SEDIMENT STORAGE AND TRANSPORT IN THE SOUTH FORK NOYO RIVER WATERSHED, JACKSON DEMONSTRATION STATE FOREST

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EXECUTIVE SUMMARY

The South Fork Noyo River (SFNR) watershed in northern coastal California has been heavily impacted by widespread clearcut logging over the last century. As a consequence, large volumes of sediment have been delivered to watercourses within the basin. Historically, large populations of anadromous fish reproduced in the river. However, drastically declining fish populations over the past several decades has raised concerns over the cumulative impacts of sediment on water quality, fish habitat, and the aquatic environment. In 1999, the U.S. Environmental Protection Agency established a Total Maximum Daily Load (TMDL) for the SFNR, and determined sediment loading allocations aimed at improving water quality criteria for sediment. The EPA acknowledged that the office-based sediment budget assessments used in the TMDL were incompatable with field geomorphic relations. Prior to this study, very little data existed on sediment storage volumes and transport rates in the SFNR.

The overall goal of this assessment was to use field mapping and data collection techniques to assess long- and short-term sediment storage and transport within the SFNR. Specific objectives of this investigation were to collect baseline data on the volume of sediment stored and transported within the SFNR watershed over the past approximately 110 years and to collect present-day stream flow and sediment transport data from the main stem SFNR and its major tributaries. This effort provides better data for calculating the sediment budget of the watershed and contributes to the evaluation of how forest management practices have affected the past and present distribution of sediment within the basin.

In this study, we performed detailed geologic mapping and surveying to quantify the volumes of sediment associated with pre-historic terraces, historic terraces, and the active channel along four stream reaches. We also collected reconnaissance-level data along three stream reaches in the South Fork Noyo River watershed. These stream reaches were selected from different portions of the watershed in order to detect spatial variability in the locations and amounts of stored sediment and to assess long-term sediment transport. Additionally, we assessed the present-day hydrology and sediment transport within the major sub-watershed areas in the SFNR watershed by establishing ten streamflow and suspended-sediment sampling locations. Data collected at these sampling stations were used to develop relations between discharge, suspended sediment load, suspended sediment concentration, turbidity, and other hydrologic parameters. Total suspended sediment loads calculated for each sampling station are used to assess present-day sediment transport through the watershed.

The total volume of post-logging sediment (active channel and historic terrace) in storage over the entire study area is estimated at 225,000 yds^3 or approximately 22,000 yds^3/mile. Comparison of the volume associated with historic terraces and the volume associated with the active channel indicates that a large portion of the sediment originally deposited beneath historic terraces has been eroded and transported downstream. A significant portion of this sediment presently is stored in the lower SFNR channel between its confluence with the North Fork of the SFNR and the mouth of the SFNR.

Present-day suspended sediment loads computed for each sampling station ranged from 14 to 684 tons. Overall, most sites produced sediment at a fairly consistent rate with discharge, although a large increase in sediment transport occurred between the mouth of the North Fork of the SFNR and Kass Creek. The sediment source for this increase in suspended sediment transport is the large amount of sediment stored in the active channel along this reach.

This research shows that sediment trapped in long-term storage along the SFNR channel is transported downstream in high-discharge events. This sediment increases the overall suspended sediment load and can lead to an overestimation of the sediment generated by upslope management practices. The data produced in this study can be used in the future to monitor sediment transport through the SFNR watershed and to assess the recovery of the SFNR channel from past logging sediment inputs.

We recommend that future sediment transport studies designed to assess the sediment contribution from upslope forest management include an assessment of in-channel storage and transport. A clear understanding of the distinction between these two sediment sources is necessary to properly evaluate sediment budget analyses.

INTRODUCTION

The South Fork Noyo River (SFNR) is a major tributary of the Noyo River, which drains to the Pacific Ocean at the town of Fort Bragg in coastal Mendocino County, California (Figure 1). The majority of the SFNR watershed is owned and operated by the California Department of Forestry and Fire Protection (CDF) as the Jackson Demonstration State Forest, and is managed for timber production and recreation. Widespread clearcut logging in the basin during the early 20th century removed most of the old-growth redwood trees and resulted in the addition of large volumes of sediment to the South Fork Noyo River and its tributaries. Historically, large populations of anadromous fish reproduced in the river. However, drastically declining fish populations over the past several decades have raised concerns over the cumulative impacts of sediment on water quality, fish habitat, and the aquatic environment.

In response to these concerns, the Noyo River watershed was listed as a sediment impaired waterbody and included in the 1998 Section 303(d) list as adopted by the State of California North Coast Regional Water Quality Control Board. Sedimentation was determined to be impacting the cold-water fishery, including the migration, spawning, reproduction, and early development of coho salmon and steelhead trout (EPA, 1999). In 1999, the Environmental Protection Agency (EPA) established the Noyo River Total Maximun Daily Load (TMDL) for sediment and identified sediment loading allocations aimed at improving water quality criteria for sediment. The EPA acknowledges incompatibilities between field geomorphic relations and office-based sediment source analyses (EPA, 1999; Mathews, 1999). In particular, large uncertainties exist in the data currently available on sediment transport and storage. The amount of sediment that is stored in the system for various lengths of time strongly influences the assessment of short-term sediment budgets. Thus, quantifying reasonable ranges of sediment transport and storage volume are critical to understanding the sediment budget within the SFNR watershed and to evaluating the long-term cumulative impacts of sediment within the SFNR ecological system.

The primary objectives of this research, therefore, are to collect basic data on volumes of sediment stored and transported within the SFNR watershed over the past approximately 110 years and to collect present -day stream flow and sediment transport data from the main stem SFNR and its major tributaries. By evaluating the watershed over this time period (the duration of management influence), these data provide information on long- and short-term storage and transport within the SFNR watershed. We use this information to evaluate how forest management practices have affected the past and present distribution of sediment within the basin. The results of this research address the uncertainties in sediment budget analysis and provide a broader base for understanding long-term watershed processes in the South Fork Noyo watershed and other watersheds throughout northwestern California.

BACKGROUND

The majority of the South Fork Noyo River watershed is characterized by narrow, deeply-incised valleys and steep mountainous terrain (Figure 1). However, subdued, low relief topography dominates the headwater region. The watershed is bordered by Riley Ridge on the northeast, Three Chop Ridge on the east, and a northwest-trending ridge occupied by state Highway 20 on the southwest. The SFNR flows in a generally northwesterly direction from its headwaters to the confluence with the main Noyo River and meanders among fluvial terraces along the valley floor for much of its length. Short, relatively straight, parallel tributaries drain the slopes southwest of the SFNR and long, dendritic drainage networks are typical on the northeastern slopes. Parlin Creek and the North Fork of the SFNR are the two main tributaries to SFNR in the study area (Figure 1). These two streams drain in a northwesterly direction from their headwaters but bend to the southwest to join the SFNR.

Logging history of the SFNR basin

The South Fork Noyo River, like most Mendocino County watersheds, experienced a varied history of land-use practice over the past approximately 110 years. These land uses influenced the sediment transport processes, and thus the entire ecological system, within the watershed. The SFNR watershed is unique in Mendocino County because major logging operations on hillslopes did not begin until 1904, almost 50 years later than most other watersheds on the coast. River log drives were performed in the basin prior to 1904, however, these logs were cut primarily from river terrace areas and not hillslopes (Marc Jameson, personal communication, 2001). During the early "old-growth" logging era, unregulated clear-cut logging methods were used, in which logs were yarded by oxen teams over skid trails and stockpiled at landing areas near stream channels. Some landings were located within stream channels, which resulted in modification of natural stream courses. The history of the "old-growth" logging era in SFNR is documented by Wurm (1986) and is summarized below.

The Caspar Lumber Company acquired property within the South Fork Noyo River watershed in 1893 and began excavation of a tunnel that would provide a railway connection from the South Fork Noyo River watershed to the existing railway in the Hare Creek drainage by way of Bunker Gulch (Figure 2). This railway connection into the South Fork Noyo basin allowed Caspar Lumber Company to transport cut logs out of the basin to their mill in Caspar. The 1000-foot-long tunnel was completed in 1903 and by 1904 a railroad grade was constructed to Camp One in the vicinity of the confluence of the North Fork of the SFNR and the SFNR. This railroad grade was constructed using fill material blasted from steep slopes east of the Bunker Gulch tunnel (Figure 3a). Camp One became the field headquarters of Caspar Lumber Company in the SFNR watershed and the junction for all logging rail lines to the north and east (Figure 3b). The majority of old-growth redwood groves were clearcut and yarded to the train cars by ox-and-bull yarder teams. In 1915, steam donkey yarders replaced the ox-and-bull yarder method. These logging techniques resulted in nearly complete destruction of stream channel morphology and likely made surface soils highly susceptible to erosion (Figure 4).

Small rail lines were constructed up virtually every significant tributary in the SFNR watershed, and the main railway extended up the main channel following the progression of logging operations (Figure 2). Along the North Fork of the South Fork Noyo River the tracks reached Camp 15 by 1923 and the logging was completed in 1927. Along the SFNR, the tracks reached Camp 5 at Parlin Creek in 1912 and Camp 19 at the headwaters in 1929. The rail line extended over the Dunlop Pass trestle in 1937, leaving the South Fork Noyo watershed. By 1946, the majority of the old-growth redwood logging was completed and all of the branch rail lines had been removed, leaving only the main line tracks.

During the late 1940's and 1950's, a second phase of intense logging began in the SFNR watershed that involved "second-growth" forests as well as residual old-growth forests. During this time, there was little or no regulation of management practices, silviculture, size of timber harvest units, or road construction. The majority of the old railroad grades were converted to haul roads, and spur roads were constructed on steep slopes and adjacent to stream channels. Side-casting of waste material was common. Logs were yarded to landings by tractors across steep slopes and in stream channels, which likely loosened hillslope surface soils and promoted erosion of channel sediments. Over time, hillslope surface erosion and landslides involving saturated side-cast material resulted in sediment contributions to the SFNR and its tributaries.

The passage of the Z'berg-Nejedly Forest Practice Act in 1973 dramatically changed timber management practices in California. The new guidelines provided for buffer zones to protect watercourses and inner gorge areas from harvest activity as well as higher standards for road construction and harvest techniques. Modern second growth-logging in the SFNR watershed is governed by the Forest Practice Rules. Although management practices conducted following the Forest Practice Act have contributed to a decrease in the rate of sediment delivery to channels in the SFNR, large volumes of sediment within the SFNR basin continue to affect the ecology of the watershed (EPA, 1999).

<u>Logging Influences on Fish Habitat</u>

Timber harvest practices have been associated with a number of hydrologic and geomorphic processes, including increased rates of surface erosion from forest roads (Lewis, 1998; Duncan et al., 1987; Ried and Dunne, 1984), and increased frequency of landslide occurrence (O'Loughlin and Ziemer, 1982; Rood, 1984; Swanston and Swanson, 1976). Accelerated erosion can have positive and negative effects on anadromous fish habitat. Positive effects include formation of new habitats for spawning, rearing, and overwintering as a result of the addition of coarse gravel to the channel (Swanston, 1991). The introduction of large woody debris from channel margins can increase cover, provide long-term storage for sediment, and create diverse aquatic habitat conditions (Napolitano, 1998). Negative effects of accelerated erosion include filling of pools, scouring of riffles, blockage of fish access, disturbing side-channel rearing areas, and siltation of spawning gravels (Swanston, 1991). The magnitude of these effects is dependent on the frequency and intensity of erosional events, as well as the sediment processing capabilities of a particular stream. The stream adjusts to these alterations downstream as well as upstream of local erosional events. As a general rule, larger streams and rivers adjust to erosional perturbations faster than smaller streams (Swanston, 1991).

Brown et al. (1994) provide anecdotal information on the presence of large populations of coho salmon and steelhead in the Noyo River watershed during the early 20th century. Limited data from stream surveys conducted by the California Department of Fish and Game (DFG) in the 1950's and 1960's suggest that coho salmon and steelhead both were present in SFNR, Parlin Creek, and the North Fork of the SFNR. Low numbers of coho salmon and steelhead were identified by DFG in the SFNR watershed in the 1980's and early 1990's (DFG, 1995a and b). In-migrant fish trap data collected by DFG since 1963 at its egg-taking station at Camp One on SFNR provides substantial data supporting the decline of anadromous fish in the basin. For example, the average number of returning coho to this hatchery-influenced system prior to the drought of 1977 were 2,819, 2,669, and 2,132 for each of the three respective coho salmon reproductive populations. The numbers of returning coho subsequent to the 1993 drought represent a decline of 93%, 60%, and 27% of the pre-1977 numbers for each of the three respective coho salmon reproductive populations (A. Grass pers. comm., in: EPA, 1999). For the 1998-99 season, the egg-taking station on SFNR reported only 5 returning males and 11 returning females (EPA, 1999). In contrast to this data, hundreds of coho salmon have been observed spawning downstream of the egg taking station in drought years (Marc Jameson, personal communication, 2001), and thus data from the egg taking station may not be indicative of salmonid population abundance for the entire basin.

DFG (1995a and 1995b) provides data on anadromous fish habitat such as, percent fine sediment within channel cobbles (embeddedness) in pool tailouts, percent of pools deeper than three feet, pool frequency, and shelter rating for Parlin Creek and SFNR. These data indicate that coho may have difficulty digging redds in a majority of the pool tail-outs because of high embeddedness. These data also suggest that infrequent deep pools, backwater pools, and low amounts of large woody debris may be limiting coho rearing and overwintering success. For our study, this is significant because the transport and storage of sediment directly influences the distribution of these fish habitat parameters.

Significance

Recently, the Noyo River watershed was placed on the 1998 Section 303(d) list by the State of California as required by the Clean Water Act. The listing was the result of water quality problems related to sedimentation and prompted the development of the Noyo River Total Maximum Daily Load (TMDL)(EPA, 1999). The TMDL outlined sediment loading allocations that, when implemented, are expected to result in improved water quality criteria for sediment. As part of the TMDL development, the recent Level One watershed analysis for the SFNR watershed provided important initial data on sediment inputs, outputs, and net storage (Matthews, 1999). However, this desktop (office-based) analysis also demonstrates that the uncertainties in evaluating these sediment parameters may be quite large. For example, the available data yielded the conclusion that the sediment input to the system is approximately 40% less than the sediment output. This estimate contradicts the geomorphic evidence of active aggradation directly downstream of the confluence between the SFNR and the main stem of the Noyo River. The incompatibility between field relations and desktop calculations is, in part, a result of large uncertainties in the data currently available on sediment input and storage. In particular, the volume of sediment eroded from roads and skid trails is poorly constrained, and the volume eroded from channel banks is unknown. The uncertainties in these volumes may be quite large, on the order of 50% to 100% or more. Quantifying reasonable ranges of sediment input from and storage in these sources is critical to understanding the sediment transport within the SFNR watershed, and thus to evaluating the long-term impacts of sediment transport within the SFNR ecological system. In addition, Graham Matthews and Associates (Matthews, 1999) and the U.S. Environmental Protection Agency (EPA, 1999) note that the discrepancy between inputs and outputs in the SFNR watershed may be a result of time lags from sediment delivery to transport through the system. In other words, the amount of sediment that is stored in the system for various lengths of time may strongly influence the assessment of short-term sediment budgets.

Based on our past experience within Mendocino County (Louisiana-Pacific Corp., 1998, EPA, 1998, Matthews, 1999), it is critical that there is a clear understanding of the background sedimentation processes in order to ensure accurate sediment budget analysis. Field-based data on sediment storage is often absent from standard sediment budget analyses. Understanding the long-term impacts of logging on sediment transport and storage is necessary to evaluate the sediment processing capabilities of forested coastal basins.

This study, therefore, was designed to evaluate the volume of sediment existing in streamside terraces, debris dams, and stream channels and to investigate the rates and processes of sediment transport through the SFNR watershed. By evaluating the SFNR watershed over the past approximately 110 years (the duration of timber operations), this report evaluates long-term sediment storage and transport within the basin and provides better constrained data for calculating the sediment budget of the watershed. These data are critical for assessing long-term cumulative impacts of sediment on the stream channel environment and for accurately evaluating the sediment budget of the SFNR watershed. Understanding sedimentation is important for evaluating watershed management plans and determining impacts on the watershed ecological system. The data presented in this report provides a broader base for understanding long-term watershed processes and thus impacts of various logging practices over time. These findings may also be directly applicable to other watersheds throughout northwestern California. In particular, this report addresses whether there is long-term sediment storage in the SFNR or if the system is efficiently transporting logging-induced sediment to the mainstem Noyo River.

APPROACH AND METHODS

<u>Sediment storage component</u>

Developing an understanding of a fluvial geomorphic framework is necessary to assessing long-term cumulative impacts of sedimentation related to logging practices. We assessed the historic and current influences on channel morphology by conducting both office-based and field data collection. This effort included meeting with CDF personnel familiar with the watershed, reviewing archival information, and performing detailed geomorphic field mapping along selected reaches. In a previous investigation of sediment storage in the Garcia River watershed (Louisiana-Pacific Corporation, 1998), we show that significant volumes of sediment accumulated at the mouths of major tributary channels. Based on this, we selected two stream reaches located at the mouths of major tributary basins that have been subjected to various degrees of upstream management activity. We then selected a stream reach on a tributary upstream of a major confluence and a stream reach on the main SFNR downstream from a major confluence. These stream reaches were selected from different portions of the watershed in order to detect spatial variability in sediment volume that may be related to different management practices occurring throughout the watershed. The stream reaches also were selected to compare sediment storage in upstream locations vs. downstream locations for long-term sediment transport analysis.

The locations of the four stream reaches for detailed study are shown on Figure 5. First, the areas located at the confluence of the SFNR and Parlin Creek (Area A) and the confluence of SFNR and the North Fork of the SFNR (Area B) were selected because these two tributaries are the largest within the SFNR watershed. Area A includes the site of Camp 5, and Area B includes the site of Camp 1 (see also Figures 2, 3 and 4). Second, an area along the North Fork of the SFNR (Area C) was selected in order to assess the sediment storage characteristics along this major tributary upstream from the SFNR confluence. This site includes the site of Camp 8 (Figure 2). Lastly, we selected a reach at the downstream end of SFNR in the Jackson State Demonstration Forest (Area D) in order to evaluate sediment volume at the forest boundary (Figure 5).

Within the selected study reaches, we developed detailed geomorphic maps of current channel conditions showing the locations of fluvial terraces, gravel bars, channels, bankfull channel margins, and detailed cross-sections. We identified three distinct geologic map units, including deposits associated with pre-historic terraces, historic terraces, and the active channel. Deposits associated with the active channel include deposits in the low-flow or summer channel, and gravel bars that are inundated during winter floods. Detailed study reaches were mapped, described and photographed in the field. For field mapping, a string line painted at 25 foot intervals was pulled tight along a straight line of sight in the channel thalweg and tied off on tree branches. The compass bearing of the string line was plotted on the field map. The distance from the line to the edge of each map unit was measured directly perpendicular to the string and also plotted on the field map. Channel and terrace storage thickness measurements were made with a survey rod and recorded in a field notebook. Detailed topographic cross sections were surveyed in each stream reach with a laser level and survey rod. Cross sections were located in areas where all of the described terraces are present and were used to calculate terrace sediment storage volume, to calibrate field mapping, and to assess volumes of sediment removed from the site since initial historic deposition. Information contained on the maps and cross sections provide a record of baseline channel conditions from which the effects of future timber management activities can be monitored.

The field geologic maps were imported into an ArcView Geographic Information System (GIS), and used to calculate the area of all of the mapped deposits. These data were combined with field thickness estimates to estimate the sediment volume associated with each deposit. Mapped deposits were sorted by origin and then cumulative terrace and channel storage volume for each stream reach was calculated as a sum of individual terrace and stream data. Thickness is the limiting measurement in the accuracy of this technique. For this study, the thickness of an individual terrace deposit was assumed to be the distance from the deepest scour in the active channel to the top of the terrace surface. Field evidence used to determine thickness of channel storage included the depth of scour pools, depth measured at the downstream side of debris dams, the diameter of logs partially buried in the channel, and where available, the surface of bedrock. Where this information was not available (i.e., sediment deposited across the channel with no observable channel or buried logs), a channel deposit thickness of one foot was assumed. For historic terraces and gravel bars, the thickness was calculated as the measured height of the terrace plus the thickness of the adjacent channel deposit. This method assumes a rectangular channel shape and does not account for an irregular buried bedrock surface.

In addition to assessing sediment storage volumes in the detailed stream reaches, sediment volume was quantified in channel reaches outside of the detailed stream reaches. In particular, we measured sediment storage volume between Areas A and B (herein designated Area G) and between Areas B and D (Area E) on the SFNR, and between Areas B and C (Area F) on the North Fork of the SFNR (Figure 5). For these areas, sediment storage volume was estimated by measuring length, width, and thickness values with pace and tape measuring techniques. For active channel deposits and historic terrace deposits, surface area was determined by approximating the shape of the surface as a rectangle. The volume of large, continuous pre-historic terraces was calculated by averaging width and thickness of the deposit and measuring the length on the map. Thickness measurement techniques used in reconnaissance reaches were the same as the techniques used in the detailed reaches. The uncertainties associated with both the detailed mapping and reconnaissance mapping technique are discussed later in this report.

Streamflow and sediment transport component

The flow of water is the driving force controlling the transport of sediment in fluvial systems. The timing, rate, duration, and frequency of these flows are important characteristics that must be understood to develop a process-based understanding of channel morphology and change. We assessed the present-day hydrology and sediment transport within the major sub-watershed areas in the SFNR watershed by establishing ten streamflow and suspended sediment sampling locations within the study area (Figure 5). This work consisted of field data collection as well as developing and completing the following tasks for each sampling site:

1. Install streamflow stations
2. Install continuous dataloggers at 4 sites
3. Develop a stage/discharge relationship,
4. Develop a turbidity/suspended sediment concentration (SSC) relationship,
5. Develop a turbidity/discharge relationship,
6. Develop a SSC/discharge relationship,
7. Develop a suspended sediment load (SSL)/discharge relationship,
8. Compute streamflow records
9. Compute suspended sediment loads for WY2001
10. Compare sediment loads between basins and compare to sediment source data developed from the TMDL (EPA, 1999)
11. Compare data to an index of relative disturbance
12. Compare data to regional data sets.

<u>Stream Flow Stage Measurement</u>

Fence posts were driven into the streambed at all but one site as stage measuring devices. River stage was measured from the water surface to the top of the fence post using a pocket surveyor's tape. One site had a standard staff plate installed in the streambed. Stage was measured directly off the staff plate at this location. Most stage locations were surveyed to a locally established benchmark using an auto level, in the case that the sites were disturbed (by vandalism or high flows) and the original gage datum needed to be reestablished.

Stage data collected using the fence post was recorded as negative stages. In order to put the data in standard form, all fence post tops were assigned a positive reference elevation. The stage reading was added to this value to determine a positive river stage from the streambed to the water surface. The advantages of fence posts are their low cost for short-term studies, lower frequency of vandalism, and ease of installation. For longer term studies, installation of standard gaging stations would be more appropriate.

<u>Continuous Stage Recorders</u>

Although the original proposal for this project included only the installation of a single datalogger at the downstream end of the watershed, it became readily apparent that our dataset would be severely compromised with just one continuous record. Instead, continuous stage recorders were installed at four locations in the South Fork Noyo Watershed: SFNBK, NFSFASFN, PASFN, and SFNAP. Table 1 lists the full site name, the site acronym, the associated watershed area (WSA), and finally whether or not a pressure transducer was installed at the site.

All continuous stage recorders were Global Water Level Loggers series #WL-14-015. Global Water Level Loggers are of a pressure transducer type, utilizing a silicon diaphragm and have a 15 ft range. The pressure transducer at each site was downloaded on a monthly or bi-monthly basis via a laptop computer.

<u>Streamflow Measurements</u>

Flow measurements were taken at all sites using standard or modified USGS methods. Most measurements were performed by wading at the gage location, however several high flow measurements were taken from bridges. Stream flow equipment included a 4 ft top-set wading rod, bridgeboard, JBS Instruments AquaCalc 5000-Advanced Stream Flow Computer, and either a Price AA or Pygmy current meter.

Due to the large number of study sites and short period of time for the study, it was necessary to modify some aspects of standard stream flow measurement methods. The Price AA current meter was used where stream flow velocities were over 3.0 ft/s and at measurement locations where surging flow or poor hydraulics were encountered. The Price AA meter typically performs better in sections with surging flows or poor hydraulics due to its added weight. Typically, the Price AA meter is not used in depths below 1.5 ft, but due to poor hydraulics and the steep gradient of many locations, the Price AA current meter was used in depths as shallow as 0.3 ft.

The maximum discharge per vertical sectionwas set as 10% instead of the more standard 5% in order to facilitate streamline flow measurements. Fewer verticals were also used in discharge measurements in order to reduce field time associated with a single measurement, thus allowing for more measurements per person-day of fieldwork. However, most discharge measurements still contained 15 to 25 verticals.

<u>Turbidity and Suspended Sediment Sampling</u>

Depth-integrated turbidity and suspended sediment sampling was performed at most locations. Sampling was performed using either a US DH-48 Depth-Integrating Suspended Sediment Sampler or a US DH-76 Depth-integrating Suspended Sediment Sampler. In the case of the US DH-48, handles of different lengths were used depending on the flow depth. The US DH-76 is a rope-deployed sampler and is typically utilized from bridges. Sampling locations were located at or near stage locations. Standard USGS methods were used for sampling.

Due to the number of sites being sampled, a tag line was not always set during sampling; instead distance between verticals was estimated. For each sample the location, time, stage, number of verticals, distance between verticals, bottle #, and whether a field replicate was taken were recorded. At locations where it was not possible to get a true depth-integrated sample, grab samples or modified depth-integrated samples were taken, and this information was recorded.

Data Analysis

Stage/discharge relationships were developed for the following seven sites: SFNBK, KASFN, NFSFANFSFN, SFNANFSFN, BASFN, PASFN, and SFNAP. Stage/discharge pairs were plotted on standard rating paper (USGS-type 9-279) and a best-fit line was then hand drawn following standard USGS procedures in order to determine the stage/discharge relationship. Skeletal rating points were then extracted from the best-fit line to develop the rating tables. Surface Water, a software package developed by Western Hydrologic Systems, was used to expand the ratings from the skeletal points. For the remaining three sites: SFNAK, SFNBNFSFN, and SFNBP synthetic stage/discharge relationships were developed through a combination of direct and indirect methods. A combination of relating stage heights, summing discharges and scaling pressure transducer records were all used to produce the necessary stage/discharge relationships.

Turbidity and suspended sediment data were analyzed in several ways. Turbidity versus suspended sediment concentration (SSC), Turbidity versus discharge, SSC versus discharge, suspended sediment load (SSL) versus discharge, and SSLPA (Suspended sediment load per unit area) relationships were developed for all sites.

RESULTS

Fluvial Geomorphology and Locations and Amounts of Stored Sediment

Delineation of Sediment Storage Locations and Amounts

Pre-historic terraces, historic terraces, and active channel deposits were delineated in each study area along the SFNR (Figures 6a to 6d). Pre-historic terraces were identified by the presence of old-growth redwood stumps in growth position on the terrace surface. This map unit approximates the terrace configuration in the SFNR watershed prior to the initiation of logging in the late 1800's. Historic terraces were delineated based on the presence of chainsawed logs within terrace deposits, and an absence of old-growth stumps. We infer that these historic terraces represent the maximum amount of channel aggradation that has occurred since the initiation of logging. Based on the presence of chainsawed logs buried in the channel, we infer that the active channel deposits are a product of post-logging incision and transport of historic sediment. Figure 7 is a schematic cross section of a typical SFNR channel, showing map unit relations.

Pre-historic Terrace Deposits

Pre-historic terraces exist along the SFNR for the majority of the study area, but do not extend upstream past Area C (Figures 6a to 6d). Bedrock exposures along the channel margin indicate that the terraces are associated with a bedrock strath surface overlain by 3 to 8 feet of sediment. Pre-historic terraces typically support second-growth redwood forests and have numerous old-growth redwood stumps (Figure 8). The terraces generally are un-paired, but are sometimes paired at the upstream or downstream portion of the terrace. Terrace surfaces dip slightly toward the channel and are incised along subvertical risers approximately 5 to 20 feet high. Most of the sediment associated with the pre-historic terraces is in permanent storage on the basis of this deep incision. We use a sediment thickness of 5 feet in our calculations of pre-historic sediment storage volume (Tables 2 and 3). Because of uncertainties in the depth to bedrock and the large width of these surfaces (some greater than 200 feet), we infer that the estimates of the sediment volume associated with the pre-historic terraces represent maximum storage values. The volume of pre-historic terrace storage appears to be an order of magnitude greater than storage volumes of the historic terrace deposits and active channel deposits.

Similar pre-historic strath terraces exist along many rivers in coastal northwestern California. Merritts and Vincent (1989) mapped strath terraces in the Mattole River, which is approximately 50 miles north of SFNR. The Mattole River terraces are approximately 9 to 18 feet above the modern stream channel (similar to SFNR) and extend at least 50 km upstream from the ocean. Radiometric dates on charcoal samples taken from the base of the alluvial gravel overlying the lowest strath along the Mattole River suggest that the lowest terrace deposit is about 6,000 years old (Merritts and Vincent, 1989). Based on this, we infer that the pre-historic terraces along the SFNR are middle Holocene in age.

Active Channel Deposits

Active channel deposits are characterized as sediment that can potentially be mobilized at bankfull stage. The active channel deposit is composed of two main parts, gravel bar and channel deposits (Figure 9). Channel deposits are present throughout the study area, but typically are wider in downstream locations (Areas B, D, and E) (Figures 5, 6b, and 6d). These deposits are submerged by the river throughout the year and range in thickness from approximately 0.5 to 4 feet, with occasional pockets as deep as 10 feet. This deposit forms a continuous thin layer of sediment over bedrock, and bedrock is only occasionally observed at the channel margin or in deep scour pools. However, in Areas F-2 and G the channel is flowing on bedrock and sediment is only present in isolated pockets. Gravel bars also exist throughout the study area, but are submerged only during storm events. Gravel bar deposits are more extensive in Areas B, D, and E than farther upstream (Figures 5 and 6). These deposits can be present on the channel margin or in the middle of the channel, and range in thickness from approximately 0.5 to 3 feet. Gravel bars typically do not support vegetation, because they are actively modified by channel processes. Chainsawed logs are present in both channel and gravel bar deposits, from which we infer that all of the sediment in the active channel post-dates the initiation of logging in the SFNR (Figure 9).

Because bedrock is rarely observed in the channel, we use buried logs and the maximum depth of scour to estimate the minimum thickness of channel deposits. In most cases, this thickness estimate is considered to be very close to the actual thickness. Based on this, we infer that the estimates of the sediment volume associated with channel deposits represent minimum reasonable values. Additionally, because information usually is not available on the depth to bedrock beneath gravel bar deposits, we estimate gravel bar thickness as the sum of the sediment thickness estimated in the channel and the height of the gravel bar. Because of this, estimates of the sediment volume associated with gravel bars represent maximum storage values. The combined storage volume of channel and gravel bar deposits, therefore, represent a maximum estimate of sediment associated with the active channel. This sediment is transported intermittently downstream in flood events.

Historic Terrace Deposits

Historic terraces exist along the entire SFNR study area (Figure 6a to 6d), but are most extensive near the confluence of major tributaries. The deposits associated with these terraces range in thickness from approximately 3 to 6 feet and support grass and alder tree vegetation. Old-growth redwood stumps and second-growth redwood trees typically are absent from the surface of these deposits; however, old-growth stumps occasionally are entombed in the deposit. The terraces maintain a relatively constant height along the stream profile and are inset into pre-historic terraces and bedrock. Historic terraces sometimes are associated with historic railroad trestles remaining in the channel from the old-growth logging era (Figure 10). Because information on the depth to bedrock beneath historic terrace deposits usually is absent, we estimate the volume of sediment associated with historic terrace deposits using the method previously described for gravel bar deposits. As noted above, this method results in maximum volume estimates.

Historic terraces exist along low-order tributary channels in nearly every watershed that has experienced old-growth redwood logging on the Mendocino coast, including the Garcia River watershed (Louisiana-Pacific Corporation, 1998), Albion River watershed, Big River watershed, and Elk Creek watershed (A. Nadig, personal communication, 2000). In the SFNR, chainsaw cut logs often are buried within the terrace deposits, from which we infer that the terraces post-date the initiation of logging (Figure 11). Additionally, based on very large alder trees growing on many of the historic terraces, we infer that these terraces date from the old-growth logging and second growth-logging prior to the passage of the Forest Practice Rules in 1973. Sediment stored in these deposits is eroded by bank erosion processes during flood events, but is trapped primarily in long-term storage sites.

We acknowledge that logs protruding from historic terraces were chainsawed during woody debris removal projects within the SFNR basin between 1955 and 1993. These removal projects resulted in the cut log ends observed today. However, based on the observation of low woody debris abundance within pre-historic terraces and high woody debris abundance in historic terraces, we infer that the chainsawed logs were originally incorporated into historic terraces by the downstream transport of sediment and logging debris. Therefore, historic terraces contain both logs that were sawed during "old-growth" logging operations and logs that were sawed during woody debris removal projects.

Analysis of sediment storage

Table 2 summarizes the total volume of each type of deposit within each detailed mapping area and each reconnaissance mapping area. Because individual mapping areas are different sizes, the total volume associated with each deposit in each stream reach is averaged over river distance for comparative purposes. Thus, the volume of sediment associated with each deposit per mile in each detailed mapping area and each reconnaissance mapping area are shown on Table 3. We schematically show active channel storage data in Figure 12 and historic terrace storage data in Figure 13 in order to graphically compare storage volumes calculated for each stream reach. We also schematically show the total volume of post-logging sediment (active channel and historic terrace volume combined) in Figure 14.

The volume of active channel sediment in storage per river mile is similar in all stream reaches with the exception of Areas A, F, and G (Table 3 and Figure 12). Areas A, F, and G have similar channel sediment storage (less than 10,000 yds^3/mile), whereas Areas B, C, D, and E have channel sediment storage of more than 20,000 yds^3/mile. The distribution of historic terrace sediment is similar for areas D, E, F, and G (less than 5,000 yds^3/mile), however areas A, B, and C have considerably more stored historic terrace sediment (Table 3 and Figure 13). Overall, the volume of sediment stored in the active channel is much more than the volume of the historic terrace deposits, with the exception of Area A. Also, these data show that a large amount of the sediment in the SFNR watershed is stored along the main channel downstream of the North Fork of the SFNR. From these relations, we infer that there has been sufficient time since the logging operations and subsequent terrace deposition to erode the historic terrace deposits and redistribute this material downstream. We speculate that this eroded material is mobilized downstream in large flood events, but is stored in the active channel for much of the year. These data suggest that a large part of the sediment produced during historic logging operations presently is being transported through the SFNR fluvial system.

Data developed during this study help address how the SFNR has responded to the large amount of sediment contributed to the watershed as a result of the early logging practices. Based on buried cut logs observed along most of the South Fork Noyo channel, we infer that the pre-logging channel was flowing on or very close to bedrock . Also, we infer that the volume of sediment stored in the active channel and historic terrace locations, combined, represents the minimum amount of material introduced to the South Fork Noyo river system by logging operations. Table 4 shows the total amount of post-logging sediment remaining in the South Fork Noyo River and tributaries within the study area. Figure 14, represents the distribution of this post-logging sediment.

Within the study area, Areas F and G contain the least amount of post-logging sediment. Both areas are located directly upstream of the confluence of the SFNR and the North Fork of the SFNR, and have bedrock exposed along much of their distance. The scarcity of historic terrace remnants and the low volume of active channel sediment within Areas F and G implies that much of the post-logging sediment has been transported downstream. This sediment may have been deposited in Areas B, D, and E. This relationship may be related to the narrow confined valley (between pre-historic terraces) in Areas F and G and the comparatively wider valleys in Areas B, D, and E. Alternatively, the low sediment storage in Areas F and G may be related to the logging practices utilized along those reaches. For example, the logging operations may have left less debris in the channel than in other areas. The sediment generated in these areas, then, could have been rapidly transported downstream.

Areas A and C have considerably more post-logging sediment in storage than stream reaches located directly downstream (Areas G and F, respectively) The channel widens within Area C, and Area A is located at a major confluence. In both situations, the channel geomorphology may be the reason for greater sediment deposition. Areas A and C have a similar amount of post-logging sediment to Areas B, D, and E. The major difference between the post-logging sediment present in Areas A and C and the post-logging sediment in Areas B, D, and E is that a larger component of the sediment in Areas A and C is stored in historic terraces. This is in contrast to the post-logging sediment in Areas B, D, and E, which is dominated by active channel storage. Therefore, the large volume of sediment in Areas A and C may reflect the timing of logging in the headwaters of the SFNR basin. The headwaters were logged approximately 30 - 40 years later than the lower basin. From this we infer that there has not been sufficient time since this logging to erode these historic terrace deposits and redistribute the material downstream. The process of eroding historic terrace deposits and incorporating this material into the active channel has been occurring for a longer period of time downstream of Areas F and G.

The SFNR channel and its tributaries apparently have the ability to transport the large amounts of sediment contributed by the logging operations. However, it appears that the transport of the sediment through the system requires a substantial period of time (perhaps tens or hundreds of years) to flush the historic sediment through to the watershed mouth. Fortunately, the relatively smaller amounts of sediment remaining beneath the historic terraces suggest that the system may soon (tens of years) begin to return to its pre-logging characteristics.

The locations of the six surveyed cross sections are shown in Figure 5. In Area A, we surveyed one cross section on the SFNR downstream of the mouth of Parlin Creek (A-1), one cross section on Parlin Creek (A-2), and one cross section upstream of the mouth of Parlin Creek (A-3) (Figure 15). Additionally, we surveyed cross sections at the upstream end of Area D (D-1), the upstream end of Area B (B-1), and the downstream end of Area C (C-1) (Figure 16). Cross section locations were chosen based on the presence of all three map units: pre-historic terrace deposits, historic terrace deposits, and active channel deposits. In at least three of the six cross sections, the historic terrace deposit is present on both sides of the channel. From this, we infer that historic terrace deposits may have once extended across the channel. In this case, the inferred deposit represents the maximum amount of historic aggradation. By comparison of the present distribution of historic terrace deposits to the inferred maximum extent of historic deposition at the cross section locations, we roughly estimate that the South Fork Noyo River has eroded and transported approximately 43-72 % of the original post-logging deposits.

Present-Day Hydrology WY2001

Streamflow measurements and sediment transport data were collected from November 2000 through March 2001, and included most of the significant storm events in the period. As it turned out, WY2001 was a critically dry year. In the Albion watershed, located 16 km south of the SFNR, WY2001 was estimated as the 8th driest year in terms of peak discharge in a 50-year synthesized record.Table 5 shows the number of measurements at each site. From 4 to 5 discharge measurements and 9 to 15 turbidity and SSC samples were collected for each of the ten sampling locations (Table 5).

The primary factor affecting surface water runoff in WY2001 was a lack of significant representative storms. WY2001 proved to be an extremely dry year and, because of this, there were relatively few opportunities to collect high-flow discharge measurements and sediment samples. As a result, it was necessary to extrapolate the developed stage/discharge relationships for some of the sites to provide discharge values for turbidity and SSC samples collected at higher flows. Generally, extrapolating stage/discharge relationships more than 100% beyond the highest discharge measurement can introduce significant errors. At some sites, we were able to obtain discharge measurements near the peak of individual storms, such as for SFNR below Kass Creek (station SFNBK), where the highest measured discharge was 798 cfs, while the peak discharge for the year was only 813 cfs.

Discharge Measurements and Peak Discharges

All discharge measurements were entered and cataloged using the standard USGS-type 9-207 discharge measurement summary form. Appendix A contains a combined 9-207 summarizing all discharge measurements made over the course of WY2001. Table 6 is a summary of the peak discharges for each of the sub-watersheds for the storm on February 20, 2001. The peak discharges for SFNBK, KASFN, NFSFASFN, SFNANFSFN, BASFN, SFNAP, and PASFN were obtained directly from the appropriate rating tables. The remaining three peak discharges for SFNAK, SFNBNFSFN, and SFNBP were obtained from the developed synthetic hydrographs. Because complete streamflow records were not available for the entire water year, typical WY statistics were not computed, although our records would cover the overwhelming majority of the runoff in the water year and certainly all events capable of transporting sediment.

Rating Curves

Stage-discharge rating curves were developed for seven of the 10 sites. Figure 17 is a typical computer-generated rating curve that is included for presentation purpose only, including a power fit function used to evaluate the stage/discharge relationship. All rating curves used in discharge calculations were developed using standard hand methods. Hand plotted ratings tend to be more accurate because few gage sites are entirely linear in their relationship between stage and discharge. Instead, the best fit-line is hand drawn and then skeletal rating points are used to develop the relationship between stage/discharge. After the ratings curves were developed, rating tables were created by a log expansion between the skeletal rating points (Table 7). With such a rating table, and knowledge of the gage height adjustment for the top of the fencepost at each site, we determined the discharge for any stage (providing the rating curve remained stable and was not altered by passage of a large storm).

Hydrographs

A hydrograph for the South Fork Noyo below Kass Creek station is shown in Figure 18. Because this site is near the downstream end of the watershed, the flows were the highest of all sites monitored. However, the shapes of the other hydrographs are very similar. The first storm of the winter occurred on November 29, 2000. Only one small storm occurred in December, which was a record dry month in parts of northern California. Two storms occurred in January (January 11 and 26), two in February (February 12 and 20), and one in March (March 5). The February 20 storm produced the annual maximum peak discharge at all sites in the watershed as shown in Table 6. None of these storms would be considered a significant storm in the hydrologic record.

Sediment Transport

Appendix B contains a summary of all sediment samples listing the site, date of sample, measurement #, turbidity, suspended sediment concentration (mg/l), stage (ft), discharge (cfs), discharge per watershed area (cfs/mi^2), suspended sediment load (tons/day), suspended sediment load per unit area (tons/day/mi^2), and notes.

Sediment transport rates

A total of 115 sediment transport measurements were made in WY2001. Various relationships were developed using the entire dataset (for the entire watershed as a whole) and for each site individually. Relationships developed included: SSC versus turbidity, turbidity versus discharge, SSC versus discharge, and finally SSL versus discharge. Table 8 shows the equations and r^2 values developed for each of these relationships.

Sediment loads were computed from these regression equations and the 15-minute discharge hydrograph. Given the relatively small number of samples, we chose to not evaluate specific site sediment relationships for intra-storm time or stage trends, although that is frequently found in sediment transport studies. Often, computation of transport records without taking into account such variability in sediment transport rates based on hydrograph position (hysteresis) may lead to considerable errors.

As an example, however, we examined the hysteresis characteristics at one station that was selected for its relatively low r^2 value. Figure 19 shows the power function relationship for the combined dataset ($r^2 = 0.68$) which has significant scatter, and then the relationships when the data are sub-divided into rising and falling limb positions based on hydrograph analysis (r^2 = 0.92 and 0.94). If data are available to support such analyses, the accuracy of sediment load calculations may be significantly improved.

In general, the most important sediment relationship is for suspended sediment load, which provides an instantaneous sediment load in tons per day for a given discharge. Using the regression equations in Table 8 for SSL (r^2 from 0.66 to 0.91), we computed total suspended sediment loads for each of the 10 sub-watersheds in the South Fork Noyo River basin. These loads for the streamflow period of record in WY2001, ranged from 684 tons at the SFNR below Kass Creek (SFNBK) to 13.7 tons for Bear Gulch (BASFN), a one square mile tributary. Table 9 shows the computed values for each site for WY2001.

The unit rate (tons/mi^2) for each site is also computed. These unit rates vary from 7.4 tons/mi^2 for the SFNR above Parlin Creek (SFNAP) to 25.4 ton/mi^2 for the SFNR above Kass Creek (SFNAK). Figure 20, represents the distribution of this suspended sediment load.

<u>Watershed Level Relationships</u>

Figures 21 to 24 summarize the collected sediment transport data for the South Fork Noyo watershed in WY2001 at a watershed scale. Figure 21 is a plot of all the turbidity and SSC samples collected to date, and the linear regression equation relating SSC to turbidity. Although there is considerable scatter, the r^2 value is still 0.82, thus turbidity explains 82% of the variability in SSC values. Although turbidity is an optical property and not a measurement of sediment concentration, it provides a proxy for estimating sediment concentration.

Figure 22 shows the log-log linear relationship between turbidity and discharge. As is common of these relationships, there is a tremendous amount of scatter and the relationship has little significance, particularly when many sites and sizes of drainage areas are combined. Figure 23 presents the log-log relationship between SSC and discharge, which again has little significance in a watershed level analysis.

However when suspended sediment load (SSL) is plotted against discharge (Figure 24), a much stronger relationship is apparent (r^2 = 0.82). This is due to the computation of suspended sediment load, which involves the equation SSL = SSC * Q * 0.0027, thus weighting the SSC by its concurrent discharge, which produces far more linear results. Although the general relationship is strong, there are still almost two orders of magnitude of scatter for the loads associated with a given discharge. Again, this is primarily due to lumping stations with different drainage areas together, as 10 cfs on a very small channel may transport considerable sediment while the same discharge on a much larger downstream channel might not transport any appreciable amount of sediment.

Individual Site Relationships

The individual sites are separated in the plot of SSL versus discharge shown in Figure 25. This figure shows that the regression equations for smaller drainage area sites tend to lie above the larger areas. Kass Creek (KASFN) and Bear Gulch (BGASFN) both plot noticeably different from the rest. In these smaller sub-watersheds, a given discharge tends to carry a greater sediment load compared to larger watersheds.

Figure 26 plots values of SSL vs. discharge normalized by dividing each value by the watershed area. This analysis highlights any sites that are transporting sediment at rates higher or lower than others for the same unit discharge and represents, in a sense, a test for outliers. Thus, we see that the SFNR above Kass Creek (SFNAK) and the SFNR below Kass Creek (SFNBK) plot noticeably higher than other sub-watersheds, while the SFNR above Parlin Creek (SFNAP) plots slightly below.

Comparison to Regional Data

In 1998, Graham Matthews and Associates developed a regional suspended sediment load equation as part of the Noyo River TMDL. The regional equation was based on data from watersheds of generally similar size and geology as the Noyo River watershed and was judged to be applicable to all of Mendocino County. In 2001, however, when applying that dataset for comparison to the much smaller Albion watershed to the south, only that portion of the regional dataset developed from small watersheds (D_A = 2.9-30.4mi^2) was used. Data collected from the South Fork Noyo for WY2001 were plotted for comparison with the regional sediment equation for smaller watersheds (Figure 27).

It appears that the collected data are generally consistent with the developed regional equation. However, lower discharges tend to produce greater sediment loads, while higher discharges produce lower loads than the regional equation, and the slope of the best-fit power function lines are quite different. This may be an artifact of the regional dataset, much of which was collected by the USGS in the 1960s and 1970s, when sediment transport rates may have been higher, due to generally greater amounts of watershed disturbance in those times, or perhaps it is simply due to generally lower sediment yields from the SFNR, at least at high discharges. We would hypothesize that the greater loads at lower discharges may be related to the extent of road construction, particularly streamside roads, in the SFNR watershed, as roads of this type are known to deliver sediment directly to the channel, and thus may become a chronic load source even in relatively small storms. Alternatively, there may be sufficient fine sediment stored in very active deposits along the channels that these are readily entrained by small discharges, although this would imply a high degree of disturbance in the watershed that does not appear to exist. Finally, the differences could simply be due to differing geology or soils.

DISCUSSION

Comparison of mapping techniques and associated sources of uncertainty in sediment volume estimation

This project quantifies the amount of sediment stored in the South Fork Noyo River watershed based on two scales of mapping: reconnaissance and detailed. The reconnaissance mapping technique is logistically simple and allows for assessment of long stream reaches in a short amount of time. Approximately two miles of stream can be surveyed in one field day. In contrast, the detailed mapping technique takes approximately twice the time as reconnaissance mapping to assess a stream reach of equal length. This is due to the logistics involved with setting up the string line and mapping the individual deposits. In the reconnaissance mapping technique, the area of each deposit is generalized by approximating the shape of each deposit as a rectangle. Because the length is measured along the river thalweg, generalizing deposit width is a source of error in approximating deposit area, and may result in an underestimation of deposit area. Although, the error in width is unknown, we infer that a rectangular shape closely approximates actual deposit area in most cases, and therefore the error in deposit width is a minor source of error in the overall volume estimation.

The detailed mapping technique has several advantages over the reconnaissance mapping technique. By digitizing the field map into an ArcView geographic information system, the area of individual deposits can be accurately determined. The maps provide a permanent record of the existing conditions of the stream channel and are useful for assessing the volume over a particular reach. If there is a need for an additional field visit (i.e., to verify deposit thickness), the field map can be used to locate individual deposits. This is not possible with the reconnaissance mapping technique because the locations of each deposit are not recorded.

A similar process was used to calculate the volume of map units delineated via both mapping techniques. The thickness of sediment is the largest source of error in estimating storage volume for both mapping techniques. The magnitude of this error varies considerably among the different map units. In both mapping techniques, minimum deposit thickness was measured for channel deposits by observing bedrock at the bottom of scour pools, and estimating the diameter of logs buried in the channel. Based on this, we infer that the channel deposit thickness error results in minimum channel volume estimates. Because there is limited data to interpret the base of gravel bar and historic terrace deposits, we add the minimum sediment thickness determined in the channel to the thickness measured for these deposits. This model assumes a rectangular channel shape and results in maximum estimates of volume for these deposits. This technique may overestimate historic terrace and gravel bar deposit volume by as much as 65%.

Age of Historic Terraces

The constant reworking of historic terrace deposits by historic floods and almost continuous timber management in the SFNR watershed makes correlating historic terrace deposits to a particular time period of logging difficult. Both old-growth logging (1904 - 1937) and second-growth logging prior to the passage of the Forest Practice Rules (1940's - 1973) used yarding techniques that involved dragging trees within stream channels. Also, both periods of logging cut trees at the margins of watercourses. Railroad grades and ox-and-bull skid trails (old-growth logging era) and haul roads and tractor skid trails (second-growth logging) were constructed in stream channels and along inner gorge side slopes. Both methods of logging resulted in the addition of large volumes of sediment to the watercourses of the SFNR watershed. The passage of the Forest Practice Rules in 1973 resulted in higher standards for road construction and harvest techniques and established buffer zones along watercourses. These rules significantly reduced the impact of logging on stream channels. In particular, the volume of sediment delivered to stream channels by logging, although still significant, was reduced. Thus, there was less sediment entering stream channels to form historic terraces. Many of the historic terraces observed in the SFNR watershed have large alder trees that are probably 30 - 40 years old. From this, we infer that the historic terraces observed in channels of the SFNR were deposited following logging at various locations within the SFNR watershed prior to 1973.

We were unable to identify criteria to differentiate historic terraces associated with second-growth logging from historic terraces associated with old-growth logging. In a previous investigation in the Garcia River watershed, we associated historic terraces with logging in the 1950's based on the presence of truck tires embedded within the deposit (Louisiana-Pacific Corp., 1998). Criteria that could potentially be used to correlate historic terrace deposition to time period of logging in the SFNR watershed include: truck tires, type of chain used to drag logs, size of trees embedded within the deposit, and saw teeth marks that could be compared to the different types of saws (hand saws vs. chain saws) used to cut trees in different periods. None of these characteristics were identified in the SFNR during this study.

Analysis of storage and transport data

Table 8 shows that the suspended sediment relationships developed for the 10 streamflow and suspended sediment study sites were variable in quality. SSC vs. turbidity can readily be described in the South Fork Noyo River sub-watersheds using a linear regression equation with r^2 values ranging from 0.51 to 0.98. Turbidity versus discharge and SSC versus discharge relationships are highly variable by nature, with r^2 values ranging from 0.24 to 0.80 and 0.12 to 0.80, respectively. SSL versus discharge is of particular interest as this regression equation is used to compute the load in tons for each of the sub-watersheds. Table 8 shows the regression equations developed for SSL versus discharge. R^2 values ranging from 0.91 to 0.66 indicate that the power function adequately describes the suspended sediment processes occurring in the South Fork Noyo River watershed.

Figure 28 relates total suspended sediment load computed at each site to the drainage area of that site. There is a clear relationship between increasing total sediment load and drainage area that is very linear from the smallest site (Bear Gulch) through the SFNR at the fish hatchery (SFNBNFSFN). Between this site and the next one downstream, SFNR above Kass Creek (SFNAK), there is a dramatic increase in sediment transport rates. This reach comprises detailed mapping Areas B-3 and D and reconnaissance mapping Area E. By subtracting the total loads, about 360 tons of suspended sediment were delivered from only 2.9 mi^2. The rate of delivery in this reach, 124 tons/mi^2, is about an order of magnitude larger than the entire watershed upstream, which consistently delivered sediment at 8-12 tons/mi^2. Figure 29 expresses this finding in a different manner, by plotting unit area suspended sediment load vs. drainage area. The present-day sediment transport rates from the upper 2/3rds of the watershed are consistent, but then they double at the confluence of Kass Creek.

The source for this sediment is most likely erosion and re-mobilization of historic sediment stored in the active channel and streamside terraces. This sediment is delivered to the watercourse by active bank erosion of historic terraces and gravel bars and incision of the channel. Areas B, D, and E, the reaches between the fish hatchery at Camp One and Kass Creek, are the stream reaches with the greatest volume of active channel storage (Figure 12). Comparison of Figure 12 to Figure 20 indicates that the location of the greatest amount of stored channel sediment is spacially coincident with the location of the largest increase in suspended sediment load. Based on this, we infer that the origin of the increased suspended sediment load measured upstream of the mouth of Kass Creek is sediment stored in the active channel. The volume of sediment stored in historic terraces along this reach (Figure 13) is less than the volume of sediment stored in historic terraces upstream of this reach. Therefore, we also infer that suspended sediment eroded from historic terraces by bank erosion is a minor component of the total suspended sediment load.

Other potential sources for the increased sediment loads observed between the fish hatchery at Camp One and Kass Creek include sediment contributions from active landslides and sediment produced by upslope land management. Because the channel in this reach is confined between large pre-historic terraces and we did not observe any significant streamside landslides during our channel mapping, it is unlikely that active landslides are a source for this sediment. Because the road density and harvest acreage in this reach do not significantly vary from the other reaches assessed in this project, we infer that land management is also not a likely source of this sediment.

Evaluation of a relative disturbance index

In an effort to see how the findings of this research compared to possible upslope watershed disturbances, we developed a simplistic relative disturbance index and herein compare that to our WY2001 data.

The relative disturbance index for current conditions was defined as the product of sub-watershed road density, the percent of sub-watershed (SW) area harvested in the 1989-1999 period, and the volume (tons) of sediment delivered by landslides in the 1979-1999 period. The simple product of these three variables equally weights all three metrics of potential or actual delivery (Table 10). The results ranged from 1,479 in the Bear Gulch sub watershed (due to a very small amount of slides) to 409,236 for the SFNR below Kass Creek subwatershed, which is essentially the entire SFNR watershed.

The computed relative disturbance index was analyzed in relation to our computations of suspended sediment load for all of the various sites throughout the watershed. As previously described, our field streamflow and sediment transport data allowed computation of total suspended sediment load for WY2001. WY2001 was a very dry year, and is probably not representative of a typical year in the watershed. However, the data still allow comparison of the relative loads between different sub-watershed areas.

Figure 30 plots the computed relative disturbance index versus WY2001 total suspended sediment load in tons. All of the sites define a relationship between relative disturbance and sediment transport, with the exception of Kass Creek which lies well below the line, indicating that less sediment was produced than the relative disturbance index would suggest. It seems likely that in a dry year like WY2001, with sediment sources not being actively mobilized, that sediment transport rates would be more consistent and related to only those sources readily available for transport (road surfaces, other bare ground areas, activation of existing small-scale bank erosion or streamside mass wasting features, active gullies, and fines delivered into channels through creep and other surficial processes). In wet years, with significant storm events, we would expect to see much greater differences between sub-watershed areas as they respond to the storm by delivering what would probably be highly variable amounts of sediment. This variability would theoretically be related to variable amounts of upslope management activity.

In WY 2001, historic stored sediment downstream of the North Fork of the South Fork Noyo River increased suspended sediment yields over what the tributaries were delivering. It is difficult to assess the relative contribution of disturbance related (upslope) and stored channel sources to the overall suspended sediment yield of the SFNR watershed based on the limited data collected in WY 2001 (low rainfall). In a normal or wetter year, when larger sediment loads would be delivered from the tributaries, the relative contribution from historic stored sediment may be less significant than in a dry year. However, the significance of the overall contribution of stored historic sediment cannot be adequately assessed without more data.

<u>Relations between long-term sediment storage and short-term sediment transport</u>

Short-term sediment budgets generally rely on the assessment of sediment inputs determined from inspection of multiple sets of aerial photographs. The office-based sediment budget prepared by Graham Matthews and Associates in 1999 for the Noyo River TMDL stated that fluvial-induced change in alluvial storage is a relatively minor term in the overall sediment budget. This statement was based on limited amounts of active bank erosion observed during fly-over reconnaissance. The sediment budget for the entire Noyo River watershed including the SFNR determined that sediment inputs over the 67 year assessment period were 4,465,000 tons and that sediment output over the same time period was 7,441,000 tons (GMA, 1999). This implies that there was a net contribution of 2,946,000 tons of sediment from channel sources (storage). Graham Matthews and Associates (Matthews, 1999) and the U.S. Environmental Protection Agency (EPA, 1999) note that the discrepancy between inputs and outputs in the Noyo River watershed may be a result of sediment input volume errors or time lags from sediment delivery to transport through the system. In contrast to previous assumptions, our sediment storage and transport study has shown that the amount of sediment stored in the SFNR for various lengths of time has a major influence on the assessment of the present-day sediment transport and the short-term sediment budget.

Detailed channel mapping performed during this project (Figures 6a to 6d) confirms that there are significant amounts of stored historic sediment in the channels of the SFNR and that this sediment likely is mobilized during winter storm flows. We identified 158,000 yds^3 of sediment stored in the active channel and 68,000 yds^3 of sediment stored in historic terraces (Table 2). By analysis of the six channel cross sections (Figures 15 and 16) we speculate that approximately 43% to 72% of the historic sediment that once existed in the SFNR watershed has been eroded and transported downstream. These relations suggest that the sediment generated by logging in the SFNR watershed is being transported through the system but has not yet been flushed out of the system. We speculate that the remaining post-logging sediment in the SFNR channel will take tens to hundreds of years to flush through to the watershed mouth.

The addition of suspended sediment eroded from historic deposits to watercourses appears to result in a dramatic increase in the overall suspended sediment load. Therefore, areas that contain large amounts of sediment stored in active channels and/or historic terrace deposits likely are large contributors to the suspended sediment measured during present-day high-discharge events. The majority of the historic terraces and active channel deposits in the SFNR watershed date from many tens to one hundered years old. Therefore, these deposits were originally introduced to the system by logging practices used prior to 1973. In particular, some of these deposits were introduced to the system prior to the 67-year record of aerial photgraphs and represent storage over a longer time interval than was assessed in 1999 for the Noyo River sediment budget. This study shows that suspended sediment eroded from long term channel storage locations significantly increases suspended sediment loads over the short-term. Clearly, a distinction must be made between the amount of sediment introduced to the system over the short-term and the amount of sediment re-introduced to the system from long-term channel storage locations. This information is critical in assessing the cumulative impacts of sediment on the aquatic environment, as well as more accurately constraining sediment budgets and sediment transport analyses.

This research has demonstrated that changes in the amount of sediment in long-term storage is a significant contributor to short-term suspended sediment load. Future field-based sediment budget analyses for the SFNR, the Noyo River, and other watersheds will benefit greatly from accurate mapping and quantification of channel deposits. An understanding of the volume and timing of sediment stored in the channel is necessary for any study attempting to relate upstream management practices to suspended sediment production. By not addressing long-term sediment storage and relying solely on present-day suspended sediment sampling, suspended sediment load entering the watercourse by modern management practices can be substantially over estimated.

The volume estimates, maps, and cross sections generated in this project will be useful in future years to estimate changes in channel sediment storage as well as to assess the sediment impacts of upslope management practices. Monitoring the response of the SFNR to logging induced sedimentation, over time, will increase the understanding of watershed processes in forested coastal basins. In particular, information on a rivers sediment processing capabilities will be useful in predicting the downstream impacts of sedimentation and assessing the rate at which a river can recover its pre-disturbance conditions.

CONCLUSIONS

We assessed the volume of past and present sedimentation within the SFNR by quantifying the volume associated with pre-historic terraces, historic terraces, and the active channel. Sediment volumes were quantified in four detailed mapping reaches (Areas A, B, C, and D) and three reconnaissance reaches (Areas E, F, and G) for a total stream length of about 10 miles. Additionally, we assessed the present day streamflow and sediment transport throughout the SFNR watershed by establishing and monitoring a stream gage network for WY 2001. Streamflow and sediment transport measurements were collected at 10 sites ranging in drainage area from 1 mi^2 to 27 mi^2 (essentially the entire South Fork Noyo watershed). Over the winter of WY2001, we recorded 125 measurements of turbidity and suspended sediment concentration.

The total volume of post-logging sediment (active channel and historic terrace) in storage over the entire study area is estimated at 225,000 yds^3 or approximately 22,000 yds^3/mile. Comparison of the volume associated with historic terraces and the volume associated with the active channel indicates that a large portion of the sediment originally deposited in historic terraces has been eroded and transported downstream. A significant portion of this sediment presently is stored in the lower SFNR channel between its confluence with the North Fork of the SFNR and the mouth of the SFNR. This sediment is stored in the channel in the dry season and is transported downstream in high-discharge events.

Suspended sediment loads computed for each sampling station ranged from 14 to 684 tons. Overall, most sites produced sediment at a fairly consistent rate with discharge, although a large increase in sediment transport occurred between sites at the fish hatchery (SFNBNFSFN) and the site upstream of Kass Creek (SFNAK). This implies that significant sources of readily accessible sediment are located in this reach. This readily accessible sediment is most likely the active channel sediment identified in the channel mapping in Areas B, D, and E.

The detailed maps and cross sections produced in this research provide a snap-shot of the distribution of stored sediment within SFNR and represent a baseline datum from which to monitor future channel recovery. The streamflow and suspended sediment transport data provide estimates of suspended sediment transport for WY 2001. This data can be used in the future to monitor sediment contributions related to upslope management practices on a sub-watershed basis. This research demonstrates that the old-growth logging practices contributed many thousands of cubic yards of sediment to channels in the SFNR watershed, and that the river has the power to eventually transport this material downstream. However, a few tens to hundreds of years is necessary for the river to achieve its pre-logging conditions. This research also demonstrates the need for an understanding of in-channel sediment storage and transport for any study attempting to relate upslope forest management practices to suspended sediment load.

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Table 1. General site description for streamflow and suspended sediment sampling locations (WY2001) in the South Fork Noyo watershed including site name, site acronym, associated watershed area, and presence of pressure transducer.

Station Name	Acronym	Area (mi^2)	Station Number*	Pressure Transducer Installed
South Fork Noyo below Kass Creek	SFNBK	27.32	1	Yes
Kass Creek Above South Fork Noyo	KASFN	2.21	2	NO
South Fork Noyo above Kass Creek	SFNAK	24.84	3	NO
South Fork Noyo below North Fork of the South Fork Noyo	SFNBNFSFN	21.93	4	NO
North Fork of the South Fork Noyo above South Fork Noyo	NFSFNASFN	9.89	5	YES
South Fork Noyo above North Fork of the South Fork Noyo	SFNANFSFN	11.9	6	NO
Bear Gulch above South Fork Noyo	BASFN	1.05	7	NO
South Fork Noyo below Parlin Creek	SFNBP	9.2	8	NO
Parlin Creek above South Fork Noyo	PASFN	4.43	9	YES
South Fork Noyo above Parlin Creek	SFNAP	3.69	10	YES

* Number correlates to suspended sediment sampling locations shown on Figure 5.

Table 2. Total volume of sediment stored in active channel deposits, historic terrace deposits, and pre-historic terrace deposits for each detailed mapping area (Area A-1 to Area D) and reconnaissance mapping area (Area E to Area G).

Stream Reach	River Dist. (miles)	Active Channel Deposits (yds^3)*			Historic Terrace deposits (yds^3)*	Pre-historic Terrace deposits (yds^3)*#
		Gravel bar deposits (yds^3)*	Channel deposits (yds^3)Ø	Total active channel deposits (yds^3)*		
Area A-1	0.96	3,906	5,369	9,275	19,155	199,350
Area A-2	0.25	530	720	1,250	1,269	N.D.∞
Area B-1	0.47	5,448	4,446	9,893	4,526	68,265
Area B-2	0.38	5,352	3,262	8,613	3,248	82,336
Area B-3	0.40	5,681	4,440	10,121	4,337	34,099
Area C	0.8	9,666	7,090	16,756	10,095	26,088
Area D	0.8	9,527	7,224	16,751	2,704	44,517
Area E	2.2	29,514	26,691	56,205	7,001	3,316,326
Area F-1	0.4	1,630	2,000	3,630	1,849	22,109
Area F-2	0.25	96	590	686	0	3,703
Area F-3	1.86	8,271	4,612	12,883	6,201	93,541
Area G	1.5	4,524	7,039	11,563	7,597	65,867
All Areas	**10.27**	**84,145**	**73,483**	**157,626**	**67,982**	**3,956,201**

* Reported values represent maximum potential storage volume due to uncertainties in terrace thickness at the back edge of the deposit.

Ø Reported values represent minimum storage volume.

\# Pre-historic terrace sediment volumes are based on an assumed 5 foot thickness except for Area A which is calculated based on 4 foot thickness determined from field observation. (range of depth error is +/- 3 feet).

∞ N.D.; no data. Prehistoric terrace volume for Area A-2 is included in the volume calculated for A-1.

Table 3. Sediment storage in active channel deposits, historic terrace deposits, and pre-historic terrace deposits averaged per river mile for each detailed mapping area (Area A-1 to Area D) and each reconnaissance mapping area (Area E to Area G).

Stream Reach	River Dist. (miles)	Active Channel Deposits (yds^3/ mile)*			Historic Terrace deposits (yds^3/ mile)*	Pre-Historic Terrace deposits (yds^3/ mile)*
		Gravel Bar Storage (yds^3/ mile)*	Summer Channel Storage (yds^3/ mile)$^{\emptyset}$	Total active channel storage (yds^3/ mile)*		
Area A-1	0.96	4,069	5,593	9,661	19,953	207,656
Area A-2	0.25	2,120	2,880	5,000	5,076	N.D.$^{\infty}$
Area B-1	0.47	11,591	9,460	21,049	9,630	145,245
Area B-2	0.38	14,084	8,584	22,666	8,547	216,674
Area B-3	0.40	14,203	11,100	25,303	10,843	85,247
Area C	0.8	12,083	8,863	20,945	12,619	32,610
Area D	0.8	11,909	9,030	20,939	3,380	55,646
Area E	2.2	13,663	12,357	26,020	3,242	1,507,420
Area F-1	0.4	4,075	5,000	9,075	4,622	55,273
Area F-2	0.25	384	2,360	2,744	0	14,814
Area F-3	1.86	4,447	2,480	6,926	3,332	50,290
Area G	1.5	3,016	4,693	7,709	5,065	43,911
All Areas	**10.27**	**8,193**	**7,155**	**15,348**	**6,619**	**385,219**

* Reported values represent maximum potential storage volume due to uncertainties in terrace depth at the back edge of deposit.

$^{\emptyset}$ Reported values represent minimum storage volume.

$^{\infty}$ N.D.; no data, pre-historic terrace volume for Area A-2 is included in the volume calculated for A-1.

Table 4. Total amount of post-logging sediment remaining in the South Fork Noyo River and tributaries by stream reach. The values represent the sum of sediment stored in the active channel and historic terrace deposits.

Stream Reach	River Distance (miles)	Total volume of post-logging sediment (yds^3)*	Total volume of post-logging sediment averaged for river distance (yds^3/mi.)*
Area A-1	0.96	28,430	29,615
Area A-2	0.25	2,519	10,076
Area B-1	0.47	14,419	30,678
Area B-2	0.38	11,861	31,213
Area B-3	0.40	14,458	36,145
Area C	0.8	26,851	33,564
Area D	0.8	19,455	24,319
Area E	2.2	63,206	28,730
Area F-1	0.4	5,479	13,698
Area F-2	0.25	686	2,744
Area F-3	1.86	19,084	10,260
Area G	1.5	19,160	12,773
All Areas	**10.27**	**225,608**	**21,968**

* Reported values represent maximum potential storage volume.

Table 5. Summary of the number of discharge, turbidity, and suspended sediment concentration (SSC) measurements by sampling station in the SFNR watershed for WY 2001.

Station name	# of discharge measurements	# of turbidity and SSC measurements
SFNBK	5	12
KASFN	4	11
SFNAK	--	13
SFNBNFSFN	--	11
SFNANFSFN	4	13
NFSFASFN	4	15
BGASFN	4	12
SFNBP	--	9
SFNAP	5	14
PASFN	4	15

Table 6. Summary of the peak discharges for each of the sub-watersheds for the storm on February 20, 2001 including watershed area and unit peak discharge.

Station Name	Date	Area (mi^2)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Note
SFNBK	2/20/01	27.32	813	29.7	
KASFN	2/20/01	2.21	69	31.3	
SFNAK	2/20/01	24.84	744	29.9	From Synthetic Hydrograph
SFNBNFSN	2/20/01	21.93	667	30.4	From Synthetic Hydrograph
SFNANFSN	2/20/01	9.89	354	35.8	From Synthetic Hydrograph
NFSFASFN	2/20/01	11.9	313	26.3	
BGASFN	2/20/01	1.05	28.5	27.1	
SFNBP	2/20/01	9.2	291	31.6	From Synthetic Hydrograph
SFNAP	2/20/01	4.43	100	22.6	
PASFN	2/20/01	3.69	188	50.9	

Table 7. Example rating table for the North Fork of the South Fork Noyo River

Discharge Rating Table 1 Begin Date: 11/08/00 14:15

DISCHARGE IN CUBIC FEET PER SECOND

ght	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	1st diff	2nd diff
1.0			2.35*	2.55	2.77	3.00*	3.04	3.08	3.11	3.15		
1.1	3.19	3.23	3.27	3.31	3.34	3.38	3.42	3.46	3.50	3.54*	0.81	
1.2	4.00*	4.34	4.71	5.11	5.54	6.00*	6.3	6.61	6.94	7.28	3.63	2.82
1.3	7.63	8.00*	8.32	8.66	9.00*	9.49	10.0*	10.4	10.8	11.2	4.01	0.38
1.4	11.6	12.1	12.5	13.0	13.5	14.0*	14.5	15.0	15.5	16.0	4.86	0.84
1.5	16.5*	17.0	17.5	18.0	18.5	19.0*	19.5	20.1	20.6	21.1	5.21	0.35
1.6	21.7	22.3	22.9	23.5	24.1	24.7	25.3	26.0	26.6	27.3	6.29	1.08
1.7	28.0*	28.8	29.5	30.3	31.1	31.9	32.7	33.6	34.4	35.3	8.23	1.94
1.8	36.2	37.1	38.1	39.0	40.0*	41.0	42.1	43.1	44.2	45.3	10.2	2.02
1.9	46.5	47.6	48.8	50.0*	50.8	51.6	52.5	53.3	54.2	55.0	9.42	-0.82
2.0	55.9	56.8	57.7	58.6	59.5	60.4	61.3*	62.7	64.1	65.6	11.2	1.79
2.1	67.1	68.6	70.2	71.7	73.3	75.0	76.6	78.3	80.0*	81.2	15.4	4.17
2.2	82.5	83.8	85	86.3	87.6	88.9	90.3	91.6	93.0	94.4	13.3	-2.13
2.3	95.7	97.2	98.6	100*	102	103	105	107	108	110	15.9	2.65
2.4	112	113	115	117	119	121	122	124	126	128	18.3	2.43
2.5	130*	132	134	136	138	140	142	144	146	148	19.6	1.24
2.6	150	152	154	156	158	160	162	165	167	169	21.6	2.04
2.7	171	174	176	178	180	183	185	188	190	193	23.8	2.16
2.8	195	198	200*	203	205	208	211	213	216	219	26.6	2.83
2.9	222	224	227	230	233	236	239	242	245	248	29.3	2.69
3.0	250.9	254	257.1	260.2	263.4	266.6	269.8	273	276.3	279.6	32.0	2.72
3.1	282.9	286.3	289.7	293.1	296.5	300.0*						

* skeletal rating point

Table 8. WY2001 regression equations and r^2 values by station for Suspended sediment concentration (SSC) vs. turbidity (T), turbidity vs. discharge (Q), SSC vs. discharge, and suspended sediment load (SSL) vs. discharge relations.

	SSC vs. T	T vs. Q	SSC vs. Q	SSL vs. Q
Sampling Station	**Equation (r^2)**	**Equation (r^2)**	**Equation (r^2)**	**Equation (r^2)**
SFNBK	$y = 2.617x - 35.615$ 0.96	$y = 1.6791x^{0.5557}$ 0.58	$y = 1.1183x^{0.6686}$ 0.35	$y = 0.003x^{1.6686}$ 0.77
SFNAK	$y = 1.7747x - 8.5746$ 0.78	$y = 3.9963x^{0.3568}$ 0.24	$y = 2.7814x^{0.4647}$ 0.28	$y = 0.0033x^{1.6609}$ 0.89
KASFN	$y = 1.7937x - 24.526$ 0.98	$y = 6.5163x^{0.538}$ 0.58	$y = 1.9284x^{0.8558}$ 0.50	$y = 0.0052x^{1.8558}$ 0.82
SFNBNFSN	$y = 1.5954x - 16.751$ 0.65	$y = 2.4806x^{0.4759}$ 0.58	$y = 0.7449x^{0.6516}$ 0.48	$y = 0.002x^{1.6516}$ 0.85
SFNANFSN	$y = 1.4932x - 13.365$ 0.85	$y = 2.6967x^{0.4759}$ 0.49	$y = 3.539x^{0.3532}$ 0.12	$y = 0.0095x^{1.3546}$ 0.66
NFSFASFN	$y = 1.6283x - 10.453$ 0.90	$y = 3.5436x^{0.4437}$ 0.31	$0.7302x^{0.7807}$ 0.39	$y = 0.002x^{1.7807}$ 0.77
BASFN	$y = 1.6388x - 16.165$ 0.90	$y = 5.7369x^{0.7085}$ 0.64	$y = 3.3978x^{0.8628}$ 0.49	$y = 0.0092x^{1.8628}$ 0.82
SFNBP	$y = 0.882x - 4.2436$ 0.63	$y = 6.5121x^{0.3223}$ 0.28	$y = 2.2697x^{0.4466}$ 0.27	$y = 0.0061x^{1.4466}$ 0.79
SFNAP	$y = 1.4621x - 10.453$ 0.61	$y = 4.6813x^{0.4601}$ 0.80	$y = 1.5719x^{0.7267}$ 0.65	$y = 0.0042x^{1.7267}$ 0.91
PASFN	$y = 1.1489x - 8.1067$ 0.51	$y = 4.2685x^{0.6368}$ 0.50	$y = 0.5871x^{1.3342}$ 0.80	$y = 0.5871x^{1.3342}$ 0.80
ALL DATA	$y = 1.9657x - 24.595$ 0.82	$y = 9.6613x^{0.2511}$ 0.28		$y = 0.0118x^{1.3985}$ 0.82

Notes: SSC = suspended sediment concentration (mg/l), T = turbidity (NTU), Q = discharge (cfs), SSL = suspended sediment load (tons/day)

Table 9. WY 2001 total suspended sediment load (SSL) in tons and tons per square mile for each sampling station.

Station Name	Area (mi^2)	SSL (tons)	Unit SSL (tons/ mi^2)
SFNBK	27.32	684.5	25.1
SFNAK	24.84	632.2	25.4
KASFN	2.21	28.7	13.0
SFNBNFSFN	21.93	273.4	12.5
NFSFNASFN	9.89	128.5	13.0
SFNANFSFN	11.90	121.6	10.2
BASFN	1.05	13.7	13.0
SFNBP	9.20	68.0	7.4
PASFN	4.43	39.5	8.9
SFNAP	3.69	39.3	10.7

Table 10. Calculation of relative disturbance index for the South Fork Noyo River Watershed.

Station name	Drainage Area		Roads	Road Density	Harvest Acreage	Harvest %	Slide Vol.	Disturbance Index	WY 2001 SS Load	
					1989-2000		1979-1999			
	(Acres)	(Mi^2)	(Mi)	(Mi/ Mi^2)	(Acres)	(%)	(tons)		(tons)	(tons/ Mi^2)
SFNAP	2,362.0	3.69	28.93	7.84	2215	93.80	4,548	33,429	39.3	10.65
PASFN	2,837.4	4.43	18.64	4.2	1436.7	50.60	7,945	16,914	39.52	8.91
SFNBP	5,889.4	9.2	54.34	5.91	4286.6	72.80	17,302	74,364	68.03	7.39
BASFN	674.8	1.05	6.85	6.5	587.8	87.10	261	1,479	13.66	12.95
SFNAN FSFN	7,613.6	11.9	72.38	6.08	5688.7	74.70	19,184	87,210	121.57	10.22
NFSFN ASFN	6,332.0	9.89	35.88	3.63	2370.9	37.40	67,065	91,065	128.46	12.98
SFNBN FSFN	14,032.1	21.93	109.37	4.99	8064.7	57.50	86,249	247,273	273.38	12.47
SFNAK	15,894.8	24.84	137.82	5.55	9765	61.40	98,010	334,137	632.17	25.45
KASFN	1,414.5	2.21	18.38	8.32	1331.3	94.10	10,977	85,910	28.7	12.99
SFNBK	17,481.8	27.32	159.52	5.84	11240.2	64.30	108,987	409,236	684.45	25.06

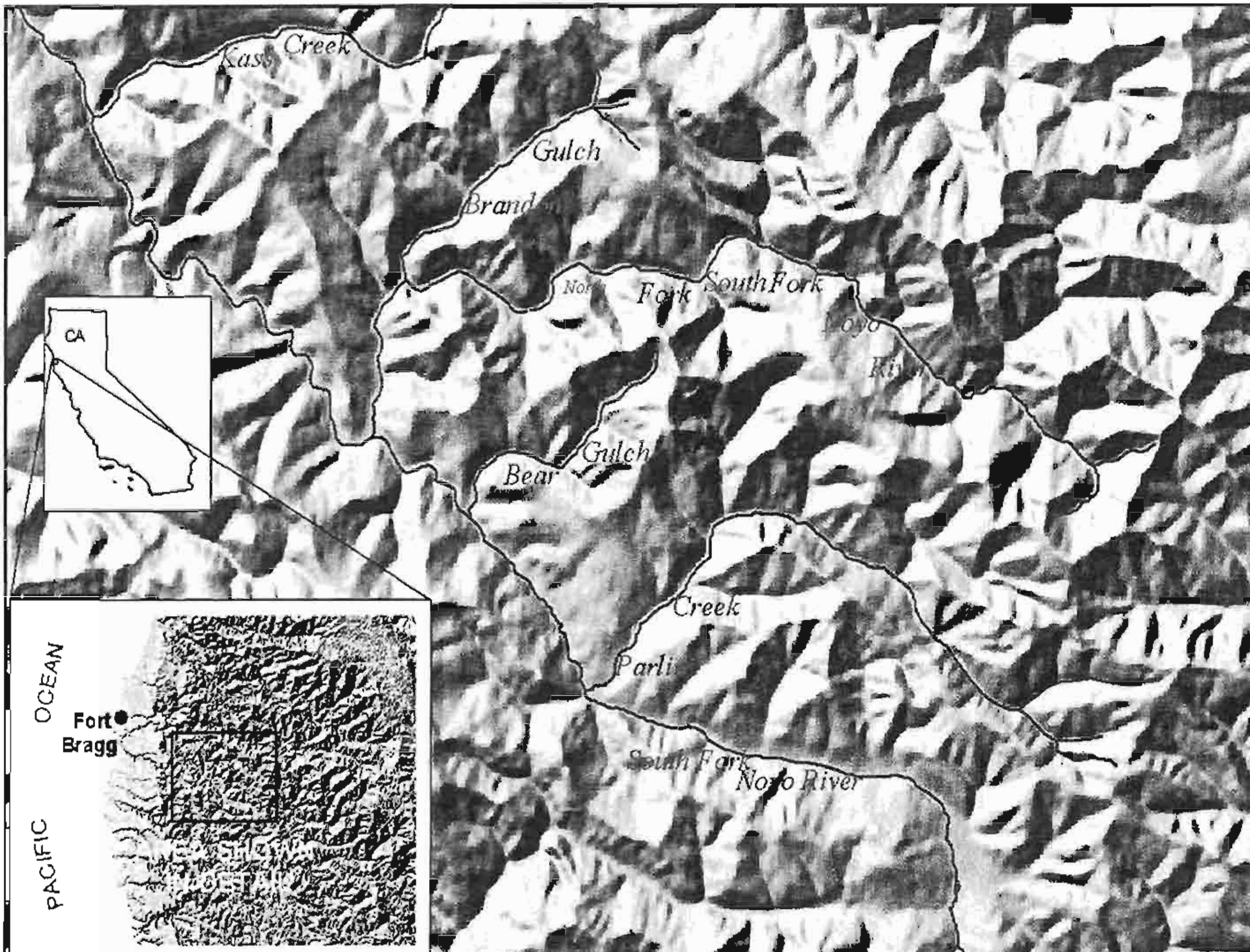

Figure 1. Location map showing the Mendocino Coast and the mouth of the mainstem Noyo River at Fort Bragg. Detailed area shows shaded relief topography along the South Fork Noyo River study area.

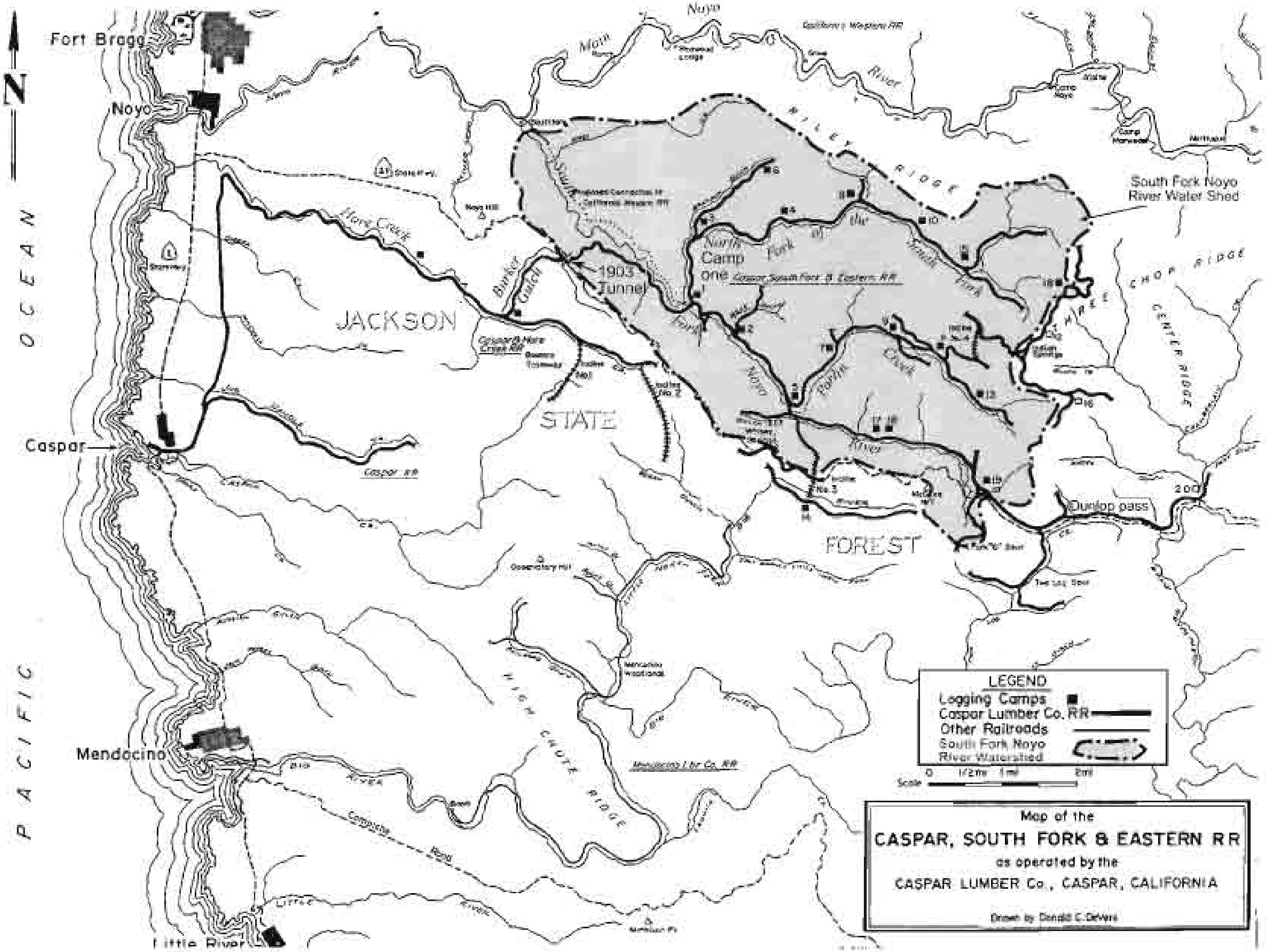

Figure 2. Map of the Mendocino Coast showing the South Fork Noyo River watershed boundary (shaded) and railroad tracks (dark lines) constructed to haul logs to the mill in Caspar.

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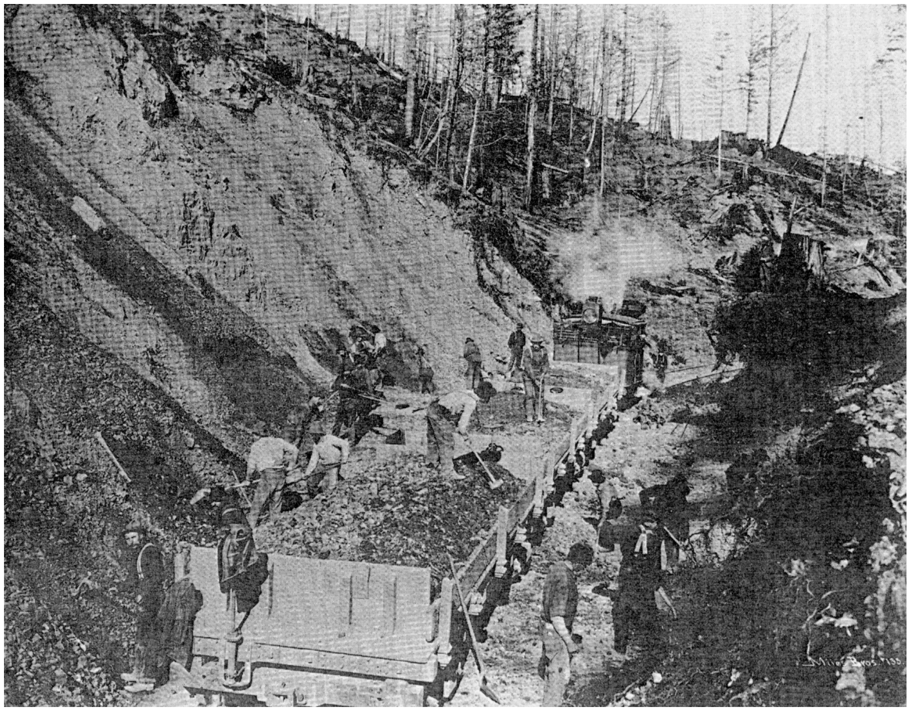
5/01

A)



B)

Figure 3. A) Work crews collect blasted hillslope material just east of the Bunker Gulch tunnel. This material was used to construct the railroad grade into the SFNR basin. Photo dated approximately 1904 (Wurm, 1986). B) The railroad reaches Camp 1 at the confluence of the SFNR and North Fork Of the SFNR. The town is built on a large pre-historic terrace and served as the woods headquarters of the Caspar Lumber Company. Photo dated approximately 1904 (Wurm, 1986).

Figure 4. This photo was taken looking upstream at the head of the North Fork of the SFNR near Camp One. Logs are being dragged to the loading zone by "steam donkey" powered skyline cables. The stream channel is completely filled with logging debris and sediment. Nearly every available tree has been cut. Photo dated approximately 1925 (Wurm, 1986).

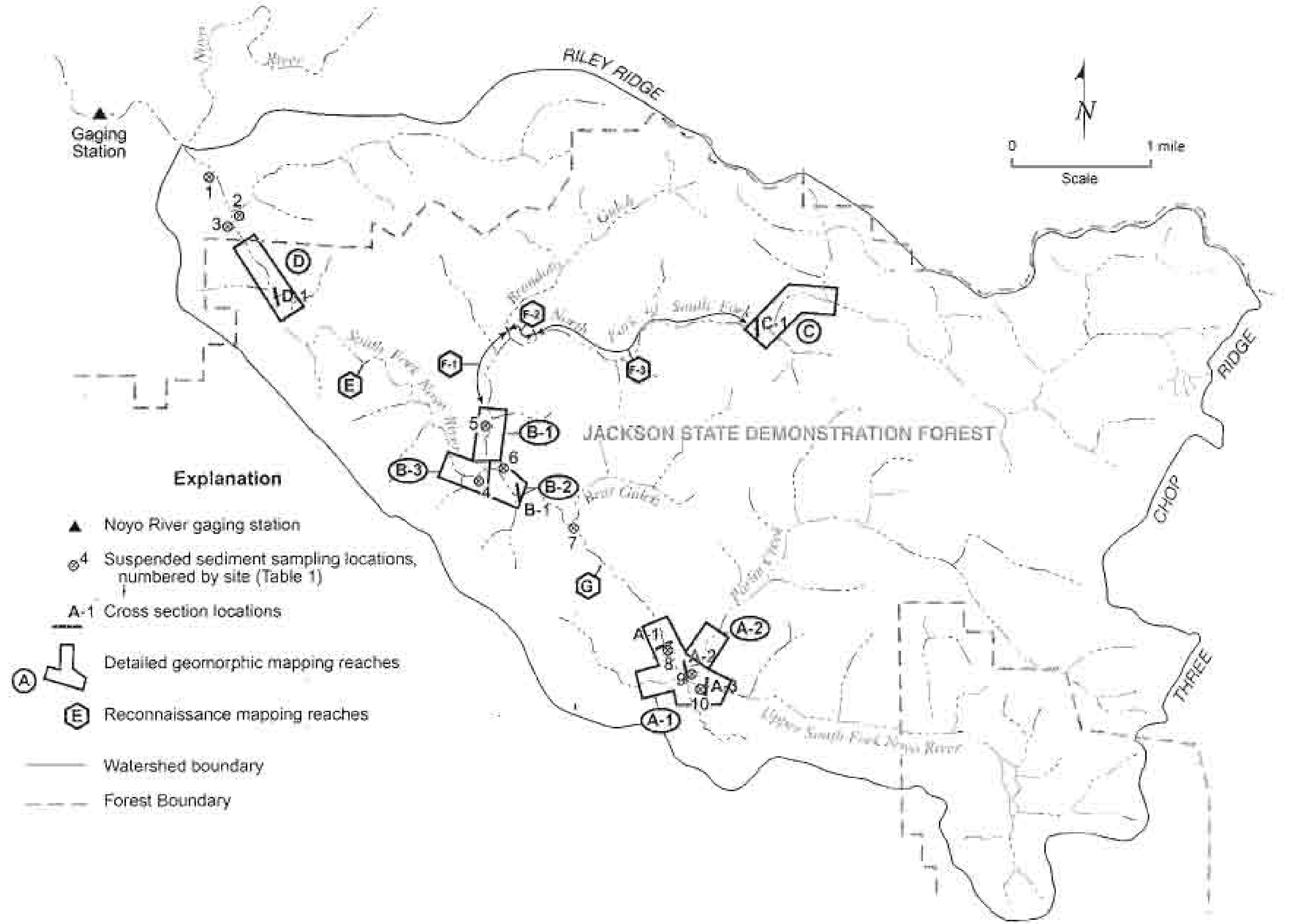


Figure 5. Drainage map of the South Fork Noyo River watershed showing detailed geomorphic mapping locations, reconnaissance mapping reaches, suspended sediment sampling locations, cross section locations, watershed boundary, and property boundary of Jackson State Demonstration Forest.

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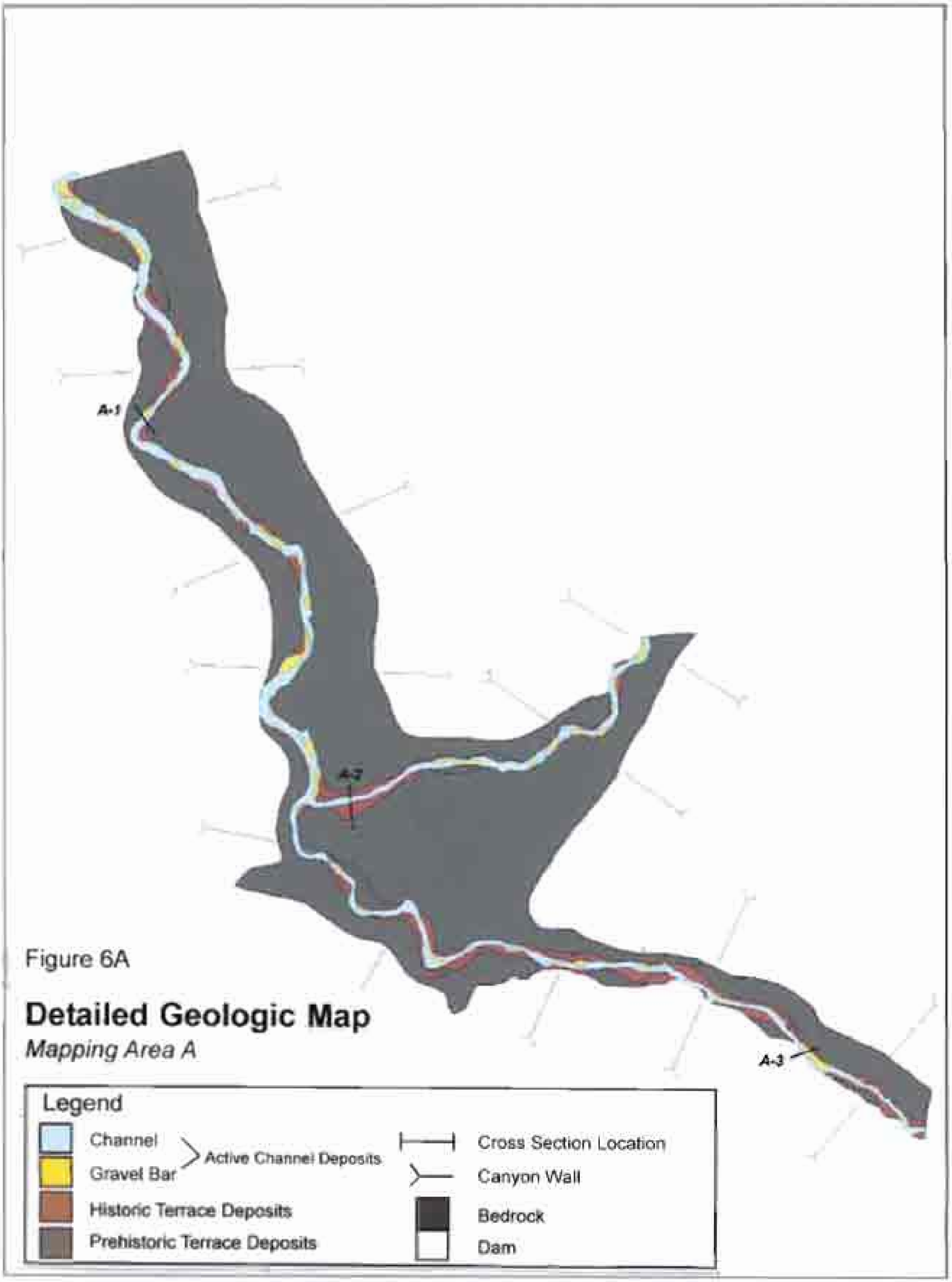


Figure 6A

Detailed Geologic Map

Mapping Area A

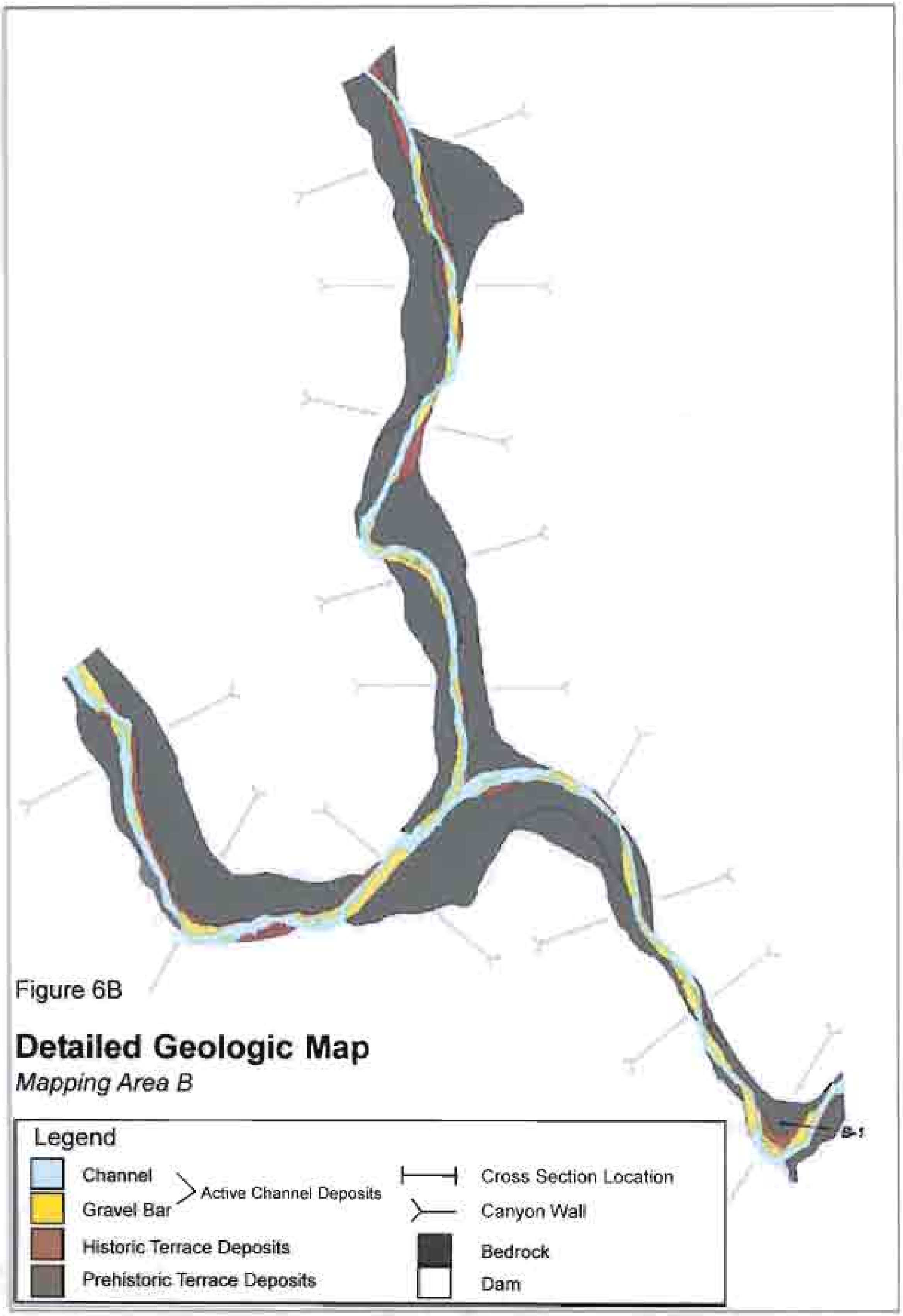


Figure 6B

Detailed Geologic Map

Mapping Area B

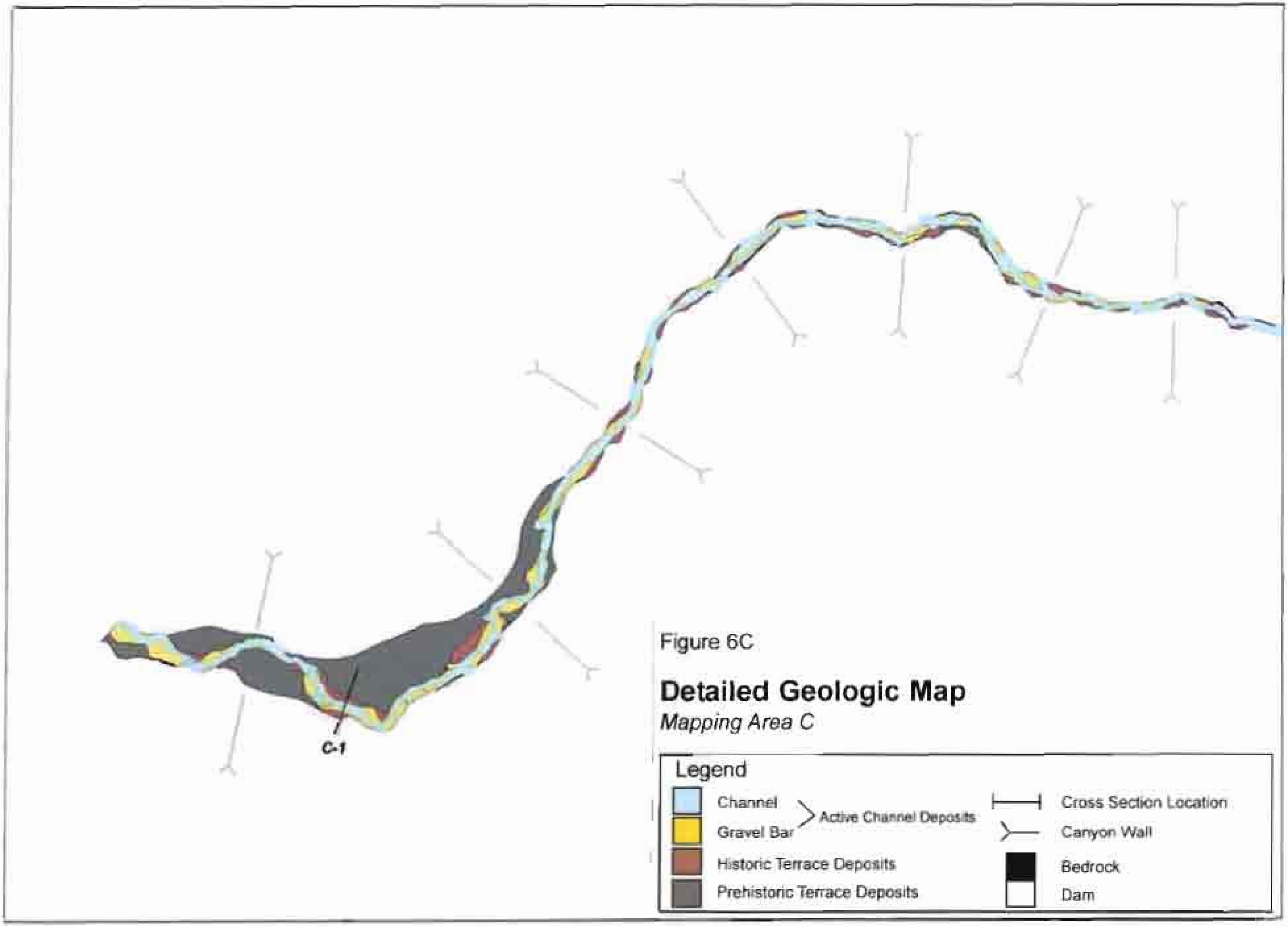


Figure 6C

Detailed Geologic Map

Mapping Area C

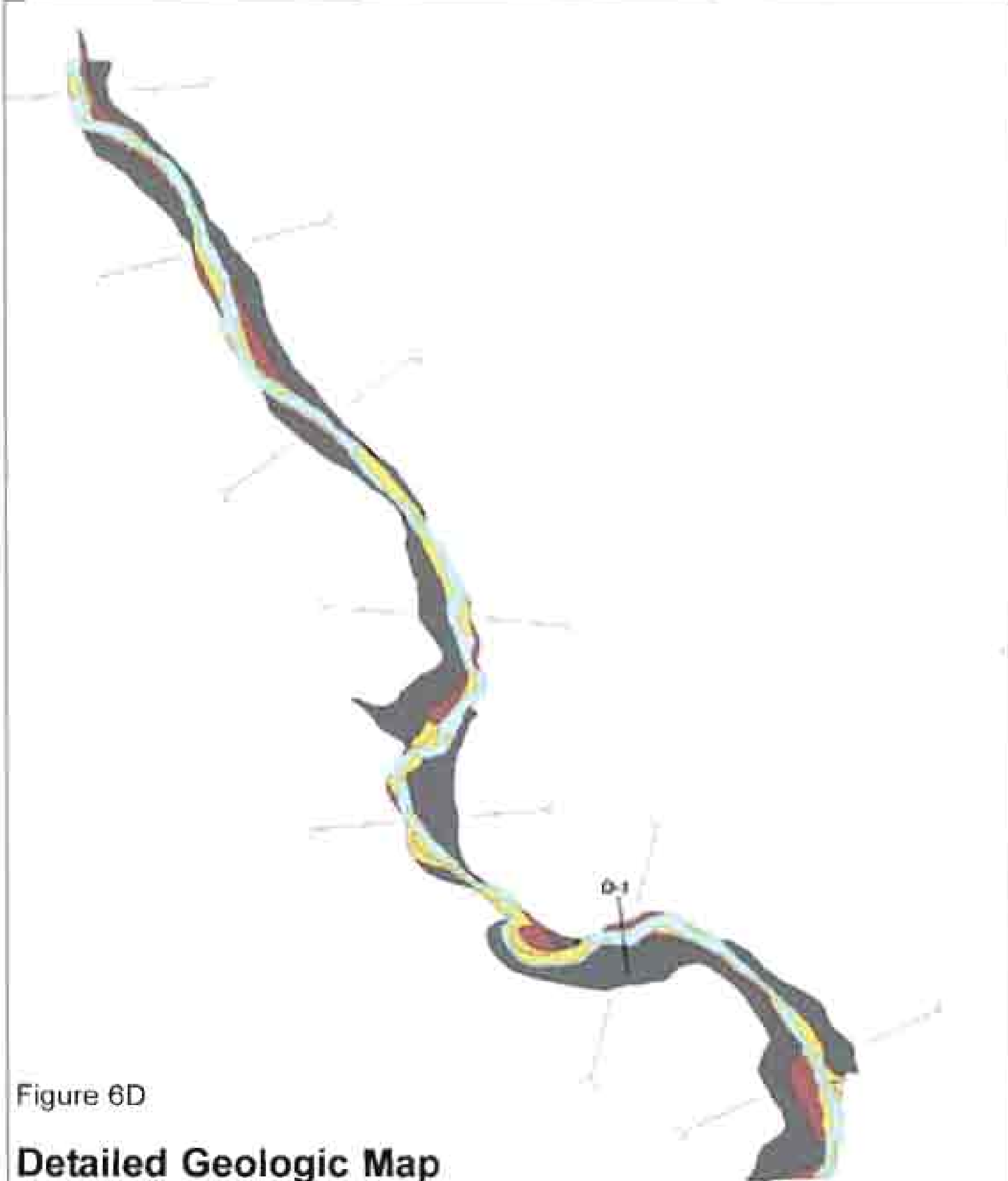
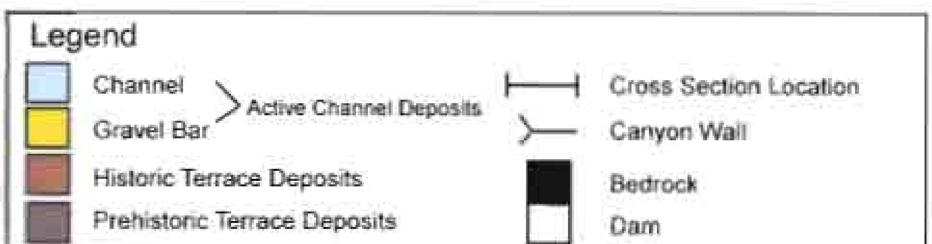


Figure 6D

Detailed Geologic Map

Mapping Area D



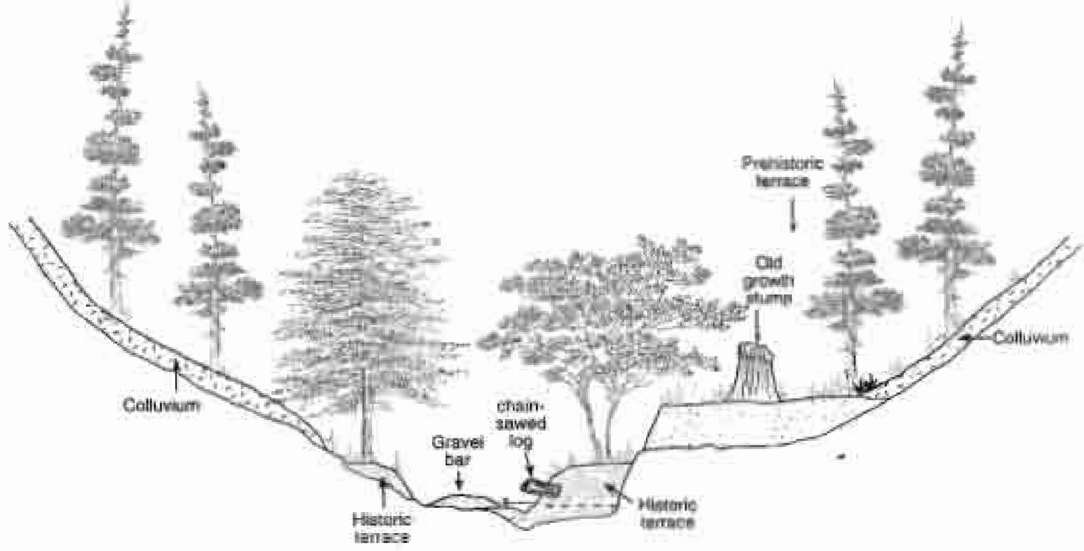


Figure 7. Schematic sketch of typical South Fork Noyo River channel showing valley margin, prehistoric terrace, historic terraces, gravel bar, and channel. Historic terrace deposits are observed on bedrock in some locations (left) and on channel deposits in other locations (right). Old growth redwood stumps are diagnostic of prehistoric deposits and embedded chain-sawed logs are diagnostic of historic deposits. Prehistoric terraces typically support second-growth redwood trees and ferns, historic terraces typically support alder trees and grasses.

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Figure 8 Photo showing second-growth redwood forest growing on pre-historic terrace in Area C. Dashed line indicates the back edge of a historic terrace inset into a pre-historic terrace (background).

A)

B)

Figure 9. A) Photo shows active channel deposits, including low flow channel and gravel bar providing a minimum estimate of active channel storage in Area E. In photo B, a large sawed log approximately 3 feet in diameter is buried in the channel. Approximately one foot of the log is exposed above the sediment, implying two feet of channel storage.

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A)

B)

Figure 10. Photos showing the association of historic terrace with historic railroad trestles remaining in the channel from the old-growth logging era. Dashed lines indicate approximate back edge of historic terrace. Photo A is from Area C and photo B is from Area B.

A)

B)

Figure 11. A) Photo showing sawed log embedded within historic terrace deposit in map Area D. Pre-historic terrace is visible in the background and gravel bar is in the foreground. Field map board is on embedded log for scale. B) Photo showing historic terrace deposit in Area C. In both photos, dashed line indicates approximate back edge of historic deposit.

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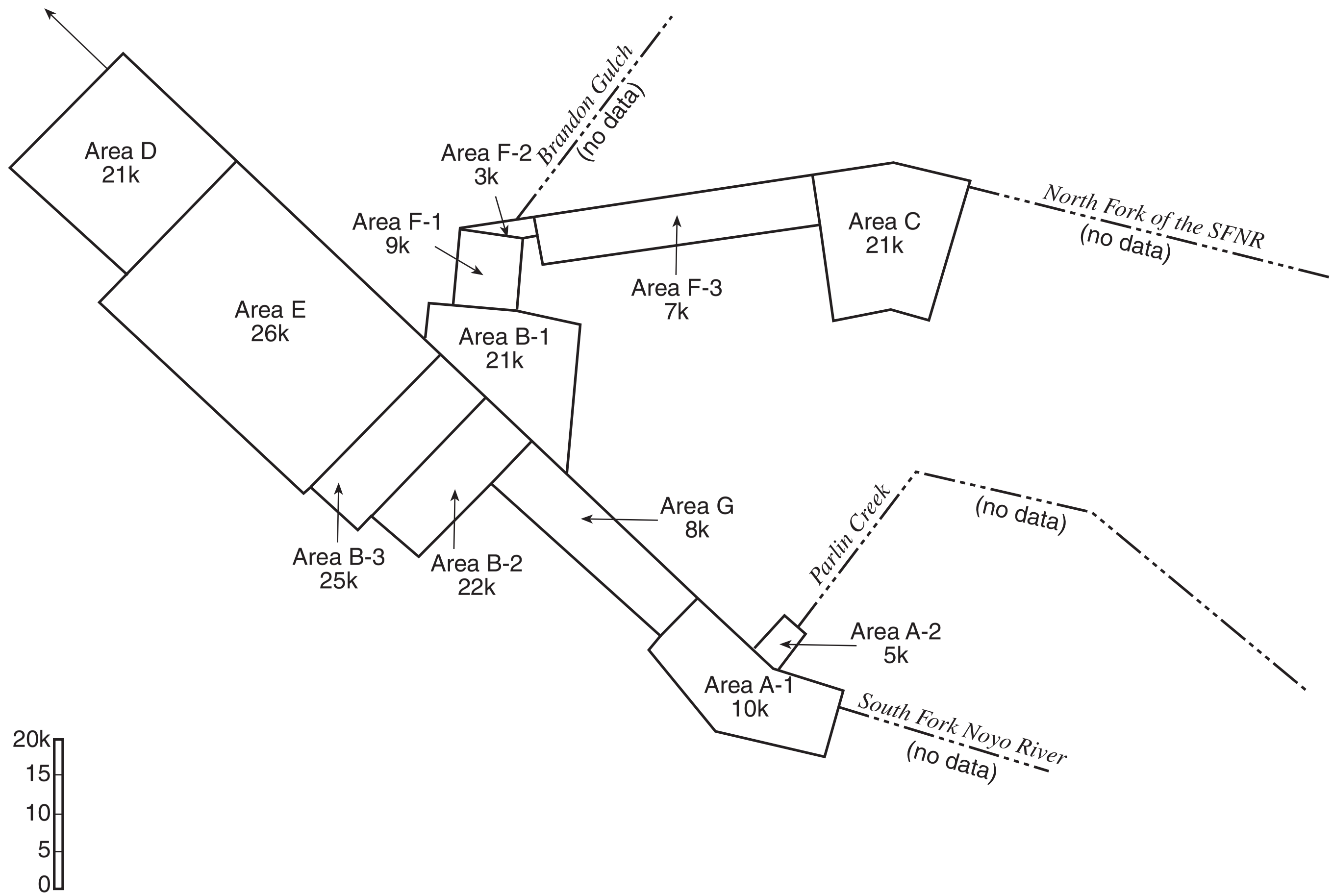

Figure 12. Box diagram showing total volume of active channel deposits per river mile in the South Fork Noyo basin. Box width is relative amount of sediment in yds^3/mile.

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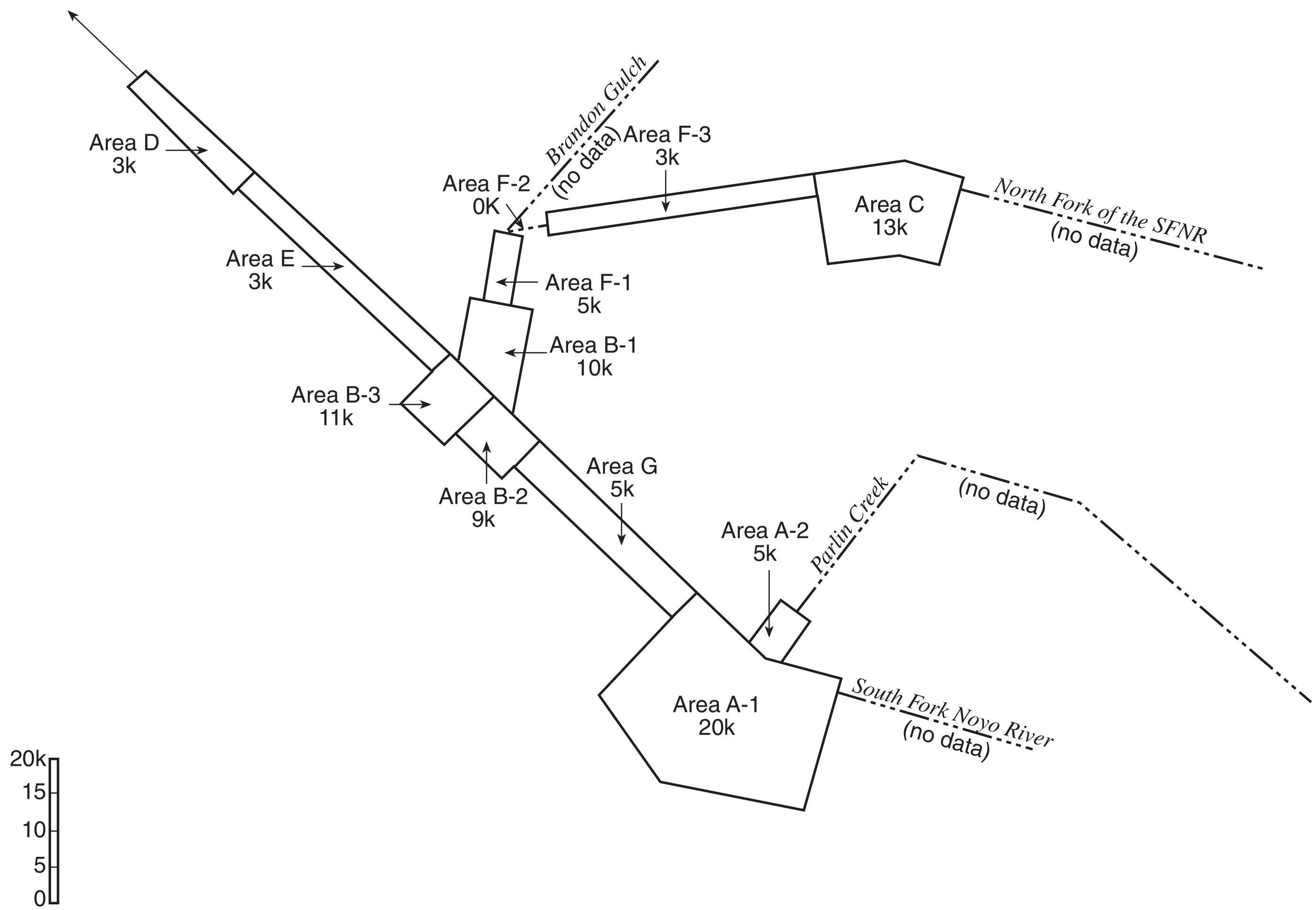

Figure 13. Box diagram showing total volume of historic terrace storage per river mile in the South Fork Noyo basin. Box width is relative amount of sediment in yds^3/mile.

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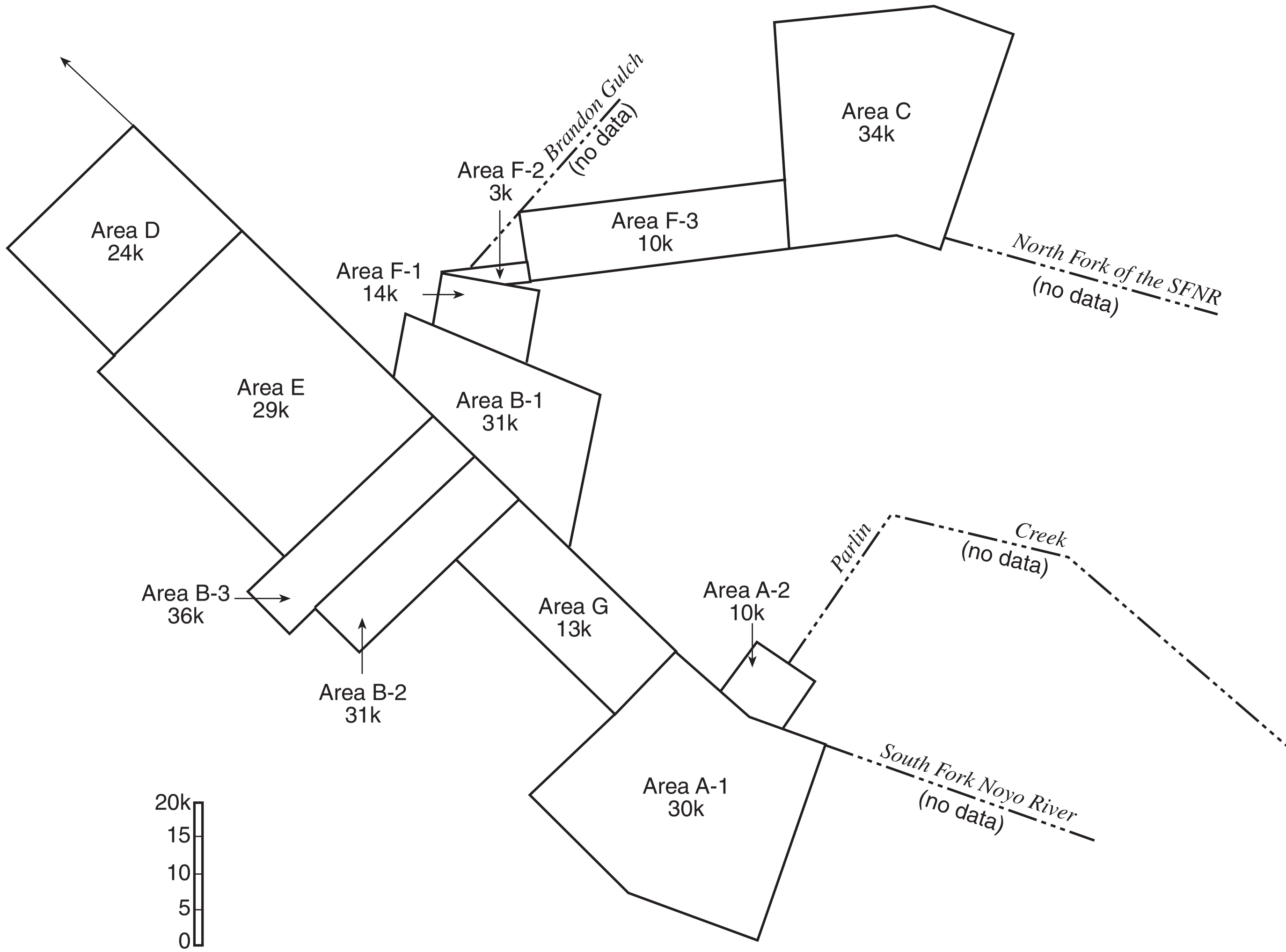

Figure 14. Box diagram showing total volume of post-logging sediment (active channel plus historic terrace deposits) in SFNR. Includes combined volume of channel and historic terrace sediment. Box width is relative amount of sediment per river mile (yds^3/mi).

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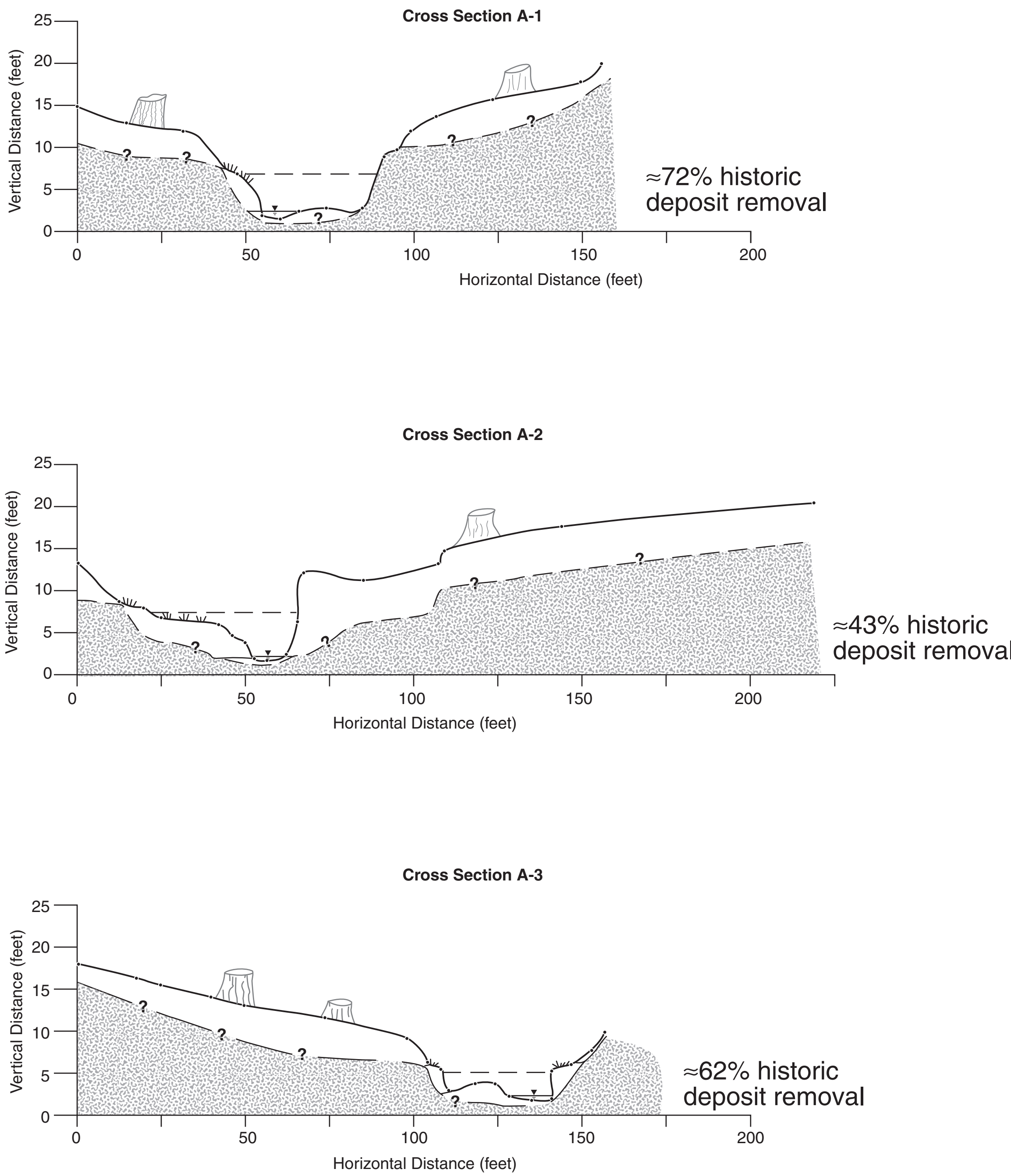


Figure 15. Surveyed cross sections A-1, A-2, and A-3. Dashed lines represent probable maximum thickness of historic aggradation used to estimate amount of material removed since time of terrace deposition.

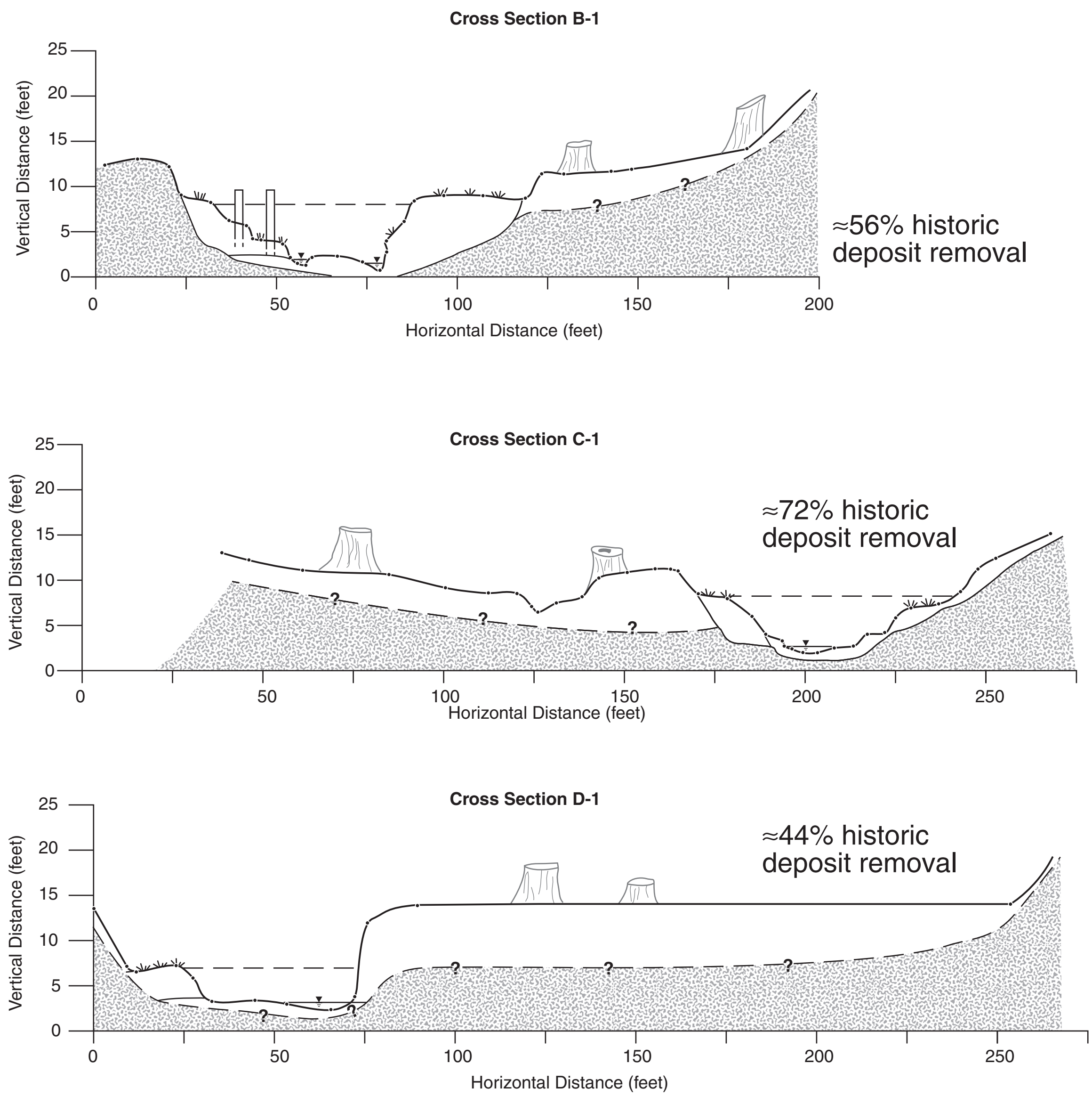


Figure 16. Surveyed cross sections B-1, C-1, and D-1. Dashed lines represent probable maximum thickness of historic aggradation used to estimate amount of material removed since time of terrace deposition.

Figure 17. Discharge Rating Curve #1 for the South Fork Noyo River above Parlin Creek. Begin Date: 2/1/01

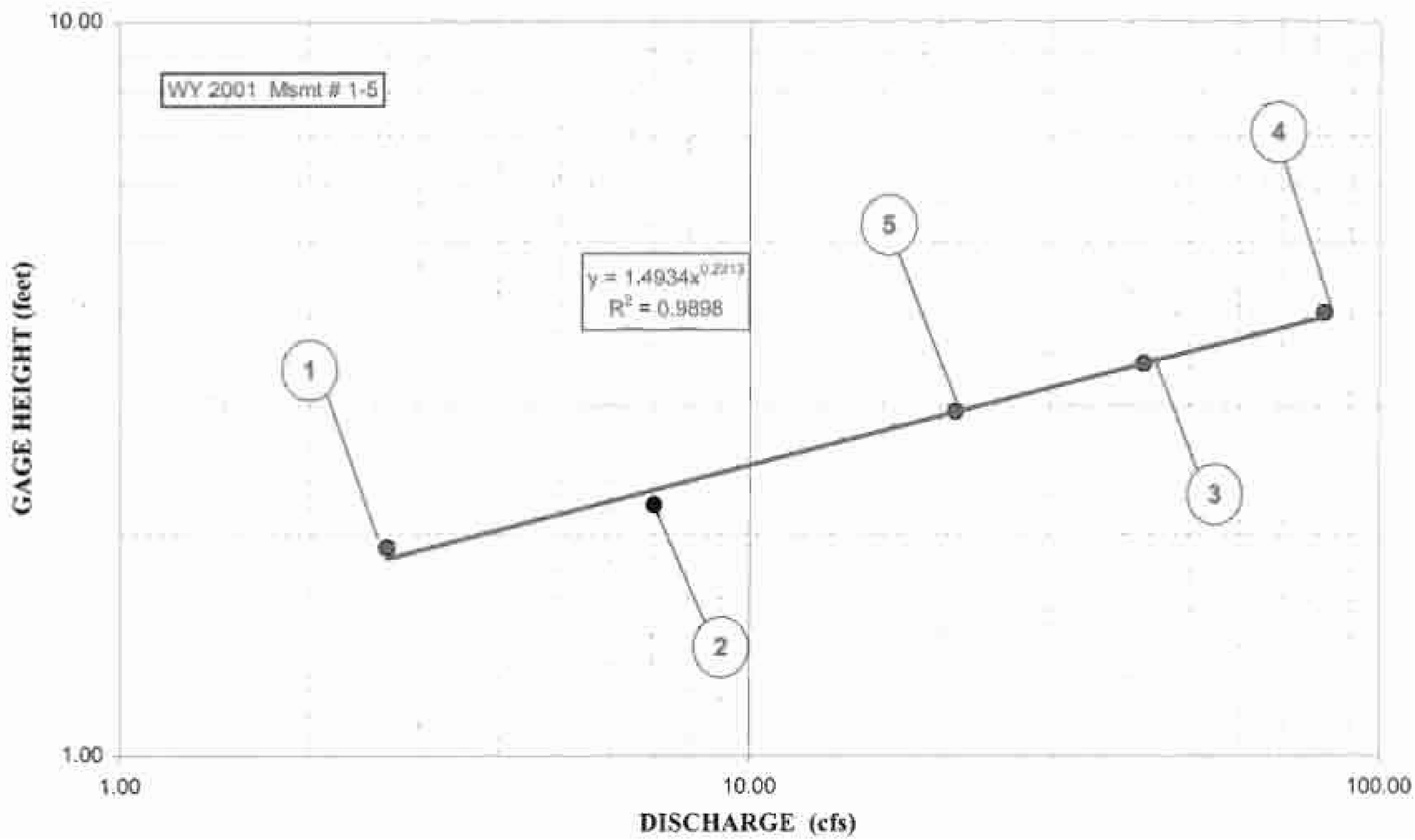


Figure 18. Discharge hydrograph for WY 2001 over the period of record South Fork Noyo River below Kass Creek.

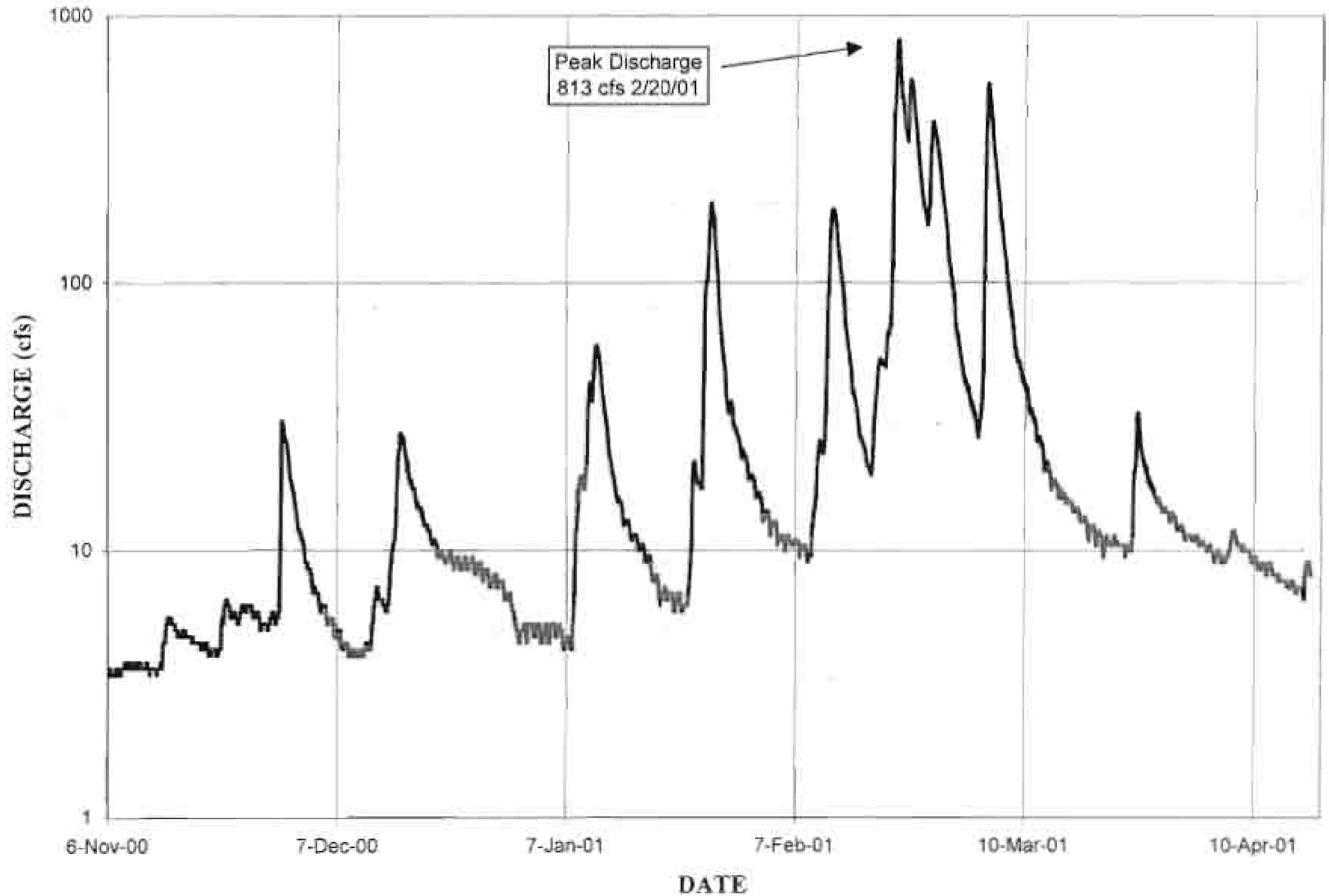
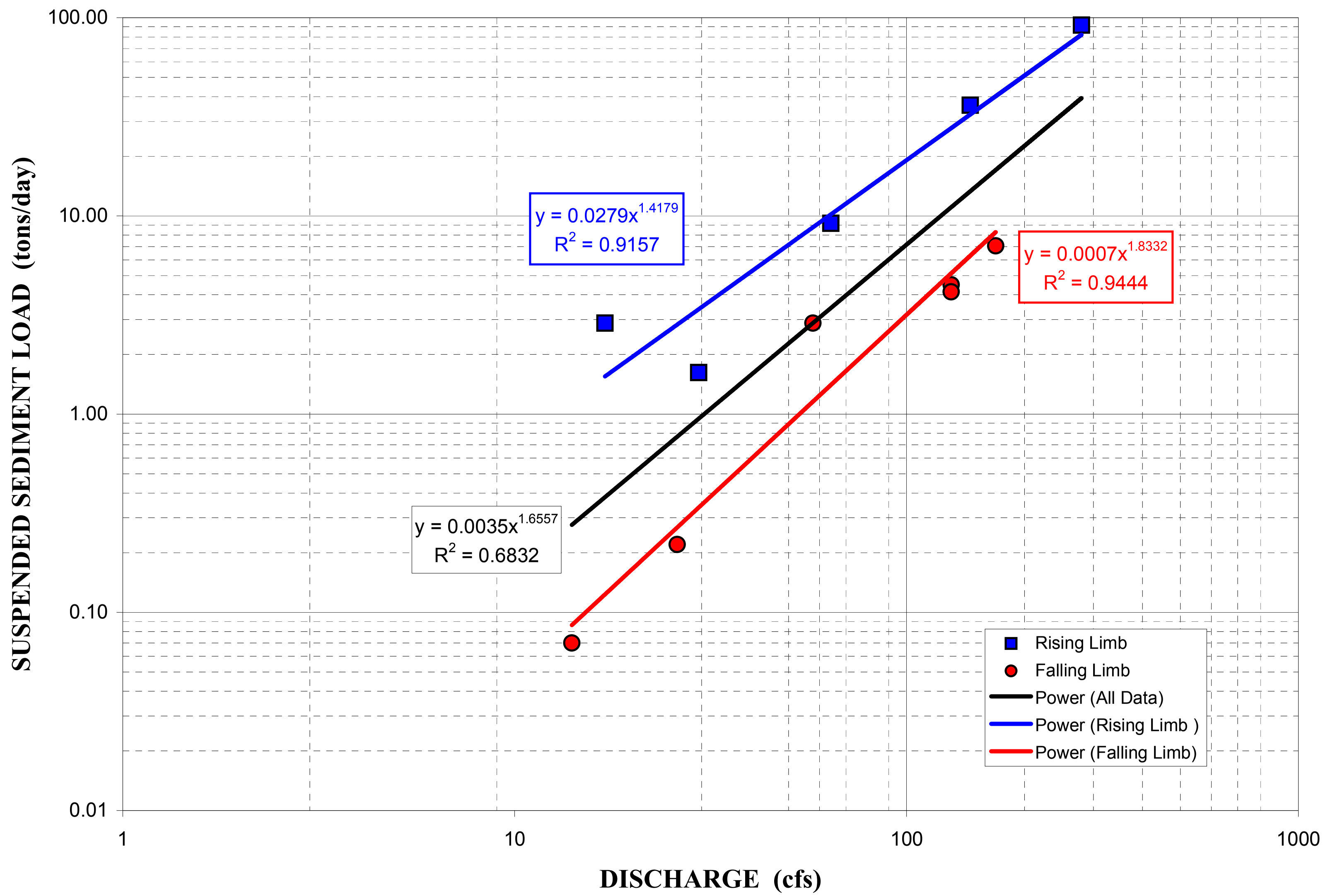


Figure 19. Analysis of WY 2001 data by hydrograph position, North Fork of the SFNR above SFNR



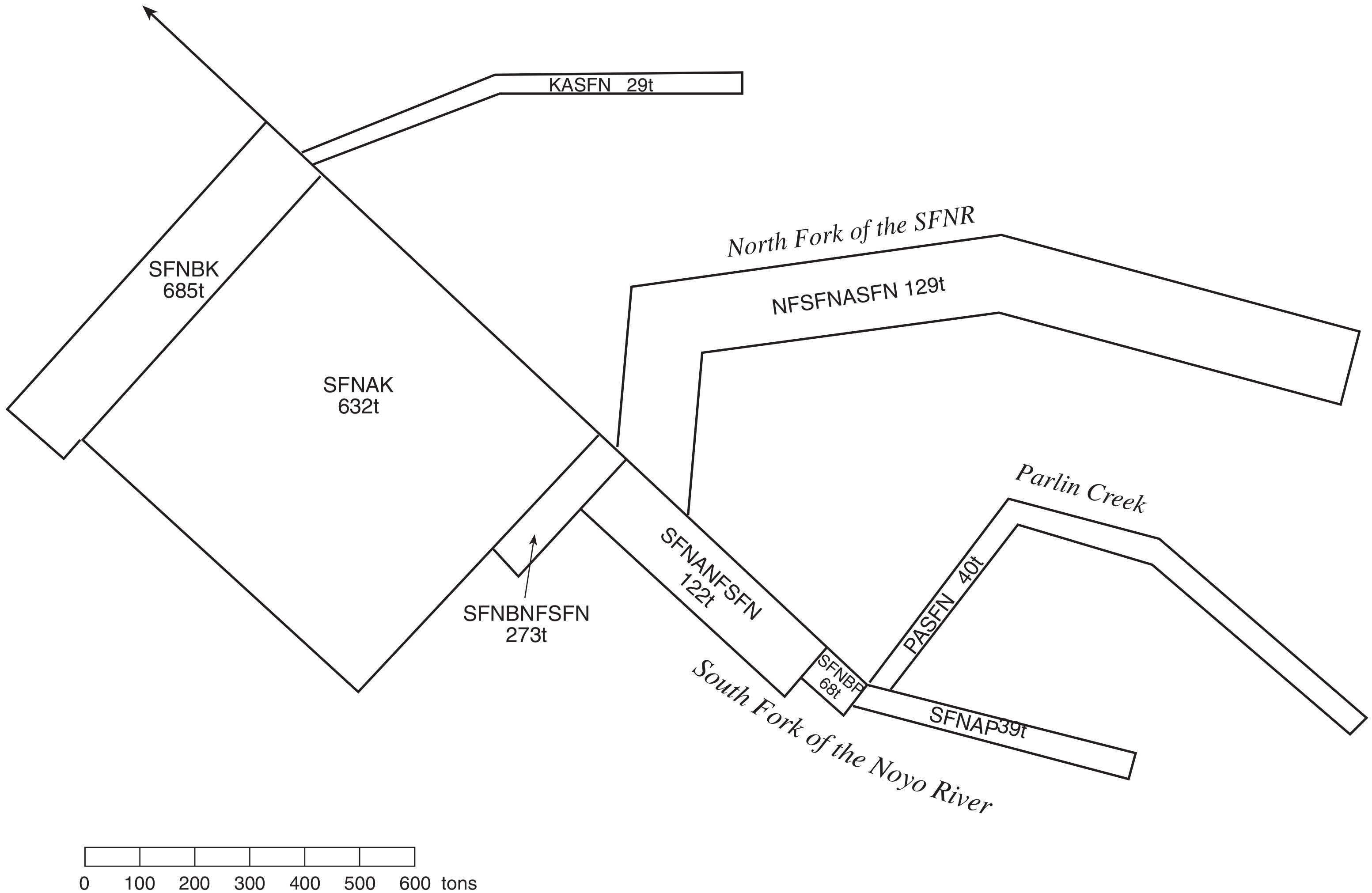


Figure 20. Box diagram showing total suspended sediment in tons for each sampling station.

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Figure 21. Suspended sediment concentration vs. turbidity rating curve, all data WY 2001, South Fork Noyo River watershed

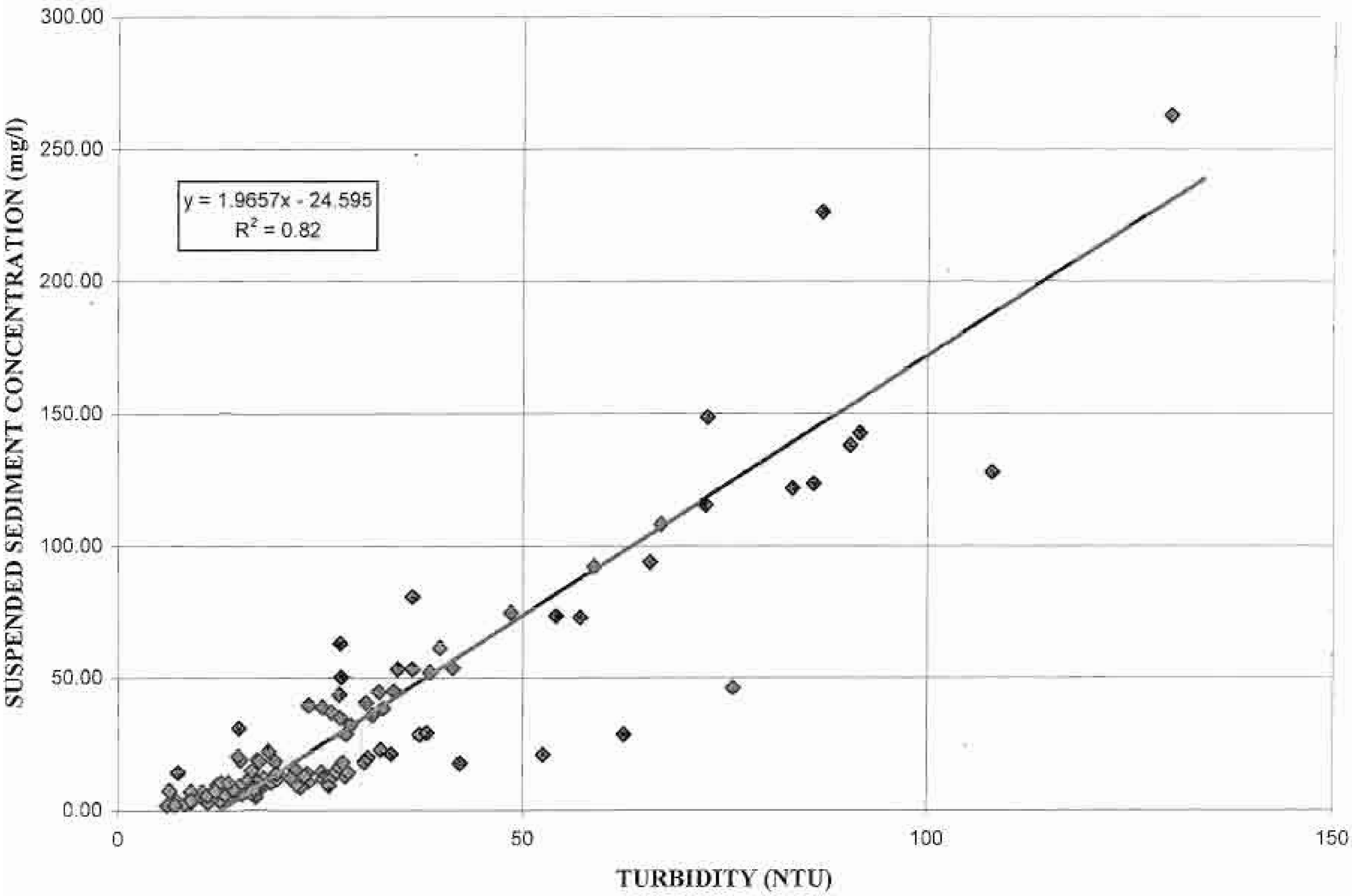


Figure 22. Turbidity vs. discharge rating curve, all data WY 2001
South Fork Noyo River watershed

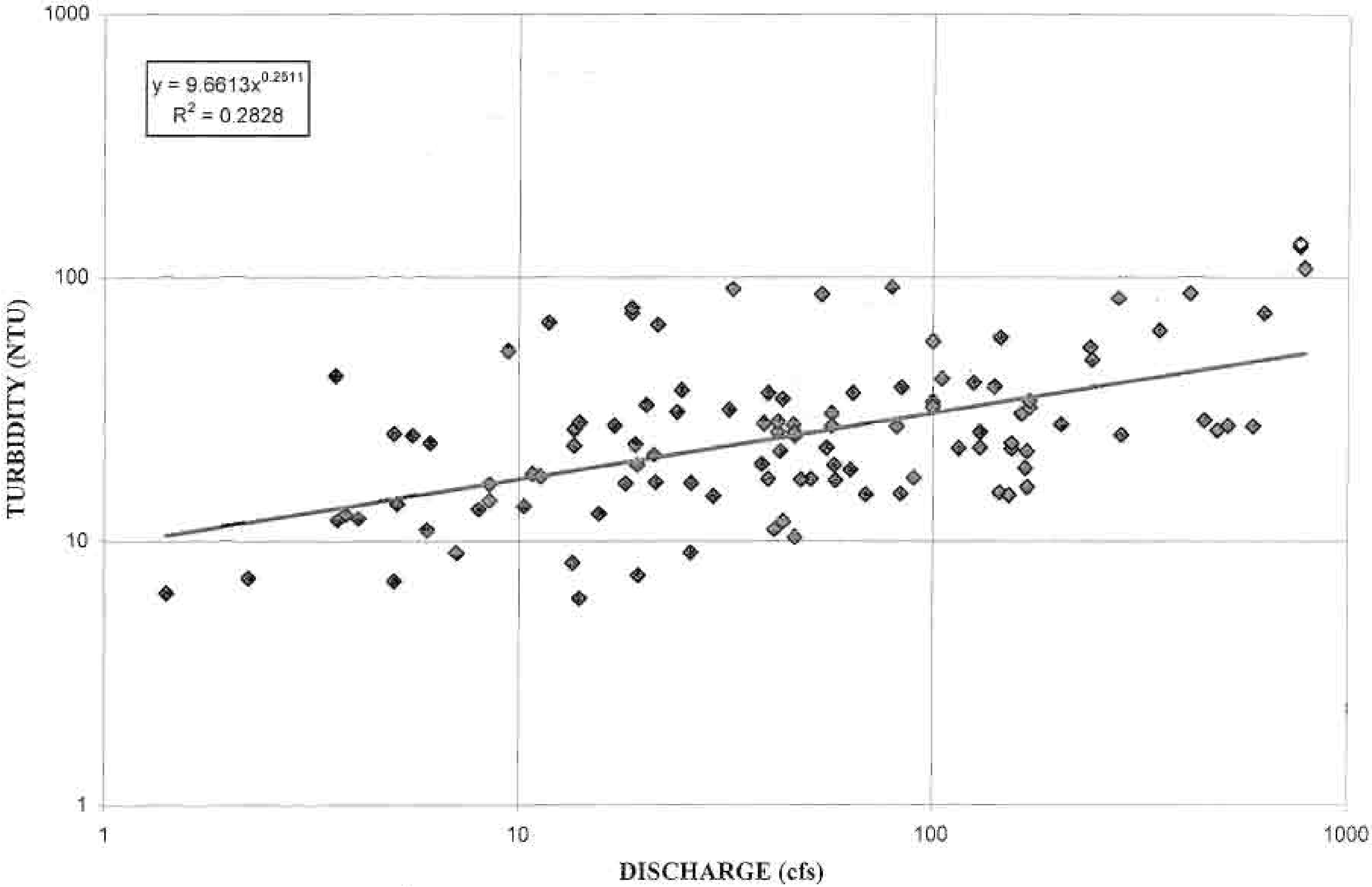


Figure 23. Suspended sediment concentration vs. discharge, WY 2001
South Fork Noyo River watershed

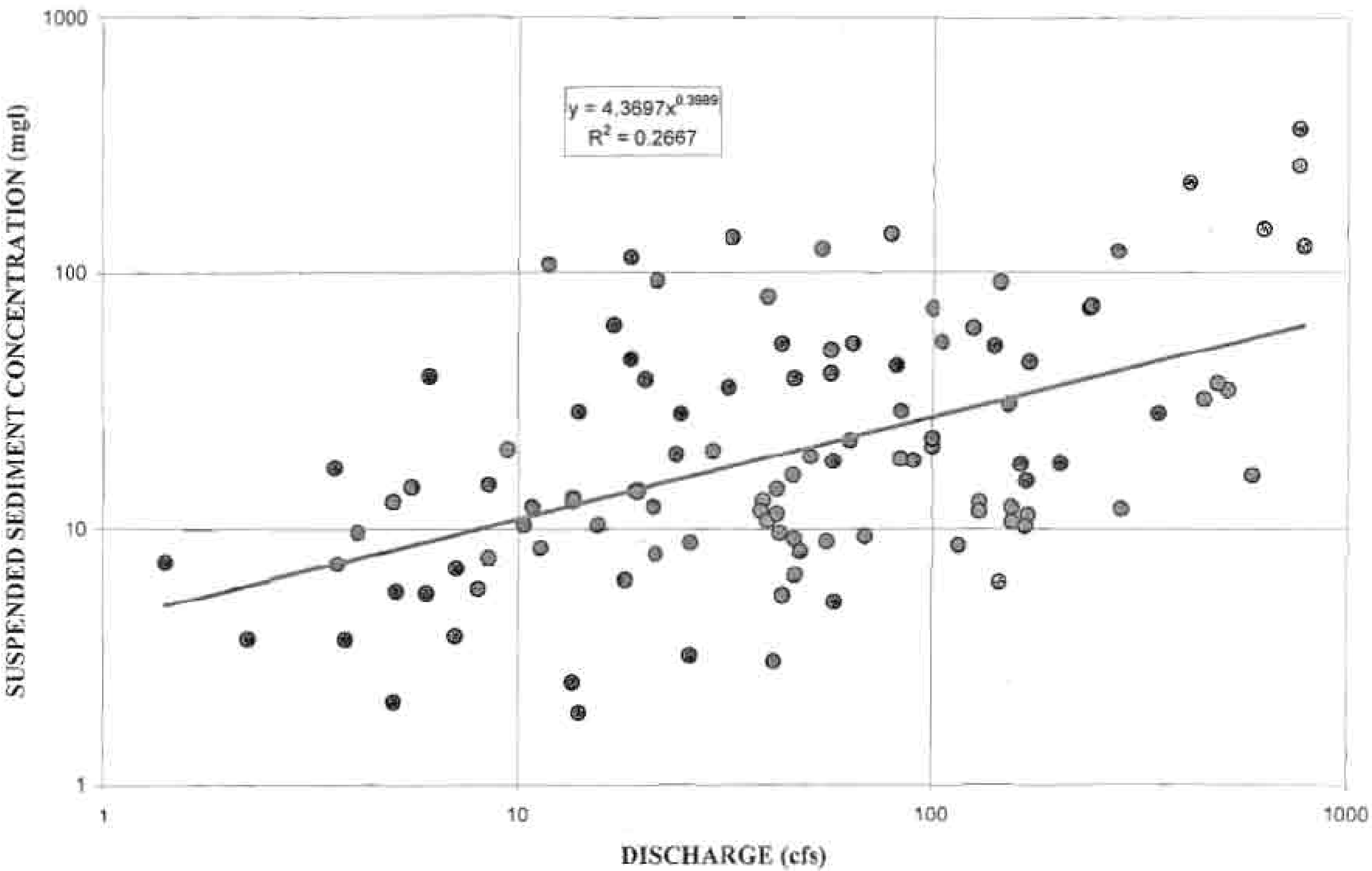


Figure 24. Suspended sediment load vs. discharge rating curve, all data WY 2001
South Fork Noyo River watershed

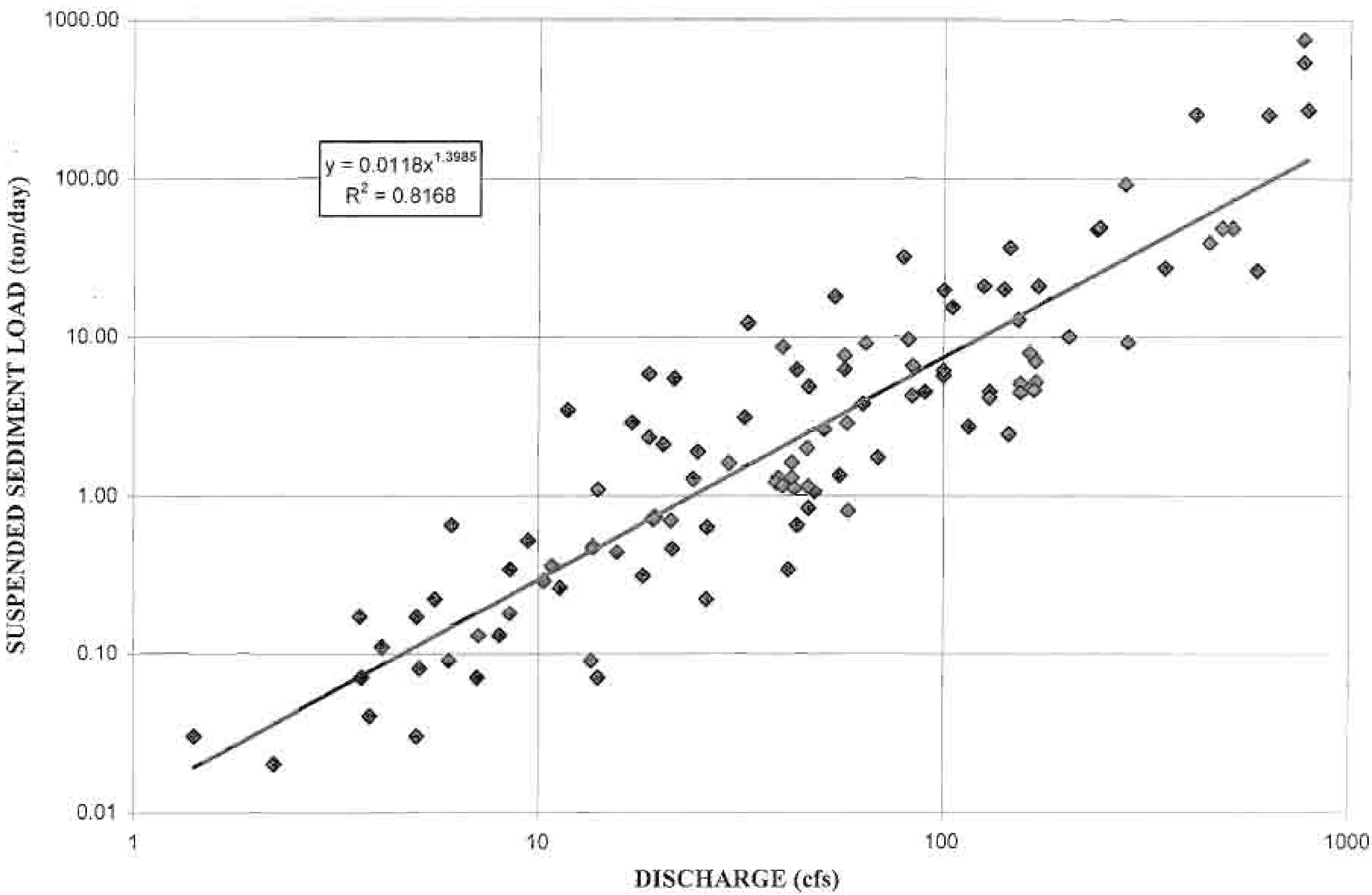


Figure 25. Suspended sediment load vs. discharge curve, data by site, WY 2001
South Fork Noyo River watershed

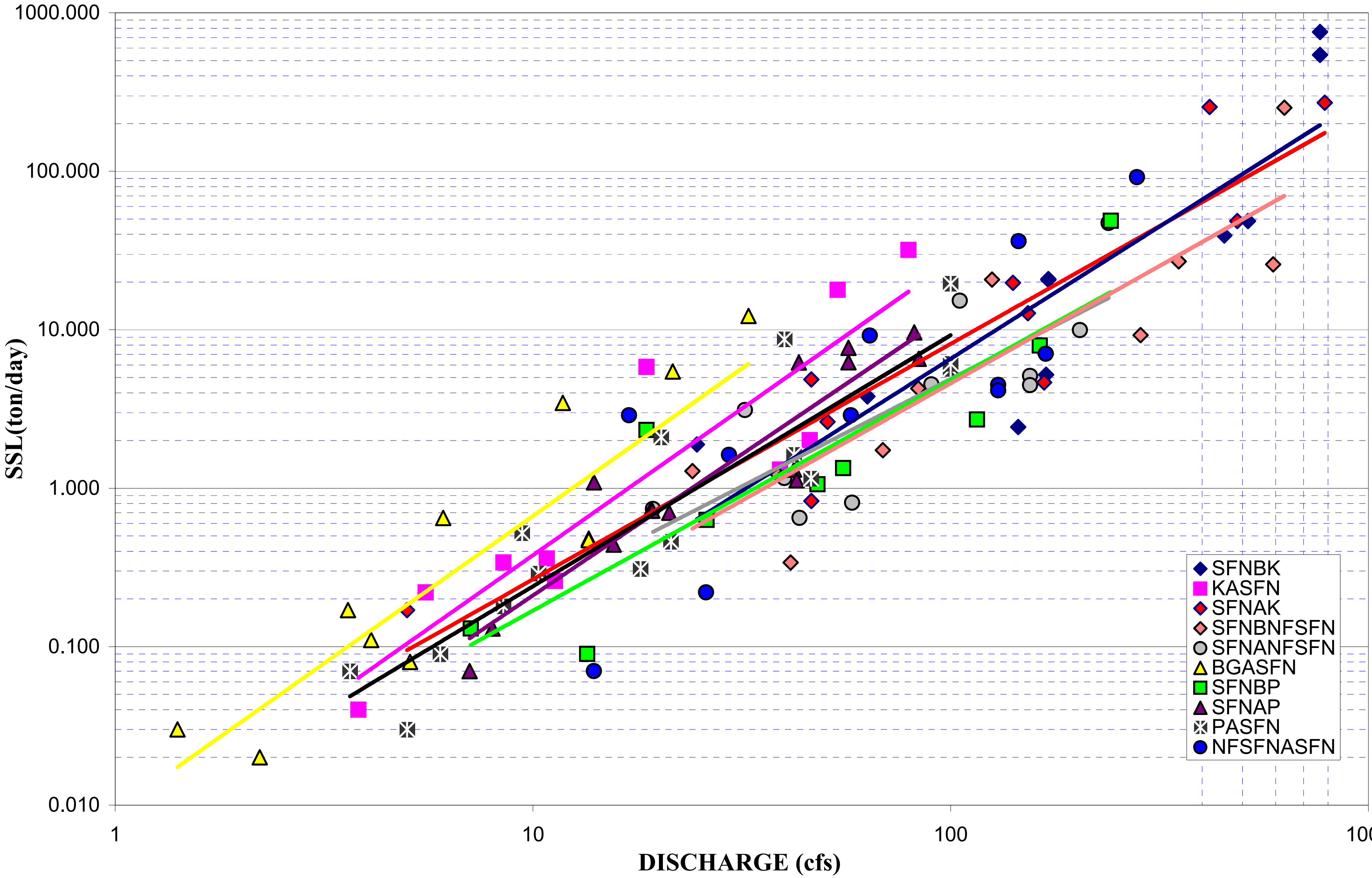


Figure 26. Suspended sediment load per watershed area vs. discharge per watershed area curve, all data
WY 2001
South Fork Noyo River watershed

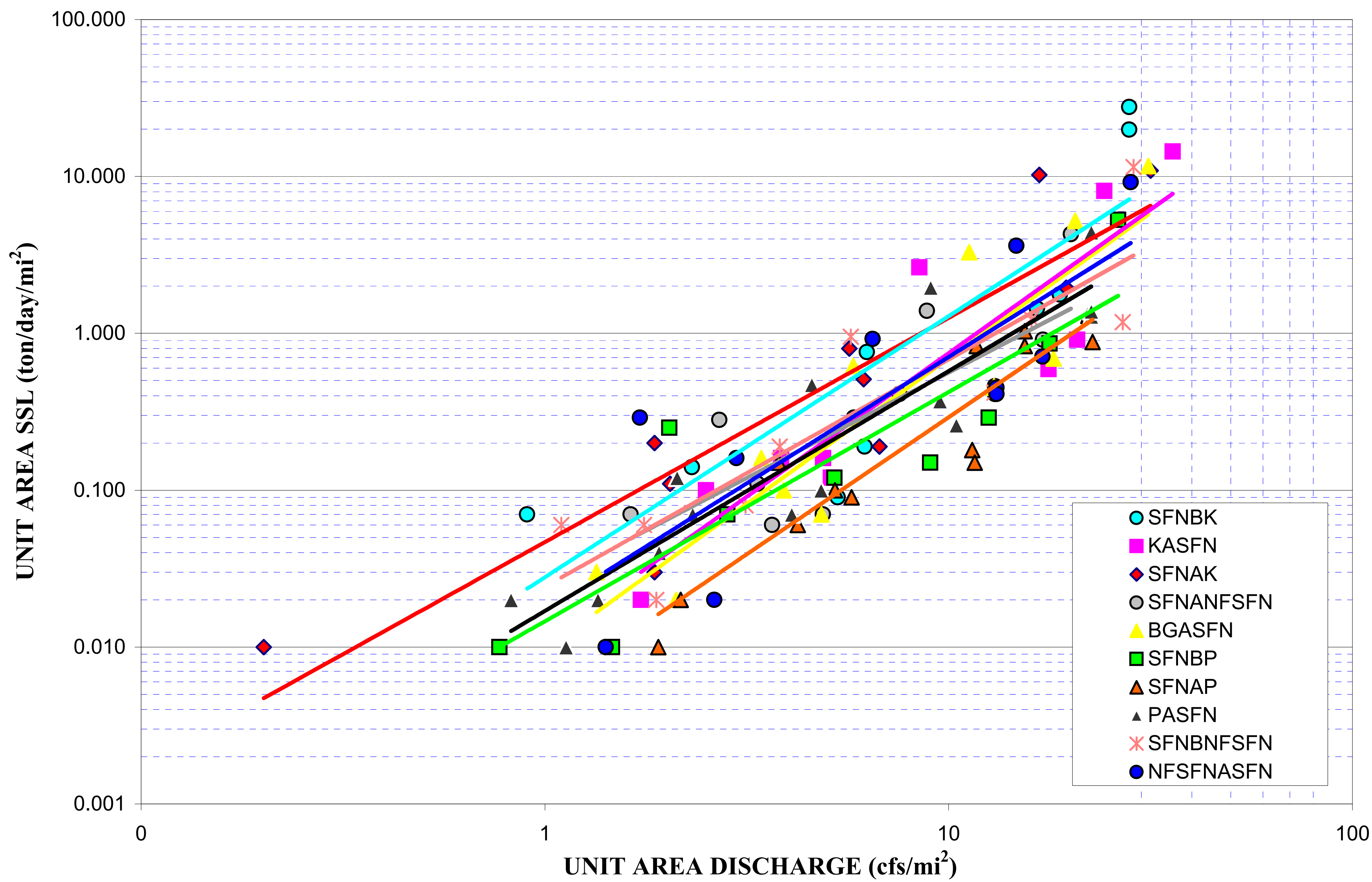


Figure. 27. Suspended sediment load vs. discharge rating curve, Regional and albion watershed data for WY2000-2001

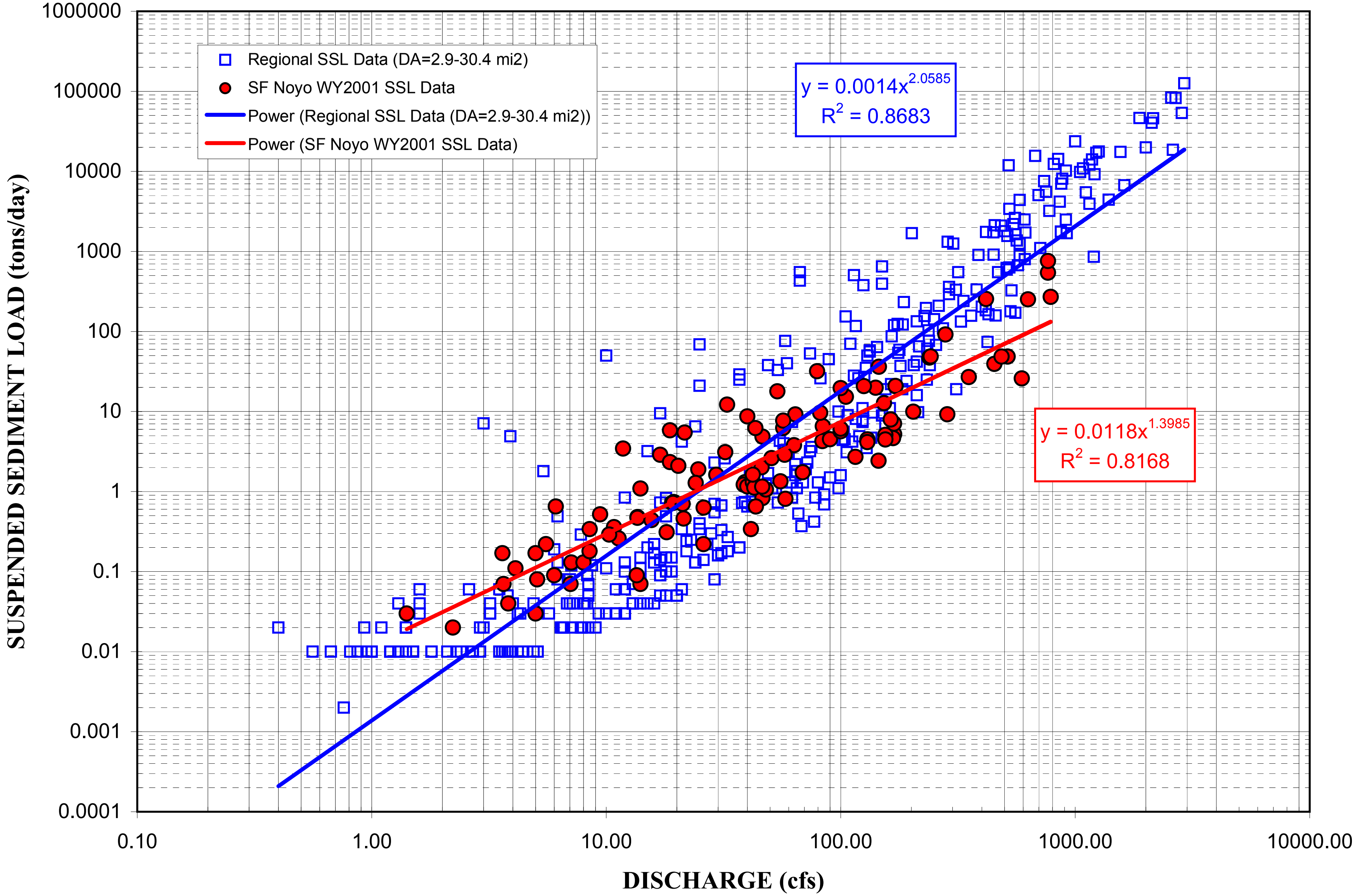


Figure 28. Drainage area vs. WY 2001 suspended sediment load, South Fork Noyo River watershed

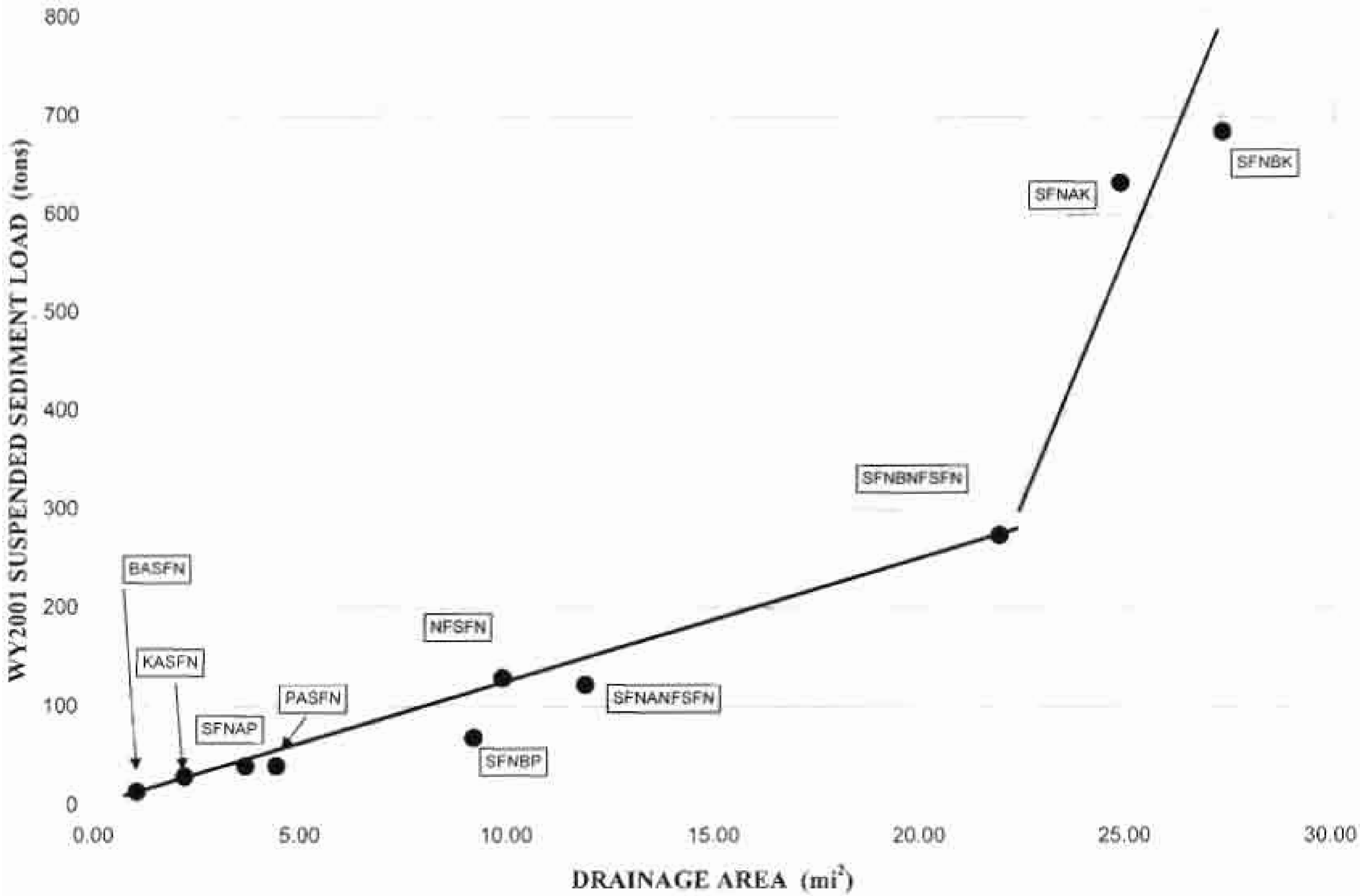


Figure 29. Relationship between drainage area and WY 2001 unit area suspended sediment load, South Fork Noyo River watershed

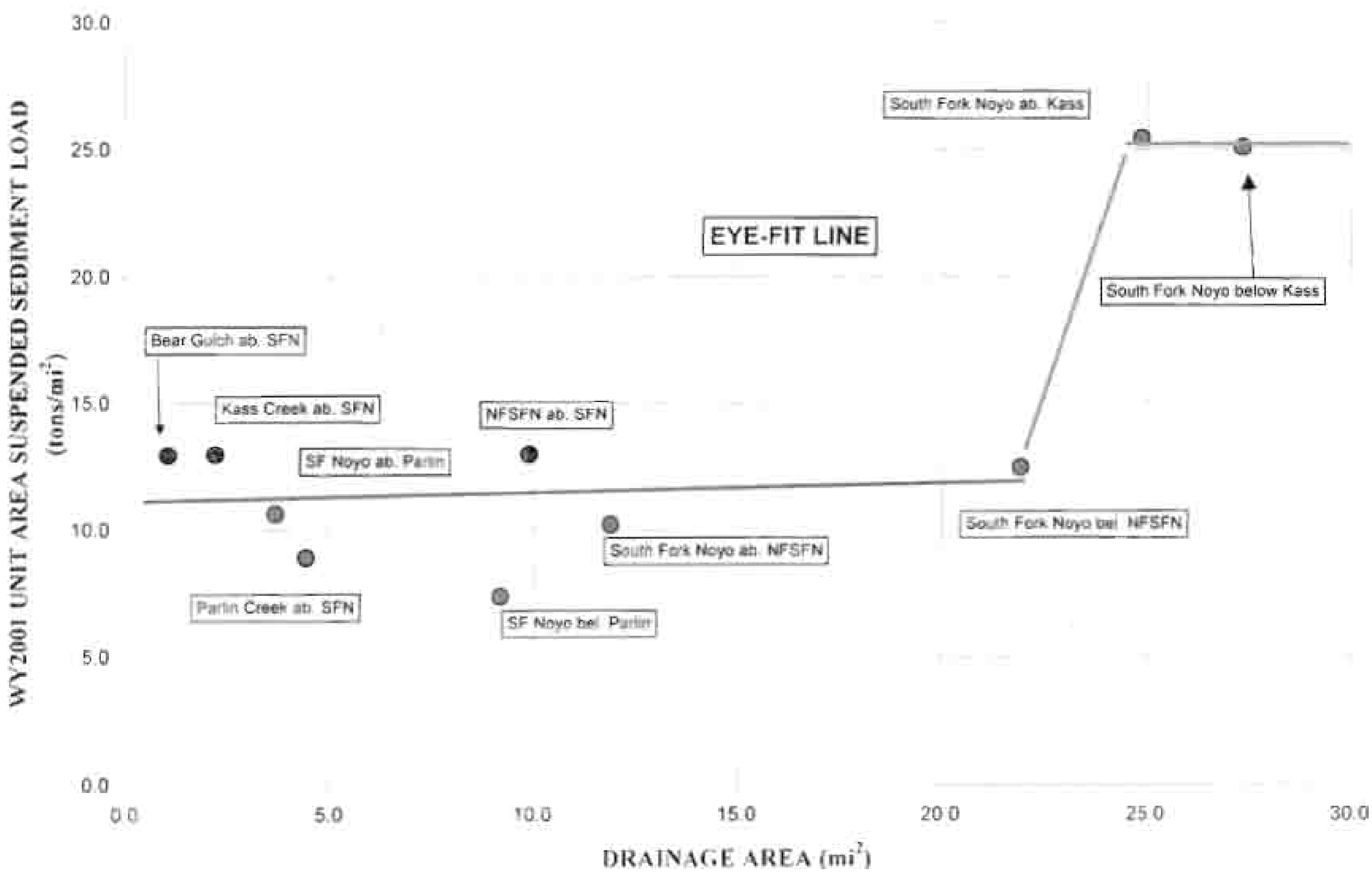
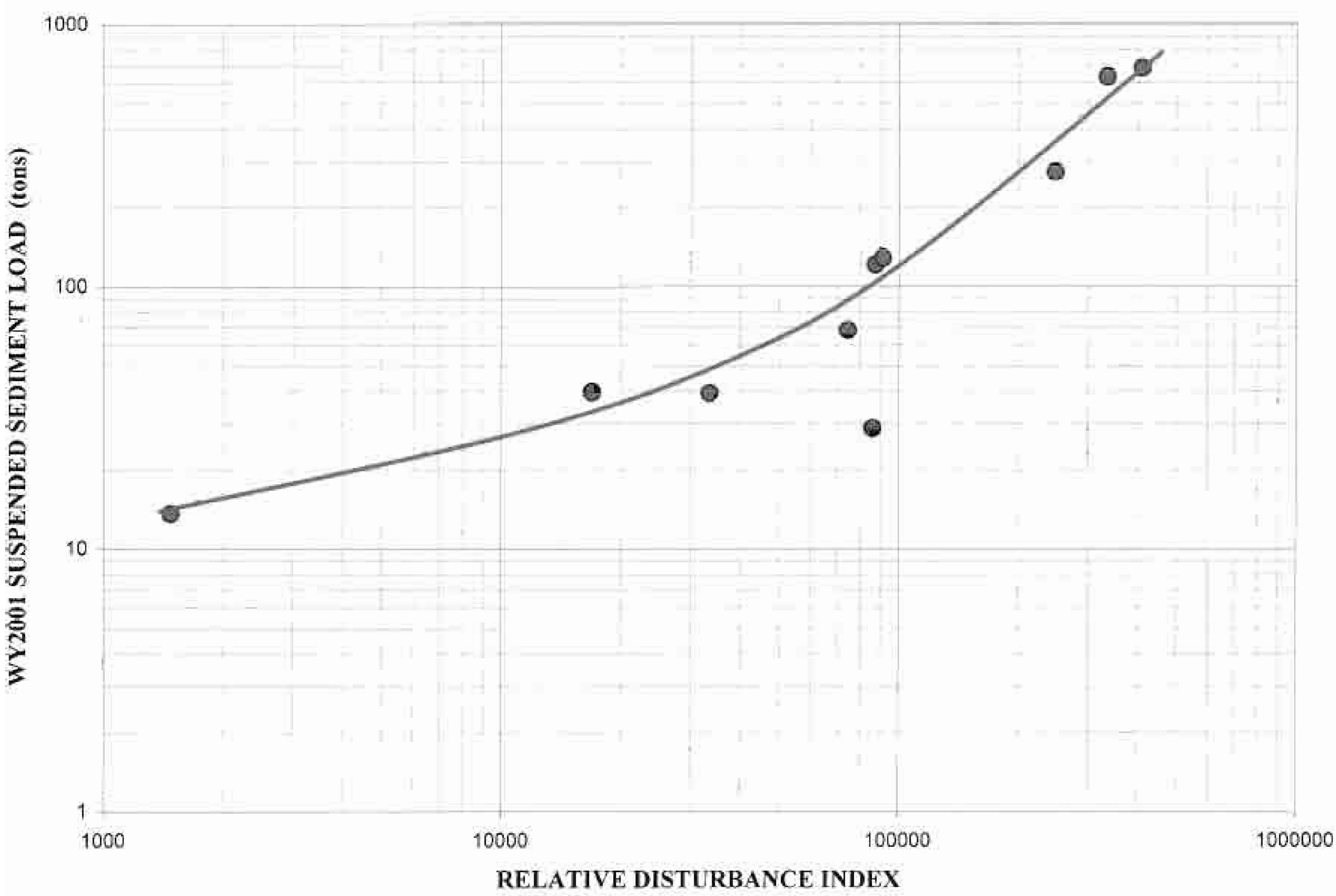


Figure 30. Relative disturbance index vs. WY 2001 suspended sediment load



Appendix A
Discharge Measurement Summary Sheet for the South Fork Noyo River Watershed, WY 2001

APPENDIX A
SOUTH FORK NOYO WATERSHED

DISCHARGE MEASUREMENT SUMMARY SHEET

WATER YEAR: 2001

Measurement Number	WY Msmt #	Date	Made By:	Width (feet)	Mean Depth (feet)	Area (ft2)	Mean Velocity (ft/sec)	Gage Height (feet)	Discharge (cfs)	Rating __1___ Shift Adj.	Percent Diff.	Method	No. of Msmt sections	Begin Time (hours)	End Time (hours)	Msmt Rating	Recorder level	Notes
LOCATION:	**SFNBK**																	
1	**2001-01**	1/11/2001	K Faucher	41.0	0.72	31.30	1.59	1.95	49.90			w	29	12:05	12:50	Good		
2	**2001-02**	1/23/2001	K Faucher	32.0	0.49	16.00	0.40	1.41	6.49			w	26	10:30	11:09	Good		
3	**2001-03**	2/20/2001	C.Pryor	48.2	4.00	193.00	4.13	4.98	798.00			c	13	14:59	16:30	fair		
4	**2001-04**	2/21/2001	C.Pryor	44.0	2.36	104.00	3.99	3.66	415.00			c	15	12:17	13:03	fair		
5	**2001-05**	3/6/2001	K Faucher	40.0	1.51	60.30	2.82	2.51	170.00			w	26	15:45	16:15	Good		
LOCATION:	**KASFN**																	
1	**2001-01**	1/23/2001	K.Faucher	5.5	0.21	1.38	0.60	1.47	0.83			w	13	11:36	12:00	f to g		
2	**2001-02**	2/17/2001	K.Faucher	7.2	0.46	3.34	1.70	1.82	5.69			w	20	18:38	19:05	good		
3	**2001-03**	2/20/2001	K.Faucher	19.0	1.14	21.60	3.67	3.23	79.30			w	21	16:49	17:20	good		
4	**2001-04**	2/21/2001	C. Pryor	9.8	1.12	9.87	3.96	2.60	39.10			w	18	13:58	14:21	f to g		
LOCATION:	**SFNSNFSFN**																	
1	**2001-01**	1/23/2001	K.Faucher	14.0	0.25	3.84	0.87	2.62	3.33			w	16	14:01	14:25	g to f		
2	**2001-02**	2/21/2001	C. Pryor	33.3	1.98	66.10	2.34	4.21	155.00			w	17	15:03	15:21	g to e		
3	**2001-03**	2/22/2000	C. Pryor	31.0	2.42	75.10	2.72	4.57	204.00			w	17	15:40	16:05	g to e		
4	**2001-04**	3/6/2001	K.Faucher	28.0	1.61	45.10	1.62	3.51	73.00			w	29	13:35	14:06	good		

DISCHARGE MEASUREMENT SUMMARY SHEET

WATER YEAR: 2001

Measurement Number	WY Msmt #	Date	Made By:	Width (feet)	Mean Depth (feet)	Area (ft2)	Mean Velocity (ft/sec)	Gage Height (feet)	Discharge (cfs)	Rating __1__ Shift Adj.	Percent Diff.	Method	No. of Msmt sections	Begin Time (hours)	End Time (hours)	Msmt Rating	Recorder level	Notes
LOCATION:	**NFSFNASFN**																	
1	**2001-01**	1/23/2001	K.Faucher	15.5	0.39	6.60	0.54	1.19	3.54			w	17	15:11	15:41	g to f		
2	**2001-02**	2/21/2001	C.Pryor	28.0	1.72	48.10	2.70	2.50	130.00			w	20	15:58	16:21	good		
3	**2001-03**	3/6/2001	K. Faucher	33.0	0.86	28.50	2.15	2.06	61.30			w	34	7:51	8:38	good		
4	**2001-04**	3/8/2001	K. Faucher	32.0	0.55	17.50	1.41	1.66	24.60			w	22	16:05	16:45	good		
LOCATION:	**SFNAP**																	
1	**2001-01**	2/1/2001	K.Faucher	10.0	0.47	4.98	0.53	1.92	2.66			w	21	14:18	14:48	good		
2	**2001-02**	2/17/2001	K.Faucher	10.0	0.47	4.65	1.52	2.19	7.05			w	21	15:40	16:10	g to f		
3	**2001-03**	2/21/2001	C.Pryor	12.7	1.06	13.40	3.15	3.42	42.20			w	18	18:30	18:46	good		
4	**2001-04**	2/22/2001	C.Pryor	16.5	1.77	29.10	2.81	4.01	81.80			w	17	13:49	14:04	good		
5	**2001-05**	3/6/2001	K.Faucher	12.5	0.96	12.00	1.74	2.94	21.20			w	26	11:38	12:13	good		
LOCATION:	**PASFN**																	
1	**2001-01**	2/1/2001	K.Faucher	12.0	0.29	3.57	0.81	1.83	2.90			w	25	15:50	16:25	good		
2	**2001-02**	2/21/2001	C.Pryor	19.1	0.78	14.90	2.83	2.59	42.20			w	19	17:39	18:04	fair		
3	**2001-03**	3/6/2001	K.Faucher	13.5	0.68	9.22	2.32	2.39	21.40			w	28	10:40	11:07	good		
4	**2001-04**	3/8/2001	K.Faucher	10.5	0.61	6.40	1.61	2.10	10.30			w	26	17:48	18:15	good		

Appendix B
Suspended Sediment Summary Sheet for the South Fork Noyo River Watershed, WY 2001

APPENDIX B

SOUTH FORK NOYO RIVER WATERSHED

Suspended Sediment Summary WY 2001

Site	Date	Msmt No.	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	WSA	Q/WSA cfs/(mi^2)	SSL (ton/day)	SSLPA (ton/day/mi^2)	Note
SFNBK	1/10/2001	2	18.6	22.22	2.04	63.2	27.32	2.3	3.79	0.14	Q ESTIMATED FROM RATING
SFNBK	1/25/2001	3	37.2	28.31	1.72	24.7	27.32	0.9	1.89	0.07	Q ESTIMATED FROM RATING
SFNBK	2/20/2001	5	32.2	44.70	2.52	171.4	27.32	6.3	20.66	0.76	Q ESTIMATED FROM RATING
SFNBK	2/20/2001	6	34.0	45.10	2.52	171.4	27.32	6.3	20.85	0.76	Q ESTIMATED FROM RATING
SFNBK	2/20/2001	7	130.0	262.70	4.89	765.7	27.32	28.0	542.50	19.86	Q ESTIMATED FROM RATING
SFNBK	2/20/2001	8	134.0	367.10	4.89	765.7	27.32	28.0	758.10	27.75	Q ESTIMATED FROM RATING
SFNBK	2/21/2001	9	28.7	32.20	3.75	452.2	27.32	16.6	39.27	1.44	Q ESTIMATED FROM RATING
SFNBK	2/22/2001	10	27.4	34.90	4.00	515.0	27.32	18.9	48.47	1.77	Q ESTIMATED FROM RATING
SFNBK	2/24/2001	11	15.3	6.20	2.42	145.1	27.32	5.3	2.43	0.09	Q ESTIMATED FROM RATING
SFNBK	3/6/2001	12	16.0	11.40	2.51	169.2	27.32	6.2	5.20	0.19	Q ESTIMATED FROM RATING
KASFN	1/8/2001	1	12.6	3.68	1.69	3.8	2.21	1.7	0.04	0.02	ESTIMATED SYNTHETIC Q
KASFN	2/17/2001	3	25.1	14.60	1.82	5.5	2.21	2.5	0.22	0.10	ESTIMATED SYNTHETIC Q
KASFN	2/19/2001	4	18.0	12.20	2.04	10.8	2.21	4.9	0.36	0.16	ESTIMATED SYNTHETIC Q
KASFN	2/20/2001	5	72.6	115.30	2.27	18.7	2.21	8.5	5.82	2.63	ESTIMATED SYNTHETIC Q
KASFN	2/20/2001	6	85.9	123.40	2.86	53.7	2.21	24.3	17.87	8.09	ESTIMATED SYNTHETIC Q
KASFN	2/20/2001	7	91.6	142.40	3.29	79.3	2.21	35.9	31.88	14.42	Q MEASURED
KASFN	2/21/2001	8	28.0	12.90	2.58	39.1	2.21	17.7	1.31	0.59	Q MEASURED
KASFN	2/22/2001	9	27.6	16.20	2.72	46.0	2.21	20.8	2.01	0.91	ESTIMATED SYNTHETIC Q
KASFN	3/6/2001	10	17.6	8.46	2.06	11.3	2.21	5.1	0.26	0.12	ESTIMATED SYNTHETIC Q
KASFN	3/7/2001	11	16.5	15.00	1.95	8.5	2.21	3.8	0.34	0.16	ESTIMATED SYNTHETIC Q
SFNAK	1/10/2001	3	17.2	19.18	1.18	50.7	24.84	2.0	2.62	0.11	ESTIMATED SYNTHETIC Q
SFNAK	1/25/2001	4	25.5	12.81	0.98	5.0	24.84	0.2	0.17	0.01	ESTIMATED SYNTHETIC Q
SFNAK	2/19/2001	5	10.4	6.60	1.35	46.4	24.84	1.9	0.83	0.03	ESTIMATED SYNTHETIC Q
SFNAK	2/20/2001	6	38.5	52.10	1.78	141.0	24.84	5.7	19.81	0.80	ESTIMATED SYNTHETIC Q
SFNAK	2/20/2001	7	86.9	226.10	2.97	416.8	24.84	16.8	254.14	10.23	ESTIMATED SYNTHETIC Q
SFNAK	2/20/2001	9	108.0	127.70	3.98	786.3	24.84	31.7	270.79	10.90	ESTIMATED SYNTHETIC Q
SFNAK	2/21/2001	10	25.2	38.80	2.68	46.4	24.84	1.9	4.86	0.20	ESTIMATED SYNTHETIC Q
SFNAK	2/22/2001	11	26.3	37.00	3.06	485.6	24.84	19.5	48.46	1.95	ESTIMATED SYNTHETIC Q
SFNAK	2/24/2001	12	14.9	30.80	2.64	153.0	24.84	6.2	12.71	0.51	ESTIMATED SYNTHETIC Q
SFNAK	3/6/2001	13	18.9	10.30	1.71	167.3	24.84	6.7	4.65	0.19	ESTIMATED SYNTHETIC Q
SFNBNFSFN	1/10/2001	2	19.6	11.76	2.31	38.6	21.93	1.8	1.22	0.06	ESTIMATED SYNTHETIC Q
SFNBNFSFN	1/25/2001	3	30.8	19.74	2.18	24.1	21.93	1.1	1.28	0.06	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/19/2001	4	11.1	3.02	2.33	41.4	21.93	1.9	0.34	0.02	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/20/2001	5	39.7	61.26	2.67	125.6	21.93	5.7	20.75	0.95	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/20/2001	6	62.5	28.41	3.03	351.8	21.93	16.0	26.95	1.23	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/20/2001	7	72.8	148.46	3.30	629.0	21.93	28.68217054	251.85	11.48	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/21/2001	8	25.3	12.02	3.01	285.0	21.93	13.0	9.24	0.42	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/22/2001	9	27.2	16.21	3.23	592.0	21.93	27.0	25.88	1.18	ESTIMATED SYNTHETIC Q
SFNBNFSFN	2/24/2001	10	15.0	9.40	2.48	68.8	21.93	3.1	1.74	0.08	ESTIMATED SYNTHETIC Q
SFNBNFSFN	3/6/2001	11	15.1	18.90	2.54	83.6	21.93	3.8	4.26	0.19	ESTIMATED SYNTHETIC Q
SFNANFSFN	1/10/2001	2	17.2	10.79	3.20	40.0	11.90	3.4	1.16	0.11	Q ESTIMATED USING RATING
SFNANFSFN	1/25/2001	3	31.4	35.86	3.12	32.2	11.90	2.7	3.11	0.28	Q ESTIMATED USING RATING
SFNANFSFN	2/17/2001	4	7.4	14.10	2.94	19.4	11.90	1.6	0.74	0.07	Q ESTIMATED USING RATING
SFNANFSFN	2/19/2001	5	11.9	5.50	3.25	43.5	11.90	3.7	0.65	0.06	Q ESTIMATED USING RATING
SFNANFSFN	2/20/2001	6	41.3	53.80	3.76	105.2	11.90	8.8	15.26	1.39	Q ESTIMATED USING RATING
SFNANFSFN	2/20/2001	8	54.1	73.20	4.99	239.1	11.90	20.1	47.20	4.29	Q ESTIMATED USING RATING
SFNANFSFN	2/21/2001	9	22.4	12.20	4.20	155.0	11.90	13.0	5.10	0.46	Q MEASURED
SFNANFSFN	2/22/2001	10	27.7	18.10	4.57	204.0	11.90	17.1	9.96	0.91	Q MEASURED
SFNANFSFN	2/24/2001	11	17.0	5.20	3.43	58.1	11.90	4.9	0.81	0.07	Q ESTIMATED USING RATING
SFNANFSFN	3/5/2001	12	23.5	10.70	4.21	155.0	11.90	13.0	4.47	0.41	Q ESTIMATED USING RATING
SFNANFSFN	3/6/2001	13	17.4	18.60	3.59	90.0	11.90	7.6	4.51	0.41	Q ESTIMATED USING RATING

Appendix B. (Cont.)

Site	Date	Msmt No.	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	WSA	Q/WSA cfs/(mi^2)	SSL (ton/day)	SSLPA (ton/day/mi^2)	Note
NFSFASFN	1/10/2001	3	14.8	20.33	1.72	29.5	9.89	3.0	1.62	0.16	Q ESTIMATED USING RATING
NFSFASFN	1/25/2001	4	27.4	62.86	1.51	17.0	9.89	1.7	2.88	0.29	Q ESTIMATED USING RATING
NFSFASFN	2/17/2001	5	6.0	1.90	1.45	14.0	9.89	1.4	0.07	0.01	Q ESTIMATED USING RATING
NFSFASFN	2/19/2001	6	9.0	3.20	1.67	26.0	9.89	2.6	0.22	0.02	Q ESTIMATED USING RATING
NFSFASFN	2/20/2001	7	36.3	53.10	2.08	64.1	9.89	6.5	9.18	0.92	Q ESTIMATED USING RATING
NFSFASFN	2/20/2001	8	58.8	92.20	2.58	145.5	9.89	14.7	36.18	3.62	Q ESTIMATED USING RATING
NFSFASFN	2/20/2001	9	83.3	121.70	3.09	279.6	9.89	28.3	91.77	9.19	Q ESTIMATED USING RATING
NFSFASFN	2/21/2001	11	25.9	12.80	2.50	130.0	9.89	13.1	4.49	0.45	Q MEASURED
NFSFASFN	2/22/2001	12	21.9	15.50	2.69	168.9	9.89	17.1	7.06	0.71	Q ESTIMATED USING RATING
NFSFASFN	3/5/2001	14	22.6	11.80	2.50	130.0	9.89	13.1	4.14	0.41	Q ESTIMATED USING RATING
NFSFASFN	3/6/2001	15	19.4	18.50	2.02	57.7	9.89	5.8	2.88	0.29	Q MEASURED
BGASFN	1/8/2001	1	6.3	7.42	1.22	1.4	1.05	1.3	0.03	0.03	Q ESTIMATED USING RATING
BGASFN	1/25/2001	2	42.2	17.40	1.53	3.6	1.05	3.4	0.17	0.16	Q ESTIMATED USING RATING
BGASFN	2/17/2001	3	7.2	3.70	1.36	2.2	1.05	2.1	0.02	0.02	Q ESTIMATED USING RATING
BGASFN	2/19/2001	4	12.2	9.69	1.58	4.1	1.05	3.9	0.11	0.10	Q ESTIMATED USING RATING
BGASFN	2/20/2001	5	67.1	108.31	2.10	11.8	1.05	11.2	3.45	3.28	Q ESTIMATED USING RATING
BGASFN	2/20/2001	6	65.7	93.67	2.46	21.6	1.05	20.6	5.46	5.20	Q ESTIMATED USING RATING
BGASFN	2/20/2001	7	90.4	137.90	2.77	32.8	1.05	31.2	12.20	11.62	Q ESTIMATED USING RATING
BGASFN	2/21/2001	8	26.5	13.21	2.17	13.6	1.05	13.0	0.48	0.46	Q MEASURED
BGASFN	2/22/2001	9	23.3	14.05	2.38	19.1	1.05	18.2	0.72	0.69	Q ESTIMATED USING RATING
BGASFN	2/24/2001	10	13.8	5.70	1.67	5.1	1.05	4.8	0.08	0.07	Q ESTIMATED USING RATING
BGASFN	3/5/2001	11	23.0	12.90	2.17	13.6	1.05	13.0	0.47	0.45	Q ESTIMATED USING RATING
BGASFN	3/6/2001	12	23.5	39.60	1.75	6.1	1.05	5.8	0.65	0.62	Q MEASURED
SFNBP	1/8/2001	1	9.0	7.02	1.68	7.1	9.20	0.8	0.13	0.01	ESTIMATED FROM SYNTHETIC Q
SFNBP	1/10/2001	2	16.6	8.90	1.02	26.1	9.20	2.8	0.63	0.07	ESTIMATED FROM SYNTHETIC Q
SFNBP	1/25/2001	3	76.0	46.22	2.17	18.7	9.20	2.0	2.33	0.25	ESTIMATED FROM SYNTHETIC Q
SFNBP	2/17/2001	4	8.3	2.50	1.95	13.5	9.20	1.5	0.09	0.01	ESTIMATED FROM SYNTHETIC Q
SFNBP	2/20/2001	5	48.5	74.60	3.55	242.1	9.20	26.3	48.70	5.29	ESTIMATED FROM SYNTHETIC Q
SFNBP	2/22/2001	6	30.4	18.00	3.38	163.5	9.20	17.8	7.94	0.86	ESTIMATED FROM SYNTHETIC Q
SFNBP	2/24/2001	7	17.1	8.20	2.44	48.0	9.20	5.2	1.06	0.12	ESTIMATED FROM SYNTHETIC Q
SFNBP	3/5/2001	8	22.5	8.68	3.02	115.6	9.20	12.6	2.71	0.29	ESTIMATED FROM SYNTHETIC Q
SFNBP	3/6/2001	9	22.6	9.00	2.56	55.4	9.20	6.0	1.34	0.15	ESTIMATED FROM SYNTHETIC Q
SFNAP	1/10/2001	2	13.2	5.85	2.25	8.0	3.69	2.2	0.13	0.02	Q ESTIMATED FROM RATING
SFNAP	1/25/2001	3	28.1	28.75	2.60	14.0	3.69	3.8	1.09	0.15	Q ESTIMATED FROM RATING
SFNAP	2/17/2001	4	9.1	3.80	2.19	7.1	3.69	1.9	0.07	0.01	Q MEASURED
SFNAP	2/19/2001	5	12.7	10.40	2.68	15.6	3.69	4.2	0.44	0.06	Q ESTIMATED FROM RATING
SFNAP	2/20/2001	6	34.5	53.10	3.45	43.3	3.69	11.7	6.20	0.83	Q ESTIMATED FROM RATING
SFNAP	2/20/2001	7	30.6	40.60	3.73	56.9	3.69	15.4	6.23	0.83	Q ESTIMATED FROM RATING
SFNAP	2/20/2001	8	27.5	50.10	3.73	56.9	3.69	15.4	7.69	1.03	Q ESTIMATED FROM RATING
SFNAP	2/20/2001	9	38.1	29.00	4.04	83.9	3.69	22.7	6.56	0.88	Q ESTIMATED FROM RATING
SFNAP	2/21/2001	10	26.1	11.50	3.42	42.2	3.69	11.4	1.31	0.18	Q MEASURED
SFNAP	2/22/2001	11	27.3	43.60	4.01	81.8	3.69	22.2	9.62	1.29	Q MEASURED
SFNAP	2/24/2001	12	19.5	13.90	2.86	19.3	3.69	5.2	0.72	0.10	Q ESTIMATED FROM RATING
SFNAP	3/5/2001	13	22.0	9.67	3.44	42.8	3.69	11.6	1.12	0.15	Q ESTIMATED FROM RATING
SFNAP	3/6/2001	14	21.3	12.20	2.94	21.2	3.69	5.7	0.70	0.09	Q MEASURED
PASFN	11/29/2000	1	11.0	5.60	1.95	6.0	4.43	1.4	0.09	0.02	Q ESTIMATED FROM RATING
PASFN	1/8/2001	2	12.0	7.27	1.88	3.7	4.43	0.8	0.07	0.02	Q ESTIMATED FROM RATING
PASFN	1/10/2001	3	14.3	7.75	2.03	8.5	4.43	1.9	0.18	0.04	Q ESTIMATED FROM RATING
PASFN	1/25/2001	4	52.5	20.61	2.06	9.4	4.43	2.1	0.52	0.12	Q ESTIMATED FROM RATING
PASFN	2/17/2001	5	7.0	2.10	1.92	5.0	4.43	1.1	0.03	0.01	Q ESTIMATED FROM RATING
PASFN	2/19/2001	6	13.6	10.40	2.10	10.3	4.43	2.3	0.29	0.07	Q ESTIMATED FROM RATING
PASFN	2/20/2001	7	32.7	38.40	2.36	20.3	4.43	4.6	2.10	0.47	Q ESTIMATED FROM RATING
PASFN	2/20/2001	8	36.3	80.60	2.57	40.0	4.43	9.0	8.70	1.96	Q ESTIMATED FROM RATING
PASFN	2/20/2001	9	57.1	72.60	2.80	100.0	4.43	22.6	19.58	4.42	Q ESTIMATED FROM RATING
PASFN	2/21/2001	10	28.4	14.30	2.59	42.2	4.43	9.5	1.63	0.37	Q MEASURED
PASFN	2/22/2001	11	33.7	21.00	2.80	100.0	4.43	22.6	5.66	1.28	Q ESTIMATED FROM RATING
PASFN	2/22/2001	12	32.4	22.60	2.80	100.0	4.43	22.6	6.10	1.38	Q ESTIMATED FROM RATING
PASFN	2/24/2001	13	16.5	6.30	2.30	18.1	4.43	4.1	0.31	0.07	Q ESTIMATED FROM RATING

PASFN	3/5/2001	14	26.0	9.20	2.61	46.3	4.43	10.5	1.15	0.26	Q ESTIMATED FROM RATING
PASFN	3/6/2001	15	16.7	8.00	2.39	21.4	4.43	4.8	0.46	0.10	Q MEASURED