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TULALIP TRIBE AND CITY OF EVERETT BRING REGIONAL WATER TO THE PACIFIC NORTHWEST WITH MASSIVE HDD PROJECT

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ABSTRACT: This Tulalip Tribes and the City of Everett have teamed to design and construct a major water transmission pipeline to deliver approximately 36 mgd from the City of Everett, Washington, to the Tulalip Tribes located near Marysville, Washington. The Tulalip Water Pipeline is a 7-mile-long water transmission pipeline that includes five trenchless (HDD) crossings made up of approximately 12,000 lineal feet of 36-inch diameter steel pipe. This paper discusses the mitigation strategies implemented in the design to reduce the risks associated with HDD construction and the challenges encountered during the construction of the pipeline.

Construction of the trenchless crossings began in May of 2011. This paper will discuss the risks associated with HDD construction (as they pertain to this project) and the mitigation strategies developed and implemented in the design to reduce and appropriately manage the risks and the challenges encountered during construction of the project.

1. INTRODUCTION

The Tulalip Water Pipeline is a 7.3 mile-long water transmission pipeline made up of 36 and 48-inch-daimeter welded steel pipe. The project is located in Northwest Washington and the greater project location is shown in Figure 1. The pipeline crosses beneath railroad yards, the Snohomish River, and several sloughs that make up a major river delta, necessitating the use of trenchless technology. The pipeline design included four major trenchless crossings that were installed by horizontal directional drilling (HDD): Snohomish River Crossing (2,200 feet); Union and Steamboat Slough Crossing (3,680 feet); Ebey Slough Crossing (2,760 feet); and Quil Ceda Creek Crossing (1,281 feet). Montgomery Watson Harza (MWH) and Parametrix teamed to design the pipeline for the City of Everett and the Tulalip Tribe. Staheli Trenchless Consultants, Inc. was the trenchless technology consultant to MWH during the design phase of the project. Parametrix led the construction services phase of the project for the Tulalip Tribe with MWH and Staheli Trenchless Consultants as primary sub-consultants for inspections services.

HDD was chosen as the preferred trenchless technology based on the suitability of the geotechnical conditions, the reduced environmental footprint, and the relatively rapid speed of construction. This paper will focus on three crossings: The 5-North Crossing beneath the Ebey Sough; the 5-Sough Crossing beneath the Union and Steamboat Sloughs; and Segment 7 beneath Quil Ceda Creek as the construction of these bores were completed at the time this paper was written.

Figure 1. General Project Site Location.

The remaining two bores will be completed by the end of 2012. The design challenges and the construction of the three bores will be discussed in this paper. The layout of the HDD bores in relation to the open cut sections of the pipeline are shown in Figure 2.

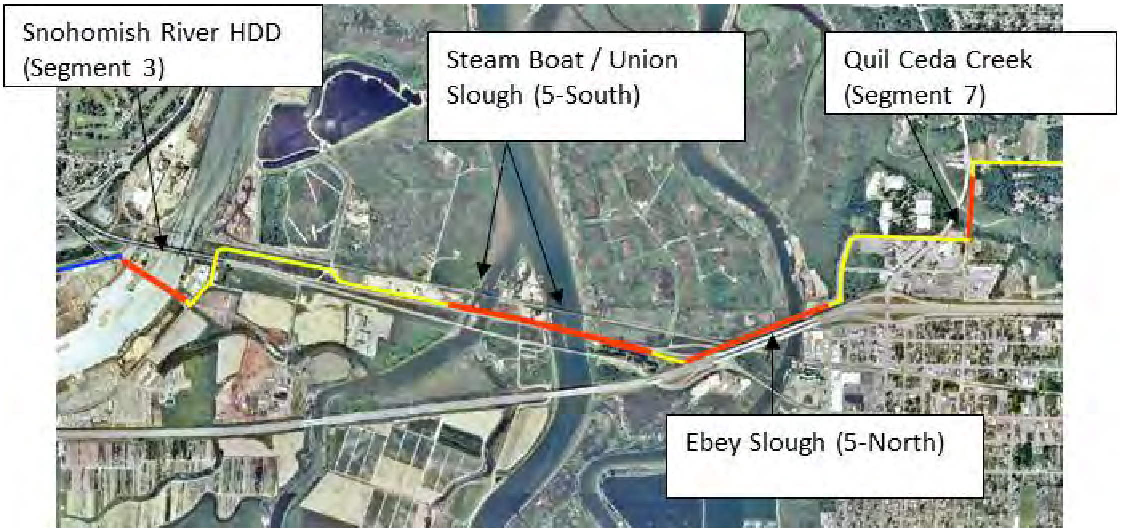

Figure 2. HDD Bore Locations Relative to Entire Pipeline

2. DESIGN CHALLENGES

The Tulalip Water Pipeline project included many design challenges. First and foremost were the geotechnical conditions along the alignment. Three of the major HDD crossings were in marsh lands that included tidally influenced wetlands. As such, the soils conditions included very soft and loose soils that were prone to hydrofracture and had strict restrictions on disturbance. In addition, the pipeline route was in close proximity to "critical bridge structures" that were owned by the Washington State Department of Transportation (WSDOT) and constructed on deep piles within and across the river delta. Acquiring permits from WSDOT to construct the pipelines with HDD was extremely challenging and required extensive analysis due to the complex geotechnical issues that involved pile/soil interaction and the zone of influence around the HDD bore. Each of the design challenges required extensive risk evaluation and mitigation during design to ensure that these risks were appropriately addressed and that the Owner had sufficient construction budget to address these risks.

3. GEOTECHNICAL CONDITIONS

The central section of the project area, where the majority of the HDD crossings were located, encompasses the channel, floodplain and delta complex of the lower Snohomish River including Smith Island, Union Slough, Steamboat Slough, Spencer Island, the area near Big Flat landfill, and Ebey Slough. The soils in this region consist of alluvial, floodplain, deltaic, estuarine, and organic-rich deposits. In the northern section of the pipeline, which includes the Quilceda Creek HDD, is underlain by alluvial and estuarine deposits. (GeoEngineers, April 2010).

Figure 3 shows an interpretive geotechnical cross section for the 5-North Crossing. This crossing was 2,760 feet long and traversed beneath Ebey Sough. Of particular concern on this crossing were the marsh deposits (shown in blue) that contained lenses of peat and zones with very low blow counts. There was concern over losing drilling mud within this formation as well as the inability to steer the drill.

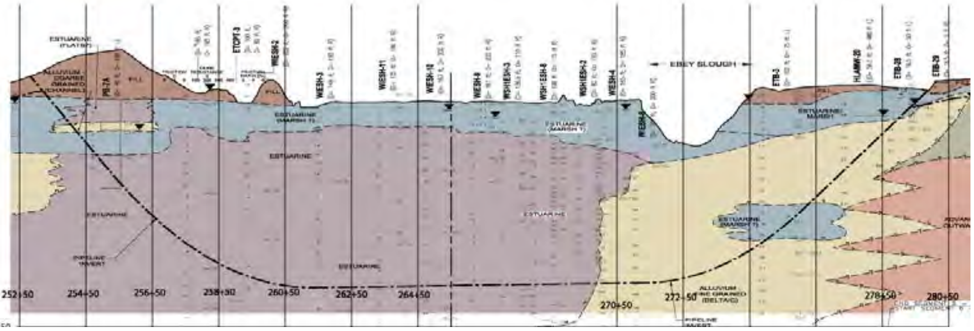

Figure 3. Geotechnical Cross Section for the 5-North Crossing

In Figure 3, the drill entry is on the left side of the figure and the drill exit is on the right. The drill entered and traversed beneath an exit ramp from Interstate 5 South. To protect this ramp and facilitate permitting the drill, a conductor casing was designed and specified at this location to protect the embankment from pressurized drilling mud and the potential for any settlement. The exit of the drill was within the marsh deposits but the option of using a conductor casing was left to the Contractor.

Figure 4 shows a cross section depicting the geotechnical conditions beneath the 5-South Crossing. Similar to the 5-North Crossing, the primary deposits were alluvial and estuarine deposits. Again, there was concern about loss of drilling fluid in the near-surface soils. However, there were no critical structures at the entry and exit locations. It was decided not to specify conductor casings on this crossing. Instead, the contractor was alerted in the contract documents of the criticality of the wetlands, the requirements of protecting Steamboat and Union sloughs, and the requirement to contain the drilling fluids and clean up any inadvertent drilling fluid returns.

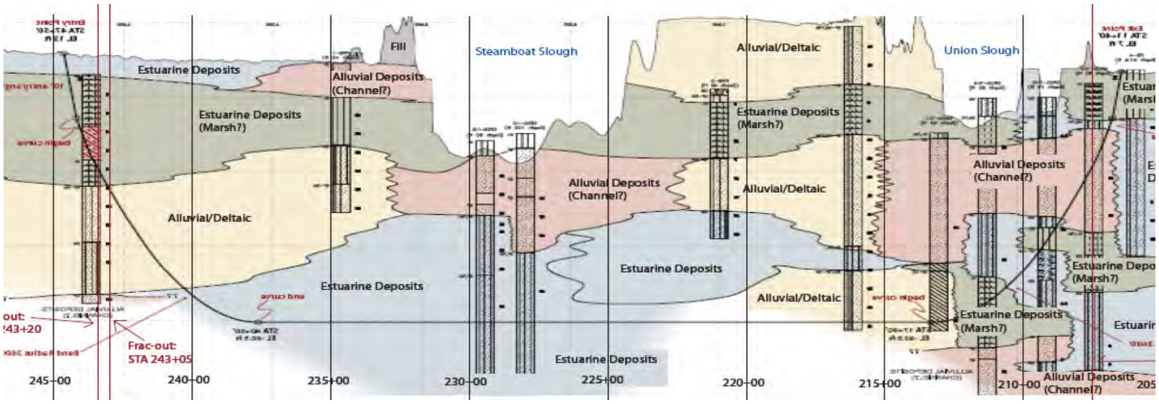

Figure 4. Geotechnical Cross Section for the 5-South Crossing

The third crossing of interest is the Quil Ceda Creek Crossing. This was the shortest of the crossings on the project and the smallest of the waterways that needed crossing. Figure 5 shows the geotechnical conditions beneath Quil Ceda Creek. The geotechnical conditions were very challenging on this crossing due to the very soft soils that were present throughout the full depth of the crossing. There were tremendous site constraints at the Quil Ceda Crossing location which constrained the entry and exit location. This, combined with the limitations of the bend radius of the 3-inch steel pipe, afforded for little flexibility with the bore geometry.

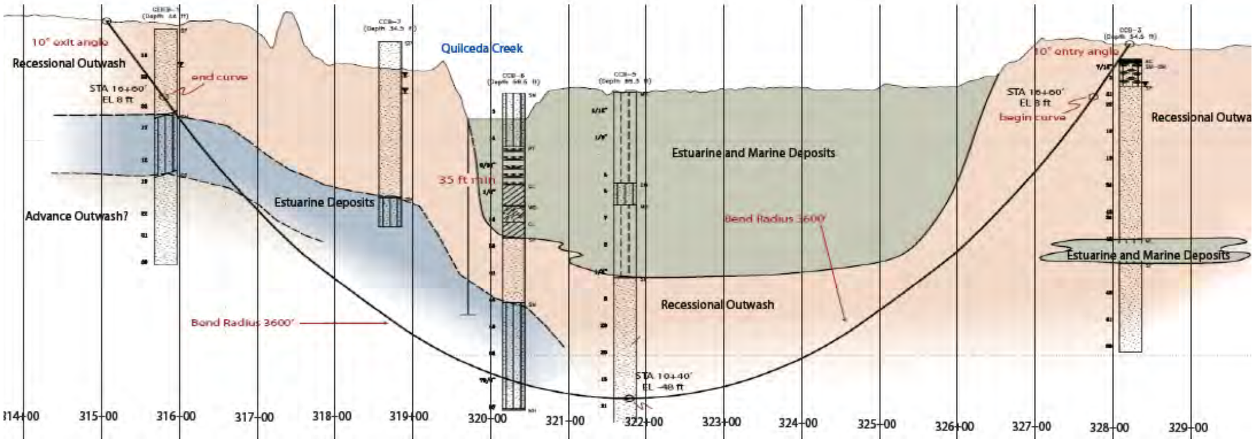

Figure 5. Geotechnical Cross Section for the Quil Ceda Creek Crossing

4. DESIGN AND CONSTRUCTION OF THE 5-NORTH CROSSING

The 5-North Crossing was 2,760 feet in length and was constructed from the South side of Ebey Slough to the North. The alignment is parallel to and located just west of the Interstate 5 bridge over Ebey Slough. The bore begins in alluvial/deltaic deposits on the north side of the slough. The bore than transitions into estuarine deposits beneath Ebey Slough. The bore terminates on the south side of the slough in a layer of estuarine (marsh) deposits, as shown in Figure 3.

The primary risks associated with the Ebey Slough Crossing were settlement of the Interstate-5 off ramp to SR 529 (southbound), hydrofracture near the exit location, and risks of the pipe binding during pullback. To mitigate the risk of settlement of the off ramp and hydrofracture, the installation of a conductor casing at the entry location was specified. To mitigate the risk of pipe binding and increased forces during pipe pullback, the pipe was designed to be pulled back in one continuous pull. However, this proved to be difficult due to the length of the pipe and the site constraints.

Pipe layout areas on both the north and south side of the crossing were considered to allow for continuous pipe pullback. Initially, pipe layout to the north was considered to avoid impacts to SR-529. Multiple iterations of layout areas were considered including pipe layout on elevated structures to avoid traffic impacts. However, it was determined that no alternative existed, with continuous pipe layout to the north, which did not involve an elevated structure over a major roadway which would require the travelling public to travel under the lofted pipe. This is a very high risk option and could have serious life safety impacts to the travelling public. The design team then evaluated the option of fabricating the pipeline within the Interstate-5 ROW along the edge of the southbound lanes. After working collaboratively with WSDOT, the design team was able to permit this alternative. The entire 2,760 of 36-inch steel pipe was assembled along the edge of Interstate-5 and then walked to the entry location at the time that the pullback was to commence. This allowed for continuous pullback of the pipe without having extended closures of roads leading into the primary business areas of the Tulalip Tribe.

The Construction of the project was awarded to Don Kelly Construction who used South East Directional Drilling (SEDD) as their HDD subcontractor. SEDD used an American Augers DD-625 drill rig to construct the drills. The drill rig was originally purchased with 625,000 pounds of pullback force but SEDD had modified the rig to allow it to provide 800,000 pounds of pullback force. SEDD was responsible for all of the directional drilling on the project. The general contractor, Don Kelly Construction, was responsible for assembly of the steel pipe which was specified as a 0.625 minimum wall thickness with a fusion bonded epoxy lining and coating.

Prior to the construction of the pilot bore, a 60-inch conductor casing was installed to a length of 240 feet. The casing was installed with a TT Technologies Taurus pneumatic hammer and the spoils were removed with a 10-foot section of 24-inch auger that was attached to the drill rig. The construction of the pilot bore for the 5-North bore began on August 2, 2011 and was completed on August 8, 2011. The average rate of advance of the pilot bore was 456 feet per day. The highest rate of production for a single day was 1,100 feet and the lowest rate of production was 96 feet. During two of the six days of pilot drilling, the pilot bore was tripped out several hundred feet to regain fluid returns or to re-steer for position. There were no inadvertent returns during the pilot bore drilling on the 5-North bore. The down-hole pressures were continually monitored in the borehole annulus during drilling. During the submittal process, the contractor was required to submit the minimum borehole pressure that was necessary to create the pilot bore, as well as the maximum or limiting pressure that would cause escape of the drilling fluid to the surface. Figure 6 shows the contractors minimum and maximum calculated mud pressures in addition to the actual annular pressures that were measured during drilling.

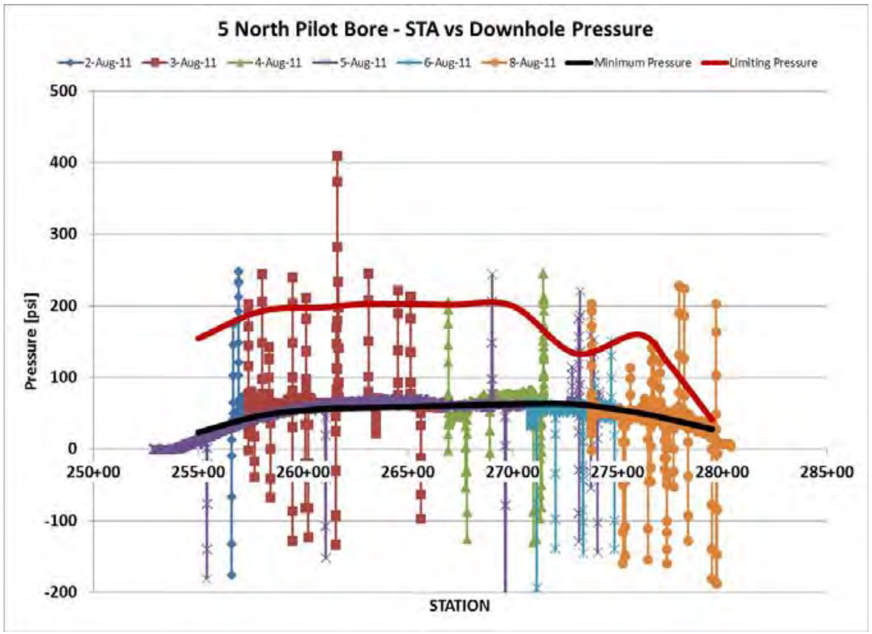

Figure 6. Measured Annular Pressure, Estimated Minimum and Limiting Annular Pressure 5-North Bore.

It is interesting to note that the actual downhole pressure exceeded the estimated limiting pressure at many locations along the alignment. However, at every location where a pressure spike exists, a corresponding pressure drop is shown on the graph. These pressure drops occurred due to the drilling operations. The downhole annular pressures were constantly monitored by the driller. When a pressure "spike" would occur, the driller would immediately turn off the mud pumps resulting in a pressure drop that would be reflected on the graph. Since the driller did not allow the mud to continue to pump at the high pressure, it is hypothesized that this may be the reason that inadvertent returns were not observed at the ground surface.

The contractor elected to ream the hole in a series of steps. The first step was a back-ream upsizing from the 10-3/8 pilot to a 36-inch fly cutter from the exit to the base of the conductor casing. The second step was to trip the 36 inch reamer back to the exit location and replace the 36-inch fly cutter with a reaming assembly that consisted of a 36-inch fly cutter followed by a 48-inch hole opener and 48-inch barrel reamer. This was then pulled from the exit location for approximately 1,500 feet where the mud jets got clogged and this step had to be aborted. The 36/48 inch reaming assembly was then tripped back to the exit. This left approximately 850 feet of the bore that was reamed to a 36inch but still needed to be reamed to a 48-inch final diameter to accept the 36-inch pipe. The contractor then elected to perform a "swab pass" with a 48-inch scorpion ball, swabbing from the exit to the entry and stopping at the base of the 240-foot 60-inch conductor casing that contained a 16-inch centralizer concentrically located within the conductor. The contractor then removed the 16-inch centralizer casing from the conductor casing by "bumping it out" with the 48-inch reamer as the reamer was pulled toward the rig.

The first 36-inch reaming pass reamed a total of 2,214 feet and began on August 11, 2011 and was completed on August 15, 2011. The average reaming rate was 554 feet per day. The highest rate of reaming was 725 feet in a single day and the lowest reaming rate was 284 feet in a single day. The remainder of the reaming was completed over the next 10 days.

Once the reaming was completed, another swab pass was conducted from the drill rig to the exit and an additional 29 drill pipe was added at the drill rig to extend the drill pipe from the exit location to the site where the steel pipe had been assembled in the Interstate-5 ROW, 1,000 feet north of the drill exit point. The Contractor was given 24 hours in which they could close a roadway while they pulled the pipe from the layout area into the borehole. In addition, the Contract was very prescriptive and would only allow the pullback to occur over the September 11th weekend. This proved to be very restrictive on the contractor and required very close coordination between the HDD contractor and the general contractor who was responsible for the assembly of the pipeline and the field lining and coating.

Pullback began on Sunday September 11, 2011. It took the contractor approximately 6 hours to move the assembled pipe from the assembly location to the exit of the borehole. Once the steel pipe was lined up with the bore, pullback began and continued through the night of September 11th and the pipe was pulled within 22 drill pipe, approximately 685 feet of the bore and was pulling with approximately 200,000 pounds. At this distance, the pipe had been pulled across the roadway and the Contractor had met the WSDOT road closure restriction. However, at this point in the pull, the drill rig blew a hydraulic seal on the rig motor resulting in approximately 3.5 hours of downtime to fix the rig seal. The drilling crew did an amazing job of repairing the hydraulic motor seal on the site; however the length of downtime proved to be highly detrimental and the drill rig could not get the pipe moving. After several hours of attempting to get the pipe moving, the Contractor elected to leave the site for eight hours (many of the crew had been on site for over 36 hours at this time) and reconvene the next day and attempt to get the pipe moving with a hammer assist.

The next day a TT Technologies Taurus pneumatic hammer was attached to the tail end of the pipe and a ram assist was attempted to get the pipe moving. The hammer was fitted with two air compressors allowing 4.2 million pounds of ramming force. While ramming, the drill rig applied approximately 500,000 pounds of pull force on the pipe. After approximately 5 minutes of ramming, the pipe started moving and the pull force dropped back down to the 200,000 pound range – the level where the force had been prior to the downtime when the rig motor seal failed.

5. DESIGN AND CONSTRUCTION OF THE 5-SOUTH CROSSING

The 5-Sough Crossing is located north of the Snohomish River crossing as shown on Figure 2, and passes under the southbound lanes of State Route 529 at a shallow angle. This is the longest HDD bore within the Tulalip Water

Pipeline project with a total distance of 3,680 feet, crossing both sloughs in a single bore from the north to the south and incorporating two horizontal curves to avoid the pilings of the Union and Steamboat Bridges as shown in Figure 4. The geotechnical conditions along the bore are also shown in Figure 4. The bore enters in a layer of estuarine deposits and transitions to estuarine marsh deposits, after which it enters a section of alluvial channel deposits prior to crossing beneath Steamboat Slough. The bore enters and remains in estuarine deposits below Steamboat Slough. While traversing beneath Union Slough, the bore enters variable geology consisting of alternating seams of alluvial/deltaic and estuarine deposits. The bore exits on the south side in near surface marsh deposits.

The primary HDD risks associated with the Union-Steamboat Crossing stem from the near surface soft soils that are identified as marsh deposits containing peat. These soft soils do not provide the strength required to contain drilling mud and prevent hydrofracture. The soft near-surface soils also do not provide the resistance necessary to steer the drill bit and maintain line and grade tolerances. The hydrofracture risk in to the slough is less of a concern on the north side due to the increased set-back from the slough. Frac-outs that may occur between the entry point and the slough can be contained at the surface with erosion and sedimentation controls to protect the wetlands. As such, a conductor casing was not specified at the entry location but could be used by the Contractor if they so elected.

Maintaining line and grade within the marsh deposits is of particular concern near the entry location where the initiation of the first curve in the bore path takes place. At the time of design, it was thought that it might be difficult to steering in the soft deposits, making it necessary to drill deeper into the alluvial deposits below the marsh deposits prior to initiating the first curve. As such, a minimum depth was specified but the Contractor was allowed to drill deeper if necessary.

The Union-Steamboat Crossing was considered long for a 36-inch pipe installation by HDD. As such, it was recognized that the Contractor might propose the intersect method. As such, the contract documents allowed the contractor to use two rigs if they felt that an intersect drill was appropriate.

The HDD entrance was placed within WSDOT right-of-way between the northbound and southbound lanes of SR-529. The bore crossed both sloughs from the north to the south and incorporated two horizontal curves to provide maximum clearance from the pilings for the bridges crossing Union and Steamboat Sloughs. Obtaining the permits from the WSDOT to place the pipes within close proximity to the bridge piles was a very challenging portion of the project. Extensive analysis was performed to determine the area of influence around the bore that could potentially impact the bridge piles. After much analysis, WSDOT allowed the pipe to be permitted as long as the design incorporated a minimum of 30 feet of clearance between any bridge pile and the pipeline. The bore geometry was then set to provide a minimum of 30 feet clear distance from the bridge piles in both the plan and profile perspective.

The depth of the Union and Steamboat Sloughs crossing was dictated by the soft near-surface soils, the bend radius of the 36” steel pipe, the minimum required setback distance from the water’s edge. The bore was designed to enter into the soil on a straight tangent until the soil was of sufficient strength to build a vertical curve. The bend radius of the pipe then dictated the final depth of the pipeline as the pipe curved through the bend radius. The final design resulted with an installation depth of approximately 40 feet of vertical clearance beneath the bottom of Steamboat Slough and approximately 50 feet of vertical clearance beneath the bottom of Union Slough. These depths provided a large factor of safety against hydrofracture at the slough locations.

The construction of the 5-South bore began after the completion of the 5-North bore. The same American Augers DD-625 rig was used for the construction of the bore. The contractor elected not to use a conductor casing at the entry location. And, as expected, experienced a significant amount of inadvertent returns at the entry location as the estuarine deposits did not have the strength to prevent the drilling fluids from escaping to the surface. Due to the loss of drilling fluids into the formation, the Contractor elected to run a 16-inch wash-over casing during the pilot bore to a depth of approximately 145 feet.

The pilot bore began on October 6, 2011 and was completed on October 19, 2011 with drilling occurring on 12 days. The average pilot bore rate was 356 feet per day with a peak day of 728 feet and a slowest day of zero advance. Two of the days were spent tripping out drill pipe and running wash-over casing which resulted in no advance, reducing the overall daily average. As with the 5-North bore, the Contractor submitted the estimated minimum annular pressure necessary to create the borehole as well as the limiting pressure that would cause escape of the drilling fluid to the ground surface. The downhole pressure was measured and continuously recorded during drilling operations. Figure 7 shows depicts the minimum, limiting, and actual drilling pressures during the 5-South Bore.

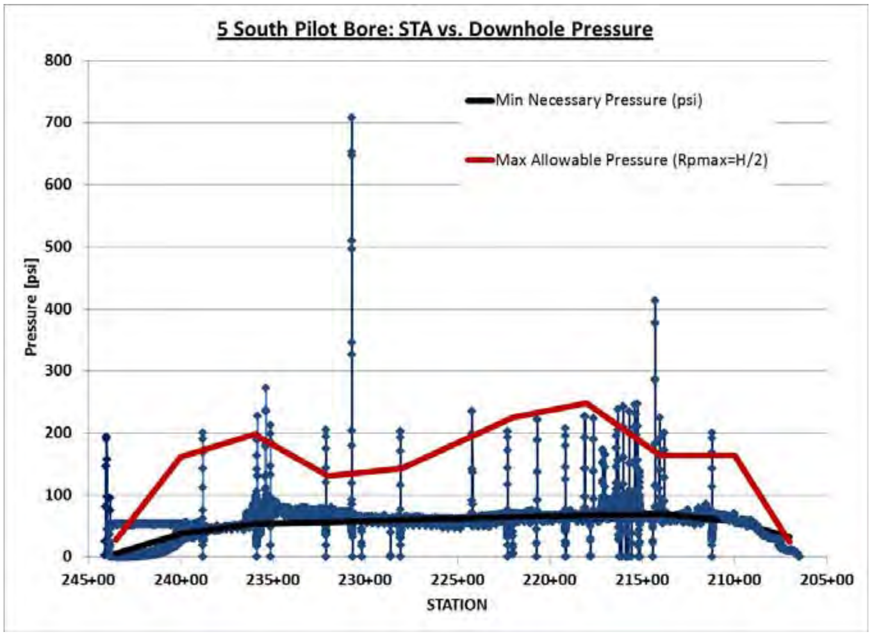

Figure 7. 5-South Downhole Pressure Measurements with Minimum and Limiting Pressures.

Interestingly, inadvertent returns were discovered on this bore at three distinct locations as shown in Figure 7 but the locations did not correspond to the locations where the bore pressure momentarily exceeded the limiting pressure but where the ground cover was shallow and the borehole pressure was near the estimated minimum borehole pressure. At these locations, if the hydrofracture is analyzed using the Delft equation (Staheli, et al. 2010) and the radius of the plastic zone (R_{pmax}) is back-calculated by setting the limiting pressure to the pressure at which hydrofracture was observed, we find that the radius of the plastic zone is approximately 3 times the bore radius.

For the 5-South bore, the Contractor elected to forward ream and to upsize the bore to the full 48-inch diameter in a single pass. They began reaming with a 36-inch scorpion reamer followed by a 48-inch scorpion ball reamer in series. This reaming configuration proved to exacerbate the frac-out at the areas where the hydrofracture had previously occurred. Although the downhole pressures were not measured during the reaming operations, it is likely that the massive increase in bore diameter in a single pass induced significant downhole bore pressures that resulted in the inadvertent returns at the surface. Reaming began on October 21 and was completed on October 29, 2011 with reaming occurring on a total of 8 days. The average reaming rate was 472 feet per day with a peak daily rate of 587 feet and a minimum daily rate of 378 feet.

The Contractor elected to perform two swab pulls: one as a push and the other as a pull swab. On the day of the pull, it took several hours to move the pipe in line with the bore; however, once the bore commenced, it was completed in just under 13 hours.

6. DESIGN AND CONSTRUCTION OF THE QUIL CEDA CREEK CROSSING

The Quil Ceda Creek crossing is located north and east of Quil Ceda Creek Casino. The crossing traverses beneath a tidally influenced creek and wetlands and is 1,287 feet long, bored from east to west. The bore exit location is north east of the intersection of Marine Drive NE and 27th Avenue NE. The bore starts in a layer recessional outwash deposits and then encounters a layer of estuarine and marsh deposits while crossing underneath Quil Ceda Creek. At approximately the mid-point of the bore, the bore transitions back into recessional outwash deposits and continues to the exit in the recessional outwash deposits.

The primary HDD risks for the Quil Ceda Creek Crossing include potential hydrofracture in the soft estuarine deposits, difficulty maintaining line and grade near the entrance and exit locations due to soft soils, and overhead constraints near the exit for pull back operations.

The bore geometry for the Quil Ceda Creek Crossing was severely limited by the site constraints and the available space for drill rig set-up and pipe layout. The site was bound by the east side by Interstate-5 and on the west by private property. The bore was designed on a near continuous curve that was based on using a bend radius that would not over stress the drill rods or the product pipe. This resulted in a depth of cover under Quil Ceda Creek that should have been sufficient to mitigate the risk of hydrofracture into the creek; however the estuarine deposits had highly variable soil properties making estimation of accurate values for predictive equations for frac-out extremely difficult. The bore radius was set at 3,400 feet for the 36-inch steel pipe. This bend radius is slightly less than the general rule of thumb for steel pipe; however, it allowed a short straight section of of bore geometry at the entrance and exit locations. The resulting maximum depth beneath Quil Ceda Creek was 55 feet.

Conductor casings were not specified at this crossing location because the set-back distance from the creek was sufficient to allow mud clean-up in shallow areas prior to crossing the creek. However, the contractor was not precluded from using a conductor casing in the contract documents.

The construction of pilot bore for the Quil Ceda Creek crossing began on November 11 and was completed on November 12, 2011, averaging 628 feet per day. Several frac-out incidents occurred during the pilot bore at a three main locations. Figure xxx shows the actual, minimum estimated pressure required to create the pilot bore and the estimated limiting pressure at which a frac-out would occur.

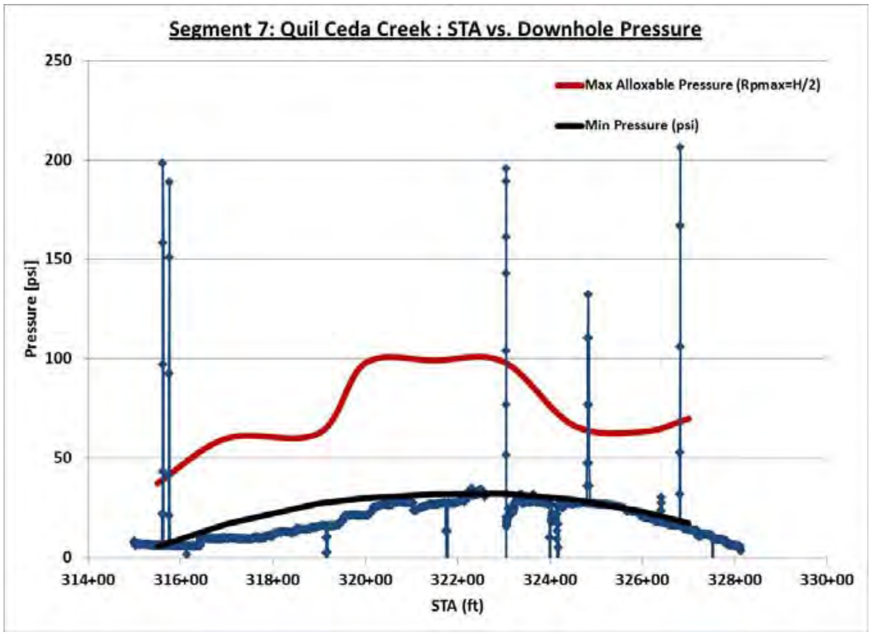

Figure 8. Annular Preesure for Quil Ceda Creek Crossing along with Minimum and Limiting Pressure Values.

The three main frac-out locations, as shown in Figure xxx did not correlate with locations at which pressure spikes occurred in the data recording. However, it should be noted that the inadvertent returns were not necessarily discovered when the drilling head was at the location that was in concert with the frac-out location. For example, the frac-out at location 318+20 was discovered when the drill head was well beyond this location. Therefore, the over-pressurization of the bore could have been caused by borehole collapse. The annular pressure sensor would have measured the pressure but the inadvertent return would have manifested at the area along the borehole that was the weakest, not necessarily at the location of the drill bit.

As with the 5-South crossing, the contractor again elected to ream in the borehole to the final 48-inch diameter in a single pass. The reaming process took place by forward reaming with a 36-inch scorpion reamer followed in sequence with a 48-inch scorpion ball reamer. Reaming began on November 14 and was completed on November 17, 2011, averaging 235 feet per day with a peak daily rate of 393 feet and a minimum daily rate of 39 feet. During the reaming process, several more frac-out locations manifested. In the soft soils, it was tremendously difficult to maintain a stable borehole and maintain the flow of returns back to the drill. As a result, the drilling fluid escaped at many locations including into Quil Ceda Creek. At one point during the forward ream, reaming was terminated to minimize the amount of mud that was escaping into Quil Ceda Creek and the reaming tools were tripped out to the entry. The reaming was then reinitiated as a pull ream to direct returns toward the exit location. Once the borehole was prepared the Contractor was put on hold as the pulling of pipe was not allowed during the week days per contract to minimize traffic disruption. The pull was then initiated on the Wednesday before Thanksgiving and was completed in less than 5 hours without incident allowing Holiday shoppers free access to the roadway.

6. CONCLUSION

At the time this paper was written, there are two HDD bores that will be constructed in 2012 to complete the Tulalip Water Pipeline Project. Although not without challenges, the project has proven to be a success largely due to successful planning, designing, and teamwork, and management. There have been a tremendous number of people who have collaborated and worked tirelessly to ensure the success of the project and continue to strive to provide value to the Owner. Through diligent planning, design, and construction management, trenchless technologies can continue to be used for the successful installation of challenging pipelines.

7. REFERENCES

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