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LOMBARDI GULCH CREEK EMERGENCY HDD UNDERCROSSING

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ABSTRACT: The City of Santa Cruz Water Department (SCWD) is currently replacing approximately 4-miles of water transmission main located along Highway 1 and the California coast line immediately northwest of Santa Cruz, California. The existing main was built in the 1950s and is part of the North Coast System, which consists of 16-miles of pipelines and stream diversion structures which supplies the City with the highest quality water amongst the City's various sources. While the primary method of replacement will be open-cut methods, the project contains five trenchless pipe installations which include four horizontal auger bores (HAB) and one horizontal directional drill (HDD) segment.

The original intent was to bid the entire project in a single contract, however it was discovered in the fall of 2015 that the existing 22-inch steel water main had ruptured resulting in a leak that discharged precious raw water at the rate of half a million gallons per day. Given the water restrictions experienced by the City, as well as the entire State of California, due to one of the worst droughts in history, it was crucial that the leak repair and replacement of the pipe in the vicinity of the leak be completed as soon as possible. As a result, the City issued Bid Documents for the Lombardi Gulch Creek Emergency HDD Undercrossing to install only the HDD segment from the North Coast Project, which entailed the installation of 24-inch Fusible Polyvinyl Chloride pipe in a 1,300-foot-long HDD undercrossing through the difficult geologic conditions at Lombardi Gulch, a sensitive riparian area inhabited by the threatened California Red-Legged Frog. Coordination and cooperation between the Owner, Engineer, Construction Manager, Contractor and Regulatory Agencies was essential to successfully overcome the challenging circumstances of the project. This paper will discuss lessons learned in context with the planning, procurement, design, and construction required to reestablish the SCWD water main.

1. INTRODUCTION

The City of Santa Cruz Water Department (SCWD) is underway on its third and largest phase of rehabilitation to a 60-year-old water main of the North Coast System (NCS). The NCS taps into springs and streams that originate from the western flank of the Santa Cruz Mountains northwest of Santa Cruz, California. The system is composed of 3 stream diversion structures, 16 miles of piping and a pump station. It also provides the highest quality water to the City and provides 30% of the City annual supply for the 93,000 customers. Historically, the NCS has been used as a municipal water supply for 130 years. The diverted stream water was first owned by competing private entities and eventually consolidated under municipal ownership in 1916. Major sections of the system were reconstructed in the 1950s, some of which are still in operation today. However, numerous repairs and environmental issues which manifested in the 2000s led SCWD to plan the replacement of the entire system over a series of phases. The newest upgrade, known as Phase 3, will provide 18,000-feet of new, primarily 24-inch, Polyvinyl Chloride (PVC) water main along Highway 1 (CA SR 1) in 16,000-feet of trenched excavations and 2,000-feet of trenchless installations. The trenchless undercrossing consist of four horizontal auger bores (HAB) and one horizontal directional drill (HDD). They are indicated below in Figure 1, in context with the full alignment of the Phase 3 pipeline replacement work.

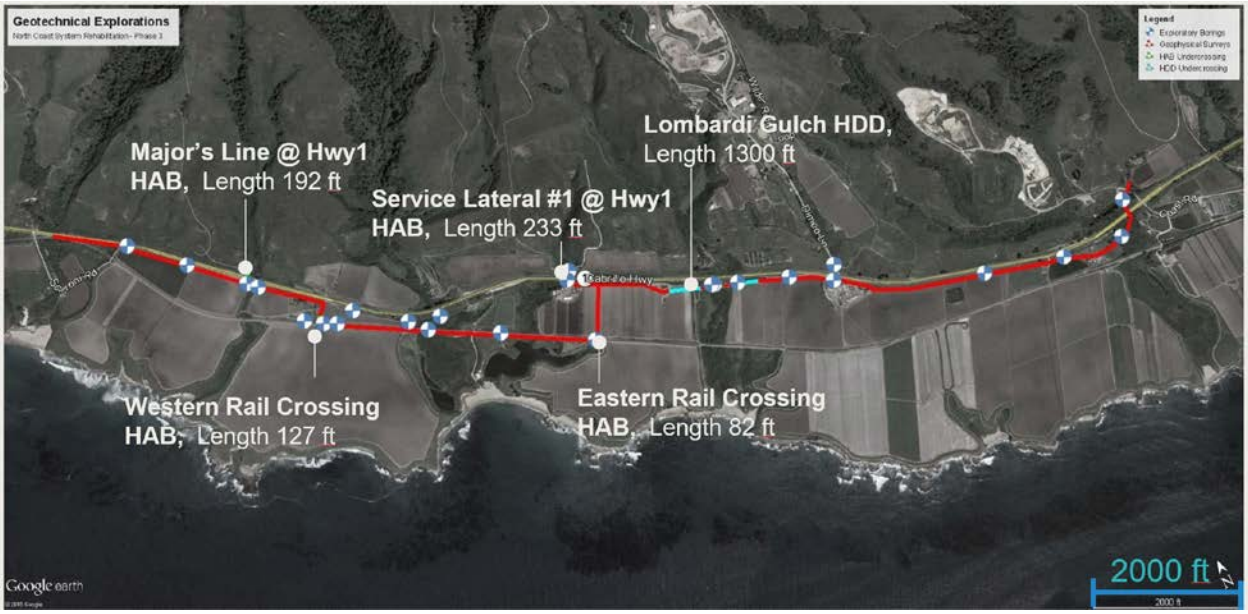

Figure 1: NCS Phase 3 Project Alignment with trenchless installations and geotechnical boring locations.

2. PIPELINE RUPTURE

The original intent was to advertise Phase 3 as a single contract in early 2016. The project would have likely been constructed by one general contractor, with subcontracts to perform all the trenchless work. However, an unforeseen localized failure of the existing water main was discovered in October of 2015, several months prior to the planned advertisement date. The existing 22-inch welded steel water main was found to be discharging half a million gallons per day of raw water approximately 40 feet to the east of Lombardi Creek. This rupture occurred mid-alignment of a planned 1,300-foot-long HDD installation parallel to the existing main as part of the Phase 3 replacement work (see Figures 2, 3 and 4).

The pipeline rupture coincided with a historically severe drought in the State of California, and it was imperative that a replacement of this portion of the pipeline was completed with expedience. Due to the importance of fresh water supply to SCWD customers, flow was maintained through the damaged pipeline in order to not excessively strain the City's other water resources. Fortunately, it was that the design of Phase 3 was already complete in terms of the geotechnical reports, plans, and specifications. Thus, an accelerated repair was a feasible goal pending on immediate permitting and the availability of qualified contractors and materials. Once aware of the situation, the land owner, California State Parks, promptly provided a right of entry permit reducing further reparation delays that could have resulted in additional hardships to the City of Santa Cruz. In the coming weeks, the replacement project was advertised and awarded as the 'Lombardi Gulch Creek Emergency Main Replacement Project' and was successfully completed in January of 2016.

Figure 2: Lombardi Gulch HDD alignment in context with location of failure in parallel existing main.

Figure 3: Ruptured water main.

Figure 4: Efforts to contain the leaking water.

3. ENVIRONMENTAL CONCERNS

Lombardi Gulch is mostly located within Wilder Ranch State Park in the County of Santa Cruz. The park, stretching from the coast of the Pacific Ocean to the upper foothills of the Santa Cruz Mountains, provides important biological, scenic, cultural, recreational, and habitat value for the surrounding community, visitors, and flora and fauna. From a biological perspective, the park provides habitat for several sensitive species including the Ohlone Tiger Beetle, Western Pond Turtle, California Red-legged Frog, Western Burrowing Owl, Migratory Birds, Steelhead, Coho Salmon and Tidewater Goby. Specifically, Lombardi Creek provides documented breeding habitat for the California red-legged frog, a federally threatened species (see Figure 5 and 6).

Due to increased environmental concerns, SCWD desired the lowest risk option, in terms of disturbances to native vegetation, wildlife, and terrain, to replace the existing water main. Thus, a 1,300-foot-long HDD installation, undercrossing the full width of Lombardi Gulch was selected for the promise of reduced environmental impacts when compared with a trenched alternative.

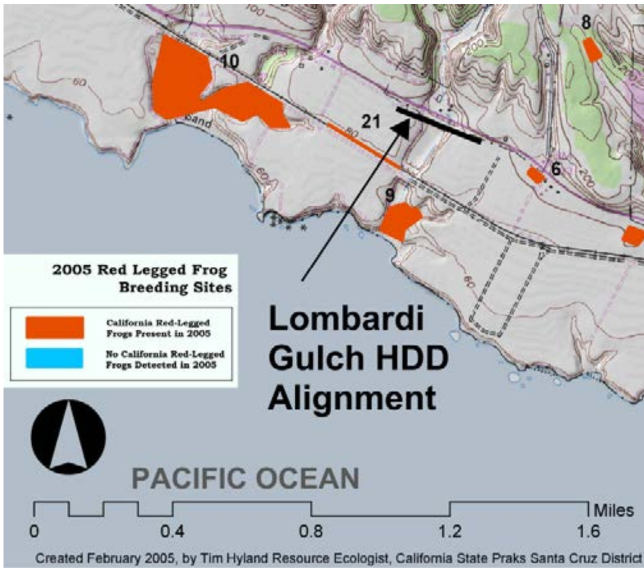

Figure 5: Observed California Red Legged Frog Breeding Sites near Lombardi Gulch.
Figure 6: California Red Legged Frog.

Permitting requirements to perform the 1,300-foot-long HDD installation under Lombardi Gulch include:

1. Central Coast Regional Water Quality Control Board CWA Section 401 Water Quality Certification
2. United States Fish and Wildlife Service (USFWS) Biological Opinion
3. California Department of Fish and Wildlife (CDFW) Lake or Streambed Alteration Agreement
4. California Department of Parks and Recreation Right of Entry Permit
5. U.S. Army Corps of Engineers Nation Wide Permit 12
6. County of Santa Cruz Coastal Development Permit

4. TOPOGRAPHIC AND GEOLOGIC CONDITIONS

At the site of the HDD installation, Lombardi Creek was a 7-foot-wide stream within a steep 60-foot-deep gulch vegetated with coastal sage scrub and riparian tree species. Preliminary desktop analyses suggested that the 870-foot-wide gulch could be undercrossed from west to east with a single 1,300-foot-long HDD bore. Subsurface conditions were investigated with three exploratory borings, field geologic mapping, and a geophysical survey. The investigations confirmed the gulch was a buried valley with an accumulation of over 100 feet of alluvially deposited sediments. The majority of those sediments were classified as loose to medium dense silty sands and gravels. There were occasional layers of medium stiff to stiff lean clay. The phreatic surface was found to be at very shallow depths in the gulch.

The banks of the gulch exposed a shallow layer of marine terrace sand that overlaid moderately hard Santa Cruz Mudstone (Tsc). With no outcrops along the Phase 3 alignment, rock coring on the eastern bank of the gulch encountered soft Santa Margarita Sandstone (Tsm) underlying the mudstone. Tsc is a Miocene-series sedimentary formation that was encountered as light orange brown to brown mudstone with medium- to thick-bedding. Tsm, also dating to the Miocene Period, was a weathered light gray to brown sandstone. Outcrops along the adjacent sea cliffs suggested that the rock bedding was roughly horizontal and consistent for both sides of Lombardi Gulch. An interpreted geologic profile that is based on these investigations, as well as the directional drilling, is provided in Figure 7. The HDD design and as-built alignments are shown on the profile for later reference.

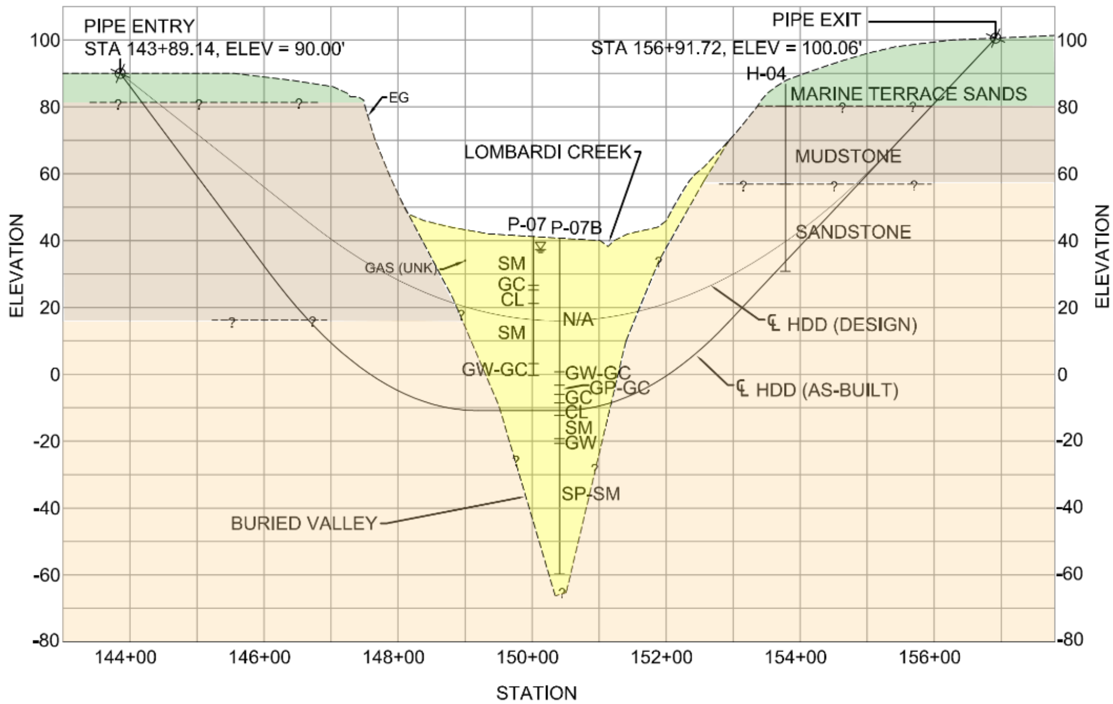

Figure 7: Interpreted Geologic Profile along Lombardi Gulch with HDD alignments

5. HDD DESIGN

Entry and exit points of the installation were established at level locations approximately 200 to 300 feet beyond the steep banks of Lombardi Gulch. Final design established the entry and exit angles at 9.1 and 11.8 degrees, respectively, so that a minimum of 20 feet of overburden soils would confine the bore in the lowest portions of the gulch, achieving a vertical curve radius of 2,400 feet. Construction staging areas for both the entry and exit pits, as well as pipe laydown space, were obtained by agreements with the land tenants, who lease the land from California State Parks to operate a brussels sprouts farm. The staging areas laid directly against endless rows of stalks and accordingly, best neighborly efforts were prioritized during construction.

In the center of the gulch, the design placed the bore a range of 20 to 25 feet below ground surface in an 18-foot-thick silty sand layer, confined by a medium-stiff lean clay. The silty sand was selected to provide a consistent and favorable drilling material while minimizing the required depth of the HDD bore. As designed, the most challenging portion of the bore would have 68 feet of drilling mud pressure in 20 feet of alluvial soil overburden. In consideration of many alternative configurations, it was clear that the challenges of the steep topography and buried valley soils would present risks of hydraulic fracturing and inadvertent drilling fluid release (frac-out). Calculations to verify this risk of the bore were based on the cavity expansion model (Bennett 2008).

The carrier pipe installed within the bore needed to meet the SCWD operational pressure of 150 pounds per square inch (psi). It would also be subject to the demands of longitudinal tensile pipe pull and bending stresses during installation through the bore. To meet these demands, the final design required a DR18 24-inch diameter fusible polyvinyl chloride (FPVC) carrier pipe with a 235-psi pressure class (AWWA C905).

During design, it was recognized that allowing contractor flexibility in appropriate circumstances could offer additional efficiency, economy and quality to the HDD project. Thus, the Lombardi Gulch HDD specifications were written to permit contractor-proposed deviations to the design alignment. However, regardless if any deviations were proposed, additional frac-out calculations were required to be submitted by the contractor. The calculations were expected to assess the ultimate bore alignment in context with the contractor's specific anticipated drilling methods and fluid rheology. The carrier pipe stresses during pull back were also required to be verified by the contractor's engineer.

6. BIDDING AND AWARD

The advertising, bidding, and award of the Lombardi Gulch HDD installation occurred in the following expedited schedule:

- Advertised: October 20, 2015
- Proposals Received: October 26, 2015
- Awarded: October 30, 2015
- Project Completion: January 2, 2016

SCWD preemptively secured the pipe from Underground Solutions as an insurance against delays in fabrication or delivery after an award. Given the fast-track schedule of the project, SCWD willingly received two bids. The low-bidder was The HDD Company (Contractor) at $1.27 million for all work and materials associated with the 1,300-foot-long bore.

7. CONSTRUCTION

One of the project team's initial priorities was to confirm the bore alignment. Acknowledging the frac-out risks in the gulch, the Contractor proposed to deepen the installation so that a minimum of 50 feet of ground cover would be obtained in the gulch (see Figure 7). The proposed deepening of the alignment changed the designed entry and exit angles to 15 degrees and 12 degrees respectively. The geologic material, as encountered by borings at this location, consisted of medium-stiff clays and medium-dense clayey gravel. Interestingly, the Contractor's subsequent frac-out analysis did not show that lowering the alignment would result in much improvement to the theoretical factor of safety, as drilling fluid pressures would correspondingly be larger, and thus the frac-out risk remained. Given the circumstances of the project, the proposed deepening was approved and focus was shifted to a comprehensive Frac-out and Surface Spill Contingency Plan. This document detailed procedures for monitoring, preventing, containment, cleanup and documentation procedures if spills or a Frac-out occurred. Specific emphasis was placed towards preventing drilling fluid losses into Lombardi Creek.

The Contractor mobilized to site on November 3, 2015, which was two weeks after the start of the California rainy season. An El Niño winter following a four-year historic drought later posed additional challenges for the outdoor work. The rigs selected for the project were a 106,000-pound pullback-capacity (70,000-pound thrust) Ditch Witch (JT 80/20) to advance the initial pilot bore until a larger 380,000-pound thrust and pullback-capacity American Augers rig was mobilized to the site for larger diameter reaming and pullback (Figure 8).

The pilot bore began on November 11, 2015 with an 8-3/4-inch diameter drill bit and initially advanced through the rock units at an average rate of 113 feet per day. To track the position of the bit while drilling the pilot hole, the Contractor used Tensor, a high resolution, wire-line steering tool system. Coordination was maintained with the local farmers to ensure the surface coil was not damaged by farming equipment, which could have had a detrimental impact on the accuracy of the alignment. As drilling proceeded with the Ditch Witch, the Contractor encountered several instances of loss circulation that did not result in a surface frac-out. The theory was that drill mud was being lost to the fractured mudstone. As a result, it was determined that intermittent reaming was necessary to enlarge the bore-hole annulus to improve circulation and carry the cuttings back to the soil separation plant. Originally, the Contractor intended to drill the pilot hole in one pass, but instead, the Contractor used a combination of both 18-in. and 15-in. reamers during pilot boring to increase circulation. This process required the Contractor to trip-out the drillstring and bottom hole assembly multiple times in order to push and pull the reamers prior to advancing the pilot bore. It also required that the Contractor maintain and submit daily documentation of the drilling fluid and directional data for review by the Construction Manager and the Designer. A typical mud weight for a clean bentonite-polymer HDD drilling fluid will be around 8.7 pounds per gallon (Bennett and Ariaratnam, 2008) and the Contractors logs showed mud weights typically between 9 and 9.5 pounds per gallon and occasionally between 10 and 10.5 pounds per gallon. The heavier drill mud (10 to 10.5 pounds per gallon) would raise a red flag for the Contractor to either perform additional cleaning of the drilling fluid, dispose of old fluids and mix new fluids and in some cases reduction in drilling penetration rates. The drilling mud was comprised of water, bentonite (Bara-Kade) along with the additives Drill-Terge and Suspend-it.

Figure 8: American Augers Rig with 380,000-Pound Thrust and Pullback Capacity. Reamer at Entry Pit.

Progress came to a halt when the pilot bore was advancing in the critical area below the center of the gulch in the alluvial soils. Drilling fluid circulation was lost in the bore and this time the drill mud reached the ground surface and on November 22, 2016, the project experienced the first frac-out. The project team stopped drilling and rapidly prioritized the containment of the spill as well as discussed methods that would minimize pressure and agitation in the hole. The mud was initially contained within a perimeter of silt fences, gravel bags, and wattles, then removed from the gulch in several 20-gallon containers. As a result of this first frac-out event, reduction in the rate of fluid circulation was immediately necessary to reduce fluid outflow through the conduit of compromised ground.

To proceed with the installation, the Contractor elected to mobilize the Ditch Witch to the exit pit on November 30, 2015 and perform a mid-path intersect method to complete the rest of the pilot bore. This change in methodology relieved the entry bore of circulation pressures until the intersect was completed on December 2, 2015. The American Augers rig was delivered to the site on the same day as this remobilization and began enlarging the entry bore, to also assist in the reduction in the entry bore circulation pressures, by pushing a 28-inch diameter reamer two days after mobilization. The added benefit of this change in methodology is that the Contractor could work on enlarging the bore-hole from both the entry and exit pit by reaming with both rigs over four days to increase production. Through the process additional returns surfaced to the ground once the reaming neared the location of the previous frac-out. At this point, further efforts were directed towards containing the mud and preventing contamination of the Lombardi Creek through an installed diversion flume built out of 15-in. corrugated HDPE pipe, which extended 100-feet along the Creek to protect the water from any potential future frac-outs. In addition, two 6-in. trash pumps and hoses were set up in series to pump contained surfaced returns up out of the gulch and into the separation plant for reuse. A timely installation of the mitigation measures was especially critical due to the constant rainy climate that was occurring during the installation. To the projects benefit, this work was performed expediently and to the satisfaction of the involved parties: SCWD, The Covello Group (Construction Manager), the Contractor, California Environmental Services (Biologists), Mott MacDonald (Designer), State Parks, CDFW, USFWS and the Water Quality Control Board. With frequent coordination between those parties, the project moved forward and the bore was eventually reamed to the final diameter of 36 inches on December 19, 2015, averaging at a rate of 242 feet per day. Survey results showed that the maximum total deviation from the target alignment was 4 feet.

During drilling activities, the 40-foot-long FPVC pipe sections were fused into two long pipe string segments (measuring 560-feet and 840-feet), as the full 1,400-foot string was unable to be placed linearly on the available pipe laydown space. The Contractor elected to fuse a 1,400-foot string for the 1,300-foot long bore, to allow excess FPVC pipe for tie-in to the existing 22-in. steel line. Joints were fused by Underground Solutions (subcontractor) at an average rate of one joint per hour using a T-900 Fusion Machine. Once the two pipe strings were constructed, they were hydrostatically pressure tested at the ground surface to the design operating pressure at 150 psi for two hours. The alternative use of pressurized air for pre-installation testing was discussed with the Contractor and pipe supplier, however deemed inadequate for the purposes of this project.

In one day, December 20, 2015, the full-bore length was swabbed by a 30-in. barrel, pulling from the exit pit towards the American Auger drill rig, then back towards the exit pit to be hooked-up to the 24-in. pull head. On December 21, 2015, pullback of 160-ft. of the shorter segment of FPVC commenced (Figure 9) and then on December 22, 2015 the remaining 1,240-ft. of FPVC pipe was pulled through the full-bore length in a total of 8-hours (including the intermediate fuse time). Water was fed through a 2-in. hose into the first shorter segment, filling the interior prior to the intermediate fuse. The water was required to reduce buoyancy-induced friction in the upper crown of the bore as the pipe was pulled through. The second pipe string was fused to the first string during pullback.

Figure 9: Commencement of Pullback of the 30-in. Barrel followed by the 24-in. Pull-head and 24-in. FPVC.

Once the two strings were fused to form one continuous pipe, the remainder was pulled through the bore at a rate of about ½-¾ feet per second (Figure 10). Pullback loads were generally kept between 48,000 and 55,000 pounds and were well under the allowable 24-in. FPVC tensile load of 307,221 pounds. Table 1 shows how the construction pull loads compared with those calculated during the submittal process.

Table 1. Comparison of Calculated (per ASTM F 1962-11) and Actual Pullback Loads

	Theoretical Pullback Loads		**Actual Pullback Loads**		
Relative Depth and Location (% of Bore)	**Force (lbs)**	**Combined Axial and Bending Stress (psi)**	**Force (lbs)**	**Combined Axial and Bending Stress (psi)**	**% of Allowable for FPVC**
Pipe Entry (0%)	19,475	536	*N/A*	-	-
Mid-Depth (15%)	24,495	581	*N/A*	-	-
Full Depth (41%)	28,245	257	*N/A*	-	-
Full Depth (50%)	28,499	618	*N/A*	-	-
Mid-Depth (70%)	29,717	629	*N/A*	-	-
Pipe Exit (100%)	27,231	248	48,000 – 55,000	414 – 475	15 – 17

The frac-outs maintained their presence during the pullback. A continuous flow of drilling fluids surfaced through the pre-existing frac-outs into the containment zone and were then continuously pumped from the gulch to the separation plant. The Contractor, Construction Manager and Biologists maintained continuous monitoring presence in this area. No sensitive species were harmed during this operation.

On January 2, 2016, the pipe string passed the in-situ hydrostatic test at 200 psi for two hours, marking a successful installation. During a one-week shutdown of the NCS the new pipe was then connected to the existing 22-in. water main by a separate tie-in Contractor (McGuire & Hester) and placed into service, thereby alleviating the leak. SCWD has since fully restored the site to a healthy coastal Californian ecosystem and the above ground portions of the bypassed pipe have been removed and recycled.

Figure 10: Completion of Pullback.

8. LESSONS LEARNED

The project had several key lessons learned:

- HDD methods provide fewer environmental disturbances, in comparison to open-cut trenching, to the sensitive creek riparian area. This is despite the frac-outs and associated remediation work.
- The emergency leak and accelerated construction schedule required effective communication and good working relationships between the Contractor, Construction Manager, Designer, Biologists, SCWD and Agencies to resolve issues in an efficient manner.
- The HDD intersect method and the use of two drill rigs is useful in emergency situations to maintain schedule and successfully complete a pilot bore when there is a high risk for frac-outs. The success of the intersect method is heavily dependent on the steering tool system and experience of the steering hand.
- Large volumes of drilling fluid during a frac-out are possible. Prudent preparation begins with a Frac-out and Surface Spill Contingency Plan. Once a frac-out has occurred, future releases in the vicinity or from the same ground conduits should be anticipated. Individual frac-outs for this project were estimated to release 2,000 gallons of mud at the ground surface, covering areas of 1,000 to 2,000 square feet.
- Lowering a bore profile does not necessarily ensure that the probability of frac-out is reduced. Placement of the bore in favorable geological material, as well as a controlled drilling methodology, both have considerable weight in frac-out calculations.
- There are many stakeholders involved when a project experiences frac-outs. Frac-outs may unfortunately occur and without warning. Agencies who may be immediately involved in the remediation must be prepared.

9. ACKNOWLEDGEMENTS

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