MEMORANDUM

FC 14 (08-21-19)

PROJECT:	Safe, Clean Water Priority F8	**PREPARED BY:**	Lydia Yiu, Associate Engineer Dipankar Sen, Senior Project Manager
SUBJECT:	Regnart Creek Rehabilitation Design Study	**DATE**:	May 3, 2023 (Updated January 12, 2024)

I. Purpose

Regnart Creek experiences severe incision and bank erosion that threatens adjacent properties and undercuts creek infrastructure throughout the reach from Festival Drive to Bubb Road. In 2018, an asset management plan for Regnart Creek was completed, which identified various high-risk assets within this reach that need repair within the next ten years. As a result, respective watersheds units began initial research to determine if a project: (1) can be done under the Operations and Maintenance (O&M) division; (2) should be implemented as part of the Watersheds Asset Rehabilitation Program (WARP) in the capital division; or (3) should be submitted as a Capital Improvement Program (CIP) project. The Asset Management Unit recommends this project be a CIP project to expedite the project and comprehensively address the issues. To kick off the project planning process, a CIP business case for a Regnart Creek Rehabilitation Project was initiated in 2022 and will be submitted in September 2023. Once validated and funding sources are determined, the project may start as early as summer 2024.

After discussions with the Safe, Clean Water F8 team, the consensus for next steps was to perform a rehabilitation design study for channel stability based on geomorphic principles with a goal of implementing a more holistic and sustainable design to address the root causes of erosion and channel incision. Post construction, this creek would continue to be monitored under the watersheds asset management program to determine that addressing root causes of systemic erosion has stabilized the channel, increasing asset remaining life, and therefore, reducing long term risk and life cycle costs. This study provides design recommendations for a CIP project on the Regnart Creek reach between Bubb Road and Festival Drive (Figure 1).

II. Background

Regnart Creek begins in the foothills of the Santa Cruz mountains and flows through residential neighborhoods before flowing into Calabazas Creek. Upstream of Bubb Road the creek flows within a 72-inch culvert and downstream of Highway 85 it flows within an 81-inch culvert. The creek also flows in a concrete channel downstream of Kim Street. It is noted a level of service (LOS) for flow conveyance only exists between Tuscany Place and Kim Street. The reach of concern and subject of this study is between Bubb Road and Highway 85, where the channel is natural, and the majority is unmodified. Multiple bank stabilization projects have taken place in the past six years, but they were limited in scope and project length.

In September 2023, an emergency repair project was completed between Bubb Road and UPRR to stabilize the creek banks that had scoured from the 2023 winter storms with large boulders. However, the scope of the emergency repair was limited and the project was only able to address the most urgent spots as shown in Figure 2.

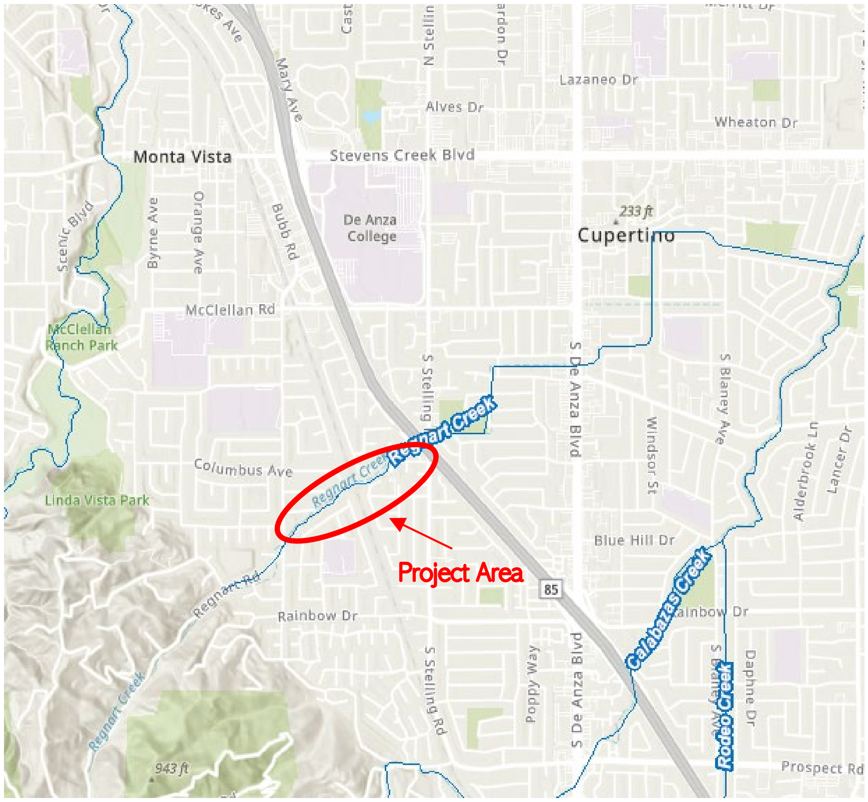


Figure 1. Map of Regnart Creek

III. Data

The data used in this study were sourced from the following:

- 2020 LiDAR
- 2021 HEC-RAS Maintenance Guidelines model
- 2020 SCVWD Flood Manual

The range of flows used in this study comprise the bankfull (approximately 1.5- to 2.33-year flow event) and the 100-year event, listed in Table 1 below. Level of service (LOS) flows only exist between Kim Street and Tuscany Place STA (with a 1% design flow of 550 cubic feet per second (cfs).

Table 1. Regnart Creek Flows

Location	Bankfull Flow (cfs)	100-year Flow (cfs)
Festival Drive to Bubb Road	80 - 100	280 - 360

IV. Design Recommendation

The main design goal is to eliminate the existing head cut in the channel and minimize future erosion scours by creating a geomorphically stable low flow channel and bench. A second goal is to allow the bank to be stabilized, where necessary, with a slope no greater than 1:1 (H:V) above the new bankfull bench. The team has identified a vertical head cut of 3 feet between Highway 85 and Union Pacific Railroad (UPRR) that increases to 5 feet at Krzich Place (STA 134+60).

To achieve this, the channel bed should be raised as shown in Figure 2 by:

1. Approximately 5 feet between UPRR (STA 124+00) and Krzich Place (STA 134+60), which will eliminate the head cut and potential for migration of the head cut upstream leading to additional bank failure; and
2. Approximately 3 feet between Festival Drive (STA 11+100) and the weir constructed as part of a prior Stream Maintenance Program (SMP) project (STA 123+00).

The new channel geometry will be raised and armored with 0.5- to 1.5-ton rock along the bed and the lower banks, which will stabilize and protect the channel from further erosion. It is recommended that the new channel invert tie into the existing channel invert as close to Festival Drive as possible to provide continuity throughout the channel.

The best access point is at Bubb Road, where the 2023 emergency repair project cleared the trees and vegetation to build an access ramp into the creek.

A. Rock Riffles

To maintain a stable channel slope, rock riffles or riffle-weirs will need to be installed at periodic intervals along the channel. These serve both as grade control structures to arrest further incision and as a method to address bank instability by raising the bed. These riffle weirs would have a drop of 2.25 feet (+/-0.25 feet); they would be similar to the one constructed as part of the SMP project downstream of UPRR (Figure 4). Suggested locations are shown in Figure 2; however, the actual locations of these weirs will depend on where they can be accommodated due to channel geometry and access.

The slope of the rock riffles should not exceed 10%, which means a 2.25-foot vertical drop should be extended over 22.5 feet. Based on an average slope of 1.9% to 2.0% from Festival Drive to Krzich Place, approximately six 1.5-ton boulders would form the riffle along the longitudinal profile and six boulders across the width to shape the low flow channel and the bench, as shown in Figure 5. Depending on how closely the riffles are placed due to limitations with access, the channel slope may be 2.3% to 2.5% when the riffles are 60 to 80 feet apart. This increases the size of boulders to the upper range of 1.5- to 2-ton.

In between the rock riffles, the channel bed would be raised with boulders that are between half- and 1-ton, with an average slope of 1% to 1.25%. The recommended spacing between riffles can vary from 60 to 200 feet. To reduce environmental mitigation impacts and costs, the raised channel would be filled in with a 1-foot layer of appropriately sized streambed gravel on top of the boulders. It was confirmed in the field that a slope of 1% to 1.25% is sufficient to maintain gravel in the channel and not get washed out.

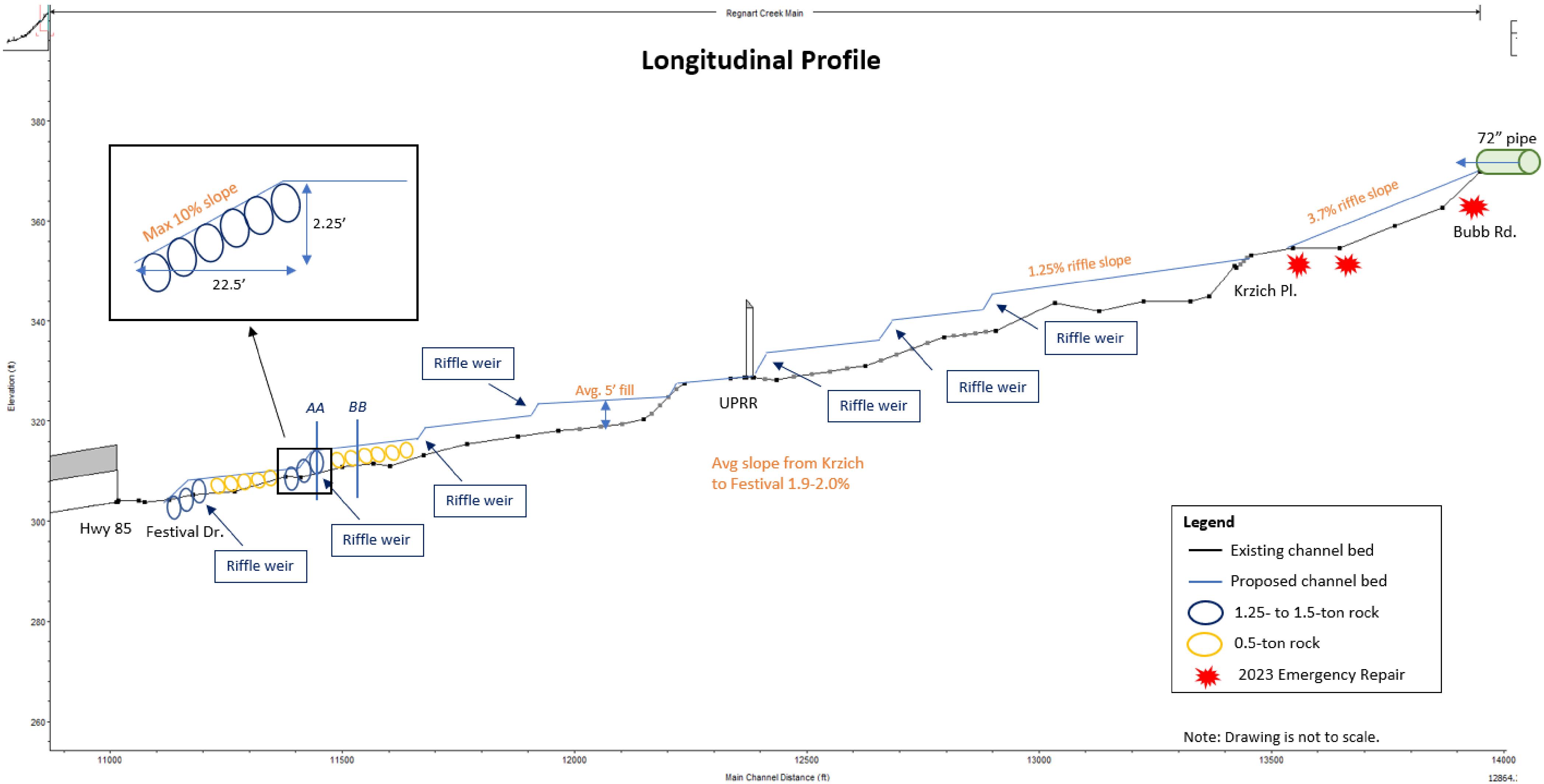


Figure 2. Channel Profile of Proposed Design

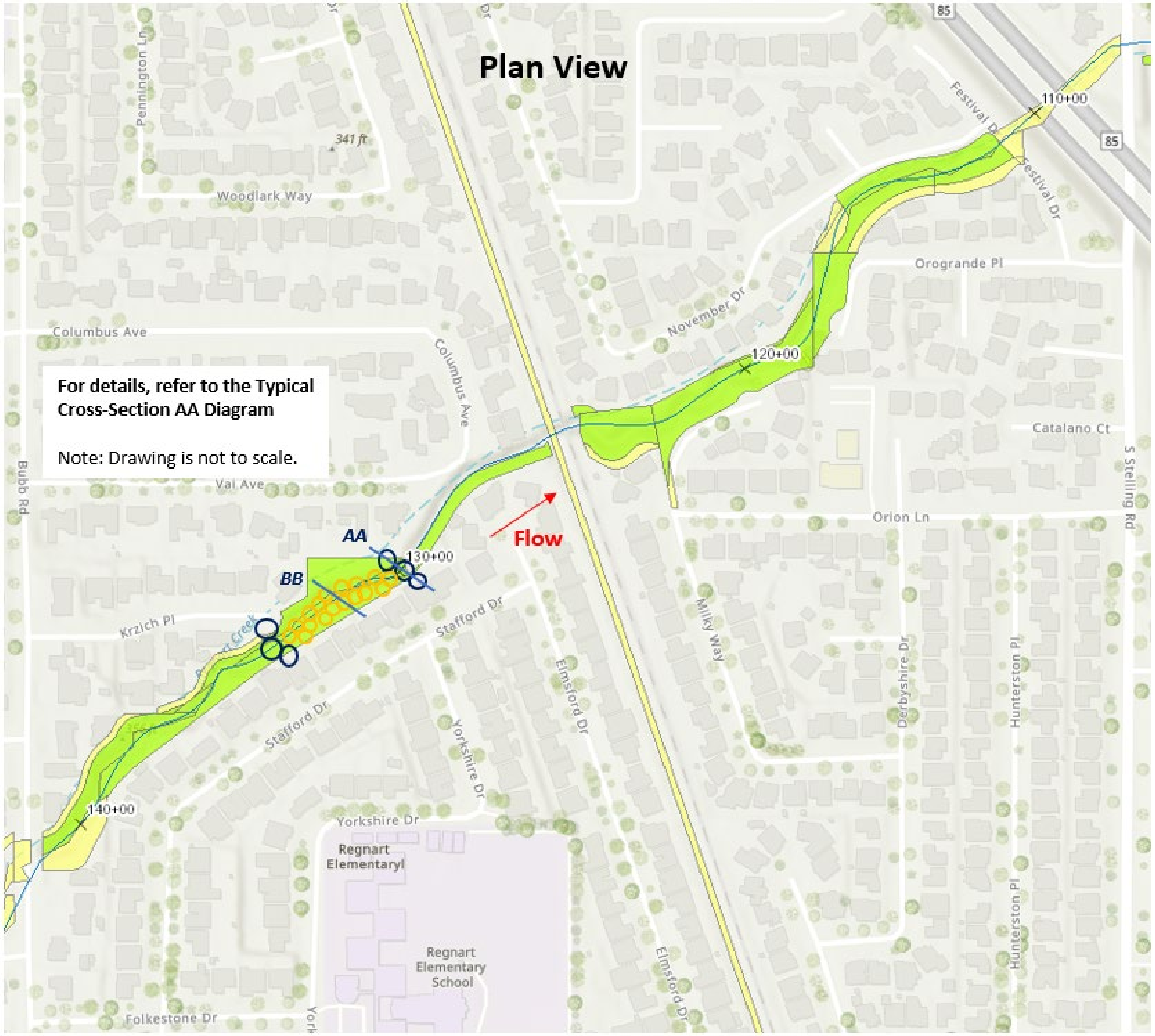
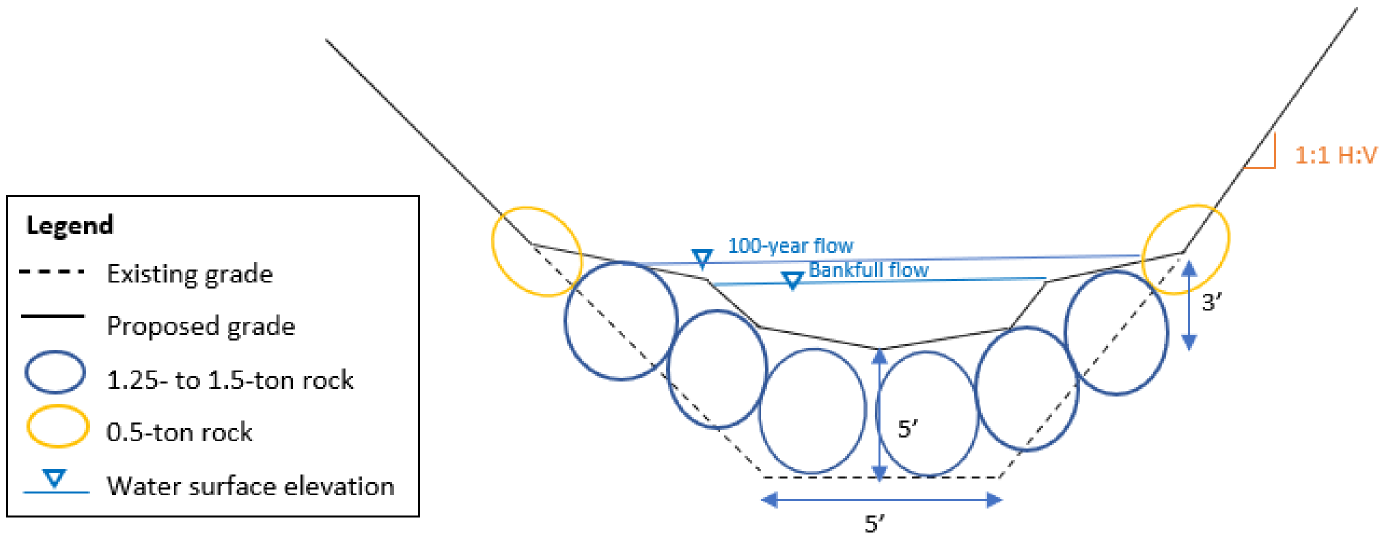


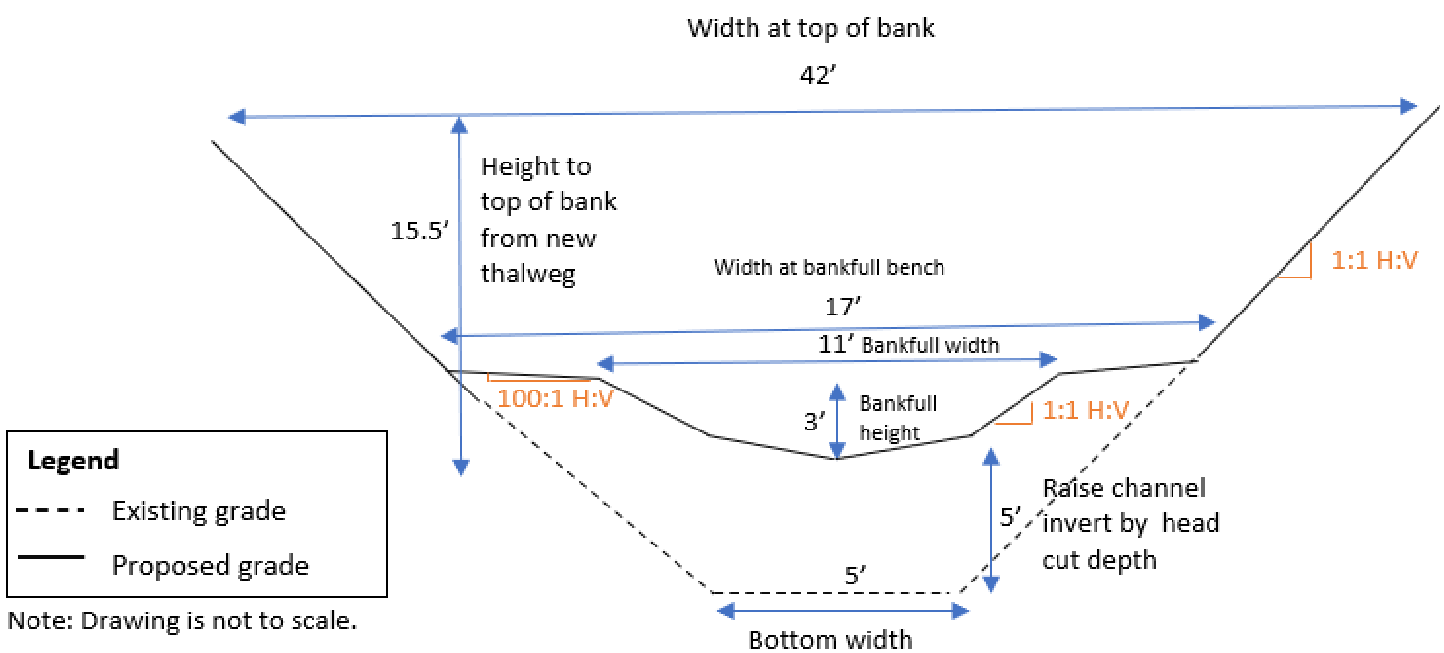
Figure 3. Plan View of Proposed Design

Figure 4. Existing Riffle Weir Downstream of UPRR (STA 123+00)



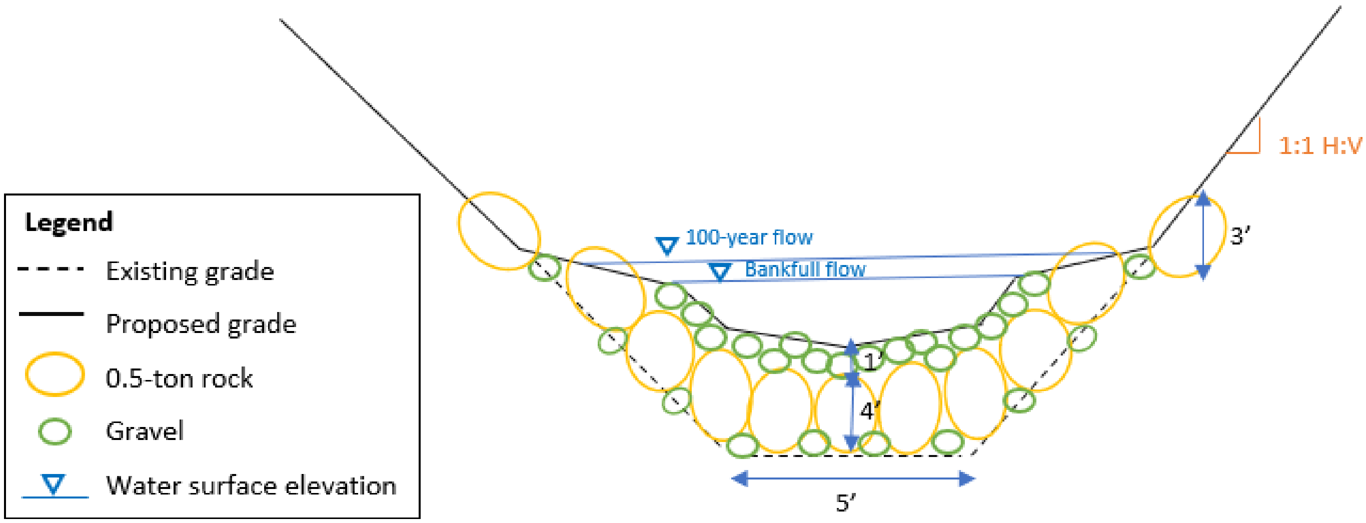
Note: Drawing is not to scale.

Figure 5. Typical Cross-Section AA Depicted with Boulders



Note: Drawing is not to scale.

Figure 6. Typical Cross-Section AA with Dimensions



Note: Drawing is not to scale.

Figure 7. Typical Cross-Section BB Depicted with Boulders and Streambed Gravel

B. Channel Geometry

The existing channel cross-section has a bankfull height of 5 feet, 1:1 (H:V) bank slope, and a 2% slope for the ground adjacent to the channel. The proposed configuration recommends a bankfull height of 3 feet, a bankfull bench, 1:1 (H:V) bank slope, and a 1.9% to 2.0% channel slope in a 100-year flow. Cross-section A-A in Figure 6 shows a typical cross section with approximate dimensions. A cross-section analysis was conducted to ensure that the channel will be stable and the existing bankfull and 100-year flows will be able to be conveyed by the new configuration.

By raising the channel, the width at the bankfull bench will increase to 17 feet (+/-), which allows for a bankfull bench on both sides in the straight sections. Above the bench, the toe of the high flow bank located 3 feet above the thalweg, has one layer of half-ton rock on each bank (Figure 5).

Analysis of incision and causes of channel instability indicates that there is not enough native material moving through the system to fill in the channel bed between the riffles. When the channel is raised with the riffles, the channel bed between the riffles will have to be raised using 0.5- to 1-ton boulders between the riffles. The shape of the low flow channel between the riffles is shown in cross-section B-B (Figure 7). The shape would be similar to cross-section A-A. At the riffles, the rock size increases to 1.5-ton boulders. This was determined through the rock size calculation worksheet (Attachment A).

The details of construction of the low flow channel at bends (where there is a bench / bar on the inside of the bend), and for pools downstream of riffles (if necessary) will be determined during the design phase.

C. *(ADDED 12/19/2023)* *Channel Rehabilitation Between Bubb Road and Krzich Place*

Figure 8. 72" Pipe Outfall at Bubb Road

At the most upstream end of Valley Water jurisdiction, Regnant Creek flows out of a 72" pipe at Bubb Road. An emergency repair was completed in October 2023 that performed patchwork bank repairs on localized erosion scours near the pipe outfall. However, over time, the channel may continue to incise at the upstream end to arrive at a slope similar to the observed slope downstream of Krzich Place (~1%). Over a 10-year period, this can lead to several feet of additional incision which undercuts the toes of the bank of the emergency project in the 500 feet of channel downstream of the pipe. To minimize channel incision and erosion scours, it is recommended that the bed and bank to be rehabilitated via one of the two options described.

Option 1: Rock Slope Protection (RSP)

Since the pipe discharges at the channel bed, it will not be possible to raise the channel bed without blocking the pipe. This alternative will place 0.5- to 1-ton boulders to create a continuous riffle throughout the channel bed from Bubb Road to the “rock riffle” built in 2023 just upstream of Krzich Place (~STA 135+00) for a total of approximately 700 feet. The rocks will stabilize the bed, prevent further incision, and maintain the channel slope of 3.7%.

To provide additional stability with the steeper channel slope, the 1-ton rock should be installed as a single row across the bed, approximately every 100 feet, in place of the 0.5-ton rock. The 0.5-ton to 1-ton rock on the bank will extend up to 7 feet in height. It will contain the 100-year flow. The slope of the bank may be steeper than 1:1 in several locations.

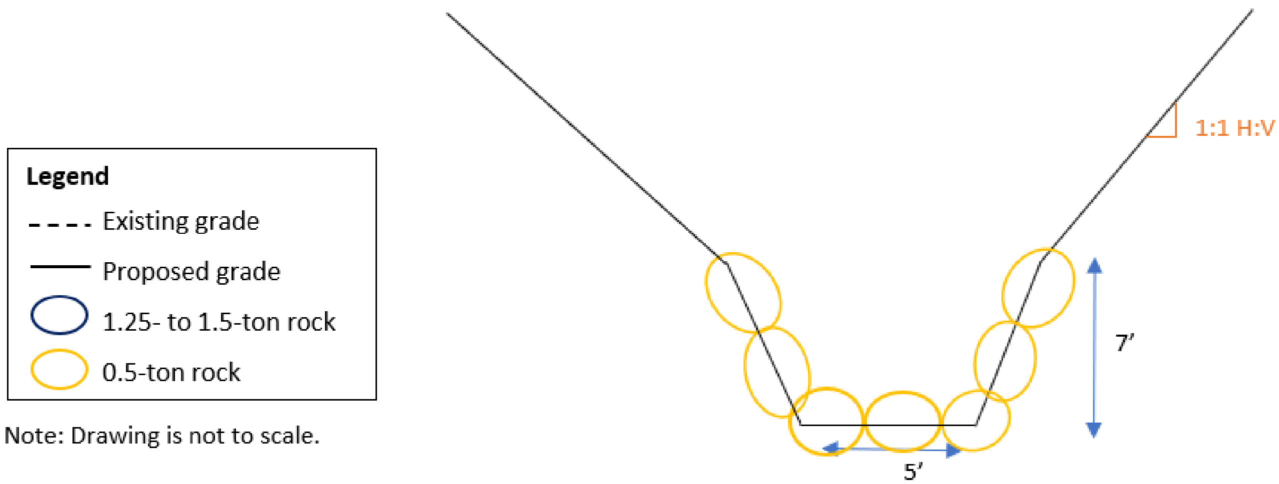


Figure 9. Option 1 – RSP Cross Section

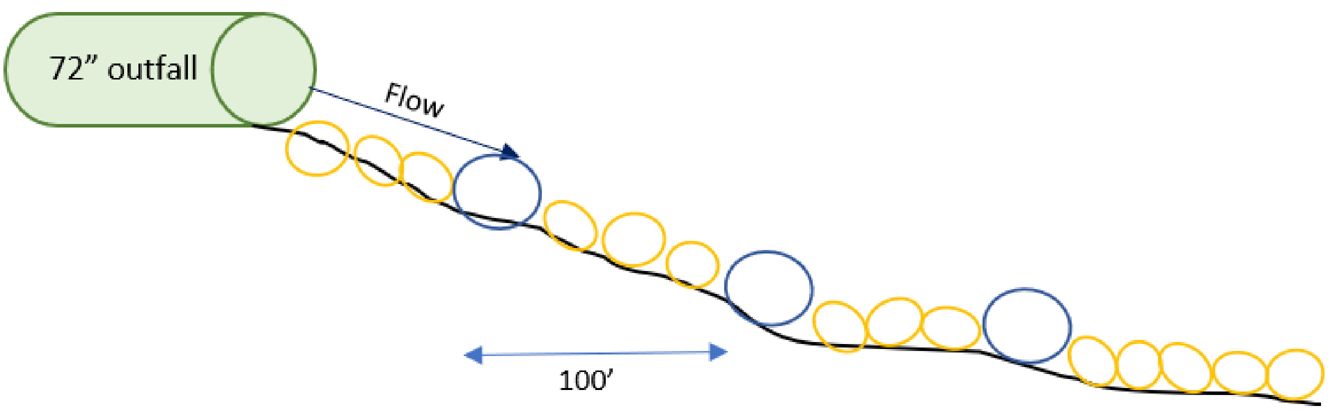


Figure 10. Option 1 – RSP Longitudinal Profile

Option 2: Pipe Extension

To achieve a more stable channel geometry and a H:V 1:1 bank slope, the channel bed can be raised approximately 7 feet by extending and burying the pipe. The pipe will be extended at a slope consistent to the existing channel slope to just upstream of Krzich Place, where it will daylight at the palm tree where a "rock riffle" was installed as part of the emergency project (The palm tree will be removed as part of this proposed project). A challenge will be installing the pipe so that follows the creek bends. On the other hand, a benefit of this alternative is that less environmental mitigation is required because the rock around the pipe will be below the bed. This alternative will restore the bed to a stable condition, as it was before the 72-inch pipe was installed.

There may be a risk of the pipe getting blocked if there are large boulders or sediment getting flushed downstream through the pipe under Bubb Road. A trash rack at the upstream end of the pipe can prevent large boulders from entering and an access point (removable cap) into the pipe can be built to clean out the blockages if required.

An alternative to the pipe is a 5-foot box culvert.

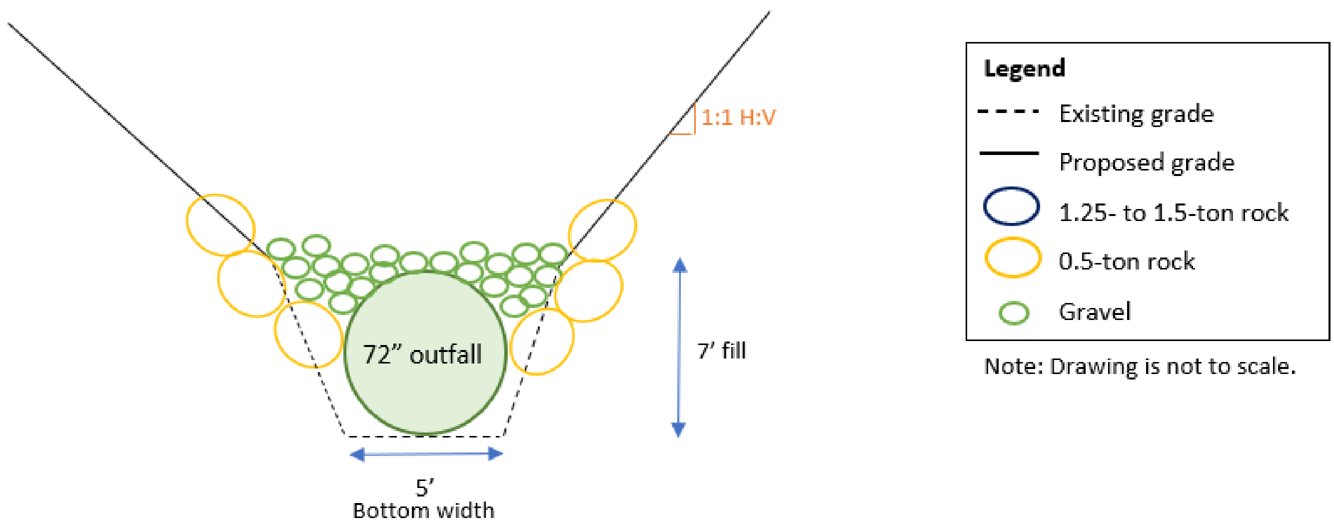


Figure 11. Option 2 – Buried Pipe Cross Section

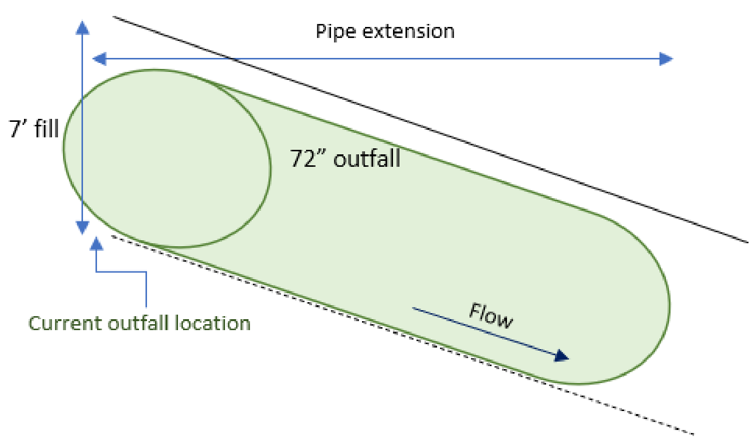


Figure 12. Option 2 – Buried Pipe Longitudinal Profile

V. Construction Cost Estimate

A construction cost estimate was calculated for the proposed channel rehabilitation design, assuming the rehabilitation from Krzich Place to Bubb Road follows the option 1 design recommendation described in Section IV.C, since option 2 is more expensive and may require more maintenance. The proposed project limit is from Bubb Road to Festival Drive, which is approximately 3,250 linear feet. The construction cost, including environmental mitigation, is approximately $4 million, which does not include planning, design, and construction management costs.

In March 2023, a geotechnical consultant was contracted to assess the worsening bank conditions after recent storm events and tree pruning/removal. The findings will help determine if any additional bank repairs are necessary. If so, the total construction cost may increase to a range from $5 million to $12 million dependent on the length and repair method.

Table 2. Construction Cost Estimate

Item	Unit Cost	Quantity	Cost	Notes
1.5-ton boulder (tons)	$220.00	436	$96,005	Referenced from Teichert Bid, Bolsa Fish Passage Improvement Project
0.5-ton boulder (tons)	$195.00	9,425	$1,837,928	Referenced from Teichert Bid, Bolsa Fish Passage Improvement Project
Streambed gravel (tons)	$75.00	3,555	$266,620	Referenced from Teichert Bid, Bolsa Fish Passage Improvement Project
Earth fill (cubic yards)	$55.00	758	$41,708	Referenced from Teichert Bid, Bolsa Fish Passage Improvement Project
		SUBTOTAL	**$2,242,261**	
Mobilization (10%)			$224,226	
Clearing & grubbing (10%)			$224,226	
Hydroseeding (10%)			$224,226	
Land acquisition (10%)			$224,226	
Mitigation (25%)			$560,565	
Contingency (15%)			$336,339	
		TOTAL	**$4,036,069**	

VI. Other Considerations

D. Bank Stabilization

During the series of storms in winter 2023, a couple of large trees fell and caused damage to the creek banks near Wallin Court and Bubb Road. At Bubb Road, the tree canopy and branches were trimmed. As additional trees have been identified for removal and said work cannot be conducted under the SMP, the Vegetation Field Operations Unit is pursuing a Lake Streambed Alteration Agreement (LSAA) with California Department of Fish and Wildlife. Similarly, a downed tree in the channel near STA 120+00 upstream of UPRR caused damage to a neighboring resident's fence and appears to have exacerbated the bank scour there.

The proposed channel rehabilitation design, which will raise the bed elevation and add benches and toe protection to the bottom half of the banks, is expected to stabilize the entire bank. It does not address the top half of the bank, which will be monitored. If after implementation of the design, it is determined the bank stability has not improved, it may be necessary to conduct additional bank stabilization work. This is recommended to include regrading the banks with earth fill and installing geotextile mats, which would be more geomorphically stable than boulders to withstand further incision and erosion. In addition, complete bank stabilization repairs may occur at the two locations identified in green in Figure 2 and any additional locations that the geotechnical consultant recommends.

E. Design Based on Geomorphic Principles

It is important to note that the proposed design is not a pure geomorphic design, but rather a *rehabilitation design for channel stability based on geomorphic principles*. A pure geomorphic design would prioritize restoring the channel back to its natural state and allow the river or creek to be self-maintaining. This would not be feasible for an urban channel like Regnart Creek, where given the limited floodplain and channel corridor, it is not realistic to achieve the geomorphic design of 4 bankfull widths at 2 bankfull depths.

As a result, this study recommends a design that brings greater stability than other options (such as stabilizing the banks only) because it incorporates geomorphic principles and complements it by accounting for the additional shear stresses for the entrenched and confined nature of the high flow channel that will remain.

VII. Conclusion

This rehabilitation design will address the widespread channel incision and erosion by raising the invert and stabilizing the new toe of bank (approximately bottom half of the bank) and shape of the channel. As a result, the banks will also become more stable with a wider, shallower channel, although additional bank stabilization projects may be recommended after monitoring the success of this design.

The proposed design is recommended to be a CIP project to implement improvements along a larger footprint, limit disturbance to the channel, and reduce mobilization costs. However, if the work does not get completed as part of the CIP project due to time constraints or budgetary restrictions, it may be undertaken as part of a Watersheds O&M project under SMP or a Small Capital project via WARP, also possibly under the SMP. Under the SMP, the project can be separated into reaches of 500 to 1000 feet in length to construct the riffle weirs.

VIII. Attachments

A. Channel Rehabilitation Rock Sizing Worksheet

B. Construction Cost Estimate Worksheet

C. Photos

Any Creek. Enter Values for Cells in Green; Optional to enter values in Cells in Blue; Evaluate values in cells in purple				Regnart -XS - Refer to Graphics to the right which show where the shear stress is computed to size boulders for that location									
Bioengineering and Sizing Rock to Rehabilitate Creeks		Analysis at flows above Bankfull up to Max or Top of Bank (TOB) Flow									Analysis at Bankfull Flow		
Location		**Thalwag at Top of Riffle** Existing		**Thalwag at Top of Riffle** With new bf bench configuration	**Toe at Top of Riffle** with new bf bench configuration	**Toe at Pool** with new bf bench configuration	**Bankfull Bench** With new bf bench configuration	**Near Toe High Flow Bank** with new bf bench configuration	**Above Toe High Flow Bank** with new bf bench configuration	**Non-Entrenched, Thalwag at Top of Riffle** for comparison bf floodplain	**Thalwag at top of riffle** not a design condition	**Toe at Pool** not a design condition	**Comments**
A. Enter Data in Cells Highlighted in Green; Optional for cells in Blue													
Bankfull height or Bankfull Depth at Top of Riffle or Weir, BFDr	feet	5	a	3	3	3	3	3	3	3	3	3	Subtract depth of Crevice and Notch of Weir, if included in the measurement
Bankfull width at Riffle, BFWr	feet	12	a	11	11	11	11	11	11	11	11	11	
Drop, Toe to Thalwag, Riffle, Dtthr	feet	0.5	a	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	See figure in powerpoint showing drop in elevation, from toe to thalwag at riffle
Width at bankfull bench or BF flood plain before or after construction, BFobenchW, at Riffle	feet	15.2	a	17	17	17	17	17	17	50	17	17	
Depth of Water at Thalwag at Max Flow used for Design (at Riffle or Weir), MWD_thalwag	feet	4.75	b	4.75	4.75	4.75	4.75	4.75	4.75	4.25	3	3	If it reaches TOB and opens to a floodplain at <100 year, use TOB
Depth of Water at Max Flow to Rock on Bed, Bench or Bank at Location of Analysis, MWD_L (see c	feet	4.75	b	4.75	4.25	5.75	1.75	1.5	0.5	4.25	3	4	For pool, add depth at toe of pool to the depth at riffle; for toe of riffle, subtract drop from toe of weir to midpoint
Is this Analysis for Location with Rock on Bank (Yes = 1), Toe or Side		0		0	1	1	1	1	1	0	0	1	
Is this Analysis for Location with Rock in Pool (Yes = 1)		0		0	0	1	0	0	0	0	0	1	
Is this Analysis for Location with Rock on Bench (Yes = 1)		0		0	0	0	1	0	0	0	0	0	
Bankfull Channel Side Slope (H:V), BFBslope		1	a	1	1	1	1	1	1	1	1	1	
Bench or Flood Plain Slope (H:V), BFPslope		5	a	100	100	100	100	100	100	100	100	100	
Channel Slope Above Bankfull Bench (H:V), HFBslope		1.32	a	1	1	1	1	1	1	1	1	1	
Drop Across Weir or Riffle: DRwrr	feet	1		1	1	1	1	1	1	1	1	1	
Ratio - Maximum Depth of Pool to Drop at Riffle, PRDth - see comment		2		2	2	2	2	2	2	2	2	2	0 if no pool; includes bowl in center; see EDF sheet and powerpoint for details
Ratio - Depth of Pool at Toe to Drop across riffle, PRDtoe - see comment		1.5		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	0 if no pool; toe is higher than bowl in middle. It excludes depth from toe to thalwag of bowl in pool, which is ~25% of pool depth
Slope of Ground or Reach of project (Sreach)		2.00%	a	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	
Ratio of Riffle Slope to Average Slope, RSrSreach		2.0		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
Manning's n Overall (for Max Flow analysis)		0.060		0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	
Manning's n Riffle Segment (for Bankfull Flow analysis)		0.080		0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	
Manning's n Pool Segment (for Bankfull Flow analysis)		0.040		0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	
Should Max Rock Size include Scour Depth (required for Riffle Footer and Weir, in bend areas for ot	1=Yes	1		1	1	1	1	1	1	1	1	1	This adds a scour depth to the D50, relevant for footer and weirs in channels subject to scour
Scour Depth / Drop across weir, depends on type of bed material at the location		2	cobble	2	2	2	2	2	2	2	2	2	Select based on type of bed, see references: TECHNICAL NOTES, U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCES CONSERVATION SERVICE, Boise Idaho, Feb 2001. Engineering - No 13, Design of Rock Weirs
Specific gravity of rock	2.85	2.85		2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	
Hydraulic gradient from HEC-RAS for surface of water		2.00%		1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	For bankfull flow riffle, slope=2*avg; pool = 0.5 avg
Bankfull flood plain slope - you may use land slope		2.00%		1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	
Q (Discharge) - Look at this to select depth of water	cfs	178		328	328	328	328	328	328	368	86	86	
B. Review Calculations to Refine the Geometry of the Cross-Section													
BF Height or Depth at Top of Riffle, BFDr	feet	5.00		3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	
BF Width at Riffle, BFWr	feet	12.00		11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	
Bottom Width, Low Flow Channel: BBWr = (BFWr - 2*BFDr * BFBslope)	feet	2.00		5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
Depth of Water at Max Flow to Bankfull Bench, inside edge, MWDthalwag - BFDr	feet	0.00	not used	1.75	1.75	1.75	1.75	1.75	1.75	1.25	0.00	0.00	
Width at Outer Edge of Bench, BFOBenchW	feet	15.20		17.00	17.00	17.00	17.00	17.00	17.00	50.00	17.00	17.00	
Bench Width Horizontal, each side, BenchWr = (BFOBenchW - BFWr)/2		1.60		3.00	3.00	3.00	3.00	3.00	3.00	19.50	3.00	3.00	
Change in Height Across Bench, CHBench = BenchWRiffle * BFPslope	feet	0.32		0.03	0.03	0.03	0.03	0.03	0.03	0.20	0.03	0.03	
Height Bankfull Bench, outer side, BFDobench = BFDr + CHBench	feet	5.32		3.03	3.03	3.03	3.03	3.03	3.03	3.20	3.03	3.03	
Depth of Water at Max Flow to Bankfull Bench, outside edge: HFWDobench = MWDthalwag- BFDol	feet	0.00		1.72	1.72	1.72	1.72	1.72	1.72	1.06	0.00	0.00	
Width at Top of Bench, BFobenchW	feet	15.20		17.00	17.00	17.00	17.00	17.00	17.00	50.00	17.00	17.00	
Width at Water Depth, WWD = BFobenchW + 2 * HFBslope * HFWDobench	feet	15.20		20.44	20.44	20.44	20.44	20.44	20.44	52.11	11.00	14.00	
Depth of Water at Max Flow to Toe of High Flow Bank, or Location on High Flow Bank, DHFBank_L	feet	0.00		1.72	1.72	1.72	1.72	1.50	0.50	1.06	0.00	0.00	
Is Location where we want to analyze rock size on HFBank?		0		0	0	0	0	1	1	0	0	0	
Bottom Width at Pool, Pbwt	feet	2		5	5	5	5	5	5	5	5	5	Set equal to bottom width at riffle (for ease of construction)
BF Depth at Toe of Pool, excluding bowl section in center: BFDptoe = BFDr + DRwwr * PRDrtoe	feet	6.5		4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	
BF Width at Pool, BFWp = Pbwt + (BFDptoe)*BFBSlope	feet	15		14	14	14	14	14	14	14	14	14	If BF Bank slope at pool is different from riffle, use the slope for pool
Bench Width at Pool, Horizontal, BenchWp = (BFOBenchW - BFWp)/2	feet	0.1		1.5	1.5	1.5	1.5	1.5	1.5	18	1.5	1.5	If negative, adjust pool depth or Width of Bench
BF Depth of Pool, including bowl section in center: BFDp = BFDr + DRwwr * PRDth	feet	7		5	5	5	5	5	5	5	5	5	

Average BF Height:BFDr*Fraction of Length riffle + BFDp * Fraction of Length pool	feet	6.0		4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	Assumes 50 % of length represented by run-riffle and 50% by pool
Entrenchment ratio, ER		2.56		2.31	2.31	2.31	2.31	2.31	2.31	5.27	2.31	2.31	If Entrenchment ratio is not adequate (<2), need to be conservative on rock size.
Width at 2 Bankfull Depth / Width at Bankfull Depth													
Area of Triangular section below Toe of Riffle, ARtrr = (Dtthr)(BBWR)/2		0.5		1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	
Area of Low Flow Channel at Riffle: ARrbf = (BBWr + BFWr)/2 * BFDr - ARtrr	sf	35		23	23	23	23	23	23	23	23	23	
Area of Mid Channel over extent of Bench: Arrbench = (BFWr + BFOBenchW)/2 * CHBench	sf	0		0	0	0	0	0	0	6	0	0	
Area of Wetted Channel above Bankfull Outer (High Flow Channel) at Riffle: Arrab = (WWD + BFOb	sf	0		32	32	32	32	32	32	54	0	0	
Total Area for Flow at Riffle, Arrtotal = Sum of Low Flow, Mid and Flow Above BF at Max Flow	sf	35		55	55	55	55	55	55	83	23	23	
Flow Area over Bed at Flow at Riffle, ARFrbed = ARrbf + (MWD_L - BFDr)(BFWr)	sf	35		42	42	42	42	42	42	37	23	23	
Flow Area over Bench at Flow at Riffle, ARFrbench = (HFWDobench)(BenchWr)+(CHBench)(Bench	sf	0		10	10	10	10	10	10	45	0	0	
Flow Area over HFBank at Flow at Riffle, ARFrhfbank = (DHFBank_L) (DHFBank_L* HFBslope)/2	sf	0		3	3	3	3	2	0	1	0	0	
Area of Low Flow Channel at Pool (see comment), Arpbf = (Pbwt + BFWpool) /2 * BFDptoe	sf	55		43	43	43	43	43	43	43	43	43	have excluded bowl section with additional 25% depth (for sub-bankfull, typically have debris in it)
Area of Mid Channel over extent of Bench at Pool:Arpbench = (BFWp+ BFOBenchW)/2 * CHBench	sf	0		0	0	0	0	0	0	6	0	0	
Area of Wetted Channel above Bankfull Outer (High Flow Channel) at Pool, Arpab = Arrab	sf	0		32	32	32	32	32	32	54	0	0	
Total Area for Flow at Pool, Arptotal = Sum of Low Flow and Flow above BF at Max Flow	sf	55		75	75	75	75	75	75	103	43	43	
Flow Area over Bed at Max Flow at Pool, ARFpbed = Arpbf + (MWD_L - BFDp)(BFWp)	sf	55		67	67	67	67	67	67	60	43	43	
Flow Area over Bench at Flow at Pool, ARFpbench = (HFWDobench)(BenchWp)+(CHBench)(Bench	sf	0		5	5	5	5	5	5	41	0	0	
Wetted Perimeter, Low Flow at Riffle, WPBFr= BBWr + 2*BFSideSlopelengthr	feet	16.1		13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	
Wetted Perimeter, Bankfull Bench at Riffle, WPBenchr = 2 * BenchSlopelengthr	feet	3.3		6.0	6.0	6.0	6.0	6.0	6.0	39.0	6.0	6.0	
Wetted Perimeter above Bankfull Bench Outer Side, at Max Flow, Riffle, WPHFABr = 2 * HFBSlope	feet	0.0		4.9	4.9	4.9	4.9	4.9	4.9	3.0	0.0	0.0	
Wetted Perimeter, Max Flow, Riffle, WPMaxFlowr = Sum of Wetted Perimeters, riffle	feet	19.4		24.4	24.4	24.4	24.4	24.4	24.4	55.5	19.5	19.5	
Wetted Perimeter, Low Flow, Pool, WPBFp = Pbwt + 2 *BFSideSlopelengthp	feet	20.4		17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	
Wetted Perimeter, Bankfull Bench at Pool, WPBenchp = 2 * BenchSlopelengthp	feet	0.7		3.0	3.0	3.0	3.0	3.0	3.0	36.0	3.0	3.0	
Wetted Perimeter above Bankfull Bench Outer Side, Pool, WPHFABp = 2 * HFBSlopelengthr	feet	0.0		4.9	4.9	4.9	4.9	4.9	4.9	3.0	0.0	0.0	
Wetted Perimeter, Max Flow, Pool, WPMaxFlowp = Sum of Wetted Perimeters, pool	feet	21.1		25.6	25.6	25.6	25.6	25.6	25.6	56.7	20.7	20.7	
Hydraulic Radius, Low Flow, riffle, RHLFr = Arbf / WPBFr	feet	2.14	for bf flow vel	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	
Hydraulic Radius, Flow, Entire XS, RHFr = Arrtotal / WPMaxFlowr	feet	1.8		2.3	2.3	2.3	2.3	2.3	2.3	1.5	1.2	1.2	
Hydraulic Radius, Flow over bed at Riffle, RHFbedr = ARFrbed / WPBFr	feet	2.1		3.1	3.1	3.1	3.1	3.1	3.1	2.7	1.7	1.7	
Hydraulic Radius, Flow over bench at Riffle, RHFbenchr = ARFrbench / Bench Width Slope Length	feet	0.0		1.7	1.7	1.7	1.7	1.7	1.7	1.2	0.0	0.0	
Hydraulic Radius, Flow Over Hfbank at Riffle, RHFhfb = ARFrhbank/HFBank_Lr	feet	0.0		0.6	0.6	0.6	0.6	0.5	0.1	0.4	0.0	0.0	
Hydraulic Radius, Flow over bench & HFBank at Riffle, RHFbbr = (ARrtotal - ARFrbed) / (WPMaxFlo	feet	0.0		1.2	1.2	1.2	1.2	1.2	1.2	1.1	0.0	0.0	For Shear Stress, we can use Bankfull Channel, Bench and Bench-HFB as three Segments; or we use BF Channel and Bench-HFB as two segments. We used three segments for narrow benches. Use two for wide benches.
													For wide bench (non-entrenched channe), Rh for Bench-HFB is pretty close to Bench
Hydraulic Radius, Low Flow at Pool, RHLFp = Arpbf / WPBFp	feet	2.71		2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	
Hydraulic Radius, Max Flow at Pool, RHMFp = Arptotal / WPMaxFlowp	feet	2.6		2.9	2.9	2.9	2.9	2.9	2.9	1.8	2.1	2.1	
Hydraulic Radius, Max Flow over bed at Pool, RHMFbedp = ARFpbed / WPBFp	feet	2.7		3.8	3.8	3.8	3.8	3.8	3.8	3.4	2.4	2.4	
Hydraulic Radius, Max Flow over bench at Pool, RHMFbenchp = ARFpbench / Bench Width Slope L	feet	0.0		1.7	1.7	1.7	1.7	1.7	1.7	1.2	0.0	0.0	
Hydraulic Radius, Flow over bench & HFBank at Pool, RHFbbp = (ARFptotal - ARFpbed) / (WPMax	feet	0.0		1.0	1.0	1.0	1.0	1.0	1.0	1.1	0.0	0.0	
Average Slope Savg = Sreach		2.00%		1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	1.90%	
Mannings'n overall, noverall		0.060		0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	
Velocity, Max Flow: vmaxflow = (1.49/n) R^(2/3) S^(1/2), see comment	fps	5.15		5.92	5.92	5.92	5.92	5.92	5.92	4.46	3.80	3.80	n = Manning's n overall; R = RHMFr, S = Savg
Velocity, Max Flow at Pool (see comment), vmaxp = vmaxflow * (Arrtotal / Arptotal)^0.5	fps	4.07		5.07	5.07	5.07	5.07	5.07	5.07	4.00	2.77	2.77	Approximated w/o HEC-RAS. When we used the ratio of areas, we raised it to power of 0.5 because velocities are lower in bottom half of pool
Ratio of Average Velocity to Velocity in Pool, vratioap = vrmaxflow / vrmaxp		1.27		1.17	1.17	1.17	1.17	1.17	1.17	1.12	1.37	1.37	
Velocity over Rock at Weir Crest, vmaxr = vratioap * vmaxflow	fps	6.52		6.91	6.91	6.91	6.91	6.91	6.91	4.98	5.20	5.20	We multiplied the average velocity by the Ratio to capture effect of change to higher slope across riffle (or drop at weir), resulting in change in energy slope used in DuBoy's equation for bed shear stress
Hydraulic Gradient at Pool, Sgrp, Using Manning's equation with vmaxp and noverall		0.743%		0.987%	0.987%	0.987%	0.987%	0.987%	0.987%	1.172%	0.474%	0.474%	For flows > BF, use average Manning's n
Hydraulic Gradient at Riffle, Sgrr, using Manning's equation with vmaxr and noverall		3.203%		2.588%	2.588%	2.588%	2.588%	2.588%	2.588%	2.367%	3.570%	3.570%	
Q (Discharge) = vmaxflow * Arrtotal	cfs	178		328	328	328	328	328	328	368	86	86	
Bankfull Flow Analysis using Local n and Slope													
Manning's n Riffle, nriffle		0.080		0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	For flows < BF, use local Manning's n
Manning's n Pool, npool		0.040		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	For flows < BF
Riffle Slope, Sriffle = Sreach * RSrSreach		4.0%		3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	
Velocity Riffle, vriffle (see comment)	fps	6.2		5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	n = nriffle; R = RHLFr, S = Sriffle
Velocity Pool, vpool (see comment)	fps	4.9		3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	vpool = vriffle * Arrbf / Arpbf
Hydraulic Gradient Pool, Sgrbfpool, using Manning's equation (see comment)		0.455%		0.314%	0.314%	0.314%	0.314%	0.314%	0.314%	0.314%	0.314%	0.314%	n = npool; R = RHLFp, vpool

C. Screen and Select Bioengineering Methods to Rehabilibate Bed and Bank												
1. Velocity												
Percent Reduction in Velocity at toe and HF bank, if applicable		5.0%		5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	Values reduced 5% for toes (except outside of bends), another 5% for High Flow bank
Multiply reduction by factor for location on high flow bank for ER>4		1		1	1	1	1	1	1	2	1	1	
v for velocity method = (vmaxr or vmaxp) (1 - % reduction for Bank)(1 - % reduction for HFB)	fps	6.52		6.91	6.56	4.82	6.56	6.23	6.23	4.98	5.20	2.63	Velocity is for the location of rock, thalwag, riffle, bf flood plain, etc. Can be based on HEC-RAS with multiple segments across X-Section
Comment regarding location of velocity		Thalwag or Bed		Thalwag or Bed	Low Flow Toe	Low Flow Toe	Bench	HF Bank	HF Bank	Thalwag or Bed	Thalwag or Bed	Low Flow Toe	
Average Manning's n over Bed (Riffle-Pool, Weir-Pool, other), noverall		0.060		0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	rough rock for channel bottom
Computed Slope from Manning's equation, Scomp = Sgrr or Sgrp, based on riffle or pool		3.203%		2.588%	2.588%	0.987%	2.588%	2.588%	2.588%	2.367%	3.570%	0.474%	v = (1.49/n) R 2/3 S 1/2
Computed slope will be close to that from HEC RAS with multiple sections in each riffle and pool													
2. Shear Stress													
Computed Slope from Manning's equation, Scomp		3.20%		2.59%	2.59%	0.99%	2.59%	2.59%	2.59%	2.37%	3.57%	0.47%	
Specific weight of Water, Ywater	lb/ft3	62.4		62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	
Specific Weight of Rock (Yrock) based on specific gravity of 2.85 (varies from 2.2 to 3.2)	lb/ft3	178		178	178	178	178	178	178	178	178	178	
Depth of Water at location, MWD_L	feet	4.8		4.8	4.3	5.8	1.8	1.5	0.5	4.3	3.0	4.0	
Hydraulic Radius (RH_L) for Location. Use IF statement to select appropriate Rh	feet	2.1		3.1	3.1	3.8	1.7	1.2	1.2	2.7	1.7	2.4	
Ratio of Depth of Submergence at Location to Max Depth for Segment, RDSLMDS		1.00		1.00	0.89	1.00	1.00	0.87	0.29	1.0	1.0	1.0	
Tb calculation based on Hydraulic Radius (select 1) or Depth of Water, see comment		1		1	1	1	1	1	1	1	1	1	Default is 1, which bases computation of shear on Hydraulic Radius
Tb, applied bed shear = (Ywater) (Scomp) (RH_L or MWD_L) (RDSLMDS)	lb/ft2	4.27		5.03	4.50	2.34	2.80	1.73	0.58	4.00	3.76	0.71	DuBoys Equation, Schwendel et al., 2009. Assessment of Shear Stress and Bed Stability. T = (Ywater)(Slope of Energy Gradient)(Hydraulic Radius for that Segment)
bank shear equals local value of bed shear													*For locations along the bank, we adjust hydraulic radius by a ratio RDSTb.*
Potential Techniques for Bench & High Flow Bank (see comments for abbv)		Location of Analysis is Below Bankfull		Location of Analysis is Below Bankfull	Location of Analysis is Below Bankfull	Location of Analysis is Below Bankfull	WS,R, VR,VCM,CR	Turf+Rest	Turf+Rest	Location of Analysis is Below Bankfull	Location of Analysis is Below Bankfull	Location of Analysis is Below Bankfull	R=Rock, VR = Veg Rock (Rock & Brush), VCM = Veg Coir Mat, CR = Coir Roll, WS = Willow Stake, B Turf = Class B Turf. Fischenich, 2001
Potential Techniques Below Bankfull		R, R-L Bed; R, LCW, RW bank		R, R-L Bed; R, LCW, RW bank	R, R-L Bed; R, LCW, RW bank	R, R-L Bed; R, LCW, RW bank	Location of Analysis is Above Bankfull	Location of Analysis is Above Bankfull	Location of Analysis is Above Bankfull	R, R-L Bed; R, LCW, RW bank	R, R-L Bed; R, LCW, RW bank	GC-C Bed, BR R LCW bank	R=Rock; LCW=Log / Crib Wall; R-L = Rock & Log Weir; RW = Root Wad; CSG = Consolidated Silt Gravel; GC-C Bed = Gravel Cobble Bed; BR Bank = Buried Rock
D. Compute Rock Size for Stabilizing Bed, LFB, Bench and HFB													
At initiation of movement, Tb = Tc, where Tc is the resistive shear of material on the bed													
Tb = Tc = (Tcr) (Yr-Yw) (Di), Di is the diameter that begins to move*													We calculated Tb; we will calculate Tcr* based on Andrews equation
D50 / Di Ratio Selected, see comment		2		2	2	2	2	2	2	2	0.5	0.5	from Stream Habitat Restoration Guidelines, Final Draft, Washington Dept of Fish and Wildlife, Sep 2004
Andrews equation for dimensionless Critical Shear, Tcr*													for rock riffles, Di = rock size for incipient motion; D50 is median rock size. For natural bed of gravel, sand, etc., use D50 of bed material - D50 moves, Di is larger than D50
Tcr* = 0.0834*(Di/D50)^(-0.872) See comment		0.15		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.046	0.046	If Andrews Tc* lower than Tc* range of 0.02 to 0.06, then use Tc*=0.02
Based on Shields Diagram, if Tcr >0.06, use 0.06. If Tcr Andrews < 0.02, modify D50/Di ratio to get to 0.02 or higher													
Tcr*, based on Shields Diagram and Andrews		0.06		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.046	0.046	for weir, the value is higher based on Andrews equation, lower for bankfull flood plain if rocks are smaller
X = (Tcr*) (Yr-Yw)	lb/ft3	6.93		6.93	6.93	6.93	6.93	6.93	6.93	6.93	5.26	5.26	
Tb = Tc = Tcr* (Yrock - Ywater) * Di													
Di bed = Tb / X	feet	0.62		0.73	0.65	0.34	0.40	0.25	0.08	0.58	0.71	0.14	
Di bed	mm	188		221	198	103	123	76	25	176	218	41	
D50 Riffle Rock = (D50/Di) ratio selected * Di	feet	1.23		1.45	1.30	0.67	0.81	0.50	0.17	1.15	0.36	0.07	
D50 Rock	mm	376		443	396	206	247	152	51	352	109	21	
Alternate form, Tb = Tc = 4 D50 (see coment)													Tc = 4 D50 (FHWA HEC-15) for Di > 1 foot; From Stable Channel Design Ch 5, US Military, and FHWA HEC-15
D50 (based on FHWA HEC-15), not used below	feet	1.07		1.26	1.12	0.58	0.70	0.43	0.14	1.00	0.94	0.18	
D50 rip rap (from Table of Permissible Shear), not used below	feet	1.00		1.00	1.00	0.50	0.75	0.50	0.50	1.00	0.75	0.50	Fishenich (2001), D50 rip-rap can then be used in the NRCS method to compute D100 weir
D50 (Far West States Lane Method, NRCS 1996, Fripp 1998), Fish Passage Design Jul 2009	feet			1.86						0.97			From Fish Passage Design and Implementation, Jul 2009, CA Salmonid Habitat Restoration Manual, XII-90. Formula Modified = 3.5 (Yw * Max Depth * Slope) / (CK); C and K = 1

1. Based on Ratios from Rip Rap sizing and Critical Shear Equation, with one modification													
At initiation of movement, Tb = Tc; Di bed = Tb / X													
Di for initiating motion of rock - rip rap rock size for grade control structures	feet	0.62		0.73	0.65	0.34	0.40	0.25	0.08	0.58	0.71	0.14	Di bed = Tb / (Tc / Di) for Tb = Tc
Dmin /Di Ratio, see comment		1.25		1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	***Modified from Stream Restoration Guidelines. SRG uses Dmin-weir = 0.75 * D50-riprap. This computation uses Dmin-weir = 1.25 * Di***
D50 / Di Ratio (from above)		2		2	2	2	2	2	2	2	0.5	0.5	from Stream Habitat Restoration Guidelines, Final Draft, Washington Dept of Fish and Wildlife, Sep 2004
D100 weir (max rock size) / D 50 weir		1.5		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	
Dmin, weir or riffle, Di * (Dmin / Di)	feet	0.8		0.9	0.8	0.4	0.5	0.3	0.1	0.7	0.9	0.2	downstream rock and rock near bed used as fill; Modified from Stream Restoration Guidelines as stated above
D50 weir: if (Dmin<1, Dmin * D50/Di, Di * D50/Di)	feet	1.54		1.82	1.62	0.84	1.01	0.63	0.21	1.44	0.45	0.08	fill rock between large rocks
D100 weir - max rock size (or top of riffle): D50 weir * (D100weir / D50weir)	feet	2.3		2.7	2.4	1.3	1.5	0.9	0.3	2.2	0.7	0.1	footer rock and protruding rock
If used as footer, (Scour Depth + Dminweir)/F for angularity.	feet	2.2		2.3	2.2	1.9	2.0	1.9	1.7	2.2	2.3	1.7	F is 1.25 or 1.5. Angularity = Long Axis / Avg Axis
	feet												
Dmin Weir rock weight: PI * Dmin^3 / 6 * Specific Weight	lb	43		70	50	7	12	3	0	35	66	0	
D50 Rock weight: PI * D50^3 /6 * Specific Weight	lb	341		557	399	56	96	23	1	280	8	0	
Method 1: Maximum Rock weight D100	lb	1152		1880	1347	677	750	590	444	961	1154	487	Max of D100 or (Scour Depth + D50)/1.5
Dimensions Cubical Rock	ft	1.9		2.2	2.0	1.6	1.6	1.5	1.4	1.8	1.9	1.4	
2. Rosgen Paper, Figure 10 - Method for bf depth of flow in unentrenched channels; adapting it for entrenched channels													
Tb, regression equation based principally on non entrenched channels	kg/m2	20.86		24.56	21.97	11.41	13.68	8.46	2.82	19.52	18.35	3.48	
D: D = 0.1724 Ln (Tb) + 0.6349	meters	1.16		1.19	1.17	1.05	1.09	1.00	0.81	1.15	1.14	0.85	D = 0.1724 Ln (x) + 0.6349; metric units. Look at non entrenched condition for expected value to use
D	feet	3.80		3.89	3.83	3.46	3.56	3.29	2.67	3.76	3.73	2.79	
Footer and protruding rock volume	ft3	28.75		30.90	29.43	21.69	23.67	18.66	9.96	27.91	27.14	11.35	
Footer and protruding rock weight	lb	5114		5496	5234	3857	4210	3318	1771	4964	4827	2018	
Safety Factor for EW													
If EW<1.8, use Safety Factor of 1.1; For toe, multiply by 0.9; For bench,													
Method 2: Rock weight	lb	5114		5496	4710	3471	3410	2986	1594	4964	4827	1816	
Dimensions for cubical rock	ft	3.1		3.1	3.0	2.7	2.7	2.6	2.1	3.0	3.0	2.2	
3. Velocity Method (Isbach, 1936)													from Stream Habitat Restoration Guidelines, Final Draft, Washington Dept of Fish and Wildlife, Sep 2004
D50 / Dmin 2 is minimum, 2.25 recommended		2.25		2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	from Stream Habitat Restoration Guidelines, NRCS "Drop Structures", Page 21 for Invert
D50 / Dmin adjusted for bank and height using ^(1/3) to get from volume to dia; set minimum to 2		2.25		2.25	2.25	2.25	2.00	2.00	2.00	2.25	2.25	2.25	modified for bench and high flow bank
D100/D50		1.5		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	
Method Alt 1													
Dmin = (Vavg/9.571)^(2.05)	feet	0.46		0.51	0.46	0.24	0.46	0.42	0.42	0.26	0.29	0.07	Costa 1983, Paleohydraulic reconstruction of flash flood peaks from boulder deposits
D50	feet	1.03		1.15	1.04	0.55	0.92	0.83	0.83	0.59	0.64	0.16	from Stream Habitat Restoration Guidelines
D100 should be 1.5 D50	feet	1.54		1.73	1.56	0.83	1.38	1.25	1.25	0.88	0.97	0.24	
Method Alt 2													
Dmin { V^2 / (1.479 *g(Densityrock - Densitywater)/Densitywater) }	feet	0.48		0.54	0.49	0.26	0.49	0.44	0.44	0.28	0.31	0.08	Isbash 1936 - Construction of dams by depositing rocks in running water
D50 should be 2 Dmin - see Table on Page 21	feet	1.09		1.22	1.10	0.59	0.98	0.88	0.88	0.63	0.69	0.18	
D100 should be 1.5 D50	feet	1.63		1.83	1.65	0.89	1.47	1.32	1.32	0.95	1.04	0.27	
If used as footer, (Scour Depth + D50weir)/1.5, OR (Scour Depth + Dminweir)/1.25; divide by 1.25 o	feet	2.06		2.15	1.93	1.60	1.65	1.25	1.25	1.76	1.79	1.32	
Weight of D100 rock	lb	811		920	673	378	420	216	216	504	538	213	this result is dependent on banfkull velocities
Dimensions for cubical rock	ft	1.7		1.7	1.6	1.3	1.3	1.1	1.1	1.4	1.4	1.1	
4. Scour Depth - Refer to Scour Depth Sheet													
Depth of fall across weir or riffle	ft	1		1	1	1	1	1	1	1	1	1	
Expected Scour Depth multiplier on Drop		2	cobble	2	2	2	2	2	2	2	2	2	Select based on type of bed, see references
Expected Scour Depth (adjusted for location by multiplying by 0.9 for Toe, 0.75 for bench, 0.5 for HF	ft	2		2	1.8	1.8	1.5	1	1	2	2	1.8	
Boulder (or Footer) crest height above elevation of Riffle; 0 to 3 inches typical	inches	3.00		3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	For rock that is footer only, enter 0. For cuboidal, enter 0
Longest Axis of footer rock	ft	3.25		3.25	3.05	3.05	2.75	2.25	2.25	3.25	3.25	3.05	
Mid Axis of footer rock, use Long Axis / Mid Axis =1.25		2.60		2.60	2.44	2.44	2.20	1.80	1.80	2.60	2.60	2.44	
Shortest Axis of footer rock	ft	2.08		2.08	1.95	1.95	1.76	1.44	1.44	2.08	2.08	1.95	
Mid Axis of footer rock	ft	2.60		2.60	2.44	2.44	2.20	1.80	1.80	2.60	2.60	2.44	
Expected Volume	ft3	9.2		9.2	7.6	7.6	5.6	3.1	3.1	9.2	9.2	7.6	
Expected Weight	lbs	1637		1637	1353	1353	992	543	543	1637	1637	1353	
Dimensions for Cubical Rock	ft	2.1		2.1	2.0	2.0	1.8	1.5	1.5	2.1	2.1	2.0	

E. Review Results													
Summary of Rock Size of D100 Rock (Footer Rock)													
1. Based on Ratios from Rip-rap sizing and bed critical shear	lb	1152		1880	1347	677	750	590	444	961	1154	487	
2. Rosgen with safety factor if EW < 1.5	lb	5114		5496	4710	3471	3410	2986	1594	4964	4827	1816	
3. Velocity Method from Isbach, 1936	lb	811		920	673	378	420	216	216	504	538	213	
4. Scour Depth Method, NRCS Tech Note, Feb 1 2001	lb	1637		1637	1353	1353	992	543	543	1637	1637	1353	
Median Value	*lb*	*1394*		*1758*	*1350*	*1015*	*871*	*566*	*494*	*1299*	*1396*	*920*	
Average Value	*lb*	*2178*		*2483*	*2021*	*1470*	*1393*	*1084*	*699*	*2016*	*2039*	*967*	
Max Value	lb	5114		5496	4710	3471	3410	2986	1594	4964	4827	1816	
Size of Rock, higher of Median and Average	lb	2178		2483	2021	1470	1393	1084	699	2016	2039	967	
Applied Shear Stress	lb/ft2	4.27		5.03	4.50	2.34	2.80	1.73	0.58	4.00	3.76	0.71	
Bioengineering Techniques on Bench and High Flow Bank		Location of Analysis is Below Bankfull		Location of Analysis is Below Bankfull	Location of Analysis is Below Bankfull	Location of Analysis is Below Bankfull	WS,R, VR,VCM,CR	Turf+Rest	Turf+Rest	Location of Analysis is Below Bankfull	Location of Analysis is Below Bankfull	Location of Analysis is Below Bankfull	
Bioengineering Techniques on Bed and Low Flow Bank		R, R-L Bed; R, LCW, RW bank		R, R-L Bed; R, LCW, RW bank	R, R-L Bed; R, LCW, RW bank	R, R-L Bed; R, LCW, RW bank	Location of Analysis is Above Bankfull	Location of Analysis is Above Bankfull	Location of Analysis is Above Bankfull	R, R-L Bed; R, LCW, RW bank	R, R-L Bed; R, LCW, RW bank	GC-C Bed, BR R LCW bank	
Ratio of diameter of spherical rock to cuboidal rock, see comment		1.24		1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	Ratio is used to convert cubic size of rock to diameter for spherical rock and B axis of elliptical rock
Diameter B axis Elliptical/Cuboidal													
Dimensions or C axis for cubical D100 rock	feet	2.3	12.2	2.4	2.2	2.0	2.0	1.8	1.6	2.2	2.3	1.8	for cuboidal rock, this is the average length of three axes
Dimensions for spherical rock D100 rock	feet	2.9	12.2	3.0	2.8	2.5	2.5	2.3	2.0	2.8	2.8	2.2	
Recommended B axis for elliptical rock	feet	2.9	12.2	3.0	2.8	2.5	2.5	2.3	2.0	2.8	2.8	2.2	
Diameter B axis Elliptical/Cuboidal		1.24		1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	

Regnart Creek Rehabilitation Construction Cost Estimate

Item	Unit Cost	Quantity	Cost	Notes
1.5 ton boulder (tons)	$ 220.00	530	$ 116,695	Referenced from Teichert Bid, Bolsa Fish Passage Project
0.5 ton boulder (tons)	$ 195.00	9,331	$ 1,819,589	Referenced from Teichert Bid, Bolsa Fish Passage Project
Streambed gravel (tons)	$ 75.00	3,555	$ 266,620	Referenced from Teichert Bid, Bolsa Fish Passage Project
Earth fill (cubic yards)	$ 55.00	758	$ 41,708	Referenced from Teichert Bid, Bolsa Fish Passage Project
		SUBTOTAL	**$ 2,244,612**	
Mobilization (10%)			$ 224,461	
Clearing and grubbing (10%)			$ 224,461	
Hydroseeding (10%)			$ 224,461	
Land acquisition (10%)			$ 224,461	
Mitigation (25%)			$ 561,153	
Contingency (15%)			$ 336,692	
		TOTAL	**$ 4,040,301**	

ROCK RIFFLE (FESTIVAL TO KRZICH)

Assume	0.35	void fraction
	2.65	specific gravity of boulder
	2.25	specific gravity of streambed gravel
Rock Riffle length	2250	Linear Feet

Fill below new thalweg

Dimensions:	140	linear feet of 1.5 ton boulder
	2110	linear feet of 0.5 ton boulder
	10	average width below low flow (feet)
	4	average height of fill (feet)

1.5 ton boulder		**0.5 ton boulder**	
5,600	cubic feet	84,400	cubic feet
62.4	lb/cf	62.4	lb/cf
601,910	lb	9,071,650	lb
301	tons	4,536	tons

Fill for bench

Dimensions:	140	linear feet of 1.5 ton boulder
	2110	linear feet of 0.5 ton boulder
	6	width of two benches (feet)
	3	height (feet)

1.5 ton boulder		**0.5 ton boulder**	
2,520	cubic feet	37,980	cubic feet
62.4	lb/cf	62.4	lb/cf
270,860	lb	4,082,242	lb
135	ton	2041	ton

Bank Rock above bench

Dimensions:	2250	linear feet of 0.5 ton boulder
	4	width, two benches
	2	height

1.5 ton boulder		**0.5 ton boulder**	
none		18,000	cubic feet
		62.4	lb/cf
		1,934,712	lb
		967	ton

Streambed gravel (1 inch layer + fill in voids)

Dimensions:	2110	linear feet

Attachment C – Photos

December 21, 2022. Severe channel incision at Krzich Place.

April 6, 2023. Steep, eroded banks at Krzich Place.

April 6, 2023. Channel incision upstream of Krzich Place.

April 6, 2023. Downed tree and bank erosion at Wallin Ct.

April 6, 2023. Channel incision and erosion at Wallin Ct.