ABSTRACT

Pipeline river crossings pose a significant challenge for pipeline owners and environmental regulators to balance the associated costs and risks, particularly where environmental impacts may occur. For years, NOVA Gas Transmission Ltd. (NGTL) has managed the regulatory approval process using a well-established process. However, regulatory expectations are increasingly neutral to the cost of crossing installations and are demanding a more thorough assessment of a wider variety of river crossing options, particularly trenchless technologies. As a result, NGTL has recently enhanced the internal process by incorporating a structured decision tool. This tool is able to quantitatively assess technical risks as well as 'soft' influences such as "Regulatory Relationship" and "Delay in Approval". The result is a clear decision with the necessary buy-in, where all risks were identified quantitatively and well understood by decision makers.

INTRODUCTION

NOVA Gas Transmission Limited is a large natural gas pipeline owner and operator, transporting over 80% of the natural gas produced in Canada. To maintain system capacity to continue to meet growing customer needs, the mainline system requires expansion. Expanding the system has become more and more difficult in today's regulatory environment. Changes have occurred in both regulatory and public expectations for pipeline construction. The complications in construction arise from the attempt to minimize impacts on the environment without a large increase in installed pipeline costs. The challenge to achieve this balance becomes more complicated when facing major river crossings.

NGTL recently faced this challenge in designing seven looping portions of mainline throughout the Grande Prairie/Edson region of Alberta. These pipeline diameters range from 42 to 48 inches. Contained within these projects, were five major river crossings which posed challenges from both technical and environmental standpoints. In attempting to meet all design and regulatory requirements, many construction methods were considered. A dilemma resulted while attempting to choose the "optimum" construction technique. Lowest prime contract cost could no longer dictate the crossing choice as it had in the past. A decision method to balance costs, risks and environmental impacts was required.

The purpose of this paper is to explain to industry how NGTL successfully modified the regulatory approval process for the Edson/Grande Prairie mainline projects. This paper will first provide background regarding the broader issues related to this problem. Following this will be a brief discussion of the specific environmental concerns and the water crossing options that are available to pipeline designers. Next will be an overview of the steps involved in the regulatory application process which will be followed by a more detailed presentation of the Decision and Risk Analysis process. The paper will close by summarizing the challenges and benefits of the entire river crossing decision process.

BACKGROUND

Among the significant challenges facing the natural gas transmission industry is compliance with increasingly stringent environmental regulations where the goal is to minimize the life cycle cost of installation and operation of facilities. In many instances of pipeline permitting, the dialogue between the pipeline proponent and the regulatory authorities may be frustrated by one or more of the following issues:
- lack of baseline data quantifying the environmental impacts of pipeline construction and operations;
lack of a consensus as to a provincial and industry-wide process to assess impacts and the costs/benefits of various river crossing options;
- mismatch of project schedules based on seasons and regulatory process timelines, and;
- owner uncertainty about the construction timing for future facilities in light of an increasing competitive business setting.

To manage these challenges, prudent pipeline companies are resorting to project permitting and execution methods that were uncommon until recently. Several smaller projects, which may span several construction seasons, are being bundled and the permitting and execution of this bundle is being managed as a single, larger project. The benefit of such an approach is to provide the regulators with a more holistic view of the expansion plans and allow the company to lower the overall average construction cost by spreading these costs over several projects and several construction seasons.

TECHNICAL ISSUES

Environmental Issues

The primary concern when determining a water crossing methodology is minimizing impacts to fisheries resources. Balancing the mitigation of this impact (with associated regulatory concerns) against the pure economics of construction is problematic.

In a recent workshop on fisheries issues for pipeline water crossings (Goodchild and Metikosh, 1994), it was generally agreed that the effects on fisheries resources by water crossing activities could be categorized as:
1. increased sedimentation with resultant fish loss or habitat degradation;
2. flow disruption with resultant fish loss or habitat degradation; and
3. direct fish mortality (generally from blasting)

Water Crossing Procedures

The greatest potential for increased sedimentation occurs during in-stream trenching and backfilling operations when watercourse substrates and trench material are introduced into the water column. In recent years, procedures to isolate the channel within the right-of-way from active flows have been effectively used to reduce this impact and have become more accepted as standard pipeline construction. However, not all watercourses have median (or low) seasonal flows which are low enough (i.e., by flow volume and/or depth) to allow conventional isolation procedures (such as a flume or dam and bypass pump system).

Therefore, a company has to evaluate several crossing procedures for these large watercourses, which can not undergo a conventional procedure. For the Edson/Grande Prairie projects, there were a total of five watercourses to evaluate. NGTL assessed a total of 11 possible procedures which included several variations on standard open cut; several more specialized procedures which would allow for partial or complete isolation; and trenchless technologies including horizontal directional drilling and micro-tunnelling. During the watercourse assessment process, it was recognized that specific procedures may be more appropriate at certain crossings and all of the procedures have limitations that have to be identified and possibly quantified for a final decision.

Table 1 illustrates the numerous crossing procedures that NGTL evaluated for the water crossings and a discussion of the technical limitations.
Table 1: Identified Limitations Of Various Water Crossing Procedures

<table>
<thead>
<tr>
<th>Technique</th>
<th>Limitation(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Summer Open Cut</td>
<td>Causes downstream sedimentation in flowing watercourses particularly when using dragline procedures for trench excavation; May also be unsafe for construction personnel and potentially not feasible within the fisheries timing window due to water flow volumes, depths, and substrates.</td>
</tr>
<tr>
<td>Standard Winter Open Cut</td>
<td>Causes downstream sedimentation in flowing watercourses but considerably less sedimentation over a shorter distance than summer open cut.</td>
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<tr>
<td>Standard Winter Open Cut and Bypass Pump(s) (no dam)</td>
<td>One ten inch pump will move up to 0.3 m³/second; Should attempt to move a minimum of 50% of expected flow. Remaining flow across open cut operation will still cause downstream sedimentation. Pumps will be most effective in moving higher percentage of water during winter low flow period. Preventing pump interference is a major problem.</td>
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<tr>
<td>Conventional Isolated Trench (dam and bypass pump)</td>
<td>One ten inch pump will move up to 0.3 m³/second; Ten pumps is the approximate logistical limit for a single crossing due to size of pump heads, space requirements of diesel electric power units, and hose obstructions on the right-of-way. Preventing pump interference is a major problem.</td>
</tr>
<tr>
<td>Isolated Trench (Standard Pipe Flume)</td>
<td>One 48 inch flume pipe will move up to 1.8 m³/second. Multiple (i.e., 2) flumes may be feasible depending upon dam structure used and materials encountered underneath flumes which may cause excavation difficulties.</td>
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<tr>
<td>Isolated Trench - Hybrid (Dam and bypass pumps combined with pipe flume)</td>
<td>Hybrid combination of above procedures. Used in situations requiring a portion greater than a single or double flume pipe where pumps attempt to move the difference or where special work arrangements require it.</td>
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<tr>
<td>Special Isolated Work Areas (Coffer Dams)</td>
<td>Stabilizing dams and maintaining a dry work area are greatest concerns. Trenching inside cofferdams causes safety concerns due to water seepage and high potential for trench failure. Risk of downstream siltation.</td>
</tr>
<tr>
<td>Special Isolated Trench (Westcoast Energy Inc. Super Flume Unit)</td>
<td>One super flume unit will move up to 15-20 m³/second; Needs flexible damming to abut to edges of unit; Very significant amount of seepage underneath dams and flume unit; Very significant potential for downstream siltation due to seepage problems and resulting isolation failure.</td>
</tr>
<tr>
<td>Horizontal Road Bore</td>
<td>Limited to watercourses with flat approaches and relatively narrow channels (30-50 metres is common limit); Requires large staging bellholes be excavated on both sides of watercourse; Requires large pumps to pump out bellholes below water table; subject to failure with gross subsurface material variations (i.e.: unexpected rocks).</td>
</tr>
<tr>
<td>Horizontal Directional Drill</td>
<td>Limited to watercourses with extensive flat or very gradual approaches; Requires suitable geology. Gravels and cobbles common in many watercourse channels in Alberta cause loss of circulation and potential collapse of hole. Significant quantities of gravel introduce mud system risks potentially resulting in inadvertent returns to watercourse and/or sealing or damage to subsurface aquifiers and hyporheic flows which could alter waterflow into nearby overwintering fisheries habitat.</td>
</tr>
<tr>
<td>Micro-Tunnelling</td>
<td>Limited to watercourses with extensive flat or very gradual approaches; Requires large deep bellholes be dug on both sides of watercourse; Requires large wellpoint pumps to maintain dry bellholes and large catchment areas to handle groundwater removed by wellpointing system.</td>
</tr>
</tbody>
</table>

**REGULATORY APPLICATION PROCESS**

The objective of this process is to obtain regulatory approval for each of the five major river crossings. At the same time, NGTL is interested in selecting the lowest life cycle cost option to cross each river. In the past, these two objectives have conflicted because of the difficulties in quantifying the costs and risks of all the issues influencing these decisions. NGTL has recently enhanced the application process by the addition of a structured decision tool which is able to account for all technical and regulatory issues.
The selection and evaluation of pipeline routing involves a nine step process:

- Planning and Design Phase
- Preliminary Regulatory Consultation
- Review of Existing Corridors
- Development of Routes
- Environmental Data Collection
- Geophysical and Geotechnical Data Acquisition and Analysis
- Follow-up Regulatory Consultation
- Evaluation of Information and Procedures by Qualified Independent Consultant(s)
- Decision and Risk Analysis

Planning and Design Phase
In spring 1996, NGTL initiated a “pre-work” stage for all of the proposed pipeline segments. This was based on the premise of decoupling project design and planning stages from the potentially critical timeline of construction schedules; addressing regulatory concerns over ongoing difficulties in managing regional land use with short advance notice of new projects; allowing NGTL to collect the necessary field data well in advance; evaluating technologies and procedures; applying for and receiving regulatory permits well in advance; approaching contractors well in advance of construction in order to seek input into improving construction methods; configuring the contractor bid package to allow for maximum cost savings; and allowing the chosen contractor(s) to schedule equipment and manpower most efficiently during the proposed two year period.

Preliminary Regulatory Consultation
In spring 1996, four (4) regional meetings were held with Alberta Environmental Protection (AEP) personnel (including representatives from Land and Forest Services, Natural Resources Services, Water Resources Administration, and Land Reclamation Division) to introduce the project.

Review of Existing Pipeline Corridors
Using alignment sheets from existing NGTL pipelines within the corridors, all of the existing rights-of-way were reviewed in detail by aerial and ground reconnaissance in 1996. Watercourse crossings, including approach slopes, were reviewed on the ground and preliminary crossing methods were evaluated at that time.

Development of Routes
Because all of the proposed pipelines paralleled existing NGTL rights-of-way and NGTL had operating experience with these corridors, the preferred routes involved paralleling and sharing the existing right-of-way disturbance if feasible. This is also the generally preferred approach by provincial regulators for routing of new pipelines.

Environmental Data Collection
NGTL undertook fisheries assessments on each of the proposed pipeline projects in either fall 1994, spring 1995, fall 1995, or fall 1996. This data was used to identify watercourses encountered by the projects that have demonstrated fisheries value and, based on that information, to determine a suitable crossing procedure for each.

Geophysical and Geotechnical Data Acquisition and Analysis
Geotechnical data collection was undertaken at each of the major watercourse crossings (i.e., Smoky River, Wildhay River, Berland River, Athabasca River, North Saskatchewan River). The objective of this activity was to support the design and application for trenchless technology crossing options. The data collection stage included the use of borehole sampling and some ground penetrating radar or seismic.

In conjunction with this data collection phase, NGTL undertook preliminary flow volume modelling (based on available upstream and downstream historical stream flow data) to estimate high, median, and low flows at the proposed crossing sites during the January-March and July-August periods.

Follow-up Regulatory Consultation
In December 1996, two (2) additional regional meetings were held with Alberta Environmental Protection (AEP) personnel (including representatives from Land and Forest Services, Natural Resources Services, Water Resources Administration, and Land Reclamation Division) to update representatives on the projects. The focus of the meetings was to review the design results along with proposed construction methods and schedule.

Evaluation of Information and Procedures by Qualified Independent Consultant(s)
In January 1997, NGTL approached two qualified consulting firms experienced in trenchless technologies and asked them to independently review the five larger water crossings to determine which crossing procedures were deemed technically feasible.

Decision and Risk Analysis
In February 1997, NGTL undertook a Decision and Risk Analysis to determine the “best overall procedure” to cross the five (5) largest watercourses based on all of the information collected to date and the uncertainty and risk associated with each option.

DECISION AND RISK ANALYSIS
The decision analysis for the Edson/Grande Prairie river crossing assessment adopted the methodology of the D&RA process. This tool provides a systematic process for decision-making, consisting of five major steps. The D&RA process clearly defines the problem, develops a number of alternative
solutions which take into account uncertainty of outcomes, and quantitatively assesses the risk of the various alternatives.

A schematic of the process showing the five major steps is shown in Figure 1.

NGTL has adopted the D&RA process for a wide spectrum of decisions from the operational level to strategic decisions impacting the business direction of the company. Details of NGTL projects which have used D&RA are contained in Craig, 1996 and O'Neil and Trigg, 1997. The application of D&RA in the current river-crossing project was particularly valuable because a decision on each of the five crossings was made within only four days of commencing the decision analysis process.

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The decision on the North Saskatchewan River crossing included variations on WOC and SOC strategies. These were strategies which included consideration of the cost of the entire pipeline segment, not just the river crossing. These are abbreviated WOC-PL and SOC-PL, respectively.

The Influence Diagram for the river crossing assessment, a pictorial representation of the decision, is shown in Figure 2;
The influence diagram is simplified by only considering those uncertainties which result in different values for different river crossing strategies.

**Analysis**

In the analysis step of D&RA, a crossing strategy is chosen based on that which is calculated to return the highest NPV to NOVA. Net Present Value simply represents the sum of a series of cash flows which have been discounted from the future to reflect a common dollar value (i.e., 1998 Canadian dollars); this type of analysis is consistent with choosing the lowest life cycle cost option. The discount rate used is either the weighted average cost of capital or one assigned by company policy to reflect the required return on investments. In this project, the stream of cash flows was estimated over 35 years, this being the estimated life of a typical pipeline.

In general, the analysis phase involves four key activities: each uncertainty is assigned probabilistic outcomes based on expert assessment; a financial model is constructed based on the Influence Diagram; the risks/reward profile is understood; and a decision is made. The following discussion focuses on the assessment of risk and the decision-making step.

Simply stated, risk is the chance of a loss. In the analysis phase both the 'chance' and the 'loss' are estimated with a sensitivity analysis. This uses the probabilistic 10-50-90 expert interview inputs to assess the impact of the range developed for each uncertainty on Net Present Value (NPV). An example of a result from this sensitivity analysis, using only the SOC-PL strategy for the North Saskatchewan River crossing, is shown in Figure 3.
In Figure 3 the horizontal line represents the 35-year NPV calculated when all uncertainties (shown on the horizontal axis) are set at their median values. To create the vertical lines for a single uncertainty, all other uncertainties are held at median values and 35-year NPV is calculated using the '10' and '90' values for the one uncertainty. This process is repeated until vertical lines are created for all uncertainties. The lengths of the vertical lines are an expression of the magnitude of uncertainty associated with this strategy.

In order to differentiate between options (i.e., make a decision) and to assess the risk of the preferred option, the results of the sensitivity analysis for each crossing option must be considered simultaneously. This is shown in Figure 4 for the North Saskatchewan River crossing, it what is known as a 'tornado diagram'.
If decisions were made based on the lowest median cost, then the decision would be to select the SOC-PL strategy for the North Saskatchewan River example. However, this would ignore the risk of uncertainty in this and other strategies. In decision-making the risk is in making the wrong decision and incurring higher costs than necessary or expected. The tornado diagram illustrated in Figure 4 allows this risk factor to be quantitatively assessed. The process to confirm that the above noted SOC-PL strategy is indeed the least-cost approach is to compare, for each uncertainty, the ‘10’ and ‘90’ NPV values at each strategy and determine at these end-points which strategy attracts the least cost. This outlines which variables are critical; i.e., for which uncertainties would the decision change if costs were driven to the ‘10’ or ‘90’ values of that uncertainty. Without a structured decision analysis process such as D&RA, the quantification of risk would not be possible.

For the North Saskatchewan River crossing, there were no critical variables. For all uncertainties, the SOC-PL strategy is the least cost at the ‘10’, ‘50’ and ‘90’ NPV values. In other words, there are no identifiable, significant risks associated with the selection of this option. The analysis also identified those uncertainties which have little or no influence on the decision. In the North Saskatchewan River example (Figure 4), “Reclamation Costs” and both uncertainties contributing to O&M costs, “No. of Repairs Required” and “Cost per Repair”, show little or no variation in NPV from the ‘10’ and ‘90’ values input.

Connection

The connection phase develops a ‘bridge’ between the decision and implementation. To manage those risks identified in the analysis, action plans are developed during Connection to monitor the critical uncertainties and to react should the magnitude of these uncertainties approach the ‘10’ or ‘90’ estimates of the experts. In the case of the North Saskatchewan River crossing, no critical uncertainties were identified and the risk of experiencing cost levels which would change the decision is low. In spite of this, it makes sense to track those uncertainties, such as “Regulatory Relationship Costs”, where ‘10’ and/or ‘90’ values for the SOC-PL option are close to overlapping those of the next lowest cost option, WOC-PL.

SUMMARY

By incorporating the D&RA approach into the regulatory approval process, NGTL was able to enhance the regulatory application for the primary construction techniques and fallback procedures proposed for the five major water crossings. These construction methods were included in both the Conservation and Reclamation application as well as Water Resources permit application. The decision tool was also presented and explained to Alberta Environment in these applications. The regulators acknowledged the significant value in considering all possible crossing techniques and all major issues associated with each technique. NGTL was also able to use the results to provide a basis for discussion regarding the risks associated with each technique.

Some of the benefits of the D&RA decision tool are: the method clearly shows which influences have the greatest effect on the net present value of the decision; the documentation can be utilized to show how any one particular technique may be very attractive when only looking at one influence, e.g., environmental impact, but may not be the best choice when evaluating all influences; the decision process considers all issues and quantifies the possible outcomes for the extreme cases (i.e.: best and worst case), and, the D&RA method provides quick results. For the Edson/Grande Prairie river crossing assessment, a final decision was available for validation within four days. For decisions of this magnitude, the timeframe exceeded expectations.

The biggest challenge in using this process is the communication of the procedure and of the results. This is a decision tool that uses a different way of thinking to make decisions which is new to many. As such the written explanation of all the details in the framing and analysis stages may be difficult to understand. In particular, the format of the tornado diagram is often unfamiliar and can require a large amount of discussion to ensure the proper interpretation of the results is understood by decision makers.

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REFERENCES

