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PHYSICAL AND BIOLOGICAL PARAMETERS, LITTLE SAND BAY, APOSTLE ISLANDS NATIONAL LAKESHORE, AND RELATIONSHIPS TO VARIOUS DOCKING DESIGNS (PHASE II)

a report by the

CENTER for LAKE SUPERIOR ENVIRONMENTAL STUDIES

of the

UNIVERSITY of WISCONSIN SUPERIOR

"Nature is Often Hidden: Sometimes Overcome, Seldom Distinguished"

Essays: Of Nature In Men
by Frances Bacon
published in 1597

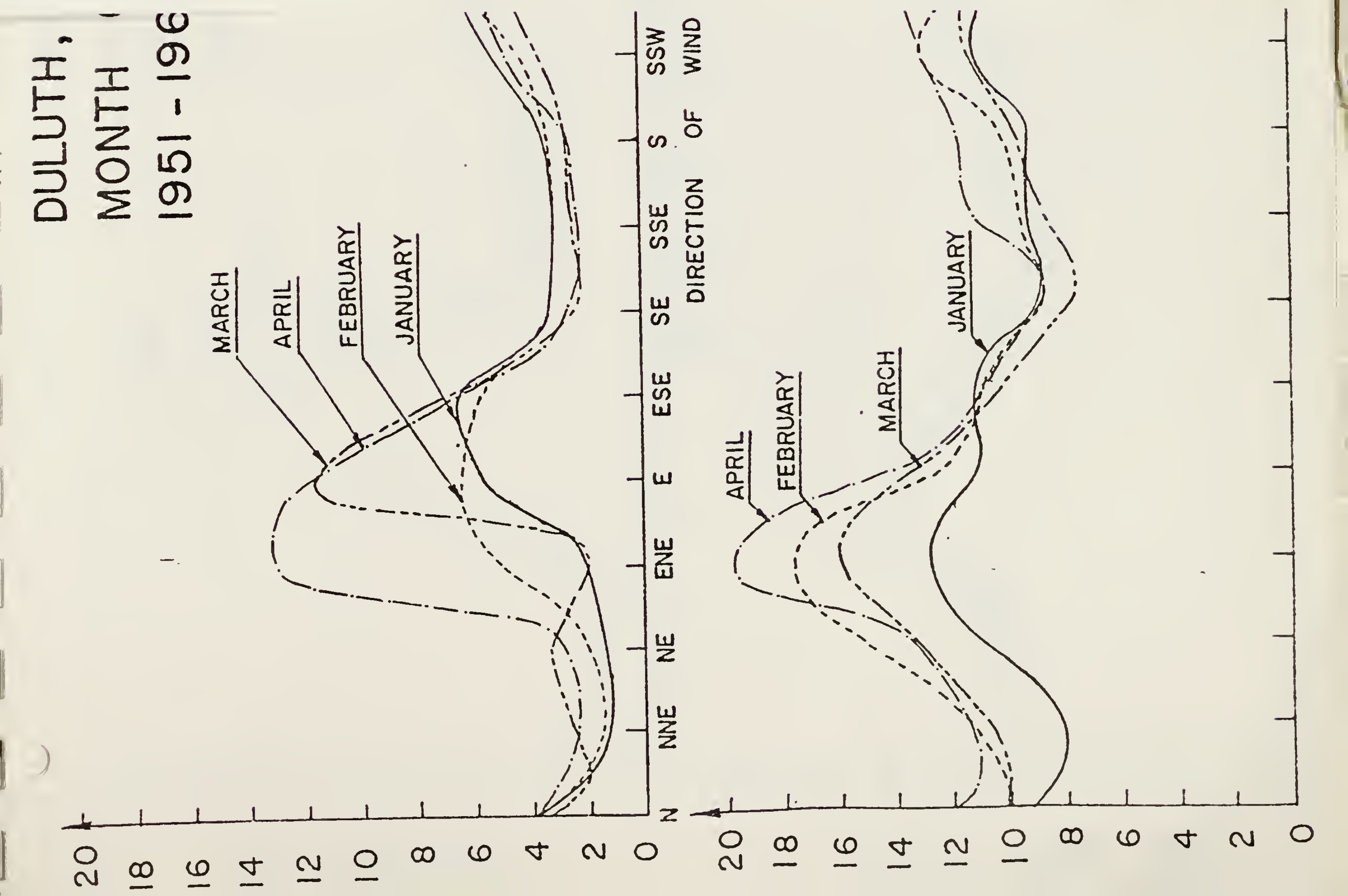
[illegible]

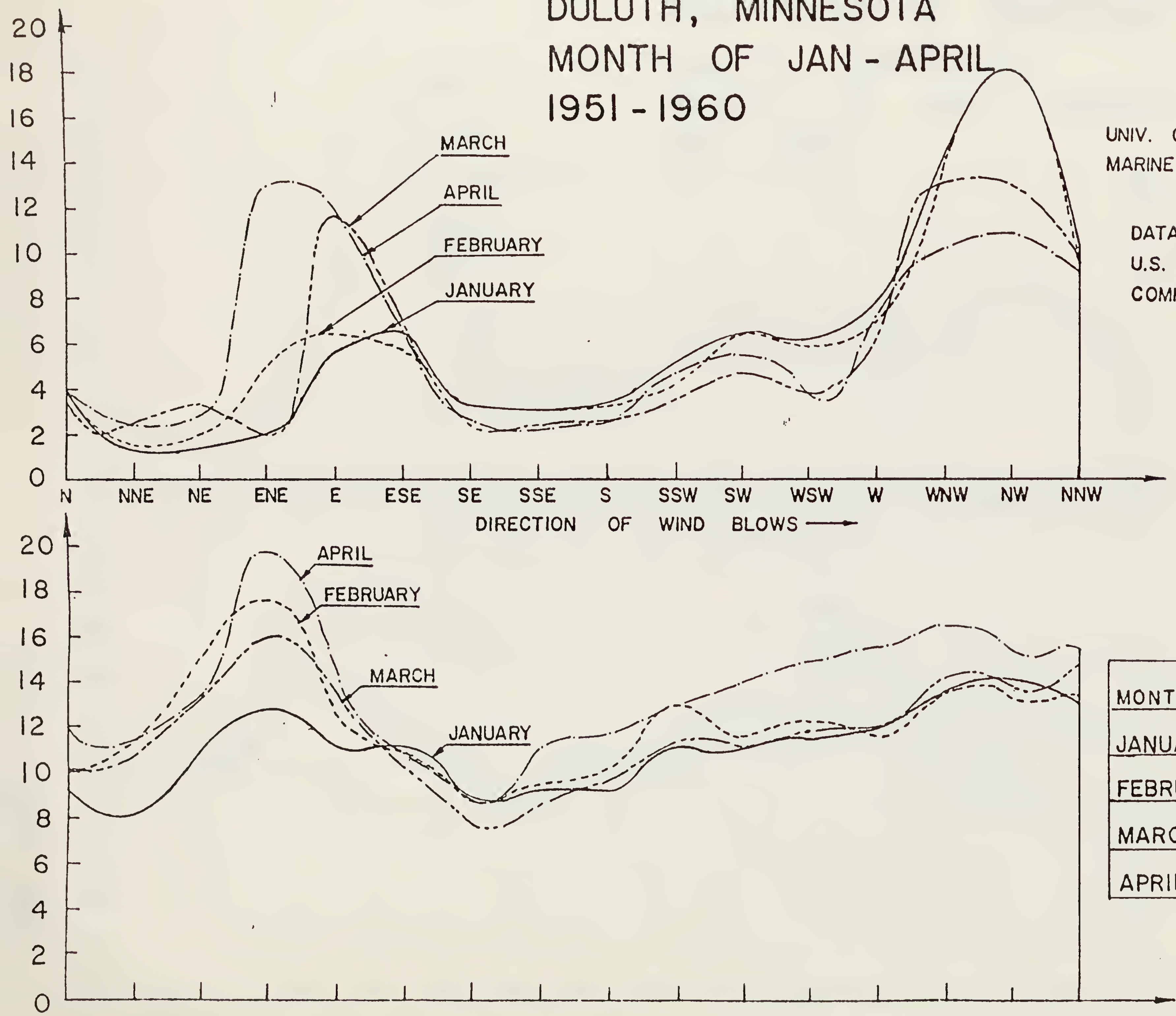
TO: Recipients of Contract #CX-2000-5-0034 Report
FROM: A. B. Dickas, Director, CLSES, Univ. of Wisconsin Superior
SUBJECT: Additional Information

Each of you has recently received a final report titled "Physical and Biological Parameters, Little Sand Bay, Apostle Islands National Lakeshore, and Relationships to Various Docking Designs (Phase II)."

Attached is a copy of supporting information I have just this morning received. It supports the data contained within our report, however, I thought you might like to have a copy.

ABD:dd





UNIV. OF WIS. - MADISON
MARINE STUDIES CENTER

DATA FROM :
U.S. DEPARTMENT OF
COMMERCE

MONTH	No. of Obs.
JANUARY	7440
FEBRUARY	6790
MARCH	7440
APRIL	7200

WIND SPEED & DIRECTION
DULUTH, MINNESOTA
MONTH OF MAY - AUGUST
1951 - 1960

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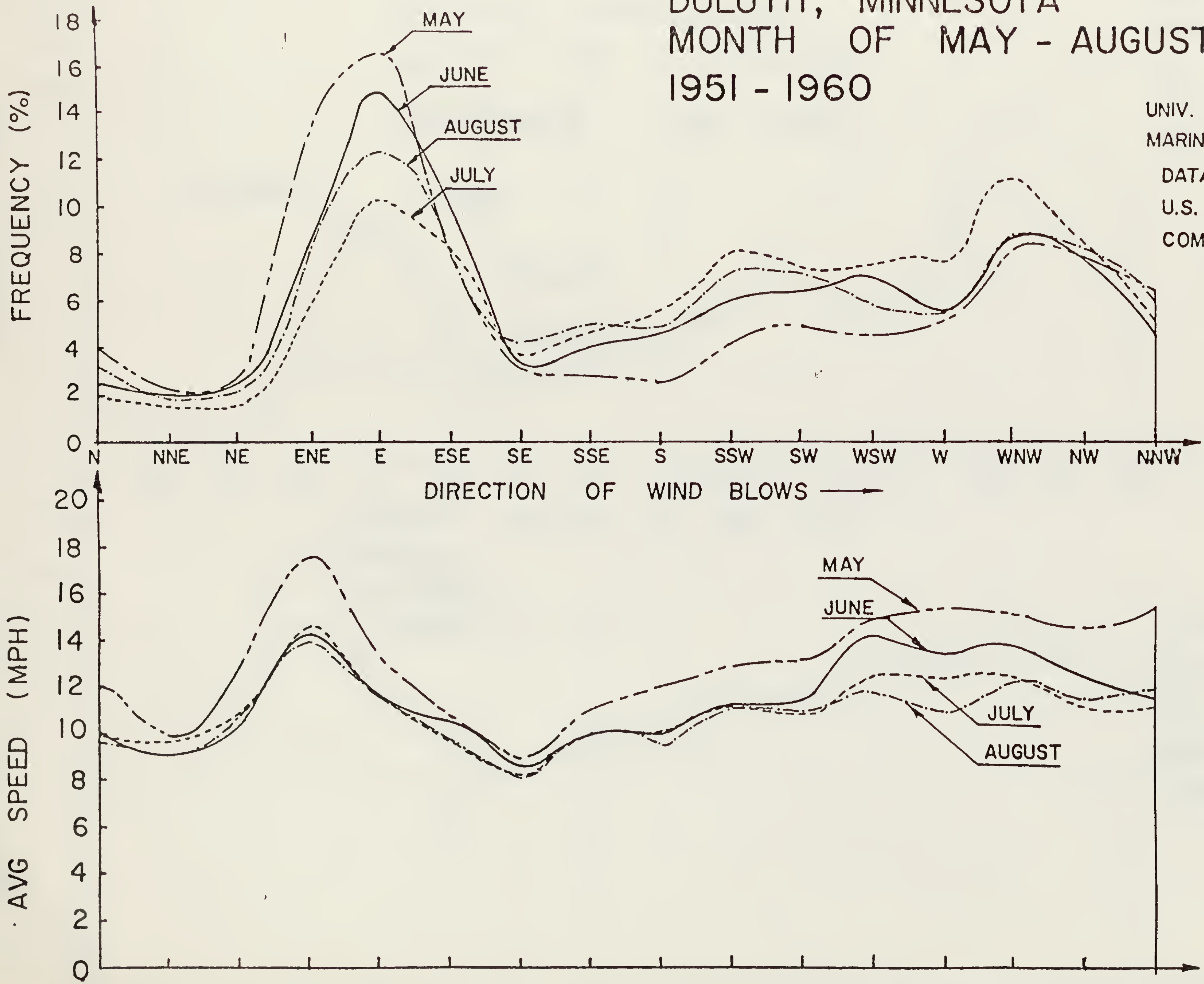
DATA FROM :
U.S. DEPARTMENT OF COMMERCE

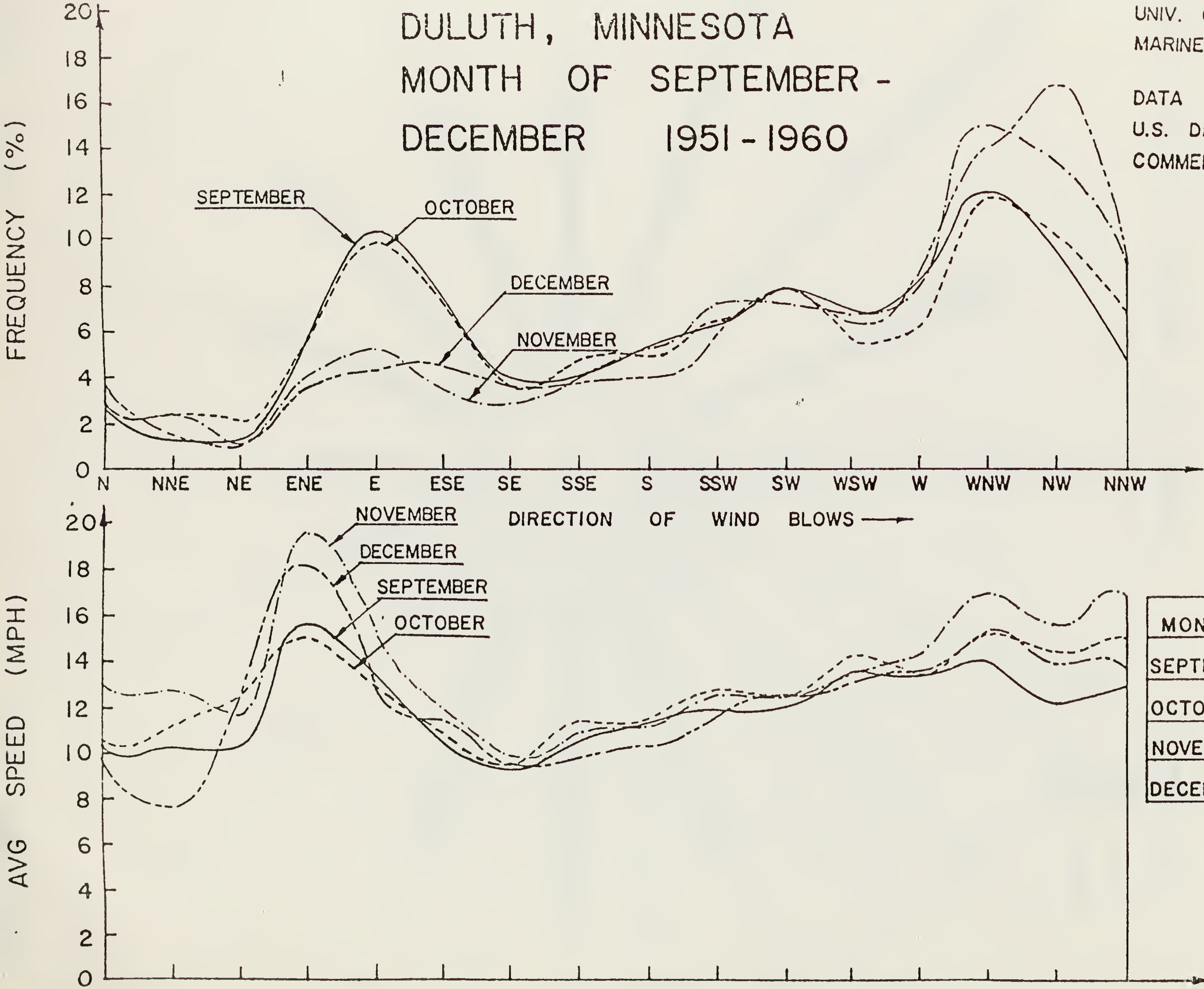


MONTH	No. of O
MAY	7440
JUNE	7200
JULY	7440
AUGUST	7440

WIND SPEED & DIRECTION
DULUTH, MINNESOTA
MONTH OF SEPTEMBER - DECEMBER 1951 - 1960

UNIV. OF WIS. - MADISON
MARINE STUDIES CENTER

DATA FROM :
U.S. DEPARTMENT OF COMMERCE



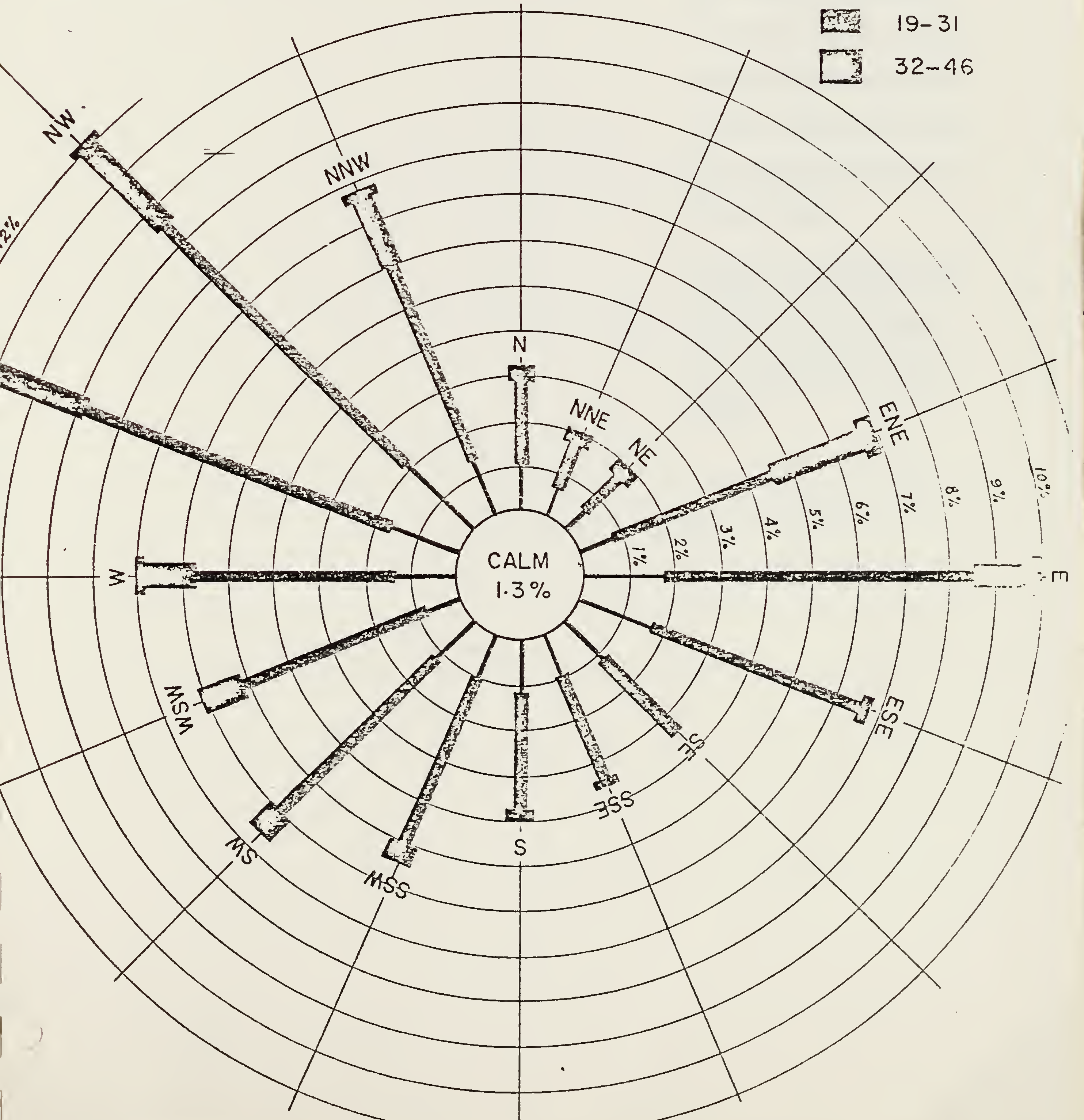
MONTH	No. of Obs
SEPTEMBER	7200
OCTOBER	7440
NOVEMBER	7200
DECEMBER	7440

ANNUAL WIND SPEED, FREQUENCY & DIRECTION. DULUTH, MINNESOTA 1951 - 1960

DATA FROM: U.S. DEPARTMENT OF COMMERCE

AVG SPEED RANGE (mph)

- 0-7
- 8-18
- 19-31
- 32-46



AVG SPEED: 12·6 mph

NO. OF OBS.: 87,672

NOTE:

This report is complete in every sense to the contract original submitted to the National Park Service except for the following change:

Original photographs (as listed on page vi) are copy reproduced in this report.

PHYSICAL AND BIOLOGICAL PARAMETERS, LITTLE SAND BAY, APOSTLE ISLANDS NATIONAL LAKESHORE, AND RELATIONSHIPS TO VARIOUS DOCKING DESIGNS

(PHASE II)

Submitted To

Denver Service Center
National Park Service
755 Parfet Street P.O. Box 25287
Denver, Colorado 80225

By The

Center for Lake Superior Environmental Studies
University of Wisconsin, Superior

Participating Investigators

1. Albert B. Dickas, Ph.D., Project Administrator, Associate Professor of Geology and Director of the Center for Lake Superior Environmental Studies
2. William F. Rittschof, B.A. Project Director and Field Geologist
3. Larry T. Brooke, M.S., Field Aquatic Biologist
4. Philip W. DeVore, M.S., Field Aquatic Biologist
5. William A. Swenson, Ph.D., Assistant Professor of (Fisheries) Biology

15 September, 1975

Work Conducted Under National Park Service Contract Number CX-2000-5-0034, Dated 28 May, 1975

Contract Publication Number 33
Center for Lake Superior Environmental Studies
University of Wisconsin, Superior
Superior, Wisconsin 54880

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~~Holder~~ mjt 10/6

placed on Regional Review
returned to PS library 10/6
copy of letter to main files
MWR Info Review 10/20-11/

1 October, 1975

Mr. Merril D. Beal
Regional Director
Midwest Region
National Park Service
1709 Jackson
Omaha, NB 68102

Dear Mr. Beal:

Mr. Joel Kussman, contracting officers authorized representative for our recently completed study (NPS contract # CX-2000-5-0034) titled "Physical and Biological Parameters, Little Sand Bay, Apostle Islands National Lakeshore, and Relationships to Various Docking Designs (Phase II)" suggested I send your office a copy for review.

We would welcome your comments as always.

Sincerely,

Albert B. Dickas

Albert B. Dickas, Director
Center for Lake Superior Environmental Studies

ABD:ds

Enclosure

cc Mr. Joel Kussman

LIST OF CONTAINED FIGURES

LIST OF CONTAINED TABLES

LIST OF CONTAINED PHOTOGRAPHS

LIST OF APPENDICES*

*Contained in back of this report.

INTRODUCTION

This study, the third of a sequence, was conducted during the period 28 May to 15 September, 1975 by personnel of the Center for Lake Superior Environmental Studies (CLSES) of the University of Wisconsin, Superior (UW-S) for the National Park Service (NPS) and concerns developmental plans relating to the Apostle Islands National Lakeshore (AINL) of northwestern Wisconsin. The initial two reports were titled:

1. Environmental Survey, Little Sand Bay Headquarters Site, Apostle Islands National Lakeshore, Wisconsin (submitted to Midwest Regional Office of the National Park Service, 30 October, 1974).
2. Physical and Biological Parameters, Little Sand Bay, Apostle Islands National Lakeshore, and Relationships to Various Docking Designs (submitted to Denver Service Center of the National Park Service, 25 January, 1975).

In brief the objectives of these studies were as follows:

Environmental Survey Study

1. Baseline analyses of existing physical, hydrologic and vegetative parameters of the immediate proposed AINL headquarters site. These investigations included topographic relief, drainage, soil analysis, water quality, organic cover (type and degree of unusual species) and geologic and biologic points of interest.
2. Recommendation of placement of eleven (11) proposed service cluster areas in relation to environmental factors, resulting in maximum use of headquarters site by NPS and visitor personnel with minimal deterioration to the local terrestrial-based environment.

Physical and Biological Parameter Study

1. Analyze the shoreline and immediate offshore area of Little Sand Bay from the viewpoints of physical littoral and beach activities and adjacent neritic biological lake floor and water column aspects.
2. Relation of this collected data to the AINL Master Plan mentioned docking/breakwater system.
3. Provision of a sound basis for decision making in the location and construction style of this (these) facility(ies).

In the spring of 1975 CLSES was again contacted by the NPS Denver Service Center to discuss a Summer Season follow-up study to the second study discussed above. Similar objectives were discussed with the principal alteration being one of a change in the priority sampling area. As compared to the second study, this program was to concentrate on that longshore and offshore area immediately to the east of the proposed Headquarters site of the Apostle Islands National Lakeshore. Additionally this newly collected summer data was to be cross-correlated to the previously collected autumn 1974 data in order to formulate a composite view of both studied regions.

All three (3) studies are an outgrowth of a preliminary, five (5) year multi-disciplinary analysis plan submitted to Apostle Island National Lakeshore personnel on 11 November, 1973. This report, requested by the National Park Service, discussed the nature and priority of applied field research CLSES personnel felt was necessary to the development processes of creating and opening this very scenic Lake Superior shoreline property to visitors.

Those members of the Center for Lake Superior Environmental Studies staff who worked on this project, and their University positions are as follows:

Dr. Albert B. Dickas:	Project Administrative Director, Associate Professor of Geology and Director, Center for Lake Superior Environmental Studies.
Mr. William F. Rittschof:	Project Field Director and Visiting Specialist in (Coastal Zone) Geology.
Mr. Larry T. Brooke:	Visiting Specialist in (Fisheries and Benthic) Biology.
Mr. Philip W. DeVore:	Visiting Specialist in (Fisheries and Benthic) Biology.
Dr. William A. Swenson:	Assistant Professor of (Fisheries) Biology and University of Wisconsin, Extension

OBJECTIVES

In the Development Concept Plan (Draft) of the Little Sand Bay area of the Apostle Islands National Lakeshore, dated April of 1974, the following statements are listed under the heading of Concessioner (p. 5):

> "The projected concessioner operation at Little Sand Bay will provide a range of services to the visitor primarily centered on overnight use of the island campgrounds. Water transportation to the islands either through boat rentals or 'taxi' boats will be anticipated. A modest mooring facility* will be required as a base for boating activities.
>
> Boat launching facilities will be constructed adjacent to the concessioner operation. The approach to the launching ramp will be so designed that the camping visitor, as well as the boaters, can use the approach road to unload his camping gear near the concession facility and then move his car to the long term parking area."

No details as to exact location, number of structures or design of this docking/breakwater system were contained within this draft report. The National Park Service felt that, prior to the determination of such architectural detail, and also prior to actual construction, the flora and fauna of the beach and coastal water ecosystems should be surveyed and considered in the development of these facilities in order to mitigate the impairments to the environment. In addition, it is suggested that an intensive study of the geomorphology and coastal processes which affect the Little Sand Bay proposed construction zone should be analyzed and consideration given to development which would minimally disturb these factors.

In more detail the contract associated with this study (CX-2000-5-0034) states that a late spring/summer seasonal assessment shall be performed on the coastal

* *Emphasis by authors*

lands (beach areas) and offshore waters of those portions of Little Sand Bay affected by the potential construction of the proposed docking/breakwater system, emphasis being placed upon the potential site due east of the existing harbor facility and within the confines of the following categories of analyses:

1. An inventory and analyses of existing published reference material.
2. A biological environmental survey which would provide information on the following relevant topics:
   a. species composition, relative abundance and distribution of plant communities, fish populations and benthic populations in the Little Sand Bay proposed construction zone.
   b. determination whether fish species spawning and nursery sites exist within the area and, if so, define such spawning and nursery boundaries.
   c. definition of special habitat and/or behavioral requirements for any other special organisms inhabiting the proposed construction zones.
   d. definition of relationship of flora and faunal communities with respect to lake depth and bottom types.
3. Geomorphology and coastal processes survey focusing upon the physical features and coastal processes.
   a. Physical makeup of beach littoral materials according to size and range.
   b. Configuration and openness of the shoreline to attack by elements.
   c. Depth of and stability of offshore waters.
   d. Wind direction, frequency, wave climate and intensity of storms to be evaluated by direct observation and/or historical records.
   e. Nearshore currents and wave-induced water motion should be surveyed and analyzed.

f. Longshore transport direction and littoral drift rates should be determined based upon the sampling period and existing records.

g. Erosion and accretion rates for the present beach zone should be estimated.

h. Erosion, sedimentation and deposition in the shallow, neritic zone should be estimated as best possible based upon the sampling period.

i. Direction and rates of on and offshore sediment motion should be determined.

Each of the above sets of parameters would be assessed technically as they may cause a positive or negative impact upon the overall Little Sand Bay environment when consideration is given to the interrelationship of these parameters and certain types of a docking/breakwater system (as an example, a solid versus flow-through versus floating system).

Such a technical evaluation on effects of establishing each one of several alternate designs and locations will include:

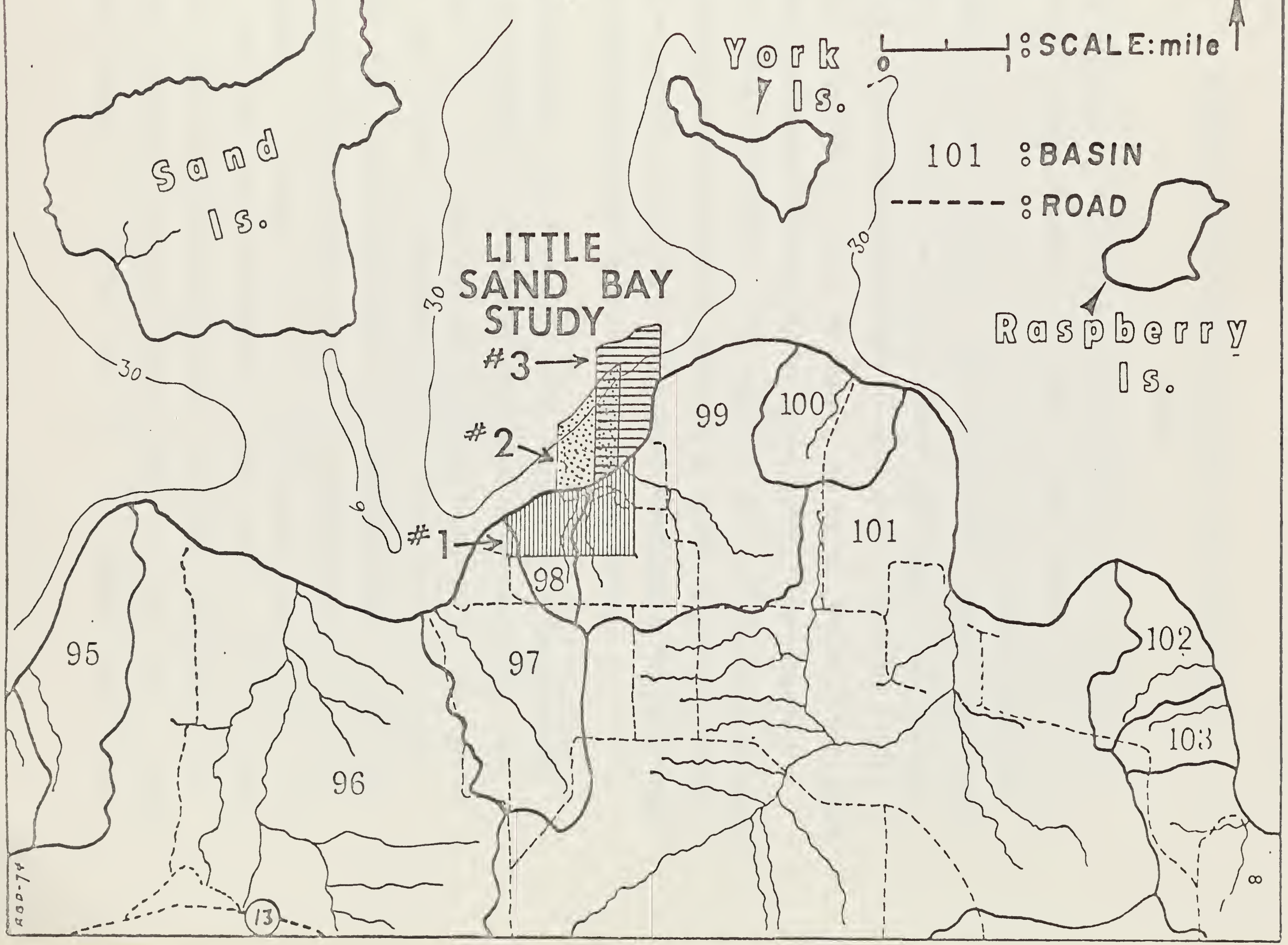
1. Effects on nearshore currents and longshore transport characteristics.
2. Effects on beach stabilization processes.
3. Effects on sedimentation and deposition rates in the shallow neritic zone.
4. Effect on material buildup proximal to the breakwater system and eventual need for dredging operations.
5. Effect on the flora and fauna in the aquatic ecosystem, such as population reduction or eliminations and habitat alterations, that might result from changes in currents, sedimentation and/or erosion.

This study covers the late spring/summer season which when combined with the previous report of the late fall/early winter season (contract number CX-2000-5-0013), should give a total yearly cycle (minus winter conditions) for both

physical and biological parameters. However, it must be emphasized such a "typical" yearly cycle does not exist, and care must be taken in extrapolating yearly trends based upon a two to three season sample period. Wherever possible, published and historical data have been sought and employed herein to allow for differing yearly trends.

Figure 1 identifies the location of this study (noted as area 3), as well as the site of the previously described and related initial two study sites (noted as areas 1 and 2; for purposes see Introduction Section).

FIG. 1 STUDY LOCATION



PHYSICAL AND BIOLOGICAL SETTING OF THE STUDY AREA

A. GEOLOGY

Little Sand Bay, a small, semi-protected reentrant on the north side of the Bayfield Peninsula, encompasses the offshore waters of Sections 28, 29 and 32, T51, R4W. The onshore area is located within the Lake Superior lowland physiographic province of Wisconsin. While elevations here generally range between 580 and 1,000 feet above sea level, the entire north sector of Bayfield County consists of rugged shoreline; portions of which face out toward the Apostle Islands. Sand and York Island (see Figure 1) are the two members of the Apostle Island group closest to Little Sand Bay. Sand Island is approximately two and one-third miles offshore, to the northwest, while York Island lies two and one-half miles to the northeast. These islands, as well as prominent headlands such as Sand Point to the west and Point Detour immediately to the east, afford some wind and wave protection to the Little Sand Bay locality.

Little Sand Bay, on the south shore of Lake Superior, is integrally related in its development to the historical development of the lake itself. Lake Superior lies in the trough of a great syncline, or downfold, in the rocks of the southern end of the Precambrian aged (>600 million years old) Canadian Shield. This lake basin was scoured out by successive glacial ice lobes that transgressed the rock syncline at various times during the Pleistocene epoch, culminating in the Superior lobe of the Wisconsin-aged glaciation about 11,000 years old. The movement of the Superior ice lobe down the axis of the syncline was one of the last great geologic events in the region and resulted both in a general depression of the land under the weight of the ice as well as a final geometric shaping of the eventual lake basin. As the Superior lobe of glacial

ice began to melt northward, a vast glacial lake was formed by meltwater ponded between resistant Precambrian rock to the west and south and the yet unmelted glacier to the north. The surface of this ancient lake, termed Glacial Lake Duluth, had a water surface almost twice as high above sea level as present Lake Superior (datum of 600 feet) (Schwartz and Thiel, 1954 and Farrand, 1969). During the last ten millennia interactions of isostatic and climatic conditions have resulted in the positioning of present Lake Superior, with the Apostle Islands being the predominant offshore landmark area of the western portion of the basin.

Little Sand Bay is underlain by ancient Keweenawan lava flows (not exposed in the study area) and overlying younger sandstone units of late Keweenawan time which comprise the Lake Superior Sandstone Group. The specific unit of Lake Superior Sandstone exposed in the study area is the Chequamegon Sandstone (Thwaites, 1912), which has a maximum thickness of 1,000 ± feet and outcrops along the western headland of Little Sand Bay. Prominent regional headlands such as Sand Point and Point Detour are underlain by and formed from this unit. The Chequamegon Sandstone is composed predominately of quartz grains (a probable source of the area's clean quartz sands) with thin lenticular beds of red sandy shale. This stratigraphic unit generally dips to the southeast at less than five degrees to the horizontal. There is considerable variance, however, in depth to bedrock due to the erratic thickness of the surface glacial deposits. Several hundred feet inshore of the western portion of the Little Sand Bay area are sandstone outcroppings exposed by wave action during times when the lake was at higher than present levels. The depth to bedrock at Sand Bay (NE 1/4 of sec. 1, T51N, R5W) is 225 feet while the maximum bedrock depth at

the Little Sand Bay beach zone is estimated to be over 40 feet (Environmental Survey, Little Sand Bay Headquarters Site AINL, UW-Superior, 1974). This situation is typical of most of the bays on this portion of the peninsula and is most likely due to scouring of the bay areas by southerly moving lobes which extended from the parent glacier within the Lake Superior Basin. The present headlands along the coast represent rock masses which partially escaped severe degradation by the ice.

Two small unnamed drainage basins (labeled 98 and 99 on Figure 1), of approximately 0.4 and 2.8 square miles, feed into Little Sand Bay from the adjacent watershed. Although too small for formal geometric classification, a study of surrounding basins indicates this is an area of dendritic drainage patterns, typical of dissected deposits of Pleistocene glacial tills. The particular soil of these drainage basins is the Gray Wooded type, subdivided into the Ontonagon, Pickford and Bergland Soils (Soils of North Central Region of U.S., 1960) which typically develop under a forest cover of deciduous or coniferous (or mixtures of both) trees. The parent material is a thin, unconsolidated, ferruginous glacial deposit, lying over the Lake Superior Sandstone unit.

A narrow sand beach, averaging between ten and twenty feet in width, extends along the shore in the eastern portions of Little Sand Bay and consists of clean, medium to coarse size fragments composed predominately of quartz (SiO_2).

B. BIOLOGY

Water chemistry in the study portion of Lake Superior, has not been studied to date in detail. On a Great Lakes regional basis, Ayers (1962) found dissolved solid concentrations have increased with time in all waters of the Great Lakes except Lake Superior. Major cations reported in Lake Superior are calcium (12.4 ppm), magnesium (2.8 ppm) and sodium (1.1 ppm). Lake Superior possesses a low phosphate level (5 ppb), as compared to 61 ppb for Lake Erie (Table 1). Because of the low nutrient concentration and low water temperatures, Superior is the least productive of the Great Lakes. Commercial fish production, described as pounds per acre of surface area, can be used as an index of productivity and has averaged 0.8 for Lake Superior. Historic averages for other Laurentian Great Lakes are; Ontario 0.92, Huron 1.22, Michigan 1.85 and Erie 7.55 (Long and Scheuler, 1968). A survey of the literature of plankton population studies suggests production of phytoplankton and zooplankton in Lake Superior is lower than in other Laurentian Great Lakes (Davis, 1966). However, Holland (1965) found plankton densities in the Apostle Island area exceeded those in other areas of waters in Lake Superior. Beeton et. al. (1959) reported zooplankton densities in the Apostle Island region also exceeded those in most other regions of the lake.

Although general productivity is comparatively low, harvest of the fishery resource represents the major biologic reason for development along the Lake Superior shoreline. Early fishing on Lake Superior was done by Indians, fur traders and settlers. The American Fur Company, with headquarters at the Village of LaPointe, Madeline Island, initiated fishing in the Apostle Islands and at other sites in 1836, in response to a reduction in the fur trade (Ross, 1960). The new industry found the islands offered physical protection as well

TABLE 1.

Physical and Average Chemical Characteristics of Lake Superior

(After Ayers, 1962)

Item	Value
Physical[1]	
Length	350 mi
Breadth	160 mi
Shoreline	2 930 mi[2]
Mean depth	487 ft
Maximum depth	1,333 ft
Elevation above sea level	602 ft
Mean discharge	73,300 cfs
Water surface	31,820 sq mi
Drainage basin	87,100 sq mi[3]
Chemical[4]	
Total dissolved solids	59 ppm[5]
Total hardness	46.8 ppm[5]
Calcium	12.4 ppm
Magnesium	2.8 ppm
Sodium	1.1 ppm
Potassium	0.6 ppm
Total alkalinity as $CaCO_3$	40 ppm[5]
Chloride	1.9 ppm
Sulfate	1.7 ppm[5]
Silica	2.1 ppm
Iron	0.06 ppm[6]
Total phosphorus	5 ppb
pH	7.4
Carbon dioxide	2.6 ppm[5]
Dissolved oxygen	saturation
Organic nitrogen	0.16 ppm[5]
Ammonia nitrogen	0.11 ppm[7]
Nitrate nitrogen	0.94 ppm[5]
Nitrite nitrogen	0.1 ppm[5]
Secchi disc	8 meters[5]
Specific conductance (at 18°C.)	78.7 micromhos

1/ Corps of Engineers, U.S. Army (1960)
2/ Tower (1962)
3/ Hubbs and Lagler (1964)
4/ Beeton and Chandler (1963)
5/ Putnam and Olson (1959)
6/ Ayers (1962)
7/ Beeton *et. al.* (1959)

as a salable resource and therefore centered operations in the region. Five thousand barrels of salted fish were shipped east in 1839. This firm, however, went bankrupt in 1840 due to a general collapse in the fur trade and the national economy.

By the twentieth century commercial fishing was again an important industry in the Bayfield, Apostle Island area. Lake trout, Salvelinus nemaycush; whitefish, Coregonus clupeaformis and lake herring, Coregonus artedii, were prominent species in the catch. The industry existed up to the 1950's when stocks of lake trout and whitefish were depressed by the parasitic lamprey Petromyzon marinus. Stocks of the important lake herring declined more recently, being replaced by chubs, Coregonus hoyi, and smelt, Osmerus mordax (Anderson and Smith, 1971a). Changes in commercial catch for Wisconsin waters are described in Table 2.

In the years prior to decline of high value fish stocks, many commercial fishermen established summer residences on various islands of the Apostle Island group. Remnents of old fishery and hunting buildings exist on several of the islands (Johannes et. al., 1970 and Stadnyk, et. al., 1974). Decline in the fishery is also illustrated by a decline in the number of licensed fishermen (Johannes et. al., 1970). Although decline in stocks and the fishery has occurred, both have been more extreme in areas away from the Apostle Islands. Commercial fishing is still an important industry in the Apostle Island area and a tradition in these waters of Lake Superior.

Reduction in commercial fishing success has promoted investigations of commercially valuable fish stocks and related animal populations in western Lake Superior. Other efforts may include increased interest in development of the tourist industry and management of resource populations for sport fishing (Northland

TABLE 2.

Production Trends of the Major Fisheries in the Lake Superior Waters of Wisconsin[1]

	CATCH, THOUSANDS OF POUNDS				
YEAR	TROUT	WHITEFISH	CHUBS	HERRING	SMELT
1941	630	273	369	5,832	--
1942	659	253	323	5,035	1
1943	618	266	190	5,535	*
1944	707	263	161	4,712	*
1945	572	338	111	6,538	*
1946	533	478	38	6,342	*
1947	518	609	117	4,641	*
1948	553	706	164	6,391	1
1949	514	764	92	5,028	1
1950	591	520	6	3,953	1
1951	504	183	6	5,347	1
1952	521	139	18	5,890	45
1953	450	170	36	5,356	21
1954	435	326	73	5,594	22
1955	553	501	94	4,359	72
1956	479	544	115	4,164	114
1957	287	288	170	3,155	138
1958	258	88	581	2,485	349
1959	182	121	767	2,833	384
1960	109	128	690	2,255	334
1961	103	93	674	2,570	569
1962	120	85	700	2,181	370
1963	39	86	802	941	619
1964	44	77	321	539	519
1965	54	46	789	430	243
1966	49	47	923	608	321
1967	53	88	910	494	465
1968	39	72	564	618	421
1969	20	87	392	333	294
1970	54	131	647	174	516
1971	46	225	599	283	485

* Less than 500 pounds

1 Fisheries Statistics of the United States; U.S. Fish and Wildlife Service

College, HUD report, 1973). Stocking programs have resulted in increased sport fishing success for lake trout, brown trout, Salmo trutta, rainbow trout, Salmo guirdneri, and brook trout Salvelinus fortinelus, in the Apostle Islands area (Johannes et. al., 1970).

FIELD AND LABORATORY METHODOLOGY

A. GEOLOGICAL

The physical parameters of this section can logically be broken down into two general categories; methods applied to the collection of field data, and those applied to laboratory analysis.

The offshore field work was conducted with the aid of R/V Gull, a 40 foot, steel hulled, harbor tug boat, equipped with a 175 horsepower diesel engine, twin hydraulic winches, a ten (10) position boom and a Raytheon DE-731 continuously recording fathometer, plus additional associative equipment.

The Raytheon recorder was used to generate data showing offshore bathymetry. Four survey stations were set up onshore, two of which were manned at any one time. Surveyors shot fixes on the radio mast of R/V Gull at thirty (30) second intervals (signaled by the captain) to establish a triangulation system which was correlated to fathometer readings. A plane table and alidade system was employed for the surveying, while the baseline for triangulation was determined by stadia rod intervals. Four survey stations were required due to obstructions on the shore which did not allow a clear view of the boat at all transects. A total of six (6) transects were made on three separate dates; 17 June, 7 July and 7 August, 1975. This triangulation method gave an accuracy of better than ten (10) feet in location while the fathometer gave an accuracy of better than 1/3 foot in depth. Such accuracy conforms to standards set by Bruun and Monohar (1963) for offshore profiling. This same triangulation technique was applied to offshore sampling locations (Figure 2). At the required depth the boat was held stationary and a sample was taken simultaneously with a fix upon the radio mast. Bottom sampling was accomplished

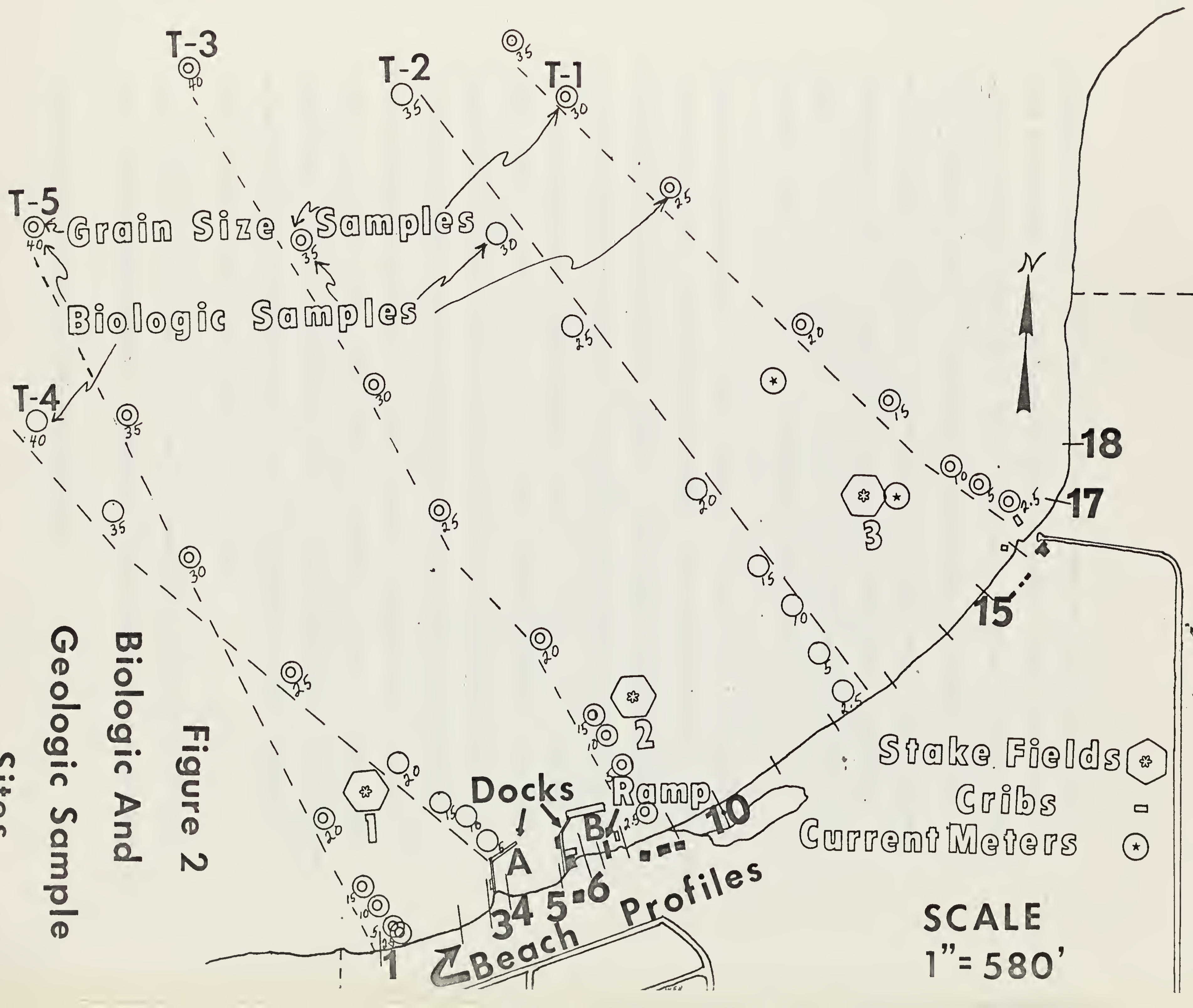


Figure 2

Biologic And Geologic Sample Sites

employing a 40 pound Ponar dredge which was lowered and raised by hydraulic winch from the boom. An approximate 500 gram sediment sample was taken at each station and stored in water-tight containers. Returns using this method were excellent except in those areas of large boulders, located near the eastern cliffed headlands on the boundary of the study area. Here repeated sampling was made until acceptable recovery was accomplished. Nearshore samples (5 and 2.5 foot depths) were taken using the Ponar dredge off a 16 foot john boat propelled by a 25 horsepower outboard motor.

This boat was also used for SCUBA diving, the latter of which was employed in the installation and measurements of three stake fields as well as installing and tending two current meters (Figure 2). Each stake field was comprised of nine (9), five-foot lengths of 1/4 inch steel rods which were driven by sledge into the sediment until approximately three feet of rod was left exposed. The stakes were placed six feet apart in a cross pattern oriented N-S and E-W. Plastic lock-ties were used to code the stakes for easy identification and bouys were anchored into the sand nearby for easy location of the fields. Stake field one was placed in 11 feet of water, stake field two was placed in 8 feet of water and stake field three was placed in 7.5 feet of water. The positioning of these fields was chosen so as to glean information on the offshore currents and sand transport as well as the interaction of these parameters with the present docks and proposed docking sites.*

These fields were measured weekly, weather permitting, using a four (4) foot long, 1/4 inch calibrated rod. The amount of sand buildup or loss was recorded

**Self Contained Underwater Breathing Apparatus.*

for each stake, measuring from the top of each stake to the level of sand, taking sand ripples into account (Appendix D).

Stake field two and three were also used as sites of fluorescent tracer studies. The existing evenly spaced cross pattern was a ready made sampling area for this study. Sand taken from near the stake field was returned to the laboratory and sprayed with waterproof fluorescent spray paint, making sure not to over spray and thus stick the grains together. Five-hundred grams of dyed sediment was then put into a 40% Calgon grain dispersal solution. This mixture was then placed by a diver within a six (6) inch radius around the center stake of each stake field. Currents were allowed to work upon the dyed grains for two (2) hours before sampling. A diver would sample with a five foot by six inch strip of 1/4 inch masonite board, calibrated at six inch intervals and coated on one side with a think layer of petroleum jelly. This board was placed on the bottom, one end touching the center stake, and pressed into the sediment, being careful not to create currents which could disturb the sediment. These boards were oriented to the eight points of a compass to get a representative sample.

Two General Oceanic Model 2010, Film Recording current meters were placed in the 20 foot and 7 foot depths of water. These meters are positively buoyant, <u>in situ</u> meters which measure both current intensity and direction using an electronically stepped movie camera to photograph a calibrated, free moving compass ball (see Photo page 68). These meters were anchored by 70 pound poured concrete anchors at the appropriate depths and buoyed for easy location.

The twenty and seven foot depths were chosen for a variety of reasons. First; two depths (one nearshore, the other deeper) were chosen to ascertain differences

in steady-state and wind driven currents. These two positions were also to be used for detecting the decrease in longshore drift intensity with increasing depth. Finally, the positions of these two meters (Figure 2) were placed so as to monitor the currents in the easternmost area, with the seven foot deep meter adjacent to stake field three.

Unfortunately, the seven foot deep current meter malfunctioned during the fluorescent tracer studies, and no correlation of currents to sand transport, i.e. bed load determination, was possible. However, wind and wave conditions were carefully noted, and correlation could be made for those parameters.

In addition to the SCUBA diving conducted for stake field analysis, fluorescent tracer study and current meter tending, reconnaissance dives were made to determine the nature of the bottom and the effect of the present docks upon the subsurface topography (the most significant observation was a large build-up of sand deposited behind, and inside, the dock "B" enclosure; this sedimentation feature also appears in the beach profile data).

Beach profiles were conducted (according to procedure described by Emery, 1961), along with a standardized Littoral Environment Observation (L.E.O.) program, developed by the Coastal Engineering Research Center of the Army Corps of Engineers (Berg, 1968) as part of the land based data collection.

Beach profiles were made with a one-meter long, calibrated Emery beach profiler, described by Emery, 1961. It is essentially a hinged parallelogram of wooden laths, used to measure the beach slope by sighting on the horizon and recording the amount of loss or gain in slope per one-meter distance. This method generates a cross section of a beach and nearshore area (Appendix C).

Eighteen (18) stations were set up along the study area taking into account all possible morphologic or shore structure situations encountered in the study area. Weekly profiles were recorded, along with shore samples taken at the swash line (furthest extent of wave runup). These samples were approximately five hundred (500) gram aliquots taken by a sample of the top five (5) centimeters of sediment at the edge of the swash line or, more accurately, an approximation of the still-water line. Samples were taken at this reference point due to the reproducibility of the sample site, as emphasized by Bascom (1951).

This sampling of sand and profiles was conducted in addition to the L.E.O. program for systematic collection of beach data (Berg, 1968). This program included the measurement of wave climate (wave height, period, length, and direction of approach), littoral current observations (velocity and direction), and systematic photography of the beach zone. Tides and water temperature were not recorded due to the minimal tides present in Lake Superior (International Great Lakes Levels Board, 1973) and the lack of application of water temperature to the physical aspect of this study.

The above observations were obtained in the following manner. Wave height was estimated visually by observing the difference between successive crests and troughs passing an offshore piling or other reference object, and assumed to be deep water wave height (Ho). Wave period was observed visually by timing ten (10) successive crests passing a reference point and averaging the observed times. Wave length was strictly a visual estimation and, therefore, does not enter into calculations. Direction of wave approach was measured with a Brunton field compass.

The Brunton was also used to determine direction of wind approach as taken from a flying flag, or the direction of strongest wind velocity as read off a Dwyer wind meter. The littoral current was measured using a brightly colored rubber ball, placed beyond the influence of translatory wind waves (breaker zone), as a drift drogue with the distance traveled per one minute interval being measured by tape. Photographs of significant features on the beach were taken with a standard 35 mm camera.

Most of the gathered data using the above methods was in a raw form and data reduction in a laboratory was needed to place the data into a more usable form.

Grain size analysis in the laboratory was accomplished in the following manner. A 500 gram sediment sample was dried at 100°F in an evaporating dish. After homogenization, a representative 100 gram sample was then run through U.S. Standard, 12 inch diameter sieves. Two stacks of these sieves were used to obtain a one-half phi size distribution (Table 4). Samples were run in a Tyler Ro-Tap apparatus for fifteen (15) minutes per stack. The samples were removed and weighed to two decimal places in a Mettler top-loading balance. Cumulative percentage curves were then drawn for each sample, and grain size parameters were calculated according to Folk (1968) as follows:

<u>Graphic Mean</u> (Mz) = $(\phi16 + \phi50 + \phi84)/3$

This yields the average grain diameter of the sample in units of ϕ.

<u>Inclusive Graphic Standard Deviation</u> (σ_I) = $\dfrac{\phi84 - \phi16}{4} + \dfrac{\phi95 - \phi5}{6.6}$

This yields the sorting or deviation from most common grain size in units of ϕ.

<u>Inclusive Graphic Skewness</u> (Sk_I) = $\dfrac{\phi16 + \phi84 - 2(\phi50)}{2(\phi84 - \phi16)} + \dfrac{\phi5 + \phi95 - 2(\phi50)}{2(\phi95 - \phi5)}$

This yields the trend of preference of a sample to "lean" towards a fine or coarse fraction.

The fluorescent tracer study data was compiled using an ultra-violet light to pick up the fluorescent grains which were counted for each six inch square on the sample board, neglecting the first square as the dump site. The percent coverage of each square was determined visually and was used to calculate a total coverage figure for each square.

A volumetric change in beach profiles was calculated for the sampling period by measuring the area between the first and last measured profile. This was done by the integration method of measuring vertical change for a small, fixed interval across the two-curve area. This area was then multiplied by the horizontal distance between two successive profile sites to give a volumetric change in cubic meters/time interval.

Current meter data was reduced using a Craig super 8 movie editor from which inclination and direction of the compass ball was tabulated. Current velocity was then determined using the calibration curve for the employed, oversized and more sensitive stability fins, supplied by General Oceanics.

Other methods for physical determinations appear in the appropriate section of this report and the results are placed in tabular or graphic forms throughout the paper and in the appendices.

B. BIOLOGICAL

The biological sampling program was designed to define the species composition, relative abundance and distribution of plant communities, zooplankton, benthic organisms and fish within Little Sand Bay and to assess the importance of the area as a spawning and nursery site for important fish species. The sampling strategy used for most sampling was a stratified random design with stratification by depth and offshore transects. Transects were designed so that differences between the two proposed docking construction zones (i.e. this study site and related site #2; see Introduction Section) could be ascertained. Samples collected in the field were returned to the University of Wisconsin, Superior for sorting and identification.

Plant communities do not appear in the proposed construction zones of Little Sand Bay and thus required no sampling program. This was confirmed by the absence of plants in bottom samples from 0 to 30 feet as determined by surface observations and observations by scuba divers.

Water samples for zooplankton analysis were taken along offshore transects in 5, 10, 20 and 30 feet of water at 10 foot depth intervals from surface to bottom. Simultaneous light readings were taken at each depth with a Kahlsico Submarine Photometer. Samples were collected with a 16 liter Kemmerer water sampler and concentrated with a 50 micron concentrating cup. The samples were then preserved in a 10% formalin solution and returned to the laboratory for identification. The zooplankton were counted using a Sedwick-Rafter cell under a compound microscope. The entire sample was counted in the June and July samples. The August samples were subsampled due to the increase in the number of organisms. Keys used for identification were Eddy and Hodson (1961), Edmondson (1959) and Pennak (1953).

During June and July bottom samples for benthic organisms were taken at five foot depth intervals from 5 to 30 feet along established offshore transects from the approximate area of the two proposed construction sites (Figures 2 and 3). The August samples were taken only at the 5, 10, 20 and 30 foot depths. Samples were also taken at 2.5 feet in June and July to assess benthic organism production in the beach zone. All benthic samples were taken with a Ponar dredge. The entire sample was preserved in 10% formalin and returned to the laboratory for sorting and identification. The samples were washed through a No. 35 sieve (32 meshes/inch). Identification was made under a dissecting microscope using keys by Pennak (1953), Usinger (1956) and Hilsenhoff (unpublished).

Fish samples were collected using a 30 foot bag seine, 250 foot experimental gill nets, an 18 foot larval trawl and a meter tow net, all operated off R/V Gull.

Shoreline sampling was conducted using a 0.1 inch mesh seine measuring 30 feet by 4 feet with a five foot by 4 foot bag with 0.06 inch mesh. Three (3) 100 foot hauls were made along the beach.

Experimental gill nets measuring 250 feet by 6 feet with five (5) meshes of 0.5, 0.75, 1.0, 1.5 and 2.0 inch square mesh were set at 10, 20 and 30 foot water depths along transects 1 and 3 to determine differences in the fish distribution at the two proposed construction sites. Nets were set in the afternoon and picked approximately 24 hours later. Fish were identified, weighed and measured in the field.

An 18 foot larval trawl with 0.25 inch mesh and a 1 mm cod liner was used to collect those species too small to be vulnerable to the gill nets as well as

yearling and young of the year of the larger species. The trawl was pulled with an 18 foot boat powered by a 25 horsepower outboard motor for six (6) minute hauls, filtering approximately 26,900 cubic feet of water. All trawling was done at night when the fish were most susceptible to capture. Organisms collected were preserved in 10% formalin.

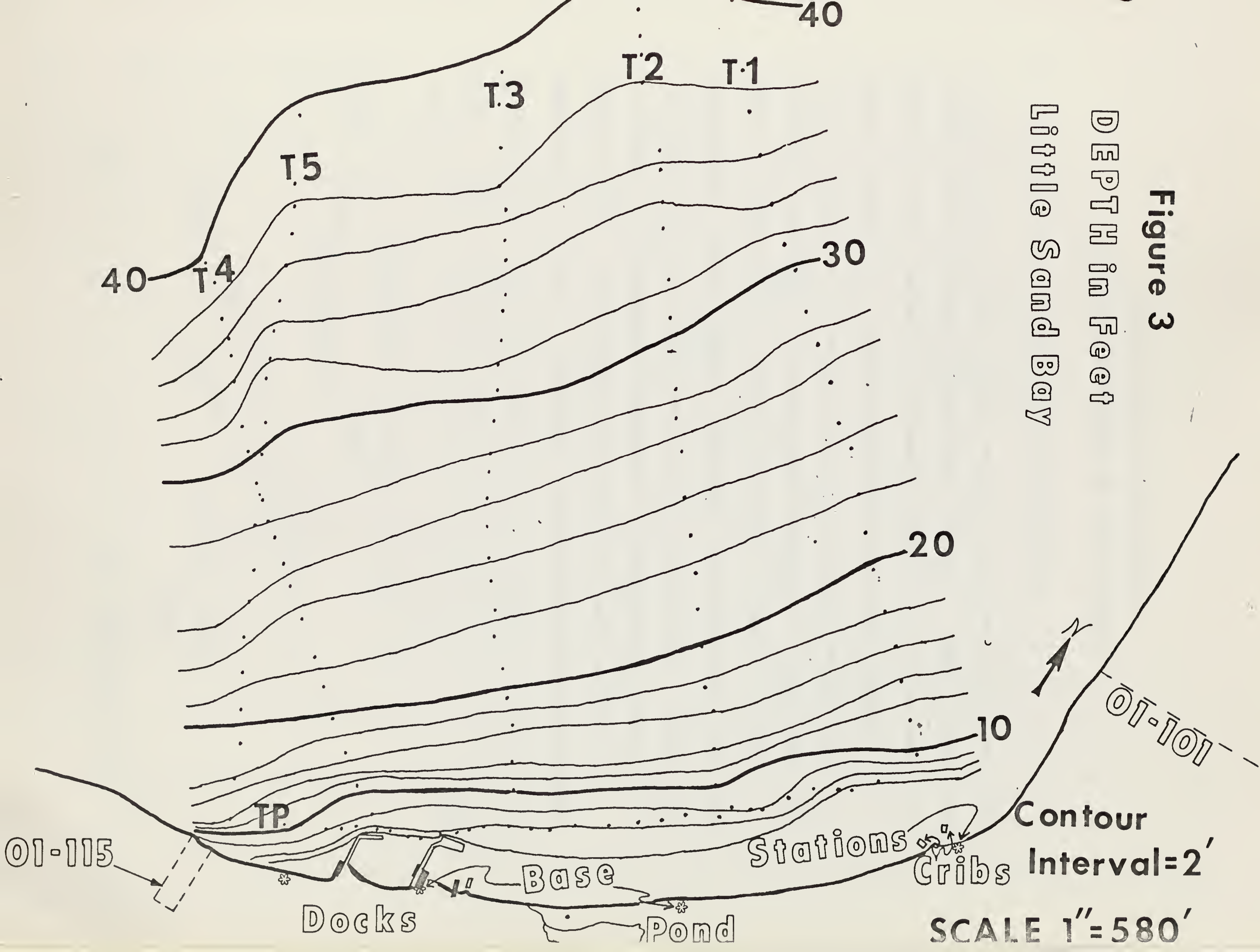
A tow net (one meter diameter hoop) with 0.5 mm mesh was used to collect larval fish to determine the importance of the area as a nursery site. A standard six (6) minute tow filtered approximately 8,000 cubic feet of water. All towing was done at night when the fish were most susceptible to capture. The organisms collected were preserved in 10% formalin for later identification and counting.

Specific dates of collection of each category of biologic field sampling are listed in associated tables distributed throughout this report (see List of Contained Tables for locations).

Figure 3

DEPTH in Feet

Little Sand Bay



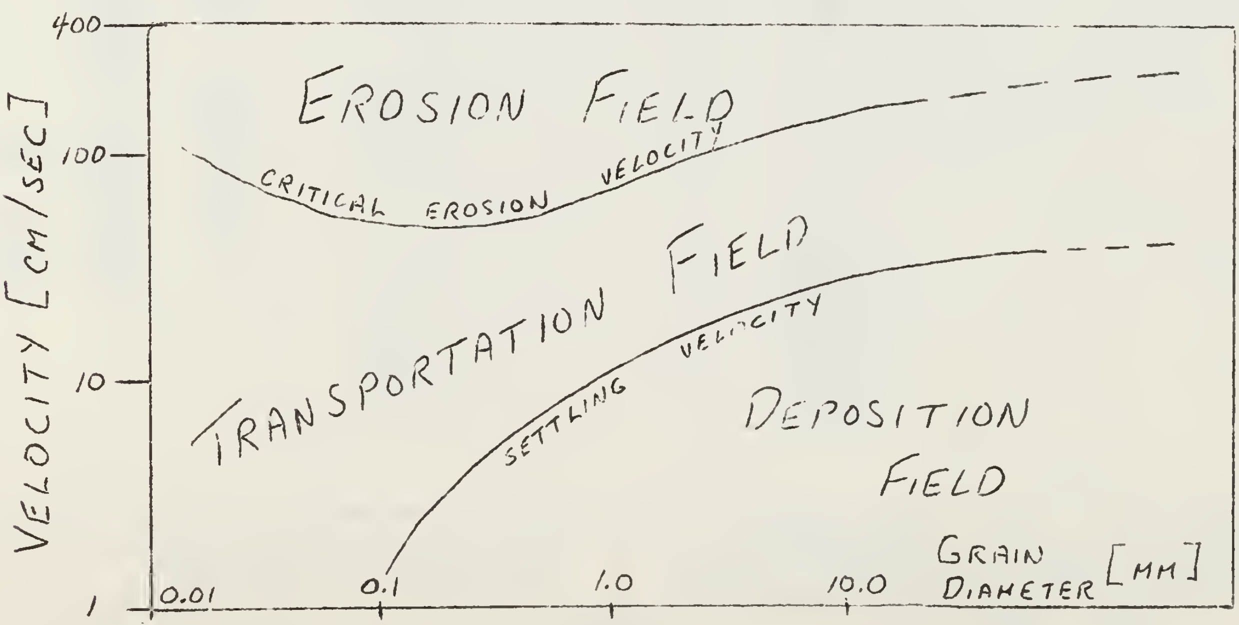
LITTLE SAND BAY ENVIRONMENT

A. PHYSICAL PARAMETERS OF LITTLE SAND BAY

1. Size and Range of Beach Littoral Materials

In general, Little Sand Bay contains a moderate to very well sorted, very coarse to medium sand suite covering the beach face (Figure 4). Before a more technical discussion of these sediments is presented, clarification of a few terms is necessary. Mean size (M_z), a parameter dependent upon both the size range of available material and the energy level of the transporting medium (Table 3), in this case wave energy, is a useful term for referring to overall grain size (Table 4). Sorting (σ_I) is a function of the type of deposition, current characteristics (whether constant or fluctuating) and time (Folk, 1968) (Table 5) and makes reference to the degree of scatter of size ranges. Skewness (Sk_I) is a measure of the prejudice the sample has to contain either a coarse or a fine size fraction. The arithmetic sign of this pure number indicates the preference, i.e. a minus (-) indicating a tendency for coarse grained material and a positive (+) indicating a preference for fine grained size ranges (Table 6).

TABLE 3: Water Velocities Versus Grain Size Movements (After Hjulström, 1955)



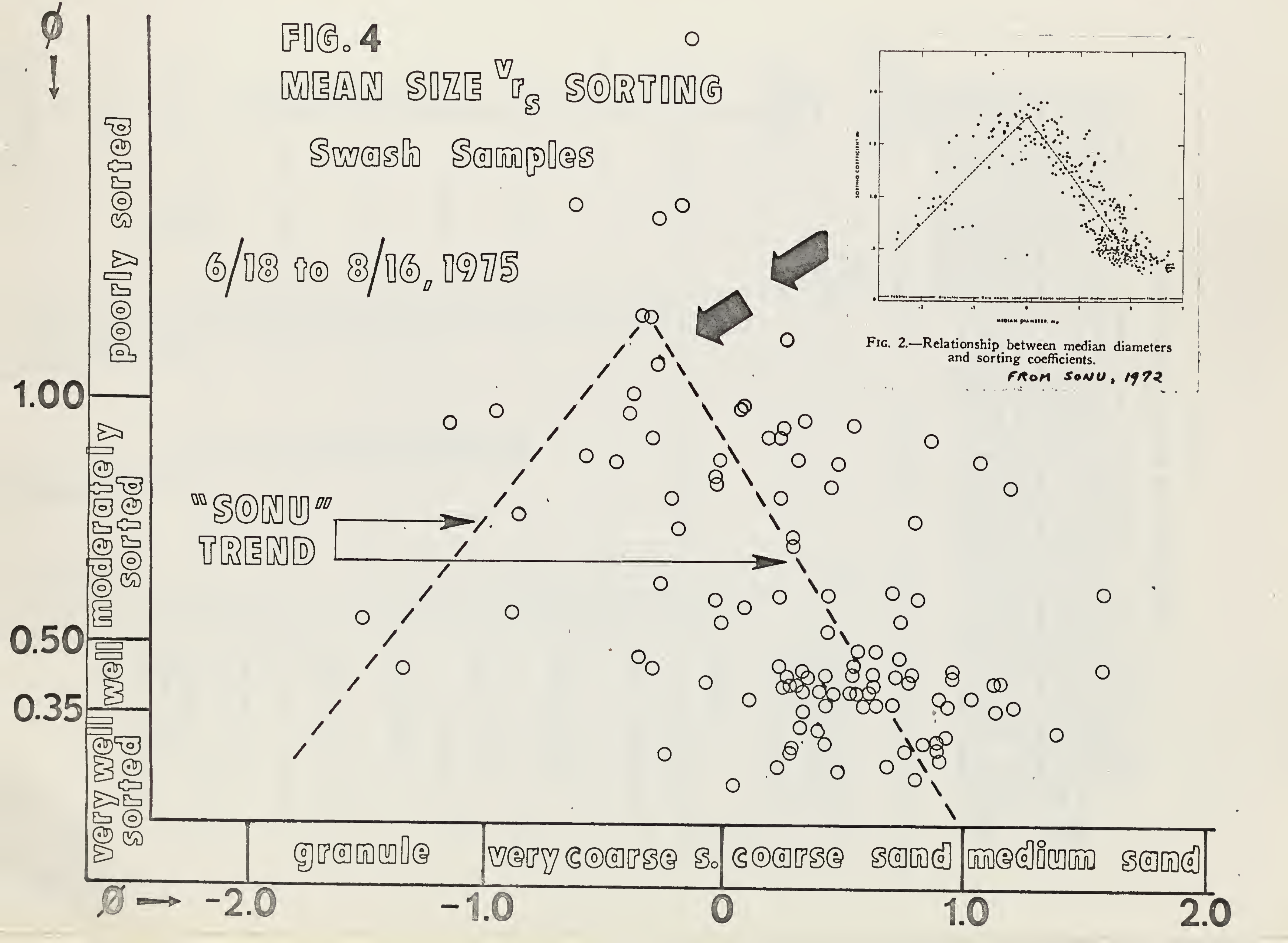


FIG. 2.—Relationship between median diameters and sorting coefficients.

FROM SONU, 1972

TABLE 4

GRAIN SIZE SCALES FOR SEDIMENTS

The grade scale most commonly used for sediments in the Wentworth (1922) scale which is a logarithmic scale is that each grade limit is twice as large as the next smaller grade limit. The scale starting at 1mm and changing by a fixed ratio of 2 was introduced by J.A. Udden (1898), who also named the sand grades we use today. However, Udden drew the gravel/sand boundary at 1mm and used different terms in the gravel and mud divisions. For more detailed work, sieves have been constructed at intervals $\sqrt[2]{2}$ and $\sqrt[4]{2}$. The ϕ (phi) scale, devised by Krumbein, is a much more convenient way of presenting data than if the values are expressed in millimeters, and is used almost entirely in recent work.

U.S. Standard Sieve Mesh #	Millimeters		Microns	Phi (ϕ)	Wentworth Size Class
		4096		-12	
		1024		-10	Boulder (-8 to -12ϕ)
Use		256		- 8	
wire		64		- 6	Cobble (-6 to -8ϕ)
squares		16		- 4	Pebble (-2 to -6ϕ)
5		4		- 2	
6		3.36		- 1.75	
7		2.83		- 1.5	Granule
8		2.38		- 1.25	
10		2.00		- 1.0	
12		1.68		- 0.75	
14		1.41		- 0.5	Very coarse sand
16		1.19		- 0.25	
18		1.00		0.0	
20		0.84		0.25	
25		0.71		0.5	Coarse sand
30		0.59		0.75	
35	1/2	0.50	500	1.0	
40		0.42	420	1.25	
45		0.35	350	1.5	Medium sand
50		0.30	300	1.75	
60	1/4	0.25	250	2.0	
70		0.210	210	2.25	
80		0.177	177	2.5	Fine sand
100		0.149	149	2.75	
120	1/8	0.125	125	3.0	
140		0.105	105	3.25	
170		0.088	88	3.5	Very fine sand
200		0.074	74	3.75	
230	1/16	0.0625	62.5	4.0	
270		0.053	53	4.25	
325		0.044	44	4.5	Coarse silt
		0.037	37	4.75	
	1/32	0.031	31	5.0	
Analyzed	1/64	0.0156	15.6	6.0	Medium silt
	1/128	0.0078	7.8	7.0	Fine silt
by	1/256	0.0039	3.9	8.0	Very fine silt
		0.0020	2.0	9.0	
Pipette		0.00098	0.98	10.0	Clay
		0.00049	0.49	11.0	
or		0.00024	0.24	12.0	
		0.00012	0.12	13.0	
Hydrometer		0.00006	0.06	14.0	

Table 7 and Figure 4 classifies Little Sand Bay sediment according to mean size, sorting and skewness. Certain size trends can be established by reviewing the graphs of offshore samples (Appendix A). It is easily noted that on all three north-south transects (Appendix A1, A2 and A3), the sand is rather homogeneous beyond the 5-10 foot isobath. The shallower samples tend to be coarser than the deeper due to increased wave energy.

The typical trend of sand becoming finer away from shore, the area of highest energy (Bascom, 1951), does not show clearly in Table 7, unless one looks closely at the skewness figures. These show, for the most part, that the nearshore samples tend to contain a coarse fraction, and the offshore samples tend to contain a finer fraction.

The above mentioned trend is more easily seen in the samples taken during the fall of 1974 (study contract #CX-2000-5-0013) when overall wave energy was higher due to the frequency of storms. In comparing the offshore data gathered in fall of 1974 with the data gathered during the summer of 1975, there is a marked decrease in mean size closer to shore (5-15 foot depth) in the summer 1975 months. This is explained by the summer seasonal trend of the beach cycle. During the summer months, the fine sand which was torn off the beach face by late fall and winter storms and deposited offshore in bars, is carried back to the beach face by the calmer, summer waves. This would bring a concentration of fine sediment closer to the shore where it can then be returned to the subaerial beach face.

All transects (Appendix A1 to A3) show a coarse trend lakeward of the 10 to 20 foot depth contour. This is probably due to the selective transport effect

caused by weak bottom currents. These currents have a carrying capacity limited to fine grains, leaving a relatively coarser deposit further offshore.

Transect T_1 (Appendix A1) shows the least amount of variation of all the transects. This is due to its location (Figure 2) adjacent to the eastern cliffed headlands. The transect is parallel to the eastern shore and therefore shows the least variation due to the normally expected shore-perpendicular oriented nature of offshore grain size distribution. This transect has easy access to the fine material eroded from the adjacent glacial till cliffs. Laboratory pipette analysis of this red till revealed 0.47% silt and 0.75% clay by weight, the remaining fraction being fine quartzitic sand.

Grain size trends can also be detected in samples taken from the area of the still water (swash) line on the beach face (Appendix A4 through A9). An interesting trend is shown in Figure 4 displaying a relation between mean size and sorting coefficient, a phenomena first reported by Sonu (1972). He stated that sorting of beach sands improves away from the very coarse/coarse sand boundary due to the ability of coarse to very coarse sand to trap finer sand without it being subsequently winnowed away, thereby making these coarser samples bimodal and thus poorly sorted. The samples represented here demonstrate this theory fairly well and show that the beach sands are mainly very coarse to coarse and moderately to very well sorted.

In a review of the graphs of the mean size (Appendix A4 through A9) there appears to be no apparent overall pattern or trend until these data are compared to the graphs of longshore drift (Figures 5 through 11), Table 11 showing wave energy, and Figure 2 showing the location of each station to the morphologic and man-made features along the shoreline. As an example the 18 June

swash sample (Appendix A4) shows a coarsening trend at station #4, a site which is partially enclosed by dock "A". If grain size were truly related to wave energy, that is the higher the energy the larger the sediment size, then this protected area should consist of fine sediment. It does not, for this date or any other during the sampling period (Appendix A5 through A9), nor was the wave energy exceptionally high for most of the sample dates, all due to the protection afforded by the docking structure. However, the longshore drift usually moves eastward in Little Sand Bay (see Longshore Drift Section), and the closed nature of the dock structure to the west of station 4 (see Photo page 34) mitigates the ability of the current to effectively pass station 3. The longshore current is usually very weak, a few meters per minute, and thus cannot generally carry coarse sand. Therefore when it is reduced in velocity it deposits the fine sand, in this case at station 3. Wave induced currents are initiated eastward of the dock, thus creating a coarse lag deposit in the vicinity of station 4.

Closeup of shore attachment of dock "A". Note buildup of sand under dock planking.

This same phenomenon can be seen in stations 5 and 6 where 5 is up drift of an obstruction and 6 is down drift. Here site 5 consists of fine sand whereas 6 is comprised of coarse sized sediment.

TABLE 5: Grain Size and Sorting Classification

GRAIN SIZE		GRAIN SORTING	
ϕ	SIZE CLASS	ϕ	DEGREE OF SORTING
>4.0	Silt and Clay	<0.35	Very Well Sorted
3.0 to 4.0	Very Fine Sand	0.35 to 0.50	Well Sorted
2.0 to 3.0	Fine Sand	0.50 to 1.00	Moderately Sorted
1.0 to 2.0	Medium Sand	1.00 to 2.00	Poorly Sorted
0.0 to 1.0	Coarse Sand	2.00 to 4.00	Very Poorly Sorted
-1.0 to 0.0	Very Coarse Sand	>4.00	Extremely Poorly Sorted
Less than -1.0	Gravel		

Moving eastward the beach sands generally fluctuate with the shifting wave energy, longshore drift direction and availability of offshore sand derived from migrating offshore bars, as will be seen in following sections.

Station 16 is a special case as it usually contains the coarsest sediment for the early sampling period (Appendix A4 through A7). This is principally due to wave energy. This station is in the southeast corner of Little Sand Bay and in the center of the proposed alternate docking site. Its geographic position places it in direct line with northwesterly approaching storms and related wave action, already noted as the most severe in the previous report (contract report CX-2000-5-0013). This area is also affected by the proximity of two offshore cribs. These cribs bracket this station, the easternmost being almost

on shore and thus protecting this site from direct wave attack. As will be seen later, this station is prograding, but with coarse rather than fine sediment (see Photo page 61). This is probably due to the nearshore absence of fine sand, this station being opposite a boulder field. This situation is similar to that which formed the protuberance in the beach behind the crib at station 8 (see Photo page 81) where the crib projects a shadow zone of low energy shoreward and allows for the accumulation of a wedge of fine grained sediment.

TABLE 6: Skewness Classification

Sk_I from 1.00 → 0.30	=	strongly fine skewed
0.30 → 0.10	=	fine skewed
0.10 → -0.10	=	near-symmetrical
-0.10 → -0.30	=	coarse skewed
-0.30 → -1.00	=	strongly coarse skewed

This situation is also a cause for buildup of fine sands within the existing National Park Service docking facility. Wave energy is expended upon the impermeable breakwater on the shore-parallel arm of the dock, allowing longshore drifting sediment to stagnate in this low energy environment, causing dredging problems and an undernourished downdrift littoral zone; a problem which must be taken into account in the construction of the new docking facility.

TABLE 7

GRAIN SIZE INVENTORY

SAMPLE NUMBER DATE AND	LOCATION	MEAN SIZE (Mz) IN Phi UNITS	MEASURE OF SORTING (σI) IN Phi UNITS	MEASURE OF SKEWNESS (Sk_I)
6/17/75	T1/2.5	1.58	0.32	0.158
6/17/75	T1/5	1.75	0.45	0.158
6/17/75	T1/10	2.11	0.43	-0.083
6/17/75	T1/15	1.96	0.62	0.056
6/17/75	T1/20	2.16	0.70	0.078
6/17/75	T1/25	1.93	0.68	0.010
6/17/75	T1/30	1.91	0.72	0.074
6/17/75	T1/35	1.81	0.77	0.091
6/17/75	T1/40	1.87	0.86	0.082
6/17/75	T3/2.5	0.38	0.84	-0.459
6/17/75	T3/5	1.83	0.49	0.213
6/17/75	T3/10	2.29	0.58	-0.030
6/17/75	T3/15	1.54	0.44	0.323
6/17/75	T3/20	1.61	0.62	0.285
6/17/75	T3/25	1.63	0.66	0.052
6/17/75	T3/30	1.74	0.67	0.041
6/17/75	T3/35	1.68	0.68	0.159
6/17/75	T3/40	2.43	0.97	0.021
6/17/75	T5/2.5	1.65	0.42	-0.123
6/17/75	T5/5	1.96	0.57	-0.027
6/17/75	T5/10	2.31	0.65	-0.170
6/17/75	T5/15	2.36	0.76	-0.245
6/17/75	T5/20	2.23	0.56	0.097
6/17/75	T5/25	1.74	0.60	0.089
6/17/75	T5/30	1.77	0.64	0.107
6/17/75	T5/35	1.82	0.66	0.132
6/17/75	T5/40	2.33	0.99	0.113
6/18/75	1/Swash	0.42	0.39	-0.63
6/18/75	2/Swash	0.52	0.47	-0.008
6/18/75	3/Swash	0.27	0.28	0.26
6/18/75	4/Swash	-0.41	0.48	-0.19
6/18/75	5/Swash	1.13	0.34	0.123
6/18/75	6/Swash	0.07	0.59	-0.234
6/18/75	7/Swash	0.55	0.44	-0.181
6/18/75	8/Swash	0.92	0.35	-0.006
6/18/75	9/Swash	0.89	0.36	0.276
6/18/75	10/Swash	0.38	0.31	-0.364
6/18/75	11/Swash	0.3	0.39	-0.13

Table 7 Continued
Grain Size Inventory

SAMPLE NUMBER DATE	AND LOCATION	MEAN SIZE (Mz) IN Phi UNITS	MEASURE OF SORTING (σI) IN Phi UNITS	MEASURE OF SKEWNESS (Sk_I)
6/18/75	12/Swash	-0.29	0.90	-0.456
6/18/75	13/Swash	-0.41	0.94	-0.341
6/18/75	14/Swash	-0.09	0.41	-0.137
6/18/75	15/Swash	-0.28	0.79	-0.017
6/18/75	16/Swash	-1.51	0.54	-0.368
6/18/75	17/Swash	1.18	0.35	0.007
6/18/75	18/Swash	0.88	0.28	-0.017
6/27/75	1/Swash	0.57	0.35	0.110
6/27/75	2/Swash	0.34	0.46	0.133
6/27/75	3/Swash	0.44	0.37	-0.438
6/27/75	4/Swash	-0.91	0.55	-0.29
6/27/75	5/Swash	1.18	0.82	-0.462
6/26/75	6/Swash	1.38	0.33	0.031
6/26/75	7/Swash	0.8	0.31	-0.225
6/26/75	8/Swash	0.52	0.43	-0.276
6/26/75	9/Swash	0.55	0.49	-0.50
6/26/75	10/Swash	0.44	0.59	-0.26
6/26/75	11/Swash	0.17	0.94	-0.208
6/26/75	12/Swash	0.52	0.45	-0.343
6/26/75	13/Swash	0.24	1.13	-0.646
6/26/75	14/Swash	-0.04	0.59	0.216
6/26/75	15/Swash	-0.29	1.34	-0.025
6/26/75	16/Swash	-0.64	1.38	0.082
6/26/75	17/Swash	1.15	0.40	-0.151
6/26/75	18/Swash	0.21	0.79	-0.321
7/7/75	1/Swash	0.41	0.30	-0.206
7/7/75	2/Swash	0.31	0.31	-0.138
7/7/75	3/Swash	0.08	0.36	-0.048
7/7/75	4/Swash	-0.31	0.46	-0.339
7/7/75	5/Swash	1.53	0.61	0.165
7/7/75	6/Swash	0.41	0.52	-0.191
7/7/75	7/Swash	0.62	0.35	-0.441
7/7/75	8/Swash	0.6	0.37	-0.0945
7/7/75	9/Swash	-0.28	0.65	-0.325
7/7/75	10/Swash	0.22	0.60	-0.0034
7/7/75	11/Swash	-1.16	0.97	-0.0579
7/7/75	12/Swash	-1.01	0.71	-0.1242
7/7/75	13/Swash	-0.88	0.76	-0.035
7/7/75	14/Swash	-0.20	0.74	-0.212
7/7/75	15/Swash	-0.97	0.98	0.064
7/7/75	16/Swash	-0.46	0.85	-0.043

Table 7 Continued
Grain Size Inventory

SAMPLE NUMBER DATE	AND LOCATION	MEAN SIZE (Mz) IN Phi UNITS	MEASURE OF SORTING (σI) IN Phi UNITS	MEASURE OF SKEWNESS (Sk_I)
7/7/75	17/Swash	0.22	0.49	-0.247
7/7/75	18/Swash	0.85	0.90	-0.112
7/15/75	1/Swash	0.26	0.41	0.087
7/15/75	2/Swash	0.33	0.43	0.003
7/15/75	3/Swash	-0.25	0.28	-0.04
7/15/75	4/Swash	-0.03	0.53	-0.32
7/15/75	5/Swash	1.13	0.45	0.076
7/14/75	6/Swash	1.04	0.35	-0.472
7/14/75	7/Swash	0.52	0.42	-0.0046
7/14/75	8/Swash	0.41	0.46	-0.252
7/14/75	9/Swash	-0.13	1.91	-0.601
7/14/75	10/Swash	-0.02	1.36	-0.695
7/14/75	11/Swash	0.29	0.88	-0.672
7/14/75	12/Swash	0.23	0.47	-0.27
7/14/75	13/Swash	1.02	0.39	-0.281
7/14/75	14/Swash	-0.39	1.01	0.095
7/14/75	15/Swash	-0.3	1.09	-0.171
7/14/75	16/Swash	-1.36	0.45	-0.056
7/14/75	17/Swash	0.89	0.32	-0.050
7/14/75	18/Swash	0.75	0.29	0.0491
7/25/75	1/Swash	0.39	0.39	0.269
7/25/75	2/Swash	0.34	0.34	-0.45
7/25/75	3/Swash	0.28	0.40	0.021
7/25/75	4/Swash	0.25	0.38	-0.203
7/25/75	5/Swash	0.63	0.49	-0.086
7/25/75	6/Swash	0.33	0.95	-0.115
7/25/75	7/Swash	0.79	0.23	0.184
7/25/75	8/Swash	0.76	0.43	-0.226
7/25/75	9/Swash	0.69	0.61	-0.378
7/25/75	10/Swash	-0.34	1.19	-0.371
7/25/75	11/Swash	0.53	0.45	-0.022
7/25/75	12/Swash	0.46	0.85	-0.498
7/25/75	13/Swash	0.28	0.72	-0.363
7/25/75	14/Swash	0.23	0.89	0.099
7/25/75	15/Swash	0.06	0.99	-0.224
7/25/75	16/Swash	0.51	0.94	-0.364
7/25/75	17/Swash	0.04	0.8	-0.047
7/25/75	18/Swash	0.94	0.45	-0.017
8/6/75	1/Swash	0.61	0.40	0.081
8/6/75	2/Swash	0.21	0.25	0.034

Table 7 Continued
Grain Size Inventory

SAMPLE NUMBER DATE	AND LOCATION	MEAN SIZE (Mz) IN Phi UNITS	MEASURE OF SORTING (σI) IN Phi UNITS	MEASURE OF SKEWNESS (Sk_I)
8/6/75	3/Swash	0.47	0.24	-0.213
8/6/75	4/Swash	0.03	0.23	0.070
8/6/75	5/Swash	0.61	0.39	-0.383
8/6/75	6/Swash	1.57	0.44	-0.317
8/6/75	7/Swash	0.89	0.26	-0.064
8/6/75	8/Swash	0.73	0.57	-0.028
8/6/75	9/Swash	0.77	0.39	0.005
8/6/75	10/Swash	0.83	0.29	0.107
8/6/75	11/Swash	0.93	0.30	0.169
8/6/75	12/Swash	0.67	0.25	0.053
8/6/75	13/Swash	0.28	0.27	-0.108
8/6/75	14/Swash	0.75	0.35	-0.078
8/6/75	15/Swash	0.32	0.40	-0.147
8/6/75	16/Swash	0.68	0.75	-0.357
8/6/75	17/Swash	-0.05	0.80	-0.07
8/6/75	18/Swash	-0.59	0.87	-0.105
8/6/75	Cliff	0.8	0.60	0.134

2. Configuration and Openness of the Shoreline to Attack by the Elements

Little Sand Bay is bounded by two cliffed headlands; the northeastern boundary, extending up to Point Detour, being more protuberant than the southwestern cliffs. This orientation gives the bay a morphologically concave opening to the north-northwest. The 4,500 foot beach area between these local headlands has a general east-northeast, west-southwest trend (Figure 1).

This configuration should, in theory, expose Little Sand Bay to the highly destructive northwesterly autumn and winter storms, were it not for the location of Sand Island. This island, located two and one-third miles off the mainland, is directly opposite the opening of Little Sand Bay. Besides the location, Sand Island is "attached" to the mainland by an incipient tombolo with a minimum depth of four feet in some areas (direct measurement with fathometer). This tombolo originates at the mouth of the Sand River in neighboring Sand Bay and extends northwesterly to intersect Sand Island on its southeast sector (Lake Survey District, Corps of Engineers, Chart L.S. 96). The importance of this tombolo lies in its ability to attenuate wave energy created by storms approaching from the west and northwest. Shepard (1973) states that a wave will start to "feel" bottom at a depth equal to one fourth its wavelength. This produces a drag on the motion of the bottom portion of the wave and thus necessarily increases the motion on the top section. If the bottom continues to shoal the wave will break, dissipating most of its energy in the surf zone. The four foot depth of the Sand Island incipient tombolo therefore makes this morphological feature a good candidate for wave energy dissipation. However, this four (4) foot depth will only retard waves with a wavelength of better than 16 feet.

Such were numerous in the fall and early winter of 1975 but were almost totally lacking in the spring and summer months of 1974. Those months when the heaviest use of the docking facility is to be expected normally have waves of length of 6 to 15 feet with the average being 8 feet. This means that westerly and northwesterly winds blow directly into the southeast corner of Little Sand Bay.

There is a similar incipient tombolo connecting York Island, which is located two and one half miles off the mainland to the northeast of Little Sand Bay. The minimum depth for this feature ranges from twenty-two (22) feet near the mainland shore to six (6) feet near the island shore (Lake Survey District, Corps of Engineers Chart L.S. 96). The position of York Island and the associated tombolo does offer some protection to the Little Sand Bay area from northeasterly storms. However, the northeastern headland of this bay protrudes to such an extent as to shelter most of the Bay from northeasterly approaching storm waves. This is especially true of the eastern proposed dock site (this study site).

Waves approaching directly from the north create the only situation for which Little Sand Bay has no defense. Northerly storm waves are rare here, probably due to the closer proximity of the north shore of Lake Superior (as compared to other storm directions), which limits the possible fetch distance.

A combination of these factors afford Little Sand Bay a good deal of protection against wave attack. However, direct observation does point out that the northwesterly wind storms are the most damaging to Little Sand Bay, even with the consideration of the Sand Island tombolo, and that northwesterly waves were most common in the summer and thus heavy-use periods. This northwesterly cate-

3. Stability of Lake Water Levels and Depth of Offshore Waters

Lake Superior is the largest and uppermost of the Great Lakes system, discharging through the St. Marys River into Lake Huron. This discharge zone of sixty-two (62) miles represents a vertical drop of approximately twenty-two (22) feet. In order to compensate for the effect on Lake Superior levels of hydroelectric power diversions around the St. Marys Rapids, a control dam was constructed in 1921. Since that year the discharge from Lake Superior has been regulated under the supervision of the International Joint Commission (IJC), through its International Lake Superior Board of Control.

At the present time, the water level manipulation plan for Lake Superior (termed SO-901) is designed so as to hold back water in Lake Superior during periods of abnormally high precipitation, for the purpose of reducing or preventing high water levels in the lower Great Lakes. In addition to this manipulation, Lake Superior (and Little Sand Bay) is affected by three categories of water level fluctuations; namely, long-term, seasonal and short-term periods.

A period of 115 years (since 1860) of recording in the Lake Superior basin indicates that there is no regular or predictable water level cycle associated with this lake. The intervals between periods of high and low levels, and the length of such periods, can vary widely and erratically over an interval of years. The maximum recorded level range for Lake Superior (and thus Little Sand Bay) is 3.83 feet (598.23 low to 602.06 high).

The building of dams on the St. Marys Rapids outlet has, however, affected the long-term fluctuations. According to information gathered by the Northwest Regional Planning and Development Commission (Spooner, Wisconsin) and the National Oceanic and Atmospheric Administration (NOAA), Lake Survey Center,

the construction of outlet dams has created the following changes:

TABLE 8: Fluctuations of Water Levels of Lake Superior

Level	Before Regulation (1860-1921)	After Regulation (1922-1972)
High Levels (erosion and shore land damaging effect)		
Above 601.0 feet	13% of time	26% of time
Above 601.4 feet	3% of time	10% of time
Above 602.0 feet (maximum legal level)	0.1% of time	0.3% of time
Low Levels (beach building and shore stabilization effects)		
Below 600.0 feet	35% of time	20% of time
Below 599.5 feet	12% of time	4% of time
Below 599.2 feet	4.5% of time	2.7% of time

It has been charged that such controls, especially plan SO-901, are causing degradation of water quality, erosion of the highly erodible red clay found along the south shore and associated property damage.

A review of the annual hydrologic cycle reflects seasonal fluctuations on Lake Superior. Generally, such is characterized by higher net supplies during the spring and early summer with lower net supplies during the remaining months of the year. The Lake Superior (and thus Little Sand Bay) magnitude averages approximately one foot. For the first six months of 1974 the seasonal range at Ontonogon, Michigan was 1.22 feet, while at Duluth, Minnesota the recorded range was 1.24 feet (refer to U.S. Department of Commerce charts in reprint section). Short-term fluctuations, which can be expected to last from a few

hours to several days, are caused by various meteorological disturbances, such as wind patterns and intensities, barometric pressure differentials and tidal action. Sustained high winds along the axis of a lake, typified by prevailing westerlies blowing along the long axis of Lake Superior, may cause this lake surface to tilt, rising as much as seven (7) feet at the east end and falling a like amount at the west end. As Little Sand Bay is located in the latter section, such seiches (atmospheric induced fluctuations (Gross, 1972)) will create initially lower than normal water levels. However, cessation or alteration of wind patterns will cause conditions resulting in seiche oscillations, yielding rapid and diminishing-with-time local water level changes (to a degree such will be broken up by the network of islands surrounding the study area). In a similar vein, atmospheric pressure changes can produce sudden lake level changes. The maximum reported seiche in the entire Great Lakes was recorded as eight (8) feet at Buffalo Harbor in Lake Erie, the shallowest of the Great Lakes and thus an area where seiches are particularly evident.

True tides, both of a solar and lunar origin, have been observed and studied on Lake Superior for years. The U.S. National Ocean Survey (Department of Commerce) reports that the spring (combined solar and lunar) effects are less than two (2) inches on Lake Superior (and thus Little Sand Bay).

Of course within the immediate area of the study, storm surges, often not related to prevailing wind directions, can cause rapid and severe water surface disturbances. Northeasterlies are of particular concern for south shore Lake Superior residents (the strongest one minute wind ever anemometer recorded on Lake Superior was on 25 June, 1950, off the northwest at a speed of 93 mph). During the study period (autumn of 1974) storm surges of six to eight feet

were experienced. Early spring and fall (October) are critical periods of time for such fluctuations due to increased cyclonic activity and large temperature differences between the water surface and the overlying atmospheric column.

During this study minor variations in water levels were measured by recording the position of the swash line or the reference point as described by Bascom (1951). Bascom emphasizes the reproducibility of this point as a stable baseline for both water level and grain size measurements. Almost all stations experienced some fluctuations (±5 - 10 cm) but the more active profiles (Appendix C1 through C9) experienced losses and gains of 20 to 30 cm in the vertical plane. These figures are in the less than one foot, short-term range and it is difficult to place the blame solely on fluctuating water levels, although wind set-up is probably the dominant factor. Being that the greatest fluctuations are localized at a few stations, it is easier to attribute these anomalies upon beach face slope fluctuations where the slope is attempting to come into equilibrium with the grain size and sand availability as described by Bascom (1951) and Schwartz (1967).

Other factors do affect, on a local and regional basis, lake levels but will not be discussed here due to their extremely long-term basis or their lack of relevance to the subject area. Included in this category is the isostatic uplift of several hundred feet within the entire Great Lakes area that has occurred in the past ten millinnia due to the melting of glacial caps and artificial factors such as dredging, discharge diversions, and consumptive use patterns.

On three occasions throughout the study period (17 June, 7 July and 7 August), information was field collected relative to offshore depths. Employing a continuously recording fathometer (Raytheon model DE-731), five profiles were established approximately perpendicular to the shoreline and carried to the forty (40) foot depth mark (T_1 through T_5, Figure 2). An additional profile (TP) composed of two segments was run parallel to the shore. Offshore depth data stations were established by the intersection of triangulation sites from onshore manned stations. Compensation for normal wave fluctuation was taken into account.

The bottom topography of Little Sand Bay has made minor changes from that measured in the fall of 1974. This study identifies the existence of two slope provinces, generally separated by the 20 foot isobath. The shoreward gradient is 2.1% in the area of the existing docks (a decrease of 0.3% over 1974), 1.4% in the area of the eastern proposed site and 2.6% in the area of the western sandstone cliffs. The gradient beyond the 20 foot contour averages 0.6% (compared to the 1974 figure of 0.7%) (Figure 3). The interesting difference between the fall and summer bathymetric data is the lack of prominent sand buildup in front of the present dock area which was evidenced in the 1974 data. Presently, this sand has moved into the existing docking enclosure and caused shoaling problems at this site. It will become apparent in later sections that the area shoreward of the 10 foot contour is the most active in terms of sand transport, and any engineering structures built in this area would thus interrupt normal sediment transport patterns.

In weighing the two proposed docking sites on the basis of slope gradient alone, the present (existing) dock site area is more promising. The existing

dock area has a 1.8% slope shoreward of ten feet and a 1.9% gradient between the 10 and 20 foot isobaths while the eastern proposed site has 1.7% slope shoreward of 10 feet and a 1.1% slope between 10 and 20 feet.

4. Evaluation of Wind Direction, Frequency and Intensity of Storms which Directly Affect Wave Conditions in the Littoral Zone

Due to the casual effect of wind upon the wave climate, this and the following section are integrally related by subject matter. Wind directions and intensity were recorded in the field by direct observation (Table 9) and through the use of a compilation of available historical data (Table 10).

In general, fall and winter winds are out of the northwest or northeast in the Little Sand Bay area with the most intense storms approaching from the northwest. Spring and summer winds are more variable in direction, and of lesser intensity, but the majority of winds which affect the Bay come from the northwest (Climate of the Great Lakes, 1972 and direct observation). Wind directions recorded at the Duluth (Minnesota) airport show northwest as the dominant direction for late winter and early spring followed closely in frequency and intensity by west and east directions. Table 10 and Appendix B show that the midsummer winds are out of the western and eastern quadrants to a proportional degree. This may be true historically, but field observations show a heavy prejudice for westerly, especially northwesterly, winds.

Table 9 does show lessening of wind intensities during summer of 1975 over that observed in the fall and early winter of 1974. In fact, 49.5% of the observations showed dead calm or non-registering gusts coming from all points of the compass. However, these were only surface winds observed along the beach of this localized area. The wave regime showed that winds were causing waves beyond the limits of Little Sand Bay. Catspaws were often observed to the south of Sand Island and in between Sand and York Islands. It appears as

TABLE 9

WIND AND WAVE OBSERVATIONS
(during study period)

			WIND		WAVE			
DATE	TIME	STATION	FORCE (mph)	DIREC-TION	DIREC-TION	HEIGHT (feet)	WAVE LENGHT (feet)	PE-RIOD (sec)
6/18/75	3:30 PM	1	calm	---	N	0-0.5	8	2.5
6/18/75	4:00 PM	2	calm	---	N	0-0.5	8	2.5
6/18/75	4:10 PM	3	calm	---	N	0-0.5	8	2.5
6/18/75	4:30 PM	4	calm	---	N	0-0.5	8	2.5
6/18/75	4:40 PM	5	calm	---	N	0-0.5	8	2.5
6/18/75	5:30 PM	6	4-6	NE	none			
6/18/75	5:45 PM	7	3-4	W	confused sea			
6/18/75	6:05 PM	8	4	N	NW	0-0.5	confused sea	
6/19/75	9:35 AM	9	3-5	NE	NNE	0.5	5	1.25
6/19/75	---	10	3-4	NE	NNE	0.5	5	1.25
6/19/75	10:00 AM	11	3-4	NNE	NNE	0.5	5	1.25
6/19/75	10:15 AM	12	4-5	NE	NNE	1	5	1.25
6/19/75	10:30 AM	13	4-5	NE	NNE	1-2	5	1.36
6/19/75	10:45 AM	14	6-7	ENE	NNE	1-2	5	1.36
6/19/75	11:00 AM	15	5-6	ENE	NNE	1-2	5	1.36
6/19/75	11:15 AM	16	5-7	E	NNE	1-2	5	1.36
6/19/75	11:30 AM	17	4-5	E	NNE	1-2	5	1.36
6/19/75	---	18	0-1	E	NNE	1-2	5	1.36
6/27/75	7:00 PM	1	calm	--	NNW	0-0.5	10	1.5
6/27/75	6:50 PM	2	calm	---	NNW	0-0.5	10	1.5
6/27/75	---	3	calm	---	NNW	0-0.5	10	1.5
6/27/75	6:45 PM	4	0-1	NNW	NNW	0-0.5	10	1.5
6/27/75	6:30 PM	5	0-1	NNW	NNW	0-0.5	10	1.5
6/26/75	6:30 PM	6	5	NW	NNW	1-2	15	2.0
6/26/75	6:20 PM	7	5	NW	NNW	1-2	15	2.0
6/26/75	7:00 PM	8	calm	--	NNW	1-2	15	2.0
6/26/75	6:00 PM	9	5	NW	NW	1-2	15	2.0
6/26/75	---	10	3-5	S	NNE	1-2	15	2.0
6/26/75	3:35 PM	11	calm	---	NNE	1-2	15	2.0
6/26/75	3:30 PM	12	calm	---	NNE	0.5-1	6	2.0
6/26/75	---	13	calm	---	NNE	0.5-1	6	2.0
6/26/75	3:10 PM	14	calm	---	NNE	0.5-1	6	2.0
6/26/75	---	15	0-2	N	NNE	0.5-1	6	2.0
6/26/75	2:50 PM	16	2-3	N	NW	0.5-1	6	2.0
6/26/75	---	17	calm	---	NNW	0.5	--	1.5
6/26/75	2:30 PM	18	calm	---	NNW	0.5	--	1.5

Table 9 Continued
Wind and Wave Observations

			WIND		WAVE			
DATE	TIME	STATION	FORCE (mph)	DIREC-TION	DIREC-TION	HEIGHT (feet)	WAVE LENGHT (feet)	PE-RIOD (sec)
7/7/75	---	1	calm	---	NNW	1	11	1.8
7/7/75	---	2	calm	---	NNW	1	11	1.8
7/7/75	5:55 PM	3	calm	---	NNW	1	11	1.8
7/7/75	5:35 PM	4	calm	---	NE	r i p p l e s		
7/7/75	5:35 PM	4	calm	---	NW	r i p p l e s		
7/7/75	---	5	calm	---	NNW	0.5	10	1.5
7/7/75	5:00 PM	6	calm	---	NNW	0.5	10	1.5
7/7/75	3:50 PM	7	8-9	NNW	choppy and refracted by crib			
7/7/75	3:35 PM	8	7	NNW	choppy and refracted by crib			
7/7/75	3:25 PM	9	9-10	NNW	NNW	1-2	6	1.5
7/7/75	3:15 PM	10	8-9	NNW	NNW	1-2	6	1.5
7/7/75	---	11	7-8	NNW	NNW	1-2	6	1.0
7/7/75	2:50 PM	12	calm	---	NW	0.5-1	6	1.0
7/7/75	---	13	3	NNW	NW	0.5-1	6	1.0
7/7/75	2:30 PM	14	calm	---	NW	0.5-1	6	1.0
7/7/75	---	15	calm	---	NW	0.5-1	6	1.0
7/7/75	2:05 PM	16	3-4	NW	NNW	0.5	3	1.0
7/7/75	---	17	calm	---	NNW	0.5	3	1.0
7/7/75	1:40 PM	18	calm	---	NNW	0.5	3	1.0
7/15/75	---	1	4-5	NW	NW	2	5	1.5
7/15/75	---	2	4-5	NW	NW	1-2	5	1.5
7/15/75	5:00 PM	3	4-5	NW	NW	1-2	5	1.5
7/15/75	5:00 PM	4	5-7	NW	NW	1-2	5	1.5
					+ set refracted off NPS dock			
7/15/75	4:45 PM	5	5-7	NW	NW	1-2	5	1.5
7/14/75	7:20 PM	6	calm	---	WNW	0-0.5	5	1.5
7/14/75	7:10 PM	7	4-6	W	WNW	0-0.5	5	1.5
7/14/75	7:00 PM	8	3-4	W	WNW	0-0.5	5	1.5
7/14/75	---	9	0-3	NW	WNW	1	7	1.5
7/14/75	---	10	2-3	W	WNW	1	7	1.5
7/14/75	6:25 PM	11	calm	---	WNW	2	12	1.5
7/14/75	6:20 PM	12	calm	---	WNW	2	12	1.5
7/14/75	---	13	calm	---	WNW	2	12	1.5
7/14/75	6:05 PM	14	calm	---	WNW	2	12	1.5
7/14/75	5:55 PM	15	calm	---	WNW	2	12	1.5
7/14/75	5:45 PM	16	3-4	W	WNW	2	12	1.5
7/14/75	---	17	6-7	W	WNW	2	12	1.5
7/14/75	5:30 PM	18	2-4	W	WNW	2	12	1.5
7/25/75	---	1	calm	---		n o n e		
7/25/75	---	2	calm	---		n o n e		
7/25/75	7:25 PM	3	calm	---	NNW	0-0.25	3	1.5

Table 9 Continued
Wind and Wave Observations

			WIND		WAVE			
DATE	TIME	STATION	FORCE (mph)	DIREC- TION	DIREC- TION	HEIGHT (feet)	WAVE LENGHT (feet)	PE- RIOD (sec)
7/25/75	---	4	calm	---	--	none		
7/25/75	7:10 PM	5	calm	---	NNE	0-0.25	3	1.5
7/25/75	6:50 PM	6	calm	---	--	none		
7/25/75	6:25 PM	7	calm	---	NNE	0-0.5	10	2.7
7/25/75	6:10 PM	8	calm	---	NNW	0-0.5	10	2.7
7/25/75	6:05 PM	9	calm	---	NNW	0-0.5	10	2.7
7/25/75	5:55 PM	10	calm	---	NNW	0-0.5	10	2.7
7/25/75	5:45 PM	11	calm	---	N	choppy		
7/25/75	5:35 PM	12	4-5	NW	NW	0.25	short choppy	
7/25/75	5:35 PM	12	4-5	NW	NNW	0-0.5	10	2.7
7/25/75	---	13	4-5	NW	NW	riffles		
7/25/75	5:20 PM	14	calm	---	NNW	0-0.5	10	2.7
7/25/75	5:10 PM	15	calm	---	NNW	0-0.5	10	2.7
7/25/75	5:00 PM	16	calm	---	NNW	0-0.5	10	2.7
7/25/75	---	17	calm	---	NNW	0-0.5	10	2.7
7/25/75	4:35 PM	18	calm	---	NNW	0-0.5	10	2.7
8/5/75	1:55 PM	boat	6-8	NW	NW	0.5-1	2-3	1.2
8/5/75	5:10 PM	boat	4-6	NW	NW	0.5-1	2-3	1.2
8/6/75	5:10 PM	1	0-2	N	N	1	10	1.7
8/6/75	---	2	calm	---	N	1	10	1.7
8/6/75	4:55 PM	3	0-2	NNE	N	1	10	1.7
8/6/75	---	4	0-1	N	N	1	10	1.7
8/6/75	4:40 PM	5	0-1	N	N	1	10	1.7
8/6/75	3:10 PM	6	1-2	SE	NNE	1	6	1.5
8/6/75	3:00 PM	7	gusts	NNW	NNE	1	6	1.5
8/6/75	2:50 PM	8	0-1	NNE	NNE	1	5	1.2
8/6/75	---	9	3-5	WNW	NNE	0.5	5	1.2
8/6/75	---	10	calm	---	N	0.5	6	1.5
8/6/75	2:25 PM	11	calm	---	N	0.5	6	1.5
8/6/75	2:10 PM	12	0-1	W	NNW	0.5	6	1.5
8/6/75	2:00 PM	13	calm	---	N	0.5	6	1.5
8/6/75	1:55 PM	14	calm	---	WNW	0.5	6	1.5
8/6/75	---	15	calm	---	WNW	0.5	6	1.5
8/6/75	---	15	calm	---	NNW	0.5	6	1.5
8/6/75	1:30 PM	16	1-2	NE	W	short chop		
8/6/75	---	17	0-1	W	W	short chop		
8/6/75	1:10 PM	18	0-1	W	WNW	0.5	6	1.6
8/14/75	---		16-18	NE	---	---	--	---

Table 9 Continued
Wind and Wave Observations

			WIND		WAVE			
DATE	TIME	STATION	FORCE (mph)	DIREC-TION	DIREC-TION	HEIGHT (feet)	WAVE LENGHT (feet)	PE-RIOD (sec)
8/16/75	5:50 PM	1	2	E	NW	1	20	2.0
8/16/75	5:40 PM	2	3-4	E	NW	1	20	2.0
8/16/75	5:30 PM	3	calm	---	NW	1	20	2.0
8/16/75	5:25 PM	4	calm	---	ripples smoothed by dock			
8/16/75	5:15 PM	5	calm	---	NW	0.5	20	2.0
8/16/75	5:15 PM	5	calm	---	NNW	0.5	10	1.0
8/16/75	4:35 PM	6	calm	---	N	0.5	6	1.2
8/16/75	4:35 PM	6	calm	---	NE	0.5	8	1.2
8/16/75	4:25 PM	7	calm	---	NNE	1.5	8	1.6
8/16/75	3:40 PM	8	calm	---	NNE	1.5	8	1.6
8/16/75	3:35 PM	9	4-6	NNE	NNE	1.5	8	1.6
8/16/75	3:20 PM	10	4-6	NNE	NW	1	10	2.2
8/16/75	3:20 PM	10	4-6	NNE	NNE	1.5	8	1.6
8/16/75	3:15 PM	11	2	E	NW	2	10	2.2
8/16/75	---	12	2-3	E	NW	2	10	2.2
8/16/75	---	13	calm	---	NW	2	10	2.2
8/16/75	2:50 PM	14	gusts	SW	NW	2	10	2.2
8/16/75	---	15	gusts	SW	NW	2	10	2.2
8/16/75	---	16	gusts	SW	NW	2	10	2.2
8/16/75	2:30 PM	17	0-2	NW-SW	NW	1-2	10	2.2
8/16/75	---	18	calm	---	NW	1	10	2.2

TABLE 10

(FREQUENCY AND STRENGTH)/MONTH
OF THE MOST COMMONLY OCCURRING WINDS
1948-1971

Duluth Airport, based upon hourly observations of surface winds

MONTH	DIRECTION	RANK ACCORDING TO FREQUENCY OF OCCURRENCE	STRENGTH IN MILES PER HOUR
January	NW	1	12.5-18.5
January	WNW	2	12.5-18.5
January	NNW	3	12.5-18.5
February	NW	1	12.5-18.5
February	WNW	2	12.5-18.5
February	NNW	3	12.5-18.5
March	NW	1	12.5-18.5
March	WNW	2	12.5-18.5
March	E	3	12.5-18.5
April	E	1	12.5-18.5
April	NW	2	12.5-18.5
April	ENE	3	12.5-18.5
May	E	1	12.5-18.5
May	ESE	2	8-11.5
May	ENE	3	12.5-18.5
June	E	1	8-11.5
June	ESE	2	8-11.5
June	WNW	3	12.5-18.5
July	WNW	1	8-11.5
July	E	2	8-11.5
July	ESE	3	8-11.5
August	ENE	1	12.5-18.5
August	E	2	8-11.5
August	WNW	3	8-11.5
September	WNW	1	8-11.5 & 12.5-18.5
September	E	2	8-11.5 & 12.5-18.5
September	NW	3	12.5-18.5
October	WNW	1	12.5-18.5
October	NW	2	12.5-18.5
October	E	3	8-11.5
November	WNW	1	12.5-18.5
November	NW	2	12.5-18.5

if the pine covered headlands to the east and west of Little Sand Bay afford the area protection from these summer winds, a phenomena which often sheltered large populations of biting dipterans.

There were no storms observed in the late spring and summer of 1975 sampling period which thus precludes any statement of the effect of summer storms upon Little Sand Bay. However, Table 10 shows a historical increase in wind intensities in the month of August and would indicate the initiation of the fall and winter wind conditions as summarized above.

5. Evaluation of Wave Climate as to Height, Period and Direction

Waves and their associated energy are perhaps the single most important factor affecting a beach littoral zone. Direct observations of this phenomona, listed in Table 9, were made and compared to historical data (Table 10).

There is a paucity of wind and wave data to be found for the Little Sand Bay area. The Data Processing Division (USAFETAC), Air Weather Service in Ashville, North Carolina reported that the Duluth Airport was the closest historical recording station on the south shore of Lake Superior (Table 10). The location (60 miles west of Apostle Islands) and altitude (1,400 feet) of this station makes this data questionable for realistic hindcasting of wave conditions for Little Sand Bay area (C.E.R.C. Tech. Rept. No. 4, 1966). Although there is a Coast Guard Station in Bayfield (10 miles southeast of Little Sand Bay), historical records are unfortunately not kept by this post. Therefore, Table 9 containing study period field measurements, must be relied upon for determination of wave climate.

As mentioned previously, beaches are cyclic in nature, that is, they seasonally erode and prograde. This phenomenon is caused by wave energy which increases directly with wind intensity. Thus the more violent winter storm waves remove sand from the beach face and deposit it offshore in a lower energy environment usually in the form of a submerged bar. This deposit of sand is later carried back to the beach face by the lower energy waves which accompany the less intense, summer conditions (Shepard, 1973).

Waves are not only responsible for movement of sands offshore, but also for their movement along shore, the latter being termed longshore drift. The

TABLE 11

WAVE ENERGY TABLE

$E_t = 40H^2T^2$

DATE	TIME	STATION NUMBER	TOTAL ENERGY (E_t) FT-LBS PER 1 FT LENGTH/WAVE
6/18/75	3:30 PM	1	62.5
6/18/75	4:00 PM	2	62.5
6/18/75	4:10 PM	3	62.5
6/18/75	4:30 PM	4	62.5
6/18/75	4:40 PM	5	62.5
6/19/75	9:35 AM	9	15.6
6/19/75	9:45 AM	10	15.6
6/19/75	10:00 AM	11	15.6
6/19/75	10:15 AM	12	62.4
6/19/75	10:30 AM	13	166.5
6/19/75	10:45 AM	14	166.5
6/19/75	11:00 AM	15	166.5
6/19/75	11:15 AM	16	166.5
6/19/75	11:30 AM	17	166.5
6/19/75	11:45 AM	18	166.5
6/27/75	7:00 PM	1	22.5
6/27/75	6:50 PM	2	22.5
6/27/75		3	22.5
6/27/75	6:45 PM	4	22.5
6/27/75	6:30 PM	5	22.5
6/26/75	6:30 PM	6	360.0
6/26/75	6:20 PM	7	360.0
6/26/75		8	360.0
6/26/75		9	360.0
6/26/75		10	360.0
6/26/75	3:35 PM	11	360.0
6/26/75	3:30 PM	12	89.6
6/26/75		13	89.6
6/26/75	3:10 PM	14	89.6
6/26/75		15	89.6
6/26/75	2:50 PM	16	89.6
6/26/75		17	22.5
6/26/75	2:30 PM	18	22.5
7/7/75		1	129.6
7/7/75		2	129.6
7/7/75	5:55 PM	3	129.6
7/7/75	5:25 PM	5	22.5

Table 11 Continued
Wave Energy

DATE	TIME	STATION NUMBER	TOTAL ENERGY (E_t) FT-LBS PER 1 FT LENGTH/WAVE
7/7/75	5 00 PM	6	22.5
7/7/75	3 25 PM	9	202.5
7/7/75	3:15 PM	10	202.5
7/7/75		11	90.0
7/7/75	2·50 PM	12	22.4
7/7/75		13	22.4
7/7/75	2:30 PM	14	22.4
7/7/75		15	22.4
7/7/75	2:05 PM	16	10.0
7/7/75		17	10.0
7/7/75	1:40 PM	18	10.0
7/15/75		1	360.0
7/15/75		2	202.5
7/15/75	5:00 PM	3	202.5
7/15/75	4:55 PM	4	202.5
7/15/75	4:45 PM	5	202.5
7/14/75	7:20 PM	6	202.5
7/14/75	7:10 PM	7	202.5
7/14/75	7:00 PM	8	202.5
7/14/75		9	90.0
7/14/75		10	90.0
7/14/75	6:25 PM	11	360.0
7/14/75	6·20 PM	12	360.0
7/14/75		13	360.0
7/14/75	6·05 PM	14	360.0
7/14/75	5·55 PM	15	360.0
7/14/75	5·45 PM	16	360.0
7/14/75		17	360.0
7/14/75	5:30 PM	18	360.0
7/25/75	7:25 PM	3	5.4
7/25/75	7·10 PM	5	5.4
7/25/75	6 25 PM	7	72.9
7/25/75	6:10 PM	8	72.9
7/25/75	6:05 PM	9	72.9
7/25/75	5:55 PM	10	72.9
7/25/75	5:35 PM	12	72.9
7/25/75	5:20 PM	14	72.9
7/25/75	5:10 PM	15	72.9
7/25/75	5:00 PM	16	72.9
7/25/75		17	72.9
7/25/75	4 35 PM	18	72.9

Table 11 Continued
Wave Energy

DATE	TIME	STATION NUMBER	TOTAL ENERGY (E_t) FT-LBS PER 1 FT LENGTH/WAVE
8/5/75	1:55 PM	Boat	24.6
8/5/75	6:00 PM	Boat	24.6
8/6/75	5:10 PM	1	116.0
8/6/75		2	116.0
8/6/75	4:55 PM	3	116.0
8/6/75		4	116.0
8/6/75		5	116.0
8/6/75		6	90.0
8/6/75	3:00 PM	7	90.0
8/6/75	2:50 PM	8	57.6
8/6/75		9	14.4
8/6/75		10	22.5
8/6/75	2:25 PM	11	22.5
8/6/75	2:10 PM	12	22.5
8/6/75	2:00 PM	13	22.5
8/6/75	1:55 PM	14	22.5
8/6/75	1:10 PM	18	25.6
8/16/75	5:50 PM	1	160.0
8/16/75	5:40 PM	2	160.0
8/16/75	5:30 PM	3	160.0
8/16/75	5:15 PM	5	40.0
8/16/75		5	10.0
8/16/75	4:35 PM	6	14.4
8/16/75	4:25 PM	7	230.4
8/16/75	3:40 PM	8	230.4
8/16/75	3:35 PM	9	230.4
8/16/75	3:20 PM	10	176.0
8/16/75		10	230.4
8/16/75	3:15 PM	11	704.0
8/16/75		12	704.0
8/16/75		13	704.0
8/16/75	2:50 PM	14	704.0
8/16/75		15	704.0
8/16/75		16	704.0
8/16/75	2:30 PM	17	396.0
8/16/75		18	176.0

direction of this drift is determined by the direction of an advancing wave train and the offshore topography (Bajorunas, 1960). As an example, a northwesterly approaching wave train will cause an easterly trending longshore current.

Wave energy increases with an increase in wave height and period and is expressed by the formula ($E_t = 40H^2T^2$), where E_t is the total wave energy in foot-pounds per 1 foot length/wave, H is the wave height in feet, T is the wave period in seconds and 40 is a constant derived from equations ($Lo = 5.12\ T^2$) and ($E_t = \frac{wLo\ H^2}{8}$) where Lo is the deep water oscillatory wave length and w= weight or 62.3 pounds/cubic foot (fresh water) (C.E.R.C. Tech. Rept. #4, 1966). Table 11 shows the relationship between the waves observed during the study period and their contained energy.

The relationship between wave energy and longshore drift intensity is easily seen in comparing Figures 5 through 11 with Table 11. One could observe that as wave energy, i.e. (E_t), increases, so does longshore drift, except for areas where the drift is obstructed, the nearshore area is sheltered or when wave reflection and refraction takes place. All of these cases are demonstrated in the area of the eastern proposed docking site, however wave refraction is the dominant factor.

As evidenced in the grain size distribution, stations 15 through 17 in the southeast corner of Little Sand Bay (Figure 2) receive the brunt of northwest storms. The beach width here is rather narrow and the beach area directly in front of the Beachcomber Bar (between stations 16 and 17) is strewn with boulders and an artificial seawall composed of old car bodies is placed 15 to 20 feet back from the still water line (see Photos page 61). All of these features;

View looking west from station 17. Note car bodies, offshore crib with attendant beach buildup and debris-strewn beach.

View looking east from station 15. Note car bodies and two cribs.

boulders, seawall and narrow beach, make excellent conditions for wave reflection. Little energy is expended upon a resistant surface such as a boulder or automobile, whereas great energy is absorbed by a gently sloping beach, which has been reduced to a narrow, steep strip. Data on wave energy and longshore drift show that the stations centering on site 16 are recipients of relatively intense conditions, being caused by refraction, reflection and protection caused by the two offshore semi-submerged cribs.

6. Evaluation of Nearshore and Wave Induced Currents

Waves approaching a shoreline at an angle, have a net forward component and the return flow has a net longshore component. These two components combined contribute to what is called the longshore current, which is responsible for the movement of material parallel to the shoreline (Shepard, 1973). Another consequence of breaking waves upon a beach is called backwash, or the return of water below the oncoming waves after the wave has run up the beach face. A strong backwash is thought to be responsible for the removal of material perpendicular to a beach in high energy conditions (Bascom, 1951). Rip currents are also responsible for returning large amounts of water to the breaker cycle, however, none were observed in the Little Sand Bay area.

Figures 5 through 11 graphically represent the observed longshore current of Little Sand Bay and a more detailed discussion of this current will appear in the following sections. In general, the direction and intensity of the longshore current depends upon the direction of wind and wave attacks, and the wave energy expended on the beach face (Loy, 1962 and Sonu, 1972). This current is modified by the offshore topography and man-made structures which are built into the shallow water zone.

To date there has been no easily applied method for measuring the effect of backwash in the breaker zone (Ingle, 1966). All that is known is that there is a return flow of water and that fine particles are carried offshore into a lower energy environment (Bascom, 1951). A current meter is useless in the zone of turbulence due to the abrasion of suspended sand particles, so surface measurement by drogues is the accepted method.

In this study, in addition to drogues, current meters were placed further offshore in safe (7.5 and 20 foot) depths so as to determine any steady state currents in the area as well as to measure the decrease in longshore drift intensity with increasing depth offshore.

Figures 5 through 11 in the following section display the longshore currents, while Table 12 displays the current meter data. It is obvious from the latter data that summer 1975 currents were minimal. The meters were usually not able to pick up a current strength within the precision of the machine, even with the larger, more sensitive fins attached, due to weak current character. However, the meters were able to register the direction from which a slight current originated. Even though the instrument target dot never reached a calibrated line on the compass ball (see Photo page 68), relative distance (velocity) could be determined. It was found that currents at the 7.5 foot depth were relatively stronger than those at the 20 foot depth (the meter here registered dead calm conditions 54% of the time) and were directly correlated to wind and wave direction, northwest being the predominant direction of approach. No steady state currents could be defined from this data due to the amount of time the meters functioned while on station (18%) and no data for bed load calculations were available. However, it can be said that the longshore current (nearshore wave induced current) does increase in intensity as depth decreases toward shore, and that the dominant direction is to the east due to dominant west to northwest trending wave approaches.

Loy (1962) in his study of western Lake Superior found no nearshore currents with an unidirectional trend, or what could be called steady state. His data was of a more historical nature than that presented here, however, his con-

TABLE 12

CURRENT METER DATA

DEPTH	DATE	HOUR	AVERAGE DIRECTION	AVERAGE SPEED
7.5 feet	7/15/75 PM	2:30-3:00	E	N.R.*
7.5 feet	7/15/75 PM	3:00-4:00	SW	0
7.5 feet	7/15/75 PM	4:00-5:00	W	N.R.
7.5 feet	7/15/75 PM	5:00-6:00	WNW	N.R.
7.5 feet	7/15/75 PM	6:00-7:00	NW	N.R.
7.5 feet	7/15/75 PM	7:00-8:00	NW	N.R.
7.5 feet	7/15/75 PM	8:00-9:00	NNE	N.R.
7.5 feet	7/15/75 PM	9:00-10:00	NNE	0.175 cm/sec
7.5 feet	7/15/75 PM	10:00-11:00	N	N.R.
7.5 feet	7/15/75 PM	11:00-12:00	NNE	0.078 cm/sec
7.5 feet	7/16/75 AM	12:00-1:00	N	N.R.
7.5 feet	7/16/75 AM	1:00-2:00	N	N.R.
7.5 feet	7/16/75 AM	2:00-3:00	NNW	N.R.
7.5 feet	7/16/75 AM	3:00-4:00	NW	N.R.
7.5 feet	7/16/75 AM	4:00-5:00	0	0
7.5 feet	7/16/75 AM	5:00-6:00	NW	N.R.
7.5 feet	7/16/75 AM	6:00-7:00	NW	N.R.
7.5 feet	7/16/75 AM	7:00-8:00	WNW	N.R.
7.5 feet	7/16/75 AM	8:00-9:00	WNW	N.R.
7.5 feet	7/16/75 AM	9:00-10:00	WNW	N.R.
7.5 feet	7/16/75 AM	10:00-11:00	NW	N.R.
7.5 feet	7/16/75 AM	11:00-12:00	NNW	N.R.
7.5 feet	7/16/75 PM	12:00-1:00	WNW	N.R.
7.5 feet	7/16/75 PM	1:00-2:00	WNW	N.R.
7.5 feet	7/16/75 PM	2:00-3:00	NNW	N.R.
7.5 feet	7/16/75 PM	3:00-4:00	NW	N.R.
7.5 feet	7/16/75 PM	4:00-5:00	NW	N.R.
7.5 feet	7/16/75 PM	5:00-6:00	W	N.R.
7.5 feet	7/16/75 PM	6:00-7:00	NW	N.R.
7.5 feet	7/16/75 PM	7:00-8:00	NW	N.R.
7.5 feet	7/16/75 PM	8:00-9:00	S	N.R.
7.5 feet	7/16/75 PM	9:00-10:00	NW	N.R.
7.5 feet	7/16/75 PM	10:00-11:00	W	N.R.
7.5 feet	7/16/75 PM	11:00-12:00	N	N.R.
7.5 feet	7/17/75 AM	12:00-1:00	NNW	N.R.
7.5 feet	7/17/75 AM	1:00-2:00	NW	N.R.
7.5 feet	7/17/75 AM	2:00-3:00	NNW	N.R.
7.5 feet	7/17/75 AM	3:00-4:00	NNW	N.R.
7.5 feet	7/17/75 AM	4:00-5:00	NW	N.R.
7.5 feet	7/17/75 AM	5:00-6:00	NW	N.R.
7.5 feet	7/17/75 AM	6:00-7:00	NW	0.078 cm/sec

Table 12 Continued
Current Meter Data

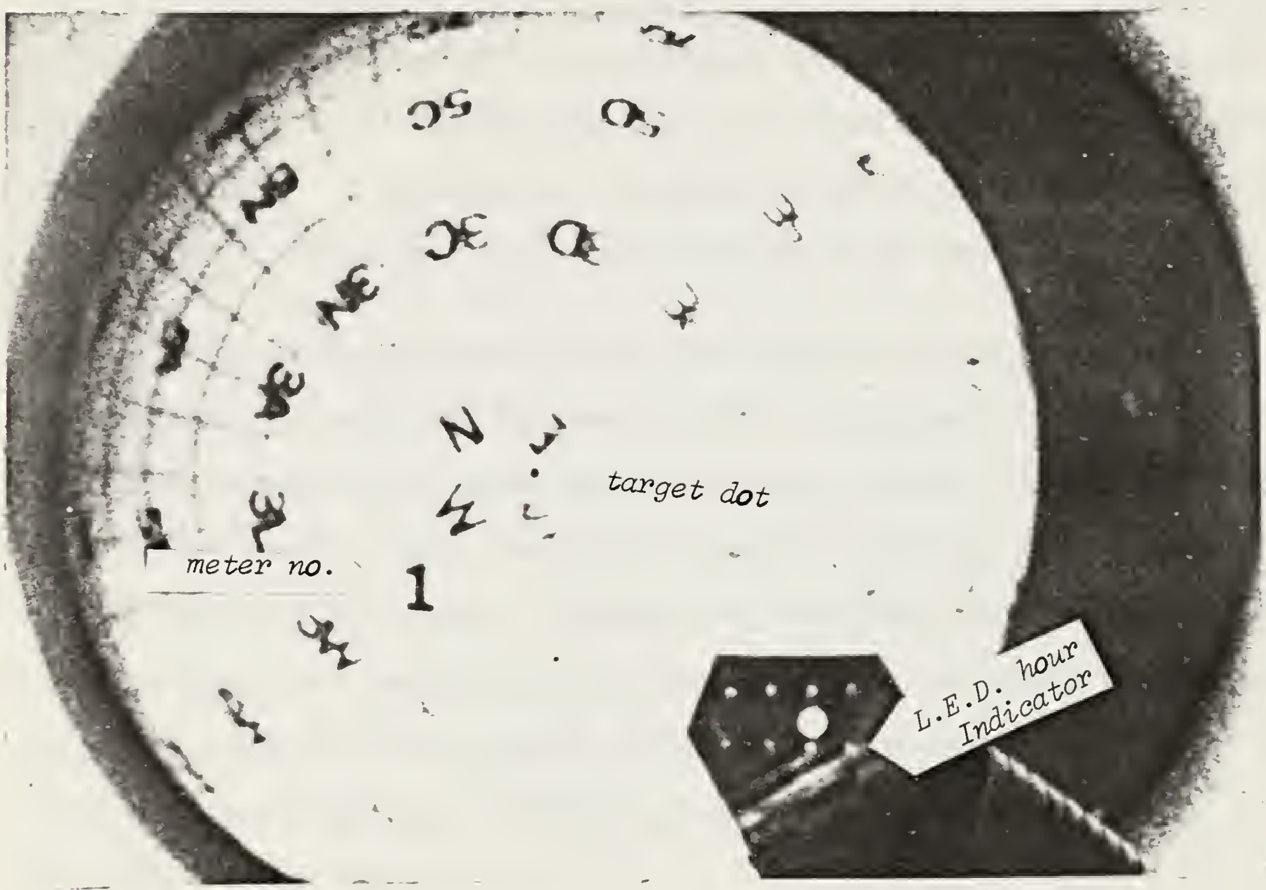
DEPTH	DATE	HOUR	AVERAGE DIRECTION	AVERAGE SPEED
7.5 feet	7/17/75 AM	7:00-8:00	NW	0.078 cm/sec
7.5 feet	7/17/75 AM	8:00-9:00	NNW	N.R.
7.5 feet	7/17/75 AM	9:00-10:00	NW	N.R.
7.5 feet	7/17/75 AM	10:00-11:00	W	N.R.
7.5 feet	7/17/75 AM	11:00-12:00	NW	N.R.
7.5 feet	7/17/75 PM	12:00-1:00	W	N.R.
7.5 feet	7/17/75 PM	1:00-2:00	NW	N.R.
7.5 feet	7/17/75 PM	2:00-3:00	NNW	0.175 cm/sec
7.5 feet	7/17/75 PM	3:00-4:00	NW	N.R.
7.5 feet	7/17/75 PM	4:00-5:00	W	N.R.
7.5 feet	7/17/75 PM	5:00-6:00	NW	N.R.
7.5 feet	7/17/75 PM	6:00-7:00	NW	N.R.
7.5 feet	7/17/75 PM	7:00-8:00	NW	N.R.
7.5 feet	7/17/75 PM	8:00-9:00	N	0.078 cm/sec
7.5 feet	7/17/75 PM	9:00-10:00	N	0.078 cm/sec
7.5 feet	7/17/75 PM	10:00-11:00	NW	N.R.
7.5 feet	7/17/75 PM	11:00-12:00	NW	N.R.
7.5 feet	7/18/75 AM	12:00-1:00	WNW	N.R.
7.5 feet	7/18/75 AM	1:00-2:00	WNW	N.R.
7.5 feet	7/18/75 AM	2:00-3:00	W	N.R.
7.5 feet	7/18/75 AM	3:00-4:00	W	N.R.
7.5 feet	7/18/75 AM	4:00-5:00	W	N.R.
7.5 feet	7/18/75 AM	5:00-6:00	W	N.R.
7.5 feet	7/18/75 AM	6:00-7:00	WNW	N.R.
7.5 feet	7/18/75 AM	7:00-8:00	WNW	N.R.
7.5 feet	7/18/75 AM	8:00-9:00	NW	N.R.
7.5 feet	7/18/75 AM	9:00-10:00	NW	N.R.
7.5 feet	7/18/75 AM	10:00-11:00	NW	N.R.
7.5 feet	7/18/75 AM	11:00-12:00	WNW	N.R.
7.5 feet	7/18/75 PM	12:00-12:30	WNW	N.R.
20 feet	8/15/75 PM	5:30-6:00	N	N.R.
20 feet	8/15/75 PM	6:00-7:00	N	N.R.
20 feet	8/15/75 PM	7:00-8:00	N	N.R.
20 feet	8/15/75 PM	8:00-9:00	NE	N.R.
20 feet	8/15/75 PM	9:00-10:00	NE	N.R.
20 feet	8/15/75 PM	10:00-11:00	NE	N.R.
20 feet	8/15/75 PM	11:00-12:00	0	N.R.
20 feet	8/16/75 AM	12:00-1:00	---	N.R.
20 feet	8/16/75 AM	1:00-2:00	---	N.R.
20 feet	8/16/75 AM	2:00-3:00	0	N.R.
20 feet	8/16/75 AM	3:00-4:00	N	N.R.

Table 12 Continued
Current Meter Data

DEPTH	DATE	HOUR	AVERAGE DIRECTION	AVERAGE SPEED
20 feet	8/16/75 AM	4:00-5:00	0	N.R.
20 feet	8/16/75 AM	5:00-6:00	0	N.R.
20 feet	8/16/75 AM	6:00-7:00	NW	N.R.
20 feet	8/16/75 AM	7:00-8:00	0	N.R.
20 feet	8/16/75 AM	8:00-9:00	0	N.R.
20 feet	8/16/75 AM	9:00-10:00	E	N.R.
20 feet	8/16/75 AM	10:00-11:00	SSE	N.R.
20 feet	8/16/75 AM	11:00-12:00	W	N.R.
20 feet	8/16/75 PM	12:00-1:00	0	N.R.
20 feet	8/16/75 PM	1:00-2:00	0	N.R.
20 feet	8/16/75 PM	2:00-3:00	0	N.R.
20 feet	8/16/75 PM	3:00-4:00	0	N.R.
7.5 feet	8/15/75 PM	3:55-4:00	--	
7.5 feet	8/15/75 PM	4:00-4:05	W	N.R.
7.5 feet	8/15/75 PM	4:05-4:10	NW	N.R.
7.5 feet	8/15/75 PM	4:10-4:15	NW	N.R.
7.5 feet	8/15/75 PM	4:15-4:20	W	N.R.
7.5 feet	8/15/75 PM	4:20-4:25	W	N.R.
7.5 feet	8/15/75 PM	4:25-4:30	WNW	N.R.
7.5 feet	8/15/75 PM	4:30-4:35	--	---
7.5 feet	8/15/75 PM	4:35-4:40	W	N.R.
7.5 feet	8/15/75 PM	4:40-4:45	NNW	N.R.

*N.R.=No Recovery

clusions as related to wave induced longshore currents are identical. Wave direction is responsible for longshore current direction and the intensity of wave energy is responsible for the longshore current velocity.



Enlargement of actual photo taken by current meter. Longitudinal lines indicate direction, latitudinal lines indicate velocity. Note target dot does not reach a calibrated line but does indicate a southeastern direction.

B. COASTAL PROCESSES ANALYSES

1. Longshore Transport Direction in Little Sand Bay

Longshore transport is the movement of beach material parallel to a shoreline as caused by waves and currents. The material transported is referred to as longshore drift and the transporting impetus is known as the longshore current (Bajorunas, 1960). A knowledge of the direction and velocity of these phenomena is necessary for the proper construction of shore-based structures.

There has been minimal analysis done on the direction of longshore drift in Lake Superior (Loy, 1962 and Bajorunas, 1960). A study made in 1956, which measured the direction of stream mouth discharges by aerial photography (University of Minnesota, 1957), indicated an easterly direction for the south shore of western Lake Superior. However, the same stream discharges have been seen to reverse to a westward direction at other times, especially during the summer, as indicated by the westward orientation and construction of river mouth sand-bar deposition. Therefore, no steady-state longshore current direction has been defined.

As previously stated, a longshore current is primarily produced by angle of wave attack; which explains the highly variable nature of the resulting direction of drift. Loy (1962) defines "beach drifting" as the net parallel motion of sand moving in a zig-zag pattern up and down the beach face. Such drifting is independent of wave induced currents and is soley dependent upon the angle of wave attack. Loy concludes that the velocity of longshore currents of the Lake Superior shoreline are not great enough to alter the first-order morphology. The authors would have to differ with this point due to the information presented

in Appendices C1 through C9. Of course, this study is one of a short-term nature and concentrates on a very small section of shoreline (slightly less than 1 mile), whereas Loy studied the entire western end of Lake Superior. When taken on a regional scale, longshore drift may appear to have no bearing upon a shoreline, however, when analyzed on a local scale the effect becomes obvious.

What Loy describes as beach drift does indeed occur in the swash zone with a minimal effect as to morphologic coastal changes. However, a study by Thornton (1969) on nearshore sediment transport, concluded that longshore drift increases in intensity with a decrease in water depth, as previously mentioned. The most intense area of transport is in the zone of turbulence (Miller and Zeigler, 1958), or plunge point where the swash meets the backwash (see Appendix C for exact location of this point). This makes longshore current measurement by floating drogue difficult due to the increasing effect of translational waves, which tend to carry the drogue toward shore in a relatively strong swash, and away from shore in a relatively strong backwash. Correlation, however, was attempted by the use of the aforementioned current meters. It was found that the general direction of longshore drift is to the east, with reversals caused by surficial winds and wave reflection and refraction.

Figures 5 through 11 graphically represent the longshore drift direction as observed between 18 June and 16 August, 1975. The obvious correlation of wind and wave approach has already been discussed.

Explanations for sudden reversals of direction are noted upon the graphs, the most common being related to changes in surficial winds. This is not unexpected, due to the gusty and vagrant nature of summer winds.

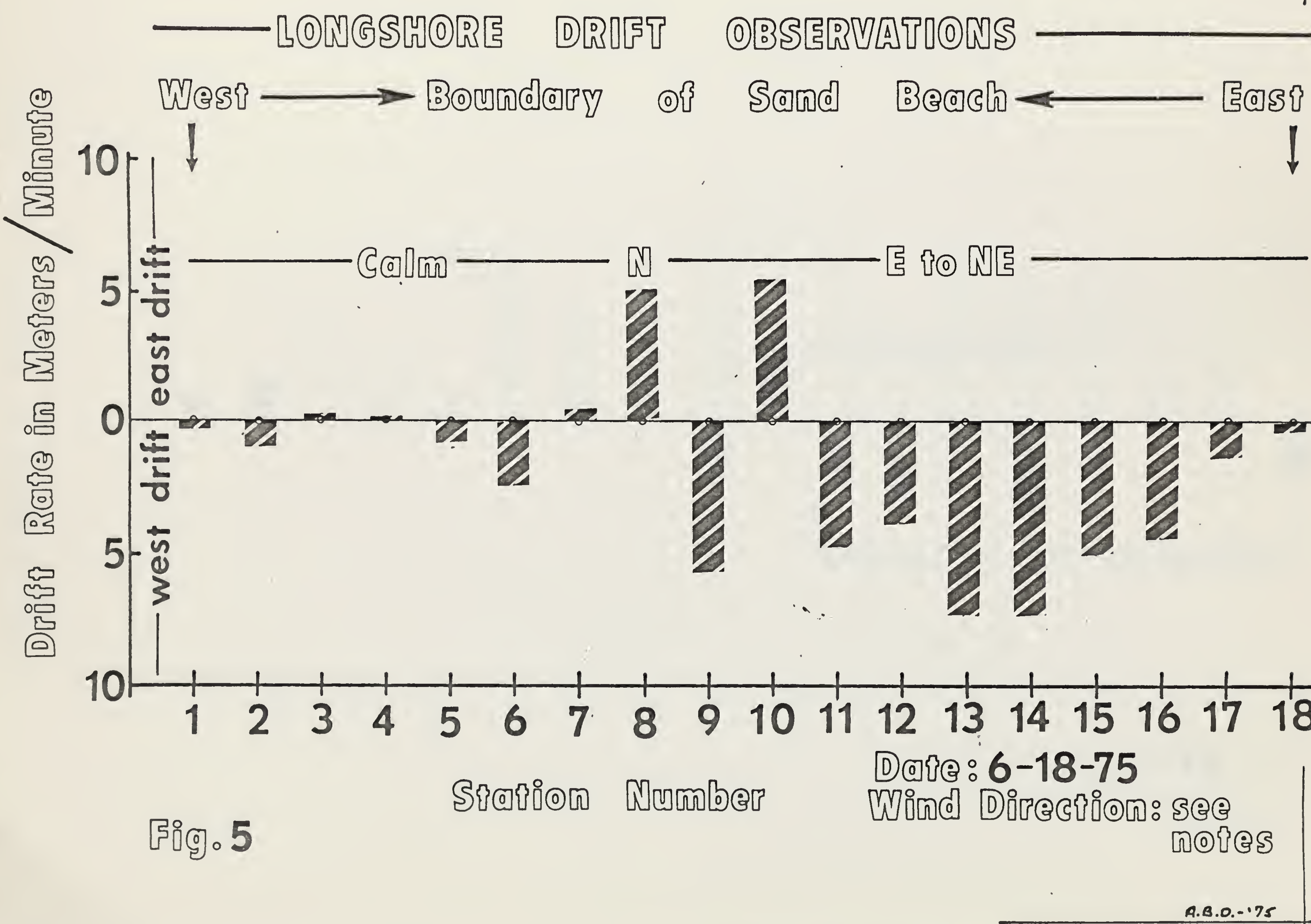

LONGSHORE DRIFT OBSERVATIONS
West → Boundary of Sand Beach ← East
Calm
N
E to NE
Drift Rate in Meters / Minute
east drift
west drift
10
5
0
5
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Station Number
Date: 6-18-75
Wind Direction: see notes
A.B.O.-'75

Fig. 5

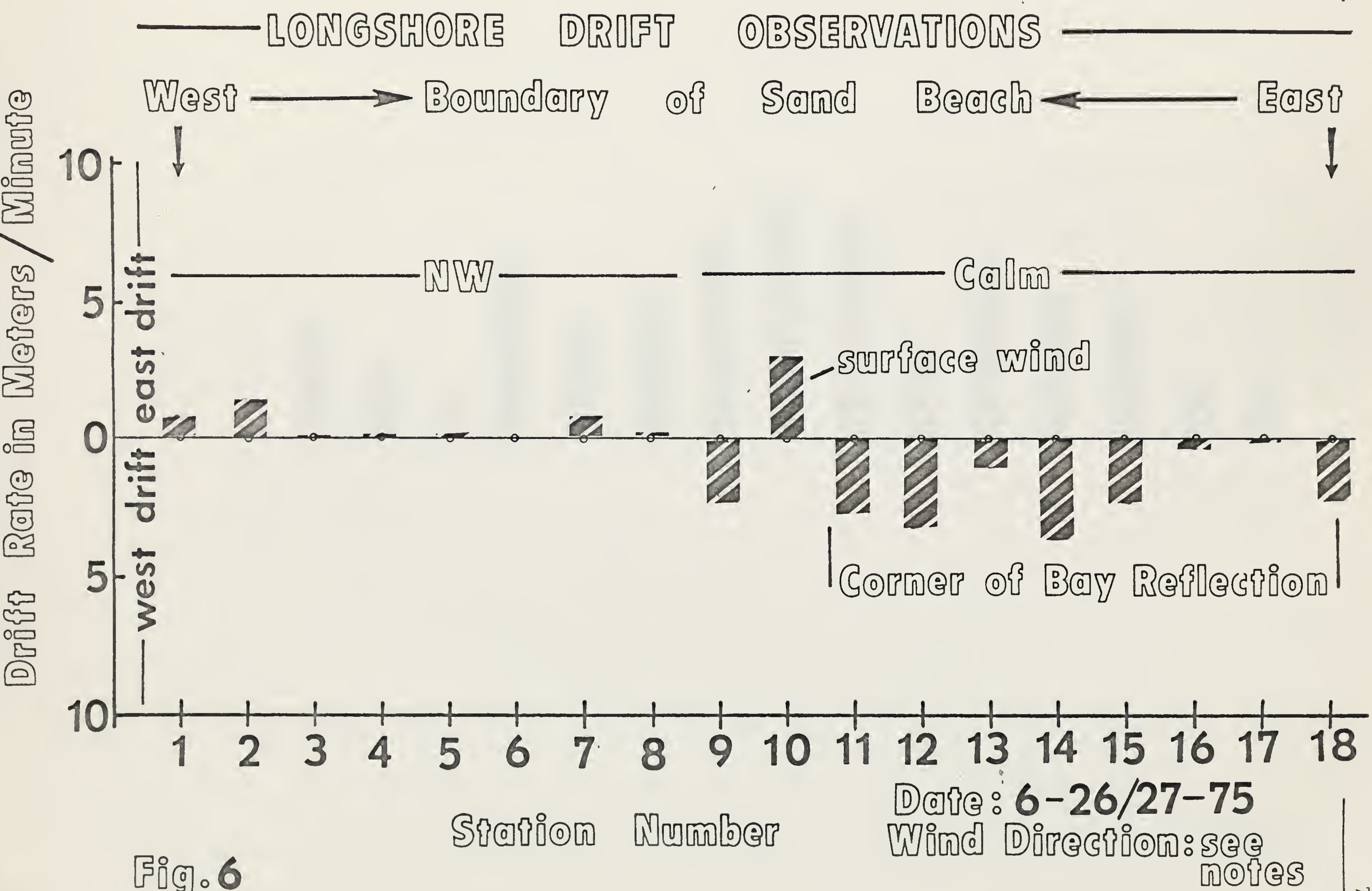

LONGSHORE DRIFT OBSERVATIONS
West → Boundary of Sand Beach ← East
Drift Rate in Meters / Minute
east drift
west drift
10
5
0
5
10
NW
Calm
surface wind
Corner of Bay Reflection
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Station Number
Date: 6-26/27-75
Wind Direction: see notes
A.B.O.-'75

Fig. 6

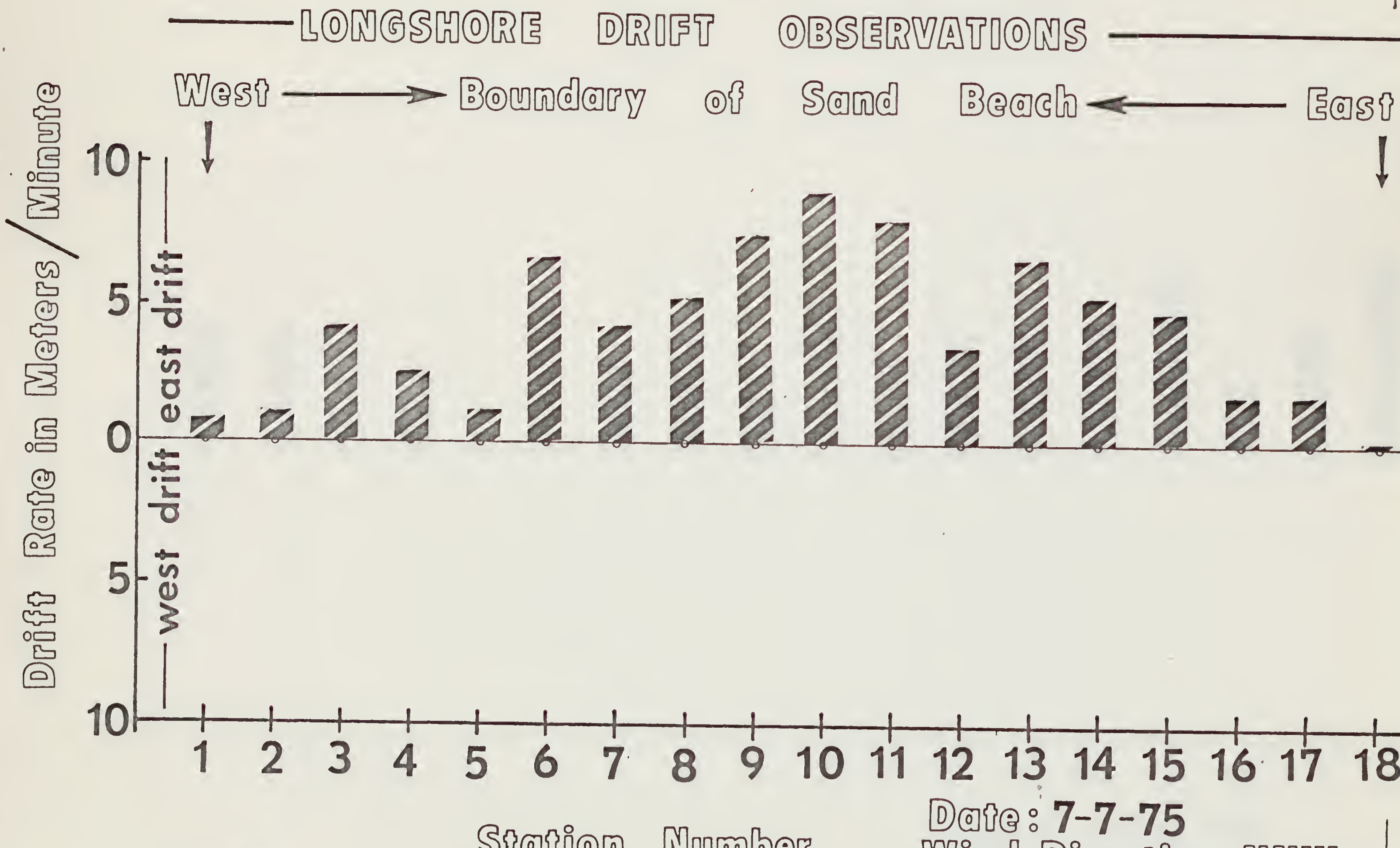

LONGSHORE DRIFT OBSERVATIONS
West → Boundary of Sand Beach ← East
Drift Rate in Meters / Minute
west drift
east drift
10
5
0
5
10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Station Number
Date: 7-7-75
Wind Direction: NNW
A.B.O.-'75

Fig. 7

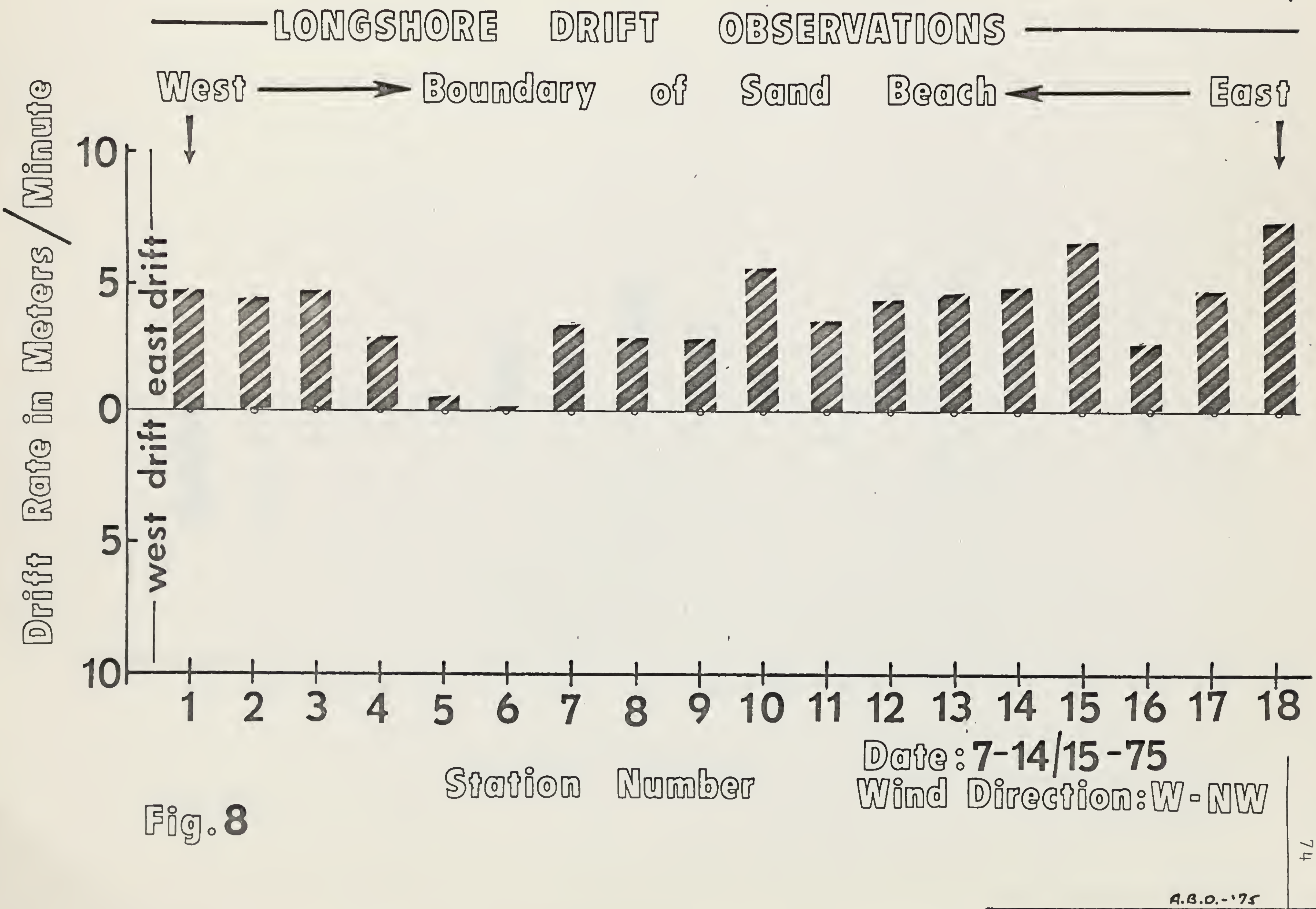

LONGSHORE DRIFT OBSERVATIONS
West
Boundary of Sand Beach
East
Drift Rate in Meters/Minute
10
5
0
5
10
east drift
west drift
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Station Number
Date: 7-14/15-75
Wind Direction: W-NW
A.B.O.-'75

Fig. 8

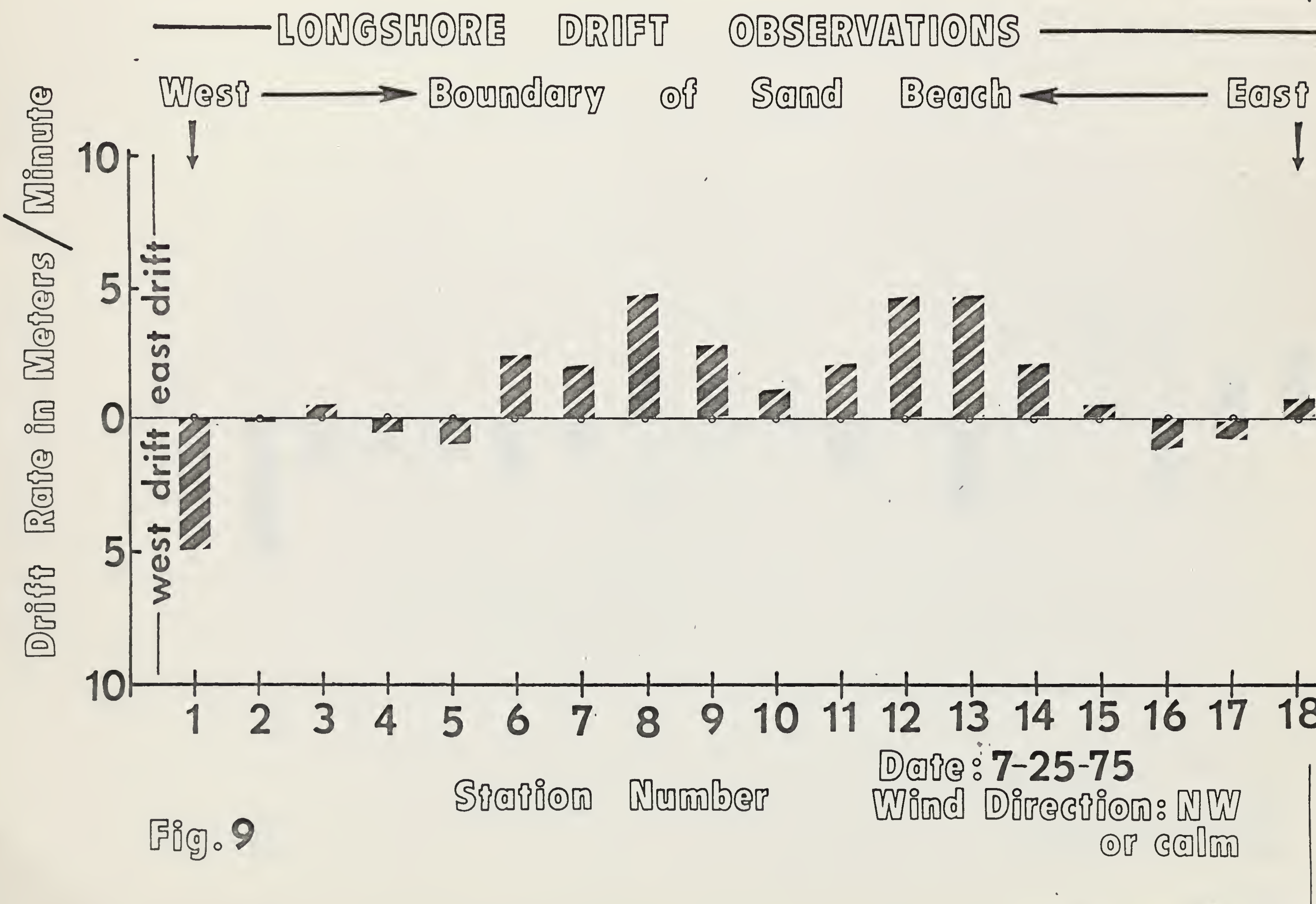

LONGSHORE DRIFT OBSERVATIONS
West → Boundary of Sand Beach ← East
Drift Rate in Meters / Minute
east drift
west drift
10
5
0
5
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Station Number
Date: 7-25-75
Wind Direction: NW
or calm
A.B.D.-'75

Fig. 9

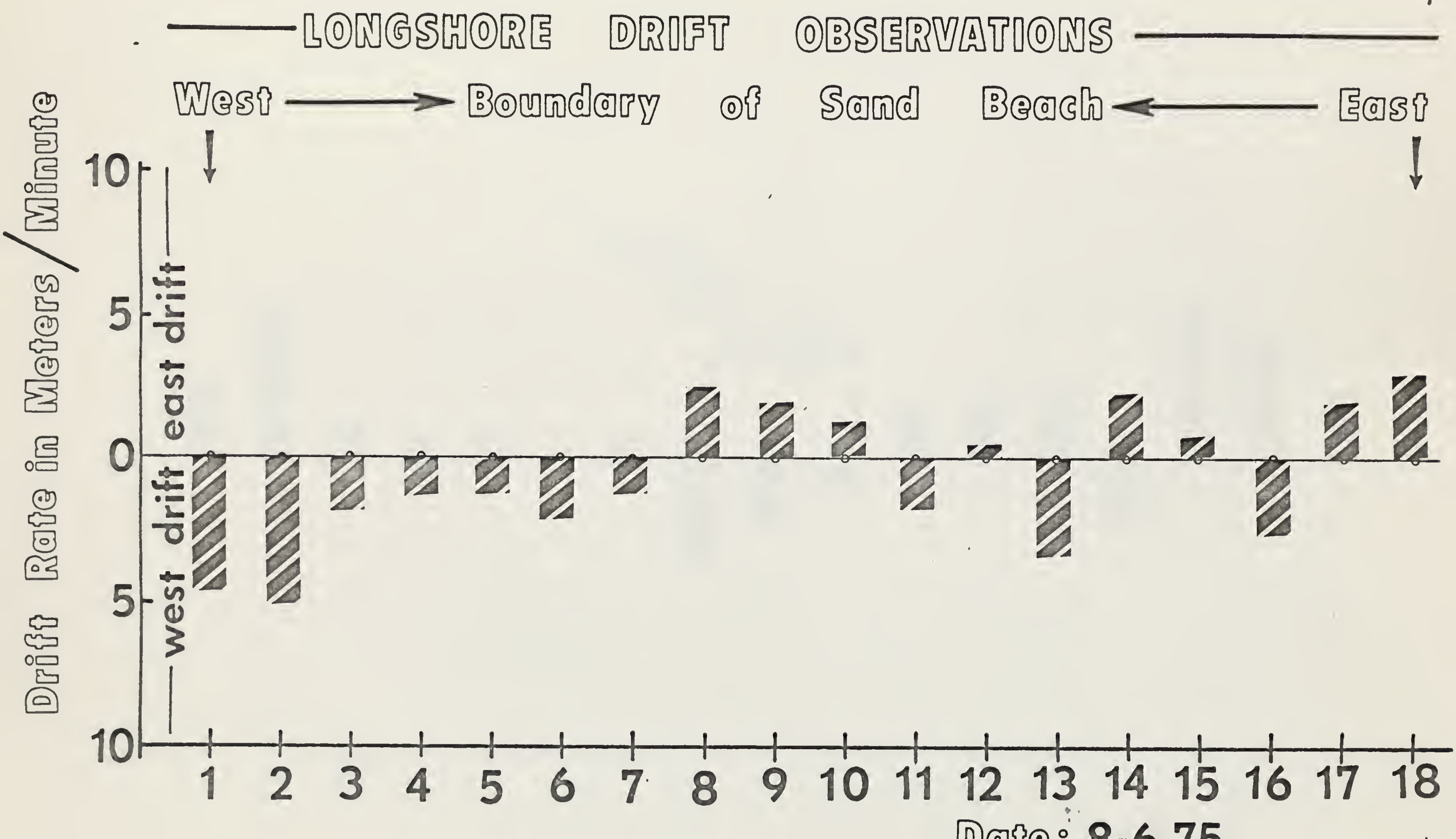

LONGSHORE DRIFT OBSERVATIONS
West → Boundary of Sand Beach ← East
Drift Rate in Meters / Minute
10
5
0
5
10
east drift
west drift
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Station Number
Date: 8-6-75
Wind Direction: gusts all directions
A.B.O.-'75

Fig. 10

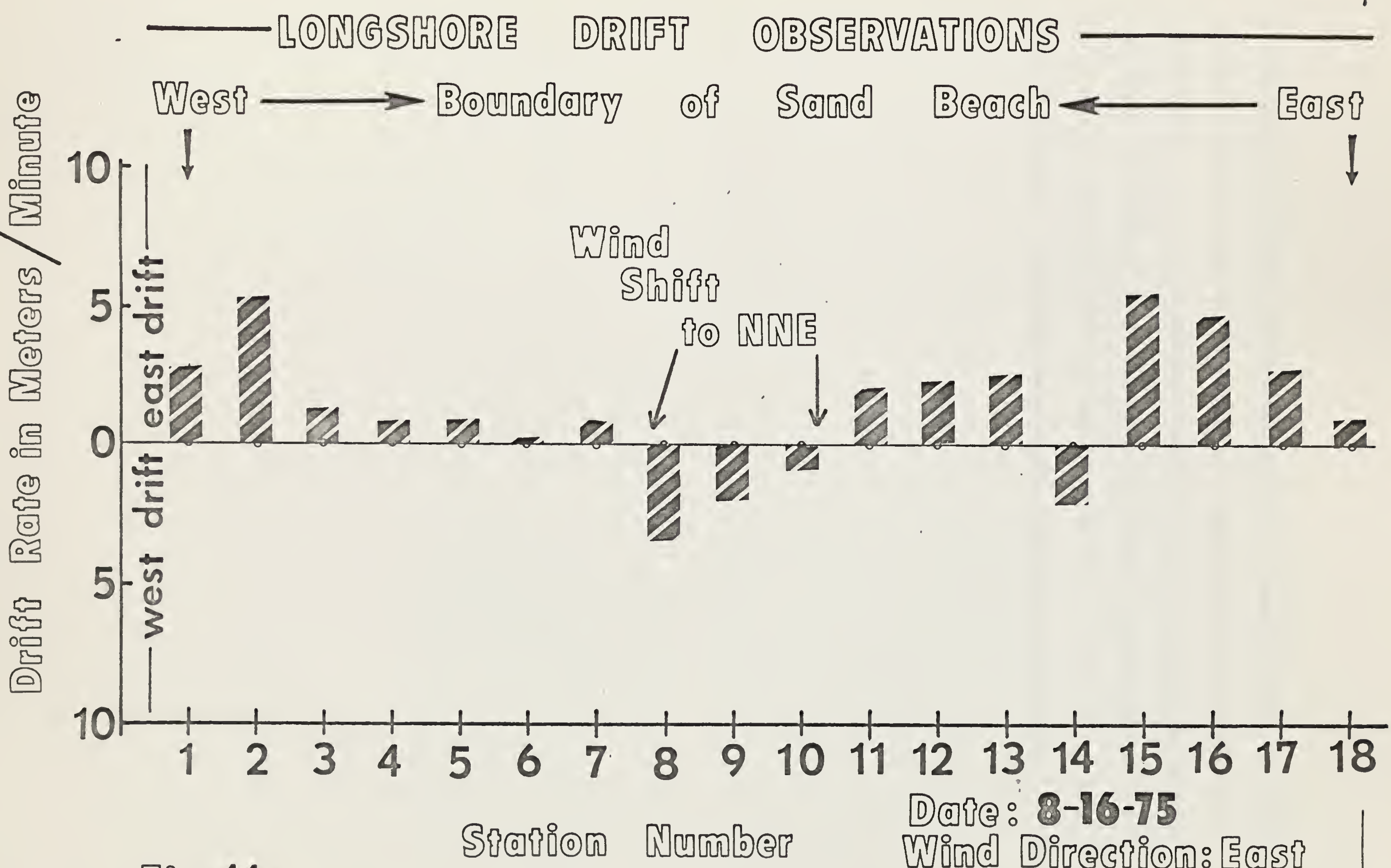

LONGSHORE DRIFT OBSERVATIONS
West
Boundary of Sand Beach
East
Drift Rate in Meters / Minute
10
5
0
5
10
east drift
west drift
Wind Shift to NNE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Station Number
Date: 8-16-75
Wind Direction: East

Fig. 11

A.B.O.-'75

In studying the longshore drift directions over a yearly period, it must be concluded that the dominant direction of longshore drift is to the east. Nevertheless, one strong northeast storm could easily reverse the physical expression of longshore drift deposition which may have accumulated for a whole season, and therefore the physical effects of the drift direction, i.e., sediment build-up, are at the mercy of the prevailing climatological conditions.

2. Discussion of Littoral Drift Rates Based Upon Sampling Period and Existing Historical Records

The generative forces of littoral or longshore drift have already been presented. What follows is a discussion of the varying rates of this drift as displayed in Figures 5 through 11.

Stations 1 through 18 (west to east) were chosen to emphasize the effects of man-made structures and differing beach morphologies, while at the same time concentrating on the eastern proposed dock site and pointing out seasonal variation against the stations established in the 1974 study (Figure 2). The numbering system for the seasonal comparison sites has been altered in this study to a more logical format. The new stations, as seen in Figure 2, are numbered consecutively from west to east. The following table explains the correspondence to the original numbering system:

	STATION NUMBER																	
Late Spring/ Summer, 1975	1	--	2	3	4	--	5	6	-	7	-	8	-	9	-	10	--	11-18*
Fall/Early Winter, 1974	17	16	15	14	13	12	11	1	2	3	4	5	6	7	8	9	10	

All discussions following will refer to the numbering of the 1975 stations.

*New sites in this study

Stations of particular interest are number 3 and 4, 5 and 6, 7 and 8 and 15, 16 and 17, due to the proximity of these stations to man-made structures in the littoral zone. Station 3 usually displays a greater rate of drift than station 4 due to the obstruction of drifting material at the latter site by dock "A" and the lessening of total wave energy caused by the sheltering effect

of this structure. The same explanation holds for stations 5, 6, 7 and 8, but is complicated by the close spatial relationship of dock "B", the launching ramp, and a partially submerged crib (Figure 2 and Photo page 81). Station 6 is generally found to have a greater rate of drift than the stations on either side, even though it is within the energy "shadow zone" projected by the present National Park Service dock. This is due to the engineering of the shore-perpendicular arm of this structure and the local bathymetry. The photo on page 81 shows the closely spaced pilings of dock "B" where it attaches to the beach. The next series of piles are more widely spaced and allow the drift to continue through this section of docks relatively unobstructed. However, a great amount of deposition had to occur before the drift could pass through the wider spaced piles. This accounts for the deeply concave outward shape of the inter-dock beach zone. The relatively higher rate of drift at station 6 as compared to 5 and 7 is also due to the shoal area inside the dock "B" enclosure. As previously presented, longshore drift increases with shoaling.

One of the processes which formed this shoal can be easily seen, on a smaller scale, at station 8. Figure 2 and Photo page 81 shows a small bulge in the shoreline behind the partially sunken crib offshore of this location. This bulge was formed by the protection from wave energy afforded by the crib, allowing wave induced currents to drop their sediment load in this low energy environment. This is also the case with additional factors, for the dock enclosure shoal. The dock would normally extend into a depth of six to seven feet of water, were it not for this shoal, and it has already been presented that the wave induced currents at this depth are small (current meter readings of 0.078 to 0.175 cm/sec), compared to the observed drift rates in the zone

View looking west from station 8. Note offshore crib and attendant beach build up, also spatial relation of crib, boat launching ramp and dock "B".

Close up of dock "B" pilings. Note spacing and impermeability of right hand portion.

of turbulence (2.25 to 7.0 cm/sec). Therefore, other forces must be partially responsible for the large volume of sand found in this enclosure. These will be discussed in the following section.

To the east of the dock area, stations 9 to 14 can be grouped together on the basis of similar beach morphology; that is, a straight and open shoreline. Any differences in littoral current rates are due directly to wave energy (Table 11). The situation changes in the area of the eastern proposed dock site due to the introduction of two more partially submerge cribs and the morphology of the shoreline. Station 15 is generally observed to have a greater drift rate than 16, due to the protection afforded 16 by the two off-shore cribs and the exposure of 15 to wave attack. Station 17 is also open to this attack and, as will be seen in the next section, both 15 and 17 sites are eroding while station 16 is prograding.

Little historical work on littoral drift rates for the Lake Superior and, notably Apostle Island area, has been conducted, but a statement of the observed rates based upon the sampling period can be made. The longshore drift averaged 4.5 cm/sec in the late spring and summer of 1975 and 8.5 cm/sec in the fall and early winter of 1974. It must be taken into account that these figures are based upon a one year sample period for a parameter which is weather dependent.

3. Estimation of Erosion and Accretion Rates for Little Sand Bay

Volumetric rates of change for the Little Sand Bay beach zones between the 1974 and 1975 periods of study are given in Table 13. The rates of change for the beach zones between dates 18 June and 16 August, 1975, on the other hand, are summarized in Table 14 while the profiles are shown graphically in Appendix C1 through C9. The rates of change were determined by calculating the area between the curves of the first and last observed profile (taken to the nearest swash line), multiplying by the horizontal distance between profiles and dividing by the elapsed weekly time interval.

TABLE 13

AVERAGE SEASONAL EROSION AND ACCRETION RATES FOR LITTLE SAND BAY
(November 19, 1974 - Juen 18, 1975)

Beach Profile Area	Erosion (Cubic meters/ week)	Accretion (Cubic meters/ week)	Horizontal Distance In Meters Between Stations
1	2.10	---	120
2	0.33	---	50
3	----	0.21	50
4	0.41	---	13.6
5	0.68	---	71
5 to dock	0.09	---	10
dock to 6	----	0.22	16
6	----	0.27	20
7	----	2.64	30
8	----	2.91	76
9	----	3.03	71
10	----	26.91	100

Over the yearly study period, stations 1 and 2 displayed steady erosion. This is due to the easterly directed longshore drift constantly carrying sediment away from the western extent of the Bay. Station 3 experienced some accretion during the time between study periods (Table 13) but had an overall loss for the summer period (Table 14), while station 4 experienced just the opposite. This was due to the cyclic nature of interruption of drift by dock "A". As the beach builds out in this area in response to the protection of the dock, the drift is cut off spatially coincident with the beach face reaching the impermeable portion of this structure (Photo page 34). Winter waves remove this blocking sand, again allowing the drift to continue through this area until the passage is once again cut off in late spring and early summer.

Profiles 6 through 10 all experienced accretion, probably during the early spring in response to the aforementioned classical beach cycle theory (Shepard, 1973).

The data for the 1975 summer period showed accretion at profile 5, west of the present National Park Service dock "B". This is caused not only by the summer phase of the beach cycle, but also be stoppage of the eastward trending longshore drift. Profile 6, on the western side of this obstruction, shows a great amount of erosion in response to sediment being picked up in order to "feed" the now "starved" easterly drift. The same explanation holds true for stations 7 and 8 on the up and down drift side of the boat launching ramp (Figure 2).

The erosion at profile 9 is caused by an intermittent stream which drains the pond behind the beach to the southwest of this station. As the spring melt waters fill the pond area, the stream overtops the narrow barrier of beach separating this pond from the lake. In 1975 the stream broke through near

TABLE 14

AVERAGE EROSION AND ACCRETION

RATES FOR LITTLE SAND BAY

(18 June, 1975 - 16 August, 1975)

Beach Profile Area	Erosion cubic meters/ week	Accretion cubic meters/ week	Horizontal Distance In Meters Between Stations
1	2.33	---	120
2	2.86	---	50
3	0.55	---	5
4	---	0.29	13.6
5	---	2.17	71
5 to dock	---	0.31	10
dock to 6	8.50	---	16
6	10.62	---	20
7	---	5.67	30
8	2.70	---	76
9	4.10	---	71
10	---	24.94	100
11	1.67	---	100
12	---	4.56	100
13	5.10	---	100
14	---	0.36	80
15	6.13	---	80
16	---	8.76	80
17	5.20	---	[illegible]

station 9 and eroded a channel across the beach. This site did show accretion in the upper beach section of the profile (Appendix C) but volume was not sufficient to fill the erosion caused by the stream channel.

Profile 10 showed a tremendous amount of accretion as the berm advanced lakeward. In the fall of 1974 (study #CX-2000-5-0013) this station showed an equal amount of erosion as the berm retreated. Thus, this site is a classical example of the frailty of a beach zone. With water on both sides it maintains a very tenuous equilibrium and is highly responsive to changing winter and summer wave energy conditions.

Profiles 11 through 14 fluctuate back and forth between erosion and accretion (Appendices C6 and C7) and a comparison of the first and last measured profiles (Table 14), is not a fair representation of the situation at these stations. The beach is very narrow in this area (1-3 meters) and the ability of this zone to remain a sandy beach is rather tenuous (see Photo page 88). There is a delicate balance between the offshore supply of sand and retreat of the wooded area directly landward of this strip of sand. Trees are constantly falling into the lake in this area as the scarp retreats to supply the beach with sand. This area is perhaps the most delicate of all in the Little Sand Bay area and care must be taken so as not to upset the already failing equilibrium which maintains this area as a beach.

Profiles 15 through 18 are in the area of the eastern proposed dock site. Profiles 15 and 17 are eroding in response to increased wave energy and 16 is accreting in response to the protection afforded by the two semi-submerged cribs (Figure 2). Station 18 is accreting due to the extension of the beach area farther north caused by the easterly trending longshore drift (see Photo page 88). This area would be greatly affected by construction of any docking facility.

To summarize, subaerial beach erosion and accretion is related to longshore drift and therefore openness to wave attack. Any artificial protection (crib) of a subaerial zone of beach will cause accretion shoreward of the structure and any blockage of longshore drift will cause accretion updrift and erosion downdrift of the obstruction.

View looking west from station 14. Note narrowness of beach and the fallen trees.

View looking northeast from station 18. Note numerous boulders and the glacial till escarpment.

4. Estimation of Erosion and Deposition in Shallow Neritic Zone

Sedimentation and erosion in the shallow neritic or nearshore zone is not as easily analyzed as that on the beach face proper. Subaqueous sediment movement is controlled by currents which create a shear stress upon the sediment layer (Krumbein and Sloss, 1963). These currents are difficult to measure without sophisticated and generally unproven equipment, thus one must rely upon the observed and direct physical effects of the currents, i.e., sedimentary structures, morphology, and deposition and/or erosion within an index stake field as described in the field methodology section.

Following is a table (15) showing the overall gain or loss of sediment in the area of the three stake fields placed within the shallow neritic zone (Figure 2). Details relating to this data is available as Appendix D.

TABLE 15

Average (Net) Gain or Loss of Stake Field Sediment*

TIME SPAN	STAKE FIELD 1	STAKE FIELD 2	STAKE FIELD 3
1) 11/7/74-6/27/75	+432 ft.^{3}	+397 ft.^{3}	NM
2) 6/27/75-7/7/75	-108 ft.^{3}	-204 ft.^{3}	NM
3) 7/7/75-7/15/75	+ 24 ft.^{3}	+ 60 ft.^{3}	NM
4) 7/10/75-8/4/75	NM	NM	-408 ft.^{3}
5) 7/15/75-8/4/75	- 36 ft.^{3}	- 48 ft.^{3}	NM
6) 8/4/75-8/23/75	- 48 ft.^{3}	- 12 ft.^{3}	+288 ft.^{3}
OVERALL TOTAL (2-6)	-168 ft.^{3}	-204 ft.^{3}	-120 ft.^{3}

*over unit area of 576 square feet.

NM = no measurement

It is obvious that there was an overall gain in both fields 1 and 2 in the elapsed time between fall and summer sampling (time span 1 in Table 15). This was probably due to plowing of winter ice. Solid ice was observed by Park Naturalist, Warren Bielenberg, to extend to the edge of stake field 2 (8 feet of water) and was probably responsible for bending most of the stakes in this field.

Another interesting feature of this table is the data for the 4 August to 23 August period. Field 1 lost the greatest amount of sediment while field 2 lost less and field 3 gained a substantial amount. This is probably the result of a shoreward moving bar of sediment. This can be better seen in Appendix D8 through D10, where the gaining section of field 2 is the southeastern quadrant and the greatest gain of field 3 is in the northern quadrant. This phenomena probably was brought about by the northwesterly trending currents recorded by the current meters. This same situation can be seen in comparing the 7 July to 15 July figures (Appendix D3 and D4) for stake fields 1 and 2. Number 1 gained the most sediment in the southeastern quadrant and field 2 gained the most sediment in the northern quadrant.

In addition to the data obtained from the three stake fields, close observation of the shoal area within the present National Park Service dock was made by beach profiling and SCUBA diving. This shoal area has been formed in response not only to the longshore drift but also to the theory of beach cycles as stated previously.

Storm waves carry fine sediment offshore to settle in an area of lower energy, usually in deep water in the form of a bar. But the impermeable, shore-parallel arm of the existing dock creates an artificial environment of low energy in

its lee. The fine sediment accumulates here and cannot be returned to the beach with the advent of relatively lower energy, summer waves due to the protection of this dock. This causes a necessity for dredging at this site which would have to be carried out every two (2) to three (3) years depending upon the energy differential between winter and summer wave regimes. It is possible that this problem could be alleviated by altering the design and position of the dock. Such will be dealt with in the discussion section.

5. Discussion of Onshore and Offshore Sediment Motion Rates and Direction

The direction and rate of sediment movement depends upon longshore current direction and velocity, swash and backwash intensity (wave energy) and interference of waves with the lake bottom, while a determination of the volume of material transported (bed load and suspended load) relates to the interaction of all these factors. In an attempt to define such sediment motion rates, and explore some of the parameters causing this movement, two fluorescent tracer studies were conducted simultaneously at stake fields 2 and 3 (logistics limited the study to two at one time with emphasis being placed upon the eastern portion of the Bay). This particular technique was a modification of that used by Ingle (1966) who studied transport in the surf zone. This study analysis applies Ingle's method to transport in 8 and 7.5 feet of water.

Unfortunately, the current meter, which was used in conjunction with this study for the calculation of bed load, malfunctioned upon entering the water. However, a comparative analysis of the two fields is possible by viewing Figures 12 and 13 which show the results in graphic form.

There was a fairly stiff, gusty wind (6-8 mph) blowing out of the northwest at the time of this sub-study, producing a short choppy sea one-half to one foot high and five to six foot wave length (Table 9). This created excellent conditions for the study and motion upon the bottom was responsive during the two hour period.

Figure 13 shows the oscillatory nature of the wave induced currents, that is that there is considerable motion to the northwest as well as the southeast.

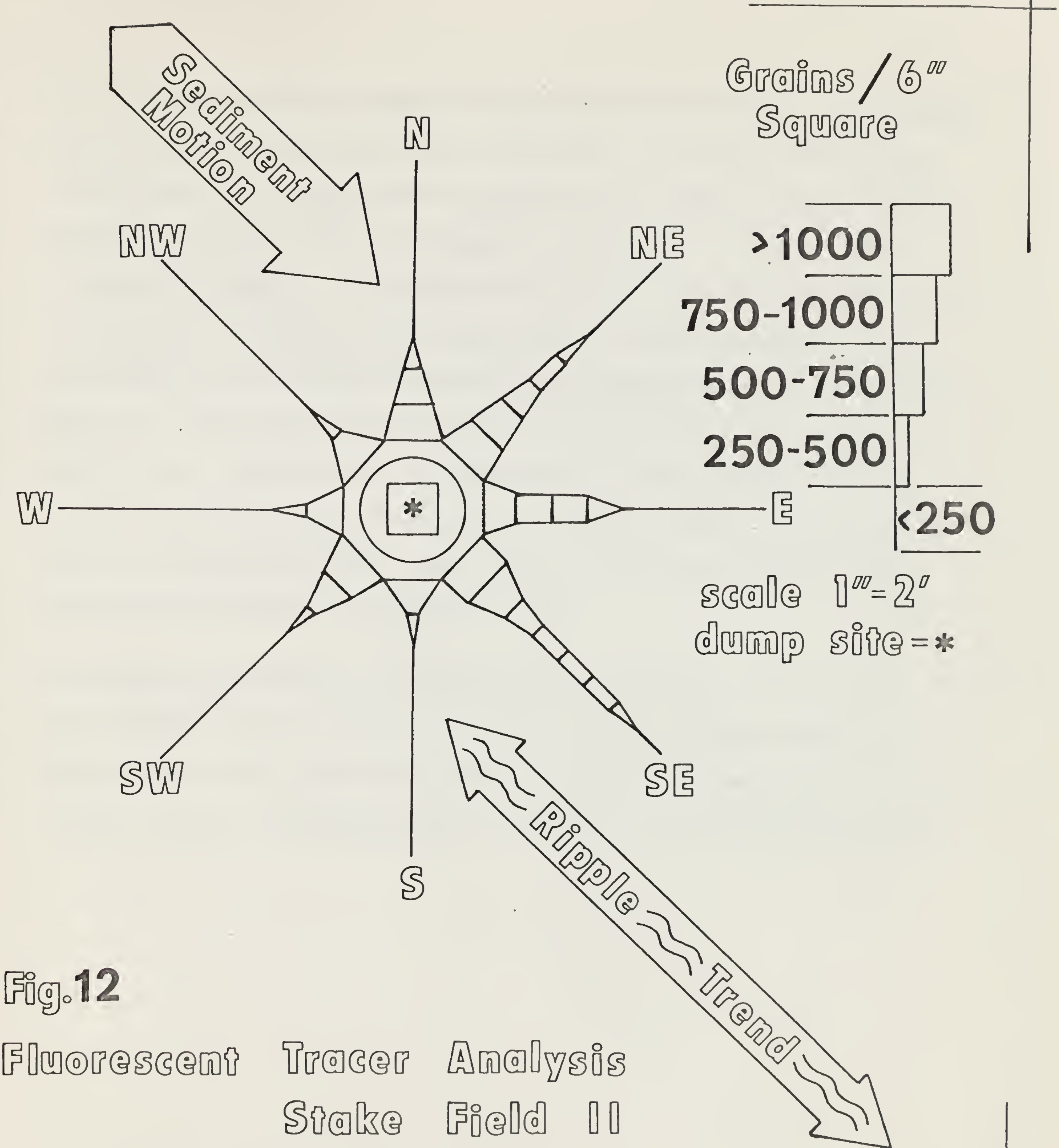


Fig. 12

Fluorescent Tracer Analysis
Stake Field II
5 Aug.-'75 2:30-5:20 pm

A.B.D.-'75

This is not as noticible in Figure 12 for field 2 and is related to the slightly deeper depth character of this site, as the short period waves were not able to have such a great effect upon the sediment at this depth (see Wave Climate Section). This also shows in the magnitude of movement observed at field 2 as compared to field 3. As for the rate of this movement, no calculation could be made due to the failure of the current meter. However, a weekly erosion/accretion rate can be estimated from the stake field measurements presented in Table 15. Stake field 1 had an overall loss of 18.6 cubic feet per week, field 2 had an overall loss of 22.7 cubic feet per week and field 3 had an overall loss of 13.3 cubic feet per week. These are average rates for three areas of 576 square feet each over a period of nine weeks, therefore they should not be considered a straight line trend.

Considering the interaction of the parameters stated above, it can be said with confidence that the direction of shallow neritic sediment movement is onshore in the summer season and offshore in the winter season with the intensity of movement increasing with increased wave energy and shoaling depth.

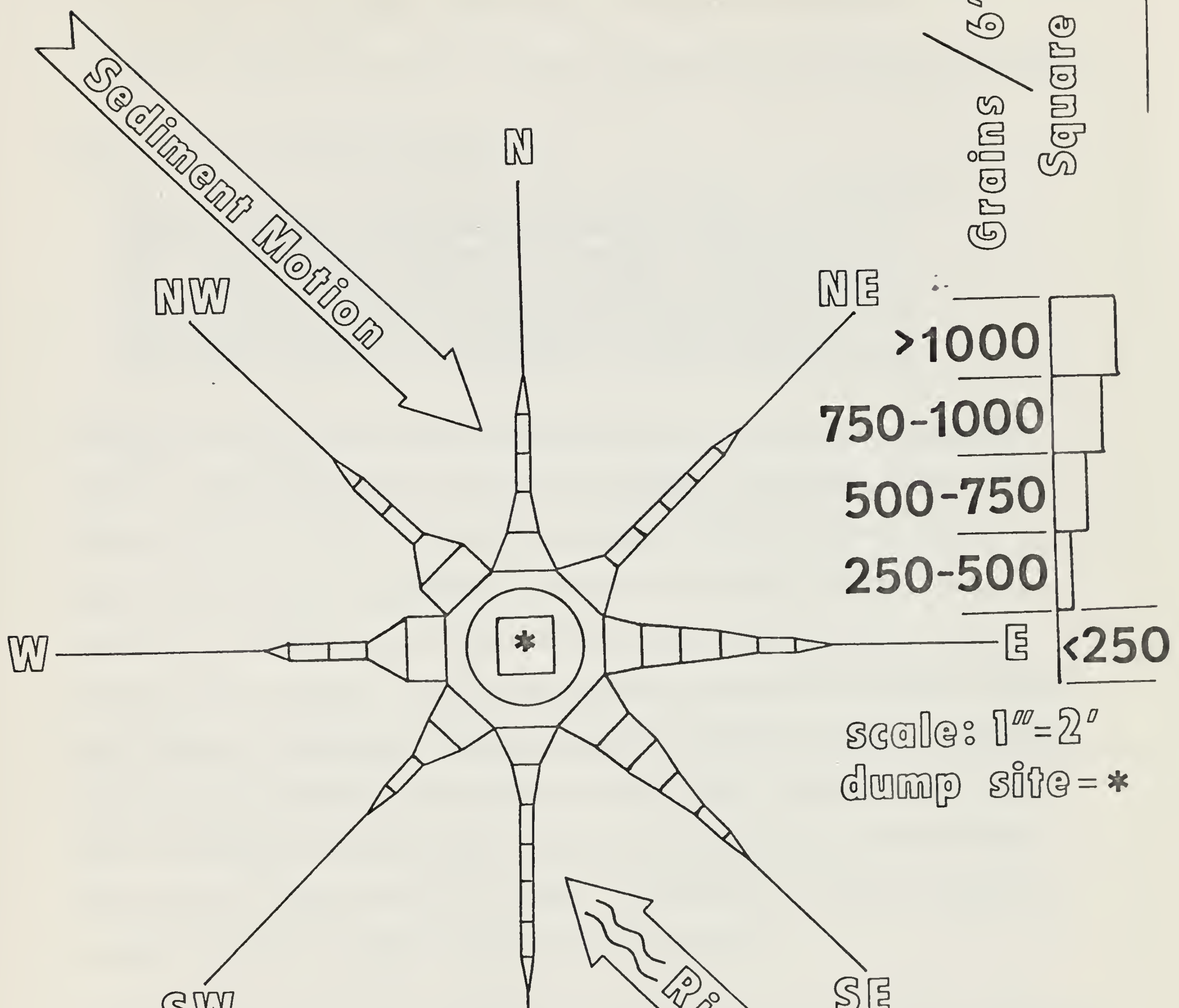


Fig. 13

Fluorescent Tracer Analysis

Stake Field III

5 Aug.-'75 2:15-4:30 pm

A.B.D.-'75

C. BIOLOGIC PARAMETERS OF LITTLE SAND BAY

1. Species Composition and Factors Influencing Periphyton Abundance

Young (1945) has defined periphyton as:

> *"that assemblage of organisms growing upon surfaces of submerged objects in water, and covering them with a slimy coat. It is that slippery brown or green layer usually found adhering to the surfaces of water plants, wood, stones, or certain other objects immersed in water and may gradually develop from a few tiny gelatinous plants to culminate in a woody, felted coat that may be slippery, or crusty with a contained marl or sand."*

Periphyton found in Lake Superior belong primarily to the phyla Chrysophyta (diatoms), Chlorophyta (green algae) and Cyanophyta (blue-green algae), (Fox, Odlaug and Olson, 1969). Although an extensive literature search did not reveal the occurrence of periphyton studies in the Apostle Islands area, a good deal of research on periphyton has taken place along the north shore of western Lake Superior. Particularly prevalent among the periphyton studied were species of Achnanthes, Synedra, Cymbella, Navicula, Cocconeis, Gomphonema and unidentified diatoms (Fox, Odlaug and Olson, 1969). More complete checklists of periphyton organisms have been provided by Nelson, Olson and Odlaug (1971) and Fox, Odlaug and Olson (1969). A combination of the two checklists arranged according to phyla is presented in Appendix E.

A comparison of the rocky substrate found along the north shore of Lake Superior to the predominantly sand bottom found in Little Sand Bay would indicate that the production of periphyton, both in quantity and number of species, would be less in Little Sand Bay than along the north shore. The east end of the bay, however, has a large boulder field beyond which are a significant number of large submerged logs. This structure would provide suitable substrate for

periphyton growth. The color and surface texture of substratum can greatly affect the growth of periphyton (Fox, Odlaug and Olson, 1969). After determining that periphyton productivity was higher on granite substratum than sand, Duffer and Dorris (1966) concluded that a favorable attachment surface is a major factor determining the magnitude of productivity.

Periphyton productivity may also be influenced by the presence of organic materials on and within the substrate (Patrick, et. al., 1954). The low total organic component (average 0.41% by weight total volatile solids) found in substrate from Little Sand Bay suggests limited production potential for periphyton populations. This was borne out through underwater observations by SCUBA divers who found a near sterile sand bottom devoid of readily observable plant and algal growth throughout the bay.

Depth of water can greatly influence the distribution of periphyton. Periphyton is limited to the euphotic zone and usually becomes more abundant near shore (Olson and Odlaug, 1966). Fox, Odlaug and Olson (1969) found that maximum periphyton production occurred at an intermediate depth (10± feet). Samples taken at 2, 10 and 20 feet, over a time period of one month, revealed the 10 foot samples showed the highest production, 20 foot samples the lowest and 2 foot samples intermediate. In shallow waters only five major genera were found whereas at 10 feet an additional thirteen genera were observed. Fox, Odlaug and Olson (1969) and Olson and Odlaug (1966) suggest that wave action is primarily responsible for reduced shallow water populations. Wave action makes the attachment process difficult for some genera. Waves may also knock periphyton from the rocks into the water, reducing both numbers and kinds of organisms. At great depths a combination of decreasing light intensity together

with decreasing water temperatures reduces periphyton productivity (Fox, Odlaug and Olson, 1969).

The field of boulders and logs occur at the east end of the bay in water depths of 0-20 feet. This is within the euphotic zone and the growth of periphyton on this substrate undoubtedly provides a food base for types of "grazing" invertebrates which are not found in the portion of Little Sand Bay where sand substrate predominates.

2. Species Composition and Factors Influencing Phytoplankton Abundance

Round (197) has defined phytoplankton as:

> *"the floating and swimming algal communities of open water."*

Most of the phytoplankton in Lake Superior consists of different species of diatoms (Chrysophyta). Major species found in the Apostle Islands region include: Achnanthes minutissima, Asterionella formosa, Cyclotella glomerata, Cyclotella ocellata, Diatoma elongatum, Fragilaria crotonensis, Melosira islandica, Rhizosolenia eriensis, Stephanodiscus sp., Synedra nana and Tabellaria flocculosa (Holland, 1965). Diatoma elongatum has been reported to be the major early summer species. It is succeeded in the fall primarily by Achnanthes minutissima, Fragilaria capucina and Melosira islandica (Holland, 1965). The presence of species of Cyclotella has been interpreted to be indicative of the oligotrophic nature of Lake Superior (Davis, 1966).

Phytoplankton studies conducted over wider areas of Lake Superior have reported additional species. Species of Striatella, Aphanocapsa and Eudorina (eddy, 1934); Batryococcus, Westella, Anabaena and Ceratum (Taylor, 1935); Dinobryon, Coccochloris and Crucigenia (Olson and Odlaug, 1966); Sphaerocystis, Anacystis, Dictyosphaerium, Pediastrum, Oscillatoria and Microtinium have been reported (National Biocentric Inc., 1973a). A checklist of phytoplankton from western Lake Superior has been compiled from papers by Eddy (1934), Taylor (1935), Holland (1965), Olson and Odlaug (1966) and National Biocentric Inc. (1973a) and is presented in Appendix F.

Putnam and Olson (1961), Holland (1965) and Davis (1966) reported phytoplankton to be very sparse throughout Lake Superior. Mean seasonal phytoplankton counts obtained for western Lake Superior by Putnam and Olson (1961) and Holland (1965), were 168,000 and 184,000 organisms per liter respectively. Holland (1965) also reported that diatoms in the Apostle Islands area averaged 614,000 organisms per liter and reached a maximum concentration of 2,200,000 organisms per liter. The number of phytoplankton organisms in the Apostle Islands area far exceeds that obtained in western Lake Superior and indicates that the Apostle Islands region is much more productive (Holland, 1965).

Studies on phytoplankton productivity in the Apostle Islands in relation to physical parameters have not been reported in the literature. Possible factors resulting in increased productivity in the Apostle Islands include increased shoreline length, associated nutrient enrichment from watershed runoff, increased areas of shallow water giving an expanded euphotic zone area, increased water temperatures in shallow water areas and protection from extreme turbulence.

3. Species Composition and Factors Influencing Zooplankton Abundance

Zooplankton has been defined by Beeton and Werner (1974) as:

> "the animal part of free-floating plankton including protozoa, rotifers, and minute crustaceans such as cladocerans, copepodes, and ostracods."

An extensive literature search did not reveal any previous in-depth studies relating to zooplankton in the Apostle Islands area. A limited sampling program by Beeton, Johnson and Smith (1959) did show the Apostle Islands region to be one of the most overall productive areas of Lake Superior. A number of studies have been performed, however, on zooplankton of western Lake Superior. One of the first of these was conducted by Eddy (1934, 1943). Particularly abundant genera reported by Eddy included: Keratella, Kellicottia, Daphnia, Bosmina, Diaptomus, Epischura, Limnocalanus and Cyclops. Additional species of Asplanchna, Polyartha and Sinantherena (Putnam, 1963); Polyphemus and Leptodora (Olson and Odlaug, 1966); Senecella and Eurytemora (Robertson, 1966); Synchaeta and Trichocerca (Williams, 1966); Alona and Holopedium (Conway et. al., 1973); and Cupelopagis, Enteroplea, Sinantherina, Carchesium and Lacinularia (National Biocentric Inc., 1973a) have also been reported. A checklist of zooplankton organisms from western Lake Superior compiled from the above authors and the present study is presented in Appendix G.

Zooplankton species composition and abundance was determined along two transects (T_1 and T_3) in Little Sand Bay (Figure 2). Samples were taken with a 16 liter Kemmerer in 5, 10, 20 and 30 feet of water depth at the surface and every 10 feet through the water column for a total of ten (10) samples per transect. Simultaneous measurements were made of temperature and light transmittance through the water. Transmittance was measured with a submarine photometer.

TABLE 16

ZOOPLANKTON ABUNDANCE OF LITTLE SAND BAY, APOSTLE ISLANDS

FOR JUNE, JULY AND AUGUST

(Numbers represent counts per 16 liter water sample)

Date	6/18	6/18		6/18			6/18			
Transect	T_1	T_1		T_1			T_1			
Station Depth	5 ft	10 ft		20 ft			30 ft			
Sample Depth	Surface	Surface	10'	Surface	10'	20'	Surface	10'	20'	30'
Species										
ROTIFERS										
Asplanchna priodonta										
Asplanchnopus sp.	1									
Conochilus sp.									1	
Epiphanes sp.										
Kellicottia longispina				2	1		5	3	1	
Keratella cochlearis										
Lecane sp.										
Polyarthra sp.			1					2		
Trichocerca sp.										
Synchaeta sp.										
Pleosoma sp.										
CLADOCERANS										
Bosmina coregoni										
Bosmina longirostris			1							
Daphnia dubia										
Daphnia galeata										
Daphnia longispina										
Diaphanosoma sp.										
Alona sp.										
Eurycercus sp.										
COPEPODS										
Cyclops bicuspidatus						1		1	1	1
Cyclops vernalis										
Diaptomus sp.	2					10		2	3	2
Limnocalanus macrurus						1			1	
Nauplius stage	40	8	13	1	2	98	4	70	95	155
TOTAL	43	8	15	3	3	110	9	78	102	158

Table 16 Continued
Zooplankton Abundance of Little Sand Bay

Date	6/18	6/18		6/18			6/18			
Transect	T_3	T_3		T_3			T_3			
Station Depth	5 ft	10 ft		20 ft			30 ft			
Sample Depth	Surface	Surface	10'	Surface	10'	20'	Surface	10'	20'	30'
<u>Species</u>										
ROTIFERS										
Asplanchna priodonta										
Asplanchnopus sp.										
Conochilus sp.										1
Epiphanes sp.										
Kellicottia longispina						1		1		
Keratella cochlearis									1	
Lecane sp.										
Polyarthra sp.								1		
Trichocerca sp.										
Synchaeta sp.										
Pleosoma sp.										
CLADOCERANS										
Bosmina coregoni										
Bosmina longirostris										
Daphnia dubia										
Daphnia galeata										
Daphnia longispina										
Diaphanosoma sp.										
Alona sp.										
Eurycercus sp.										
COPEPODS										
Cyclops bicuspidatus					1				1	
Cyclops vernalis					1	5				1
Diaptomus sp.					3	6		3	3	10
Limnocalanus macrurus						4			1	
Nauplius stage	5	4	8	13	54	157	36	17	127	198
TOTAL	5	4	8	13	59	173	36	22	133	210

Table 16 Continued
Zooplankton Abundance of Little Sand Bay

Date	7/7	7/7		7/7			7/7			
Transect	T_1	T_1		T_1			T_1			
Station Depth	5 ft	10 ft		20 ft			30 ft			
Sample Depth	Surface	Surface	10'	Surface	10'	20'	Surface	10'	20'	30'
<u>Species</u>										
ROTIFERS										
Asplanchna priodonta					1	1		1	*Sample Decayed*	4
Asplanchnopus sp.			3	3	41	85	2	21		45
Conochilus sp.								14		1
Epiphanes sp.										
Kellicottia longispina	1	1	2			5		1		1
Keratella cochlearis			1		1		1			
Lecane sp.										
Polyarthra sp.										
Trichocerca sp.										
Synchaeta sp.										1
Pleosoma sp.										
CLADOCERANS										
Bosmina coregoni										
Bosmina longirostris			1		2	4		1		
Daphnia dubia										
Daphnia galeata						1				
Daphnia longispina										
Diaphanosoma sp.										
Alona sp.										
Eurycercus sp.										
COPEPODS										
Cyclops bicuspidatus						1				
Cyclops vernalis						1				
Diaptomus sp.				1		24	2	1		31
Limnocalanus macrurus										
Nauplius stage	1	4	1	2	—	23	6	9		92
TOTAL	2	5	8	6	45	145	11	48		175

Table 16 Continued
Zooplankton Abundance of Little Sand Bay

Date	7/7	7/7		7/7			7/7			
Transect	T_3	T_3		T_3			T_3			
Station Depth	5 ft	10 ft		20 ft			30 ft			
Sample Depth	Surface	Surface	10'	Surface	10'	20'	Surface	10'	20'	30'
Species										
ROTIFERS										
Asplanchna priodonta			1	1			3			7
Asplanchnopus sp.	1		77	19	60	203	10	1	12	62
Conochilus sp.										
Epiphanes sp.										3
Kellicottia longispina	1	3	6	1		1			2	4
Keratella cochlearis					2				1	
Lecane sp.	1									
Polyarthra sp.		1	77							
Trichocerca sp.										1
Synchaeta sp.										
Pleosoma sp.										
CLADOCERANS										
Bosmina coregoni										
Bosmina longirostris	1		7		2		1	1	2	
Daphnia dubia									2	
Daphnia galeata	1					1				
Daphnia longispina										
Diaphanosoma sp.										
Alona sp.	1									
Eurycercus sp.	1									
COPEPODS										
Cyclops bicuspidatus										2
Cyclops vernalis		1				1	1			
Diaptomus sp.					2	7	5		28	24
Limnocalanus macrurus										
Nauplius stage	5	1	4	2	6	13	2	1	22	119
TOTAL	12	6	172	23	72	226	22	3	69	222

Table 16 Continued
Zooplankton Abundance of Little Sand Bay

Date	8/5	8/5		8/5			8/5			
Transect	T_3	T_3		T_3			T_3			
Station Depth	5 ft	10 ft		20 ft			30 ft			
Sample Depth	Surface	Sur-face	10'	Sur-face	10'	20'	Sur-face	10'	20'	30'
Species										
ROTIFERS										
Asplanchna priodonta	33	36	44	24	32	32	32	56	48	20
Asplanchnopus sp.	211	96	92	96	204	188	132	368	284	56
Conochilus sp.	834	16	176	16	12	4	208	520	1008	4
Epiphanes sp.										
Kellicottia longispina	72	76	76	28	72	76	56	48	92	112
Keratella cochlearis	70	72	100	40	64	68	100	160	104	56
Lecane sp.										
Polyarthra sp.	46	60	28	76	112	100	160	212	84	64
Trichocerca sp.										
Synchaeta sp.										
Pleosoma sp.						8				4
CLADOCERANS										
Bosmina coregoni	4	4	4				8			
Bosmina longirostris	6		32	4	24	12	32	8	20	12
Daphnia dubia	11	40	48	8	4	12	20	36	36	8
Daphnia galeata	13			8	24	16	16	40	88	48
Daphnia longispina										
Diaphanosoma sp.	7	4		4						
Alona sp.										
Eurycercus sp.										
COPEPODS										
Cyclops bicuspidatus	7	20	12			12	16	16	44	8
Cyclops vernalis			8		4	4		8	4	
Diaptomus sp.	29	40	80	4	36	36	16	44	116	64
Limnocalanus macrurus			8			4				
Nauplius stage	112	36	148	64	80	96	76	132	152	92
TOTAL	1455	500	856	372	668	668	872	1648	2080	556

Counts of the organisms from the samples (Table 16) showed that copepod nauplii were the most abundant zooplankters during mid-June with their abundance increased with depth. An unidentified species of Diaptomus was the most abundant adult copepoda. Rotifers were next in abundance with numbers increasing at all depths as the distance from shore increased.

Samples collected early in July showed a slight increase in the total number of organisms when compared with the June samples. The number of copepods decreased from the previous month, especially the nauplii. However, there was an increase in the number of rotifers and cladocerans in the samples. The rotifers again increased in abundance with distance from shore. Numbers also increased with depth at each station. The cladocerans were uniformly distributed in the water column.

There was a difference in the total number of organisms between the two sampled transects. Transect T_3, which includes the present docking facility, had more organisms per sample particularly at the 5 and 10 foot depths.

In August only a single transect (T_3) was sampled eliminating a comparison between transects. The total number of organisms in the sample increased greatly from previous months, with the increase due primarily to the rotifers and cladocerans. There was a tendency for the density of organisms to increase within the water column with increased depth but there was little difference between stations of different depths. This was probably due to complete mixing of the water due to a nearly homothermos (Table 17) condition of the bay at the time of sampling.

TABLE 17: Water temperature profiles of Little Sand Bay, Apostle Islands for the summer of 1975.

	TEMPERATURE (C)		
Depth (feet)	18 June	7 July	5 August
Surface	10.0[a]	17.4	19.8
10	8.6	16.3	19.7
20	8.4	9.2	19.5
30	7.4	7.6	18.5

a/ Each temperature is the mean of 2-8 measurements.

Verticle stratification of zooplankters was evident throughout the summer, indicating that there was active selection of depth. The absence of consistent horizontal distributions indicates that the general plankton distribution within the Bay is dictated by current patterns.

Light transmittance (Table 18) measurements were made during June and July (measurements were not made in August due to an instrument malfunction). The transmittance of light through the water column was nearly the same for the months of June and July. There was little difference in the zooplankton abundance for these months. Transmittance of light through the water column in August was greatly reduced according to reports from SCUBA divers who made dives to the bottom of the Bay during each of these months. The decrease in light transmittance is probably indicative of increased zooplankton production.

TABLE 18: Light (unfiltered) determinations ($\frac{\mu W}{cm^2\text{-}nm}$) above and beneath the water surface at various depths (ft.) for Little Sand Bay, Apostle Islands.

	18 June					7 July				
Station Total	Deck Cell	Sea Cell	Sea Cell	Sea Cell	Sea Cell	Deck Cell	Sea Cell	Sea Cell	Sea Cell	Sea Cell
Depth (ft)		Surface	10	20	30		Surface	10	20	30
5	19.95	10.40				83.36	54.86			
10	43.46	26.29	7.08			86.22	53.44	19.65		
20	43.46	26.93	7.70	2.33		88.35	57.72	17.10	5.63	
30	48.45	23.52	8.70	3.06	0.82	94.05	67.68	23.72	8.84	2.58

4. Abundance Species Composition and Distribution of Benthic Organisms

Benthic organisms have been defined by Fox, Odlaug and Olson (1969) as:

> *"unattached organisms living in or on the bottom sediments."*

Only a few benthic organism studies have been conducted in western Lake Superior and only one study by Hiltunen (1969) has been reported in the literature from the Apostle Islands region. Hiltunen (1969) reported species of Hirudinea (Piscicola), Amphipoda (Pontoporeia), Gastropoda (Valvata), Pelecypoda (Pisidium), Diptera (Chironomidae), Oligoschaeta (Enchytraeidae, Lumbriculidae and Tubificidae) to be especially abundant. Olson and Odlaug (1966) also reported species of Limnocalanus, Bosmina, Daphnia, Polyphemus and Leptodora as being abundant benthic organisms in western Lake Superior. Many additional species have been reported for Lake Superior by Henson (1966) and National Biocentric Inc. (1973a). A checklist of benthic organisms found in Lake Superior is presented in Appendix H.

Bottom samples were collected along offshore transects with a Ponar dredge. Sampling depths were 2.5, 5, 10, 15, 20, 25, 30, and for one transect (T_1 in June), 35 and 40 feet (Figure 2). Species of Nematoda, Oligochaeta, Amphipoda, Chironomidae and Sphaeriidae were the most numerous organisms on the bottom of Little Sand Bay during the summer of 1975 (Table 19) as they were during the fall of 1974.

The depth distribution of benthic organisms was similar to that found for the fall of the previous year. Nematods, Oligochaetes and Amphipod, Pontoporeia affinis were found at all depths and increased in abundance with depth. Species

TABLE 19

Benthic fauna of Little Sand Bay, Apostle Islands. Each sample is the total number of organisms in one Ponar grab sample, representing a surface area of 1/13 of a square meter.

Date	6/17	6/17	6/17	6/17	6/17	6/17	6/17	6/17	6/17
Transect	1	1	1	1	1	1	1	1	1
Depth in Feet	2.5	5	10	15	20	25	30	35	40
Coelenterata									
Hydra sp.									
Nematoda		2	1	5	3		1	7	1
Annelida									
Oligochaeta				15	12	15	30	68	66
Arthropoda									
Arachnida									
Hydracarina					5	4	1		
Eucrustacea									
Cladocera									
Ostracoda				1			1		
Copepoda									
Malacostraca									
Mysis relicta					1				
Isopoda									
Asellus sp.									
Amphipoda									
Pontoporeia affinis			2	1	6	38	9	12	43
Insecta									
Collembola									
Podura aquatica									
Diptera									
Chironomidae	5	19	69	92	17	63	47	23	13
Ceratopogonidae	5	4	1						
Ephydridae									
Mollusca									
Gastropoda				1	1	9	6		
Pelecypoda									
Sphaeriidae				13	8	82	16	13	24
TOTAL	10	25	73	128	53	211	111	125	147

Table 19 Continued
Benthic fauna of Little Sand Bay

Date	6/17	6/17	6/17	6/17	6/17	6/17	6/17
Transect	5	5	5	5	5	5	5
Depth in Feet	2.5	5	10	15	20	25	30
Coelenterata							
Hydra sp.						1	
Nematoda	3			4	10	39	9
Annelida							
Oligochaeta	78	2		27	48	73	59
Arthropoda							
Arachnida							
Hydracarina							1
Eucrustacea							
Cladocera							
Eurycercus sp.							
Alona sp.							1
Ostracoda				1	1		
Copepoda							
Cyclops bicuspidatus	1						
Limnocalanus macrurus				1			1
Malacostraca							
Mysis relicta							
Isopoda							
Asellus sp.							
Amphipoda							
Pontoporeia affinis				20	17	19	17
Insecta							
Diptera							
Chironomidae	102	40		161	93	128	70
Ceratopogonidae	30	8		1	5		
Ephydridae	1				3		
Mollusca							
Gastropoda				2	5	4	6
Pelecypoda							
Sphaeriidae				2	13	93	50
TOTAL	215	50		219	195	357	214

Table 19 Continued
Benthic fauna of Little Sand Bay, Apostle Islands

Date	6/17	6/17	6/17	6/17	6/17	6/17	6/17
Transect	4	4	4	4	4	4	4
Depth in Feet	2.5	5	10	15	20	25	30
Coelenterata							
Hydra sp.			1				
Nematoda		1	15	10	44	17	20
Annelida							
Oligochaeta	21	2	53	18	96	10	66
Arthropoda							
Arachnida							
Hydracarina			1	1	2	3	2
Eucrustacea							
Cladocera							
Eurycercus sp.			2				
Alona sp.			1		1		
Ostracoda				1	4		
Copepoda							
Limnocalanus macrurus						1	3
Canthocamptus sp.			1				
Malacostraca							
Mysis relicta							
Isopoda							
Asellus sp.							
Amphipoda							
Pontoporeia affinis		2	25	15	48	2	15
Insecta							
Diptera							
Chironomidae	56	56	186	29	116	33	71
Ceratopogonidae	20	2	1	7	3		
Ephydridae			2				
Mollusca							
Gastropoda			1	13	3	4	
Pelecypoda							
Sphaeriidae			3	21	33	54	65
TOTAL	97	63	292	115	350	124	242

Table 19 Continued
Benthic fauna of Little Sand Bay, Apostle Islands

Date	6/17	6/17	6/17	6/17	6/17	6/17	6/17
Transect	2	2	2	2	2	2	2
Depth in Feet	2.5	5	10	15	20	25	30
Coelenterata							
Hydra sp.				1			1
Nematoda			3	1	4	6	24
Annelida							
Oligochaeta	2	2	24	8	16	14	80
Arthropoda							
Arachnida							
Hydracarina					1		6
Eucrustacea							
Cladocera							
Ostracoda							
Copepoda							
Limnocalanus macrurus						2	4
Malacostraca							
Mysis relicta							
Isopoda							
Asellus sp.							1
Amphipoda							
Pontoporeia affinis			4	7	9	4	40
Insecta							
Collembola							
Podura aquatica		1					
Diptera							
Chironomidae	21	13	70	49	28	19	61
Ceratopogonidae	8		7		1	3	
Ephydridae					1		
Mollusca							
Gastropoda				1	3	4	2
Pelecypoda							
Sphaeriidae				1	12	4	11
TOTAL	31	16	108	68	75	46	230

Table 19 Continued
Benthic fauna of Little Sand Bay

Date	7/7	7/7	7/7	7/7	7/7	7/7	7/7
Transect	1	1	1	1	1	1	1
Depth in Feet	2.5	5	10	15	20	25	30
Coelenterata							
Hydra sp.			1		1		
Nematoda			1	8	25	8	27
Annelida							
Oligochaeta	1	2	7	36	76	29	91
Arthropoda							
Arachnida							
Hydracarina						4	4
Eucrustacea							
Cladocera							
Eurycercus lamellatus		1	3	9		1	
Daphnia pulex							1
Ostracoda			1	1	3	1	
Copepoda							
Malacostraca							
Mysis relicta							
Isopoda							
Asellus sp.							
Amphipoda							
Pontoporeia affinis		1	2	13	51	6	129
Insecta							
Diptera							
Chironomidae	9	47	67	58	104	63	90
Ceratopogonidae	30	10	4	6		1	
Ephydridae					1		
Mollusca							
Gastropoda				6	10	8	18
Pelecypoda							
Sphaeriidae				17	60	19	117
TOTAL	40	61	86	154	331	140	477

Table 19 Continued
Benthic fauna of Little Sand Bay

Date	7/7	7/7	7/7	7/7	7/7	7/7	7/7
Transect	3	3	3	3	3	3	3
Depth in Feet	2.5	5	10	15	20	25	30
Coelenterata							
Hydra sp.							
Nematoda	2	1	9	3	27	71	12
Annelida							
Oligochaeta	51	14	98	13	92	90	65
Arthropoda							
Arachnida							
Hydracarina		1	1	1	1	2	3
Eucrustacea							
Cladocera							
Daphnia pulex			10	1	11	3	
Eurycercus lamellatus							
Ostracoda							8
Copepoda							
Limnocalanus macrurus					3	24	
Malacostraca							
Mysis relicta							
Isopoda							
Asellus sp.							
Amphipoda							
Pontoporeia affinis			19	3	34	38	56
Insecta							
Diptera							
Chironomidae	18	31	146	196	94	112	60
Ceratopogonidae	46	11	1	6	9	7	
Ephydridae					3		
Mollusca							
Gastropoda			9		9	5	8
Pelecypoda							
Sphaeriidae			11		40	50	
TOTAL	117	58	304	223	283	402	212

Table 19 Continued
Benthic fauna of Little Sand Bay

Date	8/5	8/5	8/5	8/5	8/5	8/5	8/5	8/5
Transect	1	1	1	1	3	3	3	3
Depth in Feet	5	10	20	30	5	10	20	30
Coelenterata								
Hydra sp.								
Nematoda		1	15	25	3	8	16	12
Annelida								
Oligochaeta	21	28	56	52	10	81	64	97
Arthropoda								
Arachnida								
Hydracarina		2	5	1	1	1	3	8
Eucrustacea								
Cladocera								
Daphnia pulex	1	12	11	1	1		2	1
Eurycercus lamellatus	1	16			37	29	5	1
Ostracoda					3			
Copepoda								
Limnocalanus macrurus		1	21	2	3		6	5
Malacostraca								
Mysis relicta								
Isopoda								
Asellus sp.								
Amphipoda								
Pontoporeia affinis	1	3	10	27	2	5	26	41
Insecta								
Diptera								
Chironomidae	135	151	71	25	220	106	37	25
Ceratopogonidae	4				1		6	1
Ephydridae								
Mollusca								
Gastropoda			5	12		2	3	6
Pelecypoda								
Sphaeriidae	2	2	37	62		1	49	61
TOTAL	166	216	231	208	281	233	217	258

of the midge family Chironomidae, were found at all depths but increased in abundance only to a depth of 15 to 20 feet, after which they decreased in abundance. Species of the clam family, Sphaeriidae, increased in abundance with depth but were not found in water less than 10 feet deep. Species of the biting midge family, Ceratopogonidae, were distributed with the maximum abundance in the shallow beach zone and decreased in numbers with depth. They were generally not found beyond the 20 foot depth.

A difference could not be shown in a comparison of the species composition and abundance between the sampled transects. No significant difference was found between samples taken from an area inside the present docking facility and a similar area beyond the influence of the dock.

Several fish species found in the bay feed primarily on benthic organisms. The principle ones are; the lake whitefish, round whitefish, white sucker, longnose sucker, ninespine stickleback, slimy sculpin and mottled sculpin. Any declines in abundance of the benthic organisms could conceivably result in a decline in abundance of the benthos feeding fish species and those fish species dependent on the benthic feeders as a food source.

5. Species Composition and Characteristics of the Fish Community Including Descriptions of Spawning and Nursery Sites

Thirty-three (33) species of fish have been found in investigations of the Apostle Islands (Table 20). Species of the family Salmonidae are important to the area's commercial and sports fisheries and represent the most important biologic resource which could be directly or indirectly affected by the proposed docking facility. Possible effects would be the result of alteration of existing habitat which could reduce the forage base or the suitability of the area as a spawning and nursery area. The biology of the Salmonid fishes as outlined in the previous report indicated that Little Sand Bay is suited as a spawning and nursery area for lake whitefish. The bay would not be used for spawning by brown trout, a stream spawner, but is utilized as a feeding area during the summer season (Niemuth, 1967). The amount of actual spawning was impossible to estimate during the summer season as all species of interest were fall and winter spawners. For this reason, much of this season's effort was directed at ascertaining whether the area is a nursery area for lake whitefish.

Gill nets were set (24 hour sets) along transects T_1 and T_3. The nets were set parallel to the shoreline at depths of 10, 20 and 30 feet (Figure 3). The catches showed (Table 21) that round whitefish and white and longnose suckers represented the greatest numbers and biomass, as they did for the previous fall. Most trout and salmon captured were juvenile fish which were foraging in the area. Lake trout were more common in the deeper, colder water. Brown and brook trout frequented the inshore areas.

TABLE 20

FISH SPECIES, ABUNDANCE AND DISTRIBUTION IN THE APOSTLE ISLAND AREA OF LAKE SUPERIOR[1]

Scientific Name	Common Name	Source[1]	General[2] Abundance Low	General[2] Abundance High	Occurrence[3] In Shallow Water (<60 feet)
Salmonidae					
Salvelinus namaycush	lake trout	1,2,C,P		X	+
Salvelinus fontinalis	brook trout	3,P	X		NS
Salmo gairdneri	rainbow trout	1,2,P	X		NS
Salmo trutta	brown trout	4,P		X	+
Oncorhynchus kisutch	coho salmon	3,P	X		NS
Coregonus clupeaformis	lake whitefish	1,2,C,P		X	+
Coregonus artedii	lake herring	1,2,C		X	+
Coregonus alpenae	longjaw cisco	1,2	X		NS
Coregonus hoyi	bloater	1,2		X	-
Coregonus kiyi	kiyi	1,2		X	-
Coregonus reighardi	shortnose cisco	1,2	X		NS
Coregonus zenithicus	shortjaw cisco	1,2		X	-
Coregonus nigripinnis	blackfin cisco	2	X		NS
Prosopium cylindraceum	round whitefish	1,2,4,C,P		X	+
Prosopium coulteri	pygmy whitefish	1,2		X	-
Osmeridae					
Osmerus mordax	rainbow smelt	1,2,4,C,P		X	+
Catostomidae					
Catostomus commersoni	white sucker	1,2,4,P	X		+
Catostomus catostomus	longnose sucker	1,2,4,C,P		X	+
Gadidae					
Lota Lota	burbot	1,2,4,C,P		X	+
Gasterosteidae					
Pungitius pungitius	ninespine stickleback	1,2,P		X	+
Percopsidae					
Percopsis omiscomaycus	trout-perch	1,2,4,P		X	+

Table 20 Continued
Fish Species, Abundance and Distribution in the Apostle Island Area of Lake Superior

Scientific Name	Common Name	Source[1]	General[2] Abundance Low	High	Occurrence[3] In Shallow Water (<60 feet)
Percidae					
Perca flavescens	yellow perch	1,P	X		NS
Stizostedion vitreum v.	walleye	1,C,P	X		+
Etheostoma nigrum	johnny darter	1,2,4,P		X	+
Cottidae					
Cottus cognatus	slimy sculpin	1,2,4,P		X	+
Cottus bairdi	mottled sculpin	1,P	X		NS
Cottus ricei	spoonhead sculpin	1,2,P		X	-
Myoxocephalus quadricornis	fourhorn sculpin	1,2		X	-
Cyprinidae					
Notropis athernoides	emerald shiner	P	X		-
Notropis hudsonius	spottail shiner	1,4	X		+
Couesius plumbeus	lake chub	4,P	X		+

[1]The list was developed from the following sources:

1. Anderson and Smith (1971a)
2. Dryer (1966)
3. Personal communication with Mr. George King, Fisheries Manager, Wisconsin Department of Natural Resources, Bayfield
4. Fall, 1974 Survey

P. Present Survey
C. Commercial catch records for Little Sand Bay (Statistical District 1308; Appendix I).

[2]High abundance is suggested for species for which Dryer (1966) described distribution, and for those species common to samples collected during this study.

[3]The value of plus (+) is assigned for species which inhabit water less than 60 feet in depth. Minus (-) and NS suggests the species was restricted to deep water or occurrence was below levels required to define distribution.

TABLE 21: Number of fish of each species caught in three 24 hour experimental gill net sets at three depths of two transects in Little Sand Bay during the summer of 1975.

Transect	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	
Depth (feet)	10	10	10	20	20	20	30	30	30	10	10	10	20	20	20	30	30	30	
Date	6/18	7/8	8/6	6/18	7/8	8/6	6/18	7/8	8/6	6/17	7/7	8/5	6/17	7/7	8/5	6/17	7/7	8/5	
Species																			Total
Round Whitefish	9	3		3	10		2	5	2	5	3	1	18	9	3	2	6	6	87
Lake Whitefish			1				1	1	3	2	14		2	1		1		5	31
Coho Salmon		1								1								1	3
Lake Trout					1		2	1	1	1	1		1						8
Brook Trout		1																	1
Brown Trout	1	2	2						1		1							3	10
Rainbow trout																		1	1
Walleye		2	1									2							5
Longnose Sucker	15	23	8	6	3	1	1	1	3	23	33		6			2		2	127
White Sucker	9	5	17	4	8	2	1			8	8	7	2		6				77
Smelt				1	2			2				1			2			13	21
Lake Chub	1	1													3				5
Burbot						1													1
Alewife		1	3							2		3							9

The only physical difference between the two transects is a large boulder field at the east end of the bay. Only the 10 foot gill net was in this field. The boulders might be expected to provide good substrate for periphyton and benthic organisms. They thus provide both food and cover for forage fish which in turn serve as food for the larger predators. The slightly greater number of brown and brook trout caught in the 10 foot net over the boulders (Transect 1), compared to the 10 net over sand (Transect 3), is probably a result of the increased food and cover. No other differences in distribution were found from gill net catches which could be attributed to the differing characteristics of the transects.

An 18 foot larval trawl and a meter tow net were used to assess the value of Little Sand Bay as a nursery area. All trawling was done near the shore at night when the larval fish would be most susceptible to capture. Juvenile and young-of-the-year smelt were the dominant fish captured in both nets (Tables 22 and 23). The catch of most of the species of fish increased during the course of the summer reflecting the increased use of the inshore areas (≤ 10 feet of water depth) as feeding grounds for both adult and younger fish.

Coregonid larvae were captured with the one-meter tow net during June and July but none were captured in August. Lake whitefish hatch in the spring during rising water temperatures in inshore areas and utilize bay areas such as Little Sand Bay to forage for food until the summer water temperatures reaches 17°C. When this temperature has been exceeded the young whitefish follow the 17°C isotherm down, or in this case, out to greater depths of the lake (Reckahn, 1970). Little Sand Bay does not appear to be a major nursery area for coregonids based upon the catch per unit of effort during this sampling season. However, due to the elusive nature of coregonid larvae larger than 20 mm total length

TABLE 22

Number of fish of each species caught in an 18 foot larval trawl. Each pull covered approximately 1000 feet, filtering 26,900 cubic feet of water.

DATE	June 11, 1975				June 16, 1975		July 8, 1975		July 17, 1975						August 5, 1975				
DEPTH (feet)	4	6	8	10	4	3-6	5	6	10-20	10	10	10-20	5-10	5-10	3-5	5	8	15	
SPECIES																			TOTAL
Smelt YoY					7	2		5		83	47	88	75	72	200	117	900	163	1759
Smelt 1+		15	85	1		80	17		4	88	238	99	367	360	225	27	225	36	1867
Lake Chub										1	3	1	4	1			1		11
Mottled Sculpin				1	1	3							2	4	30	2	28	5	76
Slimy Sculpin YoY												5	1	3					9
Slimy Sculpin 1+			2			3				1		2	5	3				3	19
Spoonhead Sculpin													1						1
Round Whitefish						1	1	1			1		2	6	2				14
Johnny Darter		1	1		1	7					9		24	17	42	3	24		129
Walleye						1							1						2
Yellow Perch															1		2		3
Troutperch YoY							1			2	5		5	2	24	3		5	47
Troutperch 1+						3								22	11	10	51	4	101
9-Spine Stickleback YoY						3				1		5	11						20
9-Spine Stickleback 1+					1					1	1		5	5	2		23	82	120
White Sucker														1					1
Longnose Sucker											1			2	18	6	17		44
TOTAL	0	16	88	2	10	103	19	6	4	177	305	200	533	498	555	168	1271	298	

TABLE 23: Number of organisms caught in a one meter plankton tow in Little Sand Bay during the summer of 1975. Approximately 8000 cubic feet of water was filtered in each tow. Relative amounts are used to describe number of organisms where too numerous to count or separate.

Date	6/17	6/17	6/17	6/17	6/18	6/18	6/18	6/18	7/6	7/6	7/6	7/6	7/6	7/17	7/17	7/17	8/4	8/4
Sampling Depth (feet)	2	2	2	2	2	2	2	2	19	23	10	6	2	2	2	2	2	10
Organism																		
Arthropoda																		
Eucrustacea																		
Cladocera																		
Eurycercus lamellatus	F		F		F	F	F					N	N				F	F
Leptodora kindtii												N	N	N	N	N	N	N
Copepoda																		
Daphnia sp.														N	N		M	M
Limnocalanus macrurus	F	N	N	N	N	F	F		N	N	N	N	F					
Diaptomus sp.	N								F	N	N	F						
Malacostraca																		
Mysis oculata var. relicta		2	1	1	1	1	1		N	N	N	F						
Amphipoda																		
Pontoporeia affinis		F	F	F	F	F	F		F	M	F	F	F		M			F
Insecta																		
Diptera																		
Chironomidae		F	F	F	F		F		F	F			F					
Plecoptera																		
Perlodidae																		
Isoperla sp.			1															
Ephemeroptera																		
Ephemeridae																		
Hexagenia sp.				1	1	1								1				
Siphlonuridae																		
Siphlonurus sp.										1								
Heptageniidae																		
Heptagenia sp.														1				
Baetidae																		
Neocleon sp.																	1	

Table 23 Continued

Date	6/17	6/17	6/17	6/17	6/18	6/13	6/18	6/18	7/6	7/6	7/6	7/6	7/6	7/17	7/17	7/17	8/4	8/4
Sampling Depth (feet)	2	2	2	2	2	2	2	2	19	23	10	6	2	2	2	2	2	10
<u>Organism</u>																		
Fish																		
Trout-perch														10		32		
9-spine stickleback										1					24			
Sculpin			1	1	1	1			2	3	2	5	1		2			6
Sucker		1																
Smelt	1	1	1	4	3	2	5	12	28	10	8	9	6	112	73	82	47	262
Coregonid		1	1		3			3							1	5		
Cyprinid																	8	10

F - *Few*

M - *Many*

N - *Numerous*

to nets (Anderson, 1969), the number of individuals captured may not accurately represent the size of the population utilizing the bay.

Stomach analyses were made on round whitefish, lake whitefish, coho salmon, walleye, brook trout, lake trout and brown trout (Tables 24, 25, 26 and 27) to establish the most important food items for these species. Round whitefish appear to be opportunistic feeders, eating whatever organisms were most readily available, on or above the bottom although there appears to be some selection for Trichoptera larvae (caddis fly) as these did not appear in the benthic samples. The diet of the lake whitefish was composed almost entirely of those organisms most common in the substrate of the deeper waters, predominately fingernail clams (Sphaeriidae), amphipods (Pontopereia affinis), and midge larvae (Chironomidae). All the salmon and trout exhibited similar feeding habits with those fish larger than 250-300 mm entirely piscivorous and the smaller fish relying almost entirely on adult terrestrial insects. This complete reliance of the smaller salmonids on terrestrial insects as a food source (Tables 26 and 27) indicates the importance of vegetation in close proximity to the lake shore to maximize the food supply for salmonids under 250 mm (10 inches).

TABLE 24: Number of organisms in stomachs of selected round whitefish (Prosopium cylindraceum) gill netted in Little Sand Bay during the summer of 1975. Organisms were counted and identified to the taxonomic level which the state of digestion would allow.

Date	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	8/6	3/6	8/6	8/6	
Depth (feet)	10	20	20	20	20	20	20	30	30	30	30	30	30	10	10	30	30	
Total length (mm)	280	205	222	230	240	262	280	250	260	268	278	292	321	242	310	234	254	
Organism																		Total
Annelida																		
Oligochaeta		1																1
Mollusca																		
Gastropoda						5								4				9
Pelecopoda																		
Sphaeriidae									1		1							2
Arthropoda																		
Arachnida																		
Acari																		
Hydracarina	2		1	1													1	5
Eucrustacea																		
Cladocera																		
Eurycercus lamellatus	25			70+		14												109+
Isopoda																		
Asellus sp.									8	1								9
Insecta																		
Diptera																		
Chironomidae	1	5	2		17					3		5	1	24	several	7		61+
Coleoptera (adult terrestrial)						1												1
Homoptera (adult terrestrial)	2								2						30+		40	74+
Hymenoptera (adult terrestrial)											1				several			1+
Trichoptera	7		1	1		9			1	3		1						23

Table 24 Continued
Number of organisms in stomachs of selected round whitefish (<u>Prosopium cylindraceum</u>) gill netted in Little Sand Bay

Date	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	8/6	8/6	8/6	8/6	
Depth (feet)	10	20	20	20	20	20	20	30	30	30	30	30	30	10	10	30	30	
Total length (mm)	280	205	222	230	240	262	280	250	260	268	278	292	321	242	310	234	254	
<u>Organism</u>																		<u>Total</u>
Agrypnia sp.									1	1								2
Lepidostoma sp.					6		6			1								13
Oecetis sp.	16	9																25
Chordata																		
larval fish (unidentifiable)							2											2

TABLE 25

Number of organisms in stomachs of selected lake whitefish (Coregonus clupeaformis) gill netted in Little Sand Bay during the summer of 1975. Organisms were counted and identified to the taxonomic level which the state of digestion would allow.

Date	6/17	7/7	7/7	7/7	7/7	7/7	8/6	8/6	8/6	
Depth (feet)	20	10	10	10	10	10	30	30	30	
Total length (mm)	351	270	232	390	432	475	242	313	345	
Organism										Total
Mollusca										
Pelecypoda										
Sphaeriidae	60					13	15	80+	80+	248+
Arthropoda										
Arachnida										
Hydracarina	1									1
Eucrustacea										
Amphipoda										
Pontoporeia affinis	6					50+		50+	50+	156+
Insecta										
Diptera										
Chironomidae	14					4		1	3	22
Chordata										
larval fish (unidentifiable)	1									1

TABLE 26

Number of organisms in stomachs of selected coho salmon (Oncorhynchus kisutch), walleye (Stizostedium vitreum), brook trout (Salvelinus fontanalis) and lake trout (Salvelinus namaycush) gill netted in Little Sand Bay during the summer of 1975. Organisms were counted and identified to the taxonomic level which the state of digestion would allow.

Species	Coho Salmon			Wall-eye	Brook Trout	Lake Trout				
Date	6/7	7/8	8/5	7/8	7/8	6/7	7/7	7/8	7/8	8/6
Depth (feet)	10	10	30	10	10	20	10	20	30	30
Total length (mm)	360	192	252	250	252	646	410	316	370	380
<u>Organism</u>										
Arthropoda										
Insecta										
Coleoptera										
(adult terrestrial)	*numerous*		*several*		*1*					
Diptera										
(adult terrestrial)					*1*					
Lepidoptera										
(adult terrestrial)					*85*					
Homoptera										
(adult terrestrial)		*24*	*1*		*1*					
Hymenoptera										
(adult terrestrial)	*numerous*		*several*		*1*					
Chordate										
Rainbow Smelt										
(Osmerus mordax)				*2*		*1*	*1*	*1*		*4*
Unidentifiable fish						*1*				

TABLE 27

Number of organisms in stomachs of selected brown trout (Salmo trutta) gill netted in Little Sand Bay during the summer of 1975. Organisms were counted and identified to the taxonomic level which the state of digestion would allow.

Date	7/7	7/8	7/8	8/5	8/5	8/5	8/6	8/6
Depth (feet)	10	10	10	30	30	30	10	10
Total length (mm)	262	250	410	378	417	425	461	462
Organism								
Anthropoda								
Insecta								
Coleoptera (adult terrestrial)		6						
Diptera (adult)	several							
Hemiptera (adult terrestrial)	several	1						
Homoptera (adult terrestrial)	several	40+						
Hymenoptera (adult terrestrial)	several	1						
Orthoptera (adult terrestrial)		1						
Chordata								
Rainbow smelt (Osmerus mordax)			1	1	1	2	1	
9-spine stickleback (Pungitus pungitus)			3					
Unidentifiable fish							2	

DISCUSSION OF ENVIRONMENTAL EFFECTS ON LITTLE SAND BAY OF PROPOSED ALTERNATE DOCKING SITES AND DESIGNS

Prior to the discussion of environmental effects of contrasting types of docking/breakwater systems, a broader question should be analyzed. This deals with the generalized location of such docking facilities within the Little Sand Bay area (as defined by this study and contract study CX-2000-5-0013).

Article II of the professional services contract number CX-2000-5-0034 received May 28, 1975 (this study) states (page 2):

> "... further surveys should be conducted during the spring/summer months to accurately identify, interpret and analyze potential seasonal variations in the geomorphology and coastal processes which affect the Little Sand Bay potential construction zone. Preliminary planning of the Little Sand Bay mainland development also indicated at least one other potential site for the proposed docking/breakwater system existed due east of current harbor facility."

For ease of referral, the originally considered docking site in the area of the existing harbor facility will be referred to as site Alpha, and the potential site to the east of this facility, in the area of the Beachcomber Bar will be referred to as site Beta. For analysis of potential sites along the entire west flank of the Bayfield Peninsula, the reader is referred to the evaluation section (pages 110-117) of "Physical and Biological Parameters, Little Sand Bay, Apostle Islands National Lakeshore and Relationships to Various Docking Designs" (CLSES, January 31, 1975).

The first factor to be considered in the analysis of these two potential sites is that of slope gradient. It will be recalled from the depth of offshore waters section of this report that at site Alpha the slope between 0 and 10 feet of water is 1.8% and from 10-20 feet is 1.9%, while at site Beta the 0-10 foot gradient is 1.7% and from 10-20 feet is 1.1%. On this basis, site Alpha would have the more advantageous site with a natural 10 foot water depth existing less than 550 feet from shore.

Site Alpha also has an advantage over site Beta in the consideration of wave energy and openness of the shoreline to wave attack, especially those associated with prevalent northwesterly storms. The projection of the unnamed western headland of Little Sand Bay (shoreline area of drainage basin #98, Figure 1) offers some degree of protection to site Alpha while site Beta lies in the southeastern corner of this bay, bearing the full brunt of northwesterly storms.

The third, and possibly most important consideration is that of beach stabilization. With an easterly trending drift and undernourished beach area to the west of site Beta, placement of a docking facility at this site could be advantageous. The easterly drift could allow beach accretion in the area to the west of the facility, stabilizing the beach in this zone. However, extensive erosion of the unconsolidated glacial till banks is a probability on the eastern side of a dock located at this site, due to the sand starvation and high wave energy conditions encountered here. This eroded material would, in all likelihood, be deposited immediately within this dock enclosure, in much the same way it collects inside the existing harbor facilities. These phenomena should be alleviated by a properly designed docking/breakwater system, a further benefit of which should be no need for dredging or revetting.

Evaluation of the floral and faunal communities in Little Sand Bay indicates a fairly homogeneous distribution of those organisms which move with the currents and some differences in the distribution of certain fish species. Currents are important in dictating the distribution of zooplankton and pelagic larval fishes such as smelt and whitefish. Therefore, little difference in the distribution of these organisms occurs within the bay due to existing current patterns. Any structure which might interfere with current patterns could displace these species and possibly have an adverse effect on their production.

The primary differences between sites Alpha and Beta are those associated with the difference in the lake floor substrate. The large boulder field at site Beta will harbor different types and greater abundance of benthic organisms than the sand substrate characteristic of the remainder of Little Sand Bay. It may also provide cover for many types of forage fish and thus attract salmonid fish. The area around site Beta is the only portion of Little Sand Bay in which this valuable habitat occurs, and it should be protected from a structure which may cause sedimentary deposition and burial of this field. This boulder field extends from the area between stations 14 and 15 to station 18 and from depths of 3 to 15 feet of water (see Figure 2). Neither site was shown to have special significance as a nursery or reproductive area of major fish populations.

Another problem of concern in the possible choice of site Beta for a docking facility is the necessity of orienting the breakwater section (east-west portion) of the dock eastward from the shore-perpendicular arm (north-south portion) to allow protection from the highest energy waves approaching from the north-

west (Figure 14). This would necessitate a confined entry to the dock located parallel to the cliffed shoreline.

Specific design details for the proposed docking/breakwater system were by contract agreement not furnished by the National Park Service, therefore the following assessments are based upon the best judgment of the study team as determined from the gathered data.

The first type of docking design to be considered is that of a floating form. This precludes any attachment to the substrate other than anchors. Such, however, must be attached to the beach in such a manner as to probably interrupt the passage of longshore drift with resultant erosion on the downdrift side (eastern) and deposition on the updrift side (western) as demonstrated by beach profiles 3, 4, 5 and 6 (Table 14). There would also be deposition attendant to the attenuation of wave energy by floating pontoons, thus causing a buildup of sediment within the shelter of the dock.

The floating type dock would have minimal effects on the floral and faunal communities. It would provide increased surface area for attachment of periphyton and insects and would afford some degree of cover for fish, but neither of these factors would have much effect on the faunal ecology of Little Sand Bay.

It is doubtful whether this type of docking system would be economically feasible for this particular area due to the rigors of the winter season necessitating the lifting of such a structure each fall and reemplacement each spring.

The second type of system is that of a solid or impermeable breakwater and dock design. This, of course, would have the greatest effect upon the wave

induced and longshore currents as well as the material carried therein. The sedimentation and erosion situation would be similar to that described for the floating dock, but magnified tremendously due to the complete cutoff of the longshore drift which maintains the sandy beach. Shore erosion on the downdrift side would continue to cut into cliffs and forests until that time when the shoal of deposited sand on the updrift side was able to move around the outer limits of the dock and fill in downdrift sections, including that designated as the boat anchorage area. Until such downdrift shoaling took place the physical effect of such a dock upon the shallow neritic sediment would be minimal.

The interruption of the longshore currents by construction of a large solid docking facility and breakwater could also interfere with the movement of the pelagic larval fish and zooplankton. These organisms seem to be farily dependent on such currents for both locomotion and feeding purposes. Any solid type of construction could range from sloping riprap to some type of solid facing constructed perpendicular to the lake bottom. Perpendicular facing would be of little value to most organisms, due to associated high wave energy and relatively minimal surface area, but riprap would provide abundant surface area for periphyton and benthic organisms and then would be attractive to fish. However, the detrimental effects of increased sedimentation and interruption of current patterns of a solid-type dock on the bay ecosystem would seem to far out-weigh any positive biologic effects.

The last type of docking design is that of a flow-through or piling supported structure much like the present National Park Service dock at Little Sand Bay. If the pilings were spaced widely enough apart (3 foot minimum spacing) the

longshore current would not be disrupted and no changes in beach morphology would be expected to occur. This spacing of piles would have to continue to at least a natural 10 foot depth of water as shown by the data of the current meters and stake fields (Tables 12 and 15). The longshore and wave induced currents are still active at the 7.5 foot depth (0.078-0.175 cm/sec.), thus the 10 foot limitation figure would allow space for shifting of shoals and bars which is also an active feature in the 0 to 10 foot depth range. Starting the impermeable breakwater section of the dock or beyond the 10 foot depth mark should alleviate the problem of dredging the anchorage area ($\geq$ 10 feet), due to the near-cessation of deeper water neritic sediment movement caused by the inaction of bottom currents.

There would be a slight build-up of fine sediment near the pilings due to their attenuation of wave energy, but this sediment should ultimately be reworked by the relatively unobstructed longshore current and distributed upon the beach face.

The flow-through piling supported dock would also be most desirable in terms of effects on the biologic community. It would provide for minimum disruption of the natural drift of pelagic organisms while providing structure for attachment of periphyton and cover for fish. The riprap in the breakwater section of such a design could also be an attractant to game fish such as brown trout, brook trout and walleye. Such structure in relatively deep water would combine the cover provided by water depth with the food and cover provided by riprap. This could provide reasonably good fishing from the docking structure.

Figure 14 is a schematic of the type of breakwater/docking system which would combine the advantages of an impermeable breakwater (protection from northwest

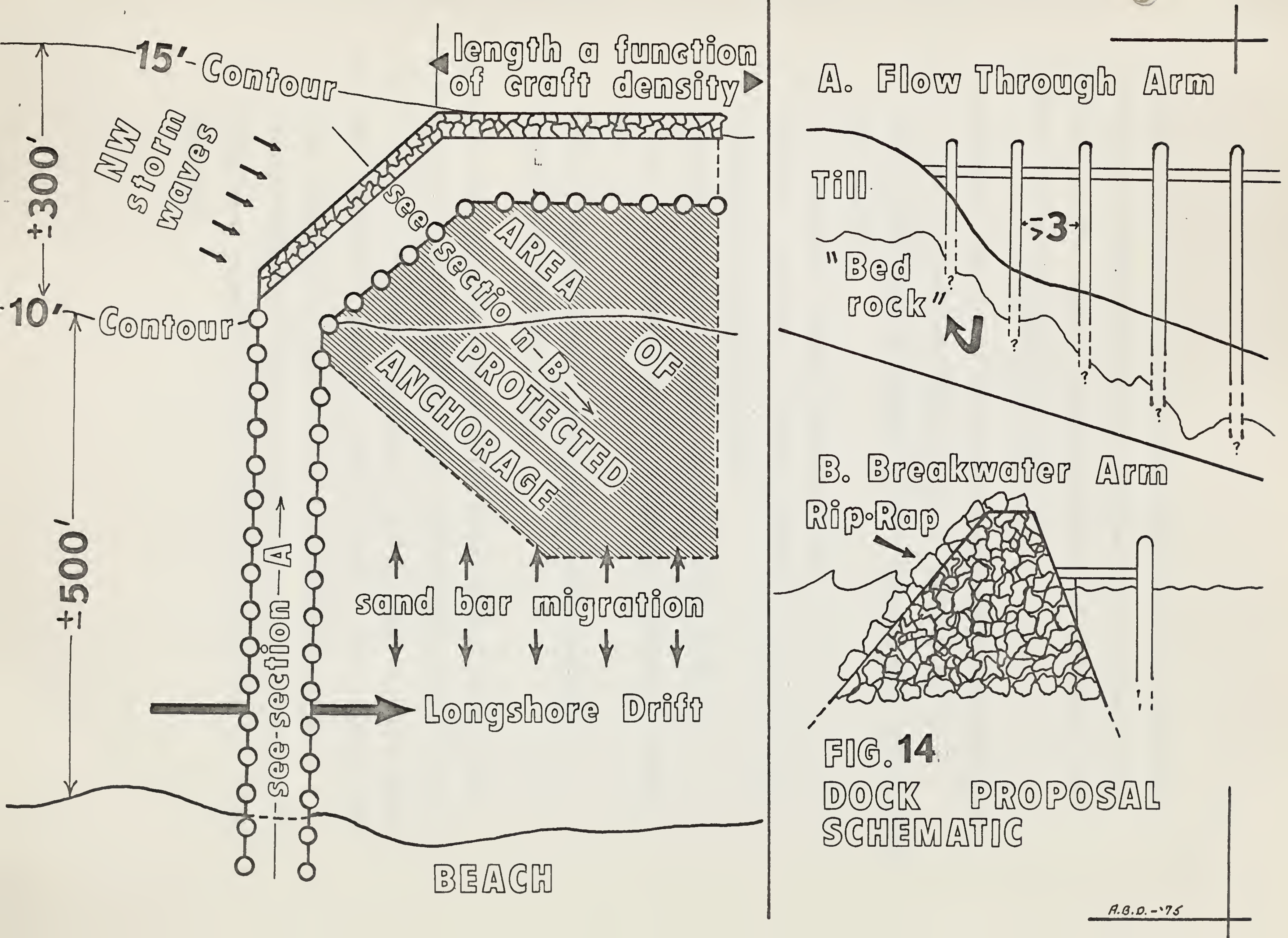


FIG. 14
DOCK PROPOSAL SCHEMATIC

prevailing storms) and a flow-through shore perpendicular arm (nondisruption of longshore and wave induced currents or shallow neritic sediment motion). All figures in this schematic are based upon data found in the body of this report and the best judgment of the study team.

In conclusion, the authors recommend a flow-through docking system exemplified by the schematic presentation (Figure 14) for the following reasons:

1. Relative nondisruption of longshore and wave induced currents with resultant beach stability.
2. Minimal impact upon near and offshore bathymetry.
3. Attenuation of storm waves and related protection to moored boats without disruption of nearshore processes.
4. Minimization of dredging problems within the docking enclosure.
5. Allowance of uninterrupted movement of biologic populations in the nearshore zone.
6. Increased attachment area for periphyton and benthic organisms.
7. Protection and attraction of fish.

It will be noted that these conclusions are similar to those reached in the previous report (contract #CX-2000-5-0013). The remaining question is one of site selection for the proposed structure. The data presented above indicates site Alpha as being more advantageous than site Beta for the following reasons:

1. Higher slope gradient between 10 and 20 foot bathymetric contours.
2. Relatively lower wave energy due to protection by western boundary headland.
3. Elimination of engineering oriented problem of sinking pilings in a boulder stream area.

4. Relative case of entry to docking enclosure.
5. Special significance of boulder substrate (site Beta) to benthic and fish populations.

However, it must be noted that site Beta is a viable alternative based upon the data gathered for the late spring and summer of 1975.

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Biological References Continued

Williams, L.G. 1966. Dominant Planktonic Rotifers of Major Waterways of the U.S. Limnology and Oceanography, 11:83-91.

Young, O.W. 1945. A Limnological Investigation of Periphyton in Douglas Lake, Michigan. Transaction American Micro. Society, 64(1):1-20.

The above (Biological) listed references were those employed in contract study CX-2000-5-0013. Following are additional references reviewed and employed in the process of writing this report.

Round, F.E. 1970. The Biology of the Algae. Edward Arnold (Publishers) LTD. London. 269 p.

APPENDIX SECTION

For Contents Refer To

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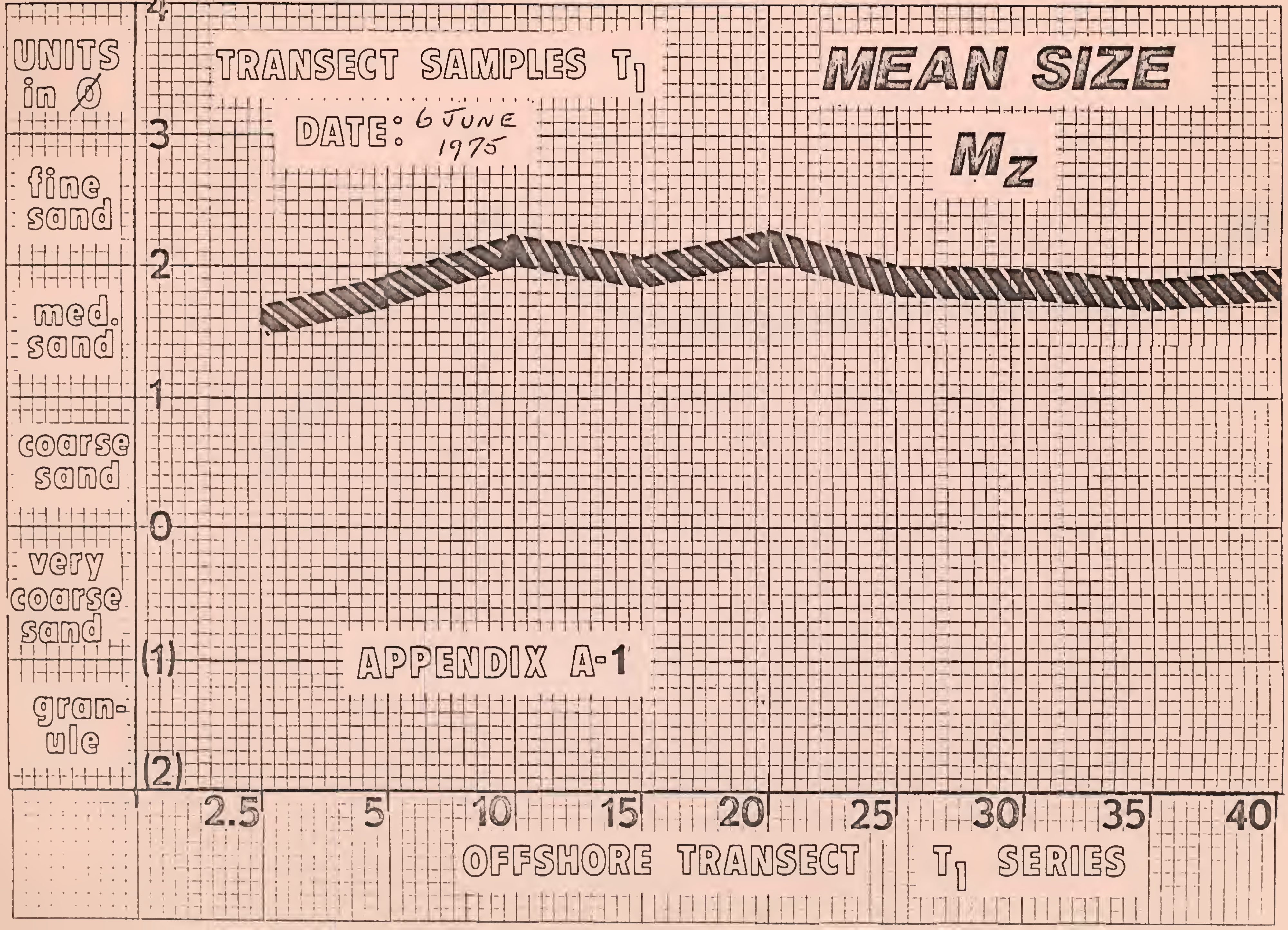
APPENDIX A



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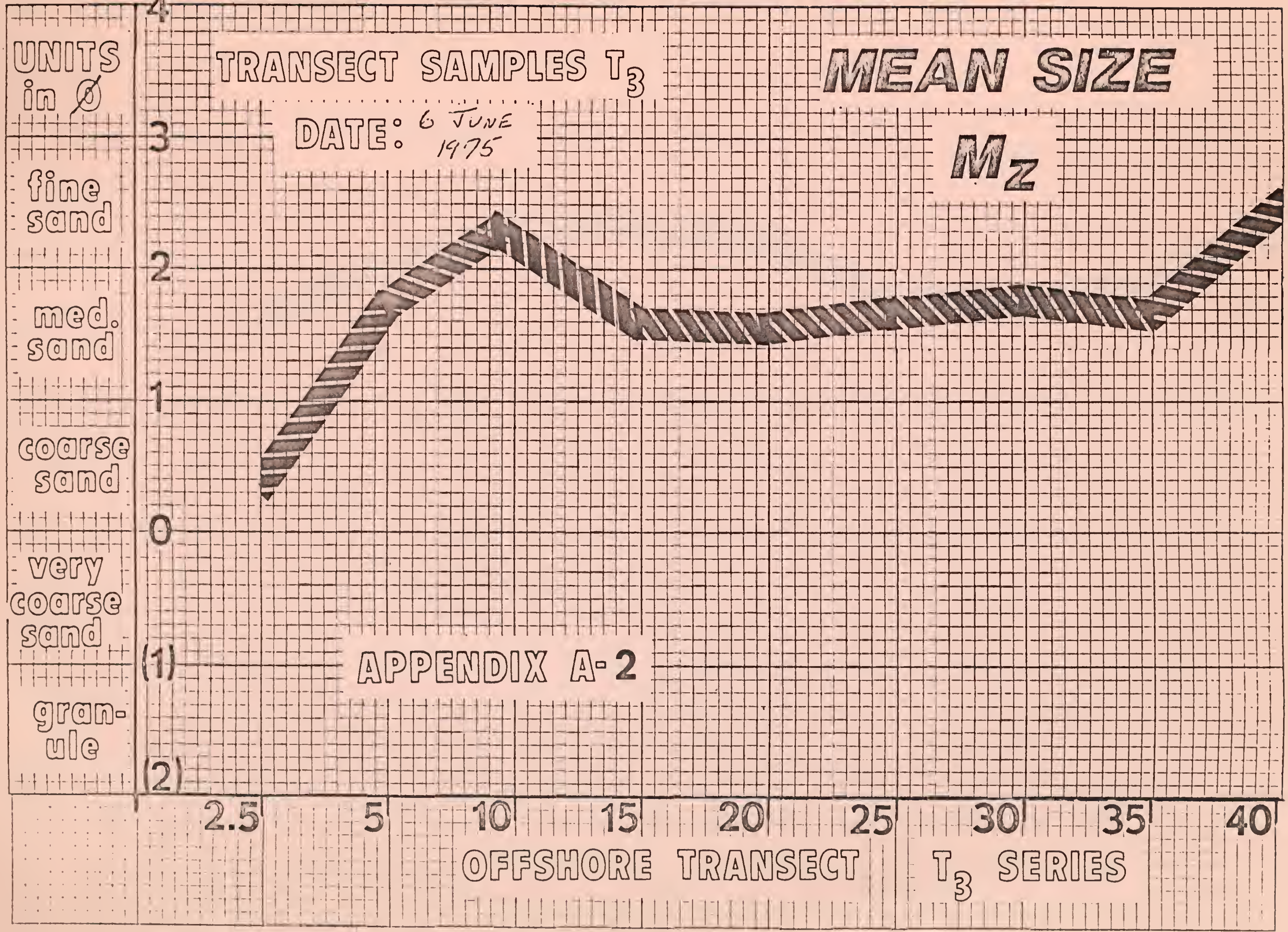

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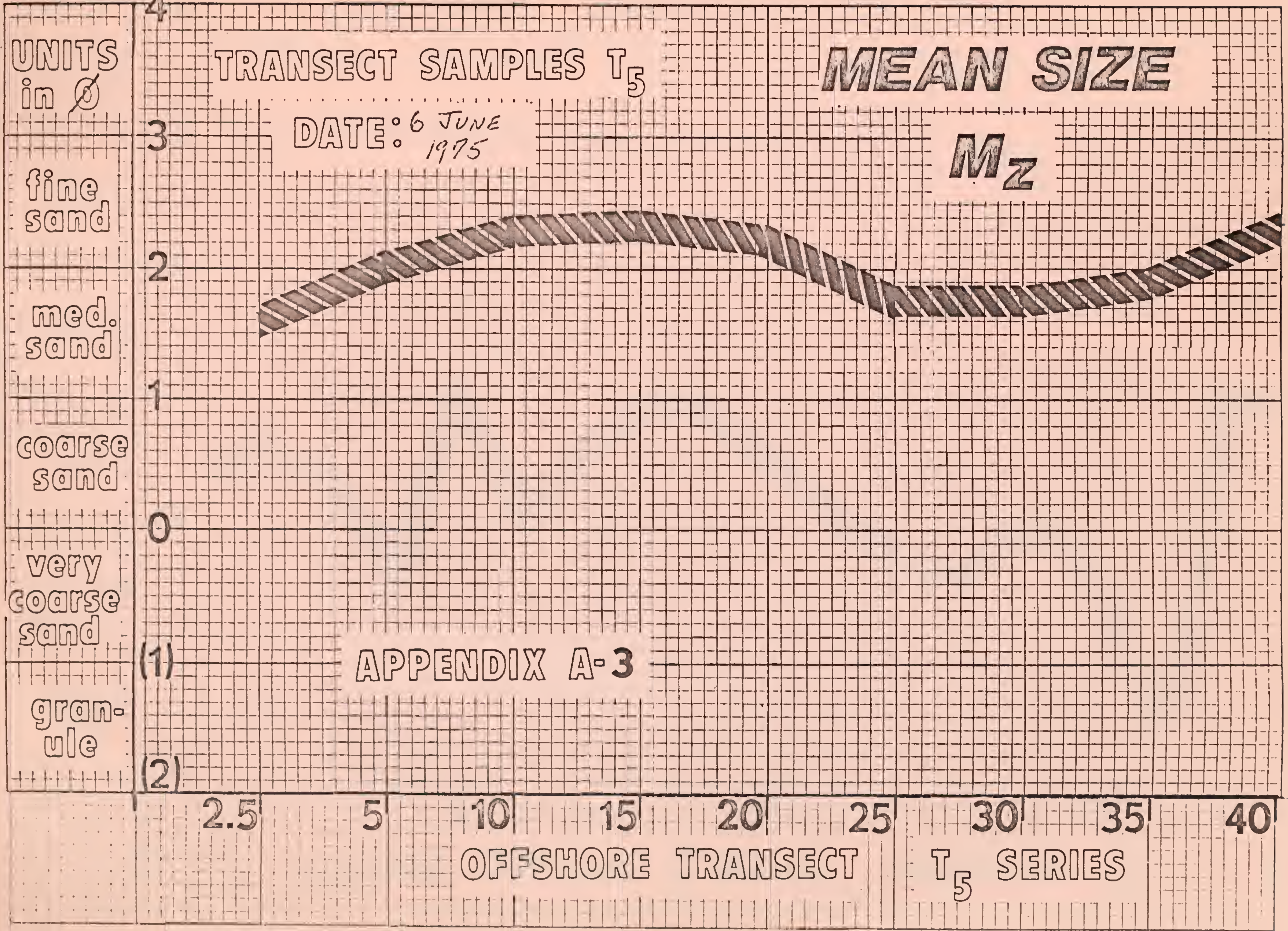

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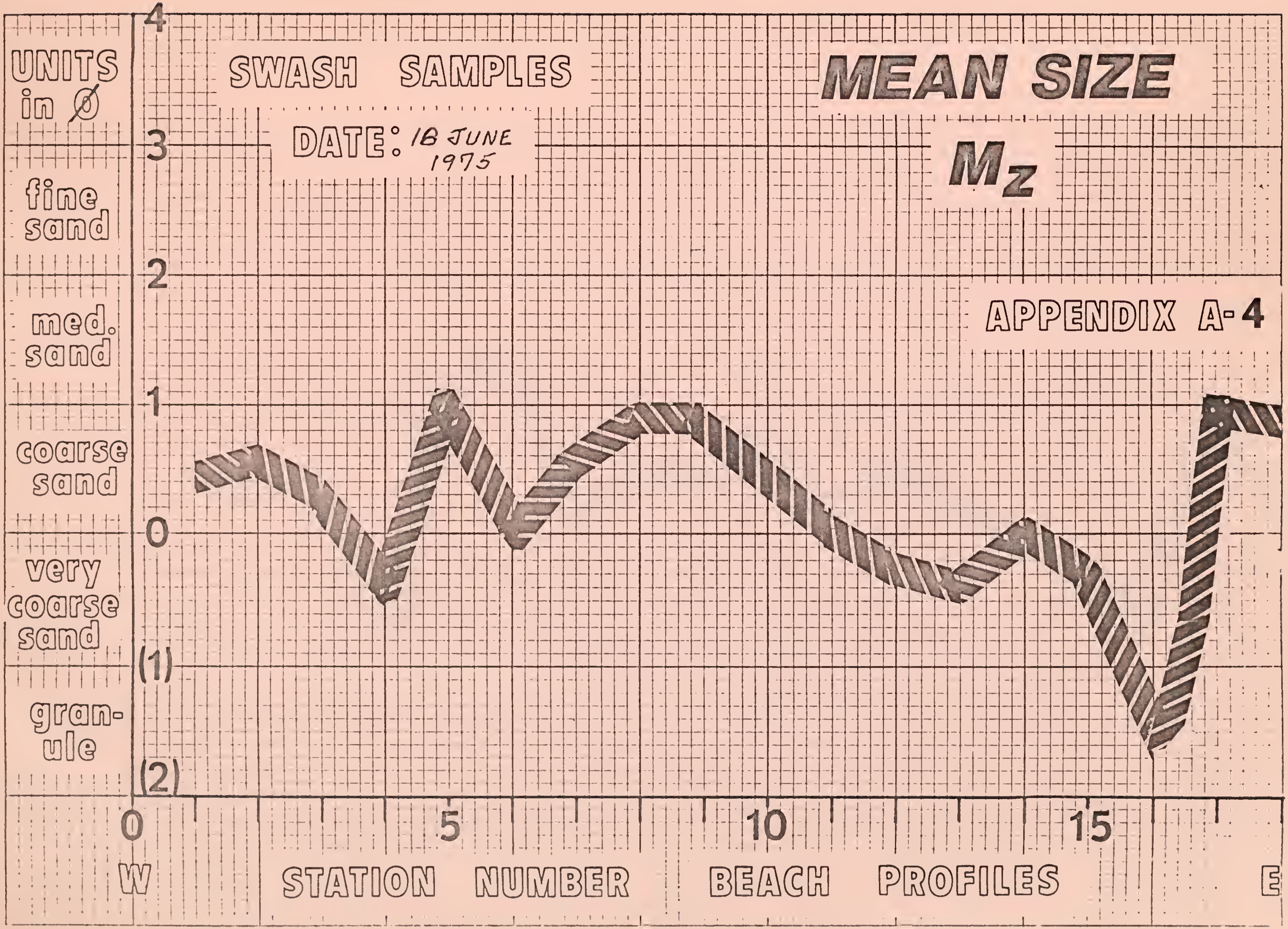
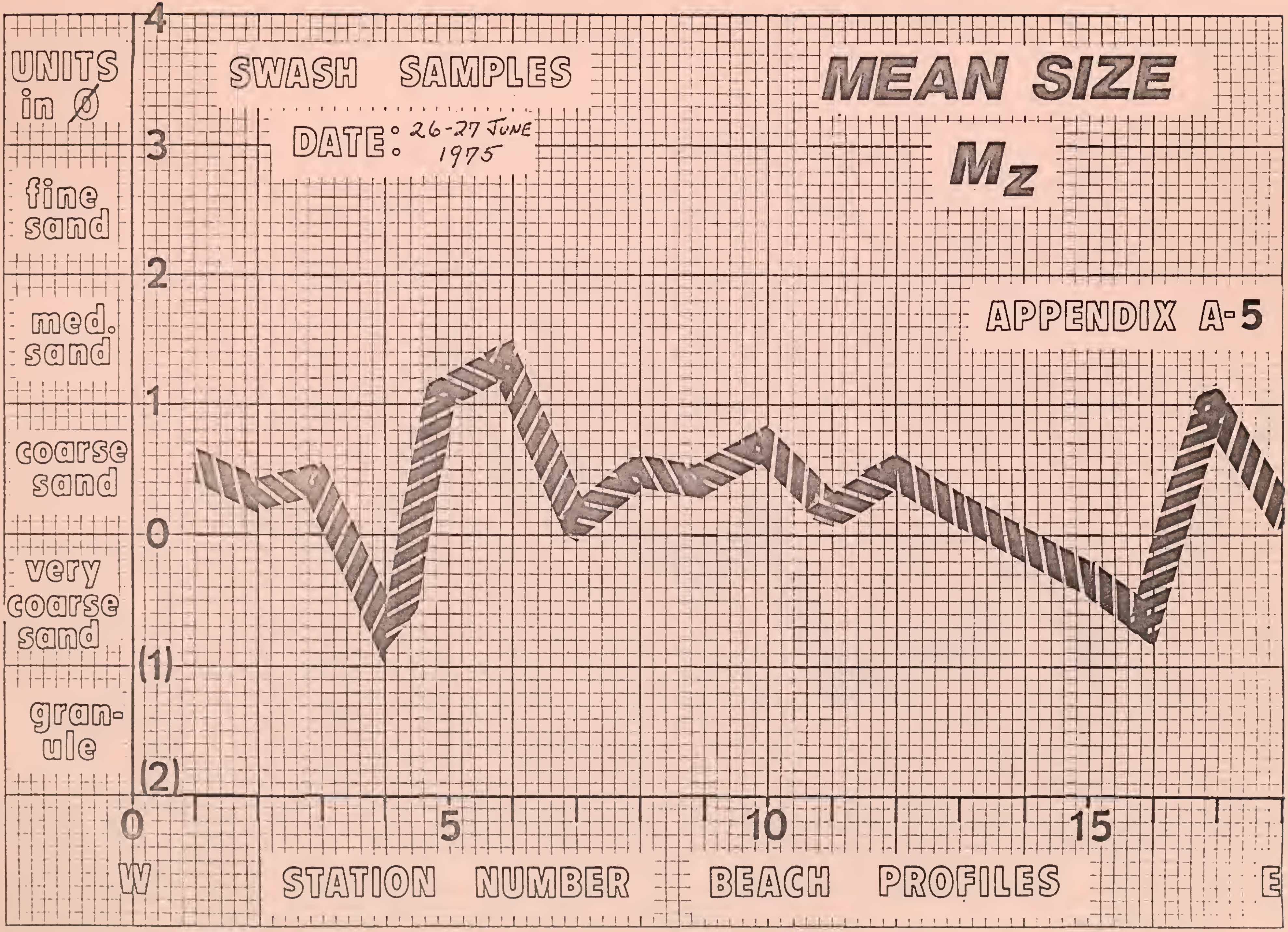


MEAN SIZE
M_z
SWASH SAMPLES
DATE: 18 JUNE 1975
APPENDIX A-4
UNITS in Ø
fine sand
med. sand
coarse sand
very coarse sand
granule
4
3
2
1
0
(1)
(2)
0
5
10
15
W
STATION NUMBER BEACH PROFILES
E



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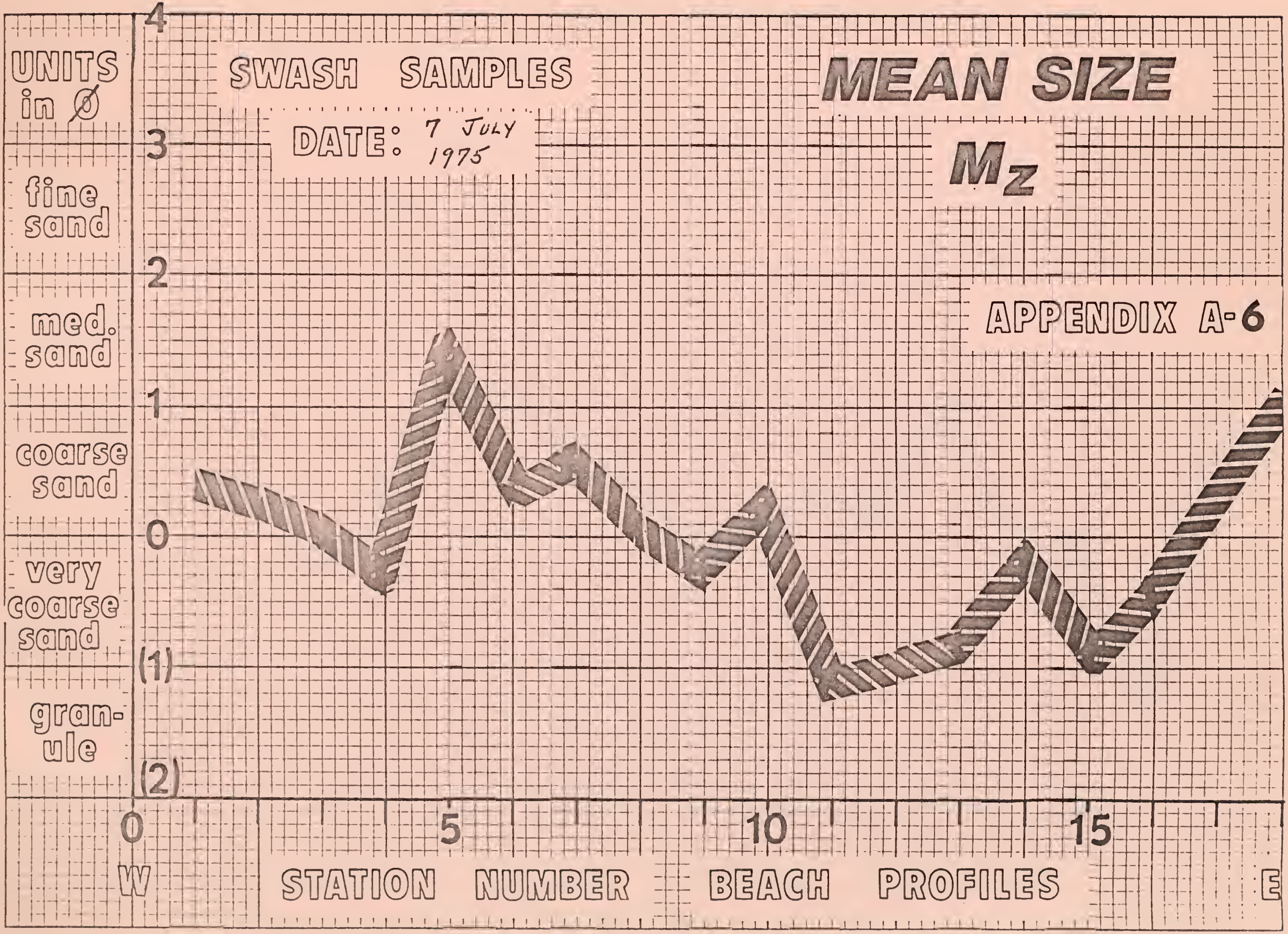
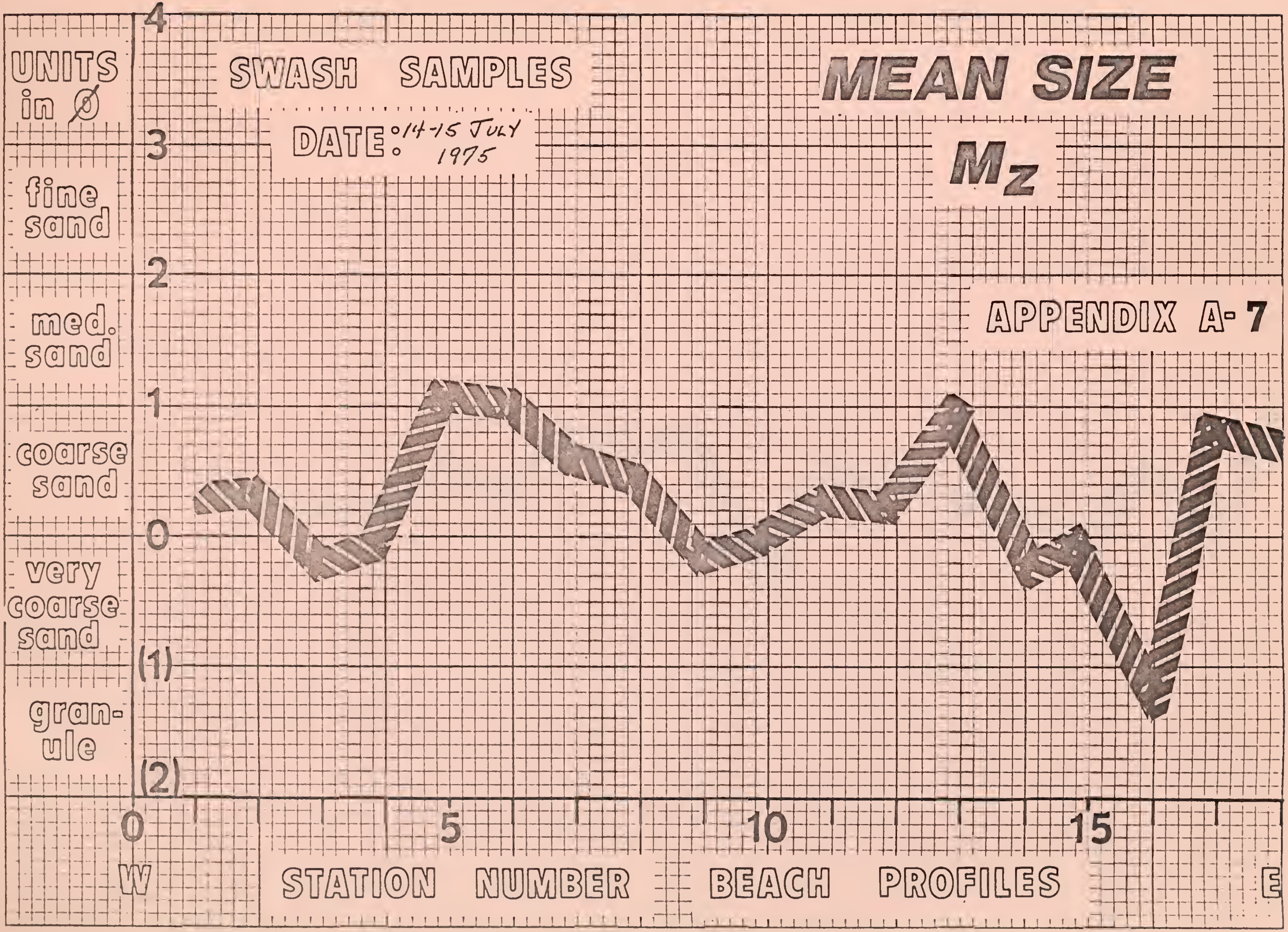

MEAN SIZE
M_z
SWASH SAMPLES
DATE: 7 JULY 1975
APPENDIX A-6
UNITS in Ø
fine sand
med. sand
coarse sand
very coarse sand
granule
4
3
2
1
0
(1)
(2)
0
5
10
15
W
STATION NUMBER BEACH PROFILES
E



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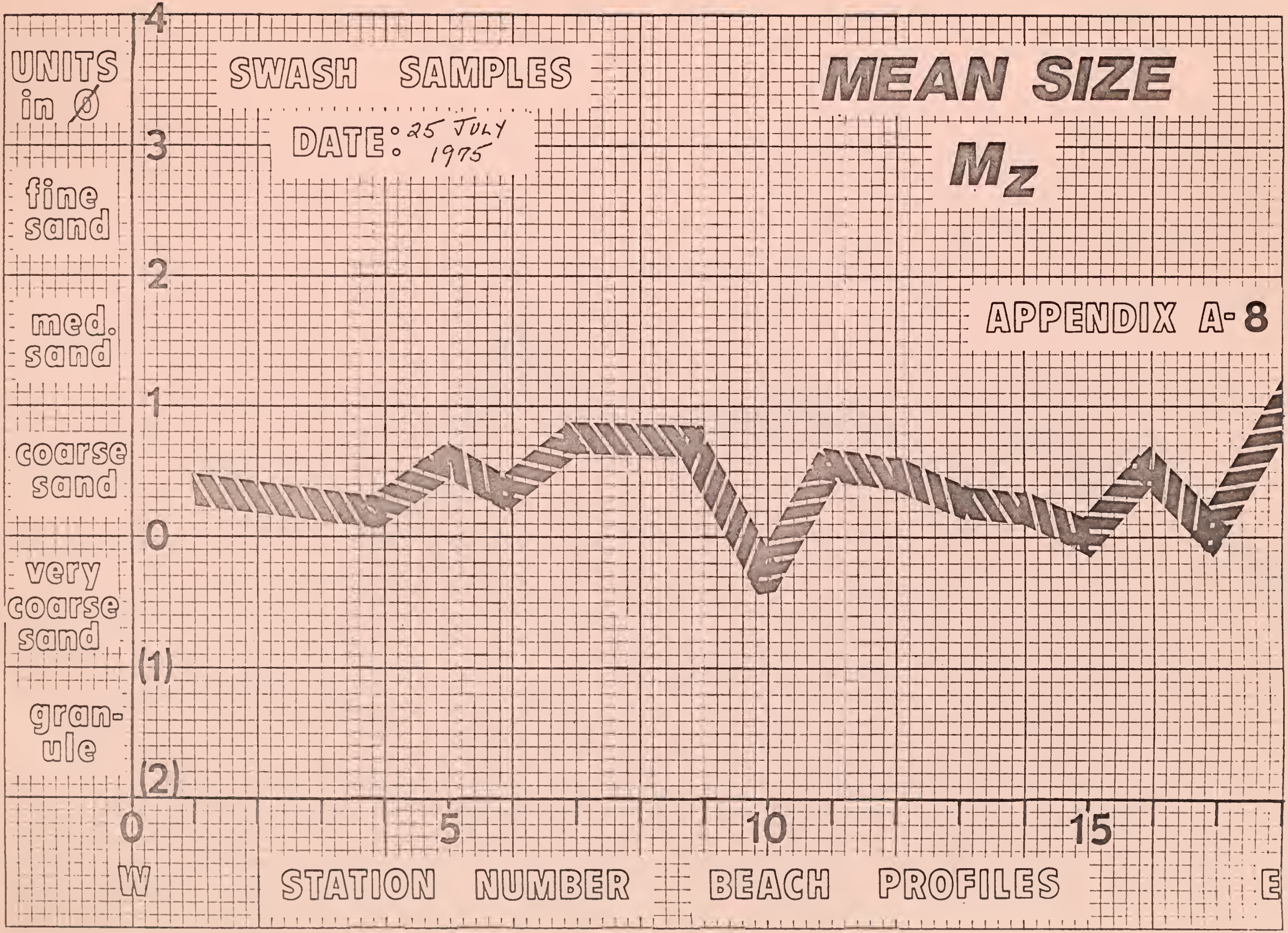
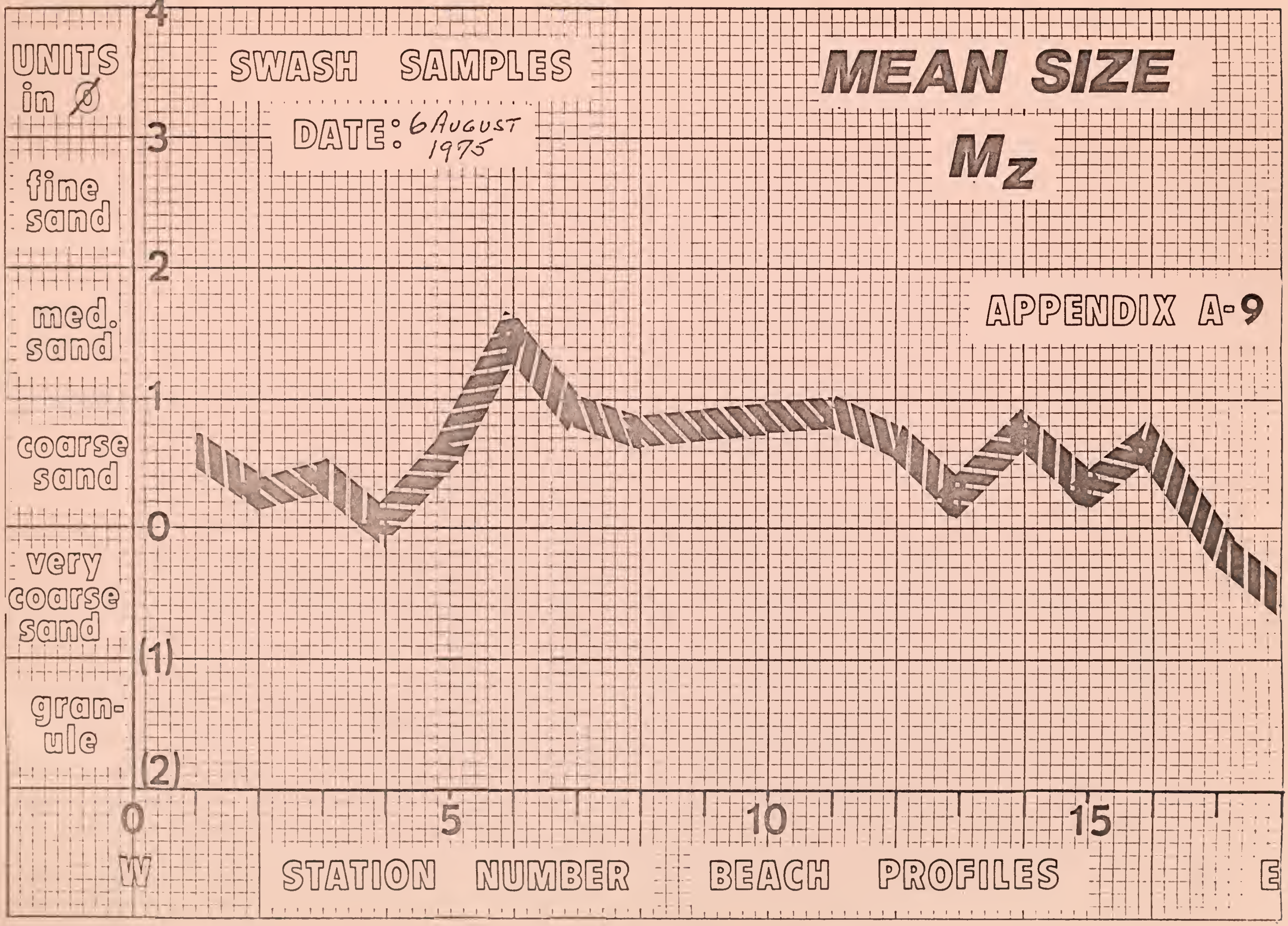

MEAN SIZE
M_z
SWASH SAMPLES
DATE: 25 JULY 1975
APPENDIX A-8
UNITS in Ø
fine sand
med. sand
coarse sand
very coarse sand
granule
4
3
2
1
0
(1)
(2)
0
5
10
15
W
STATION NUMBER
BEACH PROFILES
E



CITADEL NO 642 - CROSS SECTION - 10 SQUARES TO INCH

APPENDIX B

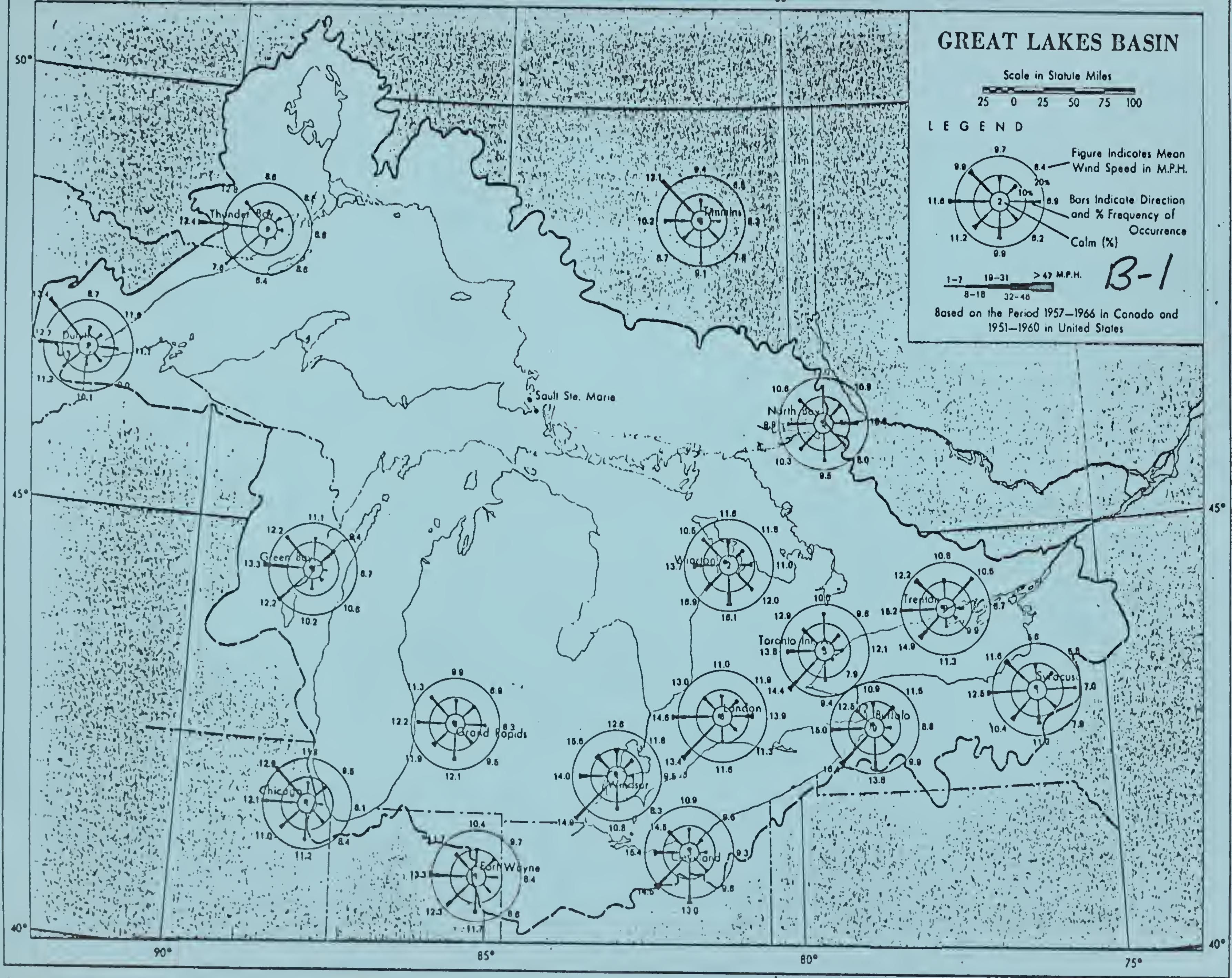


CHART 54 – JANUARY WIND ROSES FOR SELECTED AIRPORT STATIONS. The average wind speed from all directions in winter is from 6 to 19 miles per hour. Over the middle and upper lakes region, winds blow from the west and northwest 40 to 50 percent of the time, with northwest winds prevailing. South of the lakes, winds from the west and southwest direction predominent 30 to 40 percent of the time.

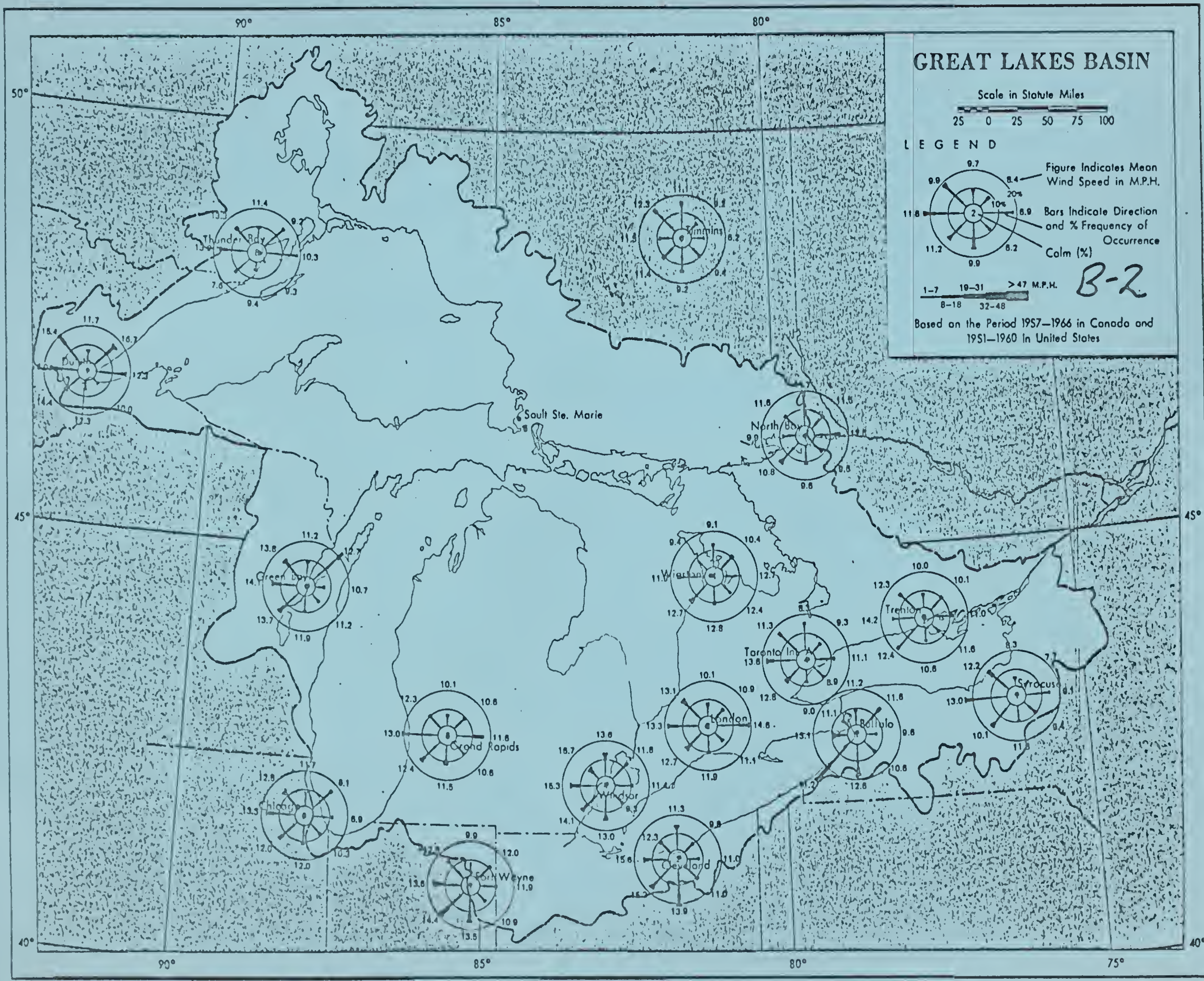


CHART 55 – APRIL WIND ROSES FOR SELECTED AIRPORT STATIONS. On the average, winds are strongest in early spring with mean speeds in all directions over 8 mph; the highest mean speeds are above 13 mph and are usually from the prevailing direction. Stronger speeds are associated with increased cyclonic activity and less surface retardation, since the ground is

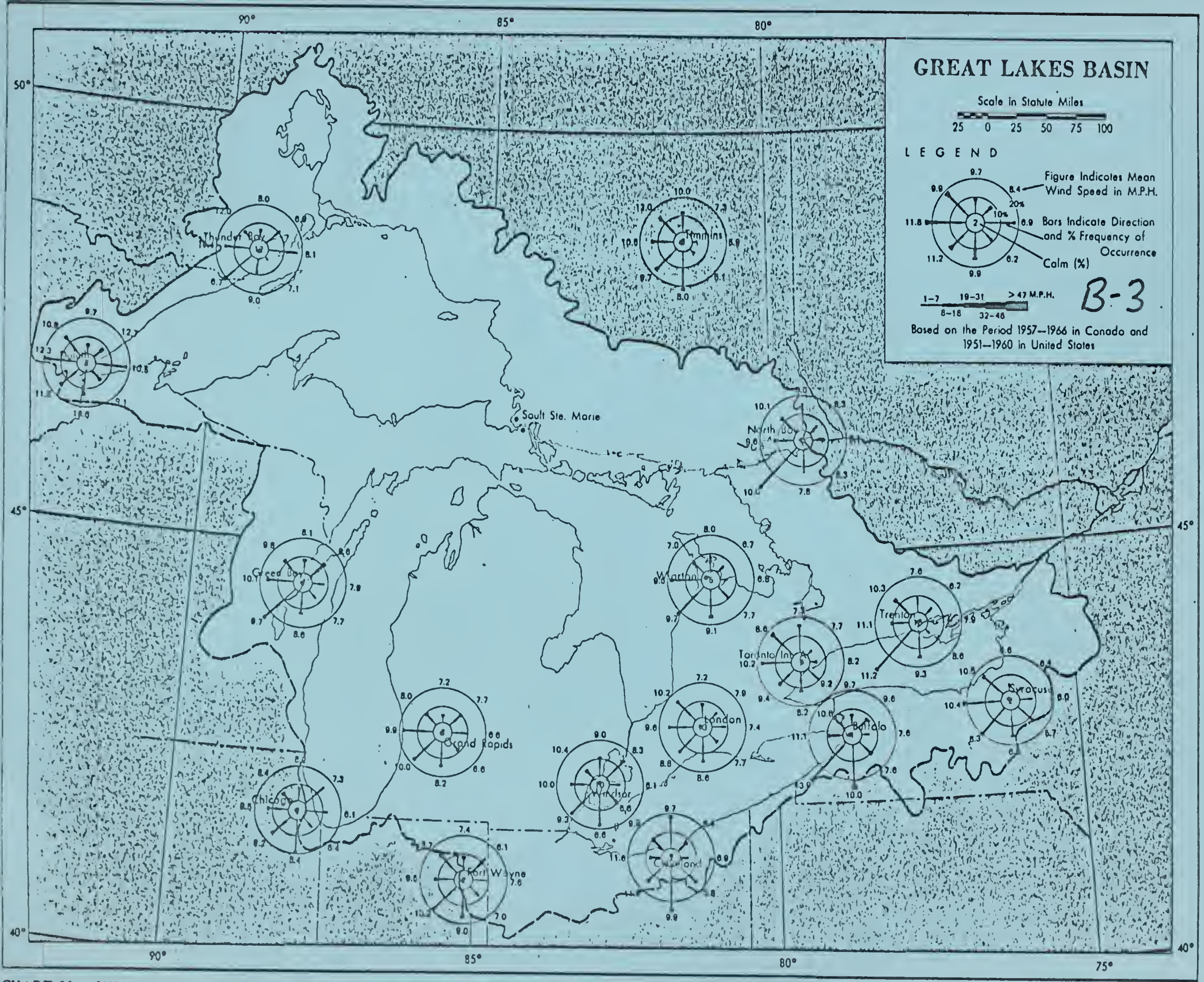


CHART 56 – JULY WIND ROSES FOR SELECTED AIRPORT STATIONS. Summer winds are generally more variable in direction than winter winds, but less variable in speed. Along the lakeshore the incidence of calms is less than at stations inland due to lake breeze circulations. These local winds have a summertime frequency of 35 percent and may penetrate 20 to 25 miles inland.

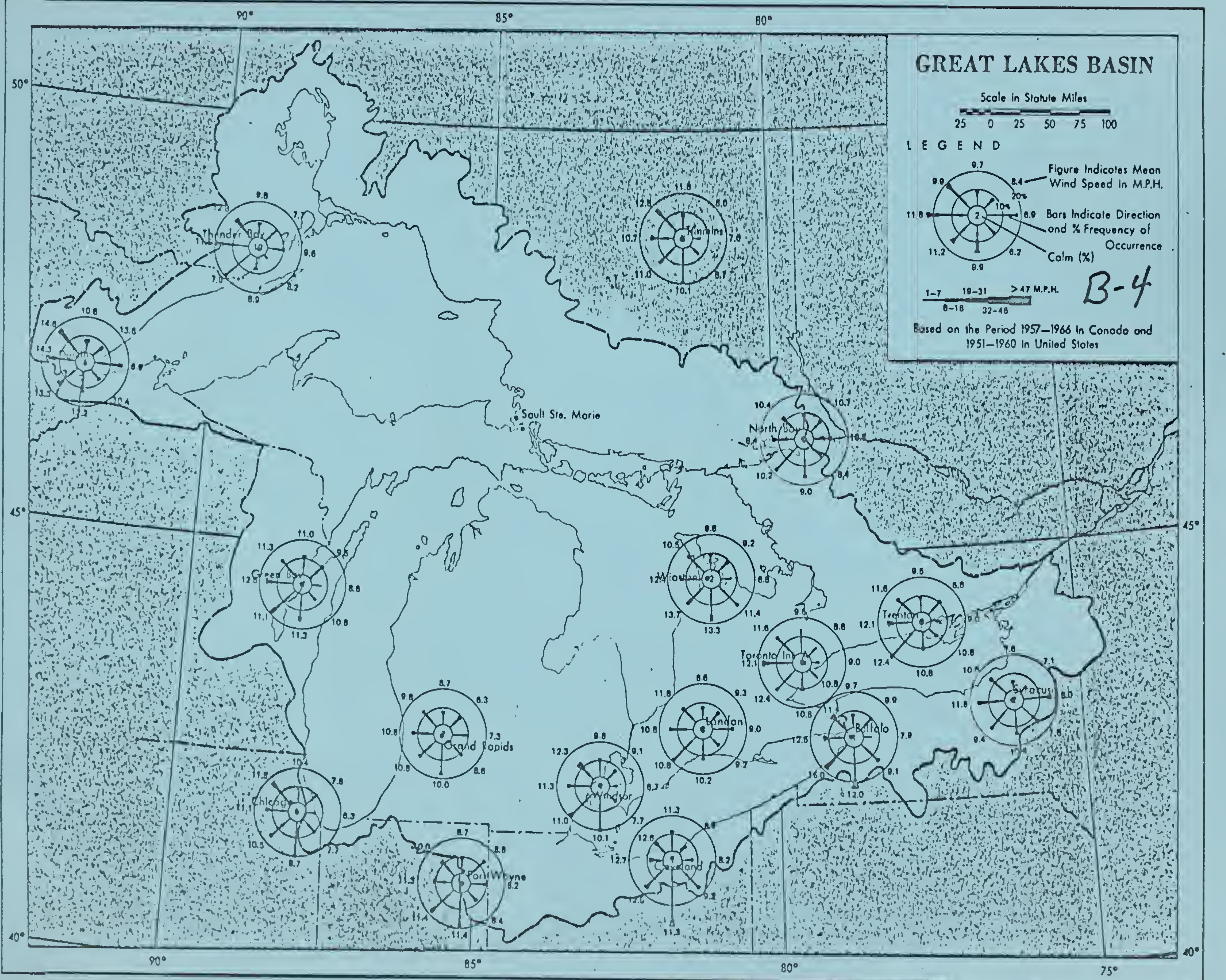
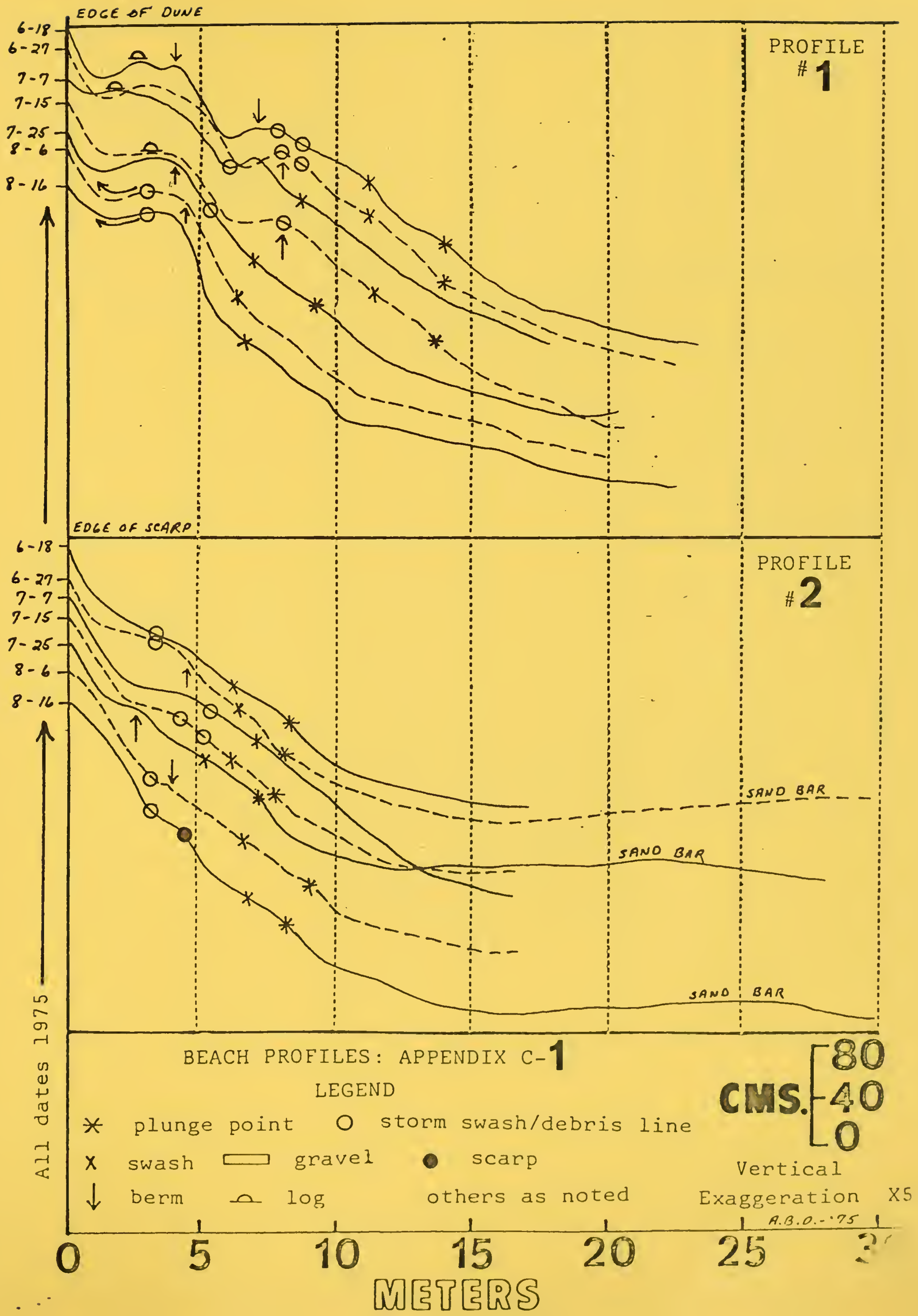
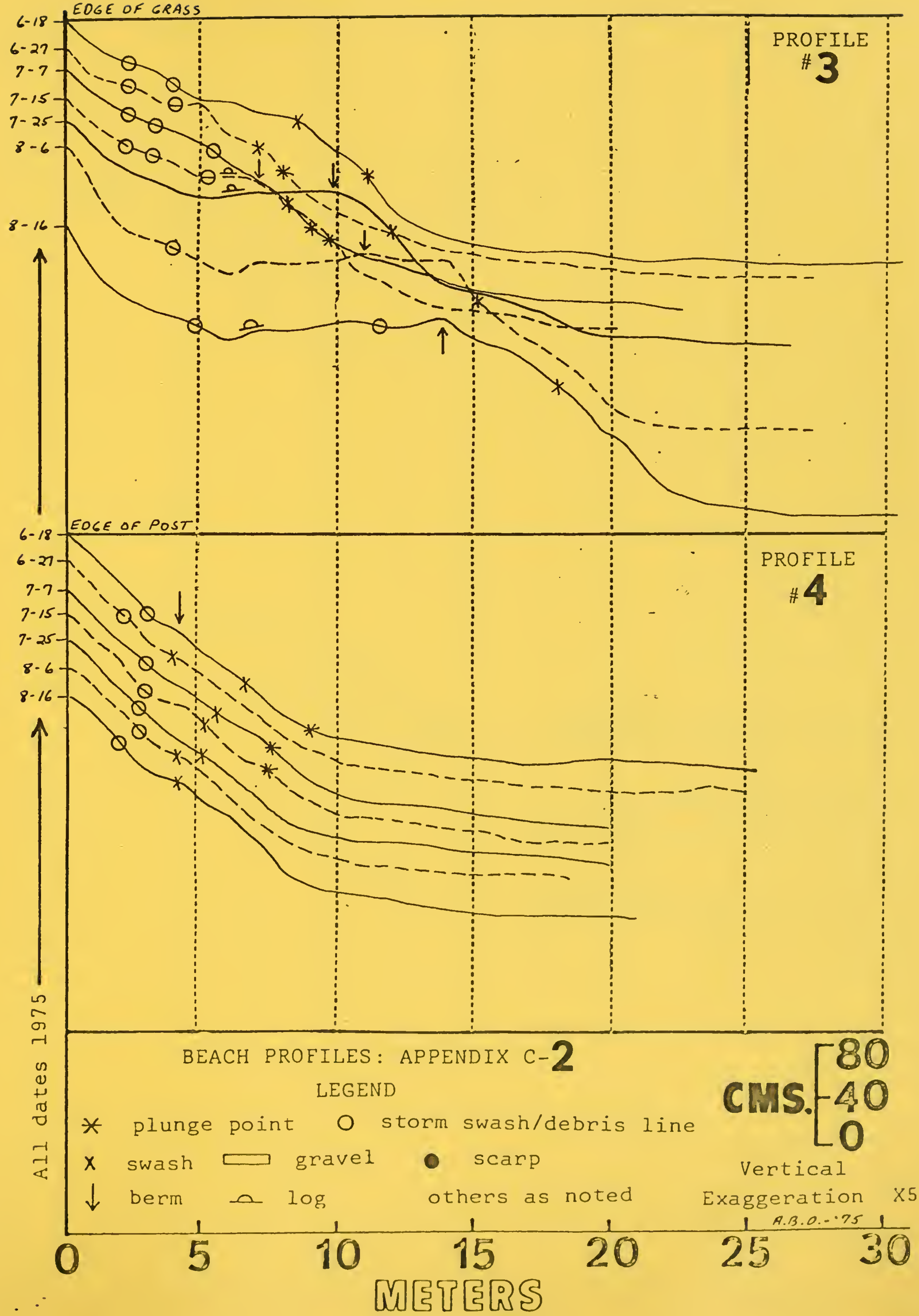
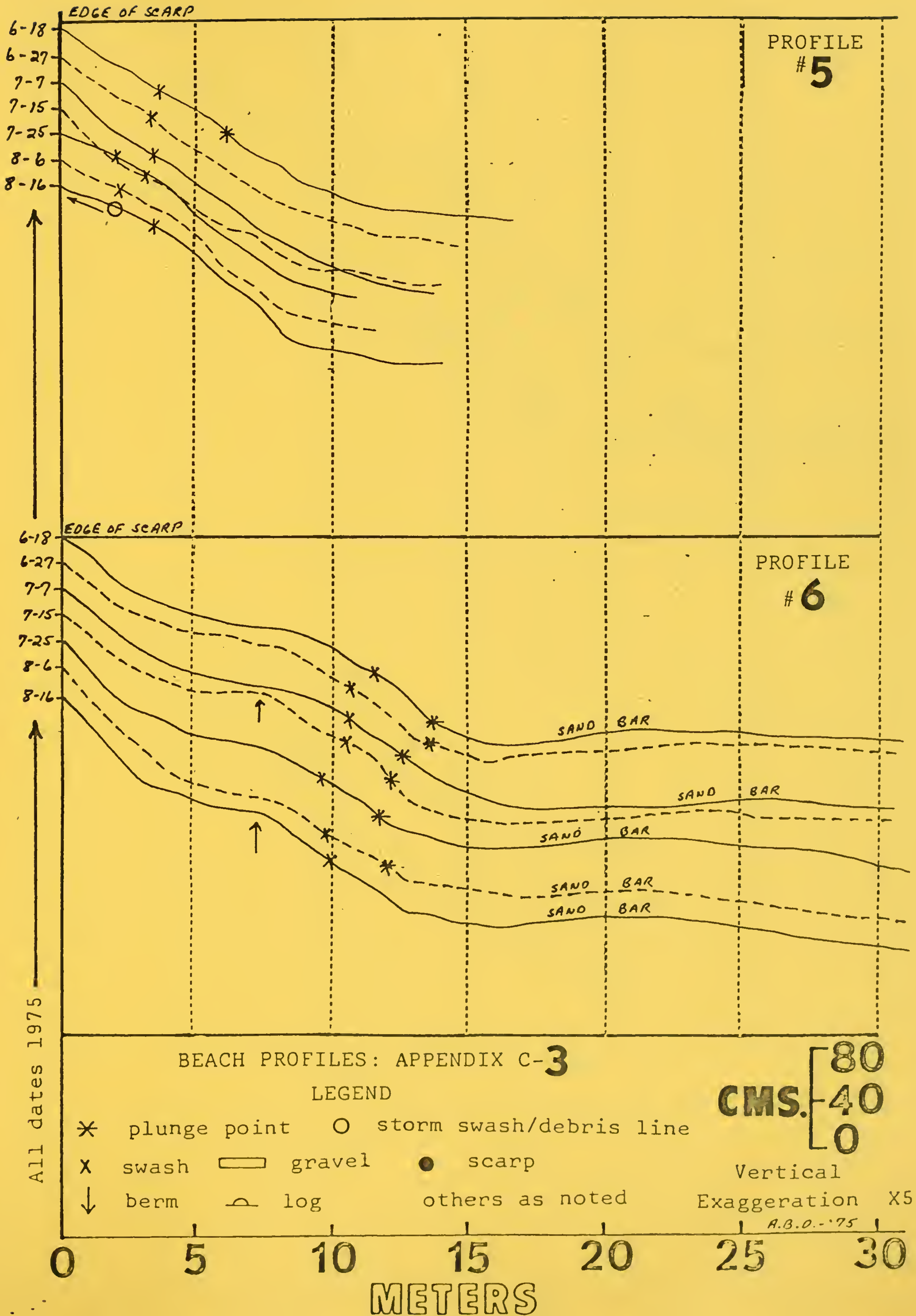


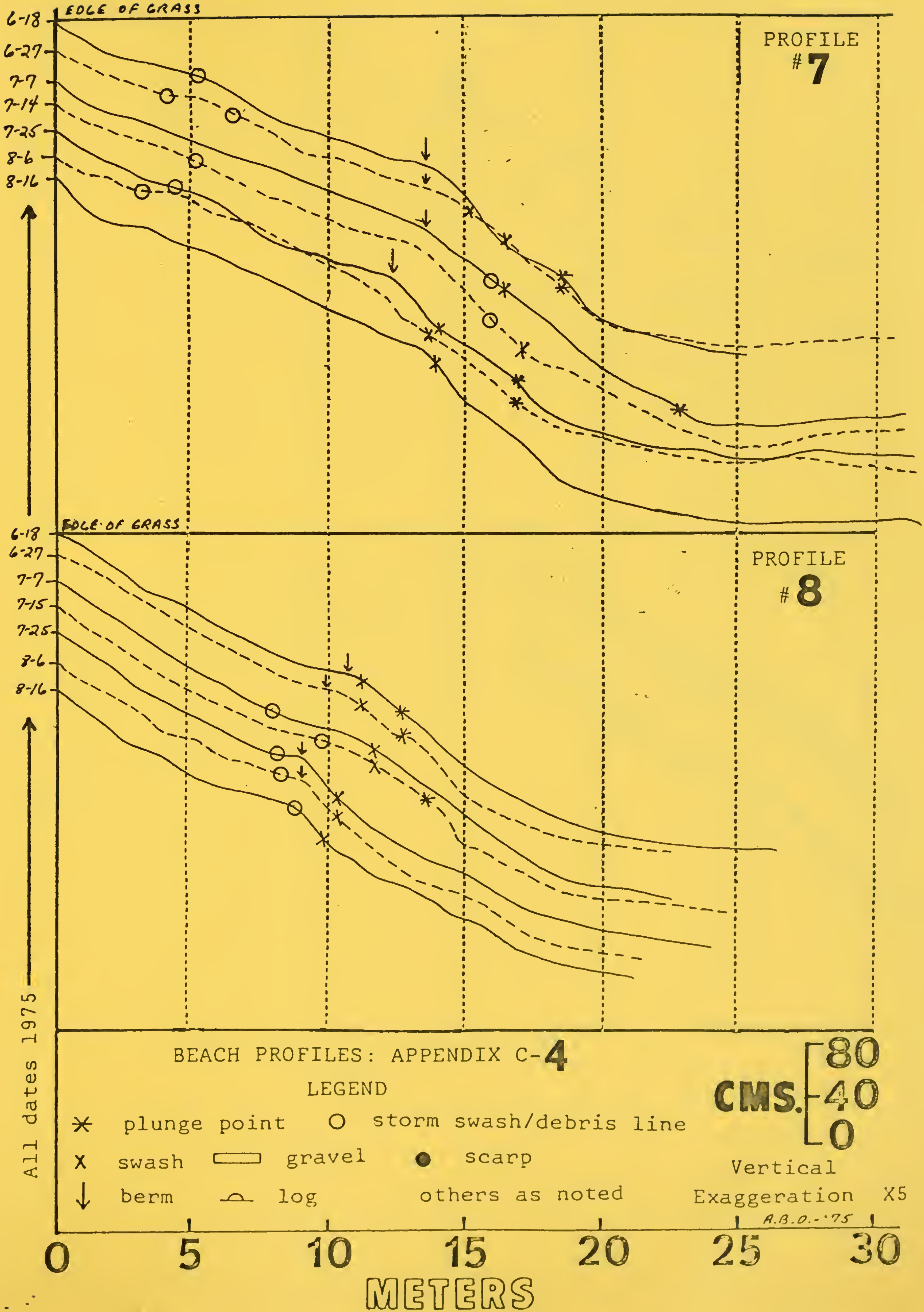
CHART 57 – OCTOBER WIND ROSES FOR SELECTED AIRPORT STATIONS. Winds in October reflect the transition between summer and winter in both speed and direction. The increase in cyclonic activity and the large thermal differences between air and water contribute to the high mean wind speed.

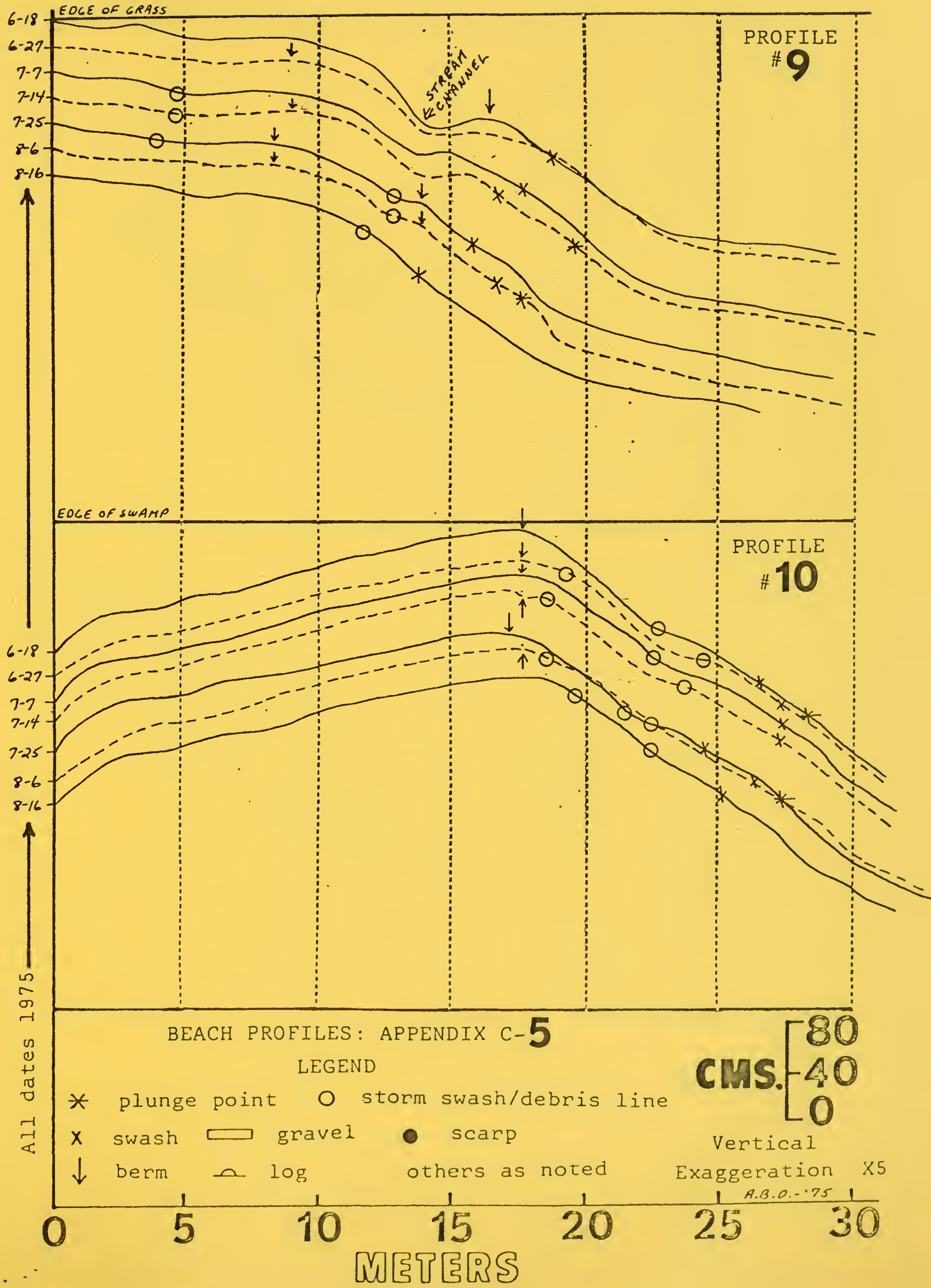
APPENDIX C


EDGE OF DUNE
PROFILE #1
6-18
6-27
7-7
7-15
7-25
8-6
8-16
EDGE OF SCARP
PROFILE #2
6-18
6-27
7-7
7-15
7-25
8-6
8-16
SAND BAR
SAND BAR
SAND BAR
All dates 1975
BEACH PROFILES: APPENDIX C-1
LEGEND
plunge point
storm swash/debris line
swash
gravel
scarp
berm
log
others as noted
CMS. 80 40 0
Vertical Exaggeration X5
A.B.O.-'75
0
5
10
15
20
25
METERS


EDGE OF GRASS
6-18
6-27
7-7
7-15
7-25
8-6
8-16
PROFILE
#3
EDGE OF POST
6-18
6-27
7-7
7-15
7-25
8-6
8-16
PROFILE
#4
All dates 1975
BEACH PROFILES: APPENDIX C-2
LEGEND
plunge point
storm swash/debris line
swash
gravel
scarp
berm
log
others as noted
CMS.
80
40
0
Vertical
Exaggeration X5
A.B.O.-'75
0
5
10
15
20
25
30
METERS


EDGE OF SCARP
6-18
6-27
7-7
7-15
7-25
8-6
8-16
PROFILE
#5
EDGE OF SCARP
PROFILE
#6
SAND BAR
SAND BAR
SAND BAR
SAND BAR
SAND BAR
All dates 1975
BEACH PROFILES: APPENDIX C-3
LEGEND
plunge point
O storm swash/debris line
X swash
gravel
scarp
berm
log
others as noted
CMS.
80
40
0
Vertical
Exaggeration X5
A.B.O.-'75
0
5
10
15
20
25
30
METERS


EDGE OF GRASS
6-18
6-27
7-7
7-14
7-25
8-6
8-16
PROFILE #7
EDGE OF GRASS
6-18
6-27
7-7
7-15
7-25
8-6
8-16
PROFILE #8
All dates 1975
BEACH PROFILES: APPENDIX C-4
LEGEND
plunge point
storm swash/debris line
X swash
gravel
scarp
berm
log
others as noted
CMS.
80
40
0
Vertical Exaggeration X5
A.B.O.-'75
0
5
10
15
20
25
30
METERS



BEACH PROFILES: APPENDIX C-5

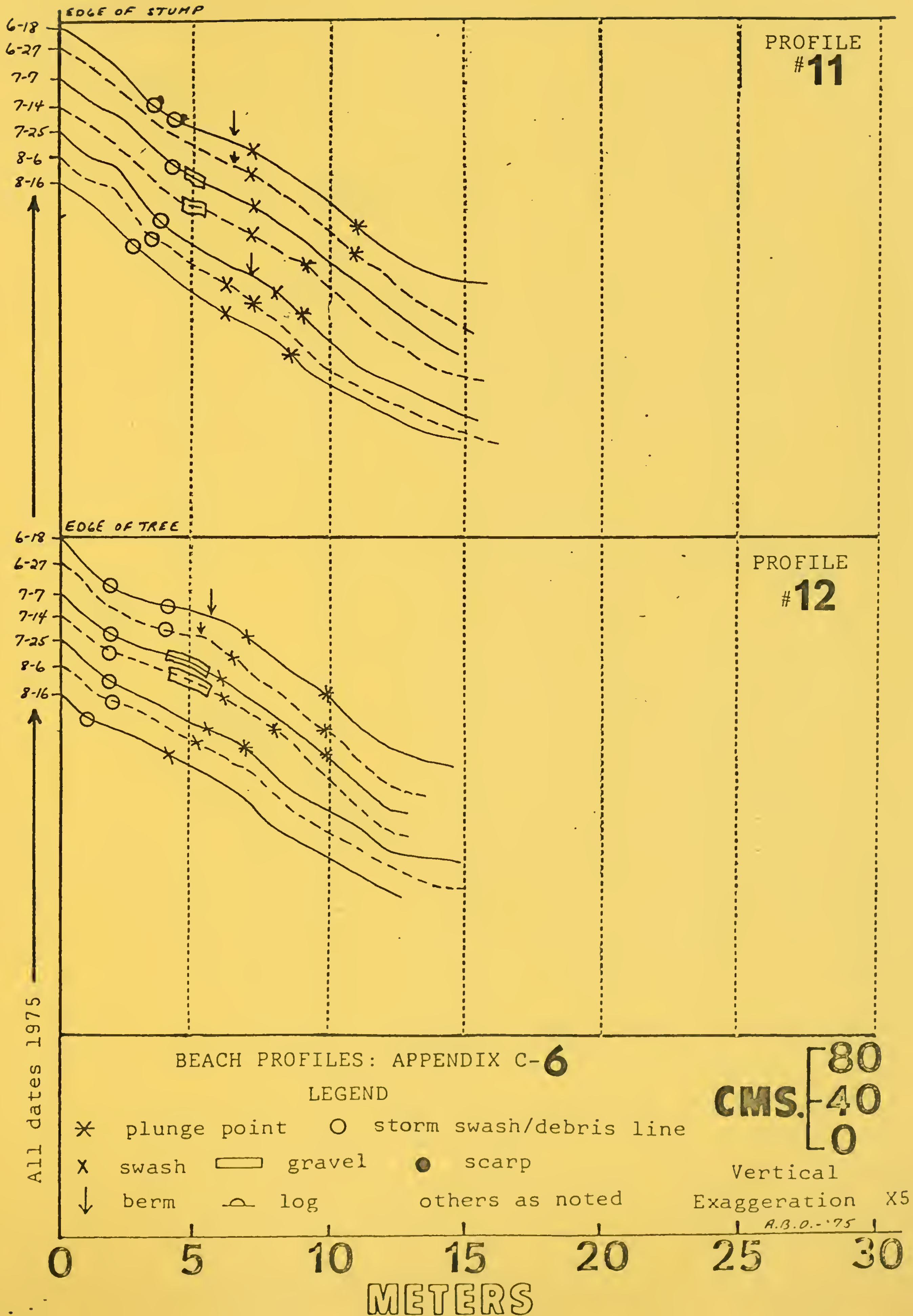
LEGEND

✳ plunge point ○ storm swash/debris line

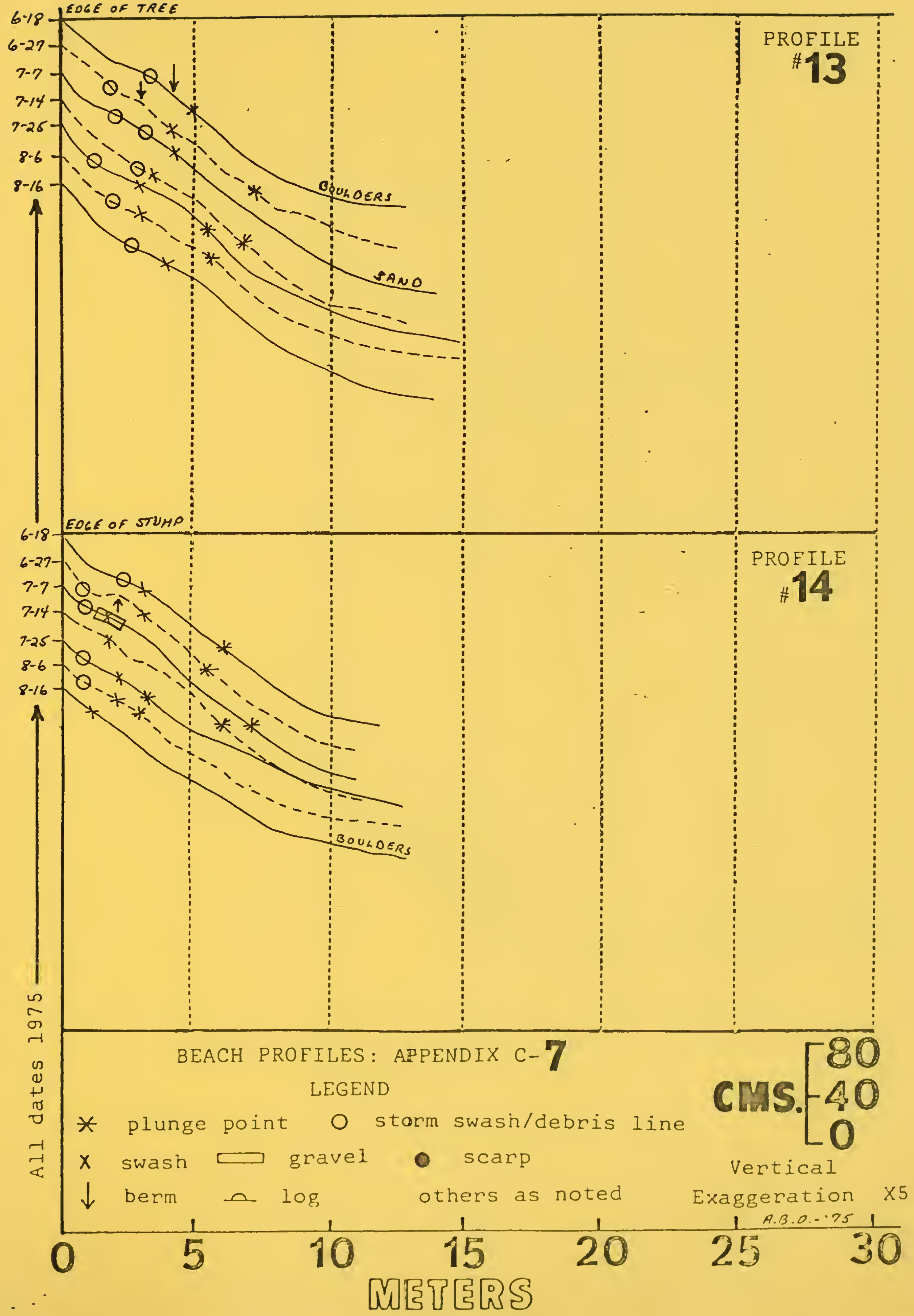
x swash ▭ gravel ● scarp

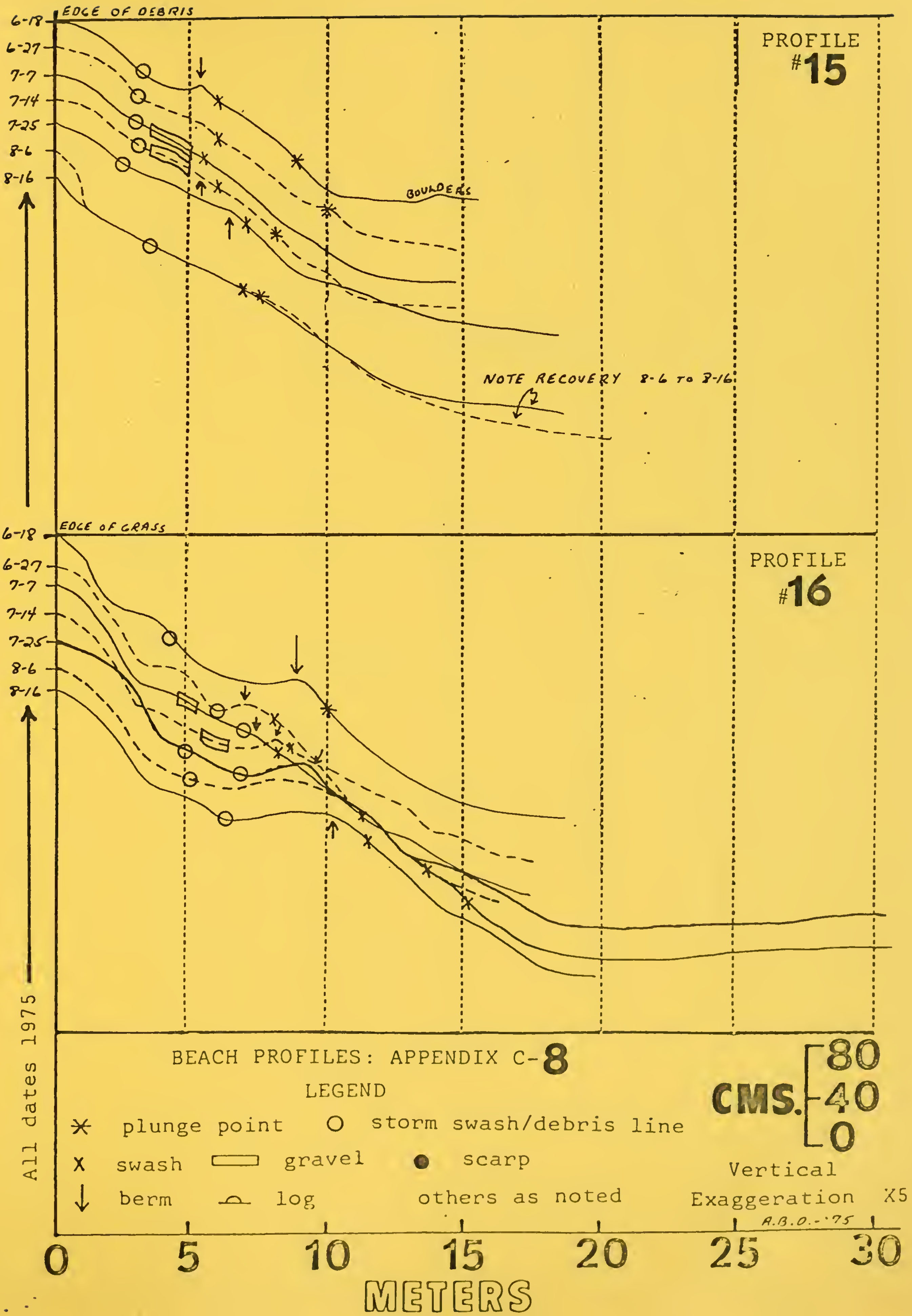
↓ berm ⌓ log others as noted

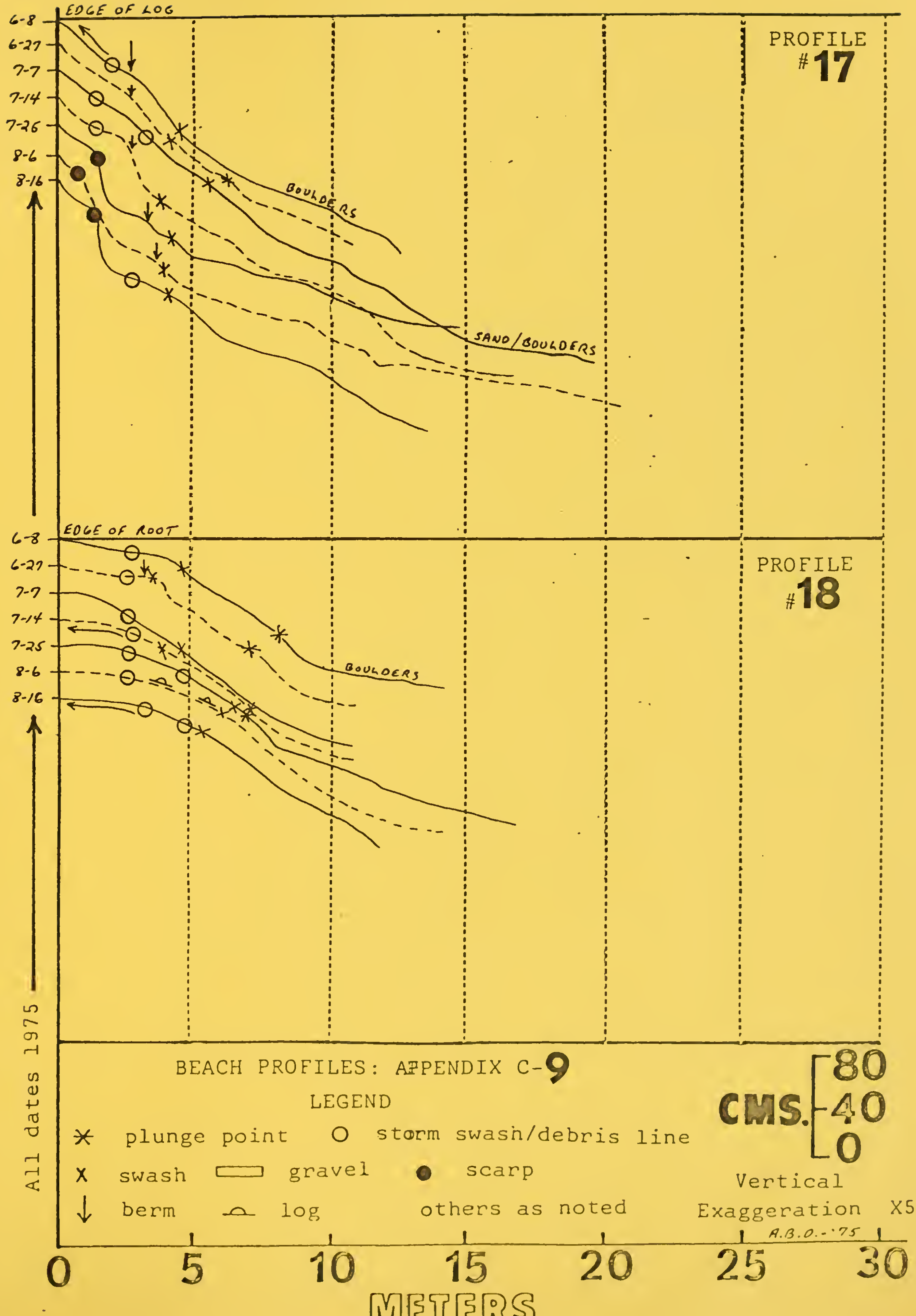
Vertical Exaggeration X5



EDGE OF STUMP
6-18
6-27
7-7
7-14
7-25
8-6
8-16
PROFILE #11
EDGE OF TREE
6-18
6-27
7-7
7-14
7-25
8-6
8-16
PROFILE #12
All dates 1975
BEACH PROFILES: APPENDIX C-6
LEGEND
plunge point
storm swash/debris line
swash
gravel
scarp
berm
log
others as noted
CMS.
80
40
0
Vertical Exaggeration X5
A.B.O.-'75
0
5
10
15
20
25
30
METERS


EDGE OF TREE
6-18
6-27
7-7
7-14
7-26
8-6
8-16
PROFILE #13
BOULDERS
SAND
EDGE OF STUMP
6-18
6-27
7-7
7-14
7-25
8-6
8-16
PROFILE #14
BOULDERS
All dates 1975
BEACH PROFILES: APPENDIX C-7
LEGEND
plunge point
storm swash/debris line
swash
gravel
scarp
berm
log
others as noted
CMS.
80
40
0
Vertical Exaggeration X5
A.B.O.-'75
0
5
10
15
20
25
30
METERS


EDGE OF DEBRIS
6-18
6-27
7-7
7-14
7-25
8-6
8-16
PROFILE
#15
BOULDERS
NOTE RECOVERY 8-6 TO 8-16
EDGE OF GRASS
6-18
6-27
7-7
7-14
7-25
8-6
8-16
PROFILE
#16
All dates 1975
BEACH PROFILES: APPENDIX C-8
LEGEND
plunge point
storm swash/debris line
swash
gravel
scarp
berm
log
others as noted
CMS.
80
40
0
Vertical Exaggeration X5
A.B.O.-'75
0
5
10
15
20
25
30
METERS



BEACH PROFILES: APPENDIX C-9

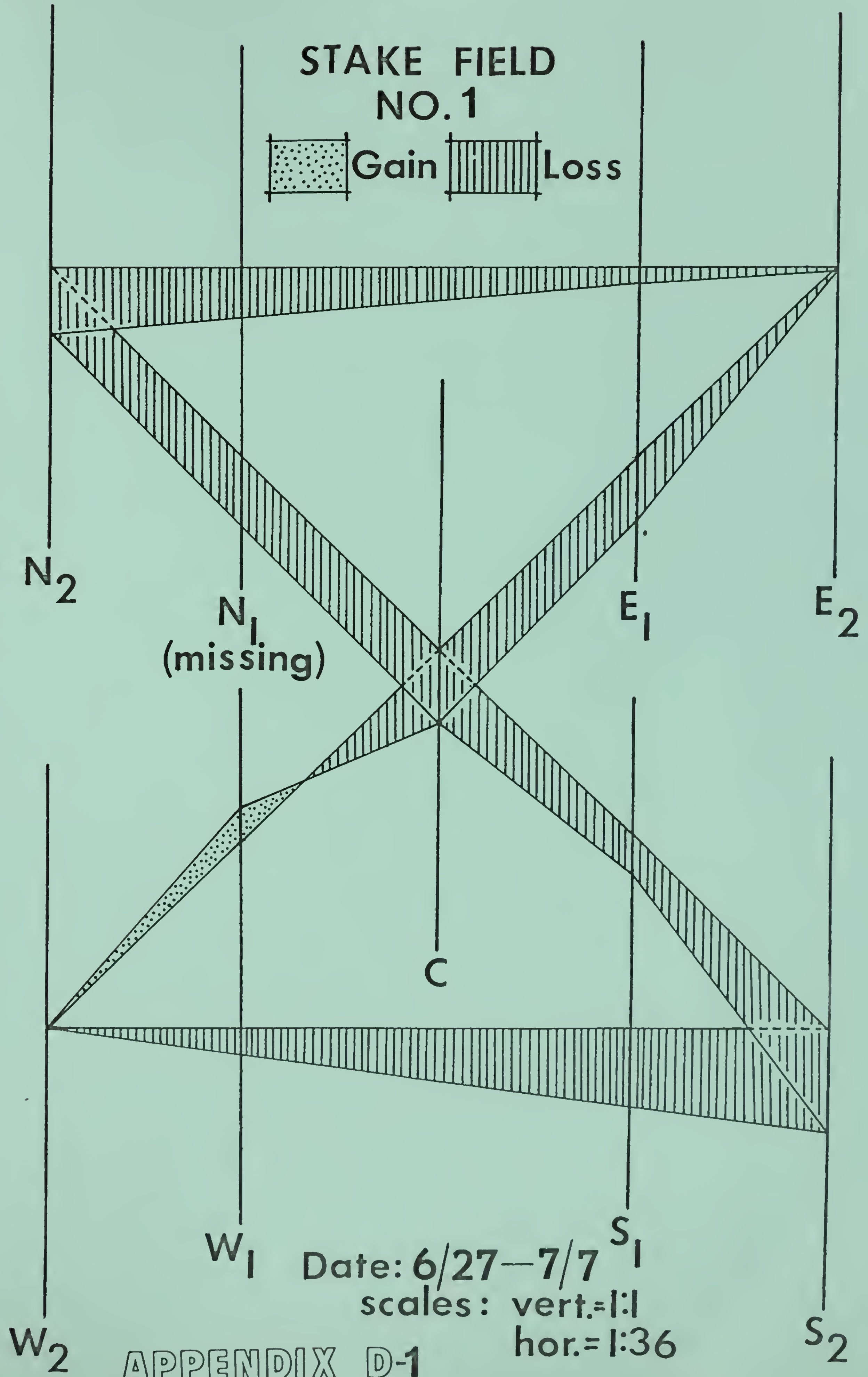
LEGEND

plunge point ○ storm swash/debris line

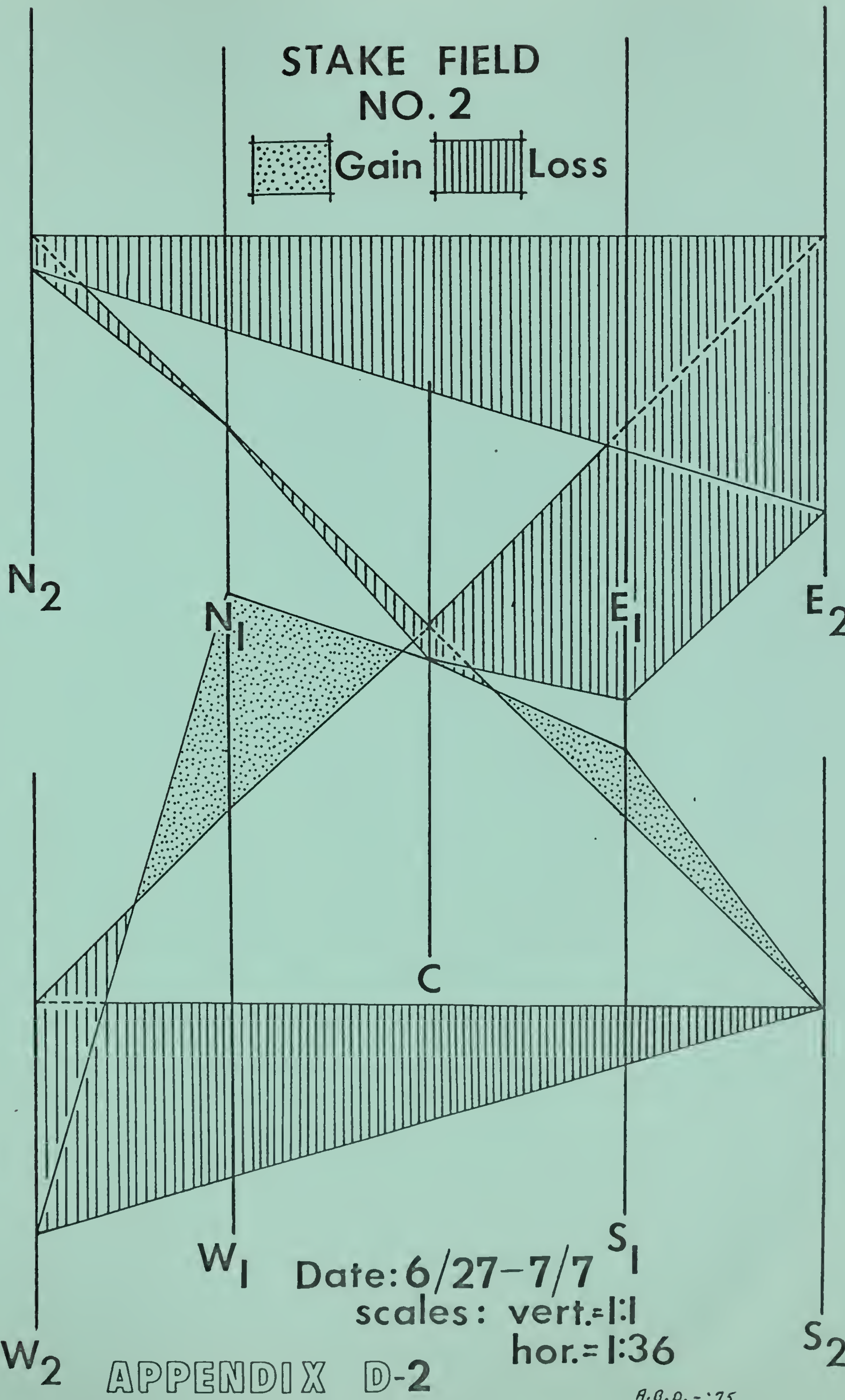
X swash gravel ● scarp

berm log others as noted

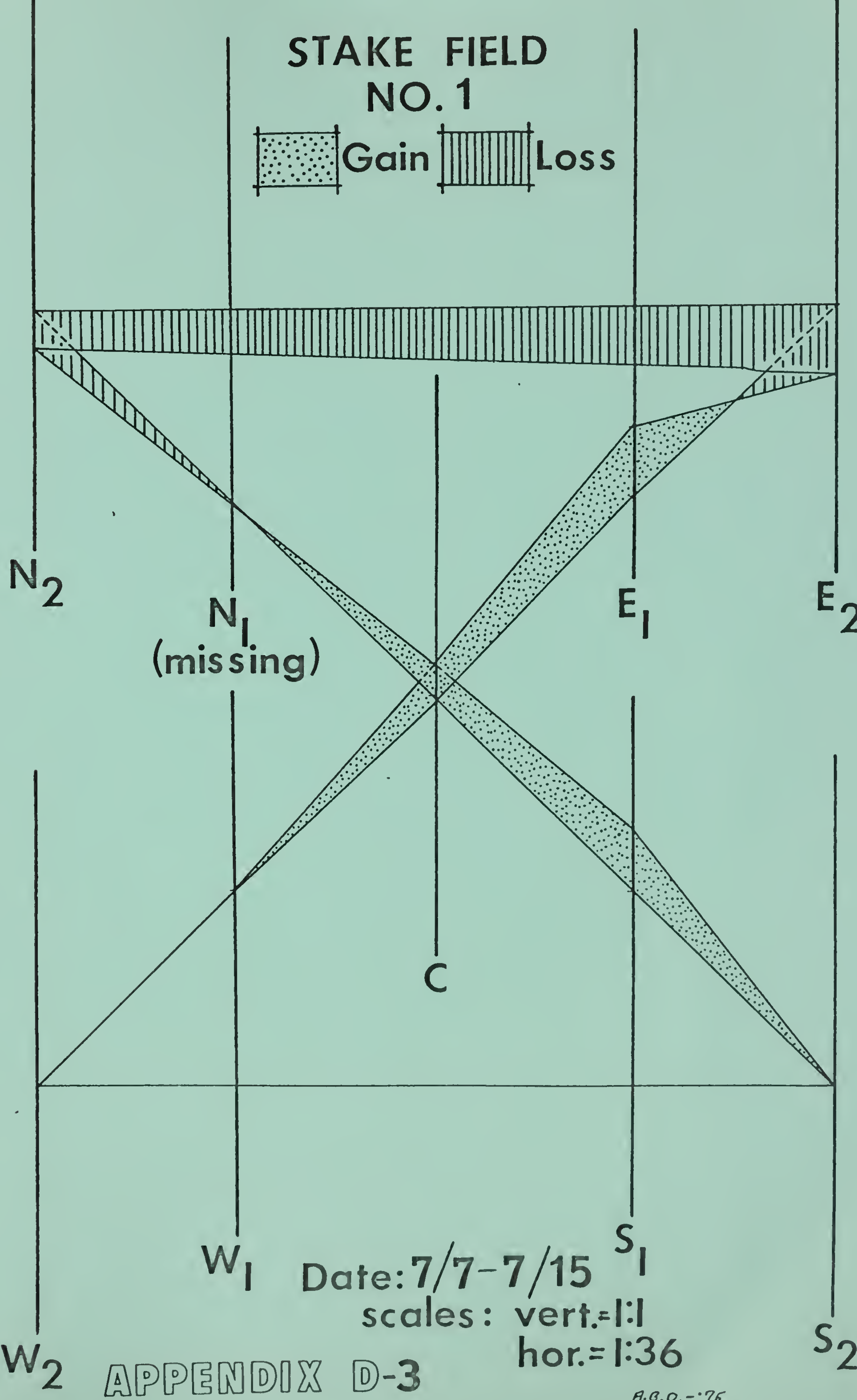
APPENDIX D


STAKE FIELD
NO. 1
Gain
Loss
N2
N1
(missing)
E1
E2
C
W1
S1
W2
S2
Date: 6/27—7/7
scales: vert.=1:1
hor.=1:36
A.B.D.-'75

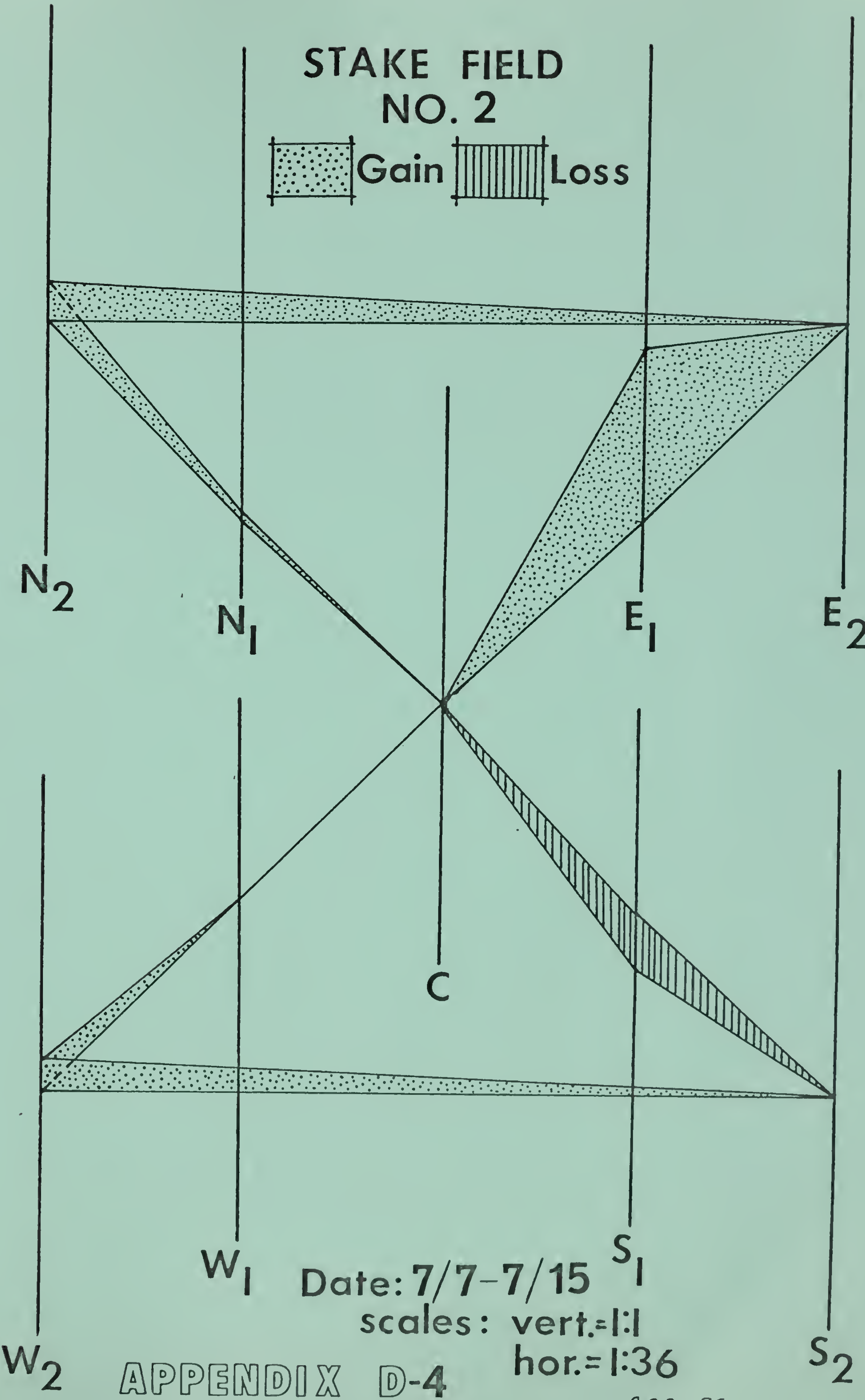
APPENDIX D-1


STAKE FIELD
NO. 2
Gain
Loss
N_2
N_1
E_1
E_2
C
W_1
S_1
W_2
S_2
Date: 6/27–7/7
scales: vert.=1:1
hor.=1:36
A.B.D. – '75

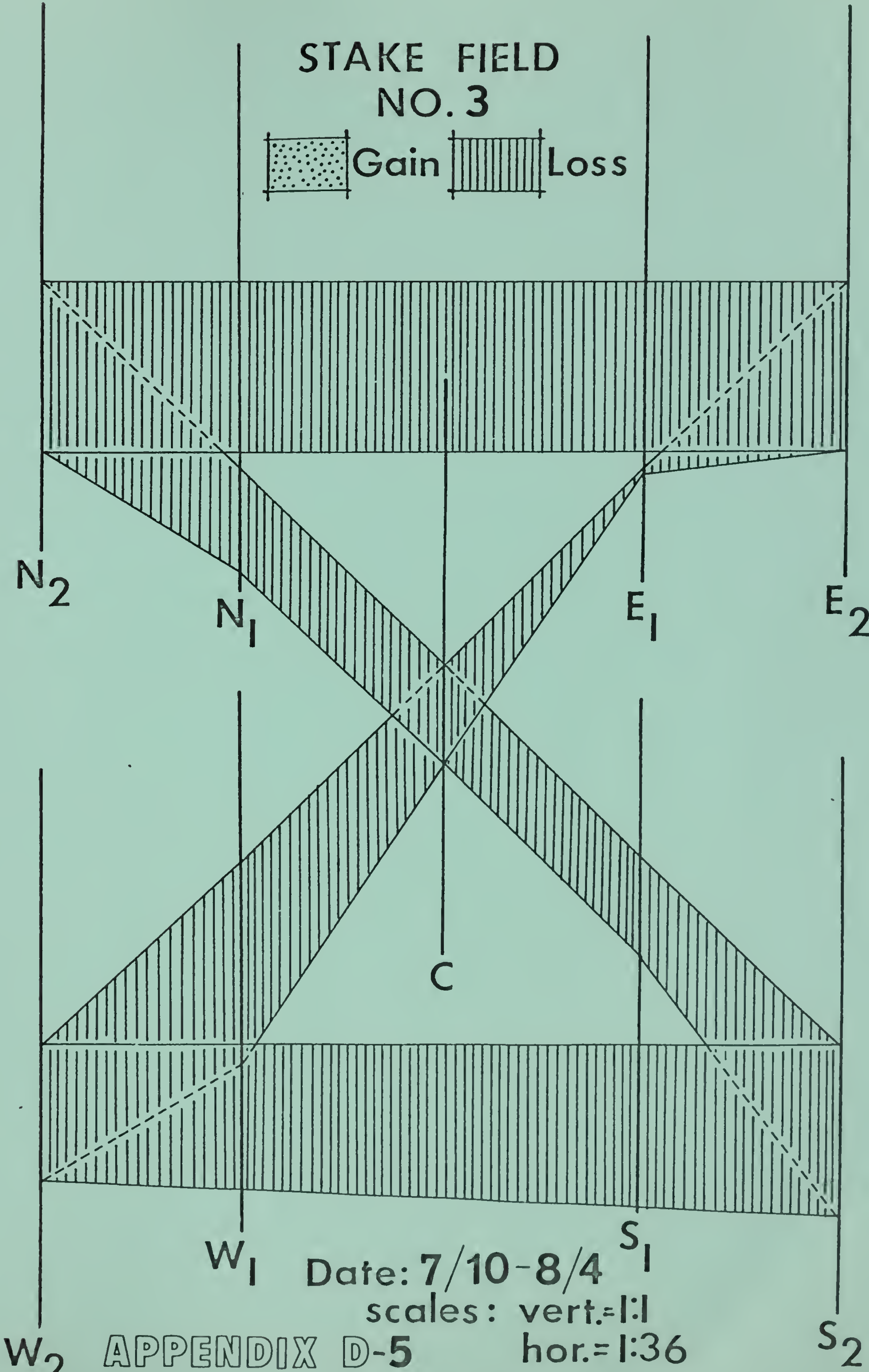
APPENDIX D-2


STAKE FIELD
NO. 1
Gain
Loss
N2
N1
(missing)
E1
E2
C
W1
S1
W2
S2
Date: 7/7–7/15
scales: vert.=1:1
hor.=1:36
A.B.O.–'76

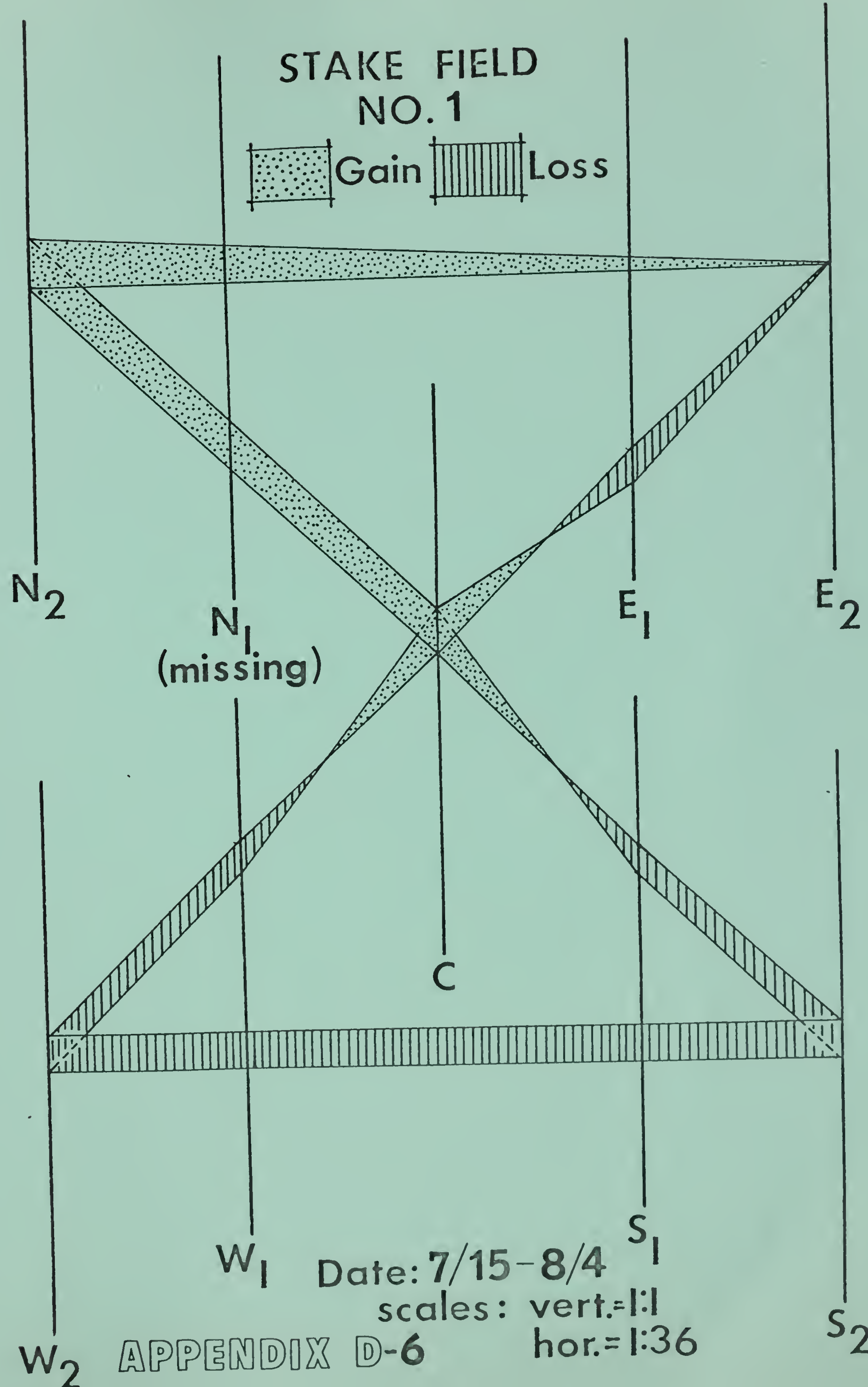
APPENDIX D-3


STAKE FIELD
NO. 2
Gain
Loss
N2
N1
E1
E2
C
W1
S1
W2
S2
Date: 7/7–7/15
scales: vert.=1:1
hor.=1:36
A.B.D. - '75

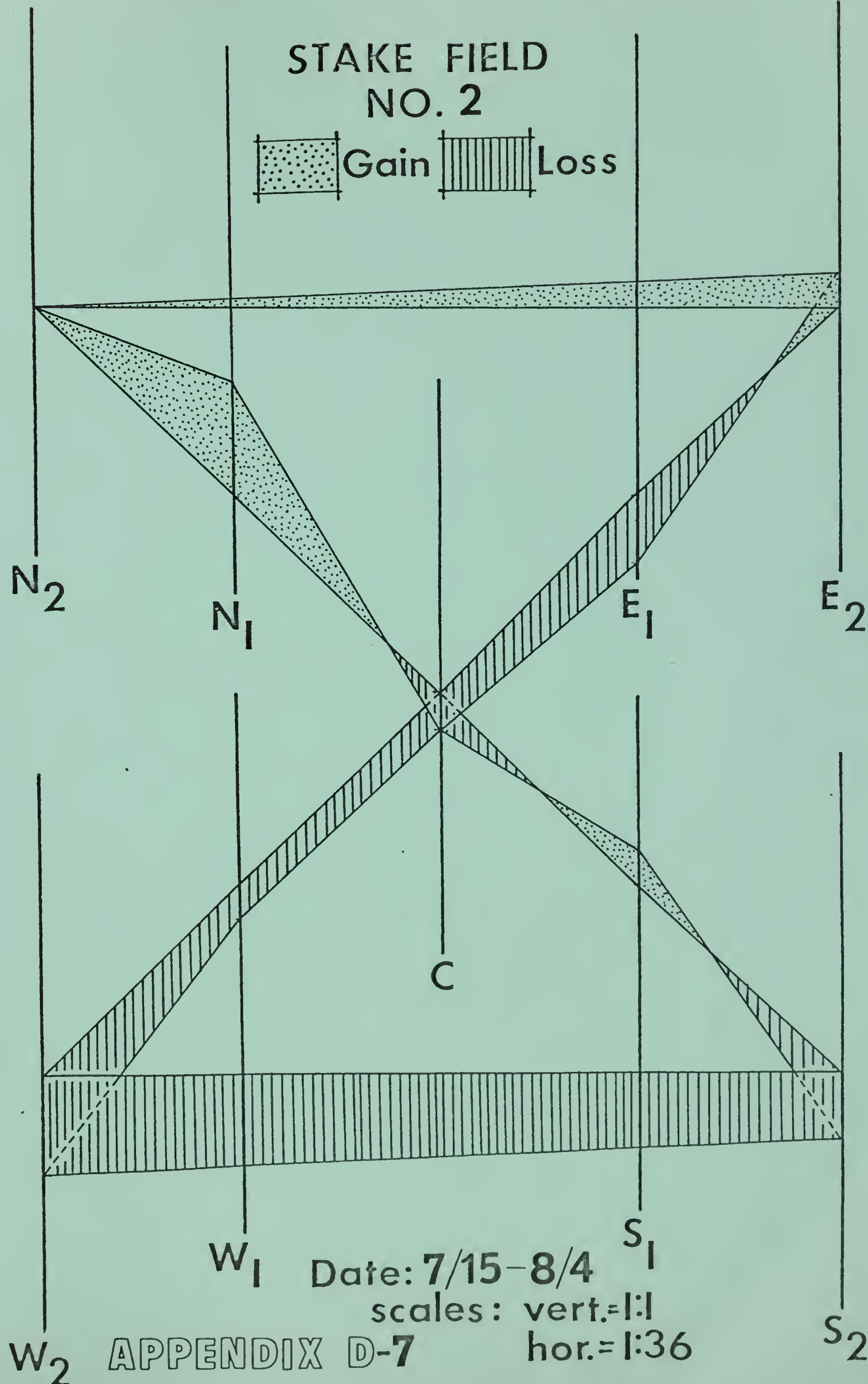
APPENDIX D-4


STAKE FIELD
NO. 3
Gain
Loss
N2
N1
E1
E2
C
W1
S1
W2
S2
Date: 7/10-8/4
scales: vert.=1:1
hor.=1:36

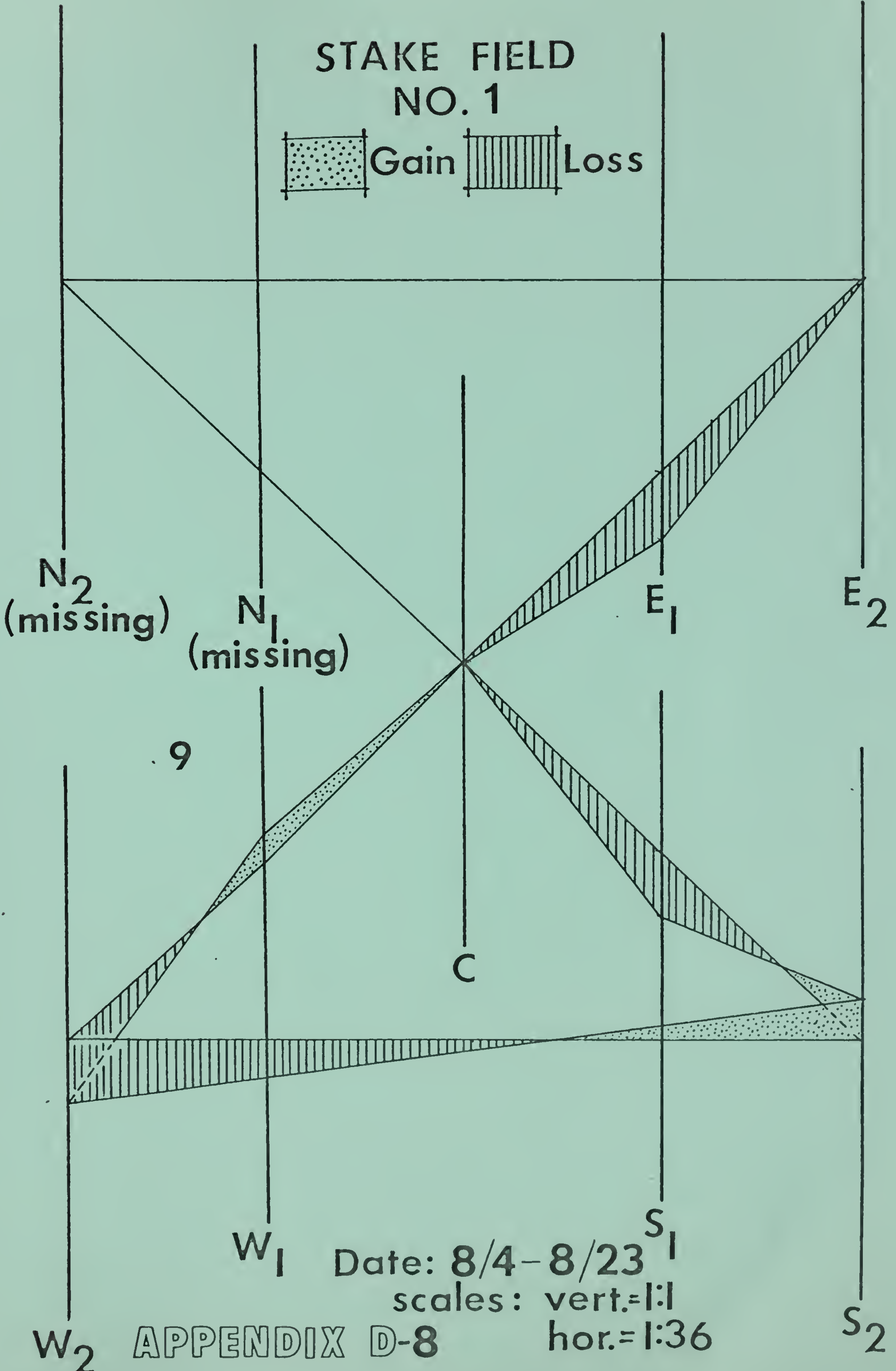
APPENDIX D-5


STAKE FIELD
NO. 1
Gain
Loss
N_2
N_1
(missing)
E_1
E_2
C
W_1
S_1
W_2
S_2
Date: 7/15–8/4
scales: vert.=1:1
hor.=1:36

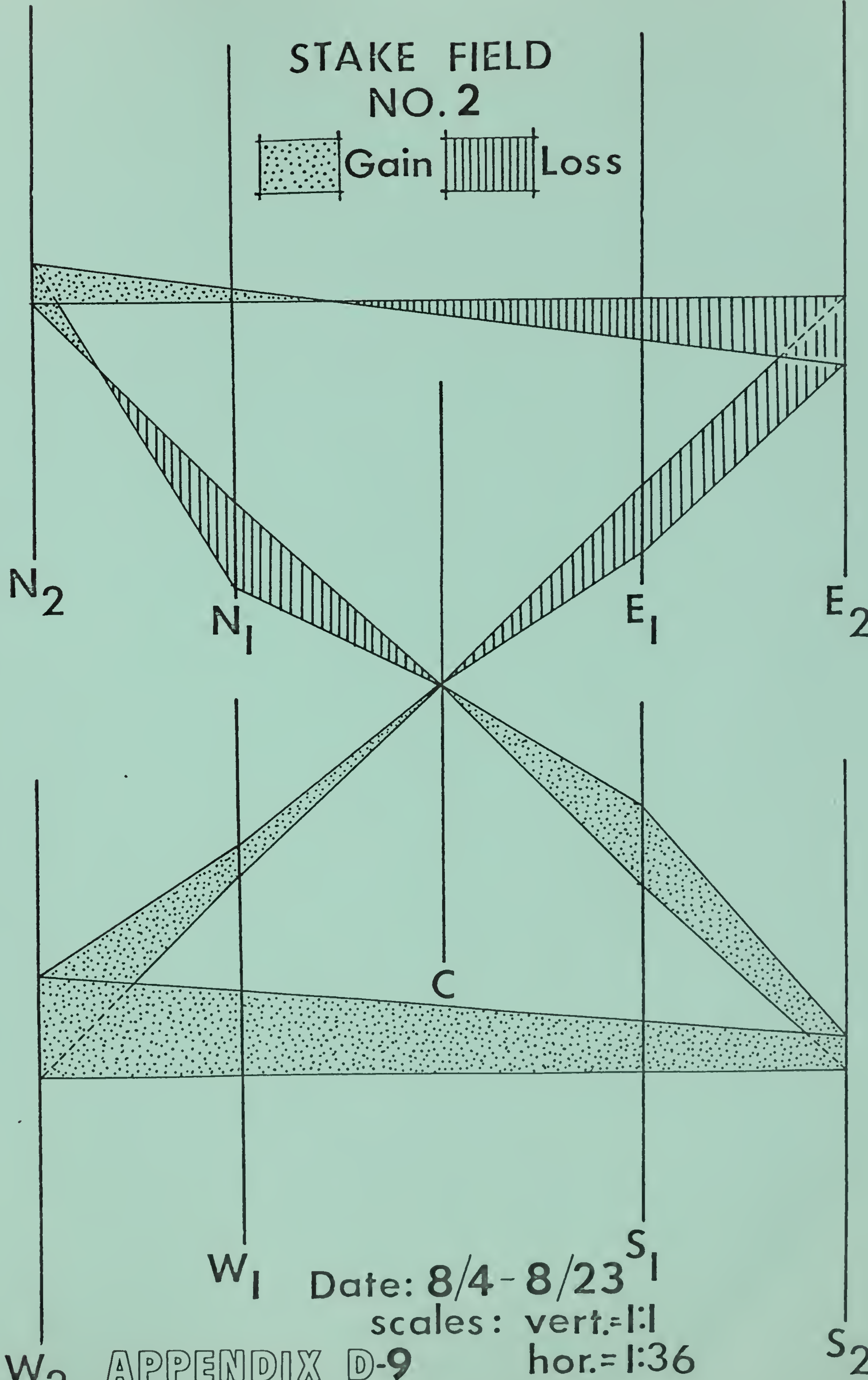
APPENDIX D-6


STAKE FIELD
NO. 2
Gain
Loss
N2
N1
E1
E2
C
W1
S1
W2
S2
Date: 7/15–8/4
scales: vert.=1:1
hor.=1:36

APPENDIX D-7


STAKE FIELD
NO. 1
Gain
Loss
N2
(missing)
N1
(missing)
E1
E2
9
C
W1
S1
W2
S2
Date: 8/4–8/23
scales: vert.=1:1
hor.=1:36

APPENDIX D-8



STAKE FIELD
NO. 2
Gain
Loss
N_2
N_1
E_1
E_2
C
W_1
S_1
W_2
S_2
Date: 8/4 - 8/23
scales: vert.=1:1
hor.=1:36

APPENDIX D-9

APPENDIX E

APPENDIX E

Checklist of Periphyton Organisms*

Phylum Chrysophyta

- *Acnanthes lanceolata*
  - *microcephala*
- *Amphiprora ornata*
- *Amphora ovalis*
- *Asterionella formosa*
- *Ceratoneis arcus*
- *Cocconeis flexella*
  - *pediculus*
  - *placentula*
- *Cyclotella antiqua*
  - *bodanica*
- *Cymatopleura solea*
- *Cymbella cistula*
  - *lanceolata*
  - *leptoceras*
  - *parva*
  - *prostrata*
  - *ventricosa*
- *Denticula thermalis*
- *Diatoma hiemale*
  - *vulgare*
- *Dinobryon sertularia*
- *Diploneis puella*
- *Epithemia turgida*
- *Eunotia monodan*
  - *pectinolis*
- *Fragilaria capucina*
  - *crontenesis*
- *Frustulia viridula*
- *Gomphonema angustatum*
  - *constrictum*
  - *geminatum*
  - *gracile*
  - *olivaceum*
- *Gyrosigma*
- *Melosira granulata*
  - *varians*
- *Navicula dicephala*
  - *oblonga*
  - *pupula*
  - *radiosa*
  - *reinhardtii*
  - *tuscula*
- *Nitzschia denticula*
  - *dissipata*
  - *hungarica*
  - *linearis*
  - *palea*
  - *vermicularis*
- *Pinnularia cardinalis*
  - *major*
  - *viridis*
- *Rhizosolenia eriensis*
- *Rhoicosphenia curvata*
- *Stauroneis anceps*
  - *obtusa*
- *Stephanodiscus* sp.
- *Surirella angusta*
  - *linearis*
- *Synedra acus*
  - *rumpens*
  - *ulna*
- *Tabellaria fenestrata*
  - *flocculosa*

Phylum Chlorophyta

- *Actinastrum* sp.
- *Ankistrodesmus* sp.
- *Chlamydomonas* sp.
- *Closterium* sp.
- *Coelastrum* sp.
- *Cosmarium* sp.
- *Maugeotia* sp.
- *Oedogonium* sp.
- *Pediastrum duplex*
- *Pithophora* sp.
- *Scenedesmus obliguus*
  - *quadricauda*
- *Schizomeris leibleinii*
- *Selenastrum* sp.
- *Spirogyra* sp.
- *Staurastrum* sp.
- *Stigeoclonium subsecuntum*
- *Tetradon* sp.
- *Ulothrix tenerrima*
  - *zonata*

Phylum Cyanophyta

- *Anabaena* sp.
- *Anacystis* sp.
- *Aphanothece microspora*
- *Chroococcus minor*
- *Lyngbya martensiana*
- *Merismopedia convoluta*
- *Oscillatoria tenuis*
- *Plectonema wollei*
- *Raphidiopsis* sp.

*Obtained from Nelson, Olson, and Odlaug (1971) and Fox, Odlaug, and Olson (1969).

APPENDIX F

APPENDIX F

Checklist of Phytoplankton Organisms*

Phylum Chlorophyta
- *Crucigenia sp.*
- *Dictyospharium*
- *Eudorina sp.*
- *Microtinium sp.*
- *Pediastrum sp.*
- *Sphaerocystis sp.*
- *Westella sp.*

Phylum Chrysophyta
- *Achnanthes minutissima*
- *Asterionella formosa*
- *Cyclotella glomerata*
- *ocellata*
- *Diatoma elonqatum*
- *Fraqilaria capucina*
- *crotonensis*
- *Melosira islandica*
- *Rhizosolenia eriensis*
- *Stephanodiscus sp.*
- *Synedra nana*
- *Tabellaria flocculosa*

Phylum Cyanophyta
- *Anabaena sp.*
- *Anacystis sp.*
- *Aphanocapsa sp.*
- *Batryococcus sp.*
- *Coccochloris sp.*
- *Oscillatoria sp.*

Phylum Pyrrophyta
- *Ceratium sp.*

*Reported from Western Lake Superior.

APPENDIX G

APPENDIX G

Checklist of Zooplankton Organisms[1]

Actinopoda
- *Difflugia globulosa*

Ciliophora
- *Carchesium*
- *Codonella cratera*

Cladocera
- *Alona guttata*[2,3]
- *Bosmina coregoni*[3]
  - *longirostris*[2,3]
  - *longispina*
- *Ceriodaphnia* sp.
- *Daphnia*[2,3]
  - *dubia*[2,3]
  - *galeata*[2,3]
  - *longispina*[3]
  - *pulex*[3]
  - *retrocurva*
- *Diaphanasoma brachyurum*[3]
- *Eurycercus lamellatus*[2,3]
- *Graptolebris testudinaria*
- *Holopedium gibberum*[2]
- *Leptodora kindtii*[3]
- *Monospilus*[2]
- *Polyphemus pediculus*
- *Simocephalus* sp.

Copepoda
- *Canthocamptus*[2,3]
- *Cyclops bicuspidatus*[2,3]
  - *leuckarti*
  - *vernalis*[2,3]
  - *viridis*
- *Diaptomus ashlandi*[2,3]
  - *minutus*
  - *oregonensis*
  - *sicilis*
- *Epischura lacustris*[2]
- *Limnocalanus macrurus*[2,3]
- *Mesocyclops* sp.
- *Nauplii* sp.[2]
- *Osphranticum labronectum*
- *Senecella calanoides*

Malacostraca
- *Mysis relicta*[3]
- *Pontoporeia affinis*[3]

Rotifera
- *Asplanchna brightwellii*
  - *priodonta*[2,3]
- *Conochilus*[2,3]
- *Cupelopagis*
- *Enteraplea*
- *Epiphanes*[3]
- *Keratella cochlearis*[2,3]
  - *quadrata*
- *Kellicottia longispina*[2,3]
- *Lacinularia*
- *Lecane*[3]
- *Pleosoma*[3]
- *Polyartha trigla*
  - *vulgaris*[2,3]
- *Sinantherina* sp.
- *Synchaeta* sp.[3]
- *Trichocerca* sp.[3]

[1]Reported from Western Lake Superior.

[2]Found in the Fall 1974 Study.

[3]Zooplankton organisms found in Little Sand Bay, Apostle Islands, by this study.

APPENDIX H

APPENDIX H

Checklist of Benthic Organisms[1]

ANNELIDA
- *Hirudinea*
  - *Helobdella*
  - *Piscicola*
- *Oligochaeta*[2,3]
  - *Stylodrilus heringianus*
  - *Limnodrilus claparedianus*
    - *hoffmeisteri*
    - *profundicola*
    - *udekemianus*
  - *Peloscolex superiorensis*
    - *variegatus*
  - *Rhyacodrilus montanus*
  - *Tubifex americanus*
    - *tubifex*
- *Polychaeta*
  - *Manayunkia*
  - *Mercierella*

ARTHROPODA
- *Arachnida*
  - *Hydracarina*[3]
- *Crustacea*
  - *Amphipoda*
    - *Crangonyx*
    - *Gammarus*
    - *Hyalella*
    - *Pontoporeia*[2,3]
  - *Cladocera*
    - *Alona*[3]
    - *Bosmina*[2,3]
    - *Daphnia*[2,3]
    - *Eurycercus*[2,3]
    - *Leptodora*[2,3]
    - *Sida*
  - *Copepoda*
    - *Canthocamptus*[2,3]
    - *Ectocyclops*
    - *Eucyclops*
    - *Limnocalanus*[3]
    - *Mesocyclops*
    - *Paracyclops*
    - *Senecella*
  - *Malacostraca*
    - *Mysis*[3]
  - *Isopoda*
    - *Asellus*[3]
  - *Ostracoda*[3]
- *Insecta*
  - *Collembola*
    - *Podura*[3]
  - *Coleoptera*
    - *Anchytarsus*
  - *Diptera*
    - *Chironomidae*[3]
      - *Chironomus*
      - *Cryptochironomus*
      - *Constempellina*[2]
      - *Heterotrissocladius*
      - *Parachironomus*[2]
      - *Procladius*[2]
      - *Stenochironomus*[2]
      - *Tanytarsus*[2]
      - *Xenochironomus*
    - *Ceratopogonidae*[3]
    - *Ephydridae*[3]
  - *Ephemeroptera*
    - *Ephemera*
    - *Ephoran*
    - *Hexagenia*[3]
    - *Heptagenia*[3]
    - *Siphlonurus*[3]
    - *Neocleon*[3]
  - *Odonata*[2]
  - *Plecoptera*[2]
    - *Isoperla*[3]
  - *Trichoptera*
    - *Cheumatopsyche*[2]
    - *Leptocerus*[2]
    - *Agrypnia*[3]
    - *Lepidostoma*[3]
    - *Oecetis*[3]

Appendix H Continued
Checklist of Benthic Organisms

MOLLUSCA
- *Gastropoda*
  - *Amnicola*[2,3]
  - *Bulimnea*
  - *Campeloma*
  - *Fossaria*
  - *Goniobasis*
  - *Gyralus*
  - *Helisoma*[2]
  - *Lymnea*
  - *Physa*
  - *Pleurocerca*
  - *Pseudosuccinea*
  - *Stagnicola*
- *Peleycypoda*
  - *Anodonta*
  - *Lampsilus*
  - *Pisidium*
  - *Sphaerium*[2]
  - *Valvata*

[1] Reported from Western Lake Superior.

[2] Benthic organisms found in Little Sand Bay in Fall, 1974.

[3] Benthic organisms found in this study.

APPENDIX I

APPENDIX I

Commercial Catch For Little Sand Bay

(Statistical Grid 1308) and adjoining areas (Stat. Grids 1307 and 1309) during the period from 1969 through 1973.

C A T C H B Y S P E C I E S (P o u n d s)

Area and Year	Lake Trout	Lake White-fish	Round White-fish	Lake Herring	Chubs	Smelt	Suckers	Bur-bot
<u>Little Sand Bay and Sand Bay (Lake Superior Grid 1308)</u>								
1969	500	12,375	45	10	5	---	635	54
1970	310	15 061	10,864	32	---	4,302	---	---
1971	---	16,537	7,142	---	---	2,645	---	---
1972	2 174	22,894	---	5	---	1 978	3,400	425
1973	1,140	14,343	3,086	32 249	---	---	2,258	---
<u>Cornucopia, Eagle Island Area (Grid 1307)</u>								
1969	2,344	628	55	5,330	52,195	9,434	1,175	2,465
1970	4,338	557	14	12,431	47,061	4,336	1,500	5,805
1971	3,337	---	4,145	4 775	46 734	8,176	---	---
1972	2,972	4,943	6 485	3 387	26,500	9,019	7,355	50
1973	6,086	19,324	1,683	2,653	24,026	684	4,157	900
<u>Oak, Basswood and Hermit Island Area (Grid 1309)</u>								
1969	1,005	32,846	13	627	3,964	9,459	180	---
1970	2,563	35,146	1,010	1,641	22,278	49 220	500	34
1971	172	68,684	---	612	4 763	17,369	---	---
1972	7,266	65,228	---	19 843	3,534	4,985	1,454	---
1973	7,005	56,207	2,868	261	1,710	2,531	4,996	87