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Issues for Northern Pipelines: A Review of Environmental Assessments, Regulatory and Monitoring Reports from the 1970s, 80s and 90s

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Foreword

The review presented in this report was undertaken in 2003 in anticipation of a Mackenzie Valley gas pipeline project submission and the related environmental and regulatory review processes. Its intent is to provide a summary of the experience and issues as documented in the findings and recommendations of regulatory agencies and their reports/reviews of Mackenzie Valley major pipeline proposals of the 1970s, 80s, and 90s. The experience of the operational Norman Wells pipeline is also briefly summarized. The review highlights the terrain and geotechnical issues and identifies those that are likely to be important issues for a pipeline in the Western Arctic. It will provide a baseline against which issues (old, evolving and new), arising from Mackenzie pipeline proposals of the 2000s, can later be compared.

A survey of expert opinion was undertaken at the same time as this review in winter 2003 (Lawrence, 2004) and together with this report, the evaluations fed into broader federal government efforts in 2003/04 to identify biophysical knowledge gaps and research priorities, and to develop initiatives and programs to address these gaps.

Any opinions expressed herein are those of the author and do not necessarily reflect those of the Geological Survey of Canada, Earth Science Sector, Natural Resources Canada.

Margo Burgess
Geological Survey of Canada

July 2004

Issues for Northern Pipelines
a
Review of Environmental Assessments
and
Pipeline Monitoring

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PREAMBLE

This document reviews the findings and recommendations of regulatory agencies that have examined proposals for northern pipelines principally in the Mackenzie Valley. In the case of the Norman Wells pipeline it also examines opinions of regulators, researchers and the pipeline owner on the construction and operation of the line as contained in post-construction assessments and environmental reports.

This review examines what are likely to be important issues for a pipeline in the Western Arctic. The intent is to determine what permafrost; terrain and geotechnical issues will be critical for the engineering design, construction and operation of a future pipeline and its technical and environmental review.

D.E. Lawrence
July 2003

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1. INTRODUCTION:

In an attempt to establish what are likely to be the major issues for northern pipelines in the Western Arctic at the opening of the 21st century it seems logical to examine the issues debated in the 1970s and 80s, when the construction of a northern pipeline in the Mackenzie Valley and/or the Yukon seemed imminent. A number of pipeline projects were proposed and public review of their technical, economic, socio-economic and environmental viability was undertaken by a number of agencies incuding the National Energy Board (NEB) and the Federal Environmental Assessment and Review Office (FEARO), government study groups (Pipeline Application Assessment Group, DIAND) and public inquiries (Berger Commission). Their probings were exhaustive and the results of their findings well documented. A review of the reports on northern pipelines from this period provides a starting point not only to examine what are likely to be issues for a new pipeline proposal but also to examine what progress has been made since the 1970-80s in filling knowledge gaps and resolving issues.

In the mid 1980s the Norman Wells, IPL (NW) pipeline, a 868 km, small diameter, ambient temperature, oil pipeline, was constructed through the Mackenzie Valley from Norman Wells to Zama, Alberta. The assessment, construction, operational experience and extensive monitoring carried out by both government researchers and the pipeline owner allows one to compare assessment issues and concerns with actual performance.

This examination of earlier reports has been undertaken simultaneously with a survey in winter 2002/03 of the opinions of experts on current pipeline issues related to terrain, permafrost and geotechnique (Lawrence, 2004). The two evaluations hopefully will help to identify potential critical issues, and gaps in our knowledge base that will assist in focusing research priorities of the GSC in preparation for new pipeline initiatives in the Western Arctic. This report draws heavily on an unpublished research manuscript from the early 1990s by this author that examined the findings of various assessment agencies and the results of monitoring of the construction and the early years of operation of the Norman Wells pipeline (Lawrence, 1992).

A number of hydrocarbon development projects have been proposed for the Mackenzie region over the past three decades. In the late 1960s, considerations for transporting Alaskan oil to the south via the Mackenzie Valley were examined. In the mid 70s, the National Energy Board (NEB) and the Berger Commission conducted extensive reviews into the possible effects of gas pipelines in the Mackenzie Valley. In 1981 the NEB gave approval and a panel of Environmental Assessment and Review Process (EARP) recommended proceeding with the Norman Wells Pipeline. In the early 1980s the EARP reviewed the concept of phased development of Beaufort Sea and Mackenzie Delta hydrocarbons. Extensive deliberation of major northern pipeline proposals issues are contained in the reports of these pipeline review agencies:

Mackenzie Valley Pipeline Assessment, DIAND 1974: This report discusses the environmental and socio-economic effects of the proposed Canadian Arctic Gas Pipeline (CAGPL)

Northern Frontier, Northern Homeland, 1977: The report of the Mackenzie Valley Pipeline Inquiry, conducted by Justice Thomas R. Berger, into the socio-economic and environmental effects of large diameter pipelines in the Mackenzie Valley

Reasons for Decision, Northern Pipelines, NEB, 1977. The report on the deliberations of the National Energy Board on the competing applications of Canadian Arctic Gas Pipelines Limited (CAGPL), Foothills Pipelines Ltd. and others to build a gas pipeline to transport Alaskan and Beaufort gas to southern markets via the Mackenzie Valley or the Yukon.

Norman Wells Oilfield Development and Pipeline Project, FEARO, 1981. The report of the Environmental Assessment and Review Panel on a small diameter oil line from Norman Wells, NWT to Zama, Alberta and associated development at Norman Wells.

Reasons for Decision, Interprovincial Pipe Line (NW) Ltd., NEB 1981. The report on the deliberations of the National Energy Board on the application to transport oil, via a small diameter pipeline from Norman Wells to northern Alberta.

Alaskan Highway Gas Pipeline, September 1982; Report of the EARP Panel on Assessment of the Foothills Pipelines (South Yukon) Ltd. proposal - 818 km large diameter pipeline across the Yukon.

Beaufort Sea Hydrocarbon Production and Transportation, FEARO, 1984. The report of the Environmental Assessment Panel on the phased development of Beaufort/Delta hydrocarbons

2. PIPELINE PROPOSALS, REVIEW OF RECOMMENDATIONS

A number of regulatory authorities, assessment panels, commissions and study groups have evaluated northern pipeline proposals in the past 30 years. The recommendations contained in some of these reports provide an insight to major issues associated with these project proposals.

A review of the terms and conditions attached to pipeline assessment from the 1970-80's in the Western Arctic provide an indication of issues of most concern at that time. These conditions and recommendations were developed in order to ensure sound engineering design, control of construction activities and ensure safe and secure operation of the pipilinealong with adequate levels of environmental protection. This is especially significant, in situations where there was some doubt surrounding the proponents' ability to carry out their undertakings and control any adverse outcomes resulting from proposed activities. The use of innovative and untested engineering design elements in hostile environments, where the consequences of unpredicted or uncontrolled events were of particular concern.

a) **Norman Wells Oil Pipeline**

The Norman Wells to Zama oil pipeline was proposed by Interprovincial Pipe Line (NW) Ltd. in April 1980. The proposal called for expansion of the Norman Wells oil field to enhance and increase the rate of recovery and the construction of a 324 mm diameter, 868 km long oil pipeline through the Mackenzie Valley to Zama in Northern Alberta. Both the NEB and EARP assessed the project.

i. EARP, 1981

The EARP issued its findings in January 1981. It concluded that the project could be built and operated in an environmentally acceptable manner but many significant engineering and environmental deficiencies would have to be addressed prior to proceeding with the project. They recommended that the project be delayed for 2 years in order to address these concerns.

The Panel had serious concerns about pipeline integrity and right-of-way stability that arose due to questions about the proponents ground thermal analysis. River crossings, contingency planning, erosion control, revegetation and pipeline routing also were noted as concerns.

Of the 32 recommendations made by the Panel, 27 dealt with engineering and environmental matters. Eight of these recommendations were intended to minimize the impact of pipeline construction and operation. Six were intended to reduce impacts to wildlife and fish. Six addressed contingency planning and pollution prevention. Two recommendations dealt with environmental impact management and one with route alternatives. Other environmental recommendations dealt with archaeology, forestry and erosion concerns.

The Panel felt that many of these concerns were directly related to deficiencies in the proponents' planning and the state of governments' preparedness.

ii. NEB, 1981

The National Energy Board issued its Reasons for Decision report on the Norman Wells pipeline in March 1981. However, due to the general nature of the application and the deferral by the company during the hearings to "available environmental information" the NEB required that the applicant file additional information. Parties of record in the hearings reviewed all of the additional information and the applicant was required to address the concerns raised in this review. Because of the requirement to review large amounts of information by parties of record following the public hearings, there was a considerable delay in the start of construction. There is a wide divergence of opinion among proponents, regulators and intervenors on the viability and desirability of the procedure of evaluating information subsequent to the public hearings and a decision being rendered on the project. Whether this would be acceptable for a future hearing of a frontier project is debatable.

This was the most heavily conditioned pipeline certificate ever issued by the Board. Four conditions dealt with the review of additional information. Ten conditions dealt with environmental and engineering design considerations that had to be satisfied prior to either the start of construction or operation of the pipeline. Five additional conditions contained requirements for the applicant to monitor and report on environmental and socio-economic matters. Most of these conditions were required to ensure the engineering and environmental viability of the pipeline system. Much of this conditioning might have been reduced had the applicant filed more comprehensive information in its initial application and in its supporting environmental assessment.

This situation highlights the desire by the applicant to obtain approval, even if only in principal, for a project prior to spending large sums of money on engineering design and environmental studies, as this reduces the financial risk in the event that the project is not approved. On the other hand, regulators and those who might be affected by a pipeline project would like to have a great deal more information before them so that they can be assured that environmental impacts are properly evaluated and mitigative measures are adequate. In the case of southern projects, where there is a long history of pipeline construction, design concepts and technology are proven and environmental impacts are fairly well known this does not arise, as there is a high level of confidence. However, in frontier situations where there are adverse conditions and natural processes are not well understood or incompletely documented, there is a lower level of confidence. Thus, a more detailed evaluation and probing are required in order to be in a position to adequately evaluate a project. In this regard the approval-in-principal process is a much less viable process for frontier projects.

b) <u>Mackenzie Valley Gas Pipeline</u>

A number of factors precipitated the proposal to move Alaskan and Beaufort/Mackenzie gas to southern markets via a Mackenzie Valley gas pipeline including the following; development of the Prudhoe Bay Oil fields and construction of the Trans-Alaska Pipeline in 1977, the increase of gas reserves in the Beaufort/Mackenzie, and insecure world oil markets. The principal proposals were:

1. Canadian Arctic Gas Pipeline Limited (CAGPL) - A Mackenzie Valley Pipeline with alternatives for the northern portion of its route either across the central Yukon via the Old Crow Plain or via the Mackenzie Delta and the Yukon Coastal Plain.

2. Foothills Pipelines - A Mackenzie Valley route from the Mackenzie Delta with no provision to move Alaskan gas.

3. Foothills (Yukon) - A Yukon and Alaska route to move only Alaskan gas with the provision to build a lateral line via the Dempster highway route to move Canadian gas, if required, at a later date.

Subsequent to these assessments several additional applications for major northern gas pipelines have been filed however, these applications are currently dormant.[1] At company request and pending the filing of additional information these applications could be reactivated.

DORMANT PIPELINE APPLICATIONS

Company	Date of Application	Description
Foothills Pipelines (Yukon) Ltd.	29 June 1979	Dempster Lateral gas pipeline
Polar Gas Ltd.	29 June 1984	Natural gas pipeline from the Mackenzie Delta
*Foothills Pipelines (Yukon) Ltd.	13 February 1985	Expansion of Eastern Leg of the Alaska Highway Natural Gas Pipeline System
Foothills Pipelines Ltd.	30 October 1989	Mackenzie Valley Pipeline gas pipeline

Modified from NEB "Regulatory Agenda", No.39, Dec. 1991
* Application later withdrawn at company request (Denis Tremblay, NEB, Mar. 2003, pers. com.).

i. Mackenzie Valley Pipeline Assessment Group, 1974

The Pipeline Application Assessment Group carried out a preliminary assessment of the Canadian Arctic Gas application. This group, assembled by the Government of Canada, reported on the issues raised by this proposal and the requirements for additional information that would have to be submitted in order to fully assess the proposal. The report, issued in November 1974, examined social, environmental and economic impact of the construction, operation and abandonment of the proposed pipeline.

The report, in its environmental assessment section, examines a wide range of northern concerns that would have to be addressed in relation to the CAGPL application. The report focused on concerns related to the physical environment, engineering, environmental quality, and route considerations. The proponent's data are evaluated with respect to a wide variety of issues, concerns are discussed and the need for additional information is identified. A request for supplementary information, which forms the final section of the report, makes 56 specific requests. Each of the requests is related to one or more of the Government of Canada's Expanded Guidelines for Northern Pipelines issued in June 1972 and for the most part are related to engineering activities.

Of the 56 requests, 45 deal with environmental impacts related to the planning, construction or operation of the pipeline. Of these, over 35 percent are related to terrain, soils or geotechnical matters. Routes and site location; erosion and river crossings; water quality and fish habitat; wildlife waterfowl and raptors; pollution, contingency planning and monitoring; each account for between 10 percent and 15 percent of the requests.

ii. NEB, 1977

[1] Editor's note: This literature review was undertaken prior to the July 2003 submission of the Preliminary Information Package (PIP) for the Mackenzie Gas Project.

Reasons for Decision, Northern Pipelines was issued by the NEB in June 1977, following 13 months of hearings, with appearances from over 70 companies, interest groups and individuals. It found CAGPL's Mackenzie Delta and Arctic Coastal Plain route environmentally unacceptable and its alternative interior route environmentally and socially sensitive. The application was denied. The Foothills' proposal, although found to be environmentally generally acceptable provided that appropriate mitigative measures would be implemented, could not be economically justified. In fact, the proponent withdrew the application prior to a decision being handed down. The Foothills (Yukon) proposal, although requiring further engineering design, environmental and socio-economic information, offered the best alternative and was issued a Certificate.

This decision indicated that the Board felt that the environmental risks were unacceptably high for the Cross-Delta and Arctic Coastal plain sections of the route and via the interior route through the Yukon. However, they felt a Mackenzie Valley route could be constructed and operated in an environmentally acceptable manner but a pipeline could not be financed solely on the basis of revenues from the Canadian gas resources in the Mackenzie Delta.

Geotechnical Issues

The NEB felt that geotechnical issues, especially those related to or dependent on permafrost soils, were critical to the viability of a pipeline system. Both frost heave and thaw settlement issues were extensively probed as the risk to pipe integrity and possible impacts to the environment were great. Design to predict and contend with the effects of these phenomena must be based on knowledge of soil conditions, soil behaviour and the availability of detailed data along the pipeline route. Knowledge of the locations of interfaces between frozen and unfrozen ground is particularly important.

The proponents were unable to predict with certainty the amounts of differential movement, either heave or settlement, that they would have to contend with in their design. In fact experimental data upon which some of these predictions were based were found to be completely unreliable because of a faulty experimental apparatus. The necessity to reconsider the frost heave design during the hearings, inconsistent and conflicting information combined with the requirement for extensive berms, deep burial, heat tracing, insulation and replacement of frost sensitive material with granular backfill for the new design, destroyed confidence in the proponent’s ability to deal with the most critical engineering aspect of the pipeline design. The Board felt that there were gaps in the fundamental understanding of the frost heave process.

For thaw settlement, the NEB felt that a safe design could be found. However, before they would be able to evaluate and approve a design for either settlement or heave, extensive additional work would have to be carried out, especially the mapping and detailing the distribution of frozen soils. Identification of the boundaries between frozen and unfrozen materials, which are critical to the design, construction and operation, would be an essential requirement.

Similarly the stability of slopes in permafrost terrain require detailed knowledge about permafrost and soil conditions, design requirements and construction procedures would have to be proven before approval could be given. Many of these aspects would have to await the final design phase.

The Board felt that adequate drainage and erosion controls were a very important requirement as the consequences of failure would be severe. They stated that they were satisfied that this could be done but examination of final design data would be required.

The Board noted flood predictions were based on sparse hydrological information that made them apprehensive about the ability to predict both channel scour and channel shifting. Again, insufficient information was presented by the applicants and additional work would be required prior to construction.

A number of unresolved issues related to borrow resources were noted. These included identification of requirements, availability of the resource, impact of pit development, excavation techniques, conflict with local use and requirements, and placement of frozen materials. Again further information would be required prior to approval.

Construction and Operations

Limiting factors such as day length, wind and temperature which would adversely affect the rate of construction were examined, as were variations in construction methods using either snow and ice or granular work pads and conventional and arctic pipeline construction techniques. Integration of these factors into a construction plan was determined to be critical to success. The Board felt that construction was feasible however, they foresaw problems in scheduling material delivery and completing work during the short winter work period especially with the possibility of down time.

Concern was raised about the dependence on snow roads and work pads in particular the ability to build a large diameter pipeline from a snow surface and the ability to make snow if insufficient quantities were available.

Similarly reliance on unproven excavation techniques and a wheel ditcher specifically designed for arctic conditions, whose design was incomplete, caused concern. The Board would require that these methods be proven and that construction specifications be filed well in advance of any pipeline construction.

The Board felt that a pipeline could be properly operated and monitored using conventional surveillance and maintenance processes. However, it was skeptical of remote operating procedures proposed by CAGPL, especially in the early operating phase of a frontier pipeline.

Environmental Issues

The Board, after deliberation on a wide variety of environmental issues including terrain, hydrological, biological, pollution, noise and archaeological issues, found that a pipeline could be constructed in an environmentally acceptable manner provided that appropriate mitigative measures were implemented. They identified that for many areas, additional environmental data and testing of procedures would be required prior to giving final approval to construct a pipeline.

Terrain damage would be inevitable especially at river crossings and borrow pits and in association with the construction and operation of snow roads, but this could be held to acceptable limits by the use of appropriate mitigative measures.

Approval of drainage and erosion control measures and borrow pit design would be required at the final design stage.

Revegetation using native species would have to be tested to demonstrate their effectiveness.

Water withdrawal and the disposal of sewage effluent, toxic materials and other wastes would all require filing of additional information prior to construction. Air emissions would be subject to monitoring and site-specific analysis and design requirements.

Inspection and supervision would have to be an integral part of the project. This would include education and orientation programs to familiarize all employees and contractors with construction specifications, environmental policies and procedures and emergency measures. Contingency plans, an environmental organization and inspection program and a post-construction monitoring program would all have to be implemented to ensure the environmental viability of a Mackenzie Valley pipeline.

iii. Berger Commission, 1977

The assessment of the Berger Commission overlapped in time and with respect to issues reviewed with that of the NEB. The mandate of the Berger inquiry however, was much broader in scope and it's hearing process less formal than the court of enquiry format of the NEB process. Justice Berger traveled to numerous communities in the Mackenzie Valley and the Yukon to hear the opinions of local individuals and groups in order to ascertain the possible socio-economic and environmental impacts of the proposed project.

In his 1977 report "Northern Frontier Northern Homeland", Justice Berger, having evaluated many of the engineering design and construction issues and environmental impacts, came to virtually the same conclusion as the Board. It stated that it would be feasible to construct and operate a large diameter gas pipeline in the Mackenzie Valley within acceptable environmental limits provided that: terms and conditions are devised to mitigate impacts to wildlife, waterfowl, raptors, fish and their habitat; construction and the operation is carefully planned and regulated; and <u>critical gaps in our knowledge about the environmental impact and about engineering design and construction on permafrost terrain are adequately researched</u>, Considerable additional data collection and detailed engineering design work would be required.

The most significant aspect of the report is the recognition of the vulnerability of the native way of life and culture and the possible socio-economic impacts of a pipeline project. Because of this, he recommended that no large-scale pipeline should be built in the Mackenzie Valley for 10 years. This would provide, he thought, sufficient time to settle native land claims and have in place a regulatory structure that would allow native peoples to manage resources and development on their lands.

iv. Alaska Highway Gas Pipeline Project, EARP, 1982

In September, 1982 the EARP issued its report on its assessment of the Foothills Pipe Lines (South Yukon) Limited application to construct the Yukon section of a large-diameter gas pipeline from the Alaskan north slope to the lower 48 states of the U.S.A. This approximately 820 km long section of the pipeline would traverse the southwest corner of the Yukon from Beaver Creek in the west to Watson Lake in the south east. The Panel found that there was sufficient information for sound environmental planning of the project however, there were outstanding concerns and unresolved difficulties. In this regard the Panel made 26 recommendations, 14 were related to physical and engineering concerns, 6 related to biological concerns, 3 on route and scheduling alternatives, 1 on alternative modes of pipeline installation and construction and 2 on other issues. Of the 14 physical and engineering concerns 7 were related to permafrost, geotechnical design associated with frost heave and thaw settlement, and pipe /soil interaction and stability of slopes, 5 on hydrology and 1 each on revegetation/erosion control and granular resource management. In addition the 4 recommendations on route alternatives, scheduling and modes of construction for the most part arose from concerns about terrain and permafrost.

v. Beaufort Sea Hydrocarbon Production And Transportation, EARP, 1984

In July 1980, DIAND initiated a formal review of oil and gas production and transportation in the Beaufort Sea. This was carried out by means of a public hearing under the EARP. Three companies, Esso, Gulf and Dome on the behalf of numerous companies holding exploration permits in the Beaufort/Mackenzie Region provided technical and environmental information on options and scenarios for production and transportation.

The Panel, in its review, developed two objectives:
1. Northerners would be able to manage effects of changes and derive long-term benefits from development; and
2. The risk to renewable resources would be acceptable.

In order to achieve these objectives, the Panel determined that a "phased approach" i.e. a number of small sequential projects would be preferable to a single large-scale project.

Transportation of hydrocarbons via pipeline(s) along a Mackenzie Valley route was included in some scenarios. The Panel felt that a small-diameter (up to 400 mm) buried pipeline to move oil could be done in an environmentally acceptable manner with appropriate monitoring and regulation. They concluded however, that a proposal for large diameter oil pipeline (i.e. 1000 mm) would have to be subjected to a comprehensive public review, unless lessons learned from the construction of smaller lines had removed concerns. The Panel stated that any pipeline greater in size than that required for a 15,000 m^3/day oil production would have to be reviewed.

The Panel expressed concern about the impact to wildlife, habitat and the people who depend upon them that would result from an oil spill. They felt that in some situations a major oil spill could not be cleaned-up using present technology.

<u>The Panel identified a need for further long-term research into physical and biological processes so that impacts could better be assessed and additional baseline data would be required in order to develop monitoring and mitigation programs. The level of research following the decline in interest in large diameter northern pipelines in the early 1980s also declined dramatically with the reduction in the capacity of government research organizations.</u>

vi. Review of recommendations and terms and conditions from previous project assessments

A review of the terms and conditions attached to pipeline assessment reports (FEARO and Berger), reasons for decision reports (NEB) and land use permits and water licenses (DIAND) from the 1970-80's in the Western Arctic provide an indication of issues of most concern at that time and a perspective on what we might expect for future pipelines. These conditions and recommendations were developed in order to ensure sound engineering design, control of construction activities and ensure safe and secure operation along with adequate levels of environmental protection. This is especially significant, in situations where there was some doubt surrounding the proponents' ability to carry out their undertakings and control any adverse outcomes resulting from their proposed projects. Innovative and untested engineering design elements in hostile environments, where the consequences of unpredicted or uncontrolled events were unknown were of particular concern.

A preliminary review of issues from the 70's and 80's based on a review of terms and conditions and recommendations related to terrain issues shows the following (see Table below) distribution of concerns/issues which appear as conditions or recommendations in reports. Although many of the recommendations could have been assigned to more than one category or to multiple categories they have been assigned subjectively to a single category.

The most frequently occurring terrain issues relate to erosion and drainage, sensitive terrain and to frost heave and thaw settlement. In fact over 40% of all terrain-related recommendations fall into these three categories. As well, many of the recommendations assigned to other categories relate to or are in part associated with concerns of the first three subject areas. By conservative estimate, probably in excessive of 60% relate in some way to concerns of the first five categories.

These recommendations and conditions have been derived from concerns that arose from a variety of reviews by a wide spectrum of scientists, engineers both from industry and government regulators. Basically they relate to concerns about permafrost terrain, the ability to accurately characterize it and predict its performance under natural conditions and the influences induced by the construction and operation of man made facilities.

Added to these factors is the increasing evidence of climatic warming in the north. Climatic warming was either not seriously considered or only considered in a perfunctory manner in the proposals of the 1970-80s. There seems to be general agreement that climatic change, a significant emerging issue (Lawrence, 2004) that was basically not a factor in the proposals of 3 decades ago would exacerbate many of the issues debated in earlier assessments.

Terrain and permafrost recommendations/conditions by type			
	Issue	No of recs/conds	%
1	Erosion Control and Drainage	42	17.1
2	Sensitive terrain protection and avoidance	33	13.5
3	Frost heave and thaw settlement	30	12.2
4	Roads	20	8.2
5	Contingency planning and monitoring	20	8.2
6	Borrow	19	7.8
7	Revegetation and vegetation	19	7.8
8	Resource extraction	15	6.1
9	Slope stability	14	5.7
10	Geotechnical (general)	8	3.3
11	Crossings	6	2.5
12	Groundwater	5	2.0
13	Clearing	4	1.6
14	Scheduling and timing	3	1.2
15	Restoration	2	0.8
16	Seismic	2	0.8
17	Education	1	0.4
18	Spills	1	0.4
19	Esthetics	1	0.4
	Total	245	

Note: The report Environmental recommendations for northern pipelines, prepared by Boreal Ecology Services Ltd. for Environmental Protection Conservation and Protection, Yellowknife, Nov. 1987, was the source of information for this tabulation.

3. NORMAN WELLS PIPELINE POST-CONSTRUCTION REPORTS

It is useful to compare concerns expressed at the project review stage with the problems experienced during the pipeline construction and operational phases in order to see if perceived concerns are manifested as operational problems. This would also be a measure of the effectiveness of the terms, conditions and mitigative measures in minimizing adverse impact.

The Norman Wells pipeline a small diameter oil pipeline operation at ambient ground temperature, built between 1983 and 1985 has been in operation for 19 years. It provides an example to compare predicted and actual concerns. Both the NEB and the operator Enbridge Pipelines (NW), formerly IPL(NW), have carried out post-construction evaluations and in addition annual monitoring reports are provided to NEB by the pipeline owner. The pipeline right-of-way has also been extensively monitored by government researchers; a summary of their findings is also useful in evaluating concerns.

a) <u>NEB</u>

In June 1986 the NEB, based on the Norman Wells Pipeline experience issued "The Norman Wells Pipeline Project", an internal report outlining the Board staff's experiences and recommendations for future frontier projects, based on lessons learned during construction. Of the forty-two recommendations, seven (18, 19, 20, 21, 22, 24, 25) dealt with the administration of environmental matters and three (23, 26, 27) with environmental impacts.

Recommendation 23 states: "In arctic and subarctic environments, the Board should encourage winter construction of mainline pipe spreads unless special justification and protection measures can be provided".

They state that winter construction proved to be one of the most effective measures for protecting the environment by:
-allowing support for heavy equipment via the frost;
-minimizing disturbance to the vegetation mat;
-facilitating work on ice rich permafrost slopes and at water crossings; and
-minimizing contact with sensitive fish and wildlife resources.

Recommendation 26 states: "For the purpose of controlling surface erosion in arctic and subarctic environments, the Board should continue to require a minimum of disruption to the existing surface vegetation mat (i.e. in addition to mitigation using physical erosion-control structures and revegetation efforts)."

The report also states "initial environmental impacts observed to date, although minor are the result of erosion from surface water movement" and that the success of IPL (NW)'s program was the result of a careful design and implementation of drainage and erosion control measures and an appreciation of surface stability in every aspect of the work.

Recommendation 27 states: "With respect to the use of wood chips for protecting thaw sensitive slopes on future frontier projects, the Board would encourage potential proponents to look for additional environmentally acceptable alternatives for supplying those chips".

They point out that 462.3 hectares of forest were cut to provide these wood chips, but only 143.1 hectares was the estimated requirement. None of the wood from the 1,796.3 hectares of right-of-way was used for chips. Most of this wood was burned.

They go on to state that "wood chips have appeared to work" but "intensive monitoring is currently underway to assess the performance of wood chips to insulate the pipeline". They do not comment on the impact of the use of wood chips but suggest ways of reducing the impacts of their future use.

In fact, the wood chips have not behaved entirely as expected. Internal heat buildup in excess of 40–C has been experienced in localized "hot spots" caused by biological action within the chips. The effect on underlying mineral soils has been investigated by the operator’s consultants and government researchers.

b) <u>Enbridge (NW) (formerly IPL (NW))</u>

IPL(NW) in their "Summary Final Report on the Norman Wells to Zama Pipeline Project" submitted to the Pipeline Coordinator's Office in September 1985, included a number of statements about environmental effects.

"One of the most significant issues to be resolved has to do with terrain disturbance."

1. "...The company believes that the flexibility to grade more of the (vegetation) mat to provide a better working surface...was very important to the efficiency and safety of the construction process and resulted in no significant revegetation or reclamation problems."

2. They also state that this flexibility was required when it came to sensitive slopes whose characteristics were harder to predict than expected.

3. The amount of erosion to date is normal.

4. There is no evidence of any real problem or damage to the fisheries resource which result from construction of steam crossings.

They say that "predictions of the nature and extent of environmental sensitivities were accurate ...resulted in a project with no unanticipated or serious environmental problems".

They further state that "regardless of the extent of detailed pre-planning, there will always be a pressing need for flexibility to change design/protection features and construction activities in the field to accommodate site specific conditions".

4. NORMAN WELLS PIPELINE ENVIRONMENTAL MONITORING

a) Permafrost And Terrain Research and Monitoring Group (PTRM)

In April 1990 after carrying out research and monitoring of the pipeline, the Northern Affairs Program, DIAND published a two-volume report "Permafrost and Terrain Research and Monitoring: Norman Wells Pipeline" (MacInnes et al., 1989 and 1990). The report summarizes the work of several government departments carried out in co-operation with IPL(NW), now Enbridge Pipelines (NW) It reports on terrain conditions, design concepts and mitigative approaches, drainage and erosion, slope stability, pipe and ground thermal conditions, permafrost conditions and the performance of sensitive slopes in the years immediately following construction.

This, detailed reporting on post construction environmental conditions is not entirely in agreement with the earlier IPL(NW) report. Government researchers and Enbridge (NW) co-operatively monitor the environmental conditions along the pipeline right-of-way. A review of performance is carried out annually. The company reports to DIAND and the NEB according to their respective agreements. Enbridge also meets with government researchers and regulators each winter for a geotechnical review and to discuss the findings of inspections and research, and effects of remedial measures.

The DIAND report contains 38 recommendations categorized under the following headings:

Research and Monitoring Process	(3)
Regional Environmental Framework	(8)
Thermal Regime	(4)
Thaw Depths	(3)
Surface Settlement	(3)
Wood Chips Insulation	(3)
Drainage and Erosion	(14)

Many of these recommendations indicate the need to continue monitoring the pipeline right-of-way because conditions had not yet reached a state of equilibrium and surface and subsurface soil conditions have not yet stabilized.

The recommendations for the most part emphasize the benefits of having sufficient baseline data to refine engineering design and environmental mitigative measures. The reports indicate that additional information would have been useful in improving the effectiveness of drainage and erosion control structures and optimizing their location. For major stream crossings where long term hydrological and meteorological information are not available for design calculations, the use of geological/geomorphic information would have been useful. Major floods resulting in damage to river training and erosion control structures and causing pipe exposure required that two river crossings be rebuilt - Ochre River and Hodgson Creek.

A number of recommendations pertain to concerns about thaw, settlement and stability of slopes and the possibility of differential settlement of the pipe. A number of factors contribute to those concerns. The pre-construction thermal conditions of sensitive slopes were not well known. Several of the construction techniques proposed by the company and approved by the NEB were not implemented i.e. restricted widths of right-of-way and hand clearing on sensitive slopes. The insulating vegetation mat cited as critical in protecting thaw sensitive terrain was in fact reduced in thickness or removed by grading sometimes down and into mineral soil. In fact, IPL(NW) states in their summary report of 1985 that grading of the vegetation mat was an important factor in improving the safety and efficiency of the construction process which in their opinion caused no significant impact.

On ice-rich sensitive slopes, as a precautionary measure to reduce possible impact during construction, IPL(NW) undertook to reduce the cleared width of the right-of-way to 13 m from 20 m and to use hand clearing methods rather than mechanized methods. These mitigative measures were never implemented.

The requirement to insulate sensitive slopes to ensure their stability was not recognized by the proponent until after its engineering and environmental review had been completed and approval for the project had been given by both DIAND and NEB. This aspect of the proposal was never examined or reviewed in a public forum.

With respect to wood chip insulation of sensitive slopes, a number of pertinent facts should be reviewed:

1. The requirement for additional insulating materials to protect ice-rich slopes was never brought before the NEB during the Norman Wells Pipeline hearing in 1980.

2. The request to use locally harvested wood chips to prevent or retard thaw on 56 "sensitive slopes" was presented to the NEB in April 1983. The NEB, without requesting supporting information on possible environmental impacts or engineering performance, approved the technique in June 1983. None of the parties of record were given the opportunity to review or comment on the proposal

3. Because of poor estimates, the acreage of forest required to harvest the necessary wood chips was in excess of 3 times the acreage requested (462.3 vs. 143.1 hectares).

4. None of the trees cut on the 1,796.3 hectares of pipeline right-of-way were used for insulating slopes.

5. Heating within the wood chip insulating blanket, caused by bacterial action, although predicted in the first year after placement, has continued for several years. Temperatures as high as $40^{o}C$ have been recorded. Remedial measures have had to be implemented and monitored efforts continued/expanded.

It would appear that the opinion of the NEB and researchers are somewhat different from IPL(NW) as to the acceptability of the wood chip technique. In fact the NEB has advised that alternative methods of thermal protection should be investigated for future projects.

Finally, the discovery that the operating temperature of the oil delivered to the pipeline in its first year of operation was considerably warmer (approximately 2 to 3^{o} C) than intended, may have contributed to degradation of permafrost. The intention was to deliver oil to the pipe at approximately -2^{o} C. No evaluation of the effects of this oversight was ever undertaken.

These facts could not only bring into question the company's diligence and ability to follow through on its undertakings given to regulatory authorities but also, whether the design and operation of the line could be undertaken within the predicted design limits. Thaw in excess of the 25 year predicted maximum has already taken place on some slopes and at several locations and the factor of safety for some slopes had fallen below the design limit of 1.25 after less than 8 years of operation. (see section c) below for more discussion).

The preceding discussion emphasizes the requirements and benefits of regulator and proponent monitoring programs for projects in frontier areas, especially where new or untested design elements or technology might be used.

b) Geological Survey of Canada Review of Geotechnical Design and Performance

The Geological Survey of Canada (GSC), in cooperation with the PTRM and the pipe line owner and operator has taken a leading role in terrain and pipeline monitoring of the Norman Wells oil line since the initial stages of pipeline construction. The GSC, in 1997 with funding assistance provided by DIAND, initiated a review that would document the design, operation and performance of the Norman Wells pipeline from a geotechnical and geoscience perspective. The findings of the review, carried out in 1997 by AGRA Earth and Environmental Limited and Nixon Geotech Limited, are the subject of a monograph entitled Norman Wells Pipeline Geotechnical Design and Performance (GSC open file 3773). This report reviews the project philosophy and design approach and as well the data inputs for the pipeline design. The major portion of the report focuses on and compares the expected impacts with the actual impacts. It includes a summary of important lessons learned that addresses the following subjects:

- construction approach
- pipe and ground thermal considerations
- pipeline design
- thaw settlement and frost heave
- seismic effects
- slope stability
- drainage and erosion
- pipe-soil interaction

In conclusion the report states that by and large there are no significant unresolved issues relative to the geotechnical design and operation of the pipeline.

c) <u>IPL(NW) Ltd /Enbridge Monitoring Of Construction And Operations</u>

In addition to the above reports, IPL(NW), as a condition of the NEB Certificate of Public Convenience and Necessity, files in the fall of each year, a report on the effects of the construction and operation of the pipeline on the environment, the condition of the right-of-way and the condition of the pipe. These reports outline remedial measures undertaken in the last year and those planned for the coming year. It also outlines the results of its monitoring programs. These reports have been issued each year since 1983. Summary of major issues and remedial measures are summarized on an annual basis. See Appendix 1

In summary, it is noted that initially the major pipeline/terrain problems were related to drainage and erosion, especially on side slopes and in situations where melt water and run-off were intercepted by a subsided ditch line. Remedial measures consisting of pipe reburial, reconstruction and relocation of drainage diversion structures and backfilling of the ditch line were generally effective, even though at some sites problems persisted.

The frequency and extent of erosion and ditch line settlement that was experienced in the first few years following construction has diminished dramatically. The focus of current monitoring of both the company and government is to determine if rates of thaw and settlement are compatible with original predictions and the pipeline design. Current evidence indicates that rates of thaw are greater than predicted. Investigations are currently underway to determine effects on soils and pipeline.

Heating within the wood chip insulating blanket on sensitive slopes, especially in the first year following construction, was significant at some locations and required remedial measures. On some slopes wood chips have been removed in the winter to promote cooling/refreezing of the underlying soils. Local heating within the wood chips seems to have continued over time. In the early 1990s many slopes exhibited the effects of local wood chip heating. This has been the subject of continued monitoring as well as the effects on the underlying soils.

Also, on insulated slopes, considerable ditch line subsidence was observed in the last few years. This may be attributed to thaw caused by the pipe and movement of water along the ditch line. This condition is being monitored and studies have been initiated to determine the extent of thaw and the implications to slope stability and pipeline integrity.

Summer storms with high rainfall caused flooding in several watercourses crossed by the pipeline. Erosion of stream banks and channel shifting in 1986 and 1988 required that the crossing of the Ochre River and Hodgson Creek be reconstructed and the exposed pipe lowered.

In August 1993, following approval by the NEB, (Board Order MO-19-93), the temperature of the oil input to the pipeline was modified allowing for warmer summer operation temperatures and cooler winter temperatures but with an annual average input temperature of approximately 0^{o} C (between –1 and 0^{o} C). This was about 2^{o} C warmer than previously. In December 1997, NEB Amending Order AO-3-MO-19-93, allowed for a further a modification of the temperature regime that provided for more gradual temperature changes from season to season but maintaining the same average annual temperature of about 0^{o} C. These orders also required more rigorous monitoring and reporting in order to ascertain the potential effects of the new temperature regime on terrain, especially permafrost slopes. These changes were required for technical and cost savings reasons. The major impact to terrain has been the increase in rate of thaw to some slopes cracking and soil settlement and the reduction of factors of safety of slopes in approximately the first 100km of the pipeline.

Currently there are a number of slopes where thaw has progressed more quickly and to a greater depth than predicted. In some cases remedial measures have been undertaken to ensure their stability. Several slopes have factors of safety approaching or below that specified in the original design and are a concern. They are being closely monitored.

In the early 1990s the pipeline operator supported the development of the GEOPIG, an inertial geometry inspection tool, a type of smart pig. Repeated annual runs of the GEOPIG and comparison of data from year to year allow detection of pipe movement, bending strain and changes in pipe wall geometry. GEOPIG data and the results of an annual geotechnical appraisal of critical slopes are the basis of an on going monitoring scheme designed to ensure the operational viability of the pipeline.

d) <u>Comparison Of Predicted And Actual Concerns IPL(NW) Pipeline</u>

Comparison of the concerns, issues and recommendations expressed at the assessment stage of the project with the actual construction and operational pipeline impacts, requirements for remedial action and maintenance activities reveal a number of factors for the IPL(NW) pipeline.

1. The concerns expressed in the hearing/review stage of the project proposal were for the most part well founded. This is borne out by the fact that post construction and operational reports are addressing impacts, which are for the most part, the same issues which were predicted to be concerns at the review stage.

2. There is a recognized requirement to ensure that mitigative measures are properly implemented. This is best done through strict construction inspection, post construction monitoring, auditing and reporting.

3. Monitoring and regulatory bodies must be responsive to the requirement to quickly evaluate changes in construction and operational methods, based on field conditions encountered during construction and operation, which may be proposed by the proponent. However, at the same time, it is of paramount importance to ensure that these changes are

fully examined and evaluated. In addition, if changes are approved there might be a requirement to modify post construction monitoring requirements.

4. Avoidance procedures, which prevent impacts by appropriate timing, routing and site selection, require a full knowledge of environmental elements and early design and planning effort. This approach seems to have been particularly effective in minimizing adverse environmental impact and is certainly preferable to dealing with remedial measures to repair damage or adverse impact later in the project.

5. Immediately following construction, the majority of problems on the IPL(NW) pipeline right-of-way were related to drainage, erosion and ditch line settlement. Erosion sites, exposed pipe and the extent of ditch line requiring backfilling diminished considerably 3 years after construction; by this time inappropriate and ineffective drainage control structures had been repaired or relocated and vegetation had largely re-established.

6. Erosion events caused by summer storms have had significant local impact. Two steam crossings have had to be completely reconstructed. Whether additional stream flow and meteorological data would have made a significant difference to design considerations for these or other streams is unknown.

7. After 18 years of monitoring it appears that the longer-term effects caused by thaw are becoming more of a concern than the earlier erosion events. Thaw of soils at some sites has progressed at a greater rate than expected and there is evidence on sensitive slopes of a growing annulus of thaw around the pipe. Factors of safety on some slopes are estimated to be less than the design factor of 1.25. Current monitoring is focused on establishing the extent of thaw surrounding the pipe and determination of slope stability and pipe stress.

8. Wood chips for insulation of sensitive slopes (a procedure not subject to public review) has produced some unexpected results. The expected yield of chips per unit area was considerably less than estimated and as a result, harvest areas were larger than expected. Secondly, the biological heating within the wood chips, although predicted in the first year after placement, has continued, thus requiring local remedial work and close monitoring. Alternative methods of insulation, as suggested by the NEB, will have to be investigated for any new pipeline in the Mackenzie.

9. Ditch line subsidence was extensive and required considerable maintenance in the early years of operation. Methods to reduce the extent of subsidence and prevent adverse impacts to drainage will be required for future pipelines.

One of the principal design concepts used to insure the viability of the pipeline in permafrost terrain and minimize environmental impact to was to operate the line at ambient ground temperatures (this would not be the operational mode for a large diameter gas pipeline). This was done by controlling the input temperature of the oil entering the line. No other temperature controlling facilities were installed along the line. Initially (first year of operation) the input temperatures to the line were about 2-3^{o} C higher than that required in the design i.e. +1^o rather than -2 ^{o} This was due to the location of the temperature measuring devices up stream of the pumps rather than down stream. Pumping energy raises the temperature of the oil by about 2-3^o . This deficiency was corrected in 1986 and delivery temperatures were dropped to –5 ^{o}. It was not until the second year that chilled oil at approx. –2 was flowing in the pipe. The effects of this over sight likely contributed to a more rapid growth of the thaw bulb around the pipeline than predicted. This deviation from the intended design was detected through evidence gathered by government researchers and serves to underline the value of independent monitoring. Pipe line operating temperatures regimes were modified with the approval of the NEB in 1993 and again in 1997. The effects of these changes and the impact on permafrost terrain are the subject of continued monitoring and reporting requirements under NEB Amending Orders.

5. <u>SUMMARY:</u>

Although issues for any new pipeline proposal will be to a large degree dependant on its location and design, the assessment of previous pipeline proposals provides a relatively good idea of what will be the major elements of concern related to terrain and permafrost in the Western Arctic. The issues arising from a number of proposals and their assessments have produced remarkably similar findings and recommendations. Future assessments of large pipeline proposals will likely debate many of the same issues once again.

Similarly, the experience of the Norman Wells pipeline shows that the areas of concern raised in the hearings and reviews of the project were largely issues that have had to be dealt with during the construction and operation of the line. The Norman Wells pipeline provides, on a relatively small scale, a base line of experience that, in many aspects, can be applied to future larger scale projects in the region.

Terrain, permafrost, hydrological and geotechnical issues account for an overwhelming proportion of the recommendations and conditions attached to assessment reports. They provide a good indication of the level of concern for these issues. Recommendations and conditions may arise due to a lack of basic data or the lack of understanding of natural processes and possible interactions with the engineered elements of the project. They may also arise due to the level of confidence held by the reviewing agency, that the proposed design and mitigative procedures will perform in the manner or to the degree stated by the project proponent. This is especially important in hostile environments or with untested design elements or technology.

There is no doubt that design, location and operation of a pipeline and related facilities in the north will be predicated on resolving issues related to permafrost, pipe/soil interaction, and associated issues especially under conditions of change i.e. climatic warming.

Although issues will for the most part be similar to those of earlier pipeline proposals, there are a number of factors that are likely to exacerbate these issues.

Lack of baseline data. Lack of baseline data was an issue with respect to the geothermal regime, hydrology and resource availability and management for earlier assessments. Government researchers, due to the drastic reduction in capacity have not been able to make good use of the relatively long interval between the last major applications and the present rise in interest for a northern pipeline. A period of 25 years, an ample period to collect long term baseline data, in the opinion of many, has been lost.

Demand for baseline data. With the advances made in engineering, modeling and limit state design there has been an ever-increasing need for a wide net work of reliable base line data required by project proponents. Also, interested parties will demand factual information, based on reliable data and sound research, to facilitate evaluations of proposals which have the potential to affect them, their resources and way of life.

Safety and security. The awareness of environmental and security issues are now at a higher level than in the 1970s and 80s. Both will have the effect of raising the requirements for information to support a proposal and increase the level of assuredness required by reviewers and interested parties that project performance will be as predicted.

Public interest. There is a higher level of public awareness, more interest groups and stakeholders with formal status and a more complex regulatory regime than there was 2 decades ago. These factors will contribute to a more rigorous and time-consuming debate of issues.

Climatic change. The potential for climatic warming in the Canadian North is a major complicating issue in the consideration of long-term impacts to the physical environment. Engineering design and environmental mitigation measures will have to take into account the potential for warming and related changes for the operational lifetime of the project.

In the case of the Norman Wells pipeline, which has been in operation for 19 years, performance generally has been as predicted. Initial problems associated with drainage control and erosion had a major impact on terrain. This was predicted and required considerable conditioning of the company's certificate. In the early years of operation remediation of these problems was a major activity. Later, concerns related to permafrost thaw, that proceeded at a rate greater than expected at numerous locations, required that sensitive slopes be subject to increased levels of monitoring and remediation and are currently under close scrutiny.

There were some unexpected issues that arose related to harvesting of wood chips, and the continued heating of wood chips used to insulate sensitive slopes. Additional mitigative measures have been implemented to contend with heating of chips and thawing of slopes. Some mitigative measures were not required or never applied. As well there was a major oversight with respect to the inlet temperatures of the oil into the pipeline during the first year of operation. The impact of some of these issues might have been avoided or reduced in the light of additional research, data and monitoring.

Berger, 1977 stated that it would be feasible to construct and operate a large diameter gas pipeline in the Mackenzie Valley within acceptable environmental limits provided that… critical gaps in our knowledge about the environmental impact and about engineering design and construction on permafrost terrain are adequately researched, Considerable additional data collection and detailed engineering design work would be required.

We must examine our state of preparedness in view of his recommendation and the time available to undertake the necessary data collection and research. How much better are we able to respond to an application today than we were 25 years ago?

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7. <u>APPENDIX 1.</u>

IPL(NW) Ltd/ Enbridge Pipelines (NW) Ltd. Annual Monitoring Reports on Construction and Operation 1983-2002 , submitted to the National Energy Board. Monitoring and remedial measures related to terrain, permafrost and slope stability as summarized from annual reports.

1983

In 1983 right-of-way clearing was undertaken on four spreads. Significant items noted in the first report included:

The sensitive slopes designated for hand clearing in order to preserve the insulation qualities of the organic mat were in fact machine cleared. These same slopes which were to have a restricted right-of-way width of 13 m were cleared to the full width of 20 m.

The requirement to use shoes on the blades of bulldozers to prevent removal of the vegetation mat was determined to be unworkable and abandoned.

According to IPL(NW), burning of slash directly on the right-of-way seemed to have caused little disturbance.

Removal of the forest canopy initiated detrimental effects to forest floor vegetation. Soil moisture, ponding and erosion increased due to permafrost thaw. This underscored the importance of the proper placement of drainage and erosion control structures.

1984

In the winter of 1984 mainline construction was started and the crossings of the Great Bear and Mackenzie Rivers were completed during that summer.

Pipe was exposed due to erosion at 5 sites; one of these, in an area of cross drainage (kmp 67) was extensive and at another location, pipe floated when saddle weights on the pipe slipped.

The most significant concern was extensive ditch line subsidence, especially in the area south of km 660. Minor erosion and drainage diversion problems were common.

Three slopes required remedial work due to slumping and as a result, the design of drainage diversion berms was changed for subsequent construction. Additional rip rap and cribbing were required at several stream crossings.

IPL(NW) reported that construction activities did not appear to interfere with wildlife movements however, trappers reported a decline in returns near the right-of-way.

1985

Mainline construction of the pipeline was completed in March 1985 and in April the pipeline was put into operation.

Settlement of the pipe was noted at 7 sites. These were noted for future monitoring.

Pipe was exposed due to erosion at 8 sites - km 142, 191, 225, 321, 656, 723, 735, and 756.

Ditch line subsidence in excess of 20 cm depth was extensive. 50,000 cu. m of material was used to backfill the subsided trench.

Erosion problems required remedial action at several sites notably Blackwater River, Hodgson Creek, at several overland areas between these two streams and between kp 560-880.

1986

Backfilling of subsided ditch line was a major maintenance activity, 48 km of ditch was backfilled using 64,000 m^3 of select material and an additional 34 km were identified as requiring backfill.

Pipe exposure due to erosion was noted at 4 sites, km 142, 285, 369 and 656.

Armouring of several stream banks was carried out.

Slope restoration work was undertaken to control erosion at 9 sites.

Internal heating of wood chips due to bacterial action was monitored at eight slopes.

1987

Thirty-seven km of subsided ditch was backfilled with 50,000 m^3 of select material. The rate of subsidence observed in the summer of 1987 diminished; only 2 km of ditchline subsidence in excess of 30 cm depth was observed.

No new pipe exposure was observed.

On five slopes, wood chips were removed to promote cooling and on two slopes the chips were thinned.

An extreme storm event in 1986 caused serious erosion at both Hodgson Creek and Ochre River. In the case of Hodgson Creek, water flowed along the right-of-way for approximately 200 m and the main channel changed its course. A protective berm was constructed to protect the pipe from erosion and to control the flow of water in the main channel.

1988

Four km of subsided ditch was backfilled. Repair of diversion berms and the installation of new berms were required.

A second extreme storm event in the summer of 1988 exposed pipe at the Ochre River crossing. At Hodgson Creek the river training berm was destroyed.

Remedial measures were required to cool wood chips on 3 sensitive slopes and at the Ochre River. An air venting system was installed.

1989

Reconstruction of both the Ochre and Hodgson crossings was undertaken in the winter of 1988/89. Deep burial of the pipe across the entire floodplain of both streams to a depth of 3 m was required.

Exposed pipe was noted at 3 locations.

A smart pig designed to provide information on pipe curvature and local distortion was run from Norman Wells to Wrigley.

1990

The section of pipeline from Wrigley to Zama was examined with the smart pig. Preliminary results indicate 34 thaw settlement sites however, because this was the initial pig run it cannot be determined if these signatures represent a change from initial conditions when the pipe was installed. Subsequent runs will provide information on changes in pipe curvature and distortion.

Repairs were undertaken to protect exposed pipe at km 142.0 and 176.0. This was done with a split casing.

Less than 3 km of ditch line subsidence required backfilling.

Ditch line subsidence on wood chip covered slopes and warm areas within wood chips were being monitored.

1991

Backfilling and remedial work at six erosion sites.

Subsided ditch of less than half a km was backfilled using 40 m^3 of select material.

Exposed pipe at two locations.

Extensive erosion along the ditch line beneath frozen wood chips discovered at the Great Bear River south slope. Cavity beneath wood chips approximately 1 x 50 m.

Removal of snow to cool wood chip insulated slopes at three sites.

Heating of wood chips up to 30 degrees C observed on six slopes.

Thaw beneath wood chips has reduced the factor of safety on four slopes.

Instrumentation (piezometers and thermistors) installed to monitor geotechnical conditions on six slopes.

Weekly monitoring instituted for slopes where factors of safety are considered critical.

Measurement of pipe stress by the use of the GEOPIG carried out between Norman Wells and Wrigley.

<u>1992</u>
Protective casing installed at kp. 5.5

60 m^3 granular fill placed at kp. 16.4 to arrest erosion

600 m^3 granular fill used to fill cavity on slope 29b

Less than 1 km,of subsided ditchline backfilled in 1992

Snow removal on slope 36 kp103 to cool wood chips

Regrading of wood chips on slope 44 to enhance cooling and 20 $m^3$of granular fill used to fill ditch line

Monitoring equipment installed on slope 48b

Pinhole leak in the pipe at kp. 490.5 repaired

180 cu.m of granular fill placed on eroded site at kp. 341.5 where the pipe was exposed

New pipe exposure observed at kp.2,8

GEOPIG inertial geometry tool run from Wrigley to Zama with 6 movement sites identified to date

Temperature and pore water pressure measurements indicate potential instability problems on slopes 45, 48b, 62 73 and 142.

Mackenzie and Great Bear crossings profiled with sonar and comparison made earlier profiles. Minimum depths of cover vary from 4.0 m at Great Bear to 2.0 m at the Mackenzie crossing. Minimum design requirement is 0.4 m.

1993
Placement of granular to control erosion at the following sites–
10 m^3 of shot rock kp. 5.5
70 m^3 granular at kp. 75
50 m^3 granular at kp. 264.5
25 m^3 granular at kp. 300.6
10 m^3 granular at kp. 305.6
35 m^3 granular at kp. 313.5
25 m^3 granular at kp. 323

Ditchline subsidence backfilled with 175 m^3 granular at kp.342

Dig, sleeve removal, pipe replacement backfill at kp.491

Slopes stability concerns continue at slopes 44,45,48b, 62 and 142

In August, following approval by the NEB (order MO-19-93) the crude oil temperature regime was modified allowing for summer temperatures of up to +9 and winter temperatures to –4

1994
Soil gravel and rock backfill applied at areas of slumping kp, 14, and 75.9

Right of way damaged by erosion caused by water bombers and as well slope failure initiated by the effects of the fire kp.182

GEOPIG run from Norman Wells to Wrigley

Pipe heave sites at kp.5.1 and 5.5. Pipe strain is within tolerable limits. These sites arethe subject of ongoing surveys of ground and pipe movement.

Slope drains installed to lower pore pressures and improve stability on slope 44, 45 and 48b

Slope stability concerns – slopes 1, 2, 8,11,12, 29b, 29b, 44, 45,48b, 62 and 142

Seeding blanket applied to slope adjacent to slope 52 at kp. 182 to prevent erosion following fire damage to the organic layer

1995
Dig to expose dented pipe, inspected–within allowable limits, backfilled and seeded , kp.67.

Cribbing damaged by fire reconstructed, kp 94.

Slumping backfilled and seeded, kp130 and 140

Several other sites reseeded

Continued uplift movement at kp.5.1 and 5.4

Very dry summer no erosion sites.

Forest fires again a concern for above ground facilities.

Wood chips burned at kp.182 (slope55).

Continued monitoring of critical slopes including #1, 2, 8, 11, 12, 29b, 44, 45, 48b, 62 and 142

Smart pig run from NW to Wrigley.

1996

GEOPIG run from Norman Wells to Mackenzie Highway Station

Dent excavated, examined and repaired kp. 656.7

Remedial work to prevent further erosion a kp. 12 and 179.5

Approx. 1200 willow trees planted at slope 182 to improve stabile of slumped area

Geotechnical review including field examination of slopes between Norman Wells and Mackenzie River crossing

Thaw bulb probing carried out on 35 sections between Norman Wells and kp.27

Bathymetric survey carried out at Great Bear River to confirm depth of cover on the pipe

Pipe exposed at kp.141 covered with sand bags

Erosion area at kp. 179.5 filled wit 40 m3 material

Mackenzie River wood chips removed on slope 142 in order to freeze the slope

1997

GEOPIG run from Norman Wells to Wrigley

Geotechnical inspection of the entire ROW from Norman Wells to Zama

Further surveying of pipe movement at kp.5.1, sand bags placed under an 11 m section for pipe support also the installation of a new bench mark adjacent to the site. Nixon Geotech Ltd. under contract to the GSC suggest that the mechanism for movement may be frost jacking and that the movement is the result of high axial stress and seasonal frost heave. AEE under contract to IPL also reviewed the uplift mechanisms and provided a plan and design for remediation

Tension cracks and GEOPIG data suggested earlier pipe movement at slope 92. This is being reexamined using current GEOPIG data

Pipe dent at kp. 461.69 excavated, examined and repaired

Cribbing replaced at kp. 273

Erosion control at kp. 313, 14 m3 of shot rock and 250 sand bags

Additional instrumentation was installed. Thermistors and piezometers were installed at slopes 1, 2. 3, 4, 11, 12, 16, 29b, 44, 45, 62, 63, and 73 in order to better evaluate the effects of the temperature regime changes initiated in 1993. The slopes most affected by the temperature changes are Slope 1, 2, 3, 4, 8, 11,12, 16 and 29b

Slopes 44,45,62 and 74 have factor of safety between 1.2 and 1.5

Continued monitoring of the cracking and movement adjacent to the ROW at Little Smith Creek

Flow slides at kp. 182 that were initiated by forest fires are being monitored for further movement

<u>1998</u>
GEOPIG run from Norman Wells to Zama

Further revisions to temperature regime

Revised frequency of inspections and monitoring approved by the NEB

Buckles at kp.300 and 318. Buckle at 318 (slope 192) dug up and instrumented

Remedial work consisting completed at kp. 5.1

Cribbing replaced at kp. 113 and 271

Additional instrumentation, thermistors and piezometers, were installed at slope 62,63 and 74

Geotechnical reconnaissance of slopes and ROW. Sited visited slopes 1, 2, 3, 4, 7, 8, 11, 12, 16, 29b, 44, 45, 48b, 62, 63, 73, 74, 75, 76, 82, 92, 109 and 112; pipe uplift at kp.4.7 and 5.1; unnamed creek at kp. 141;

run from Norman Wells to Wrigley

Wrinkles in pipe at kp.318 (attributed to slope creep) and 300 have had the affected sections cut out and replaced with heavy walled pipe and were backfilled and instrumented. At kp. 311 two wrinkles were identified. Slope indicators and thermistors were installed for further monitoring

A dent at kp. 488.745 was excavated sleeved and backfilled. The rock causing the dent was removed

Select backfill was placed on the line for a distance of 25m at kp. 4.7 and as well over the rip rap at 5.1

Cribbing replaced at kp. 241, 314 and 328

Permafrost degradation and gullying identified adjacent to the ROW at kp. 314

Slope and ROW geotechnical assessment in October New instrumentation including thermistors and slope indicators installed at slope 84 and 92

Slope 44 factor of safety now approaching 1.0
1999
GEOPIG

2000
GEOPIG run from Norman Wells to Mackenzie station. 44 locations were identified for further close scrutiny between Bosworth Creek and kp. 330

Re seeding and mitigation work carried out at kp. 300 and 311

Cribbing replaced at kp. 271, 133 and 0.36

Diversion berm replaced at slope 19

Sand bags were placed to further stabilize an erosion area at kp. 314

Slope indicators at slope 44 and 45 indicate several areas of movement at depth. This movement is categorized as creep

A geotechnical reconnaissance concentrated on 27 thawing slopes between kp. 0 and 608

2001
Bathymetric surveys of the Mackenzie and Great Bear crossings indicated adequate cover of the crossing except for a channel on the south bank of the Mackenzie crossing

GEOPIG run from Norman Wells to Wrigley, kp. 336. Areas of interest include pipe movement and bending and wall deformation located principally at slopes (29 sites) and 14 overland sites as well as the pipe up lift sites at kp. 4.7 and 5.1

Cribbing replaces on the south side of Bosworth Creek and at kp.318

Further back fill and grading undertaken at kp. 318

No new slope instrumentation installed by Enbridge however a cooperative undertaking with GSC saw the installation of slope indicators and thermistors at slope 88 and at kp. 314 to monitor creep

Slopes indicators at slope 44 and 45 continue to indicate movement within several zones with movement in the order of 2mm/month. The factors of safety are likely in the order of 1.0 and 1.3

Although there has been problems with slope indicators at these kp.311 and 318 data suggests at kp. 311 there has been down slope movement of about 50mm originating at a depth of 13m and at 318 movement is at about 8 to 9m depth

2002

Bathymetric survey of the Mackenzie River crossing. Adequate cover is being maintained however there is an area
of reduced cover near the south bank which will be monitored

GEOPIG intertial geometry inspection of the pipe from Norman Wells to Zama. Forty four areas of interest were identified for more detailed analysis

Cribbing replaced north side of slope at kp. 273

Rock fill approx. 100 m long placed at kp.314 to arrest erosion

Pipe heave at kp.4.7 and 5.1 continue to be monitored

Continued monitoring of soil creep at kp.300, 311 and 318

Topographic surveys and mapping of cracking and active layer detachment slides at slope 44/45. Factors of safety likely in the range of 1.0 to 1.3

Erosion near the ROW in the valley of Little Smith Cr. being monitored closely

Close monitoring of the slopes between Norman Wells and Tulita which are impacted by the revised oil inlet temperatures continues. Factors of safety for these slopes is estimated to be greater than 1.4 although thawing, cracking and surface disturbance and erosion is observed at some locations

Currently 34 sites (29 slopes) are of concern and the subject of more detailed study