Labrador Coast

Newfoundland Island Coast

Feasibility Study of HDD FOR THE Strait of Belle Isle

FINAL REPORT

December 10, 2010

Report No: H336344-RPT-CA01-2501

Rev 0

prepared by

HATCH™

nalcor energy

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REGISTERED PROFESSIONAL ENGINEER
M.E. McFarlane
Dec 22, 2010
PROVINCE OF ONTARIO

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EXECUTIVE SUMMARY

Horizontal directional drilling (HDD) construction methods are deemed technically feasible for constructing the shore crossings, as shown in Figures 6-1, 6-2, and 6-3, required to complete the SOBI subsea cable installations. The required installation lengths are considered to be well within the current achievable installation lengths within the HDD industry for the Labrador side (required installation length of 1,200 metres). The installation lengths are within the zone of limited application for the Island of Newfoundland side of the SOBI (required installation length of 2,700 metres) for the required ocean floor exit elevation of -80 metres. Installation lengths greater than 3,000 metres are not considered feasible at this time, as ocean installations greater than 3,000 metres have not yet been attempted within the HDD industry. These installation lengths and respective conclusions are contingent upon confirmation and consistency of the geotechnical assumptions and sea floor topography used in this report to assess the overall HDD feasibility.

Risk assessments were completed for each crossing location. While several risks were designated as high risks, appropriate risk mitigation measures, common to previously completed shore crossings, have been identified that lower these risks to a medium risk designation. It should be noted that the risk registers (provided in Appendix A – Risk Registers), used to track the geotechnical and installation risks, are living documents and should be updated continuously during design and construction. Of the risks evaluated, no fatal deterrents have been identified. Installation risks are greater for the Newfoundland Island side of the SOBI due to the required installation length, in comparison to the Labrador side. Risks for Forteau Pointe and Pointe Amour (Labrador coast) are similar due to the similar bedrock materials and installation length. Similarly, the construction risks for Savage Cove and Shoal Cove on the Island side are also similar. Risks for Yankee Point are higher due to the increased installation length for this entry location in comparison to the other Island sites.

Forteau Pointe appears to provide a shorter crossing length over Pointe Amour. In addition, Forteau Pointe is more isolated from the public in comparison to Pointe Amour. On the Island side, Shoal Cove is located closer to a water depth of 80 metres, in comparison with required installation lengths at Savage Cove and Yankee Point.

The required casing pipe diameter, and subsequent bore diameter, impacts the risk levels for this project. Larger casing pipes require larger reamed bore diameters to permit installation within the bedrock materials. Aside from an increased construction cost due to the large casing pipe and requirements for multiple reaming passes, a larger bore diameter may expose a greater quantity of natural fractures and joints within the bedrock materials increasing risks associated with ravelling, bore stability and drilling fluid loss.

Evaluated (for estimated construction costs) casing diameters were 350 mm (14 inch) and 500 mm (20 inch).

The estimated construction costs without contingencies for single (individual) installations for 350 mm and 500 mm alternatives for each coast are:

- Island Coast (Shoal Cove) – 2,700 m length
  - 350 mm -
  - 500 mm -

- Labrador Coast (Forteau Point) – 1,200 m length
  - 350 mm -
  - 500 mm -

- Shoal Cove or Forteau Point – 2,000 m length
  - 350 mm -
  - 500 mm -

The estimated one-time cost without contingencies for mobilization, demobilization, contractor submittals, and equipment procurement is This amount is representative of the total upfront costs for both sides of the SOBI.

These estimated costs are exclusive of engineering/design, construction management by Owner and Owner's Engineer, additional required geotechnical investigations, further environmental activities, contingencies and Owner's costs.

The recommended activities which are required to advance to the next phase of the HDD installations include:

- Formation of a Project Team (Nalcor Energy and Engineer) and preparation of a Project Implementation Plan.
- HDD test pilot bore investigations on both sides of the SOBI.
- Additional geotechnical investigations and testing.
- Any further environmental studies/approvals.
- Final optimization/definition, prequalification of tenderers, final design and tendering.

1. Introduction

1.1 General

This Feasibility Study has been completed by Hatch as part of the Nalcor Energy – Lower Churchill Project (NE-LCP) to evaluate the technical feasibility of using horizontal directional drilling (HDD) construction methods to install three (3) individual casing pipes to serve as individual cable conduits on both sides of the Strait of Belle Isle (SOBI). HDD is only evaluated for the shore crossings, as the required installation length to cross the entire SOBI far exceeds the capabilities of this construction method. Evaluated casing diameters included 350 mm, 500 mm (base case), and 750 mm. This feasibility report is based on identifying and managing installation and site specific risks, as shore crossing HDD projects are inherently more complex and challenging than traditional land-to-land based HDD installations where access is readily available on both sides of the alignment. Potential HDD sites on the Newfoundland Island side of the SOBI included Yankee Point, Savage Cove, and Shoal Cove. Potential HDD sites on the Labrador side of the SOBI assessed were Forteau Pointe and Pointe Amour.

The feasibility study is dependent on assessing the ability of HDD to install multiple casing pipes to an elevation of -80 metres on the ocean floor. The alternative construction sites and all data/reports used in this evaluation were provided by Nalcor Energy.

1.2 Scope of Work Summary

The objectives of the HDD study are:

- Assess current HDD industry databases to assess limitations;
- Assess feasibility of completing long HDD installations;
- Identify site and HDD installation specific risks;
- Preliminary determination of the suitability of the identified shoreline site locations;
- Develop an installation strategy;
- Recommend HDD equipment and casing diameters;
- Generate bore profiles;
- Develop construction cost estimates;
- Prepare a construction schedule;
- Determine overall feasibility.

The scope of work set forth by Hatch to fulfil the objectives of the study is summarized as follows:

- Review existing data, information and documents;
- Regular meetings/teleconferences with Nalcor Energy;
- Conduct a site visit on each side of the SOBI;

- Identify site-specific constraints and construction risks;
- Contact HDD contractors to update their industry databases and provide the updated information to Hatch;
- Develop a project Risk Register;
- Hold a Risk Workshop in St. John's with the NE-LCP and Hatch team;
- Assessment of shoreline design and construction challenges;
- Determine appropriate casing pipe diameters;
- Prepare conceptual HDD bore profiles;
- Develop appropriate construction cost estimates;
- Perform a Risk Analysis of a cost estimate to assess sensitivity of assumptions;
- Develop a construction schedule;
- Provide commentary on recommended next steps and future work;
- Draft, and final report.

1.3 Summary of Report Sections

An Executive Summary is provided first and foremost in the report providing the key conclusions and findings from the study.

Sections 2 and 3 of this report include a brief discussion on the HDD construction method and design and construction considerations. These discussions provide background information for the reader to develop an understanding of the HDD installation process and activities required to facilitate an HDD installation. Conceptual alignments are provided for each of the alternative construction sites to determine the approximate installation length at each crossing location.

Due to the required installation length and depth, a thorough review of the State of the HDD industry was completed and is detailed in Section 4. This review included contacting several large HDD contractors and requesting project portfolios of completed projects. Provided data was used to develop a chart of completed projects and determine the commonly achieved HDD installation length and diameter.

The anticipated geotechnical conditions are summarized in Section 5.

The conceptual bore profiles are discussed in Section 6.

Section 7 comments on subsea completion methods and cable installation.

Risks and mitigation discussions are provided in Section 8. These discussions characterize a particular risk and impact to an individual installation. Risk mitigation measures are also provided to lower the identified risk to its lowest practical level. It is with these mitigated risks that the overall feasibility is evaluated.

Opinions of probable construction costs are provided in Section 9 for 350 mm and 500 mm diameter casing pipes for installation lengths of 1,200 metres, 2,000 metres and 2,700 metres.

HDD construction schedules are provided in Section 10.

Recommendations are provided in Section 11 for next steps/future work in the next phases of this project.

2. Horizontal Directional Drilling Process

Horizontal directional drilling is a trenchless construction method commonly used to install pipelines beneath rivers, wetlands, shipping channels, railroads, highways, and runways. The method is also widely used to complete shore crossings or approaches of large bodies of water, such as the SOBI.

The installation process is comprised of three primary stages including pilot bore drilling, reaming/hole opening stage, and casing pipe installation, as shown in Figure 2-1. The following discussions provide a general description of the activities associated with each stage of the installation process.

2.1 Pilot Bore Drilling Process

The first stage of a large HDD installation consists of advancing a tri-cone rotary drill bit along a pre-determined path, from the drill rig entry location to the drill rig exit location. Typical pilot bore diameters range from 200 to 300 mm (8 to 12 inches), depending on the size of the downhole tooling and the anticipated geotechnical materials.

In soil environments, steering of the drill bit during the pilot bore stage is achieved using the drill rig thrust and torque capabilities and the down-hole drilling assembly. An asymmetrical bent sub positioned back from the drill bit is used to develop the steering reaction by generating a steering bias. A steering correction can be induced by orienting the drill bit in the desired direction and thrusting it forward without any rotation of the drill pipe. Here, the advancement of the drill pipe without rotation generates passive resistance within the soil on the leading edge of the drill bit due to presence of a bent sub causing a change in drilling direction. The drill bit is advanced with rotation of the drill pipe when a steering correction is not required.

In bedrock, the tri-cone rotary drill bit is attached to the end of a positive displacement mud motor. This mud motor consists of a spiral-shaped stator containing a sinusoidal-shaped rotor that is driven solely through the pumping of large volumes (flow rates) of drilling fluids (i.e. 0.025 to 0.05 m^3/s [400 to 800 gallons per minute]) through the drill pipe and mud motor. The stator converts the hydraulic energy of the pumped drilling fluids to mechanical energy and rotates the drill bit. A small adjustable bend (in the order of 1.5 to 2.0 degrees) is located between the stator of the mud motor and the drill bit to develop the steering reaction (Figure 2-2). To induce a steering correction the drill bit is oriented in the preferred direction, drilling fluid is pumped through the drill pipe and stator, and the drill rig is used to thrust the drill bit forward without rotation of the drill pipe. The steering action develops as the shoulder of the bend in front of the stator is forced against the wall of the previously drilled bore to generate a steering bias. To maintain a straight alignment, drilling fluids are pumped to rotate the stator and drill bit while the drill rig rotates the drill pipe and thrusts forward.

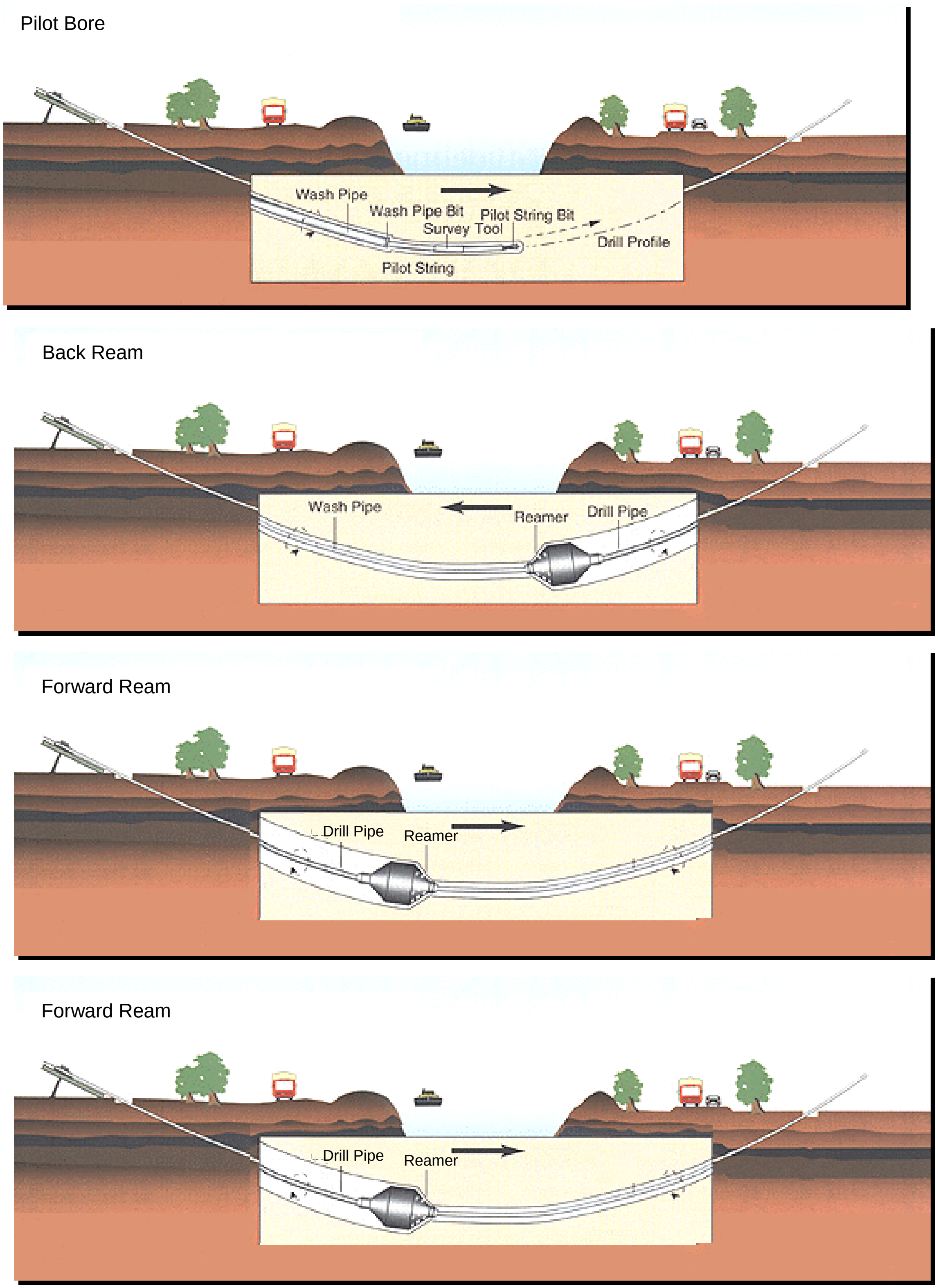


Figure 2-1: Horizontal Directional Drilling Installation Process (Courtesy of DCCA)

2.1.1 Tracking of the Pilot Bore Drilling Process

A survey tool (probe) incorporated into the bottom hole drilling assembly is used to track the location of the drill bit. In soil installations, this survey tool is located as close as possible to the drill bit. However, in bedrock installations, the requirement of a mud motor for rotating the drill bit pushes the survey tool approximately 8 to 12 metres behind the drill bit. A non-magnetic (stainless steel) pipe section is used to house the survey tool and eliminate potential interference from the presence of the drill bit, mud motor and drill pipe. A wireline placed within the interior of the drill pipe connects the survey tool to the drill rig operator control cabin. A splice is required every time a drill pipe is added to the drill string to enable continuous communication with the survey probe.

Figure 2-2: Photograph of Down-Hole Equipment Used for Pilot Bore Drilling

Traditional tracking of the horizontal and vertical positions of the drilling equipment consists of using the down-hole survey probe that utilizes the Earth's gravitational and magnetic fields to determine changes in inclination and azimuth upon completion of each drill pipe. These changes, along with the length of the drill pipe, are used to calculate the position of the survey probe based on where it was located at the end of drilling the previous drill pipe. The disadvantage of this method is that small inaccuracies in inclination and azimuth measurements can be compounded as the drilled length increases. In addition, this type of tooling is subject to significant error by any source of interference that locally distorts the Earth's gravitational and magnetic fields.

Where interference is present, the use of surface coils is highly recommended for tracking the true location of the downhole equipment. Identification of all sources of interference is one of the key actions identified to minimize risks associated with improper tracking of drilling equipment. To overcome the potential impacts from sources of interference, traditional survey practices can be augmented with surface wire coils placed on the ground surface. Here, an electrical current can be induced through the coil to generate a known magnetic field that the downhole probe uses to determine its location relative to the surveyed coil. In this manner, each survey is based on its own relative location to the surface wire coil and is not based on the previous location of the survey tool. Hence, the accuracy of the survey location is greatly improved. “Trutracker” and “Paratrack” proprietary survey systems are common types of surface coil systems used in HDD installations.

Recent advances in tracking system development have led to the use of a gyroscopic survey tool. This tool uses an inertial measurement unit to calculate the position of the survey probe. Changes in azimuth and inclination are measured through the use of fiber-optic gyroscopes. The accuracy of this tool eliminates the need for the use of a surface coil, although a coil can still be used in the early stages of the drilling process as a means of verifying the accuracy of the guidance tooling. Gyroscopic survey tools are not susceptible to interference as observed with standard downhole wireline tooling, as they do not use the Earth’s gravitational or magnetic fields.

2.1.2 Drilling Fluids

Drilling fluids, consisting of a mixture of water, bentonite and/or polymers are continuously pumped through the drill pipe and drill bit/down-hole assembly and into the bore during all stages of the installation process. These fluids are primarily used to:

- Stabilize the bore and prevent collapse or ravelling of surrounding soil/bedrock materials. Stabilization of the bore is provided from the combination of a bentonite filter cake along the bore and soil/bedrock interface and a positive fluid pressure derived from the presence of the column of drilling fluid within a bore.
- Remove soil/bedrock cuttings from the bore. As the bore is progressed, the excavated material combines with the injected drilling fluid to create slurry that flows back to the entry and/or exit locations to be processed. A volume of cuttings at least equal to the volume of the product pipe must be removed to facilitate the product pipe installation process.
- Cool and lubricate cutting tools, drill pipe string, and product pipe during its installation.
- Rotate the drill bit (in bedrock installations). In bedrock installations, the hydraulic energy of the pressurized drilling fluid is converted into mechanical energy with the use of a positive displacement mud motor, which in turn rotates the drill bit.

A fresh water source is required as the make-up water for the drilling fluids to enable development of the appropriate drilling fluid properties. Ocean water (saltwater) is not ideal for use as make-up water, due to the presence of chloride. At concentrations greater than approximately 500 ppm, the chloride interferes with the ability to properly mix the bentonite resulting in flocculation of bentonite particles. It also adversely affects the ability to develop/maintain bore stability and does not provide the same cuttings-carrying capacity. If the makeup water does contain a high concentration of chloride, organic polymers may be required to overcome the deficiencies with bentonite based drilling fluids. Dilution with fresh water can also be effective when saltwater contamination occurs, depending upon the concentration of salt within the drilling fluid.

As the pumped drilling fluids exit the down-hole tooling at the bottom of the drill pipe, the fluids are mixed with the soil and/or rock cuttings generated by the down-hole tooling to create "flowable" slurry. This slurry flows under an induced fluid pressure gradient generated by the injection of the drilling fluids into the bore toward either the entry or exit location (Figure 2-3). Controlling and maintaining fluid flow within the bore is critical to the success of an HDD installation. Installation risks significantly increase when circulation cannot be maintained within the HDD bore. Drilling fluid flow follows a path of least resistance.

Figure 2-3: Photograph of Typical Drilling Fluid Returns at Drill Rig Location

2.1.3 Spoil Separation

A separation plant is used to process the returning slurry that flows towards the drill rig entry or exit locations represented in Figure 2-4. This plant removes the soil and rock cuttings from the drilling fluid slurry to reclaim the liquid portion for re-use. The separated soil and rock cuttings are referred to as spoil (Figure 2-5). Recycling of the drilling fluids is very important in large diameter installations (especially in bedrock installations) where large quantities of drilling fluids are required during the installation. The equipment incorporated into the separation plant must be matched to the anticipated geotechnical materials and production rates to avoid delays associated with the drilling process. Equipment can include scalper vibratory screens (Figure 2-6), sand hydrocyclones (Figure 2-7), silt hydrocyclones (Figure 2-8) and centrifuge unit(s) (Figure 2-9). The purpose of the separation plant is to remove the cuttings from the slurry by separating the coarse fragments first, then sand-sized particles, followed by silt-sized particles and clay-sized particles. The cleaned fluid is then conditioned by adding additional bentonite and polymers for re-use in the drilling process.

Separated spoils from a HDD project tend to be disposed of at a landfill or local quarry, depending on permitting requirements. Small portions of cement have been added to separated spoil to solidify the material and remove the liquid component of the material. Similarly, disposal of thick drilling fluids during the drilling process and excess drilling fluids upon completion of drilling operations can be disposed of at a landfill or local quarry. Depending on permitting requirements, it may be possible to dispose of excess drilling fluids on agricultural fields, as the natural bentonite in the drilling fluid mixture helps retain moisture. Contract documents will need to address requirements for disposal of spoil and drilling fluids.

Figure 2-4: Photograph of Typical Separation Plant used to Process Drilling Fluid Returns

Figure 2-5: Photograph of Typical Spoil Piles after Processing by Separation Plant

Figure 2-6: Coarse Screen Scalper - Used for Separating Coarse-Size Cuttings

Figure 2-7: Sand Hydrocyclones - Used for Separating Sand-Size Cuttings

Figure 2-8: Silt Hydrocyclones - Used for Separating Silt-Size Cuttings

Figure 2-9: Centrifuge Unit - Used for Separating Clay-Size Cuttings

2.2 Reaming/Hole Opening Process

The second stage of the installation process consists of enlarging the pilot bore to a diameter that will accommodate the product pipe. The term "reamer" is used to describe the cutting tools that are used to enlarge the bore in soil installations while the term "hole opener" is used to describe the cutting tools that are used to bedrock installations (Figure 2-10). Depending upon the diameter of the product pipe, multiple passes with reamers/hole openers of increasing diameter may be required to incrementally enlarge the pilot bore. Reaming is traditionally completed from the exit location back towards the drill rig. This reaming direction is referred to as a "back ream." However, where access is limited at the exit location, as observed for a shoreline crossing, the reaming/hole opening process may be initiated at the drill rig location and advanced towards the exit location. This reaming direction is commonly referred to as a "forward ream".

Figure 2-10: Photographs of Typical Hole Openers used to Excavate Bedrock Materials

Upon completion of the reaming pass(es), the condition of the HDD bore can be assessed by completing what is known as a “swab pass” through the bore. This pass consists of pushing or pulling a slightly smaller diameter barrel or ball reamer through the fully reamed bore from start to finish. As this pass is conducted, the drill rig torque and thrust/pullback force are monitored as the reamer negotiates the bore. The reduced diameter of the swab pass is required to allow a portion of the drilling fluids to flow around the bore. If the swab pass is completed with little drill rig effort, the bore is typically deemed conditioned properly to accept the product pipe. However, if areas of high torque or thrust/pullback force are observed, the bore may not be fully ready for the product pipe stage of the installation process. Areas of high torque and/or thrust/pullback force can be re-worked with an additional reaming pass(es). Once this step is completed, a subsequent swab pass is completed to ensure the areas of high drill rig effort have been reduced or eliminated. This step is repeated until a successful swab pass has been completed.

2.3 Casing/Liner Pipe Installation Process

The final step in the installation process consists of installing the fully fabricated and tested product pipe (also referred to as a carrier, casing or liner pipe depending on its intended function) in the enlarged and fully conditioned bore. Traditional HDD installations, where access is available to both the HDD entry and exit locations, consist of pulling the product pipe into the bore from the exit location towards the drill rig (Figure 2-11). To facilitate the installation process, a pulling head is welded to the leading end of the product pipe. A swivel is used to connect the pulling head to the end of the drill pipe. This swivel isolates the product pipe from the required rotation of the drill pipe and reamer assembly while concurrently allowing transfer of the pull load from the drill rig to the product pipe. The use of a reamer in front of the product pipe allows for further mixing/cleaning of the drill cuttings and removal of debris that may have accumulated within the bore.

Figure 2-11: Photograph of Steel Pipeline Insertion with Pullback Towards Drill Rig

The product pipe is supported at the exit location and along the pipe staging area with a combination of roller stands and/or pipe handling equipment, including cranes, side booms, and excavators). This equipment is used to guide the product pipe into the bore at the proper orientation to prevent excessive bending as the product pipe is installed.

Water is commonly added to the casing pipe to provide buoyancy control as the pipe is installed. To prevent high surface loads, the water is commonly added only to the portion of the pipe within the HDD bore. The use of buoyancy control decreases the installation loads required to install the product pipe by achieving a "more" neutrally buoyant product pipe than if the product pipe were installed empty.

For an ocean shore crossing, where routine access to the exit location is limited or non-existent, divers are typically used to connect the product pipe to the drill string for pullback operations. Alternatively, in bedrock installations, it is possible to push the product pipe into the bore from the HDD entry location towards the bore exit location. Three alternative installation options are possible for installing the product pipe towards the exit.

1. **HDD Rig Push-In Method**: The first method involves the use of the HDD rig, where drill pipes are inserted into the product pipe against the closed end of the leading pipe or pushing head. With this method, the product pipe is fabricated one joint at a time as it is installed into the bore (Figure 2-12). This installation methodology requires significant time to complete the product pipe insertion process. The advantage of this method is that a jetting sub can be incorporated into the pushing head to allow injection of drilling fluids into the bore as the product pipe is installed to clear cuttings and/or debris within the bore.

Figure 2-12: Photograph of Drilling Rig Pushing in HDPE Casing Pipe

2. **Excavator Push-In Method**: The second method involves the use of an excavator and a sling to push in the completely fabricated product pipe into the fully conditioned bore (Figure 2-13). The process involves extending the excavator arm and pulling the product pipe towards the bore. Care must be taken to ensure the product pipe is not damaged as it is inserted into the bore. This method has been used successfully to complete shore crossing HDD installations on previous projects and is commonly combined with the HDD Rig Push-In Method to minimize the product pipe insertion duration. On a project in Australia, consisting of two 1,600-metre long 400-mm diameter HDPE pipelines spaced 10 metres apart in bedrock, an excavator and sling were used to install approximately 1,450 metres of the total length. The remaining portion of the twin installations was completed using the HDD Rig Push-In Method.

Figure 2-13: Photograph of Excavator and Sling Installing Casing Pipe

3. **Pipe Thruster Push-In Method**: The third installation method involves the use of a pipe thruster to push the completely fabricated product pipe into the fully conditioned bore (Figure 2-14). These units are fairly new to the HDD industry but are capable of providing significant forces to install the product pipe. Operation of a thrust unit consists of extending hydraulic rams approximately 10 metres away from the HDD entry location, clamping down on the product pipe, and pulling the product pipe towards the bore (Figure 2-15).

   Thrust units can accommodate casing pipe diameters between 350 mm and 1,200 mm, by changing the clamping inserts. They are also able to pull out the casing pipe should debris prevent forward progress during casing pipe insertion. Removal of the casing would then allow re-positioning of the drill rig onto the bore and re-running a hole opener through the previously completed bore to re-condition it for accepting the casing pipe. Thrusters are capable of applying pushing forces up to 450 tonnes (1,000,000 lbs). Thrust units are more suitable for pushing a steel pipe into a bore in comparison to more flexible high density polyethylene pipe materials. At least one HDD Contractor in North America (Michels Corporation) has recently purchased a thrust unit for assistance with larger diameter and longer HDD installations. These thrust units are available for purchase or rent by any HDD Contractor from equipment suppliers.

Figure 2-14: Photograph of Thruster Installing Casing Pipe

Figure 2-15: Schematic of a Thruster Unit Installing Casing Pipe (Courtesy of Herrenknecht AG)

3. HDD Design and Construction Considerations

3.1 Required Entry, Exit and Pipe Staging Areas

Typically staging areas of approximately 50 to 100 metres long by 30 to 60 metres wide are required at the drill rig site for a large HDD installation. This area is required to stage equipment necessary for the installation, which includes the drill rig, stacks of drill pipe, operator control cabin, tooling trailers, crane or excavator, separation plant, mud tanks, mud pumps, storage tanks, office trailer, and support trailers (Figure 3-1). The required HDD rig staging area is dependent upon the diameter and length of the overall installation, as larger staging areas are required for larger drilling equipment.

Figure 3-1: Typical Large Diameter HDD Entry Location Setup

Multiple HDD installations at a single site require a slightly increased staging area width. For the three proposed casing pipes associated with the SOBI shoreline crossings, a staging area width of approximately 70 to 80 metres would be sufficient to support all drilling operations. It is assumed the bores are closely spaced, i.e. 10 m apart. Due to the remoteness of the project sites sufficient staging area for stockpiling consumable equipment and materials and for storage of additional spares is provided as required. It should be noted that the HDD Contractor will likely try to centralize its supporting equipment (mud pumps, separation plant, etc.) to avoid redundant tear-downs and setups when mobilizing to the second and third installations. Centralizing equipment also decreases the need to tear-down winter shelter when equipment is moved to the second and third installations. A typical HDD site layout is shown in Figure 3-2.

FIGURE 3-2: TYPICAL HDD SITE LAYOUT FOR A SINGLE BORE

For a traditional land-based HDD installation, a typical exit location staging area of 50 metres long by 25 metres wide is required to accommodate the product pipe installation equipment, depending on the size of the equipment required to install the product pipe. This staging area is not required for shoreline crossings where access to the exit location is limited and is provided solely for future consideration to other portions of the overall project that may require a HDD installation.

In addition to these staging areas, a staging area is also required for the fabrication of the entire casing pipe string prior to installation. A typical casing pipe staging area requires a width of five (5) to ten (10) metres by a length equal to the total installation length. Greater staging area widths are required for multiple pipe strings, where the pipe strings are fabricated at once.

For the Newfoundland Island side of the SOBI, the potential shoreline crossings sites of Yankee Point, Savage Cove and Shoal Cove all provide sufficient HDD entry location staging areas to support drilling operations. However, staging areas for fabricating the product pipes will require special consideration to avoid disrupting existing roads. This may include partially fabricating the pipe strings with sufficient length to allow a stoppage in the installation process to complete one or two welds of additional pipe strings. It should be noted, however, that stopping to complete a weld will increase the risks associated with the product pipe insertion because of the increased potential for drilling fluid slurry coagulation, gel strength development, bore collapse, for example.

For the Labrador side of the SOBI, Forteau Pointe and Pointe Amour also have sufficient HDD entry location staging areas to support drilling operations. In addition, both of these locations provide sufficient staging areas to fabricate the product pipe strings in their entirety.

3.2 Line and Grade Accuracy of Guidance Systems

As stated earlier in this report, HDD equipment is steered in the vertical and horizontal planes to follow an intended design path. This is one of the main advantages of a HDD installation in comparison to inclined boring where steering is not possible. To enable steering along a pre-determined path, tracking of the down-hole equipment is required. All tracking systems have an inherent inaccuracy associated with locating the down-hole equipment at any location along an alignment, although some are better than others.

Line and grade accuracy for a HDD installation is highly dependent upon the type of tracking system used and the experience of the steering personnel monitoring the tracking system(s). Down-hole wireline survey probes that rely on the Earth's gravitational and magnetic fields are very susceptible to interference. Completing a HDD installation solely with a down-hole wireline probe is not recommended, as any error in measuring the inclination and azimuth of the survey probe is compounded as the equipment location is calculated based on its previous location.

Passive and active interferences may increase inaccuracies associated with tracking the down-hole equipment. Passive interference can be caused by anything that blocks, absorbs, or distorts a magnetic field. Active interference can be caused by anything that emits a magnetic field or signal. To avoid impacts to tracking systems, sources of interference need to be properly identified. When known, a surface coil (such as that used in the Trutracker or Paratrack guidance system) can be used to overcome the interference with less impact to line and grade inaccuracies. Because gyroscopic survey guidance systems do not rely on measuring the Earth's gravitational and magnetic fields, they are not susceptible to passive and active interference. However, these tools have been subject to inaccuracies arising from vibrations during bedrock drilling and will require frequent calibrations to ensure accurate tracking.

Trutracker and Paratrack surface systems have reported accuracies of two percent of the depth. Inclination accuracy, a driving factor in determining the depth of the tooling, is reportedly plus or minus 0.1 degrees for both systems. Trutracker systems are capable of monitoring tool locations to depths of 60 metres, although some HDD contractors have used this system to depths of 90 metres. Paratrack systems have the capability to monitor tool locations to depths of up to 300 metres.

Gyroscopic survey guidance systems are not subject to the same limitations as the Trutracker and Paratrack systems. Their depth capability is virtually unlimited, with an accuracy of plus or minus 0.02 degrees for inclination and plus or minus 0.04 degrees for azimuth.

For the SOBI ocean shore crossings, the use of a gyro guidance system is highly recommended due to the presence of magnetic anomalies on the Labrador side and the required installation depths of approximately 90 to 100 metres below ground surface (accounting for the increased depth associated with starting at an elevation greater than sea level).

3.3 HDD Bore Geometry and Alignment Considerations

3.3.1 HDD Entry and Exit Angles

Horizontal directional drilling rigs have the capability of entering the ground with an entry angle ranging between 8 and 16 degrees from horizontal. While greater entry angles have been used on previous projects, steeper angles require modifications to the drill rig platform and pose an increased safety risk for personnel working on the drill rig due to the slippery conditions when coated in bentonite. A shallower entry angle below 8 degrees would require greater setback distances from shore to achieve sufficient depth of cover to prevent hydrofracture or loss of drilling fluids (hydrofracture and loss of drilling fluid returns are discussed in greater detail in Section 8.2.1 of this Report).

HDD exit angles vary depending upon the geotechnical materials, site topography and product pipe material and diameter. Typical exit angles are on the order of 10 to 15 degrees from horizontal, although steeper exit angles can be used.

For the SOBI shore crossings, selection of the appropriate entry and exit angles is highly dependent upon the topography of the land and ocean floor, the set back distance from the shoreline, the geotechnical materials, and a bore geometry that maximizes a downward trajectory.

3.3.2 Radius of Curvature

The minimum or smallest radius of curvature required for vertical and/or horizontal curves must consider several factors. These factors include the diameter of the drill pipe/rods, the required drilling down-hole tooling, the product pipe material and diameter, and the anticipated geotechnical materials that will be encountered along the bore.

HDD installations completed in soils are typically completed with smaller (sharper) minimum curve radii than installations in bedrock. The use of a mud motor for bedrock installations requires a minimum curve radius of at least 400 metres. For steel pipe materials, the minimum allowable curve radius in feet must be greater than 100 times the outer diameter of the product pipe in inches (for example, a 500 mm or 20 inch casing pipe would require a minimum allowable curve radius of 20 x 100 = 2,000 feet or 610 metres). For a 500 mm pipe installation, a minimum allowable curve design radius greater than the allowable radius of 610 metres (i.e. a design minimum allowable curve radius of 700 metres) would provide an increased flexibility in maintaining design line and grade, as it allows the HDD contractor to drill at a sharper radius between the minimum allowable radius of 610 metres for the casing pipe and the specified design radius to maintain line and grade in the event the drill bit deviates from the design line and/or grade. A larger minimum allowable curve radius tends to be easier to drill, as it does not require as much steering per drill pipe. The specified minimum allowable curve radius must also consider the requirements of the cable installation. This will require early-on consultation with cable manufacturers during the design phase to fully understand the allowable cable bending requirements.

3.3.3 *Depth of Cover*

The depth of cover for a HDD installation is dependent on several factors. These include the geotechnical materials anticipated to be encountered along the alignment, the presence of preferential flow pathways through cracks, fissures, joints, fractures, or bedding planes, the diameter of the bore, the presence of existing utilities and/or structures, and the installation length. The most important factor in determining the appropriate depth of cover between the ground surface and a HDD bore is the material properties of the overlying geotechnical material and the resistance that it provides against the required installation-induced fluid pressures within the bore to remove the cuttings. This is discussed further in the discussions associated with construction risk considerations.

3.3.4 *Required Bore Diameter*

The diameter of the bore must be greater than the diameter of the casing pipe. This larger bore is required to facilitate flow of drilling fluids around the casing pipe, reduce the frictional force acting between the product pipe and the bore walls as it is installed, and to help the product pipe negotiate curves in the alignment. While the actual drilled bore diameter should be left to the HDD contractor to select based on their means and methods, guidelines exist within the HDD industry based on the outside diameter of the product pipe, as provided in Table 3-1.

Table 3-1: HDD Industry Bore Diameter Guidelines

Product Pipe Outside Diameter	Recommended Bore Diameter
200 to 600 mm	1.5 times the product pipe diameter
Greater than 600 mm	Product pipe diameter plus 300 mm

For example, for a 500 mm product pipe outer diameter, a bore diameter equal to 500 x 1.5 = 750 mm is recommended. A 750 mm product pipe outer diameter would require a bore diameter equal to 750 + 300 mm = 1050 mm.

3.4 Number of Reaming Passes

The number of reaming passes and incremental increase in bore diameter for each pass are influenced by several factors including, but not limited to, the required product pipe diameter, the geotechnical material and its properties, the capacity of the drilling equipment, and the required installation length. Typically, fewer incremental reaming passes are required for soil installations in comparison to bedrock installations.

Depending on the project requirements, the selected casing pipe diameter can significantly impact construction costs. This is particularly true where the pipe diameter requires multiple reaming passes to enlarge the HDD bore to facilitate the pipeline installation process. For example, a 350 mm outer diameter casing pipe would require a HDD bore diameter of approximately 525 mm. This 525 mm bore could be completed in a single reaming pass in a bedrock installation. However, a 500 mm outer diameter casing pipe would typically require two reaming passes (for a bedrock installation) to increase the bore diameter to the recommended diameter of 750 mm for this size of pipe. It should be noted that additional reaming passes can increase construction costs by as much as 25 to 35 percent in comparison to projects with a single reaming pass.

3.5 Ocean Floor Exiting Strategy

For ocean shore crossings, an exiting strategy is required to maximize drilling fluid returns for the majority of the installation process (including the pilot bore and reaming passes). A traditional HDD installation consists of completing the pilot bore and exiting the drill bit at the exit location prior to reaming the bore. The advantage of this exit strategy is that the exit location can be verified prior to initiating reaming operations. In addition, this strategy would allow for re-drilling of the pilot bore should the conditions at the exit location be unfavourable. The disadvantage of this exit strategy is that significant volumes of drilling fluids could be lost to the ocean environment during the exiting process as the bore drains by direct communication with the ocean.

If the pilot bore were fully completed through the ocean floor, the flow pathway through the bore would need to be eliminated to allow reaming operations with full fluid returns. Grouting could be used to seal this flow pathway. Sealing of highly fractured and jointed bedrock materials at the ocean floor may also be required. The drill pipe would be used to deliver the slug of grout to the end of the bore. Multiple attempts may be required to effectively seal the HDD bore. Grouting operations would likely follow a trial and error basis to determine the required length of the bore that is grouted and the mix design required to pump it down the drill pipes and into the bore. Sealing of the bore is critical to the success of reaming operations. Once the end of the bore is sealed, forward reaming operations would commence. If a single reaming pass is required, reaming would continue through to exit. If multiple reaming passes were required to enlarge the bore diameter, then the first reaming pass would likely be halted prior to exiting to allow the second reaming pass with full drilling fluid returns. A drill bit would likely be incorporated into the down-hole tooling to allow drilling of the grout plug without requiring a trip out of the bore to switch tooling. This exit strategy was recently used during construction of a 515 metre long 350-mm diameter high density polyethylene intake pipeline at the Ocean Sciences Centre in St. John's, NL. The termination elevation of this exit location was -37 metres. Sandstone bedrock materials were encountered for the entire bore. Drilling fluids were lost within a metre of drilling through the ocean floor. A total of four grouting attempts were required to seal the end of the bore to allow reaming operations with full returns. For the SOBI shore crossings, the installation lengths will require a lean grout to allow it to be pumped through the drill pipe to the end of the bore. This may take several attempts to effectively seal the end of the bore and permit reaming with full returns.

Alternatively, the pilot bore could be stopped prior to exiting the ocean floor, to allow reaming of the bore while maintaining full drilling fluid returns at the HDD entry location. This strategy would involve stopping the pilot bore upon discovery of reduced drilling fluid returns in the vicinity of the exit location. Reaming operations would then commence and be completed up to the location of where the pilot bore was terminated. Once the completed portion of the pilot bore had been fully reamed to its final diameter, the reaming tool would be removed from the bore and pilot bore tooling would be used to complete the bore to exit. Reaming of the remaining section would follow. In this strategy, the loss of drilling fluids would be limited to the last portion of the pilot bore and reaming operations. This exit strategy was recently completed on a 1,250 metre long 350-mm diameter high density polyethylene treated effluent ocean outfall project in Oceanside, Oregon (US). The termination depth of this exit location was -17 metres. The original pilot bore was completed to approximately 1,200 metres with full drilling fluid returns prior to commencing reaming operations. Full drilling fluid returns were observed for the entire reaming operation to the 1,200 metre distance.

If this exit strategy were to be used for the SOBI shore crossings, the termination point of a pilot bore would be dictated by the location of diminished drilling fluid returns. The exact location of where to prematurely cease pilot bore drilling operations and commence partial reaming of the bore is highly dependent on the encountered geotechnical conditions, the natural pattern of fractures and joints, and the presence of infilling of these features within the bedrock materials.

With either strategy, it is important to note that loss of drilling fluids cannot be entirely avoided. However, loss of drilling fluids to the ocean environment can be limited to the last portion of the bore during pilot bore drilling and reaming operations. Delays may be experienced during this process waiting for new drilling fluids to be properly mixed. Additional fluid loss would occur during the swab pass and product pipe installation. In addition to the loss of bentonite, the cuttings produced by the drill bit and reamer will need to be pushed/flushed to the ocean environment to clean the bore prior to product pipe installation. Depending on the length of the bore left to drill with fluid losses, it may be possible to use water or more “marine friendly” drilling fluids, although these fluids have been used with limited success on other ocean shore crossings.

3.6 Spacing of Multiple Bores/Installations

Multiple parallel installations require sufficient spacing between each bore. The required spacing is a function of the anticipated geotechnical conditions, required bore geometry and diameter, installation depth and length, and guidance system inaccuracies with tracking the down-hole tooling. Separation distances of 8 to 10 metres are common for traditional HDD installations. Greater separation distance between parallel bores are required with increased installation depth and length. The separation distance is required to prevent the installations from intersecting each other along the bore and to allow a column of rock between the bores for stress re-distribution.

For the SOBI shore crossings, a minimum separation distance of 10 metres between centerlines of adjacent bores at the HDD entry location is recommended. This spacing should be increased as the installation depth increases with each bore fanning outwards away from the neighbouring bore. This may require drilling of the middle bore first to allow changes in bore trajectory during drilling of subsequent bores. A visual survey of the exit floor will be needed to enable selection of the appropriate exit locations and required spatial separation between the bores.

3.7 Casing Pipe/Liner Material

Based on the known geotechnical conditions and the potential delay between completing the HDD installations and installing the electrical cable conduits, a casing/liner pipe installed in each completely reamed bore is highly recommended. While drilling costs would be lower if the bore served as the liner without insertion of a product pipe, the condition of an HDD bore would degrade with time, increasing the tendency for ravelling of loose bedrock material into the bore. In addition, there would be an additional risk to the cable as it rubbed on the surrounding bedrock bore walls, joints and fractures. A casing pipe would provide a stable and open conduit for the cable installation process.

Several different pipe materials are available for installation by HDD methods. These include high density polyethylene, polyvinylchloride, ductile iron, and steel. Selection of the appropriate pipe material is a function of several variables including installation length, depth, bore geometry, and overall functional requirement of the casing pipe. The wall thickness of the selected pipe material must be of sufficient thickness to resist the required installation loads.

For the SOBI shore crossings, steel casing pipe is recommended due to the required installation length and diameter. Steel casing pipe also provides the ability to push long installation lengths into the bore using a pipe thruster, as described previously in this report. The other pipe materials are not considered viable for use for the shore crossings due to the long installation length, anticipated installation loads and stresses, and lack of precedent at the required installation length. Use of other pipe materials such as high density polyethylene, polyvinylchloride, or ductile iron would significantly increase installation risks. Aside from increased construction costs associated with the increased installation risks, these pipe materials would also increase construction costs due to the significantly larger bore diameter required to accommodate their larger required outer diameter. For example, a 500 mm inner diameter high density polyethylene casing pipe would require a bore diameter of at least 200 mm larger than that required to accommodate a similar internal diameter steel casing pipe.

3.8 Grouting of Casing Pipe/Liner

Once the casing pipe has been installed from HDD entry to exit, a portion of the annular space between the casing pipe should be grouted to ensure casing integrity and prevent potential casing movement within the bore. The overall installation length and locations of annular space requiring grouting should be evaluated as the design progresses.

3.9 Diving/ROV Requirements

Shore crossing installations require access to the exit location prior to and during construction. Pre-construction access is required to assess potential exit locations and to determine the conditions of the geotechnical materials in the vicinity. Construction access is required to verify the location of where the drill bit has exited the ocean floor and to verify the condition/location of the casing pipe.

For the SOBI shore crossings, the target water depth of -80 metres is deemed too deep to allow a traditional pullback operation for the casing pipe installation, as stated previously. Here, the use of a remotely operated vehicle (ROV) can be better suited to these operations in comparison to diving operations. It should be noted, however, that during certain times of the year, weather and ocean conditions may not allow for mobilization and use of an ROV to provide the required support services when needed.

3.10 Project Location Considerations

Current HDD construction at the Ocean Sciences Centre in St. John's, NL has experienced difficulties arranging for diving operations, equipment rentals, and supplies in a timely manner. It has also highlighted an increased risk of loss of production/delay waiting for specialized equipment (i.e. mud motor) to arrive on-site and subcontracted portions of the work to be completed. This highlights the importance of good coordination and scheduling between the HDD contractor and its subcontractors to avoid issues with completing critical path tasks without unnecessary delay. Supply issues with required equipment can be avoided by requiring sufficient numbers of critical components on-site at the start of drilling operations. In addition, this risk can be diminished if a supply chain is established with both primary and secondary sources. Ultimately, it is the responsibility of the contractor to ensure they have sufficient tooling on-site at all times to prevent unnecessary delays. Supply chain requirements should be included in the project specifications to mitigate these risks.

3.11 Winter HDD Operations

Horizontal directional drilling operations are completed any time of the year. However, drilling in the winter months requires special considerations to prevent freezing of drilling fluid, slurry, and hydraulic lines. Fortunately, the HDD community is well experienced in drilling in cold winter weather, as several pipeline projects in Northern Canada are only accessible for construction during the winter to prevent damage to the surrounding marsh areas. Aside from winterizing their HDD rigs and equipment, different contractors have different methods to deal with the freezing conditions and protection of equipment. A few rely on the use of a large heated tent (or hoardings), as shown in Figures 3-3a, 3-3b, and 3-3c. All equipment is staged within the tent. It should be noted, however, that the potential build-up of ice inside the tent on the roof can pose an additional safety hazard.

Figure 3-3a: Installation of Test Support Structure

Figure 3-2b: Installation of Canvas Cover

Figure 3-3: Completed Tent

Some contractors use steam lines and equipment tarps to maintain temperatures above freezing. One key consideration for winter operations is to ensure the HDD Contractor is experienced for these conditions and that their equipment is properly built for winter operations.

4. State of the Practice in the HDD industry

Several horizontal directional drilling (HDD) contractors were contacted to assess the current HDD industry with respect to completed installations of similar length and diameter to that required for the SOBI shore crossings. HDD contractors from North America, Europe, the Middle East and Australia were contacted and asked to provide project listings of completed HDD installations. These contractors were selected based on their known experiences with completing projects with complex and long installation lengths. International HDD contractors were contacted due to their experience performing longer installations outside of their base country.

The provided project case histories were used to develop the state-of-the-practice HDD industry chart shown in Table 4-1. This compilation of projects includes both traditional HDD installations, where one drill rig is used to complete the entire installation, and drill and intersect installations, where two rigs are used to drill towards each other from both sides of the installation, meeting at a pre-determined target intersect location.

The majority of the longer HDD installations provided in Table 4-1 were completed in bedrock materials. It is important to note that these materials can provide better bore stability for greater periods of time, reducing the overall risk to an HDD Installation. In addition, more of the cuttings can be removed from the bore prior to pipeline installation decreasing the installation loads during product pipe insertion.

The common range of HDD industry experience/capability (shaded in green) was established based on the requirement that several contractors have completed similar installation lengths at the specific diameter. The yellow shaded cells in Table 4-1 identify the installation lengths and diameters that are considered feasible with an experienced contractor in favourable ground conditions. Cells shaded red in Table 4-1 are considered to be at or beyond the state-of-the-practice for the HDD industry.

With the exception of the three 3,000 metre long installations with pipe diameters of 400 mm, 600 mm and 750 mm, the majority of the longer HDD installations have been completed with smaller casing pipe diameters. For the base case of a 500 mm casing pipe diameter, an installation length of 2,000 metres is considered to be within the current state-of-the-practice of the HDD industry. Installations up to 2,400 metres are considered to be feasible with an experienced contractor in favourable ground conditions.

If a greater diameter casing pipe were required (i.e., a 750 mm diameter) the current typical maximum installation length is deemed to be 1,800 metres. However, installations up to 2,200 metres are considered to be feasible with an experienced contractor in favourable ground conditions.

Table 4-1: State-of-the-Practice in the HDD Industry

Installation Diameter (Casing Pipe)	Installation Length										
	1000 m	1200 m	1400 m	1600 m	1800 m	2000 m	2200 m	2400 m	2600 m	2800 m	3000 m
	3281 ft	3937 ft	4593 ft	5249 ft	5,905 ft	6562 ft	7218 ft	7874 ft	8530 ft	9186 ft	9842 ft
200 mm (8 inch)	7	3	7	8	2	3	2	0	0	0	0
250 mm (10 inch)	6	3	6	7	2	0	0	1	0	0	0
300 mm (12 inch)	10	8	5	7	0	0	0	1	0	0	0
350 mm (14 inch)	1	4	2	0	1	0	0	0	0	0	0
400 mm (16 inch)	4	1	6	4	4	1	1	0	0	0	1
450 mm (18 inch)	0	0	1	0	0	0	0	0	0	0	0
500 mm (20 inch)	9	7	5	2	2	0	2	1	0	0	0
600 mm (24 inch)	7	14	9	6	5	1	1	1	0	0	1
750 mm (30 inch)	10	4	7	6	1	1	1	0	0	0	1
900 mm (36 inch)	0	5	12	1	0	0	0	0	0	0	0
1050 mm (42 inch)	7	7	5	2	1	1	0	0	0	0	0
1200 mm (48 inch)	5	5	0	0	0	0	0	0	0	0	0

Colour Coding:

- (Green) Within typical capabilities of industry. Multiple experienced contractors.
- (Yellow) Zone of limited industry application. Considered feasible with an experienced contractor and favourable ground conditions.
- (Red) Exceeds current capabilities of industry. Considered risky even with an experienced contractor and favourable ground conditions.

NOTE: Current State of the HDD Industry shown above is based solely on the reported installation lengths and diameters. Site-specific geotechnical and installation based risks have not been considered in developing this chart.

A smaller 350 mm casing pipe diameter can reach an installation length of 2,200 metres. Installations up to 2,600 metres are considered to be feasible with an experienced contractor in favourable ground conditions.

The Newfoundland Island shore crossing (Shoal Cove) into the SOBI requires a HDD installation length of approximately 2,700 metres to achieve an ocean depth of 80 metres. Based on this required installation length and from a constructability approach, a 350 mm casing pipe diameter is considered to be within the limit of what has been successfully completed. An experienced HDD contractor certainly would be employed on this project to complete the installations. A 500 mm casing pipe diameter is considered to be just beyond the current limit of successfully completed HDD projects in favourable ground conditions. However, as the design process continues over the next couple of years, HDD contractors will continue to push or extend the achievable installation lengths including those for a 500 mm casing pipe diameter. It is anticipated that the achievable installation length for a 500 mm casing diameter will be extended beyond the required length of 2,700 metres for this crossing location in the next few years.

The deeper water closer to shore on the Labrador side (Forteau Pointe) requires installation lengths of only 1,200 metres to achieve an ocean depth of 80 metres. This installation length is well within the limits of the HDD industry, regardless of whether the casing pipe is 350 mm or 500 mm or 750 mm in diameter.

Of the ten (10) HDD contractors who provided complete project listings, five (5) of the HDD contractors have completed installations with lengths greater than 2,000 metres. These contractors include Michels Corporation (US and Canada based), Laney Directional Drilling (US based), Mears Group (North American based), AJ Lucas (Australia based), and DrillTec (Germany based). Tatco (Middle East based) provided project details for two HDD projects, which were 3,000 metres in length. It should be noted that there will be other HDD Contractors with similar or equal experience and capabilities than the ten that provided project histories.

5. Anticipated Geotechnical Materials and Conditions

Previous geotechnical investigations, reports and studies have been completed for the SOBI crossing. The discussions below summarize the general conditions of the ground surface and underlying stratigraphy as they relate to HDD installations. For greater geotechnical detail, please refer to the following reports:

1. Descriptive Overview of the Regional Bedrock Geology (2009 – Fugro) 10-3/1135
2. Geotechnical Investigations 2009, Preliminary Evaluation of Borehole Data (2010 – Landsvirkjun)

A generalized geotechnical profile is provided in Figure 5-1.

On the Newfoundland Island side of the SOBI shore crossings, the Petite Jardin Formation exists closest to the ground surface and overlies the March Point Formation which is underlain by the Hawke Bay Formation. The Petite Jardin Formation extends from the ground surface to an elevation of approximately 15 metres below sea level and consists of dolostone interbedded with shale. The March Point Formation extends below the Petit Jardin Formation to an elevation of approximately 35 metres below sea level and consists of argillaceous limestone and dolostone. The Hawke Bay Formation underlying the Petit Jardin and March Point Formations consists of sandstone and orthoquartzite interbedded with shale and conglomerate.

On the Labrador side of the SOBI shore crossings, the Forteau Formation exists closest to the ground surface and overlies the Bradore Formation. The Forteau Formation extends from the ground surface to an elevation of approximately five (5) metres below sea level and consists of shale and limestone. The underlying Bradore Formation consists of arkosic sandstone.

In general, the upper 30 metres of bedrock (closest to the ground surface) is noted to be more fractured and/or jointed (than underlying bedrock). This is postulated to be due to past glacier and iceberg scour. This 30 metre zone of fractured and/or jointed bedrock is assumed to extend beneath the entire SOBI as identified in the Landsvirkjun Geotechnical Report, based on permeability tests completed within land borings.

Sediments immediately overly the bedrock formations along much of the ocean floor of the SOBI. These are undifferentiated sediments of glacial drift, glaciomarine, and marine soils consisting of sand and gravel in both sorted and unsorted conditions that have been scoured, re-worked, and buried as a result of glacier and iceberg traverse. The thickness of these sediments typically ranges from less than three (3) metres up to five (5) metres.

5.1 Newfoundland Island Side of SOBI

Overburden soils on the Newfoundland Island side consist of glacial till immediately overlying bedrock. The glacial till consists of heterogeneous mixtures of gravel, sand, silt, and clay with cobbles and boulders. The thickness of the glacial till is typically less than three (3) metres as observed in Borehole NF-01B at Savage Cove and Borehole NF-02 at Shoal Cove.

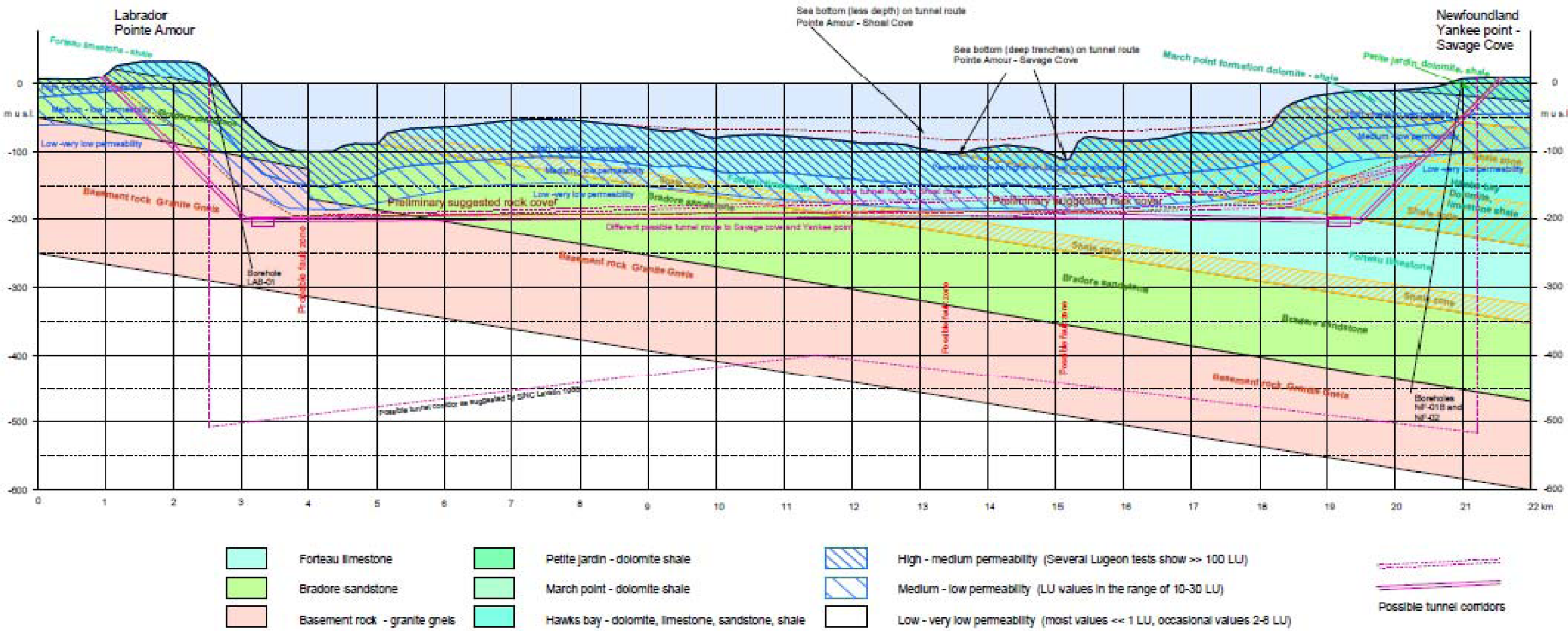


FIG 5.1

GENERALIZED GEOTECHNICAL PROFILE

HATCH™

Ground conditions in the bedrock of the Newfoundland Island side have been evaluated based on observations of rock core samples taken from Boreholes NF-01B (Savage Cove) and NF-02 (Shoal Cove). The bedrock conditions, as described in the following paragraphs, are characterized for the purposes of evaluating HDD feasibility in terms of the degree of fracturing, core loss encountered during drilling, equivalent permeability, and Rock Quality Designation (RQD) as defined in Deere and Deere (1988).

Table 5-1 summarizes the percentage of bedrock for each formation with RQD values less than 40 percent, between 40 and 60 percent and greater than 60 percent. Values greater than 60 percent are typically well suited for an HDD installation. As observed, the majority of the anticipated bedrock materials are well suited for an HDD installation. Zones where the RQD values are below 60 percent are summarized in Table 5-2.

Table 5-1: Percentage of Bedrock Materials Versus RQD Values (Newfoundland Island)

Formation	Percentage of Bedrock with		
	RQD Below 40 percent	RQD Between 40 and 60 percent	RQD above 60 percent
Petite Jardin Formation	25	20	55
March Point Formation	14	5	81
Hawke Bay Formation	9	16	75

Table 5-2: Summary of Elevations with Low RQD Values (Newfoundland Island)

Formation	Elevations of bedrock with RQD values		
	Below 40%	Between 40% - 60%	Above 60%
Petite Jardin Formation	8 to 3m, -17 to -18m	3 to -2m	-2 to -17m
March Point Formation	-18 to -20m, -39 to -42m	-34 to -36m	-20 to -34m, -36 to -39m
Hawke Bay Formation	-70 to -74m	-55 to -58m	-42 to -55m, -58 to -70m, -74 to -90m

As observed in Table 5-2, the zones of low RQD ratings are isolated with thicknesses ranging from 1 to 5 metres. In addition, the zones of low RQD (0 to 40 percent) generally correspond to zones where shale is encountered. Hence, the low RQD rating could be due to slaking and degrading of the shale as it is drilled, masking the true RQD rating for the material. While the RQD is less than ideal for an HDD installation, the limited thickness of the low RQD zones does not necessarily increase the installation risks associated with bore instability and loss of drilling fluids.

In general, rock quality is poorest within two (2) metres of a contact between two separate bedrock formations between the Petite Jardin and March Point Formations. This condition is typical in rock strata at the contact between two different rock formations due to concentrated water flow pathways and consequent concentrated weathering action.

Equivalent rock permeability was determined in rock core Boreholes NF-01B and NF-02 through the performance of water pressure testing using borehole packer systems. Based on the results of water pressure testing, very high to high permeability was observed in the Petite Jardin Formation and at the contact between the Petite Jardin Formation and the March Point Formation. This is consistent with previously-observed low RQD values in the Petite Jardin Formation and at the contact location between the Petite Jardin and March Point Formations. Medium to low permeability was typically observed in the March Point Formation with high to medium permeability was observed near the base of the March Point Formation. Medium to very low permeability was observed in the Hawke Bay Formation. The upper 20 to 30 metres of the bedrock closest to the ground surface or ocean floor is highly permeable.

Rock core loss and fracturing was encountered in all boreholes based on observation of Total Core Recovery (TCR) less than 100 percent (i.e., full recovery) and previously-described RQD observations. Core loss can result from the presence of widely-spaced joints, cavities or voids, soil-filled seams, and highly to completely weathered rock that is disintegrated and washed away during the drilling process. The boreholes exhibited overall TCR greater than 97 percent.

5.2 Labrador Side of SOBI

Overburden soils on the Labrador side consist of colluvium and talus apparently immediately overlying bedrock based on visual observations at the ground surface and shoreline at Forteau Pointe. The colluvium and talus exist in a boulder-field condition and consist of sandstone, limestone, and granite cobbles and boulders up to two (2) metres in diameter. The thickness of the colluvium and talus is undetermined and is expected to be on the order of 10 to 20 metres. This colluvium was not identified at Pointe Amour.

Ground conditions in the bedrock have been evaluated based on observations of rock core samples taken from Boreholes LAB-01 (Fox Cove) and LAB-02 (Pointe Amour). No geotechnical information is available at Forteau Pointe. Hence, the geotechnical conditions are inferred from the Pointe Amour boreholes.

Table 5-3 summarizes the percentage of bedrock for each formation with RQD values less than 40 percent, between 40 and 60 percent and greater than 60 percent. The RQD values are substantially lower in the Forteau Formation, with zero percent of the core designated with an RQD value above 60 percent. The Bradore Formation has a much higher RQD rating than the Forteau Formation. While there is an increased risk of bore instability due to the lower RQD values within the Forteau Formation, the presence of this formation at the ground surface provides some relief from the condition of this material as the poor rock is located close enough to the ground surface such that a conductor casing and/or telescoping casings could be used to support the poor rock material and prevent unwanted fluid migration through fractures and joints. A geotechnical investigation is required at Forteau Pointe to identify the actual rock conditions at this location. As stated earlier, RQD values greater than 60 percent are typically well suited for an HDD installation. Zones where the RQD values are below 60 percent are summarized in Table 5-4.

Table 5-3: Percentage of Bedrock Materials Versus RQD Values (Labrador)

Formation	Percentage of Bedrock with		
	RQD Below 40 percent	RQD Between 40 and 60 percent	RQD above 60 percent
Forteau Formation	39	61	0
Bradore Formation	5	5	90

Table 5-4: Summary of Elevations with Low RQD Values (Labrador)

Formation	Elevations of bedrock with RQD values		
	below 40 percent	between 40 and 60 percent	above 60 percent
Forteau Formation	31 to 28m, 21 to 20m, 17 to 14m, 12 to 10m, 5 to 3m	28 to 21m, 20 to 17m, 14 to 12m, 10 to 5m	No bedrock zones with RQD greater than 60 percent
Bradore Formation	3 to 1 m, -59 to -61m	-34 to -36m, 1 to -2m, -80 to -82m	-2 to -80 m

As observed in Table 5-4, the zones of low RQD ratings are isolated with thicknesses ranging from 1 to 7 metres. In addition, the zones of low RQD (0 to 40 percent) generally correspond to zones where shale is encountered. Hence, the low RQD rating could be due to slaking and degrading of the shale as it is drilled, masking the true RQD rating for the material. While the RQD is less than ideal for an HDD installation, the limited thickness of the low RQD zones does not necessarily increase the installation risks associated with bore instability and loss of drilling fluids.

In general, rock quality is poorest within two (2) metres of a contact between two separate bedrock formations. This condition is typical in rock strata at the contact between two different rock formations due to concentrated water flow pathways and consequent concentrated weathering action.

Equivalent rock permeability was determined in rock core Boreholes LAB-01 and LAB-02 through the performance of water pressure testing using borehole packer systems. Based on the results of water pressure testing, high to medium permeability was observed in the Forteau Formation and very high to high permeability at the contact between the Forteau Formation and the Bradore Formation which is consistent with previously-observed low RQD values in the Forteau Formation and at the contact location between the Forteau and Bradore Formations. Medium to low permeability was typically observed in the Bradore Formation with high to medium permeability observed in the upper 20 metres of the Bradore Formation. The upper 20 to 30 metres of the bedrock closest to the ground surface or ocean floor is highly permeable.

Rock core loss and fracturing was encountered in all boreholes based on observation of Total Core Recovery (TCR) less than 100 percent (i.e., full recovery) and previously-described RQD observations. Core loss can result from the presence of widely-spaced joints, cavities or voids, soil-filled seams, and highly to completely weathered rock that is disintegrated and washed away during the drilling process. The boreholes exhibited overall TCR greater than 97 percent with the exception of Borehole LAB-01 at Pointe Amour which had an overall TCR of 94 percent. Of particular note in Borehole LAB-01 is a combined 2.35 metres of rock core loss in the vicinity of El. -60m in the Bradore Formation which is an indication of rock that has apparently experienced tectonic action and associated degradation due to past shearing and subsequent weathering.

5.3 Site Visit

On September 2 and 3, 2010, NE and Hatch staff visited the proposed coastal sites on both sides of the SOBI.

The geotechnical materials and conditions were observed at the sites, including location of bedrock, location of gravel and/or rock quarries nearby and appearance of bedrock.

The Trip Report is provided in Appendix A – Site Visit Report.

6. HDD Conceptual Profiles

Three (3) conceptual HDD bore plan and profile alignments were developed for this feasibility study: one for the Newfoundland Island side of the SOBI (Figure 6-1) and individual alignments for Forteau Pointe (Figure 6-2) and Pointe Amour (Figure 6-3) on the Labrador side. Only one conceptual plan and profile was developed for the Newfoundland Island side of the SOBI, as the required bore geometry would be similar for each of Yankee Point, Savage Cove, or Shoal Cove. These alignments are individually discussed in greater detail in the following subsections.

The bore geometries used in developing these alignments are based on individual site constraints, typical HDD entry and exit angles, required vertical curves for steel casing pipe materials and down-hole bedrock tooling, topography, target water depth, known ocean floor elevations, targeted depths of cover below the ocean floor to decrease risks associated with loss of drilling fluids/hydrofracture, required set back distances from the shoreline, and available staging areas. The target exit elevation for each of the conceptual alignments is -80 metres. A design curve radius of 1,220 metres has been selected for all curves.

The target depths of cover shown on the profiles were selected to avoid the upper 30 metres of bedrock at the ocean floor previously identified as high permeable zones of fractured and/or jointed bedrock materials (as identified in the Landsvirkjun Geotechnical Report). It is understood that depth of cover has a significant impact on the thickness of the subsea cables. Discussions with cable manufacturers should be completed early in the design phase to obtain the required design criteria from the cable manufacturers. It should be noted that it may be possible to decrease the depth of cover between the HDD bores and the ocean floor. Additional geotechnical investigations would be required to verify the actual conditions of the upper 30 metres of bedrock materials. Once these conditions have been characterized, the design depth of cover above each HDD installation can be optimized. Similarly, depending on the results of additional geotechnical investigations, it may also be possible to decrease the setback distance from shore, thereby decreasing the required installation lengths to deep water.

Traditional surface-to-surface HDD installations typically have bore geometries that resemble that of a “U” shape. As the pilot bore is advanced, frictional forces develop along the completed bore decreasing the ability to provide a bearing or face pressure on the down-hole tooling. Face pressure is especially important in bedrock installations to provide down-hole tooling with sufficient force to excavate the encountered geotechnical material. For this reason, long bedrock installations, such as those required for the SOBI shore crossings, typically avoid long horizontal (grade of 0 percent) sections and are designed with only minimal upward drilling to maximize the ability to apply sufficient face pressure to excavate the bedrock materials. By providing a constant downward grade to the maximum extent possible, gravity acting on the down-hole tooling assists in providing the required face pressure for the cutting tools. The conceptual plans and profiles shown in Figures 6-1 through 6-3 were developed based on this concept, as observed with fairly long downward trajectories. This concept was recently used for a 1,250 metre long 350-mm diameter high density polyethylene treated effluent ocean outfall project in Oceanside, Oregon (US). For that project, the bore was designed with a constant downward slope of 0.873 percent prior to levelling out horizontally and drilling upward to the intended exit location. The encountered bedrock on this project included basalt with unconfined compressive strengths of 155 MPa.

As with all of the recommendations provided in this report, these conceptual alignments are subject to change as the design matures and additional information is collected and assessed, especially where ocean floor elevations are not defined. It is anticipated that these alignment alternatives will be modified as the design progresses.

6.1 Yankee Point, Savage Cove, and Shoal Cove (Newfoundland)

The HDD conceptual plan and profile for the Newfoundland side of the SOBI is provided in Figure 6-1. This profile would be similar for any of these potential HDD entry locations (Yankee Point, Savage Cove, or Shoal Cove). However, it should be noted that a Yankee Point alternative would require a much longer length to reach the target water elevation of -80 metres than at Savage Cove and Shoal Cove. The ocean shore elevations shown on the conceptual alignment (Figure 6-1) are based on an HDD entry location at Shoal Cove.

The required installation length on the Newfoundland Island side is approximately 2,700 metres, depending on whether Savage Cove or Shoal Cove is used for the HDD installation site. The bore was designed with a depth of cover of between 35 and 40 metres to avoid the upper portion of the bedrock materials, identified as a potential high to medium permeability zone.

6.2 Forteau Pointe (Labrador)

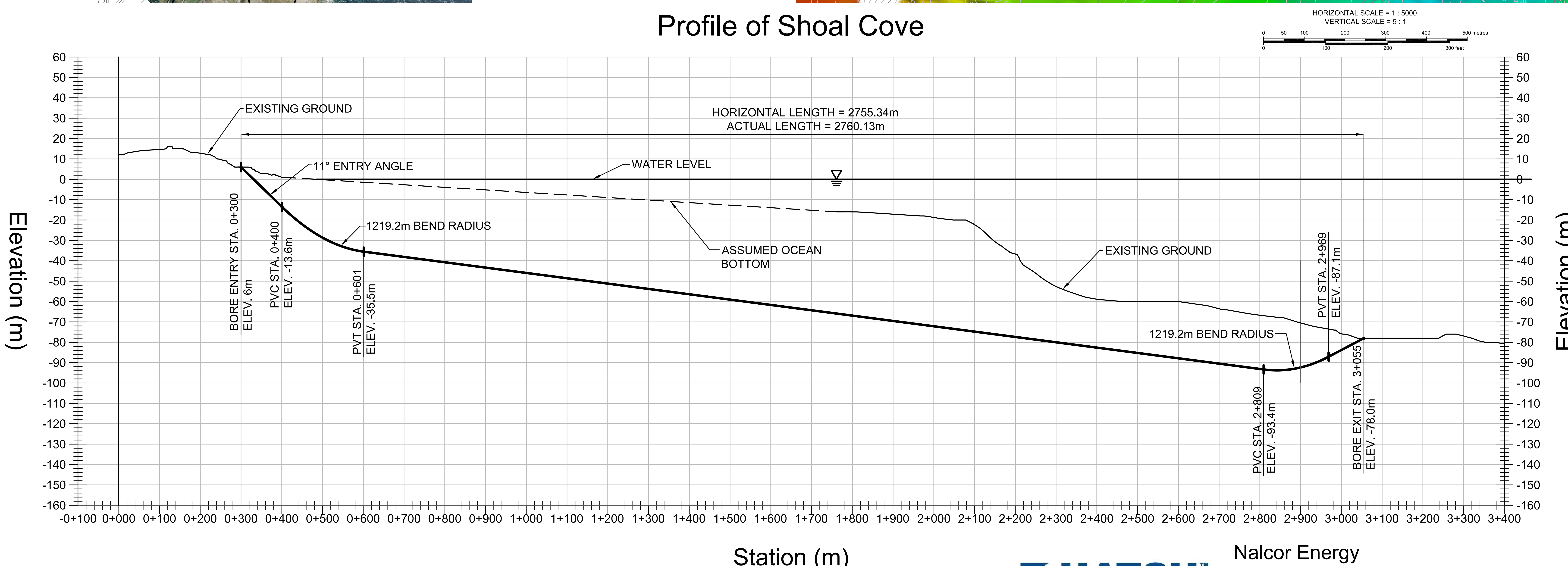
The HDD conceptual plan and profile for Forteau Pointe on the Labrador side of the SOBI is provided in Figure 6-2. The required installation length is approximately 1,220 metres. The reduced installation length, in comparison with the Newfoundland Island side, is attributed to deeper water existing closer to shore. The bore was designed with a depth of cover of between 25 and 40 metres for the majority of the installation. Greater depths of cover are available. However, attaining greater depths will require a longer portion of the bore to be drilled horizontally and upwards.

6.3 Pointe Amour (Labrador)

The HDD conceptual plan and profile for Pointe Amour on the Labrador side of the SOBI is provided in Figure 6-3. The required installation length is approximately 1,120 metres. Again, the shorter installation length is attributed to deeper water existing closer to shore. The bore was designed with a depth of cover of between 25 and 30 metres for the majority of the installation. While this alignment is directed towards the northeast from a location west of the Pointe Amour lighthouse, a similar alignment could be developed with an HDD entry location located between the lighthouse and the remnants of the British ship wreck. Both of these locations are more exposed to the public than the location at Forteau Pointe.

Plan

Profile of Shoal Cove



HATCH

Nalcor Energy
HDD Study for Strait of Belle Isle
Figure 6-1 - Shoal Cove Plan and Profile

HATCH

Nalcor Energy
HDD Study for Strait of Belle Isle
Figure 6-2 - Forteau Pointe Plan and Profile

Profile of Pointe Amour

Nalcor Energy
HDD Study for Strait of Belle Isle
Figure 6-3 - Pointe Amour Plan and Profile

7. Subsea Completion Methods and Cable Installation

Subsea completion/insertion of the subsea electrical cables will require coordination with the cable manufacturer to determine: the allowable installation loads and any constraints with respect to bore geometry; break over of the electrical cables at the transition location from ocean floor to HDD bore; additional installation requirements; and, in-casing support, protection and centralization within the individual casing pipes at the ground surface once installed. The conceptual alignments provided in Section 6 were designed with large curve radii of approximately 1,220 metres, based on initial discussions with Nalcor Energy regarding the constraints of the electrical cables. In addition, exit angles at the ocean floor were designed to be small with the bore as straight as possible.

Installation of the subsea cables will require fishing of pulling cables through the steel casing pipes. Once the casing pipes are installed, the pulling cable could be installed within the steel casing pipe. This is most easily accomplished by pushing a floatable pig connected to the pull cable through the bore from HDD entry to exit. Connection of the electrical cable pulling head and the pull cables will likely require the use of divers or a ROV. This task will also require early coordination with the cable manufacturer during design to ensure the perceived installation method is viable without any undue risk of damage to the cables.

Depending on the ocean floor topography, fill may need to be placed on the ocean floor in the vicinity of the exit location(s) to support the electrical cables as they transition from the ocean floor into the HDD bore. This transition, if required, would be used to ensure the allowable deflection of the cables is not exceeded. Subsea surveying of exit locations will be required early in the design phase to select the appropriate exit locations for the HDD bores. Special consideration will need to be given to the topography of the ocean floor and the transition area for the subsea cables.

8. Risk Components and Mitigating Measures

Risk registers were developed as part of this feasibility study based on the conceptual alignments provided in Figures 6-1, 6-2, and 6-3 for the Newfoundland Island side (Shoal Cove), Forteau Pointe (Labrador), and Pointe Amour (Labrador) potential crossing locations, respectively. As with the conceptual alignments, only one risk register was developed for the Newfoundland Island side of the SOBI, as the installation risks are similar for Yankee Point, Savage Cove, or Shoal Cove. This risk register is provided in Appendix B Table 1. Separate individual risk registers were developed for Forteau Pointe and Pointe Amour on the Labrador side of the SOBI (Appendix B - Tables 2 and 3 respectively). The risk registers presented in this Feasibility Report were reviewed and updated during a Risk Workshop conducted with Nalcor Energy and Hatch personnel on October 6, 2010.

The individual risk registers are comprised of two assessments: one based on the identified risks prior to design and one based on the identified risks following risk mitigation measures undertaken during the design phase of the project to lower the risk level. Identified risks are based on the likelihood of encountering the risk/hazard and the severity of the impact of the identified risks with respect to health, safety, environmental, financial and operational/schedule considerations. The residual risk levels provided in each table are based on proper identification and consideration during the design phase of the project. These lower risk levels assume proper design of these crossings and good construction practices used by the HDD contractor during construction. The lower residual risk assessments in each table assume that the identified risk control measure can be used to lower the overall likelihood of the risk.

It is important to note that the risk registries are working documents and should be used during the design phase to track the level of the identified risks and other potential risks as more information becomes available for the crossing and crossing-specific risk mitigation measures are considered. These risk registers should be used to track the risk control measures considered during the design phase of the project to demonstrate that the identified risks are dealt with during design, in the Contract Documents and during construction.

The following discussions summarize the HDD risks associated with the geotechnical and installation aspects of the SOBI shore crossings. General risk discussions relating to all alignments are provided prior to discussing each shore crossing individually.

8.1 Geotechnical-Based Risk Considerations

8.1.1 Soil-Based Risk Considerations

Sands, silts and clays present no significant challenge to a HDD installation. These materials are often described as good to excellent materials in terms of feasibility. Soils containing gravels and larger size particles (cobbles and boulders) range from marginally acceptable to unacceptable in terms of feasibility depending upon the percentage of gravels by weight. Only those particles that can be suspended within the drilling fluid can be removed from the bore. Gravel sized particles tend to settle out and accumulate along the bottom of the bore. Greater sized particles cannot be suspended by the drilling fluid.

To properly remove the cuttings and support the open bore, the drilling fluid must also remain within the bore without excessive loss to the surrounding formations. Open-graded deposits of gravel and cobble-sized clasts allow drilling fluids to escape into the surrounding formations. In addition, open-graded deposits (those deposits lacking a significant quantity of fines to act as a binder) tend to be unstable. This inherent instability, combined with a tendency for fluid loss and associated loss of down-hole pressure presents an increased risk for bore collapse. Bore collapse, if local, will make reaming and pullback operations difficult. If bore collapse is significant, significant difficulties will be experienced advancing or retracting the drill pipe and down-hole tooling.

Cobble and/or boulder fields present a significant challenge to a HDD installation and must be avoided. Down-hole tooling has limited ability to drill through the material. Typically, the tooling experiences severe fatigue, rapid wear, and potentially catastrophic damage. Steering issues will also exist, as the tooling is deflected off of these oversize materials. Point loading of the drill pipe by cobbles and boulders will lead to increased drill rig torque requirements that may decrease the ability to drill longer distances.

Steering response may also be poor in open-graded gravels, impacting the ability to maintain alignment. If a boulder were encountered, several drill pipes would need to be removed to permit re-drilling around the object. Care must be taken to ensure the new alignment is drilled within the allowable bending radius of the product pipe. Alternatively, it may be possible to drill through the boulder.

Conductor casings could be used to isolate the HDD bore from zones of coarse-grained soils encountered near the ground surface. Alternatively, it may be possible to remove deposits of gravels and cobbles (i.e., excavate with a bulldozer), assuming they occur near to the ground surface.

8.1.2 Bedrock-Based Risk Considerations

Bedrock materials are classified as being excellent to unacceptable with respect to HDD feasibility. Competent bedrock is well-suited for HDD as the bore tends to remain open for extended periods of time. However, heavily weathered, jointed, fractured or fissured bedrock can present challenges with respect to bore stability. In fact, poor quality/ low RQD bedrock where fracturing and jointing is extensive can present similar challenges as coarse granular deposits. The risk associated with these materials arises from the inability to establish and maintain support within the bore and potential inability to remove these materials from the bore after they ravel into it. Stability is afforded through application of supporting fluid pressure acting on the walls of the bore. Bedrock materials that are extensively jointed, fractured or weathered, such that they behave in a manner similar to gravel and/or cobble allow fluid pressures to dissipate, reducing or eliminating the supportive action of the fluids. As a HDD bore is enlarged in these materials, the larger independent particles are able to fall/ravel into the bore under the influence of gravity as the bore exposes them. Only if these particles are bridged by the surrounding rock mass or finer grained particles will ravelling not occur. Extensive jointing, fracturing and weathering of bedrock materials can also give rise to increased drilling fluid migration outside of the bore leaving less fluid available for the transport of cuttings and reducing down-hole fluid pressure available to promote drilling fluid flow. Installation risks significantly increase when circulation cannot be maintained within the HDD bore.

The unconfined compressive strength of bedrock materials can present a challenge for a HDD installation. Bedrock materials with high unconfined compressive strengths (i.e. greater than 20,000 psi) will require frequent trips in and out of the bore during the pilot bore and reaming operations to replace worn tooling. Worn tooling manifests itself in the form of reduced production. From a feasibility standpoint, higher strength bedrock materials impact construction costs associated with requiring additional drill bits, hole openers, and time/labor to replace the worn tools. Similarly, abrasive bedrock materials also impact the overall construction costs associated with a particular installation.

The current understanding of the unconfined compressive strengths of the bedrock materials is based on correlations with point load testing (Figure 8-1). Based on correlations with point load testing, the majority of the apparent unconfined compressive strengths of the upper 100 metres of vertical bedrock at the Newfoundland Island side of the SOBI are less than 175 MPa. Only four out of a total of 28 correlations indicated unconfined compressive strengths greater than 175 MPa. Additional laboratory tests are required to directly determine the actual unconfined compressive strengths and abrasivity of the bedrock materials. Abrasivity tests have not been completed.

Solution features such as cavities and/or caves are often found in limestone and dolostone bedrock materials. These features present risks to a HDD installation. If the drill bit or reamer were to encounter an extensive cavity or cavern, the down-hole tooling could buckle and separate from the drill string if unsupported. In addition, large volumes of drilling fluids could be lost to the local environment. Grouting may be required to fill large cavities.

Ocean currents are capable of transporting significant volumes of sediment as a bed load on the ocean floor. If the HDD exit location were to coincide within a location of deposition, difficulties could be experienced maintaining bore condition in the vicinity of the exit location during the reaming, swab pass and product pipe phases of the installation process. In addition, deposition of material following casing pipe insertion may impact the ability to install the electrical cables within the casing pipe. ROV surveys of potential exit locations can be used to mitigate the potential for sedimentation by allowing target exit locations that lack extensive deposits of sediment. Sub-bottom profiling and detailed bathymetric surveys are required at each exit location.

Zones of high permeability have been identified at various bedrock contacts and within the upper 20 to 30 metres of the bedrock found at the ground surface. These zones may provide preferential pathways for drilling fluid flow, depending on the features contributing to the high permeability. These features can include, but are not limited, fracture networks, joint networks, shear zones, or areas of weathered rock. While these features may be conducive to groundwater flow, drilling fluids may not flow as easily due to the plugging tendencies of the cuttings as drilling fluids flow into these features. If high permeability zones are encountered, these features can be mitigated using conductor casings installed at the ground surface or telescoping casing, depending on where they occur along the alignment. Grouting operations may also be effective in sealing these features. The conceptual alignments provided in Section 6 have been selected to avoid as much of the zone of high permeability as practical.

8.2 Installation-Based Risk Considerations

While several installation-based risks are considered in the individual risk registers, the installation risks with the highest risk ratings, as identified in all risk registers, include the following:

- Loss of drilling fluids/hydrofracture
- Inability to maintain bore stability
- Inability to advance down-hole tooling
- Damage to adjacent bores/casing pipe
- Supply chain coordination

Details of these main installation risks are provided in the following discussions. Details of risks defined as medium and low designations are provided in the individual risk registers (see Tables 8-1, 8-2, and 8-3).

8.2.1 Loss of Drilling Fluids/Hydrofracture

Proper characterization of the site geotechnical materials coupled with proper depths of cover are crucial to designing a HDD installation to maintain drilling fluid/slurry flow within the HDD bore. If a bore is designed with insufficient depth of cover the overlying soil/bedrock materials may not provide sufficient strength to resist the induced fluid pressure within the bore to facilitate the installation process. When this occurs, the slurry may find an alternate preferential flow pathway to the ground surface than the bore or create its own pathway towards the ground surface. Loss of drilling fluid/slurry returns between the entry or exit location is commonly referred to as hydrofracture. The down-hole fluid pressure required to facilitate a HDD installation is dependent on the encountered geotechnical materials, the volume of drilling fluids pumped into the bore, the density of the slurry, the available annular space between the drilling equipment and excavated bore for slurry flow, and the difference in elevations between the point in question along the bore and the entry or exit locations. Greater fluid pressures are required for longer and deeper installations due to the increased frictional losses with length and the higher hydrostatic pressures with depth. The greater fluid pressure requirement increases the possibility of losing drilling fluids to the surrounding geotechnical materials as opposed to having the fluids flow up to the drill rig entry location for reclamation and re-use.

Drilling fluid loss is a concern in bedrock formations with a high degree of fracturing and jointing. Here, the natural fractures and/or joints may provide preferential flow pathways for drilling fluid flow. If this condition exists, drilling fluids may not flow within the bore and back to the drill rig for processing but rather flow through the fracture/joint networks into the surrounding rock mass. Several options exist if drilling fluids are lost to the surrounding rock mass (and ocean). These include the installation of telescoping casing pipes to seal the bore from the surrounding bedrock materials (depending on the location of loss circulation), injection of lost circulation material designed to expand in the presence of water in an attempt to plug the fluid loss flow pathway, or grouting operations to eliminate the flow pathway.

Loss of drilling fluids represents a significant environmental concern for an ocean shore crossing, especially for a bedrock installation where the volume of required drilling fluid to support drilling and reaming operations is significant. A hydrofracture assessment will need to be completed during the design phase to determine the required fluid pressures at various locations along the bore. This assessment should be completed for each stage of the installation process. Once the anticipated drilling fluid pressures are determined, they can be compared to the geotechnical information to assess the potential for hydrofracturing during any of the drilling stages. This comparison is then used to assist in properly designing the bore within favorable geotechnical units with sufficient depths of cover to minimize the hydrofracturing potential to greatest extent possible.

In addition to the environmental issues for maintaining slurry flow solely within the bore, if complete fluid circulation cannot be maintained, a water source equivalent to the required drilling fluid pumping rate would need to be secured to prevent downtime associated with mixing new batches of fluid. This water source would need to be on the order of 0.0063 to 0.0126 m^3/sec (100 to 200 gallons per minute) for soil installations and 0.025 to 0.05 m^3/sec (400 to 800 gallons per minute) for bedrock installations, based on previous HDD experiences. When the return of fluids can be maintained, demands on a water source are greatly reduced.

If a test pilot bore investigation were to be completed on each side of the SOBI at the preferred HDD sites, it would be possible to identify zones more susceptible to drilling fluid loss, especially within the upper 20 to 30 metres of bedrock at the surface where high permeability is perceived. If completed during the initial stages of design, modifications and contingency plans could be developed to decrease impacts associated with loss of circulation. A test pilot bore investigation would also allow for testing of various drilling techniques to restore drilling fluid circulation within the bore.

8.2.2 *Inability to Maintain Bore Stability*

Maintaining bore stability is critical to the successful installation of the casing pipe. Bore stability is a function of the encountered geotechnical materials and their properties (including degree of fracturing and jointing, presence of faults/shear zones, etc.), required bore diameter, and installation length. As stated previously, heavily-fractured and/or jointed bedrock can present a ravelling risk if the surrounding rock mass can not adequately support it. Ravelling carries a significantly higher risk as the diameter of the HDD bore is increased. The increased risk is attributed to exposure/daylighting of a greater number of fractures and joints in the bore walls and crown. Hence, ravelling potential is greater for reaming pass(es) in comparison with the pilot bore phase of the installation process.

If ravelling were to occur, telescoping casing could be installed to provide additional support with these materials, assuming the zone of ravelling was located in close proximity to the drill rig. Grouting operations could also be completed, although these operations would be slow and may require multiple grouting attempts to prevent ravelling. Where identified, the preferred approach is to design the HDD bore within more favourable materials as much as possible. Current conceptual alignments place each bore within more favourable materials, based on the available geotechnical information.

If a test pilot bore investigation were to be completed on each side of the SOBI at the preferred HDD sites, it would be possible to identify zones of bore instability. If completed during the initial stages of design, modifications and contingency plans could be developed to decrease impacts associated with ravelling.

8.2.3 *Inability to Advance Down-hole Tooling*

HDD installations experience greater frictional forces with increased installation length, as more drill pipe becomes in contact with the walls of the bore. These high frictional forces can give rise to increased drill rig efforts to continue drilling. This is especially true for long and deep shore crossings in bedrock materials. As discussed previously, difficulties can be experienced applying sufficient bearing/face pressure at the drill bit to effectively cut the bedrock during the pilot bore phase. Reaming operations with hole openers can also be impacted, as these operations tend to excavate a greater surface area than that of the drill bit during the pilot bore. HDD installations are also susceptible to torque limitations during reaming operations, as the required torque to rotate the hole opener is typically derived from the drill rig. With longer installation length, the drill rig's ability to supply sufficient torque decreases dramatically. Fortunately, torque limitations can be overcome through the use of a mud motor with a zero degree bend (since steering is not required as the reamer will tend to follow the previously completed pilot bore). In this scenario, the mud motor supplies the torque required to generate rotation of the hole opener reducing or eliminating this need with the drill rig. This strategy was recently used for an ocean outfall project in Oceanside, Oregon (US).

8.2.4 *Damage to Adjacent Bore(s)/Casing Pipe*

Multiple bores require special consideration of the proximity of adjacent bores to prevent the drilling equipment of one bore intersecting the adjacent bore and/or to prevent grouting operations required for one bore from impacting the stability of the neighbouring bore. As stated in Section 3.6, the risk of a bore intersecting an adjacent bore can be removed by providing sufficient spatial separation at the entry location with the individual bores fanning outwards, increasing their separation, with depth. Damage or impact to an adjacent bore from grouting operations can be eliminated by advance grouting of known trouble zones and/or requiring casing installation of adjacent bores prior to commencing drilling operations of the next bore. Use of gyroscopic survey guidance/tracking system can also decrease risks associated with adjacent bores intersecting each other.

8.2.5 *Supply Chain Coordination*

As discussed in Section 3.10, supply issues can arise on HDD projects where an insufficient quantity of specialized equipment is readily available. These issues are usually attributed to improper coordination between equipment suppliers and the HDD contractor determining whether they actually require the additional equipment on site. Often, delays are experienced when a critical component is needed and a spare is not available. While these delays tend to be the responsibility of the contractor, the overall project can experience overall schedule and completion delays.

The majority of construction delays, especially on remote sites, can be attributed to misjudgement of the number of expendable components required for a project. These expendables can include, but are not limited to, mud motors, drill bits, tracking equipment components, reamers, swivels, separation plant parts, mud pump parts, etc. To reduce risks associated with supply chain issues, it is recommended that additional quantities of key spare parts/equipment are requested in the Contract

Documents to be available on-site prior to construction and during construction for the Newfoundland Island and Labrador sides of the SOBI at all times.

8.3 Individual Risk Assessments

8.3.1 Yankee Point, Savage Cove, and Shoal Cove (Newfoundland)

The risk register for Yankee Point, Savage Cove, and Shoal Cove is provided in Appendix B, Table 1. The risks associated with these locations are similar and carry slightly higher risks than for the Labrador side of the SOBI, due to the significantly longer required HDD installation lengths. As observed in the risk register, several potential mitigation measures are available that can be used in design to lower the likelihood of occurring and the impact of each risk. No individually defined installation risk is considered to be a fatal deterrent for use of the HDD construction process to complete the SOBI shore crossings at these locations.

8.3.2 Forteau Pointe (Labrador)

The risk register for Forteau Pointe is provided in Appendix B, Table 2. The level of risk for this crossing location is much lower than that of the Newfoundland Island sites, due to the significantly shorter installation length. Cobble/boulder fields are identified as a high risk for this crossing location. The cobble and boulder fields occur at the surface and will require a geotechnical investigation to determine their thickness, extent, and elevation. These deposits will require full removal prior to initiating drilling operations. A lack of geotechnical information at this location also increases geotechnical-based construction risks and the risk of construction claims. Alternatively, the entry location could be located in an area lacking these materials to avoid any issues.

As observed in the risk register, several potential mitigation measures are available that can be used in design to lower the likelihood of risk occurrence. No individually defined installation risk is considered to be a fatal deterrent for use of the HDD construction process to complete the SOBI shore crossings at this location.

8.3.3 Pointe Amour (Labrador)

The risk register for Pointe Amour is provided in Appendix B, Table 3. As with Forteau Pointe, the construction risks for this crossing location are much lower than those of the Newfoundland side. While cobble/boulder fields are not apparent at this location, potential interconnected fractures and/or joints communicating with the ocean have been identified in one of the boreholes completed in the vicinity of the crossing location. If encountered, these features would likely require a telescoping conductor casing strategy or grouting operations to prevent loss of drilling fluids during the pilot bore and reaming operations.

As observed in the risk register, several potential mitigation measures are available that can be used in design to lower the likelihood of occurrence. No individually defined installation risk is considered to be a fatal deterrent for use of the HDD construction process to complete the SOBI shore crossings at this location.

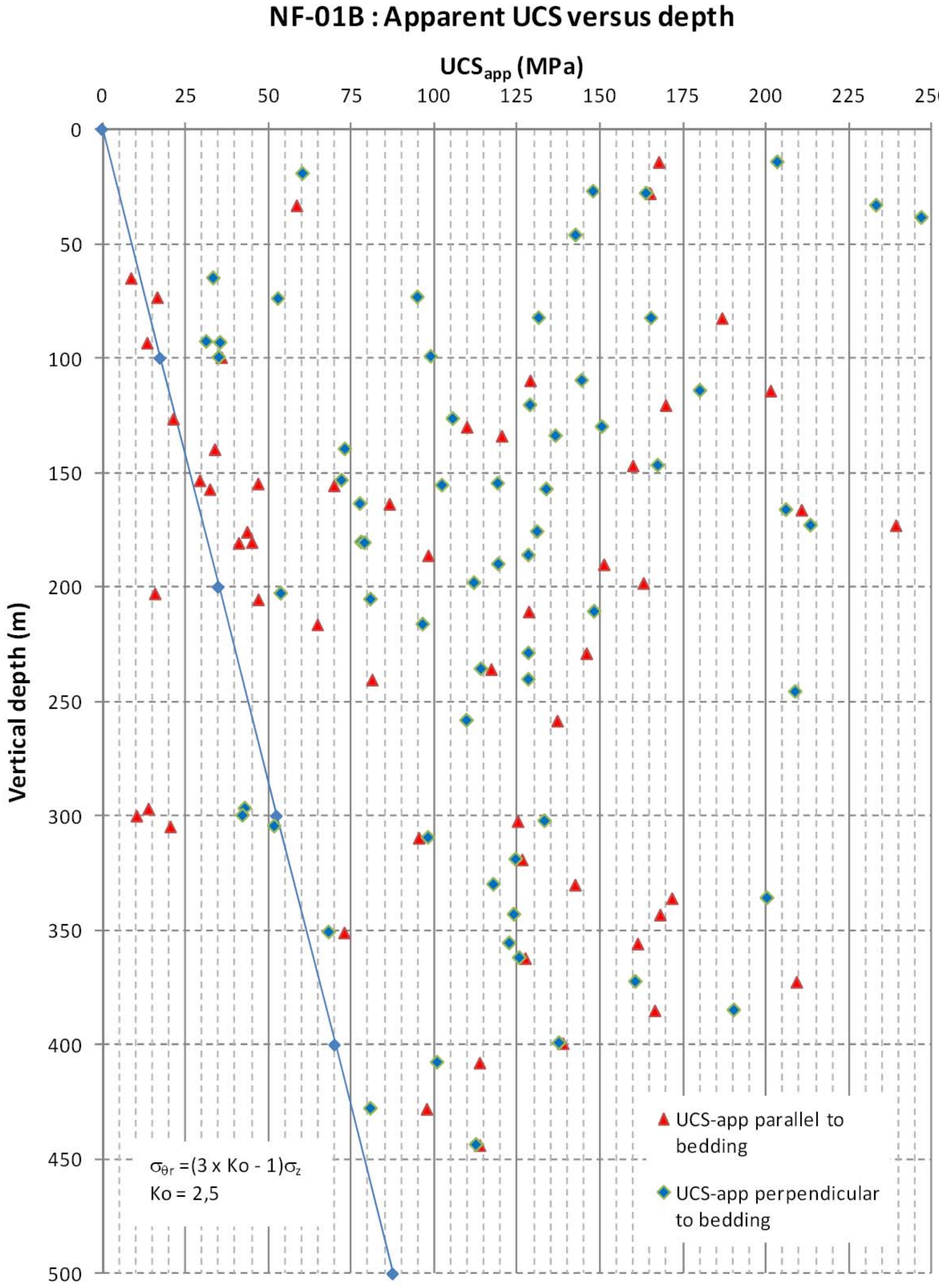


Figure 8-1: Apparent uniaxial compressive strength of rock cores, from point load tests, versus vertical depth, in borehole NF-01B. σ_θ is the estimated maximum tangential stress in roof for circular openings.

9. Construction Cost Estimates

9.1 Basis of Cost Estimates

Cost estimates were developed for the proposed HDD construction work for both sides of the SOBI. The purpose of the cost estimates is to obtain preliminary pre-feasibility level estimates based on the preliminary designs and profiles in order to evaluate and optimize alignments. The estimated costs would also be used by Nalcor Energy to assess the financial feasibility of the HDD method for the SOBI cable crossing.

The target accuracy of the cost estimates is in the range of -10 percent to +20 percent, representing a Hatch FEL 2 (or Level 2) cost estimate, equivalent to an AACEI Class 3 classification.

The construction cost estimates were compiled based on the following parameters and assumptions:

- Use of a HDD estimating breakdown structure.
- Estimated costs are in October 2010 Canadian dollars (costs are exclusive of escalation).
- Installation lengths are based on individual shore crossing requirements.
  - Required installation length of 2,700 metres for the Newfoundland Island bores.
  - Required installation length of 1,200 metres for the Labrador bores.
- Casing pipe material is steel. Minimum wall thickness 13 mm (0.5 inches), Grade 42 pipe.
- Conductor casings required for first 50 metres of drilled length for each bore.
- One reaming pass to create a 550 mm diameter bore to facilitate a 350 mm casing pipe outside diameter alternative.
- Two reaming passes to create a 750 mm diameter bore to facilitate a 500 mm casing pipe outside diameter alternative.
- Three reaming passes to create a 1050 mm diameter bore to facilitate a 750 mm casing pipe outside diameter alternative.
- One drill rig equipment spread and thruster unit for each side of the SOBI.
- Construction 7 days per week, 24 hours per day (double shift) for 2-3 weeks followed by 2-4 days off, for pilot bore, reaming pass, swab pass, and product pipe installation.
- Average unconfined compressive strengths up to 172 MPa (25,000 psi).
- Budget prices for casing pipe were received from suppliers of large diameter steel pipe.
- Labour rates were compiled from Hatch's HDD databases for union labour for HDD North American projects. The hourly rates including fringe benefits used for the cost estimates for regular time (straight time), excluding overhead and profit, for the categories of workers required for HDD operations, are as follows:

  - Superintendent [redacted]
  - HDD Operator [redacted]
  - Mud/Plant Operator [redacted]
  - Rig Mechanic/Crane/Excavator Operator [redacted]
  - Heavy Duty Repair [redacted]
  - Rig Hands (Labourer) [redacted]
  - Survey Technician [redacted]
  - Welding Technician [redacted]
- Cost estimates include the use of environmental friendly drilling fluids.
- Costs include construction direct costs, contractor's office and field overheads, contractor's profit, and construction indirects (contractor's construction facilities, temporary roads, temporary construction power, and site services, bonding and insurance, transportation of workers and subsistence).

9.2 Exclusions

The following items are excluded from the construction cost estimates:

- Further geotechnical investigations and laboratory tests.
- Environmental studies, engineering, detailed design, procurement and construction management, resident engineering, etc. by Owner's Engineer.
- Marine support for diving/ROV operations to verify location of HDD exit locations and casing pipe installation.
- Electrical cable supply and installation within the casing pipes.
- Subsea cable supply and installation on the sea floor.
- Pad construction to transition the electrical cables into the casing pipes on the sea floor.
- Construction of any permanent access roads to the site(s).
- Escalation beyond October 2010.
- HST.
- Land acquisition.
- Owner's financing/IDC.
- Owner's costs.

9.3 Contingencies and Engineering

9.3.1 Contingencies

A contingency of 20 percent was added to the summarized construction costs (in Section 9.4) to allow for quantity changes, design growth, non-itemized work and pricing inaccuracies.

9.3.2 Engineering

The estimated cost for engineering services covering services by Owner's Engineer up to the award of the HDD contract is expected to be in the [redacted] to [redacted] range. This would include preliminary engineering and optimization, engineering/assistance for geotechnical investigations, final design, technical specifications, preparation of tender documents and evaluation of tenders.

9.4 Summary of Estimated Construction Costs

9.4.1 HDD Contractor's Mobilization and Demobilization One-Time Costs

A summary of the one-time mobilization/demobilization costs for the Newfoundland Island and Labrador sides of the SOBI crossings is given in Table 9-1. These costs include one-time costs for developing submittals (including work plans), mobilization and demobilization, and equipment procurement. These one-time costs include all costs for the entire HDD project (both project sites).

Table 9-1: Opinion of Probable One-time Construction Costs

Cost Component	Estimated Cost ($)
Contractor Submittals	[redacted]
Equipment Procurement	[redacted]
Mobilization (one HDD spread to both locations)	[redacted]
Demobilization (both locations)	[redacted]
Total Without Contingencies	[redacted]
Contingencies (20%)	[redacted]
TOTAL	[redacted]

9.4.2 Shoal Cove (Newfoundland)

A summary of the construction cost estimates for 350 mm and 500 mm alternatives for the Island Coast are given in Tables 9-2, 9-3, 9-4, and 9-5 respectively.

Table 9-2: Opinion of Probable Construction Cost for Each 350 mm Casing Pipe Installation (Length 2,000 Metres)

Cost Component	Estimated Cost ($)
Site Preparation and Equipment Setup	
Conductor Casing Installation	
Pilot Bore Drilling	
Reaming Operations (one pass)	
Swab Pass	
Product Pipe Supply and Installation	
Annular Space Grouting (30 metres) and Site Cleanup	
Total Without Contingencies	
Contingencies (20%)	
TOTAL	

Table 9-3: Opinion of Probable Construction Cost for Each 500 mm Casing Pipe Installation (Length 2,000 Metres)

Cost Component	Estimated Cost ($)
Site Preparation and Equipment Setup	
Conductor Casing Installation	
Pilot Bore Drilling	
Reaming Operations (two passes)	
Swab Pass	
Product Pipe Supply and Installation	
Annular Space Grouting (30 metres) and Site Cleanup	
Total Without Contingencies	
Contingencies (20%)	
TOTAL	

Table 9-4: Opinion of Probable Construction Cost for Each 350 mm Casing Pipe Installation (Length 2,700 Metres)

Cost Component	Estimated Cost ($)
Site Preparation and Equipment Setup	
Conductor Casing Installation	
Pilot Bore Drilling	
Reaming Operations (one pass)	
Swab Pass	
Product Pipe Supply and Installation	
Annular Space Grouting (30 metres) and Site Cleanup	
Total Without Contingencies	
Contingencies (20%)	
TOTAL	

Table 9-5: Opinion of Probable Construction Cost for Each 500 mm Casing Pipe Installation (Length 2,700 Metres)

Cost Component	Estimated Cost ($)
Site Preparation and Equipment Setup	
Conductor Casing Installation	
Pilot Bore Drilling	
Reaming Operations (two passes)	
Swab Pass	
Product Pipe Supply and Installation	
Annular Space Grouting (30 metres) and Site Cleanup	
Total Without Contingencies	
Contingencies (20%)	
TOTAL	

9.4.3 Forteau Pointe (Labrador)

A summary of the construction cost estimates for 350 mm and 500 mm alternatives for the Labrador Coast are given in Tables 9-6, 9-7, 9-8 and 9-9 respectively.

Table 9-6: Opinion of Probable Construction Cost for Each 350 mm Casing Pipe Installation (Length 1,200 Metres)

Cost Component	Estimated Cost ($)
Site Preparation and Equipment Setup	
Conductor Casing Installation	
Pilot Bore Drilling	
Reaming Operations (one pass)	
Swab Pass	
Product Pipe Supply and Installation	
Annular Space Grouting (30 metres)	
Total Without Contingencies	
Contingencies (20%)	
TOTAL	

Table 9-7: Opinion of Probable Construction Cost for Each 500 mm Casing Pipe Installation (Length 1,200 Metres)

Cost Component	Estimated Cost ($)
Site Preparation and Equipment Setup	
Conductor Casing Installation	
Pilot Bore Drilling	
Reaming Operations (one pass)	
Swab Pass	
Product Pipe Supply and Installation	
Annular Space Grouting (30 metres)	
Total Without Contingencies	
Contingencies (20%)	
TOTAL	

Table 9-8: Opinion of Probable Construction Cost for Each 350 mm Casing Pipe Installation (Length 2,000 Metres)

Cost Component	Estimated Cost ($)
Site Preparation and Equipment Setup	
Conductor Casing Installation	
Pilot Bore Drilling	
Reaming Operations (one pass)	
Swab Pass	
Product Pipe Supply and Installation	
Annular Space Grouting (30 metres)	
Total Without Contingencies	
Contingencies (20%)	
TOTAL	

Table 9-9: Opinion of Probable Construction Cost for Each 500 mm Casing Pipe Installation (Length 2,000 Metres)

Cost Component	Estimated Cost ($)
Site Preparation and Equipment Setup	
Conductor Casing Installation	
Pilot Bore Drilling	
Reaming Operations (two passes)	
Swab Pass	
Product Pipe Supply and Installation	
Annular Space Grouting (30 metres) and Site Cleanup	
Total Without Contingencies	
Contingencies (20%)	
TOTAL	

9.5 Cost Risk Analysis

9.5.1 Introduction

The risk analysis was performed to apply statistical methods to the values of one of the estimates, specifically Construction Cost for each 500 mm Casing Pipe Installation, Newfoundland Side. The analysis is based on the identification of the main anticipated risk areas and quantifying the maximum overall range of likely outcomes for each.

The procedure developed is to identify and quantify construction cost risks, how the risks are profiled and analyzed to develop the construction cost profile from which the project budget will be established to include amounts for contingency and risk. The analysis allowed for the following questions to be answered:

- What is the most likely construction cost?
- What is the probability that the estimate will be exceeded?
- What risk allowance is required?
- What are the key risk drivers?

9.5.2 *Risk Identification*

The risk identification is a process to enable a cost model to be built, using the construction cost estimate and project risks that can be quantified.

The process was undertaken in two phases:

- Involves exploring the uncertainty around the items in the construction cost estimate (Cost Risk of Planned work)
- Considerers project specific risks that are not part of the construction cost estimate but can affect the eventual cost of the project.

The project risks (for this type of construction) to be considered were grouped into two (2) categories:

- Technical Risks:
    - Level of Engineering completed at the time of the estimate
    - Proven / Unproven Technology
    - Geotechnical / Site Conditions
    - Scheduling Considerations
    - Environmental Considerations
    - Efficiency and Performance of Labour and Equipment
- Commercial Risks:
    - Labour Market Conditions (supply pricing, productivity and availability)
    - Financing Variables
    - Insurance and Bonds
    - Legal Consideration
    - Labour Union Issues

9.5.3 *Developing "Cost Risk Model" for the Project*

The cost risk model uses the construction estimate with same Work Breakdown Structure (WBS). The cost model was subdivided in two main sections:

- Cost Risk of Planned Work – considers the uncertainty around the items in the Work Breakdown Structure (WBS) of the construction cost estimates.
- Specific Project Risks - assessment of the cost impact to the construction cost

The process to model and analyze uncertainty in the estimate is subjective; it was carried out by the senior cost estimator and reviewed by the lead engineer and project manager. The aim was to develop a "three-point estimate" to replace the single point estimate taken from the construction estimate.

Risk Identification – Specific Project Risks are presented in Table 9-10, and Risk Assessment in the Construction Estimate is presented in Table 9-11.

The three point estimate consists of:

- The most likely cost – base estimate (single point estimate)
- The maximum or pessimistic value (cost)
- The minimum or optimistic value (cost)

Each risk item was assessed so as to establish in addition to its base estimate or "most likely cost", the "maximum or pessimistic" cost case and the "minimum or optimistic" cost case scenario (one in a hundred of occurrence) for each item creating a range of values per each item of the cost. The risk model is presented in Table 9-12– Risk Cost Model (Data for Monte Carlo Simulation).

The following variables are used to "model" uncertainty in the construction cost estimate:

- Unit Price/Cost - what is the uncertainty of the labour rates, equipment pricing, production rates, and commodity prices (steel pipe, etc.)
- Quantity – what is the uncertainty of the quantities, given the level of design, site information, etc.
- Labour Hours – uncertainty around estimated labour hours.

9.5.4 Results of Analysis of Risk Cost Model

9.5.4.1 Monte Carlo Simulation

The commercially available program @Risk was used to run the simulation of the risk model that has been developed. @Risk uses the technique of Monte Carlo simulation to do a risk analysis. The data was entered into the program, which assumes a triangular distribution (TRIANG probability function) for each individual item, then statistically summarizes them into a single total cost estimate curve.

The output from this analysis is a distribution of likely outcomes for the total construction cost, which is summarized in a histogram that displays the shape of the distribution and the minimum, maximum and mean values of distribution. The "Simulation Results for Estimated Total Construction Cost/Most Likely Cost" are presented in Table 9-13.

For the probability of the maximum and minimum values being breached, 10 percent level is typical to assess (i.e. there is a 10 percent chance that maximum value provided may be exceeded).

It should be noted that for the Risk Analysis carried out here a combination of the specific content of the cost estimate and some identified items of risk (Tables 9-10 and 9-11) were used.

In Table 9-13 the simulation results also provide a graph showing "Regression Sensitivity for Cell I29 (Estimated Construction Cost)", a sensitivity analysis to determine which elements or risk variables are the most significant "drivers" in the risk analysis.

The index on the bar shows the correlation effect that each one (1) unit of change in input for the variable will have on the overall output. For example, in the table mentioned above, for each increase of $1.00 in "Reaming Passes (2) & Swab Pass", there will be a $ 0.794 increase in the modelled results. Obviously, the closer the correlation effect is to 1, the more sensitive the output is to that variable.

9.5.4.2 Cost Estimate Probability – Values of Total Construction Cost Estimate

Table 9-14 - Cost Estimate Probability - Values of Total Construction Cost Estimate, presents "Summary Statistics" in 5 percent increments of the probability of the total Construction Cost with two columns: Probability Not to Exceed (percentile) and Amount ($).

The analysis yields a 12 percent confidence that the costs will not exceed the base estimated cost. To achieve a higher probability, say 90 percent, Summary (1) in Table 9-14 shows that the Total Estimated Construction Cost (90 percent chance of underrun) would be increased by about 4.9 percent (P90 minus Base Cost = $1,045,698/Base Cost). To achieve 90 percent probability, the sum of [redacted] should be added as "additional contingency" and the sum of [redacted] should be added as a value of Risk Amount, to the base estimate of [redacted] Total Contingency (as a value of specific risks identified) should then be 25.9 percent of the Estimated Construction Cost without Contingencies.

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Risk Analysis of Estimated Construction Cost, 500 mm Casing Pipe Installation, Newfoundland Side (Length 2,700 Meters)

Table 9-10 - Risk Identification - Specific Project Risks

Risk Identification	Category	Cause / Comments	Mitigation
Regulatory Risk			
Non-compliance to EA requirements during construction	Environmental Application	Project may be delayed if insufficient information is submitted for regulator review. During construction, an inadvertent release of drilling fluid to the environment or other contravention of an act may result in possible charges being laid by the regulator	Environmental Management Team
Securing routine construction permits identified in proposal	Permitting (Approval Process)	Imperative that all permits/approvals are obtained and applicable conditions are implemented to demonstrate that HDD Contract and Project team can be trusted to self-regulate.	Environmental Management Team
Drilling mud seepage directly into watercourse	Environmental	Sediment load and supposition with possible adverse effects on fish, fish habitat, on wildlife, vegetation, soils, heritages, etc.	Environmental Management Team
Release of drilling fluids to the environment	Environmental/ Geotechnical	High bore fluid pressure required to induce drilling fluid flow from the drill bit/reamer location to the HDD entry / exit location	Complete through an accurate bathymetric survey of the HDD alignment in near shore environment. Entry locations as close as possible to the shoreline with elevations as low as possible.
Geology / Geotechnical			
Bore instability or collapse during drilling of the pilot hole and subsequent reaming passes, that may result in the drill string becoming stuck.	Geology	Inability to support geotechnical materials along exposed surface of bore walls. Reveling due to drilling to major joint / fracture orientations. Risk increases with increase in bore diameter. Presence of crushed rock and clay.	Maintaining drilling mud in the bore hole at all times by locating the entry and exit points. Develop contingency plan to remove cuttings from the bore. Require drilling fluid additives to reduce swelling potential. Verification of mud motor and hole openers condition on regular basis.
Inability to maintain bore stability / condition bore	Geology	Encountering bedrock materials with artesian groundwater conditions that prevent the rebuild-up a filter cake along the walls of the bore	Characterize potential risk by reviewing borehole logs and field notes. Require use of drilling fluid additives to mitigate artesian conditions.
Loss of drilling fluids to the formation	Geotechnical / Environmental	Variable depending on volume and connectivity to surface or water body. Encountering bedrock materials with significant open fracture/joint networks and communication with ocean	Complete geotechnical investigation to characterize bedrock materials. Evaluating alternative drill paths that avoid or minimize exposure to the problematic soil materials
Hole collapse during pipe pull	Geology	Poor rock quality due to crushed rock zones. This condition can result in long-term borehole instability if left unlined.	Assess potential with a proposed pilot bore drilling investigation early in the design phase.
Excessive drill tool wear requiring frequent tool replacement	Geology	Occurrence of structurally complex, hard and/or abrasive bedrock formations.	Complete geotechnical investigation, complete testing of compressive strength and abrasivity to provide means for contractor to select appropriate drilling equipment.
Design / Construction Risks			
Non compliance to perform specification	Design	Drilling execution plan did not address all specific Items	Project Design Team
Inadequate design for anchorage system	Design		Project Design Team
Poor production. Loss in ability to excavate bedrock material	Construction	Instability to provide sufficient torque with drill rig to rotate bottom hole assembly (due to bore length). Improper selection of cutting tools and hole openers.	Require the use of mud motor during pilot bore and reaming stages. Develop experience / qualification requirements for contractor's drill rig operator and site superintendent.
Damage of casing pipe within bore	Construction	Iceberg scour / impact on ocean floor. Extended duration of disturbance and potential for a red rill	Determine depth of scour /impact. Design bore with sufficient clearance below scour depth.
Washout of cavities and collapse of right-of-way	Construction	Loss of topsoil and unexpected widening of the area of disturbance	Project Management Team
Loss of circulation	Construction	Complete loss of circulation indicates a loss of drilling fluid	Perform a hydro fracture analysis to determine the allowable maximum pressure and required drilling fluid pressure.
Water source	Construction	Check water quality for bentonite mix & initial and additional drilling fluid	Project Management Team
Obstacles and local constraints	Construction	Existing pipelines, cables, steel structures	Provide adequate separation distance. Experience for operating tracking system.
Casing removal difficulties	Construction	Presence of crushed rock and clay that swell or expand into borehole trapping drill tools in the borehole.	Require successful completion of swab pass prior to casing / liner pipe insertion.
Equipment lost in hole	Construction	Encountering a large hole in limestone layers	Reviewing existing geological information. Monitor drill rig performance.
Poor reliability of construction equipment and excessive downtime	Construction	Lack of contractor experience in cold environment. Improperly prepared equipment. Weather condition	Include prequalification requirement for contractor experience in cold environment. Contingency plan to deal with potential harsh weather.

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Risk Analysis of Estimated Construction Cost, 500 mm Casing Pipe Installation, Newfoundland Side (Length 2,700 Meters) for One Bore

Table 9-11 - Risk Assessment in the Construction Cost Estimate (Range Value - Estimate Assessment)

Item No.	Description/Activity (Cost Items)	Quantity	Units	Base Estimate						Range Value		Basis of Estimate	Estimate Assessment (Cost Of Planed Works)
				Days/Shift	Labour	Equip	Material	Cost / Unit	Amount ($)	Minimum (Optimistic)	Max. (Pessimistic)		
	(1) Cost Risk of Planed Work – considers the uncertainty around the items in the Work Breakdown Structure (WBS) of the Construction cost estimate												
HDD Shoreline Crossing - Direct Costs													
1	Site Preparation	1	LS	10	[redacted]	[redacted]		[redacted]	[redacted]	95%	140%	Amount based on similar projects	(1) Include construction access roads to rig and pipe side, material for alignment improvement of existing road and equipment for road maintenance. Preparation of rig side lay-down area (60m x 60m) require granular material to be placed and compacted (app 1,200m3) and from pipe side (30m x 45m), 500m3 , total 1,700m3 * $40m3 = $68k (2) Allowance for clearing and leveling of the "Entry", "Exit" lay-down areas and pipe laydown area (right-of-way)
2	Equipment Set-up	1	LS	5	[redacted]	[redacted]		[redacted]	[redacted]	95%	110%	LS - amount based on similar projects	
3	Entry Casing Installation	1	LS	10	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	95%	110%	Average Production rate with weld casing= 60m/Day	
4	Pilot Bore Drilling	1	LS	109	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	90%	120%	Average Production rate = 30m/Shift/Day	
5	Reamings (2) & Swab Pass	1	LS	174	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	90%	120%	Average Production rate = 20m/Shift/Day	Reaming Operation (two passes) and Swab Pass
6	Product Pipe Installation	1	LS	4	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	90%	115%		
7	Hydrostatic Testing & Grouting	1	LS	4	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	90%	120%		
8	Site Cleanup / Move	1	LS	5	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	95%	140%		
	Subtotal-Direct Cost			321					[redacted]				
HDD Shoreline Crossing - Indirect Costs													
1	Indirect Cost / (Field)	1	LS	15%					[redacted]	95%	115%	% of indirect costs (field) - based on similar projects	Indirect Cost to include: Site Supervision General Items & Site Services Worker Transportation & Subsistence
	Estimated Construction Cost								[redacted]				
	Indirect Cost (Corporate / office)												
	Bond (3% of Direct Costs)	1	LS	3%					[redacted]	90%	110%		
	Overhead (10% of Direct Costs)	1	LS	10%					[redacted]	100%	100%		
	Subtotal								[redacted]				
	Profit (15% of Direct Costs)	1	LS	15%					[redacted]	100%	100%		
	Total Costs without Contingencies								[redacted]				
	Base Contingency			20%					[redacted]	100%	100%		
Total Estimated Project Cost									[redacted]				

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Risk Analysis of Estimated Construction Cost, 500 mm Casing Pipe Installation, Newfoundland Side (Length 2,700 Meters) - One Bore

Table 9-12 - Risk Cost Model (Data for Monte Carlo Simulation)

Item No.	Description/Activity (Cost Item)	Min.Value as %	MINIMUM COST ($)	Most Likely Project Cost ($)	Max.Value as %	MAXIMUM COST ($)	Estimate Cost (Base Cost)
HDD Shoreline Crossing - Direct Cost							
1	Site Preparation	95%			140%		
2	Equipment Set-up	95%			110%		
3	Entry Casing Installation	95%			110%		
4	Pilot Bore Drilling	90%			120%		
5	Reamings (2) & Swab Pass	90%			120%		
6	Product Pipe Installation	90%			115%		
7	Hydrostatic Testing & Grouting	90%			120%		
8	Site Cleanup / Move	95%			140%		
	Subtotal - Direct Cost						
1	Indirect Cost (Field)	95%			115%		
	Estimated Construction Costs						
	HDD Shoreline Crossing - Indirect Cost (Corporate / office)						
	Bond (3% of Direct Costs)	90%			110%		
	Overhead (10% of Direct Costs)	100%			100%		
	Profit(15% of Direct Costs)	100%			100%		
	Total Costs without Contingencies						
	Contingency (20%)	100%			100%		
	Estimated Total Project Cost						

* Note: These amounts are slightly less in corresponding Table 9-5 because the direct cost for Items 1 and 2 was reduced and proated for Table 9-5 to account for only one site preparation for three bores and only moving of equipment for the second and third bores.

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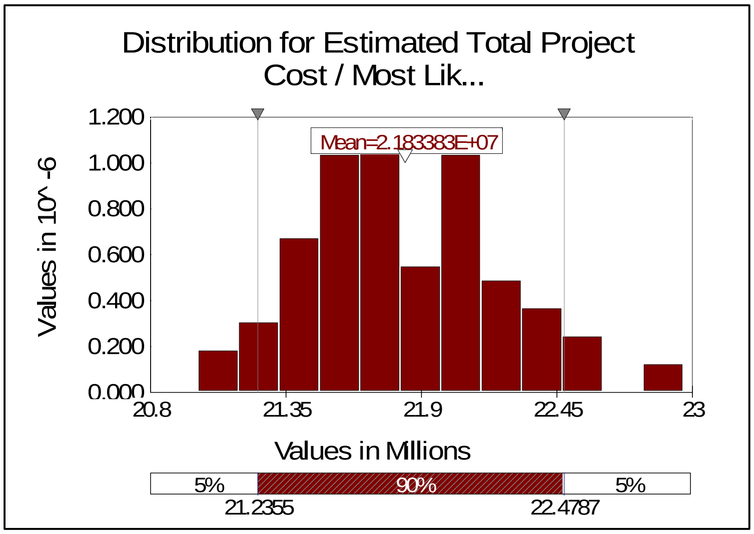
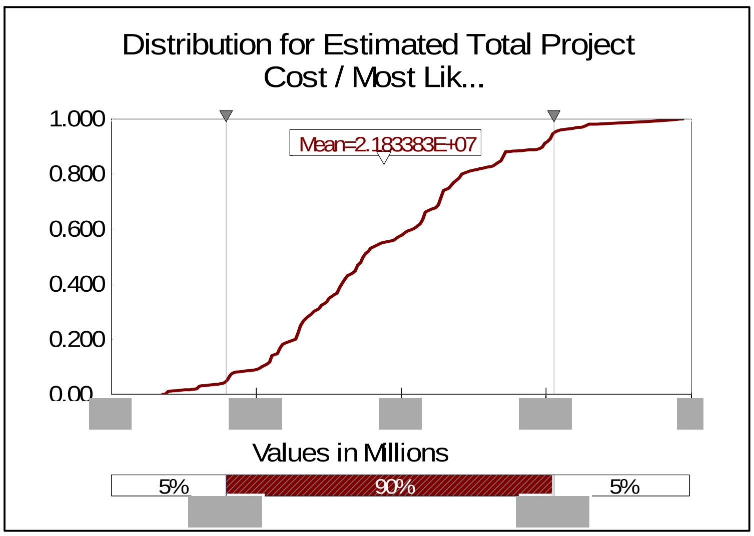
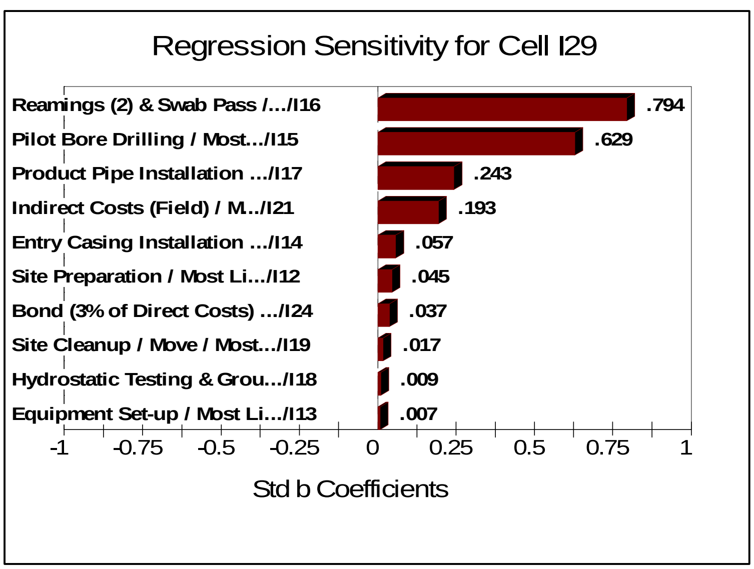
Risk Analysis of Estimated Construction Cost, 500 mm Casing Pipe Installation, Newfoundland Side (Length 2,700 Meters)

Table 9-13 -Simulation Results for Estimated Total Construction Cost/Most Likely Cost ($)







Summary Information	
Workbook Name	OBI-Table -Risks-LC-HDD-500-R2.x
Number of Simulations	1
Number of Iterations	100
Number of Inputs	13
Number of Outputs	5
Sampling Type	Latin Hypercube
Simulation Start Time	11/19/2010 10:18
Simulation Stop Time	11/19/2010 10:18
Simulation Duration	00:00:00
Random Seed	350937400

Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum		5%	
Maximum		10%	
Mean		15%	
Std Dev	4	20%	
Variance	1.61195E+11	25%	
Skewness	0.410075265	30%	
Kurtosis	2.781798004	35%	
Median		40%	
Mode		45%	
Left X		50%	
Left P	5%	55%	
Right X		60%	
Right P	95%	65%	
Diff X	1,243,166	70%	
Diff P	90%	75%	
#Errors	0	80%	
Filter Min		85%	
Filter Max		90%	
#Filtered	0	95%	

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Reamings (2) & S	0.794	0.756
#2	Pilot Bore Drilling	0.629	0.458
#3	Product Pipe Insta	0.243	0.101
#4	Indirect Costs (Fie	0.193	0.283
#5	Entry Casing Insta	0.057	0.194
#6	Site Preparation /	0.045	0.009
#7	Bond (3% of Direc	0.037	0.008
#8	Site Cleanup / Mo	0.017	-0.014
#9	Hydrostatic Testir	0.009	0.087
#10	Equipment Set-up	0.007	0.052
#11	Overhead (10% o	0.000	0.000
#12	Profit(15% of Dire	0.000	0.000
#13	Contingency (30%	0.000	0.000
#14			
#15			

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Risk Analysis of Estimated Construction Cost, 500 mm Casing Pipe Installation, Newfoundland Side (Length 2,700 Meters)

Table 9-14 - Cost Estimate Probability - Values of Total Construction Cost Estimate

Statistic Elements/ Project Elements	Probability Not to Exceed	Amount ($)
	5%	
	10%	
Total Estimated Construction Cost (Base Cost)	12%	
	15%	
	20%	
	25%	
	30%	
	35%	
	40%	
	45%	
Mean (21,833, 826)	50%	
	55%	
	60%	
	65%	
	70%	
	75%	
	80%	
	85%	
P90 (90% chance of underrun)	90%	
	95%	

Summary (1)		
Estimated Construction Cost without Contingencies		
Base Contingency (20%)		
Total Estimated Construction Cost (Base Cost)		
Additional Contingency	Mean P50% - Total Estimated Construction Cost	
Most Likely Construction Cost		
Risk Amount [P90 (90% chance of underrun) - P50]		
Total Construction Cost = Total Estimated Construction Cost + Additional Contingency + Risk Amount		
P90 (90% chance of underrun)		
Percentage Increase = P90 (90% chance of underrun) / Total Estimated Construction Cost		104.9%

Summary (2)		
Total Costs without Contingencies		
Total Contingency (Base Contingency + Additional Contingency + Risk Amount)	25.9%	
P90 (90% chance of underrun)		
Percentage Increase = P90 (90% chance of underrun) /Total Estimated Construction Costs without Contingencies		125.9%

10. Construction Schedules

Preliminary construction schedules have been prepared using Primavera for the HDD project, as follows:

- Figure 10-1 – HDD Construction Schedule – Newfoundland Side – 500 mm Casing Installation – 2,700 m length.
- Figure 10-2 – HDD Construction Schedule – Labrador Side – 500 mm Casing Installation – 1,200 m length.

The activities in the schedule are grouped into two phases or stages of project development, namely:

- Definition and Planning Phase (up to award of the HDD contract)
- Implementation Phase (HDD construction/installation).

The construction phase is further divided into sequential HDD bore installations (three casings).

The schedules were prepared based on the following assumptions:

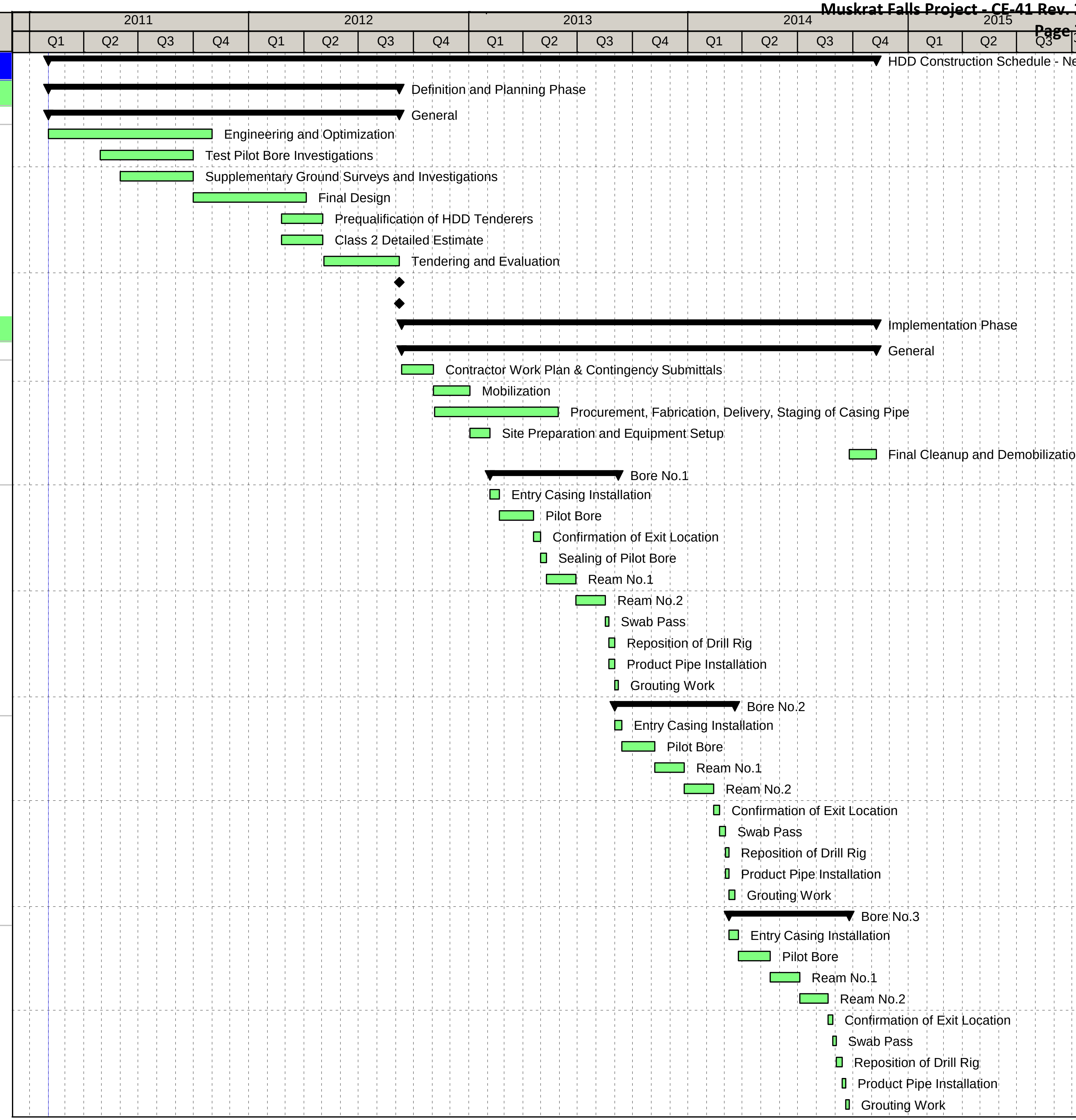
- The environmental assessment process is well underway and all required environmental approvals will be in place to facilitate proceeding with construction during the second half of 2012.
- Engineering, Procurement, Construction Management (EPCM) project delivery method and contract strategy will be adopted for the project construction execution.
- The Definition and Planning Phase will commence about the beginning of February, 2011.
- The Island side and the Labrador side HDD construction will be done simultaneously, double shift operations, three bores being completed sequentially.
- The seafloor exiting strategy is 'exit after No. 1 pilot bore' and complete verification of exit location. Then seal pilot bore. Subsequent (Bores No. 2 and No. 3) confirmations of exit location will be after reaming.
- HDD construction to be completed to facilitate start of cable installation in 2015.

Figures 10-1 and 10-2 are attached and indicate total site construction durations from the start of mobilization to demobilization will be:

Island Side (Figure 10-1) – approximately 25 months

Labrador Side (Figure 10-2 – approximately 19 months.

Activity ID	Activity Name	Orig Dur	Start	Finish
HDD Construction Schedule - Newfoundland Side		984	01-Feb-11	10-Nov-14
Definition and Planning Phase		418	01-Feb-11	07-Sep-12
General		418	01-Feb-11	07-Sep-12
A1110	Engineering and Optimization	196	01-Feb-11	01-Nov-11
A1200	Test Pilot Bore Investigations	110	29-Apr-11	29-Sep-11
A1290	Supplementary Ground Surveys and Investigations	88	31-May-11	29-Sep-11
A1350	Final Design	135	30-Sep-11	05-Apr-12
A1300	Prequalification of HDD Tenderers	50	24-Feb-12	03-May-12
A1310	Class 2 Detailed Estimate	50	24-Feb-12	03-May-12
A1320	Tendering and Evaluation	90	04-May-12	06-Sep-12
A1360	Environmental Approval to Proceed in Place	0		06-Sep-12
A1340	Award HDD Contract	0	07-Sep-12	
Implementation Phase		565	10-Sep-12	10-Nov-14
General		565	10-Sep-12	10-Nov-14
A1010	Contractor Work Plan & Contingency Submittals	40	10-Sep-12*	02-Nov-12
A1000	Mobilization	60	02-Nov-12	03-Jan-13
A1370	Procurement, Fabrication, Delivery, Staging of Casing Pipe	148	05-Nov-12	29-May-13
A1020	Site Preparation and Equipment Setup	30	03-Jan-13	05-Feb-13
A1330	Final Cleanup and Demobilization	40	25-Sep-14	10-Nov-14
Bore No.1		153	05-Feb-13	06-Sep-13
A1030	Entry Casing Installation	14	05-Feb-13	21-Feb-13
A1040	Pilot Bore	50	21-Feb-13	19-Apr-13
A1380	Confirmation of Exit Location	7	19-Apr-13	30-Apr-13
A1410	Sealing of Pilot Bore	7	30-Apr-13	09-May-13
A1050	Ream No.1	45	09-May-13	27-Jun-13
A1060	Ream No.2	45	27-Jun-13	16-Aug-13
A1070	Swab Pass	7	16-Aug-13	22-Aug-13
A1080	Reposition of Drill Rig	7	22-Aug-13	01-Sep-13
A1090	Product Pipe Installation	7	22-Aug-13	01-Sep-13
A1100	Grouting Work	7	01-Sep-13	06-Sep-13
Bore No.2		142	01-Sep-13	18-Mar-14
A1120	Entry Casing Installation	14	01-Sep-13	12-Sep-13
A1130	Pilot Bore	50	12-Sep-13	05-Nov-13
A1140	Ream No.1	45	05-Nov-13	24-Dec-13
A1150	Ream No.2	45	24-Dec-13	12-Feb-14
A1390	Confirmation of Exit Location	7	12-Feb-14	21-Feb-14
A1160	Swab Pass	7	21-Feb-14	03-Mar-14
A1170	Reposition of Drill Rig	7	03-Mar-14	09-Mar-14
A1180	Product Pipe Installation	7	03-Mar-14	09-Mar-14
A1190	Grouting Work	7	09-Mar-14	18-Mar-14
Bore No.3		144	09-Mar-14	25-Sep-14
A1210	Entry Casing Installation	14	09-Mar-14	24-Mar-14
A1220	Pilot Bore	50	24-Mar-14	17-May-14
A1230	Ream No.1	45	17-May-14	05-Jul-14
A1240	Ream No.2	45	05-Jul-14	20-Aug-14
A1400	Confirmation of Exit Location	7	20-Aug-14	29-Aug-14
A1250	Swab Pass	7	29-Aug-14	04-Sep-14
A1260	Reposition of Drill Rig	7	04-Sep-14	14-Sep-14
A1270	Product Pipe Installation	7	14-Sep-14	19-Sep-14
A1280	Grouting Work	7	19-Sep-14	25-Sep-14



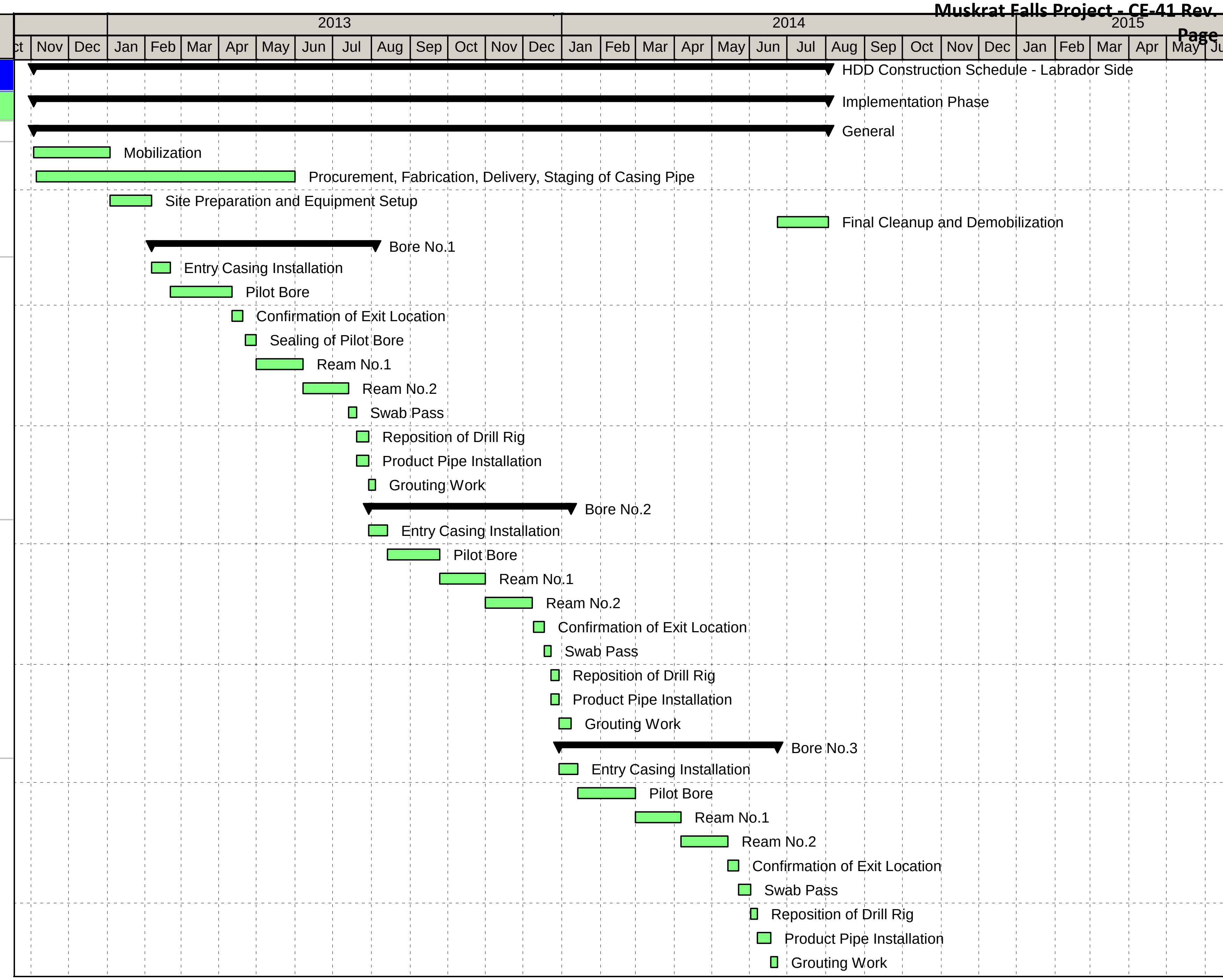
Remaining Level of Effort | Actual Work | Critical Remaining W...
Actual Level of Effort | Remaining Work | Milestone

HDD Construction Schedule - Newfoundland Side 500mm Casing Installation - 2700m Length

Figure 10-1

HATCH

Activity ID	Activity Name	Orig Dur	Start	Finish
HDD Construction Schedule - Labrador Side		455	02-Nov-12	03-Aug-14
Implementation Phase		455	02-Nov-12	03-Aug-14
General		455	02-Nov-12	03-Aug-14
A1000	Mobilization	60	02-Nov-12*	03-Jan-13
A1350	Procurement, Fabrication, Delivery, Staging of Casing Pipe	150	05-Nov-12	31-May-13
A1020	Site Preparation and Equipment Setup	30	03-Jan-13	05-Feb-13
A1330	Final Cleanup and Demobilization	40	23-Jun-14	03-Aug-14
Bore No.1		128	05-Feb-13	04-Aug-13
A1030	Entry Casing Installation	14	05-Feb-13	21-Feb-13
A1040	Pilot Bore	40	21-Feb-13	11-Apr-13
A1360	Confirmation of Exit Location	7	11-Apr-13	19-Apr-13
A1110	Sealing of Pilot Bore	7	22-Apr-13	30-Apr-13
A1050	Ream No.1	35	30-Apr-13	06-Jun-13
A1060	Ream No.2	35	06-Jun-13	14-Jul-13
A1070	Swab Pass	7	14-Jul-13	19-Jul-13
A1080	Reposition of Drill Rig	7	19-Jul-13	29-Jul-13
A1090	Product Pipe Installation	7	19-Jul-13	29-Jul-13
A1100	Grouting Work	7	29-Jul-13	04-Aug-13
Bore No.2		117	29-Jul-13	08-Jan-14
A1120	Entry Casing Installation	14	29-Jul-13	14-Aug-13
A1130	Pilot Bore	40	14-Aug-13	24-Sep-13
A1140	Ream No.1	35	24-Sep-13	31-Oct-13
A1150	Ream No.2	35	31-Oct-13	08-Dec-13
A1370	Confirmation of Exit Location	7	09-Dec-13	17-Dec-13
A1160	Swab Pass	7	18-Dec-13	23-Dec-13
A1170	Reposition of Drill Rig	7	23-Dec-13	29-Dec-13
A1180	Product Pipe Installation	7	23-Dec-13	29-Dec-13
A1190	Grouting Work	7	29-Dec-13	08-Jan-14
Bore No.3		125	29-Dec-13	23-Jun-14
A1210	Entry Casing Installation	14	29-Dec-13	14-Jan-14
A1220	Pilot Bore	40	14-Jan-14	28-Feb-14
A1230	Ream No.1	35	28-Feb-14	06-Apr-14
A1240	Ream No.2	35	06-Apr-14	14-May-14
A1380	Confirmation of Exit Location	7	14-May-14	22-May-14
A1250	Swab Pass	7	22-May-14	01-Jun-14
A1260	Reposition of Drill Rig	7	01-Jun-14	07-Jun-14
A1270	Product Pipe Installation	7	07-Jun-14	17-Jun-14
A1280	Grouting Work	7	17-Jun-14	23-Jun-14



Remaining Level of Effort — Actual Work — Critical Remaining W...
Actual Level of Effort — Remaining Work — ◆ Milestone

HDD Construction Schedule - Labrador Side 500mm Casing Installation - 1200m Length

Figure 10-2

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11. Recommendations for Future Work and Next Steps

11.1 Next Steps

1. **Formation of a Project Team (NE and Owner's Engineer) and preparation of a HDD Project Implementation Plan**

2. **Additional Geotechnical Investigations/Testing**

   Trenchless installations traditionally require geotechnical information at a regular spacing to properly characterize and assess installation risks along an alignment and ensure conditions are as assumed. Traditional land-based installations commonly have boreholes completed every 150 to 200 metres. Boreholes are especially required where geotechnical information is lacking, such as at Forteau Pointe where no geotechnical investigations have been completed to date. Marine installations carry greater installation risk and tend to have a much greater borehole spacing to characterize the bedrock materials, due to the prohibitive costs associated with completing boreholes from a barge/vessel over deep water. Additional geotechnical tests are recommended on previously drilled boreholes and any additional boreholes. These include uniaxial compressive strength tests and Cerchar abrasivity tests. Punch penetration tests should also be considered. Tests should be completed on a range of cores at regular spacing. This data is vital to selecting the appropriate drill bits and reamer assemblies for the anticipated geotechnical materials.

3. **Test Pilot Bore Investigations**

   It is recommended that Nalcor Energy considers completing a HDD test pilot bore investigation. For this, a HDD drill rig is mobilized to the preferred crossing sites on both the Labrador and Newfoundland Island sides of the SOBI to drill a pilot bore as close as possible to the preferred target exit location (without exiting the ocean floor) along a similarly preferred bore alignment. This pilot investigation would provide valuable information regarding zones of drilling fluid loss, evaluation of grouting methods within these zones, production rates and tooling life, ability to track the bore with state-of-the-art guidance systems, and any issues associated with bore instability that could influence the design of the installations. This data is very valuable to an HDD contractor, as they would be able to better characterize their construction risks and contingency plans, resulting in reduced construction costs in comparison to bids based on unknown risks. Once completed, these test pilot bores could be filled with a weak cement grout to provide some stability and potentially allow for their re-drilling and use as one of production drilling the installation pilot bores during construction. In this manner, a majority of the investigative costs associated with drilling a trial pilot bore may be recoverable as the costs to re-drill the pilot bore would be a small fraction of the original costs to drill a new pilot bore. Conceptual cost estimates for this test pilot bore investigative program are provided in Table 11-1 for the Island side for 2,700 m HDD length and Table 11-2 for a 2,000 m HDD length alternative. The indicated lengths of 2,500 metres and 1,800 m respectively are to avoid drilling out into the ocean, as this may require additional permits and environmental approvals. Conceptual cost estimates for the test pilot bores were developed assuming 24 hour operations seven days a week. The anticipated construction duration of the recommended geotechnical investigation is approximately four to six months total for both sides of the SOBI.

Table 11-1: Estimated Cost for Test Pilot Bore Investigation Program for 2,500 Metres

(Shoal Cove Drill Length of 2,500 metres)

Component	Estimated Cost ($)
Contractor Work Plan Development	[redacted]
Mobilization/Demobilization	[redacted]
Pilot Bore (Newfoundland Side of SOBI) Target Installation Length of 2,500 metres	[redacted]
Grouting of Newfoundland Pilot Bore	[redacted]
Pilot Bore (Labrador Side of SOBI) Target Installation Length of 1,000 metres	[redacted]
Grouting of Labrador Pilot Bore	[redacted]
***TOTAL**	[redacted]

Table 11-2: Estimated Cost for Test Pilot Bore Investigation Program for 1,800 Meters

(Shoal Cove Drill Length of 1,800 metres)

Component	Estimated Cost ($)
Contractor Work Plan Development	[redacted]
Mobilization/Demobilization	[redacted]
Pilot Bore (Newfoundland Side of SOBI) Target Installation Length of 1,800 metres	[redacted]
Grouting of Newfoundland Pilot Bore	[redacted]
Pilot Bore (Labrador Side of SOBI) Target Installation Length of 1,000 metres	[redacted]
Grouting of Labrador Pilot Bore	[redacted]
***TOTAL**	[redacted]

*Estimated costs exclude contingency, site preparation, permitting, temporary access road construction, site inspection etc.

4. **Proposal from Hatch for the Optimization/Definition Study and Nalcor Energy approval to proceed with the project definition**

5. **Additional (if any) environmental activities/approvals**

11.2 Future Items

Future work includes:

- Final selection of the HDD shoreline sites, arrangements and pipe casing diameters (optimization and project definition).
- Supplementary ground surveys.
- Prequalification of HDD tenderers.

- Tendering and final design.
- Construction/HDD installations.

Appendix A

Site Visit Report

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Trip Report

September 8, 2010

Nalcor Energy
Lower Churchill Project - HDD Feasibility Study
Site Visit

DISTRIBUTION

Those present

DATE: September 2-3, 2010

LOCATION: Newfoundland and Labrador Coasts at the Strait of Belle Isle

PRESENT: Brian Bugden – Nalcor Energy; Murray McFarlane – Hatch; Glenn Duyvestyn – HMM; Randy Divito - HMM; Marc Gelinas - HMM

PURPOSE: Site visits on each side of the Strait of Belle Isle to identify site specific constraints, potential HDD entry locations, preferred staging/construction areas, and observe the site topography.

1. Introduction

On September 2 and 3, 2010, Brian Bugden (Nalcor), and, Murray McFarlane, Glenn Duyvestyn, Randy Divito, and Marc Gelinas of Hatch, visited the proposed shoreline sites on Newfoundland and Labrador coasts. The sites were observed from air (helicopter) and by foot. The purpose of these visits was to:

- Observe the available staging areas and proximity to shore
- Assess fresh water resources in the immediate area
- Identify potential HDD entry and exit locations
- Observe the site topography in the areas of interest
- Observe the geotechnical materials at the proposed entry and exit locations
- Assess site specific constraints and construction risks
- Identify staging areas for fabricating the entire pipe string prior to installation

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2. Field Observations

2.1 Newfoundland Proposed HDD Locations

Three potential sites were reviewed on the Newfoundland side of the Strait of Belle Isle. These included Yankee Point, Savage Cove and Shoal Cove. Our general observations are grouped into separate headings for each of these proposed locations.

Yankee Point

- Bedrock exists at the surface and is massive. Bedding appears to be horizontal. Bedrock is fractured by fractures appear to be tight. Large blocks of bedrock.
- Borehole completed on site to support initial construction of fixed link tunnel at this location.
- Bedrock at surface appears to be well suited to an HDD installation.
- Site access is available by gravel road.
- Gravel quarry on site. Potential for on-site disposal of drill cuttings.
- Large flat staging area readily available.
- Very little shelter from weather and wind.
- Elevation of site is approximately 5 metres above ocean level.
- One moderate pond exists adjacent to the site. Appears to be fairly shallow.
- Protected plants in area.
- No residents in immediate vicinity.
- No power in close vicinity.

Savage Cove

- Bedrock exists at the surface and is massive. Bedding appears to be horizontal. Bedrock is fractured but fractures appear to be tight. Large blocks of bedrock.
- Borehole NF-01A and NF-01B completed in vicinity.
- Deeper water closer to shore in vicinity of site (than at Yankee Point).
- Bedrock at surface appears to be well suited to an HDD installation.
- Site access is available by gravel road.
- Potential for on-site disposal of drill cuttings.
- Large flat staging area readily available.
- Very little shelter from weather and wind.
- Elevation of site is approximately 5 metres above ocean level.
- Protected plants in area.

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- Site is visible to local residents. Power and water potential in area near residences.
- No ponds exist within immediate vicinity. Closest pond is located east of highway.

Shoal Cove

- Bedrock exists at the surface and is massive. Bedding appears to be horizontal. Bedrock is fractured but fractures appear to be tight. Large blocks of bedrock.
- Borehole NF-02 completed approximately 1.5 km to the northeast.
- Deeper water closer to shore in vicinity of site (than at Yankee Point).
- Bedrock at surface appears to be well suited to an HDD installation.
- Site access is available by gravel road.
- Potential for on-site disposal of drill cuttings.
- Local residents using site for disposal of landfill waste.
- Large flat staging area readily available.
- Very little shelter from weather and wind.
- Elevation of site is approximately 5 metres above ocean level.
- Protected plants in area.
- Site is visible to local residents.
- No ponds exist within immediate vicinity. Closest pond is located east of highway.

2.2 Labrador Proposed HDD Locations

Two potential sites were reviewed on the Labrador side of the Strait of Belle Isle. These were Pointe Amour and Forteau Point. Our general observations are grouped into separate headings for each of these proposed locations.

Pointe Amour

- Relatively flat grass fields offer several alignment choices.
- Pointe Amour lighthouse and associated dwellings are regarded as historical sites. Construction activities will be visible at this location.
- Site access is available by gravel road.
- Exposed bedrock outcrop southeast of lighthouse. Bedrock appears to be near horizontally bedded with thin to thick beds. Vertical fractures observed throughout cliff face. Visual evidence of block failure.
- Borehole LAB-01 and LAB-02 completed in vicinity.
- Borehole completed on site to support initial construction of fixed link tunnel at this location.

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- Potential for communication with ocean in boreholes.
- Potential for on-site disposal of drill cuttings.
- Several large flat staging areas readily available.
- Elevation of site is approximately 20 metres above ocean level.
- Site offers shortest distance to deep water.
- Some shallow ponds between lighthouse and Trans-Labrador Highway.
- Power may be available in vicinity.
- Existing corrugated metal building could be used for storage of materials.

Forteau Point

- Boulder and cobble fields exist between exposed bedrock and shoreline. Likely rockfall from adjacent cliff. Layer appears to be fairly thick. Lack of gravel and smaller cobble sizes at surface of boulder and cobble field. Material is well rounded. Some boulders appear to be granitic as opposed to sandstone.
- Rock cliff face appears to be near horizontally bedded with thin to thick beds. Vertical fractures seen throughout cliff face. Fractures appear to be tight.
- Boulder and cobble field appears to lie within a topographic low area between adjacent cliffs.
- No borehole information available at site.
- Site would require construction of access road. It would appear to be possible to mobilize a drill rig to the site to drill vertical boreholes prior to constructing a road.
- Boulder field does not exist south of exposed cliffs.
- Bedrock observed offshore below ocean level.
- Relatively flat open areas may offer several alignment choices.
- Potential for on-site disposal of drill cuttings.
- Elevation of site is approximately 10 to 20 metres above ocean level.
- Site offers short distance to deep water.
- Some moderately deep ponds in vicinity. Waterfall west of proposed HDD location.
- Power is not available at the site.
- Site is secluded and away from local residences.

Glenn Duyvestyn

GD:cdh

Appendix B

Risk Registers

Table 1: Risk Register for Shoreline Crossings at Yankee Point, Savage Cove or Shoal Cove - Newfoundland Island Side of the Strait of Belle Isle. Horizontal Directional Drilling Feasibility Assessment

Likelihood Categories

Score	Descriptor	Probability
1	Improbable	about 1 in 1000
2	Remote	about 1 in 100
3	Occasional	about 1 in 10
4	Probable	more likely than not
5	Frequent	expected to happen

Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5					
4					
3					
2					
1					

HIGH
MEDIUM
LOW

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
2	• Minor Injuries • Operative Requires First Aid Treatment • Stops Work • Medium term local damage or short term regional damage	• $10's k extra cost	• Significant revenue loss • Minor security alert • Re-routing local access
3	• Reportable / Lost Time Injury or Illness • Long term local damage	• Cost to Project ($100's k) • Delay in Project of Several Weeks (on Critical Path)	• Effects of a facility closure • Major regional impact Delay of Several Weeks (Critical Path)
4	• Major injury or illness with long term effects • Long term systematic damage	• Cost to Project ($1M's) • Delay in Project of Several Months (on Critical Path)	• Major effects to infrastructure Delay of Several Months (Critical Path)
5	• Fatalities • Permanent damage	• Potential to close down the project	• Loss of functionality / Close down of Project

Risk Level Action

Risk Level	Health, Safety & Environment Risks	Operational Risks
Low	• Check that no further risks can be eliminated by modifications of design • Proceed with Design	• Seek alternative, and assess cost to benefit of
Medium	• Consider Alternative Design or Construction Method • If Alternatives are not available, specify precautions to be adopted • List residual hazards in risk register	• Disseminate risk assessment information to
High	• Seek alternative solutions • If Alternatives are not available, specify precautions to be adopted and advise senior management and planning supervisor (where applicable) • List residual hazards in risk register	• List residual hazards in risk register

Risk Type: S= Safety, E= Environmental, O= Operational $= Financial

Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Geotechnical Risk	1	E, $, O	Loss of drilling fluids / Frac out of drilling fluids. Flow of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of significant drilling fluids to the ocean/marine environment.	Encountering bedrock materials with significant open fracture/joint networks and communication with ocean. Encountering bedrock with low Rock Quality Designations (RQD). Encountering bedrock with preferential flow pathways. Risk increases with lower RQD values.	5	3	High	3	High	3	High	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identifying potential preferential flow pathways from borehole logs including field notes. Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design alignment within bedrock units with higher rock quality designations to the extent possible. Develop contingency plan to inject loss circulation material to isolate preferential flow pathways. Determine drilling/reaming strategy to limit mud loss. Incorporate conductor casing into bore design.	Possibility remains but likelihood reduced.	3	3	Medium	3	Medium	3	Medium
HDD - Geotechnical Risk	2	E, $, O	Loss of drilling fluids / Frac out of drilling fluids. Flow of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of significant drilling fluids to the ocean environment.	Inability to effectively seal open fracture/joint networks with grout. Inability to re-establish drilling fluid returns.	3	3	Medium	3	Medium	3	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identifying potential preferential flow pathways from borehole logs including field notes. Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design alignment within bedrock units with higher rock quality designations to the extent possible. Develop contingency plan to inject loss circulation material to isolate preferential flow pathways. Determine drilling/reaming strategy to limit mud loss. Consider use of single or multiple conductor casing(s) within bore design. Consider use of temporary washover casing to provide a pathway for fluid flow to the drill rig location.	Possibility remains but likelihood reduced.	2	3	Medium	3	Medium	3	Medium
HDD - Geotechnical Risk	3	E, $, O	Loss of drilling fluids / Frac out of drilling fluids. Flow of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of significant drilling fluids to the ocean/marine environment.	Encountering bedrock materials with much higher unconfined compressive strengths than anticipated leading to decreased drilling production and increased drilling fluid pumping volumes.	4	3	High	3	High	3	High	Complete geotechnical investigation to characterize bedrock materials where geotechnical information is not available. Complete unconfined compressive strength testing of bedrock core to assess strength and provide means for contractor to select appropriate drilling equipment.	Possibility remains but likelihood reduced.	1	3	Low	3	Low	3	Low
HDD - Geotechnical Risk	4	E, $, O	Loss of drilling fluids / Frac out of drilling fluids. Flow of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of significant drilling fluids to the ocean/marine environment.	Insufficient depth of cover above bore. Bore designed within zone of high permeability as identified in Geotechnical Reports.	5	3	High	4	High	4	High	Complete thorough and accurate bathymetric survey of the HDD alignment in near shore environment. Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design bore within uniform materials and with sufficient depth of cover as quick as possible. Consider use of a conductor casing within the bore design. Perform an ROV survey of the exit location and the alignment route to determine the condition of the bedrock/ocean floor materials including infilling of joints. Further assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	2	3	Medium	4	Medium	4	Medium
HDD - Geotechnical Risk	5	$, O	Bore instability *during pilot bore drilling*. Inability to support geotechnical materials along exposed surface of bore walls. Collapse of the HDD bore. Over mining of surrounding bedrock materials while excess materials are removed from the bore.	Raveling due to drilling parallel to major joint/fracture orientations. Exposing/day lighting unstable blocks of bedrock in crown of HDD bore. Risk increases with increase in bore diameter.	3	2	Medium	3	Medium	3	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify major joint and fracture network. Design alignment such that it does not coincide with major fracture/joint orientations to extent possible. Develop contingency plan to remove cuttings from the bore and to reduce raveling potential. Complete a swab pass to gauge condition of bore prior to installation. Further assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium

Table 1: Risk Register for Shoreline Crossings at Yankee Point, Savage Cove or Shoal Cove - Newfoundland Island Side of the Strait of Belle Isle. Horizontal Directional Drilling Feasibility Assessment

Likelihood Categories

Score	Descriptor	Probability
1	Improbable	about 1 in 1000
2	Remote	about 1 in 100
3	Occasional	about 1 in 10
4	Probable	more likely than not
5	Frequent	expected to happen

Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5	Medium	High	High	High	High
4	Medium	Medium	High	High	High
3	Low	Medium	Medium	High	High
2	Low	Low	Medium	Medium	High
1	Low	Low	Low	Medium	Medium

LOW · MEDIUM · HIGH

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
2	• Minor Injuries • Operative Requires First Aid Treatment • Stops Work • Medium term local damage or short term regional damage	• $10's k extra cost	• Significant revenue loss • Minor security alert • Re-routing local access
3	• Reportable / Lost Time Injury or Illness • Long term local damage	• Cost to Project ($100's k) • Delay in Project of Several Weeks (on Critical Path)	• Effects of a facility closure • Major regional impact Delay of Several Weeks (Critical Path)
4	• Major injury or illness with long term effects • Long term systematic damage	• Cost to Project ($1M's) • Delay in Project of Several Months (on Critical Path)	• Major effects to infrastructure Delay of Several Months (Critical Path)
5	• Fatalities • Permanent damage	• Potential to close down the project	• Loss of functionality / Close down of Project

Risk Level Action

Risk Level	Health, Safety & Environment Risks	Operational Risks
Low	• Check that no further risks can be eliminated by modifications of design • Proceed with Design	• Seek alternative, and assess cost to benefit of
Medium	• Consider Alternative Design or Construction Method • If Alternatives are not available, specify precautions to be adopted • List residual hazards in risk register	• Disseminate risk assessment information to
High	• Seek alternative solutions • If Alternatives are not available, specify precautions to be adopted and advise senior management and planning supervisor (where applicable) • List residual hazards in risk register	• List residual hazards in risk register

Risk Type: S= Safety, E= Environmental, O= Operational $= Financial

Activity / Element	Risk No.	Type	Risk/Hazard	Cause	Post / Pre RCM: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Geotechnical Risk	6	$, O	Stuck drilling equipment *during pilot bore*. Inability to advance/retract drill pipe and down hole tooling.	Bore instability resulting from raveling of material into the bore behind drill bit. Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the borehole.	2	2	Low	3	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify zones of crushed rock. Design alignment to avoid or cross zones at the steepest angle possible. Develop contingency plan to reduce raveling potential or to control raveling. Require drilling fluid additives to reduce swelling potential. Require verification of mud motor and drill bit condition on a regular basis.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	4	Medium
HDD - Geotechnical Risk	7	$, O	Bore instability *during reaming*. Inability to support geotechnical materials along exposed surface of bore walls. Collapse of the HDD bore. Over mining of surrounding bedrock materials while excess materials are removed from the bore.	Raveling due to drilling parallel to major joint/fracture orientations. Exposing/day lighting unstable blocks of bedrock in crown of HDD bore. Risk increases with increase in bore diameter.	3	2	Medium	4	High	4	High	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify major joint and fracture network. Design alignment such that it does not coincide with major fracture/joint orientations. Develop contingency plan to remove cuttings from the bore and to reduce raveling potential. Complete a swab pass to gauge condition of bore prior to installation. Further assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	2	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	8	$, O	Stuck drilling equipment *during reaming pass(es)*. Inability to advance/retract drill pipe and down hole tooling.	Bore instability resulting from raveling of material into the bore after swab pass. Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the borehole. This condition was evidenced in Borehole NF-01A at 70m borehole length.	2	2	Low	4	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify zones of crushed rock. Design alignment to avoid or cross zones at the steepest angle possible. Develop contingency plan to reduce raveling potential or to control raveling. Require drilling fluid additives to reduce swelling potential. Require verification of mud motor and hole openers condition on a regular basis.	Possibility remains.	2	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	9	$, O	Bore instability *during swab pass*. Inability to support geotechnical materials along exposed surface of bore walls. Collapse of the HDD bore. Over mining of surrounding bedrock materials while excess materials are removed from the bore.	Raveling due to drilling parallel to major joint/fracture orientations. Exposing/day lighting unstable blocks of bedrock in crown of HDD bore. Risk increases with increase in bore diameter.	2	2	Low	4	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify major joint and fracture network. Design alignment such that it does not coincide with major fracture/joint orientations. Develop contingency plan to remove cuttings from the bore and to reduce raveling potential. Further assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	1	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	10	$, O	Stuck drilling equipment *during swab pass*. Inability to advance/retract drill pipe and down hole tooling.	Bore instability resulting from raveling of material into the bore after swab pass. Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the borehole. This condition was evidenced in Borehole NF-01A at 70m borehole length.	2	2	Low	4	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify zones of crushed rock. Design alignment to avoid or cross zones at the steepest angle possible. Develop contingency plan to reduce raveling potential or to control raveling.	Possibility remains.	2	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	11	$, O	Bore instability *during casing / lining pipe installation*. Inability to support geotechnical materials along exposed surface of bore walls. Collapse of the HDD bore. Over mining of surrounding bedrock materials while excess materials are removed from the bore.	Raveling due to drilling parallel to major joint/fracture orientations. Exposing/day lighting unstable blocks of bedrock in crown of HDD bore.	2	2	Low	4	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify major joint and fracture network. Design alignment such that it does not coincide with major fracture/joint orientations. Develop contingency plan to remove cuttings from the bore. Complete a swab pass to gauge condition of bore prior to installation.	Possibility remains.	2	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	12	$, O	Stuck casing / liner pipe during product *during casing / liner pipe installation*. Inability to advance/retract drill pipe and down hole tooling.	Bore instability resulting from raveling of material into the bore after swab pass. Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the borehole.	2	2	Low	4	Medium	4	Medium	Require successful completion of swab pass prior to casing / liner pipe insertion. Review drill rig rotary torque and thrust during swab pass. Consider pushing in a sample length (i.e. 10 to 50 metre section of steel casing) through the bore prior to installing the entire casing / liner pipe string.	Possibility remains but likelihood reduced.	1	2	Low	4	Medium	4	Medium

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Likelihood Categories

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Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5				HIGH	
4					
3		MEDIUM			
2	LOW				
1					

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
2	• Minor Injuries • Operative Requires First Aid Treatment • Stops Work • Medium term local damage or short term regional damage	• $10's k extra cost	• Significant revenue loss • Minor security alert • Re-routing local access
3	• Reportable / Lost Time Injury or Illness • Long term local damage	• Cost to Project ($100's k) • Delay in Project of Several Weeks (on Critical Path)	• Effects of a facility closure • Major regional impact Delay of Several Weeks (Critical Path)
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Risk Level Action

Risk Level	Health, Safety & Environment Risks	Operational Risks
Low	• Check that no further risks can be eliminated by modifications of design • Proceed with Design	• Seek alternative, and assess cost to benefit of
Medium	• Consider Alternative Design or Construction Method • If Alternatives are not available, specify precautions to be adopted • List residual hazards in risk register	• Disseminate risk assessment information to
High	• Seek alternative solutions • If Alternatives are not available, specify precautions to be adopted and advise senior management and planning supervisor (where applicable) • List residual hazards in risk register	• List residual hazards in risk register

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Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Geotechnical Risk	13	$, O	Raveling of zones of crushed bedrock materials into the bore. Borehole instability.	Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the HDD bore.	2	2	Low	3	Medium	2	Low	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify zones of crushed rock. Design alignment to avoid or cross zones at the steepest angle possible. Develop contingency plan to reduce raveling potential or to control raveling. Complete a swab pass to gauge condition of bore prior to installation. Require drilling fluid additives to condition drilling fluid.	Possibility remains.	2	2	Low	3	Medium	2	Low
HDD - Geotechnical Risk	14	E, $, O	Inability to maintain bore stability in vicinity of ocean floor.	Drilling with increasingly lower depth of cover above bore as HDD installation nears planned exit location. Encountered bedrock materials that are not self supporting (i.e. bedrock with very low RQD).	4	3	High	3	High	3	High	Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design bore within uniform materials to maximum extent possible. Develop contingency plans. Perform ROV survey of anticipated exit locations. Consider jetting/dredging to remove loose material above sound bedrock.	Possibility remains but likelihood reduced.	3	3	Medium	3	Medium	3	Medium
HDD - Geotechnical Risk	15	E, $, O	Inability to advance drill bit/hole opener. Inability to insert product pipe / liner casing.	Encountering soils on ocean floor with a high percentage of *cobbles* requiring pull back and re-drilling of the bore.	3	3	Medium	4	High	4	High	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit on sloped surface or in an area lacking cobbles. Dredge loose material away from intended exit location. May require having dredge material on standby. May experience weather delays if dredging required depending on time of year.	Possibility remains but likelihood and severity reduced.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	16	E, $, O	Inability to advance drill bit/hole opener. Inability to insert product pipe / liner casing.	Encountering soils on ocean floor with a high percentage of *gravels* resulting in raveling and bore instability/collapse.	3	3	Medium	4	High	4	High	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit on sloped surface or ina area lacking gravels. Develop ability to jet (inject drilling fluids) in front of casing / liner pipe during insertion. Jet/dredge loose material away from intended exit location. May require having jet/dredge equipment on standby. May experience weather delays if dredging required depending on time of year.	Possibility remains but likelihood and severity reduced.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	17	$, O	Inability to maintain bore stability/condition bore.	Encountering bedrock materials with artesian groundwater conditions that prevent the build-up of a filter cake along the walls of the bore.	1	2	Low	2	Low	2	Low	Characterize potential risk by reviewing borehole logs and field notes. Minimize potential by designing alignment within favorable bedrock units. Develop contingency plans to address. Require use of drilling fluid additives to mitigate artesian conditions.	Possibility remains.	1	2	Low	2	Low	2	Low
HDD - Geotechnical Risk	18	$, O	Excessive drill tool wear requiring frequent tool replacements.	Drilling through Hawke Bay Fm (NL) rock mass with very hard crystalline conglomerate in very strong host rock matrix. Drilling through abrasive bedrock materials.	2	2	Low	3	Medium	2	Low	Complete geotechnical investigation to characterize bedrock materials where geotechnical information is not available. Complete unconfined compressive strength and Cerchar abrasivity testing of bedrock core to assess strength and abrasivity and provide means for contractor to select appropriate drilling equipment. Require sufficient amount of drill bits, hole openers and mud motors to avoid delays associated with worn out equipment.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	2	Low
HDD - Geotechnical Risk	19	$, O	Loss or excessive deviation of pilot bore alignment.	Encountering a large vug in limestone layers.	2	2	Low	3	Medium	3	Medium	Assess potential by reviewing existing geologic information, and/or with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance.	Possibility remains.	2	2	Low	3	Medium	3	Medium

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Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5					
4				HIGH	
3		MEDIUM			
2	LOW				
1					

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
2	• Minor Injuries • Operative Requires First Aid Treatment • Stops Work • Medium term local damage or short term regional damage	• $10's k extra cost	• Significant revenue loss • Minor security alert • Re-routing local access
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Risk Level Action

Risk Level	Health, Safety & Environment Risks	Operational Risks
Low	• Check that no further risks can be eliminated by modifications of design • Proceed with Design	• Seek alternative, and assess cost to benefit of
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Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Geotechnical Risk	20	$, O	Loss of down hole drilling equipment.	Encountering a large vug in limestone layers.	2	2	Low	3	Medium	3	Medium	Assess potential by reviewing existing geologic information and/or with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance.	Possibility remains.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	21	$, O	Borehole instability and collapse.	Poor rock quality due to crushed rock zones, tectonic zones (faults, lineaments, etc.), and other zones where core loss was encountered in Bradore Fm (LAB) and in Hawke Bay Fm (NL) due to reduced slake durability. These conditions can result in long-term borehole instability if left unlined.	3	2	Medium	3	Medium	3	Medium	Complete geotechnical investigation to characterize bedrock materials where geotechnical information is not available. Develop contingency plans. Assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	22	$, O	Sedimentation of casing / liner pipe at exit location on ocean floor.	Strong ocean currents that are capable of carrying significant sediment bedload.	3	2	Medium	4	High	4	High	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit on sloped surface. Develop contingency plans. Consider installing a plug on bottom of casing. Select exit locations away from areas with obvious sedimentation transport.	Possibility remains but likelihood and severity reduced.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	23	$, O	Inability to steer for line and grade through ocean floor sediments. Inability to support weight of drilling equipment as drilling equipment is advanced through ocean floor sediment.	Extensive deposits of sand on the ocean floor.	2	2	Low	3	Medium	3	Medium	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit away from thick deposits. Develop ability to jet (inject drilling fluids) in front of casing pipe during insertion. Select exit locations away from areas with obvious sedimentation transport.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Geotechnical Risk	24	$, O	Inability to install casing pipe through ocean floor sediments.	Extensive deposits of soil on the ocean floor that interfere with ability to build angle and exit the ocean floor.	2	2	Low	3	Medium	3	Medium	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit away from thick deposits. Develop ability to jet (inject drilling fluids) in front of liner / casing pipe during insertion. Consider providing the ability to remove some of the water used for buoyancy control and replace with air to add buoyancy to the product pipe. Select exit locations away from areas with obvious sedimentation transport.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Installation Risk	25	E, $, O	Loss of down hole tooling (in whole or in part). Inability to remove down hole equipment from bore. Inability to retrieve down hole equipment *during pilot bore drilling*.	Mechanical failure of equipment. Excess wear of drilling equipment. Bore Instability.	2	3	Medium	3	Medium	2	Low	Require certification of all drilling equipment including operating hours since last refurbishment. Develop criteria for verification of key equipment components on a regular basis. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent. Assess potential with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance. Fish damaged tooling from bore. Re-drill around lost tooling.	Possibility remains.	2	3	Medium	3	Medium	2	Low
HDD - Installation Risk	26	E, $, O	Loss of down hole tooling (in whole or in part). Inability to remove down hole equipment from bore. In ability to retrieve down hole equipment during *ream/hole opening pass(es)*.	Mechanical failure of equipment. Excess wear of drilling equipment. Bore Instability.	2	3	Medium	4	Medium	4	Medium	Require certification of all drilling equipment including operating hours since last refurbishment. Develop criteria for verification of key components on a regular basis. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent. Assess potential with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance. Fish damaged tooling out of bore. Steering around lost equipment would require partial redrilling of pilot bore.	Possibility remains.	2	3	Medium	4	Medium	4	Medium

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Risk Level Action

Risk Level	Health, Safety & Environment Risks	Operational Risks
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HDD - Installation Risk	27	E, $, O	Loss of down hole tooling (in whole or in part). Inability to remove down hole equipment from bore. In ability to retrieve down hole equipment *during swab pass* .	Mechanical failure of equipment. Excess wear of drilling equipment. Bore Instability.	2	3	Medium	4	Medium	4	Medium	Require certification of all drilling equipment including operating hours since last refurbishment. Develop criteria for verification of key components on a regular basis. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent. Assess potential with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance. Fish damaged tooling out of bore. Steering around lost equipment would require partial redrilling of pilot bore.	Possibility remains.	2	3	Medium	4	Medium	4	Medium
HDD - Installation Risk	28	$	Difficulty/Inability to remove cuttings from within the HDD bore.	Drilling with water as opposed to drilling with properly engineered bentonite drilling fluid.	1	2	Low	3	Low	2	Low	Develop experience criteria for mud engineer to monitor and adjust drilling fluids during the drilling process. Require sufficient materials on site to prevent shortage and delays waiting for transportation of additional materials.	Possibility remains.	1	2	Low	3	Low	2	Low
HDD - Installation Risk	29	$, O	Significant/extensive delays in the drilling process while waiting for new drilling mud.	Loss of drilling fluids / Frac out of drilling fluids. Loss of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of Drilling fluids to the ocean/marine environment. Inadequate or unreliable fresh water source.	3	2	Medium	3	Medium	2	Medium	Identify primary and secondary sources of fresh water. These sources can include but should not be limited to drilling of fresh water wells, transportation of water to the site from a distant source, tapping into freshwater lakes, etc. Develop contingency plans for addressing frac out/loss of fluids.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	2	Low
HDD - Installation Risk	30	$, O	Multiple bores intersecting and damaging previously installed casing / liner pipelines.	Insufficient spacing between parallel bores. Inaccurate location / lack of verification of position of previously installed pipelines.	3	2	Medium	3	Medium	3	Medium	Provide adequate separation distance. Separate bores in horizontal and/or vertical planes. Use guidance system capable of adequately tracking down hole tooling. Require use of gyro guidance system that is not susceptible to interference. Design bore geometries in a fanning outward pattern to increase the spacing between the bores with depth.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Installation Risk	31	$, O	Multiple bores intersecting and damaging previously installed casing / liner pipelines.	Operator error, interference with guidance system, inability to track pilot bore. Using a guidance system that is subject to interference by bedrock materials with magnetic properties.	3	2	Medium	3	Medium	3	Medium	Develop contractor experience qualifications for operating tracking system. Require regular calibration checks of guidance system. Design bore geometries in a fanning outward pattern to increase the spacing between the bores. Require use of gyro guidance system. Require the use of experienced site inspectors to monitor drilling progress.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Installation Risk	32	$, O	Damage to previously installed casing / liner pipelines.	Communication of joints/fracture networks between adjacent bores. Damage caused by excessive grouting pressures during grouting operations during attempts to re-establish drilling fluid returns.	1	1	Low	2	Low	1	Low	Require insertion of steel casing / liner pipe prior to initiating drilling of subsequent pilot bore. Design bore geometries in a fanning outward pattern to increase the spacing between the bores as it increases in depth. Design casing / liner to resist anticipated forces.	Possibility remains.	1	1	Low	2	Low	1	Low
HDD - Installation Risk	33	E, $, O	Prematurely filling of HDD bore with grout during drilling of adjacent bore (assumes casing / liner pipe has not yet been installed).	Communication of joints/fracture networks between adjacent bores. Loss of grout through joint/fracture networks during grouting operations during attempts to re-establish drilling fluid returns.	3	3	Medium	4	High	4	High	Require insertion of steel casing / liner pipe prior to initiating drilling of subsequent pilot bore. Design bore geometries in a fanning outward pattern to increase the spacing between the bores as it increases in depth.	Possibility remains but likelihood and severity reduced.	1	2	Low	2	Low	2	Low
HDD - Installation Risk	34	$, O	Inability to advance drill bit/hole opener. Inability to maintain bore stability. Locking up of drilling equipment due to size of cuttings and inability to remove cuttings.	Producing gravel sized cuttings during bedrock drilling. Encountering pebble conglomerate that produces a large volume of pebble sized clasts. Encountering bedrock materials with a tendency to ravel into the bore.	3	2	Medium	3	Medium	2	Medium	Develop submittal requirements to review Contractor's planned equipment. Develop experience criteria for HDD rig operator, mud engineer and site superintendent. Develop contingency plans that may include, but are not limited to, increasing the carrying capacity of the drilling fluid by adjusting mud properties, increasing drilling fluid pumping rates, etc. Require use of experienced site inspector to monitor drilling progress.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	2	Low

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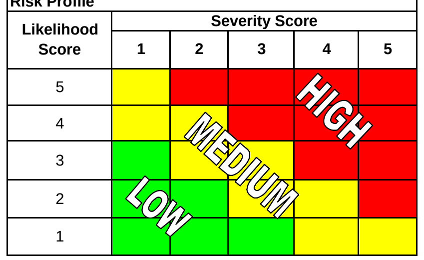

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Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Health, Safety & Environment: Risk	Financial: Severity	Financial: Risk	Schedule / Operational: Severity	Schedule / Operational: Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Health, Safety & Environment: Risk	Financial: Severity	Financial: Risk	Operational: Severity	Operational: Risk
HDD - Installation Risk	35	$, O	Loss of ability to track pilot bore(s) along proposed HDD bore path.	Encountering source of interference that disrupts tracking system. Inability to stage equipment necessary to enable traditional secondary tracking of the pilot bore(s).	2	2	Low	3	Medium	3	Medium	Determine all potential sources of interference at the crossing location. Develop experience/qualification requirements for Contractor and Guidance System personnel. Determine requirements for Contractor specific equipment (i.e. gyro survey equipment) and verify capabilities for use at the site.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Installation Risk	36	E, $, O	Inability to maintain line and grade.	Difficulty inducing a steering correction. Improper down hole tooling/equipment. Improper down hole tooling/equipment set up. Improper use of guidance equipment. Malfunction of the guidance system. Drift in the guidance system.	3	2	Medium	3	Medium	3	Medium	Develop performance criteria on tolerances for line and grade. Require immediate notification if issues arise. Develop contingency plans. Develop performance criteria for guidance system. Develop experience/qualification requirements for Contractor, drill rig operator, steering personnel, and site superintendent. Determine requirements for Contractor specific equipment and verify capabilities for use at the site. Require certificates of calibration for all guidance components.	Possibility remains.	2	2	Low	3	Medium	3	Medium
HDD - Installation Risk	37	E, $, O	Missed exiting at target exit location (long) by greater than 10 metres.	Inability to track pilot bore(s), improper use of guidance equipment. Malfunction of the guidance system. Drift in the guidance system. Difficulty inducing a steering correction (building angle at exit). Poorly defined ocean floor topography in target exit location. Discrepancy/offset of survey contours between water and land.	3	2	Medium	3	Medium	2	Medium	Develop experience/qualification requirements for Contractor and Guidance System personnel. Determine requirements for Contractor specific equipment and verify capabilities for use at the site. Require certificates of calibration for all guidance components. Consider completing a detailed bathymetric survey of the area surrounding the target exit locations. Ensure offshore survey is properly converted to onshore Geodetic survey coordinates.	Possibility remains.	2	2	Low	3	Medium	2	Low
HDD - Installation Risk	38	E, $, O	Missed exiting at target exit location (left/right) by greater than 10 metres.	Inability to track pilot bore(s), improper use of guidance equipment. Malfunction of the guidance system. Drift in the guidance system. Poorly defined ocean floor topography in target exit location. Discrepancy/offset of survey contours between water and land.	3	2	Medium	3	Medium	2	Medium	Develop experience/qualification requirements for Contractor and Guidance System personnel. Determine requirements for Contractor specific equipment and verify capabilities for use at the site. Require certificates of calibration for all guidance components. Ensure offshore survey is properly converted to onshore Geodetic survey coordinates.	Possibility remains.	2	2	Low	3	Medium	2	Low
HDD - Installation Risk	39	$, O	Missed exiting at target exit location (short). Prematurely exiting through ocean floor by greater than 10 metres.	Inability to track pilot bore(s), improper use of guidance equipment. Malfunction of the guidance system. Drift in the guidance system. Poorly defined ocean floor topography in target exit location. Discrepancy/offset of survey contours between water and land.	3	2	Medium	3	Medium	2	Medium	Develop experience/qualification requirements for Contractor and Guidance System personnel. Determine requirements for Contractor specific equipment and verify capabilities for use at the site. Require certificates of calibration for all guidance components. Ensure offshore survey is properly converted to onshore Geodetic survey coordinates.	Possibility remains.	2	2	Low	3	Medium	2	Low
HDD - Installation Risk	40	E, $, O	High installation loads. Damaged to casing / liner pipe.	Improper conditioning of the bore. Improper pipeline insertion into the HDD bore. Improper use of buoyancy compensation during pullback operations.	2	3	Medium	4	Medium	4	Medium	Fabricate pipe string in one complete length to eliminate prolonged stoppages to weld additional sections of pipe together. Determine required installation loads and compare with drill rig and pipe capabilities. Require swab pass through bore to gauge bore condition. Develop contingency plans. Remove as much of the cuttings from the bore as possible prior to insertion. Remove casing from bore with thruster to allow further bore conditioning.	Possibility remains but likelihood reduced.	1	3	Low	4	Medium	4	Medium
HDD - Installation Risk	41	E, $, O	Loss of drilling fluids / Frac out of drilling fluids.	Collapse of bore material behind down hole tooling that leads to blockage of the bore annulus and significant drilling fluid pressure increase. Producing cuttings that are too big (i.e., gravel size and larger) or too thick/viscous.	2	3	Medium	3	Medium	3	Medium	Complete geotechnical investigation to characterize site bedrock materials. Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design bore within uniform materials with sufficient depth of cover. Design bore in more favorable bedrock.	Possibility remains but likelihood reduced.	1	3	Low	3	Low	3	Low
HDD - Installation Risk	42	E, $, O	Loss of drilling fluids / Frac out of drilling fluids.	Increasing the diameter of the bore too quickly. Reaming the bore to final diameter in one pass following completion of the pilot bore (depending on bore diameter). Slurry (mud and cuttings) that are too thick and lead to pressure buildup event.	3	3	Medium	3	Medium	3	Medium	Require experience/qualification/performance requirements in the project specifications. Require multiple reaming passes through the bore. Require swab pass prior to product pipe insertion. Develop submittal requirements to review Contractor's planned equipment.	Possibility remains but likelihood reduced.	2	3	Medium	3	Medium	3	Medium

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1	Improbable	about 1 in 1000
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5	Frequent	expected to happen

Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5					
4					
3					
2					
1					

HIGH
MEDIUM
LOW

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
2	• Minor Injuries • Operative Requires First Aid Treatment • Stops Work • Medium term local damage or short term regional damage	• $10's k extra cost	• Significant revenue loss • Minor security alert • Re-routing local access
3	• Reportable / Lost Time Injury or Illness • Long term local damage	• Cost to Project ($100's k) • Delay in Project of Several Weeks (on Critical Path)	• Effects of a facility closure • Major regional impact Delay of Several Weeks (Critical Path)
4	• Major injury or illness with long term effects • Long term systematic damage	• Cost to Project ($1M's) • Delay in Project of Several Months (on Critical Path)	• Major effects to infrastructure Delay of Several Months (Critical Path)
5	• Fatalities • Permanent damage	• Potential to close down the project	• Loss of functionality / Close down of Project

Risk Level Action

Risk Level	Health, Safety & Environment Risks	Operational Risks
Low	• Check that no further risks can be eliminated by modifications of design • Proceed with Design	• Seek alternative, and assess cost to benefit of
Medium	• Consider Alternative Design or Construction Method • If Alternatives are not available, specify precautions to be adopted • List residual hazards in risk register	• Disseminate risk assessment information to
High	• Seek alternative solutions • If Alternatives are not available, specify precautions to be adopted and advise senior management and planning supervisor (where applicable) • List residual hazards in risk register	• List residual hazards in risk register

Risk Type: S= Safety, E= Environmental, O= Operational $= Financial

Activity / Element	Risk No.	& Type	Risk/Hazard	Cause	Post / Pre RCM Likelihood	Health, Safety & Environment Severity	Health, Safety & Environment Risk	Financial Severity	Financial Risk	Schedule / Operational Severity	Schedule / Operational Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Likelihood	Health, Safety & Environment Severity	Health, Safety & Environment Risk	Financial Severity	Financial Risk	Operational Severity	Operational Risk
HDD - Installation Risk	43	E, $, O	Loss of drilling fluids / Frac out of drilling fluids.	High bore fluid pressures required to induce drilling fluid flow from the drill bit/reamer location to the HDD entry/exit location. High elevation differential between horizontal section of bore and HDD entry/exit locations that would require high drilling fluid pressures in comparison to an HDD entry/exit location at a lower elevation.	5	3	High	3	High	3	High	Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Identify HDD entry locations as close as possible to the shoreline with elevations as low as possible.	Possibility remains but likelihood reduced.	3	3	Medium	3	Medium	3	Medium
HDD - Installation Risk	44	$	Inability to advance drill bit/hole opener assembly. Inability to provide sufficient face pressure at bit/hole opener assembly to advance through bedrock materials.	High frictional forces acting on the drill pipe and bottom hole assembly resulting in a reduced ability to apply face pressure to cutting tools. Risk increases with an increase in installation length, bore curves, and steering/drilling upwards toward the bore exit location.	4	2	Medium	3	High	3	High	Consider maintaining slight downward orientations of the pilot bore to the maximum extent possible to eliminate long horizontal and/or upward drilling. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent. Consider use of heavier drill pipe within drill string. Require use of properly sized equipment prior to equipment mobilization onto the site.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium
HDD - Installation Risk	45	$, O	Poor production. Loss in ability to excavate bedrock materials.	Inability to provide sufficient torque with drill rig to rotate bottom hole assembly (due to bore length). Improper selection of cutting tools and hole openers.	3	2	Medium	3	Medium	3	Medium	Require the use of mud motor during pilot bore and reaming stages. Consider slight downward orientations of both pilot bores to eliminate long horizontal stretches and upward drilling. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium
HDD - Installation Risk	46	$, O	Contamination of drilling fluid.	Seawater contamination of drilling fluid resulting from highly effective hydraulic communication of seawater along rock joints. Punch of pilot bore and inability to seal end of bore from direct communication with ocean.	3	2	Medium	3	Medium	3	Medium	Develop contingency plans to deal with using lost circulation material. Assess potential with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance. Require additional polymers that can be used to help mix drilling fluids in presence of salt. Develop exiting/punch out strategy to minimize risk.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Installation Risk	47	E, $, O	Damage to casing pipe within bore.	Iceberg scour/ impact on ocean floor. Insufficient depth of cover between installed casing and ocean floor.	4	3	High	5	High	5	High	Determine depth of scour/impact. Design bore with sufficient clearance below scour depth.	Possibility remains but likelihood and severity reduced.	3	2	Medium	2	Medium	2	Medium
HDD - Installation Risk	48	E, $, O	Damage to casing pipe at exit location on ocean floor.	Iceberg scour to depth of installation.	2	3	Medium	5	High	5	High	Determine depth of scour. Design exit locations within topographically protected areas.	Possibility remains but likelihood and severity reduced.	1	2	Low	2	Low	2	Low
HDD - Installation Risk	49	$, O	Damage to drilling equipment.	Equipment breakdown during cold weather construction resulting in damage caused by freezing/ice due to inability to operate equipment.	3	2	Medium	4	High	4	High	Develop contractor experience qualifications for working in cold environments. Require verification of overhauling of equipment prior to drilling. Require contractor to submit winterization plan.	Possibility remains but likelihood reduced.	2	2	Low	4	Medium	4	Medium
HDD - Installation Risk	50	$, O	Significant delays in the drilling process while waiting for supply items.	Improper supply chain management by contractor. Improper supply chain management by local suppliers. Disruption of supply chain by severe weather.	3	2	Medium	4	High	4	High	Require contractor to submit proposed supply chain with contingency plans for supply items that are key to production such as fuel, fresh water, drilling fluids, parts, etc. Identify primary and secondary resources. Require sufficient resources and supplies on hand for the duration.	Possibility remains but likelihood reduced.	2	2	Low	4	Medium	4	Medium

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Likelihood Categories

Score	Descriptor	Probability
1	Improbable	about 1 in 1000
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Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5				HIGH	
4					
3		MEDIUM			
2	LOW				
1					

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
2	• Minor Injuries • Operative Requires First Aid Treatment • Stops Work • Medium term local damage or short term regional damage	• $10's k extra cost	• Significant revenue loss • Minor security alert • Re-routing local access
3	• Reportable / Lost Time Injury or Illness • Long term local damage	• Cost to Project ($100's k) • Delay in Project of Several Weeks (on Critical Path)	• Effects of a facility closure • Major regional impact Delay of Several Weeks (Critical Path)
4	• Major injury or illness with long term effects • Long term systematic damage	• Cost to Project ($1M's) • Delay in Project of Several Months (on Critical Path)	• Major effects to infrastructure Delay of Several Months (Critical Path)
5	• Fatalities • Permanent damage	• Potential to close down the project	• Loss of functionality / Close down of Project

Risk Level Action

Risk Level	Health, Safety & Environment Risks	Operational Risks
Low	• Check that no further risks can be eliminated by modifications of design • Proceed with Design	• Seek alternative, and assess cost to benefit of
Medium	• Consider Alternative Design or Construction Method • If Alternatives are not available, specify precautions to be adopted • List residual hazards in risk register	• Disseminate risk assessment information to
High	• Seek alternative solutions • If Alternatives are not available, specify precautions to be adopted and advise senior management and planning supervisor (where applicable) • List residual hazards in risk register	• List residual hazards in risk register

Risk Type: S= Safety, E= Environmental, O= Operational $= Financial

Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Health, Safety & Environment: Risk	Financial: Severity	Financial: Risk	Schedule / Operational: Severity	Schedule / Operational: Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Health, Safety & Environment: Risk	Financial: Severity	Financial: Risk	Operational: Severity	Operational: Risk
HDD - Installation Risk	51	$, O	Decreased production during winter months	Lack of contractor experience in cold environments. Improperly prepared equipment or use of equipment that is not designed for use in cold environments.	3	2	Medium	3	Medium	4	High	Include prequalification requirement for contractor experience in cold environments. Require contractor to submit winterization plan.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	4	Medium
HDD - Installation Risk	52	E, $, O	Delay. Damage to equipment.	Severe weather with very high winds and rain. Tropical storm, hurricane. Flooding.	2	3	Medium	4	Medium	4	Medium	Develop contingency plan to deal with potential storm detailing securing of equipment and materials.	Possibility remains.	2	3	Medium	4	Medium	4	Medium

Table 2: Risk Register for Shoreline Crossing at Forteau Pointe - Labrador Side of the Strait of Belle Isle.
Horizontal Directional Drilling Feasibility Assessment

Likelihood Categories

Score	Descriptor	Probability
1	Improbable	about 1 in 1000
2	Remote	about 1 in 100
3	Occasional	about 1 in 10
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Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5					
4				HIGH	
3			MEDIUM		
2	LOW				
1					

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1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
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Risk Level Action

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Low	• Check that no further risks can be eliminated by modifications of design • Proceed with Design	• Seek alternative, and assess cost to benefit of
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Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Geotechnical Risk	1	E, $, O	Loss of drilling fluids / Frac out of drilling fluids. Flow of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of significant drilling fluids to the ocean/marine environment.	Encountering bedrock materials with significant open fracture/joint networks and communication with ocean. Encountering bedrock with low Rock Quality Designations (RQD). Encountering bedrock with preferential flow pathways. Risk increases with lower RQD values.	4	3	High	3	High	3	High	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identifying potential preferential flow pathways from borehole logs including field notes. Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design alignment within bedrock units with higher rock quality designations to the extent possible. Develop contingency plan to inject loss circulation material to isolate preferential flow pathways. Determine drilling/reaming strategy to limit mud loss. Incorporate conductor casing into bore design.	Possibility remains but likelihood reduced.	3	3	Medium	3	Medium	3	Medium
HDD - Geotechnical Risk	2	E, $, O	Loss of drilling fluids / Frac out of drilling fluids. Flow of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of significant drilling fluids to the ocean environment.	Inability to effectively seal open fracture/joint networks with grout. Inability to re-establish drilling fluid returns.	3	3	Medium	3	Medium	3	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identifying potential preferential flow pathways from borehole logs including field notes. Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design alignment within bedrock units with higher rock quality designations to the extent possible. Develop contingency plan to inject loss circulation material to isolate preferential flow pathways. Determine drilling/reaming strategy to limit mud loss. Consider use of single or multiple conductor casing(s) within bore design. Consider use of temporary washover casing to provide a pathway for fluid flow to the drill rig location.	Possibility remains but likelihood reduced.	2	3	Medium	3	Medium	3	Medium
HDD - Geotechnical Risk	3	E, $, O	Loss of drilling fluids / Frac out of drilling fluids. Flow of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of significant drilling fluids to the ocean/marine environment.	Encountering bedrock materials with much higher unconfined compressive strengths than anticipated leading to decreased drilling production and increased drilling fluid pumping volumes.	4	3	High	3	High	3	High	Complete geotechnical investigation to characterize bedrock materials where geotechnical information is not available. Complete unconfined compressive strength testing of bedrock core to assess strength and provide means for contractor to select appropriate drilling equipment.	Possibility remains but likelihood reduced.	1	3	Low	3	Low	3	Low
HDD - Geotechnical Risk	4	E, $, O	Loss of drilling fluids / Frac out of drilling fluids. Flow of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of significant drilling fluids to the ocean/marine environment.	Insufficient depth of cover above bore. Bore designed within zone of high permeability as identified in Geotechnical Reports.	4	3	High	4	High	4	High	Complete thorough and accurate bathymetric survey of the HDD alignment in near shore environment. Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design bore within uniform materials and with sufficient depth of cover as quick as possible. Consider use of a conductor casing within the bore design. Perform an ROV survey of the exit location and the alignment route to determine the condition of the bedrock/ocean floor materials including infilling of joints. Further assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	2	3	Medium	4	Medium	4	Medium
HDD - Geotechnical Risk	5	$, O	Bore instability *during pilot bore drilling*. Inability to support geotechnical materials along exposed surface of bore walls. Collapse of the HDD bore. Over mining of surrounding bedrock materials while excess materials are removed from the bore.	Raveling due to drilling parallel to major joint/fracture orientations. Exposing/day lighting unstable blocks of bedrock in crown of HDD bore. Risk increases with increase in bore diameter.	3	2	Medium	3	Medium	3	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify major joint and fracture network. Design alignment such that it does not coincide with major fracture/joint orientations to extent possible. Develop contingency plan to remove cuttings from the bore and to reduce raveling potential. Complete a swab pass to gauge condition of bore prior to installation. Further assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium

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5					
4					
3					
2					
1					

HIGH
MEDIUM
LOW

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HDD - Geotechnical Risk	6	$, O	Stuck drilling equipment *during pilot bore* . Inability to advance/retract drill pipe and down hole tooling.	Bore instability resulting from raveling of material into the bore behind drill bit. Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the borehole.	2	2	Low	3	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify zones of crushed rock. Design alignment to avoid or cross zones at the steepest angle possible. Develop contingency plan to reduce raveling potential or to control raveling. Require drilling fluid additives to reduce swelling potential. Require verification of mud motor and drill bit condition on a regular basis.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	4	Medium
HDD - Geotechnical Risk	7	$, O	Bore instability *during reaming* . Inability to support geotechnical materials along exposed surface of bore walls. Collapse of the HDD bore. Over mining of surrounding bedrock materials while excess materials are removed from the bore.	Raveling due to drilling parallel to major joint/fracture orientations. Exposing/day lighting unstable blocks of bedrock in crown of HDD bore. Risk increases with increase in bore diameter.	3	2	Medium	4	High	4	High	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify major joint and fracture network. Design alignment such that it does not coincide with major fracture/joint orientations. Develop contingency plan to remove cuttings from the bore and to reduce raveling potential. Complete a swab pass to gauge condition of bore prior to installation. Further assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	2	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	8	$, O	Stuck drilling equipment *during reaming pass(es)* . Inability to advance/retract drill pipe and down hole tooling.	Bore instability resulting from raveling of material into the bore after swab pass. Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the borehole. This condition was evidenced in Borehole NF-01A at 70m borehole length.	2	2	Low	4	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify zones of crushed rock. Design alignment to avoid or cross zones at the steepest angle possible. Develop contingency plan to reduce raveling potential or to control raveling. Require drilling fluid additives to reduce swelling potential. Require verification of mud motor and hole openers condition on a regular basis.	Possibility remains.	2	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	9	$, O	Bore instability *during swab pass* . Inability to support geotechnical materials along exposed surface of bore walls. Collapse of the HDD bore. Over mining of surrounding bedrock materials while excess materials are removed from the bore.	Raveling due to drilling parallel to major joint/fracture orientations. Exposing/day lighting unstable blocks of bedrock in crown of HDD bore. Risk increases with increase in bore diameter.	2	2	Low	4	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify major joint and fracture network. Design alignment such that it does not coincide with major fracture/joint orientations. Develop contingency plan to remove cuttings from the bore and to reduce raveling potential. Further assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	1	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	10	$, O	Stuck drilling equipment *during swab pass* . Inability to advance/retract drill pipe and down hole tooling.	Bore instability resulting from raveling of material into the bore after swab pass. Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the borehole. This condition was evidenced in Borehole NF-01A at 70m borehole length.	2	2	Low	4	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify zones of crushed rock. Design alignment to avoid or cross zones at the steepest angle possible. Develop contingency plan to reduce raveling potential or to control raveling.	Possibility remains.	2	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	11	$, O	Bore instability *during casing / lining pipe installation* . Inability to support geotechnical materials along exposed surface of bore walls. Collapse of the HDD bore. Over mining of surrounding bedrock materials while excess materials are removed from the bore.	Raveling due to drilling parallel to major joint/fracture orientations. Exposing/day lighting unstable blocks of bedrock in crown of HDD bore.	2	2	Low	4	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify major joint and fracture network. Design alignment such that it does not coincide with major fracture/joint orientations. Develop contingency plan to remove cuttings from the bore. Complete a swab pass to gauge condition of bore prior to installation.	Possibility remains.	2	2	Low	4	Medium	4	Medium

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1	Improbable	about 1 in 1000
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Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5				HIGH	
4					
3			MEDIUM		
2	LOW				
1					

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
2	• Minor Injuries • Operative Requires First Aid Treatment • Stops Work • Medium term local damage or short term regional damage	• $10's k extra cost	• Significant revenue loss • Minor security alert • Re-routing local access
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Risk Level Action

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Risk Type: S= Safety, E= Environmental, O= Operational $= Financial

Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Geotechnical Risk	12	$, O	Stuck casing / liner pipe during product *during casing / liner pipe installation* . Inability to advance/retract drill pipe and down hole tooling.	Bore instability resulting from raveling of material into the bore after swab pass. Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the borehole.	2	2	Low	4	Medium	4	Medium	Require successful completion of swab pass prior to casing / liner pipe insertion. Review drill rig rotary torque and thrust during swab pass. Consider pushing in a sample length (i.e. 10 to 50 metre section of steel casing) through the bore prior to installing the entire casing / liner pipe string.	Possibility remains but likelihood reduced.	1	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	13	$, O	Raveling of zones of crushed bedrock materials into the bore. Borehole instability.	Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the HDD bore.	2	2	Low	3	Medium	2	Low	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify zones of crushed rock. Design alignment to avoid or cross zones at the steepest angle possible. Develop contingency plan to reduce raveling potential or to control raveling. Complete a swab pass to gauge condition of bore prior to installation. Require drilling fluid additives to condition drilling fluid.	Possibility remains.	2	2	Low	3	Medium	2	Low
HDD - Geotechnical Risk	14	E, $, O	Inability to maintain bore stability in vicinity of ocean floor.	Drilling with increasingly lower depth of cover above bore as HDD installation nears planned exit location. Encountered bedrock materials that are not self supporting (i.e. bedrock with very low RQD).	3	3	Medium	3	Medium	3	Medium	Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design bore within uniform materials to maximum extent possible. Develop contingency plans. Perform ROV survey of anticipated exit locations. Consider jetting/dredging to remove loose material above sound bedrock.	Possibility remains but likelihood reduced.	3	3	Medium	3	Medium	3	Medium
HDD - Geotechnical Risk	15	E, $, O	Inability to advance drill bit/hole opener. Inability to insert product pipe / liner casing.	Encountering soils on ocean floor with a high percentage of *cobbles* requiring pull back and re-drilling of the bore.	3	3	Medium	4	High	4	High	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit on sloped surface or in an area lacking cobbles. Dredge loose material away from intended exit location. May require having dredge material on standby. May experience weather delays if dredging required depending on time of year.	Possibility remains but likelihood and severity reduced.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	16	E, $, O	Inability to advance drill bit/hole opener. Inability to insert product pipe / liner casing.	Encountering soils on ocean floor with a high percentage of *gravels* resulting in raveling and bore instability/collapse.	3	3	Medium	4	High	4	High	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit on sloped surface or ina area lacking gravels. Develop ability to jet (inject drilling fluids) in front of casing / liner pipe during insertion. Jet/dredge loose material away from intended exit location. May require having jet/dredge equipment on standby. May experience weather delays if dredging required depending on time of year.	Possibility remains but likelihood and severity reduced.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	17	$, O	Inability to maintain bore stability/condition bore.	Encountering bedrock materials with artesian groundwater conditions that prevent the build-up of a filter cake along the walls of the bore.	1	2	Low	2	Low	2	Low	Characterize potential risk by reviewing borehole logs and field notes. Minimize potential by designing alignment within favorable bedrock units. Develop contingency plans to address. Require use of drilling fluid additives to mitigate artesian conditions.	Possibility remains.	1	2	Low	2	Low	2	Low
HDD - Geotechnical Risk	18	$, O	Excessive drill tool wear requiring frequent tool replacements.	Drilling through bedrock with very hard crystalline conglomerate in very strong host rock matrix. Drilling through abrasive bedrock materials.	2	2	Low	3	Medium	2	Low	Complete geotechnical investigation to characterize bedrock materials where geotechnical information is not available. Complete unconfined compressive strength and Cerchar abrasivity testing of bedrock core to assess strength and abrasivity and provide means for contractor to select appropriate drilling equipment. Require sufficient amount of drill bits, hole openers and mud motors to avoid delays associated with worn out equipment.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	2	Low

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Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5					
4					
3					
2					
1					

HIGH
MEDIUM
LOW

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Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment Severity	Health, Safety & Environment Risk	Financial Severity	Financial Risk	Schedule / Operational Severity	Schedule / Operational Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment Severity	Health, Safety & Environment Risk	Financial Severity	Financial Risk	Operational Severity	Operational Risk
HDD - Geotechnical Risk	19	$, O	Loss or excessive deviation of pilot bore alignment.	Encountering a large vug in limestone layers.	2	2	Low	3	Medium	3	Medium	Assess potential by reviewing existing geologic information, and/or with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance.	Possibility remains.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	20	$, O	Loss of down hole drilling equipment.	Encountering a large vug in limestone layers.	2	2	Low	3	Medium	3	Medium	Assess potential by reviewing existing geologic information and/or with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance.	Possibility remains.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	21	$, O	Borehole instability and collapse.	Poor rock quality due to crushed rock zones, tectonic zones (faults, lineaments, etc.), and other zones where core loss was encountered in Bradore Fm (LAB) and in Hawke Bay Fm (NL) due to reduced slake durability. These conditions can result in long-term borehole instability if left unlined.	3	2	Medium	3	Medium	3	Medium	Complete geotechnical investigation to characterize bedrock materials where geotechnical information is not available. Develop contingency plans. Assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	22	$, O	Sedimentation of casing / liner pipe at exit location on ocean floor.	Strong ocean currents that are capable of carrying significant sediment bedload.	3	2	Medium	4	High	4	High	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit on sloped surface. Develop contingency plans. Consider installing a plug on bottom of casing. Select exit locations away from areas with obvious sedimentation transport.	Possibility remains but likelihood and severity reduced.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	23	$, O	Inability to steer for line and grade through ocean floor sediments. Inability to support weight of drilling equipment as drilling equipment is advanced through ocean floor sediment.	Extensive deposits of sand on the ocean floor.	2	2	Low	3	Medium	3	Medium	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit away from thick deposits. Develop ability to jet (inject drilling fluids) in front of casing pipe during insertion. Select exit locations away from areas with obvious sedimentation transport.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Geotechnical Risk	24	$, O	Inability to install casing pipe through ocean floor sediments.	Extensive deposits of soil on the ocean floor that interfere with ability to build angle and exit the ocean floor.	2	2	Low	3	Medium	3	Medium	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit away from thick deposits. Develop ability to jet (inject drilling fluids) in front of liner / casing pipe during insertion. Consider providing the ability to remove some of the water used for buoyancy control and replace with air to add buoyancy to the product pipe. Select exit locations away from areas with obvious sedimentation transport.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Geotechnical Risk	25	E, $, O	Inability to advance HDD bore through thick overburden consisting of cobble & boulder fields. Excessive loss of drilling fluids. Significant drill pipe deflection. Inability to advance downhole tooling. Bore instability.	Presence of thick layers of sandstone and granite cobbles and boulders (colluvium / talus). This condition is especially pronounced along Forteau Pt. due to excessive weathering, complete raveling, and layback of a long reach of the high escarpment between the two adjacent existing escarpments.	5	4	High	4	High	4	High	Complete geotechnical investigation to characterize bedrock materials where geotechnical information is not available. Determine if sound bedrock exists below cobble/boulder field. If so, remove with excavators and bulldozers. If not, increase setback distance from shore or move laterally to avoid area with cobbles and boulders. Determine if area lacking cobble and boulder field is present in the immediate area.	Possibility remains but likelihood and severity reduced.	2	3	Medium	3	Medium	3	Medium

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MEDIUM
LOW

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Risk Level Action

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Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Installation Risk	26	E, $, O	Loss of down hole tooling (in whole or in part). Inability to remove down hole equipment from bore. Inability to retrieve down hole equipment *during pilot bore drilling*.	Mechanical failure of equipment. Excess wear of drilling equipment. Bore Instability.	2	3	Medium	3	Medium	2	Low	Require certification of all drilling equipment including operating hours since last refurbishment. Develop criteria for verification of key equipment components on a regular basis. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent. Assess potential with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance. Fish damaged tooling from bore. Re-drill around lost tooling.	Possibility remains.	2	3	Medium	3	Medium	2	Low
HDD - Installation Risk	27	E, $, O	Loss of down hole tooling (in whole or in part). Inability to remove down hole equipment from bore. In ability to retrieve down hole equipment during *ream/hole opening pass(es)*.	Mechanical failure of equipment. Excess wear of drilling equipment. Bore Instability.	2	3	Medium	4	Medium	4	Medium	Require certification of all drilling equipment including operating hours since last refurbishment. Develop criteria for verification of key components on a regular basis. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent. Assess potential with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance. Fish damaged tooling out of bore. Steering around lost equipment would require partial redrilling of pilot bore.	Possibility remains.	2	3	Medium	4	Medium	4	Medium
HDD - Installation Risk	28	E, $, O	Loss of down hole tooling (in whole or in part). Inability to remove down hole equipment from bore. In ability to retrieve down hole equipment *during swab pass*.	Mechanical failure of equipment. Excess wear of drilling equipment. Bore Instability.	2	3	Medium	4	Medium	4	Medium	Require certification of all drilling equipment including operating hours since last refurbishment. Develop criteria for verification of key components on a regular basis. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent. Assess potential with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance. Fish damaged tooling out of bore. Steering around lost equipment would require partial redrilling of pilot bore.	Possibility remains.	2	3	Medium	4	Medium	4	Medium
HDD - Installation Risk	29	$	Difficulty/Inability to remove cuttings from within the HDD bore.	Drilling with water as opposed to drilling with properly engineered bentonite drilling fluid.	1	2	Low	3	Low	2	Low	Develop experience criteria for mud engineer to monitor and adjust drilling fluids during the drilling process. Require sufficient materials on site to prevent shortage and delays waiting for transportation of additional materials.	Possibility remains.	1	2	Low	3	Low	2	Low
HDD - Installation Risk	30	$, O	Significant/extensive delays in the drilling process while waiting for new drilling mud.	Loss of drilling fluids / Frac out of drilling fluids. Loss of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of Drilling fluids to the ocean/marine environment. Inadequate or unreliable fresh water source.	3	2	Medium	3	Medium	2	Medium	Identify primary and secondary sources of fresh water. These sources can include but should not be limited to drilling of fresh water wells, transportation of water to the site from a distant source, tapping into freshwater lakes, etc. Develop contingency plans for addressing frac out/loss of fluids.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	2	Low
HDD - Installation Risk	31	$, O	Multiple bores intersecting and damaging previously installed casing / liner pipelines.	Insufficient spacing between parallel bores. Inaccurate location / lack of verification of position of previously installed pipelines.	3	2	Medium	3	Medium	3	Medium	Provide adequate separation distance. Separate bores in horizontal and/or vertical planes. Use guidance system capable of adequately tracking down hole tooling. Require use of gyro guidance system that is not susceptible to interference. Design bore geometries in a fanning outward pattern to increase the spacing between the bores with depth.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Installation Risk	32	$, O	Multiple bores intersecting and damaging previously installed casing / liner pipelines.	Operator error, interference with guidance system, inability to track pilot bore. Using a guidance system that is subject to interference by bedrock materials with magnetic properties.	3	2	Medium	3	Medium	3	Medium	Develop contractor experience qualifications for operating tracking system. Require regular calibration checks of guidance system. Design bore geometries in a fanning outward pattern to increase the spacing between the bores. Require use of gyro guidance system. Require the use of experienced site inspectors to monitor drilling progress.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low

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HDD - Installation Risk	33	$, O	Damage to previously installed casing / liner pipelines.	Communication of joints/fracture networks between adjacent bores. Damage caused by excessive grouting pressures during grouting operations during attempts to re-establish drilling fluid returns.	1	1	Low	2	Low	1	Low	Require insertion of steel casing / liner pipe prior to initiating drilling of subsequent pilot bore. Design bore geometries in a fanning outward pattern to increase the spacing between the bores as it increases in depth. Design casing / liner to resist anticipated forces.	Possibility remains.	1	1	Low	2	Low	1	Low
HDD - Installation Risk	34	E, $, O	Prematurely filling of HDD bore with grout during drilling of adjacent bore (assumes casing / liner pipe has not yet been installed).	Communication of joints/fracture networks between adjacent bores. Loss of grout through joint/fracture networks during grouting operations during attempts to re-establish drilling fluid returns.	3	3	Medium	4	High	4	High	Require insertion of steel casing / liner pipe prior to initiating drilling of subsequent pilot bore. Design bore geometries in a fanning outward pattern to increase the spacing between the bores as it increases in depth.	Possibility remains but likelihood and severity reduced.	1	2	Low	2	Low	2	Low
HDD - Installation Risk	35	$, O	Inability to advance drill bit/hole opener. Inability to maintain bore stability. Locking up of drilling equipment due to size of cuttings and inability to remove cuttings.	Producing gravel sized cuttings during bedrock drilling. Encountering pebble conglomerate that produces a large volume of pebble sized clasts. Encountering bedrock materials with a tendency to ravel into the bore.	3	2	Medium	3	Medium	2	Medium	Develop submittal requirements to review Contractor's planned equipment. Develop experience criteria for HDD rig operator, mud engineer and site superintendent. Develop contingency plans that may include, but are not limited to, increasing the carrying capacity of the drilling fluid by adjusting mud properties, increasing drilling fluid pumping rates, etc. Require use of experienced site inspector to monitor drilling progress.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	2	Low
HDD - Installation Risk	36	$, O	Loss of ability to track pilot bore(s) along proposed HDD bore path.	Encountering source of interference that disrupts tracking system. Inability to stage equipment necessary to enable traditional secondary tracking of the pilot bore(s).	4	2	Medium	3	High	3	High	Determine all potential sources of interference at the crossing location. Develop experience/qualification requirements for Contractor and Guidance System personnel. Determine requirements for Contractor specific equipment (i.e. gyro survey equipment) and verify capabilities for use at the site.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Installation Risk	37	E, $, O	Inability to maintain line and grade.	Difficulty inducing a steering correction. Improper down hole tooling/equipment. Improper down hole tooling/equipment set up. Improper use of guidance equipment. Malfunction of the guidance system. Drift in the guidance system.	3	2	Medium	3	Medium	3	Medium	Develop performance criteria on tolerances for line and grade. Require immediate notification if issues arise. Develop contingency plans. Develop performance criteria for guidance system. Develop experience/qualification requirements for Contractor, drill rig operator, steering personnel, and site superintendent. Determine requirements for Contractor specific equipment and verify capabilities for use at the site. Require certificates of calibration for all guidance components.	Possibility remains.	2	2	Low	3	Medium	3	Medium
HDD - Installation Risk	38	E, $, O	Missed exiting at target exit location (long) by greater than 10 metres.	Inability to track pilot bore(s), improper use of guidance equipment. Malfunction of the guidance system. Drift in the guidance system. Difficulty inducing a steering correction (building angle at exit). Poorly defined ocean floor topography in target exit location. Discrepancy/offset of survey contours between water and land.	3	2	Medium	3	Medium	2	Medium	Develop experience/qualification requirements for Contractor and Guidance System personnel. Determine requirements for Contractor specific equipment and verify capabilities for use at the site. Require certificates of calibration for all guidance components. Consider completing a detailed bathymetric survey of the area surrounding the target exit locations. Ensure offshore survey is properly converted to onshore Geodetic survey coordinates.	Possibility remains.	2	2	Low	3	Medium	2	Low
HDD - Installation Risk	39	E, $, O	Missed exiting at target exit location (left/right) by greater than 10 metres.	Inability to track pilot bore(s), improper use of guidance equipment. Malfunction of the guidance system. Drift in the guidance system. Poorly defined ocean floor topography in target exit location. Discrepancy/offset of survey contours between water and land.	3	2	Medium	3	Medium	2	Medium	Develop experience/qualification requirements for Contractor and Guidance System personnel. Determine requirements for Contractor specific equipment and verify capabilities for use at the site. Require certificates of calibration for all guidance components. Ensure offshore survey is properly converted to onshore Geodetic survey coordinates.	Possibility remains.	2	2	Low	3	Medium	2	Low
HDD - Installation Risk	40	$, O	Missed exiting at target exit location (short). Prematurely exiting through ocean floor by greater than 10 metres.	Inability to track pilot bore(s), improper use of guidance equipment. Malfunction of the guidance system. Drift in the guidance system. Poorly defined ocean floor topography in target exit location. Discrepancy/offset of survey contours between water and land.	3	2	Medium	3	Medium	2	Medium	Develop experience/qualification requirements for Contractor and Guidance System personnel. Determine requirements for Contractor specific equipment and verify capabilities for use at the site. Require certificates of calibration for all guidance components. Ensure offshore survey is properly converted to onshore Geodetic survey coordinates.	Possibility remains.	2	2	Low	3	Medium	2	Low

Table 2: Risk Register for Shoreline Crossing at Forteau Pointe - Labrador Side of the Strait of Belle Isle. Horizontal Directional Drilling Feasibility Assessment

Likelihood Categories

Score	Descriptor	Probability
1	Improbable	about 1 in 1000
2	Remote	about 1 in 100
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Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5					
4					
3					
2					
1					

HIGH
MEDIUM
LOW

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
2	• Minor Injuries • Operative Requires First Aid Treatment • Stops Work • Medium term local damage or short term regional damage	• $10's k extra cost	• Significant revenue loss • Minor security alert • Re-routing local access
3	• Reportable / Lost Time Injury or Illness • Long term local damage	• Cost to Project ($100's k) • Delay in Project of Several Weeks (on Critical Path)	• Effects of a facility closure • Major regional impact Delay of Several Weeks (Critical Path)
4	• Major injury or illness with long term effects • Long term systematic damage	• Cost to Project ($1M's) • Delay in Project of Several Months (on Critical Path)	• Major effects to infrastructure Delay of Several Months (Critical Path)
5	• Fatalities • Permanent damage	• Potential to close down the project	• Loss of functionality / Close down of Project

Risk Level Action

Risk Level	Health, Safety & Environment Risks	Operational Risks
Low	• Check that no further risks can be eliminated by modifications of design • Proceed with Design	• Seek alternative, and assess cost to benefit of
Medium	• Consider Alternative Design or Construction Method • If Alternatives are not available, specify precautions to be adopted • List residual hazards in risk register	• Disseminate risk assessment information to
High	• Seek alternative solutions • If Alternatives are not available, specify precautions to be adopted and advise senior management and planning supervisor (where applicable) • List residual hazards in risk register	• List residual hazards in risk register

Risk Type: S= Safety, E= Environmental, O= Operational $= Financial

Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Installation Risk	41	E, $, O	High installation loads. Damaged to casing / liner pipe.	Improper conditioning of the bore. Improper pipeline insertion into the HDD bore. Improper use of buoyancy compensation during pullback operations.	2	3	Medium	4	Medium	4	Medium	Fabricate pipe string in one complete length to eliminate prolonged stoppages to weld additional sections of pipe together. Determine required installation loads and compare with drill rig and pipe capabilities. Require swab pass through bore to gauge bore condition. Develop contingency plans. Remove as much of the cuttings from the bore as possible prior to insertion. Remove casing from bore with thruster to allow further bore conditioning.	Possibility remains but likelihood reduced.	1	3	Low	4	Medium	4	Medium
HDD - Installation Risk	42	E, $, O	Loss of drilling fluids / Frac out of drilling fluids.	Collapse of bore material behind down hole tooling that leads to blockage of the bore annulus and significant drilling fluid pressure increase. Producing cuttings that are too big (i.e., gravel size and larger) or too thick/viscous.	2	3	Medium	3	Medium	3	Medium	Complete geotechnical investigation to characterize site bedrock materials. Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design bore within uniform materials with sufficient depth of cover. Design bore in more favorable bedrock.	Possibility remains but likelihood reduced.	1	3	Low	3	Low	3	Low
HDD - Installation Risk	43	E, $, O	Loss of drilling fluids / Frac out of drilling fluids.	Increasing the diameter of the bore too quickly. Reaming the bore to final diameter in one pass following completion of the pilot bore (depending on bore diameter). Slurry (mud and cuttings) that are too thick and lead to pressure buildup event.	3	3	Medium	3	Medium	3	Medium	Require experience/qualification/performance requirements in the project specifications. Require multiple reaming passes through the bore. Require swab pass prior to product pipe insertion. Develop submittal requirements to review Contractor's planned equipment.	Possibility remains but likelihood reduced.	2	3	Medium	3	Medium	3	Medium
HDD - Installation Risk	44	E, $, O	Loss of drilling fluids / Frac out of drilling fluids.	High bore fluid pressures required to induce drilling fluid flow from the drill bit/reamer location to the HDD entry/exit location. High elevation differential between horizontal section of bore and HDD entry/exit locations that would require high drilling fluid pressures in comparison to an HDD entry/exit location at a lower elevation.	4	3	High	3	High	3	High	Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Identify HDD entry locations as close as possible to the shoreline with elevations as low as possible.	Possibility remains but likelihood reduced.	3	3	Medium	3	Medium	3	Medium
HDD - Installation Risk	45	$,O	Inability to advance drill bit/hole opener assembly. Inability to provide sufficient face pressure at bit/hole opener assembly to advance through bedrock materials.	High frictional forces acting on the drill pipe and bottom hole assembly resulting in a reduced ability to apply face pressure to cutting tools. Risk increases with an increase in installation length, bore curves, and steering/drilling upwards toward the bore exit location.	3	2	Medium	3	Medium	3	Medium	Consider maintaining slight downward orientations of the pilot bore to the maximum extent possible to eliminate long horizontal and/or upward drilling. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent. Consider use of heavier drill pipe within drill string. Require use of properly sized equipment prior to equipment mobilization onto the site.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium
HDD - Installation Risk	46	$, O	Poor production. Loss in ability to excavate bedrock materials.	Inability to provide sufficient torque with drill rig to rotate bottom hole assembly (due to bore length). Improper selection of cutting tools and hole openers.	3	2	Medium	3	Medium	3	Medium	Require the use of mud motor during pilot bore and reaming stages. Consider slight downward orientations of both pilot bores to eliminate long horizontal stretches and upward drilling. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium
HDD - Installation Risk	47	$, O	Contamination of drilling fluid.	Seawater contamination of drilling fluid resulting from highly effective hydraulic communication of seawater along rock joints. Punch of pilot bore and inability to seal end of bore from direct communication with ocean.	3	2	Medium	3	Medium	3	Medium	Develop contingency plans to deal with using lost circulation material. Assess potential with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance. Require additional polymers that can be used to help mix drilling fluids in presence of salt. Develop exiting/punch out strategy to minimize risk.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Installation Risk	48	E, $, O	Damage to casing pipe within bore.	Iceberg scour/ impact on ocean floor. Insufficient depth of cover between installed casing and ocean floor.	4	3	High	5	High	5	High	Determine depth of scour/impact. Design bore with sufficient clearance below scour depth.	Possibility remains but likelihood and severity reduced.	3	2	Medium	2	Medium	2	Medium
HDD - Installation Risk	49	E, $, O	Damage to casing pipe at exit location on ocean floor.	Iceberg scour to depth of installation.	2	3	Medium	5	High	5	High	Determine depth of scour. Design exit locations within topographically protected areas.	Possibility remains but likelihood and severity reduced.	1	2	Low	2	Low	2	Low

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Likelihood Categories

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Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5					
4					
3					
2					
1					

HIGH
MEDIUM
LOW

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
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Risk Level Action

Risk Level	Health, Safety & Environment Risks	Operational Risks
Low	• Check that no further risks can be eliminated by modifications of design • Proceed with Design	• Seek alternative, and assess cost to benefit of
Medium	• Consider Alternative Design or Construction Method • If Alternatives are not available, specify precautions to be adopted • List residual hazards in risk register	• Disseminate risk assessment information to
High	• Seek alternative solutions • If Alternatives are not available, specify precautions to be adopted and advise senior management and planning supervisor (where applicable) • List residual hazards in risk register	• List residual hazards in risk register

Risk Type: S= Safety, E= Environmental, O= Operational $= Financial

Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Installation Risk	50	$, O	Damage to drilling equipment.	Equipment breakdown during cold weather construction resulting in damage caused by freezing/ice due to inability to operate equipment.	3	2	Medium	4	High	4	High	Develop contractor experience qualifications for working in cold environments. Require verification of overhauling of equipment prior to drilling. Require contractor to submit winterization plan.	Possibility remains but likelihood reduced.	2	2	Low	4	Medium	4	Medium
HDD - Installation Risk	51	$, O	Significant delays in the drilling process while waiting for supply items.	Improper supply chain management by contractor. Improper supply chain management by local suppliers. Disruption of supply chain by severe weather.	3	2	Medium	4	High	4	High	Require contractor to submit proposed supply chain with contingency plans for supply items that are key to production such as fuel, fresh water, drilling fluids, parts, etc. Identify primary and secondary resources. Require sufficient resources and supplies on hand for the duration.	Possibility remains but likelihood reduced.	2	2	Low	4	Medium	4	Medium
HDD - Installation Risk	52	$, O	Decreased production during winter months	Lack of contractor experience in cold environments. Improperly prepared equipment or use of equipment that is not designed for use in cold environments.	3	2	Medium	3	Medium	4	High	Include prequalification requirement for contractor experience in cold environments. Require contractor to submit winterization plan.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	4	Medium
HDD - Installation Risk	53	E, $, O	Delay. Damage to equipment.	Severe weather with very high winds and rain. Tropical storm, hurricane. Flooding.	2	3	Medium	4	Medium	4	Medium	Develop contingency plan to deal with potential storm detailing securing of equipment and materials.	Possibility remains.	2	3	Medium	4	Medium	4	Medium

Table 3: Risk Register for Shoreline Crossing at Point Amour - Labrador Side of the Strait of Belle Isle. Horizontal Directional Drilling Feasibility Assessment

Likelihood Categories

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1	Improbable	about 1 in 1000
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Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5					
4					
3					
2					
1					

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Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Geotechnical Risk	1	E, $, O	Loss of drilling fluids / Frac out of drilling fluids. Flow of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of significant drilling fluids to the ocean/marine environment.	Encountering bedrock materials with significant open fracture/joint networks and communication with ocean. Encountering bedrock with low Rock Quality Designations (RQD). Encountering bedrock with preferential flow pathways. Risk increases with lower RQD values.	5	3	High	3	High	3	High	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identifying potential preferential flow pathways from borehole logs including field notes. Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design alignment within bedrock units with higher rock quality designations to the extent possible. Develop contingency plan to inject loss circulation material to isolate preferential flow pathways. Determine drilling/reaming strategy to limit mud loss. Incorporate conductor casing into bore design.	Possibility remains but likelihood reduced.	3	3	Medium	3	Medium	3	Medium
HDD - Geotechnical Risk	2	E, $, O	Loss of drilling fluids / Frac out of drilling fluids. Flow of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of significant drilling fluids to the ocean environment.	Inability to effectively seal open fracture/joint networks with grout. Inability to re-establish drilling fluid returns.	3	3	Medium	3	Medium	3	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identifying potential preferential flow pathways from borehole logs including field notes. Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design alignment within bedrock units with higher rock quality designations to the extent possible. Develop contingency plan to inject loss circulation material to isolate preferential flow pathways. Determine drilling/reaming strategy to limit mud loss. Consider use of single or multiple conductor casing(s) within bore design. Consider use of temporary washover casing to provide a pathway for fluid flow to the drill rig location.	Possibility remains but likelihood reduced.	2	3	Medium	3	Medium	3	Medium
HDD - Geotechnical Risk	3	E, $, O	Loss of drilling fluids / Frac out of drilling fluids. Flow of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of significant drilling fluids to the ocean/marine environment.	Encountering bedrock materials with much higher unconfined compressive strengths than anticipated leading to decreased drilling production and increased drilling fluid pumping volumes.	4	3	High	3	High	3	High	Complete geotechnical investigation to characterize bedrock materials where geotechnical information is not available. Complete unconfined compressive strength testing of bedrock core to assess strength and provide means for contractor to select appropriate drilling equipment.	Possibility remains but likelihood reduced.	1	3	Low	3	Low	3	Low
HDD - Geotechnical Risk	4	E, $, O	Loss of drilling fluids / Frac out of drilling fluids. Flow of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of significant drilling fluids to the ocean/marine environment.	Insufficient depth of cover above bore. Bore designed within zone of high permeability as identified in Geotechnical Reports.	4	3	High	4	High	4	High	Complete thorough and accurate bathymetric survey of the HDD alignment in near shore environment. Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design bore within uniform materials and with sufficient depth of cover as quick as possible. Consider use of a conductor casing within the bore design. Perform an ROV survey of the exit location and the alignment route to determine the condition of the bedrock/ocean floor materials including infilling of joints. Further assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	2	3	Medium	4	Medium	4	Medium
HDD - Geotechnical Risk	5	$, O	Bore instability *during pilot bore drilling*. Inability to support geotechnical materials along exposed surface of bore walls. Collapse of the HDD bore. Over mining of surrounding bedrock materials while excess materials are removed from the bore.	Raveling due to drilling parallel to major joint/fracture orientations. Exposing/day lighting unstable blocks of bedrock in crown of HDD bore. Risk increases with increase in bore diameter.	3	2	Medium	3	Medium	3	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify major joint and fracture network. Design alignment such that it does not coincide with major fracture/joint orientations to extent possible. Develop contingency plan to remove cuttings from the bore and to reduce raveling potential. Complete a swab pass to gauge condition of bore prior to installation. Further assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium

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HDD - Geotechnical Risk	6	$, O	Stuck drilling equipment *during pilot bore* . Inability to advance/retract drill pipe and down hole tooling.	Bore instability resulting from raveling of material into the bore behind drill bit. Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the borehole.	2	2	Low	3	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify zones of crushed rock. Design alignment to avoid or cross zones at the steepest angle possible. Develop contingency plan to reduce raveling potential or to control raveling. Require drilling fluid additives to reduce swelling potential. Require verification of mud motor and drill bit condition on a regular basis.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	4	Medium
HDD - Geotechnical Risk	7	$, O	Bore instability *during reaming* . Inability to support geotechnical materials along exposed surface of bore walls. Collapse of the HDD bore. Over mining of surrounding bedrock materials while excess materials are removed from the bore.	Raveling due to drilling parallel to major joint/fracture orientations. Exposing/day lighting unstable blocks of bedrock in crown of HDD bore. Risk increases with increase in bore diameter.	3	2	Medium	4	High	4	High	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify major joint and fracture network. Design alignment such that it does not coincide with major fracture/joint orientations. Develop contingency plan to remove cuttings from the bore and to reduce raveling potential. Complete a swab pass to gauge condition of bore prior to installation. Further assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	2	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	8	$, O	Stuck drilling equipment *during reaming pass(es)* . Inability to advance/retract drill pipe and down hole tooling.	Bore instability resulting from raveling of material into the bore after swab pass. Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the borehole. This condition was evidenced in Borehole NF-01A at 70m borehole length.	2	2	Low	4	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify zones of crushed rock. Design alignment to avoid or cross zones at the steepest angle possible. Develop contingency plan to reduce raveling potential or to control raveling. Require drilling fluid additives to reduce swelling potential. Require verification of mud motor and hole openers condition on a regular basis.	Possibility remains.	2	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	9	$, O	Bore instability *during swab pass* . Inability to support geotechnical materials along exposed surface of bore walls. Collapse of the HDD bore. Over mining of surrounding bedrock materials while excess materials are removed from the bore.	Raveling due to drilling parallel to major joint/fracture orientations. Exposing/day lighting unstable blocks of bedrock in crown of HDD bore. Risk increases with increase in bore diameter.	2	2	Low	4	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify major joint and fracture network. Design alignment such that it does not coincide with major fracture/joint orientations. Develop contingency plan to remove cuttings from the bore and to reduce raveling potential. Further assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	1	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	10	$, O	Stuck drilling equipment *during swab pass* . Inability to advance/retract drill pipe and down hole tooling.	Bore instability resulting from raveling of material into the bore after swab pass. Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the borehole. This condition was evidenced in Borehole NF-01A at 70m borehole length.	2	2	Low	4	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify zones of crushed rock. Design alignment to avoid or cross zones at the steepest angle possible. Develop contingency plan to reduce raveling potential or to control raveling.	Possibility remains.	2	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	11	$, O	Bore instability *during casing / lining pipe installation* . Inability to support geotechnical materials along exposed surface of bore walls. Collapse of the HDD bore. Over mining of surrounding bedrock materials while excess materials are removed from the bore.	Raveling due to drilling parallel to major joint/fracture orientations. Exposing/day lighting unstable blocks of bedrock in crown of HDD bore.	2	2	Low	4	Medium	4	Medium	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify major joint and fracture network. Design alignment such that it does not coincide with major fracture/joint orientations. Develop contingency plan to remove cuttings from the bore. Complete a swab pass to gauge condition of bore prior to installation.	Possibility remains.	2	2	Low	4	Medium	4	Medium

Table 3: Risk Register for Shoreline Crossing at Point Amour - Labrador Side of the Strait of Belle Isle. Horizontal Directional Drilling Feasibility Assessment

Likelihood Categories

Score	Descriptor	Probability
1	Improbable	about 1 in 1000
2	Remote	about 1 in 100
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Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5				HIGH	
4		MEDIUM			
3					
2	LOW				
1					

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
2	• Minor Injuries • Operative Requires First Aid Treatment • Stops Work • Medium term local damage or short term regional damage	• $10's k extra cost	• Significant revenue loss • Minor security alert • Re-routing local access
3	• Reportable / Lost Time Injury or Illness • Long term local damage	• Cost to Project ($100's k) • Delay in Project of Several Weeks (on Critical Path)	• Effects of a facility closure • Major regional impact Delay of Several Weeks (Critical Path)
4	• Major injury or illness with long term effects • Long term systematic damage	• Cost to Project ($1M's) • Delay in Project of Several Months (on Critical Path)	• Major effects to infrastructure Delay of Several Months (Critical Path)
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Risk Level Action

Risk Level	Health, Safety & Environment Risks	Operational Risks
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Medium	• Consider Alternative Design or Construction Method • If Alternatives are not available, specify precautions to be adopted • List residual hazards in risk register	• Disseminate risk assessment information to
High	• Seek alternative solutions • If Alternatives are not available, specify precautions to be adopted and advise senior management and planning supervisor (where applicable) • List residual hazards in risk register	• List residual hazards in risk register

Risk Type: S= Safety, E= Environmental, O= Operational $= Financial

Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Geotechnical Risk	12	$, O	Stuck casing / liner pipe during product *during casing / liner pipe installation*. Inability to advance/retract drill pipe and down hole tooling.	Bore instability resulting from raveling of material into the bore after swab pass. Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the borehole.	2	2	Low	4	Medium	4	Medium	Require successful completion of swab pass prior to casing / liner pipe insertion. Review drill rig rotary torque and thrust during swab pass. Consider pushing in a sample length (i.e. 10 to 50 metre section of steel casing) through the bore prior to installing the entire casing / liner pipe string.	Possibility remains but likelihood reduced.	1	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	13	$, O	Raveling of zones of crushed bedrock materials into the bore. Borehole instability.	Presence of crushed rock and clay seams in tectonic zones (faults, lineaments, etc.) that swell or expand into the borehole trapping drill tools in the HDD bore.	2	2	Low	3	Medium	2	Low	Complete geotechnical investigation to characterize bedrock materials in near shore environment where geotechnical information is not available. Identify zones of crushed rock. Design alignment to avoid or cross zones at the steepest angle possible. Develop contingency plan to reduce raveling potential or to control raveling. Complete a swab pass to gauge condition of bore prior to installation. Require drilling fluid additives to condition drilling fluid.	Possibility remains.	2	2	Low	3	Medium	2	Low
HDD - Geotechnical Risk	14	E, $, O	Inability to maintain bore stability in vicinity of ocean floor.	Drilling with increasingly lower depth of cover above bore as HDD installation nears planned exit location. Encountered bedrock materials that are not self supporting (i.e. bedrock with very low RQD).	3	3	Medium	3	Medium	3	Medium	Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design bore within uniform materials to maximum extent possible. Develop contingency plans. Perform ROV survey of anticipated exit locations. Consider jetting/dredging to remove loose material above sound bedrock.	Possibility remains but likelihood reduced.	3	3	Medium	3	Medium	3	Medium
HDD - Geotechnical Risk	15	E, $, O	Inability to advance drill bit/hole opener. Inability to insert product pipe / liner casing.	Encountering soils on ocean floor with a high percentage of *cobbles* requiring pull back and re-drilling of the bore.	3	3	Medium	4	High	4	High	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit on sloped surface or in an area lacking cobbles. Dredge loose material away from intended exit location. May require having dredge material on standby. May experience weather delays if dredging required depending on time of year.	Possibility remains but likelihood and severity reduced.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	16	E, $, O	Inability to advance drill bit/hole opener. Inability to insert product pipe / liner casing.	Encountering soils on ocean floor with a high percentage of *gravels* resulting in raveling and bore instability/collapse.	3	3	Medium	4	High	4	High	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit on sloped surface or ina area lacking gravels. Develop ability to jet (inject drilling fluids) in front of casing / liner pipe during insertion. Jet/dredge loose material away from intended exit location. May require having jet/dredge equipment on standby. May experience weather delays if dredging required depending on time of year.	Possibility remains but likelihood and severity reduced.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	17	$, O	Inability to maintain bore stability/condition bore.	Encountering bedrock materials with artesian groundwater conditions that prevent the build-up of a filter cake along the walls of the bore.	1	2	Low	2	Low	2	Low	Characterize potential risk by reviewing borehole logs and field notes. Minimize potential by designing alignment within favorable bedrock units. Develop contingency plans to address. Require use of drilling fluid additives to mitigate artesian conditions.	Possibility remains.	1	2	Low	2	Low	2	Low
HDD - Geotechnical Risk	18	$, O	Excessive drill tool wear requiring frequent tool replacements.	Drilling through bedrock with very hard crystalline conglomerate in very strong host rock matrix. Drilling through abrasive bedrock materials.	2	2	Low	3	Medium	2	Low	Complete geotechnical investigation to characterize bedrock materials where geotechnical information is not available. Complete unconfined compressive strength and Cerchar abrasivity testing of bedrock core to assess strength and abrasivity and provide means for contractor to select appropriate drilling equipment. Require sufficient amount of drill bits, hole openers and mud motors to avoid delays associated with worn out equipment.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	2	Low

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Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5					
4					
3					
2					
1					

HIGH

MEDIUM

LOW

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
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Risk Level Action

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Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Geotechnical Risk	19	$, O	Loss or excessive deviation of pilot bore alignment.	Encountering a large vug in limestone layers.	2	2	Low	3	Medium	3	Medium	Assess potential by reviewing existing geologic information, and/or with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance.	Possibility remains.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	20	$, O	Loss of down hole drilling equipment.	Encountering a large vug in limestone layers.	2	2	Low	3	Medium	3	Medium	Assess potential by reviewing existing geologic information and/or with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance.	Possibility remains.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	21	$, O	Borehole instability and collapse.	Poor rock quality due to crushed rock zones, tectonic zones (faults, lineaments, etc.), and other zones where core loss was encountered in Bradore Fm (LAB) and in Hawke Bay Fm (NL) due to reduced slake durability. These conditions can result in long-term borehole instability if left unlined.	3	2	Medium	3	Medium	3	Medium	Complete geotechnical investigation to characterize bedrock materials where geotechnical information is not available. Develop contingency plans. Assess potential with a proposed pilot bore drilling investigation early in the design phase.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	22	$, O	Sedimentation of casing / liner pipe at exit location on ocean floor.	Strong ocean currents that are capable of carrying significant sediment bedload.	3	2	Medium	4	High	4	High	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit on sloped surface. Develop contingency plans. Consider installing a plug on bottom of casing. Select exit locations away from areas with obvious sedimentation transport.	Possibility remains but likelihood and severity reduced.	2	2	Low	3	Medium	3	Medium
HDD - Geotechnical Risk	23	$, O	Inability to steer for line and grade through ocean floor sediments. Inability to support weight of drilling equipment as drilling equipment is advanced through ocean floor sediment.	Extensive deposits of sand on the ocean floor.	3	2	Medium	4	High	4	High	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit away from thick deposits. Develop ability to jet (inject drilling fluids) in front of casing pipe during insertion. Select exit locations away from areas with obvious sedimentation transport.	Possibility remains but likelihood reduced.	2	2	Low	4	Medium	4	Medium
HDD - Geotechnical Risk	24	$, O	Inability to install casing pipe through ocean floor sediments.	Extensive deposits of soil on the ocean floor that interfere with ability to build angle and exit the ocean floor.	2	2	Low	3	Medium	3	Medium	Complete a ROV survey of intended exit locations to characterize potential risks within specific soil units. Minimize potential by designing alignment to exit away from thick deposits. Develop ability to jet (inject drilling fluids) in front of liner / casing pipe during insertion. Consider providing the ability to remove some of the water used for buoyancy control and replace with air to add buoyancy to the product pipe. Select exit locations away from areas with obvious sedimentation transport.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low

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Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5				HIGH	
4		MEDIUM			
3					
2	LOW				
1					

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
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Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Installation Risk	25	E, $, O	Loss of down hole tooling (in whole or in part). Inability to remove down hole equipment from bore. Inability to retrieve down hole equipment *during pilot bore drilling*.	Mechanical failure of equipment. Excess wear of drilling equipment. Bore Instability.	2	3	Medium	3	Medium	2	Low	Require certification of all drilling equipment including operating hours since last refurbishment. Develop criteria for verification of key equipment components on a regular basis. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent. Assess potential with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance. Fish damaged tooling from bore. Re-drill around lost tooling.	Possibility remains.	2	3	Medium	3	Medium	2	Low
HDD - Installation Risk	26	E, $, O	Loss of down hole tooling (in whole or in part). Inability to remove down hole equipment from bore. In ability to retrieve down hole equipment during *ream/hole opening pass(es)*.	Mechanical failure of equipment. Excess wear of drilling equipment. Bore Instability.	2	3	Medium	4	Medium	4	Medium	Require certification of all drilling equipment including operating hours since last refurbishment. Develop criteria for verification of key components on a regular basis. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent. Assess potential with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance. Fish damaged tooling out of bore. Steering around lost equipment would require partial redrilling of pilot bore.	Possibility remains.	2	3	Medium	4	Medium	4	Medium
HDD - Installation Risk	27	E, $, O	Loss of down hole tooling (in whole or in part). Inability to remove down hole equipment from bore. In ability to retrieve down hole equipment *during swab pass*.	Mechanical failure of equipment. Excess wear of drilling equipment. Bore Instability.	2	3	Medium	4	Medium	4	Medium	Require certification of all drilling equipment including operating hours since last refurbishment. Develop criteria for verification of key components on a regular basis. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent. Assess potential with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance. Fish damaged tooling out of bore. Steering around lost equipment would require partial redrilling of pilot bore.	Possibility remains.	2	3	Medium	4	Medium	4	Medium
HDD - Installation Risk	28	$	Difficulty/Inability to remove cuttings from within the HDD bore.	Drilling with water as opposed to drilling with properly engineered bentonite drilling fluid.	1	2	Low	3	Low	2	Low	Develop experience criteria for mud engineer to monitor and adjust drilling fluids during the drilling process. Require sufficient materials on site to prevent shortage and delays waiting for transportation of additional materials.	Possibility remains.	1	2	Low	3	Low	2	Low
HDD - Installation Risk	29	$, O	Significant/extensive delays in the drilling process while waiting for new drilling mud.	Loss of drilling fluids / Frac out of drilling fluids. Loss of drilling fluids through existing open joints/fracture networks within bedrock materials. Loss of Drilling fluids to the ocean/marine environment. Inadequate or unreliable fresh water source.	3	2	Medium	3	Medium	2	Medium	Identify primary and secondary sources of fresh water. These sources can include but should not be limited to drilling of fresh water wells, transportation of water to the site from a distant source, tapping into freshwater lakes, etc. Develop contingency plans for addressing frac out/loss of fluids.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	2	Low
HDD - Installation Risk	30	$, O	Multiple bores intersecting and damaging previously installed casing / liner pipelines.	Insufficient spacing between parallel bores. Inaccurate location / lack of verification of position of previously installed pipelines.	3	2	Medium	3	Medium	3	Medium	Provide adequate separation distance. Separate bores in horizontal and/or vertical planes. Use guidance system capable of adequately tracking down hole tooling. Require use of gyro guidance system that is not susceptible to interference. Design bore geometries in a fanning outward pattern to increase the spacing between the bores with depth.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Installation Risk	31	$, O	Multiple bores intersecting and damaging previously installed casing / liner pipelines.	Operator error, interference with guidance system, inability to track pilot bore. Using a guidance system that is subject to interference by bedrock materials with magnetic properties.	4	2	Medium	3	High	3	High	Develop contractor experience qualifications for operating tracking system. Require regular calibration checks of guidance system. Design bore geometries in a fanning outward pattern to increase the spacing between the bores. Require use of gyro guidance system. Require the use of experienced site inspectors to monitor drilling progress.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium

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3					
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1					

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Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
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HDD - Installation Risk	32	$, O	Damage to previously installed casing / liner pipelines.	Communication of joints/fracture networks between adjacent bores. Damage caused by excessive grouting pressures during grouting operations during attempts to re-establish drilling fluid returns.	1	1	Low	2	Low	1	Low	Require insertion of steel casing / liner pipe prior to initiating drilling of subsequent pilot bore. Design bore geometries in a fanning outward pattern to increase the spacing between the bores as it increases in depth. Design casing / liner to resist anticipated forces.	Possibility remains.	1	1	Low	2	Low	1	Low
HDD - Installation Risk	33	E, $, O	Prematurely filling of HDD bore with grout during drilling of adjacent bore (assumes casing / liner pipe has not yet been installed).	Communication of joints/fracture networks between adjacent bores. Loss of grout through joint/fracture networks during grouting operations during attempts to re-establish drilling fluid returns.	4	3	High	4	High	4	High	Require insertion of steel casing / liner pipe prior to initiating drilling of subsequent pilot bore. Design bore geometries in a fanning outward pattern to increase the spacing between the bores as it increases in depth.	Possibility remains but likelihood and severity reduced.	1	2	Low	2	Low	2	Low
HDD - Installation Risk	34	$, O	Inability to advance drill bit/hole opener. Inability to maintain bore stability. Locking up of drilling equipment due to size of cuttings and inability to remove cuttings.	Producing gravel sized cuttings during bedrock drilling. Encountering pebble conglomerate that produces a large volume of pebble sized clasts. Encountering bedrock materials with a tendency to ravel into the bore.	3	2	Medium	3	Medium	2	Medium	Develop submittal requirements to review Contractor's planned equipment. Develop experience criteria for HDD rig operator, mud engineer and site superintendent. Develop contingency plans that may include, but are not limited to, increasing the carrying capacity of the drilling fluid by adjusting mud properties, increasing drilling fluid pumping rates, etc. Require use of experienced site inspector to monitor drilling progress.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	2	Low
HDD - Installation Risk	35	$, O	Loss of ability to track pilot bore(s) along proposed HDD bore path.	Encountering source of interference that disrupts tracking system. Inability to stage equipment necessary to enable traditional secondary tracking of the pilot bore(s).	4	2	Medium	3	High	3	High	Determine all potential sources of interference at the crossing location. Develop experience/qualification requirements for Contractor and Guidance System personnel. Determine requirements for Contractor specific equipment (i.e. gyro survey equipment) and verify capabilities for use at the site.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Installation Risk	36	E, $, O	Inability to maintain line and grade.	Difficulty inducing a steering correction. Improper down hole tooling/equipment. Improper down hole tooling/equipment set up. Improper use of guidance equipment. Malfunction of the guidance system. Drift in the guidance system.	3	2	Medium	3	Medium	3	Medium	Develop performance criteria on tolerances for line and grade. Require immediate notification if issues arise. Develop contingency plans. Develop performance criteria for guidance system. Develop experience/qualification requirements for Contractor, drill rig operator, steering personnel, and site superintendent. Determine requirements for Contractor specific equipment and verify capabilities for use at the site. Require certificates of calibration for all guidance components.	Possibility remains.	2	2	Low	3	Medium	3	Medium
HDD - Installation Risk	37	E, $, O	Missed exiting at target exit location (long) by greater than 10 metres.	Inability to track pilot bore(s), improper use of guidance equipment. Malfunction of the guidance system. Drift in the guidance system. Difficulty inducing a steering correction (building angle at exit). Poorly defined ocean floor topography in target exit location. Discrepancy/offset of survey contours between water and land.	3	2	Medium	3	Medium	2	Medium	Develop experience/qualification requirements for Contractor and Guidance System personnel. Determine requirements for Contractor specific equipment and verify capabilities for use at the site. Require certificates of calibration for all guidance components. Consider completing a detailed bathymetric survey of the area surrounding the target exit locations. Ensure offshore survey is properly converted to onshore Geodetic survey coordinates.	Possibility remains.	2	2	Low	3	Medium	2	Low
HDD - Installation Risk	38	E, $, O	Missed exiting at target exit location (left/right) by greater than 10 metres.	Inability to track pilot bore(s), improper use of guidance equipment. Malfunction of the guidance system. Drift in the guidance system. Poorly defined ocean floor topography in target exit location. Discrepancy/offset of survey contours between water and land.	3	2	Medium	3	Medium	2	Medium	Develop experience/qualification requirements for Contractor and Guidance System personnel. Determine requirements for Contractor specific equipment and verify capabilities for use at the site. Require certificates of calibration for all guidance components. Ensure offshore survey is properly converted to onshore Geodetic survey coordinates.	Possibility remains.	2	2	Low	3	Medium	2	Low

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MEDIUM
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Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
2	• Minor Injuries • Operative Requires First Aid Treatment • Stops Work • Medium term local damage or short term regional damage	• $10's k extra cost	• Significant revenue loss • Minor security alert • Re-routing local access
3	• Reportable / Lost Time Injury or Illness • Long term local damage	• Cost to Project ($100's k) • Delay in Project of Several Weeks (on Critical Path)	• Effects of a facility closure • Major regional impact Delay of Several Weeks (Critical Path)
4	• Major injury or illness with long term effects • Long term systematic damage	• Cost to Project ($1M's) • Delay in Project of Several Months (on Critical Path)	• Major effects to infrastructure Delay of Several Months (Critical Path)
5	• Fatalities • Permanent damage	• Potential to close down the project	• Loss of functionality / Close down of Project

Risk Level Action

Risk Level	Health, Safety & Environment Risks	Operational Risks
Low	• Check that no further risks can be eliminated by modifications of design • Proceed with Design	• Seek alternative, and assess cost to benefit of
Medium	• Consider Alternative Design or Construction Method • If Alternatives are not available, specify precautions to be adopted • List residual hazards in risk register	• Disseminate risk assessment information to
High	• Seek alternative solutions • If Alternatives are not available, specify precautions to be adopted and advise senior management and planning supervisor (where applicable) • List residual hazards in risk register	• List residual hazards in risk register

Risk Type: S= Safety, E= Environmental, O= Operational $= Financial

Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Installation Risk	39	$, O	Missed exiting at target exit location (short). Prematurely exiting through ocean floor by greater than 10 metres.	Inability to track pilot bore(s), improper use of guidance equipment. Malfunction of the guidance system. Drift in the guidance system. Poorly defined ocean floor topography in target exit location. Discrepancy/offset of survey contours between water and land.	3	2	Medium	3	Medium	2	Medium	Develop experience/qualification requirements for Contractor and Guidance System personnel. Determine requirements for Contractor specific equipment and verify capabilities for use at the site. Require certificates of calibration for all guidance components. Ensure offshore survey is properly converted to onshore Geodetic survey coordinates.	Possibility remains.	2	2	Low	3	Medium	2	Low
HDD - Installation Risk	40	E, $, O	High installation loads. Damaged to casing / liner pipe.	Improper conditioning of the bore. Improper pipeline insertion into the HDD bore. Improper use of buoyancy compensation during pullback operations.	2	3	Medium	4	Medium	4	Medium	Fabricate pipe string in one complete length to eliminate prolonged stoppages to weld additional sections of pipe together. Determine required installation loads and compare with drill rig and pipe capabilities. Require swab pass through bore to gauge bore condition. Develop contingency plans. Remove as much of the cuttings from the bore as possible prior to insertion. Remove casing from bore with thruster to allow further bore conditioning.	Possibility remains but likelihood reduced.	1	3	Low	4	Medium	4	Medium
HDD - Installation Risk	41	E, $, O	Loss of drilling fluids / Frac out of drilling fluids.	Collapse of bore material behind down hole tooling that leads to blockage of the bore annulus and significant drilling fluid pressure increase. Producing cuttings that are too big (i.e., gravel size and larger) or too thick/viscous.	2	3	Medium	3	Medium	3	Medium	Complete geotechnical investigation to characterize site bedrock materials. Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Design bore within uniform materials with sufficient depth of cover. Design bore in more favorable bedrock.	Possibility remains but likelihood reduced.	1	3	Low	3	Low	3	Low
HDD - Installation Risk	42	E, $, O	Loss of drilling fluids / Frac out of drilling fluids.	Increasing the diameter of the bore too quickly. Reaming the bore to final diameter in one pass following completion of the pilot bore (depending on bore diameter). Slurry (mud and cuttings) that are too thick and lead to pressure buildup event.	3	3	Medium	3	Medium	3	Medium	Require experience/qualification/performance requirements in the project specifications. Require multiple reaming passes through the bore. Require swab pass prior to product pipe insertion. Develop submittal requirements to review Contractor's planned equipment.	Possibility remains but likelihood reduced.	2	3	Medium	3	Medium	3	Medium
HDD - Installation Risk	43	E, $, O	Loss of drilling fluids / Frac out of drilling fluids.	High bore fluid pressures required to induce drilling fluid flow from the drill bit/reamer location to the HDD entry/exit location. High elevation differential between horizontal section of bore and HDD entry/exit locations that would require high drilling fluid pressures in comparison to an HDD entry/exit location at a lower elevation.	4	3	High	3	High	3	High	Perform a hydrofracture analysis to determine the allowable maximum pressure and required drilling fluid pressure. Identify HDD entry locations as close as possible to the shoreline with elevations as low as possible.	Possibility remains but likelihood reduced.	3	3	Medium	3	Medium	3	Medium
HDD - Installation Risk	44	$	Inability to advance drill bit/hole opener assembly. Inability to provide sufficient face pressure at bit/hole opener assembly to advance through bedrock materials.	High frictional forces acting on the drill pipe and bottom hole assembly resulting in a reduced ability to apply face pressure to cutting tools. Risk increases with an increase in installation length, bore curves, and steering/drilling upwards toward the bore exit location.	3	2	Medium	3	Medium	3	Medium	Consider maintaining slight downward orientations of the pilot bore to the maximum extent possible to eliminate long horizontal and/or upward drilling. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent. Consider use of heavier drill pipe within drill string. Require use of properly sized equipment prior to equipment mobilization onto the site.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium
HDD - Installation Risk	45	$, O	Poor production. Loss in ability to excavate bedrock materials.	Inability to provide sufficient torque with drill rig to rotate bottom hole assembly (due to bore length). Improper selection of cutting tools and hole openers.	3	2	Medium	3	Medium	3	Medium	Require the use of mud motor during pilot bore and reaming stages. Consider slight downward orientations of both pilot bores to eliminate long horizontal stretches and upward drilling. Develop experience/qualification requirements for Contractor, drill rig operator, and site superintendent.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	3	Medium

Table 3: Risk Register for Shoreline Crossing at Point Amour - Labrador Side of the Strait of Belle Isle. Horizontal Directional Drilling Feasibility Assessment

Likelihood Categories

Score	Descriptor	Probability
1	Improbable	about 1 in 1000
2	Remote	about 1 in 100
3	Occasional	about 1 in 10
4	Probable	more likely than not
5	Frequent	expected to happen

Risk Profile

Likelihood Score	Severity Score 1	2	3	4	5
5					
4					
3					
2					
1					

HIGH
MEDIUM
LOW

Severity Categories (Health, Safety & Environment)

Score	Health, Safety & Environment Impact	Financial Impact ($)	Schedule/Operational Impact
1	• Minor Injuries/ Inconveniences • Operative can continue work • Short term local damage	• $1000's extra cost	• Minor revenue loss • Public relations embarrassment
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Risk Level Action

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Risk Type: S= Safety, E= Environmental, O= Operational $= Financial

Activity / Element	Risk No. & Type		Risk/Hazard	Cause	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Schedule / Operational: Severity	Risk	Risk Control Measures in Design (RCM)	Residual Hazards	Post / Pre RCM Severity / Risk: Likelihood	Health, Safety & Environment: Severity	Risk	Financial: Severity	Risk	Operational: Severity	Risk
HDD - Installation Risk	46	$, O	Contamination of drilling fluid.	Seawater contamination of drilling fluid resulting from highly effective hydraulic communication of seawater along rock joints. Punch of pilot bore and inability to seal end of bore from direct communication with ocean.	3	2	Medium	3	Medium	3	Medium	Develop contingency plans to deal with using lost circulation material. Assess potential with a proposed pilot bore drilling investigation early in the design phase. Monitor drill rig performance. Require additional polymers that can be used to help mix drilling fluids in presence of salt. Develop exiting/punch out strategy to minimize risk.	Possibility remains but likelihood reduced.	1	2	Low	3	Low	3	Low
HDD - Installation Risk	47	E, $, O	Damage to casing pipe within bore.	Iceberg scour/ impact on ocean floor. Insufficient depth of cover between installed casing and ocean floor.	4	3	High	5	High	5	High	Determine depth of scour/impact. Design bore with sufficient clearance below scour depth.	Possibility remains but likelihood and severity reduced.	3	2	Medium	2	Medium	2	Medium
HDD - Installation Risk	48	E, $, O	Damage to casing pipe at exit location on ocean floor.	Iceberg scour to depth of installation.	2	3	Medium	5	High	5	High	Determine depth of scour. Design exit locations within topographically protected areas.	Possibility remains but likelihood and severity reduced.	1	2	Low	2	Low	2	Low
HDD - Installation Risk	49	$, O	Damage to drilling equipment.	Equipment breakdown during cold weather construction resulting in damage caused by freezing/ice due to inability to operate equipment.	3	2	Medium	4	High	4	High	Develop contractor experience qualifications for working in cold environments. Require verification of overhauling of equipment prior to drilling. Require contractor to submit winterization plan.	Possibility remains but likelihood reduced.	2	2	Low	4	Medium	4	Medium
HDD - Installation Risk	50	$, O	Significant delays in the drilling process while waiting for supply items.	Improper supply chain management by contractor. Improper supply chain management by local suppliers. Disruption of supply chain by severe weather.	2	2	Low	4	Medium	4	Medium	Require contractor to submit proposed supply chain with contingency plans for supply items that are key to production such as fuel, fresh water, drilling fluids, parts, etc. Identify primary and secondary resources. Require sufficient resources and supplies on hand for the duration.	Possibility remains.	2	2	Low	4	Medium	4	Medium
HDD - Installation Risk	51	$, O	Decreased production during winter months	Lack of contractor experience in cold environments. Improperly prepared equipment or use of equipment that is not designed for use in cold environments.	3	2	Medium	3	Medium	4	High	Include prequalification requirement for contractor experience in cold environments. Require contractor to submit winterization plan.	Possibility remains but likelihood reduced.	2	2	Low	3	Medium	4	Medium
HDD - Installation Risk	52	E, $, O	Delay. Damage to equipment.	Severe weather with very high winds and rain. Tropical storm, hurricane. Flooding.	2	3	Medium	4	Medium	4	Medium	Develop contingency plan to deal with potential storm detailing securing of equipment and materials.	Possibility remains.	2	3	Medium	4	Medium	4	Medium
HDD - Installation Risk	53	$, O	Delay to Construction.	Working beside sites of historical importance.	5	2	High	2	High	2	High	Design alignment with entry and exit locations away from historic site. Perform early-on discussions with stake holders to determine up front requirements. Determine benefits to area that may be realized.	Possibility eliminated by avoiding area.	3	2	Medium	2	Medium	2	Medium