Red Deer Pipeline River Crossing- Geotechnical & Geophysical Assessments

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ABSTRACT
The Town of Sundre located approximately 100 km north west of Calgary, AB was planning to service existing residential, commercial and industrial developments on the east side of the Red Deer River. In order to service the development, new water/wastewater infrastructure will be required to cross the River to tie-in the developments with the existing Town system using Horizontal Directional Drilling (HDD). A detailed study including fisheries, hydrotechnical, geotechnical and geophysical assessments were conducted to ascertain the optimal location for the pipeline crossing. A No-Drill zone, for the optimal location, was also presented. This paper presents the findings of the geotechnical and geophysical assessments only.

RÉSUMÉ
La municipalité de Sundre situé à environ 100 km au nord-ouest de Calgary, AB avait l'intention de service existant développements résidentiels, commerciaux et industriels sur le côté est de la rivière Red Deer. Afin de service du développement, de nouvelles eaux / eaux usées infrastructures seront nécessaires pour traverser la rivière à attacher dans les développements avec le système existant en utilisant Ville Forage directionnel horizontal (FDH). Une étude détaillée, y compris la pêche, les évaluations hydrotechnique, géotechniques et géophysiques ont été menées pour déterminer l'emplacement optimal pour la traversée du pipeline. Une zone sans perçage, pour la localisation optimale, a également été présenté. Ce document présente les conclusions des évaluations géotechniques et géophysiques seulement.

1 INTRODUCTION

The Town of Sundre (Town) located approximately 100 km north west of Calgary, AB was planning to service existing residential, commercial and industrial developments on the east side of the Red Deer River. In order to service the developments, new water/wastewater infrastructure will be required to cross the Red Deer River to tie-in the developments with the existing Town system. The crossing will be sized to accommodate future growth to both the Town and Mountainview County (MC) as set out in the agreed upon annexation agreement.

The preferred option is to install two new pipelines, one for potable water and one for wastewater, below the Red Deer River in a new pipeline easement Right-of-Way (ROW) using Horizontal Directional Drilling (HDD) technology. This would eliminate the need for extensive in-stream work associated with an open cut trench-type crossing. Options to attach the new pipelines to the existing Highway 27 Bridge were considered but were not supported by Alberta Transportation (AT).

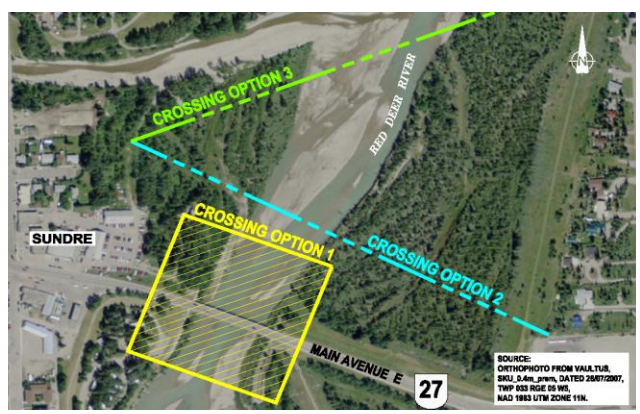
The pipelines will be 450 mm (inside) diameter and constructed using High Density Polyethylene (HDPE).

An HDD crossing beneath the River requires a multi-facet approach involving fisheries and hydrotechnical assessments in addition to a geotechnical and geophysical investigations. This study concentrates on the geophysical and geotechnical aspects of the project.

2 ASSESSMENT OF CROSSING OPTIONS

During the course of the study three pipeline crossing options were investigated. The location and alignment of each of the options assessed is shown in Figure 1. The preferred location to the Town for the new pipeline crossings (Option 1) was in the immediate vicinity of the Highway 27 bridge (approximately 100 m upstream and downstream) (Figure 1). The Town's preference was based on the ability to tie in to existing water/wastewater infrastructure, the narrower crossing width at this location of the river, and the apparent ease to acquire the required land access to undertake the HDD program.

Figure 1 Investigated crossing options



An inspection of the preferred crossing location (Option 1) was undertaken. It was evident from the inspection that the preferred crossing area (upstream and downstream) may be unfeasible on the west side of the river given the limited area to accommodate minimum drilling workspace requirements, and probable minimum setbacks from the river edge to address slope stability issues and potential lateral migration of the river. There were also concerns on the south east side of the Highway 27 Bridge associated with drilling rig access and crossing below a flood protection berm, constructed and maintained by Alberta Environment (AENV).

It was, therefore, decided to proceed with a preliminary geophysical investigation to confirm the feasibility of the preferred crossing option and/or investigate other possible options for the pipeline crossing (Options 2 and 3, Figure 1). By utilising electrical resistivity tomography (ERT) information collected from a geophysical investigation, and known geological information collected from the desktop study (WorleyParsons 2008), a quick analysis was made of the likely subsurface conditions to be encountered at the crossing location. Using this information, the depth of installation was estimated along with subsequent minimum setbacks from the river edge to verify whether the preferred crossing option (Option 1) was viable. Options 2 and 3 where also identified as possible alternative crossing options needing further assessment.

3 GEOPHYSICAL INVESTIGATION

A geophysical investigation was conducted during the preparation of this study to assist in providing a subsurface lithologic interpretation of the geological units in the area of the proposed crossing options (refer to section 2 and Figure 1), and, in particular, provide an interpretation of the distribution of granular deposits and the bedrock interface with depth.

3.1 Scope of Work

The scope of work for the geophysical field investigation included electrical resistivity tomography (ERT); and seismic refraction surveys.

The objectives of the ERT survey were to delineate lateral changes in the near surface geology along and below the proposed crossing options by imaging variations in subsurface electrical resistivity. The seismic refraction survey was conducted as a second reconnaissance tool to assist in the interpretation of the ERT results and attempt to map the depth to bedrock.

3.2 Geophysical Field Surveys

The geophysics field survey work was split over two programs (April 15-17 and May 5-7, 2009) to assist in the determination of the proposed crossing options.

A georeferenced base map showing the positions of the ERT and seismic refraction surveys is presented in Figure 2. Positions of the ERT and seismic lines were surveyed using a Real Time Kinematic Epoch 25 GPS System, providing for sub-meter (i.e. 3 cm) accuracy in eastings, northings, and elevation. Coordinates in this report are referenced to UTM NAD83 Zone 11 North. Topographic information is referenced to mean average sea level, and provided as metres above sea level (masl).

3.2.1 Electrical Resistivity Tomography (ERT)

A total of four ERT lines were surveyed using a 5 m minimum electrode separation, providing a maximum depth of investigation of approximately 60 mbgs. ERT Line 1 and ERT Line 3 were collected on the west and east banks of the Red Deer River, respectively, and perpendicular to the proposed pipeline crossing ROW. ERT Line 1 is 800 m long, and ERT Line 3 is 700 m long. The sections trend from approximately south-southwest to north-northeast.

Two lines, ERT Line 2 and ERT Line 4, were collected across the river, and along two of the suggested pipeline crossing options, Option 2 and Option 3, refer to Figure 1. ERT Line 2 and ERT Line 4 are 600 m and 700 m in length, respectively. The positions of the geophysical survey have been indicated on Figure 2, which contains a georeferenced satellite image. ERT Line 2 and ERT Line 4 positioned such that they have a common approximate starting line position on the west side of the River and each line crosses near at least one possible horizontal drilling entry point, see Figure 2.

Figure 2 Locations of the geophysical survey lines

3.2.2 Seismic Refraction

One seismic refraction line was also collected along the west bank of the river (Figure 2). Seismic Line 1 was collected parallel to the river, along ERT Line 1, and is placed safe distance from the traffic bridge to minimize the vibration caused by the moving traffic along the highway. A sledge hammer was used as a source of energy. The 48 geophones were spaced 4 m apart.

3.3 Geophysical Results and Interpretation

An overview of the results of the geophysical surveys along with a discussion of interpretation of the results is provided below.

3.3.1 Physical Properties and Interpretation

Generally, fine-grained materials tend to give lower apparent resistivity values than coarse grained materials. At this site, high resistivity values are interpreted to represent potentially unsaturated sand and gravel, and moderate resistivities are interpreted to represent potentially saturated sand/silt, or saturated sandstone or silty clay. Low resistivity values are interpreted to represent clay, clay till, shale, or mudstone.

ERT data are presented as colour shaded cross-sections, warm colours (i.e. pinks and reds) representing higher resistivity values, and cool colours (i.e. blues) representing lower resistivity values. Topography has been included during processing to correct for geometric effects caused by the elevation differences along the survey lines. The resistivity grid range is displayed between 0 ohm-m and 200 ohm-m to highlight resistive boundaries.

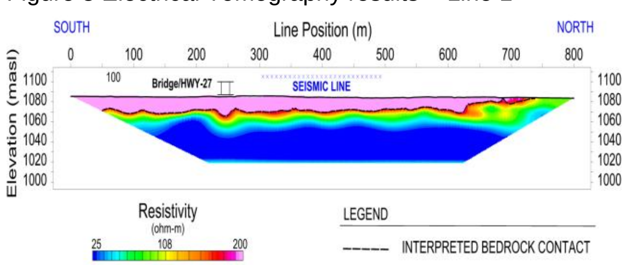
Variations in seismic velocity result from changes in physical properties of the subsurface. Less consolidated materials (i.e., overburden) exhibit a lower seismic velocity than more competent materials (i.e., bedrock). Changes in seismic velocity are not always consistent with changes in lithology, but may reflect changes within a lithologic unit. Changes in pore water chemistry do not influence seismic velocity.

Changes in seismic velocity are displayed as a colour shaded grid with warm colours (reds) representing high velocity values and cool colours (blues) representing low velocity values. Velocity seismic refraction velocity grid is displayed at 1000 m/s and 2500 m/s levels.

3.3.2 ERT Survey

The results of the ERT surveys for ERT Line 1 to ERT Line 4 are presented in Figures 3-6 respectively. The ERT data are presented as cross-sections of resistivity values (ohm-m) versus depth (masl).

Figure 3 Electrical Tomography results – Line 1



Based on the collected ERT information, the decision was made by the Town to proceed with the proposed alignment for Option 2 along ERT Line 2 (Figure 2). As such, two boreholes were drilled on each side of the river along ERT Line 2 for the geotechnical investigation component of the study to calibrate results from the ERT. The collected borehole data are superimposed on the ERT Line 2 cross section (Figure 4). The depths of the interpreted formations on the borehole logs were correlated with the resistivity value contours across the ERT line. The ERT data provide information regarding lateral continuity of the interpreted formation contacts between boreholes.

The lithologic interpretations along all of the ERT cross-sections consist of resistivity values higher than 200 ohm m extending from surface to a variable depth on each ERT cross-section. This high resistivity zone is interpreted to represent granular material (sand and gravel). This overburden material is underlain by alternating layers of siltstone and mudstone bedrock. The top contact of the more consolidated material is interpreted to be as deep as 8 mbgs in proximity to the west borehole, and 20 mbgs in proximity to the east borehole. The interpreted bedrock contact is highlighted by a dashed black contour line on all the ERT sections. ERT Line 2 and ERT Line 4 show that bedrock is shallower toward the west, and deeper toward the east bank of the river.

Figure 4 Electrical Tomography results – Line 2

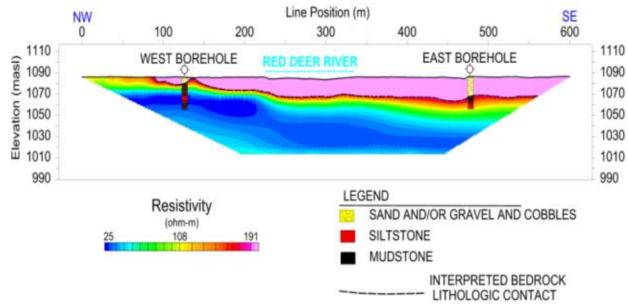


Figure 5 Electrical Tomography results – Line 3

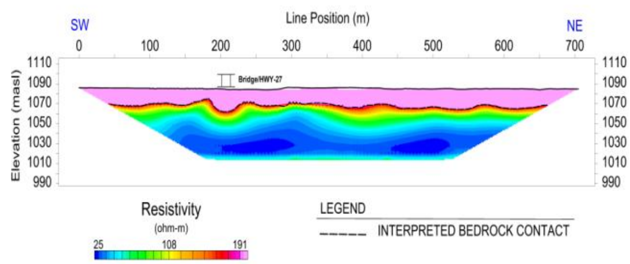
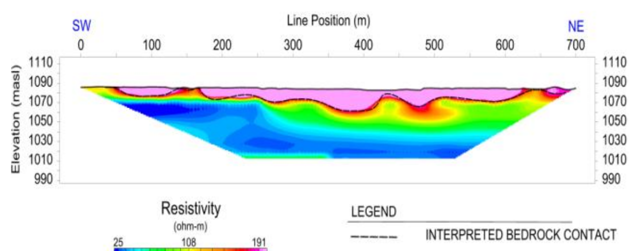
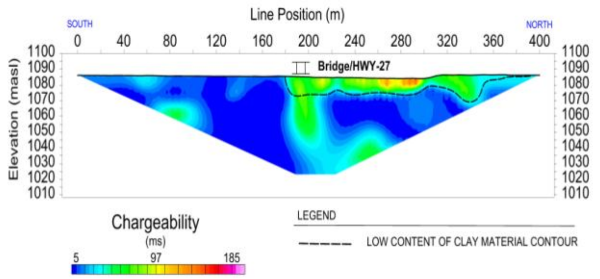


Figure 6 Electrical Tomography results – Line 4



Induced Polarization survey data (IP) has been collected on the first 400 m line segment of ERT Line 3. The results are presented in IP Line 3, Figure 7. The purpose of this survey was to determine if there is a clay material at depth along this line. The zone bounded by the green section of the cross-section indicates an increased chargeability which correlates with increased concentration of clay material contained within the top 10 m of the sand and gravel units. The vertical feature in the middle of the cross-section is caused by interference from the bridge.

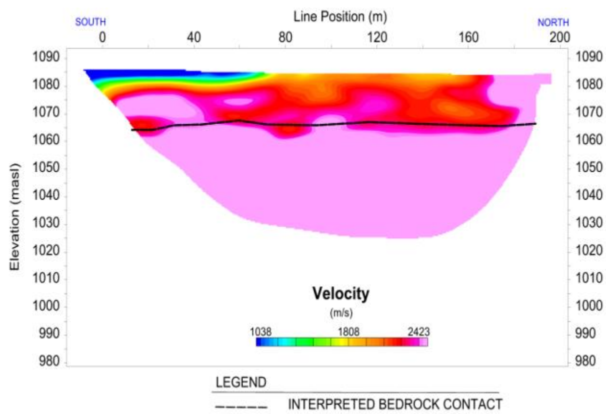
Figure 7 Induced Polarization (IP) results – Line 3



3.3.3 Seismic Refraction Survey

One seismic refraction survey line was surveyed on the west bank of the river. Seismic Line 1 (Figure 8) was collected from south-southwest to north-northeast. The seismic refraction results are presented as a velocity model showing consolidated materials with seismic velocities exceeding 2300 m/s at approximately 15 mbgs as referenced to the bottom of the river.

Figure 8 Seismic Refraction survey results – Line 3



3.4 Geophysical Discussion

The geophysical survey results delineated interpreted granular materials on all ERT lines. On ERT Line 2 the granular material extends to approximately 8 mbgs in proximity to the west borehole, and 20 mbgs in proximity the east borehole. The interpreted top of bedrock has been mapped as deep as approximately 22 mbgs, at line position 465 m on ERT Line 2, and as shallow as 4 mbgs at line position 150 m on ERT Line 4. ERT Line 1 and ERT Line 3 imaged a fairly consistent bedrock depth in the north south direction. The boundaries within mudstone and siltstone are not delineated with the ERT survey as the units are relatively thin and likely have similar resistivity values.

The IP survey was conducted to delineate clay materials. The area bounded by the green section of the cross section, with chargeabilities over 45 m/s shows a slightly higher concentration of clay which is contained within the top 10 m of the sand and gravel material. The vertical feature in the middle of the cross section is consistent to represent interference from the bridge.

Seismic Line 1 shows interpreted bedrock at approximately 15 mbgs with seismic velocities exceeding 2300 m/s. The depth is slightly greater than imaged by the ERT survey. This discrepancy may be explained by a thin layer of low velocity weathered bedrock situated at the overburden/bedrock contact.

The geological interpretation (above) was used to confirm the location and depths of the two boreholes drilled during the subsequent geotechnical investigation.

4 GEOTECHNICAL INVESTIGATION

Following the completion of the geophysical investigation, a geotechnical investigation was undertaken at the selected location of the proposed pipeline crossings to supplement information obtained from the geophysical investigation and desktop geotechnical assessment previously undertaken (WorleyParsons 2008), and, to obtain the information necessary to help identify the following potential areas of concern:

- inadvertent release of drilling fluids during installation of the HDD crossing. These releases have potential to impact fisheries resources;
- highly fractured/jointed bedrock causing loss of drilling fluids;
- circulation and stability issues – swelling clay, high gravel contents, etc;
- high water production in gravels and sands;
- obstructions such as large cobbles and boulders; and
- Site-specific problematic soils.

The following section outlines the scope of work, observations and results of the field geotechnical investigation, the conditions encountered, and a discussion of the findings.

4.1 Scope of the Geotechnical Investigation

The scope of work for the geotechnical investigation included:

- a geotechnical drilling program to:
  - calibrate results from the geophysical investigation, including the geological interpretation and lithology;
  - sample, characterize, and delineate the overburden materials;
  - sample, characterize, and delineate the bedrock; and
  - observe and record groundwater conditions during drilling;
- analysis of the geophysical and geotechnical results to create a profile of the subsurface conditions at the proposed crossing location; and
- establishment of a no-drill zone based on identified areas of concern across the HDD alignment.

4.2 Geotechnical Field Program

The geotechnical field program to evaluate subsurface conditions at the site of the proposed pipeline crossing was undertaken and included drilling two (2) boreholes, one each on the east and west sides of the Red Deer River, Figure 2, to a depth of approximately 31.5 mbgs.

4.3 Subsurface Conditions Encountered

The subsurface soil conditions encountered during the geotechnical drilling program are discussed below. The geological profile at the two borehole locations comprises surficial soils and bedrock. These units are discussed in the following sections.

4.3.1 Surficial Soils

Thickness of the surficial soils observed was found to be approximately 7.7 m and 19.5 m thick at the boring locations on the west and east sides, respectively. The surficial soils observed compose generally of sand, gravel, and cobbles.

The sand and gravel particles were generally well-graded and round to sub-rounded. Cobbles up to 0.2 m were observed near the surface and should be expected within the surficial soil.

On the east-side borehole a dense to very dense sandy gravel layer from approximately 7.0 mbgs to 15.0 mbgs was observed with gravel greater than 50% by weight. This layer is overlain by a medium dense sand/gravel/cobble layer with gravel from approximately 30% to 50% by weight and underlain by dense, predominately fine-grained sand with some gravel (approximately 15% by weight) from 15.0 mbgs to 19.5 mbgs.

On the west-side borehole cobbles, gravel, and sand were observed below 0.3 m of silty topsoil to approximately 1.0 mbgs. Around 1.0 mbgs fewer cobbles were observed. Extending from around 1.0 mbgs to 7.0 mbgs, dense sand and gravel (gravel greater than 50% by weight) was observed which was underlain by a 0.65 m thick dense, predominately fine-grained sand layer.

Overall characteristics of the surficial soils are summarized in Table 1.

Table 1. Summary of the Surficial Soils Characteristics

Description	East Side	West Side
Main Soil Fraction	Sand & Gravel	Sand& Gravel
Other Soil Fraction	Cobbles trace fines	Cobbles trace fines
Grain Size (sand)	Fine to coarse	Fine to coarse
Grain Size (gravel)	Fine to coarse	Fine to coarse
Grain surface	Sub-rounded to rounded	Sub-rounded to rounded
Relative density[1]	Medium dense to dense	Medium dense to dense
SPT N-Value[2]	45 to 87	54 to 80

[1]Description of Relative Density is based on SPT N-Value
[2]SPT N-Value may be haigh due to presence of gravel/cobbles

4.3.2 Bedrock (Paskapoo Formation)

The near surface bedrock found at the crossing location appears to be of the Paskapoo Formation. The Paskapoo Formation underlies the surficial soils and is comprised of Palaeocene age sandstone, mudstone, siltstone, and non-marine conglomerate.

The bedrock displays Rock Quality Designation (RQD) values ranging from 38% to 100% with an overall average RQD of 88%. This corresponds to RQD Classification of “good” quality (CFEM 2006). Joints were observed within the west side at approximately 10.2 m, 15.7 m, 16.0 m,4 24.4 m, 29.2 m, 29.7 m, 30.2 m, 30.6 m, and 30.7 mbgs and within the east side borehole at 27.2 mbgs. Some joints were not healed (i.e. not re-cemented or filled). It is noted that the joints/fractures within the west side borehole from approximately 10.0 m to 22.2 m showed staining, a possible indication of water flow or leaching. No staining was observed in the east side borehole

Table 2 below summarizes the findings for the competent mudstone and siltstone observed during the field program.

Table 2. Summary of the Bedrock Characteristics

Description	Mudstone	Siltstone
Main Soil Fraction	Clay	Silt
Field Strength	Moderate to Strong	Moderate to Strong
Structure	Massive/Uniform	Thinly/Med Bedded
Fracture Density	Moderately to Intensely Fractured	Moderately to Intensely Fractured
Fracture Healing	Not Healed	Not Healed
Fracture Infilling	Surface Oxidation or Staining	Surface Oxidation or Staining
Liquid Limit	41% to 53%	18% to 26%
Swelling Potential[1]	Medium to High	N/A

[1]Approximate, determined from Plasticity Indices (Terzaghi, et.al 1996)

4.4 Geotechnical Discussion

The objective of the geotechnical investigation was to sample and characterise subsurface materials from two (2) boreholes located within the proposed pipeline crossing ROW. The results of the geophysical investigation were then calibrated to provide an interpretation of geological conditions along the length of crossing ROW. Subsequently potential areas of concern that could adversely impact the installation of the new pipeline crossings were identified.

4.4.1 Geological Profile

Based on the findings of the geotechnical/geophysical investigations, a generalized geological profile at the proposed crossing site is presented below in Table 3.

Based on the top of bedrock elevation observed at the borehole locations and results from the geophysical survey, it appears that the bedrock slightly dips towards the east within the proposed crossing location.

Table 3. Generalized Profile at the Proposed Crossing

Approx. Elevation masl (West- East)[1]	Description
1088.9 – 1081.2	Surficial Soils – sand, gravel and cobbles: varies from medium dense to very dense; sand particle size varies from fine-grained to coarse-grained; gravel content varies from approximately 15% to greater than 65%; cobbles observed near surfaces and should be anticipated within layer; potentially high water production (roughly estimated at around 400 L/min in some cases).
1081.2 – 1068.4	Bedrock (Paskapoo Formation) - Palaeocene age sandstone, mudstone, siltstone; moderately to intensely fractured; potential water migration through fractures and joints (oxidization observed within fractures); medium to high swelling potential (medium to high plasticity inorganic clays observed).
1057.4 – 1056.3	Maximum depth drilled

[1]Elevation indicate approximate top of unit formation at borehole

5 POTENTIAL ISSUES DURING HDD INSTALLATION

Based on the geotechnical laboratory results and engineering judgement, Table 4 outlines the potential problems for a HDD pipeline installation for the soils encountered within the area.

The observed surficial soils and bedrock could potentially be associated with inadvertent releases of drilling fluid, losses of drilling fluids, circulation and stability issues, high water production, obstructions causing reduced drilling rates, etc. Thus, the soil conditions noted above could possibly cause some or substantial difficulties and should be planned for appropriately to reduce the risk of impeding the progress of the HDD pipe installations and/or increasing the overall cost of the installation. Furthermore, the surficial soils are generally granular materials and can pose risk during the HDD installation in particular at the exit point.

Based on the above information, drilling was recommended to commence on the east side of the river, where the surficial materials extend deepest. Prior to commencing work it is also recommended that an approximately 100 m of large diameter casing be installed (for each crossing) from surface to bedrock depth (approx. 22 mbgs), to overcome issues drilling within the surficial materials. Further geotechnical investigation was also recommended to be undertaken on the west side of the river to confirm the thickness of surficial materials (and bedrock depth) at the exit area and determine if additional casing is also required.

The additional field program was completed October 22-23, 2009. During the program five shallow boreholes were advanced to an average depth of 5.6 mbgs. The results concluded that that the bedrock interface was generally shallower and less variable than anticipated by ERT Line 2. This suggests that the drill profile will exist at a confirmed depth of about 4 to 5 m, which is about the same depth of bedrock at the exit point.

Table 4. Encountered Soil Conditions and Suitability for HDD Pipeline Installation

Condition	Generally Suitable	Some Difficulties	Substantial Difficulties
Encountered Surficial Soils			
Sand & gravel with potentially 10% cobbles			x
Potentially dense (and occasional very dense) sandy gravel (50% to 70% gravel)			x
Medium dense to dense gravelly sandy (30% to 50% gravel)		x	
Medium dense to dense sand above the water table (< 30% gravel)	x		
Medium dense to dense sand below the water table (< 30% gravel)		x	
Potential high water production (estimated around 200 L/min to around 400 L/min in some cases)			x
Bedrock Conditions Encountered:			
Moderately to intensely fractured			X[1]
Moderately to highly expansive mudstone		x	
Cemented sandstone and siltstone	x		

[1]Depending on whether or not hydraulically connected

The exit side may still require some surface casing; however, exiting at a deeper elevation would likely have required an exit side drill rig.

5.1 River Bank Stability

Results from the ERT and seismic surveys indicated that unconsolidated materials were present at the River banks. The eastern bank of the River has been cut by erosion to near vertical to an approximate height of three (3) to four (4) metres. In the long-term, bank instability can occur from the continuing river scour or erosion processes.

Further, there is a potential for slope failure at the project location should the subsurface conditions be disturbed by drilling operations or if undesirable increase in pore water pressure occurs. Steps should be taken to avoid increasing pore pressure in the river bank slopes and the recommended set-back distances should be maintained.

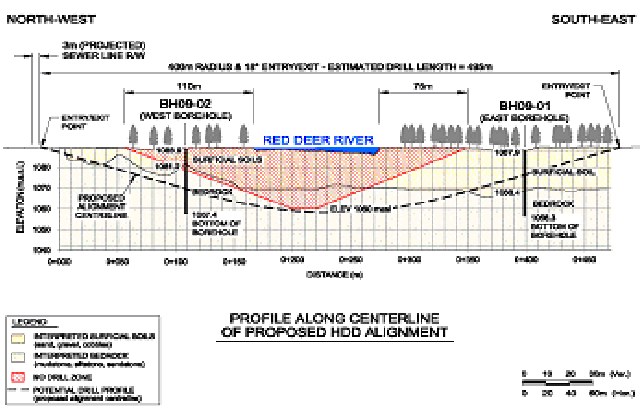
5.2 No Drill Zone

A “no drill zone” at the selected crossing location is presented in Figure 9. The “no drill zone” was established based on the following:

- a crossing design life of 100 years;
- a potential for localised bank failures occurring during the installation of the HDD facility and pipeline operation;
- undue risk of inadvertent drilling fluid releases during the installation of an HDD crossing, potentially impacting the aquatic environment and fisheries resources; and
- Potential risk of pipeline exposure due to natural channel (bed) scour and/or combination of natural bed scour and lateral stream migration (river bank erosion) during the design life of the crossing as discussed in Section 4.5.

The “no drill zone” is therefore defined by a polygonal area extending a specified distance from the River banks to a specified base elevation. The specified distances and elevations are provided in Figure 9.

Figure 9 No-Drill zone



6 CONCLUSIONS

The Town of Sundre (the Town), located approximately 100 km north west of Calgary, AB, was planning to service existing residential, commercial and industrial developments on the east side of the Red Deer River. In order to service the developments, new water/wastewater infrastructure will be required to cross the Red Deer River to tie-in the developments with the existing Town system. The crossing will be sized to accommodate future growth to both the Town and Mountainview County (MC) as set out in the agreed upon annexation agreement.

The preferred option is to install two new pipelines, one for potable water and one for wastewater, below the Red Deer River in a new pipeline easement Right-of-Way (ROW) using Horizontal Directional Drilling (HDD) technology.

A detailed study including fisheries, hydrotechnical, geotechnical and geophysical assessments was conducted to determine the best feasible location for the pipeline crossing. The outcome of the geotechnical and the geophysical assessments are summarized as follows:

- the most feasible location (optimal) for the pipeline crossing was determined to be Option 2;
- a No-Drill zone for the pipeline was provided which captured the a crossing design period of 100 years,
- Combining a geophysical investigation and geotechnical intrusive investigation provided a comprehensive and reliable approach to establish the feasible crossing options.
- Continuous communications between the multidisciplinary design team, the Owner and the eventual construction contractor at the various stages of the works was really vital for the success of the project.

7 ACKNOWLEDGEMENT

The authors would like to thank the City of Sundre for their cooperation and support throughout the works to complete this project.

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