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Record-setting HDD Success Through Collaboration of Owner, Engineer, and Contractor

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1.0 ABSTRACT

Length, vertical depth and formation can be the most challenging and limiting characteristics when it comes to underground trenchless technologies. In 2021, a record-breaking HDD was completed for WBI Energy, Inc. (WBI) for a critical crossing of Lake Sakakawea in North Dakota. Years earlier, the sheer length of the proposed crossing of 24-inch steel pipe (just more than 15,000 feet from upland to upland on either side of the lake) indicated the immense difficulty of the crossing, even before design work began. As the feasibility of the project was assessed, Horizontal Directional Drilling (HDD) emerged as the methodology with the best probability for success. WBI called on CCI & Associates Inc. (CCI) and Michels Trenchless Inc. (Michels) to complete the engineering and construction aspects, respectively. However, a collaborative approach between all parties was utilized to optimize the crossing and successfully install the landmark 15,426-foot HDD installation. The pre-job collaboration and early involvement of the various project team members throughout the three years of planning and preparation proved to be the most efficient route to successfully complete this challenging project and continue advancing the trenchless industry forward.

2.0 PROJECT BACKGROUND

Lake Sakakawea, created in 1956 by the construction of the Garrison Dam on the Missouri River in North Dakota, is part of a flood control and hydroelectric power generation project[1]. With a length of 177 miles, an average width of 1.5 to 3 miles and a maximum width of just more than 14 miles, Lake Sakakawea had limited the ability to transport natural gas takeaway from the Bakken Formation in northwest North Dakota to pipeline interconnects to the southeast. As a result, the existing infrastructure was not sufficient to meet transportation needs for the natural gas produced during the crude oil extraction process.

Faced with costly options of building hundreds of miles of pipeline around Lake Sakakawea or transporting liquid natural gas around the lake in tanker trucks, much of the natural gas was instead safely burned as a flare to prevent the release of hydrocarbons directly into the atmosphere.

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[1] https://www.nd-direct.com/travel/lake-sakakawea.php

To reduce flaring in the area, WBI initiated the North Bakken Expansion Project. According to WBI, the expansion project was designed to provide up to 250,000 dekatherms per day (Dth/d) of firm transportation service from receipt points in the Williston Basin of northwest North Dakota and near WBI's existing Tioga Compressor Station to a new interconnect with Northern Border Pipeline Company (Northern Border) in McKenzie County. The project included 63 miles of new 24-inch natural gas pipeline, including a critical crossing of Lake Sakakawea. The chosen project alignment crossed the lake near Tobacco Gardens Resort, approximately 24 miles north of Watford City, ND.

Figure 1: Proposed Crossing Location

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3.0 DESIGN

WBI enlisted the services of CCI to develop a design that could be used to successfully traverse the lake crossing. The approach to preliminary design pursued by CCI included a review of expected geological conditions, limitations of HDD methodology and equipment, estimated installation loads expected, and review of other completed HDDs in similar conditions.

3.1 PRELIMINARY FEASIBILITY ANALYSIS

3.1.1 Historical HDD Data

The first step in preliminary feasibility review was a review of historical HDD data to confirm what had been previously achieved by HDD at similar lengths, sizes, and similar ground conditions.

When Horizontal Directional Drilling (HDD) emerged in the mid-1960s as a new way to install utility lines under immovable or unavoidable obstacles, the length of the crossings reached only up to a few hundred feet guided by frequent potholing. That changed in 1971 when Martin Cherrington, widely regarded as the father of HDD, tackled the challenge of placing a 4-inch gas line under the Pajaro River in Watsonville, CA[2]. The successful 500-foot trenchless crossing was considered an astounding feat—the first in a long line of successors. Success bred success. Every time a new accomplishment was reached in terms of length, diameter, or ground condition, it was met with the question of what else was possible. Since that time, the industry has expanded its capabilities by leaps and bounds, to where at the time of the WBI expansion project's conception, multiple HDD crossings upwards of 10,000-feet had been completed. Many innovations within the HDD industry helped to make this possible, including new steering/tracking technologies (gyroscopic tools), intersect methodology, large diameter drill-stem, and ever-increasing HDD rig pull/push/rotary force capacities.

A review of recently completed large HDDs identified that multiple HDDs over the length of 10,000-feet had been completed. Most of these had been for smaller diameter installations of 12-inch pipe or smaller, but at least two <10,000-foot crossings of 28-inch and 30-inch had been completed internationally, in China and Saudi Arabia, respectively. In addition, multiple HDDs over 8,000-feet in length had been completed by drilling from one side without an intersect, theoretically validating the feasibility of completing a pilot hole of upwards of 15,000-feet with the use of an intersect methodology with two rigs. At the initiation of the WBI project, CCI was also aware of and had provided design input on a 13,158-foot crossing of 20-in. steel pipe at a crossing of Lake Sakakawea only miles from the proposed WBI location. This installation had not yet been constructed, but was planned for construction in 2019 (and was subsequently successfully installed as planned).

From a review of this data and analysis of the current equipment and technology available, it was clear that an HDD crossing of this size and length appeared to be technically feasible (pending further detailed design), but nothing of this length and size had been attempted previously.

3.1.2 Preliminary Installation Force Analysis

Using preliminary pipeline specifications provide by WBI and assumed ground conditions based on CCI's historical knowledge of the area, CCI conducted a high level installation pull-force analysis to determine the approximate range of possible required installation pullforces. This preliminary analysis yielded estimated pull-forces (including a 50% safety factor) between 660,000-lbs and 1,185,000-lbs, depending on the assumed drilling mud weight and whether or not buoyancy control was utilized. Based on this preliminary review in comparison with achievable pull-force of HDD rigs currently available within North American market (1.1 or 1.2 million lbs being the typical largest rig in most large HDD contractors' fleets), the theoretical feasibility of the installation of this length and size of crossing was confirmed.

3.1.3 Preliminary Hydrofracture and Depth Analysis

Using CCI's historical knowledge of the area, as well as publicly available information on the regional geology at this location, a preliminary annular pressure analysis was completed for the crossing. Using the output of this analysis, the estimated maximum drill depth was

[2] https://trenchlesstechnology.com/brief-history-horizontal-directional-drilling/

determined, where the risk of hydro-fracture or release of drilling fluid from the borehole was minimized. This depth was incorporated into the installation pull-force analysis noted above, as well as determining the depth requirements of the geotechnical investigation that was to be completed in order to confirm drilling conditions throughout the length and depth of the proposed drill-path. This depth was determined to be approximately 275-300-feet below water surface of the lake, and 350-375-feet below the ground surface on either side of the crossing.

3.2 GEOTECHNICAL INVESTIGATION

Thorough understanding of subsurface conditions in the vicinity of any proposed crossing is essential to determining if a HDD crossing is technically feasible. While crossing length and pipe diameter are also critical components that must be considered, technical feasibility is largely limited by subsurface conditions.

The design team, consisting of WBI, CCI, and Groundwater & Environmental Services, Inc. (GES), as the geotechnical sub-consultant under CCI, completed a detailed review of the local geology along with developing a plan for completing both land-based and water-based geotechnical borings.

3.2.4 Geological Background

A review of the regional geology indicated that the physiographic regions where the proposed HDD pipeline crossing is located consist of the McKenzie Upland Unit, located south of the Missouri River and the Coteau Slope Unit, located north of the Missouri River. These units are part of the Great Plains and characterized by rolling to hilly plains with both erosional and glacial landforms. The proposed HDD crossing is located within the historic Missouri River floodplain that was flooded with the construction of the Garrison Dam in 1956 to form Lake Sakakawea. This area is located in the central portion of the Williston Basin.

The surface geology in the area consists of thin layers of glacial deposits underlain by the Paleocene-Aged Sentinel Butte Formation and the Bullion Creek Formation. The Sentinel Butte Formation consists of layers of silt, clay, sand, lignite, carbonaceous shale, and mudstone. The Sentinel Butte Formation outcrops along the south shoreline of the Missouri River and both the Sentinel Butte and Bullion Creek Formations outcrop along the north shoreline of the Missouri River along the proposed crossing alignment generally consisted of sedimentary bedrock overlain by alluvial deposits in the Missouri River channel and thin glacial deposits in the upland areas.

3.2.5 Geotechnical Program

The geotechnical program developed by CCI and GES included 9 boreholes total, three (3) being land-based and six (6) being water-based. The maximum depth of investigation from surface was 403-feet (on-land) and 315-ft (on-water). The boreholes were spaced relatively evenly such that a suitable model of the ground conditions across the full length of the crossing could be developed.

Figure 2: Geotechnical Borehole Locations

3.2.6 Geotechnical Investigation Timeline

The on-land portion of the geotechnical investigation was completed in April and May of 2019, after obtaining permissions from landowners. This information was utilized to update CCI's design and AP models while awaiting completion of the over-water geotechnical scope.

Based on the relatively similar conditions in the land-based boreholes on either side of the crossing, the proposed over-water borehole locations were finalized and submitted to the US Army Corps of Engineers (USACE) for approval. The original schedule target was the completion of the over-water work in the fall of 2019 prior to the lake freezing over, however the permit approval process with USACE took WBI into the winter, with the permit for over-water geotechnical work finally being supplied in early 2020. The over-water boreholes were completed in May of 2020, after the ice cover had melted and prior to the busy summer season for the Tobacco Gardens Recreational Area (TGRA). New COVID-19 measures to maintain crew safety were established prior to mobilization. For the over-water geotechnical boreholes an existing nearby boat ramp within TGRA was utilized, in conjunction with an adjacent temporary crane pad, in order to launch and assemble the drilling barge.

Figure 3: Geotechnical Barge Assembly

Figure 4: Geotechnical Drilling Setup

3.2.7 Geotechnical Results

Both the on-land and on-water investigation results generally confirmed the assumptions from the local geological review, showing evidence of fine-grained sand, silty lean clay, and alternating layers of coal and weathered clay shale. The impacts of the geotechnical investigation results in the detailed design are discussed further in the Detailed Design section.

3.3 Detailed Design

3.3.8 Annular Pressure & Hydrofracture Analysis

Utilizing the subsurface data obtained from the geotechnical investigation, a revised annular pressure model was developed. Standard US Army Corps of Engineers Delft Equation calculations were completed, as well as modified Delft Equation analysis utilizing modified $r_{p,max}$ values derived from the geotechnical data. The modified Delft Equation has been found to be more accurate in predicting inadvertent returns of drilling fluids (Goerz, Boelhouwer & Taylor, 2019), so both methods of analysis were completed to ensure the IR risk in either analysis case remained low. This analysis confirmed the required minimum depth of cover that was developed in the preliminary design stage based on conservative assumptions of geotechnical conditions gathered from historical knowledge of the area. A depth of 342-ft below entry (245-ft below the lowest point of the lake bottom) was established.

3.3.9 Geotechnical Considerations

Aside from the derivation of the inputs for the IR / annular pressure analysis, the geotechnical investigation also provided useful information on the location of multiple coal seams interbedded within the clays/shales/sands. Coal seams can offer problems for HDD drilling, as the fractured nature of some seams can provide preferential routes for drilling fluid to escape from the borehole and loss of circulation to occur. Therefore, maintaining HDD drill-paths outside of any coal seams is generally preferable where possible. In evaluation of the identified coal seams from the geotechnical investigation, it was found that seams were relatively common beyond 200-ft in depth below the entry point, shallow enough that maintaining the drill-path above any seams would not be possible due to the risk of IR at shallower depths. Out of necessity, the drill-path would need to extend into the interbedded coal layers to some degree, with the goal being to drill through the encountered seams in the vertical components of the drill geometry and keep the long bottom tangent of the drill out of any coal lenses. The geotechnical boreholes, however, showed that the coal seams in general were not at distinct vertical elevations across the length of the crossing. Therefore, it would not be possible to maintain the drill-path bottom tangent at a single elevation which would remain between two coal seams throughout the majority of the drill. Based on mapping the coal seams, an optimal trajectory of the bottom tangent was developed, which targeted thicker zones of competent drilling material sandwiched between coal seams, but which required a vertical S-bend in order to maintain the drill in these optimal materials. Due to the long length of the crossing, every effort was made to minimize the additional steering difficulty of this added curve. This included minimizing the total angle change which would still achieve the drill-path within the optimal zones, as well as utilizing a large radius for the curves. The chosen geometry incorporated 2º total angle of curve, at a 10,000-ft radius.

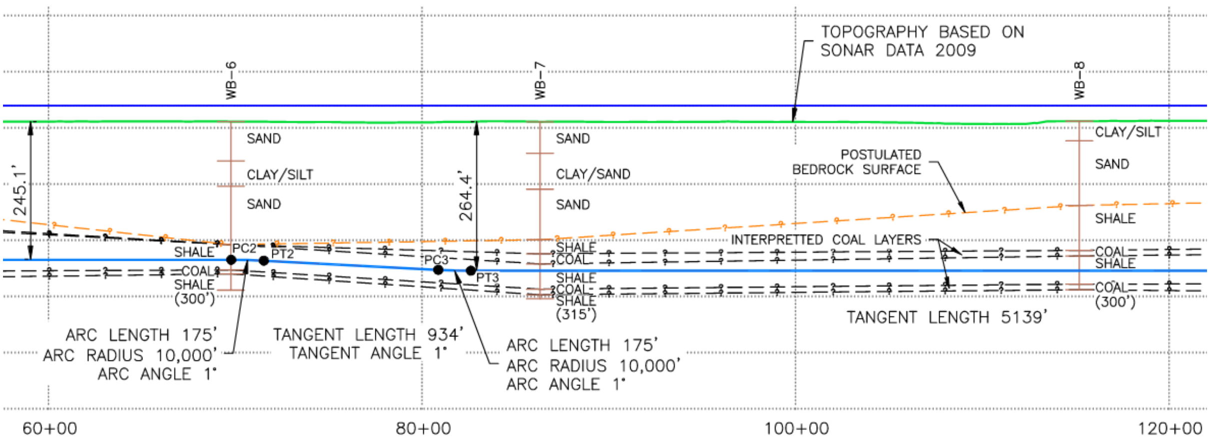

Figure 5: Vertical S-Curve Design to Avoid Interpreted Coal Layers

3.3.10 Intersect Methodology

A primary design consideration which was also integral to design choices noted above was the use of an intersect methodology, utilizing a rig on either side of the crossing. There were multiple reasons this would be a necessity for the completion of the crossing. The first consideration was just the sheer length of the crossing and associated equipment capabilities. Based on current HDD equipment and technology, a single rig would almost surely not be capable of drilling a pilot hole the full length of the crossing due to allowable torque and drag forces on the drill pipe material, aside the accumulated friction forces downhole would also minimize push-force transmitted to the bit and make steering success for the "exit" curve extremely difficult with conventional HDD techniques. Furthermore, for hole enlarging operations on a crossing of this size and length, a rig on either side would be necessary in order to provide sufficient axial and rotary forces throughout the reaming operations.

A second reason for the use of intersect method is the annular pressure analysis. As the length of pilot hole increases, so does the buildup of fluidic frictional forces required to pump fluid from the bit back up to surface (along with all the cuttings). Therefore, even if the equipment were able to drill fully from one side to the other, the downhole pressures along the last portion of the drill would be above the calculated soil containment pressures from the AP analysis. Using an intersect method means each rig only has to pump fluid for approximately half the length of the crossing and therefore reduces the maximum downhole pressure to within allowable ranges.

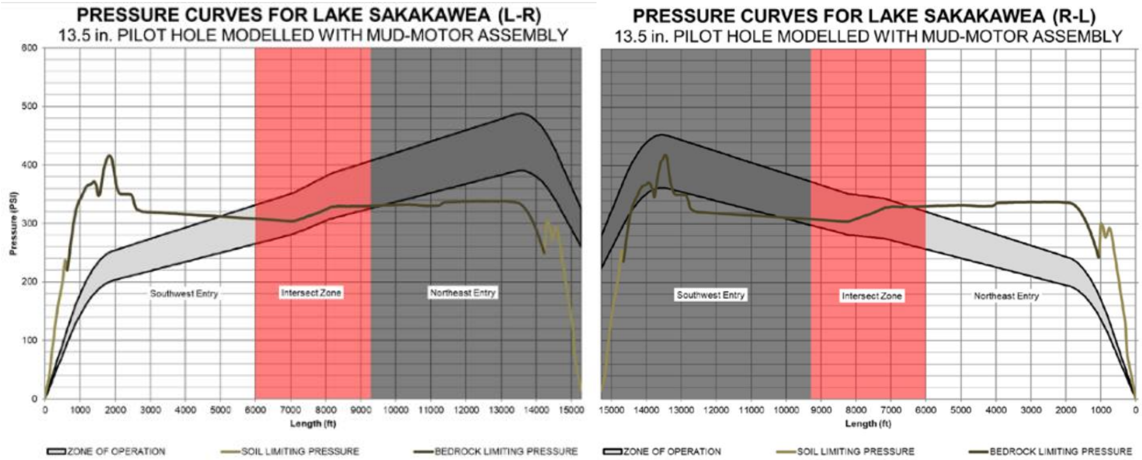

Figure 6: Annular Pressure Analysis (Modified Delft Model)

The proposed intersect zone noted in the design was chosen to extend beyond the vertical S-curve geometry present in the middle of the crossing, allowing the contractor to intersect on either side in order for the intersect to not be further complicated by the S-curves. A zone of approximately 3000-ft in length was noted in the design. During construction, the intersect was completed just south of the S-curve geometry.

3.3.11 Installation Force & Pipe Specifications

Due to the length and diameter of the crossing, installation forces were a critical concern in the design. The preliminary installation load analysis had shown that variations in the wall thickness of the pipe, and whether or not buoyancy control was used, could be the determining factors on whether the estimated installation forces were within the range achievable by the largest HDD rigs on the market or not.

Buoyancy control typically involves the filling of the product pipe with water during pullback to equalize or minimize the buoyant uplift forces of an empty pipe suspended within drilling fluid. In certain cases, rather than filling the product pipe, alternatively, a smaller pipe (typically HDPE) inserted within the product pipe can be filled with water instead, if this offers a better reduction in friction forces by getting the pipe closer to neutral buoyancy. Buoyancy control is generally useful and required for 24-inch OD pipe and larger, although use of buoyancy control on smaller OD pipes on longer crossings can be beneficial in some cases. Due to the limit-pushing geometry of the Lake Sakakawea crossing, buoyancy control alternatives were evaluated to determine what combination of inputs would optimize the estimated pull-forces.

In conjunction with this analysis, WBI confirmed with CCI that they would like to have a higher WT than would be standard or required in this case to withstand installation and operating stresses, in order to offer additional corrosion allowance and prolong the operational life of the crossing. WBI proposed a minimum WT of 0.938-inch, noting that alternatives of 0.99-inch and 1.219-inch would also be available to them. The pullback analysis completed by CCI showed that the higher wall thickness pipes would actually offer significantly reduced installation forces due to counteracting the buoyancy uplift, particularly if the mud density downhole was assumed to be 10.5 lbs/gal or higher. Utilizing a higher wall thickness than typical 24” heavy-wall pipe in this case would not only offer extended product life, but also eliminate the need for utilizing buoyancy control during pipe pullback. This would simplify the in-field pullback operations significantly and remove another operational complication that could add complexity, schedule, and risk to the pullback procedures. Both the 0.99-inch and 1.219-inch pipe had this benefit, however the 1.219-inch pipe was significantly stiffer, and therefore would result in a much higher pullback lift geometry, requiring an additional 6 crane supports beyond what would be required for 0.99-inch pipe. Therefore, it was decided to move forward with the 0.99-inch WT pipe.

3.3.12 Designer & Contractor Collaboration

In parallel with the design work noted above, WBI understood the value in involving the HDD contractor in the development of the design, prior to finalization. This full-team design approach offers many benefits. Among these benefits is a validation of the design, from the professionals who have completed similar HDDs in the past. Additionally, it allows the designers to incorporate some specifics on equipment and methodologies into the design to make it more accurate to what will actually be completed in the field, rather than assumptions on typical expected standards.

One contractor-specific consideration which can have an impact on the design and even the required drill depth is the specific combination of downhole equipment and expected operating parameters. The specific combination of drill-pipe diameter, pilot bit size, drilling mud rheology, and pump rates will impact the output of the annular pressure analysis. It is therefore key to ensure the designers assumptions and the contractors proposal are in line, as significant variation between the two can mean a much higher risk of IR than shown in the design. In the case of this crossing, Michels confirmed that they would be utilizing 7 5/8” drill pipe with a minimum 12.25” bit for the completion of the pilot hole. The annular pressure analysis was updated to match these contractor plans, and the design depth of cover was confirmed to be suitable. Discussion on use of casing was also incorporated into the design. It was determined that Michels intended to utilize small diameter casing to get down to the shale layer below the surficial sands and clays. In order to reduce the total casing length required for this installation, the entry angle was increased from 12 degrees to 15 degrees.

Another consideration in the design was the application of contractor specific support equipment. In particular, the inclusion of Michels’ pipe thruster to be placed at the exit location to assist with pullback if necessary. In coordination with Michels, the exit angle was modified to 12 degrees in order to optimize the contractor’s proposed setup of the thruster in conjunction with the required lifting equipment on the pull-back side. Although the thruster did not end up being required during pullback operations, having this secondary assist equipment setup properly included in the final design was key to ensuring the drill path and the lift plan design are in alignment with what would be completed in the field.

4.0 PERMITTING

Once the HDD design was fully prepared, the design and construction plans required review and approval from all the relevant regulatory bodies. Among these bodies were the US Army Corps of Engineers (USACE), the North Dakota DEP, and the Federal Energy Regulatory Commission (FERC). Aside from the design, a key component of many of these applications (particularly FERC) was the inclusion of a detailed HDD execution plan outlining the expected equipment, methodologies, and mitigation plans for the drilling operations. In many cases these plans are developed for regulatory applications before specific HDD contractors may be contracted for the work, and are therefore somewhat general in nature and may require modifications and even re-evaluation once the contracts are awarded. However, in this case due to the early involvement of the contractor, site-specific equipment and contractor plan documents were able to be utilized within the permit applications.

As part of the FERC permit requirements, visual monitoring of the waterbody for IRs was required. Due to the long span of water, it was determined that aerial inspection by drone was the optimal method of ensuring timely and thorough monitoring and provision of monitoring records. Due to the large span of water, 2 drones (one on each side) were utilized by CCI in order to ensure full coverage of the watercourse and maintain required visual contact with the drones.

Figure 7: Drone Conducting Visual Monitoring of Lake Sakakawea

5.0 CONSTRUCTION

With Michels having been involved in the design optimization, as well as their familiarity with the drilling conditions of the lake due to their recent experiences in drilling under it[3], they were well prepared for the construction phase of this project. The key details of the crossing construction are noted below.

5.1 EQUIPMENT AND TOOLING

5.1.1 Drill Rigs and Pipe Thruster

Two of Michels' in-house designed and fabricated drilling rigs, each with the capacity of more than 500 tons of thrust and pull force, not to mention the high torque capacity, were utilized on each side of the crossing until reaming was complete.

Total weight of the first section of pipe was estimated to be approximately 3.7million pounds, consequently breaking the inertia of the pipe to initiate and reinitiate pulling operations could

[3] https://www.houstonpipeliners.net/docs/PAH_2021_08_Design_and_Construction_for_Record_HDD.pdf

be significant. In order to ensure Pull back operations were carried perfectly, Michels installed a Pipe 750-ton pipe thruster at the exit side to assist in case it was needed.

5.1.2 Drill Pipes, and Hole Opener

To withstand the forces required to safely and accurately execute the pilot hole and subsequent reaming operations, 7 5/8" drill pipe was utilized.

Finally, custom made hole openers were fabricated to provide the highest level of efficiency as well as endurance during reaming process.

5.2 Guidance System

In Horizontal Directional Drilling, there are two types of guidance systems. Magnetic Systems, which utilizes Earth's magnetic field as a primary source of quantifiable vectors to determine the borehole direction in three dimensions, and an artificial magnetic field that confirms calculated location. The artificial magnetic field uses either AC or DC, both of which require a pre-surveyed circuit laid on the surface above the borehole trajectory. The circuit generates a magnetic field is utilized as a secondary tracking system to confirm calculated position determined previously based on Earth's magnetic field and accelerometers inclination.

Gyroscopes represent the second type of systems, also called non-magnetic. Most of the gyroscopic systems utilized on HDD are based on true north using a reference line derived from geographical coordinates. In this system, there is no need for surface auxiliary confirmation circuits, aside from near exit where they are often used to confirm location prior to punch-out.

At the location of the crossing, the Lake Sakakawea has a length of 3.7km making it almost impossible to lay out any kind of surface coil which made a gyroscopic system the ideal system for the project.

5.3 Threaded Casing

Entry and exit side upper layers were composed of unconsolidated and unstable materials, thus constituted a significant threat to the hole stability, drilling fluid circulation during operations and structural support for the drill string to allow for a better distribution of axial forces. The solution for that was the utilization of surface casing. Michels installed approximately 720m of 14-inch proprietary threated casing on each side. Michels threaded casing is designed and built to have an outstanding performance and operate such as an oversized drill pipe allowing for fast installation and high resistance to the stress during installation.

5.4 Site Management

It's not uncommon for HDD projects, especially those of larger scales, to require a high level of planning and preparation in order to ensure that the project is successful and completed within the desired timeframe. Lake Sakakawea was no different, it required extensive planning and coordination to overcome the previously mentioned various challenges.One of the challenges was the need to find and store fresh water, which is an essential component of the drilling process. The project team needed to secure a sufficient supply of water for the duration of the project, which involved coordinating with local authorities and obtaining necessary permits and approvals.

Another challenge was finding sufficient space to lay down and weld the product pipe. Given the length of the crossing (15,426 feet), large particularly area was required to lay down and weld the product pipe, that required careful coordination and planning to ensure that there was sufficient space for storage, welding, and transport.

Equipment maintenance and spare parts were critical to the project, as unexpected equipment failures or breakdowns can lead to delays and increased costs. Michels experienced team spent enough time to carefully plan for equipment maintenance and have backup equipment and spare parts available to minimize any potential disruptions.

Finally, the COVID-19 pandemic presented especial heath and logistical challenges, such as travel restrictions and safety protocols. The Safety, health and environmental team implement the necessary changing conditions and implemented measures to ensure the safety of workers and comply with local health guidelines.

5.5 PULLBACK

The effort to complete the pilot hole to design specifications and enlarge it to 36 inches in diameter over the course of two months also highlights the importance of patience and attention to detail in HDD projects. These types of projects require a high level of precision, and any errors or deviations from the original plan can lead to significant delays or even project failures.

Michels trenchless and Michels Pipeline teams were able to successfully install the product pipe using a series of high-capacity lifting equipment and accurate coordination. The importance of clear communication and coordination during the pipe load cannot be overstated, as even small mistakes or miscommunications can have significant consequences for personnel safety and project timelines. Communication and collaboration were crucial to success.

Michels trenchless and Michels Pipeline, Inc. teams have a wealth of experience and expertise in the field of Trenchless and Pipeline construction. Their ability to safely and efficiently complete one of the world's longest HDD projects at the 24-inch diameter is a testament to their skill and dedication to the industry.

6.0 SUMMARY

Technology pushing, world record trenchless installations can be completed successfully when due diligence focused on proper planning, detailed design, and construction execution by experienced contractors are made a priority. The project team consisting of WBI, CCI & Associates, Groundwater & Environmental Services, and Michels worked together from the initial feasibility phase through the successful installation of the NPS 24 pipeline. This installation, with a recorded length of 15,426 feet, marks a notable accomplishment in the HDD industry and demonstrates that seemingly infeasible crossings are achievable with the right team in place.

7.0 REFERENCES

Goerz, S., Boelhower, N., and Taylor, J. (2019). “A New Perspective in Hydro Fracture Evaluation”. North American Society of Trenchless Technology (NASTT) 2019 No-Dig Show Chicago, Illinois.