SELECTED SECTIONS OF:

NORMAN WELLS RESEARCH and MONITORING PROGRAM

Fifth Annual Summary Report

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Prepared for:

Environmental Protection
Conservation and Protection
Western and Northern Region
Department of the Environment
Yellowknife, N.W.T.

By:
Boreal Ecology Services Ltd.
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The following sections summarize the cumulative results of the research and monitoring projects conducted to date. This is the fifth annual report of the working group. Although some research and monitoring studies will continue for the next several years, the greater part of the Research and Monitoring Program has now been completed. It is therefore anticipated that the Fifth Annual Summary Report will be the last.

This summary is not intended to be a definitive or exhaustive description of each study and its results, but rather a collection of relevant information for the interested public. Persons wishing more specific information are referred to the researchers and to the specific reports listed in the individual project summaries.

Reports Available

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1. INTERPROVINCIAL PIPE LINE (NW) LTD. MONITORING PROGRAM

Agencies Participating

Interprovincial Pipe Line (NW) Ltd.
in cooperation with the Government of the Northwest Territories and the Department of Indian Affairs and Northern Development, with assistance from the Department of Energy, Mines and Resources, Agriculture Canada, and the National Research Council.

Start-up Date

1980 Baseline studies
1983 Construction monitoring
1984 Post-Construction monitoring

Objectives of Monitoring

1. to evaluate the environmental impact of pipeline construction and operation;

2. to identify the need for remedial measures and/or a change in design or procedures;

3. to assess the effectiveness of environmental protection measures; and

4. to establish reasonable environmental guidelines for future pipeline developments in the north.

From the small number of tracks seen during the monitoring studies, it was inferred that the population of animals in the study regions was exceptionally low. Furbearer track data demonstrated no consistent, positive or negative responses to habitats adjacent to pipeline clearings, although the actual cleared areas were usually avoided by the animals. Track densities were too low for other wildlife species to permit trends in abundance to be assessed.

While some avoidance by moose of habitat adjacent to the right-of-way was suggested by these data, the very low utilization of browse, even in areas well removed from the pipeline, indicated that a reduction of wildlife carrying capacity was unlikely.

Throughout the period of mainline construction, numerous wildlife were observed on or immediately adjacent to the right-of way. The track count data collected by representatives of Hunters and Trappers Associations also provided evidence that all of the major wildlife species, including moose, at least periodically utilized the right-of-way. It appeared that any displacement of wildlife away from the right-of-way was minor and of short duration.

Post-Construction Monitoring - 1984 to 1987

Terrain Monitoring

Beginning in April 1984, routine surveillance patrols were conducted on a weekly basis and in certain areas more frequently. Included among these patrols were monthly investigations and readings at 69 instrumented sites. Furthermore, in 1984, 1985, 1986, and 1987 there were a series of special monitoring trips to investigate slopes.

Overall, terrain performance has been satisfactory. Areas which have experienced active erosion represent a minor portion of the total right-of-way. The most extensive change in terrain condition continues to be subsidence of the ditch line below the original ground surface, although the rate of progression of this phenomenon has diminished significantly. Placement of borrow material to backfill subsided ditch was undertaken in summer and winter 1986 and 1987. A minor amount of backfilling of subsided ditch is planned for 1988.

No major slope instability problems have occurred although minor slumping was observed at a few locations in 1985 and 1986. Restoration works undertaken at certain slopes in the winters of 1985, 1986, and 1987 appear to have been successful. Water levels, piezometric pressures, and slope indicator readings indicate stable conditions and no slope instability problems developed in 1987.

In general, wood chip insulated slopes have performed satisfactorily. Temperatures at the wood chip/ground interface have been gradually cooling since the first year when significant heat generation was noted (Table 1.1). Efforts to cool five locations with localized heating (hot spots) by removal and replacement of wood chips in order to expose the ground surface to ambient winter temperatures were successful. However, the three sites where wood chips were cooled simply by thinning or snow removal exhibited recurrence of warm temperatures in the summer of 1987. IPL plans to cool these areas by wood chip removal and by venting the wood chips.

In 1987, twenty-four previously monitored thaw settlement sites were surveyed. At virtually all sites, depth of permafrost was found to be in excess of 2.0 m (which was the probe length). Consequently, 1987 was the first year in which thawing had a potential to significantly contribute to differential settlement along the pipe. Where pipe elevations had apparently decreased, the average settlement was found to be about 0.05 m. Generally, apparent settlement occurred over long transitions minimizing induced strains. While slight increases in strain were calculated for sites at Kp 1.5, 371.2, and 608.6, maximum recorded strain at these sites was only 0.27% (54% of design maximum).

While none of the monitored sites have developed strain values approaching the design maximum, all of the sites will continue to be monitored in 1988.

Frost heave strain gauges have been read each April. Calculations of principle stresses are all less than the yield strength of the pipe. Pipe thermistor data indicate that frost heave should not be a significant phenomenon under the current pipe temperature regime.

Aquatic Monitoring

Post-construction surveys of pipeline water crossings were conducted at least once per week beginning in April 1984. The purpose was to identify any physical conditions which could cause concern with respect to the integrity of the pipeline, or which might result in negative impacts to the aquatic resources or water quality along the pipeline route. These monitoring programs included several different studies.

Physical and chemical water quality parameters were monitored in the summer of 1985 at the Mackenzie River, Great Bear River, and Bosworth Creek pipeline crossings, all of which are used as domestic water sources. Results indicated that pipeline construction and operation had not impaired water quality at these watercourses one year after construction. No significant increases or decreases in any of the 20 chemical or physical parameters analyzed occurred downstream of the pipeline crossings relative to background levels recorded immediately upstream of the crossings.

ROW. Of the 1033 cuttings planted in the spring of 1985, only 425 or 41% were surviving in August 1986. While no monitoring of these sites was done in 1987, it is apparent that the shrubs will not significantly contribute to terrain stability for several years.

Collectively, data from the vegetation monitoring programs provide evidence that establishment of an effective cover in boreal and subarctic environments is not problematic and can be accomplished in one to two growing seasons.

Aerial Photography and Analysis

An aerial photography program has been underway since 1980 to provide a permanent chronological record of terrain and landscape conditions before, during, and after construction. Aerial photographs were taken by IPL in 1980 and by Indian and Northern Affairs Canada annually from 1983 to 1985.

In July 1986, Interprovincial Pipeline undertook black and white panchromatic photography of the entire pipeline right-of way at a scale of 1:10,000. Colour photography also was taken at 29 selected sites at a scale of 1:4000. An analysis of ground conditions on the right-of-way as shown on the photographs was then conducted. Specifically, the analysis provided a log, by kilometer post, of vegetation cover and type and major physical disturbances such as ground settlement, erosion features, slides, and ditch line settlement. Results from the analyses have been included elsewhere in this report. IPL will again produce an aerial photographic record in the summer of 1988.

Conclusions/Recommendations

The results of the post-construction monitoring programs indicate that no significant environmental impacts have resulted to date from pipeline construction or operations. Since initiation of construction, no significant variance from predicted performance has been observed with respect to terrain performance, aquatic resources, raptor populations, wildlife resources, or revegetation success. Conscientious monitoring and surveillance programs will continue to ensure that any terrain instability is rapidly identified and to allow for early restorative works where required.

Recommendations that can be drawn from the results of these monitoring programs regarding future northern pipeline development are:

1. Since monitoring data indicate stable terrain conditions and minimal impacts on wildlife and aquatic resources resulting from construction and operation of the Norman Wells pipeline, it would be prudent to implement environmental protection measures similar to those employed on this project. These protection measures include careful route selection, development of appropriate pipeline designs and activity-specific mitigation plans, on-site supervision during construction, and routine post-construction monitoring and maintenance activities.

2. No further quantitative studies regarding effects of pipeline construction and operation on wildlife or aquatic resources are recommended for future northern pipeline development in similar habitats. Current knowledge of northern wildlife and aquatic systems supported by literature and monitoring data are available to predict that impacts will be minor, localized, and temporary.

3. Since efforts to produce effective vegetative cover along the Norman Wells pipeline ROW were successful and have enhanced terrain stability, similar revegetation efforts should be afforded future northern pipeline developments.

4. Revegetation of northern pipeline rights-of-way does not appear problematic in the short-term; therefore, revegetation research should focus on long term (i.e. more than 10 years) results.

Proposed Follow-up Post Construction

Interprovincial has now concluded many of the monitoring programs but will continue with the established programs to the dates shown on Table 1.11.

Reports Available

Reports are available for viewing at the Interprovincial Pipe Line office in Edmonton, Alberta. Copies are also available for viewing at DIAND, Yellowknife, NWT; GNWT, Yellowknife, NWT; NEB, Ottawa, Ontario; Boreal Institute, Edmonton, Alberta; and Arctic Institute, Calgary, Alberta.

Raptor Monitoring

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Ealey, D.M. and R.H. McCourt. 1980. Raptor survey along the proposed pipeline route from Norman Wells, NWT to Zama Lake, Alberta, August 15-18, 1980. Prepared by McCourt Management Ltd. for Interprovincial Pipe Line (NW) Ltd.

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Eccles, D.M., R.G. Searing, J. Duncan and C. Thompson. 1985. Wildlife monitoring studies along the Norman Wells - Zama Oil pipeline January - March 1985. Prepared by LGL Limited.

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Eccles, D.M. and J.A. Duncan. 1987. Wildlife monitoring studies along the Norman Wells - Zama Oil pipeline November 1984 to May 1987. Prepared by Delta Environmental Management Group Ltd. for Interprovincial Pipe Line (NW) Ltd.

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Fernet, D.A. 1985. Aquatic monitoring survey, Norman Wells to Zama Pipeline, July 1985. Prepared by Environmental Management Associates.

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Interprovincial Pipe Line (NW) Ltd. 1984. Mackenzie River pipeline crossing, Water Licence N3L6-1126, 1983 annual monitoring and surveillance report.

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UMA. Canuck. Hardy. 1984. Revegetation program, March - April 1984. Prepared for Interprovincial Pipe Line (NW) Ltd.

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Table 1.7 Mean Percentage Plant Cover Along Permanent Transects on Areas Seeded in Winter 1984

SITES	SEEDED COVER				NATIVE COVER				LITTER COVER				TOTAL COVER			
	1984	1985	1986	1987	1984	1985	1986	1987	1984	1985	1986	1987	1984	1985	1986	1987
R.O.W.																
Overland	13	18	32	20	6	9	15	8	0	1	27	41	19	28	74	69
Slopes	17	21	30	15	5	9	13	11	0	5	27	40	22	35	70	66
All	15	20	31	18	6	9	14	9	0	3	27	40	21	32	72	67
R.O.W.																
Organic	0	1	1	0	4	8	16	16	0	0	0	0	4	9	17	16
Borrow Sites	11	10	18	12	1	4	9	8	0	1	9	11	12	15	36	31
Spoil Sites	13	25	49	36	1	2	8	15	0	8	35	41	14	35	92	92
Campsite	5	26	38	37	7	20	18	28	0	4	21	41	12	50	77	106*
Wood Harvest Sites																
Not seeded	0	0	0	0	10	23	30	38	0	0	0	0	10	23	30	38
Revegetation Trial Sites																
NS/NF	0	1	1	1	7	15	35	30	0	0	2	7	7	16	38	38
Seed Only	5	6	14	19	10	19	31	16	0	0	13	36	15	25	58	71
Fert. Only	1	1	1	2	12	25	50	36	0	0	4	11	13	26	55	49
Seed + Fert.	13	21	28	21	8	11	16	9	0	1	25	39	21	33	69	69

* indicates multi-storey plant cover

Table 1.11 Schedule of post-construction monitoring programs

PROGRAM	INITIATE	TERMINATE	FREQUENCY
STANDARD OPERATIONAL MONITORING			
Aerial Surveillance	1984	Lifetime*	Weekly
Ground Inspection	1984	Lifetime*	Annual
GEOTECHNICAL MONITORING			
Thaw Settlement	1984	Lifetime**	Annual
Frost Heave	1984	Lifetime**	Four/year
Slope Performance	1984	Lifetime**	Eight/Year
AQUATIC MONITORING			
Mackenzie and Great Bear	1985	Lifetime*	Annual
All Watercourses	1984	Lifetime*	Weekly
RAPTOR MONITORING	1983	1987	Annual
WILDLIFE MONITORING			
Right-of-way Monitoring	1984	1988	Weekly
Transect Monitoring	1984	1987	Bi-annual
REVEGETATION MONITORING			
Aerial Survey	1984	Lifetime*	Weekly
Baseline Data Collection	1984	1985	Annual
Permanent Sample Transects	1984	1987	Annual
Revegetation Trial Sites	1984	1987	Annual
AERIAL PHOTOGRAPHY AND GROUND TRUTHING	1986	1988	Biennial

* "Lifetime" refers to operational lifetime.

** Program may be discontinued if history of readings indicates an equilibrium situation.

3. ISLAND MONITORING & MACKENZIE RIVER BREAKUP

Agency Responsible

Esso Resources Canada Limited

Start-up Date

Spring 1984

Objectives

1. to determine the effects of the production islands on the breakup process;
2. to confirm the stability and design adequacy of the production islands;
3. to determine maintenance requirements for the production islands and under-river pipeline systems.

Locations

Mackenzie River, between 10 km upstream and 10 km downstream of Norman Wells.

Results to Date

1. Breakup survey data for the years 1980, 81, 82, 83, and 84.
2. Geotechnical monitoring data for Dehcho Island which includes temperature and pore pressure measurements.
3. Bathymetric data showing bottom profiles and island pipeline locations in the river.

Conclusions/Recommendations

1. Breakup timing can be closely predicted.
2. Production islands have performed as expected and do not seriously affect the breakup process.
3. Production islands are stable, well designed facilities.

Future studies

1. Continued monitoring of breakup timing and Esso's predictions.
2. Periodic bathymetric surveys of the Norman Wells reach.

Reports available

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Stagg, P.G. 1983. Ice design review of Esso Resources' artificial islands in the Mackenzie River at Norman Wells. Esso Resources Canada Limited, Research Department. IPRT.ME.83.01

Detailed breakup and island monitoring reports are submitted to the N.W.T. Water Board annually to satisfy island monitoring requirements. Bathymetric data may be viewed at the Esso Norman Wells office.

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5. PERMAFROST AND TERRAIN RESEARCH AND MONITORING

Agencies Responsible

Geological Survey of Canada, Department of Energy, Mines & Resources,
Department of Indian Affairs and Northern Development,
National Research Council of Canada,
Agriculture Canada,
Interprovincial Pipe Line (NW) Ltd.

Start-Up Date

1983.

Objectives

1. to determine and quantify the impacts of pipeline construction, operation, maintenance and abandonment on permafrost and northern terrain;

2. to evaluate the recovery processes and the effectiveness of short and long term mitigative measures;

3. to compare actual and predicted impacts in order to improve on planning, design, impact management and mitigation on northern pipelines; and,

4. to recommend improved environmental practices for future northern pipelines.

Locations

See descriptions given for specific projects.

Program Background

The Norman Wells Pipeline provides an important opportunity to examine the impacts of the first completely buried oil pipeline in the discontinuous permafrost zone of northern Canada. The small diameter (323 mm) pipeline with innovative designs and features has been in operation since April 1985. It is viewed as a pilot project from which important lessons may be learned for future oil and gas developments.

The Departments of Indian and Northern Affairs (INAC) and Energy, Mines and Resources (EMR) initiated preliminary plans in 1983 for a cooperative permafrost and terrain research and monitoring program with Interprovincial Pipe Line (NW) Ltd. (IPL) under the "Environmental Agreement" signed between IPL and the Minister of Indian and Northern Affairs in September 1982. The current program consists of the following four integrated projects:

A. Impact of the Norman Wells pipeline project on permafrost, terrain and terrain stability - Permafrost Research Section, Geological Survey (EMR) (formerly Earth Physics Branch) (See Section 5.A);

B. Terrain performance research and monitoring along the Norman Wells to Zama oil pipeline - Terrain Sciences Division, Geological Survey (EMR) (See Section 5.B);

C. Evaluation of wood chip insulation on selected thaw sensitive slopes along the Norman Wells to Zama Pipeline - Institute for Research in Construction, National Research Council (NRC) (See Section 5.C); and,

D. Norman Wells Pipeline soil temperature study - Land Resources Research Center, Agriculture Canada (Ag.Can.) (See Section 5.D).

The Permafrost and Terrain program focuses on the effects of construction, operation and maintenance of the pipeline on the surrounding ground temperature, moisture, stability and related surface conditions. The major emphasis of the research and monitoring involves:

1. thermal and associated data collection at selected sites, and
2. general observations of conditions along the right-of-way (Km. 0-818). The program is expected to continue for five to ten years or until conditions stabilize.

Funding (1983-1988) comes primarily from the Northern Oil and Gas Action Program (NOGAP) and the Northern Affairs Program (NWT Region) of Indian and Northern Affairs Canada. Additional funding and contributions are provided from the Program on Energy Research and Development (PERD), Energy, Mines and Resources, NRC, and Agriculture Canada. We wish to express our appreciation to all contributors to the program (IPL, INAC, EMR, NRC, Ag.Can) and especially to Land Resources staff F. Adlem and L. Edwardson.

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5.A. THERMAL REGIME AND TERRAIN STABILITY

Agencies Responsible

Permafrost Research Section (formerly part of Earth Physics Branch), Geological Survey of Canada, Department of Energy, Mines and Resources, in cooperation with: Department of Indian Affairs and Northern Development, National Research Council of Canada, Agriculture Canada, and Interprovincial Pipe Line (NW) Ltd.

Start-Up Date

1983.

Objectives

1. to monitor both short and long term changes in the active layer, in the permafrost and in terrain stability of the alignment area in relation to pipeline development and natural climatic change at selected study sites;

2. to assess the changes to the thermal and physical condition of terrain caused by pipeline-related activity, including right-of-way clearance, pipeline installation, operation and maintenance;

3. to compare observed terrain conditions with those predicted during the pipeline design process, including thaw depth, thaw settlement and frost heave of the surface;

4. to evaluate the effectiveness of mitigation and restoration procedures and recovery at the study sites, including thermal

performance of the pipe, wood chip insulation of slopes, drainage control and revegetation; and

5. to identify practical improvements which might be made in the planning, construction, operation, monitoring and abandonment of future northern pipelines, with special reference to the assessment of environmental impacts including route selection, thermal design, ground surface protection, land stabilization and restoration.

Locations

See Table 5.1 and Figure 5.1

Results to Date

1983-1985 Observations and Results

Six monitoring sites were established during the 1983/1984 construction season and seven sites during the 1984/85 season. These 13 locations (shown in Figure 5.1 and described in Table 5.1) were selected to:

1. investigate the terrain response to particular pipeline design features and mitigative measures, including areas of thaw sensitive terrain, frozen/unfrozen interfaces and a wood chip insulated slope; and,

2. to represent the soil and ground ice conditions along the route.

Each monitoring site generally consists of one to three instrumented cross-sections, called thermal fences and designated A, B or C. An example of the layout of a thermal fence, shown in Figure 5.2, illustrates the depth and distribution of boreholes instrumented with temperature cables. Two 5 m cables close to the pipe examine the immediate effect of pipeline installation and operation. Two 20 m cables (on and off ROW) investigate the deeper thermal characteristics and enable a comparison of the thermal regime of the disturbed ROW and surrounding terrain. A string of five thermistor sensors attached to the pipe provide a reference value for pipe-induced thermal disturbance.

Temperature cable installation at the 1984 sites began in June 1984 and was completed in September 1984; at the 1985 sites, cable installation was completed by the end of March 1985. The basic long term (10 years) monitoring program includes monthly site visits emphasizing the acquisition of thermal data.

In addition to the thermal information, geophysical surveys and topographic surveys were also conducted. Ground probing radar surveys were conducted in December 1983, June 1984, September 1984 and May 1985. Time domain reflectometry (TDR) rod installation began in September 1984 and was completed in October 1984. TDR surveys were conducted in September 1984, November 1984, May 1985 and June 1985. Ground surface elevation surveys were obtained in June 1984, August 1984, May 1985 and September 1985.

Temperature cables at remote and selected sites (Canyon Creek 2A, Great Bear 3A, Table Mountain 7A and 7B) were equipped with automatic data systems in October 1985. In collaboration with the Atmospheric Environment Service (Environment Canada), a micrometeorological station was set up at the Canyon Creek 2A site in March 1985.

The data collected during the 1983-1985 period yielded information on the following:

1. thermal regime on and off the pipeline right-of-way (ROW), in particular the effects of snow clearance during construction, pipeline trenching, water ponding, woodchip insulation, snow distribution and differential active layer development;

2. distribution and redistribution of water both on and off the ROW, within and below the active layer, and the associated changes in soil electrical characteristics;

3. variation of the active layer both with time and along continuous profiles across the ROW; and

4. terrain heave and settlement at the monitoring sites.

Late 1985 and 1986 Observations and Results

1. Data collection

Monthly site visits to collect ground temperature data continued throughout the year for all sites (as per schedule in Table 5.2) except the remote locations of Table Mountain, Redknife Hills and Petitot River (north and south). In June, ground probing radar surveys were conducted at the Great Bear monitoring sites. Downhole electrical conductivity measurements were also carried out in June using the geophysical holes at Pump station 1, Canyon Creek (A, B and C) and Great Bear (A and B). TDR measurements were taken at all sites both in May and in October. In September, all fences in the N.W.T. were resurveyed.

2. New instrumentation

In March 1986, a drilling program was undertaken at the Table Mountain sites to establish new off-ROW reference holes at each of the three fences. Three new holes were drilled in an attempt to achieve less off-ROW ground surface disturbance than had occurred during the 1985 drilling. The new hole at fence A was deepened to 93 m to provide a reference for long term climatic changes in this area of the Mackenzie Valley.

In August, shallow 1.5 m soil temperature probes were installed at 13 fences, both on and off the right-of-way, as part of a new project undertaken in cooperation with Agriculture Canada (Tables 5.3, 5.4). Permanent snow depth stakes were installed in August and September. In September, additional instrumentation was installed on the woodchip slope fence at Canyon Creek B as part of a new project, in cooperation with the National Research Council, to evaluate wood chip insulation.

In the fall of 1986, four IPL thaw settlement sites were instrumented with pairs of 10 m temperature cables. Two of these sites overlap with existing fences (km 272.0 and 608) and two are at new locations (km 135.1 and 469.7). An additional site (km 95.1) was instrumented with one cable. The instrumentation was undertaken in cooperation with IPL in conjunction with their drilling program at thaw settlement monitoring sites.

In October, a fifth automatic data acquisition system was installed at Petitot River North B to ensure that a continuous annual record was obtained in one of the remote peat plateau sites in northern Alberta. This fence now joins Table Mountain A and B, Great Bear A and Canyon Creek A on the list of sites with an automatic system. These loggers are connected to the ground temperature cables (and to the soil probes at three fences as well) but not to the pipe temperature sensors.

3. IPL remedial work at instrumented fences

Winter remedial work was carried out by IPL in February and March 1986 near several instrumented fences. Additions to erosion control berms were made at Canyon Creek C and new select backfill was added to the trenches at Manner's Creek C and Moraine South. In organic areas, organic surface material adjacent to the trench was bladed into and over the trench during March 1985 and late summer 1985.

4. Brief Climatic Perspective
   (winter 85/86 based on AES records at Norman Wells and Fort Simpson)

Early snowfall (October-November 1985) was higher than in the previous winter, while later snowfalls (January and February) were lower. Winter mean monthly temperatures were colder than normal in October, November, January, February and April, and warmer than normal in December and March. For summer 1986 conditions, see summary in Section 5.B (Terrain Performance).

5. Results

Thermal changes resulting from right-of-way widening and clearance, tree removal and ground surface grading, pipeline construction and trenching were apparent. A comparison of observations to the early and general thermal, active layer, and thaw settlement predictions of the Environmental Impact Statement and National Energy Board applications was also undertaken.

Highlights of analyses and observations through to October 1986 are as follows:

Pipeline Temperatures

A comparison of pipe temperatures and ground temperatures at a depth of 1 m on the ROW (at all EMR/INAC fences instrumented with pipe temperature sensors) were undertaken in order to determine whether the pipeline was behaving as an ambient temperature line (i.e. to examine the prediction that pipe temperatures would closely follow the temperatures of the surrounding soil).

An examination of the pipe temperature data at individual fences or small groups of fences showed that:

a. Data from Canyon Creek A, B, and C:
   Prior to oil filling the line, temperatures of the pipe and of the surrounding soil at each fence were in close agreement (within 1 degree) and pipe temperatures were distinct from one fence to the next. After oil flow, pipe temperatures at each fence no longer closely followed the ambient soil temperatures (differences of up to 4 degrees). Pipe temperatures, however, were similar at each fence.

b. Since oil flow, all fences from km 477 south to km 818, whether permafrost or non-permafrost, clearly have shown a mean annual pipe temperature above 0°C. In fact, at many of these fences (9, 10A, 10B, 11 12A, 12B; and likely 5A, 5B, and 6, although no mid-winter data were collected at the last three fences) pipe temperatures were positive throughout the last year.

c. Pipe temperatures in the northern section from site 84-1 to 85-7C (km 272), where permafrost underlies 75% of the terrain, appeared to be averaging around 0°C on an annual basis since oil flow.

d. Since oil flow, the pipe temperatures have consistently risen by

2 to 3°C from fence 9 to fence 10A (Mackenzie Highway South), a distance of only 5 km. Pump Station 3 is located between these two sites. The highest pipe temperatures of all the sites have usually been recorded at the Mackenzie Highway South fences (temperatures of up to 10°C were recorded in the summer of 1986).

Terrain Stability

a. Surface topography changes across the ROW (not only at the trench) have become apparent at several southern permafrost sites. A wide swath of relative settlement has formed on either side of the trench, covering a total width of approximately 10 m and often skewed to the spoil side (fences 6, 5A, 5B, 13A, 13B, 12B, 10B, 8C, and 8B). These changes have likely resulted from differential active layer deepening and thaw subsidence across the ROW; in addition, at some organic sites, this area was bladed for trench re-roaching.

b. Uneven (sometimes undulating) surfaces and tension cracks have appeared on several woodchip slopes; these suggest either differential settlement in the chips or in the soil beneath. Differential snow melt observed on many woodchip slopes in October 1986 suggests differential heating (decomposition) in the pile.

Changes in Permafrost Depth

The thin permafrost (less than 4 m) originally noted at fence 10B (new clearing) and fence 11 (recent helipad clearing) has now disappeared on the right-of-way.

November 1986 to October 1987 Observations and Results

1. Data collection

Monthly site visits to collect ground temperature data continued for all sites (see Table 5.2 for schedule of field work). Time domain reflectometry (TDR) measurements were taken at all sites both in May 87 and October 87. In August, topographic surveys were undertaken at all thermal fence locations with the exception of 84-2A, 84-2C, 85-9 and 85-11.

In October 1987, a sixth automatic data acquisition system (Seadata) was installed at Table Mountain 85-7C and connected to ground temperature cables T1 through T4. Seadata loggers are currently set for three readings per day. A defective logger at site 84-5B was replaced. A prototype interface unit, allowing manual readings on the cables during regular field trips without disconnecting from the Seadata loggers, has been designed and installation is planned for spring 1988. New loggers have also been installed to increase the frequency of pipe temperature readings at select sites. (See section 5.D)

2. New Instrumentation

In March 1987, a deep drilling program was undertaken at two locations in the Norman Wells area in order to examine the ground temperature profiles for evidence of climate change. The holes will provide reference sites for long term study of climate change and ground temperature relationships. The first site was at valley level (elevation 120 m) near site 84-2A, Canyon Creek, while the second was situated on top of Kee Scarp (elevation 365 m), about 5 km north of Norman Wells. The sites were selected to determine whether there is a relationship between observations and elevation and whether this might in turn be related to the temperature inversions commonly found along the valley in winter. Two holes were drilled (45 m and 129 m) and instrumented to full depth with multithermistor temperature cables at each site by September 1987.

In May 1987, soil displacement gauges (a series of ring magnets buried sequentially around teflon-covered access tubes to depths of 1.5 m) were installed both on and off ROW at two monitoring fences for experimental examination of the dynamics of near-surface materials. Measurements obtained should enable long term monitoring of relative displacements and indicate the amount of frost heave and thaw settlement. Baseline measurements were taken in October. Further readings are scheduled for May and October 1988.

3. Analyses

The first phase of laboratory investigations of the frozen cores collected from the geophysical holes drilled at the 1985 monitoring sites was completed in March 1987. This phase, undertaken in the EMR cold room at -10°C (keeping the samples undisturbed), involved a general visual description of lithology and ground ice, a photographic and video record, estimates of total density, a general survey of the thermal conductivity (at -10°C) using the needle probe technique and determination of the apparent dielectric constant by conventional intrusive TDR (time domain reflectometry) methods. Phase II of the core analyses, now underway, involves a detailed study of the physical and thermal properties and their temperature dependency, and emphasizes samples from sites 85-7B and 85-12B as well as selected samples from major soil units. Results from this research will be useful in determining the freezing point depression of the soils, in predicting thaw depths and thaw settlement at the thermal fences, and in numerical simulations of the thermal regime. Both phases of the research have been carried out under contracts to

Carleton University.

Mathematical curve fitting to the approximately monthly ground temperature and pipe temperature data collected at the monitoring sites has been undertaken (via contract) in order to interpolate between measured values. Weekly interpolated values are then used to obtain running mean annual temperatures (52 week running means). The running means can then be used to assess and compare the thermal regime adjacent to the pipe, on the ROW and off-ROW. To date, the analysis has been performed on the data collected through to the end of March 1987. Calculations including the data collected through to the end of October 1987 will take place this winter (1987/88).

Time domain reflectometry (TDR) field data will also be examined, via contract, to determine the temporal and lateral variations in soil moisture regime across each fence. Information on depth of thaw, the freezing point depression of the soils, and the presence/absence of a permanent thaw bulb/frost bulb around the pipe, will also be extracted.

4. Observations and results of analyses

Table 5.3 summarizes the mean annual pipe temperatures and the mean annual 1 m ground temperatures (on and off ROW) during the second year of operation (April 1986 - March 1987). The mean annuals were determined using the weekly interpolation values obtained by the method described in the previous section. Also provided in Table 5.3 is information on the range of settlement at the sites through to the end of the summer of 1986 based on a 20 x 20 m grid with a total of 100 points.

Figure 5.3 uses results of computer analyses of running mean annual temperatures to compare ground thermal regime (on and off ROW) with pipe thermal regime for two thermal fences, 85-7B and 85-8A.

Ground temperatures from the deep climate holes show permafrost absent on Kee Scarp but present to depths of 25 m in the valley site. Temperature profiles suggest a recent one degree increase in surface temperature at Kee Scarp but not at Canyon Creek.

Conclusions/Recommendations

1. Trends in mean annual pipe and 1 m ground temperatures over the entire observation period (1984/1985 to March 1987) (preliminary results from computer analysis of thermal data)

In general, both the temperature of the pipe and the temperature of the ROW experienced a warming trend. The warming at most sites was greatest in the first year of operation, reflecting the atypical cooling of the ground due to snow removal during construction and pipeline installation. The rate of pipe and ground temperature increase is slowing down at most sites.

By contrast, an unambiguous warming trend in the off-ROW ground temperatures was observed at only about 25% of the sites (compared to 65% showing on-ROW warming and 75% showing pipe temperature warming). These off-ROW observations do not reflect the recent warming trend in mean annual air temperatures at Norman Wells and Fort Simpson. The warming trend observed on the ROW is thus likely a result of the pipeline construction rather than a response to the atmospheric trend.

2. Summary of observations during the second year of operation

Pipe temperatures:

Mean annual pipe temperatures were generally >0° during the second year of operation and ranged from -0.3 to +5°C. Values generally averaged 1.5 degrees warmer than mean annual ground temperatures on the ROW outside the trench area at a depth of 1 m. The ground thermal regime adjacent to the pipe in the trench is thus different from the ground thermal regime of the rest of the ROW, regardless of whether the site has been previously cleared or not, because the level of terrain disturbance is greater in the trench than elsewhere.

Ground thermal regime:

Mean annual ground temperatures on-ROW (depth 1 m) several metres from the trench ranged from -1.8 to +3.8° during the second year of pipeline operation. Mean annual 1 m ground temperatures off-ROW ranged from -2.6 to +2.6° during this period. Mean on-ROW temperatures generally averaged one degree warmer.

Active layers at the end of the 1986 thaw season at sites on level terrain ranged from <0.5 m to 2.5 m on-ROW; off-ROW they were generally <1 m. Active layers on-ROW generally increased over this observation period.

Surface settlement from topographic surveys:

Maximum recorded surface settlement to the end of the 1986 thaw season ranged from 60 to >100 cm in the trench area at 9 of 20 surveyed thermal fences. Some of the settlement in the trench area likely resulted from subsidence of the roach. On the ROW beyond the trench area, the maximum ranged from 50 to 80 cm at 6 of the 20 surveyed fences. Cumulative settlement to the end of the 1987 thaw season has yet to be determined from the 1987 topographic surveys.

Visual observations of surface settlement form part of IPL's geotechnical monitoring program. They have identified areas for detailed investigation where the possibility exists for thaw settlement greater than the design differential beneath the pipe over a short distance. Surface settlements over 60 cm in the trench area and over 50 cm elsewhere on the ROW, have been recorded at three thermal fences (84-1, 85-7B, and 85-12B). These are included in the detailed thaw settlement investigation.

3. Recommendations

A longer observation period is required in order to establish:

a. whether the general warming trend observed in the pipe temperatures and on the ROW is continuing;
b. whether the deceleration in the warming trend, where observed, represents the establishment of a new, higher equilibrium surface temperature.

Future Studies

The monitoring program should continue until the ground thermal regime (active layers, permafrost thickness, mean annual ground temperatures) has achieved equilibrium with new surface temperatures and surface settlement at the study sites has subsided. Long term observations are necessary in order to fully address the project objectives, in particular 3, 4 and 5.

Some aspects of the project may be adjusted to respond to changing surface conditions and information requirements.

Monthly acquisition of ground temperature and pipe temperature data, regular collection of related data and laboratory and computer analyses will continue throughout 1988.

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Table 5.5 Description of materials to a depth of 165 cm at the Norman Wells pipeline soil temperature sites

Site No.	First Material Type	First Material Depth (cm)	Second Material Type	Second Material Depth (cm)	Third Material Type	Third Material Depth (cm)
PS1-1	peat	0-40	lacustrine (SiC)*	40-165		
PS1-2	peat	0-15	lacustrine (SiC)	15-165		
2A-1	peat	0-27	till (L)	27-100		
2A-2	peat	0-20	till (L)	20-165		
3A-1	peat	0-25	alluvium (SL)	25-165		
3A-2	peat	0-98	alluvium (SL)	98-165		
3A-3	peat	0-54	alluvium (SL)	54-165		
7A-1	peat	0-35	lacustrine (C)	35-165		
7A-2	sandy gravel	0-20	peat	20-80	lacustrine (C)	80-165
7B-1	peat	0-10	lacustrine (C)	10-165		
7B-2	peat	0-10	lacustrine (C)	10-165		
4B-1	forest humus	0-3	eolian (S)	3-165		
4B-2	eolian sand	0-165				
8A-1	forest humus	0-18	eolian (S)	18-165		
8A-2	humus - sand	0-15	eolian (S)	15-165		
8B-1	peat	0-165				
8B-2	peat	0-165				
8C-1	peat	0-165				
8C-2	peat	0-52	alluvium (S)	52-110	alluvium (Si)	110-165
10A-1	forest humus	0-5	till (CL)	5-165		
10A-2	peat	0-58	till (CL)	58-165		
12B-1	peat	0-165				
12B-2	peat	0-165				
13C-1	peat	0-165				
13C-2	peat	0-165				
5B-1	peat	0-165				
5B-2	peat	0-165				

* Abbreviations in brackets are: Si - silt, C - clay, L - loam, S - sand

Future Studies

Due to budget uncertainty and constraints as well as a lack of personnel, only a skeleton monitoring programme will be conducted. It will consist of fewer sampling periods and fewer studies.

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