TUKTOYAKTUK N.W.T.

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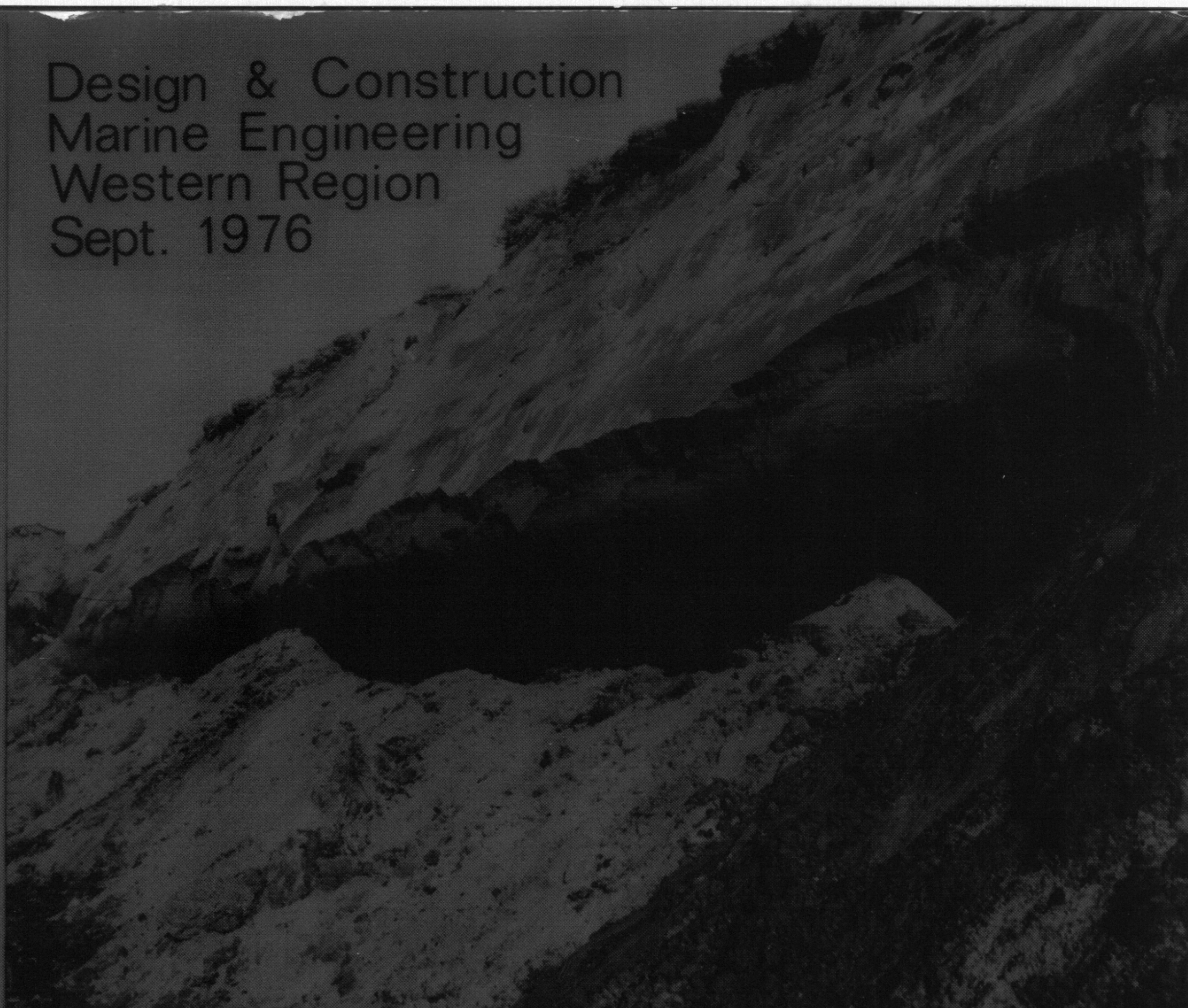

SHORE EROSION and PROTECTION STUDY

STAGE 2 REPORT

VOLUME I

Public Works Canada   Travaux Publics Canada

REPORT NO. 41

TITLE:

Shore Erosion and Protection Study - Stage 2
Tuktoyaktuk, N.W.T.

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ABSTRACT

The report reviews the morphology of the Tuktoyaktuk coastline and recommends actions that may be taken to protect the coastline against shore erosion.

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TERMS OF REFERENCE

Mr. S.M. Hodgson, Commissioner of the N.W.T. by letter of February 21, 1972 requested that Public Works Canada carry out a detailed engineering investigation on behalf of the Government of the N.W.T. to determine the most effective and economical way of combating the erosion of the seashore in the vicinity of the existing school at Tuktoyaktuk.

Assistant Commissioner C.W. Gilchrist by letter of July 14, 1972 advised Public Works to extend the site investigation to include the west seashore of the Tuktoyaktuk peninsula.

The Phase I report of April 18, 1973 to Commissioner S.M. Hodgson recommended in part that the more intensive site investigation be extended to include Tuktoyaktuk Island.

Assistant Commissioner E. Cotterill by letter of March 28, 1974 approved funding in the amount of $52,000 for a Phase II report.

In accordance with the recommendations of Phase I report, the field work carried out under this report included the Tuktoyaktuk Settlement Peninsula and Tuktoyaktuk Island.

Shore Erosion and Protection Study
Tuktoyaktuk, N.W.T.
Stage 2 Report

Background

This report has been prepared to discuss the causes of erosion occurring at Tuktoyaktuk, N.W.T. and to recommend solutions for preventing further degradation of upland property affected by the erosion.

A large natural harbour exists at Tuktoyaktuk. The harbour is protected by a peninsula and a large island. The shorelines of both the Peninsula and the island have been receding at substantial rates. Tuktoyaktuk Island is not inhabited and the shore erosion occurring there is not of immediate concern. A settlement exists on Tuktoyaktuk Peninsula and certain important buildings, among them a school, ice rink and certain other buildings located there require protection without delay.

Because of the seriousness of the threat posed by shore erosion occurring at Tuktoyaktuk Peninsula the Government of the North West Territories requested the Department in early 1972 to study the problem and make recommendations on measures it may take to safeguard the Peninsula against erosion, (see Terms of Reference).

The Department commenced the study in May 1972 and carried out literature research of available reports of studies and investigations pertinent to the subject, data acquisition of available data, consultations with specialists on topics involved in the study, limited topographical and sounding surveys and model testing of certain experimental solutions. The analysis of the information and material collected indicated that considerable further work was required to understand the causes of erosion occurring at Tuktoyaktuk and to recommend solutions for protecting the area against further erosion. The report prepared incorporating the findings and recommendations was submitted in April 1973.

Details of the April 1973 report are presented in Appendix A. Essentially, the following two actions were proposed in the report:

(1) Provision of experimental protection works at three sections of Tuktoyaktuk Peninsula at an estimated cost of approximately $530,000.

(2) A stage 2 study including certain field work to obtain information on soil stratification, thermal stability, topography and bathymetry of the coastal zone at an estimated cost of $52,000.

The Government of the North West Territories reviewed the report and made provisions for $152,000 to install certain limited protection works at the school building and to carry out the stage 2 study as recommended in the report.

The design of the test shore protection works recommended in the March 1973 report involved construction of flexible sea-walls and groins using certain patented steel wire gabions. This design was based on several assumptions. It was assumed that the materials required to fill the gabions would be available locally and that labour needed to carry out the work could be obtained from within the area. Subsequent investigations suggested that neither of these two conditions could be met. Various enquiries were therefore made to devise an alternative solution. A product known as the "Longard" tubes was at that time coming into the North American market. The "Longard" tubes which are sausage shaped merely require sand to fill them and had been found to be functioning well in Europe and in certain ice environments. The use of the "Longard" tubes as shore protection work units showed good possibilities and a decision was made to proceed with the test program using these in place of gabions. The materials required were ordered and received for installation during the summer of 1975. Owing to certain difficulties encountered in obtaining sorted sand in time the implementation of the program, however, was postponed to 1976.

The overall estimated cost of this test construction program is now $152,000.

The stage 2 study program was put underway as soon as the Government of the North West Territories advised the Department in March 1974 to proceed with the program. The necessary field work, documentation of the field work, consultations and analyses of the data and information acquired have now been completed and reported in this report.

The report is divided in two volumes. Volume 1 has been compiled to provide the findings and recommendations of the study. The supporting documents of the study are provided as appendices in Volume 2.

Shore Erosion and Protection Study

Tuktoyaktuk, N.W.T.

Stage 2 Report

1. Introduction

Tuktoyaktuk is located on the eastern side of Kugmallit Bay in the Western Arctic at north latitude of 69° 27' and west longitude of 133° 02'. It is approximately 90 miles north of Inuvik and 1450 miles northwest of Edmonton (figure 1). The area is mainly comprised of a long, narrow, boot-shaped peninsula oriented in approximately north-south direction, a complex lagoon, which has been developed as a harbour, east of the peninsula and an island straddling the mouth of the lagoon (see figure 2). Certain dwellings exist at the southern and southeasterly shores of Tuktoyaktuk Harbour. A large majority of the inhabitants reside in a settlement developed on the peninsula. Tuktoyaktuk is used as a transfer point, linking the Mackenzie River barge transport with coastwise shipping serving the western arctic seaboard and inland settlements and bases. As a result of this the TUK settlement has grown to be the largest of the western arctic coast settlements.

The Tuktoyaktuk shores have been receding at considerable rates and several buildings, among them a school, curling rink and certain other buildings located on the peninsula, are in need of immediate protection. Certain shore protection works were constructed at the peninsula but they were found to be inadequate and the erosion there has remained unchecked. This study was therefore undertaken to determine the exact nature of the erosion occurring at Tuktoyaktuk and ways in which it could be arrested.

2. Topography

Tuktoyaktuk is generally flat. Its shoreline is demarcated by steep cliffs. The Tuktoyaktuk peninsula is approximately 4,400 feet long and 1,400 feet to 300 feet wide. It is 5 to 25 feet above the sea level and covers an area of approximately 16 acres. The Tuktoyaktuk Island is approximately one mile long, and, on an average 600 feet wide. The island is characterized by its flat top which is approximately 30 feet above the sea level and cliffs steeply plunging to the sea. The harbour runs inland in a southwesterly direction and is approximately 7 miles long. The terrain around the harbour is flat and contains numerous lakes. The topographical survey data and maps prepared under the study are given in Appendix "B".

3. Bathymetry

Generally, the Tuktoyaktuk shore dips relatively very gently. The depth of water one mile away from the shoreline is only 12 to 13 feet. The depth contours are however highly rugged showing ridge, valley, plateau and intricately shaped sand bar type formations, particularly offshore of the 3 feet depth contour. The depth contours from 0 to 3 feet are generally parallel to the shoreline. Details of the hydrographic survey carried out and charts produced in the course of the study are included in Appendix "C".

4. Climate

General

The Tuktoyaktuk region lies within the sub-arctic lowland. It has 8 months of winter and 2 months of summer, separated by one month of spring and one month of fall. In the summer there is daylight round the clock. The winter time is marked by darkness (see figure 3A). The mean winter temperature is about -20^{O}F and that of the summer, 40^{O}F. In the extreme the temperatures can drop to -50^{O}F in the winter and rise to 80^{O}F in the summer. The freeze-up occurs at around the beginning of October. The ice break-up takes place at around the third week of June. Because of the low capacity of cold air for water vapour the precipitation in the Tuk region, like most arctic areas, is low. Drawing 3B shows some typical precipitation graphs. Details of the TUK climate are given in appendix D. Certain aspects of the TUK climate that influence the shore regime are discussed below in general terms.

Air Temperatures

Because of low temperatures and absence of wave action little or no littoral movement can be expected to occur during the ice covered periods of the year. We are therefore more concerned with the time when the ice is no longer restricting wave action and when the coast becomes subject to wave and thermal action, when any littoral activity can occur.

Figure 3C shows air temperature profiles of the Tuk atmosphere. The figure suggests that generally the above freezing temperature regime occurs from about mid June to mid October. In the extreme this period can be as short as 6 weeks and as long as 6 months.

In cold years, therefore, relatively little littoral activity can be expected to occur, other things, such as storm activity, being equal. In warm years comparatively more intensified littoral motion can exist.

The air temperature profiles generally suggest the active period, coastal activity wise, to be approximately 4 months.

Wind Climate

Full wind data of Tuktoyaktuk, required to predict the wave climate affecting the area, were not readily available when this study was begun. Information on winds of Inuvik and Sachs Harbour which was available at the time was therefore obtained (figure 4A). A review of the wind data suggested that for predicting the TUK wave climate winds recorded at Sachs Harbour were more appropriate and these data were therefore used to assess the TUK wave climate.

Figure 4A shows that the predominant directions of the Sachs Harbour winds are northwest and southeast. The percentage exceedances of 25 mph and higher winds are low. This suggests that generally very few storms occur at Tuktoyaktuk.

Figure 4B shows extreme winds using Sachs Harbour winds as basic data for prediction of extreme winds that can be expected to occur at Tuktoyaktuk. Figure 4B shows that the return periods of storm winds such as 40 mph and higher winds is approximately 3 years. This indicates that while on an average few storms occur at TUK high storm activity can take place in certain years. Heavy and more frequent storm activity has been noticed in the last 3 years.

Wave Climate

Tuktoyaktuk, because of its location in Kugmallit Bay, is generally well protected from wave action, except in very heavy storm conditions. Fetch lengths within the Kugmallity Bay, for example, the fetch in the west direction, are small. Consequently, the waves from within the bay would be comparatively small. The Kugmallit Bay is generally shallow and its depth contours are highly irregular. Waves from Beaufort Sea reaching Tuktoyaktuk would, therefore, undergo considerable shoaling and refraction and would also be relatively small, except at high storm water levels when higher waves can penetrate into the area.

Figures 5 and 6 show the wave climate derived from the wind climate. Figure 5 shows a wave period histogram and a percentage exceedance diagram of wave heights after shoaling and refraction. The wave period histogram shows the waves to be mainly 3 to 6 second waves. The wave height graph shows that ninety percent of the waves are smaller than 3 feet in height. The maximum wave that can exist at Tuktoyaktuk is an 8 foot wave. The wind data show the high wave activity to be from the north and northwest. However, because of refraction, the wave attack on the shore would be more or less frontal. Figure 6 shows the wave breaking and plunge points of waves at different water levels with respect to distance from the 0 foot contour towards the shore. The figure suggests that the TUK coastline is susceptible to wave attack mainly at high water levels.

Water Levels

The water levels at Tuktoyaktuk are mainly influenced by tides and storm surges. The tidal fluctuations are generally small. The storm surges or set-ups at Tuktoyaktuk are comparatively large.

The tides of Tuktoyaktuk are of the mixed semi-diurnal type. Their ranges are relatively small. The mean sea level at Tuktoyaktuk is at an elevation of 1.4' above the chart datum. The higher high waters for large and mean tides, referred to the chart datum are + 2.3' and + 1.9' respectively and the low waters for large and mean tides are 0.9' and 0.6' respectively.

High storm levels occur occasionally at Tuktoyaktuk. Strong storm winds from the west to north would tend to raise the water level at Tuktoyaktuk while easterly winds would depress the water surface. Wind set-ups of 6 to 7' and wind draw-downs of approximately 3' have been noted to occur at Tuktoyaktuk.

Approximate return periods of extreme storm water levels were estimated using data on storm water level occurrences obtained from available references and available tidal and wind records and the results are shown in figure 7. Figure 7 suggests that the TUK water levels rise to the coastal elevation only once in every two to three year time period.

Currents

Little or no published information is available on currents occurring at Tuktoyaktuk. Measurements were therefore carried out to obtain the information. Three locations were selected to make the current measurements. These were: (1) the south side of the peninsula, (2) the north side of the peninsula and (3) an area close to the western entrance of the harbour. Winds and tides were also measured simultaneously with currents.

The records of currents, winds and tides were analyzed several ways. The currents data are shown on figures 8 to 10. The drawings indicate that generally the currents are weak, ranging from 0 to 0.5 knots. They appear to be mainly wind induced. The tidal currents can be considered to be negligible. In accordance with the directions of the winds, the predominant directions of the currents are to the south and east. At the harbour entrance the currents are considerably influenced by the exchange of water between the harbour and the sea and their directions at this location are irregular. No records of currents occurring in the area during storms are available. The magnitude of currents occurring during storm conditions can be expected to be higher than those shown by the above drawings.

The instrumentation and data recording of the above measurements and their analysis was carried out for DPW by the Canadian Hydrographic Service.

5. Coastal Geomorphology

General

The coast of Tuktoyaktuk area can be described as a shallow, embayed and receding coast. It is generally flat and contains narrow beaches and steep cliffs. The area is mostly underlain by fluvial sands and silts and fine grained deltaic sands. These deposits are capped by a thin layer of a mixture of sands, peat, lacustrine deposits, gravel and clayey till like deposits. The subsurface includes permafrost and lenses and sheets of massive ice.

An extensive program of water salinity measurement test boring and laboratory analysis and measurement of subsurface temperatures was carried out. The details are presented in Appendix "E". Major highlights of the findings are discussed here.

Water Salinity

To estimate the corrosive power of the environment, salinities were measured at various locations in the sea. The measurements were carried out for this study by the Department of Energy, Mines and Resources. The results are shown in figure 11. As the drawing shows, the sea contains an extensive layer of fresh water floating on the salt water. The thickness of the freshwater layer varies depending on the occurrence of ice. Because of the existence of fresh water, little or no accelerated corrosion should result from the sea environment. Also the water can be utilized, if required, for construction.

Test Bore Results

About 44 boreholes were drilled to a depth of approximately 30 ft. except one which was extended to approximately 100 ft. 34 of these were located at the TUK peninsula. The remaining 10 bore holes were made at the TUK Island. Soil samples retrieved from the test boring were analysed in the laboratory. The laboratory analysis included soil description, description of subsurface ice, water content of soil and impure ice and grain size analysis. The borehole locations and their logs are shown on drawing 12.

The analysis indicates that generally the subsurface shown by the boreholes can be divided into two zones. These are: (1) an active zone which is frozen in the winter and thaws out in the summer and (2) a permanently frozen zone below the active zone. The active zone consists of sands, silts and gravel, in places covered by peat or organic material. In areas where there is a cover of peat the thickness of the active zone as measured was small, varying from 1 to 2 feet. In the inorganic soils, the thicknesses of the active zones measured were relatively large. The permanently frozen zone consists of layers of sands, silts and gravel together with ice crystals, lenses of ice and sheets of massive ice. The thickness of the permafrost zone was not determined. It is, however, known to straddle the sea level.

Figure 13 shows three coastal profiles of the TUK peninsula. The underwater soil is similar to that of the land area. The depth to permafrost and ice, however, increases rapidly with the depth of water. It was not possible to extend the test boring to the submerged area. However, it would be reasonably safe to assume that the ice layer disappears at approximately the 6 ft. contour. The cover over the permafrost and ice at the junction of the beach and land, and at the beach, is relatively thin.

Subsurface Temperature Profiles

To determine the adequacy of the covering layer over the permafrost and ice and to investigate the vulnerability of the permafrost layer and ice against thermal degradation and the resulting thaw settlement, a program was undertaken to measure subsurface temperature profiles. Two locations were selected for the measurements. These were: (1) the school and (2) the R.C.M.P. Garage areas. Four strings of thermistors were installed at each of the two locations, two at the top of bank, one at the bank toe and the fourth at the waterline. Each string contained ten thermistors set at 2 ft. spacing.

The thermistor readings were taken at intervals over a period of one year and are shown plotted on drawings 14 and 15.

Drawing 14 shows the thermistor readings of the R.C.M.P. Garage area. Generally, as may be expected, the ground surface temperatures varied over a wide range from approximately -20°C in the winter to 5°C in the summer.

The temperatures at a depth of approximately 20 ft. below the groundline fluctuated over a much smaller range from approximately -10° in May to 3°C in September. At the cliff area, the ground was permanently frozen below a depth of approximately 1 to 2 feet. The depth of the permafrost table at the beach varied. At the waterline the depth of the permafrost was approximately 7.5 ft. The cover over the permafrost table at the cliff end of the beach was thinner than that can be expected.

The result of the thermistor probes installed at the school area, shown on drawing 15, were similar to those of the probes of the R.C.M.P. Garage area. The depths of the permafrost table were, however, somewhat different. The depth of the permafrost table on the land side was approximately 5.5 ft. In the beach area, the permafrost table was only 4 ft. from the ground surface.

Owing to non-availability of personnel, no readings were taken during the summertime and the above thermistor results do not cover the months of June, July and August. As the temperatures during these months would be higher, the depths of the permafrost table that can be expected would be greater than those indicated above. In addition, 1974 was a cold year and therefore the recorded permafrost table elevations can be expected to be higher than those that can be expected to occur in an average or normal year.

6. Shore Erosion

General

Aerial photographs show that the Tuktoyaktuk shoreline has been receding at dramatic rates. A comparison of aerial photographs of 1950, 1969 and 1972 made for the study by officials of the Department of Energy, Mines and Resources is shown in drawing 16. Between 1950 and 1972, the coastline of the settlement peninsula receded some 130 feet. A recession of similar magnitude occurred at the TUK Island. The adjacent coastlines on either side of TUK receded at similarly high rates varying from 60 ft. to 850 ft. in the same period of time.

There are two major causes of the erosion occurring at TUK. In the warm regions of the world the usual cause of erosion is the physical force of the waves. In the arctics where ice rich soils and massive ice within the soil abound, thawing caused by the warmer temperatures in the summer and warmer sea water can be a major cause of shore recession and an accelerating factor in shore erosion. Both of these phenomena appear to affect the Tuktoyaktuk coast.

Erosion by Wave Forces

The erosion of Tuktoyaktuk shores, attributable to the physical forces of waves, can be seen to be taking place in two distinct ways depending upon the shore topography. In places where high cliffs exist, the cliffs are degraded by undermining and removal of slices from them (see figure 17). In areas where dunes occur, the dunes are shifted shoreward in varying alignments depending upon the direction of storms, (see figure 18). The importance of these two shore erosion factors compared with the factors of thermal erosion discussed in the following section, cannot however be precisely established.

The material removed from the cliffs and beaches at TUK can be deposited either in the offshore areas or transported away alongshore, depending upon the size of material and wave induced and other currents. The bathymetry of the Kugmallit Bay is highly irregular and it appears unlikely that any large amount of siltation is occurring there. A large majority of the material removed from the shores would therefore seem to be transported away along the shores and deposited at obstructions occurring at the shores. Various methods exist to estimate longshore transports. A recently published method known as the wave energy flux method is used here to evaluate the erosion caused by the physical forces of waves at TUK.

Wave energy flux is the rate at which wave energy is transmitted across a plane of unit width perpendicular to the direction of wave advance. This has been related to the longshore transport empirically with data obtained from several locations. The following transport rates were obtained for the TUK coast using the wave energy flux method:

Southward	42,000 cu.yd. per annum
Northward	2,000 cu.yd. per annum
Net Southward	40,000 cu.yd. per annum

The above are adjusted quantities based on the ice free period of the year applicable to TUK. The energy flux method has been related to transport rates of sands. Since the beach material at TUK contains gravel and as greater energy is required to move gravel than is needed to move sand, the above values may be viewed as the upper limits of sediment transport that can occur at Tuktoyaktuk.

The transport rates calculated above are comparatively very small and do not reconcile with the large coastal recession rates of TUK given by the aerial photographs.

Thermal Erosion

Thermal action is considered to be the major contributory cause of the coastal recession occurring at Tuktoyaktuk. There are two ways in which the thermal action is affecting the TUK coast. These are: (1) the melting of the ice present in the coastal land by warm water waves at high storm water levels and (2) thawing of the permafrost and ice contained in the beach and underwater soils, by the warm summer environment.

Figure 19 illustrates the effects of the warm water waves on the coastal land at Tuktoyaktuk. The massive ice and ice rich soil of the coastal land straddle the sea water level and have little material to insulate them against the thermal action by waves at high water levels. As the waves impinge on the coastal land the thin veneer of material that may be present is removed and the ice and permafrost are brought in direct contact with the warm sea water. Certain melting of the frozen water occurs and when sufficient quantity of water has been removed the overburden loses the support and collapses to form a new thin layer of insulation in place of the preceding layer removed by wave action. This process of removal of insulation by waves, thermal action on the ice and permafrost, collapse of the overburden where this exists and the resulting encroachment of the sea on the land affecting TUK is a recurring process depending on the frequency, duration and magnitude of storms and the warm temperatures.

In soils containing excess ice, a significant settlement can be expected to take place upon thawing of the ice. In the frozen state, the frozen soils contain the solid soil particles, ice, in certain cases super cooled but unfrozen water and air. Upon thawing, the ice would be melted to water which would drain out from the soil mass. The volume of the soil mass would be reduced accordingly and settlement would result.

The Tuktoyaktuk soil mass not only contains excess ice but also massive ice. Large settlements can, therefore, occur there upon thawing of the ice.

The amount of settlement that occurs on thawing is dependent upon the in situ dry weight of the soil and the final void ratio, or porosity, after completion of thawing and consolidation. The in situ dry weight of the soil, before thawing has taken place, is to a large extent governed by the ratio of ice content to the total volume. The final void ratio is dependent upon the type and grain size distribution of the soil and the overburden weight which is applied to the soil mass. The amount of settlement that can be expected after thawing has occurred can be estimated by the following expression which gives excess ice content as a ratio of the volume of excess ice to the original volume of soil mass including excess ice.

$$E_x = 1 - \frac{1 + W\,G}{1 + 1.09\,W_i\,G}$$

where

E_x = Volume of excess ice divided by the original volume of frozen soil mass including excess ice.

W = Ratio of the weight of moisture remaining after thawing and drainage of excess moisture have taken place to the weight of the dry solids in the soil mass.

W_i = Ratio of the weight of the original mass of moisture contained in the soil as frozen or unfrozen water and excess ice to the weight of the dry solids in the soil mass.

G = Specific gravity of the solids in the soil mass usually assumed to be 2.7.

The factor 1.09 appearing in the expression is the value by which the volume of ice is greater than the volume of water obtained by melting the ice. To obtain the settlement of a frozen soil stratum, E_x is simply multiplied by the thickness of the stratum.

Figures 20 and 21 show thaw settlements that can be expected at the locations of certain bore holes at the TUK settlement peninsula and the island, usng the above expression. The ordinates show the depth from the ground level. The abscissae give the settlement. For example, using Bore Hole 11 data, should thawing occur to a depth of 12 feet, a settlement of approximately 7 ft. would result at that location. Generally, the diagrams show the occurrence of excess ice to be close to the ground surface. The cover layer with excess ice varies from 2 feet to 16 feet. Where the cover layer is small, considerable settlement can be expected depending upon the penetration of thaw.

The depth to which thaw can penetrate depends upon the magnitude and occurrence of above freezing temperatures and thermal conductivity of the covering layer above the soil mass containing the excess ice. There are many methods available to calculate penetration of thaw.

One method which is based on a degree-day concept and widely used, particularly for approximate calculations, is utilized here to estimate the depth to which thaw can penetrate at TUK. The following formula is used to calculate the depth of penetration of thaw:

$$X = \lambda . \sqrt{\frac{48\,k}{\gamma_d \frac{W}{100} L_s} TI}$$

Where,

- X = Thaw depth in feet
- λ = Non dimensional coefficient (0.75 for TUK)
- k = Thermal conductivity of material in BTU/ft. hour $^{\circ}F$
- γ_d = Dry density of material in lbs/cft
- L_s = Latent heat of fusion of water in BTU/lb (144 BTU/lb)
- W = Percent moisture content
- TI = Thawing index or degree days above freezing.

Using average values of $\lambda = 0.75$, $k = 1.6$, $TI = 1,500$, $\gamma_d = 125$, $W = 10$ and $L_s = 144$ the depth to which thaw can be expected to penetrate at Tuktoyaktuk, in an average year, is 6 feet. In a cold year this depth would be smaller.

Conversely in a warm year, the depth of thaw penetration would be greater. Because of good insulating characteristics of peat moss, where this material exists as a cover layer, the thaw penetration would be smaller. In the beach areas of TUK which consist of sand and gravel, thaw can penetrate more easily and its depth of penetration could be greater.

The TUK beach areas have a thinner cover layer over the permafrost and ice table than required for its stability. Thawing of permafrost and ice can therefore be expected to occur in the beach areas and because of excess ice content, thaw settlement can be expected to take place.

As the beach is depressed by thaw settlement, the height of water over it in storm conditions would be greater. Because of the greater height of water, the permafrost and ice table would be depressed further, causing additional thaw settlement. The new depth of water at the beach would provide access to larger waves and erosion of the coast would be intensified.

Summary of Shore Erosion

Historical data show that the shoreline erosion occurring at TUK has been going on for a long time. The information also shows that the erosion occurring at Tuktoyaktuk is not limited to the usual erosion encountered in the warmer environment, where the physical force of waves is the main factor causing erosion. Considerable areas of the immediate subsurface of Tuktoyaktuk, and, of many of the Arctic coasts, contain ice and ice rich soils and the above freezing temperatures of the summer environment coupled with storm action render the TUK coast liable to thermal action of waves and the warm summer environment.

A generalized review of the littoral, morphological and thermal processes present at Tuktoyaktuk is shown on drawing 22. The drawing shows a cross-sectional view of the TUK peninsula and the various processes influencing the peninsula and the adjoining areas of the peninsula. Because of preponderence of waves from the north, the TUK coasts are subject to littoral transport from the north to south. As the drawing shows, the subsurface of TUK contains ice and permafrost. The ice and permafrost layer straddle the sea level. The thickness of the insulating cover occurring over the ice and ice rich strata is not adequate to protect them from solar heat and wave action and as a result, thawing and undermining of cliffs by warm water waves also occur, together with the depletion of littoral by the physical forces of waves and currents. An analysis suggests the littoral transport to be small. The main causes of erosion occurring at TUK are considered to be related to the instability of the TUK coasts against thermal action.

Short term rates at which the TUK coastline is receding are relatively high. Between 1969 and 1972 some parts of the TUK coasts receded as much as 60 feet. The long term erosion rates are, however, smaller, indicating that much of the erosion occurring at TUK takes place during storm conditions.

7. Protection Works

There are no precedents of shore protection works in the arctic environment. Because of this and the costs of full scale protection works, the design adopted must be fully tested prior to its application on a large scale. The decision to proceed on a full scale with any design will also depend upon the cost benefit assessment of providing the protection.

Design Constraints

A primary requirement of the design is that it be of flexible type, structurally. Aside from this, Tuktoyaktuk imposes several unusual conditions on the design. The first factor requiring careful consideration is the nature of erosion occurring at Tuktoyaktuk. Secondly, construction materials, construction expertise and equipment available at Tuktoyaktuk call for careful assessment. Another parameter that requires attention in the design is the location of Tuktoyaktuk with relation to sources of men, materials and equipment. In addition, the design must take into consideration the length of construction season occurring at Tuktoyaktuk.

As discussed in the preceding section, the erosion occurring at Tuktoyaktuk is mainly as a result of an inadequate cover over the ice and permafrost present in the ground at the site. Direct solar heat and thermal action of warm water waves are the main agents that cause the erosion at Tuktoyaktuk. During normal weather conditions the water levels are low and the waves do not impinge upon the coast. In storm weather situations, high water levels occur and the beach and the coastal areas are rendered liable to direct thermal action of warm water and thermal and physical action of waves. To protect the beach and the coast from the thermal action, an insulating cover is required over the area. To abate the wave action a barrier is needed. The insulating cover and the barrier must be of flexible type to accommodate any initial and long term settlement.

Construction materials available locally are confined to sand and gravel. The materials occur in offshore regions, along the coast and inland. The locations of the offshore sources have not been surveyed. The very little information available indicates there may be patches of offshore areas containing the required quality of sand. A detailed survey is required to confirm the quality and quantity of sand available in the offshore areas. A detailed inventory is available of the sources of granular materials occurring along the coast and inland regions, made for the Department of Indian Affairs and Northern Development. Because of the threat of accelerated erosion, the removal of materials from the coastal areas is not recommended. The inventory lists several inland sources for the materials. The nearest source listed in the inventory is a gentle knoll about 600 feet by 300 feet and 25 feet high, approximately 3.5 miles southeast of Tuktoyaktuk. The source is estimated to contain approximately 100,000 cubic yards of sand and gravel. The farthest source for sand and gravel given in the inventory is a Kame field located on the northwest shore of Eskimo Lakes, about 17 miles southeast of Tuktoyaktuk. Approximately 1.5 million cubic yards of sand and gravel are estimated to exist at this source.

While there is an abundance of sand and gravel within short distances from Tuktoyaktuk there are no sites in the vicinity of the area for any rock. Experienced contractors and heavy construction equipment similarly do not exist in the area.

To obtain the required materials other than sand and gravel, construction services and equipment, one needs to look towards Inuvik and areas as far as Edmonton. The logistics are further complicated by the inaccessibility of Tuktoyaktuk by land. Because of this, all the requisites must be either transported by water or flown by air.

The timing of transporting men, materials and equipment to Tuktoyaktuk and implementing the work is of considerable essence as far as any work in Tuktoyaktuk area is concerned, for the construction season occurring in the region is relatively very short. In warm years, construction can be carried out for three to three and a half months. In cold years, the working period may only last a few weeks and a small delay can mean postponement of work until the following year.

Alternative Designs

Basically, the designs that can be formulated for Tuktoyaktuk, taking into account the conditions discussed above, can be classified as experimental or conventional.

There are two experimental solutions that appear to promise success in protecting the Tuktoyaktuk coast. These are: (1) Longard Tube System and (2) Z-Wall System.

The Longard system consists of placing of flexible, sand filled synthetic fibre tubes as seawalls and groins in varying patterns. The tubes are made in several standard sizes. The tubes more commonly used are about 40" in diameter and approximately 330 feet in length. Before filling, the tubes are first rolled out in place and pumped full of water to expel air. One end of the tube is then connected to a sand hopper equipped with a sand/water injector. The sand slurry is forced into the tube at high velocity. The sand settles in the tube. The water injected with the sand flows out through a relief valve at the opposite end of the tube.

The main attractions of the Longard System are its apparent simplicity and its low costs. The system has not been tried in the Arctic environment. A test program was therefore devised for installation at Tuktoyaktuk in 1975. Owing to certain difficulties, the program was deferred to the summer of 1976.

The plan devised to test the Longard System in the Tuktoyaktuk environment is shown on drawings 23 and 24. The plan essentially consists of two lines of defence walls and a system of groins. The areas enclosed by the walls and groins will be filled with sand to provide the required insulating layer over the beach. The seaward line of defence is located at the waterline. The main function of this line of defence will be to break the storm waves impinging upon the coast at storm water levels. This defence line will also act as a retaining wall for fill to be placed in between the walls and groins. The upshore defence line will be a double tube with fill behind the line. This upshore line of defence is located at the cliff toe and will provide protection to the cliffs. The seaward line of defence and the groins projecting into the water will be subject to ice action and should they prove to be successful the upshore defence line will be eliminated in the final design.

A concept of the final design using the Longard System is shown on drawings 25 to 30. Drawing 25 shows the protection on plan. The design essentially consists of a line of defence close to the waterline and a system of groins projecting into the water to approximately -3 elevation. Drawings 26 to 30 show cross-sections of the design of representative areas along the coast to be protected. As the drawings show, the defence line parallel to the coast is located at approximately +2 elevation. It consists of twin Longard tubes. The lower tube will be placed on gravel to facilitate drainage. The area between the tubes and the coast will be filled with granular material to provide an insulating layer over the beach required to protect it against thaw settlement and to absorb waves to stop them from attacking the coast. The seaward areas enclosed by the groins will also be similarly filled to provide protection to the underwater areas against thaw settlement.

Drawings 31 to 38 show an alternative design using a recently developed "Z" wall system. The "Z" wall system consists of embedment of "Z" shaped pre-cast reinforced concrete panels along the coast. The plan followed in the drawings is similar to that shown for the Longard System. The upshore area will be filled with granular material to provide protection to the beach and the coast. Groins have been provided to protect the underwater area of down to -3 elevation. Weep holes will be provided in the "Z" walls to permit drainage of water. The design is essentially the same as that of the Longard System except that the Longard tubes are replaced by Z wall panels for the seawall and a system of H piles and timber planks as groins in place of the Longard tube groins.

The two alternative designs discussed above using the Longard System as alternative 1 and the "Z" wall system as alternative 2 are experimental designs. Drawings 39 to 44 show a conventional design using rubble stone as alternative 3. The cross sectional profile of the rubble stone wall very much depends upon method that may be adopted to fill the upshore area. If the fill is to be imported from inland, only the seaward face of the mound would require armour stone. Should offshore sources be developed for the fill, both faces of the mound would need protection with armour stone. The drawings 34 to 44 have been prepared assuming the fill required to protect the beach and the coast will be obtained from offshore sources by dredging and pumping the material to the fill site. The location of the rubble mound line has been selected to eliminate the need for groins.

The above shore protection proposals do not cover protection works for the TUK Island. The island is vital to the harbour as a breakwater and in time the island would also need protecting.

8. COST ESTIMATES

Alternative 1 - Longard System

1.	Site Preparation	$ 50,000
2.	Longard Tubes	427,000
3.	Filter Cloth	30,000
4.	Fill	1,365,000
		$1,872,000
5.	Unforeseen 10%	187,200
6.	Engineering and Inspection	19,000
		$2,078,200

Total Say $2,100,000 (1976$)

<u>Alternative 2 - "Z" Wall System</u>

1.	Site Preparation	$ 22,000
2.	H Piles, Nuts, Bolts and Plates	103,710
3.	Timber	110,500
4.	Concrete "Z" Panels	485,100
5.	Fill	1,365,000
		$2,086,310
6.	Unforeseen 10%	208,631
7.	Engineering and Inspection	19,000
		$2,313,941

Total Say $2,350,000 (1976$)

Alternative 3 - Rubblemound

1.	Gravel Core and Armour Stone	$1,275,000
2.	Fill	1,700,000
		$2,975,000
3.	Unforeseen 10%	297,500
4.	Engineering and Inspection	19,000
		$3,291,500

Total Say $3,300,000 (1976$)

9. RECOMMENDATIONS

Subject to sociological-economic and environmental considerations by others, our first preference is for Alternative I - Longard System - at an estimated cost of $2,100,000 (1976) should the emergency test section at the school prove reliable up to October 1977

If problems develop in this test section our second preference would be Alternative 2 - "Z" Wall System - at an estimated cost of $2,350,000 (1976).

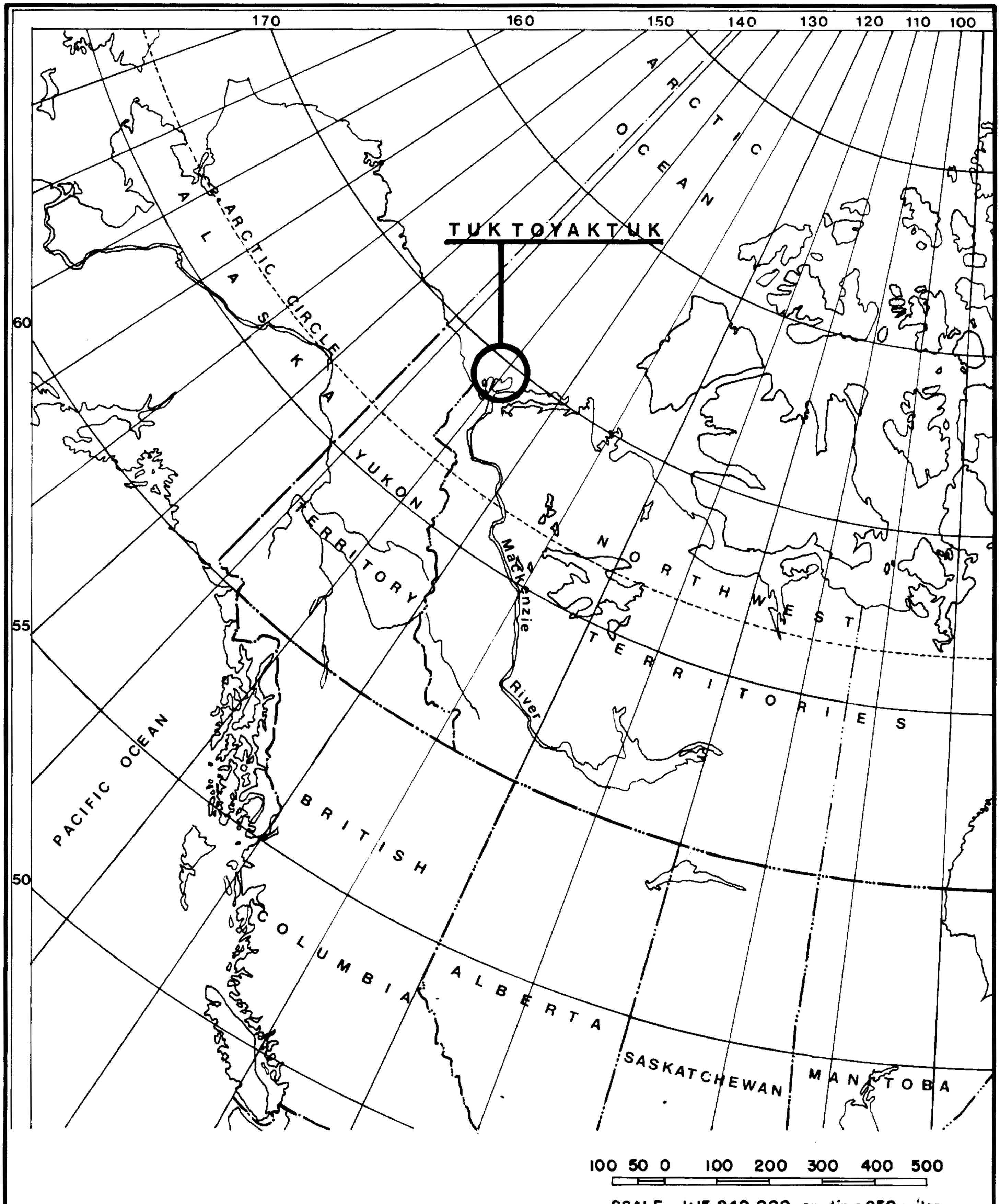
It is recommended that the whole of the settlement peninsula be protected under one project as opposed to protecting each building or length of shoreline individually under separate projects.

We also recommend that for financial planning forecasting for the project a cost estimate of $2,350,000 (1976) be used.

Should the shore protection work receive approval as recommended, it is recommended that it be coordinated with the Town Planning Group of the Municipal Government which is examining the possibility of using dredge spoil from within the harbour to build up industrial and housing area, subject to the suitability of the dredge spoil as fill required in the protection work.

No protection work is recommended for Tuktoyaktuk Island at this point in time.

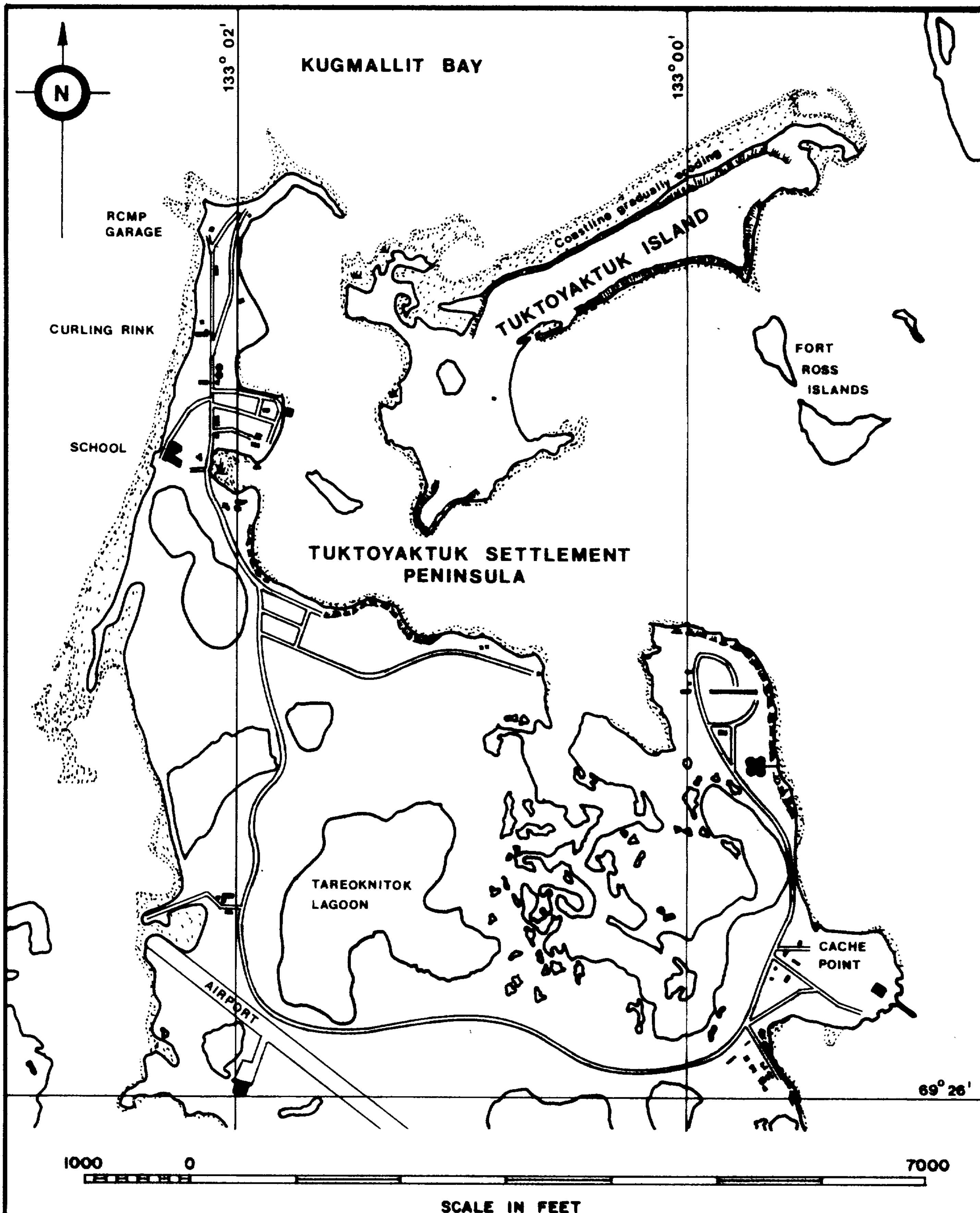
It is further recommended that a program be set up to monitor the Tuktoyaktuk shorelines on a regular basis, preferably each Spring and Fall.



SCALE 1:15,840,000 or 1in.= 250 miles

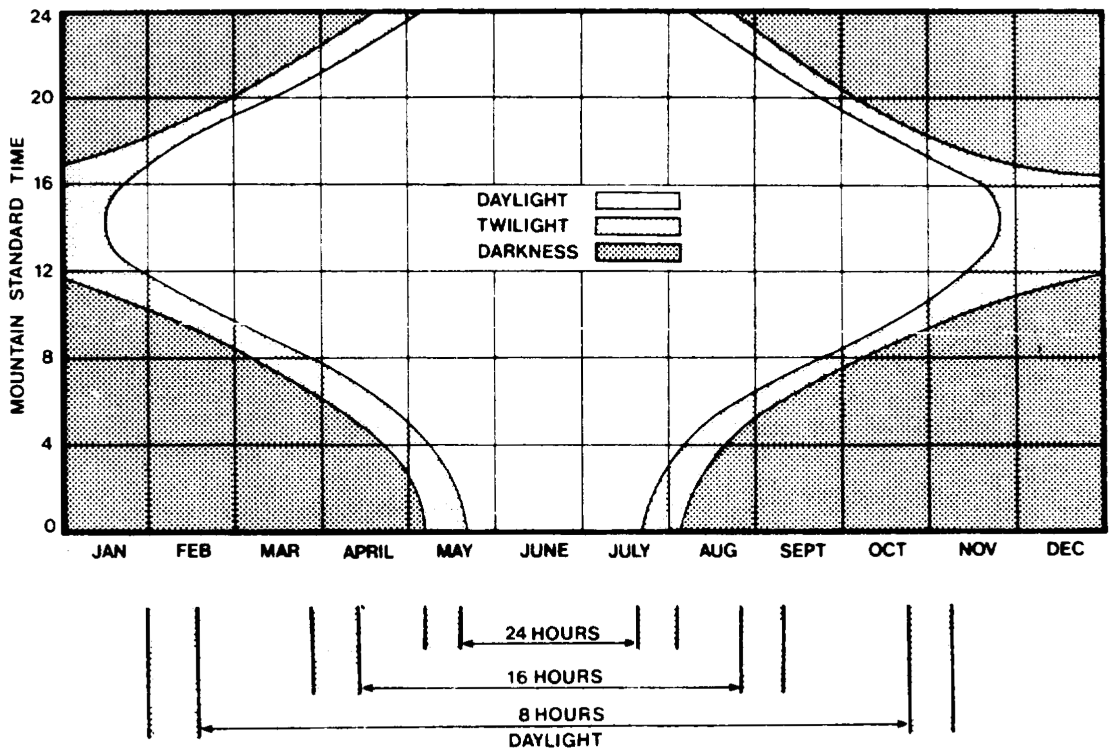
TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY
LOCATION MAP

Figure – I



TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY
SITE PLAN

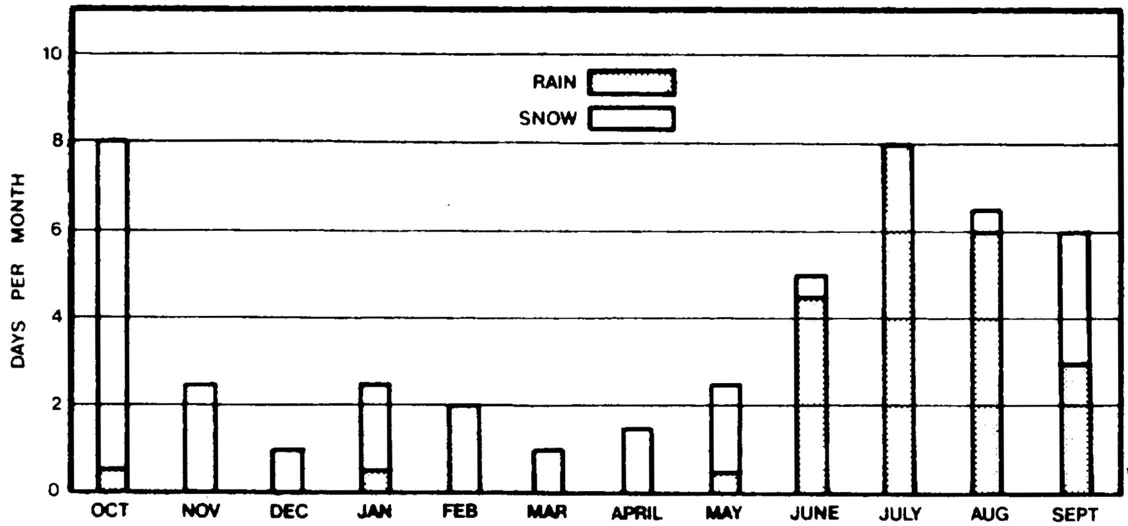
Figure — 2



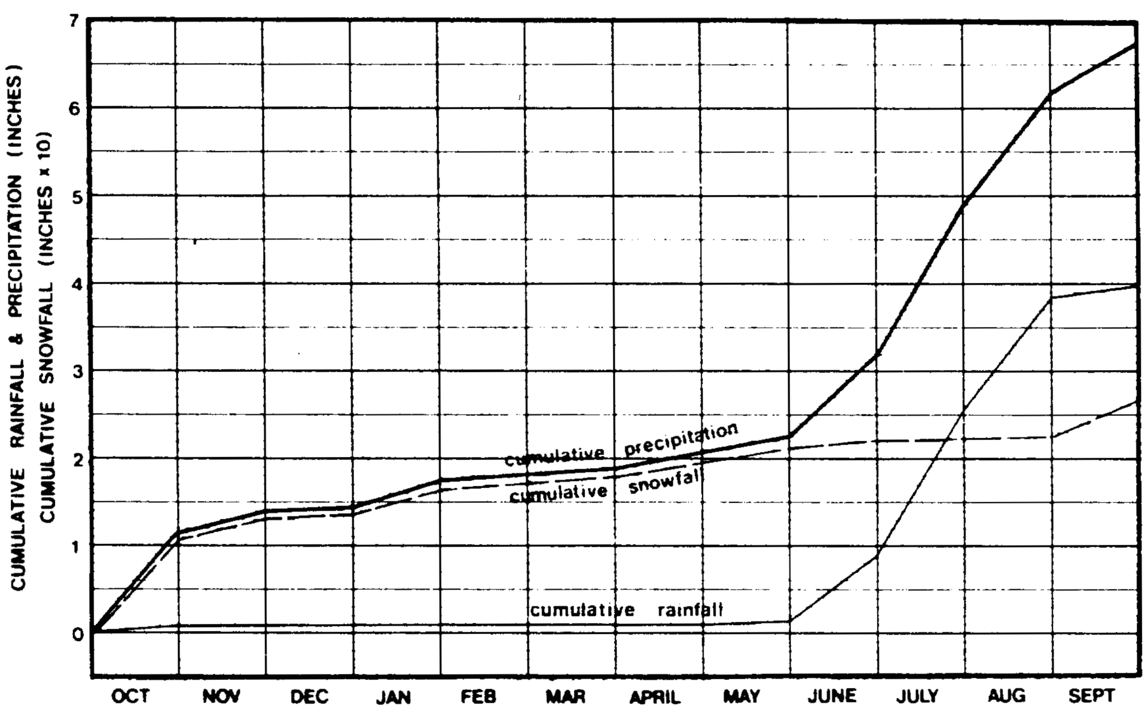
NOTE: THE TIMES SHOWN FOR THE BEGINNING & END OF TWILIGHT ARE CIVIL, FOR WHICH THE SUN'S ZENITH DISTANCE IS 96°. THE DEGREE OF ILLUMINATION AT THIS TIME (IN GOOD CONDITIONS & IN THE ABSENCE OF OTHER ILLUMINATION) IS SUCH THAT THE BRIGHTEST STARS ARE VISIBLE & THE HORIZON IS CLEARLY DEFINED.

TYPICAL DAY-NIGHT REGIME (LAT. 69° 30'N)

TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY
TYPICAL DAY-NIGHT REGIME
FIGURE 3A



MEAN DAYS RAIN & SNOW PER MONTH
HERSCHEL ISLAND

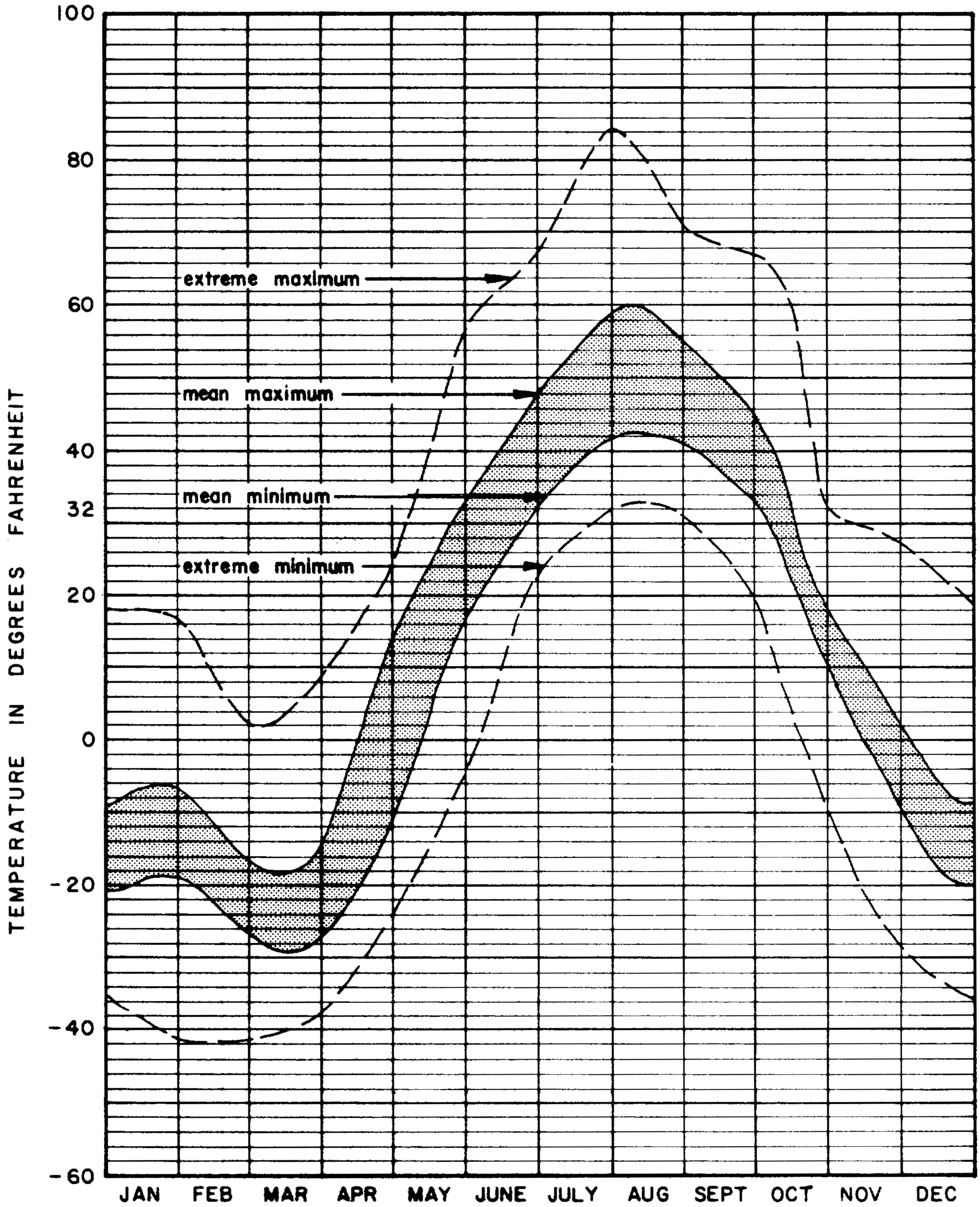


CUMULATIVE RAINFALL, SNOWFALL & PRECIPITATION
HERSCHEL ISLAND

TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY

TYPICAL PRECIPITATION GRAPHS

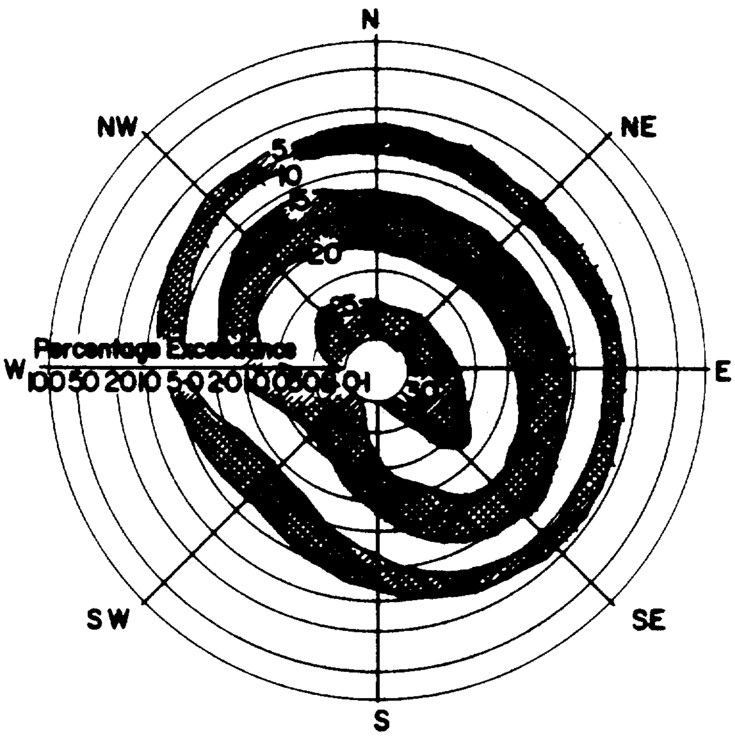
FIGURE **3 B**



TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY

TEMPERATURE PROFILE
73 & 74 RECORDS

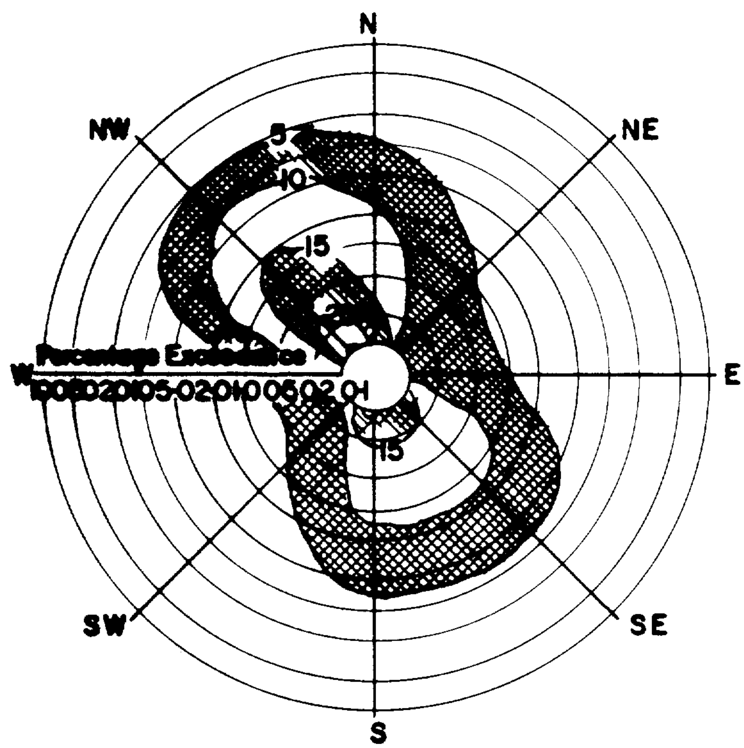
FIGURE 3C



SACHS HARBOUR WIND CLIMATE

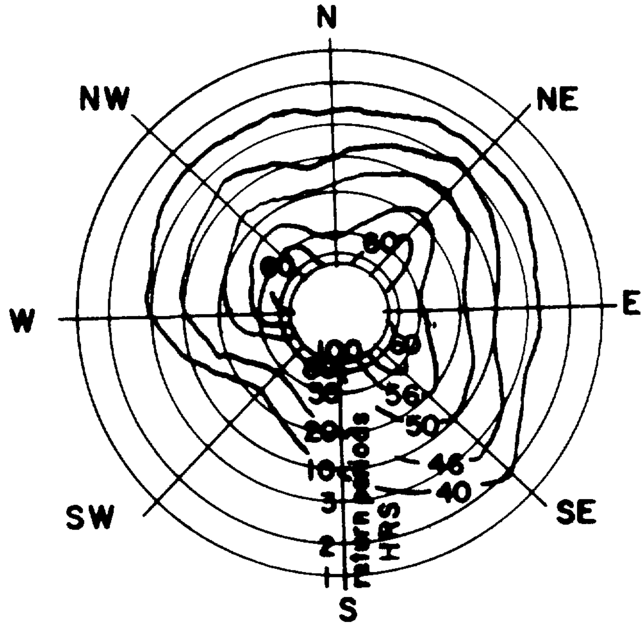
NOTE: THE RADIAL SCALE IS LOGARITHMIC GIVING THE PERCENTAGE OF TIME THE WIND SPEED IN KNOTS IS EQUAL TO OR GREATER THAN THE VALUES INDICATED.

INUVIK & AKLAVIK WIND CLIMATE

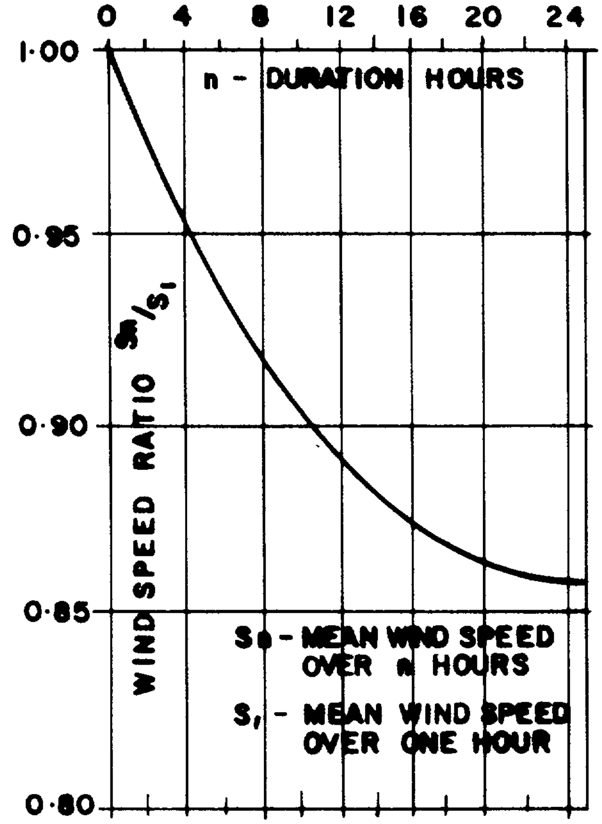


TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY
WIND CLIMATE

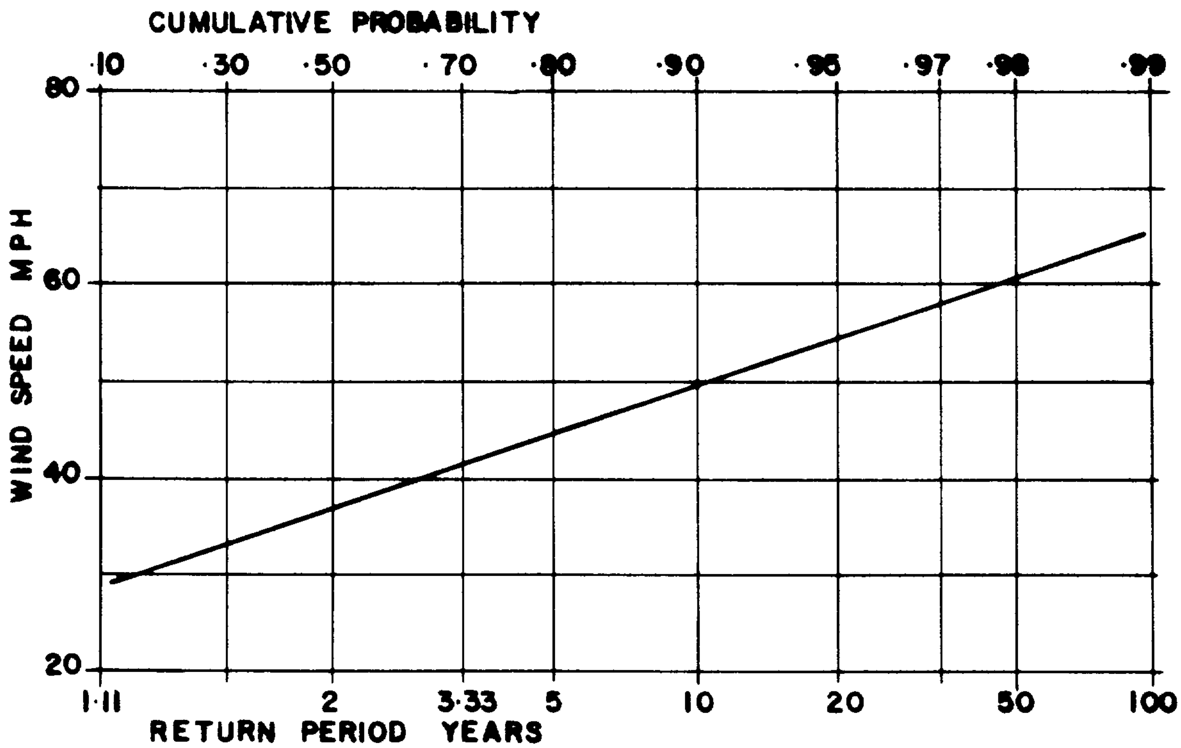
Figure 4 A



EXTREME WIND SPEEDS



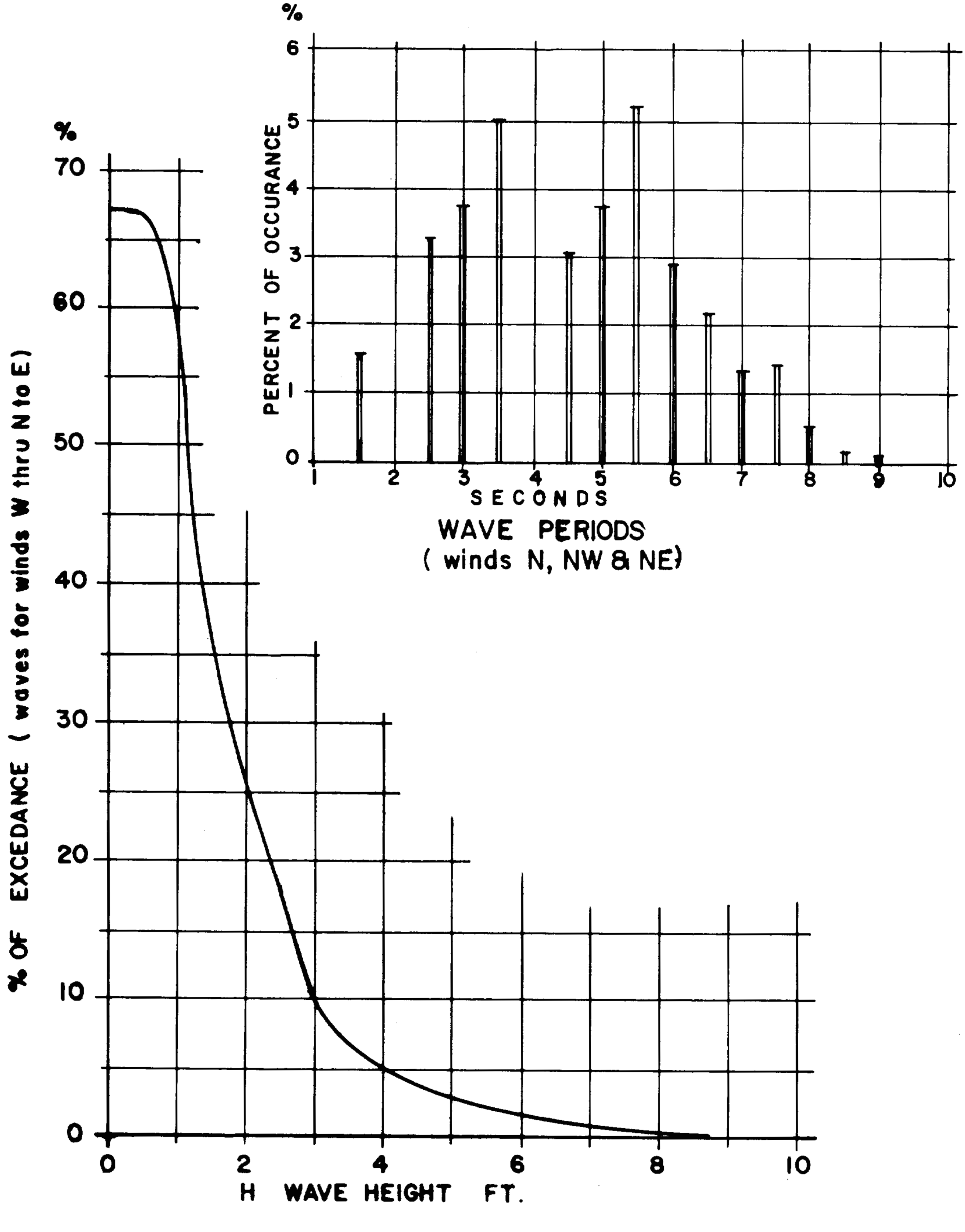
DURATION WIND SPEED RATIOS



SACHS HARBOUR – EXTREME WINDS

TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
EXTREME WINDS

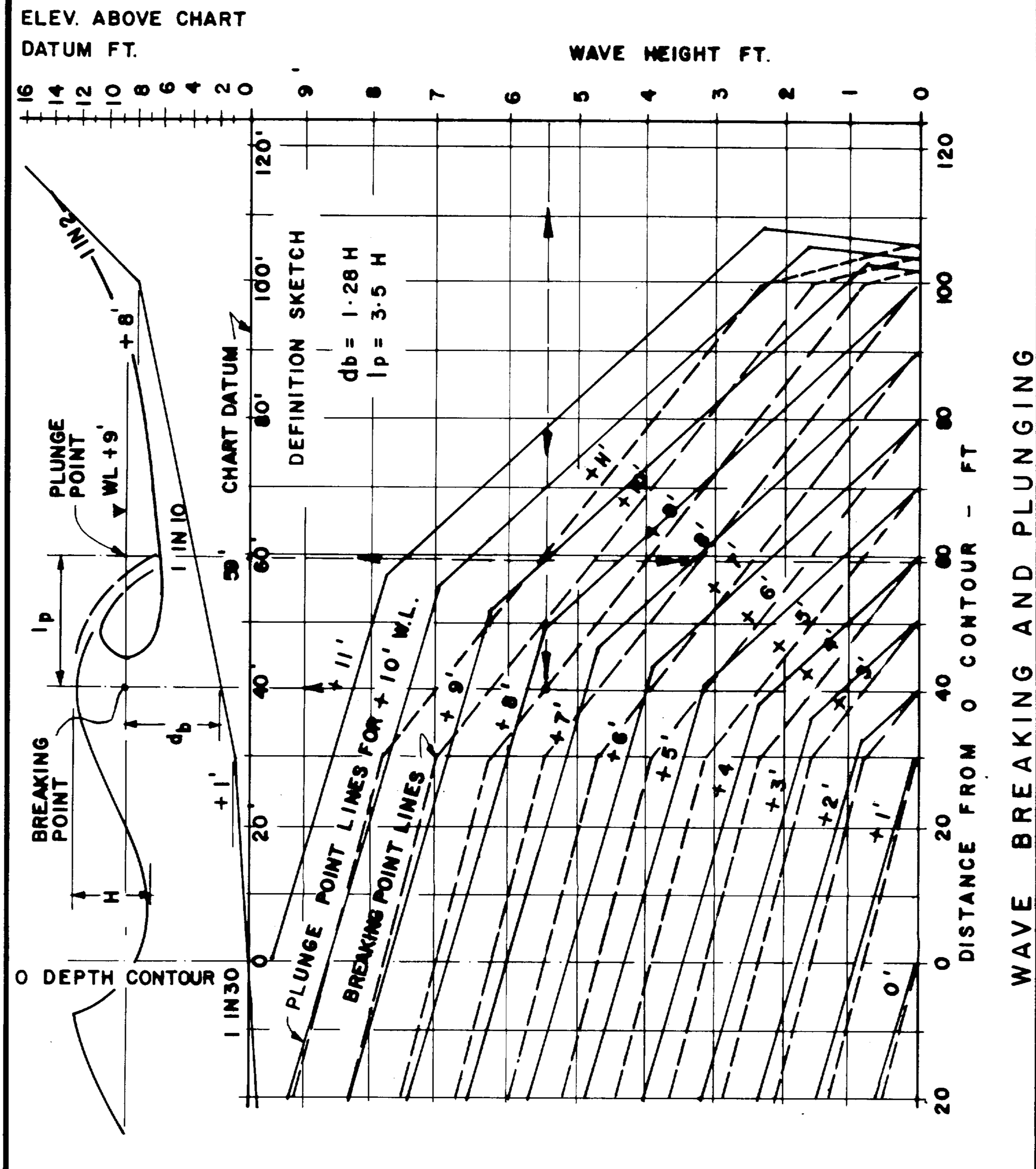
Figure 4B



TUKTOYAKTUK — WAVE HEIGHTS (after refraction) & WAVE PERIOD

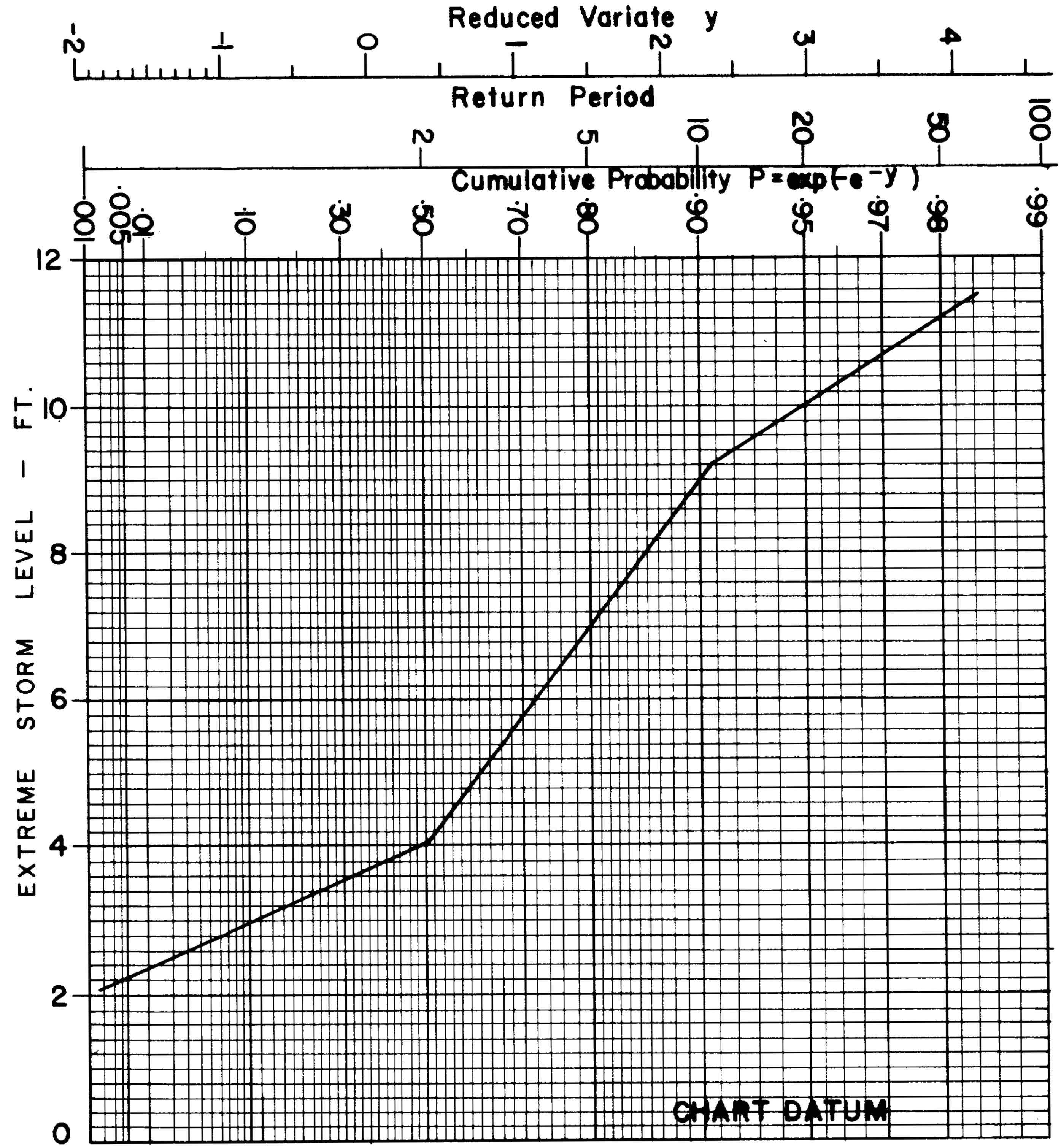
TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
WAVE CLIMATE

Figure 5



TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
WAVE CLIMATE

Figure 6

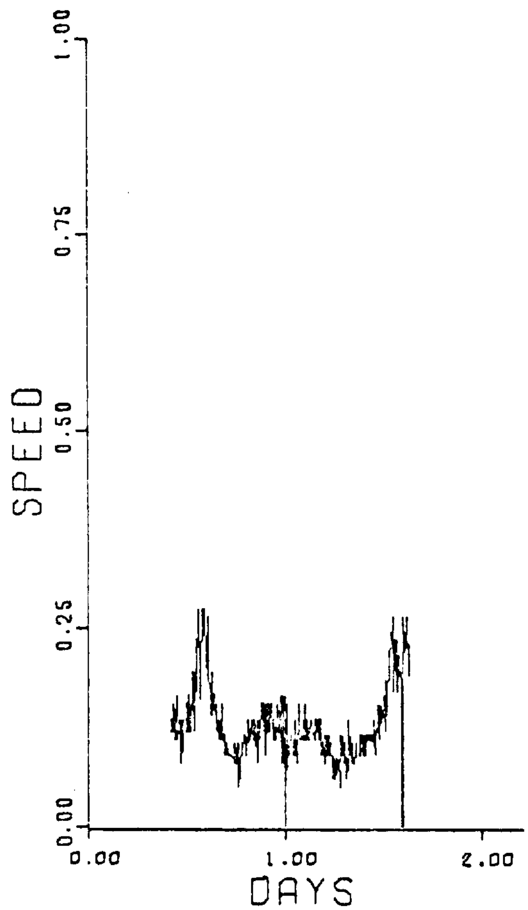


TUKTOYAKTUK — EXTREME STORM
WATER LEVELS — APPROXIMATE RETURN PERIODS

TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
WATER LEVELS

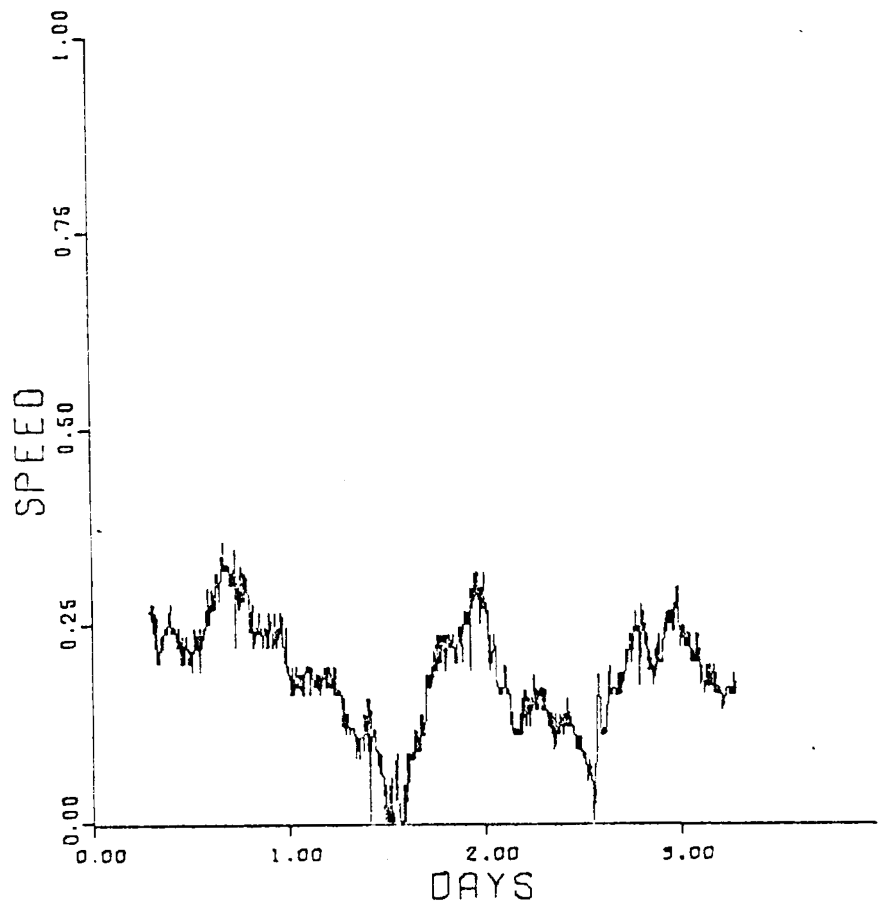
Figure 7

Velocity Record
Current Meter Location #1
1105/17/08/74 to
1605/18/08/74



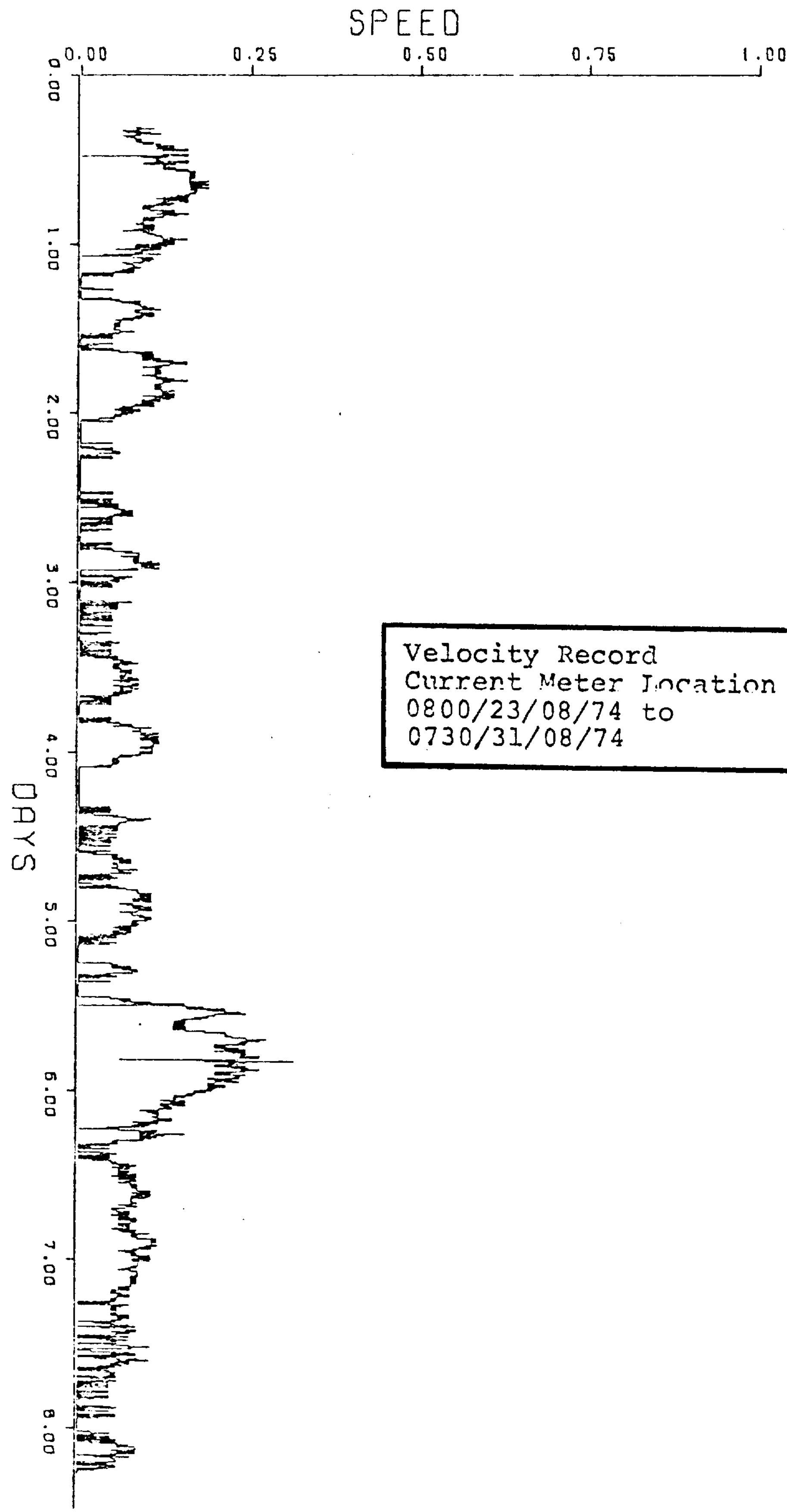
TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
CURRENT VELOCITY IN KNOTS
Figure 8

Velocity Record
Current Meter Location #2
0745/20/08/74 to
0730/23/08/74



TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
CURRENT VELOCITY IN KNOTS

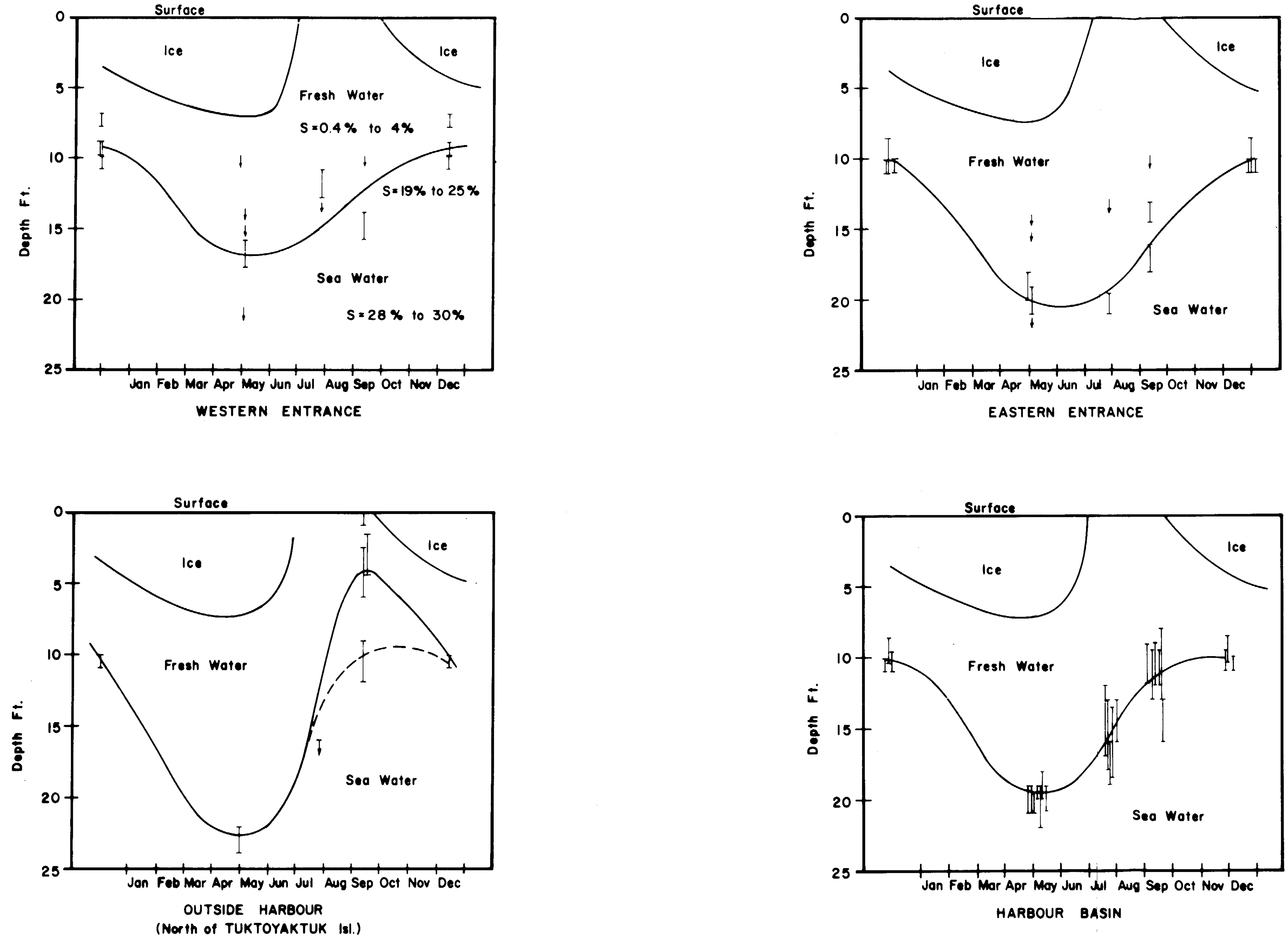
Figure 9



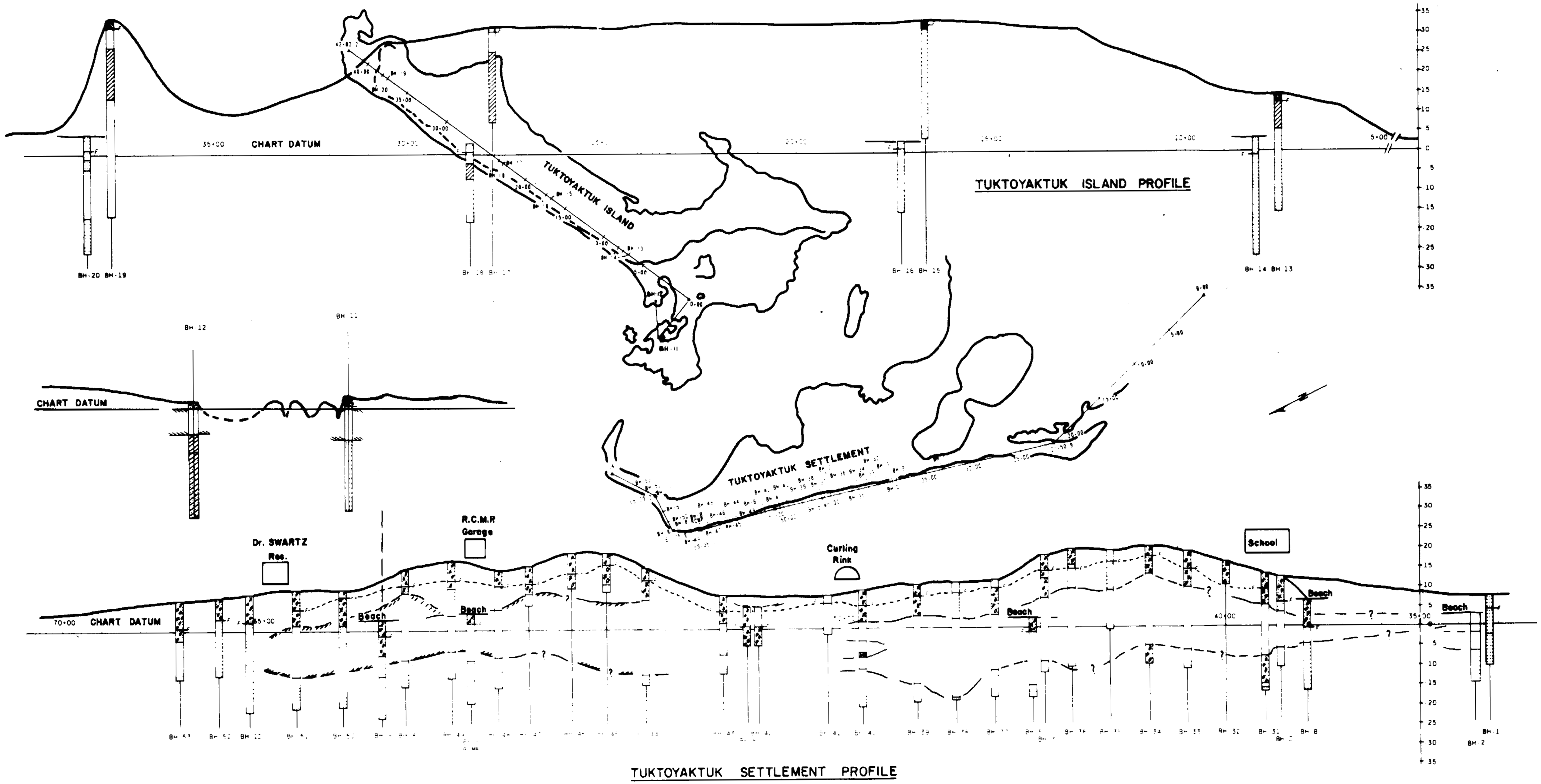
Velocity Record
Current Meter Location #3
0800/23/08/74 to
0730/31/08/74

TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
CURRENT VELOCITY IN KNOTS

Figure 10

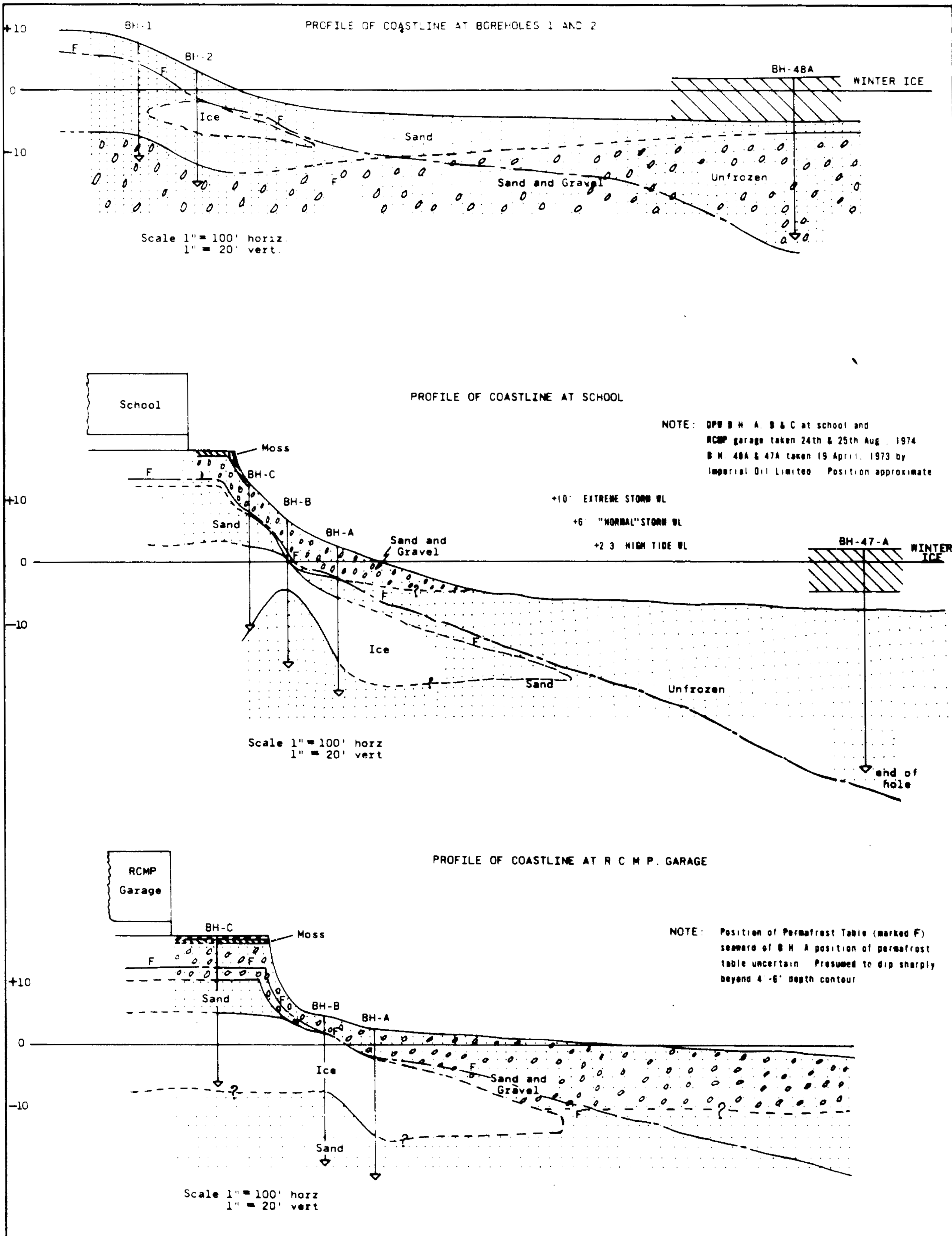


TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY
SEASONAL VARIATION of FRESH
WATER LAYERS at TUKTOYAKTUK
Figure - 11



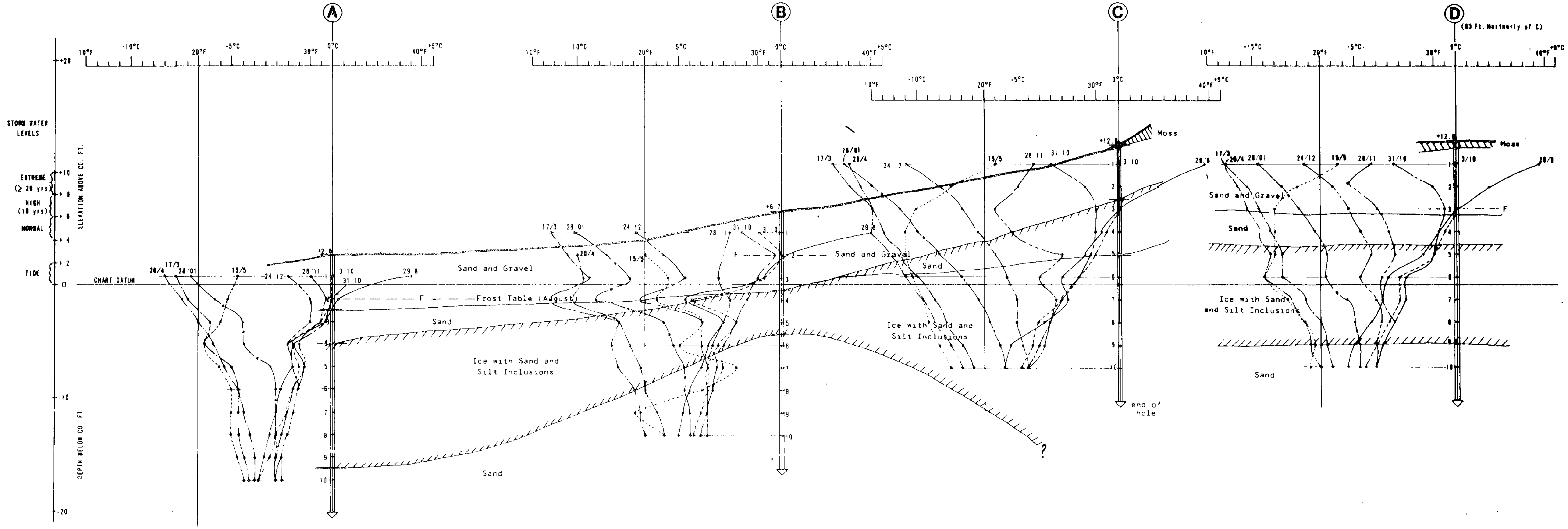
TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
TUKTOYAKTUK ISLAND &
TUKTOYAKTUK SETTLEMENT
Subsurface Profiles

Figure – 12

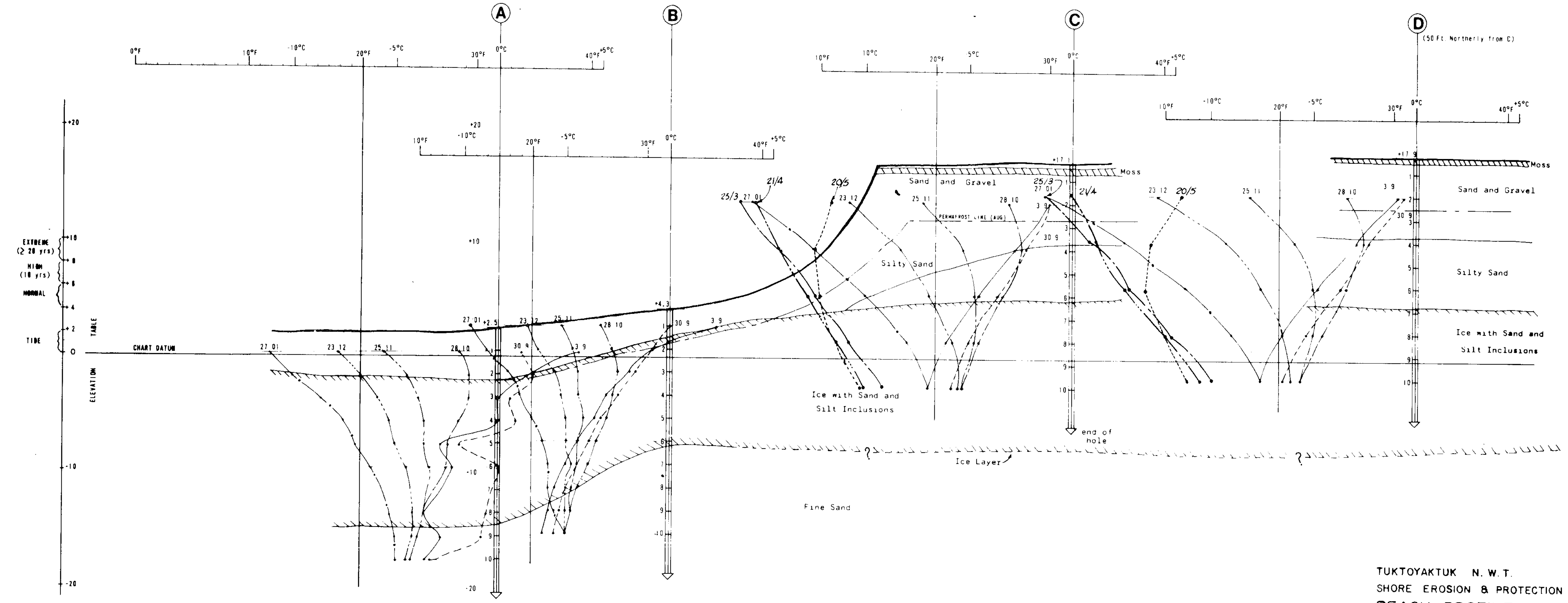


TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
COASTAL PROFILES

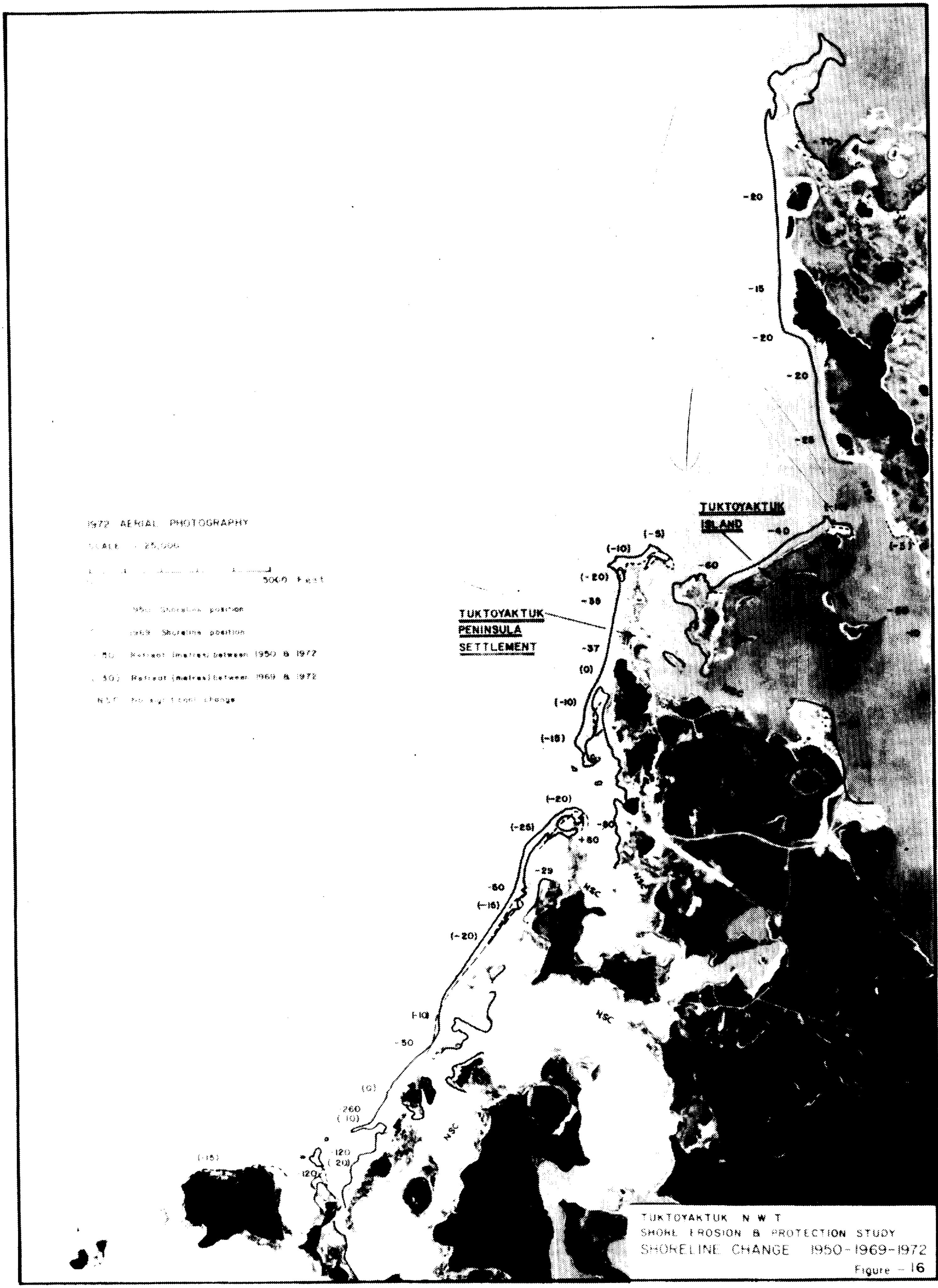
Figure - 13



TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
BEACH PROFILE AT SCHOOL
Observed Subsurface Temperatures
Figure - 14

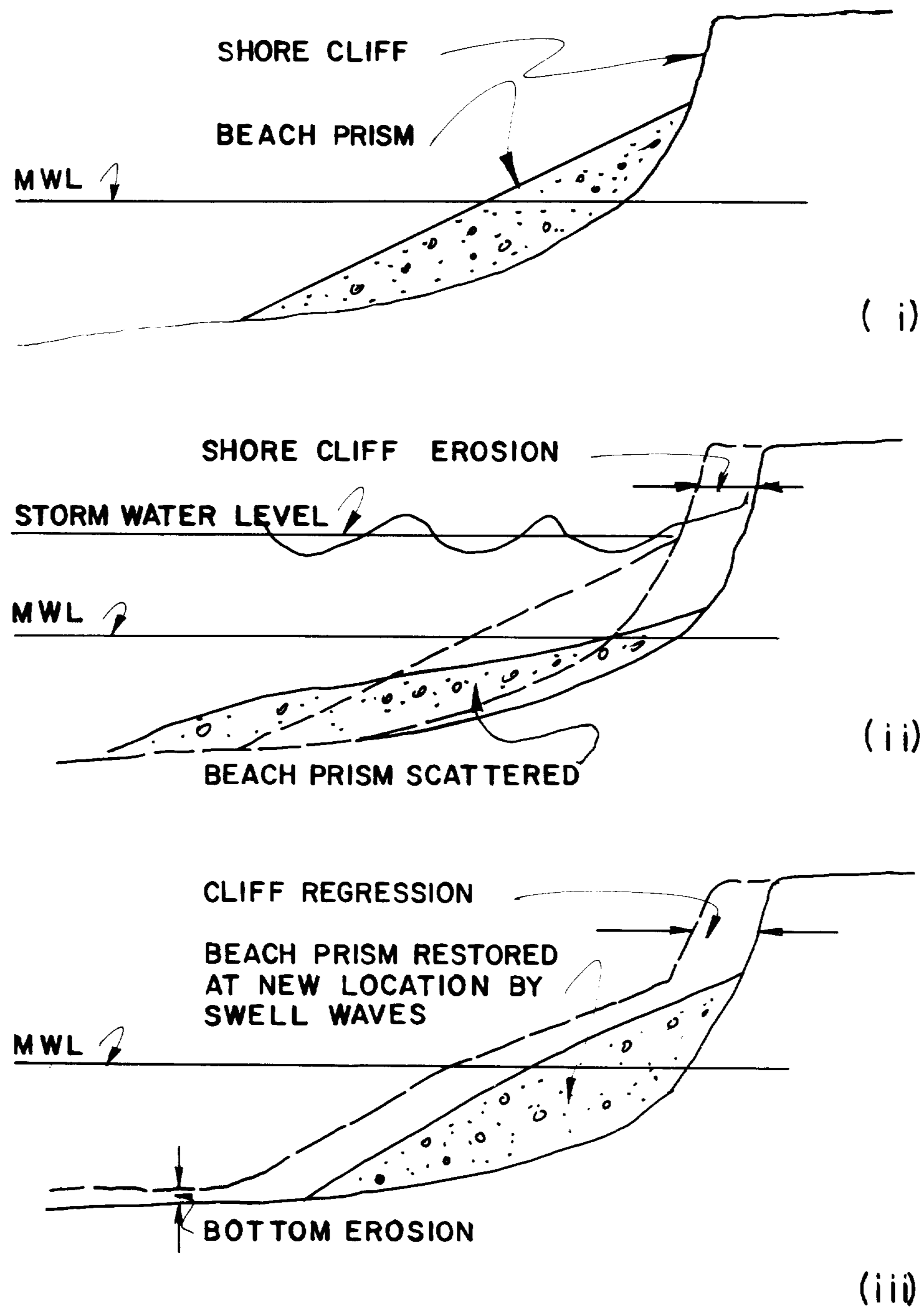


TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
BEACH PROFILE AT RCMP GARAGE
Observed Subsurface Temperatures
Figure - 15



1972 AERIAL PHOTOGRAPHY
5000 Feet
TUKTOYAKTUK ISLAND
TUKTOYAKTUK PENINSULA SETTLEMENT
TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY
SHORELINE CHANGE 1950-1969-1972

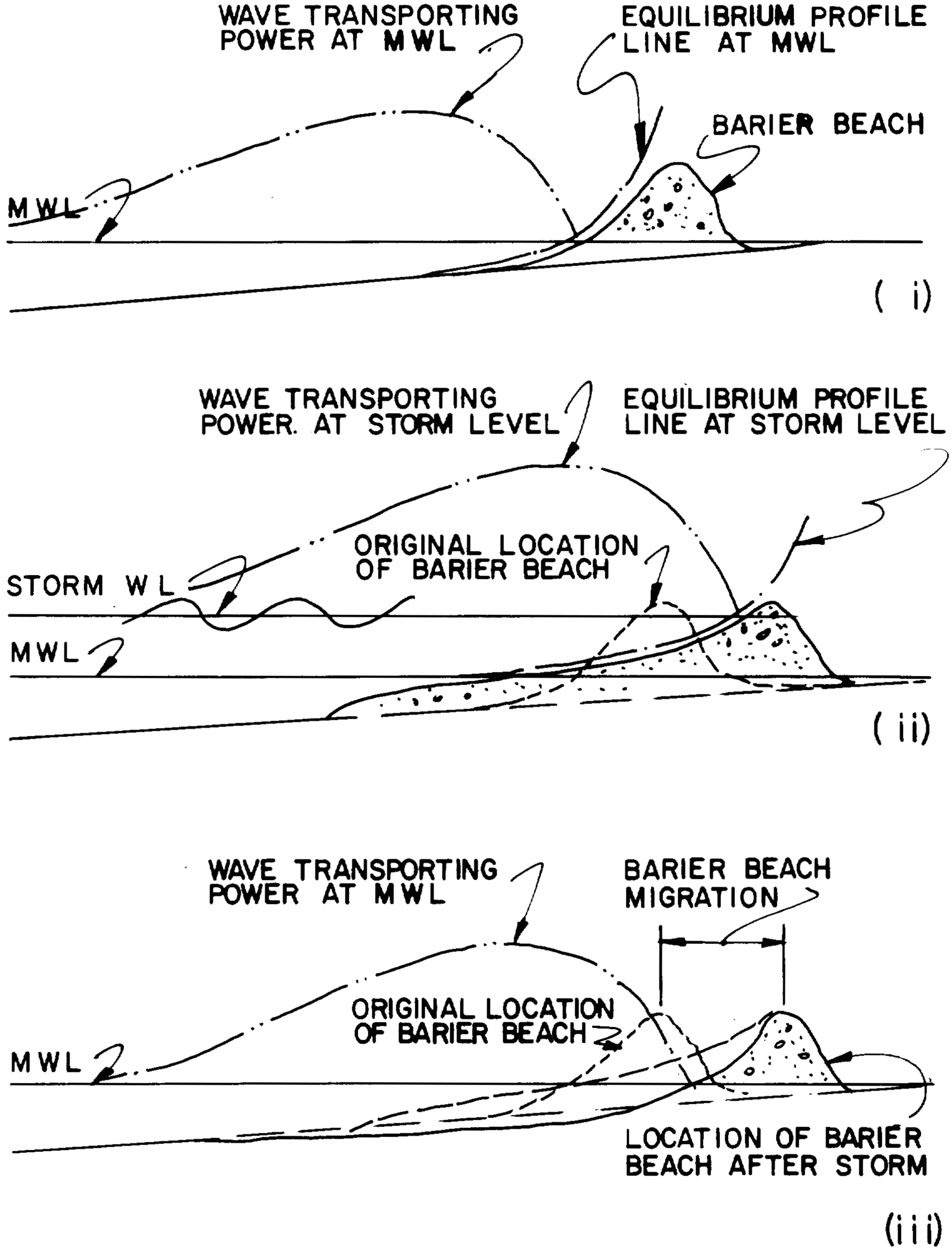
Figure - 16



DIAGRAMATIC REPRESENTATION OF BEACH AND SHORE CLIFF EROSION PROCESS

TUKTOYAKTUK N. W. T
SHORE EROSION & PROTECTION STUDY
MECHANICS OF EROSION

Figure 17

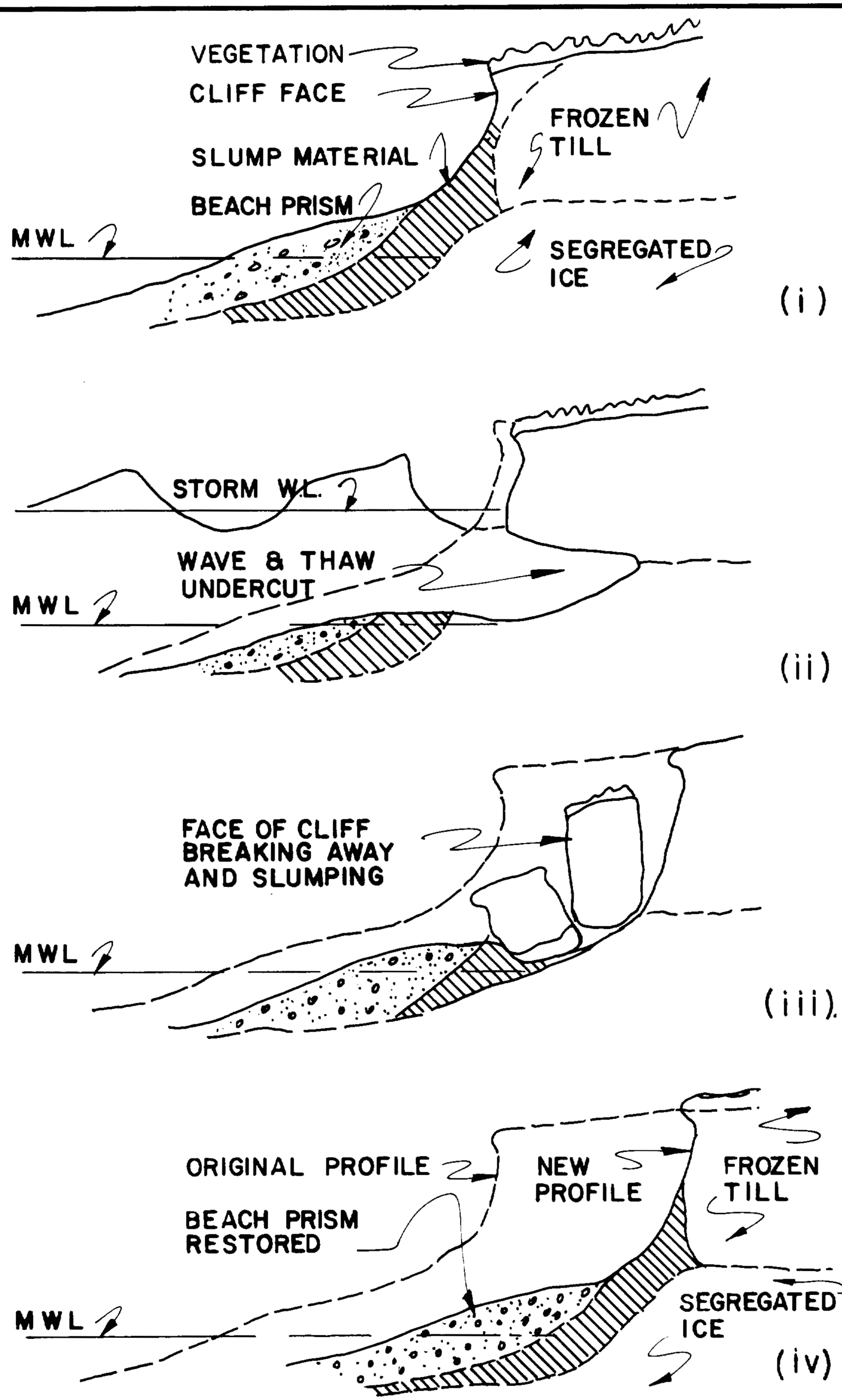


DIAGRAMATIC REPRESENTATION OF BEACH AND SHORE CLIFF EROSION PROCESS

TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY
MECHANICS OF EROSION

Figure 18

DIAGRAMATIC REPRESENTATION OF BEACH AND SHORE CLIFF EROSION PROCESS

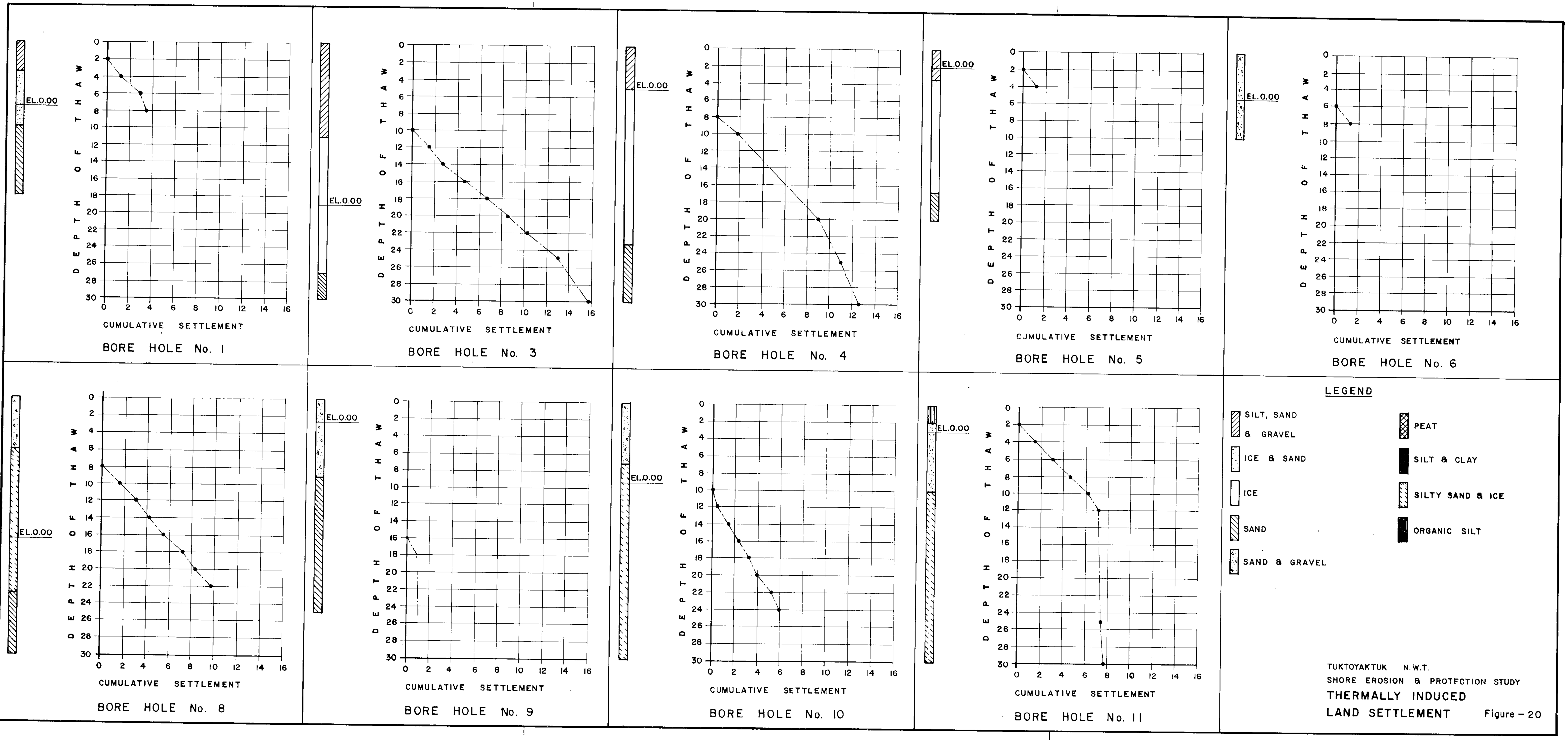


TUKTOYAKTUK N. W. T.

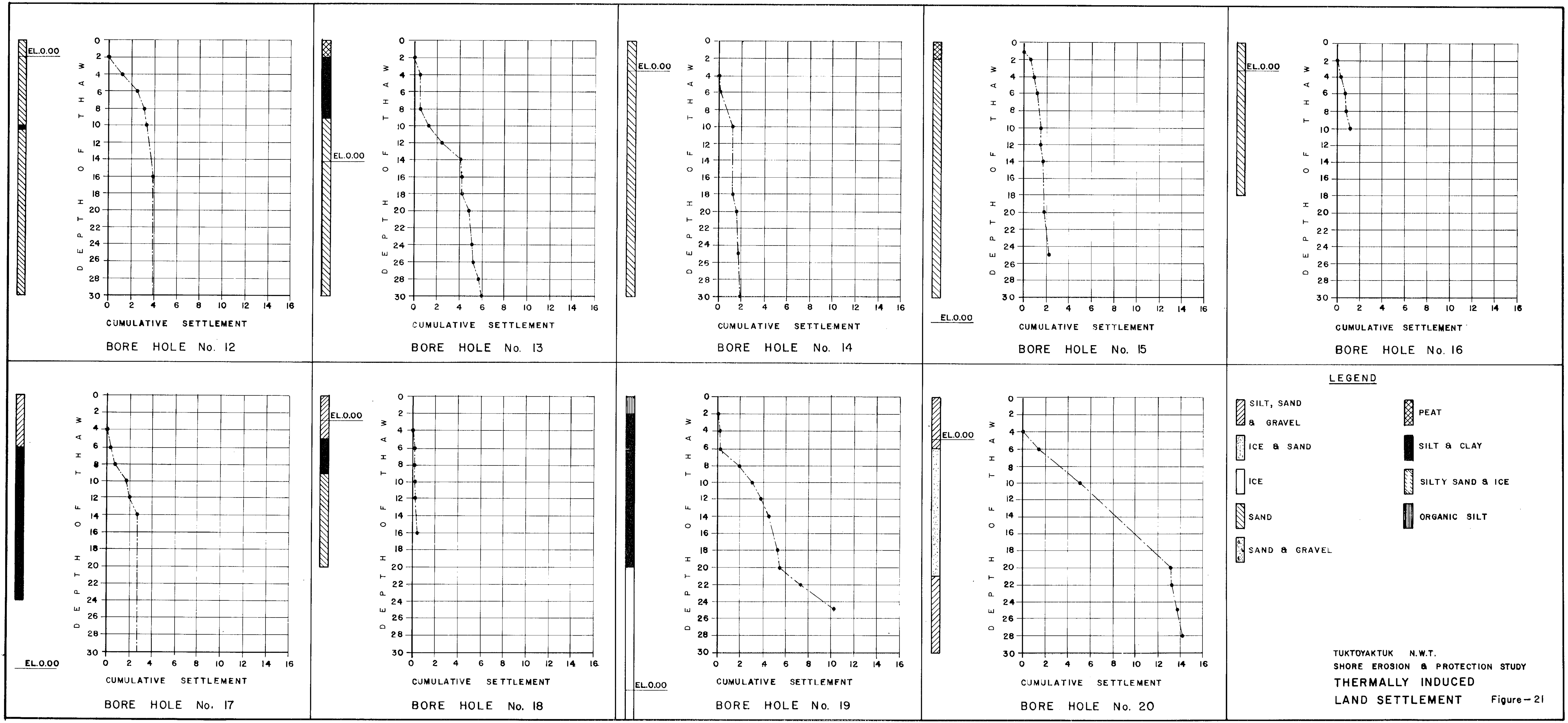
SHORE EROSION & PROTECTION STUDY

MECHANICS OF EROSION

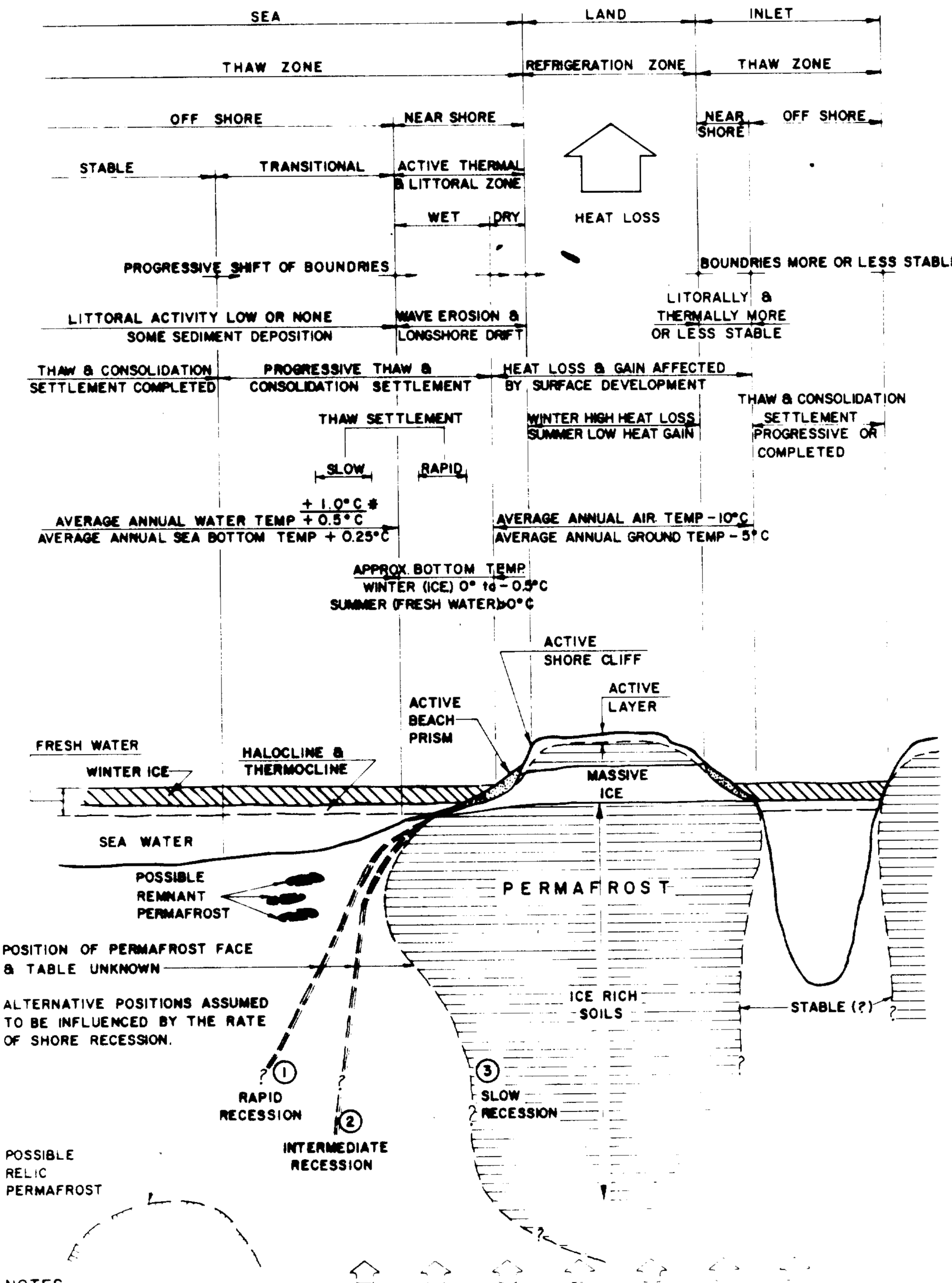
Figure 19



TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY
THERMALLY INDUCED
LAND SETTLEMENT
Figure - 20



TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY
THERMALLY INDUCED LAND SETTLEMENT
Figure – 21



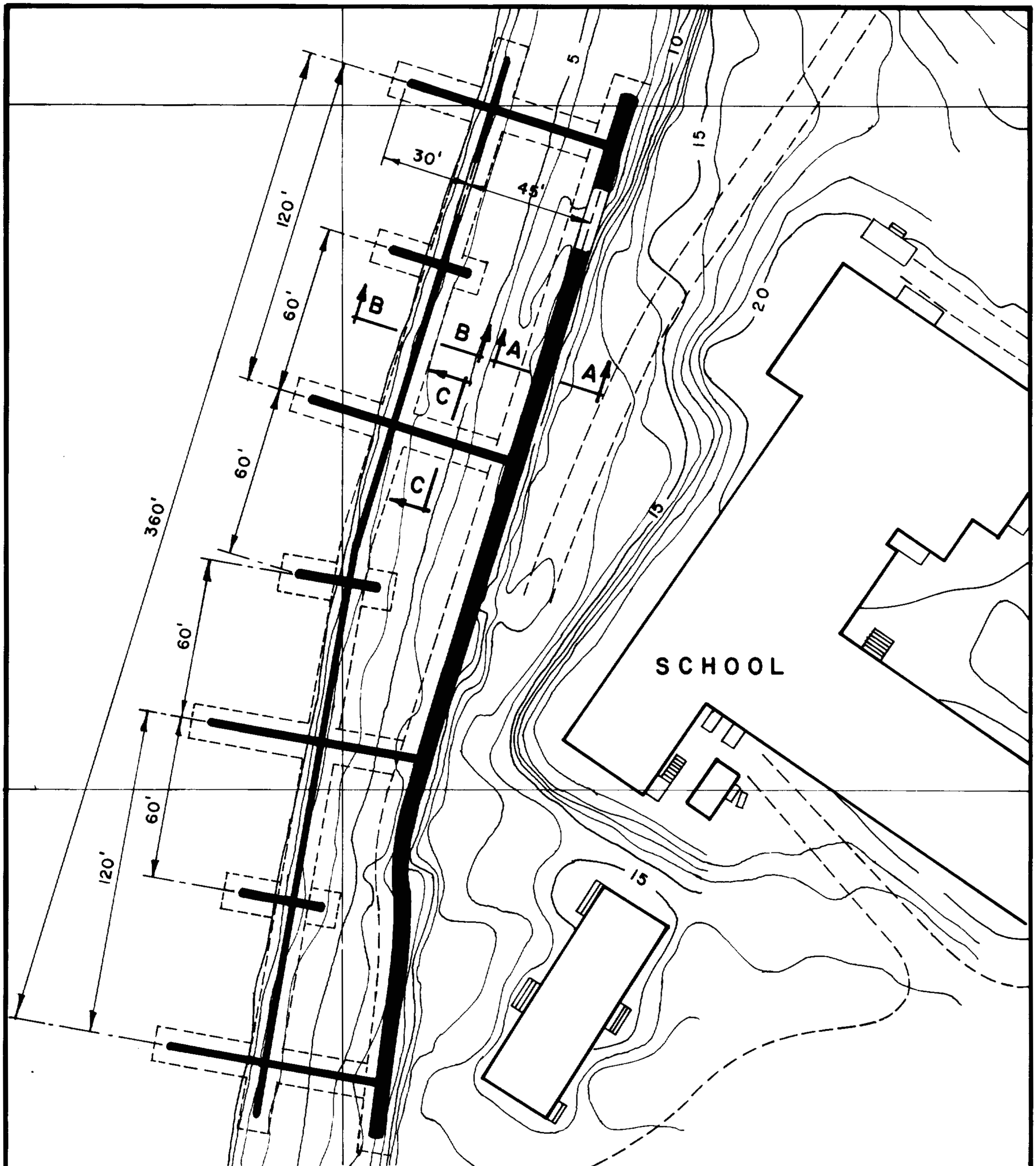
NOTES

* WATER TEMPERATURES ABOVE AND BELOW THERMOCLINE.
AVERAGE TEMPERATURES OF SEA WATER ARE INFLUENCED BY WATER DEPTH.
ALL TEMPERATURES ARE APPROX. ONLY.

DIAGRAM NOT TO SCALE

TUKTOYAKTUK N.W.T. - GENERALIZED ZONES of LITTORAL, MORPHOLOGICAL and THERMAL PROCESSES

FIGURE No. 22



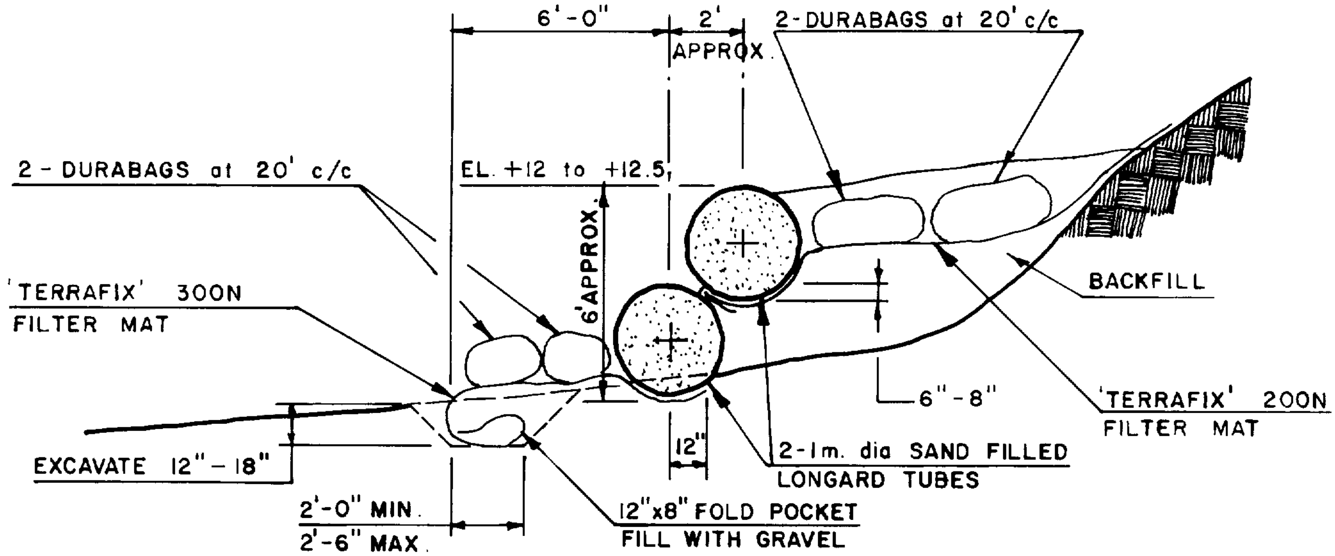
TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY

LONGARD TUBES

TEST PROTECTION WORK

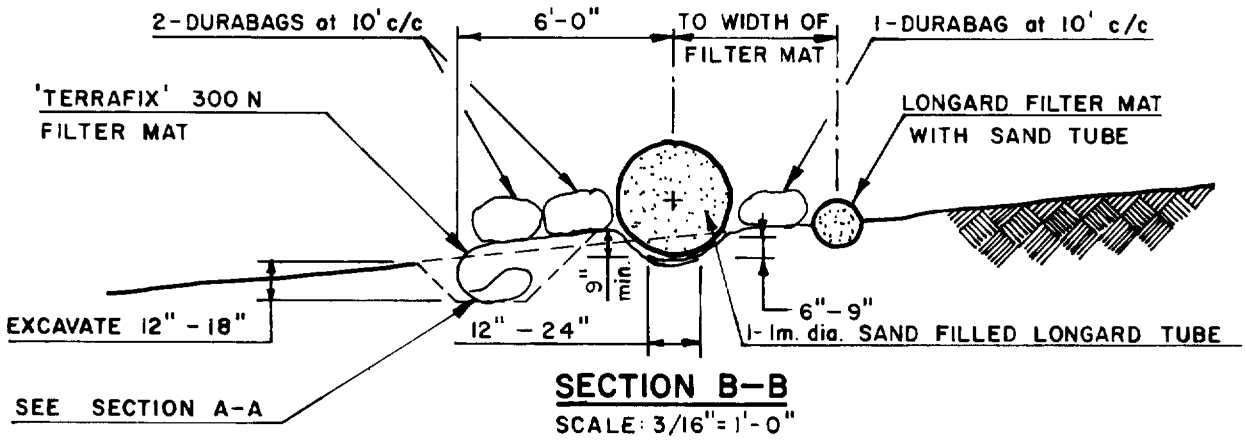
Layout Plan

Figure — 23



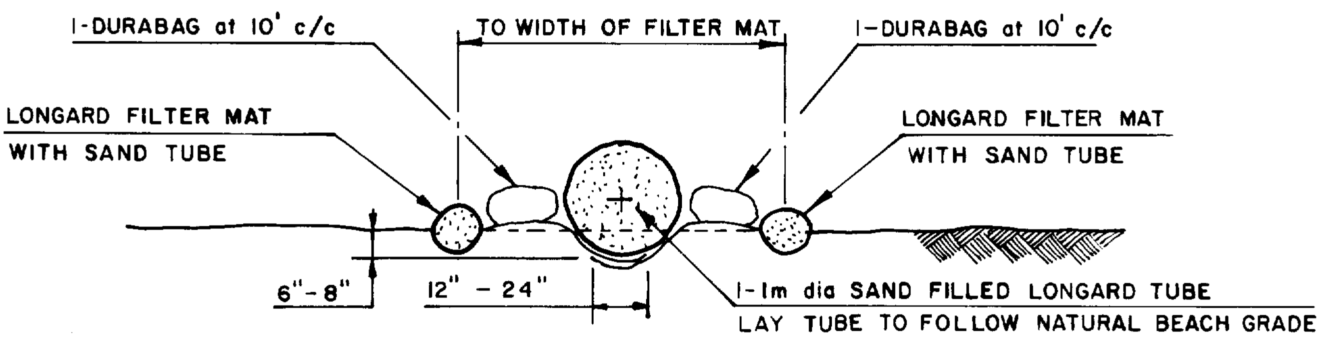
SECTION A-A

SCALE: 3/16"=1'-0"



SECTION B-B

SCALE: 3/16"=1'-0"



SECTION C-C

SCALE: 3/16"=1'-0"

TUKTOYAKTUK N. W. T.

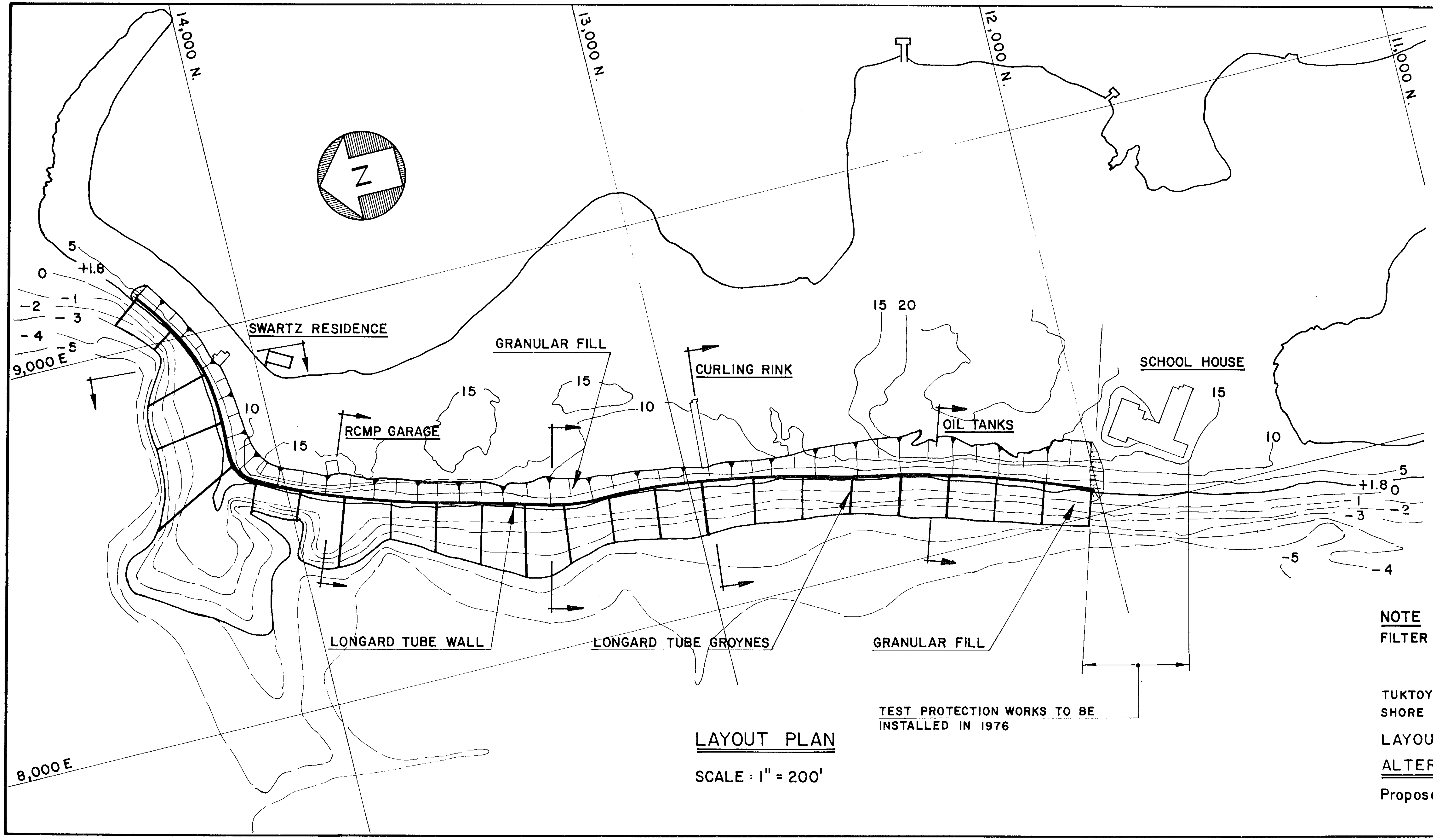
SHORE EROSION & PROTECTION STUDY

LONGARD TUBES

TEST PROTECTION WORK

Sections

Figure — 24



NOTE

FILTER CLOTH APRON REQ'D. FOR FIRST 20' OF GROYNES.

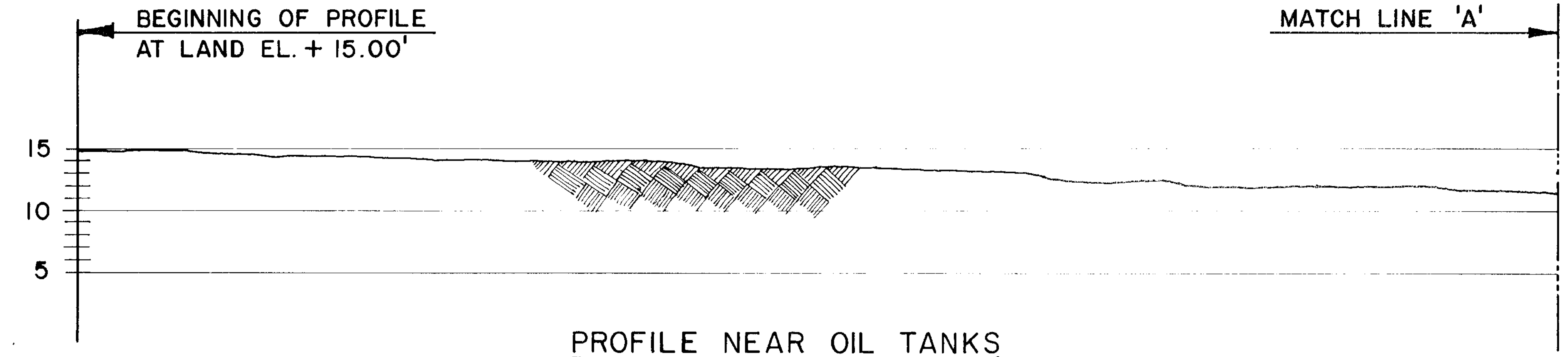
TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY

LAYOUT PLAN

ALTERNATIVE I

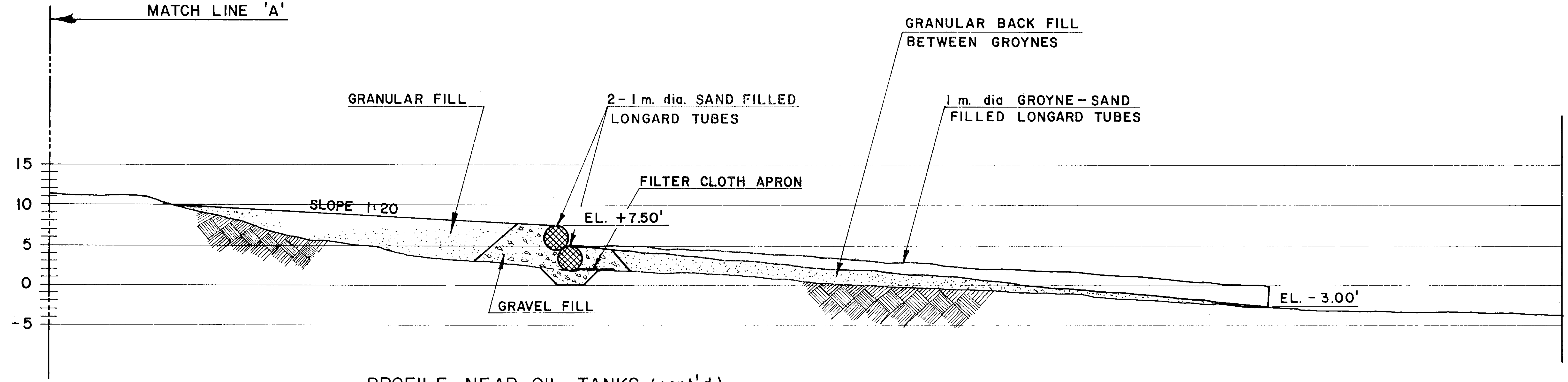
Proposed Longard Tube Shore Protection

Figure — 25



PROFILE NEAR OIL TANKS

SCALE : $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'



PROFILE NEAR OIL TANKS (cont'd.)

SCALE : $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'

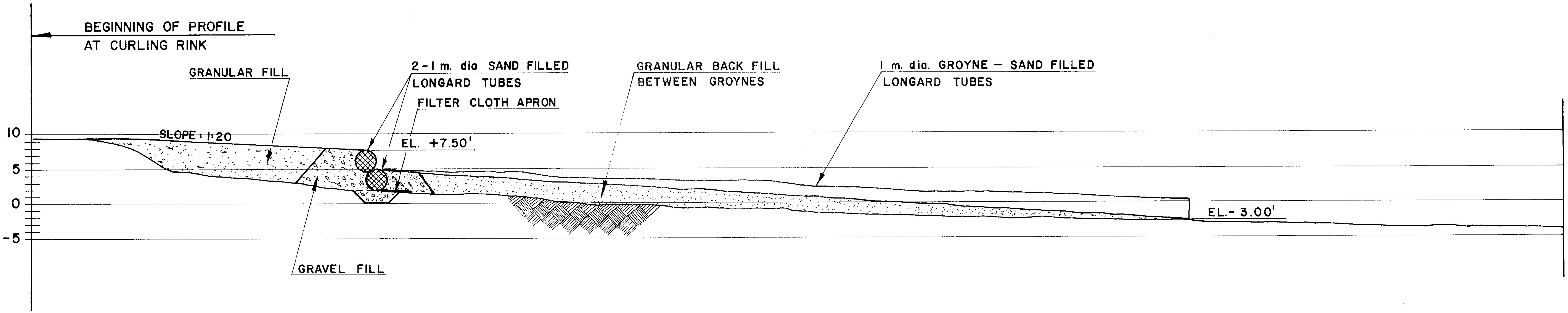
TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY

PROFILE NEAR OIL TANKS

ALTERNATIVE I

Proposed Longard Tube Shore Protection

Figure — 26



PROFILE AT CURLING RINK

SCALE: $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'

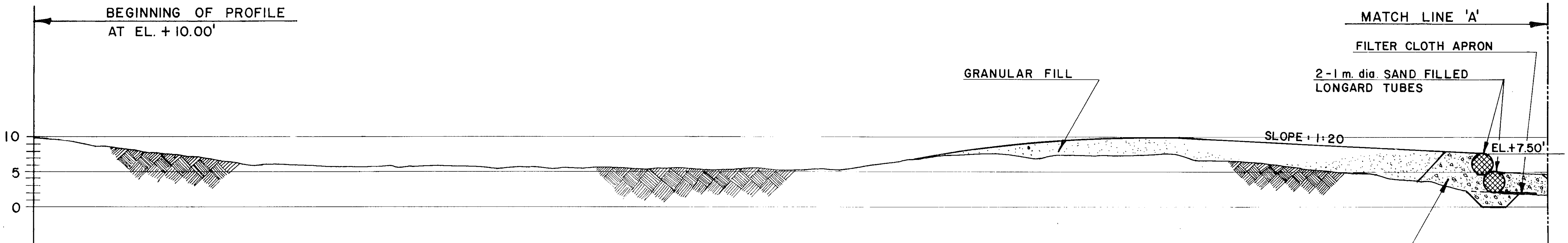
TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY

PROFILE AT CURLING RINK

ALTERNATIVE 1

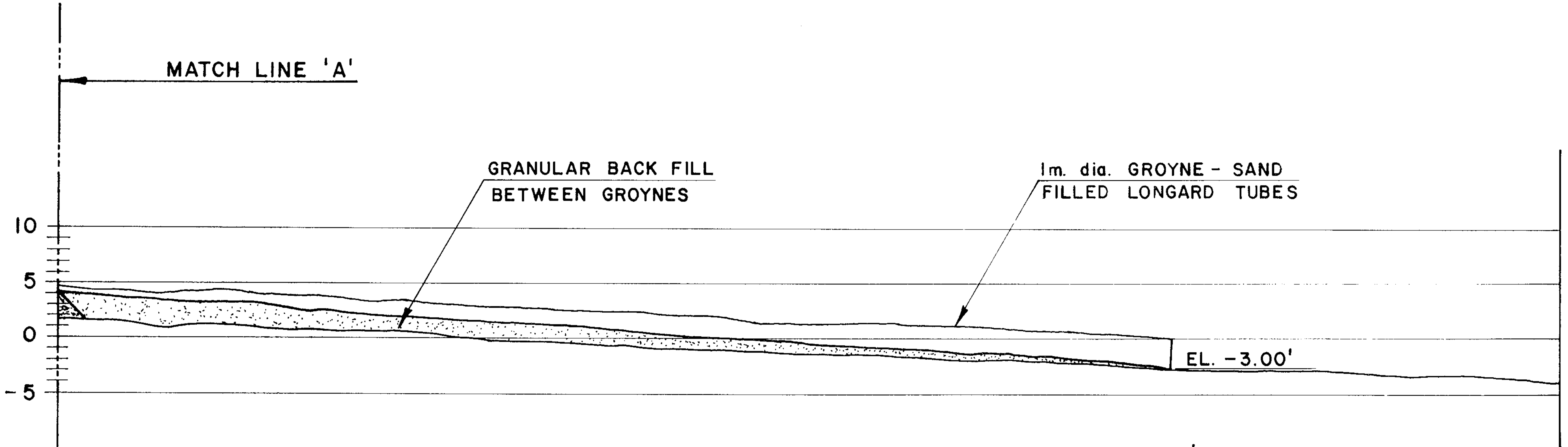
Proposed Longard Tube Shore Protection

Figure – 27



PROFILE BETWEEN CURLING RINK & RCMP GARAGE

SCALE : HORIZ / VERT 1" = 10'



PROFILE BETWEEN CURLING RINK & RCMP GARAGE (cont'd.)

SCALE : HORIZ / VERT 1" = 10'

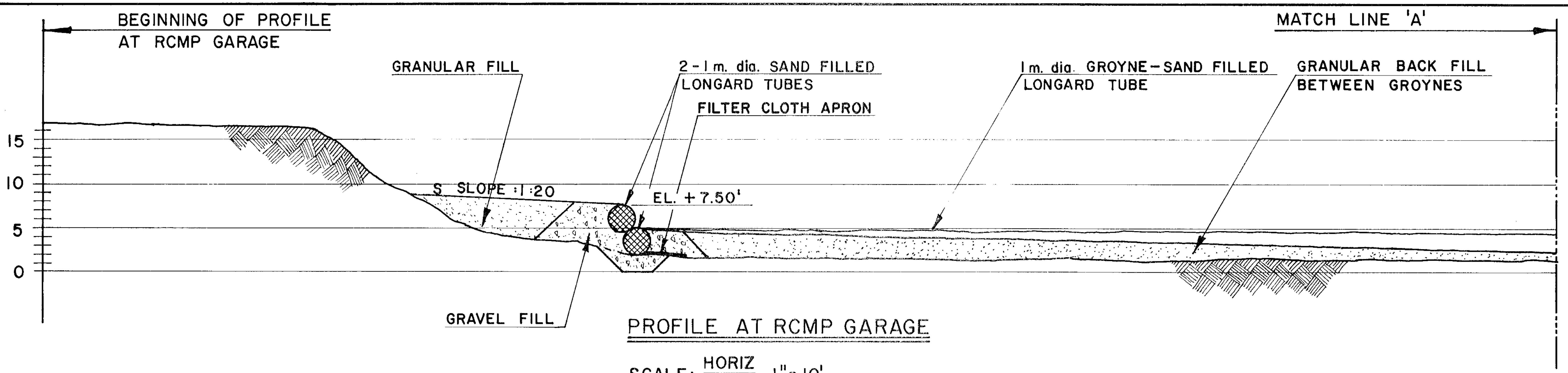
TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY

PROFILE BETWEEN CURLING RINK & RCMP GARAGE

ALTERNATIVE I

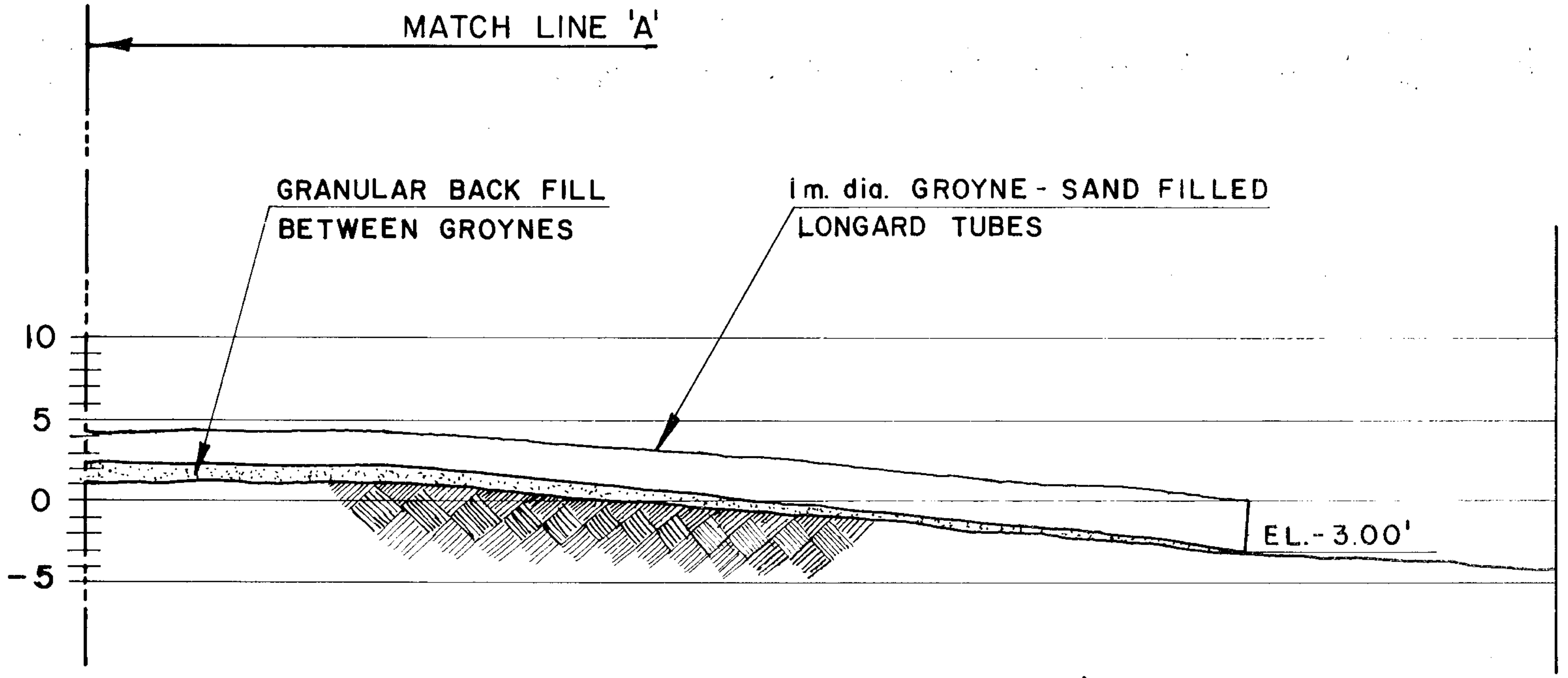
Proposed Longard Tube Shore Protection

Figure — 28



PROFILE AT RCMP GARAGE

SCALE: $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'



PROFILE AT RCMP GARAGE (cont'd.)

SCALE: $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'

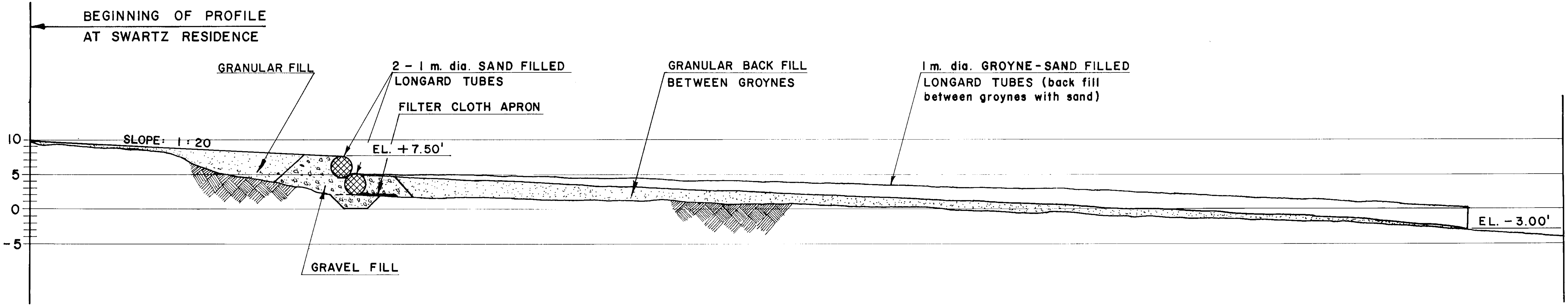
TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY

PROFILE AT RCMP GARAGE

ALTERNATIVE I

Proposed Longard Tube Shore Protection

Figure — 29

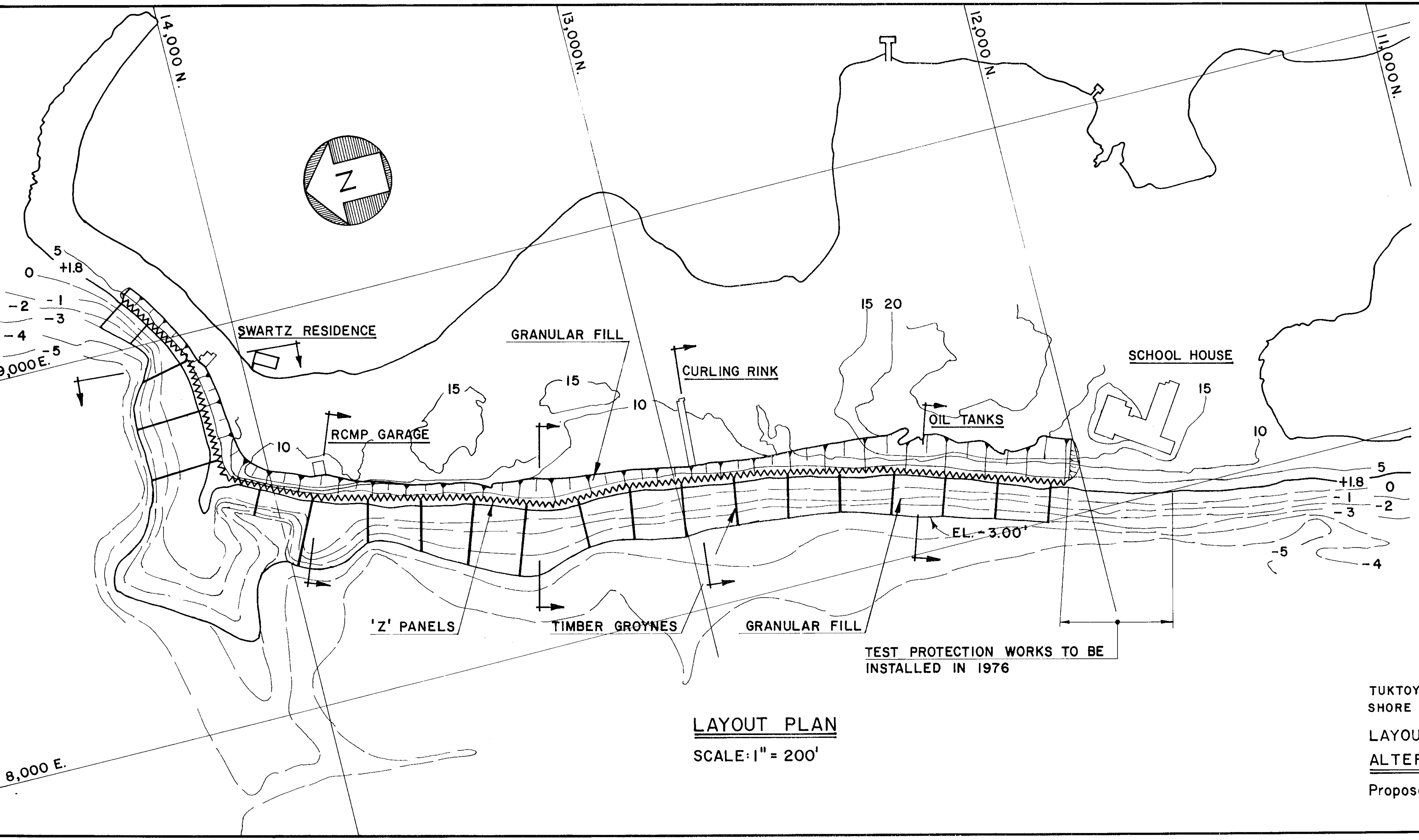


PROFILE AT SWARTZ RESIDENCE

SCALE: $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'

TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
PROFILE AT SWARTZ RESIDENCE
ALTERNATIVE I
Proposed Longard Tube Shore Protection

Figure – 30



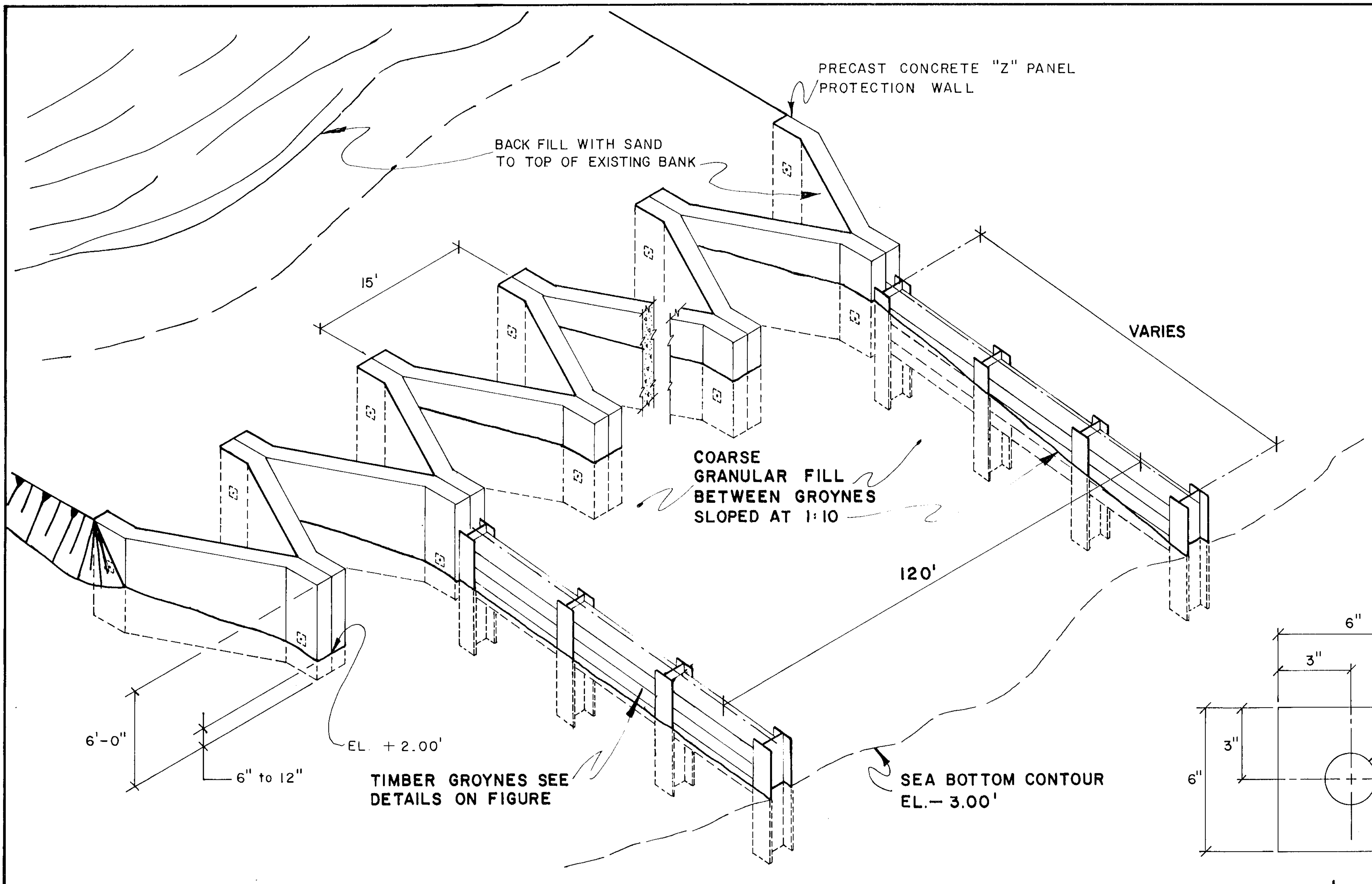
TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY

LAYOUT PLAN

ALTERNATIVE 2

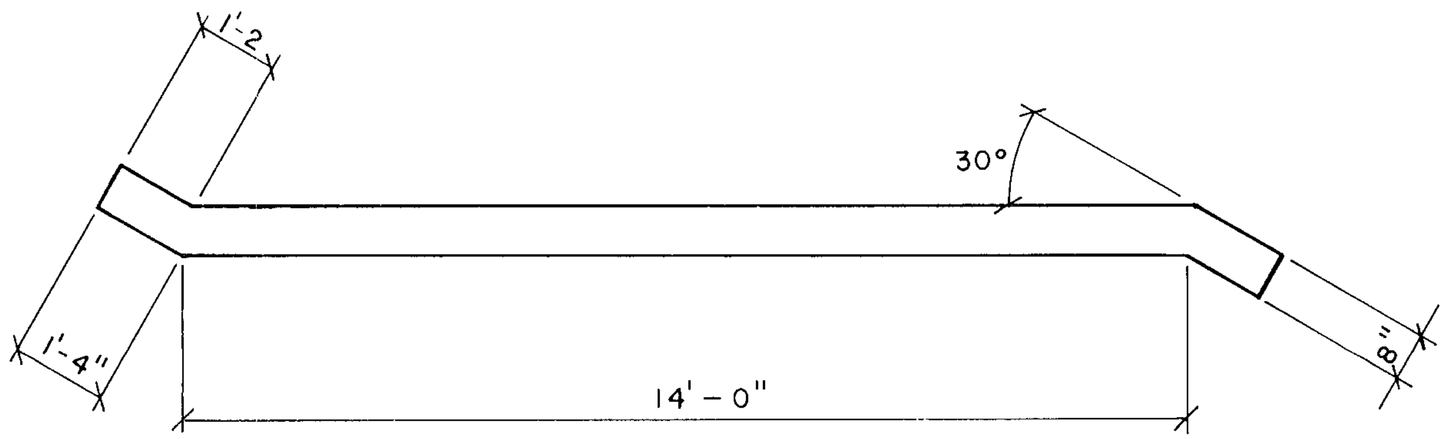
Proposed 'Z' Panel Wall Shore Protection

Figure — 31



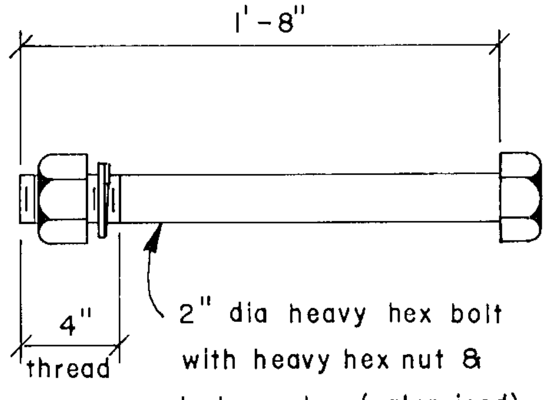
ISOMETRIC VIEW of "Z" PANEL PROTECTION WALL

NOT TO SCALE



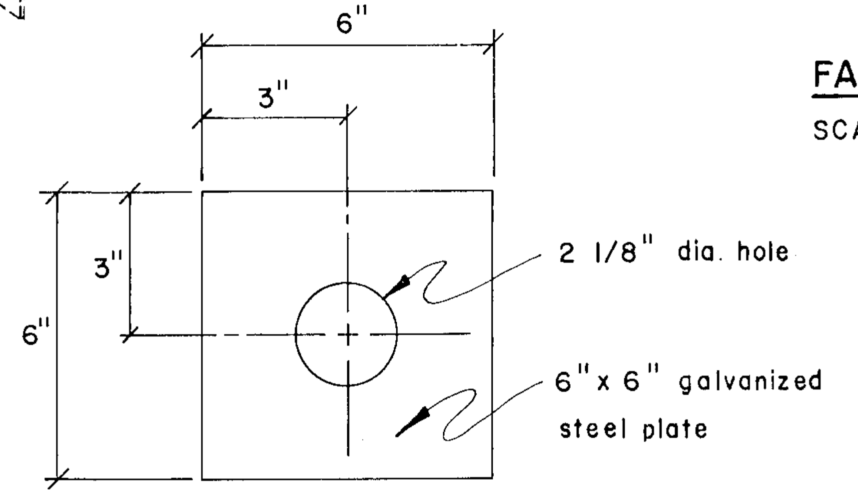
DETAILS of "Z" PANELS

SCALE: 3/8"=1'-0"



FASTENER DETAIL

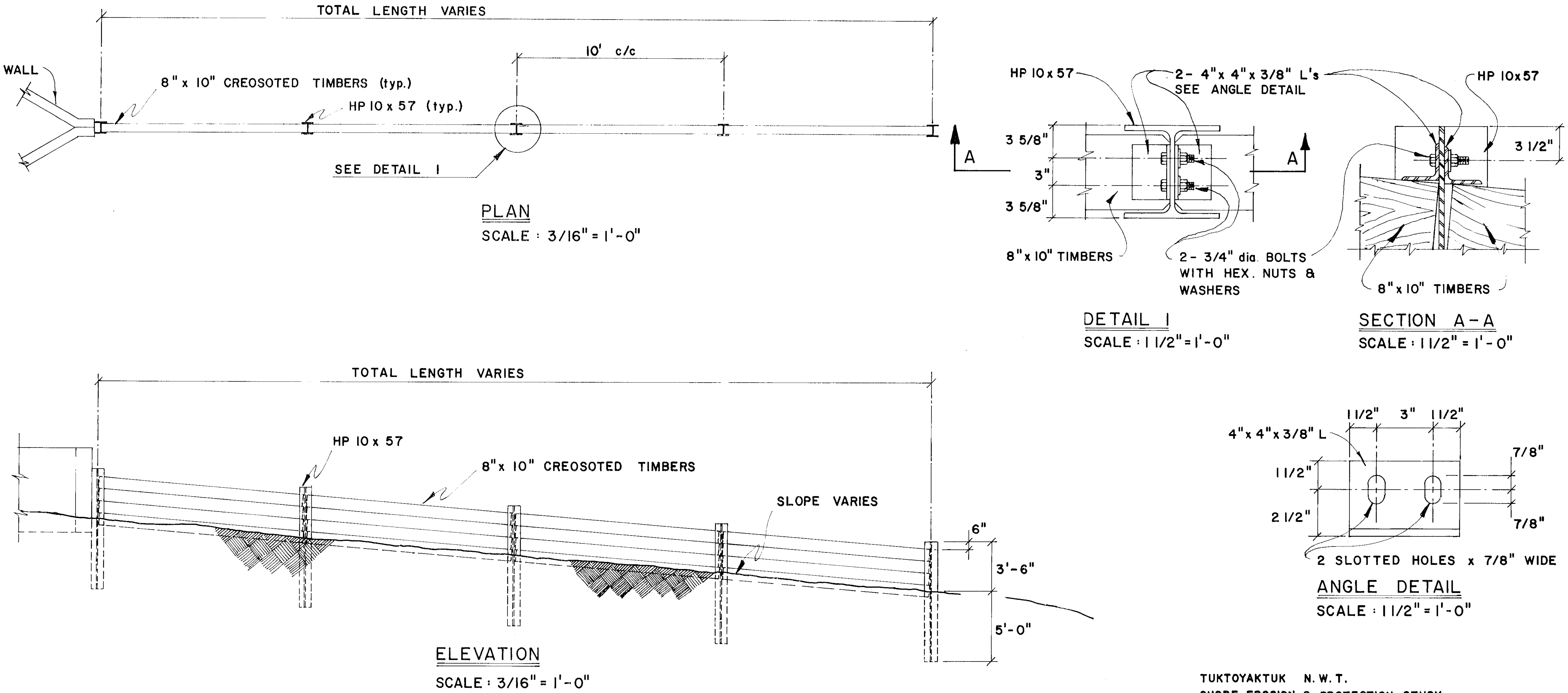
SCALE: 1 1/2"=1'-0"



FASTENER ℞ DETAIL

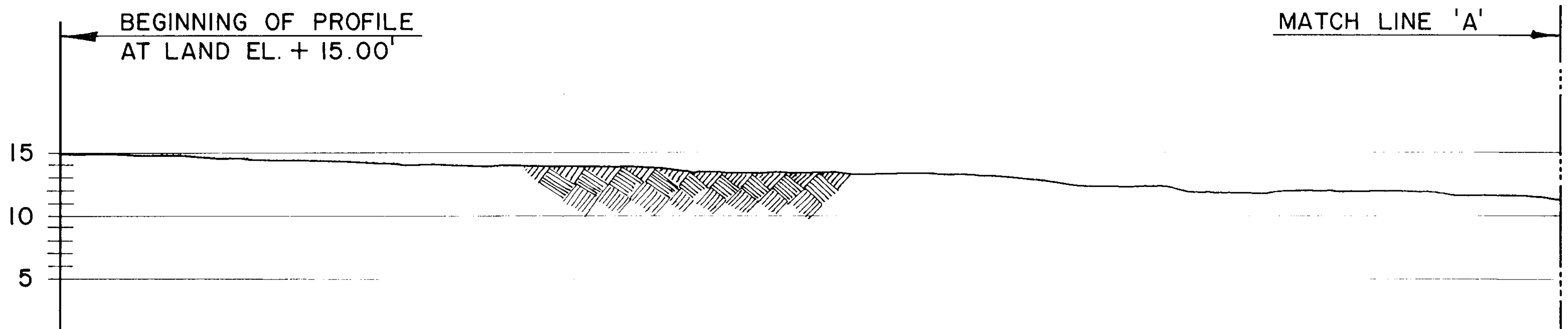
SCALE: 3"=1'-0"

TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
ALTERNATIVE 2
"Z" PANEL PROTECTION WALL DETAILS
Figure — 32



TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
ALTERNATIVE 2
TIMBER GROYNE DETAILS

Figure — 33

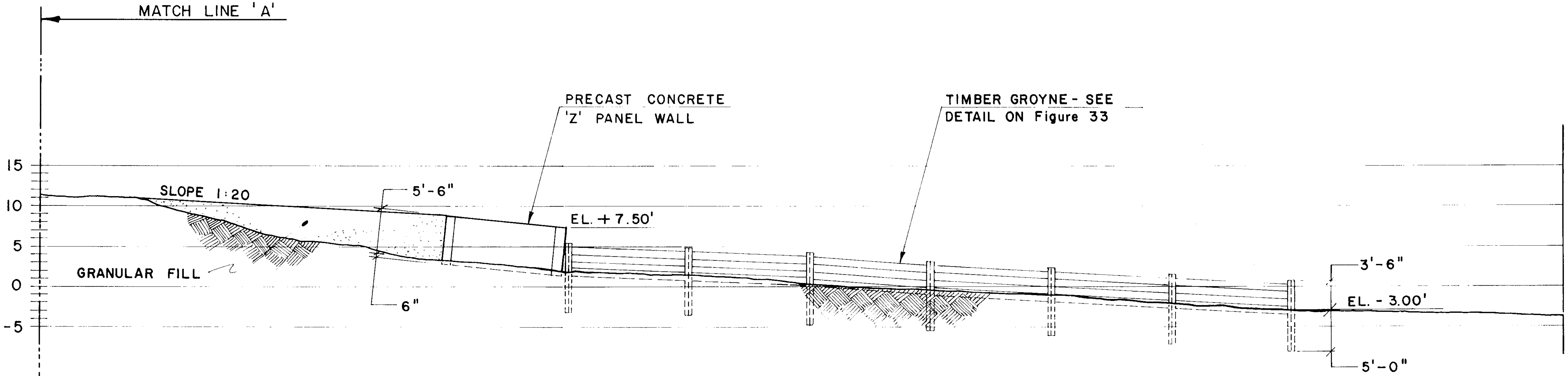


PROFILE NEAR OIL TANKS

SCALE : $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'

NOTE

GROYNES TO BE FILLED WITH COARSE GRANULAR MATERIAL AND SLOPED AT 1:10



PROFILE NEAR OIL TANKS (cont'd.)

SCALE : $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'

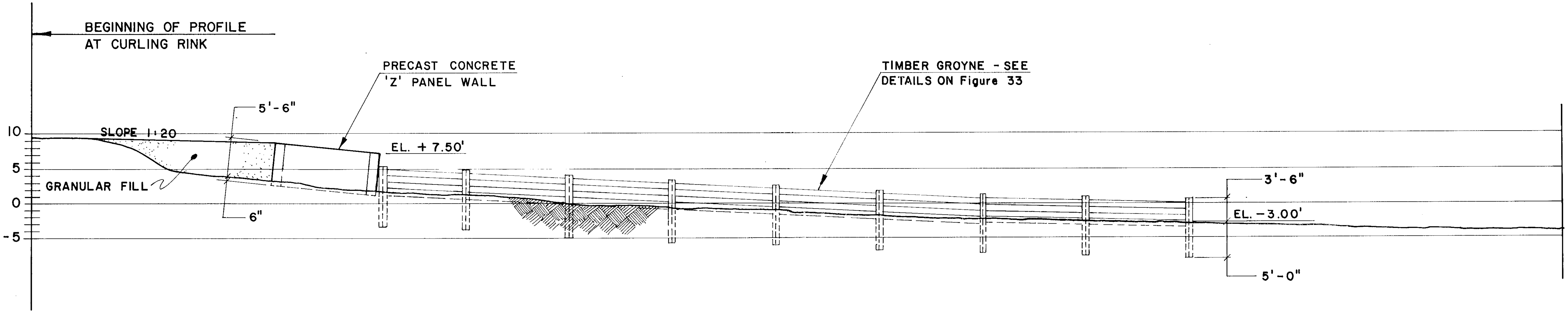
TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY

PROFILE NEAR OIL TANKS

ALTERNATIVE 2

Proposed 'Z' Panel Wall Shore Protection

Figure — 34



PROFILE AT CURLING RINK

SCALE: HORIZ / VERT 1" = 10'

NOTE

GROYNES TO BE FILLED WITH COARSE GRANULAR MATERIAL AND SLOPED AT 1:10

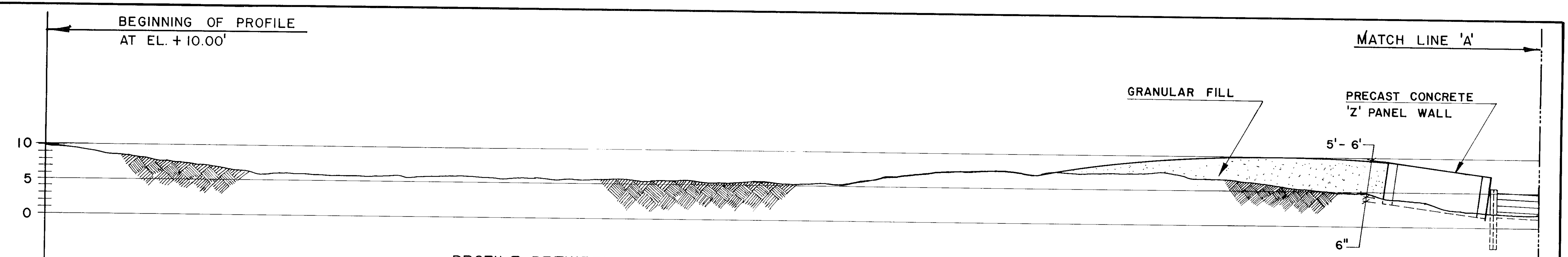
TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY

PROFILE AT CURLING RINK

ALTERNATIVE 2

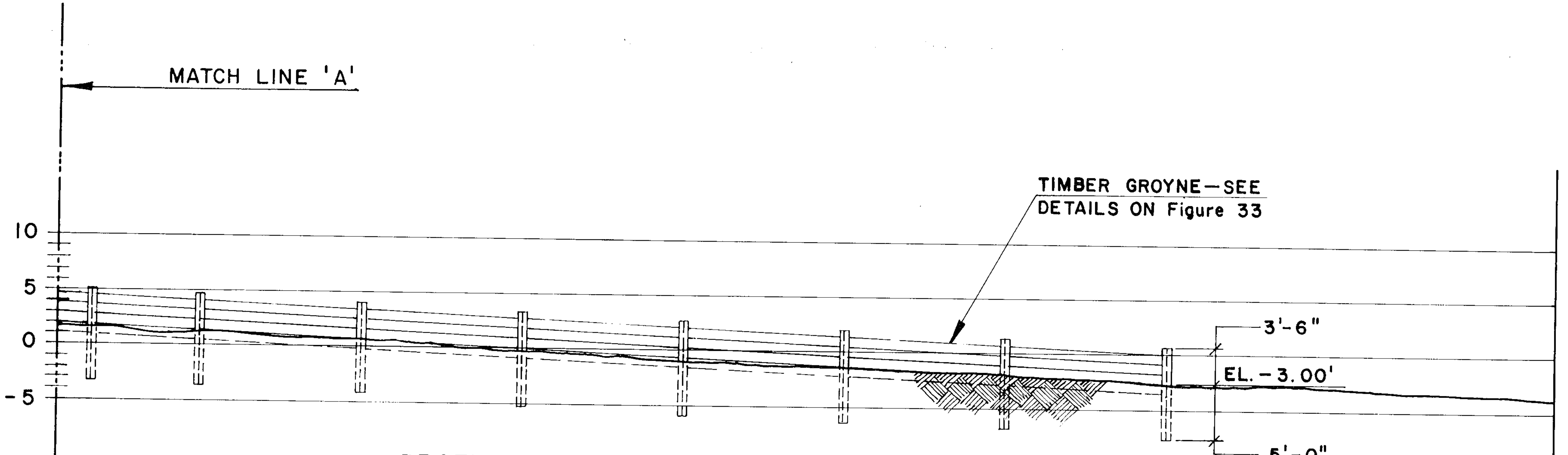
Proposed 'Z' Panel Wall Shore Protection

Figure — 35



PROFILE BETWEEN CURLING RINK & RCMP GARAGE

SCALE : $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'



PROFILE BETWEEN CURLING RINK & RCMP GARAGE (cont'd.)

NOTE

GROYNES TO BE FILLED WITH COARSE GRANULAR MATERIAL AND SLOPED AT 1:10

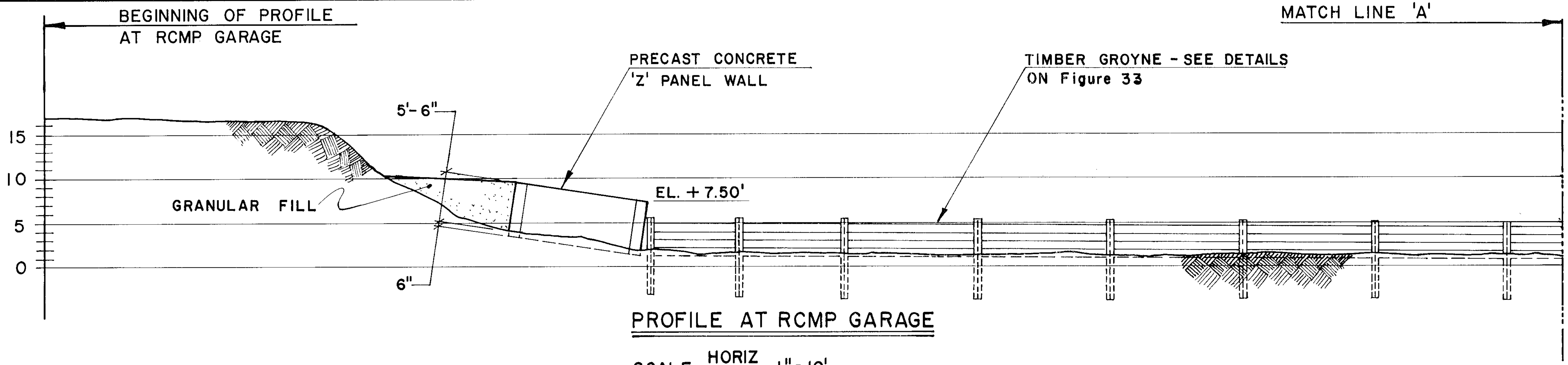
TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY

PROFILE BETWEEN CURLING RINK & RCMP GARAGE

ALTERNATIVE 2

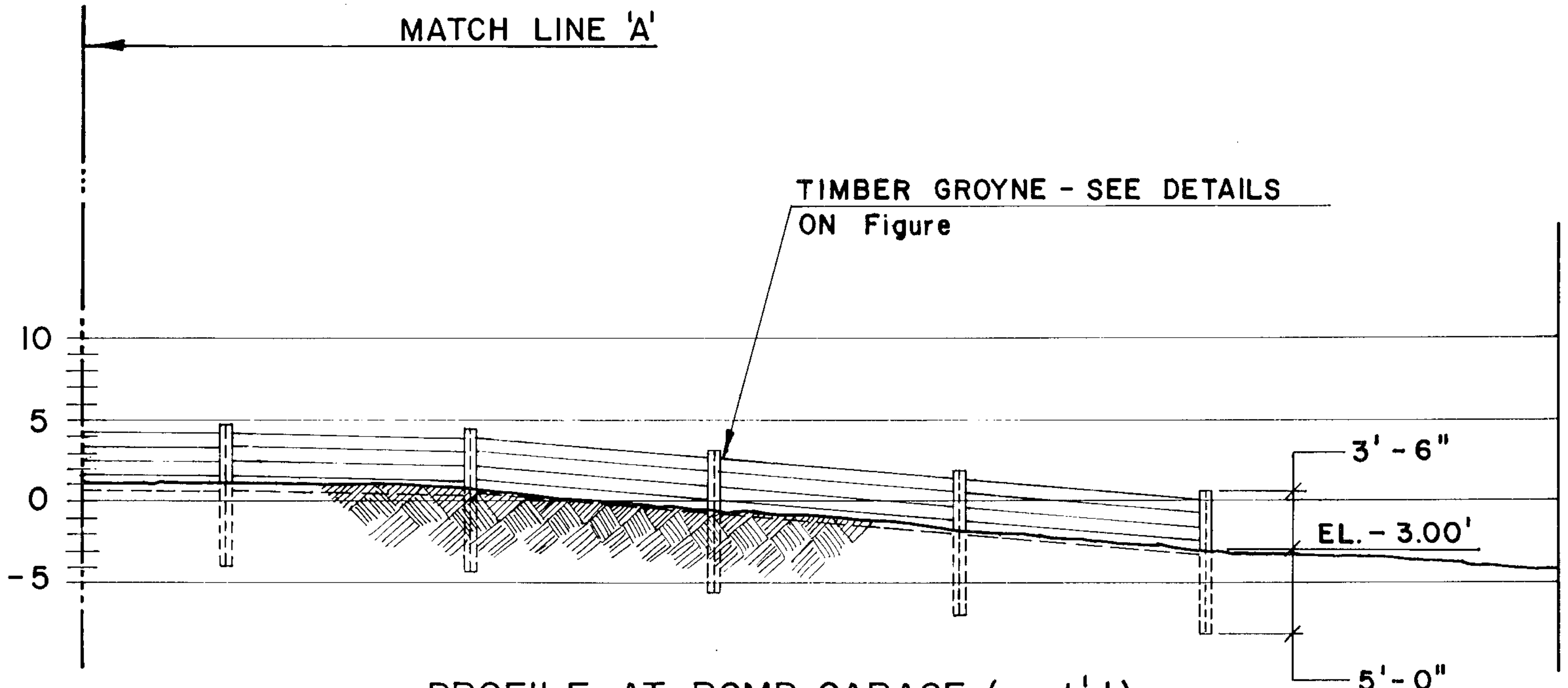
Proposed 'Z' Panel Wall Shore Protection

Figure — 36



PROFILE AT RCMP GARAGE

SCALE: $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'



PROFILE AT RCMP GARAGE (cont'd.)

SCALE: $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'

NOTE

GROYNES TO BE FILLED WITH COARSE GRANULAR MATERIAL AND SLOPED AT 1 : 10.

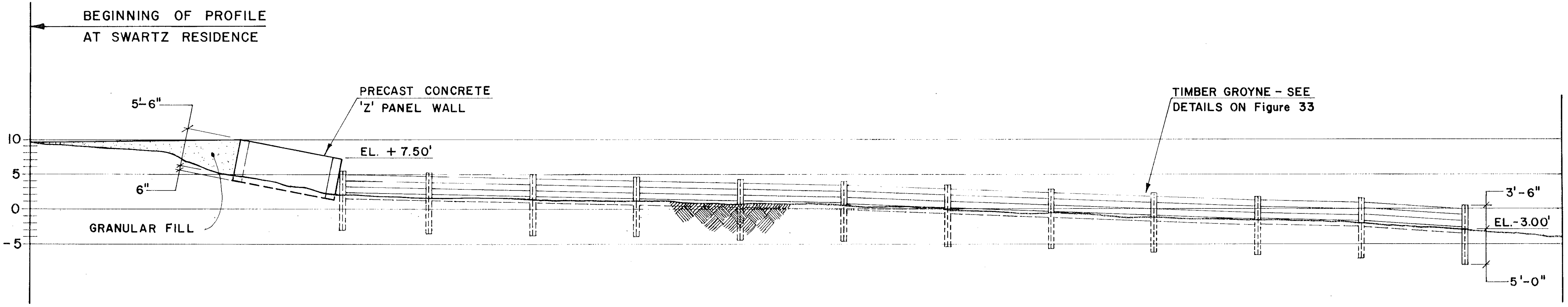
TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY

PROFILE AT RCMP GARAGE

ALTERNATIVE 2

Proposed 'Z' Panel Wall Shore Protection

Figure — 37



PROFILE AT SWARTZ RESIDENCE

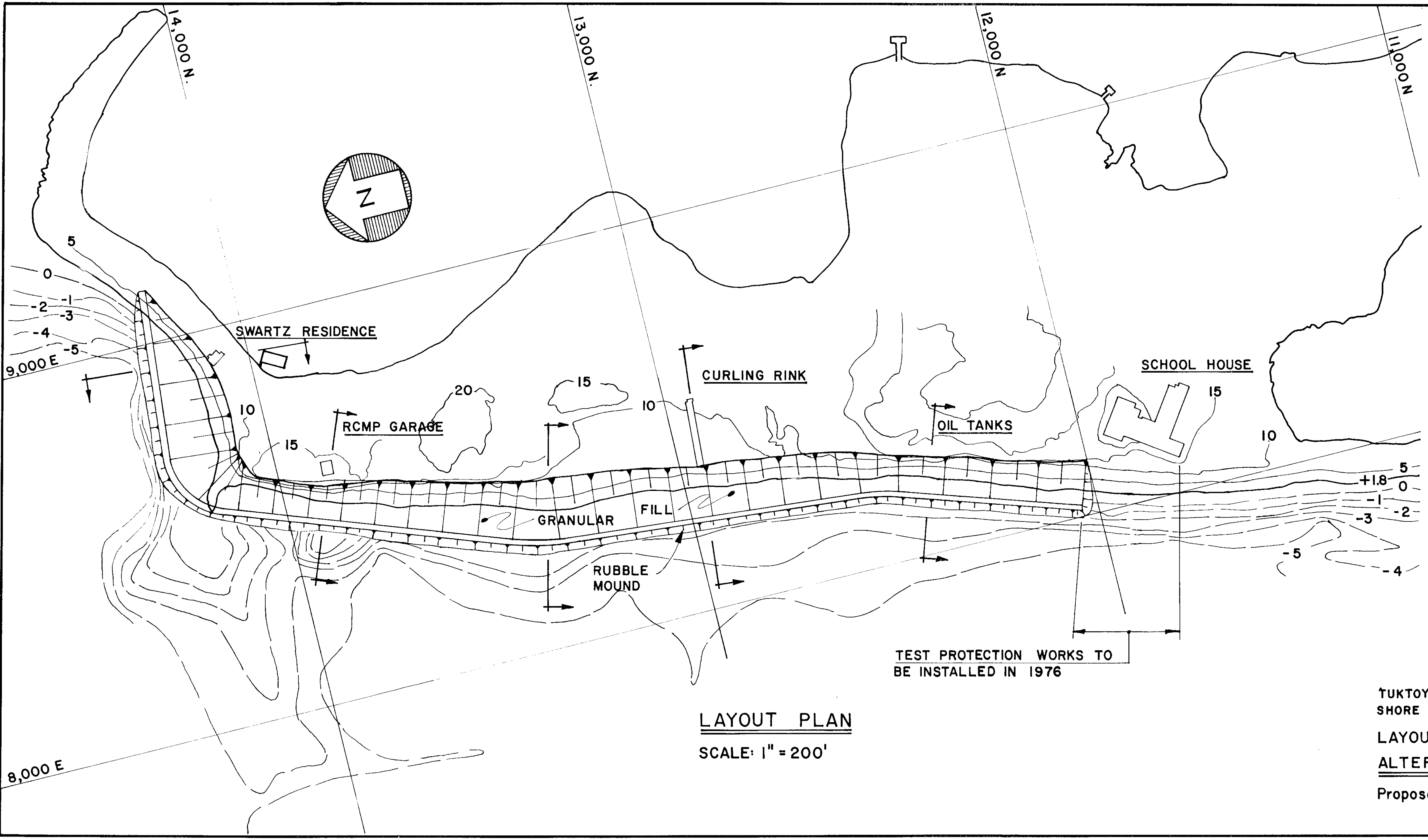
SCALE: $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'

NOTE

GROYNES TO BE FILLED WITH COARSE GRANULAR MATERIAL AND SLOPED AT 1 : 10.

TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY
PROFILE AT SWARTZ RESIDENCE
ALTERNATIVE 2
Proposed 'Z' Panel Wall Shore Protection

Figure — 38



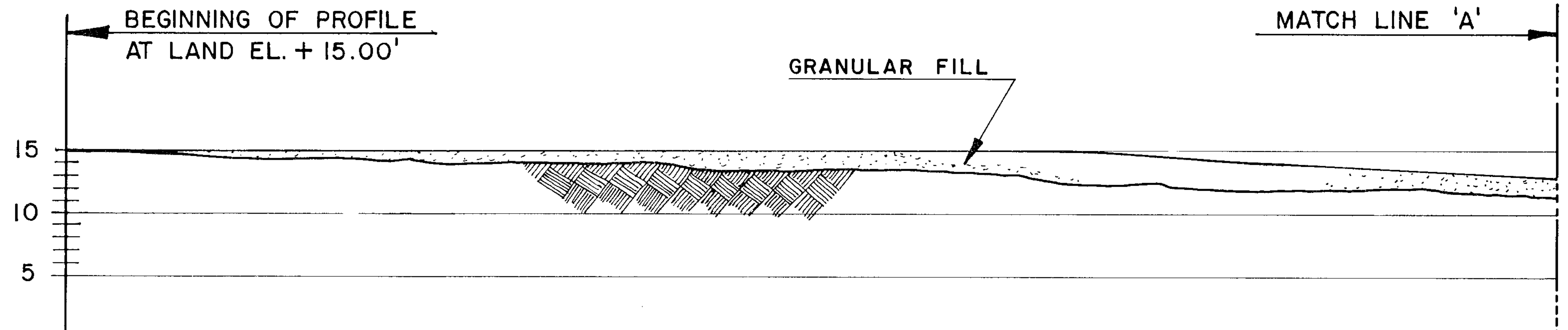
TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY

LAYOUT PLAN

ALTERNATIVE 3

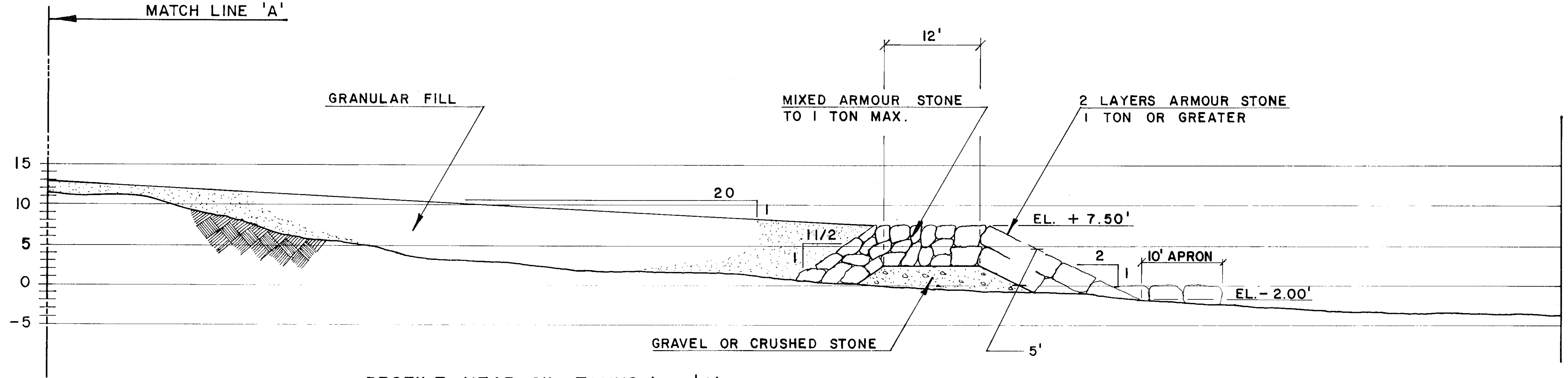
Proposed Rubble Mound Shore Protection

Figure — 39



PROFILE NEAR OIL TANKS

SCALE : $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'



PROFILE NEAR OIL TANKS (cont'd.)

SCALE : $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'

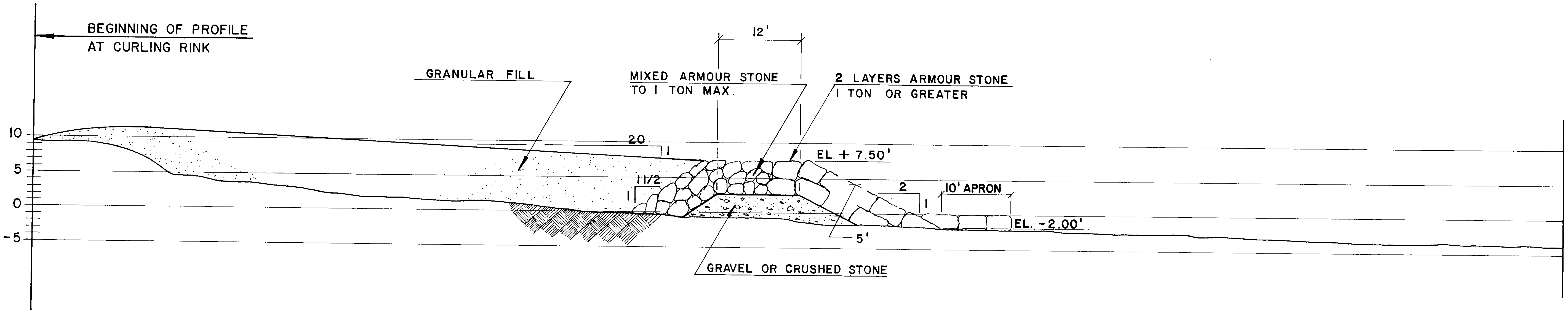
TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY

PROFILE NEAR OIL TANKS

ALTERNATIVE 3

Proposed Rubble Mound Shore Protection

Figure – 40



PROFILE AT CURLING RINK

SCALE: $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'

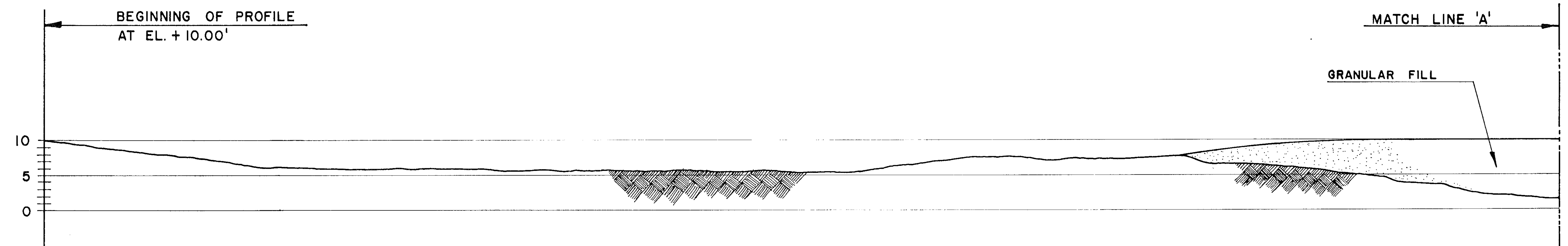
TUKTOYAKTUK N.W.T.
SHORE EROSION & PROTECTION STUDY

PROFILE AT CURLING RINK

ALTERNATIVE 3

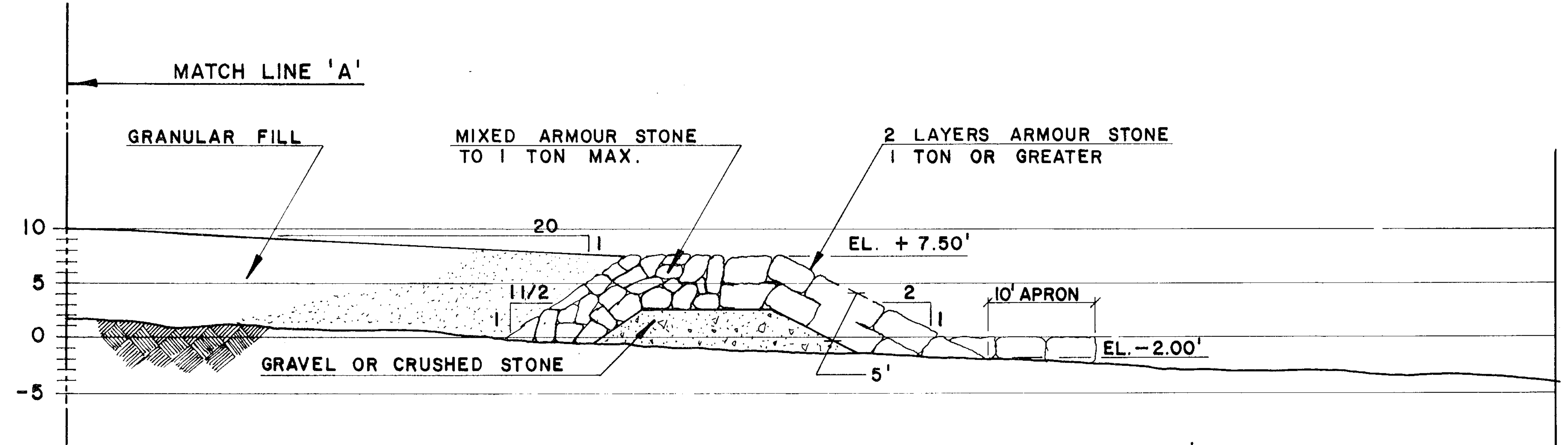
Proposed Rubble Mound Shore Protection

Figure — 41



PROFILE BETWEEN CURLING RINK & RCMP GARAGE

SCALE : $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'



PROFILE BETWEEN CURLING RINK & RCMP GARAGE (cont'd.)

SCALE : $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'

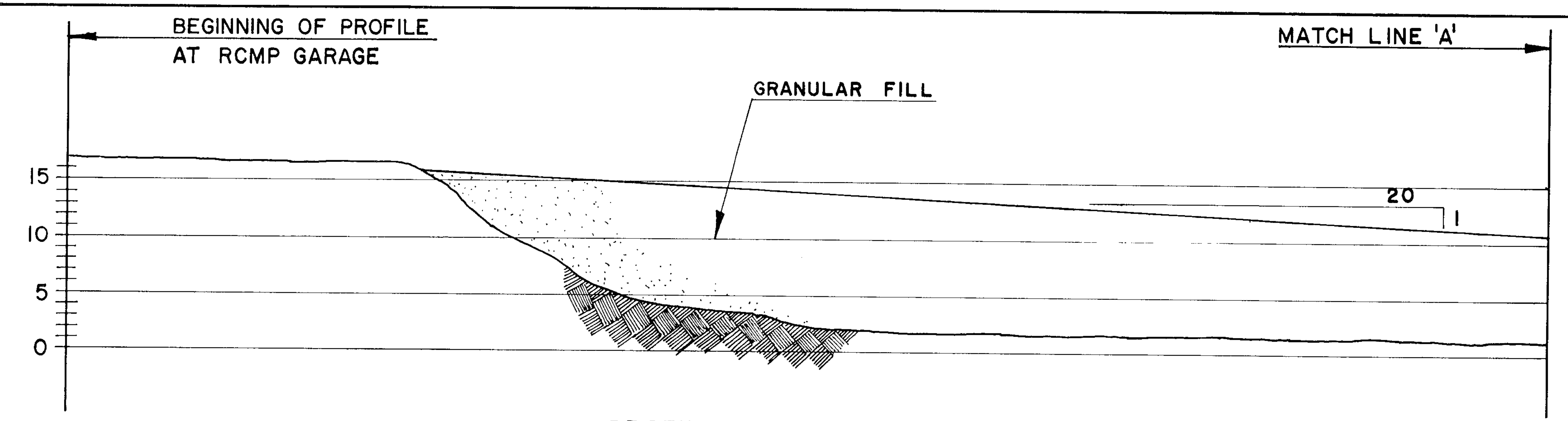
TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY

PROFILE BETWEEN CURLING RINK & RCMP GARAGE

ALTERNATIVE 3

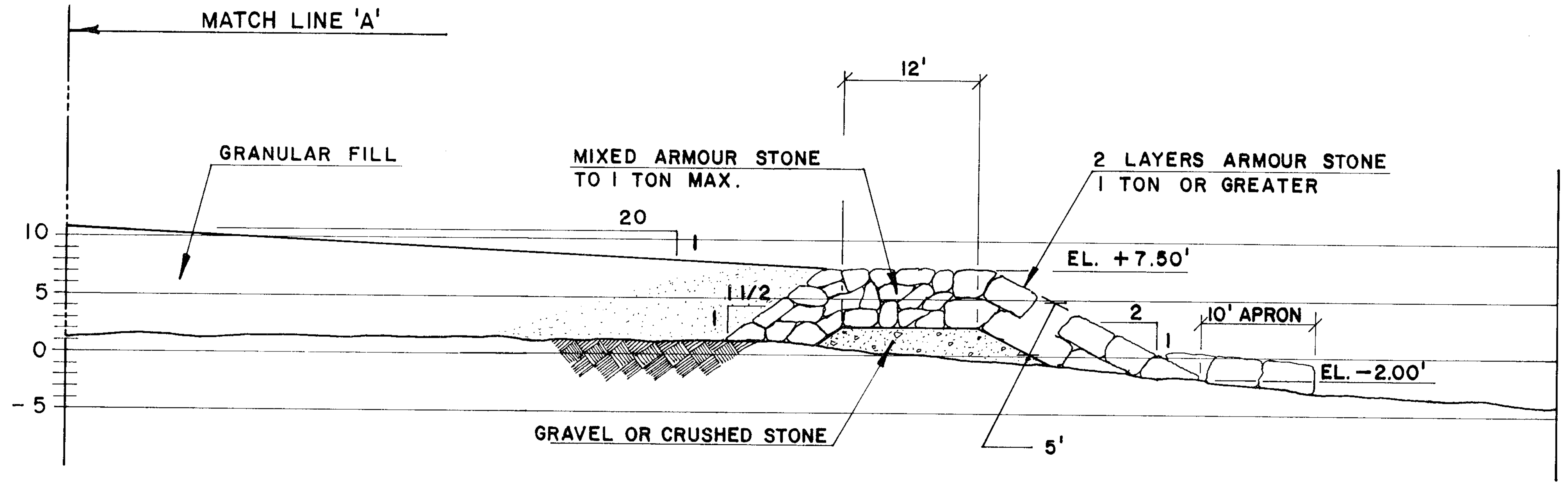
Proposed Rubble Mound Shore Protection

Figure – 42



PROFILE AT RCMP GARAGE

SCALE : HORIZ / VERT 1" = 10'



PROFILE AT RCMP GARAGE (cont'd.)

SCALE : HORIZ / VERT 1" = 10'

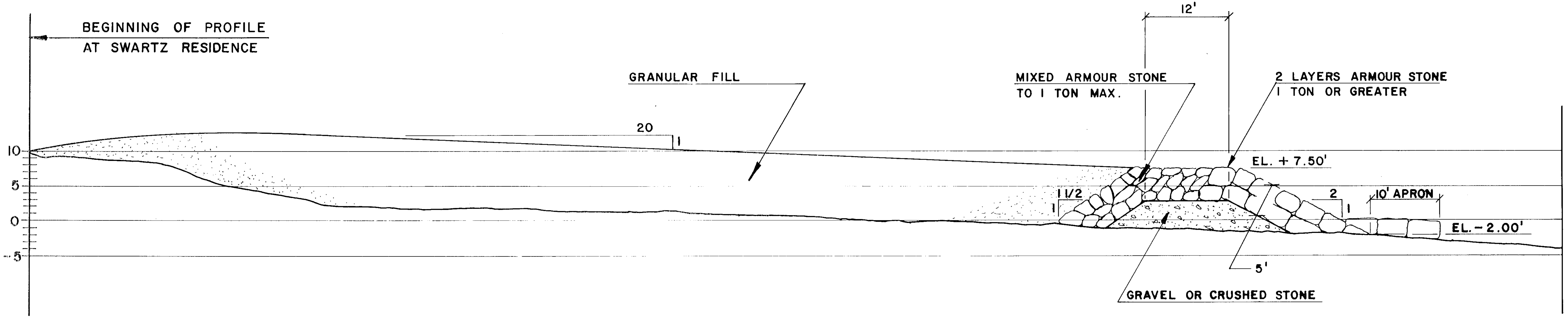
TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY

PROFILE AT RCMP GARAGE

ALTERNATIVE 3

Proposed Rubble Mound Shore Protection

Figure – 43



PROFILE AT SWARTZ RESIDENCE

SCALE: $\frac{\text{HORIZ}}{\text{VERT}}$ 1" = 10'

TUKTOYAKTUK N. W. T.
SHORE EROSION & PROTECTION STUDY

PROFILE AT SWARTZ RESIDENCE

ALTERNATIVE 3

Proposed Rubble Mound Shore Protection

Figure — 44