CANADIAN ASSOCIATION OF PETROLEUM PRODUCERS

GUIDELINE

Planning Horizontal Directional Drilling for Pipeline Construction

September 2004

CAPP Publication 2004-0022

The Canadian Association of Petroleum Producers represents 150 companies that explore for, develop and produce natural gas, natural gas liquids, crude oil, oil sands, and elemental sulphur throughout Canada. CAPP member companies produce approximately 98 per cent of Canada's natural gas and crude oil. CAPP also has 125 associate members who provide a wide range of services that support the upstream crude oil and natural gas industry. Together, these members and associate members are an important part of a $75-billion-a-year national industry that affects the livelihoods of more than half a million Canadians.

Review by June 2009

Disclaimer

This publication was prepared for the Canadian Association of Petroleum Producers (CAPP) by Entec Consulting Limited (Entec), TERA Environmental Consultants (TERA), Canadian Horizontal Drilling Ltd. (CHD) and Geo-Engineering (M.S.T.) Ltd. (Geo-Engineering). Applied Aquatic Research Ltd. (AAR) provided input on water crossings issues and assisted with the review of the document. While it is believed that the information contained herein is reliable under the conditions and subject to the limitations set out, CAPP and Entec, TERA, CHD, Geo-Engineering and AAR do not guarantee its accuracy. The use of this report or any information contained will be at the user's sole risk, regardless of any fault or negligence of Entec, TERA, CHD, Geo-Engineering, AAR, and CAPP or its co-funders.

2100, 350 – 7th Ave. S.W.
Calgary, Alberta
Canada T2P 3N9
Tel (403) 267-1100
Fax (403) 261-4622

905, 235 Water Street
St. John's, Newfoundland
Canada A1C 1B6
Tel (709) 724-4200
Fax (709) 724-4225

Email: communication@capp.ca Website: www.capp.ca

OVERVIEW

Horizontal Directionally Drilling (HDD) has proven itself over the last few years to be a very effective technique for the installation of pipelines and other utilities in sensitive or congested areas.

This document provides best practices and recommended procedures for the investigation, planning and execution of an HDD installation for pipeline construction.

It provides guidance on the regulatory, environmental, geotechnical, risk, economics, engineering, contractual and construction considerations that must be evaluated prior to any final decisions to proceed with an HDD installation.

The purpose of this document is to assist pipeline companies, contractors and regulators in planning, evaluating and constructing HDD crossings.

The document has been written to primarily address the installation of oil and gas pipelines in Canada, although concepts and practices contained within are applicable to many industries and jurisdictions.

All pipelines in Canada, including HDD projects, must comply with the requirements of CSA Z662, which is referenced by federal and provincial pipeline regulators. CSA Z662 contains requirements for the design, material selection (including coating selection), construction and operation of pipelines that would apply to HDD projects.

A glossary of technical terms used in this document is provided in Appendix A.

Contents

Figures

Tables

Acronyms

AENV	Alberta Environment
EUB	Alberta Energy and Utilities Board
ASRD	Alberta Sustainable Resource Development
BHA	bottom hole assembly
CAPP	Canadian Association of Petroleum Producers
CCG	Canadian Coast Guard
CEAA	*Canadian Environmental Assessment Act*
CPWCC	Canadian Pipeline Watercourse Crossing Committee
DFO	Fisheries and Oceans Canada
EM	electromagnetic
ERT	electrical resistivity tomography
GPR	ground penetrating radar
HADD	harmful alteration, disruption or destruction of fish habitat
HDD	horizontal directional drilling
INAC	Indian and Northern Affairs Canada
IOGC	Indian Oil and Gas Canada
I.S.R.M.	International Society for Rock Mechanics
MFO	Minister of Fisheries and Oceans Canada
NEB	National Energy Board
NEB Act	*National Energy Board Act*
NWPA	*Navigable Waters Protection Act*
O.D.	outside diameter
QAES	qualified aquatic environment specialist
SPT	standard penetration tests

1 INTRODUCTION

Horizontal directional drilling (HDD) has emerged as a preferred crossing method in many situations for the installation of oil and gas pipelines as well as other utilities under watercourses, roads, rail lines, steep slopes and other obstacles.

This technology has been enthusiastically embraced by proponents, contractors and regulators as a potentially low impact construction technique. In many cases, however, the suitability of the HDD method must be evaluated and compared to more traditional open-trench construction techniques in order to ensure that an appropriate technique is chosen for the conditions and concerns present at a particular crossing. Recognition of the advantages, limitations and potential risks of HDD is an important step in this evaluation.

The successful design and construction of an HDD is the result of a team effort combining the skills of the regulatory group, owner, engineering consultant, environmental consultant, inspection services and the specialist HDD contractor. Success in this endeavor is measured in more than the successful pull back of the pre-built pipeline drag section. It is the completion of the project for a reasonable cost with minimal environmental impact and in a manner that allows the contractor to make a fair profit. These should be the goals in any type of project including an HDD installation.

It is important to realize that an HDD may represent the critical path on the overall project schedule. In addition, an HDD may have the highest risk of failure of any activities on a project. Therefore, all aspects of planning and design for an HDD need to be assigned a high priority or importance value due to their potential effect on the overall project.

1.1 Purpose of Guidelines

The purpose of this document is to assist pipeline companies, contractors and regulators in the planning, evaluation and construction of HDD crossings. In particular, the document provides guidance for:

- corporate regulatory personnel in determining the necessary course of action during permitting and approval of projects planning an HDD;
- corporate engineering personnel in the planning, contracting and supervision of construction;
- corporate environmental personnel in the planning and provision of support to the construction team;
- contractor personnel in managing expectations of corporate and regulatory personnel; and
- regulatory managers in determining realistic expectations of HDD technology.

1.2 Description of HDD

Horizontal directional drilling is a trenchless construction method utilizing equipment and techniques from horizontal oil well drilling technology and conventional road boring. HDD construction is used to install petroleum pipelines (steel or plastic), fibre optic and electric cables, and water and waste water pipelines where conventional open trench construction is not feasible or will cause adverse disturbances to environmental features, land use or physical obstacles.

HDD technology is used in many situation, including the following:

- lake crossings;
- wetland crossings;
- canal and watercourse crossings;
- valley crossings;
- sensitive wildlife habitat; and
- road and railway crossings.

HDD installation involves four main steps:

1) pre-site planning;
2) drilling a pilot hole;
3) expanding the pilot hole by reaming; and
4) pull back of pre-fabricated pipe.

The following summarizes the main activities that take place during each phase of an HDD. Drilling of the pilot hole and pipe string pull back are illustrated on Figure 1.

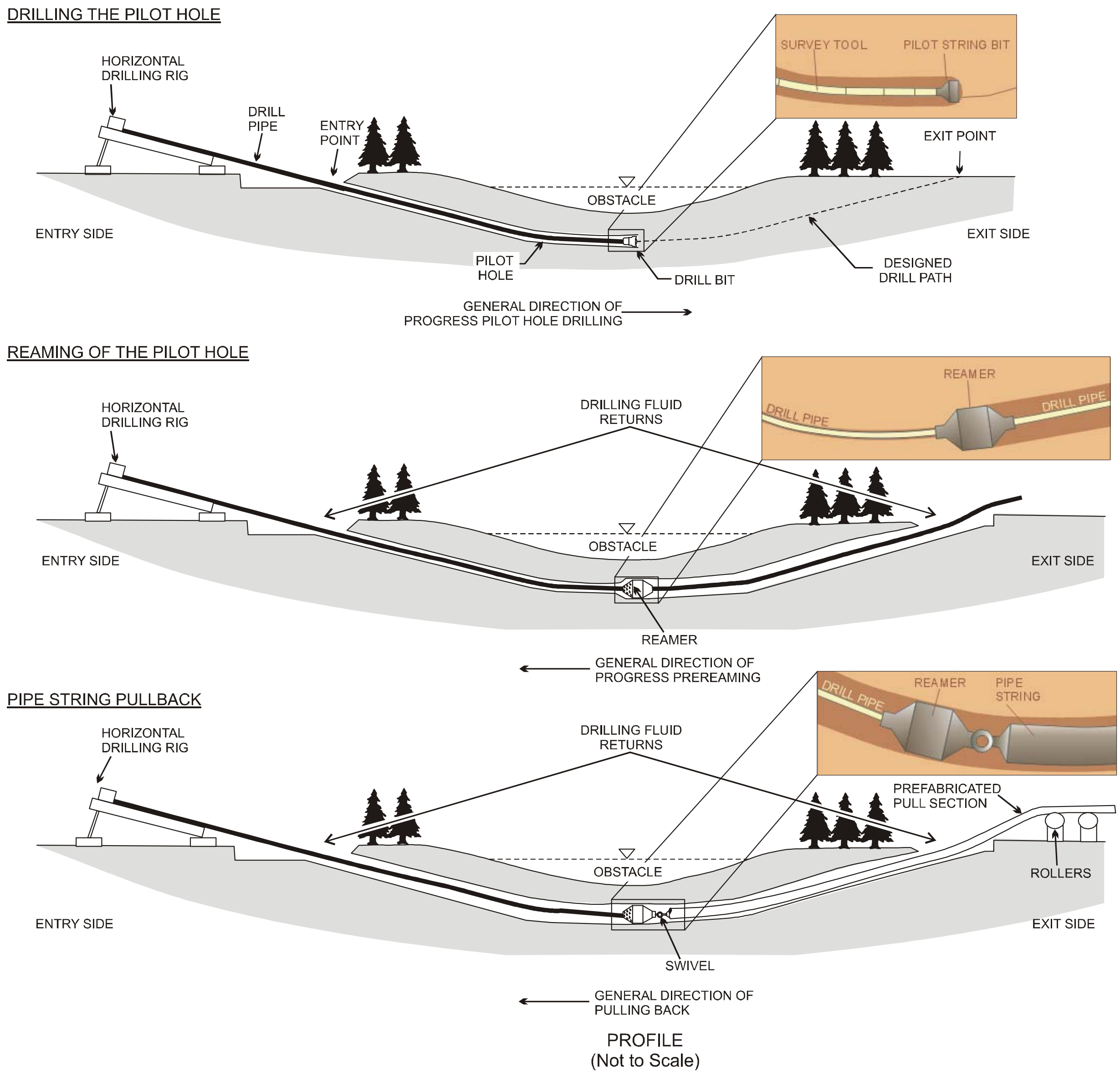
1.2.1 Pre-Site Planning

A determination is made as to whether an HDD is technically and geotechnically feasible by studying existing geological data and conducting field investigations to assess the subsurface conditions and characteristics likely to be encountered during the drill.

If an HDD is determined to be feasible, a drill path is designed to meet the requirements of the crossing and appropriate drill entry and exit locations are selected.

An allowance is made in the design of the drill path for any potential changes in the obstacle (i.e., stream migration or cutoff development) to be drilled under and the drill entry and exit points are refined.

Figure 1 Watercourse Crossing – Horizontal Directional Drill



Canadian Association of Petroleum Producers	PLANNING HORIZONTAL DIRECTIONAL DRILLING FOR PIPELINE CONSTRUCTION	
	WATERCOURSE CROSSING – HORIZONTAL DIRECTIONAL DRILL	
	1. September 2004	2. FIGURE. NO. 1

1.2.2 Drilling the Pilot Hole

An HDD drill rig and supporting equipment are set-up at the drill entry location determined during the pre-site planning phase.

A pilot hole is drilled along the predetermined drill path.

Periodic readings from a probe situated close to the drill bit are used to determine the horizontal and vertical coordinates along the pilot hole in relation to the initial entry point; the pilot hole path may also be tracked using a surface monitoring system that determines the down hole probe location by taking measurements from a surface point.

Drilling fluid is injected under pressure ahead of the drill bit to provide hydraulic power to the down hole mud motor (if used), transport drill cuttings to the surface, clean build-up on the drill bit, cool the drill bit, reduce the friction between the drill and bore wall, and stabilize the bore hole.

1.2.3 Reaming of the Pilot Hole

The down hole assembly is removed from the drill string upon breaking the ground surface at the exit location and is replaced with a back reamer;

The drill string is pulled back through the bore hole and the back reamer enlarges the diameter of the drill hole;

The reamer may be pulled from the pipe side of the HDD crossing if additional passes with the reamer are required to achieve the desired bore hole diameter; and

The reaming stage may not be necessary during HDDs for small diameter pipelines where the bore hole created by the pilot hole drill is of adequate size to pull back the pipe string (refer to Section 8.5.1).

1.2.4 Pipe String Pull back

Pipe is welded into a pipe string or drag section, that is slightly longer than the length of the drill, on the exit side of the bore hole.

The pipe is typically coated with a corrosion and abrasion resistant covering, and is commonly hydrostatically pretested to ensure pipeline integrity.

The pipe string is pulled over rollers into the exit hole and the pull back continues until the entire pipe string has been pulled into the bore hole.

The external coating of the pipe string visible at the entry point is inspected for damage upon completion of the pull back.

An internal inspection of the pipe string is performed to identify any damage done to the pipeline during the pull back.

Upon successful pull back of the pipe string, the drilling equipment is dismantled and demobilized.

The pipe string is connected to the conventionally laid pipeline and work areas are reclaimed with the rest of the pipeline right-of-way.

1.3 Workspace Requirements

Workspace for an HDD may require clearing and grading, depending on the entry and exit sites selected for the drill. Since the drill entry location or entry side accommodates the drill rig and supporting equipment, the entry side location requires satisfactory access as well as stable ground conditions to support heavy equipment (Figure 2). Equipment typically found on the entry side of a HDD include:

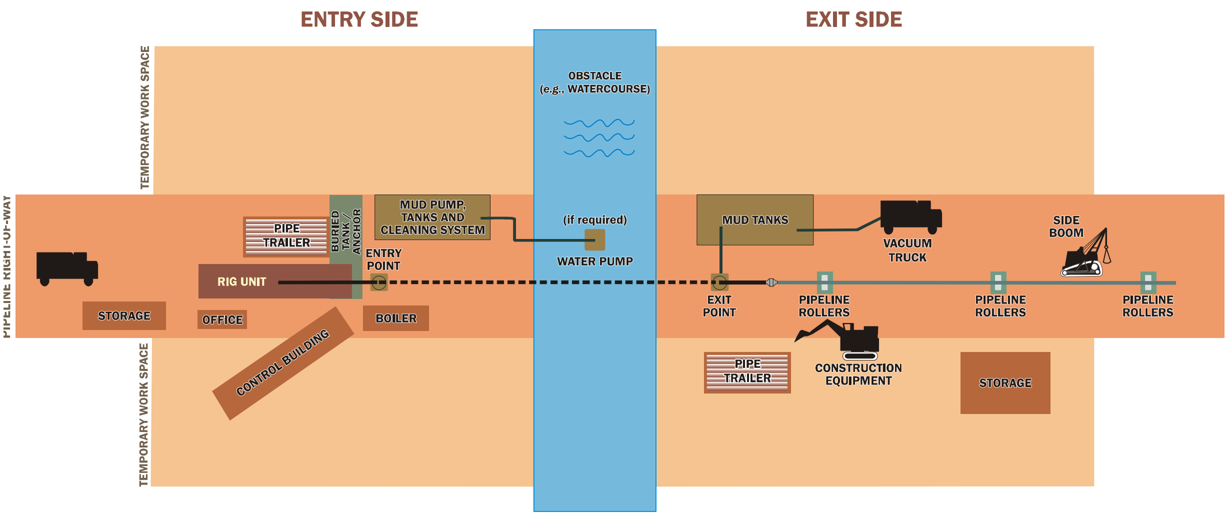
- the rig unit;
- power unit and generators;
- drill pipe rack and drill pipe;
- water pump;
- drill mud supply;
- drill mud mixing tank;
- drill mud pump; and
- mud handling and cleaning system.

Since the drill exit side is the location for the fabrication of the pipe string as well as where the pipe string is inserted into the bore hole, the workspace required is typically longer to accommodate the pipe string (Figure 2) and may require extra temporary workspace outside of the right-of-way known as "false right-of-way". Equipment typically found on the exit or pipe side of the HDD includes:

- exit mud containment tanks/pits;
- cuttings settlement tanks/pits;
- pipe racks and product pipe;
- rollers and pipeline handling equipment;
- side booms and other heavy equipment; and
- pipelines, welding, coating and testing equipment.

Selection of the drill site and exit location is addressed in Section 3.4.2

Figure 2 Horizontal Directional Drill Set-up



CAPP Canadian Association of Petroleum Producers	PLANNING HORIZONTAL DIRECTIONAL DRILLING FOR PIPELINE CONSTRUCTION	
	HORIZONTAL DIRECTIONAL DRILL SET-UP	
	1. September 2004	2. FIGURE. NO. 2

2 REGULATORY AND INFORMATION REQUIREMENTS

The regulatory requirements for undertaking an HDD in Canada depend upon the jurisdiction in which a project is to be built. Each watercourse crossing may be subject to federal, provincial, territorial and local regulatory review. Many jurisdictional agencies have codes of practice, guidelines and/or policies regarding watercourse crossings, and require notifications and/or applications for permits, authorizations or licenses.

The following sections describe the federal, provincial and territorial regulatory framework. Information requirements for each of these agencies are briefly discussed. This document has been written to reflect the regulatory information requirements at the time of publication. It does not address draft or proposed acts, codes of practice, guidelines or policies.

Appendix B provides a brief, summary checklist of the regulatory framework and the appropriate contacts. Since the regulatory requirements are complex and continually changing across the country, the responsibility to ensure that all requirements are met falls upon the proponent. Project planners should confirm with the appropriate agencies that the applicable permit applications are made and regulatory requirements have been identified.

2.1 Federal Jurisdictions

There are two federal acts which are most applicable to HDD watercourse crossings in Canada: the *Fisheries Act* and the *Navigable Waters Protection Act* (*NWPA*). Other acts are applicable but should only be considered in certain situations.

2.1.1 Fisheries Act

The *Fisheries Act* was enacted to protect fish, fish habitat and water frequented by fish, and to provide for sustainable fisheries in Canada.

There are several sections in the *Fisheries Act* (paraphrased below) which are most likely to pertain to HDD pipeline watercourse crossings:

Section 20	Provides for safe passage of fish.
Section 22	Provides for flow of water and passage of fish.
Section 30	Provides for water diversions or intakes to have a fish guard or screen.
Section 32	Prohibits the destruction of fish by any means other than fishing except as authorized by the Minister of Fisheries and Oceans (MFO) or regulation.

Subsection 35(1)	Prohibits works or undertakings that result in harmful alteration, disruption or destruction of fish habitat (HADD).
Subsection 35(2)	Allows for the authorization of HADD by the MFO.
Subsection 36(3)	Prohibits the deposition of deleterious substances in waters frequented by fish.

2.1.2 Navigable Waters Protection Act

The *NWPA* provides a legislative mechanism for the protection of the public right of marine navigation on all navigable waterways of Canada. This is accomplished through authorization of the construction of works built or placed in, over, through or across navigable waterways.

A navigable waterway is defined as being any body of water capable of being navigated by floating vessels of any description for the purpose of transportation, commerce or recreation. This includes both inland and coastal waters. The authority to determine the navigability of a waterway rests with the MFO or his/her designated representative.

The pertinent sections of the *NWPA* (paraphrased below) for HDD pipeline watercourse crossings are found in:

Section 5(1)(a)	No work shall be built or placed in, on, over, under, through or across any navigable water unless approved by the Minister.
Subsection 5(2)	Except in the case of a bridge, boom, dam or causeway, paragraph 5(1) (a) does not apply to any work that in the opinion of the Minister does not interfere substantially with navigation.

All pipelines that cross a navigable water are subject to review under the *NWPA*. In recognition of the low risk of some crossings, the Central, Arctic and Pacific regions have issued guidelines relaxing the need for application as long as certain conditions are followed. If the following conditions (paraphrased) are met, an HDD may be undertaken in these regions without applying for *NWPA* approval:

- no tools, equipment, vehicles or temporary structures are to remain in the water after completion of the work;
- any debris or other material accumulated as a result of the HDD must be removed;
- warning signs must be placed up- and downstream of construction;
- navigation must be maintained at all times;
- navigation stakeholders must be consulted in advance;

- the bed, if disturbed, must be restored to natural contours; and
- disturbed shorelines must be stabilized.

A thorough review of the guidelines (*e.g.*, Fisheries and Oceans Canada (DFO), 2003, 2004), should be made in advance on deciding to not apply for review by the Canadian Coast Guard (CCG).

In several situations these guidelines do not apply and an approval under the *NWPA* is required. These include:

- all National Energy Board (NEB) regulated pipelines;
- all crossings of waterways charted by the Canadian Hydrographic Service;
- all construction requiring a temporary bridge; and
- all crossings of a specified watercourse (21 major watercourses in the Central and Arctic regions are listed).

Where review and approval is required from CCG, applications should include a letter of application, site and construction drawings, authorization by owner, and environmental assessment documentation.

2.1.3 Other Federal Legislation

HDD watercourse crossings which are part of an international or interprovincial pipeline are subject to review under the *National Energy Board Act* (*NEB Act*) and are also subject to approval by CCG, under Section 108 of that Act and the *NWPA*.

The *Canadian Environmental Assessment Act* (*CEAA*) may also be triggered if:

- a federal authority is the proponent of a project;
- a project is being financed in whole or part by a federal authority;
- a project is being conducted on federal lands; or
- a federal authority is issuing a permit, license or approval for a project.

In the event that *CEAA* is triggered on a segment of the route (*e.g.,* the project is being undertaken on an Indian Reserve or an authorization under the *Fisheries Act* is required (*e.g.,* S. 35(2)), the Responsible Authority (*e.g.,* DFO) will establish the scope of the project and the scope of the assessment, and undertake the appropriate review process under *CEAA*.

First Nations self-government, land claims and protocols are an ever-changing consideration in the approval process. Documenting these requirements and recommendations is beyond the scope of this document. Nevertheless, to facilitate a timely review and approval, it is important that all proponents and regulators become familiar with the relevant agreements and other requirements. The incorporation of appropriate First Nations in the consultation and construction planning process will further assist in the acquisition of approvals.

Further details on these other regulatory conditions are summarized in Watercourse Crossings (Canadian Pipeline Watercourse Crossing Committee (CPWCC) 1999).

2.2 Provincial and Territorial Jurisdictions

Each provincial and territorial jurisdiction has various legislation, regulations, codes of practice, policies and guidelines affecting pipeline watercourse crossings. Most provinces and territories require a permit, license and/or other authorization to use/affect surface water and/or make alterations to streambeds and banks.

The review of applications to alter streambeds and banks generally involves the appropriate provincial fisheries management agencies and may include DFO depending on the agreement the province or territory has with DFO. The issuance of a permit, license or approval generally does not exempt the applicant from the provisions of any other applicable provincial or federal legislation, or any other processes of law including local or municipal by-laws.

The bed and banks of a watercourse are, in most instances, considered public lands in all provinces and territories in Canada. Proponents must apply to the appropriate provincial or territorial agency for approval to cross these lands.

An overview of the regulatory requirements for each province and territory is beyond the scope of this document, although Appendix B outlines the permits potentially required in each jurisdiction in Canada.

2.3 Other Guidance

With the emergence of HDD as a common construction technique, several guidance documents have been produced which may by useful in planning an HDD. These include but are not limited to:

- Directional Crossing Contractors Association. Guidelines for a Successful Directional Crossing Bid Package. 1995.
- Watercourse Crossings, Second Edition. Canadian Pipeline Water Crossing Committee. November, 1999.
- Horizontal Directional Drilling Best Management Practices Manual, Topical Report. Gas Research Institute. May, 2002.
- Horizontal Directional Drilling Practices Guidelines. HDD Consortium. 2004
- Alberta Energy and Utilities Board (EUB) Guide 50; Drilling Waste Management, Interim Directive ID 99-05

3 SELECTION OF HDD AS THE PREFERRED CROSSING METHOD

The decision to install an HDD crossing at a specific location is the result of a process that addresses the following:

- overall pipeline route selection;
- crossing location selection;
- crossing method selection;
- other selection criteria such as:
  - availability of access,
  - need for and suitability of vehicle crossings,
  - siting of entry and exit points,
  - dimensions of the No Drill Zone, and
  - availability of a water source.

3.1 Pipeline Route Section

The selection of a preferred water crossing location based on an overland pipeline routing assessment should also consider the method of crossing, alignment, and access for the HDD construction. The pipeline routing should allow for layout areas, entry/exit pads, access routes, and minimal points of inflection in the design drill path and the pipe string layout area.

3.2 Crossing Location Selection

The selection of the crossing should be undertaken in conjunction with the route selection to allow the following:

- flexibility in using various crossing methods, especially if the HDD fails and an alternative crossing technique is required;
- flexibility to use various accesses or vehicle crossing methods; and
- flexibility in refining the exact crossing location in the event that constraints prevent certain alignments.

3.3 Crossing Method Selection

In selecting a pipeline watercourse crossing method, many factors must be taken into consideration. These include, among others:

- pipeline diameter;
- project schedule (*i.e.,* desired schedule for the pipeline to be operational);
- watercourse crossing width, depth and flow;
- environmental sensitivity and associated constraints;
- geotechnical concerns;
- substrate composition;
- hydrological data;
- costs of the various alternatives;
- navigation;

- amount of working space;
- regulatory requirements and conditions including timing constraints;
- equipment availability;
- contractor expertise;
- downstream water users;
- landowner and community issues;
- engineering constraints; and
- construction season.

(CPWCC 1999)

The selection of a crossing method is an exercise in striking a balance among the considerations listed above to derive the most practical solution. The method that is preferred is usually that which is geotechnically feasible and offers the required level of environmental protection for the lowest cost. Selection of an HDD crossing when other methods are more cost effective, technically feasible and offer sufficient environmental protection may be inappropriate. If an HDD is the strongly preferred method by regulators and this method is considered to have a low likelihood of success or is otherwise impractical, the regulators should be provided detailed information on the crossing method selection process and the rationale for the rejection of the HDD method. Additional information on the crossing method selection process is available in CPWCC (1999).

3.4 Other Selection Issues

Assuming that HDD has been selected as the preferred crossing method, the following other selection issues must be evaluated.

3.4.1 Access

Pipeline routing and drilling execution planning should consider that access to both sides of the drill will be required during the HDD construction process.

If adequate access to the crossing cannot be provided on both sides of the watercourse and the watercourse is suitable for the installation of a crossing structure, a temporary crossing structure may need to be installed for vehicle and equipment traffic. As with the selection of the crossing method, selection of the vehicle crossing technique also involves striking a balance between many of the same considerations listed above for crossing method selection to derive the most practical solution. The technique that is preferred is usually one which offers the required level of environmental protection for the lowest cost.

Access will also be required:

- to a water source during the installation of the HDD (see Section 3.4.4);
- for monitoring of the drill path; and
- during clean-up operations in the event of a drilling fluid release to surface.

Sediment and erosion control protection plans may be warranted to ensure that access creation or use do not result in adverse effects.

3.4.2 Drill Entry and Exit Site Selection

The selection of the drill and exit locations will need to consider the following:

- the terrain must be cleared, leveled and suitable for the work (sites with negligible longitudinal or side slopes are preferred);
- entry and exit location should be of sufficient size and configuration to undertake the work safely[1]; this should include consideration of:
  - drill rig entry and exit points (note that generally the entry point should ideally be at an equal or lower elevation than the exit point);
  - rig size and layout requirements;
  - pipe laydown area or false right-of-way (note that a straight approach to the exit point is preferred to avoid the need for false right-of-way);
  - fabrication area;
  - returns pit; and
  - bulk storage of materials;
- the resulting drill path must be feasible with a low risk of inadvertent returns; and
- existing infrastructure and land use.

3.4.3 No Drill Zone

A No Drill Zone can be identified that addresses geotechnical issues and concerns at the proposed crossing site. As defined by the geotechnical engineer, the No Drill Zone is the upper limit of potential drill paths between specified entry and exit locations, intended to ensure that the bore is maintained within geological materials suitable for an HDD while providing sufficient cover to mitigate potential inadvertent return concerns.

As detailed in Section 6.3, definition of the No Drill Zone for a proposed HDD crossing is influenced by a number of factors, including:

- crossing area terrain conditions, in terms of the difference in elevation between entry and exit locations and along the HDD alignment, that determine, in large part, the minimum recommended depth of cover;
- subsurface soil and bedrock stratigraphic conditions, and the suitability of the various units for directional drilling;
- river engineering considerations, including depth of scour during the design flood event and potential for bank/meander migration and cut off development; and

[1] In general, for small HDD applications, entry site should be approximately 40 m x 40 m, exit site approximately 30 m x 20 m. For larger HDD applications, entry site should be approximately 60 m x 60 m, exit site should be approximately 40 m x 30 m, excluding false right-of-way, if required. The contractor should be requested to provide his specific requirements prior to construction.

- the presence of active, inactive and potential landslide features, and other geotechnical "problem" areas, which should be avoided by the design drill path.

All potential drill paths should be designed to pass outside of the No Drill Zone.

While the No Drill Zone is typically defined in terms of geotechnical considerations, it may also be influenced by environmental and socio-economic concerns, such as wildlife concerns, rare plant occurrences, social resources (*e.g.,* land use) and cultural resources (*e.g.*, archaeological sites), etc. Specific studies may be necessary to identify the presence of these environmental and cultural features. Relocation of the entry and/or exit point, thereby altering the length of the design drill path, may provide a means of mitigating some of these non-geotechnical concerns.

3.4.4 Water Source

The availability of a water supply to the HDD site should also be considered during the planning stage of the project. Water will be required for the following:

- initial drilling fluid make-up;
- additional drilling fluid as the drill progresses;
- replacement fluid for drilling fluid escaping into the formation due to seepage or hydraulic fracture; and
- pretesting, where warranted, of the pipe string.

Hydraulic fractures can greatly increase the water requirements during an HDD project.

Water can be pumped from a water body to the drill site or hauled to storage tanks onsite. Factors to be considered in selecting a water supply are:

- access to the water body;
- flow restrictions;
- regulator approval;
- construction schedule (*i.e.,* air temperature, anticipated streamflow/volume and water quality); and
- physical limitations such as the distance and/or elevation of the entry point from the water body.

4 RISK CONSIDERATIONS

As with all construction techniques, a degree of risk and unpredictability is associated with the use of HDD applications. It is recommended that a project team be assembled early in the planning and design process in order to identify and assess potential risk, as well as develop plans to minimize the risks. Although HDD projects vary widely in complexity, most encounter site-specific characteristics that differ from previous projects. The project team may be composed of the proponent; engineering, geotechnical and environmental consultants; the HDD contractor and the pipeline contractor. Close consultation with regulators and land authorities can assist in the acquisition of initial approvals as well as ensure that alternate plans can be readily implemented if insurmountable problems arise.

Risk can generally be divided into three types: regulatory risks; construction risks; and operations risks.

4.1 Regulatory Risk

Regulatory risk can be encountered during:

- the application and approvals stage of a project; and
- construction.

During the application and approvals stage, the project may be delayed or rejected if insufficient information is submitted for regulator review. In the event that an application is approved, insufficient information may cause the regulatory agency to invoke restrictive conditions to ensure protection of the environmental resources.

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 regulatory agencies. These infractions could include:

- Section 32 of the *Fisheries Act* - unauthorized killing of fish
- Section 35 of the *Fisheries Act* - unauthorized HADD
- Section 36 of the *Fisheries Act* - unauthorized release of deleterious substances

In a regulatory climate in which more emphasis is being placed on self-regulation, industry can expect that any violation of the regulatory requirements may result in more rigid interpretation of the legislation. Therefore, it is imperative that all permits/approvals are obtained and applicable conditions are implemented to demonstrate that industry can be trusted to self-regulate.

4.2 Construction Risk

Success of an HDD installation is dependent upon the ability of the project team to minimize the causes of failure. The risks associated with each crossing will vary according to many factors. These include but are not limited to:

- inadequate planning;
- lack of contingency planning;
- inexperienced field personnel;
- overestimation by the contractor in the firm's abilities;
- insufficient quantity and size of equipment onsite; and
- inadequate knowledge of subsurface conditions.

(CPWCC 1999)

Construction risk on a project can be minimized by ensuring that sufficient planning is conducted and an adequate geotechnical investigation is carried out. Another means of addressing risk on a project is through the type of contract that is used (see Section 9.1).

Table 1 summarizes some of the more common problems associated with HDD and identifies the construction risks associated with each.

Table 1 - Construction Risks Associated with an HDD

Potential HDD Difficulty	Construction Risk
Loss of drilling fluid	Variable depending on volume and connectivity to surface or water body.
Loss of circulation	Complete loss of circulation indicates a loss of drilling fluid (see above).
Drilling mud seepage directly into watercourse	Sediment load and deposition with possible adverse effects on fish, fish habitat, hydrology and downstream water users.
Drilling mud seepage onto land and then into watercourse	Sediment load and deposition with possible adverse effects on fish, fish habitat, hydrology and downstream water users. Additional adverse effects on wildlife, vegetation, soils, heritage resources and current land use may occur on land.
Collapsed hole	Loss of topsoil and unexpected widening of the area of disturbance. Extended duration of disturbance is likely.
Washout of cavities and collapse of right-of-way	Loss of topsoil and unexpected widening of the area of disturbance.

Potential HDD Difficulty	Construction Risk
Stuck drill stem	An unexpected widening of the area of disturbance if a wide and deep excavation is necessary to retrieve the equipment. Extended duration of disturbance is likely.
Lost tools	Extended duration of disturbance and potential for a redrill.
Damaged pipe or coating	Extended duration of disturbance and potential for a redrill.

4.3 Operations Risk

The risks associated with an HDD installation during operations are generally considerable less that those of a traditional trenched crossing. In particular, the risk of the following problems is minimized or eliminated:

- maintenance of disturbed banks or stream bed;
- exposure of pipe during peak flow events or due to ice scour; and
- damage of pipe due to anchors or other third party activities.

Increased risks include:

- pipe is inaccessible for repairs due to depth of cover;
- corrosion due to undetected damage to pipe coating;
- subsidence at entry and exit points; and
- visual leak detection is not possible.

5 ECONOMIC CONSIDERATIONS

5.1 Potential Economic Advantages of HDD

The development of guidance systems specifically for HDD use has made HDD technology increasingly efficient and productive. Experience acquired by HDD contractors and operators during the early period of HDD use has resulted in more competent operating directional equipment as well as more knowledgeable contractors. There are several potential economic advantages of employing HDD construction techniques as opposed to conventional pipeline installation techniques including:

- increased use of HDD technology has resulted in associated equipment and labour costs being spread over multiple projects, making individual projects more affordable;
- high installation performance;
- no additional expense arising from closed streets, irrigation canals or railways;
- minimal to non-existent reclamation costs to the obstacle crossed since surface disruption along the alignment drilled is minimized (inadvertent drilling mud release still requires mitigation);
- the need for removal, restoration, monitoring, maintenance and other long-term costs associated with trench settlement is eliminated through the use of HDD crossings;
- road cuts, which are expensive to restore, are minimized;
- HDDs are possible year-round (instream timing restrictions may apply to conventional construction methods); and
- HDD can be faster than conventional crossing methods.

5.2 Costs of HDD Applications

The costs associated with an HDD are influenced by:

- location;
- access;
- environmental setting;
- geological characteristics;
- obstacle to be crossed;
- required rig size to complete the drill;
- total length of the drill; and
- pipe diameter(s) to be installed.

The types of costs associated with HDDs, as with any construction activity, are direct costs, indirect costs and potential risks to the public. Operating and maintenance costs of completed projects should also be considered for HDD projects.

5.3 Direct Costs and Benefits of HDD Applications

Direct costs are readily identified within the scope of a project and are paid for directly from the budget of a project (*i.e.,* the cost of the project itself). Considerable direct costs are often associated with conventional pipeline construction installation methods. Common costs related to conventional construction methods include:

- excavating equipment required for trenching;
- labour;
- topsoil and spoil handling;
- backfill costs; and
- reclamation and restoration costs.

Where conventional construction impacts traffic volumes, water bodies or environmentally sensitive areas, direct costs are often substantially increased. HDD technology can be used to avoid environmentally sensitive areas, areas of large traffic volumes and water bodies, and minimizes the requirements for moving and handling large quantities of topsoil, spoil and backfill. Consequently, there are often some cost saving advantages over conventional installation techniques. In addition, the costs of using trenchless technology do not increase with depth of cover as dramatically as with conventional construction methods, thereby reducing overall costs.

5.4 Indirect Costs and Benefits of HDD Applications

Indirect costs are tangible and intangible costs which cannot be included in the project costs. Indirect costs accumulated by the proponent on a project depend upon the work site and the issues present or encountered. Factors affecting indirect costs include:

- traffic obstruction;
- road damage;
- environmental damage;
- air and noise pollution;
- project delays; and
- social costs.

With the potential to reduce the approval period and construction duration, and avoid or reduce overall disturbance, HDD applications appeal to indirect cost reduction by minimizing interference with community activities and operations, and adverse environmental effects. Air and noise pollution may also be minimized due to the often reduced installation time. Traffic obstruction and road damage are avoided, since the roads are not affected on the surface by construction. Safety issues and costs associated with HDD applications may also be less than those related to conventional construction techniques (*i.e.,* open excavation), and fewer people are required onsite for HDDs, reducing the chance of injury in the workplace.

6 GEOTECHNICAL CONSIDERATIONS

The design drill path must be developed taking into account the geological setting for the project and geotechnical and hydrogeological issues at the crossing site.

6.1 Geotechnical and Hydrogeological Issues

From a geotechnical perspective, a number of issues should be taken into account during the HDD feasibility investigation as well as during design and construction of the directional drill, including:

- the distribution and characteristics of the surficial overburden deposits;
- the presence of high plastic clay and bentonitic shale bedrock materials; and
- the occurrence of structurally complex, hard and/or abrasive bedrock formations.

These issues are briefly addressed below.

6.1.1 Surficial Overburden Deposits

In general, cohesive soils, such as clays, silty clays and silty-clayey tills, are self-supporting and an open bore should be achievable. An open bore can often also be maintained through "dirty" sands and clayey silts, and even cohesionless clean silt and sand materials (provided the bore is full of drilling mud). However, medium to coarse-textured granular materials (*e.g.*, gravels, cobbles and boulders) can give rise to a number of problems during HDD construction, including:

- bore instability or collapse during drilling of the pilot hole and subsequent reaming passes, that may result in the drill string becoming stuck;
- loss of drilling fluids to the formation; and
- release of drilling fluids to the environment.

Mitigative measures may include:

- maintaining drilling mud in the bore hole at all times by locating the entry and exit points above cohesionless silt-sand zones;
- evaluating alternative drill paths that avoid or minimize exposure to the problematic soil materials;
- casing or excavating through near surface silt, sand or coarse-textured deposits; and
- using drilling additives to consolidate and reduce the permeability of these materials.

Strict monitoring of fluid volumes, annular pressure and cutting returns will assist in ensuring that bore hole plugging and fluid losses are detected and addressed.

6.1.2 Clays and Shales

Clays and soft shale formations of low to medium plasticity (based on Atterberg Limits), have a low potential to swell and typically can be readily penetrated during directional drilling. Conversely, high plastic clays and bentonitic shales have a potential to swell and, during drilling of the pilot hole, reaming or pull back of the pipe string, the bore may be partially or completely sealed. Hydraulic fracturing of the formation and migration of fluids out of the bore can result. Mitigative approaches may include:

- avoiding high plastic clays and bentonitic shale formations, if feasible;
- designing the drill path such that exposure to these problematic materials is minimized;
- using safe drilling practices to ensure the bore hole is sized and cleaned properly; and
- adopting an annular pressure program to ensure the bore hole is being properly monitored throughout the drilling process.

High plasticity materials may also impact the viscosity of the drilling fluids. A drilling execution plan should be developed that includes a properly engineered fluids program addressing swelling clays and the removal of cuttings from the drilling fluid.

6.1.3 Bedrock Formations

From a geotechnical perspective, competent bedrock is one of the preferred materials for directional drilling. In most cases, good bore hole stability allows an open bore to be maintained during all stages of the drilling process. Nevertheless, problems can arise due to the presence of:

- structural complexity, in terms of folded and faulted bedrock strata, along the drill path;
- rock mass discontinuities related to tectonic processes (*e.g.*, joints and fractures)
- complex subsurface stratigraphic conditions, giving rise to rapid changes in lithology and bedrock properties;
- coal seams; and
- large voids related to solution processes (*e.g.*, karst openings in carbonate formations).

Where the bedrock structure is complicated by folding and faulting, the drill path will intersect discontinuities in the rock mass, such as bedding and joints, at a variety of angles. The drill bit may be deflected in competent lithologies, when the pilot hole intersects such discontinuities at low angles, and steering problems can result.

Jointing and fracturing can give rise to fluid migration during drilling and be a source of bore hole instability problems. Fluid losses can be a major concern if the bedrock is highly jointed/fractured. One mitigative approach is to consider using drilling additives to consolidate and reduce the permeability of joints and fractures.

Complex subsurface stratigraphic conditions can give rise, in turn, to rapidly changing variations in bedrock properties, potentially resulting in directional control and steering problems. Hard (high compressive strength) and/or highly abrasive bedrock will also affect schedule and costs and, in some instances, the feasibility of the HDD project could be put in question. Mitigative approaches may include avoiding high compressive strength bedrock units in the design of the drill path and/or minimizing the length of drill path that encounters these formations. Application of air hammering or air drilling techniques could also be considered if drilling through these materials is unavoidable.

All coal seams encountered during the geotechnical investigation should be identified on the bore hole logs. In many cases, they are extensively jointed/fractured and, as such, can be a source of loss of circulation and/or mud control problems. During directional drilling, coal particles can also clog pumps and create problems with cutting returns.

Depending on their extent, voids related to bedrock solution processes can also be a source of loss of circulation and mud control problems. Karst openings in limestone and dolomite formations are most commonly encountered but solution cavities can also occur in gypsum and salt- and potash-bearing bedrock formations.

6.1.4 Hydrogeology

The main hydrogeological issue relates to the presence of artesian conditions. These are typically encountered where impermeable clay or shale bedrock layers overlie permeable water-bearing sands-gravels or sandstone bedrock at depth, forming a confined aquifer. When intersected by the pilot hole, such aquifers may be large-volume sources of groundwater under pressure. As such, mud quality and fluid management problems may result. Mitigative approaches include casing or cementing off the confined aquifer zone.

Cross-contamination of aquifers may also be a concern, particularly when the directional drill path is very deep.

6.2 Geotechnical Investigation

The geotechnical investigation is a critical part of the information gathering and risk assessment phases of planning an HDD. The scope of work should include: review of background information, a field reconnaissance, completion of a program of field drilling and sampling, geophysical surveys if appropriate, laboratory testing, and office analysis. It should be recognized that subsurface conditions are generally not homogeneous and, for this reason, may be difficult to fully investigate.

Results of the investigation should be presented in a geotechnical report (Section 6.3). The report can be referenced in final design and should be suitable to be provided to prospective HDD contractors to assist them in preparing bids to construct the crossing.

6.2.1 Information Review

The first stage of the study should involve a review of background geological and geotechnical information. Data sources may include: published surficial and bedrock geology maps and reports prepared by federal, provincial and territorial government agencies, stereo air photo coverage of the crossing area, and maps and surveys prepared for the project by the proponent. If available, unpublished information on previous pipeline-related and/or HDD projects in the same general area should also be referenced.

6.2.2 Field Reconnaissance

The reconnaissance should be carried out in advance of the drilling and sampling program. The objectives should be to review and document site conditions pertinent to construction of the proposed HDD crossing as well as to review access and logistics for the drilling and sampling program.

Crossing area characteristics of interest include:

- the presence of surface or subsurface facilities, if any, in particular pipelines and other buried utilities (these must be precisely located prior to initiating the field drilling program);
- existing natural and man-made exposures of surficial overburden and bedrock materials, which should be logged and documented;
- if relevant, hydrological and river engineering characteristics of the water body being crossed; and
- active, inactive and potential landslide features and their distribution relative to the proposed HDD alignment.

During the access and field logistics review, access conditions for drilling equipment should be assessed. If ground access is available, a truck mounted or track mounted drilling rig can be utilized during the drilling/sampling program. Otherwise, a helicopter-supported investigation may need to be considered.

6.2.3 Field Drilling and Sampling Program

Logging and sampling of bore holes provides the best means of obtaining information on and gathering representative samples of the subsurface soils and/or bedrock to be encountered along the drill path. On this basis, it should be possible to develop a subsurface geological model to assist in identifying the distribution of overburden and bedrock materials to be expected along the proposed HDD alignment.

Anticipated ground and site access conditions will determine the type of drill rig to be employed. Typically, bore holes are completed using a truck-mounted or track-mounted rig capable of drilling the soil and bedrock materials expected at the site. As noted, where ground access into the proposed bore hole locations is not available, helicopter-transportable drilling equipment may have to be used. For some bedrock investigations, diamond coring equipment can be utilized. The scope of the drilling program, in terms of number of bore holes and depths, will depend on the length of the HDD, projected length of the design drill path and the anticipated complexity of subsurface conditions. The bore hole locations should be chosen to minimize the risk of interception by the HDD and subsequent inadvertent returns following the bore hole to the surface.

The soil and bedrock strata being penetrated are logged from cuttings returned to the surface during drilling, samples from standard penetration tests (SPT), spoon and Shelby tubes, as available, and observations of drill performance. If soil conditions are suitable, cone penetration tests may also be carried out. Groundwater levels may be documented either by installing and monitoring piezometers or based on observations of groundwater seepages during and after drilling.

In addition to logging and characterizing the subsurface materials and groundwater conditions, the field investigation should focus on identifying conditions that could impact the feasibility of designing and constructing an HDD, including:

- the distribution/characteristics of surficial overburden deposits, in particular the occurrence of cohesionless clean silt-sand deposits and distribution and characteristics of any coarse-textured granular layers (*i.e.*, gravel, cobbles or boulders);
- depths to and nature of the bedrock formations, including the presence of hard and/or abrasive units (that could delay the project or impacts rates of wear on drilling equipment); and
- the presence of discontinuities, joints, fractures and fissures, that could contribute to instability of the bore during drilling and/or provide a path to the surface for drilling fluids.

6.2.4 Geophysical Surveys

When the results of bore hole investigations are inclusive or incomplete, use of shallow geophysical techniques may be considered. Seismic surveys, ground penetrating radar (GPR), electromagnetic (EM) surveys and electrical resistivity tomography (ERT) can be employed, often in combination. The application of geophysical methods is affected by the soil/bedrock conditions at the site and some techniques may not be appropriate in all situations.

Depending onsite conditions and expected subsurface materials, geophysical techniques can be used to supplement the bore hole investigation results. However, use of geophysical techniques as a substitute for, rather than as a complement to, bore hole investigations is not recommended. Past experience has shown that while geophysical survey results provide information along the entire drill path, from these methods may yield results that are ambiguous and difficult or impossible to interpret without "ground truth" information from bore holes.

Seismic Surveys

Shallow seismic surveys are mostly used to delineate the upper surface of the bedrock. Analysis of seismic survey data can also provide information on bedrock strength properties.

Ground Penetrating Radar

GPR is also used to delineate the upper bedrock surface but can also provide data on the distribution and characteristics of the overlying surficial overburden deposits. Unfortunately, due to the nature of the technique, GPR is unable to penetrate and "see" through clay layers of any thickness. Electromagnetic techniques can be used, in combination with GPR, to circumvent this shortcoming.

Electromagnetic Surveys/Electrical Resistivity Tomography

These techniques are also used to define and characterize the surficial deposits overlying the bedrock. They complement GPR due to their ability to "see through" clay layers in the subsurface, allowing the underlying materials to be defined and characterized. For this reason, EM and ERT are particularly useful for delineating buried sand-gravel channel deposits within the surficial overburden sequence. Since it requires good ground contact at frequent intervals, ERT is best suited to use during the summer.

6.2.5 Laboratory Testing

Laboratory tests that may be performed on samples returned from the field can include:

- moisture content determination on surficial overburden samples;
- Atterberg Limits on clays and bentonitic shales; and
- unconfined compressive strength tests on representative bedrock samples.

The laboratory test results should be presented on the bore hole logs that are appended to the geotechnical report (see below).

6.3 Geotechnical Report

A geotechnical report should be prepared, describing and presenting the results of the study, including an evaluation of the (geotechnical) feasibility of constructing the proposed HDD crossing. Based on the bore hole data and geophysical survey results, if available, an overall geological model of the ground conditions likely to be encountered along the bore can be developed.

The analysis and interpretation of the subsurface conditions encountered should concentrate on factors pertinent to design and construction of the proposed HDD installation, including:

- the occurrence of cohesionless and coarse granular surficial materials;
- the lithology and structural characteristics of the bedrock formations;
- data on groundwater levels and the presence of artesian conditions, if anticipated to be present;
- identification of overburden or bedrock intervals where loss of circulation may be a concern; and
- bedrock strengths.

Bedrock strength is often described in terms of the International Society for Rock Mechanics (I.S.R.M.) classification. Data on expected unconfined compressive strengths can be provided, either based on laboratory testing or estimated from the I.S.R.M. classification.

Bore hole logs and the results of laboratory testing should be appended to the report. The report should also be accompanied by a surveyed cross-sectional profile showing the soil and bedrock conditions encountered and the recommended No Drill Zone.

Issues that present a challenge to HDD design and construction, or that may affect the drilling contractor's assessment of the risks associated with completing a successful crossing, should be identified and discussed. Preliminary design recommendations, including the proposed No Drill Zone, expected entry/exit conditions and anticipated drilling considerations, should be provided.

6.3.1 Preliminary Design

A recommended No Drill Zone accommodating geotechnical and, if appropriate, hydrological and hydrogeological considerations should be developed for the crossing. As far as possible, the intention should be to maintain the bore within surficial overburden units or bedrock formations that are favourable for directional drilling. The No Drill Zone will typically be defined in terms of the minimum recommended depth of cover below the valley bottom, based on crossing area geometry, expected drill orientation, anticipated ground conditions, etc. and maximum entry and exit angles.

6.3.2 Entry and Exit Areas

The entry and exit areas for the proposed directional drill should be discussed, given the proposed drill orientation, "low to high" or "high to low" (wherever feasible, the former configuration is preferred), and expected near surface soil/bedrock conditions. Any requirement for casing to isolate the bore from gravels and other problematic materials on entry should be identified. Similarly, any need to excavate a bell hole at the exit to control drilling fluids and/or retrieve the drill string should be noted. Finally, an assessment of terrain conditions in the exit area for pipe stringing, welding and testing prior to pull back should be provided.

6.3.3 Drilling Considerations

Based on the description of the subsurface soil and bedrock conditions expected along the bore, issues pertinent to completion of a successful drill should be identified. These may include, for example, the possible occurrence of cobbles and boulders in till soils, presence of soils with fissures that could provide paths for fluid migration to the surface, high plastic clay soils and shale bedrock formations with potential for swelling, jointed/fractured bedrock units, etc.

7 ENVIRONMENTAL CONSIDERATIONS

HDD crossings are often undertaken to minimize the adverse environmental effects at watercourse crossings. Nevertheless, an HDD does not guarantee that all adverse environmental effects will be prevented. Common adverse effects are the result of:

- inadvertent returns of drilling fluids into the aquatic, terrestrial or social/cultural environments; and, to a lesser extent,
- disturbance of soils, vegetation, wildlife and social/cultural elements arising from either construction of drill sites, exit areas, access roads and temporary vehicle crossings, or the HDD activity.

Further details on the environmental effects of inadvertent releases can be found in many documents, including:

- Horizontal Directional Drilling Best Management Practices Manual, Topical Report. Gas Research Institute. May, 2002; and
- Quantifying the Effects of Sediment Release on Fish and Fish Habitats, Anderson, P.G., B.R. Taylor and G. Balch. 1995. Prepared for the Department of Fisheries and Oceans.

7.1 Aquatic Issues

A fish and fish habitat assessment of the water body to be crossed may be warranted to assess potential effects on these resources. Information from this assessment would be useful in prioritizing of containment / clean-up efforts in the event of an inadvertent release into a watercourse or in the preparation of appropriate mitigation / compensation plans if the HDD was not successful and another crossing method was necessary.

Adverse effects on the aquatic environment can result from the following:

- introduction of drilling fluids and mud into a watercourse, and any subsequent clean-up;
- poor surface runoff control from the drill site resulting in erosion and material entering a watercourse;
- disruption of aquifers that feed instream upwelling;
- improper water withdrawal;
- introduction of foreign or undesirable organisms from contaminated equipment; and
- spills of fuel or other hazardous material.

Potential effects on aquatic habitat and fish populations could include:

- HADD including instream, bank and riparian habitat at the crossing;
- elevated turbidity and increased deposition of sediment downstream;

- interruption of fish movements up or downstream;
- increased stress to individuals;
- injury or mortality of fish associated with improper operation and screening of water pump intakes;
- incidental mortality/injury associated with an accidental release of toxic substances through spills; or
- introduction of disease, parasites or other pests detrimental to fish.

7.2 Terrestrial Issues

Inadvertent returns and planned physical disturbance to the terrestrial environment during construction have the potential to adversely affect vegetation, wildlife and wildlife habitat, cultural resources, land use and nearby residents.

7.2.1 Vegetation

The primary potential effects on vegetation are as a result of:

- clearing of sites for drilling and access;
- damage to vegetation during clean-up from inadvertent returns;
- smothering and direct mortality of plants with drilling mud from inadvertent returns;
- creation of a nearly impenetrable layer of clay on the surface preventing germination or colonization of new plants from inadvertent returns;
- change in surface soil characteristics, thereby creating a change in vegetation communities; and
- creation of a subsurface deposit resulting in an upheaval that changes hydrologic or soil moisture regimes, in turn affecting the vegetation community.

7.2.2 Wildlife

The primary potential effects on wildlife habitat and populations as a result of inadvertent returns or from planned activities include:

- interruption of wildlife movements as a result of general construction activity associated with the HDD;
- loss of riparian or wetland habitat as a result of inadvertent returns of drilling mud;
- direct mortality of amphibians, reptiles, invertebrates and other less mobile wildlife from inadvertent returns;
- increased stress to wildlife species reliant on adversely affected critical habitat; and
- incidental injury/mortality associated with accidental release of toxic substances through spills or, in some cases, additives to drilling mud.

7.3 Social and Cultural Issues

Potential adverse effects on communities, land use and cultural resources can result from the following causes:

- release of drilling fluids and mud into culturally or socially sensitive areas;
- spills of fuel or other hazardous material;
- noise or vibration from HDD site preparation or construction activity; and
- disruption of aquifer use for domestic or agricultural purposes.

In particular specific issues could include:

- destruction of archaeological sites (often associated with watercourses); and
- disruption of current land use including disturbance of nearby residents.

7.4 Site Investigations

Environmental site investigations are not critical to the determination of the feasibility of HDD. However, these site reconnaissances and surveys should be undertaken in situations where there is a risk that any of the following may be present:

- fish and fish habitat within the potential zone of impact (*e.g.*, up to several thousand metres downstream on a fast moving watercourse);
- rare and endangered plant or wildlife species in the vicinity of the HDD entry or exit points;
- critical habitat that would need restoration to pre-disturbance levels in the event of an inadvertent release;
- archaeological sites; or
- nearby residents.

Site investigations should be undertaken in advance of the HDD to ensure that there is sufficient baseline data to provide a bench mark for future clean-up or reclamation activities.

8 ENGINEERING DESIGN CONSIDERATIONS

8.1 Design of Drill Path

The design of the drill path should consider all of the information gathered for the crossing area. The physical limitations of the site as well as geotechnical, environmental (fish, wildlife, vegetation, land use, cultural) and hydrological information should be considered in the preparation of the drill path design.

8.1.1 Limitations of HDDs

The feasibility of HDDs is dictated by the length of the bore hole to be drilled, the diameter(s) of the pipe string, as well as the subsurface soil/bedrock conditions. As of 2000, the longest drilled crossings have been recorded at approximately 1,800 m, with small diameter pipe. The largest pipe diameter to be drilled as of 2000 was a 1,219 mm O.D. project. HDD crossings with such a large diameter pipe are rare. Entry angles of HDDs vary from 8 to 18 degrees from horizontal, with longer crossings having a longer horizontal segment at the specified depth of cover. HDD equipment can adjust for different entry angles. [*Editors Note: Newer stats to be researched*]

Existing HDD technology (*i.e.,* rig tools and drill pipe) and economic considerations are the primary factors limiting drill path length and pipe string diameter. The flexible nature of drill pipe limits the amount of pressure that can be applied to the drill string and, therefore, control of the front of the drill string decreases over longer bore lengths. The capacity of the drill pipe to transmit torque from the rotating surface to the down hole reamers is also a limiting factor.

Emergence of new HDD technologies to confront drill path length and product pipe diameter restrictions is also influenced by economics. The installation of large diameter pipe over long lengths is rare and the market for such technologies is small, thereby limiting the funding and research needed to acquire these new technologies.

The nature of the subsurface soil and bedrock materials at a proposed crossing is one of the primary geotechnical limitations to the installation of a pipeline using an HDD. A high proportion of coarse-grained materials (*e.g.,* gravel, cobbles and boulders) as well as excessive bedrock strength and hardness are the main subsurface characteristics that may impair the use of HDD. Coarse-grained soils are not readily fluidized by drilling muds and can present a serious constraint to the feasibility of an HDD if encountered. Boulders or clusters of cobble remain in the drilled path and present an obstacle to the bit, reamer as well as the pipeline, while excessively hard rock makes all phases of the HDD difficult.

Extensive fracturing or jointed rock can present problems similar to those encountered with coarse granular deposits. Competent rock with an ideal unconfined compressive strength of approximately 15,000 psi (103 MPa) and a hardness, based on Moh's Scale of Hardness, greater than 7 can be negotiated with an HDD, given today's technology. One problem often encountered when facing such characteristics at depth is the tendency of the drilling string to deflect rather than penetrate the subsurface.

8.1.2 Depth of Cover

Depth of cover requirements are dependent upon a number of factors such as subsurface conditions, type of drilling equipment, mud pressure (which is a function of the mud pump capacity), and the difference in elevation between the entry and exit points. Depth of cover is a factor used in the development of the No Drill Zone (Section 3.4.3) and should be determined by the HDD project team.

8.1.3 Entry and Exit Points

Considerations related to the entry and exit points have previously been discussed in Section 3.4.2.

8.1.4 Alignment

Angles in the easement/right-of-way alignment adjacent to an HDD crossing should be minimized. If difficulties are encountered during an HDD, it may be necessary to increase the drill length. Therefore, the entry and/or exit points would need to be moved farther back from the location being crossed. The approach alignment to the HDD crossing needs to allow for the potential need for lengthening of the crossing.

8.1.5 Right-of-Way

The drill path should be aligned to lie within the right-of-way boundaries. If this is not feasible, new right-of-way must be acquired prior to commencement of the HDD. Temporary workspace is typically required at a crossing above and beyond that necessary for conventional pipeline construction. As discussed in Section 1.2, temporary workspace is required at the entry and exit points. The pipe string will require additional workspace and, where the alignment on the exit side is not straight, additional workspace, typically referred to as false right-of-way, may be required. This area should be of sufficient length and width to allow the pipe to be welded up and tested along the full length of the pipe string. It is highly recommended that the pipe string be fabricated in one complete section since any stoppage in pulling of the pipe string adds significant risk to the success of the project.

8.2 Land Issues

The land issues listed below should be considered during the planning phase of an HDD project:

- landowner consultation during the routing and crossing selection process, and when determining a water source for drilling activities;
- landowner consultation when determining access to the water source;
- landowner consultation to avoid conflict with land use practices (*e.g.,* drill in pasture when cattle have been rotated to another pasture or during the winter to avoid the crop year);
- informing the landowner of HDD processes and applications to avoid potential issues;
- landowner consent for access across lands not on the right-of-way for monitoring purposes and potential reclamation of inadvertent returns;
- spills on the entry side and the pipe side of the drill may require reclamation and remediation as well as compensation to landowner and compensation for any habitats lost; and
- trespass off the right-of-way due to inadequate marking of designated work areas or inadequate location or amount of workspace.

8.3 Casing

Contractors often use a short section of casing that is ‘dug in’ at the start of construction. This casing is intended to prevent inadvertent near-surface returns, and allows for easy monitoring of drilling mud return levels. However, where unconsolidated deposits represent a risk of inadvertent returns on the entry side, the casing may need to be more extensive. The casing can either be driven in with a large hydraulic hammer or, possibly, in softer soils, pushed in with the drill rig.

Casing should be of sufficient length to seal into a suitable competent formation such as bedrock or cohesive stiff clay. The casing diameter should be greater than the final reaming pass to ensure down hole tools can easily enter the bottom of the casing throughout the entire drilling operation and pull back.

It is preferable to remove any casing at the end of the crossing construction since it will shield the pipeline within the crossing from cathodic protection.

8.4 Pipe

8.4.1 Type

Tensile and bending stresses that are induced on the pipe during an HDD installation should be analyzed to ensure the pipe is suitable for installation. This analysis is especially important when using thin wall steel pipe or plastic pipe.

8.4.2 Number of Pipes

In many instances it is proposed to install more than one pipe in the drilled crossing. The characteristics to consider are the size of the pull head, number of pipes, as well as the size of the individual pipes, including pipe coatings. These items will increase the final bore diameter and will dictate the minimum radius of curvature.

8.4.3 Coating

As mentioned in Section 4.3, one operational risk that should be addressed is external corrosion due to damaged pipeline coatings. Protective coatings can often be damaged during pull through by the forces involved, and by contact with soils, rocks, and other debris present in the bore hole. The consequences of coating damage are multiplied by the nature of the HDD method. A pipeline installed by HDD will not be readily accessible to make future pipeline or coating repairs.

External pipe coatings for HDDs must be carefully selected to minimize the risks. Given the potential for coating damage it may be necessary to select a different coating system for the HDD section(s) of a pipeline.

Coatings used for HDD drag sections must be flexible and have sufficient abrasion resistance to limit damage. The economic and environmental consequences of a future failure are significant. Cathodic protection (CP) compatible coatings will allow protective current to reach the pipe regardless of any damage to the coating. Certain coatings such as single or double layer extruded polyethylene, or polyethylene tape, can shield cathodic protection current when damaged. Such coatings should be avoided on HDD projects.

Often the most suitable coatings for an HDD project are Fusion Bond Epoxy (FBE) or similar liquid coatings. An additional layer of pipe coating should be applied for abrasive protection. This layer is often referred to as the abrasion resistant layer or the sacrificial layer. The exact type of coating should be selected based on a number of factors including the amount of abrasion expected.

The selection of field applied joint coatings also requires careful attention. It is recommended that the joint coatings be liquid epoxies with similar properties, especially abrasion resistance, as the main plant applied coating. Since the joint coatings are field applied, proper application methods, qualified workers/applicators, and qualified coating inspectors are recommended.

In addition to inspecting the coatings during the actual application process, a careful visual inspection should be made of the first few pipe joints at the exit location. Often these leading joints are believed to receive the most damage. If these joints are in good condition it is likely that the remaining coating is in similar, or even better condition.

Another method of inspection is an in situ electrical method to determine the coating resistance. A competent cathodic protection technician can complete this work. This type of inspection can provide a relative understanding of the coatings efficiency. The field CP measurements must be done prior to completing any tie-in welds to the rest of the overland pipeline. Therefore, the timing of this work must be carefully coordinated.

Conventional two-layer extruded polyethylene coatings are not recommended due to their susceptibility of damage, and possible shielding of cathodic protection current. More recently available three-layer polyethylene coatings (FBE coating with a polyethylene topcoat) may be considered.

External concrete weight coatings are not recommended due to their brittleness, weight, and high coefficient of friction.

Further information is available from many sources including coating manufactures and NACE International publications such as:

- Design and Coating Selection for Successful Completion of a horizontal Directional Drill (HDD) Crossing. A.I. Williams and J.R. Jamison, NACE CORROSION/2000 Paper

8.4.4 Insulation

It is typical for some pipe to be specified with a thick layer of insulation. This will necessitate the final ream to be larger than an uninsulated pipe.

8.4.5 Limits of Curvature

The design of the drill path and selection of pipe must consider the following:

- the radius of the curves in the drill path; and
- the exit and entry angle.

The radius of the arc of the drill path should consider the diameter of pipe to be installed. The minimum radius for most drilling applications is:

- the diameter of the pipe to be installed in metres multiplied by 1200; or
- the pipe diameter in inches multiplied by 100 to obtain a radius of curvature in feet.

This formula is used to ensure a conservative radius of curvature that will allow for the easy installation of the pipe and minimize the bending stresses on the pipe. If the pipe is smaller than the drill string, the larger pipe size shall be used in the minimum radius calculations. This will ensure that the drill pipe will not be overstressed and the drill can proceed as planned. In most applications, the radius of curvature will not be lower than 250 m.

8.5 Drilling

8.5.1 Reaming Diameter

The general “rule of thumb” is to ream the drill hole to 1.5 times the outside diameter including coating and insulation of the pipe to be installed. This diameter will generally provide for an adequate allowance for the installation of the pipe. The multiplier may be reduced for large pipe diameters (>36”/914 mm O.D.)

The number of reaming passes that will be determined by the hardness of the material being reamed and the ability to remove cuttings from the hole.

8.6 Testing

As noted in Section 3.4.4, the pipe string is often hydrostatically pretested prior to pull back. This segment of pipe is then also tested as part of the mainline pressure test. Pretesting and testing of the installed pipe upon completion of the drill should follow CAPP's 1996 *Guidelines for Hydrostatic Test Water Management*.

9 CONTRACTUAL CONSIDERATIONS

9.1 Types of Contracts

Prior to tendering an HDD, the owner needs to determine if this particular aspect of their project warrants special attention. Since this part of a project may present a high risk, it may be necessary to tender the HDD outside of the general pipeline contract. Upon determination of the specifics required for the project, a variety of contract types should be considered when packaging an HDD tender: unit price; lump sum; target price; daily rate; and cost plus. Depending on the quantity and quality of the available geotechnical information, perceived risk etc. a certain type of contract will suit specific crossings.

9.2 Contractual Issues Related to HDD

Contractors bidding on HDD jobs should be provided with as much information as possible from the owner company to facilitate the preparation of an accurate and comprehensive cost proposal so that the project, once awarded, can be completed as planned with very little dispute. Other advantages of owner companies providing adequate information to their contractors for bidding purposes are that it allows the project to be conducted in a safer manner and with reduced potential for environmental impacts. Once the cost proposal is accepted by an owner, the proposal becomes a binding contract between the contractor and the owner company.

As with any contractual relationship between a contractor and owner company in the construction and/or petroleum industry, contracts for any HDD project should be written agreements that both parties comprehend. Within the contract, the project must be defined and the scope of work should be detailed as precisely as possible. All plans and specifications should be incorporated into the contract. The parties to be involved in the project, price to complete the project and project performance should also be specified in the contract. Workable mechanisms should be written into the contract so that adjustments relating to schedule as well as cost can be made if difficulties or unforeseeable circumstances (*e.g.*, weather, varying geotechnical conditions) are encountered that affect the scope of the project. Since no two HDD projects are the same, contracts should clearly indicate unit prices as well as add and/or delete clauses identifying factors that could potentially change rates and overall costs. Terms of payment should be clearly addressed in the contract and payment options affecting the bid price should be taken into consideration. Late payment options and early payment discounts may also be identified within the contract. Table 2 identifies specific elements that should be given particular consideration in the contract.

9.2.1 Geotechnical Investigation

the geotechnical report containing geotechnical, geological and other information acquired during the feasibility study (*e.g.,* geophysical survey results) and including a proposed No Drill Zone (with or without a description of the design drill path), should be provided to the contractor for determining a contract price for the drill.

since unknown or unexpected ground and subsurface conditions may occur during the course of the drill, mitigation upon encountering differing ground conditions should be included in the contract.

9.2.2 Existing Underground Utilities

The owner should locate all existing utility lines and identify them in the bid package, since they may affect the drill path and No Drill Zones;

The contractor should be obligated, upon conditions set forth in the contract to have an onsite verification performed prior to the drill, the liability should be placed on the contractor for marked utilities while the liability should be placed on the owner for unmarked utilities;

General liability insurance should be carried by the contractor ensuring the insurance covers underground collapse and explosions

9.2.3 Documentation / As-builts

As-built drawings and a summary as-built report should be completed based on down hole survey data or the walkover location system;

As-built drawings and the as-built report will protect the contractor and owner from future problems (*e.g.,* future projects in the same area);

The drawings should have calculated x, y and z positions every 10 m (or other interval identified by the owner) along the alignment

9.2.4 Access

It should be the owner's responsibility to acquire access to the drill site prior to construction, since it is the owner that will have a long term relationship with landowners affected by the right-of-way or construction works;

All access agreements relevant to the hdd project should be provided to the contractor prior to construction

9.2.5 Equipment

The bid documents should identify the equipment and respective equipment specifications to be assigned to the project

9.2.6 Environmental Concerns

Owners and contractors are potentially liable if environmental damage occurs and clean-up/compensation costs.

Environmental concerns should be identified in the contract and a mitigation plan should be in place for the project.

Federal, provincial, territorial and local approvals should be reviewed and all conditions must be followed.

Water turbidity (*i.e.,* at water crossings) as well as inadvertent release of drilling mud are relatively common problems associated with HDDs and are difficult to predict; the contract should address and provisions should be included to mitigate these problems, since the contractor and owner company often share liability.

9.2.7 Allocation of Risk of Loss

Risk of loss that may occur during the course of the project should be predicted and assessed in the contract.

Owners should share the risk of loss with the contractor since the bid price is affected by unanticipated losses.

Insurance may be available for losses due to differing ground conditions or environmental issues.

9.2.8 Dispute Resolution

Alternative Dispute Resolutions (*i.e.,* arbitration or mediation) should be incorporated into the drill contract and disputes ideally resolved in the following order:

- negotiation in good faith;
- nonbinding mediation through a third party;
- binding arbitration; and/or
- litigation.

Provisions for termination, indemnification and payment terms should be clearly addressed in the contract and understood by the contractor and owner.

9.3 Pre-qualification of Bidders

If practical, bidders should be pre-qualified to ensure that they have adequate equipment, experience, personnel and specific company experience in the area of the crossing.

9.4 Drawings

In order to ensure accurate bids, the limiting parameters for a design drill path should be identified. The proposed drill path should be presented on the drawing profile along with the "No Drill' Zone and any geotechnical information, including the geotechnical report, that is available (see Section 6.3).

9.5 Sharing of Risk

HDD crossings present an inherently much higher risk than standard pipeline construction. Where possible, this risk should be mitigated by providing adequate site information such as geotechnical information. Specific contract types are in effect "shared risk" contracts and the use of these types of contracts should be considered.

9.6 Responsibilities of Parties

Specific responsibilities pertaining to the parties involved with the HDD should be clearly explained in the contract. Such responsibilities that should be included in the contract are:

- responsibility for arranging the surveying and staking of the access and entry and exit points of the drill should be clearly identified;
- the owner company should clearly state any reporting schedules and/or systems that the contractor(s) are to follow during the course of the drill (*e.g.*, phone in daily progress reports to the project manager);
- monitoring and contingency responsibilities should be clearly defined;
- the contract should specify who is responsible for the accumulation of extraordinary costs during the course of the project; and
- it should be clearly stated what each of the parties is responsible for providing, and whether separate pricing is required for specific items.

9.7 Failed Crossings

HDD projects can fail in a number of ways (see Section 10.3), including:

- unexpected geotechnical conditions that preclude the successful completion of the HDD;
- the drag section is difficult to pull back through the crossing;
- the pipe gets stuck in the hole after a successful drill and ream; and/or

- inability to prevent excessive inadvertent releases and after all possible attempts are made, the cost becomes unacceptably high and the HDD may be deemed unfeasible.

Parts or all of the down hole assembly may be lost during a failed attempt and payment for these should be addressed in the contract documents. It is technically feasible to "fish" for the equipment left down hole, however, the cost and possibility of success should be weighed against the value of the down hole equipment. These types of failures should be considered when designing the crossing and preparing the tender documents.

Since there is potential for an HDD to fail, it is imperative that alternate crossing plan(s) be prepared in advance in order that approvals have already been received or may be obtained in a timely fashion in the event of a failure.

9.8 Dispute Resolution

All contracts should contain details on how disputes will be resolved. Consideration should be given to incorporating Alternative Dispute Resolutions (*i.e.,* arbitration or mediation) into the contract.

9.9 Drilling Execution Plan

The selected contractor should develop and present to the owner a written drilling execution plan that addresses all aspects of the HDD. A full list of components of the plan is provided in Appendix C. Key topics in the plan include:

- details of each step of the HDD;
- detailed drawings;
- equipment specifications;
- workspace and water requirements;
- monitoring plans including frequency and type; and
- contingency plans.

9.10 Environmental Protection Plan

An environmental protection plan (EPP) should be developed by the owner to address mitigative measures to be implemented during execution of the HDD. Environmental protection planning should cover all aspects of the execution of the HDD including land, water and access needs. The EPP should address the following aspects and be closely linked to the drilling execution plan:

- notification and approvals;
- identification of environmental exclusion areas to be incorporated into No Drill Zones;
- environmental and social timing constraints;
- equipment inspection and servicing;
- clearing and grading of HDD sites and access;
- erosion and sediment controls; and
- monitoring.

In addition to having an EPP, it is essential to have qualified people onsite to enact the plan, to handle deviations to the plan and to report events properly to the authorities. Having an environmental specialist or biologist onsite to liaise directly with the DFO habitat biologist or other similar authority can prove useful. Effective communication of unintended events and subsequent mitigation actions to the authorities may reduce delays or unwarranted enforcement actions contingency planning, *e.g.*, inadvertent returns, (see also Section 10.3.2); and reclamation.

10 CONSTRUCTION CONSIDERATIONS

10.1 Drilling

10.1.1 Types and Sizes of Rigs

The size of HDD rigs can vary substantially. This range in sizes should be considered when planning and developing specifications for an HDD project.

In general, rigs are sized according to their available pull force and rotary torque that can be applied to the drill stem and pipe string.

The following are samples of rig sizes and the respective ranges of projects that can be completed.

Rig Torque	Length of Drill	Diameter of Pipe
0 – 54,000 Nm	up to 200 m	up to 168.3 mm
54,000 – 108,500 Nm	up to 400 m	up to 273.1 mm
108,500 – 217,000 Nm	up to 500 m	up to 323.9 mm
217,000+ Nm	over 500 m	over 323.9 mm

Note: Nm = Newton metres

The capabilities of each rig should be assessed for each project. The assessment of rig capabilities should take into account the possibility that formations or other subsurface materials may be encountered that could cause difficulties with the HDD project.

10.1.2 Casing

Considerations related to casing are discussed in Section 8.3.

10.1.3 Drag Section

The pipe installation should be designed so that, wherever possible, the pipe string or drag section can be laid out and pulled back in one continuous section.

The pipe will have to be lifted into place to match the exit angle of the drill to allow the drill rig to pull the section into place.

The pipe string is usually placed on rollers as it is pulled into the drilled hole. The drag section may be cradled through a vertical curve to achieve the proper angle at the exit point. This curvature should be no more than the limiting curvature of the pipe.

10.1.4 Steering / Survey of Drill Head

It is necessary to 'steer' the drill head or mud motor during the drilling of the pilot hole. A number of steering technologies are available. Two of the more common systems are known as the DigiTrak system and the TruTracker® system. The DigiTrak is a "walkover system" that is somewhat limited in the depth to which it is effective. The TruTracker® system is a "wireline steering tool system" and is utilized where the depth of the crossing is outside the range of the walkover system. Both of these systems provide effective steering.

10.1.5 Drilling Fluids

Drilling fluid is used for a number of tasks in the HDD process including:

- cooling and lubricating the drill stem, mud motor and bit;
- providing hydraulic power to the mud motor which in turn converts hydraulic power to mechanical power;
- carrying cuttings out of the bore hole;
- stabilizing the bore hole during the drilling process; and
- sealing fractures in the formation.

Drilling fluid is usually a mixture of freshwater and bentonite. Bentonite is naturally occurring clay that is extremely hydrophilic (*i.e.*, has high swelling characteristics). Certain polymers may also be used that enhance the drilling fluid benefits.

A drilling fluid design plan should be established before the start of the project. This plan should also be modified, when warranted, throughout the project to ensure the drilling fluid is fulfilling its function.

The contractors' drilling execution plan should identify the equipment to be maintained onsite to check drilling fluid properties. Alterations to the mix should be made, when warranted, to stay within the proposed boundaries in the drilling fluid management plan.

A mud handling system should be onsite to ensure drilling fluid parameters are within the set standards.

Appendices D and E, respectively provide a pipe volume table and conversion factors that may be of use in the calculation of drilling mud volumes or other aspects of an HDD project.

Additives

Various chemical and materials can be added to the drilling fluid to adjust its properties. This is done to control:

- density;
- viscosity;

- plugging and sealing capabilities; and
- specific conditions such as swelling.

All additives should be environmentally safe. A number of additives have been recognized as safe for the water well drilling industry and, with the proper approvals, could be used for the HDD industry. All additives must be approved before use.

10.1.6 Drilling Fluid Disposal

Samples should be acquired of the drilling fluid/cuttings and analyzed for contamination before disposal. Permits/approvals are required in some provinces and territories for the disposal of drilling wastes.

Drilling fluid and cuttings can be disposed of in three ways:

- mix and bury onsite;
- land spread; and
- haul to an approved site or disposal facility.

10.1.7 Buoyancy Control

When a drag section is pulled back through the bore, the buoyant weight of the pipe as well as the resulting drag forces between the pipe (pipe coatings) and the walls of the bore will act as resisting forces. The drag force can be severe enough to damage pipe coatings as well as collapse the pipe. Therefore, it is important to determine during the planning phase whether buoyancy control is needed. If buoyancy control is necessary (*i.e.*, for some long and large diameter drills), a buoyancy control plan needs to be implemented. Typically, buoyancy control is applied by adding water to the drag section during the pull back phase.

10.2 Monitoring

Monitoring and reporting are critical during an HDD since they provide a log of activities during the process to:

- provide early identification of issues;
- make appropriate changes;
- provide a basis for mitigation; and
- provide a record of decisions and actions to demonstrate due diligence.

It is important to ensure that sufficient records are maintained before, during and after construction to support subsequent reports prepared to satisfy contractor, owner or government reporting requirements. This should include detailed notes and photographs of all areas monitored.

10.2.1 Drilling

The following monitoring and reporting activities should be reviewed for appropriateness for the size and complexity of the HDD crossing:

- inspector daily records – a day-to-day account of the entire construction of the project;
- contractor drilling records;
- steering report;
- drilling fluid volume balance report;
- drilling fluid parameters;
- drilling fluid additives list;
- annular pressure modeling and reporting;
- turbidity monitoring report;
- surface monitoring report;
- pull force monitoring; and
- inadvertent return report.

10.2.2 Environmental

An environmental monitoring and response plan should be prepared by the contractor to address all the issues outlined in the EPP or specific concerns in the permits.

The drill path and surrounding area should be monitored up and downstream of the works. Where pressurized drilling fluids are used, monitoring should extend at a minimum 400 m up- and downstream of the crossing, and be conducted on a fixed interval basis as identified in the EPP. The exact distances will depend on the various issues at the site. Monitoring should be documented and any evidence of fluid on the surface should be reported to the owner and appropriate provincial, territorial and federal authorities as soon as possible.

Large water bodies and water bodies that are crossed when ice cover is present may warrant turbidity monitoring to identify whether inadvertent returns are entering the water body. The water body turbidity should be monitored regularly to ensure that a loss of fluid in the water body is detected as early as possible. The sample locations and sampling protocol including method and frequency of sampling, (including frequency under normal operating conditions and when loss of circulation occurs) and acceptable turbidity rates should all be determined in advance of the works by an aquatic specialist and specified in the EPP. The monitoring must be documented and any evidence of increased turbidity levels should be reported at once.

If a loss of circulation occurs during the drilling program, the frequency of monitoring should increase to detect any inadvertent returns to surface.

10.2.3 Indicators of Inadvertent Returns

Inadvertent returns occur when drilling fluids disperse into surrounding soils or randomly discharge to the surface. Such inadvertent returns are a result of the drilling fluid following the path of least resistance. To help prevent such releases the drill path should be aligned to avoid or minimize soils or formations prone to inadvertent returns, casing at the entry hole may be installed and other drilling parameters are established to maximize drilling fluid circulation and minimize the potential for unintentional drilling fluid returns. Conditions where inadvertent returns have a higher potential to occur include:

- fractured rock (pre-existing flow paths or presence of joints);
- coarse grained permeable soils (gravel, cobble and boulders);
- considerable elevation differences between the entry side and pipe side;
- areas where HDD vertical depth of cover is insufficient; and
- artifical features (existing exploratory bore holes).

10.3 Failures

10.3.1 Types and Causes

Many of the more common types of failures and their associated cause(s) are noted below in Table 2.

Table 2 - Types of HDD Failures and Their Cause

Type	Cause
Loss of drilling fluid / Loss of circulation	• permeable deposits or jointed and/or fractured bedrock along the drill path • excessive annular pressures for the bedrock formation or soils encountered
Drilling mud seepage directly into watercourse	• permeable deposits or jointed and/or fractured bedrock along the drill path • excessive annular pressures for the bedrock formation or soils encountered
Drilling mud seepage onto land and then into watercourse	• permeable deposits or jointed and/or fractured bedrock along the drill path • excessive annular pressures for the bedrock formation or soils encountered • suggests inadequate monitoring along drill path
Collapsed hole	• erosion or settling of the bore hole
Stuck drill stem or pipe string	• collapse of hole along the drill path, due to swelling of highly plastic clays, boulders, bentonic shales, coal seams • inadequate reaming to obtain optimal bore diameter for pull back
Lost tools and/or drill stands	• twisting off of drill stem or metal failure of down hole tools

Type	Cause
Damaged pipe or coating	• inadequate reaming to obtain optimal bore diameter for pull back • excessive entry or exit angle for bend radius of the pipe string • sharp objects or casing present in bore • collapse of hole along the drill path

10.3.2 Contingency Plans

A site-specific contingency plan should be prepared by the project team for each HDD. A well designed contingency plan should address the following:

- general measures;
- equipment and personnel needs for containment and clean-up;
- emergency response procedures;
- plans for continuance of drilling or alternative plans;
- time lines of acceptable response and notification;
- clean-up methods and plans;
- regulatory and stakeholder contacts;
- monitoring plans; and
- disposal plans.

Appendix E provides one example of a contingency plan.

10.3.3 Selection of Alternatives

Alternatives that may be available to allow continued use of an HDD method following an initial failure include:

- down hole cementing to either seal off the problem zone for redrilling or seal off a large portion of the existing bore hole to a point where a new drill path (generally at a lower elevation) can be attempted; note that if reaming is necessary this method may not be successful since any reaming will remove localized cementing
- a new drill can be attempted at a steeper entry angle in an attempt to get below the problem area
- the drill can be moved and an attempt made to redrill from a new location (the revised drill path should be reviewed and revised accordingly prior to drilling); and
- the feasibility of conventional (*i.e.*, trenched) crossing methods should be considered if the drill fails; consult the appropriate project staff as well as regulatory authorities.

10.3.4 Clean-up and Remediation

An important decision may be required when developing plans to clean-up an inadvertent release of drilling mud. The decision can involve determination of whether or not clean-up and reclamation of a site will incur greater adverse effects on the environment than leaving the mud *in situ* and allow natural processes to reclaim the area. In some situations, a combination of minimal intervention and letting nature take its course can also be appropriate (*e.g.,* re-establishing a channel in a blocked wetland while leaving the wetland to reclaim itself).

The determination as to whether to clean-up or not must be made in conjunction with appropriate regulatory and land authorities. In many cases, this decision will be contrary to traditional practices and must be made after thorough examination of the advantages and disadvantages of each.

The potential environmental impacts associated with HDD are addressed in Section 7.0.

Clean-up of Returns

The impacts from clean-up activities in sensitive environments are dependent upon the level of activity and equipment required to remove the residual drilling mud, terrain and aquatic conditions and season.

Containment

Several containment measures are commonly used for the uncontrolled release of inadvertent returns (Table 3). The measure(s) chosen to be used depend upon:

- the anticipated volume to be contained;
- existing access to the site;
- environmental sensitivity of the area contaminated and adjacent areas; and
- soil and weather conditions

Table 3 - Containment of Inadvertent Returns

Containment Measure	Conditions Used / Application
Silt fencing	• controls migration of drilling mud in wetlands; • retains small volumes of sediment; • decreases overland flow of drilling mud and fluids; • minimizes total suspended sediment quantities of surface waters through filtration; • suitable for wetlands and the banks and shorelines of water bodies

Containment Measure	Conditions Used / Application
Hay or Straw Bales	• retains small volumes of sediment; • decreases velocity of downslope runoff; • suitable for vegetated wetlands, and the banks and shorelines of water bodies
Sand Bags	• contains high volume inadvertent returns by creating a dam; • used where silt fences and bales are not effective
Floating Booms	• contains drilling mud in areas with a high flood potential where drilling mud returns may be spread by water flow throughout a water body; • suitable in water bodies where water level exceeds 30 cm
Plywood Sheets	• contains deeper pooled inadvertent returns; • suitable for water bodies where clean-up of returns cannot be completed before water flow disperses the returns
Culverts	• large culverts can be installed vertically over an instream point source release to contain released fluids and facilitate clean-up activities
Aquadams	• useful in diverting streamflow from an area of release or isolating the release area

Clean-up

It is important for the owner, contractor, appropriate environmental specialist(s), if warranted, and appropriate regulatory agency to discuss the clean-up goals for a site subjected to an inadvertent release of drilling fluids prior to commencement of clean-up activities. If a net gain is not anticipated as a result of clean-up, alternative measures may need to be implemented. Vehicles and equipment commonly used during the clean-up of a mud release are identified in Table 4.

Table 4 - Potential Equipment and Vehicles Used During Drilling Mud Clean-up

Equipment	Use
Backhoe	• for executing containment pits at drill sites situated in upland areas
Vacuum trucks	• for the immediate collection of drilling fluids for recycling or off-site disposal; • ground low-pressure tires may be placed on vacuum trucks to reduce footprint in sensitive areas
Dump trucks	• for removal of drilling mud to disposal areas, if required

Equipment	Use
Frac tanks	• for above ground storage of drilling fluids and to contain inadvertent returns prior to disposal; • minimizes overall disturbance to the site, since sump pits are not required
Swamp mats	• for minimizing sedimentation caused by heavy traffic in waterways; reduces compaction and rutting by heavy equipment in areas of wet terrain during nonfrozen conditions
Plywood sheets	• for use as walk ways for crews in sensitive areas, reduces footprint to the site
Brooms, rakes, spades and shovels	• for manual removal of muds from vegetated areas, for use after majority of muds are cleaned-up by larger equipment
Squeegees	• can be useful in removing residual mud from vegetation, thin residual mud so that vegetation is able to break through the mud layer
Snowshoes	• useful for workers to access areas with thickly pooled released drilling mud to assess final clean-up requirements where heavy machinery is not allowed; • reduces impact of foot traffic on vegetation
Water rinse	• softens hard or dry drilling mud

10.4 Reporting

10.4.1 Monitoring Reports

Prior to the start of construction, the contractor should be required to provide the proposed monitoring report forms as part of the drilling execution plan. Frequency and types of monitoring should also be presented in the drilling execution plan.

10.4.2 As-Built Reports

As part of project deliverables, the contractor should provide the owner an as-built drawing in a format approved or determined by the owner. The contractor should also provide a set of the monitoring reports at the end of construction.

11 REFERENCE DOCUMENTS

Alberta Energy and Utilities Board. 2000. An Update to the Requirements for the Appropriate Management of Oilfield Wastes. ID 2000-04

Alberta Energy and Utilities Board. 2000. Harmonization of Waste Management. ID 2000-03

Alberta Energy and Utilities Board. 2000. Memorandum of Understanding Between the Alberta Energy and Utilities Board and Alberta Environment on Harmonization of Waste Management. ID 2000-03

Alberta Energy and Utilities Board. 1999. Disposal of Drilling Waste Associated With Alberta Energy and Utilities Board (EUB) Regulated Pipeline and/or Other Oil and Gas Related Below Ground Boring Activities. ID 99-05

Alberta Energy and Utilities Board. 1999. Deposition of Oilfield Waste into Landfills. ID 99-04

Alberta Energy and Utilities Board. 1996. Oilfield Waste Management Requirements for the Upstream Petroleum Industry. ID 96-3

Alberta Energy and Utilities Board. 2001. Management of Drilling Wastes Associated with Advanced Gel Chemical Systems. IL 2001-3

Alberta Energy and Utilities Board. 2002. Guide 70: Drilling Waste Disposal Inspection Manual. GB 2002-1

Alberta Environment. Code of Practice for Pipelines and Telecommunication Lines Crossing a Water Body.

Alberta Environment. 2000. Guide to the Code of Practice for Pipelines and Telecommunication Lines Crossing a Water Body.

Anderson, P.G., B. R. Taylor and G. Balch. 1995. Quantifying The Effects Of Sediment Release On Fish And Their Habitats. Prepared for the Department of Fisheries and Oceans, Habitat Management, Easter B.C. Unit and Alberta Area by Golder Associates Ltd. Rpt. No. 952-2207. 142 pp + Appendices.

Canadian Association of Petroleum Producers. 1996. Guidelines – Hydrostatic Test Water Management. CAPP Pub. #1996-0014.

Canadian Pipeline Water Crossing Committee. 1999. Watercourse Crossings. Second Edition.

Chevron Chemical Co., LLC. 1999. Technical Note: Horizontal Directional Drilling (Guided Boring) With PLEXCO Pipe. Trenchless Technology Bulletin No. 1.

Directional Crossing Contractors Association. 1995a. Guidelines for Successful Mid-Sized Directional Drilling Projects

Directional Crossing Contractors Association. 1995b. Guidelines for a Successful Directional Crossing Bid Package

Fisheries and Oceans Canada. 2003. Navigable Waters Protection Program. Pipeline Crossing Guidelines, Central and Arctic Region.

Fisheries and Oceans Canada. 2004. Navigable Waters Protection Program. Guidelines for Crossing using Horizontal Directional Drilling and Bore Methodology. Canadian Coast Guard, Pacific Region. www.pacific.ccg.gc.ca/nwpd-1pen/pipelinecrossing_e.htm

Grays Harbor Pipeline. nd. Horizontal Directional Drilling (HDD). http://www.graysharbor.twc.com/HDD-fact_sheet.htm

Gas Research Institute. May 2002. Horizontal Directional Drilling Best Management Practices Manual. Topical Report (ENSR Corporation).

Guide 50 Drilling Waste Management; Alberta Energy and Utilities Board, October 1996.

Hair, J., D. Cameron, C. Tammi, E. Steel, J. Schmidt and J. Evans. 2002. A Comparative Assessment of Horizontal Directional Drilling and Traditional Construction Techniques for Wetland and Riparian Area Crossings in Natural Gas Pipeline Rights-of-Way Goodrich-Mahoney et. al. 2002. Environmental Concerns in Rights-of-Way Management - 7th International Symposium.

HDD Consortium. 2004. Horizontal Directional Drilling Good Practices Guidelines. ISBN: 1-928984-13-4. North American Society for Trenchless Technology.

Henniker Directional Drilling, L.L.C. 2003a. About HDD. http://www.hddbore.com/about_hdd.html

Henniker Directional Drilling, L.L.C. 2003b. Advantages of HDD. http://www.hddbore.com/advantages.html

Institute for Civil Infrastructure Systems. 2000. Urban Application of Trenchless Technology: Social Costs and Model Contract Practices, A Summary Report of the 2000 Life Extension Technologies Forum.

Laser Drillers Australia. nd. Info on HDD. http://www.laserdrillers.com.au/infoHDD.html

Scandrill Co. L.L.C. 2001. Horizontal Directional Drilling. http://www.scandrill.ca.ae/html/hdd.htm

Trenchless Technology British Columbia. nd. Trenchless Technology - A Canadian Perspective Guide. http://trenchless-technology.org/canguide.html

Williams, A.I. and J.R. Jamison. 2000. Design and Coating Selection for Successful Completion of a horizontal Directional Drill (HDD) Crossing. NACE CORROSION Paper

APPENDICES

Appendix A Glossary

Appendix A - Glossary

annular pressure	*fluid pressure acting on the formation measured in the space between the drill stem and the wall of the bore*
arc	*curved section completed at a predetermined radius of curvature*
Atterberg Limits	*the water content of a soil when it passes from a semi-solid to a plastic state and from a plastic to a liquid state; and can be empirically correlated with clay content and its propensity to swell.*
bentonite	*a clay mineral, primarily montmorilonite, with high swelling properties that forms the primary component in drilling muds used in HDDs*
bottom hole assembly (BHA)	*tools used in directional drilling including the bit, bent sub, mud motor, steering tool, annular pressure tool, and connections to provide directional control, information gathering and drilling power*
bore	*earth removed from between the surface entry and exit points along the drill path*
casing	*pipe installed through problematic near surface materials such as gravels and cobbles to provide a conduit for the BHA and other down-hole tools and drilling fluid*
deleterious substance	*any substance that would degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water;* *any water that contains a substance in such quantity or concentration, or that has been so treated, processed or changed, by heat or other means, from a natural state that it would, if added to any other water, degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water*
drill stem	*steel drill pipe approximately 10 m long and 114.3 to 168.3 mm O.D., used to control and transfer fluid in an HDD*
drill bit	*a device that cuts into the formation and progresses the bore*

drill cuttings	*ground and subsurface material broken by the drill bit*
drilling mud/fluid	*fluid created by mixing water and bentonite as well as other additives to facilitate drilling and transport of drill cuttings from drill bit to the surface*
down-hole tool	*tools that are used at the end of the drill string to physically complete the bore and to provide directional and other information*
entry point or rig side	*the side of the HDD where the drill rig is situated and where the pilot hole is started*
exit point or pipe side	*the side of the HDD where the pilot hole exits the crossing; where the pipeline to be installed into the bore is fabricated*
harmful alteration, disruption or destruction (HADD)	*HADD of fish habitat is defined by DFO as “any change in fish habitat that reduces its capacity to support one or more life processes of fish.”* *HADD applies when determining if or whether any of the three conditions (i.e., harmful alteration, disruption, and destruction) are likely to result from a project.*
hydraulic fracture	*the process of annular pressure inducing a fracture or opening up an existing fracture in the formation during the drilling process*
inadvertent return	*drilling fluid and cuttings that migrate from the drilled hole to the surface, along a joint, fracture or any other path of least resistance*
measured depth	*total bore length as measured from the surface to the lowest point on the drill path*
Moh’s scale of hardness	*a scale of hardness devised to aid the identification of minerals*
mud motor	*mechanical device that transforms hydraulic power to mechanical power to turn the drill bit and maintain the progress of the bore*
No Drill Zone	*upper limit of the drill path as defined by the geotechnical engineer, between potential or specified entry and exit locations. Intended to ensure the bore is maintained within geological formations suitable for directional drilling with suitable cover to assist in minimizing the potential form inadvertent returns.*
pilot hole	*the initial bore drilled along the drill path*
pipe string	*pipe to be installed through the bore at the completion of the HDD drill to carry product through the crossing*

radius of curvature	*the bend radius of the drill or pipe string*
reaming pass	*subsequent pass(es) through the pilot hole to increase the diameter of the pilot hole to the required size to accomodate pipeline pullback*
small HDD project	*generally an HDD of length less than 300 m and / or pipe less than 323.9 mm O.D.*
steering / guidance tool	*specific tools providing steering direction information to the driller*

Appendix B Primary Regulatory and Information Contacts

Appendix B - Primary Regulatory and Information Contacts

Jurisdiction	Agency	Purpose
Federal	Fisheries and Oceans Canada (DFO) • District Manager or Impact Assessment Biologist	• In the event of drilling mud release in a watercourse. • Letter of advice or authorization. • Water withdrawal during drilling and testing.
	Transport Canada • Navigable Waters Protection Officer, Canadian Coast Guard	• Navigable water approval for temporary vehicle crossings or if an HDD fails and instream activities are planned.
	Indian and Northern Affairs Canada (INAC)	• Permission and approval of easement and HDD on Indian Reservations
	Indian Oil and Gas Canada (IOGC) • Environment and Surface Manager	• Permission and approval of easement and HDD on Indian Reservations
	Prairie Farm Rehabilitation Administration (PFRA) • Land Manager	• Permission and approval of easement and HDD on PFRA land.
	Other federal land authorities (*e.g.,* Department of Defense)	• Permission and approval of easement and HDD on federal Crown land.
Alberta	Alberta Sustainable Resource Development (ASRD) • Fisheries Biologist/Technician, Fish and Wildlife Division	• In the event of drilling mud release in a watercourse.
	Alberta Environment (AENV) • Regional Water Manager	• Notification under the *Code of Practice for Pipelines and Telecommunication Lines Crossing a Water Body* • In the event of drilling mud release in a watercourse
	ASRD • Public Lands and Forest Division	• Permission to access and construct HDD on provincial Crown land. • Water withdrawal approval/notification for drilling and testing.
	Alberta Energy and Utilities Board	• In the event of a drilling mud release • Provides regulations for disposal of drilling mud
British Columbia	BC Oil and Gas Commission Project Assessment Branch • Headquarters, Fort St. John	• Permission to access and construct HDD on patented and provincial Crown lands • Submit drilling waste management and clean-up form
	Land and Water British Columbia Inc. • Regional Offices	• Approval for short-term use of water or water license

Jurisdiction	Agency	Purpose
Manitoba	Manitoba Conservation • Director of Environmental Approvals, Environmental Approvals Branch	• Permission to access and construct HDD on patented and provincial Crown lands
New Brunswick	Department of Environment and Local Government • Watercourse Alteration Program Coordinator, Operational Support Branch	• Watercourse and Wetland Alteration Regulation permit
	Department of Natural Resource (DNR) • Wetlands and Coastal Habitat Program, Regional Offices	• letter of support for HDD near a coastal wetland
	Department of Natural Resources (DNR) • Land Use Application Service Centre, Crown Land Branch	• Authorization to access and construct HDD on provincial Crown land
Newfoundland and Labrador	Department of Environment • Water Resources Management Division	• Certificate of environmental approval
	Department of Government Services and Lands • Regional Office	• Permission to access and construct HDD on patented and provincial Crown land
Northwest Territories (not including Inuvialuit Settlement Region (ISR))	Mackenzie Valley Land and Water Board, Yellowknife • Executive Director	• Land use permit and water licence to construct HDD.
Northwest Territories (Inuvialuit Lands)	Inuvialuit Land Administration (ILA), Tuktoyaktuk • Land Administrator	• Permission to access and construct HDD on ISR patented lands • Reviews and approves applications to access and use Inuvialuit lands.
	Indian and Northern Affairs Canada (INAC), Yellowknife • Land Administration Officer	• Land use permits for Crown lands
	Northwest Territories Water Board, Yellowknife • NWT Water Board Office	• Water licences for Crown lands
	Environmental Impact and Screening Committee (EISC), Inuvik • Joint Secretariat	• Environmental screening of developments for impacts on Crown and occasionally patented land

Jurisdiction	Agency	Purpose
Northwest Territories (Gwich'in Lands)	Gwich'in Land Administration, Inuvik • Lands Manager	• Permission to access and construct HDD on Gwich'in patented lands
	Gwich'in Land and Water Board, Inuvik • Executive Director	• Water licence to construct HDD
Northwest Territories (Sahtu Lands)	Sahtu Land and Water Board, Fort Good Hope • Executive Director	• Water licence to construct HDD • Regulates the use of land and water by issuing, amending, renewing and suspending land use permits and water licences on all Crown, Sahtu lands and patented lands
Nova Scotia	Nova Scotia Department of Natural Resources • Director, Land Administration Division	• Permission to access and construct HDD on provincial Crown land. • Contact for HDD for coastal waters only
	Nova Scotia Department of Environment and Labour • Regional or District Office, Environmental Monitoring and Compliance Division	• Water licence for a watercourse alteration and for water allocation. • Contact for HDD for inland waters on patented and provincial Crown land.
Nunavut	Nunavut Planning Commission (NPC)	• Permission to access and construct HDD on private and Crown land. (Note: The NPC usually forwards copies of applications to NIRB, INAC, Nunavut Water Board and RIA, as well as any other agencies they determine may require a copy.)
	Nunavut Impact Review Board (NIRB)	• Environmental screening of developments for impacts on Crown and occasionally patented land
	Regional Inuit Association (RIA)	• Permission to access and construct HDD on Inuit-owned land
	INAC	• Permission to access and construct HDD on Crown land.
Ontario	Ontario Ministry of Environment • Environmental Assessment Branch • Approvals Branch	• Approval for water withdrawal. • Verbal notification 1 day before construction.
	Local or Regional Municipality	• Topsoil removal permit (not applicable if topsoil is held and replaced)
	Ontario Ministry of Natural Resources • District Office	• Permits to access and construct HDD on provincial Crown and patented lands. • Verbal notification 1 day before construction.
	Conservation Ontario • Conservation Authority	• Permit to construct HDD

Jurisdiction	Agency	Purpose
Prince Edward Island	Department of Environment and Energy • Environmental Impact Assessment Coordinator, Pollution Prevention Division	• Application for an Environmental Impact Assessment (EIA)
	Department of Environment and Energy • Watercourse/Wetland Alteration Supervisor, Conservation and Management Division	• Water alteration permit • Approval for water withdrawal
	Department of Environment and Energy • Chief Executive Officer, PEI Energy Corporation	• Notification of pipeline/HDD
Quebec	Ministere de l'Environment • Societe de la Faune et des Parcs du Quebec	• Application for Authorization: Projects in Aquatic Environments and on Shores; demande de certificat d"autoristion pour activities en milieux aqautique, humide et riverain
Saskatchewan	Saskatchewan Environment (SENV) • Oil and Gas Coordinator • Fish Ecologist/Technician	• Aquatic Habitat Protection Permit for patented and provincial Crown land
	Saskatchewan Watershed Authority (SWA) • Coordinator - Water Resource Administration	• Aquatic Habitat Protection Permit for patented and provincial Crown land
	Saskatchewan Agriculture and Food Rural Revitalization (SAFRR) • Regional Manager	• Permission to access and construct HDD on provincial Crown land.
	Saskatchewan Industry and Resources	• Drilling mud disposal requirements
Yukon	Department of Environment • Yukon Water Board • Water Resources Branch • Environmental Protection and Assessment Branch	• Water license approvals (Type "B" license to cross watercourses greater than 5 m wide) • Regulatory/ enforcement matters • Environmental assessments

Appendix C Example Drilling Execution Plan

Appendix C - Example Drilling Execution Plan

The contractor should develop and present to the owner a drilling execution plan that addresses the following items:

5) each step to be taken during mobilization, surface preparation, sump construction, anchor installation, casing installation, pilot hole drilling, hole opening operation, pullback operation and demobilization including a detailed drawing showing the intended drill path in plan and profile, depth of cover, entry angle, exit angle, depth and size of surface casings, and any other pertinent data;
6) drill rig specifications including push/pull force, torque and other specifications of the specific rig to be used on this project;
7) a full description of the drilling fluid recycling system, fluid flow operating rate, tanks, pumps, solids control/recycling, centrifuge(s) etc.;
8) proposed water supply for drilling;
9) drilling pipe description with certifications (size, grade and quantity);
10) details of drill rig anchoring system;
11) proposed steering system with limitations and access requirements;
12) pressure monitor type and pressure range, if required;
13) electronic drilling recorder type and functions monitored (if required);
14) sample of daily drilling reports; and
15) contingency plan to be employed in event of:
    a) casing removal difficulties;
    b) inadvertent returns to surface;
    c) equipment lost in the hole;
    d) hole collapse during pipe pull;
    e) pipe getting stuck during pull back;
    f) appearance of severe damage to the coating during pullback; and
    g) appearance of severe damage to the pipe during pullback.
16) a drilling fluid mitigation plan, including:
    a) a description of the proposed fluid type and additives complete with manufacturer's specifications (MSDS, etc.)
    b) written authorization from appropriate agencies to use additives, if required
    c) emergency response plan:
        i) notification procedures;
        ii) emergency containment and clean-up procedures plan for inadvertent fluid migration or release in a water body or on land (including inadvertent returns);.
        iii) emergency response equipment on site; and
        iv) a description of the fluid cleaning, recycling and control systems, including volumes of fluids and water tankage required;

d) disposal plan composed of:
   i) an estimate of the complete composition of the drilling waste including the relative quantities of water, bentonite, other sediments and drill cuttings, and any additives which may be necessary during construction or to allow flocculation prior to disposal;
   ii) method of containment and, if appropriate, disposal of drilling fluids onsite; and
   iii) off-site disposal plan (fluid disposal options);
      1. mix and bury onsite;
      2. haul to an approved dumpsite;
      3. land spreading; and
      4. written authorization from appropriate agencies to dispose of fluids

Appendix D HDD Related Conversions

Appendix D - HDD Related Conversions

MULTIPLY	BY	TO OBTAIN
Acre feet	43560	Cubic feet
Acre feet	1233.48	Cubic metres
Barrel	35	Imperial gallons
Barrel	42	U.S. gallons
Barrel	0.1193	Cubic metres
Cubic foot	0.0283	Cubic metres
Cubic foot	6.229	Imperial gallons
Cubic foot	7.481	U.S. gallons
Cubic metre	264.17	U.S. gallons
Cubic metre	35.3144	Cubic feet
Cubic metre	220.1	Imperial gallons
Cubic metre	6.289	Barrels
Cubic metre	1000	Litres
Cubic metre	2204.6	Pounds of water
Cubic metre	1000	Kilograms of water
Cubic foot/sec	0.02832	Cubic metres/sec
Foot	0.3048	Metres
Hectare	2.471	Acre
Kilogram	2.2046	Pounds
Kilograms/hectare	0.892	Pounds per acre
Kilopascals	0.145	Pounds per square inch
Metre	3.2808	Feet
Mile	1.609	Kilometres
Pound	0.45359	Kilograms
Pounds per square inch	6.895	Kilopascals
Pounds per acre	1.121	Kilograms/hectare

Appendix E Example (Alberta) - Pipeline Horizontal Directional Drilling

Appendix E - Example (Alberta) - Pipeline Horizontal Directional Drilling

E.1 Purpose

This plan provides guidance in the even of inadvertent returns of drilling fluid during an HDD.

E.2 General

Drilling mud is classified as an oilfield waste and is regulated under the jurisdiction of the Alberta Energy and Utilities Board (EUB). A *frac-out* or inadvertent release of drilling mud is considered *"Reportable"* to the applicable regulatory authorities when:

- the inadvertent release occurs in or close to sensitive aquatic or terrestrial receptors, or
- onto land and the release is in excess of 2 m^3 within the right-of-way, or
- any size of release outside the right-of-way that may cause, is causing or has caused an adverse effect.

Depending on the circumstances of the inadvertent release, the person responsible shall immediately report the release to the applicable authorities such as EUB, AENV, any affected landowners or public and, if into or near a water body, Fisheries and Oceans Canada (DFO).

To promote landowner or public understanding of drilling waste management, an information brochure entitled *EUB Guide 50-1; Landowner's Guide for Drilling Waste Disposal From Oil and Gas Wells* has been developed. Pipeline companies are expected to distribute this brochure to surface landowners and land occupants as part of the landowner approval process.

E.3 Recommended Inadvertent Response Plan

E.3.1 Inadvertent Release Response in Water

1. The HDD contractor is to stop the drilling operations immediately.

2. The HDD contractor or party designated to be responsible as determined in the contingency plan, is to contain the drilling mud and prevent further migration into the water body. In the case of an instream release, the downstream movement of drilling mud should be prevented if possible by isolating the release point or diverting higher velocities around the release.

3. The HDD contractor will immediately notify the owner or designate who will immediately contact the appropriate EUB Field Office and other applicable regulatory authorities. If a release into water has occurred or is

suspected to have occurred, the provincial fisheries biologist, Alberta Environment, DFO and Environment Canada should be notified.

EUB Field Service/Emergency (24 hours)	______________
Regional Director	______________
Provincial Fisheries Biologist	______________
DFO Fisheries/Habitat Biologist	______________
AENV Compliance Branch	(780) 422-4505
AENV Emergency Complaint Hotline (24 hours)	1-800-222-6514 or *7378 (Telus Mobile)

4. The drilling mud must be cleaned up immediately by the HDD contractor and/or drilling mud disposal contractor, if conditions allow, and disposed of as per EUB Guide 50 and EUB ID 99-05. If the potential exists for greater environmental impact due to the clean-up process than the presence of the drilling mud, regulatory agencies (*e.g.*, EUB, Alberta Environment, Alberta Sustainable Resource Development and DFO) should be notified if clean-up of drilling mud is not to be conducted immediately and the rationale for the delay should be provided. If the drilling mud has entered a water body or could enter a water body, a qualified aquatic environment specialist (QAES) should determine the appropriate actions to be taken and schedule of activities.

5. Drilling activities will not be resumed until a site-specific drill continuance plan and monitoring program have been approved by the owner. A third party drilling or geotechnical consultant may be needed to review and assess the drill continuance plan.

6. Prepare a report summarizing the events leading up to the release as well as measures taken following the release to minimize impacts on the environment. Submit the report to the Regional Director within 7 days.

E.3.2 Inadvertent Release Response on Land

1. The HDD contractor is to stop all operations immediately.

2. The HDD contractor or party designated to be responsible as determined in the contingency plan is to contain the drilling mud and prevent further migration using berms, sandbags or other appropriate structures or materials. Where appropriate, use vacuum truck or mud/trash pumps to recover fluids and drilling mud.

3. The HDD contractor will immediately notify the owner or designate who will determine if the release is reportable (see General section for definition of reportable inadvertent release) and, if reportable, contact the appropriate EUB Field Office and other applicable regulatory authorities.

4. The drilling mud must be cleaned up immediately by the HDD contractor and/or drilling mud disposal contractor if conditions allow, and disposed of as per EUB Guide 50.

   As noted above in point 4 of F.7.1, an assessment may be necessary if the potential exists for greater environmental impact due to the clean-up process than the presence of drilling mud. Involve applicable regulatory agencies in the discussion process.

5. Drilling activities will not be resumed until a site-specific drill continuance plan and a monitoring program have been approved by the owner. A third party drilling or geotechnical consultant may be needed to review and assess the drill continuance plan.

E.4 Drill Continuance Plan

Collectively the owner, HDD contractor and appropriate regulatory agency should determine the drill continuance plan. Depending on the situation being encountered and the potential impacts to the environment, specialists (*e.g.*, geotechnical engineers, QAES) may be needed to review and assess the plan. The drill continuance plan may include each of the following four strategies.

1. Fracture Plugging (Bridging) Agents

In certain types of formations or conditions, fracture plugging agents (non-toxic) have been utilized with limited success. These agents include ground pieces of carpet, ground corn husks, sawdust, bentonite pellets, walnut husks, sealant or other commercially available products. These are pumped down the drill hole and left undisturbed for a predetermined length of time where upon drilling is restarted. If positive circulation is restored, drilling is continued using the same principles and contingency plans; if not, drilling is halted.

2. Down Hole Cementing

If the fracture zone is determined to be too large for the use of plugging agents, the drill string may be inserted to a predetermine depth to allow a quick setting cement or thermal resin (non-toxic) to be pumped down-hole in sufficient quantities to seal off the problem zone. After setting up, the hole is redrilled through the sealed zone. If no further fracturing occurs, drilling is continued using the same principles and contingency plans; if not, drilling is halted.

3. Contain and Control

If the inadvertent release is on land, determined not to be causing an adverse effect and the surface migration of the drilling mud can be adequately contained and controlled, then drilling can continue with the following conditions:

- there are no impacts to the environment or other adverse effects. (*i.e.*, no potential to contaminate surface or groundwater, third party property damage or safety risks to the landowner, public or animals);
- the area affected by the inadvertent release is minor and limited to only one spot (affected area is less than 10 m^2);
- the surface migration of the drilling mud is adequately contained (bermed with subsoil or a catch pit excavated);
- the contained free drilling mud is adequately controlled (any free drilling mud migrating to the surface is immediately and continually removed for the duration of the remaining drilling phases);
- the site is monitored at appropriate periods during the drilling cycle and the drilling contractor reduces pump/hole pressure accordingly in order to maintain control of the amount of mud being contained (note that some release points may not need continuous monitoring since they are only prone to releases during a particular period in the drilling cycle);
- the affected landowner is notified and permission for continued drilling is granted;
- the plan is discussed with the appropriate EUB authority and other agencies (*e.g.*, DFO) and their approval is obtained; and
- the affected site is remediated and reclaimed to meet Alberta Environment's requirements for a contaminated site.

4. Partial Hole Recovery

In the event that both of the above procedures are unsuccessful, down-hole cementing could be used to seal off a substantial portion of the existing hole back to a point where a "kick-off" can take place. The drilling is then advanced along a different path usually at a lower elevation. Again, careful monitoring of drilling fluids and the drill path will be carried out using the same principles and contingency plans; if not, drilling is halted.

In the event that none of the above procedures are successful or considered feasible, the hole will be abandoned, and a re-drill will be considered at a second location if it can be determined that more favourable geotechnical conditions exist, using the same principles and contingency plans.