INDIAN AND NORTHERN AFFAIRS
CANADA

GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

VOLUME 1: MAIN REPORT

FINAL REPORT

MARCH 1995

PA 2695 0301

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March 31, 1995

Indian and Northern Affairs Canada
Les Terrases de la Chaudière
Ottawa, Ontario
K1A 0H4

Mr. Bob Gowan

GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

Dear Mr. Gowan:

We are pleased to submit 25 copies of the report on the Granular Resource Potential of Beaufort Artificial Islands. The study documents 37 islands in the Canadian Beaufort Shelf which we believe represents the total number of offshore islands constructed in the area.

The project has identified that approximately four (4) million cubic metres of a mixture of sand and gravel are available as a resource in three of the abandoned offshore islands, Tarsiut N-44, Nipterk I-19 and Minuk I-53. Seven (7) million cubic metres of Ukalerk type sand are available in eight (8) of the abandoned berms that were used for the CRI, Molikpaq and SSDC deployments. An additional 200,000 m^3 of gravel is present in four older gravel filled islands constructed in the 1970's. This material represents a delineated source of high quality sand and gravel that can be readily used for future construction activities related to exploration or development in the Canadian Beaufort Shelf.

Fourteen (14) million cubic metres of finer gradation sandfill remain in place in sandbag retained and sacrificial beach abandoned islands. This material was typically obtained from local borrow sources, and is not likely to be transported for use in construction of islands at new exploration sites. However the sandfill does represent a valuable base resource for potential development at each of the individual exploration sites.

The study has been reported in three volumes. Volume 1 is the main report summarizing all aspects of the project. The FoxPro2/Quickmap/InFocus magnetic disks which contain the granular resource database are included in Appendix I of this volume. Hard copy information for each island is presented in Volume 2, including a summary of information entered into the database. A schematic cross section of the island and plan-view drawings of the various surveys are presented for each island. Volume 3 is the Canadian Seabed Research study on island erosion dynamics entitled "Sediment Transport at Artificial Island Sites, Canadian Beaufort Sea" and dated December 1994.

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Klohn-Crippen

We have enjoyed working on this assignment. If you have any questions, please do not hesitate to call the undersigned.

Yours very truly,

KLOHN-CRIPPEN CONSULTANTS LTD.

Brian T. Rogers, P.Eng.
Director, Geotechnical Division

BTR/ll

GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

VOLUME 1: MAIN REPORT

PREPARED FOR

INDIAN AND NORTHERN AFFAIRS, CANADA

PREPARED BY

KLOHN-CRIPPEN CONSULTANTS LTD.

IN ASSOCIATION WITH

B.D. WRIGHT & ASSOCIATES
CHALLENGER SURVEYS & SERVICES
CANADIAN SEABED RESEARCH

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UPDATE OF MARCH 1993

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1. INTRODUCTION

1.1 Study Objectives

Since the early 1970's, approximately 40 million cubic metres of granular material have been dredged within the Canadian Beaufort continental shelf to create artificial islands or subsea berms for caisson retained islands and drilling barges. These islands were constructed to provide temporary drilling structures for hydrocarbon exploration. Upon completion of exploratory drilling and after removal of equipment and consumables, these islands have generally been abandoned to natural erosion, or partially scalped and reused at alternate exploration sites.

The purpose of this study was to provide the following:

- An up-to-date and easily accessible summary of the location, type, quantity and quality of granular materials present in the artificial islands and berms in the area of the Canadian Beaufort Sea bounded by latitudes 69° and 70°30′ North, and longitudes 131° and 137° West.
- Selected examples of island erosion and sediment transport rates which can illustrate the importance of material type, water depth range, and environmental conditions on the potential change in the resource potential of the artificial islands with time.
- An evaluation of the constraints to possible utilization of these granular materials as a resource for future development in the Canadian Beaufort Sea.

This study was carried out on behalf of the Department of Indian and Northern Affairs, Canada, as part of the Northern Oil and Gas Action Program (NOGAP) Project A4 - Granular Resources Inventory and Management. One of the main factors in the evaluation of potential changes in the resource potential of the islands over time is information on island erosion dynamics. This topic is also of interest to the Geological Survey of Canada (GSC), from the perspective of utilization of island erosion information for estimating regional sediment transport rates and directions. Therefore, the GSC provided partial funding, under the Panel on Energy Research and

Development (PERD) Committee 6.3.1 - Beaufort Offshore Geotechnics, for the study. Mr. Bob Gowan was the scientific officer for the project and terms and conditions for the contract are outlined in Contract 38ST.A7134-2-0039. The work was carried out by a project team comprised of Klohn-Crippen Consultants Ltd. as project manager, with specialist input from B.D. Wright and Associates, Challenger Surveys and Services Ltd. and Canadian Seabed Research. Mr. Steve Blasco of the Geological Survey of Canada also provided direction for this work, in particular for the work on island erosion dynamics.

1.2 Organization of Report

The results from this study are presented in three volumes. Volume 1 titled "Main Report" (this volume) presents a summary of the work carried out during the project. Section 1 provides an introduction to the study, and Section 2 presents an historical overview of island construction in the Canadian Beaufort Sea highlighting significant incidents which occurred during the period. Section 3 describes the granular resource inventory of the artificial islands, and summarizes the use of the InFocus/Quickmap/FoxPro2 software. The appropriate electronic data disks for InFocus/Quickmap/FoxPro2 data reporting are contained in the Appendix. Section 4 introduces regional environmental conditions on the continental shelf, and the effect of ice and waves on the erosion of the islands. A summary of island erosion dynamics is given in Section 5. Project conclusions and recommendations are presented in Section 6.

Volume 2 contains a hard copy summary of information entered into the database. Section 1 provides the introduction to the project. Section 2 presents the database and discusses the use of FoxPro2 and InFocus/Quickmap. Section 3 summarizes the availability of granular resources in the artificial islands. Separate sections are then provided in Appendix I for each of the 37 artificial islands summarizing available information.

Volume 3 is the report by Canadian Seabed Research on island erosion dynamics entitled "Sediment Transport at Artificial Island Sites, Canadian Beaufort Sea". A study of selected islands over time was used to determine potential changes to the resource potential of the old artificial islands. This information is also useful for estimating regional sediment transport rates and directions.

1.3 Information Search

Data gathering for this project was undertaken during the period January to March 1993. A list of sources of information is presented in Table 1, together with the contact name and telephone number. The most complete sources of data remain the operators files,

Table 1 - Information Sources

Agency/Company	Contact/Phone Number
1. National Energy Board (NEB) Calgary, Alberta	Mr. Stephen Lord (403) 299-2797
2. Department of Fisheries & Oceans Sidney, B.C.	Mr. Brian Smiley (604) 363-6551
3. Department of Indian and Northern Affairs Canada Yellowknife, NWT	Mr. Jim Umpherson (403) 920-8184
4. Environmental Protection Service (EPS) Yellowknife, NWT	Ms. Laura Johnson (403) 873-3456
5. Canadian Hydrographic Services (CHS) Sidney, B.C.	Mr. Dan Dobson (604) 363-6360
6. Imperial Oil Resources Ltd. Calgary, Alberta	Mr. Peter Meyer (403) 237-2139
7. Gulf Canada Resources Ltd. Calgary, Alberta	Mr. Ken Gaida (403) 233-3949
8. Amoco Canada Ltd. Calgary, Alberta	Mr. Kevin Hewitt (403) 298-3500
9. Challenger Surveys & Services Ltd. Calgary, Alberta	Mr. Dave Thomson (403) 253-8101
10. CES Surveys Ltd. Edmonton, Alberta	Mr. Rae Sutherland (403) 438-1336
11. Zeeland Ltd. (ex. Volker Stevin) Calgary, Alberta	Mr. John Wainwright (403) 234-7890

in particular Esso Resources, Gulf Canada and Amoco. For this project, only the Gulf data has been looked at in detail. Due to heavy work loads at Esso, permission to directly access Esso reports had not been obtained by the end of March 1993. However Esso have made available the information obtained from surveys of old islands in 1990. This data set is a major input for the assessment of the granular resource potential of the abandoned islands.

The Canadian Hydrographic Service (CHS) in Sydney, B.C. was requested for an inventory of bathymetric data available from their records. The CHS mission was to survey navigable waters for the purpose of identifying hazards which may exist to vessels in the area. Information available at each island site largely consists of a minimum depth and location. Limited bathymetric detail of each site is available from this source.

Data was also obtained from existing government reports, conference proceedings and engineering literature. The key documents that provided background information included:

- EBA Engineering Consultants et al, 1984. Abandonment of Offshore Artificial Islands in the Beaufort Sea. Report submitted to Environmental Protection Services, Environment Canada.

- Taylor, DA, Reed MG, Simley BD and Floyd GS, 1985. Arctic Industrial Activities Compilation Volume 1. Beaufort Sea: Marine Dredging Activities 1959 to 1982. Canadian Data Report of Hydrography and Ocean Sciences No. 32 (Vol. 1)

- Shinde SB, Crooks, JHA, James DA and Williams Fitzpatrick S, 1986. Geotechnical Design for Beaufort Sea Structures. 3rd Canadian Conference on Marine Geotechnical Engineering, St. John's, Newfoundland.

- Jefferies MG, Rogers BT, Stewart HR, Shinde S, James D and William Fitzpatrick S, 1988. Island Construction in the Canadian Beaufort Sea. ASCE Specialty Conference on Hydraulic Fill Structures, Fort Collins, Colorado. Geotechnical Special Publication No. 21.

2. ISLAND CONSTRUCTION OVERVIEW

2.1 Background

During the 1960's, permits to explore for oil and gas were issued for the majority of the Beaufort Sea's continental shelf. Offshore drilling began in 1973 with the construction of shallow surface piercing artificial islands in the Beaufort's relatively sheltered nearshore waters. As "island drilling" experience was gained through the 1970's, this technology was extended from the shallow to intermediate water depths which exist further offshore.

Over the course of the 1970's, 17 surface piercing granular islands were built, with the deepest located in 19 m of water. In order to resist the forces imposed by the Beaufort Sea ice cover, these islands were massive, with their size and weight providing the necessary sliding resistance to counteract lateral ice forces year round. Local sand dredged from the seafloor was generally used as the island construction material. The first shallow water islands required modest fill volumes and were relatively inexpensive. However, with increasing water depth, the fill volumes required for island construction became larger and the costs considerably higher. As a result, caisson structures such as Canmar's Tarsiut caissons, Esso's CRI and Gulf's Molikpaq were introduced in the early 1980's to extend the island drilling concept into the intermediate water depth range at a reduced cost. These caissons were typically designed to be placed on submerged berms and filled with sand to satisfy the horizontal sliding resistance requirements, while reducing the total fill volumes that would be required for construction of "conventional" islands. Canmar's SSDC was also introduced as an alternative concept to reduce sandfill requirements.

Experience with the design and operation of these island structures has provided considerable insight into the effects of the Beaufort Sea's environment. Clearly, these structures have had to withstand the forces and effects associated with a wide range of Beaufort sea ice conditions. Depending upon the construction time frame, drilling schedule and operational philosophy, these islands have also had to sustain some of the erosional effects caused by waves and currents. The experience base acquired during the design, construction and subsequent monitoring of these structures is significant and can be directly applicable to the question of long term erosion of the remnant sandfills, and the availability of this material as a resource potential for future development activity on the continental shelf.

2.2 Islands Constructed 1973 - 1989

As presented in Table 2, a total of 37 artificial islands were constructed between 1973 and 1989. Figure 1 shows the location of each island. Detailed information for each site has been collated in Volume 2 of this study. Esso Resources (Imperial Oil Ltd.) were the operator for 26 of these islands, primarily in the shallow water zone of the Beaufort Shelf. Gulf Canada and Dome (Amoco Canada Ltd.) were the main operators for the deeper water deployments. Dome also started construction of an island at Kaglulik M-64 in the Eastern Beaufort Shelf in 27 m water depth. However the project was cancelled in late 1980 after placement of approximately 280,000 m^3 of sand.

A summary of the different types of artificial islands constructed to support drilling activities is given in the following subsections. Schematic representations of each island type are shown in Figure 2.

Table 2 - Summary of the Canadian Beaufort Artificial Islands

No	Island Name	Island Type	Latitude	Longitude	Water Depth (m)	Construction Date
1	Immerk B-48	Sacrificial Beach Island	69.618972	135.180750	3.0	1972-73
2	Adgo F-28	Sandbag Retained Island	69.454611	135.854388	2.1	1973
3	Pullen E-17	Gravel Fill Island	69.771111	134.328055	1.5	1973-74
4	Unark L-24	Gravel Fill Island	69.558389	134.616694	1.3	1973-74
5	Pelly B-35	Barge Cored Island	69.569722	135.390833	2.0	1974
6	Netserk B-44	Sandbag Retained Island	69.550833	135.932778	4.6	1974
7	Adgo P-25	Sandbag Retained Island	69.415833	135.841667	1.5	1974
8	Adgo C-15	Gravel Fill Island	69.403611	135.817500	1.5	1975
9	Netserk F-40	Sandbag Retained Island	69.656389	135.905833	7.0	1975
10	Sarpik B-35	Gravel Fill Island	69.401944	135.386111	4.3	1975-76
11	Ikkatok J-17	Sandbag Retained Island	69.277944	136.303611	1.5	1975
12	Kugmallit H-59	Sandbag Retained Island	69.639167	133.463611	5.3	1976
13	Adgo J-27	Sandbag Retained Island	69.441778	135.847444	1.8	1976
14	Arnak L-30	Sacrificial Beach Island	69.829028	133.872528	8.5	1976
15	Kannerk G-42	Sacrificial Beach Island	70.023306	131.215583	8.5	1976
16	Isserk E-27	Sacrificial Beach Island	69.938889	134.369667	13.0	1977
17	Issungnak O-61	Sacrificial Beach Island	70.016806	134.313306	19.0	1978-79
18	Issungnak 2-O-61	Sacrificial Beach Island	70.016694	134.313444	19.0	1980
19	Alerk P-23	Sacrificial Beach Island	69.882500	132.839440	11.6	1980-81
20	North Protection Island	Sacrificial Beach Island	-	-	4.6	1980-81

Table 2 - Summary of the Canadian Beaufort Artificial Islands

No	Island Name	Island Type	Latitude	Longitude	Water Depth (m)	Construction Date
21	West Atkinson L-17	Sacrificial Beach Island	69.776083	132.075666	6.0	1981-82
22	Tarsiut N-44	Caisson Retained Island	69.896139	136.193470	21.0	1981-82
23	Uviluk P-66	Single Steel Drilling Caisson	70.263444	132.313280	29.7	1981-82
24	Itiyok I-27	Sacrificial Beach Island	69.944417	134.088670	15.0	1981-82
25	Nerlerk B-67	Single Steel Drilling Caisson	70.433444	133.324556	45.1	1982-83
26	Kogyuk N-67	Single Steel Drilling Caisson	70.113722	133.328220	28.1	1982-83
27	Kadluk O-07	Caisson Retained Island	69.780083	136.021250	14.0	1989
28	Amerk O-09	Caisson Retained Island	69.982333	133.514778	27.0	1983-84
29	Adgo H-29	Sandbag Retained Island	69.479444	135.839528	3.0	1984
30	Nipterk L-19	Sacrificial Beach Island	69.810583	135.298094	11.7	1983-84
31	Tarsiut P-45	Molikpaq	69.915444	136.418000	25.5	1984
32	Minuk I-53	Sacrificial Beach Island	69.709639	136.458860	14.7	1982-85
33	Amauligak I-65	Molikpaq	70.077694	133.804556	31.0	1985
34	Arnak K-06	Sacrificial Beach Island	69.761222	133.772361	7.2	1985
35	Kaubvik I-43	Caisson Retained Island	69.875833	135.422028	17.9	1983-86
36	Amauligak F-24	Molikpaq	70.054833	133.630250	32.0	1985-87
37	Isserk I-15	Molikpaq	69.912361	134.299222	11.8	1989

2.2.1 Sandbag Retained Islands

The sandbag retained island was one of the four types of islands constructed during the early years of Beaufort Sea exploration. A protective dyke around the perimeter of the island consisting of a gravel berm and/or sandbags to about one metre above mean sea level (msl) was used to contain the fill. The method was attractive in areas where fill was scarce and had to be hauled some distance. The central core was filled with either sand (7 cases) or silt and gravel (3 cases). In most instances the fill was placed using clamshell grabs to transfer the material from the transport barge to the island core.

2.2.2 Gravel Fill Islands

Three gravel fill islands were constructed during the winter seasons from 1973 to 1976. Water depths ranged from 1.5 to 4.3 m. To construct these islands, gravel was trucked from the nearshore Ya-Ya lakes area over ice roads and then placed through slots cut into the offshore ice. Sandbags and filter cloth were placed during the summer season for erosion protection. However, the Government discouraged use of the limited onshore gravel reserve in order to preserve the material for other uses. Since alternative gravel sources were too far away to be cost effective, this type of island construction ceased to be used in the Canadian region of the Beaufort Sea.

2.2.3 Sacrificial Beach Islands

Sacrificial beach islands consisted of a drilling surface surrounded by long gradual beaches. As the name suggests, there was no expectation that the island would have a long life. The island geometry provided a working surface in the order of 100 m diameter that was resistant to wave action for the latter part of the open water season and to ice attack for approximately one year. This was achieved by using very flat perimeter beaches (typically slopes of 25H:1V) where the island penetrated the waterline. Depending on the gradation of the beach sand, sandbags were sometimes used to protect the slope at the inshore end of the beach. Erosion of the beach was expected during the open water season, but the beach was sized for the probable storm scenario and limited erosion. In winter, the beaches caused the ice to fail in bending some distance from the work surface creating a protective ice rubble field around the island.

2.2.4 Caisson Retained Islands

Caisson retained islands used a caisson to substantially reduce the fill volume in the island but still retain sufficient sand mass in the core area to resist ice loads. As exploration moved to increasing water depths, the savings in sand volume became progressively larger.

Caissons constructed to date have been designed for exploration and intended to be movable and used as several sites with differing water depths. This requirement for use in different water depths was met by placing the caisson on an underwater berm which provided the appropriate set-down depth regardless of water depth at a particular site. The berm was constructed with hydraulically placed granular material. The inner core of the caissons was also infilled with hydraulically placed sand or gravel.

Three caisson retained systems have been used in the Canadian Beaufort Sea, each substantially different from the other. The first system to be constructed was at Tarsiut N-44. This island comprised four independent concrete caissons that were founded at 6.5 m on a berm that extended down to the seabed at 21 m. The core was infilled with sand which provided the drilling surface. These units were only used at Tarsiut N-44, in 1981-2, and have since been abandoned.

The second system to be deployed was designed for Esso Resources Canada Ltd. This caisson comprised an octagonal ring with each face of the ring being an independent steel unit. The units interlocked and were held together with post-tensioned cables. The composite caisson, known as the CRI, was founded at 9 m, had 3 m of freeboard to island surface and contained wave or ice deflectors to provide another 5 m of overtopping protection. The core was filled with sand or gravel to form a drilling surface. The unit has been installed at three locations as shown in Table 2.

The third caisson retained system deployed in the Canadian Beaufort Sea was Gulf's Molikpaq. Unlike the other two caisson systems, the Molikpaq is a monolithic caisson with an integral deck which supports the drilling modules. The Molikpaq has been deployed at 4 sites at setdown depths ranging from 13.5 to 20 m.

2.2.5 Barge Islands

Drilling barges are comparable in many respects to caisson retained islands. Two such barges have been deployed to date, one in 1974 at Pelly B-35, and the second, Canmar's SSDC, at two island sites in the Canadian Beaufort, as recorded in Table 2. The SSDC used a sandfill berm to provide a setdown depth of 9 m and was deployed in approximately 30 m of water at both Uviluk P-66 and Kogyuk N-67.

2.3 Island Fill Quantities and Borrow Sources

A range of construction equipment was utilized in the Beaufort Sea for transportation of sand during fill placement. Further details on dredging equipment is given by Taylor et al (1985). As previously noted, initial islands typically used local borrow pits and stationary suction dredges to move the granular material via floating pipelines. With deeper water deployments, the importance of coarser and cleaner granular fill resulted in the use of trailer hopper dredges to haul material from key delineated borrow pits.

The estimated quantities of material used in island construction and the respective borrow sources are summarized in Table 3. Between 30 and 40 million cubic metres of granular material have been dredged from seafloor sources for island construction. Sand is quite widespread east of about 136°W longitude, and so sacrificial beach islands in this region typically used sand adjacent to the drilling site. Example gradations for material from the Tingmiark Plain and within the Isserk block are shown on Figure 3. The median D_{50} for both sites falls in the range of 0.1 to 0.28 mm, and resulted in very shallow side slopes on sacrificial beach islands.

Coarser and cleaner sand was required to achieve higher as-placed density, steeper side slopes and additional resistance to wave induced liquefaction failure. This resulted in

Table 3 - As-Built Quantities of Beaufort Artificial Islands

No	Island Name	Island Type	Fill Quantity (m^3)	Borrow Site	Primary Fill Material	Secondary Fill Material
1	Immerk B-48	Sacrificial Beach Island	180 000	Local	sand	gravel
2	Adgo F-28	Sandbag Retained Island	46 000	Local, Immerk area	silt	gravel cap
3	Pullen E-17	Gravel Fill Island	65 000	Onshore, Yaya Lakes	gravel	
4	Unark L-24	Gravel Fill Island	44 000	Onshore, Yaya Lakes	gravel	
5	Pelly B-35	Barge Cored Island	35 000	Local, Yaya Lakes	silt	gravel cap
6	Netserk B-44	Sandbag Retained Island	306 000	Pelly Island	sand	
7	Adgo P-25	Sandbag Retained Island	27 000	Local	silt	gravel cap
8	Adgo C-15	Gravel Fill Island	70 000	Onshore, Yaya Lakes	gravel	
9	Netserk F-40	Sandbag Retained Island	291 000	Pelly Pit, Garry Harbour and Spit	sand	
10	Sarpik B-35	Gravel Fill Island	118 000	Onshore, Adgo C-15 area	gravel	
11	Ikkatok J-17	Sandbag Retained Island	38 000	Local	sand	
12	Kugmallit H-59	Sandbag Retained Island	236 000	Tufts Point	sand	
13	Adgo J-27	Sandbag Retained Island	69 000	Local, Netserk B-44 area	silt	gravel cap
14	Arnak L-30	Sacrificial Beach Island	1 150 000	Local	sand	
15	Kannerk G-42	Sacrificial Beach Island	1 150 000	Local	sand	
16	Isserk E-27	Sacrificial Beach Island	1 908 000	Local, Tufts Point	sand	
17	Issungnak O-61	Sacrificial Beach Island	4 100 000	Local, Tufts Point	sand	
18	Issungnak 2-O-61	Sacrificial Beach Island	4 900 000	Issungnak 0-61	sand	
19	Alerk P-23	Sacrificial Beach Island	2 670 000	Local	sand	
20	North Protection Island	Sacrificial Beach Island	2 000 000	Local	sand	

Table 3 - As-Built Quantities of Beaufort Artificial Islands

No	Island Name	Island Type	Fill Quantity (m^3)	Borrow Site	Primary Fill Material	Secondary Fill Material
21	West Atkinson L-17	Sacrificial Beach Island	1 000 000	Local	sand	
22	Tarsiut N-44	Caisson Retained Island	1 800 000	Ukalerk, Issigak, Isserk, Herschel	sand	gravel
23	Uviluk P-66	Single Steel Drilling Caisson	1 900 000	Local, Ukalerk, Isserk, Kagluk, Issigak	sand	gravel cap
24	Itiyok I-27	Sacrificial Beach Island	1 943 000	Local, Ukalerk	sand	
25	Nerlerk B-67	Single Steel Drilling Caisson	4 000 000	Ukalerk, Local	sand	
26	Kogyuk N-67	Single Steel Drilling Caisson	1 450 000	Ukalerk, Uviluk P-66, Banks Island, Rufus River	sand	gravel cap
27	Kadluk O-07	Caisson Retained Island	450 000	Ukalerk	sand	
28	Amerk O-09	Caisson Retained Island	1 700 000	Ukalerk	sand	
29	Adgo H-29	Sandbag Retained Island	75 000	Adgo J-27, Sarpik B-35, Kadiuk O-07	sand	gravel cap
30	Nipterk L-19	Sacrificial Beach Island	1 500 000	Issigak, Ukalerk	gravel	sand
31	Tarsiut P-45	Molikpaq	350 000	Ukalerk, Tarsiut N-44, Kogyuk N-67	sand	gravel
32	Minuk I-53	Sacrificial Beach Island	2 000 000	Ukalerk, Issigak, Isserk, Kadluk O-07	gravel	sand
33	Amauligak I-65	Molikpaq	1 410 000	Ukalerk, Kogyuk N-67, Amerk O-09, Issigak	sand	gravel toe
34	Arnak K-06	Sacrificial Beach Island	700 000	Local	sand	
35	Kaubvik I-43	Caisson Retained Island	565 000	Ukalerk, Isserk, Issigak	sand	gravel toe
36	Amauligak F-24	Molikpaq	2 000 000	Ukalerk, Amauligak I-65, Minuk I-53	sand	gravel toe
37	Isserk I-15	Molikpaq	72 000	Amauligak I-65	sand	

the trend for all three operators to use the Ukalerk borrow pit and trailer suction hopper dredges for construction of artificial islands in the 1980's. The gradation envelope for the Ukalerk pit is also shown in Figure 3. The material median grain size ranges from 0.3 mm to 0.4 mm, with an average fines content of about 4%. Commonly, at least half of the silt content is lost during construction due to washing during dredge operations.

The Issigak pit, which is located in 8 to 10 m of water northwest of Richards Island, contained sand and gravel with a median grain size between 2 to 10 mm. This material was used primarily for construction of islands in the western half of the Beaufort Shelf. Material from this borrow source was also used as erosion protection material for most of the caisson retained islands.

As shown in Table 3, island construction in the mid to late 1980's made use of old abandoned islands as sources of granular material. This reduced the requirement for quality control during dredging operations.

2.4 Significant Events

Artificial islands were successfully used for exploration drilling in the Beaufort Sea. However, "unexpected" or detrimental behaviour was observed at eight of the island sites. This "unexpected" behaviour is summarized in Table 3. Useful information can be obtained on the requirements for fill material gradation through review of these incidents. The main lessons are discussed in the following subsections.

2.4.1 Excess Pore Pressures Induced by Construction

The first indication that hydraulic fill construction might be difficult using the local sand and early construction procedures came from the Arnak L-30 project in 1976. This island was constructed using a typical Beaufort Sea sand which was a little siltier than that shown for the Tingmiark Plain in Figure 3. Island construction was typical for the early years. The suction dredge "Beaver MacKenzie" was used to excavate local sand which was discharged via a floating pipeline at the island site. The above water portion of the island required the use of bulldozers and a backhoe to form a circular dyke which was then infilled with sand slurry. Trafficability of the fill was poor during dyke construction and the beach subsequently slumped downslope by several tens of metres.

Sand boils observed on the beach suggested that this slumping was caused by transient excess pore pressures in the sand. Since there were no outside disturbances, it was inferred that the excess pore pressures were entirely due to the fine sandfill gradation and construction procedures used. Considerable caution was therefore used when assessing the transient stability of hydraulically placed fine sandfills during design of caisson retained islands.

2.4.2 Wave Induced Cyclic Mobility

An examination of Table 4 indicates that wave action was a common factor in several incidents. The Alerk and Issungnak islands were both constructed in the early 1980s by pipeline placement of local sand borrow which was relatively fine and dirty. During the construction of Issungnak, observations by field staff indicated that on at least two occasions, the above water portion rapidly disappeared during storm action. During 1981, half of the Alerk island disappeared during a storm at the end of the construction stage. Analysis of failure survey data has led to the conclusion that Alerk experienced instability because of low in situ densities coupled with cyclic induced excess pore pressures.

Wave action can lead to the generation of excess pore pressure because of cyclic total stress reversals. Material type, expressed in terms of C_v, is the major factor in determining susceptibility to wave induced liquefaction. Figure 4 shows the ranges of C_v for various borrow materials. It is evident that sand from the Ukalerk pit is sufficiently clean and coarse to ensure that excess porewater pressures will not be developed under the design storm even if it is in a loose state. As indicated on Figure 4, the Issungnak sand had a $C_v < 100$ cm^2/s and this material would have been expected to liquefy under a less severe storm than the design storm. Although the C_v for the Alerk material is greater than Issungnak sand, its performance in the design storm would be expected to be marginal.

Table 4 - Significant Events

Project	Year	Incident	Cause	Action
Arnak L-30	1976	Slumping of recently constructed beach	Excess pore water pressure caused by spigotted sand	Additional sand placed; island became stable as pwp dissipated
Issungnak O-61	1979	Substantial erosion of the island fill when sand surface close to waterline	Storm waves on two separate occasions; wave induced liquefaction possible factor	Additional sandfill placed and island brought into service
Tarsiut N-44	1980	Caisson setdown offset by 20 m (25% of island diameter) Wave overtopping	Surveying error Storm waves	Toe berm constructed to avoid foundation failure and island brought into service Use of rockfill gabions for added height protection
Alerk P-23	1981	Nearly half of island disappeared	Postulated as wave induced liquefaction triggering slumping of loose sand	Additional sandfill placed and island brought into service
Nerlerk B-67	1983	General slope failures during construction	Surficial clay layer and low sand densities	Project abandoned
Adgo H-29	1984	Cracking and downward movement of sandfill in NE corner	Foundation failure in soft clay	Stabilizing toe berm placed and island brought into service
Minuk I-53	1985	Slope failures during construction Island erosion leading to loss of rig and supplies	Oversteepening of slopes during placement of gravel fill Storm substantially in excess of design conditions	Construction continued Rebuilt and brought into service
Amauligak I-65	1986	Partial fluidization of sand core	Extended cyclic loading of platform during ice crushing	Densification specified for subsequent deep water deployments

2.4.3 Erosion

A late season storm in September 1985 resulted in major damage to the Minuk I-53 island. The storm eroded nearly half the island, toppled the drilling rig and destroyed part of the camp. However, all personnel had been evacuated and there was no loss of life during the incident. Although the experience at Alerk and Issungnak might suggest that wave induced liquefaction was also the cause of the Minuk incident, review of available data suggested that the damage resulted from direct erosion by wave action.

Minuk I-53 was a sacrificial beach island. Such islands were designed by balancing the expected erosion in a design storm with the size of the beach. This is an imprecise calculation that depends on such factors as significant wave height, storm duration, sand size, and modifications to the beach itself by the erosion process. The complexity of design is further compounded by the limited history of environmental conditions in the Beaufort Sea since there are few records before the start of oil exploration in 1973.

Post-failure analysis of the Minuk I-53 performance during the storm indicated that excessive erosion was caused by a relatively rare storm with a duration approximating four times that used in the original design. The Minuk storm event is the first case where the design philosophy of accepting economic risk while preventing environmental damage/loss of life was tested. The investigation carried out after the event by the regulatory agency concluded that this design philosophy was acceptable practice.

2.4.4 Ice Induced Cyclic Mobility

Although ice loading is often considered as a quasi-static situation, much of the ice loading on the Molikpaq at Tarsiut P-45 and Amauligak I-65 at ice load levels greater than 100 MN was associated with crushing failures. The crushing failures against the near vertical face of the structure produced cyclic loads commonly at frequencies in the order of 0.5 to 3 Hz and with durations as long as about 30 min. The ice induced vibrations were comparable to a moderate earthquake of extended duration.

Ice conditions at Amauligak I-65 in winter 1985/86 included substantial amounts of multi-year ice with thicknesses in the range of 3 to 7 m. Ice loads on the structure were correspondingly high. On Saturday April 12, 1986, a 2 km x 1 km multi-year floe continuously crushed against the side of the Molikpaq. This crushing caused peak loads on the structure up to the design load of 500 MN, and was associated with horizontal acceleration on the loaded face of greater than 10% g. The vibrations were sufficiently severe to induce porewater pressure build-up in the sand core, the principal element by which the Molikpaq resisted ice load, to the extent that the ability of the platform to withstand further ice loading was degraded.

Porewater pressure build-up in the sand core was a progressive phenomenon that initiated at mid-height of the loaded side and propagated rearwards and downwards, as documented by piezometers. Fortunately, the ice action that caused fluidization ceased due to a flexural ice failure before pore pressures had risen sufficiently to cause overall platform deformation. Total measured permanent horizontal displacements were less than 50 mm for this incident. Data collected at Amauligak I-65 resulted in use of explosive densification to compact the sandfill in the core space of the Molikpaq at the next deep water deployment at Amauligak F-24 and a change in the setdown depth to place a sloped face at the waterline.

2.4.5 Large Scale Strength of Sand

The Nerlerk B-67 berm was constructed in 1982 and 1983 to provide support for Canmar's SSDC at a site in 45 m water depth. However prior to completion of the island to 9 m below mean sea level, several large failures occurred resulting in abandonment of the project. The most likely mechanism for these failures involved strain within the underlying soft clay and large scale liquefaction failure in the loose sandfill.

Much of the material in the Nerlerk berm was obtained from a local sand pit containing material that was both finer and siltier than the Ukalerk pit. This material was placed using a floating pipeline and the dredge Aquarius. Lessons learned from the Nerlerk B-67 failures included the need to remove soft surficial clay, the advantages of using coarser and cleaner sand from the Ukalerk Borrow Pit, and the use of bottom discharge from trailer hopper suction dredges to achieve higher in situ densities.

3. GRANULAR RESOURCE INVENTORY

3.1 Database

A database of information on the artificial islands in the Canadian Beaufort Sea was developed using Infocus/Quickmap/FoxPro2 software. The data disks for the database are included in Appendix I. Hard copy summaries of the data are presented in Volume 2 of this report. This section will discuss the database using Itiyok I-27 as an example.

The hard copy summary for Itiyok I-27 is included as Appendix II of this volume for reference. The first two sheets summarize the data in FoxPro2. The information entered is discussed below.

<u>Island Identification</u>

- The first line on both sheets identifies the site name, the operator, the original water depth at the site, and a reference number for the island.

<u>Location</u>

- The island centre location is also provided on both sheets in both UTM Zone 8 coordinates and geographic latitude and longitude.

<u>Island Type</u>

- Identifies the type of island constructed at the site, as discussed in Section 2.0.

<u>Construction Method</u>

- A brief description of the construction method is included in the database. Only the first part of the description is shown on the data sheet.

<u>Borrow Site</u>

- All locations used as borrow sources are identified, starting with the source providing the majority of the granular material.

<u>Fill Material</u>

- Again a listing of material types is entered, starting with the most common material type. This is followed by the range of material D_{50} and fines content.

Island Dimensions

- Information on island geometry, freeboard and total fill quantity has been entered for each available survey. Not all the data from each survey has been disseminated at this time.

Description

- This section contains a brief historical description of the island construction sequence, the drilling activities, and notes any significant occurrences at the site.

Dates

- When available, dates have been entered for the construction period, the date of rig release after drilling, and for abandonment of the island.

Seabed Conditions

- Site conditions have been summarized in terms of physiographic region and surficial soil types. An entry line has been provided for the identification of the nearest borehole, which it is understood can be accessed through another DIAND database.

Ice Zone

- Defines the ice environment characterizing the particular island or berm location in winter (i.e. landfast or transition zone). Very shallow locations (2 m or less) have been identified as being in the bottom fast ice zone, since the ice grows to the seafloor.

Freeze-Up

- The median, twenty and eighty percentile dates when new ice greater than 5/10ths in concentration covers the general vicinity of the location, established from 15 years of AES ice chart information (1977 to 1991).

Landfast Ice Occurrences

- The approximate time period is given when landfast ice normally stabilizes at the locations.

Rubble Formation and Extent

- Whether grounded rubble formations are commonly seen at these locations and their extent, based upon a review of SAR and SLAR imagery that is available during the fall and winter periods and on various field observations collected over a number of years.

- The small, moderate and large rubble extent categories refer to approximate rubble field widths of tens of metres, one hundred to several hundred metres and more than several hundred metres, respectively.

Exposure to Significant Moving Winter Ridge Keels

- An indication of the potential for significant scour action from moving ice during the winter period is given in qualitative "risk" categories which include insignificant, low, moderate and high.

Break-Up

- The median, twenty and eighty percentile dates when ice concentrations fall to 3/10ths or less in the general vicinity of the location, established from 15 years of AES ice chart information (1977 to 1991).

Open Water Days

- The median number of days of open water at the island location.

Summer Ice Intrusions

- The number of years (in 15) that significant ice intrusions have occurred in the vicinity of the location, defined as ice concentrations of 5/10th or more, comprised of thick first year, second year or old ice types. Again, these major ice intrusion "statistics" are based upon AES ice chart information from 1977 to 1991.

Wave Conditions

- Exposure to extreme storm waves is presented qualitatively as low, medium and high exposure categories, which are largely based upon wave height limitations related to wave breaking.

- Storm wave events were defined by measured significant wave height occurrences that exceeded 2 m in the general region. The available information base covered the 1974 to 1988 period, with the number of storm events experienced by each island or berm specified as the number of storm events over its lifetime until the end of the 1988 open water season.

Reference Numbers

- The lease, license and COGLA file number is entered as the final data entry. Data on the lease number has not yet been received from DIAND Yellowknife.

The two page summary of data entered in FoxPro2 is followed by a schematic cross section of the island. This figure is in DXF AutoCAD format, and is presently not in the Infocus/Quickmap system.

All available contour information has been entered into the Infocus/Quickmap system. These are presented as figures identified by the island number (Itiyok-I27 is number 24) and A for the earliest survey, B for the next date, continuing on until the 1990 survey data.

3.2 Constraints to Resource Utilization

There are various constraints to accessing the granular materials remaining in place in abandoned artificial islands. Key constraints are discussed in the following sections.

3.2.1 Environmental

Access is limited due to ice cover for typically 9 months of the year. In addition, grounded ice rubble builds up on old islands and may further reduce the open water period for accessing the inplace material. Storms also should be considered as a constraint to accessing the granular resource.

3.2.2 Water Depth

Dependent on the construction equipment available in the Canadian Beaufort Sea, both islands in very shallow water and in deeper water may not be accessible. Most of the dredges used in the Beaufort Sea area in the 1980's were limited to a water depth range of about 8 to 40 m. For sites shallower than 8 m, vessels were unable to fully load their hoppers. For sand deposits at greater than 40 m depth, the length of the drag arms were too short to reach the deposit. In addition, the smaller islands in shallow water have a greater proportion of material that will have been contaminated by local seabed soils.

3.2.3 Obstructions

Particularly in the case of sacrificial beach islands, considerable amounts of drilling debris remain on or close to the abandoned island surface. These represent a major hazard to equipment used to retrieve the granular material. In other cases, rock filled gabions, sandbags or other erosion protection measures may result in obstructions to accessing the granular material.

3.2.4 Contaminants

The islands were used as drilling platforms and near surface material was in contact with drilling fluid tanks, oil storage tanks and other drilling chemicals. A concern with retrieving granular material from old islands is that the dredging process may release potential contaminants into the ocean. The extent of this issue will vary considerably from site to site. It is not expected to be an issue at the Molikpaq or SSDC sites where drilled rigs were self-contained on the structure. However, for islands such as Minuk I-53 which suffered storm damage, the potential for contaminants is higher.

3.3 Resource Potential of Artificial Islands

A summary of approximate quantities of sand and gravel material remaining in each of the abandoned artificial islands is presented in Table 5 based on data from the most recent bathymetric surveys. The quality of material varies considerably from site to site. Therefore, islands with similar material types will be grouped together, with emphasis given to the coarser granular materials. Sites with less than 100,000 m^3 of material will not be considered as significant granular resources, except for gravel islands which represent a scarce resource.

3.3.1 Gravel and Sand Deposits

Table 6 summarizes the potential sand and gravel deposits that exist in artificial islands and identifies constraints to future utilization. The location of these islands is shown in Figure 5, which also highlights the Issigak borrow pit from which most of the gravel was obtained.

The first four islands in Table 6, representing a total of 200,000 m^3, cover gravel fill islands that primarily used onshore borrow pits. The final three islands contain an estimated 4,000,000 m^3 of Ukalerk and Issigak pit material. This coarse granular material represents a valuable resource that is well suited for future island construction in the Beaufort Shelf.

3.3.2 Ukalerk Sand Gradation

Table 7 summarizes the artificial islands that contain significant deposits of sand primarily from the Ukalerk borrow source. The location of each island is shown in Figure 6, together with the location of the Ukalerk pit.

Based on design studies and performance monitoring, this material has been identified as suitable for constructing steeper sided berms, and for use as a corefill material. The sites listed in Table 7 were all used for caisson retained islands, or the SSDC. The 7,000,000 m^3 of granular material remaining in place from these islands along with the Ukalerk borrow pit will likely be used for future construction related to exploration or development in the Canadian Beaufort Shelf. Based on experience with accessing some of these islands, no significant constraints are expected for future utilization of these deposits.

3.3.3 Other Sand Sources

Table 8 summarizes the approximately 14,000,000 m^3 of fine sand that remain in place in a further thirteen artificial islands. The location of each island is shown in Figure 7. These deposits were typically obtained from local pits adjacent to the island site. The higher fines content and gradation of the sand resulted in very flat slopes during construction, and potential instability during wave loading.

It is not expected that these islands will be utilized for construction of new exploration sites. However, they do represent existing berms that could form the core of future development at these sites. Coarser sand and gravel material could be placed to produce a stable and massive base for either setdown of purpose built production structures or large surface piercing islands.

A further 4,000,000 m^3 of sandfill is present in the Nerlerk B-67 abandoned island and the North Protection Island in McKinley Bay. However, these have not been considered as a likely resource for future construction activities in the Beaufort Shelf.

Table 5 - Latest Survey Quantities

No	Island Name	Island Type	Fill Quantity (m^3)	Fill Material	Date	Depth to Island (m)	Water Depth (m)
1	Immerk B-48	Sacrificial Beach Island	<180,000	sand	-	-	3.0
2	Adgo F-28	Sandbag Retained Island	n.a.	silt	-	-	2.1
3	Pullen E-17	Gravel Fill Island	50,000	gravel	-	-	1.5
4	Unark L-24	Gravel Fill Island	30,000	gravel	-	-	1.3
5	Pelly B-35	Barge Cored Island	n.a.	silt	-	-	2.0
6	Netserk B-44	Sandbag Retained Island	250,000	sand	08/06/85	2.2	4.6
7	Adgo P-25	Sandbag Retained Island	n.a.	silt	-	-	1.5
8	Adgo C-15	Gravel Fill Island	50,000	gravel	-	-	1.5
9	Netserk F-40	Sandbag Retained Island	250,000	sand	07/90	4.6	7.0
10	Sarpik B-35	Gravel Fill Island	70,000	gravel	-	-	4.3
11	Ikkatok J-17	Sandbag Retained Island	n.a.	sand	-	-	1.5
12	Kugmallit H-59	Sandbag Retained Island	100,000	sand	08/90	2.7	5.3
13	Adgo J-27	Sandbag Retained Island	n.a.	silt	-	-	1.8
14	Arnak L-30	Sacrificial Beach Island	1,000,000	sand	08/90	3.5	8.5
15	Kannerk G-42	Sacrificial Beach Island	1,000,000	sand	08/90	3.2	8.5
16	Isserk E-27	Sacrificial Beach Island	1,500,000	sand	07/90	5.0	13.0
17	Issungnak O-61	Sacrificial Beach Island	n.a.	sand	n.a.	n.a.	19.0
18	Issungnak 2-O-61	Sacrificial Beach Island	3,800,000	sand	07/90	4.0	19.0
19	Alerk P-23	Sacrificial Beach Island	2,000,000	sand	07/90	3.1	11.6
20	North Protection Island	Sacrificial Beach Island	2,000,000	sand	-	above msl	4.6

Table 5 - Latest Survey Quantities

No	Island Name	Island Type	Fill Quantity (m^3)	Fill Material	Date	Depth to Island (m)	Water Depth (m)
21	West Atkinson L-17	Sacrificial Beach Island	800,000	sand	08/90	2.1	6.0
22	Tarsiut N-44	Caisson Retained Island	1,000,000	sand & gravel	09/14/84	6.5	21.0
23	Uviluk P-66	Single Steel Drilling Caisson	1,500,000	sand	-	>9	29.7
24	Itiyok I-27	Sacrificial Beach Island	1,500,000	sand	07/90	4.0	15.0
25	Nerlerk B-67	Single Steel Drilling Caisson	2,000,000	sand	1983	20	45.1
26	Kogyuk N-67	Single Steel Drilling Caisson	1,000,000	sand, gravel cap	08/29/85	8.0	28.1
27	Kadluk O-07	Caisson Retained Island	300,000	sand	-	?	14
28	Amerk O-09	Caisson Retained Island	1,000,000	sand	09/10/85	9.0	27.0
29	Adgo H-29	Sandbag Retained Island	<75,000	sand	-	-	3.0
30	Nipterk L-19	Sacrificial Beach Island	1,000,000	gravel & sand	07/90	2.0	11.7
31	Tarsiut P-45	Molikpaq	300,000	sand	1985	>10	25.5
32	Minuk I-53	Sacrificial Beach Island	1,000,000	sand & gravel	07/90	awash	14.7
33	Amauligak I-65	Molikpaq	900,000	sand	08/17/89	16.0	31.0
34	Arnak K-06	Sacrificial Beach Island	600,000	sand	08/90	2.5	7.2
35	Kaubvik I-43	Caisson Retained Island	400,000	sand, gravel toe	07/90	4.5	17.9
36	Amauligak F-24	Molikpaq	1,600,000	sand, gravel toe	08/17/90	10	32.0
37	Isserk I-15	Molikpaq	60,000	sand	1990	10	11.8

Table 6 - Gravel and Sand Islands

No.	Island Name	Island Type	Approximate Fill Quantity (m^3)	Constraints to Utilization
3	Pullen E-17	Gravel Fill Island	50,000	Shallow Water Depth
4	Unark L-24	Gravel Fill Island	30,000	Shallow Water Depth
8	Adgo C-15	Gravel Fill Island	50,000	Shallow Water Depth
10	Sarpik B-35	Gravel Fill Island	70,000	Shallow Water Depth
22	Tarsiut N-44	Caisson Retained Island	1,500,000	Piles/Clay and Rock Content
30	Nipterk I-19	Sacrificial Beach Island	1,000,000	Minor Drilling Debris
32	Minuk I-53	Sacrificial Beach Island	1,500,000	Drilling Debris and Potential Contaminants
		Total	4,200,000 m^3	

Table 7 - Ukalerk Type Sand Islands

No	Island Name	Island Type	Approximate Fill Quantity (m^3)	Constraints to Utilization
23	Uviluk P-66	SSDC	1,500,000	Minimal
26	Kogyuk N-67	SSDC	1,000,000	Minimal
27	Kadluk O-07	CRI	300,000	Minor Drilling Debris
28	Amerk O-09	CRI	1,000,000	Minor Drilling Debris
31	Tarsiut P-45	Molikpaq	300,000	Minimal
33	Amauligak I-65	Molikpaq	900,000	Minimal
35	Kaubvik I-43	CRI	400,000	Minor Drilling Debris
36	Amauligak F-24	Molikpaq	1,600,000	Minimal
TOTAL			7,000,000 m^3	

Table 8 - Other Sand Islands

No.	Island Name	Island Type	Approximate Fill Quantity (m^3)	Constraints to Utilization
1	Immerk B-48	Sacrificial Beach Island	100,000	Shallow Water
6	Netserk B-44	Sandbag Retained Island	250,000	Shallow Water
9	Netserk F-50	Sandbag Retained Island	250,000	Drilling Debris
12	Kugmallit H-59	Sandbag Retained Island	100,000	Minor Drilling Debris
14	Arnak L-30	Sacrificial Beach Island	1,000,000	Drilling Debris
34	Arnak K-06	Sacrificial Beach Island	600,000	Drilling Debris
15	Kannerk G-42	Sacrificial Beach Island	1,000,000	Drilling Debris
16	Islerk E-27	Sacrificial Beach Island	1,500,000	Drilling Debris
18	Issungnak 2-O-61	Sacrificial Beach Island	3,800,000	Drilling Debris
19	Alerk P-23	Sacrificial Beach Island	2,000,000	Drilling Debris
21	W. Atkinson L-17	Sacrificial Beach Island	800,000	Minor Drilling Debris
24	Itiyok I-27	Sacrificial Beach Island	1,500,000	Drilling Debris
Total			13,900,000 m^3	

4. REGIONAL ENVIRONMENTAL CONDITIONS

4.1 Environmental Influences

A wide variety of environmental influences have been considered during the Beaufort Sea artificial island and caisson structure design phase, and further evaluated in subsequent construction and field monitoring programs. The environmental influences associated with potential erosion of these structures while they were active are similar to those that can lead to erosion of their sandfill remnants once the locations are abandoned.

In the Beaufort Sea, erosion and material loss can be caused by a variety of factors, including direct wave action, current and ice scouring, and sediment failure mechanisms. By understanding the physical processes associated with these sediment erosion mechanisms, including rates of sediment removal and redistribution, the longer term impact of various environmental influences on changes to the fill volumes, shapes and elevations of remnant islands and berms can be predicted.

During the summer period, erosion is primarily driven by the energy from storm waves and currents. This is obvious from previous observations at islands, with storm frequencies governing erosion rates and extreme wave occurrences controlling the depth to which islands will ultimately erode. The most significant winter process that can lead to erosion of island remnants and berms is ice scouring. However, even if large scour events are commonplace, the non-cohesive sediments comprising remnant sandfills are expected to remain largely within the island system and not be transported further than the distance achieved by natural island migration. It has been suggested that the ice scour process plays a relatively minor role in the overall erosion of remnant islands and berms.

From earlier work (Canadian Seabed Research, 1990), it has been tentatively concluded that the rate and depth to which islands and shallow berms ultimately erode is controlled by water depth, the fill materials and the frequency of extreme storm conditions. In the deeper water areas, surface piercing islands have been observed to erode fairly quickly, becoming submerged within two or three years. By contrast, islands in very shallow waters do not appear to erode rapidly below the waterline. However, the amount of beach protection material left in place upon island abandonment has also been identified as having a strong influence on erosion rates.

In the following sections, the influence of ice and sea conditions on island and berm erosion is discussed in more detail. Information on typical ice conditions and the variability in these conditions, typical wave and current states, and significant environmental events is also provided. Local information regarding environmental conditions is contained in the project database in Volume 2 for each specific artificial island, to the extent permitted by the existing database.

4.2 Regional Overview

The Beaufort Sea is best characterized as one of the most severe operating environments in the world. Although sea ice is recognized as the primary environmental constraint in the area, low temperatures, strong winds, fog, poor visibility, and the storm waves and currents that occur during the brief open water season are also important environmental influences. A brief description of the relevant environmental conditions is given in this section along with some background information regarding environmental influences on remnant island and submerged berms.

The primary environmental constraint in the Beaufort Sea is sea ice, since the area is usually ice covered for at least nine months of the year. Normally, the Beaufort Sea begins to freeze-up in October with landfast ice forming in the shallow water areas and progressively growing seaward. This landfast ice zone usually extends 50 to 60 km offshore to the 20 m water depth contour, where it stabilizes in early January. Nearshore, the landfast ice is relatively smooth but typically contains increasing numbers of pressure ridges towards its outer edge. The first year ice which comprises the fast ice zone normally grows to thicknesses of about 2 m during the winter period. However, the pressure ridges contained within it cover a wide thickness range, with many being grounded in 10 to 20 m of water. Although not common, multi-year ice floes and small ice island fragments may also be incorporated into the fast ice in some years. Over the course of the winter, the landfast ice is quasi-stationary but undergoes sporadic movements in response to storms and thermal effects. Nearshore, landfast ice displacements in the order of meters are common while further offshore, typical displacements of tens of meters are more typical.

The seasonal or transition ice zone is located between the landfast ice and the more northerly polar pack. The ice in the transition zone is primarily first year, although in some years substantial concentrations of multi-year ice, and on occasion, ice island fragments can be found here. The transition zone's ice cover is in near continuous motion throughout the winter period, with differential movements resulting in significant ridging, frequent leads and open water areas, and a wide range of ice thicknesses. Typical maximum winter ice thicknesses range between 1.5 to 1.7 m while first year ridges may be anywhere from a few metres to 40 or 50 m in total thickness. Large multi-year floes containing thick, consolidated ridges and heavily deformed multi-year hummock fields may also be present and represent the most formidable ice features commonly seen in the transition zone. The permanent polar pack, comprised primarily of multi-year ice, lies further offshore to the north of the transition zone and is well beyond the area of interest for current petroleum exploration. Long term motion of both the polar pack and transition ice zones are from east to west, following the clockwise Beaufort Gyre. Typical movement rates are in the order of several kilometres per day with extremes of tens of kilometres per day.

Break-up of the landfast and transition ice zones normally occurs in the late June to mid July period, giving rise to the Beaufort's brief summer season. Although several months of open water may be expected throughout most of the area, significant variations can be experienced from year to year. For example, if northerly winds persist for most of the summer, a poor ice year will result with high ice concentrations, including multi-year ice from the north, drifting in the area. Alternatively, if offshore winds predominate, an extensive open water season will be experienced in the Beaufort Sea.

During the summer season, winds acting over the Beaufort's open water area give rise to variable but typically small waves. In combination with the MacKenzie River's outflow, current patterns are generally stronger than those occurring during the ice covered period. In a relative sense, the Beaufort's wave climate is quite mild since the presence of pack ice limits the wind fetch, and hence, the wave heights that occur. However, in years when the ice is well offshore and large open water fetches are available, strong winds can cause high storm waves. Normal significant wave heights in the area are generally no more than a metre, although during storms extremes may be as great as 5 to 6 m. Similarly, the Beaufort's currents are relatively low with surface layer means of 10 to 20 cm/s and extremes in the order of 100 cm/s. Tides and storm surges are usually small and are generally not a significant consideration.

4.3 Ice Conditions and Influences - Normal Scenario

The range of ice conditions found at the artificial island sites is discussed in this section, along with the potential influence of sea ice on the erosion of these remnant islands and berms. Canadian Seabed Research (1990) has suggested that ice scouring is the predominant winter ice action that can lead to island erosion and reduced fill volumes. However, this work concluded that ice scour was not a significant factor in removing fill material, at least in comparison to wave related effects. This conclusion was primarily based on observational information obtained from repetitive island surveys. However, seafloor scour frequencies were also noted as generally high around the island locations considered. Although the potential for ice scour was discussed from a sandfill materials perspective, there was little other explanation offered to explain the difference between the apparently high local seafloor scour rates and the notion that ice scouring effects on abandoned islands were largely inconsequential.

In order to address typical ice conditions around the locations of interest and to further assess the potential for ice scour on these remnant islands and berms, the ice and ice interaction scenarios that usually occur each winter are reviewed. Examples of relevant field observations are given where applicable to substantiate these scenarios and related points that have been made regarding ice scour and ice induced erosion of abandoned islands.

4.3.1 Freeze-Up

During the freeze-up period, the Beaufort Sea is transformed from an open water to an ice covered environment as new ice forms throughout the area. This freeze-up process normally begins in the shallow water areas and progressively extends offshore into the Beaufort's deeper waters with the persistent low winter temperatures. As the general ice cover continues to grow in thickness throughout the fall, it is free to move in response to winds and currents for time periods of several weeks to several months before becoming progressively landfast in the area between the shoreline and the 20 m water depth contour. Beyond the landfast ice edge, the pack ice comprising the transition zone's ice cover remains mobile throughout the freeze-up and winter periods.

Implications:

- Shallow water locations (0 to 5 m) are only exposed to very thin, moving ice conditions for brief time periods during freeze-up.
- Intermediate water depth locations (5 to 12.5 m) are exposed to moving, slightly thicker new ice, but only until the early to mid November time frame.
- Deeper water landfast ice locations (12.5 to 20 m) can be exposed to thicker moving ice for two or three months prior to stabilization of the offshore fast ice zone.
- Locations in the transition zone are exposed to moving pack ice throughout the winter period.

4.3.2 Early Season Ridge Occurrence

During the initial stages of freeze-up, the ice is very thin and tends to raft with pressure ridges being very infrequent. Once the ice reaches 30 to 60 cm in thickness, typically in mid November to mid December time frame, ridging becomes more common. The landfast ice zone itself is normally established in a series of discrete onshore ice movement events. These events occur when storm winds from the northerly quadrants drive offshore ice landwards, creating bands of ridging that stabilize given areas of the growing landfast ice zone. Ridging is very uncommon in water depths to 10 m, with increasing ridge frequencies and sizes encountered as the landfast ice edge is approached as shown on Figure 8. Most ridges are formed between the late November and late January period.

Implications:

- Locations in the shallow to intermediate water depth range (0 to 12.5 m) will not be exposed to moving ridge keels of any significance prior to landfast ice formation.
- Deeper water locations in the landfast ice zone will encounter some significant ridging prior to landfast ice stabilization, but these occurrences will be infrequent and the ridges largely unconsolidated and weak.
- Locations near the 20 m depth contour can be exposed to large moving ridges into the early winter period, and, when sections of the fast ice edge break off later in winter, these locations may occasionally encounter thick winter ridge fields.

- Locations in the transition zone will be exposed to moving ridge keels throughout the winter period, with deeper berms exposed to the keel depth distributions that are normally assumed for ice scour frequency calculations.

4.3.3 Grounded Rubble Formations

Remnant islands and berms exposed to thin, moving ice during the freeze-up period normally capture grounded ice rubble shortly after the freeze-up process begins. For islands at or near the waterline, rubble building is clearly related to ice failure at the ice/island interface and generally follows the formational sequence schematically illustrated in Figure 9. For submerged islands and berms, the processes that initiate rubble formation are not well understood but observationally, their occurrence is well known.

In the shallow nearshore waters of the Beaufort Sea, the period of free ice drift is relatively short (several weeks), since landfast ice normally stabilizes in this area first. As a consequence, rubble formations at shallow island locations are typically small compared with those further offshore. In addition, the surrounding ice cover is generally smooth and there is little exposure of remnant islands to moving ice with significant ridging prior to landfast ice formation. After the fast ice stabilizes, movements are very small and the stable, grounded rubble formations protect remnant islands against subsequent ice action.

With increasing water depth, landfast ice occurrence and stabilization occur later and island locations are exposed to moving ice for longer time periods. As a result, the rubble formations observed further offshore usually grow to larger sizes (in a series of discrete formational events), than those in shallower waters. This is illustrated in Figure 10, which shows the rubble formation around Issungnak O-61. Even though these deeper areas are typically in moving ice into the November/December time frame, significant ridging has not yet occurred in the Beaufort's ice cover and the remnant islands and berms are not exposed to many potential scour events. Moreover, these locations are already protected by stable, grounded rubble formations which normally form quite early during freeze-up. Even if these remnant islands and berms were exposed to some large, moving ridge keels, the general ice cover is still quite thin and the ice driving forces not capable of sustaining the forces required for scouring of any significance.

Obviously, the occurrence of grounded rubble and the ease with which it forms is related to the depth of the submerged island or berm surface. From observations around caisson structures having shallow, intermediate and deep drafts (ie: the Tarsiut caissons, Esso's CRI, the SSDC and the Molikpaq, respectively), it is clear that rubble fields quickly form on berms 0-5 m in depth, take longer but assuredly form on berms 5 to 10 m deep, form much later (because of thicker ice) on berms to 15 m, and are difficult to form in deeper waters. These observations are relevant to structures presenting a wide obstacle to the oncoming ice cover. An example of rubble build-up around the caisson retained island at Amerk O-09 is shown in Figure 11.

Once formed over old island locations or berms, grounded rubble formations present the same type of wide obstacle to moving ice. For example, rubble is known to form perennially at the old Tarsiut and Issungnak island locations, which are usually near the fast ice edge and have submerged berms about 4 to 5 m below the waterline. Similarly, grounded rubble is known to form in almost every year at the landward island remnant locations.

However, deeper berms such as those at Amauligak I-65 and F-24, Kogyuk and Uviluk are not characterized by grounded rubble formations, although they may form on a "hit or miss" basis. In this regard, some natural shoals in the deeper, transition zone areas of the Beaufort are known to have grounded rubble formations in some years as shown in Figure 12. For the deeper berm locations in the transition zone, some scour from moving ridge keels should be expected in the normal winter scenario. This effect could cause some ice erosion and material redistribution or loss at these deeper berm locations.

Implications:

- Grounded rubble formations normally from soon after freeze-up at remnant island locations in the landfast ice zone and protect the fill materials at these locations against subsequence ice action and scour.

- The rubble and ridges that comprise these grounded rubble fields form from relatively thin ice, involve low formational ice force levels and are primarily a vertical rather than horizontal ice action process (ie: they form in place and build up and down until their keels ground).
- Deeper caisson berms that are located in the moving transition zone ice do not normally have grounded rubble fields over them and are exposed to the full range of moving keel depth distributions over the winter period.

4.3.4 Break-Up

During break-up, rubble formations located in the landfast or transition ice zones normally stay in place until most of the surrounding ice cover has fragmented, decreased in concentration and started to clear from the general area. Rubble formations usually move off several weeks after break-up. This move-off process normally involves individual sections of rubble being undercut and eroded by early season wave action or given areas of the rubble melting and gaining buoyancy with segments floating off from time to time. On occasion, large drifting floes may interact with these rubble formations, fail them locally and force some rubble sections off. During the rubble break-up process, some rubble keels may drag on submerged islands and berms but the environmental driving forces acting on these rubble pieces are small, and accordingly, their scour potential is low. Rubble formations do not move off as a single unit under ice action which, given their rough keel morphology, would represent a potentially severe scouring situation.

Implications:

- The break-up of rubble fields at remnant islands and berms normally lags the general ice break-up by several weeks.
- This tends to provide continued protection for these remnant sand fills against ice action during the break-up period.
- The rubble break-up process is usually quite mild, involves low force levels, and results in rubble segments floating off, with a low potential for significant scouring.

4.3.5 Winter Ice and Rubble Scour of Berms

Some side scan sonar has been acquired over submerged islands, berms and natural shoals to assess the degree of grounding and scour that is associated with grounded rubble formations. Results from side scan sonar surveys obtained in the summer of 1979 for a natural shoal location are presented in Figure 13. This sonar survey was undertaken shortly after the grounded rubble formation over the shoal had broken up and moved off. A number of shallow, pock like depressions are common on the shoals submerged surface and slopes but linear scours are, for the most part, absent. Ice investigations carried out on the rubble formation the preceding winter documented the distribution and geometry of rubble sails and keels and allowed correlation between high relief ice areas in the rubble and depressions seen on the shoal. This result is representative of similar information collected at island locations and confirms that winter scour in normal situations is not a significant consideration.

4.4 Ice Conditions and Influence - Extreme Events

The variability associated with Beaufort Sea ice conditions during both the summer and winter periods is well known. Poor ice years can be associated with early freeze-up, late break-up, slow summer ice clearance or multi-year ice intrusions from the north. However, the term "poor" should be defined within the context of a particular operation that is being constrained, or a given operation that is being considered.

In terms of ice influence on abandoned islands, an earlier than normal freeze-up or later than normal break-up will only modify the timing of the rubble formation, growth and decay sequence that was discussed in the previous section. Remnant islands and berms will still be protected from ice action by rubble formations and as a result, their exposure and behaviour will not be substantially different from that expected in the normal scenario. Late ice clearance during the early summer period is similar, since the break-up of rubble over the locations of interest will simply occur later. In addition, late ice clearance or the presence of summer ice will limit the open water area available for wave generation and, in this sense, is beneficial in terms of reducing erosion.

Extreme conditions are most often associated with summer ice intrusions, particularly the occurrence of multi-year ice moving southwards from the polar pack edge. From the perspective of potential island erosion by ice, the presence of multi-year ice or thick, heavily ridged first year ice in summer represents the most severe situation for ice scouring. This is discussed in the following subsections.

4.4.1 Multi-Year Ice Intrusions

Ice intrusions occur with strong persistent winds from the northerly quadrants. Although the summer pack edge is normally located at least 250 km offshore (between 71°30'N and 72°N), strong storms can move this ice cover into the nearshore waters over periods of a few days to several weeks. The ice that enters the shallow to intermediate waters of the Beaufort Sea is normally a matrix of medium and thick first year, second year and multi-year ice. Floe sizes can be quite variable but normally range from a few hundred metres to several kilometres in extent. The ice is typically rough with individual floes containing frequent ridges. Some discrete rubble or parallel ridge field formations, termed floebergs, may also be present within the ice cover. The concentrations associated with ice intrusions are highly variable both spatially and temporally, but generally increase as the pack continues to come down.

Typical first year ice thicknesses are between 1 and 1.5 m and old ice floes from 3 to 7 m in thickness. The ridge keels present within these floes cover a wide range of depths but average about 10 m, with frequent extremes of 20 to 25 m. It is important to note that ice intrusions normally do not come inshore of the 10 m water depth contour, since most floes ground out in the 10 to 20 m water depth range.

Implications:

- Locations within the 10 m water depth contour will rarely be exposed to heavy moving ice and potentially severe scouring during summer ice intrusions.
- Deeper water locations can encounter thick floes and ridges during these intrusions and related scour effects.
- A poor summer season in terms of ice coverage in the nearshore Beaufort waters is good in the sense of reducing the erosion potential associated with severe storm waves.

4.4.2 Ice Scouring

From a scouring perspective, individual ridge keels or groups of keels contained in summer ice intrusions are the most significant consideration related to ice erosion of remnant islands and berms. These ridge keels are an integral part of drifting ice floes that are often quite massive and can move at relatively high speeds when driven by strong winds. Although the environmental driving forces that act on these floes in summer are not as high as those in the winter (when they are frozen into a near continuous ice cover), their kinetic energies can be significant and their scouring potential high. For example, an ice intrusion in early October, 1983 drove old ice and floebergs shorewards at speeds approaching 70 cm/s causing grounding in the 15 to 20 m water depth range along the Tuk peninsula. Winter field investigations around a number of grounded ice features indicated typical scour depths of 1 to 2 m and extremes as high as 4.5 m.

Implications:

- Large, thick and heavily ridged ice floes moving at high speeds during summer ice intrusions have the potential to cause significant scour on remnant islands and berms in water depths greater than 10 m.

4.4.3 Extreme Ice Interactions with Abandoned Islands

Although the potential for significant ice scouring of remnant islands and berms appears high during summer ice intrusions, a number of ice interaction processes tend to mitigate the effect. During the 1970's and early 80's, drifting floes were often encountered at various island or caisson structure locations while construction activities were ongoing. The most relevant case history was in 1981 while the Tarsiut N-44 berm was being constructed in about 21 m water depth. In early September, a moderate ice intrusion brought ice from the north into the general vicinity of the location. A ridged multi-year floe, more than 1 km in extent and drifting at a moderate speed, grounded at the berm and quickly stopped. This feature remained in place for less than a day, causing a short suspension of dredging activities over this period (until the floe moved off). A quick qualitative grounding survey indicated a short small scoured area, with a simple redistribution of plowed sand fill material on the submerged berm. Observations at the Tarsiut caisson location during a major ice intrusion in 1983, a year after drilling activities had concluded, showed the presence of a summer rubble formation that again would tend to protect the Tarsiut berm. Again in 1988, well after the Tarsiut caissons were removed, a grounded rubble formation was observed to occur at the beginning of an October, during an ice intrusion event.

Esso experiences were similar, with minimal scour damage observed during ice intrusions. Floes would typically ride up on Esso islands under construction, fail in flexure and stop over relatively short distances. Alternatively, they would rotate around the artificial island and move off. It is important to note that most of the Esso construction locations were in relatively shallow water and were protected from extremely large floes that grounded further north. As a result, most floes seen around the Esso locations in the summer or fall period were quite small, in the order of hundreds of metres.

4.5 Open Water Conditions and Influences - Normal Conditions

Typical conditions found at the locations of interest during the summer open water season are described in this section. As mentioned earlier, the Beaufort's open water environment plays a very significant role in the erosion of remnant islands and berms. Previous work has identified storm waves as the primary erosional influence on islands, with currents being important, but in a secondary sense. In this regard, it has been suggested that the frequency of storm waves governs the overall rate at which islands erode. The role of storm induced waves and currents on the erosion of remnant islands and berms, the associated physical processes, and insights provided by this study's new and historical data sets are addressed in detail in Volume 3. In the following sections, information on the typical wave and current regimes in the Beaufort Sea is given along with information on expected extremes.

4.5.1 Waves

The wind generated wave climate of the Beaufort Sea is mild in comparison with most other offshore areas, but is very important in terms of its influence on island erosion. The height of waves depends on wind strength, duration, water depth and the extent of open water (or fetch) over which the wind blows. Because of the presence of sea ice and local landmasses throughout the area, Beaufort Sea waves are fetch limited. As a result, normal sea states in the area are small, with typical significant wave heights in the order of a metre or less. Locally generated wind waves dominate the energy spectrum and there is little, if any, contribution from swell. Since predominant summer winds are from the east and the strongest storm winds from the northerly quadrant, these are the two primary directions associated with significant wave occurrences.

Wave measurements have been acquired at a number of locations throughout the Beaufort Sea since the early 1970's, primarily in conjunction with offshore drilling activities. However, these measurements have generally been spotty in the sense of their continuity in space and time. Consequently, hindcast techniques have normally been used to estimate long term normal and extreme wave distributions for the area.

From a normal wave climate perspective, the results of hindcast work compare well with wave height statistics derived directly from measured data, with either information source considered sufficiently representative. Assessments of wave climate data have shown that most of the wave power is concentrated in significant wave height classes of 1 to 2 m. These wave heights are typical of moderate summer and fall storm events with recurrence intervals between 2 and 10 days. Previous work has also shown that a significant portion of the wave power is present in less frequent, but more severe storm events, that having wave heights up to 4 m or more, and are dominated by storms from the northerly quadrant.

A significant wave height exceedance distribution that is representative of the Beaufort's normal wave climate is given in Figure 14. This distribution is for a deeper water location and will place some variation in intermediate and shallow waters. Variations in the normal wave regime will occur from site to site. However, the information provided in Figure 14 is considered appropriate as a general description of normal waves. From an erosional perspective, normal waves are of interest but not of real significance, since storm events tend to drive the erosion process.

4.5.2 Currents

Beaufort Sea currents tend to be controlled by winds, but are modified by the MacKenzie River outflow and by local bathymetry. In winter, the presence of the Beaufort's perennial ice cover dampens the wind's influence and currents are generally small. In summer, currents are stronger, with the two main regional circulation patterns being governed by predominant winds from the east and from the north to northwest. On the shelf area where the artificial islands are situated, wind driven currents are generally aligned with the trend of the coastline. Easterly winds tend to cause westerly and northwesterly circulation patterns, while northwesterly and westerly winds result in shoreward and eastward currents.

The surface waters of the nearshore and continental shelf areas are known to respond fairly quickly to local winds, typically within a day. These surface water movements are more variable near the coastline where the influence of river discharge and shoaling waters become increasingly important. In the absence of significant winds, currents are low and variable with the MacKenzie River outflow moving with a slow easterly set along the coastline. Mid water and near bottom currents are not well correlated with surface winds unless the storm events are strong. Normal subsurface circulation is generally weak and variable over most of the shelf area.

Generally, current speeds increase throughout the summer and into the fall, until the Beaufort Sea's ice cover begins to form. This is a reflection of a progressive increase in the area's "storminess" and typical wind speeds over the summer and fall periods. Extreme value surface, mid water and near bottom current speed distributions for the Amauligak location in 30 m of water are shown in Figure 15. Extreme currents, which occur in combination with extreme waves during storm events, are of most significance to island erosion, and are addressed further in the next section.

4.6 Storm Events

The waves and currents that are associated with summer storms in the Beaufort Sea are well recognized as the primary mechanism causing sediment transport in the area, and the most significant influence on island and berm erosion. Previous work has considered the erosional effects of these storms primarily in terms of extreme Beaufort Sea wave heights. Wave periods, storm durations, and coincident storm currents are also very important factors in the erosion process, but have not been explicitly addressed. In this section, "extreme storm" characteristics have been summarized since the overall nature of the Beaufort's summer storms, rather than significant wave height values in exclusion, determines their erosion potential.

Summer storm information has been extracted from a recent Gulf Canada study entitled "Design Storm Characteristics, Amauligak Region, Beaufort Sea" which provides a good representation of storm wave and current parameters of importance for the island and berm erosion assessment. In this storm parameter evaluation study, all of the relevant wave and current data that has been acquired in the Beaufort Sea up to 1988 was analyzed to obtain as complete a description of extreme storm events as possible. Figure 16 shows the wave and current databases that were used in this work. Information includes 14 years of wave rider information and 7 years of current measurements, spanning a range of water depths.

The approach taken was to describe design storm events in terms of significant wave height, wave period, current speed and storm duration at locations in 5, 15 and 30 m of water within the Amauligak pipeline corridor. Extreme storms at these locations were developed for recurrence intervals of 1, 5, 25, 50 and 100 years. Based upon the measured wave rider data, a total of 62 summer storm events that had occurred from 1975 to 1988 were selected as a basis for the analysis, with the selection criteria based upon a significant wave height exceedance of 2 m. Each storm event was then transformed into an extreme wave time series at the 30, 15 and 5 m locations with a spectral refraction model. In addition to refraction, this model accounted for shoaling, depth dependent wave breaking and repeated wave breaking as an energy limit. The storm wave profiles were then considered in terms of their shape, relative wave heights and storm durations. Storm event characteristics were developed through the use of a normalization procedure and an extreme value analysis used to determine the extreme storm wave parameters (height, period and duration). In order to address coincident storm currents, measured current data was grouped within the water depth ranges of interest (5, 15 and 30 m) and by depth in the water column (surface, mid water and near bottom), subjected to an extreme value analysis and associated with the storm wave events. The results of this work provided a series of extreme storm event descriptions, including wave height and period, currents through the water column and storm duration, as summarized in Figure 17.

The results of this design storm evaluation study have been used directly, since they are considered to be the best characterization of extreme storm conditions at the island and berm locations of interest. Although storm conditions will clearly be location dependent, these quantitative storm event characterizations are considered representative and, in terms of relevant information content, superior to the fragmented wave and current data that is available for some of the individual island sites.

The following general comments can be made regarding these storm wave and current descriptions.

- Extreme wave heights (about 5.5 m for 100 year intermediate and deeper water locations) have been compared with the results of other hindcast studies and are in reasonable agreement.
- Extreme storm durations range between 30 and 66 hours, depending upon storm event return period.
- Extreme currents associated with these storm events range from about 50 cm/s to slightly more than 1 m/s, depending upon return period and depth in the water column.
- Peak storm waves generally lag peak currents by 4 to 6 hours and are not necessarily co-linear with the storm wave direction, particularly at the mid water and near bottom levels.

5. ISLAND EROSION DYNAMICS

5.1 General

Canadian Seabed Research Ltd. completed a study on thirteen artificial islands to determine how the islands change with time after abandonment. Active seafloor processes, climatic and design influences, and sediment transport mechanisms were explored using bathymetric and sidescan data collected from the islands over the years.

Each island's bathymetric map provides a snapshot of the island's shape at the time of the survey. Each island was described with respect to the two dimensional plan and profile. Composite profiles were plotted to show the change in island profile over the years. Bathymetric plans were overlain to determine the change in position of specific contours, and to identify areas of sediment depletion and accretion. The sidescan data provides an acoustic image of the seafloor at the time of the survey. The seafloor geology was characterized by establishing the acoustic facies of the island and beyond, as islands are usually of lower reflectivity than the surrounding seafloor. Sidescan data can be used to identify scouring, scour infill, bedforms, sediment slumps and sediment contact. Sediment transport has occurred if the island facies is evident on the seafloor, or if bedforms or infilled scours are present. Underwater imagery from the Remotely Operated Vehicle (ROV) was also reviewed for evidence of seafloor processes, but could not be used to quantify objects due to lack of scale.

Each island was described in terms of design, environment, changes in island morphology, seafloor features, and direction and magnitude of sediment transport, as summarized on Table 9.

5.2 Island Evolution

Island migration is primarily towards the southeast with a magnitude ranging from 6 to 45 m/year as can be seen on Figure 18. The greatest migration occurs within several years of island abandonment, and appears to be independent of island construction materials and water depth.

The rate of island submergence is time dependent, with the greatest rate of submergence occurring immediately following abandonment. Erosion is also water depth dependent, with islands in water depths less than 12 m submerging to a depth of 2 to 3 m within 2 to 3 years of abandonment. The islands then continue to gradually submerge with time. Islands in water depth greater than 12 m quickly erode to a depth of 3.5 to 4 m within 2 to 3 years of abandonment and submerge very slowly thereafter.

As the islands submerge, the volume of sediment loss ~~increases~~ decreases with depth of submergence. The rate of submergence influences the rate of sediment loss, with quickly submerging islands losing sediment more rapidly. Once the islands stabilize with depth, however, sediment loss decreases. The volume of sediment loss generally increases with water depth. This may be related to the fact that larger islands are constructed in deeper waters, and offer more volume to be eroded. A summary of volume loss is shown on Figure 19.

~~materials and water depth.~~

Table 9 - Summary of Canadian Seabed Research Study

Island Name	Island Type	Water Depth (m)	Date Constructed	Date Abandoned	Abandoned Freeboard (m)	1990 Freeboard (m)	No. years abandoned to 1990	% Vol loss to 1990	Erosional Type of Island	Time Frame	Bearing of Sediment Transport	Dist (m) of Sediment Transport
Netserk F-40	SBR	7	1975	1976	+4.6	-4.6	14	55	4	1975-81	SSE	130
										1981-90	E	55
Kugmallit H-59	SBR	5.3	1976	1977	+4.6	-2.7	13	40	1-2	1982-90	ESE	35
Arnak L-30	SB	8.5	1976	1977	+5.2	-3.5	13	15	2	1984-90	SE	60
Kannerk G-42	SB	8.5	1976	1977	+5.2	-3.2	13	5	3	1984-90	ESE	85
Isserk E-27	SB	13	1977	1978	+5.0	-5	12	40	1	1982-90	ESE	85
Issungnak O-61	SB	19	1978/79	1981	+5.0	-4	9	20	2	1981-90	SE	95
Alerk P-23	SB	11.6	1980/81	1982	+4.5	-3.1	8	25	3	1982-90	SE	105
West Atkinson L-17	SB	6	1981/82	1982	+4.5	-2.1	8	35	3	1982-90	SE	200
Itoyok I-27	SB	15	1981/82	1983	+4.0	-4	7	25	2	1982-90	SE	100
Nipterk L-19	SB/SG	11.7	1983/84	1985	+5.0	-2	5	0	3	1984-90	SE	230
Minuk I-53	SB/SG	14.7	1982/85	1986	+5.0	+0.2	4	20	2-3	*-1990	N/A	N/A
Arnak K-06	SB	7.2	1985	1986	+5.0	-2.5	4	20	1	1985-90	SE	140
Kaubvik I-43	CRI	17.9	1983/86	1987	+3.0	-4.5	3	N/A	2	1986-90	S	45

Island Type
SBR - Sandbag Retained Island
SB - Sacrificial Beach Island
SG - Sand and Gravel
CRI - Caisson Retained Island

Erosional Type of Island
1 - Concentric
2 - Moderately Polarized
3 - Highly Polarized

5.3 Erosional Models

Four models have been derived to describe the varying sediment depletion/accretion styles observed at the island sites, as shown on Figure 19. The models vary according to the degree of polarization of sediment depletion and accumulation, and appear to be part of a spectrum of island erosion patterns.

The Type 1 erosional and depositional pattern is the least polarized with erosion occurring over the entire island and deposition occurring around the entire periphery. The amount of sediment accumulation varies by quadrant, with areas to the south receiving more sediment than the north, east and west. The resultant island form is concentric with a very small degree of elongation. Arnak K-06, Isserk E-27 and possibly Kugmallit H-59 are represented by this model.

The Type 2 erosional and depositional pattern is slightly polarized with sediment depletion located over the centre of the island and in the northwest quadrant of the island periphery. Sediment accumulation occurs in all other quadrants of the island periphery, with the greatest amount of sediment accumulation in the southeast. The resultant island form displays a low to moderate degree of elongation. Itiyok I-27, Kaubvik I-43, Arnak L-30, and possibly Kugmallit H-59, Issungnak 0-61 and Minuk I-53 are represented by this model.

The Type 3 erosional and depositional pattern is characterized by sediment accumulation in only one quadrant (primarily the SE quadrant). Sediment depletion occurs from the centre of the island and minor sediment depletion and accretion occur in other quadrants. The resultant island form is moderately to highly elongated, indicating a strong directional component to the sediment transport. Nipterk L-19, Kannerk G-42, Alerk P-23, West Atkinson L-17, Netserk F-40 and possibly Minuk I-53 are represented by this model.

The Type 4 erosional pattern is anomalous, with no direct spatial link between the areas of erosion and accretion as represented by Netserk F-40.

Early migration patterns may be characterized by the Type 3 model, as can be seen in surveys of Netserk F-40, Nipterk L-19 and Kaubvik I-43 four, five and six years after abandonment. They are highly elongated in plan view with a gentle inclined northwest face and steeper southeast face.

5.4 Environmental Factors Affecting Island Erosion

Several environmental processes active in the Beaufort Sea that are responsible for affecting island erosion include:

- extreme storm events
- winds and near bottom currents
- ice scouring, and
- sediment slumping

Extreme storm events are widely regarded as being the process most influential in island erosion. Wind is the driving force behind waves and near bottom (non tidal) currents. The dominant wind directions in the open water season are easterly, and northwesterly. The stronger northwesterly winds are most often associated with storm events. In the shelf area, wind driven currents are generally aligned with the trend of the coastline. Easterly winds tend to cause westerly and northwesterly circulation patterns, while the northwesterly and westerly storm winds result in shoreward and eastward currents. The dominant island accretion direction is toward the southeast, indicating the northwesterly storm winds appear to be generating bottom currents which erode sediment from the northwest inclined face and island top, where it is deposited along the southeast face. In the absence of significant winds, however, currents are low and variable with the Mackenzie River outflow moving with a slow easterly set along the coastline.

The extreme storm climate varies from shallow to deep water sites throughout the Beaufort Sea. Deep water sites may be expected to experience a significant wave height of twice that experienced in shallower water sites on average every 10 years, which infers the deeper water sites are prone to progressively more severe conditions throughout the life of the islands. This likely reflects the contrasting rate of submergence observed with water depth, in which deeper islands submerge quicker than shallower islands. Since most submergence occurs within several years of abandonment, an extreme storm in the early stages of island submergence would be expected to have a much greater impact on the fate of the island than an extreme storm event several years later.

The islands appear to create a local ice scour regime at a number of sites, with several sites displaying intense scouring on the north side, which abruptly terminates on the island margin. In contrast, scouring is absent or light along the south margin. These islands appear to have altered the scouring pattern and have produced a shadow zone relatively protected from scours, which may be the seafloor expression of a grounded rubble formation. Ice scouring appears to plow the surficial veneer of coarse material into berms, thus exposing the underlying sand which is more prone to transport. Despite this, ice scouring appears to be only a minor factor affecting island degradation.

Sediment slumping is interpreted to have occurred at two island sites studied. In both cases, the sediment slumping occurred in zones of sediment depletion, and appears to play a very minor role in sediment transport.

The most important mode of sediment transport appears to be bedload transport associated with storm-driven winds and currents. Bedforms occur on top of the islands, along the island margins and on the surrounding seafloor; range in scale from centimetres to several metres in wavelength; and are best developed on sand and gravel islands. Very high velocity plain bed conditions may persist during extreme storms on areas of the island undergoing erosion prohibiting bedform development, resulting in featureless and smooth, rounded or flat island tops with a topographic high on the leading edge.

5.5 Impact on Available Resources

The submerged islands are, and will continue to be, a major aggregate resource. Comparison of the aggregate potential of the six oldest islands indicates that the volume of sediment decreases from 100% at abandonment to approximately 90% at 5 years and 85% at 10 years. There are exceptions, with Netserk F-40 experiencing a 55% loss.

Netserk F-40 is a sandbag retained island, and may be more susceptible to erosion once the sandbag dykes are destroyed.

Large areas of the islands are undergoing sediment depletion, but the sediment is deposited in specific directions resulting in a gradual migration and elongation of the islands rather than sediment loss from the island system. Some sediment may be lost from the island system in the process, however, as sediment is transported in suspension beyond the limits of the island and deposited in a thin blanket on the seafloor.

6. CLOSURE

This report has documented the construction of 37 islands in the Canadian Beaufort Shelf. The prime purpose of these islands was to support offshore exploration and delineation drilling, after which all permanent equipment was removed from the island. This report documents the changes to each island since drilling abandonment, and provides an initial estimate of the available resource potential of each site for use is future development.

The survey data collected during this project is included on disk, and as hard copy plots in Volume 2 after the report. Many of the islands do not have recent survey information, therefore it is recommended that additional surveys should be undertaken to better understand the ongoing process of erosion on old islands, and to update the inventory of potential delineated offshore sand and gravel resources.

PERMIT TO PRACTICE
KLOHN-CRIPPEN CONSULTANTS LTD.
Signature
Date Mar 31/95
PERMIT NUMBER: P 433
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

Respectfully Submitted,

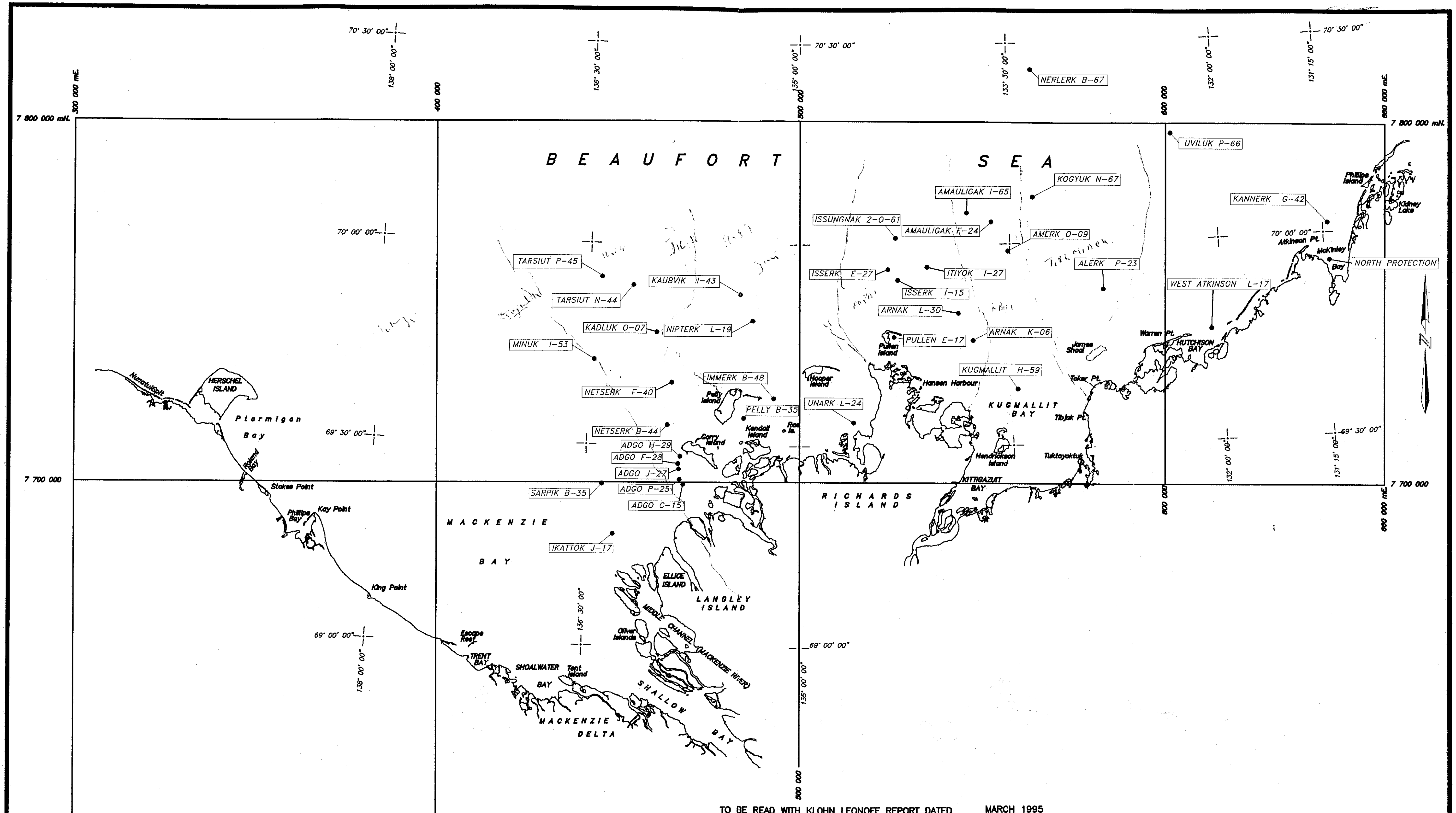
KLOHN-CRIPPEN CONSULTANTS LTD.

Marcia E. Maclellan, P.Eng.
Geological Engineer

for Brian T. Rogers, P.Eng.
Project Manager

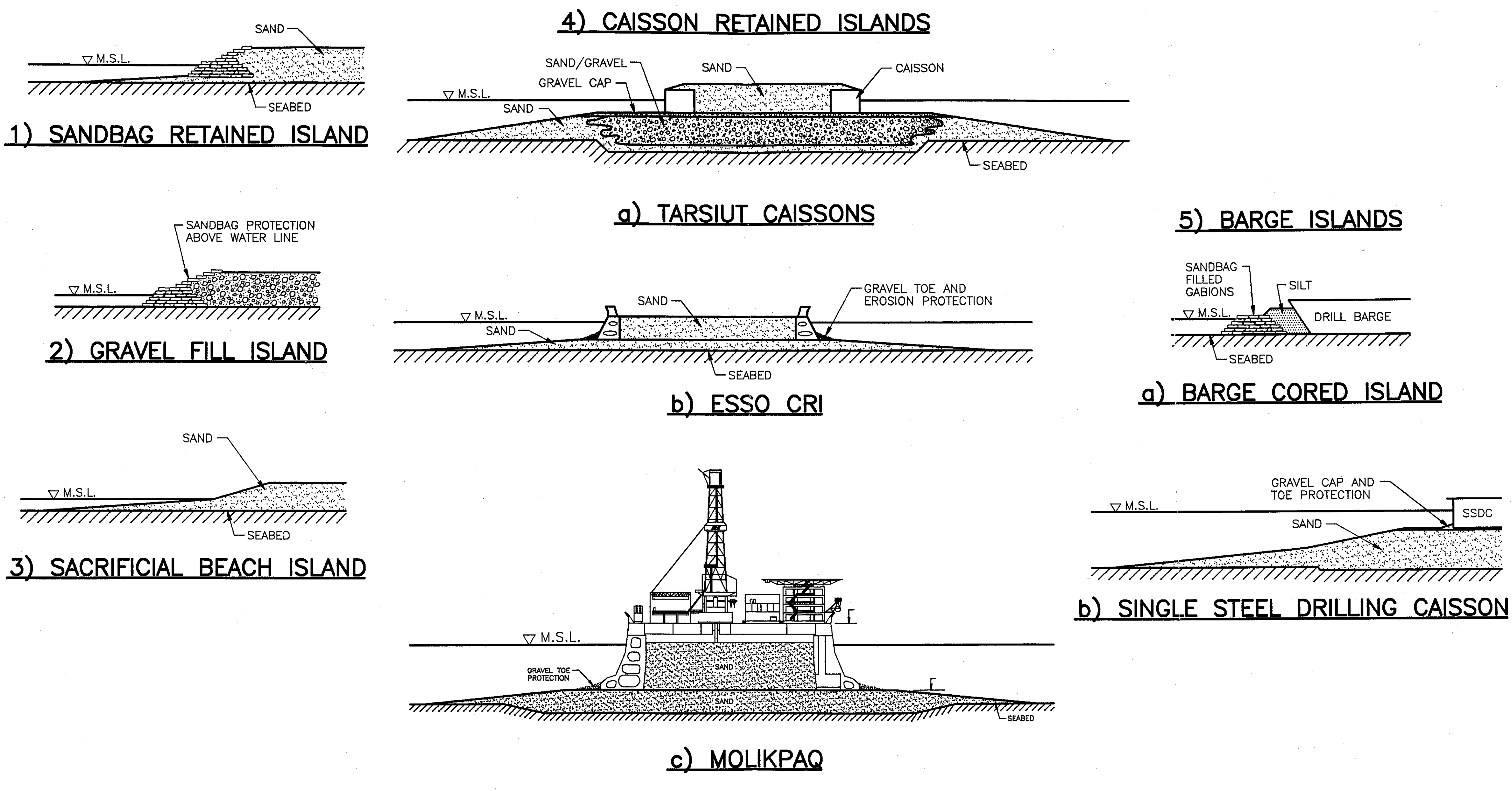
BTR/MEM/ll

FIGURES



TO BE READ WITH KLOHN LEONOFF REPORT DATED MARCH 1995

KLOHN-CRIPPEN	PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS			
	TITLE: LOCATION PLAN			
CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA	DATE OF ISSUE: MARCH 95 APPROVED	PROJECT No. PA2695.03	DWG. No. FIGURE 1	REV.



KLOHN-CRIPPEN

PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

TITLE: SCHEMATIC REPRESENTATION OF ISLAND TYPES

CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
MAR 95	PA2695.03	FIGURE 2	

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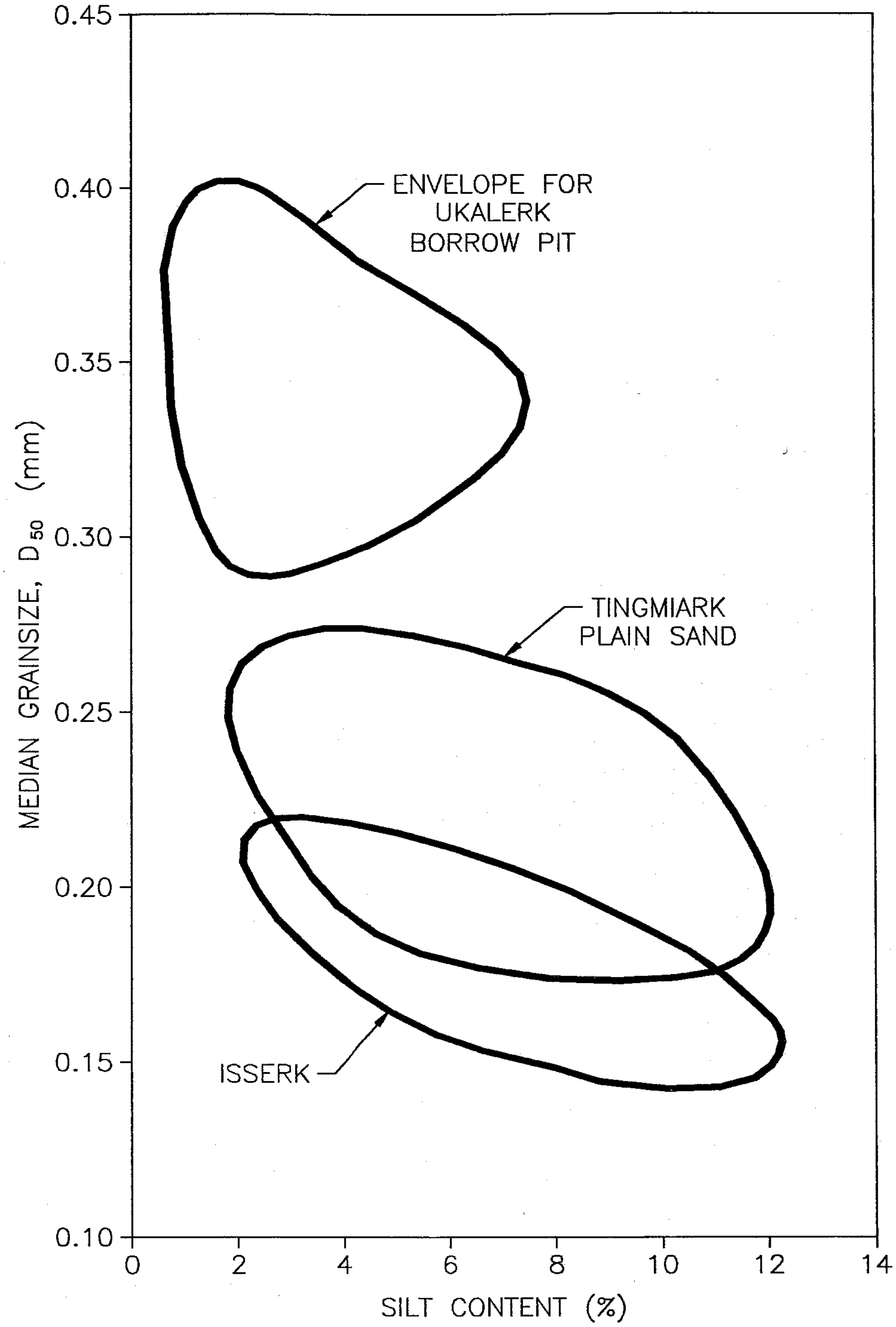
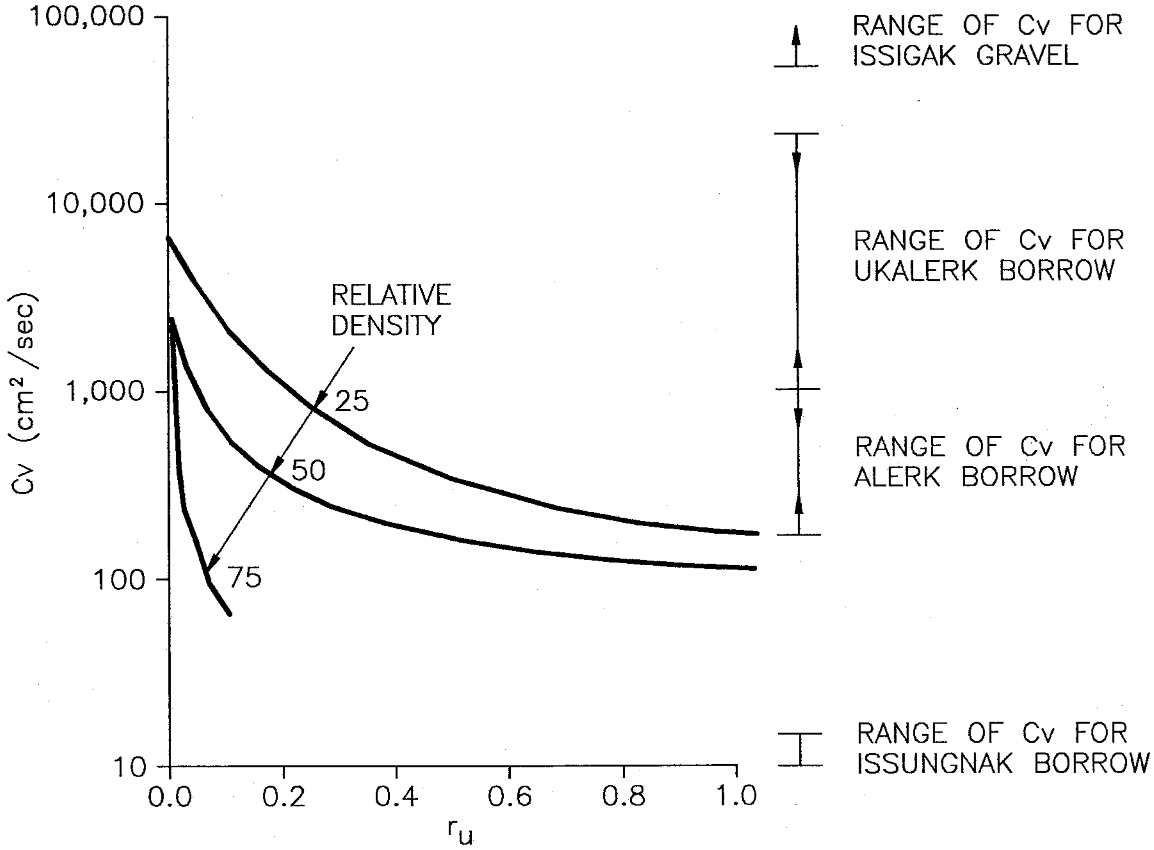
2695w002.dwg



2695w003.DWG

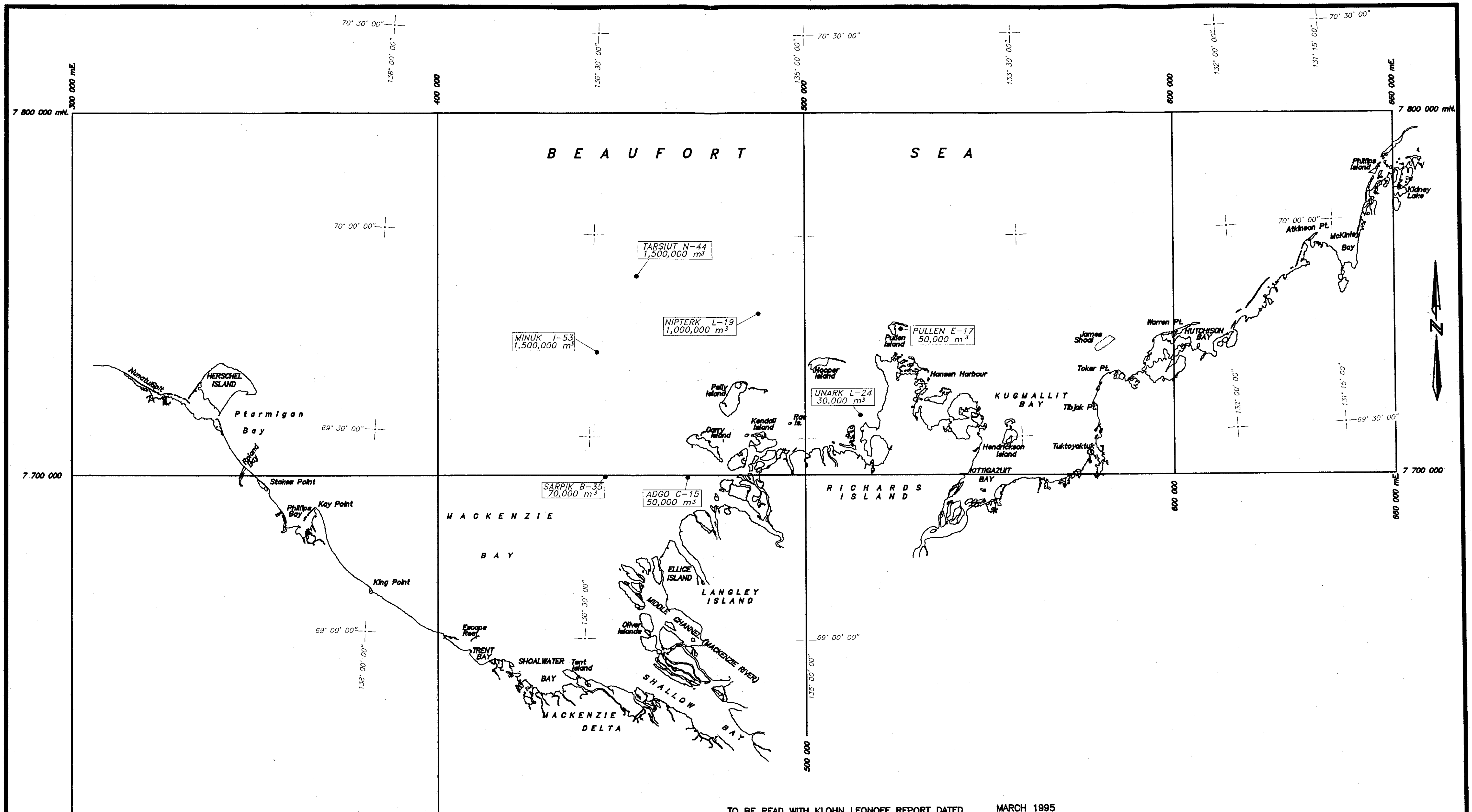
KLOHN-CRIPPEN	PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS			
	TITLE: SUMMARY OF IN-SITU GRADATION FOR SAND BORROW SOURCES			
CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA	DATE OF ISSUE: MAR 95 / APPROVED	PROJECT No.: PA2695.03	DWG. No.: FIGURE 3	REV.



2695w003.DWG

KLOHN-CRIPPEN

PROJECT	GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS			
TITLE	WAVE INDUCED EXCESS PORE PRESSURE			
CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA	DATE OF ISSUE: MAR 95 / APPROVED	PROJECT No.: PA2695.03	DWG. No.: FIGURE 4	REV.



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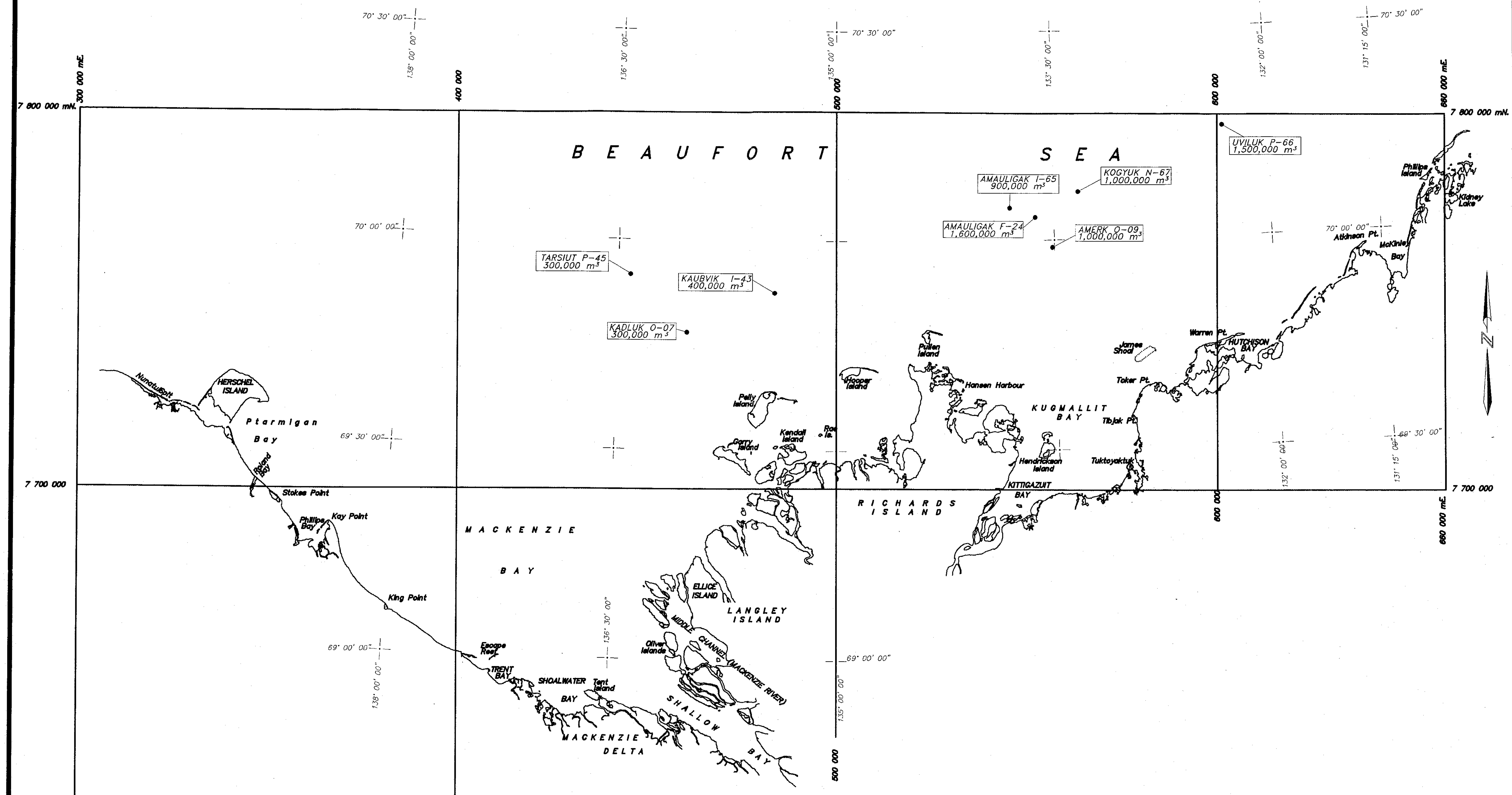
KLOHN-CRIPPEN

CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA

PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

TITLE: APPROXIMATE FILL QUANTITIES AT GRAVEL AND SAND ISLANDS

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
MARCH 95	PA2695.03	FIGURE 5	
APPROVED			



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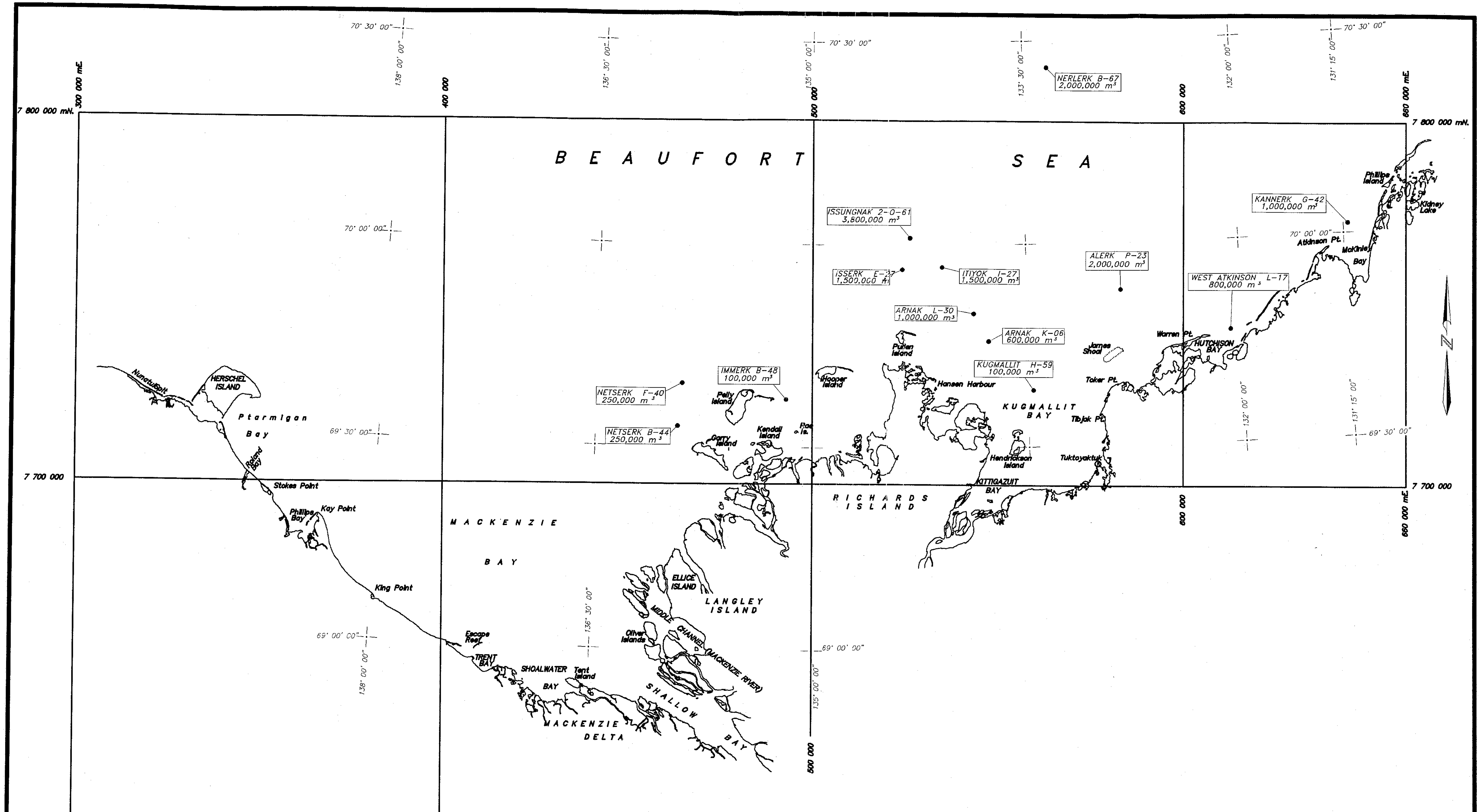
KLOHN-CRIPPEN

PROJECT	GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS
TITLE	APPROXIMATE FILL QUANTITIES AT UKALERK TYPE SAND ISLANDS
CLIENT:	INDIAN AND NORTHERN AFFAIRS CANADA
DATE OF ISSUE	MARCH 95
APPROVED	
PROJECT No.	PA2695.03
DWG. No.	FIGURE 6
REV.	



2695w058.dwg

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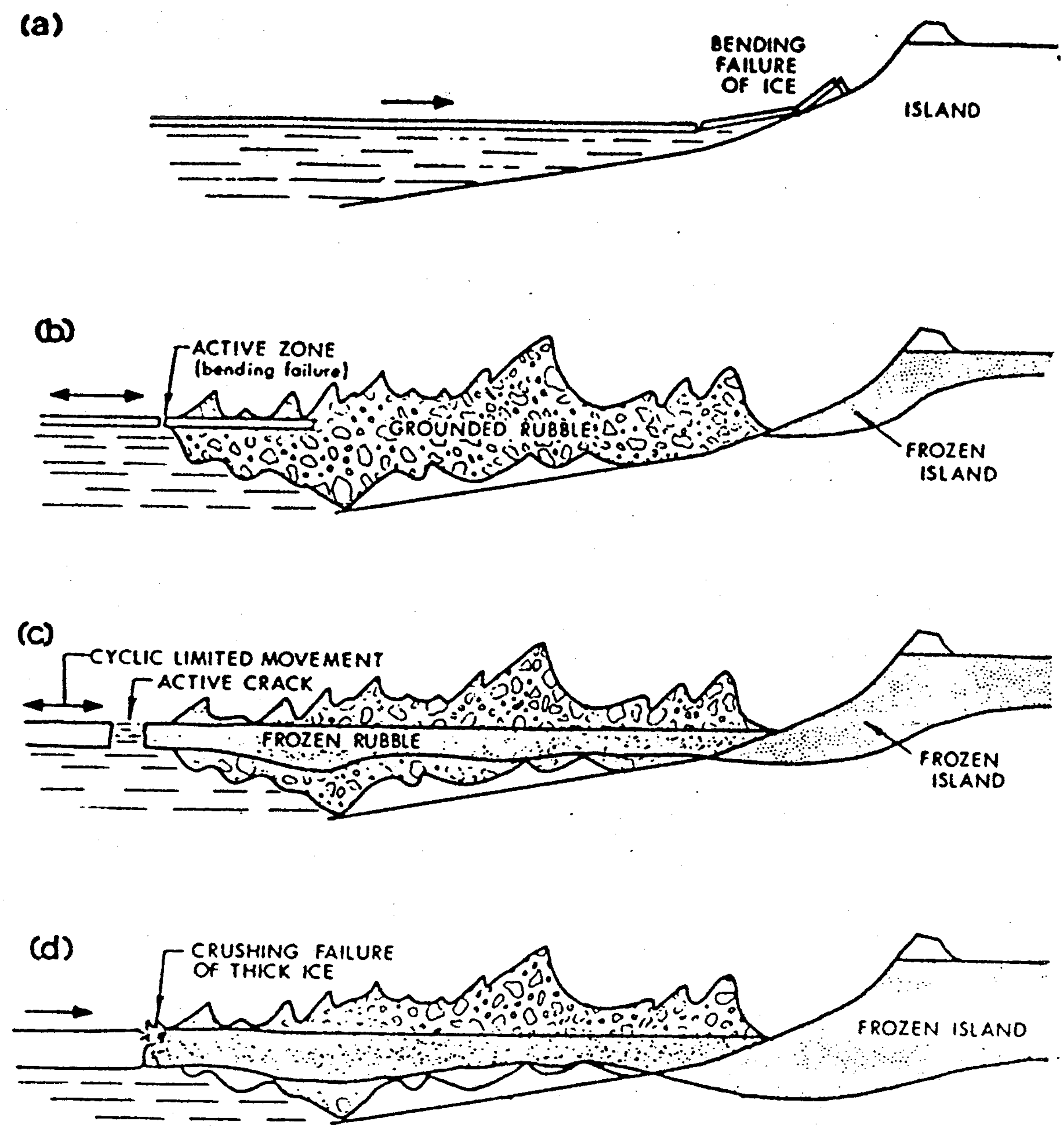
KLOHN-CRIPPEN

PROJECT	GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS
TITLE	APPROXIMATE FILL QUANTITIES AT OTHER SAND ISLANDS
CLIENT:	INDIAN AND NORTHERN AFFAIRS CANADA
DATE OF ISSUE	MARCH 95
APPROVED	
PROJECT No.	PA2695.03
DWG. No.	FIGURE 7
REV.	

RIDGING NORMALLY OCCURS IN A SERIES OF ONSHORE ICE MOVEMENT EVENTS AND IS MOST SEVERE NEAR THE OUTER EDGE OF THE LANDFAST ICE. RIDGING IS UNCOMMON IN WATER DEPTHS TO 10m BUT INCREASES IN FREQUENCY AND SIZE TOWARDS THE LANDFAST ICE EDGE. THIS FIGURE SHOWS THE LANDFAST ICE EDGE WITH THE OPEN WATER LEAD WHICH OPENS AND CLOSES UNDER THE INFLUENCE OF WINDS.

2695w003.DWG

KLOHN-CRIPPEN	PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS			
	TITLE: ICE RIDGING			
CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA	DATE OF ISSUE: MAR 95 APPROVED	PROJECT No.: PA2695.03	DWG. No.: FIGURE 8	REV.

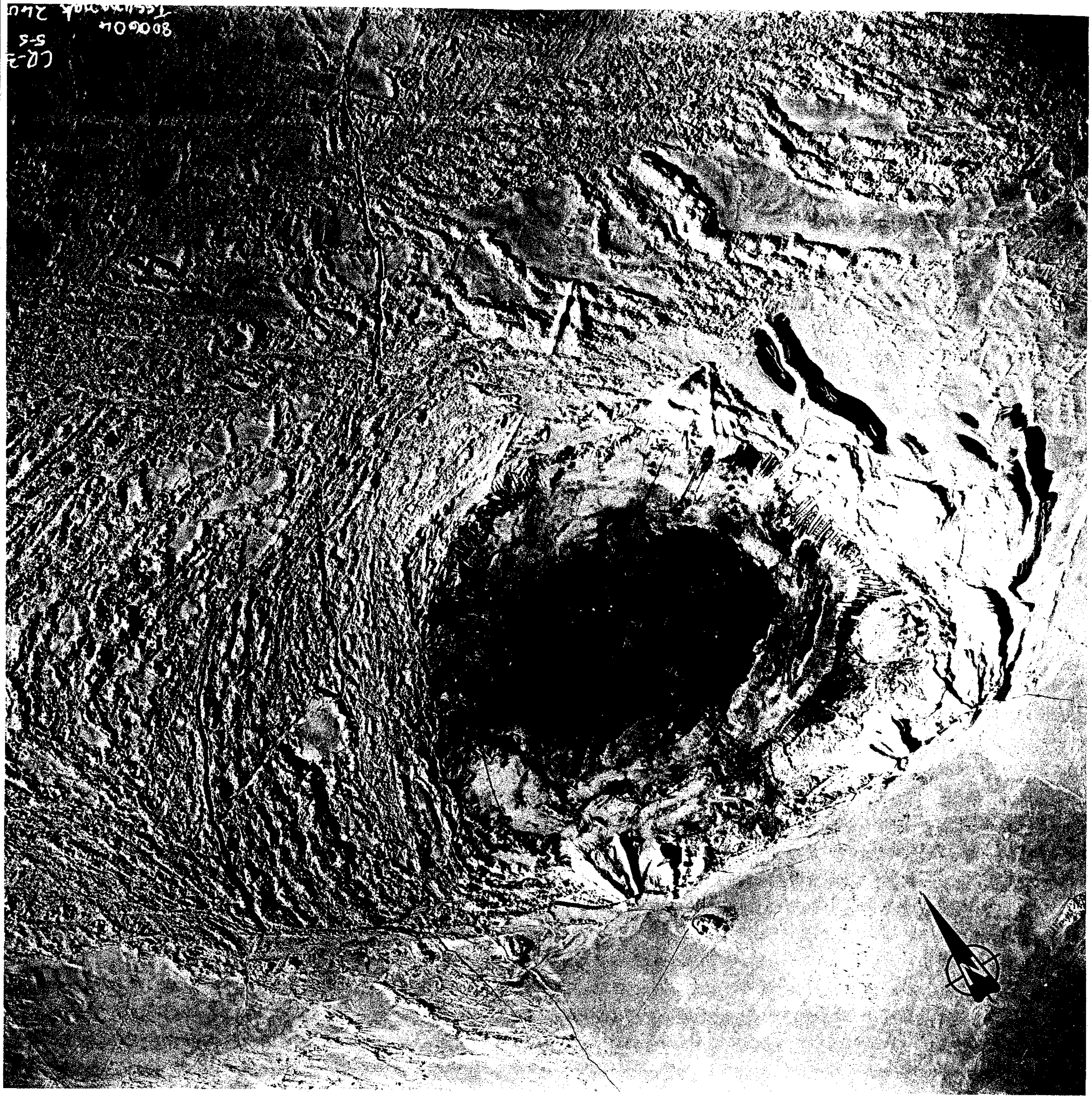


SEQUENCE OF ICE ACTION ON ISLAND BEACH (EXPOSED ISLAND):
(A) INITIAL MOVEMENTS OF THIN ICE,
(B) EXTENSIVE ICE MOVEMENT CAUSES GROUNDED RUBBLE,
(C) ACTIVE ZONE REMAINS OUTSIDE RUBBLE THAT FREEZES,
(D) THICK ICE FAILS IN CRUSHING.

2695w003.DWG

KLOHN-CRIPPEN

PROJECT	GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS			
TITLE	RUBBLE FORMATION SEQUENCE			
CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA	DATE OF ISSUE: MAR 95 APPROVED	PROJECT No.: PA2695.03	DWG. No.: FIGURE 9	REV.



2695w003.DWG

KLOHN-CRIPPEN

PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

TITLE: EXAMPLE OF RUBBLE FORMATION AROUND ISSUNGNAK ISLAND

CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
MAR 95	PA2695.03	FIGURE 10	
APPROVED			

2695w003.DWG

KLOHN-CRIPPEN

PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

TITLE: RUBBLE FORMATION FOR THE CRI AT AMERK 0-09

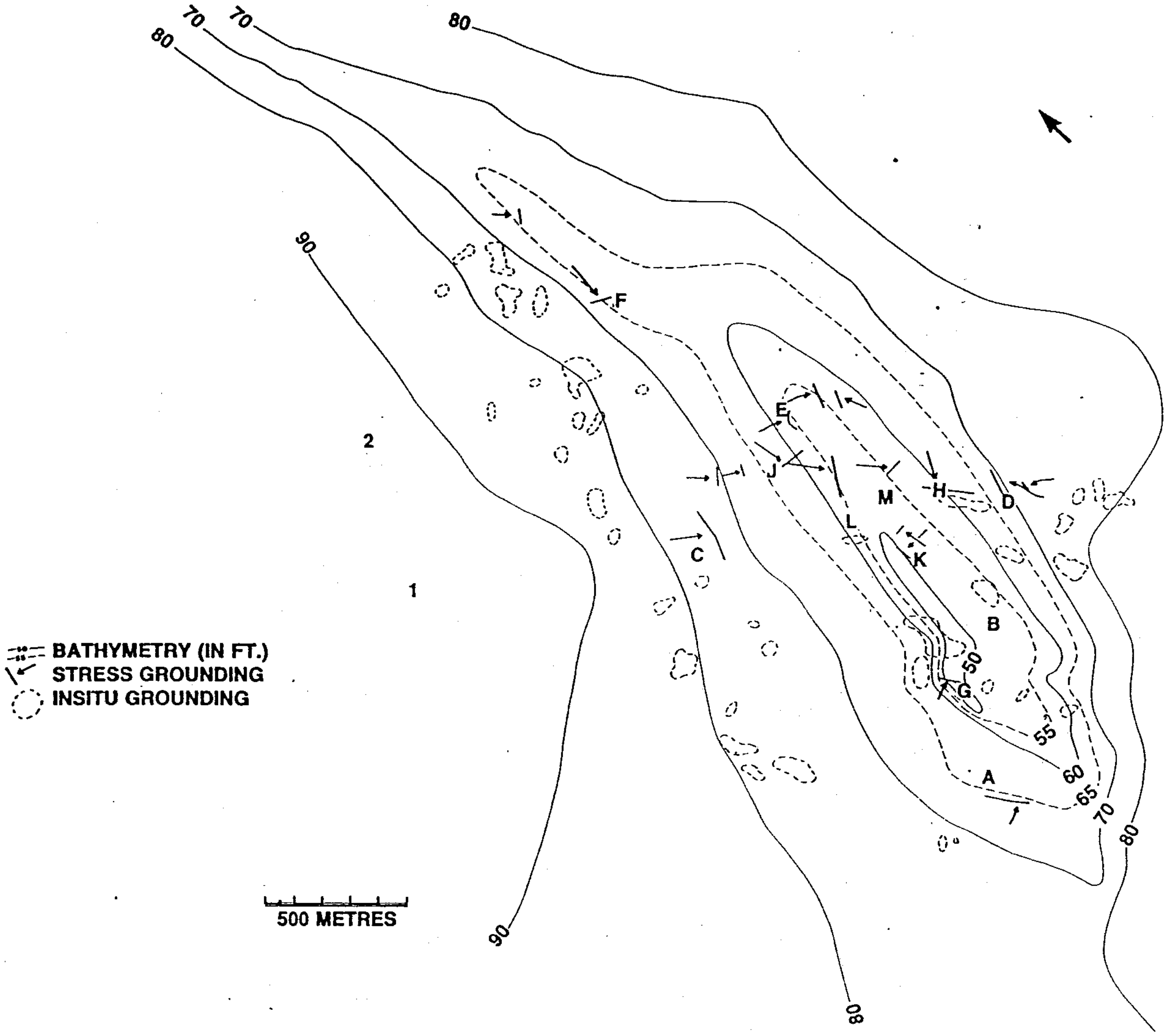
CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
MAR 95	PA2695.03	FIGURE 11	
APPROVED			

2695w003.DWG

KLOHN-CRIPPEN

PROJECT	GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS			
TITLE	RUBBLE FORMATION ON A NATURAL SHOAL			
CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA	DATE OF ISSUE: MAR 95; APPROVED	PROJECT No.: PA2695.03	DWG. No.: FIGURE 12	REV.

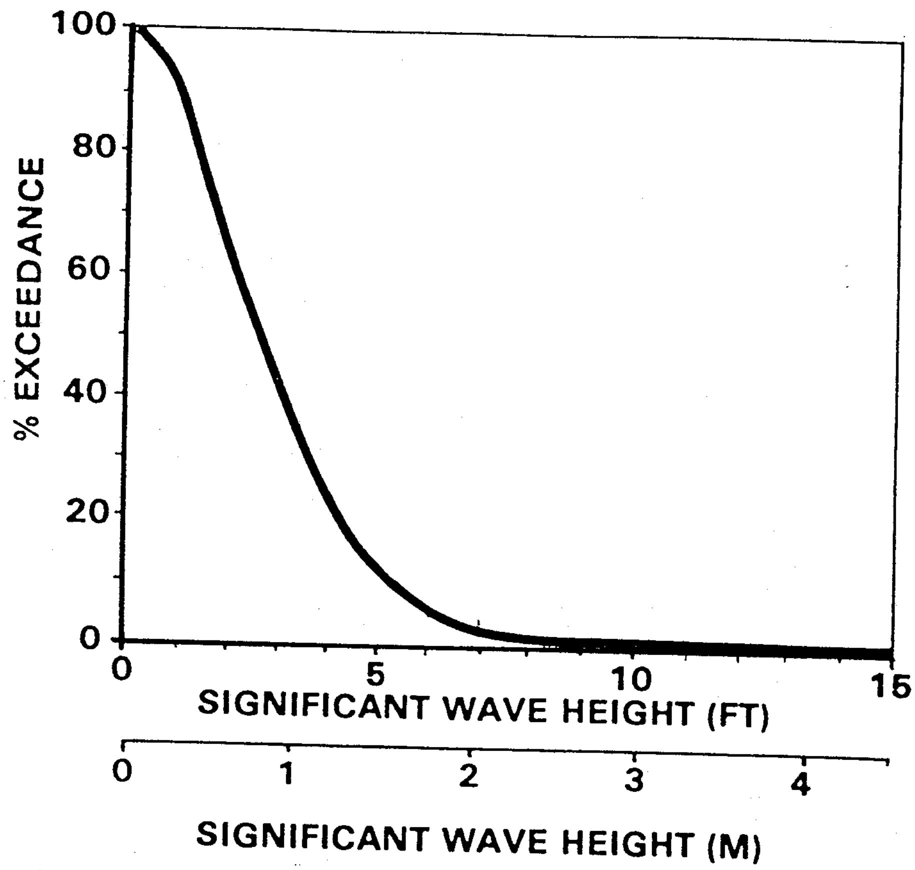


2695w003.DWG

KLOHN-CRIPPEN

PROJECT	GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS
TITLE	DISTRIBUTION OF RIDGE GROUNDING AND SCOURS ON THE NATURAL SHOAL

CLIENT	DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
INDIAN AND NORTHERN AFFAIRS CANADA	MAR 95	PA2695.03	FIGURE 13	
	APPROVED			



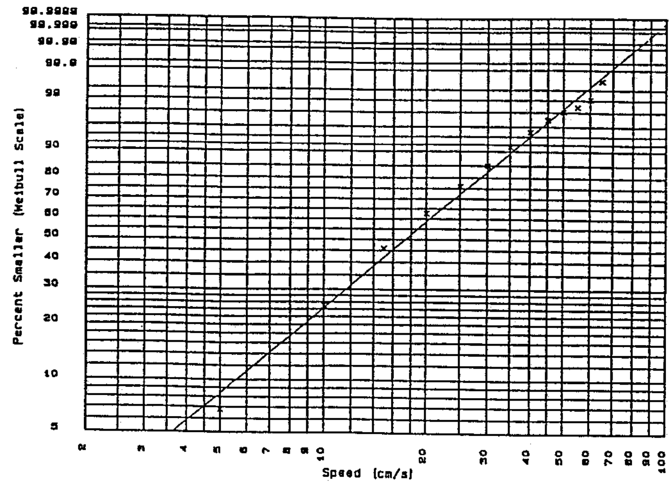
2695w003.DWG

KLOHN-CRIPPEN

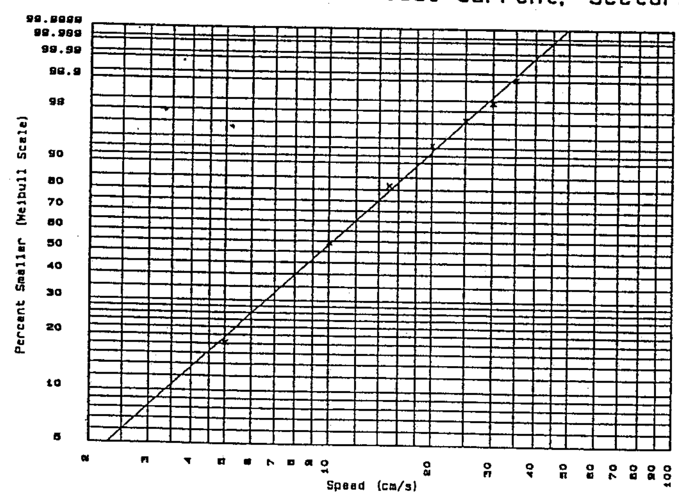
CLIENT
INDIAN AND NORTHERN AFFAIRS CANADA

PROJECT	GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS		
TITLE	TYPICAL SIGNIFICANT WAVE HEIGHT EXCEEDENCE DISTRIBUTION FOR THE BEAUFORT SEA		
DATE OF ISSUE MAR 95 / APPROVED	PROJECT No. PA2695.03	DWG. No. FIGURE 14	REV.

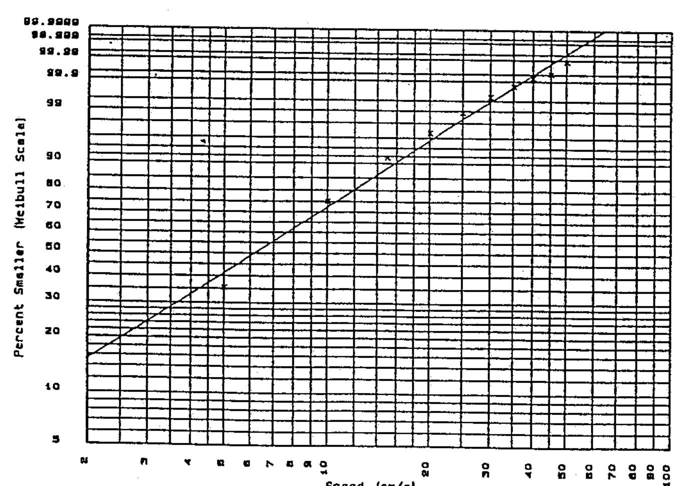
Near Surface : Site Amauligak, Nontidal Current, Sector: All



Mid Depth : Site Amauligak, Nontidal Current, Sector: All



Near Bottom : Site Amauligak, Nontidal Current, Sector: All

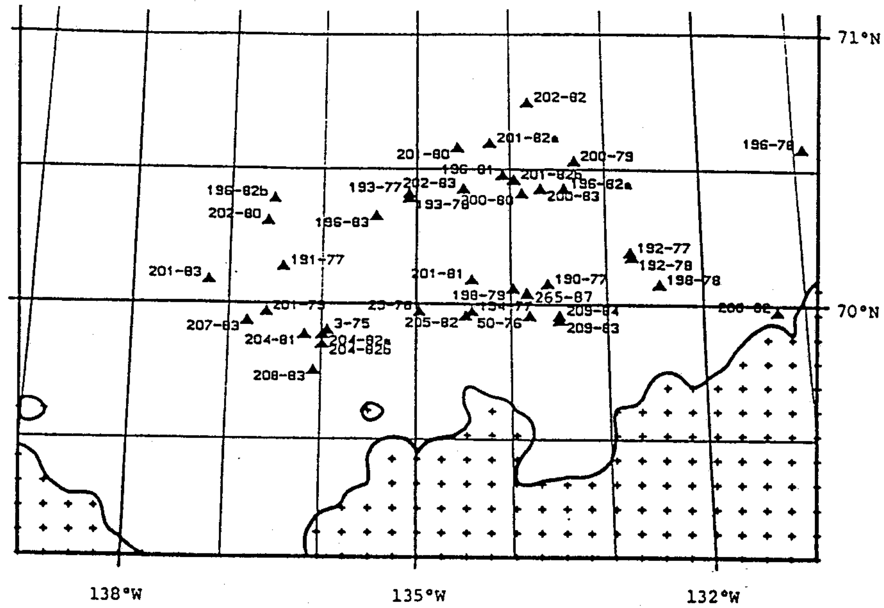


2695w003.DWG

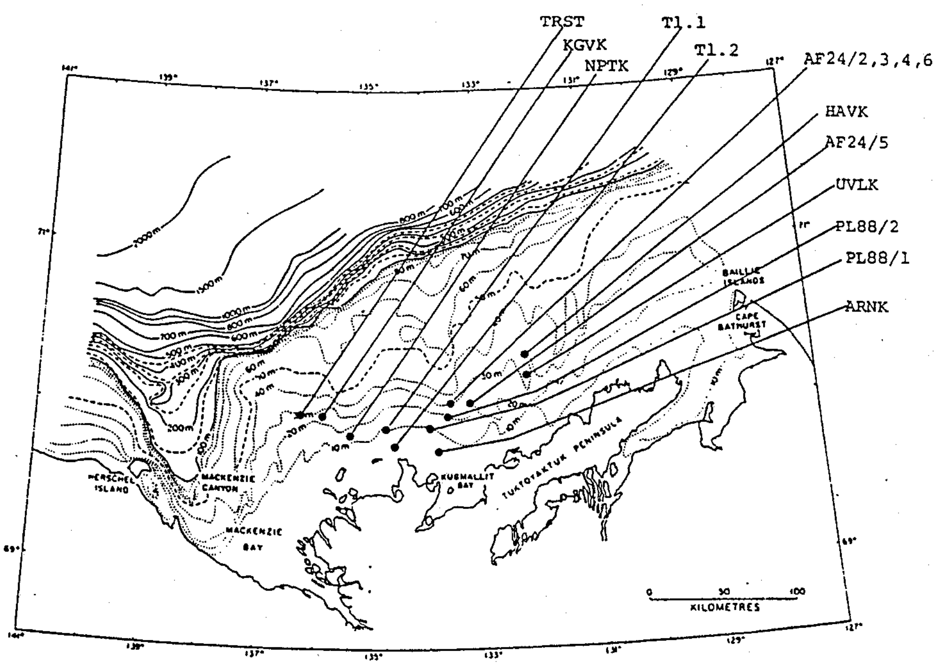
KLOHN-CRIPPEN

CLIENT
INDIAN AND NORTHERN AFFAIRS CANADA

PROJECT	GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS
TITLE	EXTREME VALUE CURRENT SPEED DISTRIBUTIONS FOR THE AMAULIGAK LOCATION
DATE OF ISSUE	MAR 95
APPROVED	
PROJECT No.	PA2695.03
DWG. No.	FIGURE 15
REV.	



Waverider locations in the Beaufort Sea.



Current meter locations in the Beaufort Sea.

Legend

Abbreviation	Site Name
AF24	Amauligak F-24 Sites 2 to 6
ARNK	Arnak
HAVK	Havik
KGVK	Kigavik
NPTK	Nipterk
PL88	Pipeline Sites 1 & 2 1988 Gulf Program
TRST	Tarsuit
UVLK	Uviluk

2895W003.DWG

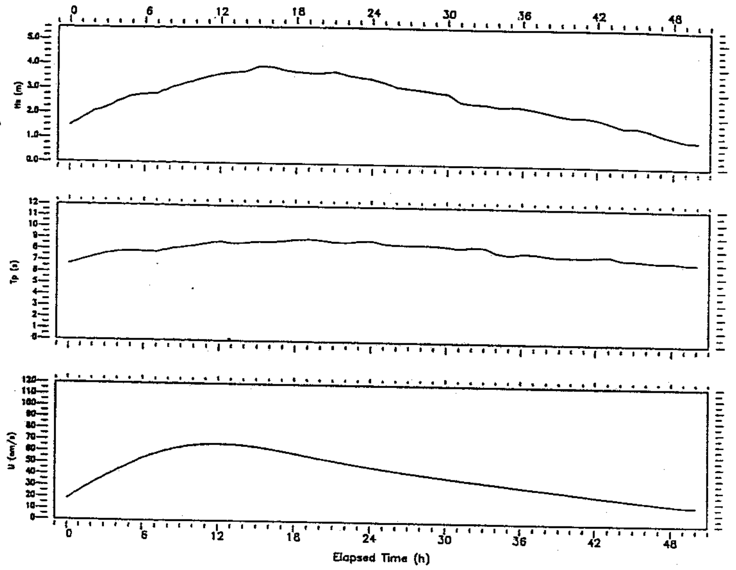
KLOHN-CRIPPEN

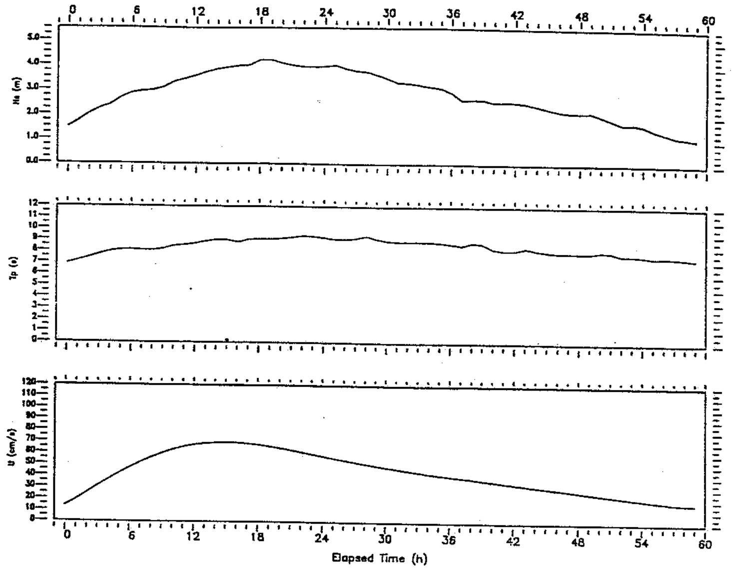
PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

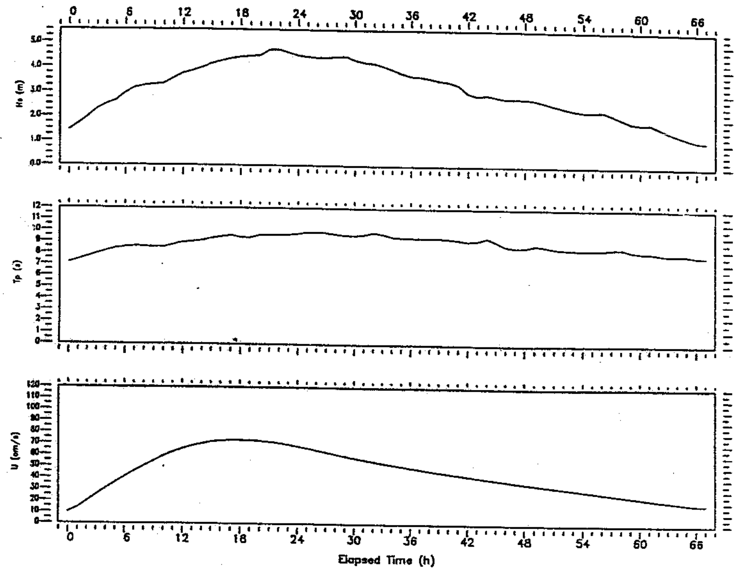
TITLE: WAVE AND CURRENT DATA USED IN THE GULF CANADA STORM ASSESSMENT STUDY

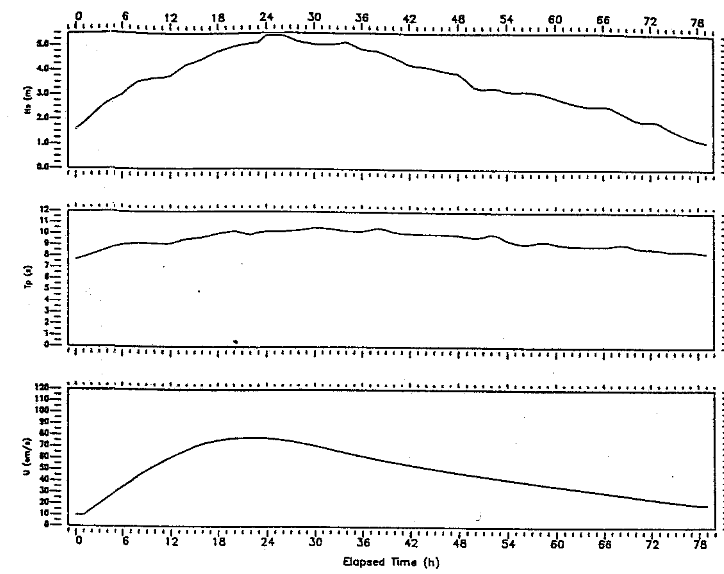
CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
MAR 95	PA2695.03	FIGURE 16	
APPROVED			









Elapsed Time hours	Sig. Wave Height (m)	Peak Period (s)	Current Speed (cm/s)
0.0	1.48	6.71	18.4
1.0	1.76	7.02	25.0
2.0	2.07	7.33	31.5
3.0	2.23	7.64	37.6
4.0	2.50	7.83	43.4
5.0	2.70	7.88	48.7
6.0	2.77	7.81	54.1
7.0	2.80	7.81	58.2
8.0	3.03	8.10	61.6
9.0	3.19	8.26	64.1
10.0	3.33	8.40	65.9
11.0	3.49	8.62	66.8
12.0	3.60	8.78	67.0
13.0	3.66	8.61	66.7
14.0	3.70	8.68	65.8
15.0	3.90	8.80	64.5
16.0	3.90	8.80	62.9
17.0	3.76	8.88	61.0
18.0	3.68	9.01	59.0
19.0	3.65	9.07	56.9
20.0	3.66	8.97	54.9
21.0	3.72	8.82	53.0
22.0	3.57	8.80	51.2
23.0	3.49	8.95	49.4
24.0	3.43	8.99	47.8
25.0	3.29	8.70	46.2
26.0	3.12	8.62	44.6
27.0	3.06	8.61	43.2
28.0	3.01	8.61	41.7
29.0	2.93	8.59	40.4
30.0	2.88	8.51	39.0
31.0	2.55	8.36	37.7
32.0	2.49	8.53	36.5
33.0	2.47	8.47	35.2
34.0	2.38	7.99	34.0
35.0	2.41	7.83	32.8
36.0	2.37	8.02	31.6
37.0	2.28	7.97	30.4
38.0	2.17	7.79	29.2
39.0	2.06	7.72	28.0
40.0	2.00	7.72	26.8
41.0	2.01	7.72	25.5
42.0	1.94	7.79	24.3
43.0	1.78	7.84	23.1
44.0	1.61	7.53	21.9
45.0	1.63	7.52	20.7
46.0	1.51	7.41	19.6
47.0	1.33	7.35	18.5
48.0	1.20	7.40	17.5
49.0	1.09	7.24	16.5
50.0	1.07	7.22	16.5

5 Year Extreme Storm Profile

Elapsed Time hours	Sig. Wave Height (m)	Peak Period (s)	Current Speed (cm/s)
0.0	1.48	6.88	13.5
1.0	1.74	7.15	18.7
2.0	2.03	7.42	24.7
3.0	2.25	7.70	30.6
4.0	2.40	7.97	36.2
5.0	2.69	8.11	41.6
6.0	2.87	8.14	46.7
7.0	2.95	8.07	51.4
8.0	2.98	8.07	55.7
9.0	3.11	8.21	59.4
10.0	3.34	8.48	62.6
11.0	3.45	8.55	65.2
12.0	3.58	8.68	67.0
13.0	3.73	8.89	68.3
14.0	3.84	9.03	68.9
15.0	3.91	8.99	69.0
16.0	3.97	8.79	68.8
17.0	3.99	9.06	68.1
18.0	4.20	9.09	67.1
19.0	4.20	9.09	65.8
20.0	4.07	9.16	64.3
21.0	3.98	9.26	62.6
22.0	3.93	9.40	60.8
23.0	3.93	9.33	59.0
24.0	3.95	9.23	57.2
25.0	4.00	9.09	55.5
26.0	3.85	9.09	53.8
27.0	3.76	9.20	52.2
28.0	3.73	9.40	50.7
29.0	3.60	9.13	49.2
30.0	3.46	8.96	47.8
31.0	3.30	8.89	46.5
32.0	3.28	8.89	45.2
33.0	3.22	8.89	43.9
34.0	3.15	8.89	42.6
35.0	3.09	8.82	41.4
36.0	2.91	8.72	40.3
37.0	2.60	8.58	39.1
38.0	2.65	8.86	38.0
39.0	2.63	8.75	36.9
40.0	2.52	8.28	35.8
41.0	2.55	8.14	34.7
42.0	2.53	8.17	33.6
43.0	2.48	8.38	32.6
44.0	2.38	8.17	31.5
45.0	2.27	8.04	30.5
46.0	2.17	7.97	29.4
47.0	2.12	7.97	28.4
48.0	2.11	7.97	27.3
49.0	2.13	7.97	26.2
50.0	1.98	8.11	25.1
51.0	1.82	8.04	24.0
52.0	1.66	7.77	23.0
53.0	1.69	7.77	21.9
54.0	1.61	7.70	20.9
55.0	1.43	7.56	19.9
56.0	1.30	7.63	19.0
57.0	1.18	7.59	18.0
59.0	1.08	7.46	17.2

10 Year Extreme Storm Profile

Elapsed Time hours	Sig. Wave Height (m)	Peak Period (s)	Current Speed (cm/s)
0.0	1.43	7.13	10.0
1.0	1.70	7.38	13.7
2.0	1.97	7.63	19.3
3.0	2.27	7.89	24.8
4.0	2.47	8.14	30.2
5.0	2.62	8.39	35.5
6.0	2.92	8.52	40.5
7.0	3.14	8.59	45.4
8.0	3.22	8.53	49.9
9.0	3.27	8.50	54.2
10.0	3.30	8.50	58.7
11.0	3.52	8.73	62.2
12.0	3.73	8.94	65.2
13.0	3.83	9.01	67.8
14.0	3.97	9.13	69.8
15.0	4.13	9.32	71.4
16.0	4.24	9.46	72.4
17.0	4.34	9.56	72.9
18.0	4.40	9.37	73.0
19.0	4.44	9.36	72.8
20.0	4.47	9.61	72.2
21.0	4.70	9.58	71.4
22.0	4.70	9.58	70.3
23.0	4.57	9.64	68.9
24.0	4.46	9.72	67.4
25.0	4.41	9.85	65.8
26.0	4.38	9.86	64.1
27.0	4.38	9.80	62.4
28.0	4.43	9.68	60.7
29.0	4.44	9.58	59.1
30.0	4.28	9.58	57.5
31.0	4.19	9.67	56.0
32.0	4.16	9.86	54.5
33.0	4.05	9.70	53.1
34.0	3.92	9.46	51.7
35.0	3.76	9.40	50.4
36.0	3.65	9.36	49.1
37.0	3.63	9.36	47.9
38.0	3.56	9.36	46.6
39.0	3.48	9.36	45.5
40.0	3.43	9.30	44.3
41.0	3.30	9.22	43.2
42.0	2.98	9.09	42.1
43.0	2.88	9.19	41.0
44.0	2.93	9.44	39.9
45.0	2.84	9.07	38.9
46.0	2.77	8.69	37.9
47.0	2.79	8.56	36.8
48.0	2.78	8.60	35.8
49.0	2.73	8.79	34.8
50.0	2.63	8.67	33.8
51.0	2.52	8.49	32.8
52.0	2.42	8.43	31.9
53.0	2.33	8.39	30.9
54.0	2.28	8.39	29.9
55.0	2.28	8.39	28.9
56.0	2.31	8.39	27.8
57.0	2.15	8.52	26.8
58.0	1.99	8.53	25.8
59.0	1.83	8.28	24.8
60.0	1.78	8.18	23.8
61.0	1.81	8.18	22.8
62.0	1.64	8.06	21.8
63.0	1.47	7.98	20.9
64.0	1.34	8.04	20.0
65.0	1.22	8.01	19.1
66.0	1.11	7.88	18.2
67.0	1.09	7.86	18.2

25 Year Extreme Storm Profile

Elapsed Time hours	Sig. Wave Height (m)	Peak Period (s)	Current Speed (cm/s)
0.0	1.57	7.68	10.0
1.0	1.83	7.91	10.0
2.0	2.11	8.13	15.0
3.0	2.40	8.36	20.0
4.0	2.65	8.59	25.0
5.0	2.81	8.82	29.9
6.0	3.00	9.02	34.7
7.0	3.30	9.13	39.3
8.0	3.54	9.20	44.7
9.0	3.62	9.15	49.0
10.0	3.69	9.10	53.1
11.0	3.71	9.10	57.0
12.0	3.78	9.14	60.6
13.0	4.02	9.37	63.9
14.0	4.24	9.57	66.9
15.0	4.34	9.63	70.1
16.0	4.45	9.70	72.4
17.0	4.61	9.87	74.3
18.0	4.77	10.04	75.7
19.0	4.87	10.15	76.8
20.0	4.97	10.24	77.6
21.0	5.03	10.07	77.9
22.0	5.08	9.92	78.0
23.0	5.11	10.15	77.9
24.0	5.40	10.25	77.4
25.0	5.40	10.25	76.7
26.0	5.40	10.25	75.8
27.0	5.27	10.31	74.8
28.0	5.14	10.37	73.5
29.0	5.08	10.48	72.2
30.0	5.03	10.59	70.7
31.0	5.02	10.55	69.2
32.0	5.02	10.49	67.7
33.0	5.07	10.38	66.1
34.0	5.13	10.27	64.6
35.0	4.99	10.25	63.1
36.0	4.83	10.25	61.7
37.0	4.79	10.40	60.3
38.0	4.76	10.57	58.9
39.0	4.64	10.41	57.6
40.0	4.51	10.18	56.4
41.0	4.36	10.09	55.1
42.0	4.20	10.04	53.9
43.0	4.14	10.02	52.7
44.0	4.12	10.02	51.6
45.0	4.05	10.02	50.5
46.0	3.97	10.02	49.4
47.0	3.91	9.98	48.3
48.0	3.86	9.92	47.2
49.0	3.61	9.83	46.2
50.0	3.30	9.71	45.2
51.0	3.24	9.84	44.2
52.0	3.29	10.07	43.3
53.0	3.24	9.87	42.3
54.0	3.13	9.47	41.3
55.0	3.11	9.26	40.4
56.0	3.14	9.14	39.5
57.0	3.11	9.21	38.6
58.0	3.06	9.38	37.6
59.0	2.98	9.35	36.7
60.0	2.87	9.17	35.8
61.0	2.76	9.07	34.9
62.0	2.66	9.01	34.0
63.0	2.58	8.99	33.1
64.0	2.53	8.99	32.2
65.0	2.52	8.99	31.3
66.0	2.54	8.99	30.4
67.0	2.48	9.04	29.5
68.0	2.32	9.16	28.6
69.0	2.16	9.11	27.7
70.0	2.00	8.88	26.7
71.0	1.92	8.76	25.8
72.0	1.95	8.76	24.9
73.0	1.89	8.71	24.0
74.0	1.70	8.59	23.1
75.0	1.54	8.55	22.3
76.0	1.40	8.61	21.4
77.0	1.28	8.60	20.6
78.0	1.18	8.48	19.8
79.0	1.11	8.41	19.8

100 Year Extreme Storm Profile

KLOHN-CRIPPEN

PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

TITLE: AMAULIGAK LOCATION EXTREME STORM PROFILES

CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA

DATE OF ISSUE: MAR 95

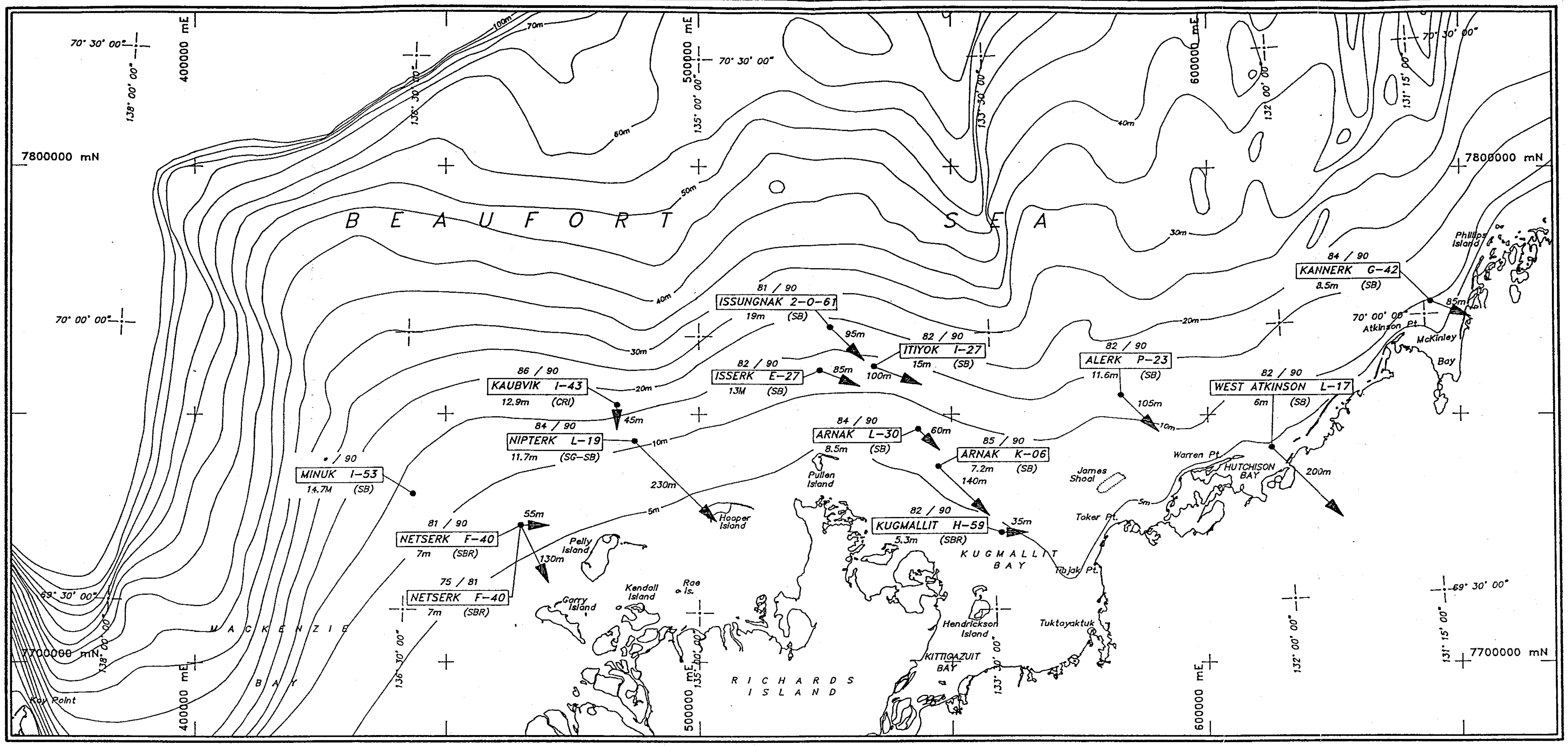
APPROVED:

PROJECT No.: PA2695.03

DWG. No.: FIGURE 17

REV.:

2695w003.dwg



ISLAND KEY

COMPARISON YEARS
INITIAL YEAR — 84 / 90 — FINAL YEAR
KANNERK G-42 — ISLAND NAME
BASE WATER DEPTH (BSL) — 8.5m
(SB) — ISLAND DESIGN

SEDIMENT TRANSPORT

ISLAND LOCATION
105m
PROMINENT BEARING AND MAGNITUDE OF SEDIMENT TRANSPORT.

ACTUAL MAGNITUDE : ARROW LENGTH
1 : 100

ISLAND DESIGN

SB	SACRIFICIAL BEACH
SG	SAND AND GRAVEL
SBR	SAND BAG RETAINED
CRI	CAISSON RETAINED ISLAND

TO BE READ WITH KLOHN CRIPPEN REPORT DATED MARCH 1995

KLOHN-CRIPPEN

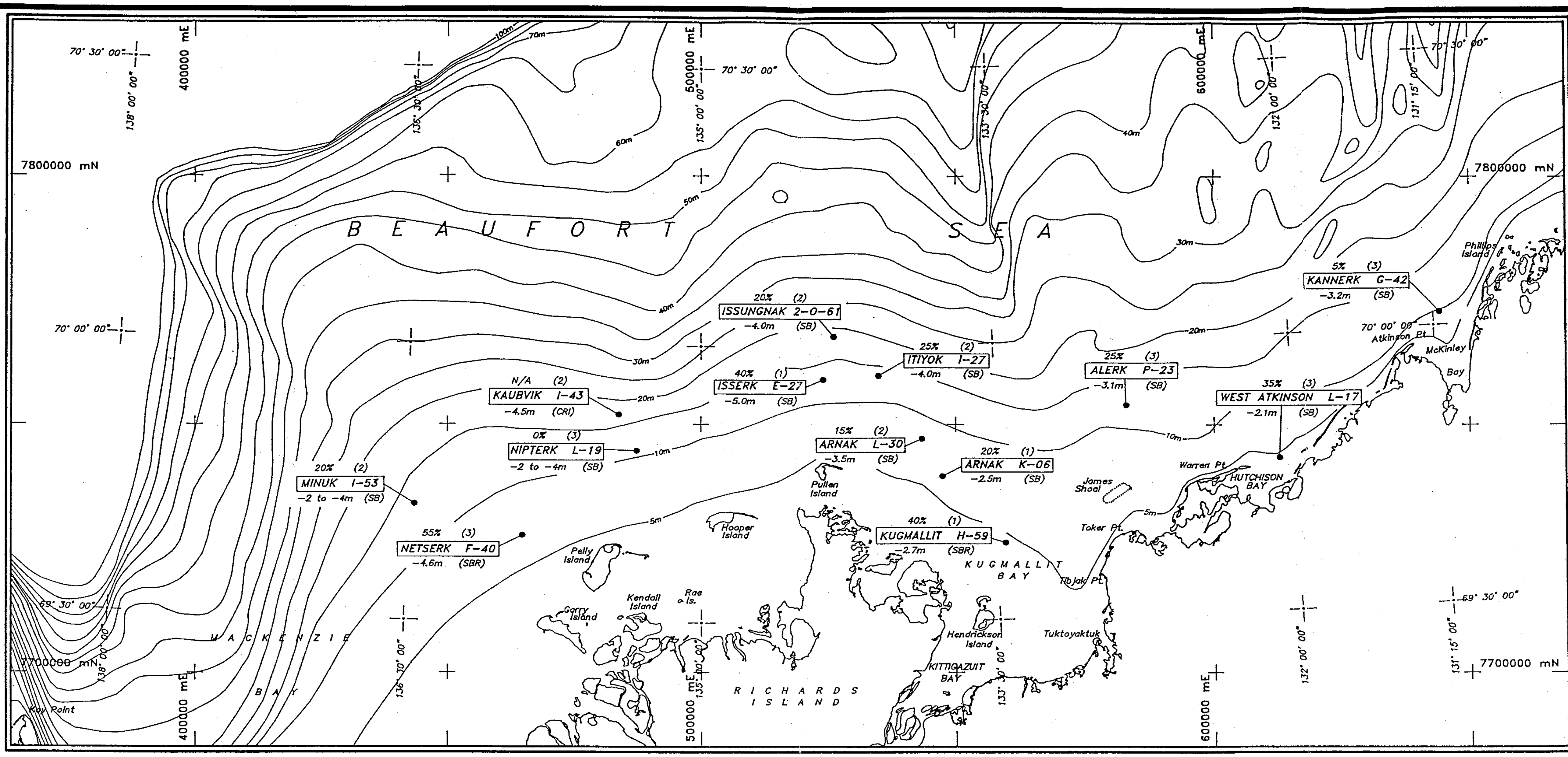
PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

TITLE: ISLAND SEDIMENT TRANSPORT SUMMARY

CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
MARCH 95	PA2695.03	FIGURE 18	
APPROVED			

2695w039.dwg



ISLAND KEY

APPROX. % VOLUME LOSS TO 1990 — 25%

SEDIMENT TRANSPORT PATTERN — (3)

ISLAND NAME — KANNERK G-42

SUBMERGENCE DEPTH (m), 1990 — -3.1m

ISLAND DESIGN — (SB)

SEDIMENT TRANSPORT PATTERN

TYPE 1	CONCENTRIC
TYPE 2	MODERATELY POLARIZED
TYPE 3	HIGHLY POLARIZED

ISLAND DESIGN

SB	SACRIFICIAL BEACH
SG	SAND AND GRAVEL
SBR	SAND BAG RETAINED
CRI	CAISSON RETAINED ISLAND

TO BE READ WITH KLOHN CRIPPEN REPORT DATED MARCH 1995

KLOHN-CRIPPEN

PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

TITLE: ISLAND SEDIMENT TRANSPORT PATTERN AND VOLUME LOSS SUMMARY

CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA

DATE OF ISSUE: MARCH 95

APPROVED:

PROJECT No.: PA2695.03

DWG. No.: FIGURE 19

REV.:

2695w040.dwg

APPENDIX I

INFOCUS/QUICKMAP/FOXPRO2 DATABASE

1. Microcomputer-accessible Electronic Data Set

The artificial island information has been compiled into a relational and graphical database compatible with QUICKmap/inFOcus GIS software. The database is comprised of two main components, a relational database and a graphical database. The QUICKmap/inFOcus software provides the means in which to link the relational and graphic databases in a seamless operation.

1.1 Relational Database

The relational database contains information on island type, fill material characteristics, island dimensions, ice, wave and local conditions, significant dates, and lease and file numbers. Several fields of the relational database are assigned to represent graphical display characteristics used by QUICKmap. The database was developed using Foxpro2 software. Field names are shortened or abbreviated versions of the actual field entry name.

Field Descriptions

No:
Each island was assigned a reference number based on the order of island construction. The numbers range from 1 to 37.

Lbl_Text:
The island name.

Operator:
The principal operator, which often represents a group of oil companies involved in the project.

Mn.North, Mn.East and Mn.Zone:
The UTM Northing, Easting and Zone of the island centre.

Latdec and Longdec:
The Geographical Northing and Easting location of the island centre given in decimal degrees.

Waterdep:
The depth in metres from mean sea level to the seabed prior to island construction.

Borsite:
The name of the borrow site from which material was extracted for fill in island construction.

Fillmat and Fillmat2:

The type of fill material used in island construction. Generally, Fillmat2 is the secondary material used, such as gravel cap, but may be a major component (e.g. sand and gravel).

D50 and D502:

The average D50 of the fill particles is entered into "D50", or a range of both "D50" and "D502" are used.

Fines:

The average fines content of the fill used in island construction.

Type:

The type of island (e.g. sacrificial beach island) constructed.

Method:

The method used in construction is entered into this memo field. Only the first line in the memo field is printed on the summary sheet.

The dimensions of the island corresponding to up to four surveys are tabulated in the following fields. The four surveys are referred to as an "as-built", two "interim" surveys, and a "present" survey. Field names are identical for each survey except for the suffix. All "as-built" survey fields are preceded with "as". The first interim survey fields are preceded with "in", while the second interim survey have fields preceded by "int". The "present" survey fields are preceded with "pr". The "as-built" survey fields are described below.

Asbath:

The survey company to perform the as-built bathymetric survey.

Asdate:

The date the survey was completed. Dates are shown in the mm/dd/yy format, when all information is available.

Asfree:

The measured freeboard of the island in metres. The value is positive for height above water and negative for depth to island or berm surface. In the case of caisson retained islands, the freeboard refers to the height of sand inside the core, and not the depth to berm.

Assurf:

For surface piercing islands, this field represents the dimensions of the working surface in metres. For caisson retained islands, it represents the surface dimensions of the core fill, and for SSDC's, the surface area of the top of the berm.

Asbase:

The dimensions of the base of the island structure.

Asslope:

The average slope of the as-built island given in mH:mV. Occasionally several slopes are given, as in a sacrificial beach island, and represent the various slopes on the island. For subsequent surveys, a range is given representing the shallowest and steepest slopes.

Assubdep:
The depth of subcut below the island in metres prior to island construction.

Asfillq:
The quantity of fill in cubic metres required to construct the island. This value includes fill in the subcut, berm or island, and core. In subsequent surveys, this is the total volume of the island structure.

Asfillsub:
The quantity of fill in cubic metres required to fill the subcut only.

Astarg:
The number of targets, or possible man-made debris, identified on the island from side scan sonar surveys.

Asqual:
The quality of the survey.

Comments:
A summary of each island in paragraph form is entered into this memo field.

Leaseno:
The lease number.

License:
The license number.

Cogla:
The COGLA file number.

Physloc:
The physiographic location of the island in the Beaufort Sea.

Seabed:
The geologic conditions of the seabed at the island location.

Neahole:
The nearest hole to the island structure.

Waterdep:
The depth in metres from mean sea level to the seabed prior to island construction.

Dconst:
The date of island construction.

Drigrel:
The date the rig was released from the island.

Daband:

The date the island was abandoned.

Icezone:
The ice environment characterizing the particular island or berm location in the winter.

Freezemed, Freezeearl and Freezelat:
The median, twenty and eighty percentile dates when new ice greater than 5/10ths in concentrations covers the general vicinity of the island location.

Landice:
The approximate time period at which landfast ice normally stabilizes at the location.

Rubblefm:
Whether grounded rubble formations are commonly seen at the island location.

Extent:
The extent of grounded rubble formation, if applicable.

Icescour:
The potential for significant scour action from moving ice during the winter period at the island site.

Breakmed, Breakearl, and Breaklat:
The median, twenty and eighty percentile dates when ice concentrations fall to 3/10ths or less in the general vicinity during break-up in the summer.

Openwater:
The number of days of openwater at the island location (median).

Summerint:
The number of years (in the last 15) that significant summer ice intrusions have occurred in the vicinity of the location.

Exposure:
The exposure to extreme storm waves at the island location is largely based upon wave height limitations related to wave breaking.

Extreme:
Extreme storm wave events were define by measured significant wave height occurrences that exceeded 2 m in the general region. The number of storm events (from 1974 to 1988) experienced by each island or berm over its lifetime is tabulated.

The following fields are used by the QUICKmap software to control graphical attributes.

DATA_TYPE:
S,P,L defining whether the line of information begins with a symbol, or polygon line.

KEY:
Reserved for a key field and not used at this time.

SYM_LN_TYP, SIZE_THICK, DATA_COLOR, SYM_ANGLE, HATCH_PATT:
Defines symbol type, size, color, angle and fill pattern.

LN_PLY:
Stores the polyline information.

LBL_TEXT, LBL_SIZE, LBL_COLOR, LBL_FONT, LBL_ANGLE:
Label, label size, color, font and angle.

PLY_AREA:
Area of the polygon defined by LN_PLY.

LN_PLY_LEN:
Length of the polygon defined by LN_PLY.

HIDN_LEN:
Length of the hidden polygon defined by LN_PLY.

VIS_LEN:
Length of the visible polygon defined by LN_PLY.

OPERATION:
A communication variable used by QUICKmap.

FILE_NAME:
Name of associated PCX file to be viewed with the data base.

1.2 Graphical Database

The graphical database contains the graphical line work associated with the relational database. The graphics include the coastal line work and the contour information digitized from the various site plans of each island. Information was compiled and digitized in AutoCad (Release 12) then exported into QUICKmap. The data is organized into one graphical database with each island survey assigned to a different layer. Layer names are based on the island's unit number and year of survey.

1.3 Directory Structure

The data is organized in two directories, one dedicated to the relational database and the second to the graphical database. The structure is similar to that recommended by the inFOcus software.

The data is delivered on two disks, one containing the relational database and the second containing the graphical database. The graphical database is stored in a compressed format and may be expanded by executing the file BEAUFORT.EXE.

APPENDIX II

ITIYOK I-27 EXAMPLE OF DATABASE

1

GRANULAR RESOURCE POTENTIAL OF THE BEAUFORT ARTIFICIAL ISLANDS

Name: Itiyok I-27 Operator: Esso Water Depth: 15.0m No: 24

Location

UTM N:	7759760	Latitude:	69.944417
UTM E:	534880	Longitude:	134.088670

Island Type:	Sacrificial Beach Island
Construction Method:	Hydraulically placed sand, dredged onsite with
Borrow Site:	local, Ukalerk
Fill Material:	sand,
D50:	0.075 to 5.000mm
Fines:	n/a %

Island Dimensions

	As Built	Interim	Interim	Present
Survey:	CES	CES	CES	CSS
Date:	10/10/82	08/17/84	09/10/89	1990
Freeboard (m):	4.0		-3.7	-4.0
Surface Area (m):	108 dia			
Base Area (m):	560 dia			
Slopes (ave.):	31-18-2:1	12-5:1	20-10:1	20-6:1
Subcut Depth (m):				
Total Fill Quantity (m3):	1943000			1500000
Subcut Fill Quantity (m3):				
No Targets:				25
Survey Quality:				poor

Description

Itiyok I-27 was constructed by Esso in the 1982 open water season on a sandy seabed in 15.0 m of water. This sacrificial beach island required 1,943,000 m3 of sand fill dredged from an onsite borrow pit and placed using a floating pipeline. The island had a 108 m diameter working surface, 4.5 m freeboard, and 560 m base. Slopes were maintained at 9H:1V. The island was abandoned in September 1983, and surveyed in 1990 by Challenger. The island had eroded to 4 m below sea level, and 25 targets were identified on the surface.

GRANULAR RESOURCE POTENTIAL OF THE BEAUFORT ARTIFICIAL ISLANDS

Name: Itiyok I-27 Operator: Esso Water Depth: 15.0m No: 24

Location

UTM N:	7759760	Latitude:	69.944417
UTM E:	534880	Longitude:	134.088670

Date (mm/dd/yy)

Construction: 1981-82
Rig Release: 05/02/83
Abandoned: 08/83

Physiographic Location: Akpak Plateau
Seabed Conditions: sand
Nearest Hole:

Ice Conditions

Ice Zone: landfast

Freeze-up (median): Oct 8
Freeze-up (earliest): Sept 24
Freeze-up (latest): Oct 29

Landfast Ice Formation: mid Nov
Rubble Formation: yes
Extent: large
Ice Scour Potential: moderate

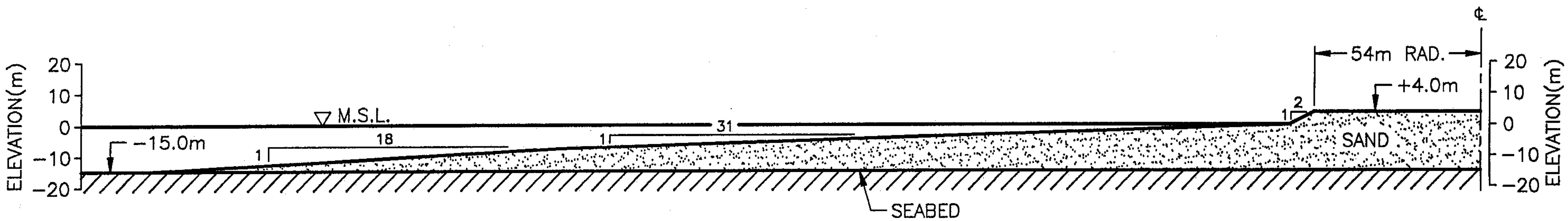
Break-up (median): June 25
Break-up (earliest): June 11
Break-up (latest): Sept 10

Open Water Days (median): 104
Summer Intrusions (in 15): 4 in 15

Wave Conditions

Exposure: high
Extreme Storm Events: 17 in 6 yrs

Lease No.:
License:
COGLA file: 9413-J1-1-3



ITIYOK I-27 – SACRIFICIAL BEACH ISLAND

OPERATOR: ESSO

0 40 80m

(1:2000)

TO BE READ WITH KLOHN-CRIPPEN REPORT DATED MARCH 1995

KLOHN-CRIPPEN

PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

TITLE: ITIYOK I-27

CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA

DATE OF ISSUE: MARCH 95

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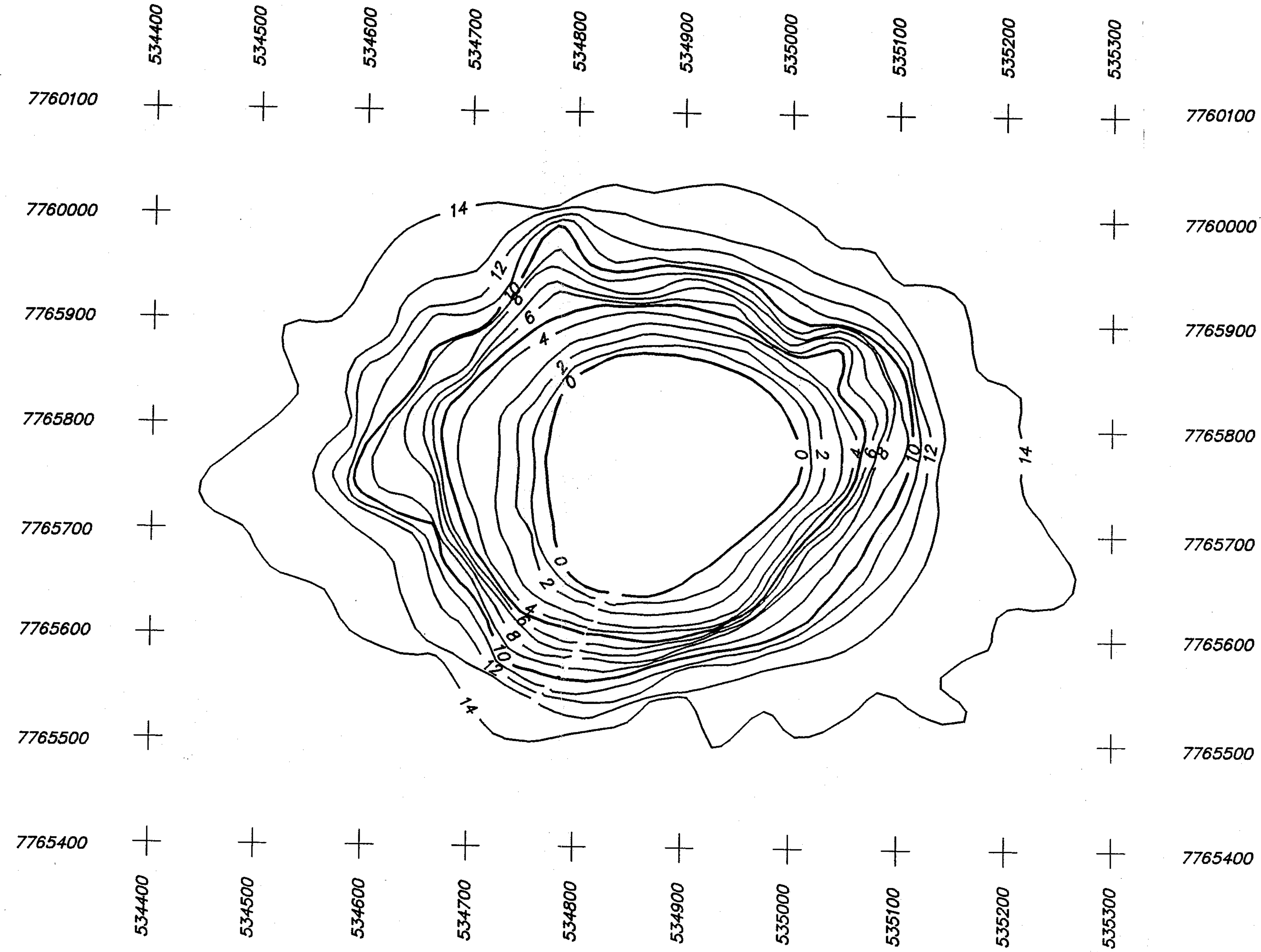
2695w027.dwg



ORIGINAL SEABED : 15.0m BELOW MSL.
DATE OF SURVEY : OCTOBER 1982, CANADIAN ENGINEERING SURVEYS CO. LTD.

TO BE READ WITH KLOHN LEONOFF REPORT DATED MARCH 1995

SCALE 1 : 5000

KLOHN-CRIPPEN

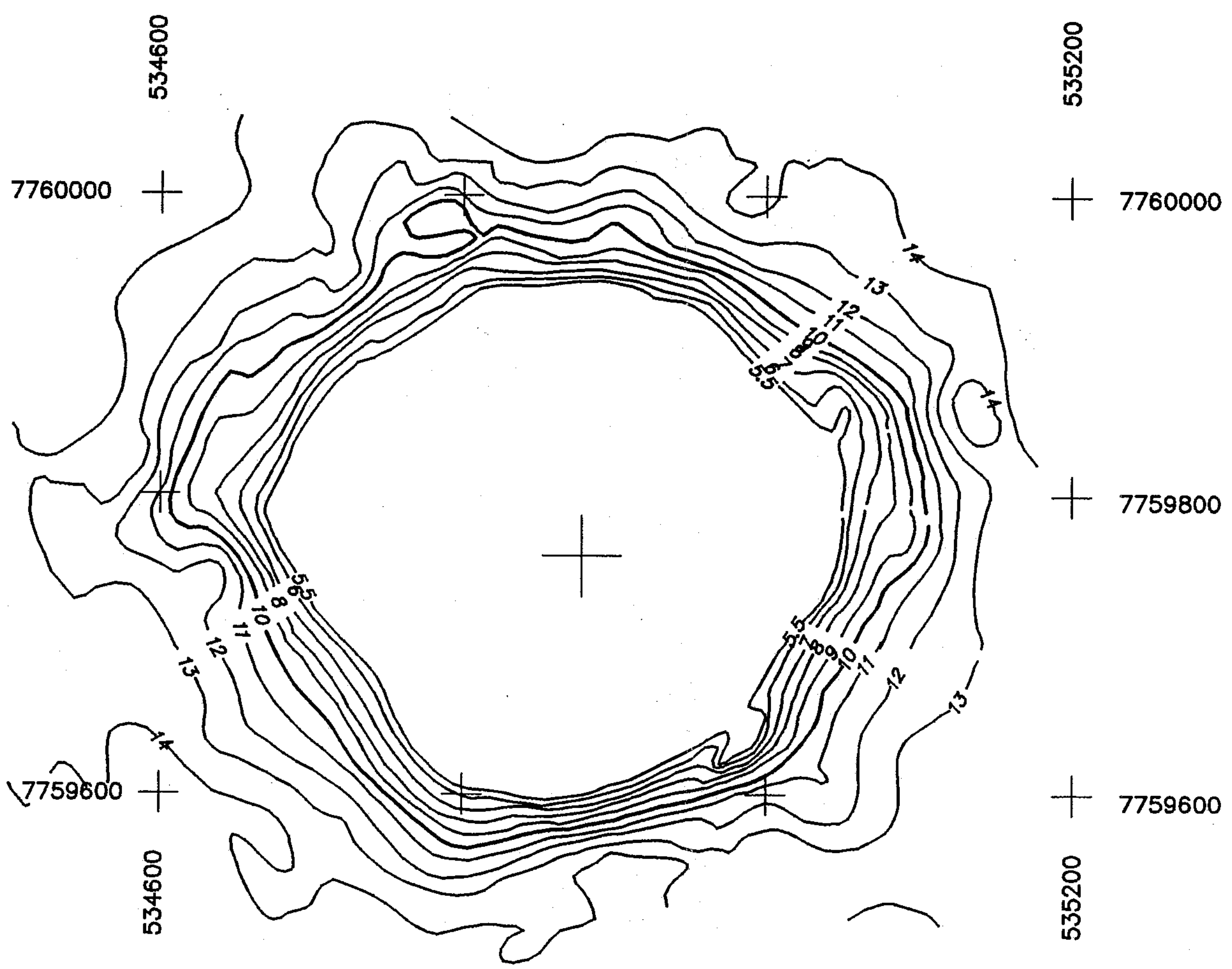
PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

TITLE: ITIYOK I-27 (OCT., 1982)

CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
MARCH 95	PA2695.03	B-2695-03-24A	
APPROVED			

2695w075.dwg



ORIGINAL SEABED : 15.0m BELOW MSL.
DATE OF SURVEY : AUGUST 1984, CANADIAN ENGINEERING SURVEYS CO. LTD.

2695w074.dwg

TO BE READ WITH KLOHN LEONOFF REPORT DATED MARCH 1995

SCALE 1 : 5000

KLOHN-CRIPPEN

PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

TITLE: ITIYOK I-27 (AUG, 1984)

CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA

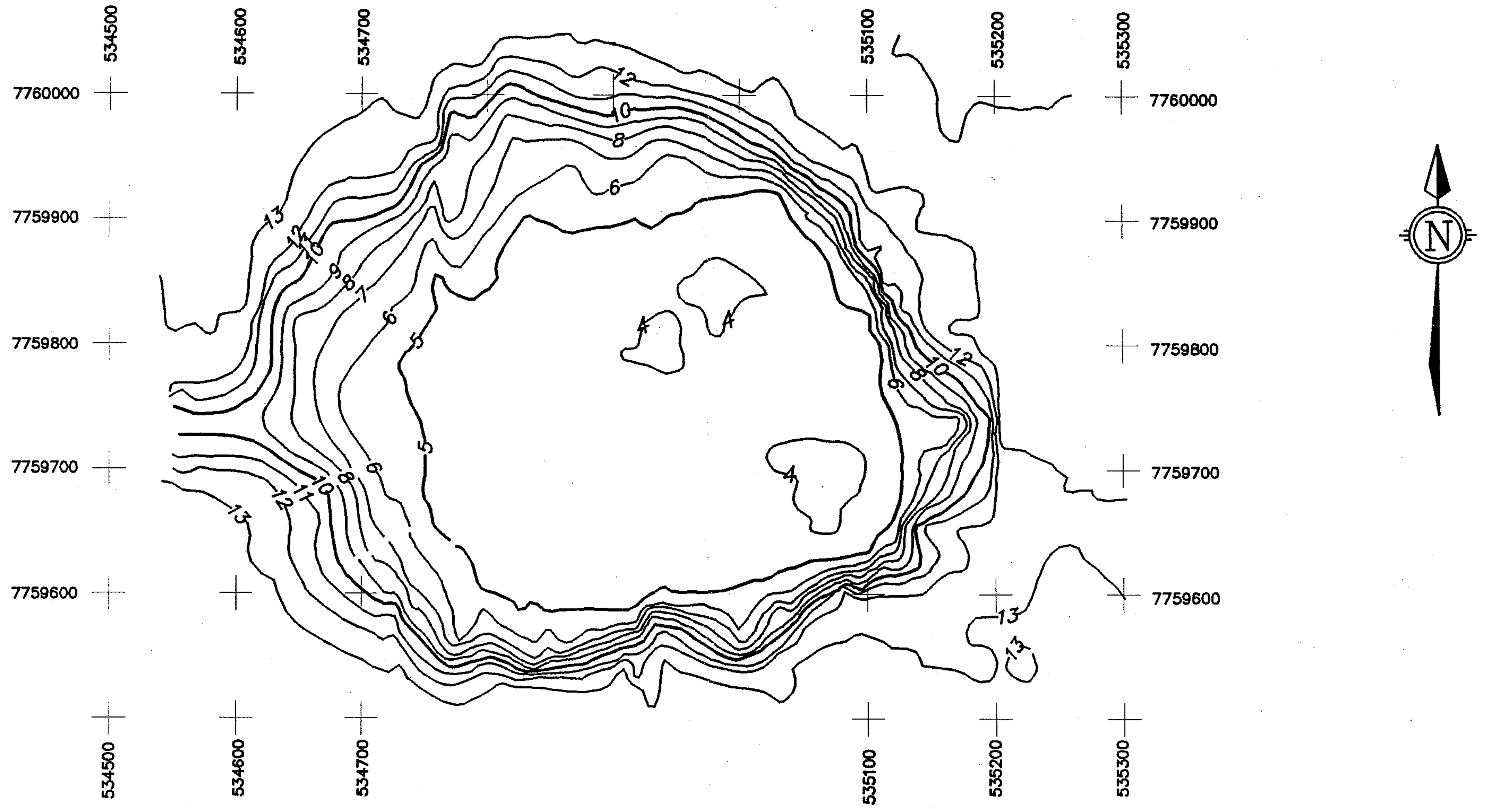
DATE OF ISSUE: MARCH 95

APPROVED:

PROJECT No.: PA2695.03

DWG. No.: B-2695-03-24B

REV.:



ORIGINAL SEABED : 15.0m BELOW MSL.
DATE OF SURVEY : SEPTEMBER 1989, CDN. SEABED RESEARCH LTD.

TO BE READ WITH KLOHN LEONOFF REPORT DATED MARCH 1995

SCALE 1: 5000

KLOHN-CRIPPEN

PROJECT: GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS

TITLE: ITIYOK I-27 (SEP. 1989)

CLIENT: INDIAN AND NORTHERN AFFAIRS CANADA

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
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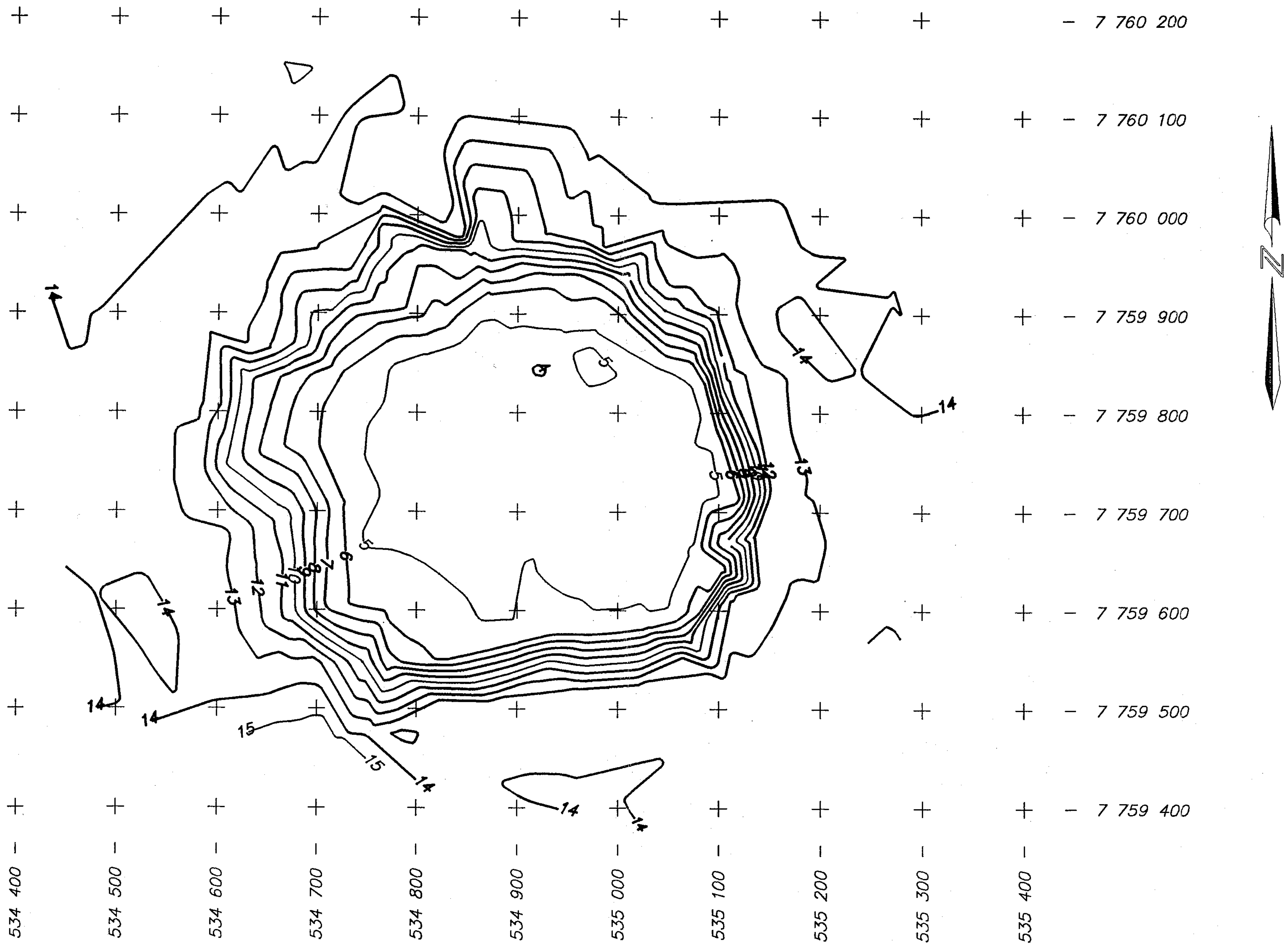
APPROVED			

2695w076.dwg



ORIGINAL SEABED : 15.0m BELOW MSL.

DATE OF SURVEY : JULY 1990, CHALLENGER SURVEYS AND SERVICES LTD.

TO BE READ WITH KLOHN LEONOFF REPORT DATED MARCH 1995

SCALE 1 : 5000

KLOHN-CRIPPEN

PROJECT	GRANULAR RESOURCE POTENTIAL OF BEAUFORT ARTIFICIAL ISLANDS
TITLE	ITIYOK I-27 (JUL., 1990)
CLIENT:	INDIAN AND NORTHERN AFFAIRS CANADA
DATE OF ISSUE	MARCH 95
APPROVED	
PROJECT No.	PA2695.03
DWG. No.	B-2695-03-24D
REV.	

2695w045.dwg