Michael Love & Associates
Hydrologic Solutions

Technical Memorandum

Date: December 29, 2010

To: Sandra Guldman, President, Friends of Corte Madera Creek Watershed
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Subject: Basis of design for a roughened channel to provide grade control and fish passage under a replacement bridge at Saunders Avenue on San Anselmo Creek

1 PURPOSE

This memorandum is intended to provide reviewers of the current design plans for the channel work at the Saunders Avenue Bridge (provided in Attachment 1) a brief description of the proposed project and the basis of decisions that guided preliminary design development for the roughened channel fish passage alternative. This represents a refinement of the roughened channel alternative prepared for Friends of Corte Madera and presented in the memorandum by Michael Love & Associates (MLA) dated July 6, 2010, which assumed the existing bridge apron would be retrofitted. The design presented here assumes that the Saunders Avenue Bridge will be replaced with a free span bridge. Stetson Engineers is responsible for developing the conceptual bridge design and conducting the bridge hydraulic capacity analysis.

2 BACKGROUND

San Anselmo Creek is a major tributary to Corte Madera Creek, which drains into San Francisco Bay in Marin County. San Anselmo Creek supports populations of anadromous steelhead trout, which are listed as threatened under the Federal Endangered Species Act.

Saunders Avenue crosses San Anselmo Creek within the town of San Anselmo. The crossing is in a residential neighborhood and consists of a concrete bridge on concrete abutments and bents. A large apron spans the abutments and serves as grade control. The apron was likely constructed in multiple phases during the lifetime of the bridge to protect its structural integrity as the downstream channel incised. As a result, the channel grade upstream of the bridge is about 6 feet higher than downstream of the bridge.

The bridge crossing is also considered undersized for conveyance of the 100-year flood event. Water overtopped the banks of San Anselmo Creek upstream of the bridge during the flood of December 31, 2005, causing flow to be diverted onto Saunders Avenue and then down Agatha Court. Immediately downstream of the bridge the channel appears to have adequate capacity to convey the 100-year return period flow.

Spanning the upstream end of the bridge apron is a concrete weir that encases an abandoned sewer line. This concrete weir creates a nearly vertical 4 foot drop. About 12 feet upstream of

Figure 1. The existing crossing at Saunders Avenue has been extensively modified and (a) the grade is maintained with various concrete structures. An Alaskan Steeppass fish ladder and low-flow channel (b) provides marginal adult steelhead passage conditions.

the bridge apron is another sewer line encased in concrete that is currently in-service. The rough concrete encasing the in-service sewer line is exposed at the surface of the streambed, producing shallow sheeting flow over the concrete during baseflow conditions.

In the 1980's an Alaskan Steeppass fish ladder was installed at the concrete weir and training walls were constructed on the apron to form a low-flow channel to improve upstream passage for adult anadromous steelhead (Figure 1). However, the Steeppass and low flow channel are poorly suited for providing adult steelhead passage at typical migration flows. At migration flows the hydraulic capacity of the Steeppass is overwhelmed, and there is inadequate attraction flow for fish to find the outlet. At lower flows there is inadequate depth in the low-flow channel for adult steelhead to swim through. The fish passage facility also lacks a pool at the transition from the low flow channel into the Steeppass, making entry difficult for fish. Additionally, an Alaskan Steeppass does not provide passage for juvenile salmonids and is highly susceptible to plugging by debris.

A fish passage assessment of road-stream crossings in Marin County identified the Saunders Avenue site as a high priority for treatment (Taylor, 2003). The Friends of Corte Madera Creek Watershed received grant funding to develop design alternatives for improving fish passage at the site. As part of this project, MLA developed a crossing retrofit alternative using a pool and weir fishway for the project site (MLA 2006). As part of the same grant, Stetson Engineers evaluated a natural-grade alternative for the site and found it to be infeasible due to the presence of the in-service gravity sewer line and the severe channel head-cutting and incision that would be initiated upstream of the bridge if the apron and sewer line were removed or lowered.

Based on comments received by the National Fisheries Marine Service (NMFS) following review of the pool-and-weir fishway alternative, Friends of Corte Madera have requested MLA and Stetson Engineers to develop a nature-like fish passage alternative that involves rebuilding the channel at crossing to create a rock-lined roughened channel that would provide fish passage if a new bridge were constructed at the site.

2.1 AGENCY REVIEW MEETING

On August 10, 2010 a design review meeting was held at the project site to discuss the preliminary channel design, hydraulic model results, project constraints and agency comments. Staff from, MLA, Stetson Engineers, Ross Valley Sanitary District, and NMFS attended the site meeting. The meeting was summarized in a memo by Stetson Engineers dated, August 27, 2010.

A primary conclusion of the meeting was the need to address the possibility of a bridge replacement in the cast that the existing bridge fails to meet current seismic safety standards. Currently the seismic stability of the bridge is unknown, but if the bridge requires replacement this could have a significant impact on the type of channel design under the bridge and the overall timeline and cost of the project. MLA was directed to refine the roughened channel alternative under the scenario of a full bridge replacement. Stetson Engineers are developing the conceptual bridge design and preliminary hydraulic analysis for the bridge replacement alternative.

3 FISH PASSAGE OBJECTIVES AND CONSTRAINTS

3.1 FISH PASSAGE

The primary objective of the project is to improve upstream passage conditions for adult anadromous, adult resident and juvenile steelhead/rainbow trout across a reasonable range of flows. NMFS and the California Department of Fish and Game (CDFG) have requested that the overall slope of the roughened channel not exceed 4 percent to accommodate upstream passage of juvenile steelhead.

3.2 FLOODING

The project must not increase the 100-year water surface elevation, and it would be beneficial for the project to lower the 100-year water surface sufficiently to eliminate flooding at the Saunders Avenue crossing. This could remove the adjacent properties from the FEMA designated 100-year floodplain and make the implementation phase of the project more competitive for funding. Flood level elevation and improvements to reduce flooding will be addressed by Stetson Engineers following further bridge design.

3.3 SEWER LINE CROSSING

A primary site constraint is the existing in-service gravity sewer line that crosses the channel upstream of the Saunders Avenue crossing. Based on sewer line drawings provided by the Ross Valley Sanitary District, the downstream most gravity sewer line is abandoned and capped, and can be removed. However, the second gravity sewer line, located immediately upstream and encased in concrete exposed in the channel, is currently in-service (Figure 2).

Given the location and elevation of the in-service gravity sewer line, it is not feasible to construct a roughened channel fishway at an overall slope of 4 percent or less (Figure 3). The resulting profile of the roughened channel would raise the channel bed at the upstream bridge face by as much as 3 feet and would place the downstream end of the roughened channel more than 100 feet downstream of the crossing. The raised channel bed would decrease hydraulic capacity of the bridge and downstream channel.

Stetson Engineers, working with Friends of Corte Madera Creek Watershed and the Ross Valley Sanitary District, explored the feasibility of various alternatives to relocate the sewer line. They have determined that the most feasible alternative relocates the gravity sewer line to cross the stream channel approximately 20 feet upstream of the existing line. The top of the new encased sewer line would be about 1.8 feet lower than the elevation of the existing encasement. This would allow the roughened channel to be moved 20 feet upstream and lower the elevation of the upstream end by 1.8 feet, making it a feasible alternative.

3.4 STRUCTURAL

If a new bridge were constructed at the Saunders Avenue crossing, the entire structure, including the concrete apron and abutments would be removed. To facilitate design of the roughened channel, proposed location and configuration for the new bridge abutments and bridge deck were provided by Stetson Engineers. Based on the provided information, the new bridge would have a clear span of approximately 46.5 ft and the elevation of the bottom of the bridge deck would be at 61.18 feet (NGVD 29). Existing residential retaining walls up and downstream would remain and be protected. The floodwalls upstream of the new bridge may need to be extended vertically to accommodate backwatering by the bridge at flood flows.

3.5 RIPARIAN VEGETATION

A secondary design objective was to minimize loss of riparian trees as part of the project. Most of the riparian vegetation within the project area is located downstream of the bridge.

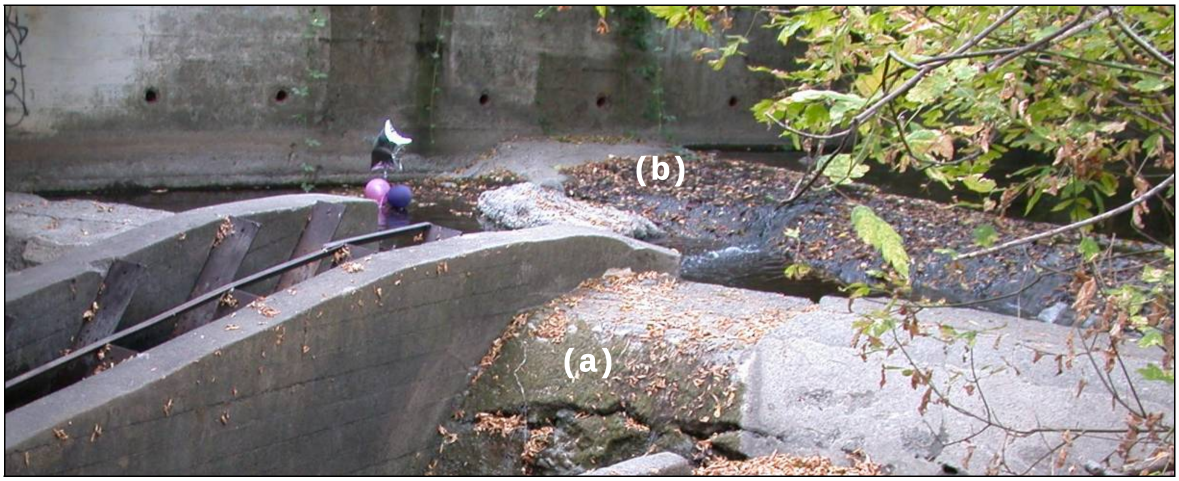

Figure 2. Looking upstream at existing fish ladder exit. Two gravity sewer lines encased in concrete cross the channel (a) an abandoned line at the weir across the inlet apron and (b) an in service line approximately 12 feet upstream of the apron.

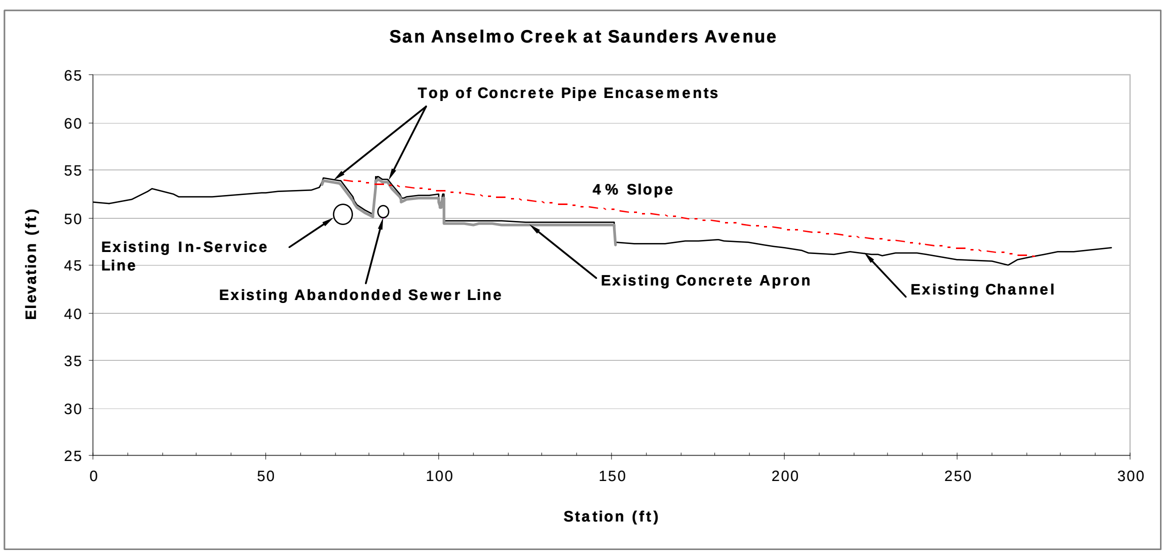

Figure 3. Channel profile through the existing bridge crossing with a 4 percent grade-line starting at the elevation of the existing in-service gravity sewer line.

4 FISH PASSAGE DESIGN CRITERIA

NMFS and CDFG classify roughened channels under the hydraulic design approach, which requires providing a hydraulic environment within the fishway that does not challenge the swimming and leaping abilities of the target fishes at specific flows. The target fish for this project are juvenile, adult resident, and adult anadromous steelhead/rainbow trout.

Both agencies have hydraulic design guidelines and criteria for adult and juvenile salmonid passage at road-stream crossings (CDFG, 2002; NMFS, 2001) that were used to guide this design. The guidelines were written jointly and are intended to be functionally equivalent. The guidelines recognize that for retrofit of an existing crossing, meeting the hydraulic design criteria should be "a goal for improvement and not the required design threshold".

4.1 FISH PASSAGE FLOWS

The low and high fish passage design flows define the range of flows that passage should be provided. Both NMFS and CDFG have recommended fish passage design flow criteria that are based on annual exceedance flows (Table 1). The low and high fish passage flows for juvenile, adult resident, and adult anadromous steelhead/rainbow trout are estimated from exceedance flows for the site. Because San Anselmo Creek at Saunders Avenue is not gaged, exceedance flows from the following two nearby stream gaging stations were utilized:

USGS Station No.:	**11460100**	**11460000**
Station Name:	Arroyo Corte Madera D Pres A Mill Valley	Corte Madera C A Ross
Drainage Area:	4.68 mi^2	18.1 mi^2
Years in Operation:	1965 -1986	1951 - 1993

The two streams have very similar flow characteristics and their drainage areas bracket the 9.1 mi^2 drainage area of San Anselmo Creek at Saunders Ave. Exceedance flows for the two streams were scaled by drainage area to develop a flow duration curve for the project site (Figure 4). From the flow duration curve, fish passage design flows were obtained (Table 1).

Table 1. Estimated fish passage design flow for San Anselmo Creek at Saunders Ave., based on CDFG (2002) and NMFS (2001) criteria.

	Low Passage Flow		***High Passage Flow***	
Species and Lifestage	**Criteria**	**Flow**	**Criteria**	**Flow**
Juvenile Steelhead/ Rainbow Trout	Greater of 95% Exceedance Flow of 1 cfs	**1 cfs**	10% Exceedance Flow	**28.3 cfs**
Adult Resident Rainbow Trout	Greater of 90% Exceedance Flow of 2 cfs	**2 cfs**	5% Exceedance Flow	**65.1 cfs**
Adult Anadromous Steelhead	Greater of 50% Exceedance Flow of 3 cfs	**3 cfs**	1% Exceedance Flow	**252.8 cfs**

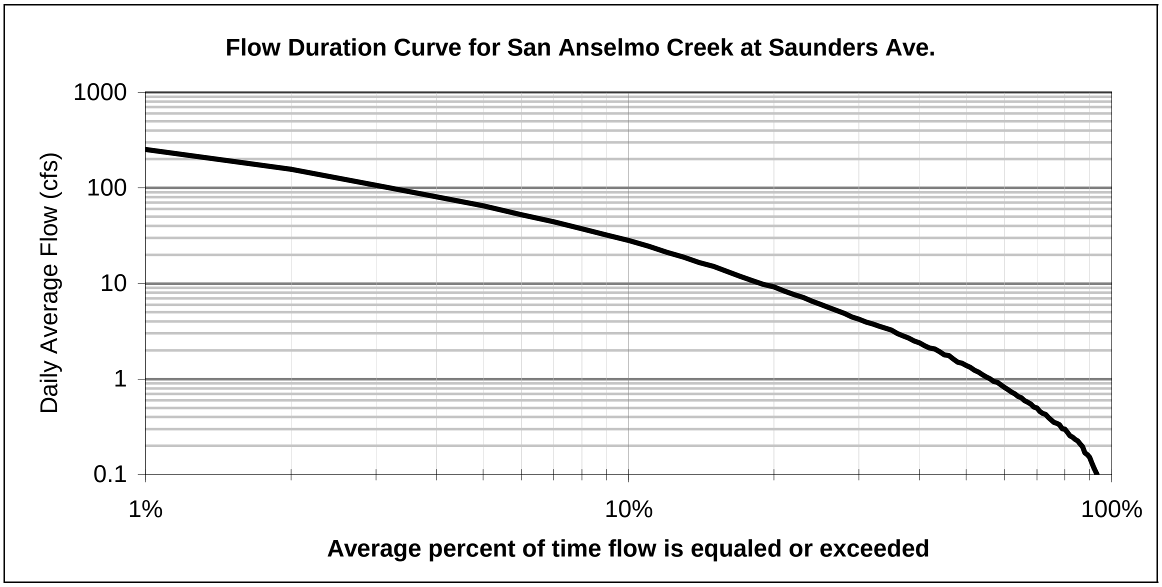

Figure 4. Estimated annual flow duration curve for San Anselmo Creek at Saunders Avenue based on exceedance flows from two nearby gaged streams, scaled by the contributing drainage area at the bridge.

4.2 HYDRAULIC DESIGN CRITERIA

For hydraulic design of roughened channel fishways, CDFG (2002), NMFS (2001), and CDFG (2009) provide the following criteria:

Maximum water surface drop over weirs

Juvenile Salmonids:	6 inches
Adult Resident Trout:	12 inches
Adult Steelhead:	12 inches

Maximum Cross-Sectional Averaged Water Velocity (less than 60 feet between resting pools)

Juvenile Salmonids:	1 foot per second
Adult Resident Trout:	4 foot per second
Adult Steelhead:	6 foot per second

Maximum Turbulence/Energy Dissipation Factor (EDF)

Adult Steelhead:	7.0 foot-pounds/second/cubic foot

Minimum Pool Depth

Adult Steelhead:	2.0 feet

5 DEVELOPMENT OF ROUGHENED CHANNEL DESIGN

5.1 EVALUATION OF VARIOUS ROUGHENED CHANNEL TYPES

A roughened channel fishway is designed to have an immobile bed that is stable up to the design flood flow. The framework of small and large rock mixed with finer material forms a continuous stable channel structure emulating steeper natural channels that the target fish species is capable of traversing.

Fish passage hydraulics for several different types of roughened channel morphologies were evaluated for this site. They included a single rock ramp at a constant slope, a series of cascades and pools using perturbation boulders, boulder step-pools, and a series of chutes (rapids) and pools, all of which are described in CDFG (2009). Each of the evaluated roughened channel types used an overall slope of 4 percent with an overall drop from upstream to downstream of about 7 feet.

The rock ramp was considered too long and lacked resting areas. A general rule of thumb provided by CDFG (2009) is to avoid creating an exhaustion barrier by inserting resting pools when there is more then 5 feet of drop across a rock ramp.

Evaluation of a cascades and pools type channel found it requires too high of flow to achieve sufficient water depth for fish passage. Using methods outlined in DVWK (2002), a 6 percent sloping cascade placed between resting pools requires about 28 cfs to provide 12 inches of water depth for passage of adult steelhead. This is approximately the 10% exceedance flow and far higher than the low passage design flow of 3 cfs. At this site, a cascade and pool type of roughened channel fishway would only provide a small window of operating streamflows and would preclude low-flow passage for adult steelhead during typical migration periods.

A boulder step-pool roughened channel at an overall slope of 4 percent was evaluated but found to be overly constrained. Factors that made the step-pool channel infeasible include the large rock size required to form stable steps, and the extremely close spacing between pools to keep water surface drops to 6 inches or less.

5.2 PREFERRED ROUGHENED CHANNEL TYPE

A chutes-and-pools morphology was found to be the best suited for the roughened channel fishway at the Saunders Avenue crossing. This type of fishway consists of a repeating bedform of a steep chute or rapid followed by a pool. The chutes often have several bands of large boulders embedded in a mix of smaller "engineered streambed material" (ESM). Both the bands and the coarser material in the ESM create hydraulic roughness and diversity that supports fish passage and dissipates the flow's energy. The drop across the chute is commonly limited to two feet, followed by a large pool that dissipates the kinetic energy of the incoming flow and provides resting and holding areas for fish.

For the Saunders Avenue crossing, the chutes were found capable of providing suitable fish passage hydraulics at low and moderate fish passage flows; although they would be excessively turbulent at higher passage flows for adult steelhead.
The following sections describe basis of design and anticipated fish passage performance for the proposed roughened channel alternative.

5.3 ROUGHENED CHANNEL LAYOUT AND PROFILE

The design for the roughened channel alternative consists of three cycles of a chute and pool. The chutes have a slope of 6 percent, and combined with the pools the overall slope does not exceed 4 percent. The drop across the chutes does not exceed 2 feet and the pools have a residual depth of 2 feet. The new channel is divided into three sections; the upper chute beginning at the relocated sewer line, the middle chute under the bridge and the lower chute that transitions back into the native channel. A series of boulder bands at roughly 8-foot spacing span the chute to create hydraulic roughness and structural stability. They are embedded into engineered streambed material (ESM) that is 4 feet thick. The cross sectional shape of the chutes (Figure 5) is designed to provide good hydraulic conditions for passage of both adult and juvenile salmonids at both summer low-flows and during frequently occurring higher flows.

The upstream end of the roughened channel (fishway exit) is located at the proposed gravity sewer line. The exit elevation is based on a one foot thick encasement over the top of the line. The first chute is 33 feet long, with a drop of 2 feet across the chute. The upstream end of the new channel will have rock banklines that tie into the southern retaining wall and northern channel bank, and will help direct lower flows into the roughened channel. The upper chute flows into a 17-foot long pool.

The middle chute would be located under the new bridge deck and is 33 feet long with a 2-foot drop across the chute. The chute ends at the downstream end of the existing apron. The middle chute flows into an 18-foot long pool armored with ESM located within the existing outlet scour pool. The pool is oriented to turn the flow before it enters into the lower chute.

The lower chute is 58 feet long and slopes at 6 percent. At the downstream end of the fishway the channel transitions back to the native channel and narrows to 19 feet. Below the lower chute a self-forming scour pool will form as the channel transitions from the roughened channel back to the native channel. To accommodate changes in the downstream channel bed, the end of the lower chute extends approximately 1.5 foot below the existing channel. The chute contains rock banklines that tie into the retaining walls on both banks. The rock should be placed in a manner that preserves the existing riparian vegetation, where feasible.

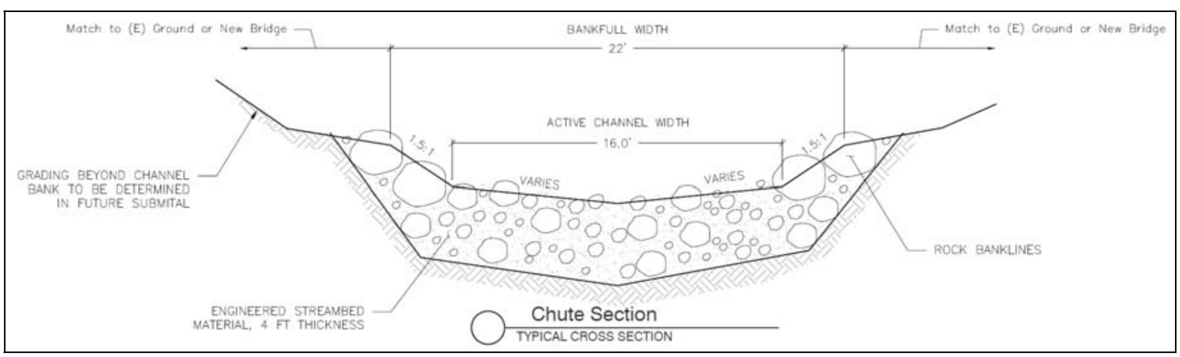

Figure 5. Cross section of the roughened channel chute.

5.4 HYDRAULIC MODELING OF ROUGHENED CHANNEL

A spreadsheet model was developed for estimating stable rock sizes and analyzing fish passage hydraulics for a variety of channel configurations at various flows. The hydraulic conditions were estimated assuming uniform flow. Roughness coefficients were estimated using depth-dependent methods, as described in CDFG (2009).

5.4.1 Preliminary Rock Sizing

A preliminary estimate of the stable rock size for the roughened channel at the "stable bed design flow" was made using methods outlined in CDFG (2009). With this, the gradation of the engineered streambed material (ESM) was developed. The ESM contains a wide gradation of rock sizes, ranging from large boulders to fine sand and silt. The larger half of the material forms the stable framework and the smaller material fills the voids to control subsurface flow.

Typically, the stable bed design flow for roughened channel design is the 100-year return period flow. Stetson Engineer's preliminary bridge sizing calculations are based on a 100-year design flow of 3,693 cfs, which was used for this stability calculation and rock sizing.

Initial bridge hydraulics at the design flow of 3,693 cfs were provided by Stetson Engineers. Information included the water surface slope, depth and velocity at various cross section locations along the new channel. A portion of the total discharge conveyed in the 16-foot wide active channel was calculated using the average velocity and cross sectional area of flow. A unit discharge was estimated and used to develop an initial estimate of stable rock size.

A range of water surface slopes were predicted by Stetson Engineers along the project reach at the 100-year design flow. The steepest water surface slope of 0.0365 ft/ft was used for the stability calculations. The preliminary stability calculation yields a D_{84} rock size of 3.8 feet for the chutes within the roughened channel. Using methods described by in CDFG (2009) the following rock sizes was calculated:

Particle Distribution of Engineered Streambed Material

Percentile	8	16	50	84	100
Diameter	Sand and Silt	0.12 ft	1.5 ft	3.8 ft (~2 ton)	4.1 ft (~3 ton)

The largest rock (D_{84} to D_{100}) will be used to form the boulder bands in the chutes. The remaining material will be used for the engineered streambed material (ESM) between the rock bands and armoring the pools.

Rock sizing will be revised using final results from flood flow modeling to be conducted by Stetson Engineers. Final model results will better define the water surface slope and the unit discharge within the roughened channel at the stable bed design flow.

5.4.2 Fish Passage Hydraulics

To predict the hydraulic conditions at fish passage flows the roughened channel was modeled assuming uniform flow conditions in each of the 6 percent sloping chutes. The Manning's roughness coefficient was based on a depth-dependent method developed by Mussetter (1989)

Table 2 summarizes the hydraulic conditions at the low fish passage design flow for each target fish life stage. Water depth and velocities satisfy design criteria for all of the rainbow trout/steelhead life stages, with one exception. The depth at the adult anadromous steelhead low design flow of 3 cfs is only 0.8 feet, which falls slightly short of the 1.0 feet depth criteria. Water depth reaches 1.0 feet at 5.9 cfs. Because the channel side slope varies as the shape of the channel transitions from chute to pool, the depth at each flow will vary and likely provide sufficient depth for passage.

The high fish passage design flows for San Anselmo Creek are relatively large in magnitude. After exploring numerous roughened channel configurations, it became apparent that the roughened channel would not be able to meet passage criteria at the CDFG and NMFS recommended high passage design flows for adult steelhead/rainbow trout. Instead, a somewhat smaller range of operational flows would be provided by the roughened channel.

The upper operational flows and corresponding hydraulic conditions for the proposed roughened channel alternative are provided in Table 3. For juvenile steelhead/rainbow trout, the water velocity exceeds 1 ft/s at 30.4 cfs, which is above the high passage flow for juveniles. For adult steelhead, the EDF exceeds the recommended threshold of 7 ft-lb/s/ft^3 at 109 cfs, which is approximately the 3 percent exceedance flow. While there is no recommendation for turbulence for adult resident trout, it is safe to assume that it is equal to or less than the EDF threshold for adult steelhead. Areas of lower velocity and turbulence along the margins of the wetted channel may allow some fish to migrate through the fishway at higher flows.

Table 2. Predicted hydraulic conditions at the low passage design flow for the Saunders Avenue chute and pool roughened channel fishway alternative.

Low Passage Design Flow:	Flow	Velocity	Depth	EDF
Juvenile Steelhead/Rainbow Trout	1 cfs	0.36 ft/s	0.6 ft	1.3 ft-lb/s/ft^3
Adult Resident Trout	2 cfs	0.42 ft/s	0.7 ft	1.6 ft-lb/s/ft^3
Adult Steelhead	3 cfs	0.47 ft/s	0.8 ft	1.8 ft-lb/s/ft^3

Table 3. Predicted hydraulic conditions at the upper operational flow for the Saunders Avenue chute and pool roughened channel fishway alternative.

Upper Operational Flow[1]	Flow	Approximate Annual Exceedance	Velocity	Depth	EDF
Juvenile Steelhead/Rainbow Trout	30.4 cfs	9%	1.0 ft/s	1.7 ft	4.0 (ft-lb/s/ft^3)
Adult Resident Trout	109 cfs	3%	1.9 ft/s	2.6 ft	7.1 (ft-lb/s/ft^3)
Adult Steelhead	109 cfs	3%	1.9 ft/s	2.6 ft	7.1 (ft-lb/s/ft^3)

[1] Upper Operational Flows are defined by hydraulic conditions within the chute.

6 CONCLUSIONS

While the proposed chutes-and-pools roughened channel fishway does not meet all of the CDFG and NMFS design criteria for passage of steelhead/rainbow trout, it represents a vast improvement to the existing condition. The proposed design utilizes the maximum accepted dimensions to meet the physical site constraints and criteria.

Additionally, the proposed fishway provides a stable grade control at the upstream end, to accommodate 1 foot of fill over the proposed pipeline. The concrete encasement for the existing sewer line currently forms a pool in the upstream channel. The proposed roughened channel will require removal of this concrete, thereby lowering the control point by 1.6 feet. While this will reduce the backwater and pool volume upstream, it may improve the hydraulic transition at the bridge face during flood flows.

While the proposed channel will lower the grade and improve the hydraulic efficiency of the transition into the bridge, the roughened channel is substantially rougher than the existing concrete. The detailed flood analysis to be conducted by Stetson Engineers will ultimately determine the affect of the project on flooding.

7 REFERENCES

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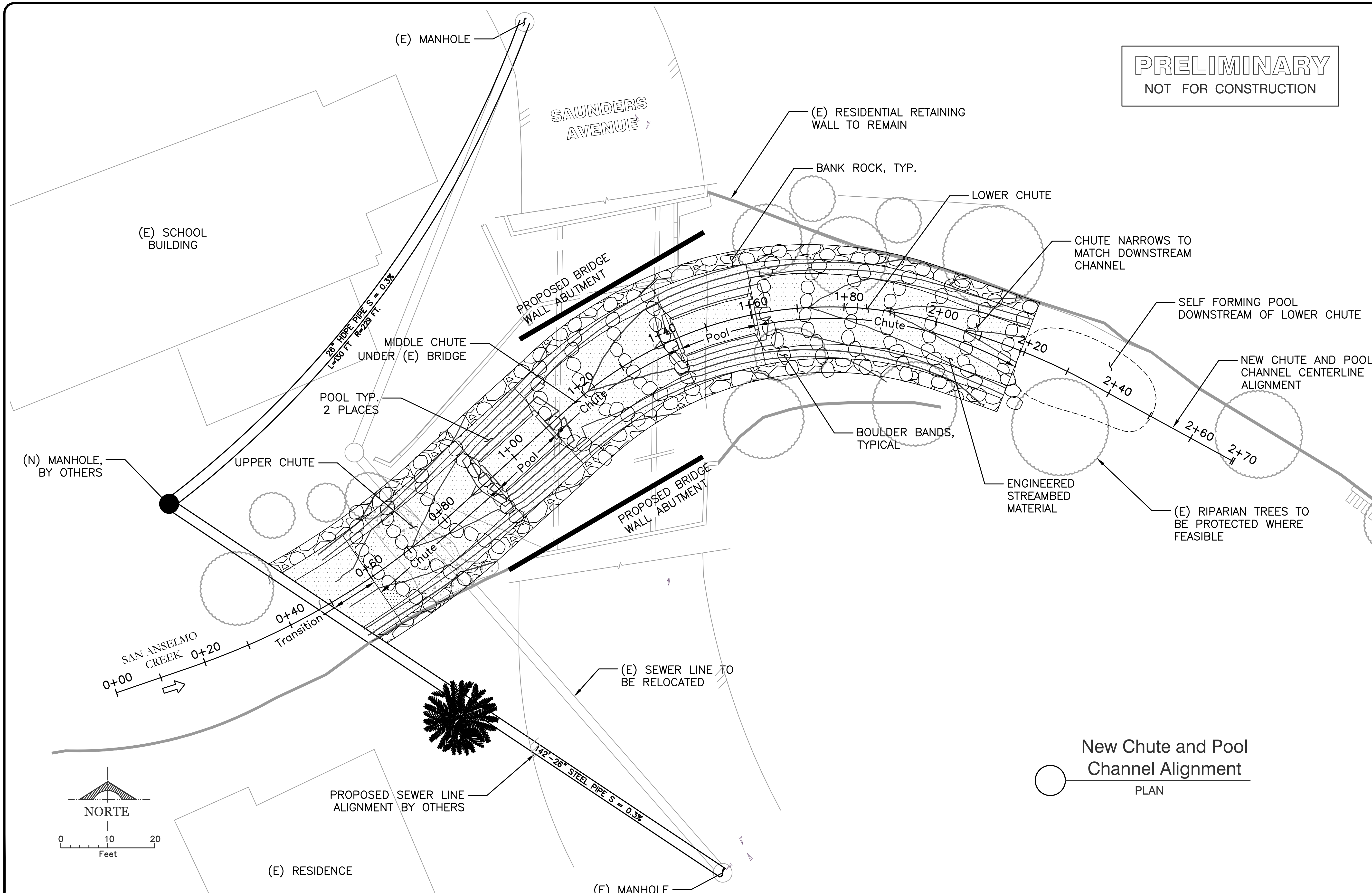
Attachments: Schematic drawings of roughened channel alternative (3 sheets).



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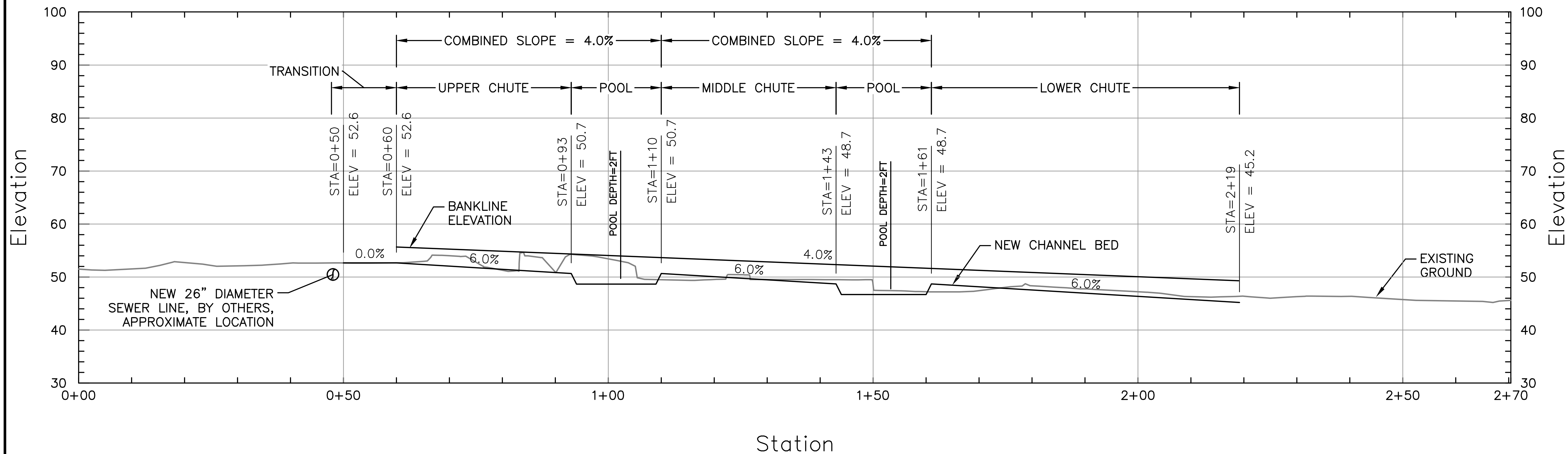
FRIENDS OF CORTE MADERA CREEK WATERSHED

Saunders Ave. Fish Ladder Replacement

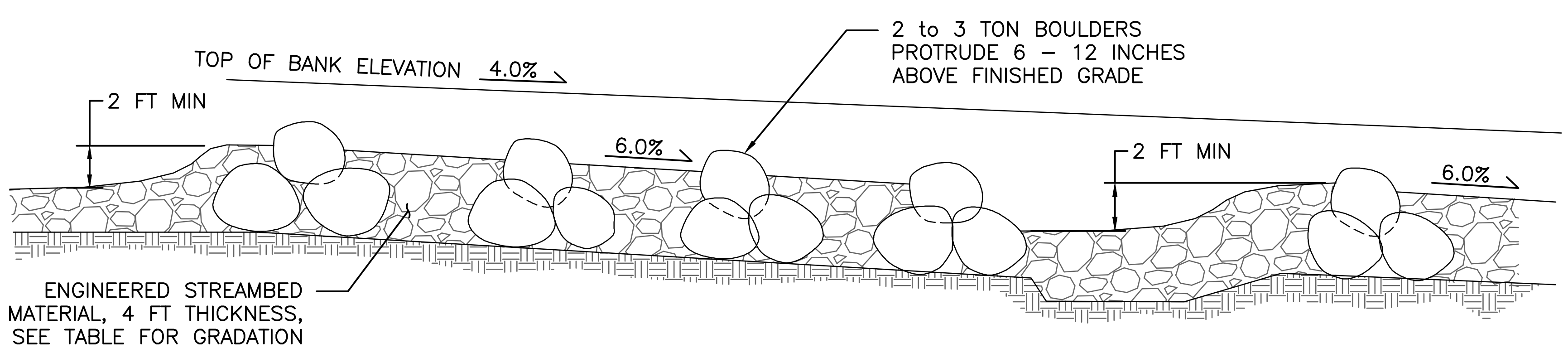
PLAN
CHANNEL LAYOUT

Date	Dec. 2010
Submittal	50% Design
Design	Love / Llanos
Drawn	Llanos
Sheet	1 of 3



Chute and Pool Channel

PROFILE ALONG CENTERLINE ALIGNMENT



Detailed Profile

STATION 1+10 to 1+70
(NTS)

ENGINEERED STREAMBED MATERIAL GRADATION

PERCENTILE	DIAMETER
8	SAND / SILT
16	0.11 FT
50	1.0 FT
84	2.5 FT
100	3.6 FT (2 TON)

PRELIMINARY
NOT FOR CONSTRUCTION

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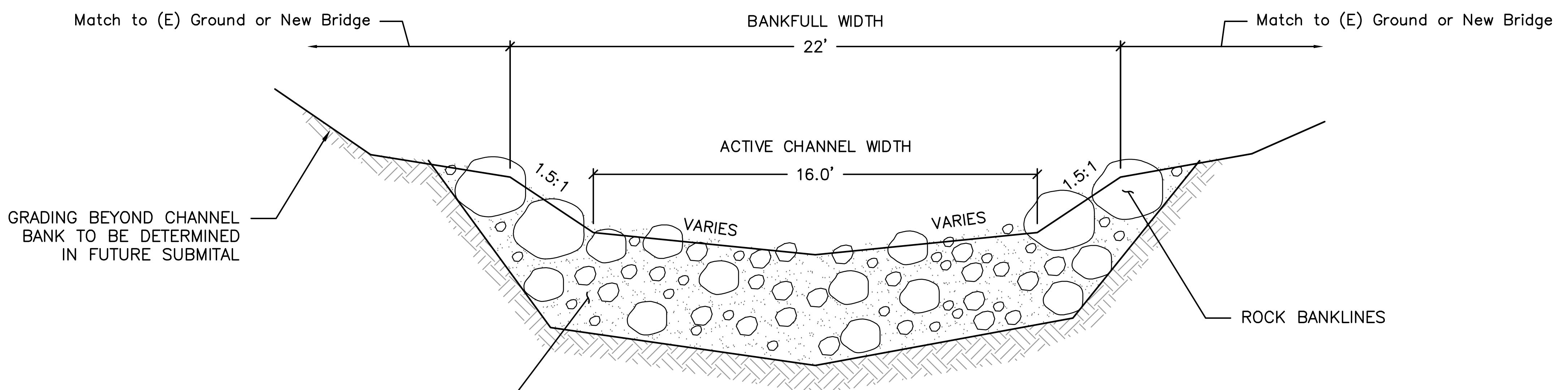
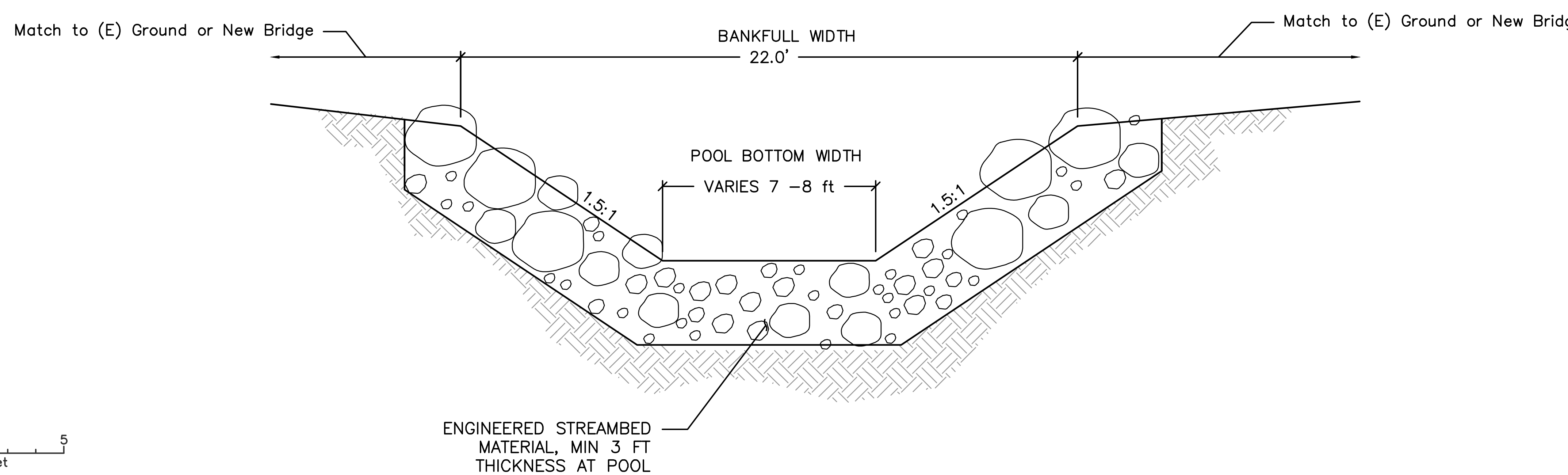
FRIENDS OF CORTE MADERA CREEK WATERSHED
Saunders Ave. Fish Ladder Replacement

CHUTE AND POOL CHANNEL PROFILE

Date	Dec. 2010
Submittal	50% Design
Design	Love / Llanos
Drawn	Llanos
Sheet	2 of 3



Chute Section
TYPICAL CROSS SECTION



0 5
Feet

Pool Section
TYPICAL CROSS SECTION

PRELIMINARY
NOT FOR CONSTRUCTION

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CIVIL
STATE OF CALIFORNIA

FRIENDS OF CORTE MADERA CREEK WATERSHED
Saunders Ave.
Fish Ladder Replacement

TYPICAL CHANNEL CROSS SECTIONS

DATE
Dec. 2010
SUBMITTAL
50% Design
DESIGN
Love / Llanos
DRAWN
Llanos
SHEET
3 of 3