AN EVALUATION OF THE FEASIBILITY OF DEVELOPING GRANULAR BORROW FROM THE BED OF THE MACKENZIE RIVER

Submitted to:

INDIAN AND NORTHERN AFFAIRS CANADA

Prepared by:

EBA ENGINEERING CONSULTANTS LTD.
CALGARY, ALBERTA

0301-34288 APRIL, 1987

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

EXECUTIVE SUMMARY

On behalf of Indian and Northern Affairs Canada, a review has been completed of the feasibility of developing granular materials from the Mackenzie Riverbed for use as construction borrow. The project was completed for Supply and Services Canada by EBA Engineering Consultants Ltd. who had submitted an unsolicited proposal for the work. EBA were assisted by ESL Environmental Sciences Ltd. and GVM Geological Consultants Ltd. in the office study.

River regime data, primarily channel morphology and river gradient/current data were combined with geological and terrain evidence of granular alluvium to develop a rating system for 25 km reaches of the river. Approximately 22 percent of the riverbed was interpreted to have a high potential to supply granular borrow. The area between Camsell Bend and Fort Good Hope appears to have the greatest potential; however, local areas between Fort Providence and Fort Simpson have a moderate to high potential.

To develop an understanding of where riverbed borrow production might be required, data pertaining to upland or conventional borrow deposits within 15 km of the riverbank was reviewed. Almost 66 percent of the length of the Mackenzie Valley appears to be deficient in upland borrow resources. In particular, the 500 km section upstream of Willowlake River and the 175 km section immediately upstream of the Mackenzie Delta have noticeable shortages of upland granular resources.

A cost comparison of conventional versus dredge and barge haul borrow development demonstrated the economic feasibility of riverine borrow production. Although excavation and start-up costs would be more than twice as high ($\$11.90/m^3$ versus $\$4.90/m^3$) for dredge and barge methods, haul costs would be considerably less for longer distances. Evidence is presented suggesting that for hauls of greater than 7 km, river operations may be more practical. For high production rates, the potential cost benefits are even greater.

Environmental considerations primarily focused on the fish population and the impact of dredging on water quality and suspended sediments. Generally it was concluded that the Mackenzie River's naturally high flow rate and high suspended sediment content during the open water season will mask any effects summer dredging might have. Similarly resuspension of sorbed heavy metals and hydrocarbons is not expected to be a major concern. Some concern does exist, however, for the interference dredging may have on the migration of fish along the Mackenzie and spawning areas could be impacted. Therefore site specific evaluation will be required before major borrow operations are initiated.

The shortage of data upon which to base this study affected both the geotechnical and environmental components. Site specific information of the riverbed materials and fish populations is virtually non-existent, except for the Norman Wells area and tributary streams and rivers. Therefore, considerable effort will be required before the potential value of the riverbed alluvium as a resource material can be established.

1.0 INTRODUCTION

In September 1986, Indian and Northern Affairs Canada (INAC) through Supply and Services Canada (SSC) retained EBA Engineering Consultants Ltd. (EBA) to evaluate the feasibility of recovering granular borrow resources from the main channel of the Mackenzie River. This project which was awarded as a result of an unsolicited proposal was conducted under SSC Contract No. A7134-6-0017/01-ST. Mr. Bob Gowan was INAC's Scientific Authority for the project.

In the mid '70's, there were several studies of the granular borrow prospects in the Mackenzie Valley, excluding the river. Indian Affairs and Northern Development sponsored a broad inventory of the valley's resources including studies by EBA (1973), Pemcan (1972), and the Geological Survey of Canada (1972, 1973). Subsequently studies for a Mackenzie Valley gas pipeline and the Mackenzie and Dempster highways examined granular borrow supplies in more detail, but along much narrower corridors. None of these studies appears to have considered the riverbed as a potential source of granular borrow. The concept of recovering borrow materials from the riverbed was, at that time, considered to be environmentally unacceptable.

Geotechnical investigations for the Norman Wells Expansion Project (NWEP) completed between 1978 and 1983 by ESSO Resources Canada Ltd. (ESSO) encountered significant thicknesses of granular riverbed alluvium. ESSO recognized the economic value of this material in part because of its experience with constructing Beaufort Sea islands by dredging. Almost 1.8 million cu.m. of riverbed sand and gravel was used for construction of six islands in the river by the NWEP.

On the basis of ESSO's successful development of granular borrow resources from the riverbed and with the knowledge that some sections of the river valley are deficient in upland granular borrow resources, it was appropriate to investigate the potential for other reaches of the river to supply granular borrow. The project can best be described as a study of the potential for finding granular resources along separate reaches of the river and of the feasibility for developing such deposits if they do exist. Environmental, and economic factors have been included in assessing the general feasibility of riverbed borrow development.

2.0 PROJECT DESCRIPTION

The study area was restricted to the main river channel and did not consider the tributary streams and rivers except as sediment sources. The upstream end of the study was at Great Slave Lake (km 0.0 on the hydrographic (navigation) charts). The downstream end was at Point Separation (km 1475) where the Mackenzie Delta begins.

The basic objective of the study was to identify where the development of riverbed alluvium as a source of granular borrow materials would be feasible. The primary questions to answer were:

a) where do geologic and hydrologic evidence suggest that coarse granular alluvium will be found in the riverbed?
b) where might these deposits satisfy local shortages in conventional (upland) borrow material supplies?
c) how do the economics of dredging and transporting riverbed alluvium compare with conventional borrow pit development?
d) what environmental constraints might affect riverbed dredging?

A rating system was developed combining geologic and hydrologic data in order to identify the potential for granular material in various parts of the river. In addition, the available upland borrow resources were identified for various parts of the river.

Another major component of the overall study was a review of the riverbed borrow development undertaken for the Norman Wells Expansion Project. The information acquired prior to and during the NWEP is by far the most detailed available assessment of any part of the riverbed and the effects of dredging on the Mackenzie River.

The final requirement of this study was to outline subsequent work needed to develop an inventory of riverbed granular resources. Suggestions for both geotechnical and environmental field studies are provided.

3.0 NORMAN WELLS EXPANSION PROJECT

3.1 RIVER REGIME

The channel in the middle part of the Mackenzie River is described by Northwest Hydraulics (1979) as being irregular and slightly sinuous. It is characterized by alternations of single-channel reaches with much wider multi-channel reaches, divided by islands. The Norman Wells area is typical of the multi-channelled reaches. Northwest Hydraulics (1979) interprets that the Mackenzie is somewhat oversized and that the islanded reaches are even more oversized than the general case in terms of cross-sectional area for the present flow. Two possible explanations are given for this. These are:

i) the dominant flow that shapes the river occurs when the channel is partially blocked by ice, or
ii) the channel was formed by larger flows in the past and it has not reached equilibrium for present flow rates

In evaluating these alternatives Northwest Hydraulics (1979) noted that there is little direct evidence that ice jams and the flooding at break-up constitutes an important part in the shaping of the river. There are no scour holes associated with ice damming and rapid shifts of the river are not common. Therefore, it was concluded that the Norman Wells reach appears likely to be one of sediment accumulation and slowly rising bed levels.

The riverbed alluvium therefore should be representative of the present bedload rather than some previous (post-glacial?) depositional environment. ESSO's data clearly shows that along the main channel, the alluvium consists of sandy fine gravel. The source of this gravelly alluvium could be from the numerous tributary rivers which enter the Mackenzie upstream of Norman Wells. Analysis suggests that a substantial local reach of the river, extending from the Great Bear River almost to Sans Sault Rapids, may have a similar bedload.

3.2 ESSO'S DREDGED GRAVEL

As part of the Norman Wells Oilfield Expansion project, ESSO dredged approximately 174,000 m^3 for each of six islands, 114,000 m^3 for pads and roads and 400,000 m^3 for pipeline trench fill. In total, approximately 1,800,000 m^3 of river borrow was anticipated in ESSO's dredging permit application (ESSO, 1982). An allowance of approximately 15 percent was included for losses during construction.

ESSO's dredging permit allowed for the recovery of granular borrow from the slopes of the main channel adjacent to the island sites but not in the shallow, flat areas nearer the islands because of the risk to fish habitat (S. Hunter, personal communications). The dredge areas were typically between 100 and 150 m from the islands depending on the floating pipeline and the river currents. Figure 3.1 shows where dredging is believed to have occurred. The actual dredge areas were selected for convenience rather than on the basis of some previously identified preferred location. This implies that ESSO was able to find, within the construction area, useable borrow wherever they required it.

Figure 3.2 shows a composite gradation curve for 27 samples of dredged borrow that was used for island fill. These samples were taken from the above-water part of the islands. They therefore represent an 'as-dredged' evaluation of the borrow in contrast to the gradation that would be determined from borehole samples. The borrow would be classified as a sandy gravel to a gravelly sand with a topsize of at least 150 mm (6 inches) and a fines (silt and clay) content of less than 5 percent. Although on some individual gradation curves gap grading of the borrow is indicated, this is interpreted to be the results of gradation separation during the placement of materials. Generally the material is well-graded (to an engineer, and poorly graded to a geologist).

3.3 SOURCE OF BORROW

Very little has been reported on the nature and origin of the gravelly alluvial sediments at Norman Wells. However, there is more information resulting from the Norman Wells Expansion Project than for almost any other location on the river.

The following description of the surficial geology has been taken from Komex (1980).

3.3.1 Quaternary Geology

The Quaternary history of the Mackenzie Valley in the vicinity of Norman Wells is described by Mackay and Mathews (1973). During the last (Wisconsin) glaciation, glaciers advanced northward along the Mackenzie Valley, removing interglacial soil and leaving a veneer of glacial till. A second ice lobe moved westward through the area of Fort Good Hope. While the ice front through Fort Good Hope dammed the valley's natural drainage, recession of the Mackenzie Valley ice lobe caused the formation of a small proglacial lake having a maximum elevation of about 240 m (790 feet). Recession of the Fort Good Hope ice lobe extended this lake into the Ramparts River lowland, eventually allowing drainage over the Ontaratue-Rampart divide about 11,000 years B.P. The lake elevation at this stage was reduced to about 95 m (310 feet). (Mean water level at the Norman Wells dock is approximately 39.5 m).

Existing beach lines and silty clay encountered in exploratory wells in the Norman Wells area indicate that the upper level of the (glaciolacustrine) deposit was likely about 70 m (230 feet) (Hughes, 1970; Kurfurst, 1973; Isaacs, 1974).

Two major spillways formed in the divide near Fort Good Hope. The higher of the two, the Fossil Lake spillway at 65 m (215 feet), was abandoned about 6,000 years B.P. Downcutting continued through the Upper Ramparts to form the present Mackenzie river channel and valley.

In recent times, the Mackenzie River has cut through the lacustrine clay deposits, which have been removed to varying degrees along the north (right) bank. The clay has apparently been eroded completely from the area of the (NWEP) Fieldgate and Settling Ponds. However, Isaacs (1974) reports that glaciolacustrine clay is found further downstream of these sites on the north (right) bank of the Mackenzie. Following erosion of the clay, an alluvial flood plain developed along the north (right) bank of the Mackenzie River and formed alluvial deposits of clayey silt and silty clay, with traces of sand and gravel. In addition, alluvial deposits of silt and fine sand have formed a series of islands in the Mackenzie River, including Bear and Goose Islands. The alluvial deposits in the riverbed range from silty fine sands to gravels, and overlie the glaciolacustrine clay.

3.3.2 Recent Alluvium

From the preceeding description, it appears that the gravel and sand that ESSO dredged comprises recent alluvial sediments. Figures 3.3 and 3.4 provide short cross-sections compiled from boreholes by EBA (1978). The approximate location of these sections is shown on Figure 3.1. They indicate that the recent alluvium is approximately 2 to 3 m thick above the glaciolacustrine clay.

The alluvium is probably highly mobile. Navigation charts prepared by the Canadian Hydrographic Service show that during the navigation season the river flows at about 3.5 knots (1.8 m/sec.) at Norman Wells. Seasonally this will vary and it is not clear whether the reported velocity is a maximum or an average. This velocity is sufficient to move particles to 7 mm diameter by bedload transport (Church and Gilbert, 1975). At break-up, the river level may rise and fall more than 4 m during which current velocities of as much as 2.05 m/sec. are possible. This would move gravel up to 10 - 12 mm ie: fine gravel (Northwest Hydraulics, 1979). Therefore with some degree of confidence, it is possible to interpret that most of the granular material is part of the active, contemporary bedload alluvium. The distribution of similar conditions can be reasonably expected to extend downstream to at least Sans Sault Rapids and upstream to Fort Norman (River Zones XIII to XV described in Section 4.0 of this report).

Northwest Hydraulic Consultants Ltd. (1979) suggests that deposits of coarser gravel and cobbles are likely to have originated from inflows of higher energy tributary streams, from local erosion of coarser deposits in banks or from ice rafting. In the deeper portions of the river, however, active bedload transport of sand and fine gravel probably occurs under most open water conditions.

3.4 BORROW EXPLORATION

3.4.1 Sampling Methods

When ESSO planned the NWEP river construction, they conducted, through geotechnical consultants, several riverbed sampling programs. Subsequently they developed designs for the islands based on the use of sand for borrow. Their data suggested that they would have to be selective of the borrow because the alluvium was quite silty in places. It was only when the dredging actually commenced, did it become apparent that the quality of borrow was much better. This is pointed out, not to be critical of ESSO or their consultants (which included EBA), but to demonstrate the limitations of the sampling procedures they employed.

In EBA's 1978 program and Komex's 1981 and 1982 programs for ESSO at Norman Wells, a B-40 hollow stem auger drill was used to test the borrow prospects. In 1980, the Komex-Geocon program relied on a diamond drill to advance casing. With either rig, sampling was achieved by driving a 381 mm split-spoon sampler.

Split-spoon sampling is not totally representative, because it is intermittent and limited to material that will enter the sampler. Generally the 45.7 cm sampler is driven at 45.7 m intervals to sample about 50 percent of the material penetrated. However, in gravelly soils recovery is poor because large gravel blocks the sampler or the non-cohesive soil slips (washes) out as the sampler is withdrawn through the casing. Recovery therefore depends on the relative density of the non-cohesive sediment and on the topsize of the sediments. Figure 3.2 suggests that at Norman Wells, up to 30 percent of the particles would have been too large to be sampled.

It is believed that the sampling program conducted for ESSO indicated silty sand and not the sandy gravel that was eventually dredged, because the split-spoon sampler will recover most silty sediments and lose most clean sediments. Also it will not recover gravel in representative proportions.

In EBA (1978) these sampling limitations were noted with the following comments. 'Very few texturally-representative samples of sand or silt were taken as a result of foreseeable difficulties that were encountered in retaining loose, cohesionless soils below water level. Judging from drill action observed while penetrating the surficial sands and gravels, it is thought that the actual gravel content is substantially higher than the grain size curves (EBA, 1978) would suggest. Both standard and dynamic cone penetration resistance varied considerably within this (riverbed alluvium) stratum probably as a direct result of the significant gravel content'. This report indicated that cobbles and boulders were also suspected.

Komex (1980) noted the presence of cobbles and boulders was inferred in at least five of their boreholes. 'Undetected cobbles and boulders may exist at other (locations), either randomly or in concentrations'. Elsewhere it is reported that the cobbles and boulders are 'more likely along the north (right) side of the main channel'.

3.4.2 Geophysical Methods

ESSO also tried to map the riverbed alluvium by means of a ground penetrating radar system. It was operated from the surface of the ice in the 1981 program conducted by Komex. Thirteen profiles were completed mainly for proposed riverbed pipeline crossings. In some areas, there was penetration of the alluvium and the contact with the underlying glaciolacustrine clay could be distinguished. However, for most of the profiles penetration was not achieved and the profiles were only suitable for determining water depth (Steve Hunter, personal communication).

More conventional seismic or E-M techniques were not attempted at Norman Wells. ESSO at that time believed they had sufficient and reliable riverbed information from the boreholes.

It is now thought that E-M techniques would have been successful at mapping the thickness of recent alluvial sediments and may have successfully identified gravelly zones from silty sand sediments (C. Nelson, personal communication). Experience with E-M mapping of granular sediments underwater is relatively limited even at present. In 1980-82, it was an untried method in northern Canadian borrow exploration.

Conventional high resolution shallow seismic methods would not likely have contributed much to the evaluation of borrow at Norman Wells. The relatively dense surface of the riverbed alluvium would have a high reflection coefficient for which multiples would mask the next several metres of the sediment profile. Since these deposits are generally only 2 to 4 m thick too much critical data would have been lost. The relatively shallow water and variable water depth would also have created problems. The interference from echos of that surface would obscure significant parts of the records.

4.0 GEOLOGIC FRAMEWORK - MACKENZIE RIVER

4.1 RIVER ZONES

The morphologic properties of various reaches of the Mackenzie River can be identified, grouped, and used in association with certain controlling variables (eg. gradient, sediment type, discharge) to subdivide the entire river between Great Slave Lake and Point Separation into nineteen sections with distinctive fluvial regimes. These zones vary in length from 26 km to 176 km. Table 4.1 summarizes geographic features identifying the River Zones.

Information on regional Quaternary and bedrock geology (including the description and distribution of surficial bedrock and unconsolidated deposits in the upland) was intergrated with river regime data to describe the overall hydrologic and geologic setting of each river zone. The geologic setting contains the basic information used to determine the granular material potential for the riverbed, the relationship of potential granular riverbed deposits to upland deposits, and the properties for each zone. The compilation of this regional information appears on Table 4.2.

4.2 MORPHOLOGIC PROPERTIES OF THE RIVER

The morphologic properties and regime relationships observed for the Mackenzie River near the Norman Wells deposit (Northwest Hydraulics, 1979) have been applied to the entire Mackenzie River between Great Slave Lake and Point Separation. The morphologic features observed for each of the nineteen river zones of the river include: a) channel pattern, b) presence of islands, c) height of river banks, d) width of channel, and e) depth of channel. These are discussed below.

4.2.1 Channel Pattern

Channel patterns show the configuration of the river in plan view and represent the channel adjustment to channel gradient and cross section (Reineck and Singh, 1975). Controlling variables including channel gradient, quantity and character of sediments carried, and amount and nature of flow, affect the channel pattern.

The Mackenzie River as a whole is an irregular and slightly sinuous river characterized by alternation of single channel reaches with much wider multi-channel or braided reaches. The entire channel pattern is intermediate between the continuous single channel and a fully braided pattern and as a result the Mackenzie has a relatively higher bedload and gradient than a single channel river (Northwest Hydraulics, 1979).

Three major channel patterns were identified including; a) straight and single, b) braided, and c) meandering were identified. Several transitional cases including; a) straight transitional to braided, b) braided transitional to straight, and c) braided transitional to meandering were also indicated (see River Landforms, Table 4.2). For the most part the braided and braided transitional to straight zones with higher bedloads had better potential for granular material sources in the riverbed than did the straight channel sections.

4.2.2 Islands

The presence or absence of islands in each river zone was important to the classification of the channel pattern as single, braided, meandering or transitional. Generally, numerous islands are found in multi-channel or braided reaches. Information on alluvial sediments in the islands was obtained from surficial geology maps, from boreholes in the river (Public Works Canada, 1976), and from notes on hydrographic maps (Canadian Hydrographic Service, 1983-1986).

4.2.3 Channel Cross Section

The morphology of the channel or the channel cross-section (including width and depth of channel and height of banks) is a function of flow, quantity and character of sediment being moved and the character of sediment in the channel and the banks or upland. Single channel sections are generally wide and shallow and somewhat oversized in terms of cross sectional area. Single and straight channel reaches usually have bank-to-bank widths from 0.75 to 3 km; although through three straight channel sections near Great Slave Lake and at Mills Lake the river can be from 4 to 17 km wide.

The multi-channel reaches are even more oversized in cross sectional area than single channel reaches. Multi-channel or braided reaches have significant variations in bank-to-bank widths but are usually from 1.0 to 6.5 km wide. In the wider multi-channel reaches bank-to-bank width unobstructed by islands can be to 4 km or more. This may indicate that during dominant flow condition ice jams may have rendered a substantial part of the cross section ineffective. However, the channel pattern for the Mackenzie River is similar to other southern rivers and scour features formed when ice causes local concentrations of bottom currents and found on most northern rivers are missing from the Mackenzie. Therefore, the oversized nature of the Mackenzie channel is not totally understood and it may be caused by other factors in its history (Northwest Hydraulics, 1979).

4.3 VARIABLES AFFECTING RIVER REGIME

Channel gradient, sediment type and quantity, and amount and nature of discharge are variables which affect both channel patterns and the channel cross section. Some information relating to these variables have been compiled for the nineteen river zones.

4.3.1 Channel Gradient

Channel gradient has a weak inverse relationship to dominant discharge (Northwest Hydraulics, 1979). In sand bed channels like the Mackenzie River, gradient is relatively insensitive to discharge and more sensitive to channel pattern or bed-sediment load. The river profile, Figure 4.1, was developed to show channel gradients along the Mackenzie relative to the zones with distinctive channel patterns.

The channel gradient was also used as a factor in rating the granular potential in the riverbed of each zone. For example, eight river zones have straight channels with few islands. These eight have low channel gradients (0.01 to 0.10 m/km) and also exhibit low potential for granular deposits in the riverbed. Conversely, in the four of the five river zones with high or moderate to high potential for granular material, channel patterns are braided or transitional to braided. Channel gradients in these four high potential zones range from 0.12 to 0.30 m/km.

4.3.2 Sediment Type and Quantity

Sediment data for the entire Mackenzie River is limited. Surficial geology maps, notes on 1:50,000 navigation maps, boreholes from river dredging programs, some riverbed sediment sampling at Norman Wells (Section 3.0), and suspended sediment sampling at Arctic Red River and Fort Simpson are the only sources of this type of data. There is essentially no detailed bedload information except for near Norman Wells.

Suspended sediment concentrations (discussed in Section 6.1.2), at gauging stations near Ft. Simpson and Arctic Red River show high concentrations of silt and clay with only 10 to 20% fine sand carried during higher flows (Northwest Hydraulics, 1979). In 1974, both stations recorded peak sediment concentrations of nearly 10,000 mg/litre (approximately 1 percent by weight, but concentrations are usually <1000 mg/litre).

Calculations of bed material mobility done by Northwest Hydraulics for the Norman Wells area indicates that the maximum size of transportable material is from 6 to 12 mm (fine to medium gravel) depending on flow. Deposits of coarse cobbles or gravel in the riverbed near Norman Wells have probably originated from the inflow of higher energy tributary streams, from local erosion of coarser bank deposits, as from transport by ice (Northwest Hydraulics, 1979).

In Table 4.2, information on the principal types of alluvium found in the river deposits of each zone is compiled. Surficial geology and navigation maps provided the first level of information. Boreholes (approximately 270) giving some indication of riverbed conditions for Zones I to IV, VI to VIII, XI to XIII and XV, provided the more site specific information on river sediments. The locations and schematic logs of 50 of these boreholes appear on strip maps presented as Drawings 4.1 (a to g). These 50 have been selected to be representative of conditions encountered in each area. Because the 270 boreholes were clustered in areas where water depths presented potential navigational problems, many of them can be represented by one log.

Table 4.1, also contains a listing of the principal rivers and creeks which supply sediments to the Mackenzie. Those with gravel beds which could actively provide coarse material to the Mackenzie are so indicated in this column. Notes on the table regarding the landforms and topography of the river bank or upland indicate aspects of the geologic setting (eg; grain size of surficial deposits) which could affect sediment supply to the Mackenzie and its tributaries.

4.3.3 Discharge

Flood frequency and dominant flow rates are major factors in the transportation and riverbed exposure or burial of granular alluvium. Although some data is available on flow rates (see Section 6.1 and Appendix A) it could not be reliably related to each of the nineteen separate river zones. Detailed extrapolation of historical data from the four mainstem hydrometric stations to the nineteen river zones was beyond the scope of this assignment.

4.4 PHYSIOGRAPHY AND REGIONAL GEOLOGY

Elements of physiography and regional geology including the distribution of bedrock and Quaternary deposits as well as river regime data have contributed to development of the geologic model or framework used to predict the occurrence of granular deposits in the Mackenzie River. These are discussed below for the four major physiographic divisions identified by Bostock, 1969.

4.4.1 Great Slave Plain (River Zones I to VII)

From km 0 at Great Slave Lake to km 410 near Camsell Bend, the Mackenzie River crosses the Great Slave Plain of the Interior Plains region. This area is comprised for the most part of low lying terrain. It is generally below an elevation of 305 m, rising gently to the south and has a regional relief near Ft. Simpson of 152 m in 80 km (Rutter et al, 1973). Northwest of Ft. Simpson the plain rises more steeply culminating in the Martin Hills Uplands to the south and the Ebbutt Hills to the north.

Upper Devonian and Cretaceous sedimentary bedrock (limestone, sandstone, siltstone, mudstone, shale) underlies the plain. Quaternary glacial deposits comprising fine-grained morainal and glaciolacustrine deposits with scattered coarse-grained glaciofluvial deposits, and fine and coarse-grained post-glacial deposits (alluvial, colluvial, and organic) overlie the bedrock. Scattered permafrost is present, particularly in till and glaciolacustrine materials beneath the ice-rich organic cover.

Major rivers which flow into the Mackenzie include; the Liard, Trout, Redknife, Jean Marie, Harris and Martin rivers. Only the Trout and Jean Marie which drain on limestone upland south of Mackenzie River have gravel beds (see River Topography, Table 4.2).

4.4.2 Mackenzie Plain (River Zones VIII - XIII)

From km 410 (Burnt Island south of Camsell Bend) to km 955.7 (Patricia Island north of Norman Wells), the river crosses the Mackenzie Plain which is a narrow area that lies between the Mackenzie and Franklin Mountains. The river is located toward the eastern side of the Mackenzie Plain near the Franklin Mountains. The land west of the river and east of Mackenzie

Mountains is a dissected piedmont. Local relief throughout Mackenzie Plain varies but a difference of 915 to 1219 m between the river and the mountains over a distance of 6.5 to 8 km is not uncommon (Rutter et al, 1973).

The highly folded Franklin and Mackenzie Mountains contain complex bedrock including limestone and dolomite of Devonian age. The lowland adjacent to the Mackenzie River is underlain by mudstone, shale, and sandstone of Upper Devonian and Lower Cretaceous age. Bedrock outcrops are confined to the mountains, deeply dissected piedmont areas, and major rivers, outcrops are more common along the Mackenzie River toward the north end of the Mackenzie Plain.

Bedrock is overlain by a covering of glacial and post-glacial deposits. Fine-grained morainal and glaciolacustrine deposits are the most common surficial materials in lowland areas. Glaciolacustrine silts and clays are often found at ground surface below 150 m in the Mackenzie Plain with some occurrences to 300 m west of Ft. Simpson. Morainal deposits of silty clay till (<20 percent gravel) underlie glaciolacustrine materials and are at ground surface above the glaciolacustrine plain inland from the river. Some glaciofluvial deposits containing sand and gravel are also found on Mackenzie River high terraces, in abandoned meltwater channels, and as scattered ice contact deposits overlying fine-grained till.

Recent gravel and sand alluvium is found along existing rivers and streams and mostly fine with some coarse-grained colluvium is associated with steep slopes. Recent organic materials overlie fine-grained glaciolacustrine and morainal deposits. Permafrost is discontinuous in fine-grained materials south of Willowlake River (km 520) and fairly continuous in these materials north of Willowlake River.

A dense, well-intergrated drainage network is present. Some streams flow into the Mackenzie off the adjacent piedmont and uplands and others cut across the mountains from the plains to the east and from mountain ranges to the west. Major rivers with sand and gravel beds flowing from the limestone mountainous terrain to the west into the Mackenzie include the Nahanni, Root, Dahadinni, Redstone, Keele, and Little Bear Rivers. Rivers from the east (with gravel beds) which cross limestone mountains and which at some time during glaciation carried coarse-grained glaciofluvial materials included the Willowlake River, River-Between-Two-Mountains, Ochre, Blackwater, Wrigley, and Great Bear Rivers. Also approximately 37 smaller rivers and creeks, many with sand and gravel beds, drain into the Mackenzie River across Mackenzie Plain from the east and the west.

4.4.3 Franklin Mountains - Mackenzie Plain (River Zone XIV)

From km 955.7 (Patricia Island north of Norman Wells) to km 1017 at Sans Sault Rapids the Mackenzie River forms the boundary between the Franklin Mountains on the east and Mackenzie Plain on the west. Elements of Franklin Mountains persist east of the river and Mackenzie Plain features are to the west. The Norman Range of the Franklin Mountains lies 10 km east of the Mackenzie River. Carcajou Ridge and East Mountain, east-west trending outliers of the Franklins, lie adjacent to Mackenzie River.

The Franklin Mountains are isolated structural ridges separated by broad, drift-filled valleys. The ridges are developed on resistant Paleozoic carbonate rocks (Hughes, et al, 1973). The Mackenzie Plain is an area of low elevation and relief, underlain by shale, siltstone, and sandstone of Cretaceous and Tertiary age. Locally in the Imperial Hills relief is developed on Lower Paleozoic carbonate rock.

Fine-grained glaciolacustrine and morainal deposits with thick organic cover are the most common surficial materials at ground surface. On the east side of the Mackenzie, glaciolacustrine silts and clays predominate in low-lying areas. On the west side of the Mackenzie River, morainal deposits are found close to the Mackenzie from km 966 northward to Maida Creek (km 1001). North of this area, below 150 m, glaciolacustrine materials are at ground surface. Extensive coarse-grained glaciofluvial deposits are also found upstream on the Mountain River and a fairly large glaciofluvial deposit is located on the north side of Carcajou Ridge. Permafrost is fairly continuous in the Mackenzie Plain and high ice contents exist in the fine-grained morainal and glaciolacustrine deposits. Thermokarst features are also common in the glaciolacustrine materials.

Recent alluvial and colluvial deposits are located along modern rivers and on bedrock and river valley slopes. The Carcajou and Mountain rivers with sand and gravel beds drain into the Mackenzie River from the uplands to the west. Mountain River also cuts through extensive glaciofluvial deposits.

4.4.4 Peel Plain - Anderson Plain (River Zones XV to XIX)

The Mackenzie River forms the boundary between the Anderson Plain and Peel Plain from San Sault Rapids (km 1017) northward to Pt. Separation (km 1475). Peel Plain on the southwest side of the Mackenzie River is a remarkably flat, poorly drained plain except for relief of 229 m in Grandview Hills and a few prominent morainic hills between Ft. McPherson and Arctic Red River (Hughes et al, 1973). The southern and central parts of the plain are underlain by flat-lying Lower Cretaceous shale and minor sandstone and the northern part by flat-lying shale and sandstone of the Devonian Imperial Formation.

Anderson Plain to the east of the Mackenzie is broadly dissected, undulating terrain distinctly different from Peel Plain (Hughes et al, 1973). East of 130° 30' the plain is underlain by Middle Devonian limestones and shales with some plateau summit areas capped by Cretaceous sandstone and shale; the western part is underlain by sandstone and shale of the Upper Devonian Imperial Formation. The highest parts of Anderson Plain lie close to the Mackenzie River and much of the plain has a broad regional slope northward. Local relief of 150 to 228 m in Anderson Plain was sufficient to control movements of the last Laurentide ice-sheet. As a result a complicated array of glacial deposits (frontal moraines, meltwater channels, glaciofluvial deposits and glaciolacustrine materials) are superimposed on the irregular upland.

From San Sault Rapids to the Ramparts (River Zone XV) fine-grained glaciolacustrine deposits predominate east and west of the Mackenzie. Near the Ramparts (River Zone XVI) fine-grained moraine plain deposits are most common east of the river and moraine veneered bedrock lies west of the river.

In River Zones XVII and XVIII both fine-grained morainal and glaciolacustrine materials are present. From the Ramparts north to Payne Creek east of the river, flat moraine plain deposits are most common. To the west of the river glaciolacustrine materials predominate.

East of the Mackenzie from Payne Creek in River Zone XVII to Rabbit-Hay River in River Zone XVIII glaciolacustrine silts and clays are wide-spread below 150 m and morainal deposits of till cover the uplands above 150 m. On the west side of the river morainal deposits are more continuously at ground surface.

From Rabbit-Hay River in Zone XVIII to Pt. Separation at the north end of Zone XIX, fine-grained moraine plain, veneer, and hummocky moraine lie both east and west of the Mackenzie River.

Glaciofluvial sand and gravel deposits are scattered throughout the Anderson Plain - Peel Plain region and exist as ice contact deposits overlying moraine plain materials. Large glaciofluvial deposits are found west of the Mackenzie River near the Ramparts and east of the river near Ft. Good Hope. Smaller deposits occupy old glaciofluvial channels including the valleys of Loon, Tieda, and Thunder Rivers. Ice contact deposits, eg; the esker at Arctic Red River, are at scattered localities overlying moraine plain deposits.

Organic deposits form an extensive cover over fine-grained glaciolacustrine and morainal materials. Permafrost is continuous in these fine-grained deposits and ice inclusions are also found in some of the coarse-grained glaciofluvial materials.

Alluvial deposits exist along present rivers and streams. Many of the rivers which cross glaciolacustrine plain deposits have sandy alluvium while the rivers and streams which dissect morainal deposits have both sand and gravel alluvium.

Approximately 23 small to medium sized rivers and streams dissect the Anderson-Peel Plain physiographic division. Arctic Red River, which is fairly large, flows into the Mackenzie River in River Zone XIX.

5.0 ECONOMIC CONSIDERATIONS

5.1 UPLAND GRANULAR RESOURCES DATA

Granular resources information from two reports (Hardy, 1986; and Pemcan, 1972) were utilized to compile a summary of the available granular materials data along the length of and within approximately 15 km on either side, of the Mackenzie River. Data north of Norman Wells was obtained from the Hardy report, and the information south of Norman Wells was from the Pemcan series of reports. The information in the Hardy report appears to be complete. The Pemcan reports are obviously dated and do not exclude any significant granular resources that may have been used for pipeline, road construction or local community use, since 1972. For comparative purposes, however the information is adequate for the level of this study.

All deposits 15 km either side of the Mackenzie River were identified and are summarized in Table 5.1. Environmental factors, access concerns, specific quality, permafrost conditions etc. were not considered. The volumes shown, represent the total volume indicated in the references. Table 5.1 also includes a summary of the information available for fine sand and sand/gravel occurring the channel for each River Zone.

In order to better characterize the location and availability of the upland resources, the river was divided into 59, 25 km subzones for which the granular resources data was summarized. Figure 4.1 indicates the volumes of coarse sand and gravel available only and excludes any fine sand material.

Figure 4.1 shows that there is a scarcity of good granular material at the north and south ends of the river. Zones I to VIII (0-500 km) lack good identified material except for a small section downstream of Fort Simpson.

Similarly, from 1325 km to 1475 km, there doesn't appear to be much upland borrow. Furthermore, there appears to be two other sections, 750 to 875 km, and 1000 to 1100 km, that may be short of upland borrow.

5.2 GRANULAR RESOURCES DEMAND INFORMATION

5.2.1 Local Community Requirements

INAC community officers and GNWT granular resources managers were contacted regarding Mackenzie River community granular requests from 1987 to 1991. Table 5.2 summarizes the granular materials requirements that were identified. Generally, adequate local supply exists in all areas except for:

Jean Marie River:	Granular material is imported in the winter
Arctic Red River:	Granular material is hauled in the winter from the Fort McPherson area

5.2.2 Highway Requirements

Public Works Canada were contacted regarding the locations where granular resources might be required. Information provided by Public Works is summarized below.

a) Fort Providence to Fort Simpson:	-no information available
b) Fort Simpson Area (km 475-552):	-63,000 m^3 are presently stockpiled and additional 10 - 60,000 m^3 is required.
c) Hardie River to River Between Two Mountains:	-DPW are apparently presently searching for additional gravel.

d) Willowlake River Area: -63,000 m^3 have been stockpiled and and additional 10,000 m^3 will be required.

e) Wrigley Area (km 631-693): -48,000 m^3 have been stockpiled and an additional 10,000 m^3 are required. A new nearby pit has been developed for this requirement.

It appears that at present, most Mackenzie Highway granular resources requirements are being satisfied adequately utilizing local gravel pits.

5.2.3 Airport Requirements

Transportation Canada was contacted regarding future granular resources requirements for airport construction and maintenance along the Mackenzie River. In summary, the following information was provided:

Norman Wells: Granular material will be required in 1987. Approximately 10,000 m^3 will be removed from local quarries and an additional 1-2 tonnes will be excavated from the riverbed.

Fort Good Hope: 20,000 m^3 will be required for a new runway. Date required is unknown.

Arctic Red River: Approximately 150,000 m^3 will be required to accommodate a 1.5 m thick permafrost design pad. Date of construction is not known.

Fort Providence: Approximately 8,000 m^3 is required for cut and fill purposes. No date is known.

From the information presented, it appears that the required volumes can be satisfied with the present available sources except in the Arctic Red River area which lacks good local granular material.

5.2.4 Pipeline Requirements

Gulf Canada Corporation was contacted regarding borrow requirements for pipeline construction. Gulf Canada, PeBen and partners completed in 1986 the most recent of many pipeline studies. This study considered a 508 mm (20 inch) to 610 mm (24 inch) diameter pipeline, from Richards Island in the north to Zama Lake in the south. The specific location of the route is proprietary but in general follows the course recommended during the Beaufort Delta Project. This study group identified that their project would require approximately 2 million m^3 of select granular material.

In contrast to this, an analysis of the Canadian Arctic Gas Pipeline Limited (CAGPL) proposal for a 1220 mm (48 inch) gas pipeline which was conducted by EBA (1980) for Polar Gas Pipeline Ltd. indicated much greater volume requirements. Between Thunder River (km 1300) and the Jean-Marie River area (km 270), CAGPL's construction plans required 11.1 million m^3 of borrow material. North of Thunder River and south of Jean-Marie River the CAGPL route is a considerable distance from the river. Part of the difference between CAGPL's and Gulf Canada's pipeline design may be that the CAGPL figures include all borrow requirements for compressor stations, airstrips, construction campsites and access roads; whereas Gulf are only considering pipe bedding and select backfill.

5.2.5 Potential Borrow Demand

Although upland granular material is scarce in many areas along the Mackenzie River, current demand by the communities, for airstrips and highways can be met in the majority of cases by the present available upland resources. It is not clear whether the demand for granular material would increase if economical supplies of riverine borrow became available. Furthermore, as long as large diameter pipeline projects such as Polar Gas are being considered, it is feasible that very major demands might develop.

5.3 BORROW DEVELOPMENT COSTS

5.3.1 Upland Deposits

Gulf Canada Corporation, IPL, PeBen Ltd. and Public Works Canada (PWC) were contacted regarding upland borrow economics, for pipeline and road construction purposes. The following cost figures for borrow material were presented for pipeline construction:
$39/m^3 north of Norman Wells
$23/m^3 south of Norman Wells

Due to the proprietary nature of the pipeline studies, no detailed breakdown of these figures was provided, however they are all-inclusive of:

- access road development
- excavation
- stockpiling
- haulage
- equipment mobilization
- borrow area development etc.

It is assumed that the costs are higher north of Norman Wells due to the more sensitive nature of the terrain (permafrost conditions requiring additional preparatory work), higher excavation costs in frozen (permafrost) granular deposits, and higher equipment mobilization costs.

It was indicated by Gulf Canada that these figures include an average haul distance, which was not specified. A review of maps by Hardy (1986) and Pemcan (1973) indicated that on average potential borrow areas occur every 5 km along the 'proposed' pipeline route. However, it would be likely that greater haul distances, say, on the order of 12 to 15 km, would be selected because of the high cost of pit development.

Public Works Canada (PWC) presented the following cost figures, for material being removed from an existing pit:

Excavation cost: $3.90/m^3$

Haulage cost: $1.20/m^3/km$

These figures do not include many of the development cost factors included in the Gulf Canada cost figures, and represent a minimum condition.

Some estimated production costs for the Tuktoyuktuk area were presented in a report to INAC by EBA (1983). In this area, pit development costs are generally low because there is no tree clearing and generally low overburden ratios. Haul costs vary depending on whether there is overland or ice road hauling involved. A general breakdown of the Tuktoyuktuk cost would suggest the following cost factors are appropriate for that area:

a) Pit Development	$1.00 - $1.50/m^3$
b) Excavation	$3.50 - $4.00/m^3$
c) Haul Road Development (Winter)	$0.20/km/m
d) Overland Haul	$1.00/m^3$/km

e) Ice Road Haul $0.80/m^3/km$

For areas along the Mackenzie River south of the treeline and north of Fort Good Hope where the granular deposits are naturally frozen (permafrost) (EBA, 1973), the following cost factors appear to be reasonable:

a) Pit Development	$1.00/m^3
b) Excavation	$4.50/m^3
c) Access Road Development	$1.00/m^3/km (all weather road)
d) Overland Haul	$1.20/m^3/km (from PWC)

South of Fort Good Hope, excavation costs would be about $4.00/m^3 (approximately PWC's $3.90/m^3) and the cost of haul road construction would be $0.50/m^3/km because of less stringent requirements to protect permafrost terrain.

On this basis, the pipeline rates of $39./m^3 and $23./m^3 obtained from Gulf Canada appear high. In that regard, the following comments are presented:

a) The break between $39./m^3 and $23./m^3 rates would likely be at Fort Good Hope, not Norman Wells. Work by EBA (1973 and 1974) suggests that deposits between Norman Wells and Fort Good Hope will not be frozen.
b) Assuming an average haul distance of 15 km of which 10 km in on pre-developed pipeline right-of-way, the appropriate cost figures would appear to be $28.50/m^3 and $25.50/m^3. The disparity between north and south appears to be unreasonable.
c) The pipeline cost of select gravel probably includes a processing cost including crushing, screening or washing, and stockpiling. Although this will add to the cost of developing borrow, it is unlikely to

exceed $1.00/m^3 in the worst areas (for pipeline requirements). However, if material must be re-handled to remove from stockpiles which have been allowed to freeze, it could add $3.00 to $4.00/m^3 to the cost.

d) The relatively low volume of material indicated for pipeline requirements (only 2 million m^3 for over 2000 km of pipeline) suggests that the pits would be small. Therefore the development cost per cubic metre would be relatively high.

5.3.2 Riverbed Deposits

The cost of developing riverbed borrow and moving it to the site where it will be used has several components. Excavation can be by dredging or for small quantities drag line, clam shell or even backhoe equipment can be used. Transportation can be by barge or direct pumping by pipelines. For the following cost analysis dredging and barge transport has been considered because it appears most cost effective for moderate to high production rates.

For the Norman Wells Oilfield Expansion Project, a floating discharge pipeline was used to move the dredged borrow to the site of the islands or drill pads on Goose or Bear Islands. Costs to do this were approximately $2.70/m^3 for bulk dredging and $5.70/m^3 for pipeline dredging and backfilling. These figures include operating costs (fuel, oil, support equipment, etc.) but not mobilization or capital costs for the dredges and tugs.

ESSO costs for dredge mobilization were $570,000. for a 14 inch dredge and $1,100,000. for the 24 inch Arctic Northern (R. Tibbats, personal communications). For 1.8 million cubic metres of dredging, an equipment mobilization cost of $0.93/m^3 can be determined. For smaller quantities only one dredge would be required but mobilization cost on the order of \$1.00 to \$2.00/m^3 would be reasonable. Mobilization for tugs and barges must also be included.

Beaver Dredging (Western) Ltd. provided some useful information on the equipment requirements and economics of river dredging operations. Exclusive of equipment mobilization (and capitalization) there are four cost components to a river dredging for borrow operation. These are:

a) Excavation and loading at the borrow site
   - basic equipment would include a dredge and tender tug
b) Hauling equipment (assuming distance greater than 1 km which could be serviced by pipeline)
   - a number of barges and tugs would be required depending on the haul distance and the capacity of the dredge
c) Off-Loading Equipment
   - for small quantities loaders and trucks might work but this would limit production rates
   - for larger operations the borrow could be redredged off the barge and stockpiled on land or pipelined a short distance inland to the site of need
d) Rehandling Equipment
   - a conventional truck and loader operation to remove borrow from the docksite stockpile and move it to the site of need

Clearly, there are many variables in calculating the cost of dredging river borrow. The selection of equipment and production rates will change with haul distances, quantity requirements, and the relative distance of the site to which borrow is to be delivered from the landing or dock site. Typical operating cost for individual pieces of equipment (J. Waring, personal communications) are as follows:

a) Barge loading (or unloading) dredge (capable of producing 60,000 m^3/week) - \$35,000/week
b) River barges to transport the borrow (there are a limited number of these available in Canada) - \$ 4,200/week
c) Tugs to move barges and dredges - \$35,000/week
d) Loaders and trucks at the stockpile - \$21,000/week

Dredging is geared to high production rates and large volumes. For small quantities it is much too costly. Similarly, river hauling is most cost effective when distances are greater. Figure 5.1 provides a comparison of conventional upland borrow development costs with dredge and barge costs. Two cases are presented for dredging costs; large volume river production (8600 m^3/day) and volumes more comparable to conventional borrow pit production rates (1400 m^3/day). Table 5.3 summarizes estimated unit cost factors for the three cases presented in Figure 5.1.

There are a couple of significant factors that cannot be easily included in these estimates. The initial cost of mobilizing equipment is hard to define. For small operations, trucks and loaders can be contracted from the various communities along the river. For large volume operations, additional ones must be mobilized from the south. Similarly, for dredges and barges, if a small operation, say in the order of 100,000 m^3, was planned, locally available equipment could be modified to do the job. For a larger project or very long hauls, however, specially designed barges and dredges might be required to optimize the cost of the operation. Small production dredges are generally constructed on a job specific basis; however, ESSO was able to bring an existing dredge to Norman Wells when it was needed. Sand hauling barges are not a common commodity along the Mackenzie system. For a small operation it would be possible to convert same existing barges to suit; however, it might be more economic to construct appropriate ones if a large number of them were required for high volume operations or hauls exceeding 40 km.

6.0 ENVIRONMENTAL CONSIDERATIONS

6.1 HYDROLOGY

6.1.1 Hydrologic Regime

The purpose of this section of the report is to provide a general review and assessment of the natural variations in discharge, suspended solids, bedload transport, morphometric features and substrate conditions in major reaches along the Mackenzie River. A more detailed hydrologic description of mainstem reaches is provided in Appendix A.

The Mackenzie River is characteristically a turbid river and carries a relatively heavy silt load. In contrast, its smaller tributaries are generally gravel bottomed, faster flowing streams with clear water much of the year (F.F. Slaney and Company Ltd., 1973). Floodplain deposits of the Mackenzie River are dominantly silt and sand, except immediately downstream of major streams entering from the west (notably the Redstone, Keele and Mountain Rivers), where gravel typically overlain by silt, can be found for a few miles downstream (Hughes et al., 1973).

The Water Survey of Canada conducts hydrometric measurements at designated stations on the Mackenzie River. There are historical streamflow records for four hydrometric stations along the Mackenzie mainstem, between the outlet of Great Slave Lake to Point Separation at the head of the Mackenzie Delta (Inland Waters Directorate, 1985). Discharge summaries for these four stations are provided in Table 6.1.

The hydrologic regime of the Mackenzie River upstream of Fort Simpson is controlled by the natural regulating effects of Lake Athabasca and Great Slave Lake. The effects of regulating the Peace River at Bennett Dam are also apparent but not prominent. The ratio of highest to lowest flows have never exceeded 2 in any one year at Fort Providence; and, since 1968, minimum flows have generally occurred in September and October and maximum flows in June and July. At Fort Simpson, below the Liard confluence, the ratio of highest to lowest flows in any one year has varied from about 6 to 12; and, since 1968, minimum flows have generally occurred in November and December or late March and early April and maximum flows in June and July. Downstream of Fort Simpson, the large unregulated discharge conditions from the Liard and other major tributaries continue to dominate, and the ratio of maximum to minimum flows in any one year increases in a northerly direction to approximately 10 to 15 at the Mackenzie Delta.

6.1.2 Suspended Sediments

There are limited long-term data available on suspended sediment concentrations along of the Mackenzie River as a result of Inland Waters Directorate (IWD) monitoring. However, only three of the nine stations are located upstream of the Mackenzie Delta (Inland Waters Directorate, 1984; Western Ecological Services Ltd., 1985) and most sampling results are for the open water period only. Numerous short-term samplings of suspended sediments have also been reported during aquatic field surveys of various descripts. These 'spot' data were typically individual water quality samplings taken at different locations during fisheries surveys or at one location over short-term major events, eg: spring or summer flood events, break-up, freeze-up, etc.

All data indicate that most suspended sediment (98 percent) is carried in the May to October period and daily loads are highly variable and strongly influenced by storm events in the basin. Concentrations are typically in the range of 50 - 1500 mg/l below Fort Simpson although peak values of over 9,000 mg/l have been recorded (Inland Waters Directorate, 1980). Above the confluence with the Liard, concentrations are much lower and less variable. Brunskill et al (1973) recorded 100 to 200 mg/l of suspended sediment in the East Channel of the Mackenzie Delta in mid-summer, compared to 62 mg/l in October and 10.7 mg/l in November. In contrast Heigenbottom 1978 reported peak suspended sediment concentrations that have approached 10,000 mg/l near Arctic Red River. More direct data in this regard is presented in Appendix A.

6.1.3 River Morphology

Morphological aspects of the Mackenzie River have been studied extensively, however, most studies are either limited to a short river reach (such as the vicinity of a proposed pipeline crossing), or to a particular aspect of fluvial morphology (over a larger reach) such as ice-thrust ridges. Much of the watercourse is relatively stable, with well-defined channels. Incised reaches with banks of non-fluvial materials are common. These can be expected to be relatively insensitive to changes in the discharge regime. Sensitive unstable channel reaches, with low, erodible banks and shifting channels also occur. The most morphologically sensitive area of the Mackenzie River is the Delta which is outside the area being studied. The river reach from the Liard/Mackenzie confluence at Fort Simpson downstream to Camsell Bend is also rather unique. The east and west banks of the Mackenzie are morphologically very different due to slow mixing between the Liard and Mackenzie Rivers. The east bank resembles a lake outlet channel, characterized by a very stable coarse armour of cobbles and boulders. The west bank has an unstable sand substrate, characterized by shifting bars and islands (McDonald and Kellerhals, 1978).

The Mackenzie River system shows evidence of long-term degradation: valley entrenchment, unpaired terraces, and knick points in the long profile. Channel degradation, bank erosion and hillslope erosion supply more materials over extensive reaches than the river is capable of carrying. This results in the formation of islands and bars where channel conditions are favourable (Inland Waters Directorate, 1986). Under high flow conditions the river can transport sand and gravel up to about 10 mm in size as bedload, and it carries a substantial load of silt and clay in suspension. Rates of change in the locations of the major banks and islands are generally very slow. Changes in major sand bars are more rapid, although slow compared to many large alluvial rivers (Northwest Hydraulic Consultants Ltd., 1979).

There are large variations in sediment deposition in different stretches of the Mackenzie River. Public Works Canada have estimated the frequency of required maintenance dredging (ie: time for fill-in of previous dredging operations) for different segments of the river. From Great Slave Lake to Cameron Point (kp 425), the Mackenzie River is considered to need re-dredging 1 in 30 years. At Cameron Point, the estimate for maintenance dredging is 1 in 20 years. Other more rapid infilling areas include the west side of McGern Island and the Fish Trap Creek area where a dredging factor of 1 in 10 years is estimated, and the Blackwater River and Dahadinni River areas where the maintenance dredging requirement is estimated at 1 in 3 years (Public Works Canada, 1976).

6.1.4 Hydrology Concerns Related to Granular Materials Removal

The principal hydrologic concerns related to the removal of granular bed materials from the Mackenzie mainstem will be:

a) The resuspension of silts, clays and some sands into the water column (increased suspended load) as a result of the removal of the larger more desired bed materials.
b) The potential downstream redisposition of interstitial silts and clays (and some sands) in areas of other bed types as a result of the increased suspended load associated with the removal of granular materials upstream.
c) The potential change in channel width (wider or narrower) as a result of gravel removal; an associated shallowing or deepening of the water column; and a reduction or increase in stream velocities.
d) The alteration of bedload movement and composition within and downstream of the granular materials removal area.

On the basis of assessment and monitoring results related to the dredging by Public Works Canada of sections of the Mackenzie River mainstem for navigation purposes, the recent construction by ESSO Resources Canada Limited of several artificial islands in the Mackenzie mainstem near Norman Wells, the construction by Interprovincial Pipe Line Limited of a Mackenzie mainstem pipeline crossing upstream of Fort Simpson, and the workshop reviews during the 1985-1986 Mackenzie Environmental Monitoring Project, the effects on downstream suspended loads of major in-stream operations on the Mackenzie mainstem should be short-term and minimal (and in many cases negligible). The large dilution factor offered by the large year-round Mackenzie discharge is perhaps the single most important factor.

Interprovincial Pipe Line Limited and Indian and Northern Affairs Canada conducted aquatic monitoring programs in 1984 and 1985 to detect impacts on water quality of in-stream blasting, ditch excavation and backfilling operations during construction of their pipeline crossing upstream of Fort Simpson (Interprovincial Pipe Line Limited (NW) Ltd., 1984). The results of water quality analyses both during and after the in-stream blasting revealed minor and short-term (less than 24 hour) increases in turbidity and suspended solids at some stations downstream from the blast. All objectives established for domestic consumption of water were met.

The monitoring program to detect increases in sediment concentrations from ditch excavation and backfilling operations showed that turbidity and suspended solids upstream and downstream did not differ significantly. The excavation released very little fine (silt and clay sizes) sediment. The large volume of natural flow through the construction area was identified as having a significant dilution effect on whatever sediment was suspended in the water column.

ESSO's dredging of almost 2,000,000 m^3 of gravel from the Mackenzie River was expected to cause some increase in silt loads and some sedimentation which would be unavoidable but negligible (ESSO Resources Canada Ltd., 1980). On a recent (September 1986) aquatic monitoring survey by Seakem/ESL staff in the Norman Wells area, the presence of sediment deposition tails which were predicted to extend downstream from the artificial islands, was clearly evident. Two of the islands in fact were almost joined by the deposition tail from the upstream station (pers. comm. Blair Humphrey, Seakem Oceanography Ltd.).

The Mackenzie Environmental Monitoring Project (MEMP, 1986) participants suggested that gravel extraction could alter both channel morphometry and bed material composition but that the effects would be relatively short-lived in streams or rivers with high bedload transport rates such as the Mackenzie River. More long-term effects would be possible 'if (1) boulders are removed from the stream and they cannot be naturally replaced by the river; and (2) the volume of excavated material is large in comparison to the rates of bedload transport'. Short term effects must be considered on a site specific basis because the fines content of the dredged sediments, the flow rates and water quality at the time of dredging and the fish species in the nearby downstream area will vary considerably along the river and seasonally.

6.2 WATER QUALITY

6.2.1 General Concerns

The major environmental threat to water quality posed by the removal of granular borrow material from the riverbed is the potential release of sorbed chemicals as a result of the resuspension of fine-grained (silt/clay) particulates. The magnitude of the effect will be a function of the relative increase in suspended particulate concentrations that might occur and the associated particulate concentrations of environmentally important chemicals. These would include several trace metals as well as various types of hydrocarbons (non-polar and aromatic).

There have been several reviews of water quality in the Mackenzie River based on Inland Waters Directorate monitoring over the past twenty years (see for example Reeder, 1973; Reeder et al., 1972; Reid et al., 1975; Mackenzie River Basin Committee, 1981). Previous monitoring has not included hydrocarbons so that there is very limited data available and none above detection limits before 1985. Trace metal data in the water is collected on a regular basis but much of this, especially for some key elements such as Cd and Hg, is below detection limits or of questionable quality. The data for trace metals and hydrocarbons associated with suspended sediments and bed sediment is even more limited. Recent and on-going monitoring programs being conducted for IWD are examining hydrocarbons associated with suspended sediments.

6.2.2 Hydrocarbons

The Mackenzie River potentially could have locally high levels of hydrocarbons because of oil and gas deposits along the river and its tributaries. Oil seeps along the Mackenzie River are an often cited but poorly documented occurrence. It has been known for many years that oil seepage occurs in the vicinity of Norman Wells and indeed the presence of surface oil led to the early development of the Norman Wells oilfield (Kindle and Bosworth, 1920). Outcrops of bituminous or oil containing sands and limestones are located along the shores of Great Slave Lake and along stretches of the Peace, Athabasca and Lesser Slave Rivers. Below Great Slave Lake, the only other documented oil seepage or bituminous outcrop, other than near Norman Wells, is in the vicinity of Fort Good Hope. Bituminous Devonian shales are exposed on the river bank upstream of Old Fort Good Hope while tar springs exist inland from Fort Good Hope.

There are however no good estimates of the volumes of hydrobarbons that may enter the river from these sources nor any information regarding their fate. Recent data from the summer of 1985 suggest that there are some hydrocarbons of petrogenic origin detectable on particulates below Norman Wells (Nagy et al., 1986). However, this was based on a single bed sediment sample. More recent hydrocarbon data from the Mackenzie River Delta in the winter of 1986 gave no indications of hydrocarbons of petrogenic origin (Erickson and Fowler, 1986). In both studies, dissolved hydrocarbon concentrations were below detection. In response to Dene and Metis concerns, both EPS and IWD are continuing studies in this regard.

Even when sediment hydrocarbon concentrations are high, resuspension will result in only brief and localized increases in particulate hydrocarbon concentrations. Dissolved hydrocarbon concentrations are unlikely to be altered. The reason for this conclusion are:

1. resuspension will occur in summer when flows are greatest ensuring the greatest dilution rate,
2. natural suspended particulate loads are high and variable in the summer months, and
3. hydrocarbons have a strong affinity for particulate and will tend to remain associated with the particulate phase.
4. hydrocarbons will be preferrentially absorbed to silt and clay sized particles which will rarely exceed 15 percent of the volume of exploitable granular borrow.

6.2.3 Trace Metals

The available data on trace metal concentrations in bed sediments and suspended particulates do not indicate any unusually high levels of any metals with the exception of some mercury data in the reports by Reeder (1973) and Reed et al. (1975). These studies gave some very high mercury concentrations compared to typical unpolluted riverine or marine sediments (Forstner and Wittmann, 1979). Recent winter data (Erickson and Fowler, 1986) found much lower levels and it is felt that the earlier results may be in error due to analytical problems or contamination. Even with the extremely high levels reported, it is unknown how much, if any of the particulate associated metal might be released into solution. As for hydrocarbons, any effect will be transitory and short-lived due to rapid dilution with the main river flow.

6.3 FISHERIES

6.3.1 Data Base

The following discussion focuses on fish resources in the Mackenzie River, with particular attention to the area between Trout River (km 228) and the confluence of Arctic Red River (km 1454). In Appendix B, fisheries related data is summarized for each river zone. The information review is based largely on intensive studies conducted during the early 1970's associated with several large-scale development proposals, principally the Mackenzie Highway and the Canadian Arctic Gas Pipeline project (eg: Hatfield et al 1972a,b; Dryden et al 1973; Stein et al 1973; Brunskill et al 1973; McCart, 1974; McCart et al 1974; Jessop et al 1974), and several summary and review documents based largely on these studies (Doran 1974; McCart and Den Beste 1979; Dome Petroleum et al 1982). These studies dealt almost exclusively with resources associated with Mackenzie River tributaries on the east side of the valley, and usually only provided indirect information with respect to utilization of mainstem habitats, the primary focus of potential gravel removal operations.

Recently, additional studies were completed with respect to the Norman Wells Expansion Project (Hardy Assoc. Ltd. 1979; Envirocon Ltd. 1980; ESSO Resources 1980) and its associated pipeline project undertaken by Interprovincial Pipe Line (NW) Ltd. These studies provided some site specific information for the mainstem river, but were generally limited to areas in the immediate vicinity of Norman Wells. Other supplemental information was obtained from results of the Mackenzie Environmental Monitoring Project (MEMP) (Indian and Northern Affairs Canada et al 1986), contact with the Freshwater Institute, unpublished monitoring surveys of domestic fisheries in the Mackenzie corridor provided by MacLaren Plansearch (1985), and other unpublished reports.

6.3.2 Species Present

A total of 38 species are known to occur within the Mackenzie Valley corridor (see Table 6.2), however only a portion of these are utilized to any degree in domestic, commercial, or sport fisheries. Further, not all of the species are abundant or distributed within the entire Mackenzie mainstem study area. Nevertheless, the region possesses some unique fish resources. For example, the Mackenzie River is suspected to be the only drainage supporting Arctic cisco spawning in Canada and possess the largest populations of broad whitefish in Canada (INAC et al 1986).

Utilizing information from McCart and Den Beste (1979) and the Dome et al (1982) summary, a total of 16 species have been identified to have some significance for domestic, or sport fishery uses, and therefore are considered major species within the mainstem corridor upstream of Arctic Red River (Table 6.2). Other species are not generally utilized or occur predominantly in areas of the Mackenzie Delta. For example, although Arctic char is a highly prized species, it generally only occurs in areas of the western Delta (Peel, Rat, and Big Fish Rivers), and has not been considered as a major species for the purpose of this study.

As indicated in Table 6.2, some species are anadromous, spending some portion of their life history in the marine environment, returning to spawn in freshwater habitats. In addition, the species include both spring and fall spawners, indicating the general period during which spawning activity occurs.

There is very little data on the abundance of individual species, and estimating the numbers of fish is further complicated by the different migratory patterns which result in highly variable numbers, depending on the time of year. Generally, south of the Delta, grayling is most widely distributed, along with northern pike and longnose suckers. Although both northern pike and grayling are widely distributed throughout the system, northern pike are generally more abundant and occur in larger tributaries and low-gradient regions of the mainstem Mackenzie River. Arctic grayling are more widespread but are most abundant in some tributary streams, particularly within the southern portion of the mainstem corridor. Some of the species, including mountain whitefish, Dolly Varden char, and yellow walleye are generally restricted to areas south of Norman Wells, near the northern limits of their range (Dome et al 1982). In contrast, ciscos and whitefish appear to be the most abundant in the northern areas of the Mackenzie corridor, downstream from Norman Wells.

6.3.3 Seasonal Life Patterns

a) Spawning: Spawning characteristics of the major species within the Mackenzie corridor have been summarized by Doran (1974), Dome et al (1982), and McCart and Den Beste (1979). Most of the major species within the study area (11 of 16) are fall or winter spawners. As a result, these species require habitats that will provide sufficient oxygen, water levels, and protection from severe ice conditions over the winter months. Consequently, they tend to utilize larger rivers for spawning, such as the Mackenzie mainstem, Arctic Red and Great Bear Rivers, in addition to lakes accessible within the Mackenzie corridor. Although mainstem spawning, particularly for whitefish and ciscos has been suggested (Dome et al 1982), there is almost no documentation of these areas, since most surveys have concentrated on tributary systems. However, recent studies by DFO have documented whitefish spawning activities in the mainstem just below the Upper Ramparts area (late October early November). Other known areas near or within the mainstem are at the mouth of Arctic Red River and Point Separation (Stein, DFO Winnipeg, pers. comm.).

In contrast, spring spawners (Arctic grayling, northern pike, yellow walleye, suckers) generally spawn during periods of relatively high flow during and following spring ice break-up (normally during May and June). Since the eggs of these species are not required to survive the harsh conditions of northern winters, these species may utilize smaller watercourses which might completely freeze during the winter. The spawning period also commonly coincides with periods of relatively high concentrations of suspended solids in many of the larger watercourses, and it has been suggested that some of the species (particularly Arctic grayling) migrate into clearer tributaries to spawn during this period (Doran 1974).

Stein et al (1973) suggested that in the southern portion of the Mackenzie corridor, the onset of spawning occurs approximately 2 weeks earlier for spring spawners and 2 weeks later for fall spawners, compared to areas near the Delta, as a result of the differences in latitude between these areas.

b) Migrations: The Mackenzie River mainstem and its major tributaries, such as Arctic Red, Great Bear and Liard Rivers represent major migratory pathways for both anadromous and resident freshwater species. For most species, spawning, nursery, and overwintering areas can occur in distinctly different habitats. Most of the anadromous species are concentrated principally below Norman Wells, however almost all these species have been reported in the Mackenzie drainage as far south as Fort Simspon. For example, whitefish represent a significant proportion of the domestic catch throughout the corridor (Section 6.3.4). Also, small runs of chum salmon are reported to ascend the river to Great Slave Lake in September or October (McPhail and Lindsey 1970). Normally, these species (with the exception of chum salmon) migrate upstream during the summer months, and may return to mainstem overwintering areas following spawning in the fall. For example, Stein et al (1973) documented the upstream movement of Arctic cisco and Inconnu in the mainstem by monitoring the successive occurrence of peak abundance from downstream to upstream sites over the course of the summer.

Spring spawning species normally migrate from overwintering areas into spawning habitats following ice break-up. After spawning, they may return to summer feeding areas in mainstem habitats or larger tributaries. For example, grayling from tributaries near Norman Wells were documented to move from tributary spawning areas into the Mackenzie mainstem and upstream into the Great Bear River over the summer (Jessop et al 1974). Concentrations of Arctic grayling and longnose suckers have been documented in numerous smaller clearwater tributaries throughout the Mackenzie corridor. Although relatively little is known about migrations of other spring spawning species, it is suspected that the other common species (eg: northern pike and burbot) do not undertake large scale migrations within the Mackenzie corridor. For example, in recent sampling for burbot near Norman Wells it was assumed that burbot are generally confined to river areas less than approximately 40 km in length (ESL Environmental Sciences Limited and Aquatic Environments Ltd. survey; B. Humphries, pers. comm.).

c) Nursery Areas: Nursery habitats exist throughout the Mackenzie system, and generally most streams supporting spawning also provide some rearing capacity. Many tributaries, including small unnamed watercourses, also support juvenile populations of grayling, northern pike and longnose suckers. For example, tributaries of the Norman Wells area consistently supported young Arctic grayling (Dome et al 1982), and tributaries of the Great Bear River provide nursery habitat for Arctic grayling, northern pike, Arctic cisco, whitefish, inconnu, suckers, and burbot. Near Norman Wells, Envirocon Ltd. (1981), reported the presence of juvenile and underyearling fish along shallow gravel/cobble bars, particularly near the mouths of tributaries on the east shore, such as Billy, Oscar, and Elliot Creeks. Most of the juvenile fish were non-salmonid forage species (lake chub, trout, perch). However, juvenile burbot and some salmonids (particularly whitefish and cisco) were also present. Although whitefish and ciscos occur throughout the Mackenzie system, the Mackenzie Delta as well as lakes and rivers on the Tuk Peninsula have been identified as significant rearing areas for whitefish and cisco species which have spawned upstream (Dome et al 1982).

Within the Mackenzie mainstem, Stein et al (1973) and Jessop et al (1974) reported consistent use of backeddies and side channels by juvenile pike, suckers, walleye, and burbot. In the southern portion of the corridor, tributaries such as the Trout River provide nursery habitat principally for pike, grayling, walleye and suckers (Dome et al 1981).

d) Overwintering: Overwintering habitats are important to identify, since they represent areas where fish can become concentrated and relatively sedentary over several months between freeze-up and break-up. Most overwintering habitats have been identified to date from surveys associated with the Arctic Gas Pipeline Project (eg: McCart 1974; McCart and McCart 1982). These habitats occur in permanently flowing tributaries, spring-fed streams, lakes, and Mackenzie Delta habitats. The Delta region, below Arctic Red River has been identified from several surveys as a major overwintering area for whitefish and cisco species (Stein et al 1973 and Mann 1975). It has been consistently hypothesized that overwintering also occurs throughout the Mackenzie mainstem, however there are no direct surveys of mainstem overwintering available to date.

6.3.4 Resource Harvesting

a) Domestic Fishing: The harvesting of fish resources in the Mackenzie corridor, particularly for domestic use, represents one of the most important activities and food sources for communities along the river (Dome et al 1982). Increasing emphasis has also been placed on the development of sport and, at times, on selected commercial fishing activities throughout the area.

Generally domestic fisheries occur around tributary mouths near settlements and in the Mackenzie Delta (Hatfield et al 1972a; LGL et al 1986; Dome et al 1982). Most intensive fishing occurs just after freeze-up and spring break-up, the most active periods of fish migration (Hatfield et al 1972a). Within the study area, general locations of intensive domestic fishing include Arctic Red River, Fort Good Hope, Norman Wells, Fort Norman, Fort Simpson, and Trout Lake (Dome et al 1982).

The amounts of fish taken and the relative importance of various fishing areas have been difficult to determine, since there have been few consistent studies of domestic fisheries, and the data over the years has exhibited wide variability. McCart and Den Beste (1979) cited one study undertaken throughout the Mackenzie corridor (Table 6.3). They indicate that the greatest proportion of the catch is obtained from the Mackenzie Delta to Arctic Red River (approximately 68 percent of the catch). In the lower Mackenzie region, whitefish are the major species harvested. Other species include ciscos, inconnu, northern pike and burbot. In the other regions of the Mackenzie corridor (Fort Good Hope to Trout Lake), whitefish species are also prevalent, however inconnu, northern pike, Arctic grayling, walleye and suckers also contribute to the catch (Dome et al 1982; McCart and Den Beste 1979; MacLaren Plansearch 1985). In the Norman Wells area, fishing for Arctic grayling occurred at Stewart Creek and the mouth of the Three Day Lake drainage. Local fishermen also harvest small numbers of whitefish, inconnu, Arctic cisco, pike, and walleye from other areas of the river (LGL et al 1986).

b) Sport Fishing: Locations of sport and commercial fisheries have been summarized by Dome et al (1982) and McCart and Den Beste (1979). Sport fishing is mainly concentrated away from the Mackenzie mainstem on various lakes and tributary streams. Some sport fishing occurs near Fort Norman in the Mackenzie River, and near the mouth of the Great Bear River. Residents of all communities also utilize various mainstem areas and small local lakes and tributary streams. Northern pike, Arctic grayling, lake trout and whitefish are the most commonly sought species (Dome et al 1982). LGL et al (1986) report that in the Norman Wells area Arctic grayling, northern pike, and yellow walleye are fished near the mouths of smaller tributaries, such as Bosworth Creek, the DOT lake drainage (KP 897), and Oscar Creek. In the southern portion of the corridor, some fishing activity occurs in the Mackenzie River near Fort Simpson and near the mouths of the Liard and Trout Rivers. Common species are northern pike, Arctic grayling, whitefish, and walleye.

c) Commercial Fishing: There is virtually no commercial fishing activity within the mainstem study area, since most commercial activity is restricted to the Delta or areas near Great Slave Lake (McCart and Den Beste 1979). Some past commercial activity has been reported in the area between Norman Wells and Fort Norman and near Fort Simpson.

6.3.5 Habitat Uses

Available information on fish use and resource harvesting within each of the specific reach zones (see Table 4.1) is provided in Appendix B. It includes the following information:

- o Major tributaries
- o Major species present

- Documented or suspected habitat uses
- Resource harvesting areas
- Summary of fisheries concerns

The reach zones of particular significance are shown in Table 6.4. These reaches are characterized by a combination of the factors, particularly the presence of domestic fishing areas, several tributary systems with documented spawning and rearing populations, and physical characteristics such as gravel bars and/or side channels which are typically associated with mainstem rearing or spawning.

The lack of specific information with respect to utilization of mainstem habitats makes it difficult to evaluate in detail any of the river areas. In addition, the information to date, suggests that all areas of the mainstem river are utilized at some times for major migration of most of the important species. At present some studies, including the Mackenzie Environmental Monitoring Project (MEMP), are in progress to identify the different stocks of whitefish, including major migratory routes and times (INAC et al 1986), and these kinds of studies will aid in the subsequent evaluation of various river reaches.

6.4 FISHERIES CONCERNS RELATED TO GRANULAR MATERIALS REMOVAL

The following section summarizes the major concerns associated with fish resources and the potential removal of granular materials from the Mackenzie mainstem. The major objective is to summarize those aspects of these operations that represent significant issues, and identify those species or life history stages that are of particular concern. Consistent with the overall objectives of this phase of the study, the following discussion is not intended to provide a detailed evaluation or assessment of the potential degree of impact from any specific dredging proposals, so much as clarify those issues or areas which should receive particular attention in subsequent studies.

6.4.1 Potential Sources of Disturbance

Although there are no details on the types of gravel removal operations which might be utilized within the Mackenzie mainstem, some form of dredging will be likely. The effect of dredging operations will be similar in many ways to other forms of instream disturbances which have occurred previously, including the Norman Wells Expansion project, various pipelines and highway developments. There have been numerous reviews indicating a range of potential sources of disturbance and effects anticipated from these types of operations (INAC et al 1986; Department of Fisheries and Oceans 1986; Dome et al 1982; Arctic Laboratories Limited et al 1985; Jessop et al 1974; and Stein et al 1973). The specific issues include:

- Increased levels of suspended sediments
- Downstream sedimentation
- Re-suspension of contaminated sediments
- Alteration of habitat characteristics
- Direct interference with migrations/spawning
- Decreased fishing success
- Mortality from dredging machinery

6.4.2 Suspended Sediments and Sedimentation

Potential problems related to suspended sediments and downstream sedimentation are probably the most often cited concerns regarding proposals for instream activities such as dredging. The range of potential effects from increased levels suspended sediments generally include behavioral changes in fish, reductions in fish food organisms, and direct effects on fish health, such as lethal or sublethal reactions associated with increased levels of stress. Potential problems associated with downstream sedimentation include the degradation of fish spawning and rearing areas, and reductions in benthic prey organisms.

Obviously the extent of the disturbance will depend on many factors, including the gradation and fines content of materials present in the river bottom, the nature of river flows, the specific time and location of the granular removal activity. In a recent review of the potential effects of instream activities for the Mackenzie Environmental Monitoring Project (Indian and Northern Affairs Canada et al 1986), it was concluded that the effects of suspended sediments were a valid concern with respect to instream activities. Although fish can generally tolerate relatively high levels of suspended sediments without any mortality, recent studies have documented significant sublethal effects in Arctic grayling at levels of suspended solids of a few hundred ppm. However, it was pointed out that other species (whitefish) appear to have been attracted to turbidity plumes associated with instream disturbances. Further, grayling are generally associated with clear-water tributaries, rather than mainstem habitats, and the effects of suspended sediments may, therefore, be more pronounced for this species.

The Mackenzie mainstem is normally turbid and experiences relatively high levels of suspended solids (several thousand ppm) during the open-water period. As a consequence, it is anticipated that where instream activities associated with gravel removal are of a relatively short duration, the effects of suspended sediment additions to the Mackenzie mainstem may be virtually undetectable.

The most pronounced effects of increased suspended sediments might occur during the winter months, when the water is normally relatively clear, however, it is unlikely that any dredging would occur then. At these times it is assumed that some species (principally whitefish ciscos, burbot, pike, suckers) would be overwintering in mainstem habitats within the corridor, but there is virtually no supporting documentation on the abundance or specific habitats utilized at this time. Available survey information has suggested that most intensively utilized mainstem area is in the vicinity of the Delta, including Arctic Red River.

The Mackenzie Environmental Monitoring Project concluded that the most significant potential problem associated with downstream sedimentation would be its effect on spawning areas (Indian and Northern Affairs Canada et al 1986). There is substantial documentation, particularly for salmonids (salmon and trout species) that the survival of eggs or larval fish can be reduced by the introduction fine sediments to the substrate. Further, the Mackenzie Environmental Monitoring working group concluded that it could take a considerable time for some sediments to be flushed out of the system. It was also concluded that the most serious effects would be from large scale or chronic inputs of sediments and on species with relatively local distributions, long incubation times and relatively large eggs (low surface to volume ratios). Arctic char, which generally occur outside of the area affected by potential gravel removal operations, appear to be most sensitive to this potential effect. There are relatively few studies which have examined the actual impact of instream disturbances on spawning grounds, however, one study (Zallen 1984) documented the increased levels of sediments during pipeline trenching operations in B.C. had no significant affect on incubating mountain whitefish eggs within 1 km downstream.

The extent to which sedimentation could be a problem, will depend on the specific habitats utilized downstream of potential removal sites, however there is relatively little known with respect to mainstem spawning in the Mackenzie mainstem, at this time.

6.4.3 Resuspension Of Contaminated Sediments

The potential concern associated with resuspension of contaminated sediments was addressed with respect to Water Quality concerns Section 6.2. It was concluded that although localized areas of hydrocarbon concentrations may exist, it was unlikely that significant hydrocarbon would be released by dredging activities in coarser sediments. No major resuspension of hydrocarbons or other potential contaminants (eg: trace metals) as a result of the removal of granular materials is anticipated. As previously noted, however, Dene and Metis residence of the Mackenzie Valley have concerns for the hydrocarbons in the Mackenzie system, whether they be naturally occurring or the product of regular activities on the Mackenzie. Several studies by EPS and IWD including the Mackenzie Environmental Monitoring Program are examining these concerns. Prior to any major dredging activities a site specific evaluation would be needed to determine the potential for significant resuspension of hydrocarbons or heavy metals.

6.4.4 Alteration Of Habitat Characteristics

The removal of materials from the riverbed in sufficient quantities could alter the channel configuration to the degree that its habitat value is decreased. The effects on fish, will of course depend on the type of utilization prior to gravel excavation. For example, a mainstem corridor principally utilized for migration may not be significantly affected, however the removal of gravel bars which provide a complex of shallow habitats with diverse flow conditions utilized for rearing could significantly reduce the area's capacity to support juvenile fish. The results of limited sampling in the Mackenzie mainstem, has indicated that shallow gravel/cobble shores in the vicinity of Norman Wells are utilized to some degree (Envirocon 1980).

6.4.5 Interference With Migration/Spawning

Instream activities are capable of disrupting large numbers of fish if they occur during the periods of major movements or during spawning. While this concern is often cited with respect to dredging (eg: Department of Fisheries and Oceans 1986), the effects can be minimized by selecting appropriate timing windows for instream activity to avoid sensitive periods. These periods may vary in different portions of the Mackenzie corridor, since peak migrations in the north occur at different times than in the south. Various sensitive periods have been proposed for the tributaries of the Mackenzie corridor. For example, Jessop et al (1974) proposed that from mid-June to mid-July, juveniles are emigrating out of tributaries into the mainstem. In addition, sensitive periods for fall spawning and spring spawning species were reported to be September 1 to November 15 and May 1 to June 30, respectively. Any further analysis of potential gravel removal areas where large equipment would be utilized instream should include site specific information on probable timing for migrations and an evaluation of potential spawning potential in the immediate areas to be affected.

6.4.6 Decreased Fishing Success

The Mackenzie Environmental Monitoring Project (Indian and Northern Affairs Canada et al 1986) examined the possibility that instream activities would reduce fishing efficiency through decreased water clarity. However, the conclusion was that in the Mackenzie mainstem, domestic fishing (the dominant fishing activity) occurs predominantly during open-water when the river is naturally turbid and any increases in turbidity due to development activities would likely be undetectable. Further, in some situations whitefish captures actually increased in turbidity plumes associated with dredging activities in Alaska. As a result, the potential negative effects on fishing success is not considered to be a significant concern.

6.4.7 Mortality From Dredging Machinery

One of the greatest concerns with respect to instream dredging equipment is the direct entrainment of fish, particularly juveniles, within the dredging machinery. Suction dredging has been identified in this regard (Department of Fisheries and Oceans 1986). The greatest risk is during periods of fish migration or spawning. By timing dredging to avoid these periods, the risk can be substantially minimized. Species of particular concern are whitefish, ciscos, and grayling, since they represent a significant proportion of the domestic or sport fisheries in the Mackenzie mainstem. In some areas of the river which are utilized for rearing throughout the summer, possibly for northern pike, burbot, or whitefish, this many not be feasible. Therefore site specific fish population information is needed where the potential for gravel removal exists.

7.0 FEASIBILITY OF RIVERBED BORROW DEVELOPMENT

7.1 LIMITED DATA BASE

As noted in Section 4.0, most of the interpretation of riverbed materials is based on indirect evidence such as gradient, channel morphology, tributary rivers (size and bed character) and on the upland geology. There is a critical shortage of reliable instream data and some of that appears to be very site specific. For examples, Public Works Canada (1976) reports that six boreholes encountered only silty clay near Norman Wells (see Drawing 4.1e); however, Esso's experience (Figures 3.2 and 3.3) show that there may be several metres of dredgeable gravel there.

The identification of areas of the riverbed with the potential to supply granular borrow is somewhat hampered by the scarcity of directly relevant published information. At Norman Wells, ESSO and its contractors and engineers have shown that borrow production from the river is possible. Public Works Canada (1976) has provided 267 boreholes and most of those are clustered in a few areas where river navigation might be improved by dredging. The only other direct geotechnical data for the riverbed was gathered for site specific investigations for pipeline crossings and possible docksites. Surficial geology maps and notes on navigation charts prepared by the Canadian Hydrographic Service also contain pertinent information on the alluvial landforms (islands, bars and shoals) exposed above waterline.

7.2 RATING THE RIVER

A rating system was developed to evaluate the contribution made to the potential for finding granular borrow in each river zone by the local hydrologic regime and tributary rivers or streams. Table 7.1 shows the rating factors assigned to the three most important characteristics of the hydrologic regime. Table 7.2 shows the relative contribution of each to a cumulative rating. There are two other factors that have a significant impact on the potential development of riverbed borrow. These are the relative accessibility of suitable reserves of upland (conventional) granular borrow and the environmental sensitivity of each area, particularly as it relates to fisheries activities. Table 7.3 summarizes these two factors and the river regime rating from Table 7.2.

Table 7.3 provides an overall assessment of the borrow development potential for each zone. This information is also included on Figure 4.1 and Drawing 4.1. One important caution is noteworthy in this overall evaluation of potential resource areas. As discussed in Section 6.3, there is insufficient data relating to fisheries activities to develop a reliable rating of sensitivity for each river zone. Presently there is no data which would seem to rule out borrow development anywhere on the mainstem of the Mackenzie, but several concerns have been raised which require additional study.

7.3 POTENTIAL AREAS FOR RIVERBED BORROW DEVELOPMENT

The river zones which are between 26 and 176 km long were identified on the basis of the morphological properties of the river. Conditions within each zone do vary such that not every section within the zone is of equal potential as a source of granular borrow. For that reason, it was decided to analyze a series of 25 km long subzones. The three factors which were given most weight in these localized evaluations were:

a) tributary creeks, streams and rivers with gravel beds (indicating potential source material)

b) upland borrow sources (alternate economics)
c) direct evidence of gravelly alluvium in Public Works Canada (1976) boreholes

The subzone analysis is summarized on the lower part of Figure 4.1. This indicates thirteen subzones with a high potential and six with a moderate to high potential to supply granular riverbed alluvium. However, the feasibility of development is significant only where potential supply matches with potential demand. Table 7.4 lists the highly feasible areas, subject to the economics of haul distance (Section 5 and Figure 5.1) and possible sources of upland supply that are more than 15 km inland of the river.

In summary, there are major portions of the river where riverbed borrow development appears feasible. Table 7.4 identifies that along approximately 975 km of the 1475 km length of the Mackenzie (exclusive of the Delta) riverbed borrow is potentially available where there are shortages of upland borrow. In fact, if the subzone rating were applied to each bank of the river separately, because upland borrow on one side cannot readily be used on the other, more areas might be identified where riverbed borrow development might be feasible.

8.0 RECOMMENDATIONS FOR SUBSEQUENT EVALUATION WORK

8.1 RIVERBED INVENTORY

As the preceeding section concluded, there are good reasons to believe that riverbed alluvium could be potentially developed for borrow materials to satisfy local shortages along the river. However, it is also clear that a significant gap exists between potential source areas identified on the basis of indirect evidence and establishing proven reserves. Recommendations for follow up work are presented below.

INAC may wish to develop an inventory of potential reserves of granular materials or it may wish to focus on identifying reserves to supply specific areas. Regardless, it appears that direct field/river work is required and many of the steps are similar in any event.

Initially, a general survey of the river is required to confirm or extend the interpretation of potential areas presented herein. Both geophysical and direct sampling methods are necessary. The scale of operation and level of effort could vary considerably from a broad reconnaissance program examining the entire length of the river to a more site specific one that concentrates on establishing the nature of the riverbed alluvium in various parts of the river with the highest potential for future development.

The riverbed inventory should focus on the areas identified in Table 7.4 as potential supply reaches, but it must also consider the need for baseline data along the entire river length. Considering the importance of the Mackenzie River, there is very little information about its riverbed, its hydrology or its fish population. A baseline study might significantly alter some of this report's conclusions which are based on so much indirect evidence.

It is suggested that the most effective way to acquire the baseline data would be for a joint geophysical and geotechnical program, probably working from separate river craft. The geophysical survey comprising bathymetric, seismic and possibly E-M equipment would search for the most promising places to sample. The slower moving geotechnical program would sample the substratum to a depth of about 2.5 to 3 m at these target locations. The hydrology and basic fisheries sampling would be done in conjunction with the geotechnical baseline sampling.

8.2 NORMAN WELLS FIELD TRIALS

If the field work is to be successful, reliable geophysical methods and sampling techniques must be demonstrated where there is gravelly riverbed alluvium. Since the Norman Wells area constitutes the only proven deposits of borrow, there might be some justification for an initial program to evaluate the extent of deposits similar to those that were dredged.

The data base available for Norman Wells would support a trial run for seismic, E-M, ground penetrating radar or other geophysical techniques. Similarly alternate reconnaissance level sampling techniques could be tested to demonstrate which has a better ability to recover the gravelly alluvium. There is a need to sample material to a depth of 3 m below the riverbed. Grab samplers are unable to do this. Perhaps light Vibra coring techniques would work, economically. Demonstrating reliable recovery methods would be a significant part of a trial program. In other areas of the river, misleading sample recovery (ie. fine fraction only) would prejudice future development.

The sensitivity of the geophysical equipment to different subbottom conditions might also be explored near Norman Wells. The riverbed changes from glaciomarine clay, to bedrock, to gravelly alluvium to silty alluvium in the area. Furthermore there are single-channel, deep channel, and multi-channel reaches within 40 km of Norman Wells. Near Goose and Bear Islands, is the multi-channel reach. South of Sans Sault the river is straight and narrow along Carcajou Ridge; whereas on the north side it is shallow, and fast at the rapids and changes to slow and meandering by

Dummit Island. Single-channel reaches also occur about 25 km upstream (above Ten Mile Island) and 18 km downstream (below Rader Island). The Rader Island section reportedly has a clay till riverbed (Public Works Canada, 1976, Northwest Hydraulics, 1979). The Carcajou Ridge section is probably bedrock controlled.

8.3 ENVIRONMENTAL DATA REQUIREMENTS

8.3.1 Water Quality

There is very limited sediment data available for trace metals or hydrocarbons along the Mackenzie River. Although the effects of removal of granular borrow material from the riverbed is unlikely to have any measurable effect on the concentrations of either metals or hydrocarbons in the water column, it would be informative to take samples of the fines content at all potential borrow sites. This would be relatively inexpensive and require little time or effort. These sediments should be analysed for PAH and selected metals with unusually high concentrations. A relatively inexpensive screening method for hydrocarbons using UV/fluorescence could be used. Based on these results and assumptions regarding the proportion of any particular variable that might be released on resuspension, a rough estimate could be made of whether an impact on water quality is likely. If these preliminary calculations suggest a problem, an actual leach test should be conducted.

8.3.2 Hydrology

For any potential dredge site in the Mackenzie River there is a need for specific hydrologic information pertaining to spatial and temporal variation in water depth, velocity, volume discharge, stability of banks, width of watercourse, bed type variability, flood regimes, etc. within, upstream and/or downstream of the site. This type of information will be essential in the final evaluation of the potential effects of granular materials removal on suspended load, bedload movement and fluvial morphology at each specific reach where granular materials may be extracted. It is therefore recommended that during on-site testing of potential sources of granular materials, the above hydrologic observations be made at spatially representative locations within and adjacent to each of the reaches being testing.

8.3.3 Fisheries

Apart from some areas in the vicinity of Norman Wells, there is very little information on fish utilization of mainstem habitats within the Mackenzie River. The use of backeddies, side channels and gravel bars near tributaries for spawning and rearing are the only documented instances in the mainstem. As a result there is no analysis of physical habitat characteristics or fish utilization where development of gravel deposits appear possible. Since gravel substrates are commonly utilized for both spawning and rearing, information for these areas of the mainstem would be required on a site specific basis. Baseline data on the use of various habitats and timing of fish activities should be collected for the mainstem.

There are, however, significant difficulties in identifying habitats within large, turbid systems, such as the Mackenzie River, and major field surveys would be required to map large areas of the river. Consequently, the next phase of studies should concentrate on examining only those areas which have significant potential for subsequent gravel removal. A systematic examination of these areas should include detailed airphoto and mapping exercises to identify probable habitat characteristics on a large scale. In addition, selected profiles of depths and substrates should be prepared in pre-determined lengths of these reaches. If feasible, selected sampling (gillnetting and seining) should be conducted at least three times during the year to assess site specific utilization. If instream activities are more likely during winter, studies should also occur prior to freeze-up to assess overwintering potential in the mainstem reaches.

9.0 CLOSURE

The evaluation of the feasibility of developing granular borrow from the Mackenzie Riverbed has required the assistance of several subconsultants and the input from a wide range of industry and government personnel. Recognition of those firms and individuals is provided in Appendix C.

This study has demonstrated the feasibility of producing riverbed gravel for construction borrow uses. There was not, however, enough direct evidence, except adjacent to Norman Wells, to conclusively prove developable reserves anywhere. This lack of direct data is remarkable considering that the Mackenzie is one of the largest rivers in Canada and that the river is a vital access corridor to the frontier resources of the Beaufort Sea.

The economics of riverbed dredging and long distance barge hauling of granular materials appears to justify further examination of the riverbed. The study has identified parts of the Mackenzie Valley which have shortages of conventional borrow within 15 km of the riverbanks. A substantial number of those areas could benefit from the use of riverbed derived borrow.

The environmental concerns relating to riverbed dredging have also been considered. Primarily, these relate to the impact of dredging on the seasonal use of the river by fish populations. Unfortunately, the level of baseline data on mainstem fish activities is clearly inadequate. Although no evidence was uncovered to preclude the development of riverbed granular resources anywhere on the river, site specific studies are needed before significant development could take place.

In conclusion, it appears that riverbed granular borrow development is both feasible and potentially economic. In some areas it may even be necessary if major construction is contemplated. It is not possible, at this stage, to identify specific source areas or potential dredge sites and it is not possible to predict the impact of dredging on the important fish life of the river. Clearly baseline geologic data and fisheries related data must be acquired before development of this potentially valuable resource can proceed.

Prepared by:

EBA ENGINEERING CONSULTANTS LTD.

THE ASSOCIATION OF PROFESSIONAL ENGINEERS, GEOLOGISTS and GEOPHYSICISTS OF THE NORTHWEST TERRITORIES
P 018
EBA ENGINEERING CONSULTANTS LTD.

N.R. MacLeod, P.Eng.

NRM:jms

REFERENCES

Arctic Laboratories Limited, ESL Environmental Sciences Limited and EBA Engineering Consultants Limited in association with Tekmarine Inc, 1985. Environmental assessment of dredging technologies. Prepared for Environmental Protection Service. Environment Canada, Yellowknife, N.W.T., 95 pp.

Brunskill G.J., D.M. Rosenberg, N.B. Snow, G.L. Vascotto and R.W. Wagemann, 1973. Ecological studies of the aquatic systems in the Mackenzie-Porcupine drainages in relation to preposed pipelin and highway developments. Environmental-Social Committee, Northern Pipelines. Task Force on Northern Oil Development, Winnipeg. Report No. 73-40, 131 pp.

Brunskill G.J., P. Campbell, S.E.M. Elliott, B.W. Graham, W.J. Dentry and R. Wagemann, 1975. The chemistry, minerology and rates of transport of sediments in the Mackenzie and Porcupine River watersheds, N.W.T. and Yukon, 1971-1973. Environment Canada, Fisheries and Marine Service, Winnipeg. Technical Report No. 546, 69 pp.

Campbell P., J. Dentry, G.W. Morden, S. Elliott, G.J. Brunskill, R. Wagemann, B.W. Graham, 1975. General physical and chemical data for water and sediment of the Mackenzie and Porcupine watersheds and rates of transport of dissolved and suspended elements at selected stations in the Mackenzie and Porcupine watersheds 1971-74, Part 1. Technical Report No. 556 prepared by Environment Canada, Fisheries and Marine Service, 302 pp.

Canadian Hydrographic Services, 1983-1986. Mackenzie River Navigational Charts No. 6404 to 6426.

REFERENCES

Canadian Marine Transportation Administration, 1972. Effect of proposed dredging on water levels, Mackenzie River, N.W.T., Phase 1. Ministry of Transport, Ottawa, 23 pp plus appendices.

Chang-Kue K.T.J. and R.A. Cameron, 1980. A survey of the fish resources of the Great Bear River, N.W.T. Fisheries and Marine Service, Western Region, Department of Fisheries and the Environment, Winnipeg. Manuscript Report No. 151, 59 pp.

Church M., 1971. Reconnaissance of hydrology and fluvial characteristics of rivers in the Mackenzie Valley, N.W.T., and in Northern Alberta. Prepared for Mackenzie Valley Pipeline Research Limited. 48 pp plus figures.

Church M., and Gilbert R., 1975. Proglacial fluvial and lacustrine environments in glaciofluvial and glaciolacustrine sedimentation. Soc. of Econ. Paleontalogists and Mineralogists Special Publication No. 23. A.V. Jobling and B.C. McDonald.

Code J.A., 1973. The stability of natural slopes in the Mackenzie Valley. Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development. Report No. 73-9, 18 pp. plus maps.

Davies K.F., 1974. Hydrometric data summary Mackenzie River basin 1973. Prepared by Water Survey of Canada, Department of the Environment for the Environmental-Social Program Northern Pipelines. 84 pp.

Department of Fisheries and Oceans, 1986. Fraser River Dredging Guidelines. Draft Copy. DFO Fisheries and Habitat Management Branch. Pacific and Yukon Region, New Westminster, B.C. 15 pp.

REFERENCES

Department of Indian Affairs and Northern Development (DIAND)/MPS Associates Limited, 1973. Regional impact of a northern gas pipeline. Vol. 5. Environmental-Social Committee. Northern Pipelines Task Force on Northern Oil Development. Report No. 73-32.

Dirschl H.J., 1975. Mackenzie Valley and northern Yukon pipelines, regional analysis. Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development. Unpublished report Vol. 1.

Dome Petroleum Limited, ESSO Resources Canada Limited and Gulf Resources Inc., 1980. Mackenzie Valley Setting. In environmental impact statement for hydrocarbon development in the Beaufort Sea - Mackenzie Delta Region. Vol 3C.

Dome Petroleum Limited, ESSO Resources Canada Limited and Gulf Canada Resources Inc., 1982. Environmental impact statement for hydrocarbon development in the Beaufort Sea-Mackenzie Delta region, research and monitoring. Vol. 7.

Doran L.D., 1974. Fish and Aquatic Systems. Environmental impact assessment of the portion of the Mackenzie Gas Pipeline from Alaska to Alberta. Environmental Protection Board, Winnipeg. Vol. IV, Chapter 8, 205-268 pp.

Dryden R.L., B.G. Sutherland and J.N. Stein, 1973. An evaluation of the fish resources of the Mackenzie River Valley as related to pipeline development. Environmental-Social Committee, Northern Pipelines Task Force on Northern Oil Development, Fisheries Service, Department of the Environment, Winnipeg. Report No. 73-2, 176 pp.

REFERENCES

EBA, 1973. Mackenzie highway geotechnical evaluation, Fort Good Hope to Norman Wells, N.W.T. A report submitted to Public Works Canada.

EBA, 1974. Granular materials inventory Stage III. A report submitted to Indian and Northern Affairs.

EBA, 1978. Geotechnical investigation for drilling islands, Norman Wells N.W.T. A report submitted to ESSO Resources Canada Ltd. (EBA Project No. 11-2113).

EBA, 1980. Geotechnical engineering overview of Mackenzie Valley route data. A report submitted to the Polar Gas Project. (EBA Project No. 101-2591).

EBA, 1983. Granular resource development and management plan for Tuktoyaktuk. A report submitted to Indian and Northern Affairs Canada.

EBA, 1985. Construction verification, artificial islands and berms, Norman Wells Oilfield Expansion project. A report submitted to Canada Oil and Gas Lands Administration. (DSS Contract No. OGT84-00609). (EBA Project No. 101A-4173).

Envirocon Limited, 1980. Survey of benthic macroinvertebrate and fish populations in the Mackenzie River at Norman Wells, N.W.T. Prepared for ESSO Resources Canada Limited, Calgary.

Envirocon Limited, 1981. A survey of fish rearing areas and hydrocarbon analysis of water samples from the Mackenzie River near Norman Wells, N.W.T. Prepared for ESSO Resources Canada Limited, Calgary. 32 pp.

REFERENCES

Environment Canada, 1960-1979. Water quality data Mackenzie River basin. Prepared by Inland Waters Directorate for the Mackenzie River Basin Committee. 1080 pp.

Environment Canada, 1982. Sediment data reference index. Prepared by Inland Waters Directorate. 47 pp.

Environment Canada, 1983. Historical water levels summary Yukon and N.W.T. Prepared by Inland Waters Directorate. 37 pp.

Environment Canada, 1983. Sediment data Canadian rivers. Prepared by Inland Waters Directorate. 233 pp.

Environment Canada, 1983. Surface water data reference index. Prepared by Inland Waters Directorate. 386 pp.

Environment Canada, 1984. Historical streamflow summary Yukon and N.W.T. Prepared by Inland Waters Directorate. 128 pp.

Environment Canada, 1985. Surface water data Yukon and N.W.T. Prepared by Inland Waters Directorate. 110 pp.

Erickson P. and B. Fowler, 1986. The flux of suspended particulates, petroleum related hydrocarbons, trace metals and nutrients from the Mackenzie River during the winter season, a pilot study of the East Channel. A report prepared for the Department of Indian and Northern Development, Ottawa. 123 pp plus appendices.

REFERENCES

ESSO Resources Canada Limited, 1980. Norman Wells oilfield expansion. Environmental impact statement. Oilfield development. ESSO Resources Canada Limited, Edmonton. Vol. 2 (n.p.).

ESSO Resources Canada Limited, 1980. Norman Wells oilfield expansion, environmental impact statement. Oilfield Development. Vol. 2.

ESSO, 1982. Norman Wells Project, dredging operations plan 1983-1984. Data prepared in support of ESSO's Water Licence Application to the Water Resources Division, Department of Indian and Northern Affairs.

ESSO, 1983, 1984, 1985 and 1986. A series of annual bathymetric surveys of the Norman Wells expansion project area. Prepared by Canadian Engineers Surveys Co. Ltd. (1983) and W.D. Usher and Associates Ltd. (1984-1986).

Foothills Pipe Lines (Yukon) Ltd., 1979. The Dempster highway lateral gas pipeline project, environmental impact statement. Foothills Pipe Lines (Yukon) Ltd., Calgary. Vol. 4, 632 pp.

Forstner U. and G.T.W. Wittmann, 1979. Metal pollution in the aquatic environment. Springer Verlag, Berlin.

Fox M.F., 1979. An exploratory study of fluvial sites and processes in the Mackenzie, Liard and lower Fort Nelson rivers. Part 1. Overview of erosion and deposition. Department of Indian and Northern Affairs, Ottawa. Vol. 1.

Geological Survey of Canada, 1969. Map of the physiographic regions of Canada. (Number 1254A).

REFERENCES

Geological Survey of Canada 1972 and 1973. Reconnaissance granular resource inventory of the Mackenzie Valley. Reports for Indian and Northern Affairs.

Hardy Associates (1978) Ltd., 1982. Engineering recommendations for Bosworth Creek and Great Bear River crossings.

Hardy Associates (1978) Ltd., 1979. Preliminary environmental impact assessment, Norman Wells development plan. Prepared for Esso Resources Canada Limited.

Hardy Associates (1978) Ltd., 1986. Granular resource potential, Lower Mackenzie Valley. A report submitted to Department of Indian and Northern Affairs.

Hatfield C.T., J.N. Stein, M.R. Falk and C.S. Jessop, 1972a. Fish resources of the Mackenzie River Valley. Environment Canada. Fisheries Service, Winnipeg. Interim Report I, Vol. 1, 249 pp.

Hatfield C.T., J.N. Stein, M.R. Falk, C.S. Jessop and D.N. Shepherd, 1972B. Fish resources of the Mackenzie River Valley, Department of Environment, Fisheries Service, Winnipeg. Interim Report I, Vol. II, 289 pp.

Heginbottom J.A., 1978. Third International Conference on Permafrost, Edmonton, Alberta. Field Trip No. 3, Lower Mackenzie River Valley. Geological Survey of Canada. 66 pp. plus appendices.

REFERENCES

Hollingshead G.W. and L.A. Rundquist, 1977. Morphology of the Mackenzie Delta channels. Third National Hydrotechnical Conference. Canadian Society for Civil Engineers, Laval University, Quebec. 309-326 pp.

Hughes, O., 1970. Surficial geology maps. GSC Open File No. 26.

Hughes O.L., J.J. Veillette, J. Pillon, P.T. Hanley and R.O. van Everdingen, 1973. Terrain evaluation with respect to pipeline construction, Mackenzie tranportation corridor. Central part, Lat. 64 to 68 N. Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development. Report No. 73-37, 74 pp.

Indian and Northern Affairs Canada, Environment Canada, Fisheries and Oceans Canada, Government of the Northwest Territories and the Yukon Territorial Government, 1986. Mackenzie environmental monitoring project 1985-86 Final Report. 308 pp. plus appendices.

Inland Waters Directorate, 1980. Historical sediment data summary, Canadian rivers, to 1978. Inland Waters Directorate, Water Resources Branch, Water Survey of Canada, Ottawa.

Inland Waters Directorate, Yellowknife, 1985. Hydrology information series. Prepared by Western Ecological Serivces Ltd., Victoria, B.C. Mackenzie Delta; Aklavik; Fort Norman; Carcajou Canyon; Mahony Lake; Norman Wells; Travaillant Lake; Arctic Red River; Fort McPherson; Ontaratue River; Fort Good Hope; Sans Sault Rapids.

REFERENCES

Interprovincial Pipe Line (NW) Ltd., 1984a. Post construction monitoring programs for the Norman Wells to Zama pipeline.

Interprovincial Pipe Line (NW) Ltd., 1984b. Water quality monitoring in relation to 1984 pipeline construction. 14 pp.

Isaacs, R., 1974. Geotechnical studies of permafrost in the Fort Good Hope-Norman Wells Region, N.W.T. Report 74-16, Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development.

Jessop C.S., K.T.J. Chang-Kue, J.W. Lilley and R.J. Percy, 1974. A further evaluation of the fish resources of the Mackenzie River Valley as related to pipeline development. Environmental-Social Program. Northern Pipelines Task Force on Northern Oil Development. Report No. 74-7, 95 pp.

Jessop C.S. and J.W. Lilley, 1975. An evaluation of the fisheries resources of the Mackenzie River Valley based on 1974 data. Fisheries and Marine Service, Department of the Environment, Winnipeg. Technical Report Series CEN/T-75-6. 97 pp.

Kenny, T.C., 1976. Formation and geotechnical characteristics of glacial-lake varved soils. From Laurits Bjerrum Memorial Volume - Contributions to Soil Mechanics, ed. Jambu, Jorstand and Kjea, NGI, Oslo.

Kindle E.M. and T.D. Bosworth, 1920. Geological Survey of Canada Summary Report.

REFERENCES

Komex, 1981. Norman Wells expansion project, 1981 subsurface investigations.

Komex, 1982(a). Norman Wells expansion project, 1982 geotechnical investigations. A report submitted to ESSO Resources Canada Ltd. (Komex File No. 921-2).

Komex, 1982(b). Norman Wells expansion project, settlement of artificial island hydraulic sand fill. Revised April, 1982. A report submitted to ESSO Resources Canada Ltd. (Komex File No. 944).

Komex-Geocon, 1980(a). Norman Wells expansion project, 1980 geotechnical investigations. Interim data report. Submitted to ESSO Resources Canada Ltd.

Komex-Geocon, 1980(b). Norman Wells expansion project, 1980 geotechnical investigations. A report submitted to ESSO Resources Canada Ltd.

Kurfurst, P., 1973. Terrain disturbance susceptibility, Norman Wells area, Mackenzie Valley. Report 73-24 Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development.

LGL Limited, ESL Environmental Sciences Limited, ESSA Environmental and Social Systems Analysts Limited and P.J. Usher Consulting Services Limited, 1986. Cited under Indian and Northern Affairs Canada et al, 1986.

REFERENCES

Levinson A.A., B. Hitchon and S.W. Reeder, 1969. Major element composition of the Mackenzie River at Norman Wells, N.W.T., Canada. Geochimica et Cosmochimica. Acta 33: 133-138 pp.

Lombard North Group Ltd., 1974. Environmental impact study, Mackenzie Highway, Mile 550-725. Field Research Report. Prepared for Department of Public Works, Edmonton. Vol. 1, (various paging).

Mackay D.K., 1967. Discharge of the Liard and Mackenzie rivers. Geographical Bulletin, 9 (1): 11-19 pp.

Mackay J.R., 1972. Applications of water temperatures to the problem of lateral mixing in the Great Bear-Mackenzie River system. Canadian Journal of Earth Sciences 9: 913-917 pp.

Mackay J.R., and Mathews, W., 1973. Geomorphology and Quaternary History of the Mackenzie River Valley near Fort Good Hope, N.W.T., Canada. Can. Journal of Earth Sciences 10, 26.

Mackenzie River Basin Committee, 1981. Mackenzie River basin study report. 231 pp.

Mackenzie River Basin Committee, 1981. Mackenzie River basin study report supplement 2, alluvial ecosystems. 129 pp.

Mackenzie River Basin Committee, 1981. Mackenzie River basin study report supplement 3, spring break-up.

REFERENCES

Mackenzie River Basin Committee, 1981. Mackenzie River basin study report supplement 4, hydrometeorologic network design. 101 pp.

Mackenzie River Basin Committee, 1981. Mackenzie River basin study report. A report under the 1978-81 Federal-Provincial Study Agreement respecting the water and selected resources of the Mackenzie River Basin. 231 pp. plus 9 supplement volumes.

Mackenzie River Basin Committee, 1981. Mackenzie River basin study report supplement 5, hydrometeorologic network design, background reports.

Mackenzie River Basin Committee, 1981. Mackenzie River basin study report supplement 8, daily hydrologic model user manual. 184 pp.

Mackenzie River Basin Committee, 1985. Mackenzie River basin study report supplement 9, water quality. 201 pp.

MacLaren Plansearch Limited, 1985. Unpublished data from the Mackenzie River.

McCart P.J. and D. de Graaf, 1974. Effects of disturbance on benthic fauna of small streams in the vicinity of Norman Wells, N.W.T. P.J. McCart (ed.), Fisheries research associated with proposed gas pipeline routes in Alaska, Yukon and Northwest Territories. Arctic Gas Biological Report Series 15(4). 29 pp.

REFERENCES

McCart P.J., 1974. Late winter surveys of lakes and streams in Canada and Alaska along the gas pipeline routes under consideration by Canadian Arctic Gas Study Ltd., 1972-73. P.J. McCart (ed.), Fisheries research associated with proposed gas pipeline routes in Alaska, Yukon and Northwest Territories. Arctic Gas Biological Report Series 15(1). 183 pp plus maps.

McCart P.J., and J. Den Beste, 1979. Aquatic resources of the Northwest Territories. Prepared for the Science Advisory Board of the N.W.T., Yellowknife. 55 pp.

McCart P.J., W Griffiths, C. Gossen, H. Bain and D. Tripp, 1974. Catalogue of lakes and streams in Canada along routes of the proposed Arctic Gas pipeline from the Alaskan/Canadian border to the 60th parallel. Arctic Gas Biological Report Series 16. 251 pp. plus appendices.

McCart D. and P.J. McCart, 1982. Late winter surveys of aquatic resources along the IPL Pipeline Route, Norman Wells, N.W.T. to Zama Terminal, Alberta. Prepared for Interprovincial Pipe Line (NW) Ltd., by Aquatic Environments Limited, Calgary. 28 pp. plus maps.

McPhail J.D. and C.C. Lindsey, 1970. The freshwater fishes of north-western Canada and Alaska. Fisheries Resources Board of Canada Bulletin 173. 381 pp.

Nagy E., Carey J.H., Hart J.H., Ongley E. and Tisdale J., 1986. Hydrocarbons in Mackenzie River Suspended Sediments. National Water Research Institute, Burlington Ontario. NWRI Contribution 86 - 65.

REFERENCES

Mann G.J., 1975. Winter fisheries survey across the Mackenzie Delta. P.C. Craig (ed.), Fisheries investigations in a coastal region of the Beaufort Sea. Arctic Gas Biological Report Series 34(3). 54 pp.

Neill C.R., 1973. Technical report on aerial reconnaissance and study recommendations for rivers in the Mackenzie Basin N.W.T. Hydrologic assessments of northern pipeline development. Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development. Report 73.3, 259-312 pp.

Northwest Hydraulic Consultants Ltd., 1979. Regime of Mackenzie River at Norman Wells in relation to artificial island scheme. Prepared for ESSO Resources Canada Ltd. 39 pp.

Northwest Hydraulic Consultants Ltd., 1982. Hydraulic effects of proposed dredging in Mackenzie River near the Ramparts. Prepared for Public Works Canada, Edmonton. Vol. 1.

Pemcan Services, 1972. Granular materials inventory done for DIAND.

River investigation, prepared navigation channel improvements, test drilling program. Report to the Design and Construction Branch.

Reading, H.G., 1978. Sedimentary environments and facies. Elsevier Publishers, New York.

Reconnaissance granular resource inventory on the Mackenzie Valley for Indian and Northern Affairs by the Geological Survey of Canada, 1972 and 1973.

REFERENCES

Reeder S.W., 1973. Annual water quality report of the Mackenzie River Drainage Basin. Report 73-12.

Reeder S.W., B. Hitchon and A.A. Levinson, 1972. Hydrogeochemistry of the surface water of the Mackenzie River drainage basin, Canada. I-Factors controlling inorganic composition. Geochem. Cosmochem. Acta 36:825-865 pp.

Reid K.W., H.O. Block and J.T. Chapman, 1975. Water quality investigations in the Mackenzie Basin with special reference to the potential for impairment of water quality by pipeline or road construction. Report 74-45. Environmental-Social Committee, Northern Pipeline Task Force on Northern Oil Development. Information Canada, Ottawa.

Reineck and Singh, 1975. Depositional sedimentary environments, Springer-Vorlag Publishers, New York.

Renewable Resources Consulting Services Ltd., 1978. Environmental review and assessment proposed Mackenzie River dredging project. Prepared for Public Works Canada and Department of Transport, Edmonton. Vol. 2, 838 pp.

Rutter, N.W., Boydell, A.N., Savigny, K.W. and Van Everdingen, R.O., 1973. Terrain evaluation with respect to pipeline construction, Mackenzie Transportation Corridor, Southern Part. Report submitted to the Environmental-Social Program for Northern Pipelines, Task Force on Northern Oil Development.

REFERENCES

Stein J.N., C.S. Jessop, T.R. Porter and K.T.J. Chang-Kue, 1973. Fish resources of the Mackenzie River Valley. Environmental-Social Program, Northern Pipelines Task Force on Northern Oil Development. Interim Report II, 260 pp.

Water Quality Branch, 1983. Mackenzie River Basin water quality interpretive report. Inland Waters Directorate, Water Quality Branch, Yellowknife. Final Draft. Vol. 1d (various paging).

Water Survey of Canada, 1977. Miscellaneous stream flow measurements in Alberta and Northwest Territories, 1894-1976. Department of Environment, Water Resources Branch, Water Survey of Canada, Ottawa.

Water Survey of Canada, 1983. Historical streamflow summary, Yukon and Northwest Territories, 1982. Environment Canada, Inland Waters Directorate, Water Survey of Canada, Ottawa. 115 pp.

Water Survey of Canada, 1983. Surface water data reference index, Canada, 1983. Environment Canada, Inland Waters Directorate, Water Survey of Canada, Ottawa. 386 pp.

Water Survey of Canada, 1984. Sediment data Canadian rivers, 1982. Environment Canada, Inland Waters Directorate, Water Survey of Canada, Ottawa. 268 pp.

REFERENCES

Zallen M, 1984. Effects of pipeline construction on juveniles and incubating eggs of mountain whitefish (Prosopium williamsoni Girard) in the Moyie River, B.C. A.F. Crabtree (ed.), Proceedings of the Third International Symposium on Environmental Concerns in Right-of-Way Management February 15-18, 1982, San Diego, CA. 488-498 pp.

LIST OF TABLES

TABLE 4.1
IDENTIFICATION OF THE RIVER ZONES

RIVER ZONE NO.	RIVER[1] KILOMETRE POSTING	GEOGRAPHIC BOUNDARIES	NTS MAP SHEETS	GEOGRAPHIC FEATURES
	0	Great Slave Lake		
I			85F	South Channel
	26	West side of Big Island		
II			85F	Beaver Lake
	60	West end of Beaver Lake		
III			85E&F	Providence Rapids
	107	Horn River and Mills Lake		Fort Providence (km 79)
IV			85E	Mills Lake
	130	West end of Mills Lake		
V			85E, 95H	
	229	Trout River		
VI			95H	Jean-Marie River (km 270)
	300	Rabbitskin River		Green Island Rapids (km 320)
VII			95H & J	Liard River, Ft. Simpson (km 340)
	410	East of Burnt Island		
VIII			95J	Camsell Bend (km 461)
	520	Willowlake River		McGern Island (km 492-514)
IX			95J & O	River Between Two Mountains (km 538)
	580	Wrigley River		Wrigley (km 574)
X			950 & N	Ochre R. (km 605), Johnson R. (km 635)
	665	Blackwater River		
XI			95N, 96C	Dahadinni River (km 678)
	714	Redstone River		

TABLE 4.1
IDENTIFICATION OF THE RIVER ZONES

RIVER ZONE NO.	RIVER[1] KILOMETRE POSTING	GEOGRAPHIC BOUNDARIES	NTS MAP SHEETS	GEOGRAPHIC FEATURES
XII			96C	Saline Is. (km 724), Keele R. (km 737)
	828	Great Bear River		Fort Norman (km 827)
XIII			96C, D&E	Norman Wells (km 905)
	966	Patricia Island		
XIV			96E, 106H	
	1017	Sans Sault Rapids		Mountain River (km 1015)
XV			106H & I	Dummit Island (km 1020-1026)
	1087	Entrance to Ramparts		
XVI			106I	
	1098	Exit to Ramparts		Fort Good Hope (km 1101)
XVII			106I, J&O	Ontaratue River (km 1200)
	1261	North of Little Chicago		
XVIII			1060 & N	Thunder R.(km1299) Travaillant R.(km1327)
	1438	Lower Ramparts		
IX			106N	Arctic Red River (km 1454)
	1475	Point Separation		

Note: 1) Kilometre postings are interpreted from the Mackenzie River Navigational Charts prepared by the Canadian Hydrographic Service. Chart Numbers 6404 to 6426.

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE I 0-26 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: <157 m to <156 m B) Width: 2-10 km C) Depth: .5-4 m mostly .5-2 m D) Tributary Rivers: none E) Current in channel 1.5 to 4 knots	A) Straight Channel Divided B) Numerous islands in wide south channel; Brabrant,Sinclair,Matheson, Lobstick,Naylor,Grassey,Range, 25 unnamed C) Alluvial deposits silt and sand D) River banks low relief E) Boreholes show till in channel F)*Low potential for granular material in this stretch	A) Flat plain adjacent to river B) N. side of channel is Big Island	A) Shale sandstone beneath till and glaciolacustrine materials B) Glaciolacustrine plain deposits overlie moraine plain deposits C) Organic deposits overlie fine-grained glaciolacustrine material and till D) Scattered permafrost beneath organics E)*No good upland sources of granular material

*Comments relative to granular material sources

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE II 26-60 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: Big Island <156 m; Beaver Lake 153 m	A) Straight Channel - expanded in Beaver Lake	A) Flat plain adjacent to river	Same as Section I
B) Width: 4-11 km	B) Islands at junction with N. channel; submerged bars		
C) Depth: .5-4 m	C) Low relief river banks		
D) Tributary Rivers: north channel	D) 6 boreholes show till; 1 shows sand		
	E)*Low potential for granular material in this stretch		

*Comments relative to granular material sources.

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE III 60-107 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: <153 m at km 60 to 143.5 m at Mills Lake	A) Divided Channel - Braided River	A) Undulating to flat plain adjacent to river	A) Bedrock: Sandstone, shale beneath till and glaciolacustrine material
B) Width: 2-10 km widest where channel divides	B) Islands - Meridian, Providence, Green, Whitlock, Misson		B) Glaciolacustrine plain deposits overlie moraine plain deposits. Total thickness of these Quaternary materials is 12-20 m
C) Depth: <1 m-14 m; usually .2-6 m deep	C) Alluvial deposits to 153 m		C) Organic deposits overlie fine-grained moraine plain till and glaciolacustrine silt and clay
D) Deeper: channels Beaver Lake to Fort Providence	D) Alluvial deposits of silt and sandy; some gravel		D) Scattered permafrost beneath organic deposits
E) Tributary Rivers: Bluefish, Horn	E) River bank low relief; 153 m contour marks break with upland		E)*Only source of granular material along MacKenzie Hwy. 10+ km south
F) Current velocity in channels 3.5-5 knots except Providence Rapids where it is 4.5-8.5 knots	F) Providence Rapids		
	G) Many boreholes show sand and gravel		
	H)*Moderate to high potential for granular material in this section		

*Comments relative to granular material sources.

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE IV 107-130 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: 143.5 m	A) Expanded Straight Channel - Lake	A) Same as Zone III	A) Same as Zone III
B) Width: 6-17 km	B) Lacustrine/Alluvial Plain deposits		
C) Depth: .2-6 m	C) Alluvial Plain deposits of silt and fine sand		
D) Deeper channel off Horn River S. central part of lake	D) River bank low relief; 153 m contour marks break with upland		
	E) Boreholes show silty and clay		
	F)*Low potential for granular material in this section		

*Comments relative to granular material sources.

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE V 130-229 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: 143.5 Mills Lake to 141 m at km 228.5 B) Width: 1-4 km C) Depth: 2-12 m; usually 2-8 m D) Deeper: channel - Bouvier River to Redknife River E) Tributary Rivers: Bouvier (gravel bed) Trout (gravel bed) Redknife (gravel bed) Axe C. Small Axe C. Wallace C. Skull C. Morrisey C. Hair Stand C. Several unnamed creeks	A) Straight Channel B) Alluvial Plain and terrace deposits to 153 m C) Alluvial deposits of silt and sand D) Two very small unnamed islands E) River banks low relief F) 153 m contour marks break with upland G)*Possible gravel in river near mouth of gravel bed tributaries, ie; Trout, Redknife, Bouvier. H) Low to moderate potential for granular material in river	A) Undulating to flat plain B) Upland area Horn Plateau 75 km to N. C) Low ridges (240 to 300 m) representing shorelines of Glacial Lake McConnell rise slightly above the glaciolacustrine/moraine plain N. of the river D) Escarpment of limestone rock lies 7 to 25 km S. of river	A) Shale, Sandstone in lowland by river; limestone along escarpment 7-25 km S. of river; Sandstone and shale in Horn Plateau B) Glaciolacustrine plain and veneer deposits (up to 5 m thick) overlie morainal deposits C) Total depth of glaciolacustrine and till is 12-20 m D) Organic deposits overlie till and glaciolacustrine materials. Scattered permafrost beneath organics E)*Upland granular material in beaches and along escarpment in glaciofluvial deposits

*Comments relative to granular material sources.

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE VI 229-300 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: W. of Trout River 141 m to Rabbitskin River 137 m B) Width: .75-1.5 km C) Depth: 2-15 m D) Deeper channel; Jean Marie Creek to Cache I E) Tributary Rivers: Jean Marie (gravel bed) Spence	A) Straight Channel B) Alluvial plain and terrace deposits to 153 m C) Alluvial deposits of sandy silt, also till on river bed D) Some boreholes show granular alluvium E) River banks show some relief - cutbanks Spence River to Rabbitskin River	A) Similar to Section V	A) Similar to Section V except 1) Fewer glaciolacustrine deposits overlie till on N. side of River 2) Glaciolacustrine and morainal deposits only 12 m thick N. of river 3) Glaciolacustrine deposits - over till very thick (20 m) S. of River 4) Dunes developed on glaciolacustrine material S. of river 5) Extensive high ice content permafrost in glaciolacustrine material and till with organic cover

*Comments relative to granular material sources.

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE VII 300-410 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: E. of Rabbitskin 137 m to E. of Burnt Island <120 m B) Width: 1.5-3 km C) Depth: 1-10 m usually 2-7 D) Tributary Rivers: Liard Harris Martin Trail Several unnamed creeks	A) Straight Channel: 3 Minor Multi-channel stretches B) Alluvial deposits to 153 m C) Near Rabbitskin River 3 terrace levels representing old river D) Islands (all small) Green, Hanson, Martin, Ft. Simpson, 5 unnamed E) Alluvial plain and terrace deposits of sand and silt F) River bottom in till; boulder pavement (6 m till/bedrock) G) River banks high and steep particularly S. side H) Green Island Rapids I) Some boreholes show gravel near Green Island Rapids J)*Low potential for granular material in river except downstream of Green Island Rapids	A) Undulating to flat plain W. of river B) Flat plain with dunes S. of river C) 152 m represents glaciolacustrine/till boundary N. of river; 213 m on S. side of river D) Martin Hills rise above plain to S. E) Ebbutt Hills rise above plain to N.	A) Bedrock: Shale, Sandstone in low land near river B) Shale and Sandstone in Ebbutt and Martin Hills C) Morainal deposits above 152 m N. of river; above 213 m S. of river D) Glaciolacustrine deposits thickest S. of river E) Dunes on glaciolacustrine plain F) Quaternary deposits 12 m thick N. of river, 12-20 m S. of river G) Intermittent high ice content permafrost beneath organics in fine-grained deposits H)*Only several upland granular deposits associated with glaciofluvial and alluvial terraces

*Comments relative to granular material sources

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE VIII 410-520 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: E. of Burnt Island <120 m; N. of Willowlake <105 m B) Width: 1-6.5 km; widest in areas of multichannels C) Depth: 1-10 m; usually 2-7 m D) Tributary Rivers: Nahanni (gravel bed) Root (gravel bed) Willowlake (gravel bed)	A) Braided River B) Alluvial plain and terrace deposits to 153 m C) Islands (many) - 22 unnamed. Also McGern, Barry, and Burnt Island D) Alluvial deposits of sand, silt, gravel E)*McGern Island has gravel in lower alluvial plain; also gravel in higher elev. from Willowlake River sources F) Some steep banks on W. and S. side of river G) Some boreholes near McGern Island and Burnt Island show gravel H)*High potential for granular material in this section	A) Undulating to rolling moraine plain E. of river; flat glaciolacustrine and moraine plain W. of river B) Glaciolacustrine deposits to 300 m E. and W. of river C) Camsell Range W. of river 10-30 km D) Old river channel E. of Mackenzie River near Camsell Bend	A) Bedrock: Shale, Sandstone near river; Limestone in Camsell Range B) Till and glaciolacustrine deposits overlie bedrock (12-20 m thick) C) Low-Moderate ice contents in intermittent permafrost except where organics overlie fine-grained till and glaciolacustrine D)*A few large scattered glacio-fluvial granular deposits particularly near Willowlake River and Root River

*Comments relative to granular material sources.

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE IX 520-580 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: W. Willowlake River <105 m to Wrigley River <95 m	A) Straight Channel Transitional to Braided River	A) Rolling to ridged plain; minor sections of flat plain E. of Mackenzie	A) Bedrock: Shale, Sandstone near river; Limestone and Dolomite in Camsell and McConnell Ranges
B) Width: 1-2.5 km	B) A few alluvial islands	B) Flat to undulating plain W. of river	B) Drumlinoid moraine, moraine plain, and glaciolacustrine deposits 5-30 m thick E. of Mackenzie River
C) Depth: 1-10 m	C) Islands: Old Fort, 7 small unnamed islands	C) McConnell Range 10 km E. of river	C) Moraine plain and hummocky moraine deposits W. of river
D) Deepest section Fish Trap Creek to Wrigley	D) Alluvial deposits to 153 m	D) Camsell Range 30 km W. of river	D)*Large glaciofluvial terrace of sand and gravel near Wrigley. Glaciofluvial deposits of sand/gravel near River-Between-Two Mountains
E) Tributary Rivers: River-Between-Two-Mountains (gravel bed) Wrigley (gravel bed) Fish Trap Creek (gravel bed) Hodgson Creek Moose Pasture Creek	E) Moderate to high banks near river		E) Intermittent to extensive permafrost
	F) Alluvial deposits of sand, silt possible minor gravel in river deposits near mouth of River-Between-Two-Mountains and Wrigley River		
	G)*Moderate potential for gravel in this stretch		

*Comments relative to granular material sources

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE X 580-665 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: Wrigley River <95 m Blackwater River <90 m B) Width: .75-1 km C) Depth: 1-18 m mostly 2-7 m except deepest channels D) Tributary Rivers: (all gravel beds) Ochre Johnson Blackwater Eetseemoday Mountain People C. Three Finger C. Mountain Sand C. White Sand C. Dam C. Phillips C. Gashoday C.	A) Straight Channel B) No alluvial islands C) Steep banks D)*Alluvial terraces of silt, sand, some gravel to 153 m E)*Glaciofluvial terraces of sand/gravel at higher elev. between Dam Creek and Blackwater River F)*High potential for gravel in this section particularly near Ochre River, Blackwater River outlets	A) Flat glaciolacustrine and moraine plain deposits fill narrow valley (20 km wide) between McConnell River and Wrigley Plateau B) Minor creeks are deeply incised as they exit McConnell Range and Wrigley Plateau	A) Bedrock: permafrost sandstone, shale near river; Dolomite, limestone in Camsell Range; Sandstone, shale in Wrigley Plateau B) Morainal and glaciolacustrine plain deposits 5-30 m C) Thick organics developed on fine-grained deposits D) High ice content permafrost in fine-grained organic covered deposits - intermittent to extensive in this region E)*Glaciofluvial sand and gravel in upland near Ochre, Johnson, Blackwater Rivers

*Comments relative to granular material sources

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE X 665-714 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: Blackwater River <90 m to <75 m Redstone River	A) Straight Channel Transitional to Braided River	A) Flat glaciolacustrine and moraine plain in valley between McConnell River and Wrigley Plateau	A) Bedrock: Shale and Sandstone in valley and Wrigley Plateau; Limestone and Dolomite in McConnell Range
B) Width: .5 to 3.5 km; widest near Birch Island	B) Alluvial Islands - Birch I, 6 unnamed	B) Valley wider than in Section X eg: 40 km	B) Morainal and glaciolacustrine deposits 5-30 m thick
C) Depth: .5 to 18 m; mostly 1-8 m	C) Moderately steep banks especially near Dahadinni River	C) Flat glaciofluvial and alluvial terraces to 150 m+	C) Fairly extensive permafrost in fine-grained deposits
D) Tributary Rivers: (all gravel beds) Dahadinni, Redstone, Saline, Nodaddy C., Several unnamed creeks	D)*Alluvial deposits of silt, sand; some gravel in these deposits from Blackwater to Dahadinni River	D) Old meltwater channels E. of Mackenzie, S. of Birch I	D)*Large glaciofluvial deposits in terraces near Redstone and Blackwater Rivers; Also small scattered deposits associated with glaciofluvial channels on moraine plain
	E) Some boreholes show gravel and sand upstream of Birch I		
	F)*Moderate to high potential for granular material in this section especially near Blackwater, Dahadinni River and Birch I at S. end of zone		

*Comments relative to granular material sources

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE XII 714-828 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: at Redstone River <75 m and at Great Bear <60 m	A) Braided River - Transitional to Meandering	A) Flat to rolling moraine plain deposits above 153 m; flat glaciolacustrine plain below 153 m	A) Bedrock: Shale, Sandstone in river valley; Limestone/Dolomite in mountains
B) Width: 1 to 12 km; widest in vicinity of alluvial islands formed by meander cut-offs	B) Meander Cut-Off Islands - very large including 6 large unnamed islands and Police I	B) McConnell Range/Franklin Mtns. 15-25 km E. of river	B) Morainal deposits more common from Redstone River to Big Smith Creek
C) Depth: .5-12 m; usually 1-7 m	C) Also many small islands - 18 in number	C) MacKay Range 25 km W. of river	C) Glaciolacustrine deposits more common; Big Smith Creek to Great Bear River
D) Tributary Rivers: Keele (gravel bed) Little Birch Big Smith Creek (gravel bed) Little Smith Creek (gravel bed)	D)*Alluvial deposits are mostly silt and sand; some gravel in the islands from Redstone River to Big Smith Creek; some gravel N. of Keele River in islands; also gravel reported on charts near Seagull I and in boreholes near Great Bear River	D) Numerous thaw lakes in glaciolacustrine deposits	D) Dunes on glaciolacustrine deposits
	E) 1 borehole shows gravel near Saline Island; 1 downstream of Redstone River; 2 boreholes show thin gravel over till and shale just upstream of Great Bear River		E) Organics and extensive permafrost associated with fine-grained deposits
	F)*Moderate potential for borrow in river. Upland sources are small and scattered with some permafrost		F)*Small scattered glaciofluvial deposits - especially near Little Smith Creek; few granular deposits from Little Smith Creek to Great Bear River

*Comments relative to granular material sources

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE XIII 828-966 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: at Great Bear <60 m at Patricia I <45 m	A) Braided River	A) Norman Range (Bear Rock) at river; E. side of river Norman Range 0-5 km from river; W. 32 km to Mackenzie Mountains	A) Bedrock: Shale, Sandstone in low-land; Limestone in Mackenzie and Norman ranges
B) Width: 1.5 to 6.5 km; widest in vicinity of islands	B) Numerous islands; Windy, Gaudet, Halfway, Ten Mile, Bear, Goose, Rader, Ogilvie, Judith, Perry, Stanley, Willard, Patricia, Six Mile, Mac, 4 unnamed	B) Mostly flat to rolling narrow plain between two mountain ranges	B) Bedrock shallow beneath morainal, glaciolacustrine materials
C) Depth: 2-11 m; usually 2-8 m; 1-4 m near islands	C) Islands mostly of sand and silt	C) Stretches of flat glaciolacustrine plain below 120 m	C)*Alluvial plain deposits to 90 m along river; these may have minor gravel
D) Tributary Rivers and Creeks: (all gravel beds) Great Bear, Little Bear, Slatter Rivers Creeks: (all gravel beds) Jungle Ridge, Vermillion, Prohibition, Christina, Helva, Francis, Canyon, Joe, Bosworth, Billy, Oscar, Elliott, Bluefish, MacKay, Bogg, Stewart, Loon, Ray, Devo, Windy, Fair	D)*Gravelly alluvial deposits at mouth of Little Bear River, possibly Oscar Creek and other creeks	D) Beach ridges at 120 m	D)*Large glaciofluvial plain near Little Bear River; also alluvial fan deposits behind Kee Scarp
	E)*Gravel in channel deposits - Esso	E) Flat to sloping morainal plain and veneered bedrock above 120 m	E)*Scattered small granular glacio-fluvial deposits along streams in uplands
	F) 6 boreholes show silty clay till (4 m) over shale right near Norman Wells	F) Deeply incised creeks; E. of river	F)*Granular materials in beach ridge deposits
	G)*Moderate to high potential for gravel in river in this section; gravel bed tributary sources of gravel		G)*Chance of granular material in terraces on W. side of river
			H)*Large glaciofluvial deposit up Great Bear River 10 to 15 km known as 'Bennett Field'
			I) Fairly continuous permafrost

*Comments relative to granular material sources

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE XIV 966-1017 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: Patricia I <45 m to Mountain River <40 m B) Width: .75 to 3 km; widest at Axel I C) Depth: 1-19 m; shallowest near Axel I D) Tributary Rivers: Carcajou (gravel bed) Mountain (gravel bed) Maida Creek Trapper Creek	A) Straight Channel Transitional to Braided River B) Islands Axel I, 2 unnamed C) Alluvial deposits of sand and silt D)*Gravel in alluvial deposits near Mountain River E) Steep banks F)*Moderate potential for granular material, especially near Mtn. River where gravel is coarse-grained	A) Franklin Mountains (Carcajou Ridge and East Mountain) border E. side of river; with one flat plain section adjacent to river B) Flat glaciolacustrine plain and undulating moraine veneered bedrock to W. of river in Mackenzie Plain	A) Shale/Sandstone in Mackenzie Plain W. of river and in lowlands between Carcajou Ridge and E. Mountain B)*Sand and gravel glaciofluvial and fine-grained glaciolacustrine deposits in flat plain between Carcajou Ridge and E. Mountain C) Moraine veneered bedrock W. of river Patricia I to Maida Creek D) Glaciolacustrine from Maida Creek to Mountain River E)*Gravel in river at San Sault test site F)*Extensive coarse-grained glacio-fluvial deposits >10 km up Mountain River G) Fairly continuous permafrost

*Comments relative to granular material sources

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE XV 1017-1087 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: Mountain River <40 m to Ramparts <30 m B) Width: 1.5 to 5 km C) Depth: .5-12 m; usually .5-7 m D) Tributary Rivers: (no gravel beds except possibly Donnelly River) Hanna Donnelly Tsintu Ramparts Hume Snafu Creek	A) Braided River B) Numerous Is. Incld.: Dummit, Hanna, N. Hanna, Hardie, Hume, Spruce, 11 unnamed C)*Alluvial deposits sand&silt except downstream of San Sault Rapids where sand&gravel is present on Dummit Is. & between Dummit and Hardie Is. D) Steep banks in glaciolacustrine clay from San Sault to Spruce I E) Steep banks in bedrock from Spruce I to Ramparts F) San Sault & Ramparts Rapids G) 2 boreholes show gravel upstream of Donnelly River; probe holes show gravel near Dummit Is. H)*Moderate to high potential for gravel in the southern 15 km of this section; particularly downstream of San Sault Rapids near Dummit Is. & Donnelly R. the rest of the area will probably be mostly sandy and of low to moderate potential	A) Flat glaciolacustrine plain (Anderson Plain) E. side of river with several ridges of Franklin Mts. (Beavertail Mtn. and Bat Hills) B) Flat glaciolacustrine plain W. of river/Peel Plain C) Thaw lakes and permafrost in glaciolacustrine plain	A) Sandstone and Shale in lowlands; Limestone in lowland from Spruce Island to the Ramparts; Limestone in Beavertail Mtn. and Bat Hills B) Glaciolacustrine plain of sand, silt, clay (thick) with organics and fairly continuous permafrost C) No granular material in upland areas except alluvial terrace silt/sand D)*Glaciofluvial or alluvial Class 2 deposits (Hardy Assoc.) W. of river near Ramparts. This zone and Zone XVI E) Extensive permafrost

*Comments relative to granular material sources

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE XVI 1087-1098 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: S. end Ramparts <30 m, N. end Ramparts 28 m	A) Straight Channel	A) Flat moraine plain E. of river	A) Limestone beneath morainal deposits
B) Width: .5-1 km	B) No Islands	B) Flat to undulating moraine veneered bedrock W. of river	B)*Glaciofluvial or Alluvial deposit of Class 2 material has been reported W. of river by Hardy Assoc Part of this deposit is in Zone XV
C) Depth: .5-18 m	C) Steep banks in bedrock (limestone)		C) Moraine plain <5 m E. of river; moraine veneer deposits 1-5 m W. of river
D) Tributary Rivers: none	D) Low potential for gravel in river		

*Comments relative to granular material sources

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE XVII 1098-1261 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: N. end Ramparts 28 m to K.P. 1261 <23 m	A) Braided River	A) Flat moraine plain E. of river from N. end of Ramparts to Payne Creek (Anderson Plain)	A) Sandstone; Shale, Limestone in low-lands
B) Width: 1-5 km; widest in multi-channel areas	B) Numerous large & small islands including: Manitou, Askew, Bryan, 23 unnamed; same shallow bars	B) Flat glaciolacustrine plain adjacent to river on W. side; also on E. side from Payne Creek to N. of Little Chicago	B) Limestone exposed in higher river banks from Ft. Good Hope to Askew I
C) Depth: .5-23 m; usually 1-19 m and 1-4 m near islands	C)*Alluvial deposits of sand/silt; possible gravel near Tieda River from charts	C) Thaw lakes and permafrost features in morainal & glaciolacustrine plain	C) Moraine deposits of till; glacio-lacustrine deposits of silt/sand
D) Tributary Rivers: Hare Indian (gravel bed) Loon (gravel bed) Tieda (gravel bed) Gills Ontaratue Gossage Payne Creek	D) Steep banks in limestone from Ft. Good Hope to Askew Islands		D)*Scattered glaciofluvial deposits on moraine plain
	E) Moderate banks Askew Islands to N. of Little Chicago		E)*Large upland sand and gravel glaciofluvial deposit near E. of river at Ft. Good Hope
	F)*Low to moderate potential for gravel in river; most alluvial deposits will be sandy		F)*Most other upland deposits are small and are near Tieda and Loon Rivers
			G) Some glaciofluvial material possible on W. side of Mackenzie River near Yeltea Lake outlet

*Comments relative to granular material sources

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE XVIII 1261-1438 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) <u>Elev</u>: km 1261 <23 m to Lower Ramparts <21 m	A) Braided River Transitional to <u>Straight Channel</u>	A) Flat glaciolacustrine plain E.&W. of river from K.P. 1261 to Rabbit-Hay River	A) Sandstone shale in lowland
B) <u>Width</u>: 2-4 km, widest in multi-channel areas	B) Alluvial islands - 11 unnamed of silt, sand	B) Flat to rolling moraine plain E. and W. from Rabbit-Hay River to Arctic Red River	B) Sandstone in steeper banks from 1350 km to Arctic Red River
C) <u>Depth</u>: .5-20 m usually 1-7 m	C) Many partially submerged islands of sand, silt 23 total	C) Thaw lakes and permafrost features in glaciolacustrine and moraine plain	C) Morainal deposits of till; glaciolacustrine deposits of silt/sand
D) <u>Tributary Rivers</u> Travaillant Thunder (gravel bed) Tree Rabbit-Hay Pierre Creek Adam Creek Fat Rabbit Creek Benoit Creek	D) Steep banks in sandstone/shale from 1350 km to Arctic Red River		D)*Scattered glaciofluvial deposits on moraine plain - eg: near Thunder River (E. and W. of Mackenzie River) and the Lower Ramparts, and Rabbit Hay River
	E) Moderate banks 1350 km to Ft. Good Hope		E) Fairly continuous permafrost
	F)*Low potential for gravel in river; most alluvial deposits will be sandy		

*Comments relative to granular material sources

TABLE 4.2
MACKENZIE RIVER TERRAIN AND BORROW SUMMARY
(RIVER ZONE XIX 1438-1475 km)

RIVER TOPOGRAPHY	RIVER LANDFORMS	UPLAND TOPOGRAPHY	UPLAND LANDFORMS
A) Elev: <21 m Lower Ramparts to <20 m Pt. Separation B) Width: 1 km C) Depth: 1-23 m; usually 1-12 m D) Tributary Rivers: Arctic Red Tsial Trein Creek	A) Straight Channel B) Several small alluvial bars of sand below Lower Ramparts C) Steep banks in shale D)*Low potential for gravel in river except possibly in channel below Lower Ramparts	A) Rolling to hummocky moraine Arctic Red River area B) Thaw lakes and permafrost in hummocky moraine C) Moraine plain (flat) downstream of Arctic Red River to Pt. Separation	A) Shale in lowlands B) Steeper banks in shale C) Morainal deposits in till D)*Scattered glaciofluvial deposits in moraine plain and hummocky moraine, eg: esker near Arctic Red River E) Frog Creek glaciofluvial complex >10 km S.W. of Arctic Red River F) Fairly continuous permafrost

*Comments relative to granular material sources

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone I 0-26 km)

		RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
				No known deposits				
0							No. 3, 4, 5, 6	Sandy Silty, Clay Till
5							No. 19	Till
10							No. 34	Till
15							No. 44	Till
20							No. 52	Till
25							No. 66	Till

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone II 26-60 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	RESERVES OF KNOWN GRANULAR MATERIALS[2]: MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
				No known deposits				
29							No. 82	Till
36							No. 127	Silty Clay
40							No. 114	Silty Clay
45							No. 102	Silty Clay
55							No. 2	Gravelly Silty Sand
60							No. 99	Silty Clay

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone III 60-107 km)

		RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
				No known deposits				
59-63							Strewn boulders & gravel in shallow water left & right banks	
65						No. 96		Sand & Gravel
66-72							Shallow water with boulders & gravel ledges left & right banks	
73						No. 19		Sand & Gravel
82						No. 31		Sand & Gravel
87						No. 37		Clayey Sand & Gravel
99						No. 39		Till
105						No. 42		Silty Clay w/ Gravel

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone IV 107-130 km)

		RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
				No known deposits				
128							No. 84	Silty Clay

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone V 130-229 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
				RESERVES OF KNOWN GRANULAR MATERIALS[2]			RIVERBED DATA	
				No known deposits				
155-170							Sand near left bank between tributaries of alluvium-Axe Cr.-Bouvier Cr.	
188	Alluvium		L	Minor sand & gravel	Tributory Redknife River	N/D		
219	Alluvium		L	Minor sand & gravel	Tributory Trout R.	N/D		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone VI 229-300 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	RESERVES OF KNOWN GRANULAR MATERIALS[2]: MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
				No known deposits				
269							No. 76	Sand & Clay w/ Gravel
276							No. 75	Sand & Clay w/ Gravel
298							No. 48	Sandy Clay w/ Gravel

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone VII 300-393 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
	RESERVES OF KNOWN GRANULAR MATERIALS[2]						RIVERBED DATA	
				No known deposits				
305							No. 55	3' Sandy Gravel over Till
314							No. 64	Silty Sands w/ Gravel
322							No. 69	Sand & Fine Gravel
324							No. 75	Sand & Gravel
334	FS-1		L	Sand & Gravel	3 km S. of Ft. Simpson along Laird R. N. side	500,000		
	FS-11		L	Sand & Silt	4 km S. Ft. Simpson S. side Liard R.	N/D		
335							Sand & Gravel left bank, intersection w/ Liard R. just S. of Ft. Simpson	
336-347	FS-3		L	Fine Sand	1	Unlimited		
340-344							Left Bank-Isle	Sand
340-352	FS-12	R		Sand & Gravel	0.0	N/D		
342-349	FS-13	R		Gravel	1.5	1,500,000		
347-350	FS-8		L	Fine Sand	4	15,000,000	Left Bank	Sand
353							Left Bank-Shoreline	Gravel
355	FS-7		L	Fine Sand	3-6	2,000,000		
360	P101	R		Sandy Gravel	0.0	N/D		
366	P102	R		Sandy Gravel	0.0	N/D		
369-370							Mid-Channel-Isle	Sand
370-373	P103		L	Sand & Gravel	1.5	N/D		
375	P104	R		Fine Sand	3.5	N/D		
383	P105	R		Fine Sand	5.5	N/D		
393							Left Bank	Sand

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone VII 393-410 km)

		RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
394	P107	R		Silty Sand	0.5	N/D	Left Bank	Sand
398	P106	R		Fine Sand	5.0	N/D	Mid-Channel & Left Bank-Isle	Sand
400-408							Left Bank	Sand
407	P109	R		Silty Sand	0.5	N/D		
Zone Borrow Summary			L	Fine Sand		17,000,000+N/D		
			L	Sand & Gravel		500,000+N/D		
Zone Borrow Summary		R		Fine Sand		N/D		
		R		Sand & Gravel		1,500,000+N/D		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1

MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone VIII 410-516 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R) LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
	RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
410						Mid-Channel-Isle	Sand
413	P110	R	Fine Silty Sand	0.5	N/D		
416	P111	R	Silty Sand	0.5	N/D		
417						Mid-Channel-Isle	Sand
422						No. 60	Sand
430						Mid-Channel-Isle	Sand
438-447						Mid-Channel-Isle	Sand
455						Left Bank	Sand & Gravel
457							
460						No. 56	Sand & Gravel
468						Mid-Channel-Isle	Gravel
470						Mid-Channel-Isle	Gravel
493						No. 55	Silty Sand
495	P129	R	Sand & Gravel	McGern Is.	N/D		
498						No. 4	Sand
499						No. 5	Fine Sand
501						No. 51	Sand-Clay Till
502.5						No. 7	5' Sandy Gravel, over Till
506						No. 50	Till
509	P135	R	Silty Sand	5.5	N/D		
510	P134	R	Silty Sand	2	N/D		
510	P136	R	Silty Gravel	5	N/D	No. 46	Sand & Gravel
512						Left Bank	Sand
512.5	P139	R	Sand & Gravel	6.5	500,000	No. 45	Sand & Gravel
514.5	P140	R	Fine Sand	3.5	3,000,000		
515						No. 37	Silty Sand
516	P133					Isle	Sand & Gravel

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone VIII 516-520 km)

		RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
516-518							Left Bank-Isle	Sand
517							No. 30	Till
519	P141	R		Sand & Gravel	11	N/D		
Zone Borrow Summary			L	Fine Sand	No known deposits			
			L	Sand & Gravel				
Zone Borrow Summary		R		Fine Sand		3,000,000+N/D		
		R		Sand & Gravel		500,000+N/D		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XI 520-577 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	RIVERBED DATA: MATERIAL
		RESERVES OF KNOWN GRANULAR MATERIALS[2]						
532	P142	R		Sand & Gravel	5	3,000,000		
536	P143	R		Sandy Gravel	7	1,000,000		
537	P144	R		Sand & Gravel	3	N/D		
540	P146	R		Sand & Gravel	4	600,000		
540	P148	R		Sand & Gravel	7	N/D		
542	P147	R		Sand & Gravel	1	N/D		
547	P151	R		Sand & Gravel	3.5	1,500,000		
549	P150	R		Sand & Gravel	6	N/D		
550	P152	R		Sand	1.5	N/D		
551							Left Bank	Sand & Gravel
553	P153	R		Gravel	4	3,000,000		
554.3	P154	R		Sand & Gravel	0.5	10,000,000		
556	P155		L	Sand & Gravel	0.5	N/D		
556	P156	R		Silty Sand & Gravel	4	N/D		
560	P157	R		Silty Sand & Gravel	8	N/D		
560-565							Left Bank-Isle	Sand & Gravel
562.5	P158	R		Silty Sand & Gravel	7	N/D		
564	W1	R		Sandy Gravel	0	5,000,000		
565.5	W20		L	Gravel	0.5	200,000		
566	W3	R		Silty Gravel	1.5	1,000,000		
567.5	W11	R		Sandy Gravel	0	150,000		
569	W2	R		Sandy Gravel	0.5	40,000,000		
571-582							Left Bank-Wrigley R. Intersection	Gravel
573	W5	R		Sandy Gravel	0.5	10,000,000		
574								
575	W6	R		Sandy Gravel	0.5	1,000,000		
576	W10	R		Sandy Gravel	2	300,000		
577	W7	R		Sand & Gravel	4.5	250,000		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XI 577-580 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	RESERVES OF KNOWN GRANULAR MATERIALS[2]: MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
577.5	W13	R		Sandy Gravel	0.06	1,000,000		
579	W12	R		Sandy Gravel	0	600,000		
580								
Zone Borrow Summary			L	Fine Sand				
			L	Sand & Gravel		200,000+N/D		
Zone Borrow Summary		R		Fine Sand		N/D		
		R		Sand & Gravel		78,400,000+N/D		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone X 580-664.5 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	RESERVES OF KNOWN GRANULAR MATERIALS[2]: MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	RIVERBED DATA: MATERIAL
590	P159	R		Sand & Gravel	8	1,000,000		
602	P163		L	Sand & Gravel	0.5	N/D		
604	P164	R		Sand & Gravel	0.5	1,500,000		
605	P165	R		Sand & Gravel	0.5	N/D		
606	P168	R		Sand & Gravel	0.5	3,000,000		
612	P169	R		Sand & Gravel	0.5	1,000,000		
613	P170	R		Sand & Gravel	0.5	2,000,000		
613	P171		L	Sand & Gravel	0.5	N/D		
614	P172	R		Sand & Gravel	4	N/D		
618	P174	R		Sand & Gravel	6	N/D		
625	P176	R		Sand & Gravel	0.5	10,000,000		
629	P177	R		Sand & Gravel	0	250,000		
632	P178	R		Sand & Gravel	0	2,000,000		
635								
636	P179		L	Silty Sand	0.5	N/D		
637	P180		L	Sand & Gravel	0.5	N/D		
644	P183	R		Silty Gravel	1.5	1,000,000		
649	P184	R		Sand & Gravel	0.5	1,500,000		
655	P185	R		Sand & Gravel	0.5	2,500,000		
661	P191	R		Sand & Gravel	5	20,000,000		
663	P190	R		Sand & Gravel	1	10,000,000		
664	P189	R		Sand & Gravel	0.5	50,000		
664.5	P186		L	Sand & Gravel	0	N/D	Right bank inter- section w/ Blackwater R.	Gravel
Zone Borrow Summary			L	Fine Sand		N/D		
			L	Fine Sand		N/D		
Zone Borrow Summary		R		Fine Sand		N/D		
		R		Sand & Gravel		$55.8\times10^6/m^3$+N/D		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XI 664.5-712.5 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	RESERVES OF KNOWN GRANULAR MATERIALS[2]: MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	RIVERBED DATA: MATERIAL
665	P188	R		Sand & Gravel	0	N/D		
666	P187		L	Sand & Gravel	0	N/D		
669							Mid-Channel R. Bend	Gravel
671	P194	R		Sand & Gravel	1	N/D		
672	P195	R		Sand & Gravel	2	10,000,000		
677							Left Bank Inter-section w/ Dahadinni R.	Gravel
678	P193	R		Silty Sand	12	N/D		
681	P196	R		Sand & Gravel	3.5	40,000,000		
688							Right Bank	Sand & Gravel
690	P197	R		Sand & Gravel	4.5	15,000,000	No. 9	Silty Sand over Gravel
695							No. 11	Sand & Gravel
696	P200	R		Sand & Gravel	13	N/D		
696.5							Mid-Channel	Gravel
697.5	P209	R		Fine Sand	2	3,000,000		
698.5	P201	R		Sand & Gravel	11	N/D		
700	P203	R		Sand & Gravel	10	N/D		
702	P202	R		Sand & Gravel	15.1	N/D		
702	P208	R		Silty Sand & Gravel	0.5	N/D		
702.5	P210		L	Silty Sand	0.5	N/D		
703	P204	R		Sand & Gravel	9	N/D		
705	P205	R		Silty Sand	8	N/D		
710							Mid-Channel-Isle	Sand
711	P211	R		Sand & Gravel	5	N/D		
711-722							Left Bank-Isle Intersection w/ Redstone R.	Gravel
712.5	P212	R		Sand	7	N/D		
712.5	P213	R		Sand	3	5,000,000		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XI 712.5-714.5 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
		RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
714	P214	R		Sand	1	N/D		
714.5	P216		L	Silty Sand	1	N/D		
714.5	P215	R		Silty Sand	2	N/D		
Zone Borrow Summary			L	Fine Sand		N/D		
			L	Sand & Gravel		N/D		
Zone Borrow Summary			R	Fine Sand		8,000,000+N/D		
			R	Sand & Gravel		65,000,000+N/D		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XII 714.5-763 km)

		RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
717	P219	R		Sand & Gravel	12	N/D		
718	P217	R		Sand & Gravel	0	N/D		
722-730							Right Bank-Isle	Gravel
724	P222		L	Silty Sand	0	N/D		
725							No. 14	Sand & Gravel
730-737							Left Bank-Isle	Gravel
730	P224	R		Sand & Gravel	11	2,000,000		
732	P223		L	Silty Sand	0.5	N/D		
733	P225	R		Sand & Gravel	10	N/D		
735	P229		L	Silty Sand	2	N/D		
738	P228	R		Sand & Gravel	2	8,000,000		
738	P230		L	Silty Sand	3	N/D		
739-742							Mid-Channel-Isle	Gravel
740	P227	R		Sand & Gravel	5	25,000,000		
740	P231	R		Sand	2.5	N/D		
743	P233	R		Sand & Gravel	14	N/D	Left Bank	Gravel
744-747							Mid-Channel	Gravel
744	P232	R		Sand & Gravel	10	500,000		
745	P235	R		Sand & Gravel	15	N/D		
747-753							Right Bank-Isle	Sand & Gravel
752	P241	R		Gravelly Sand	12	N/D		
753	P236	R		Sand & Gravel	11	N/D		
754-758							Left Bank-Isle	Gravel
755	P243	R		Sand & Silt	7	N/D		
756.5	P237	R		Silty Sand	10	N/D		
756.5	P242	R		Sand & Gravel	8	N/D		
758	P238	R		Silty Sand	10	N/D		
759	P239	R		Silty Sand	10	N/D		
760	P244	R		Silty Sand	3	N/D	Mid-Channel	Sand
763	P240	R		Silty Sand	8	N/D		
763	P245	R		Silty Sand	6	N/D		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1

MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XII 763-824 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	RESERVES OF KNOWN GRANULAR MATERIALS[2]: MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	RIVERBED DATA: MATERIAL
766	P246		L	Silty Sand	0	N/D		
766.5	P248	R		Sand & Silt	0	N/D		
767							Mid-Channel	Gravel
768	P247		L	Silty Sand	0	N/D		
769							Right Bank	Gravel
770							Left Bank	Gravel
771	P251	R		Fine Sand	8	5,000,000		
773	P250	R		Fine Sand	4	N/D		
778	P249	R		Fine Sand	2	700,000		
779							Right Bank	Gravel
786							Right Bank	Gravel
788	P252	R		Fine Sand	11	1,000,000		
790							Right Bank	Gravel
791	P255	R		Fine Sand	4.5	7,000,000		
792	P253	R		Fine Sand	10	2,000,000		
792	P254	R		Fine Sand	7	1,000,000		
795	P256	R		Fine Sand	5	1,500,000		
802	P257	R		Fine Sand	4	250,000		
808							Left Bank	Sand
815-826							Left Bank-Isle	Sand
816	FN8	R		Gravel	0	N/D		
816	FN16	R		Fine Sand	5	1,000,000		
820	FN11	R		Fine Sand	0-Great Bear R.	N/D		
820	FN12	R		Gravel & Sand	0-Great Bear R.	N/D		
822	FN13	R		Silty Sand	Great Bear R.	1,000,000		
823	FN10	R		Silty Sand	0-Great Bear R.	400,000	No. 1	Silty Sand & Gravel over Shale
824							No. 15	Sand & Gravel over Till

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XII 824-828 km)

		RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
825	FN14	R		Fine Sand	1	300,000		
825	FN23	R		Sand & Gravel	0	5,000		
827	FN5	R		Silty Sand	2-Great Bear R.	10,000		
828	FN6	R		Silty Sand	0.5	N/D		
Zone Borrow Summary			L	Fine Sand		N/D		
			L	Sand & Gravel		N/D		
Zone Borrow Summary			R	Fine Sand		$21.16 \times 10^6/m^3$+N/D		
			R	Sand & Gravel		$35.5 \times 10^6/m^3$+N/D		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XIII 827-879 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R) LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
	RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
827-835						Mid-Channel-Isle, Great Bear River	Sand
828							
829	FN22	R	Sand & Gravel	7	100,000		
830	FN7	R	Gravel & Sand	0	25,000		
832	FN31	R	Sand & Gravel	2.5	75,000		
837	FN26	R	Sand & Gravel	3.5	2,000,000		
837	FN29	R	Gravel & Sand	7	300,000		
839						Left Bank	Sand
840	FN21	R	Gravel	3	N/D		
840	FN27	R	Silty Sand	0	700,000		
842							
843	FN19	R	Gravel	4.5	N/D		
843	FN20	R	Silt & Sand	0	N/D	Left Bank Intersection w/ little Bear River	Gravel
843.5	P259	R	Silty Sand	0.5	N/D		
844	P260	R	Fine Sand	3	250,000		
846-850						Left Bank-Isle	Sand & Gravel
854-863						Mid-Channel-Isle	Sand
857	P262	R	Sand	10	N/D		
860							
865						Mid-Channel	Sand
867	P263	R	Sand & Gravel	10	N/D		
867	P266	R	Silty Gravel	4	N/D		
870-880						Left Bank	Sand
870	P267	R	Silty Sand	6	N/D		
873	P268	R	Sand & Gravel	4.5	N/D		
876	P269	R	Sand & Gravel	0.5	N/D		
876.5	P270	R	Sandy Gravel	4	200,000		
879	P274	R	Silty Sand	4.5	N/D		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XIII 880-910 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
		RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
880	P273	R		Sandy Gravel	4	N/D		
880	P283	R		Sand & Gravel	3.5	N/D		
881	P275	R		Sand & Gravel	4.5	2,000,000		
882-890							Mid-Channel-Isle	Sand
883	P276	R		Sand & Gravel	2.5	200,000		
884	P277	R		Sand	4	N/D		
884	P278	R		Silty Sand & Gravel	5.5	2,000,000		
886	P279	R		Sand & Gravel	2	1,000,000		
886.5	P280	R		Sand & Gravel	4	1,500,000		
887.5	P281	R		Sand & Gravel	6	2,000,000		
887.5	P282	R		Silty Sand & Gravel	2	N/D		
889.5	NW14	R		Silty Sand	2.5	1,500,000		
890.5	NW12	R		Silty Sand	2	200,000		
892	NW9	R		Sandy Gravel	6	700,000		
893	NW18	R		Sand	3	100,000		
894	NW8	R		Gravel	6	1,000,000		
896.5								
899.5	NW10	R		Gravel	6	1,000,000		
900-910							Mid-Channel-Isle	Sand
900	NW17		L	Silty Sand	5	3,000,000		
900	NW1(7.52)	R		Sand & Gravel	0	200,000		
903.5	NW14	R		Silty Sand	2.5	1,500,000		
904							No. 3	Silty Clay over Shale
905							No. 4	Silty Clay
906								
907	NW6		L	Silty Sand	5	1,500,000		
907	NW2(7.50)	R		Sand & Gravel	1.5	75,000-250,000		
908	NW3	R		Sandy Gravel	3	125,000-500,000		
910-916							Left Bank	Sand
910	NW5		L	Silty Sand	4	1,500,000		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1

MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XIII 910-963 km)

		RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
910	NW15	R		Sandy Gravel	5	1,000,000	No. 21	Silty Clay
912-921							Mid-Channel-Isle	Sand
912	NW7		L	Silty Sand	3	500,000		
916	NW11		L	Silty Sand	1	750,000		
920-924							Righ Bank Inter- section w/Billy Cr.	Sand
920	NW19(7.46)	R		Sand & Gravel	5	700,000		
925	P285	R		Silty Sand	6	N/D		
926-933							Mid-Channel-Isle	Sand
934	P287	R		Fine Sand	3	3,500,000		
937-940							Left Bank	Sand
938.5	P289	R		Gravel & Sand	4	1,500,000		
939	P291(7.37)	R		Sand & Gravel	1	N/D		
940	P288(7.35)	R		Gravel & Sand	4	10,000,000		
941								
943.5	P292	R		Fine Sand	0.5	10,000,000		
944							Mid-Channel-Isle	Sand
947.5-967							Mid-Channel-Isle	Sand
953.5	P296(7.25)	R		Gravel	4	$2.5-15 \times 10^6$		
954	P299	R		Fine Sand	0.5	2,000,000		
958.5	P299A	R		Fine Sand	1.5	N/D		
960	7.22	R		Sand & Gravel		50-150,000		
963	P300	R		Fine Sand	1	N/D		
963	7.19	R		Sand, Silt	5.5	15×10^6		
Zone Borrow Summary			L	Fine Sand		$7.25 \times 10^6/m^3$		
			L	Sand & Gravel		N/D		
Zone Borrow Summary		R		Fine Sand		$33.25 \times 10^6/m^3$+N/D		
		R		Sand & Gravel		$43.9 \times 10^6/m^3$+N/D		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Pemcan 1972.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XIV 963-1017.5 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	RESERVES OF KNOWN GRANULAR MATERIALS[2]: BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
977	P302	R		Sand & Gravel	11	N/D		
978	P303	R		Sand & Gravel	11	N/D		
979-980							Mid-Channel	Sand
981-982							Left Bank	Sand
990	7.17	R		Sand & Gravel	1-2	$5\text{-}25\times10^6$		
1001-1010							Mid-Channel-Isle	Sand
1010-1013							Left Bank-Isle Intersection w/ Carcajou River	Sand
1015							Left Bank Intersection w/ Mt. R.	Sand & Gravel
1017								
1017.5								
Zone Borrow Summary			L	Fine Sand		N/D		
			L	Sand & Gravel		N/D		
Zone Borrow Summary		R		Fine Sand		15×10^6+N/D		
		R		Sand & Gravel		$5\text{-}25\times10^6$		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Hardy 1986.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XV 1017.5-1086.5 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
		RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
1018-1020							Left Bank	Sand
1020-1025							Mid-Channel-Isle	Sand
1030							Left Bank	Sand
1031							No. 19	Sand & Gravel
1031							No. 20	Sand & Gravel
1033							Mid-Channel-Isle	Gravel
1034								
1034.5-1043							Mid-Channel-Isle	Sand
1040-1051							Mid-Channel-Isle	Sand
1050-1059							Right Bank-Isle	Sand
1058-1070							Mid-Channel Hume River Intersection	Sand
1068-1084							Left Bank-Isle Ramparts R. Intersection	Sand
1082-1086.5	6.84		L	Sand & Gravel	1	$300,000-1.5 \times 10^6$		
Zone Borrow Summary			L	Fine Sand		N/D		
			L	Sand & Gravel		$.3-1.5 \times 10^6/m^3$		
Zone Borrow Summary		R		Fine Sand		N/D		
		R		Sand & Gravel		N/D		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Hardy 1986.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XVI 1086.5-1097 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	RESERVES OF KNOWN GRANULAR MATERIALS[2]: MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
1086.5-1093	6.84		L	Sand & Gravel	1-2	$300,000-1.5x10^6$		
1091	P318	R		Silty Sand	23	N/D		
1097	P315	R		Sandy Gravel	27	600,000		
Zone Borrow Summary			L	Fine Sand		N/D		
			L	Sand & Gravel		$.3-1.5x10^6/m^3$		
Zone Borrow Summary		R		Fine Sand		N/D		
		R		Sand & Gravel		$.6x10^6/m^3$		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Hardy 1986.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XVII 1098-1163 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R) LEFT (L)	RESERVES OF KNOWN GRANULAR MATERIALS[2]: MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	RIVERBED DATA: MATERIAL
1070-1150						Mid-Channel-Isle Intersection w/ Hare Indian River	Sand & Gravel
1098	6.83	R	Sand & Gravel	0.5	100,000-1x10[6]		
1100	6.82	R	Sand & Gravel	0.5	750,000-10x10[6]		
1101							
1102	FGH2(6.80)	R	Sandy Gravel	0.5	30,000,000		
1102	FGH8	R	Sand & Gravel	1	1,000,000		
1103	FGH7	R	Sand	11	100,000		
1103.5	FGH3	R	Sandy Gravel	0.5	7,000,000		
1104	P316	R	Silty Sand	23	N/D		
1104	P317	R	Silty Sand	25	N/D		
1104	FGH1	R	Sandy Gravel	5	4,000,000		
1104.5	FGH4(6.79)	R	Sandy Gravel	1	400,000		
1105	FGH9	R	Sand	12	6,500,000		
1109-1114						Mid-Channel-Isle	Sand
1111	FGH6	R	Silty Sand	9	100,000		
1112-1126						Left Bank-Isle	Sand
1113	FGH5	R	Sand	2	30,000		
1115						Right Bank	Sand
1126-1133						Righ Bank-Isle	Sand
1132	6.55	R	Sand	1	.8x10x10[6]		
1134	6.53	R	Sand & Gravel	3	.1-3x10[6]		
1136-1138						Mid-Channel-Isle	Sand
1140-1145						Left Bank	Sand
1149	6.43	R	Gravel	1	300,000-600,000		
1150-1153	6.41	R	Gravel & Sand	0.5	90,000-10x10[6]		
1151-1160						Mid-Channel-Isle	Sand & Gravel
1154	6.42	R	Gravel & Sand	2	.4-6.5x10[6]		
1160-1163						Left Bank-Isle Tieda River	Sand

1) Upland deposits greater than 15 km from the river have not been considered.
2) Hardy 1986.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XVII 1163-1255 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	RESERVES OF KNOWN GRANULAR MATERIALS[2]: MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	RIVERBED DATA: MATERIAL
1162								
1164.5	6.37	R		Gravel	1.5	$.1-1x10^6$		
1168-1177							Mid-Channel-Isle	Sand
1178-1183							Left Bank	Sand
1192-1198							Mid-Channel-Isle	Sand
1200-1205							Mid-Channel-Isle	Sand
							Ontaratue River Intersection	
1207-1215							Mid-Channel-Isle	Sand
1210	6.11	R		Gravel	5	$.3-10x10^6$		
1215-1218							Mid-Channel-Isle	Sand
1217	6.9	R		Sandy Gravel	6	$150,000-10x10^6$		
1221							Mid-Channel	Sand
1222-1225							Right Bank-Isle	Sand
1225-1230							Left Bank-Isle	Sand
1230	5.4	R		Sand	0-3	$72x10^6$		
1234							Mid-Channel-Isle	Sand
1236-1241							Mid-Channel	Sand
1246-1260							Left Bank-Isle	Sand
1252							Mid-Channel	
1255							Right Bank	Sand
Zone Borrow Summary			L	Fine Sand		N/D		
			L	Sand & Gravel		N/D		
Zone Borrow Summary		R		Fine Sand	8.28	$83.5x10^6$+N/D		
		R		Sand & Gravel	3.09	$94.5x10^6$		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Hardy 1986.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XVIII 1255-1390 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	RESERVES OF KNOWN GRANULAR MATERIALS[2]: MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
1261-1274							Mid-Channel-Isle	Sand
1265	5.23	R		Sand & Gravel	2	$50,000-40\times10^6$		
1272	5.21		L	Sand & Gravel	5	$1-5\times10^6$		
1274-1279							Left Bank	Sand
1281	5.20		L	Sand, Silty Gravel	1.5	$.3-3\times10^6$		
1282	5.18		L	Silty Gravel	1	$45,000-3.5\times10^6$		
1283							Mid-Channel	Sand
1283.5-1294							Mid-Channel-Isle	Sand
1284	5.19		L	Silty Gravel	7	$10,000-4\times10^6$		
1297	4.104	R		Silty Sand & Gravel	1	$25,000-10\times10^6$		
1300							Mid-Channel, Thunder River intersection	Sand
1300-1307							Left Bank	Sand
1307-1318	4.109		L	Silty Sand & Gravel	4-5	$20,000-7.5\times10^6$		
1307-1318	5.12	R		Sand & Gravel	1	$5-20\times10^6$		
1314-1320							Right Bank	Sand
1318	4.107		L	Sand & Gravel	1-2	$5-20\times10^6$		
1318	5.13	R		Gravelly Sand	1	$70,000-2\times10^6$		
1318	5.14	R		Silty Sand	1	$150,000-2\times10^6$		
1326-1330							Mid-Channel	Sand
1336							Left Bank-Isle	Sand
1351-1358							Left Bank-Isle	Sand
1360-1363							Left Bank	Sand
1365							Mid-Channel	Sand
1366-1379							Mid-Channel	Sand
1381							Mid-Channel	Sand
1386							Left Bank	Sand
1387-1393							Right Bank intersection w/ Rabbit Hay River	Sand
1390								

1) Upland deposits greater than 15 km from the river have not been considered.
2) Hardy 1986.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XVIII 1390-1440 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	RESERVES OF KNOWN GRANULAR MATERIALS[2]: MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	RIVERBED DATA: BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	RIVERBED DATA: MATERIAL
1405							Mid-Channel	Sand
1410							Left Bank	Sand
1417							Right Bank	Sand
1423							Mid-Channel	Sand
1425-1434							Left Bank-Isle	Sand
1430							Right Bank	Sand
Zone Borrow Summary			L	Fine Sand		N/D		
			L	Sand & Gravel		$6.4\text{-}43 \times 10^6/m^3$		
Zone Borrow Summary		R		Fine Sand		$.15\text{-}2 \times 10^6$		
		R		Sand & Gravel		$5.14\text{-}72 \times 10^6$		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Hardy 1986.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.1
MACKENZIE VALLEY UPLAND[1] AND CHANNEL DEPOSITS (River Zone XIX 1440-1475 km)

KILOMETRE POSTING (km)	DEPOSIT NUMBER	BANK RIGHT (R)	BANK LEFT (L)	MATERIAL	DISTANCE FROM RIVER (km)	ESTIMATED[3] VOLUME (m^3)	BOREHOLES[4]/ HYDROGRAPHIC OBSERVATIONS	MATERIAL
		RESERVES OF KNOWN GRANULAR MATERIALS[2]					RIVERBED DATA	
1440	3.16	R		Sand & Gravel	0-1	$.175\text{-}2\times10^6$	Right Bank	Sand
1444							Mid-Channel	Sand
1444-1449							Left Bank	Sand
1453								
1473							Left Bank	Sand
Zone Borrow Summary			L	Fine Sand		N/D		
			L	Sand & Gravel		N/D		
Zone Borrow Summary		R		Fine Sand		N/D		
		R		Sand & Gravel		$.175\text{-}2\times10^6$		

1) Upland deposits greater than 15 km from the river have not been considered.
2) Hardy 1986.
3) N/D - Quantity not determined.
4) Public Works Canada, 1976.

TABLE 5.2

ANTICIPATED GRANULAR BORROW REQUIREMENTS
FOR THE MAJOR MACKENZIE VALLEY COMMUNITIES

COMMUNITY	LOCATION (km)	VOLUME (m^3 x 100) 1987	1988	1989	1990	1991	TOTAL
Fort Providence	79	47	36	-	-	100	183
Jean Marie River	270	12	17	100	-	-	129
Fort Simpson	340	use 10 - 20,000 m^3/year					
Wrigley	574	13	90	10	100	16	229
Fort Norman	827	35	-	57	15	-	107
Norman Wells	905	Not Available					
Fort Good Hope	1101	165	15	23	32	-	235
Arctic Red River	1454	140	90	-	15	-	245

TABLE 5.3
COST COMPARISON FOR CONVENTIONAL AND RIVERBED BORROW PRODUCTION

COST COMPONENT	CONVENTIONAL UPLAND BORROW PRODUCTION[1] (SOUTH OF NORMAN WELLS)	RIVERBED DREDGING COSTS[2]	
		8600 m^3/day	1400 m^3/day
a) Equipment Mobilization ($/$m^3$)	-	5.00	6.00
b) Pit Development ($/$m^3$)	1.00	-	-
c) Excavation ($/$m^3$)	4.00	0.60	2.00
d) Overland Hauling[3] (Access Road & Trucking) ($/$m^3$/km)	1.70	1.70[5]	1.70
e) River Hauling (Barge) ($/$m^3$/km)	-	0.15	0.75
f) Docksite Rehandling & Stockpiling[4] ($/$m^3$)	-	3.50[5]	3.50

Notes:
(1) Conventional production rates would be 1000 to 1500 m^3/day.
(2) Capital costs for dredging and barging equipment not included.
(3) Approximately $0.50/$m^3$/km for access road development and $1.20/$m^3$/km for hauling.
(4) Assumes that stockpile is well drained and not allowed to freeze.
(5) For cases where river borrow must be moved inland, both are required.

TABLE 6.1
SUMMARY OF DISCHARGE RECORDS FOR THE MACKENZIE RIVER TO 1984
(INTERPRETED FROM WATER SURVEY OF CANADA RECORDS)

	SITE NUMBER	YEARS OF RECORDS*	MEAN FLOW YEARS (M3/S)	MEAN ANNUAL DAILY FLOW/ YEARS OF RECORD (M3/S)	PEAK OF RECORD (M3/S)	MEAN ANNUAL MINIMUM DAILY FLOW/ YEARS OF RECORD (M3/S)	LOWEST MEAN MINIMUM DAILY FLOW OF RECORD (M3/S)
Mackenzie River Near Fort Providence (KP 80)	10FB001	9S 10C	4280 over 21 yrs	7580 13 yrs	8840	1680 10 yrs	1040
Mackenzie River At Fort Simspon (KP 340)	106C001	26S 21C	6550 over 21 yrs	16400 40 yrs	23500	2010 22 yrs	1500
Mackenzie River At Norman Wells (KP 905)	10KA001	20S 17C	8400 over 17 yrs	22270 29 yrs	30300	2500 17 yrs	1950
Mackenzie River Above Arctic Red River (KP 1454)	10LA003	1S 12C	8940 over 12 yrs	28600 12 yrs	32000	2560 12 yrs	1680

S - Seasonal Records Only C - Continuous Records

TABLE 6.2
FISH SPECIES LOCATED WITHIN THE MACKENZIE VALLEY STUDY AREA
(Adapted from Dome et al 1982)

COMMON NAME	SCIENTIFIC NAME	SPAWNING PERIOD *	TYPE**
Major Species			
Dolly Varden	Salvelinus malma	F	A
Lake Trout	Salvelinus namaycush	F	F
Lake Cisco	Coregonus artedii	F	F
Arctic Cisco	C. autumnalis	F	A
Least Cisco	C. sardinella	F	A
Humpback Whitefish	C. clupeaformis	F	A
Broad Whitefish	C. nasus	F	A
Round Whitefish	Prosopium cylindraceum	F	A
Mountain Whitefish	P. williamsoni	F	F
Inconnu	Stenodus leucichthys nelma	F	A
Arctic Grayling	Thymallus arcticus	S	F
Goldeye	Hiodon alosoides	S	F
Northern Pike	Esox lucius	S	F
Yellow Walleye	Stizostedion vitreum vitreum	S	F
Longnose Suckers	Catostomus catostomus	S	F
Burbot	Lota lota	S	F
Minor Species			
White Suckers	Catostomus catostomus	S	F
Chum Salmon	Oncorhynchus keta	F	A
Arctic Char	Salvelinus alpinus	F	A
Arctic Lamprey	Lampetra japonica	S	A
Pond Smelt	Hypomesus olidus	S	F
No.Redbelly Dace	Chrosomus eos	S	F
Finescale Dace	Chrosomus neoeus	S	F
Longnose Dace	Rhinichthys cataractae	S	F
Pearl Dace	Semotilus margarita	S	F
Lake Chub	couesius plubeus	S	F
Flathead Chub	Platygobio gracilis	S	F
Emerald Shiner	Notropis atherinoides	S	F
Spottail Shiner	Notripis hudsonius	S	F
Fathead Minnow	Pimephales promelas	S	F
Brook Stickleback	Culea inconstans	S	F
Ninespine Stickleback	Pungitius pungitius	S	F
Trout Perch	Percopsis omiscomaycus	S	F
Yellow Perch	Perca flavescens	S	F
Slimy Sculpin	Cottus cognatus	S	F
Spoonhead Sculpin	Cottus ricei	S	F

* Spawning Period: F-Fall, S-Spring, W-Winter

** Type: A-Anadromous, F-Freshwater

TABLE 6.3
ESTIMATED ANNUAL HARVEST OF THE MACKENZIE VALLEY DOMESTIC FISHERIES
(From: McCart and Den Beste 1979)

COMMUNITY	NO. OF POUNDS	MAIN TYPES OF FISH HARVESTED
Mackenzie Delta and Tuktoyaktuk	111,000	Arctic char, whitefish, inconnu, herring
Fort McPherson and Arctic Red R.	450,000	Whitefish, cisco, Arctic char, northern pike, suckers
Fort Good Hope, Colville Lake	100,000	Whitefish, cisco, inconnu, trout
Fort Norman, Norman Wells	29,000	Lake trout, Arctic grayling, whitefish, cisco, inconnu
Wrigley	2,500	Whitefish, northern pike, suckers
Fort Simpson	1,000	Whitefish, northern pike, suckers
Jean-Marie River	800	Whitefish, northern pike, suckers
Trout Lake	1,000	Whitefish, northern pike, suckers

TABLE 6.4
REACH ZONES WITH SIGNIFICANT FISHERIES ACTIVITIES*

REACH ZONE	BOUNDARIES (km)	GEOGRAPHIC LOCATION
VII	300- 410	E. of Rabbitskin R. to E. of Burnt Is.
IX	520- 580	N. of Willowlake R. to Wrigley R.
X	580- 605	Wrigley R. to Blackwater R.
XII	714- 828	Redstone R. to Great Bear R.
XIII	828- 956	Great Bear R. to Patricia Is.
XV	1017-1087	Sans Sault Rapids & Mountain R. to the Ramparts
XVII	1098-1261	N. end of Ramparts to N. of Little Chicago R.
XIX	1438-1475	Lower Ramparts to Point Separation

*These are noted as Zones with High Fisheries Activities on Figure 5.1.

TABLE 7.1
RATING SYSTEM FOR THE GRANULAR MATERIALS POTENTIAL OF THE RIVER ZONES

RATING POINTS	
	A. RIVER CHANNEL CHARACTERISTICS
	Type of Channel
4	Braided
3	Braided transitional to straight
2	Braided transitional to meandering
2	Straight
1	Meandering
0	Expanded
	B. RIVER GRADIENT
	Gradient
1	.001 - .09 m/km
2	.1 - .19 m/km
3	.2 - .29 m/km
4	.3 - .39 m/km
	C. TYPE OR NUMBER OF TRIBUTARIES
	Description
5	Three or more large gravel bed tributaries and five or more small gravel bed tributaries
4	Three large gravel bed tributaries and no or a few small gravel bed tributaries,
3	One to two large gravel bed tributaries and many small gravel bed streams
2	One to two large gravel bed tributaries and a few or no gravel bed tributaries
1	No large gravel bed tributaries but several small gravel bed streams
0	No gravel bed tributaries
	D. CUMMULATIVE RATINGS (TOTAL OF POINTS FROM A, B AND C)
	Rating
1 - 4	Low
5	Low to Moderate
6 - 7	Moderate
8	Moderate to High
9 - 13	High

TABLE 7.2
EVALUATION OF RIVER REGIME CHARACTERISTICS FOR EACH RIVER ZONE

RIVER ZONE (km)	RIVER MORPHOLOGY	AVERAGE RIVER GRADIENT (m/km)	TRIBUTARY BED CHARACTERISTICS	RIVER REGIME RATING
I (0-26)	Straight (2)	0.04 (1)	None (0)	Low (3)
II (26-60)	Straight (2)	0.03 (1)	None (0)	Low (3)
III (60-107)	Braided (4)	0.25 (3)	2 non-gravel (0)	Moderate (7)
IV (107-130)	Expanded (10)	very low (1)	None (0)	Low (1)
V (130-229)	Straight (2)	0.02 (1)	3 gravel creeks (1)	Low (4)
VI (229-300)	Straight (2)	0.056 (1)	1 gravel river (1)	Low (4)
VII (300-410)	Straight (2)	0.15 (2)	4 non-gravel (0)	Low (4)
VIII (410-520	Braided (4)	0.15 (2)	3 large gravel (4)	High (10)
IX (520-580)	Straigtht-Braided (3)	0.17 (2)	2 gravel rivers, 1 gravel creek (3)	Moderate-High (8)
X (580-665)	Straight (2)	0.06 (1)	3 gravel rivers, 5 gravel creeks (5)	Moderate-High (8)
XI (665-714)	Straight-Braided (3)	0.3 (4)	3 gravel rivers, 5 gravel creeks (5)	High (12)
XII (714-828)	Braided-Meandering (2)	0.13 (2)	1 gravel river (2)	Moderate (6)

TABLE 7.2
EVALUATION OF RIVER REGIME CHARACTERISTICS FOR EACH RIVER ZONE

RIVER ZONE (km)	RIVER MORPHOLOGY	AVERAGE RIVER GRADIENT (m/km)	TRIBUTARY BED CHARACTERISTICS	RIVER REGIME RATING
XIII (828-966)	Braided (4)	0.11 (2)	3 gravel rivers, 21 gravel creeks (5)	High (11)
XIV (966-1017)	Straight-Braided (3)	0.08 (1)	2 gravel rivers, 2 gravel creeks (3)	Moderate (7)
XV (1017-1087)	Braided (4)	0.14 (2)	No gravel tributaries (0)	Moderate (6)
XVI (1087-1098)	Straight (2)	0.17 (0)	None (4)	Low
XVII (1098-1261)	Braided (4)	0.03 (1)	3 gravel creeks (1)	Moderate (5)
XVIII (1261-1438)	Braided-Straight (3)	0.011 (1)	1 gravel river, 3+ gravel creeks (1)	Low-Moderate (5)
XIX (1438-1475)	Straight (2)	0.03 (1)	No gravel tribuaries (0)	Low (3)

Note: The cumulative Rating is the total of the three rating scores, which are the numbers in parenthesis, as defined in Table 7.1.

TABLE 7.3
RIVERBED BORROW POTENTIAL FOR EACH RIVER ZONE

RIVER ZONE (km)	RIVER REGIME RATING[1]	UPLAND BORROW DEPOSITS[2] SAND (m^3)	SAND & GRAVEL (m^3)	FISHERIES ACTIVITIES[3]	POTENTIAL FOR RIVER BORROW SOURCES
I (0-26)	Low	None		D F M (Moderate)	Low
II (26-60)	Low	None		D F M (Moderate)	Low
III (60-107)	Moderate	None		D S R M (Moderate)	Borehole data (dwg. 4.1) suggests Moderate-High potential between km 75 and 100
IV (107-130)	Low	None		D M (Low)	Low
V (130-300)	Low	Some near Trout & Redknife River		M D (Moderate)	Low-Moderate between km 170 and 229
VI (229-300)	Low	None		D M	Moderate near Jean-Marie Creek (km 270) otherwise low
VII (300-410)	Low	Unlimited	2,000,000	M D S	Moderate between km 310-330 otherwise low
VIII (410-520)	High	Unlimited	<500,000	D M S R (Moderate)	High near McGern Island (km 490-520) Camsell Bend (km 460)
IX (520-580)	Moderate-High	Unlimited	>67,000,000	D M	High near Wrigley River (km 580) and River Between Two Mountains (km 539)
X (580-665)	Moderate-High	Unlimited	>56,000,000	D M (High)	High near Ochre River (km 605) and Blackwater River (km 664)
XI (665-714)	High	Unlimited	>65,000,000	M S R (Low)	High

TABLE 7.3
RIVERBED BORROW POTENTIAL FOR EACH RIVER ZONE

RIVER ZONE (km)	RIVER REGIME RATING[1]	UPLAND BORROW DEPOSITS[2] SAND (m^3)	SAND & GRAVEL (m^3)	FISHERIES ACTIVITIES[3]	POTENTIAL FOR RIVER BORROW SOURCES
XII (714-828)	Moderate	Unlimited	>36,000,000	D M S R (High)	Moderate between km 725 and 780 High near Fort Norman (km 825)
XIII (828-956)	High	>40,000,000		<u>M</u> <u>D</u> <u>E</u> S R (High)	High (proof is at Norman Wells (km 905)
XIV (966-1017)	Moderate	15,000,000	$5-25x10^6$	S R M (Moderate)	High near Sans Sault Rapids Moderate between km 966 and 1000
XV (1017-1087)	Moderate		>2,000,000	<u>M</u> R S (High)	High between km 1017-1030, low beyond
XVI (1087-1098)	Low		Limited	M (Low)	Low
XVII (1098-1261	Low	Some large and deposits	many small	<u>D</u> S R M (High)	Moderate near Tieda River (km 1163) Loon River (km 1136) and Hare Indian River (km 1105). Low between km 1140
XVIII (1261-1438)	Low-Moderate	Unlimited	$12-115x10^6$	<u>M</u> D S R (Moderate)	Moderate near Thunder River (km 1299) otherwise low
XIX (1438-1475	Low		2,000,000	<u>M</u> S <u>D</u> (High)	Low to moderate below Arctic Red River (km 1454) otherwise low

Note: (1) From Table 7.2
(2) From Table 5.1
(3) From Appendix B, Symbols are:
D - Domestic Fisheries, F-Sprot Fisheries
S - Spawning Arears, R - Rearing Areas, M - Migratory Routes
Where higher level of sensitivity has been noted in Appendix B
it is indicated by underlined symbol (eg: <u>D</u>)

TABLE 7.4
AREAS WHERE DEVELOPMENT OF RIVERBED BORROW APPEARS FEASIBLE[1]

DEMAND REACHES (km)	POTENTIAL SUPPLY REACHES (km)	Rating[2]
0- 200	50- 100	C - Moderate
200- 400	275- 300	C - Moderate
200- 400	300- 325	B - Moderate to High
	400- 425	C - Moderate
	450- 475	B - Moderate to High
	475- 500	A - High
400- 525	450- 475	B - Moderate to High
	475- 500	A - High
700- 725	700- 725	A - High
750- 875	750- 775	C - Moderate
	800- 825	A - High
	825- 850	A - High
	850- 875	C - Moderate
	875- 900	A - High
1000-1100	1000-1025	A - High
	1025-1050	A - High
1175-1200	1150-1175	C - Moderate
1225-1250	1275-1300	C - Moderate
1325-1475	1275-1300	C - Moderate

Notes:

1) From riverbed subzones of High, Moderate to High, or Moderate Potential.

2) From Figure 4.1

LIST OF FIGURES

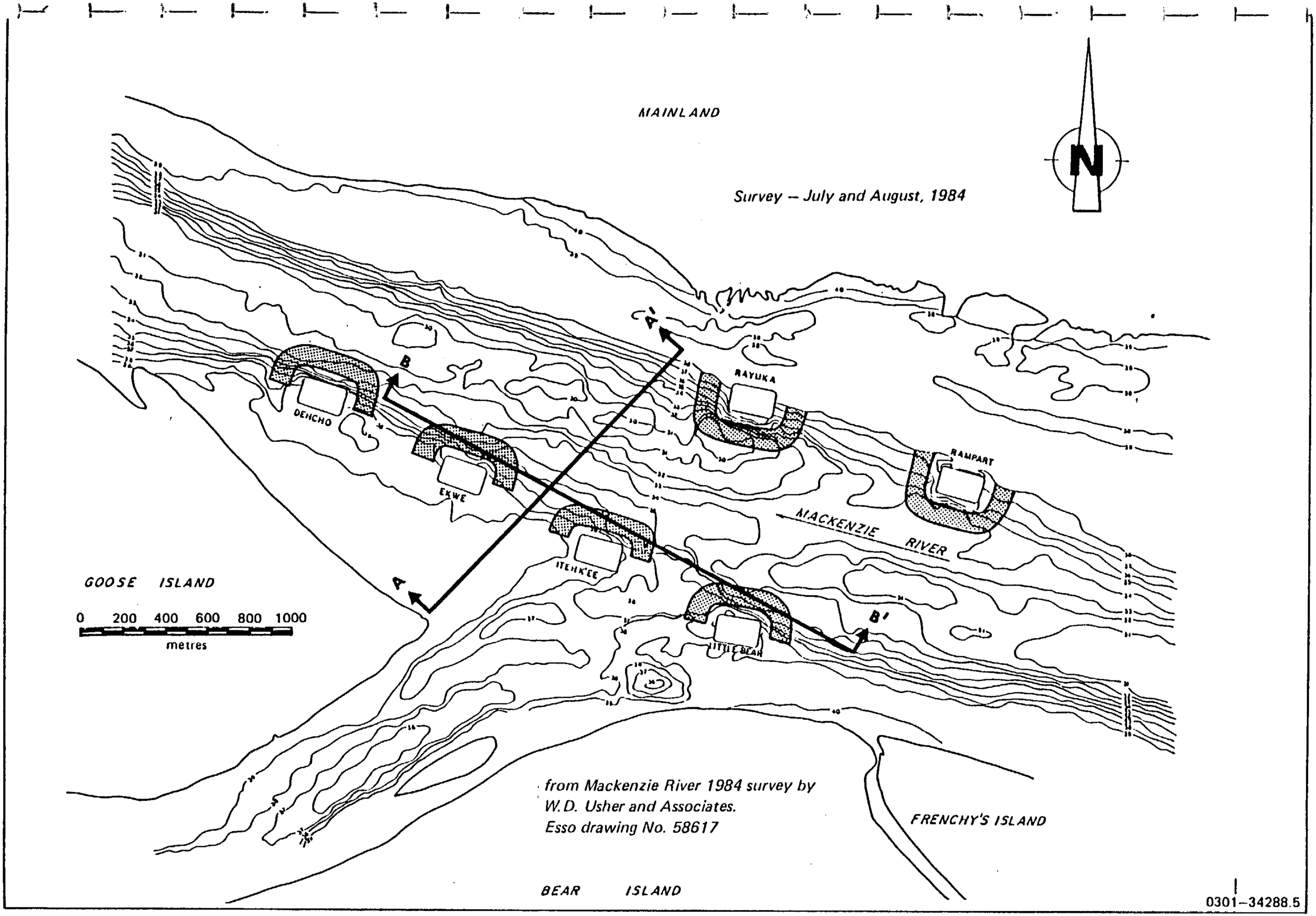
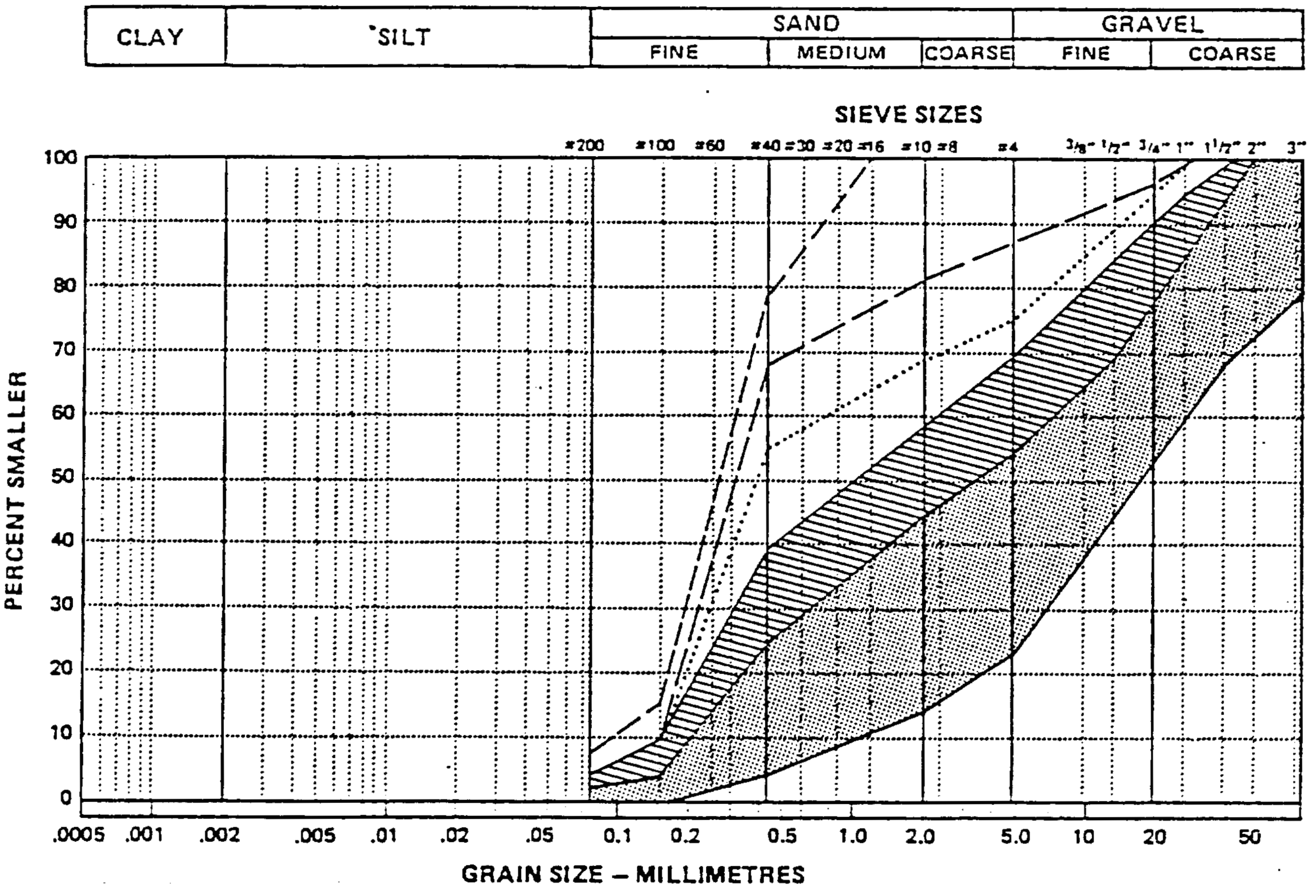


FIGURE 3.1 NORMAN WELLS EXPANSION PROJECT RIVER WORKS



LEGEND

RANGE FOR 50% OF TEST RESULTS

RANGE FOR 75% OF TEST RESULTS

UPPER LIMIT FOR 90% OF TEST RESULTS

UPPER LIMIT FOR 95% OF TEST RESULTS

UPPER LIMIT FOR ALL TEST RESULTS

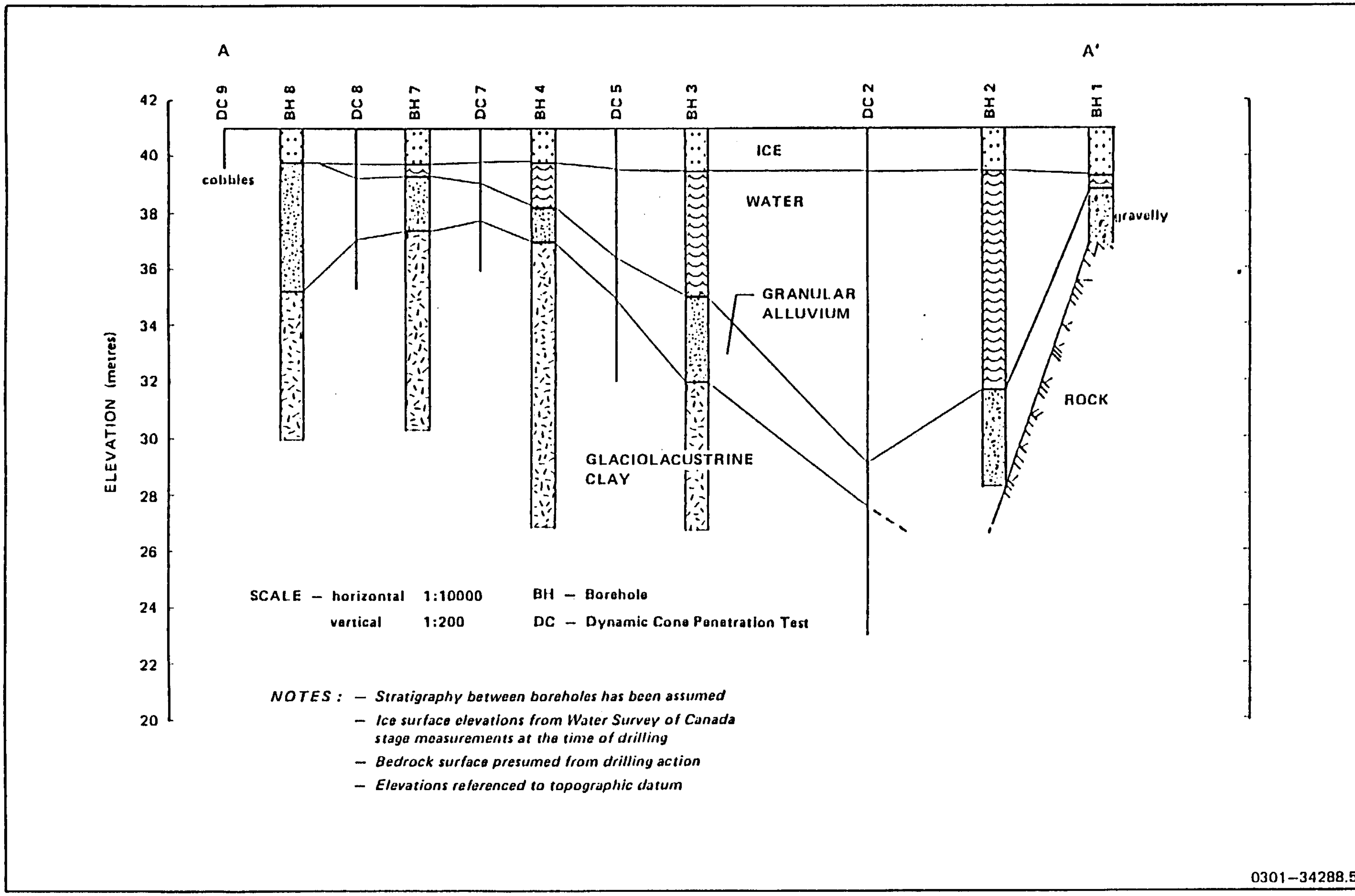
NOTE : BASED ON 27 GRAIN SIZE TESTS TAKEN DURING CONSTRUCTION

from EBA 1985

0301–34288.5

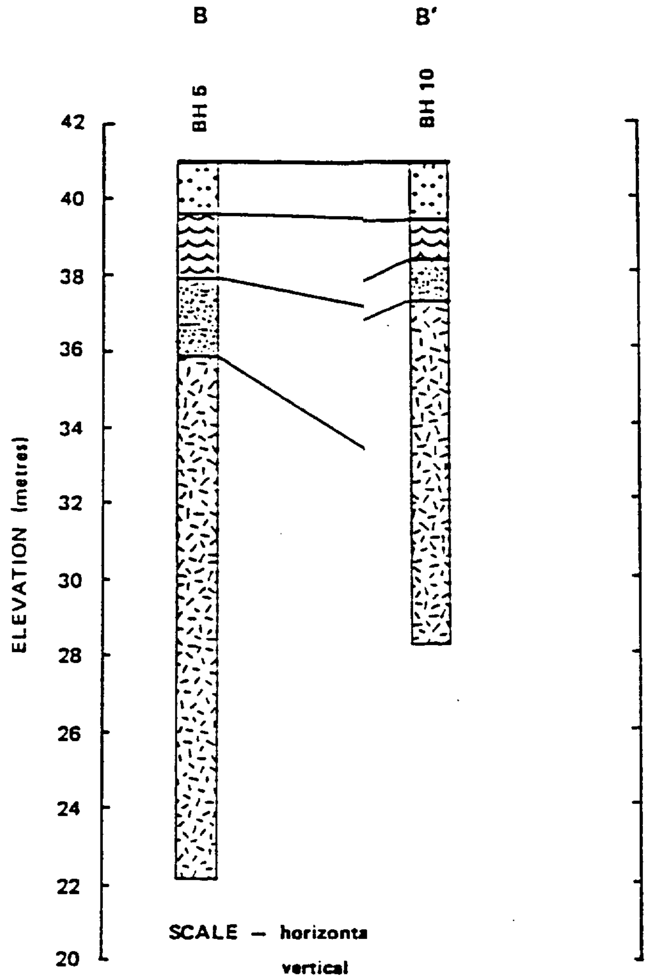
FIGURE 3.2 GRADATION DISTRIBUTION OF THE DREDGED ISLAND FILL AT NORMAN WELLS

EBA Engineering Consultants Ltd.



EBA Engineering Consultants Ltd.

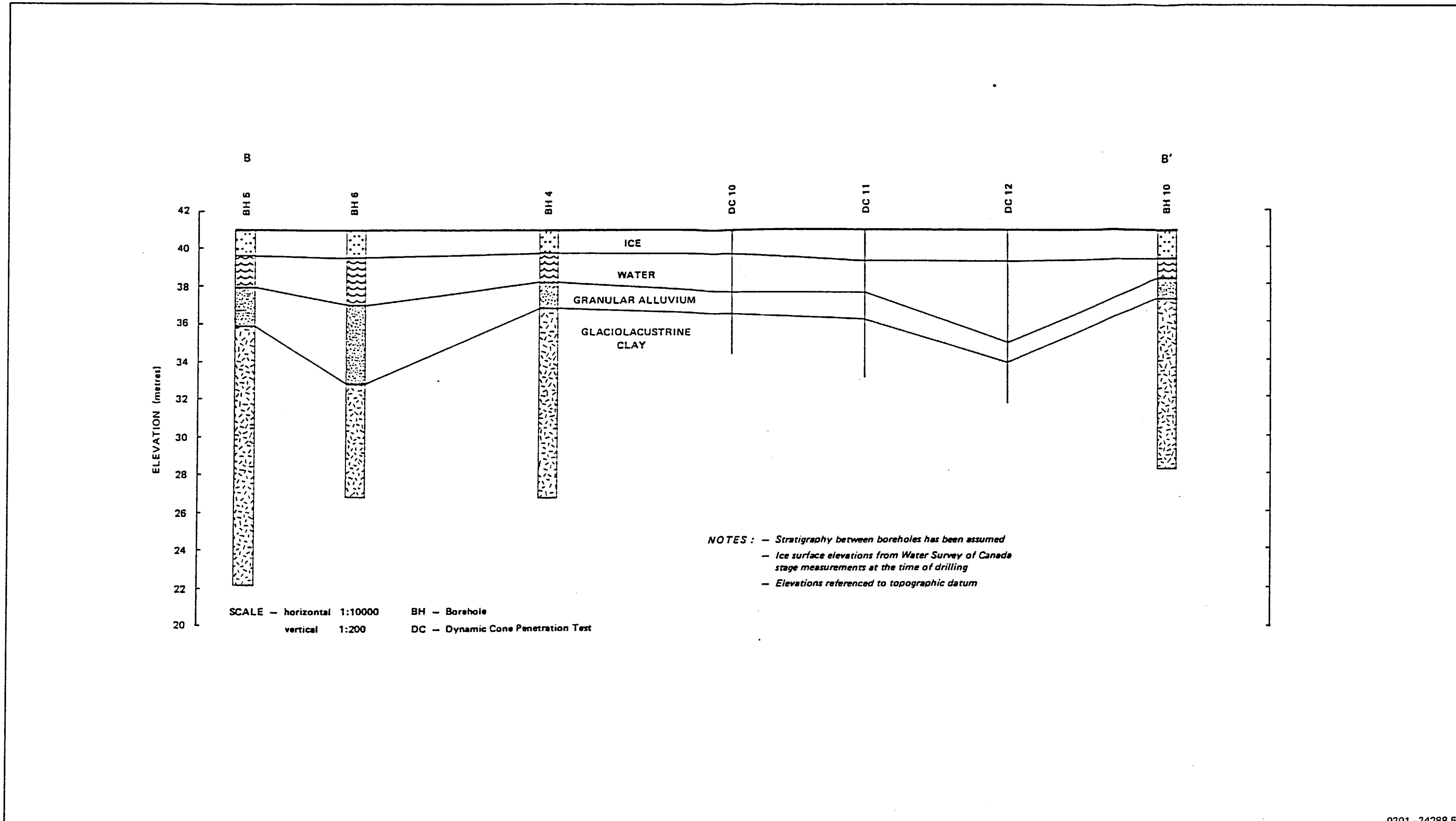
FIGURE 3.3 SECTION A – A



0301–34288.5

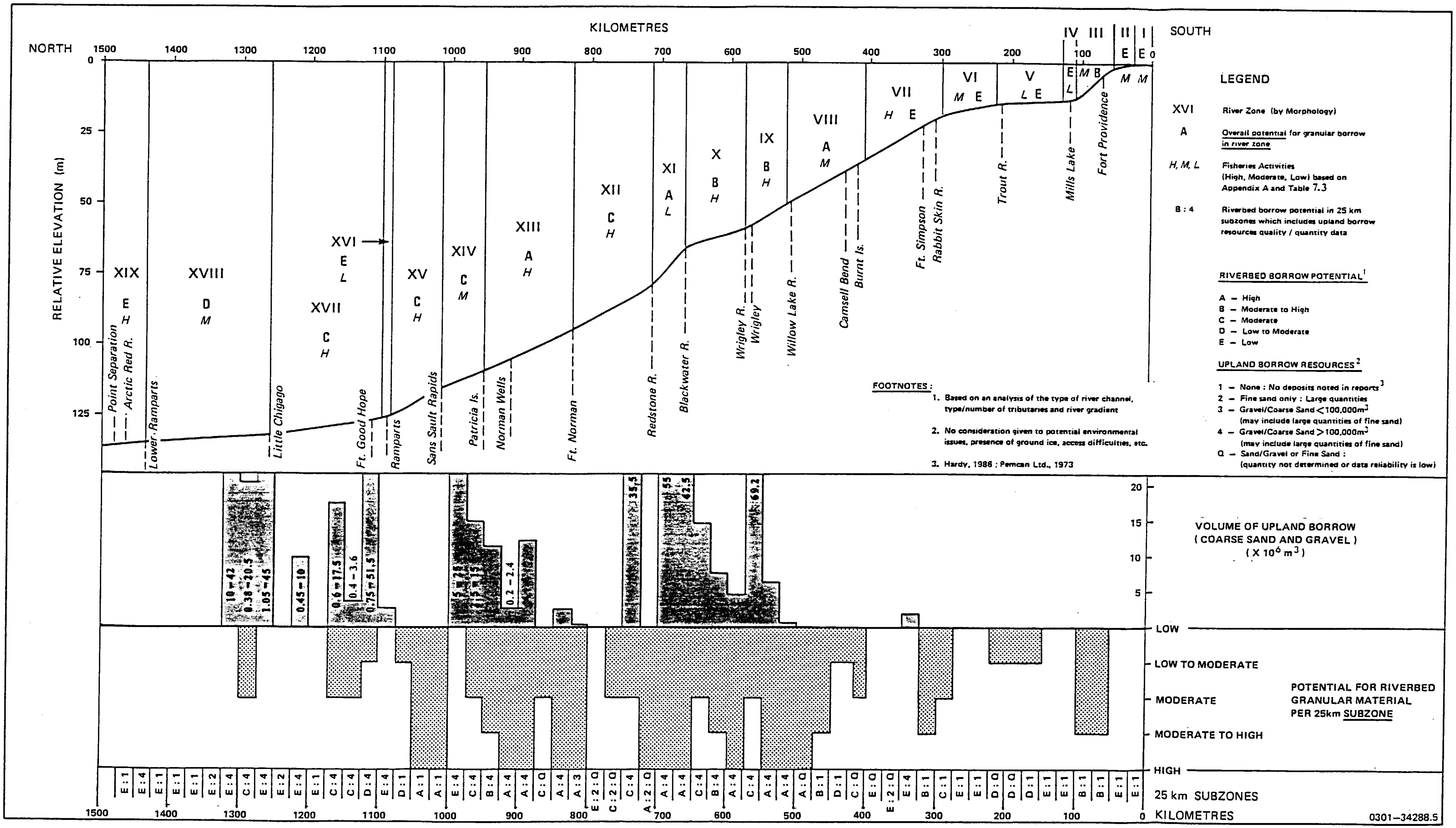
EBA Engineering Consultants Ltd.

FIGURE 3.4 SECTION B – B



EBA Engineering Consultants Ltd.

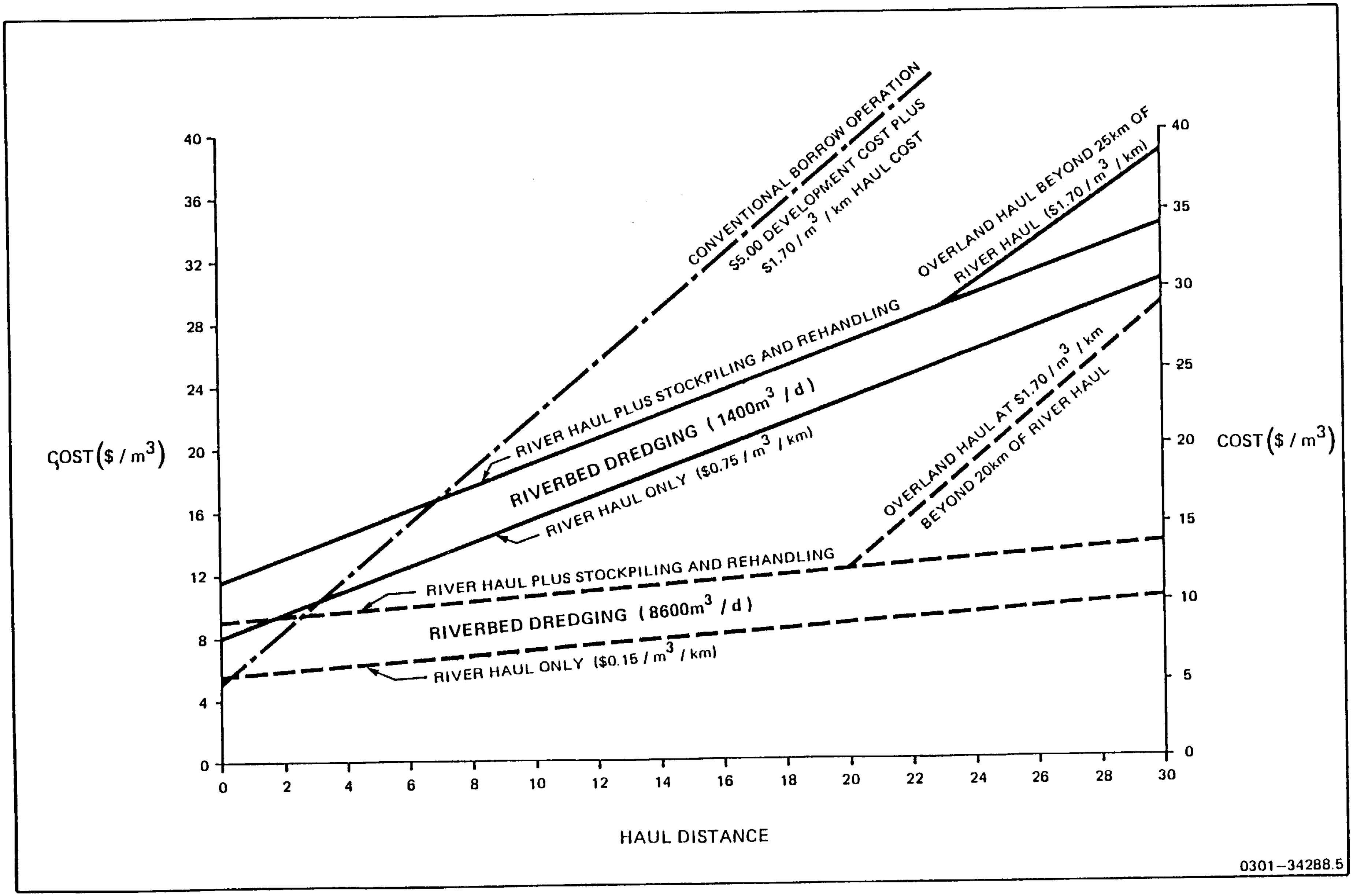
FIGURE 3.4 SECTION B – B



EBA Engineering Consultants Ltd.

FIGURE 4.1

NORTH – SOUTH LONGITUDINAL CROSS - SECTION
MACKENZIE VALLEY



EBA Engineering Consultants Ltd.

FIGURE 5.1 THE RELATIVE COST OF CONVENTIONAL AND RIVERBED BORROW PRODUCTION

LIST OF DRAWINGS

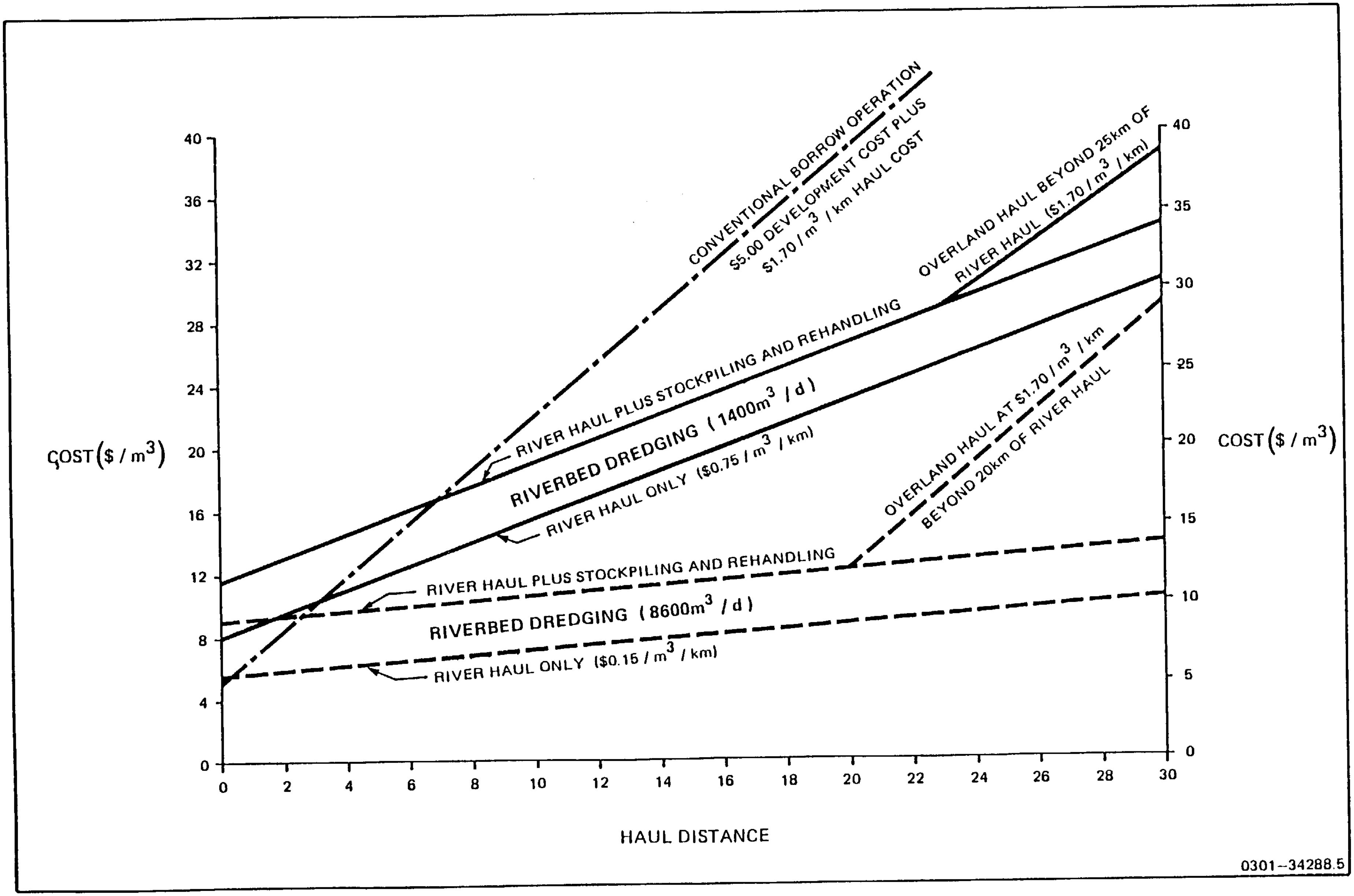
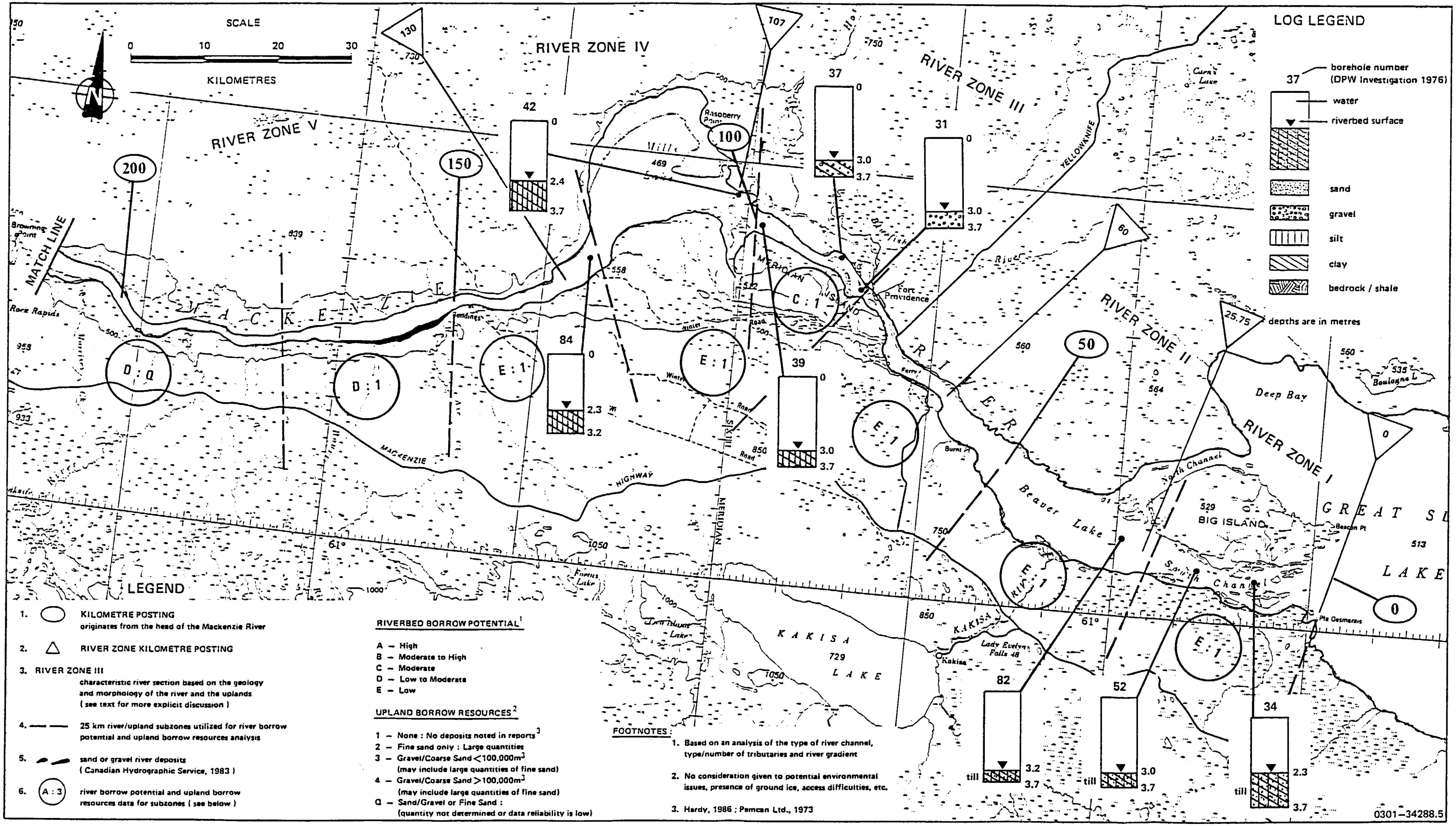


FIGURE 5.1 THE RELATIVE COST OF CONVENTIONAL AND RIVERBED BORROW PRODUCTION

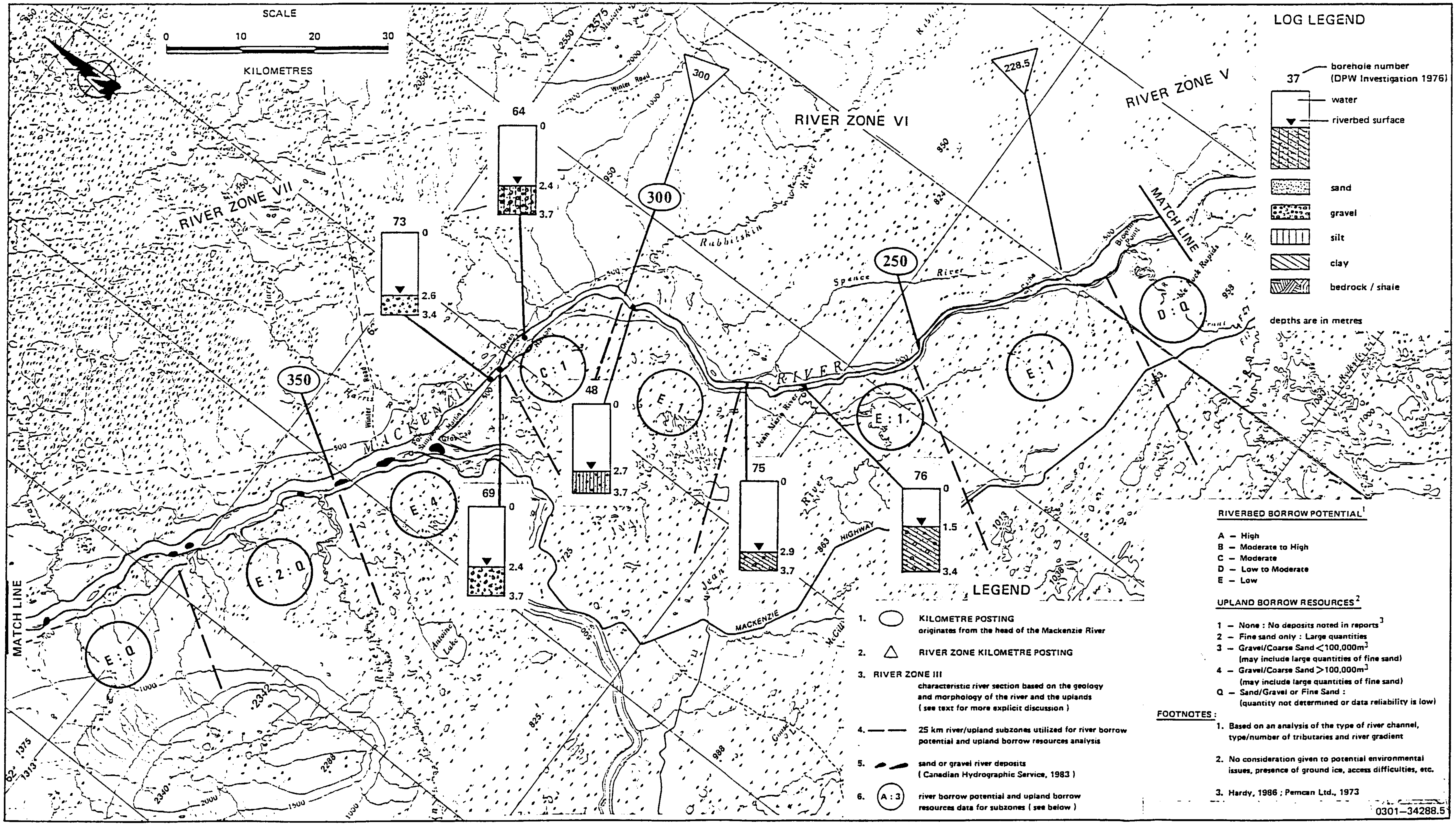
EBA Engineering Consultants Ltd.



EBA Engineering Consultants Ltd.

DRAWING 4.1a

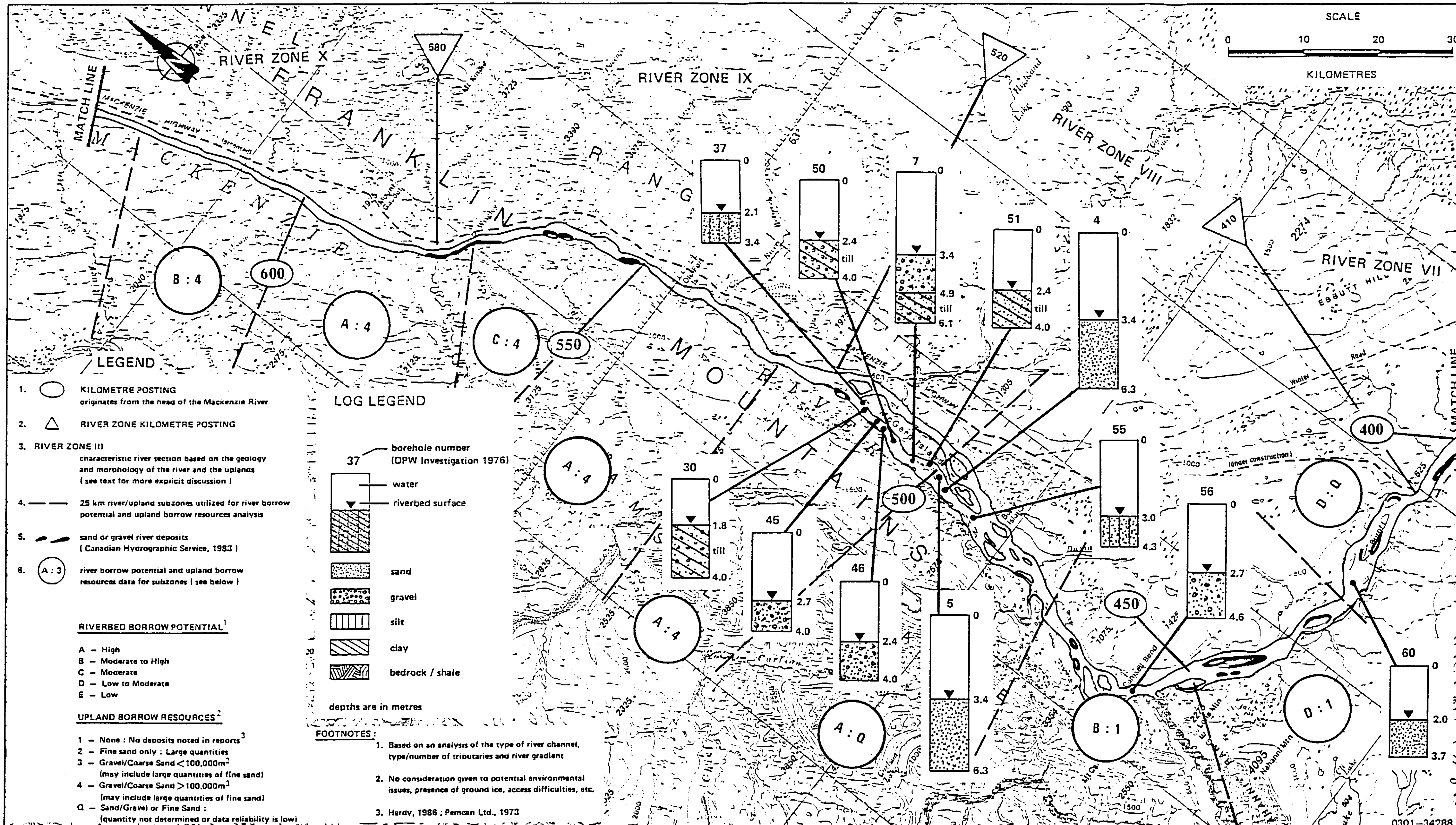
GEOGRAPHIC FEATURES OF THE MACKENZIE RIVER VALLEY



EBA Engineering Consultants Ltd.

DRAWING 4.1b

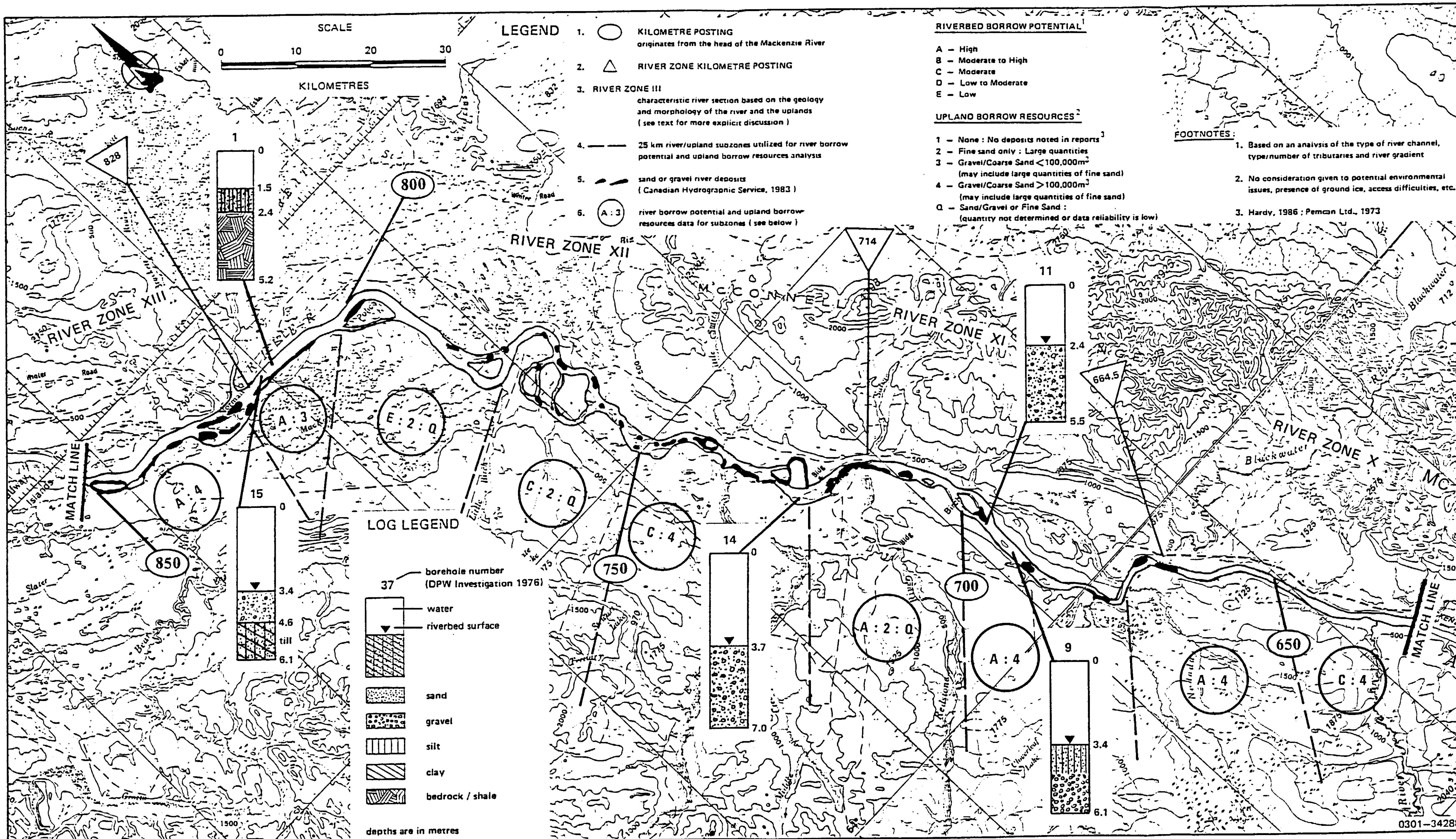
GEOGRAPHIC FEATURES OF THE MACKENZIE RIVER VALLEY



EBA Engineering Consultants Ltd.

DRAWING 4.1c

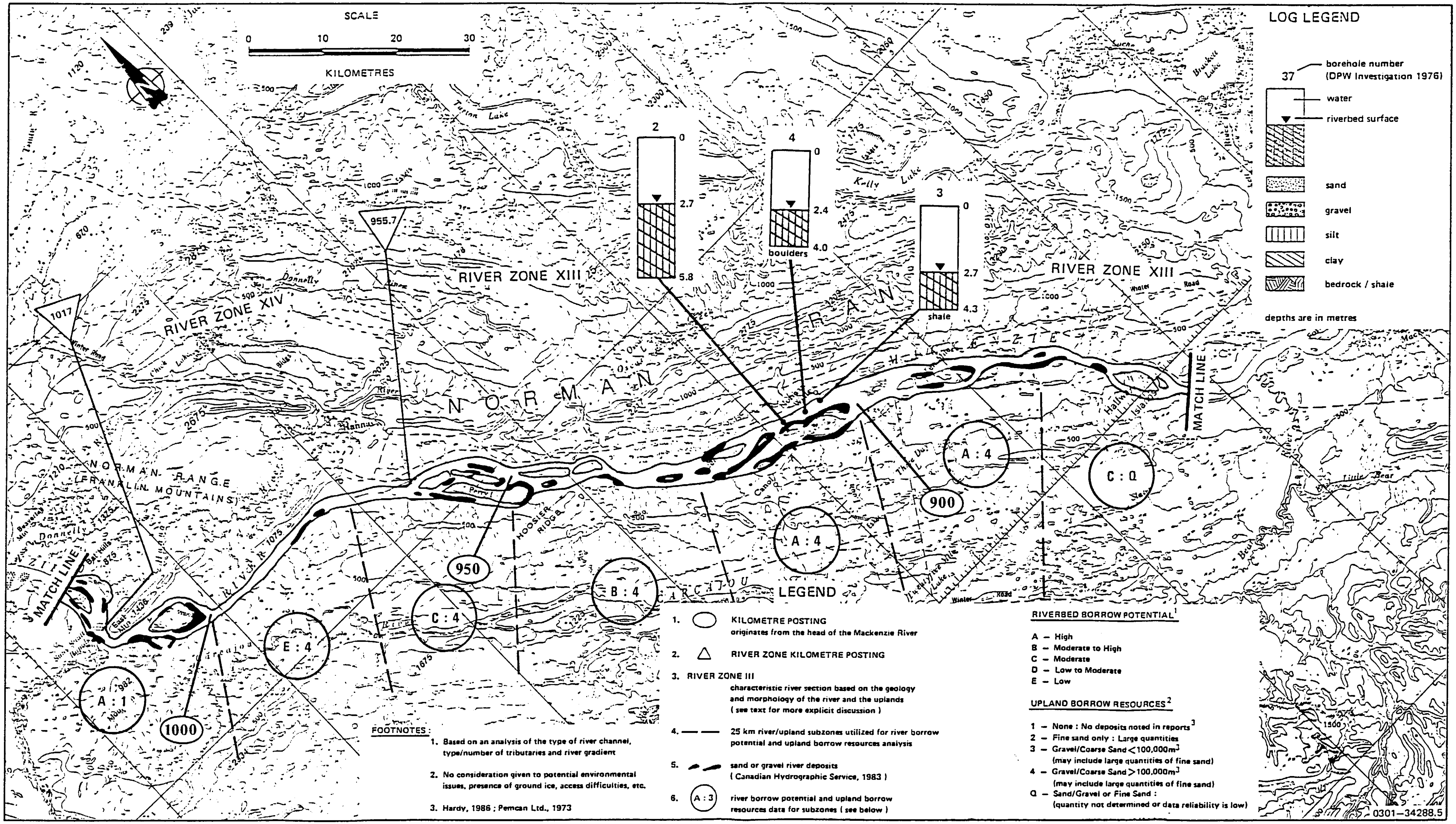
GEOGRAPHIC FEATURES OF THE MACKENZIE RIVER VALLEY



EBA Engineering Consultants Ltd.

DRAWING 4.1d

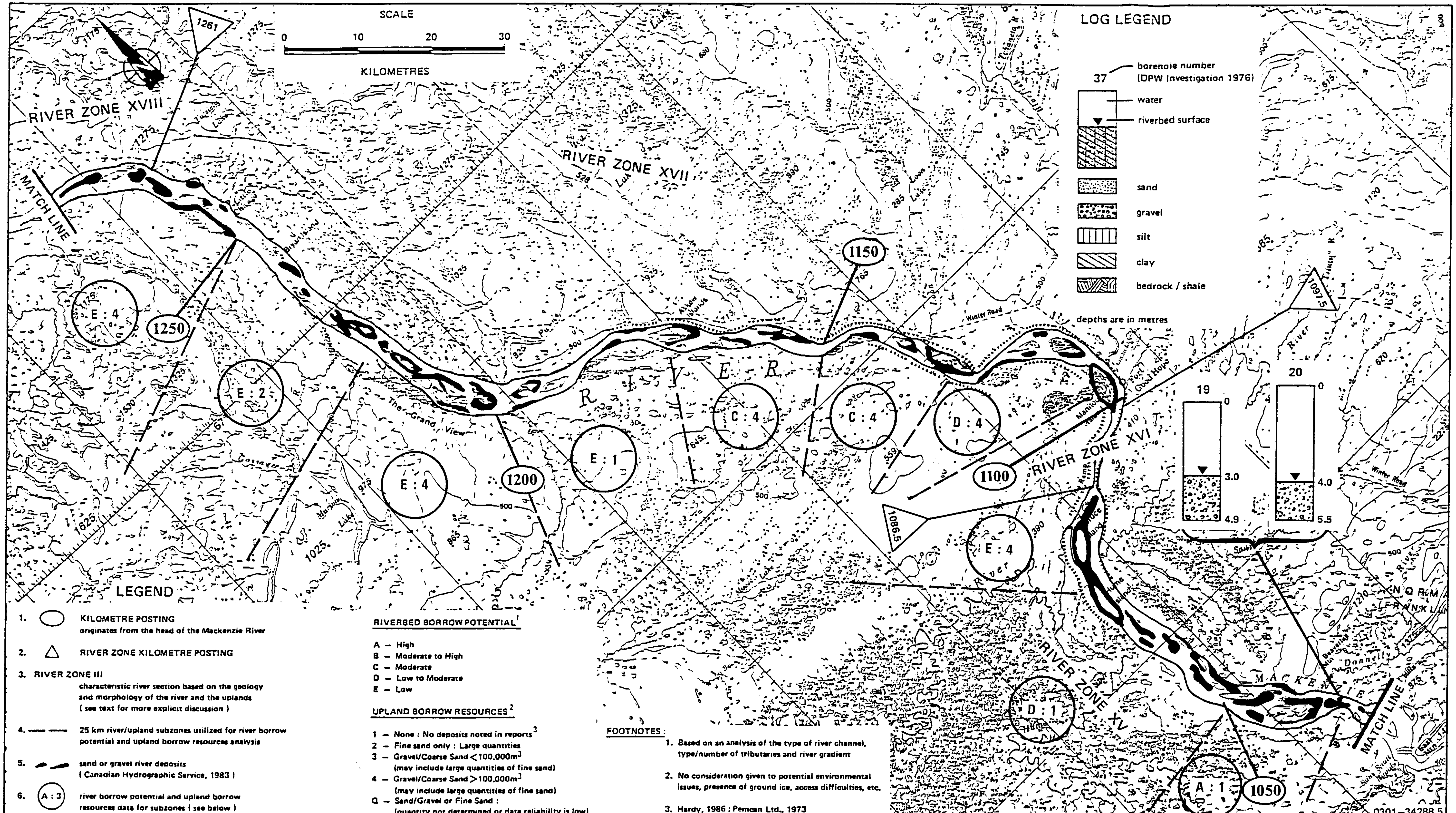
GEOGRAPHIC FEATURES OF THE MACKENZIE RIVER VALLEY



EBA Engineering Consultants Ltd.

DRAWING 4.1e

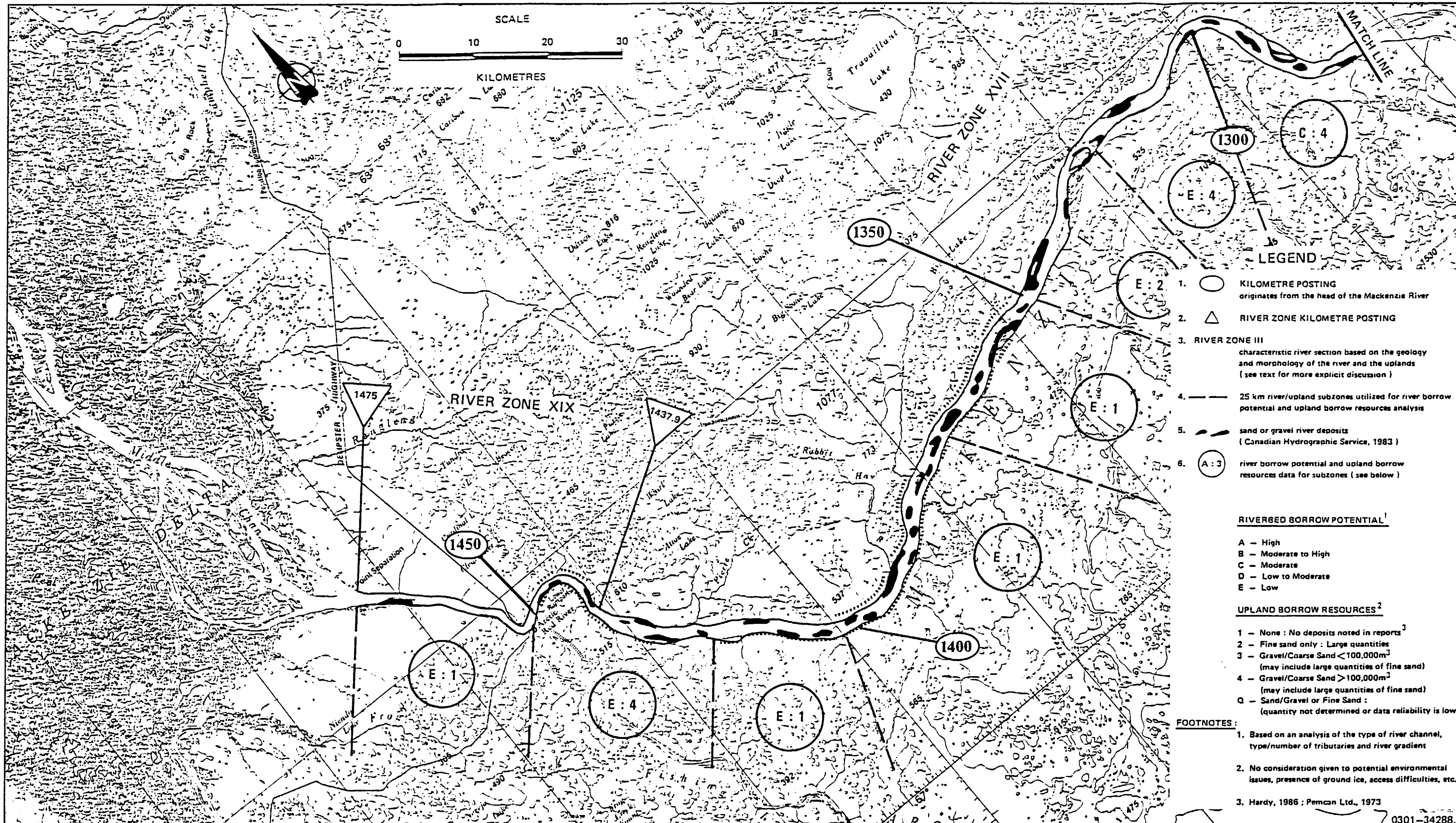
GEOGRAPHIC FEATURES OF THE MACKENZIE RIVER VALLEY



EBA Engineering Consultants Ltd.

DRAWING 4.1f

GEOGRAPHIC FEATURES OF THE
MACKENZIE RIVER VALLEY



EBA Engineering Consultants Ltd.

DRAWING 4.1g

GEOGRAPHIC FEATURES OF THE MACKENZIE RIVER VALLEY

LIST OF DRAWINGS

APPENDIX A

HYDROLOGY AND SEDIMENT CHARACTERISTICS OF MAINSTEM REACHES

A.1 NTS MAP 85-F (KM 0 TO KM 100)[1]

The Mackenzie River from km 0 on Great Slave Lake to km 325 near Fort Simpson is regulated by Great Slave Lake. This portion of the Mackenzie River also carries relatively little sediment. Mean annual discharge at Fort Providence is 4280 m^3/sec; the summer monthly mean (May to October) is 6,630 m^3/sec and winter monthly mean (November to April is 2,370 m^3/sec based on data from 1943 to 1979 (Mackenzie River Basin Committee 1981).

Just downstream of the Mackenzie Highway ferry crossing (10 km upstream of Fort Providence at km 65) the river significantly narrows from 2.2 km to half the width. Here Providence Rapids (km 60 to km 72) forms a narrow, winding reach with some shoal areas in the navigation channel with currents of 5.6 to 9.3 kg/m. Providence Narrows (km 72 - km 78) forms the northwest end of the rapids where the current reaches its maximum speed, about 9.6 to 17.7 kg/hr. (Canadian Hydrographic Service 1985). Downstream of Beaver Lake, the Mackenzie riverbanks are relatively steep and rise 6 to 12 m, particularly in Providence Narrows where the channel is narrow and confined between 12 m high mud banks (Renewable Resources Consulting Services Ltd. 1987). Bed material through Providence Narrows is bouldery till. Between km 77 and km 106, several large islands are located in the channel, the biggest being Meridian Island.

In the Mackenzie River, above the Liard River (km 340), normal low-flow sediment concentrations are about 20 mg/l. Based on records from 1966 to 1978, maximum instantaneous discharge on the Mackenzie River near Fort Providence (Station No. 10FB001) was 8,010 m^3/sec on 1966 July 10. Between 1962 and 1984, maximum daily discharge was 3,880 m^3/sec on 1969 June 1 (Water Survey of Canada 1985).

Footnote: 1 Cross correlation between NTS Map sheet and River Zone are provided in Table 4.1

A.2 NTS MAP 85-E (KM 100 TO KM 195)

Flows from the Fort Providence reach downstream to the junction with the Liard range from 2,000 to 8,500 m^3/sec (Renewable Resources Consulting Services, 1978). From Fort Providence downstream to Fort Simpson, the Mackenzie is relatively free of sediment. The reach is incised, single channelled and free of islands or significant floodplain.

A.3 NTS MAP 95-H (KM 195 TO KM 370)

The channel between Rabbitskin River and Berens Landing (km 300 to km 314) has some shoal bars and from Green Island Rapids (km 314 to km 323) is constricted between two narrow dredged rock cuts. Currents through the rapids approximate 9.6 kph but subsequently drop to about 3.7 kph above the Liard junction on the west side of the Mackenzie upstream of Fort Simpson (Canadian Hydrographic Service 1985). A section of the Mackenzie at Green Island Rapids is designated a priority area for dredging and similar priority areas occur off the mouth of the rabbitskin River and at Strong Point (Canadian Marine Transportation Administration 1974).

In the Fort Simpson area, the Mackenzie River follows a relatively straight course with little sign of meandering since its inception following deglaciation. Its banks consist of glacial drift, mostly till and fine grained lacustrine sediments. The Mackenzie essentially separates the area of thick, fine-grained lacustrine sediments in the south from till, or lacustrine sediments over till in the north. There appears to be a minimum amount of deposition associated with the down-cutting. The surfaces have been scoured, exposing till, lake sediment or lag gravels. There are, however, remnants of terraces that contain thick gravels and sand, usually with overlying silt at various locations along this segment.

Scarps near Fort Simpson reach heights of 60 m but decrease in height upstream from Fort Simpson (Rutter et al. 1973).

In July 1969, Reeder et al. (1972) recorded total dissolved solids of 177 mg/l in the Mackenzie River just upstream of its confluence with the Liard River. Discharge at the time was 7,985 m^3/sec and suspended matter totalled 5.8 mg/l. At the same time the Liard River at Fort Simpson had a discharge of 2,407 ms/sec, and total dissolved solids were recorded at 200 mg/l and suspended matter 16.0 mg/l. In 1973 the Mackenzie River just upstream of the mouth of the Liard River had an annual rate of transport of total suspended sediment estimated at 4,490,000 tonnes/yr. which, on a drainage area basis, was equivalent to about 4,400 kg of total suspended sediment/km^2/yr. (Campbell et al. 1975). The corresponding estimates for 1972 were 3,340,000 tonnes/yr. and 3,270 kg/km^2/yr.

Based on records from 1968 to 1984, maximum instantaneous discharge recorded In the Mackenzie River at Fort Simpson (Station No. 10GC001) was 23,000 m^3/sec on 1977 June 6; for records from 1939 to 1984, maximum daily discharge was 23,500 m^3/sec on 1980 November 24, based on records from 1961 to 1984 (Water Survey of Canada 1985).

Growth rate of point bars and islands along the Mackenzie River are variable with the fastest rate occuring beside active channels and slower beside high water channels. Also, location, rate of sedimentatio and rate of plant invasion contribute to this variation. At the island at Camsell Bend, apparent horizontal growth rate of the island was 13.5 m/yr.

A.4 NTS MAP 95-J (KM 370 TO KM 545)

Between Camsell Bend (km 465) and McGern Island (km 520), the Mackenzie River channel is wide and frequently split around islands, likely due to inflow of coarse bed material supplied by the Root and North Nahanni rivers. Some larger scale instability is evident in the vicinity of McGern Island (Neill 1973) and the 29 km reach at and below McGern Island is a priority dredging area with a potential repeat factor of 1 in 10 years.

Fox (1981) assessed changes in spatial pattern of river banks, islands and bars along the Mackenzie over a recent 10- to 25-year period. Changes were relatively marked in the reaches below Fort Simpson and before Camsell Bend with evidence of island erosion, shifting of bars and collapse of river banks, all of which make these reaches a source of large amounts of sediment. The reach before Camsell Bend includes an area of extensive slope failure. Here riverbanks are composed of lacustrine silts and clays and fine fluvial deposits over shales. Recent erosion is particularly marked in lacustrine deposits (Fox 1981).

Between Camsell Bends and Willowlake River (km 515) there are a variety of deposits such as gravel, peat, fine fluvial materials and till over sandstones, siltstones and dolomites. Riverbanks are mainly stable; exceptions are isolated sites on the west bank, and there is marked sedimentation on islands and bars, (Fox 1981). Between Willowlake River and River Between Two Mountains (km 538) the channel is well established between banks of till and lacustrine clay overlying shales and siltstones of Devonian age and recently eroded. Deposition in this reach is slight. Sediment from Wrigley River and Hodgson Creek is carried downstream.

It is common that large landslides can be found in the glacial lake basin soils which are common in the reach of the Mackenzie River between Fort Simpson and Camsell Bend (McRoberts and Morgenstern, 1973).

A.5 NTS MAP 95-O (KM 545 TO KM 650)

Between the junction of the Redstone River (km 715) and Wrigley (km 574), the Mackenzie flows in a single channel of fairly regular width. There is little sign of lateral shifting or bank instability except at the right-angle bend below the Blackwater River (km 663). In July 1969, Reeder et al. (1972) recorded total dissolved solids of 196 mg/l in the Mackenzie River near Wrigley. Suspended matter totalled 46.4 mg/l at the time and discharged was 10,590 m^3/sec.

Downstream of River Between Two Mountains (km 538), the Mackenzie narrows its channel for a distance of 29 km with shallows and drying banks bordering the channel (Canadian Hydrographic Service, 1985). Sand and gravel banks and shallow water border the west bank before Fish Trap Creek (km 556.8) enters from the west, and these continue beyond this creek downstream to opposite the settlement of Wrigley. Currents in this stretch to 6.4 km before Wrigley are between 9.3 to 11.1 kph, part of a swift section. Downstream from this point to Blackwater River mouth the current is about 6.4 kph. Hodgson Creek joins the Mackenzie from the east through a gravel beach immediately downstream of Wrigley.

The Ochre River mouth (km 605) is restricted by sand flats separated by a narrow , shallow channel at the entrance. At this point immediately downstream of the Ochre River, the Mackenzie is only about 0.48 km wide the lower stages. The delta off the mouth of Johnson River (km 635) dries at low water stages.

A.6 NTS MAP 95-N (KM 650 TO KM 680)

The Mackenzie River follows a straight course to downstream of the Blackwater River entering from the east. Between Blackwater River and Old

Fort Point (km 772), the Mackenzie is winding with frequent expansions containing islands, drying banks and river crossings (Canadian Hydrographic Service, 1985). River banks are clay and gravel varying in height form 20 to 60 m. The current in this section is turbulent with a rate between 9.3 and 12.8 kph. At km 666.2, the Mackenzie makes an abrupt turn west for 4.8 km before continuing a northward course. Around this end the navigation channel follows the west bank during higher water levels and the east ban during low water levels. A drying gravel area separates the two channels. Downstream of this end, the Dahadinni River joins the Mackenzie from the west. This river is divided over long stretches into several shallow channels and at its mouth it flows over a drying bar of sand and gravel.

A.7 NTS MAP 96-C (KM 680 TO KM 845)

The reach of the Mackenzie River between the Redstone River (km 714) and Seagull Island (km 790) is probably the most unstable one along the entire river. In this section, the river has an irregular meander pattern with frequent islands and bars. The banks of the river and islands are slowly being eroded; the natural concentration of sediment may be as high as 7,000 mg/1 or 8,000 mg/1 during high flow. Both the Redstone and Keele Rivers (km 737) bring large quantities of silt, sand and coarse bed material into the Mackenzie. The width of the Mackenzie at its confluence of the Redstone is substantially reduced by the build-up of a large side-channel bar. This bar is composed of material from the Redstone River which would be too large to be moved by the Mackenzie. The river slope trough this reach has increased considerably, probably due to the build-up of sediment at the upper end of this reach. Because the Keele River is somewhat more stable than the Redstone, it does not carry as much sediment into the Mackenzie (Renewable Resources Consulting Services Ltd., 1978).

The high sediment transport into the Mackenzie by the Redstone has resulted in many bar and island formations downstream. Deposition is heavy in this area and much silt and sand is either in transition or is being deposited along the edges of the islands. Banks adjacent to the river are veneered with sands and gravels. Between the Redstone and Keele Rivers, erosion along the banks of the Mackenzie is light except on the northeast bank of the river opposite the Keele River (Fox 1979).

No mainstem sediment sampling stations are located in this map area.

A.8 NTS MAP 96-D (KM 845 TO KM 855)

The reach from Seagull Island (km 790) downstream past Halfway Islands (km 860) to Ten Mile Island (km 885) is characterized by an irregular meander pattern and occasional islands and bars. The substrate is generally sand and gravel. The river narrows to a single channel in this reach. The Great Bear River (km 827), which enters this reach just below Fort Norman, brings in only small quantities of gravel to the Mackenzie (Renewable Resources Consulting Services Ltd. 1978). Islands within this map area near present stream level, consist of silt, sand and gravel, and are subject to periodic flooding (Lombard North Group Ltd. 1974).

A.9 NTS MAP 96-E (KM 855 TO KM 975)

Some sections of the river bank in this map area exhibit large scale, retrogressive failures accompanied by gullying (Code 1973). Changes in plan configuration from the main river and island banks at Norman Wells have been examined by a detailed comparison of airphotos taken in 1950 and 1972. Some of the main features noted were: the downstream bank of Bear Island facing Goose Island has cut back by about 100 m in 22 years, averaging 5 m per year; a 1.6 km length of the left river bank opposite the upstream part of Bear Island may have cut back by up to 30 m; changes in Six Mile, Frenchy and Goose Islands are more difficult to define because the islands have few well-defined banks and are surrounded by low bars and shoals. There is evidence of mainly lateral shifting in the principal bars around the island.s At Six Mile Island some shorelines have apparently shifted by up to 250 m, or about 11 m/yr.; the Goose Island shoreline that faces Bear Island appears to have receeded about 180 m, which means that the channel between the islands has widened by some 280 m. Changes inn well-defined banks of the higher wooded islands do not exceed 5 m per year on the average; changes in the shorelines of major sand bars are more rapid and may be up to 12 m per year on the average. The overall rates of change are very small in relation to the size or the river (Northwest Hydraulic Consultants Ltd. (1979)

The reach upstream of Ten Mile Island is characterized by an irregular meander pattern and occasional islands and bars. The substrate is generally sand and gravel. The river narrows to a single channel in this reach. The Great Bear River, which enters this reach just below Fort Norman, brings in only small quantities of gravel to the Mackenzie, because the suspended load of the Great Bear is low (Renewable Resources Consulting Services Ltd. 1978). The cold, clear water from Great Bear River does not readily mix with the warm, turbid water of th Mackenize River; in fact complete mixing does not occur for 500 km downstream (Mackay 1972). This is a reach of light to moderate deposition.

The river downstream of Ten Mile Island, within this map area, is characterized by an expansive, weakly entrenched, straight channel incorporating numerous river islands and bars. This reach of the river appears to be more unstable than the reach upstream of Ten Mile Island.

Banks are generally high and bank erosion is evident in many locations. The flow along this reach varies from a low of 70,500 cfs, to a high of 900,000 cfs (2,000 m^3/sec to 25,500 m^3/sec) during the summer; natural suspended sediment concentrations range from 300 mg/l to 8,000 mg/l (Renewable Resources Consulting Services Ltd. 1978). Records from Water Survey of Canada (1985) indicate that the maximum daily discharge at Norman Wells id 30,300 m^3/sec (1975 May 24) and the minimum daily discharge is 1,950 m^3/sec (1979 December 26).

Brunskill et al. (1975) estimated the average annual mass of suspended sediments at Norman Wells to be about 101,000,000 metric tonnes/yr. and the annual mass of sediments per unit area of watershed was estimated at 64.5 metric tonnes/km^2/yr. This compares with 621,000 metric tonnes/yr. and 0.64 metric tonnes/km^2/yr. at Fort Providence for the same observation period 1971 to 1974. In general, the Mackenzie River increased its sediment load and its dissolved mineral content in its course downstream. The sediment load is acquired mainly from rivers from the west; for the tributary streams on the east carry a low sediment load. The dissolved mineral content is acquired mainly by effluent groundwater seepage to the river and to its tributaries. Campbell et al. (1975) reported a range of concentration of total suspended sediment at Norman Wells of 3.5 to 1,800 g/m^3 with quartz, colomite, calcite, chlorite, illite, and plagioclase present in samples collected from 1971 to 1974.

Weighted averages for dissolved solids in Mackenzie River waters at Norman Wells averaged 173 ppm and varied seasonally in a narrow range between 162 and 176 ppm. On a higher, intermediate and low discharge-based evaluation it is shown that during periods of high discharge the river carried more total dissolved solids per unit volume than during periods of low discharge. During periods of low discharge, river waters are characterized by increased contents of Na and Cl, and during periods of high discharge by increased contents of Ca and HCO_3. Amounts of NO_3 and possibly K and Mg increase with lowered discharge. These phenomena are attributed to the varied and relative contributions of groundwater inflow, surface runoff and lake storage. In periods of low flow on the Mackenzie River, Great Slave and Great Bear lakes contribute possible 75 to 80 percent of total discharge, evidence of the significant of lake storage (Levinson et al 1969).

The Mackenzie River in the Norman Wells area (km 905) is exceptionally wide (5.6 km) and is characterized by numerous islands and shoal areas. The materials on the river bed at Norman Wells are mainly 1 to 4 m of medium sand with gravel occurring locally over caly, bedrock or till. The alluvial cover is not continuous (Esso Resources Canada Ltd. 1980).

The river downstream of Ogilvie Island is in a region of flow to moderate erosional potential. Deposition has been moderate to heavy resulting in extensive island development. Bars are continually in a state of flux as silts and sands constantly redistribute themselves. Vegetation has stabilized the majority of the islands and river banks (Fox 1979).

Only one suspended sediment station (NO. 10KA001; Lat. 65 16 54, Long. 126 50 580) is located in this map area. The data were gathered by Davies (1974) between June 5 and October 11, 1973 (seven individual depth integrated samples) during which suspended sediment concentration ranged from 3.5 to 1,800 mg/l in the Mackenzie River at Norman Wells, with daily rates of transport of total suspended sediment from the Mackenzie River, 20 km downstream of Norman Wells, for determination of chemical composition.

A.10 NTS MAP 106-H (KM 975 TO KM 1060)

The Mackenzie River from Axel Island (km 1005) to the north end of this map area is characterized by shoals, lateral channels and riffles. The river has an irregular width, occasional islands, and several bedrock controls that result in rapids. The Mountain River enters from the west, just upstream from the Sands Sault Rapids (km 1017), and brings sand and gravel into this reach. Much of the material is transported through the rapids and deposited on islands and bars downstream. The Mackenzie River becomes wider and exhibits more splitting around bars and islands from some distance downstream of the Mountain River mouth. The relative instability of the reach is probably due to the excess of coarse sediment brought down the Mountain River and through Sans Sault Rapids. The slope of the Mackenzie River below the rapids is through to be increasing slowly as the deposition at the upstream end of this reach continues (Renewable Resources Consulting Services Ltd. 1978).

Erosion is severe along the west bank of the Mackenzie River, opposite Snafu Creek, where slopes are moderate and have undergone severe sloping and gullying. The Mountain River valley has also undergone extensive slumping, depositing large quantities of sediment into the Mackenzie.

Over the past 25 years bars have shifted substantially but island growth has been minimal in the stretch downstream from the Sans Sault Rapids (Fox 1979). All islands within this map area are near present stream level, consist of silt, sand and gravel, and are subject to periodic flooding (Lombard North Group Ltd. 1974).

The Sans Sault Rapids are considered the most difficult and dangerous section of the Mackenzie River to navigate. The rapids are formed by a rocky ledge that extends into midstream from the east bank. At high stages they are drowned out by the turbulent, swift-running river. At low stages the rapids are shallow and less turbulent with water depths in the order of 1.2 to 2.4 m, but contain numerous eddies with currents between 1.5 and 2.0 m/sec (Canadian Marine Transportation Administration 1972). Flash floods on the Mountain River have been known to jam the Mackenzie River with debris at Sans Sault Rapids.

Boulders and cobbles occur downstream of the Sans Sault Rapids along both sides of the river. The shores of Dummit Island (km 1025) are composed of boulders and cobble with large isolated patches of sand and gravel on some sheltered beaches (Renewable Resources Consulting Ltd. 1978).

Suspended sediments in this stretch of the Mackenzie River are not well documented but are through to be similar to those at Norman Wells (300 mg/l to 8,000 mg/l). The only deviation from this might be the water along the south shore below the confluence of Mountain River. In Autumn, water from the Mountain River is much less turbid than that from the Mackenzie River, and the clear water from the Mountain River extends for a considerable downstream (Renewable Resources Consulting Services Ltd. 1978).

Horizontal growth rate of an island beside an active channel in the Mackenzie River near Sans Sault Rapids was estimated by Hardy Associates (1978) Ltd. (1982) as 6.6 m/yr. within a range from 1.8 to 13.5 m/yr. for six sites sampled on the Liard and Mackenzie Rivers. Variation in sedimentation rate is due to location, rate of deposit and rate of plant invasion.

A.11 NTS MAP 106-I (KM 1060 TO KM 1195)

Upstream of The Ramparts (km 1087 to km 1097), the Mackenzie River is characterized by a wide channel with numerous sand bars. The width of the river varies considerably and banks are undergoing erosion at some locations. The instability of this reach is probably due to the excess of coarse sediment (sand and gravel) which is brought down the Mountain River and through Sans Sault Rapids to be deposited in this area.

On this map area, the portion of the Mackenzie River upstream of the Loon River (km 1130) forms a highly complex reach. Erosion is moderate to heavy along most river banks. Channel deposition is moderate to heavy throughout this reach. Silt and silty-sands have been deposited along the river channel, forming a network of islands and bars. Vegetation creates a temporary stabilizing force on many of the islands (Fox 1979). Spruce Island and the large un named island just upstream are above present floodplain levels and are composed of gravel, sand and silt. Other islands in the area are subject to periodic flooding (Lombard North Group Ltd. 1974).

Based on the Water Survey of Canada records from Norman Wells, the following discharges were projected for The Ramparts segment of the Mackenzie River: mean discharge, 14,400 m^3/sec; highest discharge recorded 28,600 m^3/sec; lowest discharge recorded, 6,100 m^3/sec; mean October discharge, 9,700 m^3/sec; discharge exceed on October 12 in 90 percent of years, 8,100 m^3/sec (Northwest Hydraulic Consultants Ltd. 1982).

From the Loon River mouth to the northwest edge of this map area the northeast side of the Mackenzie River is dominated by steep-terraced slopes. Deposition is moderate to heavy in this reach. Islands and bars consisting of silt and silty sands have accumulated in the river channels. Bar shifting is quite evident in some places which vegetation has, at least temporarily, stabilized other bars (Fox 1979).

At The Ramparts, the river is straight, entrenched and confined by high limestone cliffs. Bed material is bedrock and boulders. Flows range from 2,000 m^3/sec to 25,500 m^3/sec but water level changes are predominantly controlled by ice jams that form through The Ramparts (Renewable resources Consulting Services Ltd. 1978).

There are no mainstem sediment survey stations located in this map area.

A.12 NTS MAP 106-J (KM 1195 TO KM 1235)

Moderate to heavy deposition of sands and silts along the Mackenzie River in this map area has resulted in numerous bars and islands which show some evidence of erosion. The Ontaratue River (km 1200) is currently a major source of sediment. historically, the southwest bank of the Mackenzie River is thought to have provided substantial amounts of sediment because it is composed of weak shale overlain by a veneer of silt and silty-sand. The southwest bank, however, was degraded a considerable time ago and vegetation is well established. The northwest bank is much steeper and composed of more resistant rocks (Fox 1979). The only area of relatively unstable river banks on this map area is a short segment on both sides of the Ontaratue River, about 6 km upstream from the mouth of the river (Dirschl 1975).

There are no mainstem sediment survey stations located in this map area.

A.13 NTS MAP 106-0 (KM 1235 TO KM 1355)

River banks within the upstream third of the Mackenzie River in this map area vary from gentle to moderate slopes. Mass movement, in the form of flows, has occurred in glaciolacustrine deposits that overlie the resistant sandstones on the northeast bank. Where recent deposits are thin, banks are more stable and well wooded. Silts and silty-sands have accumulated in the river channel forming frequent bars and islands (Fox 1979).

Deposition is light to moderate in the downstream two thirds of the Mackenzie River in this map area. Multiple retrogressive landslides along the Thunder River (km 1299) and the unnamed tributary o the east side of the Thunder River about 2 km upstream from the Mackenzie River supply, supply the Mackenzie with large amounts of sediment. The banks of the Mackenzie show some evidence of erosion along the north bank, west of the Travaillant River mouth (km 1327) (Fox 1979).

A.14 NTS MAP 106-N (KM 1355 TO KM 1470)

The reach of the Mackenzie River from the eastern edge of this map area to about Pierre Creek (km 1424) is in a region of moderate deposition resulting in both island and bar formation. The river banks and bluffs have undergone considerable gullying, rill erosion and landslides. Terraces are well developed in a variety of recent deposited (Fox 1979).

Turbidity increases from Fort Providence to Wrigley, declines slightly at Norman Wells then rises again upsteam of the confluence with the Arctic Red River. This reflects the input of essentially lake water to the Mackenzie River from Great Bear River upstream of Norman Wells and the accumulation of dissolved and suspended material from numerous tributaries and groundwater sources along the main river channel. The turbidity trend highlights the important role of Great Bear Lake as a sediment settling basin in the Mackenzie drainage network (Water Quality Branch 1983).

From data gathered by the Water Survey of Canada at Sediment Survey Station 10LA003 for the years 1973 to 1979 inclusive, mean monthly suspended sediment concentrations were calculated by B.C. Hydro and Power Authority (1980) as follows, expressed in mg/1 with ranges in parantheses: Jan. 0.7 (0-3); Feb. 0.9 (0-3); Mar. 0; Apr. 0.4 (0-3); May 631 (85-1303); June 716 (409-1001); July 489 (246-781); Aug. 243 (83-765); Sept. 89 (46-151); Oct. 38 (14-16); Nov. 12 (0-48); Dec. 0.7 (0-3). For this sediment survey station, estimates of annual sediment loads (megatonnes) for the years 1973 through 1979 were 97.4, 138.5, 155.4, 111.7, 101.6, 55.1 and 105.1, respectively. Sediment are carried almost entirely in the ice-free season (May to October inclusive) with insignificant amounts in winter (Hardy Associates (1978) Ltd. 1982).

Using 1982 data as an example, the highest daily mean concentration of suspended sediments recorded at sediment survey station 10LA003 was 723 mg/1 on 1982 June 24 at which time daily discharge was 25,000 m^3/sec and daily load was 1,560,000 metric tonnes/day. In that year, daily loads averaged 953,000 tonnes in June, 231,000 in July, 455,000 in August, 122,000 in September and 27,700 in October, with no values shown for the other seven months of the year (Water Survey of Canada 1984).

Suspended load composition of the Mackenzie River at Arctic Red River is 12 percent sand, 60 percent silt and 28 percent clay, a significant change from the typically 20 percent fine sand, 55 percent silt and 25 percent clay contributed by the Liard at its junction with the Mackenzie. Sediments that form point bars and islands on the main river stem are predominantly fine sand and silt (Hardy Associates (1978) Ltd. 1982).

The high sediment load of the Mackenzie River, in the order of 1,000 mg/1 (Renewable Resources Consulting Services Ltd. 1978), is also significantly influenced by sediment derived from west-side tributaries that issue from the Mackenzie Mountains onto the Mackenzie Plain. Very large deposits of glaciofluvial gravel are associated with major meltwater channels where

the Mackenzie Plain meets the Mackenzie mountains (Hughes et al. 1973).

A.14.1 Mainstem Sediment Survey Stations on this Map

1. Station No. 10LC003; Lat. 67 45 25, Long 133 51 25; manual sampling, seasonal operation 1973, manual sampling, miscellaneous data only in 1974; data are not published for this sediment survey station.

2. Station No. 10LA003; Lat. 67 21 30, Long. 133 30 30; manual sampling miscellaneous data only in 1972 and 1975; manual sampling, season operation in 1973 to 1974 and 1980 to 1982.

A.15 NTS MAP 106-M (KM 1470 TO THE DELTA)

At Point Separation the mean discharge of the Mackenzie River into the delta is of the order of 400,000 cfs (11,320 m^3/sec). Annual flood peak at this point is estimated at 947,000 cfs (26,800 m^3/sec) or more than twice the mean discharge (Mackay 1967). Instantaneous flows as high as 76,450 m^3/sec were associated with a comparitively mild ice jam in May 1975 but the predicted daily discharge corresponding to a 100-yr. flood is 36,800 m^3/sec (Hollingshead and Rundquist 1977).

The Mackenzie River at Point Separation has a high potential for scour, primarily as a result of ice jamming, and because of fine-grained (sand) bed material to great depth. bank erosion potential is minor (Foothills Pipe Lines (Yukon) Ltd. 1979) but channel banks are high enabling the development of larger ice jams.

Data are scarce with respect to suspended sediment concentrations. For the Mackenzie River above Arctic Red River, measured concentrations in the summer season have been mostly in the 100 to 1000 mg/1 range. On 1974 August 12 a daily extreme of 9640 mg/1 was recorded, with the river discharge at 28,000 m^3/sec giving a daily suspended sediment yield of 23.3 million tonnes. Concentrations have been observed to decline below 100 mg/1 by the end of September and remain low untill the next spring flood (Heginbottom 1978).

APPENDIX B

SUMMARY OF FISHERIES INFORMATION FOR REACH ZONES

MACKENZIE RIVER REACH ZONE: I (0 - 25.75 km)

GEOGRAPHIC LOCATION: Great Slave Lake to west side of Big Island

MAJOR TRIBUTARIES: None

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively

Lake Trout	Arctic Grayling	Burbot
Humpback Whitefish	Northern Pike	
Round Whitefish	Yellow Walleye	
Inconnu	Longnose Sucker	

HABITAT USES:

FISHING AREAS:

Domestic fishing in the Great Slave Lake outlet harvest whitefish spp., primarily while sport fishermen target lake trout, Arctic grayling, northern pike and yellow walleye (McCart and Den Beste, 1979).

SUMMARY OF CONCERNS:

- The river in this reach has been described as a straight channel bearing no tributary streams. Probably functions as a migratory route for species moving between the Mackenzie mainstem and Great Slave Lake.

MACKENZIE RIVER REACH ZONE: II (25.75 - 60 km)

GEOGRAPHIC LOCATION: West side of Big Island to west side of Beaver Lake

MAJOR TRIBUTARIES: Kakisa River

MAJOR SPECIES PRESENT: Fall and spring spawners grouped, respectively.

Lake Trout	Arctic Grayling
Humpback Whitefish	Northern Pike
Round Whitefish	Yellow Walleye
Inconnu	Longnose Sucker

HABITAT USES:

Kakisa River - Spring runs including Arctic grayling, northern pike, yellow walleye and longnose suckers, spawn in the river and it is probable that fall spawners migrate via this watercourse (McCart *et al.*, 1974).

FISHING AREAS:

Primarily humpback whitefish are caught domestically within the area defined by the reach boundaries. In addition, sport fishermen concentrate along the Mackenzie mainstem to catch mainly grayling, pike and yellow walleye (McCart and Den Beste, 1979). Excellent grayling catches have also been reported in the Kakisa River below the rapids (Hatfield *et al.*, 1972b).

SUMMARY OF CONCERNS:

- Potential concerns have yet to be identified, although intensive domestic and sports fishing in the area suggest that migrations will be a probable concern.

MACKENZIE RIVER REACH ZONE: III (60 - 107 km)

GEOGRAPHIC LOCATION: Beaver Lake to Horn River and Mills Lake

MAJOR TRIBUTARIES: Horn River

MAJOR SPECIES PRESENT: Fall and spring spawners grouped, respectively.

Lake Trout	Arctic Grayling
Humpback Whitefish	Northern Pike
Round Whitefish	Yellow Walleye
Inconnu	Longnose Sucker

HABITAT USES:

FISHING AREAS:

Whitefish spp., northern pike, yellow walleye and suckers catches have been reported by local residents (Fort Providence) at the mouth of the Horn River (Hatfield *et al*., 1972b).

SUMMARY OF CONCERNS:

- Mainstem defined as braided with sand and gravel throughout, and could include spawning and rearing habitats. Probably provides a migration route during fish movements.

MACKENZIE RIVER REACH ZONE: IV (107 - 130 km)

GEOGRAPHIC LOCATION: Horn River and Mills Lake to west end of Mills Lake

MAJOR TRIBUTARIES: None

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Lake Trout	Arctic Grayling
Humpback Whitefish	Northern Pike
Round Whitefish	Yellow Walleye
Inconnu	Longnose Sucker

HABITAT USES:

FISHING AREAS:

Possible domestic fishing locations for Fort Providence residents.

SUMMARY OF CONCERNS:

MACKENZIE RIVER REACH ZONE: V (130 - 228.5 km)

GEOGRAPHIC LOCATION: West end of Mills Lake to west of Trout River

MAJOR TRIBUTARIES: Trout River (including Trout Lake)
Redknife River
Bouvier River

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Lake Trout	Arctic Grayling	Burbot
Lake Cisco	Northern Pike	
Arctic Cisco	Yellow Walleye	
Humpback Whitefish	Longnose Sucker	
Round Whitefish		
Inconnu		

HABITAT USES:

Trout River - Spawning and nursery areas are for present Arctic grayling, northern pike, yellow walleye and longnose suckers (McCart et al., 1974; Dryden et al., 1973). Possible overwintering areas (McCart and McCart, 1982). Summer feeding areas for grayling, pike and longnose suckers and occasionally juvenile cisco and whitefish spp. (McCart et al., 1974).

Redknife River - Rearing grounds occur at tributary mouth and large backeddies (Stein et al., 1973).

Bouvier River - Nursery stream for Arctic grayling (Jessop and Lilley, 1975).

FISHING AREAS:

Domestic fishermen harvest whitefish spp. (humpback and round) during migration at tributary mouths e.g. Trout River (McCart and Den Beste, 1979) and also whitefish spp., pike and suckers in Trout Lake (DIAND/MPS, 1973). Sport fishing is also common in these areas, concentrating mainly on pike, grayling, and walleye (McCart and Den Beste, 1979).

SUMMARY OF CONCERNS:

- Spring spawning movements into the Trout River.
- Summer movements of fry and juveniles from Trout, Redknife and Bouvier rivers.
- Fall spawners moving through the mainstem.
- Domestic fishery at Trout River.

MACKENZIE RIVER REACH ZONE: VI (228.5 - 300 km)

GEOGRAPHIC LOCATION: West of Trout River to east of Rabbitskin River

MAJOR TRIBUTARIES: Jean-Marie Creek
Spencer River

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Lake Cisco	Arctic Grayling	Burbot
Humpback Whitefish	Northern Pike	
Broad Whitefish	Yellow Walleye	
Mountain Whitefish	Longnose Sucker	

HABITAT USES:

Jean-Marie Creek - Migration route for spring runs of Arctic grayling, northern pike,, yellow walleye and suckers in the lower reaches and a strong possibility of grayling and walleye spawning at the mouth. A fall run of whitefish has also been observed (Dryden et al., 1973). Possible fall spawning of whitefish and cisco spp. (McCart and McCart, 1982).

Spencer River - A spawning and nursery river for Arctic grayling, northern pike and longnose suckers. Summer feeding also occurs (McCart et al.,1974).

FISHING AREAS:

Domestic fishing takes place from spring through to fall at the mouth of the Jean-Marie Creek where the creek enters the Mackenzie mainstem (Dryden et al., 1973). Whitefish spp., pike and suckers are harvested (DIAND/MPS, 1973).

SUMMARY OF CONCERNS:

- Migration route through the Mackenzie mainstem for spring and fall spawners accessing Jean-Marie Creek and Spencer River.
- Important domestic fishery at the mouth of Jean-Marie Creek.

MACKENZIE RIVER REACH ZONE: VII (300 - 410 km)

GEOGRAPHIC LOCATION: East of Rabbitskin River to east of Burnt Island

MAJOR TRIBUTARIES:
- Rabbitskin River
- Bluefish Creek
- Liard River
- Harris River
- Martin River
- Trail River

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Lake Trout	Arctic Grayling	Burbot
Arctic Cisco	Northern Pike	
Humpback Whitefish	Yellow Walleye	
Broad Whitefish	Longnose Sucker	
Round Whitefish		
Mountain Whitefish		
Inconnu		

HABITAT USES:

Mackenzie Mainstem - Humpback whitefish, Arctic grayling, northern pike and longnose suckers were identified as the most abundant species caught in the Mackenzie mainstem in earlier studies (Stein *et al.*, 1973; Jessop and Lilley, 1975). Emigration of whitefish, Arctic grayling and longnose sucker fry from tributary streams to the Mackenzie mainstem observed during June and July (Jessop *et al.*, 1974).

Rabbitskin River - Fall spawning mountain whitefish, spring spawning grayling, pike and walleye and possibly burbot (winter spawner) utilize this watercourse to spawn. Nursery area for humpback whitefish, inconnu, grayling, northern pike and longnose suckers (McCart *et al.*, 1974). Overwintering potential (McCart, 1974). Summer feeding grounds for walleye (Jessop *et al.*, 1974) and likely other species (McCart *et al.*, 1974).

Bluefish Creek - Suspected spawning for Arctic grayling and northern pike. Nursery grounds for grayling (McCart *et al.*, 1974). Cisco spp. and humpback whitefish fry observed moving out of the creek in early July followed by Arctic grayling in mid-July to early August (Jessop *et al.*, 1974).

Liard River - Major migratory route for many species (McCart *et al.*,1974).

Harris River - Grayling, pike, longnose sucker and possibly walleye spawning occurs in the spring. As well, nursery areas are present in the stream for humpback and broad whitefish, northern pike and longnose suckers (McCart *et al.*, 1974). Possible overwintering in the river (McCart, 1974).

Martin River - Spawning area for Arctic grayling (Stein et al., 1973).

Trail River - Possibility that fall spawning species (e.g. whitefish and cisco spp.) and summer feeders utilize the river. Overwintering is suspected (McCart and McCart, 1982). Arctic grayling have moved into the stream under the ice early in May in preparation for spawning and have been observed moving upstream as far as the Harris River following spawning (Jessop et al., 1974).

FISHING AREAS:

Whitefish spp., northern pike and longnose suckers are caught for domestic use along the Mackenzie mainstem in the Fort Simpson area (DIAND/MPS, 1973). Significant sport fishing takes place in the Fort Simpson area and upstream on the Liard River particularly for Arctic grayling, pike and walleye (McCart and Den Beste, 1979).

SUMMARY OF CONCERNS:

- Mackenzie mainstem in the area as well as the Liard River function as major migration routes for spring, fall and winter spawners to a number of tributary streams in the area.
- Fry move into the mainstem in the summer (June to August).
- Important domestic and sport fishery in the vicinity of Fort Simpson.

MACKENZIE RIVER REACH ZONE: VIII (410 - 520 km)

GEOGRAPHIC LOCATION: East of Burnt Island to north of Willowlake River

MAJOR TRIBUTARIES: Willowlake River
Root River
Nahanni River

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Lake Cisco	Arctic Grayling	Burbot
Humpback Whitefish	Northern Pike	
Round Whitefish	Yellow Walleye	
Mountain Whitefish		
Inconnu		

HABITAT USES:

Willowlake River - Spawning area for spring runs of Arctic grayling, northern pike and longnose suckers (McCart *et al.*, 1974). Suspected spawning for fall runs of whitefish and cisco spp. and possible overwintering grounds (McCart and McCart, 1982). Summer feeding area for lake cisco, humpback whitefish, northern pike, walleye, longnose sucker and burbot (McCart *et al.*, 1974).

FISHING AREAS:

Whitefish spp., inconnu, northern pike and suckers are harvested domestically at the mouth of Willowlake River (Jessop and Lilley, 1975).

SUMMARY OF CONCERNS:

- Domestic fishing at the mouth of Willowlake River.
- Spring and fall spawners moving through the McGern Island area into Willowlake River and possibly Root River.
- Braided river sections including a number of islands, indicate potential fish spawning and/or rearing habitat, however past surveys in the area are lacking.

MACKENZIE RIVER REACH ZONE: IX (520 - 580 km)

GEOGRAPHIC LOCATION: North of Willowlake River to Wrigley River

MAJOR TRIBUTARIES:
River Between Two Mountains
Smith Creek
Hodgson Creek
Wrigley River

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Lake Trout	Arctic Grayling	Burbot
Humpback Whitefish	Northern Pike	
Round Whitefish	Yellow Walleye	
Mountain Whitefish	Longnose Sucker	
Inconnu		

HABITAT USES:

River Between Two Mountains - Important Arctic grayling and round whitefish spawning and moderate longnose sucker spawning exists as well as a migratory route for a number of spawners. Nursery areas for mountain whitefish and longnose sucker and important rearing habitat for grayling and round whitefish are present. The river also provides summer feeding for round whitefish, grayling and pike. Overwinter conditions are suitable (McCart et al.,1974; McCart, 1974; McCart and McCart, 1982).

Smith Creek - Possesses potential for spawning, rearing, summer feeding and overwintering areas (McCart et al., 1974).

Hodgson Creek - Identified as grayling overwintering area and possibly other species (McCart et al., 1974; McCart and McCart, 1982). Spawning grounds for round whitefish, grayling and longnose suckers and nursery areas for longnose suckers and possibly Arctic grayling as well. Grayling, northern pike and longnose suckers rear and summer feed in the stream (McCart et al., 1974).

FISHING AREAS:

Arctic grayling are fished for sport near the mouth of River Between Two Mountains (Dryden et al., 1973). Whitefish spp., northern pike and longnose suckers are caught for domestic purposes near the settlement of Wrigley (McCart and Den Beste, 1979; DIAND/MPS, 1973).

SUMMARY OF CONCERNS:

- Domestic fishery within the vicinity of Wrigley e.g. Wrigley River and River Between Two Mountains.
- Spring and fall migrations to spawning areas. Adult and juvenile fish move through the mainstem to overwintering areas.

MACKENZIE RIVER REACH ZONE: X (580 - 664.5 km)

GEOGRAPHIC LOCATION: Wrigley River to Blackwater River

MAJOR TRIBUTARIES:
- Ochre River
- Johnson River
- Noname Creek
- Blackwater River

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Humpback Whitefish	Arctic Grayling	Burbot
Round Whitefish	Northern Pike	
Inconnu	Yellow Walleye	
	Longnose Sucker	

HABITAT USES:

Ochre River - Little overwintering potential although longnose suckers caught in open water area (McCart and McCart, 1982).

Noname Creek - Spawning, rearing and summer feeding for grayling and suspected spawning for *Prosopium* species (McCart *et al*., 1974). Possible overwintering area for some species (McCart and McCart, 1982).

Blackwater River - Migratory route as well as spawning and rearing grounds for Arctic grayling (McCart *et al*., 1974) and possibly utilized by fall spawning species (e.g. whitefish and cisco species)(McCart and McCart, 1982). Summer feeders include Arctic grayling and longnose suckers (McCart *et al*., 1974). Good overwintering potential because of good flow and well oxygenated water (McCart and McCart, 1982).

FISHING AREAS:

Domestic fishing for whitefish spp., northern pike and longnose suckers occurs downstream of Wrigley (McCart and Den Beste, 1979; DIAND/MPS, 1973).

SUMMARY OF CONCERNS:

- Domestic fishing at the Blackwater River mouth.
- Migration route for spring and fall spawners and possibly burbot.

MACKENZIE RIVER REACH ZONE: XI (604.5 - 714 km)

GEOGRAPHIC LOCATION: Blackwater River to Redstone River

MAJOR TRIBUTARIES: Dahadinni River
Birch Island Creek
Saline River
Redstone River

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Humpback Whitefish	Arctic Grayling	Burbot
Round Whitefish	Northern Pike	
Inconnu	Longnose Sucker	

HABITAT USES:

Birch Island Creek - Spawning, rearing and summer feeding for Arctic grayling (McCart *et al.*, 1974). Suspected Arctic grayling overwintering area (McCart, 1974).

Saline River - Rearing, summer feeding, overwintering and incidental spawning areas for *Prosopium* spp., Arctic grayling and longnose suckers (McCart *et al.*, 1974; McCart, 1974).

FISHING AREAS:

Specific areas unknown at this time. No settlements occur within the immediate vicinity of reach.

SUMMARY OF CONCERNS:

- Domestic fishing areas unknown.
- Fish movements to spawning streams during spring and fall.
- Possible spawning and rearing habitat near mainstem islands. (Probably a minor concern since the reach is relatively uniform and a single channel).

MACKENZIE RIVER REACH ZONE: XII (714 - 828 km)

GEOGRAPHIC LOCATION: Redstone River to Great Bear River

MAJOR TRIBUTARIES: Keele River
Little Smith Creek
Big Smith Creek

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Dolly Varden Char	Arctic Grayling	Burbot
Arctic Cisco	Northern Pike	
Least Cisco	Yellow Walleye	
Humpback Whitefish	Longnose Sucker	
Broad Whitefish		
Round Whitefish		
Mountain Whitefish		
Inconnu		

HABITAT USES:

Little Smith Creek - Spawning area for spring runs of grayling, walleye, longnose suckers, winter run burbot and possibly fall spawning round whitefish. Summer feeding grounds for Dolly Varden char, round whitefish, grayling, pike and longnose suckers. Nursery areas are also present (McCart et al., 1974). No overwintering potential (McCart and McCart, 1982).

Big Smith Creek - Spawning area for Arctic grayling and also summer feeding area for grayling and pike (McCart et al., 1974). Limited overwintering potential (McCart and McCart, 1982). Barrier to upstream migration about 4 miles from the creek mouth (Dryden et al., 1973)

FISHING AREAS:

Mainly cisco spp., whitefish spp., inconnu and Arctic grayling are caught by local fishermen from Fort Norman although other species including pike, burbot, walleye and sucker spp. comprise the catches (DIAND/MPS, 1973; Unpublished data from MacLaren Plansearch).

SUMMARY OF CONCERNS:

- Local domestic fishing sites along the mainstem.
- Mainstem use during summer by juveniles and adults enroute to overwintering areas.
- A number of islands within Reach XII may offer spawning and/or rearing potential.

MACKENZIE RIVER REACH ZONE: XIII (828 - 965.7 km)

GEOGRAPHIC LOCATION: Great Bear River to Patricia Island

MAJOR TRIBUTARIES:

Great Bear River	Helava Creek
Little Bear River	Francis Creek
Slater River	Canyon Creek
Bluefish Creek	Stewart Creek
Jungle Ridge Creek	Bosworth Creek
Nota Creek	Billy Creek
Vermilion Creek	Oscar Creek
Prohibition Creek	Elliot Creek

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Dolly Varden Char	Arctic Grayling	Burbot
Lake Trout	Northern Pike	
Arctic Cisco	Yellow Walleye	
Least Cisco	Longnose Sucker	
Humpback Whitefish	Goldeye	
Broad Whitefish		
Round Whitefish		
Inconnu		

HABITAT USES:

Mackenzie Mainstem - Rearing habitat reported for young-of-the-year and/or juvenile salmonids (whitefish, cisco, inconnu and grayling), burbot, pike and walleye in gravel-cobble areas near Billy, Oscar and Elliot creeks (Envirocon, 1981).

Great Bear River - Migratory route for populations of fall spawning runs of Arctic cisco, round whitefish, inconnu and spring runs of grayling and pike. Possible spawning grounds for burbot and longnose sucker and suspected nursery for all of these species. Nursery for lake trout (Dryden et al., 1973; McCart et al., 1974). Summer feeding for grayling (Chang-Kue and Cameron, 1980).

Bluefish Creek - Nursery area for broad and/or round whitefish (McCart et al., 1974). Important nursery and spawning areas for grayling (Stein et al., 1974).

Jungle Ridge Creek - Important Arctic grayling and moderate longnose sucker spawning, rearing and summer feeding area (McCart et al., 1974).

Nota Creek - Major grayling spawning, rearing, summer feeding and migration route. Incidental longnose sucker summer feeding (McCart et al., 1974).

Vermilion Creek - Moderate spawning and rearing of grayling and longnose suckers near the mouth. Nursery stream to Arctic cisco, humpback whitefish, broad witefish, grayling and walleye. Summer feeding for humpback, broad and round whitefish, inconnu, grayling, longnose sucker and burbot (McCart et al., 1974). Overwintering for Arctic grayling (McCart, 1974).

Prohibition Creek - Moderate spawning and rearing for grayling. Nursery stream to humpback and/or broad whitefish. Summer feeding for these three species in addition to Arctic cisco, round whitefish, Arctic grayling and longnose suckers (McCart _et al_., 1974).

Helava Creek - Summer feeding for grayling and pike (McCart _et al_, 1974).

Francis Creek - Arctic grayling utilize the creek for spring spawning, rearing and summer feeding to a minor degree (McCart _et al_., 1974).

Canyon Creek - Spawning and rearing area for grayling. Summer feeding area for grayling and longnose suckers (McCart _et al_., 1974). Possible areas for overwintering (McCart, 1974).

Stewart Creek - Migration route for spring spawning Arctic grayling to Three Day Lake (Stein _et al_., 1973; McCart _et al_., 1974). Post-spawning migration out of the stream occurs either immeditately after spawning or following summer feeding, moving upstream into Great Bear River (Stein _et al_, 1974; Jessop and Lilley, 1975).

Bosworth Creek - The creek mouth provides minor spawning and rearing for grayling, longnose suckers and burbot (McCart _et al_., 1974). Probable overwintering grounds (McCart, 1974).

Billy Creek - Spawning, rearing and overwintering grounds for northern pike (McCart _et al_., 1974).

Oscar Creek - Suspected migration route for spring runs of Arctic grayling, northern pike, yellow walleye and longnose suckers. Spawning, rearing and summer feeding grounds present for grayling and longnose suckers. Nursery area for whitefish spp. and possible overwintering grounds (McCart _et al_., 1974; McCart, 1974). Walleye have been observed spawning in the creek in early June, some remaining there to feed during the summer then movement out occurs in early September (Jessop _et al_., 1974).

Elliot Creek - Spawning and rearing grounds present in addition to summer feeding for Arctic grayling (McCart _et al_., 1974). Potential overwintering grounds (McCart, 1974).

FISHING AREAS:

Domestic fishing occurs along the Great Bear River and in the Mackenzie mainstem near Fort Norman (Dryden _et al_., 1973; Unpublished data from MacLaren Plansearch, 1985). The main species caught include lake trout, cisco spp., whitefish spp., inconnu and grayling (DIAND/MPS, 1973) although other species including northern pike, yellow walleye, burbot and suckers are also taken (MacLaren Plansearch unpublished data, 1985). Domestic fishing occurs in the vicinity of Norman Wells for similar catches (McCart and Den Beste, 1979; DIAND/MPS, 1973). Grayling are taken at the mouth of Stewart Creek during spring and summer migrations (Jessop and Lilley, 1975).

SUMMARY OF CONCERNS:

- Primary fish resource area due to the many tributary streams which offer spawning, nursery, summer feeding and potential overwintering habitats.
- Migrations at almost all times. (Probably a major concern).
- Important domestic and sport fishing.
- Numerous islands in the channel suggest potential spawning and rearing habitats in mainstem.

MACKENZIE RIVER REACH ZONE: XIV (966 - 1017 km)

GEOGRAPHIC LOCATION: Patricia Island to San Sault Rapids and Mountain River

MAJOR TRIBUTARIES: Mountain River
Carcajou River

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Humpback whitefish	Arctic Grayling	Burbot
Broad whitefish	Northern Pike	
Round whitefish	Yellow Walleye	
Inconnu		

HABITAT USES:

Both the Mountain and Carcajou rivers carry a high silt load and likely do not provide important spawning or rearing habitat, however, potential mainstem habitats have yet to be surveyed.

FISHING AREAS:

Occurance of specific fishing sites is not known, although the reach does not lie within an area immediate to any settlements.

SUMMARY OF CONCERNS:

- Potential spawning and rearing habitat in braided sections of the mainstem.
- Migration route via the mainstem to upstream tributaries e.g. Great Bear River.

MACKENZIE RIVER REACH ZONE: XV (1017 - 1086.5 km)

GEOGRAPHIC LOCATION: San Sault Rapids and Mountain River to the Ramparts

MAJOR TRIBUTARIES:
- Hanna River
- Donnelly River
- Snafu Creek
- Hume River
- Tsintu River
- Ramparts River

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Arctic Cisco	Arctic Grayling	Burbot
Humpback Whitefish	Northern Pike	
Broad Whitefish	Yellow Walleye	
Round Whitefish	Longnose Sucker	
Inconnu		

HABITAT USES:

Hanna River - Spawning, summer feeding and suspected overwintering for Arctic grayling and northern pike. Grayling nursery river (McCart et al., 1974).

Donnelly River - Arctic grayling have been observed migrating upstream from the Mackenzie mainstem in early spring (i.e., beginning of May) and spawning in the stream in late May to early June (McCart and de Graff, 1974). Grayling have been reported to move out of the Donnelly River following spawning and upstream into the Great Bear River (Jessop et al., 1974). Primary spawning and nursery areas for grayling and longnose suckers and probable fall spawning in lower reaches near mouth for round whitefish and inconnu. Pike spawning occurs upstream in the Chick Lake outlet (McCart et al., 1974).

Snafu Creek - Spawning and rearing for Arctic grayling, northern pike and longnose suckers occurs in the stream (McCart et al., 1974).

Tsintu River - Spawning and rearing stream for Arctic grayling, northern pike, yellow walleye and longnose suckers (McCart et al., 1974).

FISHING AREAS:

SUMMARY OF CONCERNS:

- Fishing areas not identified.
- Movement of spring spawning species between the mainstem and tributary streams. Probable migration of anadromous fall spawning species to upstream areas.
- Braided channel and numerous islands suggest rearing and/or spawning habitats.

MACKENZIE RIVER REACH ZONE: XVI (1086 - 1097.5 km)

GEOGRAPHIC LOCATION: The Ramparts

MAJOR TRIBUTARIES: None

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

HABITAT USES:

Mackenzie mainstem - Due to the high gradient and turbulent nature of the Ramparts, there is probably little relevant fish habitat in the area, however, it is potentially utilized by most major species as a migration route.

FISHING AREAS:

SUMMARY OF CONCERNS:

- Migrations.
- Possible fishing for Fort Good Hope residents.

MACKENZIE RIVER REACH ZONE: XVII (1097.5 - 1261 km)

GEOGRAPHIC LOCATION: North end of Ramparts to north of Little Chicago

MAJOR TRIBUTARIES:
Hare Indian River
Loon River
Tieda River
Ontaratue River
Payne Creek

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Lake Trout	Arctic Grayling	Burbot
Arctic Cisco	Northern Pike	
Least Cisco	Yellow Walleye	
Humpback Whitefish	Longnose Sucker	
Broad Whitefish		
Round Whitefish		
Inconnu		

HABITAT USES:

Hare Indian River - Spawning and nursery areas are present of Arctic grayling and longnose suckers. The river is also serves as a migrating route, summer feeding location and overwintering grounds (McCart et al., 1974).

Loon River - Arctic grayling, northern pike and longnose suckers spawn and rear in the river and it is suspected that whitefish and cisco spp. do as well (McCart et al., 1974). Possible overwintering grounds (McCart, 1974).

Tieda River - Arctic grayling and longnose suckers utilize spawning and rearing areas present in the river. Summer feeders include broad and round whitefish, northern pike and longnose suckers (McCart et al., 1974). No overwintering potential (McCart, 1974).

Payne Creek - Spawning and rearing habitat for grayling (McCart et al., 1974).

FISHING AREAS:

Whitefish spp., cisco spp., inconnu and lake trout are domestically fished near Fort Good Hope (McCart and Den Beste, 1979), in particular, at the mouth of the Hare Indian River during the summer and occasionally during winter (Jessop and Lilley, 1975).

SUMMARY OF CONCERNS:

- Domestic fishery for the Fort Good Hope residents.
- Potential spawning and/or rearing habitat in mainstem due to the presence of many islands in the channel. No past surveys.
- Migration timing of spring and fall spawners.

MACKENZIE RIVER REACH ZONE: XVIII (1261 - 1437.9 km)

GEOGRAPHIC LOCATION: North of Little Chicago to Lower Ramparts

MAJOR TRIBUTARIES: Thunder River
Travaillant River
Tree River
Rabbit Hay River

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Lake Trout	Arctic Grayling
Humpback Whitefish	Northern Pike
Broad Whitefish	Yellow Walleye
Round Whitefish	Longnose Sucker

HABITAT USES:

Thunder River - Spawning runs to headwater lakes and nursery areas are present for broad and round whitefish, lake trout and grayling (McCart *et al*., 1974).

Travaillant River - Spawning and rearing areas for longnose suckers occur in the river and possible grayling spawners (McCart *et al*., 1974). Conditions are suitable for overwintering in the river (McCart, 1974).

Tree River - The river supports a good run of Arctic grayling in the clear water (Hatfield *et al*. 1972a).

FISHING AREAS:

Domestic fishing for whitefish and cisco spp., Arctic char, northern pike and suckers occurs upstream of Arctic Red River near the Tree and Thunder rivers (McCart and Den Beste, 1979; DIAND/MPS, 1973).

SUMMARY OF CONCERNS:

- Primary fish migration route.
- Domestic fishery.
- Braided nature of the channel suggests potential spawning and/or rearing habitats.

MACKENZIE RIVER REACH ZONE: XIX (1437.9 - 1475 km)

GEOGRAPHIC LOCATION: Lower Ramparts to Point Separation

MAJOR TRIBUTARIES: Arctic Red River

MAJOR SPECIES PRESENT: Fall, spring and winter spawners grouped, respectively.

Arctic Char	Arctic Grayling	Burbot
Lake Trout	Northern Pike	
Arctic Cisco	Yellow Walleye	
Least Cisco	Longnose Sucker	
Humpback Whitefish		
Broad Whitefish		
Round Whitefish		
Inconnu		

HABITAT USES:

Mackenzie mainstem - Broad and humpback whitefish appear to spawn in back eddies of the Mackenzie River near Arctic Red River in early October (Stein *et al*., 1973). Broad whitefish are thought to be more abundant than humpback whitefish in the Delta area (Stein *et al*., 1973; Jessop and Lilley, 1975). Emigration of pike juveniles from tributary streams in the Arctic Red River area has been observed mid-June to early July (Jessop *et al*., 1974).

Arctic Red River - This system drains a number of tributary streams and large populations of many species occur between the Mackenzie River delta (Aklavik) and the Arctic Red River area (Jessop and Lilley, 1975). Probable broad and humpback whitefish spawning occurs at the river mouth from late October to early November (Jessop *et al*., 1974).

FISHING AREAS:

Intense fishing for whitefish spp., cisco spp., Arctic char, northern pike and suckers occurs in the Arctic Red River area by local residents for domestic purposes (McCart and Den Beste, 1979; DIAND/MPS, 1979).

SUMMARY OF CONCERNS:

- Major migratory path for large populations of fish present in the Mackenzie Delta, Arctic Red River and Mackenzie mainstem.
- Some spawning documented in the mainstem.
- Important domestic fishing grounds.

APPENDIX C
ACKNOWLEDGEMENTS

C.1 PROJECT TEAM

Several specialist subconsultants were involved in addressing various aspects of the study. These included the following:

a) ESL Environmental Sciences Ltd., Sidney, British Columbia: responsible for identification of environmental issues relating to dredging in the river, including fisheries, water-quality and hydrology.
b) GVM Geological Consultants Ltd., Calgary, Alberta: assisted EBA with the evaluation of conventional borrow sources, the development of the geologic model to describe the location and distribution of alluvial materials, and the classification of the potential of various reaches of the river
c) Hydrocon Engineering (Continental) Ltd., Calgary, Alberta: assisted EBA and ESL with the evaluation of the hydrologic regime of various reaches of the river, and the assessment of the sediment transport characteristics of the river

At EBA, Mr. N.R. MacLeod was the project manager and prepared the section pertaining to Norman Wells. Mr. A.F. Stirbys contributed significantly to the evaluation of upland borrow resources and economic considerations. Several others including Mr. T.E. Hoeve, from EBA's Calgary office and Mr. B.A. Brown from EBA's Edmonton office also particiapted in the technical aspects of the project.

C.2 ACKNOWLEDGEMENTS

In completing this assignment many people representing a number of private and government agencies have been contacted to provide data, knowledge or advice. Their assistance has been appreciated. Some of the major contributors are listed below.

ESSO Resources Canada Ltd.:	Ron Tibbatts, Steve Hunter, Cathy Nelson, Sanjay Shinde, David James, Cal Sikstrom
Indian and Northern Affairs Canada:	Gerry Kowalchuk, Nick Galan
IPL Pipelines Ltd.:	William Pierce
PeBen Construction:	Charles Ivan, Gene Carson
Institute of Sedimentary And Petroleum Geology:	Owen Hughes
Transport Canada:	Elmer Shultz
Public Works Canada:	Carl Urtech, Harry Jacobs, Bob Smith, John Piard
Geoterrex:	Rick Quinn
Beaver Dredging (Canada) Ltd:	John Waring
Western Ecological Services Ltd.:	Everett Peterson
Mike Miles and Associates Ltd.:	Mike Miles
Freshwater Institute:	J. Stien
Government Northwest Territories:	Sandy Murray, Jim Bentley, Peter Morris
Northern Transportation Company:	Ken Simpson
Gulf Canada Corporation Ltd.:	Dave Watson, Dave Townsend
Canadian Coast Guard:	Ozzie Isfeld