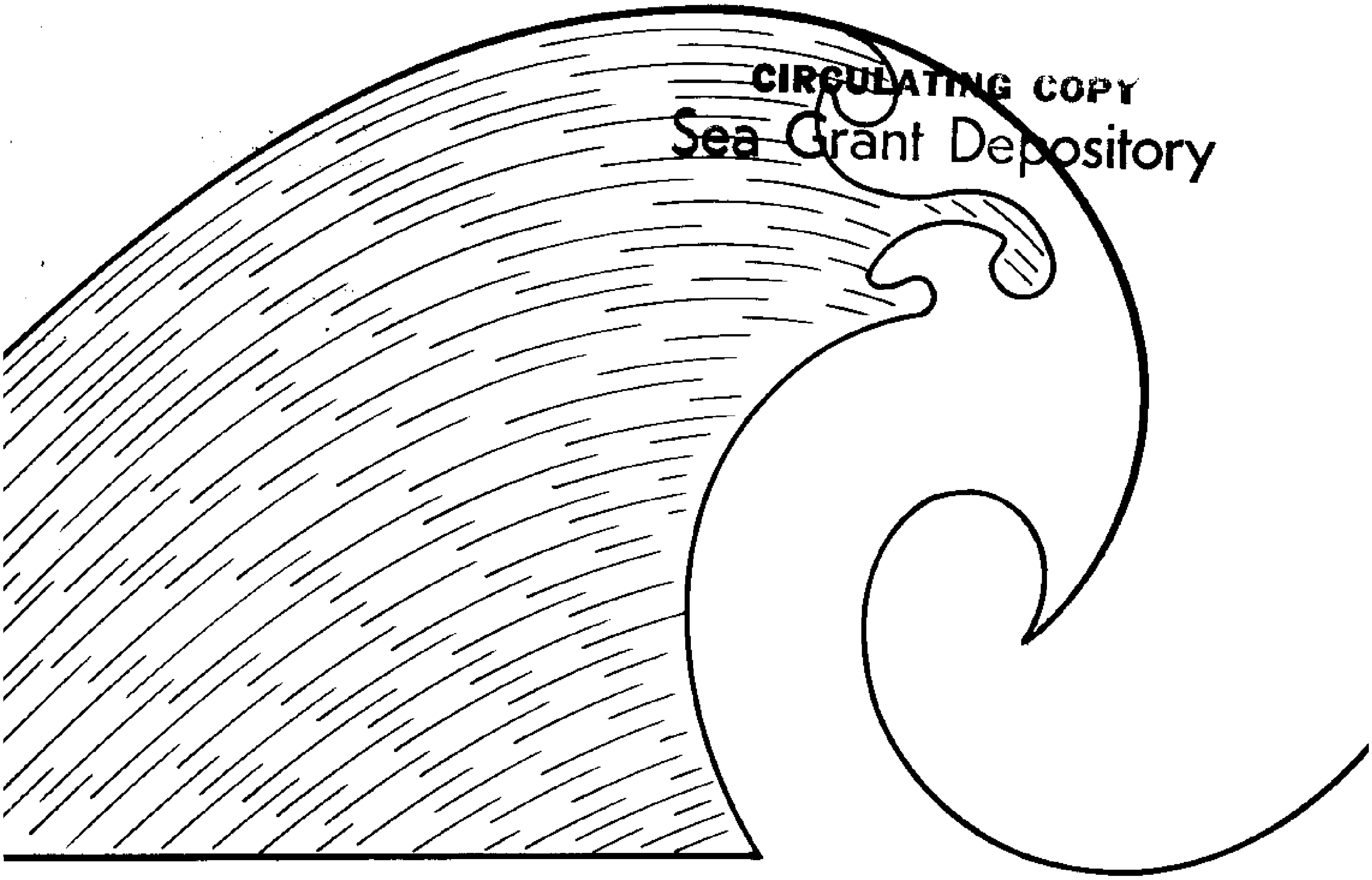
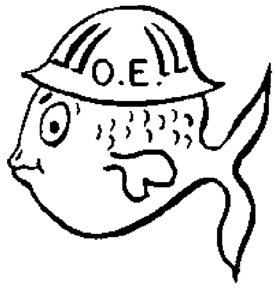


DEPARTMENT OF OCEAN ENGINEERING

SEA GRANT PUBLICATIONS

COLLEGE OF ENGINEERING UNIVERSITY OF RHODE ISLAND

MEMORANDUM NUMBER 1M



TURBIDITY PROFILES OF POINT JUDITH POND and WEST PASSAGE

by
H. Schenck

16 September 1970

MEMORANDUM NUMBER 1M

TURBIDITY PROFILES OF POINT JUDITH POND AND WEST PASSAGE, NARRAGANSETT BAY

by

Hilbert Schenck, Jr.

Prepared for

National Science Foundation

Under

Sea Grant Contract Number GH-99

by

Department of Ocean Engineering

University of Rhode Island

16 September 1970

TABLE OF CONTENTS

1.0 INTRODUCTION

The optical characteristics of a given mass of natural water are of considerable interest and importance when one undertakes to understand and control the mechanics of inshore and estuarian processes. Biological processes in shallow water are importantly effected by changes in solar energy transmission, while the degradation of many pollutants importantly depends on the access of sunlight to the material. It would appear that thermal studies involving localized heat injection from power plants would also require a knowledge of radiant energy transmission characteristics of the water both for the visible and infra-red spectrum. Recreational uses of the coastal area are considerably effected by turbidity, especially swimming and diving activities. Although not widely used at present, it appears to this writer that certain, easily-measured optical parameters may serve to illuminate related problems involving tidal currents, bottom scour by waves and currents, mixing of discrete water flows, stratification of a water column, river and sewer outfall extents, and in fact most of the dynamic behavior of inshore waters.

Any attempt to describe the optical character of a mass of natural water must carefully distinguish between those parameters that are inherent to the water itself, and those parameters that depend on both the water and the nature of radiation passing through it. The most important inherent optical property of water is its <u>total attenuation coefficient</u> (Jerlov, 1) or its <u>volume attentuation coefficient</u> (Duntley, 2) This quantity, called "alpha" (α) in most literature is found by sending a collimated light beam through a water path of known length and letting it impinge on a photocell having an area exactly equal to that of the beam cross-section.

With such an experiment

$$P_r/P_o = e^{-\alpha r} \qquad (1)$$

where P_r is the beam intensity at the photocell r distance from the source, and P_o is the beam strength at the source. If the light beam is monochromatic, the attenuation coefficient for a particular wavelength, α_λ, is found. Alpha is made up of two parts, the scattering coefficient, s, and the absorption coefficient, a. Thus

$$\alpha = a + s \qquad (2)$$

Each of these parameters are also wavelength dependant in many cases.

Light in natural water is provided by the sun and sky, by bottom reflections, and by biological processes. Complex interactions occur between the water and its illumination so that a variety of in-situ parameters can be identified; reflectance of the surface layer, surface effect of bubbles, polarization patterns, color of the light and the water itself, ratio of upwelling to downwelling radiation, and so on. Such non-inherent parameters are effected by both the water properties and the incident light properties, as well as weather and sea-state factors.

The most fundamental of these non-inherent parameters is the <u>attenuation function for scalar irradiance</u>, k. This quantity is found using a specially-mounted photocell that "sees" an entire upward-facing hemisphere.

Then

$$\frac{h_{l + \Delta l}}{h_l} = e^{-k \Delta l} \qquad (3)$$

where $h_{l + \Delta l}$ is the total downwelling irradiance at depth, $l + \Delta l$; h_l is the irradiance at shallower depth l, and Δl is the difference between the two stations. In actual practice, it is necessary to reference h to an intensity readout from a surface cell so that changes in solar intensity during the measurements will not effect the computed k. That is, k is defined on the assumption that the natural illumination remains constant during the measurement.

k is somewhat dependant on solar angle, sea state, and cloud cover. However, in most practical situations where either visibility or biological considerations are involved, it is important to know the amount of light at a given depth and thus, k.

In this reported work, alpha from a collimated white (tungsten) light and k using natural incident light were determined at selected locations in Narragansett Bay and Point Judith (Salt) pond.

2.0 METHODS

Alpha and k meters manufactured by Hydro Products were used in these determinations. The alpha meter was towed from an outboard pontoon of a trimaran (three-hulled) sailboat. These outer hulls are very fine and produce almost no wake or bubbles to disturb the water column inside the alpha meter. No attempt was made to tow at a particular depth, but the device was usually from three to four feet below the surface. Percent loss of light intensity over a one-meter path was read directly, and at frequent intervals. Ship position was obtained by intersecting a compass-course line with range lines of sight using visual marks noted on standard nautical charts. In Narragansett Bay, a tow from Point Judith to Greenwich Bay was made on Saturday, Sept. 13, 1969. This course was then retraced in the opposite direction on Sunday, Sept. 14. This scheme was followed to attempt to detect tidal-current effects on alpha in the West passage of the bay. Figure 1 shows the course followed during these towing experiments. The general West Passage channel was followed and no study of shallow-water or edge effects made.

The k-meter was used at three locations on Saturday; Point Judith Harbor of Refuge, north of Beavertail Point in the West Passage, and in Greenwich Bay, in an attempt to obtain k for three locations having widely-different alpha values. The above-water solar intensity was obtained using a calibrated source, and the k-meter was lowered on a marked line and several readings were taken during raising and lowering.

In addition, the alpha meter was used in Point Judith Pond on Friday, Sept. 12, Saturday, and Sunday in the same manner as in the bay. Figure 2 shows the three courses followed in Point Judith Pond and the Harbor of Refuge on the three days. Again, the main deep channel was followed.

3.0 ALPHA VARIATION IN NARRAGANSETT BAY

Alpha is generally given in the units "natural log"/meter (ln/meter) or "natural log"/feet (ln/ft). The "ln" terminology is used to distinguish alpha computations using the natural log from those defined using base 10, as is sometimes done in the literature. The results from these experiments are presented in the form, ($1/\alpha$) with units "feet/ln" or just "feet". Inverse alpha has a very simple physical meaning; it is the distance a collimated light beam must travel before losing half of its starting energy through absorption and scattering. Duntley (2) and others suggest that the visibility of a "large" object (diver, mooring etc.) is equal to $4/\alpha$. However, this rule of thumb appears to be a considerable oversimplification.

Figure 3 shows the value of inverse alpha as a function of distance north of an east-west line through Point Judith Light. Arrows show the sequence with which the data was made; from Judith to Greenwich Bay on Saturday and back on Sunday.

Referring first to the northward tow, the current tables (3). show that the current in West Passage turned south soon after the start of the tow. However, high values of inverse alpha seem to be typical of the open water until the narrows off Beavertail Point are reached. Presumeably, the turbid water from the north end of the bay is being carried out through this channel and producing the noted sharp decrease in inverse alpha. The boat was anchored at point "A" in Figure 3 for about 50 minutes to make a "k" determination. Note that inverse alpha decreases at this station over this period, as would be expected if the south flowing current is bringing turbid water to this area. Further moderate decreases in inverse alpha are evident until the entrance to Greenwich Bay is reached when a sharp turbidity increase is evident.

On the Sunday tow, the current was north at the start and inverse alpha is somewhat above the values of the previous day. However, the current turns south again before the Jamestown Bridge is reached and the inverse alpha value drops below that of the previous day by the time Beavertail Point is reached. However, it is probable that the considerable difference in alpha in the Point Judith to Beavertail Point region between the two days is at least partly due to weather factors. The wind on Saturday was mild and south-west. By afternoon on Sunday the wind was easterly and much stronger. A considerable onshore chop had developed by the time Beavertail Point was passed and these steep waves may have stirred up the bottom in the region just north of Point Judith.

Summarizing Figure 3:

1) In general, northward currents bring clear water, and southward currents, cloudy water, but there is a considerable time lag in the effect.

2) The region studied breaks logically into three turbidity regions; Point Judith to Beavertail Point (clearest), Beavertail Point to Warwick Point (more turbid) and Greenwich Bay (murky). However, there appears to be a definite overall trend

throughout the region of increasing turbidity in a northward direction.

3) Variations of turbidity in the West Passage itself appears to be less than in the more open water to the south. However, more data is needed at different seasons and under various weather conditions before reasonable standard deviations in alpha at any location can be established.

4) In the twenty mile north-south region covered, turbidity variations of almost an order of magnitude were observed.

4.0 ALPHA VARIATION IN POINT JUDITH POND

Figure 4 suggests that Point Judith Pond shows alpha variations similar to those in Narragansett Bay itself. That is, visibility increases as one goes southward and away from the stagnant upper end of the pond. However, the results are rather spotty. The eastern entrance to the Harbor of Refuge shows a consistent increase in turbidity, suggesting a scour effect produced by currents through this breach. Inside the Harbor of Refuge, visibility is quite good. No current effect was detected in either the pond or harbor, but overlapping readings were not made at two different current directions. It appears possible that there is a turbidity "microstructure" within the harbor related to bottom conditions, tidal currents, and weather factors, but the data taken is insufficient to detail it. However, it does appear that the Harbor of Refuge offers possibilities for engineering studies requiring moderately good visibility.

5.0 ALPHA VARIATION WITH DEPTH

The Figure 3 and 4 alpha readings were always taken near the surface. During the photocell lowering experiments in the Harbor of Refuge and north of Beavertail Point, the alpha meter was lowered to several depths to see how much alpha might change as the bottom is approached. Tables I and II give the results.

TABLE I

Harbor of Refuge, Point Judith

($1/\alpha$) feet:	3.4	3.3	3.1	2.75	2.7
Depth, feet:	surface	4.0	8.0	12.0	16.0

TABLE II

North of Beavertail

$(1/\alpha)$ feet:	2.4	2.4	2.4	2.35
Depth, feet:	surface	4.0	8.0	12.0

Apparently, a definite turbidity gradient exists in the Harbor of Refuge, probably due to bottom currents and the complex inflow and outflow situation produced by the various openings. In the West Passage, such a gradient is less evident.

6.0 SCALAR IRRADIANCE ATTENUATION

The k-meter is first calibrated on deck and checked against a known voltage to obtain the local incident solar intensity. For the three stations at which the k-meter was used, Table III gives this value:

TABLE III

Location:	Harbor of Refuge	Beavertail Point	Greenwich Bay
Solar irradiation of Surface photocell in foot-candles (lumens/ft^2)	4350	3340	940

It should be noted that k is not too sensitive to the absolute value of solar irradiation, although it is effected by a change from bright sunlight to an overcast day. The reason for obtaining the values in Table III is simply for reference purposes and to enable other k values to be compared. The low value at Greenwich Harbor resulted from the time (6:00 p.m.). However, the sun was shining during all three determinations.

The underwater photocell was raised and lowered several times at each location. Near-surface readings are difficult to make with any accuracy due to wave-focusing effects and changes in the water column length. Also care must be taken not to shade the cell by boat. This was accomplished by lowering from a small tender. However, a more rapid way of accomplishing this test is needed. From Equation 3 it is apparent that if the relative intensity is plotted on a logarithmic scale and the depth of the cell is plotted on a linear scale, the resulting plot should be straight if k is constant with depth. Figure 5 shows this for the three locations. Although Table I suggests a moderate variation in properties with depth in the Harbor of Refuge, the three lines appear to satisfy the requirement of Equation 3. Straight lines are drawn through these points and the slopes of these lines give k directly. Table IV gives the result of these computations:

TABLE IV

Location:	Harbor of Refuge	Beavertail Point	Greenwich Bay
k, feet $^{-1}$:	.127	.232	.335
α, feet $^{-1}$:	.19	.415	.86
k/α :	.67	.56	.39

Although k is a complex quantity dependant on a number of water and weather variables, it is most strongly effected by the absorption coefficient, a. Light scattering by water is mainly in the forward direction. Thus, while scattering redirects the path of a light ray by a small amount, it does not greatly effect the general downward travel of sun and sky light into the water. k is thus a rough measure of the importance of absorption mechanisms in the water under examination, and the ratio of k to alpha is a means of estimating the relative importance of absorption in an alpha measurement. Table IV suggests that as water grows more turbid, absorption becomes less and less significant as a contributor to alpha and thus, that scattering increases as we move north in the bay. Jerlov (1) suggests that the relative sizes of the scattering and absorption coefficients are measures of the "fertility" of the water. In any case, the increasing importance of scattering in the turbid regions of the bay suggest that a correlation between k and alpha may be possible in restricted areas, thereby enabling underwater illumination predictions to be made on the basis of a single alpha measurement. However, more data is needed to establish such a correlation or even to demonstrate that one exists.

7.0 FUTURE WORK

The prediction of alpha and k for a single point in Narragansett Bay is obviously a complex problem. These and other optical properties are functions of three spatial dimensions, the state of the tide, probably the season of the year, and at least in the southern regions, the sea state, wind direction, and time the wind has been blowing. On the other hand it may prove true that some of these parameters have only a minor effect on the optical nature of the bay, at least in some of the areas.

An extremely useful study might involve the simultaneous recording of both optical and current data followed by an attempt to correlate these for different regions. Alpha is easily obtained from a vessel moving at six to eight knots while any measurement of current is more difficult and lengthy. Photocells are among the least expensive and most easily waterproofed sensors available. A large number might be emplanted in subsurface floats at chosen locations and their readout might yield information on other Bay parameters less easily measured in many locations.

The spreading of sewage outfalls and the dynamics of river-bay mixing might be clarified if a detailed turbidity map were available. This would be especially possible just following heavy rainfall when runoff was at a maximum.

Questions of scour and sediment transport as a function of current and wave parameters are amenable to optical instrumentation. However, as with most other such applications, a map of baseline values is probably needed first.

ACKNOWLEDGMENTS

The optical sensors used in this study were provided by the University of Rhode Island Sea Grant Office, while the preliminary studies were supported under a grant from the Public Health Service. Thanks are due to Dean John Knauss of the Graduate School of Oceanography for his support of our various optical research programs, to Mr. Joseph VanRyzin who checked out the equipment and ran preliminary experiments at Wickford, and to Mssrs. Garret and Grantley Schenck who assisted during boat operations.

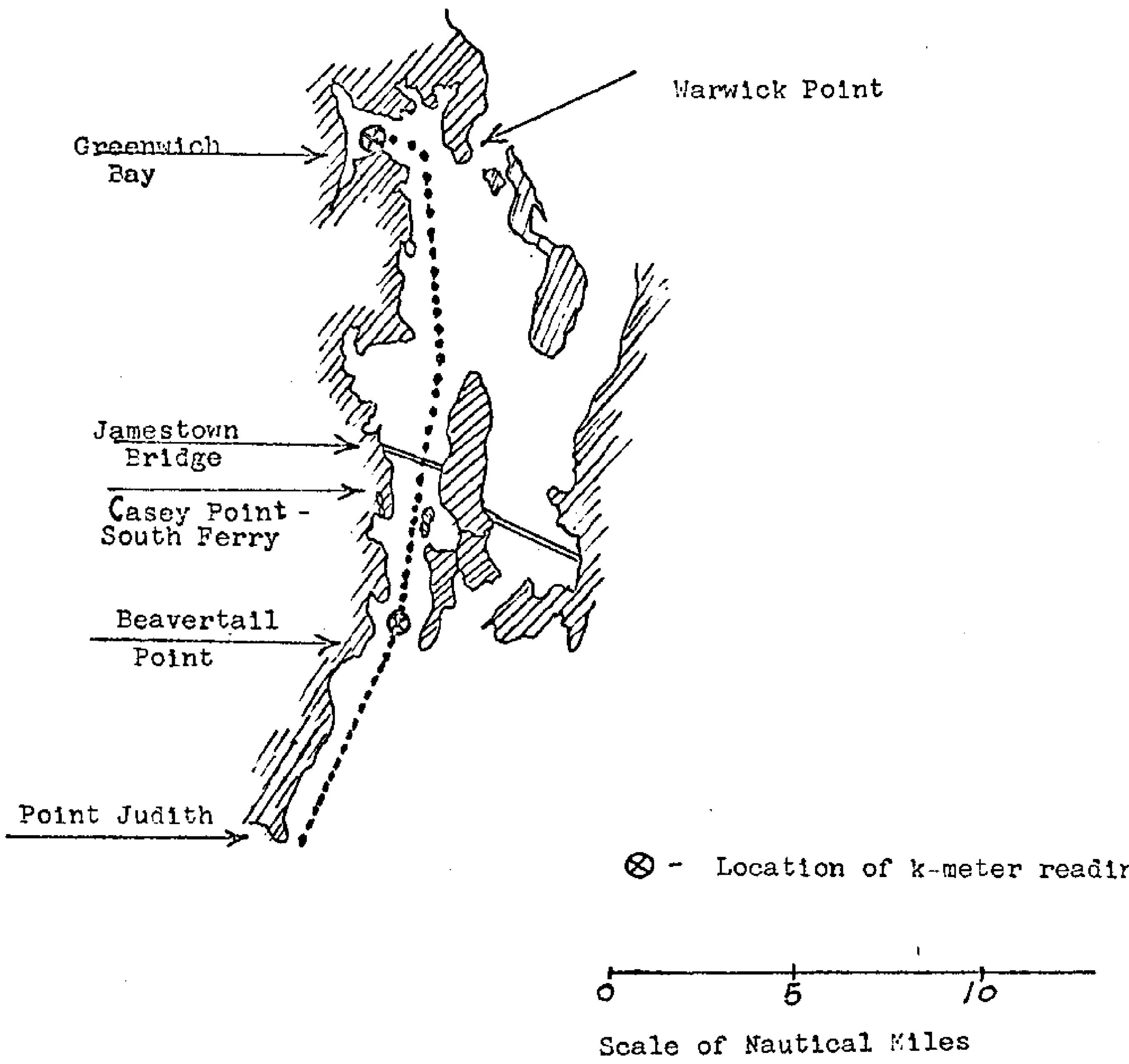
REFERENCES

1) Jerlov, N. G., "Optical Oceanography", American Elsevier Publishing Co., New York, 1968.

2) Duntley, S. Q., "Light in the Sea", J. Opt. Soc. Amer., 53, Feb., 1963, 214-233.

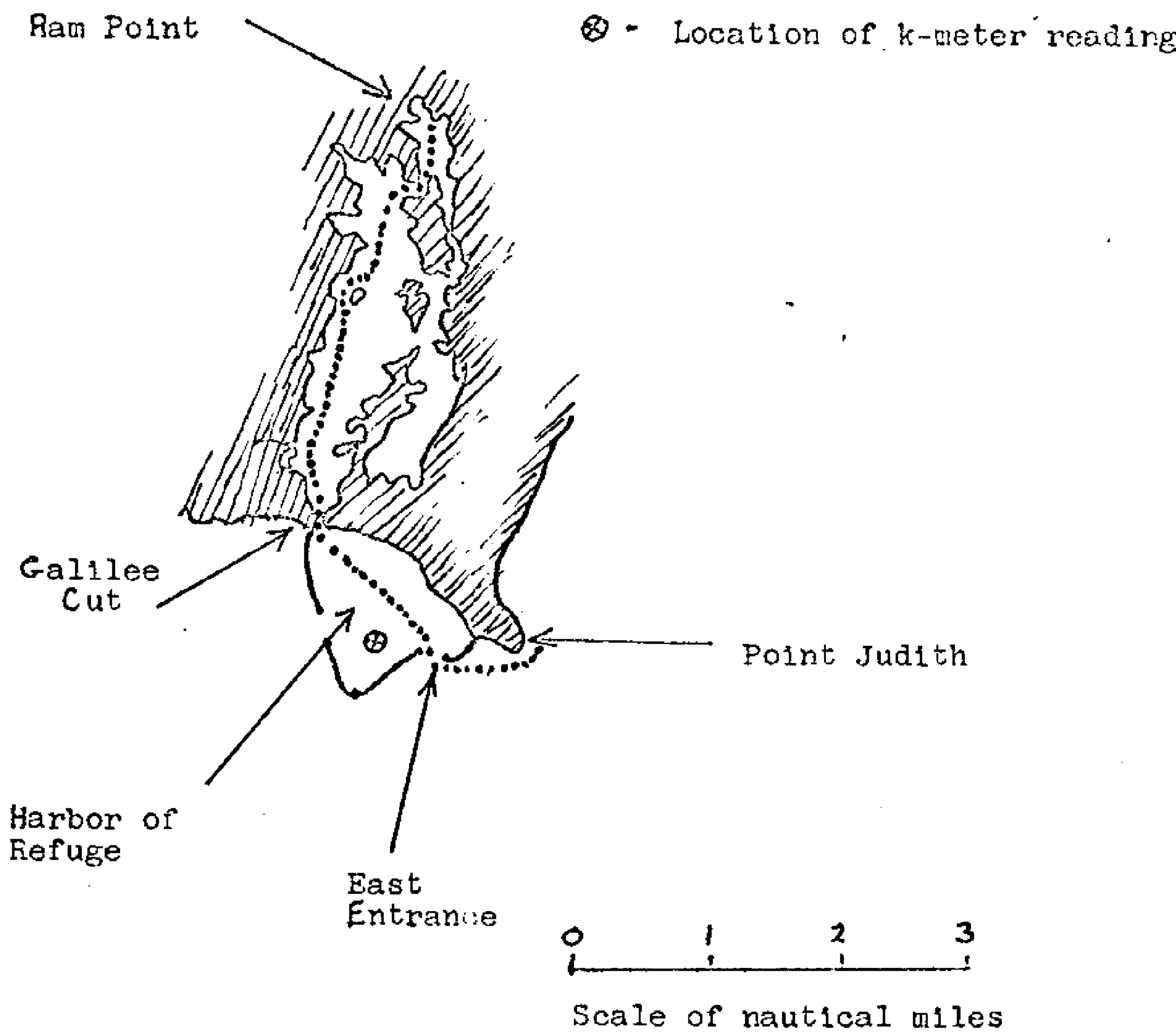
3) "Tidal Current Charts, Narragansett Bay to Nantucket Sound", Dept. of Commerce Environmental Science Services Adm., Rockville, Md.

FIGURE I



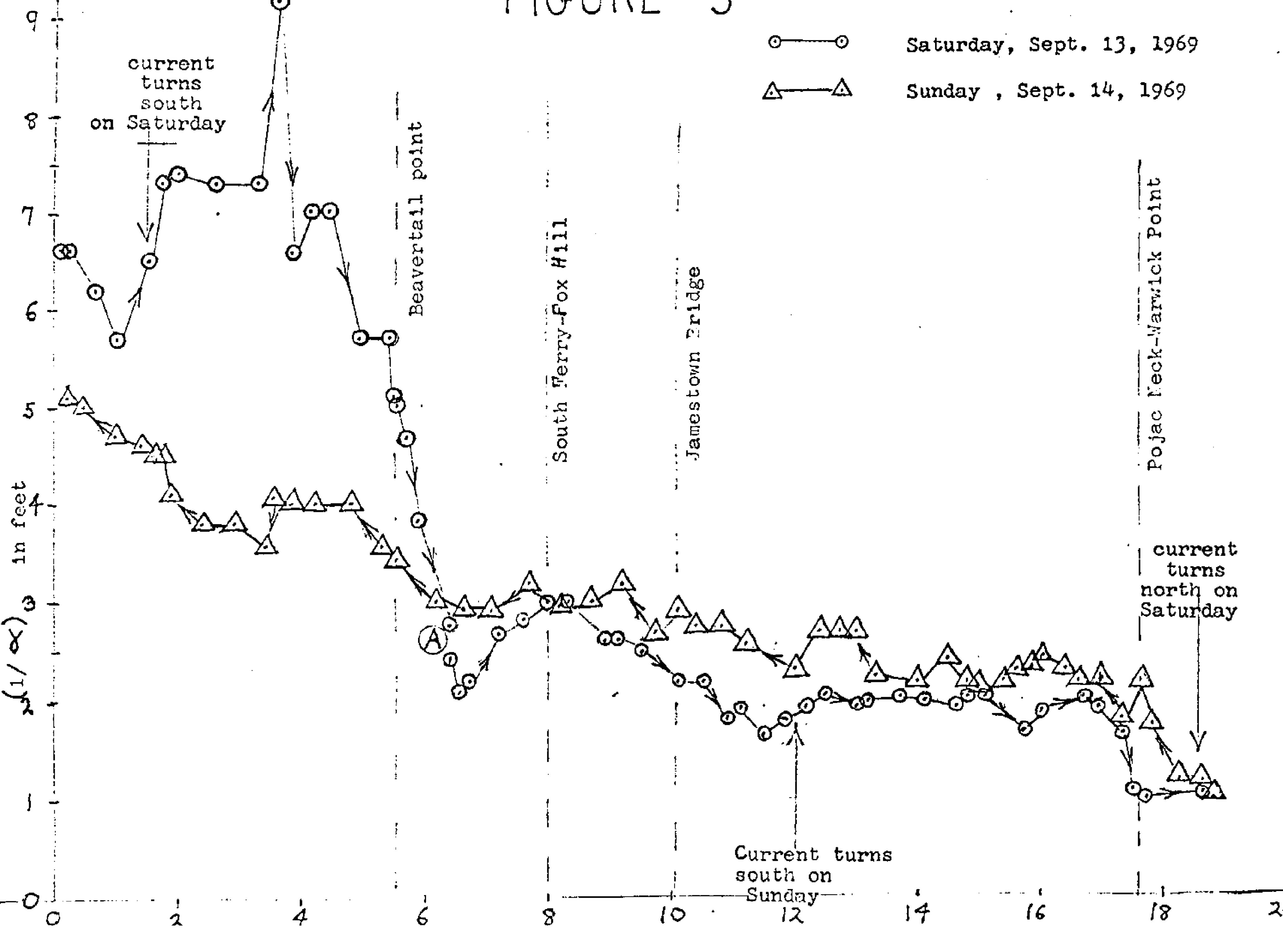
Dotted line shows course along West Passage

FIGURE 2

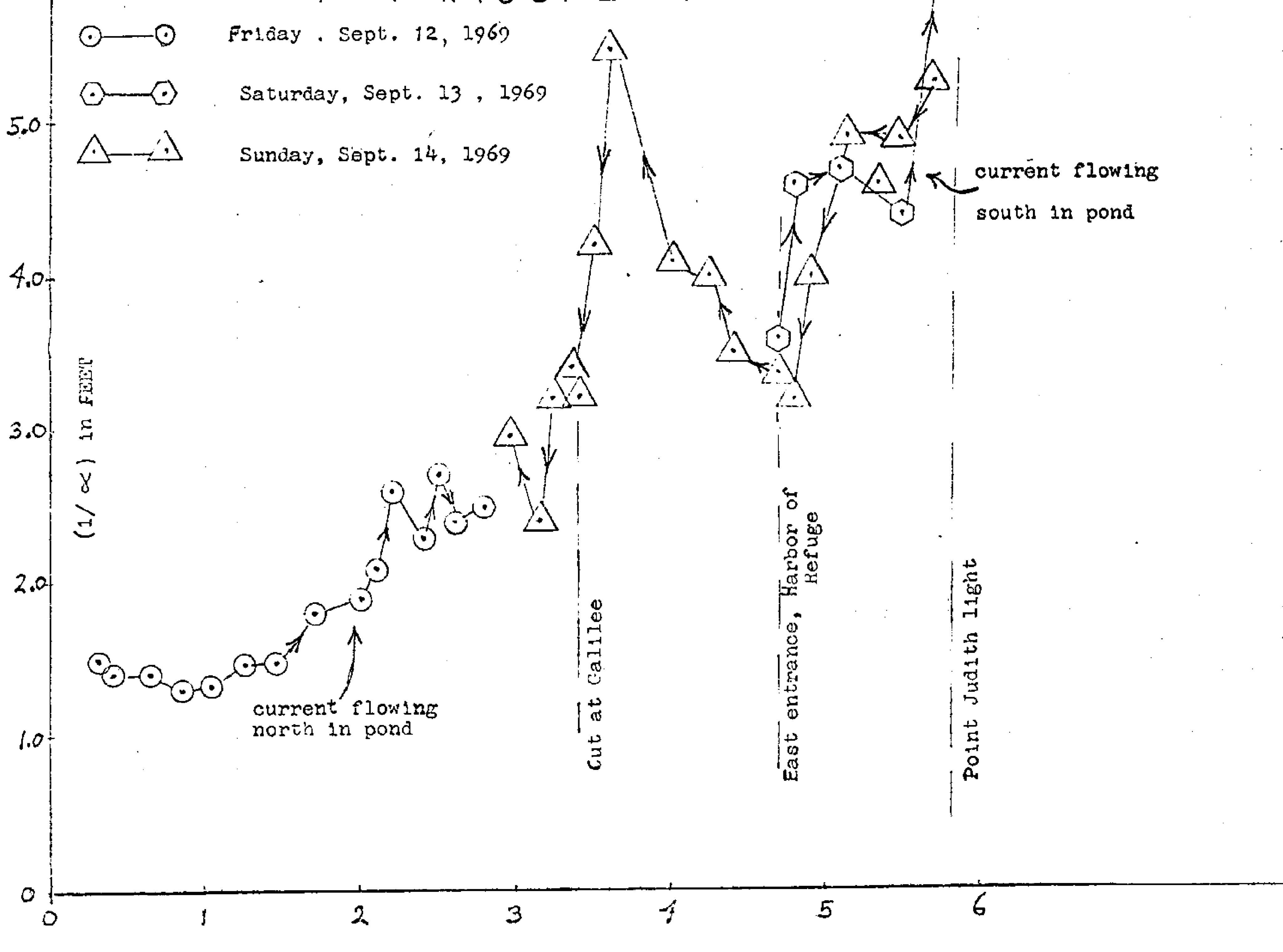


Dotted line shows course in pond and harbor

FIGURE 5



Saturday, Sept. 13, 1969
Sunday , Sept. 14, 1969
current turns south on Saturday
Beavertail point
South Ferry-Fox Hill
Jamestown Bridge
Pojac Neck-Warwick Point
current turns north on Saturday
Current turns south on Sunday
A
$\lambda(1/\alpha)$ in feet



Friday . Sept. 12, 1969
Saturday, Sept. 13 , 1969
Sunday, Sept. 14, 1969
(1/ ∝) in FEET
5.0
4.0
3.0
2.0
1.0
0
0
1
2
3
4
5
6
current flowing north in pond
current flowing south in pond
Cut at Galilee
East entrance, Harbor of Refuge
Point Judith light

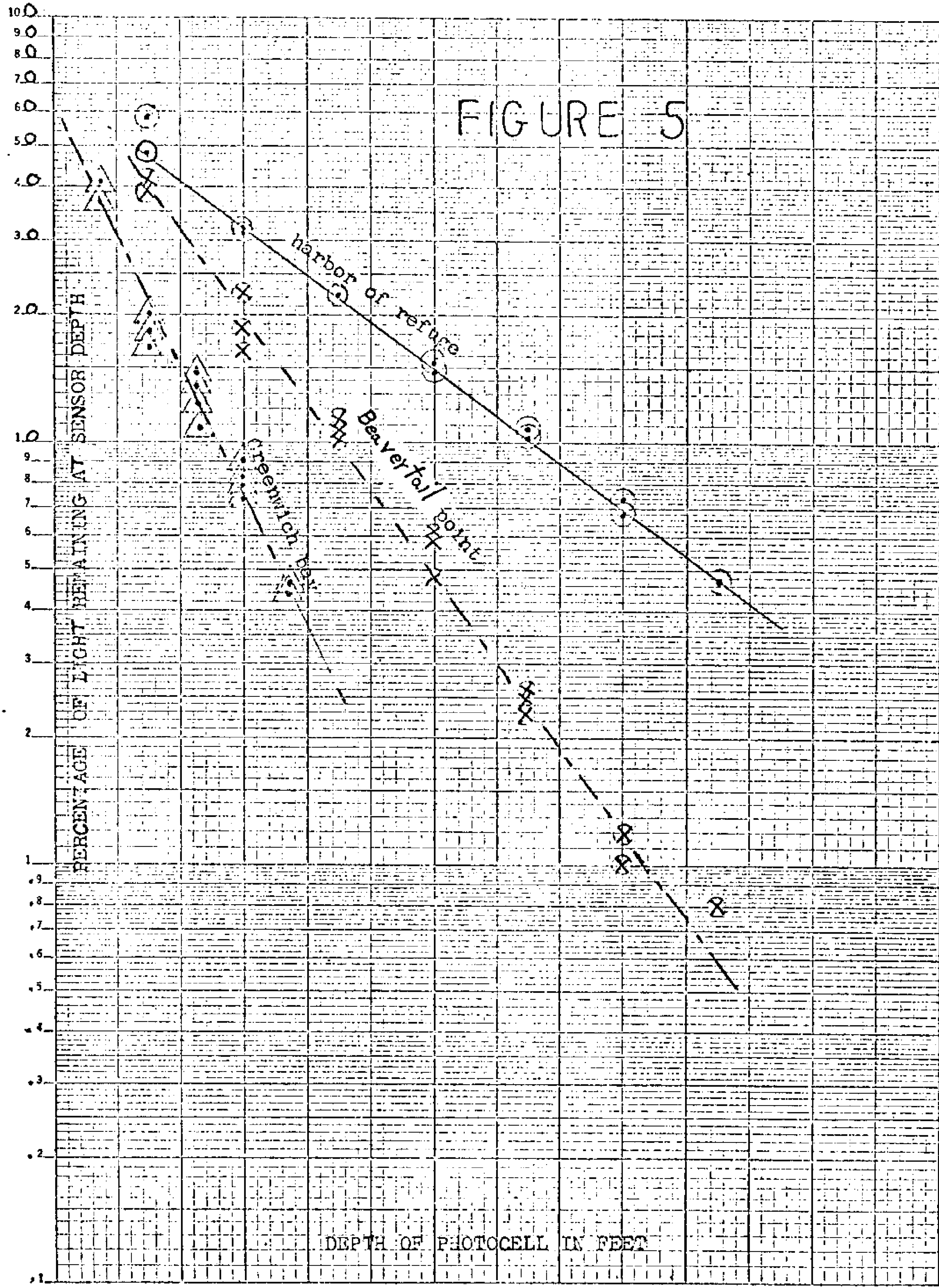


FIGURE 5
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
PERCENTAGE OF LIGHT REMAINING AT SENSOR DEPTH
DEPTH OF PHOTOCELL IN FEET
harbor of refuge
Beavertail point
Greenwich bay