Environmental Impacts Of Arctic Oil And Gas Development
Type of Study: Analysis/review
Mining/oil/energy, Energy General
Date of Report: 1975
Author: Inuit Tapirisat Of Canada
Catalogue Number: 6-5-33

INUIT TAPIRISAT OF CANADA — RENEWABLE RESOURCES PROJECT

ENVIRONMENTAL IMPACTS OF ARCTIC OIL AND GAS DEVELOPMENT

sector: Mining/Oil/Energy

CS

6-5-33

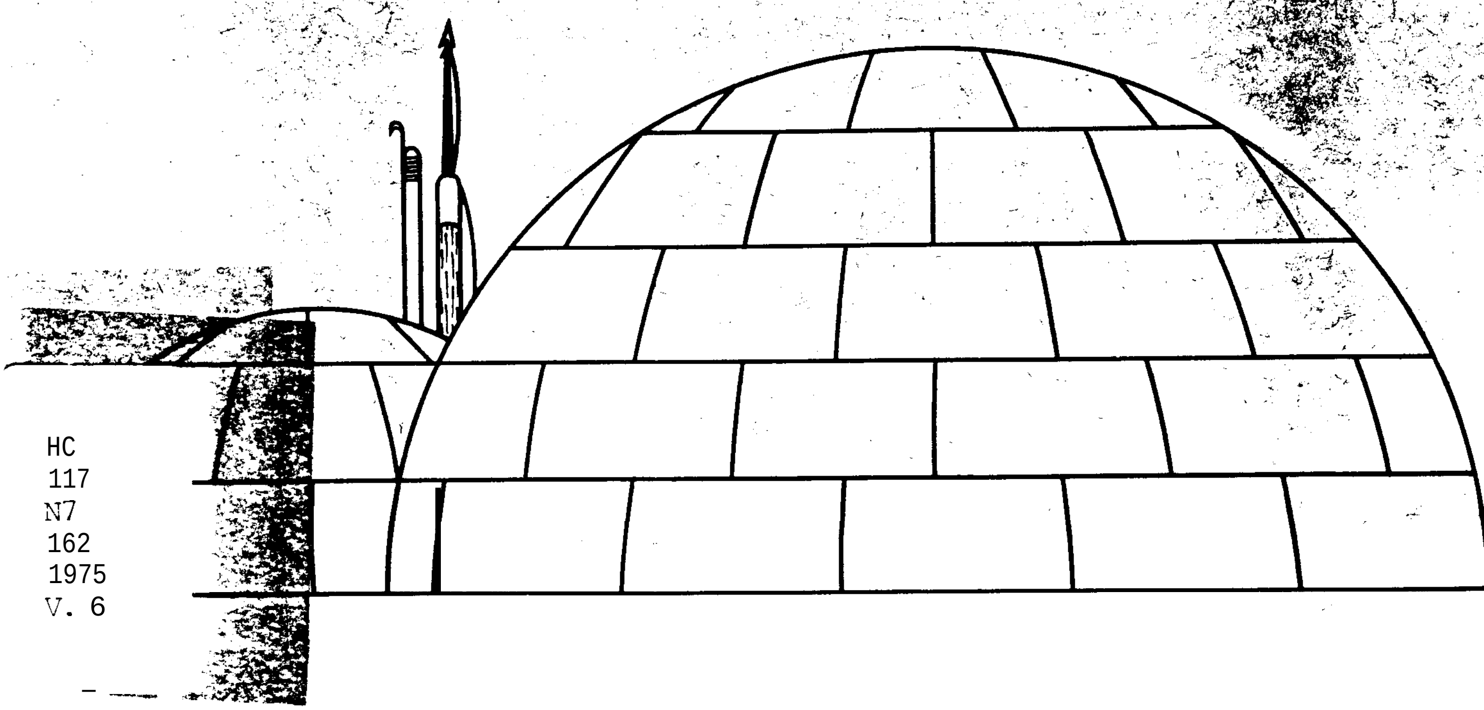
Analysis/Review

6

VOLUME

ENVIRONMENTAL IMPACTS OF ARCTIC OIL AND GAS DEVELOPMENT

SJ BROWN



PREFACE

The Renewable Resources Project is one of three research projects conducted by Inuit Tapirisat of Canada as part of its overall land claims research. Along with the Inuit Land Use and Occupancy Project and the Non-Renewable Resources Project, this research was commissioned to assist in the development of a comprehensive land settlement for Inuit lands in the Northwest Territories and Northern Yukon.

The Inuit Land Settlement Proposal, Nunavut, was presented to the Federal Cabinet on February 27, 1976. Readers of these reports are urged to study the Nunavut proposal to gain a full understanding of the Inuit position.

The Renewable Resources Project was under the overall direction of Dr. Gordon Nelson, Dean of Environmental Studies, University of Waterloo. The views expressed in these reports are those of the authors and not necessarily of Inuit Tapirisat of Canada.

RENEWABLE RESOURCES PROJECT REPORTS

Vol. 1	Exploration, Settlement and Land Use Activities in Northern Canada : Historical Review, Robert C. Scace.
vol. 2	Canadian Arctic Renewable Resource Mapping Project, Boreal Institute for Northern Studies.
vol. 3	Historical Statistics Approximating Fur, Fish and Game Harvests within Inuit Lands of the N.W.T. and Yukon 1915-1974, Peter J. Usher.
vol. 4	Socio-economic Evaluation of Inuit Livelihood and Natural Resource Utilization in the Tundra of the N.W.T., D. DePape, W. Phillips, A. Cooke.
vol. 5	Biophysical Impacts of Arctic Hydroelectric Developments, Richard J. Turkheim.
Vol. 6	Environmental Impacts of Arctic Oil and Gas Development, Si Brown.
vol. 7	The Impact of Mining on the Arctic Biological and Physical Environment, Philip-Van Diepen.
Vol. 8	The Socio-Economic Impact of Non-Renewable Resource Development on the Inuit of Northern Canada, Donald Mann.
vol. 9	The Development of Tourism in the Canadian North and Implications for the Inuit, Richard Butler.
Vol.10	Potential Inuit Benefits from Commercial and Sports Use of Arctic Renewable Resources, Fred Friesen.
Vol.11	Summary and Recommendations, J. G. Nelson.

Impact of Mining and Hydroelectric Projects and
Associated Developments on Arctic
Renewable Resources and the Inuit

Consultant and Editor

J. C. Day

ENVIRONMENTAL IMPACTS OF ARCTIC OIL AND GAS DEVELOPMENT

Si Brown

Renewable Resources Studies

Inuit Tapirisat of Canada

Director

J. G. Nelson

University of Western Ontario
University of Waterloo

July, 1975

$160.00 set

Impact of Mining and Hydroelectric Projects and
Associated Developments on Arctic
Renewable Resources and the Inuit

PREFACE

This report, Environmental Impacts of Arctic Oil and Gas Development, is one of a series concerning impacts of mining and hydroelectric projects. It is prepared to assist the Inuit Tapirisat of Canada in the forthcoming Land Claims Settlement with the Canadian Federal Government.

The examination of impacts is divided into four parts:

Biophysical Impacts of Hydroelectric Developments in the Arctic by Richard J. Turkheim,

Environmental Impacts of Arctic Oil and Gas Development by Si Brown,

The Impact of Mining on the Arctic Bilogical and Physical Environment by Philip van Diepen, and

The Socio-Economic Impact of Non-Renewable Resource Development on the Inuit of Northern Canada by Donald Mann.

The documents present a summary of selected literature on each subject. Inasmuch as each of the topics reviewed is immense, and in most cases scientific knowledge of the consequences of development is imperfect, the conclusions should be regarded with caution. The reports attempt to highlight areas of ignorance arid potential danger which could prove significant for Inuit welfare. In light of their exploratory nature, the documents should be read in the sequence noted above as material presented in the first three companion volumes is complementary. It is important to realize that Turkheim's report presents the first summary of hydroelectric potential in selected Arctic study areas and a synthesis of biological and physical impacts related to hydroelectric dams. Mann's report covers the socio-economic impacts associated with the biophysical changes explored by Turkheim, Brown, and van Diepen.

It is intended that these reports will be examined in conjunction with the renewable resource and other studies being conducted for the Inuit Tapirisat.

J. C. Day holds a B. Sc. degree in geology from the University of Western Ontario and a Ph. D. degree in geography (resources management) from the University of Chicago. He is currently Associate Professor of Geography, Faculty of Environmental Studies, The University of Waterloo. Within the general field of resource management, Dr. Day is especially interested in environmental impact or project assessment. In this context he has done research on the Rio Grande, U.S.A., The Parana, South America, and various reservoir and drainage projects in Ontario. He worked for a number of years in the North as a geologist and has been a consultant for or grant recipiant from the federal Department of Environment, Ontario Hydro, Canada Council and the National Research Council. Dr. Day is the author of two books and numerous scientific articles.

Si Brown obtained a B.Sc. in Geography and an M.Sc. in Biogeography from McGill University. Following this, he undertook a year's study in Resource Management at the University of Western Ontario, and is currently enrolled in a Environmental Planning Ph.D. program at the University of Waterloo School of Urban and Regional Planning. He is presently lecturing within the Faculty of Environmental Studies at the University of Waterloo. Mr. Brown's areas of specialization are in urban and regional environmental management and the impact of technology on ecological systems. His M.Sc. research dealt with the effects of crude oil on herbaceous plant communities, while his doctoral dissertation examines selected socio-economic and environmental impacts of large diamenter oil and gas pipelines in southern Ontario.

TABLE OF CONTENTS

SECTION

FIGURES

SUMMARY

Purpose of Report. --This report contains an abbreviated review of the findings of selected environmental impact studies related to arctic oil and gas development. Potential problems not satisfactorily considered in published studies, or which present serious hazards, are highlighted. Recommendations focussing upon knowledge deficiencies, environmental hazards, and potential alternative strategies are included.

1.0 CANADIAN ARCTIC OIL AND GAS RESERVES

1.1 Initial Discoveries. --While oil was first discovered in the Canadian Arctic in 1920, the petroleum industry focussed exploration and development in southern Canada until the late 1950's. By this time the federal government was encouraging northern fossil fuel exploration to expand tax revenues from the territories.

1.2 Recent Exploration.--In 1960, the petroleum industry acquired exploration rights to 60-million acres of the northern territories. By the end of 1972, this area increased to 447-million acres. Exploration expenditures rose from $30 million in 1968 to $200 million in 1972. Gas was found in the Mackenzie Delta and on Melville, King Christian, Thor, and Ellef Ringnes Islands. Oil was discovered in the Mackenzie Delta and on Ellesmere Island and Ellef Ringnes Islands.

1.3 Mackenzie Valley Gas Line. --Based on Mackenzie Delta gas reserves of 30-40 tcf the threshold volume required to support construction of a

48-inch gas line has been attained. In addition, should a Mackenzie aas line be used to transfer 1 to 2 billion cu.ft./day of Alaskan gas to southern markets, its profitability and lifespan would increase substantially.

1.4 Other Pipelines.--A Mackenzie Valley oil pipeline estimated to cost $3.38 billion (in 1972 prices) is under investigation. Representatives of the Polar Gas Project are considering an additional pipeline to connect the Arctic Archipelago gas fields with southern Canada.

1.5 Present Scope of Development.--Between 1970-73, approximately 300 exploratory wells were drilled in the Northwest Territories. The majority of these were concentrated in the Mackenzie Delta and adjacent waters. In recent months exploratory activities expanded to include some of the most remote and isolated Arctic Archipelago areas.

1.6 Federal Policies.--The federal government's northern policies are related to 4 major objectives. These are: to maintain the northern environment with due consideration to social and economic development; to promote the contribution of the territories to the Canadian social and cultural fabric; to advance local self-government; and to develop leisure and recreational opportunities, industry and resource exploitation.

In deference to these objectives, the government appears willing to proceed with northern oil and gas exploitation if development is subject to strict environmental and social controls.

2.0 EFFECTS OF OIL AND GAS DEVELOPMENT ON ARCTIC VEGETATION

2.1 Vegetation Characteristics.--Greater than 80% of the Low Arctic has a continuous plant cover. The warmest archipelago habitats are characterized by dwarf heath shrubs, low grasses, bryophytes and sedges. The High Arctic is a rock desert with discontinuous vegetation.

2.2 Vehicular Traffic. --permanent road construction may alter vegetation patterns through drainage modification and erosion. Temp- orary hauling tracks may lead to thermokarst, rutting, and vegetation destruction through cutting and scattering. Grass, sedge, and moss dominated communities are most susceptible to damage from vehicular traffic.

2.3 Vegetation Clearing_.--Forest and scrub clearing is acceler- ating with increases in the number of seismic lines, hauling tracks, airports, helicopter-landing pads, work camps, and borrow pits. In addition, approximately 32 square miles of'' predominantly forested land would be cleared to support construction of a Mackenzie Valley gas pipeline.

2.4 Fire Hazards. --Northern forest fires are caused by people and lightning in approximately equal proportions. It is probable that as settlement and development expand the proportion of forest fires caused by human carelessness will increase. This may lead to a suppression in the area of forested or forest-tundra lands and loss of numerous wildlife habitats. It is equally possible that improved fire protection will de- crease the number of fires and reduce" the pace of fire-related success- ional processes.

2.5 Non-Indigenous Species. --The effects of an accidental intro- duction of non-indigenous species into established arctic ecosystems are unknown. Should this occur, ecological reprecussions may be significant.

2.6 Gas Pipeline Ruptures. --It is possible that as much as l-billion cu. ft. of gas may be lost in a major arctic pipeline rupture. The most serious ecological impacts would be related to explosion - generated thermokarst and fire.

2.7 Oil Pipeline Ruptures. --Over the proposed Mackenzie Valley Oil pipeline lifespan an average of two spills annually of tens of thousands of barrels magnitude may occur. Freshly spilled oil is extremely phytotoxic. Through evaporation, oxidation, and bacterial degradation, oil toxicity decreases rapidly over time. Nevertheless, soil and plant contamination by petroleum products may retard vegetation growth for several years. Woody species generally have a higher regenerative capacity following crude oil contamination than mosses and lichens.

3.0 EFFECTS OF OIL AND GAS DEVELOPMENT ON BIRDS AND MAMMALS

3.1 Faunal Stress. --Development may increase stress levels on faunal. Primary stress sources may be linked to harassment by aircraft, construction and compressor station noise, interference with migration routes, ingestion of oil following spillage and habitat loss or impairment following forest cutting, construction activity, and fires.

3.2 Caribou. --Presently over 500,000 caribou reportedly occur north of 60° latitude. Should one or more herds encounter a settlement or construction camp they may: by-pass the noise and activity; halt their migration and refuse to move; or move through the construction zone possibly leading to injuries or deaths.

3.3 Muskox. --In a 1965 census, 9,890 muskox were recorded in Arctic Canada. Oil and gas wells and associated campsites may adversely affect Muskox if established within their primary feeding grounds. Due to their low reproduction rate, a population decline of even a few hundred could require generations to correct.

3.4 Bears.--The impact of terrestrial oil and gas development on the polar bear may be of only minimal significance. The greatest dangers facing the barren-ground grizzly are hunting and harassment pressures from settlement and construction camps.

3.5 Foxes and Wolves.--Foxes and wolves generally avoid contact with people and they may be expected to circumvent drilling rigs, pipeline installations, and other infrastructure facilities. However, abandonment of den sites may follow disturbance from cons"truction activity and related human contacts.

3.6 Birds.--More than 85 species inhabit the tundra of which 8 are full-time residents. Pipelines, compressor stations, helipads, airstrips, and communication towers may have a negligible impact on birds if they are carefully located. However, a significant impact could result from construction or drilling near nesting or feeding grounds. In addition, nesting waterfowl are extremely vulnerable to hunting. They require protection. Construction within 2-3 miles of raptor nests may lead to their abandonment.

3.7 Oil Contamination and Fauna---It is improbable that crude oil spills would have a significant effect upon terrestrial fauna. They are mobile, intelligent, and generally avoid oil contaminated terrain. None-theless, should some mammals become contaminated their closely-packed hairs would trap oil reducing their thermal insulation capacity. Ingestion may lead to gastritis and enteritis. Waterfowl feather contamination by oil, causes a loss of insulation and bouyancy. Swimming is impeded; flight can become impossible. Ingestion may cause lipid pneumonia, severe intestinal irritation, fatty changes in the liver, and adrenal enlargement.

4.0 EFFECTS OF OIL AND GAS DEVELOPMENT ON FRESHWATER RESOURCES

4.1 Characteristics of Ecosystem.--Many Arctic freshwater fish require different habitats for spawning, rearing, summerfeeding, and over-wintering. Large stream channels are utilized as Primary migration routes. Spawning and rearing are often restricted to back eddies and smaller tributaries. Because Arctic freshwater ecosystems are low in species diversity, small environmental disturbances could precipitate great changes in biotic characteristics.

4.2 Seismic Exploration. --The shock wave and accompanying pressure changes following seismic testing in stream channels are major causes of fish death and injury. Injuries may include tearing of muscle tissues, disruption of the nervous system, and ruptures of the abdominal cavity, internal organs, and blood vessels.

4.3 Gravel Bed Removal ---Gravel is used widely as a permafrost insulating material in road, pipeline, and building construction. Its removal from stream channels may destroy fry and incubating eggs, and mobilize gravel-retained silt leading to the destruction of similar habitats downstream.

4.4 Erosion and Siltation.--Vegetation clearing and improper construction methods may induce slumping, subsidence, and increased erosion. Near river banks this may drastically increase silt loads. The added sediment mav kill fish immediately downstream and destroy fish eggs and organisms eaten by fish through sediment burial.

4.5 Ice Thickening. --Compaction or removal of a snow layer on ice by machinery and vehicles may lead to ice thickening. In shallow streams the thickening may result in flow blockage causing depletion of winter water and food supplies for overwintering fish downstream.

4.6 Washing Compounds. --The proposed Mackenzie Valley Gas Pipeline will require 25,000-tons of methanol for cleansing and pressure testing. Methanol is highly toxic, Accidental spillage of the fluid could inflict severe ecological damages. Over 100-million gallons of a 1% methanol-water solution will be released into northern waters following pipeline testing if current testing technology is used. Evnironmental implications are unknown.

4:7 Sewage Effluents. --A northern construction camp of 600 to 700 workers may generate between 1,800 and 2,700 kilograms of industrial and municipal wastes oer day. If dumped untreated into rivers or lakes, strong algal growth will occur. This may eventually result in oxygen depletion and suffocation of aquatic organisms. Slow-discharging swamps or lagoons may provide the best waste disposal habitat.

4.8 Brine Disposal. --Some oil wells withdraw more than 100-cubic meters of brine with each cubic meter of oil. Rich wells extract less than 10% brine hut this value may rise with increasing age. Arctic brine disposal poses potentially serious problems. Because brine is biotically toxic, it cannot be directly discharged into fresh or salt-water bodies. Improper subsurface disposal may lead to thermokarst and the eventual contamination of freshwater aquifers. Ecologically-safe disposal methods have not been thoroughly researched.

4.9 Freshwater Oil Contamination. --Freshwater oil contamination may kill aquatic vegetation and invertebrates, eliminating fish food. Direct oil contamination at a concentration of 50 ml/1 is toxic to many freshwater fish.

5.0 THE IMPACT OF OFF-SHORE OIL AND GAS EXPLOITATION ON MARINE ECOSYSTEMS

5.1 Offshore Exploration. --The focus of oil and aas exploration is shifting from terrestrial sites to potentially rich tracts in Hudson Bay, Mackenzie Bay, the Beaufort Sea, and the Archipelago waters. To date exploration wells have been drilled in Hudson Bay, along the Beaufort Coast, in the Belcher Channel, and in Hecla and Griper Bay. More are planned.

5.2 Offshore Seismic Surveys.--Thousands of miles of offshore seismic surveys have been undertaken in recent years. Blasting with linear explosives causes injury or death to nearby fish. If these traditional seismic survey methods continue unabated, biological productivity of arctic waters will likely decline.

5.3 Conventional Rigs.--Most offshore drilling operations have been conducted from barges, drillships, and semi-submersible rigs. Provided that no wellhead leakage occurs, these are generally innocuous exploration methods with few negative environmental implications.

5.4 Ice-Island Wells.--Direct ice platform drilling is attracting increased attention due to simplicity and low cost. This method of exploration is inherently unstable. Lateral ice pressures may shear the drill pipe, possibly leading to an unrestricted flow of subsurface petroleum or gas for many months.

5.5 Artificial Islands.--Several artificial islands have been constructed in Mackenzie Bay. They have been used as "terrestrial" platforms from which to drill for oil and gas. The large volume of fill withdrawn from the sea floor for their construction may have adverse biological implications for benthic biota. Plastic and metallic materials used in shoreline slope support are a potential hazard to whales, polar bears, seals and walrus if the debris breaks loose from disintegrating islands.

5.6 Blowout Risks.--On a global scale, 47 blowouts were reported for 200,000 wells drilled. In the Arctic 2 blowouts were reported but both involved relatively non-destructive gas deposits.

Hydrocarbon gases may contain impurities such as hydrogen sulfide. These are toxic to aquatic biota even in minute concentrations. Gas fields with large quantities of these impurities represent a particular danger.

Methane, which constitutes the bulk of natural gas deposits dissipates rapidly in water or air and it is relatively harmless.

5.7 Crude Oil and Marine Biota.--Effects of oil spills on salt-water fish are variable. Fish eggs and larvae are particularly sensitive. They may be killed by concentrations as small as 10^{-4} ml/litre. Zooplankton experience increased mortality following crude oil exposure. Whales could ingest finely dispersed oil while filter feeding on planktonic crustaceans. Gastro-intestinal diseases may result.

6.0 CONCLUSION>

6.1 The Prospect.--The pending arctic oil and gas boom will dramatically change the face of Canada's least culturally disturbed land-scape. However, if resource policy were oriented towards a cautious exploitation rate based upon sound environmental management guidelines, development impacts may be minimized.

6.2 The Choice.--The Inuit may demand a participatory role in northern energy exploitation. In so doing, they might successfully modify the extent of development in areas most threatening to their way of life. Yet, active participation might also compromise their lifestyle in exchange for fuller economic integration into the North American industrial society. Whatever course of action they choose, fundamental aspects of their destiny will be irrevocably altered.

1.0 CANADIAN ARCTIC OIL AND GAS RESERVES

1.1 Report Objectives

In anticipation of large-scale arctic resource exploitation, government and industry are today committing millions of dollars and thousands of man days to investigate the environmental impact of northern hydrocarbon energy development. Implications of proposed oil and gas extraction programs are examined at great length within these studies. This report contains an abbreviated review of the findings of selected environmental impact studies related to arctic oil and gas development.

Potential problems which have not been satisfactorily considered in published studies or which may present serious hazards are highlighted. A series of general recommendations focussing upon these problem areas follow each discussion. These recommendations were intended to serve as suggestions for the Inuit in their negotiations for a territorial land-claim settlement with the Canadian federal government.

1.2 Initial Discoveries

In 1920, the first commercially valuable deposit of petroleum oil in the Canadian Arctic was discovered at Norman Wells. The total estimated recoverable reserve was only 60-million barrels. But the ramifications of the discovery far outweighed the limited volume of oil detected. It suggested that other arctic sedimentary basins might also contain large oil or natural gas deposits, and that further exploration was warranted. Nonetheless, the petroleum industry focussed its attention in southern Canada until the late 1950's. Here exploration costs were lower and the sources of supply comparatively nearer to potential markets.

It was not until the late 1940's that circumstances made arctic oil and gas exploration a more economically attractive investment. First, the federal government commissioned a detailed aerial photography program for the north. This provided geologists with an opportunity to study areas of potential interest with relative ease. Second, the inaccessibility of the Arctic was greatly reduced with the construction of numerous weather and military installations, each equipped with small airstrips. The earliest of these were on Ellesmere, Cornwallis, Prince Patrick, and Ellef Ringnes Islands.

Through these actions, the federal government passively, and later actively, encouraged northern fossil fuel exploration. Moreover, the Department of Indian Affairs and Northern Development (then the Department of Northern Affairs and National Resources) wanted to demonstrate Canadian sovereignty in the Arctic and to expand tax revenues from the territories so as to offset the millions of dollars it annually dispersed in housing and social welfare benefits. The exploitation of oil and gas reserves was seen as an excellent way in which to meet these goals.

1.3 Exploration in the Sixties

In April 1960, the federal government adopted a set of policies designed to regulate arctic oil and gas exploration. After years of relative indecision the government had defined its position and a major element of uncertainty was removed. The petroleum industry immediately responded.

Within a few weeks, the industry requested exploration rights to 60-million acres. The first well was drilled at Winter Harbour on Melville Island in 1962. It was dry. Results of subsequent drilling have been mixed. In 1967, a consortium of 19 petroleum corporations, in partnership with the national government holding a minority 46% interest, created a joint exploration venture known as Panarctic Ltd.. Panarctic could not commence extensive drilling operations until 1969. By this time, the oil and gas rush was on.

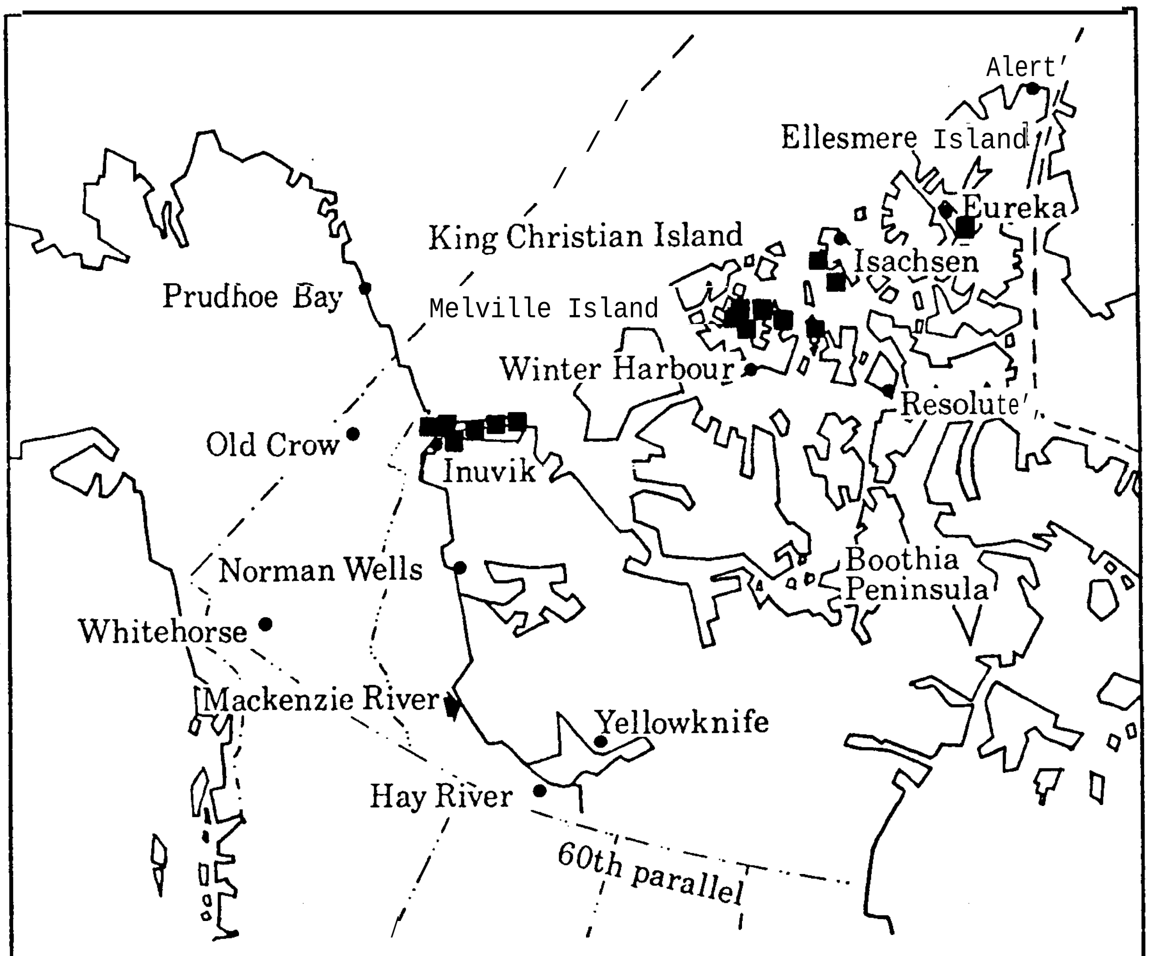
In 1968, Atlantic Richfield discovered the estimated 10-billion barrel oil field 200 miles west of the Canada-Alaska boundary at Prudhoe Bay. It was generally believed that the geologic features responsible for the Prudhoe Bay field extended eastward along the Canadian arctic coastline. Not surprisingly, Canadian acreage under permit doubled in 12 months, and by the end of 1972, exploration permits for 447-million acres were issued.(53, 8) Simultaneously exploration expenditures rose from $30 million in 1968 to approximately $200 million in 1972.

The increase in arctic investments was potentially profitable. Panarctic discovered large gas reserves on Melville, King Christian, Thor, and Ellef Ringnes Islands. They also found oil on Ellesmere Island and Ellef Ringnes Island. In the Mackenzie Delta and the Beaufort Sea coastline, Imperial Oil found significant petroleum concentrations at Atkinson Point, Mayogiak, Atutuk and Ivik, and gas at Ivik, Malik, and Taglu, while Gulf and Mobil discovered gas at Parson's Lake. Principal discovery sites are illustrated in Figure 1.

1.4 Economic Feasibility of a Mackenzie Valley Gas Pipeline

As of July, 1974, 88 wells were drilled in the Mackenzie Delta with 19 successful tests to yield 1:5 success ratio. In mid-1974, estimated delta gas reserves were placed at 30- to 40-tcf.(41, 8) Although this represents an enormous energy reserve, the profitability of its

Figure 1. Principal Exploration Points in the Canadian Arctic[a]



■ Indicates natural gas or oil discovery.

[a]Adapted From Reference No. 25, p. 18.

extraction and transportation to southern markets remains in doubt. This largely reflects the enormous cost of arctic energy exploitation.

It is estimated that between 1971 and 1974, total exploration costs in the Northwest Territories were in excess of $947 million (36, 28). Average terrestrial drilling costs per foot (1972 prices) are only $16.75 in western Canada, but $236.72 in the Northwest Territories (32, 25). In addition, the estimated cost of the Mackenzie Valley Canadian Arctic Gas Pipeline (Fig. 2), is $5.7 billion in 1973 prices, or approximately $2.2-million per-mile (38, 8).

In view of these enormous expenses, Mackenzie gas fields would have to be gigantic to be profitable. From the oil industry's viewpoint, this prerequisite has already been met. Based on delta gas reserves of 30-40 tcf, the total investment for the projected pipeline would be less than 10-cents per Mcf. Present reserves indicate that the threshold volume necessary to justify gas development in the Mackenzie Delta has already been reached. This assessment is based on a projected transfer rate of 4.5 billion cu. ft./day or 1.64 tcf/year. If this transport rate were extended over a projected 22-year pipeline lifespan, only 36-tcf of natural gas would be required to meet the threshold volume. This is 4-tcf less than present maximum estimated reserves. Under these circumstances, the federal government estimates that the petroleum industry may realize a 20% rate of return, after taxes, on its arctic investments (25, 26).

Although it appears that a Mackenzie gas pipeline would be a profitable venture, there are several complicating factors. Economic viability of the gas line is based on the assumption that the indicated reserves can be extracted efficiently. Seismic studies indicate that the shallow and potentially rich Beaufort waters were subjected to intense thrust folding which created many structural traps. This could conceivable hamper extraction, and increase costs. In addition, future delta well-head prices have not been set. As a consequence, the discounted rate of return to the oil companies cannot be positively established. Also no definitive U.S.A. policy statements are available concerning the possibility of transporting large quantities of Prudhoe Bay gas through the Mackenzie line (34, 15). Should the Mackenzie line be used to transfer 1- to 2-billion cu.ft./day of an estimated 26 tcf of Alaskan gas to southern markets, its profitability and lifespan would be substantially increased.

Finally, in view of present inflationary pressures and a weakening economy, final investment costs, and the ultimate consumer demand vis-a-vis other energy sources cannot be accurately ascertained. These unsolved problems and unanswered questions represent formidable risks to the multi-billion dollar investment: risks that could spell the difference between substantial profit or a net loss.

1.5 Other Proposed Pipelines

In the mid-1960's, a group of 16 oil and gas related companies formed the Mackenzie Valley Pipeline Research Ltd. Corporation. Its purpose was to investigate the profitability of constructing an overland oil pipeline to carry Prudhoe Bay oil to southern markets through the Mackenzie Valley. The Americans selected a trans-Alaskan route for their oil but research continued in the hope that enough petroleum might be found in the Mackenzie Delta to warrant construction of a 48-inch oil line adjacent to the proposed 48-inch Mackenzie Valley Gas Pipeline.

Capital construction costs for the oil pipeline were estimated at \$3.38-billion in 1972 prices[25, 43]. The threshold volume required to make the oil line feasible was considered 2- to 3-billion barrels[53, 10]

As of mid-1974, estimated delta reserves were placed at 6-billion barrels, or approximately twice the volume necessary to insure complete " utilization of the line through its projected lifespan (41, 8). In comparison, total proven oil reserves throughout southern Canada are only 12-billion barrels (53, 10).

The ultimate recoverable potential for arctic crude oil may be much higher than present indicated reserves. This can be assessed by calculating the total material volume in Canadian sedimentary basins, multiplied by a petroleum yeild factor based on extraction statistics in similar basins elsewhere in the world. Commutations of this type by the Canadian Petroleum Association suggest that the potential recoverable oil reserve for all Canadian sedimentary basins,including the continental shelf, is approximately 121-billion barrels of which half ultimately may be found in the Mackenzie Valley, the Arctic Archipelago, and adjacent waters (53, 7).

The oil is there but again, the profitability of its extraction is subject to doubt. Unlike the cold buried gas line, the oil would be transported in a gravel-supported, insulated hot line. To reduce potentially serious environmental hazards related to heat loss, the line may require extra-thick heavily insulated pipe. In permafrost areas, hundreds of miles of pipe may need pile supports. Such modifications would substantially raise construct"ion costs, lower profitability, and possibly increase the price of the oil bevond marketable levels.

Intense Arctic Archipelago exploration mav also lead to future exploitation of its gas and oil reserves. Industry spokesmen predictthat in early 1976, representatives of the Polar Gas Project will file an application to construct a natural gas pipeline from the arctic islands to southern markets (37, 12). The first phase of the estimated $6 billion project would consist of a 3,000-mile, 48-inch pipeline, from Melville

Island through the eastern Arctic terminating in either Montreal or the Niagara-Toronto region (Fig. 2). A second phase would tie in other northern fields on Ellesmere, King Christian, Axel Heiberg, and Ellef Ringnes Islands. To profitably undertake the project, a threshold volume of 36-tcf would be required.

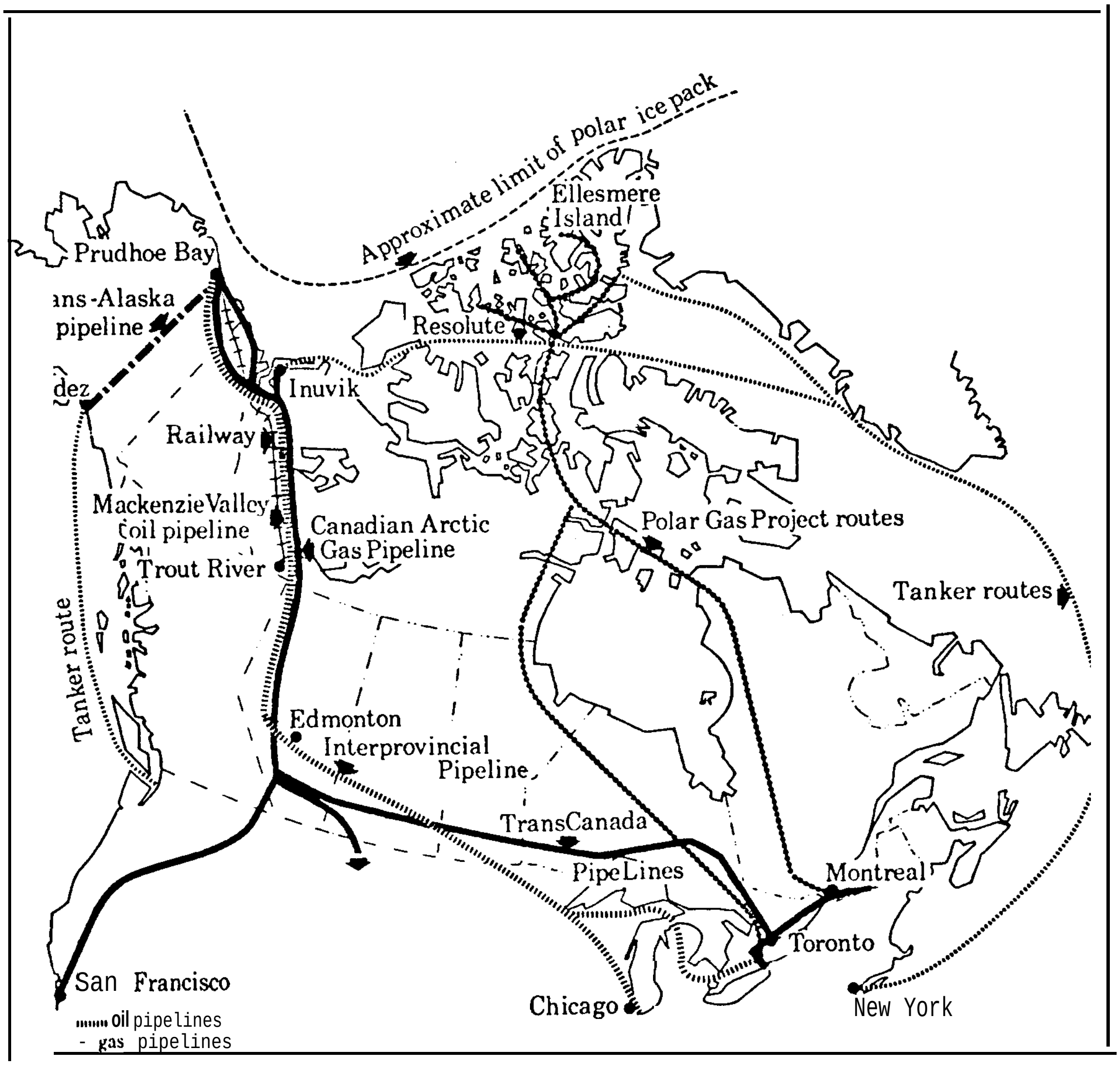
If a pipeline network were to be constructed between the arctic islands, it would necessitate laying approximately 540-miles of 36-inch diameter pipe coated with up to 5-inches of concrete in water up to 900-feet deep [30, 70]. Serious environmental hazards are inherent in such an undertaking.

Engineering technology for pipelaying in ice-infested arctic waters has not been sufficiently developed. Ice-scouring is a formidable danger; direct construction costs would be enormous as would the costs of maintaining backup harbour facilities and a logistical support infrastructure. Given millions of dollars annually in research support over a decade, many engineers believe that ice scouring, which is potentially the most serious problem, can be overcome. But for the present, an adequate solution has not been formulated to counter this and other problems associated with an inter-island pipeline network.

1.6 The Present Scope of Development

In the 1970-73 period, exploratory drilling rigs were established at approximately 300 locations in the Northwest Territories [32, 25]. Attention focused primarily in the Mackenzie Delta and adjacent Beaufort Sea tracts where the largest concentration of well sites presently exists. However, in the past 24 months there has been an acceleration toward establishment of exploration rigs in the most isolated Arctic Archipelago areas.

Figure 2. Proposed Transportation Systems for the Arctic[a]



[a]From Reference No. 25, p. 33.

The ultimate manifestation of this process occurred in March, 1974, when the Adeco #4 rig, under contract to Panarctic, was spudded on the desolate Neil Peninsula in the northwestern extremity of Ellesmere Island. Adeco #4, 1200-miles northeast of Inuvik, is the most northerly wildcat in the world. And despite its isolated location, many components were transported to the site by truck. In February, 1974, a convoy of 10-ton trucks made a 96-mile, 28-day journey from the Taleman J-34 drill site near Eureka, overland and across the frozen Greely Fiord to the Neil Peninsula (39, 13). There, access roads and other elements of a transportation and communication support infrastructure were constructed.

Following this, 315 tons of additional equipment was heliported to the site in 150 excursions, each a 200-mile return journey from the Taleman J-34 rig. One sealift of supplies was brought in from another well site at May Point on Axel Heiberg Island. Direct Hercules aircraft support is anticipated in the near future (39, 16).

The Adeco #4 development is highlighted to illustrate that even in the most inaccessible arctic areas intense development with an accompanying potential for ecological stress is proceeding rapidly. Similar new drilling sites are being established today in the Arctic approximately once a week. Seismic lines, storage dumps, access roads, airstrips, port facilities, quarry pits, and a host of associated landscape changes are affiliated with such developments. Unfortunately the low biomass and productivity, the limited growing season, the permafrost, and the general fragility of arctic ecosystems, suggest that even if the most rigid environmental protection standards were adopted, ecological impacts of arctic oil and gas development would still be considerable.

Industry spokesmen often cite the fact that there are 470,000 square miles of Canadian territory north of Latitude 60° which are within sedimentary basins. It is claimed that only 1,350 sq. miles (0.3% of the total) would be required for roads, drilling rigs, pipelines, campsites, and associated works. They conclude that since 99.7% of these areas would not be directly disturbed, ecological effects would be minimal [42, 124].

Such conclusions cannot be justified if one considers that a number of critical wildlife feeding, reproductive, migration, and staging sites may be encompassed in a very small area. As an example, in late summer almost all of the lesser snow geese in the Americas crowd into Beaufort Sea coastal areas. In such areas, even limited environmental stress could have serious implications.

1.7 Federal Policies and Objectives vs. The Proposed Pipelines

In the 1950's and early 1960's, the federal government's objectives in Arctic Canada as reflected in policy statements and legislation were:

1)"to maintain sovereignty through effective occupation;"

2)"to maximize the contribution of Arctic Canada to the Gross National Product, and to the national welfare through commercial exploitation of its resources;"and

3)"to raise the quality of life and the standard of living for northern residents"[53, 16].

For the 1970's, the policy is essentially a refinement and an extrapolation of the earlier objectives. In an effort to broaden its northern development strategy through the inclusion of specific social and environmental goals, the national government now has committed Canada:

1)"to maintain the northern environment with due consideration to social and economic development;"

2)"to promote the potential contribution of the Yukon and the Northwest Territories to the Canadian social and cultural fabric;"

3)"to advance local self-government;"

4)"to develop fully northern leisure and recreational opportunities, light industry, and renewable resources, particularly those which offer economic advancement to native communities"(53, 16-17).

But the government now faces a potentially embarrassing situation. Southern Canadian energy reserves are dwindling rapidly. In the foreign market, embargoes, artificial shortages, and political extortion from the Organization of Petroleum Exporting Countries (OPEC) cartel quadrupled the market price of petroleum between October 1973 and February 1974. On one hand, the government stands committed to the preservation of the northern ecological equilibrium and "the protection of the native cultural character and social fabric. Simultaneously, it is committed to the provision of adequate energy supplies at reasonable cost to southern consumers.

Based on historical precedent, the voting structure and, most importantly, the spatial distribution of economic and political power, it is likely that, should the need become acute, the many proposed arctic oil and gas development programs will be implemented whatever the financial, socio-cultural, and environmental implications.

At best, it appears that the government is willing to proceed with oil and gas development, provided it is subject to strict regulations designed to limit the impact of the development on native lifestyles and arctic ecology. It is clear that a dichotomous approach to northern development results from this position. As an example, the allocations for northern roads have recently been doubled to allow for an early completion of the infrastructure necessary for resource exploitation. Simultaneously, the qovernment initiated extensive studies and issued policy statements intended to maintain native cultures and protect the arctic environment.

2.0 THE EFFECTS OF OIL AND GAS DEVELOPMENT ON ARCTIC VEGETATION

2.1 General Vegetation Cover

Greater than 80% of the Low Arctic above the treeline has a continuous plant cover, dominated by grasses, sedges, lichens, mosses. and dwarf shrubs. Discontinuous tree and shrub communities grow in protected valleys along river terraces, steep slopes, and adjacent to stream channels. Further north, the warmest Arctic Archipelago habitats are characterized by a flora of dwarf heath shrubs, low grasses, bryophytes, and sedges. The High Arctic is essentially a rock desert with discontinuous vegetation patches. Here in low lying and protected regions, exemplified by areas of Western Queen Elizabeth Islands, as many as 21 floral species are recorded, most of which are lichens and mosses[3]. Exposed High Arctic environments are completely devoid of plant cover.

2.2 Effects of Vehicular Traffic

Few permanent all-weather roads exist north of Latitude 60°. At Present, a majority of government funds for arctic road development are concentrated in the Mackenzie and Dempster Highway projects. The impact of these roads on vegetation is largely restricted to the right-of-way corridor. Early roads were prepared by blading the active layer into a strip which served as a road base. Unfortunately, this procedure induced thermokarst and subsequent erosion.

Recent research on road-building Procedures to minimize environmental impacts recommends that 1.5 to 2.0 meters. of gravel should be placed directly on top of the undisturbed tundra to avoid thermokarst[3s 5], In forested areas, vegetation damage and erosion are minimized by:

1) cutting a right-of-way swath no larger than the road width;

2) leaving tree stumps intact; and

3) using chipped logging debris as a road base insulant and erosion-control agent(49).

Aside from logging, filling, excavation, and other processes directly associated with road construction, other significant vegetation disturbances related to major road developments arise when ecosystems are disturbed through drainage changes. Because major highways are permanent, culverts are placed at sufficient intervals to limit pending and washouts. Nevertheless, some ponding and modification to drainage systems may be associated with road construction. These in turn may alter vegetation patterns in some regions.

Much more severe vegetation disturbances are associated with temporary hauling tracks, winter roads, and open tundra where vehicles move equipment and supplies over inadequate road beds. On the open tundra, lighter vehicles cause less damage than heavier vehicles and the degree of ecological disturbance varies directly with the amount of traffic. In some cases, a single pass with a large motorized vehicle can leave tracks visible for several years. Thermokarst is often induced by track ruts although permafrost table subsidence usually amounts to no greater than one or two inches(12, 22).

The susceptibility of a soil to rutting is related to its texture and moisture content. In the High Arctic polar desert little or no rutting occurs if soils are dry. Further south, finer textured soils, particularly if near saturation, are especially prone to rutting although the propensity for such disturbance decreases as coarseness increases(3, 5).

The impact of rutting on vegetation is highly variable. On Melville and King Christian Islands, and the Sabine Peninsula; extensive rutting occurred during the transfer of supplies and, equipment to drilling rigs. In some cases, there was little effect on vegetation. Initially, dominant grasses, sedges and mosses were flattened and some subsidence occurred. But inasmuch as healthy vegetation completely recolonized these tracks the following growing season, long-term effects on the flora appear negligible.

In other areas where deeper rutting occurred, or where more than 10% of the vegetation was destroyed through cutting and scattering, no significant recoverywas apparent over two subsequent growing seasons[12]. In addition, serious damage resulted from the reuse of abandoned tracks or old seismic lines. In these areas the recolonizing vegetation, which often includes species of *Carex*, *Eriophorum*, *Ranunculus* and *Petasites*, is intolerant of disturbance. Reuse causes severe degradation[14,>1].

Intensive vehicular traffic through low-lying grass, sedge, and moss marshes represents one of the most serious hazards. Soils associated with these habitats are fine textured and water saturated. They often experience severe rutting. Much of the vegetation within these ruts is killed. This may in turn destroy critical muskox range. Although they occupy less than 2% of the polar desert, these relatively productive marshes are widely scattered, occurring as far north as Devon, Axel Heiberg, and Ellesmere Islands. Until recently, there has been no effort to map and protect these areas of critical biologic importance. Consequently, through ignorance they could be subject to heavy vehicular traffic in the course of arctic development.

Winter transportation often minimizes vegetation damage. When the active layer is frozen transportation of supplies to drilling rigs is frequently achieved through construction of smooth-surfaced compacted snow roads. Minor damage to herbaceous vegetation may be expected from top crushing if such roads are only used for one season. Under these circumstances almost complete revegetation will occur the following growing season.

In some areas problems arise if extensive preliminary road-gravelling is undertaken in hummocky terrain to fill minor depressions. Bliss and Peterson (1973) report that revegetation may be difficult if such gravel beds are greater than 15 cm. in depth. However, this viewpoint may be at variance with observations in Alaska where gravelled and thoroughly compacted roads soon became revegetated(49, 51). They further report that up to 180, 20- to 30-ton loads can be transported over adequately covered snow roads with little damage to underlying vegetation. Unfortunately, in light snowfall areas snow-gathering vehicles are used to deepen temporary snow-covered hauling tracks. This management action produces a classical case of a cure which is worse than the disease. In earth hummock and polygon areas, snow-harvesting equipment can seriously damage underlying vegetation through churning, cutting, and scattering(24, 234-236).

There has been experimentation with a variety of other construction techniques for temporary roads and hauling tracks. Some roads intended for brief but intensive summer use were built with an 18-inch gravel surface underlain by polystyrene boards placed directly on top of the active layer(35, 20). On muskeg, corduroy roads were constructed by placing whole trees across roadbeds overlain by smaller trees, brush, and fill (53). The impact of these experiments has not been adequately assessed to date.

Areas of Concern and Recommendations

1) The period for which snow roads may be used is presently unregulated. Substantial evidence suggests that if snow roads are used intensively for more than two seasons, vegetation recovery may be severely retarded. Use should be limited to one season to avoid injury to plant communities.

2) Periods for road construction are often defined arbitrarily. It is generally agreed that road construction is best undertaken in winter, but there are no criteria to define the beginning of winter. Road construction should only commence in the presence of at least 8-inches of snow, and several inches of frost penetration.

3) Snow harvesting for road construction should generally be avoided, particularly in areas where micro-topographic undulations and earth hummocks are prominent.

4) Tracked vehicles whose effects are particularly disruptive should be replaced, whenever possible, with vehicles having floatation-t.ype tires.

5) Particularly sensitive plant communities, and those highly valued as faunal food sources should be mapped. Whenever possible, vehicular traffic should be avoided in such areas.

2.3 Vegetation Clearing and Cutting

Approximately 32 square miles of predominantly forested land will be cut and cleared along the length of the 120-foot wide right-of-way planned for the Mackenzie Valley Pipeline. Additional clearing for seismic lines, hauling tracks, helicopter landing pads, airports, work camps, borrow pits, etc. is currently in progress on a moderate scale, and may in the future accelerate as the exploitation of arctic oil and gas reserves increases. It is estimated that 6-million board feet of commercial grade lumber will be required to support the construction of a Mackenzie Valley Gas Pipeline(24, 73). This volume of wood is small in comparison with the approximately 2-billion cubic feet of merchantable timber in Mackenzie Valley forests(10, 4-5). However, inasmuch as this high-grade timber requires 100 to 150 years to reach maturity, the effect of large-scale cutting operations may have a long-term impact.

Wooded areas are also subject to extensive cutting during seismic exploration. The forested area directly south of the Mackenzie Delta is criss-crossed by a large number of seismic lines. Within these seismic corridors soil subsidence of 45 to 65 cm is common. The active layer depth may be extended 10 to 20 cm. Revegetation within the corridors is slow. Species which existed on these sites prior to clearing have little ability to recolonize the disturbed terrain. Initial revegetation within such disturbed sites is often dominated by species of _Calamagrostis_, _Arctagrostis_ and _Arctophilia_(9, 2, 53, 136). Implications of such modifications in plant community composition are not well understood.

Areas of Concern and Recommendations

1) Despite the prospect of large-scale cutting and clearing in the Mackenzie Valley, the Canadian Forestry Service stated as late as March, 1974 that "Little is known about the success of various methods for establishing or regenerating forest and other vegetation (in the Mackenzie Valley). Natural plant succession is also poorly understood"(23, 81). Until better knowledge of the regenerative capacity of northern forests is acquired, large-scale cutting programs should not be permitted.

2) With the extension and ultimate completion of the Dempster and Mackenzie Highways strong pressure to exploit newly accessible forest resources will likely occur. Management plans for northern forests have not been fully developed. Accordingly, strictly protected forest reserves should be established until adequate management guidelines are established.

3) For aesthetic reasons, cuttinq should be prohibited within the immediate vicinity of highways, settlements, pipeline, and utility corridors.

4) Potentially serious unresolved differences between good forest management and good highway construction practices are evident. Northern highway engineers suggest that logging debris and slash be used on road banks as erosion-control agents. Yet, forestry service representatives claim that freshly-cut trees and slash, if left unremoved, provide excellent breeding grounds for destructive bark beetles and wood borers[23, 85]. An acceptable solution to this problem has not been achieved, although highway construction and pockets of standing slash continue to spread over the Low Arctic landscape.

5) Mass-clearing operations, especially along relatively steep slopes, stream banks, and in areas subject to permafrost can increase the risk of erosion, slope failure, and siltation of water bodies[24, 191-195]. Clearing 'in these sensitive areas should be avoided.

2.4 Fire Hazard

The role of fire as an ecological process has been the subject of controversy among environmentalists. It is generally recognized that fire plays a positive role in maintaining ecological balances. With respect to the proposed pipelines, a significant ecological disequilibrium may occur if either the acreage of burnt forest per annum increases sharply, or conversely, if exhaustive fire prevention and containment practices are developed to protect arctic pipelines and settlements.

Due to low biomass, saturated soils, and a discontinuous plant cover, open tundra fires are not as common as those within northern boreal forests and forest-tundra (3, 6). Unfortunate y, the burn 1 evel in northern forests which would he sufficient to maintain an ecological balance, and allow moderate community rejuvenation through the introduction of heliophytes on burnt ground, is unknown. Consequently, proper management" guidelines cannot as yet be devised. It is almost certain however, that as a result of carelessness the frequency of arctic forest fires will increase as settlement and development expand. This viewpoint is supported by recent research in the Mackenzie Valley which indicates that northern forest fires are now caused by people and lightning in approximately equal proportions (21, 35)*

If the number of forest fires were to increase, it is possible that in some regions, destroyed plant associations may never reestablish themselves. This is particularly true near the tree line. Research in the Soviet Union and in northern Manitoba suggests that fires in a discontinuous forest-tundra ecotone will ultimately lead to an advance of the tundra, and a consequent reduction in the area of forested land (21, 4). The implications are potentially serious. For should the number of fires in the vicinity of the Mackenzie Valley tree line increase substantially, the previously existing forested land may not regenerate for centuries, resulting in permanent loss of certain wildlife habitats.

Most vegetation is destroyed in fires, although the roots of some dwarf trees such as white birch, willow, and alder may survive. In wet soils the vegetation destruction is less severe. Tundra fires temporarily eliminate the insulating effect of ground cover which, in turn, may deepen the active layer within two growing seasons by 50 to 100 percent [16, 15]. Initially, the after-fire revegetation of dry areas is dominated by mosses and liverworts. As the moss layer builds up over many years the permafrost table rises and the active layer depth decreases to pre-fire levels. In moist regions cottongrass and sedge tussocks often survive fires and later thrive in the absence of competition from less fire-resistant species [15, 61].

Areas of Concern and Recommendations

1) The ecological impact of improved fire protection is not well understood. The absence of fire may, over many years, lead to a reduction in ground cover of lichen species consumed by caribou [18, 136]. Accordingly, where it is desirable to maintain adequate long-term food for caribou little should be done to interfere with natural fires in the absence of a direct threat to pipelines, storage facilities, settlements and infrastructure components.

2) Although some authorities (e.g. Bliss and Peterson, 1973) suggest that fires on the open tundra are rare, this has recently been disputed (Wein, 1974). Recent research indicates that as much as five years may be required to attain 10% revegetation following tundra fires [21, 1]. In response to the absence of vegetation, birds and rodents often abandon the burnt terrain. In turn arctic fox populations, which prey upon birds and rodents, may decline. Consequently, in some regions the preservation of tundra wildlife populations may require strong fire prevention and containment measures.

2.5 The Introduction of Non-Indigenous Species

Throughout the world, both favorable and unfavorable ecological repercussions are associated with the introduction of non-indigenous species into established ecosystems. The effects of an accidental or purposeful introduction of new plant species to the tundra are presently incalculable.

Areas of Concern and Recommendations

Currently, no controls exist over the possible introduction of exotic species. Despite harsh environmental conditions, it is suspected that many hardy plant species in southern Canada could survive in the Arctic. Because the effects of a potential infusion of new species are unknown, a significant element of risk is present. Care should be taken to avoid the introduction of such species until extensive examination of the ecological consequences is undertaken.

2.6 The Effects of Gas Pipeline Ruptures

Should arctic gas reserves be exploited, occasional gas pipeline ruptures may occur. In southern Canada most major gas pipelines experience ruptures. These" are usually caused by manufacturing defects, corrosion, incorrect installation, improper operating procedures, and damage by excavating equipment. Self-ignited fires are associated with more than 50 percent of investigated gasline ruptures in the south[17, 6]. In all instances, such fires are accompanied by explosions which often blow out or zipper tens of feet of pipeline. The force of these explosions may scatter debris for more than 100-feet from the rupture point. Craters exceeding 25-feet in depth often develop; diameters up to 100-feet have been recorded[17, 34).

Should no explosion occur, the gas, which is largely methane, tends to dissipate into the atmosphere causing little long-term damage to surrounding vegetation. Short-term effects are not documented. But it is known that the volume of gas expelled in a rupture can be very great. The design capacity of the Polar and Mackenzie Valley gaslines is approximately 4.5-billion cu. ft./day, at a pressure of 1,700-lbs./sq. in.[24, 34]. If block valves were placed at 24-mile intervals, complete between-valve depletion would require one hour during which 1.051-billion cubic feet of gas would be lost. The depleted volume is based on data in Reference No. 23. Canadian Arctic Gas Pipeline Ltd. estimates that a complete between-valve depletion would only result in a loss of 250-million cubic feet of gas,

Although the short-term ecological impacts of massive arctic gasline ruptures are not thoroughly investigated, it is believed that the most significant environmental problems would be related to explosion-generated thermokarst and fire. Fire-damaged permafrost may extend over several acres and this could lead to increased erosion.

The response of vegetation to natural gas exposure is not well understood. Research in Kansas and New York indicates that gas-saturated soils have a detrimental influence on vegetative growth[1, 41-44]. Such soils frequently experience an increase in porosity and water retention with a corresponding decrease in bulk density. Substantial increases in the level of total carbon, exchangeable manganese, and exchangeable ferric iron are observed[1, 41-44].

Areas of Concern and Recommendations

1) Because detailed investigations of the short-term biotic toxicity of massive gas leaks are not available, an evaluation of the potential environmental impact is difficult.

2) The Probable degree of thermokarst, and the extent of erosion following arctic gas induced fires, is unknown.

3) As a precautionary measure, settlement in the immediate vicinity of arctic gaslines should be discouraged where the lines are most subject to stress such as seacosts, riverbanks, and points of inflection on moderate and steep grades.

2.7 The Effects of Oil Pipeline Ruptures

Based on existing records of corrosion, leaks, and pipeline failures, it is estimated that over the lifespan of the proposed Mackenzie Valley Oil Pipeline, an average of two spills annually of tens of thousands of barrels magnitude will occur[20, 8]. Freshly spilled oil is extremely phytotoxic. The toxicity decreases rapidly over time for the most lethal components of crude oil also tend to be the most volatile (those with the lowest molecular weights and the shortest hydrocarbon chains). Some phytotoxic components are water miscible, others evaporate, while virtually all are subject to bacterial degradation. Exposure to ultra-violet radiation of less than 4,000 angstroms promotes oxidation; water and carbon dioxide are the end products. Crude oil, when freshly applied to a terrestrial ecosystem, is a dynamic substance whose chemical characteristics and toxicity are subject to much modification. After an extended period, which may span several growing seasons in the Arctic, an involatile, non-toxic residue is produced.

The effects of spillage from oil pipelines on arctic vegetation recently have been studied intensively. In some instances, contamination of soils and plants by petroleum products retards vegetative growth for long periods. Fifteen years after spillage of jet fuel along the Alaskan Haines-Fairbanks pipeline, little vegetative recovery was observed[3, 15].

Other experimental diesel fuel spills on the Canadian high-arctic tundra indicate that within two growing seasons vascular plants "visibly recover" (albeit at a slow rate), following contamination levels of .05 and .25 litres/m^2 [9, 151, 156]. Recent summer experimental crude oil spills in the Tuktoyaktuk area suggest that dwarf shrub species, especially those of Betula and Salix, have a greater regenerative capacity than sedges [151, 672-682]. In these tests lichens were particularly sensitive to oil and none recovered in the following growing season. However, total vegetative recovery following applications of 0.25 to 1.50 cm. of oil per unit area varied from 20-55 percent.

The high regenerative capacity of woody species in comparison with lichens and mosses may reflect reestablishment from the meristems of their subsurface rhizomatous tissues. In contrast, mosses and lichens have no true roots or protected terminal buds. Consequently, they have little built-in morphological protection from crude oil contamination. This viewpoint is supported by observations of the regenerative behavior of grasses and sedges vis-a-vis herbaceous and woody species following experimental terrestrial oil spills in southern Canada [4].

Crude oil penetrates through epidermal cell layers upon contact with leafy tissues. It invades through inter-cellular spaces and may travel at 4-5 cm/hour [2, 88]. Cell membranes are damaged by contact with hydrocarbon chains. This permits leakage of cell contents and provides a pathway for the entry of oil through the compound middle lamellas and secondary cellular walls. Necrosis of plant tissue results. Among oil-contaminated plants the rates of photosynthesis and transpiration are known to decrease. Interference with transpiration is probably due to stomatal blockage. This may be responsible for decreases in photosynthesis although a disruption of chloroplast membranes, or inhibition caused by

an accumulation of end products, could be contributing factors [2, 88].
Internal translocation is also inhibited by the presence of oil.

Crude oil phytotoxicity stems from its capability to seriously disrupt the vital metabolic and Physiologic processes indicated above. Not surprisingly, the regenerative capacity of oil-contaminated plant communities is dependent upon the contamination level. The upper contamination limit in the Low Arctic which will permit regeneration is represented by the maximum oil absorptive capacity of the active layer, which is approximately one gallon per square foot.

Experimental Alaskan spills reveal that long-term damage is much more severe if soils and root systems are thoroughly inundated with oil than if root systems escape complete contamination [26, 34]. This is particularly evident among low species such as mosses and lichens. In addition, refined fuel spills are reportedly more toxic than crude oil [26, 34].

Crude and fuel oil spills often remain within subsurface soil layers for years. This may not necessarily inhibit revegetation. A dead organic mat often acts as a barrier preventing contact between oil residues and newly-restored vegetation. Restoration of plant communities is promoted as oil residues slowly degrade.

Under arctic conditions a wide-range of aerobic and anaerobic soil bacteria are capable of degrading crude oil [16, 13-14]. Indeed, soil microflora populations are stimulated by the presence of crude oil. In the Mackenzie Delta, observations of oil-contaminated soils suggest that one month after terrestrial oil spills a 100% increase in soil respiration, and a tenfold increase in bacterial population may be common [13, 1].

Increased bacterial levels promote oil biodegradation. Recent studies designed to artificially increase the concentration of soil micro-organisms on arctic oil-contaminated sites reveal that fertilizer applications. raise bacterial levels by artificially increasing available nitrogen. Its absence limits bacterial growth. Fertilizer-treated arctic soils have higher vegetative recovery rates (19, 93).

The behavior and phytotoxicity of crude oil on frozen, snowcovered ground is much different from that of oil spills on arctic terrain during the brief growing season. The pour point for Prudhoe Bay oil is only 15° F while that from the Mackenzie Delta and Arctic Islands may be quite similar. Consequently, when air temperatures are beneath 15° F, the viscosity of freshly-spilled hot crude oil would quickly rise upon contact with ice or snow. The flow rate would be dramatically cut, reducing the contamination area. U.S. Coast Guard experiments in northern Alaska show that hot crude oil has a surprisingly limited ability to penetrate snow. A 60-gallon spill penetrated only one-half inch into a 6- to 9-inch snow cover with a 55% average porosity (6, 4-5). Similar Canadian studies in Ontario and at Norman Wells indicate that snow acts as an excellent cold oil retainer (20, 98-105, 113-117, 125-126).

Because of the chemical and physical instability of fresh crude, it is likely that the phytotoxicity of oil after exposure to air, water, and ice over several winter months would be much less than oil freshly spilled on the active layer at the height of the growing season.

Areas of Concern and Recommendations

Periodic oil spills are certain to accompany expansion of the petroleum industry in arctic Canada. Fortunately, terrestrial spills have limited mobility. Implementation of proper management practices could reduce contamination and promote revegetation. Management methods most likely to encourage the reestablishment of environmental equilibrium following terrestrial oil spills during arctic summer months are listed below:

1) Standing oil pools should be removed.

2) Where necessary, oil flow should be diverted from critical water supplies and freshwater resources. Diking may induce small-scale thermokarst and/or erosion but possible contamination of water bodies could conceivably have a more serious environmental impact.

3) Often the best wav to manage small spills is to leave them unmolested. Removal of oil-contaminated litter mats, while beneficial from a cosmetic viewpoint, is in many cases environmentally destructive.

4) In areas where rapid revegetation is desirable, artificial soil fertilization should he considered.

5) Much attention has focused on the effectiveness of innoculating contaminated soils with oil-utilizing bacteria. This technique causes faster microbial degradation but it can introduce a significant environmental hazard. It is likely that gram negative rods such as Pseudomonas sp. would be used in the bacterial seeding of oil spills. They work well but can be pathogenic to many mammals including man. Application of this procedure is not recommended therefore in areas frequented by animal herds or those used for human settlement.

6) Although many short-term environmental impact analyses of oil spills have been conducted, relatively little is known about long-term implications.

7) With respect to winter spills, it is often suggested that burning and/or harvesting of oil-polluted snow may alleviate ground contamination during spring thawinq. This seems reasonable, provided snow and temperature conditions are sufficient to prevent scarring of underlying litter mats. However, guidelines designed to indicate

when such conditions are met in terms of parameters such as temperature, snow depth, and porosity have not been prepared.

3.0 EFFECTS OF OIL AND GAS DEVELOPMENT ON BIRDS AND MAMMALS

3.1 Sources of Stress on Faunal Populations

Since the commencement of extensive 17th century trading and whaling operations, arctic wildlife resources have been under increased pressure. By the beginning of this century, muskox were virtually extinct in all but the most isolated regions and fox and polar bear populations also decreased. In more settled and accessible areas, a chronic scarcity of wildlife was common.

Recently the implementation of conservation practices induced a population resurgence among many species. Yet, if extensive arctic oil and gas development were to occur it would likely precipitate renewed pressures and heighten the attrition rate of wildlife resources. Effects on wildlife of arctic resource exploitation could be analogous to prairie development and its effect on the buffalo.

Areas of expected stress on wildlife which are a direct consequence of oil and aas development, may be linked to:

1) increased harassment by aircraft;
2) noise associated with pipeline construction and the operation of compressor stations;
3) interference with traditional migration routes by raised pipelines acting as artificial barriers, or buried pipelines in which right-of-ways, through an interruption of drainage become very marshy and act as moats which block or entrap migratory animals;
4) ingestion of, and external contamination by oil following accidental spills; and

5) habitat loss or impairment by construction of pipelines and transportation facilities, by sand and gravel extraction, and by timber harvesting.

Potential indirect sources of stress associated with oil and gas development are:

1) habitat modification from positive or negative changes in the annual frequency and spatial distribution of fires;
2) increased wildlife hunting Pressures;
3) increased opportunity for wildlife to ingest toxic substances due to improper industrial and domestic waste disposal; and
4) interference with access to foraging areas or with migration routes caused by the general tendency of wildlife to circumvent human settlement areas.

Increased harassment levels would likely force many species to increase their daily energy expenditure. This in turn would have to be compensated through increased food consumption if negative energy balances are to be avoided. The carrying capacity of the biome would then be reduced. If a species' population were close to the carrying capacity prior to increases in harassment, any significant reduction in capacity would increase mortality rates. It is therefore Possible that a continuous high-harassment level alone could cause animal populations to decline in some areas.

A brief analysis of major arctic wildlife resources and probable effects upon them of increased oil and gas development are outlined below. Low Arctic species such as moose, Dan sheep, beaver, and muskrat which are of minimal importance to the Inuit are not considered.

3.2 Caribou (*Rangifer tarandus*)

Many of the approximately 500,000 northern caribou are associated with five-large herds (45, 206). Lichens are their most important fOrage though they feed on a wide variety of other plants. In the Mackenzie Delta the carrying capacity is approximately one caribou per square mile; on the barren archipelago islands it is considerably less.

The impact of arctic pipeline construction on migrating caribou may take several 'forms. Should they come into contact with a large construction camp, continuous air and vehicular traffic, and miles of open pipe ditch, they may retreat and by-pass the noise and activity. They may halt their migration and refuse to move around the construction, or they may ignore the pipelaying operation and move through the construction zone. In this case, it is possible that a large number of caribou may blunder into the pipe ditch (up to 8-feet deep and 10-feet wide) resulting in injury or death.

Occasional harassment by air traffic may temporarily disrupt feeding and migration. Continuous low-level air traffic or "buzzing" could cause abortion, exhaustion, and death among parturient cows, or the abandonment of dependent calves (5, 63),

Following pipeline construction, the presence of relatively luxuriant artificially seeded vegetation in right-of-ways may attract caribou. Should a large herd repeatedly traverse a right-of-way where the insulation layer had already been disrupted during pipeline construction, serious thermokarst could develop.

Short-term noise associated with blasting, vehicular traffic, construction, air transport and other functions may frighten caribou away from preferred calving and staging areas, migration routes, and river crossings.

Exploration drilling rigs employ from 40 to 60 people [40, 11]. The many activities associated with a camp of this size could further disrupt caribou. The drilling rig itself may have an influence for caribou tend to be deflected by tall, "unnatural" features which break the horizon [45, 207]. Thus drilling rigs could act detrimentally by diverting caribou away from favorable migration routes and feeding areas, or they could be used to channel caribou in a desired direction.

Areas of Concern and Recommendations

1) The potential impact of oil and gas pipeline construction on caribou can be minimized if close surveillance of herds is maintained so that, if necessary, they may be physically diverted away from construction zones. Unfortunately, relatively little experimentation with possible deflection techniques nor their effects on the Caribou has been initiated.

2) The medium and long-term effects of continuous noise from compressor and refrigeration stations are unknown. Thirty-one compressor and 13 refrigeration stations are planned for the Mackenzie gas line alone [38, 8]. Should an adjacent oil line and/or the proposed Polar gas pipelines be constructed, dozens of such permanent structures would dot the Arctic. The potential for interference with normal migratory Patterns would be substantial, and the degree of risk should be thoroughly investigated before further developments are permitted.

3) If drilling or pipelaying have a deleterious impact upon nearby caribou despite precautionary adjustments, a temporary pause in construction might be desirable until the animals migrate to another location.

3.3 Muskox (Ovibos moschatus)

In a 1965 census, 9,890 muskox were reported in Arctic Canada, 5,000 of which lived on Ellesmere and Axel Heiberg Islands [45, 213]. Small muskox herds are generally susceptible to the same oil and gas development disturbances as those described for caribou. However, one aspect of petroleum development in their habitat deserves special attention. Muskox inhabit the most desolate of Canadian environments. The carrying capacity of their High Arctic biome is extremely low.

As an evolutionary response they have developed a very low reproduction rate. Therefore should their population decrease by even a few hundred as a consequence of oil and gas exploitation complete recovery from such losses may require several generations. The terrain is nonproductive throughout much of their range. Oil and gas wells and associated campsites could have a serious impact if "established within primary feeding grounds. Displaced muskox herds may have nowhere to go if their preferred grazing grounds are occupied.

Areas of Concern and Recommendations

1) The muskox is a rare species and as such, it would be highly valued by trophy hunters. Protective regulations are insufficiently strong, particularly along the coastal plain of the Yukon, where muskox have recently been reintroduced after a 100-year absence.

2) Not all primary muskox feeding grounds have been located. These should be mapped and delineated as non-development areas.

3) The muskox habit of forming phalanxes for mutual defence is an excellent shielding technique against wolves but it Is ridiculous as a protective measure against firearms. Caribou will run. Muskox will hold their ground and be slaughtered. This strategy leaves them virtually defenseless against the rifle and highlights the need for strict gun-control regulations in muskox-rich areas.

3.4 Bears

Polar Bear (Ursus maritimus)

Polar bears are the most carnivorous arctic mammals, feeding mostly on seals and young walruses. Preferred habitats are massive off-shore ice flows from which they hunt. Den sites are generally located on the leeward slope in areas of deep snow. The present and probable future impact of terrestrial oil and gas development upon the polar bear may be of only minimal significance. There are reports of polar bears being forced off Herschel Island by the noise and activity of drilling rigs [59, 127]. But unlike the muskox, their food supply is not restricted to specific sites. The greatest hazard facing the polar bear is potential poisoning from off-shore oil spills.

Barren-Ground Grizzly (Ursus arctos)

Barren-ground grizzly bears are found in a variety of habitats within the Low Arctic. They are omnivorous, but prefer rodents, caribou, and moose. Recent studies indicate that they often follow herds, preying upon old, infirm, and newborn caribou. Unlike caribou they are solitary, and have no developed social "structure. It is likely, should strict controls he placed on hunting, that an increase in the exploitation of petroleum resources will have only a minor impact upon small numbers of scattered bears. The chance of man-bear confrontations may be significant in areas where activities are undertaken within 10 to 15 miles of den sites; otherwise, they are remote [5, 85].

Areas of Concern and Recommendations

1) Grizzly denning sites and habitats should be located and excluded from development zones. Like the muskox, bears have a low reproduction rate. Grizzlies often use the same dens year after year but may abandon them if disturbed. This could lead to a population reduction which may require many years to reverse.

2) Bears have a very keen sense of smell. The scent of garbage attracts them to construction camps. It is often suggested that garbage be incinerated and buried on a regular basis to discourage bear-settlement contacts. However, there is little evidence that this advice is being seriously followed.

3) Construction activity may drive bears away from some areas. Being omnivorous, their food is in general abundance, so they may not suffer from occasional relocations. However, native Inuit who depend upon this species may be adversely affected by its absence.

3.5 Arctic Fox (Alopex ragopus) and Wolves (Canis lupus)

Arctic fox are found sporadically throughout the tundra from Churchill to Eureka. They are omnivorous, feeding on birds, rabbits, rodents, fish, grasses, and wild fruits. Arctic wolves are distributed over a smaller area. They are carnivorous and have a' particular preference for caribou. Like the grizzly they migrate with the caribou preying upon weak members of the herd. Compared to the muskox and caribou the probable impact of development upon arctic fox and wolf populations is likely to be minimal. They generally avoid contact with people and so may be expected to circumvent drilling rigs, pipeline installations, and other infrastructure facilities while hunting. Den sites are selected in a wide variety of habitats insuring that petroleum exploitation will not rob them of critical grounds in which to raise their young.

Areas of Concern and Recommendations

1) Like the grizzly bear, wolves and foxes often use the same dens repeatedly. Some eastern arctic fox dens have been in continual use for over 200 years[5, 93]. As a consequence, arctic members of the Canidae family (which includes all wolves and foxes) generally exhibit the same abandonment reaction as bears following den disturbances.
2) Wolves and foxes are also attracted to camps by garbage. This is a source of concern for when hungry, they show little fear of man.

3.6 Birds

More than 85 bird species inhabit the tundra. Of these, only 8 are full-time residents[52, 3]. The rest are migratory species which come to the Arctic each spring to nest. A number of these, in particular the lesser and greater snow geese, are dependent upon the tundra for their continued existence. Many such birds return year after year to the same cliffs, marshes and heaths, crowding into relatively small nesting sites.

Pipelines, compressor stations, helipads, airstrips, and communication towers may have a negligible impact on arctic birds if located in non-critical areas. It is equally possible that a significant impact could be associated with any of these features should they be established within the vicinity of prime nesting or feeding grounds. For example, in mid-August as many as 500,000 snow geese mav gather within the Mackenzie Delta[24, 296]. Their nesting season is only four to six weeks. Goslings barely reach flight size before being obliged to undertake an exhausting 2,000- to 3,000-mile migration to southwestern United States wintering grounds. Their energy intake during summer nesting and feeding is sufficiently close to energy expenditures during late-winter migration that, should oil and gas exploitation interfere with feeding, nesting, or behavior patterns, large numbers of geese and goslings may not have the endurance to successfully complete the winter migration. They would perish. A similar scenario is possible for numerous other species, in particular the arctic tern, which migrates as far as 11,000 miles from the archipelago to South and West Africa or Antarctica.

The construction of pipelines and a supporting network of roads, airstrips, and settlements could lead to significant habitat losses. In the past some marshes were converted to solid waste dumps and subsequently filled. Depending upon individual circumstances, the construction of roads and pipelines may drown other marshes through pending. Still others may be drained should roads or pipelines cut across and redirect natural drainage routes. Refrigerated gas lines or hot oil lines, if improperly insulated, could alter the thermo-regime of shallow lakes and swamplands.

The removal of gravel from shingle beaches and eskers may destroy critical, nesting sites. Sand harvesting from offshore sand bars and spits for construction could expose sheltered nesting areas to wind and wave action, and thereby degrade or destroy the migration habitat. An increase in the number of fires could drastically reduce sedge and berry food supplies for several years.

Nesting waterfowl are very intolerant of disturbance. The noise and activity of drilling rigs may temporarily reduce the population density of about 40 percent of the summer bird species in the Mackenzie Delta for a distance of at least 1.5 miles from the source of disturbance[3, 11]. Displacement from migration habitats has, within the Mackenzie Delta, led to a marked decline in their reproduction rate near major construction zones [5, 117]. Harassment from low-flying aircraft and helicopters may cause incubating birds to desert their clutch leaving the eggs subject to attack by avion and terrestrial predators. Finally, it is probable that the expanding presence of man in construction camps and on drill sites will considerably heighten the attrition rate through increased hunting pressures on bird populations.

It would be insufficient to simply regulate the usage of firearms within construction camps. Nesting birds are extremely vulnerable, and they can easily be harvested in a variety of methods. Regular camp inspection, coupled with strict enforcement of game regulations, will be required to suppress illegal hunting.

Aside from migratory waterfowl, arctic Canada is one of the last refuges for many North American raptors. In southern Canada, habitat degradation through the spread of mechanized agriculture and urbanization, and the increased use of pesticides, herbicides, and a variety of toxic wastes, all contributed to a steady population decline among falcons, ospreys and eagles. These birds of prey are strictly "wilderness species" which steadily retreated for over 200 years in the face of expanding human settlement on the North American continent. They are generally subject to the same level of disturbance as other bird species outlined above. But in some cases they are even more susceptible because many raptors return to the same nesting site year after year. Construction activity within 2-3 miles of these nests could lead to their abandonment (5, 123). Once displaced from traditional nesting sites, it is unlikely that they would return.

Areas of Concern and Recommendations

1) Although it is not practical to cease drilling and pipelaying operations during summer-nesting periods, the impact of such activities could be substantially reduced if migratory habitats were circumvented.

2) Sand and gravel removal from migratory habitats has not been legally prohibited. It should be; the present extent and effects of such harvesting is not being documented.

3) Much attention has focused on potential direct effects of future pipeline construction upon birds. Disturbance levels are often determined with reference to activities within the right-of-ways alone, while the effects of more distant borrow pits, airstrips, hauling tracks, and supply and staging sites are given an unjustifiably low-level of concern.

3.7 Effects of Crude Oil Contamination on Terrestrial Fauna

It is improbable that terrestrial crude oil spills would have a significant effect upon terrestrial mammals. They are mobile, comparatively intelligent, and would avoid contact with oil-contaminated terrain. Nevertheless, should caribou, fox, bears, or muskox accidentally become contaminated the effects would be similar. Their closely packed hairs would trap oil reducing the thermal insulation which they provide. Ingestion of oil may lead to gastritis and enteritis. Contact with eyes or nostrils is equally irritating.

The potential hazard facing migratory waterfowl is much more serious. Though they nest on land and are consequently considered as terrestrial fauna within this discussion, they spend considerable time in fresh or salt water. Should their aquatic habitats be contaminated with petroleum products, foraging birds easily could come into direct contact with oil slicks. Total annual bird losses related to spilled oil in the North Sea and North Atlantic are estimated at 150,000 to 400,000[27, 144]. A similar attrition rate may be experienced in arctic waters within the next 15 years.

The effects of single,massive oil-tanker or submarine-pipeline spills could be catastrophic. The 1955 strandinq of the "Gerd Maersk" in the Elbe Estuary caused the death of 250,000 to 500,000 birds, while the "Torrey Canyon" grounding resulted in 40,000 to 100,000 fatalities (27, 145). Similar effects may be expected following equally large spills off the Mackenzie Delta or in the vicinity of other arctic migratory habitats.

Most waterfowl species that frequent the Canadian Arctic have an undercoating of fluffy down-feathers which collectively produce a spongy layer of small air pockets. This layer is protected and water-proofed by an outer layer of flattened contoured feathers. Although epidermal oil-glands contribute to waterproofing, the single most important factor is the tightly interlocking micro-structure of the outer feathers. Fresh crude oil penetrates the contoured feathers and adheres to the down. This destroys the air-pocket structure enabling water to enter the air spaces causing a loss of insulation and bouyancy. Swimming is impeded; flight becomes impossible. Some authors report that "a spot of oil no bigger than a dollar on the breast of a bird is enough to bring about death by exposure" (27, 147).

Ingestion of oil occurs through the preening of contaminated feathers. Waterfowl that consume oil are reported to suffer from lipid pneumonia, severe intestinal irritation, fatty changes in the liver, and adrenal enlargement. Should they survive, chronic ailments often develop, in particular, aspergillosis and arthritis.

Many attempts to rehabilitate oil-contaminated birds have followed massive spills. Following the Torrey Canyon disaster, 8,000 birds were collected alive. Thev were cleaned, fed, and given antibiotics at rehabilitation centers. Yet, fewer than 1% successfully returned to their natural habitat. Ahout 1,500 birds were treated following the

Santa Barbara spill in 1969, but only 10% survived the first three months (27, 160).

Bird populations which survive moderate levels of direct oil contact are still subject to considerable stress. Surviving birds are often obliged to leave the area because of food contamination. Crude oil reduces egg shell permeability resulting in an average decrease in "matchability" from 90 to 20 percent. A single ingested oil dose at the rate of 2g/kg of body weight is sufficient to halt laying completely and to suppress reproductive behavior (27, 148).

Areas of Concern and Recommendations

1) Based on the history of oil and gas development throughout the world, it is inevitable that a significant oil pollution problem will develop in the Canadian Arctic in direct proportion to the level of petroleum exploitation. Evidence of this is already accumulating. Between January 1, 1973, and June 30, 1974, 34 refined and crude oil spills ranging in size from 70 to 49,000 gallons were reported north of 60° latitude. In that 18 month period, a total of 262,000 imperial gallons were lost (24, 320). To lower this toll strict building standards and redundant control and containment systems are advisable for Pipelines, storage tanks, and transfer terminals. However, no leakproof extraction, refining, or transporation system for oil products has been devised to date.
2) One could demand that pipelines, storage tanks, terminals, and tankers be kept a minimum 5, 10, or 25 miles from waterfowl refuge areas hut even these measures mav be ineffective in the event of aquatic contamination. Oil spills on water are extremely mobile. They could easily float for tens and even hundreds of miles through

the artic islands. Birds may then contaminate themselves and their eggs by using oiled seaweeds and grasses in nest-building.

3) Effective rehabilitation techniques for oil-contaminated birds have not been devised.

4) The outlook is not encouraging. Future spills are inevitable and the consequences may be disastrous for arctic waterfowl. No truly effective preventive or post-contamination physical containment procedures are available. Therefore, one of the "trade-offs" for arctic oil and gas exploitation may be the partial or complete destruction of a number of migratory bird habitats.

4.0 EFFECTS OF OIL AND GAS DEVELOPMENT ON FRESHWATER RESOURCES

4.1 Introduction

Freshwater ecosystems of the Canadian north are estimated to have a potential yield of several million kg of fish per year[3, 13]. Species having the highest commercial, domestic, or tourist value include: arctic char, broad and humpback whitefish, inconnu, arctic and least ciso, arctic grayling, northern pike, and yellow walleye. Most of these species require a number of different habitats for spawning, rearing, summerfeeding, and overwintering. Present research suggests that large stream channels such as the Mackenzie River are utilized primarily as migration routes. Spawning, rearing, and summer feeding are generally restricted to the smaller tributaries or back eddies of major rivers. Deep tributary pools and large river channels are the preferred over-wintering grounds of non-migratory species[8, 99].

The productivity of arctic waters is largely determined by nutrient supply. Over-fertilization can have spectacular consequences. For example, nutrient-rich sewage discharged into Meretta Lake on Cornwallis Island led to a 20-fold increase in vegetative primary production compared with neighboring unpolluted waters. The magnitude of this increase normally would be much smaller were it not for the slow rate of growth and production in northern freshwater ecosystems. Arctic lakes produce approximately one-half pound of fish/acre/year which is a full order of magnitude less than equivalent southern production[45, 171]. As a consequence of low productivity and slow growth, biological time-scales are extremely long. Moderate-sized fish which would be considered young in the south may actually be 40-years old.

Arctic freshwater ecosystems are low in species diversity. Ecosystems with a .1ow diversity index are inherently unstable. Small environmental disturbances could precipitate great changes in biotic characteristics. Reestablishment of ecological equilibrium following such change may require many generations due to the extended biological time scale.

Bliss and Peterson (1973) state that in some ways arctic freshwater fish populations are very stab"le. Extended effects following massive short-term habitat disruptions may be limited because total populations would be composed of many year-classes. A few missing year-classes could be replaced by slightly older or younger fish with few long-term deleterious effects.

Finally, it should be noted that the "natural" characteristics of arctic freshwater habitats are as variable as those in southern Canada. Some streams such as the lower Mackenzie carry a sediment load as high as 2,000 mg/litre. Only 100 mg/litre is necessary to induce a turbid appearance. Many clear streams carry as little as 10 mg/litre of sediment (45, 172), Drainage systems associated with muskeg and deep organic soils generally have high acid levels and a low mineral content while those in sedimentary strata are characterized by a comparatively lower pH and higher dissolved-mineral content.

The major environmental hazards to freshwater ecosystems as a consequence of oil and gas development are:

1) seismic blasting;

2) the removal of gravel from stream beds;

3) a greater risk of erosion and siltation;

4) increases in the frequency of "icings";

5) water contamination from pipeline washing and drilling compounds;

6) sewage effluents from construction caroms;

7) improper brine disposal in oil extraction operations:

8) oil contamination.

Ramifications of each of these processes are outlined below.

4.2 Seismic Exploration

The number of seismic crews operating in the Northwest Territories increased from 52 in 1967, to an estimated 230 in 1972[7, 43]. Much of this exploratory activity was concentrated in shallow-marine waters and inland lakes and rivers during ice-free periods. Shallow-draft boats and hovercrafts are the primary vessels used to lay charges. The shock wave and accompanying pressure changes following seismic testing are major causes of death and injury to fish. In the immediate test vicinity severe injuries may be expected. These include tearing of muscle tissues, disruption of the nervous system, ruptures of the abdominal cavity, internal organs, and blood vessels. At more distant sites less-severe injuries such as loss of scales and minor blood-vessel ruptures occur[7, 10]. The degree of injury is dependent upon the fish species, the distance from the blast epicentre, and the nature of the charge used.

The susceptibility of many species to death by seismic blasting is related to swimbladder morphology. The swimbladder is an organ which maintains equilibrium by artificially making a fish's mean density equal to that of the surrounding water. It is extremely sensitive to rapid pressure changes such as those accompanying seismic shock waves. These cause the organ to burst. Death often follows either from internal hemorrhaging, impaired feeding ability, or an increased risk of predation. Species without swimbladders are more likely to survive seismic blasts than fish with them. Similarly, fish with thin-walled swimbladders are more susceptible to injury than those with thick-walled ones.

The destructive impact of seismic blasting is receiving much attention. The linear high explosives widely used in the north cause much injury. One of these, "Aquaflex" is lethal to fish within a 36,000 square feet area, when detonated in 165-foot lengths in water in-feet deep (7, 31). In the summer of 1973, over 300 miles of seismic surveys were undertaken with Aquaflex in Mackenzie Bay alone (31, 19). Its usage in freshwater ecosystems may be as widespread.

There are other, relatively non-destructive seismic testing methods available. The use of air guns represents one of the safest methods. Pressurized air supplied by compressors provides the guns with a shock wave generating capacity of approximately 2,000 psi.. In experimental air-gun shooting along the Mackenzie River, no mortalities were observed in 10 miles of testing in water depths from 5 to 30 feet (7, 36).

Areas of Concern and Recommendations

Air guns are presently not used as extensively as traditional explosives. Their usage should be encouraged wherever possible to protect fish copulations.

4.3 The Removal of Gravel Beds

Gravel is widely used in the Arctic as a permafrost insulating material in road, pipeline, and building construction. It is in great demand and there are no equivalent-cost substitutes. Millions of tons of gravel may be required in the next decade for construction of the Mackenzie Valley and Polar Gas Pipelines. Basically, there are only three types of landforms capable of satisfying the gravel requirements. These are stream channels, shingle beaches, and glacial landforms such as eskers and outwash morraines. Removal of gravel from any of these areas could have detrimental ecological consequences.

The impact of gravel extraction could be minimized if it were only removed from ecologically non-sensitive areas. The most. sensitive freshwater habitats are spawning beds and nurseries within clear-running streams. Gravel removal from such areas could destroy fry and incubating eggs while simultaneously mobilizing qravel-retained silt leading to the destruction of similar habitats downstream. Utilization of gravel from turbid or intermittent streams have much less-severe ramifications.

Areas of Concern and Recommendations

Freshwater habitats which are potentially sensitive to the multiple impacts of oil and gas development have not been extensively explored or evaluated with the possible exception of those in the Mackenzie Valley. Such sensitive areas should be located. Strict **regulations governing gravel extraction in these aquatic habitats are needed immediately.**

4.4 Erosion and Siltation

Vegetation clearing and improper construction methods for Pipelines, drilling camps, and related facilities may induce thermokarst. This, in turn, may lead to substantial slumping and subsidence resulting in increased erosion. Eroded sullies and trenches further expose permafrost which leads to greater melting and accelerated erosion. It is a self-perpetuating process. Where it occurs along or near river banks, such erosion mav drastically increase silt loads in watercourses. The added sediment may kill fish immediately downstream, and destroy fish eggs and organisms eaten by fish through sediment burying[18, 133]. The normally clear water and clean rocky beds of stream headwaters would likely experience a more pronounced degree of ecological degradation from sediment overload than siltier downstream waters.

Growth rates for fish are much slower in waters with high-sediment loads. The average annual fish biomass in northern streams is 3-times higher in water with 15 to 40 ppm sediment concentrations than in streams with a 40-80 ppm sediment content. Clearly, an extended period of increased siltation following pipeline construction could have potentially severe environmental consequences. Relatively-small sediment increases are sufficient to decrease markedly fish and invertebrate copulations. Tests show that an 80 ppm increase in suspended sediment may decrease invertebrate populations bv 60 percent [11, 36].

Areas of Concern and Recommendations

Pipeline stream crossings should be constructed near stream mouths where natural-silt loads are comparatively high and drifting organisms from the headwaters could easily recolonize disturbed sites downstream. Conversely, river mouths are rich feeding grounds for migratory waterfowl, important rearing areas for fish, and they provide the first spring open-water areas. It could, therefore, be argued that crossings should be restricted where possible to stream headwaters.

The literature does not as vet favor one set of arguments over the other. Should either set be accepted, one could foresee far-reaching ecological implications. Perhaps no one correct approach would be applicable to all streams. A definitive government guideline on the stream-crossings issue has not been formulated to date.

4.5 Icings

Icings are common in arctic waters. Normally they appear as extensive tabular ice bodies on river channels. Natural icings form when groundwater emerges at a frozen surface, spreads out downstream, and freezes as a sheet on top of a previously existing ice sheet. Man-made icings may develop following construction or trenching operations which force groundwater to the surface.

A modified form of icing may also occur if the insulating snow layer on an ice sheet is compacted or removed by machinery, vehicles, or trampling. Under these circumstances ice thickening will develop. In shallow streams this thickening may be sufficient to reach the channel bed. The resulting blockage may lead to a depletion of winter water and food supplies for over-wintering fish downstream. Furthermore, large icings often remain intact until middle or late summer. Spring runoff and channel flow may then be laterally deflected causing intensified river-bank erosion and increased-sediment load (24, 210).

Areas of Concern and Recommendations

Present knowledge of groundwater and geothermal characteristics of the Canadian Arctic is insufficient to identify areas of potentially high-icing susceptibility. The groundwater-hydrology data base should be expanded and potential icing zones identified prior to construction of pipelines, ice roads, ice airstrips, and similar facilities. This information would permit developments to be directed into relatively non-sensitive areas.

4.6 Pipeline Washing and Drilling Compounds

One aspect of oil and gas development which has not received sufficient attention is the potential for water contamination from drilling and testing compounds. All pipelines are flushed, cleansed, and pressure tested for leaks with a washing fluid prior to commencement of operations. Under arctic conditions, the fluid most commonly used for this purpose is a water-methanol mixture. The proposed Mackenzie Valley

Gas Pipeline will require approximately 25,000 tons of methanol for pressure testing. As much as 3.9-million gallons of the testing mixture may occupy 10-mile lengths of pipe during preliminary flow trials. The mixture will be composed of 74% water and 26% methanol by volume (24, 324). Similar fluid proportions and testing methods probably will be used for other possible pipelines such as the Polar Gas Pipeline.

Methanol is highly toxic to most aquatic organisms, particularly spawning fish and their eggs. Accidental spillage of the test fluid could inflict severe ecological damages. In the proposed Mackenzie line, the Petroleum industry intends to dilute the fluid to a 1% methanol content and discharge it into waterbodies following each pipe test (24, 324). Over 100-million gallons of the diluted mixture would be released into northern drainage systems if such a practice were adopted. Environmental implications have not been seriously investigated.

Lubricating oils and additives used in drilling muds also possess toxic fractions. These substances may further contaminate small drainage systems if improperly released. Resultant toxicity in water chemistry may kill fish.

Areas of Concern and Recommendations

1) Inasmuch as the ecological consequences of low-level methanol contamination are not well understood, a conservative approach to test-fluid disposal is warranted. One method by which the biotoxicity of the fluid could be substantially reduced would be to distill the methanol-water mixture and recapture the methanol. The aqueous residue could be discharged into specially selected areas where percolation into drainage systems would be limited.
2) At present, there is little evidence that the disposal of other toxic industrial substances is being strictly regulated. Such

regulations may not be forthcoming in the near future because the spatial and volumetric extent of their usage is unknown. An examination of the short- and long-term effects of industrial oils, lubricants, anti wastes should be instituted prior to additional oil and gas development in the vicinity of rich-aquatic habitats.

4.7 Sewage Effluents from Construction Camps

A northern constructing camp of 600 to 700 workers may be expected to generate between 1800 and 2700 kilograms of industrial and municipal wastes per day[20]. Much of this can be burnt, buried, or dumped on land. If disposal sites are well chosen the environmental impact will he restricted to the disposal site alone. However in many cases, industrial and domestic wastes are dumped untreated into swamps, natural lagoons, rivers, and lakes. If stream discharge carries waste-contaminated waters away, large areas would be exposed to potential ecological imbalances. Accumulated nutrients from sewage outfalls may induce strong algal growth during summer months. At a later period, bacterial degradation of algal residues can lead to oxygen depletion and subsequent suffocation of aquatic organisms. Oxygen starvation may be particularly severe in winter months when ice inhibits gaseous exchange between water bodies and the atmosphere.

The waste-disposal problem is compounded by the low carrying capacity of arctic waters. The difference in “ecological” sewage capacity between equivalent volumes of water in arctic versus southern lakes and rivers can he as great as one order of magnitude[45, 175]. Recent research suggests that if liquid wastes must be released into surface waters, slow-discharging swamps may provide one of the best habitats for this purpose Approximately 35-square meters of swamp per person per year would be adversely affected by this disposal method (22, 1). The rate of recovery for sewage modified swampland in northern Canada is unknown.

Because swamplands often serve as important wildlife feeding, nesting, and staging habitats, the least destructive way to dispose of sewage would be through the construction of artificial lagoons in natural depressions. Aesthetically, they are unsightly, but if sites are properly chosen the ecological impact may be minimal.

Areas of Concern and Recommendations

1) Swamps and natural depressions which may be converted into discharge lagoons should be mapped.
2) In potentially useful swamps, water-flow rates should be documented for several years prior to dumping to ensure that pathogenic bacteria will not contaminate drinking water supplies during spring high-water overflow periods.
3) A swamp allowance of at least 100 sq m/person/year would be advisable to limit the severity of the effects of discharge on natural ecosystems.
4) None of the waste disposal methods discussed above are totally acceptable from an environmental viewpoint. Some degree of eco-degradation is inevitable. Given this, present waste disposal technology presents another ecological "trade-off" that will be necessary in the pursuit of arctic energy supplies.

4.8 Brine Disposal

Some oil wells withdraw more than 100-cubic meters of an unwanted saltwater or brine solution for each cubic meter of oil (50, 39). Substantial volumes of brine are commonly found in oil-laden strata.

Since the brine is miscible in oil, it is extracted with it and must later be separated. Relatively-rich oil wells extract less than 10% brine but brine content may substantially rise with increasing age thereby decreasing profitability of the well.

Oil brines differ in salinity. The primary salt is sodium chloride, which may occur in concentrations ranging from 5,000 to more than 200,000 ppm; the average is approximately 40,000 ppm. In comparison, seawater has about 20,000 ppm of chlorides. In addition, large quantities of sulfates (SO_4^{-2}), bicarbonates (HCO_3^{-1}) and the cations of calcium (Ca^{+2}), and magnesium (Mg^{+2}) are normally found in oilfield brines (48, 1).

Inorganic ions within brine solutions are known to have adverse effects on animal and plant life. In the 1920's and early 1930's, oilfield brines were permitted to flow freely into natural-drainage systems. Within a short time, rich fishing areas became impoverished, fur-bearing animals disappeared, and luxurious vegetation along stream banks was converted into decaying litter on barren soils".

In recent years, legislation for freshwater protection has obliged the oil industry to discharge most brines into specially prepared evaporation ponds or into saltwater bodies. Until a few years ago, ocean discharge was the common disposal method utilized in California and along the Gulf of Mexico. But in the U.S., this too has been outlawed. Today, virtually the only environmentally acceptable brine-disposal procedure in North America is reinfection into subsurface strata.

Arctic brine disposal poses potentially serious problems. In many cases, surface discharge into fresh or salt-water bodies cannot legally be undertaken without abrogating sections of the Arctic Waters Pollution Prevention Act and the Northern Inland Waters Act. Due to climatic considerations, narticularly low evapotranspi ration, evaporation ponds cannot function successfully in the far North. Subsurface disposal is probably the onlv effective and comparatively nondestructive brine removal procedure. However, this course of action would still entail environmental risks.

An incomplete understanding of the subsurface formation into which the brine is beinq pumped may lead to its migration along fault and fracture planes. In areas of discontinuous permafrost such wastewaters mav eventually enter and contaminate freshwater aquifers. Another problem may arise as a result of the heat associated with freshly extracted brine. In the Prudhoe Bay area brine temperatures are approximately 160° F. Consequently, its reinfection may introduce the risk of thermokarst should the casings of disposal wells leak or subsurface migration permit brine to contact Permafrost.

Areas of Concern and Recommendations

1) At present it cannot be assumed that reinfected brine will be completely contained within the geologic formation selected for disposal.

2) The potential risk of thermokarst has not been sufficiently investigated.

3) Because reinjection mav be unfeasible in some oilfields alternate disposal methods should be prepared in advance.

4.9 Oil Contamination of Freshwater Ecosystems

Arctic fish resources could he severely threatened by leakage of crude oil or refined petroleum products into drainage systems. A 48-inch diameter pipeline such as the one currently favored for the Arctic has a capacity of 500,000 gallons of crude oil per mile. With shut-off valves placed at 10- to 30-mile intervals a major pipeline spill could be massive and potentially disastrous for many freshwater ecosystems.

It is also likely that leakage of refined fuels will occasionally pollute freshwater bodies. This may occur if tanks on oil barges are ruptured. On the Mackenzie River some barges have storage tanks with a 400,000 imperial gallon capacity. Spillage may also arise from improper coupling of hoses during the transfer of fuel from barges to terrestrial storage tanks. The refined fuels such as gasoline, kerosene, and diesel oil are generally more toxic than crude oil and in some respects presents greater danger.

Oil contamination may kill aquatic vegetation and invertebrates eliminating food supplies for the fish which occupy the pinnacle of aquatic food pyramids. Fish may also be killed through direct oil contamination. However, a natural mucus coat which covers the outer surfaces of fish mouths and gill chambers tends to inhibit oil penetration and subsequent poisoning[27, 110]. The toxicity of crude oil to fish varies from species to species. Oil concentrations of 1 ml/litre of water have little effect on guppies (Lebistes reticulates), although 50 ml/litre concentrations are toxic to a wide variety of freshwater fish[27, 112].

Areas of Concern and Recommendations

1) Automatic shut-off valves placed at river crossings would limit the degree of freshwater contamination in the event of a pipeline rupture.

2) If terrestrial storage tanks were surrounded by containment dykes, the Potential for petroleum runoff into nearby stream channels would be reduced.

3) Oil containment and clean-up equipment should be stored at various

points along pipeline routes.

4) Oil-storage tanks and transfer terminals should not be located near rich aquatic habitats.

5.0 THE IMPACT OF OFF-SHORE OIL AND GAS EXPLOITATION ON MARINE ECOSYSTEMS

5.1 Introduction

Since 1960, oil and gas exploration permits covering almost 500-million acres of Arctic Canada were issued. Initially, the number of offshore permits represented only a small proportion of the total exploration acreage. But today, the focus of attention is shifting in favor of potentially rich tracts in Hudson Bay, Mackenzie Bay, the Beaufort Sea, and the waters of the Arctic Archipelago. Indeed, the Department of Indian Affairs and Northern Development now believes that the greater part of arctic energy reserves lies in offshore waters[28, 2].

From the oil-extraction perspective arctic waters are the most hazardous in the world[43, 20]. Throughout most of the year they are covered by floating or pack ice. Drilling operations are threatened by massive slow-moving ice islands ranging from one to 10 miles in length, and as much as 100 feet in depth. Summer storms may induce hurricane-strength winds, 25-foot waves, and 12-foot storm tides[28, 11]. Under these conditions exploration wells are drilled in waters up to 1500-feet deep.

Based on the frequency of offshore oil and gas contamination in other areas of the world such as the Caspian Sea, the Gulf of Mexico, the Santa Barbara Channel, and the Gulf of Suez, one may conclude that serious arctic offshore oil spills are a near certainty. A risk-free technology for petroleum extraction in marine environments does not exist. Each offshore oil-extraction rig is in essence a time bomb with a potential to inflict massive ecological disruption.

Such opportunities are multiplying. In the past 5 years, exploration wells were established in Hudson Bay, along the Beaufort Coast, in the Belcher Channel, and in the Hecla and Griper Bay. More are planned. If contemporary trends continue, offshore activity will burgeon by the end of the decade and it may surpass terrestrial exploration in economic cost.

5.2 Impacts of Offshore Seismic Surveys

The selection of offshore drill sites is partially determined by seismic survey results. Thousands of miles of surveys have been undertaken in potentially oil-rich arctic waters. Blasting with Aquaflex linear explosives is one of the most common methods used. In the previous section, it was reported that the shock wave generated by seismic blasting can have serious consequences for freshwater fish. Effects on marine species are similar. Small fish in the immediate blast area may be killed while larger fish and mammals are often injured or frightened away from the area for weeks or months.

In a recent case, poor whale harvests in Tuktoyaktuk Bay were attributed to seismic blasting (45, 178). Other traditionally fauna-rich arctic waters may now be experiencing a similar population reduction.

One way to decelerate this process would be to undertake future seismic testing with submarines. The world's first submarine designed for seismic surveying was constructed by Arctic Canadian Continental Shelf Exploration Services Ltd. of Toronto. The 3-man, all-electric vessel is 45-feet long with a maximum operating depth of 800 feet (33, 11). It was scheduled to begin High Arctic service in April, 1975. Contract coverage called for 6,000 miles of exploration in 1975 and 1976. The primary environmental benefit of under-ice seismic surveys is a major reduction in noise and associated shock levels.

Areas of Concern and Recommendations

1) If the traditional offshore seismic survey methods continue unabated, the productivity of some arctic waters will likely decline. Comparatively-rare species may even become extinct.
2) Aquisition of seismic data through non-destructive technology must be encouraged. Submarine and other environmentally acceptable survev methods may be no more expensive than traditional procedures if the destruction of fish and mammal resources is considered.

5.3 Conventional Offshore Drilling Rigs

The majority of arctic-offshore drilling operations have been conducted from barges, mobile drill shins, and semi-submersible rigs towed to well sites bv barges. Provided that oil or gas leakage does not occur from the wellhead, these are generally innocuous exploration methods with few negative environmental implications. In some respects, offshore rigs may actually improve marine habitats.

Studies in the Gulf of Mexico indicate that the subsurface support structures of drilling rigs provide a favorable habitat for the growth of algae and seagrasses (46, 28). Fish are attracted to these rigs by the vegetation. They feed upon it, and through their presence attract large predators, thus enriching population density and species diversity near the drill site.

Areas of Concern and Recommendations

Little is known about the long-term ecological effects of artificially induced bioenrichment in highly-localized areas. Once east the exploration stage it is possible that the introduction of permanent drilling rigs may alter migration routes as well as feeding and staging grounds of fish and marine mammals. This possibility should he investigated before long-term extraction rigs are established in arctic waters.

5.4 Ice Island Drilling Wells

Severe climatic and operating conditions in the far north are stimulating experimentation with new drilling concepts geared to the arctic environment. The construction of "ice-island" drilling platforms represents one such trend. The first ice-platform well was established in Hecla and Griper Bay by Panarctic in the winter of 1973-74. It was drilled in 420 feet of water. Construction of the island was achieved by flooding an area of the coastal ice shelf to create an artificial ice thickening 400 feet in diameter[29, 2]. In this manner ice depth was extended from 7.5 to 17.5 feet. The added depth was sufficient to support a conventional 500-ton terrestrial drilling rig eliminating the need for a drillship or a conventional semi-submersible rig. The cost of the well was a modest $2 million[44, 23].

Other ice-platform wells are planned. The technique is attracting increased attention because of its simplicity and low cost. From an environmental viewpoint this method of exploration is undesirable for it is inherently unstable. Ice-platform rigs can only tolerate a maximum of 5% lateral movement before drill-pipes buckle. Should lateral ice pressures shear the pipe, oil or gas might easily escape from the damaged section. Construction of a relief well may have to be postponed until the following winter. In the interim, a potentially disastrous level of continuous petroleum contamination would devastate biotic communities.

Areas of Concern and Recommendations

The serious environmental hazards associated with ice-platform drilling should be sufficient to preclude further use of this method for oil and gas exploration. However, because of economic advantages, petroleum corporations may be expected to favor its continued usage.

5.5 Artificial Island Drill Wells

In the shallow waters of Mackenzie Bay, artificial islands were constructed from which to drill for oil using conventional terrestrial rigs. Five islands presently exist and several more are planned. Petroleum engineers believe that artificial islands are feasible to depths of at least 40 feet.

With each new island the construction methods are steadily being refined. In 1973, the first island, known as Immerk, was constructed by Imperial Oil using 250,000 cubic yards of gravel hydraulically dredged from Mackenzie Bay. Erosion on the steep island slopes was reduced by covering the periphery of Immerk with plastic sheets covered by wire mesh, anchored by steel piles and timber, and finally, overlain by war-surplus anti-torpedo nets (28, 5). After a short-drilling period, Immerk was abandoned. But the pile of gravel, plastic, steel, and wire from which it was created remains a lasting monument to the development of arctic-energy supplies.

Adgo Island, also constructed in 1973, was of a somewhat different design. In the first development phase 5,000 cubic yards of gravel and sand were dumped through an ice hole to form a base. Silt extracted from Mackenzie Bay was then placed over the gravel foundation and supported by sand bag dikes. When frozen, the silt provided a foundation for normal drilling operations. One advantage of the Adgo construction method was a 50% construction cost reduction vis-a-vis Immerk Island, from $10 million to $5 million. Another advantage is that unlike Immerk, Adgo-type islands self-destruct (28, 6). With the spring thaw, the silt loses strength, gains mobility, and the island is eroded to the depth of effective wave and current action.

Other designs for artificial islands include steel drilling platforms surrounded by gravel cofferdams, and conical drilling platforms designed to sink to the sea floor through controlled flooding.

Areas of Concern and Recommendations

1) Each of the construction methods outlined above will in some way disturb benthic biota. Where large amounts of fill are withdrawn from the sea floor, significant habitat destruction may be expected. Biological implications of such disruptions have not been extensively investigated.

2) The selection of sites for gravel, sand, and silt extraction are not adequately regulated by federal authorities. At well-chosen sites the impact of borrow operations may be minimal. In other areas, particularly feeding and spawning mounds, the effects may have a lasting impact. Such sensitive areas should be mapped and protected.

3) Plastic and metallic debris of abandoned Immerk-type islands are a hazard to whales, polar bears, seals and walrus. Over time, bits of debris may break away from disintegrating islands. These may be ingested by large mammals causing internal injury.

4) All future artificial islands should be removable or se" f-destruct ng.

5.6 Risks of Drill Well Blowouts

The global frequency of oil or gas leaks from offshore well sites is extremely low. Yet on the few occasions when leakage occurred, the volume of spilled petroleum has usually been massive. Most instances of offshore leaking originate from well blowouts. On a global scale, 47 blowouts were reported for 200,000 wells drilled [43, 103].

In the Canadian Arctic 2 blowouts are reported. Roth involved relatively nondestructive gasdeposits. Nevertheless, some detrimental effects may he expected. In one case on Melville Island, a blowout resulted in the creation of a 125-foot-high salt dome which engulfed the rig (45, 299). The ecological impact of this localized salt concentration is not well understood.

The environmental hazards associated with oil blowouts are far more severe than equivalent gas leaks. It is widely believed that a catastrophic offshore arctic oil blowout will inevitably occur unless such risks are reduced to negligible proportions.

The major oil companies are concerned about the prospects for potentially disastrous blowouts. They realize that in the event of a blowout it may require up to a year before a relief well could be drilled. They appreciate the consequences of this delay with respect to public relations and the arctic ecology. Consequently, they have invested heavily in an effort to advance blowout prevention technology.

One corporation recently designed a new blowout preventor featuring a 10,000 lb. working pressure, two automatic controls, a fail-safe unit, and a set of shearing blocks for use as a final resort. The device will cost $1.2 million (41, 16) Despite these advances, a totally reliable blowout preventor does not yet exist. Until a completely safe unit is developed significant environmental risks will continue to accompany offshore oil and gas exploration.

The environmental effects of a gas-well blowout are dependent upon the chemistry of the expelled gas. Lighter gases such as methane which constitute the bulk of natural-gas deposits are relatively harmless. They dissipate rapidly in water and the atmosphere. Hydrocarbon gases with a comparatively high molecular weight present a more serious hazard. Impurities in these gasses, such as hydrogen sulfide, are toxic to aquatic biota even in minute concentrations (29, 2). Gas fields with big concentrations of these impurities represent a particular danger.

Gas blowout assessment reports commissioned by Panarctic Oil Ltd. provide only a general statement of expected ecological effects. Little field research has been undertaken to assess the potential impact of a blowout on individual Canadian Arctic marine mammal and fish species.

5.7 Impacts of Crude Oil on Marine Biota

As northern oil and gas fields are exploited, the potential for oil contamination of marine resources increases. Marine oil spills may follow well blowouts, tanker collisions, leakage from coastal storage facilities, and inter-island pipeline fractures.

Effects of oil spills on salt-water fish are variable. Some species are very sensitive; others are not. The survival of fish depends upon the manner in which they come into contact with petroleum. Tiny droplets of emulsified oil products cause much greater damage than surface spills [47, 223]. Indeed, pelagic fish have good eyesight and are known to avoid oil slicks. Fish eggs and larvae are particularly sensitive. Eggs of some species are killed by oil concentrations as small as 10^{-4} ml/litre [47, 223]. Unlike adult fish, the chemoreceptors of larvae are unable to recognize oil spills. They will not circumvent oil slicks. Once contaminated they have little chance of survival [47, 317-318].

Zooplankton, an important food supply for many fish and whales, experience increased mortality following crude oil exposure. A 0.001 ml/litre oil concentration in seawater is sufficient to accelerate their death rate [47, 223].

The wreck of the "Arrow" off Nova Scotia in 1970 provides some clue to what may happen to marine mammals should they become oil-contaminated. Shortly after the "Arrow" spill. several young grey seals were rendered sightless by contact of oil with their eyes. They were found blundering through forested areas 1/2-mile from shore (27, 149). In addition to causing temporary or permanent blindness, oil is also trapped by seal fur. Ingestion may then occur through cleaning. A similar effect on walrus is expected.

The primary danger to arctic whales is that they may ingest finely dispersed oil while filter-feeding on planktonic crustaceans. They may then develop gastritis, enteritis, or other gastro-intestinal diseases. As with pelagic fish, whales probably would avoid large oil slicks. Evidence of this was obtained following the 1969 Santa Barbara oil spill. Normally, grey whales pass through the channel on their annual migration. However in 1969, most whales digressed from their traditional migratory route to circumvent the polluted waters (27, 150).

In some respects, arctic oil spills may have a longer impact period than equivalent spills in temperate and tropical areas. Due to climatic conditions, the rate of degradation may be comparatively low. Mechanical dispersion is inhibited by pack ice under which oil pockets may gather. Finally, biological time scales are so slow that a complete population recovery following a major spill may require a much longer period than would be necessary in warmer regions.

Areas of Concern and Recommendations

1) Technology to improve the Performance of today's blowout preventers is advancing at a steady pace. It is likely that the blowout technology of the middle 1980's will be superior to that Presently in use. Immediate consideration should be given to a five- or ten-year moratorium in offshore drilling until greater environmental safeguards can be assured.

2) Contemporary population and distribution data for northern marine fish and mammals are extremely sketchy. It would be difficult to accurately assess the number of deaths and injuries caused by oil

contamination in the absence of a reliable data base.

3) Tank farms, pipelines, oil wells, and shipping routes should be precluded from major migration routes, feeding, and breeding grounds.

4) Oil cleanup supplies should be stockpiled at strategic locations.

5) A greater policing effort by the appropriate federal authorities would improve the effectiveness of existing environmental protection regulations.

6.0 CONCLUSIONS

6.1 The Prospect

It is clear that the pending arctic oil and gas boom will irrevocably change the face of Canada's last pristine wilderness. Each of the arctic biomes will in some way be affected by the frenetic development pace. In southern Canada "progress" and "development" have through conditioning been ecologically equated with fouled streams, littered forests, decreasing wildlife, and polluted air. The same images need not apply to the North. The twin goals of exploiting arctic energy resources while maintaining ecological stability are not mutually exclusive.

Industry, in the classic capitalistic context, is dedicated to mass production in the shortest period and at the lowest competitive price. If this philosophy is applied to the exploitation of arctic energy reserves, the worst prospects outlined in this report may become reality. Conversely, if resource policy were deliberately oriented towards a cautious exploitation rate based upon sound environmental management guidelines, development impacts may be minimal. The cost of arctic energy would then be high and the pace of exploitation curtailed. But this is the price to be paid for the maintenance of viable, self-perpetuating arctic ecosystems.

6.2 The Choice

The Inuit face critical issues. They may opt to participate fully in northern energy-resource exploitation. In so doing, they may successfully modify the extent of development in areas where it most threatens their lifestyle. Alternatively, they may attempt to block proposed developments in the courts.

In the latter scenario Inuit objections may be overriden in the "national interest", or as a result of "national security" considerations. Such a development could effectively exclude them from the decision-making process. They would cease to play an effective role in controlling fundamental aspects of their destiny.

Now that arctic energy exploitation is at an incipient stage of development the Inuit are in an excellent position to obtain some influence over future events. Yet it must be recognized that a demand for active participation in development decisions jointly with oil companies and the federal government, may eventually compromise the viability of their traditional lifestyle, in exchange for fuller economic integration into the North American industrial society. The choice is theirs.

GLOSSARY: TECHNICAL TERMS AND ABBREVIATIONS

Active Layer: the zone between the soil surface and subsurface permafrost within which major chemical processes and macrobiotic colonies occur.

Aquifer: a water-bearing stratum of permeable rock, sand, or gravel.

Aspergillosis: a severe respiratory disease of birds caused by the mold Aspergillus.

Bryophyte: a moss or liverwort.

Cofferdam: a temporary water-tight enclosure from which water is pumped to expose the bottom of a river, lake, or sea in support of construction activities.

Enteritis: an inflammation of the intestines.

Esker: a long, narrow and often sinuous ridge or mound of sand, gravel and boulders deposited between ice walls by a stream flowing on, within or beneath a stagnant glacier.

Gastritis: an inflammation of the stomach.

Mcf: million cubic feet.

Meristem: an active area within plants from which primary tissue production is generated.

Necrosis: the death of living tissue.

Photosynthesis: a photochemical process by which plants convert carbon dioxide and water into carbohydrates and oxygen.

Phytotoxic: something which is poisonous to plants.

ppm: parts per million.

Dsi: . pounds per square inch.

Raptor: a bird of prey belonging to the order Raptores

Rhizome: an elongate stem or branch of a plant usually underwound, which behaves like a root but which is distinguished from a true root in that it possesses buds and scalelike leaves.

Sedge: a grasslike plant of the family Cyperaceae.

tcf: trillion cubic feet.

Thermokarst: the melting of Permafrost frozen soil.

Threshold volume: the volume of oil or gas necessary to insure economic utilization of a pipeline through its estimated lifespan.

Transpiration: the emission of water vapour from the surface of plant tissues.

REFERENCES

1. Adams, R.S. & Ellis R. 1960. "Some Physical and Chemical Changes in Soil Brought About by Saturation with Gas". Proc. Soil. Sci. Soc. Amer., Vol. 24.

2. Raker, J.M. 1971. "The Effects of Oils on Plant Physiology." in Proceedings of 1970 London Symposium on the Ecological Effects of Oil Pollution on Littoral Communities. E.B. Cowell, ed. London, England: Instit. of Petrol.

3. Bliss L.C., & Peterson E.B. 1973. The Ecological Impact of Northern Petroleum Development, 5th International'Conqress, Le Harve, France: Foundation Francaise d'Etudes Nordiques.

4, Brown, S. 1974. The Effects of Crude Oil on Terrestrial Vegetation, unpublished M.Sc. thesis, McGill University, Montreal, Quebec.

5, Canada, Canadian Wildlife Service. Environmental-Social Program, Northern Pipelines. 1973. An Inventory of Wildlife Habitat of the Mackenzie Valley and the Northern Yukon. 'By Special Habitat Evaluation Group, Canadian Wildlife Service. Cat. No. R72-12273. Ottawa, Ont.: Information Canada.

6. Canada Department of the Environment. Inland Waters Branch. 1972. Arctic Winter Oil Spill Test U.S. Coast Guard. By E. C. Chen. Technical Bulletin No. 68. Ottawa, Ont.:

7. ______. Fisheries and Marine Service. 1973. Seismic Exploration: Its Nature and Effect on Fish. Technical Report No. CEN/T-73-9. Winnipeg, Man.: Environment Canada.

8. Canada. Department of Indian Affairs and Northern Development. Environmental-Social Program, Northern pipelines. 1973. . . An Evaluation of the Fish Resources of the Mackenzie River Valley as Related to Pipeline Development. vol. 1. By J.N. Stein, T. R. Jessop, T. R. Porte and K. T.J. Chang-Kue. Cat. No. Fs37-1973/1-1. Ottawa, Ont.: Information Canada.

9. ______. 1973. Botanical Studies of Natural and Man-Modified Habitats in the Mackenzie Valley, Eastern Mackenzie Delta Region and the Arctic Islands. L. C. Bliss (cd.). Cat. No. R72-8673. Ottawa, Ont.: Information Canada.

10. ______. 1973. Impact of a Pipeline on Territorial Transportation Facilities, Resource Output and Industrial Development. By Economic Staff Group, Northern Economic Development Branch. Cat. No. R57-4/1973-7. Ottawa, Ont. : Information . Canada.

11. ______. 1973. The Influence of Pipeline Development on Freshwater Fishery Resources of Northern Yukon Territory. Aspects of Research Conducted in 1971 and 1972. By J. E. Bryan. Cat. No. R72-9773. Ottawa, Ont.: Information Canada.

12. ______. 1973. Lena Term Effects of Summer Traffic by Tracked Vehicles on Tundra. By J. R. Radforth, Cat. No. R57-2/1973. Ottawa, Ont.: Information Canada.

13. ______. 1973. Oil Spillage on Microorganisms in Northern Canadian Soils. By D. Parkinson. Cat. No. R72-8573. Ottawa, Ont.: Information Canada.

14. ______. 1973. Studies of Vegetation, Landform and Permafrost in the Mackenzie Valley. By R. M. Strang. Cat. No. R72-8173. Ottawa, Ont. : Information Canada.

15. ______. 1973. Studies of Vegetation, Landform and Permafrost in the Mackenzie Valley: Terrain, Vegetation, and Permafrost Relationships in the Northern Part of the Mackenzie Valley and Northern Yukon. By S. C. Zoltai and W. W. Pettapeice. Cat. No. R72-7973. Ottawa, Ont.: Information Canada.

16. ______. 1974. Effects of Oil Spillage on Northern Canadian Soils. By D. Parkinson. Cat. No. R72-12874. Ottawa, Ont.: Information Canada.

17. ______. 1974. Gas Pipelines in the Mackenzie River Valley: Estimation of Fire and Explosion Hazards Caused by pipeline Rupture. By Beak Consultants Ltd., & Intercomp Resource Development and Engineering Ltd.. Cat. No. R72-12974. Ottawa, Ont.: Information Canada.

18. ______. 1974. "Mackenzie Valley and Northern Yukon Pipelines: Socio-Economic and Environmental Aspects. By A.D. Hunt, G.M. MacNabb, J.S. Tener. Cat. No. R57-7/1974. Ottawa, Ont.: Information Canada.

19. ______. 1'374. Microbiological Degradation of Northern Crude Oils. By F. D. Cook, & D. W. S. Westlake. Cat. No. R72-12774. Ottawa, Ont.: Information Canada.

20. ______. 1974. The Physical Aspects of Crude Oil Spills on Northern Terrain. By D. Mackay, M. E. Charles, & C. R. Phillips. Cat. No. R72-9173. Ottawa, Ont.: Information Canada.

21. ______. 1974. Recovery of Vegetation in Arctic Regions After Burning. By R. W. Wein. Cat. No. R72-13574. Ottawa, Ont.: Information Canada.

22. ______. 1974. Swamplands for Sewage Effluents. By R.C.B. Hartland-Rowe & P. B. Wright. Cat. No. R72-13174. Ottawa, Ont.: Information Canada.

23. ______, 1974. Vegetation Types of the Mackenzie Corridor, By Forest Management Institute. Canadian Forestry Service. Cat. No. R72-9973. Ottawa, Ont.: Information Canada.

24. Canada, Department of Indian Affairs and Northern Development. 1974. Environmental and Socio-Economic Effects of the Proposed Canadian Arctic Gas Pipeline on the Northwest Territories and Yukon. By the Pipeline Application Assessment Group. Ottawa, Ont.: Information Canada.

25. Maxwell, J. 1973. Energy From the Arctic: Facts and Issues. Montreal, Que.: Canadian-American Committee.

26. McCown, B.H., Deneke F.J., Richard W.E., & Tieszen L.L. 1972. "The Response of Alaskan Terrestrial Plant Communities to the Presence of Petroleum." Proceedings of the Symposium on the Impact of Oil Resource Development on Northern Plant Communities. Fairbanks, AlasPa: Institute of Arctic Biology.

27. Nelson-Smith, A. 1972. Oil Pollution and Marine Ecology. London, England.: Paul Elek Ltd..

28. Northern Perspectives. Vol. 2: No. 2.

29. Northern Perspectives. Vol. 2: No. 4.

30. Oilweek. Vol. 24: No. 38.

31. Oilweek. Vol. 24: No. 40.

32. Oilweek. Vol. 24: No. 42.

33. Oilweek. Vol. 24: No. 48.

34. Oilweek. Vol. 24: No. 50.

35. Oilweek. Vol. 24: No. 52.

36. Oilweek. Vol. 25: No. 3.

37. Oilweek. Vol. 25: No. 4.

38. Oilweek. Vol. 25: No. 52.

39. Oilweek. Vol. 25: No. 21.

40. Oilweek. Vol. 25: No. 9.

41. Oilweek, Vol. 25: No. 18.

42. Pearse P.H. 1974. The Mackenzie Pipeline: Arctic Gas and Canadian Energy Policy. Toronto. Ont.: McClelland & Stewart.

43. Pimlott. D.H. 1974. "Delta Gas: Time and Environmental Considerations." Proceedings of Conference on Gas from the Mackenzie Delta: Now or Later? May, 1974. Ottawa, Ont.: Canadian Arctic Resources Committee.

44. Pimlott D.H. 1974. "The Hazardous Search for Oil and Gas in Arctic Waters." Nature Canada. Vol. 3: NO. 4.

45. Pimlott D.H., Vincent K., McKnight C. 1973. Arctic Alternatives-. Ottawa, Ont.: Canadian Arctic Resources Committee.

46. Sea Technology. Vol. 14: No. 9.

47. United Nations Food and Agriculture Organization. 1972. Marine Pollution and Sea Life. M. Ruivo (ed.) London, England.

48. U.S. Environmental Protection Agency. 1974. Brine Disposal Treatment Practices Relating to the Oil-Production Industry. Report No. EPA-660/2-74-037. Washington, D.C.: EPA.

49. __ 1974. Environmental Guidelines for Development Roads in the Subarctic. By Lotspeich F.B. & Helmers, A.E. Report No. EPA-660/3-74-009. Corvallis, Oregon: EPA Office of Research and Development.

50. ___ 1974. Saline Groundwater Produced with Oil and Gas. Report No. EPA-660/2-74-010. Washington, D.C.: EPA.

51. Wein R.W., & Bliss L.C. 1973. "Experimental Crude Oil Spills on fl.retie Plant Communities." Journal Appl. Ecol. Vol. 28.

52. Wilkinson D. 1970. The Arctic Coast. Toronto, Ont.: Natural Science of Canada Ltd..

53. Woodward H.W. 1972. Northern Canada Resources and Resource extraction Policies of Development. Conference on Policies on Northern Development. January, 1973. Kingston, Ont.: Queen's University.