14 River and Stream Crossings

The crucial importance of stream crossings from social, environmental and technical points of view was highlighted by expert and lay witnesses throughout the Inquiry hearings. I was told that several technically favourable sites proposed for crossings are a threat to fish, are near areas traditionally used by local people, are near some important archaeological sites or would disturb local environmental or socio-economic values.

To a great extent, the choice of the pipeline route will be governed by the location of favourable (or least unfavourable) stream crossing sites. The objectives in selecting a stream crossing site are similar to those of route selection that I have described earlier, namely to choose a safe and economical pipeline route that will have minimal social and environmental impact. However, the technical considerations involved in the selection of sites for river crossings are different from those that involve the rest of the route. The main technical points that I have heard about include the stability of the valley wall, of river bank slopes, and of the river bed, water levels, floods, scour depth, and river ice phenomena. And, as I have said in Volume One and in the chapter on The Physical Environment, river valleys are not only important to fish populations, and to fish harvesting, they are also biologically more productive than the surrounding terrain. The social importance of river crossings is evident from the native peoples' traditionally high dependence on fishing, on trapping beaver, muskrat and other aquatic furbearers, and on rivers for travel routes.

The choice of sites for river crossings must be made with regard to severe technical constraints as well as many important environmental and socio-economic concerns. The possibility of conflict in such choices is great, and these choices will be among the most troublesome along the entire route.

1. A special review process for the selection of sites for river crossings and their design, construction and monitoring should be established within the framework of the Agency.

The design of river crossings is not regulated by a specific design code, and the general pipeline design code, Canadian Standards Association (CSA) code Z-184-1975, does not touch upon the hydrological aspects of crossing design. It is obvious from the evidence that considerable controversy exists concerning these hydrological design criteria. For example, some of the criteria proposed by the pipeline companies differ significantly from those imposed on the trans-Alaska pipeline, and I have heard vigorous objections to the imposition of the stringent criteria used in Alaska. There is, however, general agreement that specific hydrological design criteria can be and should be drawn up.

2. A design and construction code dealing with the engineering, environmental and local land use criteria for stream crossings should be developed immediately in consultation with the Company.

Development of this code will involve experts from widely differing backgrounds. Geotechnical and pipeline engineers will provide the detailed project requirements; biologists and land use specialists will underline the issues that relate to the physical and living environment. A useful starting point in this task will be the hydrological information contained in the evidence, cross-examination and final arguments before this Inquiry. Commission Counsel's final argument is particularly useful. Therefore, I present below a compendium of the information available to me under five main headings: definitions, design flows and levels, design criteria, construction, and monitoring. Before these guidelines are incorporated into a code, they should be reviewed and expanded by the broadly based group of experts I have just mentioned.

Definitions

Fundamental to any discussion — particularly one involving several disciplines — is a common understanding of technical terms. It became apparent early in the discussion of river and stream crossings at the Inquiry that there were different understandings of basic terminology. Furthermore, in the technical literature the use of certain terms related to hydrology and fluvial land forms is not consistent. To provide clear regulations, some clarification of these terms is required. I have, therefore, assembled definitions of the fluvial terms that are used in this report and I present them here – although some of them are used mainly in connection with matters other than stream crossings.

Watercourses

Strictly speaking, any identifiable trace of concentrated run-off water can be called a stream. Pipeline construction, however, involves at least four levels of effort in crossing streams, and it is useful to tie regulations to these four levels. The Company should not, of course, be in a position to define these four classifications for regulatory purposes.

At the lowest level, there are small intermittent drainage courses, which require the provision of berm breaks. However,these drainage courses do not involve the pipe itself and they are, therefore, considered to be problems of drainage and erosion control. The remaining three levels involve some type of stream-crossing design. The second level comprises small streams for which ordinary crossing designs should be adequate. Crossings of streams in the third level are likely to require site-specific designs and procedures. All crossings within the first three levels are usually carried out as part of the main pipeline construction by the spread contractor. The fourth level comprises the large streams: these crossings may be built under separate contract and possibly before the main pipeline itself is laid in that area.

The reason for classifying streams along the proposed route is to ensure that the Company will undertake appropriate hydrological and biological studies and will evolve design and construction procedures that do not damage the stream. The definitions presented below are intended to serve as a basis for specifying the extent of the studies that will have to be undertaken before a stream is approached and the procedures that will have to be followed to obtain a permit to proceed with construction across it.

3. *The Company and the Agency should use the following definitions of watercourses in river engineering design.*

Watercourse: *a comprehensive term for any identifiable trace made by concentrated run-off water on the earth's surface.*

Drainage course: *any watercourse smaller than a stream (as defined below) for which drainage and erosion control procedures are obviously necessary, but which do not require hydrological or biological work beyond initial identification through mapping and field work.*

Stream (*also* river *or* creek): *any watercourse that seasonally offers habitat suitable for fish or that has an average width of channel greater than three feet or that carries perennial flows of water in excess of 0.05 cubic feet per second or that has a drainage basin greater than one square mile. For pipeline construction purposes, streams require hydrological and biological study. The groups of* designated streams *and* designated major rivers *are introduced to subdivide further the streams and rivers.*

Designated stream (*also* designated river): *any stream or river for which site-specific crossing designs and procedures are required by the Agency. The following streams will be included in this category: streams with drainage areas greater than 10 square miles; streams with the potential for significant channel shift and scour at the crossing site; streams that support significant fish populations at some time of the year near the crossing site; and streams the crossing of which may involve significant technical or environmental hazards.*

Designated major river: *any river that will probably be crossed under a separate construction contract or that will be crossed at a time significantly different from the main pipeline construction there. This category includes Great Bear River, Peel River and Mackenzie River.*

4. *Before the submission of the preliminary river crossing design, the Agency (in consultation with the Company) should prepare a complete listing of all designated streams and all designated major rivers to serve as a reference in design review.*

Fluvial Landforms

5. *The Company and the Agency should use the following definitions of valley components in river engineering planning.*

Stream channel zone (*also* river channel zone): *it is generally the smaller of the following two areas: the area between the top of distinct stream banks or between distinct trim-lines of forest or tundra vegetation; or the area of the stream channel that is covered by flowing water at least once in two years over a long-term average. In the case of braided streams, which are characterized by multiple, laterally unstable channels, the channel zone includes the entire braided zone.*

Flood plain: *a low-lying area adjoining a stream channel that is underlain by alluvial (river-deposited) materials and subject to flooding at least once in 100 years over a long-term average.*

Terrace: *an area that was a flood plain at some earlier period in geological time but that is now relatively higher than the stream and therefore not subject to flooding or that is subject to only very infrequent and minor flooding.*

Design Flows and Levels

A basic consideration for the design of a project related to a natural waterbody is the establishment of the worst conditions that the project will have to withstand over its useful life. Except in the case of major civil works, such as large dams or dyking projects, the worst conditions that are assumed are always well below the worst field conditions that can be expected to occur. This fact implies that some risk is accepted. Generally speaking, there are three aspects to such risk: cost, safety and environment.

The Company will handle problems related to cost, but it is widely accepted that the Agency should state the general criteria regarding safety and environment. The primary reason for presenting engineering evidence before the Inquiry was to discuss the environmental consequences of any failure of the pipeline and subsequent repair operations. In setting the criteria for risk, we must remember that the stiffer the criteria, the larger the engineering structure is likely to be and the greater the initial impact on the environment. In the long run, it may be environmentally preferable to accept the risk of occasional failures in return for less initial disturbance. The converse could also be true, depending on the magnitude of the initial disturbance and the cumulative disturbance associated with maintenance and repair.

In any event, one of the basic determinations to be made is the design flow at pipeline-crossing sites. Other flow criteria to be determined include the maximum flows to be expected during the period when the crossing is to be built, design flows for road crossings (culverts or bridges), design flows for gravel mining in channel zones and on flood plains, and drainage design flows. In situations that may involve severe ice jams, fluctuating lake levels, and tides or storm surges in coastal areas, water levels rather than flows will have to be evaluated.

To ensure conservative design and to reduce potentially adverse environmental impact, there must be uniform design flow and design level criteria. However, there is little information about streamflow and water levels from the northern part of the region the pipeline will cross. Meteorological observations are more abundant, so it seems reasonable to adopt a meteorologically based design flood criterion (standard project flood).

6. *Pipeline crossings of all designated rivers shall be designed to withstand standard project flood conditions. The standard project flood is a stream flow estimate based on the assumption that the most severe storm or other meteorological condition that may reasonably be considered as characteristic of the specific region is occurring (Beard, 1975). The largest flood that is considered physically possible, if all flood-producing factors were to combine, is the probable maximum flood. It is roughly twice the standard project flood under normal circumstances.*

7. *Design water levels that take into account ice jamming, storm surges or any other meteorological or hydrological phenomena affecting the design of the designated stream crossings shall be at least as conservative as the standard project flood. The most severe meteorological or hydrological conditions that may reasonably be considered as characteristic of the general region have to be assumed in determining such design levels, and this estimate is generally achieved by imagining that the most severe conditions ever observed anywhere in the region may possibly occur at the site of interest.*

8. *Design flows and levels for all other (that is, non-designated) stream crossings shall be selected so that they bear the same degree of risk as the standard project flood; however, in these cases individual standard project floods do not need to be determined.*

9. *Permanent stream crossings by access roads shall be designed to withstand a 1-in-50 year condition of flow or water levels. Temporary facilities, such as work pads in rivers, perimeter dykes of gravel-mining operations in channel zones, and coffer-dams are to be designed on the basis of the probability of levels that are appropriate to the work in question, bearing in mind the siting, timing and anticipated life of the structure concerned.*

Return periods, such as the 1-in-50 years floods may be difficult to determine accurately with the data that is at present available, but the intention here is that these return periods should be used as rough guides in applying engineering judgment. The design flows for culverts along the Mackenzie Highway, for example, are based on 50-year flood return periods besides having to meet several requirements for the passage of fish, that are often more stringent. With time, the data base for final design will be much better, and the specified return periods can then be evaluated more precisely.

10. *In addition to design flow specifications, structures shall also meet hydraulic criteria for fish passage. (See Fish.)*

11. *Before the final design phase, the Company shall submit to the Agency the supporting data and computations that have been used to determine design flows and levels.*

Design Criteria

Generally, the design for a river crossing incorporates criteria for avoiding or reducing environmental impact. These criteria should be adjusted to reduce the possibility of a failure of the crossing, for that would lead to environmental disruptions and to the need for emergency repairs. The criteria I propose below are related to the location of crossings, location of sag bends, river training works, groundwater flow, overhead crossings, buoyancy control, scour computations, and dual crossings. All of what is said below about these criteria is intended to serve as the basis for discussion among the parties concerned.

Location of Crossings

Some of the most difficult geotechnical problems in pipeline design are caused by stream crossings and, to a considerable degree, the alignment of the right-of-way is governed by the availability of suitable sites for stream crossings. An associated problem, which I discuss in the chapter entitled Geotechnical Considerations, is to maintain the stability of river banks or valley wall slopes. Other problems that I deal with here are more directly related to rivers.

12. *In the selection of sites for crossing rivers and river valleys, sites that are unsuitable for technical, environmental or land use reasons shall be avoided. The selection of these sites should precede final selection of the pipeline route.*

13. *Crossings shall be carefully sited in reaches of rivers in which the stream flow is reasonably stable and straight. Crossings of flood plains and channel zones shall be as short as practicable.*

14. *A site-by-site evaluation shall be undertaken to determine the approach to be adopted at sites where highway and pipeline crossings are close together. Safety, aesthetics and geotechnical problems tend to favour wide separation but, in some locations, close spacing could minimize the impact of these crossings on fisheries and facilitate future maintenance.*

Location of Sag Bends

A buried pipeline that must cross an obstacle, such as a river or a valley, is designed with what the industry calls overbends and sag bends to permit the pipe to run under the obstacle. A typical river crossing involves two of each: the first overbend directs the pipe from the horizontal down the slope of the river bank, then a sag bend enables the pipe to pass horizontally under the obstacle, the second sag bend turns the pipe up the bank, and the second overbend enables the pipe to continue horizontally, as before.

If a river to be crossed flows in a single, well-defined and stable channel, the sag bends are located a relatively short distance landward of the river banks, thus allowing for minor bank erosion and channel shifts during the life of the pipeline. But the problem is not so easily solved when crossing wide, braided channels or channels that migrate at significant rates across a flood plain. There the designer has two options: he can either locate the sag bends outside the present and potential future channel zone, burying the pipeline deeply all across these channel zones, or he can squeeze the channel zone with river training works and build only a short river crossing. The environmental effects of the two alternatives differ because the first involves considerably more initial work, but less permanent interference with the river, than the second. From an environmental point of view, the first alternative – placing the sag bends well outside the present or any future channel zone – is usually preferable because it reduces the risk of having to undertake major repair or maintenance work.

15. *The sag bends of all designated stream crossings shall be located far enough beyond the channel zone to ensure that they will still be a safe distance outside the channel zone after 50 years of natural, unimpeded migration of the channel zone. The Agency may waive this requirement if deep burial beyond the channel zone will do more damage than the construction of the river training works that will be needed to avoid deep burial, if channel zone migration cannot be predicted, or if it would be economically unreasonable.*

River Training Works

River training works are structures that are used in a variety of circumstances to alter the direction of river flow or to contain it within a particular location. For instance, by the use of river training works, the channel zone of a river can be narrowed to reduce permanently the length of river crossings, or it can be confined temporarily to make room for a borrow operation in the channel zone. River training works can also be used to arrest the normal process of the migration of channel meanders to provide a stable river-crossing site, and they can be built on the flood plain to prevent future meander cut-offs or other channel changes.

Besides the aesthetic considerations involved in despoiling a natural river, training works may interfere considerably with a river by obstructing the passage of fish or causing siltation. Moreover, they require continual maintenance, and many of them can fail, thereby magnifying detrimental environmental effects.

16. *Permanent river training works in the channel zone shall be avoided wherever practicable. Where training works are necessary to prevent a river from flowing along the right-of-way of the pipeline or from entering a gravel pit on the flood plain, or to prevent cut-offs or avulsions, they shall be located on flood plains rather than in channel zones.*

Groundwater Flow

There is a certain amount of groundwater flow in the materials below most rivers and their flood plains. The quantity of water involved is normally very small compared with the river flow but, in the case of rivers that have little or no flow during certain parts of the year, it may have biological significance. In many parts of the North, rivers freeze to the bottom in shallow places, thus severely restricting or stopping normal channel flow. Under such circumstances, groundwater flow may maintain pools of water in the deep parts of the river or it may emerge as springs at certain locations along the channel. These groundwater-fed areas can be crucial for overwintering fish and eggs (see Fish). If a chilled gas pipeline is buried in alluvial materials, the groundwater flow needs to be maintained.

The effects on groundwater of various construction techniques for crossing rivers and the possibility of obstruction by a frost bulb below a stream are matters for serious concern (see Geotechnical Considerations). These problems are not yet adequately understood. Whether or not there may be a problem with the groundwater flow at a river crossing cannot be known definitely without site-specific knowledge of river and groundwater flow during winter over a number of years, the aquatic ecosystem, and the design for the crossing. This same detailed knowledge is also necessary before mitigative measures can be prepared.

17. *Design proposals for all designated stream crossings (and for any other crossings as required by the Agency) shall be accompanied by conclusive evidence that the maintenance of winter groundwater flow in the general area of the crossing is not of environmental importance or that the maintenance of such flow is of environmental importance but that the installation of a crossing without special mitigative measures will not have adverse environmental effects. Where special protection measures are known to be needed or where there is no conclusive demonstration that they are not needed, the crossing design shall incorporate measures that ensure continued winter groundwater and channel flow across the installation to provide adequate protection for fish populations and the aquatic ecosystem that supports them.*

18. *The Company shall build a test stream crossing at a typical site that has little or no winter channel flow but that does have significant groundwater flow. This test installation should show that the structures can be installed without significantly increasing the environmental impact of the construction process. The test shall demonstrate the effectiveness of the crossing design to maintain a flow of water around the pipeline to points downstream similar to the flow that would occur naturally; normal physical characteristics of water quality, such as suspended sediment, dissolved oxygen, and temperature; normal chemical characteristics of water quality, such as pH, conductivity and colour; and normal invertebrate and fish communities including eggs in the overwintering areas downstream from the crossing.*

Overhead Crossings

Generally speaking, pipeline designers are reluctant to use overhead crossings – even though they provide a technically feasible alternative for crossing most streams – because they introduce construction and maintenance problems that are quite different from those found along the rest of the buried line. Overhead crossings are not part of either of the pipeline companies' proposals for the main pipeline. Nonetheless, there are at least four reasons why they may be environmentally preferable to buried crossings at certain sites. Such structures would avoid the problems of slope stability and erosion in narrow, deep valleys, difficult scour problems in rivers, frost bulbs that might interfere with groundwater flow, and frost heave.

19. *Where preliminary design review indicates that a buried crossing would involve major unresolved environmental concerns, the Agency should instruct the Company to prepare a comparison of the buried crossing with an overhead crossing and to justify its choice of the mode of crossing in both engineering and environmental terms.*

Buoyancy Control

Buoyancy control at river crossings involves standard procedures that are not expected to cause direct environmental concern. However, if the techniques used to control buoyancy prove inadequate – a concern of particular importance with regard to the periodically innundated flood plain – then the pipe will float and will have to be repaired. If these repairs are necessary in sensitive locations or at sensitive times, then the possibility of environmental damage is greatly increased.

20. *Buoyancy control weights shall be required at river crossings for the entire length of pipe that, under design flow conditions, would be submerged.*

Another buoyancy control problem, although not one that exclusively concerns river crossings, is the tendency of saddle weights (concrete blocks that straddle the pipe) to slip off. This slippage may be caused by their having been incorrectly installed, but the problem seems to be particularly acute in muskeg areas, where there is insufficient lateral resistance in the soil to keep the weights stable over the pipe.

21. *Where weights are used for buoyancy control, techniques shall be used to ensure that the weights will not slip off the pipe. Where saddle weights are used, the Company shall demonstrate to the satisfaction of the Agency that the construction procedures used will ensure proper centring of the weights and that, after backfilling, the soils will have* *sufficient lateral resistance to prevent movement of the weights.*

Scour Computations

A considerable amount of evidence was presented to the Inquiry about the unusual and poorly understood phenomenon of the scouring of river beds by ice along the proposed pipeline routes. Scouring occurs under massive ice jams, such as those observed upstream from Point Separation on the Mackenzie River. Related problems include the migration of very deep and not well-understood scour holes that occur in the Mackenzie Delta and scouring associated with spring run-off that flows over and beneath icings. In addition to scouring by run-off, up-ended cakes of ice can scour or gouge the river bed during the break-up period. These kinds of scouring could threaten the integrity of the pipe and cause engineering problems that would have significant environmental consequences.

22. *At the request of the Agency, the Company shall submit the data and computations it has used to calculate scour and the general degradation of the river bed at stream crossings. In general, the security of all crossings shall be assured to a level of risk comparable to that of the standard project design flood.*

Dual Crossings

At certain times of the year, such as at freeze-up and break-up and during spring flood, it would be impossible to repair pipeline failures at some of the larger rivers. These are, however, the times at which failures are most likely to occur, because then various fluvial processes, such as scouring and bank erosion, are most active.

Although Arctic Gas proposed dual crossings for economic reasons, they may also have an environmental advantage: with dual crossings, repairs in the river or on river banks would not need to be done on an immediate or contingency basis, but they could be scheduled in an orderly way, and due allowance made for environmental protection. Of course, the chance of major environmental degradation caused by emergency repairs at an unsuitable time at any particular single crossing has to be weighed against the detrimental effect of building two pipelines there rather than just one.

23. *The Company, in submitting preliminary designs to the Agency for each designated major river crossing, shall explain the reasons, including environmental considerations, that were involved in deciding whether to use a single or a dual crossing. The Agency may extend this requirement to crossings of other large rivers. The preliminary design for any dual crossing shall include the approaches to it as well as the crossing itself.*

24. *If the project involves long sections of dual pipeline, an adequate number of cross-overs or connections between the two pipes should be installed during construction to increase flexibility in the scheduling of repairs.*

Construction

The problems that are encountered in carrying a buried pipeline under rivers and the techniques used to overcome these problems set the construction of stream crossings distinctly apart from the rest of the pipeline construction. Although river crossings amount to only a small fraction of total pipeline construction, they are a major factor in terms of potential environmental impact.

Timing of Construction

Most of the pipeline will be built during winter, but the construction of the major river crossings is scheduled for summer. In permafrost areas with ice-rich soils, summer construction activities on the approaches to the river crossings could cause problems of terrain instability, erosion and siltation.

The construction of a large river crossing, whether in summer or winter, involves a fairly rigid sequence of different activities, of which the most important are discussed in subsequent sections. These engineering requirements must also be scheduled to accommodate seasons of environmental sensitivity and of land use activity by local people. My concern is that, even with the best of intentions on the part of the Company, unforeseen delays, which are common in any level of construction, combined with very rigid overall deadlines, could disrupt any schedule that was organized, in the first place, to take environmental considerations into account. Unforeseen delays are even more likely in the North than in more temperate latitudes.

25. *The Company shall prepare detailed schedules for all construction work associated with crossings of designated streams and shall submit evidence to show that the schedule is realistic and contains adequate allowances for contingencies. In particular, the Company shall show that the proposed schedule for construction and its logistics does not unduly interfere with significant biological resources or with traditional hunting and fishing activities.*

26. *On request from the Agency, the Company shall draw up construction plans for the crossing of selected designated streams at times other than in winter, and it shall evaluate these plans for feasibility, cost and environmental impact. These plans shall be implemented if so requested by the Agency.*

27. *Summer construction of river training works shall be avoided unless all necessary materials and equipment can be brought to the site without damage to sensitive terrain.*

28. *The work pads and approaches to river crossings to be* *constructed during summer shall be built in winter unless the Company can demonstrate that summer construction is more desirable at a particular site.*

Installation of the Pipe

The various methods of installing a pipeline below a stream bed give rise to a number of closely related concerns. Easiest to cross are streams that dry up during winter, particularly if the excavation for the pipe ditch does not encounter taliks (unfrozen zones) below the channel. Such crossings can be carried out as part of the normal pipe-laying procedure. However, if the ditch intersects taliks, they will complicate construction. Any excavation through them will fill with water, which will then freeze rapidly.

In the chapter on Fish, I have outlined the environmental problems that are involved in winter crossings of streams that carry limited flows and contain overwintering fish or eggs. It may be impossible to predict which streams will be flowing, particularly because there may be marked differences from year to year. Nevertheless, crossings must be installed without interrupting stream flow and without damaging downstream reaches of the river by increased sedimentation.

29. *The Company shall endeavour to make or have available periodic observations of winter flow over at least two years for all designated stream crossings before the completion of final design.*

30. *To minimize the adverse effects of sedimentation and the interruption of stream and groundwater flow, the time between the excavation of the ditch and backfilling it shall be kept to a minimum.*

31. *All winter construction across watercourses that contain overwintering fish or that have fall spawning areas downstream, which could possibly be affected by the construction, is to be done under dry conditions. These conditions may be achieved by waiting for the stream to dry up, by diverting the stream, or by staging construction through the use of coffer-dams. Water flow, including flow through the gravel under the stream bed, shall be maintained to any areas where there are fish or eggs overwintering, and siltation shall be controlled to the levels outlined in the chapter on Fish.*

Much of the material excavated from the ditches at stream crossings will be used as backfill, but any material that is left over must be disposed of in a manner that does not interfere with the stream. The proposed summer crossings of large rivers may create problems of spoil disposal. The excavation by dredge that has been proposed for crossing large channels will primarily involve the removal of sand and silt. The discharge of these materials into the river downstream leads to two basic concerns: an increase in the sediment load of the river and obstruction of the river. The excavation of a ditch by dragline provides much less flexibility in the disposal of spoil than dredging, and the obstruction of the river channel by this method could be a concern. Spoil from both dragline and dredge operations can be disposed of on land or by barging it to suitable dump sites. Selection of the method to be used should involve a careful review of local environmental factors.

32. *Ditch plugs shall be left in place on both sides of a stream crossing until the last possible moment to ensure that little or no flow from the ditch can enter the stream and that no stream flow can enter the ditch.*

33. *The interference with aquifers below channels that are dry in winter shall be minimized. In particular, the Company shall avoid plugging aquifers with silt or contaminating the groundwater in a significant way. The construction time of crossings that might interfere with such aquifers shall be made as short as possible.*

34. *The ditch across the stream shall be backfilled with material from the channel bed unless otherwise approved by the Agency.*

35. *As part of the planning for crossings to be built in summer and for any other crossings that are not built in dry conditions, the Company shall, at the request of the Agency, evaluate alternative schemes for excavation and spoil disposal from an engineering and environmental point of view. If it is proposed to dispose of spoil in the river channel, the Company must show that such disposal will not increase the channel velocity enough to interfere with navigation or with fish migration and that it will not lead to an increase in suspended sediment that may be hazardous to fish. (See Fish.)*

36. *Blasting should conform to the recommendations listed in the chapter on Fish: Underwater Blasting and in Terrain Considerations: Blasting.*

Work Pads and Berms in Channel Zones

At rivers to be crossed in summer, the pipe should be assembled into segments of several hundred feet on a work pad, then pulled across the river. This operation can be done in stages, depending on the size of the work pad and on the width of the crossing. Depending on the topography of the valley, the work pad may be built on a flood plain beside the channel, which is the preferred location, but it may have to be built in the channel zone itself, where it might interfere with stream flow or might get washed away during a flood. If the river erodes part of a work pad, it may cause siltation problems that may be more or less serious, depending on the materials that have been used in constructing the work pad.

Similar problems can arise if the channel or parts of it are dyked off by a coffer-dam to permit pipe laying in dry conditions. An obstruction in the channel will increase the velocity and erosive power of the remaining flow, which could interfere directly with navigation or with fish migration, and it could also cause erosion of the channel bed and of the banks.

37. The size of work pads or of the dyked areas in the channel shall be limited at any one time so they will not interfere with navigation or with fish migration and will not cause significant erosion at the design flood condition.

38. In general, a work pad or a dyked area should not occupy more than two-fifths of the width of the channel zone.

39. Any borrow or spoil materials that are left in the river after the removal of a work pad and any other materials that the river may erode shall not alter the morphology of the channel, bank or river bed in a way that may be detrimental to fish or wildlife or to any other use of the watercourse.

Sedimentation

Many of the concerns related to fish and fisheries have to do with the possibly harmful introduction of sediment into streams. The effects of suspended sediment on stream biota are complex and by no means fully understood. It is, therefore, difficult to state in simple terms what may be harmful to fish and what may not. Whether or not a certain sediment concentration is harmful depends on where and when it occurs. The introduction of fine sediments (silt and sand) into a stream is, however, likely to be harmful – certainly it will not be beneficial – so it should be avoided so far as practicable.

If concentrations of suspended sediment are kept within the natural range typical for the stream site, the time of the year, and the prevailing discharge, no harmful effects are likely to result. Discharge is particularly important because naturally high concentrations of sediment are associated with flood discharges that rapidly wash the sediment down the channel without significant deposition. A similarly high concentration of sediment during a period of normal or low discharge would settle out on the stream bed with environmentally unacceptable consequences.

Many of the recommendations in this section and in other sections of this report that deal with river crossings have the control of sedimentation as their main objective. Further recommendations relating to suspended sediment occur throughout the chapter on Fish.

Restoration of River Beds and Banks

The ditch across a stream channel is normally backfilled with the materials that were previously excavated from it. If the backfill is made to correspond roughly to the original shape of the stream bed, the stream will regrade its bed during the next flood. There is little potential here for significant long-term effects, apart from the initial impacts caused by construction work, which I have discussed above. Fills placed on top of streambeds for work pads, ramps and so forth, must be removed, but their removal generally has little potential for long-term effects on the environment as long as the work is done properly.

The restoration of river banks may have effects in the longer term. Poor restoration is unaesthetic and it could lead to slides of earth into the river and associated siltation, or the river might break through a cut bank to find a new course. Rivers with broad flood plains and river channels in deltas are normally contained by natural levees. Such levees tend to be very resistant to erosion and are rarely breached by flood flows, although they may be frequently submerged. All of the distributaries in the Mackenzie Delta have such levees associated with them and it is particularly important that they be properly restored at all pipeline crossings.

If the river bank material is ice-rich, a cut into it that is left exposed could initiate a lengthy cycle of thaw erosion. The proposed method for dealing with such cuts is to backfill them with native material, then to blanket them with select backfill to prevent gullying and thaw erosion. If the installation of the river crossing has reduced the resistance of the river bank to erosion, riprap or other measures to control bank erosion, such as gabions and spurs, must be used. My concerns for these problems have been discussed above under the heading River Training Works. The pipeline will frequently approach streams through a cut in the bank, and the cut will naturally attract run-off water. Many river banks are too steep to be restored to their original shape and, unless properly protected, these cuts will develop into deeply scoured gullies and the pipe may become exposed. The Kotaneelee River crossing of the Pointed Mountain pipeline, in the southwestern part of the Northwest Territories, was cited at the Inquiry as an example of this sequence of events.

The danger of erosion to steep river banks and valley walls is one of the most important and most frequently stated environmental concerns related to the proposed pipeline project. The means of preventing such erosion are well-known: they include granular backfills and blankets, insulation, revegetation, and diversion of storm run-off away from the pipeline right-of-way (see Terrain Considerations: Drainage and Erosion Control). These measures are relatively expensive and they are not, therefore, always applied. The problems at river banks are not intrinsically different from those on any other slope.

40. On the completion of pipeline construction across a stream, the stream bed must be restored to its original shape using native or closely similar materials. On request, the Agency may relieve the Company from this requirement if the Company can show that the stream in question is sufficiently active to ensure restoration of its bed during the first freshet following construction, and that it will not interfere with the biological resources of the stream.

41. Stream banks are to be restored as close to their original shape as drainage and slope stability will permit. The restored banks must be as erosion-resistant as the natural banks immediately upstream and downstream from the crossing.

Monitoring

Although a river crossing is designed to withstand changes in flow and the position of the channel, and to avoid disturbing the natural processes of fluvial evolutión, not all changes can be predicted accurately in advance. Prediction of the behaviour of rivers in the North is particularly uncertain because it involves processes that are not encountered elsewhere, such as the formation of icings and the thermal erosion of ice-rich soil along the banks. Although catastrophic changes must be dealt with as contingencies, slower changes can be monitored by repeated measurements that will provide a basis for the planning of countermeasures. Changes that are seasonal or cyclical, as well as those that are progressive, must be monitored. Parameters to be recorded include the rate of channel shift, changes in channel depth relative to the position of the pipe (scour depth), ice jams and their effects, river icings and subchannel flow in streams that have low winter flow, changes in suspended sediment, and pipe movements caused by buoyancy and frost heave.

41. *A monitoring plan and schedule shall be submitted to the Agency for approval with the final design for each designated river crossing. Site-specific adjustments to the plan may be submitted up to the time the pipe is commissioned. During operation of the pipeline, the appropriate governmental body may carry out or instruct the Company to carry out additional monitoring at particular river crossing sites.*

42. *The following components should be part of the monitoring program. Vertical stereoscopic aerial photographs at an appropriate scale should be taken once a year or, for any crossing of a stream that shows significant past channel migration or bank erosion, more frequently. Channel soundings should be made once a year in designated major stream crossings that have mobile beds or are subject to scour; the soundings should extend over a channel reach of about ten channel widths, both upstream and downstream from the pipeline. Soundings and other observations should be made at crossings where major ice jams occur; as soon as possible after each ice jam has formed, the crossing site should be sounded for scour holes; a procedure for detecting scour depth beneath ice jams should be developed. Water flow and levels should be measured during winter at crossings where low water flow or the flow of groundwater is important to overwintering fish; these measurements could include water yield of springs, piezometric measurements of groundwater and observations on icings. Suspended sediment concentrations should be observed as outlined in Fish. The position of the pipe relative to an established datum should be measured at crossings where any freezing of the soil around the chilled pipe could encounter frost-susceptible soils.*

43. *The Company may request permission to drop its monitoring program at any crossing for which there is enough evidence to show that a reduced monitoring program is not likely to lead to engineering and environmental problems.*