TP 671

ADVISORY
COMMITEE
ON
NORTHERN
DEVELOPMENT

WESTERN ARCTIC MODERATE DRAFT HARBOUR

TRANSPORTATION COMMITTEE
STEERING GROUP ON
MARINE TRANSPORT

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ACND TRANSPORTATION COMMITTEE

STEERING GROUP ON MARINE TRANSPORT

WESTERN ARCTIC

MODERATE DRAFT HARBOUR

FEBRUARY 1977

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EXECUTIVE SUMMARY

Canadian Marine Drilling Limited, CANMAR, commenced exploratory drilling in the Beaufort Sea in the summer of 1976, using three drillships, five support vessels and one base vessel. In 1975, they requested that the Federal Government dredge the approach channel to Tuktoyaktuk harbour to accommodate this fleet. Following Treasury Board rejection of preliminary study funding, ACND Transportation Committee undertook a study of the requirements for and cost of a moderate draft (20 feet) facility in the Western Arctic.

The study examines sixteen possible sites between Herschel Island and Paulatuk on the basis of operational acceptability, hydrography, meteorology, ice regime, infrastructure, environmental impact and costs. In view of an apparent lack of interest and requirements among other prospective users, it was considered that the CANMAR requirements were representative in general of moderate draft port requirements and were therefore used as a basis for the study.

The study concludes:

(1) This port development would constitute public expenditure for a single direct beneficiary.

(2) A port could not be made operational in a lesser period than the duration of the current exploration program and would, therefore, be of little or no value to the program.

(3) A port developed concurrently with the exploration program could be rendered obsolete in a period of five years in the event of a) failure of the exploration program; or b) a geographical shift in the location of the drilling program beyond the region serviced by the port.

(4) The continuing value of a port would therefore depend on either the discovery and exploitation of hydrocarbon deposits within the port's vicinity or on the justification of the need for expanded exploration.

(5) CANMAR's investment in highly mobile marine exploration equipment is geared to the petroleum industry's capital reserves for exploration purposes whereas the government's investment in a port would be a nonrecoverable cost in the event of failure of the exploration program.

(6) The offshore ice regime prevents increasing the drilling season by choice of port site.

(7) Environmental data is incomplete.

(8) Sites other than Tuktoyaktuk could provide adequate harbours at a much lower marine cost.

(9) Notwithstanding (8), certain natural and man-made amenities of Tuktoyaktuk make it an attractive candidate.

It is recommended that Government take no direct action for the development of a moderate draft harbour in the Western Arctic at this time. The situation should, however, be monitored, and if significant hydrocarbon or other major marine activities develop, Government may wish to reconsider the decision. In order that the Government be in a position of preparedness in the event of successful hydrocarbon exploration, environmental impact studies should be carried out at Tuktoyaktuk, Letty Harbour and King Point.

I. INTRODUCTION

Canadian Marine Drilling Limited, CANMAR, a subsidiary of Dome Petroleum Limited, has developed drilling systems specifically for offshore exploration in the Beaufort Sea. The operations are on leases held by Dome and other companies. A fleet of three drillships, five support vessels and one base vessel is used.

In May 1975, officials of Dome and CANMAR approached the Department of Transport with a request for dredging of the approach channel to Tuktoyaktuk harbour in time to permit the wintering of the drillships in 1976 and operation of supply vessels at full load from a base to be located at Tuktoyaktuk.

The CANMAR requirement would be at minimum a channel 18 feet deep, 300 feet wide extending about 10 miles. Their preference was for a channel 20 feet deep, 400 feet wide and 15 miles long.

Subsequent discussions held between officials of CANMAR, CMTA, DPW, DOE, ARTA and others, determined that the dredging could not be undertaken without a study of Hydrographic and Environmental aspects as well as actual Test Borings and a Test Dredging operation. It was determined that the preliminary work could be carried out during the 1975 navigation season, with the environmental study and dredging feasibility study extending into 1976. A Treasury Board submission seeking approval for funding of the preliminary study was rejected on the basis that such investment was properly the responsibility of the private sector. However, because of a perceived interest in a Western Arctic moderate draft harbour, the ACND Transportation

Committee, Steering Group on Marine Transport, was asked to assess the requirement and examine possible locations for such a facility. As this work was being carried out it became apparent that the CANMAR requirement was the only current bona fide need and the study has, as a consequence, been oriented towards it.

II. PORT REQUIREMENTS

A. CANMAR

1. Channel - The harbour entrance channel requirements are dependent upon the following vessel specifications:

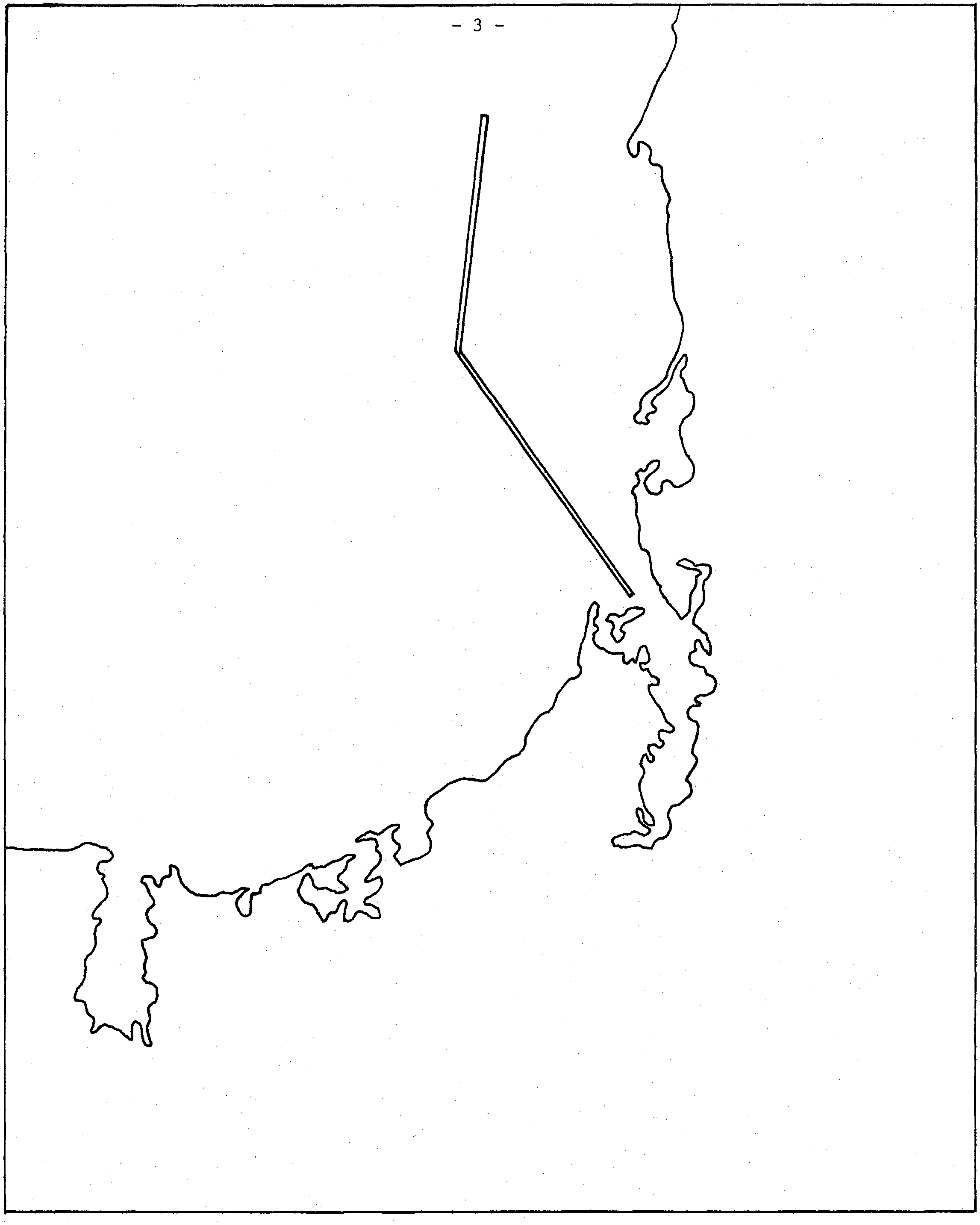
Drillships:	Length:	358 ft.	
	Beam	70 ft.	
	Draft	16 ft. min.	
Supply Vessels:	Length	205 ft.	
	Beam	45 ft.	
	Draft	15.5 ft.	100%
		14.5 ft.	60%

A minimum 2 ft. clearance is required under the keel, and preferably 4 ft. to prevent foreign material ingress through the cooling system intakes.

Two channel requirements have been requested by CANMAR:

Minimum:	Depth	18 ft.
	Width	300 ft.
Desirable:	Depth	20 ft.
	Width	400 ft.

The proposed channel alignment at Tuktoyaktuk is shown in Figure 1. The general harbour layout is shown in Figure 2.



PROPOSED DREDGED CHANNEL INLET TO TUK HARBOUR

FIG.1

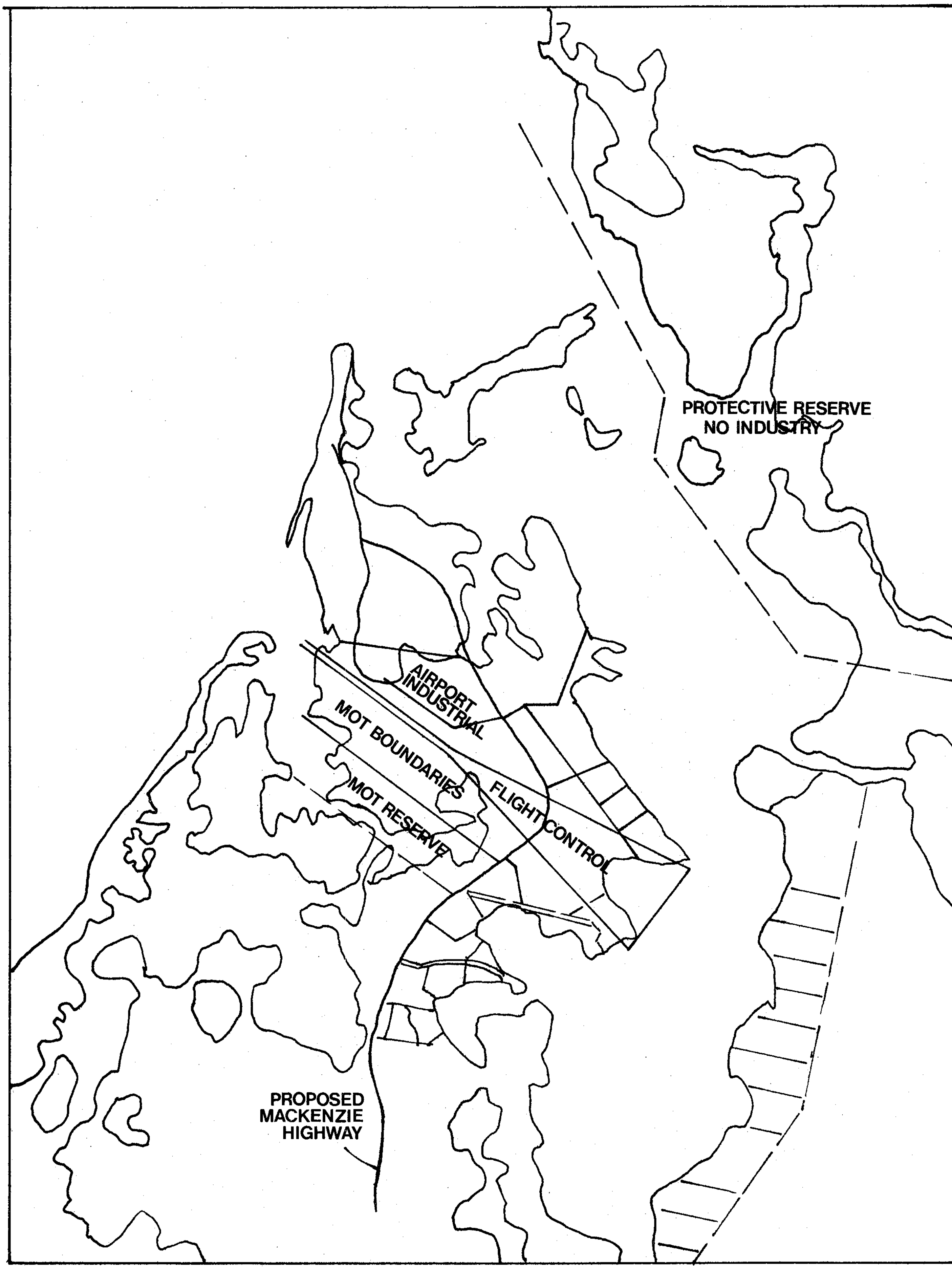

PROTECTIVE RESERVE
NO INDUSTRY
AIRPORT
INDUSTRIAL
MOT BOUNDARIES
MOT RESERVE
FLIGHT CONTROL
PROPOSED
MACKENZIE
HIGHWAY

FIG. 2

2. Wharf Facilities - Operator will require wharf frontage of 250' minimum accommodating a 150T crane, crawler mounted. General cargo up to 50T max lift will be handled plus bulk loading of fresh water, fuel, cement and barites. CANMAR would provide these facilities.

3. Roads - Roads suitable for heavy vehicle transport will be required between storage area, airstrip and wharf.

4. Airstrip - The requirement is a landing strip suitable for a Hercules 130 at partial load for heavy/bulky items. Tuk airstrip is deemed to be minimally acceptable.

5. Water and Sewer - A source of fresh water at the base would benefit operator but is not an absolute requirement.

The rig makes its own drinking water and can use sea water for mud if necessary. Sewage facilities are not a significant problem.

6. Mail - This is not a significant problem.

Operator is an authorized mail carrier for ship personnel.

7. Communications - Operator is not dependent on local facilities, unless an independent radio link with Alberta is disallowed.

8. Medical - Medic would be provided by operator.

9. Recreational - No requirement.

10. Police - No requirement

11 Hydro Power - Operator has no requirement for hydro but would use it at base, if available.

12. Living Accommodation - Would be provided by operator.

13. Maintenance Support - Maintenance support facilities would be used if available, but are not expected from an Arctic operations base.

14. Freight Delivery - Not required.

15. Meteorological - Operator will have at his base full time MET office staff with radio links to Edmonton.

16. Land Requirement - An area of 10 to 15 acres is required for storage of material and equipment.

B. Other Prospective Users

Other prospective users, including Imperial Oil Ltd., Gulf Oil Ltd., Shell Canada and Cominco did not respond positively to a letter of inquiry concerning possible needs. The study is therefore confined to examination of adequate facilities for CANMAR needs.

III. ALTERNATIVE SITES

A. Identification

In view of the excessive preliminary cost estimates by DPW for providing the required channel at Tuktoyaktuk (up to $40 million), a number of alternate sites from Herschel Island to Pearce Point were examined. The following assessment criteria were developed for this purpose:

1. Channel Length - i.e., the length at each site requiring dredging to provide the minimum 300 ft. width, 18 ft. depth entrance requirement.

2. Spoil - An estimate of the amount of spoil to be removed at each site for the purpose of estimating dredging costs.

3. Basin Dredging - The amount of dredging to provide a fleet winter storage basin is estimated on the basis of a basin, 1000 ft. long, 300 ft. wide and 18 ft. deep.

4. Dynamic Ice Protection - Fleet wintering requires protection from dynamic ice pressure, which normally occurs from a northwesterly direction as a consequence of wind. Where no natural protection is available, the length of the required breakwater is estimated.

5. Average Open Season - The average ice free season for each site is assessed. This is discussed fully in paragraph III B.

6. Ocean Access - A qualitative assessment of the ease with which vessels could be manoeuvred into the harbour is made.

7. Nature of Bottom - The holding quality of the bottom is an important factor for anchoring of vessels.

8. Infrastructure - Existing infrastructure at each site is compared with requirements discussed above (Part II).

9. Distance to Drill Site - This is an important factor in site selection from the considerations of costs and available drill time. For this purpose, an assumption was made regarding the location of the effective centre of drilling operations.

10. Distance to Inuvik - Inuvik is assumed to be the most northerly point from which supplies would diverge to the base site.

The following sites were evaluated:

1. Herschel Island - Pauline Cove
2. King Point
3. Tuft Point
4. Mason Bay
5. Warren Point (west)
6. Atkinson Point (west)
7. Atkinson Point (east)
8. McKinley Bay
9. Liverpool Bay
10. Wood Bay
11. Police Point
12. Letty Harbour
13. Sachs Harbour
14. Paulatuk
15. Tuktoyaktuk
16. Pearce Point

Figure 3 shows the locations of these candidate sites. The assessment data is presented in Table 1.

B. Operational Evaluation

1. Hydrographic Considerations - The most recent Canadian Hydrographic Service large scale sounding field sheets were utilized, where available. Where no field sheets were available, large scale navigation charts of the area were used. These reference documents are listed in Table 2.

The scale of sounding plans or charts varies from 1/3,000 to 1/150,000 but is generally 1/25,000 or 1/50,000. The soundings were taken between 1955 and 1971 and most of them are detailed enough for the purpose of the study.

The Canadian Hydrographic Service has no immediate plans for surveys of the area under study.

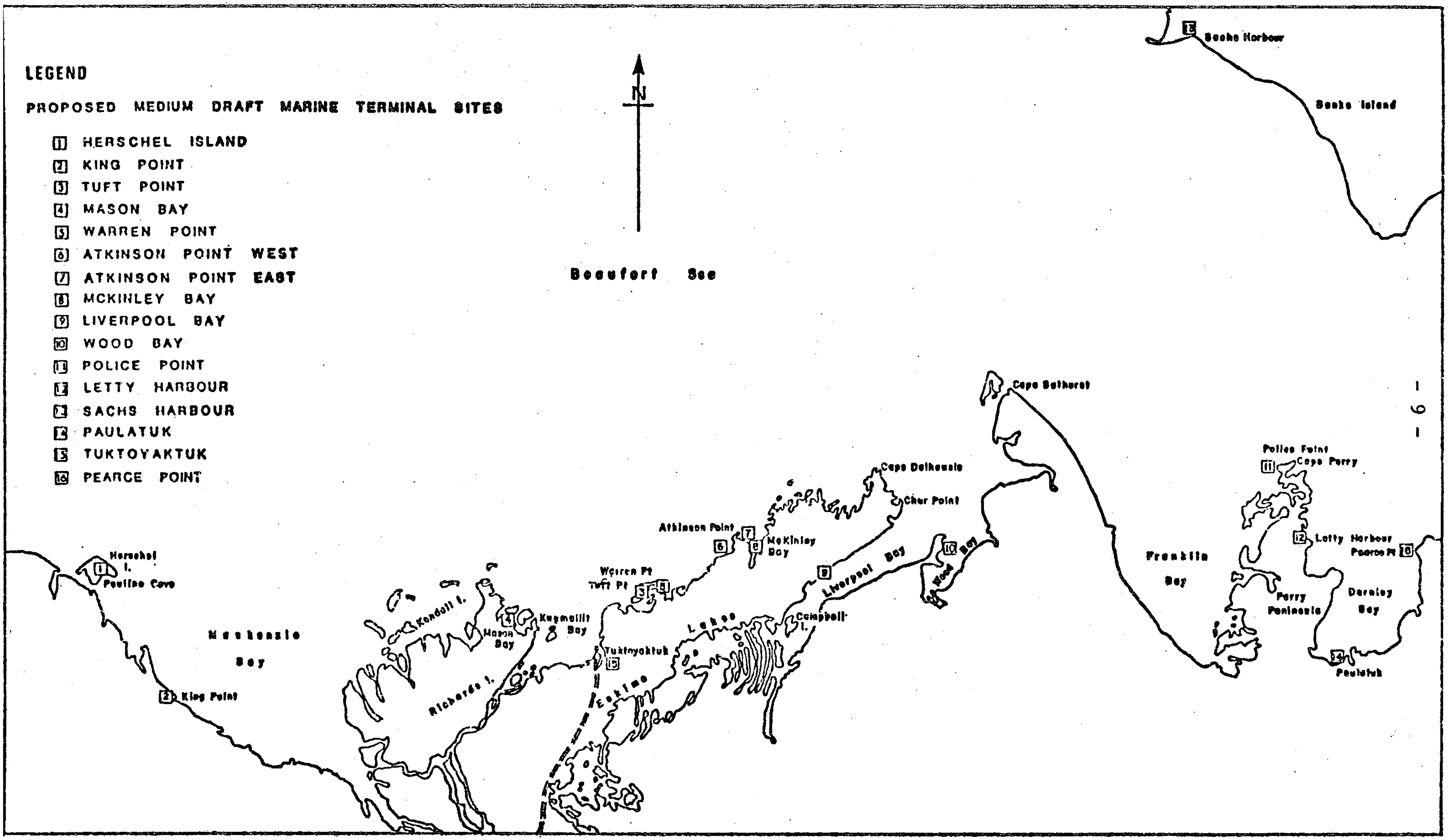

LEGEND
PROPOSED MEDIUM DRAFT MARINE TERMINAL SITES
1 HERSCHEL ISLAND
2 KING POINT
3 TUFT POINT
4 MASON BAY
5 WARREN POINT
6 ATKINSON POINT WEST
7 ATKINSON POINT EAST
8 MCKINLEY BAY
9 LIVERPOOL BAY
10 WOOD BAY
11 POLICE POINT
12 LETTY HARBOUR
13 SACHS HARBOUR
14 PAULATUK
15 TUKTOYAKTUK
16 PEARCE POINT
N
Beaufort Sea
Sachs Harbour
Banks Island
Cape Bathurst
Police Point
Cape Parry
Letty Harbour
Pearce Pt
Franklin Bay
Perry Peninsula
Darnley Bay
Paulatuk
Cape Dalhousie
Char Point
Atkinson Point
McKinley Bay
Warren Pt
Tuft Pt
Liverpool Bay
Wood Bay
Campbell I.
Eskimo Lakes
Tuktoyaktuk
Kugmallit Bay
Mason Bay
Kendall I.
Richards I.
Mackenzie Bay
Herschel I.
Pauline Cove
King Point

Fig. 3

	Herschel	King Point	Tuft Point	Mason Bay	Warren Point West	Atkinson Point West	Atkinson Point East	McKinley Bay	Liverpool Bay	Wood Bay	Police Point	Letty Harbour	Sachs Harbour	Paulatuk	Tuktoyaktuk	Pearce Point
18' Channel Length (FT.)	NIL	3,500	3,500	72,720	15,150	4,000	15,665	2,500	NIL	9,090	NIL	NIL	4,400	6,878	90,900	NIL
Spoil (YD^3)	NIL	375,000	485,067	10,075,760	1,521,689	554,815	1,659,852	373,748	NIL	737,031	NIL	NIL	511,541	1,185,814	5,600,000	NIL
Req'd Ice Protection	2400 ft BKWR OPTIONAL	NIL	3000 ft BKWR OPTIONAL	NIL	NIL	NIL	NIL	NIL	3000 ft BKWR OPTIONAL	7000 ft BKWR OPTIONAL	800 ft BKWR ESSENTIAL	NIL	NIL	NIL	NIL	600 ft BKWR OPTIONAL
Bottom	SAND?	SAND	MUD	SAND?	SAND MUD	MUD	MUD	SAND MUD	SAND MUD	MUD	ROCK SAND	SAND	SAND MUD	SAND	SAND	SAND MUD
Ocean Access	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	VERY GOOD	GOOD	VERY GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
Dist. to Drill Site (Miles)	125	128	81	73	72	75	74	75	143	136	206	269	204	301	83	259
Dist. to Inuvik (Miles)	135 (TO ARUVIK)	101	131	116	141	159	171	171	307	282	359	399	378	431	109	412
Infrastructure	NIL	NIL	NIL	NIL	NIL	SOME PILOT VOL 111	SOME PILOT VOL 111	NIL	NIL	SOME PILOT VOL 111	SOME PILOT VOL 111	NIL	SOME PILOT VOL 111	SOME PILOT VOL 111	YES	SOME
Basin Dredging (Ft.)	NIL	1000	1000	NIL	1000	1000	1000	1000	NIL	1000	NIL	1000	NIL	NIL	NIL	NIL

TABLE 1

ALTERNATE SITES - CHARACTERISTICS

TABLE 2

BEAUFORT SEA MEDIUM DRAFT MARINE TERMINAL STUDY

HYDROGRAPHIC SITUATION AT POSSIBLE SITES

Possible Site	Reference Field Sheet	Chart	Scale	Year	Depths in
Herschel Island	3588		1/50,000	1969	m.
King Point	WA 10071		1/50,000	1970	m.
Tuft Point	2758		1/24,000	1957	ft.
Mason Bay		7604	1/150,000		m.
Warren Point West	2758 E5		1/50,000	1962-64	ft.
Atkinson Point West	WA 10085		1/100,000	1971	m.
Atkinson Point East	WA 10028A		1/50,000		ft.
	WA 10028B		1/50,000	1964	ft.
McKinley Bay		7622	1/50,000	1962-64,1971	m.
Liverpool Bay	WA 10035		1/150,000		ft.
		7606	1/150,000		m.
Wood Bay		7622	1/50,000	1962-64,1966	m.
Police Point		7637	1/50,000	to 1964	fath.
		7630	1/12,000	1955-56	m.
Letty Harbour		7611	1/200,000		m.
Sachs Harbour	WA 10047B		1/50,000	1968	fath.
	WA 10014		1/25,000	1963	fath.
		7630	1/25,000	1963-68	m.
Paulatuk		7640	1/50,000	1951,66,69	m.
			1/25,000		
Tuktoyaktuk	2651 part 2		1/6,000	1956	ft.
	2758		1/24,000	1957	ft.
	WA 10053		1/3,000	1966	ft.

Source - Canadian Hydrographic Service, Department of the Environment

Note - 1. The Canadian Hydrographic Service has no immediate plans for surveys of above locations.

2. Meteorology - For the purpose of the study, wind and visibility are considered to be the two most important meteorological factors to the selection of a marine terminal for supply and drilling operations in the Beaufort Sea.

Wind - Wind has several effects. It influences the length of the shipping season by moving ice fields in and out of the work and harbour areas and raises or lowers water levels in shallow areas such as the approaches to Tuktoyaktuk harbour. Wind waves and forces affect ships at sea and at dock, and also have an impact on airport design and operations.

Detailed information on wind in the study area is available at Tuktoyaktuk and Cape Parry on the coast, at Inuvik in the Mackenzie Delta and at 8 Grid Points in the Beaufort Sea. The type of data available and its references have been listed in Table 3. Generally, the records started in the mid-fifties. They are continuous at shore stations but cover only the July through September period at the Beaufort Sea Grid Points where data was obtained from ships operating in the area. Refer to Figures 4 and 5.

In the Beaufort Sea area, the largest extremes occur in the winter but the most destructive storms take place in the fall. Winds greater than 40 m.p.h. generally persist for less than 13 hours along the coast. Higher hourly winds occur more frequently in the eastern than the western Beaufort Sea: 50% of the hourly winds exceed 8 kt in the east as compared to 4 kt in the west (Cape Parry is representative of the wind regime in the eastern Beaufort Sea and Tuktoyaktuk and Inuvik of the regime in the western Beaufort Sea).

TABLE 3

BEAUFORT SEA MODERATE DRAFT MARINE TERMINAL STUDY

WIND DATA

LOCATION	TYPE OF DATA	FORMAT	REFERENCE
Cape Parry, Inuvik	Hourly wind speed vs Month	Graph	Climate Vol. 1[1] Fig. 5.1, 5.2
	Max. duration of hourly wind speed by various classes for all directions	"	" Fig. 5.8
	Wind direction: Percentage probability for any speed during specific periods	"	" Fig. 5.13, 5.14
	Wind direction: Percentage probability for any speed during the year	"	" Fig. 5.20
	Monthly hourly wind speeds (mph) for selected stations	Table	" Table 5.1
	Mean annual and extreme hourly wind speeds (mph) and computed peak gusts (mph)	"	" Table 5.2
	Percentage probability of the hourly wind speed (mph) being greater than or equal to specified values	"	" Table 5.4
	Return periods (yrs) of annual maximum hourly wind speed (mph)	"	Table 5.5
Inuvik	Mean Monthly wind speed frequency	Table	HDS-96 Table 3
	Wind speed classes	"	" Table 4, 6a,b,c.
	WMO climatological summary - Model C	"	" Table 5
	Wind percentage frequency		
Tuktoyaktuk	Wind speed frequency - Mean Monthly	"	
	Means extremes and standard deviation of mean speed (mph)	"	
Beaufort Sea Grid Points	Wind direction: Percentage frequency for all speeds during period July through September	Graph	Climate Vol. 1 Fig. 5.11, 5.12
	Percentage probability of the hourly wind speed (kts) being greater than or equal to specific values for the period July through September	Table	" Table 5.3

Note - 1. Ref."The Climate of the Mackenzie Valley - Beaufort Sea" DOE
2. See Fig. 4 for location of stations

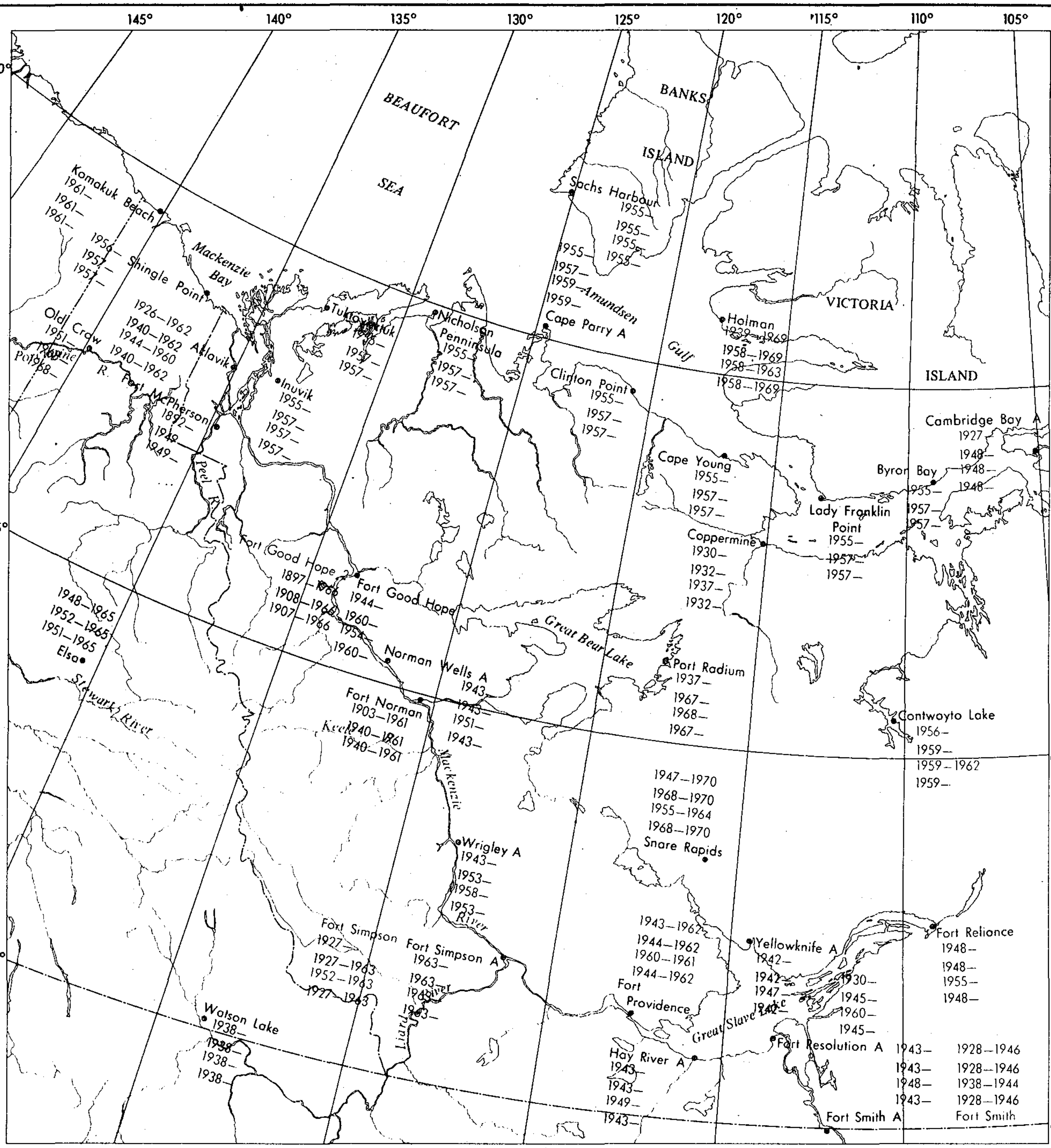
At Grid Points 3 to 7 (Figure 5), covering the study area in the Beaufort Sea, winds from July to September are primarily easterly (NE to SE) and westerly (SW to NW). Easterly winds which occur with a probability of 43%, carry the ice pack away from the area and result in a longer open water season, while westerly winds, which occur with a probability of 34%, guide the Beaufort Sea ice landwards and result in a shorter open water season.

Winds from the northwest quadrant can, if they are strong enough or last several consecutive days, raise the water level at Tuktoyaktuk, while winds from the southeast quadrant lower the level. Data in Table 4 shows that the percentage frequency of these winds from June to October to be 33% and 40% respectively. The probability of wind lowering the level increases as the season progresses.

A general analysis of the wind data indicates that sites in the western Beaufort Sea should be given preference.

<u>Visibility</u> - Visibility, like wind, is an important parameter for the planning of port and airport facilities.

In the summer, when most drilling and related activities take place, fog is largely responsible for reduced visibility along coastal areas. At Cape Parry the incidence of fog reaches a high of 6 to 8 days during the month of August. At Inuvik the highest frequency of 3 days is in September. At Cape Parry and Inuvik between June and October visibility greater than 6 miles is found more than 80% of the time and more than 75% of the time in the Beaufort Sea from July to September. Generally, the visibility is poorest along the coast in the spring and fall and in the western Beaufort Sea in the late summer.



LEGEND

Fort Smith	
1928–1946	Total period of record
1938–1944	Temperature
1928–1946	Wind
1928–1946	Precipitation

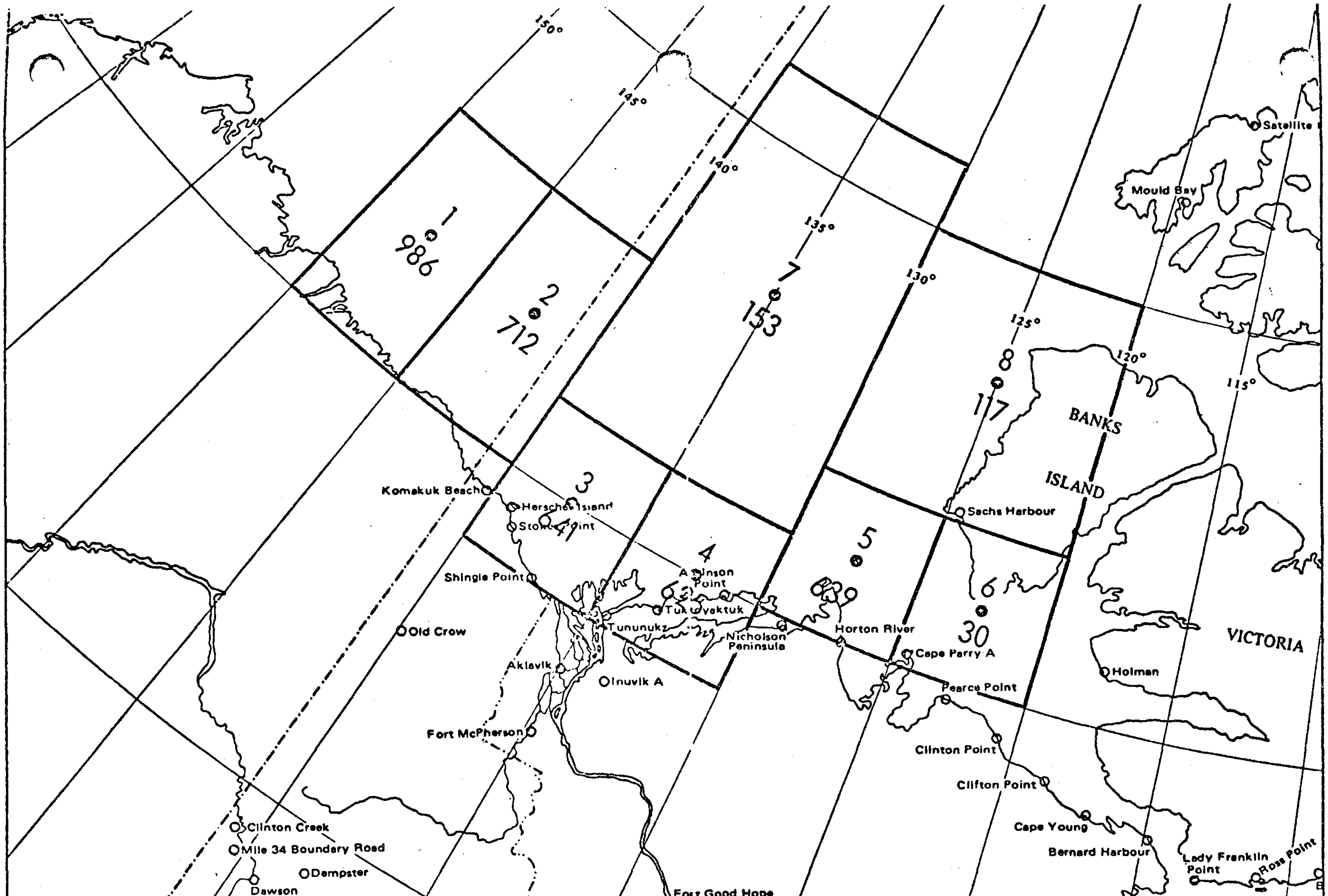
Blank second date shows continuance of record.

Scale in Statute Miles

100 50 0 100 200

STATIONS USED IN ANALYSES
WITH LATEST CONTINUOUS PERIOD OF RECORD
(Years)

Fig. 4



BEAUFORT SEA GRID POINTS FOR AREAL COMBINATIONS OF MARSDEN SQUARE SUB-SQUARES

LEGEND

8 ● Plotting points for enclosed areas

117 Number of hourly reports during period of record

Period of record 1954—1970 (Discontinuous)

Fig.

TABLE 4

BEAUFORT SEA MODERATE DRAFT MARINE TERMINAL STUDY

WIND DATA AT TUKTOYAKTUK

1958-1972

SHIPPING SEASON - JUNE TO OCTOBER

I ADVERSE WINDS (E - S) - LOWERING OF WATER LEVELS

Month	No. of Hours Wind at X.M.P.H.								Total	
	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	No. of Hrs.	% Monthly
June	2.4	28.0	107.9	87.9	18.0				244.2	33.9
July	5.6	50.0	123.6	81.3	18.4	2.0	.4		281.3	37.8
August	4.0	45.3	140.2	79.5	19.3	1.6			289.9	39.0
Sept.	5.6	51.2	135.2	85.6	24.0	5.6	.4		307.6	42.7
October	13.2	57.4	140.9	83.1	29.6	4.8			329.0	44.2
Jun-Oct. Period	30.8	231.9	647.8	417.4	109.3	14.0	.8		1452.0	39.5

II FAVOURABLE WINDS (W - N) - RAISE OF WATER LEVELS

Month	No. of Hours Wind at X.M.P.H.								Total	
	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	No. of Hrs.	% Monthly
June	6.8	55.7	107.1	49.2	12.0	4.8	1.6		237.2	32.9
July	10.4	42.8	87.2	76.0	36.0	9.2	2.0	.4	264.0	35.5
August	10.4	40.2	86.6	74.6	38.2	10.9	3.2		264.1	35.5
Sept.	3.2	33.6	76.4	65.6	42.0	12.0	2.4	1.2	236.4	32.8
October	3.6	22.0	64.2	60.1	34.8	12.8	1.6	.4	199.5	26.8
Jun-Oct. Period	34.4	194.3	421.5	325.5	163.0	49.7	10.8	2.0	1201.2	32.7

In the winter, blowing snow is the most frequent cause of low visibility. Blowing snow occurs at Cape Parry about 10 to 15% of the time between November and April, but only 1 to 2% of the time at Inuvik.

Arctic "whiteout", a phenomenon which causes loss of orientation and sense of perspective most frequently occurs in late winter, early spring and autumn.

Detailed statistics are available showing the probability of a given ceiling and visibility occurring in combination with a particular wind direction or speed class. For example, a ceiling over 1,000 ft. combined with a visibility of more than 3 miles occurs 70% and 85% of the time from June to October at Cape Parry and Inuvik respectively.

Available data shows that visibility conditions are slightly better at Inuvik than at Cape Parry. However, since Inuvik is not on the coast it cannot be assumed that the Inuvik visibility conditions apply to the entire western coast.

Conclusion - Data regarding visibility conditions at the candidate sites is insufficient to permit preference to be determined.

3. Hydraulics

Tides and Levels - The reference port for tidal information in the study area is Tuktoyaktuk where the mean range is 1 ft. and the higher high water elevation for a mean tide is 1.9 ft. At the other possible sites these values vary from 0.6 ft. at Hooper Island to 1.5 ft. at Paulatuk and from 0.9 ft. at Pelly Island to 2.4 ft. at Paulatuk and Atkinson Pt.

Water levels are also affected by winds during periods of ice-free conditions which can cause much larger fluctuations at the shoreline than the astronomical tides if they are strong enough, last long enough and the fetch is great enough to allow the interactive hydraulic, atmospheric and wind friction forces to be fully mobilized. Maximum fluctuations occur along shorelines where the continental shelf is shallow, uninterrupted and uniform. The area between King Point in the west and Cape Bathurst in the east is particularly susceptible to high wind - induced water level fluctuations because of this feature. Winds from the northwest quadrant can raise the water level while winds from the southeast quadrant can lower it. Refer also to paragraph III.B.2, page 14.

For example, a westerly gale over a period of two days raised the water level at Tuktoyaktuk almost nine feet above normal high tide level and a moderate easterly wind lowered the level three feet below normal low tide level.

A general analysis of the wind data indicates that sites in the Western Beaufort Sea would be influenced less by winds and its related effects, and that the probability of wind lowering the level increases as the season progresses.

<u>Currents</u> - The pattern of surface currents derived from ship records and ice island drifts shows that currents form a large clockwise gyre over the Beaufort Sea with a shear zone north of the Mackenzie Delta

and a weak minor gyre in Amundsen Gulf - Figure 6*. These currents are mainly wind driven with the result that they appear to be irregular and unpredictable when considered in the short run. Coastal currents are generally weak, irregular and dependent on prevailing winds. Currents may occasionally attain a speed of 2 knots under sustained winds.

Due to their low speed, currents should not be a problem at any of the possible sites.

4. Ice - In the study area ice usually begins to form in late September or early October and begins to deteriorate in June.

Freeze-up begins after about 200 celsius freezing degree days. The ice forms first on the northern edge of the open water at the outer fringes of the pack. Soon afterwards formation occurs in the shallow coastal areas. The two ice covers then move towards each other. The last area to be covered by ice is some 10 to 20 miles offshore. It normally takes 20 to 25 days from the first ice occurrence (after approximately 200 celsius freezing degree days) to the complete freeze over.

Break-up begins in the Mackenzie Bay and then progresses northward and along the coast on either side. The deterioration process starts approximately one week after the mean temperature exceeds $0^{o}C$ and lasts 30 to 50 days before water is clear of ice.

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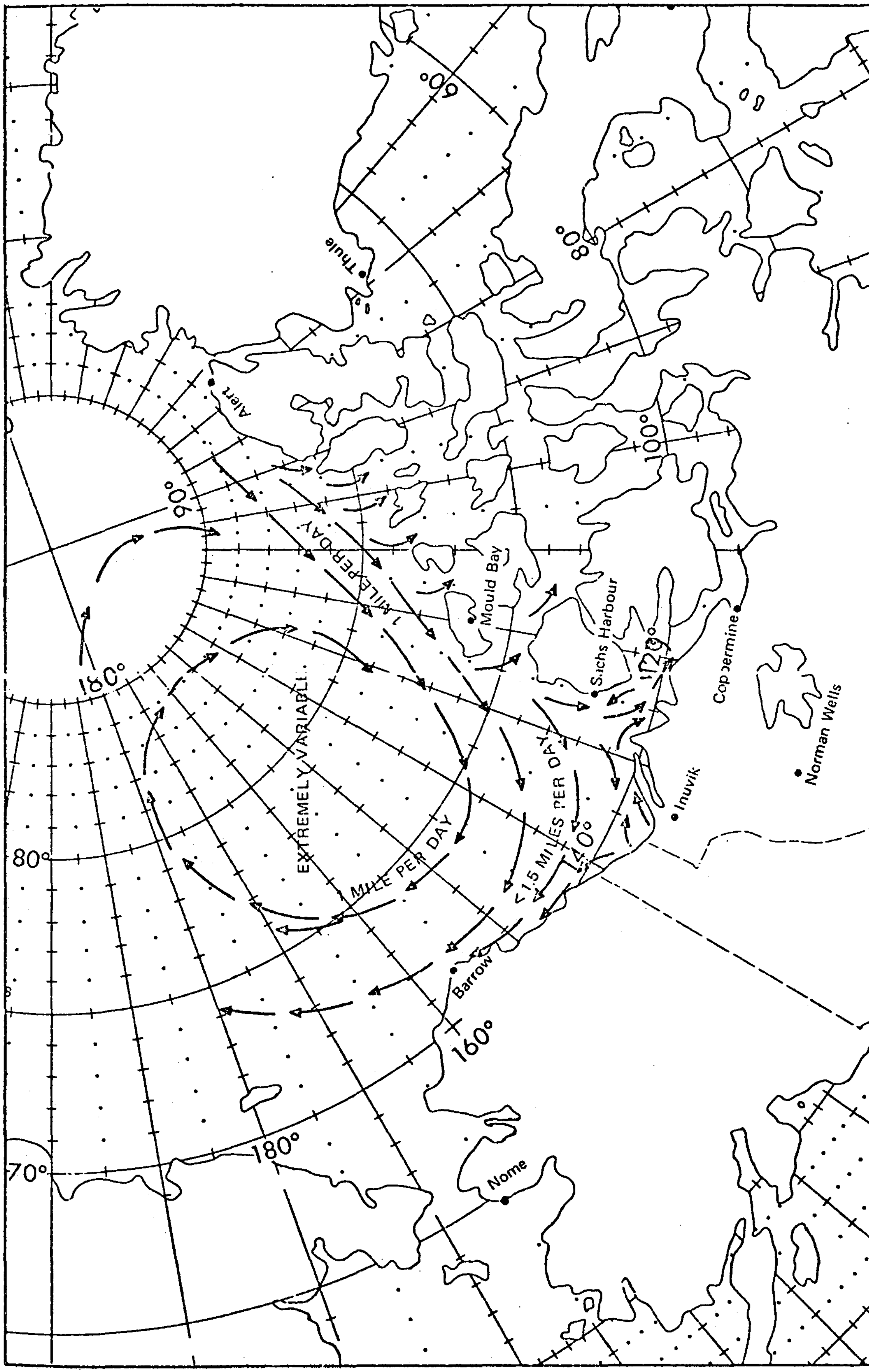
*Burns - The Climate of The Mackenzie Valley - Beaufort Sea, 1973.



OCEAN CURRENTS

(After U.S. Navy Hydrographic Office, 1958)

Fig. 6

Table 5 gives mean dates that the area is free of ice and completely frozen over. It can be seen that the average open water season varies from 91 days at Sachs Harbour to 115-117 days at Cape Parry (Police Pt.) and Shingle Pt. (King Pt.). Between Richards Island and Cape Bathurst the season is approximately 102 to 107 days.

Monthly charts of greatest and least ice cover from June to October (Figures 7 to 16)*, show that when the ice concentration is less than 17 at the drill site it is also less than 17 at all possible sites. The length of the working season will therefore be determined by ice conditions at the drill site. However, these charts would indicate that access to sites east of Cape Bathurst may occasionally be difficult in July, August and September due to heavy ice concentration (> .7) advancing between Cape Bathurst and Banks Island.

Ice conditions however, can vary significantly from year to year depending primarily on wind (which is a major force affecting drift and convergence of ice) and temperature conditions. In bad years, for example, break-up may occur in August only and ice will start forming again in September, whereas in good years the open water season lasts from late June to late October.

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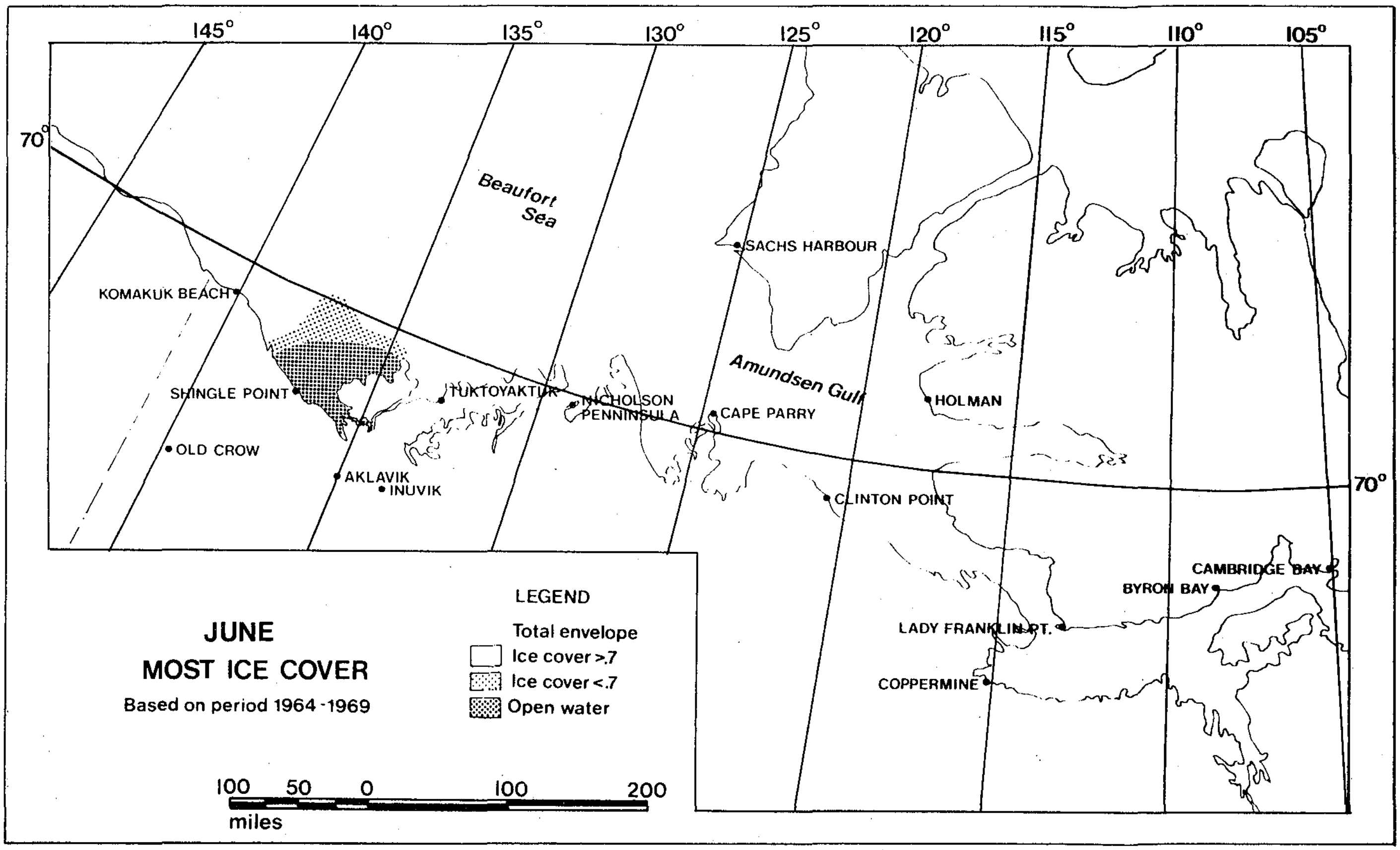
*Burns - The Climate of The Mackenzie Valley - Beaufort Sea, 1973.

TABLE 5

BEAUFORT SEA MODERATE DRAFT MARINE TERMINAL STUDY

MEAN DATES CLEAR OF ICE AND OF COMPLETE FREEZE OVER

Location	Possible Sites in Area	Date Clear of Ice	Date of Complete Freeze-over	Open Water Season-Days
Shingle Point	Herschel Island King Point	June 26	Oct. 21	117
Tuktoyaktuk	Mason Bay Tuktoyaktuk Tuft Point	June 30	Oct. 15	107
Atkinson Point	Warren Point Atkinson Point McKinley Bay	July 20	Oct. 31	103
Nicholson Peninsula	Liverpool Bay Wood Bay	July 24	Nov. 5	104
Cape Parry	Police Point Letty Harbour Paulatuk	July 23	Nov. 15	115
Sachs Harbour	Sachs Harbour	July 16	Oct. 15	91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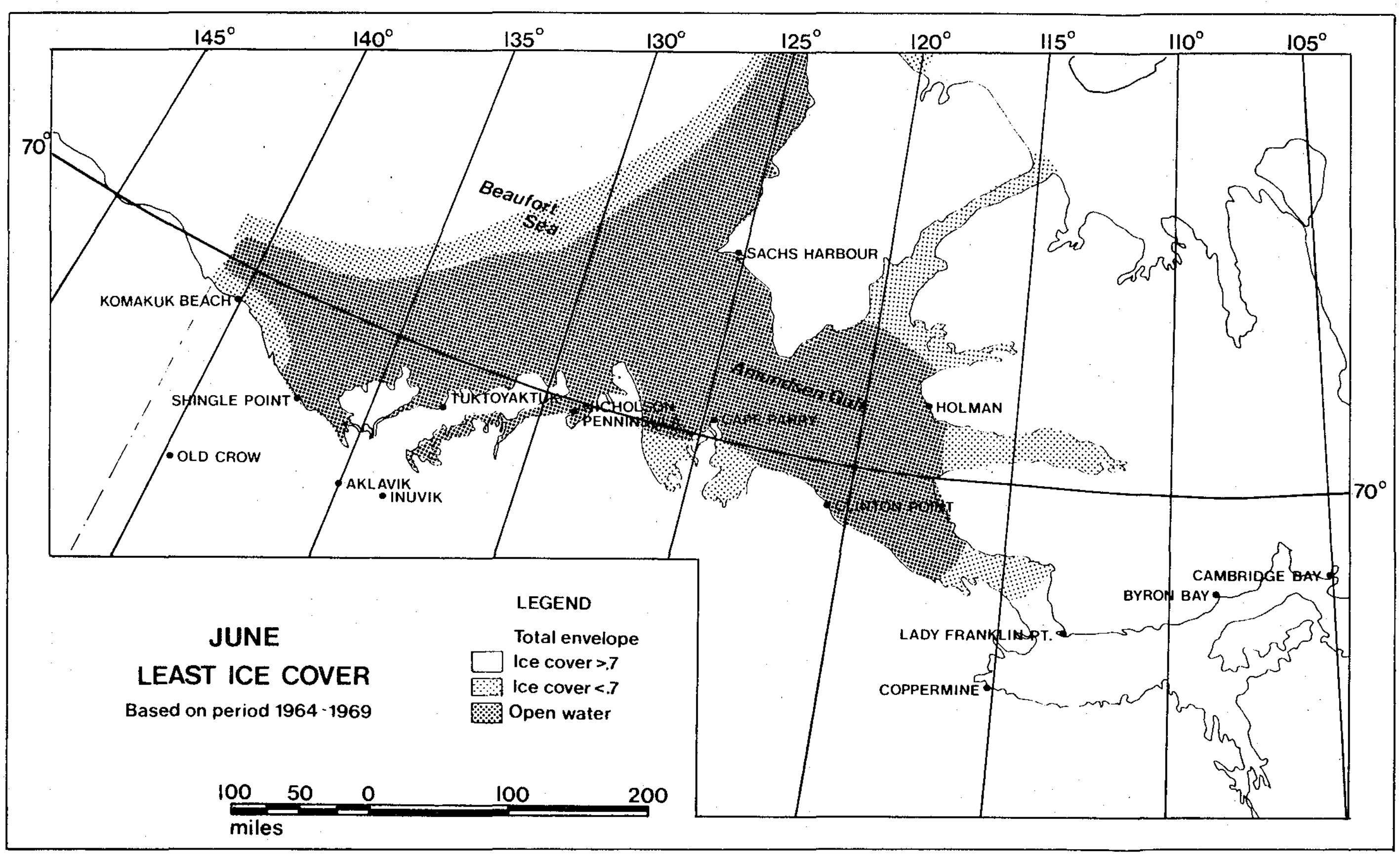
KOMAKUK BEACH
Amundsen Gulf
SHINGLE POINT
TUKTOYAKTUK
NICHOLSON PENNINSULA
CAPE PARRY
HOLMAN
OLD CROW
AKLAVIK
INUVIK
CLINTON POINT
70°
CAMBRIDGE BAY
BYRON BAY
LADY FRANKLIN PT.
COPPERMINE
JUNE
MOST ICE COVER
Based on period 1964-1969
LEGEND
Total envelope
Ice cover >.7
Ice cover <.7
Open water
100 50 0 100 200
miles

Fig. 7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LADY FRANKLIN PT.
COPPERMINE
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LEAST ICE COVER
Based on period 1964-1969
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Ice cover >.7
Ice cover <.7
Open water
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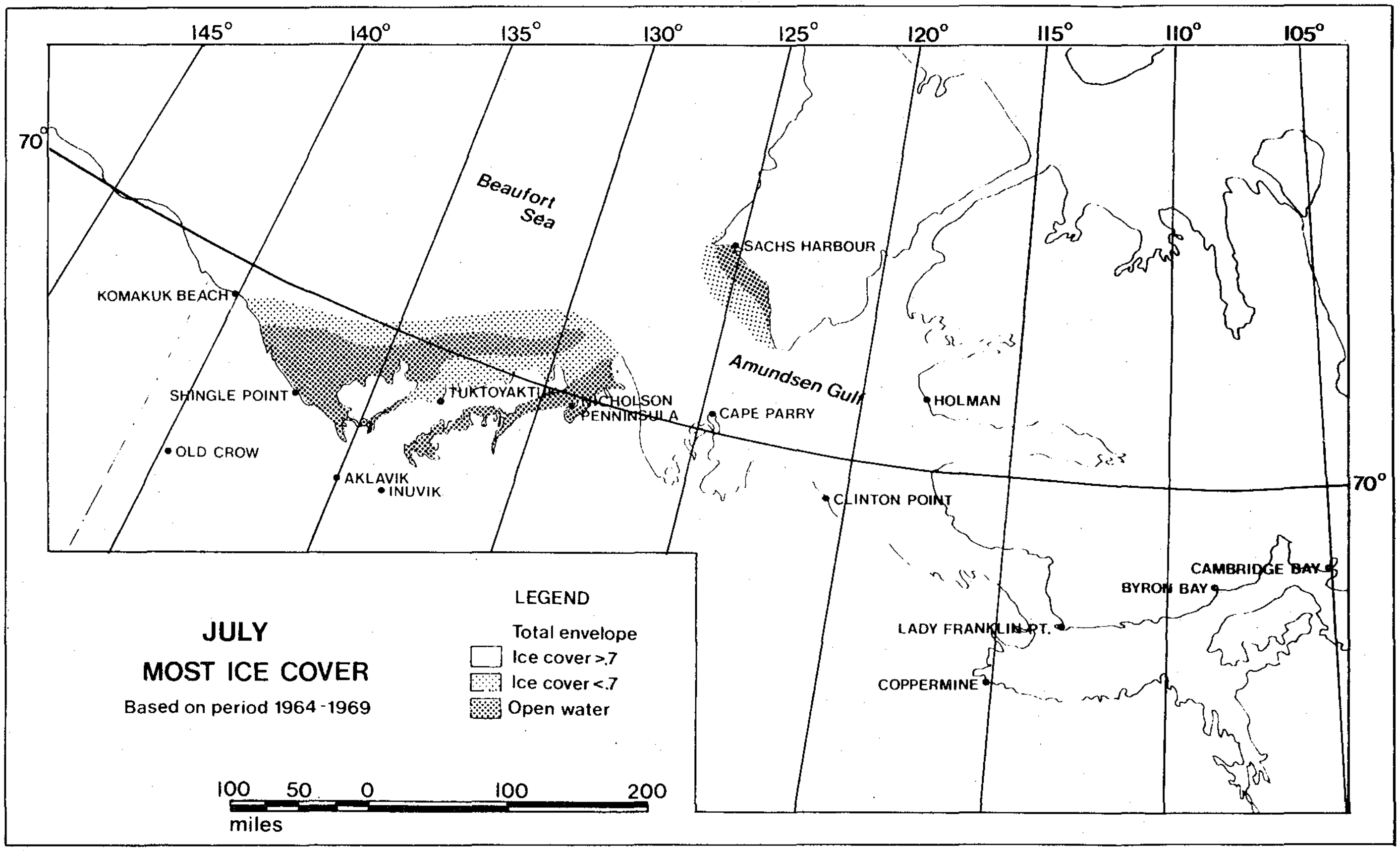
miles

Fig. 8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CAMBRIDGE BAY
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LADY FRANKLIN PT.
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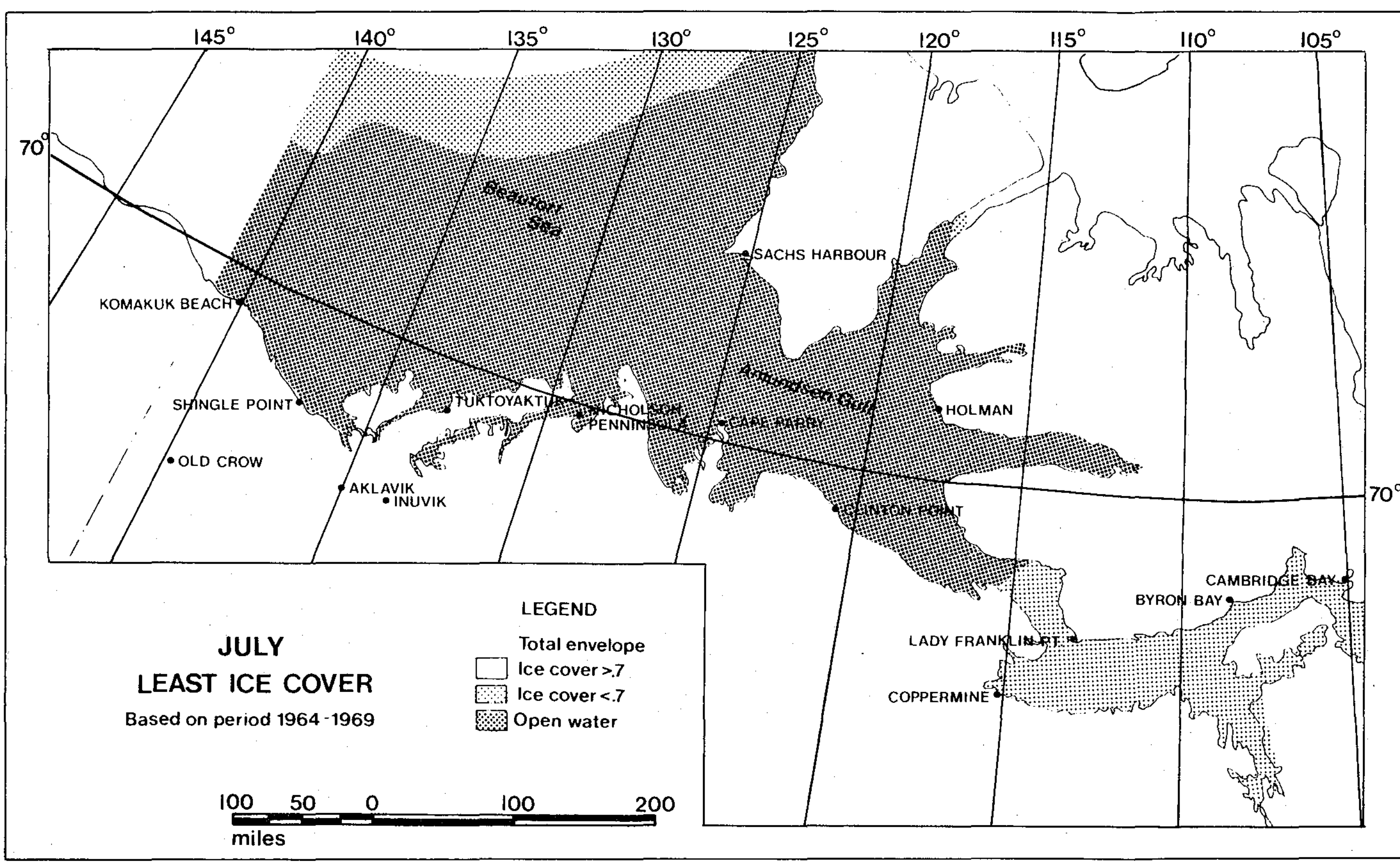
Total envelope
Ice cover >.7
Ice cover <.7
Open water
JULY
MOST ICE COVER
Based on period 1964-1969
100 50 0 100 200
miles

Fig. 9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CAMBRIDGE BAY
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LADY FRANKLIN PT.
COPPERMINE
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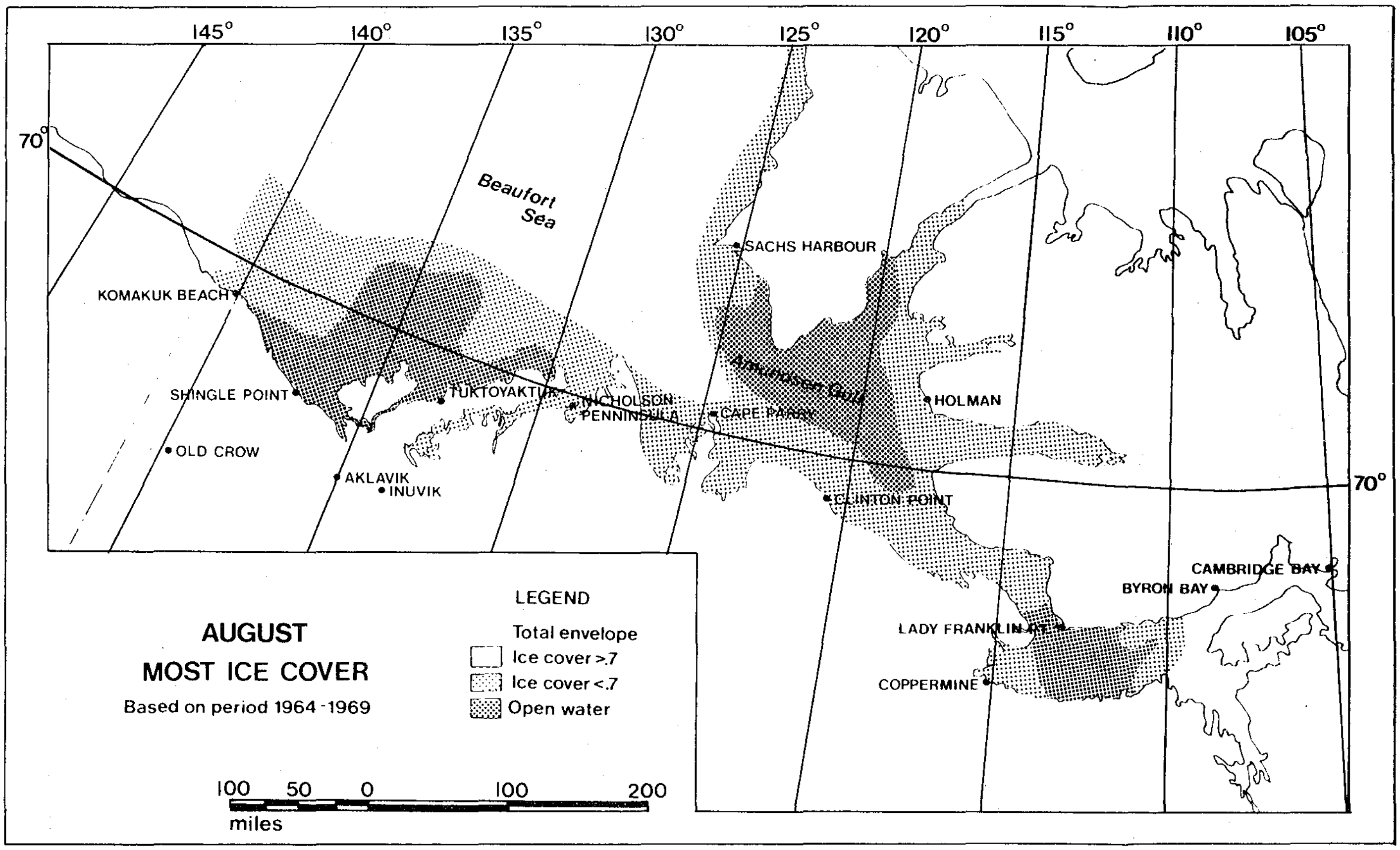
Total envelope
Ice cover >.7
Ice cover <.7
Open water
JULY
LEAST ICE COVER
Based on period 1964-1969
100 50 0 100 200
miles

Fig. 10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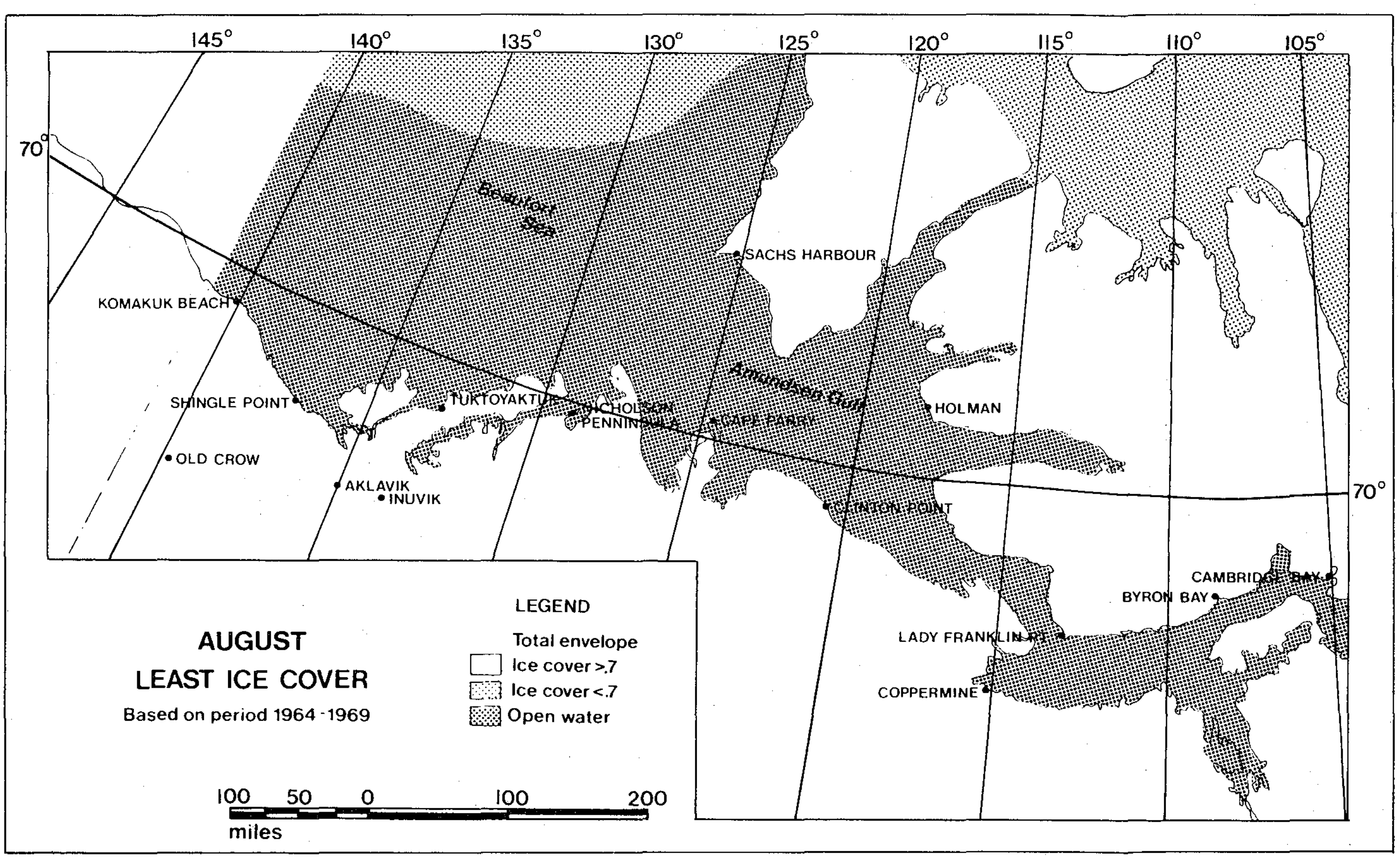
CAPE PARRY
HOLMAN
OLD CROW
AKLAVIK
INUVIK
CLINTON POINT
CAMBRIDGE BAY
BYRON BAY
LADY FRANKLIN PT
COPPERMINE
AUGUST
MOST ICE COVER
Based on period 1964-1969
LEGEND
Total envelope
Ice cover >.7
Ice cover <.7
Open water
100 50 0 100 200
miles

Fig. 11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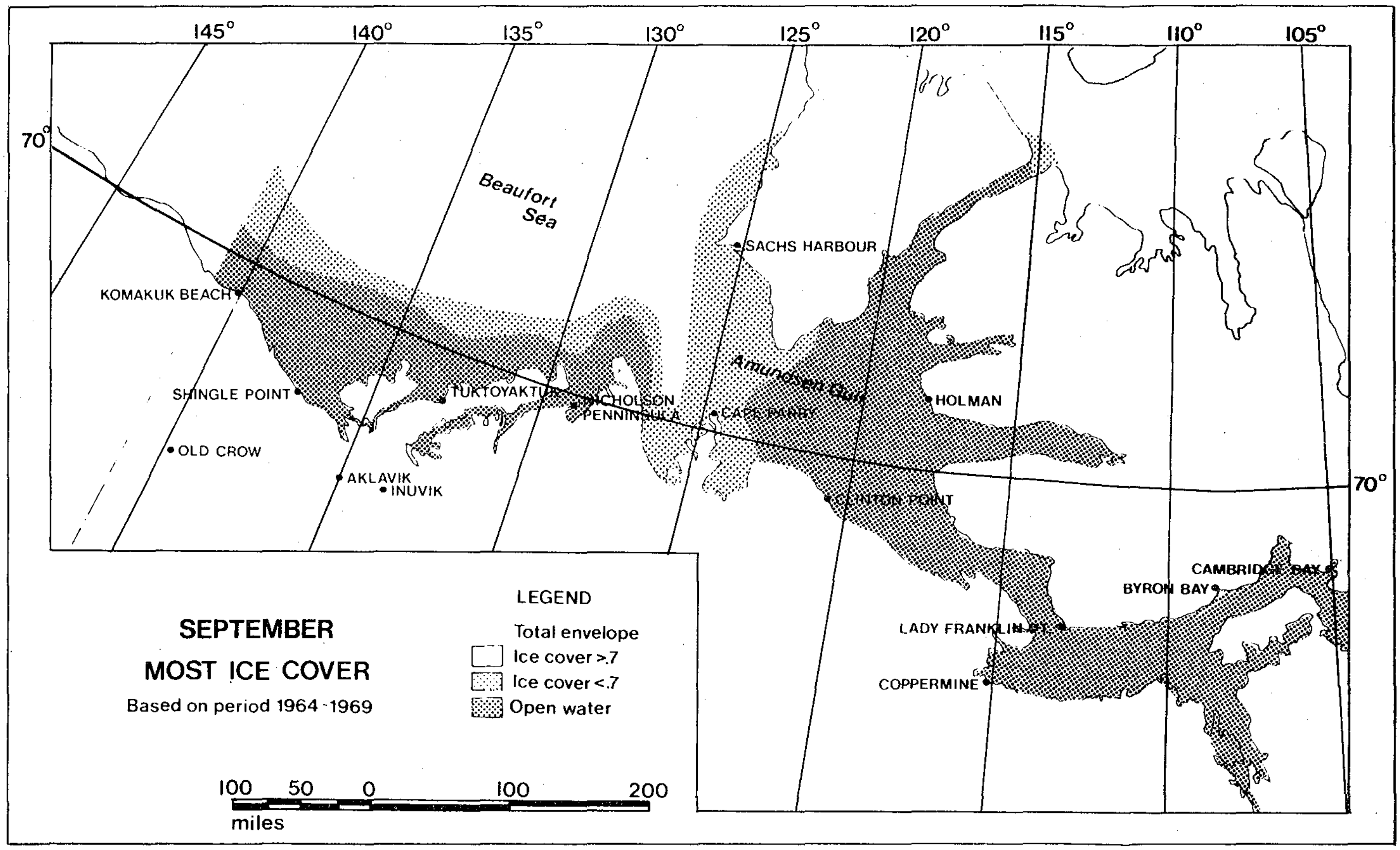
CAPE PARRY
HOLMAN
OLD CROW
AKLAVIK
INUVIK
CLINTON POINT
CAMBRIDGE BAY
BYRON BAY
LADY FRANKLIN PT
COPPERMINE
AUGUST
LEAST ICE COVER
Based on period 1964-1969
LEGEND
Total envelope
Ice cover >.7
Ice cover <.7
Open water
100 50 0 100 200
miles

Fig. 12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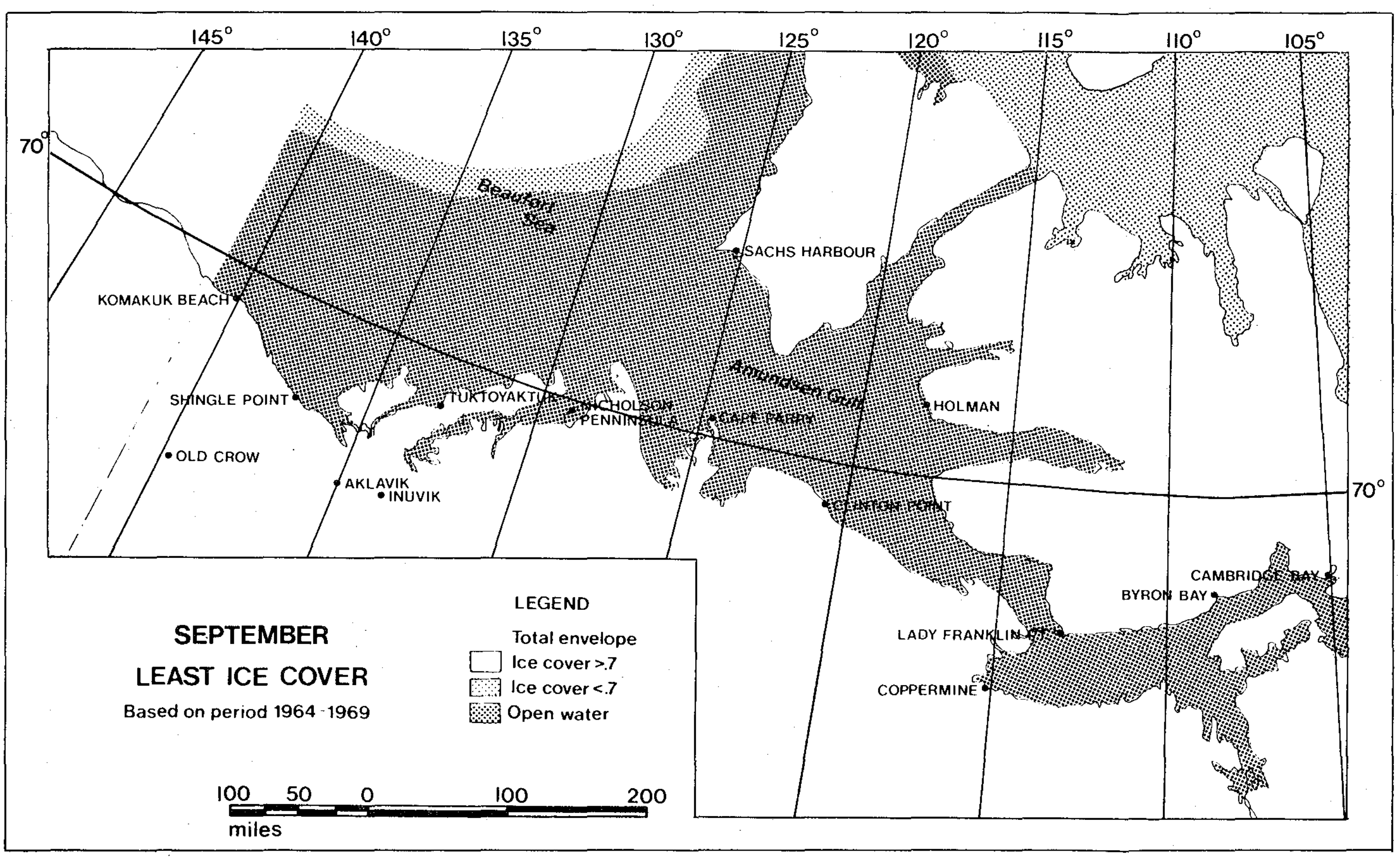
OLD CROW
AKLAVIK
INUVIK
CLINTON POINT
CAMBRIDGE BAY
BYRON BAY
LADY FRANKLIN PT.
COPPERMINE
LEGEND
Total envelope
Ice cover >.7
Ice cover <.7
Open water
SEPTEMBER
MOST ICE COVER
Based on period 1964-1969
100 50 0 100 200
miles

Fig. 13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OLD CROW
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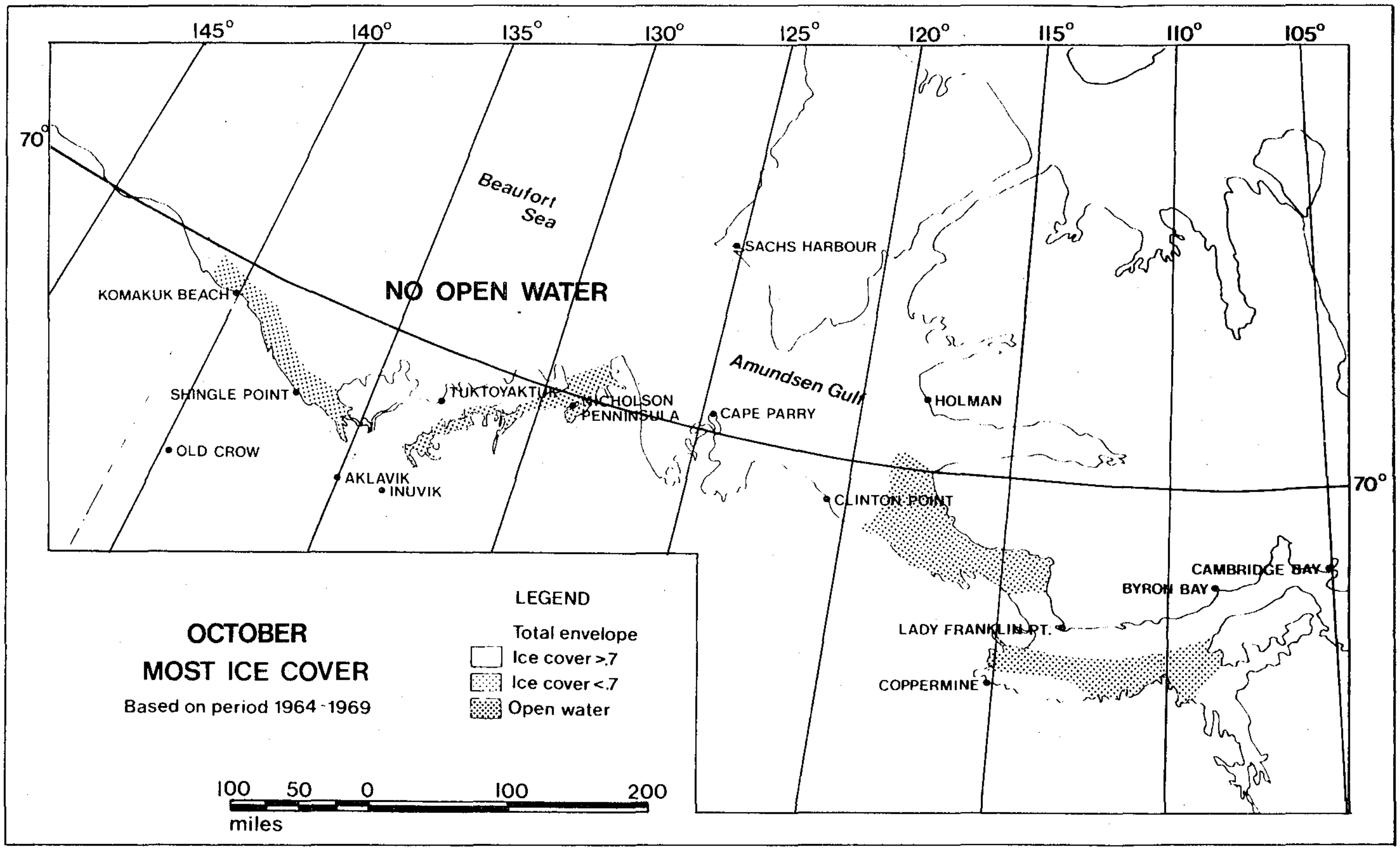
CLINTON POINT
CAMBRIDGE BAY
BYRON BAY
LADY FRANKLIN PT.
COPPERMINE
LEGEND
Total envelope
Ice cover >.7
Ice cover <.7
Open water
SEPTEMBER
LEAST ICE COVER
Based on period 1964-1969
100 50 0 100 200
miles

Fig. 14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Beaufort Sea
NO OPEN WATER
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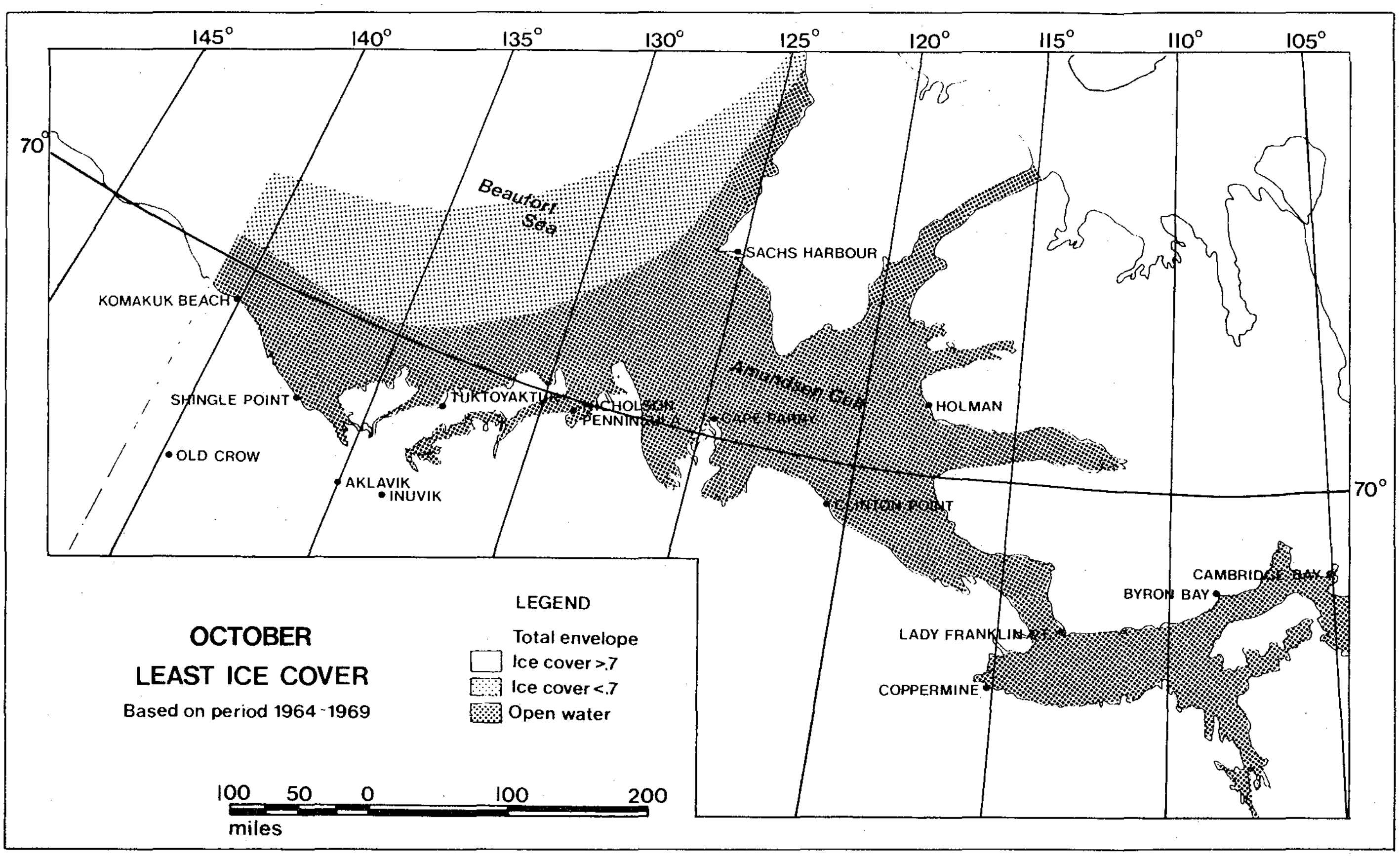
KOMAKUK BEACH
Amundsen Gulf
SHINGLE POINT
TUKTOYAKTUK
NICHOLSON PENNINSULA
CAPE PARRY
HOLMAN
OLD CROW
AKLAVIK
INUVIK
CLINTON POINT
CAMBRIDGE BAY
BYRON BAY
LADY FRANKLIN PT.
COPPERMINE
OCTOBER
MOST ICE COVER
Based on period 1964-1969
LEGEND
Total envelope
Ice cover >.7
Ice cover <.7
Open water
100 50 0 100 200
miles

Fig.15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CAPE PARRY
HOLMAN
OLD CROW
AKLAVIK
INUVIK
CLINTON POINT
CAMBRIDGE BAY
BYRON BAY
LADY FRANKLIN PT.
COPPERMINE
OCTOBER
LEAST ICE COVER
Based on period 1964-1969
LEGEND
Total envelope
Ice cover >.7
Ice cover <.7
Open water
100 50 0 100 200
miles

Fig.16

This review of ice conditions indicates that none of the possible sites has an open water season shorter than the drill site. Also, access to the drill site from possible sites located east of Cape Bathurst, including Sachs Harbour, will be more difficult than from sites west of the Cape. As a result, the sites of Police Point, Letty Harbour, Paulatuk, Sachs Harbour and Pearce Point should be considered only as second choices unless they have other significant advantages.

C. Environmental Requirements

The requirements are examined under the following general considerations:

1. The extent to which the Beaufort Sea Study data may be useful to the Beaufort Sea Medium Draft Marine Terminal Study;

2. The relative environmental sensitivities among the proposed alternate sites;

3. Any further environmentally related comments such as concerns, studies, impact report requirements, etc.;

4. The adequacy of existing data; and

5. Estimated costs of further environmental studies or requirements.

This summary documents the results of the preliminary review of the information which was readily available. It was found that such pertinent environmental information was deficient. The concerns expressed herein are of a preliminary nature and further information and/or review could alter the thrust of some of the concerns.

1. The Extent to which the Beaufort Sea Project data may be useful to this study

The Beaufort Sea Study final reports are now published, but examination of the 1974 reports and discussions with the various authors (and others), have led to the following conclusions:

(a) The Beaufort Sea Studies would be very useful in providing wildlife, atmospheric, oceanographic, fisheries, oil pollution, and other such information needed in the preliminary and final site selection of any proposed marine terminal(s), (or other man-made activity), in the Beaufort Sea area.

(b) Further study would be required at specific site locations, once the field has been narrowed, to select the best alternate site(s).

Atmospheric - Reports E2, Meteorological Study and Development of a Wave Climatology and G1, Ice Climatology in the Beaufort Sea, see Appendix I, would be useful for assessing the atmospheric environmental suitability of the harbours in the geographical area as far as general conditions are concerned. The Atmospheric Environment Service has considerable data on the break-up and freeze-up of ice and also on weather conditions for this area, of which a large part will be included in the Beaufort Sea Study. Specific site data are lacking for most of the individual harbours with regard to weather and ice, storm damage and ice damage, so further site specific studies would be required.

To summarize, the information required for many atmospheric studies is available in one form or another through the many years of back-logged surveys and satellite imagery, but it requires interpretation directed towards a specific goal - in this case, harbour location alternatives.

Marine Ecology - As pointed out by E.H. Grainger in his interim report on Biological Productivity (B6), we still know very little about the marine ecosystem in the Beaufort Sea. The existing data are good, but sparse, particularly for many of the site alternatives, and obviously inadequate for more than a very superficial assessment.

Wildlife - The Beaufort Sea Studies A1 - A4 on seals, polar bears, sea birds and whales, will undoubtedly provide summarized information, but too little is known about the effect of man's interaction with the animals of this area. The 1974 Beaufort Sea Study reports vary in detail with the least information being available on seals. Further site specific studies on local and regional habitats will probably be required as well as the effects of air, land and sea traffic where they interact with migrating or indigenous species. (Refer to Table 6).

Fisheries - The results of the Beaufort Sea Project will be very relevant. Fisheries and Marine Service are preparing three reports in the Beaufort Sea Study series, which describe

Table 6: Canadian Wildlife Service - Table of Wildlife Concerns and Sensitivities
Beaufort Sea Medium Draft Marine Terminal Study Sites

	ATKINSON PT EAST	ATKINSON PT WEST	HERSCHEL I	KING PT	LETTY HARBOUR	LIVERPOOL BAY	MASON BAY	McKINLEY BAY	PAULATUK	POLICE PT **	SACHS HARBOUR	TUFT PT	TUKTOYAKTUK	WARREN PT	WOOD BAY **
BEARS															
POLAR			X												
GRIZZLY				X		X									
FISH															
(ARCTIC CHAR)			X	(X)		X	X		X						X
SEABIRDS	X	X	X			X		X		X		X		X	X
WATERFOWL															
DUCKS	X	X	X	X		X	X	X	X			X	X	X	X
GEESE	X	X	X				X	X	X						
SWANS					X		X		X						
SEALS			X		X					X	X				X
WHALES															
BELUGA			X	X			X	X			X	X	X	(X)	
BOWHEAD			X	X							X				

** Migratory Bird Sanctuary
X Potential for adverse environmental impact
(X) Uncertain potential for environmental impact

the baseline fisheries resources of the area and delineate areas sensitive to disturbance from development related activities.

Report Bl, prepared by Fisheries and Marine Services, Pacific Region, examines the Yukon coastline between Herschel Island and Shingle Point. This encompasses the potential harbour sites at Herschel Island and King Point.

Report Bl prepared by Fisheries and Marine Services, Arctic Biological Station, deals with that section of the Tuktoyaktuk Peninsula between Tuktoyaktuk and Atkinson Point including the potential harbour sites of Tuk Harbour, Tuft Point, Warren Point and Atkinson Point East and West.

The Mason Bay site is described in report B2, Anadromous and Freshwater Fish of the Outer Mackenzie Delta, prepared by Fisheries and Marine Services, Central Region.

2. <u>The relative environmental sensitivities among the proposed alternate sites</u>

Table 6 summarizes the wildlife concerns and sensitivities at each of the proposed marine terminal sites.

More detailed information regarding the relative environmental sensitivities among the potential terminal sites is presented in the following summaries. This information is addressed as:

(a) Prime concerns, directly or indirectly affecting migratory birds, rare and/or endangered birds land and sea mammals and fishes.

(b) Secondary concerns, involving location in, or proximity to areas established to protect biological values such as:

migratory birds - (sanctuaries)
land mammals - (reserves)
vegetation & range - (I.B.P. sites).

(c) Other concerns, affecting cultural, economic, archeological and historic aspects of Eskimo and white societies, past and present.

(i) Herschel Island

- only known nesting site for black guillemot in western arctic;
- important for nesting eiders, gulls, brant, and shore birds;
- traditional moulting area for scaup, scoters, and old squaw duck;
- eiders and glaucous gulls nest on Nunnaluk Spit;
- feeding and rearing area for Arctic Char and cisco;
- beluga and bowhead whales pass through the area on fall migration;

- seals common seaward and eastward off Herschel, seals in Pauline Cove are migrants from about mid-August until late September and are numerous with catches up to 800 animals per season;
- polar bear, red fox and arctic fox in the area;
- capelin occur sporadically;
- unique flora on the island;
- significant archeological sites require protection
- Herschel Island is proposed as a National Historic Site and as a Yukon Territory Park;
- inshore coastal areas are nursery grounds for isopods, important food species for fish of the region;
- area of greatest numbers and biomass of benthic marine fish;
- only known area of the non-Communist world where Pogonophora occur in waters shallow enough for the recovery of live specimens (for physiological studies, etc.);
- inshore coastal areas of this region are principal known nursery grounds for the isopod Mesidotea that forms the principal food base of anadromous white-fish and sculpins, and to some extent other species such as burbot and pike.

(ii) King Point

- moulting area for scaup, scoters and old squaw;
- Bowhead whales arrive there in September;
- snow geese are present in fall only;
- fox, bear, anadromous fish in the area;
- grave site for one of Amundson's crew - maintained by Government of Norway and Canada as an historic site.

(iii) Mason Bay

- important for moulting scaup, scoters, old squaw;
- swans nest nearby;
- migrating brant often stop there;
- bearded seals occasionally use the Bay;
- feeding grounds for Arctic and red-throated loons;
- Beluga whales migration and harvest in adjacent Kugmallit Bay;
- no local exploitable mammals;
- important nursery and feeding area for many anadromous and marine fish species;
- area is relatively late in becoming ice free.

(iv) Tuft Point

- important for moulting old squaw, scoters, scaup;
- glaucous gulls and arctic terns nest nearby;
- it is on migration route for eiders, brant and snow geese;

- importance to Beluga whales is potential;
- traditional and important hunting site for Eskimos.

(v) Warren Point

- important for moulting old squaw, scoters, scaup;
- glaucous gulls and arctic terns nest nearby;
- it is on migration route for eiders, brant and snow geese;
- importance to Beluga whales is uncertain - more information is needed; (possible whale congregation area);
- traditional and important hunting site for Eskimos.

(vi) Atkinson Point East and West

- important nesting grounds for brant, swans, white-fronted geese, gulls, terns and shorebirds;
- moulting and staging area for brant, white-fronted geese, swans, eiders, scaup, old squaw and scoters;
- would affect 600,000 moulters and 1,000,000 migrants;
- this Archeological site is very important - Thule small-tool culture;
- centre for native reindeer herders;
- important to native hunters.

(vii) McKinley Bay

- very important site for combinations of nesting, moulting and staging for eiders, scaup, old squaw, scoters, brant, swans, gulls, white-fronted geese, terns, shorebirds and cranes;
- reindeer herds present seasonally; part of reindeer grazing preserve;
- important area for reindeer herding native hunting;
- Beluga whales are present;
- archeologically it contains the best Mackenzie Eskimo sites;

(viii) Liverpool Bay

- staging area for snow geese and brant;
- nesting and moulting area for Sabines gull, terns, glaucous gulls, eiders, old squaw, scoters and scaup;
- high importance to water fowl generally;
- moderate importance to herring, flat fish and cod;
- within reindeer reserve;
- adjacent to bird sanctuary
- native trapping and hunting site.

(ix) Wood Bay

- nesting, moulting and staging area for swans, gulls, terns, brant, snow geese, white-fronted geese;
- nesting of peregrine falcons, a rare and endangered species;

- presence of golden eagles, rough leg hawk, old squaw, eiders, scaup, scoters, pintail, widgeon, numerous shorebirds;
- site of Anderson River Delta Migratory Bird Sanctuary;
- stated to be "a very sensitive area";
- contains fish stocks of lake herring, whitefish and inconnu;
- Baillie Island (50 miles distant) important to seals and polar bears, stocks of herring and other pelagic marine species of fish.

(x) Police Point

- area of concentration of ringed and bearded seals;
- Cape Parry Migratory Bird Sanctuary, only Canadian western arctic Colony of Thick Billed Murre;
- this location is in a precarious position because of the DEW line site and its unprotected fuel tanks.

(xi) Letty Harbour

- little problem regarding birds - some eiders in vicinity;
- Harp seals in area.

(xii) Sachs Harbour

- the area of the sanctuary northerly from Sachs is important for snow geese and brant, and northeasterly for eiders, cranes and swans; capelin, small char and lake Herring occur in the vicinity;

- ringed and bearded seals and whales support considerable mammal exploitation;
- in general, least sensitive from wildlife standpoint;
- Banks Island Migratory Bird Sanctuary #1 surrounds the village (five mile radius).

(xiii) Paulatuk

- nearby nesting of eiders, brant and swans;
- some general waterfowl conflicts;
- Hornaday River supports substantial commercial char fishery.
- large summer populations of Lake Herring;

(xiv) Tuktoyaktuk

- many swans in south end of harbour and up nearby creeks;
- large breeding groups of beluga whale nearby with local exploitation;
- large populations of whitefish and population of 'relict' prickleback found elsewhere only in the Sea of Japan;
- many migrant freshwater species which are captured by gill nets;
- large late summer populations of sea herring frequently occur.

(xv) Pearce Point Harbour

- little environmental data is available.

3. Any further environmentally related comments such as concerns, studies, impact report requirements, etc.

   (i) The following comments are worth noting:

      (a) Several scientists connected with the Beaufort Sea project believe that existing marine terminals, such as Tuktoyaktuk, should be expanded, if possible, to limit development, movement, and disruption in other so-called pristine areas. Conversely, in consideration of the high capital cost of expanding Tuktoyaktuk Harbour by dredging and the high annual cost of maintaining the expanded capacity with almost continuous environmental disruption over a wide area extending some fifteen miles or more into the open sea, it may be desirable to select an alternate location with lesser need for capital and annual dredging and consequently with lesser environmental disruption.

      (b) Concern is raised that ship traffic, possible oil spills, surface vehicle movement, and air traffic associated with any marine terminal will have as disruptive an effect as the terminal itself. Traffic corridors will require special environmental consideration.

(c) Ancillary facilities and special requirements for the sites must also be given attention, when deciding on their environmental acceptability. Besides traffic corridors including roads and airstrips, items for consideration include:

- fresh water supply;
- availability of aggregate;
- location of batch plant and quarry;
- protective breakwater requirement;
- amount of dredging;
- types of commodities to be handled and stored;
- area requirements of the terminal;
- environmental impacts of harbour development such as dredge spoil, solid and liquid waste disposal, provisions for spill clean-up.

(d) The need to apply EARP procedures should be emphasized, particularly the preparation of an appropriate initial environmental evaluation.

(e) DOE and DIAND should be involved, at a very early phase, in the drafting of any proposed Memorandum to Cabinet in order to ensure that the environmental issues are considered adequately.

(ii) The following list of publications, research studies, maps, etc., should be used extensively in any further environmental analysis. The list is far from complete, but gives a good indication of what is immediately available.

(a) The study entitled, "Herschel Island-Feasibility of a marine terminal", prepared by K.A. Rowsell of the Department of Public Works examined not only Herschel Island in detail but also explored alternate locations for harbour sites in the Beaufort Sea area.

(b) Beaufort Sea Project Study - Final Reports, 1976 (see attached list).

(c) Land Use Information Map Series (Scale 1:250,000) prepared by Lands Directorate DOE for DIAND and published by the Canada Map Office
- maps fish, wildlife, hunting and trapping, recreation potential, proposed ecological reserves and others in the north.

(d) CWS Arctic Ecology Map Series (scales 1:500,000 and 1:1,000,000)
- notes critical wildlife areas
- text is provided (separately), for locations marked on map.

(e) Canadian Arctic Gas Pipeline Limited Application for Mackenzie Valley Gas Pipeline - Report series.

(f) Environmental Social Committee on Northern Pipelines (Task Force on Northern Oil Development) - Report series and map series (scale 1:1,000,000).

(g) Wildlife of the Mackenzie Delta Region by Arthur M. Martell (Boreal Institute).

(h) (CAGSL) Environmental Protection Board - Environmental Impact Assessment, interim and final reports and map volumes.

(i) ALUR Report Series.

(j) Polar Continental Shelf Project.

(k) Federal and Territorial Government Reports.

(l) CWS 1973 Wildlife Habitat Inventory Atlas Series.

4. <u>The adequacy of existing data</u>

(i) The existing data cited in Point 3, plus the Beaufort Sea Study (yet to be published), should contain enough information to narrow the selection of fifteen sites down to five or fewer sites. Available information is inadequate to choose the best site on environmental grounds and to recommend further measures to reduce environmental disturbance and damage.

(ii) Present data should be properly assessed and additional studies conducted where warranted.

5. <u>Further environmental studies or requirements</u>

(i) A thorough review of existing and forthcoming literature is required in order to determine costs of additional environmental studies.

(ii) Detailed site specific studies will be required when the number of possible terminal sites has been narrowed down.

IV. COST ESTIMATES FOR PORT DEVELOPMENT AND VESSEL OPERATION

The costs related to marine only are developed for the various candidate sites. Those costs for items other than marine (i.e., water supply availability, road alignments etc., for the individual sites) are not considered owing to a lack of detailed data. Marine costs include dredging costs, breakwater construction costs and operating costs of drillship supply over both a five year and ten year period.

A. Port Development Cost Estimates

Dredging Costs - The dredging costs are developed from the estimated spoil quantities given in Table 1 using a flat unit cost of $5.00 per cubic yard. The costs for the various sites are given in Table 10.

For Tuktoyaktuk, the alternative of using the port as a supply base only is examined and the dredging cost for various channel depths corresponding to a range of supply vessel loading drafts is developed. In this instance, some quantity discounting is assumed. The various costs are given in Table 7. These are based on a supply vessel load curve as shown in Figure 17.

Breakwater Costs - Where breakwaters are required to provide protection from dynamic ice pressure, the construction costs are based on the use of mass concrete blocks prefabricated at Inuvik, transported to site by barge and placed by crane.

TABLE 7

TUKTOYAKTUK

Approach Channel Dredging Estimates

Vessel Load %	Vessel Draft Ft.	Design Depth Ft.	Quantity c.y.p.m.	Unit Cost $/c.y.p.m.	Total Cost $1000
0	13.0	17.5	3,751,000	5.11	19,172
40	14.0	18.5	5,253,000	4.87	25,596
60	14.5	19.0	5,971,000	4.82	28,758
80	15.0	19.5	6,712,000	4.77	32,020
100	15.5	20.0	7,500,000	4.91	36,807

Source: DPW Nov. 1975.

Note: The channel depth for a given vessel draft includes provisions for normal under-keel clearance and for the squat of vessels underway.

Supply Vessel
Estimated Draft/Load Curve

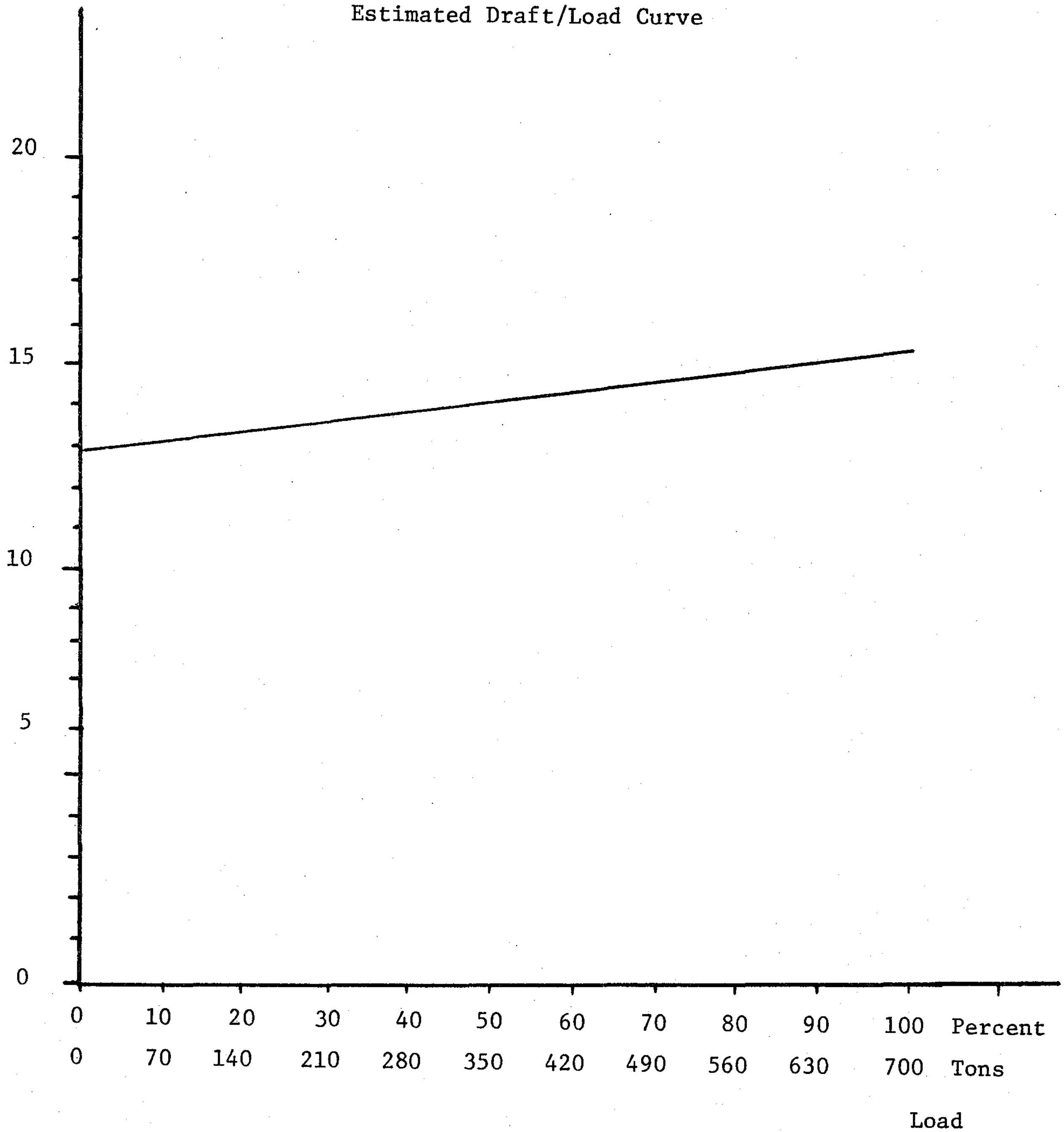

FIGURE 17

Concrete was selected because of the absence of durable stone which could be quarried and transported to the sites at reasonable cost, except in the foothills of the Richardson mountains. Furthermore, in consideration of the possible temporary nature of the port, it might be advantageous if the units could be recovered and moved to a new location if the centre of drilling operations shifted appreciably. Concrete with embedded handling devices would meet this need. The costs as estimated by DPW are:

Herschel Island	(2400 ft.)	$5,700,000
Tuft Point	(3000 ft.)	$6,900,000
Liverpool Bay	(3000 ft.)	$10,400,000
Wood Bay	(7000 ft.)	$22,750,000
Police Point	(800 ft.)	$3,000,000
Pearce Point	(600 ft.)	$2,250,000

B. Vessel Operating Costs

Supply Vessel Operating Costs for Alternate Base Sites

1. Drillship Supplies -

It is estimated that each drillship will consume the following per day:

a) Fuel: 2,000 gals. Arctic Diesel @ 241 imp. gals/ton

$$\frac{2000}{241} = 8.299 \text{ tons}$$

b) Drill Pipe and Mud: 1/5 of fuel weight

$$1/5 \times 8.299 = 1.66 \text{ tons}$$

c) Camp Supplies: 5 lbs./crew member

For a crew of 20: 100 lbs.

Total (a b c): 10 tons per day

Therefore, for a 100 day season, each drillship will require 1,000 tons of supplies.

2. <u>Supply Vessel Capacity</u> -

The supply vessel dimensions are:

length	205 ft.
beam	45 ft.
draft	15.5 ft. (100% laden)
	14.5 ft. (60% laden)

Thus, a 1 ft. change in draft represents 40% capacity. For the simplifying assumption of a rectangular plan, the vessel 40% capacity may be estimated from Archimedes:

$$\frac{205 \times 45 \times 62.5}{2000} = 288 \text{ tons}$$

Therefore, 100% vessel capacity is about:

$$\frac{100}{40} \times 288 = 720 \text{ tons}$$

The two given drafts are plotted against capacity in Figure 18. Assuming a linear relationship, the corresponding drafts for various loadings may be found. Empty draft is 13 ft.

3. <u>Supply Vessel Fuel Requirements</u> -

Heuristically, a vessel of this size consumes 0.4 lbs./HP/HR of fuel. Assuming 4500 HP, the vessel consumes .4 x 4500 = 1800 lbs./HR

Marine Diesel is 231.137 gals/ton. Thus the vessel is estimated to consume:

$$\frac{1800}{2000} \times 231.137 = 208 \text{ gals/HR}$$

Table 8 gives the distance from the drill site centroid to each prospective site. Assuming an average vessel speed of 6 MPH in ice, the two way travel time and the required fuel per round trip is calculated.

$$\text{i.e., time} = \frac{\text{distance}}{\text{vessel speed}} \times 2$$

$$\text{fuel consumption} = 208 \times \text{time.}$$

4. Fuel Costs -

Marine diesel fuel at Norman Wells was about 43.14¢ per gal. in 1976. The cost of fuel at the various candidate sites is the Norman Wells price plus the transportation costs. This latter is calculated by summing the NTCL 1976 Norman Wells to Inuvik POL rate of $1.30/100 lbs., which is equivalent to $0.1125/gal., and an Arctic Coast rate, applied beyond Inuvik, derived as follows:

1976 NTCL POL:

Norman Wells - Paulatuk	391¢/100 lb.	1122 miles
Norman Wells - Tuktoyaktuk	178¢/100 lb.	531 miles
Tuktoyaktuk - Paulatuk	213¢/100 lb.	591 miles

or	2.13 x 20	=	$42.60/ton
or	42.60/ 231.137	=	18.431¢/gal.
or	.18431/591	=	$.000312/gal/mile

The transportation costs from Inuvik to the various sites are the product of the distance (Table 9, column (1)), and the $.000312/gal/mile rate. These costs are given in Table 8, column (5).

TABLE 8

Annual Operating Costs (Fuel Only) - Various Base Sites

(1) Station		(2) Distance to Drill Site (miles)	(3) Two-way Time (hrs.)	(4) Fuel Consumption (gals)	(5) Transport Cost $/gal	(6) Fuel Cost $/gal	(7) Trip Cost $	(8) Season Cost (3 Rigs) $
A Herschel		125	42	8736	.0421	.5860	5119	30714
B King		128	42	8736	.0315	.5754	5027	30162
C Mason		73	24	4992	.0362	.5801	2896	17376
D Tuk	100%	83	28	2877	.0340	.5779	1663	9978
	80%	83	28	2877	.0340	.5779	1663	9978
	60%	83	28	2877	.0340	.5779	1663	14967
	40%	83	28	2877	.0340	.5779	1663	19956
E Tuft		81	26	5408	.0410	.5849	3163	18978
F Warren		72	24	4992	.0440	.5879	2935	17610
G Atkinson		75	24	4992	.0496	.5935	2963	17778
H McKinley		75	24	4992	.0533	.5972	2981	17886
I Liverpool		143	48	9984	.0958	.6397	6387	38322
J Wood		136	46	9568	.0880	.6319	6046	36276
K Police		206	78	16224	.1120	.6559	10641	63846
L Letty		269	90	18720	.1245	.6684	12512	75072
M Paulatuk		301	100	20800	.1345	.6784	14111	84666
N Sachs		204	78	16224	.1179	.6618	10737	64422
O Pearce Pt.		259	86	17888	.1285	.6724	12028	72167

TABLE 9

Transportation Costs - Inuvik to Various Sites

	Station	(1) Distance to Inuvik (miles)	(2) Bulk Fuel Cost $ per Drillship	(3) Dry Cargo Cost $ per Drillship	(4) Total Annual Cost $ per Drillship	(5) Total Annual Cost $ for Three Drillships
A.	Herschel	135	8079	4487	12566	37698
B	King	101	6044	3358	9402	28206
C	Mason	116	6943	3856	10798	32394
D	Tuktoyaktuk	109	6523	3624	10147	30441
E	Tuft	131	7839	4354	12193	36579
F	Warren	141	8438	4886	13124	39372
G	Atkinson	159	9515	5284	14799	44397
H	McKinley	171	10233	5682	15915	47745
I	Liverpool	307	18372	10197	28569	85707
J	Wood	282	16876	9367	26243	78729
K	Police	359	21484	11924	33408	100224
L	Letty	399	23877	13252	37129	111387
M	Paulatuk	431	25792	14314	40146	120438
N	Sachs	378	22621	12555	35176	105528
O	Pearce Pt.	412	24655	13678	38333	114999

Therefore, the cost at Inuvik is 43.14 + 11.25 = 54.39¢ per gal. Adding this to the transport costs of Inuvik to site as given in Table 8, column (5), the fuel costs at each site are obtained and listed in column (6). The fuel cost for a round trip is calculated by the product of columns (4) and (6). This is given in column (7). The seasonal cost for fuel for servicing 3 drillships is found by multiplying trip cost by number of trips. For 100% and 80% vessel loading, this is 2 trips per drillship; for 60% loading, 3 trips per drillship; and for 40% loading, 4 trips per drillship. Vessel loadings of less than 100% apply only at Tuk. The costs are given in column (8).

The least cost choice in terms of supply vessel cost of operation is Tuktoyaktuk harbour, dredged to produce 100% or 80% vessel loading. Dredging Tuktoyaktuk for 60% vessel loading is second best. Mason Bay, Warren Point, Point Atkinson or McKinley Bay third; Tuft Point fourth; and Tuktoyaktuk 40% fifth.

Transportation Costs:
Inuvik - to Various Sites

The selection of the most suitable site will require consideration of the costs of transporting drilling supplies from some common point, assumed to be Inuvik, to each individual candidate site.

The supply quantities are estimated in the previous section concerning supply vessel costs and are:

Bulk Fuel:	830 tons per rig per year
Dry Cargo:	166 tons per rig per year

The 1976 NTCL bulk fuel/Arctic Coast calculated previously rate is 7.21¢ per ton mile. This rate is applied to the various sites in Table 9.

The 1976 NTCL Dry Cargo rate (Class 6 for exploration cargo) from Inuvik to Tuktoyaktuk was $21.80 per ton plus a $5 per ton terminal charge. The $21.80 rate converts to 20¢ per ton mile. This rate plus the terminal charge is applied to the various sites in Table 9.

The total marine costs are compiled in Table 10. The transportation and operating costs for both a five and a ten year program are adjusted to present value at a 10 percent discount rate. These operating costs are very small compared to the capital costs of dredging and breakwater construction. On the basis of the total costs, a ranking is possible:

	$ millions	
	5 year	10 year
Letty Harbour	0.7	1.2
King Point	2.1	2.3
McKinley Bay	2.2	2.3
Atkinson Point (west)	3.1	3.2
Pearce Point	3.2	3.6
Police Point	3.6	4.0
Herschel Island	5.9	6.1
Paulatuk	6.7	7.1

	$ millions	
	5 year	10 year
Warren Point	7.8	7.9
Atkinson Point (east)	8.6	8.7
Tuft Point	9.5	9.6
Liverpool Bay	10.8	11.1
Tuktoyaktuk (40%)	25.8	25.9
Sachs Harbour	26.2	26.6
Wood Bay	26.8	27.1
Tuktoyaktuk (60%)	28.9	29.0
Tuktoyaktuk (80%)	32.1	32.3
Tuktoyaktuk (100%)	36.9	37.1
Mason Bay	50.6	50.7

The data exhibits a sharp division into two sets, less than $11 million and greater than $25 million. All except Letty Harbour require dredging, breakwater construction, or both. The operating costs are so relatively small, that the effect of geographic location is completely submerged by the development costs.

V. BENEFITS

Identification of Beneficiaries

A. The Government of Canada -

(a) Royalties - Royalties accrue to the government under the Canadian oil and gas regulations for oil and gas produced. The rate at which oil and gas pools are produced will depend, in part, upon the exploration rate. It is assumed that exploration will continue whether or not government contributes in the form of harbour facilities. However, the incremental exploration rate increase attributable to harbour facilities, if any, needs be

TABLE 10

COST ESTIMATES - VARIOUS BASE SITES

(Millions of Dollars)

		HERSCHEL IS.	KING PT	TUFT PT	MASON BAY	WARREN PT	ATKINSON PT W.	ATKINSON PT E.	MCKINLEY BAY	LIVERPOOL BAY	WOOD BAY	POLICE PT	LETTY HARBOUR	SACHS HARBOUR	PAULATUK	PEARCE PT	TUKTOYAKTUK 40%	TUKTOYAKTUK 60%	TUKTOYAKTUK 80%	TUKTOYAKTUK 100%
Dredging Cost		–	1.9	2.4	50.4	7.6	2.8	8.3	1.9	–	3.7	–	–	25.6	5.9	–	25.6	28.7	32.0	36.8
Breakwater Cost		5.7	–	6.9	–	–	–	–	–	10.4	22.7	3.0	–	–	–	2.5	–	–	–	–
Trans.	5 year	.1	.1	.1	.1	.1	.2	.2	.2	.3	.3	.4	.4	.4	.5	.4	.1	.1	.1	.1
Cost	10 year	.2	.2	.2	.2	.2	.3	.3	.3	.5	.5	.6	.7	.6	.7	.7	.2	.2	.2	.2
Operating	5 year	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.2	.3	.2	.3	.3	.1	.1	.0	.0
Cost	10 year	.2	.2	.1	.1	.1	.1	.1	.1	.2	.2	.4	.5	.4	.5	.4	.1	.1	.1	.1
Total Marine	5 year	5.9	2.1	9.5	50.6	7.8	3.1	8.6	2.2	10.8	26.8	3.6	0.7	26.2	6.7	3.2	25.8	28.9	32.1	36.9
Costs	10 year	6.1	2.3	9.6	50.7	7.9	3.2	8.7	2.3	11.1	27.1	4.0	1.2	26.6	7.1	3.6	25.9	29.0	32.3	37.1

assessed. The incremental increase in production rate ensuing, can be evaluated in terms of the value of advanced as opposed to deferred consumption.

(b) <u>Corporate Tax Revenues</u> - These can be assessed under two items:

1. Taxes Related to Accelerated Production - The analysis method outlined for royalties would apply. This aspect however, would be difficult to assess since the absorption of profits into a complex organization with cross-subsidization of operations would make tax revenue attributable to accelerated production difficult to identify.

2. Government Contribution to CANMAR - The cost of dredging could be considered a cost saving to CANMAR which would be reflected in an increased profit and hence taxes. It is, however, questionable that CANMAR would undertake any harbour improvement unilaterally. It would therefore be inappropriate to attribute a determinable portion of profits to this source.

B. <u>The Canadian Populace</u>

(a) Industrial Impact - CANMAR is more or less committed to undertake its program. However, the existence of suitable harbour facilities could attract increased drilling activity, the impact of which could spread through the economy, under the provisions of the Canadian Content requirements.

(b) Domestic Foreign Energy Substitution - The availability of domestic frontier energy would preclude the need of foreign purchasing. This would have to effects:

1. A possible cost-saving owing to domestic/foreign price differentials. This may not necessarily transpire if domestic exploration and development costs continue to rise.

2. Balance of Payments Deficit Reduction. The displacement of foreign energy could be a favourable factor towards a balance of payments deficit reduction.

C. Dome Petroleum Ltd. (CANMAR) -

(including drilling customers i.e. Esso, Gulf, etc.)

The drilling company could anticipate cost savings from adequate harbour facilities in three areas:

1. Reduced Supply Costs - The base case for supply is taken as Tuktoyaktuk with no channel dredging. It is assumed that the supply vessels would be loaded to 40% of capacity, giving a draft of 14 feet. The shallowest water in the harbour entrance is 13 feet on the chart, with the customary 1 foot margin. The high tide is + 2.0 AV HHW. Thus if the channel is used only at high tide, a clearance of 2 feet would be obtained. An alternate solution would be to lighter the cargo to the supply vessel outside the harbour. The cost

per season of supplying three drillships from Tuktoyaktuk at 40% load is $19,956 as previously derived. The freight charges of moving supplies for three drillships from Inuvik to Tuktoyaktuk is $30,441 also previously determined. Thus the total supply cost per season for the base case is $50,397. The following Table 11 gives the annual supply cost for each candidate site, the annual cost differential over the base case, and the present value of the costs taken over both a five year and a ten year drilling program:

TABLE 11

CANMAR COST SAVINGS

Site		Total Annual Supply Cost	Base Case Differential Cost	P.V. 5 Yr. Program	P.V. 10 Yr. Program
Herschel		$68412	18015	68291	110695
King		58368	7971	30216	48979
Mason		49770	-627	-2377	-3853
Tuktoyaktuk	100	40419	-9978	-37825	-61311
	80%	40419	-9978	-37825	-61311
	60%	45408	-4989	-18912	-30655
	40%	50397	0	0	0
Tuft		55557	5160	19560	31706
Warren		56982	6585	24962	40462
Atkinson		62175	11778	44648	72371
McKinley		65631	15234	57749	93607
Liverpool		124029	73632	279124	452439
Wood		115005	64608	244916	396990
Police		164070	113673	430912	698475
Letty		186459	136062	515784	836047
Paulatuk		205104	154707	586463	950613
Sachs		169950	119553	453201	734605
Pearce		187166	136784	518521	840483

It may be seen that the costs to CANMAR of supplying via any site other than Tuk or Mason Bay, are greater than the base case. The cost saving of using Mason Bay is miniscule and the cost savings over both the five year and ten year drilling period of having a dredged harbour at Tuktoyaktuk are both very small.

2. Reduced Risk of Drillship Ice Damage - It may be assumed that the provision of protection from dynamic ice pressure for the drillships during wintering by either natural land formations or artificial break waters will produce the same degree of risk no matter where the wintering base. If breakwaters are not provided, the risk could be up to the total capital cost of the vessels plus the value of the time lost in replacement.

D. Other Potential Harbour Users -

A poll of other possible users, i.e., Gulf Oil Ltd., Imperial Oil Ltd., Shell Canada and Cominco, elicited no positive response for specific harbour requirements in the area. NTCL, which operates a transshipment base at Tuktoyaktuk, considered that cost savings to be gained from a deeper harbour entrance at Tuktoyaktuk would be negligible.

E. <u>The Marginal Productivity of Harbour Facility</u> -

Several of the foregoing benefits, including royalties, tax revenues and domestic/foreign energy substitution, have been based on the premise that harbour facilities would accelerate the exploration program and hence also the production of oil and gas from the Beaufort Sea. The value of an accelerated program lies in the value of immediate, as opposed to deferred consumption. It is therefore necessary to demonstrate that harbour facilities, in the form of channel dredging and/or dynamic ice protection, could in fact accelerate the drilling program. A previous section has shown that the supply vessels' capacity is adequate to provide all supplies which the drillships require, from any of the candidate sites, without improvements. Productivity increase would therefore derive only from the potential increase in the average length of the drilling season as a consequence of the choice of wintering base for the drillships.

The amount of exploration drilling may be considered to vary directly with the length of the season. The season is approximately 100 days at Tuktoyaktuk and hence each day by which the season length is increased represents about a one percent increase in drilling footage.

The relationship between exploration footage drilled and the possible discovery and production rates might be forecast by extrapolation from the on-shore Delta experience. This method is tenuous at best.

Hydrocarbon discovery and production growth patterns normally follow a bell-shaped logistics or Gompertz curve in the aggregate. In the Delta, exploration is too immature to permit an evaluation of the curve parameters. An approximation however, can be attained. A total of 989,833 feet had been drilled at 105 wells with a discovery rate of 6.2 MMcf gas and 360 bbls. oil per foot drilled as of 1975. Since 6,000 cf is equivalent to one barrel of oil, the gas may be converted to barrel of oil equivalents (BOE). Thus:

$$\frac{6.2 \times 10^6}{6 \times 10^3} = 1033 \text{ BOEs}$$

The total BOEs per foot drilled is then:

$$1033 \quad 360 = 1393 \text{ BOEs/ft.}$$

The on-shore and off-shore discovery rates are assumed equal.

CANMAR have estimated a drilling capability of 6 wells per year when the wrinkles have been worked out of the three drill systems. Allowing 12,000 ft. per well, this is a discovery rate of:

$$1393 \times 12{,}000 \times 6 = 100{,}296{,}000 \text{ BOE/yr.}$$

Assuming a domestic frontier oil well head price of $10 per bbl., this becomes a value of $1,002,960,000 per year.

It is of interest to note that the 100×10^6 BOE/yr. is equivalent to $100 \times 10^6 \times 6{,}000 = 0.6 \times 10^{12}$ cf. Therefore over a 10 year drilling period, only 6 trillion cf of a possible estimated 30 to 300 tcf might be discovered by the present CANMAR fleet. This suggests that there may well be ample opportunity for other drillship operation.

Growth curves of other areas suggest that production closely follows the exploration pattern. Thus it is assumed that while lagged by some time interval, the production rate would be about 100,000,000 BOE/yr. in the steady state condition.

On the assumption that the present CANMAR fleet will be the only equipment in the Beaufort Sea during the 10 year program period, and that there will be no 'learning' effect so that the discovery rate will remain constant at 100,000,000 BOEs/yr., the annual value of a one percent increase in production as a result of a one day per season extension, and based on a $10 per BOE price, will be .01 x 100,000,000 x 10 = $10,000,000. The present value of this sum over 10 years at a discount rate of 10% is: $61,446,000.

The amount would be distributed by Dome and their customers over exploration and production costs, royalties, taxes and profits. Additionally, a cost savings might be expected from the substitution of domestic for foreign energy sources, also resulting in a positive effect on the balance of payments deficit. Specifically:

a) Royalties and Taxes:	65%
.65 x 61,446,000	$39,939,900
b) Industrial Impact:	20%
.20 x 61,446,000	$12,289,200
c) Corporate Profit:	15%
.15 x 61,446,000	$9,216,900

d) Domestic/Foreign Substitution Cost Savings:

On the basis of $2.50 price differential between domestic and foreign energy, the cost savings would be over a 10 year period:

$$\frac{12.50 - 10.00}{10.00} \times 61,446,000 = \$15,361,500$$

Thus the incremental value of the increased drill season over the 10 year period is $76,807,500 per day.

The analysis is, of course, based on many unsubstantiated assumptions, including drilling rates, success rates, numbers of drillships, etc. It it presented only to demonstrate the order of magnitudes which might be encountered.

It is extremely important to refer to the results of paragraph III.B.4 which indicates that the ice regime at the centroid of the drill site will determine the season length, rather than the choice of wintering base. It is estimated that every candidate site experiences break up prior to the drill site and freezes up (12") after the drill site. It is therefore apparently impossible to extend the drill season by base choice or by harbour improvements.

VI. CONCLUSIONS

The following factors are apparent from the study:

1. CANMAR is the only organization, of several engaged in resource development or other activity in the area, that has expressed serious desire for port facilities. It is foreseen that there are in fact other potential users but they apparently did not wish to commit themselves at this time. Most prospective industrial users do not have firm requirements and cannot plan and

commit resources for such long lead times. It is therefore questionable whether public expenditure should be made for a single direct beneficiary. Expenditures of this nature are properly the responsibility of the private sector. It might, however, be argued that if indirect benefits to the nation, through reduced energy costs, could be assured, expenditure of public funds would be warranted.

2. The CANMAR drilling program plan entails the completion of about fifteen exploratory wells over a five year period. If the success rate experienced is insufficiently high, the program will presumably terminate at the end of the period. A major dredging work to develop a moderate draft harbour in the area would require a minimum of one year to complete hydrographic surveys, sample coring and preliminary environmental work, one year to perform the detailed environmental work and up to four years to complete the actual dredging. It is therefore a definite possibility that the harbour development would be successfully completed co-incident with the termination of offshore exploration activity. It must be recognized, however, that discovery of significant hydrocarbon reserves could lead to a much higher level of activity and a much greater requirement for a harbour. It is anticipated that this need would stem from oil and gas production activity.

3. To date, while extensive seismic exploration has indicated a high potential for hydrocarbon discovery, the presence of oil and gas in the Beaufort Sea will not be proven by means other than actual drilling. The continuing value of a developed port in the area can only be established by the discovery of significant oil and gas fields.

4. As noted above, the actual existence and exact locations of the fields are unknown. Further, in recognition of this, the CANMAR drill systems are highly mobile. Recently, CANMAR have advised that the operations base, now planned for Tuktoyaktuk, will be a bulk cargo vessel, to provide base mobility. While the cost estimates for breakwaters are based on a modular relocatable design, a dredged channel is very much a fixed investment.

5. The limited data available indicates that the choice of site for a harbour development in support of offshore drilling operation is not affected by the ice regime, because the open water season at the estimated centroid of the drilling activity is shorter than at any candidate harbour site.

6. Cost savings to the drillship supply operations as a result of dredging are insignificant compared to dredging costs.

7. Environmental data from the specific candidate sites is incomplete and considerable acquisition and analysis would be required before definite conclusions regarding environmental impact at various sites could be drawn. However, areas in bird sanctuaries should not be considered for development. These include, Liverpool Bay, Wood Bay, Police Point and Sachs Harbour. The sites at Herschel Island, Mason Bay and McKinley Bay have a high potential for adverse environmental impact on the wildlife resources. Similar, but less certain, indications exist for King Point, Tuft Point, Warren Point and Atkinson Point.

8. Sites other than Tuktoyaktuk, notably Letty Harbour, King Point, McKinley Bay, Atkinson Point, Police Point and Herschel Island could provide adequate harbours at a much lower marine cost. Meaningful cost estimates for the provision of shore-based infrastructure at these sites however, could not be developed as little or no data was available. Prior to making any final choice of site, a detailed environmental impact study would be necessary.

9. While other sites offer adequate or better shelter and lower marine costs, the natural and man-made amenities of Tuktoyaktuk such as its geographic position in the mouth of the Mackenzie River and its available infrastructure

including drydock, airfield, hydro power and prospective highway connection make it an attractive candidate.

VII. RECOMMENDATIONS

It is recommended that:

1. Government take no direct action for the development of a moderate draft harbour in the Western Arctic at this time. The situation should, however, be monitored, and if significant hydrocarbon or other major marine activities develop, government may wish to reconsider the decision.

2. In order that the government be in a position of preparedness in the event of successful hydrocarbon exploration, environmental impact studies be carried out at Letty Harbour, King Point and Tuktoyaktuk.

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APPENDIX I

LIST OF BEAUFORT SEA PROJECT INTERIM REPORTS

A1 - DISTRIBUTION AND ABUNDANCE OF SEALS IN THE EASTERN BEAUFORT SEA

A2 - DISTRIBUTION AND ABUNDANCE OF POLAR BEARS IN THE BEAUFORT SEA

A3 - SEABIRD POPULATIONS IN THE COASTAL BEAUFORT SEA

A4 - BIOLOGY OF THE BOWHEAD AND WHITE WHALE IN THE BEAUFORT SEA

A5 - THE EFFECT OF CONTACT AND INGESTION OF CRUDE OIL ON RINGED SEALS OF THE BEAUFORT SEA

B1 - MOVEMENTS, DISTRIBUTION, POPULATION AND FOOD HABITS OF FISH IN THE EASTERN COASTAL BEAUFOR SEA

B1 - MOVEMENTS, DISTRIBUTION, POPULATION AND FOOD HABITS OF FISH IN THE WESTERN COASTAL BEAUFORT SEA

B2 - ANADROMOUS AND FRESH WATER FISH OF THE OUTER MACKENZIE DELTA

B4 - NITROGEN FIXATION IN ARCTIC MARINE SEDIMENTS

B5a - BIODEGRADATION OF CRUIDE PETROLEUM BY THE INDIGENOUS MICROBIAL FLORA OF THE BEAUFORT SEA

B5b - EFFECTS OF CRUDE OILS ON ARCTIC MARINE INVERTEBRATES

B6 - BIOLOGICAL PRODUCTIVITY OF THE SOUTHERN BEAUFORT SEA

C1 - DISTRIBUTION OF TAR AND OTHER PARTICULATE POLLUTANTS ALONG THE BEAUFORT SEA COAST

C3 - BASELINE INFORMATION ON CHEMICAL OCEANOGRAPHY AND PETROLEUM-BASED HYDROCARBONS IN THE SOUTHERN BEAUFORT SEA

D1 - MACKENZIE RIVER INPUT TO THE BEAUFORT SEA

D2 - NEAR BOTTOM CURRENTS AND OFFSHORE TIDES

D3 - SURFACE CURRENT SURVEY IN THE SOUTHERN BEAUFORT SEA

D4 - PHYSICAL OCEANOGRAPHY IN THE SOUTHERN BEAUFORT SEA

D5 - STORM SURGES IN THE SOUTHERN BEAUFORT SEA

E1 - A REAL-TIME ENVIRONMENTAL PREDICTION SYSTEM

E2 - METEOROLOGICAL STUDY AND DEVELOPMENT OF A WAVE CLIMATOLOGY

F1 - THE STUDY OF FROZEN SEABED MATERIALS IN THE SOUTHERN BEAUFORT SEA

F2 - BOTTOM SCOUR BY SEA ICE IN THE SOUTHERN BEAUFORT SEA

F3 - SEDIMENTS AND SEDIMENTARY PROCESSES YUKON BEAUFORT SEA

F4 - SEDIMENT DISPERSAL IN THE SOUTHERN BEAUFORT SEA

G1 - ICE CLIMATOLOGY IN THE BEAUFORT SEA

G2 - AN INVESTIGATION OF THE ENTRAINMENT OF CRUDE OIL IN ARCTIC SEA ICE

G2a - HYDRODYNAMIC ASPECTS OF AN OIL WELL BLOWOUT UNDER SEA ICE

G2b - GEOLOGICAL AND BIOLOGICAL OBSERVATIONS AT BALAENA BAY, CAPE PARRY, N.W.T.

G3 - DISTRIBUTION OF ICE THICKNESS IN THE BEAUFORT SEA

H1 - OIL-SPILL COUNTERMEASURE STUDY FOR THE SOUTHERN BEAUFORT SEA

S1 - SOCIO-ECONOMIC IMPORTANCE OF RENEWABLE RESOURCE UTILIZATION IN THE BEAUFORT SEA