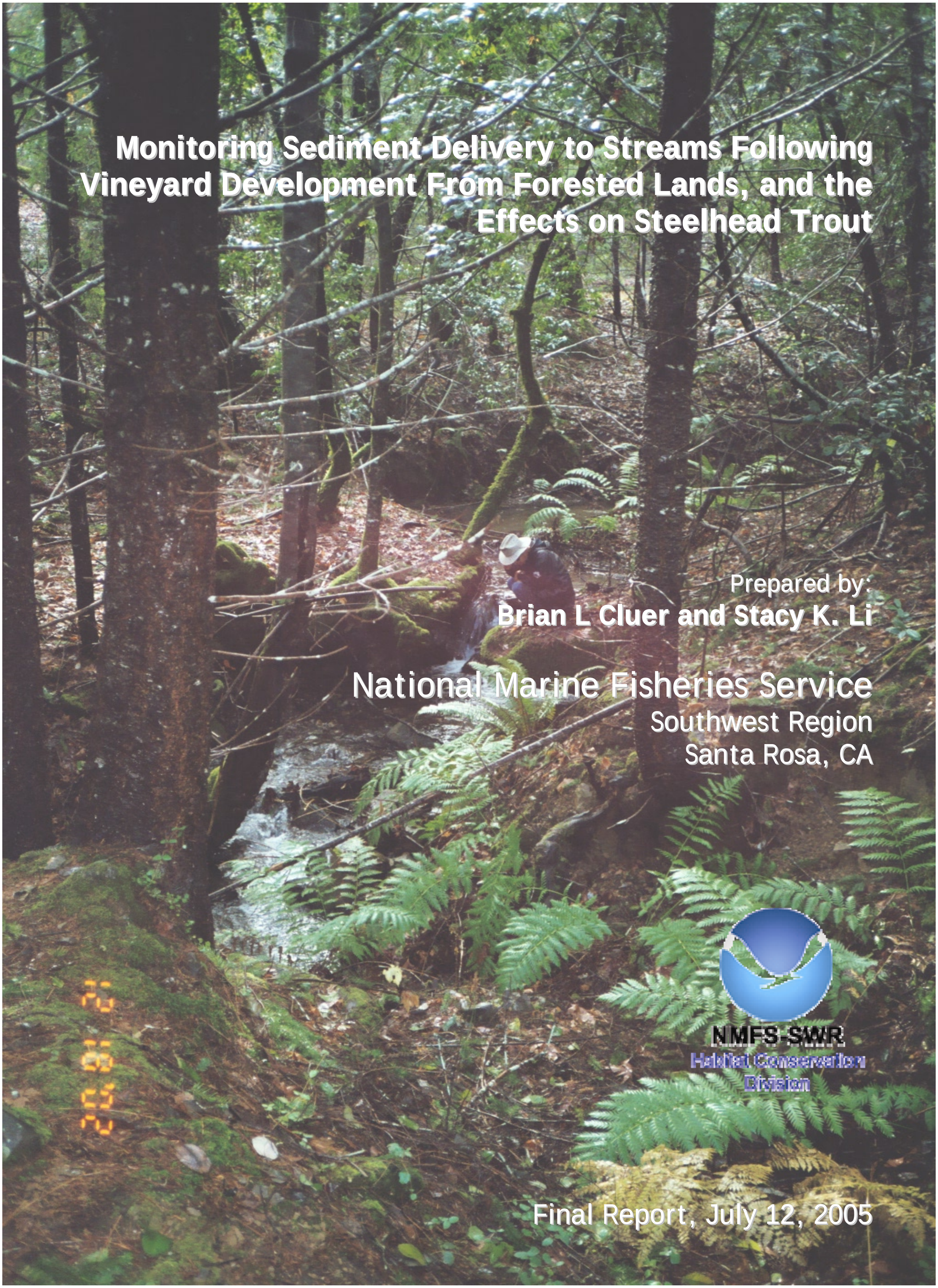

Monitoring Sediment Delivery to Streams Following Vineyard Development From Forested Lands, and the Effects on Steelhead Trout

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Cover photo: unnamed tributary to upper SF Mud Springs Creek, near monitoring Station B.

ABSTRACT

A tract of land undergoing conversion from forest/grassland to vineyard cultivation, adhering to State forestry rules, was monitored to quantify the ill-effects of sediment delivery on water quality. Two streams were monitored using automatic turbidimeters during the 2003-04 runoff season. Repeated population estimates in the steelhead bearing streams were coordinated temporally and spatially with continuous water quality monitoring. Agency staffs observed that hillslope failures and surface runoff delivered substantial volumes of sediment to the streams during the 2001-02 and 2002-03 winter rainy seasons.

The turbidity monitoring results showed increased turbidity, and the sediment source assessment linked sediment sources with recent land development. Turbidity increased in the downstream direction while stream flow also increased, however the steep channels (0.07-0.08 ft rise/ft run) were not fine sediment storage locations or sources. A consistent clear-water zone in an upstream area not affected by land development allowed comparison with downstream turbid zones. Suspended sediment samples had high proportions of sand, known to be particularly deleterious to juvenile salmonids. Two published models were applied to predict the adverse effects to salmonids from (1) turbidity and (2) suspended sediment. The highest scores for ill-effects to juveniles from suspended sediment were magnitude 10 (corresponding to mortality up to 20%) in one stream, and magnitude 11 (predicting mortality of 20 to 40 %) in the other stream.

Twelve juvenile salmonids were collected from the study streams and otolith analysis demonstrated that all subjects were anadromous steelhead. Fish passage barriers to juvenile steelhead in each study stream limited juvenile movement to the downstream direction. Electrofishing during three seasons: early summer, later summer, and fall, tracked steelhead abundance. Abundance did not change markedly between early summer and late summer, but declined sharply with the onset of seasonal storms.

Results from the independent assessments of physical water quality changes and fish population changes converged. Both predicted approximately 20% mortality due to suspended sediment derived from recent land disturbances. Despite considerable remedial efforts by the land owner to control sediment production and runoff (implementing BMP’s, in addition to meeting the requirements of State forestry rules) this investigation documented steelhead mortality caused by suspended sediment associated with timber harvest and land use conversion.

1 INTRODUCTION

Suspended sediment in the water column causes turbidity. Turbidity is a change in the optical property of water which causes light to be scattered and absorbed as opposed to transmitted in straight lines (APHA 1980). Turbidity may be caused by suspended sediments such as silts or clays, fine particulate organic material or microorganisms such as plankton. Chronic increased turbidity has been associated with precipitous population declines in Northern California streams (Harvey and Railsback *in* press). High turbidity is also associated with scouring of algae growing on rocks and decreased survival of aquatic insects.

It is likely that chronic (and even relatively minor) turbidity is an important limiting factor for salmonid growth and survival. Increased turbidities can be injurious to fish and aquatic life, particularly if conditions of high turbidity persist for a long duration (Newcombe and MacDonald 1991), or from repeated exposures (Railsback *et al.* 2002; Harvey and Railsback *in press*). Documented effects on fish range from avoidance of highly turbid areas and reduced growth to direct mortality (Bisson and Bilby 1982; Sigler *et al.* 1984; Cordone and Kelley 1961).

Steelhead, like other salmonids, are affected by the quality of water available within their habitat. The effects of suspended sediment, and reduced water clarity, range from sublethal (avoidance behavior, reduced feeding and growth rates, respiratory impairment, reduced tolerance to disease and toxicants: all forms of physiological stress) to lethal (Noggle 1978; Sigler *et al.* 1984; Waters 1995). Adults migrating from the ocean to spawning grounds are relatively tolerant of suspended sediment observed in natural, relatively unpolluted streams. Juvenile salmon and steelhead, however, are less mobile and less physiologically robust; therefore they are more vulnerable to poor quality water and suspended sediment in their habitat. Sigler *et al.* (1984) found that turbidities as low as 25 nephlometric turbidity units (NTU) caused a reduction in juvenile steelhead and coho salmon growth. High turbidity during winter impacts the feeding ability of juvenile salmon, steelhead or cutthroat trout by increasing individuals reactive distance to drifting prey (Railsback and Harvey 2002), and consequent population declines (Railsback *et al.* 2002). Holtby *et al.* (1990) found that ocean survival rates decrease for coho salmon as the size of out-migrating smolts decreases. Shapovalov and Taft (1954) found the same relationship for steelhead.

It is well documented in the scientific literature that timber harvesting generally results in increased sediment production and lower water quality in nearby streams. The increase in sediment production is from several physical mechanisms: mass wasting triggered from harvesting and grading unstable hill slopes, erosion of exposed surfaces, and erosion of roads where sediment is mobilized due to traffic and road drainage. The dominant water quality change that occurs in forested watersheds is the transport of soil and other fine-grained mineral particles liberated from constructed roads and drainages, and from harvested land tracts during storms. It is plausible that the conversion of timberlands to vineyard exacerbates the problems attributed to forestry practices alone. Vineyard cultivation is a protracted land-use practice that may continue to disturb watersheds, and deliver elevated sediment loads as compared to timber harvest, which is generally characterized by a brief disturbance that subsides after a few years.

Vineyard development on forest lands starts with harvesting the marketable timber and then removes all of the remaining trees, their stumps and root structures. The next steps are the removal of any vegetative under-story, deep ripping of the soil, and sometimes extensive contouring of fields to achieve desired aspects for sunshine and microclimate. The final steps are the cutting and developing of numerous roads, and developing water supplies and distribution systems. Once developed, vineyards continually use road networks, and typically practice repeated annual field tilling to control unwanted plants and to manage soil moisture. Various fertilizers and chemicals are typically applied to the vines and soil, all of which can be harmful to aquatic organisms in high concentrations.

Sediment production from timber harvest tracts generally declines within a few years of road building and harvesting, when shrubs and early succession stabilize the soil and traffic and human entry is discontinued. Conversely, vineyard agricultural practices continue the use of numerous roadways, till the soil between the rows of vines, and perpetuate many of the same disturbances that would be brief and short-lived in a timber harvest setting. Because of the prolonged use of vineyard roads and land cultivation, nearby aquatic habitat is placed at continued risk of harm, primarily due to reduced water quality.

The role of suspended sediment in the water quality of streams is largely a function of the amount of sediment carried in suspension by flowing water. Suspended sediment is an integral part of the hydrological, geomorphological, and biological processes of streams. However, water quality, steelhead, and their habitat can suffer as a result of excessive suspended sediment concentration, both in terms of increased magnitude and duration over background levels. This report describes the results from water quality monitoring integrated with fish monitoring efforts undertaken by National Marine Fisheries Service (NMFS) staff during 2002-03, and 2003-04.

1.1 Problem Statement

Disturbance of small watersheds, tributaries to Ten Mile Creek, has occurred as a result of vineyard development from a tract of mixed forest-grassland. Development included the removal of trees, roots and deep soil ripping, construction of roads and stream crossings, grading and earthmoving, construction of artificial drainage with collectors and outlets, piping drainage outlets to areas not previously channeled, and fence line clearing and construction. Ongoing disturbances that can also impair water quality occur from repetitive vineyard soil treatments such as disking, irrigating, and fertilizing. Initial observations made during the winter 2002-03 revealed that surface drains from recently disturbed areas delivered visibly reduced water quality to the larger fish-bearing streams. Reconnaissance turbidity measurements made during winter 2002-03 showed that runoff from converted lands reduced water quality in the fish-bearing streams sufficiently to warrant a focused field investigation.

This report documents the results of: (1) water quality changes due to the conversion of timber land to vineyard; (2) impacts and responses of native steelhead to water quality changes; and (3) a discussion of the linkages between the cause and effect relationships leading to harm and mortality of federally listed steelhead. The objectives of this report are to establish: (1) the presence of federally listed steelhead in affected stream reaches, (2) the continued presence of steelhead during pollution events, (3) that water pollution originated from land-use activities, (4) the magnitude and duration of water pollution events, and (5) an assessment of the effects of the pollution on steelhead.

1.2 Study Area

The study area is approximately seven miles west of Laytonville California in the center of the Cahto Peak 7.5 minute USGS Quadrangle, on what is known the Alder Springs Ranch,. Watersheds in the study area include Little Case Creek, Mud Springs Creek, and unnamed tributaries, all originating from the east-facing Signal Peak and Cahto Peak areas which reach 4000-4200 feet elevation. The North (NF) and South Forks (SF) of Mud Springs Creek are the subjects of this investigation (Figure 1). These watersheds drain into Ten Mile Creek, a tributary to the South Fork Eel River.

The main stream channels in the study area are approximately 10-20 foot wide boulder dominated cascades with weakly developed step-pool bedforms composed of boulder clusters. The average gradient of SF Mud Springs Creek is steep (0.08 foot change in vertical distance per foot of horizontal distance [ft/ft]). The total drainage area is approximately 483 acres with a disturbed sub-watershed area of approximately 33 acres (approximately 7%). The overall gradient of NF Mud Springs Creek is also steep (0.07 ft/ft), total drainage area is 435 acres, and approximately 48 acres (approximately 11%) are disturbed by vineyard development (Figures 2 and 3).

The underlying geology of the Mud Springs Creek watersheds is characteristic of the Tertiary Coastal Belt Franciscan Complex containing Franciscan mélange with isolated blocks of serpentine. Kilbourne (1983) mapped steep “amphitheater slopes” in the headwaters of both streams, and small but active slides midway along SF Mud Springs Creek that are spatially associated with an abandoned logging road. Located near the confluence of the two subject streams, Mud Spring itself is an interesting geologic feature that apparently discharges splatters of mud when exceptionally wet conditions cause high groundwater pressures (mapped by Kilbourne 1983 as an earthflow or slide). The Franciscan mélange formation, common throughout California’s North Coast Region, is typically associated with unstable slopes and relatively high sediment production, especially where disturbed by roads or other earth moving activities.

Soils in the study-area watersheds have been mapped by USGS and California Department of Conservation (Division of Mines and Geology). The USDA Natural Resources Conservation Service classified the soils as having moderate to severe erosion hazard with slope/erodibility indexes from 0.5-1.0 (on a 0.01 to 1.0 scale, with 1.0 the greatest hazard). Accordingly, the soils are poorly suited for roads because of steep slopes and low material strengths.

1.3 Antecedent Conditions

As detailed below, the Alder Springs Ranch was undergoing conversion from timberland to vineyard under a California Department of Forestry (CDF) approved Timber Harvest Plan (THP). Remnant stumps of massive redwood trees hint at prior logging impacts on the Alder Springs Ranch. The early logging impacts that are still evident include logging roads on steep slopes, and road fill prisms that have acted as man-made sediment sources over the past half-century. Presently, sediment production from the remnant land-uses appears to be relatively small, consistent with the several decades time period for drainages to develop and armor. A careful observer can make out remnants of skid trails along and in the streams, and decayed redwood log stream crossings. Large woody debris with its attendant sediment storage and habitat function is noticeably absent in the stream channels where log skidding probably occurred.

While timber harvest and land conversion were in progress, water quality conditions in the two winters previous to this investigation were markedly less favorable for steelhead and habitat. Land slides occurred in both cultivation units in winter 2002-2003. Other sources of elevated sediment production also affected the streams. On June 21, 2002, the North Coast Regional Water Quality Control Board (WQCB) issued a cleanup and abatement order and a request for technical reports [#R1-2002-0068]. Two consulting firms were hired by the landowner to develop and implement erosion control plans for the vineyard cultivation areas and roads.

NMFS involvement in this project began with a Timber Harvest Review in 2000. Subsequently, Regional prioritization identified the documentation of continued harmful effects on steelhead of timber harvest practices by operators adhering to the California Forest Practice Rules (CFPR's) as an important study. Beginning in late fall 2002, we made diverse reconnaissance-level observations of potentially affected salmonid-bearing streams, on the Alder Springs Ranch property. During winter 2002-2003 we established the presence of steelhead in all of the class 1 watercourses on the Alder Springs Ranch, and made rough estimates of the fish populations in each stream using electrofishing techniques.

During reconnaissance we observed tributaries delivering poor water quality to the trout-bearing streams (Figure 4) and traced the sediment sources to (1) cultivated lands, (2) roads, (3) fences, and (4) constructed drainage systems. We obtained the boundaries of the CDF approved timber harvest plan and compared the implemented plan outlines to approved outlines using GPS equipment and GIS mapping. We mapped the outlines of cultivated land, roads, and the engineered drainage systems located on the property. We also observed and mapped the outlines of landslides (Figure 5) within the plan boundaries. This information led to the design and implementation of the study presented in this report.

The Alder Springs Ranch has been undergoing vineyard development since 1999. Some of the currently used roads are evident on the 1967 Cahto Peak Quadrangle map and were presumably used originally for logging and subsequent cattle ranching activities. The current land conversion activities presumably began with logging in 1999, followed shortly thereafter by the first wave of vineyard development in 2000. This process of logging and vineyard conversion has been repeated on other tracts within the Alder Springs Ranch property and continues in the south cultivation unit.

During the summer 2003 reconnaissance we observed many substantive improvements on the ranch that should have reduced the production and delivery of sediment to the salmonid-bearing streams. These improvements included: (1) out-sloping existing roads to reduce flow concentration in inboard ditches; (2) building rolling dips to break up overland flow on roads; (3) covering road surfaces with coarse rock to reduce that sediment source; (4) enlarging culverts to reduce sediment transport interactions; and (5) planting barren soil surfaces with cover crops before the onset of winter storms. The land owner also restricted winter-time road travel, although we also observed 18-wheel trucks delivering soil amendments to stock piles in the cultivated areas during the 2002 and 2003 winter seasons.

A new culvert was placed on the lower-most tributary to SF Mud Springs Creek (input between sensors at Station A) prior to the winter rains in 2002 (Figure 6). This same culvert was replaced a second time with a larger culvert in late fall 2003 (Figure 7), but not without causing a substantial water quality problem during a particularly sensitive time of year for salmonids.

Land cover crops on the cultivated fields have varied markedly during our investigation. We observed no cover crop on the entire south cultivated unit at the beginning of winter 2002-03 (Figure 8). Conversely, the entire south unit was well-covered going into fall 2003, with a thriving grass crop. In fall 2004, both the north and south cultivated units had: 1) remnants of the 2003 cover crop; 2) only sparse new growth; and 3) large areas of uncovered terraces that were excavated during summer 2004.

In addition to the provisions of the CFPR's, the land development project was modified with two generations of erosion control plans (hereafter referred to as best management practices, or BMP's) over the past 3 years. All of the land improvements completed prior to and during our investigation likely reduced the quantity of sediment entering the streams on the Alder Springs Ranch. The greatest improvements, and therefore greatest potential reductions in sediment delivery, were applied on the north watershed; NF Mud Springs Creek. Nonetheless, we were able to document that substantial quantities of sediment originating from the developed land continued to enter the streams during winter 2003-04, causing significantly impaired conditions for occupant salmonids.

Ongoing development of the property is likely to continue delivering deleterious sediment concentrations to the salmon bearing streams. New terracing construction was observed in the south vineyard unit in May 2004 (Figure 9). The terraced slope drains into the tributary between sensors at Monitoring Station B. The riparian forest and channel were encroached upon and fresh soil was placed at the channel head, priming the channel for sediment delivery with the onset of storm runoff in fall 2004. Additional earth-work for terrace construction was observed on the north agricultural unit in August 2004. This area drains into NF Mud Springs Creek at monitoring Station C. In May 2004 we also observed the filling and cultivation of areas that had been serving as sediment retention basins during the past two winters (Figure 10).

1.4 Steelhead Life History in Mud Springs Creek

The steelhead (*Oncorhynchus mykiss irideus*) is an anadromous strain of rainbow trout that migrates to sea and later returns to freshwater to spawn as an adult (Moyle 2002; Behnke 1992). Unlike Pacific salmon, not all steelhead die after spawning. In California, 82 percent of the adults are typically spawning for the first time and only 17% spawn twice (Shapovalov and Taft 1954). Less than 5 percent have spawned more than twice. Adult steelhead typically return to their natal stream, but straying is not uncommon.

The steelhead of Mud Springs Creek are winter-run that commence their immigration with the onset of the rainy season. The Mud Springs Creek watershed is over 100 miles from the Pacific Ocean so it takes considerable time for adult steelhead to arrive after the fall rains begin. Adult steelhead must ascend the mainstem Eel River, swim up the South Fork Eel River, and then enter the Ten Mile Creek drainage before finally reaching Mud Springs Creek on the Alder Springs Ranch. The peak of the steelhead run generally coincides with the storm peaks occurring between January and March. Peak flows are necessary for successful immigration into the upper reaches of Mud Springs creeks because there are steelhead passage impediments that make immigration difficult at lower flows (Figures 11 and 12).

Spawning gravel is unevenly distributed and sparse in Mud Springs Creek because of large dominant substrate size, steep gradients, and turbulent flow. These conditions are common to steelhead spawning in steep low-order streams of coastal Northern California. Judging from the locations where steelhead fry were found during our stream visits, adult steelhead move well above our study sites in the Mud Springs drainages. Adult steelhead will typically populate the Mud Springs Creek drainage from early January through March and into April in a wet year.

Steelhead prefer to spawn in clean, loose gravel in cool, swift, shallow water. Female winter-run steelhead have mature eggs when they enter freshwater. They do not have to hold in pools waiting for gonads to mature, but are ready to spawn upon arrival at spawning grounds. Where gravel is available, the female digs a pit and deposits eggs on the downstream side of the pit. The male fertilizes the eggs as they are being deposited in the pit. The eggs are buried as pit digging proceeds upstream. Preferred substrate particle sizes generally range from 0.25 to 3 inches in median diameter. Water upwelling through the gravel supplies oxygen to the developing embryos and removes their metabolic byproducts from the nest (redd). Typically, 550 to 1,300 eggs are deposited in each redd. Adults will spawn in relatively turbid water, but not during peak turbidities when they tend to hold in deep pools. Steelhead tend to spawn quickly during high flows and emigrate downstream soon after spawning, sometimes before the stream clears. Therefore, they are rarely observed spawning.

Steelhead are less tolerant of fines than Pacific salmon because oxygen requirements for developing steelhead embryos are higher (McEwan and Jackson 1996). There is a direct relationship between embryo survival and percolation rate through the gravel (Bjornn *et al*. 1977; Waters 1995). Oxygen concentration is also positively correlated with steelhead embryo and alevin survival. Deposition of fines in redds reduces percolation the through gravel, increasing embryo and alevin (sac fry) mortality.

Newly hatched steelhead sac fry (alevins) are susceptible to environmental perturbation. They remain in the gravel for 4 to 6 weeks until the yolk sac is absorbed. Scour events kill embryos and alevins. High turbidity events kill alevins due to decreased interstitial percolation and because alevin gills are small and easily clogged (Newcombe and Jensen 1996). Alevins are also more sensitive than embryos to redd dewatering because they are dependent solely upon gills for respiration. Fine sediment deposition can prevent alevins from successfully emerging from the gravel.

When steelhead alevins emerge from the gravel as fry, they actively feed on small terrestrial insects and invertebrate drift. As they grow they move from the quiet shallow margins of the stream to deeper and faster water (Bjornn and Reiser 1991). Upstream juvenile steelhead movement is limited in Mud Springs Creek because of 3 foot high passage impediments (*e.g.* waterfalls), and numerous smaller but steep gradients located throughout the study reaches.

Young of the year (YOY) steelhead do not emerge at the same time because they originate from different spawning episodes that occur during different storms. Since embryo incubation begins at different times, emergence as fry also occurs at different times. YOY are thus represented by a wide range of sizes within the brood year. Mud Springs Creek steelhead fry began to emerge from the gravel in April and continued to emerge through July. Juvenile steelhead typically remain in freshwater for at least a year. In California, juveniles typically rear for two years before emigrating to the sea.

Summer juvenile steelhead rearing habitat is generally a limiting factor in California steelhead populations as a result of recurring low stream flows and potentially adverse high water temperatures. Preferred rearing and adult water temperatures are between 50^{o} F and 58^{o} F in the Sacramento River watershed but 65^{o} F in the Sierra foothills (Moyle 2002). Preferred spawning and incubation water temperature is lower, 50^{o} F. The rate of steelhead embryo development is directly related to water temperature. Hatching occurs in 31 days at 50^{o} F and 24 days at 55^{o} F (Leitritz 1980). Summer base flows of less than 1 cfs in the Mud Springs streams ranged between 59^{o} F and 62^{o} F in July and August in 2003.

High stream flow events can also change juvenile steelhead abundance. In Northern California coastal streams, high flow events typically only occur during the winter rainy season because these systems have negligible snow pack. Steelhead movement can also result in increases in local juvenile abundance. Kahler and Quinn (1998) note that fall and winter freshets trigger upstream movement from larger rivers to smaller tributaries or off-channel habitats. They also note that upstream movement may occur throughout the summer and may be more prevalent than downstream movement.

Juvenile steelhead prefer winter habitat with cover and coarse substrate (Morgan and Hinojosa 1996). Johnson *et al.* (1986) found that steelhead parr move from stream sections that had been clear-cut to areas of old growth forest or buffered areas with more pools and LWD during winter. Hartman and Brown (1987) found that steelhead avoided stream segments with soft or silty bottoms. Murphy *et al.* (1989) found that juvenile steelhead selected winter habitat based primarily on water velocity and that turbidity was a secondary factor.

Steelhead smolt emigration appears to be more closely related to size than age. Most downstream migrants are between 6 to 8 inches long. There is generally an initial run of smolts with the first rain storms (Zedonis 1992). These early running fish are usually 2 year old juvenile steelhead that have attained smolting size during the summer. The major annual smolt emigration period is between April and May.

In addition to emigration, recent studies indicate juvenile steelhead move for a variety of reasons. They move from summer rearing habitat to winter refuges (Bjornn 1971), into and out of and back into estuaries to increase growth (Kahler and Quinn 1998), and possibly into and out of non-natal tributaries to gain favorable rearing conditions (Hartman and Brown 1987, Hubble 1992).

Decline in juvenile steelhead abundance because of high stream flow is generally expected because of the many juvenile passage impediments that limit movement to the downstream direction. However, refuges from high stream flow, such as large woody debris (LWD), backwater pools, and secondary channels ameliorate the losses because of high relative roughness and boundary layer habitat. In the Mud Springs Creek drainage, juvenile steelhead are generally limited to downstream movement because of several upstream passage impediments.

2 WATER QUALITY MONITORING

2.1 Turbidity, Suspended Sediment, Rainfall and Stream Flow

Increased turbidity of excessive magnitude or duration adversely affects salmonids. The harmful effects result from sediment suspended in the water column (e.g. Henley *et al*. 2000; Madej *et al*. 2002). This study monitored water turbidity continuously, at 10 minute intervals, at 8 locations on 2 streams (Figures 2 and 3). Water depth was also monitored at 10 minute intervals. Suspended sediment and discharge measurements were made during runoff events.

Turbidity

The turbidity of stream waters can be monitored continuously using electronically controlled optical turbidimeters along with automatic data recorders. In this study Global Water model WQ710 turbidity sensors were used. This sensor is designed in accordance with USEPA Method 180.1 for turbidity measurement; the sensor is a 90 degree scatter nephelometer which directs a focused beam into the monitored water. The light beam reflects off particles in the water, and the resultant light intensity is measured by a photodetector positioned at 90 degrees to the light beam. The detected light intensity is directly proportional to the turbidity of the water. The turbidity sensor utilizes a second light detector to correct for light intensity variations, color changes, and minor lens fouling.

Each monitoring Station included four turbidity sensors, two sets of two. One pair was located upstream from a tributary suspected of contributing sediment and another pair of sensors was located downstream a sufficient distance to allow for complete mixing of the two waters. In each pair, one sensor was calibrated from 0-50 nephelometric turbidity units (NTU), and the other from 0-1000 NTU. Each sensor's accuracy was 2% of its range, so the pair of sensors provided optimal accuracy over the range 0-1000 NTU. The upper limit of turbidity measurement with this equipment was 1000 NTU, which was frequently exceeded.

The manufacturer certified the sensor calibration prior to installation. Spot measurements of turbidity were made in the field using a handheld turbidity meter of the same manufacturer (Global Water model WQ770) calibrated over the range 0-1000 NTU.

In situ turbidity sensor pairs were mounted in custom made aluminum housings floated by air chambers. The sensor housing was free to pivot with changes in flow depth to maintain sensor submergence of approximately three inches below the water surface. The housings were located in midstream where the greatest depth and quantity of water passed over the irregular streambed (Figure 13).

The housing and swinging arm arrangement provided a measure of defense from potentially harmful floating debris. The sensors themselves, enclosed in black anodized aluminum pressure caskets with screw-on hoods to shield the sapphire sensor optics against ambient light and debris, were pointed upstream to reduce the effect of possible bubble formation along the sensor and housing, and to generate a self-cleaning action from inflowing water.

Suspended Sediment Sampling

To ascertain the relationship between turbidity and suspended sediment, samples of suspended sediment were taken from the streams at the turbidity sensors during various runoff conditions. Suspended sediment was sampled with a DH-48 depth-integrating suspended-sediment sampler following standard protocols published by the Federal Interagency Sedimentation Project. Samples were taken from the streams when turbidity values ranged from approximately 3 to 55 NTU. We were unable to obtain samples during high turbidity storm periods because of the flashiness of storms (a few hours), lack of real time weather information, and the travel distance to the study site.

Hand-mixed samples were prepared in order to estimate the suspended sediment concentrations corresponding to higher turbidity values. This was accomplished by preparing several dilutions of suspended sediment collected from a channel-margin storage site that developed over the course of the winter flows at the culvert outlet located at upstream Station A. In a five gallon bucket filled with stream water of 0 NTU measured turbidity, sediment from the channel-margin deposit was mixed to achieve a range of turbidity values starting at approximately 110 NTU and ranging as high as 600 NTU. The mixture of suspended sediment and water was slowly stirred while the handheld turbidimeter monitored turbidity values and fluctuations. When a target turbidity value was reached and turbidity fluctuation ranged less than ± 10% of the target value, a sample bottle was submerged into the bucket at the same depth as the turbidimeter sensor. This procedure was repeated by adding additional sediment to the mixture until seven samples of various concentrations were obtained. The channel margin deposit had hand texture of fine sand to clay. We considered this deposit to be qualitatively representative of suspended sediment transported through the system during winter 2003-04.

The filled bottles were capped and labeled, and all suspended sediment samples were shipped to the US Geological Survey sediment lab at the Cascades Volcano Observatory for analysis. Lab analysis included sediment concentrations (*mg/l*) and grain size discrimination in two size fraction categories: sand (greater than 0.0625 mm), and combined silt and clay (smaller than 0.0625 mm).

Rainfall

Rainfall was continuously monitored at one Station in the study watersheds to establish a record of the timing and sequences of storm magnitude and duration for the study period. Rainfall measurements were derived from a Global Water 6” tipping bucket rain gage (model RG200) located at monitoring Station A at approximately 1900 feet elevation. Additional rainfall data were obtained from the nearby Laytonville weather station operated by the Western Regional Climate Center-Desert Research Institute. Co-located with the California Department of Forestry Fire Station, the Laytonville weather station is located approximately one mile northeast of Laytonville at 1838 feet elevation. A regression relationship between the two rain gages for total daily rainfall permitted filling in data gaps in our rainfall record.

Stage and Stream Flow

Water depth sensors (Global Water model WL300 pressure sensors) were co-located with turbidity monitoring Stations. The stage sensors were located at stream cross sections sensitive to changes in flow and conducive for discharge measurements. Stage measurements were recorded at the same time interval as turbidity, every 10 minutes. Staff plates were installed at each stage sensor location to facilitate observations of flow depth during service visits and discharge measurements. Closed-loop level surveys were conducted at each monitoring Station immediately upon installation to provide elevation relationships between staff plates, stage sensors, and crest stage gages.

Stream flow was measured at the four monitoring Stations to determine (1) the relationship between stage and discharge, and (2) the relative flow contribution of the small sub-watersheds between the sensors. At least three discharge measurements were made for each discharge cross section. Discharge was measured during storms and winter base flows to include the widest range of flow rates available during the study period.

Discharge measurements were made using standard methods for integrating velocity measurements over cross sections using (1) acoustic Doppler current profiler (RDI “StreamPro” ADCP) equipment and techniques for small streams (Huang 2004) during storm flows, and (2) velocity meters on wading rods (Rantz *et al.* 1982) during winter base flow conditions. When tributary flows occurred between turbidity sensor pairs, discharge was measured upstream and downstream from the input source. The difference in flow was considered the tributary flow.

2.2 Equipment Maintenance and Data Handling

During each site visit the optical sensor components were cleaned and inspected to assure data quality by comparing turbidity measurements with a calibrated hand held meter. The sensor optics and mounting housings were also inspected and cleaned of any obstructions during site visits by the fishery survey crews. Overall, the sensors were inspected and cleaned approximately every two weeks, and after every storm event. Data recorded at the turbidity monitoring Stations were retrieved electronically at approximately monthly intervals during the winter storm period.

Data Handling, Processing, and Correction

The raw binary data files were converted with the Global Water conversion software utility into comma delimited ascii text files. Test files were opened in *Excel* spreadsheets and separate files were copied and pasted into one large file spanning the period of record for each monitoring Station. The raw data were preserved as separate sheets in the *Excel* files. Corrections, described below, were applied to copies of the raw data files.

Data from paired sensors with alternate calibration ranges were combined using a logic test. When values exceeded 50 NTU on the 0-50 NTU sensor, data from the 0-1000 NTU sensor were selected; otherwise the values from the 0-50 NTU sensor were selected. This procedure resulted in two columns of data representing the water quality upstream and downstream from respective tributary inputs.

Raw time-series turbidity data may have several potential inaccuracies. Continuous turbidity records may include data gaps, irregular data, and spurious data points. In-situ sensors can also experience drift in their output signal caused by other variables not internally corrected. For these reasons, it is necessary that raw turbidity data from the field is reviewed and corrected prior to analysis and interpretation. The review and correction of raw electronic turbidity data was a multi-step process.

Suspect turbidity values are typically of two types: (1) abruptly rising values that result from either true spikes in turbidity or rapid fouling of the sensor optics by floating organic material; or (2) gradually ascending values that usually reflect algae growth or sediment film deposition on the sensor optics. Algal growth and other forms of bio-fouling are most prevalent during the warm summer months and were not expected to present problems during this investigation. Sediment film formation is most prevalent during the winter months when storm flows reach their highest sediment concentrations. Sediment film formation was expected to affect both sensors in a housing. Spurious dips in a series of elevated turbidity values can occur when random highly reflective particles pass through the sensor. The periodic site visits included sensor-cleaning procedures recommended by the manufacturer. A value shift following sensor-cleaning indicated if (a) cleaning the optics was necessary and if (b) the previous data needed correction accordingly.

The entire time-series of turbidity data were scrutinized to identify (1) suspect spikes and dips, (2) sensor drift, and (3) dissimilar behavior between sensors. Once combined, the records of the upstream and downstream sensor locations were plotted and examined graphically and in tables for the various inaccuracies expected in continuous turbidity records. A smooth transition from the 0-50 NTU sensor to the 0-1000 NTU sensor occurred part of the time; however, occasionally the 0-50 sensor would exceed its range while the 0-1000 sensor recorded below 50 NTU. In this case the lower values were selected for the combined record. Excessive sensor fouling was evident in some records where a maximum value was recorded continuously for periods of several days. In these cases, the companion sensor record was examined for responsiveness to stage changes and for response similar to the other sensors at that Station.

Spurious values were defined as individual high or low points in a field of dissimilar values. Peaks and dips were defined as single point value changes greater than three times the adjacent values. Single point peaks are errors likely resulting from transient large floating particles or air bubbles and are expected to affect individual sensors, not a pair. The single point peaks were either deleted or replaced by the value at the companion sensor if the value fell between the adjacent data points. Single point dips were also examined and considered relative to the performance of its companion sensor. For example, each sensor has a unique peak value that is obvious in the tabular data set. When a 0-1000 NTU sensor registered a single point dip in excess of three times the adjacent values, that point was deleted if its companion 0-50 NTU sensor registered off-scale.

Peaks in NTU values were also compared to changes in stream stage. Increases in stream stage were expected to accompany increases in turbidity. Short duration increases in turbidity values (duration of 30 minutes or less) not accompanied by increases in registered stream stage were deleted. When the turbidity records of companion sensors disagreed, the trend in stage was used to determine which turbidity sensor was following the stage trend and the other previous correction routines were overruled.

Some short duration turbidity peaks were retained in the corrected record if (a) they were accompanied by increases in stream stage, (b) the companion turbidity sensors indicated the same trend, and (c) peaks were preceded or followed by progressively changing values. The maximum range of the turbidity sensors was exceeded on many occasions. Sensor fouling was evident when turbidity values held constant for multiple measurements at the peak value of the particular sensor. Apparent sensor fouling sometimes cleared with stage changes. Our periodic site visits were intended to clean the sensor optics. Shifts in turbidity values that followed visits indicated prior fouling.

The record of site visits for maintenance and repair of the equipment, downloading data, and the biological sampling visits was compared with the turbidity record. Any possible occurrence of our activities inducing increased turbidity values was noted and those data potentially affected were deleted.

Zero Adjustment

All sensors were calibrated following standard procedures by the manufacturer prior to field installation. Nonetheless, sensors may show relatively minor turbidity values in visibly clear water once installed. The continuous record of turbidity was divided into sections bounded by site visits, when sensor optics were known to be clean, and when handheld turbidity values were taken. The low turbidity values during these periods were adjusted so that the corrected records were essentially reset to zero following every site visit. A second, more conservative, zero-setting procedure was followed where upstream and downstream sensors were corrected to agreement after the passage of storms, as indicated by recession in the stage records.

Data Gaps and Equipment Failures

Inadequate battery power created data gaps at three Stations (A, B, and C) from December 24 - 30, 2003. In addition, the 1000 NTU turbidity sensor at downstream Station C became inoperative on December 11, 2003. As a result the subsequent record at downstream Station C is limited to the peak range of the 0-50 NTU sensor. This gives the impression that after December 11, water quality was worse at the upstream sensor which is not the case because the downstream 0-50 NTU sensor was actually off-scale during high turbidity events, for 15% of the total time.

Synopsis of Data Collection and Handling

Following the conservative study philosophy implemented for this investigation, in no case were turbidity values increased when correcting for errors. Data adjustments were made by decreasing or deleting suspect high values and by resetting the base flow periods to zero or to agreement between the upstream and downstream sensors. The adjustment performed on the raw data before any analyses were performed ensures that the turbidity records were applied conservatively.

2.3 Sediment Source Assessment

We evaluated various processes of sediment production from the study watersheds to distinguish between sediment sources, and ranked their relative contribution to water quality. To accomplish this we mapped: (1) the drainage network of the converted land, including intake and outlet points; (2) roads and the associated drainage networks; (3) fence lines, clearings and associated drainage networks; (4) areas of active landslide; and (5) sources of sediment pre-existing along the stream courses. Sources 1-4 above were delineated with GPS mapping equipment. Sediment sources along the stream courses were delineated on enlarged topographic maps, measured, and then transferred to the GIS system for mapping.

The sediment monitoring Stations of this study were selected to evaluate the effects of sediment delivery to the study streams from recently disturbed areas, as compared to relatively undisturbed watershed areas. As part of the sediment source evaluation, we mapped and took measurements of eroding banks, slumps, landslides, and dry-ravel slopes from the downstream monitoring Stations to the abandoned road, a length approximately equal to ½ of the total stream length in the study watersheds.

Other sediment sources observed during reconnaissance site visits in winter 2002-03 included (1) the incision and head-cut migration of tributary channels, and (2) new channels in early stages of development on previously smooth hillslopes. Samples of these sediment sources were monitored with repeated cross sectional measurements between monuments driven into the ground.

Roads and cultivated fields were sediment sources to the streams, especially during intense rainfall events that increased surface flow and entrainment of surface sediment. The man made drainage systems at the study site generally concentrate surface flow and sediment into collectors, distribute collected flow through pipes, and then deliver the flow and sediment to an outlet location. Depending on delivery location, the quantity of sediment, and the energy of the issuing flow, the entrained sediment was either discharged along a hill slope or delivered directly to a stream. The surface flow collectors had small settling basins constructed of vertical pipes with inlets cut a few inches above the surrounding basin floor; drop inlet structures. We observed that most drop inlet basins adjacent to fields and roads were filled to capacity with sediment during the winter 2002-03, and not cleaned out prior to onset of winter 2003-04. In some locations, but not all, the surface collectors drained into a larger settling basin before discharging into streams.

The landowner undertook measures during summer 2003 to reduce delivery of sediment to streams by constructing three additional sediment retention basins at the surface flow collector outlets, down slope from the prior landslide area in NF Mud Springs Creek. We periodically observed the performance and integrity of the retention basins throughout the study period and noticed a mixture of success and failure.

Landslides within the cultivated areas were observed and their outlines mapped with GPS. During winter 2002-03 a large cultivated area adjacent to NF Mud Springs Creek slid, overwhelming the surface drainage and collection systems and settling basins, and delivering a large quantity of sediment from the hillslope to the stream. The North Coast Regional Water Quality Control Board (WQCB) documented that this location also slid the previous winter, delivering a large quantity of sediment into NF Mud Springs Creek. In response to WQCB "Cleanup and Abatement Order and Request for Technical Reports #R1-2002-0068" issued in June 2002, the landowner contracted O'Connor Environmental Inc. to develop an Erosion Control Plan (2002), and Pacific Watershed Associates to refine and implement the plan in summer 2003.

The Alder Springs Ranch property has witnessed a history of logging activities that used skidding, yarding, and road construction practices that are now banned in California. An abandoned road that is mapped on the USGS 7.5’ quadrangle is the most evident feature remaining today. However, we observed skid roads in and along the existing stream channels, defunct Humboldt stream crossings, and a lack of large woody debris (LWD) in stream channels throughout the property, all evidence of past logging practices.

3 BIOLOGICAL MONITORING

Steelhead relative abundance and seasonal growth were monitored in a coordinated effort, both spatially and temporally, with the water quality monitoring program.

3.1 Objectives and Study Hypotheses

The objective of the fish abundance monitoring was to document level of abundance, relative growth, year class composition, and the sustained presence of steelhead in the reaches of the Mud Springs Creek system subjected to high turbidity and suspended sediments. This was accomplished by sampling for steelhead abundance, and measuring fork lengths (FL) and weights (in grams) of individuals over several seasons and at variable stream flow levels and water turbidities. If a decline in steelhead abundance occurred after exposure to concentrations of suspended sediments known to be deleterious to steelhead, then harm to steelhead could be inferred.

3.2 Confirmation of Steelhead Presence and Age Analysis

Qualitative electrofishing in 2002 and 2003, in SF Mud Springs Creek, NF Mud Springs Creek, and Little Case Creek indicated that trout existed in sufficient numbers to make this investigation meaningful. However the parental origin of these fish was uncertain. Some component of the population may have been resident rainbow trout. For that reason, twelve specimens, six from both SF Mud Springs Creek and the NF Mud Springs Creek, were sacrificed for verification of anadromy. Sagittal otoliths were removed from each specimen and sent to the University of California at Davis for strontium analysis (Zimmerman and Reeves 2000; Volk *et al.* 2000; Kalish 1990). Mr. David Woodbury (NMFS) also established the brood year for each specimen by examining each sagitta for growth patterns using a binocular dissecting microscope.

3.3 Habitat Mapping

During the summer of 2003, basic habitat parameters were mapped in SF and NF Mud Springs Creek. Each mapped stream reach encompassed areas upstream of known sediment sources and areas subject to varying degrees of disturbance in the downstream direction. Habitat mapping included the delineation of habitat type, habitat unit length, and local habitat unit gradient following protocols established by the California Department of Fish and Game (1998).

A number of habitat mapping conventions were followed: (1) habitat units were numbered sequentially beginning at the starting point, the downstream-most unit, and increasing by one positive integer with each succeeding habitat unit; (2) location of the habitat unit was identified by its cumulative station or the number of feet upstream of the starting point; (3) in the case of split channels, only the channel carrying the most water was mapped; (4) habitat types with length less than its width were lumped with the next habitat unit upstream; and (5) when habitat type borders were not perpendicular to the banks, the midpoint of the transitional length between the upstream and downstream unit was selected as the border.

Habitat unit lengths were measured along the deepest portion of the channel (thalweg) using either a string-based distance meter (hip chain) or a hand-held laser distance meter. Local gradient between habitat units was measured with a hand held laser distance inclinometer. The target for the inclinometer was the observer's eye height marked on a surveyor's stadia rod. Gradient was based on water surface elevations at the boundaries of habitat units.

The habitat types identified were pool, run, riffle, cascade, and pocket water. Pools were scour zones with a downstream hydraulic control. Runs were flowing flat water with flow typically parallel with the banks. Riffles were relatively shallow areas with dropping water surface elevations with turbulence and sometimes with exposed substrate. Cascades were steep riffles with vertically dropping water. Pocket waters were swiftly flowing units containing large obstructions which created scour holes behind the obstruction. Steps were a series of like habitats separated by short riffles or cascades.

The habitat map of SF Mud Springs Creek began at the confluence between NF Mud Springs Creek and SF Mud Springs Creek and consisted of 149 habitat units over 3092 feet. The habitat map for NF Mud Springs Creek began 578 feet downstream of the road culvert, continued upstream for 2593 feet, and consisted of 113 habitat units.

Each habitat map referenced the turbidity monitoring Stations and included substantial stream lengths upstream and downstream. These maps were the basis for electrofishing site selection.

3.4 Electrofishing

Seasonal steelhead abundance was documented by electrofishing using a Smith-Root Model LR24 backpack electrofisher. Pass depletion techniques (Van Deventer and Platts 1986 and 1989; Seber and LeCren 1967) were used at each electrofishing site. The upstream and downstream site boundaries were blocked with nets to prevent immigration or emigration of steelhead during sampling. An electrofishing pass consisted of completely fishing the site's surface and then checking the downstream blocking net for fish.

Captured fish were anesthetized with MS-222, measured for fork length (FL) to the nearest millimeter and usually weighted to the nearest gram (Acculab electronic scale - model 4 kg or 6 kg with 1 gram precision). Pesola spring scales which measure to the nearest 0.1 gram were used when the electronic scale malfunctioned. Typically, water and air temperature were measured along with the time of measurement at each electrofishing site. Time in seconds of each electrofishing pass was also recorded.

Captured steelhead were returned to the capture site after sampling was completed either by distributing them evenly throughout the site or placing them in the pools if the site was very steep. Electrofishing was limited to three sampling episodes at each site, to limit the potential for injury from repeated electrofishing exposure.

There were two sets of electrofishing surveys. The first set of electrofishing sites in both creeks were evenly distributed, approximately 300 feet apart so that an electrofishing site would be near any source of sediment delivery. Typically electrofishing sites were around 50 feet in length and contained at least one pool. These sites were used to document steelhead abundance, year class composition, and relative growth during three time periods: early summer, late summer/early fall-prior to the rain season, and during the rainy season.

Ten electrofishing sites were selected for the first set on SF Mud Springs Creek (Figure 14). They were located from downstream to upstream: Two electrofishing sites (1 and 3) were selected downstream of turbidity monitoring Station A. Sites 4 and 5 were within the downstream turbidity monitoring Station A. Three electrofishing sites (6, 9, and 12) were located between the two turbidity monitoring stations and three electrofishing sites (14, 15, and 16) were located upstream of or within the upstream turbidity monitoring station B.

Twelve electrofishing stations were selected for the first set on the NF Mud Springs Creek (Figure 15). They were located from downstream to upstream: Three sites (3, 4, and 5) were downstream of the downstream turbidity Station C. Sites 6 and 7 were within turbidity monitoring Station C. Four sites (8, 10, 13, and 14) were between the turbidity monitoring stations. Sites 16 and 17 were within turbidity monitoring Station C and site 19 was upstream of turbidity monitoring Station C.

The second set of electrofishing sites documented pre- and post-storm steelhead abundance and documented winter and spring conditions. The additional electrofishing sites were located close to the original electrofishing sites (Figures 14 and 15).

3.5 Chronology of Sampling

During the first set of electrofishing surveys there were three major periods that were sampled for steelhead catch rate; early summer, late summer/fall and fall/winter. The primary purpose of early summer sampling was to establish a baseline condition for steelhead catch rate in the Mud Springs creeks. During early summer alevins have emerged as fry and adults have emigrated. Streamflow is declining toward summer baseflow conditions, and water temperatures remain sufficiently cool to be suitable. The late summer season is thought to be a period of relative decline in abundance resulting from high water temperatures and minimal streamflow conditions. Finally, the return of seasonal rains in November increased stream discharges and turbidities in NF and SF Mud Springs creeks. The fall/winter streamflows in Mud Springs Creek were generally about 5 to 7 cfs; however, population sampling was conducted when flows were as high as 15 cfs. A second set of electrofishing surveys occurred between February and May 2004.

3.6 Sampling and Weather Prediction

Steelhead population sampling was scheduled to coincide with a range of stream flows and storm runoff events. Field visits were scheduled based on daily weather reports from National Weather Service (NWS) to anticipate storms in the Laytonville area. Weather satellite images and weather forecasts used were from Western Regional Headquarters in Salt Lake City and the California - Nevada River Forecast Centers (in Salt Lake City, Utah, and Eureka, California).

4 RESULTS

Water quality and biological data were collected over a 12-month period from June 2003 through May 2004. The water quality results are presented first, followed by the biological results. These complementary investigations are integrated in the Discussion and Conclusion chapters.

4.1 Water Quality

Water quality of small headwaters streams is determined by the processes of rainfall, the resulting surface runoff, and the consequent transferring of mobile constituents including sediment suspended in the water column via stream channels. Small steep streams, such as headwaters channels, are not limited in their capacity to transport small constituents such as silt and clay. The available supply of mobile constituents is the limiting factor in the maximum concentration of suspended constituents in streams. Watershed disturbances and land-use practices determine the available supply of sediment that is delivered to nearby aquatic habitat.

Rainfall

The tipping bucket rain gage installed at monitoring Station A recorded rainfall with the precision of 0.1 inch increments every 10 minutes. Figure 16 shows the rainfall record and accumulated rainfall in 24-hour intervals at the study site. Additional rainfall data were obtained from a weather station near Laytonville to fill in a mid-season data gap caused by data logger memory limits and data logger malfunction in mid-February. With the exception of one point, where nearly 4 inches of rainfall in the Laytonville record corresponds with 0.24 inches at Alder Springs - which is an outlier, the relationship between the two rain gages is reliable (r^2=0.82). The differences between the two rain gages indicate Alder Springs Ranch exists in a partial rain shadow. This is explained by the prevailing westerly source of storms and the Ranch's location on the east facing slopes of the 4,000 foot Cahto Peak mountain range.

The comprehensive rainfall record (Figure 17) shows that one storm (in a 24-hour period) produced in excess of 3.5 inches, five storms exceeded the range 2-3 inches, and 16 storms produced more than 1 inch of total daily rainfall. The first storms occurred in mid-November and the last in late April. A total of 48.6 inches of rainfall accumulated during the 2003-04 winter season (Figure 18).

Runoff

Each monitoring Station included a pressure transducer to measure changes in flow depth; or stream stage. Three or four discharge measurements at each monitoring Station relate stage with discharge (Figure 19). The maximum discharges were all measured within a few hours of each other during a moderately high (ranks #4) storm event on February 26, 2004. Corresponding flow rates for SF Mud Springs Creek were 25 cfs at the upstream Station and 38 cfs at the downstream Station, representing an increase of over 50% in the downstream direction. Corresponding flow rates for NF Mud Springs Creek were 30 cfs at the upstream Station, and 37 cfs at the downstream station, representing an increase of 23% in the downstream direction.

Sediment Source Assessment

Maps of the sediment sources are presented in Figures 20-24. Many of the sediment sources are small channels draining the upslope drainage system from cultivated tracts. Between Stations A and B a fence line was a source of sediment because it was cleared and graded during construction, and has caused a concentration of surface flow and erosion in several locations. Other sediment sources were from the erosion of pre-existing tributary channels caused by increased storm runoff or destabilization of the channel by other anthropogenic activities associated with land use changes. Sediment sources were identified relative to their proximity to the monitoring Stations and their potential to affect water quality.

Cross sections established in three small tributary channels during spring 2003 were re-measured in spring 2004 (Figure 25). The locations of the cross sections are keyed to the sediment source maps (Figures 20-24).

Turbidity

Monitoring Stations were strategically located. Upstream sensors were located to monitor ambient conditions. Downstream sensors were located to monitor sediment inputs from small tributary streams that were affected to varying degrees by the recent land development. Time series records of turbidity and stream stage were obtained for the four water quality monitoring Stations A, B, C, and D (Figures 26-33). The compressed time scales of the one-page plots covering the entire periods-of-records make it difficult to distinguish between upstream and downstream differences in turbidity for individual storm events. Expanded plots for each Station show examples of early season storms in more detail.

Suspended Sediment

Suspended solids obstruct the transmittance of light through a water sample and impart a qualitative characteristic known as turbidity, which can be interpreted as a measure of the relative clarity of water (Sadar 1998). Turbidity is an indirect measure of suspended particles in water that cause light scattering effects. The color of sediment particles has been shown to substantially affect turbidity measurements (Sutherland *et al.* 2000). It is well known that turbidity is strongly influenced by particle size (e.g. Foster *et al.* 1992) and orientation of the sediment sample (Sadar 1998). Nonetheless, turbidity monitoring is the most common means of obtaining water-clarity data and for inferring suspended-sediment concentrations (Gray 2002).

It is common practice to measure turbidity for documenting the effects of land use changes on water quality because water clarity and light penetration have significant effects on aquatic ecology (e.g. Henley *et al.* 2000; Waters 1995). Henley *et al.* (2000) recommend turbidity measurements be correlated to suspended sediment concentrations on an individual watershed basis.

Nineteen suspended sediment samples were taken over the course of this investigation to compare with turbidity measurements. Particle size of the suspended materials in the samples was also determined. These results are presented in Table 1. The scatter plot of turbidity and suspended sediment (Figure 34) verifies turbidity is caused primarily by the suspension of sediment in SF Mud Springs and NF Mud Springs creeks. Grain size analysis of the suspended sediment samples found a high percentage, 28%, of the total solids weight is attributable to sand and coarser particles (Figure 35). Samples taken during storm events had the most prominent sand fraction. Important implications for the ill-effects of suspended sediment on fish are indicated by the substantial fraction coarser than sand.

The turbidity results, in their mid-range of values, are comparable to results from Caspar Creek, California (Lewis 2002). The Caspar Creek data range from approximately 10 to 500 mg/l suspended sediment concentration and approximately 10 to 175 NTU turbidity. The Caspar Creek data trend suggests a steeper slope than the Mud Springs data, giving confidence that data from this study are reliable. Although figure 34 shows good correlation (r^2=0.78) between turbidity and suspended sediment concentration, it was determined that more than 19 samples were needed to support translating the turbidity data records to suspended sediment concentrations.

Measured suspended sediment concentrations were used to examine the ill-effects caused by suspended sediment during peak events. This was considered essential for two reasons: (1) the suspended sediment model provides ill-effects scores for multiple life stages of salmonids; and (2) it accounts for the ill-effects of suspended fine sand particles. The highest measured suspended sediment concentration was 9,859 mg/l, corresponding to 600 NTU turbidity. This peak concentration value was used without extrapolation for analyzing the ill-effects of individual short duration turbidity events. Given that 600 NTU was commonly exceeded this is another conservative step in our analysis.

4.2 Biological Responses

The electrofishing surveys in this study documented juvenile steelhead exposure and responses to turbidity and suspended sediments during winter 2003-04. Surveys also measured juvenile steelhead relative abundance by season for the following reasons: (1) steelhead relative abundance is subject to annual and seasonal variation, (2) year-class size in some watersheds is determined by the mortality rate during summer conditions of low flow and high water temperatures, and (3) seasonal high flows and high suspended sediments can reduce steelhead relative abundance. Therefore, seasonal steelhead abundances were compared with the records of elevated turbidity and high concentrations of suspended sediment.

Anadromy and Age Determination

Electron probe microanalysis (EPMA) scans a transect from the primordial to the edge of the sagittal otolith for strontium and calcium. The EPMA showed that each of twelve *Oncorhynchus mykiss* specimens had strontium to calcium ratios (Sr/Ca) between 1.8 and 1.6 in the primordium. These ratios declined with distance to about 1.2, reflecting a lack of strontium during freshwater growth (Baxter 2004)**.** A decline of Sr/Ca ratio from the primordium to the edge of the sagitta is diagnostic of anadromy (Zimmerman and Reeves 2002, Rieman *et al.* 1994). Therefore, all specimens were found to be anadromous steelhead, not resident rainbow trout.

It was noted that four of the steelhead had a different Sr/Ca ratio decay pattern than the other eight. These four (FL 50mm to 75 mm) were found to be YOY (brood year 2003) and the other eight were older. The age of steelhead between FL 75 mm and 90 mm could not be determined with this assessment, but specimens between 90 mm and 130 mm were in their second summer (1+, brood year 2002) and one of the 130 mm was in its third summer (2+, brood year 2001) (Table 2), accepting 85 mm FL as the border between YOY and over-yearlings. Some longer and older specimens exhibited spike increases in strontium concentrations after the initial strontium decay. Spike increases in strontium can only be explained by consumption of exogenous strontium from sources such as steelhead eggs and fry, or scavenging of adult steelhead carcasses.

Summer low-flow water samples from Mud Springs Creek were analyzed (Baxter 2004) for strontium and calcium by mass spectrometer. Mean concentrations of strontium were 54.1 parts per billion *(ppb)* in SF Mud Springs Creek and 62.2 ppb in NF Mud Springs Creek. Mean calcium concentrations were 5.72 parts per million (*ppm*) in SF Mud Spring Creek and 5.70 *ppm* in NF Mud Springs Creek. The low concentrations of ambient strontium in the stream water confirm that there is not a strontium source in the Mud Springs Creek watershed. This result strengthens the determination of anadromy.

Water and Air Temperatures

Water and air temperatures recorded during electrofishing episodes showed that water temperatures were never stressful during the summer or so low during the winter to preclude growth (Figure 36 and 37) despite the fact that air temperatures during the summer frequently exceeded 37.8^{o}C and winter air temperatures were sometimes less than freezing (Figure 38).

Habitat Composition

The dominant habitat types in both SF and NF Mud Springs creeks are riffles, pools and runs, in that order. Habitat composition in both creeks was similar, with NF having slightly more riffles and SF having slightly more pools (Figure 39). The habitat type proportions of sampling sites in each creek under-represented riffle and over-represented pool (Figure 40 and 41). Pools were used as the basis for electrofishing site selection and most steelhead were caught within or near the pool.

Stream Gradient

Stream gradients were similar for both study streams. SF Mud Springs Creek had a calculated gradient of 0.07 ft/ft and NF Mud Springs Creek had a calculated gradient of 0.08 ft/ft (Figures 14 and 15). Given the consistent gradient of both creeks, the large substrate size and its associated large interstitial space, and the shape of the channel in both creeks, the effects of high flows were expected to exert a similar influence at any location.

Juvenile Steelhead Passage Impediments

Local gradients of 0.1 ft/ft are generally considered difficult for juvenile steelhead to ascend. Measured local gradients exceeding 0.15 ft/ft were selected as potential juvenile steelhead passage barriers (Figures 42 and 43). Using this criterion, the potential juvenile steelhead passage barriers were found to be numerous and widely distributed in each creek. This suggests that movements by juvenile steelhead would be limited primarily to the downstream direction.

Steelhead Growth

Estimates of steelhead YOY growth were made by comparing the mean fork lengths measured between samples from the same locations, and dividing by the number of days between sampling. In NF Mud Springs Creek, steelhead YOY growth-rate between July and August 2003 was 0.27 mm per day. Between August and December 2003 growth rate was small, 0.02 mm per day. Growth-rate between August 2003 and January 2004 was also small, 0.12 mm per day.

After August, growth rate typically slows due to pupation of benthos (less aquatic food available) and colder air temperatures (less terrestrial food available, slower metabolism).

In SF Mud Springs Creek, steelhead YOY growth rate between July 8 and August 26 was 0.06 mm per day; an increment so small that it is not detectable in the length/frequency figures. Between July 11 and October 2 the growth rate was small and negative (-0.11 mm per day). There were insufficient numbers of steelhead YOY between October and January to estimate growth-rate during this period.

Differences in steelhead growth-rate between the study streams may be related to food availability, relative fish abundance and competition, or diversity of fish lengths in the population. NF Mud Springs Creek had a greater diversity of steelhead sizes than SF Mud Springs Creek (see below). Harvey and Nakamoto (1997) also found that steelhead growth rate was slower when smaller steelhead were under-represented in samples of the population.

Steelhead Abundance

The first set of electrofishing surveys documented steelhead catch rate throughout the two study streams during three major seasons (Tables 3 and 4). Both study streams were sampled in lower, middle, and upper sections during mid summer, fall, and mid-January. Surveys in NF Mud Springs Creek also extended from summer 2003 through the following winter, with the last survey occurring March 31, 2004.

In SF Mud Springs Creek, during the first set of electrofishing surveys, the most upstream two sites (15-16) were important because they represented portions of the study area that were consistently free of suspended sediment. Unlike SF Mud Springs Creek, there were no study segments in the NF that remained unimpaired by suspended sediment.

Subsequent steelhead surveys continued in areas of clear water conditions (Sites 17-18) as well as the middle and lower segments of SF Mud Springs Creek during late winter and spring 2004. A single station was sampled on May 5 (Site 2) where numerous recently emerged steelhead fry were collected. At that site in early May, 56 recently emerged fry were caught, and only one older steelhead (age 1+). The monitoring effort was terminated with the finding in early May of numerous recently emerged steelhead fry that had not been exposed to the previous winter's conditions. May is a month when many of the larger juvenile steelhead migrate downstream, reducing the number of juvenile steelhead in the resident population.

EARLY SUMMER ABUNDANCE

SF Mud Springs Creek

SF Mud Springs Creek was electrofished at ten sites during July 8-11, 2003. These sampling sites covered a total of 533 linear feet of stream, representing 19.8 % of the SF Mud Springs Creek study segment. Both the median and mean catch rates during this sampling period were 8.7 steelhead/100 feet of stream. The estimated total population of steelhead in the SF Mud Springs Creek study area in July was 220 juvenile fish. Steelhead fork lengths ranged from 45 mm to 190 mm (Figure 44). Steelhead over-yearlings (defined as > 85mm FL) represented 67% of the total catch.

Two other species that generally inhabit streams with high water quality were found in SF Mud Springs Creek. The larval and adult life stages of the Pacific giant salamander (*Dicamptodon ensatis*) were abundant, and tailed frog tadpoles (*Ascaphus truei*) were caught in the riffles near turbidity monitoring Station B.

NF Mud Springs Creek

NF Mud Springs Creek was electrofished at 12 sites during July 7-9, 2003. These sites collectively covered 500 linear feet of stream, representing 24.5% of the NF Mud Springs Creek study segment. Median and mean catch rates during this sampling period were 18.0 and 18.6 steelhead/100 feet of stream, respectively. The total estimated juvenile steelhead population for the NF Mud Springs Creek study segment was about 328 fish using the median catch rate, and 340 fish using the mean catch rate.

Steelhead fork lengths ranged from 25mm to 195 mm. There was a gap between 55 mm and 85 mm FL, where no steelhead in this size range were found (Figure 45). Steelhead YOY dominated, representing 65% of the total catch. Pacific Giant Salamanders (*Dicamptodon ensatis*) were common in NF Mud Springs Creek, but no tailed frogs (*Ascaphus truei*) were found.

LATE SUMMER ABUNDANCE

SF Mud Springs Creek

The same ten electrofishing sites sampled during early summer were sampled again for late summer abundance. Two site visits were necessary to document late summer conditions in SF Mud Springs Creek due to equipment malfunction. Electrofishing sites 1, 3, 4 and 5 were sampled during August 26th and sites 6, 9, 12, and 14-16 were sampled October 1-2, 2003. Seasonal rains had not begun prior to the October sampling effort and temperature conditions remained relatively stable during the intervening period. An examination of the data indicate that abundances of steelhead were unchanged between late August and the first days of October (one-way ANOVA, F = 0.02, 9 df, P=0.89).

Median and mean catch rates during late August/early October 2003 were 6.4 and 7.6 steelhead/100 feet of stream, respectively. The total estimated juvenile steelhead population for the SF Mud Springs Creek study segment was about 162 fish using the median catch rate, and 193 fish using the mean catch rate.

Steelhead fork lengths ranged from 46 mm to 200 mm (Figure 46). Steelhead over-yearlings, the minority part of the catch in August (47%), were the dominant part of the catch (76%) in October. The practical explanation for the switch is that the YOY grew sufficiently in this stream to be considered over-yearlings.

NF Mud Springs Creek

The same twelve electrofishing sites sampled during early summer were sampled again for late summer abundance. Median and mean catch rates in NF Mud Springs Creek for late August 2003 were 19.6 and 17.5 steelhead/100 feet of stream, respectively. The total estimated juvenile steelhead population for the NF Mud Springs Creek study segment was about 358 fish using the median catch rate, and 320 fish using the mean catch rate.

Steelhead fork lengths ranged from 42 mm to 178 mm (Figure 47). The wide gap of missing steelhead shifted from 55-85 mm to 77 -92 mm FL. Steelhead YOY represented 64% of the total catch.

FALL and WINTER ABUNDANCE

SF Mud Springs Creek

The third electrofishing survey in SF Mud Springs Creek occurred January 14-16, 2004 and used the same ten electrofishing sites as the early and late summer surveys. During this survey the field crew observed turbidity in this creek and traced the source to lands disturbed by the development project. The electrofishing crew, which was present during several storms, observed that flow upstream from the upstream most monitoring site (turbidity Station B - US) remained clear and that turbidity increases were the result of inflow from lateral sources in disturbed areas. The median and mean catch-rates of juvenile steelhead in mid-January 2004 were 4.2 and 3.8 steelhead/100 feet of stream, respectively.

Steelhead fork lengths ranged from 75 to 205 mm (Figure 48). Steelhead over-yearlings represented 90% of the total catch.

NF Mud Springs Creek

The third electrofishing survey on NF Mud Springs Creek sampled the same twelve sites as those during the early and late summer surveys. Two site visits were necessary to document fall/winter conditions in NF Mud Springs Creek due to equipment malfunction. The December 17-18 survey entailed seven electrofishing sites, 3 through 8, and 10, which included the downstream half of the study segment. Five sites 13, 14, 16, 17, and 19 were sampled on January 13, 2004. The difference between the mid-December data and the mid-January data was not significant (ANOVA, F = 1.38, 11 df, P = 0.27). However, three storms occurred in the watershed between the December and January surveys, so relative abundance is reported separately for the two sections of NF Mud Springs Creek. December median catch-rate for the seven downstream sites was 10.6, and the mean catch-rate was 10.9 steelhead/100 ft of stream. Median and mean catch-rates at the five upstream sites in mid-January were 3.6 and 5.8 steelhead/100 ft of stream, respectively.

Steelhead fork lengths ranged from 45 to 192 mm in December 2003, and 52 to 184 mm in January 2004 (Figure 49). Steelhead over-yearlings represented 18% in December 2003 and 31% in January 2004.

5 DISCUSSION

An objective of the investigation was to detect the differences in water quality between recently disturbed and undisturbed portions of the watersheds. This was accomplished by integrating over time the cumulative turbidity exposures for each monitoring Station. Figure 50 shows the cumulative turbidity exposure (in NTU*days) for all of the monitoring Stations on SF Mud Springs Creek. By mid December, the upstream Station B had a cumulative dose of less than 1,000 NTU*days, while the downstream Station B dose was over 15,000 NTU*days. The upstream sensor at Station B continued to show very little accumulated turbidity through January 17, 2004 when the Station data logger malfunctioned. The downstream sensor at Station B exceeded 15,000 NTU*days by January 14, 2004. The difference between the two Stations shows that the small tributary entering between the upstream and downstream sensors contributed substantial turbidity. The clear difference in the lines shows that the contributing drainage area between the Stations (20 acres, 9 disturbed by development) acted as additional source area for turbidity (refer to Figures 2 and 21).

Turbidity monitoring Station A showed a notable difference between the upstream and downstream sensors in November and December 2003 (Figure 50). The difference was caused by the replacement of a road culvert sometime in November, and subsequent runoff was observed to be flowing under and around the exterior of the culvert (see figures 6 and 7). This caused a high turbidity event at the earliest onset of winter storms when stream flow remained relatively low. This event, high turbidity combined with low flow, may have resulted in unusually high stress to steelhead downstream from Station A. After January 2004 the difference between upstream and downstream sensor records was negligible, indicating that turbidity contributions from the small tributary were similar to the water quality in SF Mud Springs Creek and that sediment production from the nearby road and culvert had diminished.

In NF Mud Springs Creek, turbid runoff was observed flowing directly from drainages originating from the north cultivation unit and its roads during both winters 2002-03 and 2003-04. The downstream Station C 0-1000 NTU sensor failure precluded additional evaluation of the effects of that sediment source. Monitoring Stations C and D on NF Mud Springs Creek showed separate cumulative exposure curves, increasing in the downstream direction (Figure 51). However, cumulative turbidity exposure in NF Mud Springs Creek followed a different pattern from SF Mud Springs Creek. The upstream monitoring Station (C) shows a progressive increase in exposure as the rainy season proceeds. This is explained by the watershed upstream from Station C contributing more sediment as compared to upstream Station B, and by not placing the sensors far enough upstream to detect unpolluted water. This result is supported by the sediment source mapping results that show a larger area (17 acres, refer to Figure 3) disturbed by cultivation, and relatively large areas of old landslides (Figure 23) that may be intermittently active in the area upstream from Station C. The early rise in cumulative turbidity exposure at upstream Station C, as compared to upstream Station B, is explained by two factors; the less stable slopes in the watershed producing more sediment available for transport by early season storms, and more development-disturbed acres contributing sediment.

The separation of the cumulative turbidity exposure lines in the downstream direction for both creeks shows that turbidity increased in the downstream direction. This result is significant because if the tributaries between the monitoring Stations contributed clear water, or even less turbid water, turbidity would decrease in the downstream direction due to dilution. The maximum cumulative turbidity exposures, measured at the downstream sensors of both SF Mud Springs and NF Mud Springs creeks, were approximately equal at 30,000 NTU*days on February 9, 2004. This indicates that the old watershed disturbances in the NF were not substantial contributors of sediment during the monitoring period. The cumulative turbidity exposures continue to rise at both Stations until the records end due to equipment faults. Although the water quality at upstream Station B is good, the similarity between SF Mud Springs and NF Mud Springs creeks maximum cumulative turbidity exposures indicates that the effects of tributary inflows from the disturbed areas approximately equal each other at the downstream monitoring Stations (A and D). This indicates that equally impaired conditions existed downstream from the confluence of SF Mud Springs and NF Mud Springs Creeks, with important implications for the growth and survival of fishes inhabiting, or migrating to those areas.

5.1 Predicting the Impacts to Steelhead

Extensive literature about the effects of suspended sediments on salmonid fishes exists, beginning with the first published, by M.M. Ellis in 1936. Thorough published reviews [Cordone and Kelly (1961); Sorensen *et al.* (1977); Langer (1980); Alabaster and Lloyd (1982); Newcombe and MacDonald (1991); Waters (1995); Newcombe and Jensen (1996)] point out that salmonids can be affected by inert sediment by: (1) acting directly on free-living fish, either by killing them or by reducing their growth rate or resistance to disease, or both; (2) interfering with the development of eggs and larvae; (3) modifying natural movements and migrations of fish; and (4) reducing the abundance of food organisms available to the fish (Newcombe and Jensen 1996).

The storm-season record of turbidity was analyzed using the impact assessment model for clear water fishes exposed to conditions of reduced water clarity developed by C.P. Newcombe (2003). The model was applied to the turbidity records from each monitoring Station. This model is most appropriate for juvenile salmonids exposed to fine-grained sediment, in the size range of silt and clay.

The Newcombe (2003) water clarity model is similar in structure to the model for fishes exposed to concentrations of suspended sediment (Newcombe and Jensen 1996). Both models compare the ‘dose’ of water pollutant (product of turbidity magnitude * duration, or suspended sediment concentration * duration) to the suite of ill-effects available from literature (the meta data). The models are structured to account for events of high magnitude and short duration having equivalent ill-effects to events of low magnitude for long duration. Table 5 lists the continuum of ill-effects associated with the severity scores of the models.

Examining the rainfall record revealed that most storms were of 2-4 days duration. This duration suggested that a suitable time increment for analyzing the turbidity time series records would be a 6-day interval: a middle time interval in the Newcombe (2003) model. A 6-day interval would be sufficient to encompass individual storm events, and short enough to avoid combining storms of different magnitude. This approach resulted in a ‘chronic exposure’ evaluation of the data, described below. A complimentary approach suggested by C.P. Newcombe (personal communication August 6, 2004) examined each turbidity event in one hour intervals. The results of these two analyses follow.

Exposure to Reduced Visual Clarity

Turbidity records were summed over sequential 6-day intervals. The 6-day average NTU was located on the model look-up matrix. The resulting severity of ill-effect score (SEV score), along with the date of the last day of the 6-day interval, was entered in a spreadsheet. Following the recommendation of C.P. Newcombe (personal communications, June 17-18, 2004), the average over a 6-day interval was treated as a 'base SEV score' and the peak turbidity during the interval was examined separately.

A second SEV score for the ill-effect of brief high-magnitude turbidity events was created by counting the number of turbidity values exceeding the various matrix turbidity intervals and converting the counts to time equivalents. This resulted in a separate column of 'peak SEV scores' for each 6-day interval. The Newcombe (2003) model assumes a continuum of effects and dose, but each score (base and peak) was rounded down. This is another conservative step in the process of determining the severity of ill-effects.

Base and peak SEV scores for each of the downstream and upstream sensors at each Station were examined in time series. It is evident that some turbidity events delivered predominantly a chronic exposure, while other events delivered episodic exposures. Figures 52-55 show the SEV scores for each Station as derived by selecting the largest of the base and peak scores for each time increment. The rational for selecting the largest value among the base and peak SEV scores is that the highest dose of either the chronic or episodic evaluation is representative of the exposure visited upon aquatic organisms.

The plots of SEV score integrate the turbidity results over sequential 6-day time intervals, providing an effective means for discussing the effects of turbidity on the steelhead population. Each 6-day interval was plotted separately, not accumulatively. Therefore this is a conservative analysis.

SF Mud Springs Creek

Station A (Figure 52) shows the prominent effect of the nearby culvert replacement and subsequent turbidity caused by flow piping through the poorly compacted fill around the culvert in mid-November. A SEV score of 8 corresponds to moderately serious (sublethal) impacts. It is the highest level of sublethal impacts in a range of 4-8 which Newcombe (2003) corresponds to significant impairment, including reduced fish growth rate, reduced habitat size, or both. The incoming water quality, as measured by the upstream sensors of Station A, ranged between SEV 0-2, nil to low level impact, during the same time interval. After passage of high turbidity produced locally at the culvert, accompanied by erosion in the tributary channel upstream (Figure 25), the SEV scores for the upstream and downstream sensors followed similar patterns. Maximum values of 5 were reached on two more occasions; mid-December 2003 and early January 2004.

The upstream monitoring Station on SF Mud Springs Creek (Station B) shows SEV scores of 0 from early November to early December (Figure 53), because good water quality persisted over this early winter time period. The first large storm of the season occurred on December 6, 2003 and its effect on water quality is evident by pronounced increases in SEV scores. SEV score for the upstream sensors at Station B reached 3 while the downstream sensors recorded SEV score of 6. A SEV score of 3 corresponds to slightly impaired with changes in feeding and other behaviors, while a SEV score of 6 lies in the middle of the significantly impaired range, where reduced growth rate, reduced habitat, or both can occur.

The December 6th storm produced the highest SEV score at the upstream sensors at Station B; subsequent storms resulted in a 0-1 SEV score. The well known *first flush* phenomenon is a reasonable explanation for this pattern. First flush is the delivery and transport, during the first large storm of the season, of mobile sediment accumulated within the watershed over the dry season. In contrast, after the December 6th storm, the downstream sensors at Station B recorded two additional events. SEV scores for those events were 2 in mid- to late–December, and a SEV score of 7 in early-January. The SEV score of 7 is in the upper portion of the significantly impaired range (4-8). The difference between the upstream and downstream SEV scores at Station B is explained by 9 additional sub-watershed acres which are disturbed by land development and cultivation (see Figure 2). Our electrofishing crews observed turbid tributary discharge between the sensors.

NF Mud Springs Creek

Station C, the upstream Station on NF Mud Springs Creek, shows SEV scores of 5 for the upstream sensors and 7 for the downstream sensors during the December 6th storm (Figure 54). SEV scores of 5-7 are in the significantly impaired range (4-8) where reduced growth rate, reduce habitat, or both are possible effects. Figure 54 suggests that subsequent to the first storm there was little difference between the upstream and downstream sensors. However, that is not accurate because the 0-1000 NTU sensor in the downstream housing became inoperative on December 13. Subsequent data are artificially truncated at 50 NTU and episodic peak SEV scores are not represented for the upstream Station C after December 13, 2003.

Higher SEV scores are indicated downstream in NF Mud Springs Creek as shown in Figure 55 for monitoring Station D. An early season peak SEV score of 3 in mid- to late-November lasted for two 6-day time intervals. This corresponds to the first rainfall recorded in the study area and can be interpreted as the *first flush* phenomena. The same pattern of peaks during subsequently larger storms. The greatest SEV score, 7, followed by two additional peak scores of 6, was in the significantly impaired range where reduced growth rate, reduced habitat, or both are possible consequences.

The turbidity data indicate impairment of visual clarity in SF Mud Springs and NF Mud Springs creeks. The analysis based on turbidity, above, integrates all the various modes of ill-effect identified in the literature (summarized by Newcombe and Jensen 1996) and generates values that give a good overall indication of the impacts caused by land development. However, the turbidity model is best suited for suspended particles smaller than sand, a condition not indicated by our samples. Further analysis using suspended sediment containing substantial percentages of sand-sized particles is necessary to conclusively predict the ill-effects to salmonids.

Exposure to Suspended Sediment, Including Sand

The occurrence of substantial percentages of sand (mean 28%) in the suspended sediment samples indicates that the visual clarity model (Newcombe 2003), applied above, would underestimate the severity of ill-effects on salmonids. Suspended sand and all suspended particles greater than 0.075 mm diameter physically abrade the delicate respiratory tissues (*e.g.*, gills) (two references cited in Noggle 1978; Herbert and Merkens 1961; Southgate 1962). This is because sand is relatively massive and is comparable in size to the interlamellar space within fish gills. Suspended sand also scours periphyton, the food base for fishes, from the stream substrate, leading salmonids to abandon habitat to find adequate food supplies.

Each storm, defined as a turbidity spike of 100 or more NTU, was analyzed using the suspended sediment model of Newcombe and Jensen (1996). In this analysis, it was assumed that the harmful effects of each storm lasted for one day. This assumption is justified because fishes exposed to brief high concentrations of suspended sediment that includes sand particles do not recover from the ill-effects caused by the peak concentrations as quickly, if at all This approach was suggested by C.P. Newcombe to examine the ill-effects caused by sediment pollution events containing sand-sized particles. As applied in this study, the recommended approach is further conservative in that (a) the maximum range of the turbidity sensors (1000 NTU) was exceeded during some storms and other sediment delivery events, (b) the highest measured suspended sediment concentration corresponded to 600 NTU, and (c) the higher measured turbidity values were not incorporated into the analysis by optionally extrapolating the good relationship.

Suspended sediment concentrations corresponding to each turbidity peak were derived from the relationship in figure 34. It is advantageous to use the Newcombe and Jensen (1996) model also because it separates the ill-effects for different life stages of salmonids present in the study streams. The resulting figures show SEV scores for each storm event and the life stages present in the Mud Springs creeks (Figures 56-59). Overlaying the corresponding life stages that were present for each storm facilitated accurately predicting the harm caused by individual sediment pollution events.

SF Mud Springs Creek

The ambient water quality entering the monitoring reach of SF Mud Springs Creek (upstream sensor record for Station B) followed a *first flush* pattern, expected for all watersheds. The first large storm on December 6, 2003 exposed juvenile steelhead to SEV score 7 (Figure 56), known to cause poor physical condition, impaired homing, reduction in feeding rates, avoidance, and abandonment of cover. Although SEV scores of 7 for adults, and 9 for eggs, occurred, adults and eggs were not likely present during this first winter storm. Subsequent storms, although creating larger stream flows, had lower ill-effects scores. The second and third storms resulted in SEV scores of 6 for juveniles and adults, and 8 for eggs. Adults and eggs were probably present beginning in mid-December. SEV score of 8 corresponds to physiological stress and histological changes to sensitive tissues (i.e. gills, embryo surface), in addition to causing poor physical condition, impaired homing, reduction in feeding rates, avoidance, and abandonment of cover.

Substantially increased ill-effects are predicted at the downstream portion of monitoring Station B. The first storm resulted in SEV 9 exposures for juveniles, and 9 and 10 for adults and eggs (although not likely present). SEV 9 corresponds to the lowest score in the severely impaired range, where reduced growth rates are found. The second storm exposed steelhead juveniles to scores of SEV 6, adults to scores of SEV 7, and eggs to scores of SEV 9. The third and final storm in the record exposed all steelhead life stages to a SEV score of 10, indicating potential mortality of up to 20% of the population, in addition to physiological stress and histological changes to sensitive tissues (i.e. gills, embryo surface), poor physical condition, impaired homing, reduction in feeding rates, avoidance, and abandonment of cover. Juvenile steelhead would have experienced high physiological stress, histological compromise, reduced growth rates, and up to 20% mortality. The increased ill-effects are caused by the contribution of sediment from tributary B1 which originates on a cultivated area. Tributary B1 also showed recent channel incision due to land development, and lacked pre-existing sediment sources.

The ill-effects predicted from suspended sediment events at Monitoring Station A began with two episodes in November 14-16, 2003 (Figure 57). The first, November 14, was a result of less than 1 inch rainfall, but localized sediment production at the newly installed culvert on tributary A1. Juvenile steelhead were exposed to a SEV score of 7, corresponding to poor condition and moderate habitat degradation, causing impaired homing, reduction in feeding rates, avoidance, and abandonment of cover. On November 16, juvenile steelhead were exposed to a SEV score of 10, causing up to 20% mortality in addition to physiological stress and histological changes to sensitive tissues (i.e. gills, embryo surface), poor physical condition, impaired homing, reduction in feeding rates, avoidance, and abandonment of cover. These ill-effects, which reach mortality, are due to runoff from a new road crossing.

The first large storm of the season (over 3 inches of rainfall) occurred on December 6th, exposing juvenile steelhead to a SEV score of 8. Four additional storms were recorded, producing severely impaired conditions for eggs and larvae that were likely present, in addition to reduction in feeding rates, avoidance, and abandonment of cover.

NF Mud Springs Creek

Equipment malfunction at the downstream sensor portion of monitoring Station C prevents discrimination of the effects caused by inflow from tributary C4. However, the upstream record indicates that the main stem of NF Mud Springs Creek had much poorer water quality than the incoming water monitored at the upstream Station (A) on SF Mud Springs Creek. The December 6, 2003 storm resulted in a SEV score of 10, potentially lethal to 20% of the population of juveniles present (Figure 58), in addition to physiological stress and histological changes to sensitive tissues (i.e. gills, embryo surface), in addition to causing poor physical condition, impaired homing, reduction in feeding rates, avoidance, and abandonment of cover. On December 14, 2003, all present life stages, which may include adults and embryos in addition to juveniles, may have experienced significantly impaired conditions.

There is no reason to believe that the additional storms were not potentially lethal to present life stages, but the remainder of the winter 2003-04 record is truncated due to sensor malfunction. Steelhead living near the downstream monitoring Station (D) on NF Mud Springs Creek experienced potentially lethal conditions for juveniles on December 6, 2003 (Figure 59). That first storm reached a SEV score of 10. Subsequent storm events occurring on January 1 and February 17, 2004 delivered SEV scores of 11. These events potentially caused up to 40%

mortality for eggs and larvae present, in addition to physiological stress and histological changes to sensitive tissues (i.e. gills, embryo surface), in addition to causing poor physical condition, impaired homing, reduction in feeding rates, avoidance, and abandonment of cover.

Failure of the sediment retention pond on tributary D1 (Figure 60) was observed on December 6, 2003. Piping around large unsorted materials and poor compaction are the probable causes of pond collapse. The retention pond was not repaired for the remainder of the winter 2003-04 storm season, so its function was negligibly effective. In fact, ill-effects to lower NF Mud Springs Creek may have been amplified by pond collapse and berm erosion releasing the stored volume of water with high sediment concentration.

Habitat and Other Physical Conditions Effecting Steelhead

Undisturbed watersheds provide salmonids with water quality refuges during storms and brief poor water-quality episodes (e.g. Bell 2001). Under pre-disturbance conditions, it is reasonable to believe that the Mud Springs creek tributaries, some of them spring fed, acted as water quality refuges as well. Those tributaries are now polluted by sediment originating on cultivated land, or have undergone channel incision associated with an increased quantity of runoff from their disturbed watersheds. Multiple observations, and data collected during the lengthy course of this study, found that there are no water quality refuges available in the study area. Juvenile steelhead seeking refuge may move upstream where upstream movement is possible, but generally they must move downstream because of numerous passage impediments. Water quality downstream does not likely improve from that measured because there is no evidence of (a) dilution by clear water, or (b) sediment deposition within the channel. The sand found in all of the suspended sediment samples, indicative of relatively high turbulence and shear stress for suspending sand within the water column, supports this interpretation.

The study area prior to initiation of this study was more severely disturbed. During the winters of 2001-02 and 2002-03, slope failures occurred in the newly planted vineyards and entered the stream systems. Recently constructed vineyard drainage systems also delivered sediment-laden water to the streams. The sediment detention basins were either too small, or not well-maintained, or they failed. Road culverts were replaced without sediment control devices, so sediment also entered the streams from these sources. The access roads to the vineyards were not surface rocked, did not have rolling dips, and were not out-sloped. Turbid surface flow was observed entering the streams from roads. Any one of these sediment sources could decrease steelhead productivity, but the combination likely contributed to depressed steelhead populations in 2003-04.

Other land-use operations were observed that adversely affected rearing steelhead. At 12:15 pm on October 1, 2003, a turbid water discharge was observed from a relief valve on the pipe spanning SF Mud Springs Creek. Water from the relief valve entered the creek because the valve was located directly over the creek centerline. The water discharged from the pipe was measured at 20^{o}C while the receiving water of SF Mud Springs Creek was measured at 12.2^{o}C. The discharge continued for 15 minutes and increased the stream temperature to 14.4^{o}C. The water clarity was diminished so that the stream bottom was not visible at one foot depth. By 1:30 pm, when the stream was clear enough to resume electrofishing, the water temperature was still elevated at 13.3°C. The ranch owner and an assistant inspected the discharging valve and told the field crew that the discharge was a routine well test.

SF and NF Mud Springs creeks are physically similar. Both are consistently steep in their respective study reaches. Habitat type composition is similar between the streams. Substrates in both streams are cobble/boulder dominated. Both streams have numerous juvenile upstream passage impediments. The typical pool in both streams was short with only moderate depths and a strong downstream hydraulic control. Spawning gravels are not abundant or evenly distributed in either stream. Riparian canopy closure in both streams was excellent. Because of the ongoing vineyard conversion, both streams were adversely affected by fine sediment prior to initiation of our studies.

The nature and number of the upstream passage impediments in these streams indicates that distribution of steelhead in both creeks was due to adult migration. There were at least a half-dozen passage impediments with vertical jumps greater than 3 feet. Only the adults are sufficiently large to successfully ascend these barriers. In low order streams, steelhead tend to move far upstream, a behavior that reduces risk of redd scour during high stream flows, while providing the greatest food availability to juveniles. The pattern of distribution of YOY steelhead was the result of the gradual downstream movement from upstream spawning areas. The number of adults spawning in these creeks is not known, but widespread distribution of newly emerged fry in May 2004 far upstream, downstream, and through the study reaches was observed. Given the size of these streams, the number of spawning pairs needed to saturate the rearing habitat is not high, probably less than 10 pairs.

Steelhead relative abundance was examined by life stage because YOY are more susceptible to adverse affects of suspended sediment than the larger over-yearlings. The gills are smaller and therefore clog more easily (Bell 1973). The smaller YOY are also more susceptible to gut packing in turbid waters with high suspended sediments. Based on age-to-length assessment of the twelve steelhead used in otolith analysis, any steelhead over 85 mm FL was considered to be an over-yearling.

Steelhead were more abundant in NF Mud Springs Creek than in SF Mud Springs Creek during any season. The source of the difference in steelhead numbers was from YOY, not over-yearlings. There was no difference in the catch rate of over-yearling steelhead; a life stage that is more resistant to the adverse effects of high suspended fine sediment concentrations.

During the annual spawning run, adult steelhead movement was coordinated with storm events. The steelhead YOY length frequency distribution of the early July 2003 catch reflects differential emergence of as many as three separate broods from different storms. These data also show a gap between 55mm and 85mm in the YOY fork length frequency where no fish were represented. The YOY from this gap would correspond to broods from earliest spawnings and may indicate the adverse effects of a large slope failure, known to have delivered sediment to the stream during early winter 2002. Succeeding storms may have scoured fines from the spawning grounds to allow subsequent successful fry emergence. This is indicated by abundant steelhead YOY, exceeding the catch in SF Mud Springs Creek. However, YOY in SF Mud Springs Creek were longer. The implications of the missing and smaller YOY in NF Mud Springs Creek are that smaller fish (1) have greater sensitivity to suspended sediment exposure, (2) require longer residence time prior to emigration, thus they are exposed to more poor water quality events, and (3) ultimately, a progressively lower adult return rates lead to local extirpation (Harvey and Railsback 2002).

In contrast to the NF, the SF Mud Springs Creek low steelhead abundance numbers and lower growth rates during the summer are suggestive of some chronic adverse effect. This may indicate a degraded food supply, increased emigration, or increased mortality of the YOY. Competition may have been higher in SF Mud Springs Creek causing higher rates of emigration or slower growth because of the lack of diversity of YOY sizes (Harvey and Nakamoto 1997).

Relative abundance in either stream did not change significantly corresponding to increased summer temperatures or decreased summer base flows. Temperatures during the summer and fall were never stressful. The closed streamside canopy kept summer water temperatures cool. Cold winter temperature has been attributed as a lethal agent in some salmonid stream systems (Hall 1984). Recorded water temperatures never dropped to levels that would preclude active behavior or growth. The closed streamside canopy also served to keep the stream warm during the winter. While summer baseflows were not high, there was no significant decline in relative abundance during the warm low flow period. Significant declines in steelhead abundance occurred with the onset of fall/winter high flow events.

High flow flushing of steelhead was an effect expected to be similar throughout each stream. Each stream has a cobble/boulder substrate. The large substrate size in each study reach provides ample velocity refuge from high-flow events. Interstitial space was large and substrate roughness was high. The other important parameter affecting high flow flushing is local gradient. The gradient profile of each stream shows the consistent slope within the study reaches, so gradient effects should be similar throughout the study areas.

The non-linearity of growth, when comparing between sampling periods from early summer through winter, suggests that movement occurred in these streams, so different individuals were sampled each sampling episode. Power (2003) has shown with field experiments that increasing fine sediment deposition increases movement by steelhead. Sigler *et al.* (1984) also noted increased emigration from experimental channels under turbid conditions. There can only be limited upstream movement for YOY and over-yearlings due to numerous passage impediments in each stream. Therefore, the onset of winter storms and high flow flushing effects should increase relative abundance in the downstream sample areas. Because catch rates did not increase in the downstream sampling areas, which would be expected if downstream movement was an effective strategy to avoid high suspended sediment loads, the ill-effect on the steelhead population increased in the downstream direction.

5.2 Effects of Poor Water Quality Episodes on the Steelhead Population

The winter period is known to have high rates of steelhead mortality (Hall 1984). In some streams, low flow and extremely low temperatures kill fish, in others low temperatures and severe freshets (Cuenco and McCollough 1996); in still other streams the occurrence of anchor ice kills fish either through freezing or dewatering caused by ice dams (Jenkins 1991 cited in Aquatic Systems Research 1993). Both high flows and high concentrations of suspended sediments can occur during this period. Exposure to sufficiently high concentrations of suspended sediments kills steelhead (Newcombe 2003). No literature was found that examined the relative importance of high suspended sediment load and high flow to mortality. This study documented that steelhead relative abundance declined in both streams after high suspended sediment flow events that were sufficiently high to cause steelhead mortality, as predicted by the impacts assessment models. In the following discussion the results of this are examined to address the relative importance of high flows and high suspended sediment episodes on local steelhead populations.

SF Mud Springs Creek

Juvenile steelhead SEV scores from SF Mud Springs Creek were lower than NF Mud Springs Creek. The turbidity events converted to suspended sediment concentrations were sufficiently adverse on SF Mud Springs Creek in winter 2003-04 to predict adult, embryo and alevin steelhead mortality. Station A recorded a magnitude 10 for steelhead adults, eggs, and alevins on November 16, 2003. The Station B downstream sensor recorded a magnitude 10 event for those same steelhead lifestages on January 1, 2004. Although adults were not observed during the field investigation, the presence of steelhead fry in the system is proof that adult steelhead were present during the study period. Since embryos and alevins occur within the stream bed, they were unavailable for mortality assessments through electrofishing.

Because of small sample sizes and limited number of observations, data derived from electrofishing surveys are inadequate to achieve a level of statistical significance when comparing these data between sampling stations. The data, although not statistically significant, are, however, different (Figure 61). They suggest that 18% of the winter reduction of steelhead was due to factors other than downstream movement during high flow episodes. Steelhead were also exposed to episodes of high suspended sediment exposure in SF Mud Springs Creek (See Appendix, #16). Upstream inflow during storms remained remarkably clear in SF Mud Springs Creek, while the stream became progressively turbid with distance downstream, from lateral sediment inputs. Two electrofishing sites upstream from known sediment inputs declined 36% in population from the summer/fall survey to the after storm winter survey. These sites were exposed only to high flow effects. Eight electrofishing sites that received high sediment loadings in addition to high flow declined by 54% in population, while also experiencing sublethal harm such as induced avoidance.

An 18% population difference is an estimate of the fatal adverse effects of suspended sediment exposure, in addition to high flows and all other adverse effects steelhead encountered in these streams. Mean steelhead catch rate in the downstream eight sites was 7.50 per 100 feet in the late summer. Multiplying 18 % by the 7.5 steelhead per 100 feet represents the decline in catch rate due to the ill-effects of suspended sediment. This resulted in 1.33 steelhead per 100 feet. The length of stream affected by sediment polluted water in the study area was 2,345 feet. Therefore, approximately 31 juvenile steelhead were lost due to sediment polluted water in SF Mud Springs Creek.

NF Mud Springs Creek

There were suspended sediment concentration episodes in NF Mud Springs Creek during winter 2003-04 that were sufficiently high to cause direct mortality to adult steelhead. Station C recorded two adult SEV magnitude 10 suspended sediment events on December 6 and 12, 2003. Station D recorded four adult SEV magnitude 10 events: December 6 and 13, 2003, January 1, 2004 and February 17, 2004.

Steelhead embryos and alevins also were adversely affected from suspended sediment episodes in 2003-04. Station C recorded two SEV magnitude 10 events on December 6 and 14, 2003. Station D recorded two SEV magnitude 10 events on December 6 and 13, 2003 and two magnitude 11 events on December 13, 2003 and February 17, 2004. There were two events on NF Mud Springs Creek that had SEV scores of magnitude of 11, corresponding to 20-40% mortality. One of these occurred just before (12/13/03) an electrofishing sampling (12/17-18/03). Mean catch rate at the seven sites in NF Mud Springs Creek in December 2003 was 12.5 juvenile steelhead/100 feet. The estimated juvenile steelhead population within the 2,593 foot NF Mud Springs Creek study reach was 324.

While the pattern of storm flows between the streams was very similar in magnitude, duration, timing and number, steelhead mortality from suspended sediments should be higher in the NF than in SF Mud Springs Creek in 2003-04. Suspended sediment concentrations were higher and the steelhead YOY in NF Mud Springs Creek were smaller, so adverse effects from suspended sediments would be greater.

As previously stated, because of small sample sizes and limited number of observations, electrofishing data alone are inadequate to achieve a level of statistical significance when comparing these data between sampling stations. However, it’s important to note that the following two estimates of decline in relative abundance echo the same pattern; a decline in total catch rate over 40%, and a larger decline in steelhead YOY than steelhead over-yearlings. The first estimate is based on differences in steelhead abundance in late August and mid December 2003. This estimate was based on the seven downstream sites and 271 feet sampled, representing the lower half of the study area. Total population reduction was 58.2%. Steelhead YOY losses indicated that they were more susceptible to water pollution; catch rates declined by 63% while over-yearlings declined by 27%.

The second estimate was based on differences between the five upstream-most sites, representing the upper half of the study area, sampled between late August 2003, and the same sites sampled in mid-January 2004. The total population decline was 67.3%, a greater decline than the first estimate. Steelhead YOY declined by 88.5% and over-yearlings declined by 33%. Three additional storms may have affected the greater declines in this second estimate.

Applying a very conservative mortality estimate of 20% mortality to the projected juvenile steelhead population of 324, results in a loss of 65 juvenile steelhead in NF Mud Springs Creek. This estimated reduction of juvenile steelhead abundance is less than the observed reduction in the NF Mud Springs Creek study area by 43% to 62%.

6 CONCLUSIONS

Permitted land development is an ongoing process on Alder Springs Ranch in Mendocino County, California. The Timber Harvest Plan (THP) was approved by the California Department of Forestry, who considered the impacts of this conversion from forest/grassland to vineyard cultivation to be minor, and accepted a Negative Declaration as the California Environmental Quality Act document.

Steelhead-bearing streams flow through the land conversion area where regulatory agencies have raised concerns over sediment delivery to nearby fish habitat. Hillslope failures and surface runoff delivered sediment to the streams during the 2001-02 and 2002-03 winter rainy seasons. The land owner subsequently employed best management practices (BMP) to stabilize slopes and control erosion over the last three years.

Under this study, NMFS staff installed automated equipment to monitor turbidity, stream stage, and rainfall on the SF and NF of Mud Springs Creek, tributaries to Ten Mile Creek, tributary to the South Fork Eel River. Monitoring equipment was distributed at upstream and downstream stations to account for ambient or previously disturbed, and recently disturbed zones in both watersheds. A sediment source identification effort guided the location of turbidity sensors to settings immediately upstream and downstream from small drainages originating on land disturbed by the vineyard conversion.

Water quality monitoring data generated from turbidimeters resulted in peak truncation, data gaps, and periods of sensor fouling. Subsequent shifts and corrections to the turbidity records reduced the indications of poor water quality conditions, a conservative step applied to already conservative data. Nonetheless, the results showed that increased turbidity in Mud Springs Creek resulted from the recent land disturbances.

Each stream was gaged to develop stage/discharge relationships, and sampled for suspended sediment concentration. Suspended sediment sampling was limited to the concentration corresponding to 600 NTU turbidity. Significant sand-sized particles were found in the suspended sediment samples. Analysis of ill-effects did not extrapolate suspended sediment concentrations to the corresponding higher turbidity values that were measured.

Estimates of the ill-effects experienced by steelhead were determined from applying the published impacts assessments models, which are inherently conservative in their design. Two published models were applied to predict levels of ill-effects to salmonids. The suspended sediment samples were found to have high proportions of sand. Turbidity and suspended sediment records were analyzed, resulting in indices for severity of ill-effect. Conservative assignments of ill-effects were made, with allowance for the high proportion of sand transported in suspension during storms in the study streams. Suspended sand is particularly injurious to juveniles and embryos/larvae because the particle size is abrasive. The highest ill-effects score for suspended sediment on SF Mud Springs Creek was a magnitude 10, which predicts mortality of up to 20% of the population. The highest ill-effect score for NF Mud Springs Creek was magnitude 11, which predicts mortality ranging from 20 to 40% of the population.

A biological investigation was temporally and spatially coordinated with the water quality investigation. Twelve trout were collected from the study streams and otolith analysis demonstrated that all were steelhead. Habitat mapping found steep streams (gradients 0.07-0.08), with consistent local gradients. Passage barriers to juvenile steelhead were found in each study stream that limited juvenile movement to the downstream direction. Selection of electrofishing sites was based on even distribution along each study stream, and included sites upstream and downstream from the turbidity monitoring stations. Electrofishing spanned three seasons, early summer, later summer and winter. Steelhead abundance did not change markedly between early summer and late summer, but declined sharply with the onset of seasonal storms.

Mortality estimates of 20-40% for severity 11 scores in NF Mud Springs Creek correspond to a reduction of 65 to 130 steelhead within the study reach. The severity 10 scores on SF Mud Springs Creek predict mortality up to 20%, corresponding to 35 steelhead within the study reach. The SF Mud Springs Creek mortality estimate of 20% is supported by: (1) the local stream gradient was constant between clear and turbid zones in SF Mud Springs Creek, so the effects of high flows were similar; (2) the proportional decline in relative steelhead abundance from late summer to fall/winter was less in the clear zone upstream from sediment sources than downstream in the turbid zone. The difference between proportional decline of abundance between clear and turbid zones approximates the predicted effect of sediment delivery causing elevated turbidity and suspended sediment concentrations. This difference was 18% in SF Mud Springs Creek. The independent assessments converged to common agreement on SF Mud Springs Creek. These estimates are conservative because they do not account for repeated exposure to concentrated suspended sediments in conjunction with upstream passage barriers. This may explain why juvenile steelhead populations remained low in the turbid areas during the rain season instead of increasing due to recruitment from upstream flushing.

Adverse effects on Alder Springs Ranch are much greater than what is reported here because our effects analysis is limited to the effects to the study areas which are only portions of the streams affected by land uses. Lethal levels of water pollution, caused by suspended sediment inputs from the roads and cultivated areas of the vineyard land development, were documented in winter 2003-04. Lethal levels were delivered to the steelhead-bearing streams in spite of implementing two generations of BMP’s in addition to the provisions required in the approved THP. Landslides occurred in the two previous winter seasons that likely caused much higher levels of lethal sediment delivery to the streams than were measured in winter 2003-04.

This report shows that a relatively well-implemented THP and vineyard development, after initially delivering lethal sediment concentrations to nearby streams for a few years, will continue to cause low levels of steelhead mortality, in addition to causing poor physical condition, impaired homing, reduction in feeding rates, avoidance, and abandonment of cover for years to come. The continued and cumulative ill-effects of vineyard operations deserve careful consideration. Repeated low levels of mortality can ultimately extirpate local salmonid populations after 3-5 years (Harvey and Railsback 2002).

REFERENCES CITED

Alabaster, J.S., and Lloyd, R. 1982. Finely divided solids. Pages 1-20 *in* J.S. Alabaster and Lloyd, editors. Water quality criteria for freshwater fish, 2nd edition. Butterworth, London, England.

APHA-AWWA-WPCF. 1980. Standard Methods for the Examination of Water and Wastewater. 15th edition, APHA, Washington, USA.

Aquatic Systems Research. 1993. Lee Vining Creek. Stream Evaluation Report 93-2, Volume 1. California Department of Fish and Game, Sacramento, California:183 pp.

Baxter, G. 2004. Sr/Ca ratios in otoliths from *Oncorhynchus mykiss* collected from Mendocino County, California: Evidence for parental anadromy. Final Report. Submitted to Special Agent J. Giordano. University of California, Davis Microprobe Facility, Davis, California. Dated: July 2004

Behnke, R.J. 1992. Native trout of Western North America. American Fisheries Society Monograph 6, Bethesda, Maryland: 275 pp.

Bell, E. 2001. Survival, growth and movement of juvenile coho salmon (*Oncorhynchus kisutch*) over-wintering in alcoves, backwaters, and main channel pools in Prairie Creek, California. Master of Science thesis in Fisheries, Humboldt State University, Arcata, California: 75 pp.

Bell, M.C. 1973. Fisheries Handbook of Engineering Requirements and Biological Criteria. Fisheries Engineering Research Program, U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Bisson, P.A. and R.E. Bilby. 1982. Avoidance of suspended sediment by juvenile coho salmon. North American Journal of Fisheries Management 4: 371-374.

Bjornn, T.C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, stream flow, cover, and population density. Transactions of the American Fisheries Society 100(3): 423-438.

Bjornn, T.C. and D. Reiser. 1991. Habitat requirements of salmonids in streams. In Meehan, W.R. (ed.). Influences of forest and rangeland management on salmonid fishes and their habitats. Special Publication 19. American Fisheries Society, Bethesda, Maryland: 83-138.

Bjornn, T.C., , M.A. Brusven, M.P. Molnau, J.H. Milligan, R.A. Klamt, E. Chacho and C. Schaye. 1977. Transport of granitic sediment in streams and effects on insects and fish. Bulletin 17, College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow, Idaho: 43 pp.

California Department of Fish and Game. 1998. California Salmonid Stream Habitat Restoration Manual. Department of Fish and Game, Sacramento, California.

Cordone, A.J., and Kelley, D.W. 1961. The influences of inorganic sediment on aquatic life of streams. California Fish and Game 47: 189-228.

Cuenco, M.L. and D.A. McCollough. 1996. Framework for estimating salmon survival as a function of habitat condition. Technical Report 96-4, Revised August 19, 1997. Columbia River Inter-Tribal Fish Commission, Portland, Oregon:119 pp.

Ellis, M.M. 1936. Erosion silt as a factor in aquatic environments. Ecology 17: 29-42.

Foster, I.D.L., Millington, R., and Grew, R.G. 1992. The impact of particle size controls on stream turbidity measurement; some implications for suspended sediment yield estimation. In: Erosion and Sediment Transport Monitoring Programmes in River Basins (ed. By J. Bogen, D.E. Walling, and T.J. Day) IAHS Publ. 210: 51-62, Proc. Oslo Symp., August 1992.

Gray, J. R. 2002. Synopsis of outcomes from the Federal Interagency Workshop on Turbidity and other Sediment Surrogates. In: Turbidity and Other Surrogates Workshop, April 30-May 2, 2002, Reno, Nevada. (ed. By G.D. Glysson and J.R. Gray)

Hall, T.J. 1984. The effects of fine sediment on salmonid spawning gravel and juvenile rearing habitat – a literature review. NCASI Technical Bulletin Number 428. National Council of the Paper Industry for Air and Stream Improvement, Inc., 260 Madison Avenue, New York, New York:66 pp.

Hartman, G.F. and T.G. Brown. 1987. Use of small, temporary, floodplain tributaries by juvenile salmonids in a west coast rain-forest drainage basin, Carnation Creek, British Columbia. Canadian Journal of Fisheries and Aquatic Science 44: 262-270.

Harvey, B.C. and S. F. Railsback. *in press*. Elevated turbidity reduces abundance and biomass of stream trout in an individual-based model.

Harvey, B.C. and R.J. Nakamoto. 1997. Habitat –dependent interactions between size-classes of juvenile steelhead in a small stream. Canadian Journal of Fisheries and Aquatic Science 54: 27-31.

Henley, W.F, M.A. Patterson, R.J. Neves, and A. D. Lemly. 2000. Effects of sedimentation and turbidity on lotic food webs: a concise review for natural resource managers. Reviews in Fisheries Science, 8(2): 125-139.

Herbert, D.W.M. and J.M. Richards. 1963. The growth and survival of fish in some suspensions of solids of industrial origin. International Journal of Air and Water Pollution 7: 297-302.

Holtby, L.B., B.C. Andersen, R.K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (Oncorhynchus kisutch). Canadian Journal of Fisheries and Aquatic Science 47: 2181-2194.

Huang, H. 2004. Index-velocity rating development for rapidly changing flows in an irrigation canal using broadband StreamPro ADCP and ChannelMaster H-ADCP. Rivers'04, 1st International Conference on Managing Rivers in the 21st Century: Issues and Challenges.

Hubble, J.D. 1992. A study of summer steelhead, *Oncorhynchus mykiss* in several intermittent tributaries of the Satus Creek basin, Washington. Master of Science thesis. Central Washington University, Ellensburg, Washington.

Jenkins, T.M., Jr., D.R. Dawson, D.B. Herbst, and R. Perloff. 1991. Significance of flow volume in the winter ecology of brown trout (*Salmo trutta*) in a mid-elevation Sierra Nevada stream, Final Report. California Department of Fish and Game contracts FG5C2001, FG8232, and FG 9345. Cited in Aquatic Systems Research. 1993. Lee Vining Creek. Stream Evaluation Report 93-2 Volume 1, California Department of Fish and Game, Sacramento, California: 183 pp.

Johnson, S.W., J. Heifetz and K.V. Koski. 1989. Effects of logging on the abundance and seasonal distribution of juvenile steelhead in some Southeastern Alaska streams. North American Journal of Fisheries Management 6: 532-537.

Kahler, T.H. and T.P. Quinn. 1998. Juvenile and resident salmonid movement and passage through culverts. Final Research Report, Research Project T9903, Task 96. Washington State Transportation Commission and the U.S. Department of Transportation.

Kalish, J.M. 1990. Use of otolith microchemistry to distinguish the progeny of sympatric anadromous and non-anadromous salmonids. U.S. National Marine Fishery Service Fishery Bulletin. 88: 657-666.

Kilbourne, R.T. 1983. Geology and geomorphic features relating to landsliding, Cahto Peak 7.5' quadrangle, Mendocino, California. California Department of Mines and Geology. DMG open-file report 83-89.

Klein, R. 2003. Duration of turbidity and suspended sediment transport in salmonid bearing streams, North Coastal California; a report to the U.S. Environmental Protection Agency, San Francisco, California.

Langer, O.E. 1980. Effects of sedimentation on Salmonid stream life. *In* K. Weagle, editor, Report on the technical workshop on suspended solids and the aquatic environment. Department of Indian Affairs and Northern Development, Contract Ott-80-019, Whitehorse, Yukon Territory.

Leitritz, E. and R.C. Lewis. 1980. Trout and Salmon Culture (hatchery methods) California Fish Bulletin Number 164, Department of Fish and Game, Sacramento, California:197 pp.

Lewis, J. 2002. Estimation of suspended sediment flux in streams using continuous turbidity and flow data coupled with laboratory concentrations. Turbidity and Other Sediment Surrogates Workshop, April 30-May 2, 2002, Reno, Nevada.

Lloyd, D.S. 1987. Turbidity as a water quality standard for Salmonid habitats in Alaska. North American Journal of Fisheries Management 7: 34-45.

Madej, M.A., M. Wilzbach, K. Cummins, C. Ellis, and S. Hadden. 2002. The contribution of suspended organic sediments to turbidity and sediment flux. Turbidity and Other Sediment Surrogates Workshop, April 30-May 2, 2002, Reno, NV.

McEwan, D.W. and T. Jackson. 1993 Steelhead Recovery Plan, California Department of Fish and Game, Sacramento, California.

Morgan, A. and F. Hinojosa. 1996. Winter habitat utilization by juvenile salmonids – a literature review. Northwest Indian Fisheries Commission and Grays Harbor College.

Moyle, P.B. 2002. Inland Fishes of California, Revised and Expanded, University of California Press, Berkeley, California:502 pp

Murphy, M.L., J. Heifetz, J.F. Thedinga, S.W. Johnson and K.V. Koski. 1989. Habitat utilization by juvenile Pacific salmon (*Oncorhynchus*) in the glacial Taku River, southeast Alaska. Canadian Journal Fisheries and Aquatic Sciences 46: 1677-1685.

Newcombe, C.P . 2003. Impact assessment model for clear water fishes exposed to excessively cloudy water. Journal of the American Water Resources Association: 529-544.

Newcombe, C.P. 2001. Impact assessment model for clear water fishes exposed to conditions of reduced visual clarity. American Water Resources Association.

Newcombe, C.P., and Jensen, J.O.T. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16: 693-727.

Newcombe, C.P., and MacDonald, D.D. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11: 72-82.

Noggle, C.C. 1978. Behavioral, physiological and lethal effects of suspended sediment on juvenile salmonids. Master of Science Thesis, College of Fisheries, University of Washington, Seattle, Washington: 87 pp.

Pacific Watershed Associates. 2004. Progress report for stream surveys and erosion control activities for Alder Springs Vineyard and Ranch, Laytonville, CA: Two reports dated February 2, 2004 and April 22, 2004.

Power. M.E., 2003. Streambed texture, food web structure, and juvenile salmonid rearing in North Coast California rivers. UC Water Resources Center Technical Completion Report Project No. W-947: 6 pp.

Railsback, S.F., Harvey, B.C., Lamberson, R.H., Lee, D.E., Claasen, N.J., and Yoshihara, S., 2002. Population-level analysis and validation of an individual-based cutthroat trout model. Natural Resources Modeling 15: 83-110.

Railsback, S.F., and Harvey, B.C. 2002. Analysis of habitat-selection rules using an individual-based model. Ecology, 83: 1817-1830.

Rantz, S.E., 1982. Measurement and Computation of Streamflow. US Geological Survey Water-Supply Paper 2175.

Rieman, B.E., D.L. Myers, and R.L. Nielsen. 1994. Use of otolith microchemistry to discriminate *Oncorhynchus nerka* of resident and anadromous origin. Canadian Journal of Fisheries and Aquatic Science 51: 68-77.

Sadar, M.J., 1998. Turbidity Science. HACH, Technical Information Series Booklet No.11, 26 pp.

Seber, G.A.F. and E.D. LeCren. 1967. Estimating population parameters from catches large relative to the population. Journal of Animal Ecology 36(3): 631-643.

Shapovalov, L. and A.C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. Fish Bulletin No. 98. California Department of Fish and Game, Sacramento, California: 375 pp.

Sigler, J.W., T.C. Bjornn, and F.H. Everest. 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. Transactions of the American Fisheries Society 113: 142-150.

Siegel, S. 1956. Nonparametric Statistics for the Behavioral Sciences, McGraw-Hill Book Company, New York: 312 pp.

Sorensen, D.L., McCarthy, M.M., Middlebrooks, E.J., and Porcella, D.B. 1977. Suspended and dissolved solids effects on freshwater biota: review. U.S. Environmental Protection Agency, Ecology Research Series EPA-600/3-77-042.

Southgate, B.A. 1962. Water Pollution Research. 1959. Cited in: Klein, L. (ed.), River Pollution II Causes and Effects. Butterworth, London: 456 pp.

Sutherland, T.F., Lane, P.M, Amos, C.L., and Downing, J. 2000. The calibration of optical backscatter sensors for suspended sediment of varying darkness levels. Marine Geology, 162: 587-597.

Suttle, K.B., M.E. Power, J. M. Levine and C. McNeely. 2004. How fine sediment in riverbeds impairs growth and survival of juvenile salmonids. Ecological Applications 14(4): 969-974.

Van Deventer, J.A. and W.S. Platts. 1985. A computer software system for entering, managing and analyzing fish capture data from streams. Research Note INT-352. Intermountain Research Station, U.S. D.A., Forest Service, Ogden, Utah: 12 pp.

Van Deventer, J.A. and W.S. Platts. 1989. Microcomputer software system for generating population statistics from electrofishing data – User's guide for MicroFish 3.0. General Technical. Report INT-2543. Intermountain Research Station, U.S.D.A., Forest Service, Ogden, Utah: 29 pp.

Volk, E.C., A. Blakey, S.L. Schroeder, and S.M. Kuehner. 2000. Otolith microchemistry reflects migratory characteristics of Pacific salmonids: using otolith core chemistry to distinguish maternal associations with sea and freshwaters Fisheries Research 46: 251-266.

Waters, T.F. 1995. Sediment in Streams; Sources, Biological Effects and Control. American Fisheries Society Monograph 7, Bethesda, Maryland: 251 pp.

Zedonis, P.A. 1992. The biology of the juvenile steelhead (*Oncorhynchus mykiss*) in the Mattole River estuary/lagoon, California. Master of Science Thesis, Humboldt State University, Arcata, California.

Zimmerman, C.E., and G.H. Reeves. 2002. Identification of steelhead and resident rainbow trout progeny in the Deschutes River, Oregon, revealed with otolith microchemistry. Transactions of the American Fisheries Society 131: 986-993.

Zimmerman, C.E., and G.H. Reeves. 2000. Population structure of sympatric anadromous and nonanadromous Oncorhynchus mykiss: evidence from spawning surveys and otolith microchemistry. Canadian Journal of Fisheries and Aquatic Sciences 57: 2152-2162.

Table 2. Fork lengths, the number of summers, and brood year of steelhead caught in the Mud Springs Creek watershed based on saggital otolith assessment.

Fork Length	Number of summers	Brood Year
50	1	2003
63	1	2003
68	1	2003
71	1	2003
75	1	2003
90	2	2002
100	2	2002
101	2	2002
106	2	2002
111	2	2002
130	2	2002
130	3	2001

Table 3. Catch rate of steelhead (number of steelhead/100 ft of stream) at 20 sites located along 2500 feet of NF Mud Springs Creek. Turbidity data do not extend beyond March 2004.

Station #	**Site**	**Early July**	**Late Aug**	**Early Dec**	**Mid Jan**	**Early Feb**	**Late Feb**	**Early Mar**	**Late Mar**	**Early Apr**	**Early May**
2572	20	--	--	--	--	5.2	1.3	0.0	--	--	--
2501	19	18.9	10.8	--	5.4	--	--	--	--	--	--
2452	18	--	--	--	--	9.6	3.8	0.0	--	--	--
2401	17	8.3	10.4	--	2.1	--	--	--	--	--	--
2292	16	4.6	9.1	--	2.3	--	--	--	--	--	--
2189	15	25.5	20.0	--	3.6	--	--	--	--	--	--
2096	14	--	--	--	--	16.5	--	--	--	2.4	--
1875	13	33.3	26.7	--	15.6	--	--	--	--	--	--
1794	12	--	--	--	--	19.8	6.3	14.6	--	--	--
1683	11	--	--	--	--	20.5	18.9	18.9	--	--	--
1512	10	14.3	27.0	12.5	--	--	--	--	--	--	--
1304	9	--	--	--	--	5.6	--	--	7.4	8.4	--
1223	8	17.0	19.2	8.5	--	--	--	--	--	--	--
889	7	23.4	8.5	10.6-	--	--	--	--	--	--	--
788	6	17.0	11.3	13.2	--	--	--	--	--	--	--
700	5	14.0	20.9	4.7	--	--	--	--	--	--	--
568	4	20.0	20.0	0.0	--	--	--	--	--	--	--
554	3	26.7	26.7	26.7-	--	--	--	--	--	--	--
285	2	--	--	--	--	--	--	--	18.9	11.8	--
76	1	--		--	--	--	--	--	17.9	20.5	--
	Mean	**18.6**	**17.5**	**10.9**	**5.8**	**12.9**	**7.6**	**8.4**	**14.7**	**10.8**	NA

Table 4. Catch rate of steelhead (numbers of steelhead/100 ft of stream) along 3000 feet of SF Mud Springs Creek. Nineteen sites include clear water upstream (sites 16-19), to downstream sites affected elevated turbidity (sites 1-18). Turbidity data do not extend beyond Late February 2004.

Station	**Site**	**Early July**	**Late Aug**	**Early Oct**	**Mid Jan**	**Early Feb**	**Late Feb**	**Early Mar**	**Late Mar**	**Early Apr**	**Early May**
3092	19	--	--	--	--	0.0	--	--	3.8	3.0	--
2949	18	--	--	--	--	5.6	2.7	6.8	--	--	--
2858	17	6.7	--	4.4	4.4	--	--	--	--	--	--
2820	16	16.2	--	10.8	5.4	--	--	--	--	--	--
Clear	**MEAN**	**11.5**	**--**	**7.6**	**4.9**	**5.6**	**2.7**	**6.8**	**3.8**	**3.0**	**--**
2708	15	9.1	--	11.4	2.3	--	--	--	--	--	--
2661	14	--	--	--	--	4.3	4.3	1.4	--	--	--
2357	13	8.3	--	2.1	2.1	--	--	--	--	--	--
2290	12	--	--	--	--	7.7	3.9	3.9	--	--	--
2289	11	--	--	--	--	13.7	2.7	2.7	--	--	--
2127	10	--	--	--	--	7.3	2.4	9.8	--	--	--
1919	9	10.8	--	10.8	1.5	--	--	--	--	--	--
1842	8	--	--	--	--	8.6	10.3	8.6	--	--	--
1781	7	--	--	--	--	--	--	--	6.5	2.2	--
1618	6	9.1	--	5.5	7.3	--	--	--	--	--	--
1230	5	2.4	7.3	--	4.9	--	--	--	--	--	--
1086	4	1.2	4.7	--	4.7	--	--	--	--	--	--
743	3	1.6	1.6	--	1.6	--	--	--	--	--	--
591	2	--	--	--	--	--	--	--	8	5	69
407	1	21.6	17.7	--	3.9	--	--	--	--	--	--
Turbid	**MEAN**	**8.0**	**7.8**	**7.5**	**3.5**	**8.3**	**4.7**	**5.3**	**7.3**	**3.6**	**69**
Grand	**MEAN**	**8.7**	**7.8**	**7.5**	**3.8**	**6.7**	**4.4**	**5.5**	**6.1**	**5.1**	**69**

Table 5. Ranking of ill-effects (severity index, or SEV score) of turbidity/suspended sediment on fish and aquatic life, from Newcombe and MacDonald 1991. Although in nature there exists a continuum of ill-effects, the slightly impaired range includes feeding and behavioral changes with severity of effect increasing with duration. The significantly impaired range includes water quality causing reduced fish growth rate, habitat reductions, or both. The severely impaired range causes habitat alienation and reduced fish health and survival, including ranges of mortality.

Rank	Description of effect	Ranges and Thresholds
14	>80 to 100% mortality	Severely Impaired-Lethal
13	>60 to 80% mortality	Severely Impaired-Lethal
12	>40 to 60% mortality	Severely Impaired-Lethal
11	>20 to 40% mortality	Severely Impaired-Lethal
10	0 to 20% mortality	Severely Impaired-Lethal
9	Reduction in growth rates	Severely Impaired
8	Physiological stress and histological changes	Significantly Impaired
7	Moderate habitat degradation	Significantly Impaired
6	Poor condition of organism	Significantly Impaired
5	Impaired homing	Significantly Impaired
4	Reduction in feeding rates	Significantly Impaired
3	Avoidance response, abandonment of cover	Slightly Impaired
2	Alarm reaction, avoidance reaction	Slightly Impaired
1	Increased cough rate	Slightly Impaired

Table 1. Suspended sediment samples from Mud Springs Creek, and corresponding turbidity. Sand and larger particles make up 28% of the total mass.

Lab number	Sample location and name	Date/Time	Notes:	Mass total	Mass sand	Mass fines	Concen-tration (Mg/l)	Corres-ponding NTU
CA -04-005-1	SF-A trib A1	12/5/03, 12:20 p	center of stream	0.0669	0.0424	0.0245	229	55
CA -04-005-2	SF-A lower	12/5/03, 12:25p	center of stream	0.0155	0.0055	0.0100	55	4.7
CA -04-005-3	SF-A upper	12/5/03, 12:30p	center of stream	0.0140	0.0070	0.0070	46	3.2
CA -04-005-4	SF-B upper	12/5/03, 12:45 p	center of stream	0.0037	0.0007	0.0030	12	2.5
CA -04-005-5	SF-B lower	12/5/03, 12:50p	center of stream	0.0048	0.0006	0.0042	13	3.0
CA -04-005-6	NF-D upper 8	12/5/03, 1:55p	center of stream	0.0278	0.0163	0.0115	97	13.7
CA -04-005-7	NF-C upper 6	12/5/03, 2:10p	center of stream	0.0132	0.0052	0.0080	44	11.0
CA -04-005-8	NF-C lower 7	12/5/03, 2:12p	center of stream	0.0169	0.0086	0.0083	53	24.4
CA -04-005-9	NF-D lower	12/11/03, 11:07a	center of stream	0.0072	0.0071	0.0001	23	5.0
CA -04-005-10	NF-C upper (b)	12/11/03, 12:10p	center of stream	0.0003	0.0002	0.0001	1	4.2
CA -04-005-11	SF-A lower (b)	12/11/03, 1:20 p	center of stream	0.0031	0.0018	0.0013	10	8.8
CA -04-005-12	SF-B upper (b)	12/11/03, 2:15 p	center of stream	0.0006	0.0002	0.0004	2	3.4
CA -04-005-13	110	5/6/2004	hand mixed sample	0.0928	0.0120	0.0808	248	110
CA -04-005-14	190	5/6/2004	hand mixed sample	0.1314	0.0200	0.1114	348	190
CA -04-005-15	200	5/6/2004	hand mixed sample	0.1224	0.0051	0.1173	289	200
CA -04-005-16	315	5/6/2004	hand mixed sample	0.1558	0.0016	0.1542	371	315
CA -04-005-17	380	5/6/2004	hand mixed sample	0.3004	0.0490	0.2514	664	380
CA -04-005-18	530	5/6/2004	hand mixed sample	1.5474	0.0033	1.5441	3342	530
CA -04-005-19	600	5/6/2004	hand mixed sample	4.1224	1.6996	2.4228	9859	600

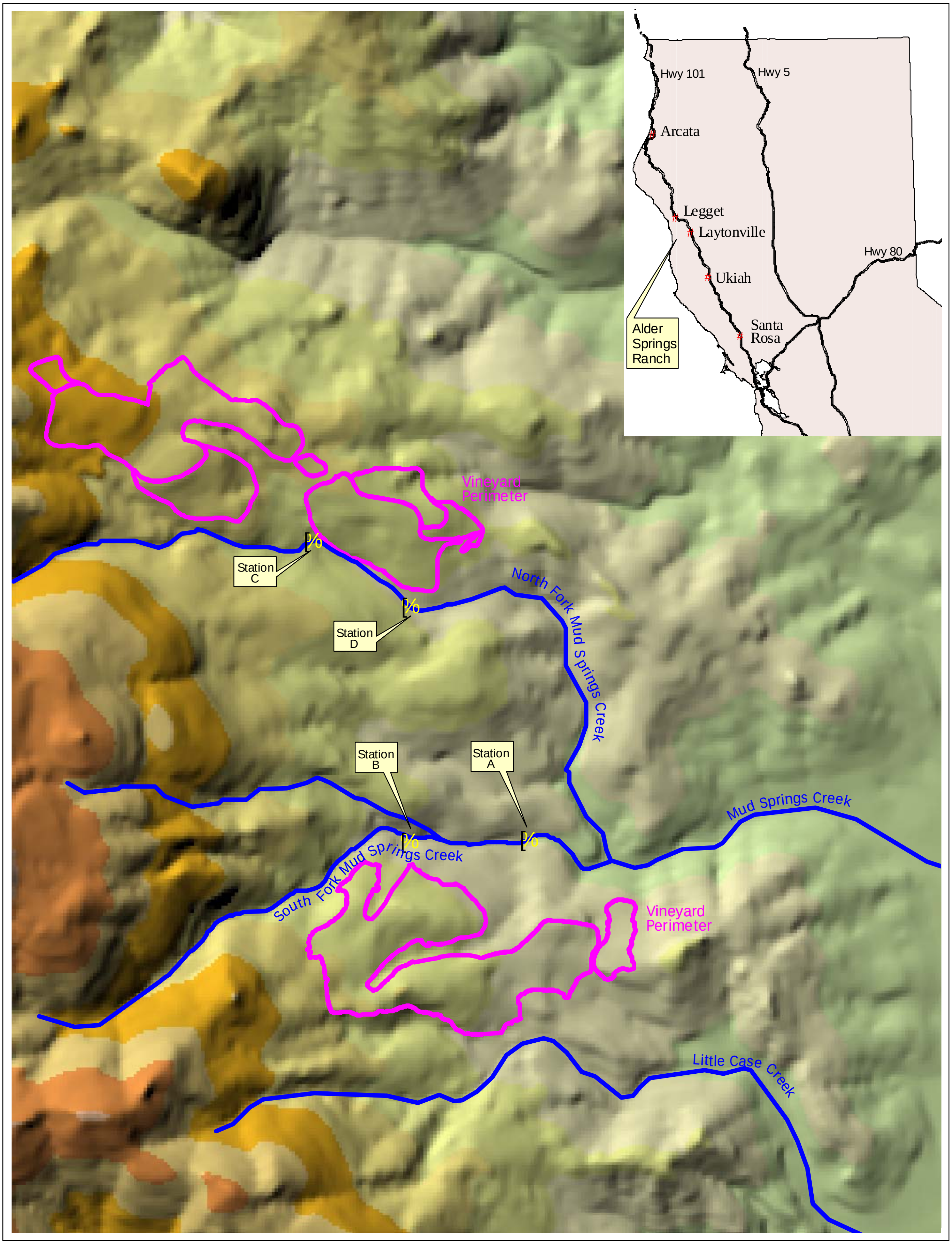


Figure 1. Location maps of the Mud Springs Creek study area on Alder Springs Ranch, Mendocino County, California

Figure 4. Turbid runoff from a small tributary (left) to the clear-flowing NF Mud Springs Creek (right) during a storm in mid-March 2003. The turbid runoff originates on nearby cultivated land, passes through a drainage collection system, and discharges into a pre-existing stream channel. That channel has undergone degradation during our investigation due to increased runoff (see Figure 25, cross section D12).

Figure 5. Landslide on south-facing slope of north unit; drainage to NF Mud Springs Creek in early 2003. The straw bales stacked two rows high along the wire mesh fence retained a majority of the coarse grained soil; however the surface drains and roadway funneled substantial sediment into the nearby salmon-bearing stream between sediment monitoring Stations C and D. A larger landslide occurred at approximately the same location during the previous winter; still evident by the different ground cover planting and lack of grape stakes. Silt deposits on tree trunks between the road and NF Mud Springs Creek record the evidence of 1-2 feet sediment burial. The landowner installed subsurface drainage in the slope and 3 sediment retention/settling basins between the road and stream in summer 2003. At least one of these basins ruptured during winter 2003-04 (see Figure 60).

Figure 6. New culvert on tributary to lower SF Mud Springs Creek in December 2002. Tributary collects drainage from nearby fence and upslope cultivated area, and discharges into SF Mud Springs Creek at monitoring Station A.

Figure 7. Same tributary as above with 2002 culvert replaced by a larger size, installed in late fall 2003. Notice swale in road surface between the two people; caused by flow piping around the outside of the culvert. The installation of, and piping problems around this culvert, caused severe turbidity events in lower SF Mud Springs Creek in November 2003.

Figure 8. Aerial view of SF Mud Springs Creek and the barren land of the south cultivation unit at the onset of winter storms in 2002. Stream flow is from west, upstream (Station B in foreground) to east, downstream (Station A in background). Arrows indicate approximate location of the upstream and downstream turbidity sensors at each Station.

Figure 9. New terracing on south unit that drains into SF Mud Springs Creek, May 2004. Riparian stand on left is the upper end of the tributary stream that flows in between sensors at monitoring Station B. Terraces create steeper slopes over half the surface area. The dozer had pushed soil into the head of this steep head of the stream that is likely to experience high sediment concentrations next winter. New terracing was also completed above monitoring Station C in NF Mud Springs Creek during 2004.

Figure 10. Fill and preparation for planting in May 2004 of an area that previously functioned as a sediment retention basin. We observed the basin acting as intended during the previous two winters by trapping sediment produced from the cultivated surface.

Figure 11. Passage barrier on NF Mud Springs Creek near monitoring Station D. This barrier does not affect adults, but is a complete upstream barrier to juveniles. Passage impediments with gradient of at least 15% were found throughout the study area.

Figure 12. Passage barrier for juveniles migrating upstream on NF Mud Springs Creek.

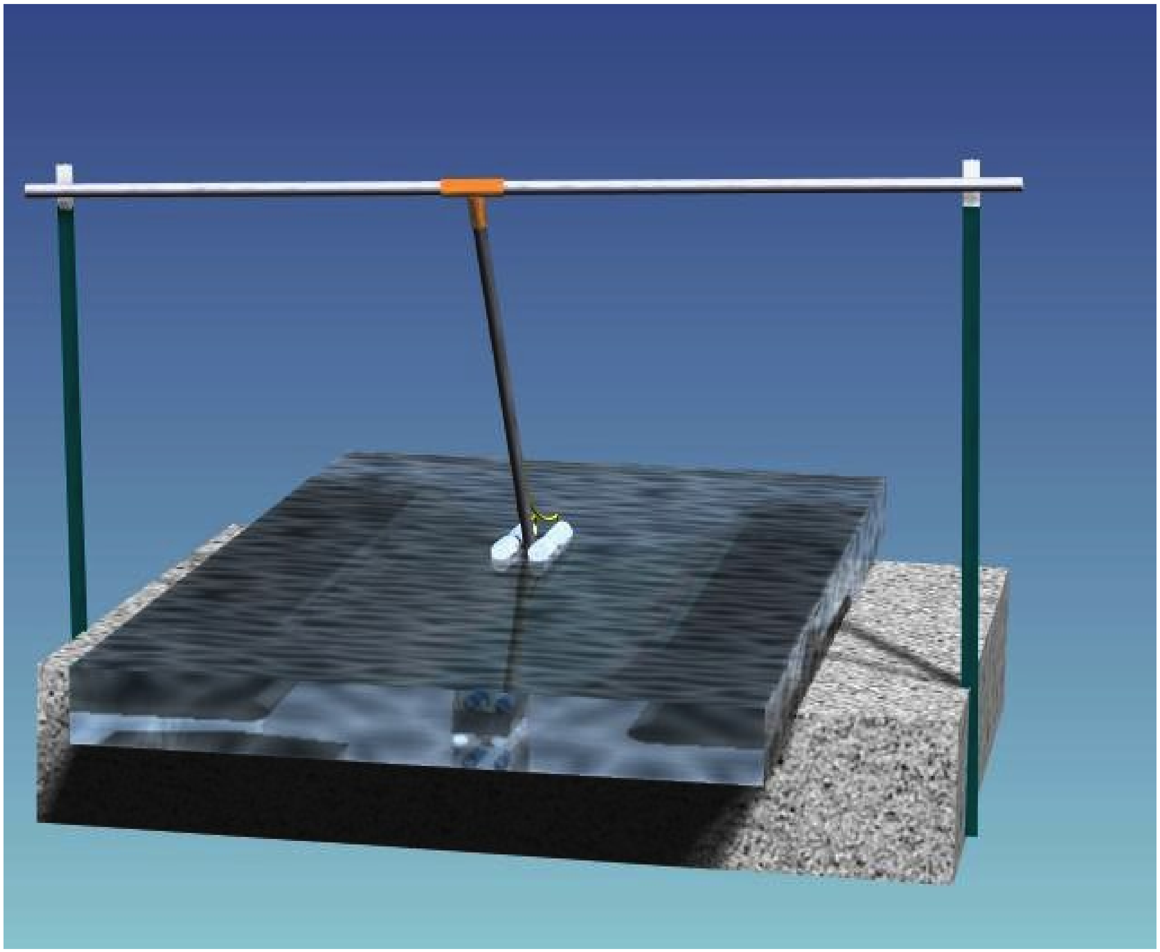
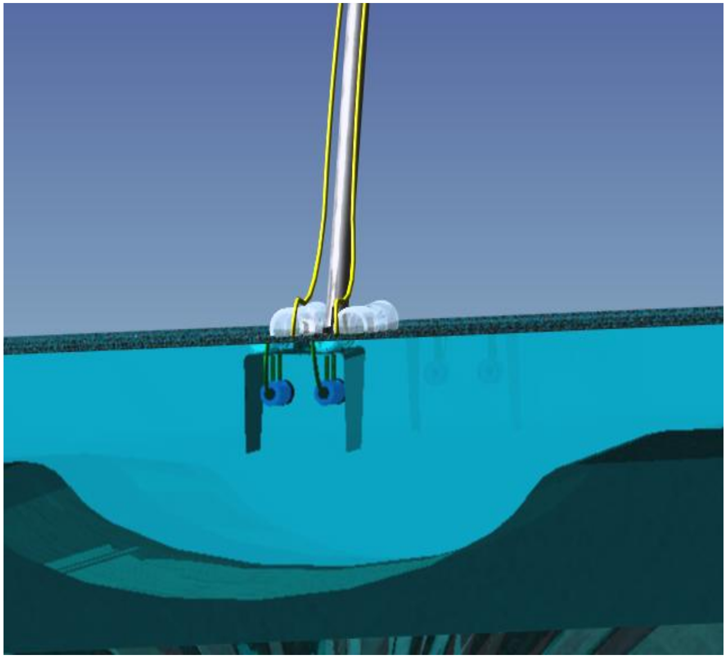


Figure 13. Turbidity sensor housing and swinging arm attachments. View from above and upstream (above) and from downstream at water surface (right). Wiring from the sensors to the data logger was secured along the vertical posts and then buried below soil or suspended in trees en route to the data logger. Data logger housings that contain the logger, wiring panel, and power supply were attached to vertical T-posts and covered with waterproof bags.



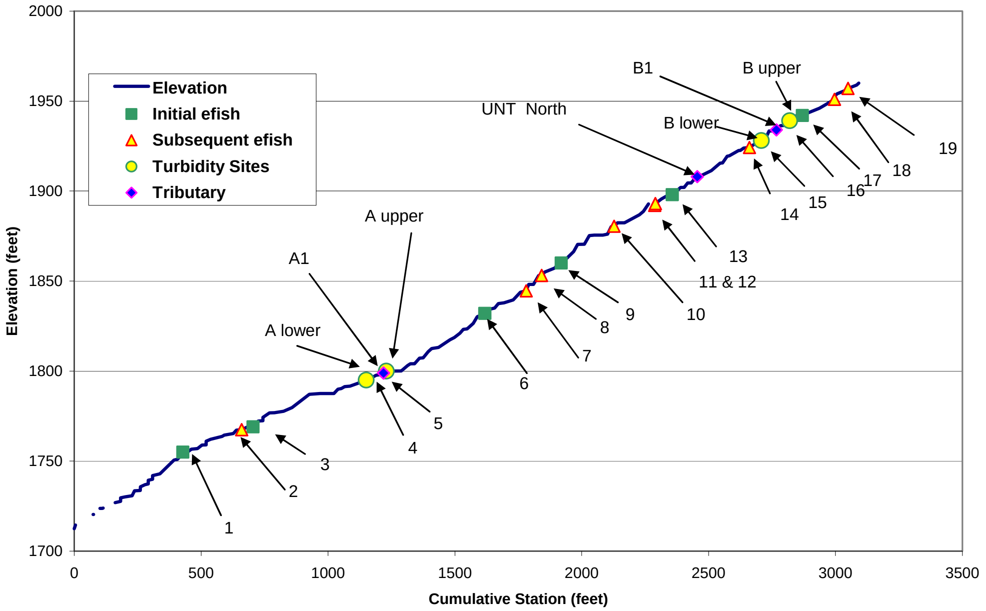


Figure 14. Surveyed profile of SF Mud Springs Creek showing electrofishing sites, tributaries, and turbidity monitoring Stations A and B.

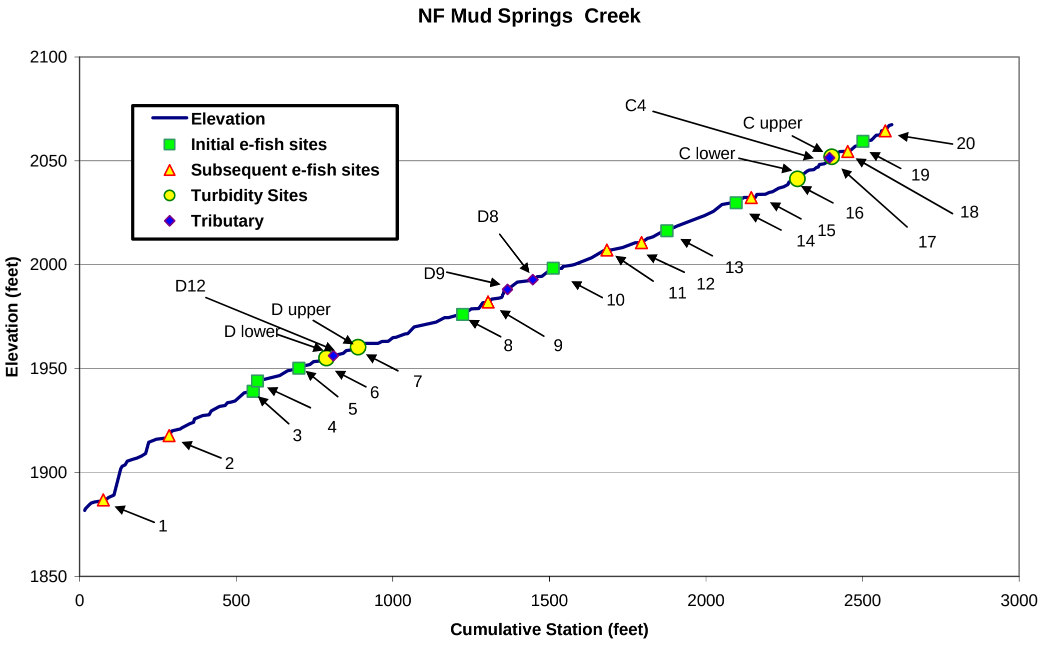
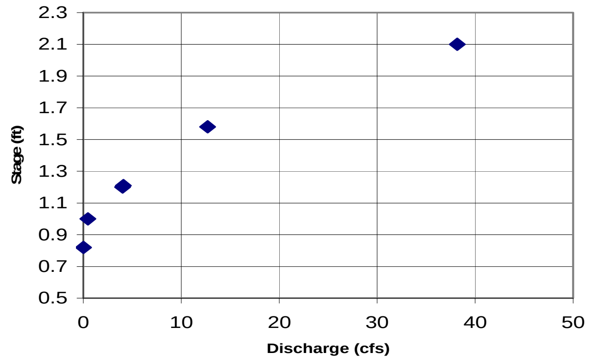
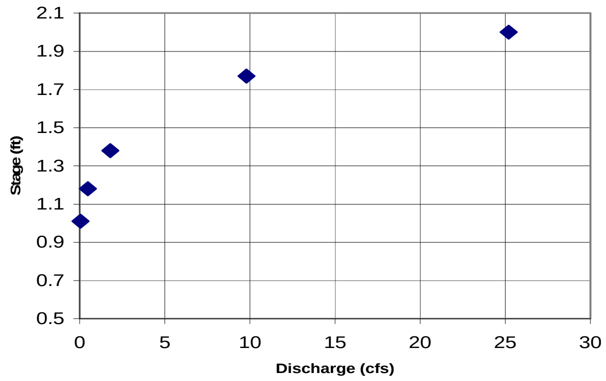


Figure 15. Surveyed profile of NF Mud Springs Creek showing electrofishing sites, tributaries, and turbidity monitoring Stations C and D.

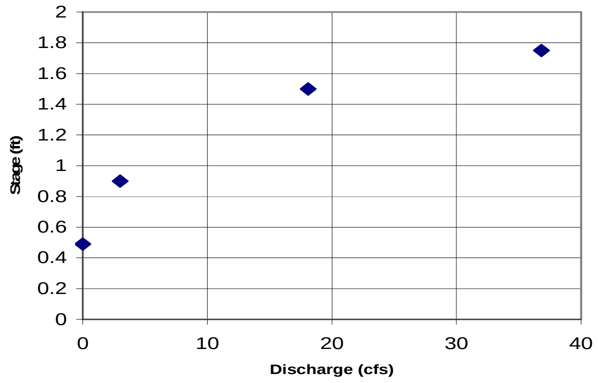
Station A



Station B



Station D



Station C

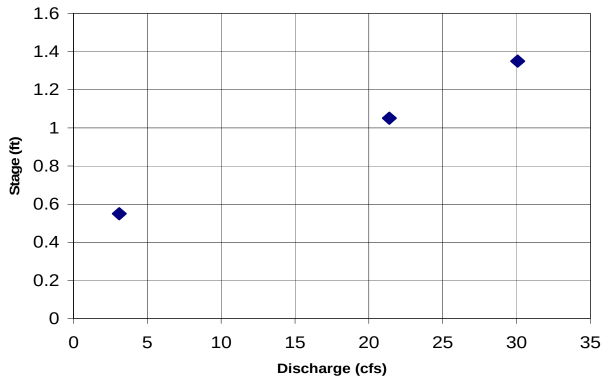
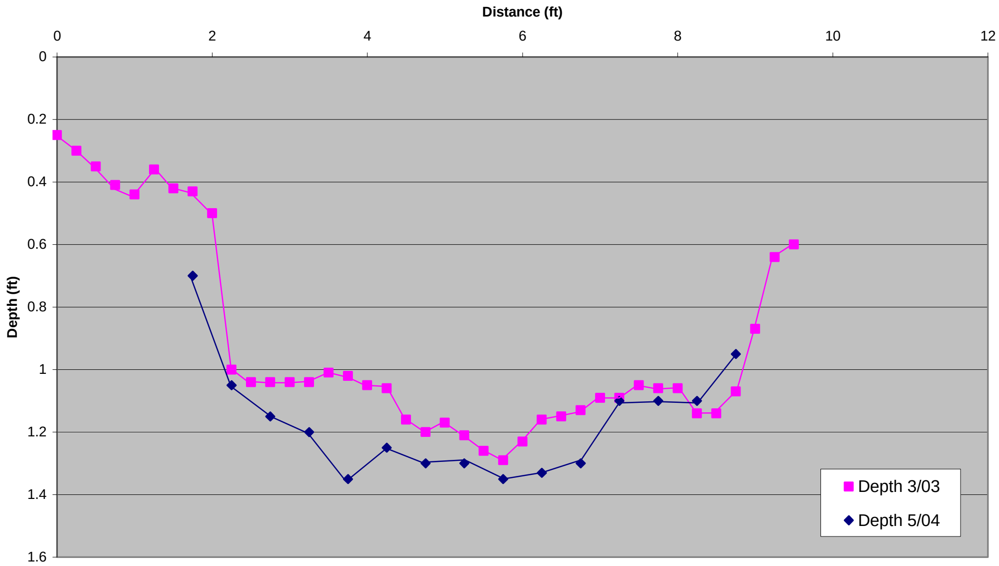
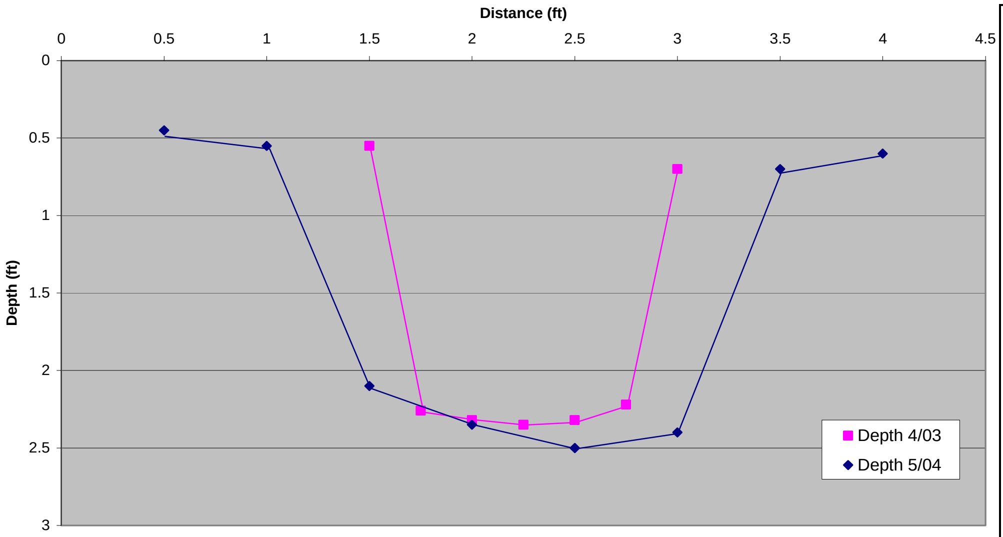


Figure 19. Stage-discharge relationships for Station A-the downstream Station on SF Mud Springs Creek, Station B-the upstream Station on SF Mud Springs Creek, Station D-the downstream Station on NF Mud Springs Creek, and C-the upstream Station on NF Mud Springs Creek. The maximum discharges were all measured within a few hours of each other during a moderately high (ranks #4 for the 2003-2004 rainfall season) storm event on February 26, 2004. Corresponding flow rates for SF Mud Springs Creek were 25 cfs at the upstream Station and 38 cfs at the downstream Station, representing an increase of over 50% in the downstream direction. Corresponding flow rates for NF Mud Springs Creek were 30 cfs at the upstream Station, and 37 cfs at the downstream station, representing an increase of 23% in the downstream direction.

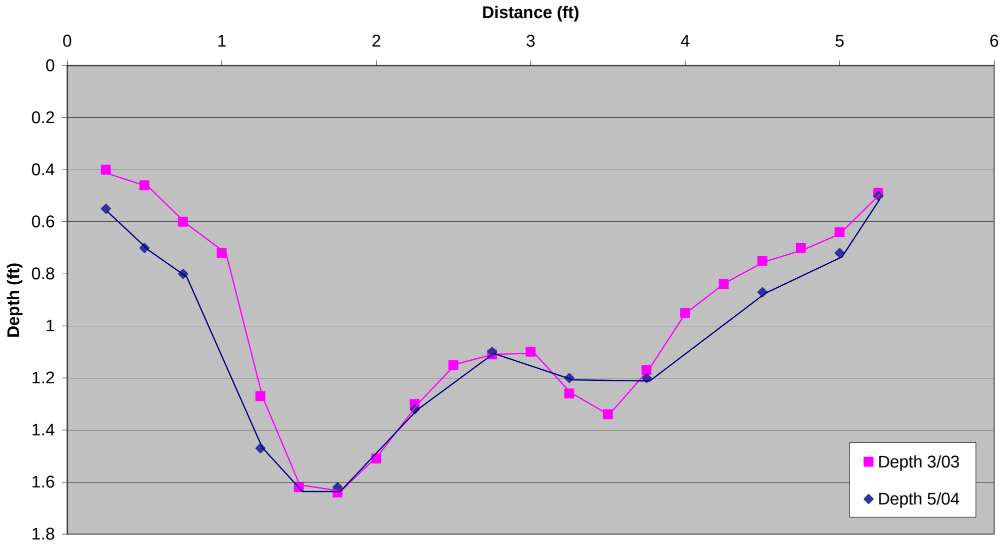


Cross Section A1



Cross Section B1

Figure 25. Repeated cross sections at three minor tributary locations, keyed with sediment source maps (Figures 20-24). Cross sections were selected because the channels drain cultivated or road drainage, and appeared to be recently active in winter 2002-03, indicating erosion since vineyard development began. Overall, erosion of all three cross sections occurred during winter 2003-04.



Cross Section D12 (@ "Green cube")

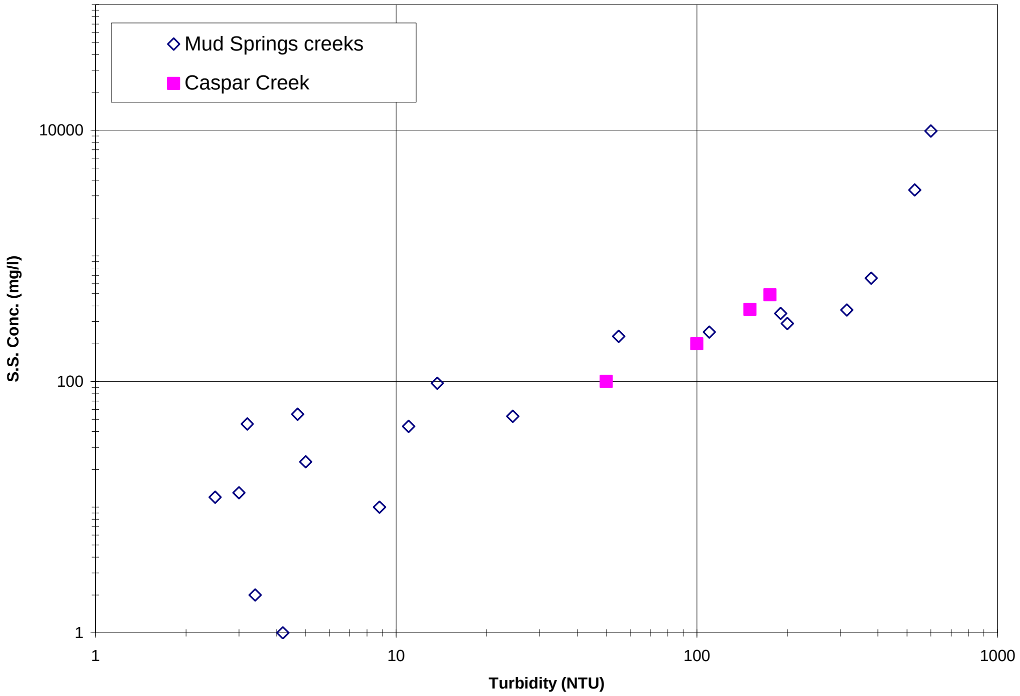


Figure 34. Scatter plot of suspended sediment concentration and turbidity. The Caspar Creek data (from regression line in Lewis 2002) are shown for comparison with the Mud Springs Creek data.

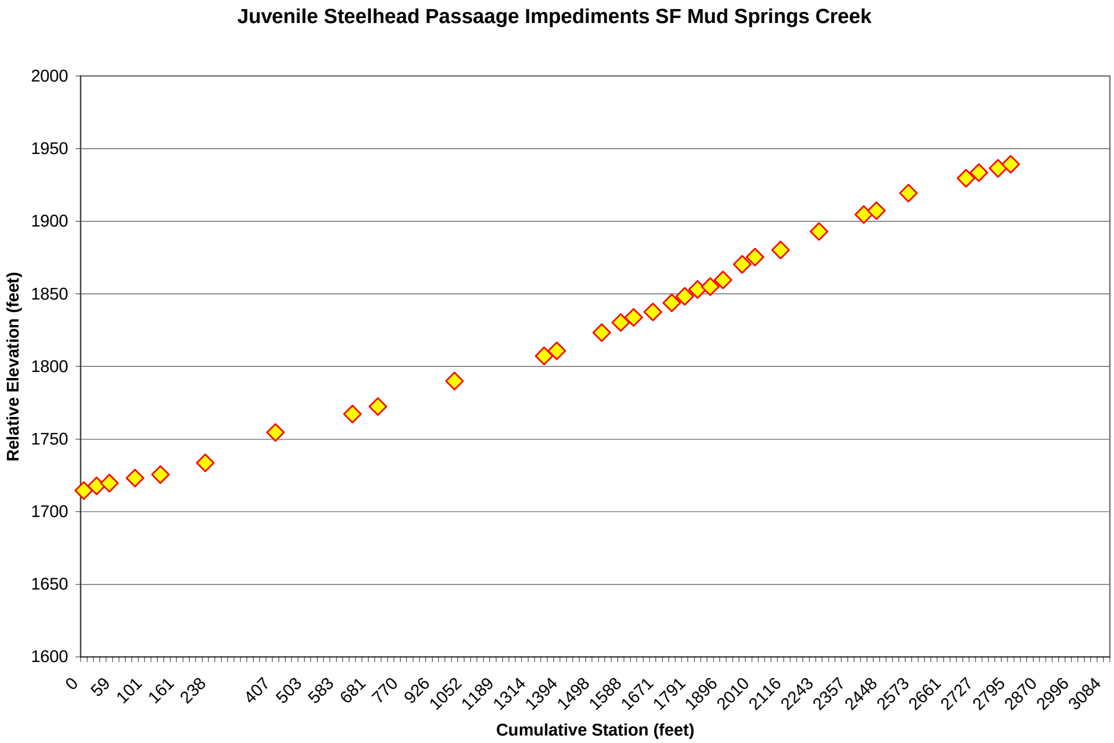


Figure 42. Locations where local stream gradient exceeds 15%, representing upstream passage impediments for juveniles on SF Mud Springs Creek.

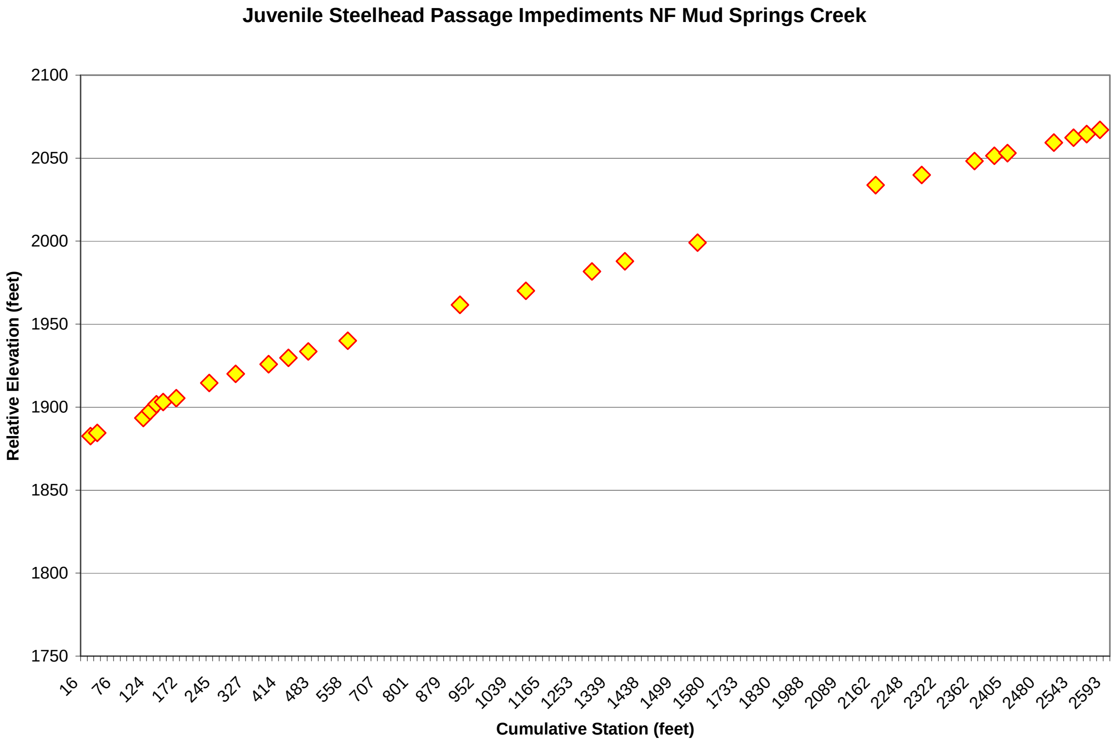


Figure 43. Locations where local stream gradient exceeds 15%, representing upstream passage impediments for juveniles on NF Mud Springs Creek.

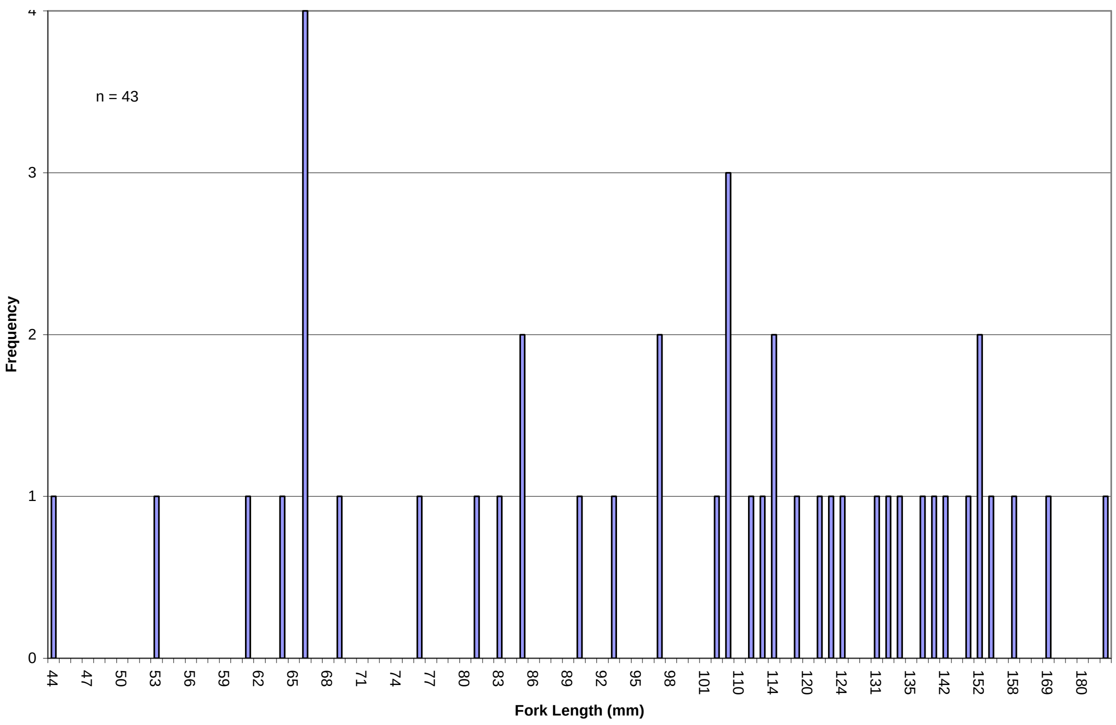


Figure 44. Juvenile steelhead length frequency relationships in early July 2003 in SF Mud Springs Creek.

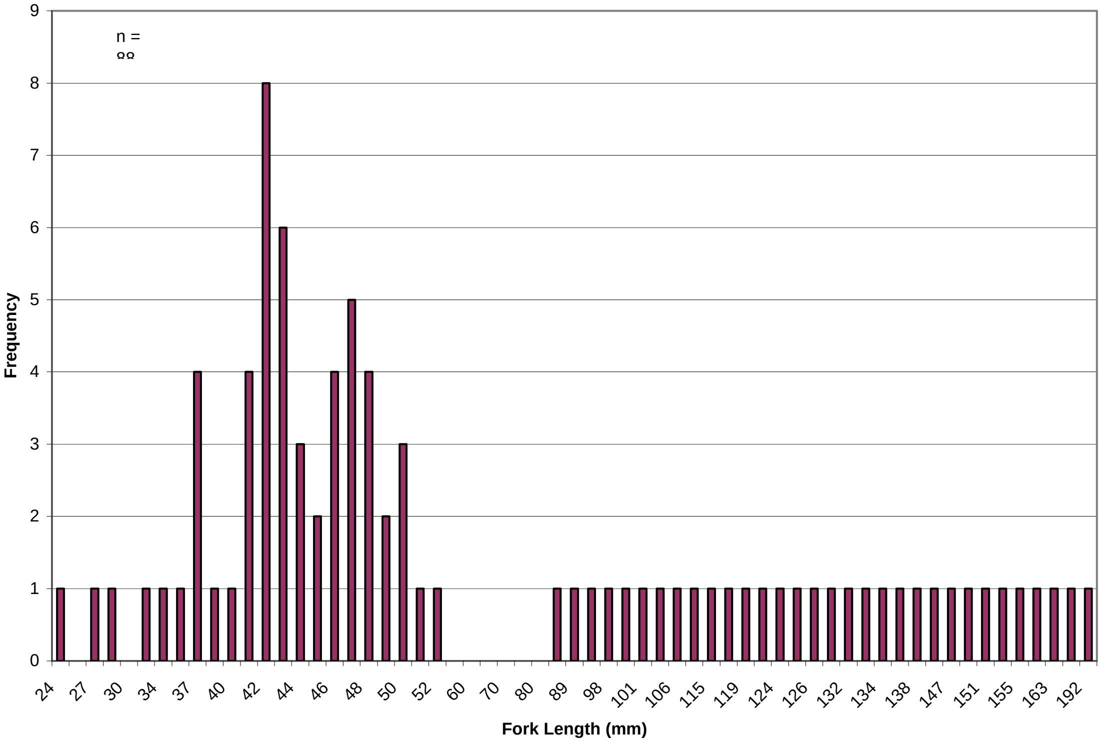


Figure 45. Juvenile steelhead length frequency in early July 2003 in NF Mud Springs Creek. The data gap from 60-80 mm may represent a fish kill during the previous winter.

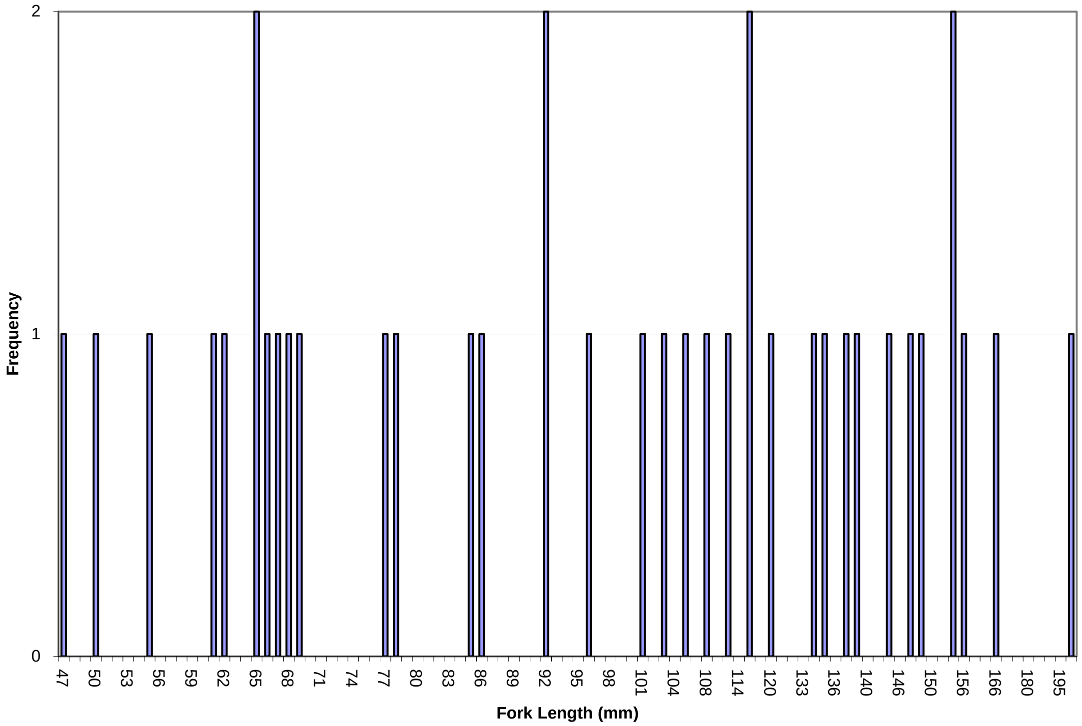


Figure 46. Juvenile steelhead length frequency in late summer 2003 in SF Mud Springs Creek.

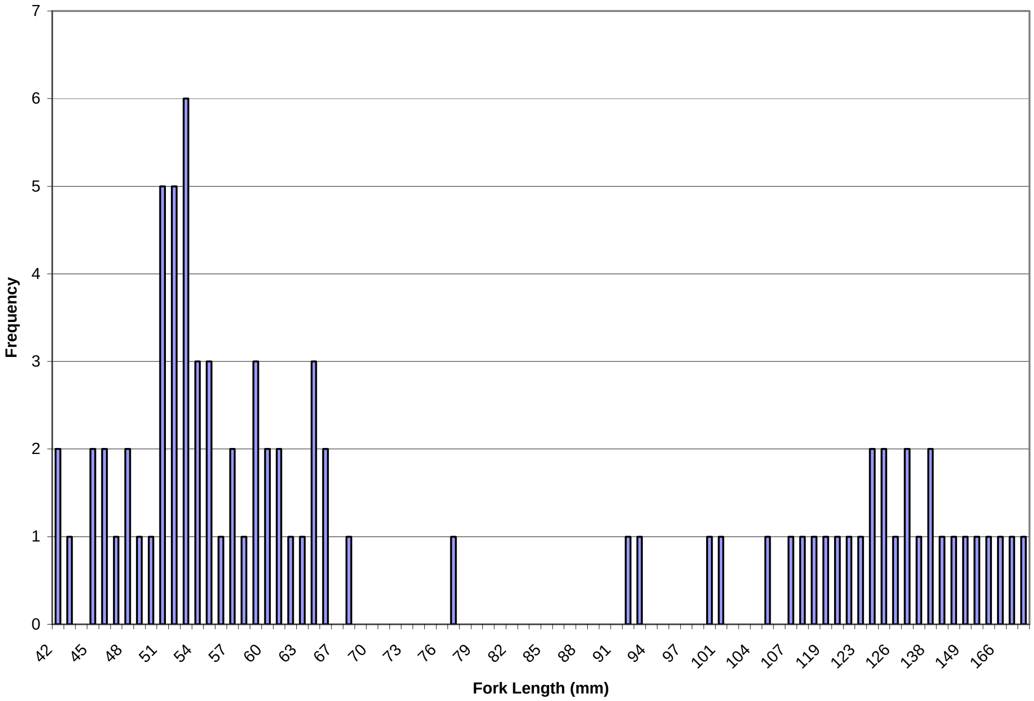


Figure 47. Juvenile steelhead length frequency in later summer 2003 in NF Mud Springs Creek.

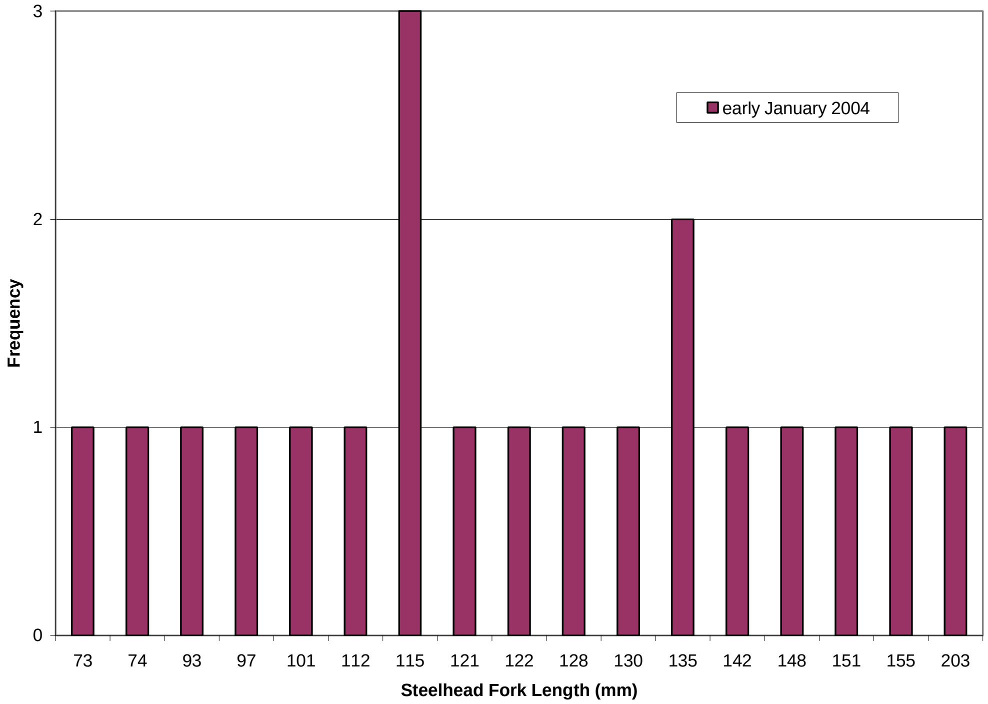


Figure 48. Juvenile steelhead length frequency in winter in SF Mud Springs Creek.

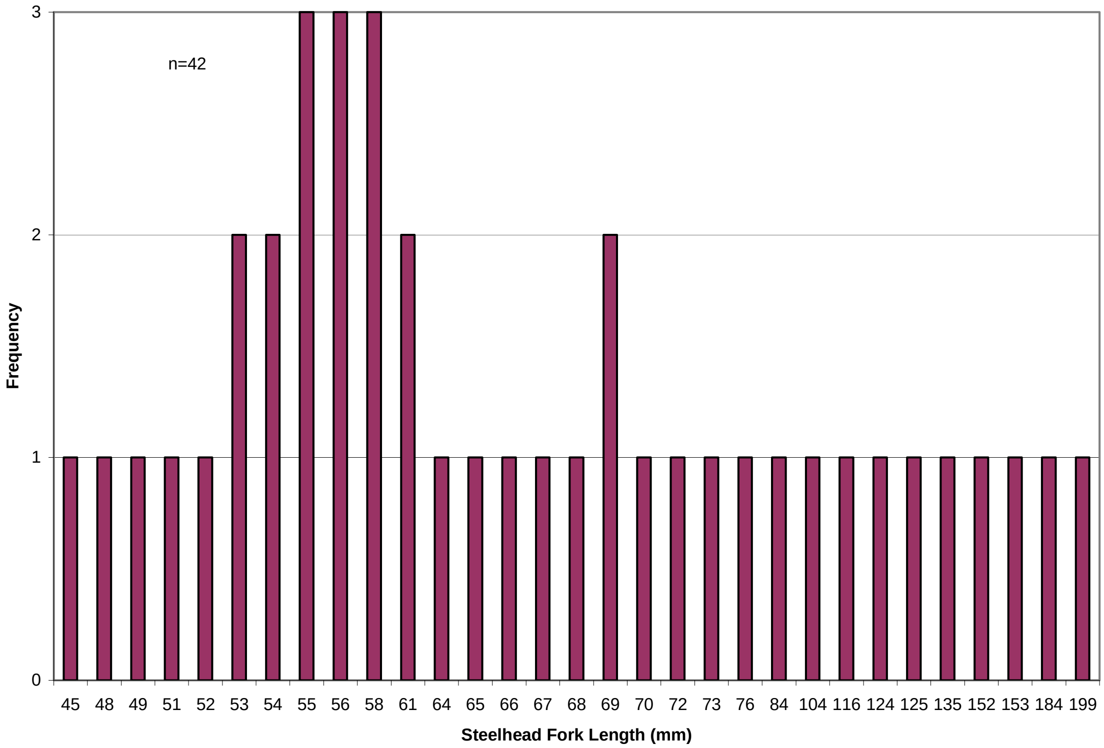


Figure 49. Juvenile steelhead length frequency in winter in NF Mud Springs Creek.

Figure 60. Sediment retention basin on tributary D12 to NF Mud Springs Creek, constructed in summer 2003. Tributary D12 originates on cultivated land, incorporates road drains, and discharges between upper and lower sensors of turbidity monitoring Station D. Photo was taken on December 6, 2003 within a few hours of the season's first heavy rainfall. Poor construction materials and methods resulted in failure of the basin berm, as indicated by the low water level. Closer examination shows piping failure along the right side of the outlet pipe, behind the large stones. This basin was not repaired during the 2003-04 runoff season, nor during summer-fall 2004. It was last observed on October 25, remaining un-repaired.

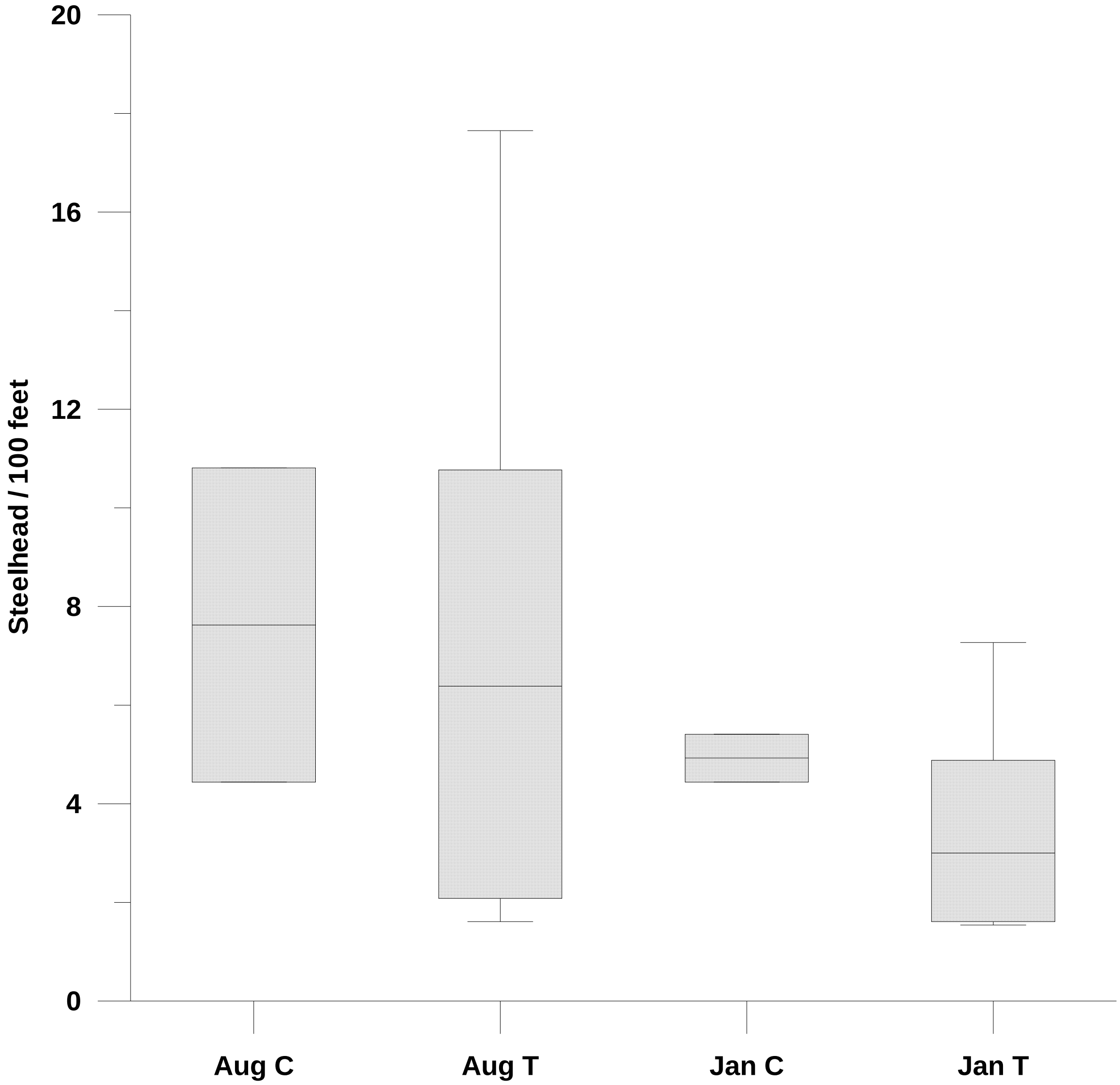


Figure 61. Box and whisker graph of steelhead abundance in clear water (C) and turbid water (T) for August and January sample dates in SF Mud Springs Creek.

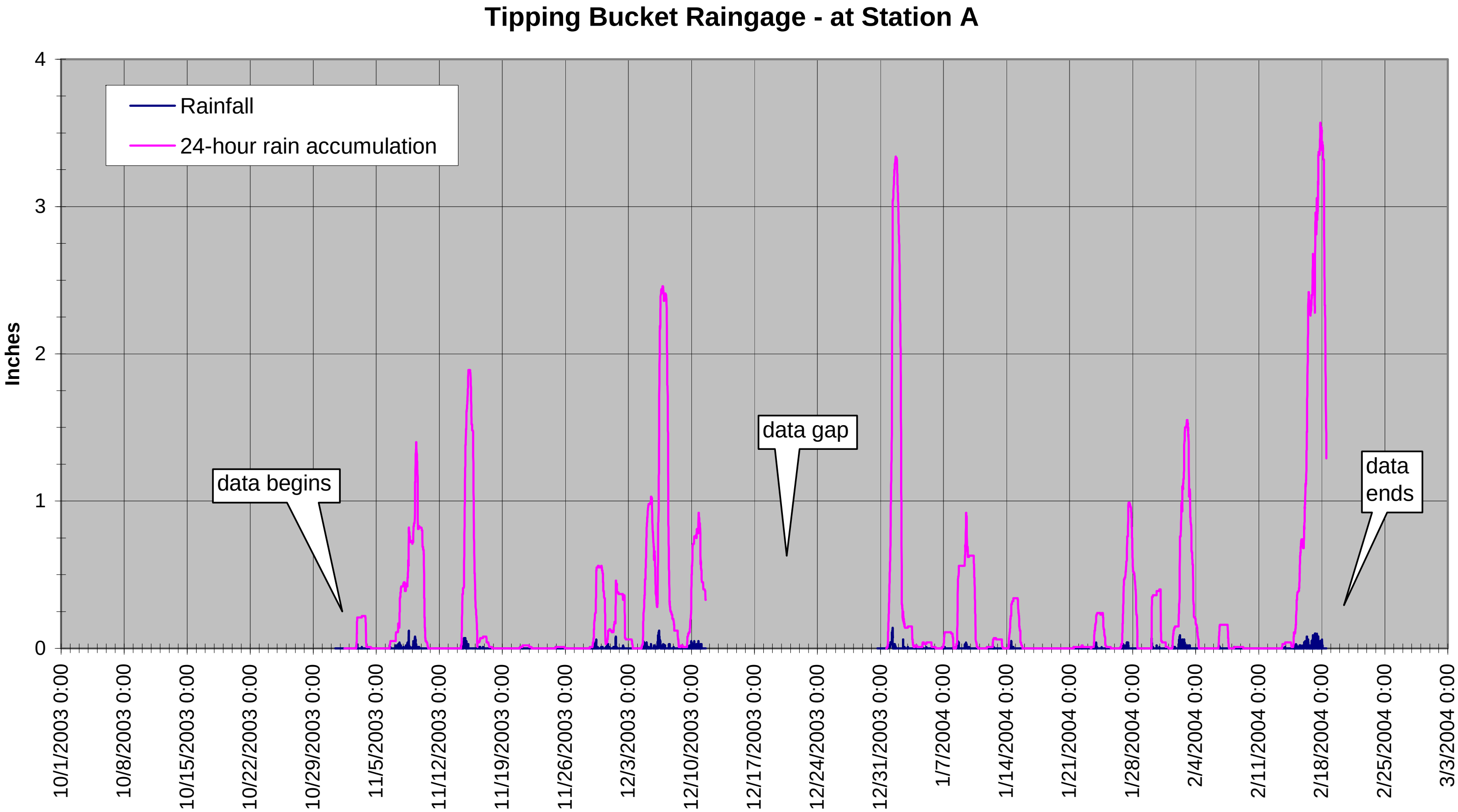


Figure 16. Time series plot of rainfall for the Mud Springs Creek watershed, measured at monitoring Station A. Black histogram blocks are 0.1 inch rainfall increments in 10-minute intervals. Magenta line is the running 24-hour rainfall accumulation.

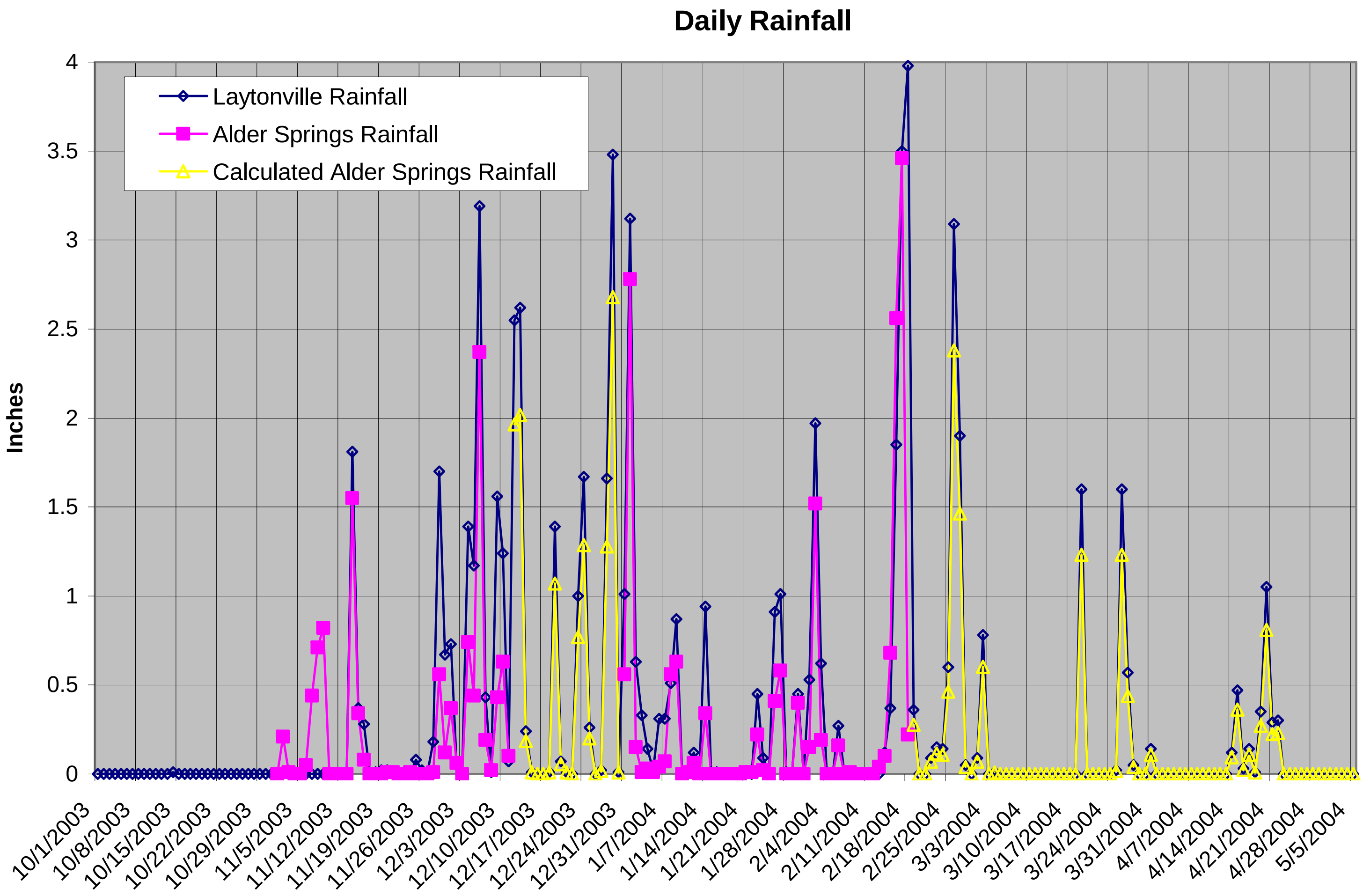


Figure 17. Reconstructed record of daily total rainfall for the Mud Springs Creek watershed.

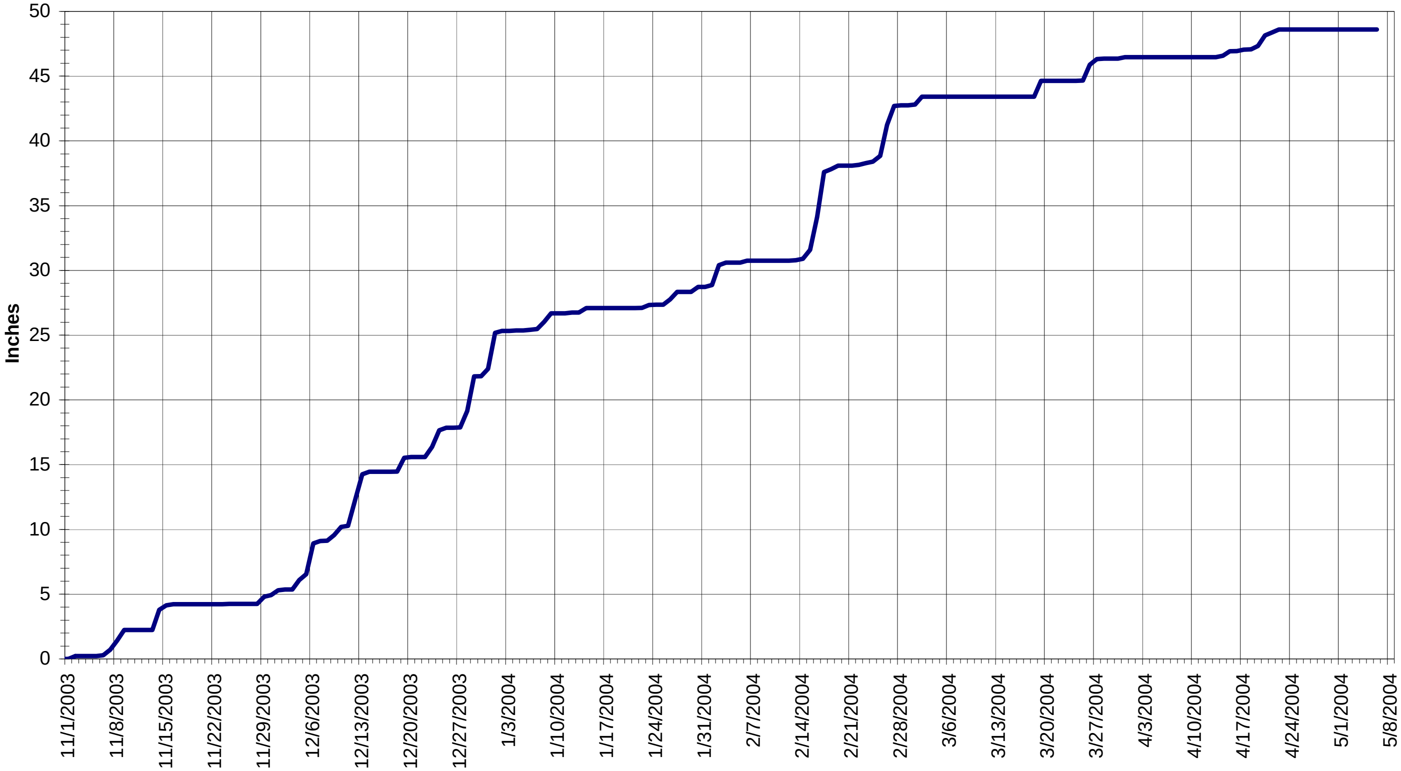


Figure 18. Rainfall accumulation for the Mud Springs Creek watershed for the 2003-2004 rainy season, measured at monitoring Station A.

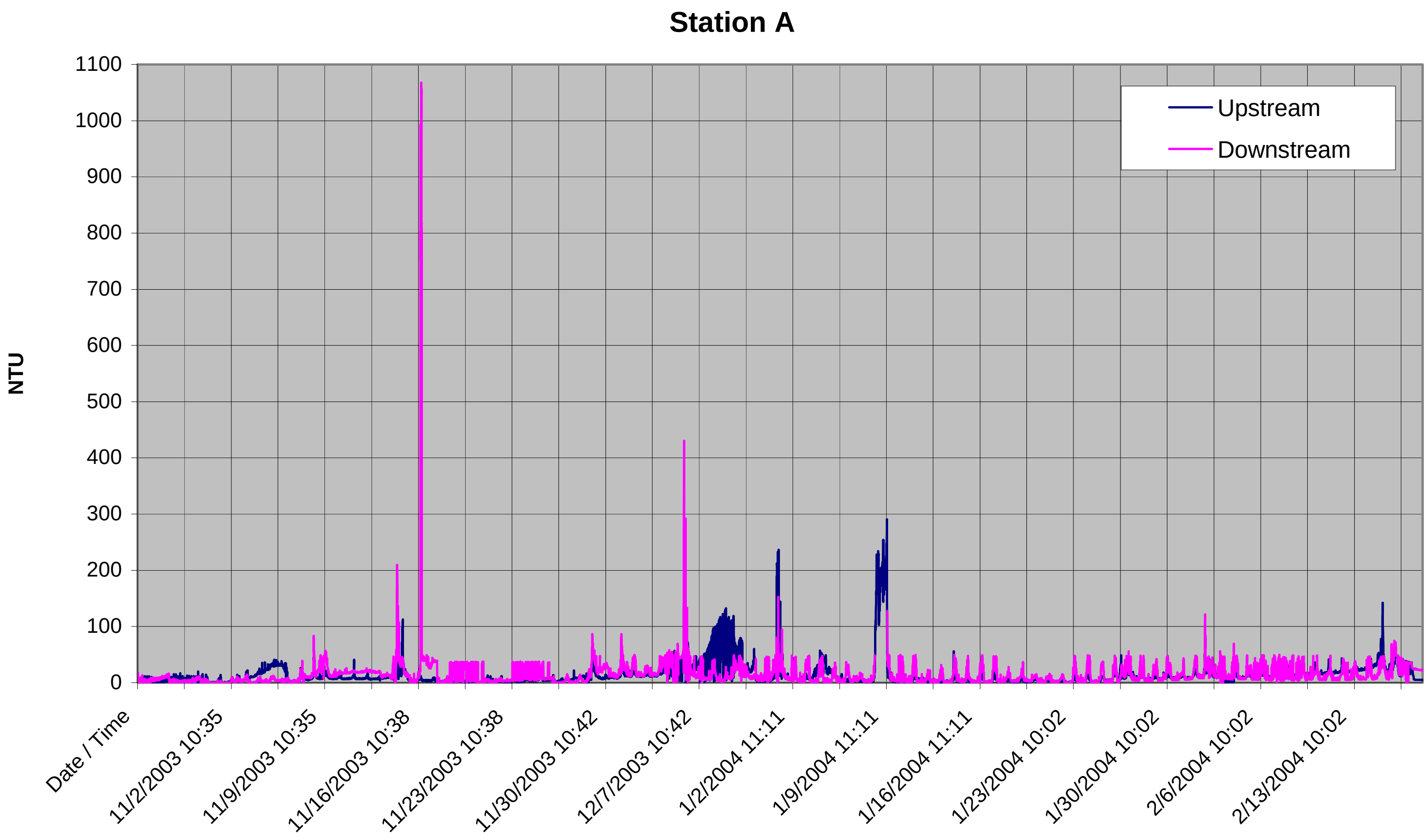


Figure 26. Time series plot of 10-minute turbidity monitoring for Station A, on SF Mud Springs Creek. The difference between the upstream and downstream lines is approximately 100 feet stream length, with a small tributary (A1) flowing in between. Data greater than 1000 NTU exceeds the sensor limits.

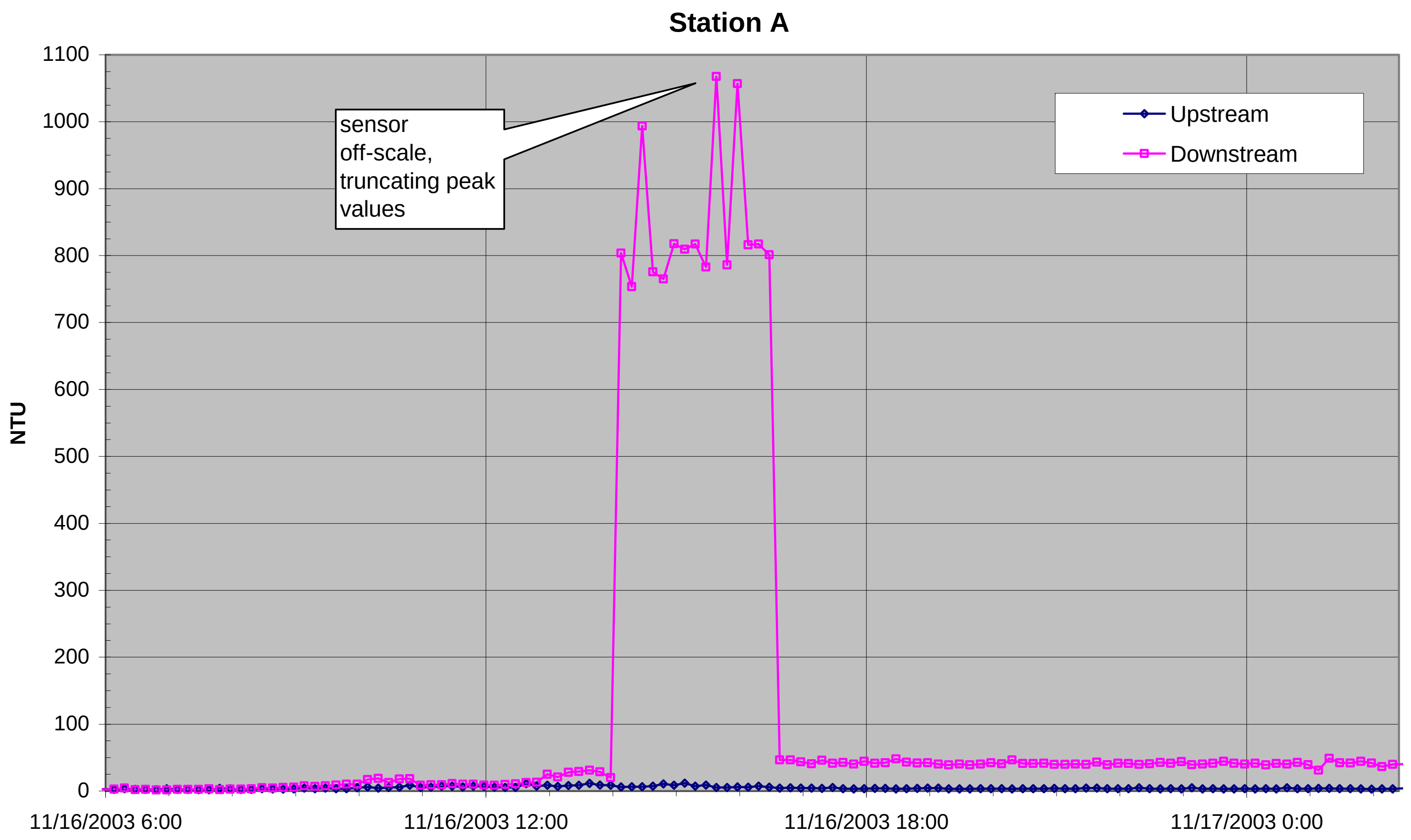


Figure 27. Time series plot of turbidity at Station A showing the effects of small tributary stream (A1) that enters SF Mud Springs Creek between the two sensors. This turbidity peak, which exceeded sensor limits, is attributable to erosion of fill from around a recently replaced culvert (see Figures 6 and 7), and channel erosion upstream from the culvert (see cross section A1). Data greater than 1000 NTU exceeds the sensor limits.

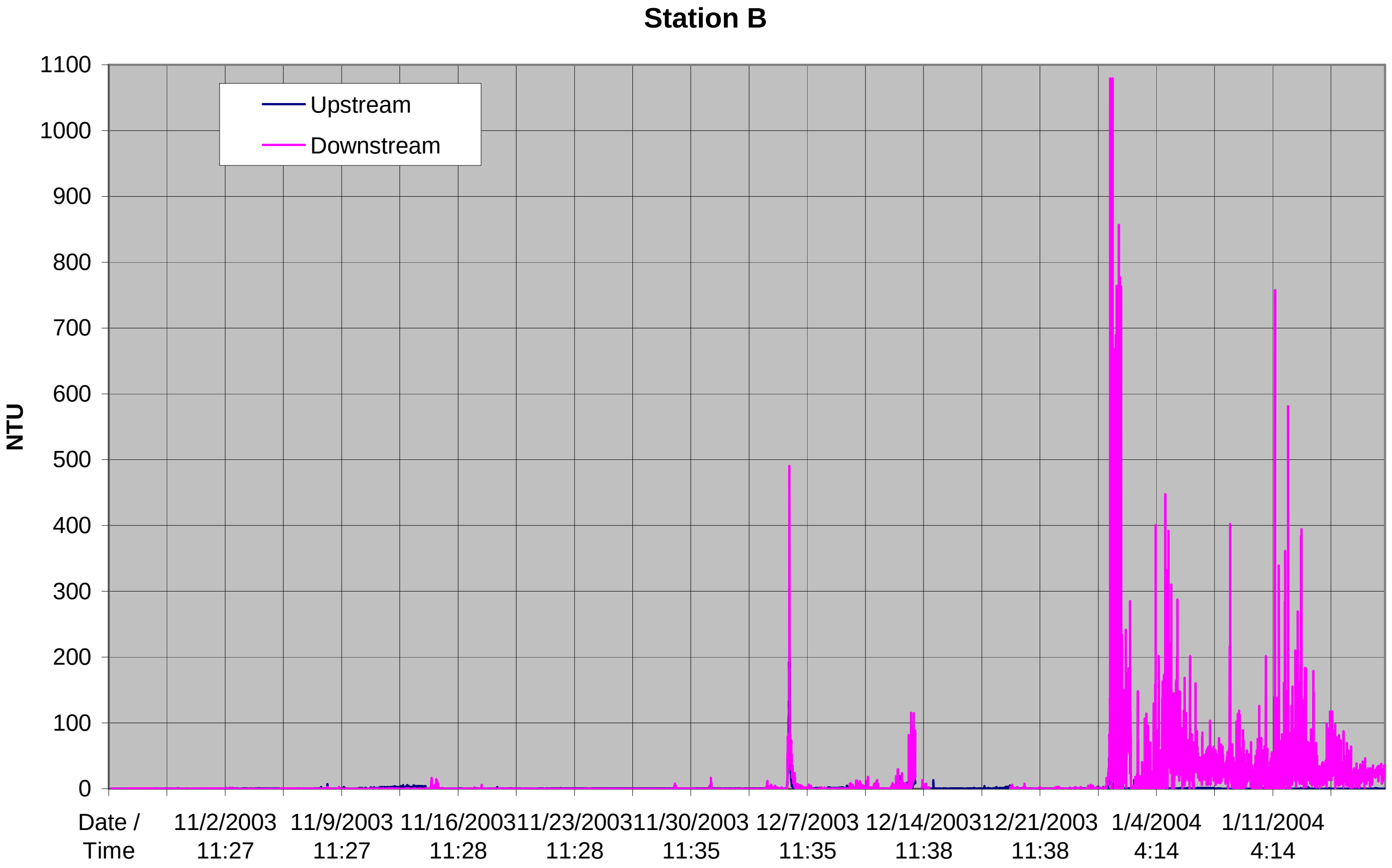


Figure 28. Time series plot of 10-minute turbidity monitoring for Station B, on SF Mud Springs Creek. The difference between the upstream and downstream lines is approximately 150 feet of stream length, with tributary B1 flowing in between. Data greater than 1000 NTU exceeds the sensor limits.

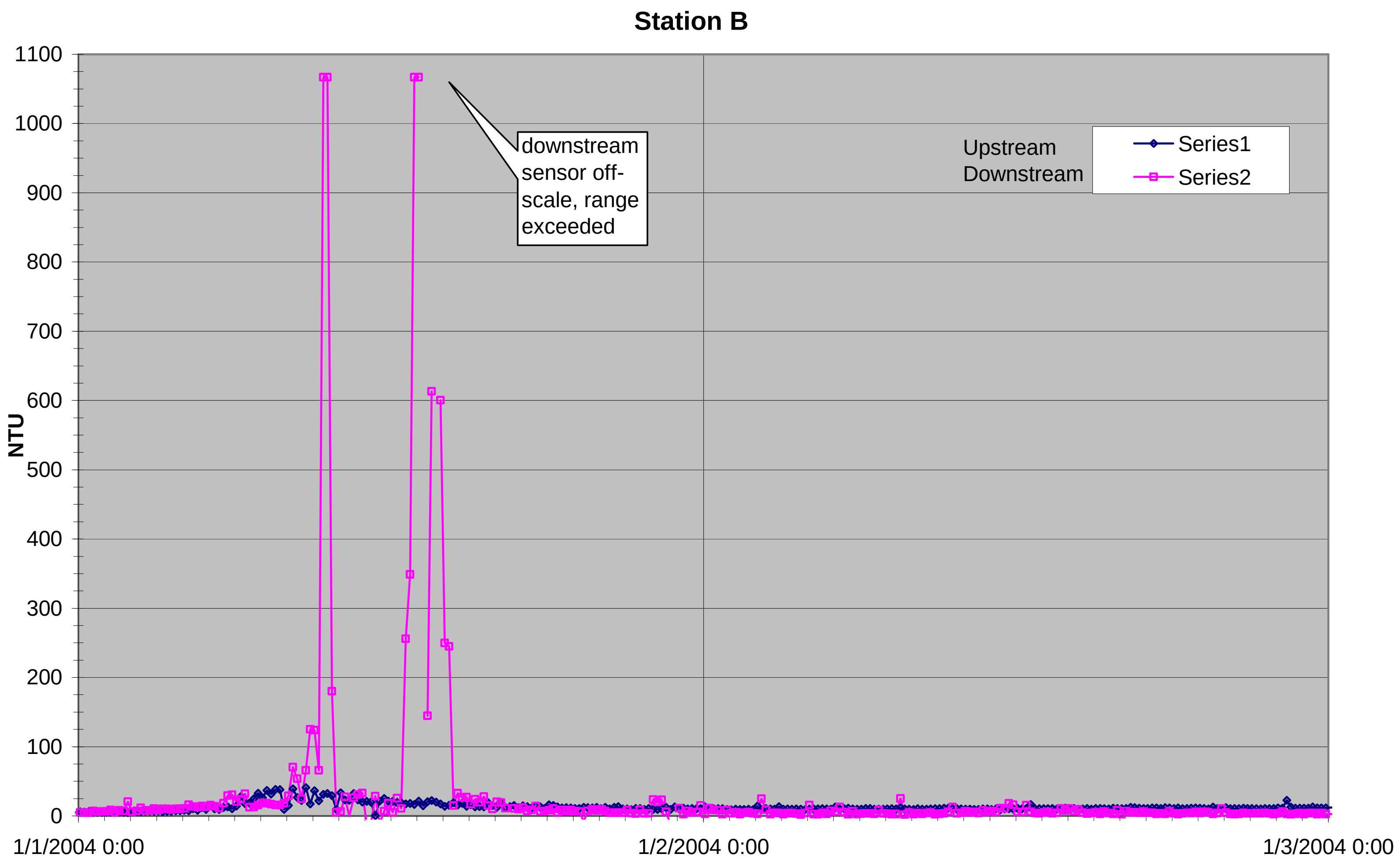


Figure 29. Time series plot of turbidity for Station B showing the effects of small tributary stream B1 that enters between the upstream and downstream sensors on SF Mud Springs Creek. This tributary existed prior to land development, but shows recent enlargement, incision, and headcut migration (see cross section B1). The drainage originates on some of the steepest cultivated slopes and has two vineyard road crossings composed of fill. New fill material sources were observed at the head of this drainage due to terrace construction in summer 2004 (see Figure 9), in position for delivery to SF Mud Springs Creek in winter 2004-2005. Data greater than 1000 NTU exceeds the sensor limits.

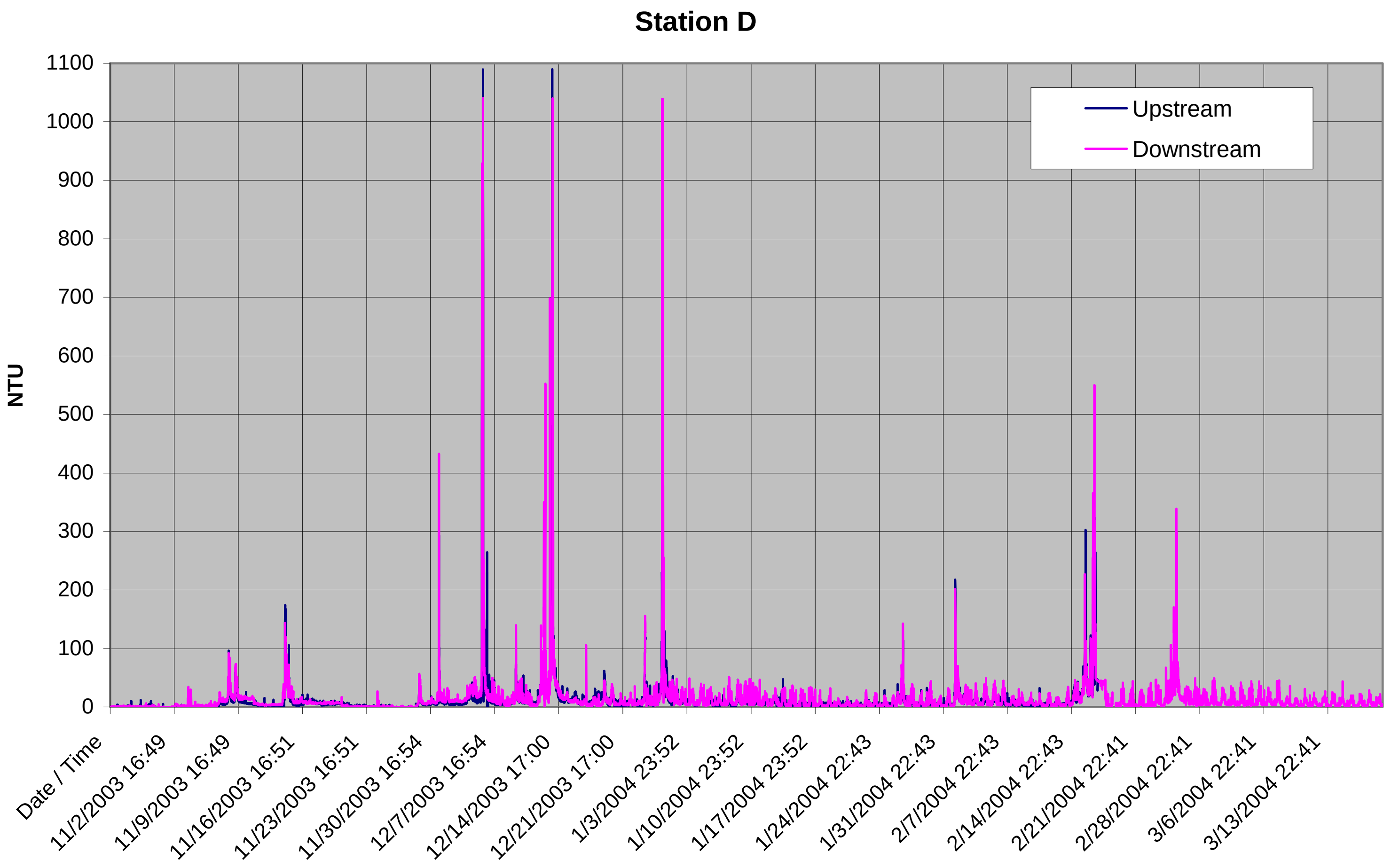


Figure 30. Time series plot of 10-minute turbidity for Station D, on NF Mud Springs Creek. The difference between the upstream and downstream lines is approximately 150 feet stream length with tributary D12 flowing in between. Data greater than 1000 NTU exceeds the sensor limits.

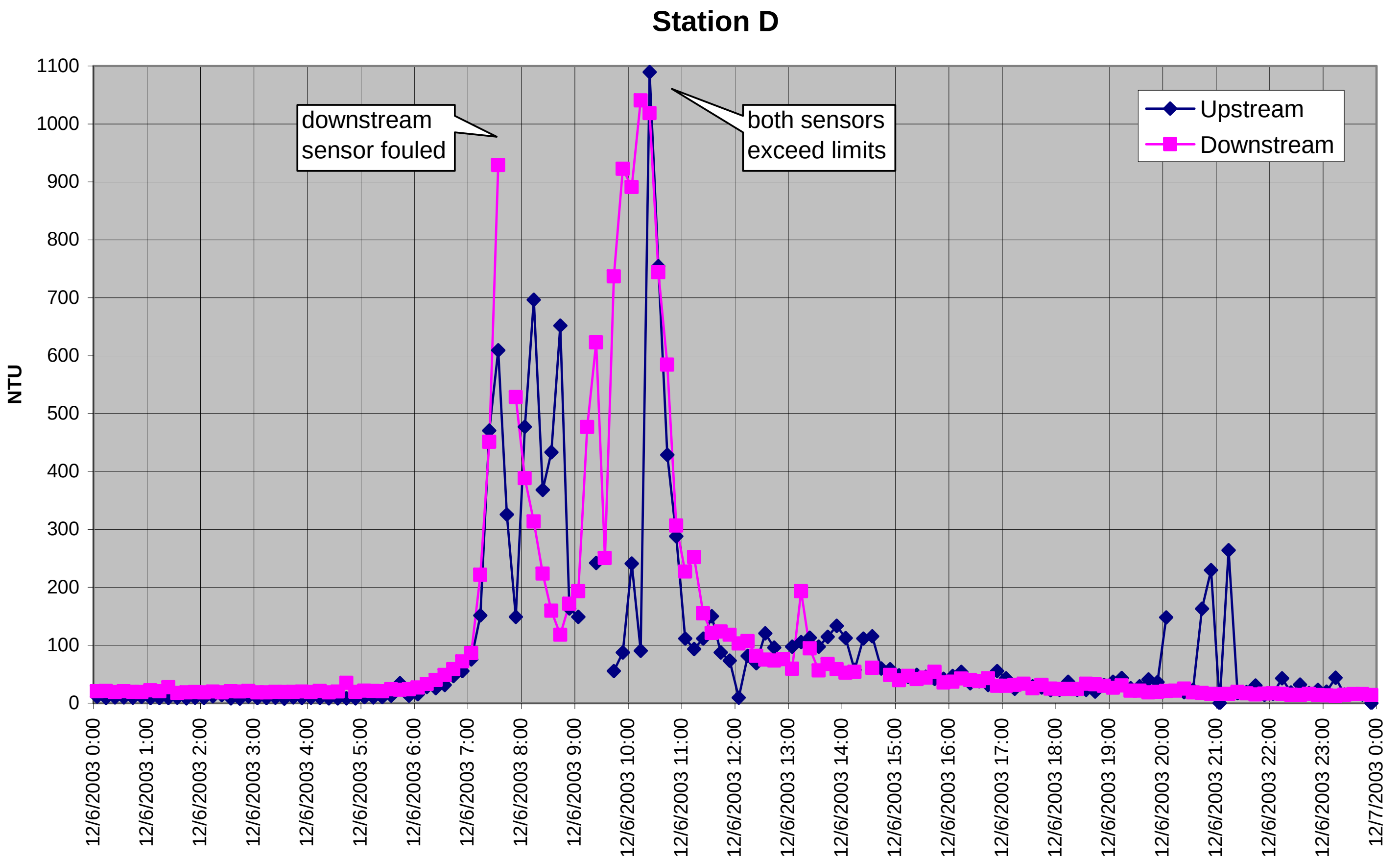


Figure 31. Time series plot of turbidity for Station D, NF Mud Springs Creek, showing the effects of small tributary stream D12 that enters between the upstream and downstream sensors. Tributary D12 originates from cultivated land, enters drainage collectors which also collect road runoff, and spill into a sediment retention basin constructed in summer 2003. The channel of tributary D12 underwent erosion during winter 2003-2004 (cross section D12), and the sediment retention basin failed by December 6, 2004 (see Figure 60). Data greater than 1000 NTU exceeds the sensor limits.

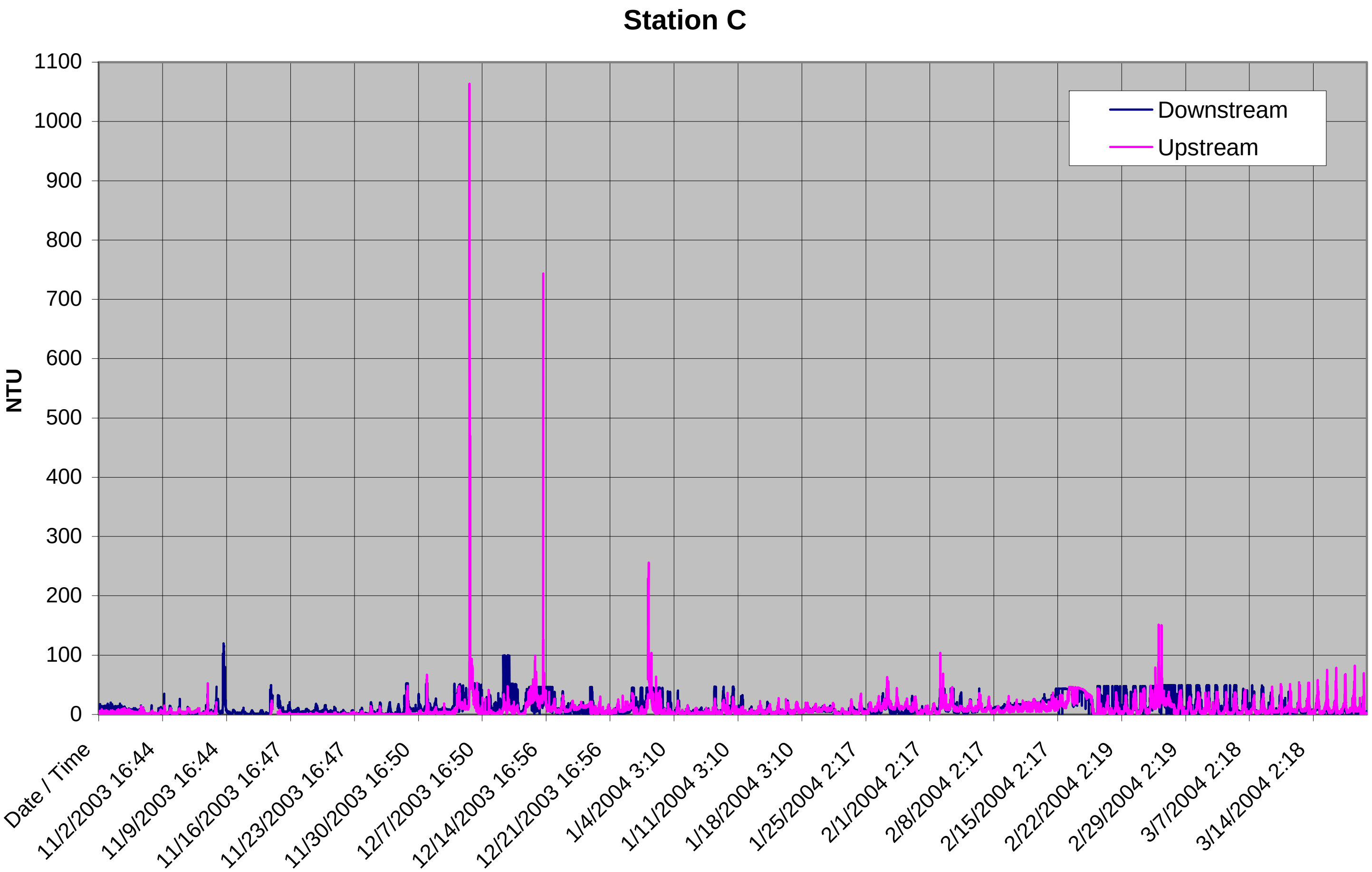
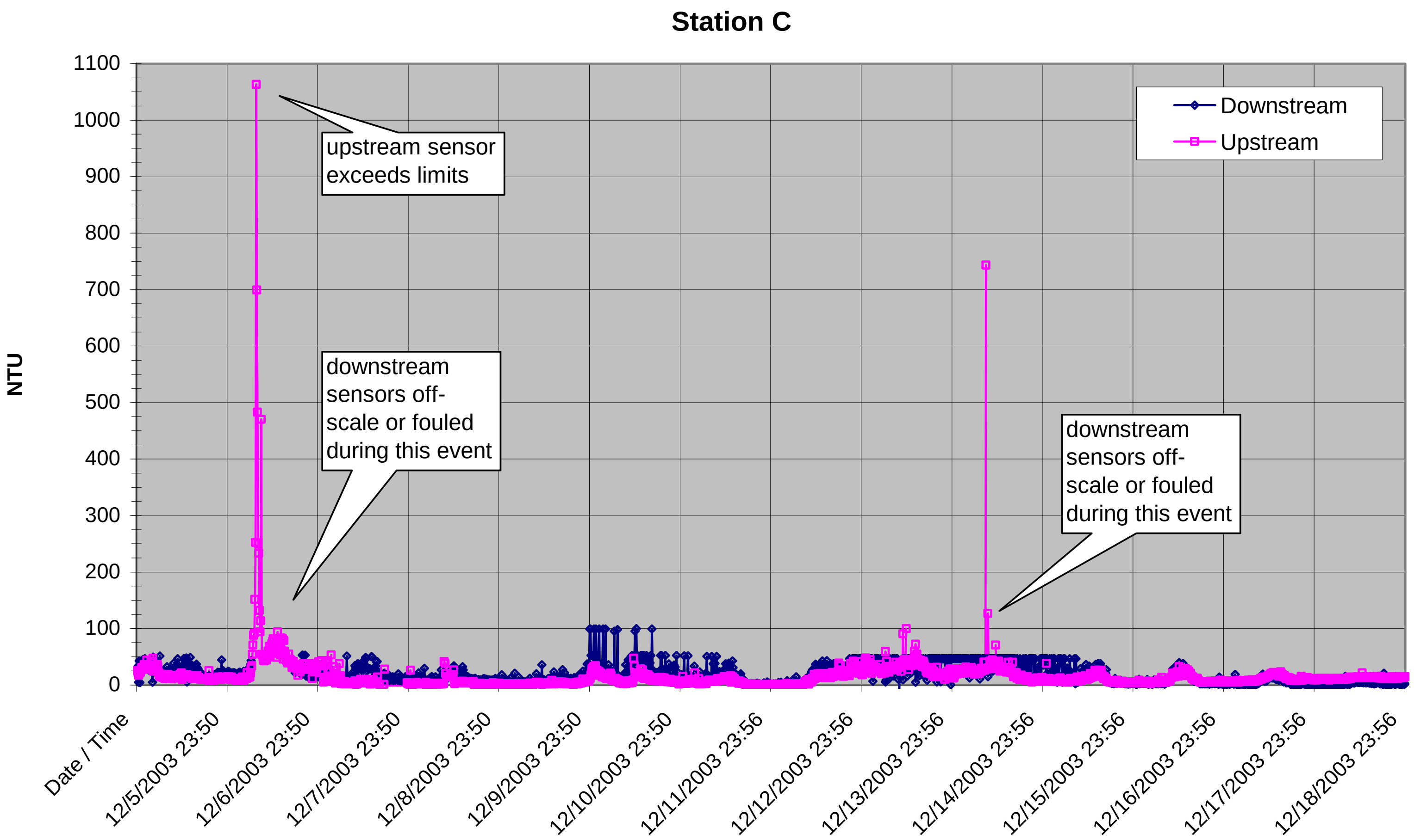


Figure 32. Time series plot of 10-minute turbidity for Station C, on NF Mud Springs Creek. The difference between the upstream and downstream lines is approximately 150 feet, with tributary C4 flowing in between. The downstream turbidity sensor on monitoring Station C experienced fouling with sediment during most storm events, thwarting the discrimination of tributary sediment deliveries to upper NF Mud Springs Creek. Data greater than 1000 NTU exceeds the sensor limits.



upstream sensor exceeds limits

downstream sensors off-scale or fouled during this event

downstream sensors off-scale or fouled during this event

Figure 33. Time series plot of turbidity for Station C, upper NF Mud Springs Creek, located at small tributary stream C4 that enters between the upstream and downstream sensors. Tributary C4 originates from cultivated land, enters drainage collectors which also collect road runoff, and spill into a preexisting channel. The channel of tributary C4 is partially bedrock controlled at its confluence with NF Mud Springs Creek. The downstream turbidity sensor on monitoring Station C experienced fouling with sediment during most storm events, thwarting the discrimination of tributary sediment deliveries to NF Mud Springs Creek. Data greater than 1000 NTU exceeds the sensor limits.

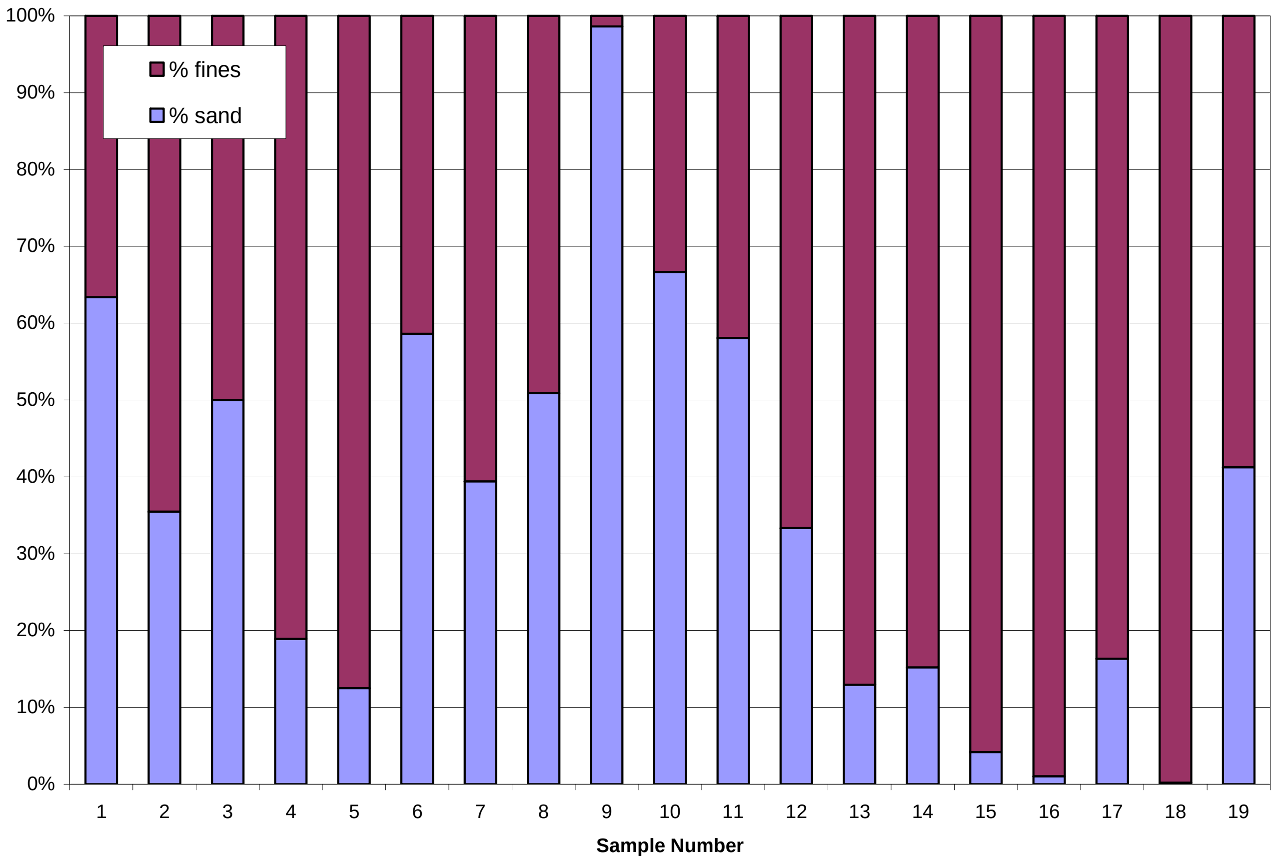


Figure 35. Histogram of particle size classes for the Mud Springs Creek suspended sediment samples (Table 1). Sand and larger particles make up 28% of the total.

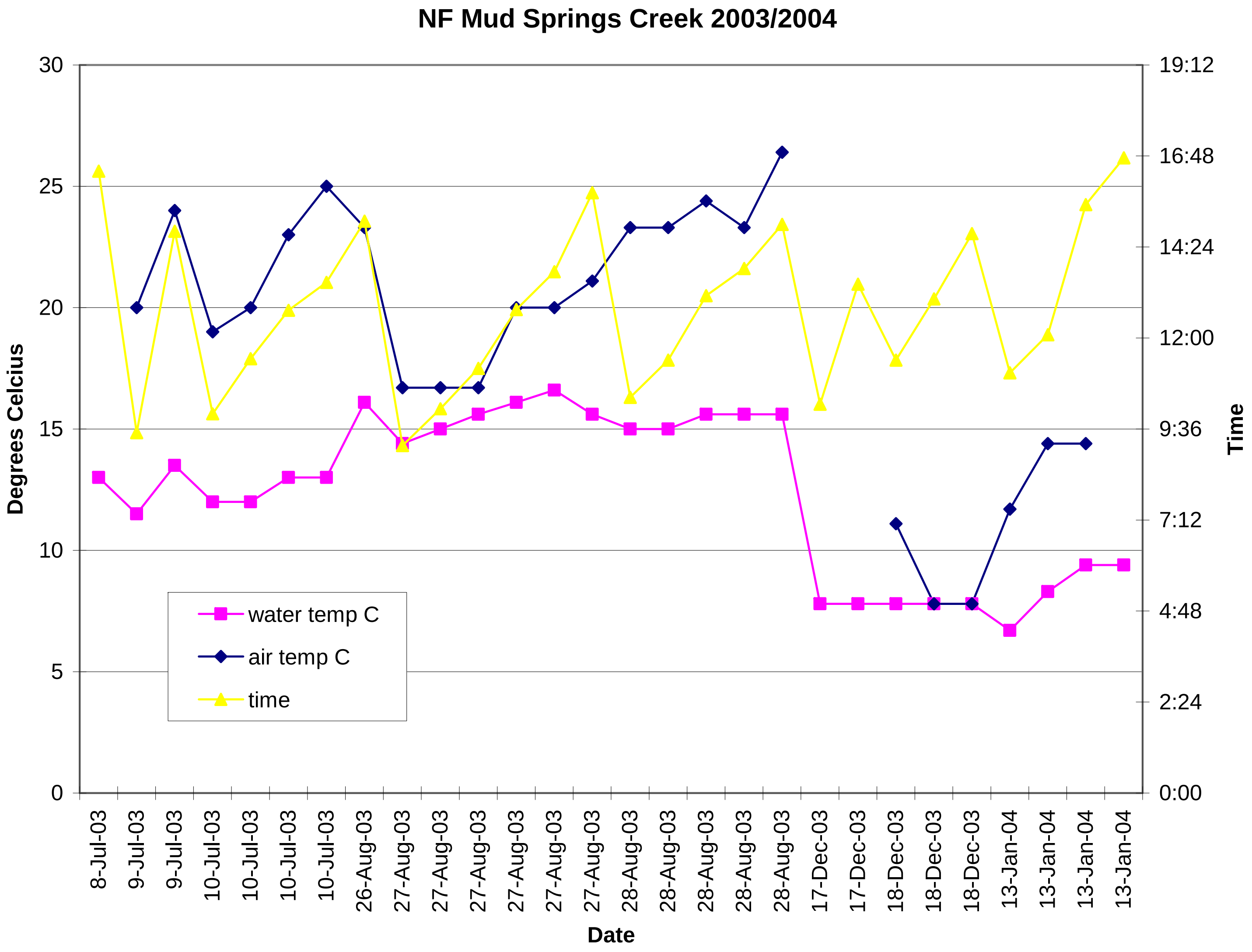


Figure 36. Measured water and air temperatures in NF Mud Springs Creek.

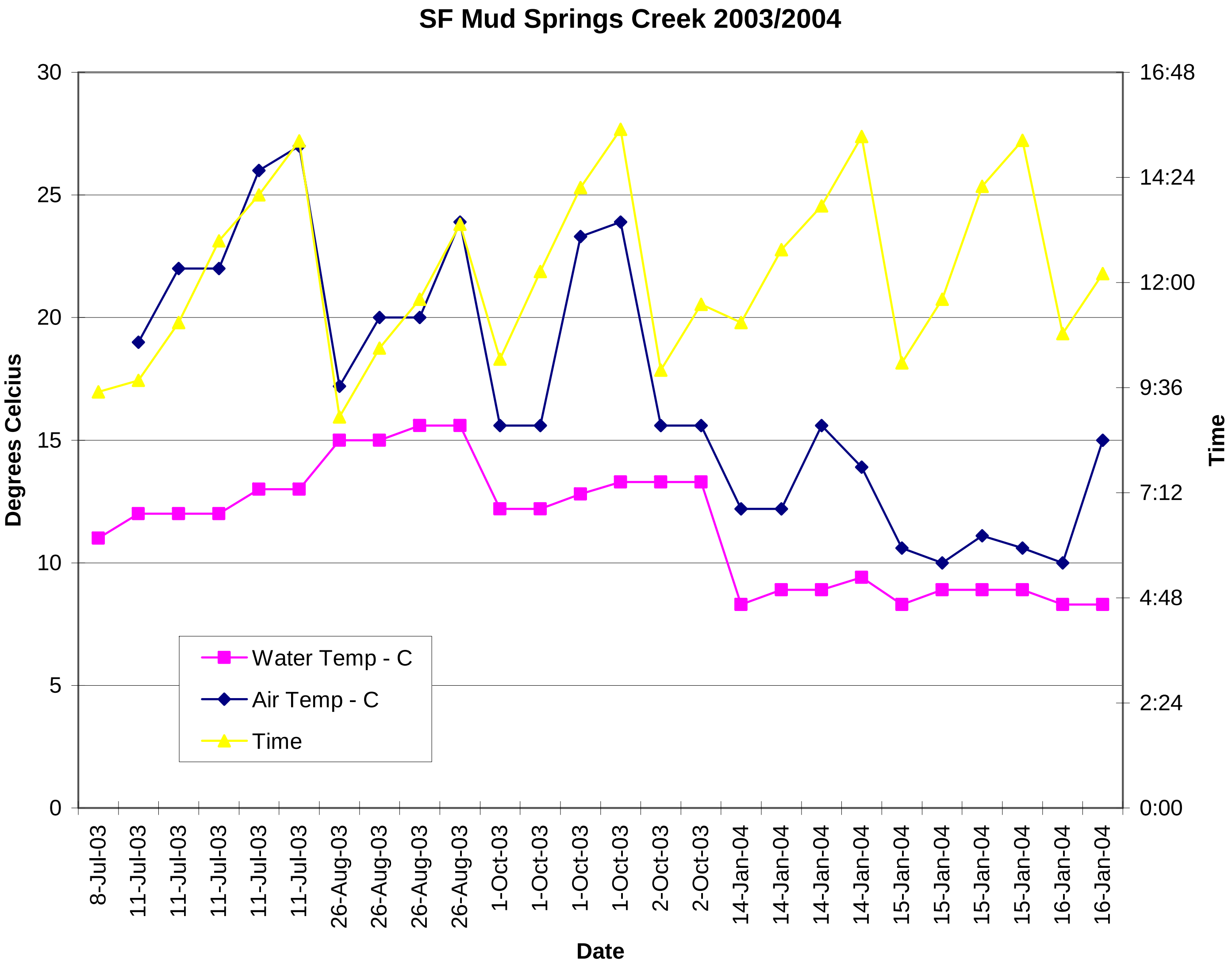


Figure 37. Measured water and air temperatures in SF Mud Springs Creek.

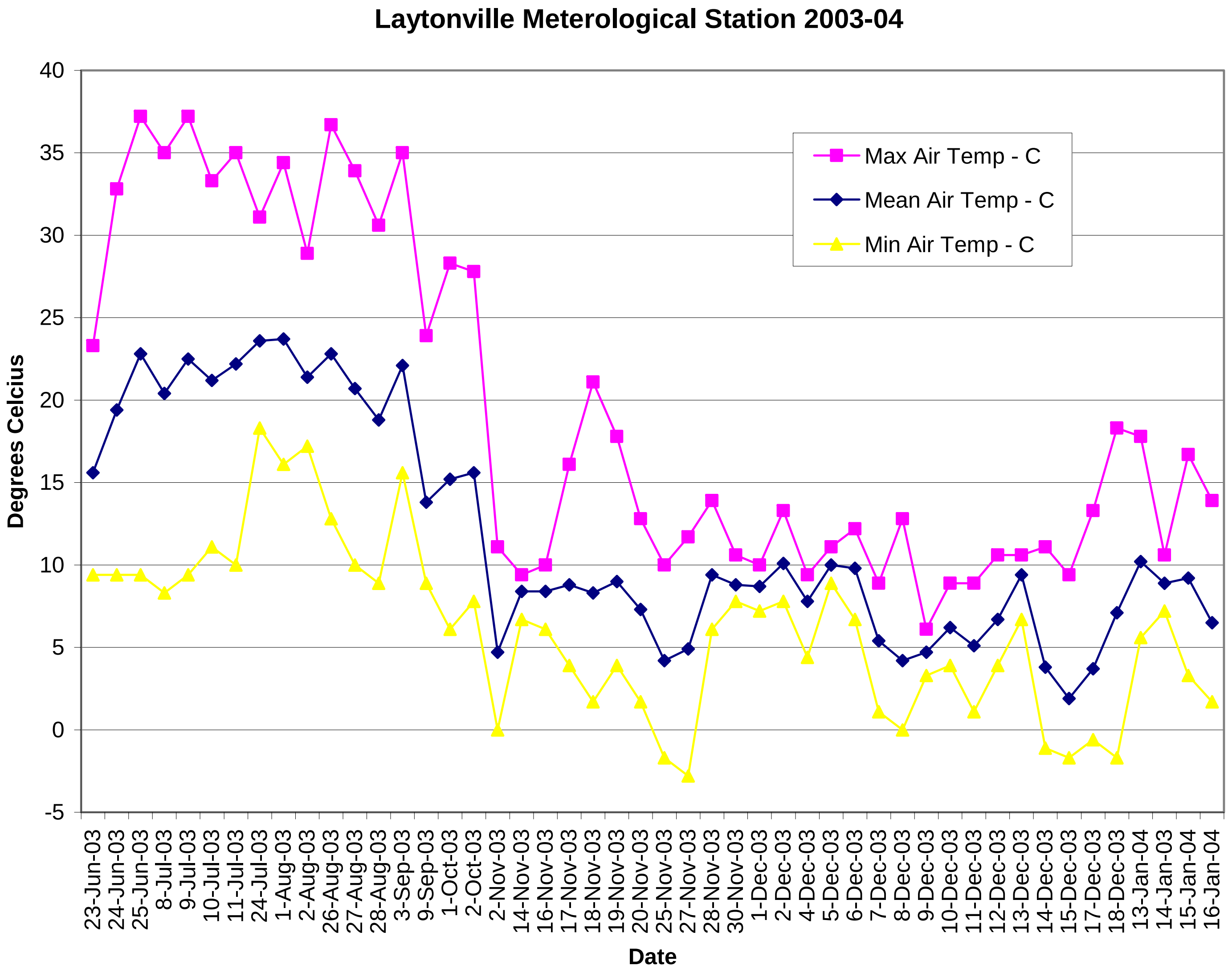


Figure 38. Maximum, mean, and minimum air temperatures recorded at the Laytonville meteorological station.

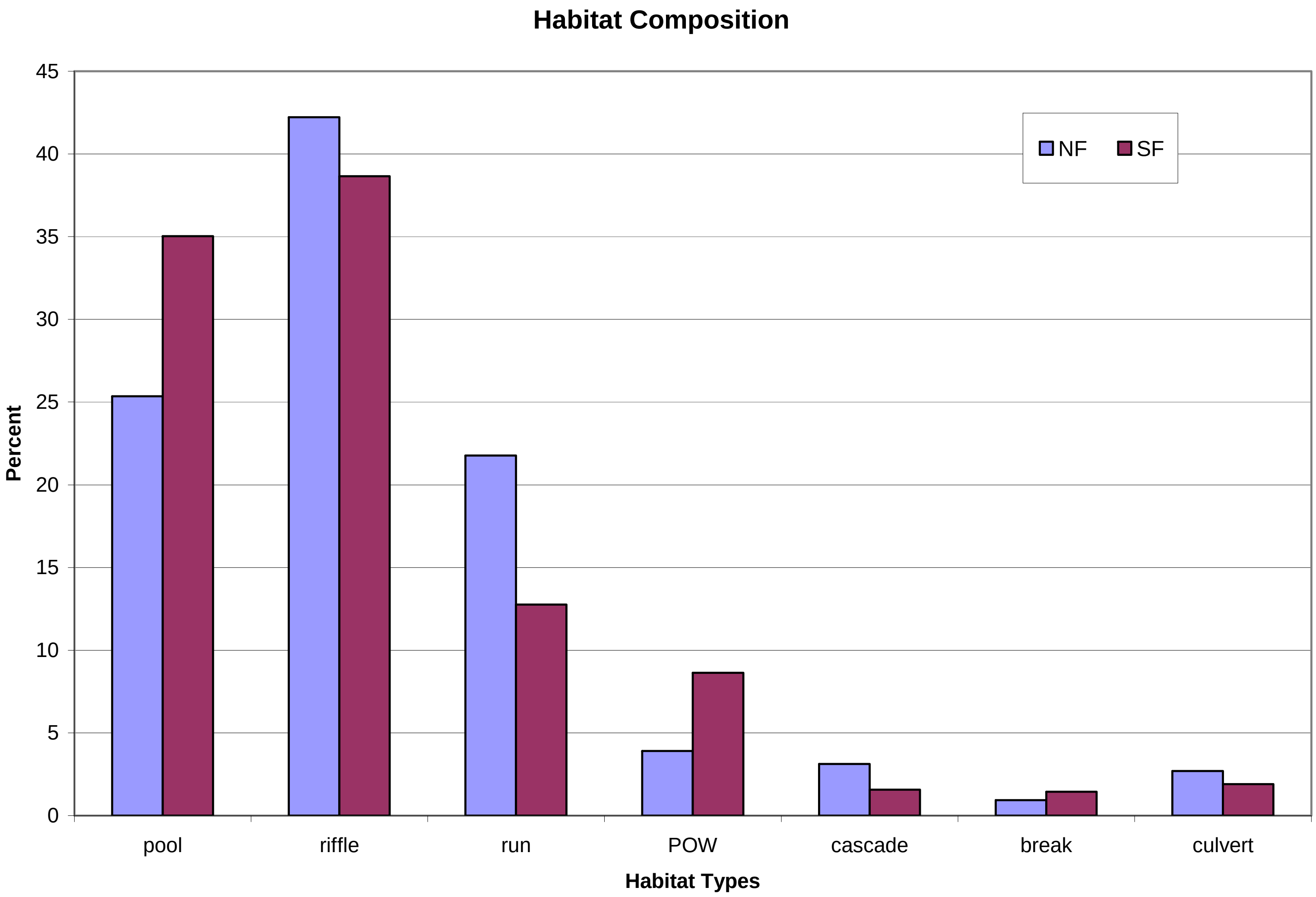


Figure 39. Habitat type proportions within the study areas of NF and SF Mud Springs Creek in 2003-04.

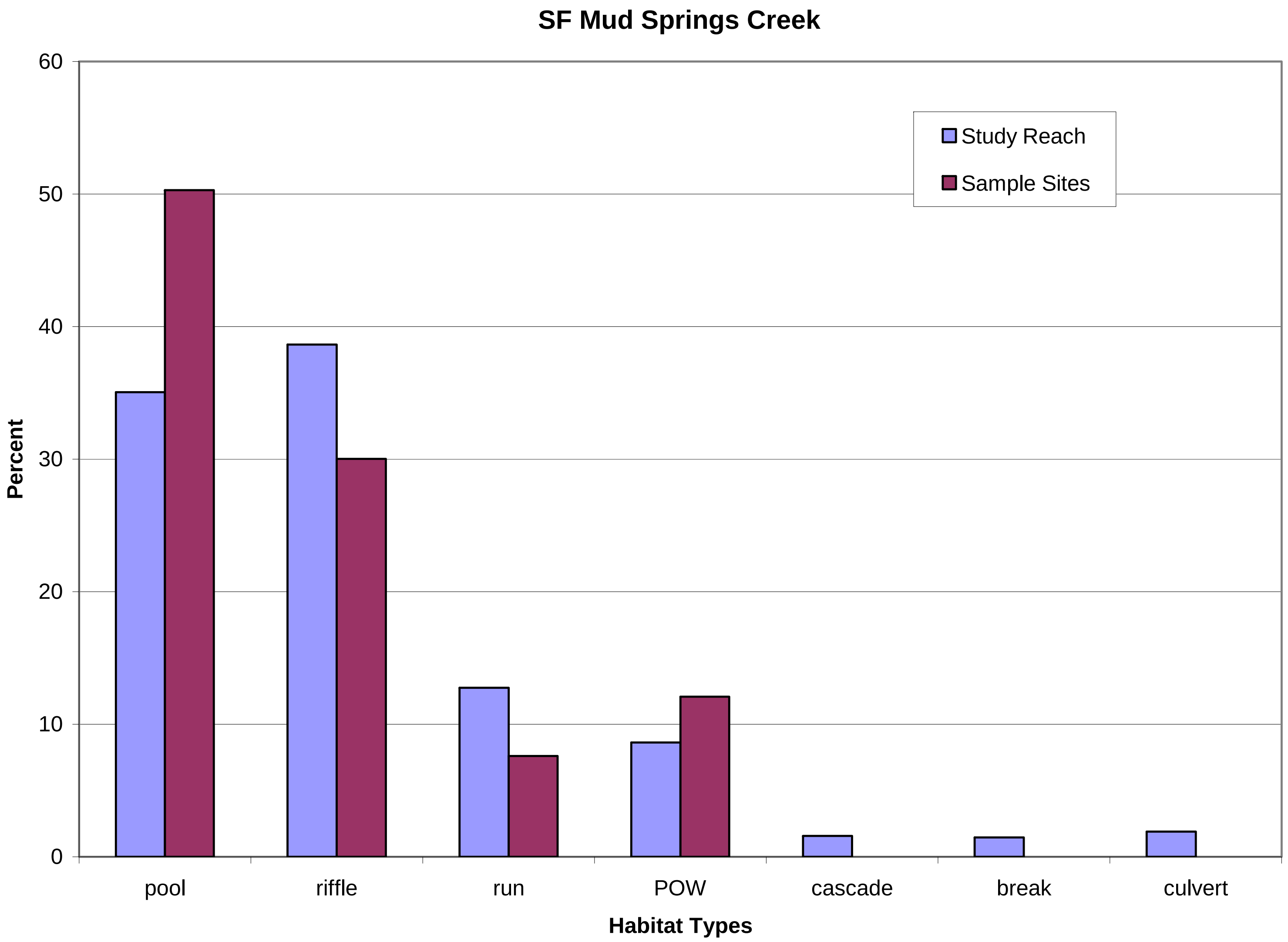


Figure 40. Habitat type proportions in the first set of electrofishing sites and the study in SF Mud Springs Creek.

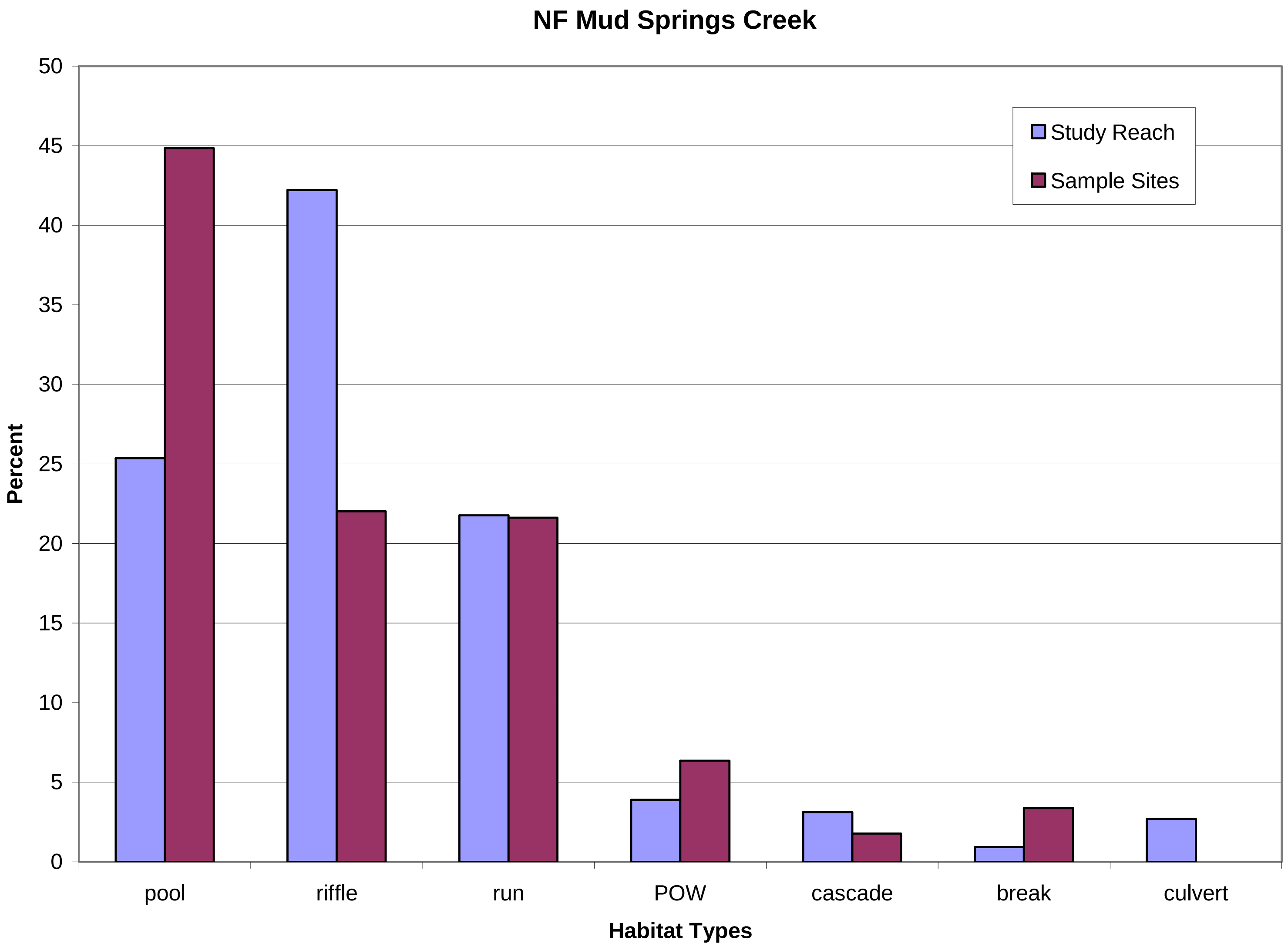


Figure 41. Habitat type proportions in the first set of electrofishing sites and the study area in NF Mud Springs Creek.

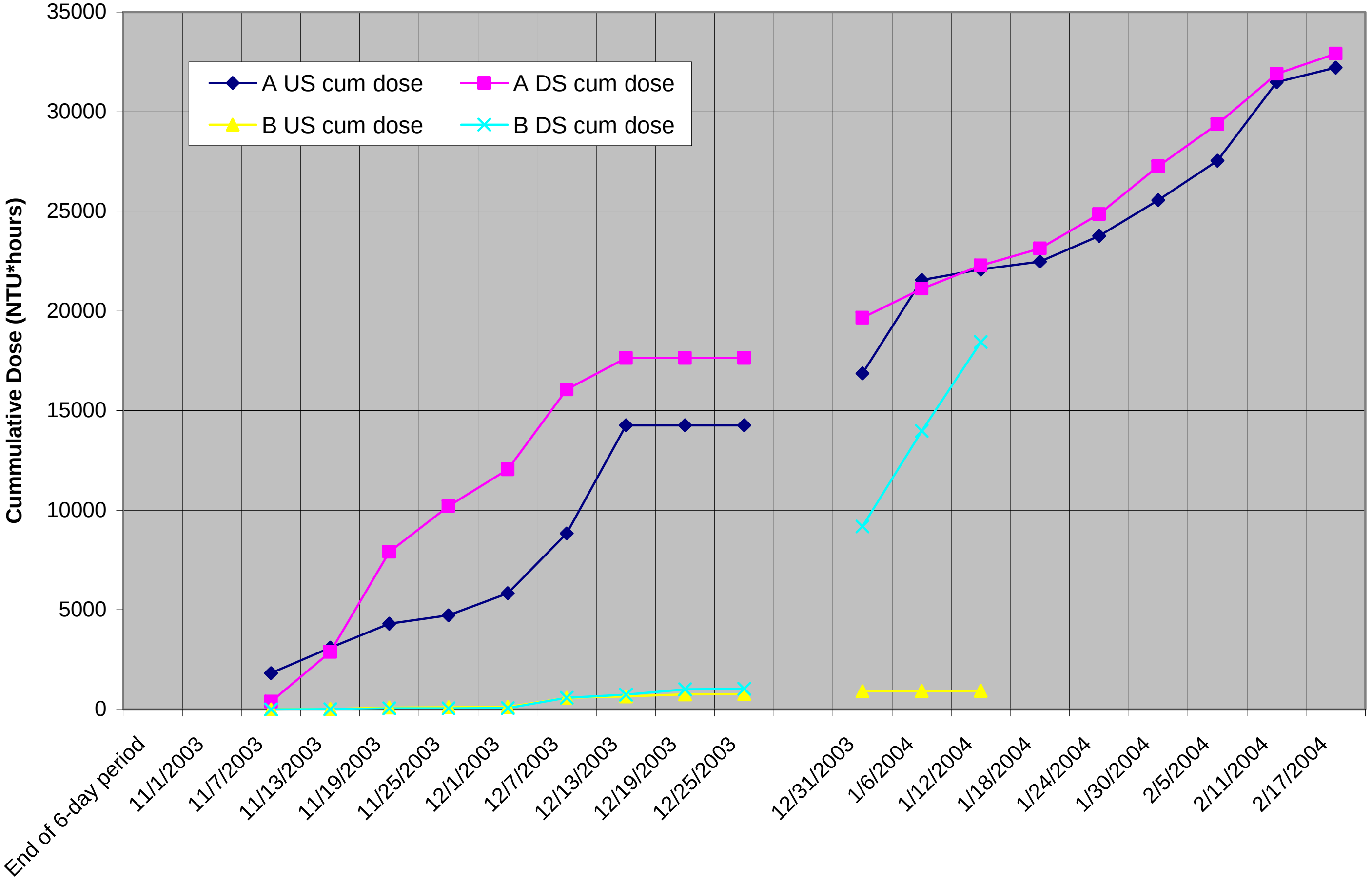


Figure 50. Cumulative turbidity exposures (dose = magnitude x duration) at the sensor locations on SF Mud Springs Creek.

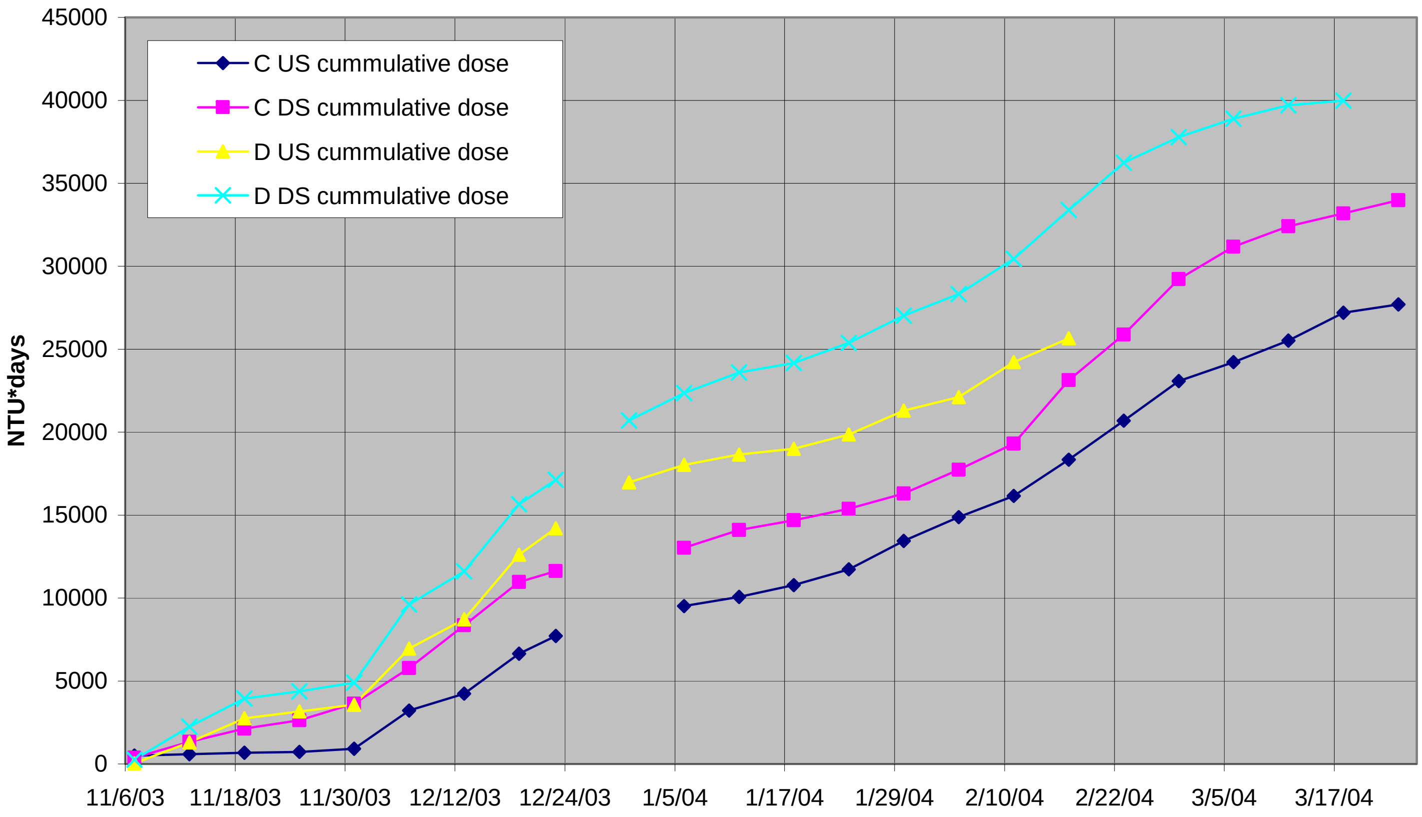


Figure 51. Cumulative turbidity exposure (dose = magnitude x duration) at the sensor locations on NF Mud Springs Creek. Monitoring Station C downstream under represents exposure due to repeated sensor fouling during storm events.

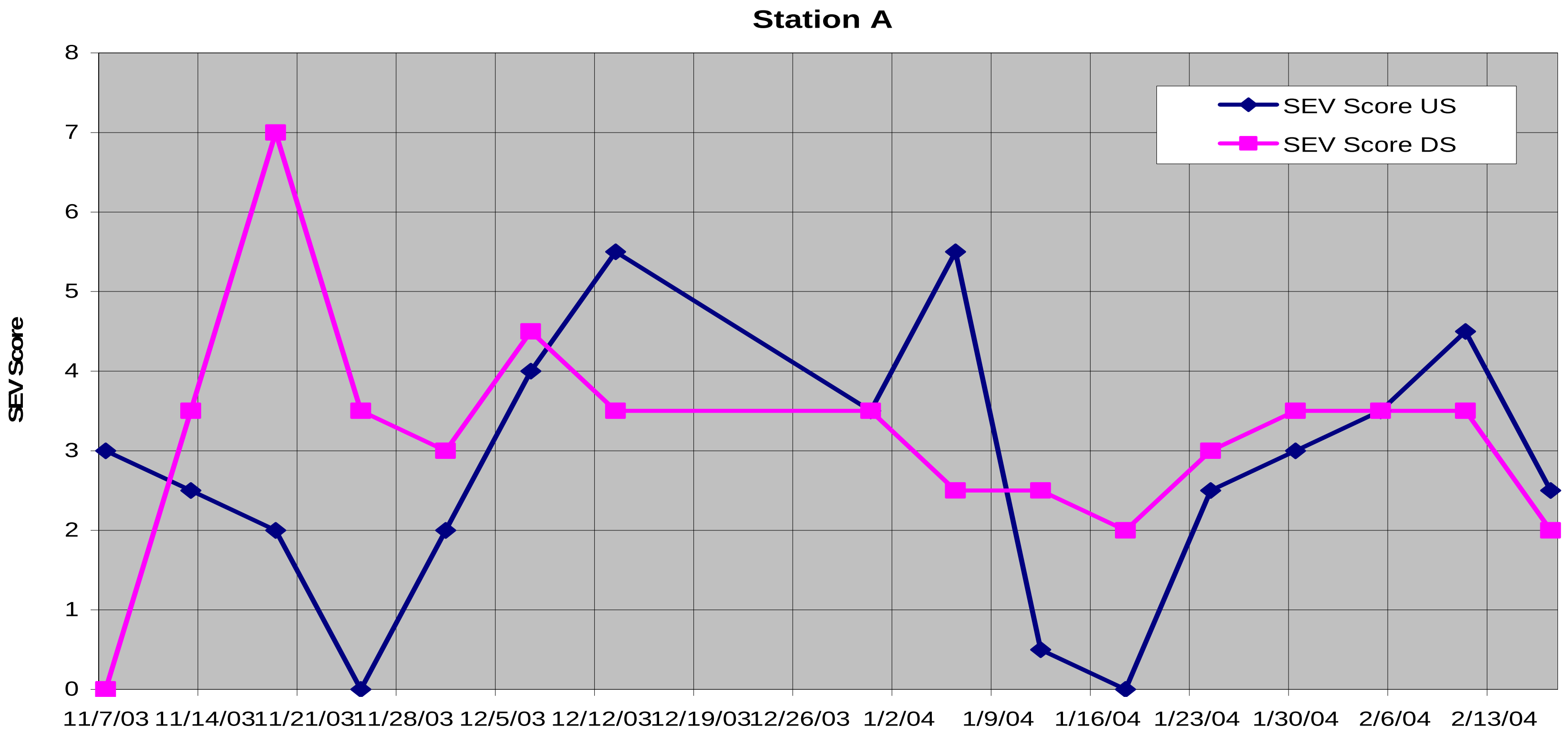


Figure 52. Time series plot of SEV scores predicted with the Newcombe (2003) model for reduced visual clarity for SF Mud Springs Creek monitoring Station A, upstream and downstream from tributary A1.

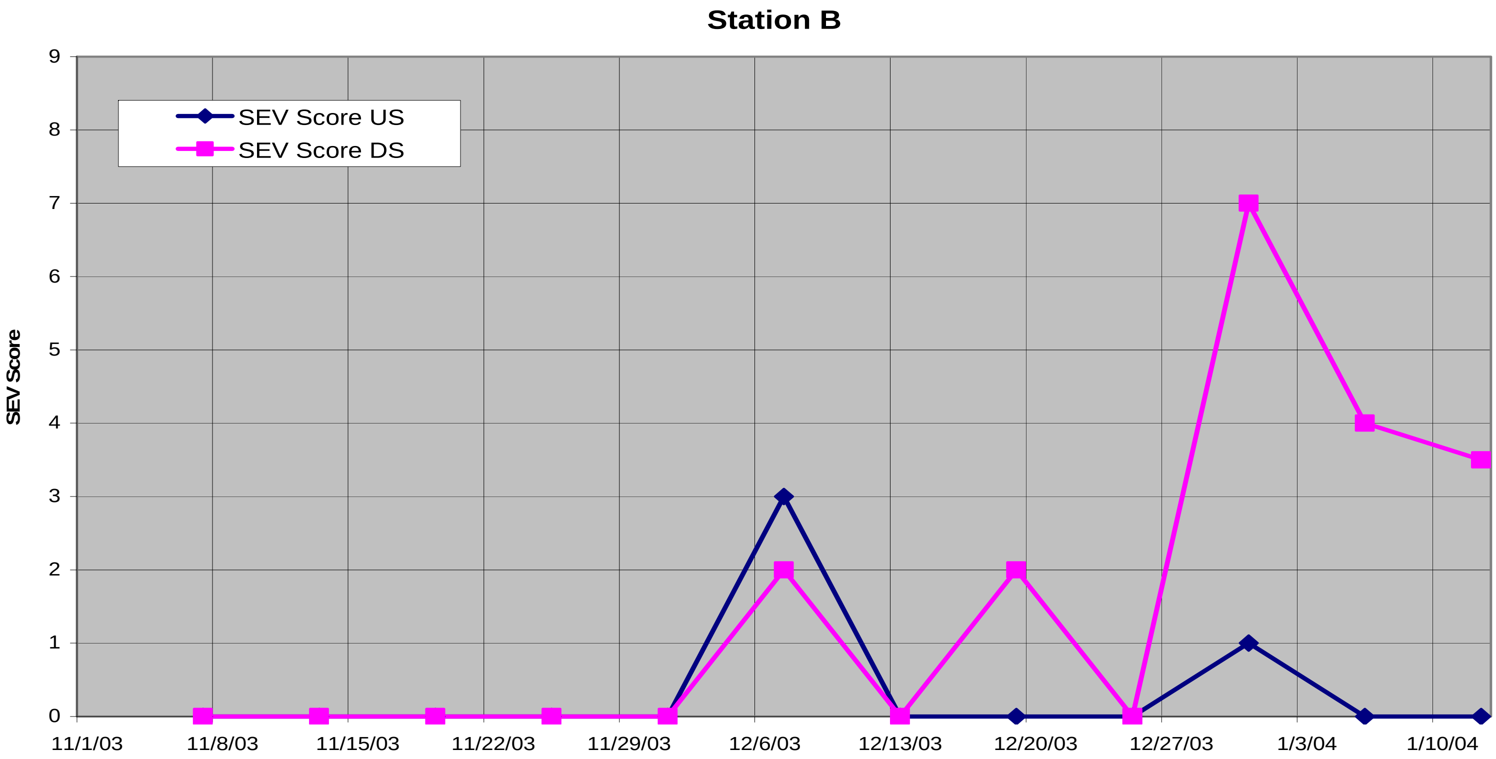


Figure 53. Time series plot of SEV scores predicted with the Newcombe (2003) model for reduced visual clarity for SF Mud Springs Creek monitoring Station B, upstream and downstream from tributary B1.

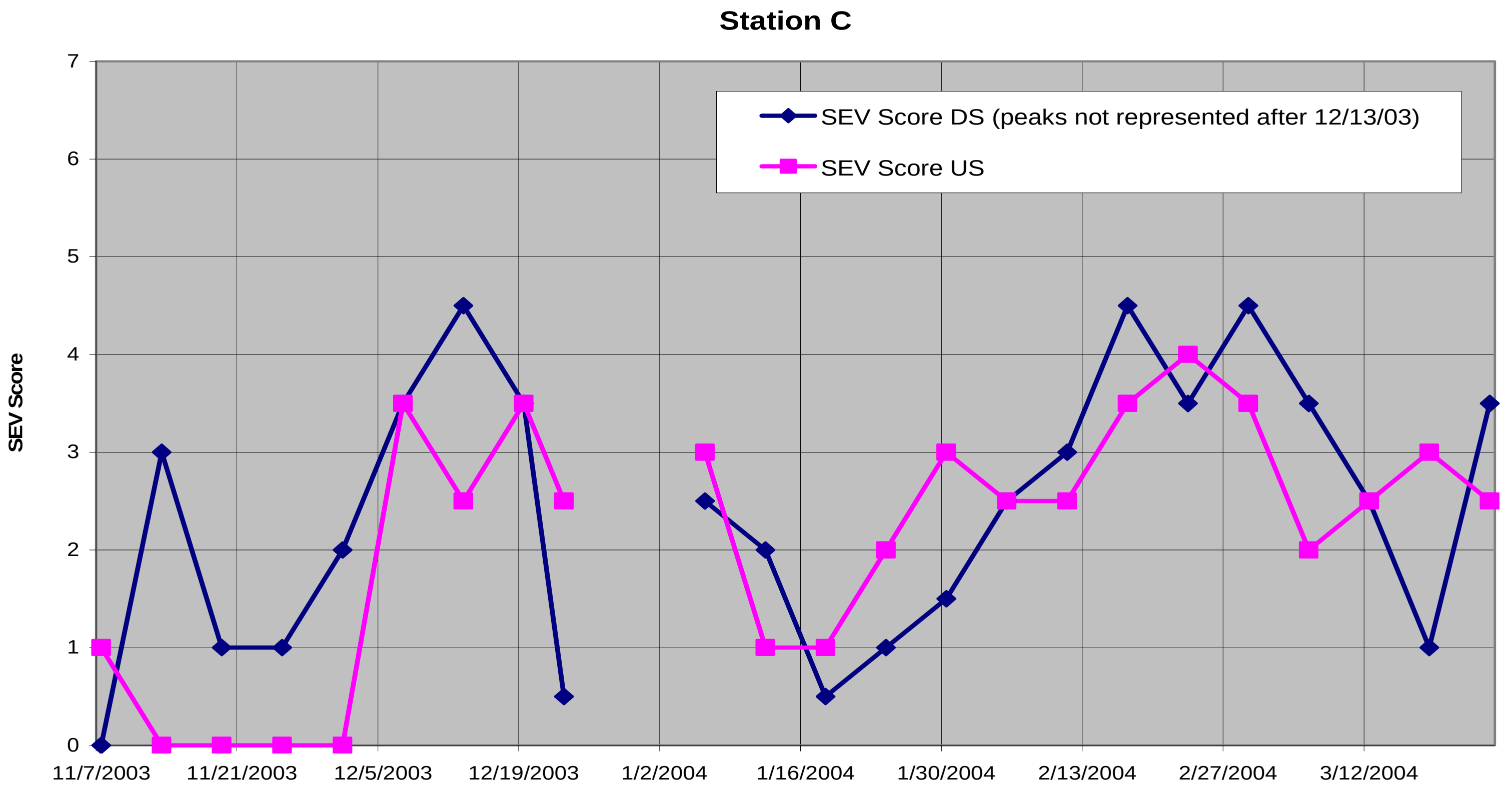


Figure 54. Time series plot of SEV scores predicted with the Newcombe (2003) model for reduced visual clarity for NF Mud Springs Creek monitoring Station C, upstream and downstream from tributary C4.

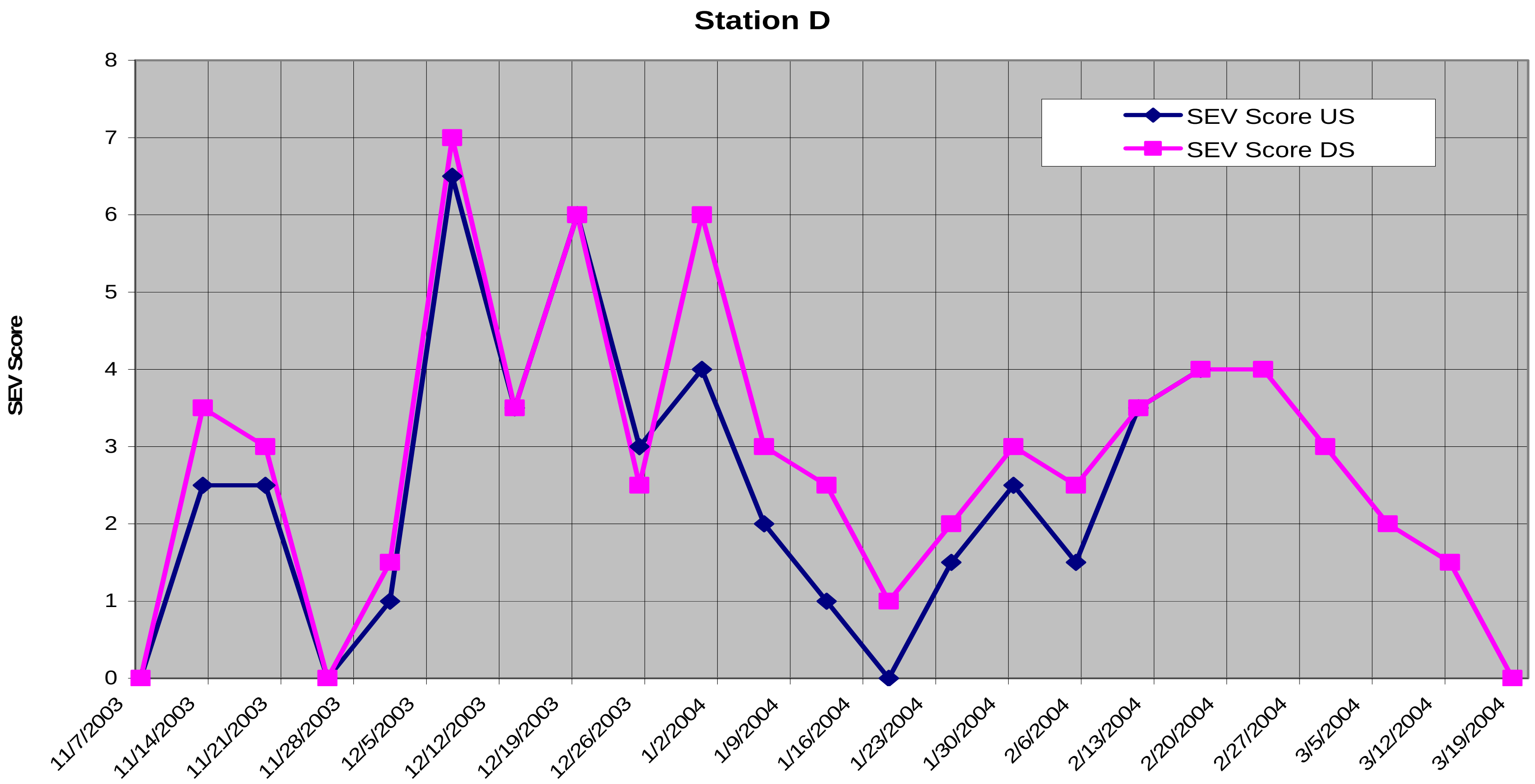


Figure 55. Time series plot of SEV scores predicted with the Newcombe (2003) model for reduced visual clarity for NF Mud Springs Creek monitoring Station D, upstream and downstream from tributary D1.

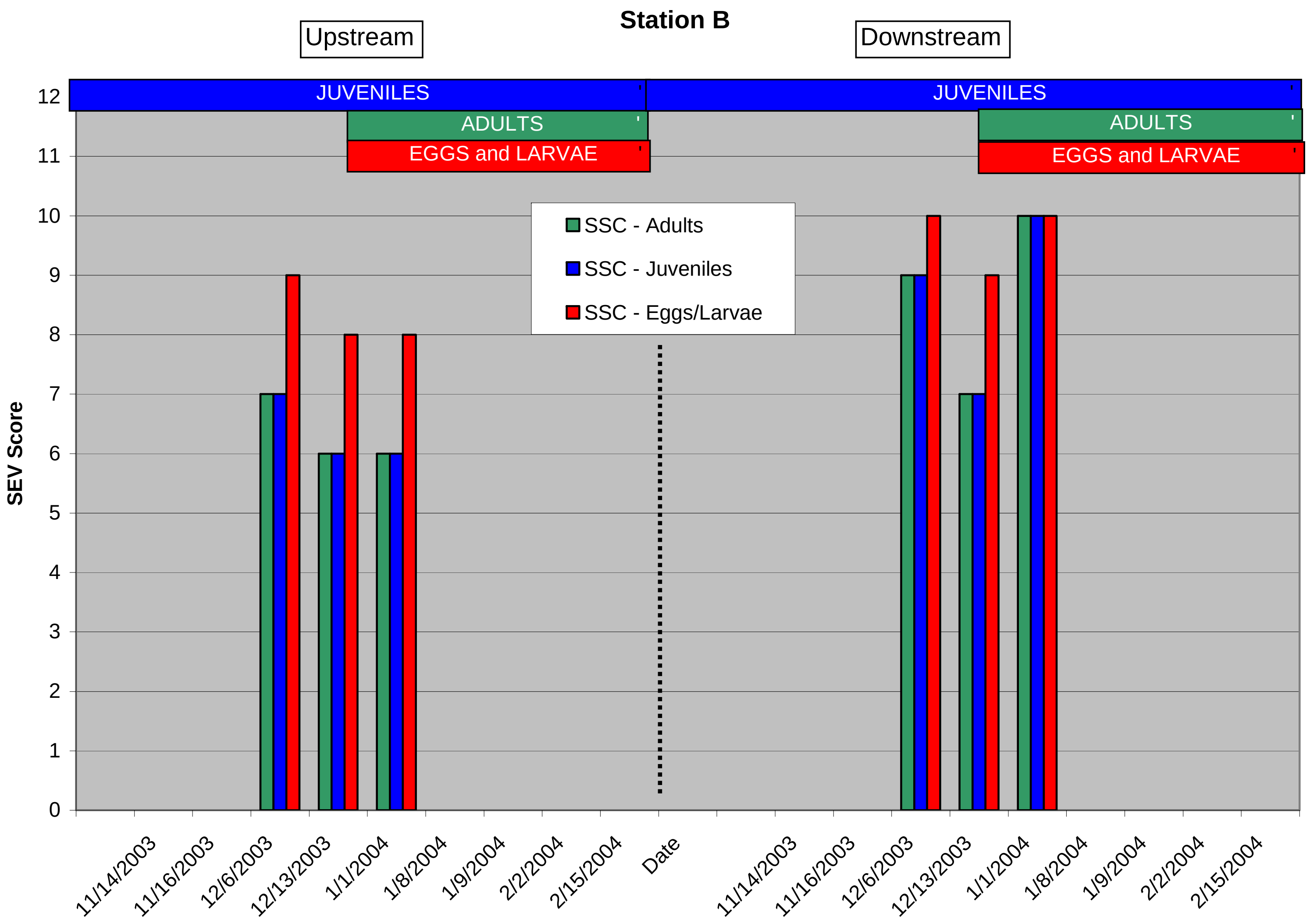


Figure 56. SEV scores (vertical bars) by life stage (horizontal bars) from the suspended sediment concentration models (Newcombe and Jensen 1996) for SF Mud Springs Creek at monitoring Station B. Upstream water quality conditions were sublethal for all recorded storms. The addition of tributary B1 created lethal conditions for 0-20% of all life stages present during the third recorded storm.

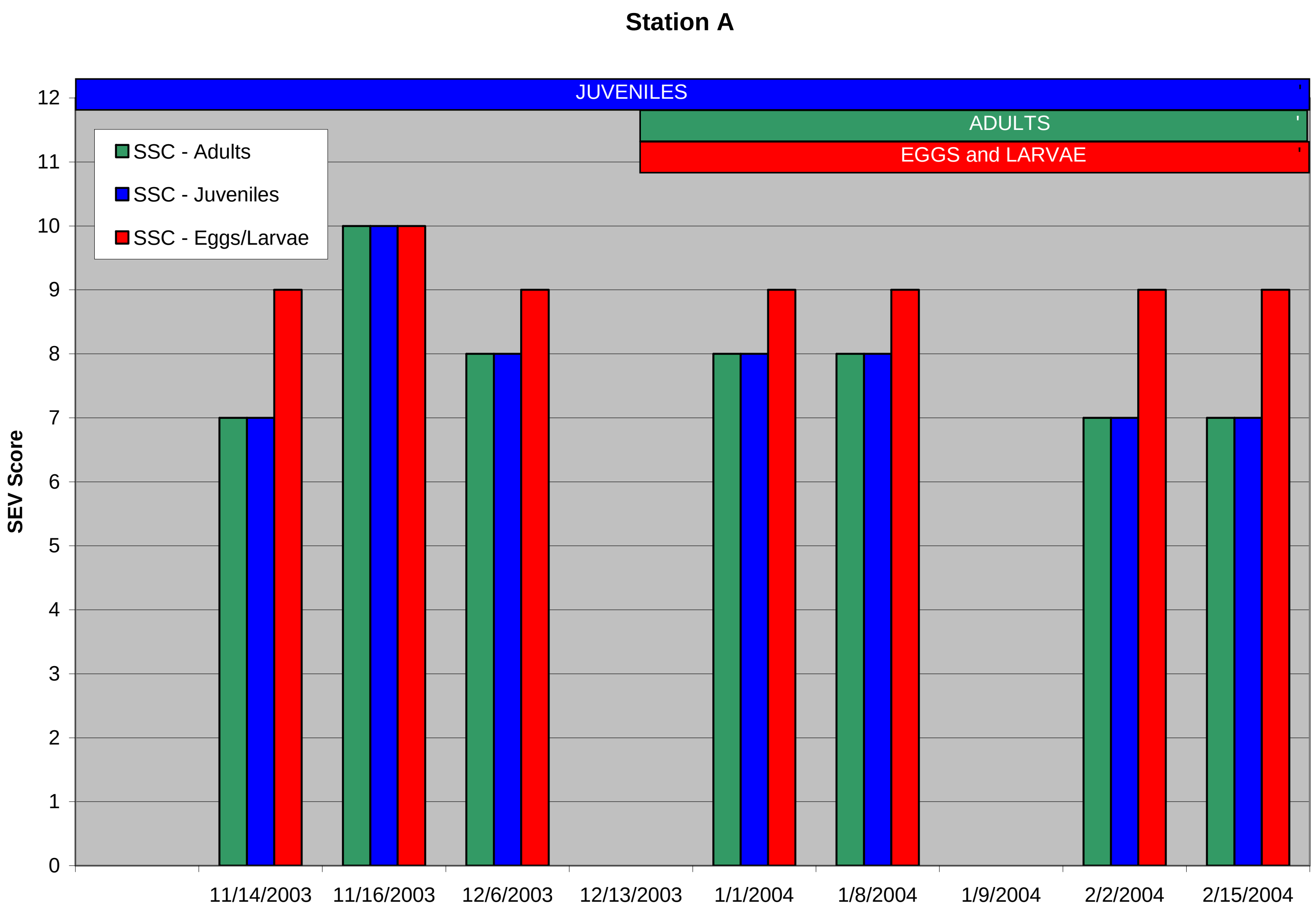


Figure 57. SEV scores (vertical bars) by life stage (horizontal bars) from the suspended sediment concentration models (Newcombe and Jensen 1996) for SF Mud Springs Creek at monitoring Station A. The water quality conditions were severely impaired beginning with the November 14, 2003 storm. Potentially lethal conditions (0-20% mortality) were experienced by juveniles on November 16, 2003. Severely impaired conditions existed for eggs and larvae during all subsequent recorded storms.

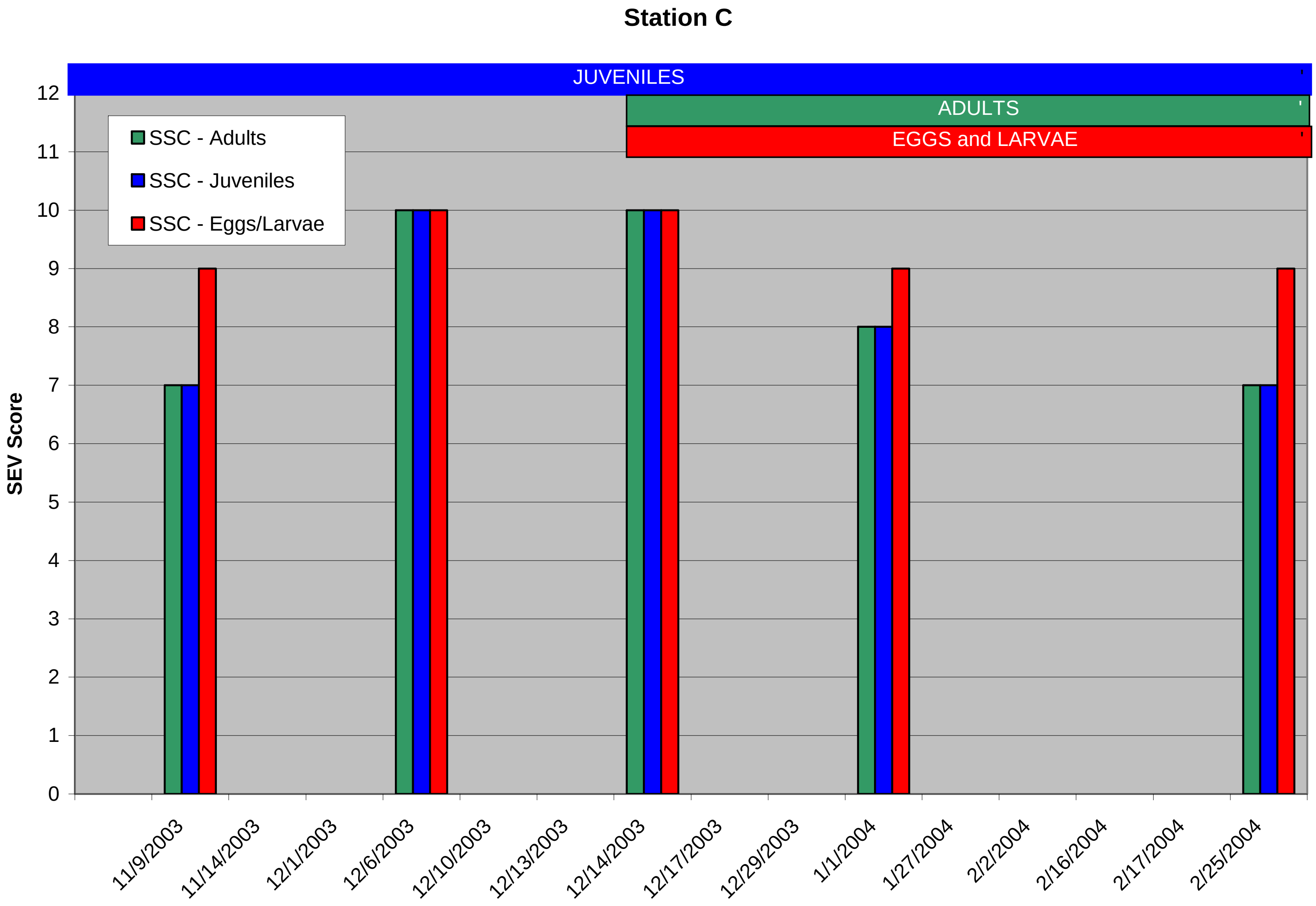


Figure 58. SEV scores (vertical bars) by life stage (horizontal bars) from the suspended sediment concentration models (Newcombe and Jensen 1996) for NF Mud Springs Creek monitoring Station C. Although equipment malfunctions downstream from tributary input C4 prevent discrimination of effects from that source, the main stream was potentially lethal (0-20%) to juveniles on December 6, 2003, and to all life stages on December 14, 2003. Subsequent storms would have severely impaired the survival of eggs and larvae.

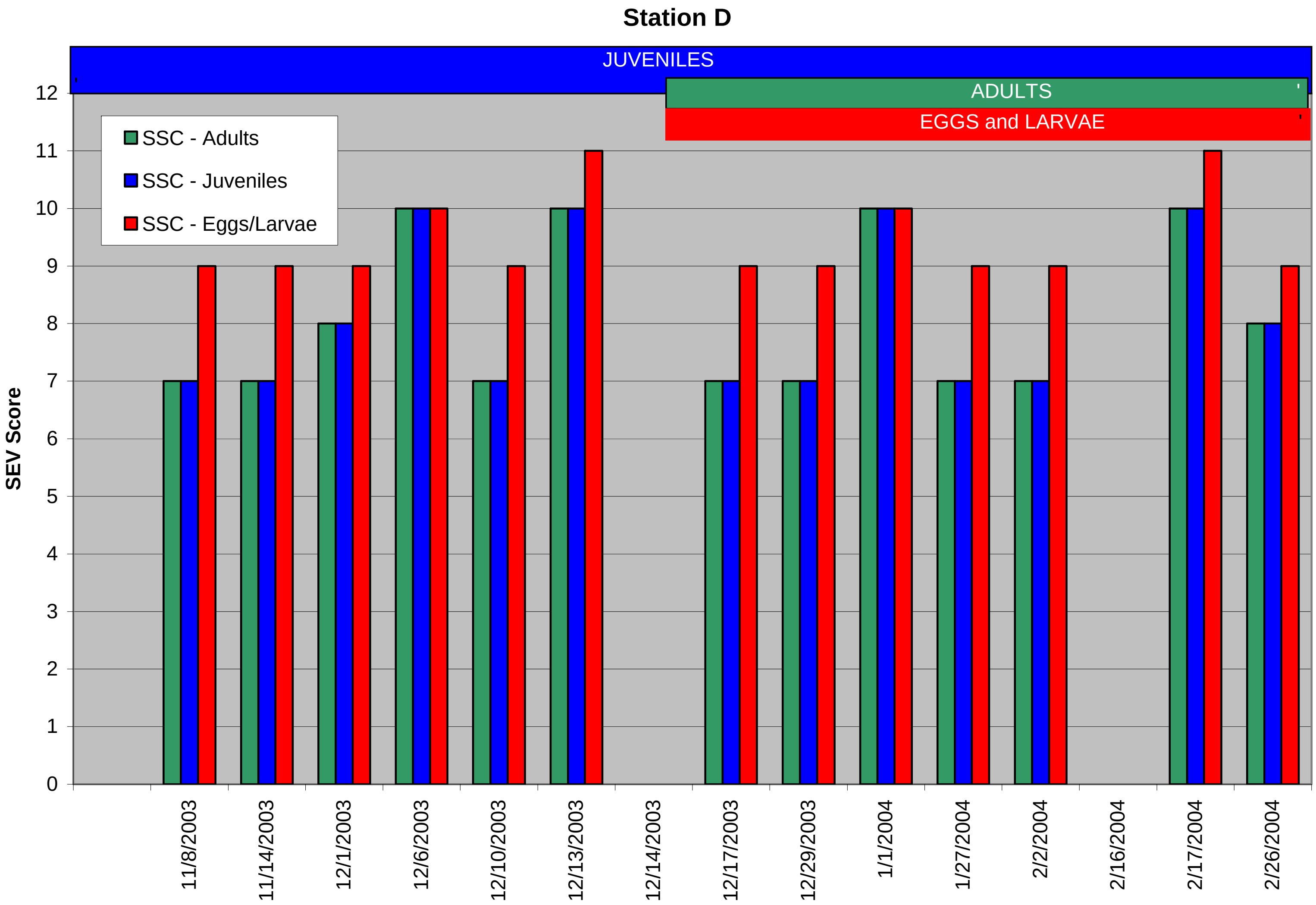
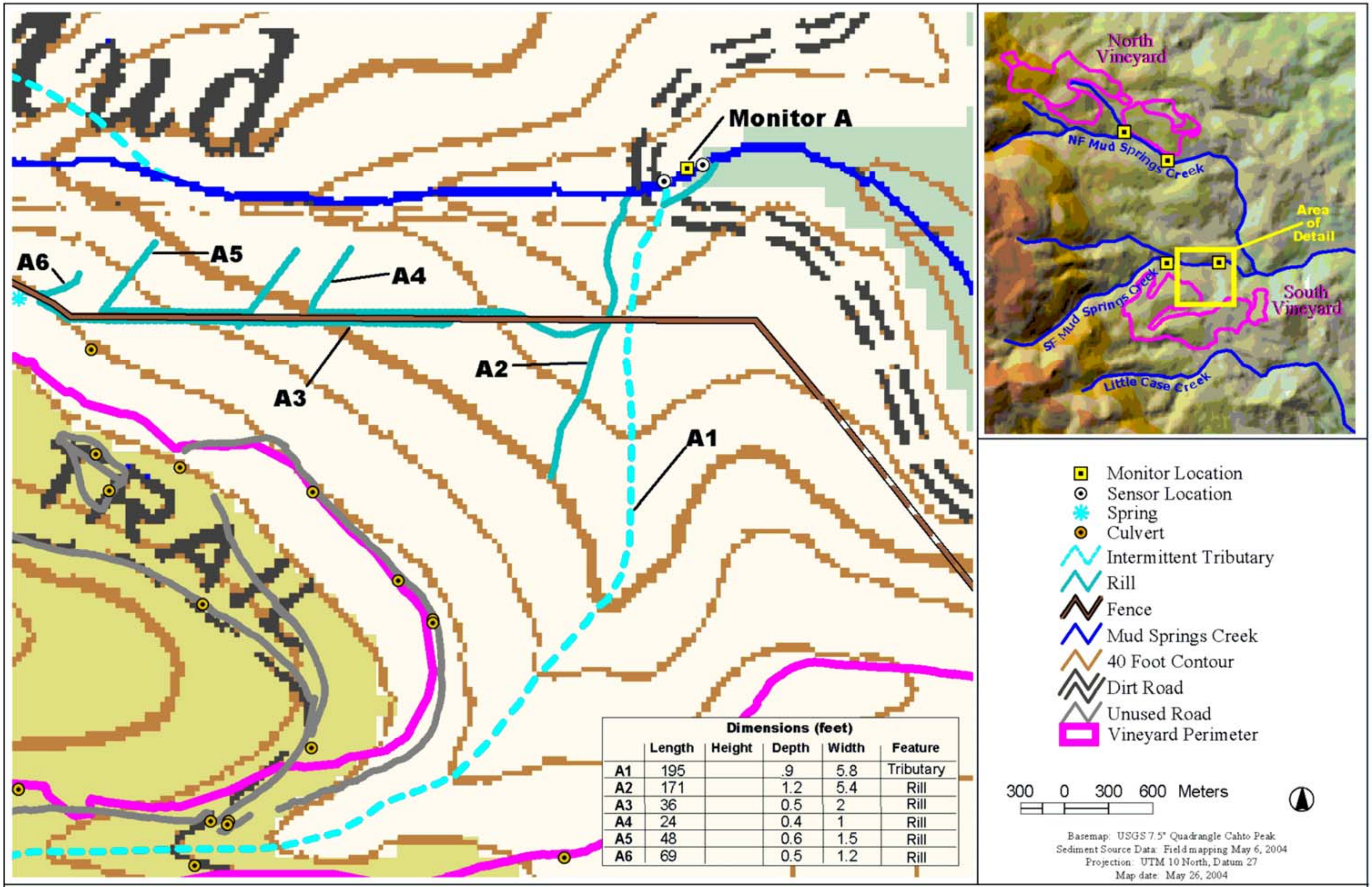


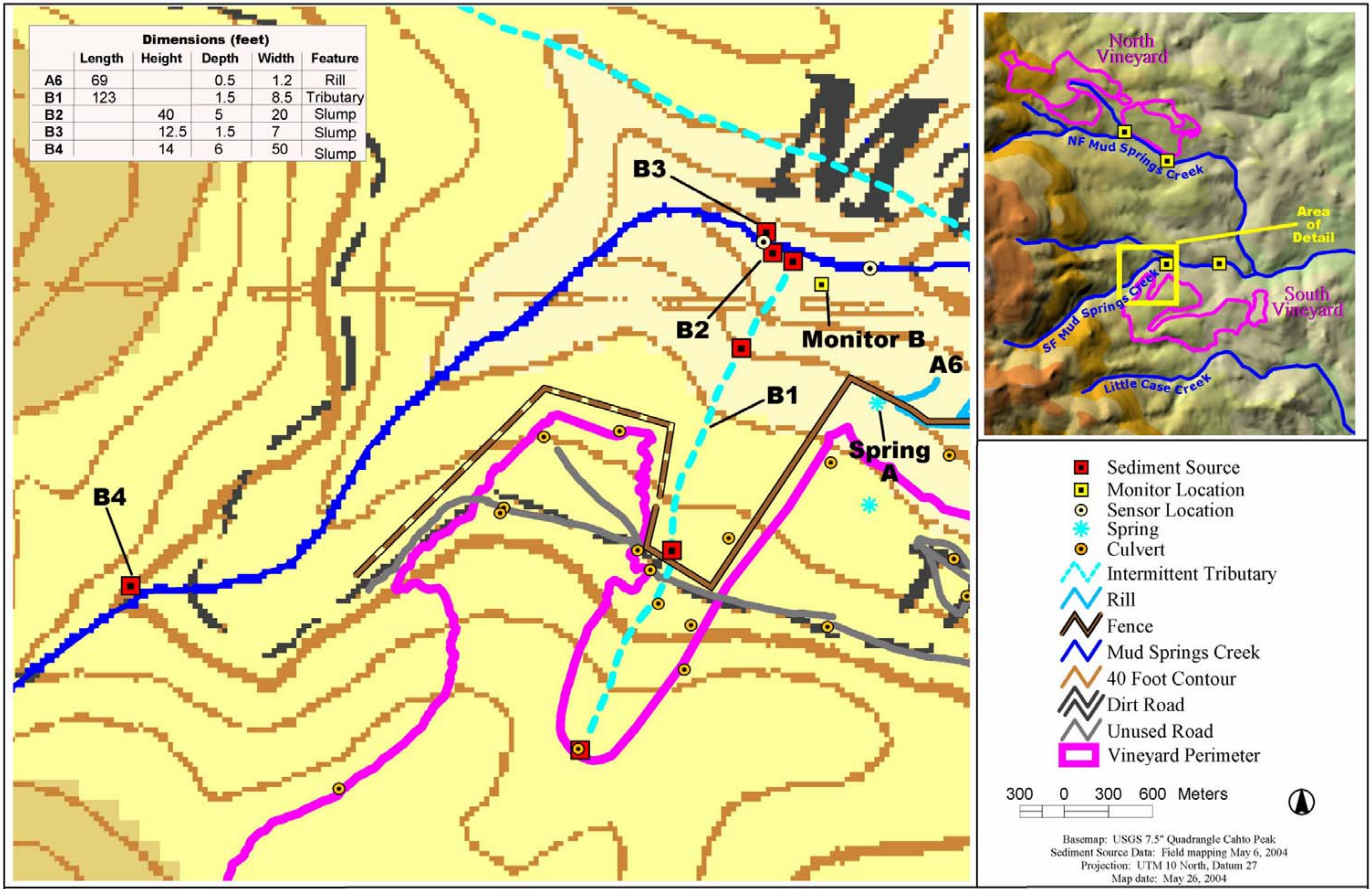
Figure 59. SEV scores (vertical bars) by life stage (horizontal bars) from the suspended sediment concentrations models (Newcombe and Jensen 2003) for NF Mud Springs Creek and monitoring Station D. Potentially lethal conditions for juveniles (0-20%) occurred on December 6, 2003. Additional lethal events for all life stages occurred on January 1, and February 17, 2004. Mortality ranging 20-40% is predicted for eggs and larvae present during the February 17, 2004 storm.



	Dimensions (feet)				
	Length	Height	Depth	Width	Feature
A1	195		.9	5.8	Tributary
A2	171		1.2	5.4	Rill
A3	36		0.5	2	Rill
A4	24		0.4	1	Rill
A5	48		0.6	1.5	Rill
A6	69		0.5	1.2	Rill

Basemap: USGS 7.5" Quadrangle Cahto Peak
Sediment Source Data: Fieldmapping May 6, 2004
Projection: UTM 10 North, Datum 27
Map date: May 26, 2004

Figure 19. Location of Sediment Sources in South Fork Mud Springs Creek, Alder Springs Ranch, Mendocino County, California.

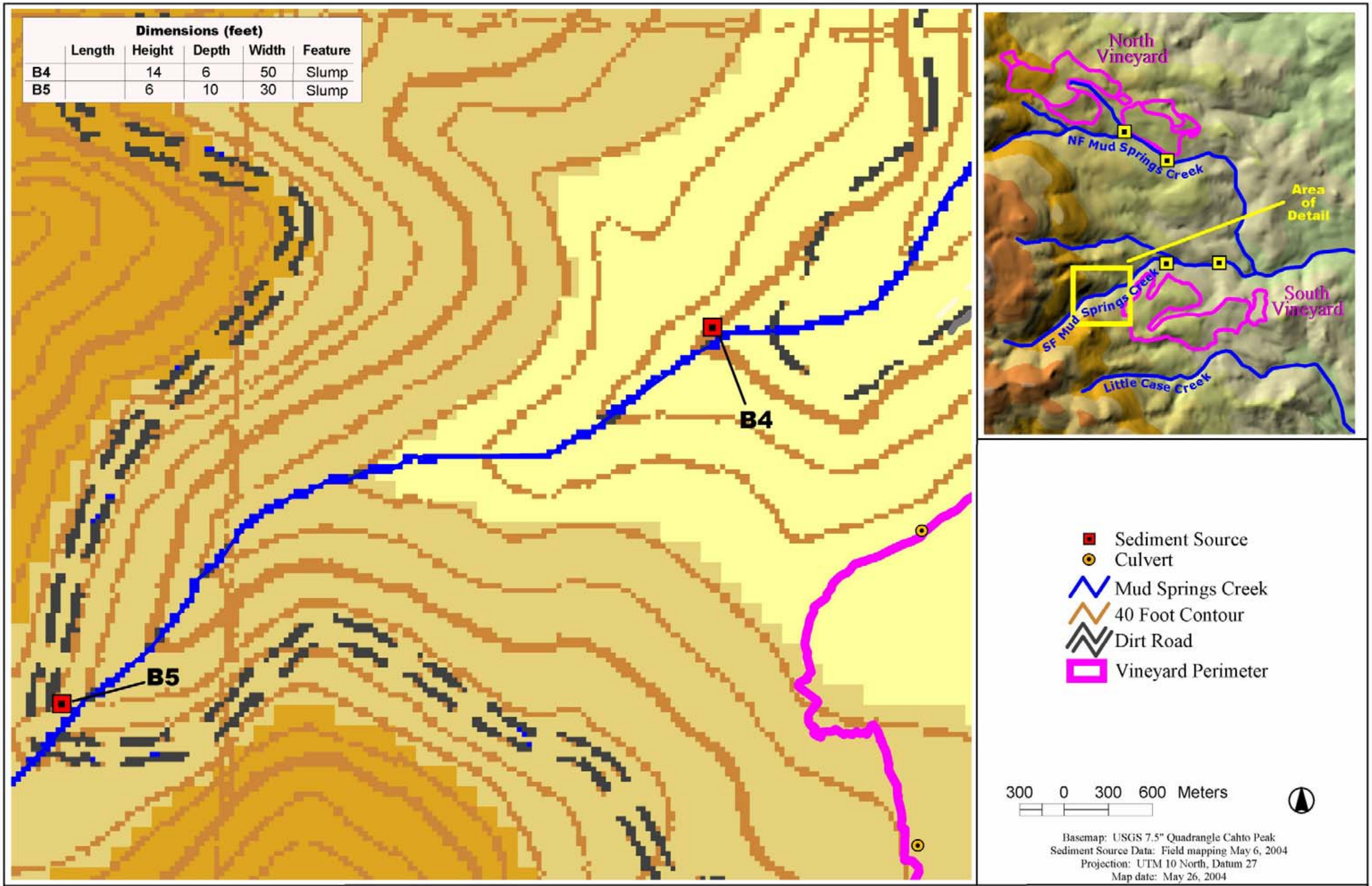


Dimensions (feet)

	Length	Height	Depth	Width	Feature
A6	69		0.5	1.2	Rill
B1	123		1.5	8.5	Tributary
B2		40	5	20	Slump
B3		12.5	1.5	7	Slump
B4		14	6	50	Slump

Basemap: USGS 7.5" Quadrangle Cahto Peak
Sediment Source Data: Field mapping May 6, 2004
Projection: UTM 10 North, Datum 27
Map date: May 26, 2004

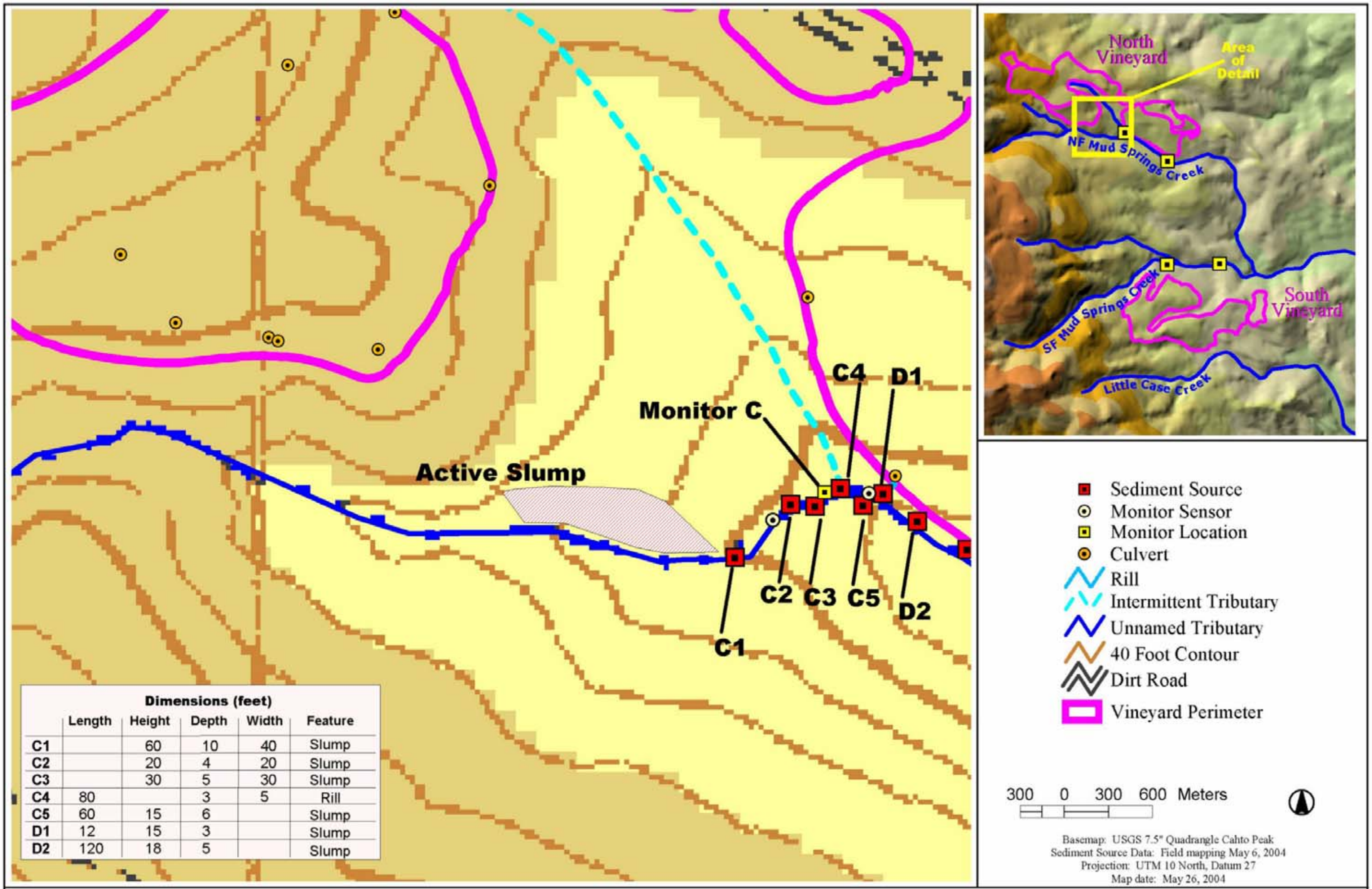
Figure 20. Location of Sediment Sources in South Fork Mud Springs Creek, Alder Springs Ranch, Mendocino County, California.



	Dimensions (feet)				
	Length	Height	Depth	Width	Feature
B4		14	6	50	Slump
B5		6	10	30	Slump

Basemap: USGS 7.5" Quadrangle Cahto Peak
Sediment Source Data: Field mapping May 6, 2004
Projection: UTM 10 North, Datum 27
Map date: May 26, 2004

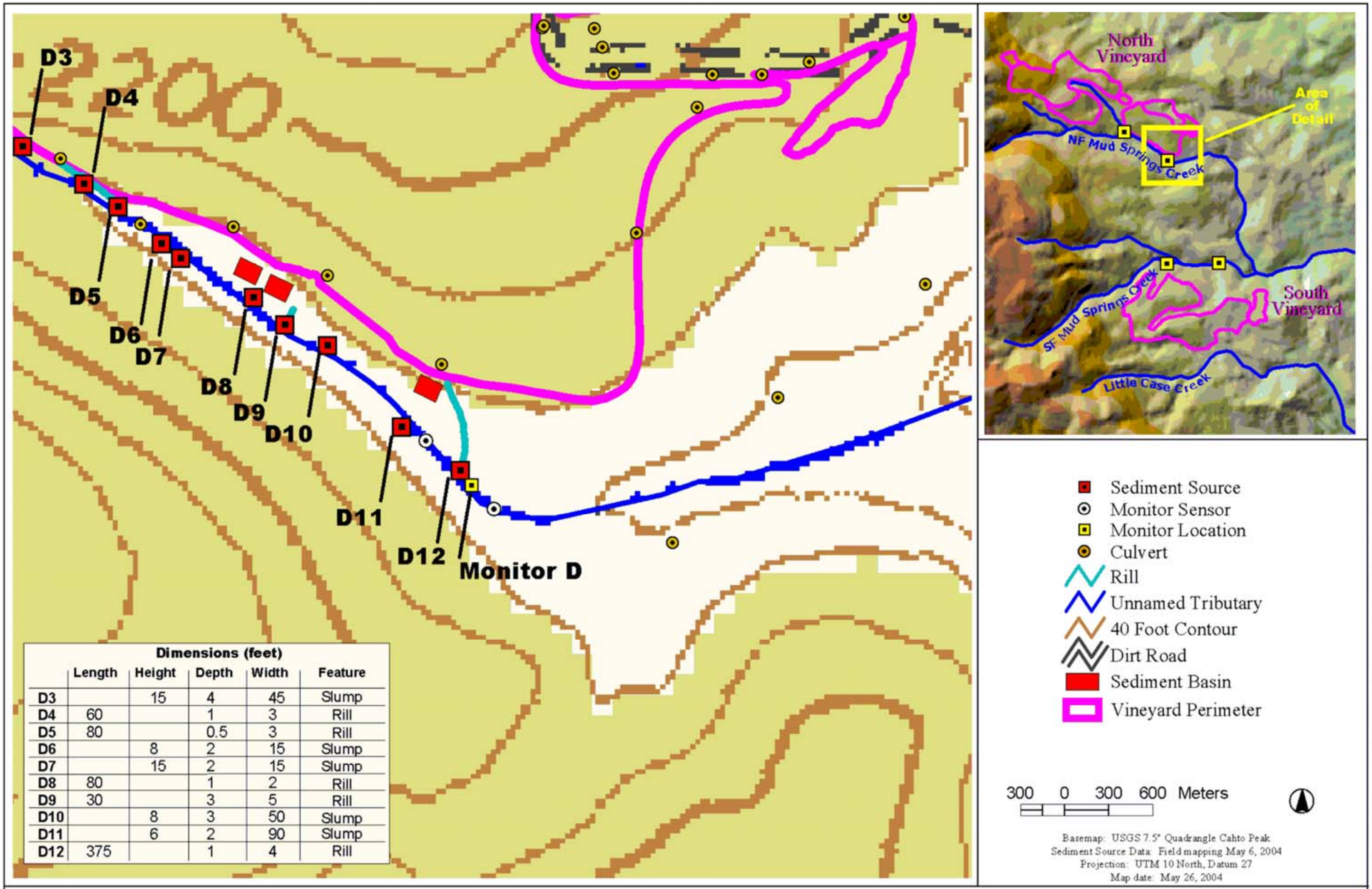
Figure 21. Location of Sediment Sources in South Fork Mud Springs Creek, Alder Springs Ranch, Mendocino County, California.



	Dimensions (feet)				
	Length	Height	Depth	Width	Feature
C1		60	10	40	Slump
C2		20	4	20	Slump
C3		30	5	30	Slump
C4	80		3	5	Rill
C5	60	15	6		Slump
D1	12	15	3		Slump
D2	120	18	5		Slump

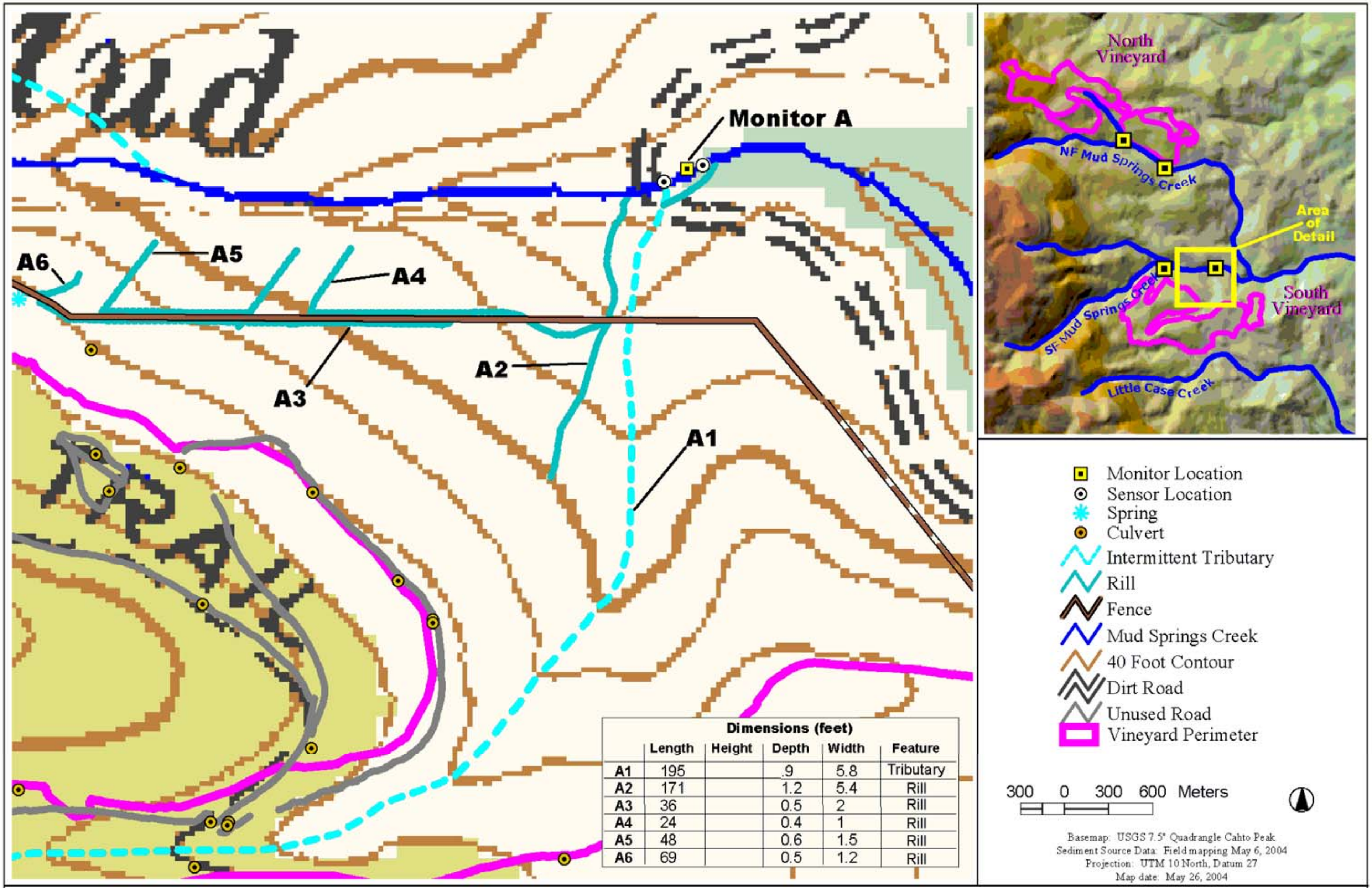
Basemap: USGS 7.5" Quadrangle Cahto Peak
Sediment Source Data: Field mapping May 6, 2004
Projection: UTM 10 North, Datum 27
Map date: May 26, 2004

Figure 22. Location of Sediment Sources in North Fork Mud Springs Creek, Alder Springs Ranch, Mendocino County, California.



	Dimensions (feet)				
	Length	Height	Depth	Width	Feature
D3		15	4	45	Slump
D4	60		1	3	Rill
D5	80		0.5	3	Rill
D6		8	2	15	Slump
D7		15	2	15	Slump
D8	80		1	2	Rill
D9	30		3	5	Rill
D10		8	3	50	Slump
D11		6	2	90	Slump
D12	375		1	4	Rill

Figure 23. Location of Sediment Sources in North Fork Mud Springs Creek, Alder Springs Ranch, Mendocino County, California.

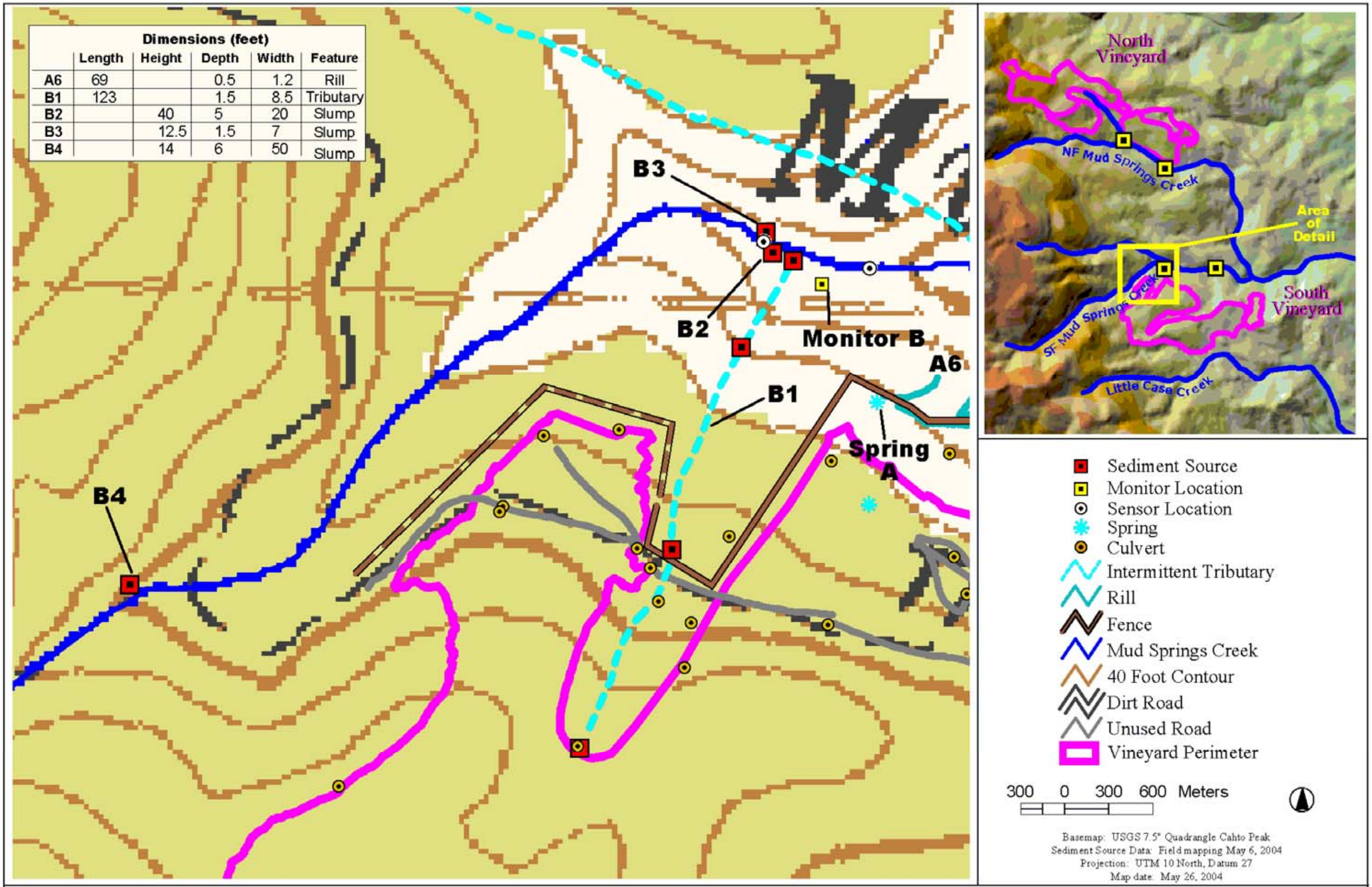


Dimensions (feet)

	Length	Height	Depth	Width	Feature
A1	195		.9	5.8	Tributary
A2	171		1.2	5.4	Rill
A3	36		0.5	2	Rill
A4	24		0.4	1	Rill
A5	48		0.6	1.5	Rill
A6	69		0.5	1.2	Rill

Basemap: USGS 7.5' Quadrangle Cahto Peak
Sediment Source Data: Field mapping May 6, 2004
Projection: UTM 10 North, Datum 27
Map date: May 26, 2004

Figure 20. Location of Sediment Sources in South Fork Mud Springs Creek, Alder Springs Ranch, Mendocino County, California.

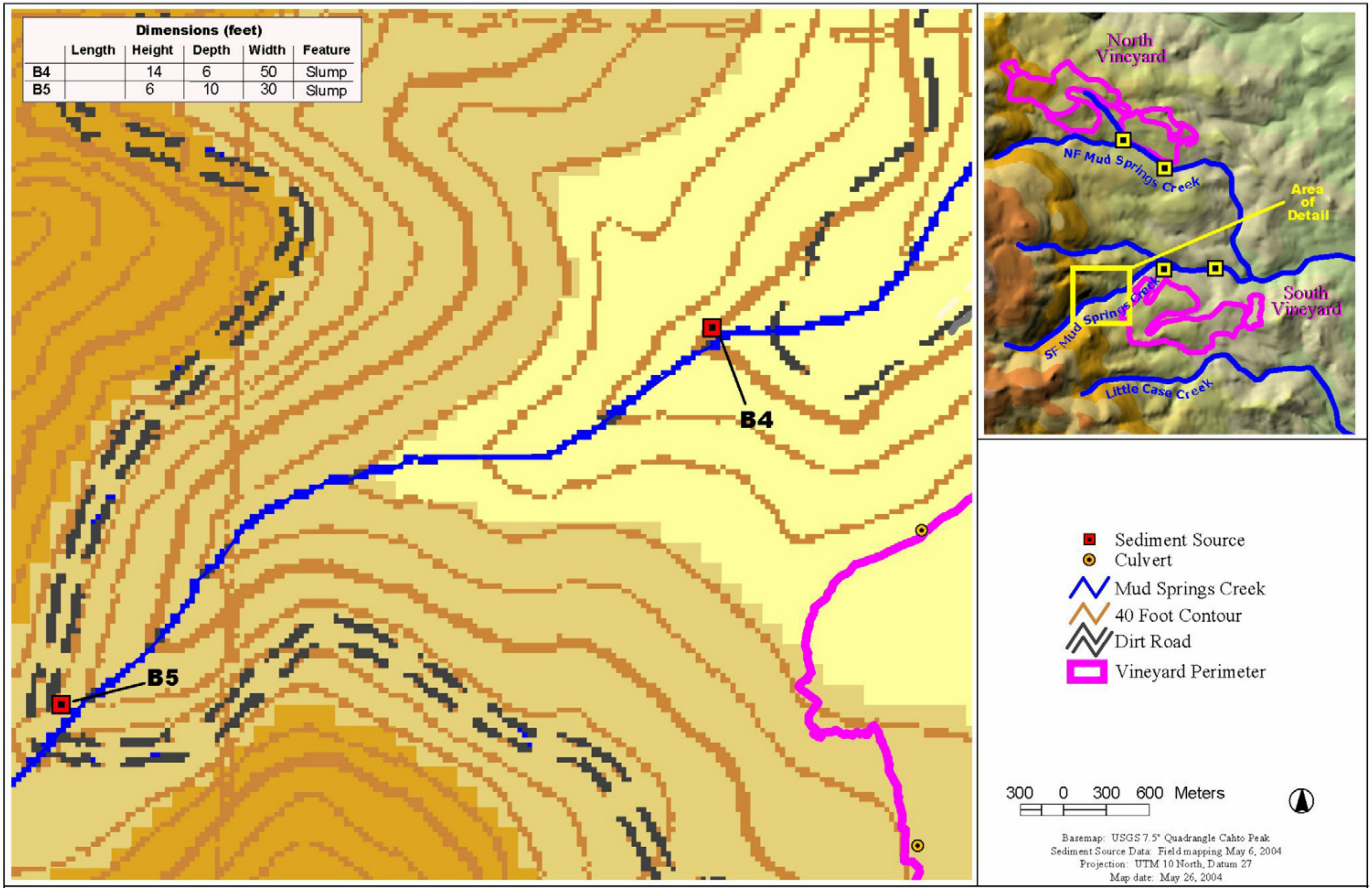


Dimensions (feet)

	Length	Height	Depth	Width	Feature
A6	69		0.5	1.2	Rill
B1	123		1.5	8.5	Tributary
B2		40	5	20	Slump
B3		12.5	1.5	7	Slump
B4		14	6	50	Slump

Basemap: USGS 7.5" Quadrangle Cahto Peak
Sediment Source Data: Field mapping May 6, 2004
Projection: UTM 10 North, Datum 27
Map date: May 26, 2004

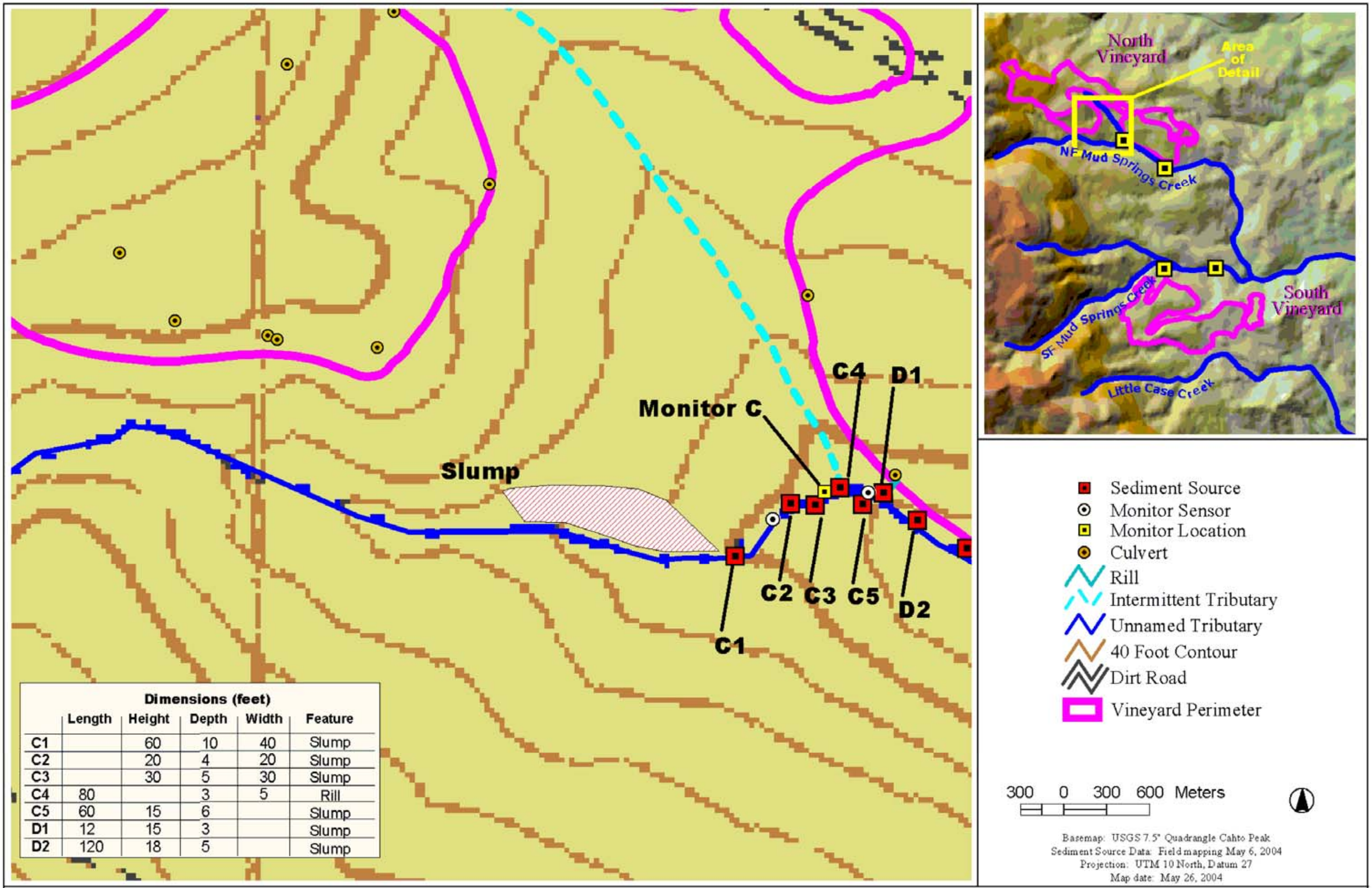
Figure 21. Location of Sediment Sources in South Fork Mud Springs Creek, Alder Springs Ranch, Mendocino County, California.



	Dimensions (feet)				
	Length	Height	Depth	Width	Feature
B4		14	6	50	Slump
B5		6	10	30	Slump

Basemap: USGS 7.5" Quadrangle Cahto Peak
Sediment Source Data: Field mapping May 6, 2004
Projection: UTM 10 North, Datum 27
Map date: May 26, 2004

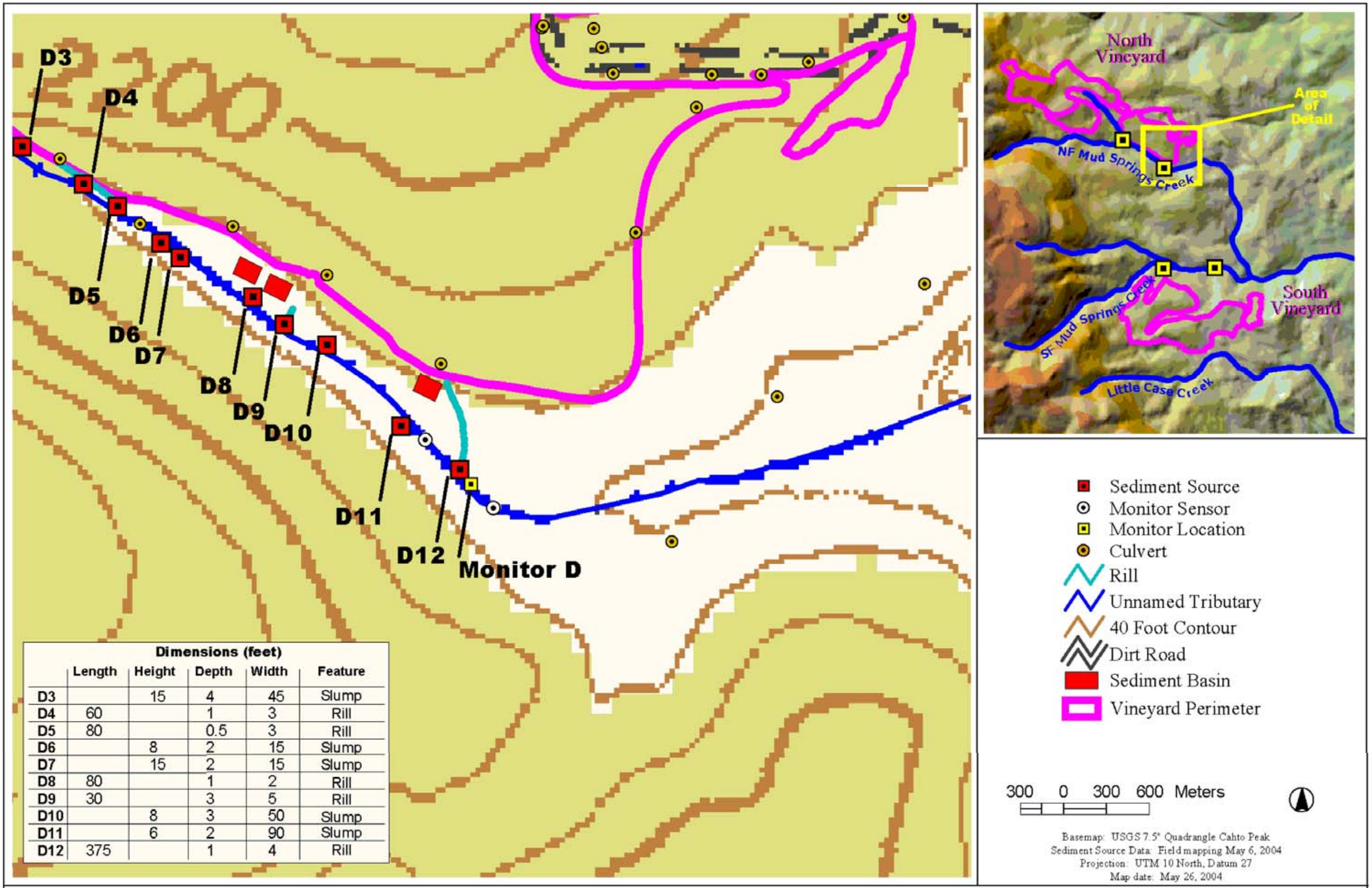
Figure 22. Location of Sediment Sources in South Fork Mud Springs Creek, Alder Springs Ranch, Mendocino County, California.



	Dimensions (feet)				
	Length	Height	Depth	Width	Feature
C1		60	10	40	Slump
C2		20	4	20	Slump
C3		30	5	30	Slump
C4	80		3	5	Rill
C5	60	15	6		Slump
D1	12	15	3		Slump
D2	120	18	5		Slump

Basemap: USGS 7.5" Quadrangle Cahto Peak
Sediment Source Data: Field mapping May 6, 2004
Projection: UTM 10 North, Datum 27
Map date: May 26, 2004

Figure 23. Location of Sediment Sources in North Fork Mud Springs Creek, Alder Springs Ranch, Mendocino County, California.



	Dimensions (feet)				
	Length	Height	Depth	Width	Feature
D3		15	4	45	Slump
D4	60		1	3	Rill
D5	80		0.5	3	Rill
D6		8	2	15	Slump
D7		15	2	15	Slump
D8	80		1	2	Rill
D9	30		3	5	Rill
D10		8	3	50	Slump
D11		6	2	90	Slump
D12	375		1	4	Rill

Basemap: USGS 7.5" Quadrangle Cahto Peak
Sediment Source Data: Field mapping May 6, 2004
Projection: UTM 10 North, Datum 27
Map date: May 26, 2004

Figure 24. Location of Sediment Sources in North Fork Mud Springs Creek, Alder Springs Ranch, Mendocino County, California.