EFFECTS OF SUCTION DREDGE MINING ON ANADROMOUS SALMONID HABITAT IN CANYON CREEK, TRINITY COUNTY, CALIFORNIA

by

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EFFECTS OF SUCTION DREDGE MINING

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ABSTRACT

The effects of suction dredge gold mining on the stream habitat of chinook salmon (Oncorhynchus tshawytscha), coho salmon (O. kisutch), and steelhead trout (Salmo gairdneri) were investigated at Canyon Creek, Trinity County, California during 1984 and 1985. In 1984, a total of 1136 m^2 of streambed was disturbed by 20 suction dredge operations. In 1985, 1075 m^2 were disturbed by 15 dredge operations. Increased levels of stream turbidity and total suspended solids were detected 100 m below active dredges. Gravel and fine sediment deposited 10 to 50 m downstream of dredge outflows aggraded the channel, reduced substrate particle size, and increased substrate embeddedness. Other adverse effects on stream habitat included bank undercutting, bank sluicing, channelization, and riparian vegetation damage. A stream flow of approximately 24 cms during Water Year 1985 (October 1984 through September 1985) effectively obliterated instream mining disturbance from the previous season. At the onset of the 1985 dredge season less than ten percent of the area disturbed by 1984 dredging was visible. Direct observation of anadromous fish indicated that young-of-the-year steelhead abundance and the holding locations of adult spring-run chinook salmon and adult summer-run steelhead were not affected by dredge mining operations. Current California regulations limit suction dredge impacts by requiring permits, seasonal closures, aperture size restrictions, and exclusion from designated areas. Adverse dredging effects could be additionally reduced by establishing procedural

guidelines, educating miners to the habitat needs of salmonids, and an increased presence of Department of Fish & Game and U.S. Forest Service personnel.

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INTRODUCTION

Placer gold deposits are usually found in existing and ancient stream channels near the alluvial gravel-bedrock interface (Weber 1986). Generally, organic and inorganic material (overburden) must be removed before the gold-bearing stratum is uncovered. Prior to the development of the portable suction dredge in the late 1950's, placer mining was restricted to the use of pick and shovel, or to large earth moving equipment such as bulldozers, draglines, and hydraulic monitors for the removal of overburden. Some of these mining practices, hydraulic mining in particular, had long-lasting detrimental effects upon stream banks, channels, and receiving waters (Sumner and Smith 1940). The modern suction dredge (Figure 1), however, has been claimed to be the answer to meeting new environmental restrictions (Fraser 1980) as well as being a convenient and low-cost method for accessing instream placer gold deposits (Thornton 1979). The versatility of the new suction dredge combined with rising gold prices during the late 1970's led to a rapid increase of suction dredge use on California streams. The number of suction dredge mining permits annually issued by the California Department of Fish and Game (CDFG) rose from 3,981 in 1976 to 12,763 in 1980, but has since declined to about 7,500 (Figure 2).

Suction dredges are now a common feature on many streams throughout the western United States, but little is known about the effects of dredge mining. The potential for damage to streams and fish habitat may be considerable due to the widespread use of the suction dredge and the total amount of dredging effort expended annually

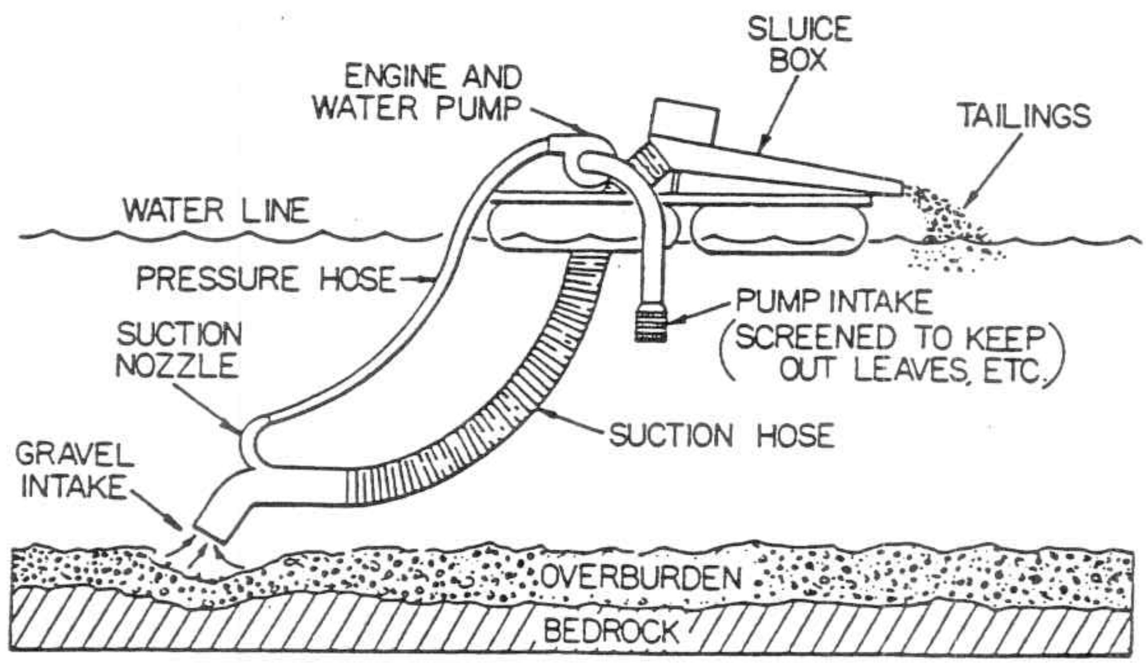


Figure 1. Components of the Modern Suction Gold Dredge. (Thornton 1979)

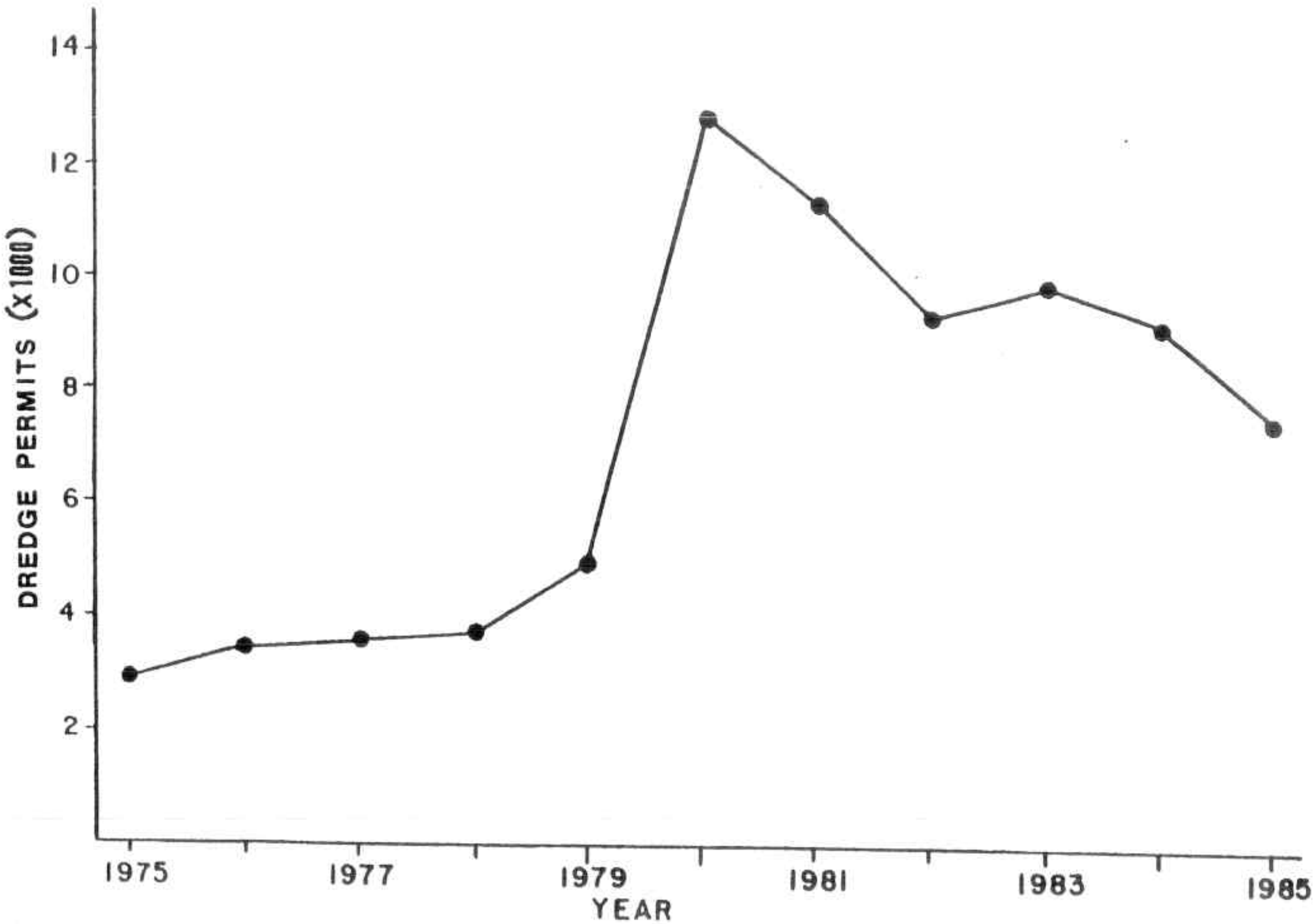


Figure 2. Total Number of Suction Dredge Mining Permits Issued by California Department of Fish and Game. 1975-1985.

(McCleneghan and Johnson 1983). Suction dredge mining can affect fisheries by entraining fish eggs and fry, degrading water quality, increasing substrate embeddedness, reducing instream cover, depressing aquatic invertebrate populations, destabilizing stream channels and banks, damaging riparian vegetation, and generally decreasing instream habitat diversity and complexity. In California, there is a need to assess the effects of dredge mining on salmonid habitat to facilitate management decisions concerning instream mineral resources.

Suction dredges release clay, silt and coarser sediment into the water column and onto the stream bottom. Literature concerning the detrimental effects of fine sediment on streams is extensive (Cordone and Kelley 1961; Gibbons and Salo 1973; Iwamoto et al. 1978). Many investigators have shown that sediment released by timber harvesting and road construction can degrade stream habitat used by fish and benthic invertebrates (Tebo 1955; Hall and Lantz 1969; Burns 1972; Moring and Lantz 1975; Newbold et al. 1980; Murphy et al. 1981; Murphy and Hall 1981). Increased sediment loads can widen and shallow stream channels (Leopold et al. 1964) and fill pools which may reduce the amount of suitable habitat for salmonids (Bjornn et al. 1974). Intrusion of fine sediments into the streambed can reduce intergravel permeability and negatively impact the survival of incubating salmonid eggs and larvae (Shaw and Maga 1943; McNeil and Ahnell 1964; Phillips et al. 1975; Hausle and Coble 1976).

The effects of placer mining on aquatic life have been investigated in the western States since the 1930's. Ward (1938) concluded that placer mining had not harmed the anadromous salmonid stocks of the Rogue River, Oregon. Sumner and Smith (1940) found that chinook salmon (Oncorhynchus tshawytscha) avoided spawning in muddy and silted-in areas below placer mines on the Yuba River, California. An experimental study by Shaw and Maga (1943) demonstrated that the yield of salmon fry was greatly reduced when spawning beds were subjected to mining silt.

Recently investigators have documented the effects of placer mining on Alaskan stream ecosystems. Simmons (1984) found that arctic grayling (Thymallus arcticus) consistently avoided turbid waters below placer mining operations. Bjerklie and LaPerriere (1985), LaPerriere et al. (1985), and Van Nieuwenhuyse and LaPerriere (1986) reported that a dramatic increase in turbidity, suspended solids and heavy metals occurred downstream from placer mining in Alaska. Wagener and LaPerriere (1985) concluded that placer mining sedimentation decreased the density and biomass of benthic invertebrates. Weber and Post (1985) and Weber (1986) reported that Alaskan placer mining had eliminated riparian vegetation, increased stream bottom embeddedness, and adversely impacted both fish and aquatic invertebrate populations.

The effects of placer mining with large gold dredges in active stream channels have been investigated. Casey (1959) observed the elimination of trout from a reach of Idaho stream degraded by a tractor-mounted dredge. Campbell (1962) held rainbow trout (Salmo gairdneri) eyed eggs and fingerlings 2.4 km below a gold dredge in Oregon and found that all the eyed eggs and 57% of the fingerlings died, while a control group had only 6% mortality of eyed eggs and 9.5% mortality of fingerlings.

Lewis (1962) was the first to investigate the effects of the portable suction gold dredge on the aquatic habitat of fish and benthic invertebrates. He operated a 12.7 cm aperture dredge in Clear Creek, Shasta County, California and found that dredging could improve the intergravel environment for both fish eggs and benthos if the stream was mined in a uniform manner. Griffith and Andrews (1981) used a 7.6 cm aperture suction dredge to evaluate the effects of entrainment on trout eggs and sac-fry in Idaho. They found that uneyed cutthroat trout (Salmo clarki) eggs had 100% mortality, eyed cutthroat trout eggs had 35% mortality and hatchery rainbow trout sac-fry had 83% mortality after entrainment. McCleneghan and Johnson (1983) surveyed suction dredge operations on 54 streams in the Sierra Nevada Mountains of California and found that during 74,616 hours of suction dredge operation in 1982 the following operational impacts occurred and were judged detrimental to the stream and its resources: undercutting banks, stream channelization, riparian damage, and bank sluicing. Thomas (1985) who used a 6.4 cm aperture suction dredge in Montana reported that dredging created localized changes in aquatic insect abundance and stream bottom habitat in the area dredged. Harvey (1986) investigated the effects of suction dredge mining on fish, aquatic invertebrates, and water quality in California streams and found that suction dredges caused significant localized alterations of the streambed which adversely affected the habitat and abundance of several species of aquatic insects and the riffle sculpin (Cottus gulosus).

The principal objective of this study was to assess the extent of suction dredge mining effects on anadromous salmonid habitat in Canyon Creek, Trinity County, California. Specific objectives were to:

1) Determine water quality.
2) Measure and evaluate instream and riparian habitat disturbed by suction dredge operations in Canyon Creek during the 1984 and 1985 mining seasons.
3) Measure the effects of an individual dredge on channel morphology, water quality, and fish habitat parameters at four mining sites.

STUDY AREA

Canyon Creek, a fourth order stream, originates in large glacial cirques and tarn lakes on the southern slope of the Trinity Alps. The stream flows south 32 km through a narrow, mountainous, and partially glaciated canyon to the Trinity River at Junction City, California (Figure 3). Most of the 167.8 square km watershed is forested by douglas fir (*Pseudotsuga menziesii*), incense cedar (*Libocedrus decurrens*), black oak (*Quercus velutina*), canyon live oak (*Quercus chrysolepis*), and Pacific madrone (*Arbutus menziesii*) (Figure 4). Alder (*Alnus* sp.), maple (*Acer* sp.), and willow (*Salix* sp.) provide overhead cover along much of the stream. Average annual precipitation in the Canyon Creek Basin is approximately 140 cm (DWR 1980).

Pools are numerous in the upper portion of Canyon Creek, but become smaller and fewer towards the stream mouth. Three bedrock gorges in middle and lower Canyon Creek contain pools 2.5 to 3 meters deep, but in between these gorges, long reaches of stream have few or no pools (Figure 5). The streambed is predominantly gravel and cobble and becomes finer downstream. Stream gradient averages 5.2% in the upper 12 km of the basin and 2.3% in the lower 20 km.

Instream and overhead cover are highly variable along Canyon Creek. Boulders provide instream cover throughout most of the stream. However large organic debris and aquatic vegetation is sparse in many downstream areas. Overhead cover ranges from well-developed (60 to 80%) along the upper stream to moderate and sparse (0 to 40%) in the middle and lower reaches. Two portions of Canyon Creek, totalling 5.1 km,

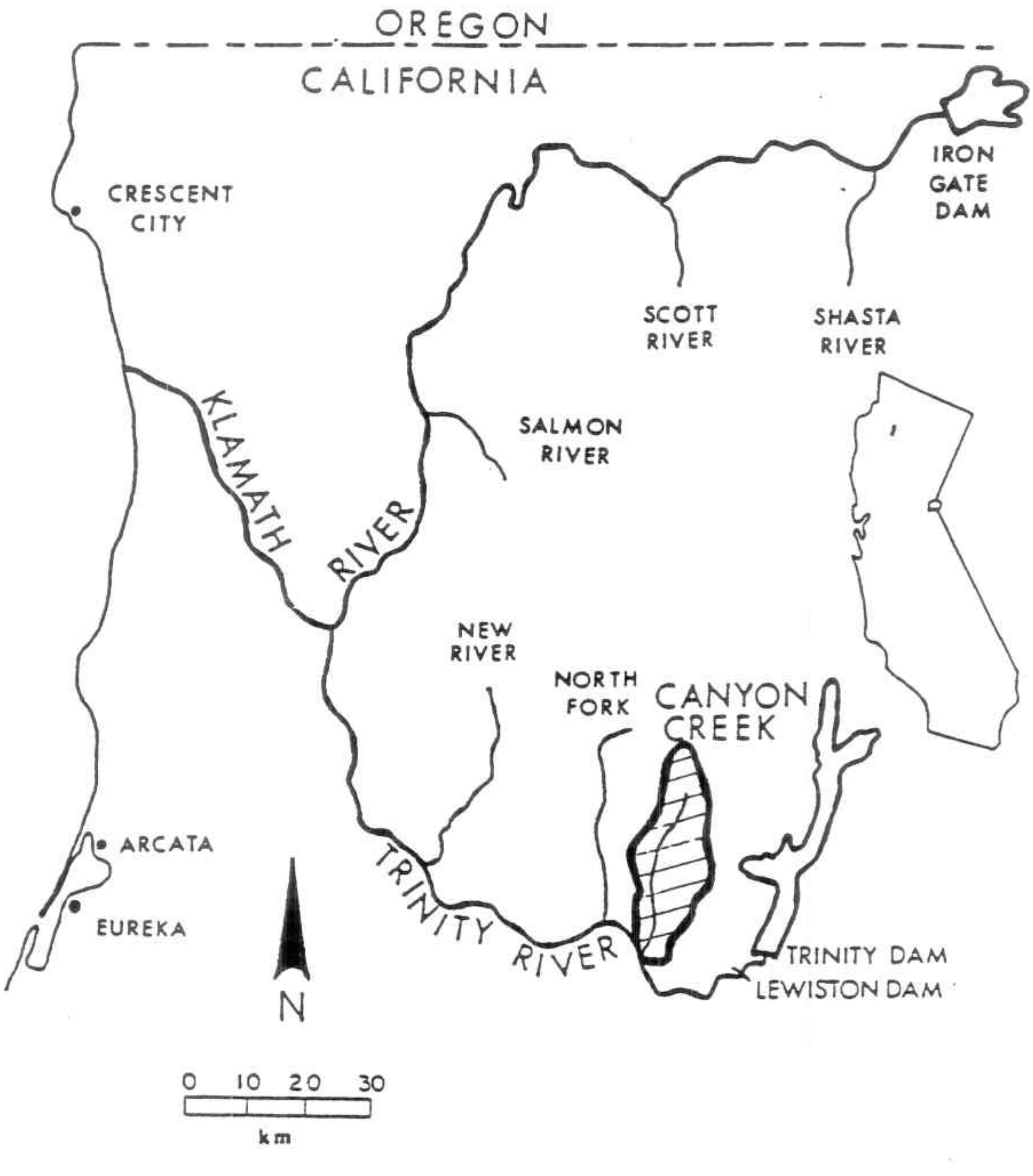


Figure 3. Klamath-Trinity River Basin with Canyon Creek, Trinity County, California.

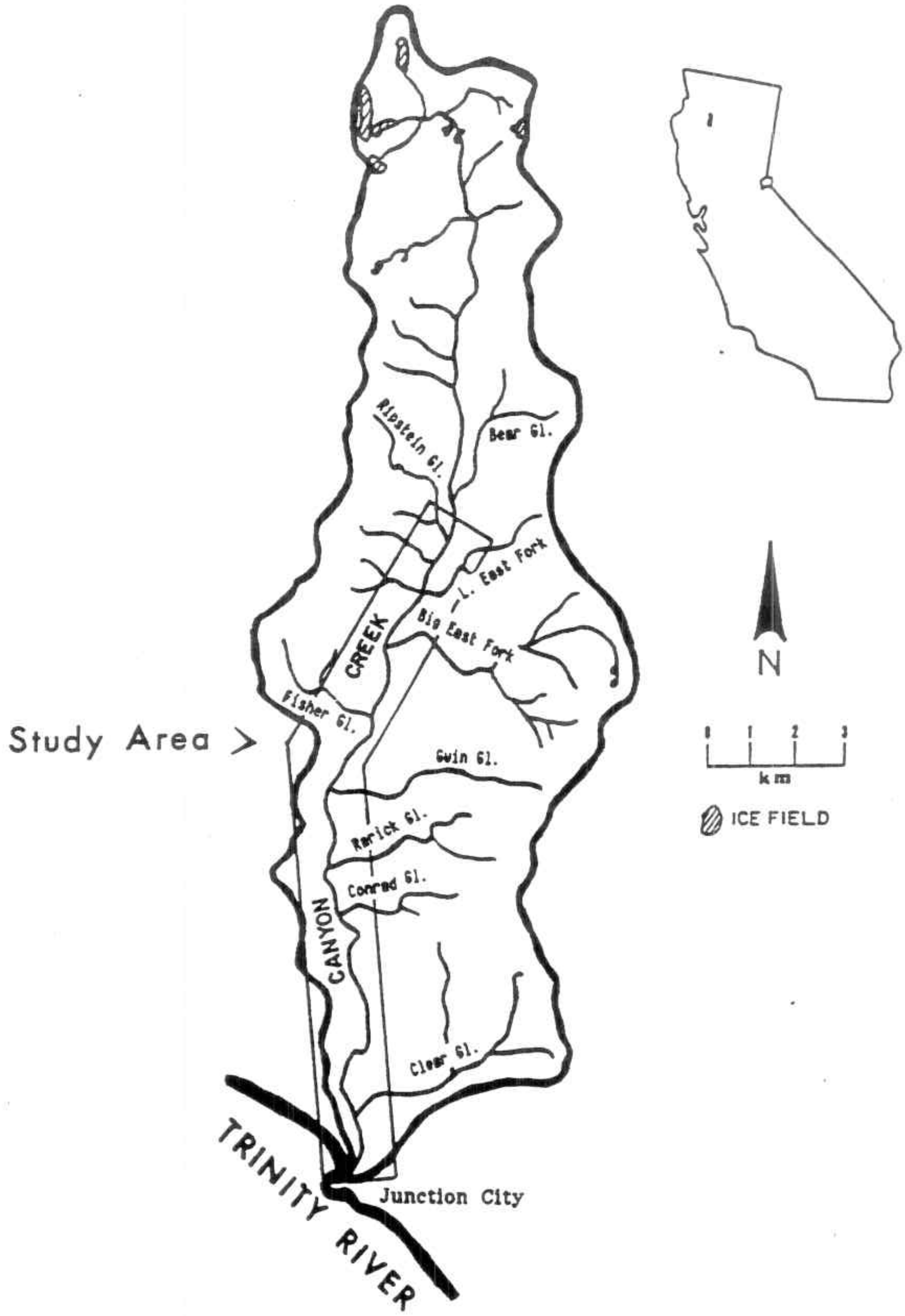


Figure 4. Canyon Creek Watershed and Study Area, Trinity County, California.

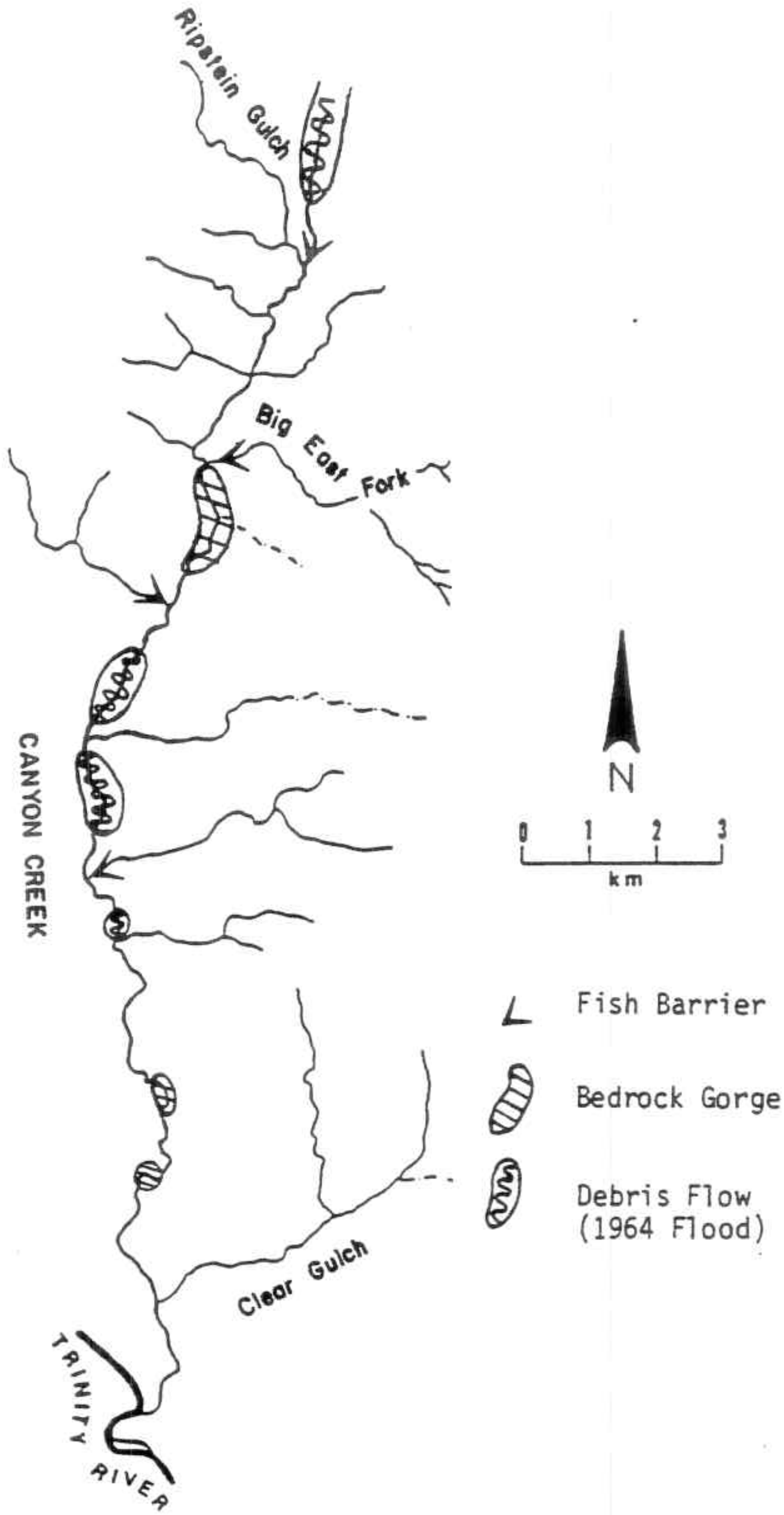


Figure 5. Anadromous Fish Barriers, Bedrock Gorges, and Debris Flows (1964 Flood) in Canyon Creek.

received debris flows during the 1964 flood (DWR 1980) and are characterized by a wide and open channel with large boulders, unstable banks, and little overhead cover (Figure 5).

The major rock unit which underlies the Canyon Creek drainage is Salmon Hornblende Schist of the Klamath Mountains Central Metamorphic subprovince (Figure 6). The Salmon formation consists of dark, well-foliated hornblende and chlorite schists formed by metamorphism of what were probably mafic igneous rocks (Hotz 1971). During the late Jurassic, a large granitic body intruded the schists of the Salmon formation at the head of Canyon Creek (Cox 1967) (Figure 6). This elliptical-shaped pluton, Canyon Creek pluton (Hotz 1971), is composed of plagioclase, quartz, biotite, and hornblende (Lipman 1962). The Canyon Creek pluton is the largest (77.7 square km) granitic body in the Trinity Alps.

Canyon Creek has long been famous as a gold-bearing stream. Two mining communities, Canyon City (founded in 1851) and Dedrick (founded in 1890), have occupied its banks since gold mining began in the drainage during the 1850's (Gudde 1975). Gold has been extracted from stream and terrace gravel deposits (placer) by a variety of hydraulic methods and from quartz veins (lode) of the Salmon formation by hardrock mining. The first placer mining by early Canyon Creek pioneers was accomplished with pan, rocker, dip-box and sluice box. During the late 1800's and the 1930-40's, hydraulic giants were employed to wash auriferous gravels from terrace and bench deposits through rock-lined sluice boxes (Table 1 and Figure 7). Water was brought to the placer deposits by ditch, flume, pipe, and tunnel. Remnants of water delivery systems, hillsides washed away by hydraulicking, and spoil piles of

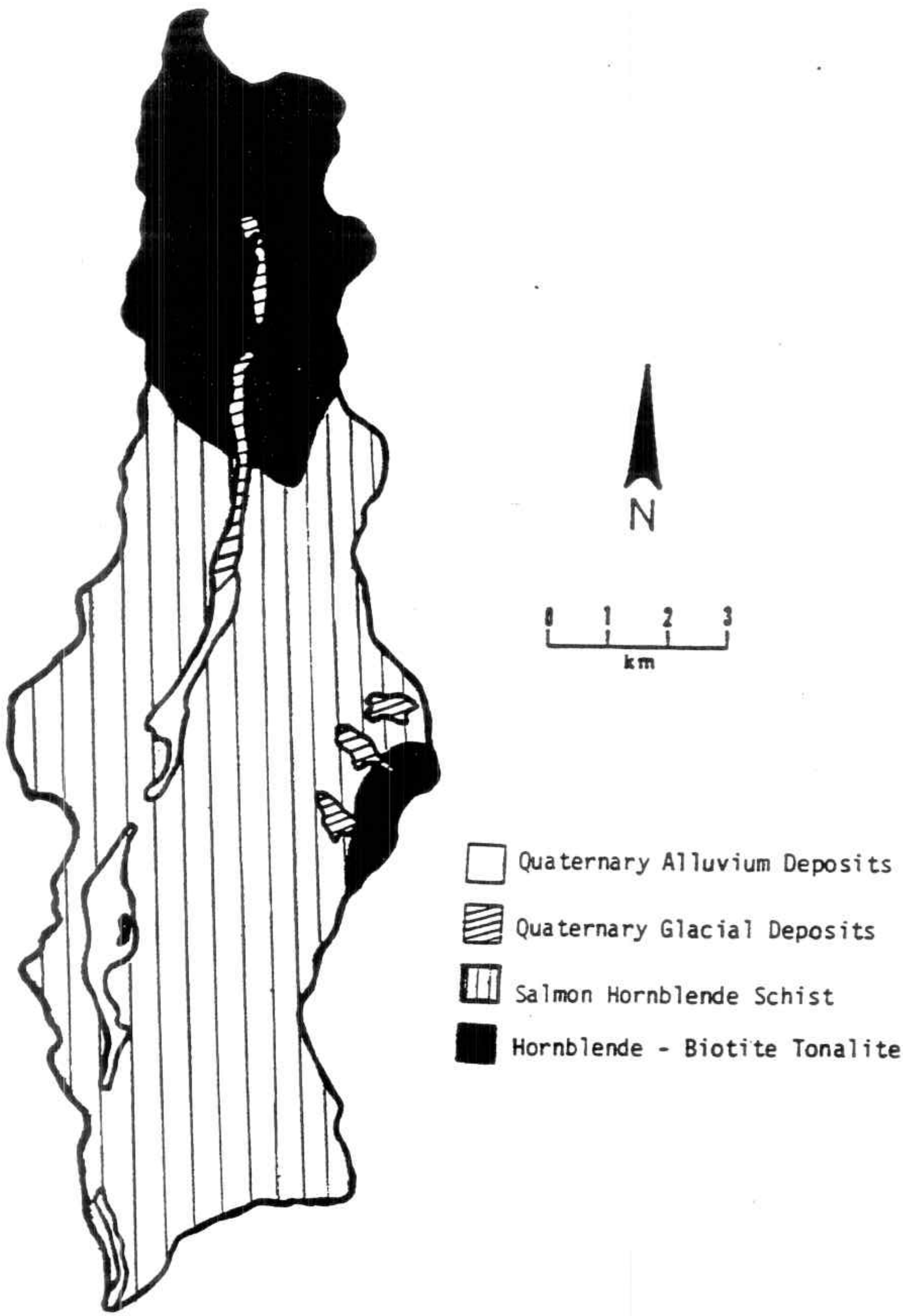


Figure 6. Geologic Map of Canyon Creek Watershed.

Table 1. Historic Gold Mines and Diversions at Canyon Creek, Trinity County, California.

Map No.	Owner(s)	Water Source	Purpose/method	Indicated date of appropriation or first use	Description/remarks
1[a]	J.H. Wickline, J.J. Spears	Jones Gulch	Placer mine, domestic power (3 kw)	1910	Diversion - gravity; 30.5 cm diameter pipe with 0.2 km of earth ditch.
2[a,b]	L.L. Turney, D.L. Freeman, Canyon Creek Enterprises	Little East Fork	Placer mine/ hydraulic	1946	Diversion - gravity; timber and rock dam with 0.8 km of earth ditch and 0.5 km of 5 cm diameter pipeline.
3[a,b,c]	Dannenbrink, Canyon Placers, Inc., Roy and Ray DeHaven	Big East Fork	Placer mine/ hydraulic	1890	Diversion - gravity; rock and gravel dam 1 meter high, 3.6 meters long with wood flume and earth ditch; early hydraulic mines and tunnels; 36 claims in area consolidated by Canyon Creek Placers, Inc. were extensively hydraulic mined in 1940-1, 1945, 1946, 1948 and 1950.
4[a]	Hardy F. Fisher	Fisher Gulch	Placer mine/ hydraulic	1946	Diversion - gravity; log crib dam 1.2 meters high, 3.6 meters long with earth ditch.
5[a,b]	Albert Hayes Mine Co., Cie Fae Mining Co., North Mountain Power Co., Westerns States Gas & Electric Co., Pacific Gas & Electric Co.	Canyon Creek	Placer mine/ hydraulic (1882 - 1900) Power production (1904-05)	1882	Diversion - gravity; timber-faced, gravel-filled dam 6 meters high, 23 meters long with 9.6 km of earth ditch, 2.4 km of steel flume and 0.6 km penstock; dam damaged by 1964 flood and subsequently demolished by P.G.& E.; hydraulic mines served by this diversion were located on Trinity River.
6[c]	Uphill Mining Co.	Canyon Creek	Placer miue/ dredge	1949	Short-lived operation during 1949 and 1950; dredged alluvial gravels 1 to 5 deep meters over bedrock.
7[b,c]	Dannenbrink, Canyon Placers, Inc.	Canyon Creek	Placer mine/ hydraulic	1862	Extensive hydraulic mining by Canyon Placers, Inc. during 1940's.
8[c]	Clipper Placer Mine	Canyon Creek	Placer mine/ hydraulic	1953	?

Table 1. Historic Gold Mines and Diversions at Canyon Creek, Trinity County, California. (continued)

Map No.	Owner(s)	Water Source	Purpose/method	Indicated date of appropriation or first use	Description/remarks
9[b,c]	Various owners since late 1800's.	Conrad Gulch	Placer mine/ hydraulic	?	Diversion - gravity; 0.75 km of earth ditch, Gold Dollar mining claims include Forty Dollar Gulch Gold Dollar Gulch and 100 acres along creek; mined extensively.
10[b,d]	Joseph McGillivary, Francis Heurtevant, Red Hill Mining Co.	Canyon Creek hydraulic	Placer mine/	1870	Diversion - gravity; timber-faced, gravel-filled, dam 9 meters high with 6.4 km ditch; water diverted over Butler's Saddle, across Trinity River to Red Hill Mine; wooden fish ladder at dam judged as barrier to fish and removed by CDFG in 1951.

[a] Land and water use in Trinity River hydrographic unit. 1964. Dept. of Water Resources, Bulletin No. 94-2.

[b] Trinity County Historical Sites. 1981. Alice G. Jones, Editor, Trinity County Historical Society, Weaverville, California.

[c] Frederiksen, Kamine and Assoc. 1980. Final proposal: Trinity River Basin Fish and Wildlife Management Program. Prepared for U.S. Bureau of Reclamation, Sacramento, California. 6 volumes.

[d] Handley, J. and M. Coots. 1953. The removal of abandoned dams in the upper Klamath River drainage, California. California Fish and Game, 39 (3):365-374.

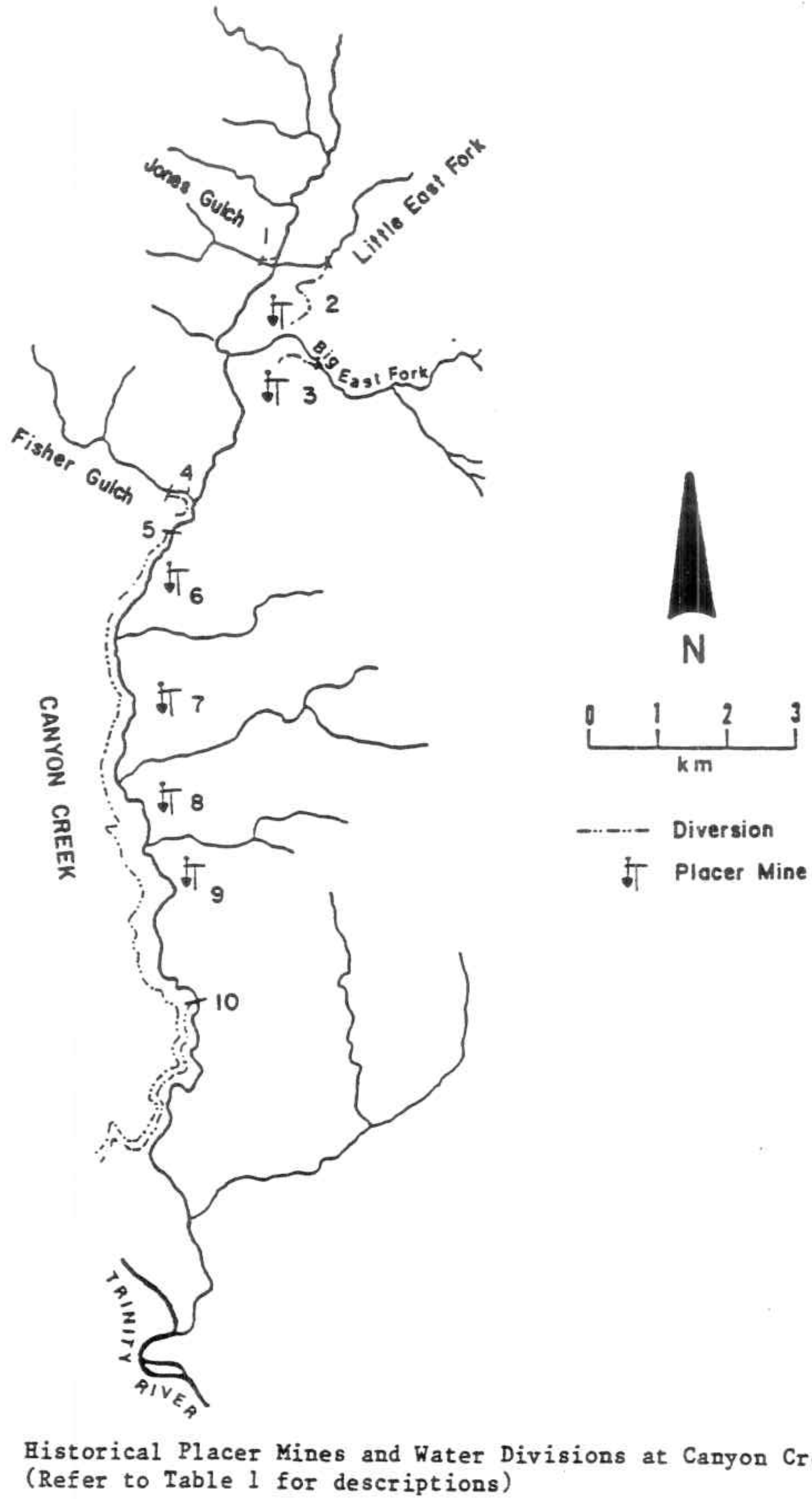


Figure 7. Historical Placer Mines and Water Divisions at Canyon Creek. (Refer to Table 1 for descriptions)

barren rubble are still visible along the lower 18 km of Canyon Creek and provide evidence that the original character of the channel and floodplain has been greatly altered by historic placer mining operations.

The study was limited to the lower 20 km of Canyon Creek (Figure 4) because all suction dredge mining is restricted to this portion of stream by road access and exclusion from the Trinity Alps Wilderness Area. Anadromous salmonids are also restricted to the lower 20 km of stream by a series of bedrock waterfalls which are a barrier to upstream migration (Figure 5). All field studies were conducted in this area from January 1984 to October 1985.

Chinook salmon (Oncorhynchus tshawytscha), coho salmon (O. kisutch), and steelhead trout (Salmo gairdneri) spawn and rear in Canyon Creek. Other fish species found in the study area are the Klamath small scale sucker (Catostomus rimiculus), speckled dace (Rhinichthys osculus), Pacific lamprey (Lampetra tridentata), and threespine stickleback (Gasterosteus aculeatus). A small sport fishery for trout, most of which are juvenile steelhead in the study area, occurs during summer.

The study area contains many active placer mining claims (Figure 8). The majority of these claims are 20 acres in size. To maintain possession of a mining claim, the owner(s) must complete $100 worth of labor annually at each claim (U.S. Statutes at Large, 1872, Chap. 152, Sec. 5). Suction dredges are currently the most popular method for the owners of placer mining claims on Canyon Creek to perform their annual mineral assessment.

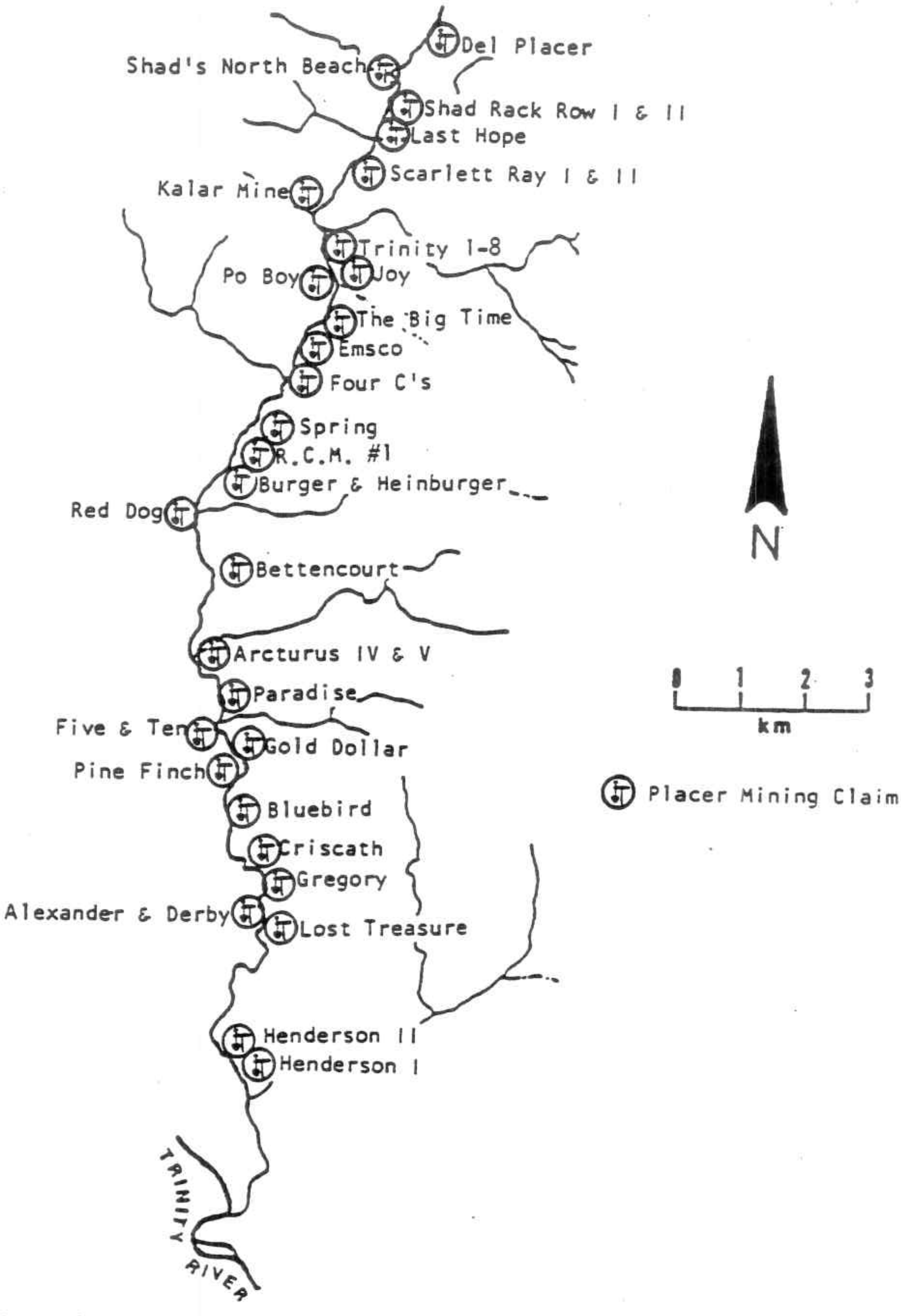


Figure 8. Active Placer Mining Claims (1985) at Canyon Creek.

California Department of Fish and Game (CDFG) regulates suction dredge operations by requiring a standard permit of all dredge miners and designating open areas and seasons. Canyon Creek has been classified as zone D (dredging is permitted June 1 to September 15) and the diameter of dredge intake nozzels is restricted to 15.24 cm (6 inches) or less (Cal. Admin. Code, Title 14, Sec. 228). To operate a suction dredge outside of these regulations, a special permit must be obtained from CDFG.

MATERIALS AND METHODS

Hydrology

A stream gauging station was operated in Canyon Creek three km above the confluence with the Trinity River from January 1984 to October 1985 (Figure 9). A staff gauge and crest gauge were secured firmly to a stable post in the stream about 60 m above the Powerhouse Road bridge. The crest gauge was a clear plastic tube (2.54 cm in diameter) placed upright alongside the porcelain staff gauge. Both ends of the crest gauge tube were open to permit stream water inside to rise and fall with river stage. Burnt cork fragments floating on the water surface inside the tube were deposited at the highest river stage (Buchanan and Somers 1968). Gauge readings were made every 7 to 10 days throughout the study period.

Periodic discharge measurements were taken along a 25 m transect at the gauging station with a USGS top-setting wading rod and pygmy or Price AA current meter. A log linear stage-discharge relationship was established and an equation fitted to the curve (Kennedy 1984). Flows not measured directly were estimated from the rating curve. Flows during periods of no gauge-height record were estimated from Department of Water Resources (DWR) records for North Fork Trinity River daily mean discharge (Rantz and others 1982). Mean winter and summer discharges during Water Year (WY) 1985 (October 1984 to September 1985) were calculated. A hydrograph and flow duration curve for WY 1985 were developed (Dunne and Leopold 1978).

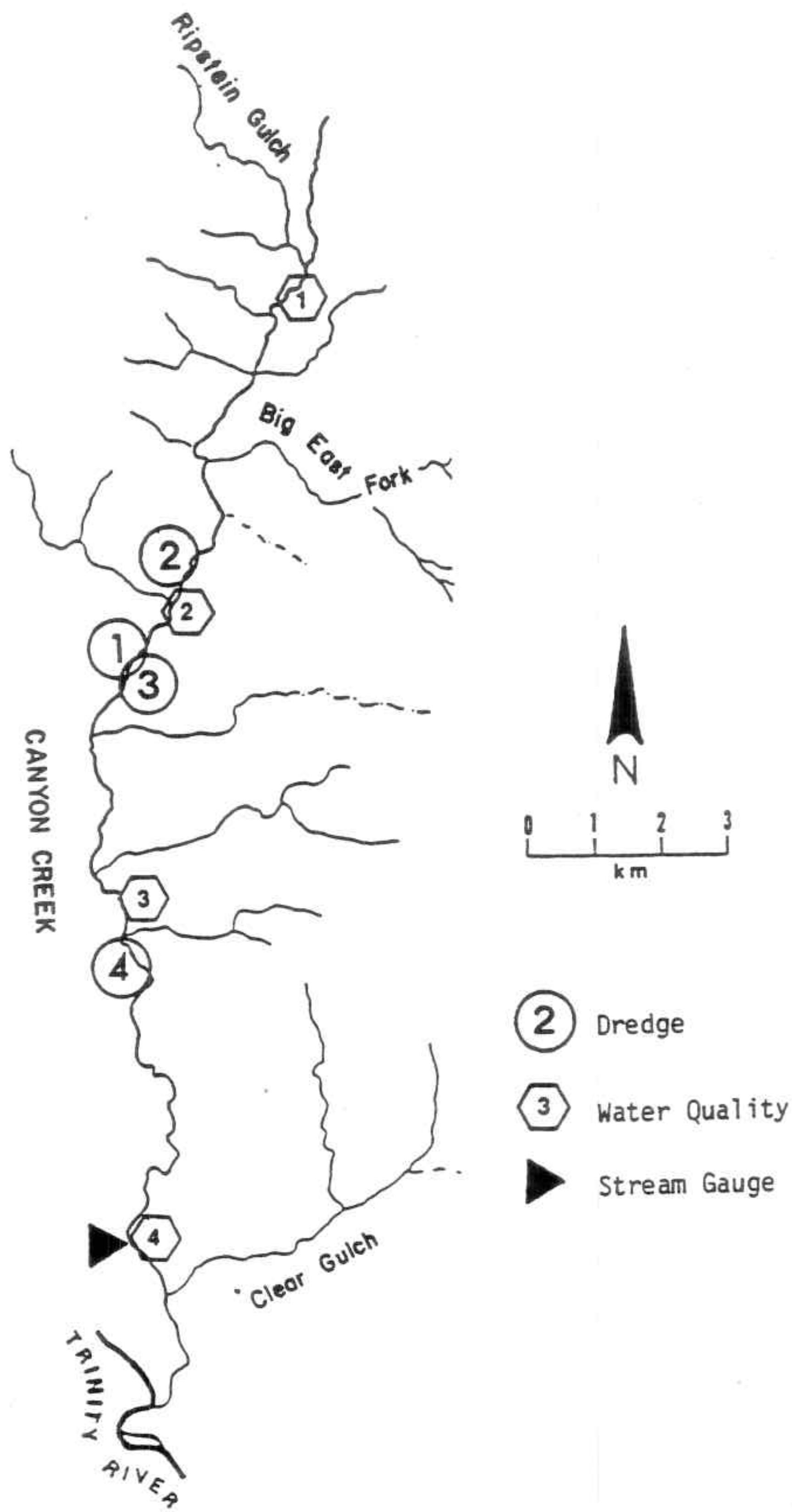


Figure 9. Sampling Stations at Canyon Creek.

Water Quality

Water quality was measured regularly at the stream gauge and three other stations (Figure 9). Water samples were collected with a DH-48 depth-intergrating sampler by the equal-transit-rate (ETR) method (Guy 1969). All samples were analyzed in the laboratory for turbidity by a Hach Turbidimeter (Model 2100A) and conductivity by a Beckman Solubridge (Model RB-5) or Yellow Springs Instrument Conductivity Bridge (Model 31). Some water samples were further analyzed for total suspended solids (TSS) by vacuum filtration through Whatman GF/C filter paper. Residue remaining on the filter was dried for one hour at 100°C and weighed. Stream temperatures were measured at the time of sample collection by hand-held pocket thermometer. At station 1 (gauging station) maximum and minimum stream temperatures were recorded by a Taylor No. 5458 self-registering thermometer.

Suction Dredge Mining

Suction Dredge Operations

The study area was surveyed weekly during the 1984 and 1985 dredge mining seasons. At each dredge operation the following information was recorded:

1) Diameter of suction dredge aperture (intake nozzel).
2) Number of suction dredge operators.
3) Whether the dredgers classified themselves as recreational or professional miners.
4) Dates and hours of suction dredge operation.

Immediately following the closure of both the 1984 and 1985 mining seasons, all suction dredge-created holes and tailing piles in the stream channel were identified. The length, width, and depth of each dredge hole were measured with a two-meter wading rod and an optical tape measure (Ranging model 103X). The surface area of each tailing pile was measured and their composition fractioned into 5 size classes (greater than 250 mm, 250-128 mm, 128-32 mm, 32-4 mm, and less than 4 mm). Dredge mining sites were sketched to scale and flagged with surveyor's tape for future identification. Subjective determination of the following operational impacts were assessed in a manner similar to that of McCleneghan and Johnson (1983):

1) Stream channelization
2) Bank undercutting
3) Riparian damage
4) Sluicing of the bank

Following spring run-off in 1985, each site of 1984 suction dredging was revisited for examination and measurement of hole, tailing pile and/or operational impact remnants. The stream bottom profile at a large dredge excavation site (15.24 cm aperture suction dredge operated for approximately 90 hours during July and August 1984) was surveyed by automatic level and stadia rod after mining in October 1984 and after spring run-off in July 1985.

Adult Anadromous Salmonids

The study area was surveyed, by diving with mask and snorkle, for spring-run chinook salmon and summer-run steelhead in mid-August 1985. Each pool and run deeper than 0.6 m was examined for adult salmonids. All adult fish (greater than 40 cm total length) were identified to species and examined for tags or marks. Total body lengths were estimated visually. Water depth, instream cover, and proximity to suction dredge activity were recorded at each adult salmonid holding area.

Localized Effects

The downstream effects of an individual dredge were measured at four dredge mining operations during the study (Table 2 and Figure 9). In 1984, water quality and sediment deposition were measured above and below two suction dredge operations. In 1985, water quality, sediment deposition, substrate particle sizes, substrate embeddedness, channel scour and fill, and abundance of young-of-the-year steelhead were measured above and below two other suction dredge operations. At suction dredge sites 1 and 2 (1984), five transects were located below the suction dredge at 10, 22, 42, 72 and 100 m, respectively, and one control transect was located upstream of the dredge (Figure 10). At suction dredge sites 3 and 4 (1985), six transects were located below the dredge at 4, 9, 16, 25, 36 and 49 m, respectively, and one control transect upstream of the dredge (Figure 11). Transects were monumented with iron rebar or epoxyed pins. Upstream control transects were placed in areas with aquatic habitat characteristics (substrate, cover, depth, velocity) similar to those below dredged areas.

Water quality. Temperature, turbidity, conductivity, and TSS were measured at dredge sites 1 - 4 during suction dredge mining. Water samples were collected along each transect and analyzed as previously described. Temperatures were measured in the center of each transect by pocket thermometer.

Table 2. Suction Dredge Operations Studied at Canyon Creek, Trinity County, California.

Dredge Site	Dredge Aperture (cm)	No. of Operators	Recreational/ Professional	Total Hours Operated	Dates Operated
1	15.24	2	pro	40	8/30/84 - 9/12/84
2	10.16	1	rec	45	8/01/84 - 9/15/84
3	12.70	2	rec	75	6/25/85 - 8/22/85
4	10.16	1	pro	28	7/25/85 - 9/15/85

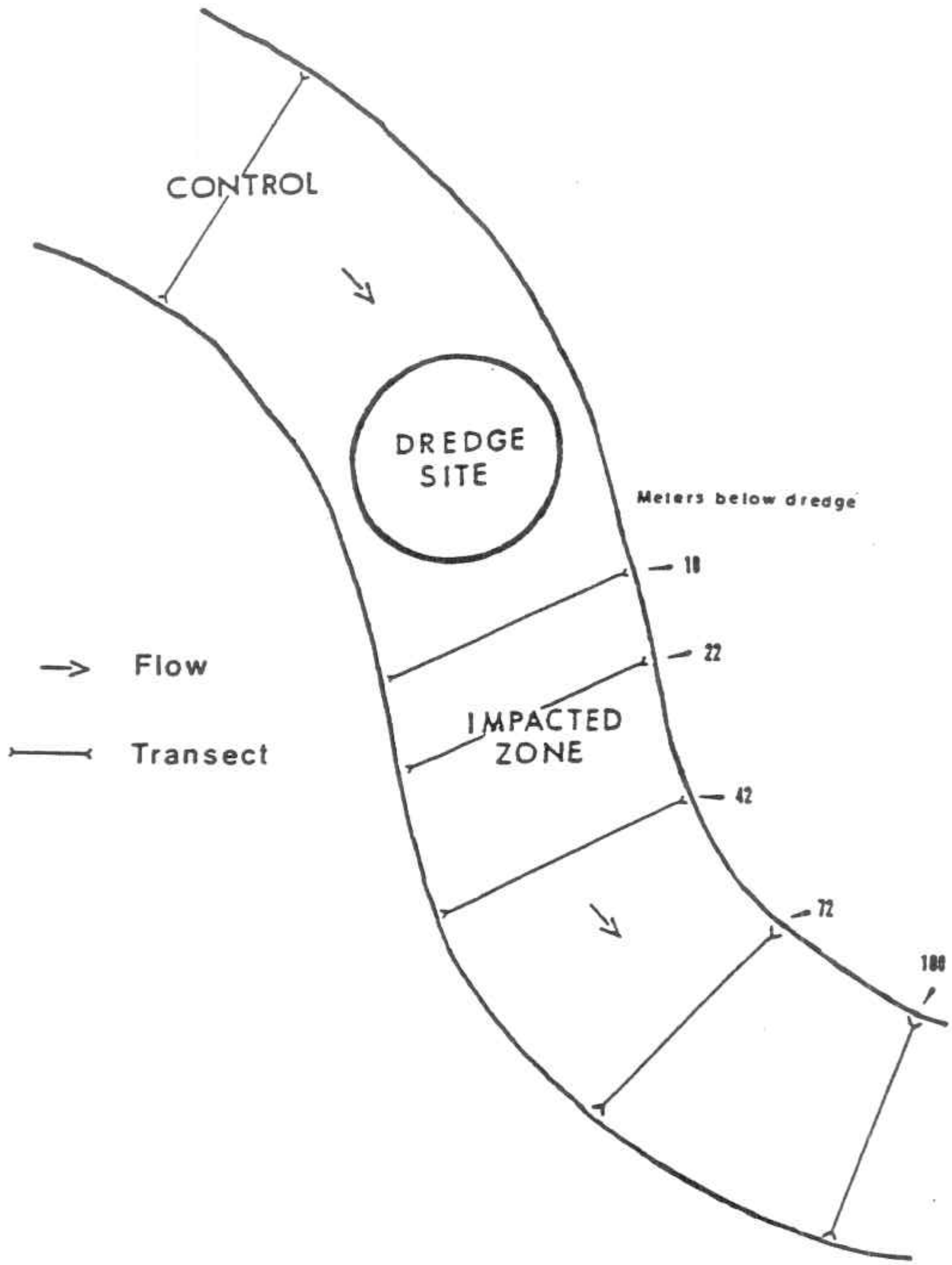


Figure 10. 1984 Study Design at Canyon Creek.

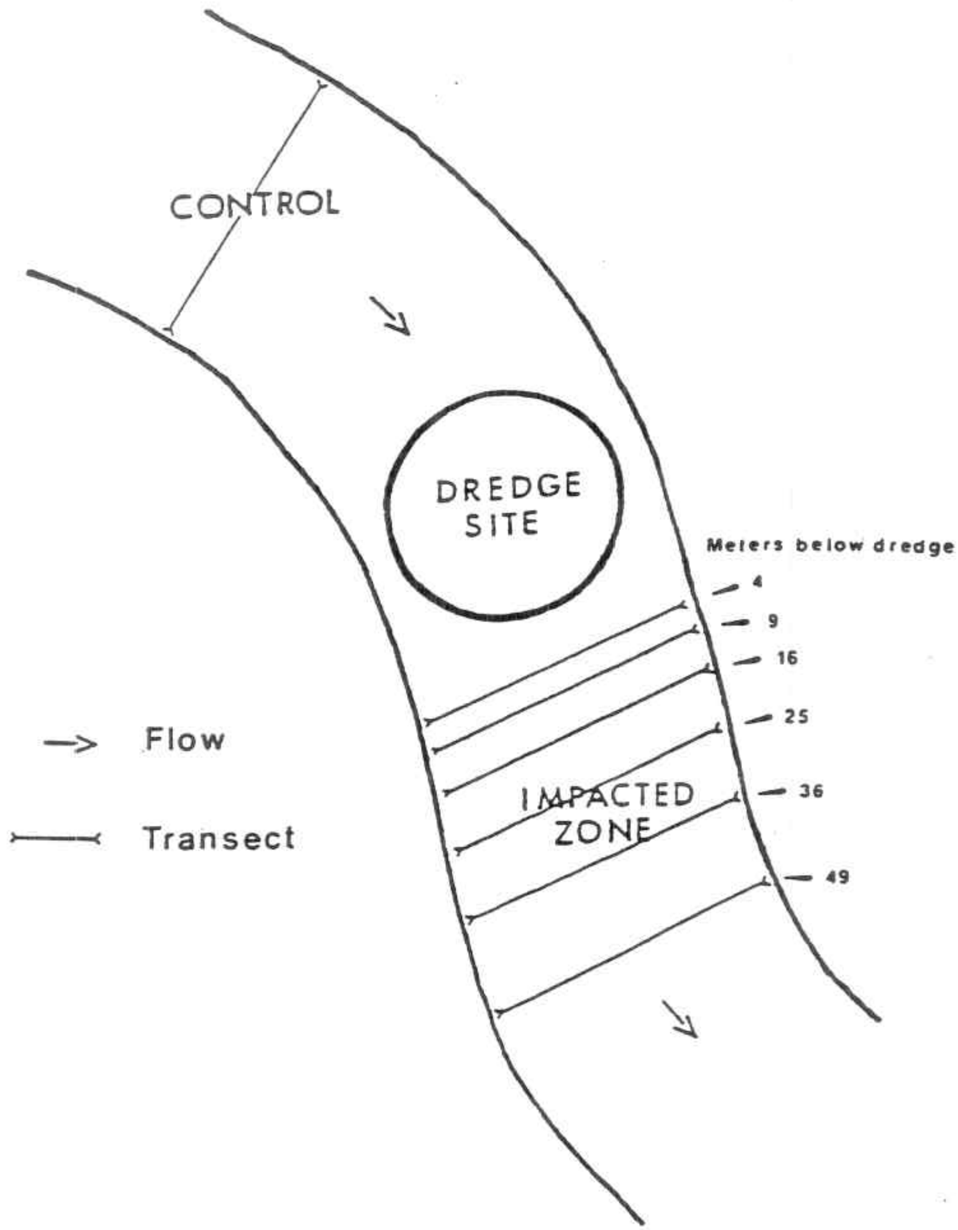


Figure 11. 1985 Study Design at Canyon Creek.

Least squares linear regression analysis was used on transformed (log10) data to express turbidity and TSS as a function of distance below the suction dredge. Regression coefficients (slopes) were considered significant at less than or equal to five percent probability of type one error. Significant regression coefficients for both parameters were tested for equality among dredge sites by the GT2-method (Sokal and Rohlf 1981).

Sediment deposition. Sediment deposition was measured at dredge sites 1 - 4 during mining. Deposited sediment, less than 2 mm in diameter, was sampled with no. 10 cans (Meehan and Swanson 1977). Cans were filled with clean, rounded gravels (2.54 to 10.16 cm in diameter) and buried flush with the streambed surface along transects 1 through 4 below the dredge and at the upstream control. Six cans were placed on each transect at dredge site 1 and three cans on each transect at dredge sites 2, 3, and 4. Cans were removed from the streambed 2 to 10 days later. The gravel matrix was removed and the deposited sediment was dried at 100°C for three hours, sieved by a motorized Burrell lab shaker for 10 minutes into 6 size classes (2-1 mm, 1-0.5 mm, 0.5-0.25 mm, 0.25-0.125 mm, 0.125-0.063 mm, and <0.063 mm), and weighed. Sediment deposited per square meter per dredge day ($g/m^2/day$) was calculated. A dredge day is defined as 2.5 hours of dredging.

Data were transformed (log10) and least squares linear regression analysis was used to express sediment deposition as a function of distance below the suction dredge. Regression coefficients were considered significant at less than or equal to ten percent probability of type one error. Significant regression coefficients were tested for equality among dredge sites by the GT2-method (Sokal and Rohlf 1981).

Substrate particle sizes. The size distribution of channel substrate was determined at dredge sites 3 and 4 before and after dredge mining. Along each transect, approximately 100 substrate particles were sampled by pebble count (Dunne and Leopold 1978) and assigned to one of 13 sediment size classes (modified Wentworth scale) (Platts et al. 1983). The Mann-Whitney U-test was employed to determine statistically significant differences from pre- to post-mining at each transect (Sokal and Rohlf 1981). Less than or equal to five percent probability of type one error was considered significant.

Substrate embeddedness. Substrate embeddedness was assessed before and after mining at dredge sites 3 and 4. Embeddedness along each transect was estimated at 0.5 meter intervals by a visual rating of the percent of large particles (greater than 3 cm) buried in sand or silt (Platts et al. 1983). The distribution of embeddedness ratings at each transect was compared from pre- to post-mining by Mann-Whitney U-test (Sokal and Rohlf 1981). Less than or equal to five percent probability of type one error was considered significant.

Scour and fill. The channel cross-section of each transect at dredge sites 3 and 4 was surveyed pre- and post-mining with an automatic level and stadia rod (Emmett 1974). Cross-sectional plots and calculations of scour and fill (net change of cross-sectional area) were accomplished with the assistance of the U.S. Forest Service Pacific Southwest Laboratory computer facilities.

Young-of-the-year steelhead. The abundance of young-of-the-year steelhead was estimated at dredge sites 3 and 4 by diving with mask and snorkle. By slowly swimming and crawling up designated lanes, divers enumerated young steelhead in a 30 m reach of stream immediately below the dredge and in a 30 m reach above the dredge. Fish counts were made before dredge mining occurred at the site and immediately after mining was completed. Upstream control reaches contained habitat characteristics (depth, velocity, width, cover) similar to those below dredged areas. A paired t-test was used to compare pre- and post-mining young steelhead numbers (Sokal and Rohlf 1981). Less than or equal to five percent probability of type one error was considered significant.

RESULTS

Hydrology

During WY 1985, streamflow in Canyon Creek ranged from 0.23 cms on October 5, 1984 to 23.7 cms on November 12, 1984. A frequency analysis of annual peak discharges in the North Fork of the Trinity River indicated that the high flow had a recurrence interval of 1.9 years. Mean winter discharge was 3.28 cms and summer 0.92 cms. Four instantaneous peak discharges of 23.7, 11.2, 14.7, and 14.3 cms occurred on November 12, November 28, April 6, and April 15, respectively. A discharge rating curve, hydrograph, and flow duration curve for WY 1985 are presented in Figures 12, 13, and 14, respectively.

Water Quality

Turbidity, conductivity, and TSS levels in Canyon Creek were generally low during the study. At water quality sampling stations 1 - 4, turbidity (NTU) averaged 0.53, 0.63, 0.38, and 0.29 (Table 3), conductivity (umho) averaged 54, 53, 46, and 17 (Table 4), and TSS (mg/l) averaged 2.5, 2.1, 1.4, and 0.9 (Table 5), respectively. Stream temperatures ranged from 3 to 23°C (Table 6) and diurnal temperature change at water quality station 1 ranged from 1.7°C in mid-November to 10°C in early April (Figure 15).

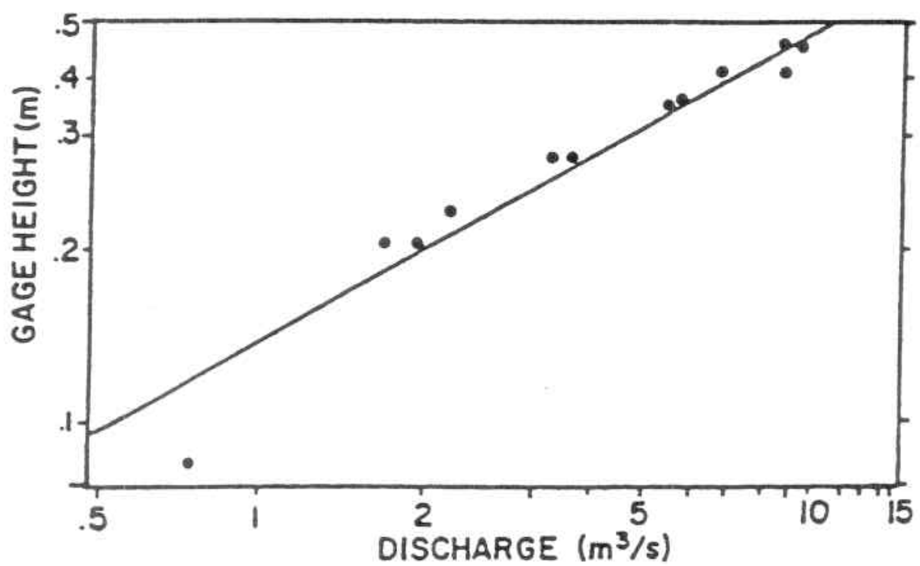


Figure 12. Stage-Discharge Relationship for Water Year 1985.

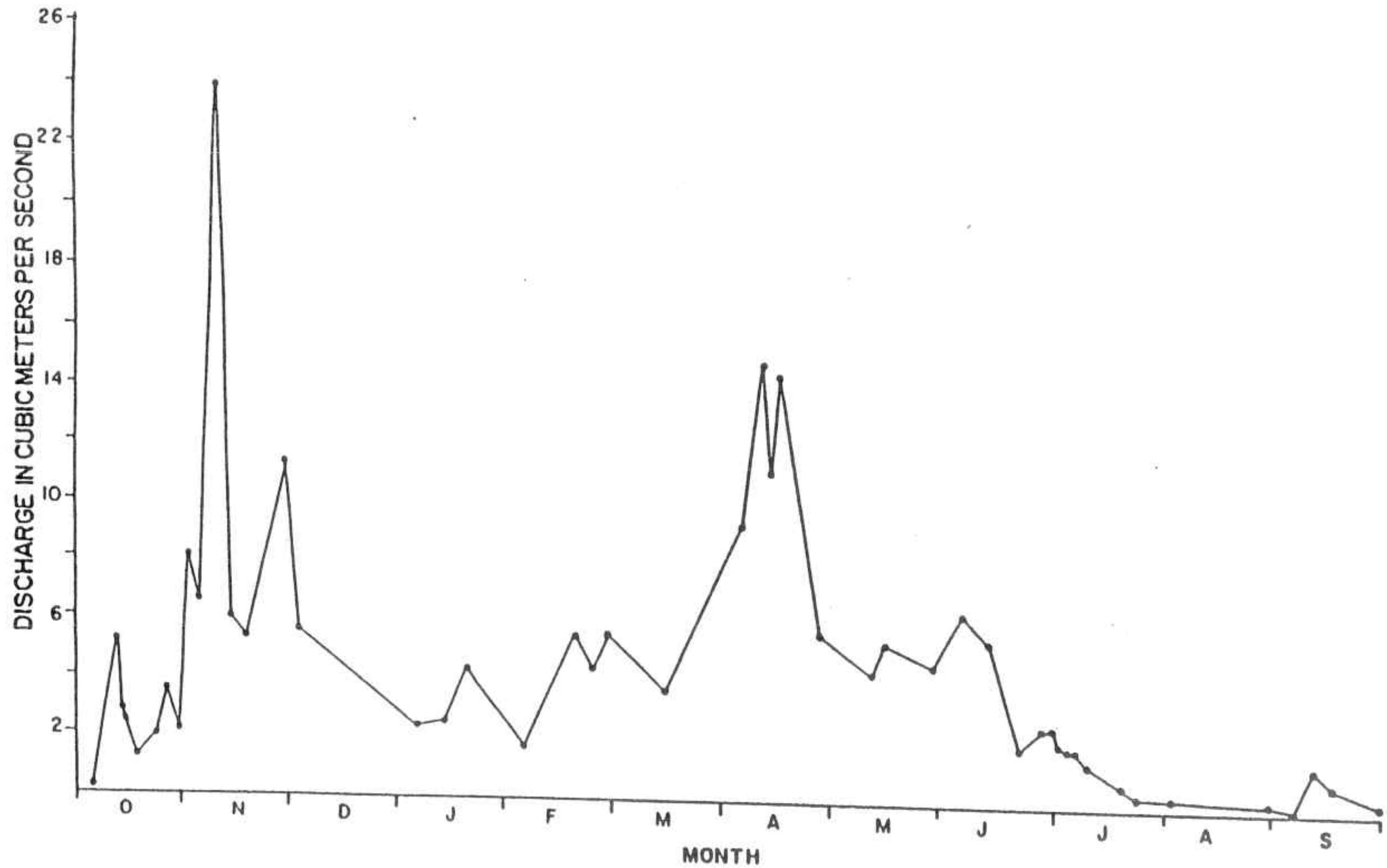


Figure 13. Hydrograph for Water Year 1985.

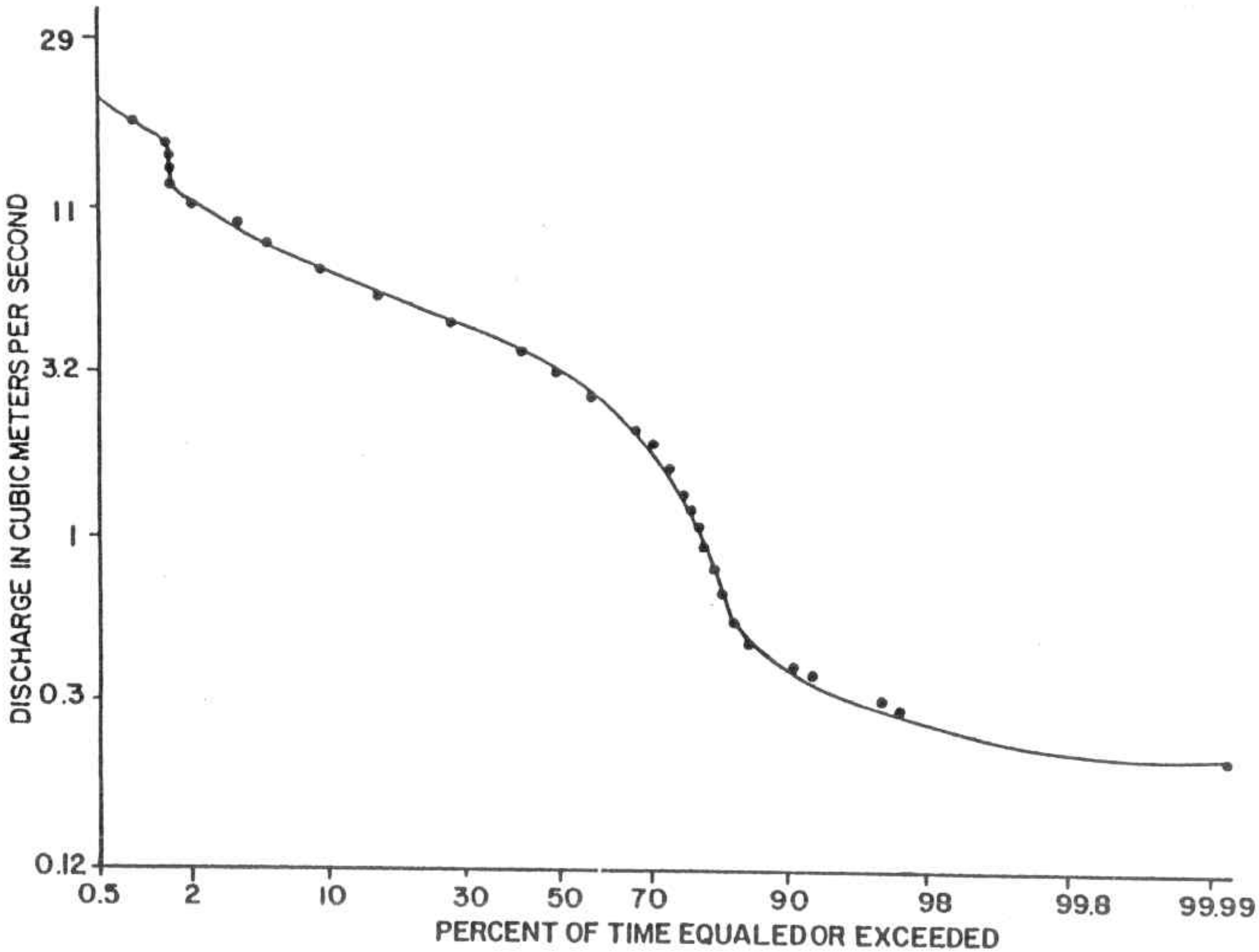


Figure 14. Flow Duration Curve for Water Year 1985.

Table 3. Turbidity (NTU) at Water Quality Sampling Stations in Canyon Creek, Trinity County, California.

Date	Station 1	Station 2	Station 3	Station 4
09/07/84	0.23	0.46	0.19	0.18
09/10/84	0.21	0.28	0.25	0.25
09/12/84	0.32	0.27	0.24	0.13
09/15/84	0.29	0.27	0.29	0.17
10/05/84	1.20	2.70	0.15	0.16
10/14/84	0.32	0.42	0.24	0.19
10/19/84	0.39	0.53	0.18	0.14
11/03/84	0.80	0.59	0.53	0.42
12/02/84	0.52	0.48	0.43	0.19
01/06/85	0.21	0.19	0.27	0.19
02/05/85	0.23	0.24	0.19	0.17
02/19/85	0.32	0.23	0.22	0.22
03/19/85	0.20	0.36	0.49	0.21
04/05/85	0.93	0.74	0.71	0.53
04/14/85	0.80	0.50	0.48	0.42
05/13/85	0.56	0.42	0.27	0.24
05/29/85	0.27	0.97	0.34	0.25
06/08/85	1.30	1.60	0.50	0.37
06/26/85	0.55	0.61	0.39	0.29
07/03/85	0.48	0.50	0.33	0.29
07/19/85	0.44	0.49	0.36	0.39
08/07/85	0.48	0.67	0.55	0.44
08/29/85	1.00	1.00	1.10	0.65
09/17/85	0.68	0.68	0.42	0.43
Mean (S.D.)	0.53 (0.321)	0.63 (0.538)	0.38 (0.209)	0.29 (0.137)

Table 4. Conductivity (micromhos) at Water Quality Sampling Stations in Canyon Creek, Trinity County, California.

Date	Station 1	Station 2	Station 3	Station 4
09/07/84	58	65	50	nd
09/10/84	60	53	nd	nd
09/12/84	68	65	51	nd
09/15/84	60	68	57	nd
10/05/84	66	79	64	nd
10/19/84	60	57	50	nd
12/02/84	80	76	75	nd
01/06/85	57	70	55	nd
02/05/85	68	50	55	nd
02/19/85	50	62	55	nd
03/19/85	52	50	nd	nd
04/05/85	40	34	35	18
04/14/85	25	26	24	13
05/13/85	34	33	28	16
05/29/85	29	27	23	13
06/08/85	20	24	20	12
07/19/85	49	47	26	20
08/07/85	62	64	56	26
08/29/85	91	65	65	nd
09/17/85	52	52	nd	nd
Mean	54	53	46	17
(S.D.)	(17.8)	(16.9)	(16.9)	(5.0)

nd = not detectable with Beckman Solubridge Model RB-5.

Table 5. Total Suspended Solids (mg/l) at Water Quality Sampling Stations in Canyon Creek, Trinity County, California.

Date	Station 1	2	3	4
10/05/84	4	3	nd	nd
04/05/85	6	6	7	4
05/13/85	3	2	nd	nd
05/29/85	nd	1	1	nd
06/08/85	6	3	1	3
07/19/85	nd	nd	nd	nd
08/07/85	nd	nd	nd	nd
08/29/85	1	2	2	nd
Mean	2.5	2.1	1.4	0.9
(S.D.)	(2.62)	(1.96)	(2.39)	(1.64)

nd = not detectable

Table 6. Stream Temperature (^{o}C) at Water Quality Sampling Stations in Canyon Creek, Trinity County, California.

Date	Station 1	Station 2	Station 3	Station 4
09/07/84	20	19	17	16
09/10/84	19	20	18	17
09/12/84	17	18	16	15
09/15/84	18	18	16	16
10/05/84	15	14	13	13
10/14/84	11	11	10	9
10/19/84	9	9	9	8
11/03/84	8	7	6	6
12/02/84	6	6	6	4
01/06/85	5	5	5	4
02/05/85	3	4	4	3
02/19/85	6	7	6	4
03/19/85	6	7	8	7
04/05/85	9	8	8	6
04/14/85	9	10	9	9
05/13/85	13	12	11	8
05/29/85	11	11	9	4
06/08/85	14	15	14	12
06/26/85	18	19	17	14
07/03/85	18	18	18	16
07/19/85	23	22	22	19
08/07/85	20	19	19	16
08/29/85	19	18	15	14
09/17/85	18	18	11	11

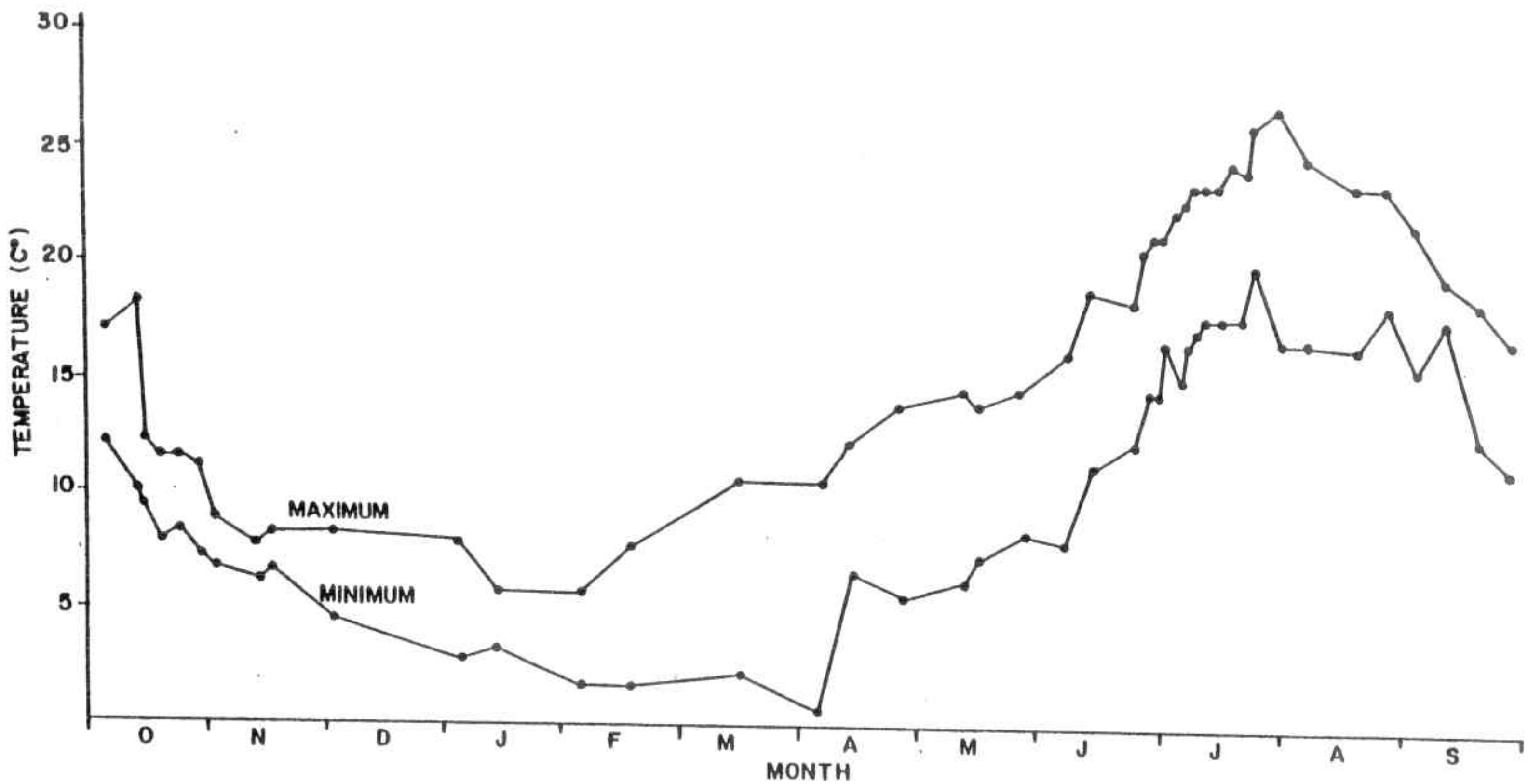


Figure 15. Maximum and Minimum Water Temperatures for Water Year 1985 at Stream Gauging Station.

Suction Dredge Mining

1984 Season

Twenty suction dredge operations excavated 29 holes in the streambed during the 1984 mining season (Table 7). Mean dredge hole depth was 1.2 m (S.D. = 0.47) below the original bed surface; mean surface area of the tailing piles was 22.3 m^2 (S.D. = 44.12); mean surface area disturbed by a dredge was 39.2 m^2 (S.D. = 61.06); and the total instream surface area disturbed was 1136.4 m^2 (Table 8). One year later, 101.6 m^2 (8.9%) of the disturbed streambed remained visible. The longitudinal stream bottom profiles at dredge hole 18 indicated that bedload movement during the winter and spring following 1984 mining filled in the dredge hole and eroded the tailing piles (Figure 16).

Fifty percent of the dredgers classified themselves as professional miners; 25 percent undercut stream banks; 15 percent channelized waters of the creek; and 25 percent caused some damage to riparian vegetation (Table 7). In 1984, at least 852 hours of suction dredging was done in Canyon Creek.

1985 Season

Fifteen suction dredge operations excavated 22 holes during the 1985 season (Table 9). Mean dredge hole depth was 1.5 m (S.D. = 0.31); mean surface area of the tailing piles was 27.9 m^2 (S.D. = 24.57); mean surface area disturbed by a dredge was 48.9 m^2 (S.D. = 46.63); and the total instream surface area disturbed was 1075.3 m^2 (Table 10).

Forty-seven percent of the dredgers classified themselves as professional miners; 47 percent undercut stream banks; 13 percent channelized waters of the creek; 13 percent damaged the riparian zone;

Table 7. Suction Dredge Mining Activity in 1984, Canyon Creek, Trinity County, California.

Operation No.	Dredge Aperture (cm)	Operators	Recreational/ Professional	Hours Operated	Dredge Hole No.[a]	Operational Impacts: Bank Undercut	Operational Impacts: Stream Channelized	Operational Impacts: Riparian Damaged
1	12.7	3	rec	45	1	x		x
2	7.6	3	rec	18	2,3			
3	15.2	1	pro	110	4,5,6			
4	10.2	1	pro	60	7,8,9,10			
5	6.4	2	rec	25	11			
6	15.2	2	rec	80	12	x		x
7	10.2	2	rec	20	13			
8	10.2	2	pro	30	14		x	
9	15.2	2	pro	168	15			x
10	6.4	2	rec	6	16			
11	10.2	1	pro	30	17	x	x	
12	6.4	1	pro	30	18			
13	15.2	2	pro	40	18		x	
14	6.4	1	pro	40	19,20	x		x
15	10.2	2	pro	-	21,22,23			
16	10.2	1	rec	45	24	x		x
17	6.4	1	rec	25	25			
18	-	1	rec	-	26			
19	10.2	2	rec	30	27,28			
20	15.2	2	pro	50	29			

[a] refer to Table 8

Table 8. Suction Dredge Holes and Tailings in 1984, Canyon Creek, Trinity County, California.

Dredge Hole	Depth (m)	Length (m)	Width (m)	Surface Area (m^2)			
				Hole	Tailings	Total	Visable Following Year
1	0.9	3.7	2.7	10.0	4.8	14.9	0.6
2	0.5	4.6	2.1	9.8	25.7	35.5	0
3	0.5	2.4	2.1	5.2	9.9	15.1	0
4	1.5	5.5	4.6	25.1	19.6	44.7	0
5	1.2	3.0	2.1	6.5	7.4	13.9	0
6	1.2	2.7	3.4	9.2	12.3	21.5	0
7	1.1	4.6	4.0	18.1	12.1	30.3	0
8	1.5	5.5	4.6	25.1	23.8	48.9	0
9	1.2	4.9	3.7	17.8	12.1	29.9	0
10	1.2	4.0	1.5	6.0	4.8	10.9	0
11	0.6	4.0	2.9	11.5	11.5	23.0	0
12	2.4	7.6	6.1	46.5	15.3	61.8	1.5
13	1.5	6.4	2.4	15.6	18.7	34.3	0.1
14	1.4	4.6	3.0	13.9	21.6	35.5	1.5
15	2.4	13.1	5.5	71.9	91.5	163.4	11.1
16	0.9	2.1	1.8	3.9	9.5	13.4	2.3
17	0.9	1.8	3.0	5.6	13.4	19.0	0
18	2.1	12.8	6.6	83.9	237.9	321.8	78.7
19	0.9	1.8	1.8	3.3	0.1	3.4	0
20	0.9	2.4	1.5	3.7	2.2	5.9	0
21	1.2	3.0	2.4	7.4	14.9	22.3	0
22	1.2	1.5	2.4	3.7	5.6	9.3	0
23	1.2	2.7	2.1	5.9	6.7	12.5	0
24	0.9	8.2	3.4	27.6	11.9	39.5	5.8
25	0.9	6.1	3.7	22.3	1.9	24.2	0
26	1.6	1.8	4.6	8.4	9.8	18.1	0
27	0.9	2.7	1.4	3.8	1.4	5.2	0
28	1.2	2.1	1.2	2.6	0	2.6	0
29	1.5	4.9	3.0	14.9	41.0	55.9	0
Stream total				489.9	647.4	1136.4	101.6

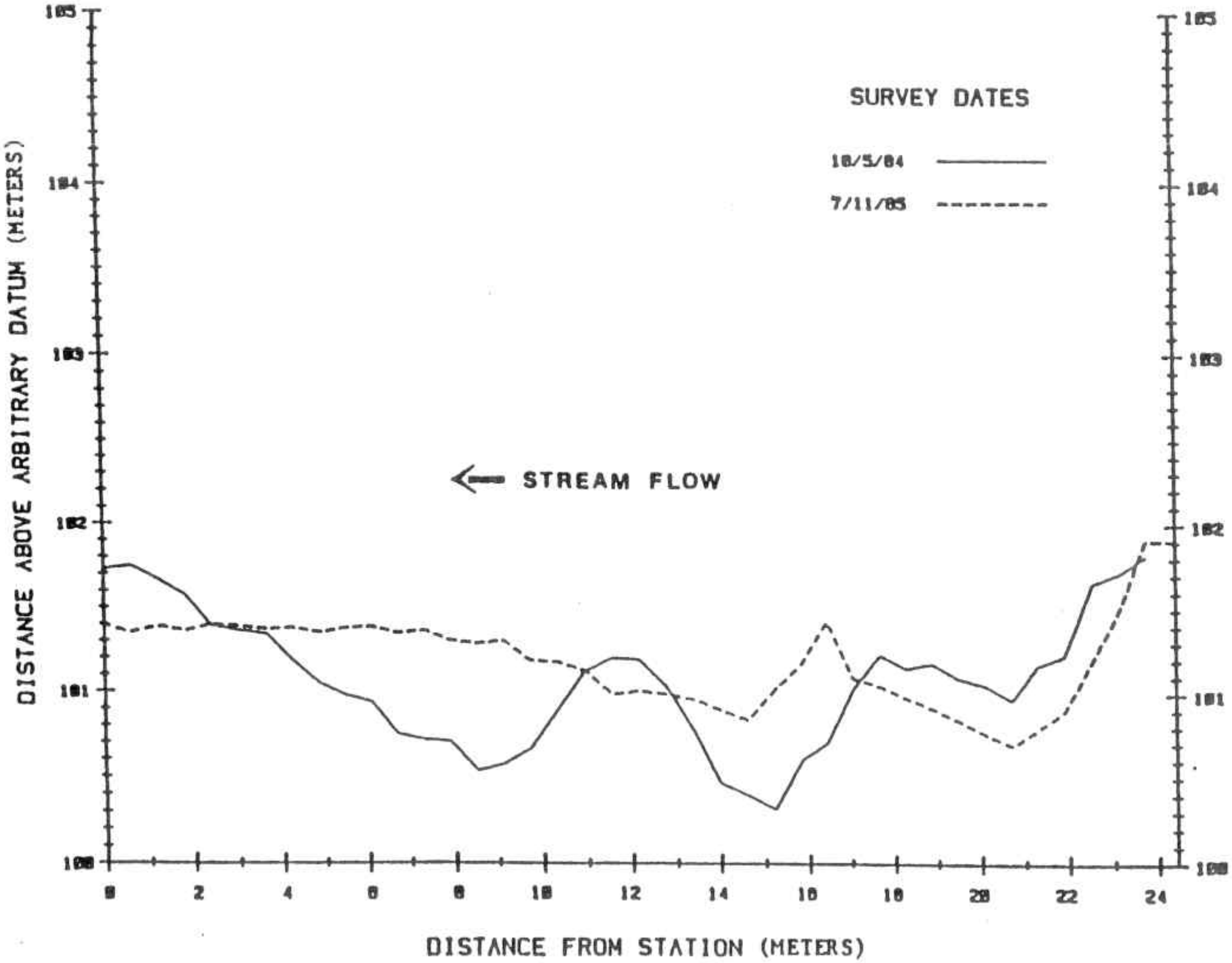


Figure 16. Longitudinal Channel Profile at Dredge Hole #18.

Table 9. Suction Dredge Mining Activity in 1985, Canyon Creek, Trinity County, California.

Dredge Operation No.	Aperture (cm)	Operators	Recreational/ Professional	Hours Operated	Dredge Hole No.[a]	Operational Impacts: Bank Undercut	Bank Sluice	Stream Channelized	Riparian Damaged
1	10.2	2	rec	-	1,2,3	x			x
2	12.7	1	pro	30	4				
3	10.2	1	pro	25	5				
4	12.7	2	rec	130	6,7	x			
5	12.7	1	pro	-	8				
6	10.2	1	rec	28	9	x			
7	10.2	2	pro	35	10	x			
8	12.7	2	rec	75	11	x	x	x	
9	10.2	1	pro	38	12,13			x	
10	12.7	1	pro	70	14,15,16				
11	10.2	2	rec	110	17,18				
12	12.7	1	rec	10	19				
13	10.2	3	rec	100	20				x
14	12.7	3	rec	60	21	x			
15	12.7	2	pro	120	22	x			

[a]refer to Table 10

Table 10. Suction Dredge Holes and Tailings in 1985, Canyon Creek, Trinity County, California.

Dredge Hole	Depth (m)	Length (m)	Width (m)	Surface Area (m^2)		
				Hole	Tailings	Total
1	1.2	4.3	2.4	10.4	21.5	31.9
2	1.5	2.4	2.1	5.2	11.7	16.9
3	1.7	4.0	3.2	12.7	20.7	33.4
4	1.4	3.7	2.1	7.8	7.2	15.0
5	1.1	2.1	2.7	5.9	11.1	17.0
6	1.1	2.7	3.0	8.4	0	8.4
7	1.5	10.7	4.3	45.5	55.5	101.0
8	1.8	6.1	7.6	46.5	26.0	72.5
9	1.1	1.8	5.5	10.0	49.4	59.5
10	1.4	6.1	2.7	16.7	21.4	38.1
11	2.0	6.1	5.2	31.6	66.5	98.1
12	1.5	3.0	4.3	13.0	41.3	54.3
13	1.1	2.7	2.4	6.7	24.5	31.2
14	1.5	3.7	2.7	10.0	14.1	24.2
15	1.5	1.8	2.4	4.5	6.1	10.6
16	1.8	2.7	3.0	8.4	10.0	18.4
17	1.5	2.4	6.1	14.9	30.7	45.5
18	1.8	3.7	7.3	26.8	24.2	50.9
19	0.8	3.0	1.8	5.6	3.3	8.9
20	1.8	6.1	5.5	33.4	21.7	55.2
21	1.8	3.7	6.1	22.3	35.7	58.0
22	1.8	15.2	7.6	116.1	110.2	226.3
Stream total				462.1	612.8	1075.3

and 7 percent sluiced material from upper stream banks (Table 9). In 1985, at least 831 hours of suction dredging was done in Canyon Creek.

Adult Anadromous Salmonids

In August 1985, 29 spring-run chinook salmon adults and 10 summer-run steelhead adults were observed in the study area (Table 11). Total length of spring-run chinook salmon ranged from 48 to 77 cm and summer-run steelhead from 38 to 48 cm. Seventeen percent of the chinook salmon were adipose fin-clipped and one also was spaghetti tagged at the CDFG weir at Willow Creek, Trinity River. No marks or tags were observed on steelhead. Seventy-two percent of the summer-holding adult salmonids were located in pools 1 to 2.5 m deep. Twenty-eight percent were in the vicinity of active suction dredge operations.

Localized Effects

Four suction dredge mining operations in Canyon Creek were investigated during the study to determine localized effects of an individual dredge. The characteristics of the four dredge study sites are summarized in Table 2.

Water quality. At dredge sites 1 - 4, turbidity and TSS levels decreased with distance below the dredge (Tables 12 and 13). Values 50 m below the dredge were at least 2 to 3 times higher than that of the control, but at 100 m below values approached control levels. Statistically significant relationships between turbidity and distance downstream of the dredge were determined at sites 1, 2, and 3 (Figure 17) and between TSS levels and distance below the dredge at sites 1, 3, and 4 (Figure 18). The slopes of the regression lines for turbidity and TSS did not differ significantly among dredge study sites by test for

Table 11. Adult Anadromous Salmonids Observed during August 1985, Canyon Creek, Trinity County, California.

Species	Total Length (cm)	Mark/Tag	Stream Depth (m)	Cover	Dredge Activity
Chinook	66	ad clip	2.4 pool	depth, ledge	-
Chinook	56	-	0.5 run	whitewater	-
Chinook	74	ad clip	1.0 glide	ledge	-
Steelhead	46	-	2.0 pool	depth	250 m upstream
Steelhead	48	-	2.0 pool	depth	250 m upstream
Chinook	69	-	0.6 run	whitewater	150 m upstream
Steelhead	46	-	0.8 pool	whitewater	30 m downstream
Chinook	61	-	1.2 pool	depth	-
Chinook	61	-	1.5 pool	depth, ledge	-
Chinook	51	-	1.2 pool	depth, whitewater	-
Chinook	56	-	1.2 pool	depth, whitewater	-
Steelhead	38	-	1.2 pool	depth, whitewater	-
Chinook	61	-	1.2 pool	depth	100 m downstream
Steelhead	38	-	0.8 pool	whitewater	100 m downstream
Chinook	48	-	1.8 pool	depth	-
Steelhead	43	-	1.8 pool	depth	-
Chinook	56	-	1.4 pool	depth, ledge	-
Chinook	69	-	1.0 pool	whitewater	-
Chinook	61	-	1.0 pool	whitewater	-
Chinook	56	-	1.0 pool	whitewater	-
Chinook	64	-	0.6 pool	whitewater	-
Chinook	56	-	0.9 pool	depth	-
Chinook	56	ad clip	1.1 pool	depth	-
Steelhead	46	-	0.3 pool	whitewater	-
Chinook	64	-	0.9 pool	depth	-
Chinook	51	-	2.1 pool	depth	-
Chinook	71	-	1.1 pool	depth	-
Chinook	64	-	1.1 pool	depth	-
Steelhead	41	-	1.1 pool	depth	-
Chinook	61	-	0.4 run	whitewater	200 m upstream
Chinook	58	-	0.9 pool	whitewater	220 m downstream
Chinook	51	-	1.1 pool	whitewater	330 m downstream
Steelhead	38	-	1.1 pool	whitewater	330 m downstream
Chinook	58	-	1.2 pool	depth	-
Chinook	77	ad clip	2.1 pool	depth	-
Chinook	61	-	1.4 pool	whitewater	-
Chinook	74	-	2.0 pool	whitewater	50 m upstream
Steelhead	41	-	1.2 pool	depth	-
Chinook	64	ad clip, tag	2.4 pool	depth	-

Table 12. Average Turbidity and Total Suspended Solids (TSS) at Suction Dredge Sites 1 and 2, Canyon Creek, Trinity County, California.

Transect	Distance below dredge (m)	Turbidity (NTU)		TSS (mg/l)	
		Site 1 n=4	Site 2 n=3	Site 1 n=2	Site 2 n=2
Control		0.24	0.23	0	0
1	10	2.22	1.81	62.5	21.0
2	22	1.24	0.65	15.0	274.0
3	42	0.66	0.57	4.0	2.0
4	72	0.48	0.44	1.0	2.0
5	100	0.44	0.27	4.5	1.0

Table 13. Average Turbidity and Total Suspended Solids (TSS) at Suction Dredge Sites 3 and 4, Canyon Creek, Trinity County, California.

Transect	Distance below dredge (m)	Turbidity (NTU) Site 3 n=2	Turbidity (NTU) Site 4 n=2	TSS (mg/l) Site 3 n=2	TSS (mg/l) Site 4 n=2
Control		0.5	0.9	0	0
1	4	20.5	5.6	244.0	47.5
2	9	5.8	3.7	31.5	14.0
3	16	4.8	2.7	22.0	7.5
4	25	3.8	3.5	14.5	4.5
5	36	4.0	4.0	16.5	6.5
6	49	3.3	2.8	11.5	4.0

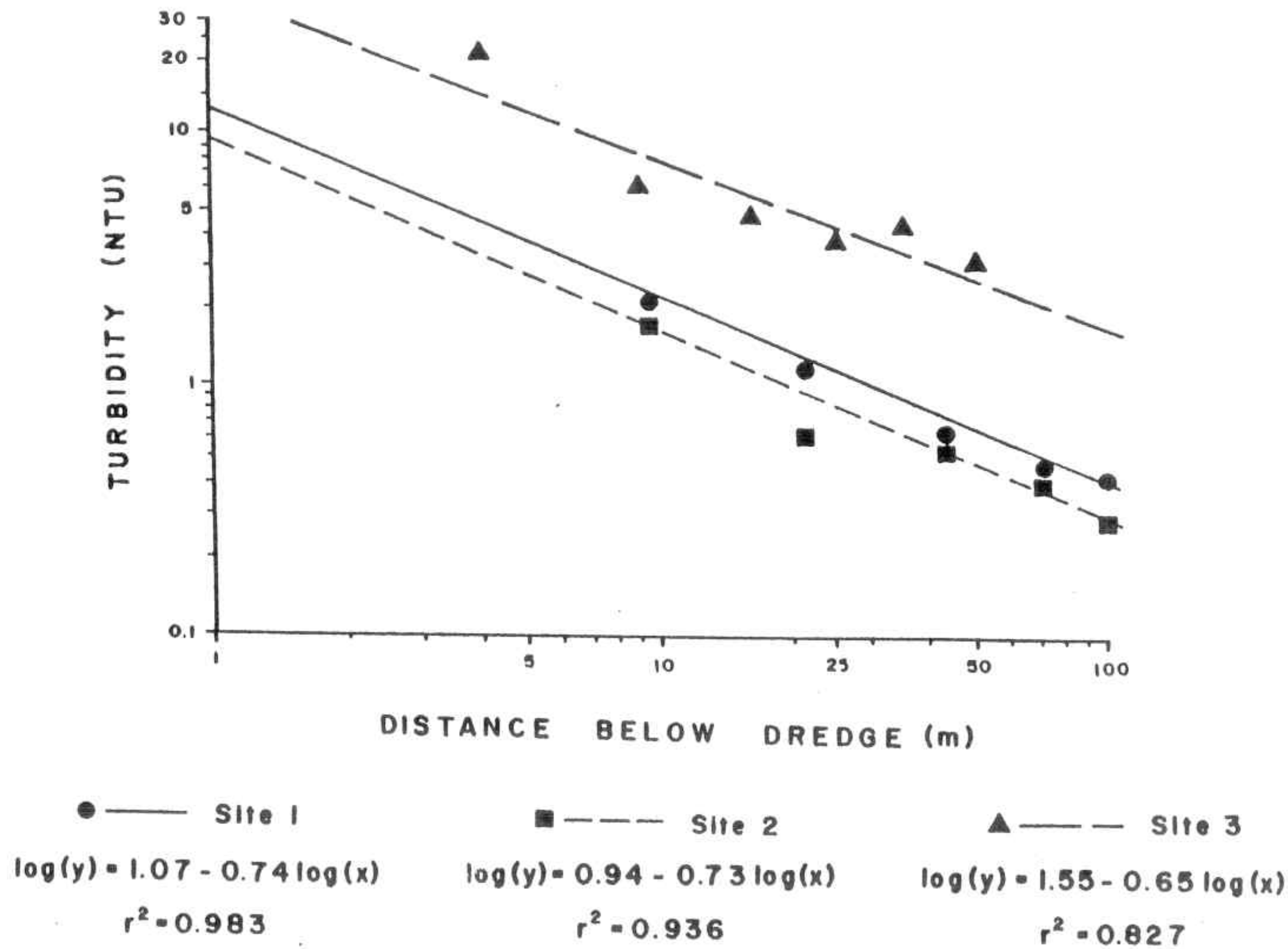
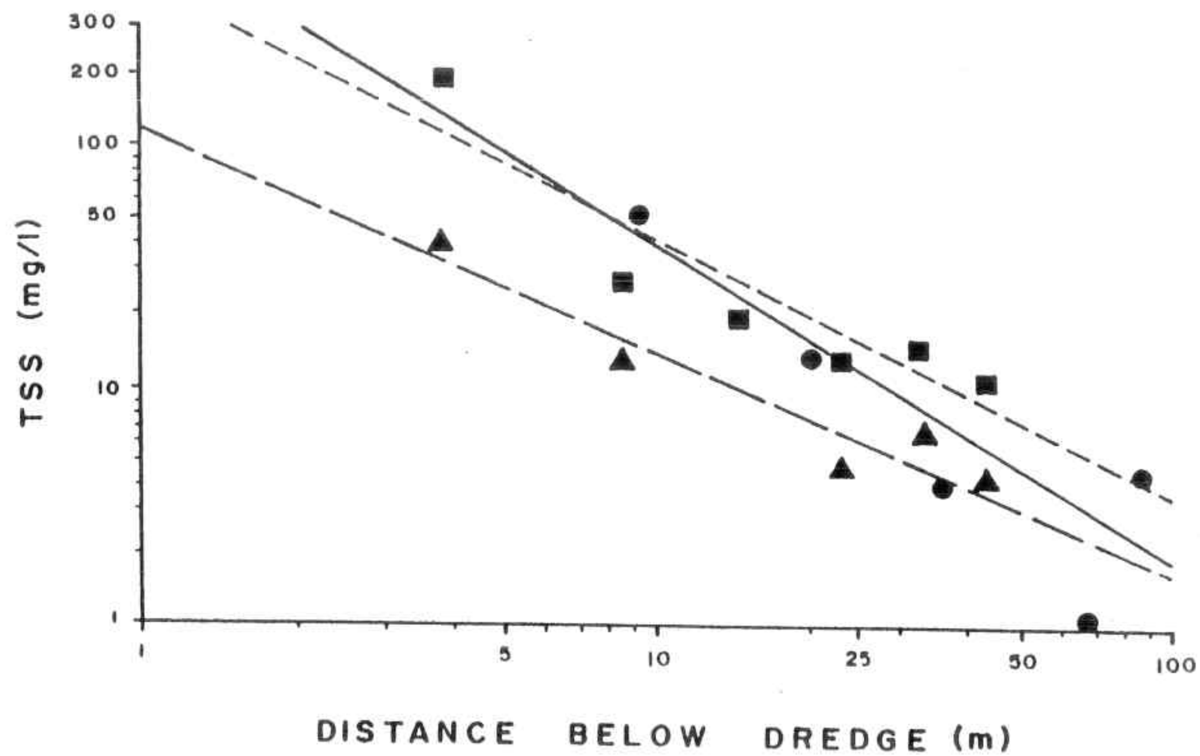


Figure 17. Turbidity at Various Distances Below Dredge for Sites 1, 2, and 3.



● ——— Site 1

$\log(y) = 3.16 - 1.48 \log(x)$

$r^2 = 0.774$

■ – – – Site 3

$\log(y) = 2.81 - 1.10 \log(x)$

$r^2 = 0.844$

▲ —— —— Site 4

$\log(y) = 2.11 - 0.93 \log(x)$

$r^2 = 0.892$

Figure 18. Total Suspended Solids (TSS) at Various Distances Below Dredge for Sites 1, 3, and 4.

equality of regression coefficients (GT2-method; $p \leq 0.05$). Stream temperature and conductivity were not affected by suction dredge mining. Temperatures during dredge mining ranged from 15.5 to 20.5°C and conductivity from 47 to 85 umho.

<u>Sediment deposition</u>. Sediment deposited at dredge sites 1 - 4 decreased with distance below the dredge (Table 14). At 9 and 10 m below dredge, average deposited sediment ranged widely between dredge sites (674 to 42,366 $g/m^2/day$). Statistically significant relationships between sediment deposition and distance below the dredge were determined at sites 1, 2, and 4 (Figure 19). Slopes of the regression lines did not differ significantly among dredge sites by test for equality of regression coefficients (GT2-method; $p \leq 0.05$).

<u>Substrate particle sizes</u>. Substrate particle size distributions at dredge site 3 decreased significantly from pre- to post-mining along transects 1 and 2 (Mann-Whitney U-test; $p \leq 0.05$). At dredge site 4 only transect 1 showed a significant decrease of particle size distribution from pre- to post-mining (Mann-Whitney U-test; $p \leq 0.05$). Particle size distributions did not differ significantly along controls or other downstream transects.

<u>Substrate embeddedness</u>. Substrate embeddedness along all transects below the dredge at site 3 increased significantly from pre- to post-mining (Mann-Whitney U-test; $p \leq 0.05$). Embeddedness at site 3 control transect did not differ significantly over time. Substrate embeddedness at site 4 was significantly increased from pre- to post-mining along transects 3 - 6 (Mann-Whitney U-test; $p \leq 0.05$). Transects 1, 2 and control did not differ significantly.

Table 14. Average Deposited Sediment (grams/m^2/day) at Dredge Sites 1, 2, 3, and 4, Canyon Creek, Trinity County, California.

Transect	Distance below dredge (m)	Deposited Sediment ($g/m^2/day$) Site 1	Site 2	Site 3	Site 4
Control		7	46	22	105
1	4	-	-	-	12080
2	9	-	-	42366	674
1	10	1859	3204	-	-
3	16	-	-	1154	362
2	22	330	3858	-	-
4	25	-	-	1207	285
3	42	199	238	-	-
4	72	62	117	-	-

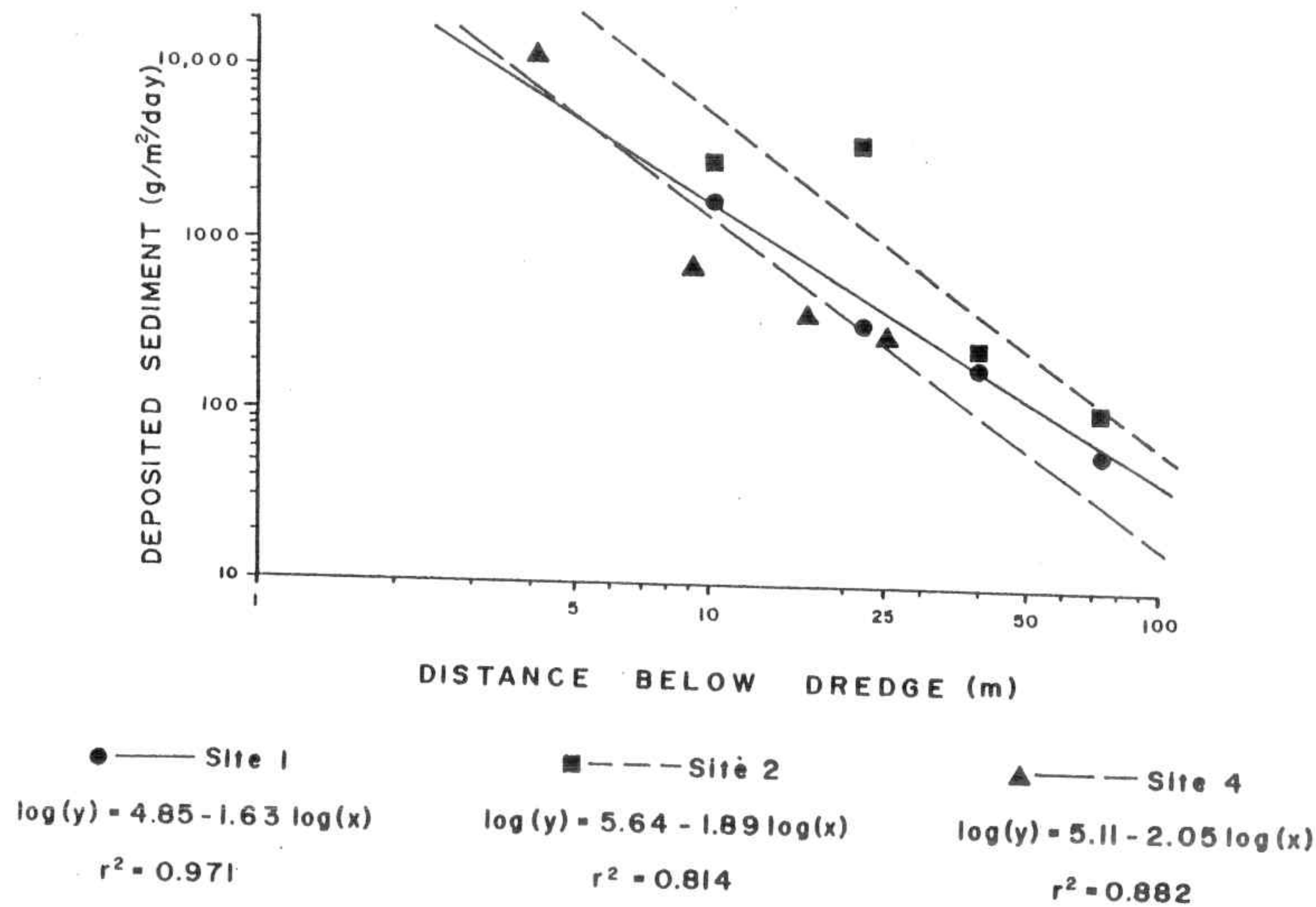


Figure 19. Deposited Sediment at Various Distances Below Dredge for Sites 1, 2, and 4.

Scour and fill. At dredge site 3, the cross-sectional area of transect 1 was reduced by 0.77 m^2 (6.3%) and transect 2 was reduced by 1.29 m^2 (10.5%) (Figure 20). Transects 3 - 6 and control showed minor changes in cross-sectional area; net fill occurred at transects 3 and 5 and net scour at transects 4, 6, and control (Figure 20). At dredge site 4, the cross-sectional area of transect 1 was reduced by 1.19 m^2 (7.7%) (Figure 21). Minor amounts of net scour occurred at transects 2, 3, 4, and control; and minor amounts of net fill occurred at transects 5 and 6 (Figure 21).

Young-of-the-year steelhead. Numbers of young-of-the-year steelhead declined from pre- to post-mining at upstream control areas and below dredged areas. At site 3, young steelhead decreased 31 percent (137 to 94) below dredge and 24 percent (95 to 72) at the control. At site 4, young steelhead decreased 13 percent (103 to 90) below dredge and 14 percent (119 to 102) at the control. Paired t-tests did not show the rates of decline to differ significantly between control areas and below dredged areas.

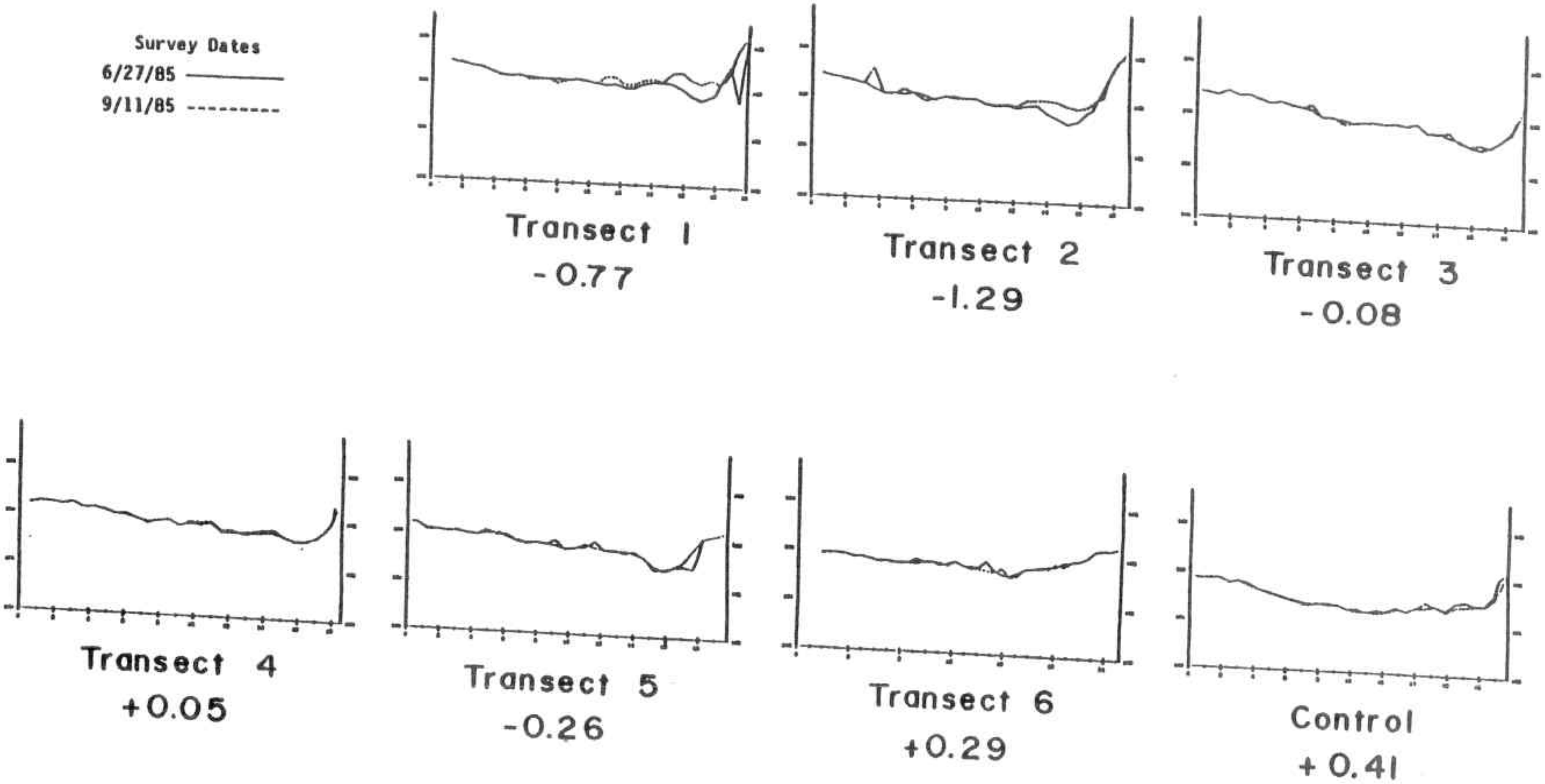


Figure 20. Channel Cross-sections and Net Change (m^2) of Cross-sectional Areas at Dredge Site 3.

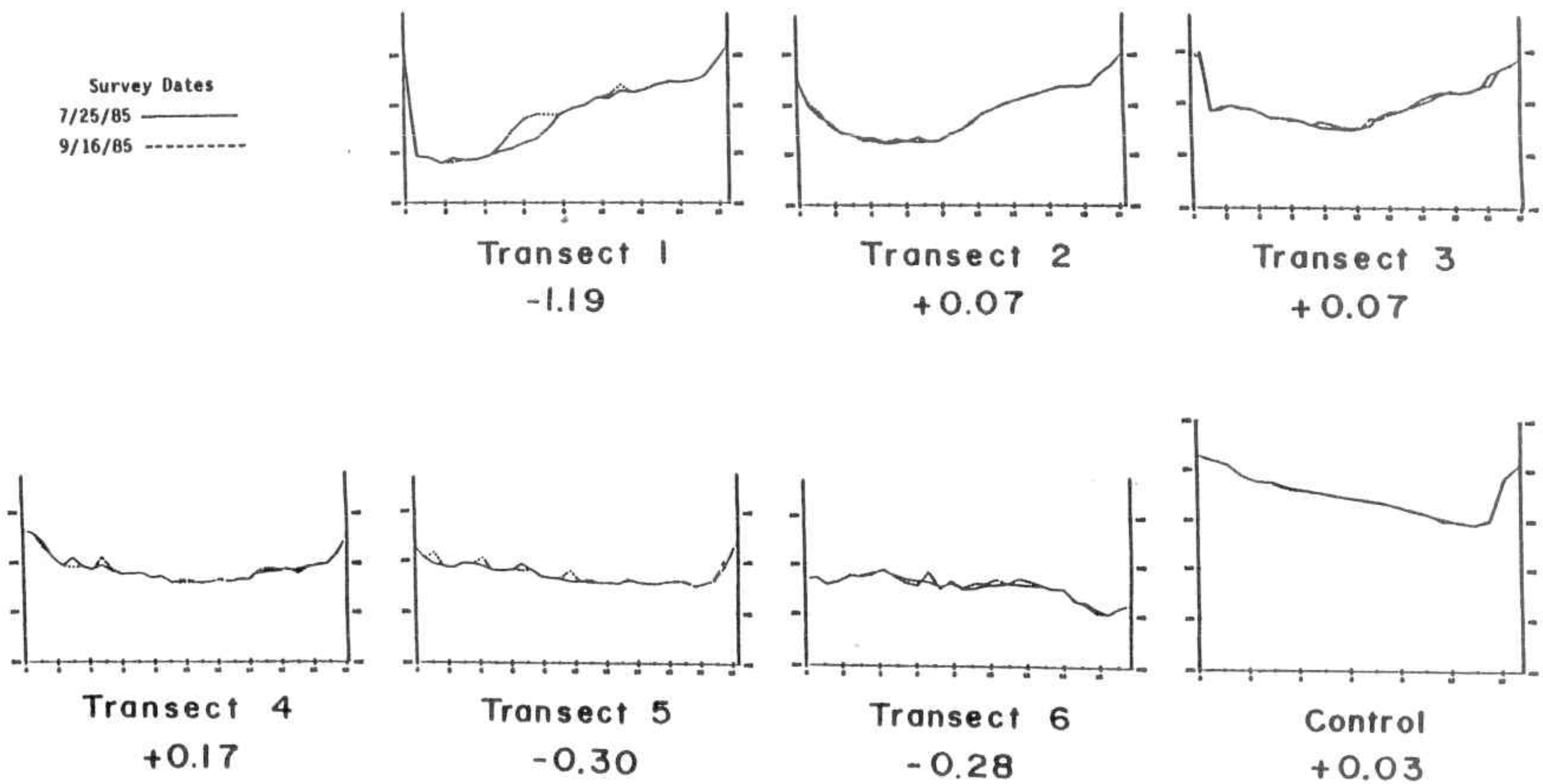


Figure 21. Channel Cross-sections and Net Change (m^2) of Cross-sectional Areas at Dredge Site 4.

DISCUSSION

Hydrology

Streamflow variation in Canyon Creek is an advantage to suction dredge miners. Low summer flows create ideal conditions for dredge mining by providing easy access to alluvial deposits in the active stream channel, and usually there is enough water to float and operate a dredge. High winter flows transport large quantities of bed material which fill in dredge holes, disperse tailing piles, and redistribute placer gold deposits. Streamflows in Canyon Creek were not atypical during the study. Low flows commonly persist through the months of August and September while autumn, winter and spring flows fluctuate widely. The highest stream discharge recorded during the study (23.7 cms on 11/12/85) was estimated to be bankfull level for the channel and have an average recurrence interval of 1.9 years. This discharge played a crucial role in WY 1985's channel maintenance by moving silt and sediment, forming and reforming bars and riffles, and obliterating most of the dredge holes and tailing piles created during the 1984 mining season.

Water Quality

In comparison to other Trinity River tributaries, Canyon Creek has excellent water clarity (DWR 1980). Turbidity, TSS, and conductivity levels were generally very low. All water quality parameters were lowest at the most upstream sampling site, station 4, due perhaps to its location 3 km downstream of the Trinity Alps Wilderness boundary. The gradual increase of turbidity, TSS, and conductivity levels with distance downstream was probably a result of dredging, road maintenance, logging and home development in the study area. On a few occasions improper mining practices at a large high-bar placer mine raised turbidity for a distance of 7 or 8 km downstream. A coagulant that was used in settling ponds at the high-bar mine leeched into the stream for a period of 5 to 6 days, and on two occasions banks overloaded with mine tailings collapsed into the stream. Stream temperatures in the study area were generally well within the recommended ranges for migration, spawning, incubation, and rearing of salmonid fishes (Reiser and Bjornn 1979).

Suction Dredge Mining

Suction Dredge Operations

In 1984, an array of dredge operators worked small areas in the streambed for 2 or 3 weeks at a time. In 1985, fewer dredge operators worked larger areas for longer periods of time. The total hours of dredge operation and total streambed surface area disturbed in both 1984 and 1985 were similar.

Damage to fish habitat by dredgers included undercutting of stream banks, channelizing waters of the stream, and clearing of riparian vegetation. These adverse operational impacts were not uncommon on Canyon Creek and have been reported by other investigators (Harvey et al. 1982; McCleneghan and Johnson 1983) (Table 15). Undercutting of streambanks was the most common adverse impact on Canyon Creek. This removal of materials along and under the base of a bank can

Table 15. Suction Dredge Operation Impacts.

Impacts	No. of dredge operations		
	Sierra Foothills[a]	Canyon Creek	
	1983	1984	1985
Bank undercutting	14	5	7
Channelization of stream waters	12	3	2
Riparian damage	7	5	2
Sluicing of bank	1	0	1
Total No. surveyed	270	20	15

[a]McCleneghan and Johnson (1983).

destabilize the slope and trigger bank failure. Thirty-four percent of the miners undercut banks as compared to 7 percent reported in Sierra Nevada foothill streams (McCleneghan and Johnson 1983). Bank undercutting may have been more extensive in Canyon Creek due to the small size of the creek channel and its steep, narrow banks. In addition to undercutting, dredging along banks also led to channelization of the stream to bring water to working areas and the removal of overhanging vegetation, protruding logs and rocks, and root clusters. This type of activity can change diverse and intricate stream banks to relatively straight and uniform stream margins.

The condition of the stream bank and riparian zone is closely linked to the stability of the channel and the quality of fish habitat. The woody and fibrous roots of riparian species provide a physical barrier to the erosive forces of flowing water and create banks with considerable surface roughness. Overhanging banks and associated root complexes often provide important cover for rearing and adult fish. Overwintering juvenile steelhead and coho salmon are particularly dependent on undercut streambanks for cover (Bustard and Narver 1975). California law limits the operation of suction dredges to the wetted perimeter of the stream (Cal. Admin. Code, Title 14, Sec. 228) and to "... substantially change the bed, channel or bank of any river, stream or lake designated by the (California Department Fish and Game) ..." is prohibited (Calif. Fish and Game Code, Sec. 1603, 1982). Therefore, this type of dredge mining damage to fish habitat is not always prohibited by law. Impacts must be deemed "substantial changes" by law enforcement officers to warrant a violation of the Fish and Game Code.

This vague wording of the law and the absence of procedural guidelines for suction dredge operators have created difficulties for Fish and Game wardens as well as dredge miners.

Activities by miners supporting the dredge operation were also detrimental to the stream bank and riparian zone. Trails were blazed up and down banks, and through the riparian zone for accessing people and equipment to the dredge site. Shrubs, limbs and even small trees were pruned or removed for the stringing of cables, pulleys and winches. One miner trimmed riparian vegetation from bedrock crevices on his placer claim so the plants' roots would not break apart rock formations. Some dredgers cleared areas for campsites in the riparian zone. Harvey et al. (1982) and McCleneghan and Johnson (1983) reported similar damage to riparian zones along the Yuba River, Butte Creek and other Sierra foothill streams.

Not every case of bank undercutting and riparian damage observed on Canyon Creek warranted a violation of the law or contributed to reducing the integrity of the streambank. However there were some cases that did and their mode of dredge operation should have been questioned or cited. Dredging on or directly below the bank must be conducted with caution to avoid undermining the bank and damaging the root systems of riparian species. Trails and campsites should be planned and carefully constructed to avoid gully erosion, bank wasting, and vegetation damage. The single case of sluicing materials from the upper bank into the stream observed during 1985 was clearly illegal, and did contribute to accelerated bank erosion during the following winter.

undesirable spawning substrate since these gravels are deposited on top of the streambed during summer low flows and are easily transported by fall and winter peak flows. The longitudinal bottom profile of a dredge hole and tailing pile presented in figure 16 exemplifies their erodibility. Salmonid redds constructed in loose, unconsolidated gravels are susceptible to scour and often result in a direct loss of eggs and larve (Gangmark and Bakkala 1960).

The absence of fines and the well-sorted nature of tailing piles also make dredge tailings undesirable for salmonid spawning. Platts et al. (1979) found that spring and summer-run chinook salmon in the Salmon River Basin of Idaho did not select channel substrates devoid of fine sediment. The "weathering" of gravel, required for acceptance by salmonid spawners (Reeves and Roelofs 1982), may be important for substrate stability and embryo survival (Platts et al. 1979).

Adult Anadromous Salmonids

Canyon Creek supports a small population of spring-run chinook salmon and summer-run steelhead trout. The number of spring-run chinook salmon (29) observed in August 1985 matched the number observed by Freese (1980) in 1980 and closely approximated the number trapped by CDFG in 1983 (M. Zuspan pers. comm.) (Table 16). This suggests that spring-run chinook salmon in Canyon Creek have been relatively stable from 1980 to 1985. Marcotte (in prep.) suggested that the present spring-run chinook salmon of Trinity River tributaries are mostly hatchery strays. This is probably true for Canyon Creek because 17.2 percent of the spring-run chinook salmon observed during 1985 were known to be of hatchery origin (adipose fin clip) and 26.5 percent of the spring-run chinook salmon that returned to the Trinity River hatchery in

Flushing Flows

The autumn, winter and spring peak flows of WY 1985 at Canyon Creek were adequate to disperse dredge tailing piles and fill in dredge holes. Less than 9% of the holes and tailings from 1984 mining were visible at the start of the 1985 dredge season. Only two sites from 1984 had clear remnants of holes and tailings in 1985. Both of these were far from the stream's thalweg. At a few sites large cobbles and boulders piled along the shore remained visible one year later. Thomas (1985) reported that piles of cobbles remained along the shore one year later at Gold Creek, Montana, but holes and instream tailings had vanished. Harvey et al. (1982) found virtually no evidence of dredge mining the following year in the American River, California. Most streams with mobile beds and good annual flushing flows should be able to remove the instream pocket and pile creations of small suction dredges, although regulated streams with controlled flows may not.

Anadromous Salmonid Spawning

Dredge tailing piles are sometimes referred to as good salmonid spawning substrate. In the Trinity River, chinook salmon have been observed spawning in dredge tailing piles (E. Miller pers. comm.). Steelhead trout in Idaho streams have been reported to spawn in gravels recently disturbed by human activities (Orcutt et al. 1968). Prokopovich and Nitzberg (1982) have shown through petrographic analysis that in the American River Basin, California present channel gravels, including salmon spawning gravels, have mostly originated from old placer mining operations. In Canyon Creek, several spawning surveys located approximately 60 salmonid redds in the study area, but none were within a dredge tailing pile. In general, tailing piles were judged as

Table 16. Summer-run Adult Salmonids in Canyon Creek, Trinity County, California.

Year	Steelhead	Chinook Salmon Marked[a]	Chinook Salmon Unmarked	Chinook Salmon Total
1980[b]	6			29
1983[c]	3	6	21	27
1985[d]	10	24	5	29

[a]Adipose fin clip.

[b]Freese, L. NMFS, Auke Bay, Alaska, personal communication. Method: direct observation.

[c]California Department of Fish and Game, Anadromous Fisheries Branch, Arcata. Method: upstream migrant trap (July-August).

[d]Present study. Method: direct observation.

1985 had adipose fin clips (G. Bedell pers. comm.). The numbers of summer-run steelhead observed in Canyon Creek have been too low for meaningful comparison.

Suction dredge mining did not appear to influence the locations of adult anadromous salmonid summer-holding areas. One spring-run chinook salmon was observed 50 m below an operating dredge and a summer-run steelhead was seen at the upper end of a 30 m-long pool while a dredge was operating at the lower end. Seven other adult salmonids were observed within 250 m of an active dredge operation and none appeared to be disturbed by mining activities. During a 1980 diving survey by Freese (1980), an adult spring-run chinook salmon was observed holding at the bottom of an abandoned dredge hole in Canyon Creek and other adult salmonids were found in close proximity to active dredges. No relation between holding areas of spring/summer-run fish and suction dredge mining operations was apparent during this study or in 1980 (L. Freese pers. comm.).

Localized Effects

Water quality. Turbidity plumes below suction dredges are often markedly visible due to extremely low ambient turbidity levels in mountain streams. The extent of the plume depends on the grain size and volume of the material passing through the dredge. Horizons of silt-laden substrate were disturbed at all dredge sites in Canyon Creek and created highly visible turbidity plumes.

Although distinct to even the most casual observer, dredge plumes in Canyon Creek were probably of little direct consequence to fish and invertebrates. Suspended sediment concentrations of 20,000 to 100,000 mg/l which impact fish feeding and respiration (Cordone and

Kelley 1961) greatly exceed the highest level of 274 mg/1 measured in Canyon Creek. In general, dredge turbidity plumes were highly localized and occurred during midday which is not a peak feeding period for steelhead (Moyle 1976). Laboratory studies by Sigler et al. (1984) found that steelhead and coho salmon preferred to stay in channels with clear water, and turbidities as little as 25 NTUs caused a reduction in fish growth. In contrast to Sigler's results, young steelhead in Canyon Creek appeared to seek out dredge turbidity plumes to feed upon dislodged invertebrates even though clear flowing water was available nearby.

Sediment deposition. A number of factors influence the deposition of sediments below a suction dredge. These include the size and availability of fine sediments; the size and capacity of the suction dredge; and stream power. Although these variables make comparison of sediment depositional rates among investigations difficult, some parallels do exist. Thomas (1985) measured a mean sediment deposition of about 1000 $g/m^2/day$ 10 m below a 6.4 cm aperture dredge and Harvey et al. (1982) measured a high of 2075 $g/m^2/day$ at 12 m below a 15.24 cm aperture dredge. In Canyon Creek, sediment depositional rates ranged from 674 to 42,366 $g/m^2/day$ at 9 m below a 10.16 and 12.70 cm aperture dredge. The high value was from an extremely silted-in site and was not typical of Canyon Creek. A range of 1000 to 3000 $g/m^2/day$ was more typical. Thomas (1985) stated that the majority of sediment was deposited in the middle of the channel. In Canyon Creek, sediment was distributed down the thalweg and throughout the middle of the channel if the sluice box outflow was in the vicinity of the thalweg. If the dredge outflow was located at the stream margin, sediment was deposited along the shore for a shorter distance.

Substrate particle sizes and embeddedness. Deposition of tailings downstream of a dredge results in a sorting-out of streambed materials. In Canyon Creek, larger gravels were deposited closest to the dredge outflow and fine sediments either blanketed the stream channel below or collected in pockets some distance below the dredge. Cobbles and boulders too large to pass through the dredge aperture were piled alongside the hole or on the bank.

Streambed substrate is important rearing cover for salmonids. Newly emerged salmonids tend to hide beneath stones for cover (Hartman 1965). Boulders and other large rocks create "focal points" for juvenile salmonids as territory and feeding stations (Wickham 1967). In Canyon Creek, the substrate is an important cover component for rearing salmonids since most instream areas lack aquatic vegetation and large organic debris. Gravel tailings and fines deposited below dredges significantly decreased substrate particle sizes for 5 to 10 m and increased streambed embeddedness for 50 m. Instream cover losses could lead to reduced abundance of young salmonids below suction dredge mining sites. Boussu (1954) and Elser (1968) showed that fish abundance declined when cover was reduced. Harvey et al. (1982) found that riffle sculpin densities were reduced up to 50 percent below suction dredges due to increased cobble and boulder embeddedness.

Increased stream bottom embeddedness can also harm incubating salmonid eggs and fry. By filling gravel interstices, fine sediments reduce intergravel water velocities and dissolved oxygen levels

(Phillips 1971). Developing salmonid eggs and fry require high intergravel permeability to carry away metabolic wastes, bring oxygen supplies and permit emergence (Silver et al. 1963; Phillips et al. 1975; Hausle and Coble 1976). Gravel permeability was not measured in Canyon Creek, but Lewis (1962) and Thomas (1985) both reported increased intergravel permeability in dredged areas and Thomas found no significant change below dredged areas. Further study of intergravel permeability is necessary to document the downstream effects of dredge silt upon developing salmonids.

Scour and fill. The accumulation of tailings below a suction dredge may affect the shape of the downstream channel. In Canyon Creek, pre- and post-mining cross-sectional surveys below dredges documented net scour and fill. Immediately downstream of the dredge, transects filled due to the accumulation of tailings below the sluice box outflow. Filling at these transects reduced cross-sectional areas and possibly the amount of living space for fish. Bjornn et al. (1977) found that the loss of pool volume from sediment addition resulted in a proportional decrease in fish numbers in Knapp Creek, Idaho. Further downstream of the dredge, streambeds filled or scoured locally, but the net change was not appreciable.

New sediment is not introduced into the stream if dredge mining regulations are observed. Dredge miners typically excavate streambed materials from one site in the channel and redistribute them to another site downstream. Fish living space may be reduced within the first few meters below the dredge, but just upstream a new pool is created by the cone-shaped dredge hole. During the study, young steelhead, dace and suckers were observed in active and abandoned dredge holes.

Season

Young-of-the-year steelhead. Young steelhead in Canyon Creek were less abundant after mining at both control and below dredge reaches of stream. The percent of decline was similar at both sites. Evidently, reduced streamflow and increased water temperature during the late summer were the cause of reduced fish abundance. Harvey (1986) found that rainbow trout did not move long distances in response to small suction dredges and that summer declines in fish numbers were more likely a result of decreased stream flows than mining activities.

Young steelhead and coho salmon may have been attracted to Canyon Creek dredges since fish were observed feeding on dislodged invertebrates. Lewis (1962) reported that during dredge mining on Clear Creek, California as many as 12 squawfish (*Ptychocheilus* sp.) appeared at the outflow to feed on insects. Thomas (1985) observed cutthroat trout (*Salmo clarki*) and Harvey et al. (1982) observed rainbow trout feeding on dislodged invertebrates during suction dredging.

SUMMARY AND RECOMMENDATIONS

A high level of suction dredging was evident in Canyon Creek, but adverse effects on anadromous fish habitat were minimal to moderate. Excavated holes, gravel tailings, and fine sediment deposition, which affected over 1000 m^2 of streambed each season, were obliterated by peak flows during the course of a normal water year. High stream turbidity and TSS levels immediately below dredges were localized and never reached concentrations that would directly cause physiological harm to salmonids (Cordone and Kelley 1961). Bank undercutting, bank sluicing, removal of instream woody debris, and riparian vegetation damage during dredging has greater and longer-term adverse effects upon the channel and fish habitat than dredge holes or tailing piles.

Mining activities in stream channels, along banks, and in riparian zones are governed by California law. However the regulations are vague, poorly understood, and minimally enforced. It is also unclear as to whether or not a 'Plan of Operations' must be filed with the Federal Government when suction dredging on Bureau of Land Management or U.S. Forest Service lands. If dredge mining regulations were expounded upon and miners were made aware of the instream habitat needs of salmonids, the most serious impacts of suction dredge mining could be reduced. Suction dredgers may even be able to enhance certain areas of the channel for rearing and spawning fish, if some of the limiting factors of a reach of stream are identified (ie. cover, woody debris, low velocity refuges, clean gravels).

In Canyon Creek, current CDFG suction dredge regulations eliminate conflicts with salmonid spawning, incubation, and fry emergence by restricting mining to summer months. The 15.24 cm maximum aperture size for dredges is appropriate since stream substrate is large, but larger apertures may be too disruptive in the small channel. California Fish and Game Code, Section 1603 which prohibits activities that "...substantially change the bed, channel or bank..." is too vague for establishing dredge mining guidelines. Legislative revisions are necessary to delineate boundaries of "acceptable change" in terms of effects on fish habitat and to establish procedural guidelines in the following areas:

1) working along and under stream banks
2) moving large rocks, boulders and organic debris with power winches
3) trimming and removing riparian vegetation

I also recommend that the U.S. Forest Service and CDFG increase their inspection of areas subject to intensive suction dredge use, both before and during the mining season, because the education and cooperation of miners are essential to the maintenance of healthy stream habitat for fish.

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