NOVATO CREEK WATERSHED
EROSION INVENTORY AND SEDIMENT CONTROL PLAN

Prepared for

MARIN COUNTY DEPARTMENT OF PUBLIC WORKS

P.O. Box 4186
San Rafael, CA 94913-4186
(415) 499-6528

Prepared by

PRUNUSKE CHATHAM, INC.

ecological restoration • civil engineering • hydrology • forestry • revegetation • erosion control

P.O. Box 828 Occidental, California 95465
(707) 874-0100 FAX: (707) 874-1440

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1. EXECUTIVE SUMMARY

As part of the Section 401 water quality certification for removing accumulated sediment in portions of Novato Creek, Warner Creek, and Arroyo Avichi Creek, the Regional Water Quality Control Board, San Francisco Bay Region (RWQCB), has placed conditions on the Marin County Flood Control District (MCFCD). Condition 10 requires preparation of a "long-term management plan to address sediment sources in the watershed with the objective of reducing the need for ongoing flood control maintenance and associated impacts."

Prunuske Chatham, Inc. (PCI) has conducted an erosion inventory and developed a sediment control plan, which are included herein. Both sediment sources and control methods available were considered. Based on recommendations from the RWQCB, contacts were made with all the landowners in the Leveroni and Bowman watersheds. Access was granted to the upper Bowman watershed, but access was denied to lower Bowman and all of Leveroni Canyons. As an alternative to inventorying lower Bowman and Leveroni Canyons, the mainstem of Novato Creek from Leveroni to Sutro Avenue was inventoried (see Map 2).

The sediment inventory identified sites that are actively eroding. Fifteen high priority, eleven medium priority, and forty low priority sites were identified. The future amount of potential sediment was estimated for each identified site. Upper mainstem Novato, lower Bowman, and upper Bowman have recently incised, and currently the channels are widening. Channel widening after incision is a natural channel evolution that leads to increased stability. In portions of Bowman Canyon, channels are still incising and should be stabilized.

Approximately 9,680 cubic yards per year have been depositing in the Novato Creek Flood Control Project (NFCP) since 1991. Future potential sediment load is estimated to be 7,900, 50,000, and 43,600 cubic yards from identified erosion sites in upper Bowman, from channel adjustment in lower Bowman, and channel adjustment in mainstem Novato from Sutro Avenue to Leveroni, respectively. This sediment will be eroded from the identified sites over the course of several decades.

- Repairs of gullies, headcuts, and nick points in upper Bowman are recommended.
- Repairs on the mainstem of Novato Creek are recommended only where the channel has already widened. Repairs that would hold the mainstem in an entrenched configuration are not recommended because of undesirable ecological consequences.

- Further evaluation of a maintainable, in-stream sediment trap upstream of Redwood Boulevard and downstream of Diablo Avenue is recommended. Removing sediment at this location may have less negative ecological impact than removing sediment further downstream.

- Monitoring of cross-sections and gullies to measure rates of erosion is recommended.

- Determining the distribution of salmonid habitat is recommended.

- Acquisition of access to the lower Bowman and Leveroni watersheds is needed to inventory and repair suspected erosion sites.

2. INTRODUCTION

As part of the Section 401 water quality certification for removing accumulated sediment in portions of Novato Creek, Warner Creek, and Arroyo Avichi Creek, the Regional Water Quality Control Board, San Francisco Bay Region (RWQCB), has placed conditions on the Marin County Flood Control District (MCFCD). Condition 10 requires preparation of a "long-term management plan to address sediment sources in the watershed with the objective of reducing the need for ongoing flood control maintenance and associated impacts." The RWQCB stated that the plan must include:

> "Proposals for addressing upstream sediment sources that are on private lands, particularly in grazed areas. Particular emphasis should be placed on improved land management practices and fencing along Leveroni and Bowman Creeks, which have been demonstrated to be major and continuing sediment sources in the upper watershed."

The MCFCD contracted with Prunuske Chatham, Inc. (PCI) to conduct an erosion inventory and develop a sediment control plan in the Bowman and Leveroni watersheds (Figure 1. Site Location Map and Figure 2. Novato Creek Watershed above Sutro Ave.). Two types of sediment sources and control methods available were considered.

3. NOVATO CREEK BACKGROUND

The Novato Flood Control Project (NFCP) was constructed between 1987 and 1990. The project has been dredged three times since construction (Lewis, personal communication, 2001). Table 1 provides the years and estimated quantities of sediment removed at the NFCP.

A study of the Novato Creek watershed, *Sediment Sources and Fluvial Geomorphic Processes of Lower Novato Creek Watershed,* was conducted by Laurel Collins in 1998. Collins identified the primary sources of sediment in the NFCP as erosion from channel banks, bed, and terraces. Alternate sources of sediment in the watershed may include landslides, dirt roads, agricultural lands, especially cattle trails and poorly vegetated pastures, new construction, and existing urban land uses. In addition, sediment from the bay deposited in the NFCP by tidal processes contributes a small but unknown quantity of silts and clays. Although these sources are probably not individually as significant as in-stream sources, collectively they may be significant. A discussion of possible alternate sediment sources in lower Novato Creek watershed is provided in Technical Attachment 1.

Table 1. Estimated Quantities of Excavated Sediment from the NFCP

Approximate Date	Sediment Quantity (cubic yards)
1992	49,000
1996	47,200
2000	49,000
Minimum total sediment quantity excavated between 1990-2000 (10 yrs)	145,200
Adjusted total sediment quantity *in situ* (eroded) between 1990-2000 (10 yrs)*	96,800
Minimum erosion rate from the watershed between 1990-2000 (10 yrs)	9,680 / year

* Soil particles that have naturally settled over time (i.e., sediment in stream banks) have been compacted and are denser than newly excavated and disturbed particles. A loose clay and sand mixture may weigh approximately 2,700 lbs / yd^3. Clay or sand in the bank *(in situ)* may weigh around 3,400 lbs / yd^3. Thus, a conversion factor of 1.3 would be applied in converting the volume of sediment in the stream bank to the volume of sediment excavated in the NFCP. In addition, a portion of the excavated material is a slurry-like soil and water mixture. This slurry mixture further increases the ratio of the density of dredged soil to the density of soil eroded from the bank. Thus, when comparing the volume of eroded sediment from the watershed to the excavated amount in the NFCP, a conversion factor of 1.5 is applied.

For the purposes of this report, watershed sediment sources are categorized into two broad groups:

1) In-stream sources, i.e., those that are driven by channel downcutting, headcutting, and lateral migration.

2) Upland sources (non in-stream sources), i.e., those that are independent of channel stability.

The first group includes stream bank erosion, most gullies, and channel bed downcutting. The second group includes dirt and paved roads, rock quarries, bare or poorly vegetated ground either as part of an agricultural or urban landscape, human and cattle trails, and construction. Upland sources can be delivered to the channel network via overland flows during major rain events, as well as via the human-altered channel network, which includes roads, ditches, trails, or stormdrains. As explained by Collins (1998), the largest source of chronic long-term sediment supply in the Novato Creek watershed is in-stream erosion.

4. METHODOLOGY

An upland sediment source reconnaissance and an in-stream erosion inventory of both upper Bowman Canyon and the upper mainstem of Novato Creek was conducted. Aerial photographs were reviewed to identify possible land uses that could contribute significant amounts of upland sediment. The general watershed was also visually surveyed. An erosion survey of the channel network was conducted where safety permitted (99% of channel reach). All possible erosion was examined and classified as "active" or "non-active." PCI defines "significant accelerated erosion" as:

> "Highly active, bare soils with a chronic yield of sediment and a high potential to continue to erode at a rapid rate into downstream water courses and which may reasonably be expected to negatively affect water quality or habitat values on or off site."

Landslides identified by Collins that were active between 1975 and 1998 are not included unless they fit the above definition. Thus episodic landslides that are currently vegetated or banks that have historically eroded but currently have moss or vegetation growing on them are not included in the inventory.

All actively eroding sites were inventoried if they met both of the two following criteria:

1) The site is hydrologically connected to the channel network.
2) The downstream channel network has sufficient sediment transport capacity to move the eroded sediment downstream (i.e., there was no natural downstream sediment sink, grassy swale, or standing waterbody).

All inventoried sites were described in terms of dimensions, erosion potential and activity, predominant bank and bed material, cause of erosion, access rating, and the future potential volume of sediment that will erode in cubic yards (cy). In addition, in order to help estimate the amount of future sediment volume (cy) that could erode from the actively eroding sites on mainstem Novato Creek and the mainstem of lower Bowman Canyon, a simple geomorphic assessment was conducted. The geomorphic assessment consisted of visual observations, measuring cross-sections, and a very general classification of the channel type based on Rosgen stream classifications (Rosgen 1996).

For in-stream sites, a repair option and construction cost range were selected. The cost range is not an actual construction cost estimate. It is the observer's estimate of which preset cost range category best describes the approximate size and difficulty of the site. The lower number in the range should not be used as an estimate for construction as this may result in underestimating the total costs. Repairs can include source control or sediment trapping. Source control is preferred and recommended whenever feasible. For actively eroding upland sites that are hydrologically connected via overland surface flow during large storms (i.e., pastures), either repairs or management changes are recommended.

5. RESULTS

5.1 Landowner Outreach

Before the erosion inventory was begun, requests to meet with landowners in the Bowman and Leveroni watersheds were made. Contact was made with the following individuals (see Maps 1 and 2 for property boundaries):

- Mr. Crawford Cooley, owner of property covering most of the upper Bowman watershed.
- Mr. Jim McIsaac and Mrs. Sue McIsaac, long-time leaseholders of Crawford Cooley property.
- Mr. Jay Garlick, who claimed to represent himself and Utah-based owners, Roger Richards, W.B. Richards, Indian Hills of Marin #1, and Calmar, owners of property covering the lower Bowman watershed.
- Leveroni family, owners of property covering most of the Leveroni watershed.

One-on-one meetings occurred with the McIsaacs and the Leveronis. Access was granted by Mr. Cooley and Mr./Mrs. McIsaac to the upper Bowman watershed. Access was denied by Mr. Garlick and the Leveronis. As an alternative to inventorying lower Bowman Canyon and Leveroni Canyon, the mainstem of Novato Creek from Stafford Lake to Sutro Avenue was inventoried.

5.2 Watershed Processes

A site-specific erosion inventory and subsequent repairs can only be successful with an understanding of watershed-scale geomorphic and hydrologic processes. Collins' report (1998) lays the foundation for understanding the geomorphic and hydrologic processes in Novato Creek watershed.

5.2.1 Hydrology

The flow in the mainstem of Novato Creek is year round. Flow over the Novato Creek Dam usually occurs between January and February and lasts about one month (Lewis, personal communication, 2001). The remainder of the year, the dam typically does not spill. The dam significantly affects the water flows and channel shape of Novato Creek downstream. Storm events that generate peak flows that are large enough to spill over the dam are attenuated; however, the duration of the peak flow is prolonged. This results in lower shear stresses overall (less erosion), but shear stresses occur over a longer period of time (more erosion). In addition, because the dam captures all the bedload and a significant portion of the suspended load from the watershed upstream of the dam, the sediment supply is depleted. This may have resulted in erosion of the streambed below the dam. The mainstem between the mouth of Leveroni Canyon and Stafford Lake was completely dry on March 6, 2001, when the erosion survey was conducted and did not spill over in the winter of 2000/2001 (Lewis, personal communication, 2001). The upper reaches of mainstem Novato Creek and Bowman and Leveroni Canyons are the primary sources of summer baseflow, as well as ecologically beneficial gravels.

The upper Bowman watershed includes four subwatersheds (see Map 1). Subwatersheds #1, #2, and #3 appear to be intermittent, flowing in the winter but dry in the summer. Subwatershed #4, also known as Two Lewis Creek, appears to be perennial. On October 30, 2000, and November 2, 2000, subwatersheds #1, #2, and #3 were dry, and subwatershed #4 was flowing. On March 23, 2001, all subwatersheds were flowing.

5.2.2 Geomorphology

The channel of Novato Creek is not in equilibrium and is currently adjusting to altered hydrological/hydraulic conditions. Figure 3 summarizes the probable causes for such an adjustment. Natural stream systems are in quasi-equilibrium when hydrological processes have not undergone recent natural (i.e., wide spread fire, glaciers) or man-made (i.e., dam construction, urban development) alteration. Stable, natural channels still migrate laterally and undergo localized bank erosion; however, the channel is self-maintaining, and the overall channel dimensions are stable.

Alterations in hydrology, channel hydraulics, and/or the sediment transport capacity often result in channel downcutting or incision. Typically, an incised channel will redevelop a stable and natural channel dimension by migrating laterally, eroding the vertical banks caused by incision, and developing a new floodplain within the incised banks. During the period of adjustment, the banks of the creek experience significant erosion (see Figure 4. Channel Evolution Model).

From a long-term geomorphic and ecologic perspective, channel evolution is desirable. The time it takes for a channel to adjust to altered hydrology/ hydraulics can range from a few years to hundreds of years. In other words, the channel must naturally adjust (or be reconstructed using heavy machinery) for the stream to be self-maintaining and to be in equilibrium with the new, altered hydrological regime.

In practical terms, this means that for an incised, erodable-bottomed stream that occurs in an urban or suburban environment, four management choices are available:

- Arrest channel evolution and adjustment by permanently armoring and/or stabilizing all of the eroding channel reaches. Significant grade controls would be required. This alternative would contribute to the degradation of the long-term ecological integrity of the stream system. Over time, lateral channel migration will result in new erosion that may have to be stabilized. An engineered channel will need on-going maintenance to maintain sediment transport and flow capacity.
- Reduce the rate of channel evolution and adjustment by stabilizing actively eroding channel reaches utilizing biotechnical and rock repairs. This may reduce sediment loading in the short term but will not prevent channel migration, channel widening, and eventual failure of bank stabilization repairs. This type of stabilization may protect capital improvements (i.e., roads) but will not reduce the total long-term sediment load as the channel continues to widen. In the short term, this alternative will result in no change in the existing, somewhat degraded, ecological integrity of stream system. In the long term, this alternative would allow the channel to adjust into a naturally stable, wide channel that would result in an improvement of the ecological integrity of the stream system.
- Within the incised bed and banks, allow the development of a natural, self-maintaining channel with an active floodplain. Only certain channel geometries are naturally stable. Stabilizing locally eroding banks in a channel with a naturally stable geometry is typically successful. In the short term, sediment loading from eroding banks will continue; however, in the long term, the ecological integrity of the stream system will improve over conditions found in an incised channel.
- Mechanically construct a natural, self-maintaining channel with an active floodplain. In the long term, the ecological integrity of the stream system will improve over conditions found in an incised channel.

Mainstem Novato Creek between Sutro Avenue and Stafford Lake

Mainstem Novato Creek between Sutro Avenue and Novato Creek Dam, which forms Stafford Lake, has incised and widened. Three bedrock controls, which indicate that the stream can no longer incise, were identified during the stream inventory. Rates and timing for incision are discussed by Collins (1998). After a period of incision, subsequent widening typically occurs, and the banks of the creek experience significant erosion. Most of the existing channel fits into the G and F Rosgen classification with occurrences of a C channel (Rosgen 1996). The final stable geometry of the mainstem of Novato Creek is likely to be similar to a Rosgen C channel. Figure 4 shows the typical sequence of a channel evolution similar to what is occurring in Novato Creek. Cross-sections that were measured with a laser level in the field are presented below in Section 5.4: Sediment Quantity Estimates.

On the mainstem of Novato Creek between Sutro Avenue and Novato Creek Dam, a total of 36 actively eroding sites were identified. All the eroding banks are due to channel incision and lateral migration of the channel. Location of sites on mainstem Novato is shown on Map 2.

Lower Bowman Canyon

Lower Bowman Canyon has also incised and is currently widening. Because access to lower Bowman Canyon was not granted, the channel was not surveyed, and only limited observations were made to determine whether or not the channel is still incising. The banks of lower Bowman Canyon, some portions of upper Bowman Canyon, and most of Novato Creek between Sutro Avenue and Stafford Lake are heavily treed with oaks and laurels. The roots of these trees have significantly reduced the rate of lateral erosion and thus the rate of widening. This is best evidenced by treed and non-treed sections of channel on lower Bowman Canyon as seen from the road. The reaches of lower Bowman Canyon have a typical top of bank width of 35 to 50 feet; the non-treed reaches are probably twice as wide (Photos 1 and 2). While the treed reaches of lower Bowman are probably a Rosgen F channel, the non-treed reaches have widened significantly more, and a Rosgen C channel may be present. Cross-sections that were measured above and below the Garlick property with a laser level in the field are presented in below in Section 5.4: Sediment Quantity Estimates.

Upper Bowman Canyon

Bowman Canyon is incising and widening. Incision in the canyon is likely to have occurred as a series of nick points eroding headward through the channel network. The in-stream erosion survey indicated that significant nick points (about 60-70% upstream from the mouth) exist in all four subwatersheds. These will continue eroding headward unless stabilized. In some upper reaches of subwatersheds #1, #2, and #3, some nick points have already naturally stabilized due to a bedrock and boulder channel bottom (Map 1). A significant, non-stabilized nick point exists in subwatershed #4 (aka Two Lewis Creek; see erosion site B4.1). If this nick point is not stabilized, it will unravel the upper portions of subwatershed #4.

Erosion in upper Bowman watershed is mainly from in-stream sources. The erosion in the channel network is triggered by historical and, in some portions of the watershed, on-going incision. Since the incision is probably primarily triggered by incision in the mainstem of Novato Creek, changes to management practices in upper Bowman are of secondary importance. In addition, existing management and erosion control in upper Bowman are excellent (Photo 3).

Existing livestock control fencing creates a buffer along most main channels, most dirt ranch roads are constructed without inboard ditches, and some gullies have already been stabilized by the McIsaacs. Most of the active erosion sites identified in the survey are in-stream sources. "Improved land management practices and fencing," as suggested by the RWQCB, may be more applicable in uninventoried portions of Bowman and Leveroni Canyons.

5.3 In-stream Erosion Survey

Recommended repairs of "actively eroding sites" were prioritized based on access, amount of future potential sediment load (cy), and level of erosion activity. Variability of environmental conditions may lead to different long-term erosion patterns and rates; however, the estimate indicates an order of magnitude of the potential erosion at each site. Sites are explained in the following section according to a priority rating of high, medium, and low. Tables 2 through 4 summarize the future potential sediment load, access, erosion activity, and range-of-cost for each high, medium, and low priority site. Potential types of erosion connected to the channel network include the following:

1) Nick point is used to describe a location in a channel bed where an abrupt break in slope occurs. A channel bed exists upstream and downstream of the nick point. Nick points can be naturally stable (i.e., a bedrock waterfall) or unstable (i.e., a 5-foot drop in an erodable channel bed). Unstable nick points typically undergo headward erosion that destabilizes the channel.
2) Headcut (i.e., channel head or gully head) is used to describe an abrupt, vertical headwall at the end of the channel network or gully. Also, a new headcut that has not yet eroded headward to create a significant gully is simply termed a headcut.
3) Gully is used to describe a first order channel that is formed via a combination of surface and subsurface flow. An active gully will have an abrupt headcut at the head of the gully. It typically is differentiated from the active channel network in that it has a small drainage area and does not convey surface water from a large drainage area. Gullies typically have high erosion rates and lack sorted bed material.
4) Slope failures are also referred to as landslides on the field data sheets included in Appendix 2. For the purposed of this report, in some areas the channel network intersects hillslopes, scours the toe of the slope, and causes a slope failure.

Site locations are shown on Map 1 for upper Bowman watershed and Map 2 for mainstem Novato Creek between Sutro Avenue and Stafford Lake. All inventoried sites are coded based on their watershed location. All sites on the mainstream of Novato Creek are coded with an M for mainstem, a number for each group of erosion sites (1 through 18), and a decimal number for each specific erosion site, (i.e., M1.1, M1.2, M2.1, M2.2, etc.). The sites in upper Bowman Canyon are coded with a B for Bowman, followed by a number indicating the subwatershed (1 through 4), followed by a number for each erosion site (i.e., B1.1, B1.2, B2.1, etc.). Photos are in Appendix 1. Field data sheets are in Appendix 2.

5.3.1 High Priority Sites

1. **Site B1.5**. In this section of subwatershed #1, the right bank of the channel intersects a hillslope. An approximately 50-foot long and 40-foot high hillslope failure has occurred due to stream incision and scour of the toe of the slope. In addition, an approximately 3-foot high nick point, temporarily stabilized by trees and roots, is beginning to show signs of destabilization. The nick point is likely to migrate headward to the non-eroable (boulder-dominated) section of channel. Possible repairs for the slope failure include a loose rock revetment, loose rock toe protection, and planting native vegetation. Possible repairs for the nick point include a rock-lined channel. The project will require an engineering design and survey.

2. **Site B1.6.** Channel incision has caused major bank slumping and erosion on the left bank. A 4- foot high headcut has formed and will continue to migrate headward. Loose rock revetment, toe protection, and a rock-lined channel are recommended to stop further destabilization of the bank. In addition, the headcut should be stabilized using loose rock and possibly willows. General re-grading, seeding, and revegetation of the site should occur. This project should be included with the engineering design and survey for site B1.5.

3. **Site B1.7.** An approximately 4-foot high and 10-foot wide headcut has migrated from the left bank approximately 25 feet out. No obvious upslope source of water and a small drainage area indicate that the headcut could be stabilized with a willow or brush headcut repair.

4. **Site B1.8.** A previously eroding livestock crossing of the creek (exasperated by upslope drainage) appeared to be partially stabilized during the fall inventory. A re-visit to the site in the spring revealed new disturbance. In addition, scour of the toe of the left bank may cause the bank to slump in the future and create more headcuts. A small, 3-foot high headcut already exists. Both surface and subsurface flows are likely to converge in this location due to the wetland and small gully slightly upslope. The upslope, discontinuous gully is not expected to continue eroding. Discontinuous gullies indicate that surface water reinfiltrates and prevents downstream transport of sediment. A

loose rock revetment or toe protection in the main channel at the base of the bank is recommended. A loose rock headcut repair is recommended for the small headcut. Since livestock use this spot as one of only two locations to cross the creek channel, a rock and gravel wet crossing should be installed.

5. **Site B1.9.** Another previously eroding livestock crossing of the creek (exasperated by upslope drainage) appeared to be partially stabilized during the fall inventory. A re-visit to the site in the spring revealed new disturbance. Scour of the toe of the left bank is temporarily stabilized with the roots of a living tree. A headcut immediately upslope from the livestock crossing area is approximately 2 feet high. Upslope from the headcut, the gully narrows and continues back at least another 100 feet almost to the road. This upper section of the gully is grassy and not currently actively eroding. A rock or biotechnical repair is recommended for the lower section. Since livestock use this spot as one of only two locations to cross the creek channel, a rock and gravel wet crossing should be installed. Rock toe protection at the toe of the slope is probably not necessary; however, if repaired, impacts on the living tree roots should be considered.

6. **Site B2.4.** An approximately 100-foot long gully leads to an approximately 8-foot high, 160-foot long, 30-foot wide headcut. Upslope a discontinuous, smaller gully / headcut exists. A loose rock and willow / brush headcut repair is recommended for the large headcut. The gully should be stabilized with loose rock. The small, upslope headcut does not currently have the potential to deliver sediment to the downstream channel; however, the large headcut could migrate upslope. Other portions of the surrounding grassy slopes may develop gullies and headcuts in the future. Planting oaks in areas that are devoid of trees may help stabilize the slope. Temporary fencing will be needed if the willows / brush headcut repair is utilized.

7. **Sites B2.5 & B2.6**. A series of three headcuts and a gully, ranging from 2 feet to 8 feet deep. Two of the headcuts have the potential to migrate headward and take out the road. The first is semi-stablized, and monitoring to determine future erosion potential is recommended. The future quantity of sediment available to erode from the two active headcuts (near the road) could increase significantly if they are allowed to migrate upslope of the road. Loose rock headcut repair, loose rock toe protection, and a loose rock-lined channel are recommended for the two active headcuts and the gully near the road.

8. **Site B2.9.** A 200-foot long cow trail along the fence has turned into a gully that is about 1.5 feet deep and 1.5 feet wide. Dual nick points, one downslope from the drainage that crosses a road and one upslope of the road, exist

where this gully drains into the main channel. These nick points have been somewhat stabilized by the placement of rock. A loose rock headcut repair, filling the gully with small, loose rock, and a rock and gravel wet crossing where the drainage runs across the road are recommended.

9. **Site B3.2.** A headcut is migrating towards the road due to flow convergence on the hillslope from a new culvert. Apparently this culvert was installed by a fiber optics company who runs their line across the Cooley property. It is likely that the company would repair any erosion sites, including this site, that threaten the fiber optics line. The exact location of the line is unknown at this time; however, it does appear to run along a significant portion of the ridge road. Mr. Crawford Cooley should be contacted about this option. The headcut and gully are, on average, 4 feet high, 50 feet long, and 45 feet wide. A loose rock headcut repair and a loose rock-lined channel are recommended.

10. **Site B4.1**. **This site is the single largest source of sediment in the entire upper Bowman watershed.** This nick point is approximately 13 feet high. Vertical banks downstream of the nick point are around 20 feet high, and the top of bank width is approximately 30 feet wide. The vertical banks upstream of the nick point are approximately 10 feet high, and the top of bank width is approximately 12 feet wide. This nick point has caused significant slope failures on both banks of the channel. This stream is the main channel of subwatershed #4, which appears to be the property line between Mr. Cooley and Mr. Garlick. The nick point is causing slope failures on the Cooley property. Lack of access to the Garlick property prevented a complete survey of this site. Photos and estimated measurements were taken from the top of the left bank on the Cooley property. This nick point has the potential to unravel the upper portion of subwatershed #4, causing continued massive slope failures, massive incision, and massive bank erosion. This site requires an engineering design. Repair would likely require boulder drop structures, laying back of vertical banks, compacted channel fill, a rocked channel, and revegetation.

11. **Site B4.2.** Two small, partially stabilized nick points threaten the road if they migrate headward. The nick points are approximately one and two feet high. Repairing the nick points with loose rock is recommended. Associated bank slumping could be stabilized with native vegetation.

12. **Site B4.3.** Two existing sediment traps exist for the rock quarry. One is on the north side of the quarry, and the other is on the south. The sediment trap on the north side has a small drainage area and appears to be functioning. The sediment trap on the south side has a large drainage area and is full. The trap needs to be excavated and monitored on an annual basis. Significant

active erosion and gullying are visible on exposed surfaces and piles of loose rock within the quarry. The bare and eroding quarry should be reclaimed, regraded, and revegetated. A cost estimate for reclaiming the rock quarry is beyond the scope of this project and is not included herein.

13. **Site M5.4.** Significant amounts of newly accumulated sediment were found in tributary 2 (see Map 2). Following this tributary from the mainstem of Novato Creek leads to a significant sediment source, a new housing development. The sediment loading into Novato Creek coming from this housing development will continue both in the short term due to construction without proper sediment control practices and in the long term due to lack of detention for increased stromwater runoff. The following are sources of sediment:

    - Improperly maintained and failing sediment controls (i.e., silt fences).
    - Ineffective installation of sediment controls (i.e., silt fences in waterways). Silt fences are not effective in waterways and should not be utilized to control sediment.
    - Stockpiled sand, rock, and/or sediment without sediment controls in areas that are hydrologically connected to the creek.
    - Downstream channel incision due to increased peak flows in tributary 2. The one-foot incision in the tributary is very recent (i.e., the last several years) and is a textbook example of increased runoff from development resulting in erosion. The increased peak flows could be from impervious areas such as roof tops/roads, an increase in efficiency of delivery of water to the channel from the storm sewer network, and the concrete interception channels on the slope above the development.

14. **Site M12.2.** Along the mainstem of Novato Creek between Sutro Avenue and Novato Creek Dam, approximately 36 sites with eroding banks were identified. In most cases, these sites given a low priority due to feasibility and environmental and concerns (see discussion in Sections 5.2.2 and 6, respectively); however, approximately 200 feet of vertical eroding bank are recommended for high priority repair. This eroding bank is located on a section of the mainstem that is over 100 feet wide. The channel was classified as a Rosgen C channel, and the dimensions are geomorphically stable. Therefore, bank stabilization is likely to be successful and environmentally beneficial.

15. **Site M14.** This site has a significant headcut with a developing gully approximately 6 feet high, 45 feet long, and 10 to 12 feet wide. Laying back the banks at a 1:1 slope and stabilizing the headcut with a rock headcut repair

are recommended. Seeding, mulching, and planting the regraded areas are also recommended. One of the side slopes should also be stabilized with rock because during runoff the flow is directed towards the left bank, potentially causing a headcut to form in this location in the future.

5.3.2 Medium Priority Sites

1. **Site B1.1**. Slope failure and bank erosion due to channel incision and scouring of the toe of the slope. The slide is approximately 15 feet high, 150 feet long, and varies from 10 to 30 feet wide. Two alternative approaches could be taken at this site. For either approach, an engineering design and survey are recommended:

   - Repairs consisting of a rock toe revetment, a rock-lined channel, and rock toe protection could be constructed. A small headcut at the top of the slide should also be stabilized with rock.
   - Constructing a rock check dam and bringing up the grade behind the check dam to stabilize the toes of slopes that are failing at this site and upstream. The grade resulting from such a check dam should be designed to match the existing grade up to the nick point at site B1.5 (so that the upstream reaches are not encouraged to meander and cause additional erosion).

2. **Site B1.3.** An approximately 5-foot high headcut has migrated about ten feet out from the right bank. Upslope, a gully drains to the headcut. A loose rock headcut repair, toe protection, and revetment are recommended.

3. **Site B1.4.** A series of small headcuts ranging from one to two feet in height. Loose rock headcut repairs are recommended.

4. **Site B1.10**. One 8-foot and two 3-foot headcuts have migrated approximately 10 to 20 feet out from the left bank. Loose rock headcut repairs are recommended. Some toe protection in the main channel may be needed.

5. **Site B2.2** A partially stabilized nick point is located where the tributary enters the main channel in subwatershed #2. Walking upslope from this nick point, a poorly defined "path" where water flows across the pasture is visible. No easily defined channel exists. Upslope from this pasture in the main eroding gully, which is approximately one-foot deep and 250 feet long, an approximately 150-foot long side gully is connected to the main gully. These gullies are hydrologically connected to the main channel network. The nick

point should be stabilized with a rock headcut type repair, and the gully should be filled with small loose rock.

6. **Site B2.3.** Some bank erosion is occurring along approximately 1,500 feet of channel bank. Planting the banks with native vegetation is recommended. Approximately 75 feet of bank that are vertical should be graded out before planting.

7. **Site B2/3.1.** The lower channel sections of subwatersheds #2 and #3 converge to become one channel here (see Map 1). The lower portion of this reach has been planted with native vegetation such as oaks by the Students & Teachers Restoring a Watershed (STRAW) program. For areas with vertical banks, regrading and additional plantings of native trees are recommended. Monitoring and maintenance of existing installed plants would help their long-term survival. Native planting should extend approximately another 1,000 feet upstream to the culvert identified on Map 2 as C7. The McIsaacs are not interested in planting willows through this reach, but other native trees would be acceptable.

8. **Site B3.3.** A one-foot high nick point within an approximately 250-foot long gully and a 5-foot high headcut at the top of the gully. The headcut is approximately 50 feet long and 40 feet wide. Loose rock to stabilize the nick point, gully, and headcut is recommended. The headcut is somewhat stabilized as indicated by grass growth, although the headward migration of the smaller headcut could further destabilize the larger.

9. **Site 3.5.** Three nick points in the lower main channel of subwatershed #3 should be stabilized with loose rock. Since this site is not a high priority site, monitoring (i.e., marking the nick points with stakes) is recommended. Rate of erosion can provide insight into headward migration rates of nick points and help with reprioritization of the site, if necessary.

10. **Site 3.6.** A single nick point that has been temporarily stabilized by roots and rocks. When this nick point fails, it will migrate headward and destabilize the channel for at least several hundred feet, where it may be stabilized by naturally-occurring rock. A rock headcut repair is recommended.

11. **Site 3.7.** 300 feet of rilling in the road has resulted in sediment loading to the downstream channel network. Two rolling dips, regrading the road, and re-rocking the road are recommended. Most roads in the upper Bowman watershed are outsloped and are not hydrologically connected to the channel network. Sediment eroded from this road, however, is delivered to the

downstream channel network. This road may be maintained by the fiber optics cable company previously discussed (see Site B3.2).

5.3.3 Low Priority Sites

1. **Site B1.2**. A gully that appears to have somewhat self-stabilized as indicated by the partially grassy cover. Some erosion and delivery of sediment to the main channel are still occurring. The access to this site is low. A loose rock headcut repair and a loose rock channel are recommended.

2. **Site B2.1**. Two headcuts approximately 5 feet long, 5 feet wide, and 3 feet high are threatening the ranch road. A loose rock headcut repair is recommended.

3. **Site B3.4**. Some historical and currently active bank erosion is going on along approximately 1000 feet of channel bank. Planting the banks with native vegetation is recommended. Some banks should be graded out before planting.

4. **Site 3.8.** A small nick point at the upper end of the channel network that has potential to run out another 40 feet at most. A loose rock headcut type repair is recommended.

5. **M1-M18 (except M5.4, M12.2, M14).** On the mainstem Novato Creek between Sutro Avenue and Stafford Lake, most of the sites are eroding vertical or near vertical banks due to channel incision and lateral channel migration. A total of 36 eroding banks were identified; however, unless private property needs to be protected, stabilization of most of these sites is not recommended. If these sites are to be stabilized for the short term on a site-specific basis, a series of rock or log vanes are recommended in most cases. A combination of rock and log toe protection is preferred at some sites (see field data sheets for site-by-site specifics). All sites would require engineering design and surveying.

Table 2. High Priority Sites

Site #	Type of erosion	Access	Potential load (cy)	Erosion activity	Eng. Design (Y/N)	Construction Cost Range (not an estimate)*
B1.5	Slope failure triggered by toe scour	Med	450	High	Yes	$10,000 -$25,000
B1.6	Headcut/bank erosion	High	200	Med	Yes	$10,000 - $25,000
B1.7	Headcut	High	40	High	No	$1,000-$5,000
B1.8	Headcut repair, livestock crossing	High	90	High	No	$2,000-$5,000
B1.9	Headcut repair, livestock crossing	High	150	High	No	$5,000-$10,000
B2.4	Headcut	Medium	450	High	Yes	$25,000-$50,000
B2.5/ B2.6**	Headcuts	High	65	High	No	$5,000-$10,000
B2.9	Nick point, gully, livestock crossing	High	30	High	No	$5,000-$10,000
B3.2**	Headcut	High	300	High	No	$1,000-$5,000
B4.1	Giant nick point	High	3,700	High	Yes	$80,000-125,000
B4.2**	Several nick points	High	30	High	No	$1,000-$5,000
B4.3	Existing sediment pond	High	No Data	High	No	$1,000-$5,000/yr***
M5.4	Erosion from construction	High	No Data	High	No	$10,000 - $25,000 initial costs
M12.2	Eroding bank	High	350	High	Yes	$25,000-$50,000
M14	Headcut	High	200	High	No	$10,000 - $25,000
Total	**15 sites**		**6, 055 cy**			**$312,500-$425,000**

* Lower value is the sum of the average of each line item.
** Threatening a ranch road.
*** Yearly rate calculated over 10 years to include in total volume number.

Table 3. Medium Priority

Site #	Type of erosion	Access	Potential load (cy)	Erosion activity	Eng. Design (Y/N)	Construction Cost Range (not an estimate)*
B1.1	Slope failure and bank erosion due to channel incision	High	850	Medium	Yes	$10,000 -$25,000
B1.3	Headcut and gully	Medium	60	High	No	$5,000-$10,000
B1.4	Gully	High	10	Medium	No	$1,000-$5,000
B1.10	Three headcuts	Medium	20	High (1); Low (2)	No	$1,000-$5,000
B2/3.1	Eroding banks	High	90	Low	No	$5,000-$10,000
B2.2	Gully	High	30	High	No	$5,000-$10,000
B2.3	Bank erosion	High	50	Medium	No	$1,000-$5,000
B3.3	Gully, nick point, headcut	Medium	200	Low	No	$5,000-$10,000
B3.5	Nick points	High	150	Medium	No	$5,000-$10,000
B3.6	Nick point	High	150	Medium	No	$5,000-$10,000
B3.7	Rilling in road	High	10/year**	High	No	$1,000-5,000/yr**
Total	**11 sites**		**1,710 cy**			**$74,500-150,000**

* Lower value is the sum of the average of each line item.
** Yearly rate calculated over 10 years to include in total volume number.

Table 4. Lower Priority Sites

Site #	Type of erosion	Access	Potential load (cy)	Erosion activity	Eng. Design (Y/N)	Construction Cost Range (not an estimate)*
B1.2	Gully	Low	30	Low	No	$10,000-25,000
B2.1**	2 headcuts	High	20	High	No	$1,000-$5,000
B3.4	Bank erosion	Medium	50	Med	No	$1,000-$5,000
B3.8	Small nick point	High	10	Medium	No	$1,000-$5,000
M1-M18***	Eroded bank due to lateral channel migration	Low to Med	45,000	High to Medium	Yes	$900,000-$1,800,000
Total	**4 sites**		**110 cy¥**			**$26,500-40,000¥**

* Lower value is the sum of the average of each line item.
** Threatening a ranch road.
*** 36 sites of eroding banks. Does not include M5.4, M12.2, and M14.
¥ Sites along the mainstem (M1-M18) are not included in sediment or price estimate.

5.4 Sediment Quantity Estimates

5.4.1 Upper Bowman Canyon

In Tables 2 through 4, the amount of potential future sediment is reported from a field estimation of each accelerated erosion site. This estimate is based on the assumption that if the baseline conditions in the channel network or watershed hydrology do not change, the estimated potential load of sediment will erode from the indicated site as it becomes naturally stable. Quantities were estimated in the field by examining multiple factors such as composition of soil, vegetative cover, angle of slopes, upstream drainage area, past erosion rates based on roots or tree evidence, and other considerations. For bare upland areas without stabilizing tree roots, such as many of the identified gullies, the sites are expected to stabilize on average in 5 to 25 years. In areas where trees may slow erosion rates, the time period may be longer.

Erosion rates can be calculated from the estimated sediment quantities by the following methods:

- Utilize erosion rate equations for specific features (i.e., Dunne and Reid's (1996) equation of gully erosion rates).
- Determine an average expected time for erosion to occur based on future monitoring of cross-sections and stakes.
- Compare to regional or national erosion rates. Review existing literature for sediment yields for different land use types (tons / mi^2 / year).
- Investigate in the field using vegetative indicators or cross-sections associated with bridge construction.

In upper Bowman Canyon, the main channels are still incising in some subwatersheds and widening in all subwatersheds. Although these sites do not qualify as bare, actively eroding sites due to the slow rates of erosion, they still contribute to the overall sediment load coming from Bowman Canyon. If a sediment budget were to be compiled for Bowman Canyon, the sediment load from the geomorphic adjustment of channels in upper Bowman Canyon should be included.

5.4.2 Mainstem Novato Creek between Sutro Avenue and Novato Creek Dam

Because the entire stream system is adjusting and widening on the mainstem of Novato Creek and in lower Bowman Canyon, it is not practical to estimate the amount of potential future sediment load on a site-by-site basis. As an alternative, the potential future sediment load was calculated by measuring the average existing channel dimensions and comparing these to the predicted future stable channel dimensions. Assuming the baseline hydrologic and hydraulic conditions do not change, measurements of channel widths and average cross-sections of existing channel reaches provide a basis for estimating the amount of sediment that will potentially erode from in-stream sources on the mainstem of Novato Creek.

Several cross-sections were measured (see Figure 5), and bankfull and floodprone channel widths were measured continuously between Sutro Avenue and the mouth of Leveroni Canyon. Table 5 summarizes the drainage areas for different locations along the mainstem, the measured average bankfull width, and the predicted bankfull width based on a Rosgen channel classification and evolution model and reference reaches. Sometimes a regional curve that relates drainage area to average bankfull width, bankfull depth, and cross-sectional area (developed for the San Francisco area by Dunne and Leopold, 1978) can be utilized to predict average bankfull dimensions. In the Novato Creek watershed, however, the dam attenuates and prolongs the duration of any peak flows. In some years, for example the winter of 2000-2001, the dam does not overspill at all (Lewis, personal communication, 2001). This significantly alters the hydrology and geomorphology downstream of the dam. In addition, bankfull indicators in the field suggested that bankfull dimensions are significantly less than those predicted by the regional curve.

Table 5. Mainstem Novato Creek between Sutro Avenue & Novato Creek Dam

Location	Drainage Area (mi²)	Drainage Area minus area above dam (mi²)	Avg. Existing Bankfull Depth (ft)*	Est. Bank-full Width (ft)*	Avg. Existing Bank-full Width (ft)	Est. Flood-prone Width (ft)**	Avg. Existing Floodprone Width (ft)
Mainstem above Sutro Ave	19.8	11.1	2.2	31.5	27-33	70	35-89
Mainstem above Bowman	19.1	10.4	2.0	26	21-26	58	31-45
Mainstem above Leveroni	10.7	2.0	No data	No data	No data	No data	No data
Mainstem above Dam	8.7	0.0	NA	NA	NA	NA	NA

* Average existing bankfull width and depth were measured in the field based on field indicators and then averaged. Estimated bankfull width and floodprone width are the predicted stable widths based on the Rosgen stream classification and evolution database, as well as measurements of C type channel reference reaches in Novato Creek and Arroyo Sausal Creek.

** The mainstem of Novato Creek is evolving towards a stable channel type that will resemble a Rosgen type C channel. A C type channel has a floodprone to bankfull width ratio of 2.2.

Potential future sediment volume is estimated by calculating the amount of sediment that will be eroded from both banks as the existing channel geometry evolves towards a predicted stable geometry. The average cross-sections were compiled by taking all measured bankfull widths and measured floodprone widths and averaging these values. A slope of 1:1 is assumed beyond the floodprone width. Typical average cross-sections were plotted in AutoCAD for each Rosgen channel type identified. Separate average cross-sections were generated for two locations—above Sutro Avenue below the mouth of Bowman Canyon (approx. 5, 270 ft) and above the mouth of Bowman Canyon below the mouth of Leveroni Canyon (approx. 2,880 ft) (see Map 2). The reach of the mainstem above the mouth of Leveroni and below the dam (approximately 1,000 ft) was not measured due to the complex effects of the dam. For above Sutro Avenue below the mouth of Bowman Canyon, typical average cross-sections were generated for the channel types encountered there: Rosgen types G (approx. 836 ft), F (approx. 2.255 ft), F evolving towards a C (approx. 1,687 ft), and a C channel (approx. 492 ft) (Figure 9). For above Bowman and below Leveroni, typical average cross-sections were generated for the channel types encountered there: Rosgen types G (approx. 1,494 ft), G evolving towards an F (approx. 992 ft, and F evolving towards a C (approx. 395 ft) (Figure 9). In addition, two cross-sections were taken with a laser level of an F channel (Photos 5 and 6; Figure 5). The average gradient throughout the entire channel reach was approximately 0.5%.

The mainstem of Novato Creek between Sutro Avenue and the dam is evolving towards a stable channel that will resemble a Rosgen type C channel. A C channel typically has a minimum floodprone to bankfull width ratio of 2.2 based on Rosgen's database of channel types. This was confirmed as a realistic minimum value based on general measurements made of an existing C type channel in Novato Creek (floodprone widths were 80 to 100 feet and still eroding) and cross-sections of a reference reach in Arroyo Sausal where the floodprone to bankfull width ratio may be as high as 3.3 (Photo 9; Figure 8). The future predicted bankfull width at each reach is based on an average of measured bankfull widths from stable or semi-stable reaches within Novato Creek. The future predicted floodprone width at each reach is generated by multiplying the average of measured bankfull width by 2.2. The area of bank that will erode from each typical average cross-section was then measured from the plotted cross-sections and multiplied by the total channel length represented by each channel type (Figure 9). The total length is approximately 8,150 feet. Of this, approximately 500 feet (6% of the total length) is a Rosgen C type channel. An assumption was made that no soil will erode from this "stable" C type channel for the purpose of calculating the future total sediment volume. Using this methodology, it is estimated that approximately 43,600 cubic yards will erode from both banks. This value is a minimum because the final C type channel will have a floodprone width that is at least 2.2 times the bankfull width. In reality, the channel may continue eroding after it has a floodprone width of 2.2 times the bankfull width. In such cases (i.e., at site M12.2), the eroding bank should be stabilized.

5.4.3 Lower Bowman Canyon

Sediment for lower Bowman Canyon was estimated in basically the same way as for the mainstem Novato; however, since access was not granted to most of the lower Bowman watershed, an alternative to measuring the existing cross-sections was employed. Access was allowed to the mainstem of lower Bowman Canyon creek below and above the Garlick property. Two cross-sections of lower Bowman were measured with a laser level (Figure 6; Photos 1 and 7). The road next to the creek was driven, and a visual estimate was made of what percentage of the channel applied to each stream type. The following stream types were estimated: a Rosgen G type channel with characteristics of cross-section 1 (approx. 510 ft) and a Rosgen G type channel with characteristics of cross-section 2 (approx. 4,590 ft) (Figure 6). The total length of the channel is approximately 5,500 feet. Approximately 7% of the channel (400 ft) shows the characteristics of an F channel evolving to a C type channel (Photo 2). Due to lack of access, no cross-section is available, and thus no sediment is calculated to erode from this reach. The sediment volume was estimated to be approximately 50,000 cubic yards for both banks. Drainage areas, average measured bankfull width, estimated future bankfull width, average measured floodprone width, and estimated future floodprone width are summarized in Table 6. In addition, a cross-section of the main channel of subwatershed #1 was measured with a laser level (Figure 7; Photo 8).

Table 6. Lower Bowman Canyon

Location	Drainage Area (mi^2)	Estimated Bankfull Width (ft)*	Avg. Existing Bankfull Width (ft)*	Estimated Floodprone Width (ft)z	Avg. Existing Floodprone Width (ft)
Drainage area at mouth of Leveroni	2.0	No data	No data	No data	No data
Drainage area at mouth of Bowman	3.2	21**	17	46	30
Drainage area of subwatershed #1, Bowman	0.49	11	See Fig. 7.**	24	See Fig. 7.**
Drainage area of upper Bowman at XS 2	1.66	17	12	37	15
Drainage area of subwatershed #2, Bowman	0.52	11	No data	24	No data
Drainage area of subwatershed #3, Bowman	0.37	10	No data	22	No data
Drainage area of subwatershed #4, Bowman	0.77	12	No data	28.5	No data

* The regional curve for the San Francisco Region, which relates bankfull width and depth to drainage area, was utilized in combination with bankfull indicators to determine estimated bankfull width, bankfull depth, and floodprone width.

** A single cross-section was measured on the mainstem of subwatershed #1 near the McIssac/Garlick property line, but no clear bankfull indicators were found.

5.4.4 Leveroni Canyon

Sediment quantity estimates where not made for Leveroni Canyon because access onto the property was not granted. However, when the main channel erosion inventory was conducted, there was a significant increase in fine sediment deposition in the channel upstream from the mouth of Bowman Canyon and downstream from Leveroni Canyon. At the time of the inventory, Novato Creek Dam was not spilling over. In other words, all water and sediment draining to the upper mainstem of Novato Creek above Bowman Canyon came from Leveroni Canyon. Approximately 0.5 to two feet of fine sediment, mostly silts and clay-sized particles, were deposited in most most more slowly moving areas such as pools (Photo 4).

6. ECOLOGICAL IMPLICATIONS

Excessive fine sediment accumulation in the stream bed, typically sediment smaller than 0.85 mm (coarse sand), has adverse effects on aquatic life (see Attachment 3 – Life History of Salmonids for further discussion). On the other hand, coarser sediment, especially spawning-sized gravels for steelhead (0.5 inches to 5 inches), is essential for properly functioning, gravel-bedded rivers. Stabilizing erosion sites in the stream typically reduces both types of sediment (assuming the banks are composed of both materials). Because sediment from upland erosion is typically carried by overland flow, only fine suspended sediments (i.e., silts and clays) are delivered to the active channel network.

6.1 Instream Bank Stabilization

A connected floodplain is a key component of a stable and ecologically healthy stream system. As a creek spills onto its floodplain, the rate of increase of the average shear stresses decreases (Andrews 1984). In other words, as flood stage rises, the tractive forces increase more slowly in a channel with a floodplain than in one without. It is difficult for animals that use the stream gravel, such as salmonids and aquatic insects, to survive in a channel that is incised and without a floodplain. In addition, floodplains provide valuable, complex habitats (high flow refuge, backwater pools, side channels) that are not available in an incised channel without a floodplain where aquatic organisms have no place to escape high velocities and scouring forces.

6.2 Sediment Traps

Streambeds are naturally dynamic. Sediment is continuously mobilized during storms, transported downstream, and replenished by upstream sources. Bedload, typically gravels and sand, makes up only 5 to 20% to the total sediment load, with the load being suspended load. However, the gravel component of bedload is very important ecologically. Without a continuous supply of upstream gravel, spawning beds will quickly become depleted of spawning-sized gravels.

Sediment traps are very effective at sediment control; however, sediment traps capture both fine and coarse sediment. The benefits of controlling sediment must be weighed against the need for beneficial gravels in spawning beds. Because Novato Creek Dam effectively captures 100% of the bedload (as well as a significant amount of suspended load), gravel-sized bedload delivered from Bowman and Leveroni Canyons is critical to spawning areas in mainstem Novato Creek. Maintainable sediment traps permanently deplete downstream reaches of beneficial gravels.

The construction of a maintainable sediment trap upstream of Redwood Boulevard and downstream of Diablo Avenue on the mainstem of Novato Creek to capture bedload and suspended sediment is recommended. This section of the mainstem has low ecological integrity. The channel downstream does not appear to provide spawning beds and is probably primarily utilized for migration by salmonids and other fish. The channel is more or less straight and trapezoidal in this area without wetlands and with few opportunities for aquatic organisms to rest or feed.

7. MONITORING AND MAINTENANCE

7.1 Monitoring and Maintenance for Erosion Site Repairs

Following each winter rainy season, newly constructed sediment projects should be inspected to see if they are performing as designed. Sites that show signs of instability or new erosion should be repaired. Monitoring of both source control and sediment trap projects should occur. Source control projects should be monitored for stability. Monitoring of medium or low priority sites before they are repaired (using stakes to mark the location of nick points or gully heads) can help determine whether or not repairs need to be made. All newly installed native plants should be maintained and monitored for 5 years. This includes watering through the dry season, weeding twice a year, and replacing some plants if high mortality occurs.

7.2 Monitoring Erosion Rates

Due to the inherent variability in estimating the amount of sediment produced by a site or a watershed, any sediment traps should be monitored for sediment accumulation to estimate sediment production from subwatersheds and specific land use types. The existing sediment trap for the rock quarry and the newly proposed trap in the mainstem should be monitored as follows:

- Establish a survey monument and survey sediment traps if possible. If it is not possible to survey the trap after excavation, keep notes of volume of sediment excavated.
- Keep a record of annual sediment removal.
- Collection of several years of data will provide locally reliable amounts of sediment production that can be compared to previously estimated sediment quantities.

In order to determine the rate of channel widening and incision in the mainstem of Novato Creek and Bowman Canyon watersheds, monumented cross-sections should be established and surveyed for two years. Collecting cross-sectional data is very cost effective, is needed to accurately determine erosion rates, and will be an important aid in future management decisions. Surveying frequency can be every two or even three years. Surveying should go on until sediment delivery from this portion of the watershed to the NFCP is no longer of concern. The following steps are recommended:

- Establish 4 to 9 cross-sections on mainstem Novato Creek, 2 or 3 above Sutro Avenue, and 2 or 3 above the mouth of Bowman Canyon. Additional sites could be located upstream of the mouth of Leveroni Canyon. Additional sites downstream Sutro Avenue would be necessary to estimate downstream conditions in Novato Creek. Proper selection of these sites is critical and should be geomorphically representative.
- Establish 1 to 2 cross-sections on lower Bowman Canyon downstream of the Garlick property, 1 cross-section upstream of the Garlick property on the mainstem of Bowman Canyon Canyon, and 2 to 3 cross-sections in subwatershed #4, if possible.
- Establish 1 to 2 cross-sections on the main channel of each subwatershed (#1, #2, and #3).

Selected nick points and gullies should be monitored by installing monuments and measuring headward erosion once a year. Monuments should be immediately installed at several high priority sites before repairs are made. Keep records of erosion rates of nick points and gullies. This will help in the overall accurate calculation of sediment production from specific features and the overall watershed.

8. CONCLUSIONS

1) The NFCP is an effective sediment trap and will continue to function like one unless reconstruction of channel dimensions, modification of constrictions, and wetland restoration (to increase the tidal flood volume) are undertaken (Collins 1998). If sediment is controlled at the sources or captured before entering the NFCP, the frequency of dredging in the NFCP can be reduced.

2) The main source of sediment deposit in the NFCP is from in-stream watershed sources. Bedload (gravels and sands) make up 50% of sediment trapped in the NFCP (Collins 1998). 100% of bedload material (sand and gravels) from upstream of Stafford Lake is captured by the lake. 100% of bedload in the NFCP is from sources downstream of the dam.

3) Coarser bedload (gravels) is beneficial to the ecological integrity of the stream system, especially for salmonids. Repairs should focus on the elimination of fine sediment loading, which is detrimental to ecological integrity, throughout the watershed. Fine sediment loading from channel

banks, channel bed, gullies, roads, construction, bare pastures, and other upland sources exists.

4) The mainstem of Novato Creek between Sutro Avenue and Novato Creek Dam and the mainstem of lower Bowman Canyon are evolving towards naturally stable channels. The incised channels are developing floodplains within the incised channel banks. A natural channel with an active floodplain is self-maintaining, relatively stable, and has high ecological intergrity (i.e., more complex habitat and lower shear stresses during flood flows).

5) The erosion inventory identified approximately 15 high priority, 11 medium priority, and 4 low priority sites (excluding low priority sites on mainstem Novato Creek). The high, medium, and low priority sites will contribute a total future potential load of 6,055, 1,710, and 110 cubic yards respectively. In addition, 50,000 and 43,600 cubic yards are expected to erode from lower Bowman Canyon and mainstem Novato Creek between Sutro Avenue and Novato Creek Dam, respectively. Erosion rates were not calculated. Historical evidence can be used to determine past and to predict future erosion rates; however, monitoring of current rates produces the most reliable information. It is expected that the future potential sediment load described above will be yielded episodically over the course of the next several decades to a century.

6) Bank erosion from channel adjustment is expected in upper Bowman Canyon subwatersheds #1, #2, and #3; however, due to some natural stabilization, it is not expected to be as high as other major sources in the upper Bowman Canyon watershed. A significant amount of sediment is expected to erode from subwatershed #4.

9. RECOMMENDATIONS

1) No repairs on the mainstem of Novato Creek that would prevent the channel from evolving to a natural, stable, self-maintaining geometry are recommended. Currently, less than 10% of the main channel has evolved to a state where bank stabilization is appropriate.

2) A maintainable sediment trap upstream of Redwood Boulevard and downstream of Diablo Avenue on the mainstem of Novato Creek should be evaluated as an alternative to trapping sediment downstream of Redwood Boulevard. A trap can be constructed in a way that does not reduce flood conveyance and that would capture bed sediment, as well as suspended sediment. This reach of the mainstem has low ecological

integrity. The channel is probably primarily utilized for migration by salmonids and other fish. The channel is more or less a straight, trapezoidal channel in this area without wetlands and with limited opportunities for aquatic organisms to rest or feed.

3) An evaluation of alternative channel cross-section configurations for the lower reaches of the Novato Flood Control Project is recommended. The purpose of this evaluation would be to identify channel cross-section configurations that will maintain flood conveyance and that are more effective at transporting sediment than the current channel configurations.

4) High priority erosion sites in upper Bowman Canyon should be repaired. Repairs should focus on stabilization of eroding sites in the upper tributaries beyond the main channel that are actively adjusting and beyond the distribution of salmonid habitat. In lower Bowman Canyon, significantly eroding and repairable sites are visible from the road and the McIsaac farm. The single largest erosion site (site B4.1)—a 12-foot nick point—is on the border between the McIssac farm and the property owned and/or managed by Mr. Garlick. This actively eroding site is causing slope failures on the McIsaac farm. The property in the lower Bowman Canyon is currently for sale.

5) Gullies and nick points should be monitored for a minimum of 2-3 years or longer if site-specific conditions require (i.e., site shows signs of potential erosion). Cross-sections and existing/future sediment traps should be monitored for as many years as possible. Information provided by cross-sections will be immensely valuable in determining at what rate the channel is geomorphically adjusting and what erosion repairs, if any, are appropriate.

6) Identify areas of potential and existing spawning and rearing salmonid habitat. Determine if subwatershed #4 is salmonid habitat. Integrate existing data, if any, from a habitat survey conducted by the California Department of Fish and Game or conduct a salmonid habitat survey in Novato Creek watershed. The presence or absence of salmonid habitat will influence the type, cost, and feasibility of different types of erosion repairs that may be implemented.

7) Fine sediment deposited in the bed of Novato Creek upstream of the mouth of Bowman Canyon and downstream of the mouth Leveroni Canyon indicates the extremely high rates of erosion of fine sediment in

Leveroni Canyon. Acquisition of access to the property for erosion site surveys is recommended.

8) The absence of a sediment budget prevents an accurate estimation of the amount and rates of sediment erosion in the watershed. A rapid sediment budget built upon the information collected by Laurel Collins (1998) and during preparation of this sediment plan would help to create a complete picture of sediment sources and yields from different areas of the watershed.

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TECHNICAL ATTACHMENTS

TECHNICAL ATTACHMENT 1
DISCUSSION OF POSSIBLE ALTERNATE SEDIMENT SOURCES

Although in-stream erosion is the most significant sediment source in the watershed, other sources may be collectively significant. Landslides, dirt roads, livestock trails, poorly vegetated pastures, and tidal sediments are discussed by Collins (1998). These and other sources are further discussed below.

Construction and Existing Urban Land Use

Construction and urban land cover as a sediment source were not considered by Collins (1998). The lower portion of Novato Creek watershed is currently undergoing urbanization; however, no quantitative information about the percentage of urban land cover in lower Novato Creek watershed was available for this report. Sediment yields from urbanizing watersheds are approximately two orders of magnitude higher than rural watersheds (Wolman and Shick 1967). Wolman (1967) showed that sediment yields increase dramatically during the construction phase of urbanization and subsequently decreases in the post-construction phase. Nevertheless, urban land use continues to have a higher yield than rural or wooded watersheds. Besides increased sediment loading from channel erosion, urbanization results in elevated sediment yields from new construction, unvegetated open spaces, foot trails, and accumulated particles on paved surfaces. Private or public works construction sites are known to contribute significant amounts of sediment from urbanizing watersheds. One study showed that 85% of the sediment yield in a watershed came from a single highway construction project constituting 11% of the basin area (Vice 1969). In addition, increased drainage density (i.e., trails, roads, road ditches, and storm sewers) increases the efficiency of delivery of sediment to the channel network and sediment sources that would otherwise not be delivered to the channel network are in fact delivered. In addition, erosion control practices are often not correctly maintained and implemented in the field. Runoff from a construction site in the Novato Creek watershed just above Sutro Avenue (Site M5.4) is an example of high sediment loading from a new construction site.

Tidal Sources

The total load of sediment transported by stream flow out of a watershed can be categorized primarily in the following two ways:

- **Suspended load**. Particles that are lifted up and kept in suspension by eddies and move long distances downstream before settling out. Suspended sediment may not settle out until reaching a large, still body of water (lake or ocean). Typically these particles are silts and clays.
- **Bedload.** Larger particles that constitute the bed of the stream and are typically mobilized only once or twice a year. When mobilized, these larger

particles slide and roll along the bottom of the stream. Typically these particles are cobbles, gravels, and sands.

Typically in lowland rivers the bedload makes up 4% to 8%t of the total load (Vanoni 1975). The fine silts and clays in the NFCP could be either suspended load from the watershed or fine silts and clays that are deposited by tidal action. Bed cores were taken in the NFCP to determine what portion of the sediment deposited in the NFCP was from upslope sources and what portion was from the bay (Collins 1998). At least 50% of the sediment was found to be gravels and sands, indicating upslope sources. The remaining portion of the sediment is silt and clays. Silt and clay can come from the watershed (i.e., banks that have a high silt/clay content, pasture, construction) or from the bay. These silts and clays could be from the following sources and undergo different depositional processes: 1) upslope watershed sources, deposited by in-stream flows; 2) upslope watershed sources, reworked and deposited by tidal processes; and 3) bay sediment sources, reworked and deposited by tidal processes.

Although stabilization of upslope erosion sources on the mainstem of Novato Creek and Leveroni or Bowman Canyons will reduce upslope sediment sources that are directly depositing in the NCFP, the role that tidal processes play in redeposition of upslope clays and silts is not understood. Theoretically at least, a reduction of upslope sources could reduce the quantity of silts and clays that are available to tidal processes; however, silts and clays available for tidal deposition in the NCFP may be tied to other factors such as timing or frequency of dredging the bay or bay transport mechanics.

Dirt Roads

Dirt roads can be a significant source of sediment in a watershed; however, they do not appear to be a significant source in upper Bowman Canyon. Unimproved ranch roads in the upper Bowman Canyon watershed typically do not have inboard ditches and do not show significant surface road erosion or gullies associated with the roads. The few spots of erosion occurring on ranch roads were inventoried as part of the erosion survey. Pacific Watershed Associates (PWA) have calculated an average figure of 0.1 feet of road surface loss per decade on typical dirt forest roads in northern California (Weaver and Hagans 1999). Dirt roads can tend be a problem, especially when a delivery mechanism such as an inboard ditch exists. Also, Collins (1998) does not mention the presence of dirt roads in other subwatersheds of lower Novato Creek. Dirt roads above Novato Creek Dam may contribute sediment if constructed with inboard ditches. Although Stafford Lake captures all bedload (sand and gravel) upstream from the lake and a significant portion of the suspended load, a portion of the suspended load (i.e., silts and clays) is transported downstream of Stafford Lake when the dam overflows.

TECHNICAL ATTACHMENT 2
GULLY FORMATION

Due to the fundamentally different sediment transport processes that occur on hill slopes and channel networks, the field of geomorphology is subdivided into two disciplines: hill slope and fluvial geomorphology. The head of a channel is the most upslope location of the channel network, a transition between channel forming sediment transport processes to hill slope sediment transport processes. The change of position of the channel head may be the primary landscape response to significant changes in land use, such as changes to the vegetation coverage or hydrology due to grazing. In Novato Creek, many of the side channel heads (branched from incised channels) are associated with gully heads. Channel heads and gully heads differ only in that gully heads occur in incised, existing channels. Creation of gully heads and their headward migration appears to be dependent on both a convergence of subsurface flow and sufficient overland flow to transport accumulated debris (Montgomery 1991). Creation of gullies and headward migration of gully or channel heads are caused by overall channel entrenchment, probably created by grazing, and changes in hydrologic processes and vegetative cover, also caused by grazing. Montgomery suggests that grazing, channel entrenchment, and abrupt channel or gully head development are linked. The following alteration of the watershed vegetation and hydrology by grazing are proposed by Montgomery based on his field observations in Marin County:

1) In ungrazed valleys, a thick mat of grass growing along the valley axes shields the ground surface from erosion of even rapid overland flow. Reduction of the vegetation reduces the resistance to erosion. Overland flow over grazed, disturbed areas may initiate or accelerate incision. This is especially true in nearly saturated valley bottoms.
2) Trampling may reduce infiltration capacity, which would result in overland flow where it did not exist before. Observations described by Montgomery indicate that overland flow only occurs in the valley hollow in undisturbed, ungrazed valleys, but that overland flow is often seen even on hillslopes (on poorly defined trails) in grazed valleys.
3) Initial local incision caused by grazing creates a positive feedback loop.

Additionally:

4) The conversion from deep-rooted perennials grasses to shallow-rooted annual grasses (with roots that decay in the winter) that has accompanied grazing in coastal California is typically presented as a cause for extensive gully erosion.
5) Based on field observations in the upper Bowman Canyon watershed, significant gullies are primarily located on grassy, non-wooded slopes.

An understanding of gully formation and headward migration of gully and channel heads can lead to management recommendations to reduce conditions that result in the formation of new gullies rather than just stabilizing existing gullies.

TECHNICAL ATTACHMENT 3
GENERAL LIFE HISTORY OF SALMONIDS

Salmonids is a collective term used for both salmon and trout. Several of these species (or subspecies), including steelhead, are found in Novato Creek, are at risk of extinction, and have been listed as federally threatened or endangered over at least a portion of their range.

Steelhead spend most of their adult lives in the ocean but lay their eggs (spawn) in freshwater. This type of life cycle is called anadromous. Steelhead spend between 2-5 years in the ocean before entering freshwater to spawn. Adults dig nests in the streambed gravel (know as redds), lay their eggs in the gravel, and cover the nest with gravel for protection. The adults select locations where the velocity in the streambed is adequate enough to provide ample dissolved oxygen to the developing eggs yet deep enough in the streambed to protect the eggs from high flow scour. After spawning, adult steelhead may return to the ocean and spawn again in future years.

The eggs take approximately 100 days to incubate. When the salmonids emerge from the gravel bed, they are called fry. Steelhead fry live and feed in freshwater (known as rearing) for up to three years before migrating to the ocean. Other species of salmonids may head straight for the ocean immediately after emerging from the gravel, or they may stay in freshwater their entire life cycle. When finally heading downstream for the ocean, the fry undergo a physical change to prepare them for ocean conditions and become known as smolts. Most fry and smolts migrate during the night for protection from predators.

Steelhead juveniles (this term includes all phases of the young salmonid) require specific habitat to survive. The small fry may utilize whatever cover they can find, including gravel interstices, aquatic vegetation, algae mats, organic debris, or woody debris. Larger juveniles, such as several year old juvenile steelhead, may require larger hiding places such as those created by large woody debris, boulders, and irregularly edged habitat. “Good” rearing habitat for any juvenile salmonids, including steelhead, includes locations with adequate clean, cool water, food, and cover from predators. Such habitat usually includes the following features:

- A continuous riparian forest with a closed canopy over the stream. This provides the shade needed to keep the waters cool. The target water temperature for salmonids is 50 ^{o} to 55^{o} F. Lethal temperature is around 75^{o} F.
- Non-polluted, clear water. Salmonids are visual predators; turbid waters minimize their ability to feed.

- Adequate summer-time low flows to maintain water quality.
- Frequent deep pools with cover from predators. The depth and cover allow young juveniles to escape predators. Excessive fine sediment can fill up these pools and degrade rearing habitat.
- Intact, stable gravel riffles with gravels between 0.5 and 5 inches. The gravel riffles provide habitat for aquatic insects that the young steelhead feed on. An ideal habitat situation might include a pool with adequate depth and cover downstream of a stable gravel riffle.
- Riffles that have less than 20% fine sediment (by volume). Excessive fine sediments eliminate the spaces for aquatic insects that salmonids feed upon, reduce dissolved oxygen needed for developing salmonid embryos, and trap emerging fry in the gravel (Chapman 1988).

Juvenile salmonids, both fry and smolts, are opportunistic feeders and may feed on zooplankton, benthic macroinvertebrates (bottom dwelling bugs), and small fish.

MAPS AND FIGURES

APPENDIX 1
PHOTOGRAPHS

APPENDIX 2
COPIES OF FIELD DATA FORMS

APPENDIX 3
GENERAL DETAILS
(NOT INTENDED FOR CONSTRUCTION)