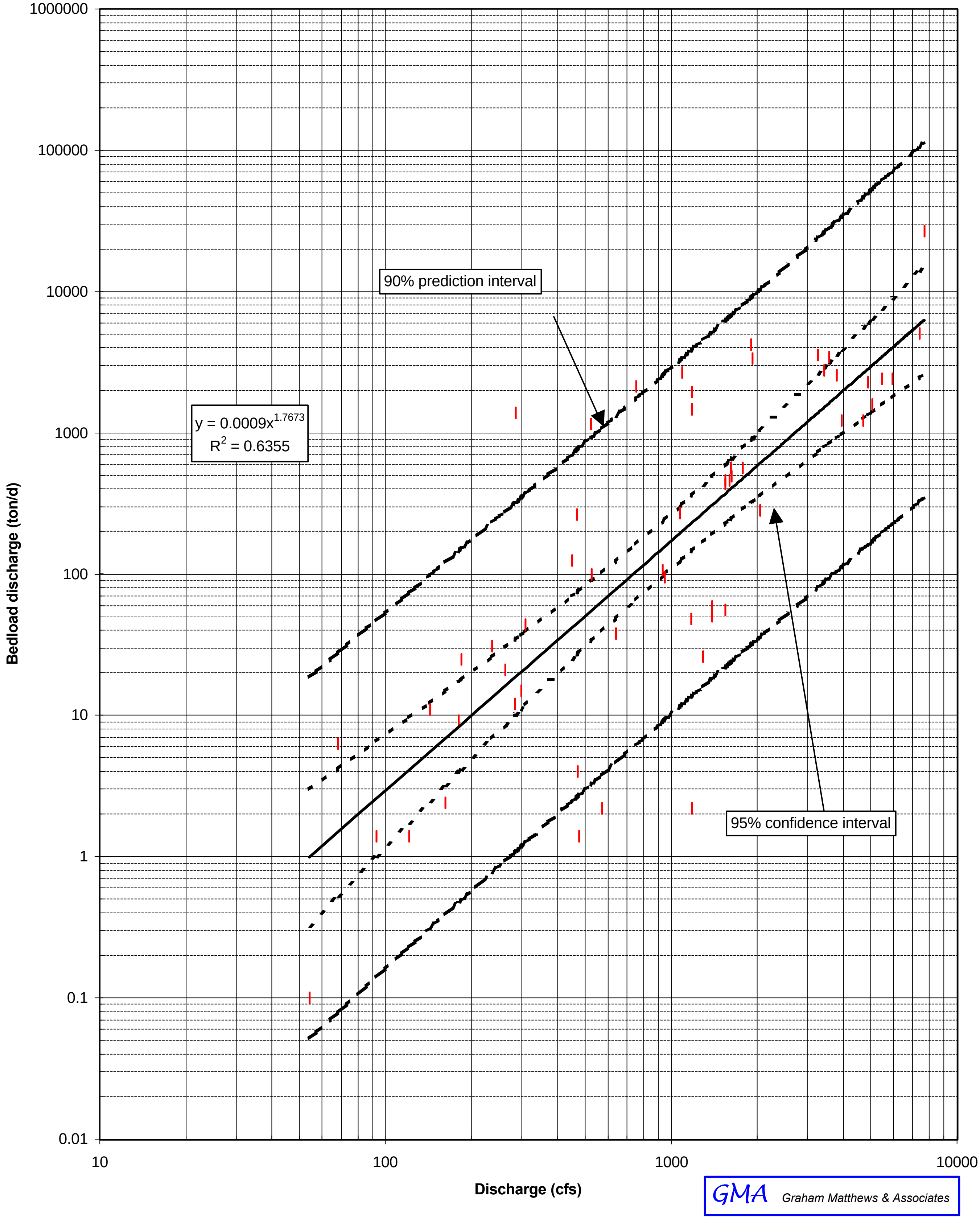
FIGURE 15
TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
Regional Data used to Develop Bedload Discharge Equation



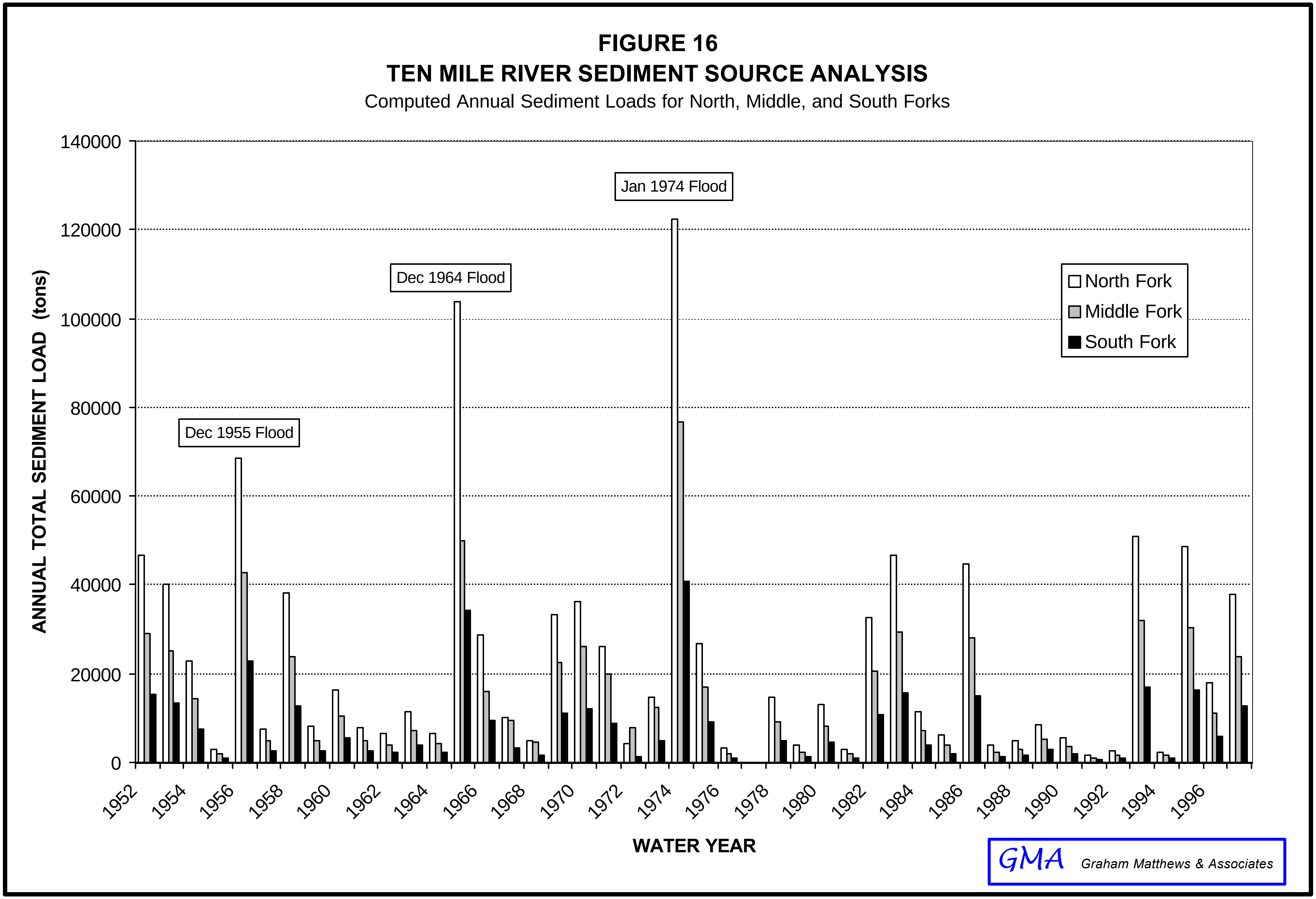


FIGURE 16
TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
Computed Annual Sediment Loads for North, Middle, and South Forks
ANNUAL TOTAL SEDIMENT LOAD (tons)
140000
120000
100000
80000
60000
40000
20000
0
Dec 1955 Flood
Dec 1964 Flood
Jan 1974 Flood
North Fork
Middle Fork
South Fork
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
WATER YEAR
GMA Graham Matthews & Associates

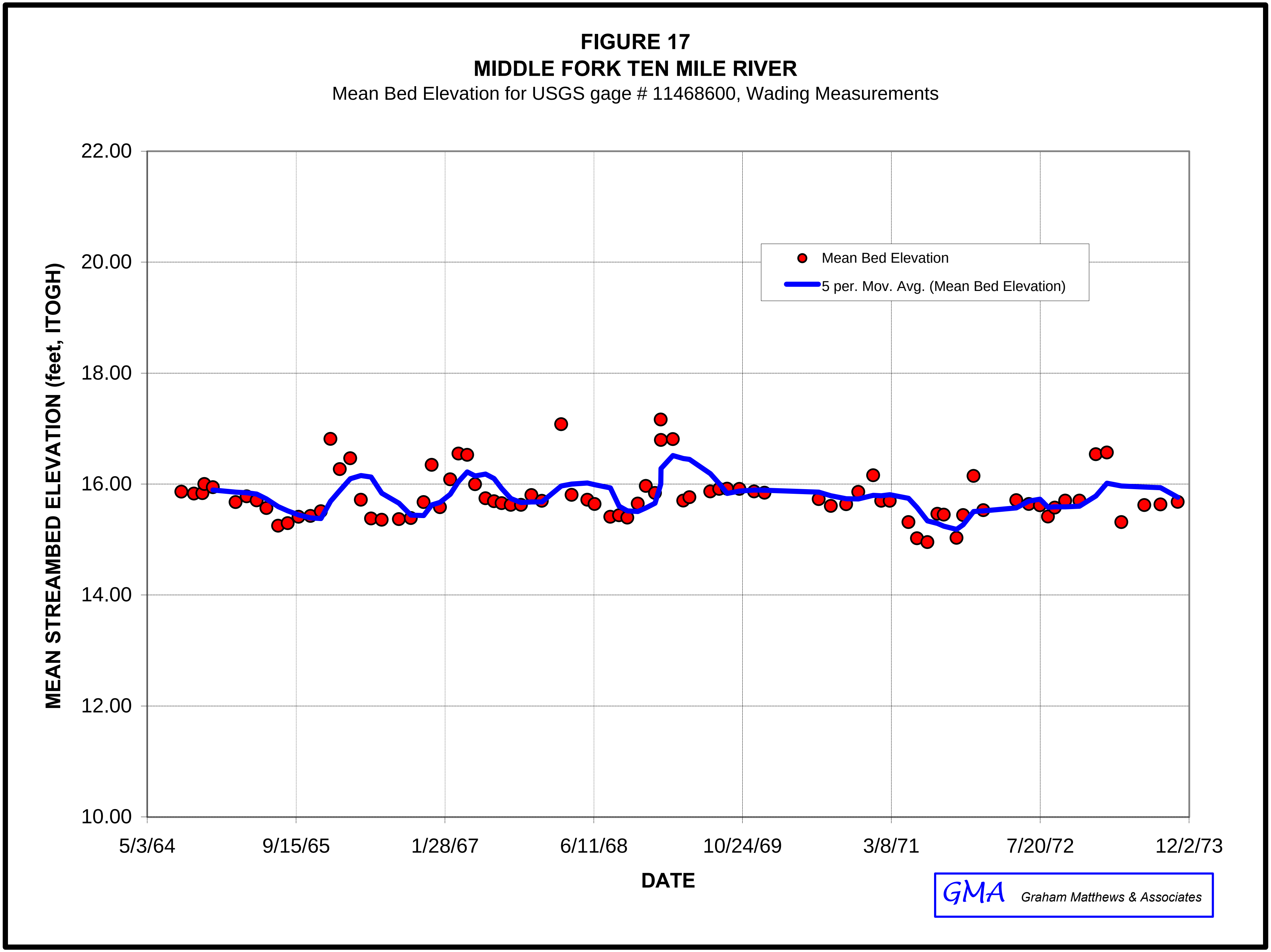


FIGURE 17
MIDDLE FORK TEN MILE RIVER
Mean Bed Elevation for USGS gage # 11468600, Wading Measurements
MEAN STREAMBED ELEVATION (feet, ITOGH)
22.00
20.00
18.00
16.00
14.00
12.00
10.00
5/3/64
9/15/65
1/28/67
6/11/68
10/24/69
3/8/71
7/20/72
12/2/73
DATE
Mean Bed Elevation
5 per. Mov. Avg. (Mean Bed Elevation)
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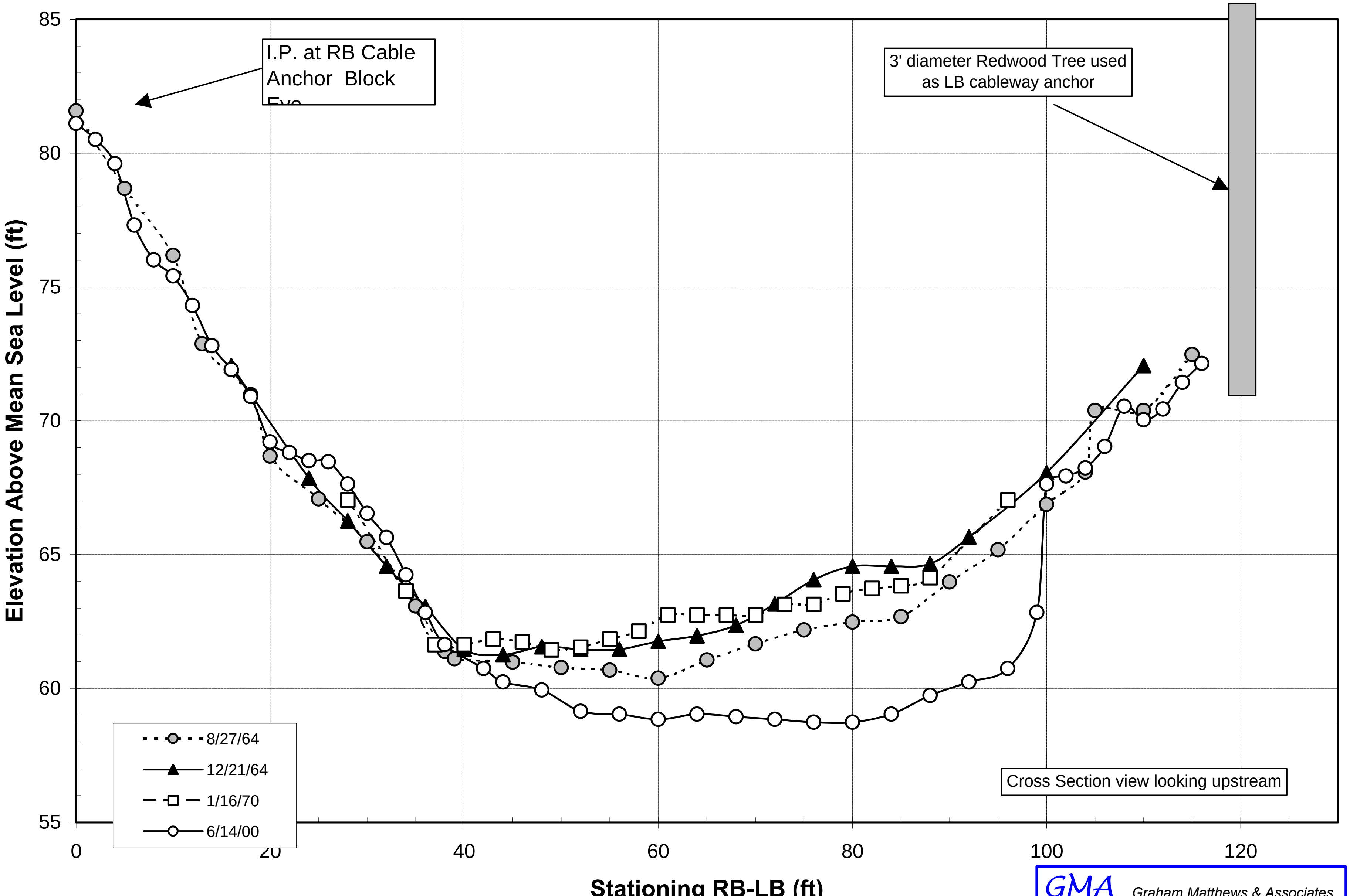
FIGURE 18
MIDDLE FORK TEN MILE AT FORMER USGS GAGE, #11468600
Channel Cross Sections at Cableway ~1000 ft Upstream of Gage



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1941-1942

1952

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
AERIAL PHOTOGRAPHS OF LOWER ALLUVIAL REACH

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(530) 623-5327 ph (530) 623-5328 fax wvgm@snowcrest.net

N

SCALE

0 300

FIGURE

19

1965

1999

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
AERIAL PHOTOGRAPHS OF LOWER ALLUVIAL REACH

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N

SCALE

0 300

FIGURE

20

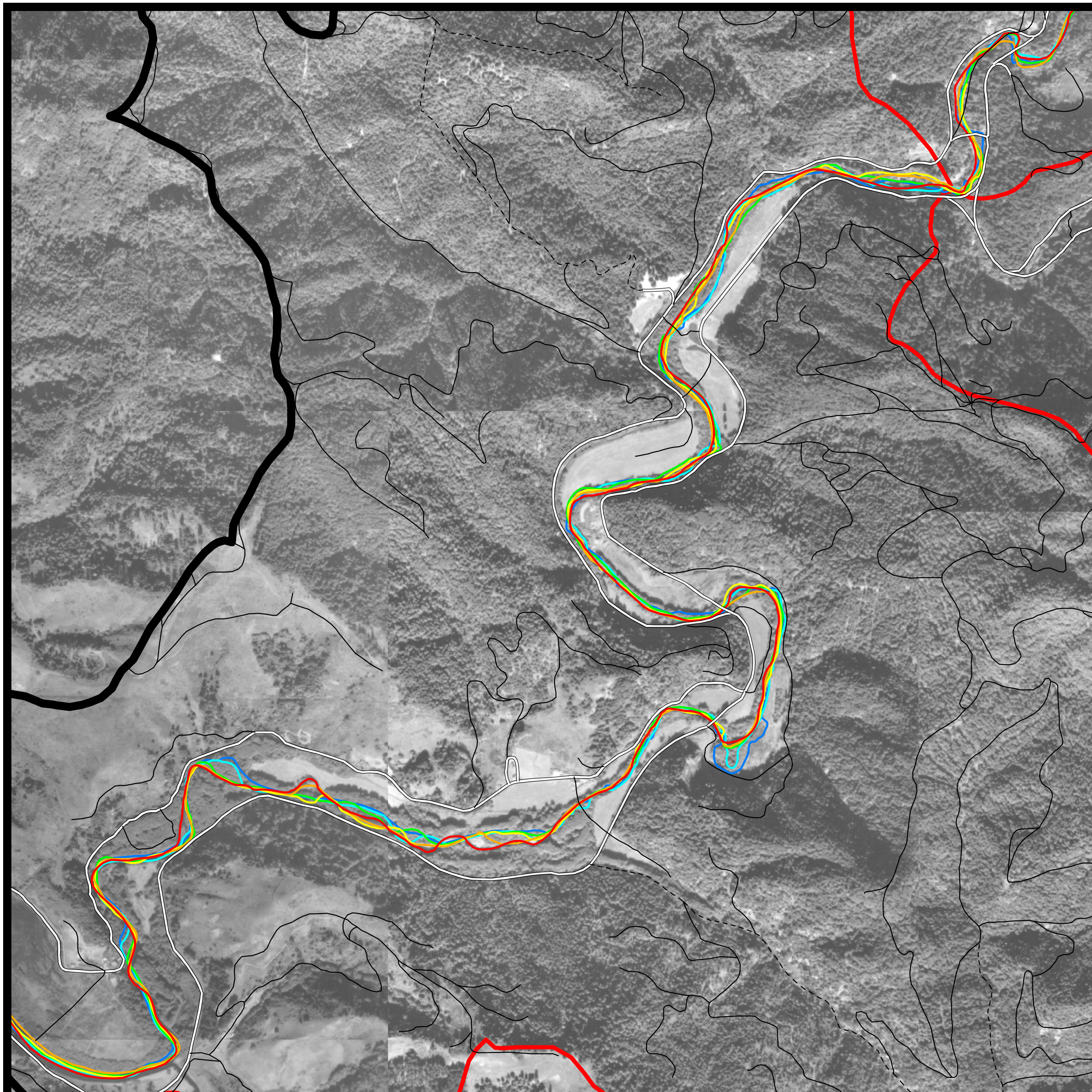

FIGURE 21

TEN MILE RIVER WATERSHED
Historic Channel Changes
Lower Ten Mile, 1941-1999

Watershed Boundary

Planning Watersheds

Channel Location

1941
1952
1965
1978
1988
1999

Roads

Secondary
Improved
Unimproved
Temp. & 4WD

Aerial Mosaic: 1999

Basemap Data Source: Calif. Dept. of Forestry

4

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Prepared By

Trinity County Resource Conservation District

August 3, 2000

Scale: 1 = 24,000

500 0 500 1000 1500 2000 2500 3000 Feet

150 0 150 300 450 600 750 Meters

KDS

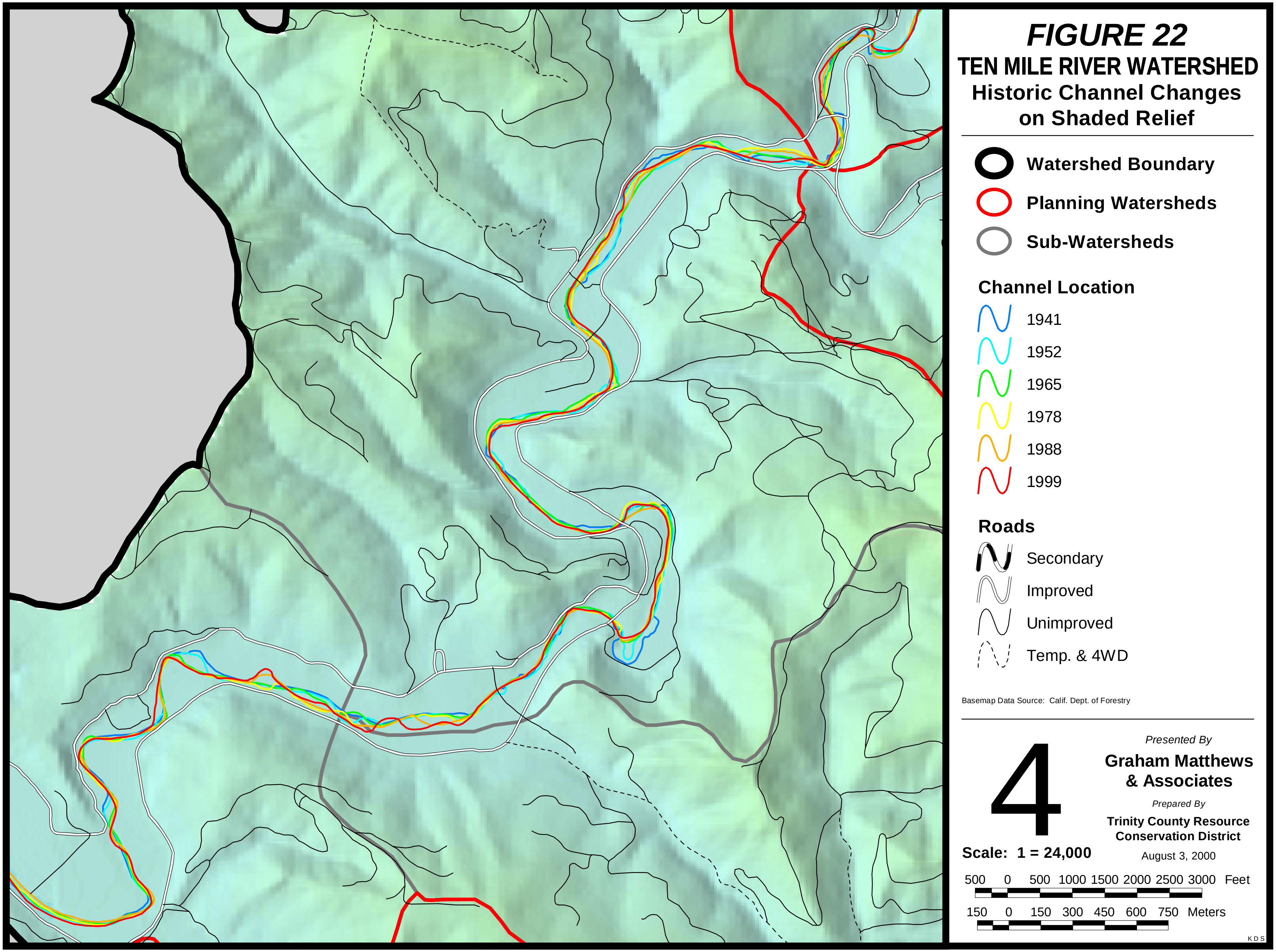
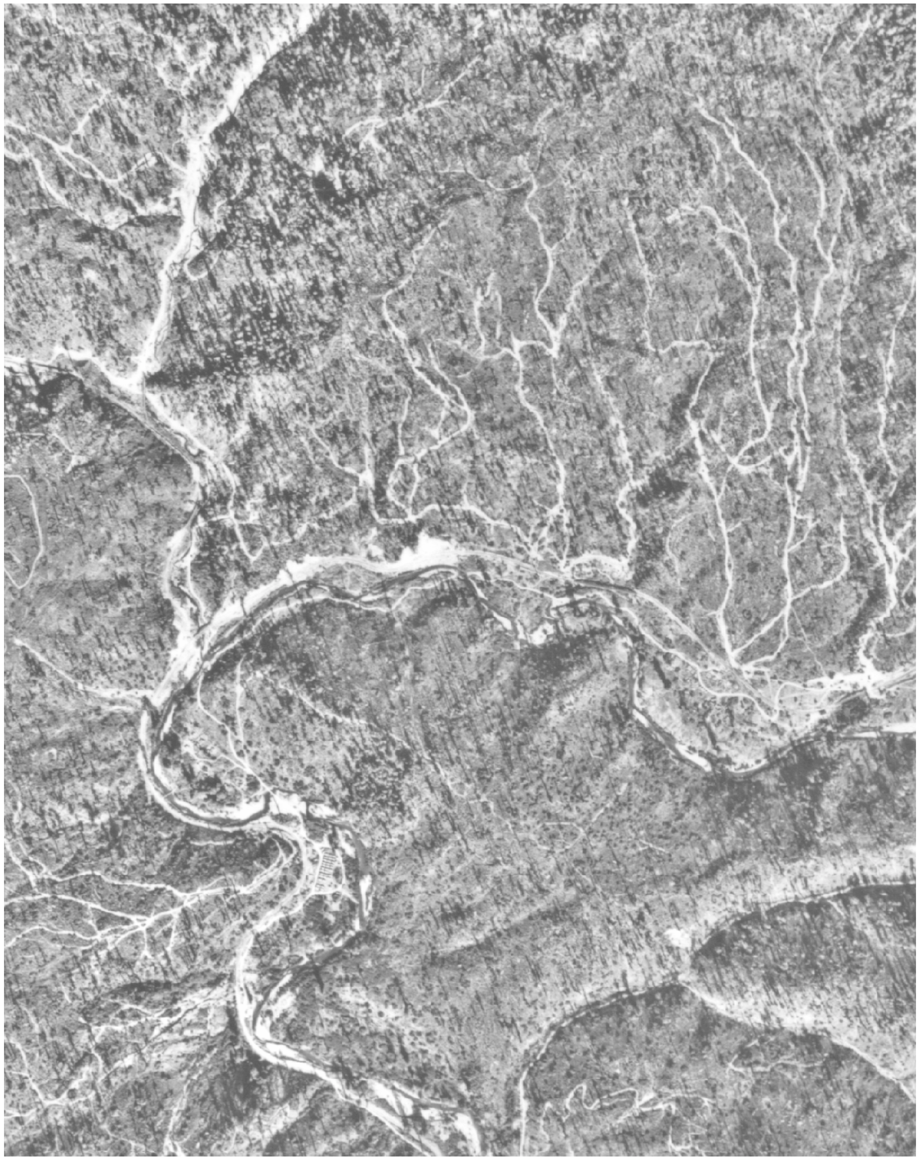


FIGURE 22
TEN MILE RIVER WATERSHED
Historic Channel Changes
on Shaded Relief
Watershed Boundary
Planning Watersheds
Sub-Watersheds
Channel Location
1941
1952
1965
1978
1988
1999
Roads
Secondary
Improved
Unimproved
Temp. & 4WD
Basemap Data Source: Calif. Dept. of Forestry
4
Scale: 1 = 24,000
Presented By
Graham Matthews & Associates
Prepared By
Trinity County Resource Conservation District
August 3, 2000
500 0 500 1000 1500 2000 2500 3000 Feet
150 0 150 300 450 600 750 Meters
KDS



1941-42

1999

LOWER NORTH FORK TEN MILE RIVER
COMPARISON OF 1941-42 & 1999 AERIAL PHOTOGRAPHY

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4

SCALE
NTS

FIGURE
23

1941-42

1999

UPPER MAINSTEM TEN MILE RIVER
COMPARISON OF 1941-42 & 1999 AERIAL PHOTOGRAPHY

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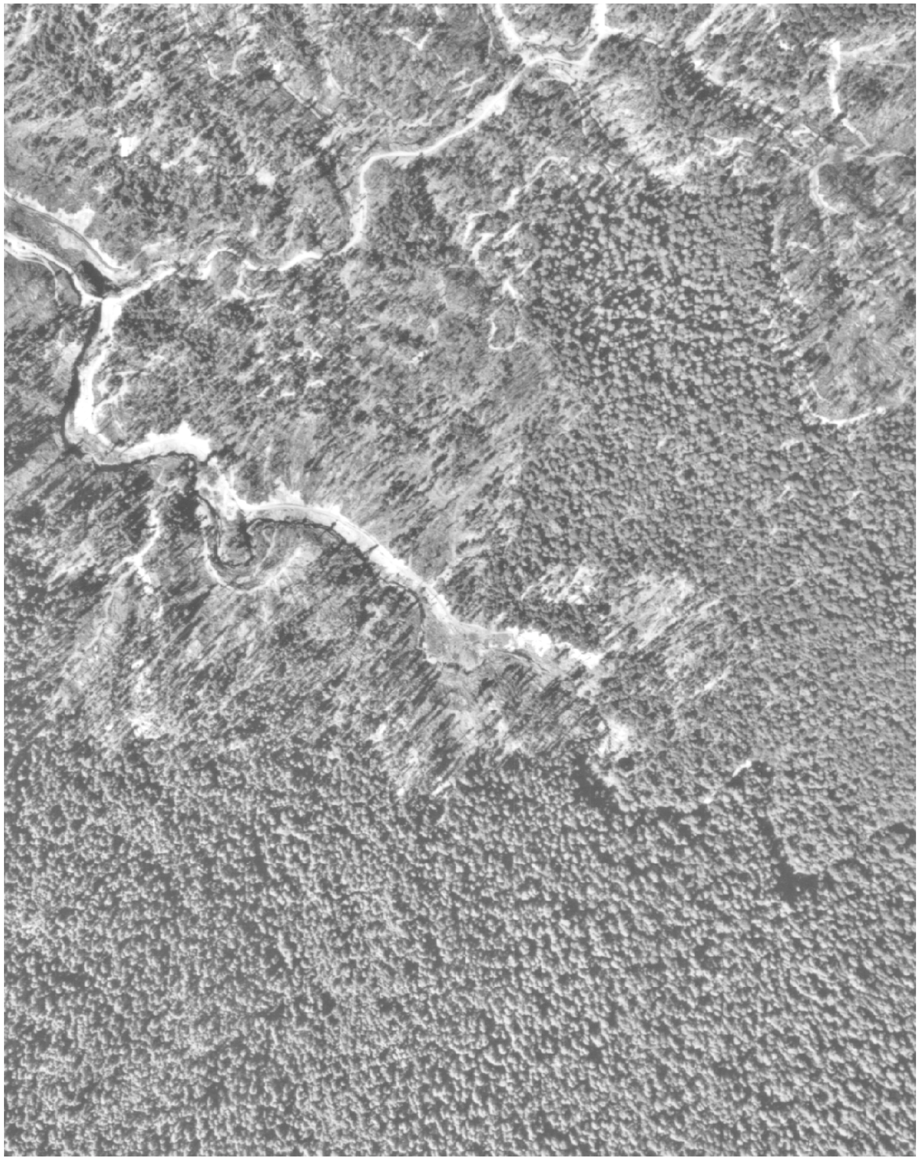
4

SCALE
NTS

FIGURE
23a



1941-42

1999

LOWER MIDDLE FORK TEN MILE RIVER
COMPARISON OF 1941-42 & 1999 AERIAL PHOTOGRAPHY

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4

SCALE
NTS

FIGURE
24

1941-42

1999

MIDDLE FORK TEN MILE RIVER
COMPARISON OF 1941-42 & 1999 AERIAL PHOTOGRAPHY

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4

SCALE
NTS

FIGURE
24a

1941-42

1999

LOWER SOUTH FORK TEN MILE RIVER
COMPARISON OF 1941-42 & 1999 AERIAL PHOTOGRAPHY

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4

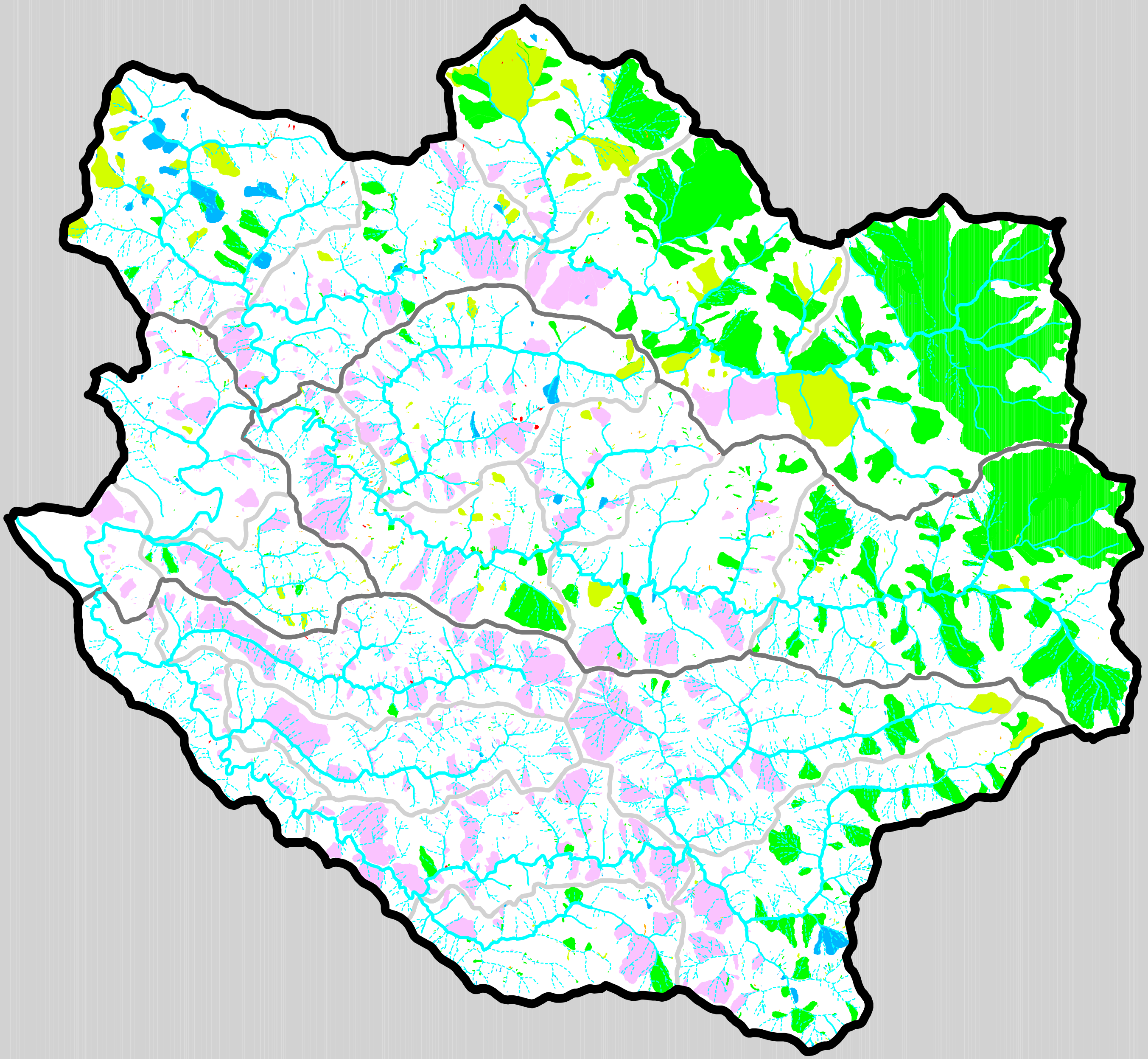
SCALE
NTS

FIGURE
25

FIGURE 26

TEN MILE RIVER WATERSHED

Distribution of Mapped Landslides



Watershed Boundary

Planning Watersheds

Sub-Watersheds

Mapped Landslides

1941

1952

1965

1978

1988

1999

Streams

Perennial

Intermittent

Ephemeral

Basemap Data Source: Calif. Dept. of Forestry
Slide Data & Location: John Coyle & Assoc.

4

Scale: 1 = 130,000

1 0 1 2 3 Miles

1 0 1 2 3 4 Kilometers

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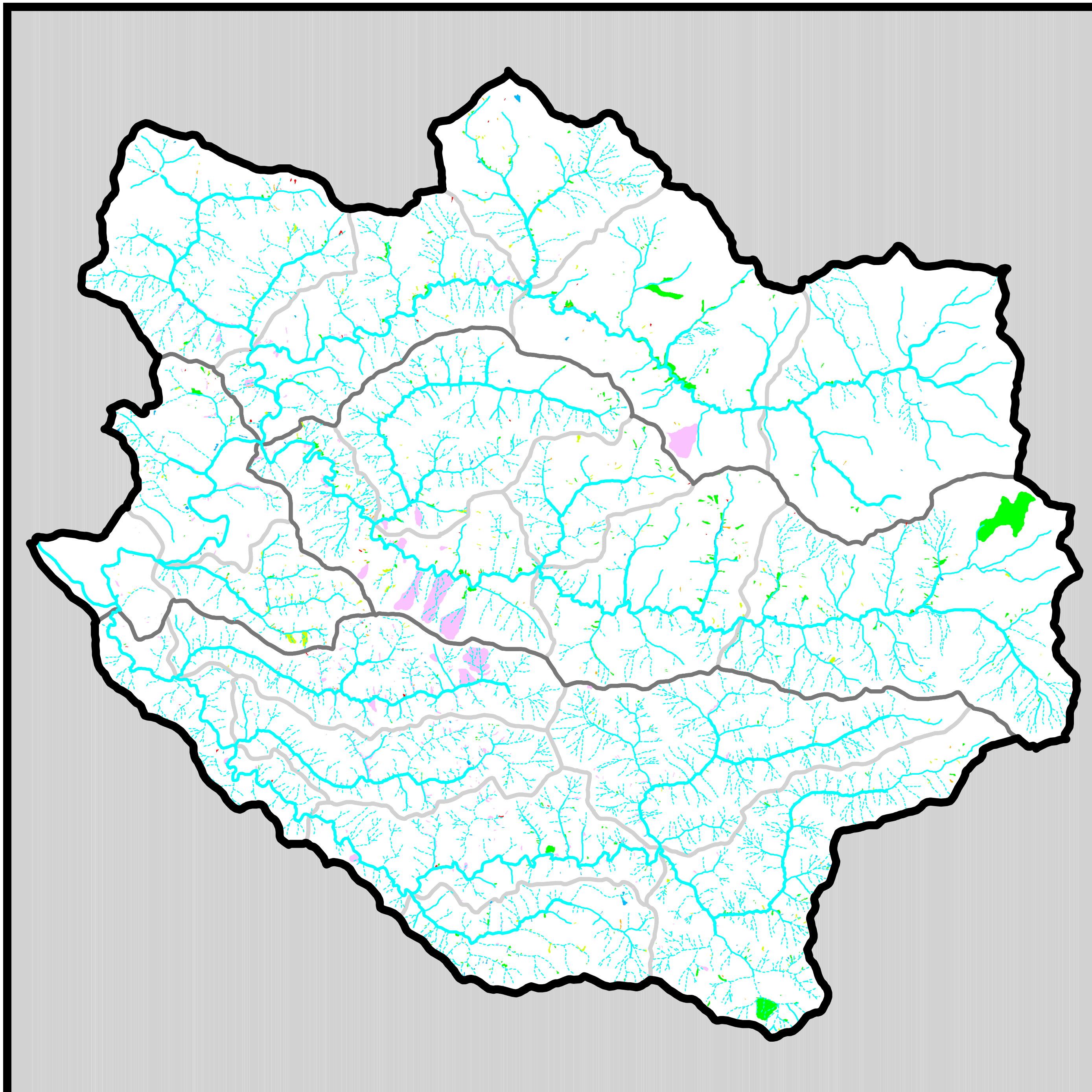

FIGURE 27

TEN MILE RIVER WATERSHED

Distribution of Delivering Landslides

Watershed Boundary

Planning Watersheds

Sub-Watersheds

Delivering Landslides

1941

1952

1965

1978

1988

1999

Streams

Perennial

Intermittent

Ephemeral

Basemap Data Source: Calif. Dept. of Forestry
Slide Data & Location: John Coyle & Assoc.

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4

Scale: 1 = 130,000

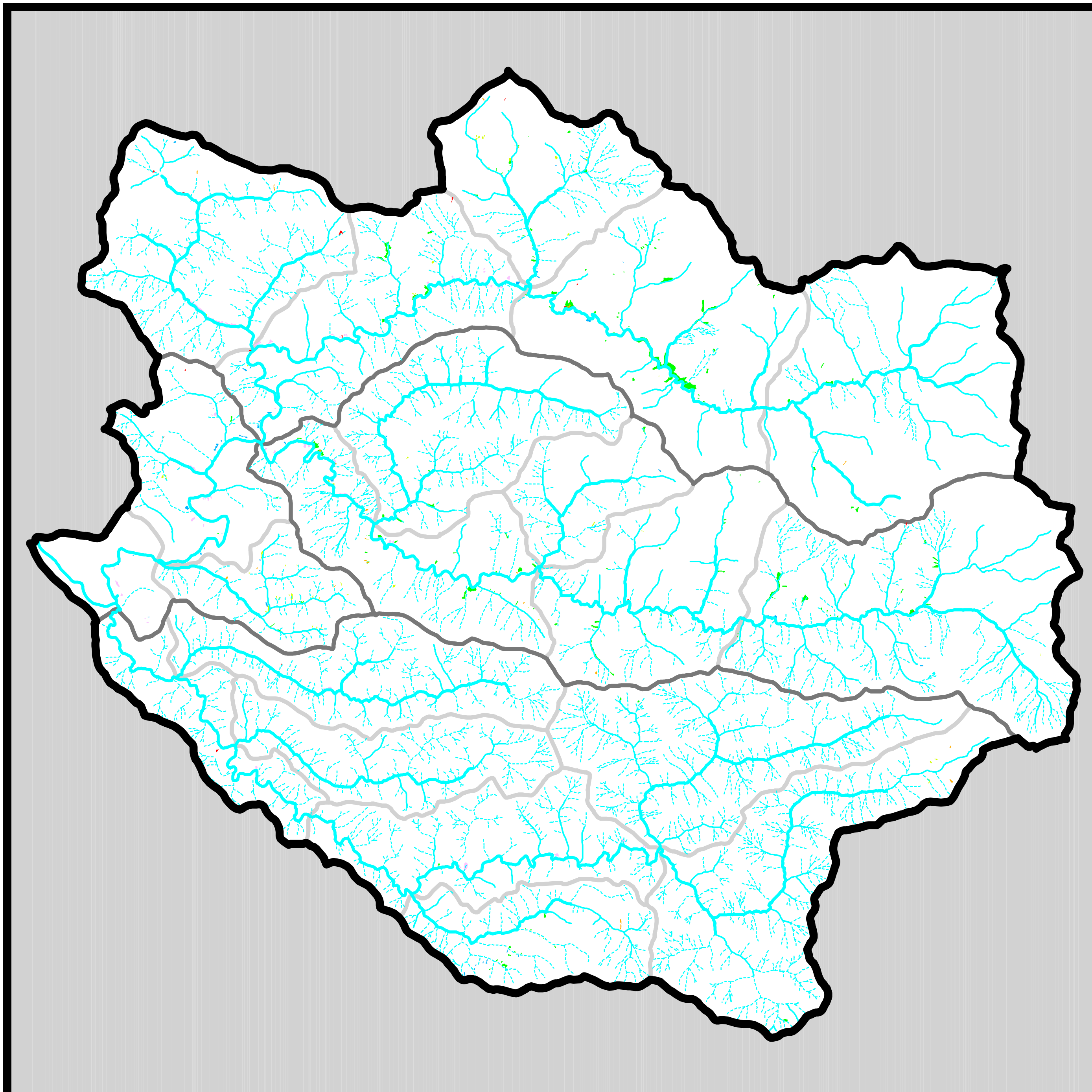
1 0 1 2 3 Miles

1 0 1 2 3 4 Kilometers

KDS

FIGURE 28

TEN MILE RIVER WATERSHED
Distribution of Road-Related Landslides



Watershed Boundary

Planning Watersheds

Sub-Watersheds

Road-Related Landslides

1941

1952

1965

1978

1988

1999

Streams

Perennial

Intermittent

Ephemeral

Basemap Data Source: Calif. Dept. of Forestry
Slide Data & Location: John Coyle & Assoc.

4

Scale: 1 = 130,000

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1 0 1 2 3 Miles

1 0 1 2 3 4 Kilometers

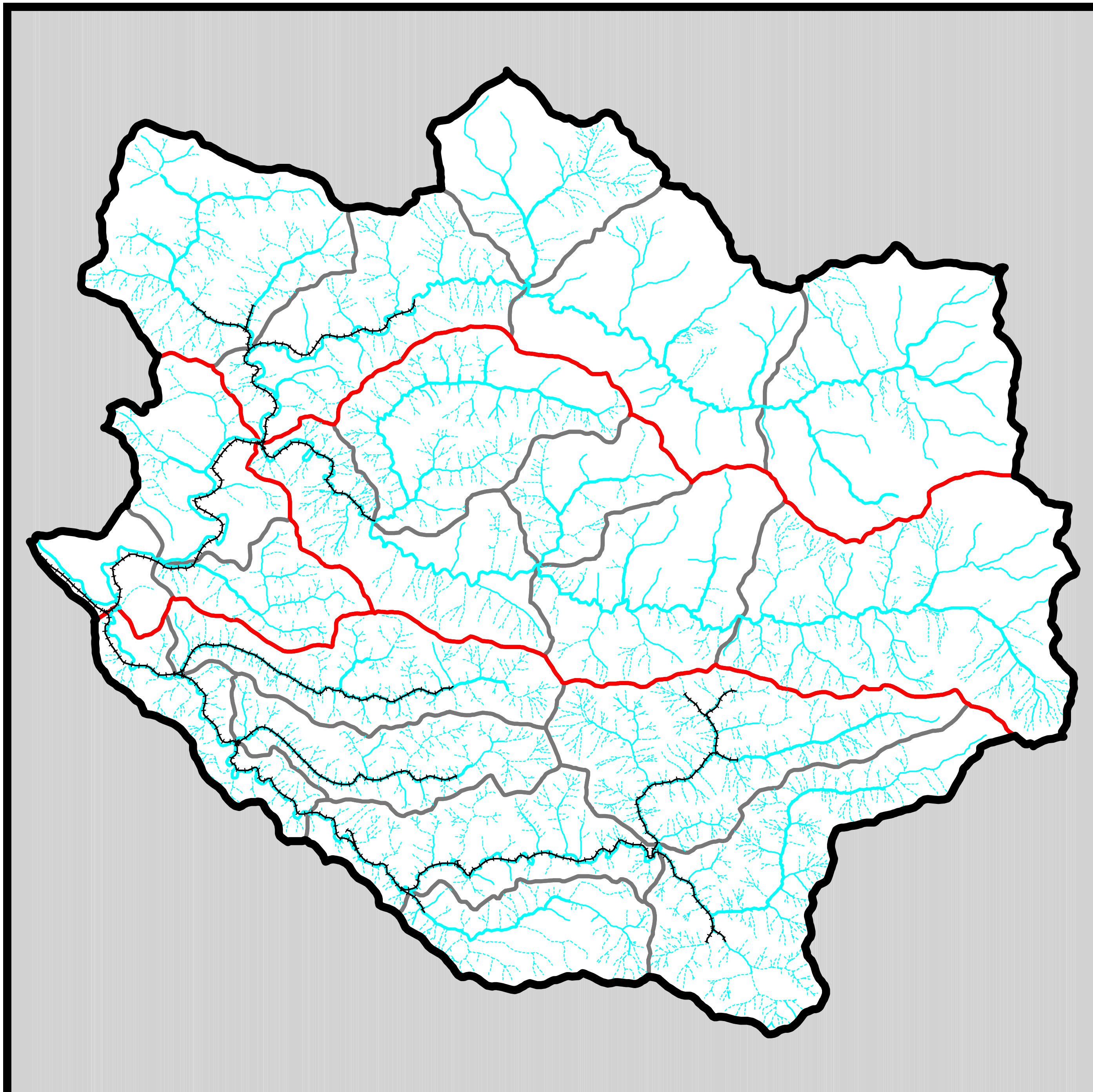
KDS

FIGURE 29

TEN MILE RIVER WATERSHED

Railroad Network

1941-42



Watershed Boundary

Planning Watersheds

Sub-Watersheds

Railroad Network

Streams

Perennial

Intermittent

Ephemeral

Basemap Data Source: Calif. Dept. of Forestry
Railroad Network Location: John Coyle & Assoc.

4

Scale: 1 = 130,000

Presented By

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1 0 1 2 3 Miles

1 0 1 2 3 4 Kilometers

KDS

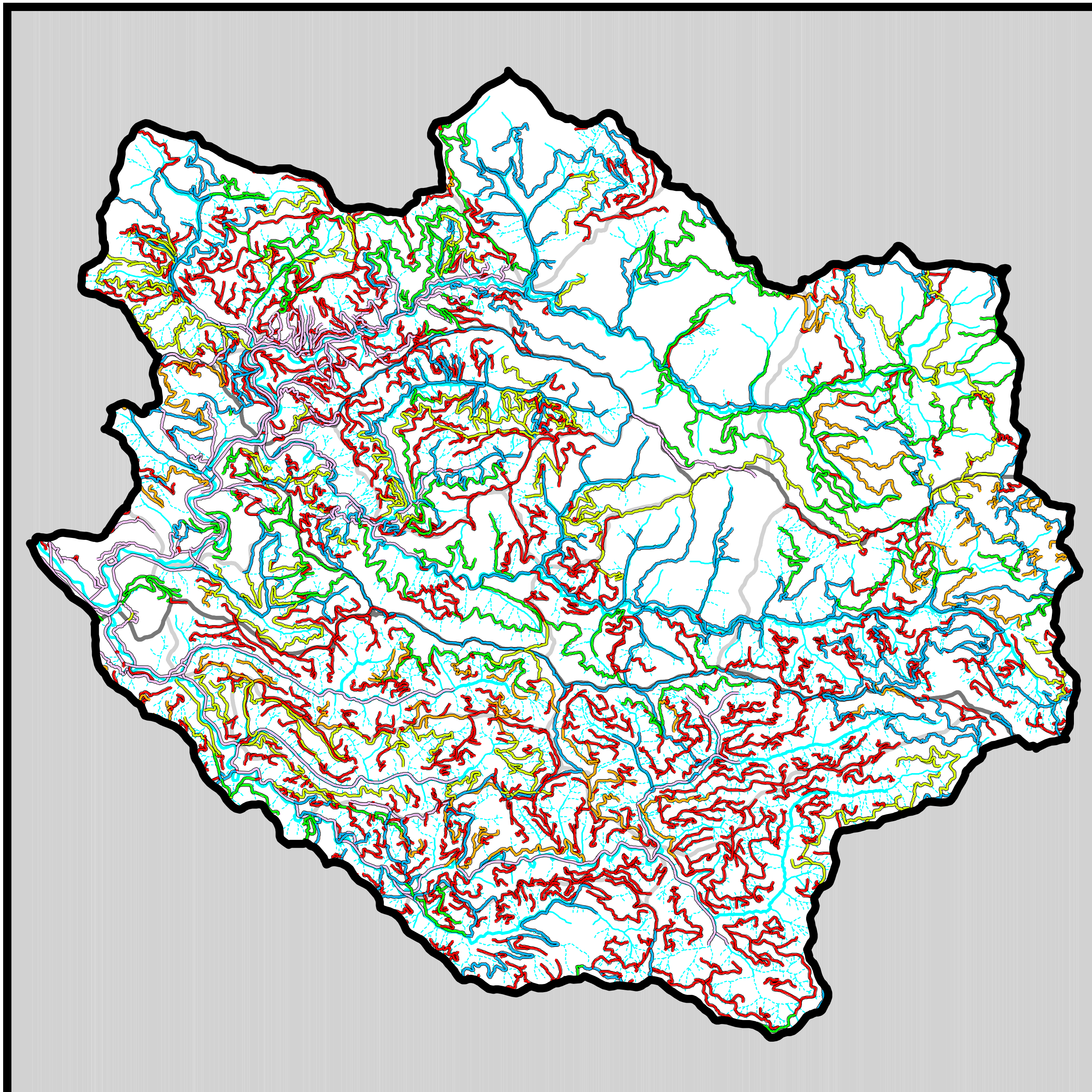

FIGURE 30
TEN MILE RIVER WATERSHED
Road Network
1941-1999

Watershed Boundary

Planning Watersheds

Sub-Watersheds

Road Network

1941

1952

1965

1978

1988

1999

Streams

Perennial

Intermittent

Ephemeral

Basemap Data Source: Calif. Dept. of Forestry
Additional Road Network Data & Location: John Coyle & Assoc.

Presented By

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Prepared By

Trinity County Resource Conservation District

August 3, 2000

4

Scale: 1 = 130,000

1 0 1 2 3 Miles

1 0 1 2 3 4 Kilometers

KDS

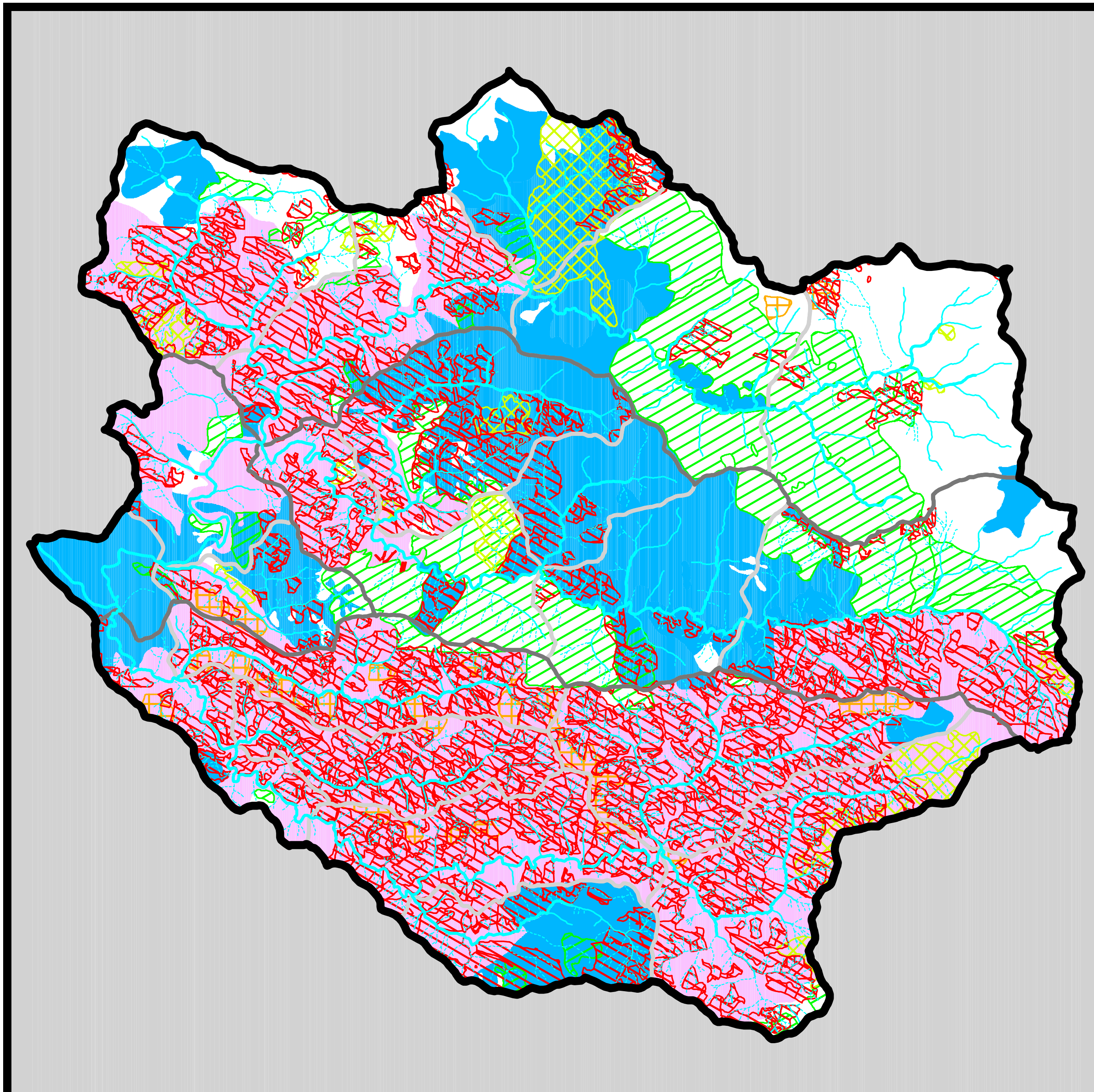

FIGURE 31
TEN MILE RIVER WATERSHED
Timber Harvest Areas
1941-1999

Watershed Boundary
Planning Watersheds
Sub-Watersheds

Harvest Areas

1941
1952
1965
1978
1988
1999

Streams

Perennial
Intermittent
Ephemeral

Basemap Data Source: Calif. Dept. of Forestry
Additional Harvest Data & Location: John Coyle & Assoc.

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Scale: 1 = 130,000

1 0 1 2 3 Miles

1 0 1 2 3 4 Kilometers

K D S

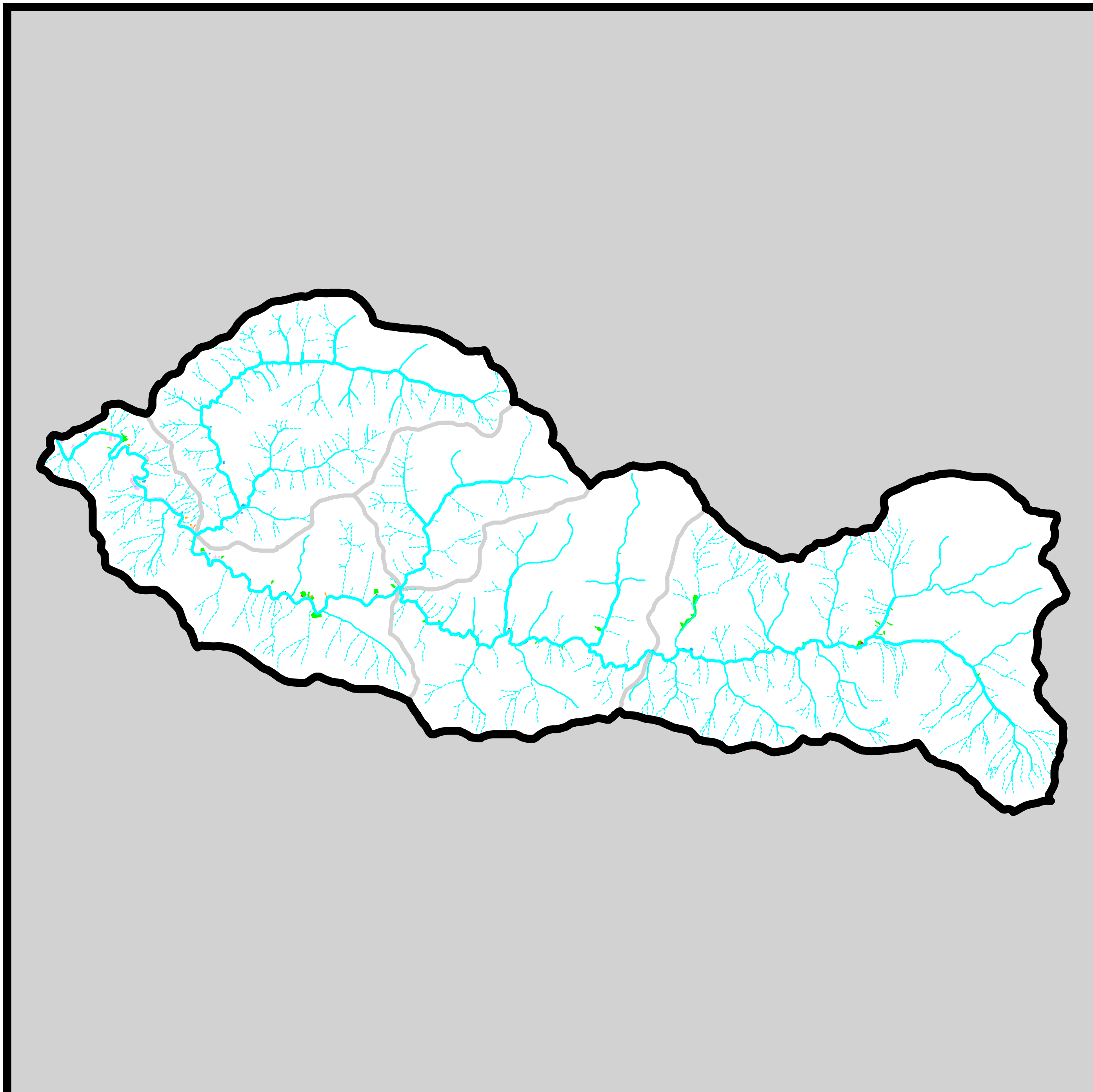

FIGURE 32

TEN MILE RIVER WATERSHED

Dist. of Inner Gorge Slides
Middle Ten Mile, 1941-1999

Planning Watershed

Sub-Watersheds

Inner Gorge Landslides

1941

1952

1965

1978

1988

1999

Streams

Perennial

Intermittent

Ephemeral

Basemap Data Source: Calif. Dept. of Forestry
Slide Data & Location: John Coyle & Assoc.

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August 3, 2000

Scale: 1 = 105,000

1 0 1 2 Miles

1 0 1 2 3 Kilometers

KDS

FIGURE 33

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Landslide Frequency by Type by Photo Period

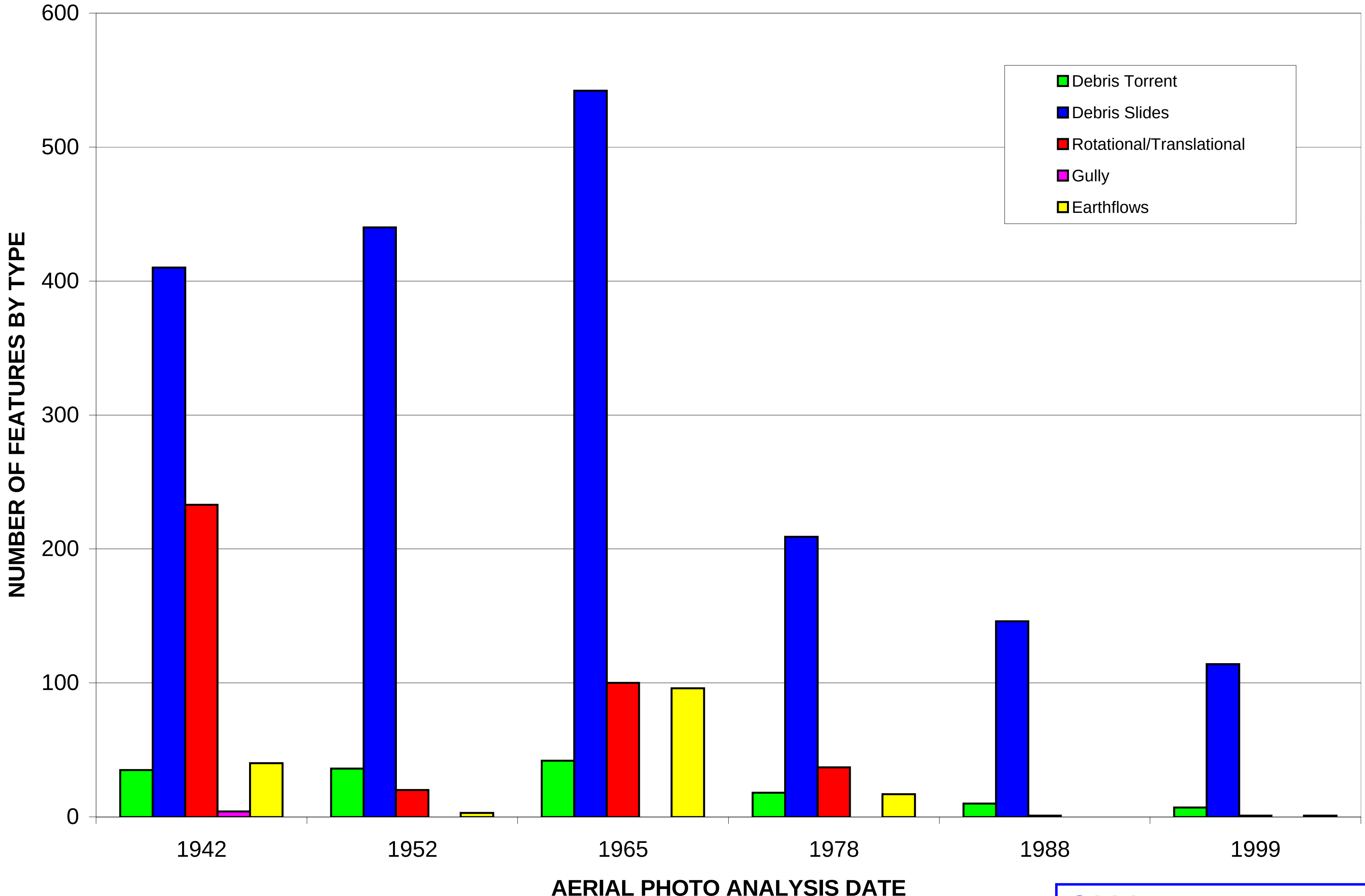

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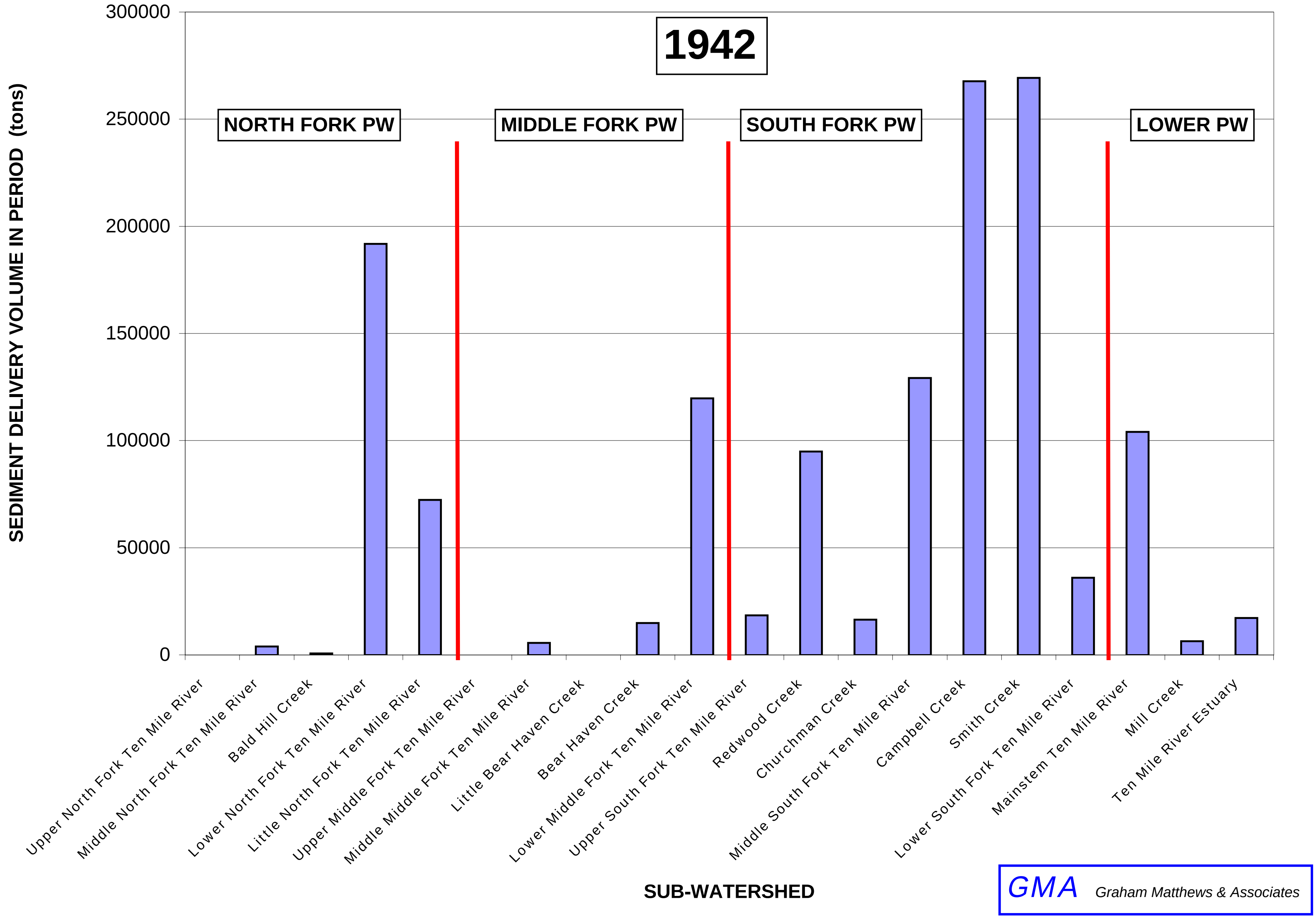
FIGURE 34

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Computed Mass Wasting Sediment Delivery Volume by Sub-Watershed for 1942 Budget Period



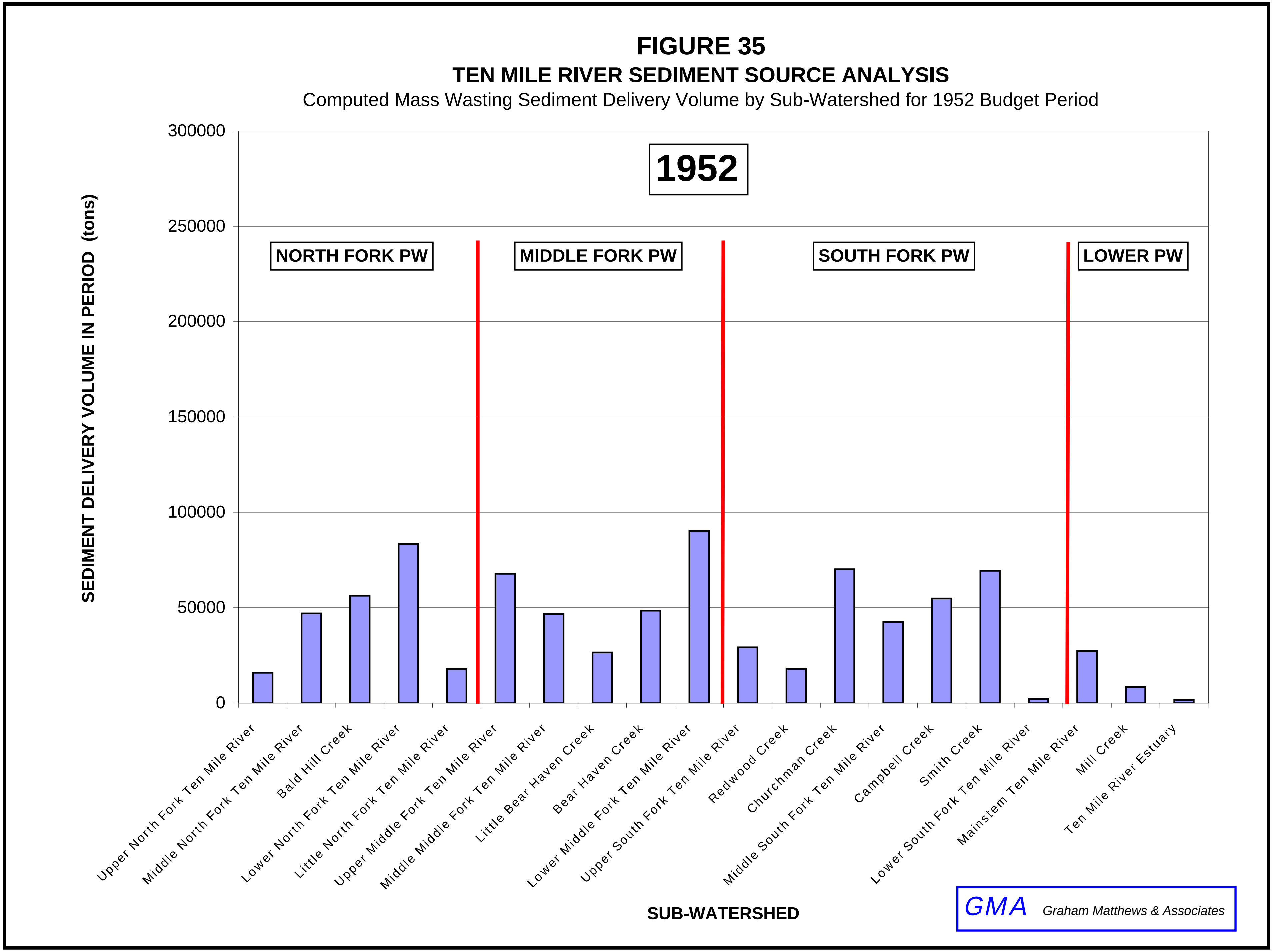


FIGURE 35
TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
Computed Mass Wasting Sediment Delivery Volume by Sub-Watershed for 1952 Budget Period
1952
NORTH FORK PW
MIDDLE FORK PW
SOUTH FORK PW
LOWER PW
SEDIMENT DELIVERY VOLUME IN PERIOD (tons)
0
50000
100000
150000
200000
250000
300000
Upper North Fork Ten Mile River
Middle North Fork Ten Mile River
Bald Hill Creek
Lower North Fork Ten Mile River
Little North Fork Ten Mile River
Upper Middle Fork Ten Mile River
Middle Middle Fork Ten Mile River
Little Bear Haven Creek
Bear Haven Creek
Lower Middle Fork Ten Mile River
Upper South Fork Ten Mile River
Redwood Creek
Churchman Creek
Middle South Fork Ten Mile River
Campbell Creek
Smith Creek
Lower South Fork Ten Mile River
Mainstem Ten Mile River
Mill Creek
Ten Mile River Estuary
SUB-WATERSHED
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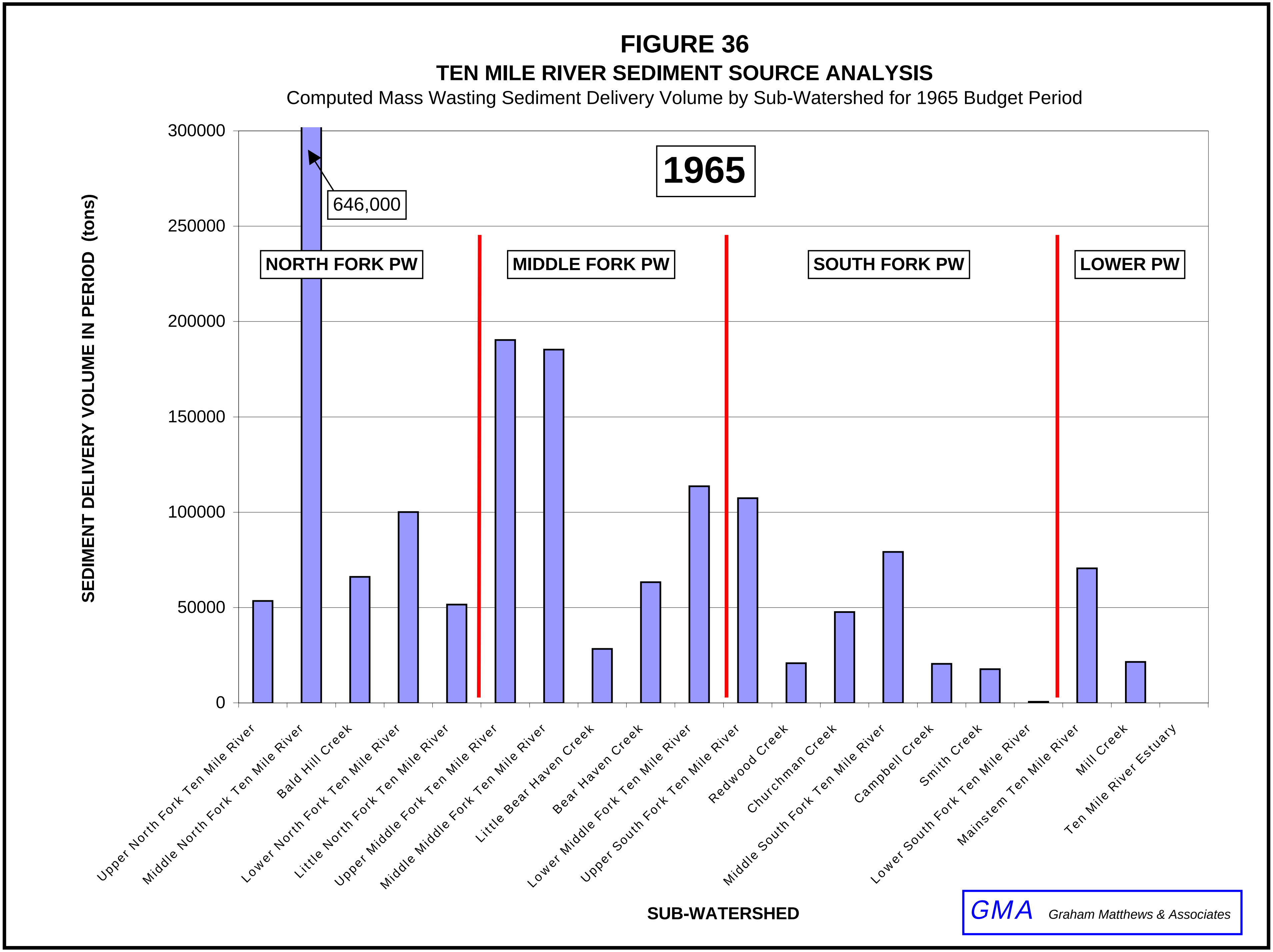


FIGURE 36
TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
Computed Mass Wasting Sediment Delivery Volume by Sub-Watershed for 1965 Budget Period
1965
646,000
NORTH FORK PW
MIDDLE FORK PW
SOUTH FORK PW
LOWER PW
SEDIMENT DELIVERY VOLUME IN PERIOD (tons)
300000
250000
200000
150000
100000
50000
0
Upper North Fork Ten Mile River
Middle North Fork Ten Mile River
Bald Hill Creek
Lower North Fork Ten Mile River
Little North Fork Ten Mile River
Upper Middle Fork Ten Mile River
Middle Middle Fork Ten Mile River
Little Bear Haven Creek
Bear Haven Creek
Lower Middle Fork Ten Mile River
Upper South Fork Ten Mile River
Redwood Creek
Churchman Creek
Middle South Fork Ten Mile River
Campbell Creek
Smith Creek
Lower South Fork Ten Mile River
Mainstem Ten Mile River
Mill Creek
Ten Mile River Estuary
SUB-WATERSHED
GMA Graham Matthews & Associates

FIGURE 37

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Computed Mass Wasting Sediment Delivery Volume by Sub-Watershed for 1978 Budget Period

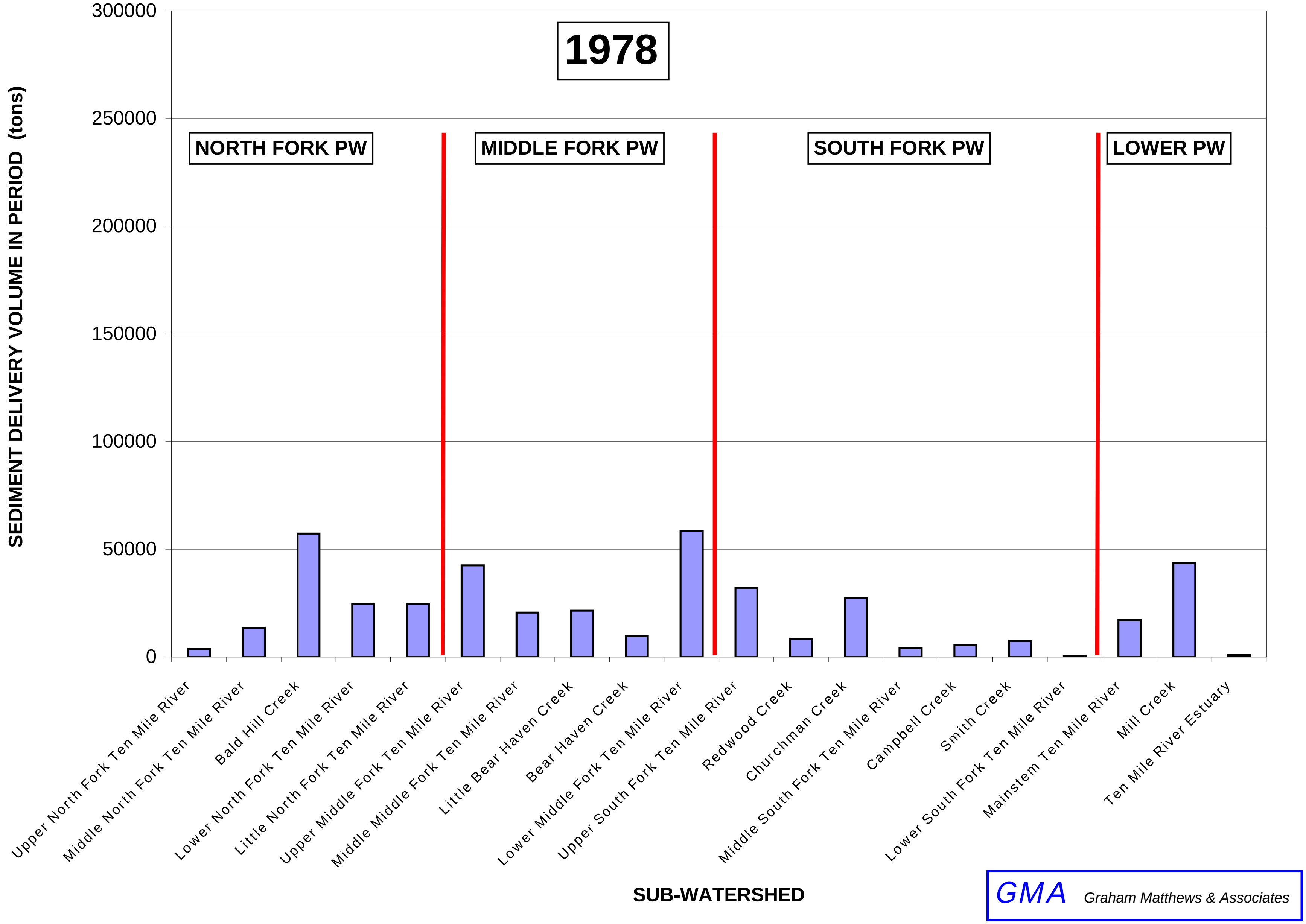


FIGURE 38
TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
Computed Mass Wasting Sediment Delivery Volume by Sub-Watershed for 1988 Budget Period

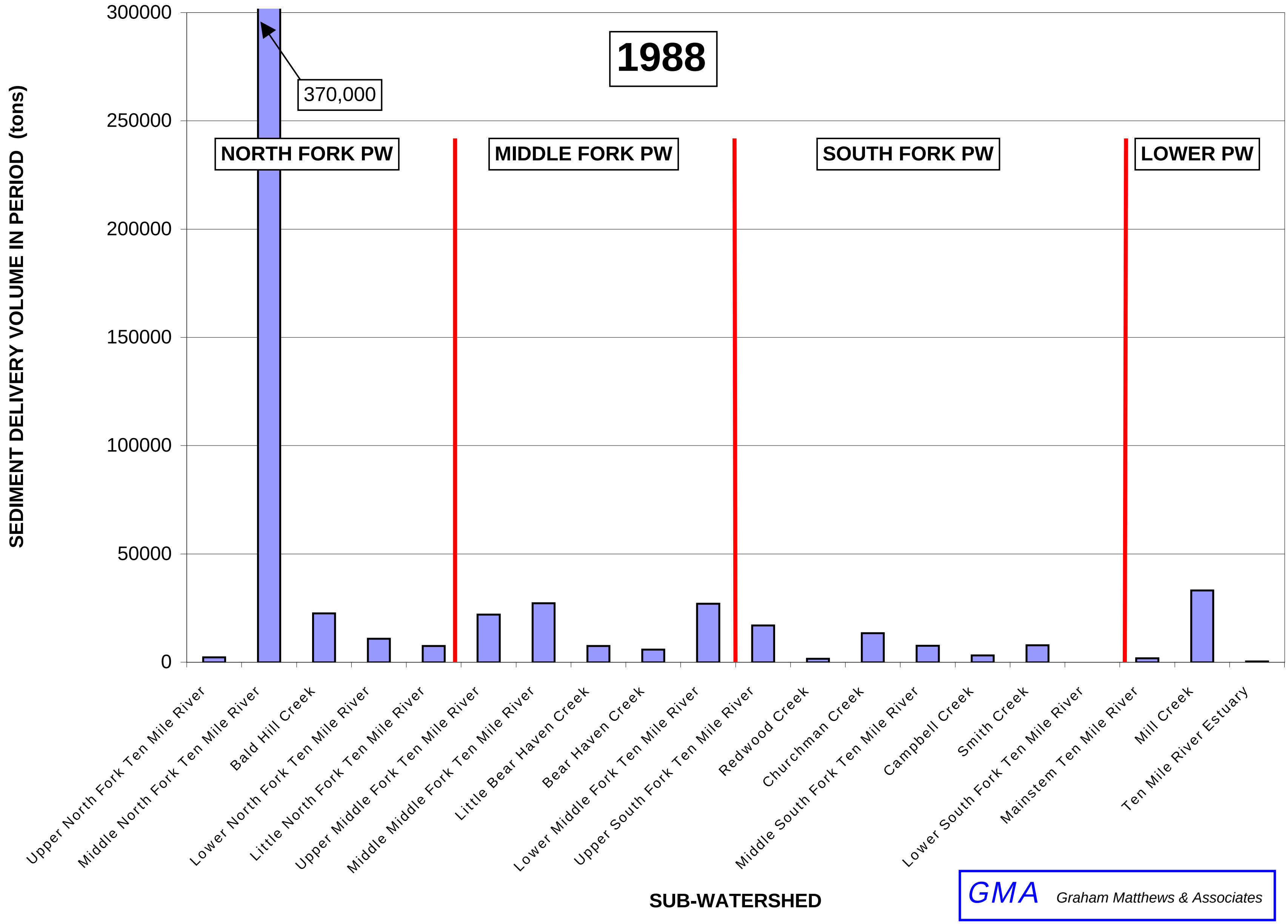


FIGURE 39

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Computed Mass Wasting Sediment Delivery Volume by Sub-Watershed for 1999 Budget Period

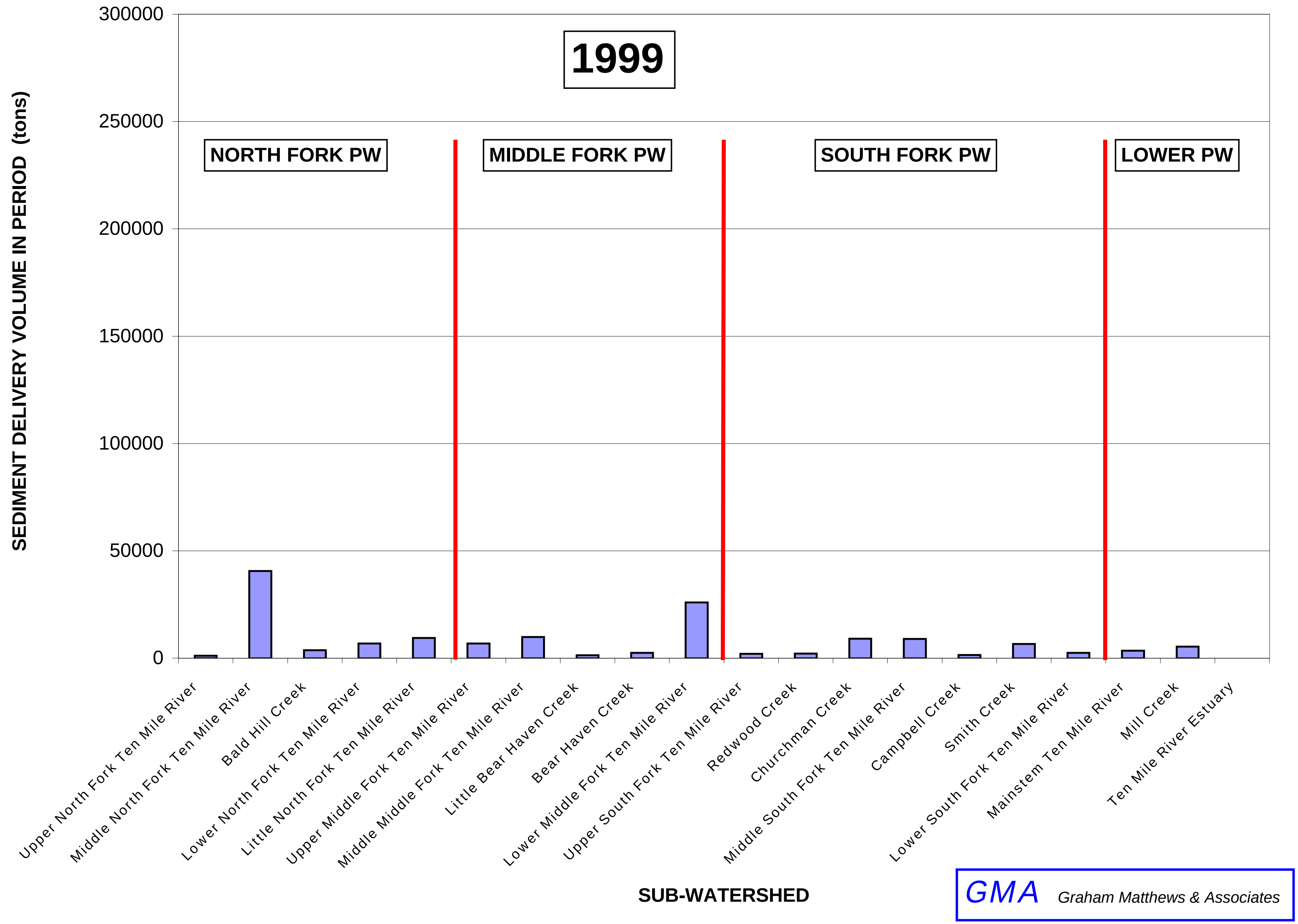


FIGURE 40

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Total Road Network by Sub-Watershed

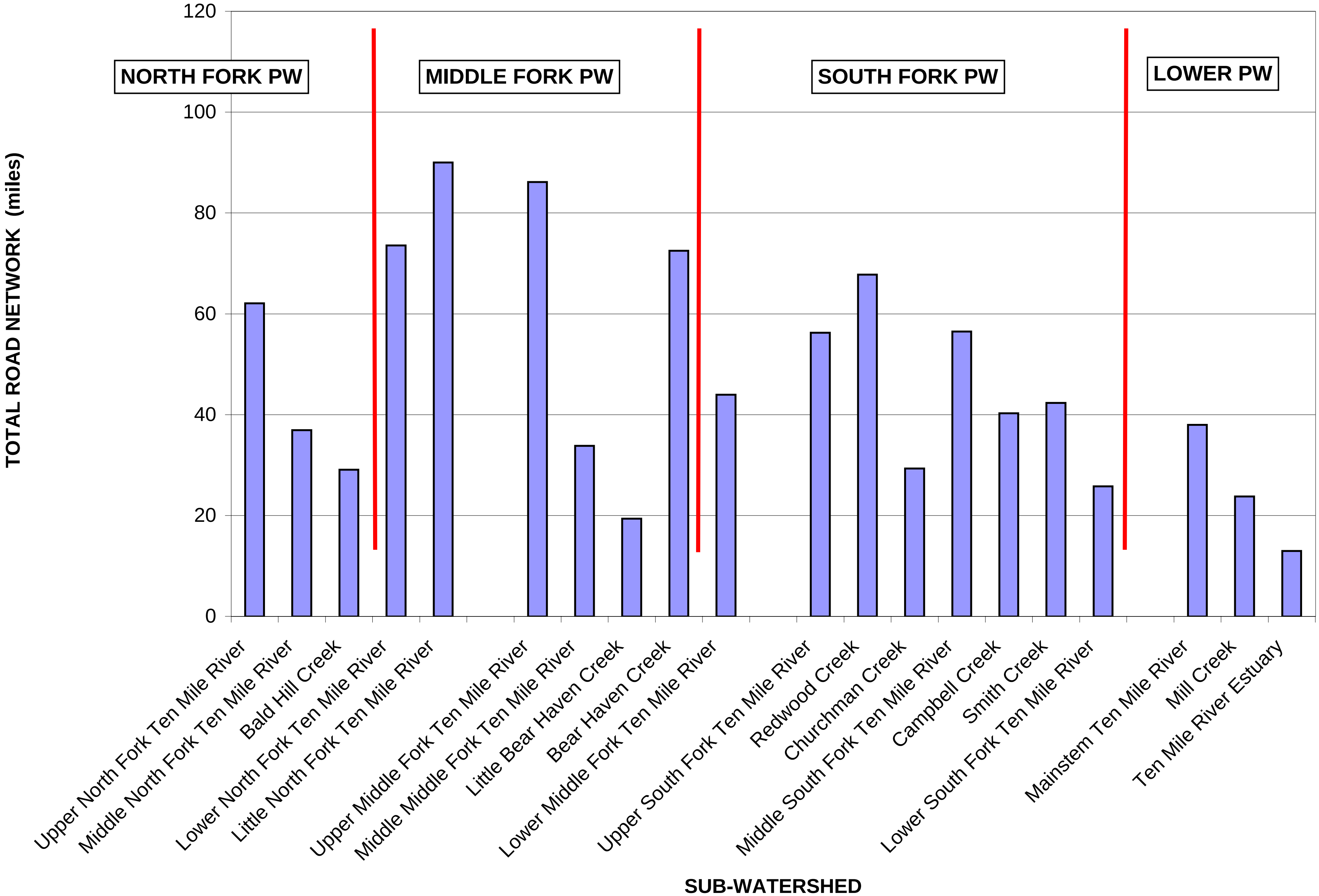


FIGURE 41

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Road Density by Sub-Watershed

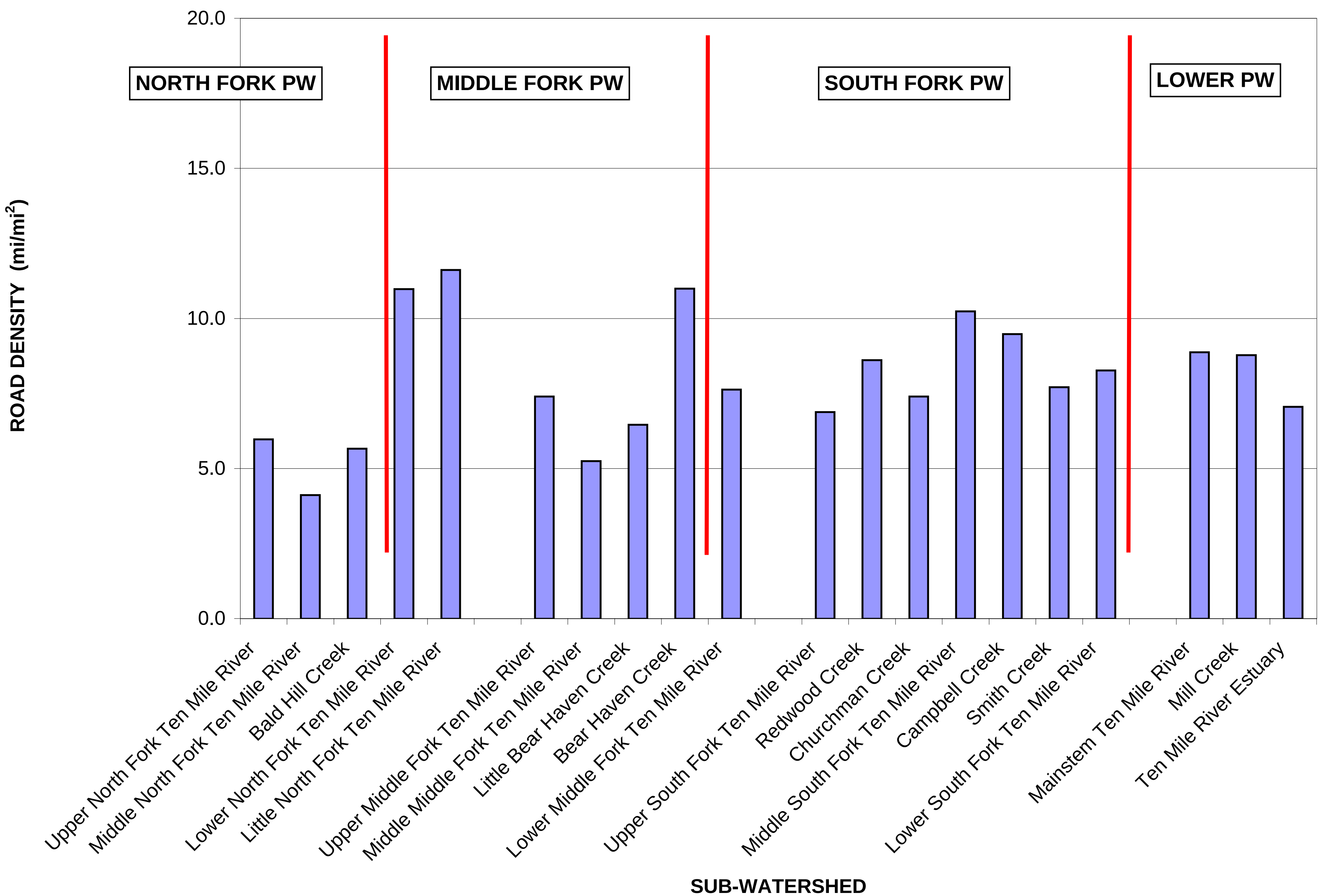
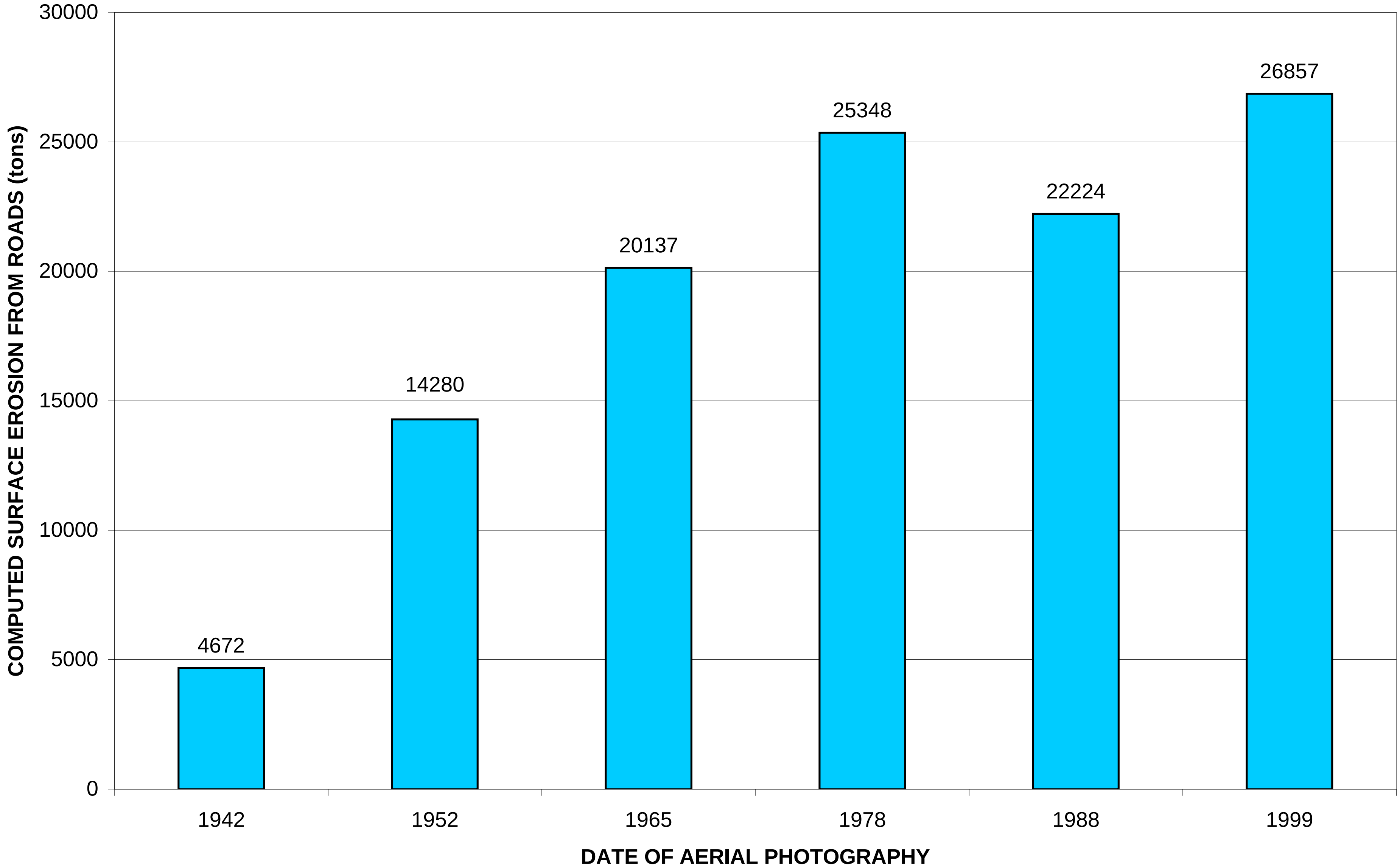


FIGURE 42

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Computed Road Surface Erosion by Study Period



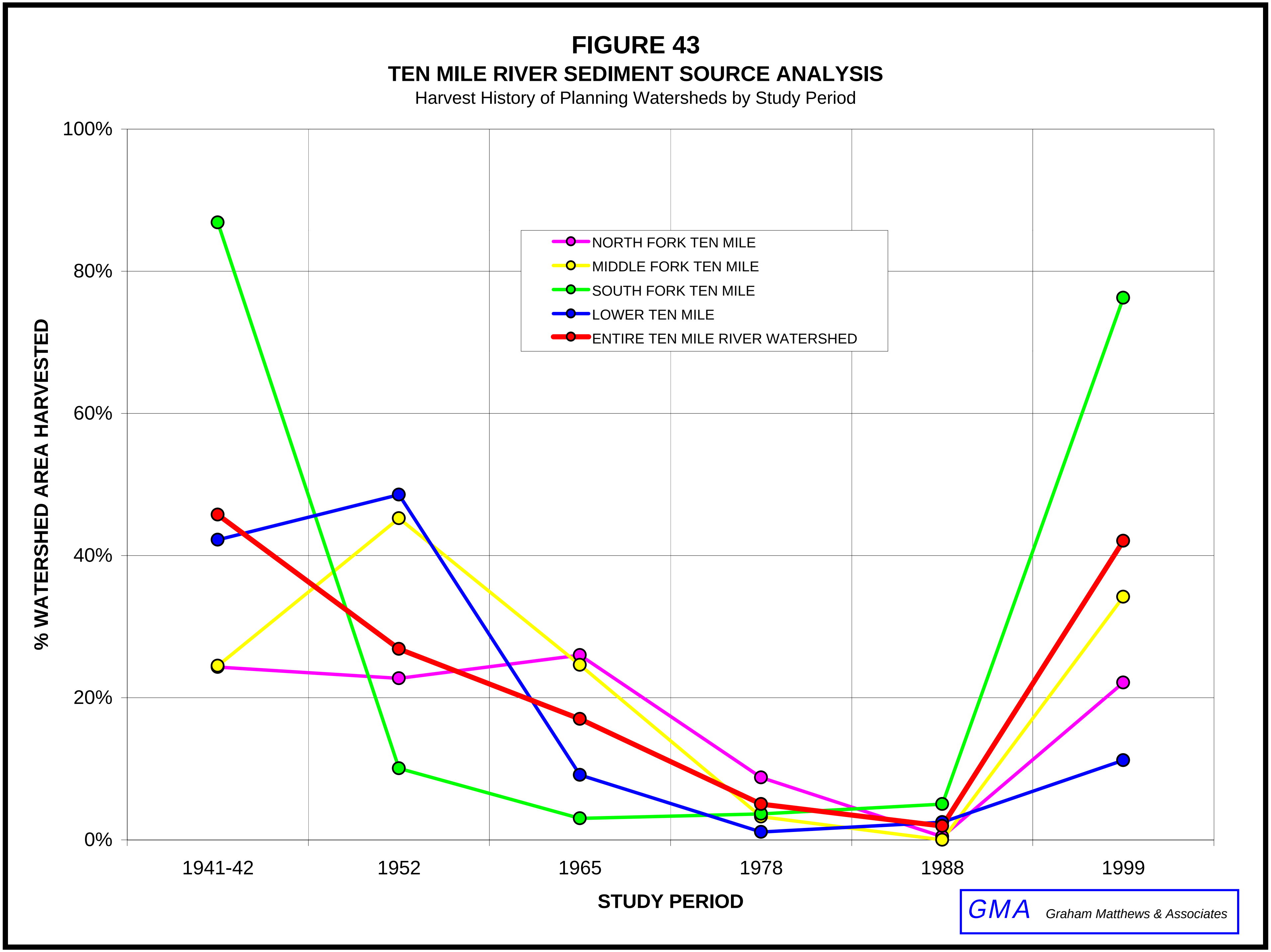


FIGURE 43
TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
Harvest History of Planning Watersheds by Study Period
100%
80%
60%
40%
20%
0%
% WATERSHED AREA HARVESTED
NORTH FORK TEN MILE
MIDDLE FORK TEN MILE
SOUTH FORK TEN MILE
LOWER TEN MILE
ENTIRE TEN MILE RIVER WATERSHED
1941-42
1952
1965
1978
1988
1999
STUDY PERIOD
GMA Graham Matthews & Associates

FIGURE 44

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Harvest Acreage vs. Number of Slides for Analysis Periods

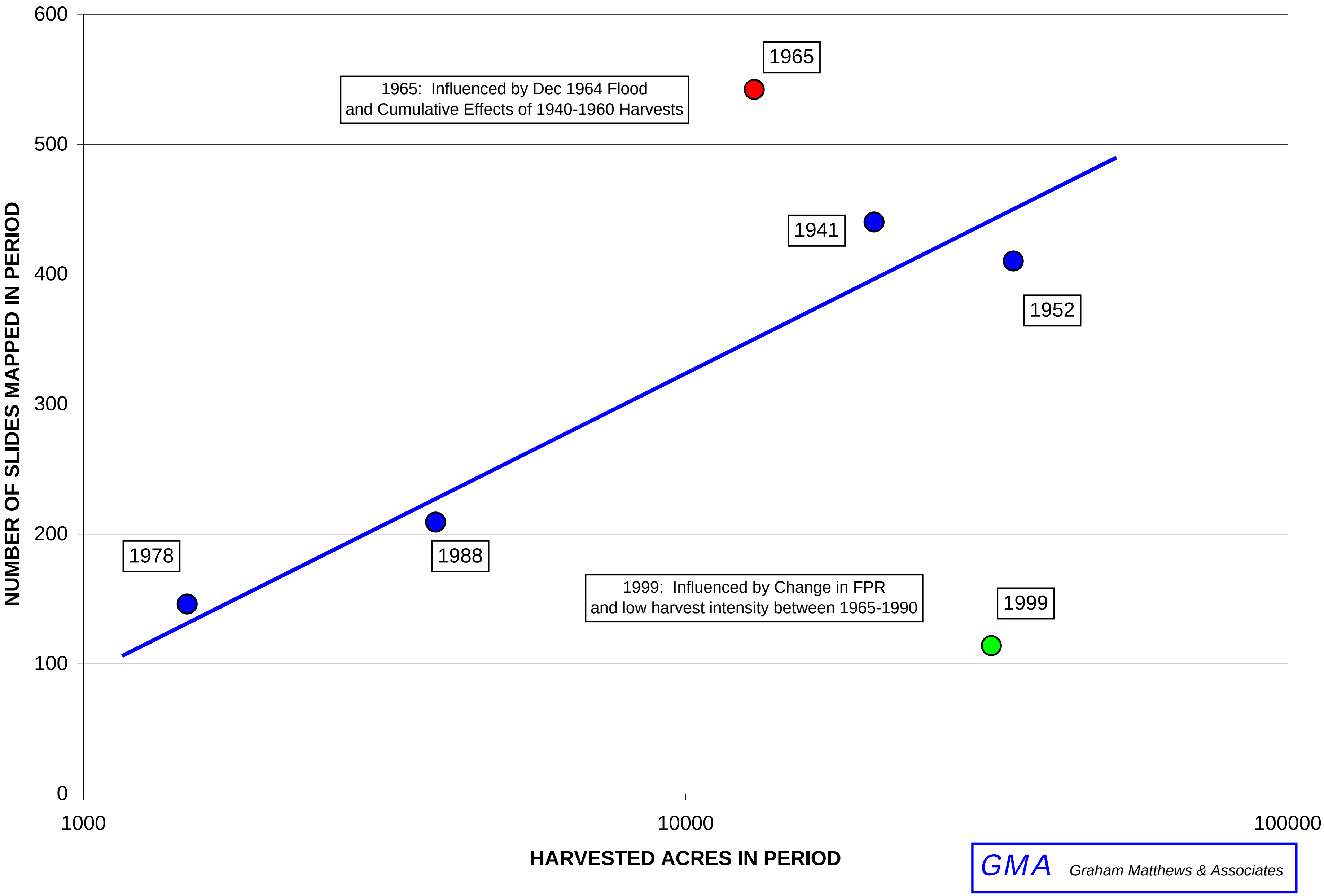


FIGURE 45
TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
Summary of Harvest Areas by Date with Given Density of Skid Roads

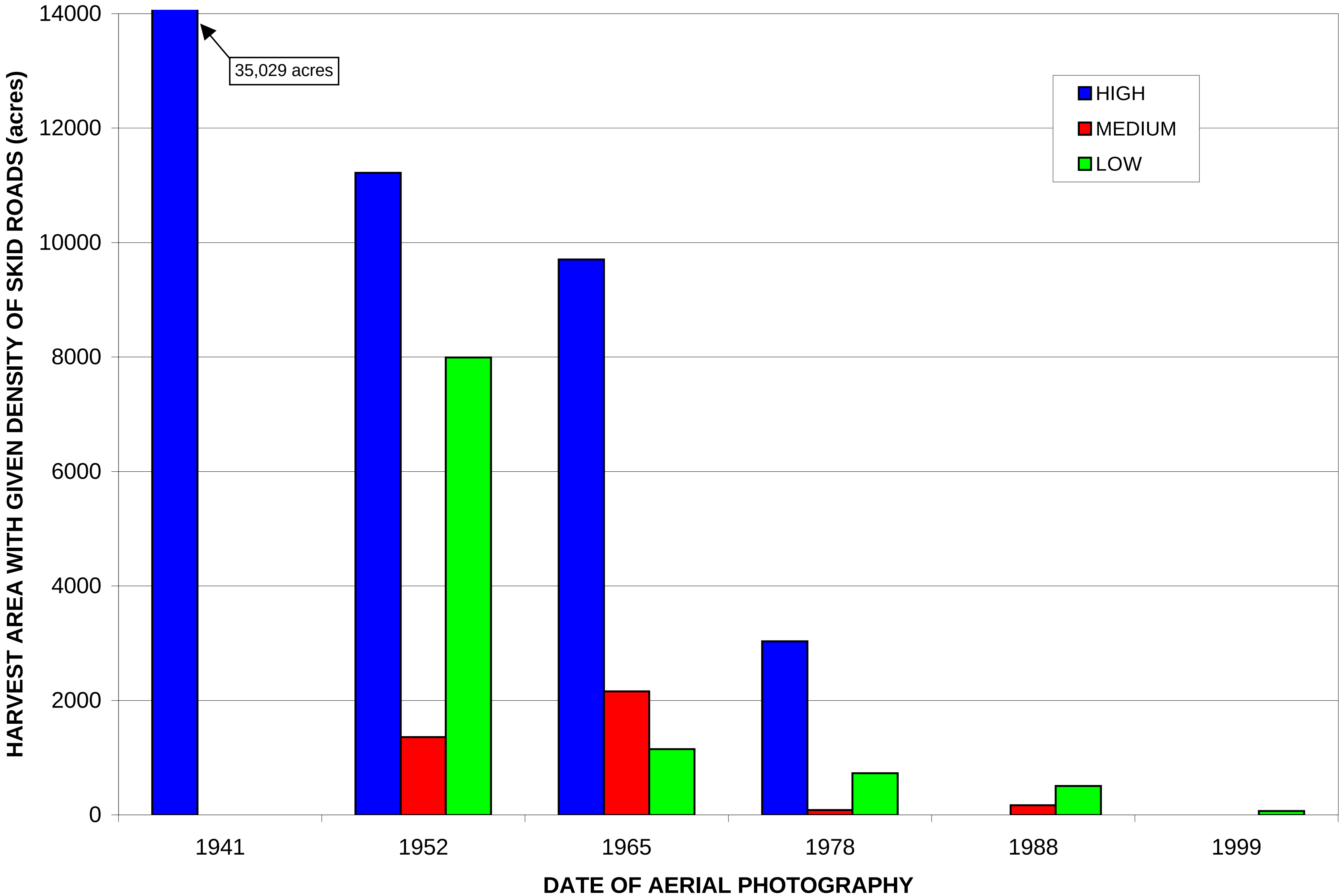


FIGURE 46
TEN MILE RIVER SEDIMENT SOURCE ANALYSIS
Computed Sediment Delivery from Harvest Areas by Study Period

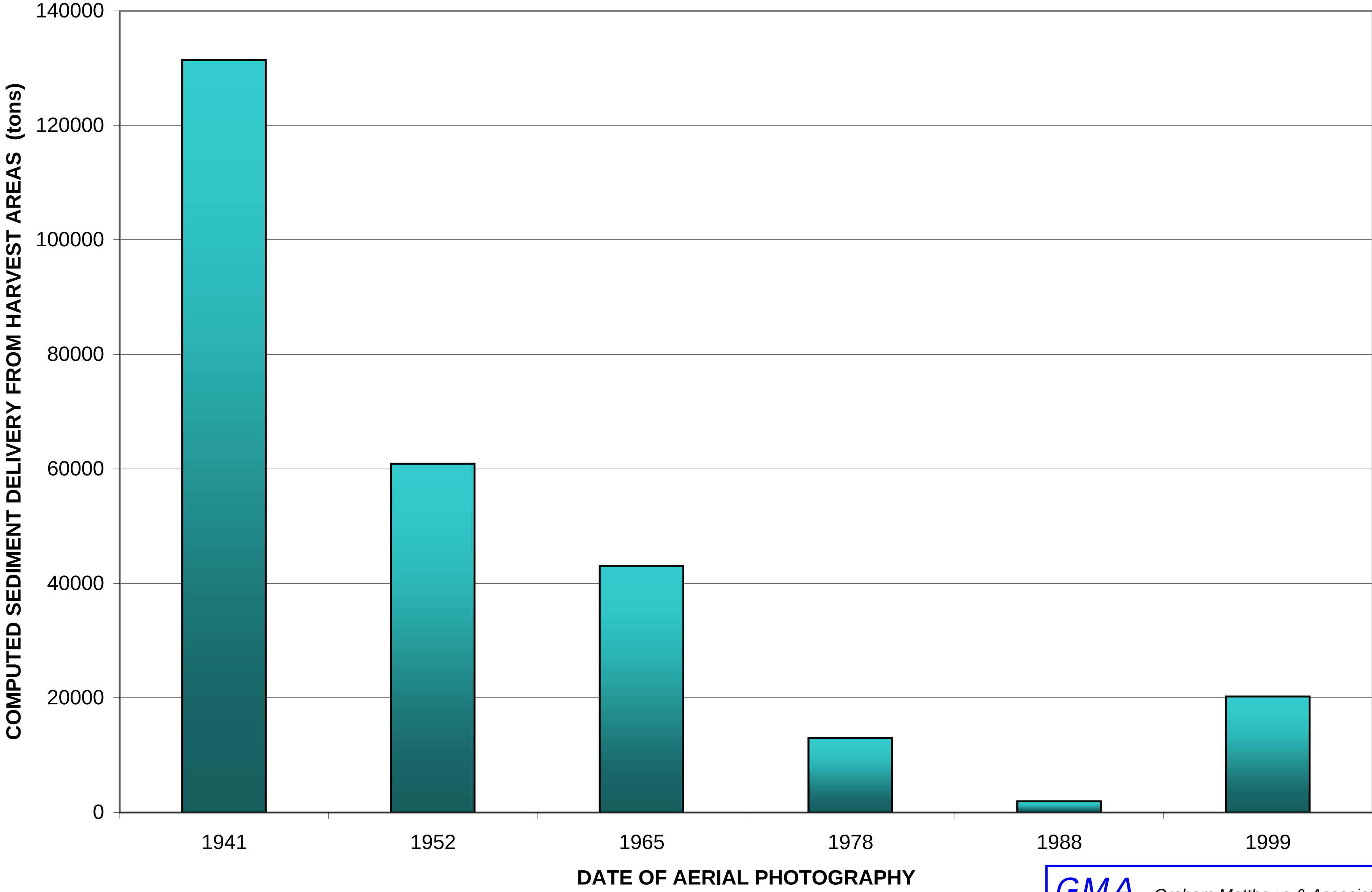


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FIGURE 47

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

RELATIVE DISTURBANCE INDEX VS. SUBSTRATE QUALITY

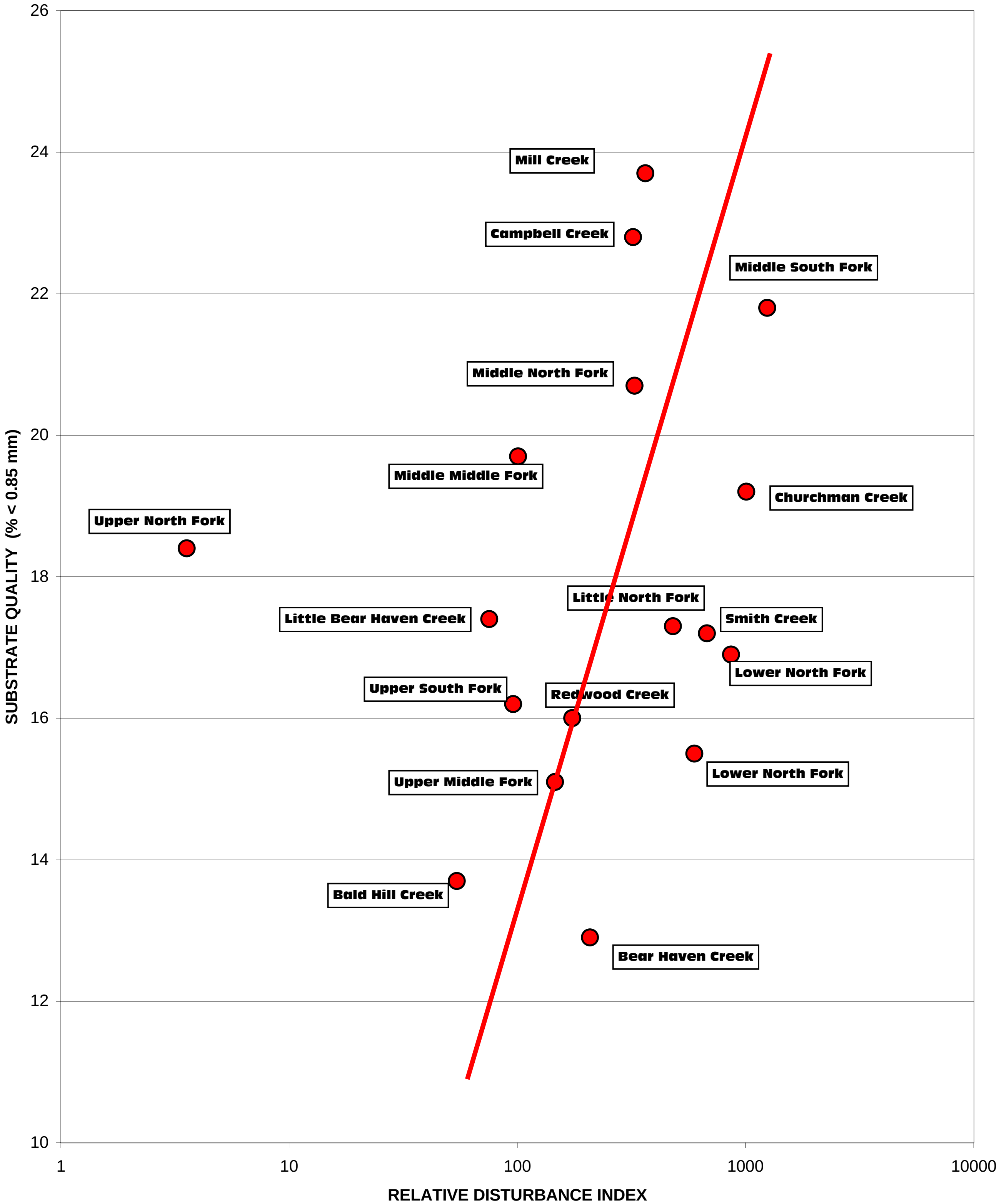

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FIGURE 48
TEN MILE RIVER WATERSHED
RELATIVE DISTURBANCE INDEX VS. SUBSTRATE QUALITY

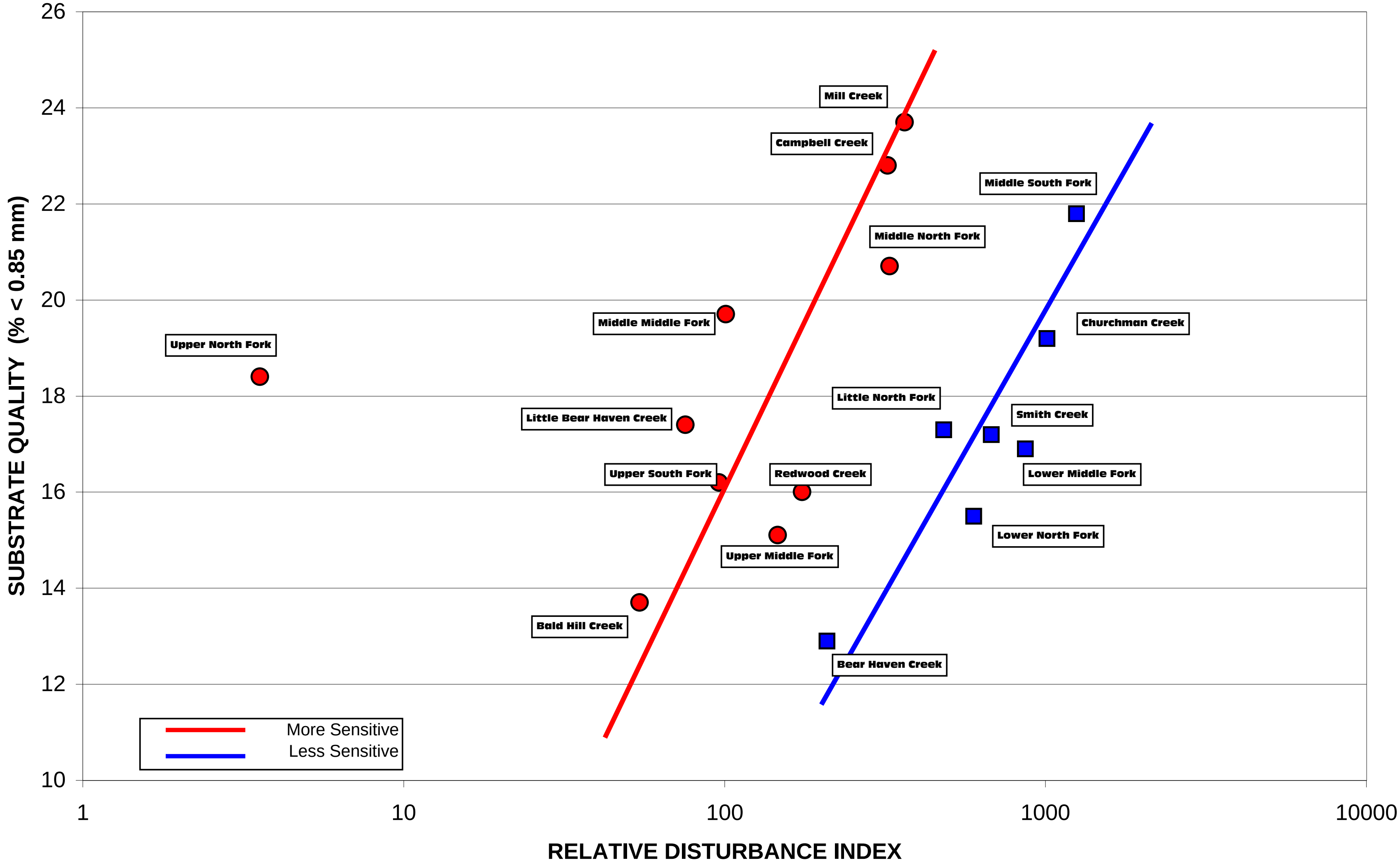

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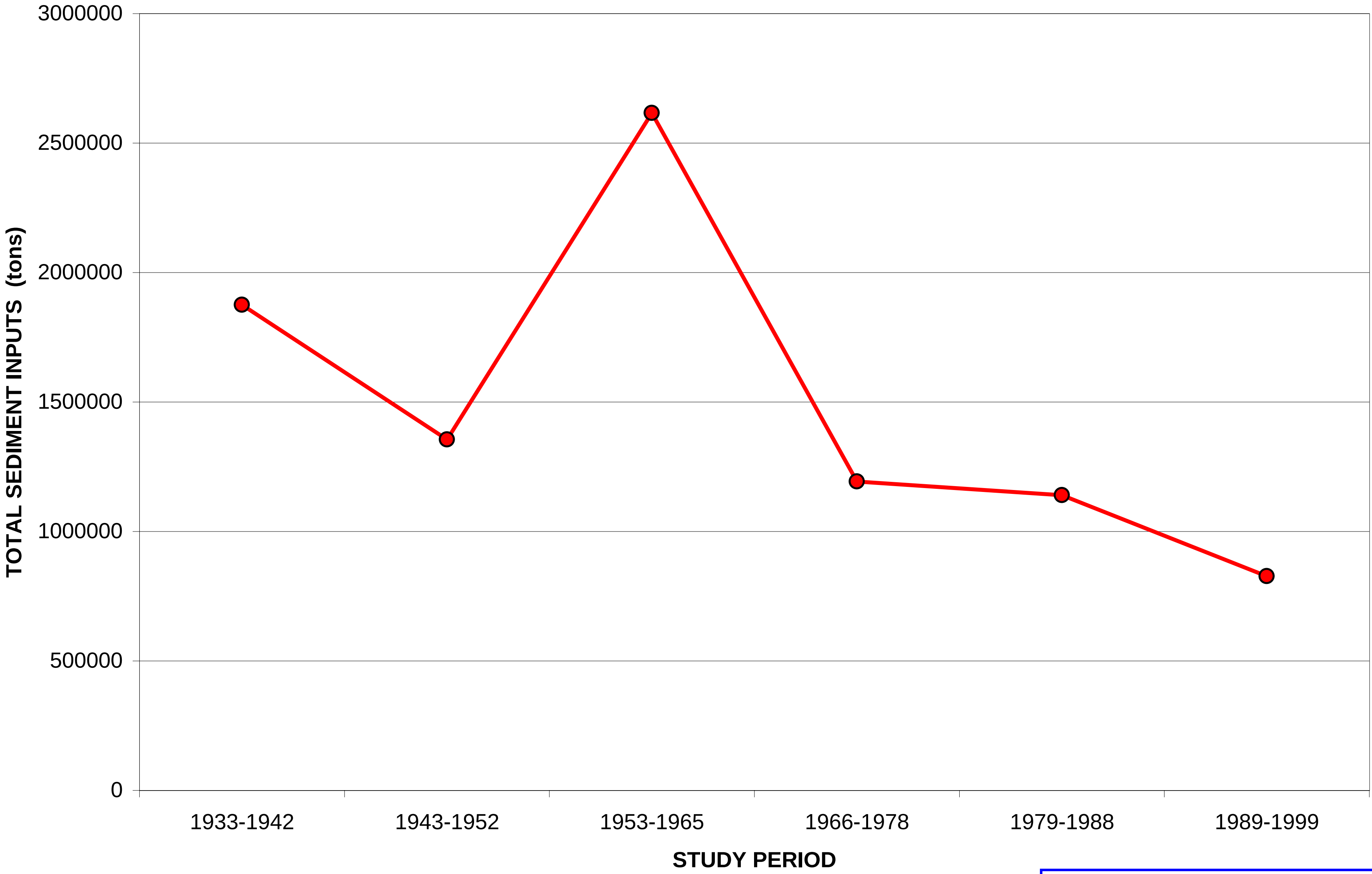
FIGURE 49

TEN MILE RIVER SEDIMENT SOURCE ANALYSIS

Estimated Total Sediment Inputs by Study Period



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