SEDIMENT SOURCES AND FLUVIAL GEOMORPHIC PROCESSES OF LOWER NOVATO CREEK WATERSHED

Report to
Marin County Flood Control and Water Conservation District

by

Laurel Collins
2338 Valley St
Berkeley, CA 94702
~~(510) 549-1209~~
home 510-524-8204
office 510, 231-9416
laurel@sfei.org

JULY 1998

SEDIMENT SOURCES AND FLUVIAL GEOMORPHIC PROCESSES OF LOWER NOVATO CREEK WATERSHED

Report to
Marin County Flood Control and Water Conservation District

by

Laurel Collins
2338 Valley St
Berkeley, CA 94702
(510) 549-1209

JULY 1998

TABLE OF CONTENTS

ACKNOWLEDGMENTS
I thank Liz Lewis for her commitment to the collection of field data, Dale Hopkins, Joanna Charlton, and John Neville for their field assistance and Josh Collins for his technical review.

EXECUTIVE SUMMARY

This is a report of a field and office study of sediment sources and geomorphic changes within the lower Novato Creek drainage network. The field work was restricted to the main stem channel and selected tributaries downstream of Stafford Dam. The Marin County Flood Control and Water Conservation District (the District) requested this study to explore ways to reduce dredging needs but preserve flow capacity in the Phase 1-4 segments of the Novato Flood Control Project (NFCP or the Project). The report includes analysis of historical conditions uncovered through library searches and field work, and analysis of existing conditions based upon detailed maps of channel terraces, bed and banks, coring of past sedimentary deposits, dating of channel changes by rephotography and tree ring analysis. The results are referenced to study reaches that are delineated by bridges and confluences for easy recognition on existing maps and photographs, and for future investigations.

This report is consistent with the fundamental concepts of river and stream science. It is assumed that the usual or average physical form of the stream depends upon the average supplies of water and sediment that enter the stream from its watershed. Extreme events such as drought and deluge can cause significant changes in the location and configuration of a channel, but over time the average form of the channel will be re-established. There are many complicating details, but in essence the channel bed will erode if there is a general decrease in sediment supply or an increase in water supply. Vertical erosion of the channel bed results in lateral erosion of the banks of the channel, and perhaps erosion of the terraces, which are above the active banks. Vertical erosion is also called channel degradation, downcutting, or incision. Vertical erosion cannot happen unless the sediment can be transported downstream. A channel becomes entrenched when it holds flood flows that are twice the height of bankfull flow. The transport capacity of the channel is a function of its slope and discharge. Channel slope, width, depth, sediment transport capacity, and the volume of water flowing through the channel are interrelated. Change one of these parameters and the others will change in predictable ways. The predictable nature of these relationships provides a basis for watershed analysis.

This study was not designed to provide any engineering specifics. The study has produced a general analysis of watershed conditions that can lead to more specific, quantitative analysis of land use changes or new engineering to solve local problems with water and sediment supplies.

During the last 165 years, or since the local advent of modern land uses, the Novato Creek watershed has experienced a major shift in dominant sediment

supply from landsliding on the hillsides to bank and terrace erosion of the channel network. This shift in the source of sediment has caused increases in both sediment and water supply. The increase in water supply is due to local increases in surface water runoff, rather than groundwater or water imports from another watershed. The increase in runoff has been caused by a combination of intensive grazing and urbanization, both of which have significantly decreased infiltration and the water holding capacity of the watershed. The increase in sediment supply is due to the channel adjusting to the increased runoff.

The result is ongoing entrenchment or down-cutting of the channel network and bank erosion throughout the upper reaches of the channel network and into much of the lowland valleys. This erosion will continue until the channels are wide enough to enable the formation of a stable, vegetated floodplain between the terrace banks. The patterns of upstream down-cutting and downstream in-filling are predictable responses by the channel system to alterations in water supplies.

Two episodes of accelerated erosion can be discerned from the distribution and ages of overstory trees along Novato Creek. The first period appears to have started during the 1830's, when the watershed began to support intensive grazing and agriculture. The second episode, which continues today, appears to have begun during the 1950's, and probably relates to the function of Stafford Dam as a sediment trap for the upper 8.4 sq mi. of the watershed, and to the urbanization of the lowland valleys. These two time periods accelerated erosion rates during the last 200 years.

The primary source of sediment for Novato Creek is local bank and terrace erosion. Part of the sediment supply moves in and out of temporary storage on point bars, lateral bars, and behind debris jams within the channel bed. The upper reaches of the channel network have the capacity to transport the sediment supply downstream to the flood control project. Much of the sediment that reaches the project tends to be stored there. The flood control channel causes the water surface slope to flatten, and hence there is a loss of sediment transport capacity. The NFCP is essentially a trap for sediment derived from upstream bank and terrace erosion. The supply of sediment reaching the NFCP from landsliding, dry ravelling, surface erosion, and the tides is probably orders of magnitude less than the supply of sediment from the channel banks, bed, and terraces.

Sedimentation within the tidal reach of Novato Creek is encouraged by the railroad crossing and tidal marsh reclamation. The railroad crossing is a bottleneck. The cross-sectional area of the channel at the railroad crossing is much less than required for downstream transport of sediment reaching the flood control project. Historical reclamation of the tidal marshlands has caused a significant loss of tidal flows to and from the tidal reaches of the creek. The channel has narrowed and aggraded in response to the decrease in tidal flows. The entire length of Novato Creek downstream of the railroad crossing is less than one half its historical width and depth.

Rapid sedimentation within the flood control channel will continue given the present scenario of increased runoff throughout the valleys and headward reaches of the watershed, chronic channel entrenchment above the tidal reach, an undersized railroad crossing, large-scale tidal marsh reclamation, and an excessively wide flood control channel. Modern land uses have increased the sediment supply from the upper parts of the watershed, and decreased downstream sediment transport capacity, especially within the reaches of the tides. This has increased the flooding hazards on the reclaimed and urbanized tidal marshlands, and decreased the efficacy of the flood control project. Simply stated, an upstream problem of channel degradation has become a downstream problem of channel aggradation.

Overall rehabilitation of the watershed would begin with reduction of runoff from urbanization and grazing, raising the railroad crossing, and large-scale restoration of tidal marshlands. This would begin the restoration of ecological resources along the creek while decreasing flood hazards. It is not clear from this study what amount of urban setbacks would be required to enable the channel to achieve a stable configuration between its terrace banks. It is clear that without such an approach there will be an ongoing need to repeatedly build and repair erosion control structures for most of the banks and channel bed of Novato Creek. In the absence of watershed restoration, the flood control project will not be able to carry its design capacity discharge without frequent and regular dredging.

If an objective of the District is to reduce the frequency of dredging in the tidal reaches of Novato Creek, then the NFCP above the tidal zone should be redesigned and managed as a sediment catchment basin.

Principle objectives and related study results

Determine the location of sediment sources.

The locations of major sediment sources are pervasive terrace and channel bank erosion throughout the channel network from largest to smallest stream order.

Determine the processes by which sediment is being produced and supplied to the stream system.

The major process by which sediment is being produced and supplied to the stream system is from fluvial erosion of the channel bed and banks from flows that are equal to or above bankfull and that have increased in frequency during the last century and a half.

Determine change through time and space of sediment sources and landscape processes.

Change through time and space of sediment sources and landscape processes is indicated by a shift of the most active sites of erosion from hillsides to the channel network, and from the valley bottom channels to the headwater channels. The large high-order channels along the valley bottoms may have passed through their peak rates of incision and are now aggrading in some restricted areas. Bank erosion, on the other hand, will likely continue until the channels are wide enough to form a new floodplain within the entrenched channels. The large high-order channels, if left entirely to natural processes, will likely become stable sooner than the headward, small order reaches, which began to degrade later.

Determine, if possible, the extent to which the drainage density has changed.

There have been large and sudden historical changes in drainage density. The early construction of irrigation and drainage ditches increased drainage density in the valleys, whereas the reclamation of tidal marshland decreased drainage density within the tidal reaches of the watershed. Since the advent of irrigation, there has been a further increase in drainage density above the tidal reaches due to gullying in the headward rangelands and the addition of storm drains in the urbanized lowland valleys. Drainage density has also been increased by the incision of alluvial fans that once separated the tributary channels from the main stem channels.

Identify reaches for intensive monitoring of future changes in channel profile and geometry.

Study reaches have been established through this study. These study reaches should be considered for an ongoing program of locally intensive empirical observations of the sources and disposition of sediment and water supplies within the watershed. There should be developed a system of repeated observations among these study reaches that would enable a fluvial geomorphologist to recognize changes in the relative importance of natural processes and land use on sediment and water supplies. Some of the details of the required measurements may be provided by this report.

The purpose of an ongoing monitoring program should be to understand interrelations among upstream and downstream events and processes. For example, there needs to be an operational understanding of the feed-back mechanisms between upstream land use or climate change, downstream grade change, flooding, dredging and upstream riparian habitat loss.

Discuss observations about the relative abundance of tidal versus terrigenous sediments within the NFCP from Diablo Ave to the NWPRR Bridge.

The abundance of fine silt and clay-sized sediment versus sand and larger-sized sediment increases towards the marsh. The sand and larger-sized sediment is certainly derived from terrigenous sources, but it is unclear how much of the fine-sized sediment is derived from the tides. Additionally, fines from the uplands can be reworked by incoming tides. Sand and larger-sized terrigenous sediments comprised more than 50% of the sediment volume for the upper 2/3 of the NFCP in 1997. The amount of clay-sized sediment from the uplands may represent anywhere from another 10-40%. Following the 1998 winter, it is likely that the percentage of sand and large-sized terrigenous sediment was substantially greater than 50% of the total sediment from Diablo Ave. to the NWPRR Bridge.

Provide recommendations for reducing upstream sediment production.

General Recommendations

This study indicates that the greatest changes in Novato Creek have evolved from increased runoff. Therefore, the long-term solution would be to reduce runoff from both urban and grazed landscapes. To reduce runoff from grazed lands, regulations restricting heavy grazing practices and encouraging best management practices would be needed. To reduce urban runoff, there is a need for urban development plans and ordinances that promote infiltration and discourage the concentration of runoff into storm drains that serve as point sources of excess flow to the natural channel network. A new storm drain system could be designed to ultimately bypass Novato Creek.

Specific recommendations

1. Stabilize many of the precariously undercut trees on the high terrace banks before they collapse into the channel and cause bank erosion to proceed unchecked from loss of root strength in the banks. This would also help preserve an important ecological and aesthetic resource.

2. Consider restoration techniques to divert high velocity flows and associated high shear stresses away from eroding banks.

3. Consider converting more of the diked marshlands into functional tidal wetlands that would dissipate flood flows and increase channel capacity for sediment transport by increasing tidal prism.

4. Consider piping urban runoff into a separate and constructed drain system that does not connect to Novato Creek but leads separately to a flood control basin in the wetlands or to San Pablo Bay. This would effectively reduce the amount of water going into the channel, which could reduce flood frequency and associated damages. Consider that water caught in a basin before going to San Pablo Bay could be filtered by natural vegetation.

5. Consider constructing on tributary channels such as Arroyo Avichi sediment traps that would funnel some, but not all of the bedload away from Novato Creek into a separate catchment.

6. Reduce the input of fine sediments from cattle trail crossings by fencing the main tributary channels of Bowman and Leveroni Creeks from cattle access.

FIGURE 4A

BACKGROUND AND HISTORY OF NOVATO WATERSHED

The sediments that are deposited in the NFCP have two primary sources, San Pablo Bay and the Novato Creek watershed, including its tributary streams. The Bay source is termed tidal, and the watershed sources are collectively termed terrigenous.

Tidal sediments are fine-grain silts and clays that are carried into the flood control channel as the suspended sediment load of the rising, or flood, tide. These tidal sediments have terrigenous sources, but they are re-worked and mixed within San Pablo Bay and the tidal reaches of local streams before they are deposited in the NFCP. In general, the tidal sediments are moved by stream flow and falling, or ebb, tides from local streams to deeper bay waters. Tidal currents deliver a portion of these sediments into shallow waters and onto mud flats, where they are temporarily stored before they are resuspended by wind-generated waves and carried landward by the rising tides. The deposition and resuspension of sediments from deeper to shallower waters separates the fines from the coarser sediments, such that only the very fine sediments reach the landward margins of the Bay. Dredging in San Pablo Bay may temporarily contribute to the suspended sediment load of the tides. Since the NFCP exists at the landward margin of the Bay, it can be a place of deposition for fine-grain tidal sediment.

Terrigenous sediments are derived by numerous kinds of erosion from hillsides, stream terraces (abandoned flood plains), stream banks, and channel beds. Hillside processes that can generate sediment include dry ravel from steep slopes, rills and gullies, and various kinds of landslides. These processes are not very important to the NFCP unless they provide sediment into the stream system. Terrace and bank sources include lateral erosion (also called retreat) and tree fall. The channel bed can be a sediment source if the bed degrades, meaning that it cuts down or incises. Channel degradation can lead to bank and terrace undercutting, which can lead to bank retreat and tree fall. The sediment that enters a stream or is derived from it can be stored dowstream through bed aggradation (in-filling). Sediment bars, debris jams, and man-made dams are sediment storage features. A bar or debris jam may persist for many years, although the sediments that comprise the bar or that are stored on the bed surface behind a debris jam change, as sediments are delivered from upstream sources, and then pass through the bar or jam on their way downstream. Landslides, bank failures, and the loss of debris jams can generate large pulses of sediment.

All of these terrigenous sources of sediment interact with each other in rather complex ways. And their interactions are affected by climate, geology, and land use. A review of the overall environmental character of a watershed and its land use history is required to understand the relative importance of tidal and terrigenous sediment sources.

Novato Creek drains eastward to San Pablo Bay, Figure 2. Watershed elevation ranges from less than 0' to about 1900' National Vertical Geodetic Datum (NGVD) and mean annual precipitation is about 28". The estimated maximum high tide above Mean Sea Level (MSL) is 6.5' (also equal to 9.5' above the datum for the San Francisco Tide Station) (1983, Camp Dresser & McKee Inc). The total drainage area of Novato Creek at its mouth is 44 sq mi. There are six major tributaries: Arroyo Avichi and Warner Creek which have confluences downstream of the Diablo Avenue bridges and are confluent to Novato Creek within the tidal reach; Vineyard and Wilson Creeks, which are tributaries to Warner Creek; and Bowman and Leveroni Creeks which enter about a mile and a fifth of a mile downstream of Stafford Dam, respectively. The dam is about 4 miles upstream of the NFCP. It captures water from the upper 8.4 square miles of the watershed and was completed in 1951. Drainage area for each of the tributaries is reported below in Table 1.

Table 1. Drainage Area in Square Miles

Novato at mouth	44
Novato at Redwood Blvd	24.5
Novato Creek above the NFCP	18
Arroyo Avichi at mouth	1.8
Warner Creek at mouth	5.1
Vineyard Creek at mouth	2.6
Wilson Creek at mouth	1.9
Bowman Creek at mouth	3.1
Leveroni Creek at mouth	2.1

This study focuses on the drainages below the dam, since bedload is captured by the dam and only suspended sediments are transported from the upper watershed during uncontrolled winter flows over the spillway. In 1985 the spillway was raised and its width was decreased to increase flood storage .

Major landscape features in Novato watershed include steep hillsides, underlain by Franciscan bedrock, and a broad flat valley composed of Quaternary-aged alluvium. The older alluvium is a terrace, which is an abandoned floodplain. Bay muds are found across the plain of the former tidal wetlands that extended to San Pablo Bay. In the watershed upstream of Stafford Reservoir and on the south-facing slopes of Burdell Mountain ridge below the dam, where grasslands predominate, dairy ranching is the principal land use. Suburban development is advancing onto north-facing slopes where oak-bay woodlands predominate. Some of the woodlands may have been altered by early settlers during the mid 1800's when chopping and exporting of wood was also a principal industry in Novato (verbal communication from staff at the Novato Historical Society).

The alluvial valley below Stafford Dam has been almost entirely altered by residential and commercial development. There remains a ribbon of riparian forest along Novato Creek which supports bay, willow, ash, and buckeye trees. Elderberry and walnut are infrequent. Alder trees, abundant in watersheds to the west and south, are very rare to absent along Novato Creek. Coast live oaks and valley oaks are commonly found along the valley flat and at the edge of the terrace banks, which stand about 10' - 14' above the channel bed.

The valley bottom may have had open-range cattle grazing as early as the 1820's, after the mission in San Rafael was established. Before this period the valley flat probably supported a mixture of oak and grasslands. Mexican land grants were given for Rancho Novato in 1839. By 1856, thousands of apple trees had been planted in the valley and Novato became one of the largest apple orchards in the world (Novato Chamber of Commerce). A photocopy of a circa 1860 (?) etching of Rancho Novato is provided in Appendix A4. The original is at the Novato Historical Society Museum. As early as this time, flow from tributaries, such as Warner Creek, had been altered and ditched for irrigation. The etching shows a riparian corridor along Novato Creek but not along Warner Creek, suggesting it had been recently constructed as a drainage ditch. A 1909 Subdivision Map, Appendix A4, also shows it as a ditch.

The extensive tidal marshlands and the network of sloughs at the eastern margin of the alluvial valley were diked and drained for agriculture around the 1860's. At this same time, there was also rapid sedimentation and bayward growth of the marshlands due to deposition of hydraulic mining sediment from the Sierra Nevada. Levees were built along Novato Creek to reclaim the new marshlands that developed during this wave of sedimentation. Novato Creek was thus extended toward the bay. The levees cut off the distributary sloughs from tidal flow and prevented upland floods from dissipating over the marsh surface. This loss of tidal prism caused the tidal reaches of Novato Creek to narrow and shallow, thus altering the ability of the channel to transport terrigenous sediment. Transport of upland sediment out of the watershed became less efficient.

Dedrick's research (1992) has shown narrowing of Novato Creek Slough since 1854. By 1941 a 1500' segment near the mouth was only about 10% of its former width, see Table 2 below. During the previous century, Novato Creek supported commercial navigation (Dedrick 1993), suggesting that the channel was also deeper, not just wider. Figure 3 shows a circa 1895 photo of a sloop,

P83-
C38

FIGURE 3

FROM Novato Historical Society

"OLD TOWN NOVATO, SOUTH OF CURRENT DOWNTOWN AREA; Note sloop IN NOVATO CREEK AT LEFT. Nave homes ARE IN the middle of picture (IN trees). House ON Right built by Ramon Pacheco. It was adobe, covered later by wood."

"I [illegible] No[illegible] P[illegible] dated circa 1895" the Solferina, approaching the landing near the present Novato Fair Shopping Center on Redwood Blvd. Further references to this photo are in Appendix A4. Today, the Novato Fair bridge is the headward maximum extent of tidal action, and has insufficient tidal flow to function for navigation. The channel must have been several feet deeper in the historical past.

Table 2. Novato Creek Tidal Reach Width Changes

Year	Width of Novato Slough at distance from San Pablo Bay			
	100'	500'	1000'	1500'
1854	1170'	1110'	840'	740'
1898	380'	290'	260'	290'
1921	290'	170'	160'	190'
1941	90'	70'	80'	80'

From Dedrick (1992).

Novato Creek tidal reach, between Warner Creek and the NWPRR Bridge, was straightened and channelized sometime after 1912, but before 1935 (compare the 1912 USGS topographic map, Appendix A4 to 1935 photograph, Figure 4A). This is roughly estimated to have occurred around the mid 1920's. An estimated 1,720' of channel length was removed by channelization. The USGS map does not properly delineate the location of Novato Creek below Diablo bridge; a drainage ditch is mistaken for the main channel. This study recreates the original Novato Creek alignment from the 1935 photo, Figure 4B.

Flood Control Management Activities

Construction of the NWPRR also had significant impacts upon the tidal and terrestrial flood flows from Novato Creek. The low steel, on the railroad bridge and the top rail intersect flows that occur at 6.58' and 9.35' above msl, respectively (Camp Dresser & McKee, Inc, 1983). Extreme high tides alone can overtop the rails. High flows that coincide with high tides, for example in February 1998, intersect the NWPRR Bridge and cause local flooding. Additionally, woody debris becomes trapped at the upstream edge of the bridge, exacerbating flood damages, Photo 9. The obstruction to flow has caused backwaters to extend into downtown Novato and have augmented deposition of sediment within the NFCP. The February 1998 floods caused damages to sections of the NWPRR Bridge and the bed beneath it to aggrade. Its replacement will be required (verbal communication, Liz Lewis, Creek Naturalist MCFCWCD).

The existing Phases 1-4 NFCP were started in 1987 and completed in 1991. It involved some excavation, realignment, widening, construction of trapezoidal channel banks, and levees. Presently, flows less than 3,300 cubic feet per second (cfs) (determined at the USGS gage upstream of 7th St Bridge), are confined within the NFCP, unless: 1) the design capacity is reduced by sedimentation; and/or 2) the flooding doesn't coincide with high tide. Dredging of this reach every three to four years is required in this reach to maintain the design capacity, 50-year flood protection (verbal communication from Liz Lewis). In 1996 the MCFCWCD dredged 45,000 cubic yards of sediment from a 1-mile segment of Novato Creek and a 0.3-mile segment of Warner Creek tributary. Dredging has been done every few years since the construction of the Flood Control Project.

The MCFCWCD management activities from Diablo Avenue to Novato Blvd. Bridge at station 131-40' (Watershed map #4) include maintenance activities such as removal of woody debris that obstructs flow, trimming and/or removal of willows or cattails (*Typha sp.*) that have encroached upon the channel bed, and construction of bank stabilization structures. Upstream of Novato Blvd. bridge, portions of Novato Creek are within private property and open-space lands. Within these lands, the stream course is not actively managed. A small segment just downstream of the dam is maintained by the local water district.

USGS Gage Records

The USGS gage is within the proposed Phase VIII Flood Control Project that extends approximately 4,500' from Diablo Ave to Grant Avenue Bridge. At the gage, discharges of 3,300 cfs have approximately a 26-year recurrence interval (see Appendix A3, Flood Frequency Curve from Jim Fain, MCFCWCD). Thus flooding in the reach between Diablo and Grant Bridges is predicted to be more frequent than flooding downstream in the NFCP. Additionally, because culvert outfalls (inverts) of small tributaries and urban storm drains are below the 3300 cfs, local flooding from these drains occurs before overbank flooding on Novato Creek.

During the 52-year period of record, the most significant flooding occurred in 1982 with an estimated 5,000 cfs at the USGS gage station. The second highest flow, 3,194 cfs, occurred February 1998 (see Frequency Analysis Data in Appendix B3). According to the Flood Frequency Curve, the "bankfull flow", as defined by a recurrence interval of about 1.5 years, would produce a discharge of about 500 cfs. Bankfull flow corresponds in elevation to the level of the floodplain, when one is present. From Diablo Avenue Bridge to Stafford Dam, Novato Creek typically has a poorly developed to nonexistent floodplain. This is because the channel is entrenched, which means that the ratio of floodprone width (measured at twice the height of maximum bankfull depth) to bankfull width is less than 1.4. This is called the entrenchment ratio, after Rosgen (1996). Entrenched channels are inherently unstable. Changes in water and sediment supply, as affected by land use, are causing the channels to rapidly adjust their width, depth and slope. The rate of adjustment is rapid enough to indicate instability, or disequillibrium. A stable channel has hydraulic geometry that is maintained over time; even though the channel may be laterally migrating, it neither aggrades or degrades and its gradient remains constant.

GENERAL METHODOLOGIES

A complete survey of the sediment sources throughout the watershed would have been beyond the intended scope of this study. The required general characterization of the sediment sources was achieved through a combination of field reconnaissance, interpretation of aerial photographs, and locally intensive field measurements in selected areas of typical terrain from the upper limits of some tributaries to the tidal reach of the mainstem channel.

Field Reconnaissance

During late spring through fall 1997, the mainstems of Novato Creek and its tributaries Arroyo Avichi, Warner, Vineyard, Bowman and Leveroni Creeks were walked by the author and Liz Lewis. A tape was stretched so that notes on channel characteristics could be correlated to a general field location. Other than a 7.5" USGS quadrangle, a base map of the channel was not available at the time of the reconnaissance and it was not of sufficient scale to make distance station notations, so all field notes were originally referenced to their taped distances and not mapped on location. The Novato Creek Field Notes above Diablo Avenue Bridge are in Appendix A1. Specific field methods and standards are described at the beginning of the Field Notes. For all data and graphs, references to right and left bank are for looking toward the downstream. Distance Station 0 + 0.0 is located at the upstream edge of Diablo Avenue Bridge. Distances are reported as negative values upstream of Diablo Avenue Bridge and positive values downstream of the bridge. They are written in standard survey notation. The extent of each channel reach studied is reported below.

Table 3. Length of Channel Studied during Field Reconnaissance

Novato Creek upstream of Diablo Avenue Bridge	26,265'	5.0 mi
Novato Creek downstream of Diablo to NWPRR Bridge	6,500'	1.2 mi
Arroyo Avichi mouth to upstream	10467'	2.0 mi
Bowman Creek mouth to upstream	2974'	1.8 mi
Leveroni Creek mouth to upstream	1070'	0.2 mi
Vineyard Creek mouth to upstream	10110'	1.9 mi
Warner Creek mouth to upstream	6600'	1.2 mi

Channel bed condition was assessed with regard to woody debris and pools. Notes were also made of the number and type of trees that had fallen across the channel or that had become uprooted. Trees that intersected bankfull flow were noted separately from trees that had fallen across the terrace banks. Trees that were still rooted but slowly slumping or leaning into the channel were not counted, for example see Photo 43 as opposed to 238. Woody debris jams were described by their location and condition, such as whether they were blocking the entire channel, partly blown out, or remnant from a former debris jam. Pool locations were measured only if their low flow depth exceeded or equaled 1'. The pools were measured during fairly steady flow throughout the summer, as maintained by specified flow releases from the dam (Liz Lewis personal communication). Pools were also categorized by their cause. For example, if the pools were formed by natural channel curvature (i.e., bends, bedrock or lateral bars), their cause was identified as natural. Large, natural woody debris (LWD) was regarded as a special type of natural cause of pools, due to its ecological importance. Pools that were caused by man-made objects such as cement abutments or rip rap that had slipped from the banks or had been transported downstream were classified as having unnatural causes. These classifications permitted an analysis of the differences in pool forming mechanisms among the different reaches. The raw data are located in the Novato Pools/Wood Data Table, Appendix A2.

Photographs were taken of different features along Novato Creek. These photos are arranged in Photo Albums I and II. The Albums are arranged with the downstream photos first, and the upstream photos last for each of the six channels. Photos and field notes are cross-referenced to distance stations on the Watershed Maps (Appendix A) and to each other. Photographs from previous years were obtained to rephotograph the sites and determine potential changes. In particular, many photographs from 1987 were used from the report on Novato Creek Erosion Control Study (1987, Stuber-Stroeh. Inc) to analyze potential change over a 10-year period. The Novato Creek photos and rephotography, in Photo Album I, are interspersed with the 1997 reconnaissance photos so that the downstream to upstream order is consistent. Some additional older photos from unidentified individuals are also included. The station distances assigned to the older photos are very approximate, since their location in the field was not established during the rephotography.

Reconnaissance of the headwater channels in Bowman and Vineyard Creeks was conducted to determine if the small 1st order channels were stable, incising, or aggrading their beds, and/or widening their banks. Field notes and photos for the small tributaries were keyed to locations on USGS topographic maps, located in corresponding figures for each relevant channel.

Locally Intensive Field Measurements

Height measurements were made from the thalweg (deepest point in the channel bed at any given location) to a key feature identified in the field, that could also be observed on the older photograph, (Photos 55 and 56 for example). The measurement points are identified with arrows on the photographs. The photos also have "x's" that serve for match points. The original numbering system was left on the older photos so they could be cross-referenced to their original Stuber-Stroeh Location Maps in Appendix B4. The field notes and photos for the following creeks can be found in the following Appendices:

Photo Album I	Novato Creek DST of Diablo Avenue Bridge	Appendix B
Photo Album 1	Novato Creek UST of Diablo Avenue Bridge	Appendix A1
Photo Album II	Arroyo Avichi	Appendix C
Photo Album II	Bowman Creek	Appendix D
Photo Album II	Leveroni Creek	Appendix E
Photo Album II	Vineyard Creek	Appendix F
Photo Album II	Warner Creek	Appendix G

For selected reaches of the mainstem channel, bank condition was assessed as the amount of erosion and the abundance and types of revetment along the right and left banks. The banks were divided vertically between bankfull, usually less than 5', and terrace, ranging from 5'-14' in height, and then noted relative to station distance. Many banks were bare due to a complex of factors, including dense shading of the riparian floor and the alleopathic soil conditions beneath the bay trees. However, the banks were not considered eroding unless they had a threshold of 0.5' average bank retreat. Exposed tree roots proved to be excellent indicators of the amount of bank loss, see Photos 38 and 50 for example. In a few areas, the volume of sediment stored in bars was measured by measuring their width, length, and height above the mean bed level. Types of bank revetment and erosion control structures were identified and their lengths were measured along the centerline tape. Their vertical extent on the bank was not quantified. The raw data are located in the Novato Banks Data Table, Appendix A2.

Repeated measurements of bank condition in 1996 and 1997 along the channel centerline did not match precisely, particularly in the reach upstream of Sutro Avenue Bridge. Later notes on bank condition were referenced to the earlier notes on channel distance. Although the measures of relative amounts of different bank conditions for different years are comparable, the measures are not geo-rectified and therefore, their exact location in the field may be slightly off, as well as their actual length.

The distances measured in the field were later put on Watershed Maps 1-6 which can be found in Appendix A. These maps were supplied by the Marin County Community Development Agency after most of the measures of bank and bed condition had been completed. Planform position of creeks on these maps is not exact, especially because much of Novato Creek is hidden beneath its riparian canopy. These maps were the best available base maps for plotting station distances recorded in the Field Notes. Based upon field sketches of channel bends, adjustments were made in the alignment of the channel on these maps. For example, the new adjustments are shown in black ink and the former outline of the creek is shown in solid blue, see Watershed Map 4 for example. These maps do not reflect channel width, and their degree of accuracy, relative to their pre-existing planform or added adjustments, is not known.

Elevations relative to terrace height and bed height were made on certain selected trees that were growing within the terrace banks. Measurement of diameter (DBH) were made for selected trees and their coring was planned to permit development of correlations between tree diameter and tree age. Based upon such correlation, local rates of channel incision might be derived. Unfortunately, the quality of some of the tree specimens prohibited coring.

Bank condition and revetment type was also measured downstream of Diablo Avenue Bridge along the tidal reaches of the NFCP. These measurements were taken in January 1998 when the channel was not wadeable, so a tape was pulled along the top of the left bank to the Redwood Blvd. Bridge. Below this point, most of the channel banks are earthen with levees, but channel shape is still a wide trapezoid. One type of revetment found between Diablo and Redwood Bridges, but not found upstream of Diablo was "Armorlock", which was used to maintain the constructed trapezoidal banks.

In May and again in October 1997, the channel bed within the tidal reach of the NFCP was cored to determine size characteristics and spatial distribution of sediment deposited in the bed during the 1997 Water Year. The NFCP was dredged the previous fall of 1996. The coring was performed by the author, with assistance from Liz Lewis and other MCFCWCD staff. Field methods and standards are described in detail at the beginning of the Field Notes for the Channelized Reaches, Appendix B. The raw data are located in Appendix B1.

Interpretation of Aerial Photographs

Field reconnaissance of the hillsides in Bowman Canyon was conducted by the author and Liz Lewis to verify landslide mapping interpreted from stereo aerial, black and white photographs taken in 1995 (scale 1:12,000) and 1950 (scale 1:6,000). The 1950 photos only covered the northern portion of the canyon. The purpose of the landslide mapping was to identify whether slides were contributing sediment directly to the channel network. Delineation of landslide types was not considered necessary for this analysis. Instead, only landslides that appeared to be recently active within the last 25 years were mapped. Landslide mapping was not performed for the rest of the lower watershed because the woodland canopy hid many of the landscape features and because it was beyond the scope of this study.

RESULTS AND DISCUSSION

Novato Creek

Findings for the Tidal Reach Downstream of Diablo Avenue Bridge

Bank Condition

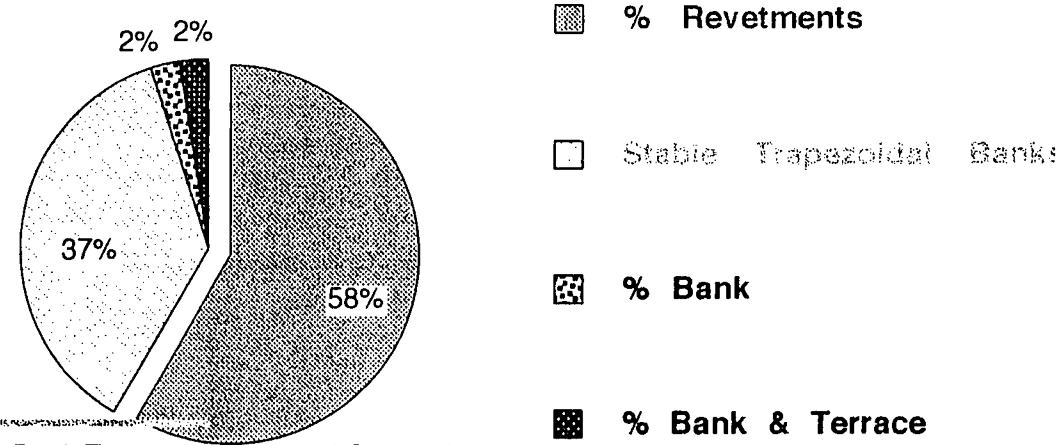
The lateral extent of eroding banks and revetment within the NFCP was measured to compare bank condition to upland reaches and to show whether any of the sediment within the NFCP was locally derived. The raw data are located in the Channelized Bank Condition Table, Appendix B1. Figure 5 shows two pie charts that represent channel conditions from Diablo Avenue to Redwood Blvd. bridge crossings. The top diagram shows the percent length of stable and eroding trapezoidal banks and the percent revetted bank, while the lower diagram shows the total percentage of different types of revetment used. Stable banks represent 37% of the length, while only 4% of the channel bank is eroding and contributing sediment to the project bed. About 58% has been revetted. Most of the revetment is poured concrete walls. Natural bank conditions do not exist along this reach.

Sediment Cores

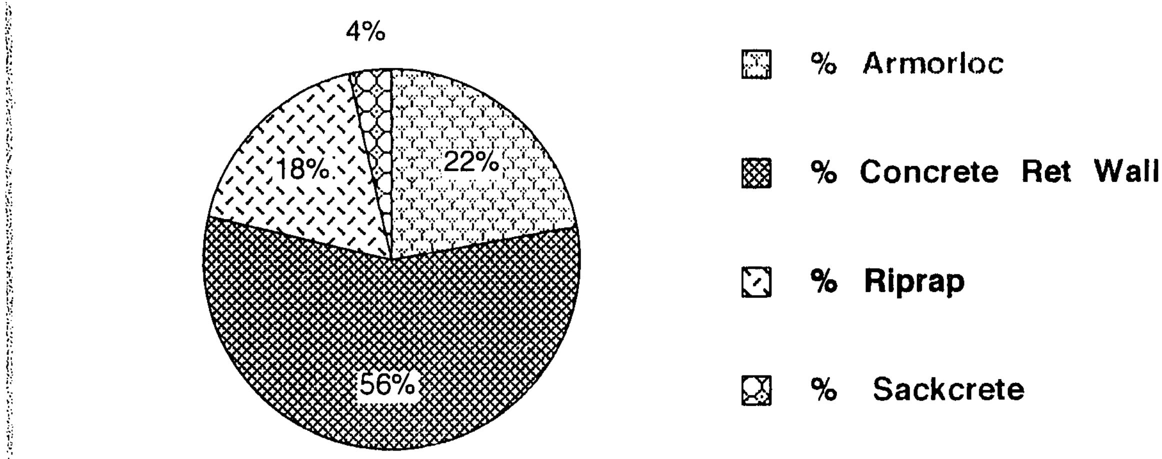
Watershed Map 1 shows the locations of the different coring stations. The Field Notes are located in Appendix B. Figure 6 shows a plot of the bed cores that were taken in May 1997 in the tidal reaches of the Flood Control Project. The single cores were located about 33' to 40' from the left bank. The figure shows cores from upstream near Warner Creek confluence, on the left side of the page, to downstream of the NWPRR Bridge on the right side of the page. The data show that sand-sized sediment extended to at least 3,755' downstream of the zero station at Diablo Avenue Bridge. Gravels were found further downstream than core station 3 (23+85') which is near the confluence of Arroyo Avichi. Station 2 had gravel up to 10 mm in size within the core near Warner Creek confluence. A bar near Station 3 had gravel up to 30 mm

Novato Flood Control Project Bank Physical Conditions From Redwood Blvd to Diablo Avenue

(most of this reach is influenced by both tidal and terrestrial flow)



% Bank Types per Length of Channel for both Banks
Channel reach length = 3460'



% Total Revetment Types for Both Banks
Channel reach length = 3460'

FIGURE 5

Channel Bed Cores from Novato Creek Flood Control Project

5/27/97

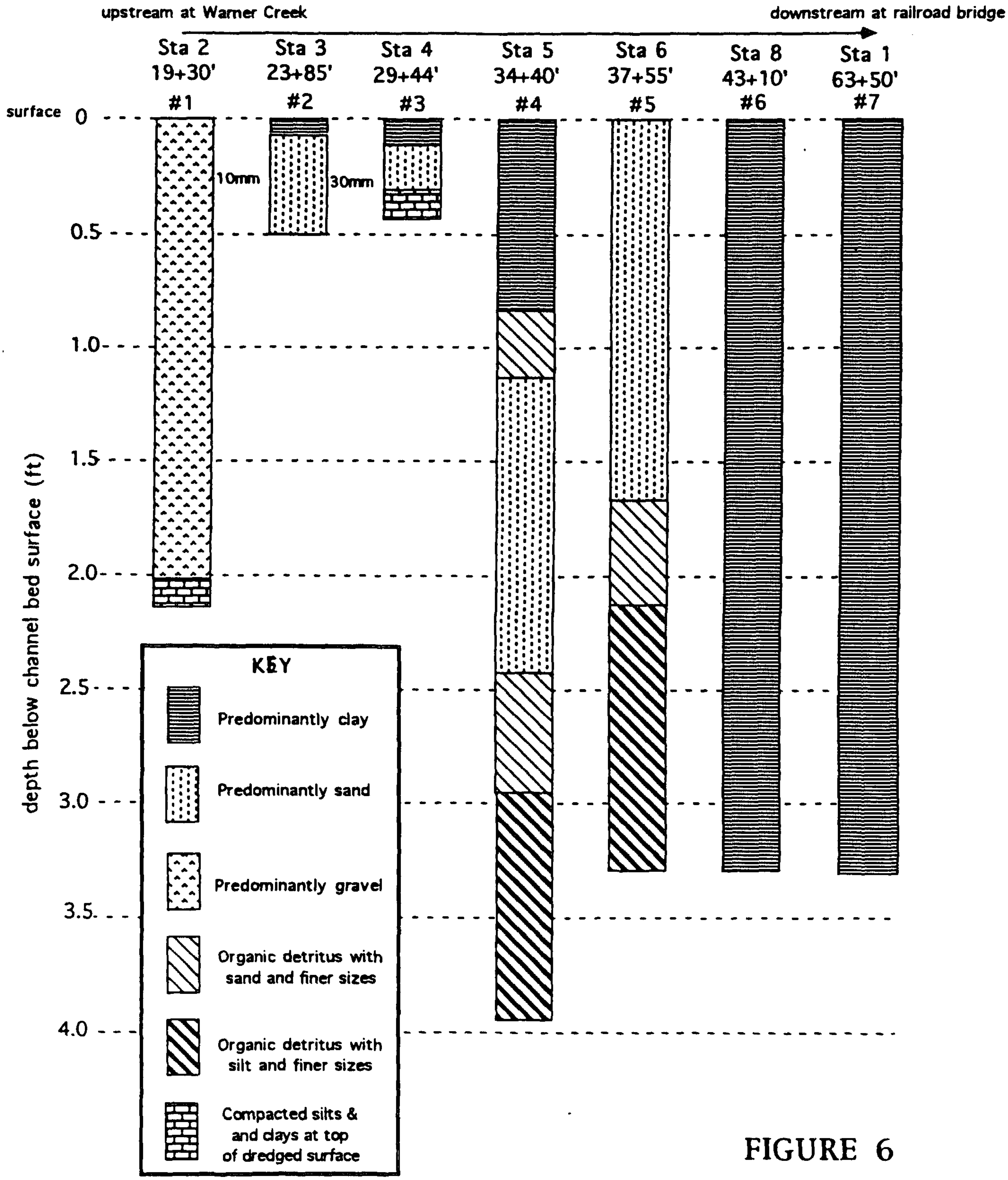


FIGURE 6

near Arroyo Avichi confluence. Both these tributaries have created alluvial fans, with gravel-sized sediment, at their NFCP confluence, Photos 19 and 22.

The significance of sand and larger gravel-sized sediment is that the source of this material is the upland watershed, not the tides. Tidally derived sediment is not expected to be larger than fine silt to clay-sized. Figure 6 shows another interesting stratum that is associated with organic debris, at core stations 5 (34+40') and 6 (37+55'). At the latter stations, the mixture of organic debris and sand or finer sediment accounts for more than 45% of the volume or bulk of each core. Much of the organic detritus was leaf litter from bay trees and deciduous riparian vegetation, such as willows.

At station 39+00', which is upstream of the Highway 101 Bridge, sediment on top of hay bales that had been placed on top of the flood control banks exhibited a veneer of fine silt to clay sediment about 1" thick, Photo 11. It is presumed that the hay bales were placed in November 1996. This gives a deposition rate on the Flood Control Channel banks of at least 1" in half a year. It is not known if this can be extrapolated to 2" per year since the hay bales had decomposed by the end of 1997. The source of the sediment may be the suspended supply from both tidal and upland winter flood flows.

Since the NFCP had been dredged the winter before this study, core stations 2 and 4 intersected the top of the dredge surface that had compacted silts and clays. The surface of the dredged bed may have been very uneven such that the amount of deposition at these discrete points may be the minimum amount that occurred during 1 winter. The cores at station 8 (43+10') and station 1 (63+50'), in Figure 6, show that mostly clay-sized sediment was present following the dredging and the 1997 winter flows. However, Photos 7 and 8 show stratification of fine sand-sized sediment in 1996 dredge spoils that had been placed on the levees downstream of the railroad bridge. The spoils indicate that sand from terrestrial sources had been transported and deposited within the flood control channel beyond the extent of railroad bridge.

Figures 7a, b and c show the distribution of sediment in cores that were taken in October 1997, five months after the first set of cores. This later coring was done to determine the contribution of sediments from tides alone, when terrestrial flows would be minimal and not transporting bedload or significant suspended sediment. An attempt was made to take three cores at approximately the same distance stations but along a transect across the channel bed to better define the range of variation. In the downstream reaches at core station 6 (37+55'), it was too difficult to wade across the channel bed so only two cores were taken.

Channel Bed Cores from Novato Creek Flood Control Project

10/15/97

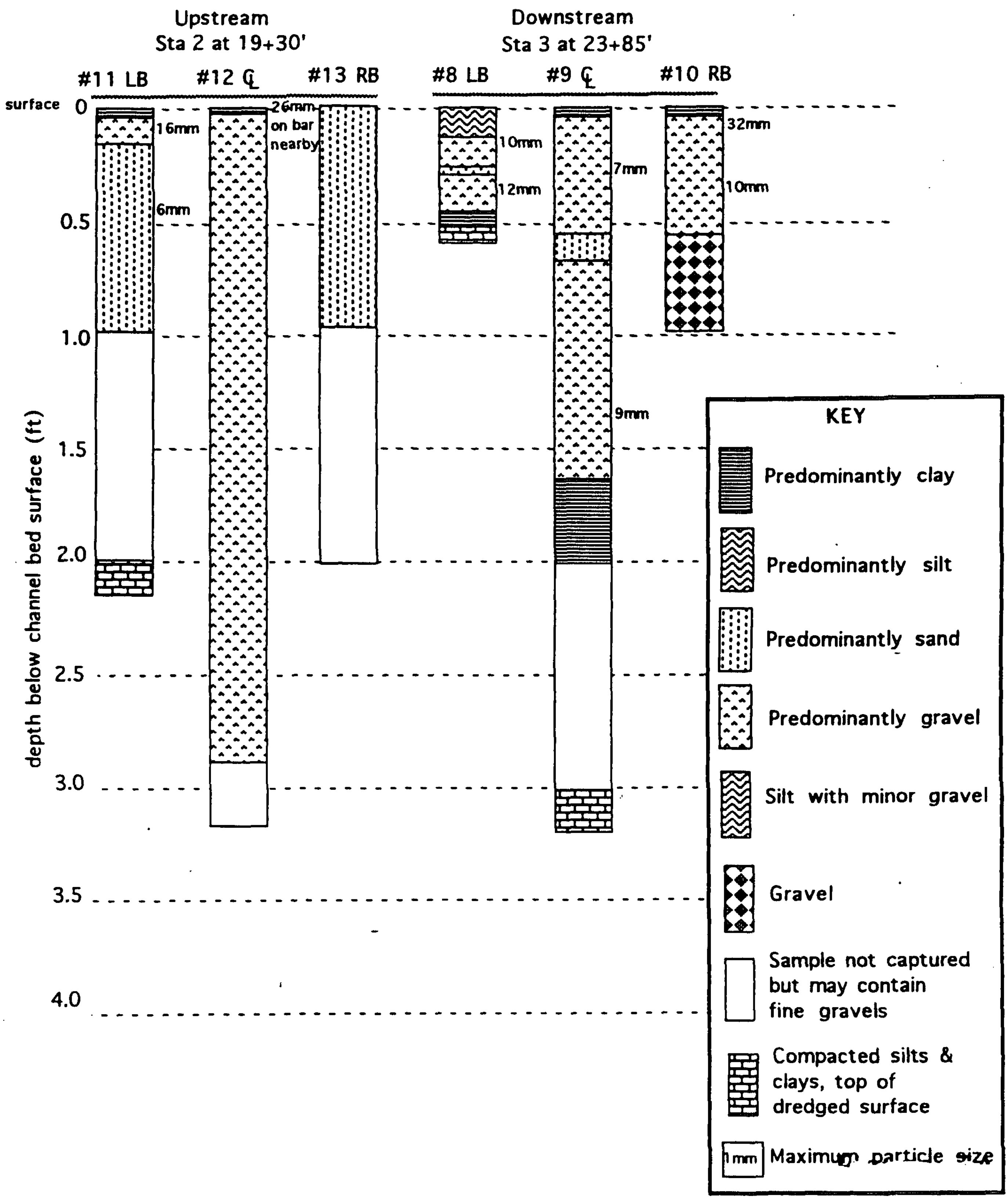


Figure 7A

Channel bed Cores from Novato Creek Flood Control Project

10/15/97

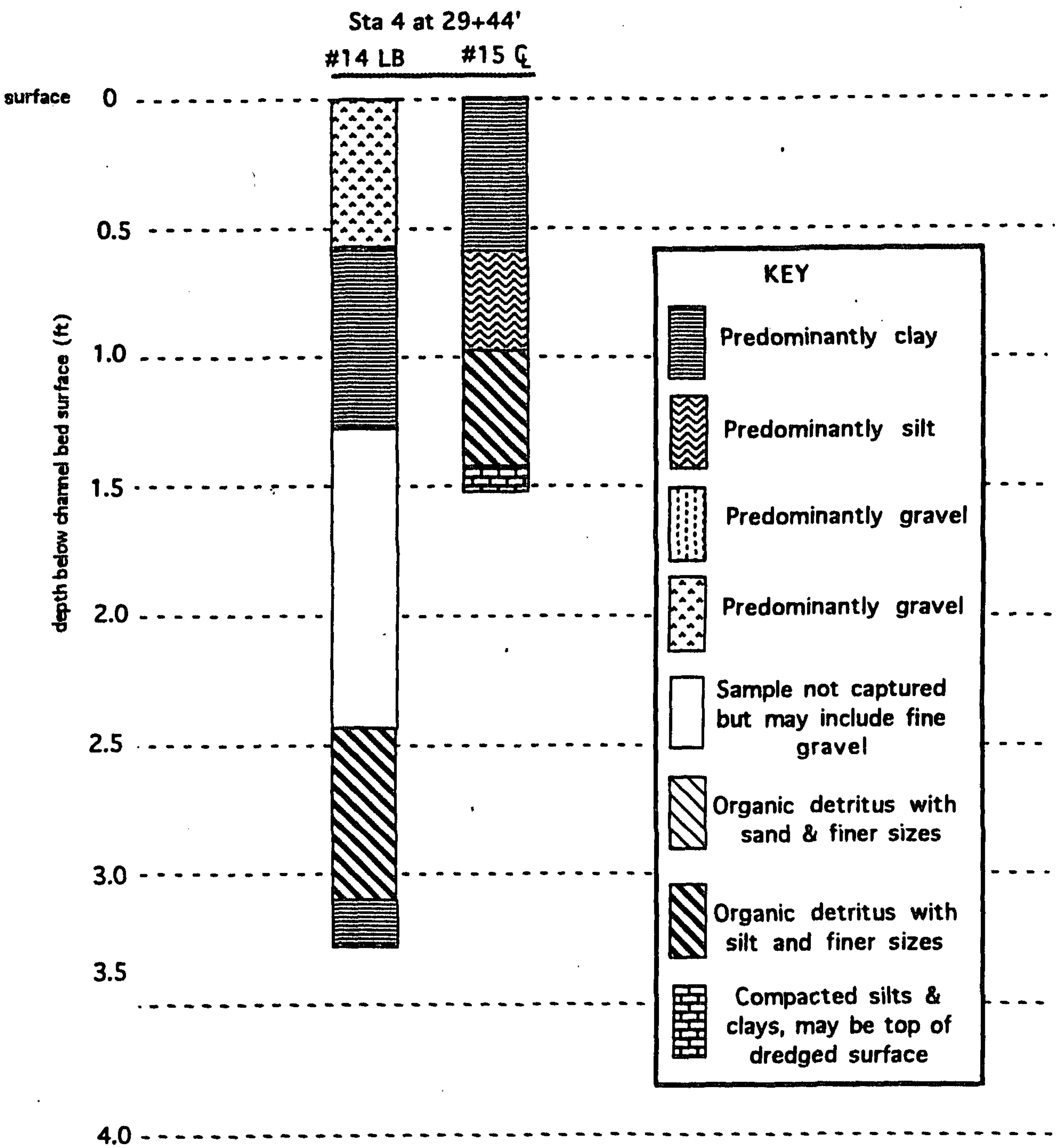


FIGURE 7B

Channel Bed Cores from Novato Creek Flood Control Project

10/24/97

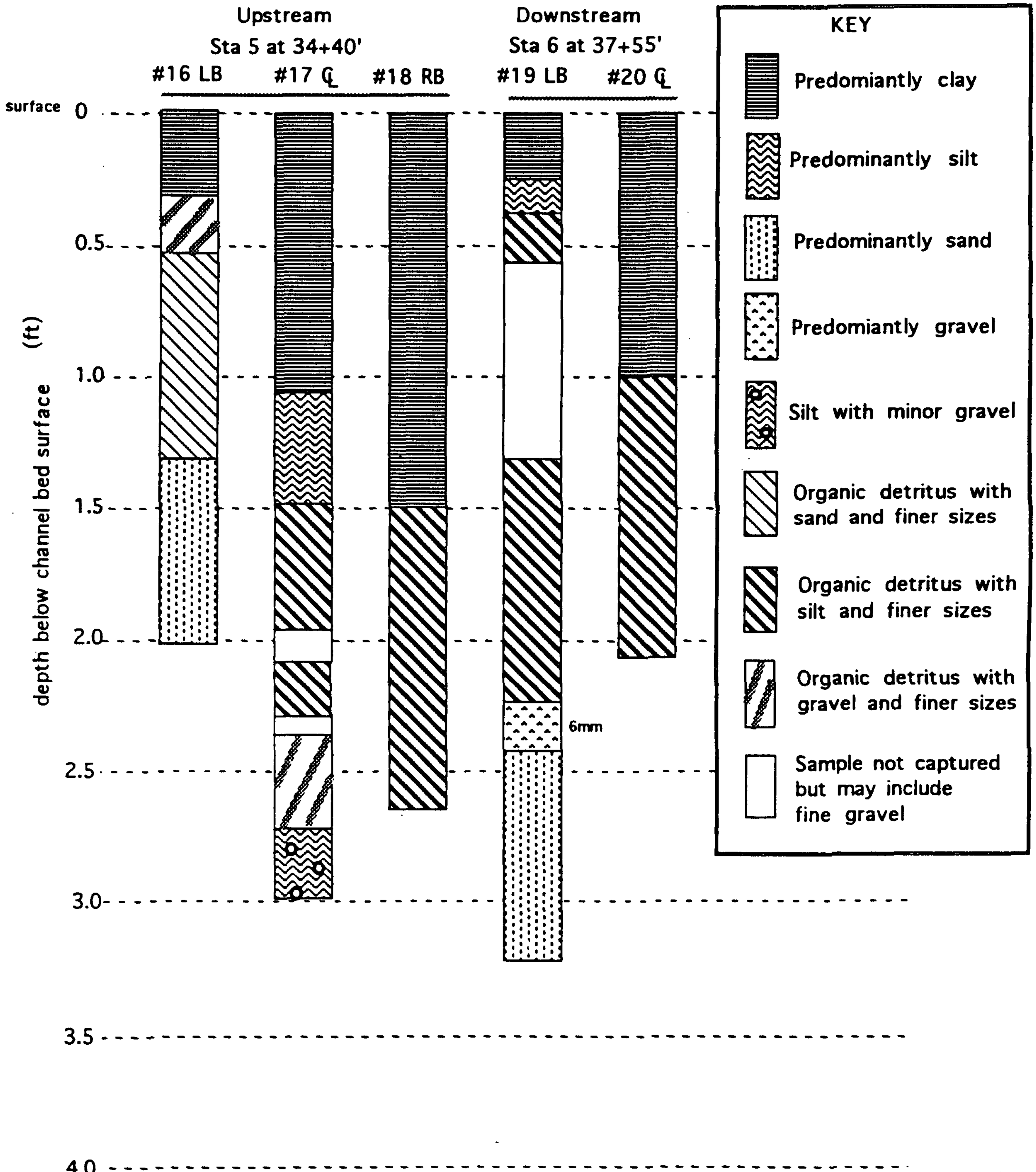


FIGURE 7C

The three cores at core station 2 (19+30') show an insignificant veneer of silt at the top of the core and sand to gravel-sized sediment at the transect. Gravel up to 26 mm was observed. The voids in most of these cores may have been noncohesive, sands and gravels. Varying amounts of gravel were found at core stations 2 through 6, with particle sizes up to 6 mm at the latter station. Core stations 1, 7 and 8 were not recored. The cores at stations 5 (34+40') and 6 (37+55') showed that the organic leaf litter and debris accounts for over 40% of the volume. Evidently, the detrital matter that washes downstream during the first significant winter flows substantially bulk and contribute to filling of the tidal channel. When there was a functional marsh system, before diking and reclamation, these rafts of organic litter would have settled onto the marsh surface or channel banks, or they would have been washed to the bay.

The coring indicates that the upper third of the flood control channel is dominated by sand and larger-sized particles from upland sources and that fine grained tidal sediment probably amounts to less than 20% of the measured sediment volume. From one third of the distance to more than half the length of the NFCP study reach, tidal sediment probably amounts to less than 50% of the total volume. Further downstream at the railroad bridge, fine grained silt and clay predominate the total volume, but it is not presently possible to determine the percentage of this sediment that is derived from tides or that is reworked fine sediment derived from upland sources. Also, it is not presently clear if the veneer of tidal sediment that is deposited during the summer remains on the bed or is reworked during high winter discharges, when bed shear stresses would be greater.

In March of the 1998 Water Year, after very high winter storm flows, Liz Lewis and other MCFCWCD staff went to some of the same reported coring stations. They found sand and fine gravel-sized sediment downstream of the railroad bridge, with gravel up to the 6 mm size at the NWPRR Bridge. The higher peak flows of 1998 (3,194 cfs) were able to transport coarse-sized sediment farther downstream than the previous flows of 1997, (1,893 cfs).

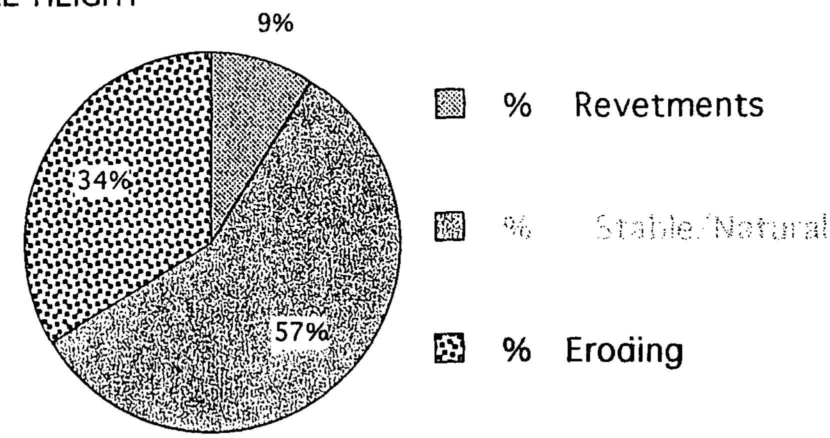
Findings for Novato Creek Upstream of Diablo Avenue Bridge

Bank Conditions

The lateral extent of eroding banks and revetment upstream of Diablo Avenue Bridge to Stafford Dam spillway was measured to determine the existing conditions of the channel and terrace banks and to establish whether bank erosion was a significant source of sediment supplied to the NFCP. The raw data are compiled in the Novato Bank Data Table, Appendix A2. Figure 8 shows three pie charts that represent channel bank condition and revetment

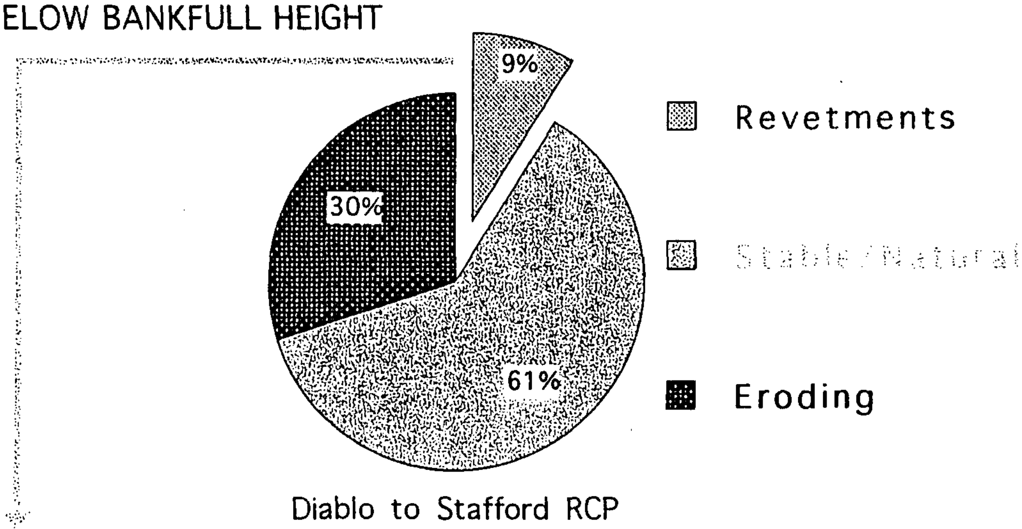
Novato Creek
Bank Physical Conditions for All Study Reaches Combined Upstream of Diablo Avenue Bridge

BELOW BANKFULL HEIGHT



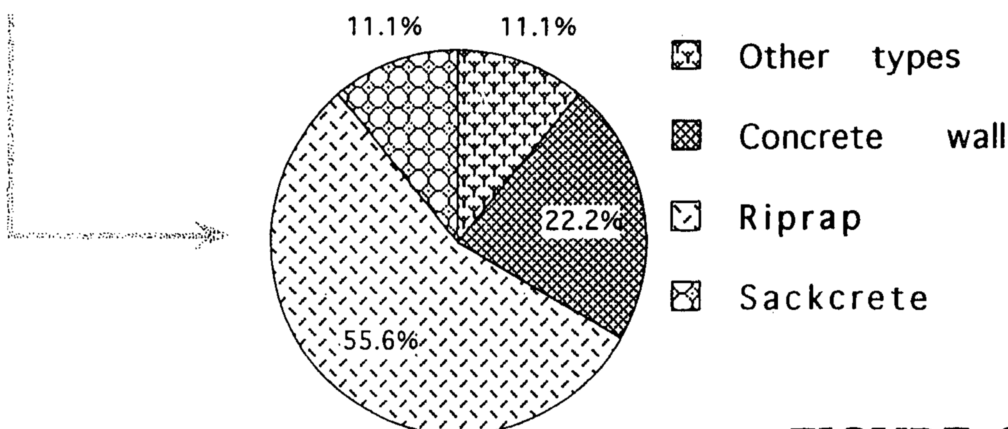
Diablo to Stafford RCP

ABOVE AND BELOW BANKFULL HEIGHT



Diablo to Stafford RCP

TYPES OF REVETMENT
ABOVE AND BELOW BANKFULL HEIGHT



Diablo to Stafford RCP

FIGURE 8

type for the entire Novato Creek study reach to Stafford Dam. The top chart shows the percentage of eroding, stable and revetted banks below bankfull,

while the middle chart shows the percentage of these conditions when terrace banks are combined. For both pie charts, the percent revetment is the same because its vertical extent was not measured separately for bank and terrace.

The charts show that if just the bankfull banks are considered, 34% of the bank length has eroded more than 0.5', and 9% of the total length has been revetted. It is likely that some portion of that 9% was also eroding and supplying sediment to the channel in the past before revetment. The middle chart shows that when the terrace banks are considered, a larger proportion is stable, reducing the total percentage of eroding channel length to 30%. These charts also show that only about 60% of the channel banks provide natural stable habitat. The bottom pie chart shows that the most widely used revetment type is riprap, contributing 56% to the total.

Figure 9 shows a histogram representing the total distances, along 8 different reaches, of eroding, revetted or natural banks below the approximate 5' bankfull level. These reaches are simply defined by bridge crossings (Diablo Ave., 7th St., Grant Ave., Simmons Lane, and Sutro Ave.) or significant tributary confluences (Bowman Creek and Las Dias Creek). This chart shows that the amount of revetment decreases upstream, and that there is a slight trend of more stable natural banks upstream of Simmons Lane Bridge. If a large proportion of the revetted banks in the downstream area were eroding and supplying sediment prior to revetment, then downstream reaches have been even more significant sediment sources than at present.

Figure 10 shows pie charts representing the percentage of total length of eroding, revetted and stable banks below the bankfull level for each of seven reaches. The charts indicate that eroding banks range from 22% of the total length in the Simmons to Las Dias reach, to 40% in the Bowman reach. If most of the revetted portions of the banks were once supplying sediment, then the banks of 7th and Grant reaches have been the most significant sediment sources, since less than 48% of their bank length is classified as stable. The Simmons reach has the highest percentage of stable banks, 68%.

The abundance of bank erosion in the Novato Creek reach upstream of Bowman tributary is likely due to the immediate effects of the trapping of bedload by the dam. Subsequent adjustments in channel geometry and gradient were caused by changes in sediment and water supply. The abundance of eroding and revetted banks in the first three downstream reaches may be due to grade adjustment that propagated upstream from

Extent of Eroding and Revetted Banks Below Bankfull Height, for Both Right and Left Banks Along All Study Reaches upstream of Diablo Ave Bridge

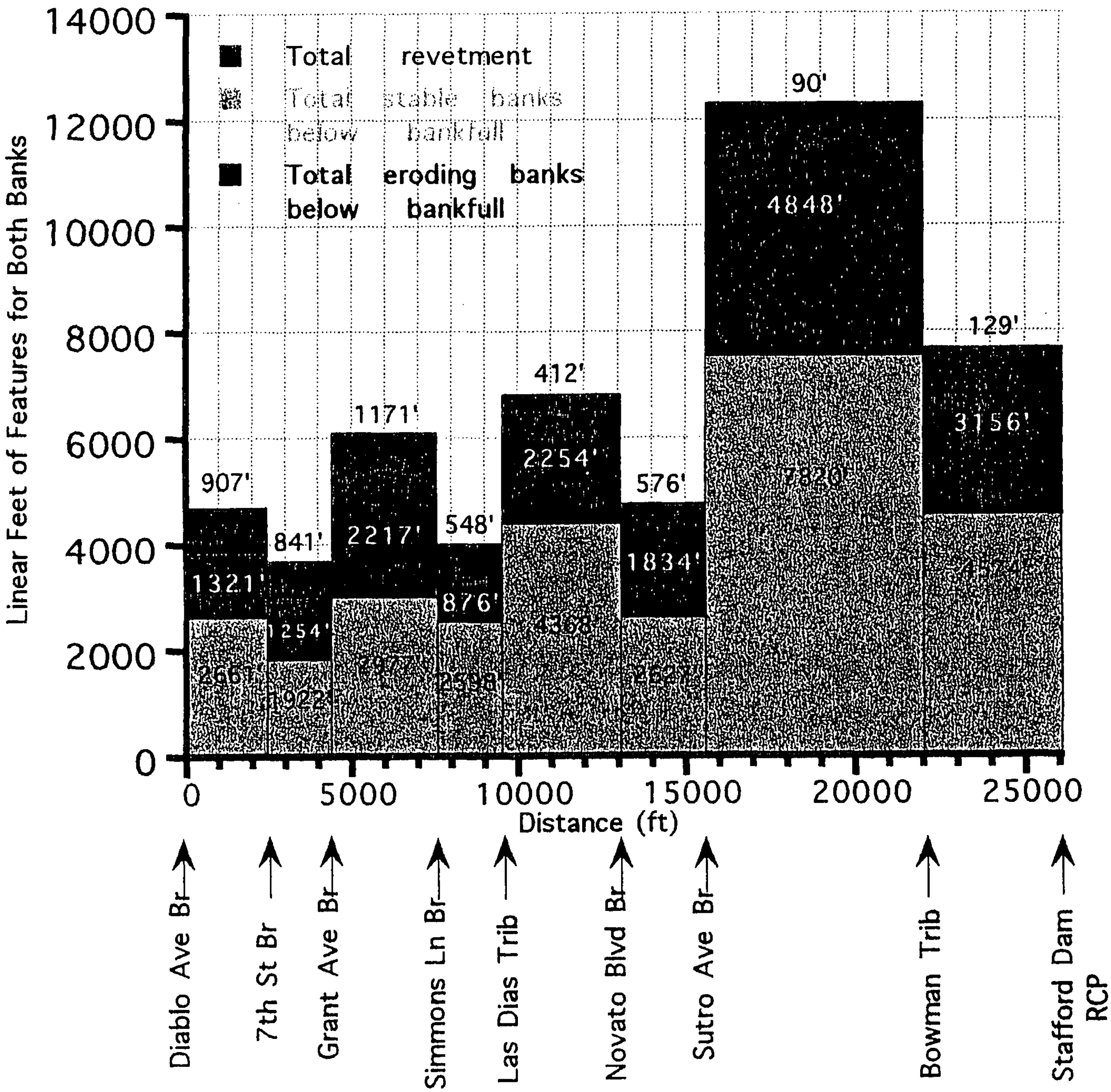


FIGURE 9

Novato Creek
Bank Physical Conditions Below Bankfull Height for Individual Reaches

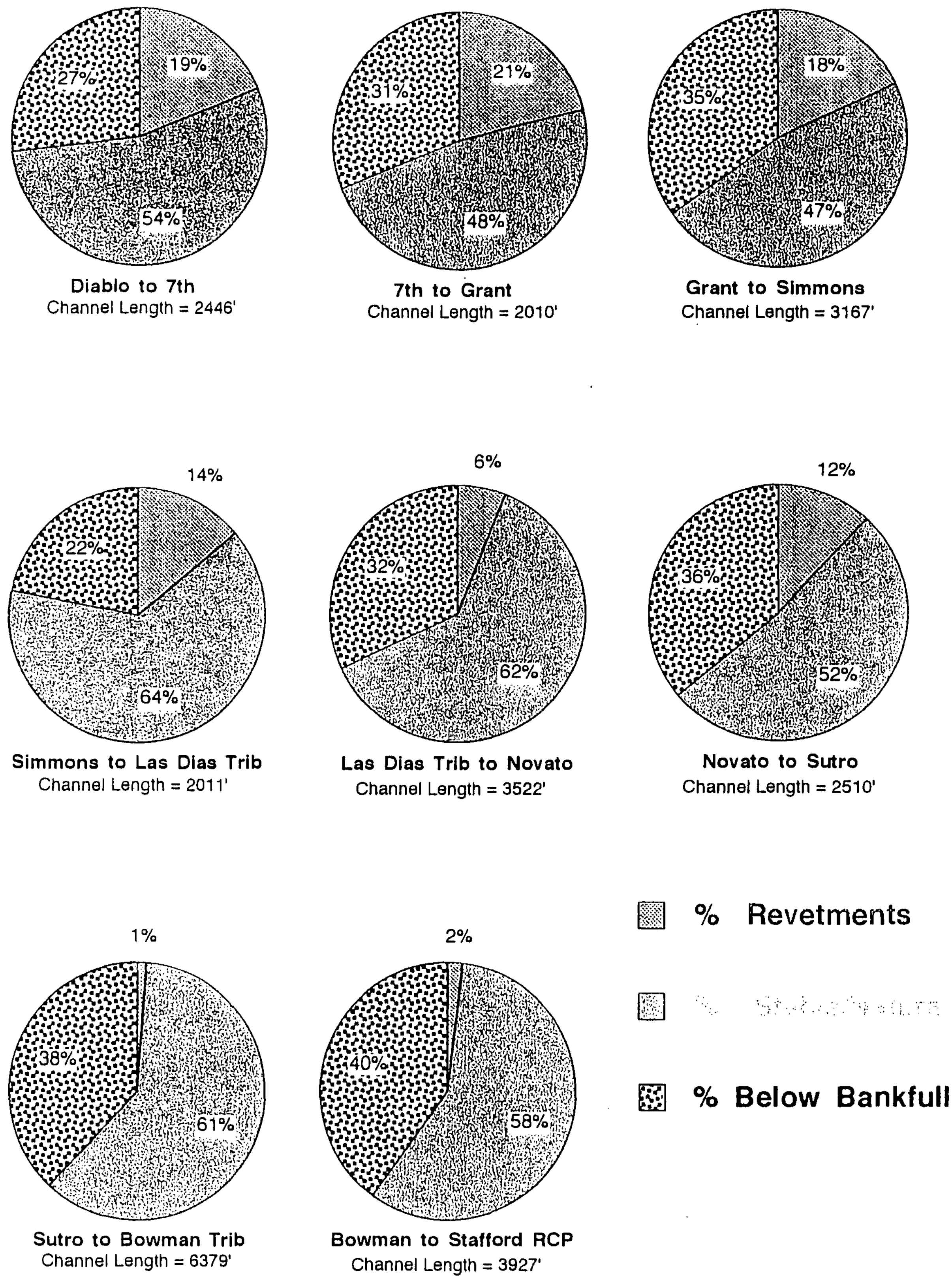


FIGURE 10

Novato Creek
Bank Physical Conditions Above and Below Bankfull Height for Individual Reaches

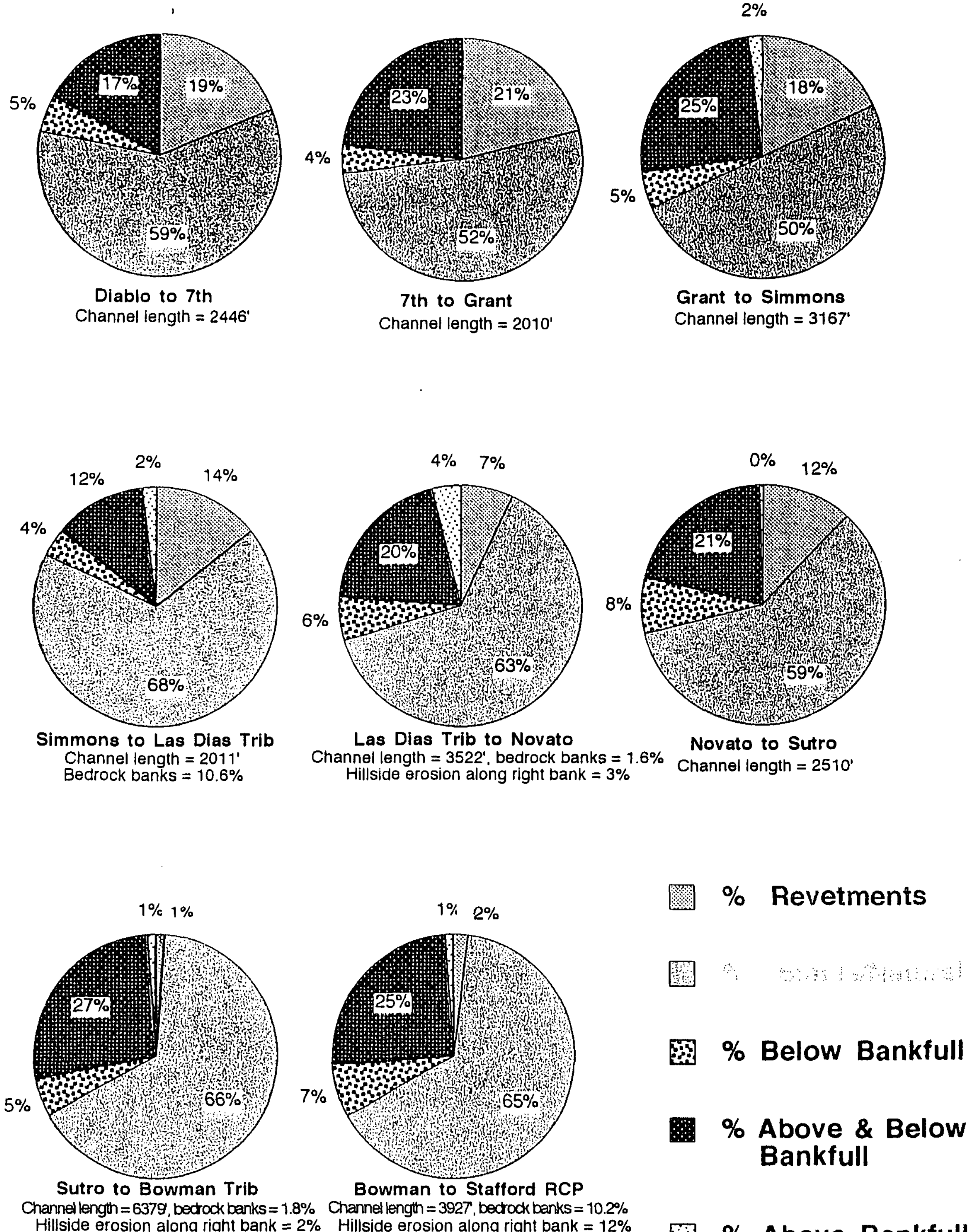


FIGURE 11

earlier channelization projects, revetments that had poor hydraulic design and thus exacerbated erosion on the opposite bank or at the edges of the revetment. Additionally, increased urban runoff is likely affecting the entire channel. Even though the effect of the dam reduces peak flows, it also attenuates the length of time that moderately high flows on the recession limb of the hydrograph are able to erode channel banks. The natural hydrograph would have a sharper peak but a more rapid drop on the recession limb. Thus, with the dam, there is more time for shear stresses that are capable of causing erosion, to work on the banks.

Figure 11 shows the percentage of eroding banks on the terrace and bankfull banks. The solid red areas represent where the combined vertical extent of terrace and bankfull bank is eroding. Heavy stippled areas represent where the bankfull banks are eroding, and light stippling represents just the terrace bank erosion. The reaches of 7th to Grant, Sutro, and Bowman all have combined terrace and bankfull bank erosion that exceeds 25%, with the latter as high as 27%.

Point measurements were made of the amount of bank retreat along Novato Creek. These raw data are in the Field Notes in Appendix B1 and in Bank Erosion Data Tables in Appendix A2. The maximum amount of bank retreat measured was 52' at station 233-91' (Watershed Map 6). If just the spot checks are averaged, then an average value of bank retreat is about 5'. Since the spot measurements may have been skewed to measure the more severe erosion sites, a conservative estimate of 3.5' average bank retreat is estimated to roughly quantify the volume of sediment supplied to Novato Creek from local bank erosion. The onset of the erosion could be assumed to be no older than the oldest tree that has its roots exposed. The bankfull bank height is estimated at an average of 5'. If the combined height of terrace and bankfull bank is generally 11' to 14', a conservative estimate of 11.5' can be used for the average height of the terrace and bankfull banks. The terrace bank average height would be about 6.5'. Estimated volumes of bank erosion are reported in the table below.

Table 4. Conservative Estimate Sediment Volume from Bank Erosion Along Novato Creek

Bankfull Erosion	11,511 cu yds
Terrace and Bankfull Erosion	17555 cu yds
Terrace Erosion	1105 cu yds
TOTAL	30171 cu yds

The channel bed is another source of sediment to the NFCP, particularly if there is abundant sediment stored as gravel bars. Bars above the mean bed

Novato Creek
Type of Bank Revetment for Individual Reaches

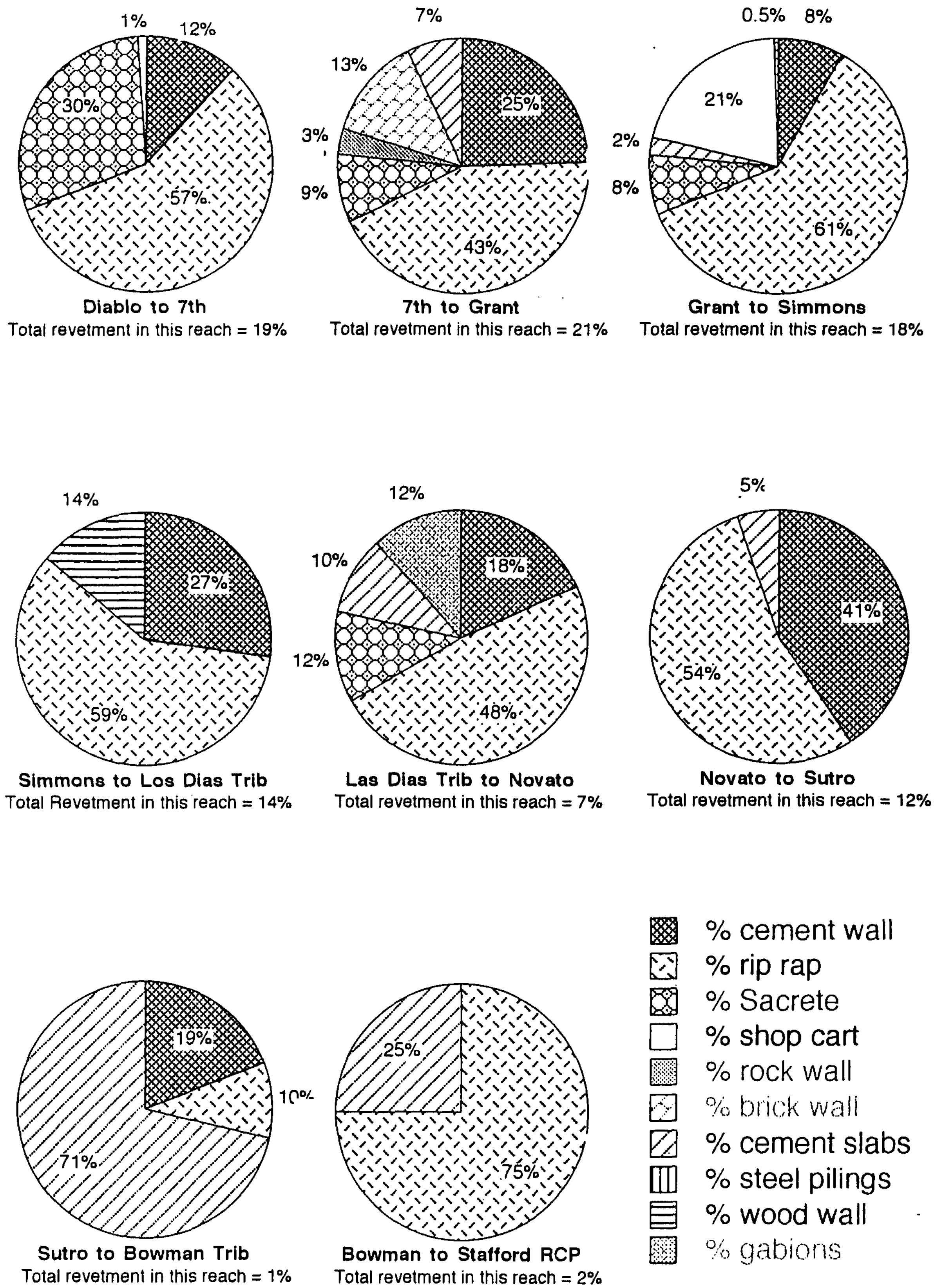


FIGURE 12

height were measured between Diablo and 7th St bridges to ascertain the minimum amount of sediment stored in the bed. This was a minimum estimate because actual depth of the bed could not be measured. The bar volume amounted to about 500 cu yd. This is only about 33% of the total supplied by long-term bank erosion in this reach, which is estimated at about 1,500 cu yds. If the 500 cu yds was spread over the length of this 4456'-long reach, on a 25' wide bed, then the average height would equal 0.12'. This value will be compared to other tributary channels where bed storage estimates were conducted. It was noted during the field reconnaissance that there was abundant fine, sand-sized sediment throughout Novato Creek. The erosion of the local terrace banks, probably account for a high percentage of the fines since the banks are mostly sand and finer sizes. Gravel banks were observed infrequently. The bed exhibited little relief and it appeared aggraded at station 5-34', coinciding with the maximum extent of the backwater that could be created by the top rail of the NWPRR Bridge during high peak flows.

Revetment and the percentage of different types used in Novato Creek, can also be viewed on a reach basis as shown in Figure 12. Except for the Sutro reach, riprap is used more widely than any other revetment. Sackcrete and concrete walls are the other most common bank structures. Erosion along the ends and opposite banks of these revetments was often observed as indicated by the Bank Condition Charts in Appendix H. These graphs depict 1,000'-long reaches and show the distribution of eroding banks, revetment, pools and debris jams. The insert maps on each chart correspond to the Watershed Maps in Appendix A. These maps can be used as future tools for monitoring change as well as assessing existing condition.

Canyon slopes, rather than terrace banks, are more frequently intercepted upstream of Sutro Avenue Bridge. Bedrock banks are relatively uncommon, amounting to less 3% of the overall length of channel banks. As noted in Figure 11, Las Dias and Bowman reaches have about 10% of their total bank length as bedrock, while Las Dias and Sutro reaches have less than 2%. Simmons reach has the highest percentage of stable banks, 68%. This may be due to the fact that about 10% of its banks are bedrock and it is relatively far away from the upstream impacts of the dam and the downstream impacts from the realignment of Novato Creek tidal reach and excessive urban runoff in the more concentrated urban zone.

Bed Condition Relative to Pools and Wood

Pool and woody debris characteristics upstream of Diablo Avenue Bridge were measured to: 1) determine whether the bed was following the usual relationships of pool/riffle ratios; 2) to gain insight into the causes of what was forming the pools which is of interest to the MCFCWCD as habitat. The raw data are located in the Pools/Wood Table and Bank Summary Table in Appendix A2.

In natural channels there is an expected relationship between the number of pools and their spacing relative to bankfull width. In general, there should be a pool for a every 5-7 channel widths. Excessive sediment deposition can contribute to the loss of pools and thus pool frequency measurements can be made to assess sediment transport capacity and channel condition. Channel curvature alone will usually produce the expected ratio. The estimated average bankfull width for the Diablo to Stafford reach is 30'. Thus, pools would be predicted to occur at a minimum, every 150' - 210'. The table below reports the spacing of pools greater than 1' for the seven different reaches.

Table 5. Pool Distribution for Individual Reaches of Novato Creek

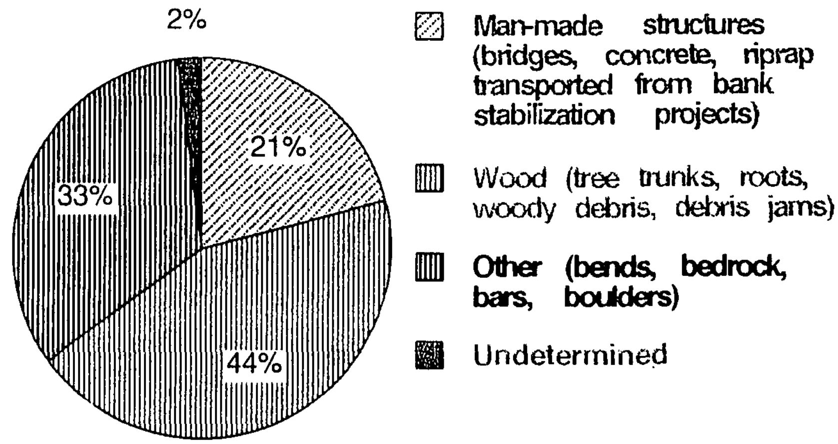
Location	Total Distance (ft)	Number of Pools	Pool Spacing (ft)
Diablo to 7th	2446	12	204
7th to Grant	2010	19	107
Grant to Simmons	3167	23	137
Simmons to Las Dias	2011	9	223
Las Dias to Novato	3522	30	117
Novato to Sutro	25160	29	87
Sutro to Bowman	6379	65	98
Bowman to Stafford	3927	28	140
Diablo to Stafford	25978	215	121

Pool spacing for Novato Creek ranges from 1 pool every 87 feet in the Novato to Sutro Reach, to 223' in the Las Dias reach. The latter reach has 1 pool per every 7.4 channel widths and appeared to have more sediment stored in large high gravel bars. The bars appeared to be relatively mobile (loose gravels and little establishment of vegetation) and could contribute to bedload transport to downstream reaches. Except for this latter reach and the Diablo to 7th reach, pool spacing is more frequent than every 5 channel widths. relative to the discharge of the channel were observed to be quite small.

The three pie charts shown in Figure 13 show the percentage of different causes of pools, the percentage of tree types that have contributed to large woody debris (LWD) within the channel banks, and the characteristics of the debris jams. The top chart shows that of the 215 pools in the entire Diablo to Stafford reach, 44% of the pools are formed by wood (i.e., LWD, roots, tree trunks), 33% are formed by natural features (i.e., bends, bars, bedrock), and 21% are formed by man made structures (i.e., concrete abutments, riprap) that inadvertently cause bed scour.

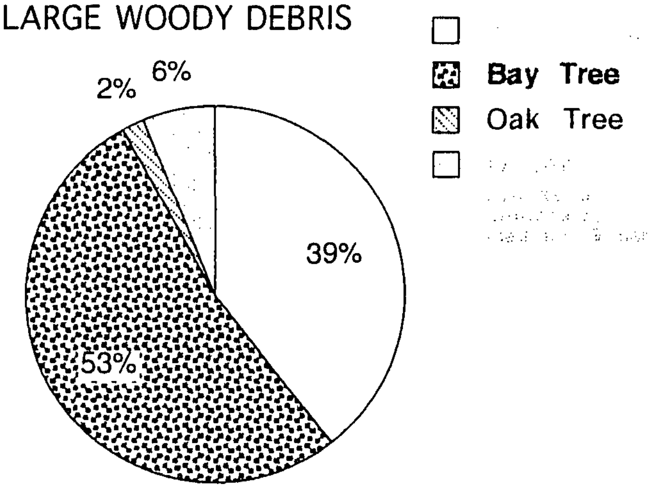
Novato Creek Pool and Woody Debris Characteristics for All Study Reaches Upstream of Diablo Ave Bridge

CAUSES OF POOLS GREATER THAN 1' DEEP



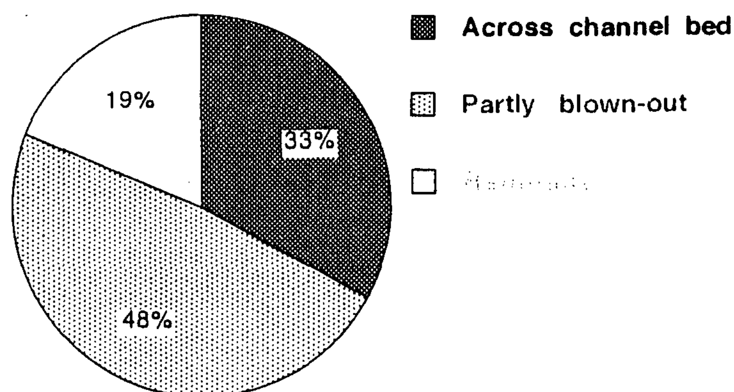
Diablo to Stafford RCP
Total # of pools = 215,
Average pool spacing = 121'

TYPES OF TREES COUNTED AS LARGE WOODY DEBRIS BELOW BANKFULL HEIGHT



Diablo to Stafford RCP
Of the total 84 pieces of LWD, 44 are bay trees that have fallen from terrace banks.

DEBRIS JAM CHARACTERISTICS



Diablo to Stafford RCP
Of the total 21 debris jams, 18 occur upstream of Sutro Ave Bridge

FIGURE 13

Wood is of interest to sediment studies because it can increase sediment storage in gravel bars behind the wood, it can increase the number of pools even if a channel is aggrading, it can force flow into opposing channel banks and induce bank erosion, it can trap huge quantities of sediment behind debris jams and change local channel gradient and sediment transport, and it can suddenly release slugs of sediment downstream when debris jams are blown out. The recruitment of wood to the stream is also of interest because it may be associated with inputs of sediment from landslides or bank collapse. LWD and woody debris jams are natural features to a proper functioning stream

The middle pie chart in Figure 13 shows that of the 84 pieces of LWD that were tallied, 53% found in the Diablo to Stafford reach are formed by bay trees that have uprooted and fallen into the channel. The actual number of bay trees is 44. Willow trees represent about 39% of the LWD. Interestingly both tree species can withstand substantial disturbance to the roots such that some can remain viable after they fall. Nevertheless, their collapse into the channel can represent the loss of a riparian resource, especially if they fall within flood control jurisdiction because their trunks will most likely be cut for flood control purposes.

The debris jam characteristics shown in the lower pie chart of Figure 13 show that of the 21 debris jams that have formed upstream of Diablo Bridge, 18 of them occur upstream of Sutro Ave and only 33% of these debris jams extend across the channel. The rest are either partially or entirely blown out remnants. The Sutro pie chart in Figure 10 showed that this reach, and the upstream Bowman reach, which is just downstream of Stafford Dam, both had very high percentages of bank erosion, 38% to 40% respectively.

The lack of debris jams downstream of Sutro bridge is demonstrated in Figure 14. These downstream reaches reflect the MCFCWCD management activities of wood removal. If the Bowman and Sutro reaches are viewed in the histogram, then the impacts of the dam become more apparent upon quantity of trees and debris jams in the upstream reaches. The excessive bank erosion in these reaches has lead to the subsequent loss of trees and the positive feed back loop that increases bank erosion even more after the trees fall and bank cohesion is diminished. The segment of channel upstream of Sutro Avenue Bridge provides the highest concentration of bank derived sediment, as demonstrated in Figure 11, that showed the highest percentage of combined bank and terrace erosion.

Quantity of Pools > 1' Deep and Large Woody Debris, Along Novato Creek from Diablo Ave Bridge to Stafford Dam

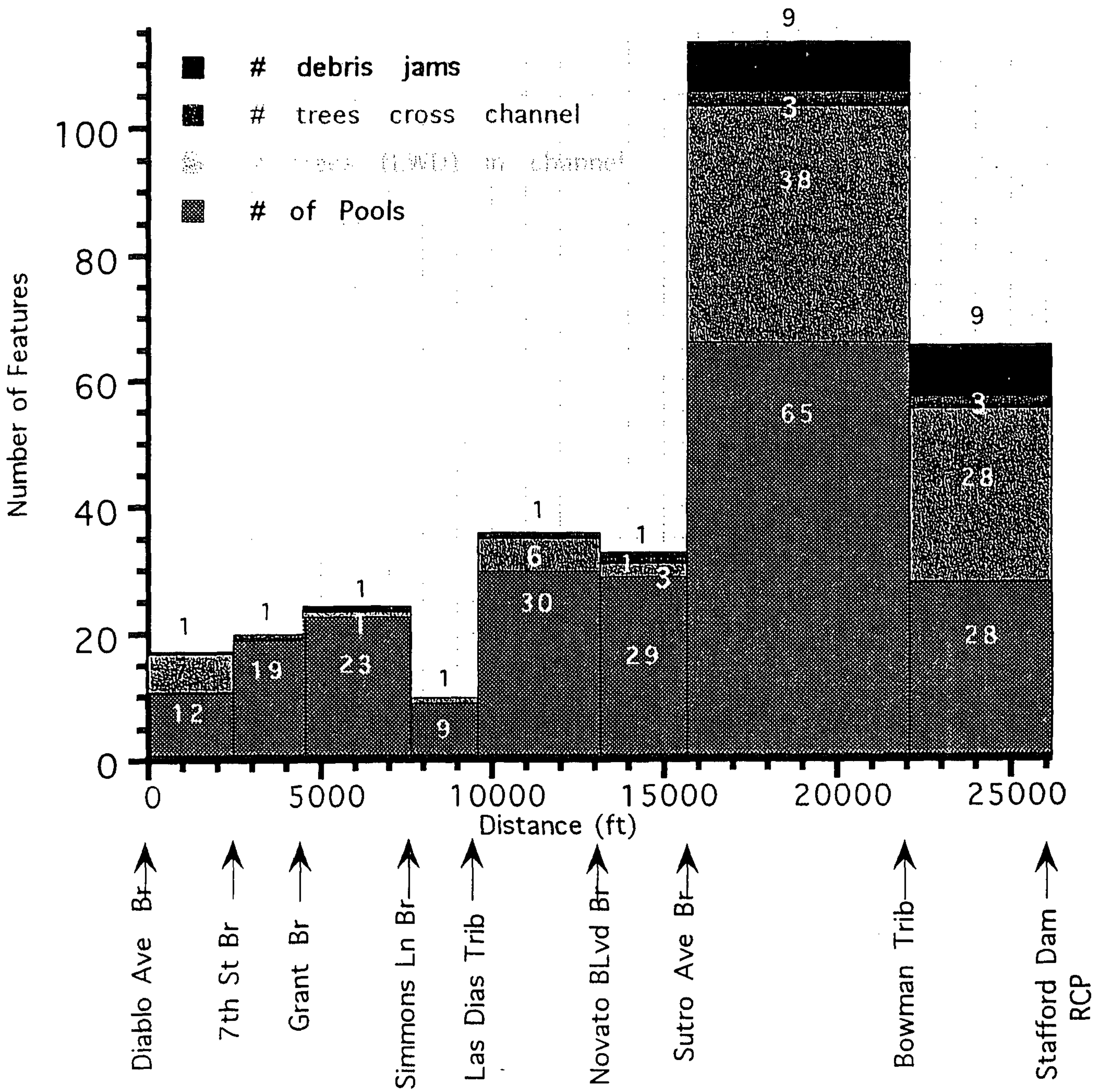


FIGURE 14

The pool forming causes are viewed on an individual reach basis (Figure 15) Sutro and Bowman reaches have over 50% of their pools formed by wood. A discussion of pools is not undertaken in detail since this a report on sediment sources and supply, not of fish habitat. It is notable, however, that pools fill in when sediment supply exceeds transport capacity or unless there is sufficient scour caused by flow obstructions such as LWD. An interesting note is that, the Diablo to 7th reach shows that it doesn't have any pools that are formed by natural features such as bends or bars. In fact 58% of its pools are formed inadvertently by man-made structures. One of the common observations in this reach was that many of the pools were formed by riprap that had fallen out of place from the banks or that abutted into the bed. The 42% of pools that were formed by wood in this reach were mostly scour pools that formed beneath large bay trees with their roots exposed by bank erosion. This is true in many of the other reaches as well.

Figure 16 shows, on a reach basis, the percentage of different types of trees that have already been uprooted and fallen into the channel bed. Although most of the LWD is bay trees from the Sutro and Bowman reaches of Novato Creek, the Las Dias Reach also had a significant input of bays. The other reaches have most of their woody debris supplied by willows. Typically, the willows are growing much lower near the bankfull elevation, whereas most of the bay trees in Novato Creek grow on terrace banks. Bay trees have been observed to grow at the bankfull elevation, which may imply that the large bay trees growing at or near the top of the terrace banks may have established when it was a functional floodplain.

Bankfull Geometry

According to regional curves (Leopold, 1994) which were developed for an average of 30" mean annual rainfall, a drainage area of 17.6 sq mi in the Bay Area would have bankfull width (Wbf) equal to 46', a mean bankfull depth (Dbf) equal to 3.3', and cross sectional area at bankfull (CAbf) equal to 152 sq ft. The drainage area above Stafford Dam is 8.4 sq mi. Therefore, when there is no flow over Stafford Dam, only 9.2 sq mi of area drains to the Novato Creek at the USGS gage site. Flow over the spillway usually lasts about one month, between January and February (Liz Lewis, verbal communication). The predicted bankfull geometry from the regional curve for the smaller drainage area below the reservoir is Wbf = 37', Dbf2.6', and CAbf96 sq ft.

Field indicators of bankfull stage in Novato Creek are not definite. This is because ongoing adjustments in channel geometry have been caused by changes in water and sediment supply from the construction of Stafford Dam, urbanization below the dam, increased drainage density and bank erosion, bed incision, and changes in channel gradient due to realignment and

Novato Creek
Causes of Pools Greater Than 1' Deep for Individual Reaches

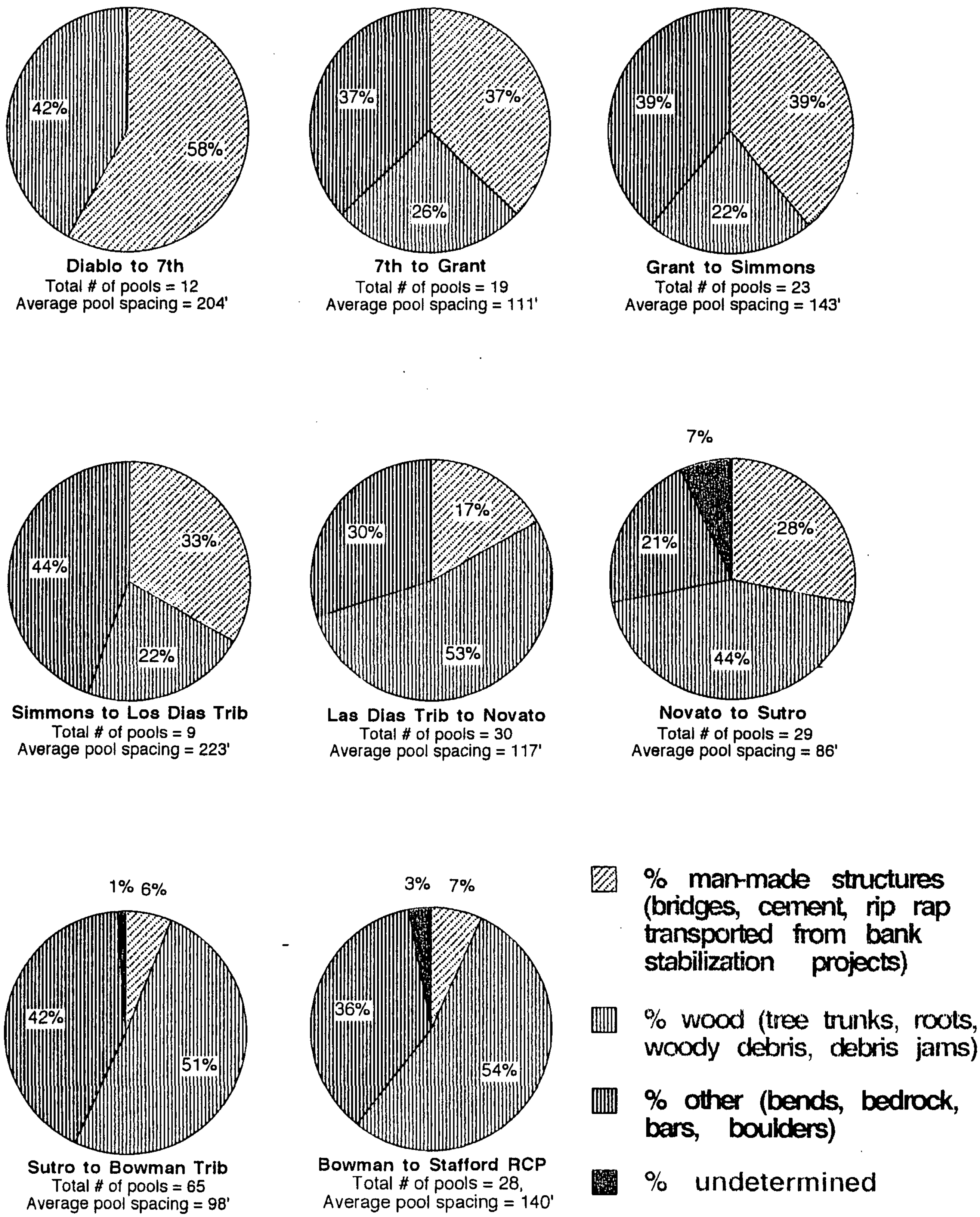


FIGURE 15

Novato Creek
Types of Trees Counted as Large Woody Debris (LWD) Below Bankfull Height for Individual Reaches

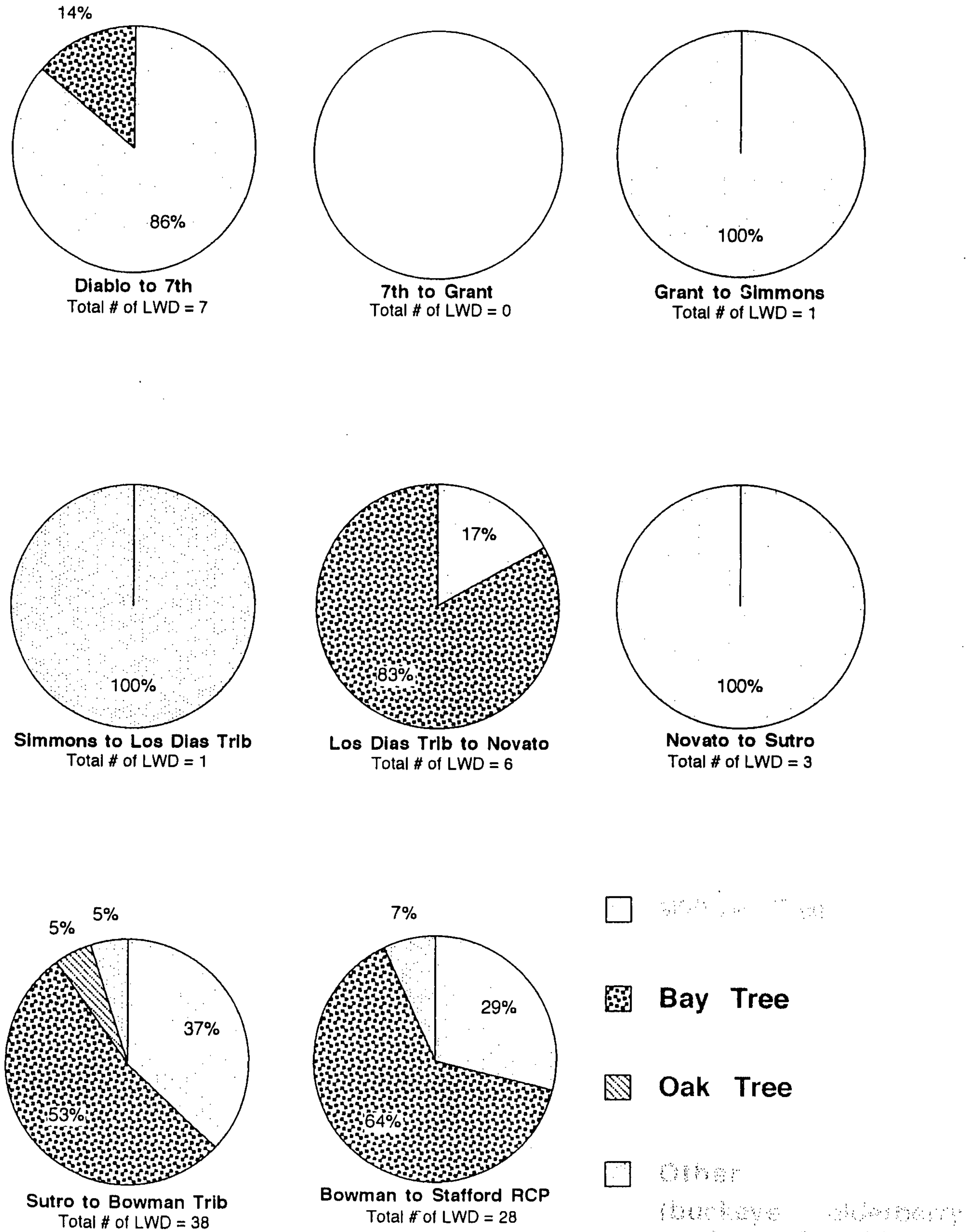


FIGURE 16

channelization. Stability is needed to produce identifiable bankfull features. Based upon occasional spot measurements of bankfull width in the field and a few cross-sectional surveys, see Figures 17a-c, Novato Creek does not fit the expected bankfull geometry of 46' wide and 3.3' deep. The average bankfull width estimated for the entire reach is about 30'. It ranges from 22' to 57'.

The cross sections in Figure 17 were surveyed to show a range of variation in Novato Creek. The Cross Section Stations are also located on the Watershed Maps in Appendix A. The cross section at Station16+00' was surveyed to show the typical channel geometry of a straight reach in the lower portion of Novato Creek. Cross Section Station 212-15' was chosen because it was one of the few reaches that actually appeared to have a floodplain. Here the Wbf is about 48', close to the predicted value of 46' from Leopold's regional curve. This site is shown in Photos 256-266, but the floodplain is hidden from view by vegetation. Cross Section Station 214-90' was chosen because it had significant bank and terrace erosion and substantial gravel bars, See Photo 273. Cross Section Station 216-46', Photo 275 was chosen because it was just upstream of the latter station and probably represented the previous geometry. It shows a Wbf of about 28', whereas the lower site has a Wbf of 57'. The Cross Section Station 238-46' was surveyed to see if there was any substantial change in cross sectional area above Bowman Creek. The cross sectional area was 114 sq ft as opposed to 310 sq ft at Cross Section Station 16-00'. The Cross Section Data for the surveys are located in Appendix A2.

An initial attempt was made to identify bankfull stage in these graphs. The red arrows pointing to the right show the estimated maximum height of bankfull. The thin red line below the red arrow shows a low bank observed in the field. What this low bank corresponds to is not known, but it is above the summer base flow level. The cross sectional area tends to be less than the predicted value from the regional curves for just the drainage area below the dam, that excludes flow from further upstream.

These cross sections give a general impression about the form of the terrace and bankfull banks. Often they are nearly vertical and not distinct from each other. Indeed, in many of the reaches of Novato Creek, if there is bank erosion of the bankfull bank, the terrace bank becomes destabilized as well. But in many areas the top fourth of the terrace bank overhangs the lower portion because it is held together by tree roots, Photo 38 and 235 for example. Many trees are precipitously clinging to the terrace banks.

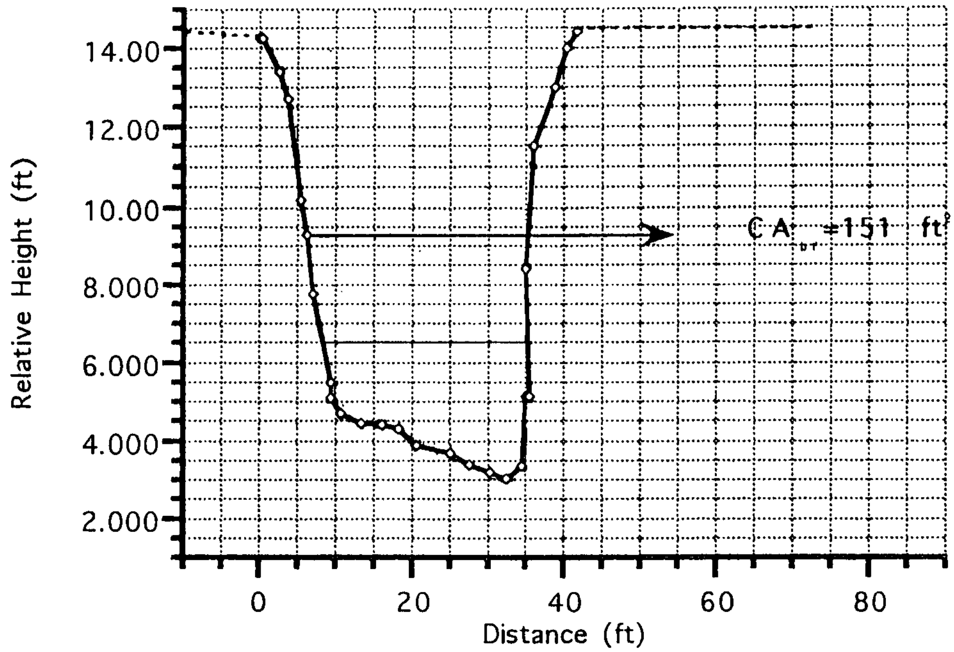
Rosgen Classification

During the field reconnaissance Novato Creek was casually categorized by its Rosgen classification (Rosgen, 1986). Since there wasn't a base map available

Cross Section at 16-00' Novato Creek

Field measured low bank cross sectional area = 65 ft²

Terrace cross sectional area = 310 ft²



Cross Section at 212-15' Novato Creek

Field measured low bank cross sectional area = 64 ft²

Terrace cross sectional area = 725 ft²

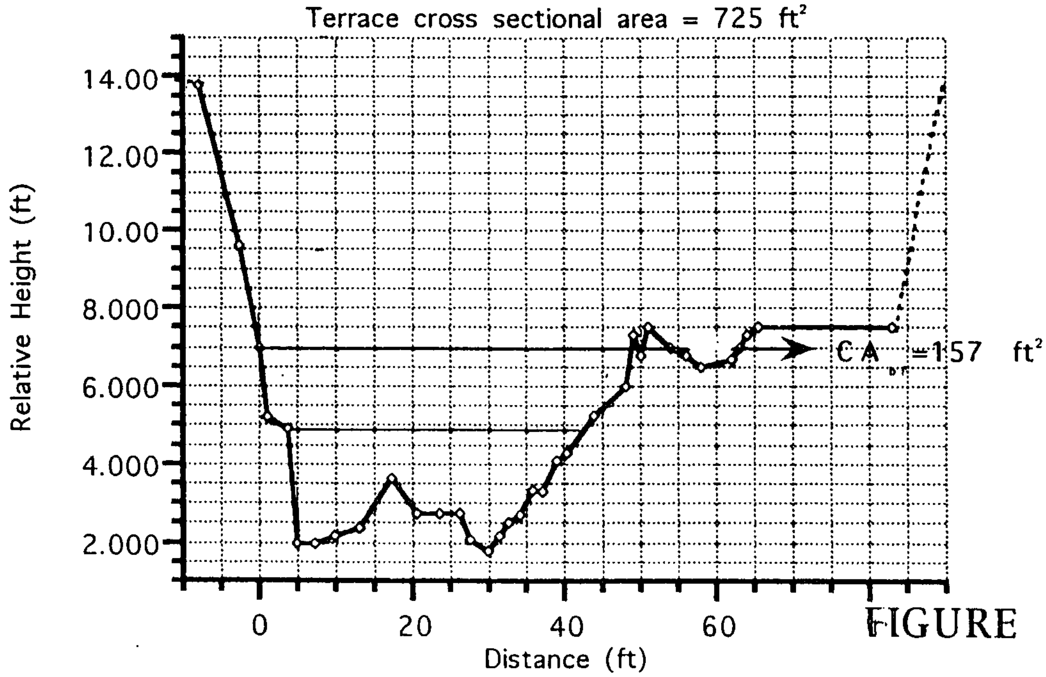
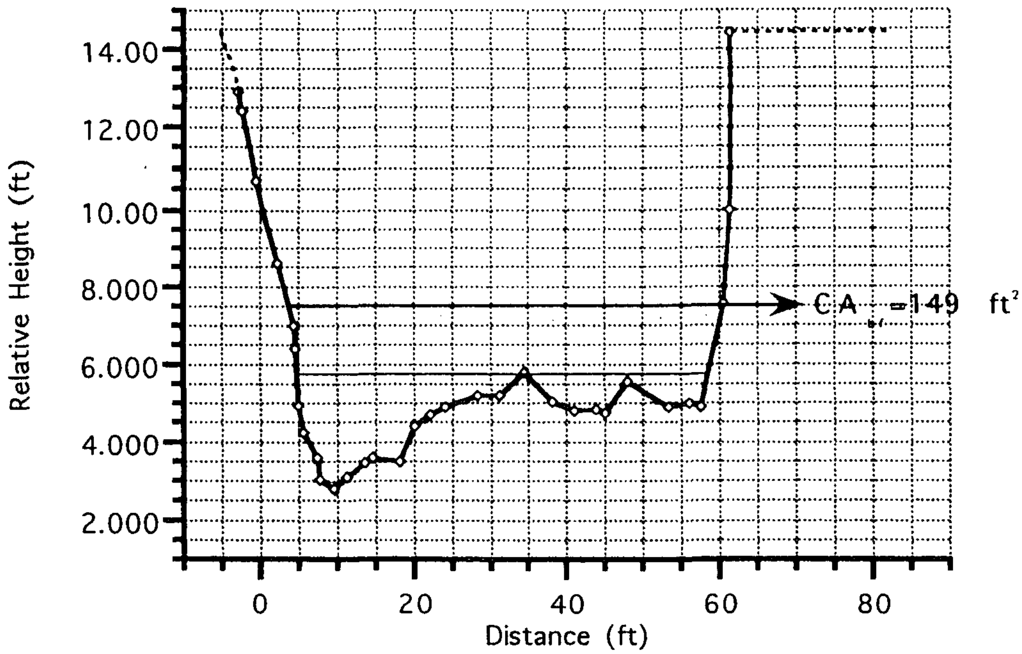


FIGURE 17A

Cross Section at 214-90' Novato Creek

Field measured low bank cross sectional area = 57 ft²

Terrace cross sectional area = 577 ft²



Cross Section at 216-46' Novato Creek

Field measured low bank cross sectional area = 50 ft²

Terrace cross sectional area = 257 ft²

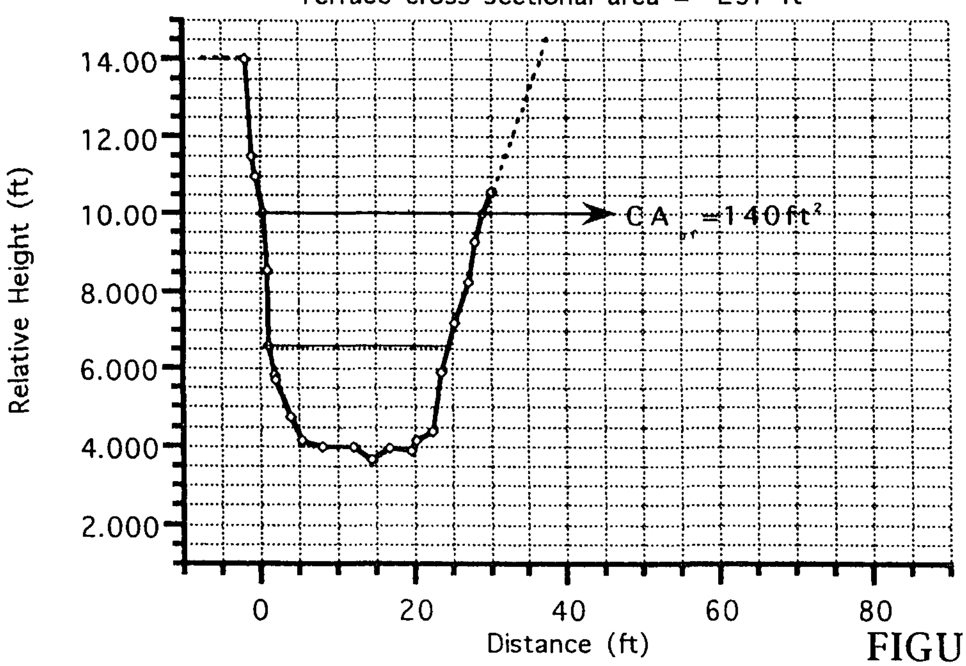


FIGURE 17B

Cross Section at 238-46' Novato Creek

Field measured low bank cross sectional area = 38ft²

Terrace cross sectional area = 307 ft²

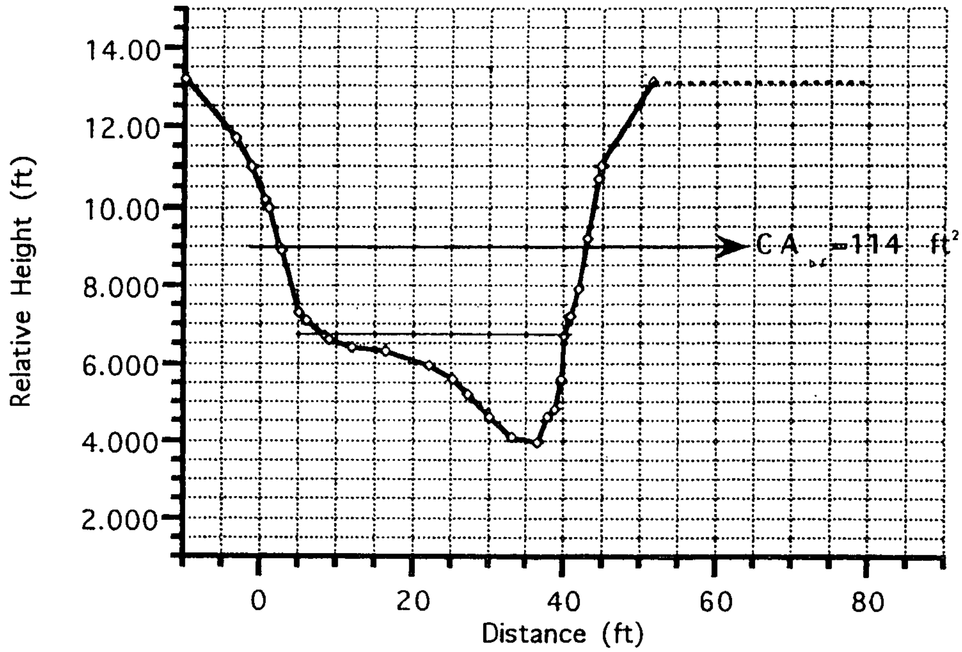


FIGURE 17C

or information on slope, a rigorous delineation was not undertaken. In general, much of Novato Creek fits into the G4 and F4 classification with some occurrences of the B4 class in the Sutro reach, and a small segment of D4 class in the Bowman reach. For a graphic example of the Rosgen Classification scheme see Rosgen Classification Key A and B, Appendix B4.

Rosgen (1997) has described the evolution of entrenched channels through his stream classification system. The central tendency of the incising, entrenched G4 stream type is to have a floodplain, a sinuous channel, and a lower gradient. It will continue to erode its bed and banks in order to increase its meander width (belt width). As lateral extension proceeds, the stream changes morphology from a G4 to a F4 stream type, which is still entrenched, but has a higher width/depth ratio and has ceased to incise. Instead, it continues to erode its banks. When the belt width is sufficiently wide, a new channel is incised into the bed of the F4 stream, making the previous bed the new floodplain of a C4 type channel. Rosgen's graphic representation of this evolution is located in The Channel Adjustments Figure in Appendix B4.

The cross sections in Figure 17 reflect some of the Rosgen classes shown in Table 6.

Table 6. Rosgen Classification Characteristics

Cross Section Distance Station	Rosgen Stream Class
16-00	G4c
212-15	B4c (?)
214-90	F4
216-46	G4
238-46	B4(?)

It is notable that the channel geometry in the lower half of the Diablo to 7th reach almost fits the geometry for an E-type channel because twice the maximum bankfull depth is barely contained within the terrace banks. If the channel aggraded slightly, its entrenchment ratio would change and the channel would become an E-type channel. The Rosgen Classification suggests that this portion of Novato Creek was, perhaps, an E4 channel that has entrenched, thereby initiating a sequence of bank erosion and bed incision characteristic of a G-type channel. The channel within the tidal reaches, before man's alterations, were E-type channels.

Comparison to Earlier Photography and Channel Bed Incision

The comparisons to the 1987 Stueber-Stroeh Associates' photographs, taken between Grant Avenue Bridge and Novato Blvd Bridge, show a tendency of channel bed incision over a ten year period. The table below gives the photo numbers in Album I. A few of the earlier photographs were taken by staff of the MCFCWCD. The original numbering system for the Strueber-Stroeh photos can be found at the top of the "xerox" photograph in Album I and their map location, as shown in the Stuber-Stroeh report, can be found in Appendix B4. For the older photos, station distances are very rough approximations and were estimated from the Watershed Maps, Appendix A1. Rephotography of the sites was performed to compare changes over the last ten years.

Table 7. Rephotography Comparisons

Album Photo #	Stuber-Sroeh Photo #	Roughly estimated Sta dist (ft)	Measured Ht	Incision Apparent	Est. amount (ft)	Notes
53-54	2	45-50		no	0	
56-57	3	45-80	2' root to thwg	yes	1.5	
58-59	4	46-50	3.2' root to thwg	yes	0.5-1.0	
61-62	5	47-50		yes	?	bar has shifted
65-66	6	49-00	6.8' root to thwg	yes	0.5-1.0	
68-69	7	50-50		yes	0.5	bar shifted & less riprap
73-74	8	51-80		?	?	LB bars
77-78	9	54-00	1.4' top of slab to thwg	?	0-0.3	
79-80	10	55-50	A. 1.8' edge conc. to thwg B. 2.2' top of ledge to thwg C. 2.3' top of ledge to thwg	no	0	
81-82	11	57-00	3.5' sackcrete footing to thwg	yes	?	more sackcrete
83-84	12	58-00	3.5"base of trunk to thwg	?	0-0.3	
85-86	13	59-40	1.7' trunk base to thwg	yes	0.3-0.5	more roots exposed on bar & tree slumped into stream
87-88	14	60-50	A. 2.8' root to bed B. 3.2' root to thwg C. 0.55'= root to bed	?	?	

(continued)

89-90	16	62-80		no	0	
91-92	15	64-50	A. 7.5' = bend in root to thwg B.4.7' = root to NC thwg & 2.5' roots to trib bed C. 3.6'= ledge to thwg	yes	2.5 in trib 0.3-0.5 in Novato Creek	
94-95	17	66-00	A. 0.5' = root to bar B. 3.4' = trunk base to thwg	yes	0.1	exposed roots on bar
97-98	18	66-00	2.5' = break in slope to thwg	?	0-0.3	bar missing
99-100	19	70-00	1.9' = 7th row of sackcrete to thwg	?	?	
101-102	20	70-60	1.3' = ledge of concrete to thwg	?	0-0.3	exposed roots
106-107	21	72-70	3.1' =root to thwg	yes	0.3	
108-110	22	73-50	5.1' =root to thwg	yes	0.5	exposed roots, tree has fallen
112-113	23	75-30		yes	0.3-0.5	low bank forming & exposed roots
115-116	24	76-50	2' = root to top of bar	yes	0.5	bar missing, more capacity
118-119	25	77-40	4.2' = root to thwg	?	?	4.2' bank loss @ B, behind tree trunk
120-121		77-68		yes	?	
122-123	26	79-50	A. 1.5' = top of rock to bed B. 1.3' = base of fence to bed	yes	0.3	
126-128	27	82-40	A. 2' =root to bed B. 2' =trunk base to bed	yes	0.3-0.5	bank more defined
133-131	28	88-00	4.8' =root to bed	yes	0.5	bank erosion = 8.2'
135-139	29	91-00	A. 2' = top of grouted rock to thwg B. 2.5' = bdrk to thwg	?	?	
140-142	30	92-80	4.5' = base of rip rap	?	?	riprap apron progressively eroded
143-144a	31	93-00		?	?	some loss of rip rap
145-146	32	93-28	2.8' = edge of boulder to bed	?	?	

147-148	33	95-00	A. 1.9' = top of can to bed B. 2.1' = top of can to bed C. 2.1 = top of apron to bed	yes	0.6 0.8 1.1	
149-151	34	99-00	4.8' = top of wood to thwg	?	?	
156-158					0.5	incision since 1971
159-160	35	107-25	2' = bottom of gab-bion to bed	yes	0.5	
164-165						1978
166-167	36	113-50	1.2' = edge of cmt to thwg	?		slabs have slipped
168-170				yes		2nd slab has slipped
172-173	37	116-00		yes	0.3-0.5	tree collapsed 1996
175-177	38	117-30		yes	0.3-0.5	1974 increased LB bed erosion
171-182						1973-1974
183-184	39	117-30	0.9' = base edge sand bag to thwg	yes	0.3	
186-188	42	120-00	2' = base corner rock to thwg	?	?	
191-192	43	121-00	10.2' = top of terrace to thwg	?	?	bank erosion & tree collapse
	44	122-50	3.8' = top of root to thwg	yes	0.5	more bank erosion
	45	125-50	A. 5.2' = top bdrk to bed B. 2.7' = base of trunk to thwg	?	?	
	46	127-50	A. 12.7' =terrace to thwg B.10.8' = trunk base to thwg	?	?	
	47	128-50	1.7' = bottom of fence to thwg	?	?	
	48	131-00	2' = top of pipe to thwg	?	?	

The average for 31 values of incision reported in Table 7 equals 0.42' in ten years. If the unknown amounts are considered to have no incision, then for 49 values the average incision equals 0.26' in ten years. The average of both these values gives 0.034' per year.

To account for this incision it may be valuable to consider the impacts of the realignment of the tidal reach that is estimated to have occurred about 1925. Roughly 1,750' of channel length was removed, Figure 2. If the channel

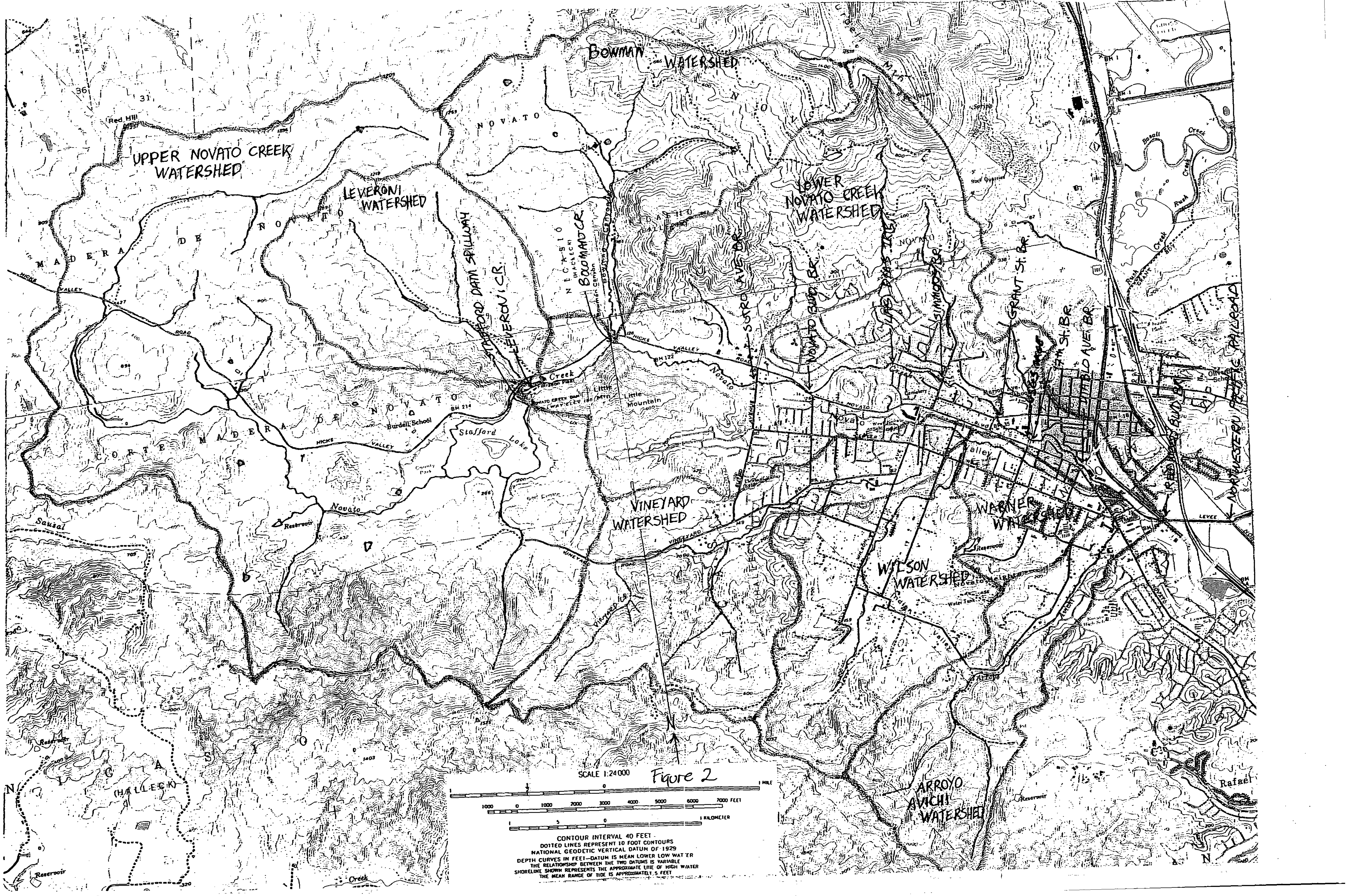

BOWMAN WATERSHED
UPPER NOVATO CREEK WATERSHED
LEVERONI WATERSHED
LOWER NOVATO CREEK WATERSHED
STAFFORD DAM SPILLWAY
LEVERONI CR.
BOWMAN CR.
GRANT St. BR
VINEYARD WATERSHED
WILSON WATERSHED
ARROYO AVICHI WATERSHED
Stafford Lake
Red Hill
Burdell School
Little Mountain
SCALE 1:24000
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10 FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929
DEPTH CURVES IN FEET—DATUM IS MEAN LOWER LOW WATER
THE RELATIONSHIP BETWEEN THE TWO DATUMS IS VARIABLE
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 5 FEET

Figure 2

gradient before channelization in the mid 1920's is assumed to be about 0.00077, which is a pre-channelization slope measured from the 1983 channel profile of Camp Dresser and McKee, then the realigned channel would have to adjust to a drop in elevation of at least 2.2'. Such a drop could have initiated a head cut, causing the channel to incise headward toward the upstream. Interestingly, if downcutting of 2.2' is spread over a 72 year period from 1925 to 1997, it would occur at an average rate of 0.031' per year, similar to the estimated rate from the photos.

Reading Trees and Rates of Incision

Another way to estimate rates of incision is to measure the trunk/root transition height (relative to bed or terrace) and DBH of some of the older trees growing on the channel banks. The data are located in the Tree Data Table in <u>Appendix A2</u>. Certain trees still need to be cored to establish their maximum age, in order to complete this aspect of the analysis. A very tentative discussion of potential incision rates established by analysis of the vegetation is located in <u>Appendix B5</u>. The table below was derived from the discussions in <u>Appendix B5</u>. It is important to keep in mind that incision rates are averaged over time, while actual incision may be pulsed by individual storms and punctuated by channel disturbance.

Table 8. Potential Rates of Incision and Associated Years of Initial Instability

Distance Station (ft)	Photo #	Time Span	Possible Year Growth Began	Roughly est. Rate (ft/year)
7-66	33	long-term recent	1886 1949	0.034
33-65	46a & 46b	mid term	1925	0.036
77-68	117	recent	1949	0.034
101-51	154-155	long-term recent	1873 1952	0.034 0.034
103-19	156	long-term	1850	0.033
103-35	none	long-term	1900	^0.04
103-69	155	long-term	1859	0.030
115-00	171	long-term	1888 or 1835	0.034 0.034
151-24	217	recent	1976	0.045
162-00	225	recent	1952 or 1976 ?	0.059 or 0.045 ?
198-00	251	long-term	1835	0.034
202-90	255	long-term	1835	0.034
206-30	206	long-term	1835	0.046
209-45	261	long-term	1835	0.041
251-47	297	recent	1952	0.046

The reported rates are considered conservative estimates that relied upon the older range of potential tree ages. The estimated rates of erosion show that long-term and recent rates of downcutting are higher upstream than downstream. This may be actual or may represent the fact that the downstream has subsequently aggraded. The estimated years that incision was initiated show two distinct categories. One that ranges around the middle of last century, correlating to the onset of grazing and settlement of the watershed, and the other around the middle of this century, correlated to the construction of Stafford Dam. These estimates may be revised, if tree dating is performed.

Comparison to Previous Studies
Six cross sections installed in the Diablo to Grant reach in 1985 by the MCFCWCD were resurveyed by staff during 1998. The cross sections are located in Appendix A3. The rate of downcutting for these sections was determined to be 0.13' per year (verbal communication from Liz Lewis), almost 4 times more than the estimated amount from the rephotography analysis that spanned the reaches from Grant Ave Bridge to Novato Blvd Bridge. If this rate was applied to the Diablo and 7th St reaches the channel would have incised 9.5' in the last 73 years. Perhaps the higher rate downstream for the ten year period reflects some influence of dredging and channelization.

In 1986 Prunuske Chatham described and documented sediment sources by walking portions of Warner Creek and Arroyo Avichi, and the main stem Novato Creek between Grant Ave and Stafford Dam. They quantified the length of bank erosion per length of channel (see Table 9) and determined that the ratio of stream bank failure to channel length was 1 : 2.2. Data from this 1997 study gives a ratio of 1 : 1.6, showing a possible 57% increase in bank erosion. Unfortunately, it is not known if the sites of "bank failures" measured by Prunuske Chatham were actual slumps or just eroding banks. There is no reported threshold for their identification of these features. Thus it is difficult to definitively establish that bank erosion has increased by 57% over the last 11 years or if the process of assessing is different.

Table 9. Length of Stream Bank Failures (feet)

Data Source	Stafford to Grant	Stafford to Sutro	Sutro to Grant
Prunuske Chatham 1986, total length of failures	9385	4495	4890
Collins 1997, total length of eroding banks (> 0.5' bank retreat)	16488	8677	7811

In 1977 the nearby 69 sq mi watershed of Walker Creek was assessed by William Haible for changes in its longitudinal profile. Haible (1979) reported 5' of incision in the uplands during 60 years, which equals a rate of 0.08' per year, and aggradation in the lowlands of 4' at a rate of 0.07' per year (Haible, 1980). This is twice the conservatively estimated rate for Novato Creek. Haible concluded that the whole longitudinal profile was adjusting to become less steep and that these adjustments of depth, velocity, and roughness were caused by changing watershed conditions from cattle grazing. He also found that all the tributaries showed the same sequence of aggradation and degradation. Similar observations have been made in Novato Creek watershed.

Changes in Drainage Density

The drainage density (length of channel per unit area of drainage basin) of the watershed has increased since pre-European settlement due to early agricultural ditching, impervious surfaces, roads and road drains (including dirt roads and ditches in the agricultural zoned areas), foot and cattle trails, gullies, headward extension of 1st-order channels, and incision of previously unchannelized alluvial fans. The extent to which drainage density has increased is unknown, but it has dramatically increased over the last 160 years. This could also account for the downstream channel adjustments in channel geometry.

The early etching of Rancho Novato, <u>Appendix B4</u>, shows that major channels such as Warner Creek were not connected to the main Novato Creek. It is possible that Warner Creek and its tributaries spread out in a fan at the base of the steep hillsides, causing the water to go subsurface and contribute to the overall water table of the valley bottom. Warner Creek, which meets below S. Novato Blvd Bridge accounts for about 12% of the total drainage area. Clearly, the tidal channel below Warner confluence has had to adjust to flows and gravel-sized sediment that the Warner drainage ditch carried when it was constructed in the 1800's.

Along the Sutro to Bowman reach of Novato Creek, several small streams that flow from the southern grassy hillslopes were observed to have small channelized fans at the base of the hills. It is probable that many of these small channels never reached Novato Creek prior to the 1830's because the channels had insufficient capacity to carry the sediment supplied by debris flow processes across the flat gradient of the valley bottom. Alluvial fans were aggrading the base of the steep slopes and surficial flows infiltrated to groundwater supply before they reached Novato Creek. The tributaries draining the slopes of Burdell Mountain may have been similarly disconnected. As a result of increased runoff from grazed hillsides channels eventually incised into the fans and directly supplied water and sediment to mainstem Novato Creek. These tributaries now convey water by subsurface storm drains through the urbanized areas of Novato. The process alluvial fan incision is documented from the field reconnaissance in Vineyard Creek. First order channels have also been observed to be actively eroding headward in Bowman, Vineyard Creeks and Arroyo Avichi. The observed processes in these sub watersheds can likely be extrapolated to other unobserved headward channels throughout the watershed.

The changes brought about by cattle grazing caused more water to be transported from the headwater hillslopes, which then had sufficient stream power to erode a channel into the fan and connect the supply of sediment and water to the main Novato Creek. The generation of more water from the hills was caused by the impacts of grazing, i.e., change in perennial bunch grasses to annual grasses, increased soil compaction, reduced infiltration, and reduced interception due to minimal thatch cover in early winter.

As Novato Creek incised, the tributaries that had been graded to a certain base level also began to have upstream migrating headcuts. Some steps or nick points can be observed near the confluences of many of the channels.

If Novato Creek is still adjusting to relatively permanent alterations in drainage density by continuing to incise its bed upstream of the NFCP, then excessive bank erosion will continue, due to the greater shear stresses exerted by larger contained flows. As more trees collapse into the channel, the reduction in bank cohesion by loss of root strength will accelerate bank retreat (see Photo 267-268). For this reason it will also become increasingly difficult to establish riparian vegetation within the entrenched banks until sufficient widening occurs to create a floodplain within the high terrace banks.

Roads and Urban Runoff

Like any urbanized development the increased impervious in impervious areas has increased the drainage density of Novato Creek and effected the hydrograph in ways already discussed. It is worth noting that along the open space and undeveloped areas very few gullies associated with road runoff were observed. Most of the paved areas have runoff that enters the storm drain system and enters Novato Creek through a culvert, the location of which were noted in the Field Notes.

Hillslopes and Landslides along Mainstem Novato Creek

On the hillsides adjacent to mainstem Novato Creek, there are few landslides that flow directly into the channel. Most of the channel is separate from the slopes because it is entrenched within its broad alluvial terrace. Only the right bank occasionally intercepts the hillside canyon walls. The reaches where the landslides occur are Las Dias, Sutro & Bowman reaches, as shown in the Pie Charts in Figure 11, where the percent of total length of bank effected by landslides within each reach is 3%, 2% and 12%, respectively. The total percentage for the Diablo to Stafford reach is only 2.7%. Most of these slides were more active in the past and appear to be stabilizing. Thus landslides adjacent to Novato Creek, supply minimal sediment compared to local bank erosion. The types of slides ranged from earthflows (revetted by gabbions, Photo 160), debris flows (Photo 293), debris slides (Photo 193), to inner gorge dry ravelling within older landslide scars (Photo 287).

Gully erosion was minimal, but most prevalent in the Bowman and Sutro reaches where cattle pastures are situated along the left bank (Photos 264 and 282). The lateral extent of these gullies is small. Gullies associated with road erosion were not observed.

Conclusions for Mainstem Novato Creek

The total conservatively estimated volume of sediment from bank erosion in Novato Creek is approximately 30171 cu yds. This total amount is only 67% of the volume of sediment that was dredged from the NFCP in 1996, which was about 45,000 cubic yards. Even if this conservative estimate was doubled, similar volumes of sediment have been dredged in years past. This indicates that significant sediment sources exist elsewhere in the watershed and that tributary channels must be additionally transporting high amounts of sediment to the NFCP. The volume of sediment from the banks can be visualized by spreading it over the bed along the length of the Diablo-Stafford study reach. If the bed averages 25' wide, the sediment from the bed would raise the bed 0.9' thick. However, the bed presently stores more than this amount of sediment, based upon observations of gravel bar height. These observations indicate that a high proportion of the sediment load is provided from sources other than local banks and terrace erosion of Novato Creek proper.

To a small extent the additional sediment sources that might account for the large amount of sediment stored in the creek bed of the Diablo-Stafford study reach include adjacent hillsides. However, the sediment supply from the hillsides is exceeded by the supply from banks and terraces.

Bankfull discharges appear capable of transporting and distributing the load downstream to the tidal reaches. No particular site appeared completely overwhelmed by sediment although local aggradation was occasionally noted. The amount of storage, as bars in the channel bed, was greatest in the reaches that have widened enough to become Rosgen B-type channels and it is in these areas that terrace bank erosion is shutting down and habitat complexity is greatest. The rest of the entrenched G and F-type channel, which comprises most of Novato Creek, effectively transports the sediment eroded from local banks and conveyed by tributaries to the NFCP.

The reduction in tidal channel gradient caused by diking of the marshes, realignment, channelization, dredging, and backwater from the NWPRR Bridge, has caused the NFCP to become a sediment trap that cannot, under present conditions, maintain the desired design capacity without continued dredging. The bulk of the deposited sediment in the NFCP is from upland sources as demonstrated by the gravel-sized sediment deposited beyond the railroad bridge and the organic matter that ranges in size from large woody debris to leaf litter.

The adjustments in channel geometry and stream gradient are associated with land practices during the last two centuries. Two dominant periods of channel incision appear to be associated with 1) the early to mid 1800's when cattle grazing and agricultural development of the valley began, and 2) the mid 1900's when Stafford Dam was constructed. Sediment production from combined bank erosion and bed incision appears greatest in the reaches closest to the dam. The channel gradient from NWPRR Bridge to Stafford Dam is effectively flattening by incision in the uplands and deposition in the lowlands as it adjusts to sediment load contributed by the entire watershed that is much greater now than prior to the early 1800's. The total amount of water supplied to the channel has increased since this time due to greater drainage density caused by headward extension and connection of tributary channels, urban storm drains, ditches, impervious surfaces, and impacts of cattle grazing. Steam flow and its distribution has been altered by water diversion and retention in Stafford Reservoir. Sediment supply from bank erosion of just Novato Creek has compensated, in part, for the trapping of bedload upstream of the dam. The fact that the total volume of sediment supplied from the banks is only 67% of the amount of one cycle of dredging in the NFCP indicates that there is substantial supply and transport from the five main tributaries of Leveroni, Bowman, Warner, Vineyard and Arroyo Avichi.

BOWMAN CREEK

General Background

Bowman Creek is within a 3.1 sq mi watershed in the northern portion of the Novato Creek watershed, Figure 2. Vegetation in Bowman watershed is a mixture of grasslands on the south facing slopes ranging to mixed oak-bay woodland on north facing slopes. The main Bowman Creek flows southward from an elevation of 1458' to about 140' where it meets the Novato Creek at Distance Station 220-51'. Data collection of the mainstem Bowman Creek extended from Station 0-00 at the confluence to 29-74' upstream. Further data collection in the channel was not possible when trespass was prohibited onto private property. Unlike the other main tributaries to Novato Creek, landslides were mapped and a hillside reconnaissance was performed to assess headwater channels and to verify landslide interpretations. The hillside reconnaissance has station numbers that correspond to stations shown in Photo Album II and the topographic map, in Figure 18.

Hicks Valley Road crosses Bowman Creek at Station 2-87' to 3-25' upstream of Bowman's confluence with Novato Creek. The possible extent of backwater influences from Novato Creek and the hicks Valley Road box culvert may extend to Station 6-25'. The study reach flows mostly through alluvium of terrace deposits, but in two reaches we called 2A-type (Field Notes, Appendix D), bedrock and canyon slopes are intersected along the right bank. These bedrock reaches may have slightly steeper gradients than the alluvial reaches.

Historical and present day land use in Bowman watershed has been primarily cattle grazing and dairy ranching. A number of unsurfaced ranch roads access the ridges and valley lands. There is also a gravel quarry in the middle of the watershed on a small, isolated hill. It is presently inactive and runoff drains into a sediment catchment basin.

Channel Reaches and Rosgen Classification

During the reconnaissance Bowman Creek was divided into geomorphic reaches, as discussed herein. There is no map accurate enough to display the channel Distance Stations for Bowman Creek. Reach 1 extends from the confluence to 8-37', see Photos # 302 and 305 for example. The channel flows continuously through alluvium. Many of the banks are composed of gravels. It's Rosgen Stream Classification is G4-G5. Bank erosion and bay tree root exposure is pervasive. Many of the trees are still standing upright along the terrace banks even though they have been severely undermined. These trees form a continuous riparian canopy and few other vegetation types are present between the bare terrace banks. The reach is dominated by

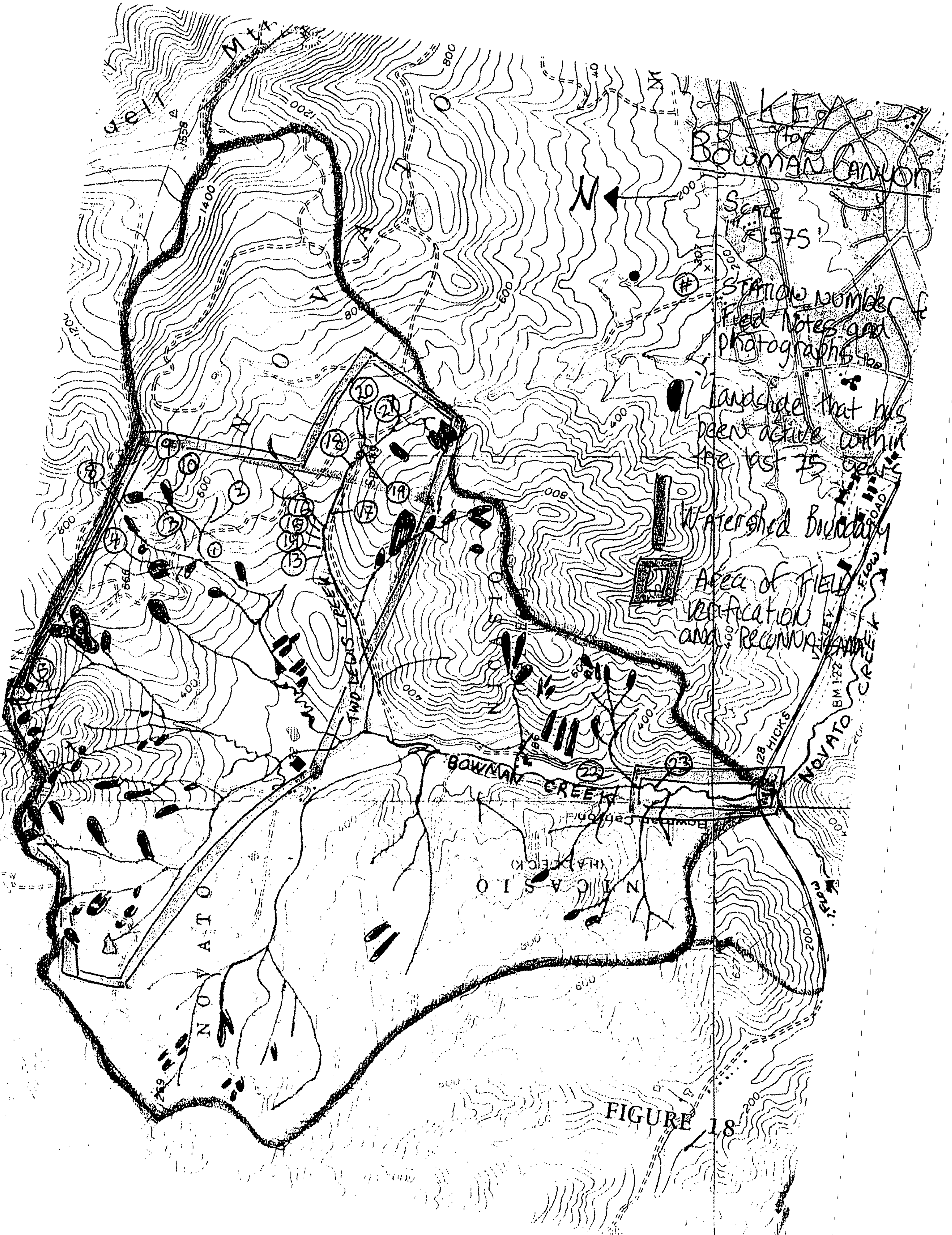

KEY for
Bowman Canyon
N
Scale
STATION NUMBER for Field Notes and photographs
Landslide that has been active within the last 75 years
Watershed Boundary
Area of Field verification and
BOWMAN CREEK
NOVATO
NICASIO
NOVATO CREEK
HICKS
ROAD
FLOW

FIGURE 18

abundant fine gravel and sand. There are no significant pools, yet trout fry are observed. This reach is influenced by backwaters that form from high flows in Novato Creek and from debris that catches at the Novato Blvd Bridge. Such backwaters have contributed to the deposition of gravel bars that are as much 2.3' high.

Reaches 2a, from 8-37 to 9-78 (Photo # 315, for example) and 12-22 to 13-35, have steeper slopes, tend to be narrower, and intersect bedrock from the RB hillside. Rosgen classification is G4. This reach may also be above possible backwater influences from Novato Blvd Bridge. Larger cobble-sized clasts are contributed from the hillside. Plant diversity along the channel is slightly higher because of the hillside soils providing a different substrate than the alluvium. Poison oak, snowberry and ferns are occasionally present. The relative proportion of gravels to sand is slightly greater than in Reach 1. Gravels are also larger.

Reaches 2b, Station 9-78' to 12-22' and 13-35' to 18-35' (Photo 318) have terrace and bankfull banks that do not intersect hillsides. Bay trees predominate the terraces but there are more grasses and herbs beneath the tree canopy. Stream gradient is gentler than 2a reaches. This is a Rosgen G4 type channel but bankfull width is wider and terraces are higher than 2a reaches.

Reach 3 extends from 18-35' to 25-22'. It is an extremely wide reach in open grasslands with no trees on the banks. The trees may have eroded away long ago. Segments range from a G4 to something between a C4 and B4 Rosgen Class, see Photos # 22 and 26. The terrace banks are mostly fines but have lenses of gravels. Bank erosion has been significantly higher in this reach than any of the others due to lack of root strength in the banks. Several sets of terrace banks exist in this reach with the highest being over 14'. A predominant inner terrace between a meander bend is about 8' below the highest terrace and a smaller less developed terrace is about 10' below the high terrace. The latter may have been the bed level of the former channel. The current floodplain, which was likely a former bed level, is about 1.8' above the present bed level. This reach may have changed from a Rosgen F-type channel to a C-type channel.

Reach 4 analysis is incomplete because we could not continue on private property. Most likely this section is similar to the 2b reaches, see Photo # 332 for example.

Bank Condition

Although the lateral extent of eroding banks and revetment was not measured for any channels other than Novato Creek, notes were taken about the amount of bank retreat at discrete points during the Bowman Creek reconnaissance. The Field Notes and Bowman Creek Data are located in Appendix D.

Maximum bank retreat measured was 14' at Station 22-50. The average of all point measurements is about 7.1'. Since these measurements tended to be taken at the more severely eroded sites, but also noting that bank erosion appeared almost continuous throughout the study reach, a more conservative estimate of a foot or two less might be plausible for the average amount. On the other hand, analysis of width between the exposed roots on the terrace banks suggests otherwise.

For example, at Station 8-60 the width of the channel between exposed roots of bay trees growing on the terrace demonstrated that the historical channel width used to be narrower: about 12' wide when the valley flat (present day terrace) was the functional floodplain, as compared to the presently entrenched 16.5' bankfull width at this station. Near this site some channel widths, between roots along the terrace banks, range from as little as 6'-9'. Three other sites where bank erosion and bankfull width were measured showed that the historical channel width was 10', 12' and 14'. If all the discrete point measurements of present day bankfull width were averaged, 21' would represent bankfull width. If the average bank erosion value of 7.1' is subtracted from the 21' bankfull width, then the historical average bankfull width would have been about 14', which is on the high end of the four historical width measurements. The estimated historical widths indicate that the estimate of 7.1' average bank erosion for Bowman Creek study reach may be reasonable.

Bank condition was also observed on Two Lewis Creek tributary, which is confluent to Bowman Creek, see Figure 18. In some areas it has eroding, unstable banks that exceeded 18' in height and it has evidence of continuous bank retreat as demonstrated by exposed tree roots, see Photos 351 through 356 The rate of supply of fine sediment per linear foot of these banks is expected to be chronic and exceptionally high.

Bankfull Geometry

Regional curves for the Bay Area (Leopold, 1994) predict that bankfull width should equal to about 23', mean depth should equal 2', and cross sectional area 46 ft^2. Measurements collected in the field for this study give averages of 21', 1.9', and 40.5 ft^2, respectively. The historical channel, as of about 165 years ago, may have had a narrower and deeper channel geometry, and it would have been less entrenched. This would be due to the lower amount of runoff coming from the hillsides that had not yet been grazed or converted to European grasses. Based upon the width measurements between roots on the high terrace and the amount of measured bank erosion, if the historical average bankfull width was somewhere between 7.1' to 14' , and grossly assuming that bankfull cross sectional area would have been 90% of the present amount because of reduced drainage density, then mean depth could have been between 5' and 2.5', respectively. Perhaps depending upon whether it was in a bedrock or an alluvial reach.

Channel geometry was also noted on the third order tributary Two Lewis Creek. At Station 19 the configuration of roots in Photos 359 and 361 silhouetted the former shape of the channel before it was entrenched. The historical cross section was about 6' wide by about a maximum of 1.5' deep. The cross sectional area may have been about 7 ft^2. The present channel is much wider, shallower and entrenched. Slightly downstream at Station 14, the bankfull width is 6' and may have a bankfull depth of about 1.8'. Determination of bankfull was imprecise since the channel was actively incising. The best guess of mean bankfull depth is about 1.8'. This suggests that at this site the historic bankfull cross sectional area was 83% of today's amount, substantiating that the channel has had to adjust its bankfull cross sectional area to accommodate more runoff.

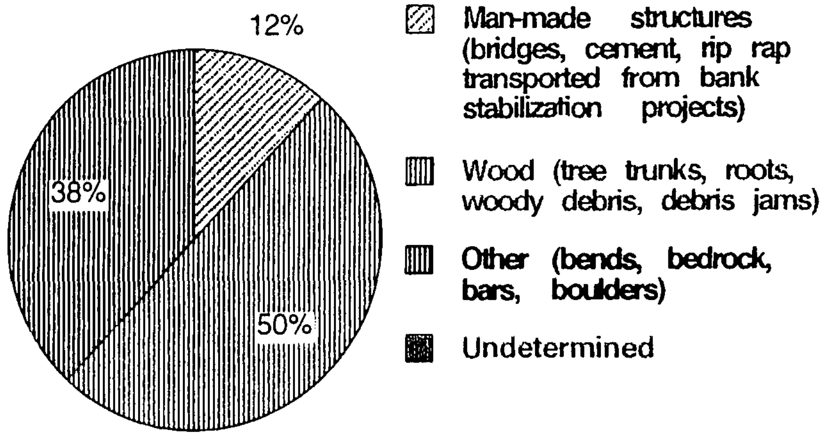
From the analysis of the historical stereo photos of Bowman Canyon, it is apparent that the process of headward erosion of first order channels, bank erosion of all orders of channel, and incision of fans at the base of steep canyons was well underway by the 1950's. Field analysis verified that these processes are still ongoing and perhaps most active within headward reaches. For example, Photos 336 and 337 show a headcut migrating up into a tiny ephemeral channel. The cross sectional area for the gully is about 20 times greater. Photos 344, 345 and 346 show the same phenomenon on another tributary where the difference in cross section is similar. Many of the headwater reaches in Bowman Canyon are anticipated to be in a similar condition.

<u>Bed Condition Relative to Pools, Wood and Sediment Storage</u>

Figure 19 shows the results of the pool and woody debris analysis for the 2974' long study reach in Bowman Creek. The upper pie chart shows the total number of pools greater than 1' deep within the study reach was 8. One pool was formed by rip rap, three were from bends, two were from bay tree trunks and the other two were from woody debris. The total number of pools is less than that which would be normally expected for every 5-7 bankfull widths. For example, assuming that the average bankfull width is 21', pool

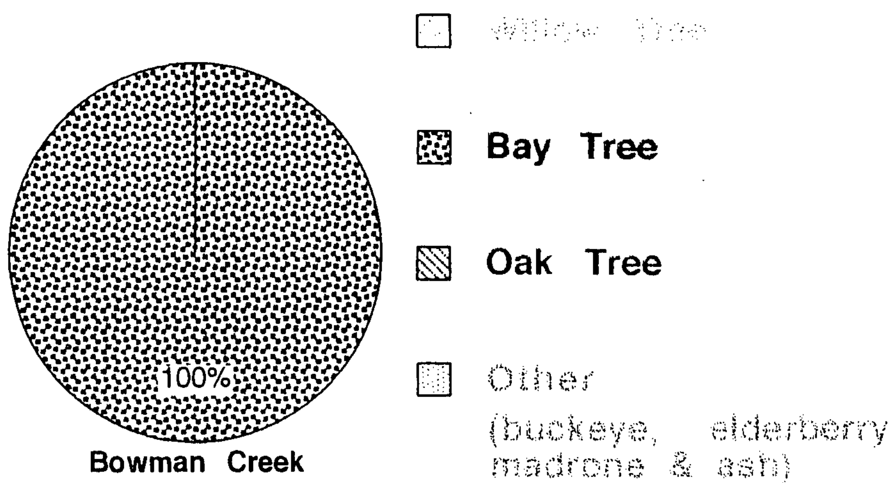
Bowman Creek Pool and Woody Debris Characteristics for All Study Reaches

CAUSES OF POOLS GREATER THAN 1' DEEP



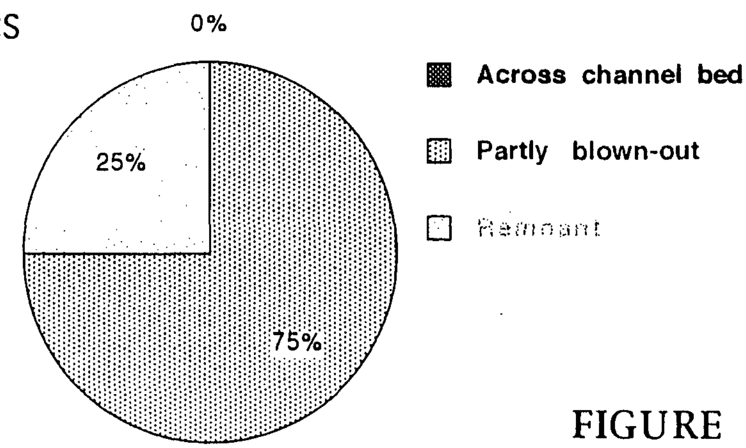
Bowman Creek
Total # of pools = 8, average pool spacing = 368', study reach distance = 2974'.

TYPES OF TREES COUNTED AS LARGE WOODY DEBRIS BELOW BANKFULL HEIGHT



Bowman Creek
Total # of LWD = 13

DEBRIS JAM CHARACTERISTICS



Bowman Creek
Total number of debris jams = 6

FIGURE 19

should be spaced within 115'-175', but Bowman Creek pool spacing was only 368' (equal to 17.5 bankfull widths), indicating that even though the channel has perennial flow, sediment load overwhelms the capacity of the channel to maintain pools deeper than 1'.

The middle pie chart shows that all the large woody debris in the channel was from bay trees. The lower pie chart shows that of the total of 6 debris jams noted, none of them fully blocked the channel.

Sediment storage within the active bed was also quantified from stations 3-47' to 21-33'. For this 1786' long reach, total volume of sediment in storage, above the mean bed level, was 482 cu yds. If this amount was spread out over the length of the channel, on a bed that averaged about 16' wide, then the amount of fill above the mean bed level would equal 0.46'. If the volume is divided into the appropriate amounts for Reach 1 (backwater influenced area, 483') and Reach 2 (upstream of backwater, 1303'), then the height of fill would equal 0.33' and 0.81', respectively. This corroborates that Reach 1 is more of a depositional reach than Reach 2.

Within the Two Lewis Creek, sediment storage within the bed was low. Sediment on the bed was usually a shallow veneer, usually less than 10% the largest cobble-sized particles that were left behind as a lag deposit, see Photos 352 and 364 for example. This is because the discharge and gradient are sufficient to transport most of the supplied sediment to the lower gradient reaches.

In the observed steep headwater channels sediment storage on the bed ranged from minimal where debris flows had scoured to bedrock (Photo 339), to minor where the bed was composed of coarse gravel and cobble lags of colluvium or debris flow deposits (photo 335). Where slopes were less steep or where there was no source of coarse-sized colluvium the bed was composed of fine soil-sized particles derived from either erosion of gully walls (Photo 336) or surface erosion of grassland soils by overland flow and raindrop impact (Photo 346).

Reading Trees and Rates of Incision

Throughout the length of the study reach on main Bowman Creek, there is evidence that there were two periods of relative channel stability, see Photo # 313 for example. These periods are represented by roots at heights that average for the whole study reach about 5' and 8.7' below the terrace of the valley flat, which has an average height of 10.7' above the bed. These elevations may represent former stable bed levels. In the reaches where historical channel width was 6'-9' wide, bankfull depth must have been at least 5'. If the channel, like Novato Creek, has cut down 5' in the last 165 years since the onset of grazing, and 2' since the construction of Stafford Dam, (which lowered the base level of Novato Creek thereby producing a migrating headcut through Bowman Creek), then the earlier downcutting rate would have equaled 0.031' per year and the 2' of recent incision would have a rate of 0.043' per year. The long term average would be 0.34' per year. These rates correspond to the rates reported for Novato Creek.

On the third order Two Lewis Creek tributary at Station 19, roots of a bay tree were exposed 4.5' above the channel bed, see Photos 359 and 361. The bay tree is estimated to be no older than 100 years. This would give a downcutting rate of 0.045' per year. Downstream at Station 15, Photo 353 shows a person standing on roots that define a former bed. The current bed is 2' lower, corresponding well with the observed recent 2' incision level in Bowman Creek.

At Station 20 , Photos 362 and 364, a second order tributary channel to Two Lewis Creek has a bed that is showing incision within a few feet of the confluence. A few feet back it's bed is 5' higher than the bed of Two Lewis Creek. This corresponds to the stable root level noted in mainstem Bowman Creek and the level of the exposed roots at Station 19. The recently exposed tree roots indicate that an active headcut is beginning to incise the second order tributary.

<u>Hillslopes and Landslides in Bowman Watershed</u>

Figure 18 shows the distribution of recently active landslides in Bowman Canyon, as mapped from the 1995 stereo photos, that have moved within the last 25 years. The area outlined in pink shows the boundary of the area inspected during field reconnaissance. Without substantial field reconnaissance it is not possible to determine the linkage of all the slides to the channel network, especially for those within the tree covered slopes. The landslide mapping does demonstrate, however, that numerous slides exist at the heads of first order drainages and at isolated locations on the hillslope. The active slides were shallow features that ranged in type from slumps to soil slips.

Slides at the heads of drainages within the zero order basins are obviously more problematic at supplying sediment to the stream system than the slides on the open hillsides. Not only because they have direct input to the channel, but because when the debris slide occurs, it tends to scour all the sediment in its downstream path until it can either be deposited at a lower gradient or until it is sufficiently diluted by additional tributary flow that stream flow can continue to transport it as bedload. The total amount of sediment that becomes bulked within the debris flow can ultimately be orders of magnitude larger than the initial shallow failure at the head of the drainage. Within the observed reconnaissance reaches, sediment input to channels from landslides was mostly associated with saturated hillslope conditions at the heads of first order channels rather than from removal of lateral support by stream cutting along the channel length.

The active failures in Bowman Canyon do not typically have their entire scar fully evacuated of sediment, see photos 340-343, and 347-348. Instead, the slump areas in particular may be fairly chronic suppliers of fine sediments every few years since their episodic movement may occur with storms that have a recurrence interval of 5-15 years, and the time required for stabilization and revegetation may be 10 to 25 years.

Shallow landsliding and slumping appears as though it might have been more active in the 50's than in 1995 when the stereo photos were taken. An initial hypothesis is that the frequency of shallow landsliding has increased since the mid 1800's. Such an increase may be largely due to associated grazing and conversion of perennial, native bunch grasses to the annual European grasses. Such conversion would decrease soil cohesion that helps resist landsliding on steep slopes because: 1) the roots of the perennial grasses would remain viable year round, whereas roots of the annuals decay during winter; 2) the bunch grasses have much deeper rooting depths than the annuals, often 6' for perennials as compared to 3' for annuals; and 3) soil saturation that causes slides would occur with less rainfall, since soil coverage of remaining thatch of the grazed, dead annual grasses would be much less than the thatch associated with ungrazed, viable bunch grasses.

As drainage density has increased from more runoff in the grasslands and channel heads have migrated upslope, unchannelized fans have also become incised, channels have adjusted their geometry to larger bankfull discharges by entrenching, and gullies have dissected the hillsides. Within the zero order basins, it may be likely that the modern landscape has more shallow landslides than there were 165 years ago and scouring from the resulting mobilized debris flows has moved channel heads upslope to the base of the debris slide scars. The formation of gullies may also be more likely in the converted grasslands. For example, surface erosion is more likely if there is more runoff and if the soil cohesion is reduced. Both of these requirements have been achieved. Photo #338 shows an example of a gully that is presently stabilizing. In concept, if grazing practices in this watershed were most intensive during the earlier part of this century, then improved land management strategies and grazing practices could account for the more stabilized appearance of the landscape in 1995 (and 1997) than in 1950.

As grass conversion and grazing proceeded to increase runoff and channel entrenchment, it is possible that downstream transport of mobilized landslide debris has concomitantly become more proficient and residence time for stored debris flow sediment may have similarly decreased. For example, if a debris flow is carried within a shallow or wide channel, the slurry can spread out over the banks as berms (where its residence time as stored sediment will likely be long) or as bars within the channel bed where the gradient flattens. If the channel becomes deeply entrenched then sediment will be kept within the banks of the channel (thus no long residence times), shear stress to banks will be increased (thus more sediment will be entrained and transported), confinement within entrenched channel banks will carry more entrained sediment farther, and larger bankfull discharges will more rapidly rework and transport sediment stored on the bed.

Landslides are an important landscape forming mechanism in the watershed. But it appears that recent contributions of sediment from individual landslide sources in Bowman Canyon is less significant than bank/terrace erosion sources throughout the stream network. Especially since the latter sources supply sediment more chronically than the hillsides. The historic landscape of 165 years ago may have been the opposite case such that landslides were the predominant sediment source before channels became entrenched. The modern landscape has effectively shifted the importance of sediment supply from mass wasting to fluvial erosion. The entrenched stream network is the product.

Roads and Trails

The unimproved ranch roads that were inspected within Bowman Canyon hillsides did not typically have inboard ditches, high cut banks, or significant fills, see Photo 341. Few gullies were observed to be associated with road runoff. Although the dirt roads contribute to the production of fine grained sediment that is transported in suspension, the overall impact of roads as a sediment source in Bowman Canyon does not appear significant compared to bank erosion or landsliding. The greatest impact is likely the effect of roads upon increasing and concentrating runoff to the channels, thereby increasing the overall drainage density and the rate at which water is delivered to the stream. Cattle trails are observed to have a similar effect.

Cattle Trails

The number of cattle trails on both banks of the main stem Bowman Creek study reach was 19. Each of these trails was associated with inputs of fine sediment that contribute to the wash and suspended load from both banks. Runoff from the pastures located on the terraces was commonly funneled down these paths so sediment contribution was not just from the banks alone. If cattle trail spacing is determined the same as per pool spacing, then the spacing for the 2940' long reach is 154'. Since most trails are associated with a nearby trail on the opposite bank, it may be better to consider trail crossings as spaced about every 300'. Since no data has been collected on the density of cattle trail crossings in the past, it is impossible to compare this number to any other stream. Yet, based upon the impacts of the trails, this number seems unnecessarily high and could be reduced by fencing, thereby reducing some of the immediate input of fine sediment.

Sediment Characteristics
Based upon observations of stream turbidity during storms, suspended sediment load from Bowman Creek appears quite high as compared to that upstream in Novato Creek at the confluence. Flow from Bowman Creek has a distinct orange coloration during storm flow, perhaps from the volcanic rocks in the watershed. The amount of fine material in the bed of Bowman Creek appears much greater than that in Novato Creek, where most of the bedload below the dam is supplied by Leveroni Creek. Of the tributary channels Bowman Creek is suspected to be supplying the largest proportion of both bedload and suspended load to Novato Creek for average bankfull flow conditions. During extreme storms it is not known if the concentration of suspended load that comes over the spillway at Stafford Dam is greater.

The fines that emanate from this watershed are associated mostly with terraces and banks which are composed of mostly fine sediment particles, even though gravels are also a component. To a lesser extent each of the following other parameters also contribute fine sediment: hillslope soils, gullies, landslides, roads, concentrated dairy activities, cattle trails, and abandoned quarry. The relative importance of the combined total contribution of sediment from all these other sources compared to that from bank erosion alone can not be estimated within the scope of this study, but should be considered in the construction of any sediment budget that might be done for the watershed.

Conclusions for Bowman Creek
The quantitative and qualitative analysis indicate that Bowman Creek has a high supply of sediment generated from bank erosion. Most of this sediment is sand and finer sizes. Cattle grazing activities directly and indirectly have contributed to the entrenchment and increased sediment production within this watershed. Bowman Creek has the competence to transport its supplied bedload to the point of backwater influences from Novato Blvd. Bridge and Novato Creek confluence. Within the backwater influence zone some proportion of the bedload will temporarily aggrade the bed but be reworked

at lower flows. The suspended load moves entirely through the system to Novato Creek. Sand may comprise a high proportion of the suspended load. The wash load may become some of the reworked silt and finer-sized sediments associated with the tides.

LEVERONI CREEK

Leveroni Creek, as named in this report, is confluent to Novato Creek downstream of the Stafford Dam Spillway and about 3000' upstream of Bowman Creek, see Figure 2. Its drainage area is roughly estimated at 1.5 sq mi. Principle land use in the drainage is dairy ranching. Reconnaissance was very limited within this watershed since access was denied by the private land owner. We observed a continuous 1,070' of channel upstream of its confluence with Novato Creek. The hillslope relief extends to 1219'. Vegetation patterns are similar to Bowman Canyon with grasslands predominating.

For the short distance observed, evidence of very recent bed incision appeared to be on the order of 2'. Evidence of earlier periods of erosion and stability was consistent with that observed in Bowman Creek. Based upon a crude approximation of tree ages, we estimated that 2' of bed incision has occurred over the last 45 years, yielding an erosion rate of 0.04' per year.

Abundant sand and gravel-sized sediment choked the channel bed with bars as high as 2.2'. Within the observed reach, terrace and bankfull bank erosion provided a high localized supply of sediment. Terrace banks averaged about 11.5' high. In some areas the channel bank retreat was a full bankfull width of about 14.5'. Due to the excessive bank erosion, we observed 7 debris jams (3 of which fully crossed the channel) within the study reach. The spacing of debris jams, 1 per 152', was much closer together in Leveroni Creek than any other reach observed in Novato Creek. The spacing distance was half that observed for Bowman Creek. Bay trees, oaks and willows contributed to the supply of large woody debris.

Based upon cursory observations of the hillsides, surface and gully erosion from the heavily grazed grasslands is an important source of sediment that is more significant in this watershed than any other observed in Novato Creek downstream of Stafford Dam. During a1998 winter rainfall, rill networks and overland flow was observed on some of the over-grazed hillsides where little thatch cover existed. Like Bowman Creek, cattle trail crossings were also providing much fine sediment to the channel. The impact and extent of ranch roads was not observed.

For the small size of Leveroni Creek watershed, sediment supply appears disproportionately higher than the other major tributaries.

VINEYARD CREEK

ackground

Vineyard Creek has a drainage area of 1.69 square miles. It flows eastward from a relief of 1575', see Figure 2. The headwaters are mostly oak/bay woodlands and the lowlands are developed for suburban residential use. The land use and fire history are not known for this area and should be researched. Reconnaissance of the upland channel heads and landslide mapping was not within the project scope.

Reconnaissance was performed on about 10600' of channel length, including the lower portions of several tributaries. Field Notes, located in Appendix F, record the observations for taped Distance Stations over a 10110' channel length. The lowermost section of Vineyard Creek, below Wilson Ave, is an old ditch (see Photos 419) that meets the Warner Creek ditch near the bend in Wilmac Ave, see Watershed Maps 9, 10 and 11. Before the ditch to Warner Creek was constructed it is not known where or if Vineyard Creek ever connected to Novato Creek. It may have been entirely disconnected by an unchannelized alluvial fan at the base of the hills. This needs further investigation. If this is true, the drainage density to Novato Creek would have significantly increased causing a subsequent alteration in channel geometry to adjust for more water and sediment. Upstream of Wilson Ave Vineyard Creek has natural meandering, tree-lined terrace banks that are actively eroding, similar to portions of lower Bowman Creek, see photos 438, 463 and 495 for example. Within the study reach, bedrock is frequently intercepted and several steps in channel gradient were found to range from 2' to 4'. At Station 44-67' there is a spillway that causes a grade change of 8'.

Rosgen Classification typically varies in the valley bottom reaches from G4, F4 and B4. Since suburban development has occurred along the terrace banks, bank revetments of sackcrete, riprap and concrete are found.

Geometry

For the reach between Stations 0+00' and 51-10', the average width of a low geomorphic bank was 12.9'. According to Leopold's regional curves (1994) the cross sectional area for bankfull should equal 31 sq ft with width averaging 17' and mean depth equal to 1.8'. The geomorphic bank that we measured in the field is too low, according to the regional curves, to be a associated with mean annual flow or bankfull. Our low bank generally provides a cross sectional area that is half of Leopold's predicted value. In one section of channel we were able to determine that the "older pristine condition" bankfull was probably about 14' while the new bankfull had adjusted to 21'. The range of our low bank widths was from 8' to 22.5'. One possible explanation is that our low geomorphic banks represent a buried bankfull of a previous bed level that has subsequently become incised.

Bank retreat measurements average 3.4'. Figure 20 shows a representative cross section that was taken at Station 29-90 that typifies the general look of a G4 Vineyard Creek reach.

Bed Condition Relative to Pools, Wood and Sediment Storage

Over the full reconnaissance including the channel downstream of Station 0+00, we observed 34 pools, seven of which had trout in them. The largest fish was 10". Figure 21 upper pie chart shows the causes of pools greater than 1' deep in Vineyard Creek, from Station 0+00' to 50-00'. About 38% of the pools were formed by natural conditions such as bends, bars, boulders and bedrock. The data is located in Appendix F. Another 31% were formed by wood such as roots, tree trunks and debris, and 31% were associated with man-made structures. The middle pie chart of Figure 21 shows that of only 4 pieces of LWD, 67% entering Vineyard Creek is from willows, while 33% is from bays. The lower pie chart shows that two debris jams extend all the way across the channel.

Channel Incision

In general, in the lower natural portions of Vineyard Creek, the channel appears to have gone through an initial phase of bed incision and bank erosion. It is now aggrading its bed and continuing to erode its banks. This suggests that either sediment supply has increased from upstream bank erosion thereby overwhelming the channel capacity and causing a decrease in channel gradient or the local bank erosion has significantly widened the channel to cause a flattening of the slope and hence aggradation. A combination of both scenarios is hypothesized since extensive erosion of channel bed and banks was observed ubiquitously.

Very recent bed incision does not appear to be as abundant or as active as other Novato Creek tributaries, possibly because of the scenario of aggradation that has followed initial incision. Between Stations 0+00' and 51-10', recent bed incision averages about 1.36' but the depth to maximum incision is obscured by recent deposition in many reaches. Overall patterns of erosion and stability for the last 165 years was not determined for Vineyard Creek. The construction of Warner ditch in the 1800's and its connection to Vineyard Creek may have influenced rates and timing of bed incision within Vineyard Creek.

Vineyard Creek, Cross Section 29-90

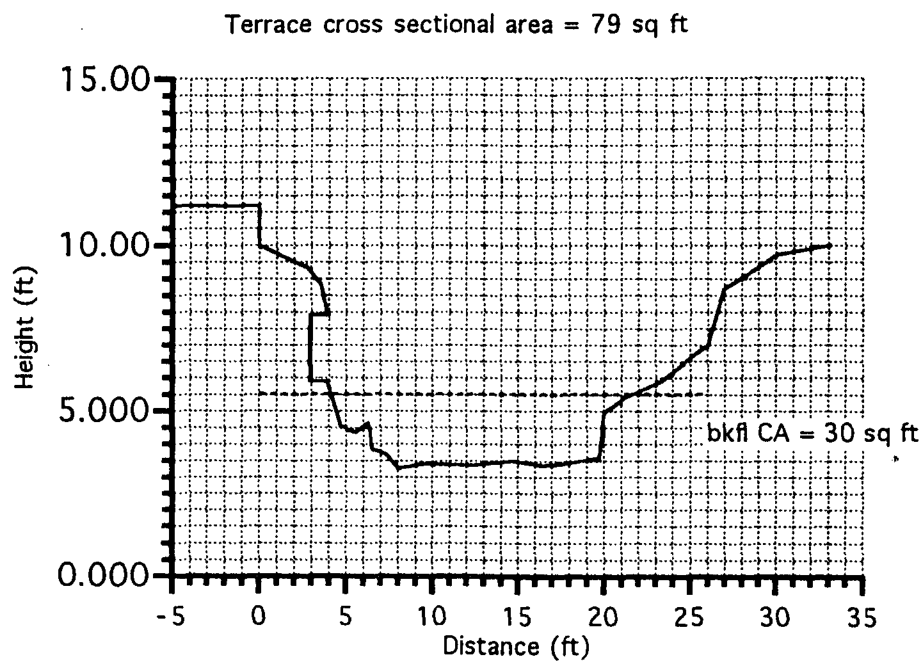
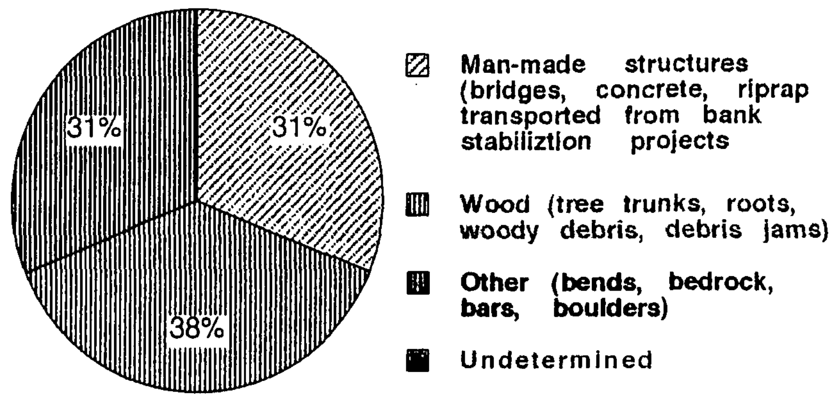


FIGURE 20

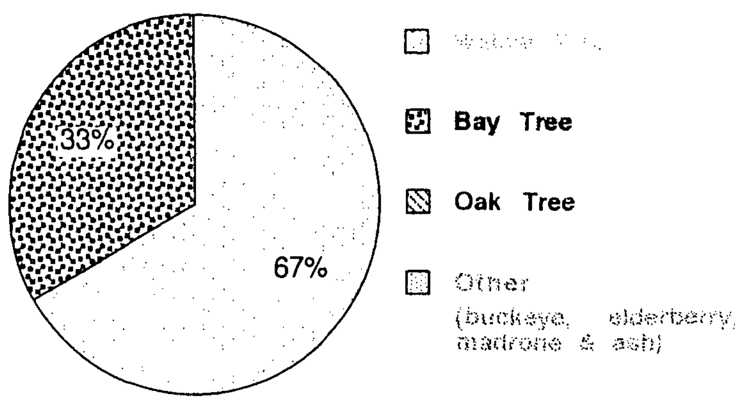
Vineyard Creek Pool and Woody Debris Characteristics for Study Reach between 0+00' AND 50-00'

CAUSES OF POOLS GREATER THAN 1' DEEP



Vineyard Creek
Total # of pools = 32, average pool spacing = 160', study reach distance = 5110'.

TYPES OF TREES COUNTED AS LARGE WOODY DEBRIS BELOW BANKFULL HEIGHT



Vineyard Creek
Total # of LWD = 4

DEBRIS JAM CHARACTERISTICS

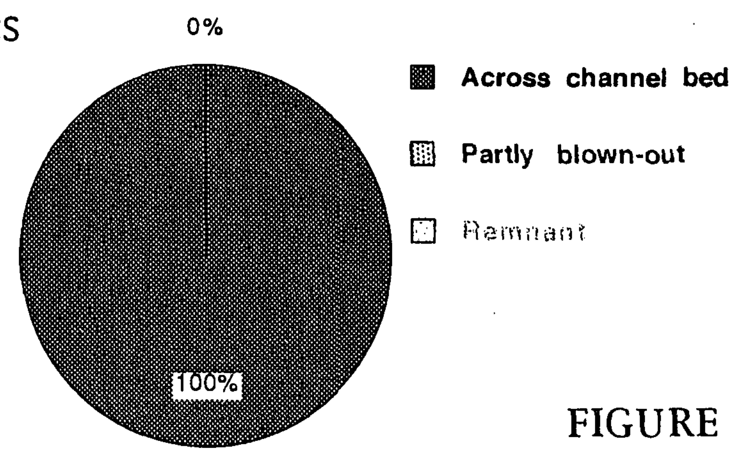


FIGURE 21

Vineyard Creek
Of the total 2 debris jams

Several small tributaries were inspected along the western headwaters of Vineyard Creek. These sites are shown as either LB or RB designations in the Vineyard Creek Station Map in Appendix F, and are shown as Photos 560 through 575. Pages 13 - 15 of the Field Notes for this section correspond to the photos. The data show that the actively eroding headcuts through alluvial fans have an average incision of 3.8', much greater than the average for the valley bottom channels. Additionally, the cross sectional area of the bankfull flow is much less than the cross sectional area of the total gully. The bankfull cross section often represents only 15% of the total volume of soil removed. demonstrating substantial sediment supply from these small channels. Examples include Station LB #3 where an additional 8.4 sq ft has been removed by a bankfull cross sectional area of 1.5 sq ft and Photo 544-45 shows where 22 sq ft has been removed by a bankfull cross section of 4 sq ft. These small upland channels are exhibiting rates of very active bed incision that exceed rates along the higher order, valley bottom channels. The field evidence indicates that incision is related to upstream increases in flow rather than headcuts propagating upstream from a change in base level of the main channel, see Photo 573 and corresponding Field Notes.

Only one tributary of 8 observed in the headwaters of Vineyard Creek, RB #2, shows evidence of a stable channel. It has moss covered rocks and minor bed incision. The change in cross sectional area is only 0.58 sq ft. Why this channel is stable and the others are actively eroding has not been investigated.

Hillslopes and Landslides in Vineyard Watershed

Only a few small landslides were observed along Vineyard Creek, Photos 571 and 574 for example. Contribution of sediment from landslides in this watershed is estimated to be relatively low compared to amounts provided by bank and bed erosion. Some of the steep tributaries are occasionally influenced by debris flows as indicated by the presence of boulders, Photos 575 and 579 for example.

Roads and Urban Influences

Paved and undeveloped open-space trails undoubtedly increase the drainage density in the watershed and therefore contribute to increased runoff and peak of the hydrograph. Their extent and impact was not directly investigated.

for Vineyard Creek

Vineyard Creek's main influence on Novato Creek may have been the added drainage density it provided when it was connected to the Warner Creek ditch. It presently supplies and stores abundant quantities of sediment. The amount that actually gets mobilized to Novato Creek is unknown.

WARNER CREEK

Warner Creek has a drainage area of 5.18 sq mi, and includes Wilson and Vineyard Creeks, see Figure 2. Based upon historical evidence such as the Subdivision Map shown in Appendix A4, Warner Creek is a man-made ditch. Its age is unknown but it may predate the 1850's when apple orchards were in full production in central Novato, see Rancho Novato Etching in Appendix A. There is no indication that a previous channel existed along the ditch alignment, and whether Vineyard Creek ever connected to Novato Creek is questionable. Excluding the upstream tributaries of Vineyard and Wilson Creeks, the principle land use along Warner Creek drainage is suburban residential development. The ditch is entrenched within terrace deposits along its entire length.

The lower portions of Warner Creek from its confluence of Novato Creek to the South Novato Blvd Bridge crossing became part of the Phase IV NCFCP in 1990, and by 1995 the Project extended to McClay Bridge. During fall 1997 sediment dredging was performed from the mouth of Warner Creek to Diablo Ave Bridge. Because the whole channel is a constructed ditch, we did not assess the numbers of pools or make detailed notes relative to stream Distance Stations. Instead we performed a general reconnaissance and recorded some observations which are noted in Appendix G, Field Notes for Warner Creek. Photographs of Warner Creek are shown in Photo Album II. Warner Creek meets Novato Creek at Station 20+00', as shown on Watershed Map 1. Watershed Maps 8 and 9 show its upstream continuation to Vineyard Creek.

Our reconnaissance indicates that the ditch of Warner Creek, since the time of its construction, has undergone perhaps at least 2' of average bed incision, and ranges up to as much as 3.5' at discrete locations. In several sections incision has extended into silty clay beds of Quaternary Alluvium, see Photos 384, 388 and 404. Extensive sackcrete revetment has been placed along the banks of the ditch, and in areas where both banks have been revetted, bed incision appears most pronounced. Presently, the process of channel incision appears to predominate over bank erosion in Warner Creek. The decreased roughness associated with sacreted banks likely imparts higher water velocities and higher shear stresses on the channel bed. Interestingly, we have observed evidence that the channel often cuts to the level of the footer ditch that is excavated below the original channel bed. Concrete aprons poured over the remaining bed during the time of construction now stand well above the present bed level, see Photo 393. It is likely, however, that most of the channel incision is associated with a combination of changes in channel geometry that have been caused by increased amounts of upstream runoff and by poor hydraulic design of the original ditch. Photo 402 and 406 show a series of headcuts in the channel bed that have 3.5' and 2.5' steps in thalweg gradient at tree roots. These roots indicate a former bed level of the ditch. Its original dimensions are unknown.

Sediment storage in Warner Creek is only abundant in an alluvial fan at Wilson Creek confluence, Photos 392. A fan at the Novato Creek confluence is also evident, Photo 22-23. Elsewhere, Warner Creek has sufficient capacity to transport its sediment load through the system. Vineyard Creek has an ample sediment sources, the relative amount that is transported to Warner Creek versus stored within the bed of Vineyard is unknown. In some areas Armorlock is the largest sediment size mobilized, see Photo 371.

ARROYO AVICHI

General Background

Arroyo Avichi has a drainage area of 1.78 square miles. It flows northward from a relief of 1280', see Figure 2. The headwaters are mostly oak/bay woodlands and the lowlands have suburban residential development. Land use and fire history are not known for this area and should be researched. Reconnaissance of the upland channels and landslide mapping was not within the project scope.

Reconnaissance was performed on about 10500' of channel length. The Field Notes, located in Appendix C, record the observations for taped Distance Stations from the mouth of Arroyo Avichi at Novato Creek confluence to beyond the Indian Valley Road Bridge. Photo Album III shows corresponding photographs. Bedrock was frequently intercepted and several steps in channel gradient were found to range from 1.7' to 2.8'. The lower portions of Arroyo Avichi, generally below Station 43-70' are intermittent with a few isolated pools. There is a small dam at Station 60-67 that has a 5.4' change in gradient. Rosgen Classification typically varies as per Vineyard Creek.

In 1986 Arroyo Avichi had an overflow channel constructed at Station 0+00' to lead to Baccaglio Basin. The reach of channel below South Novato Blvd to Station 13+50 was dredged in 1996, and on average is dredged about every three years (Liz Lewis, verbal communication).

Arroyo Avichi is unique because it provides medium-sized gravel material directly to the tidally influenced reach of Novato Creek. The lower portion of Arroyo Avichi is also influenced by the tides up to Station 12+07', which is about 175' upstream of the confluence.

Bank Condition

The lateral extent of eroding banks was not quantified for Arroyo Avichi. However, during the reconnaissance, measurements were made at discrete points to determine the extent of bank retreat. The Arroyo Avichi Data are located in the Field Notes in Appendix C.

The average of the point measurements for bank retreat indicate that bank erosion equals about 3.9'. As in the other tributaries, bank erosion appears to be the predominant process of sediment supply to this channel rather than bed incision or landsliding. Occasional bank revetments of sackcrete, riprap and concrete have been placed along the channel. At the extreme upper limit of our reconnaissance we noted that a few inner gorge landslides along the inside bends of the channel were contributing sediment directly to the channel.

Bankfull Geometry

Figure 22 shows three representative cross sections for channel conditions of Arroyo Avichi. The bottom graph is a G4 channel and the middle is an F4. As in Vineyard Creek a low geomorphic bank was occasionally measured in the field and noted in the Field notes. It's cross sectional area was not consistent with Leopold's (1994) regional curves for bankfull geometry. The hydraulic flow responsible for this low bank is not known. Leopold predicts that the bankfull cross sectional area should be about 36 sq ft, bankfull width should equal 18.5' and mean depth should equal 1.9'. Our few measurements suggested an average bankfull width of 15.5', ranging up to 20.5'.

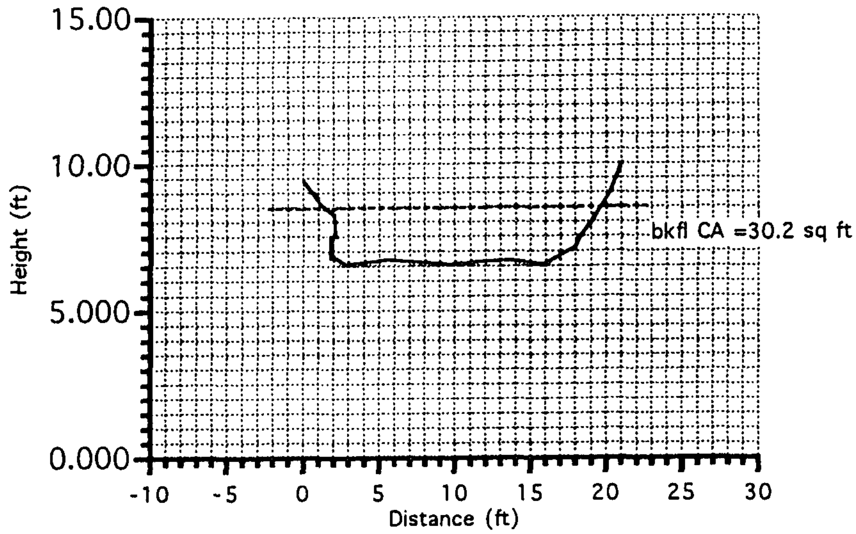
Bed Condition Relative to Pools, Wood and Sediment Storage

Figure 23 shows the pool and woody debris characteristics for Arroyo Avichi. Of the 30 pools greater than 1' deep in the study reach, about 67% of the pools were associated with natural features such as bends, bars and bedrock. This is greater than any of the other channels assessed. On the other hand, the 23% of pools associated with wood was lower than other reaches, as was the 10% associated with man-made structures. Pool spacing is 302', over the total distance measured. The middle pie chart shows that 70% of the LWD in the channel comes from willows, 20% from oak and 10% from bay trees. There were 11 pieces identified. The lower pie chart shows that of the two debris jams, one crossed the channel and the other was partly blown-out.

Channel Incision and Adjustments in Geometry

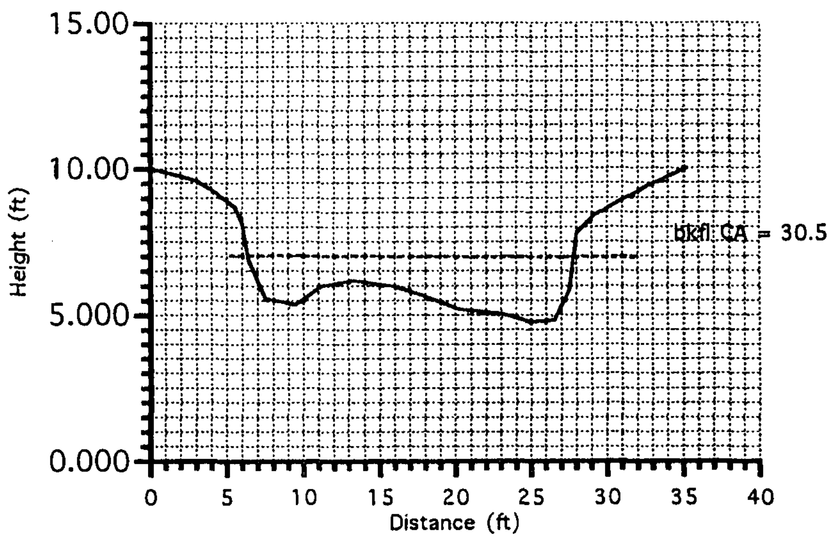
Recent incision of the main Arroyo Avichi appears to average 1.2'. Rates of recent tributary incision, like in Vineyard Creek, tends to be greater than in the main channel. The total amount of incision since the early 1800's has not

Arroyo Avichi, Cross Section at 10+90



Arroyo Avichi, Cross Section at 44-47

Terrace cross sectional area = 97.5



Arroyo Avichi, Cross Section at 44-47

Terrace cross sectional area = 23.7 sq ft

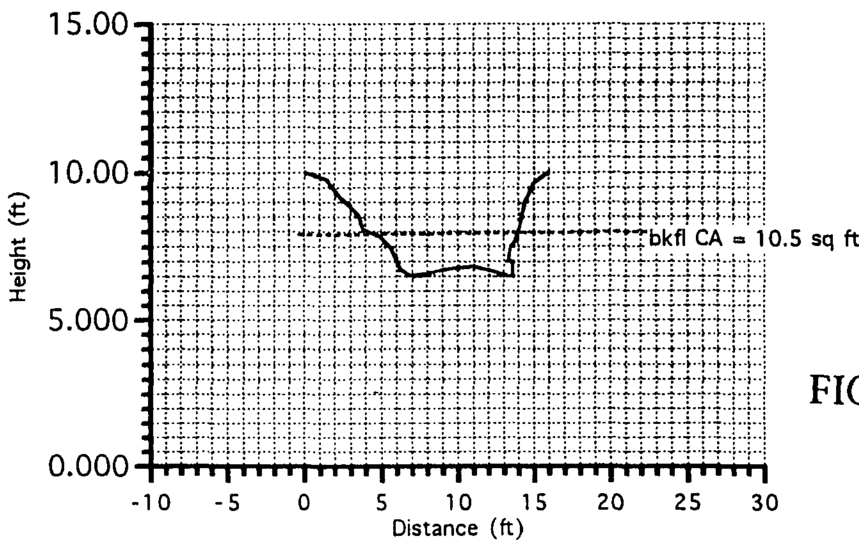
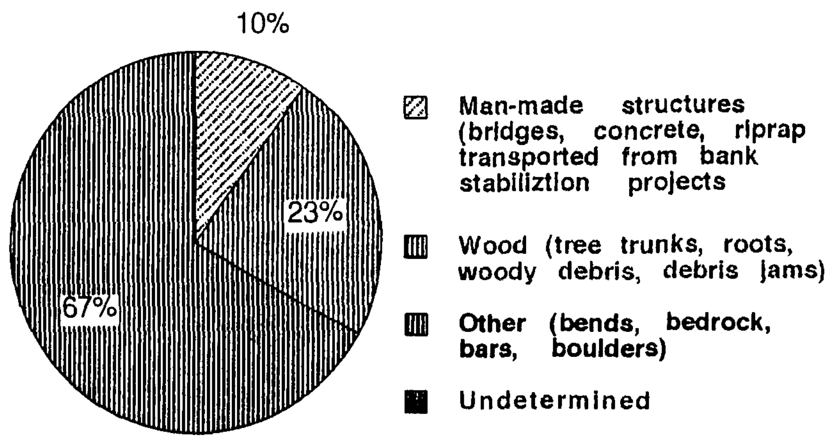


FIGURE 22

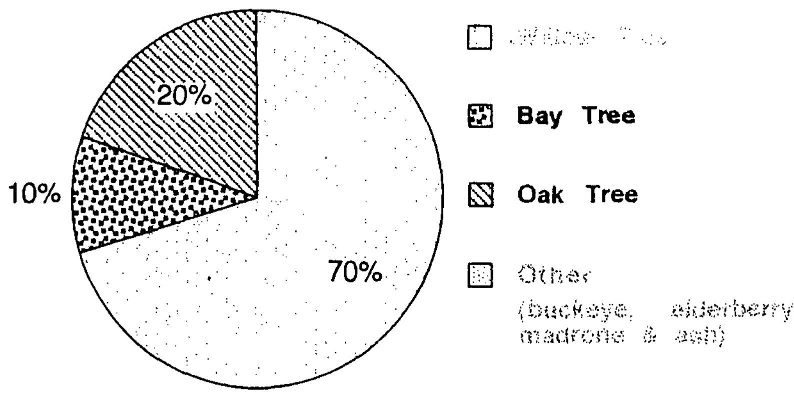
Arroyo Avichi Pool and Woody Debris Characteristics for Study Reach between 0+00' AND 90-85'

CAUSES OF POOLS GREATER THAN 1' DEEP



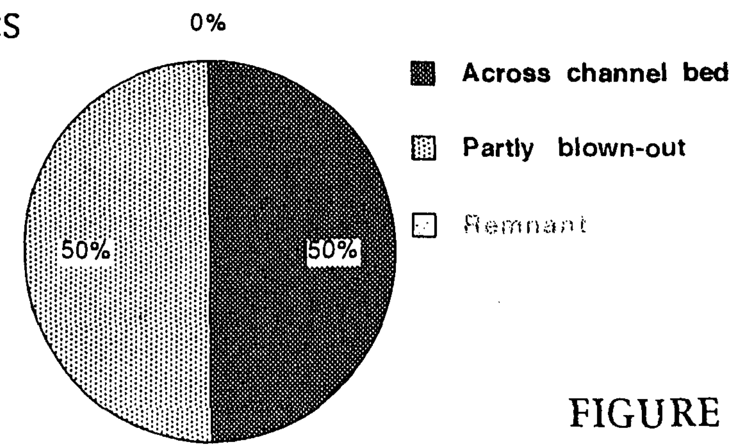
Arroyo Avichi
Total # of pools = 30, average pool spacing = 302', study reach distance = 9085'.

TYPES OF TREES COUNTED AS LARGE WOODY DEBRIS BELOW BANKFULL HEIGHT



Arroyo Avichi
Total # of LWD = 11

DEBRIS JAM CHARACTERISTICS



Arroyo Avichi
Of the total 2 debris jams

FIGURE 23

been determined. There were a few stations on the lower portions of Arroyo Avichi, such as 4-01' and 36-96', that indicate that portions of Arroyo Avichi have incised a similar 5' as per Novato Creek. Other segments in the lower portions of Arroyo Avichi seem to follow the same scenario as Vineyard Creek such that periods of channel incision, were followed by bank erosion, then aggradation and continued bank erosion.

We also observed some reaches that had fairly severe erosion problems along Stations 69-00' through 79-50'. This section includes a meander cutoff as seen in Photo 661-62. Bar heights are often as high as 2.5' through this reach and some segments have had bank retreat equal to a bankfull width. The horse stables along the upper segment were contributing to water quality degradation.

Conclusions for Arroyo Avichi Creek

Significant coarse sediment, principally from bank erosion, is supplied to the NCFCP from Arroyo Avichi and its tributaries.

SUMMARY CONCLUSIONS

Novato Creek has the capacity to transport its supplied sediment load from local bank erosion and tributaries to the existing channelization project where there, it losses capacity and aggrades its bed. Sediment is predominantly supplied by channel bank and terrace erosion throughout the entire drainage system from the lowland valleys to the headwater tributaries. The secondary source of sediment to the NFCP is from bed erosion of stored sediment within the active channel bed. Supply of sediment from the tides, landsliding and surface erosion is estimated to be orders of magnitude less than the combined latter two sources.

With regard to sediment supply the modern landscape has effectively shifted the importance of geomorphic processes from mass wasting to fluvial erosion. The entrenched stream network is the product in the tributaries and mainstem Novato Creek from Stafford Dam to the zone of tidal influence. If no changes had occurred within the tidal zone, perhaps Novato Creek would have adjusted to transport its increased load out of the system to the bay. With the present scenario of increased runoff and sediment generation in the headwater reaches, channelization, obstructing railroad bridge ,and loss of functional tidal creeks and marshland, the tidally influenced system is destined to aggrade. Overall rehabilitation of the watershed would involve reduction in runoff and large scale restoration of tidal marsh. The feasibility of applying extensive erosion control to channel and terrace banks throughout the entire channel network is impractical.

A simplified summary of answers to the initial study objectives are stated below, a synopsis of the conclusions is in the Executive Summary.:

1) The locations of major sediment sources are pervasive terrace and channel bank erosion throughout the channel network from largest to smallest stream order.

2) The major process by which sediment is being produced and supplied to the stream system is from fluvial erosion of the channel bed and banks from flows that are equal to or above bankfull and that have increased in frequency during the last century and a half.

3) Change through time and space of sediment sources and landscape processes is indicated by a shift of the most active sites of erosion from hillsides to the channel network, and from the valley bottom channels to the headwater channels. The large high-order channels along the valley bottoms may have passed through their peak rates of incision and are now aggrading in some restricted areas. Bank erosion, on the other hand, will likely continue until the channels are wide enough to form a new floodplain within the entrenched channels. The large high-order channels, if left entirely to natural processes, will likely become stable sooner than the headward, small order reaches, which began to degrade later.

4) There have been large and sudden historical changes in drainage density. The early construction of irrigation and drainage ditches increased drainage density in the valleys, whereas the reclamation of tidal marshland decreased drainage density within the tidal reaches of the watershed. Since the advent of irrigation, there has been a further increase in drainage density above the tidal reaches due to gullying in the headward rangelands and the addition of storm drains in the urbanized lowland valleys. Drainage density has also been increased by the incision of alluvial fans that once separated the tributary channels from the main stem channels.

5)Study reaches have been established through this study. These study reaches should be considered for an ongoing program of locally intensive empirical observations of the sources and disposition of sediment and water supplies within the watershed. There should be developed a system of repeated observations among these study reaches that would enable a fluvial geomorphologist to recognize changes in the relative importance of natural processes and land use on sediment and water supplies. Some of the details of the required measurements may be provided by this report.

The purpose of an ongoing monitoring program should be to understand interrelations among upstream and downstream events and processes. For example, there needs to be an operational understanding of the feed-back mechanisms between upstream land use or climate change, downstream grade change, flooding, dredging and upstream riparian habitat loss.

6) The abundance of tidal versus terrigenous sediment increases towards the marsh. Terrigenous sediments probably comprised more than 50% on the 1997 volume for the upper 2/3 of the NFCP. Following the 1998 winter, the percentage from terrigenous sources may be substantially larger all the way to the NWPRR Bridge.

RECOMMENDATIONS

1. Stabilize undercut trees on the high terrace banks before they collapse into the channel and cause bank erosion to proceed unchecked .
2. Consider restoration techniques to divert high velocity flows and associated high shear stresses away from eroding banks.
3. Consider converting more of the diked marshlands into functional tidal wetlands that would dissipate flood flows and increase channel capacity for sediment transport by increasing tidal prism.
4. Consider piping urban runoff into a separate and constructed drain system that does not connect to Novato Creek but leads separately to a flood control basin in the wetlands or to San Pablo Bay. This would effectively reduce the amount of water going into the channel, which could reduce flood frequency and associated damages. Consider that water caught in a basin before going to San Pablo Bay, could be filtered by natural vegetation.
5. Consider constructing on tributary channels such as Arroyo Avichi sediment traps that would funnel some, but not all of the bedload away from Novato Creek into a separate catchment.
6. Reduce the input of fine sediments from cattle trail crossings by fencing the main tributary channels from cattle access.

REFERENCES

Atwater, Brian F., 1980, *Attempts to correlate Quaternary Climatic the Mokelumne River, California*, PhD dissertation, University of Delaware, 214 pp.

Camp Dresser & McKee, Inc., 1983, *Novato Creek Flood Control Project*, prepared for Marin County Flood Control and water Conservation District. (Survey maps of stream gradient for Preliminary Design are separate from report.)

Dedrick, Kent G. and Linda Chu, 1992, *Draft for Tidal Waterways of San Francisco Bay, Historic Widths and Depths on NOS/NOAA & USGS Topographic and Hydrologic Surveys*, 28 pp.

Dedrick, Kent G. and Linda T. Chu, 1993, *Historical Atlas of Tidal Creeks San Francisco Bay, California*, "Coastal Zone '93, Proceedings of the Eighth Symposium on Coastal and Ocean Management", published by American Society of Engineers, Vol 3, p2464-2478.

Haible, William W., 1980. *Holocene Profile Changes along a California Coastal Stream*, "Earth Surface Processes", Vol 5, pp 249-264.

Langbein, W. B. and Leopold, Luna B., 1966 *River meanders: theory of minimum variance*; "U. S Geological Survey Professional Paper 422-H".

Leopold, Luna B., 1994, *View of a River*, University Science Books, Sausalito, California, 185 pp.

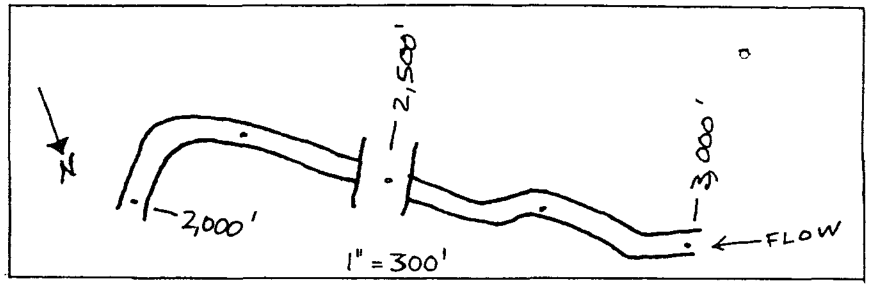
Prunuske Chatham, 1986. *Erosion and Revegetation Chapter V* in Novato Creek Flood Control Project enhancement Plan Workbook, prepared for California State Coastal Conservancy.

Rosgen, David L., 1997, *A geomorphological Approach to restoration of Incised Rivers*, "Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision", S.S.Y. Wang, E.J. Langendoen and F.D. Shields, Jr. (eds.). ISBN 0-937099-05-8. 11 pp.

Rosgen, David L., 1996, *Applied River Morphology*, Published by Wildland Hydrology, Pagosa Springs, Colorado.

Novato Creek-Bank & Pool Conditions: Diablo Blvd to Stafford Dam

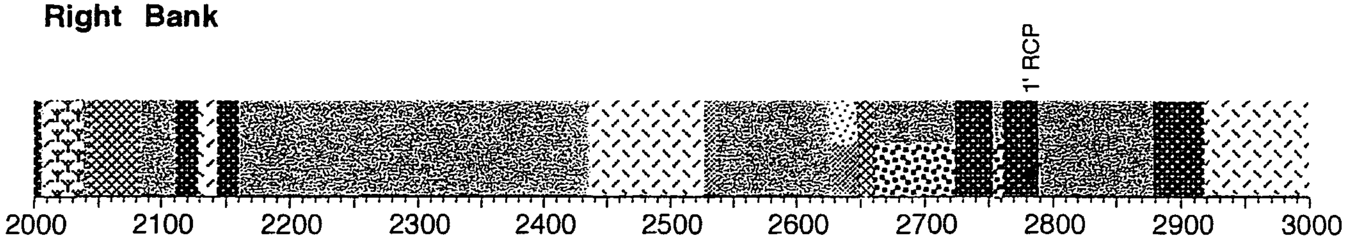
Novato Creek Bank & Pool Conditons, Fall 1997



REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

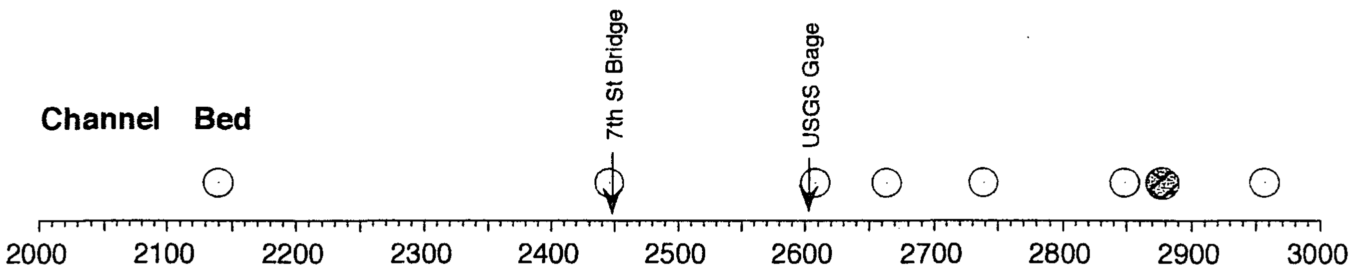
Right Bank



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- [illegible]
- Wood across terrace banks
- Debris jam
- Bedrock bed

Channel Bed



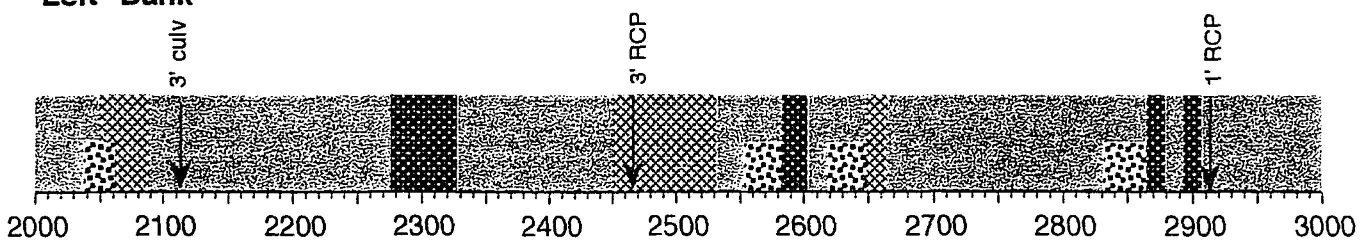
BANKS:

- Bedrock
- Stable/Natural banks

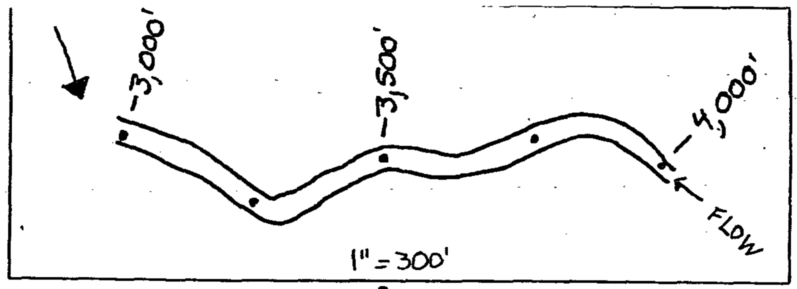
ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock

Left Bank



Novato Creek Bank & Pool Conditons, Fall 1997



REVETTED BANKS

- % cement wall
- % rip rap
- % Sacrete
- % shop cart
- % rock wall
- % brick wall
- % cement slabs
- % steel pilings
- % wood wall
- % gabions

CHANNEL BED:

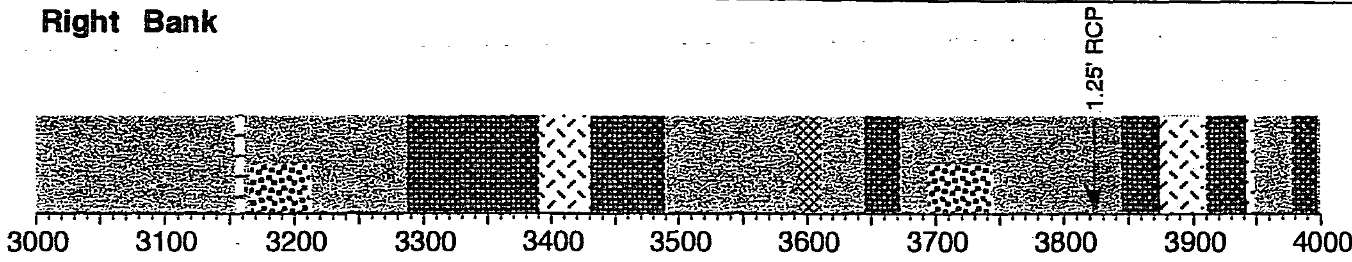
- Bedrock pool
- Pool at least 1' deep
- Wood across terrace banks
- Debris jam
- Bedrock bed

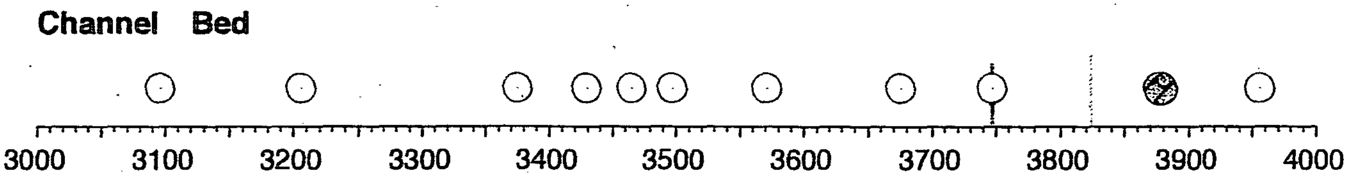
BANKS:

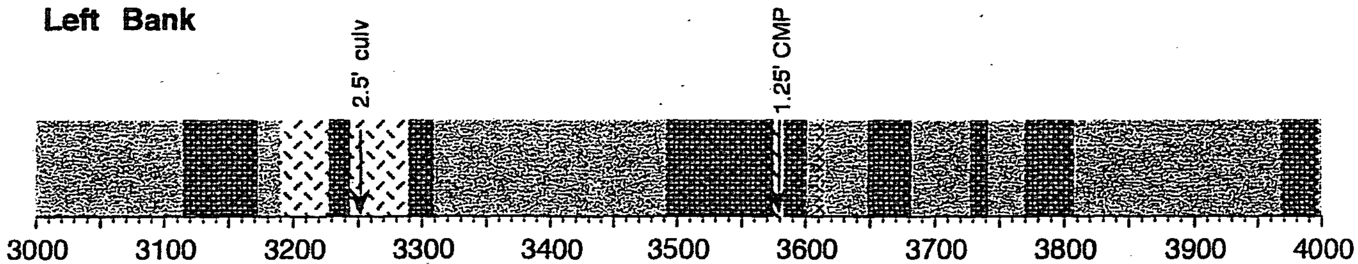
- Bedrock
- Stable/Natural banks

ERODING BANKS:

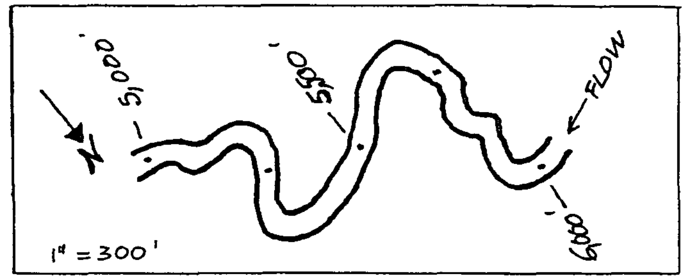
- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock
- Hillside erosion/slide







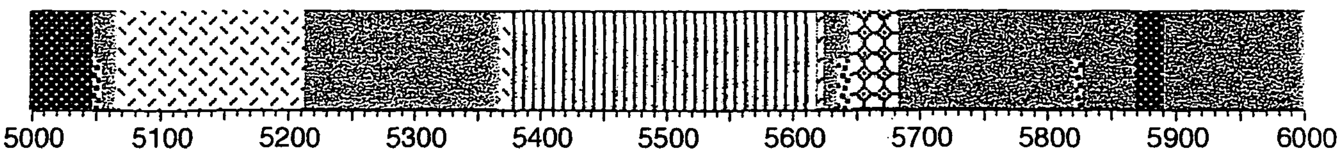
Novato Creek Bank & Pool Conditons, Fall 1997



REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

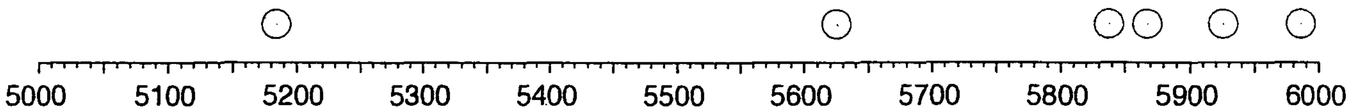
Right Bank



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

Channel Bed



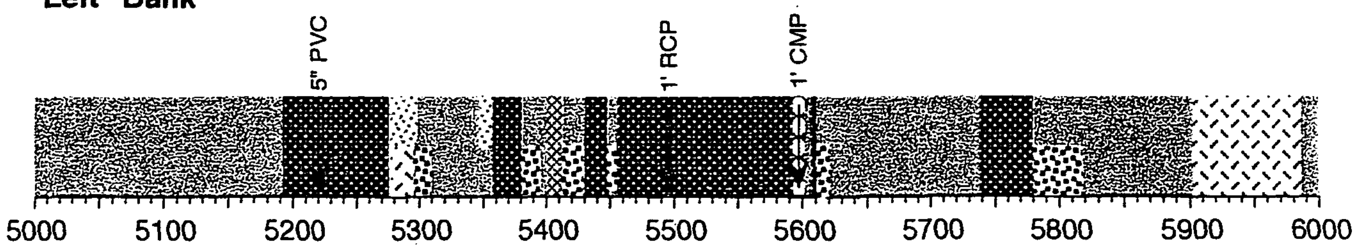
BANKS:

- Bedrock
- Stable/Natural banks

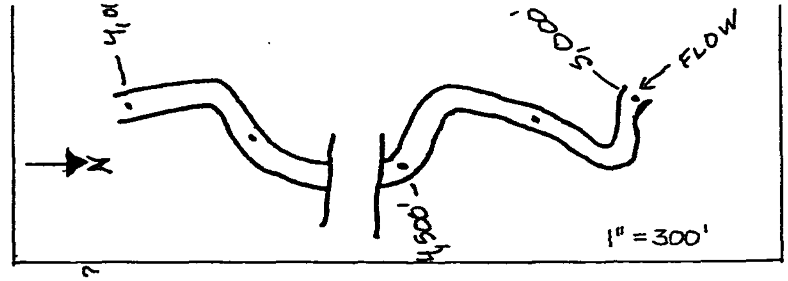
ERODING BANKS:

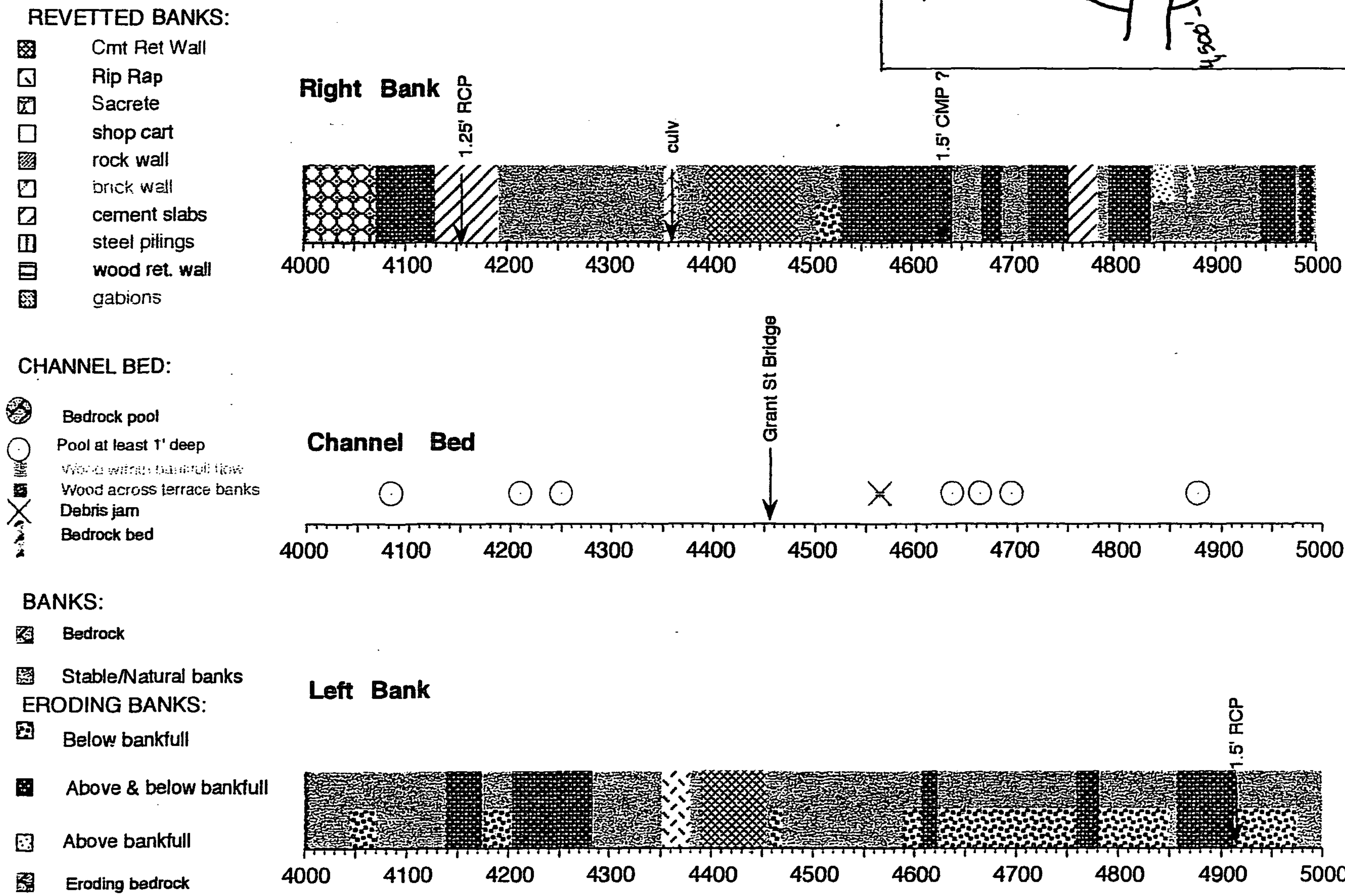
- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock

Left Bank

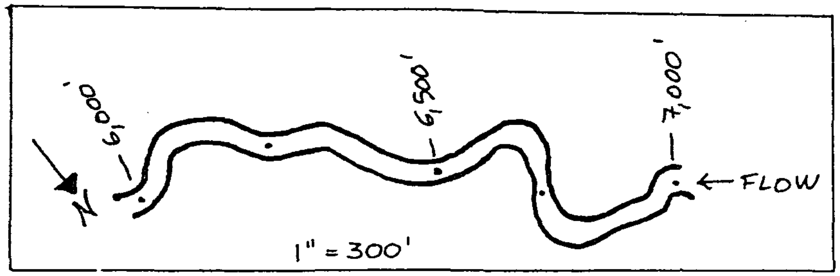


Novato Creek Bank & Pool Conditons, Fall 1997





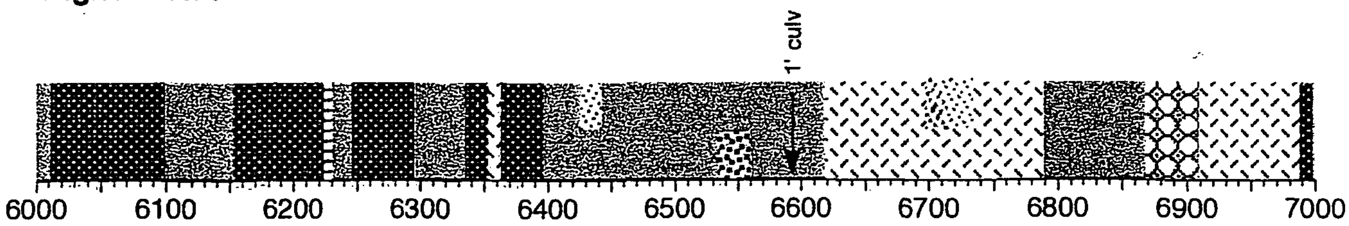
Novato Creek Bank & Pool Conditons, Fall 1997



REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

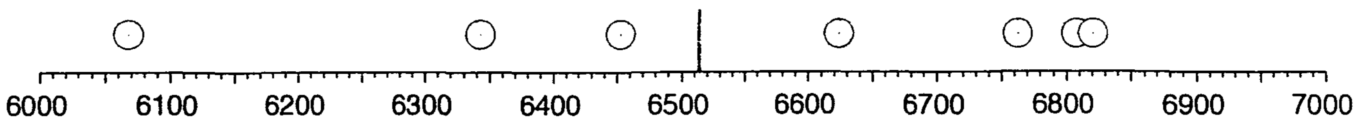
Right Bank



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

Channel Bed



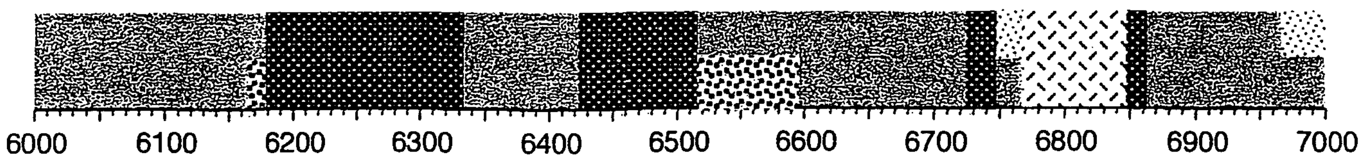
BANKS:

- Bedrock
- Stable/Natural banks

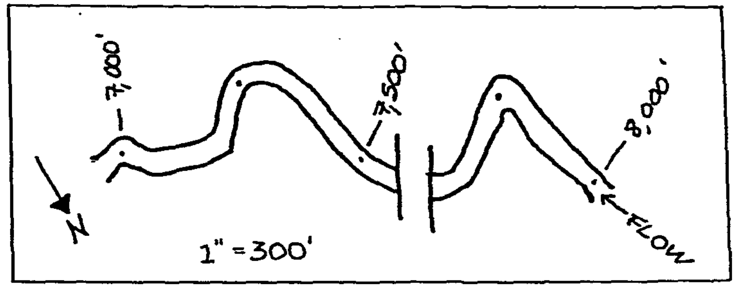
ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock

Left Bank

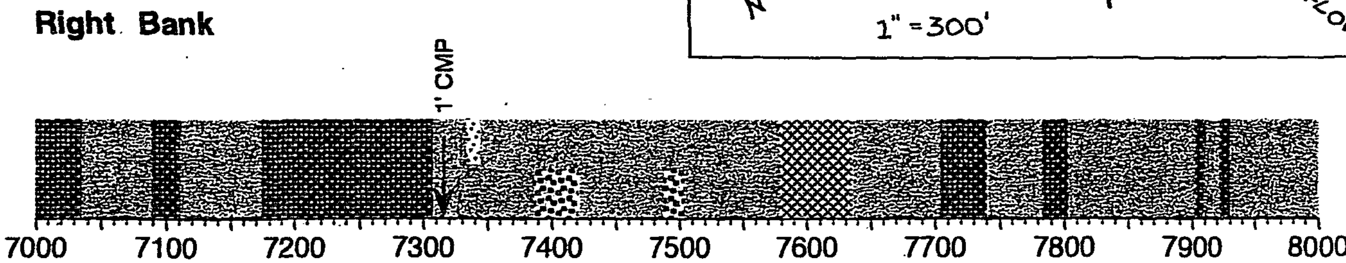


Novato Creek Bank & Pool Conditons, Fall 1997



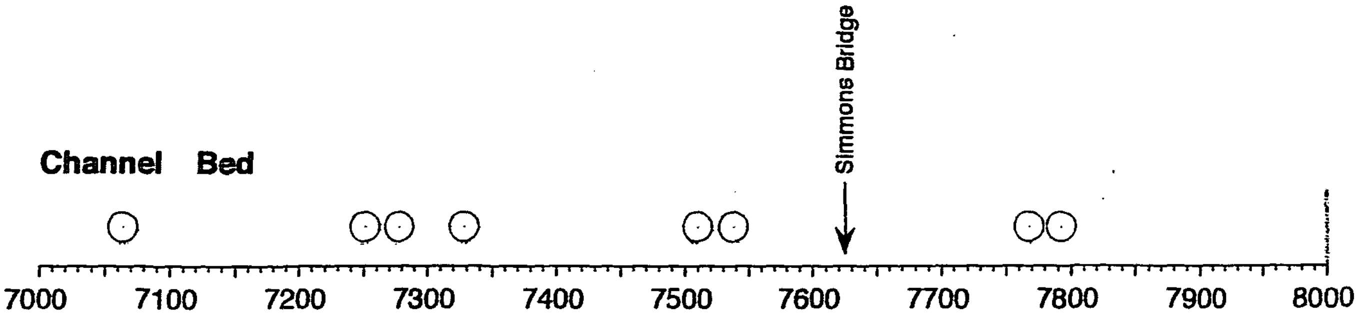
REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

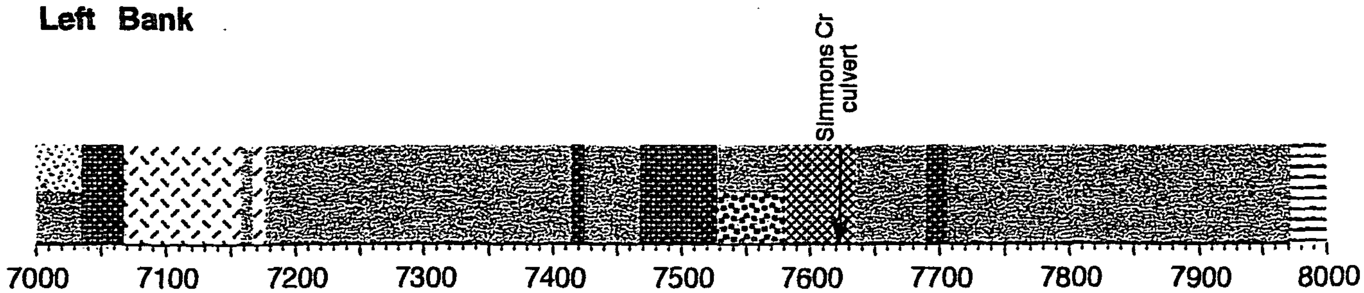


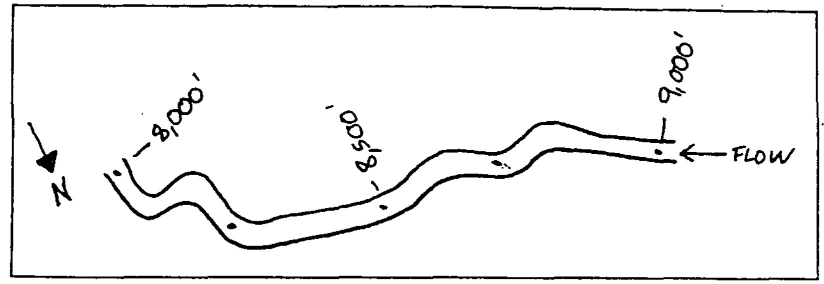
BANKS:

- Bedrock
- Stable/Natural banks

ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock



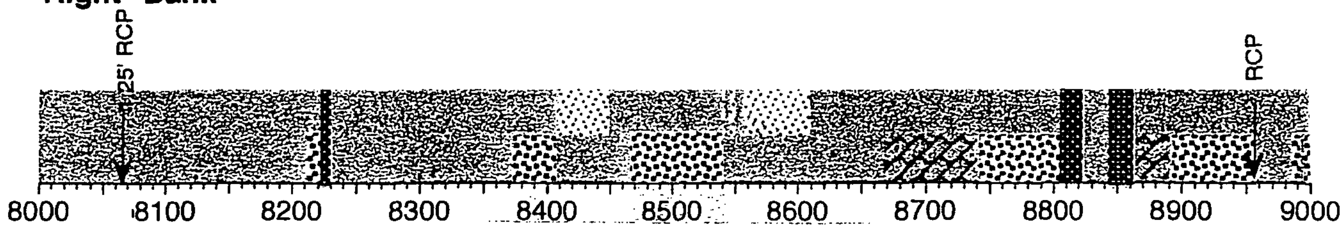


Novato Creek Bank & Pool Conditons, Fall 1997

REVETTED BANKS:

- Cmt Ret Wall
- Rip Raap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

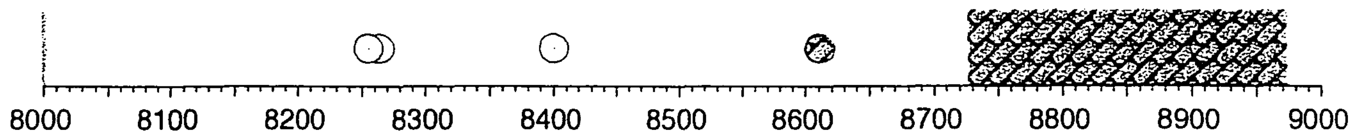
Right Bank



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

Channel Bed



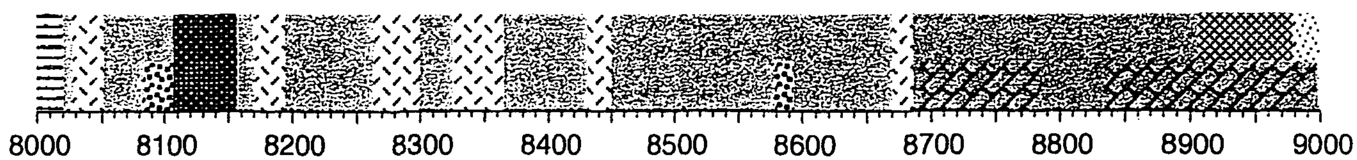
BANKS:

- Bedrock
- Stable/Natural banks

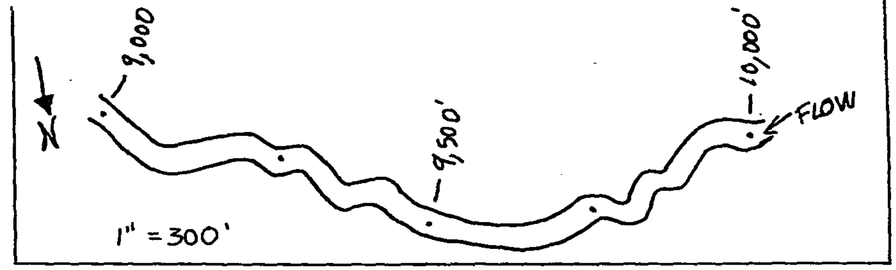
ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock

Left Bank

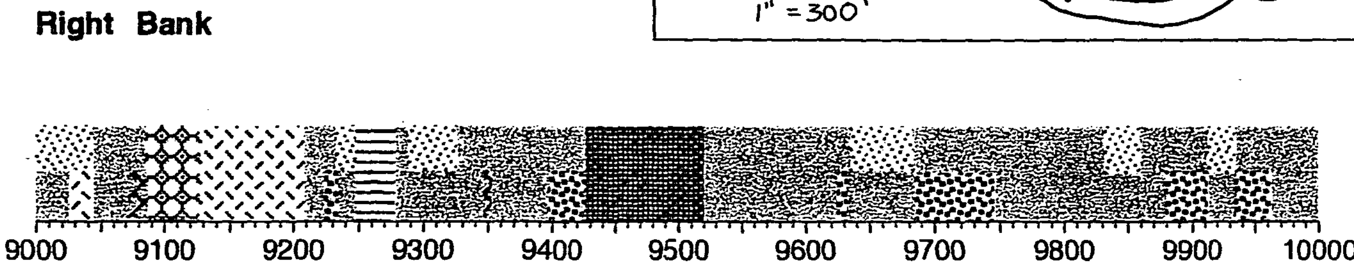


Novato Creek Bank & Pool Conditons, Fall 1997



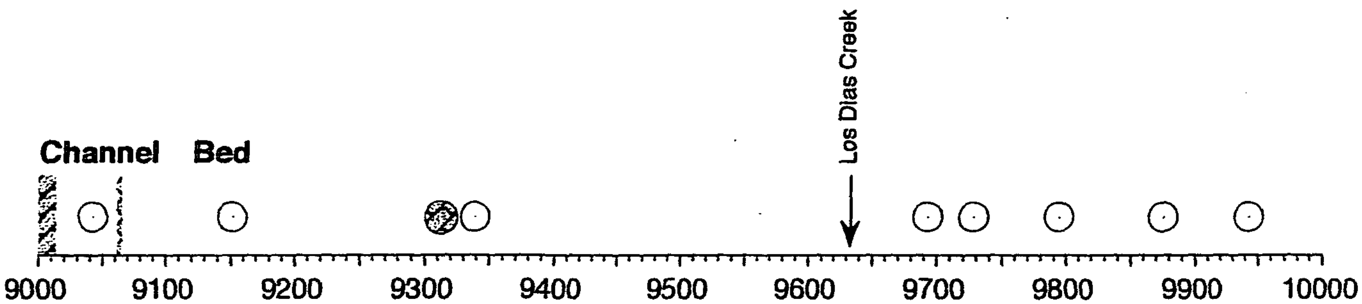
REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

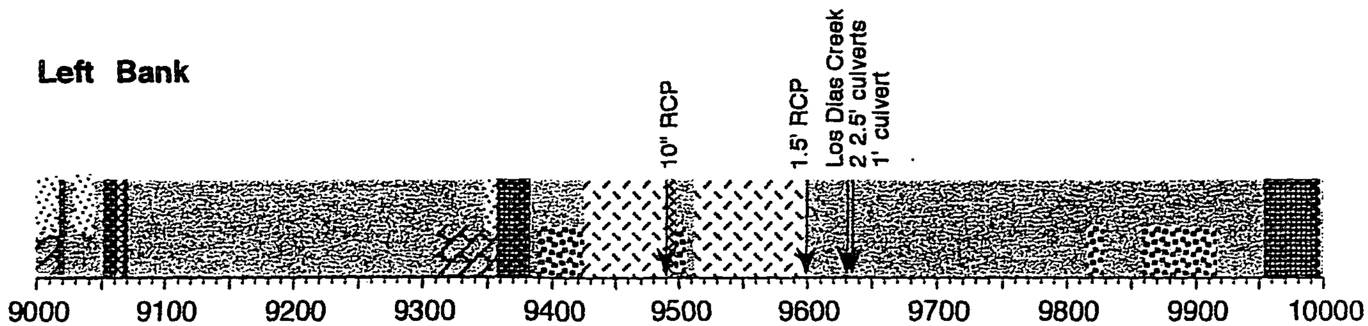


BANKS:

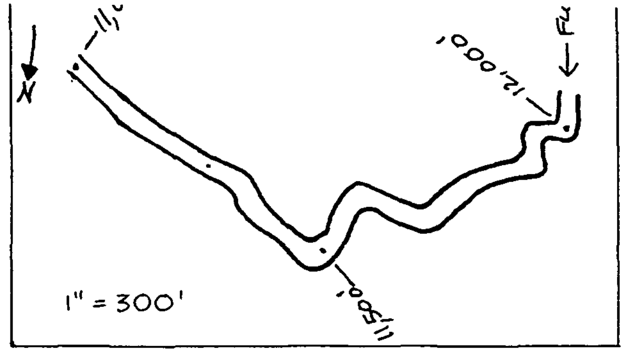
- Bedrock
- Stable/Natural banks

ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock



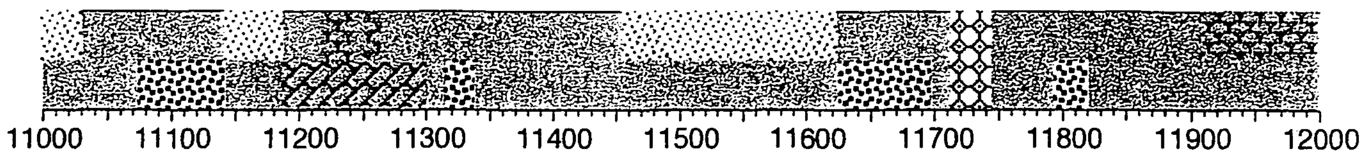
Novato Creek Bank & Pool Conditons, Fall 1997



REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

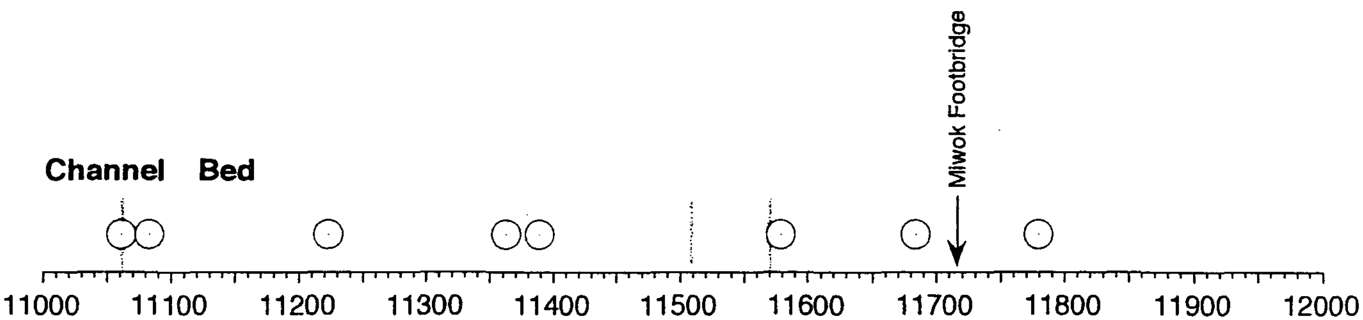
Right Bank



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

Channel Bed



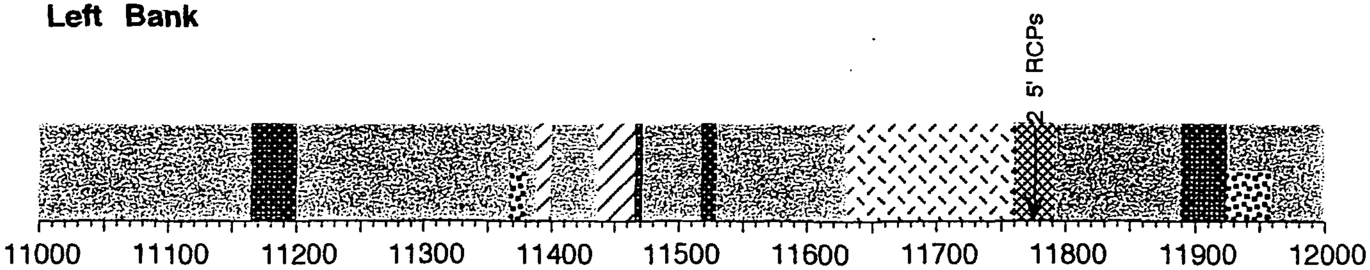
BANKS:

- Bedrock
- Stable/Natural banks

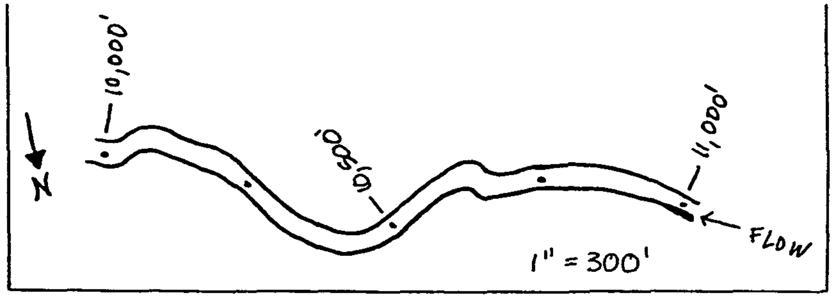
ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock
- Hillside erosion/slide

Left Bank

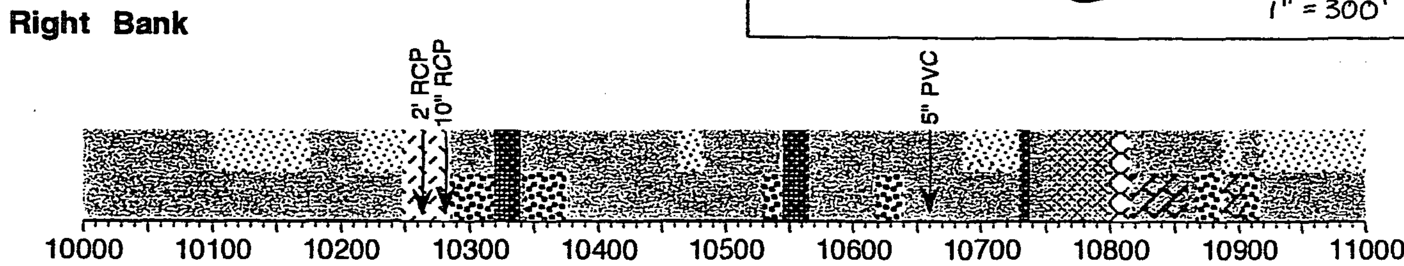


Novato Creek Bank & Pool Conditons, Fall 1997



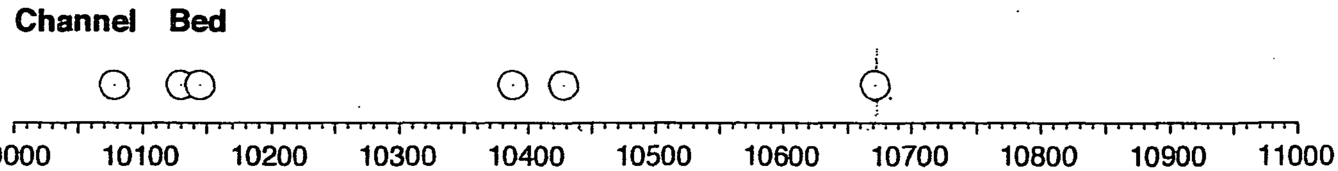
REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

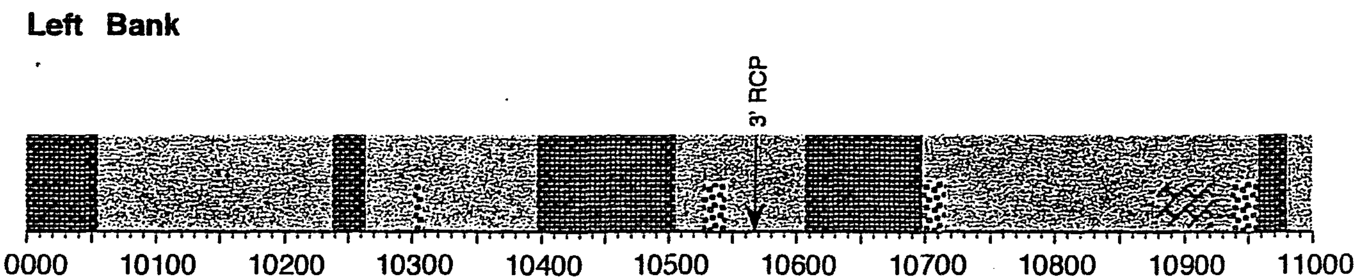


BANKS:

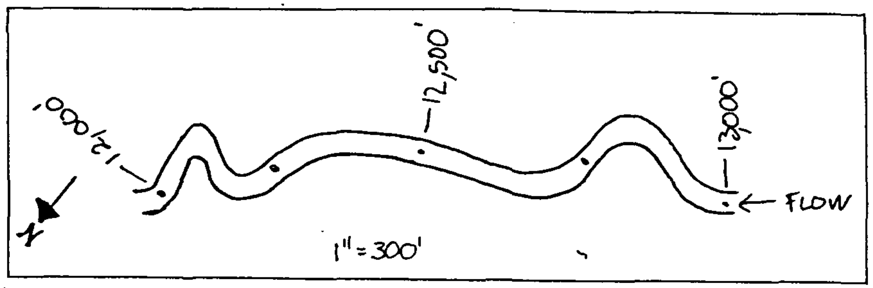
- Bedrock
- Stable/Natural banks

ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock



Novato Creek Bank & Pool Conditons, Fall 1997



REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

CHANNEL BED:

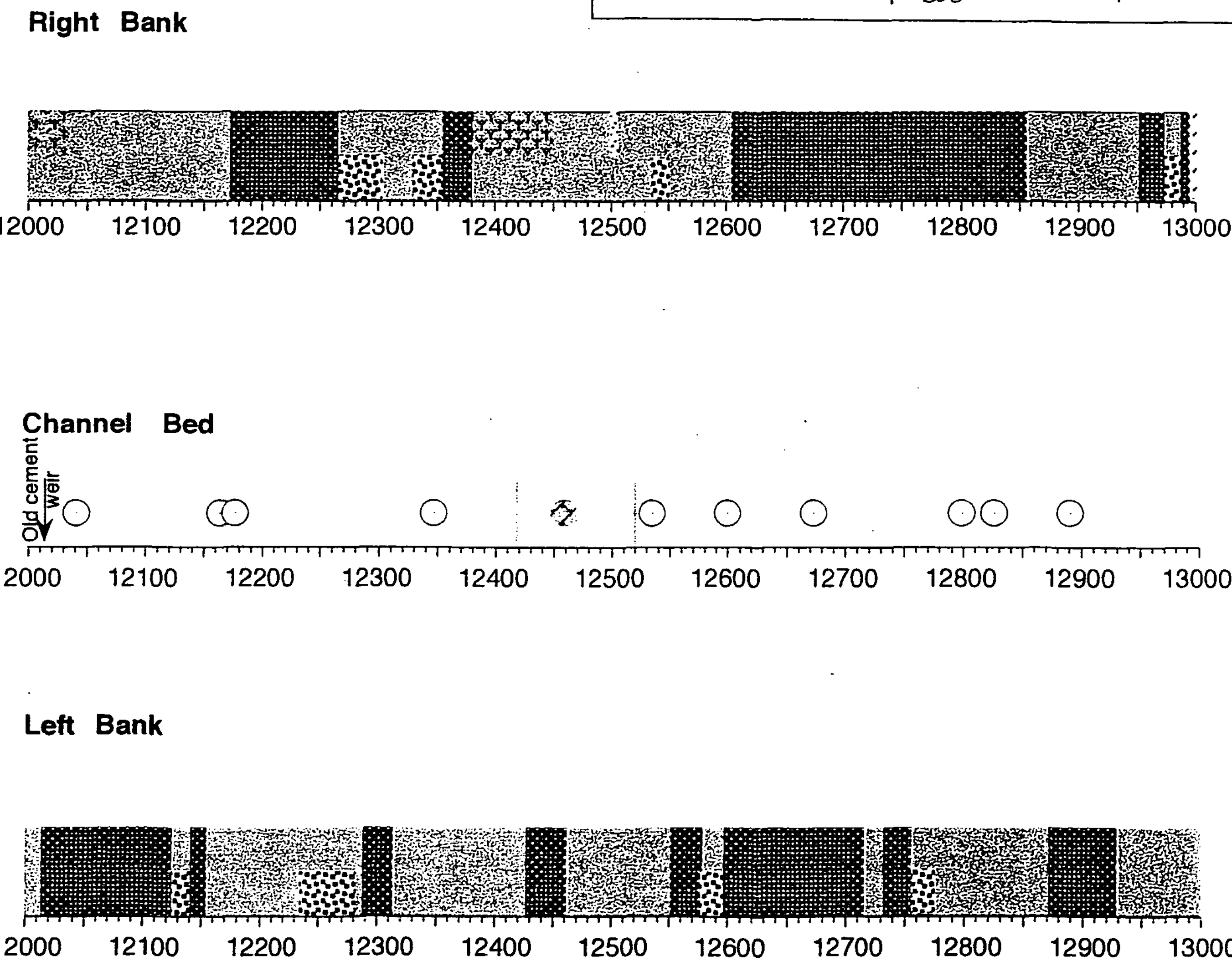
- Bedrock pool
- Pool at least 1' deep
- [illegible]
- Wood across terrace banks
- Debris jam
- Bedrock bed

BANKS:

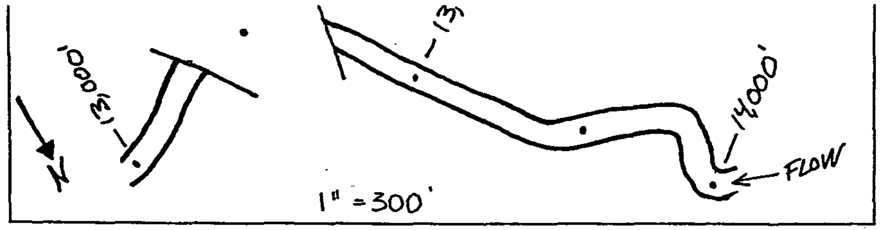
- Bedrock
- Stable/Natural banks

ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock
- Hillside erosion/slide



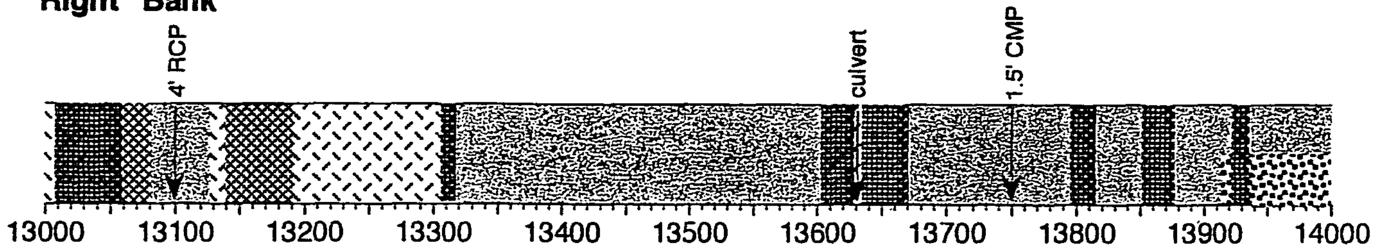
Novato Creek Bank & Pool Conditons, Fall 1997



REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

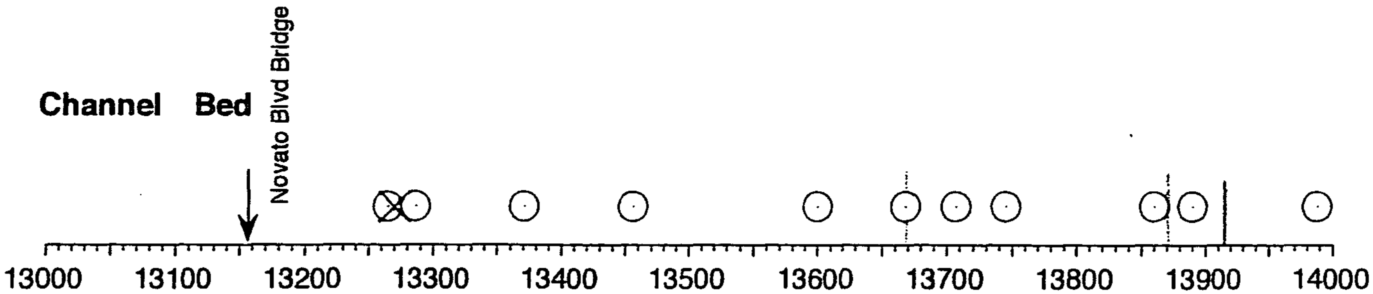
Right Bank



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

Channel Bed



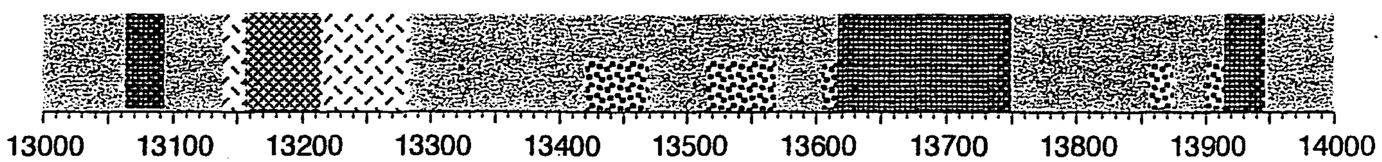
BANKS:

- Bedrock
- Stable/Natural banks

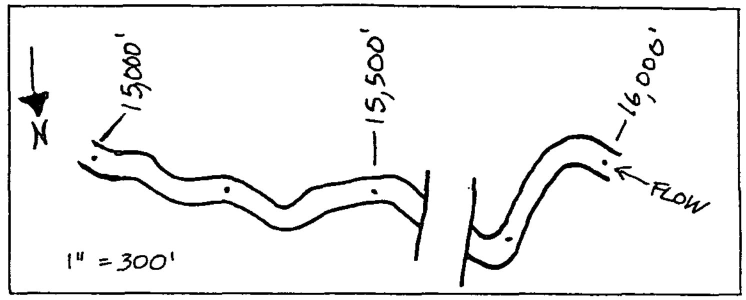
ERODING BANKS:

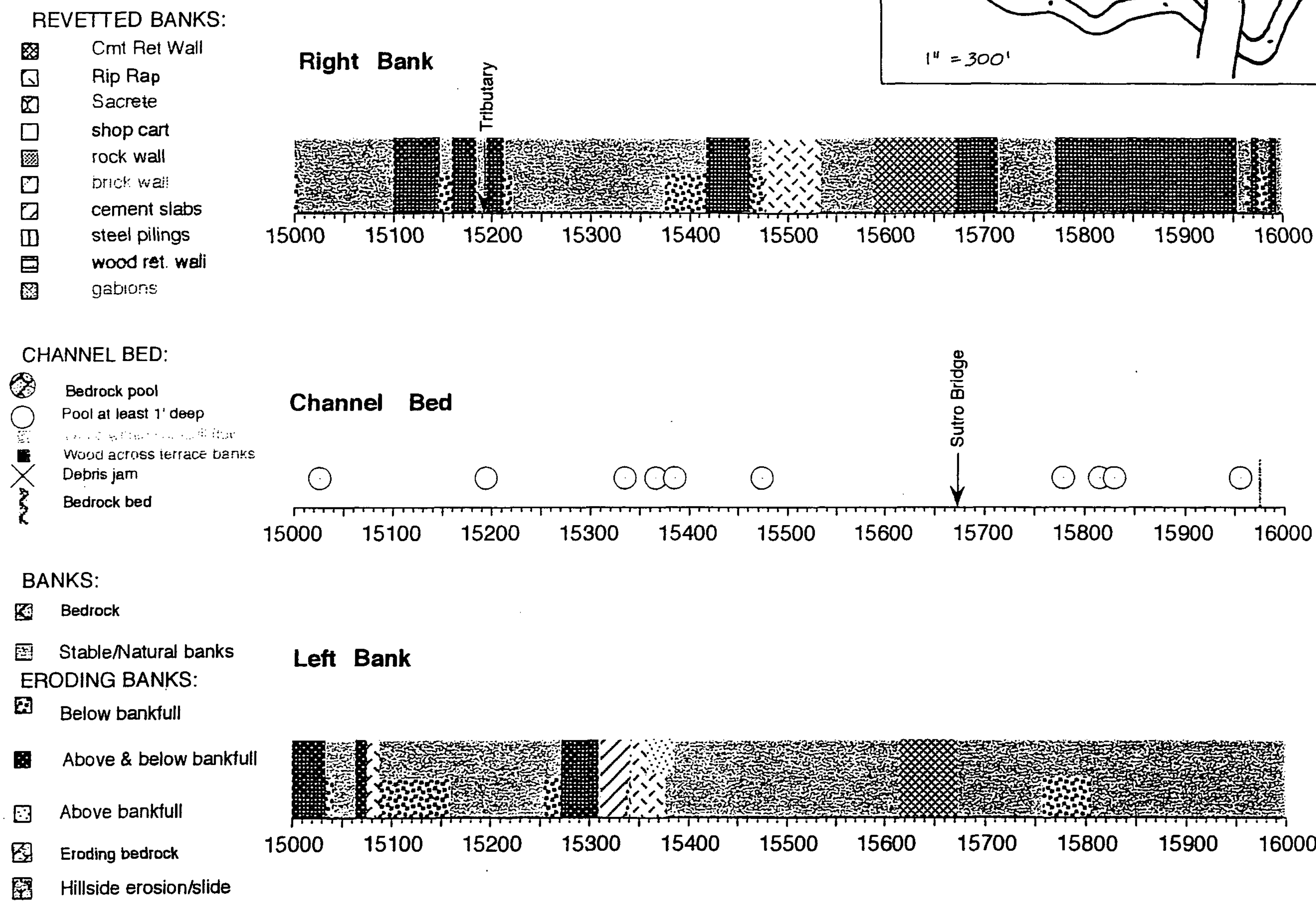
- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock
- Hillside erosion/slide

Left Bank

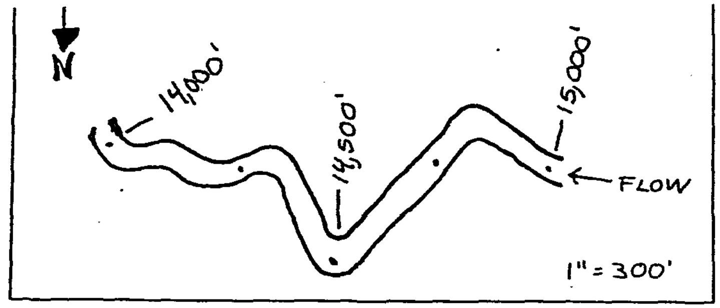


Novato Creek Bank & Pool Conditons, Fall 1997



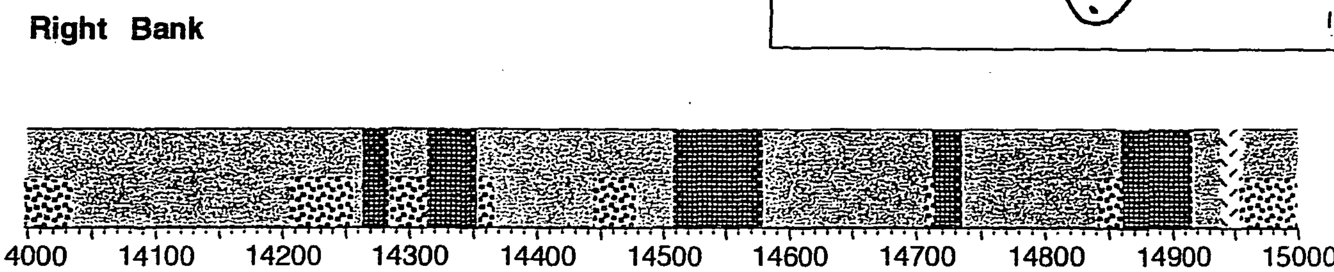


Novato Creek Bank & Pool Conditons, Fall 1997



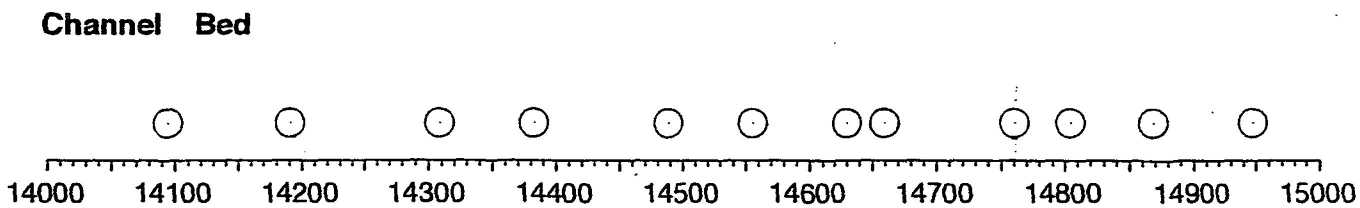
REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood rat. wall
- gabions



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- [illegible]
- Wood across terrace banks
- Debris jam
- Bedrock bed

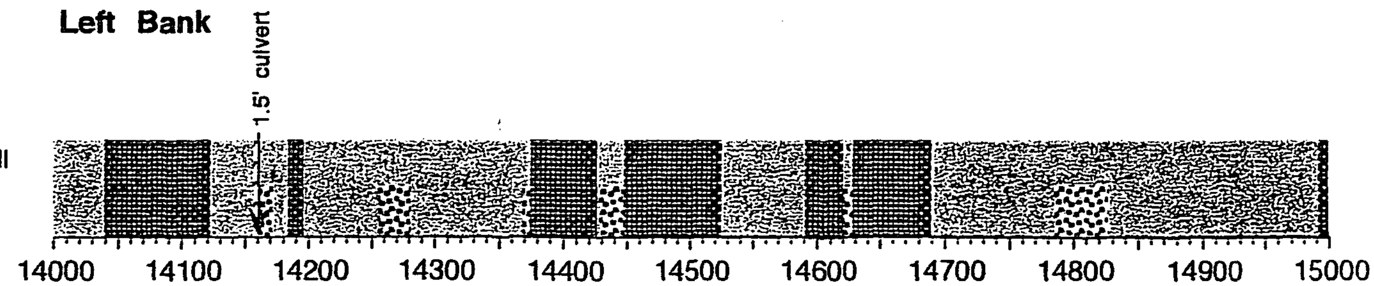


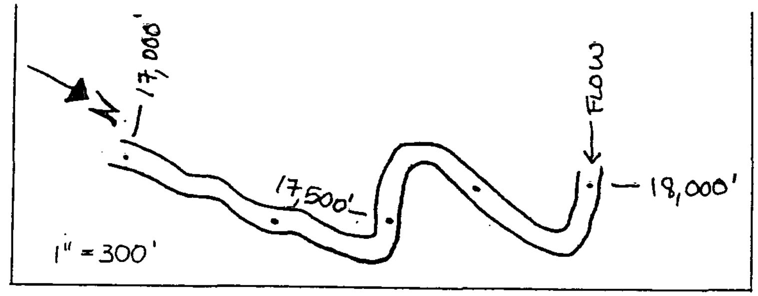
BANKS:

- Bedrock
- Stable/Natural banks

ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock
- Hillside erosion/slide



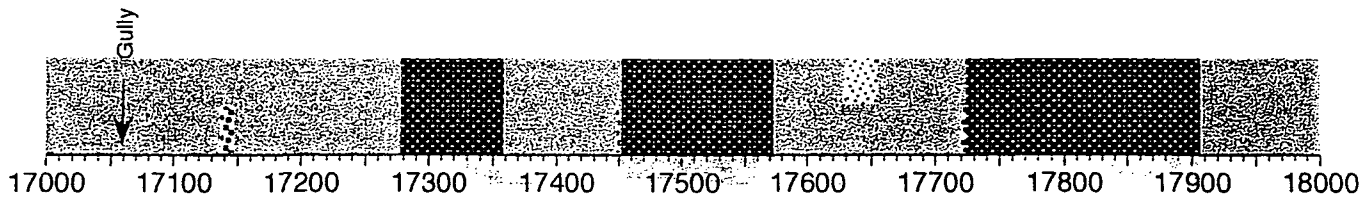


Novato Creek Bank & Pool Conditons, Fall 1997

REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

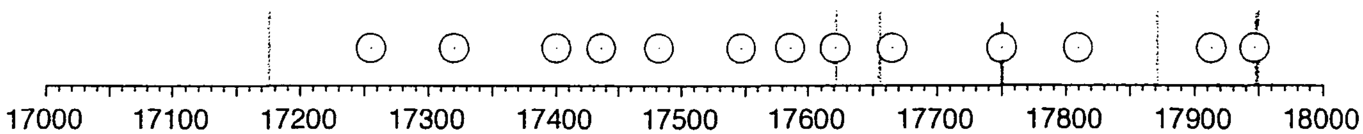
Right Bank



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

Channel Bed



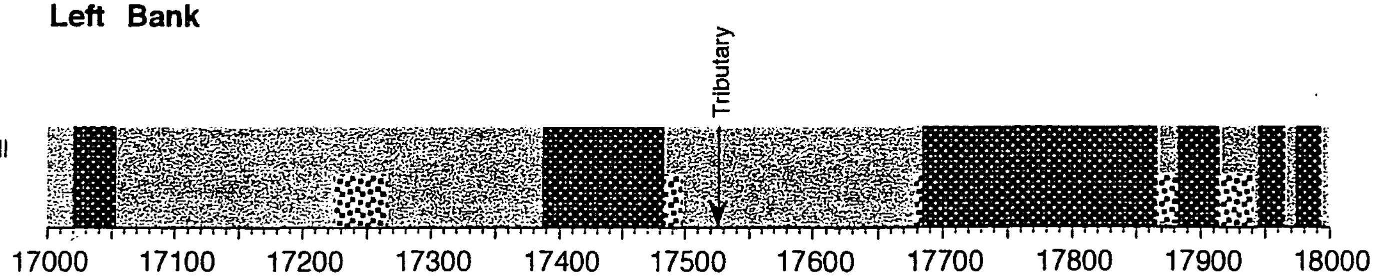
BANKS:

- Bedrock
- Stable/Natural banks

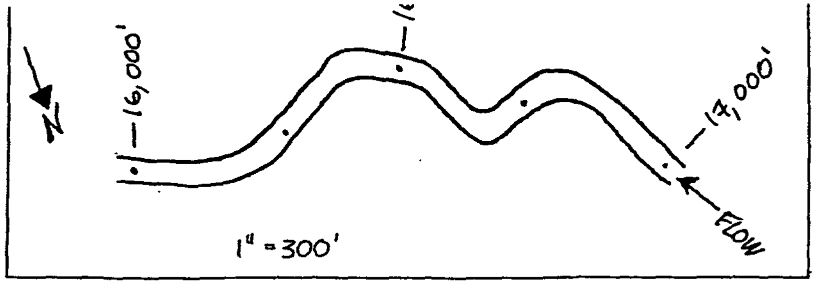
ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock

Left Bank



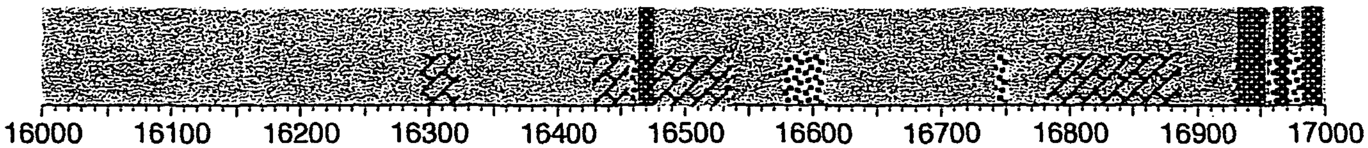
Novato Creek Bank & Pool Conditons, Fall 1997



REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

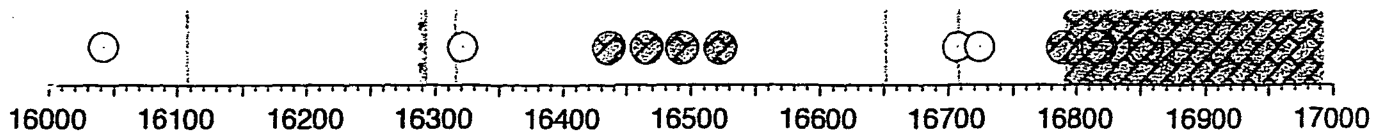
Right Bank



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

Channel Bed



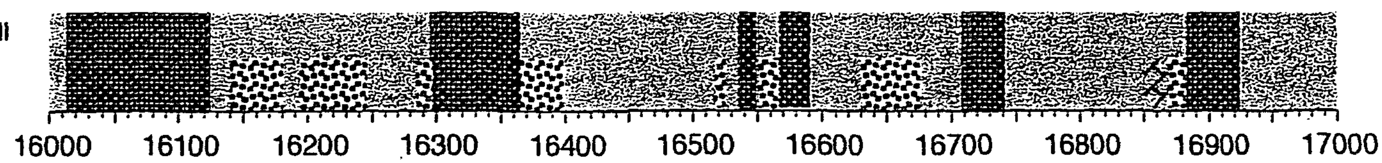
BANKS:

- Bedrock
- Stable/Natural banks

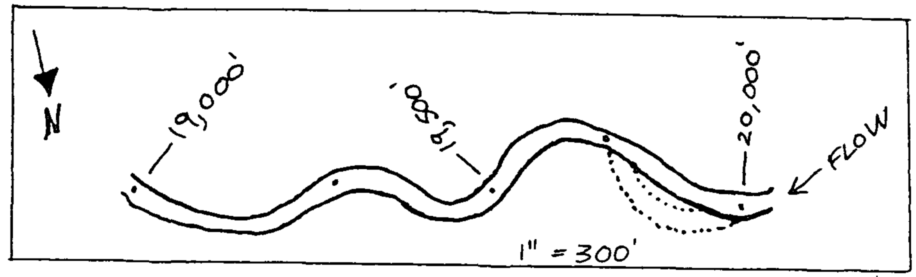
ERODING BANKS:

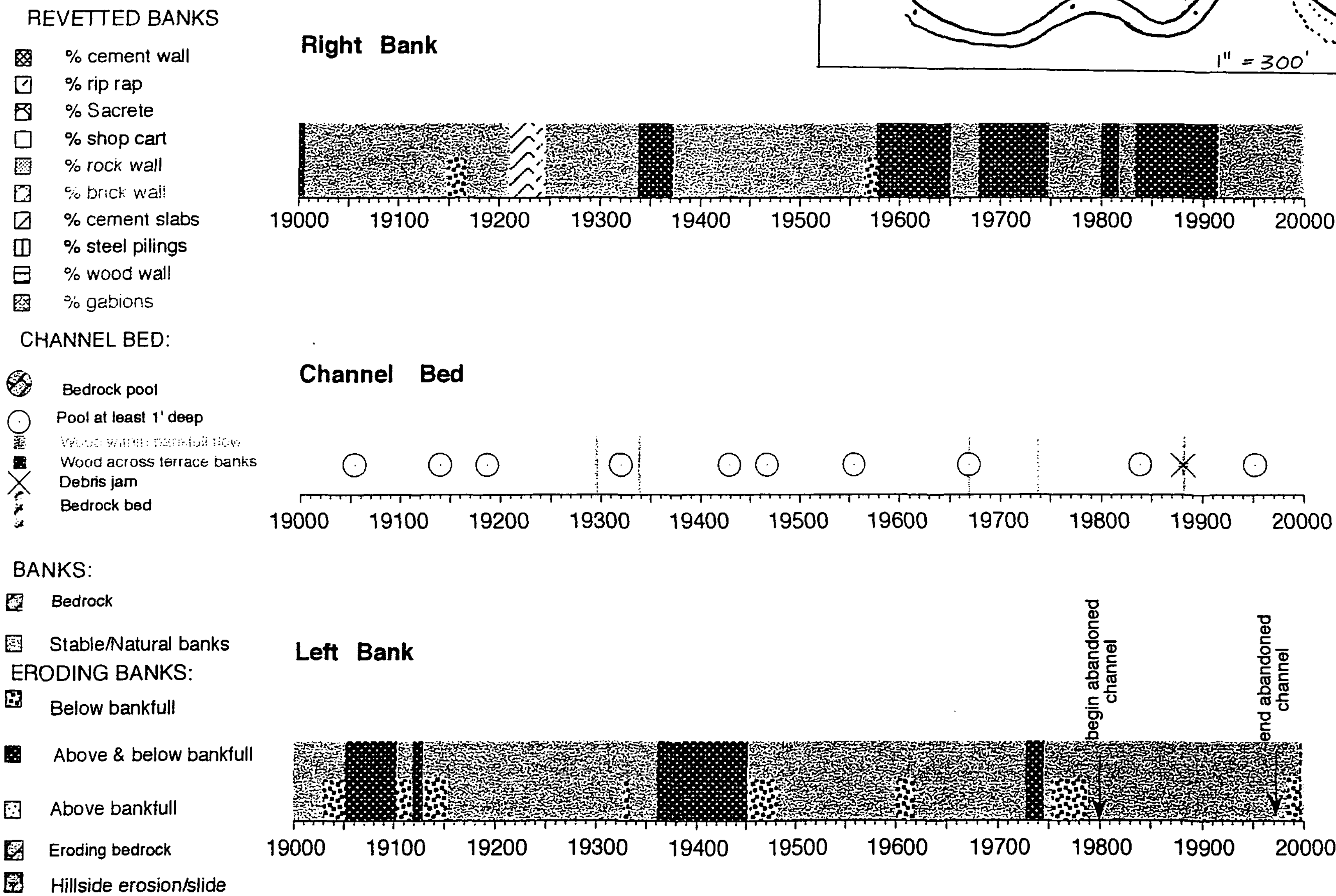
- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock

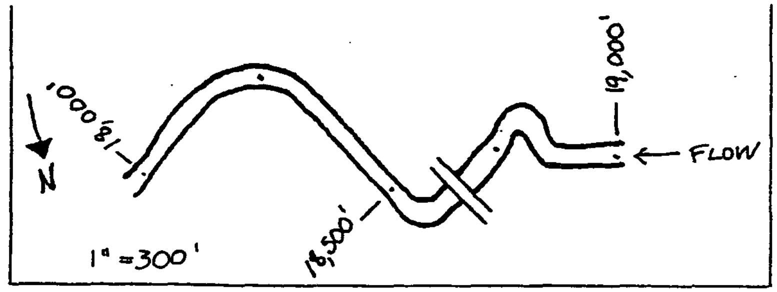
Left Bank



Novato Creek Bank & Pool Conditons, Fall 1997





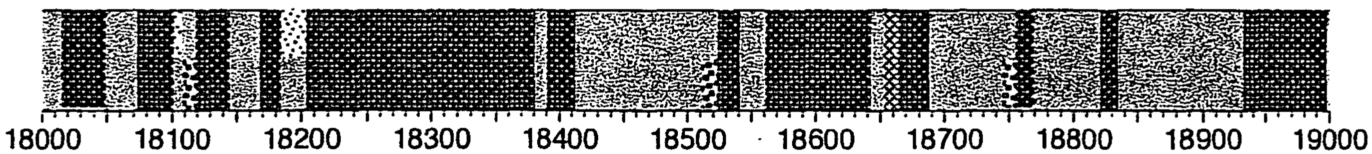


Novato Creek Bank & Pool Conditons, Fall 1997

REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

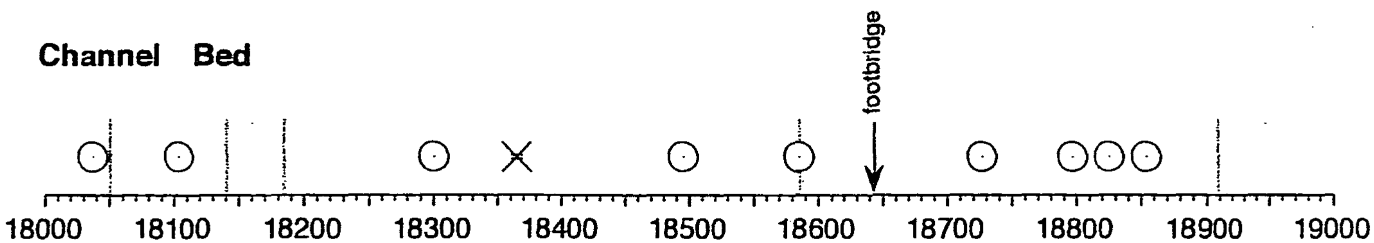
Right Bank



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

Channel Bed



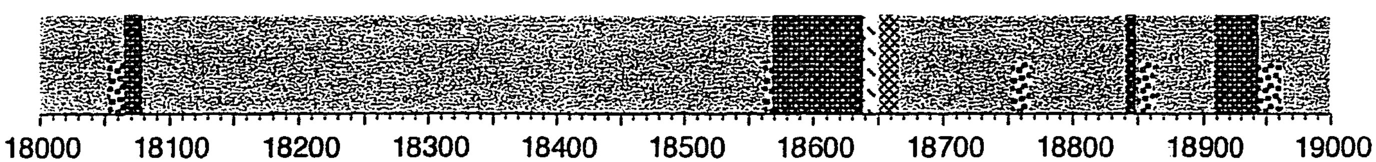
BANKS:

- Bedrock
- Stable/Natural banks

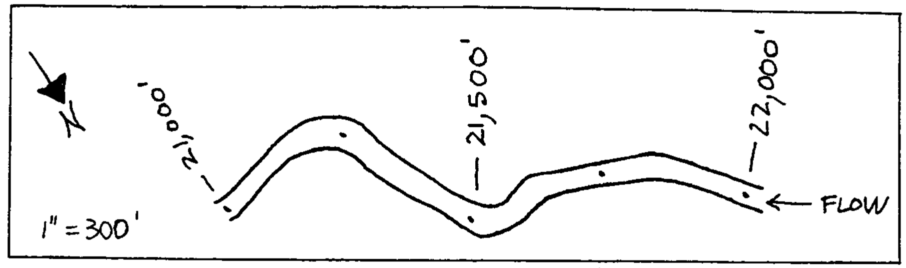
ERODING BANKS:

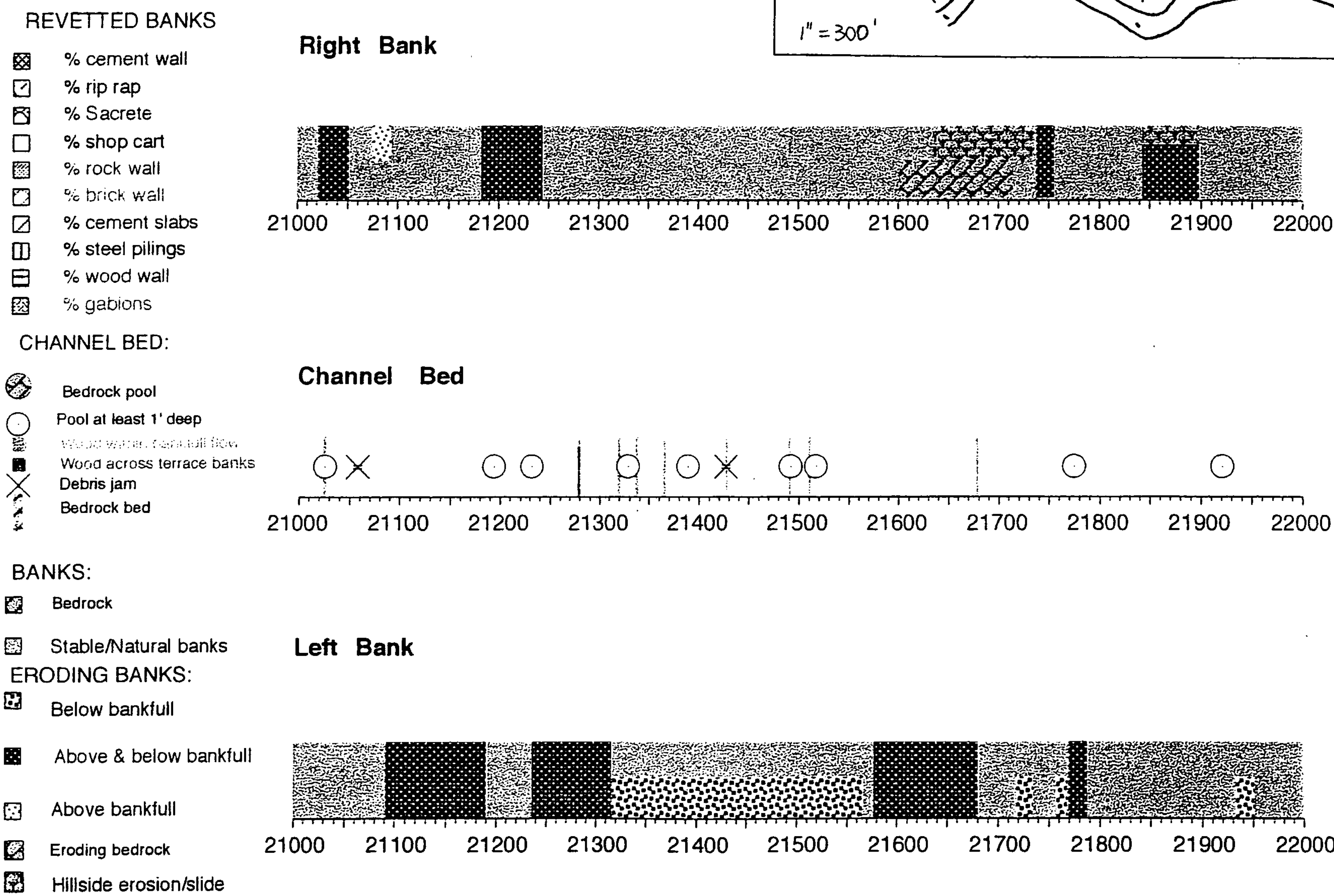
- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock

Left Bank

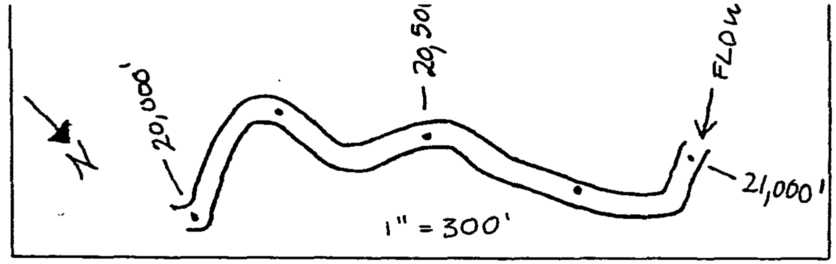


Novato Creek Bank & Pool Conditons, Fall 1997





Novato Creek Bank & Pool Conditons, Fall 1997



REVETTED BANKS

- % cement wall
- % rip rap
- % Sacrete
- % shop cart
- % rock wall
- % brick wall
- % cement slabs
- % steel pilings
- % wood wall
- % gabions

CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- [illegible]
- Wood across terrace banks
- Debris jam
- Bedrock bed

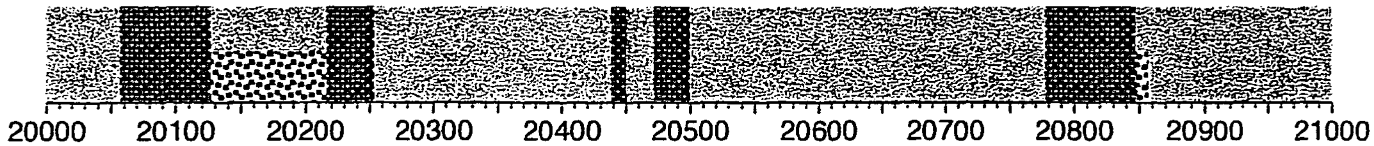
BANKS:

- Bedrock
- Stable/Natural banks

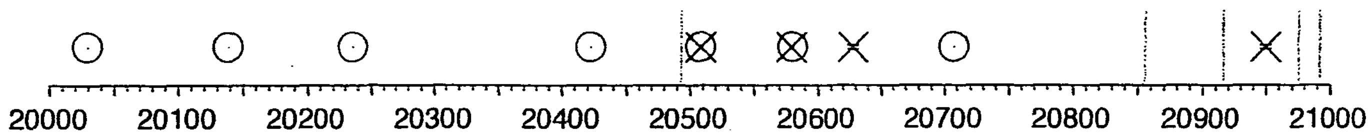
ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock
- Hillside erosion/slide

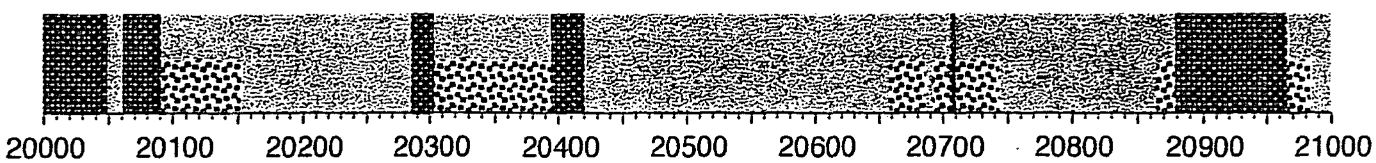
Right Bank



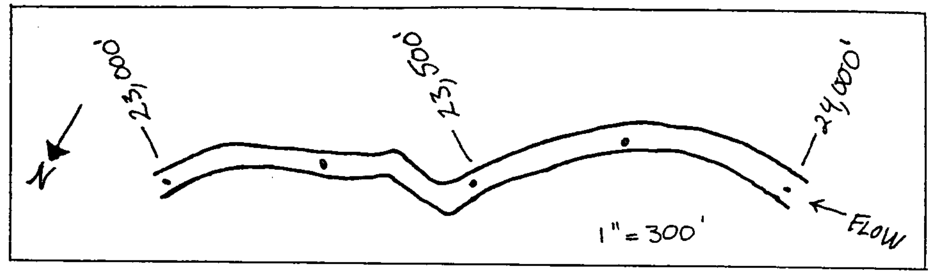
Channel Bed



Left Bank

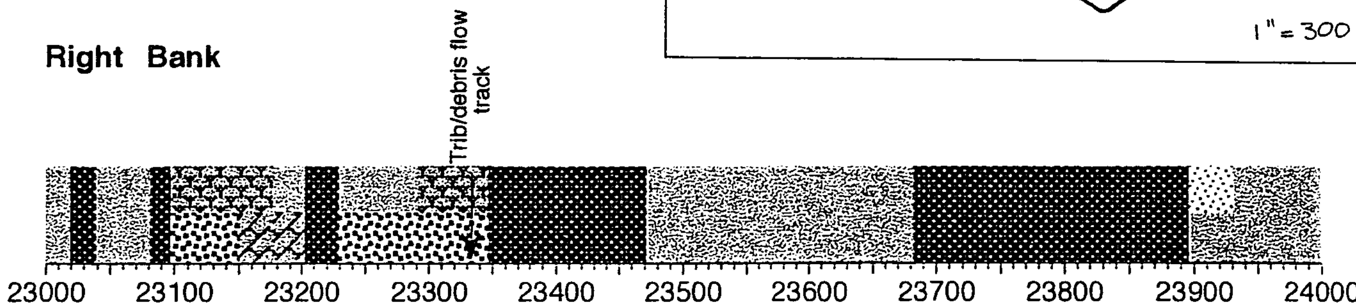


Novato Creek Bank & Pool Conditons, Fall 1997



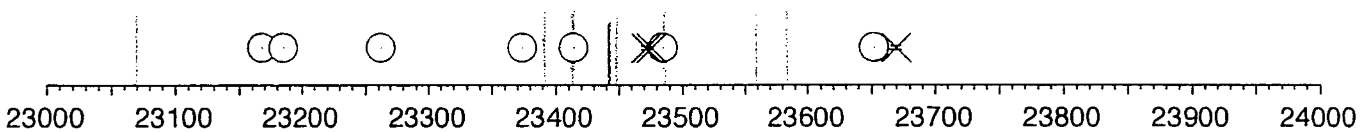
REVETTED BANKS:
- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

Right Bank



CHANNEL BED:
- Bedrock pool
- Pool at least 1' deep
- Wood across terrace banks
- Debris jam
- Bedrock bed

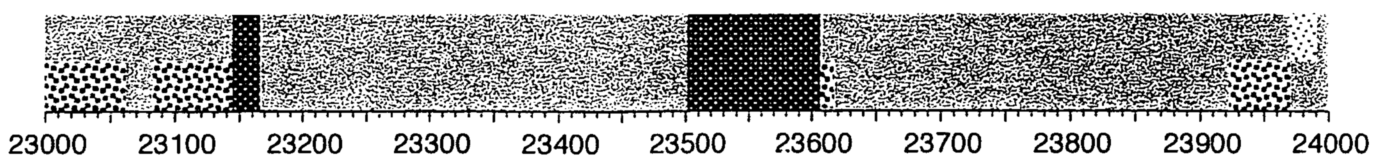
Channel Bed



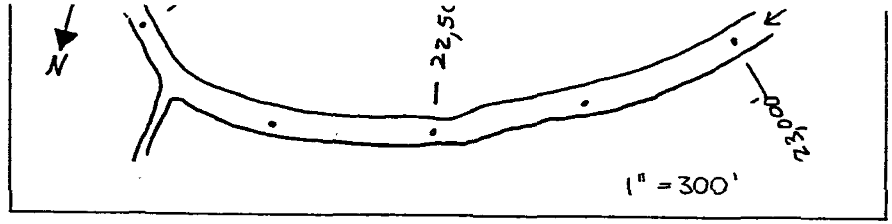
BANKS:
- Bedrock
- Stable/Natural banks

ERODING BANKS:
- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock
- Hillside erosion/slide

Left Bank



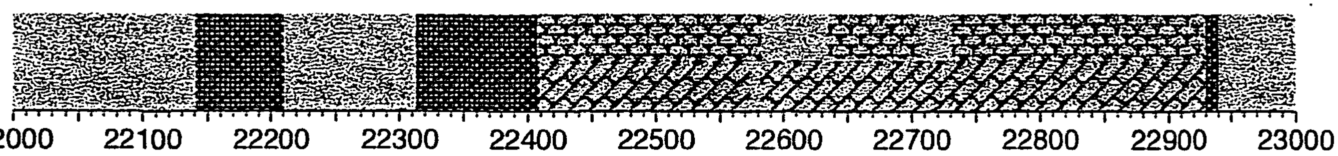
Novato Creek Bank & Pool Conditons, Fall 1997



REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

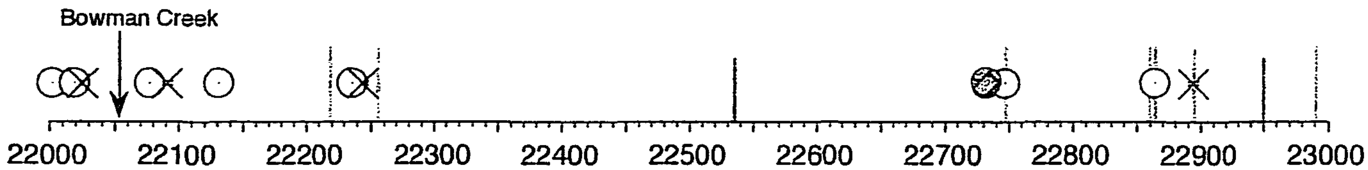
Right Bank



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

Channel Bed



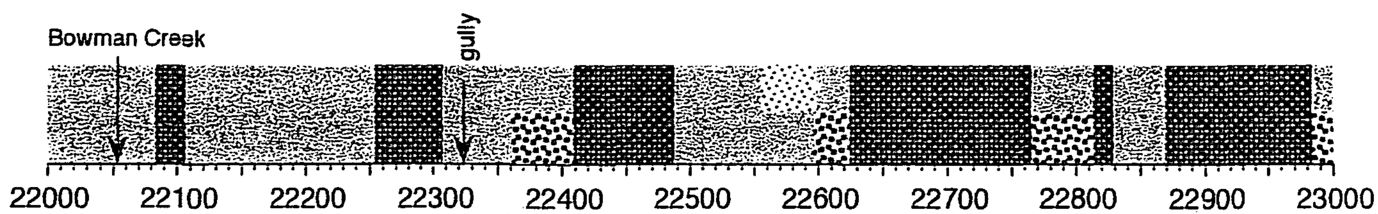
BANKS:

- Bedrock
- Stable/Natural banks

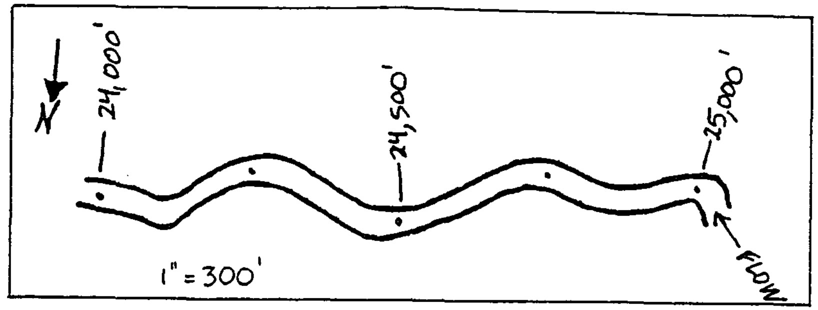
ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock
- Hillside erosion/slide

Left Bank

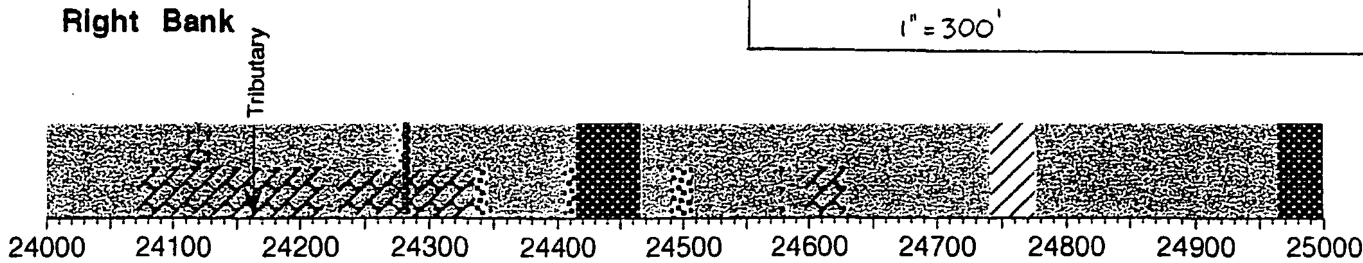


Novato Creek Bank & Pool Conditons, Fall 1997



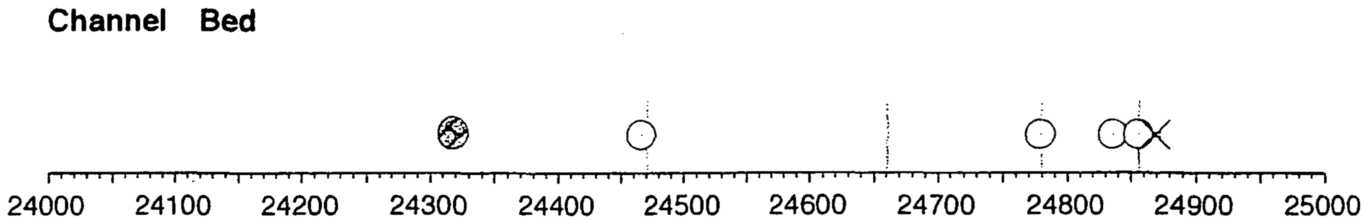
REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood across terrace banks
- Debris jam
- Bedrock bed

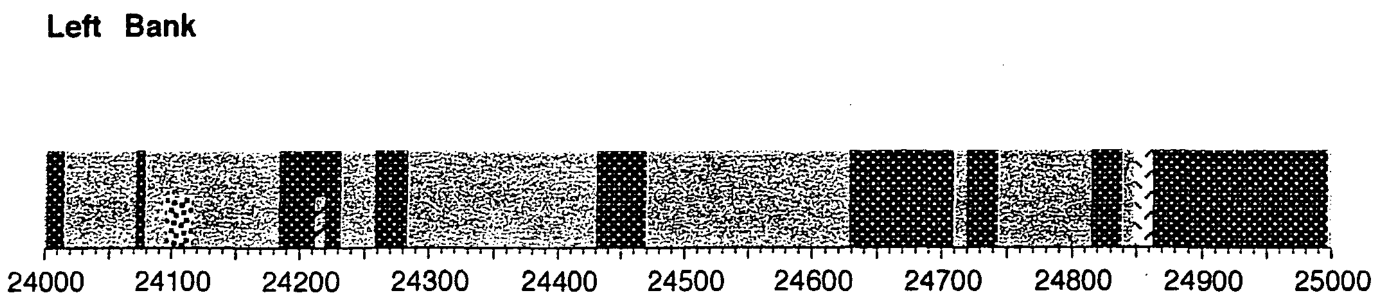


BANKS:

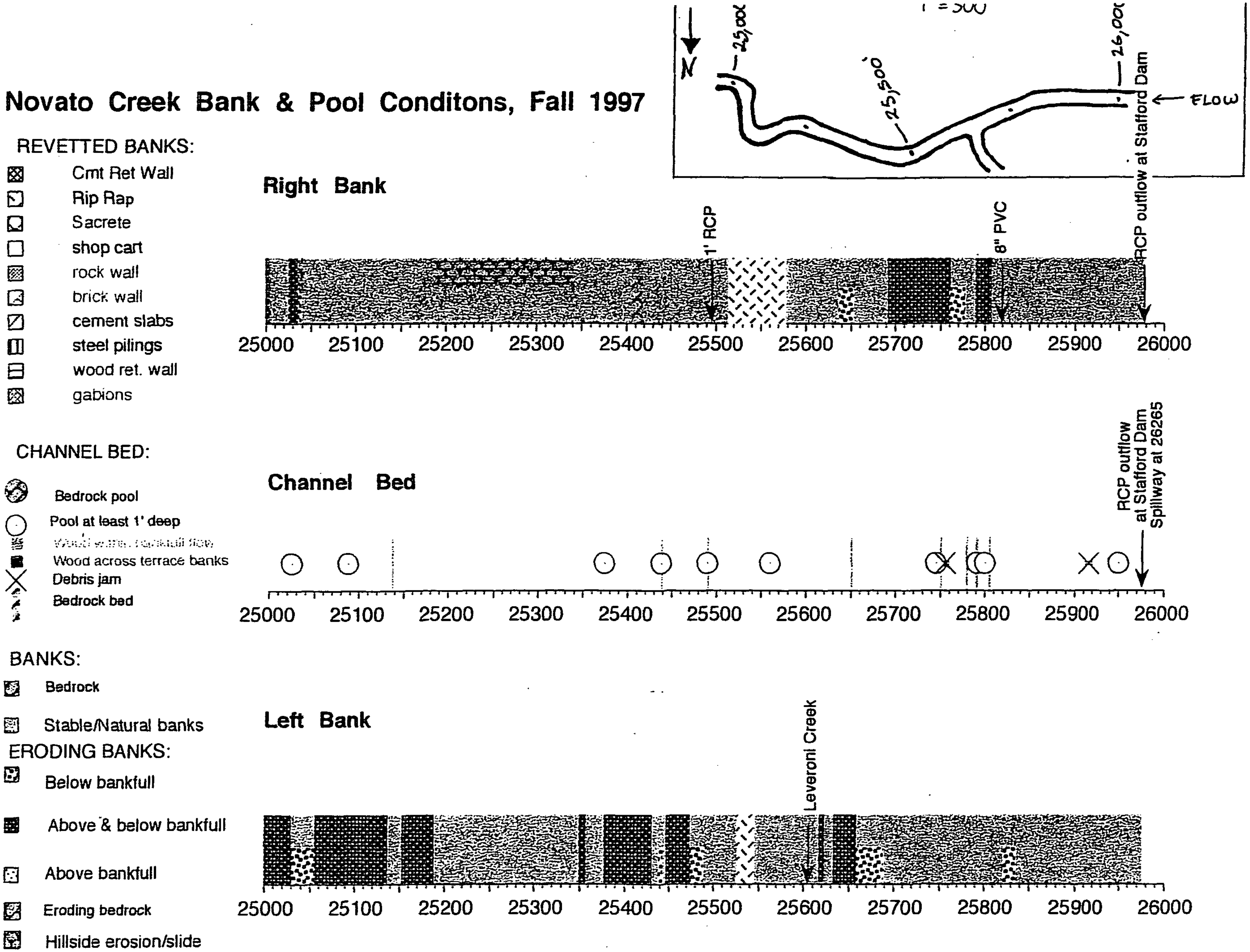
- Bedrock
- Stable/Natural banks

ERODING BANKS:

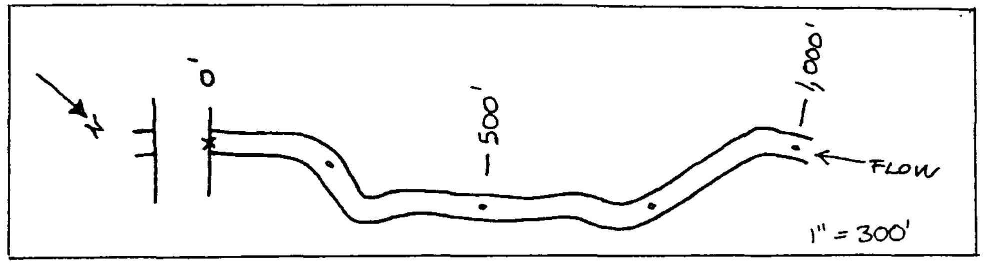
- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock
- Hillside erosion/slide

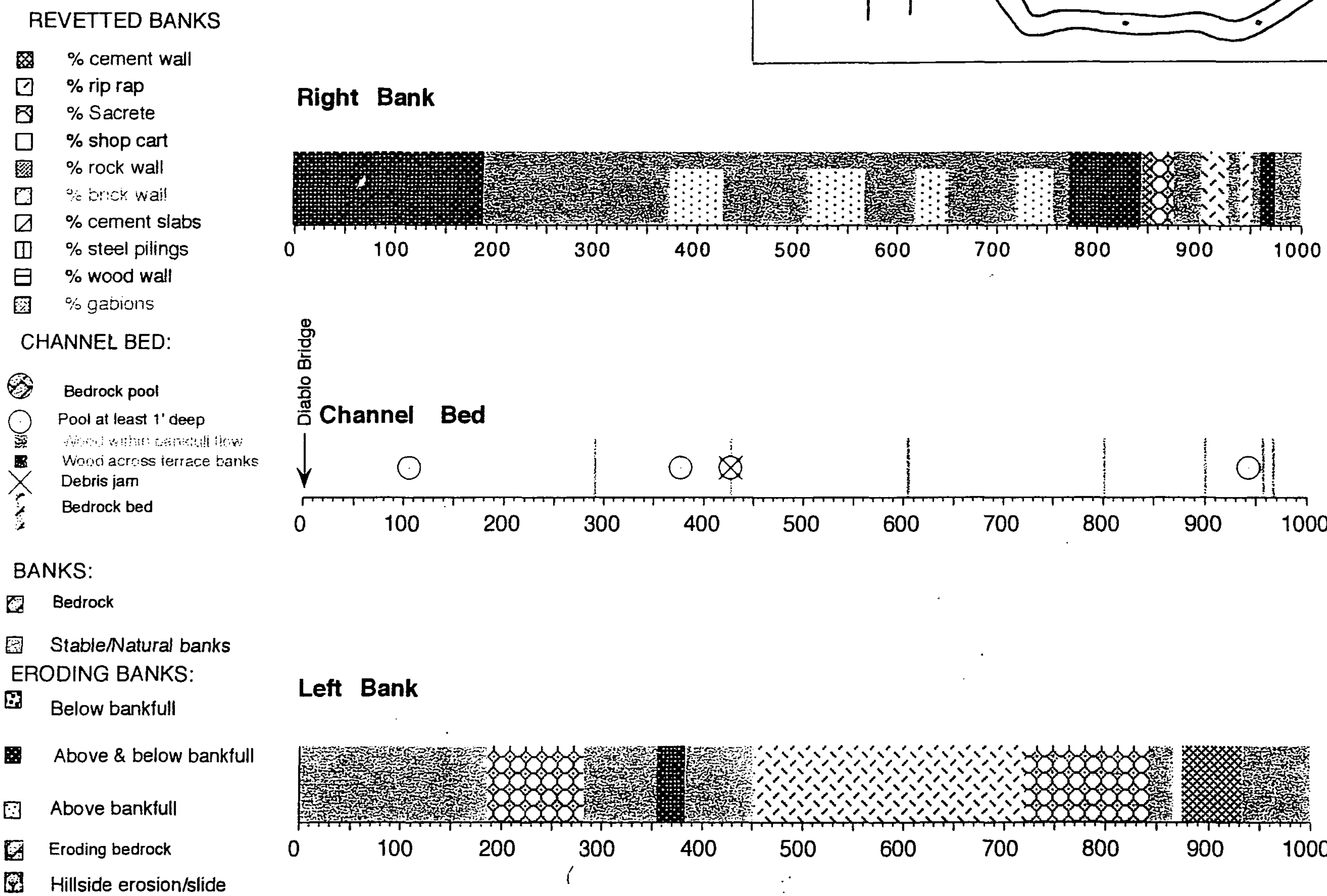


Novato Creek Bank & Pool Conditons, Fall 1997

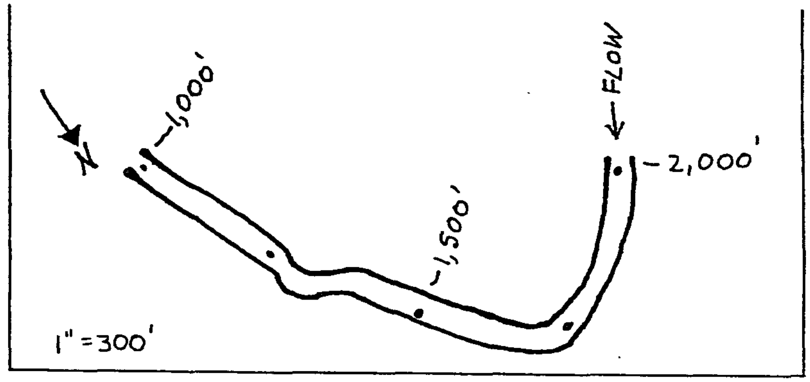


Novato Creek Bank & Pool Conditons, Fall 1997





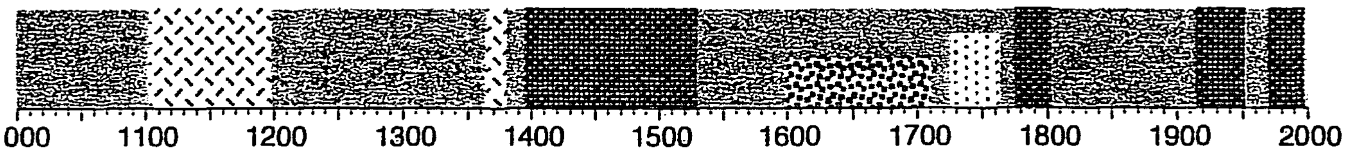
Novato Creek Bank & Pool Conditons, Fall 1997



REVETTED BANKS:

- Cmt Ret Wall
- Rip Rap
- Sacrete
- shop cart
- rock wall
- brick wall
- cement slabs
- steel pilings
- wood ret. wall
- gabions

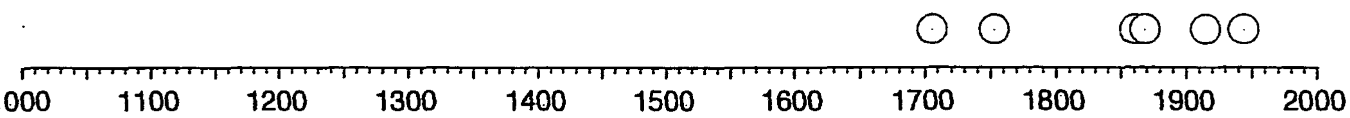
Right Bank



CHANNEL BED:

- Bedrock pool
- Pool at least 1' deep
- Wood within bankfull flow
- Wood across terrace banks
- Debris jam
- Bedrock bed

Channel Bed



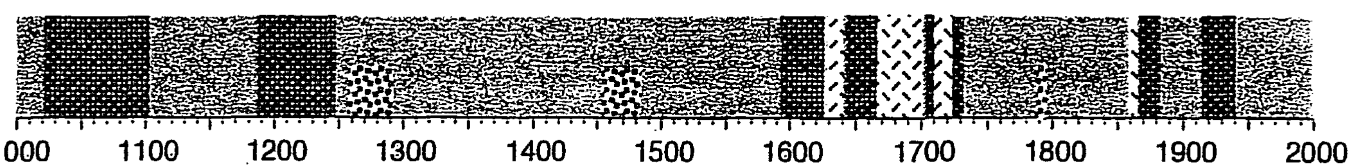
BANKS:

- Bedrock
- Stable/Natural banks

ERODING BANKS:

- Below bankfull
- Above & below bankfull
- Above bankfull
- Eroding bedrock
- Undifferentiated

Left Bank



Novato Creek Field Reconnaissance Notes
Above Diablo Ave Bridge

4/11/97, Laurel M. Collins

METHODS AND STANDARDS:
-Station 0 is located at the upstream (UST) edge of Diablo Ave Bridge. This section of channel is not influenced by tidal flow.
-Field note stations are reported as negative values, in standard English units, from the zero point at Diablo Bridge. They are written in survey notation. For example, 1-06 and 13-26 are equal to 106 and 1,326 feet upstream (UST) of Diablo Bridge, whereas 5+25 would equal 525 feet downstream (DST) of the bridge.
- Distances UST from Diablo Bridge were measured by pulling a 300' fiberglass tape along the length of Novato Creek UST to Stafford Dam spillway.
-All references to left bank (LB) and right bank (RB) are standardized to looking toward the DST flow direction.
- References to average particle diameter (D50) are given in millimeters (mm).
- Width and depth measurements were made with either a telescoping survey rod or a measuring tape during a level line survey of cross section. Measurements are referenced to flow at bankfull (BKFL) stage. The reported amounts of undermining and/or bank erosion are maximum amounts at a discrete point unless otherwise noted.
- Photo references in the field notes include order number for the photo album (shown in the green squares in the Photo Album I), roll number (R#) and photo negative number (P#). All photos that were accompanied by field notes are labeled for their roll and negative numbers on their back side. Negatives are located at consultant's office. Photographs in the album also include early photographs from unidentified individuals and black and white xerox copies of pictures from the 1987 Novato Creek Erosion Control Feasibility Study by Stuber-Stroeh Assoc., Inc.
-Tree number (#) refers to trees that were previously labeled in the field by the MCFCD. New tags were placed on trees that had significance to this study regarding their age and elevation relative to the bankfull stage and terraces. They are referred to as Tag numbers rather than tree #.

Abbreviations include:
BDRK - bedrock

CA - cross sectional area
CMP - corrugated metal pipe
D50 - Diameter of average particle size in gravel bars, excluding sand which is less 2 mm.
Dbf - mean depth of bankfull flow
DBH - Diameter of tree at breast height
Dmn - mean depth at bankfull stage
Dmx - maximum depth, measured at thalweg
DST - downstream
ER - Entrenchment Ratio which equals the flood prone width divided by bankfull width.
LB - left bank
PVC - Polyvinylchloride pipe.
RB - right bank
RSC- Rosgen Stream Classification (Rosgen, 1996)
RCP - reinforced concrete pipe
UST - upstream
Wbf - width of bankfull flow
WDR - width to depth ratio which equals the bankfull width divided by the mean depth.
Wfp - width between banks at two times the maximum depth at bankfull flow.
WS - water surface

Distance
Station
(feet)

~0+100 Photo 24 Album I (R3P1) looking DST from Diablo Ave Bridge at new, 1996 rip rap project on the LB and older sacrete wall on the RB.

0-0 Photo 26 (R3P2) looking UST from DST end of Diablo Bridge. Note the two cement sills at each end of the bridge that maintain channel gradient but impede fish migration during low flow. Flow capacity within the bridge does not appear to be impeded by sediment storage.

1-06 Photo 27 (R3P4). An approximately 17" steelhead is trapped in the long pool just UST of the grade control sill at the UST edge of Diablo Blvd Bridge. Numerous smaller fish, including fry, are noted in the pool. Silt is more prevalent in this stretch than DST of the bridge or UST of the debris jam at 4-27'. The terrace banks are very silty in this segment and bank erosion along this reach is increasing the local supply of fine sediment.

Two culverts are present at RB: a 1.8' box and 1' RCP.
Photo 28 (R3P6), looking UST at RB erosion along outside bend of the creek (in background of photo).

3-38 Photo 29 (R3P7), looking UST. Orundo, a non-native invasive vegetation, is located on RB (right center of photo) A leaning willow, at 4-27, is impeding flow (center of photo).

3-70 Willow # 291 is in the channel at this station.

4-27 Photo 30 (R3P8), looking DST at debris jam that was formed by a leaning willow.

5-34 Photo 31 (R3P9), looking UST at lateral gravel bars. The channel appears slightly aggraded as compared to segments downstream of the debris jam at 4-27. The D50 of the bar is ~ 17 mm. According to the MCFCD channel survey of 1985, the bed elevation near this point would coincide with the top railing of the railroad bridge. This means that the water surface slope of backwater from the railroad bridge that occurs during very high flood flows could extend this far back into the channel. Evidence of sedimentation suggests the possible effects of backwater to this vicinity. According to the MCFCD survey the terrace banks are also at their lowest about 80' downstream of here. which would be the point of imminent flooding during the 33,000 cfs discharge event.

7-21 Photo 32 (R3P10), looking UST at partially blown-out cement weir or old sewer crossing. Note sediment accumulation behind structure.

7-66 Photo 33 (R3P11), looking at RB bay tree #229. Minor bank erosion has exposed two distinct root layers that have made two distinct banks. One at 3.77' and the other at 1.64' above the bed. RSC = G4

7-79 1' CMP

8-01 Willow tree #270 down in channel.

9-00 Photo 34 (R3P12), looking at tree #209 with berries and branches piled behind it. A crude estimate of growth rings gives an approximate age of 50 years. Its diameter is 2.25'. In general, the section from 1-00 to here has banks that are typically covered with berries and are not commonly raw from bank erosion. There is good riparian shading, unlike many of the reaches below Diablo Bridge where channelization has taken place.

9-67 Willow growing in channel, impeding flow.

9-87 Willow growing in channel, impeding flow. A large LB bar is 3.2' high above WS.

10-42 Photo 35 (R3P13), looking UST at partially raw, eroding RB (person with rod in photo is standing at 10-88). The terrace banks are predominantly fine silts and sands.

11-75 Undermined oak tree. The height from the bed to the trunk base is 5.9'. Bank erosion = 4'.

12-70 Photo 36 (R3P14), looking DST at LB bay tree #262, that is starting to pull from the bank. Average bank erosion = 5.9'. Sand is more abundant in the bed here than in downstream reaches. Note that shading has precluded vegetative growth on the channel bed.

12-75 Average bank erosion = 4'.

13-13 Wide section ends and channel becomes much narrower. D50 is about 7 mm.

13-88 Sediments appear more embedded here than the DST reach. RSC = G4.

14-82 Photo 37 (R3P15), looking at tree # 328. Bank erosion = 3.9'.

~16-00 Photo R10P7 (missing), looking DST at Level line survey at tree #343. See Cross Section Survey at 1600, Figure 17A in report.

16-01 Channel type changes from G4 to F4 RSC

17-53 Photo R10P9 (missing). 1' RCP on LB.

17-76 Photo 38 (R3P16), looking at RB erosion = 4'. Note the proximity of the building to the edge of the bank.

18-69 RB erosion = 4' at bay tree # 468.

19-44 Poplar tree # 412.

19-42 LB culvert hidden by vegetation. This site is near the Dept of Motor Vehicles building.

21-57 Photo 39 (R3P17), looking UST at RB erosion.

21-71 Photo 40 (R3P18), looking UST at 7th St Bridge. RSC may change in here. Note the densely vegetated bar on the LB (right side of photo).

23-07 The channel bed has coarse gravels that are being buried by fines.

23-70 Channel bed is mostly sand and fine gravel.

24-46 LB bar is inhibiting flow on downstream end of 7th St Bridge.

24-60 DST edge of 7th Street Bridge has a pool that has formed at the end of the concrete bed underneath the bridge. The height of the box beneath the bridge is 9.5'. There is a 3' RCP at LB.

25-27 UST edge of 7th St Bridge. There is abundant sand upstream of the bridge. A LB willow growing in the channel is impeding flow under the left side of the bridge. The willow should be removed, but could be used for bank protection elsewhere.

26-08 Photo 42 (R3P19), looking UST at the former USGS gage.

26-64 Location of stream gage.

27-00 RSC = G4

27-58 RB undercut 5'.

27-84 1' RCP. In this reach the sands and gravels appear to have same proportion of fines as observed in lower Bowman Cr.

28-49 Photo 43 (R3P20), looking UST at massive bay tree roots that have slumped down along bank at 28-88.

29-08 UST edge of Library footbridge.

29-19 1' RCP LB.

30-00 Photo 44 (R3P21), looking DST at RB rip rap and undercut LB bay tree. From here to some distance upstream, there is abundant sand deposition.

30-96 Pool due to narrowing and lateral bar, and possibly due to backwater effect of downstream sand deposition.

32-52 LB 30" CMP

33-00 Photo 45 (R3P23), looking DST at eroding banks near structure. Note that much of the rip rap has been redistributed. Photo 47 (R3P23), looking UST at relatively natural looking banks. Lots of sand noted in channel bed.

33-75 RB erosion = 9.3'.

33-95 0.5' PVC.

34-29 RB erosion = 2.0'

34-97 Bridge abutment pier.

36-00 Photo 48 (R3P24), looking toward LB. DST edge of foot bridge with concrete base in channel bed. LB erosion = 4.6'.

37-47 Bay tree across terrace banks.

38-23 RB willow slumped into channel and growing across bar.

38-76 Very sandy reach.

39-24 RB 15" CMP.

39-56 RB bank erosion = 4.9'. roots and bedrock pool present in channel.

39-18? Photo 49 (R3P26), looking DST at RB oak tree that is growing within the terrace banks. This tree may have slumped.

39-99 Photo 50 (R3P25), looking DST at Bank erosion = 4.6'. Upper terrace height above bed = 10.8' Height of oak tree above bed = 8.2' DBH = 2.7'. Height of oak tree below terrace = 2.6'

41-44 Photo 51 (R3P27) looking DST at cross section.
RSC = F4
LB and RB erosion = 7.2'
Upper terrace height above bed = 11.3'

Height of oak tree above bed = 6.7' DBH = 2.9'
Height of oak tree below Terrace = 4.6'.

41-54 RB 15" RCP.

42-10 Photo 52 (R3P28), looking UST at Grant St bridge. Note silt stone terraces deposits exposed in pool bottoms at this location.

43-24 DST edge Grant St Bridge.

43-94 DST edge of foot bridge and wall abutments.

44-56 Photo 53 (R3P29), looking DST through the Grant Ave box culvert. This station = UST edge of foot bridge at Grant Ave. Note the deposition of gravels on the RB of box culvert. The capacity of the box culvert has been diminished by about 22%. The way the box culvert meets the stream at an angle has augmented sediment deposition within the box.

45-20 Pool due to narrow channel and RB bar.

45-31 Photo 57 (R3P30 & 31), looking DST at willow on lateral bar that is growing within the CAbf. The tree probably slumped down as part of the ongoing RB erosion, which = 16 to 20'. DBH = 2.9'

46-30 RB erosion = 3.6'. Pool formed by boulder.

46-64 Photo 60 (R3P32), looking UST at roots exposed by bank erosion and pools formed by boulders. The boulder in the background, next to person standing in picture is at this station. RB erosion = 3.2'

48-00 The RSC appears to be in transition between F4 and G4. Bank erosion = 5'.

48-88 Photo 63 (R3P33), looking at a private fence line that is being undermined

49-11 Photo 67 (R3P34), LB erosion = 11.2' beneath bay tree at outside bend of channel. Note sand deposition on point bar on inside of bend. This may be coming from UST bend erosion shown in photo R3P36.

51-00 Photo 70 (R3P36), looking DST at eroding RB on outside of bend near structure.
Photo 71 (R3P35), looking UST at rip rapped RB.

52-25 Constricted section of channel due to willow branches and large bay tree trunk.

52-39 LB PVC = 5".

53-66 Photo 75 (R3P37), looking UST at new retaining structure on RB. Note height of point bar in center portion of photo is 4.6', higher than other bars observed so far.

54-00 New erosion around LB cement walls shown on the center right portion of photo R3P37.

54-55 Photo 76, (R5P11). Gravel bar height along steel-piling (I-beams) retaining wall = 4.6'.

54-97 LB 1' RCP.
56-27 Section of bank on the outside of bend, between retaining structures, will be likely loci of future erosion.
57-65 Bank erosion = 9.5'.
58-03 RSC = F4 (trans G4)
58-38 Willow tree is given new Tag 1. The tree slumped in from 4' but it is presently at water surface level of pool. DBH = 23". The pool = 3' deep.
60-00 Sediment deposition on LB high terrace.
60-36 Bank erosion = 7.9'.
60-68 Bank erosion = 6.2'. Orundo vegetation present.
62-27 RSC = F4 (trans G4)
62-76 LB erosion = 5.3'.
63-71 Right bank bend eroding near structure.
64-53 Silt stone bedrock in channel bed.
65-14 Bay tree across terrace banks.
69-90 Continuous rip rap and sad bags on LB or RB to this station from about 66-20.
70-50 RSC = G4
70-64 Pool, begin rip rap LB.
71-75 End LB rip rap.
72-34 Photo 103-105,(R5P22-24), looking UST at RB erosion. RSC = F4.
72-41 Bank undercut = 9.7'. Terrace = 11.8'
72-78 RB erosion = 8.3'.
73-16 1' CMP at RB.
73-90 Photo R5P25, (last picture on roll not developed) looking at RB erosion. This may be about where Photo 107 is located.
75-00 Photo 111 (R6-P1), looking UST at Simmons Bridge. Notice exposed root along low flow bank.
75-80 DST end of Simmons Bridge.
76-18 Culvert to Simmons Creek at LB
76-23 Photo 114 (R6P2), looking DST beneath Simmons Bridge. Station number pertains to UST end of Simmons Bridge.
76-64 Orundo on LB
77-24 Channel aggraded upstream of bridge.
77-68 Photo 117 (R6P3) and 121 (R6P4), looking at RB tree that is leaning in toward channel. Pool at old ash tree with DBH = 24.5", tree Tag 2.
79-83 Photo 124 (R6P5), looking UST along fairly stable reach. RSC = F4
80-28 Begin RB rip rap.
80-51 End RB rip rap.

80-66 RB 15" RCP.
81-00 Photo 125 (R6P6), looking UST into stable channel RSC = F4
82-64 Begin LB rip rap & pool.
83-55 End LB rip rap.
85-04 Photo 129 (R6P7), looking UST into fairly stable reach that has a steeper gradient and narrower width than previous sections. There is also more cobble and occasional boulders.
86-11 Pool in narrow BDRK section. RSC = G4.
86-68 RB BDRK = serpentinite.
87-22 Photo 130 (R6P8). looking DST along narrow BDRK gorge = 7.7' wide.
89-11 BDRK pool, Wbf = 22', bank erosion = ~ 2'.
90-17 RB erosion = 3', end of BDRK reach.
90-42 Boulder pool.
90-64 Small amount of BDRK and also an LB concrete crib wall.
91-31 Grouted sacrete on RB.
91-51 Rip rap pool.
92-06 Rip rap and grouted concrete ends on RB.
92-49 Begin concrete and wood retaining wall RB.
92-71 End concrete and wood retaining wall RB
93-12 BDRK pool.
93-00 Photo 135 (R6P9), looking DST at LB bedrock reach.
93-12 Large, old RB willow, DBH = ~ 30", Tag 3. Located along bankfull (?), about 3' higher than the mean bed level.
93-28 Old weir with flash board in BDRK segment of channel.
94-26 RB erosion = 3.5'. Continuous erosion to 94-88.
94-52 RB erosion = 5'.
94-60 RB erosion = 9'
95-38 LB bank erosion = 4.5". RB bank erosion = 1'.
96-00 18" RCP at LB.
96-33 LB tributary confluence. 1-2' diameter pipe, and 2-5' diameter pipes
99-00 RSC = F4, RB bank erosion = 4', LB bank erosion = 1.5'.
99-22 RB erosion - 6.5'.
99-64 15" RCP at RB, and LB erosion = 7'.
100-32 Photo 151 -153 (R6P10-12), looking DST at section 9-83. Channel widens substantially in this reach.
100-78 This section of channel narrows with a tree that has been cut after it feel in the channel.
101-51 Photo 156 (R6P13-14), looking DST at RB oak tree that has fallen over. The exposed small roots indicate recent incision of 1.5' following a period of bed stability, while the exposed

moderate-sized roots show about 2' additional incision following some other period of stability. The previous flood plain has been abandoned. Wbf = 25.5'. If oak is to be saved, it needs some support beneath the roots.

102-56 Begin RB rip rap.

102-65 2' RCP.

102-81 10" RCP.

102-93 End RB rip rap.

103-19 Photo 156 (R6P15), looking at old valley oak (?) behind apartments on RB, DBH = 3.7'. The address for this site is 1730 Novato Blvd. The height of the trunk/root transition is 9.' from the mean bed level. The terrace is 14.45' from the bed. Old stable banks exist at about 5.' and 7.5' above the mean bed level. Tree Tag 4. RB erosion = 6.5'. The tree should be dated. Two periods of incision are apparent: first 2.35' and then 2.5'. Each seems to have been followed by a period of relative stability. Since oak trees do not grow at bankfull elevation and are found on abandoned terraces, then the floodplain that used to be located at the 9.85' level was probably abandoned before the turn of the century. If present bankfull is around 4.5' to 5' high on the bank, then there has been at least 4.5' incision during this century.

105-68 3' RCP. Abundant sand in this area.

106-33 Bank erosion = 7.5'.

106-61 5" PVC pipe at RB.

106-90 Bank erosion = 5'.

107-52 Begin RB wire basket gabbion.

108-00 Photo 161 (R6P16), looking at the RB gabbion that has bowed-out due to possible landslide creep. End wire basket gabbion, begin RB sacrete. From this station to 110-61 there is abundant fine sediment in the channel and few pools.

108-15 Photo 132-162 (R6P17-18), looking UST at RB erosion where the channel cuts along the nose of a hillside ridge. Channel gradient steepens along here. End RB sacrete, begin RB bedrock. Note boulders in this reach which is unusual for Novato Creek. Begin RB Bedrock

109-71 LB erosion = 3.5', RB erosion = 3.0'. Note that flood control periodically mows vegetation from channel bars.

112-61 First pool in this section. RB erosion = 5.0', LB erosion = 1.5'.

112-99 End RB BDRK.

113-92 Photo 165 (R6P19) looking UST at LB slabs. Begin concrete slabs on LB.

114-69 Photo 168-169 (R621-22), looking DST at LB slabs stacked along the bank. This station pertains to the UST end of the concrete slabs on LB.
115-00 Photo 171 (R6P20), looking at RB bay tree along Miwok Park, tree Tag 5, DBH = 60". The root/trunk transition is at 11', but the tree may have slumped in from the 12.5' terrace. Two periods of relative bank stability are indicated by the exposed roots. Bank tops were previously 5.5' and 3.7' above the present mean bed level. This reach has much more sediment storage as gravel bars. RSC= F4
116-32 Begin LB rip rap.
117-17 Photo 178 (R6P23), looking UST at rip rap along the banks near Miwok footbridge. Station is the DST end of Miwok Bridge.
117-50 Approximate end LB rip rap.
117-75 Photo 189 (R6P24), looking UST at LB tributary confluence with 2-5' RCPs. One is clogged with sediment and has lost ~ 1/3 of its capacity.
119-07 Photo 185 (R6P25), looking at LB erosion. LB erosion = 7', RB erosion = 1.3'.
119-48 RSC= G4
120-14 Old cement weir.
120-25 Photo 193 (R6P26), looking at RB slide along the nose of hillside ridge that is just upstream of old weir that used to dam the creek for fishing derbies. Other weir sites were reportedly used for water supply for irrigation (Liz Lewis).
121-41 End of RB hillside knob, begin RB terrace.
121-52 Photo 194 (R6P27), Looking DST at gravel bar behind weir. The weir has caused a noticeable increase in gravel deposition upstream while there is much more sand DST of the weir. Photo 195 (R6P28), looking upstream from weir.
122-72 LB bank erosion = 2', RB bank erosion = 1.5. Transition from a Rosgen G type channel to an F type.
123-47 Pool and RB erosion = 8' beneath bay tree.
123-95 Begin knob and BDRK slide on RB.
124-59 Sandstone BDRK in channel bed.
125-19 Photo 199 (R6P29), looking DST at RB bay tree that has fallen at eroding bend in channel.
126-88 Photo 202 (R6P30), looking DST from 127-25 at LB bank erosion = 5'. RB erosion = 0.5'. Channel reach is F type.
128-23 Old channel sediments exposed in RB terrace.
128-91 Channel changes again from an F type to a G type.
130-70 Photo 206 (R6P31), looking UST toward Novato Blvd bridge.

Photo 204 (R6P32), looking DST from below Novato Blvd bridge. Marin Flood Control District does not manage stream above the bridge.

130-57 Begin RB concrete wall.
130-82 End RB concrete wall.
130-92 Begin concrete rip rap in bed.
132-17 End concrete rip rap in bed.
131-00 RB tributary confluence with 4' RCP.
131-40 DST end Novato Bridge, begin LB and RB grouted rip rap.
132-?? Photo 207 (R6P33), looking DST at UST end Novato Blvd Bridge.
132-86 End LB rip rap.
133-06 End RB rip rap.
134-00 Photo 208 (R6P34), looking UST from Novato Blvd Bridge where gravel bars are less sandy, and the banks are not so eroded.
134-81 RSC= F4 (G4 transition, bank erosion = 6'.
136-30 Photo 209 (R6P35), looking UST at recent LB erosion and a fallen willow at 136-68.
136-68 Photo 210 (R6 P36), looking at LB terrace banks that supply medium-sized gravels and sand from erosion at bend.
138-55 Photo 211 (R6P37), looking DST from 138-90 at concrete slabs that may have been a weir. The channel is also constricted by a fallen willow on RB and willow branches from LB Lots of gravel bars noted upstream of the constricted site.
139-15 Photo 212-213 (R7P1-2), looking UST at Bay tree across channel that has fungal rot in its trunk. LB erosion = 3.5', RB erosion = 1.5'.
139-22 LB erosion = 5', RB erosion = 1.5'.
140-80 LB erosion = 4.5'.
140-94 Lots of recent deposition of sand and fine gravel.
141-90 Channel is very aggraded with lots of sediment storage bars of gravel and fine gravels and sand in the bed resulting in an apparent loss of capacity. This may represent a slug of sediment moving downstream. Bank erosion = 8' in some areas.
143-22 The aggraded reach has ended, but there was lots of bank erosion in the reaches before this point.
144-45 DST end of private driveway bridge (with dog).
146-29 Bank erosion = 4.5'.
146-69 Photo 214-215 (R7P3-4), looking DST at large gravel bar on the RB is at least 2' high. LB erosion = 4.5'., RB erosion = 2.0'.
149-38 DST edge of private driveway bridge. Gravel bars are about 3' high. Begin RB rip rap. RSC= G4 , bank erosion = 4.5'.

149-48 End RB rip rap.
150-00 Bank erosion = 5'.
150-26 Photo 216(R7P5), looking DST to bridge. Bank erosion = 5.5'. Gravel bar is 3' high..
150-75 Begin LB rip rap. Channel still appears aggraded. This could be due to a former debris jam that could have formed upstream of the bridge.
151-24 Photo 217 (R7P6), looking DST at 7' high water mark in RB ash tree that is growing at 2.25' on low bank. DBH = 0.5'. Note high bar on RB is 2.7'. Bank erosion since the establishment of the ash tree is 3.5'. This tree should be dated.
151-84 Photo 218 (R7P7), looking at RB tributary confluence which is graded to Novato Creek thalweg. Fence structure could potentially increase channel blockage.
153-10 Begin LB rip rap.
153-39 End LB rip rap.
153-41 Begin LB rip rap.
153-77 End LB rip rap.
153-85 LB bank erosion = 4.5'.
154-74 Photo 219 (R7P8), looking UST at Sutro Bridge. Begin RB rip rap.
155-34 End RB rip rap.
156-17 DST end of Sutro Bridge.
156-72 Photo 220 (R7P9), looking DST at UST end of Sutro Bridge. The bridge has a cement bottom that sets grade of channel Less than 1' of sediment deposition on LB side of bridge.
157-59 Photo 221 (R7-P10), looking UST at sand bag dam for fishing derby at horse stables area.
159-00 RB erosion = 3'
159-38 Photo 223 (R7P11), looking at RB erosion beneath undercut oak tree. RB erosion = 7'. This would be a good tree to date to determine rate of bank loss.
159-75 Bay tree leaning across channel
159-97 Water diversion pump.
161-07 RB oak tree top in channel.
161-34 Photo 224 (R7P12), looking upstream at F type channel. The terrace height along this reach appears low relative to the bed height.
162-00 Photo 225 (R7P13), looking at LB bay trees of 1' DBH. They are growing about 2.6' above the mean bed level (bankfull?). Bank erosion exposing roots = 1-2'. These would be good trees to date. RSC= F4
162-92 Bedrock across bed and bay tree partially across channel.

163-53 Bank erosion = 3.5'.
165-00 Photo 226 (R8P3), looking UST where channel narrows and RB hillslope, rather than terrace is adjacent to channel.
165-90 RSC= F4
169-93 Photo 227 (R8P6), looking DST End bedrock influenced reach. Channel widens slightly upstream.
170-59 Confluence RB tributary/gully from road, graded to bankfull flow. Male Wilson's warbler observed singing in riparian vegetation.
172-77 Photo 228 (R8P8), looking UST where widening of channel and magnitude of gravel bars is more significant.
173-20 Bank erosion = 3'.
174-36 Photo 230-233 (R8P9-11), looking DST at large RB point bar and LB erosion.
175-25 Confluence LB tributary that is not graded to Novato Creek. It is gullied just at confluence and does not carry much sediment load.
176-21 Photo 234 (R8P12), looking UST at bay tree in channel
176-55 Bay tree in channel. Lots of bank erosion upstream on LB.
177-00 Photo 235 (R8P13), looking UST at LB erosion = 3.5'.
178-48 RB erosion = 2.5'.
180-40 Bank erosion ~ 2.5'.
181-84 Photo 236 (R8P14), looking UST at fallen bay tree from RB. RB erosion = 6'.
182-70 Photo 237 (R8P15). Two 6" trout observed to be spawning in upstream of the pool. Also a singing male Wilson's warbler was observed.
183-14 Fry in riffle.
185-85 Photo 238-239 (R8P16-17), looking DST at RB bay tree in channel and area where pools and riffles have developed in association with large point bars. Some bars nearly got to top of terrace banks behind blown out debris jams. RB erosion = 5.7'.
186-51 Photo 240 (R8P18), looking UST at DST end of old bridge. More Fry observed upstream of bridge at 186-79.
Photo 241-242 (R8P19-20), looking DST from bridge(?) at riffles and gravel bars.
188-25 LB erosion = 9'.
188-76 Frog in creek, possible red legged? RSC= G4
189-94 Photo 243-245 (R8P21-23), looking DST at floodplain-level bar or old bed along the LB. Also note Wilson's warbler singing. RSC= B4
192-14 Photo 246 (R8P24), looking DST at blown out dam that has a 4' step in grade at its DST end.

192-95 RB willow has fallen into channel.
193-48 Singing Bullocks Oriole, 5/5/97.
193-63 LB erosion = 2.5'.
194-29 A 4" trout observed in pool.
194-44 Bank erosion = 6'.
195-48 Photo 247 (R8P25), looking UST at wide reach of channel. This reach has mid channel and lateral bars. RSC= B4
195-89 RB erosion = 4'.
196-69 Photo 248-250 (R8P26-28), looking upstream at B type channel where willow has fallen into channel.
197-37 Tree down in channel.
198-00 Photo 251 (R8P29), looking DST in cutoff oxbow channel on LB.

Photo 252 (R8P30), looking UST in old oxbow cutoff. The terrace is about 5' above the oxbow bed.

Wbf = 22.5 Dmn = 3.2 CAbf = 72 Dmx = 4
WDR = 7.03

There is a 17" DBH bay tree 1.6' above the oxbow bed, which has probably filled somewhat since it became cut off.

Photo 253 (R8P31), looking DST in oxbow at a 1.4' DBH willow practically in the bed of the channel at the DST end of its confluence with the main channel.

199-71 UST end of cutoff meander that is 5.5' above the mean bed level of main Novato Cr. There are 1.5' of fines over gravels in t he oxbow bed at its confluence, indicating the possible amount of filling.

Photo 254 (R8P32), looking upstream above oxbow cutoff confluence.

200-46 Bend with 2 obvious terrace levels. The highest is on the RB.
200-90 Terrace heights which are different on both sides of the channel (higher on the LB). RB erosion = 7.5'. LB erosion = 5.2' for ~ 37'.
202-90 Photo 255-256 (R8P33-34), looking DST at RB where person is standing on a prominent inner bank. RB erosion = 8'.
203-53 Photo 257 (R8P35), looking UST at LB erosion = 7'.
204-22? Photo 258 (R8P36), looking DST at fallen RB bay tree.
204-49 LB willow tree with DBH of 1.8' on terrace at 5.8' above mean bed level.
204-92 Bay tree in channel.
205-08 Bull frog identified.
206-27 Blown-out debris jam.

206-30 Photo 259 (R9P1), looking at LB willow in old channel. Two trees in an old cut off channel. Willow tree = Tag 6. DBH = 36" located 5.5' below terrace and 2' above old channel bed. The old bed is a maximum of 7.4' above the present bed level. elderberry tree DBH = 0.6' at bed.
Photo 260 (R9P6), looking DST at meander cut off.

208-04 RB erosion = 3'.

209-15 Photo 261 (R9P2), LB (?) willow (given Tag 7) has DBH = 36" at 6.5' below terrace and 6,6' above present bed level.

209-50 Major LB erosion = 14.5'. Channel is very wide.

209-90(?) Photo 262 (R9P3), looking UST at tree fall and RB erosion.
Photo 263 (R9P4), looking DST at woody debris in middle of channel.

210-67 RB erosion =12'.

210-82 RB gravel bar = 2.2'.

211-87 RB erosion = 4.5', LB erosion = 1'.

212-15 Photo 265-266 (R11P8-9), looking DST at cross section area. See Cross Section Survey 121-15, Figure 17A in report.

212-53 RB debris flow chute from hillslope, not presently active.

213-63 LB erosion = 10.7.

214-09 Photo 267-268 (R10P36-37), looking UST at LB where there has been substantial bank erosion. Bay trees on the terrace are gone although remnants of their roots are still present. Terrace height = 13'.

214-11 Photo 269 (R11P1), looking at RB pond where a bull frog tadpole was observed. This is the first off-channel habitat (for low flow) that has been observed along Novato Cr.
Photo 270-271 (R11P2-3), looking DST toward LB erosion seen in Photo 267-268. Note that the pond is just to the right of the debris shown in the right center of the photo.

214-85 Photo 267 (R11P10) looking at LB cliff swallow nest.

214-90 Photo 268 (R11P7), looking DST at cross section. See Cross Section Survey 214-90, Figure 17B in report.

215-10 Photo 274 (R11P5), looking UST at another off-channel pond on RB. Both ponds occur where there is woody debris anchored in large gravel bars, that only occur where the width of the channel has been substantially increased from bank and terrace erosion.

215-17 Salmonids in pool.

215-95 Change to bedrock in banks, channel narrows and much less erosion.

216-46 Photo 275 (R11P6), looking DST at cross section. See Cross Section Survey 216-46, Figure 17B in report.

217-07 LB bar about 7.1' below terrace, and bed is about 6.8' below top of bar. The bar may be in an abandoned bend.
217-66(218-66?) Willow on abandoned channel bed. DBH = 18", Tag 8. Another willow near this location has a DBH = 17.2"
217-90(218-90?) LB bay tree, Tag 9, which has a DBH = 17" and is growing on the bed of an abandoned meander.
Photo R276 (11P14), looking at RB Bay tree Tag 10, growing at possible edge of bank, has a DBH = 13.6". The old bed is about 4.1' below the edge of the terrace.
218-44 Photo 277 R11P11) Looking DST at old Plymouth in channel.
218-82 Photo 278-279 (R11P12-13), looking UST where channel widens significantly toward the confluence with Bowman Canyon.
219-37 Photo 280 (R11P15), looking at LB willow, tree Tag 11, that has a DBH = 0.6'. It is growing on a bar that is 4' above the thalweg and 7.5' below the terrace banks.
220-02 There is a metal tank in the middle of the channel that forms a pool filled with Salmonids. This each has lots of sediment stored in high gravel bars.
220-51 Centerline of confluence with Bowman Canyon Cr.
221-06 RB erosion = 3.5'. RB bar = 4.4' above thalweg.
221-68 RB erosion = 3.5'. Note that above Bowman the channel has lots of bars at many different levels, suggesting that flow is insufficient to move sediment but most appears to be trapped due to woody debris and vegetation encroachment up to Station 223-00.
222-86 (?) LB erosion = 3'.0
223-00 Photo 281 (R11P17), looking UST where channel narrows and becomes relatively stable. Sediment storage appears limited and there is little vegetation encroachment.
223-25 Photo 282 (R11P16), looking at LB eroding gully with exposed roots of bay tree. The gully has been caused by excess runoff from grazed field.
223-94 RB erosion = 4', LB undercut = 2'.
224-13 Begin bedrock in banks.
226-61 RSC= B,F,G4? Terrace height = 12.4', bank erosion = 2'.
228-14 Photo 283 (R11P18), looking at UST car wreck (Rambler ?)
228-65 Photo 284-285 (R11P19-20), looking UST at bank erosion = 37', fallen trees and midchannel bars that are 2' high. There is ample localized sediment supply from the banks.
229-05 Photo 286 (R11P21), looking UST at LB erosion = 5'
231-00 Photo 287 (R11P22), looking UST at RB inner gorge and bank erosion.

231-68 Photo 288 (R11P23), looking at willow, tree Tag 12, on midchannel bar. DBH = 8".

233-14 Photo 289 (R11P24), looking DST at large point bar with stable vegetation. Near this station there is an old channel bed about 5.4' above the thalweg on RB. Add 0.5' to roots that are exposed indicating that the bed was 6' above the thalweg. The terrace on RB is 8.6' above the bar/bed feature.

233-31 RB debris flow track at ephemeral tributary opposite the point bar, which is 5.5' below the terrace. The bar may be an old floodplain.

233-91 LB erosion =52'. The channel changes to major bank erosion with braided channels occurring both above and below the previous bankfull elevation.
Photo 290 (R11P25), looking toward the LB from the top of the terrace where the old fence is missing.

234-14 Trout pool.

235-12 Bull frog in pond upstream of debris jam.

236-15 Upstream extent of extreme 52' wide LB erosion.

237-00 Photo 291 (R11P26), looking DST at UST end of debris jam. The channel is choked with vegetation and sediment from about station 235-15 to this station. The LB is also eroding.

238-08 Five newts observed.

238-46 Photo 292 (R11P27), looking UST at cross section. See Cross Section Survey 238-46, Figure 17C in report.

240-00 Channel appears aggraded in long straight reach. There are no pools and terrace is only 9.8' above the bed.

241-37 BDRK in RB.

241-95 Photo 293 (R11P28), looking UST at RB debris flow chute along a tributary with exposed roots.

244-70 Photo 294-295 (R11P29-30), looking DST at debris jam from fallen bay tree.

247-13 RB tributary with sediment supply disconnected from main stem Novato Cr.

247-34 Photo 296 (R11P31), looking at LB erosion where bay tree has collapsed into channel. Terrace height is 13.9' above the thalweg.

249-06 LB erosion = 6'.

251-47 Photo 297 (R11P32), looking at LB erosion = 5. RB erosion = 4', and recent bed incision = 2.2'.

252-89 The channel bed is armored with coarse gravel. The supply is from local terrace banks.

255-38 Lazuli bunting sighted, 5/21/97.

255-14 Begin RB rip rap.

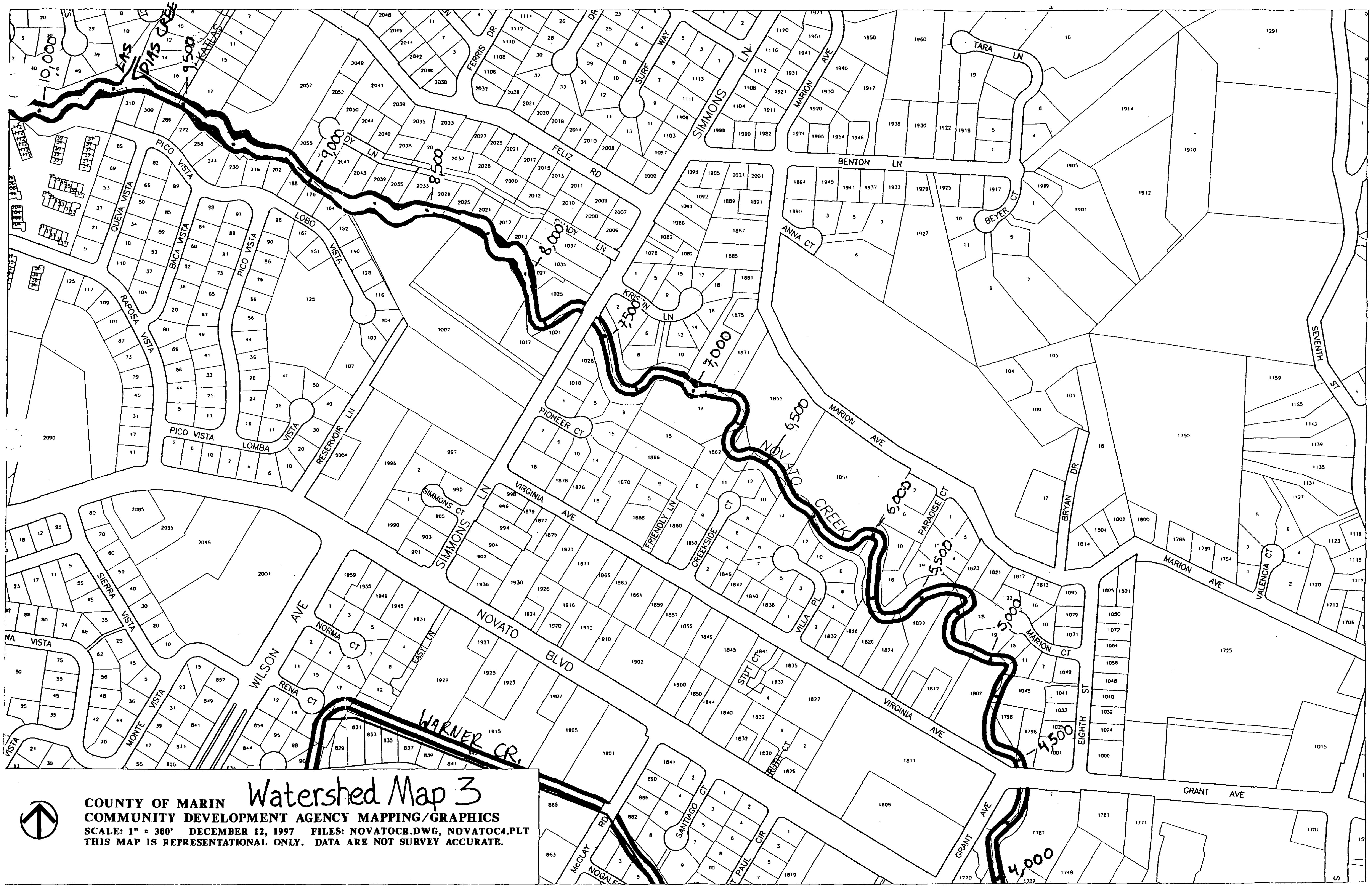
255-78 End RB rip rap.
256-03 Confluence of LB tributary (Leveroni). The main Novato Cr channel has a fallen willow and overhanging vegetation blocking the main stem at the upstream end of the confluence to station 256-60.
256-93 Photo 298 (R12P22), looking DST at LB oak tree on ivy-covered bank.
257-? Photo 299 (R12P23), looking UST at willow that has fallen into channel. This section is narrow and has lots of small willows in the channel. Fine and gravel-sized sediment is present with lots of large rip rap pieces and broken culvert parts scattered in the channel bed.
259-78 Photo 300 (R12P24) looking at RB RCP outflow for reservoir. Above this station toward the spillway structure, there is evidence of past significant bank erosion that has stabilized. There are lots of willows choking the channel bed through this section.
261-80 Begin rip rap in channel bed.
261-95 Begin concrete/rip rap channel bed.
262-65 Photo 301 (R12P25), looking UST at beginning of cement spillway.

COUNTY OF MARIN **Watershed Map 1**

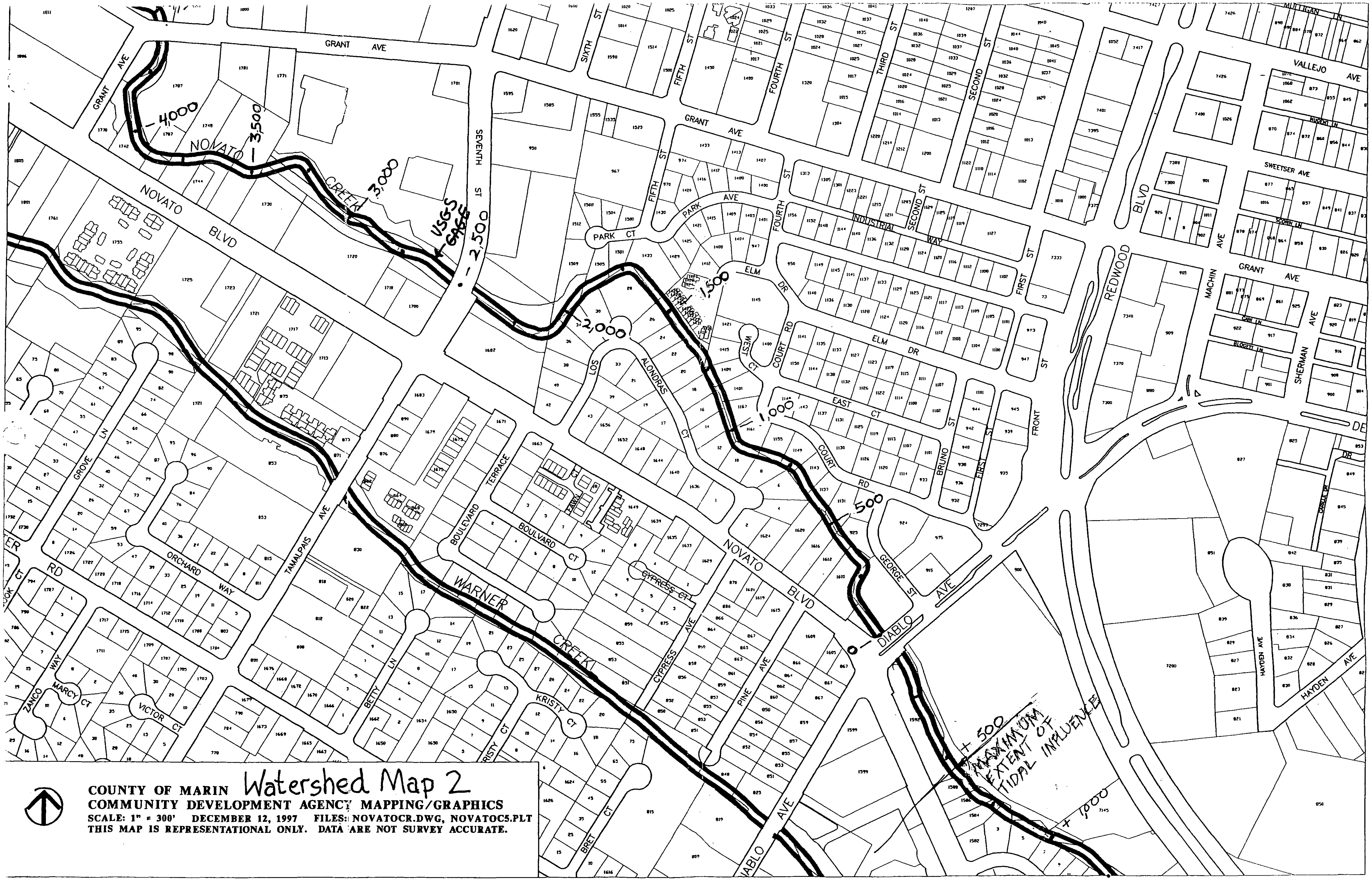
COMMUNITY DEVELOPMENT AGENCY MAPPING/GRAPHICS

SCALE: 1" = 300' DECEMBER 12, 1997 FILES: NOVATOCR.DWG, NOVATOC6.PLT

THIS MAP IS REPRESENTATIONAL ONLY. DATA ARE NOT SURVEY ACCURATE.

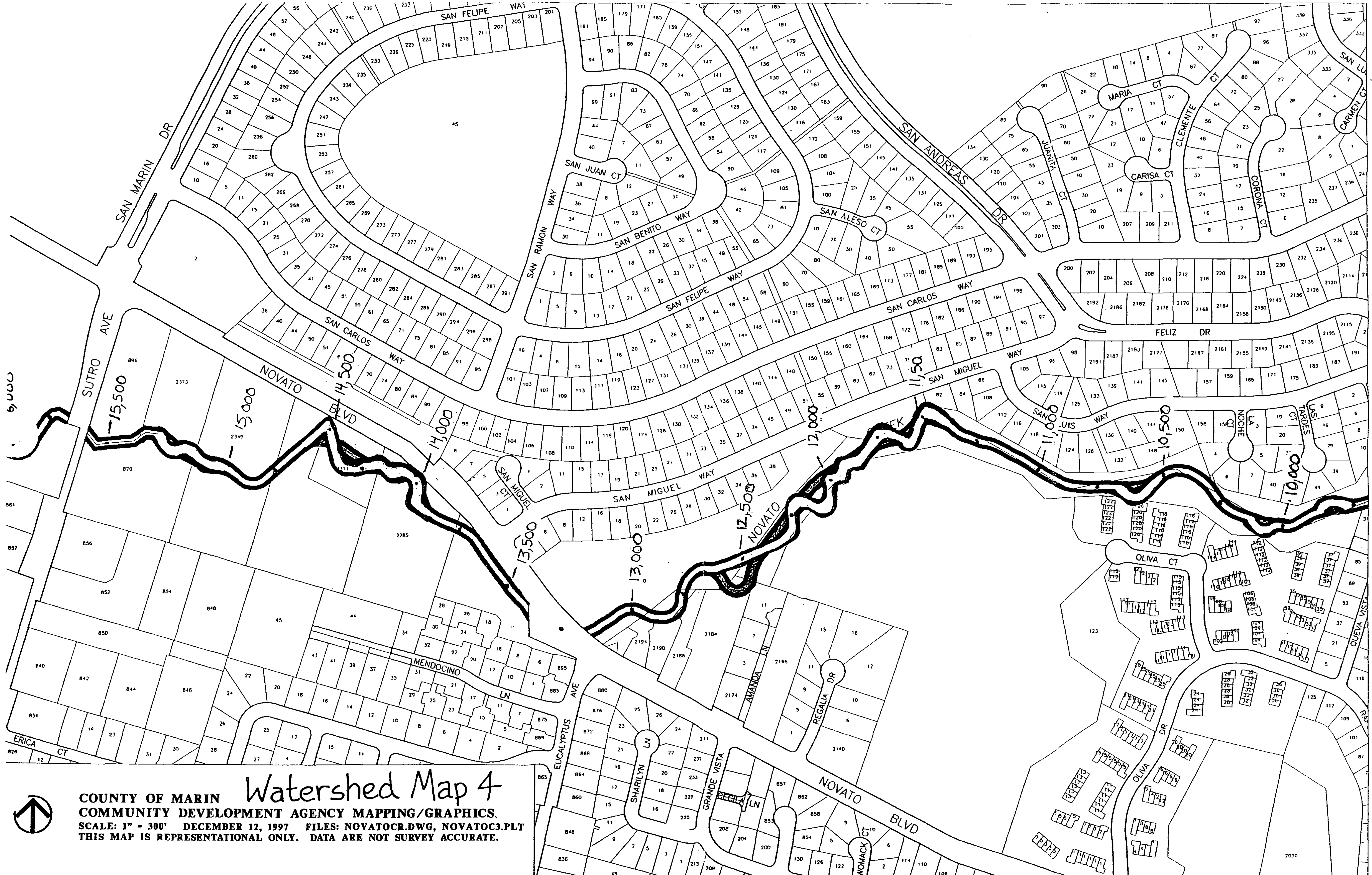


COUNTY OF MARIN Watershed Map 3
COMMUNITY DEVELOPMENT AGENCY MAPPING/GRAPHICS
SCALE: 1" = 300' DECEMBER 12, 1997 FILES: NOVATOCR.DWG, NOVATOC4.PLT
THIS MAP IS REPRESENTATIONAL ONLY. DATA ARE NOT SURVEY ACCURATE.

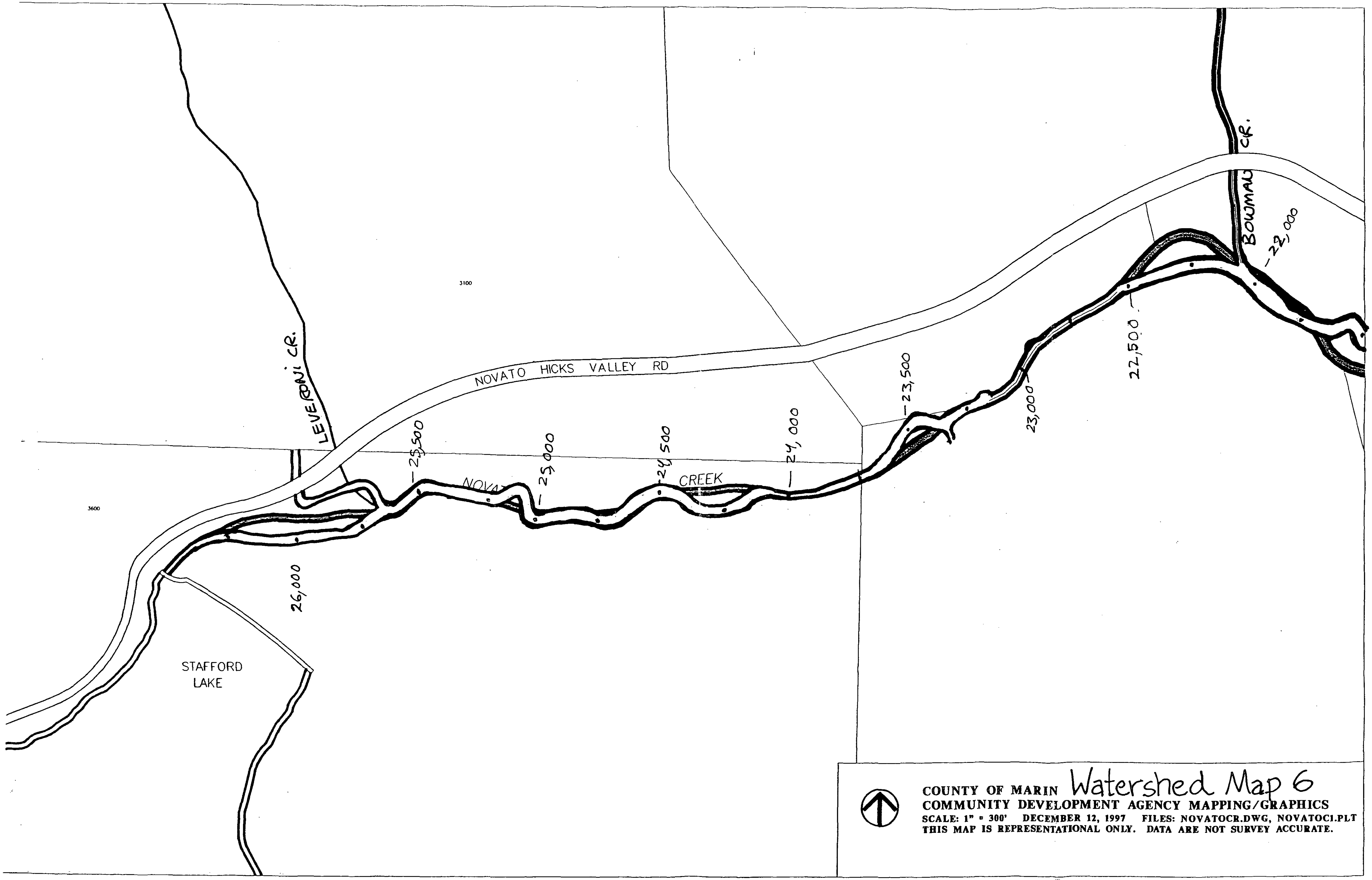


COUNTY OF MARIN Watershed Map 2
COMMUNITY DEVELOPMENT AGENCY MAPPING/GRAPHICS
SCALE: 1" = 300' DECEMBER 12, 1997 FILES: NOVATOCR.DWG, NOVATOC5.PLT
THIS MAP IS REPRESENTATIONAL ONLY. DATA ARE NOT SURVEY ACCURATE.

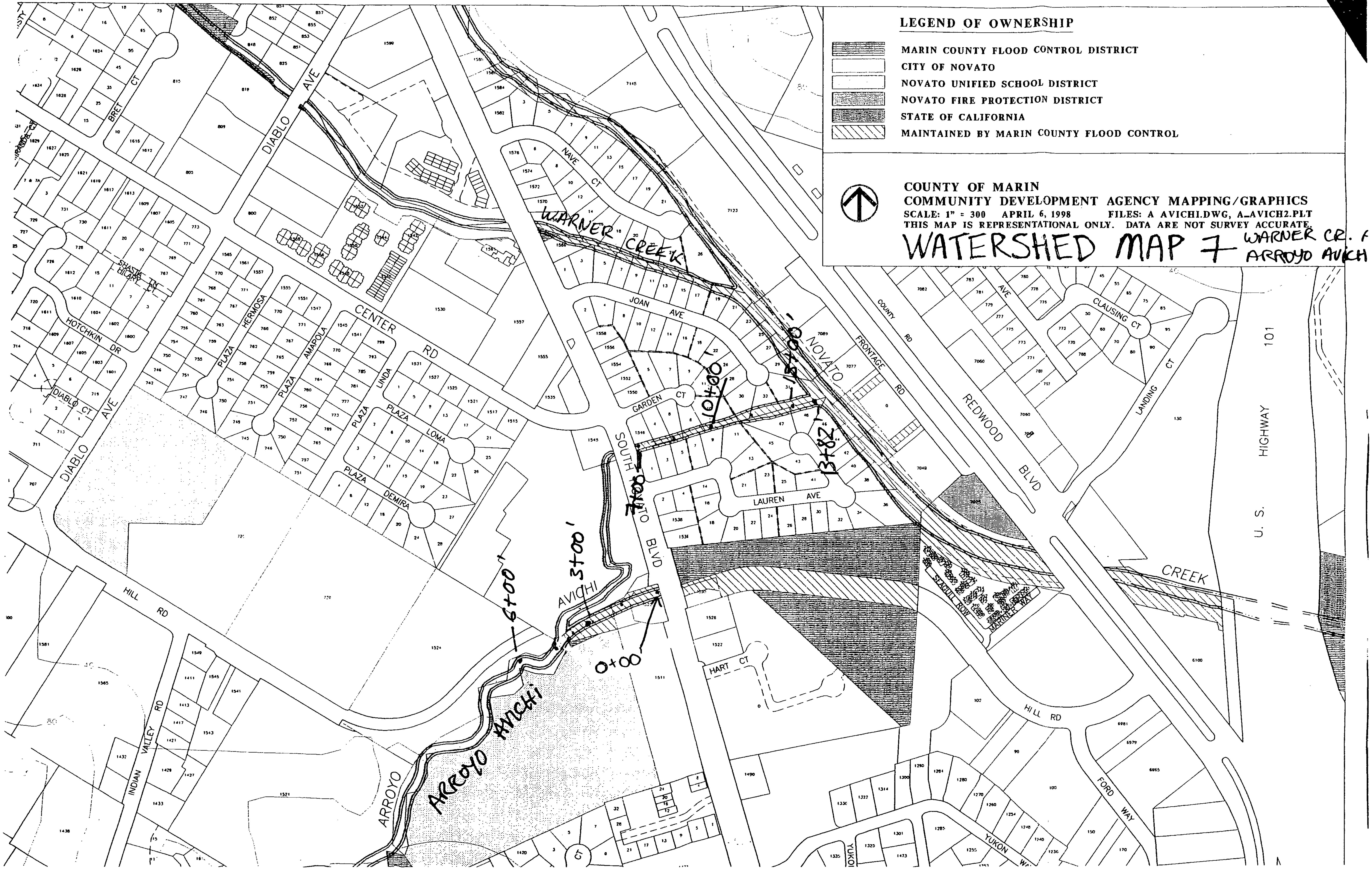
SAN ANDREAS DR
MARIA CT
CLEMENTE CT
CARISA CT
CORONA CT
CARMEN CT
SAN LU
JUANITA CT
SAN ALESO CT
WAY
SAN CARLOS WAY
FEIZ DR
SAN MIGUEL WAY
SAN LUIS WAY
LA NOCHE CT
LAS TARDES CT
NOVATO
CREEK
12,500
12,000
11,500
11,000
10,500
10,000
OLIVA CT
OLIVA DR
QUEVA VISTA
AMANDA LN
REGALIA DR
NOVATO BLVD
WOMACK CT
LN

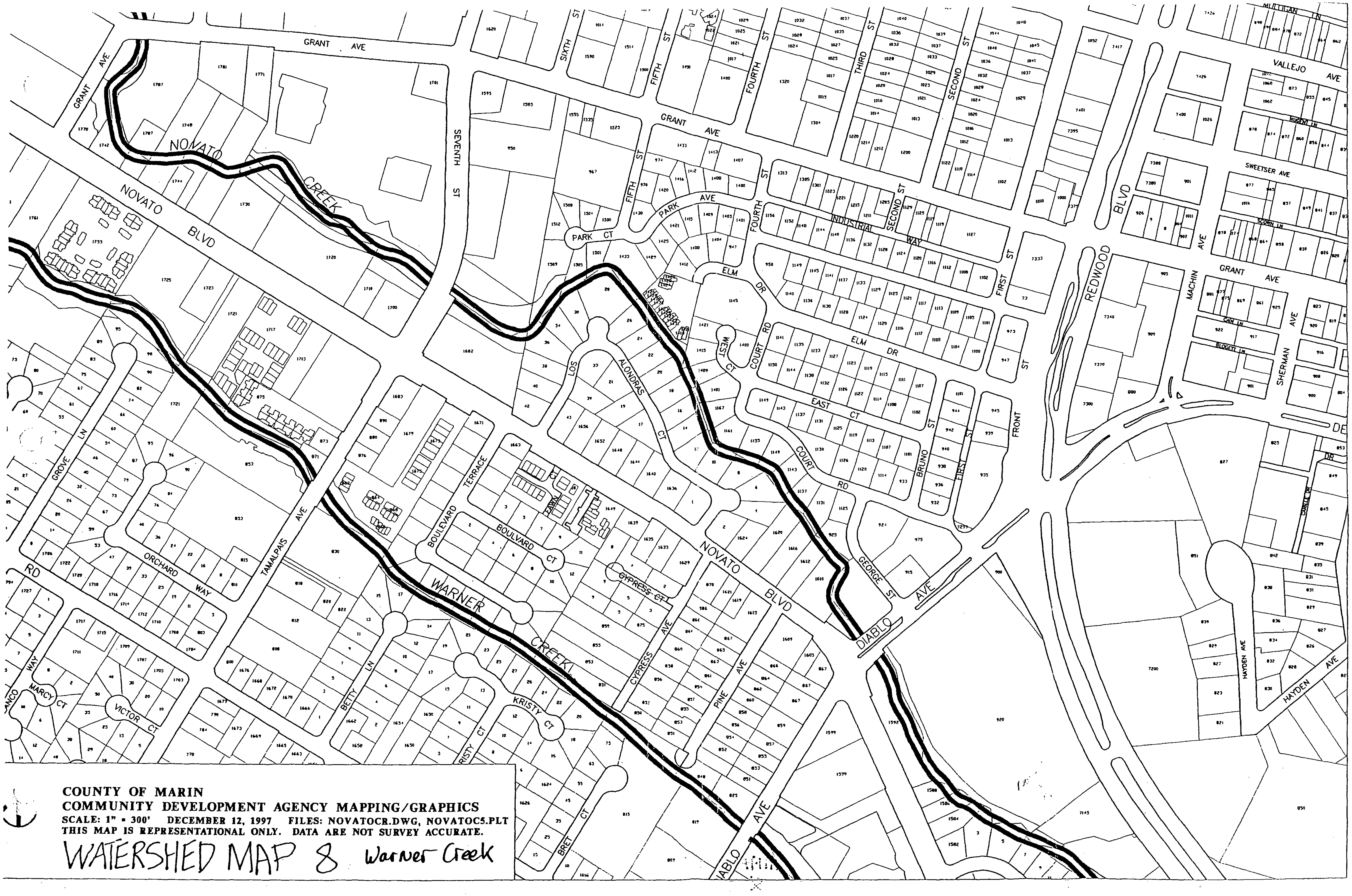

Watershed Map 4
COUNTY OF MARIN
COMMUNITY DEVELOPMENT AGENCY MAPPING/GRAPHICS.
SCALE: 1" = 300' DECEMBER 12, 1997 FILES: NOVATOCR.DWG, NOVATOC3.PLT
THIS MAP IS REPRESENTATIONAL ONLY. DATA ARE NOT SURVEY ACCURATE.
SAN MARIN DR
SUTRO AVE
NOVATO BLVD
SAN FELIPE WAY
SAN JUAN CT
SAN RAMON WAY
SAN BENITO WAY
SAN CARLOS WAY
SAN ALESO CT
SAN ANDREAS DR
SAN MIGUEL WAY
SAN MIGUEL CT
JUANITA CT
MARIA CT
CLEMENTE CT
CARISA CT
CORONA CT
CARMEN CT
FELIZ DR
SAN LUIS WAY
LA NOCHE CT
LAS TARDES
OLIVA CT
OLIVA DR
QUEVA VISTA
MENDOCINO LN
EUCALYPTUS AVE
ERICA CT
SHARILYN LN
GRANDE VISTA
REGALIA DR
AMANDA LN
WOMACK CT
NOVATO CREEK
15,500
15,000
14,500
14,000
13,500
13,000
12,500
12,000
11,500
11,000
10,500
10,000

COUNTY OF MARIN Watershed Map 5
COMMUNITY DEVELOPMENT AGENCY MAPPING/GRAPHICS
SCALE: 1" = 300' DECEMBER 12, 1997 FILES: NOVATOCR.DWG, NOVATOC1.PLT
THIS MAP IS REPRESENTATIONAL ONLY. DATA ARE NOT SURVEY ACCURATE.



COUNTY OF MARIN Watershed Map 6
COMMUNITY DEVELOPMENT AGENCY MAPPING/GRAPHICS
SCALE: 1" = 300' DECEMBER 12, 1997 FILES: NOVATOCR.DWG, NOVATOC1.PLT
THIS MAP IS REPRESENTATIONAL ONLY. DATA ARE NOT SURVEY ACCURATE.


LEGEND OF OWNERSHIP
MARIN COUNTY FLOOD CONTROL DISTRICT
CITY OF NOVATO
NOVATO UNIFIED SCHOOL DISTRICT
NOVATO FIRE PROTECTION DISTRICT
STATE OF CALIFORNIA
MAINTAINED BY MARIN COUNTY FLOOD CONTROL
COUNTY OF MARIN
COMMUNITY DEVELOPMENT AGENCY MAPPING/GRAPHICS
SCALE: 1" = 300 APRIL 6, 1998 FILES: A AVICHI.DWG, A_AVICH2.PLT
THIS MAP IS REPRESENTATIONAL ONLY. DATA ARE NOT SURVEY ACCURATE.
WATERSHED MAP 7 WARNER CR. & ARROYO AVICH
WARNER CREEK
ARROYO AVICHI
AVICHI
CREEK
0+00
3+00'
6+00'
10+00'
13+82'
15+00'
DIABLO AVE
CENTER RD
HILL RD
SOUTH NOVATO BLVD
NOVATO
REDWOOD BLVD
FRONTAGE RD
U. S. HIGHWAY 101
JOAN AVE
GARDEN CT
LAUREN AVE
NAVE CT
HART CT
CLAUSING CT
LANDING CT
HOTCHKIN DR
DIABLO CT
BRET CT
PLAZA HERMOSA
PLAZA AMAPOLA
PLAZA LINDA
PLAZA LOMA
PLAZA DEMIRA
SHASTA CT
INDIAN VALLEY RD
ARROYO
SEAGULL ROW
MARINER WAY
FORD WAY
YUKON WAY



COUNTY OF MARIN
COMMUNITY DEVELOPMENT AGENCY MAPPING/GRAPHICS
SCALE: 1" = 300' DECEMBER 12, 1997 FILES: NOVATOCR.DWG, NOVATOC5.PLT
THIS MAP IS REPRESENTATIONAL ONLY. DATA ARE NOT SURVEY ACCURATE.

WATERSHED MAP 8 Warner Creek

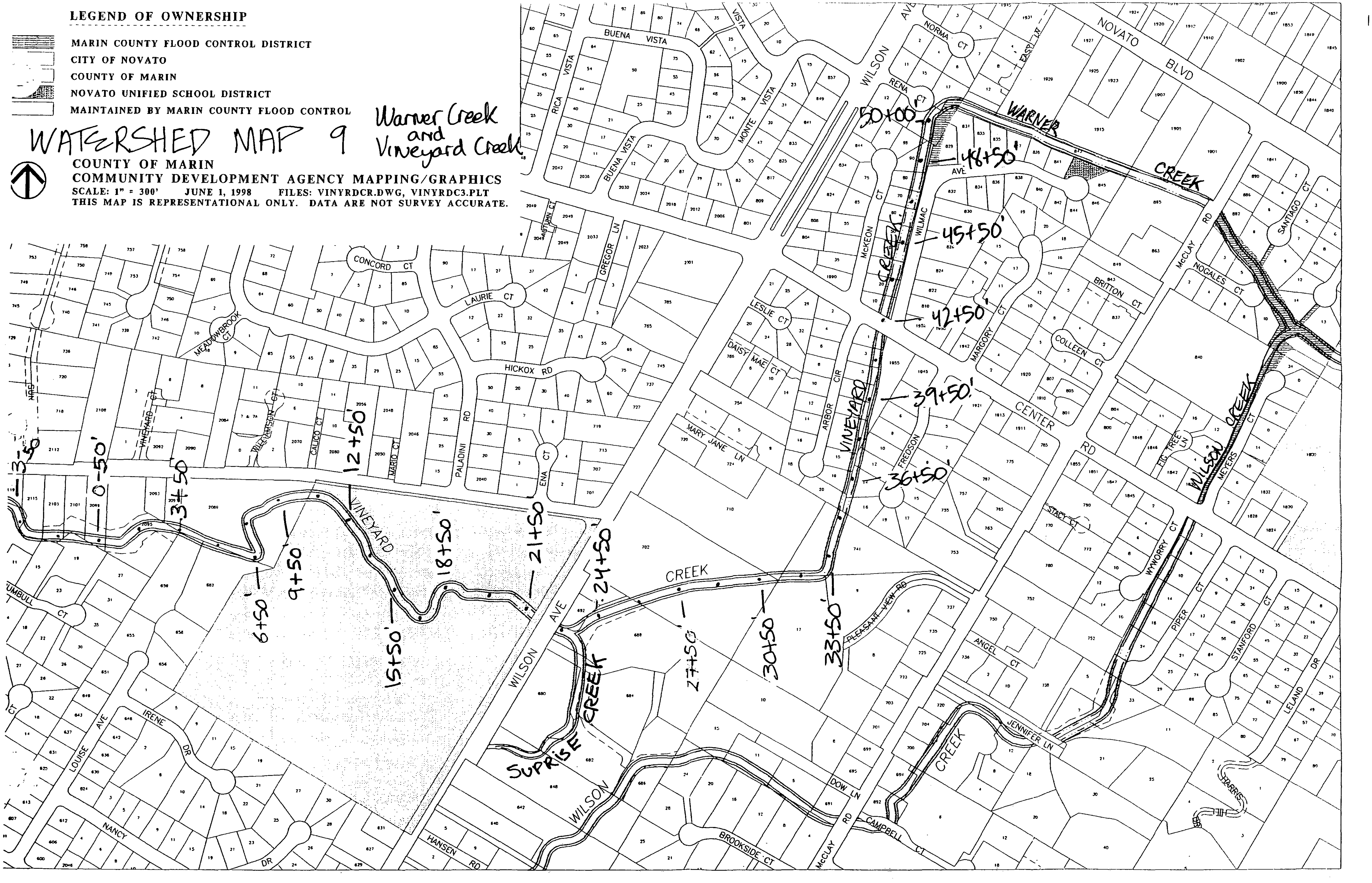
LEGEND OF OWNERSHIP

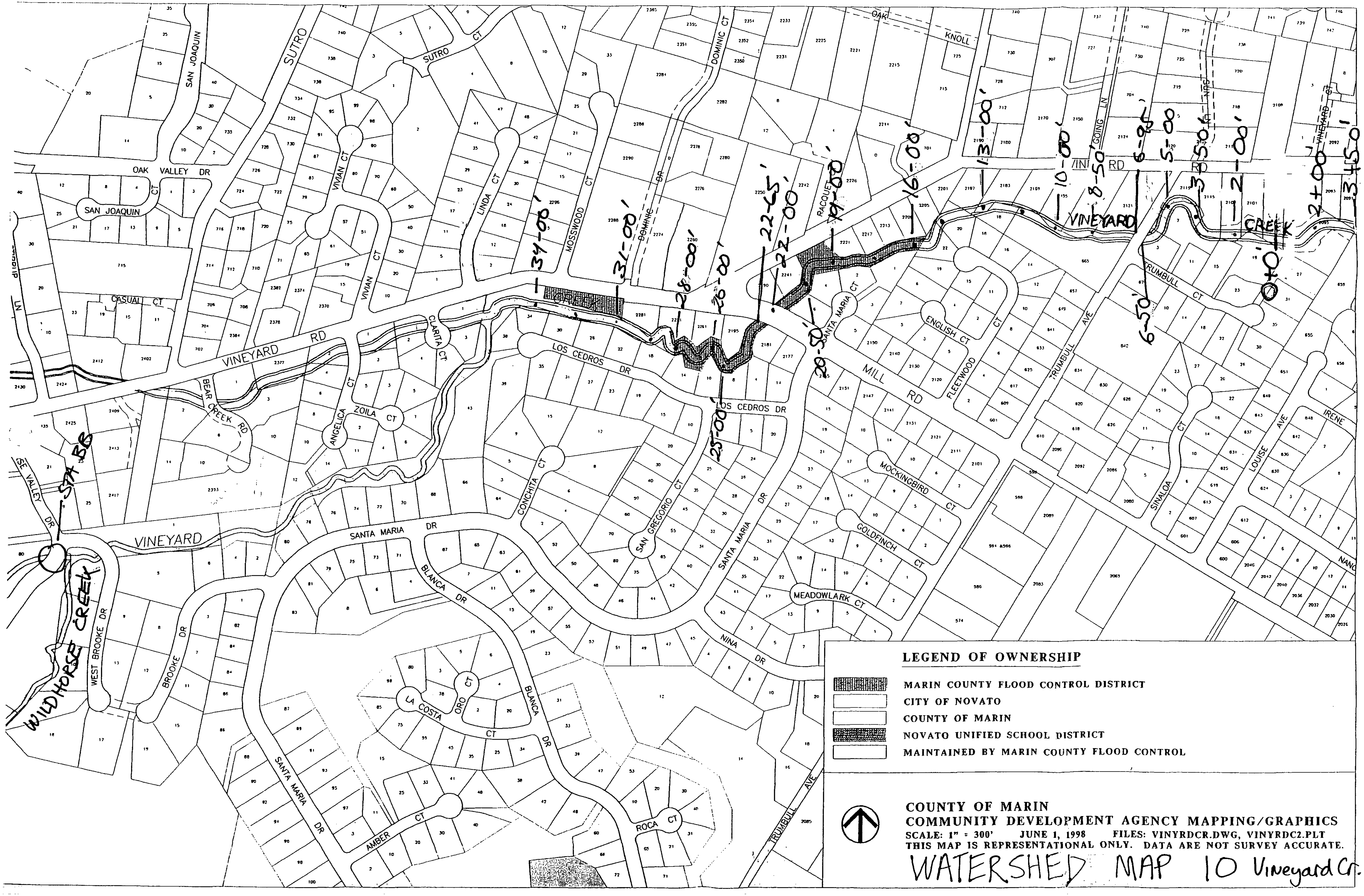
- MARIN COUNTY FLOOD CONTROL DISTRICT
- CITY OF NOVATO
- COUNTY OF MARIN
- NOVATO UNIFIED SCHOOL DISTRICT
- MAINTAINED BY MARIN COUNTY FLOOD CONTROL

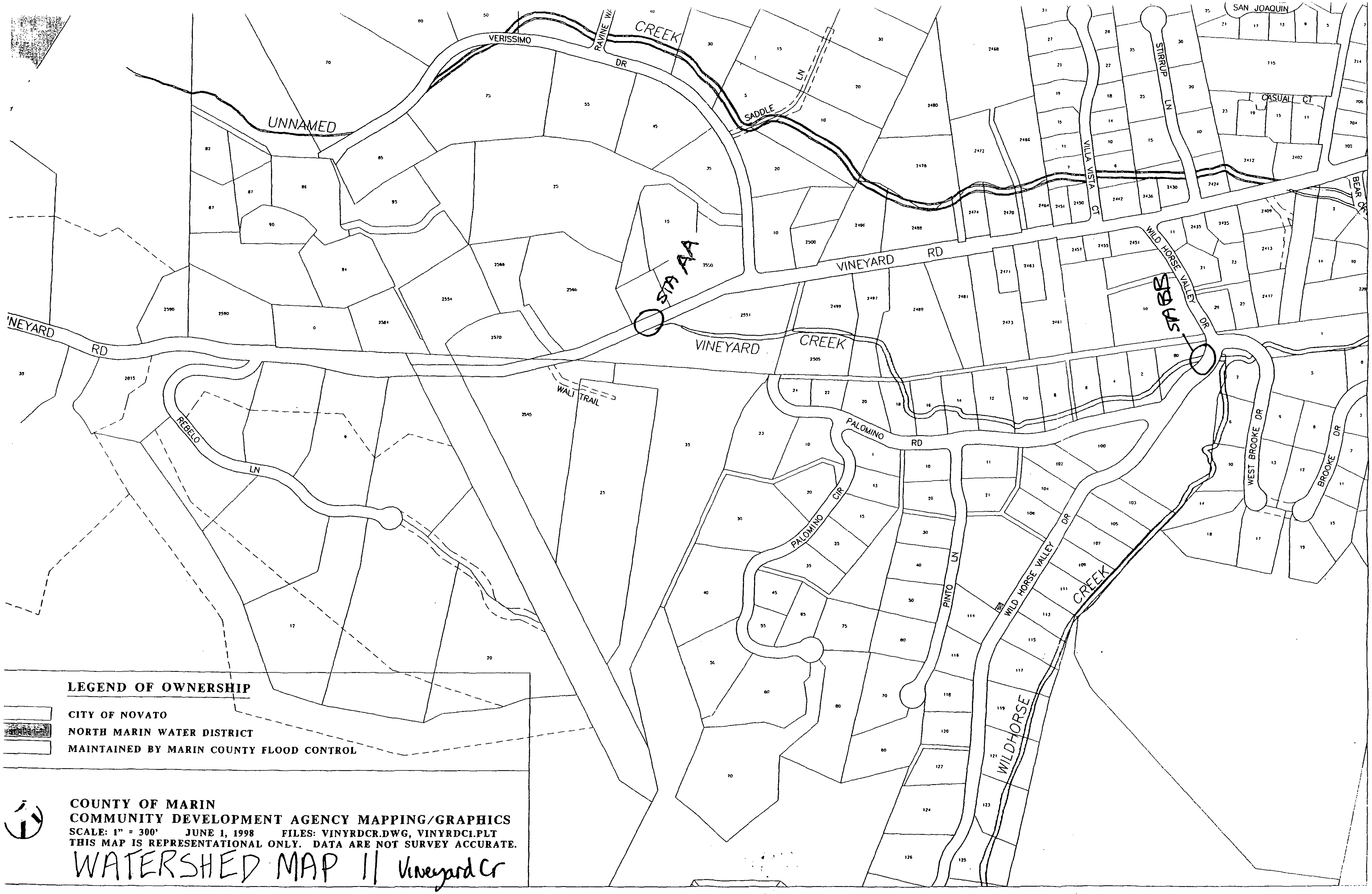
WATERSHED MAP 9

Warner Creek and Vineyard Creek

COUNTY OF MARIN
COMMUNITY DEVELOPMENT AGENCY MAPPING/GRAPHICS
SCALE: 1" = 300'   JUNE 1, 1998   FILES: VINYRDCR.DWG, VINYRDC3.PLT
THIS MAP IS REPRESENTATIONAL ONLY. DATA ARE NOT SURVEY ACCURATE.




LEGEND OF OWNERSHIP
MARIN COUNTY FLOOD CONTROL DISTRICT
CITY OF NOVATO
COUNTY OF MARIN
NOVATO UNIFIED SCHOOL DISTRICT
MAINTAINED BY MARIN COUNTY FLOOD CONTROL
COUNTY OF MARIN
COMMUNITY DEVELOPMENT AGENCY MAPPING/GRAPHICS
SCALE: 1" = 300' JUNE 1, 1998 FILES: VINYRDCR.DWG, VINYRDC2.PLT
THIS MAP IS REPRESENTATIONAL ONLY. DATA ARE NOT SURVEY ACCURATE.
WATERSHED MAP 10 Vineyard Cr.
VINEYARD RD
VINEYARD CREEK
WILDHORSE CREEK
MILL RD
LOS CEDROS DR
SANTA MARIA DR
OAK VALLEY DR
SUTRO CT
OAK KNOLL
TRUMBULL AVE
BLANCA DR
NINA DR

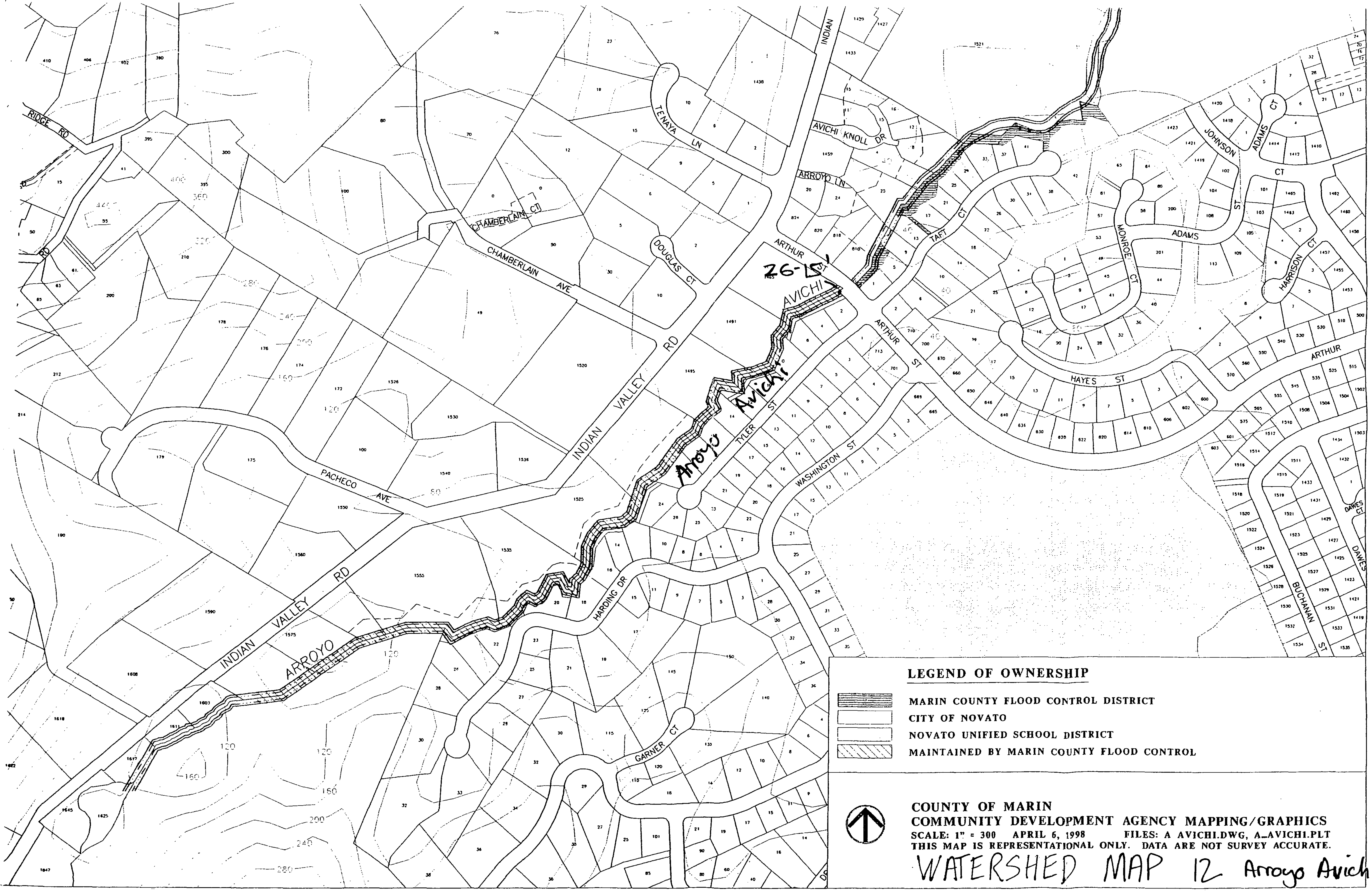


LEGEND OF OWNERSHIP

- CITY OF NOVATO
- NORTH MARIN WATER DISTRICT
- MAINTAINED BY MARIN COUNTY FLOOD CONTROL

COUNTY OF MARIN
COMMUNITY DEVELOPMENT AGENCY MAPPING/GRAPHICS
SCALE: 1" = 300' JUNE 1, 1998 FILES: VINYRDCR.DWG, VINYRDC1.PLT
THIS MAP IS REPRESENTATIONAL ONLY. DATA ARE NOT SURVEY ACCURATE.

WATERSHED MAP 11 Vineyard Cr



LEGEND OF OWNERSHIP

- MARIN COUNTY FLOOD CONTROL DISTRICT
- CITY OF NOVATO
- NOVATO UNIFIED SCHOOL DISTRICT
- MAINTAINED BY MARIN COUNTY FLOOD CONTROL

COUNTY OF MARIN
COMMUNITY DEVELOPMENT AGENCY MAPPING/GRAPHICS
SCALE: 1" = 300 APRIL 6, 1998 FILES: A AVICHI.DWG, A_AVICHI1.PLT
THIS MAP IS REPRESENTATIONAL ONLY. DATA ARE NOT SURVEY ACCURATE.

WATERSHED MAP 12 Arroyo Avichi