Proposed
Bank Stabilization Guidelines
for
Novato Creek

Prepared for:

Marin County
Department of Public Works
P.O. Box 4186
San Rafael, CA 94913-4186

Submitted by:

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July 2007

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EXECUTIVE SUMMARY

To address bank erosion on Novato Creek, Questa Engineering Corporation was retained by the Marin County Flood Control and Water Conservation District to develop a suite of bank stabilization designs that consider bank stabilization, flooding, and sensitive fisheries resources. This report focused on two specific reaches of Novato Creek:

- Reach 1 - Grant Avenue to Simmons; and,
- Reach 2 - Miwok Park from Las Tardes to Novato Boulevard

A survey was performed to determine existing erosion conditions in the study reaches. This was accomplished through multiple site visits as well as research of past data sets. These are presented on the accompanying large size sheets and in tabular format.

Analysis of the stream system included historic longitudinal stream profile analysis, hydraulic analysis, determination of present geomorphic channel geometry, and sediment transport analysis. It was determined that the channel has evolved and will continue to evolve in response to factors such as dam construction, urbanization of its watershed, and human management activities such vegetation/woody debris removal and bank stabilization. It is believed that the channel is close to reaching a quasi-equilibrium to altered watershed conditions and the rating of erosion and response to these factors may be slowing as it reaches this state. It is believed that the primary response mechanism will be lateral movement of the channel alignment and the development of stable geomorphic geometry within the greater incised channel. Vertical bed movement has generally slowed or stabilized throughout much of the study reach.

The latter part of this report addresses the analysis and design of individual bank stabilization projects within the study reach. A methodology was developed that uses four primary factors, 1) building locations, 2) size and position of mature riparian trees, 3) channel top width, and 4) channel mid-bank width, to guide property owners to appropriate bank stabilization approaches. Three main approaches are presented: channel in-fill, channel bank cut, and vertical or semi-vertical stabilization. Numerous applicable bank stabilization treatments and alternative options are discussed and presented. Finally, **Appendix A** provides a step-by-step procedural guideline for individual landowners who want to address erosion problems on their property. A guide to permitting and submittal requirements for appropriate federal and state permits to implement stabilization plans is also included.

INTRODUCTION

Urban streams and watercourses require comprehensive management strategies to meet the needs of multiple goals, including but not limited to flood control, riparian and aquatic habitat, and public and private property rights. Balancing these goals is a difficult task that requires balancing the needs of people and the need to have a natural, healthy, and self-sustaining creek system. As urbanization and industrialization of many areas press people closer to watercourses, conflicts arise between natural erosion cycles and residential structures and infrastructure. Stream bank erosion is a natural phenomenon associated with low-gradient (i.e., slopes less than 2%) alluvial creeks by which material is transported from high-energy areas to low-energy areas. Often this natural cycle is exacerbated in the urban context, as sediment and hydrologic supply regimes are altered such that the sediment input is reduced and the hydrologic response (i.e., runoff) is increased. To mitigate such effects on valuable property, banks are often protected using a plethora of techniques ranging from riprap to steel walls. Bank protection in urban settings can have the unwanted effects of increasing base flood elevations, deferring the erosion downstream, and degrading and/or destroying valuable aquatic habitat. In an effort to maintain the stream banks of Novato Creek, with the goal of minimizing and/or completely reducing negative environmental effects associated with potential bank repairs, this document has been prepared to develop bank repair approaches that are tailored to the complex issues facing the creek-side property owners.

The Novato Creek basin is one of the largest drainage basins in Marin County, encompassing roughly 44 square miles of terrain that range from upland and foothill erosional provinces, floodplain and alluvial valleys, and coastal provinces. The creek extends 17 miles from its headwaters above Stafford Lake down to the San Pablo Bay changing form from rills and gullies in the upland areas to meandering riffle and pools in the floodplain and alluvial valleys. In its natural state, rainfall would cause upland and foothill areas to erode and deposit sediments in the alluvial valley, where fluvial processes would maintain a quasi-equilibrium between the amount of water and sediment supplied.

The creation of Stafford Lake Dam in 1951 and the ensuing urbanization and development throughout the alluvial valley have lead to several distinct anthropogenic impacts that lead to creek instability, including the following:

1. The Stafford Lake Dam traps coarse sediment derived from the hillslopes and upland areas, a major source of sediment to the system. The lack of sediment delivered downstream has resulted in accelerated bank erosion and vertical incision.

2. Urbanization has increased the timing and magnitude of peak runoff events such that more water flows to the creek at a quicker rate than in pre-development conditions; this is best illustrated by the number of storm outfalls that now line the creek banks.

The combination of decreased sediment and increased runoff has lead to unstable creek conditions that jeopardize adjacent structures and imperil the quality of the aquatic resources of Novato Creek. The increase in fine sediment loadings to depositional areas within the bayplain provinces can increase turbidity and decrease dissolved oxygen, affecting water quality and aquatic resources. Typically, bank protection methods under these conditions can ensure the safety of streamside structures and reduce fine sediment loadings to the watercourse. However, along with bank stability and water quality, flooding issues and physical habitat for threatened and endangered migrating salmonids are important management considerations for the creek. Previous reports have documented the geomorphic history of the drainage basin and creek in order to focus on sediment sources and sinks within the basin. These issues have been considered and incorporated into this report where needed, but have not been explicitly explored. The goal of this document is to provide working solutions for residential streamside stewards to protect their banks in a manner consistent with the multi-use objectives of the creek. Along with logistical techniques for selecting and designing a bank protection solution, guidance is given towards preparing appropriate documentation for obtaining permits in a timely and cost-effective manner.

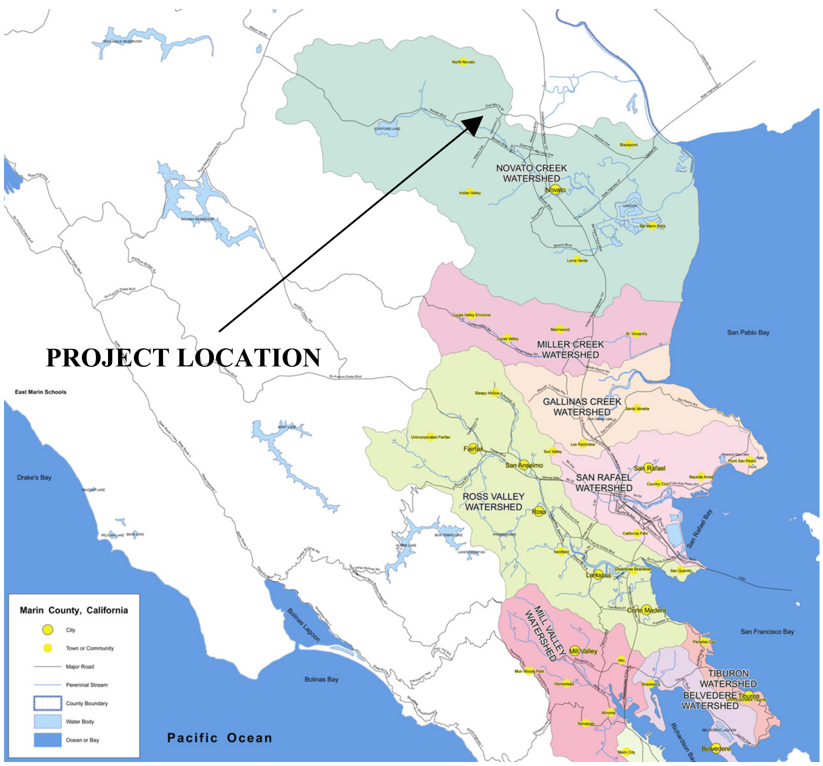
REGIONAL SETTING

The regional setting of Novato Creek dictates to a large degree existing creek morphology and streamflow, as well as future projections on how these features evolve. The existing geologic and climatic constraints of a drainage basin interact to form soils and drainage features that dictate runoff and streamflow responses. A brief description of the regional setting of Novato Creek (i.e. climate, geology, soils, and geomorphic provinces) is warranted, as it can provide useful information on past and future trends that are dictated by the landscape.

Novato Creek is located in the City of Novato in Marin County, California (**Figure 1**).

Figure 1. Regional Location Map for Novato Creek

(Not to scale)



Climate

The City of Novato is located in northeast Marin County, within the greater San Francisco Bay Area of Northern California. The climate of northeast Marin County is strongly influenced by the Pacific Ocean and is typical of the climate throughout the San Francisco Bay Area; winters are mild and summers are moderately warm. Minimum and maximum daily temperatures vary by approximately 30 degrees in the warm summer months, and by about 15 to 20 degrees in the cooler months. Average summer temperatures range from 52º F to 78º F, and average winter temperatures range from 41º F to 55º F (National Oceanic and Atmospheric Administration (NOAA), 1997).

Rainfall in the San Francisco Bay region is greatly influenced by geographic features and varies significantly by elevation and by location within the region. The average annual precipitation in the Novato Creek Basin varies from a maximum of over 30 inches in the western and southern portions of the basin to a minimum of about 22 inches in the northern and eastern portions of the basin, with a basin-wide mean of 28 inches (City of Novato Flood Insurance Study, FEMA, 1989). Over 90 percent of the annual precipitation occurs in the six-month period from November through April. The prevailing winds are usually from the west and southwest.

Geology and Soils

Regionally, the project site is located within California's geologically and seismically active Coast Ranges Geomorphic Province. The province is characterized by a series of northwest-trending faults, mountain ranges, and valleys. The Novato Creek watershed is formed mostly of steep hillsides underlain by sandstone and shale of the Franciscan Formation, and a broad flat valley composed of Quaternary-aged alluvium. The soils along Novato Creek consist of Tocaloma-McMullin, Urban land-Ballard, and Xerorthents-Urban land.

The Tocaloma-McMullin soil is 40 percent Tocaloma loam and 35 percent McMullin gravelly loam. Runoff is very rapid and the hazard of water erosion is very high. It is found on hills with slopes of 50 to 75 percent. The Tocaloma soil is moderately deep and well drained. Permeability is moderately rapid. The permeability of the McMullin soil is moderate.

Xerorthents-Urban land soil is on valley floors, toe slopes, and tidelands with slopes of 0 to 9 percent. Forty-five (45) percent is Xerorthents and 40 percent is Urban land. Xerorthents is made up of cut and/or fill areas. The properties are highly variable.

Urban land-Ballard complex is on alluvial fans and bench terraces and has 0 to 9 percent slopes. This soil is 55 percent urban land and 25 percent Ballard gravelly loam. The Ballard soil is deep and drains well. Permeability is moderate, runoff is medium, and the hazard of water erosion is minimal. This soil has the potential for shrinking and swelling. The Urban land, however, has rapid runoff and minimal water erosion hazards. Urban land makes up a majority of the land surrounding the project sites, and due to its rapid runoff, contributes to flooding potential during high intensity storms.

EXISTING CONDITIONS ANALYSIS

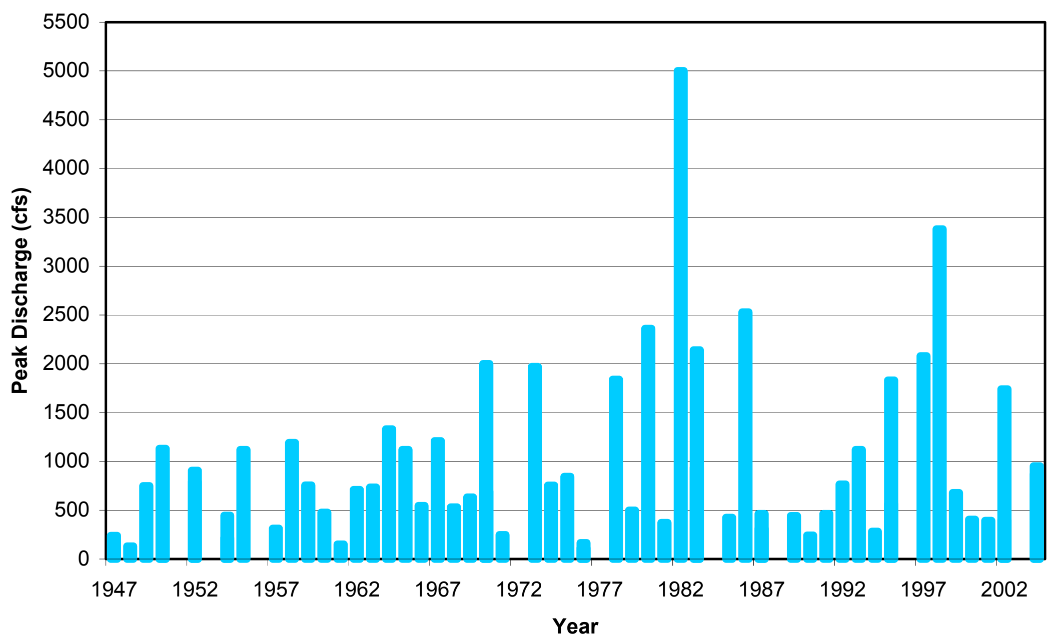
A thorough analysis of existing conditions within the study reaches was performed to develop existing and projected conditions that may affect the feasibility of various bank stabilization alternatives. Specifically, the following was performed:

1. Hydrologic analysis
2. Geomorphic analysis
3. Stream bank inventory
4. Existing erosion inventory
5. Existing riparian and aquatic resources
6. Hydraulic analysis

Hydrologic Analysis

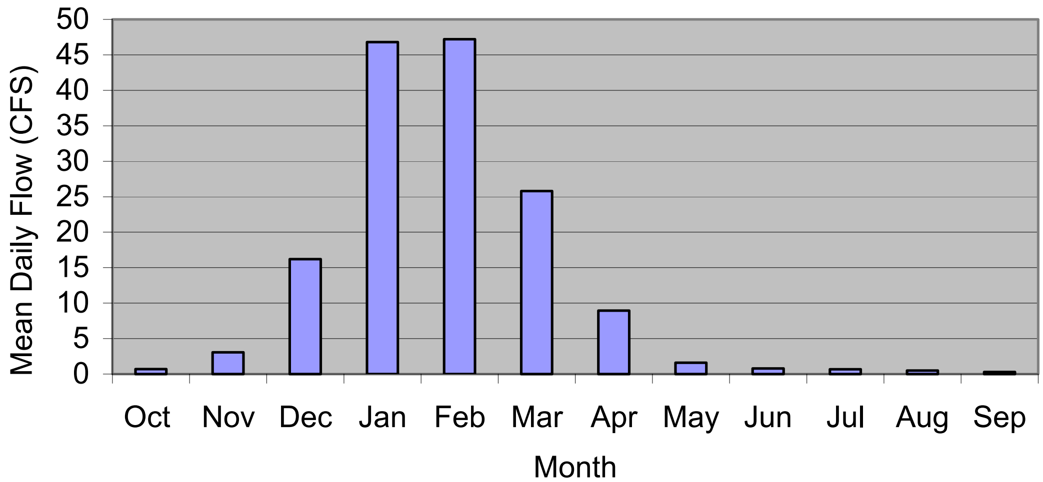
The Novato Creek basin drains a watershed of 28,160 acres (44 sq. miles). Elevations range from less than 0 feet. (much of the city of Novato is at or below sea level) to approximately 1,900 feet National Geodetic Vertical Datum (NGVD). Stafford Dam, the only flow diversion structure on the creek, was completed in 1951 and is operated by the North Marin County Water District. The main stem of Novato Creek has year-round flows. The largest flow on record is 5,000 cubic feet per second (cfs), which occurred in the early 1980s. There has been a relatively consistent increase in recorded peak discharges, despite Stafford Dam, and largely associated with urbanization in the lower portions of the basin (**Figure 2**). In the two study reaches, there are 20 outfalls, which increase the time to peak and peak discharges.

Figure 2. Annual Peak Discharges in Novato Creek at USGS Gage



Utilizing the gage data, the 50 percent exceedance for the flow record is 733 cfs. This is typically referred to as the 2-year peak flow discharge. When 2-, 10-, 50-, and 100-year peak discharges were plotted on a probability graph, the 1.5-year recurrent discharge was determined to be approximately 510 cfs. The flows between 500 and 730 cfs are frequent enough to be considered the dominant range of channel-forming flows. The mean monthly average flows in the creek are greatest in the winters when rainfall is high (**Figure 3**). When winter rains begin in late October/early November, flows are on average less than 5 cfs, and in especially wet years can exceed 17 cfs. Mean December flows are usually less than 20 cfs. Mean January and February discharges are on average 47 cfs. January and February usually experience the largest flows, with mean flows typically greater than 40 cfs and the highest peaks occurring in February. From May through November, flows are typically less than 5 cfs.

Figure 3. Mean Daily Flows by Month for Water Years 1947-2005



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The Federal Emergency Management Agency (FEMA) discharges for Novato Creek were obtained and used to develop design flood discharges at the Grant Street Bridge by drainage basin scaling (**Table 1**).

Table 1. FEMA Peak Flows
(at Grant St. Bridge)

Recurrence Interval	*Discharge (cfs)*
10-year	2,070
50-year	3,225
100-year	3,950
500-year	5,200

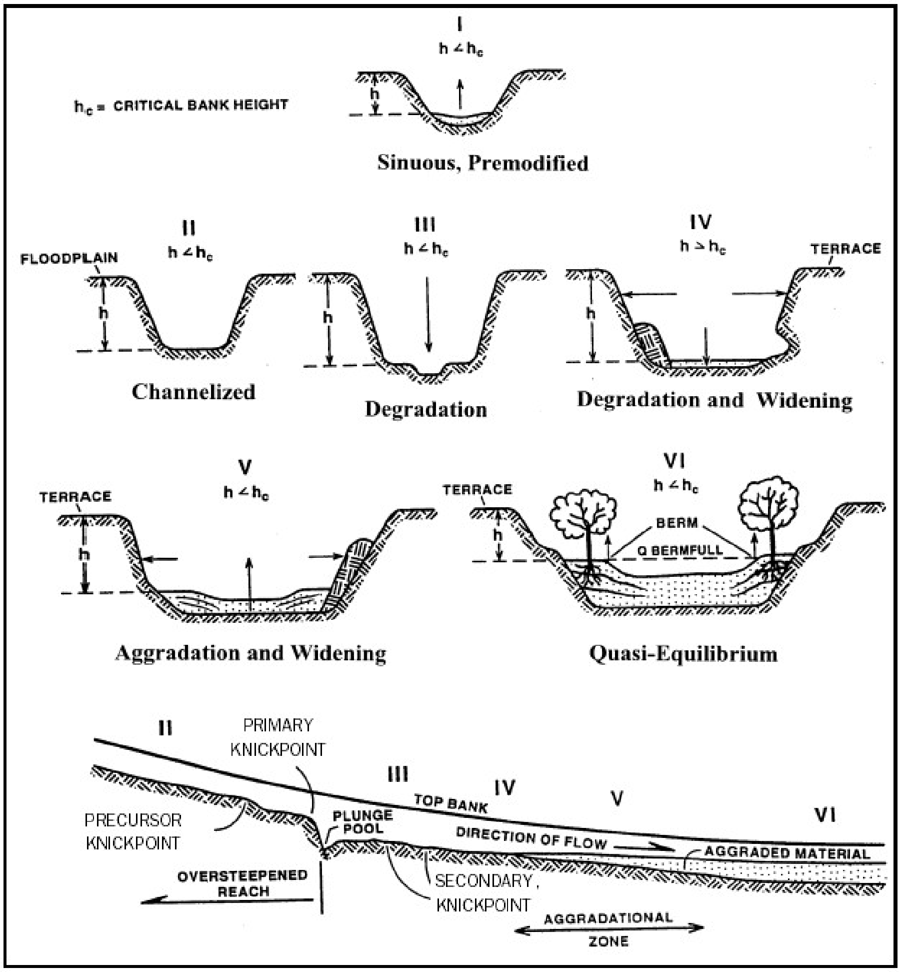
Geomorphic analysis

Historical changes in the Novato Creek watershed, including the clearing of woodlands, urban development, and construction of the Stafford Lake Dam, have caused changes in the peak discharge of floodwater and the volume of sediment delivered to the channel. These, in turn, have impacted channel morphology. Local changes in the stream course, such as meander realignment, channel armoring, and construction of bridges and other hydraulic structures, have also created both short-term, localized effects and long-term, far-reaching effects.

Natural streams typically have an ever-changing equilibrium in which the components of the fluvial system (runoff, sediment yield, and channel morphology) are constantly evolving in relationship to one another. This dynamic equilibrium determines the degree and extent of channel bed and stream bank erosion, sediment transport, and depositional processes of streams. Changes in flow regimes and sediment yield occur naturally in a watershed, but often at much slower rates than from anthropogenic disturbances. The equilibrium can be upset by land-use changes in the watershed, channel straightening and enlargement, or other modifications such as bank armoring. Urbanization often causes a typical response of incision and widening. As more development occurs in a watershed, the increased impervious surface area results in an increase in storm water runoff, increasing both the total runoff volume and peak of stream flows. Streams typically respond to increased total flow volumes and peak flows following urbanization by channel widening through bank erosion and channel deepening, or stream incision. It appears that channel incision is the primary process occurring within Novato Creek. "Urban equilibrium" is the term used to describe a channel that has changed from its natural or original shape, but has finished adjusting to the urban influences affecting it so that it is relatively stable in its planform and meander, and has achieved a new balance in its bankfull width and depth. A channel in urban equilibrium is neither excessively eroding nor depositing sediment and has a healthy riparian growth. This analysis is geared toward determining existing channel dynamics, active ordinary high water (OHW), and other geometric parameters to be used in guiding bank stabilization efforts.

Channel evolution models can often be used to put urban creek adjustments in relative context (**Figure 4**). In general, the lower Novato Creek appears to be between stages IV and V in the context of urban channel evolution. Degradation has occurred and the "daylighting" of bedrock features leads to the hypothesis that the creek may soon be reaching the end of this degradation phase. The majority of the adjustments in Novato Creek are from lateral erosion and widening. Sediment from eroding banks is being temporarily stored in point bars that increase lateral erosion from bar growth into the channel.

Figure 4. Conceptual Channel Evolution Model



Longitudinal Profile

Slope is one of the fundamental variables that controls geomorphic processes and will be considered here by analyzing the longitudinal profile of the channel bed through the study reaches. A longitudinal profile of a creek shows the channel bed elevations plotted against distance from the creek mouth. The longitudinal profile can provide information about sediment aggradation and degradation, delineate reaches of channel incision, and show anomalies, such as knick points (i.e. high slope areas that migrate upstream until an equilibrium slope or local control is reached), or points along the profile where a significant change in grade exists that may be more unstable than the rest of the reach. The long profile analysis was used to determine the presence of local controls on slope and to determine reach-averaged trends. A survey was performed for both reaches in December of 2006 and compared with a FEMA profile from 1989 to look for evidence of aggradation or degradation for both reaches (**Figures 5** and **6**). Natural and anthropogenic grade controls were also mapped to identify local slope controls. The FEMA stationing was adopted so that the data from this study could easily be compared with any future profile surveys.

Figure 5. Reach 1 Longitudinal Profile

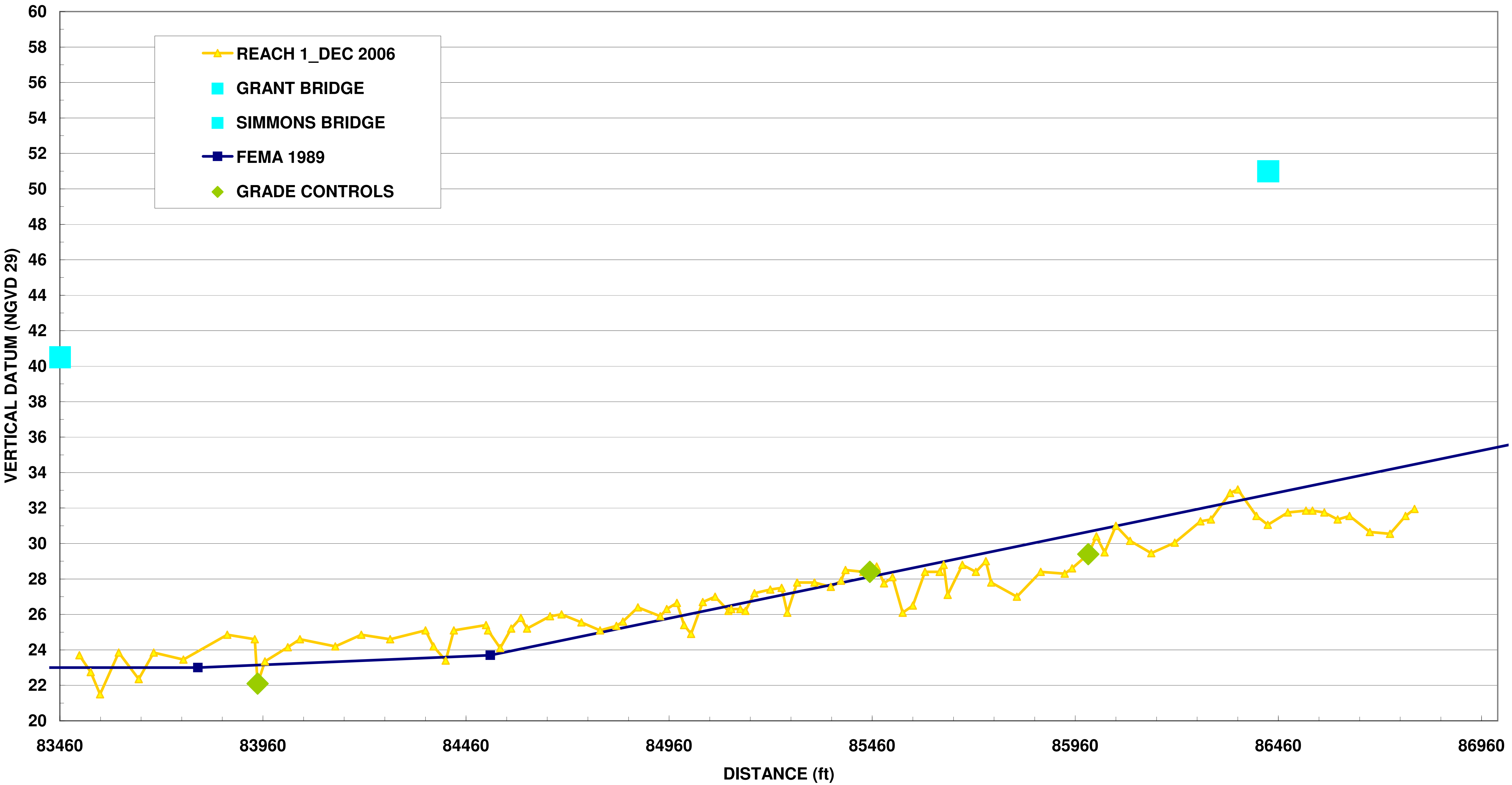
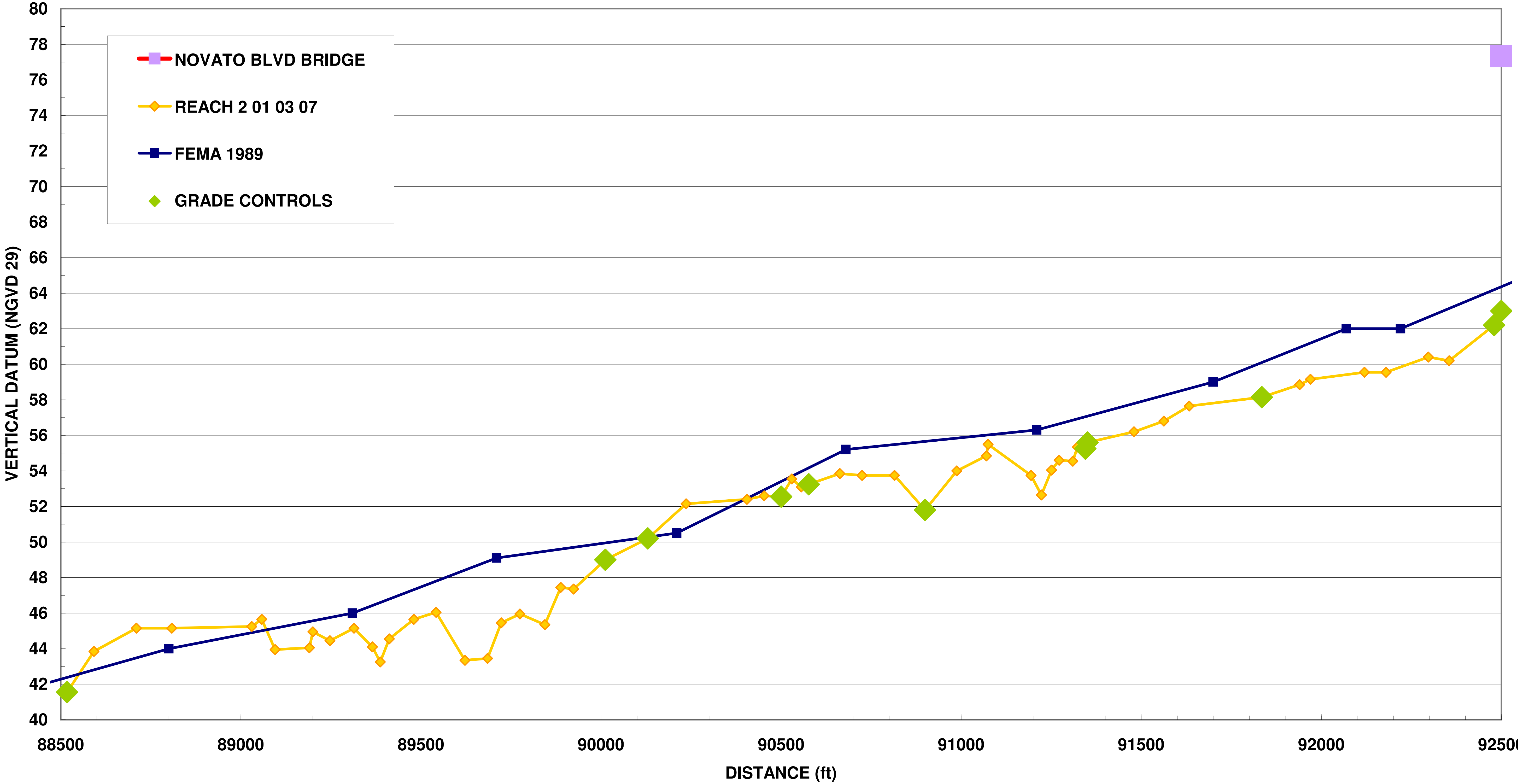


Figure 6. Reach 2 Longitudinal Profile



Reach 1
Reach 1 (**Figure 5**) has an average slope of 0.25%, with two distinct sections with slopes of 0.1% and 0.3%. Most of the reach has a slope of 0.3% and at approximately station 84700, the slope flattens to about 0.1%. We identified three bedrock grade controls in Reach 1 at stations 83947, 85454, and 85992 (**Figure 5**; **Table 2**). These will serve as slope controls over any fluvial degradation that may occur. In comparison to the FEMA profile it appears that sediment degradation has occurred above station 85454 (a bedrock-controlled area) and is being temporarily stored in bar-pool morphology in the flatter downstream areas. This is consistent with the conceptual profile in **Figure 4**, which shows stages IV to V as a transition between upstream bed degradation and downstream aggradation.

Table 2. Reach 1 Grade Controls

Elevation	*Station*	*Material*
22.1	83947	Bedrock
28.4	85454	Bedrock
29.4	85992	Bedrock

Reach 2
The average slope of Reach 2 (**Figure 6**) is 0.5%, roughly twice as great as the downstream study reaches. We identified several natural and anthropogenic grade controls throughout the project reach (**Table 3**). In comparison to the FEMA profile it appears that there has been roughly 1.5-2 feet of degradation since 1989.

Table 3. Reach 2 Grade Controls

Elevation	*Station*	*Material*
63	92500	Concrete under Novato Blvd.
62.2	92480	Concrete Pipe Casing/ Bedrock
58.15	91835	Bedrock
55.6	91351	Old Dam Footing
55.25	91345	Bedrock
51.8	90900	Bedrock
53.25	90577	Bedrock
52.55	90500	Bedrock
50.2	90130	Bedrock
49	90012	Bedrock
41.55	88517	Bedrock/ Old Dam Footing

The profile comparison and number of surveyed grade controls reveals important information about this reach. There are a high number of grade controls within Reach 2, suggesting that the creek is at the end of a degradation cycle. However, it is likely that future channel adjustments will be made laterally, increasing the risk of bank erosion.

Bed Material

Bed material sizes are important because they can be used along with the hydraulics of the channel to determine the flow ranges that bedload sediment is likely to mobilize, and can be used in models that predict relative change. This can be useful in evaluating bank stabilization options that change the channel geometry. The relative change in transport capacity can be calculated to give an indication of whether a proposed project will cause potential aggradation or degradation. A sieve analysis was performed at four locations within the project reaches for both the surface (armor) and subsurface layers to characterize the particle sizes in the creek for both reaches (**Table 5**). There is a weak armor layer that forms when flows recede and finer material in winnowed away by selective sorting. The armor layer ratio (i.e. ratio between surface and subsurface median particle sizes) is approximately three. The closer the armor ratio is to one, the greater the sediment supply. The armor ratio reveals a sediment deficit in the reach manifested in the grain size distribution of gravel bars. An armor ratio greater than one also means that more forces are needed to mobilize the gravel bars than the alluvial channel banks, increasing the probability of lateral erosion of finer bank materials. Particle mobility can be assessed using critical velocities and shear stresses. For the grain sizes found in the creek, we computed shear stresses for lower Novato Creek (**Table 4**).

Table 4. Grain Sizes and Critical Stresses

Particle Size Finer Than	*Subsurface (mm)*	*Surface (mm)*	*Surface Critical Shear Stress (lbs/ft^2)*	*Subsurface Critical Shear Stress (lbs/ft^2)*
D_{15}	0.25	11	0.16	0.00
D_{50}	4.8	17	0.24	0.07
D_{85}	11.5	23	0.32	0.16

In the following section, we examine the hydraulics of the channel and we can then determine which flows cause bed motion in the creek.

Bedforms

The bedforms in the project reaches vary from bar-pool to riffle and run with a few bedrock-controlled sections. Bar-pool topography is associated with high sediment supply and low slope conditions in which the delivered bed sediments become self-sorted into meandering riffles and pools (**Figure 7**). Flow through these areas curves from one side of the channel to the other, creating deep, slow pools with fine sediment and fast bar areas with coarser sediments. Runs are straight creek sections that have a higher relative D_{50} particle size and uniform depths and velocities. Pools within the study areas were correlated with woody debris, bedrock constrictions, and meander bends. Pools are extremely valuable habitat for all lifestages of salmonids. Maintaining and protecting pool habitat is critical to management of this natural resource.

Figure 7. Attributes of Bar-Pool Morphology
(Modified From Trush et. al. 2004)

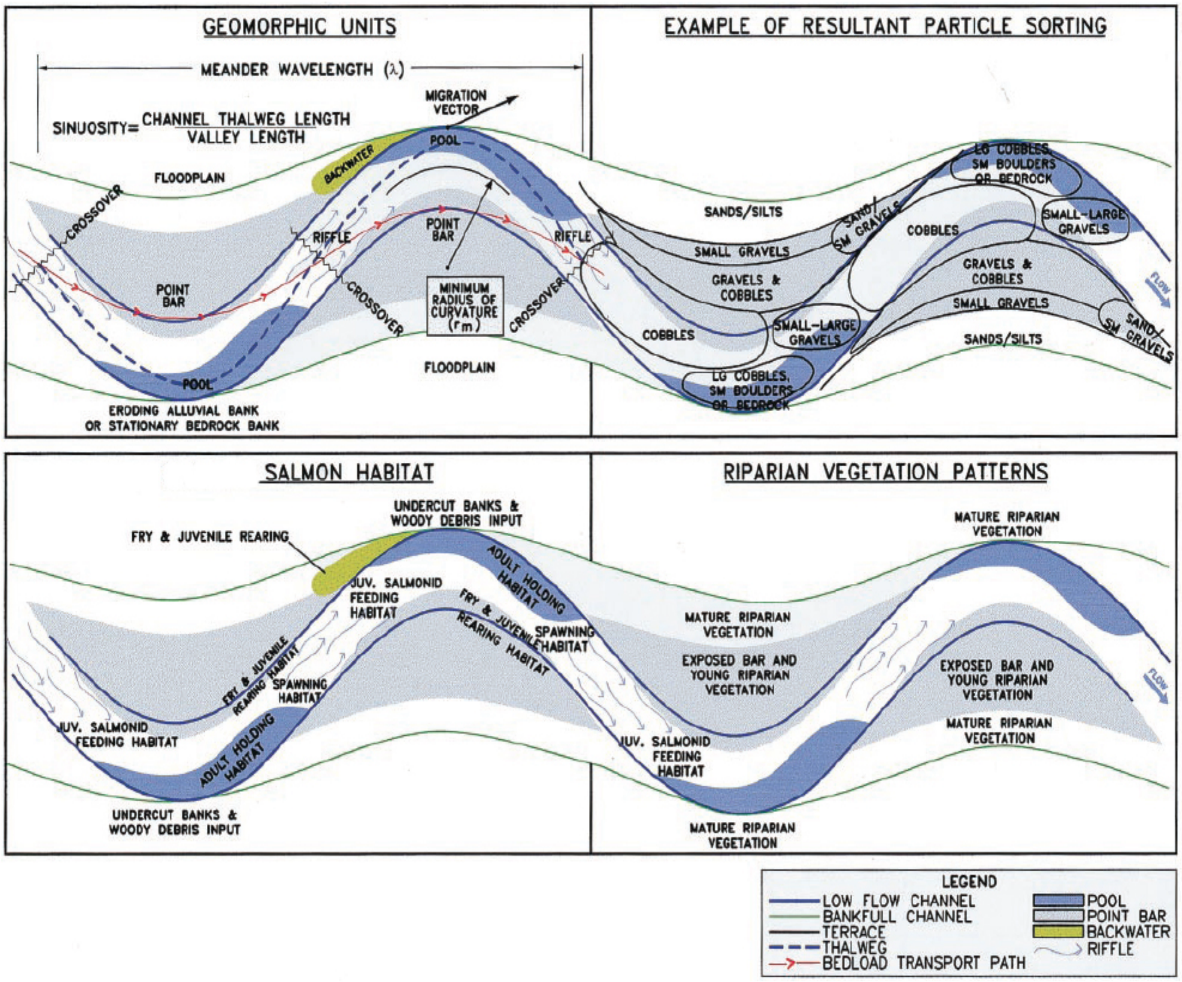


Figure 7. Is useful to illustrate how multiple components of a stream (i.e., grain size, flow fields, fish use, and vegetation) interact within a typical morphology seen in lower Novato creek. This could potentially be used to conceptually evaluate methods of bank protection with regards to the physical and biological dynamics within the creek.

Large woody debris is an important component to streams because it can help form pools, trap sediment, and contribute to overall biological productivity. Large woody debris is defined at stumps and or logs having a diameter greater than 6 inches and a length greater than 10 feet (Fishnet4C, 2004). Large woody debris was likely a historical component to the lower reaches of Novato Creek, as the upper watershed was forested and is geomorphically unstable. However, prior studies (Collins, 1997) reveal a lack of large woody debris in the study reaches.

Bankfull Analysis

Bankfull is the term used to describe "channel-forming" or "most-probable" discharge. It is considered to be the discharge that forms the creeks active channel. Bankfull can be determined a number of ways. In hydrology, it is usually determined by a frequency analysis whereby it is associated with a 50% probability, corresponding to the 1.5- to 2-year discharge. This has previously been identified as between 500 and 730 cfs. The incised nature of Novato Creek study reaches makes it difficult to determine bankfull from field geometric indicators. However, utilizing Dunn and Leopold's regional curves for bankfull dimensions in the Bay Area, the bankfull channel is expected to have the following parameters:

- Cross-sectional area = 150 square feet
- Width = 45 feet
- Depth = 3.3 feet

Utilizing our reach hydraulic models (described in the following sections) with 500 to 750 cfs, Novato Creek Reaches 1 and 2 have the following average geometric properties:

- Cross-sectional area:
  Reach 1 = 144 to 187 square feet
  Reach 2 = 132 to 173 square feet

- Width:
  Reach 1 = 40 to 43 feet
  Reach 2 = 44 to 47 feet

- Depth:
  Reach 1 = 6 to 7 feet
  Reach 2 = 4 to 5 feet

Novato Creek appears to conform fairly well to regional geometric trends predicted by Dunn and Leopold.

Another useful channel geometry and flow indicator is ordinary high water (OHW). OHW is used by regulatory agencies to determine jurisdiction. It can also be used by designers to configure the active channel of the creek. Several field indicators of the active channel or OHW were measured and averaged. The depth from the invert of the channel to where perennial vegetation is established was used as a vegetative guide to predicting OHW depths. This depth is defined as the line of scour within the channel or height at which little no vegetation is growing. Depths corresponding to scour and debris lines were also used. The bar-terrace height was also used where appropriate and verifiable. The stage rating curve average refers to the inflection point along a rating curve (a plot of flow depth versus flow) where increases in discharge yield relatively small changes in depth. Usually, this is where flows leave the channel and begin to spread out rather than increase depths. The average of all of these methods suggests a maximum active flow depth of roughly 3 feet. Using the hydraulic HEC-RAS model described in the following hydraulic analysis section, active average flows in Reach 1 are approximately

150 cfs and in Reach 2 are approximately 250 cfs. One reason that active channel flow estimations are significantly lower than predicted 2-year recurrence interval flows is the fact that Stafford lake upstream of the site may have significant muting impacts on the lower recurrent flows in the watershed, by reducing the magnitude and duration of the high flows and releasing lower flows over longer periods of time. This would tend to lower the active scour line in the channel.

Based on active flow depths, field surveys, and hydraulic modeling, we determined ranges of active flow channel dimensions for channel geometries found in Novato Creek. Although active flow depths were averaged, we portioned bankfull geometric characteristics by reach. In fluvial geomorphology there are no "absolute" values due to the dynamic nature of hydrologic and hydraulic processes, and the constantly changing driving forces of climate and rainfall. Regardless, **Table 5** provides a baseline geometric description of typical active channel characteristics in both study reaches.

Table 5. Active Channel Estimations for Lower Novato Creek (ft)

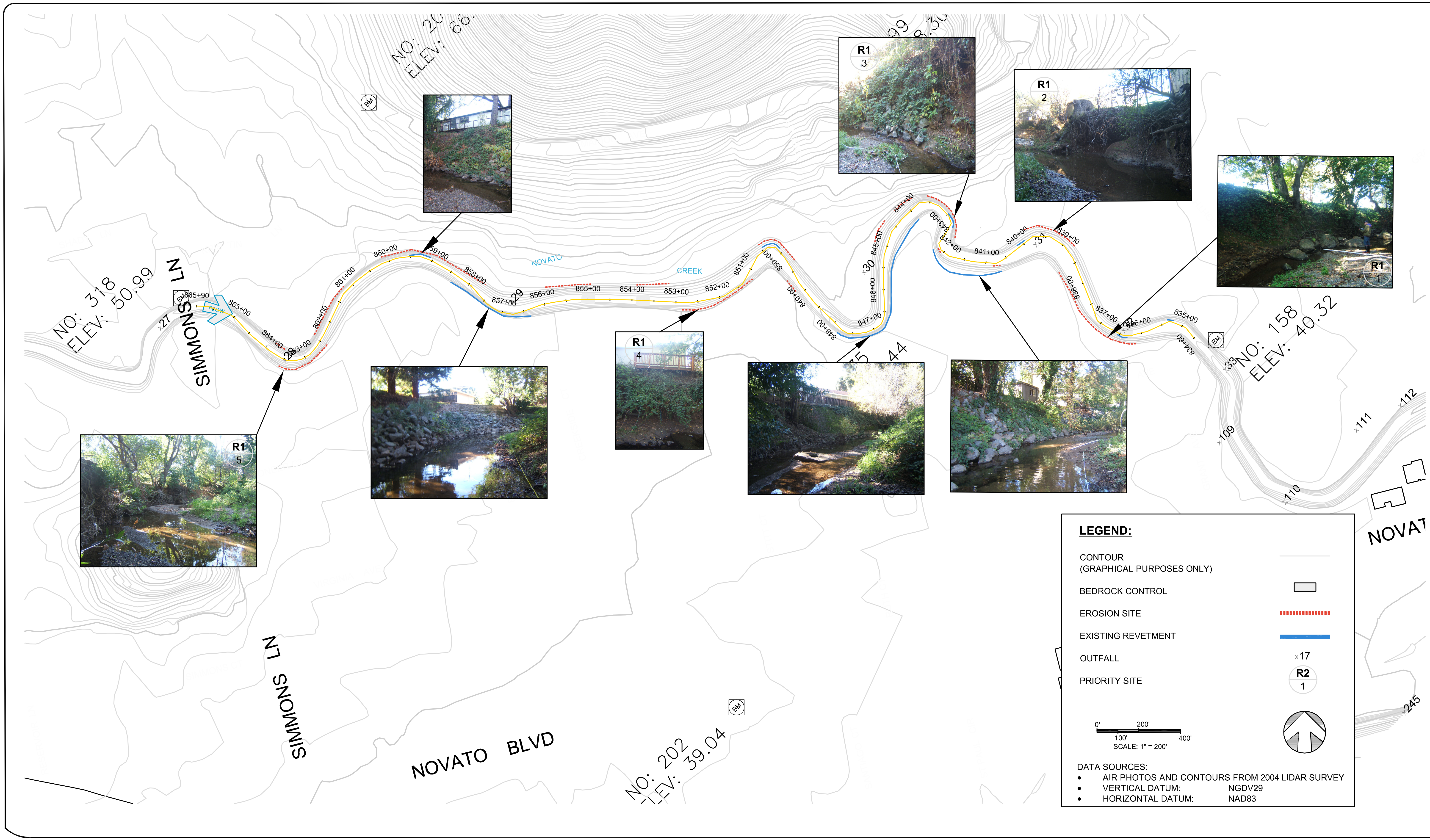
	Reach 1			*Reach 2*		
	Flow Area (sq ft)	*Top Width (ft)*	*Low Flow Width (ft)*	*Flow Area (sq ft)*	*Top Width (ft)*	*Low Flow Width (ft)*
AVERAGE	67	33	11	58	34	10
STANDARD DEVIATION	27	7	3	31	15	2
MAXIMUM	123	46	14	117	68	12
MINIMUM	28	19	8	22	16	7

General Conclusions from Geomorphic Analysis

Novato Creek is experiencing the effects of hydromodification and sediment starvation from land use changes and the upstream dam. It appears that the creek is at the end of a degradation cycle, due to the recurring "daylighting" of bedrock within the study reaches. The dominant morphology found in the creek is confined, alternating bar-pool topography. The bars exhibit armoring in which the critical stress required for mobilization is greater than the underlying sediment and the channel banks. Thus, fluvial adjustments are occurring laterally via bank erosion as bank sediments are finer than the armor layer found in the gravel bars. This results in a cyclical process of terrace and bar growth that forces the channel to grow laterally, leading to bank erosion that may threaten adjacent properties that line the majority of the channel banks.

Existing Bank Inventory

A survey of the existing bank conditions was performed and mapped to provide a baseline for characterizing the types and amounts of bank erosion in the project reaches. We summarized this information on the accompanying **Sheets 1** and **2** and in **Table 6**. A considerable fraction of the banks are undergoing toe erosion, causing vertical and even overhanging creek banks. In many cases the extensive root structures of mature bay and oak trees are stabilizing the banks and slowing erosion. This is most common on the outside of meander bends, where water



NOVATO CREEK BANK STABILIZATION MEASURES

CITY OF NOVATO
NOVATO, CALIFORNIA

QUESTA ENGINEERING CORP. Civil Environmental & Water Resources
P.O. Box 70356 1220 Brickyard Cove Road Point Richmond, CA 94807

Sht:	Rev:	Date:	By:	Description:	App'd:

Design: X.X.
Drawn: Y.Y.
Checked: Z.Z.
Appr'd: S.T.

REACH 1
EXISTING CONDITIONS INVENTORY

GRANT AVE. TO SIMMONS LANE
NOVATO, CALIFORNIA

Size: D | Dwg. No.: 260207 | Rev.:
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Date: 4/4/2007
Sheet: 1 OF 2

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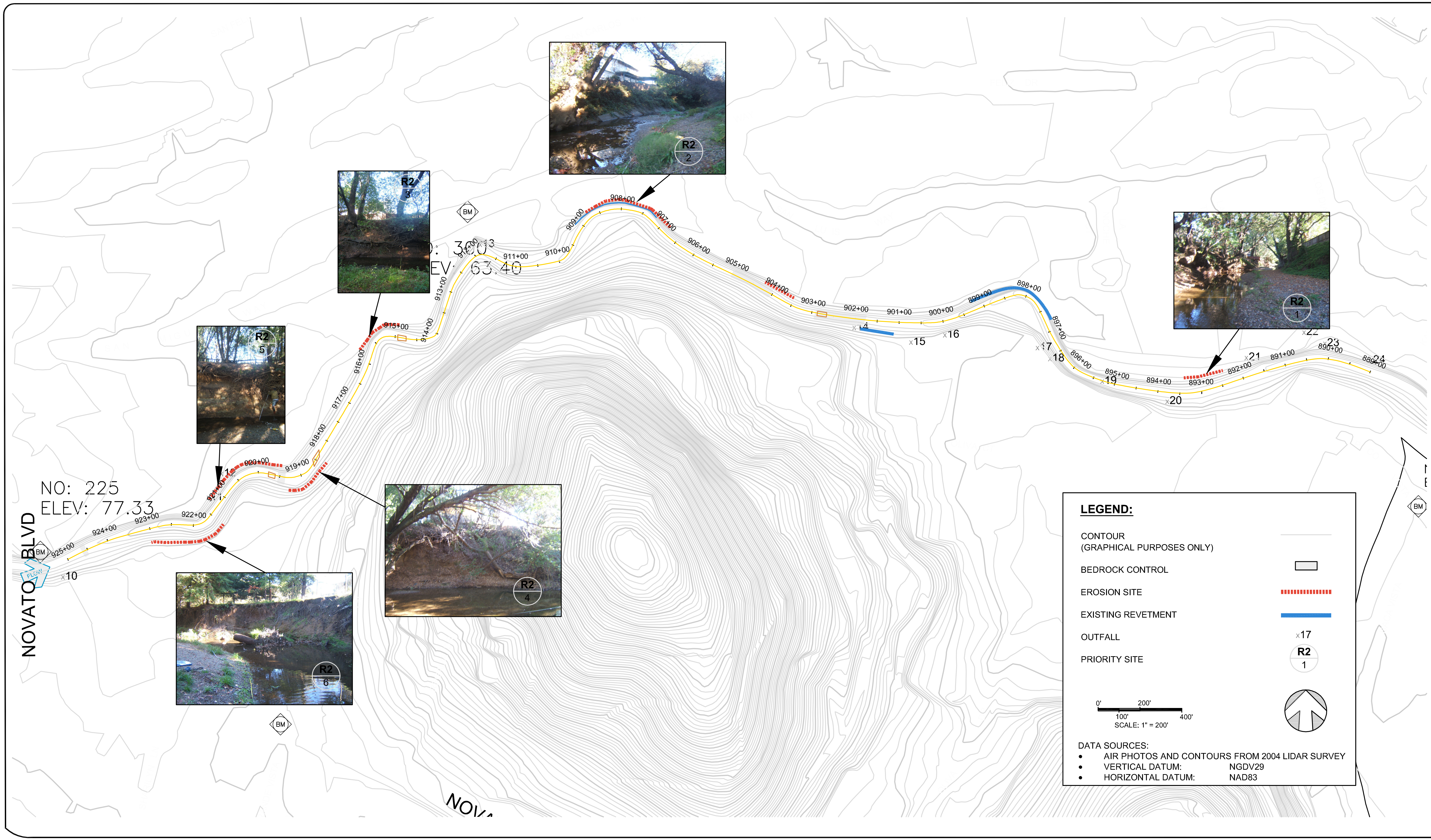

NOVATO CREEK BANK STABILIZATION MEASURES

CITY OF NOVATO
NOVATO, CALIFORNIA

QUESTA ENGINEERING CORP.
Civil
Environmental
& Water Resources
P.O. Box 70356 1220 Brickyard Cove Road Point Richmond, CA 94807

Sht	Rev:	Date:	By:	Description:	App'd:

Design: X.X.
Drawn: Y.Y.
Checked: Z.Z.
Appr'd: S.T.

REACH 2
EXISTING CONDITIONS INVENTORY

NOVATO BLVD. TO LOS TARDES CT.
NOVATO, CALIFORNIA

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Sheet: 2 OF 2

P:\2006\260207\CAD\WORKING\260207_BASEMAP.dwg velocities and trajectories promote the greatest erosion. In the event that these unstable banks adjoin a residential property, some form of revetment has often been constructed, primarily out of riprap or broken concrete.

Erosion Mechanisms in Lower Novato Creek

Erosion is a natural aspect of landform development. Although natural, erosion is often accelerated by anthropogenic disturbances. In general, the majority of the erosion in Lower Novato Creek is associated with meander bends. Meander bends are susceptible to bank erosion due to high velocities from centripetal acceleration around the bend. This phenomenon is often exacerbated by point bar development on the inside of the bend. This occurs when the inside of the bend has lower velocities and depths, causing deposition. As more and more deposition occurs, the point bar grows and pushes the high velocity flow field into the opposite bank.

The incision occurring in the channel is also leading to bank failures in lower Novato Creek. As channel incision progresses, channel bed elevations are lowered and bank heights increase, eventually reaching a situation where the strength of the native soils is no longer sufficient to support the near-vertical banks, and progressive bank collapse can occur. Typically, this sort of geotechnical failure occurs following periods of high flows and prolonged soil saturation. Subsequently, moderate to high velocity flows can undercut the toe support of the over-steepened bank slopes, causing toe scour and hydraulic failure. When this process occurs, the channel widens.

A third type of erosion has occurred from rilling, or concentrated runoff spilling over the top of bank. This downcuts through the top of bank, undermines vegetation, and can significantly weaken the bank slope.

General Erosion Conditions in Lower Novato Creek

Erosion conditions within the study reaches are relatively similar, with critical erosion areas associated with channel bends. Bank heights range from 12 to 15 feet in Reach 1 and 15 to 25 feet in Reach 2, with bank profiles being typically convex (curving inwards) in both reaches. The predominant erosional mechanism noted in the study reach was toe scour, with subsequent bank slumping from the unsupported slope. Vegetation and associated root structures support the banks in stable and unstable areas. However, tree slumping can and will occur when the soil within the root matrix is winnowed away under large trees and the weight of the trunk becomes unsupported. Tree slumping can be a great hazard because it can redirect high-velocity flow from one area of the creek to another bank. With that in mind, it is also important to note that large woody debris can also act to trap sediment and slow down channel degradation. Most bank profiles have a typical stratification of alluvial and colluvial deposits overlaying bedrock and in some cases an unusual clay stone material. Field inspections of this soil reveal that exposed portions in the creek banks vary from 1 to 3 feet in depth and that it is typically overlaying bedrock, 10 to 13 feet below the alluvial deposits. These formations do provide some form of toe protection; however, above the formations erosion is continuing to cut into the banks, causing failure. These formations will also pose a unique design challenge to "keying" toe protection. Keying is a term that refers to the trenching of rock or toe supports at depths below the existing grade to anticipate possible vertical creek adjustments.

Prior to any erosion assessments, Reach 1 and 2 can be distinguished by adjacent land use and the density of residential structures. In terms of disturbances to creek stability, Reach 2 has the advantage over Reach 1 by flowing through Miwok Park, where natural cycles of erosion and deposition are not impeded or accelerated by bank top anthropogenic disturbances. The amount of stable banks between reaches differs only by 15% (**Table 6**).

Table 6. Summary of Existing Conditions Bank Erosion Inventory

	Reach 1	***Reach 2***
Stable	61%	75%
Eroded	26%	16%
Protected	14%	9%
Priority Sites	5	6
Active Erosion (ft)	1685	1194

Roughly 61% of Reach 1 is stable; 26% of Reach 1 is experiencing active erosion with no form of revetment. Within Reach 1, 14% of the reach has some form of revetment stabilizing bank toes that would otherwise be actively eroding. In Reach 2, 9% of the banks are protected, with another 16% of the reach experiencing active erosion. The remaining 75% of the banks are stable and not experiencing active erosion at this time.

Compared to the 1997 study done for the two study reaches, it appears that both reaches are slightly more stable and are experiencing less erosion. Given that different parties using different methods quantified the erosion, some discrepancies are expected. Reach 1 does not exhibit any major differences in bank protection, erosion, and stability. In Reach 2, the greatest differences seem to be that the reach is apparently more stable than in 1997.

Table 7. Comparison of Bank Erosion Inventories

	Reach 1		***Reach 2***	
	1997	***2007***	***1997***	***2007***
% Protected	18	14	2	16
% Stable	47	61	58	76
% Eroding	35	26	40	9

At present, the existing revetment in the channel does not appear to have significant impacts on existing erosion areas, nor was it solely responsible for causing additional erosion.

Priority Sites

During the reconnaissance survey performed for the study reaches, we identified priority areas within the creek in which property and or residential structures were at risk (**Tables 8** and **9**). For each priority we used a generic ranking of low-medium-high based on the severity of the erosion and the inherent risk the erosion may pose. Moreover, possible constraints that may impact design development were identified.

Table 8. Reach 1 Priority Sites

Priority Code	Center of Station	Risks	Erosion Mechanism (s)	Bank Height	Length	Canopy Cover	Priority	Possible Constraints
R1-1	83700	Fence; Road is 20' from TOB	Meander/Toe Scour	14	130	75%	High	Bedrock For Toe Keys; Canopy Cover
R1-2	83925	Shed; House is < 20' from TOB	Meander/Toe Scour	14	260	10%	High	Claystone for Toe Keys
R1-3	84350	Multiple Erosion Areas; Fence; Shed; House is < 20' from TOB	Meander/Toe Scour	16	210	10%	Medium	Existing Revetment
R1-4	85250	Fence; House is <10' from TOB	Meander/Toe Scour	16	180	75%	High	Claystone for Toe Keys; Lateral Distance For Keys
R1-5	86300	Unknown	Meander/Toe Scour	15	133	50%	Medium	Exposed Large Tree Roots

Table 9. Reach 2 Priority Sites

Priority Code	Center of Station	Risks	Erosion Mechanism (s)	Bank Height	Length	Canopy Cover	Priority	Possible Constraints
R2-1	89300	Fence; House is < 20' From TOB	Meander/Toe Scour	15	100	75%	Medium	Large Trees; Close Proximity Of Structures
R2-2	90800	Fence; House is < 20' From TOB	Meander/Toe Scour	17	220	25%	Medium	Existing Revetment; Close Proximity of Structures
R2-3	91550	House is < 20' from TOB	Meander/Toe Scour	16	120	75%	Medium	Large Trees
R2-4	91900	House is < 10' from TOB	Meander/Toe Scour	25	120	80%	High	Bank Height; Close Proximity of Structures
R2-5	92050	No Structures in Proximity	Meander/Toe Scour	17	200	45%	Low	Large Trees
R2-6	92200	No Structures in Proximity	Meander/Toe Scour	17	177	80%	Medium	Bank Height

Existing Vegetation Conditions

Riparian environments in the Novato area are typically composed of a mosaic of plant communities that include Central Coast Riparian Scrub, Central Coast Live Oak Forest, Mixed Riparian Forest, Valley Oak Woodland, and Non-native Grassland. The mid-to-lower reaches of the Novato Creek watershed has been significantly altered by urban development. Novato Creek provides a thread of riparian forest weaving through an otherwise urban landscape. This corridor supports bay, willow, ash, big-leaf maple, and buckeye trees, with scattered elderberry and walnut trees. Within the project reaches, Valley Oak, Coast Live Oak, and bay trees are dominant, creating a considerable canopy cover. The mature oaks found along these banks are the oldest living representatives of historic riparian conditions in the Novato area.

Canopy Cover

Where sufficient light penetrates through the overstory, some mature willows have quickly grown. These willows tend to grow in the channel itself, closer to the waterline, while the oaks and bays typically grow along the tops of the banks. Where overstory vegetation is mature and well developed, the oaks and bays tend to shade out willows and other understory vegetation. In fact, these trees and their immense root structures are the main force protecting against bank erosion throughout the reach. The density of overstory vegetation can have a large impact on the types of bank stabilization techniques that can be implemented in lower Novato Creek. As the creek is already entrenched, too much shade can completely limit the use of biotechnical approaches, as sunlight cannot penetrate to bank-side vegetation. To determine how much of a constraint canopy cover would be in bank stabilization techniques, we did a visual survey of canopy cover in both reaches (**Tables 10** and **11**).

Table 10. Reach 1 Canopy Cover

Station	Canopy Cover
83510	25%
83610	90%
83760	75%
83910	10%
84060	25%
84210	25%
84360	10%
84510	50%
84660	10%
84960	75%
85110	75%
85260	75%
85410	75%
85560	75%
85710	50%
85860	75%
86010	25%
86160	25%
86310	50%
86460	50%
86610	75%

Table 11. Reach 2 Canopy Cover

Station	Canopy Cover
88900	75%
89050	75%
89200	75%
89350	70%
89500	60%
89650	65%
89800	90%
89950	90%
90100	90%
90250	25%
90400	90%
90550	40%
90700	50%
90850	10%
91000	75%
91000	80%
92400	80%

Existing Aquatic Resources

Novato Creek drains to San Pablo Bay and ultimately is connected to the Pacific Ocean, thus supporting populations of anadromous fish species. Anadromous fish species are those that require riverine and ocean environments to complete their life cycles. A reconnaissance-level field survey was conducted in 1996, in Novato Creek from Diablo Avenue to Grant Avenue, to characterize existing fisheries resources in the creek (Rich, 1996). The survey revealed that several fish species are common to Novato Creek (**Table 12**). Although all of these species were found in the creek, it was stated that only steelhead trout, California roach, and threespine stickleback use the creek to reproduce and grow.

Table 12. Fish Species Known to Occupy Study Reaches

Common Name	Scientific Name
California Roach	*Hesperoleucus symmetricus*
Threespine Stickleback	*Gasterostreus aculeatus*
Steelhead Salmon	*Oncorhynchus mykiss*
Sacramento Sucker	*Catostomus occidentalis*
Chinook Salmon	*Oncorhynchus tshawytscha*
Prickly Sculpin	*Cottus asper*

Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead salmon (*Oncorhynchus mykiss*) are state and federally threatened species and thus protected. Steelhead are the anadromous form of rainbow trout, a salmonid native to western North America and the Pacific Coast of Asia. They begin life in fresh water, rear in rivers or creeks, and then migrate to the ocean where they mature and finally return to their river of origin to spawn and complete the cycle. After birth, steelhead spend their first one to three years of life in their natal streams before emigrating to the ocean. Steelhead spend between one to four growing seasons in the ocean before returning to their native fresh water streams to spawn. Unlike Pacific salmon, steelhead do not always die after spawning and are able to spawn more than once. To complete this lifecycle, migration corridors must be free of structures inhibiting upstream movement. Steelhead prefer clean waters with low turbidity and siltation. Juveniles rely on the presence of pools and a gravelly substrate for rearing. Good canopy coverage benefits the species at all life cycle stages, providing cover, cool water, and food production. Chinook salmon are the largest salmonids and can weigh over 100 pounds. Because of their size they typically spawn in the mainstem of larger gravel bed rivers. Spawning in streams that are larger and deeper than other salmon utilize, chinook salmon spawn from late summer to late fall, depending on the run. Fry and smolts usually stay in freshwater from one to 18 months before traveling downstream to estuaries, where they remain up to 189 days. Chinook salmon may spend between one to eight years in the ocean before returning to their natal streams to spawn, though the average is three to four years. **Figure 7** shows how different geomorphic units (i.e., riffle/pool/run) can provide habitat for feeding and shelter for various salmonid lifestages. In the context of this report, the pool habitat is the most important component because of its location on the outside of meander bends, where the majority of erosion in the study reaches occurs. Bank stabilization measures will thus have to consider impacts to the aquatic and riparian habitat of these species.

HYDRAULIC ANALYSIS

Hydraulic Model

Hydraulic analysis consists of modeling the flow regime through the channel reach as characterized by surveyed cross-sections and the supplied topographic map. The field data were imported into HEC-RAS (Hydrologic Engineering Center River Analysis System version 3.1, 2002) hydraulic modeling software developed by the U.S. Army Corps of Engineers. The hydraulic model predicts flow velocity, water surface elevations, and water depths, among other hydraulic parameters. Sediment transport capacity was assessed using an internal submodel within HEC-RAS to determine the maximum amount of material the stream can move.

The following methods were used:

- **1D Hydraulic Model**
  HEC-RAS is a one-dimensional hydraulic model capable of calculating water surface profiles for steady, gradually varied flow. The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's *n* coefficient) and contraction/expansion (coefficient multiplied by the change in velocity head). This hydraulic analysis was performed with the assumption that flows in Novato Creek are steady, uniform, open-channel flow. A mixed regime steady flow analysis was computed, where flow can be either sub- or super-critical.

- **Cross-section Geometry**
  Cross sections were surveyed in December of 2006 using a level and tied into known benchmarks. A total of 23 cross sections were used for the existing conditions HEC-RAS analysis for Reach 1 and 16 were used for Reach 2.

- **Roughness**
  Roughness coefficients were assigned to left overbank, channel, and right overbank segments of each cross-section. Different roughness coefficient values reflect different surface "roughness" qualities. Generally, the channel was assigned a Manning's *n* ranging from 0.04 to 0.06.

- **Steady Flow Analysis**
  In a modeled flow regime, boundary conditions are necessary at the upstream and downstream ends of the river system. This analysis used a "Normal Depth" boundary condition, which requires an energy slope to be used. The average reach slopes were used for this analysis.

- **Sediment Transport Capacity Analysis**
  Several transport formulas are available for assessing transport capacity within the study reaches. The Meyer-Peter Muller formula was chosen for its simplicity. Because we are more concerned with relative change, the specific transport formula chosen is not necessarily very important.

Existing Conditions Hydraulic Model Results

The hydraulic model was used to characterize and evaluate lower Novato Creek. Specifically, the model was used to determine the ranges of depths and velocities associated with various discharges that may affect channel stability and bank stabilization designs. The 10-year event and a typical bankfull flow (based on field indicators) were used as representative discharges. Based on the average bankfull depth calculated in the preceding sections, multiple flows were run to find the corresponding discharge. Our analysis resulted in a bankfull flow of roughly 150 cfs. The 50- and 100-year discharges were not used because flow overtops the surveyed top of banks and spreads onto the floodplain.

Bankfull Hydraulic Analysis Results

Reach 1

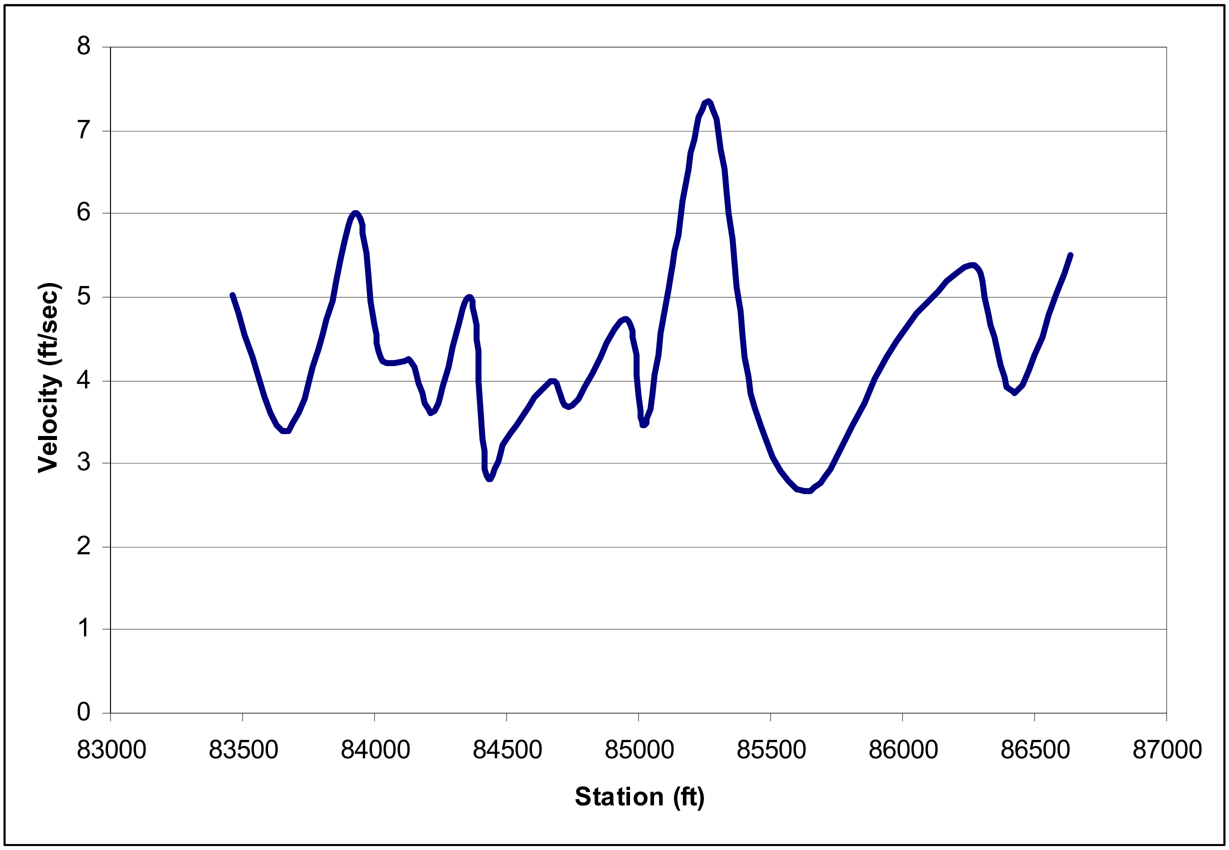
At the channel forming discharge, the velocities in Reach 1 of Novato Creek range from 2.66 to 7.32 ft/s with a mean velocity through the reach of 4.4 ft/s (**Table 13**). Shear stresses in Reach 1 range from 0.25 to 1.21 lbs/ft^2 and the Froude number ranges from 0.2 to 0.62. No critical flow was predicted in Reach 1 at the bankfull discharge.

Table 13. Bankfull (730 cfs) Reach 1 Hydraulic Properties

	Average Velocity (ft/s)	*Maximum Depth (ft)*	*Total Shear (lbs/ ft^2)*	*Froude Number*
Maximum	7.32	8.22	1.21	0.62
Mean	4.4	6.7	0.5	0.35
Minimum	2.66	4.66	0.25	0.2

There are four relative velocity spikes that occur at stations 83930, 84954, 85275, and 86250, respectively (**Figure 8**). These high velocity areas have a much narrower top width and flow area than other sections in the reach. Referring to **Sheet 1** of the erosion inventory reveals that these stations all correspond to active erosion sites. Station 83930 is noted as a priority erosion site. Only station 84954 has some form of revetment. A plausible deduction from these results in that the creek is adjusting to increase it's cross sectional area via bank erosion so that energy within the creek can be minimized.

Figure 8. Bankfull (730 cfs) Velocity Profile Reach 1



Reach 2

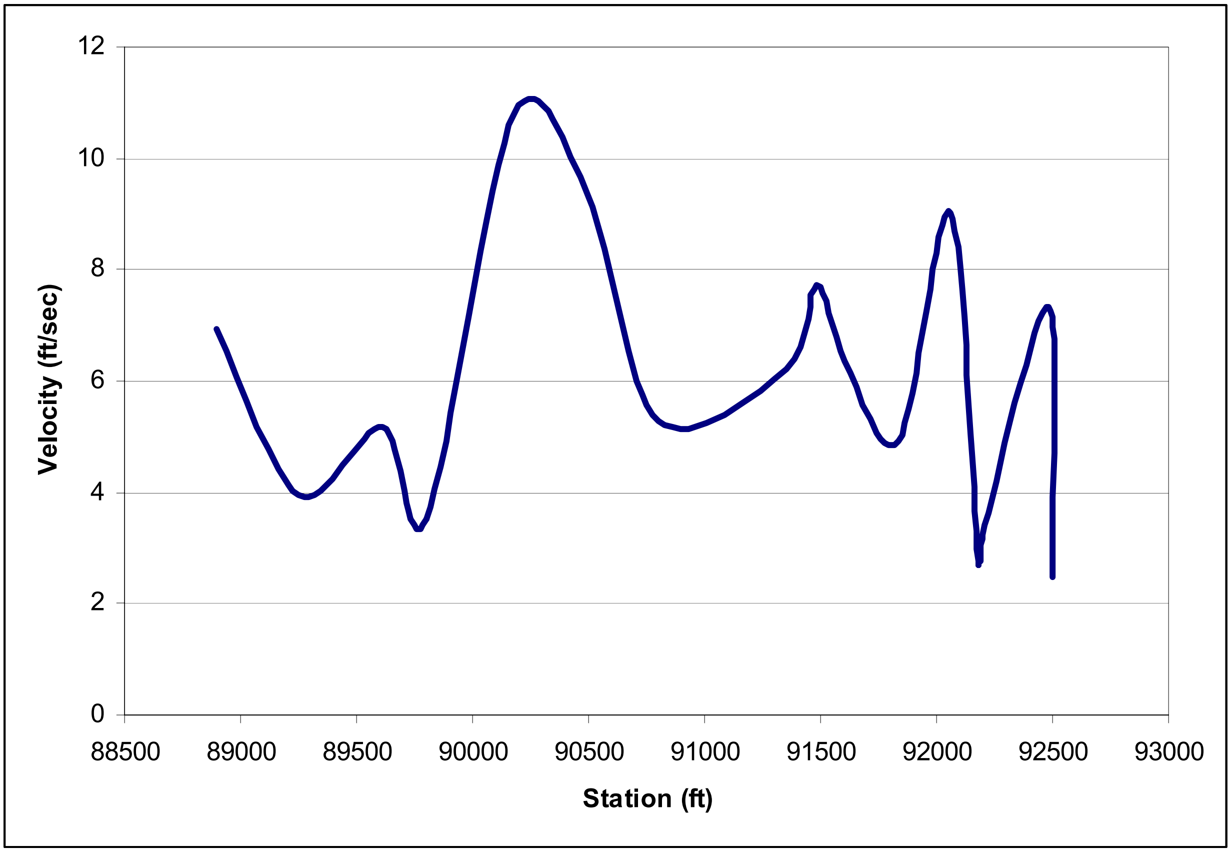
At the channel-forming discharge, the velocities in Reach 2 of Novato Creek range from 2.47 to 10.8 ft/s with a mean velocity through the reach of 5.9 ft/s (**Table 14**). Shear stresses in Reach 1 range from 0.12 to 2.2 lbs/ft^2 and the Froude number ranges from 0.21 to 1.2. Critical flow was predicted in Reach 2 at the bankfull discharge at three stations, 90180, 90500, and 92060.

Table 14. Bankfull (730 cfs) Reach 2 Hydraulic Properties

	Average Velocity (ft/s)	***Maximum Depth (ft)***	***Total Shear (lbs/ ft^2)***	***Froude Number***
Maximum	10.8	6.1	2.2	1.2
Mean	5.9	4.7	0.74	0.6
Minimum	2.47	3.4	0.12	0.21

There are four relative velocity spikes that occur at stations 90180, 91480, 92060, and 92480 respectively (**Figure 9**). These high velocity areas have a much narrower top width and flow area than other sections in the reach. Referring to **Sheet 2** of the erosion inventory reveals that station 90180 is bedrock controlled and has some form of bank revetment. It is likely that this velocity spike may persist because the flow area cannot be easily adjusted. Station 91480 is experiencing active bend erosion. Station 92060 is a priority erosion site and is experiencing active erosion through large point bar growth. Out of all of the meander bends considered, this station had the most pronounced bar terraces. Station 92480 is at a concrete pipe casing that acts as a grade control. No active erosion was found at this station.

Figure 9. Bankfull (730 cfs) Velocity Profile Reach 2



10-year Event Hydraulic Analysis

Reach 1

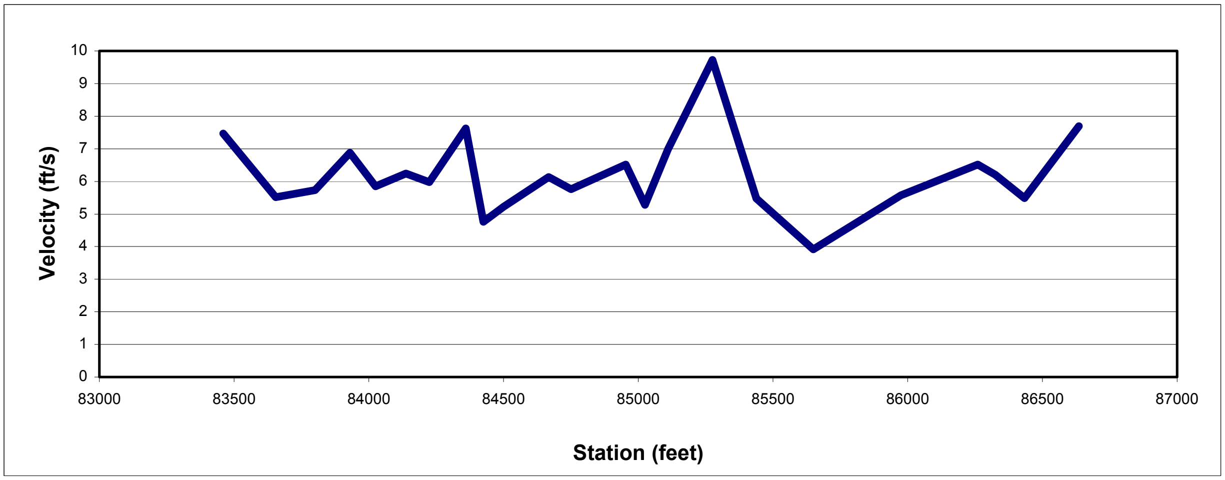
For the 10-year event (2,070 cfs), the velocities in Reach 1 of Novato Creek range from 3.92 to 10.8 ft/s with a mean velocity through the reach of 6.2 ft/s (**Table 15**). Shear stresses in Reach 1 range from 0.26 to 1.47 lbs/ft^2 and the Froude number ranges from 0.22 to 0.60. No critical flow was predicted in the reach for this discharge.

Table 15. 10-year Event (2,070 cfs) Reach 1 Hydraulic Properties

	Average Velocity (ft/s)	*Maximum Depth (ft)*	*Total Shear (lbs/ ft^2)*	*Froude Number*
Maximum	9.73	12.38	1.47	0.60
Mean	6.20	10.72	0.69	0.37
Minimum	3.92	8.39	0.26	0.22
Standard Deviation	1.19	1.12	0.29	0.08

There are two relatively large velocity spikes at this discharge (**Figure 10**) corresponding to stations 84360 and 85275, which are both areas of active erosion.

Figure 10. 10-year Event (2,070 cfs) Reach 1 Velocity Profile



Reach 2

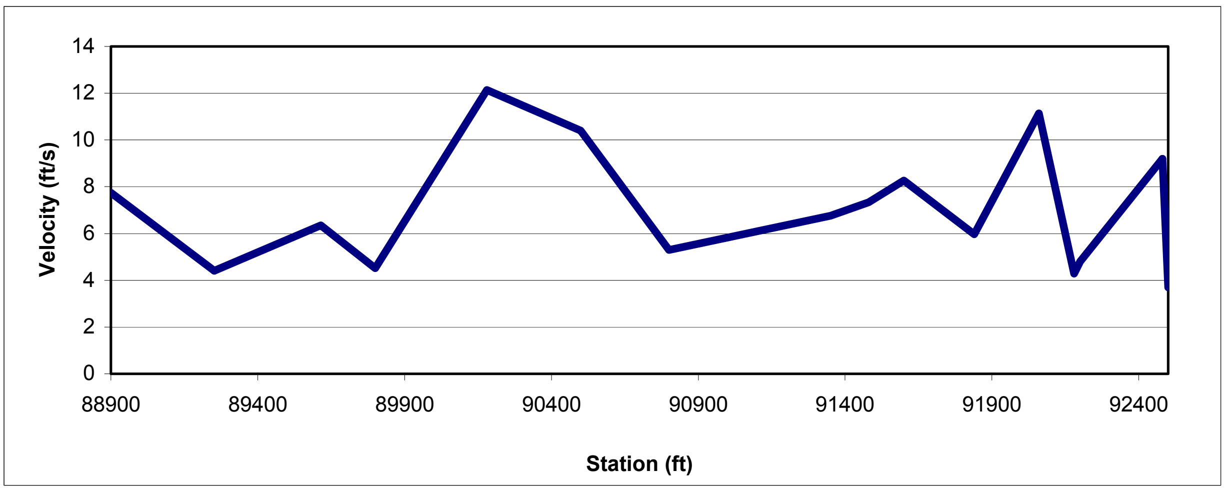
For the 10-year event (2,070 cfs), the velocities in Reach 2 of Novato Creek range from 3.70 to 12.14 ft/s with a mean velocity through the reach of 7.02 ft/s (**Table 16**). Shear stresses in Reach 1 range from 0.33 to 4.18 lbs/ft^2 and the Froude number ranges from 0.23 to 1.01. Critical flow was predicted in reach at stations 92060 and 90180.

Table 16. 10-year Event (2,070 Cfs) Reach 2 Hydraulic Properties

	Average Velocity (ft/s)	*Maximum Depth (ft)*	*Total Shear (lbs/ ft^2)*	*Froude Number*
Maximum	12.14	9.42	4.18	1.01
Mean	7.02	8.27	1.44	0.53
Minimum	3.70	6.66	0.33	0.23
Standard Deviation	2.62	0.82	1.19	0.24

There are three relative velocity spikes that occur at stations 90180, 92060, and 92480 respectively (**Figure 11**). These high-velocity areas have a much narrower top width and flow area than other sections in the reach. Referring to **Sheet 2** of the erosion inventory reveals that station 90180 is bedrock controlled and has some form of bank revetment. It is likely that this velocity spike may persist because the flow area cannot be easily adjusted. Station 92060 is also experiencing active erosion through large point bar growth. Out of all of the meander bends considered, this station had the most pronounced bar terraces. Station 92480 is at a concrete pipe casing that acts as a grade control. No active erosion was found at this station.

Figure 11. 10-year Event (2,070 cfs) Reach 2 Velocity Profile



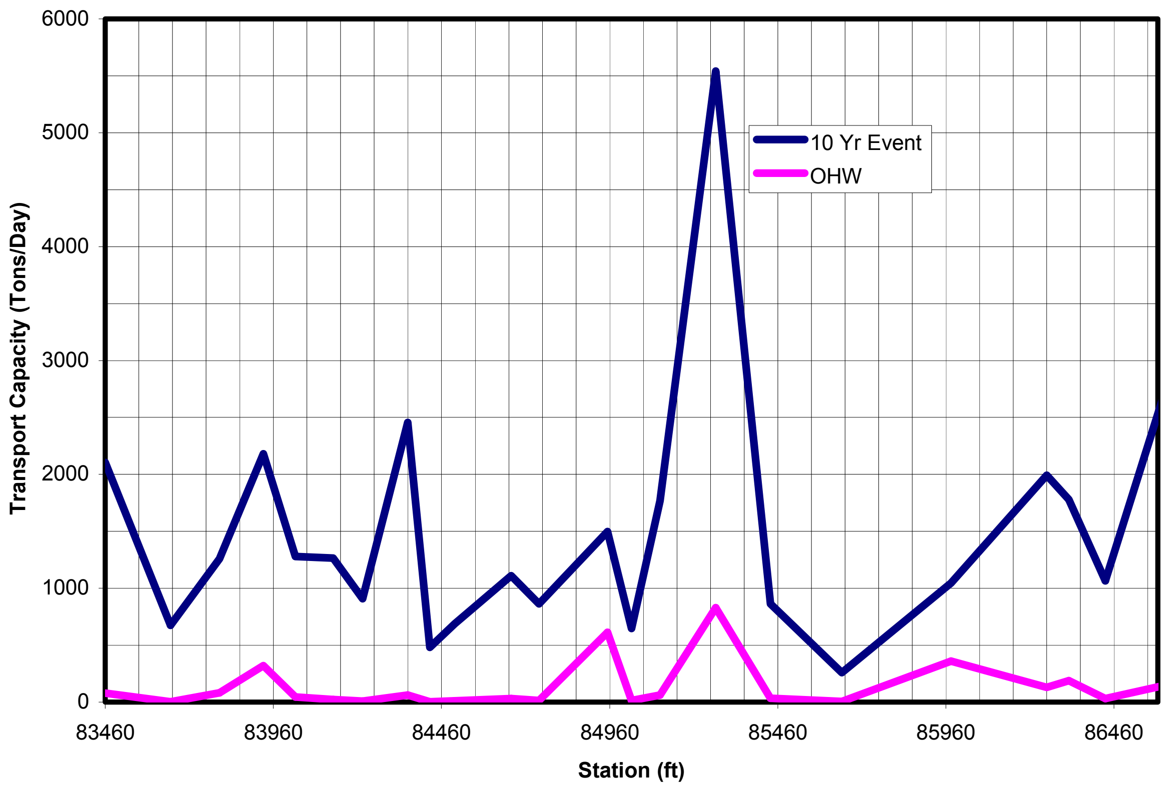
Sediment Transport Analysis

In order to evaluate the long-term erosion trends within the study reach, a longitudinal analysis of the each reach's sediment transport capacity analysis was conducted. This is done by comparing the transport capability at each cross section in the hydraulic model with other sections in the model. The theoretical sediment transport capacity at the bankfull discharge should be close to zero in a system that has adjusted its bankfull geometry, such that the channel-forming discharge causes the cross section to neither experience degradation nor aggradation, but to remain stable. Abrupt changes in the transport capacity within the reach potentially indicate that those areas may experience erosion, in the absence of controlling structures or geology, as the channel adjusts its geometry such that they become stable. In other words, the analysis helps pinpoint areas that may be the most susceptible to erosion and channel adjustments in the future.

Reach 1 Sediment Transport Analysis Results

The sediment transport capacity profile for Reach 1 at the ordinary high water (OHW) shows a relatively smooth profile of almost zero transport with several profile spikes at stations 83930, 84954, 85275, and 85975 (**Figure 12**). At the 10-year event these spikes become much more pronounced and extreme. The model is predicting erosion areas within the creek that coincide well with field indicators mapped. The stations in which the peaks occur are in fact major erosion areas and it is likely that these areas will continue to adjust until they match baseline hydraulic and transport conditions in the creek. The analysis indicates that Station 83930 is likely to experience more lateral erosion in the future; it also indicates that the revetment filling into the channel will likely reduce channel capacity, potentially exacerbating erosion sites downstream and across the creek. Moreover, at the 10-year event, two peak areas arise that were not present at the OHW discharge at stations 84360 and 84667. Station 84360 is a medium-priority site that has a partial revetment. Station 84667 currently has an existing revetment in fair condition.

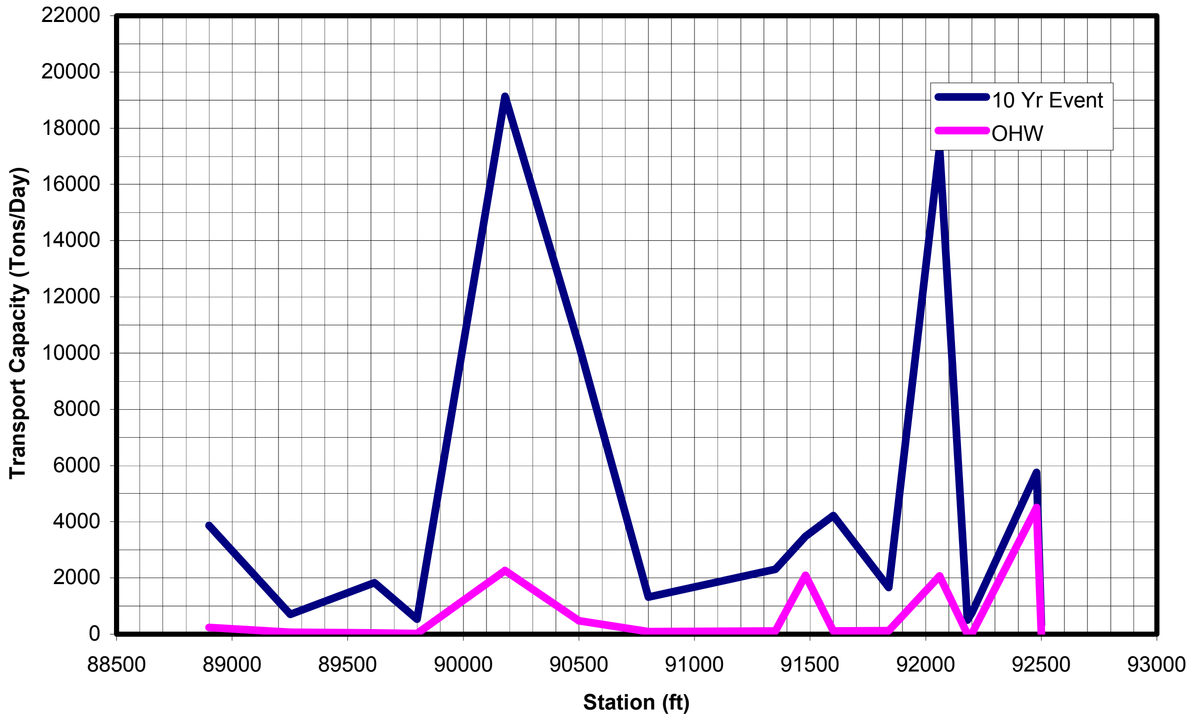
Figure 12. Reach 1 Transport Capacity Profile



Reach 2 Sediment Transport Analysis Results

The sediment transport capacity profile for Reach 2 at the OHW discharge shows a relatively smooth profile of almost zero transport with several profile spikes at stations 90250, 91480, 92075, and 92450 (**Figure 13**). The stations in which the peaks occur are in fact major erosion areas (as stated above). Two of the indicated sites, 90250 and 92450 are in bedrock-controlled areas so the change in transport is likely a factor of that bedrock control. The other sites, 91480 and 92075, are outside of bends and this analysis indicates that are likely to grow. However, these sites are located in the park area and do not have sensitive infrastructure or structures near the top of bank, so channel adjustments should be allowed to continue in these areas.

Figure 13. Reach 2 Transport Capacity Profile



Hydraulic Analysis Conclusions

The results of this analysis should be used as baseline hydraulic design criteria for any proposed bank stabilization projects. Bank protection designs can displace the toe of slope, maintain the existing toe, or cut back the existing slope. In the event that the existing top of bank is maintained and the proposed revetment protrudes into the channel, the available cross-sectional area for flow can be reduced, possibly increasing velocities, changing flow trajectories, and altering the sediment transport capability of that channel reach. This in turn may alter sediment transport and erosional dynamics in adjacent areas. Only in areas where the channel has sufficient bottom and top widths will channel infill have negligible effects. Our sediment transport analysis indicated that the majority of the channel geometries in the study reaches have developed a quasi-equilibrium. The inconsistencies in the transport capacity indicate areas of potential erosion but do not predict all areas of erosion that have been mapped in the reaches. Some mapped erosion areas do not correspond to spikes in transport capability. It is believed that these areas represent historic erosion areas and have gone through the majority of their adjustment. The rate at which some of these site will erode is predicted to decrease and become more episodic, primarily driven by rare large events. Some sites have developed adjacent gravel bars and, because the channel is wider in these locations, more sunlight is causing fast-growing riparian vegetation to become established on these gravel bars. This stabilizes the gravel bar and increases deposition, potentially upsetting the geomorphic equilibrium and instigating a renewed period of lateral bank migration, which may impact existing private property and renew calls for additional bank slope revetment. The vegetation establishment in these areas should be monitored and thinned as necessary to enhance the long-term stability of these areas.

CREEK MANAGEMENT APPROACHES

The management of urban creeks is often a complex balance between multiple and competing resources and stakeholders. Novato Creek is experiencing a high degree of lateral bank erosion threatening adjacent property, structures, utilities, and large trees. These same threatened structures also make bank stabilization within the creek difficult, due to the close proximity of structures and utilities that may be impacted. The creek also supports populations of state and federally listed species that require special consideration and design elements.

There are four main considerations when determining bank stabilization projects and design:

1. *Protection of Private Property*
2. *Flood Control*
3. *Channel Stability*
4. *Preservation of Aquatic Resources*

The conflict between each of these aspects lies in the inherently entrenched nature of the creek and the close proximity of adjacent properties. The goal is to provide stabilization that satisfies these main considerations while maintaining a consistent geomorphic template. The channel morphology found in Novato Creek provides a geomorphic template that supplies a large amount of habitat heterogeneity for multiple species and life stages for resident salmonids. Approaches to bank stabilization that disrupt this template could have further negative effects on the available habitat for fisheries resources, as well as initiating erosion on relatively stable banks.

Impacts of Bank Stabilization Structures

When bank stabilization structures are constructed, there is potential for erosion impacts to be transferred to other locations along the channel if the project is not adequately thought through and correctly designed. One of the fundamental concepts of bank stabilization design is to stabilize the bank without moving the erosion problem to another portion of the channel. This is generally done by maintaining to the extent possible the basic channel geometries found within the creek system. This is one of the main reasons for the analysis presented in previous sections of this report. Utilizing this baseline channel geometry information will help ensure that basic channel geometries are maintained within new stabilization projects, minimizing potential impacts to other portions of the channel. Stabilization schemes that do not mimic controlling channel geometries will likely move the erosion to other locales within the system and will develop controlling channel geometries over time.

Stabilization projects that significantly reduce the frictional resistance of the channel will most likely transfer the erosive energy downstream of the site. This can occur when vegetation is removed and replaced with concrete rock revetment that prohibits the growth of a good vegetation matrix. Therefore, it is essential that biologic or biotechnical, revegetative, and woody debris techniques be used to the greatest extent possible. These features increase vegetative and physical roughness in the channel and help dissipate energy gained in an erosion area before it is transferred to other portions of the channel to create erosional problems.

Factors Controlling the Stabilization Solution

Stable channels usually have channel dimensions that dissipate fluid forces and can pass the sediment load. Changes in the equilibrium cross-sectional area will likely mean that the energy in the creek will be expended elsewhere in the form of erosion. The challenge is to determine appropriate bank stabilization approaches in the context of an urban stream. Constraints in these situations include adjacent structures, significant riparian trees, and the overall balance in the channel. Normally, creeks would be allowed to shift position and adjust to alterations in the watershed hydrology, sediment transport regime, and riparian vegetation recruitment. In an urban context, typically only a small amount of lateral alignment shift can be tolerated before some type of stabilization or bank armoring is necessary to preserve property and structures.

The density of residential structures at the top of bank and the existing flood hazards in the area make balancing flood control and private property an important consideration for bank stabilization projects. Fisheries resource issues are related to bank protection because typically erosion occurs on the outside of meander bends where pool habitat is often located. Repairing eroded banks can often impact this pool habitat by filling it in or removing overhanging banks and debris that shade pools in the summer time**.** The amount and size of riparian tree canopy also present an issue in the study reaches. Many times large, mature trees at the top of bank provide key canopy and shade for the creek. If these trees were removed from the system, willows and other sun-loving species would colonize the gravel bars and create additional pressure on the channel to adjust and laterally migrate. The large bank top trees have extensive root systems that provide key stability to the banks. The three main factors that need to be considered when considering a stabilization approach are top of bank structures, top of bank mature trees, and the average channel geomorphic context of the creek reach.

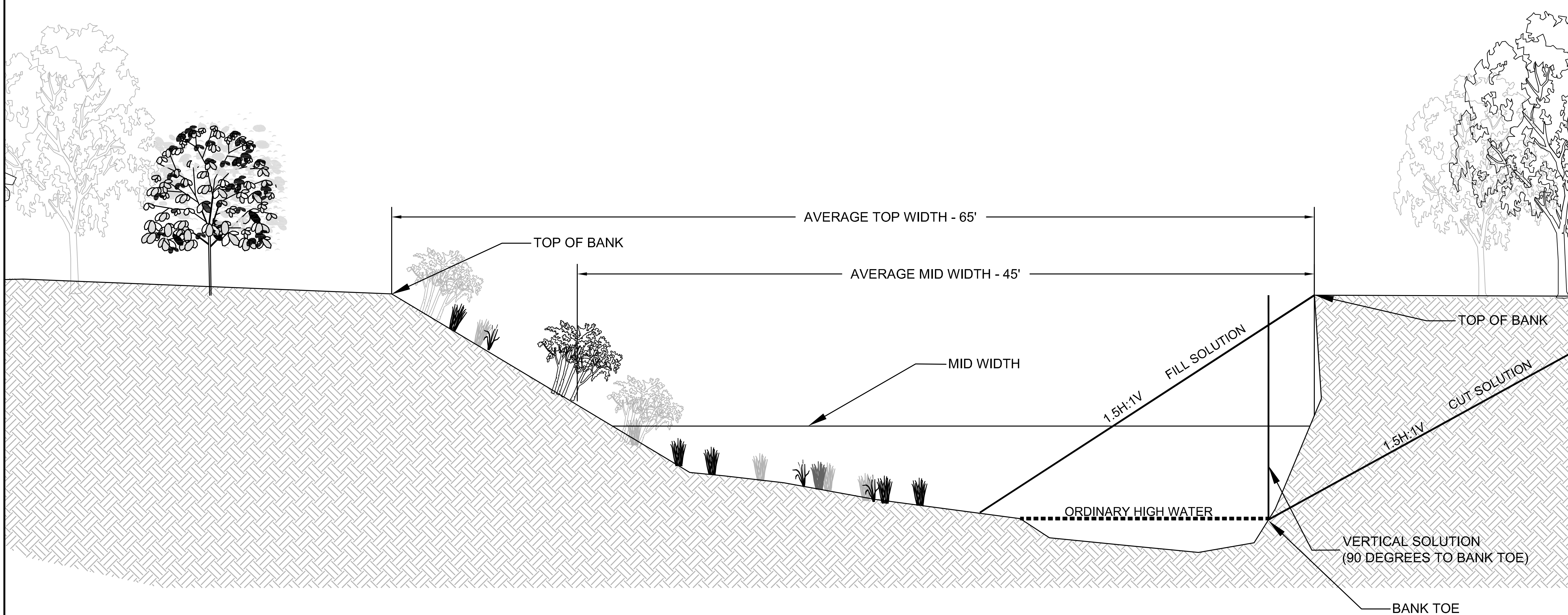
Where eroding banks are typically near vertical cuts, there are three basic types of stream bank stabilization approaches: “fill,” “cut,” and “vertical.” **Figure 14** shows these basic techniques applied on a typical meander cross section.

Fill stabilization techniques involve maintaining the existing top of bank and constructing a new slope and channel toe or placing fill in the existing channel. This type of technique has the potential to create the largest impacts to the creek system and should only be used in areas determined to safely accommodate this technique. The typical impacts of traditional “in-fill” bank stabilization projects into entrenched urbanized channels that have below-average bottom widths are:

1. *Reducing cross sectional area, increasing and possibly redirecting high velocities causing erosion on downstream banks;*

2. *Reducing conveyance and possibly raising base flood elevations;*

3. *Filling in valuable aquatic habitat; and*



TYPICAL SECTION AT A MEANDER EROSION SITE LOOKING UP STREAM

NTS

NOTES:

1. "TOB" denotes top of bank
2. Bank toe is defined at the edge of water at ordinary high water
3. Mid width is the width at half of the bank height

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TYPICAL BANK STABILIZATION SOLUTIONS

FIGURE 14

4. *Disrupting the natural geomorphic template for ecological communities in the creek.*

It is important that basic average channel widths be maintained in order to avoid these impacts.

The *cut* technique involves keeping the channel bank toe in the same location and cutting back the bank to a 1 (V):1.75 (H) or gentler slope. In this case the channel top width is widened. This alternative has the greatest impact on top of bank property. Existing riparian vegetation usually has to be removed to accommodate the grading. The cut solution may not be feasible if existing structures are in the way.

The third solution is a *vertical* solution. This is typically the most expensive solution and may only be used when there are few other options. Typically the solution entails supporting a top of bank structure in a narrow incised portion of the channel. This may be used where a cut solution cannot be accomplished because of a nearby building or structure, and where a fill solution into a narrow channel would likely mean moving the erosion site to another location, so that constructing vertical stabilization is the only option to avoid impacts.

There is a need to provide a framework for the individual property owners to address their bank stabilization issues in the most geomorphically and ecologically sound manner. With this in mind, a project approach decision tree was developed (**Figure 15**). This decision tree is intended to be used by property owners to determine the most appropriate bank stabilization approach (fill, cut, or vertical) for an individual property. There are four primary factors used to guide property owners to appropriate design approaches to bank stabilization:

1) **Location of habitable/permitted buildings**

2) **Location and size of mature riparian trees**

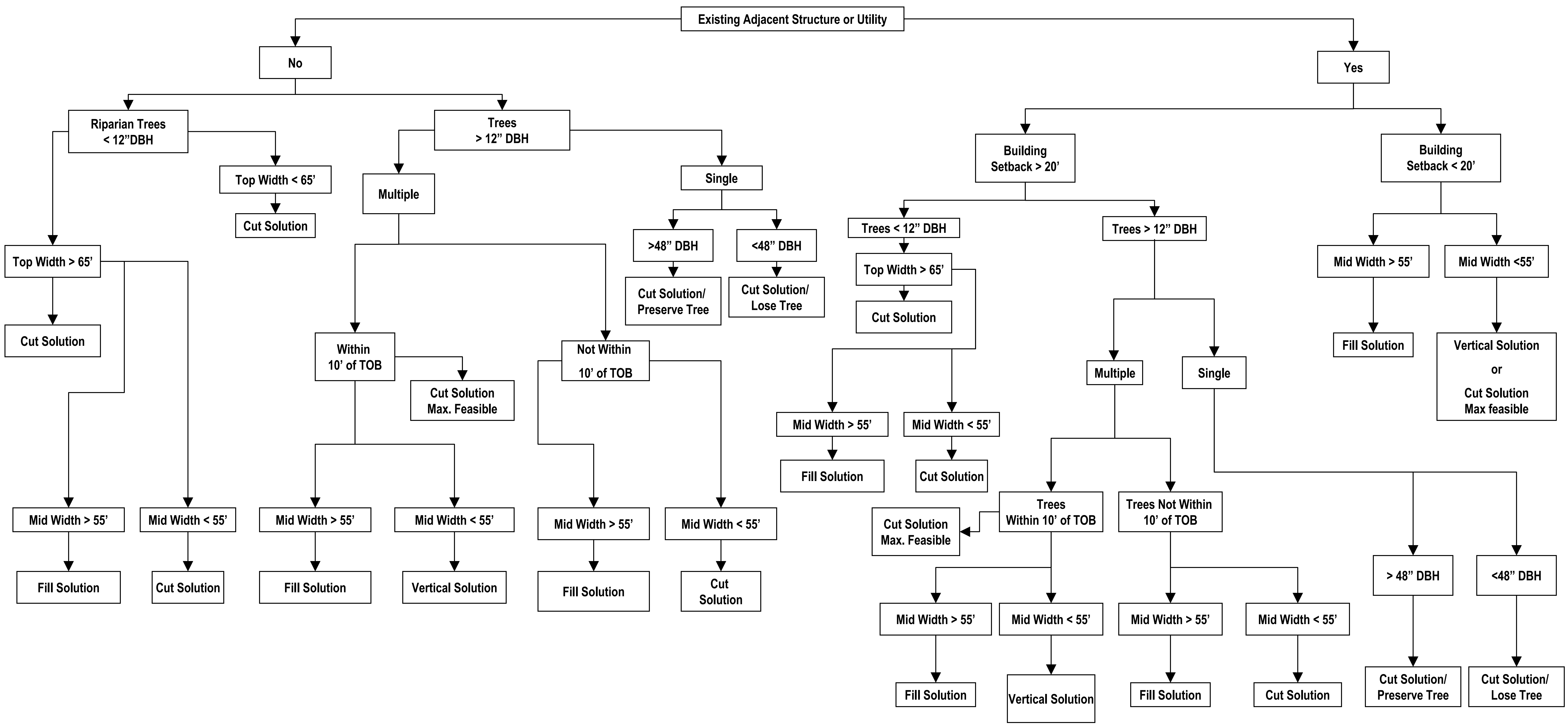
3) **Existing channel top width**

4) **Existing channel mid-width or ± bankfull water surface width**

The location of a habitable structure in relation to the creek channel is one of the first factors that needs to be considered. An applicable structure is one that is served by utilities, or requires permits from the city for construction. Because most of the banks are 10 to 15 feet high, a setback limit of 20 feet was used in our analysis. A building 20 feet back from the top of bank allows for a cut slope of between 2:1 and 1.5:1. Thus, if the building is closer than 20 feet from the bank, a cut solution is usually infeasible.

The second factor is the presence of significant, mature, riparian trees. These trees provide shade and cover for the creek and are ecologically important. Their position and size often dictate how a bank stabilization project is designed. For these guidelines, it was assumed that a mature tree was at least 12 inches in diameter at chest height.

Bank Stabilization Design Approach Decision Tree



- *Top Width is defined as the distance from top of bank to top of bank .*
- *Mid Width is defined as the width at half the distance to top of bank from the channel thalweg*
- *TOB = Top of Bank; DBH = diameter as base height (~4' above ground)*
- *Riparian tree is defined as any tree within 10 feet of existing top of bank*
- *Adjacent structure/utility is a structure that is permitted through existing city ordinances or is more than 10 years old*
- *Fences are not considered structures*

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FIGURE 15

The third and fourth factors involve basic geometry trends of the channel; two easily measured parameters, top width and mid-bank width, are used. An average top width of 65 feet was determined in the reach analysis and used as a minimum guideline. By mandating minimum top widths, no more significant channel encroachment will occur as a direct result of these guidelines. The channel mid-width is defined as the distance between the banks, halfway up the bank slopes. The average channel mid-width through the reaches is 45 feet, or generally corresponding with average bankfull widths. A minimum distance of 55 feet was determined as a guideline, based on the 45-foot average, with an additional 10 feet to ensure that the bankfull width will not be less than 45 feet if a fill stabilization approach is used.

Using these four major factors in a hierarchical form allows for the property owner and regulator to quickly determine which approach to bank stabilization is appropriate for individual sites. Once the approach is determined, more in-depth analysis is completed to determine the type and design of the individual bank slope. Following are two examples of how the decision tree in **Figure 15** can be used.

Example 1:

Mr. Jones has a property in which buildings are set back over 20 feet from the top of bank. The channel on his property is fairly wide, with over 65 feet in top width and a mid-width of 58 feet, measured at halfway to bank height. He has top of bank trees but they are less 12 inches diameter and not quite mature. Using the decision tree in **Figure 15** and assuming an adjacent structure at greater than 20 feet, the channel top widths and bottom width indicate that he has two options, either cut or fill. If wants to preserve the trees, fill is the best option but would likely be more expensive than just cutting the bank back, stabilizing the toe, and replanting.

Example 2:

Ms. Thompson's property has a garage is within 10 feet of the top of bank. Her bank is vertical now and she may lose the structure in the next few years. The channel is fairly narrow on her property, 55 feet from top of bank to top of bank. The mid-width is 40 feet. The decision tree indicates that she cannot cut bank because of the garage, and if she fills into the channel she will constrain the bottom, potentially moving her erosion problem downstream. Her only alternative would be to pursue some type of vertical bank stabilization solution.

Feasible Stabilization Treatments

The previous section discussed how to determine appropriate generalized approaches to bank stabilization: fill, cut, or vertical. This section provides more detail and varying specific techniques and bank stabilization treatments that can be used under the general approach scenarios. It is up to the designer, following the procedures outlined in **Appendix A**, to determine which treatment best suits a particular site. **Table 17** lists treatments and the bank stabilization approaches under which they could be used.

Table 17. Bank Stabilization Treatments and Approaches

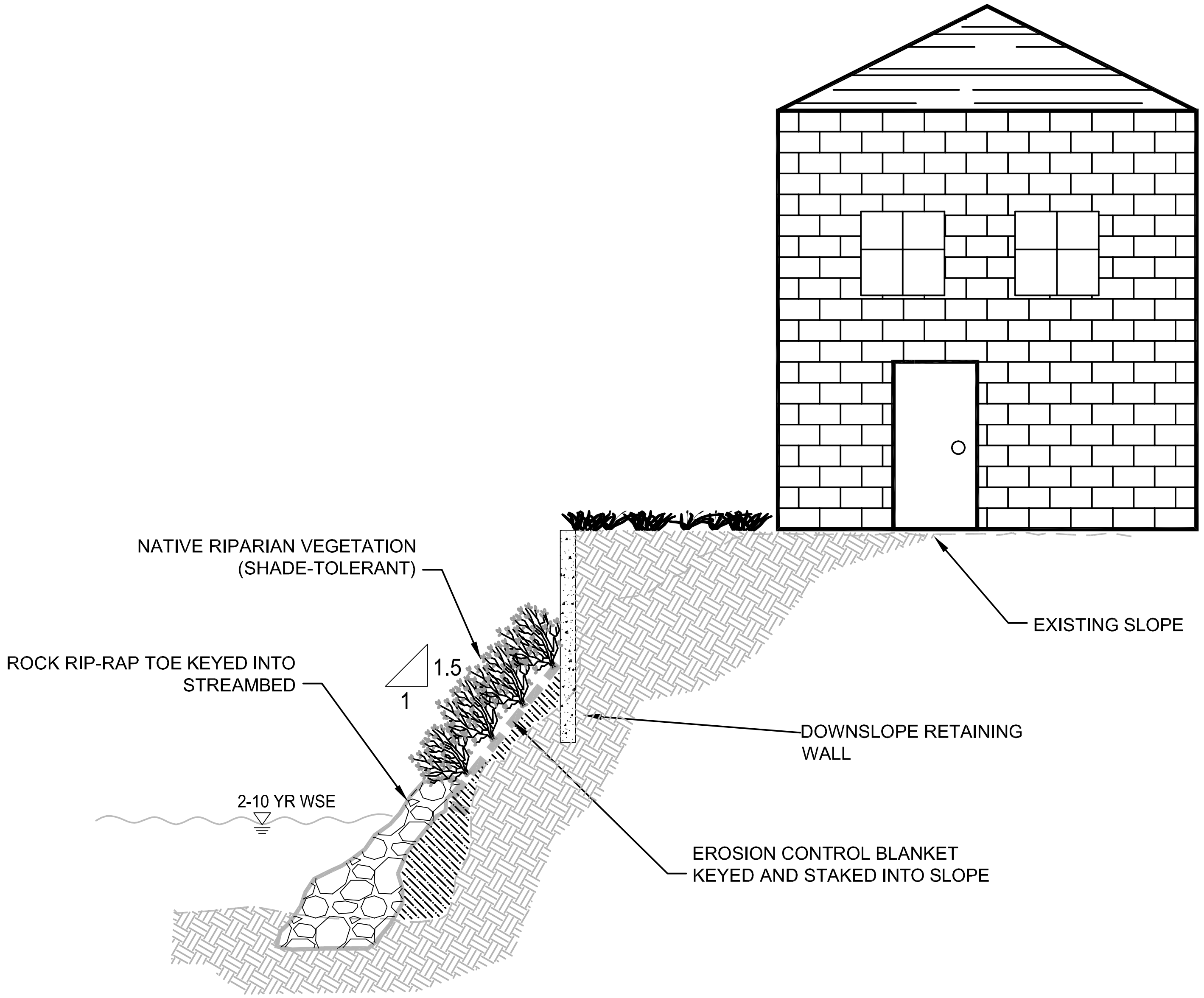
Bank Stabilization Treatments	*Bank Stabilization Approaches*		
	Vertical	*Cut*	*Fill*
Rock Toe-Retaining Wall Combination	X		X
Stitch Piers	X		
Rock Slope with Live Plantings and Rootwad Deflector		X	X
Vegetated Earth Filled Geogrids	X	X	X
Live crib-wall	X		
Modular Pre-cast Units	X		
Planted Rock Revetment		X	X
Loose Rock Revetment		X	X
Live Staking and Willow Wattles		X	X
Erosion Control Fabric Planted w. Rooted Trees/Shrubs		X	X
Brush Mattress		X	X
Fiber rolls/ fiber rock rolls/ coir erosion blankets	X	X	X
Flow deflectors/Rock Spurs	X	X	X
Log, Rootwad, and boulder revetments	X	X	X
Boulder Clusters and Rock Vortex Weirs	X	X	X
Lunker Structures		X	X

There are many combinations of biotechnical, structural, and hybrid approaches, which can also be integrated with habitat enhancement elements. These treatments are discussed below. There are many techniques that can be applied to bank stabilization issues on Novato Creek, but these were chosen because they have specific applicability to the study area. It should be noted that there is a strong preference to utilize treatments that minimize the use of hard revetments such as rock and concrete. Vegetative and non-structural solutions are preferred.

Stabilization and Habitat Enhancement Treatments for Vertical Solutions

Rock Toe-Retaining Wall Combination

A rock toe-retaining wall repair scheme (**Figure 16**) is a hybrid approach, which partially reconstructs a new slope and uses either a vertical or semi-vertical wall to reduce the amount of channel in-fill necessary for typical rock slope approaches. Gravity type retaining walls such as keystone or other fabricated interlocking walls are example applications. This bank treatment strives to bring a balance between preserving bank top property and bank stabilization with minimal infringement into the existing channel. The vertical wall near the top of bank preserves existing bank top property.



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ROCK TOE WITH RETAINING WALL

FIGURE
16

Rock Slope with Live Plantings and Rootwad Deflector

This is one of the more common repairs and habitat enhancements used in bank stabilization projects on environmentally sensitive watercourses. It consists of a placed stone revetment sized to a design flow that is planted with live cuttings (**Figure 17**). To maintain pool habitat, rootwad deflectors are used to create scour pools and dissipate energy. Woody debris provides valuable aquatic habitat for native fisheries. Small rock spurs or adjacent boulder clusters may be substituted for woody debris where appropriate. Recent projects downstream have used this technique extensively. The amount of plantings that can be incorporated into the design is highly dependant on the amount of canopy cover and sunlight penetration into the channel. This type of habitat enhancement technique should be designed into each vertical-type bank stabilization project.

Stitch Piers

Stitch piers (**Figure 18**) consist of a series of offset vertical supports that maintain the existing top of bank. A key attribute of this type of protection scheme is that variations can be constructed from the top of bank, minimizing potential encroachment impacts. This type of repair can also be used as a precautionary method of ensuring property safety. These piers can be installed set back from bank top, eliminating the need impact the existing channel. This allows the bank to erode naturally but ensures protection of the property. When this is done, permitting is minimized as well disturbance to the existing channel. Thus property or residential structures can be protected with little or no creek impacts.

Vegetated Earth Filled Geogrids

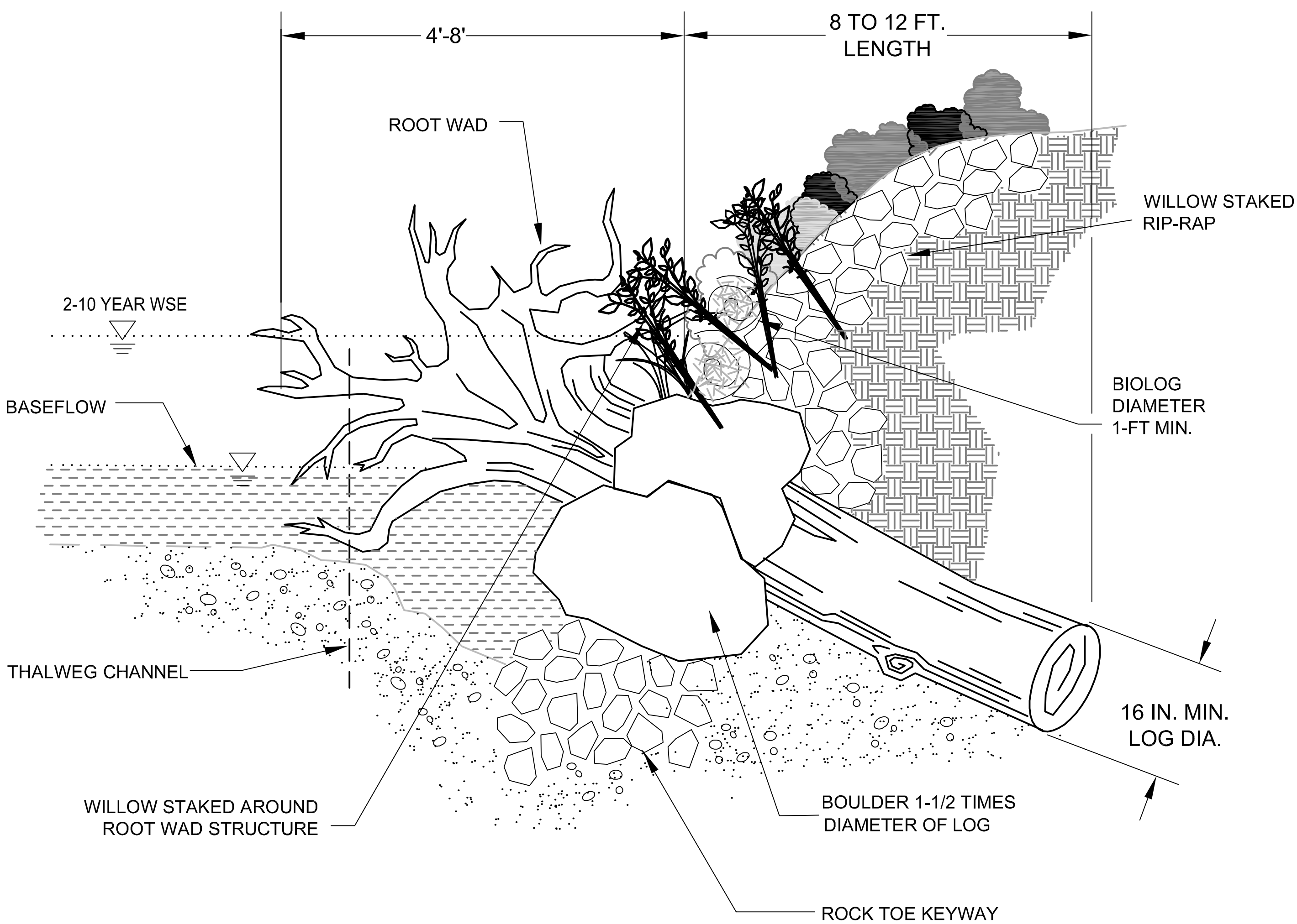
These structures are earth-filled structures enveloped in natural or synthetic geotextile materials (**Figure 19**). The soil lifts are end-wrapped on the creek channel side with layers of live brush or willow cuttings placed between the lifts. Typically, the geogrids are established on a foundation of rock fill, placed on the channel bottom. Vegetated geogrids can be constructed with a slope of 0.5H:1V. Vegetated geogrids can sometimes be an expensive alternative where reconstruction of steep slopes is not required. However, they can be incorporated for several feet above rock riprap toe protection. This technique can be used when a more vertical solution is desired or necessitated.

Live Crib-walls

These structures consist of a box-like interlocking arrangement of log, timber, or concrete members that are backfilled with layers of soil, and with live brush cuttings extending through openings into the channel bank and open channel (**Figure 20**). Properly designed, they can withstand very high channel velocities and shear forces. Since they are somewhat inflexible, a stable foundation and protection from scour and undermining are critical. Live crib walls can be constructed nearly vertical.

Modular Pre-cast Units

Interlocking modular pre-cast units of different sizes, shapes, heights, and depths have been developed for a wide variety of applications. Units with void areas can allow the establishment of vegetation. They provide verticality in tight areas as well as durability. Many types are available with textured surfaces. They also act as gravity retaining walls. They should be



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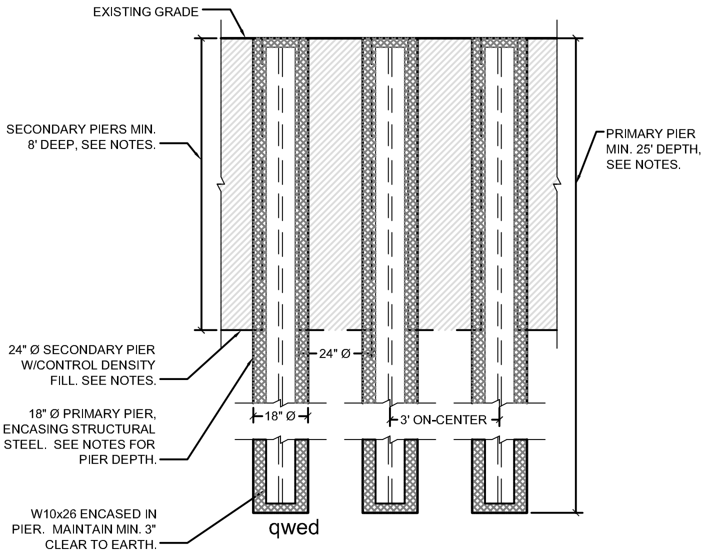

STITCH PIER ELEVATION VIEW

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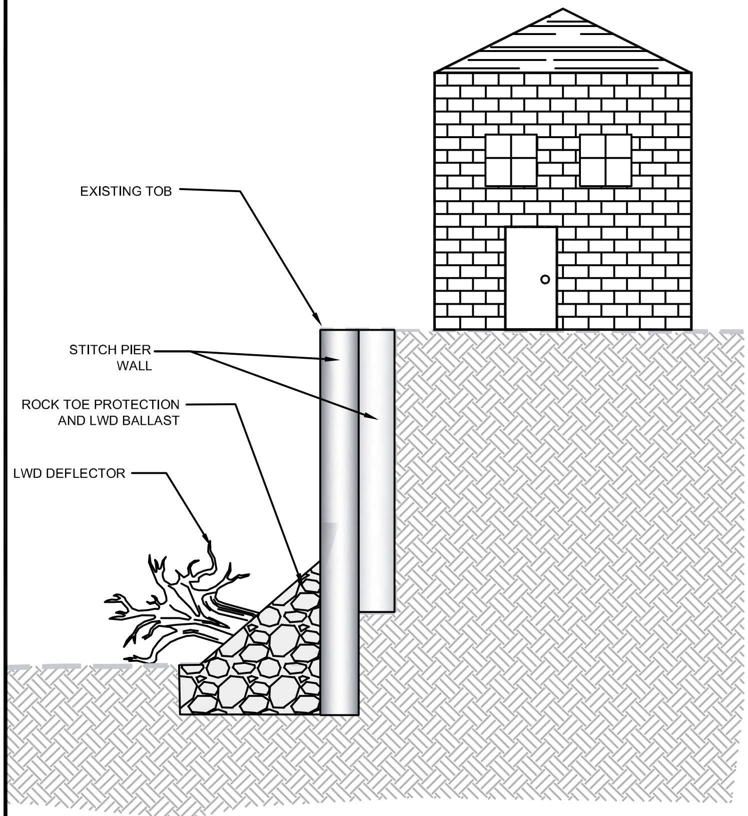

SECTION VIEW

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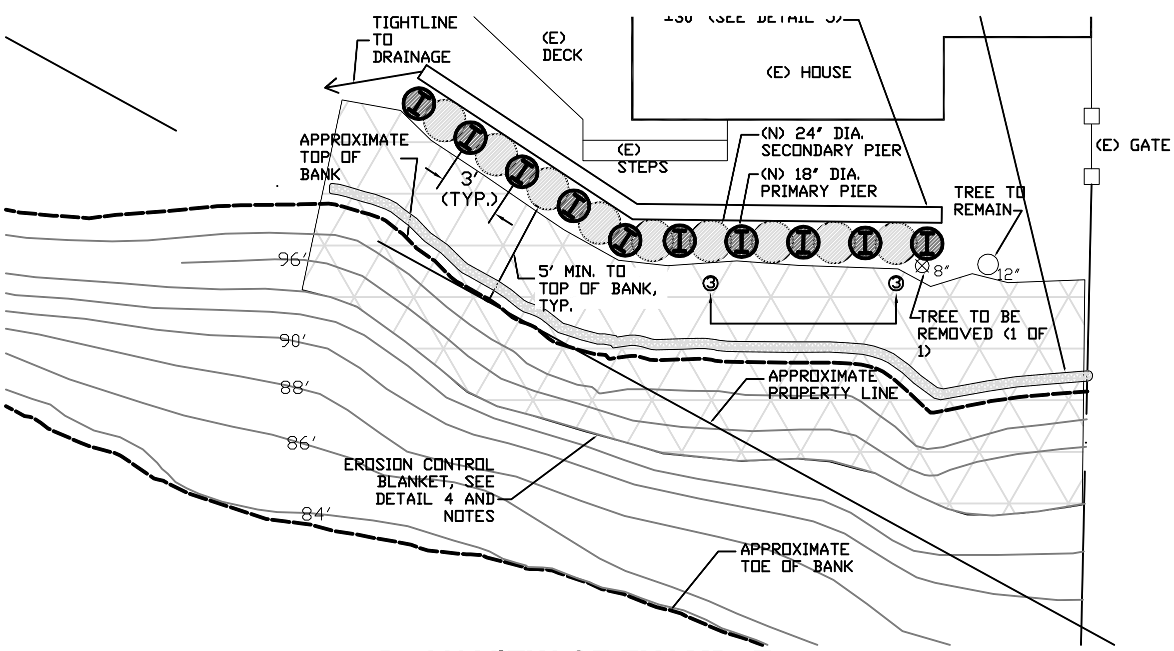

PLAN VIEW OF EXAMPLE

LWD NOT SHOWN

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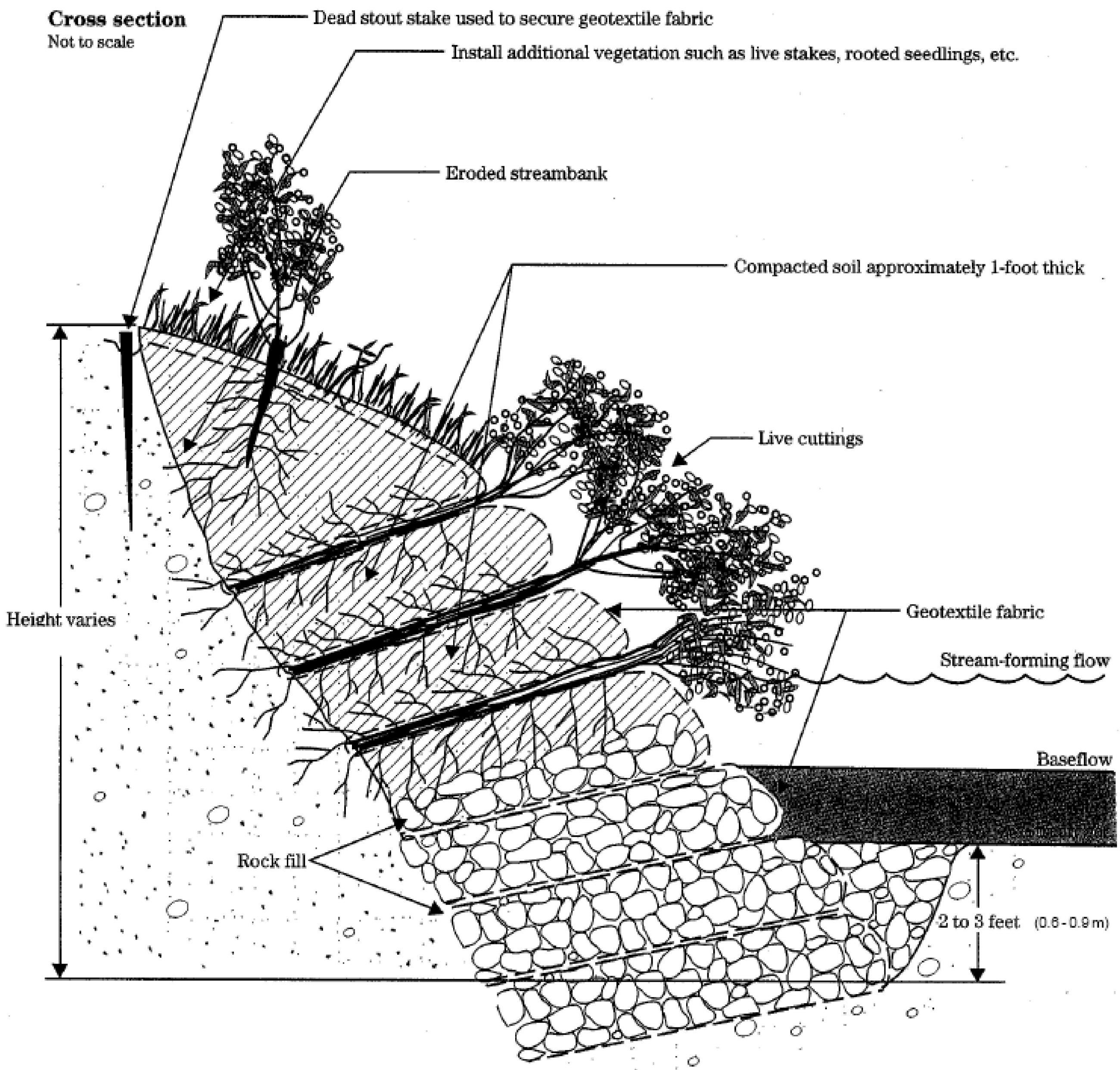
STITCH PIERS

FIGURE

18



Note: Rooted/leafed condition of the living plant material is not representative of the time of installation.

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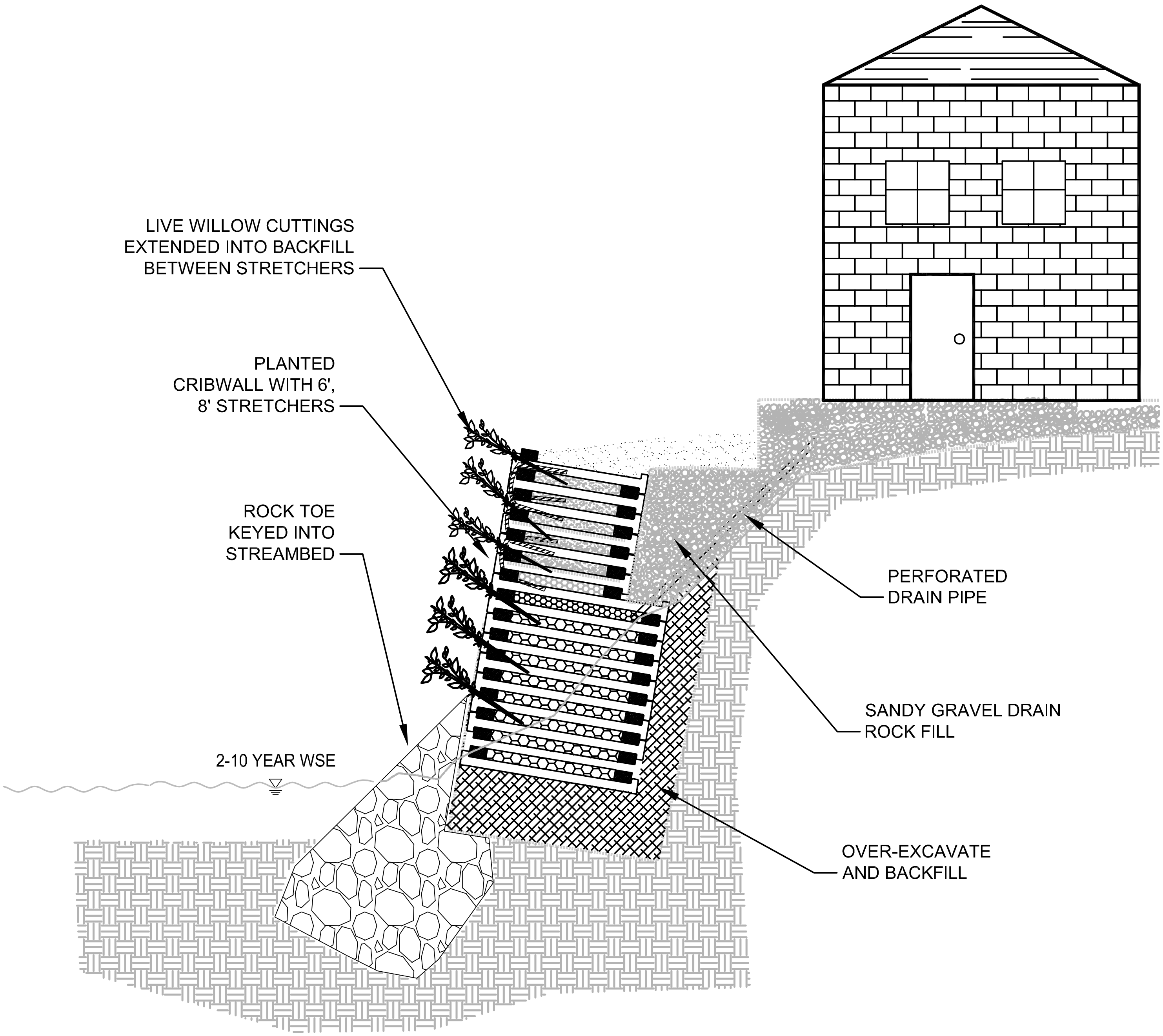

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VEGETATED CRIB WALL AND ROCK TOE

FIGURE 20

designed and installed in accordance with the manufacturer's recommendations. These can also be used in conjunction with toe scour protection.

Stabilization and Habitat Enhancement Treatments for Cut and Fill Solutions

Planted Rock Revetment

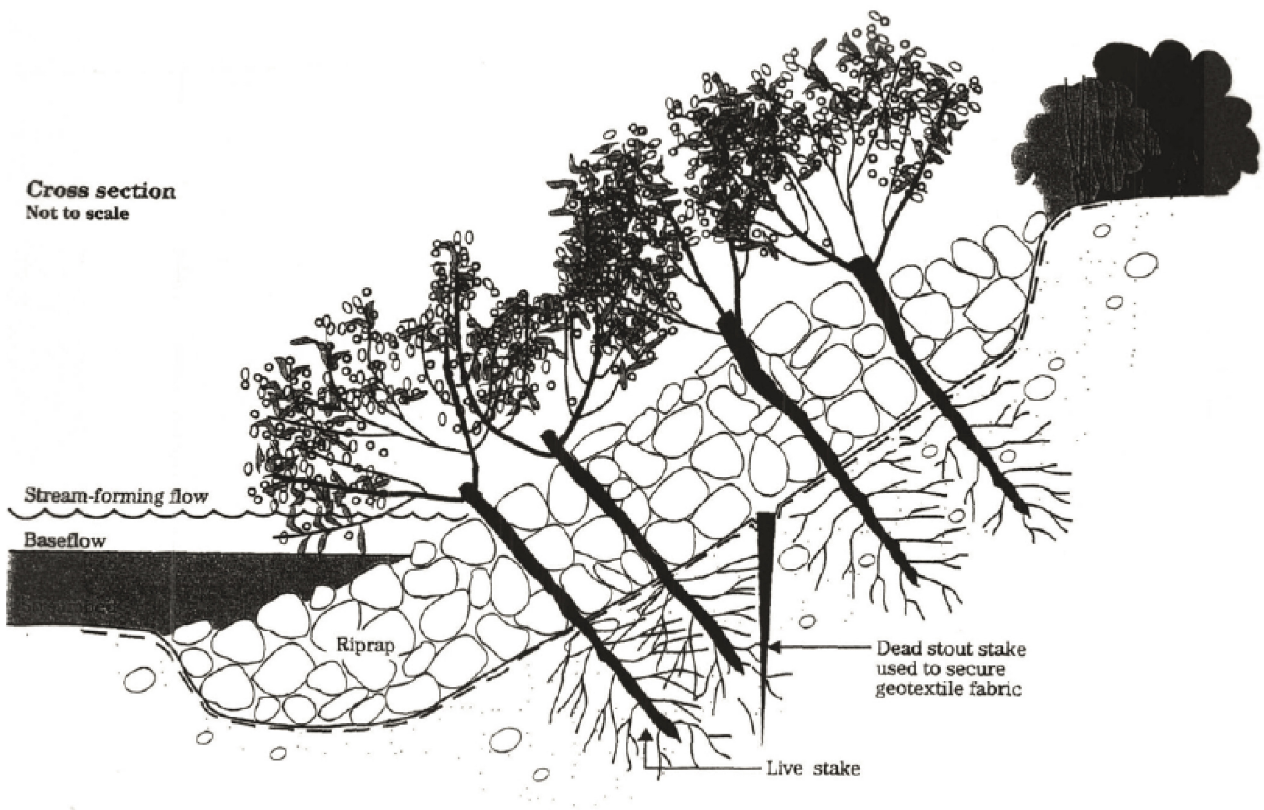
This treatment consists of a specially constructed rock riprap structure that has soil and live stakes (usually willows, sometimes cottonwoods) inserted into the open voids or joints between the rocks (**Figure 21**). Design issues include selection of rock size and gradation, depth of toe placement, and height on the embankment in consideration of flow velocities, flow depth, and scour depth. The objective is to limit the height of the structure while also limiting encroachment into the channel or top of bank zone necessitated when laying the slope back. The rock structure is best constructed in stages or lifts working up-slope to allow insertion of soil and live willow stakes. Planted rock riprap has been constructed on slopes as steep as 1.25H:1V, but 2H:1V or 2.5H:1V slopes are more common. Because of its relatively low cost and proven track record, this is often the preferred toe protection alternative.

Loose Rock Revetment

This treatment consists simply of placement of rock on existing slopes grades with little or no slope preparation. Generally a toe structure is not constructed. The advantage of this method is that rocks can be placed around obstacles such as trees. The disadvantage is that the finished embankment is not as stable as a properly engineered and constructed slope, because of the possible lack of toe support and the fact that frequently the slopes are steep, to 1H:1V. Sometimes pipes are driven into the toe of the channel to provide support for the looser rock. This technique requires careful selection and placement of rock material. As with planted rock riprap, live willow stakes can be inserted in voids between rocks. Loose rock can often be used as a transition structure upstream and downstream from the main bank protection element.

Vegetative and Biotechnical Techniques

Revegetation is one of the most useful and successful forms of biotechnical bank stabilization. However, due to the significant canopy cover through the project sites, this will have to be determined on a site-by-site basis, depending on the amount of available light. Moreover, many sites are almost entirely devoid of direct sunlight, making it extremely difficult to revegetate with any reasonably fast growing species. Cutting back some overhanging limbs could potentially reduce canopy cover, allowing more light. At sites with sufficient sunlight, willow stakes will be planted and used in conjunction with other engineering solutions. Consequently, available sunlight will play a critical role in the bank stabilizing design at a given site. **Tables 10** and **11** showed typical canopy cover percentages for various sections of both reaches. A visual assessment of canopy cover by an experienced professional should be conducted prior to selecting vegetation for bank stabilization. The limitations of sufficient canopy cover do not completely rule out biotechnical approaches. Rooted shade-tolerant vegetation, such as creek dogwood (Cornus sericea occidentalis), Box Elder (Acer negundo californica), California Bay (Umbellularia californica), Native Blackberry (Rubus vitifolius), Deer Fern (Blechum spicant), and California Blackberry (Rubus ursinus), can be used in these conditions. A full list of available plant species for varying canopy conditions is provided at http://mcstoppp.org/Plants.htm, courtesy of the Marin County Flood Control District.



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PLANTED ROCK REVETMENT

FIGURE 21

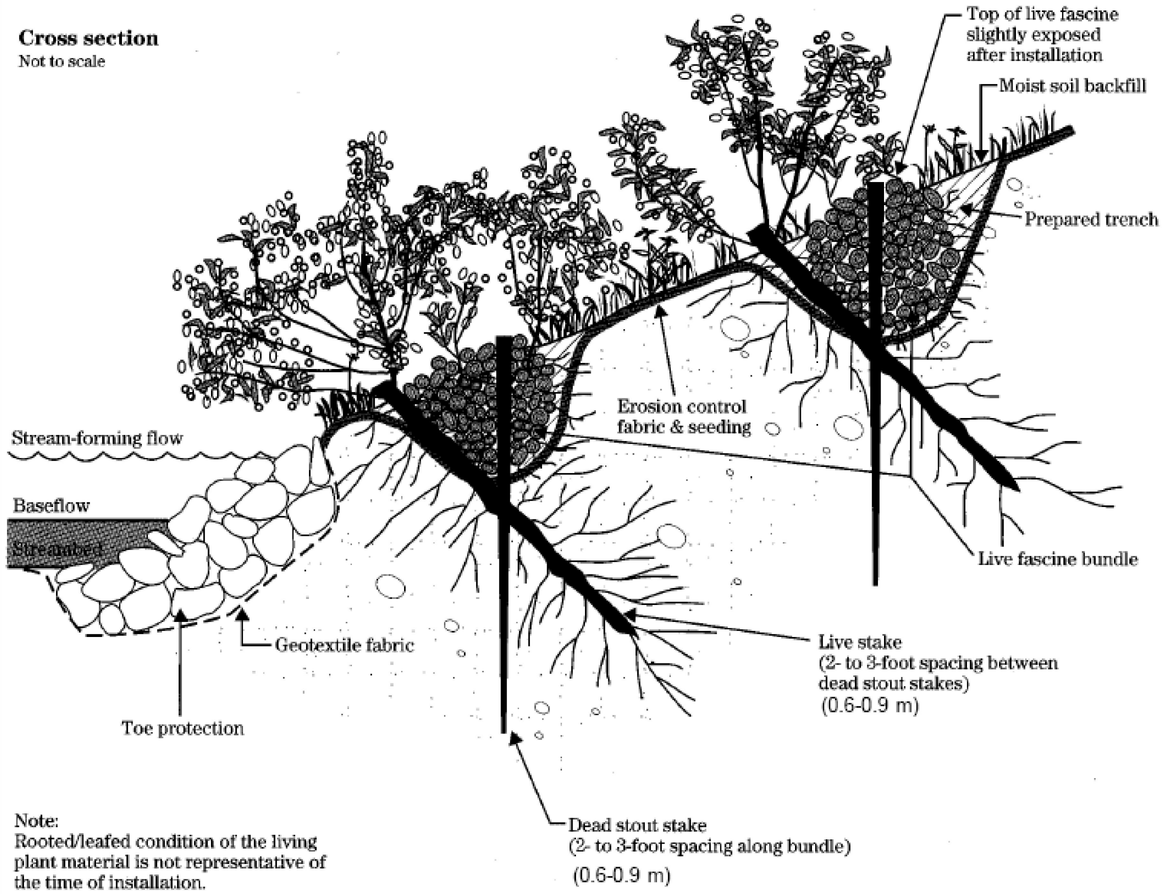
In selecting an approach using biotechnical methods, the following should be considered:

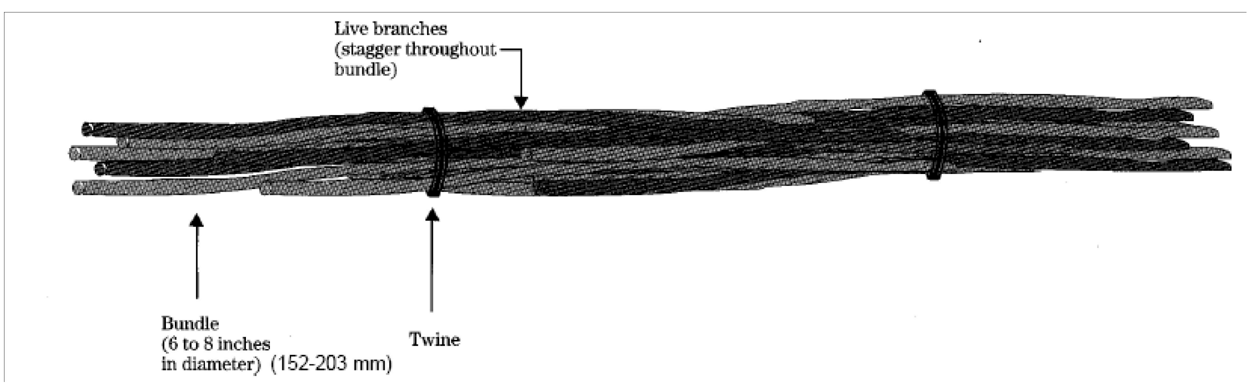
1. Vegetative and biotechnical methods require a "grow-in" period and may require temporary erosion control products, such as biodegradable erosion control fabrics, coconut fiber logs or blocks, and supplemental seeding.
2. These methods typically are not strong enough to provide toe protection, particularly at channel bends, where shear forces are highest and where most of the initial failure occurs. They typically work best from OHW to above. OHW corresponds roughly to the bankfull depth, which for both reaches is 3 feet above the bottom of the channel.
3. These methods typically can provide stability into the bank only 3 to 5 feet deep and cannot address deeper-seated failure zones.

- **Live Staking and Willow Wattling**. These techniques utilize live cuttings or slips of sprouting and fast growing riparian plants to stabilize bank slopes by buffering flow with aboveground foliage, while providing soil stabilization with root growth. Willow wattles (also called live fascines) are long bundles of branch cuttings bound together in cylindrical structures (**Figure 22**). They are placed in shallow trenches on contour. They are principally used to prevent slope erosion and very shallow slumping and rilling**.** Since these techniques rely on rapid plant growth for stabilization, they are best used on sunny sites, or in combination with erosion control blankets at most bank repair sites. The MCFCD (415-499-6528) can provide guidance as to where willow stakes can be harvested.

- **Erosion Control Fabric Planted w. Rooted Trees/Shrubs**. This technique involves preparing a smooth surface along the upper bank, seeding with grass and appropriate fertilizer, and covering this surface with an appropriate biodegradable erosion control fabric (**Figure 23**). The erosion control fabric provides temporary protection against surface rilling and gullying while the grass becomes established and, when properly installed and stapled to the ground, can provide protection against scour from high stream flow. Rooted native trees and shrubs, selected based on the sun and water availability on the bank, are planted through the erosion control fabric at relatively close spacing. These plantings are then irrigated periodically for several years until they become permanently established and can be counted on for permanent scour protection for the upper bank. This is one of the most labor-intensive upper bank protection techniques and is the preferred alternative for projects where toe erosion or stream velocities are not high or where equipment access is poor. At some locations, use of rock toe protection is needed with this technique.

- **Erosion Control Fabric Planted with Rooted Trees/Shrub**. This technique is also called branch packing. It consists of constructing a slope fill section by alternating layers of live sprouting branches and compacted earth backfill. The front of the live branches should protrude slightly into the channel, while it is important that the butt ends contact native bank soils at the rear of the fill. Brush layering can be used to repair small, localized slumps and holes in stream banks. The upper limit of the fill section should be less than 9 or 10 feet in thickness, while depth can extend back 8 to 10 feet. Fill sections are designed in consideration of soil conditions, slope, and water velocities. Typical





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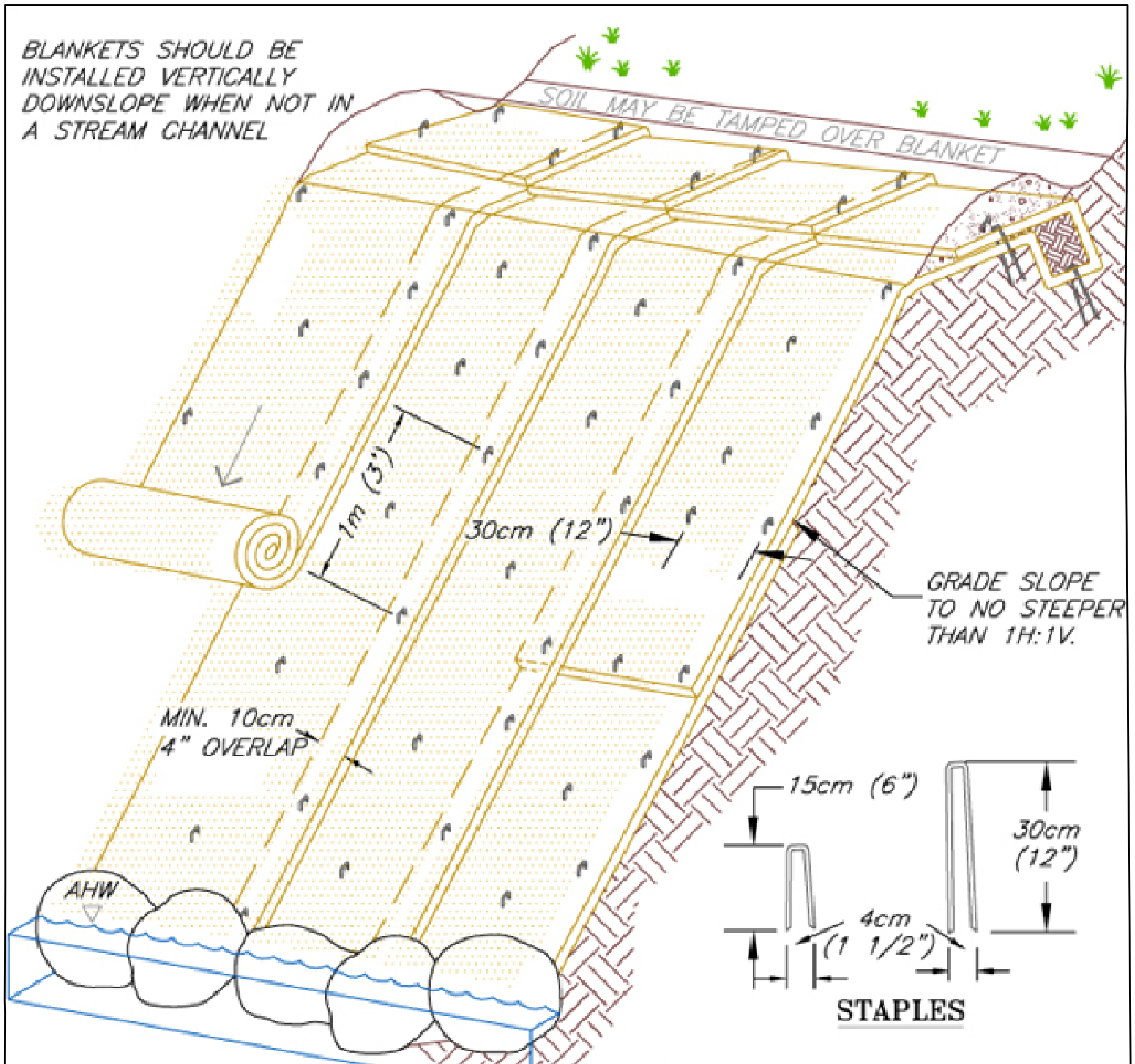
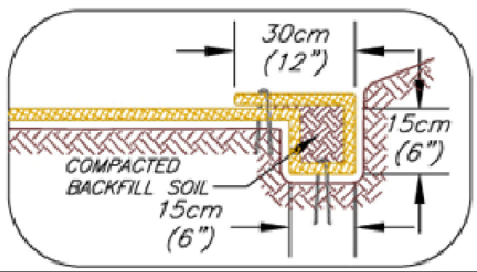


ISOMETRIC VIEW



TYPICAL SLOPE SOIL STABILIZATION

NOTES:

1. SLOPE SURFACE SHALL BE FREE OF ROCKS, CLODS, STICKS AND GRASS. BLANKETS SHALL HAVE GOOD SOIL CONTACT.
2. APPLY PERMANENT SEEDING BEFORE PLACING BLANKETS.
3. LAY BLANKETS LOOSELY AND STAKE OR STAPLE TO MAINTAIN DIRECT CONTACT WITH THE SOIL. DO NOT STRETCH.
4. CAN ALSO USE FASCINES IN LIEU OF POINT ATTACHMENTS FOR BETTER CONTACT (SEE DESIGN GUIDELINES).

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EROSION CONTROL BLANKET

FIGURE **23**

vertical section spacing ranges from 3 to 5 feet, and slopes as steep as 1.5H: 1V can be constructed. This technique has limitations on dry or shady sites.

- **Brush Mattress**. A brush mattress is a combination of live stakes (usually willow), live fascines or willow wattles, and branch cuttings installed to cover and stabilize eroding stream banks (**Figure 24**). They are usually twine or wire constructed and held in place using stout stakes as a sort of cross-laced grid system to hold the brush down until some of it begins to sprout. This method can be used to form a live armor against fast-flowing water with abrasive power, but is less effective in combating toe scour or slumping. The brush layer is usually cross-tied to the slope using stakes and rope or wire. Adequate channel flow capacity must also exist. This technique is best used where banks are not particularly steep or high.

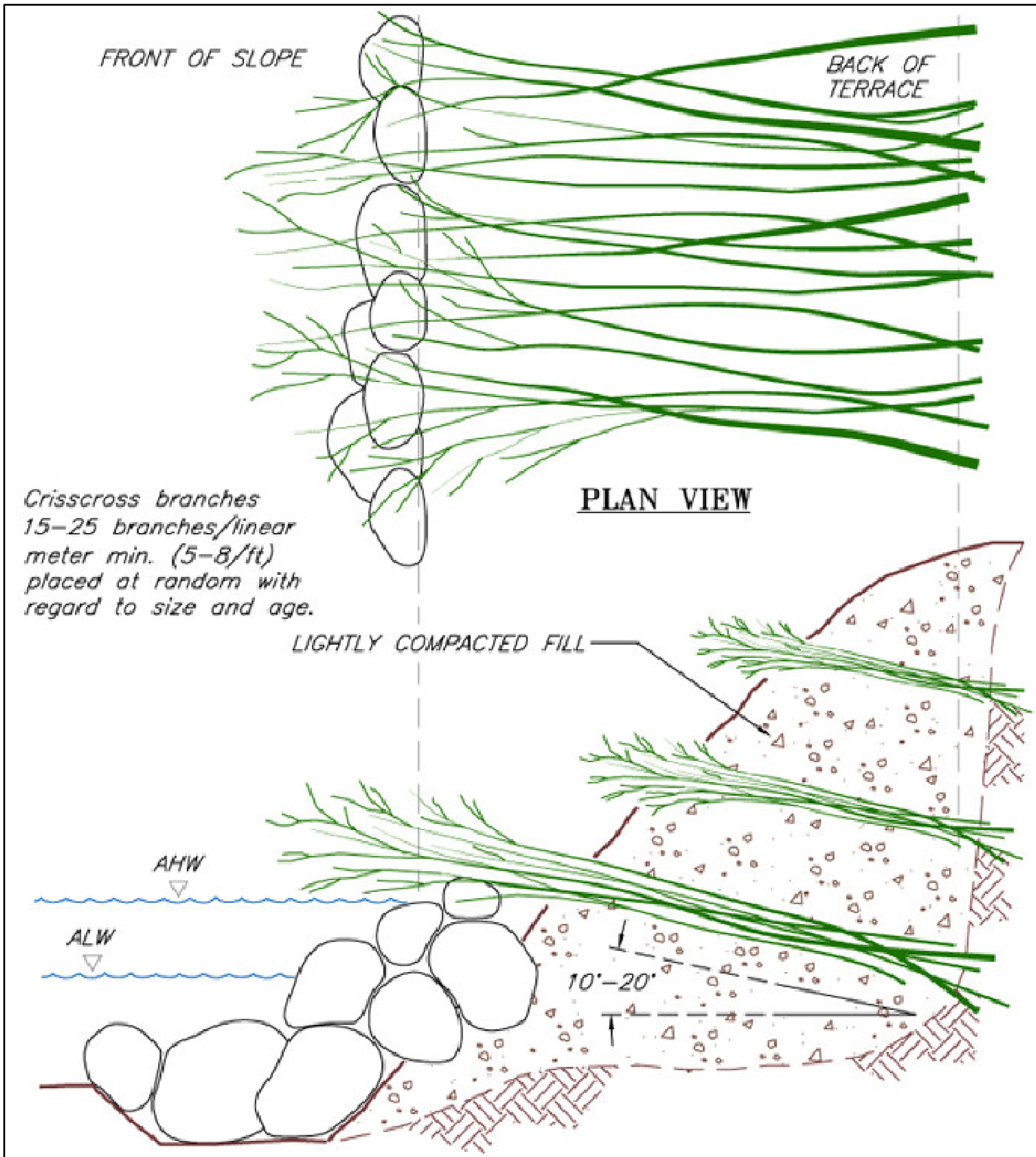
- **Fiber Rolls/ Fiber Rock Rolls/ Coir Erosion Blankets.** Fiber rolls are cylindrical structures filled with coconut husk fibers bound together with twine woven from coconut (**Figure 25**) Typically they are available in 12- or 18-inch-diameter sizes and 10- to 20-foot lengths. Fiber rock rolls are similar, except that the twisted twine encasement is constructed of long-lasting synthetic rope and the structure is filled with rounded stream cobbles, sometimes available on site. Often several rolls are stacked atop each other with the lowest structures composed of rock rolls buried in a trench and anchored using hooked rebar, with fiber rolls (sometimes called biologs) placed atop. These structures are very flexible and adaptable, conforming to irregularities of the bank with little need for excavation and site disturbance. The fiber rolls can also be used to transition upstream and downstream from planted rock riprap sites. Often they can be entirely constructed using hand labor. Live willow stakes are inserted through or between the rolls, which gradually degrade as they trap sediment. Many times a biodegradable erosion blanket and live willow staking is used on the slope above the roll-stabilized toe. This alternative should often be used as a transition between harder techniques and upstream/downstream unprotected banks.

In-Stream Structures and Habitat Enhancement

The following in-stream features can provide some protection to eroding stream banks. They are primarily intended to increase aquatic habitat value and to be used in conjunction with other bank stabilization methods. A careful hydraulic and geomorphic analysis should be conducted prior to their use. These techniques should be incorporated into some projects.

Flow Deflectors/Rock Spurs

Flow deflectors/rock spurs consist of rocks and rock-log combinations arranged diagonally from the stream banks and protruding into the stream channel (**Figure 26**). They are placed and oriented so as to redirect the stream flow away from the failing bank to strike the opposite bank or bar and promote scour and low-flow meander. The pools created in this manner provide important rearing habitat and cover for fish. It may be necessary to protect both the repair site and the opposite bank with a revetment or armoring device. These devices must be used carefully in urban settings because the redirected flow can destabilize downstream embankments.



NOTES:
1. Tilt branches down into the slope 10°–20° min.
2. Brushlayering may be constructed with non-compacted or compacted backfill without damage to the brush layer.
3. Branches irrespective of length, should protrude 20–45 cm (8–18in.) beyond the face of the slope.

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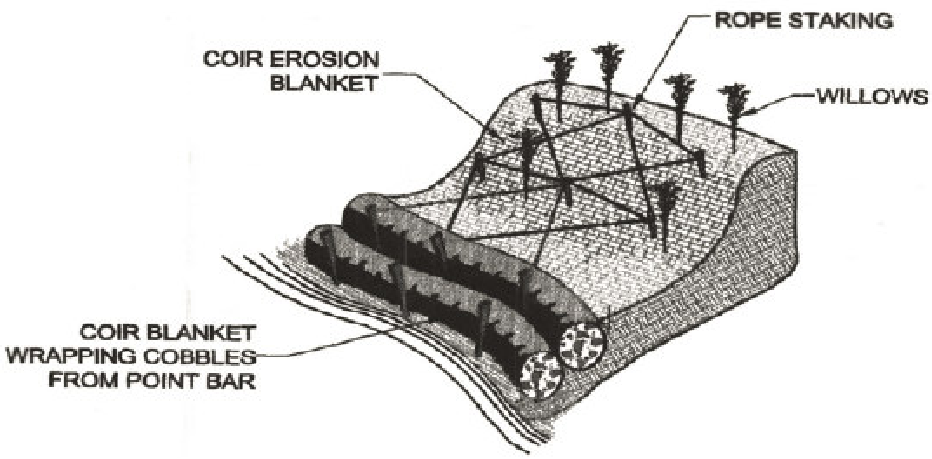
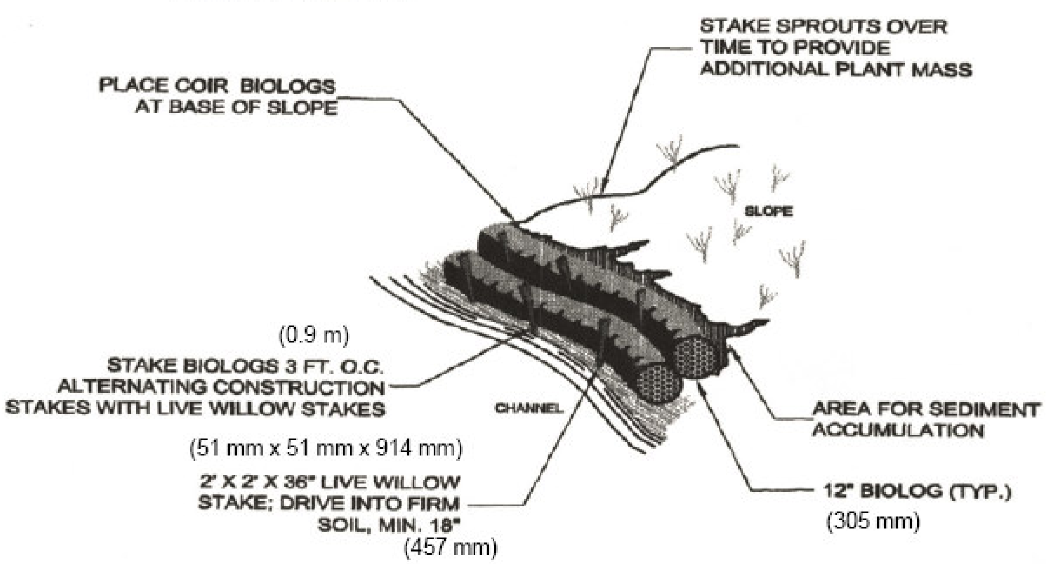
BRUSH MATTRESS

FIGURE **24**



FIBER ROCK ROLL



BIOLOG TOE PROTECTION

Date: 5/16/2007	QUESTA ENGINEERING CORP. Civil Environmental & Water Resources	COIR LOGS	FIGURE 25
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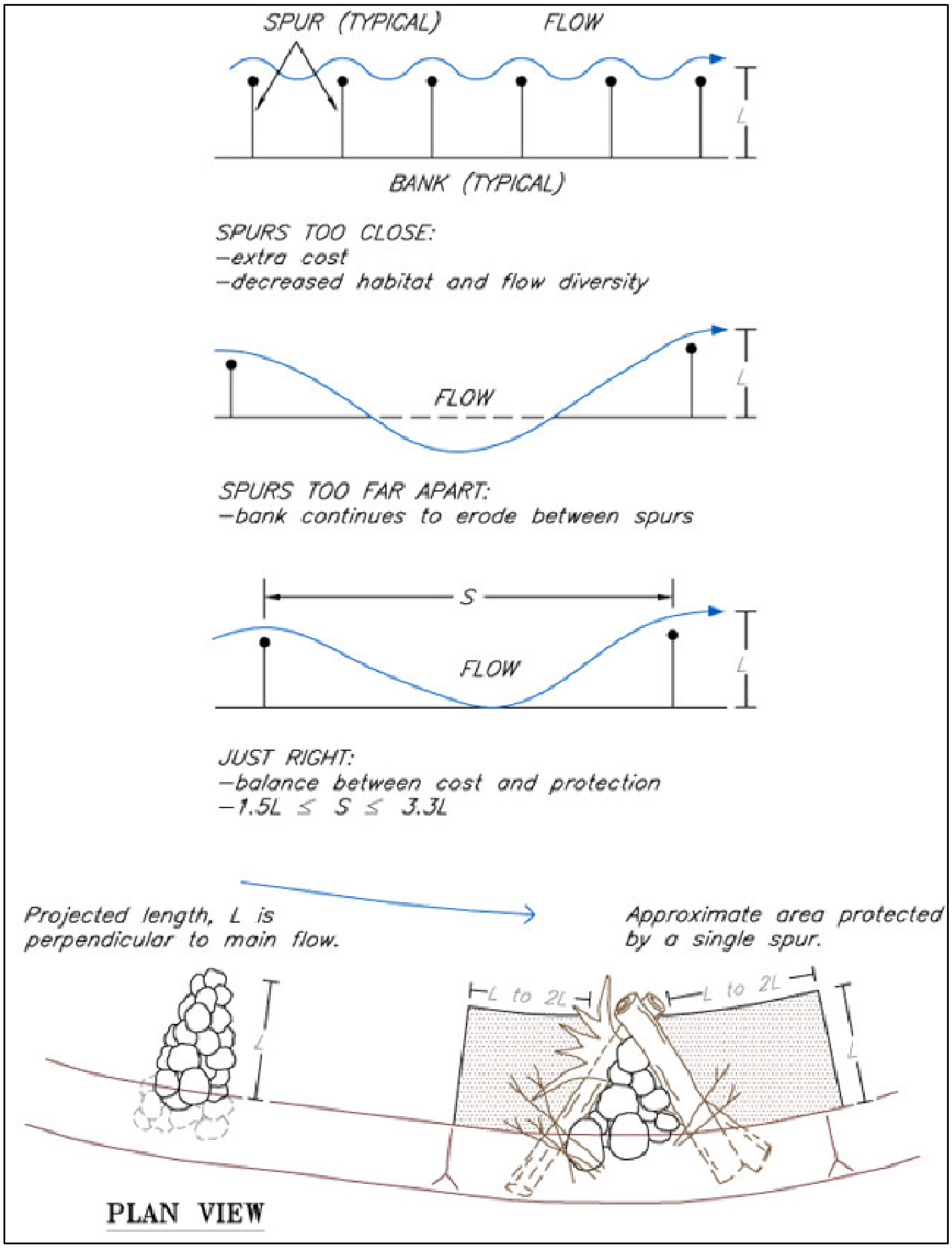

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SPUR DIKE/ FLOW DEFLECTOR

FIGURE

26

Log, Rootwad, and Boulder Revetments

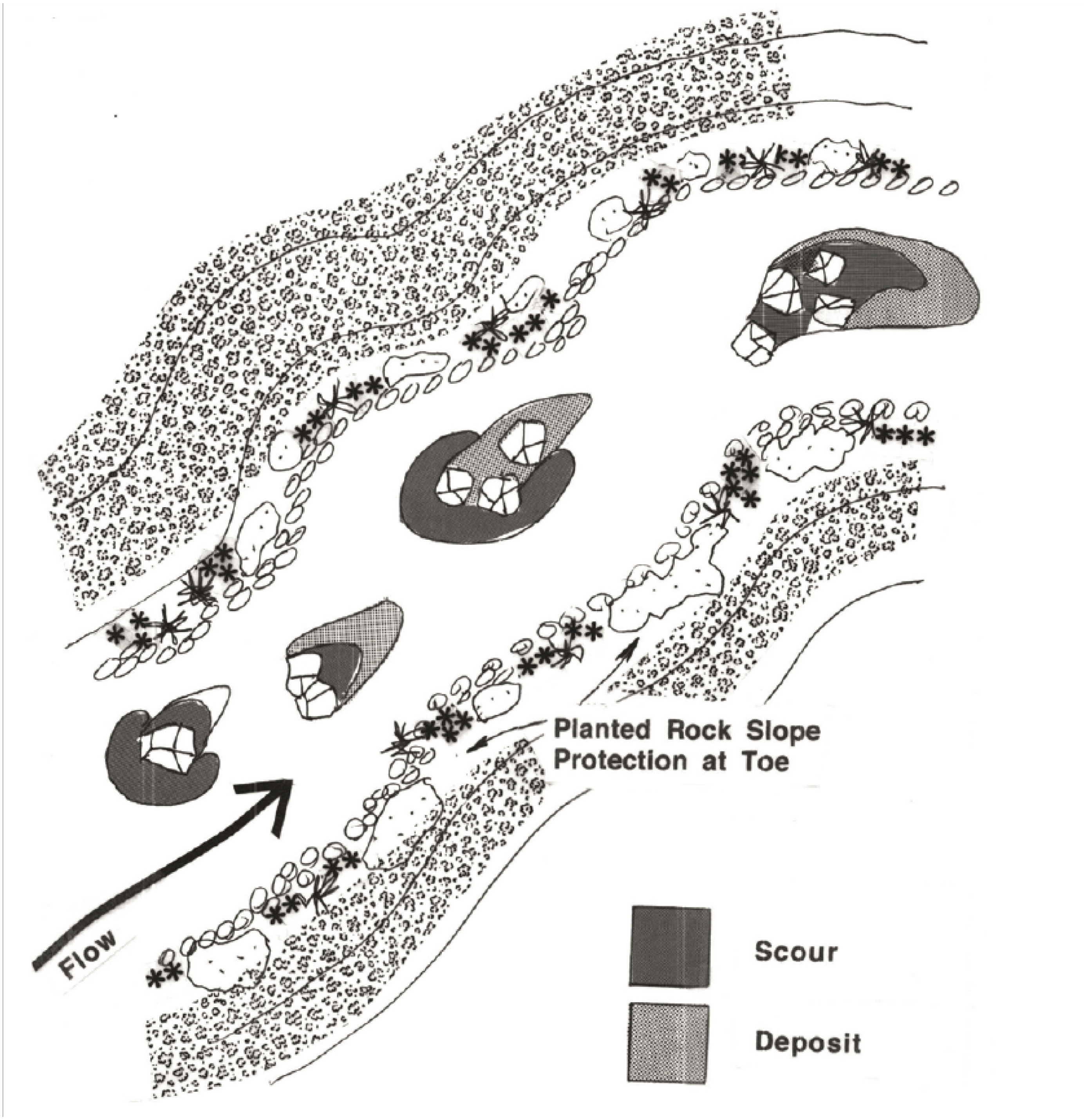
Log, rootwad, and boulder revetments are composed of logs, rootwads, and large boulders selectively placed in and on stream banks. Generally boulders and cables are used to anchor the woody debris. These structures provide excellent hiding habitat and local scour holes, but can deflect flow at the bank toe and undermine bank stability. A vegetated geogrid can be constructed atop the rootwad-boulder revetment. If large flat-oblong rocks are carefully selected and placed at the base of the slope, along with cabled logs, slopes as steep as 1.25H:1V can be constructed. As with all bank stabilization structures, keying into the toe and channel bank are critical to their performance. This technique requires considerable contractor experience, skill, and care to construct, and there is a high degree of uncertainty in the performance and hydraulic impacts of these structures. Because of design and engineering uncertainties, these structures are best utilized in natural areas that do not have high-value structures at bank top.

Boulder Clusters and Rock Vortex Weirs

Boulder clusters (**Figure 27**) can be used to redirect stream flow and reduce flow velocity. Typically, a boulder cluster consists of three or more boulders, with the largest placed upstream to protect the smaller boulders from washing out at high flows. The boulders should be partially buried using a footer rock. Generally flat-oblong (not round) rocks are selected for use. The area around and under the boulders provides fish with escape cover. It may be desirable to also create fast moving water by placing boulders in a cluster to constrict flow (rock vortex weir), and strategically place clean gravels and cobbles downstream of the constriction. Most often boulder clusters are used to provide compensation or mitigation for project elements that fill pools. Such areas are important for insect production and water oxygenation. Downstream boulders create plunge pools, and scour pools may develop and provide fish resting and feeding areas. The best fisheries habitat is provided where overhanging banks provide cover and bank slope vegetation shades the stream.

Lunker Structures

Lunker structures are designed to provide artificial overhanging shade and protection while serving to stabilize the toe of a stream banks (**Figure 28**). They are constructed from wood or plastic lumber and resemble a sort of rough, large coffee table in appearance. They are preconstructed, set in place at the toe of a stream along the outside of a bend, and filled around and on-top with planted rock or geogrids. Placement is critical to insure that they stay submerged and provide critical summer low flow habitat, and do not become filled with sediment. These structures are also used to compensate for lost aquatic habitat, or as part of a stream enhancement project.



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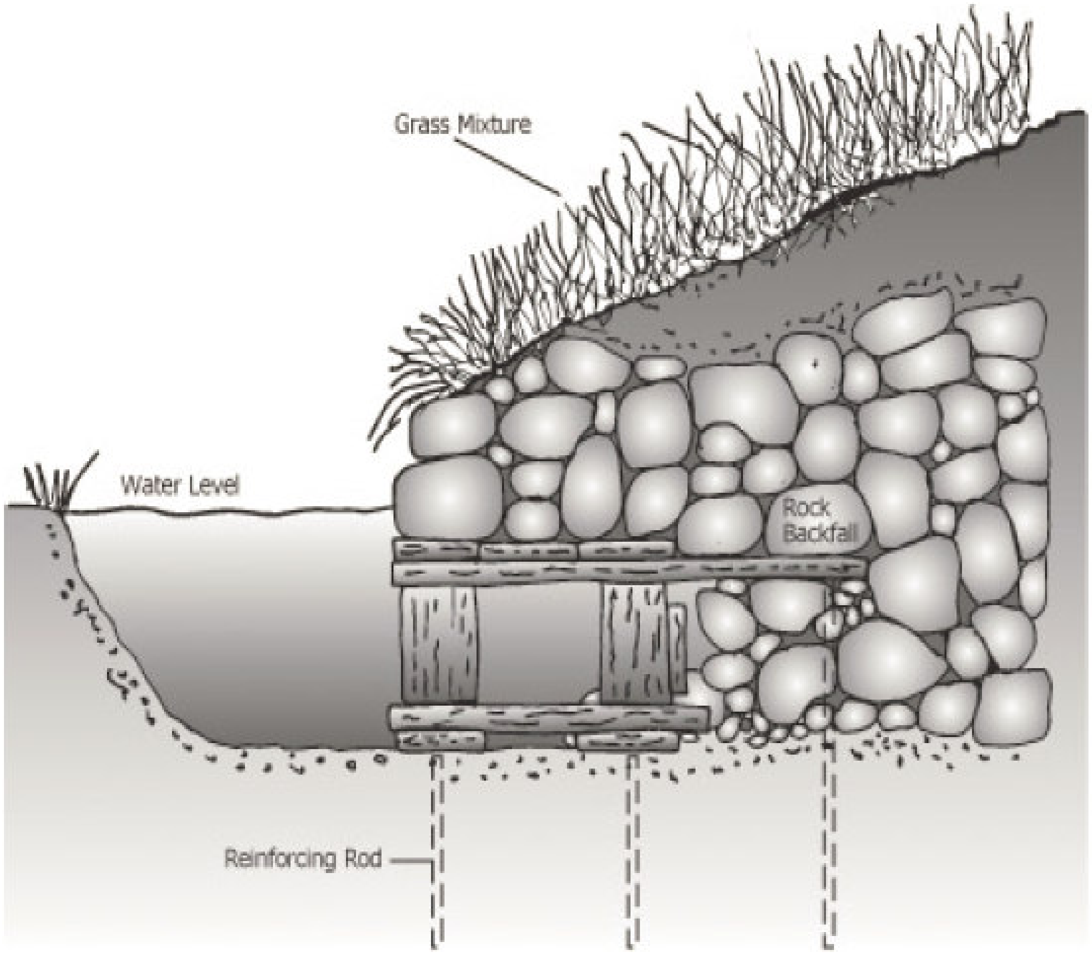
BOULDER CLUSTERS

FIGURE 27



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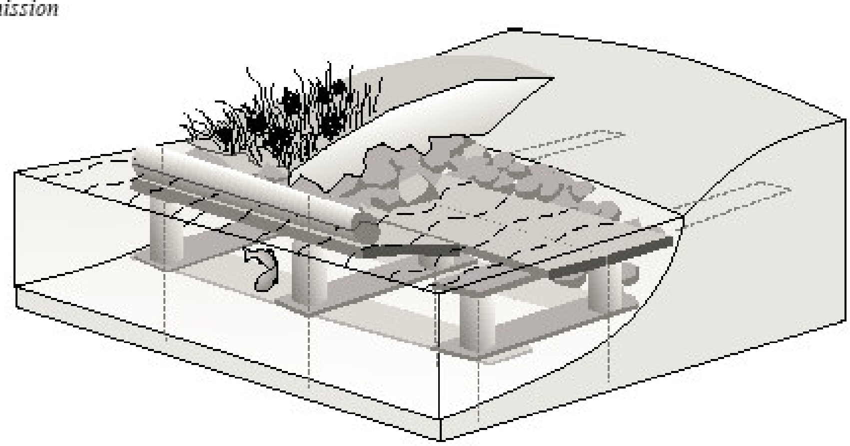

"Stream Corridor Restoration: Principles, Processes, and Practices, 10/98, by the Federal Interagency Stream Restoration Working Group (FISRWG)."

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LUNKER

FIGURE 28

The following are additional references for the design of in-stream habitat structures:

- *Flossi, G., S. Downie, J. Hopelain, M. Bird, R. Coey, and B. Collins, 1998.*
- *California Salmonid Stream Restoration Manual State of Calif. Dept. of Fish and Game, Sacramento, CA.*
- *Hunt, R.L., (1993) Trout Stream Therapy, University of Wisconsin Press, Madison, Wisconsin.*
- *Hunter, C., (1991) Better Trout Habitat: A Guide to Stream Restoration and Management, Island Press, Covelo, California.*
- *Riley, A., (1998) Restoring Streams In Cities: A Guide for Planners, Policymakers and Citizens.*
- *Newbury, R., M. Gaboury, and C. Watson, (1999) Field Manual of Urban Stream Restoration Conservation Technology Information Center, W. Lafayette, Indiana.*

CONCLUSION

Streams are dynamic—they are rarely static. They play an important part of our ecosystem and our society. Throughout history humans have been drawn to streams and major civilizations have been built around river systems. They provide food, water, economic benefits, and respite. Streams are constantly changing, constantly adjusting to the conditions of their watersheds. Erosion, deposition, and vertical and lateral movement of streams are natural processes that respond to the unique set of watershed variables. Past urban development along streams has created unique management issues by quickly changing watershed variables and initiating geomorphic responses in stream channels. Fifty years ago we did not fully appreciate their dynamic nature and the consequences of development adjacent to their banks. Now we are burdened with the difficult task of balancing human needs in the context of an incredibly dynamic system. Urban bank stabilization is about trying to find that balance between property protection/safety and the ecological and geomorphic needs of a dynamic stream system.

This report has strived to find this balance by assessing the current condition of the Novato Creek, analyzing its hydraulic and sediment transport properties, and using this information to propose techniques and procedures to design and implement the most sensitive bank stabilization schemes possible. The study reaches have been mapped to show the extent of erosion areas, and the existing revetments in the system. We have examined trends in the longitudinal profile and sediment transport. This has lead us to make some conclusions regarding the future geomorphic evolutionary trends in the system. The major findings of this analysis indicate that:

- The creek channel is in the later stages of evolving towards an "urban equilibrium";
- Channel bed degradation has nearly stabilized throughout most of the reach;
- Many places exhibit relatively stable ordinary high water geomorphic geometry; and,
- The erosion dynamic in the future is likely to be lateral creek channel movement.

Using these conclusions, we proposed a decision-making tree that utilizes basic stream geometry measurements, location of adjacent structures, and occurrence of mature riparian vegetation to determine the most appropriate approach to stabilizing an individual property bank. Because each site and property owner are unique, we described and introduced basic stabilization treatments that can be used in conjunction with the overall stabilization approach. This report has purposely avoided mandating specific stabilization measures at specific locations, and instead has strived to outline specific design steps and analyses to be taken by individual property owners to develop techniques and projects that meet their specific needs and budget, while ensuring that aquatic resources and geomorphic balance are preserved to the greatest extent possible. The report is also meant to aid property owners in understanding the design and permit process so they can understand the overall management context, and in the end become better stewards of their property and the creek resources. In the future, it is anticipated that management of Novato Creek will become less a reactionary process to erosion dynamics and more of an ongoing stewardship of the system. This stewardship will entail the preservation of aquatic habitat resources like retention woody debris and pools, the installation of aquatic enhancement features, preservation of stable geomorphic channel geometry, and the management of canopy conditions and riparian vegetation.

REFERENCES

Collins, L. 1998. Sediment Sources and Fluvial Geomorphic Processes of Lower Novato Creek Watershed. Report to Marin County Flood Control and Water Conservation District.

Fishnet4C. 2004. Guidelines for Protecting Aquatic Habitat and Salmon Fisheries for County Road Maintenance.

FISRWG (10/1998). Stream Corridor Restoration: Principles, Processes, and Practices. By the Federal Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US gov't). GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN3/PT.653. ISBN-0-934213-59-3. http://www.nrcs.usda.gov/TECHNICAL/stream_restoration/newgra.html

Prunuske Chatham Inc. 2001. Novato Creek Watershed Erosion Inventory and Sediment Management Plan. Report to Marin County Flood Control and Water Conservation District.

Rich, A. 1996. Fishery Resource Conditions From Diablo Avenue to Grant Avenue. Report to Marin County Flood Control and Water Conservation District.

Trush, W. McBain, S., Leopold, L. 2004. Attributes of Alluvial River and their Relation to Water Policy**.** *Proceedings of the National Academy of Sciences of the United States of America*, 97:22

APPENDIX A.
DESIGN AND PERMITTING OF BANK STABILIZATION STRUCTURES

General

This appendix provides the recommended approach for the design and implementation of public and private bank repair and protection projects on Novato Creek. It is intended to inform private property owners and public resource managers about the effort and analysis that should be taken to design and implement bank stabilization measures. Due to the great variability in conditions within the watershed, stream bank erosion control and bank stability design should be based on site-specific conditions, including:

- Site biological resource values;
- Physical conditions such as bed slope, channel roughness, location (inside or outside of channel bend), soil type and geotechnical stability requirements;
- Hydraulics, including flow velocity and shear forces, and;
- Characteristics of the channel and adjacent site including the available right-of-way, and structures at the top of bank.
- Design Approach Decision Tree (**Figure 15**)

The design team should place emphasis on the assessment and understanding of the overall geomorphic and general characteristics of the stream reach. These conditions have been previously discussed and presented in the body of this report.

Design Goals and Design Requirements

The goals of the design process are to ensure selection, design, and construction of a project that:

1. Is stable over the long term;
2. Is the most environmentally sensitive and beneficial;
3. Does not induce other local stream instabilities, and;
4. Enhances riparian and aquatic habitat.

Biologic, geotechnical, geomorphic, and hydraulic analyses described here should be completed prior to the design of bank repair structures.

Vegetative or biotechnical slope repair and bank stabilization techniques will be the preferred approach on Novato Creek. Where biologic, geomorphic, hydraulic, and geotechnical studies indicate that "hard" elements such as rock rip-rap or retaining structures are required, vegetation must be included in the design in an "integrated" project approach. Native plant revegetation of the bank top and adjacent bank slope areas, to the maximum extent feasible, is also an important component of a project. The type and density of vegetation will be dependent on the method of bank protection used and the physical properties of the stream bank, such as the amount of light the site receives.

Stream bank stabilization usually involves one or a combination of the following activities:

- Regrading and revegetating the stream banks to create a more stable slope;
- Deflecting high velocity water flow away from vulnerable sites;
- Altering the geometry of the channel to influence flow velocities and sediment deposition;
- Armoring or protecting the bank to control erosion, particularly at the toe of slope.

Armoring the bank takes a variety of forms, some of them structural, but most capable of incorporating revegetation as an essential component. The optimum, or preferred, treatment at any location along a creek is to be a function of:

- Existing bank conditions;
- Proximity of structures;
- Appropriate geomorphic geometry;
- Cost, and;
- Environmental impacts.

The least environmental damaging solution feasible must be selected.

Determination of the appropriate bank erosion control method should be based on an inspection of the stream upstream and downstream of a project site to determine if there is an identifiable cause of the erosion. In some cases, the cause of erosion is obvious, such as a blockage (e.g., downed tree), or weak stream banks of silt or gravel. In other cases, a further inspection is necessary to determine if flows are being directed toward the bank from a source upstream, or whether the channel (bed) is down-cutting. These factors can affect selection of the bank protection technique to be implemented.

Design Steps

A **seven (7)-step** approach should be used in project planning, design, and review for all bank repair and bank stabilization projects located on Novato Creek. Conformance with the steps listed herein is highly recommended. This detailed analysis and design approach is geared to larger project sites. It is recommended that individual projects with stream stabilization needs totaling less than **50 feet** not normally be required to conduct a detailed geomorphic and hydraulic analysis and alternatives investigations, unless significant channel modification is proposed. All proposed projects with bank stabilization needs greater than **50 feet** and requiring a grading or building permit for work along a stream bank should be required to meet the submittal requirements of these guidelines.

A team of professionals retained by the property owner, typically including a civil engineer, a biologist, a geomorphologist and/or geotechnical engineer, and a landscape architect or revegetation specialist, should develop a detailed bank stabilization project design. The project design team will need to conduct site-specific studies to adapt the design schematics outlined in previous sections for the project site.

Following is an overview of design steps:

Step 1. Site Evaluation and Analysis

- Identify the problem.
- Determine geomorphic context.
- Determine hydraulic sensitivity.
- Determine sensitive biological resources.
- Conduct geotechnical investigation (where needed).
- Compile a scaled site map.

Step 2. Develop and Screen Alternatives

- Define goals and objectives of the stabilization project.
- Develop and screen stabilization options and alternatives.
- Select Preferred Alternative

Step 3. Develop Concept Plan

- Develop and refine Conceptual Bank Stabilization Plan that summarizes the results.

Step 4. Project Approval and Permitting

- Complete and submit permit applications to:
  - U.S. Army Corps of Engineers Sect. 404 Permit
  - Regional Board Water Quality Certification
  - Fish & Game Stream Bed Alteration agreement
- Review for compliance with City/County Policies and Requirements.
- Submit to the City/County for California Environmental Quality Act (CEQA) review and compliance.
- Attain local Grading/Building Permits, as necessary.

Step 5. Construction Drawings

- Submit Construction Drawings for Plan Check review; revise as necessary.

Step 6. Construction Inspection & Monitoring

- Provide for inspection by project engineer and City or County Building/Public Works Inspector.

Step 7. Post-Construction Maintenance and Monitoring

- Monitor project for erodibility/stability maintenance needs and conformance with mitigation requirements.
- Biological inspection/monitoring for permit conditions and mitigation requirements.

Step 1. Site Evaluation and Analysis

The following describes the types of analysis that should be completed as part of the project design.

Problem Identification and Geomorphic Context. The first step is to determine the cause of the bank stabilization problem. Is the site located at the outside of a meander bend? Has an obstruction in the channel changed flow direction? Has deposition or degradation caused the problem? Is it important to understand the causative factors of the erosion problem? When this is known, appropriate solutions can be devised.

Hydraulic Sensitivity. There are several ways to determine hydraulic sensitivity. The first involves the use of computer models and should be reserved for larger sites. The second is through site inspection. Are there structures immediately adjacent to the site? Is there a low bank top that appears susceptible to flooding? Is there a downstream erosion site that may be sensitive to a bank repair? Is the site located adjacent to a bridge or culvert? These are questions that should be investigated and discussed as part of the design process.

Biological Analysis. An assessment of existing biological conditions and potential project impacts on riparian habitat, fisheries, and water quality and aquatic species should be completed prior to preparing a conceptual design. Special attention should be paid to characterizing the occurrence of shaded pools and overhanging banks, and the presence of woody debris in the vicinity of the project site. Depending on the creek reach, a protocol search for endangered species may also be required, and appropriate mitigations developed.

A Biological Assessment should be prepared that identifies and maps jurisdictional wetlands (also see the **Existing County and City Ordinances** section), endangered species, aquatic habitat and fisheries protection needs. For small projects this can be included as a section of the Conceptual Design Report. The Assessment should also include recommendations for aquatic habitat enhancement, for instance by recommending the location and placement of such in-stream structures as root-wads or channel boulders to create stable pool features. The California Salmonid Stream Habitat Restoration Manual (www.dfg.ca.gov/nafwb/pubs/1998/manual3.pdf) should be referred to for design considerations for these in-stream structures. The project biologist can also help to determine plant suitability based on local microclimates and soil conditions for riparian habitat mitigation and biotechnical planting selection and specification.

Geotechnical Analysis. In addition to a geomorphic and hydraulic evaluation, a geotechnical review should be completed by a California Registered Geologist, Engineering Geologist or Geotechnical Engineer whenever deep-seated or mass failure is suspect at a site, for proposed vertical retaining structures, or where slopes steeper than 2.50:1V are proposed. The City/County may require such an investigation, based on their review of the site and surrounding area. The geotechnical analysis requirement should include mapping surficial features and failure areas, and a program of drilling and laboratory testing to determine index soil properties and soil shear strengths necessary for geotechnical analysis and design. The drilling and laboratory analysis program may be necessary to describe foundation-bearing conditions and drainage requirements, especially where retaining walls and crib walls are under consideration. Use of a slope stability model such as Slope-W is an efficient way to determine geotechnical stability for banks over 12 feet high. Soil shear strength and engineering index properties, weak soil conditions and potential failure surfaces should be identified and described in a Geotechnical Report, or as a geotechnical section of an overall bank stabilization Conceptual Design Report.

Construction Factors. The design team should also identify site and channel access and work conditions, restricted seasons, mobilization and materials storage areas and needs, and the need for and allowable methods of flow diversion and dewatering. Do not leave these factors up to the construction contractor, but include construction details, limits of work, diversion methods, access and mobilization sites, etc., in the Conceptual Design Report and detail them in the project Plans and Specifications.

Base Map Preparation. It is important to develop an accurate base map to show proposed bank stabilization and habitat enhancement features. Aerial photos can work if tree canopy cover is limited. The City of Novato has a large-scale topographic map available, which may be used, although additional site detail should be added. A base map should have a scale of 1”=20’ or larger.

Step 2. Develop and Screen Alternatives

Define Project Goals and Objectives. It is important to define the Goals and Objectives early on in the bank repair planning process as a tool to be used in formulating and screening alternatives. In particular, Goals and Objectives for habitat protection, restoration, and enhancement need to be determined as part of possible project mitigation requirements. In general, use of a vegetative or biotechnical approach should be given highest consideration. The design should also consider including additional adjacent area, such as top of bank planting, or upstream/downstream aquatic habitat enhancement through installation of channel boulders and root wads.

Most projects should be multi-objective with property protection, bank protection, habitat enhancement, and water quality protection foremost. Common Goals and Objectives include:

- ***Affordability*** - What is the most cost effective solution, and what are the costs relative to other alternatives and benefits?
- ***Acceptability*** - What is acceptable to the property owner, environmental interest groups, neighbors, and local government in terms of biological and water quality impacts, loss of property, appearance, and access and recreation issues?
- ***Permitting*** **-** The plans should be consistent with City and County policy and regulations and should not conflict with state and federal regulations governing activities in navigable waters, wetlands, floodplains, endangered species habitat, and riparian corridors.
- ***Sustainability*** - The project should provide the risk and hazard reduction targeted for the design flow and shear forces at the site in terms of durability and maintenance needs.

Generally a review and evaluation of design alternatives is required by most permitting agencies to ensure that the least environmentally damaging, technically and economically feasible alternative is selected. Alternatives should be developed and evaluated with the following questions in mind:

- ***The No Action Alternative.*** If no action is taken, can the fluvial system heal itself at this location in a reasonable amount of time without causing or contributing to other problems? Is there room for the channel to meander with appropriate setbacks?
- ***The Minimum Interference Alternative.*** If a minimum amount of work is done to "clean and dress" the problem, will the fluvial system heal itself at this location in a reasonable amount of time without causing or contributing to other problems?
- ***Flexible Boundary Alternative.*** Can biotechnical stabilization measures secure this bank? Is canopy cover open enough to allow successful and vigorous revegetation? Is there sufficient capacity to convey the design flow with an increase in vegetative roughness? Is there right-of-way flexibility to accommodate natural geomorphic processes? Is restoration of this reach valuable as mitigation for another problem area?
- ***Rigid Boundary Alternative.*** Is some form of hard bank protection required due to hydraulic constraints, public safety concerns, or to protect from the loss of private or public property, and can the consequences of this approach be kept on-site? Can some vegetation be accommodated with the hard structures?
- ***Integrated Solution Alternative.*** How high up the bank is a rigid structure required? How far laterally? Can a combination of approaches, such as a hard toe and soft vegetated top, work? Can the project transition to stable areas using a soft approach?

- ***Short-term vs. Long-term Alternative.*** Is this a reach that could be better served by inclusion in future, larger scale projects? Is the risk imminent; are there interim solutions that long-term projects can build upon?

Most channel modifications to a creek system can have consequences upstream and down stream from the project area. These consequences should be anticipated and evaluated prior to construction. Impingement into the stream by hard structures can cause a local backwater effect, raising water surface elevations and/or causing sediment accumulation. Channel constrictions from bank repair projects can also accelerate flow immediately downstream, causing scour and increasing bank erosion risk. Hard structures can force and deflect flow against the opposite bank. The hydraulic model constructed to define existing conditions should also be used to evaluate the consequences of alternative channel modifications. Unfortunately, standard one-dimensional hydraulic models cannot determine the consequences of possible flow deflection; this evaluation must be left to the judgment and experience of the project team.

In addition to hydrologic evaluation, geotechnical review and an assessment of potential impacts on riparian habitat, fisheries, water quality, and aquatic species should be completed as a prelude to Conceptual Design so that impacts are minimized.

To be considered potentially acceptable and worthy of further consideration, the bank stabilization approach must successfully meet the following criteria:

- ***Environmental***. The least environmentally damaging alternative consistent with subsequent criteria (cost and durability) should be selected. There should be no net loss of aquatic, wetlands, or riparian habitat from the project design.
- ***Cost***. The design must be cost effective, and have a favorable benefit-cost ratio. The benefits (property protection) must exceed project costs. The incremental environmental benefits from a "softer" approach should not be greatly overshadowed by increased costs.
- ***Durability***. The project must be long lasting, with a design life of at least 25 years. The project should be designed to handle at least the 25-year flood velocities where structures are not at risk, and increasing to at least the 50-year flood velocities where valuable structures are potentially at risk. Comparison of calculated toe shear stress and the shear strength of the stabilization approach is a good test of durability.
- ***Maintenance***. Maintenance costs should be low. Annual maintenance costs should typically be less than 1/20th of the cost of the structure.
- ***Flow Deflection***. Generally, the project should not deflect flows downstream against unprotected banks.
- ***Channel Conveyance Effects***. The design should not create an increased water surface elevation (through channel constriction) of more than 0.5 feet, as estimated by HEC-RAS.

Step 3. Develop Concept Plan and Design Report

After developing and screening project alternatives and selection of the preferred alternative, a Concept Plan and Design Report should be prepared and submitted to the City or County for preliminary review. The objective of this step is to provide a preliminary review and confirmation of the design concept before time and effort is spent in preparing detailed construction drawings, and in permitting and project approval.

The preferred plan alternative as selected in step 2 should be refined and developed into the Concept Plan that will be the basis for subsequent environmental and permit review. The Concept Plan should portray graphically (through sketches, and plan, profile, and cross-section drawings) the approach to bank stabilization that deals with all of the design factors and constraints. The Concept Plan should be considered a tool for conveying ideas and information to the plan and permit reviewers, and provides the basis to guide the subsequent development of the more detailed Construction Drawings. Planning-level cost estimates developed for the alternatives analyses should be refined at this stage for public projects.

The Concept Plan Design Report should be submitted to the appropriate City and County Departments for review and approval along with any permit application paperwork. The Concept Plan should include a discussion of the site constraints, information on the geomorphic, hydraulic, and biological investigations, including recommendations, the geotechnical report (if required), the alternatives evaluated, and the rationale for selection of the preferred alternative. This will be especially important if a purely structural approach is proposed.

Step 4. Local, State and Federal Agency Permitting and Project Approval

Obtaining all necessary regulatory approval for bank stabilization work near or within streams in the Novato Creek watershed has historically been a time-consuming and often confusing process. By law, a project usually requires approval from a number of agencies. This section is intended to help guide and simplify this process.

While agencies with jurisdiction over stream projects will not waive their responsibility to review project plans before construction, the strategy employed here is intended to help facilitate the review process involving coordination between the City/County (depending on project location) and all regulatory agencies. If these guidelines are followed, many of the questions, as well as design backup, will be provided to regulatory agencies. Given this framework, it is likely (though not impossible) that the project will not stall in the approval process and will be approved in a reasonable amount of time, with minimal changes to the plan. The City or County will reserve the right to request modifications to privately proposed projects, or reject those that they do not consider as appropriate and consistent with this report.

Vegetative and biotechnical approaches to bank repair should be the preferred approach, and that structural bank stabilization will be used only sparingly at highly constrained sites. Repair projects will likely be allowed within the same footprint of the failing structure and using the same design approach, retrofitted with native plantings where possible.

Several federal, state, and local agencies have responsibilities for the protection of wetlands and creeks in the Novato area. The U.S. Army Corps of Engineers (ACOE), California Department of Fish and Game (CDFG), and the Bay Delta Regional Water Quality Control Board (RWQCB) all require permits and/or approvals for projects that may affect wetlands and creeks, including stream bank stabilization projects. The following agencies should be contacted to determine whether or not a project requires their approval.

- ***U.S. Army Corps of Engineers 404 Permit*** - If the project proposes removal or placement of any materials in the stream area, or if the project area is a wetland, the applicant must apply to the ACOE to determine if a Section 404 permit is necessary, pursuant to the Clean Water Act. If a federally listed endangered species is potentially found on the site, the ACOE must consult with either or both the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS). These agencies must review and comment on the application prior to its approval. Either of these agencies has the ability to request more information or changes in project design and mitigations.
- ***Endangered Species Act***- The USFWS and the NMSF enforce the federal Endangered Species Act (ESA) rules that prohibit the "taking" of listed species through human activities. "Taking" means destroying a species ability to breed, feed, or find shelter, and includes taking as result of a erosion/siltation, landslide, mudflow, or bank failure from a poorly designed and executed management action or construction project. The NMFS enforces the ESA for marine fish, which in Marin County are mainly steelhead trout and select species of salmon. The principal species of concern of the USFWS along stream corridors is the red-legged frog, but there are other species of concern that also must be considered. In its permit processing, the ACOE will contact USFWS and/or NMFS to determine whether a proposed activity may impact a listed species. Legally it is up to the applicant to show that species are not impacted, and if the Corps is not involved in the permit processing under a Nationwide Permit, or a Regional Programmatic permit, then the landowner must contact the USFWS or NMFS directly.
- ***Department of Fish and Game Code Section 1601/1603*** - The Department of Fish and Game Code section 1602 requires any person, state or local governmental agency, or public utility to notify the CDFG before beginning any activity that will do one or more of the following: 1) substantially obstruct or divert the natural flow of a river, stream, or lake; 2) substantially change or use any material from the bed, channel, or bank of a river, stream, or lake; or 3) deposit or dispose of debris, waste, or other material containing crumbled, flaked, or ground pavement where it can pass into a river, stream, or lake. Fish and Game Code section 1602 applies to all perennial, intermittent, and ephemeral rivers, streams, and lakes in the state. Therefore, a Lake or Streambed Alteration Agreement (LSAA) is likely required for any stream bank stabilization project conducted under the guidance of this document.
- ***Regional Water Quality Control Board Water Quality Certification*** - Section 401 of the Clean Water Act requires that RWQCBs determine consistency (Water

Quality certification or waiver) between proposed projects, California water quality laws, and certain sections of the Clean Water Act.

- ***City of Novato or Marin County Grading/Building Permit*** - A local permit issued by the City or County is required for any excavation or fill that will encroach on or alter a natural drainage channel or water course, including adjacent floodplain areas. In addition, some kinds of structural stabilization approaches, such as a live crib wall will require a building permit. The plan reviewer may request a copy of the project geotechnical report and structural calculations and analysis. It is also recommended that all projects be consistent with Marin County's Countywide Plan *Stream Conservation Area (SCA)* policy.
- ***California Environmental Quality Act (CEQA)*** - Any time permits are required to be issued by the City, County, the CDFG, RWQCB, or ACOE, an environmental review is necessary. Depending on the specific project parameters, a Negative Declaration, a Focused Expanded Initial Study/Mitigated Negative Declaration, or focused Environmental Impact Report may be required. Certain small repair and replacement projects may be "Exempt" from environmental review. The City of Novato is responsible for completing the CEQA review of projects. Project descriptions and plans should be submitted to the planning department for this review.

The City and County environmental review officer will assist the applicant in determining which permits are necessary from which agencies, and how the project can be dealt with in an efficient and expedited fashion if it is consistent with this report and guidelines.

Step 5. Preparation and Submittal of Construction Plans and Specifications

Preparing formal Plans and Specifications, including the Engineer's Estimate of Probable Costs, will help ensure that the constructed project meets all of the project Goals and Objectives and considers all of the regulatory requirements and design constraints. The Plans and Specifications should include the following:

- Contractual language, including method of measuring work for payment, and applicable unit and lump sum costs, bonds, and retentions;
- Method for change orders and payment provisions for unforeseen circumstances;
- Construction schedule and any penalties for delayed work;
- Detailed description of the Scope of Work;
- Materials specifications and suppliers list;
- Construction methods, tolerances and work requirements;
- Access, right-of-way, utilities, limits of work, mobilization and staging areas;
- Plan sheets, details, and typical cross sections; (following City/County Engineering Standards);

- Notifications, submittals, and construction inspection;
- Regulatory requirements, permit conditions, and work restrictions;
- Plan for water diversion and de-watering, and construction erosion control (SWPPP);
- Plan for protection or relocation of sensitive aquatic vertebrate species and fish;
- Post- construction maintenance and monitoring requirements.

Step 6. Construction Observation, Inspection and Monitoring

For large stream bank repair, stabilization, and revegetation projects, on-site construction inspection could be performed by City/County staff or contract inspectors. This could include both public projects and privately constructed projects. The purpose will be to interpret plans (for public works projects), to ensure that the project plans and specifications are followed, and that sensitive areas, including any sensitive species, fisheries and water quality protection measures are correctly implemented according to the conditions of the permit and approved project plans.

The City/County inspectors will ensure that appropriate construction quality control procedures are followed and documented for the record. This is especially important for construction contractors not familiar with biotechnical bank stabilization methods, which often cannot be specified to the same level of detail as more traditional bank stabilization projects, and may require more field adjustments and field decisions. Proper location, handling, and installation of structures and plant materials are critically important, and the project designer may need to provide on-site direction, as they are most familiar with the construction design intent. The construction inspector will also need to resolve problems with specifications and materials, approve changes, and deal with unforeseen problems and difficulties, particularly any geotechnical and drainage problems uncovered during soil excavation and foundation preparation. Any field changes should be documented in a project As-Built Plan.

Construction site erosion control, stream diversion, and water handling methods should be a main focus of the review and construction inspection. For public projects, the City or County will normally have a project biologist/monitor that will assist in construction observation and ensure that appropriate water quality, wetlands, and sensitive species protection protocols are being followed. The City, County, or other regulatory agencies may also require a biologist/monitor be on site for private construction projects. The City/County inspector, and project biologist/monitor will be given the authority to shut down or suspend work at a project site as appropriate if the terms of the construction plans and permit conditions are not being followed. If historically or archaeologically significant objects are uncovered, the City and County will also normally shut down a project until an expert review by a qualified archeologist is completed and appropriate recommendations and mitigations are developed.

It is emphasized here that the construction contractor is responsible for complying with all permit conditions relating to erosion and sediment control, traffic and job site safety, and compliance with regulatory permit conditions, especially those relating to the Endangered Species Act.

Step 7. Post-Construction Maintenance and Monitoring

A program of observation, monitoring, maintenance, and management is very important to ensure project success for vegetative and biotechnical designs which depend on successful plant establishment for erosion protection and bank stabilization. Most repair project sites should be visited, inspected for damage and planting success, and photographed following all major storm flows, and at least monthly during the first growing season. Replanting, maintenance of the irrigation system, weeding and pest control, and re-securing erosion blankets and fiber rolls may be necessary, as well as other work such as additional rock placement, filling any voids with smaller rock and soil, and joint planting additional willows and other woody species.

A minimum three-year maintenance contract should be included in the construction contract for large bank stabilization management public projects, particularly those that utilize vegetative and biotechnical approaches. The City/County may also require private parties to contract with a biologist or landscape contractor to monitor and maintain the restoration and stabilization site's irrigation and landscaping/ native plantings.

Often the permit conditions issued by the regulatory agencies will require submittal of a Habitat Mitigation and Monitoring Plan, which will outline maintenance and monitoring protocols, times, and methods, and provide specific success criteria against which the monitoring results are to be judged.

Existing County and City Ordinances

The following is a list of applicable City of Novato ordinances that may pertain to a bank stabilization project in the study reach. The full ordinances can be found at http://ordlink.com/codes/novato/maintoc.htm

- Chapter 19.35 Waterway and Riparian Protection.
- Chapter 19.39 Woodland and Tree Preservation.
- Chapter 19.36 Wetland Protection and Restoration.

Marin County also has ordinances that may pertain to projects along Novato Creek:

- Chapter 23.09 FLOODPLAIN MANAGEMENT
- Chapter 22.27 NATIVE TREE PROTECTION AND PRESERVATION
- Chapter 13.12 EXCAVATIONS AND ENCROACHMENTS
- Chapter 11.08.010 Interfering with water flow.
    - 11.08.020 Duty of owner.
    - 11.08.040 Free flow of water required--Issuance of building permits.
    - 11.08.050 Permit required for construction.
    - 11.08.060 Application--Fees.
    - 11.08.070 Structures deemed nuisance.

The full text of these ordinances may be found at:
http://municipalcodes.lexisnexis.com/codes/marincounty/.