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WILLAMETTE RIVER POSES HDD CHALLENGES

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ABSTRACT: The City of Newberg installed a waterline beneath the Willamette River using horizontal directional drilling to increase reliability of its water supply system. The river crossing measured 2,600 feet in length and consisted of a 30-inch DR 9 HDPE product pipe. The pipeline connected the City's well field system and treatment plant. A depth of cover of 40 feet was maintained beneath the river. On the banks of the river, however, the depth of cover was greater than 180 feet. The HDD bore traversed through challenging gravels and beneath a wetlands area near the bore termination point on the north side of the river.

Horizontal directional drilling and microtunneling emerged as the two technically feasible alternatives for completing the new pipeline. Multiple alignments were established and the risks and costs of each alternative were identified. Microtunneling alternatives offered the lowest construction risk but with substantially higher construction costs than the HDD alternative.

The HDD alignment was selected in an area that limited the extent of the installation through the aquifer materials to minimize construction risks. This paper presents the issues that were considered during design to choose the most appropriate trenchless technology and presents and construction issues associated with river crossing.

1. INTRODUCTION

The City of Newberg, Oregon, located approximately 45 miles southwest of Portland, needed a new pipeline to cross beneath the Willamette River for their water supply system. The City's water supply well field was located on the south side of the Willamette River. The City's existing water treatment plant was located on the north side of the river across from the well field. The existing pipeline crossing the river was constructed on an old bridge. Concerns about structural stability of the bridge and safety motivated the City to investigate the construction of a river crossing that would increase the capacity and security of their existing system.

A number of trenchless alternatives were evaluated for crossing the Willamette River with a proposed 30-inch water line. Horizontal directional drilling (HDD), microtunneling, open shield pipe jacking, auger boring, and pipe ramming were evaluated for technical feasibility. Factors that were considered for technical feasibility included geotechnical conditions, site constraints, limitations on pipe materials, staging and layout areas, and easements. Two trenchless technologies, microtunneling and HDD, emerged as technically feasible and were carried forward for further evaluation. Multiple alignments were established for both technologies, and risks and costs were identified for each alternative. A risk/cost matrix was developed, comparing two HDD alignments and two microtunnel alignments. The microtunneling alternatives offered the lowest construction risk for the installation of the pipeline beneath the Willamette River; however, the microtunneling estimated costs were substantially higher than the HDD costs. HDD installation techniques proved to have a higher installation risk, but at a substantial cost savings. The recommended alternative for the Willamette River crossing was the installation of a HDPE water line using HDD techniques.

2. GEOTECHNICAL CONDITIONS

The geotechnical conditions below and adjacent to the Willamette River impacted the feasibility of the construction alternatives and the selection of an appropriate trenchless construction technique. The preliminary geotechnical analysis of the site soils indicated three distinct geotechnical formations in the vicinity of the proposed pipe crossing locations: alluvium, Willamette Silt, and Troutdale Formation. In the well field, the sub-surface soils were comprised of alluvial deposits made up of an upper sandy clay to silty sand layer, a middle sand and gravel layer, and a basal layer of clean and loose gravel (up to three inches in diameter). The Troutdale Formation was under the alluvium units and also found beneath the Willamette River. The Troutdale Formation consisted of clay, silt, and sand and contained local gravel layers. On the treatment plant side of the river, the Willamette Silt formation was underlain by the Troutdale Formation. The Willamette Silt formation consisted of silt and discontinuous interbeds of clay and sand (Squier-Klienfelder, 2006).

The well field alluvial deposits had an average thickness of 90 feet. The upper 30 to 50 feet consisted of sandy clay to silty sand which was underlain by sand and gravel. A basal layer of clean loose gravel was beneath the sand and gravel unit and was up to 20 feet thick. The basal gravel layer was indicated to consist primarily of gravels less than three inches in diameter; however, particles greater than three inches were anticipated. The basal gravel layer was indicated to contain little silt and sand sized particles in the soil matrix. Figure 1 shows the results of a geophysical survey that mapped the thickness of this basal gravel layer. The thickness of the clean basal gravel layer thinned downstream of the existing pipe bridge. This greatly impacted the choice of trenchless alignments because some trenchless methods such as HDD have difficulty in clean gravels. Therefore, the alignments were shifted downstream to minimize the impact of these clean gravels.

The geotechnical conditions identified at the site did not preclude the use of HDD or microtunneling. Both the Willamette Silt and Troutdale Formation are ideal materials for microtunneling and HDD. The alluvial soils presented the greatest risks to the trenchless construction. Microtunneling can generally perform well in alluvial soils. However, open-graded gravel deposits present challenges to HDD and may preclude the use of HDD if the extent or thickness of the gravel deposits can not be bridged. Analysis of the alluvial deposits did not eliminate HDD, but required special construction considerations.

Groundwater was present at the site and was within 30 feet of the ground surface on the well field side of the Willamette River. High groundwater heads were expected to be encountered when installing the pipeline beneath the river. In the Willamette Silt and the Troutdale Formation, the soils were expected to be very stiff/dense and have low permeability. As a result, perched groundwater could be within or near the top of these geologic units. In the alluvial soils below the groundwater, the permeability was expected to be high with recharge occurring from the Willamette River and the soil were expected to exhibit flowing characteristics.

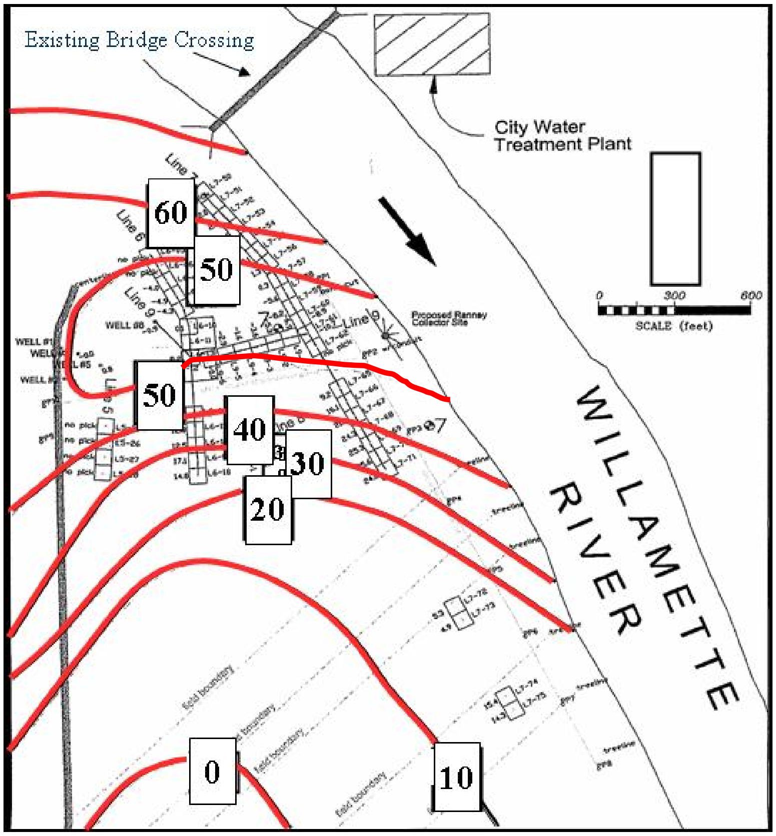


Figure 1 : Geophysical map indicating the thickness of gravel layers in the vicinity of the proposed Willamette River crossing (Contours represent gravel layer thickness in feet).

Each of the trenchless technologies was evaluated based on geotechnical conditions, groundwater levels, and length of crossing. The presence of groundwater within the alluvial soils, along with the 550-foot length of the river crossing, precluded the use of open shield pipe jacking, auger boring, and pipe ramming. Only microtunneling and HDD were considered technically feasible for the geotechnical and groundwater conditions encountered during the geotechnical investigation as indicated on Table 1.

Table 1 : Trenchless Technology Evaluation

Trenchless Technology	Troutdale Formation	Willamette Silt	Alluvial Deposits	Groundwater	Crossing Length
Horizontal Directional Drilling	Good Material for Drilling	Good Material for Drilling	Some Challenges for HDD	No Problems for HDD	Achievable
Microtunneling	Good Material for Tunneling	Good Material for Tunneling	Good Material for Tunneling	No Problems for Microtunneling	Easily Achievable
Open Shield Pipe Jacking	Good Material for Tunneling	Good Material for Tunneling	Good Material to Tunnel above Groundwater	High Groundwater Heads Preclude Use of Method	Easily Achievable
Auger Boring	Good Material for Boring	Good Material for Boring	Good Material for Boring above Groundwater	High Groundwater Heads Preclude Use of Method	Length Presents Serious Challenges
Pipe Ramming	Difficult to Ram due to Density	May be difficult to Ram due to Stiffness	Good Material for Ramming above Groundwater	High Groundwater Poses Significant Challenges for Use of Method	Length is Prohibitive

3. FACTORS USED TO EVALUATE AND COMPARE HDD AND MICROTUNNELING

The primary factors driving the trenchless design of the Parallel Pipeline River Crossing Project were construction risks and costs. The factors that influenced these risks and costs included: alignment selection based on site constraints; geotechnical conditions along the alignment; pipe flow diameter and pipe material to address installation parameters and limitations; alignment elevation to limit geotechnical challenges and provide sufficient depth of cover between the pipeline and the Willamette River bottom; layout areas; and the potential for contaminating the well field. Each of these factors was evaluated for HDD and microtunneling to determine their relative risk.

4. MICROTUNNELING

The major site constraint that drove alignment selection for microtunneling was the site topography and the steepness of the riverbank on the treatment plant side. To minimize the length of the microtunneling drive, it was necessary to place the microtunneling shafts as close to the riverbank as practical. In addition, microtunneling alignments were chosen to minimize shaft depths on the treatment plant side of the Willamette River. Two microtunneling alignments, the upstream and downstream alignments were selected and are shown in plan view in Figure 2. The microtunneling alignment lengths were comparable with the upstream alignment measuring approximately 950 feet compared to the downstream alignment measuring approximately 875 feet. Both alignments had clear and open access on the well field side of the river; however, access and easement issues on the treatment plant side of the river differed greatly for the two alignments.

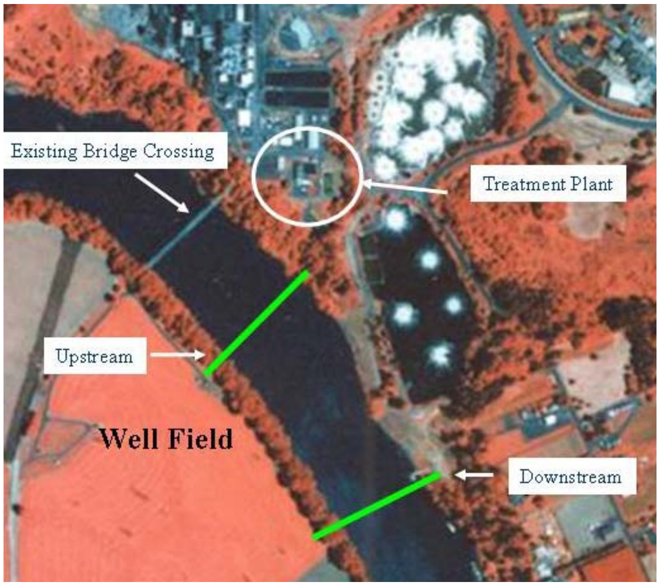
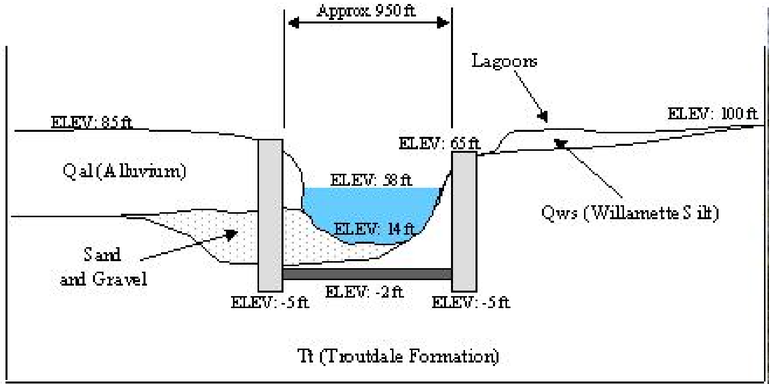


Figure 2: Microtunnel Alignments

The upstream alignment would be constructed from the well field side of the river to a reception shaft on the treatment plant side of the river. The existing bank on the treatment plant side of the river was steep, but leveled off to a flat area next to the river. This reception shaft area required extensive contractor modification for the construction of a reception shaft. On site evaluation of this area revealed that this work could be accomplished within the environmental permits; however, constraints would have to be placed on the contractor in the specifications to protect the river from soil inflows, and intense construction monitoring would be recommended during construction to avoid any problems with regulatory agencies. Figure 3 shows the upstream microtunnel alignment and reception shafts.

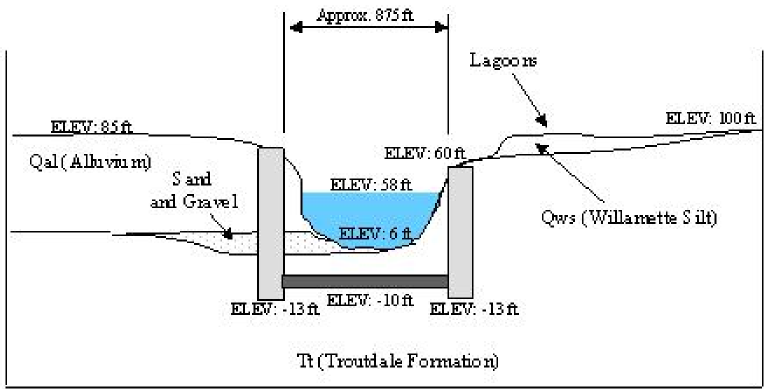


Upstream Microtunnel Profile

Reception Shaft Location

Figure 3: Upstream Microtunnel Alignment and Reception Shaft Area

The downstream alignment would also be constructed from the well field side of the river to a reception shaft on the treatment plant side of the river. Unlike the upstream alignment, the site for the reception shaft adjacent to the river was very flat and would not require modification for construction. However, the site was on private property and would require a construction easement from the property owner. Figure 4 shows the downstream microtunnel profile as well as the reception shaft location.



Downstream Microtunnel Profile

Reception Shaft Location

Figure 4: Downstream Microtunnel Alignment and Reception Shaft Area

5. HORIZONTAL DIRECTIONAL DRILLING

There were several site constraints that affected the alignment selection for the horizontal directional drilling option including the geotechnical conditions, proximity to the well field, and the steepness of the bank on the treatment plant side of the river. The HDD operations would commence from the well field side of the river with the entry location downstream from the well field. The entry locations were chosen to minimize the potential for contamination of the well field and to limit the thickness of gravel through which the bore would traverse. On the treatment plant side of the river, the most significant site constraint was the steep river bank. The steepness of the bank forced the geometry of the bore away from the river in order to minimize the potential for escape of pressurized drilling mud into the river. The topographical constraints lengthened the bore and pushed the exit locations beyond the existing lagoons. The steel and HDPE HDD alignments are shown on Figure 5.

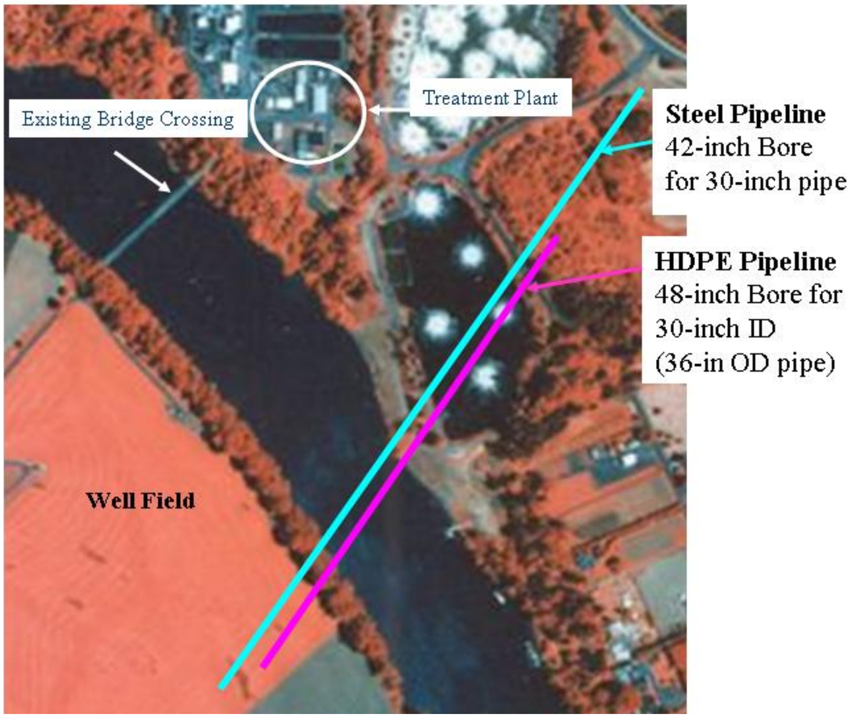


Figure 5: HDD alignments for HDPE and Steel Pipe

On the well field side of the river, the alignment was moved downstream to minimize the length of open graded gravel through which the bore would traverse. The presence of the sand and gravel units did not generally present a significant installation risk to HDD where finer grained materials were present in the soil matrix and the percentage of gravel was generally lower than 50 percent of the soil. In these soils, HDD construction is capable of providing the necessary support/soil stabilization during the installation process as the larger rocks are effectively supported by the finer grained constituents and by application of fluid pressure imparted to the surrounding soils during the installation process. However, layers of loose gravels lacking finer soil constituents increased installation risks. When loose gravels containing little to no fines are encountered during an HDD installation, the drilling fluid injected into the bore to stabilize the surrounding soils is free to migrate into the gravel layer and will not provide the required soil support to stabilize the bore. As a result, the surrounding soils will likely collapse into the bore blocking the area through which the product pipe is to be installed.

Beneath the Willamette River, the pipeline was located within the Troutdale Formation. Soils within this formation are ideal for HDD and were not expected to present any problems or complications. On the treatment plant side of the river, the site soils were expected to be Willamette Silt. The dense silt provided a good medium through which to drill. The Willamette Silt and Troutdale Formation were expected to provide a stable bore hole and a productive drilling environment.

The pipeline elevation (or depth of cover) beneath the river was chosen to minimize the potential for hydrofracture, inadvertent returns, or frac-out in the river. It was important to choose a pipeline depth where the strength of the overlying soils could resist the magnitude of the induced fluid pressure gradient so the drilling fluid/slurry mixture will flow along and out of the bore at either the entry or exit location. The key to minimizing risks associated with the loss of drilling fluids was to maintain sufficient depths of cover along the bore alignment. A hydrofracture analysis resulted in a recommended HDD depth of 30 to 35 feet below the river bed.

Since HDD uses pressurized drilling mud to create the bore hole, the drilling process itself presented a risk of contamination of the well field. Minimizing the risk of contamination was one of the factors that drove the alignment selection and pushed the bore entry location downstream to keep the alignment away from the active wells. In addition, it was a requirement of the contract that the HDD contractor install a conductor casing through the open graded gravel section which was expected to be on the order of 10 feet thick at the proposed bore location to help prevent the migration of drilling mud through the aquifer. Analysis of the geotechnical information suggested that a casing would be required for over 220 feet of length.

The City of Newberg preferred HDPE pipe material for the installation. The required thickness of the pipe would result in a DR of 9, with a 30-inch inside diameter. They also preferred that the new installation extend to the location of their new treatment plant, yet to be constructed at the time of the drilling. Figure 6 shows the resulting HDPE alignment.

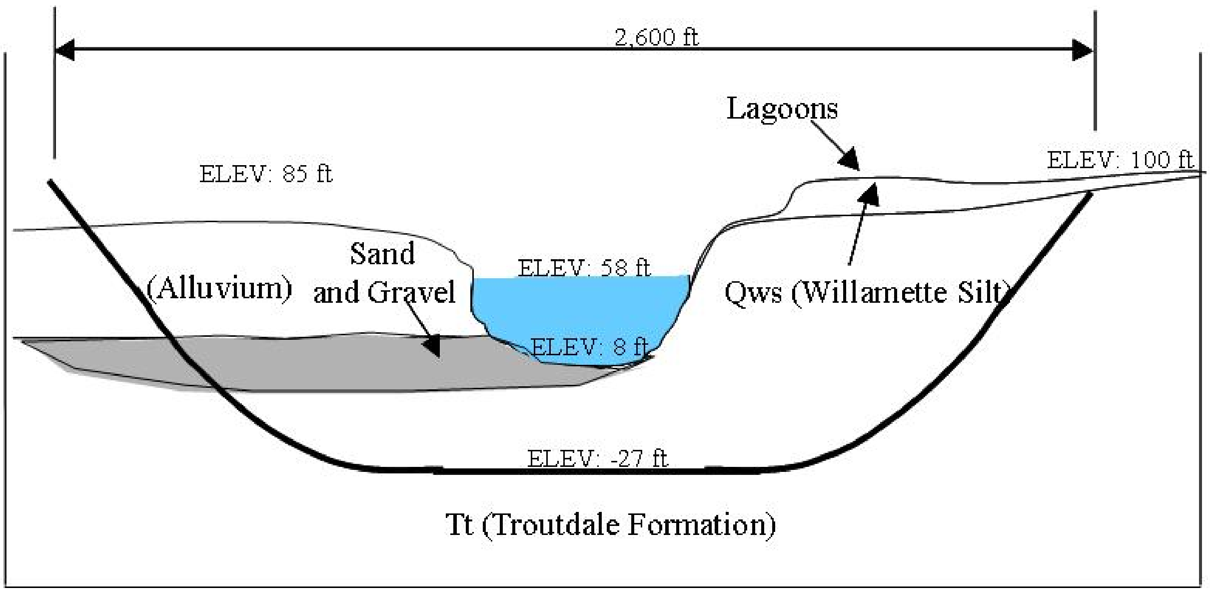


Figure 6: HDPE HDD Alignment

6. RISK – IMPACT – COST ANALYSIS

A relative risk-impact matrix was prepared and detailed the specific risk components of each microtunnel and horizontal directional drilling alternative for various events and conditions. The risk columns represented the likelihood that the event/condition would be encountered or would occur during construction. A high risk was color coded as red, a medium risk was color coded as yellow, and a low risk was color coded as green. This allowed a qualitative evaluation of the risks.

Based on the analysis, the microtunnel options represent the lowest risk alternatives to completing the pipeline project. The primary difference in risk reflected geotechnical conditions that were more conducive to microtunneling than to HDD as well as shorter microtunnel lengths compared to longer HDD lengths. However, the evaluation did not indicate that HDD is a "high risk" option but rather that microtunneling is a "low risk" option. Table 2 shows the risk evaluation for the trenchless alternatives.

Table 2: Risk Evaluation Matrix

Alternative	Potential for Well Field Contamination	Risk of Drilling Fluid Loss into the River	Risk of bore collapse	Risk of Encountering			High Installation Loads	Pipe Stuck Beneath River
				Boulders	Gravel	Wood		
Upstream Microtunnel	Med	Low	Low	Low	Low	Low	Low	Low
Downstream Microtunnel	Low	Low	Low	Low	Low	Low	Low	Low
HDD - HDPE	Med	Med	Med	Low	Med	Low	Med	Low

The impact of each risk was also quantified, representing the cost impact that would be incurred if the event/condition were to occur. Table 3 shows the impact matrix for the HDD alternative. Impacts were classified as low if the estimated financial impact was less than $50,000.00; medium if the estimated financial impact were between $50,000.00 and $150,000.00; and high if the estimated financial impact were greater than $150,000.00

Table 3: Impact Matrix for HDD Alternative

HDD Alternative	Potential for Well Field Contamination	Risk of Drilling Fluid Loss into the River	Risk of bore collapse	Risk of Encountering			High Installation Loads	Pipe Stuck Beneath River
				Boulders	Gravel	Wood		
Risk	Med	Med	Med	Low	Med	Low	Med	Low
Impact	High	Med	Med	Low	Med	Low	Med	Med

The construction costs for the trenchless components of the Willamette River Crossing were also estimated. These estimates included all costs associated with completing the trenchless portions of the crossings. The microtunnel alternatives assumed one microtunnel crossing with a 48-inch diameter pipe that would house the 30-inch waterline. The horizontal directional drilling alternative with HDPE pipe produced the lowest trenchless construction cost of approximately $1,800,000. The upstream and downstream microtunnel alternatives had estimated construction costs of $4,000,000 and $4,200,000 respectively. The higher microtunneling cost estimates were primarily related to higher per-foot installation cost associated with microtunneling and the costs associated with construction of the jacking and reception shafts

Although the risks of construction were higher with the HDD alternative, they were not prohibitive. In addition, the impact matrix revealed that the risks were acceptable given the cost differential between the HDD and microtunneling alternatives. The HDD alternative was selected and designed.

7. CONSTRUCTION

The low bid contractor was The HDD Company, one of the HDD contractors that were pre-qualified for the project. The HDD Company mobilized an American Augers DD-140 HDD rig that had been upgraded to deliver a thrust/pull capacity of 370,000 pounds. In accordance with the specification, a detailed frac-out plan was prepared by the Contractor that addressed mitigation procedures should a frac-out event occur during drilling. The HDD Contractor elected to bore from the well-field side of the river and pull back from the treatment plant side. Prior to HDD construction, the Contractor elected to install a 60-foot long, 48-inch diameter conductor casing to provide bore stability in the near surface soils. Figure 7 shows the drill rig during construction of the pilot bore. Figure 7 shows the HDD rig in the well field at the beginning of the bore.

Figure 7 HDD Rig at the Beginning of the Pilot Bore.

Construction began on August 30, 2006 with the initiation of the pilot bore. The pilot bore progressed without difficulty until approximately 345 feet into the 2,580 foot bore when circulation of the drilling fluid was lost. The Contractor made several modifications to the slurry in an attempt to regain circulation; however, it was determined that circulation could not be maintained. At approximately 500 feet into the bore, the drill pipes were retracted to within the conductor casing and the borehole was re-drilled with a higher viscosity mud mixture. Re-drilling progressed without event; however, when the drill bit was back to the previous termination point, circulation was lost once again. At this location, the drill was entering the open graded gravel lens that contained less than 10 percent fines. Throughout this section, the Contractor continued to have difficulty maintaining drilling fluid returns.

As the bore progressed, there were many locations at which the drilling fluid returns were lost. The Contractor would have to pull back many drill pipes, (at one time as many as 40 pipes – 1200 feet) to recondition the borehole and try to regain circulation. In addition, two weeper subs were connected down-hole to aid in mud circulation. After fighting the circulation issues for seven (7) days, the bore was drilled to a length of 1,740 feet of the 2,580 foot bore. However, due to the amount of pull-back and re-drilling, the contractor had drilled more than 3,000 feet of pilot bore drilling. The Contractor decided that the best solution would be to install a 12-inch casing approximately 180 feet into the bore to provide a conduit through which the drilling fluids could travel and bridge the gravel soils.

The drill pipes were retracted approximately 200 feet and an 18-inch reamer was placed in line. The reamer was advanced from the drill rig approximately 200 feet. The reamer was then removed and a 12-inch casing pipe was inserted over the drill rods, into the reamed hole. The installation of the casing proved to markedly improve bore fluid circulation and the pilot bore was completed on September 9, 2006, 10 days after starting the pilot bore.

Maintaining circulation in the gravel formation proved to be an ongoing battle throughout the drilling and reaming processes. When the pilot hole was complete, the Contractor elected for forward ream the bore from an 8 ¾-inch drill bit to a 36-inch reaming assembly. However, in order to ream, the entire 200-feet of casing that had been installed for pilot bore drilling had to be removed. As drilling progressed, it was then necessary to re-install the casing into the reamed bore in order to maintain circulation of the drilling fluids. This process of removing and re-inserting the casing had to be repeated throughout each reaming step for the bore.

The reaming process consisted of reaming a 36-inch bore, a 42-inch bore, and completing several swabbing passes. Throughout these processes, drilling fluid returns continued to be a major problem due to the presence of the gravel layer in the well field. However, after much hard work by the Contractor, the bore was successfully completed. The pullback of the 2,580 feet of HDPE pipeline was completed in less than 12 hours. The only location of inadvertent returns was within close proximity to the exit location and no drilling fluid was lost to the Willamette River.

8. CONCLUSION

An extensive evaluation was completed to select the most appropriate trenchless construction method for crossing the Willamette River. Although HDD did not offer the lowest construction risk, the risks associated with HDD were deemed acceptable in lieu of the considerable cost savings the method offered over microtunnel construction. The main risks associated with the HDD operation were due to the presence of open-graded gravels along the alignment. These gravels proved to be highly problematic during construction. However, through the diligent efforts of the Contractor the bore was successfully completed. The pre-qualification process that was executed during the design phase of the contract, proved to be very valuable as it limited the contractors to companies with river crossing experience in similar soil conditions. Without the use of pre-qualification, an inexperienced contractor may not have been able to overcome the challenges presented by the geotechnical conditions.

9. REFERENCES

Squier-Kleinfelder (2006). Geotechnical Baseline Report, Parallel Pipeline River Crossing Project, Newberg, OR.