1. **ABSTRACT**

The City of Santa Cruz Water Department (SCWD) is currently replacing 18,000 linear feet of water transmission main located three miles northwest of Santa Cruz, California. The existing pipeline was built in the 1950s and is part of the North Coast System (NCS), which consists of 16 miles of pipe network and stream diversion structures. While the primary method of replacement is open trench methods, the project contains five trenchless pipe installations, four horizontal auger bores (HAB) and one horizontal directional drill (HDD).

With the intent to bid the entire project in a single contract, it was discovered in fall 2015 that the existing water main had suffered premature failure in the location of the HDD — on land owned and operated by California State Parks — and was leaking at the rate of 500,000 gallons per day. During a severe drought in the State of California, it was imperative to replace the leaking pipe quickly. Correspondingly, the installation of the 1,300-foot-long HDD undercrossing through the difficult geologic and topographic conditions at Lombard Gulch, a sensitive riparian area inhabited by the threatened California red-legged frog, was bid and completed as an emergency project. Coordination and cooperation between the Owner, Engineer, CM, and Contractor was required 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.

2. **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 fed from the western flank of the Santa Cruz Mountains northwest of Santa Cruz, California. The system is composed of 3 stream diversion structures, a spring box, and 16 miles of piping. It also provides the highest quality water to the City and provides 30% of the City annual supply for 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 1950’s, some of which are still in operation today. However, numerous repairs and environmental issues which manifested in the 2000’s led the 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, 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 undercrossings 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.
3. 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 22-inch welded steel water main was found to be discharging 500,000 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 Figure 2 and Figure 3).
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 expediency. 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.

4. 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 many native reptile, fish and amphibian species. Specifically, Lombardi Creek provides documented breeding habitat for the California red-legged frog, a federally threatened species (see Figure 4Error! Reference source not found.).
Due to increased environmental concerns, the 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.

5. 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 5. The HDD design and as-built alignments are shown on the profile for later reference.
6. 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.

Figure 6: Schematic Alignment of the HDD Undercrossing at Lombardi Gulch (in black) (looking north)

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 returns (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.

7. 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: December 18, 2015

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, the 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.

8. 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 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 hydraulic fracturing occurred. Specific emphasis was placed towards preventing drilling fluid losses into Lombardi Creek.

The Contractor mobilized to site on November 3, 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 pull-capacity Ditch Witch to advance the initial portions of the bore until a larger 380,000-pound pull-capacity American Augers machine was mobilized to the site for larger diameter reaming and pull-back. The pilot bore began with an approximately 9-inch diameter bit and was advanced through the rock units at an average rate of 113 feet per day. As drilling proceeded with the Ditch Witch, a mid-size reamer was pushed into the bore at several intervals to improve fluid circulation.

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 the mud reached the ground surface as a 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 contained within a perimeter of silt fences, gravel bags, and wattles. Reduction in the rate of fluid circulation was immediately necessary to reduce fluid outflow through the conduit of failed ground.

To proceed with the installation, the Contractor elected to mobilize the Ditch Witch to the exit pit and perform a mid-path intercept for the rest of the pilot drill. This change in methodology relieved the entry bore of circulation pressures until the intercept was completed. The American Augers rig was delivered to the site shortly after this remobilization and began enlarging the entry bore by pushing a 28-inch diameter reamer. 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. 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), and the Department of Fish and Wildlife. With frequent coordination between those parties, the project moved forward and the bore was eventually reamed to the final diameter of 36 inches, averaging at a rate of 242 feet per day. Survey results showed that the maximum total deviation from the target alignment was 4 feet.

**Figure 7: American Augers Rig with 380,000 Pound Pull Capacity**

During drilling activities, the 20-foot-long FPVC pipe sections were fused into two long pipe string segments, as the full 1,300-foot string was unable to be placed linearly on the available pipe laydown space. Joints were fused by Underground Solutions (subcontractor) at an average rate of one joint per hour. Once the two pipe strings were constructed, they were hydrostatically pressure tested at the ground surface to the design operating pressure. 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.

The pullback of the FPVC was performed the day following a push and pull of a swab for the full-bore length. Water was fed continuously into the first pipe string, filling the interior, to reduce buoyancy-induced friction in the upper crown of the bore as the pipe entered. The second pipe string was fused to the first string during pullback (Figure 8).
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 9). Pullback loads were generally kept between 48,000 and 55,000 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

<table>
<thead>
<tr>
<th>Relative Depth and Location (% of Bore)</th>
<th>Theoretical Pullback Loads</th>
<th>Actual Pullback Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Force (lbs)</td>
<td>Combined Axial and Bending Stress (psi)</td>
</tr>
<tr>
<td>Pipe Entry (0%)</td>
<td>19,475</td>
<td>536</td>
</tr>
<tr>
<td>Mid-Depth (15%)</td>
<td>24,495</td>
<td>581</td>
</tr>
<tr>
<td>Full Depth (41%)</td>
<td>28,245</td>
<td>257</td>
</tr>
<tr>
<td>Full Depth (50%)</td>
<td>28,499</td>
<td>618</td>
</tr>
<tr>
<td>Mid-Depth (70%)</td>
<td>29,717</td>
<td>629</td>
</tr>
<tr>
<td>Pipe Exit (100%)</td>
<td>27,231</td>
<td>248</td>
</tr>
</tbody>
</table>

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. The contractor maintained monitoring presence in this area and continuously pumped the mud to remove it from the gulch. The pipe pull was completed in just about one long work day.
Several days later, and two months after the initial Contractor mobilization, the pipe string passed the in-situ hydrostatic test at 200 psi, marking a successful installation. The pipe has since been connected to the existing water main and placed into service, thereby alleviating the leak. SCWD has since fully restored the site to a healthy coastal Californian ecosystem and portions of the bypassed pipe will be removed and recycled.

Figure 98: Final Stage of Pullback

9. LESSONS LEARNED

The project had several key lessons learned:

- HDD methods did provide fewer environmental disturbances, in comparison to open-cut trenching, to the sensitive ecosystem along the creek. This is despite the frac-outs and associated remediation works.
- The risks of challenging geological conditions must be conveyed to the full project team—from the managers to the operators—and prudent preparation begins with a Frac-out and Surface Spill Contingency Plan.
- Large volumes of drilling fluid during a frac-out are possible. 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
We would like to thank the City of Santa Cruz Water Department, Melanie Carrido from The Covello Group, and the HDD Company, for their participation leading to the success of the project.

10. REFERENCES
