THE UNIVERSITY OF MICHIGAN - SEA GRANT PROGRAM -

Technical Report No. 35

DROGUE MEASUREMENTS OF THE CIRCULATION IN GRAND TRAVERSE BAY, LAKE MICHIGAN

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Multidisciplinary Research in the Great Lakes

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The University of Michigan Sea Grant Program is a part of the National Sea Grant Program, which is maintained by the National Oceanic and Atmospheric Administration of the US Department of Commerce.

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Mrs. Elizabeth A. Monahan sewed the flags used on the twelve buoys and Mrs. Janet H. Michelena sewed the panels for the original "Vee" drogues. We thank them for this voluntary service.

The Great Lakes Maritime Academy of Northwestern Michigan College (NMC) provided us with a place on the shore of the west arm of Grand Traverse Bay to work and store our equipment. We are grateful to NMC for allowing us the use of those facilities. We also thank the numerous cottage owners along the bay who welcomed our transit crews onto their beaches and the several boaters who returned to us flag buoys blown away in foul weather.

INTRODUCTION

In 1970, the University of Michigan Sea Grant Program began an intensive multidisciplinary field study of Grand Traverse Bay of Lake Michigan. That portion of this study directed at obtaining a description of the currents, periodic and aperiodic, that exist in Grand Traverse Bay, has involved two distinct types of current measurement: Lagrangian and Eulerian. The current-meter mooring systems used in making the Eulerian measurements, and the initial results of that aspect of our study, have been described elsewhere (Johnson and Monahan, 1971). The present report will be devoted to describing our application of essentially conventional drogue techniques to the quasi-Lagrangian measurement of the circulation in Grand Traverse Bay and the results thus obtained. A technique whereby drogues are monitored via VLF radio retransmission as they drift about in the bay has been developed in our research group and will be described in another report (Michelena, 1973).

The technique used to obtain the results described in this report has been used for well over 100 years. Early examples of the application of this general technique are to be described by Scoresby (1853), Tizard et al. (1885), and numerous others.

Our first measurements were made in the west arm of Grand Traverse Bay on 23 July 1970 using four flag-buoy/Vee drogue units. One of the flag-buoys is shown in Figure 1. The float proper is a 1.5-ft diameter, polyurathane disc, 9 in. thick. The polyurathane disc is armored with a fiber-glass

Figure 1

Launching of Flag Buoy during Equipment Demonstration

NOTE: Folded Vee drogue can be seen at the stern of the vessel.


7

covering. A 10-ft long, thin-walled, electrical conduit passes through the center of the float and serves both as a mast for the flag and a rigid point of attachment for the drogue line. Each 3 ft-by-3 ft flag has its own color combination and number.

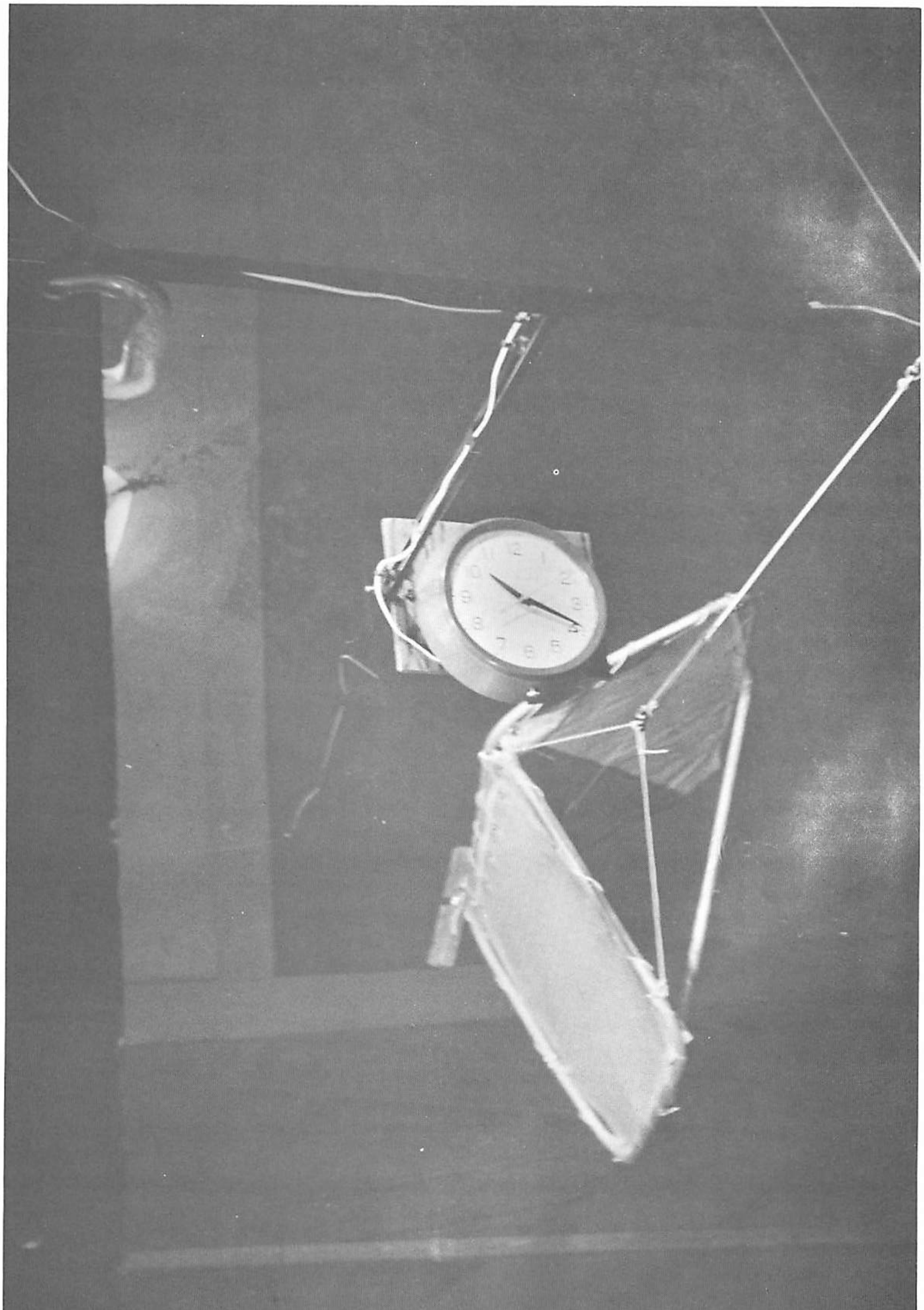
Each Vee drogue is composed of two 6 ft-by-4 ft canvas panels laced to rectangular frames of thin-walled conduit. The two panels are hinged together along a pair of 6-ft sides. When a drogue is deployed, the two panels are held at right angles to one another by means of a horizontal conduit spreader; when stowed, the spreader is removed and the panels are folded together. Figure 2 shows a one-half linear scale model of a Vee drogue as it appeared during towing tank tests. Our Vee drogue design is based on the "GLI" canvas drogue used by the Great Lakes Institute (GLI) of the University of Toronto, as described by Hamblin and Rodgers (1967).

The effective depth of the current being measured is determined by the length of line used to suspend the Vee drogue beneath the flag-buoy. With a multiplicity of flag-buoy/Vee drogue units we are able to simultaneously measure currents at several different depths in several portions of the bay.

At the beginning of our study all drogues were positioned by means of triangulation from shore locations. At each of the two shore sites were an observer, a transit, and a Citizens Band radio transceiver. The radio communications greatly aided us in synchronizing our readings at the several shore locations. Under conditions of good visibility and moderate sea state, this positioning technique was good up to a range of 3 mi.

Figure 2

Submerged One-half Linear Scale Model of Vee Drogue Being Towed Toward the Left in Towing Tank



In addition to the problems posed by nature, a problem that was encountered in Grand Traverse Bay, with its many vacationers, was that of vandalism. On one occasion, youngsters were observed through the transit telescopes while they were bending a flag-buoy mast. On another occasion, we received word that our flag-buoy #1 had been taken to Manassas, Virginia. After several exchanges of letters, the various components of that buoy were returned.

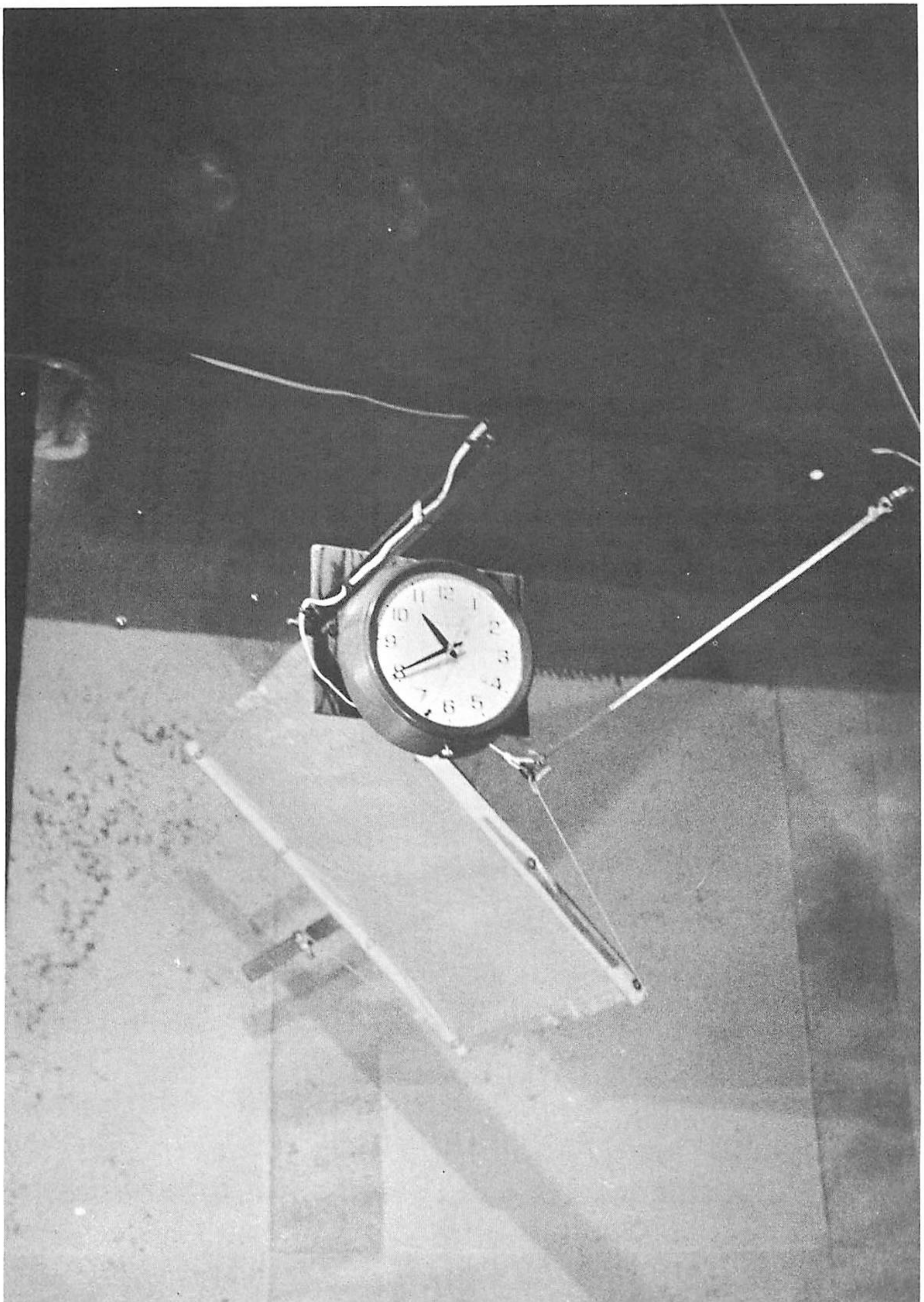
By August 1970 we had increased the number of flag-buoy/Vee drogue units to six, and by January 1971 we had eight such units. Twelve flag-buoys were available for the 1972 field season, and four "window-shade" drogues had been added. A one-half linear scale model of a "window-shade" drogue is illustrated in Figure 3. Each full-scale drogue consists of a 5 1/2-ft wide sheet of canvas, 6 1/4 ft long, suspended from a horizontal length of electrical conduit and weighted at the bottom with a horizontal length of iron pipe. This design is similar to the polyethylene drogue described by Terhune (1968). These "window-shade" drogues are the modern version of the sail drogue which was in use 300 years ago (Deacon, 1968).

Positioning of the numerous flag-drogue buoys during our 1972 field work was accomplished with a sextant. Using the R/V *Sea Grant I*, we would repeatedly visit each of the drifting flag-buoy/drogue units, and at each visit a shipboard observer using a sextant would obtain a pair of nearly simultaneous horizontal angles using three landmarks.

In addition to their use in Grand Traverse Bay, the flag-buoy/drogue units have been used elsewhere to some extent. We used them in the Gulf

Figure 3

Submerged One-half Linear Scale Model of "Window-Shade" Drogue at Start of Run in Towing Tank



of Mexico in February 1971 (while using the facilities of the Edward Ball Marine Laboratory of Florida State University, located at Sopchoppy) and in Vineyard Sound in May and June of 1971 and 1972 (in connection with the Sea Grant-sponsored Oceanography Field Practicum conducted by The University of Michigan each spring in Woods Hole, Massachusetts, with the cooperation of the Marine Biological Laboratory and the Woods Hole Oceanographic Institution).

In the following section of this report, the two tank tests of the various buoy components will be described. That will be followed by a section in which the results of the Grand Traverse Bay field work are presented.

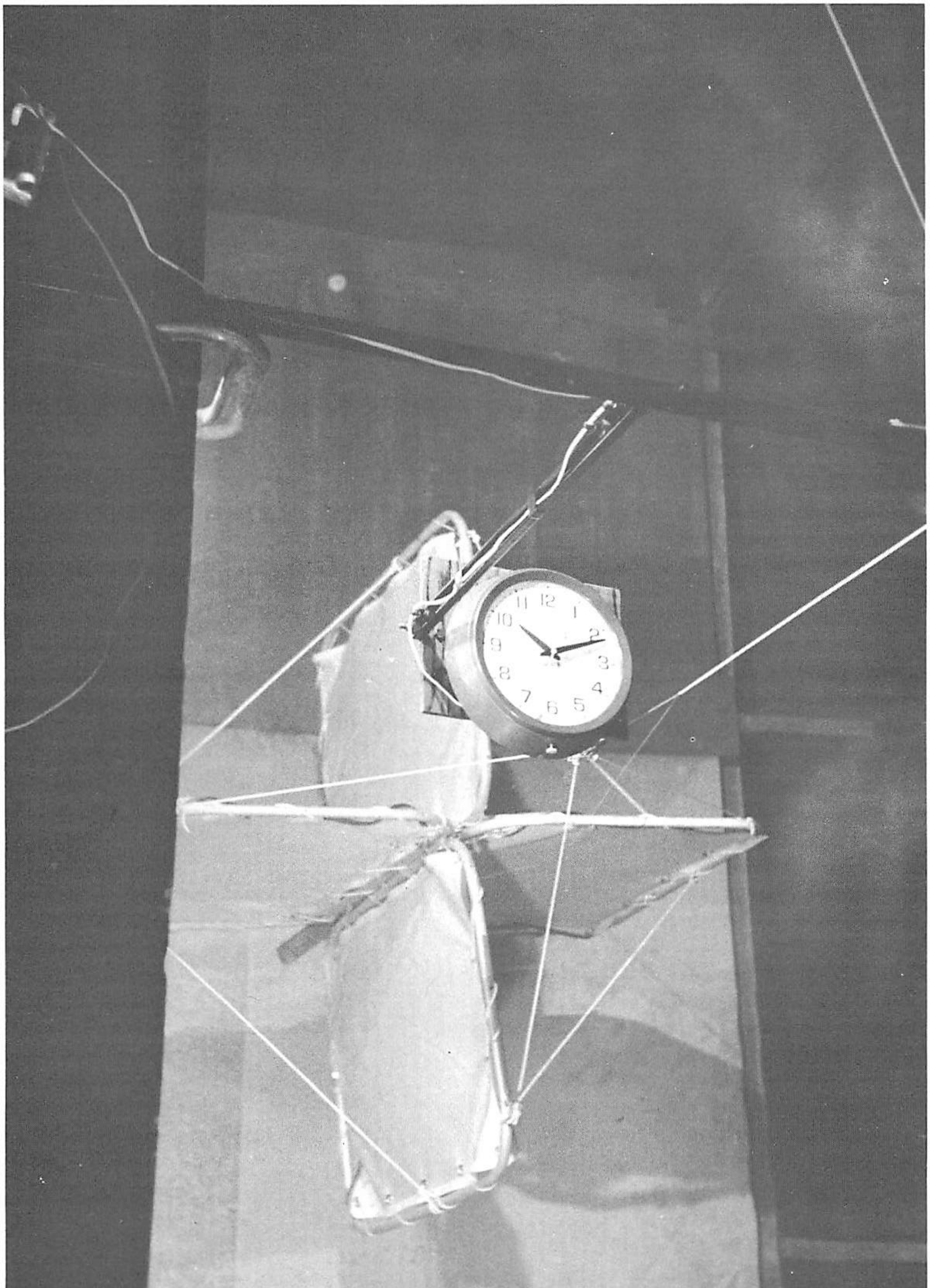
TOWING TANK TESTS OF DROGUES

Two sets of towing tank tests were conducted in connection with our drogue measurement program. The first set of tests was conducted to determine the drag force on each of the components of the flag-buoy/drogue unit as a function of that component's velocity relative to the water. Measurements were made not only on a flag-buoy and a full-scale Vee drogue but also on a full-scale current-cross unit constructed by putting together, hinge to hinge, two Vee drogues. A model of the current-cross unit used in the second set of tests is shown in Figure 4. This latter design has been a popular one for the construction of current drogues since at least the time of the Challenger Expedition (Tizard et al., 1885).

The force versus velocity measurements were made in the following manner: The two full-size drogues were tested at the University of Michigan towing tank by suspending them below the towing carriage in a swing-like arrangement. Light-weight steel tubes, 10 ft long, were attached on both sides of the drogue. These tubes extended about 4 ft upward from the top edge of the panels. A pipe, also 10 ft long, was U-bolted across the upper ends of the vertical members. The ends of this horizontal pipe rested on top of the steel channels on either side of the towing carriage, where loose-fitting U-bolts allowed rotation about a level axis but restricted all horizontal motion relative to the carriage. A 2-in. diameter, schedule 40, steel pipe was mounted vertically in the center of the carriage and forward of the drogue. To the lower end of this pipe was fastened a ballbearing-type pulley which lined up with the center of the drogue. The horizontal

Figure 4

Submerged One-half Linear Scale Model of Current-Cross Unit, Constructed from Two Vee Drogues



distance between the pulley and the drogue was 6 ft. The tow cable, a 1/8-in. diameter, wire rope, stretched from the center of the submerged drogue, made a 90-degree bend around the pulley, and came up along the inside of the pipe to a load cell which was fastened to a level support beam located 8 ft above the floor of the carriage. The load cell was of the electrical, strain gauge type with a maximum axial force rating of 100 lb. The wire tension, and thus the drag force exerted by the water on the drogue, was measured by observing the displacement of the pen of an x-y recorder connected to the output of the load cell's electrical bridge. A calibration curve of pen displacement versus wire tension was constructed prior to conducting the series of drag tests by suspending known weights from the load cell and recording the magnitude of the x-y recorder response. The corresponding drag force exerted by the water flowing past the drogue at a given speed then was measured by translating the towing carriage at the same speed over the still-water tank and thus dragging the test object through the fluid.

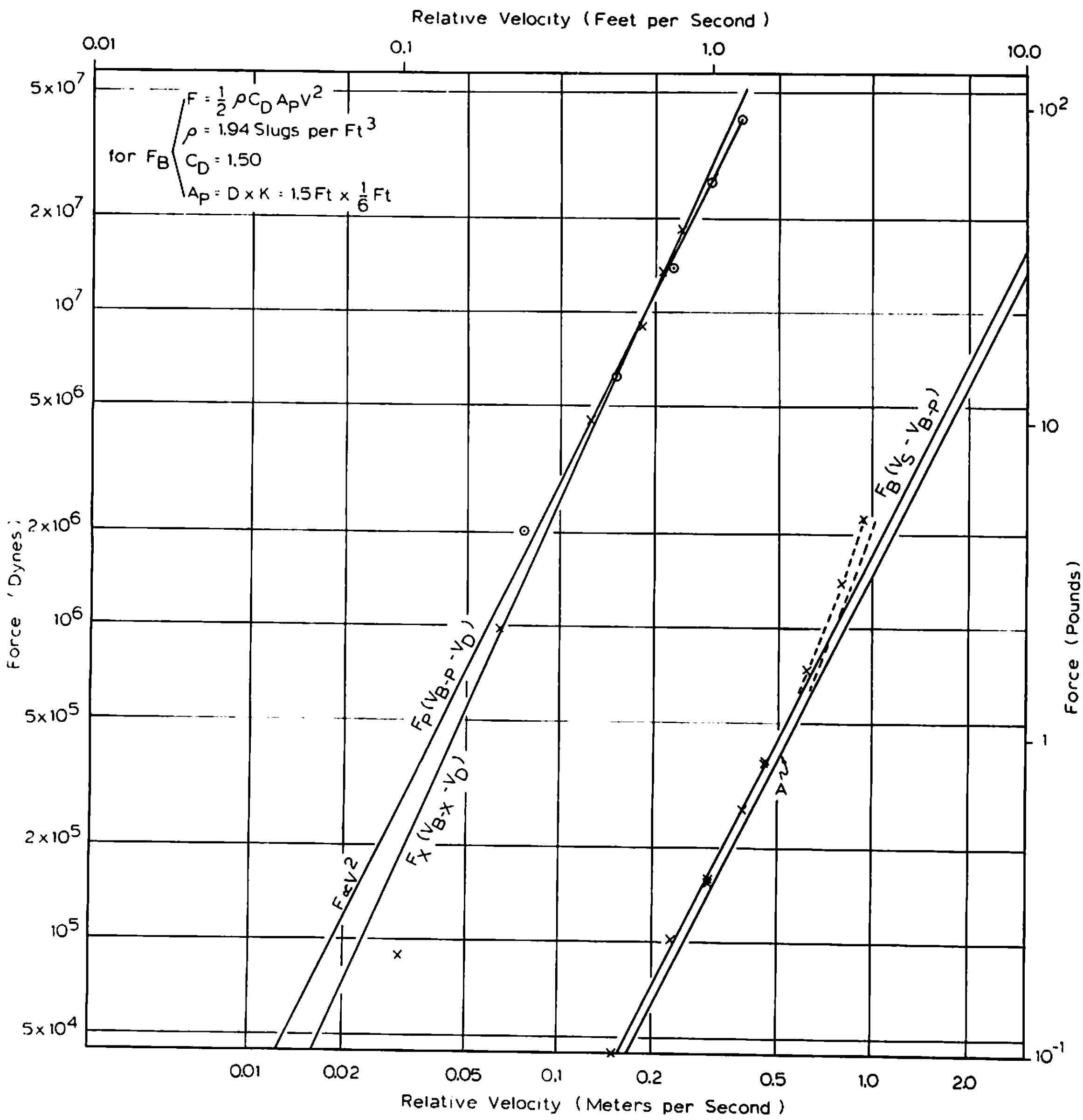
The drag force versus velocity measurements for the flag-buoy were performed in a manner similar to the drogue tests except that the buoy was floating on the surface of the water and pulled along by a string fastened to the force-measuring apparatus normally used to test ship models.

The results of these tests are plotted in Figure 5. Further results are given in Table 1. Using these results, we could calculate, for an assumed vertical current profile, the error in current measurement that would be experienced using one of our flag-buoy/Vee drogue units (or a

Figure 5

Drag Force vs. Relative Velocity for Flag Buoy (F_B), Vee Drogue (F_p), and Current-Cross Unit (F_x)

NOTE: Curve A and other symbols are described in the text.

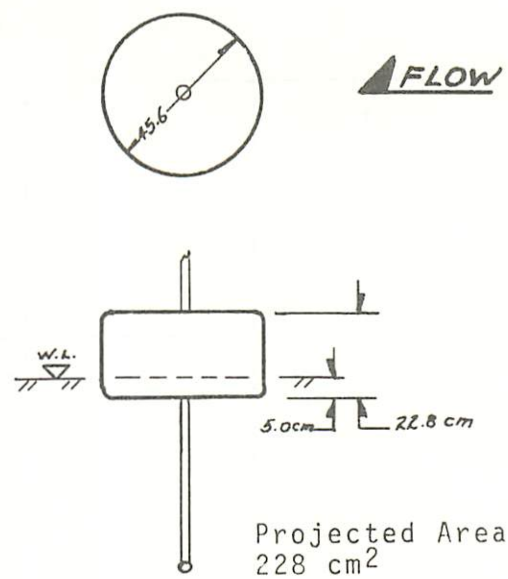


Relative Velocity (Feet per Second)
0.01
0.1
1.0
10.0
5x10^7
2x10^7
10^7
5x10^6
2x10^6
10^6
5x10^5
2x10^5
10^5
5x10^4
Force (Dynes)
10^2
10
1
10^-1
Force (Pounds)
for F_B
F = 1/2 ρC_D A_P V^2
ρ = 1.94 Slugs per Ft^3
C_D = 1.50
A_P = D x K = 1.5 Ft x 1/6 Ft
F_P (V_B-P - V_D)
F_X (V_B-X - V_D)
F∝V^2
F_B (V_S - V_B-P)
A
0.01
0.02
0.05
0.1
0.2
0.5
1.0
2.0
Relative Velocity (Meters per Second)

Table 1. Results of Testing

FLAG-BUOY

Towing Speed (cm/sec)	Drag Force (Dynes)
0	0
30.5	0.1558×10^6
45.8	0.3780×10^6
62.0	0.7350×10^6
79.6	1.3910×10^6
92.8	2.2460×10^6



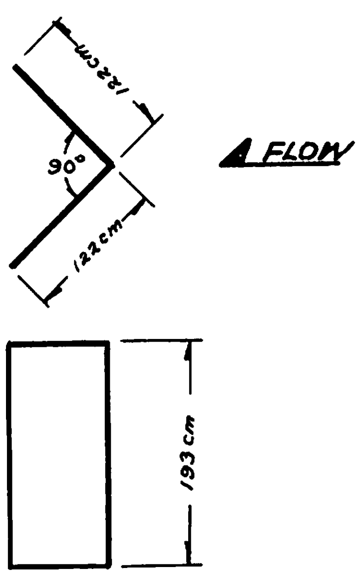
Projected Area: 228 cm^2

VEE-DROGUE

Towing Speed (cm/sec)	Drag Force (Dynes)	Reynold's Number	Drag Coefficient
0	0	0	-
7.64	2.040×10^6	1.30×10^5	2.12
15.26	6.350×10^6	2.60×10^5	1.64
22.90	14.100×10^6	3.90×10^5	1.62
30.50	26.800×10^6	5.20×10^5	1.73
38.20	42.000×10^6	6.50×10^5	1.74

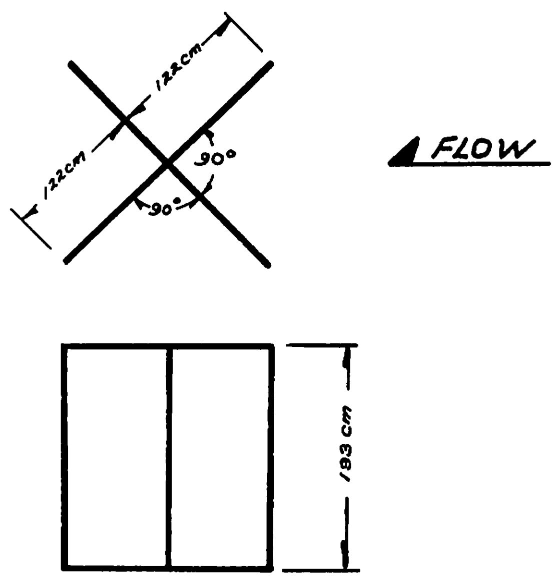
CURRENT CROSS

Towing Speed (cm/sec)	Drag Force (Dynes)	Reynold's Number	Drag Coefficient
0	0	0	-
3.05	0.088×10^6	0.520×10^5	0.576
6.41	0.977×10^6	1.090×10^5	1.436
12.50	4.480×10^6	2.130×10^5	1.730
18.30	9.160×10^6	3.120×10^5	1.648
21.40	13.510×10^6	3.640×10^5	1.786
24.40	18.490×10^6	4.160×10^5	1.871



Projected Area:
33,200 cm^2

VEE-DROGUE



Projected Area:
33,200 cm2

CURRENT CROSS

flag-buoy/current-cross unit). Indeed, if the currents at all depths can be assumed to be flowing in the same direction but at different speeds, then a knowledge of the surface current velocity (such as could be determined from observing a small, freely floating, surface float) can be coupled directly with the curves shown in Figure 5 to yield the exact current velocity at the depth of the drogue panels. The key is to remember that the magnitude of the drag force exerted on the panels of a Vee drogue at their depth of deployment, F_p, is the same as the magnitude of the drag force exerted on the flag-buoy by the surface current, F_B. Thus, each point on the Vee drogue drag curve (F_p vs. relative velocity, V_{rel}) is physically associated with the point on the flag-buoy drag curve (F_B vs. V_{rel}) that falls on the *same* horizontal line, i.e., has the same ordinate value. Specifically, if we know the magnitude of the surface current, V_s, from observing an untethered surface float, and the speed of the flag-buoy/Vee drogue unit, V_{Bp}, from observing the flag buoy, then we can subtract V_{Bp} from V_s and determine the speed of the surface water relative to the flag-buoy. By drawing a vertical line on Figure 5 through the point on the horizontal axis corresponding to the value of $V_s - V_{Bp}$, the value of the drag force on the flag-buoy is the point where this line intersects the F_B curve. Moving horizontally from this point of intersection over to the F_p curve, and then vertically downward to the horizontal axis, we can obtain the speed of the Vee drogue panels through the water at their depth, i.e., $V_{Bp} - V_D$, where V_D is the magnitude of the current at the depth of the drogue. Since

V_{Bp} is known (from our observations of the flag-buoy), we subtract the value of $V_{Bp} - V_D$ from V_{Bp}, and thus arrive at the exact current velocity at the depth of the drogue, V_D. It should be noted that the magnitude $V_{Bp} - V_D$ is the size of the error incurred if one makes the usual assumption that the flag-buoy/Vee drogue unit is moving at the speed of the currents at the depth of the drogue.

If the speed of the flag-buoy/Vee drogue unit, V_{Bp}, is to be used as an approximation of the speed of the current at the depth of the drogue, V_D, then by means of curve A in Figure 5, the maximum error, $(V_{Bp} - V_D)_{max}$, that will be incurred can be determined if one has an estimate of the maximum value of the current shear, $V_s - V_D$, that will be encountered in the body of water in which the work is to be undertaken. This is done by going along the horizontal axis to a point corresponding to the value of $(V_s - V_D)_{max}$ assumed, then by moving vertically upward to intersect with curve A. From that point on curve A, move horizontally to point of intersection with curve F_p, and then vertically downward until the axis is reached. The value given at this intersection with the horizontal axis corresponds to $(V_{Bp} - V_D)_{max}$, the maximum error to be incurred. (Curve A was generated by adding the abscissa value of the point on curve F_B and the abscissa value of the point on curve F_p for each ordinate value, and then by plotting the resulting sum along the same horizontal line.)

The second set of drogue tank tests were carried out to determine the orientation assumed by various drogue types when in use. The drogue designs tested via one-half linear scale models were those of Vee drogues (Figure 2), "window-shade" drogues (Figure 3), and current-cross units (Figure 4). A fourth design tested was a parachute drogue. Rather than construct a scale model of a large, personnel parachute, we made use of a pilot parachute (Figure 6). While the parachute has been a popular drogue over the past several decades (Volkman, Knauss, and Vine, 1956; Gerard and Salkind, 1965), we have made only limited use of it in our Grand Traverse Bay work (refer to Figure 16 in the following section).

These tests were conducted by towing the model drogues at slow speeds through the same towing tank as was used in the first set of tests. Speeds of 6 cm/sec and 12 cm/sec were used in these tests. The drogue models were also observed as they were accelerated from rest. The results were recorded on 16-mm motion picture film. (A 8.3-min motion picture entitled "A Tow Tank Study of the Behavior of Four Drogue Types" has been prepared by E. C. Monahan and J. H. Allender, assisted by D. L. McCown, for presentation at a forthcoming conference).

The Vee drogue model behaved well. Its stable orientation was with the vertex (bottom) of the Vee pointed in the direction of the drogue's relative motion through the water, as shown in Figure 2. Even when the drogue was shifted 180 degrees from this orientation at the outset of a test run, it soon swung around to its stable orientation.

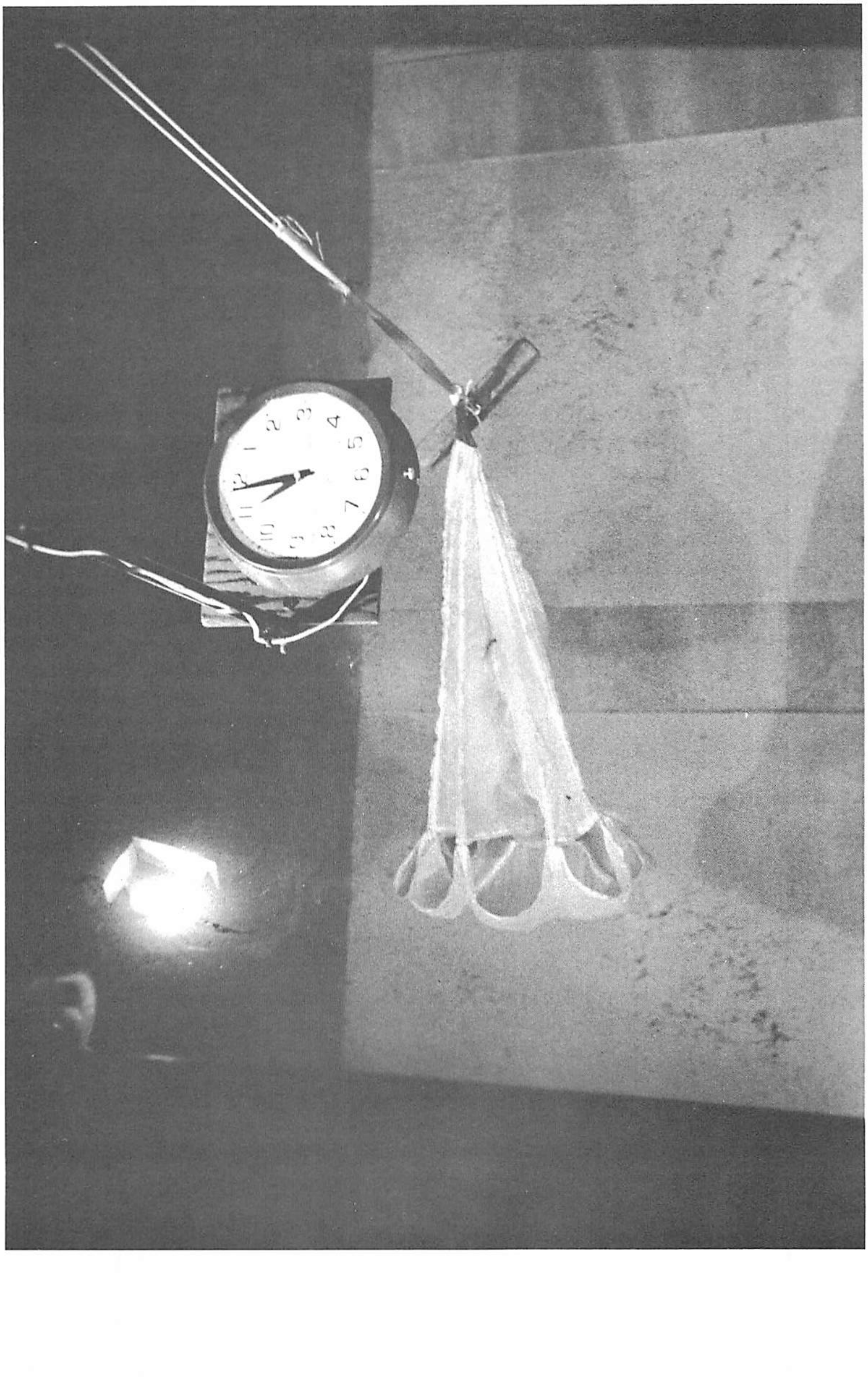
The "window-shade" drogue model proved by its behavior that the stable orientation for this design was when the plane of the canvas was perpendicular to the direction of the drogue's motion through the water. We did not observe any clear indication of a marked oscillation about the stable position, as was observed by Terhune (1968) when he conducted similar tests on a polyethylene "window-blind" drogue. We did observe, as did Terhune with the polyethylene drogue, that even when initially oriented with its plane parallel to the direction of motion, the canvas "window-shade" drogue rapidly swung around to its preferred orientation.

In every test run, the canvas current-cross unit developed a rotational motion about its vertical axis. A smaller, weighted, wooden current-cross unit which we had tested earlier also displayed this same tendency to revolve about the line of intersection of its two planes. It is our tentative opinion that this slow spinning of a current-cross unit may induce it, and the flag-buoy to which it is attached, to develop a slight component of motion in the direction normal to the direction of motion of the current at the depth of the current-cross unit, similar to a weak "curve ball" in baseball.

The most noticeable feature of the behavior of the pilot parachute was the limited extent to which it spread out when it was towed at slow speeds. The fact that at the relative velocities encountered in actual drogue usage such a parachute hangs in the water like "limp laundry" is important when calculating the effective cross-sectional area of such a drogue. While most groups that use parachutes as current drogues incorporate spreaders to help keep the parachute open (e.g., Volkman, Knauss, and Vine, 1956; Gerard and Salkind, 1965; Hamblin and Rodgers, 1967), it is well to keep in mind that a parachute, no matter how modified, will not be as effective a current drogue as one might think from handling it on a wind-swept deck, or from attempting to draw it rapidly aboard a boat. In looking at the pilot parachute in Figure 6, it should be noted that it contains a large coil spring which guarantees its partial opening (and which originally served to pop the pilot parachute out into the air-stream when the rip cord was pulled).

Figure 6

Pilot Parachute Being Towed from Left to Right in Towing Tank



RESULTS OF FIELD WORK, 1970-72

On the following pages, the drogue trajectories obtained from our field observations are plotted on charts. Each chart is accompanied by a wind history showing graphically the wind speed and direction throughout an interval beginning well before the drogues were deployed and terminating shortly after the drogues were retrieved. The time interval set off by hash marks is that during which the drogues were being observed.

Whenever possible, data on the vertical temperature structure of the bay at that locale were obtained. When such information was available, it was incorporated in the figures in the form of individual bathythermograph traces or of vertical temperature sections constructed from numerous BT traces.

Figure 7 is a chart of the entire bay showing the regions covered in the subsequent larger scale charts. Figures 8 through 21 present the results. A general interpretation of these results must await the final report on the complementary Eulerian measurements, which will appear later this year (Johnson, 1973). However, from the results given here, certain characteristic features of the circulation of Grand Traverse Bay will become apparent.

These results, in addition to being of immediate interest in themselves, are suitable for use in verifying the numerical dynamical model that has been developed for the circulation in Grand Traverse Bay by other Sea Grant Program participants. Such applications of our results are already in evidence (Smith, 1972).

Figure 7

Grand Traverse Bay of Lake Michigan: Regions Marked Appear in Subsequent Charts; Numbers Correspond to Figure Numbers

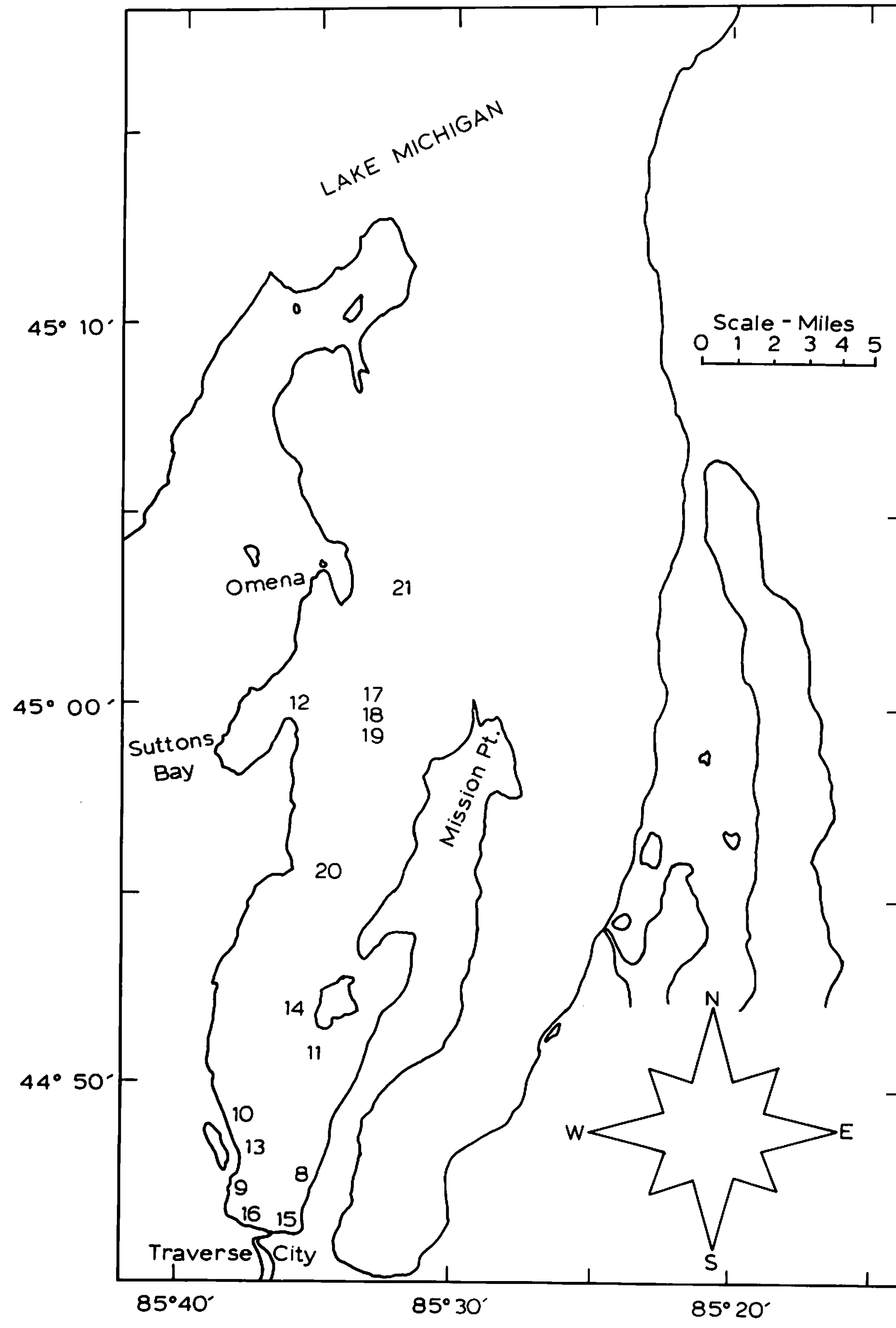
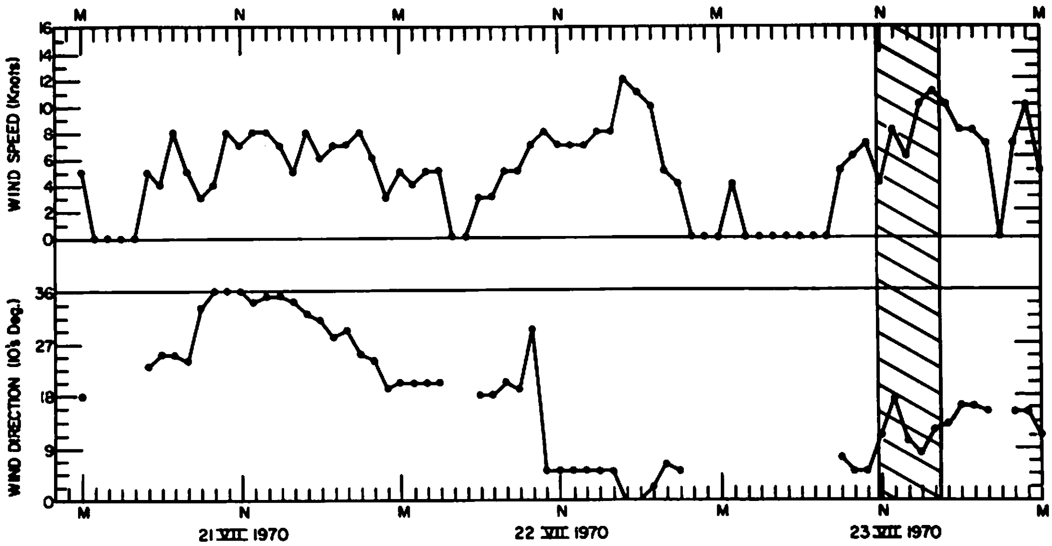

LAKE MICHIGAN
Scale - Miles
0 1 2 3 4 5
45° 10′
45° 00′
44° 50′
85°40′
85°30′
85°20′
Omena
21
12
17
18
19
Suttons
Bay
Mission Pt.
20
14
11
10
13
8
9
16
15
Traverse
City
N
S
W
E

Figure 8

Drogue Pattern in West Arm Approximately 2 Miles North of Traverse City on 23 July 1970; Drogues 1 and 3 at 20 Meters Depth, 2 and 4 at 5 Meters


WIND SPEED (Knots)
WIND DIRECTION (10's Deg.)
M N M N M N M
21 VIII 1970
22 VIII 1970
23 VIII 1970

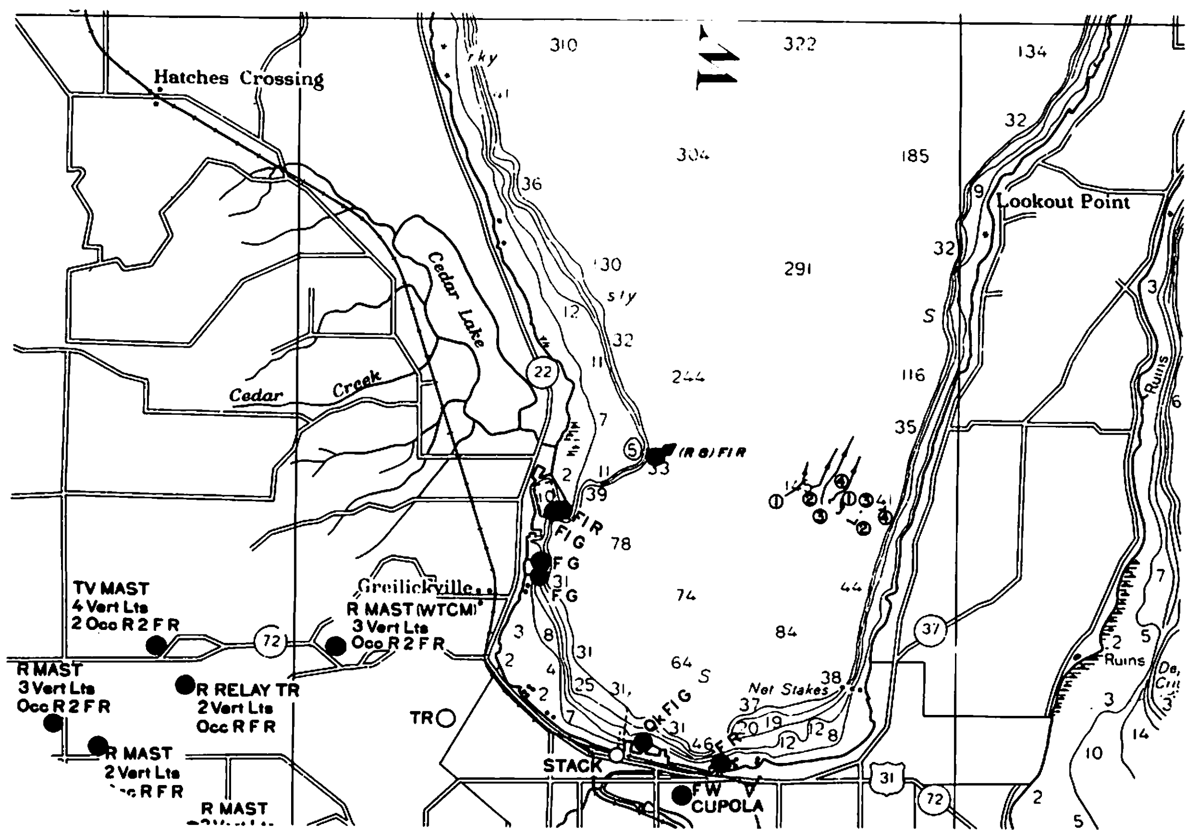
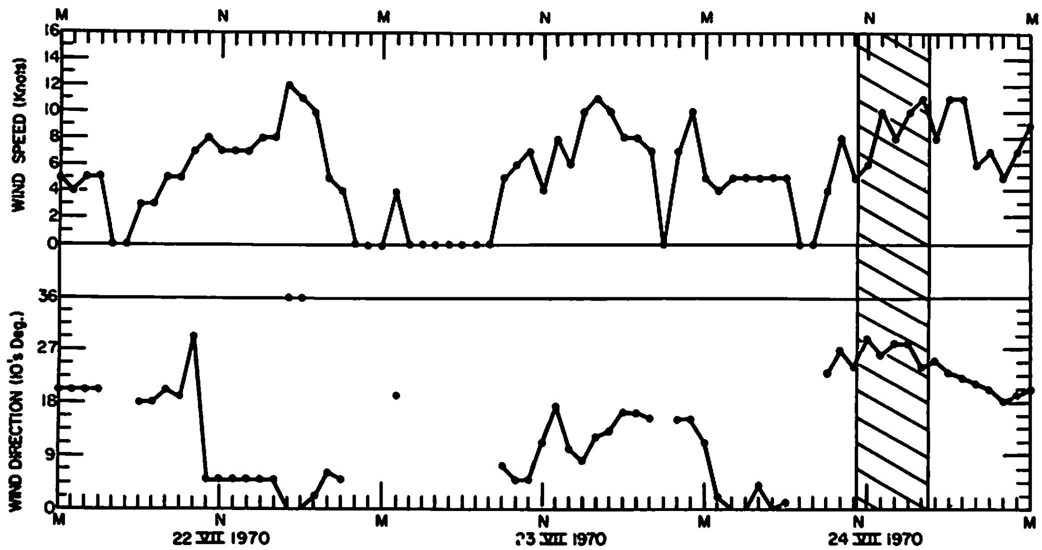

Hatches Crossing
Lookout Point
Cedar Lake
Cedar Creek
Greilickville
TV MAST
4 Vert Lts
2 Occ R 2 F R
R MAST (WTCM)
3 Vert Lts
Occ R 2 F R
R MAST
3 Vert Lts
Occ R 2 F R
R RELAY TR
2 Vert Lts
Occ R F R
R MAST
2 Vert Lts
R MAST
TR
STACK
CUPOLA
Net Stakes
Ruins

Figure 9

Drogue Pattern in West Arm North of Traverse City on 24 July 1970; Drogues 1 and 3 at 20 Meters Depth, 2 and 4 at 5 Meters


WIND SPEED (Knots)
WIND DIRECTION (10's Deg.)
22 VII 1970
23 VII 1970
24 VII 1970

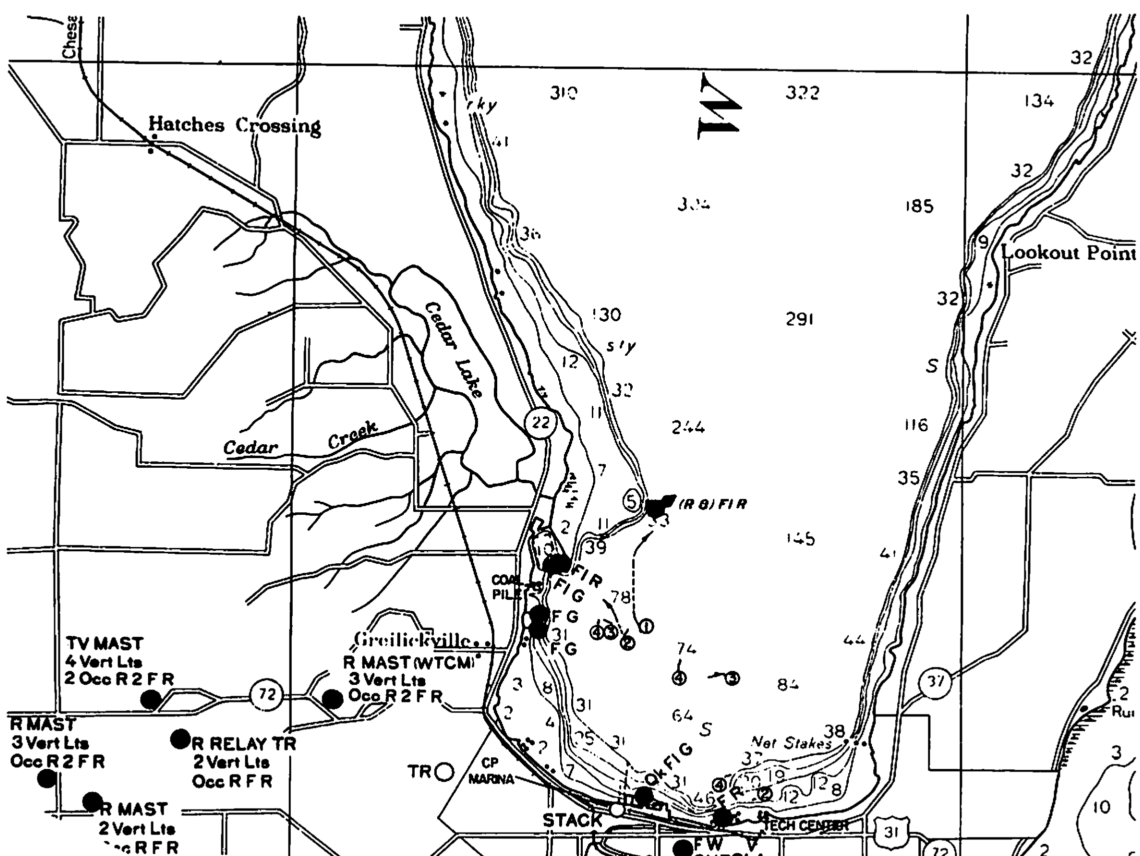
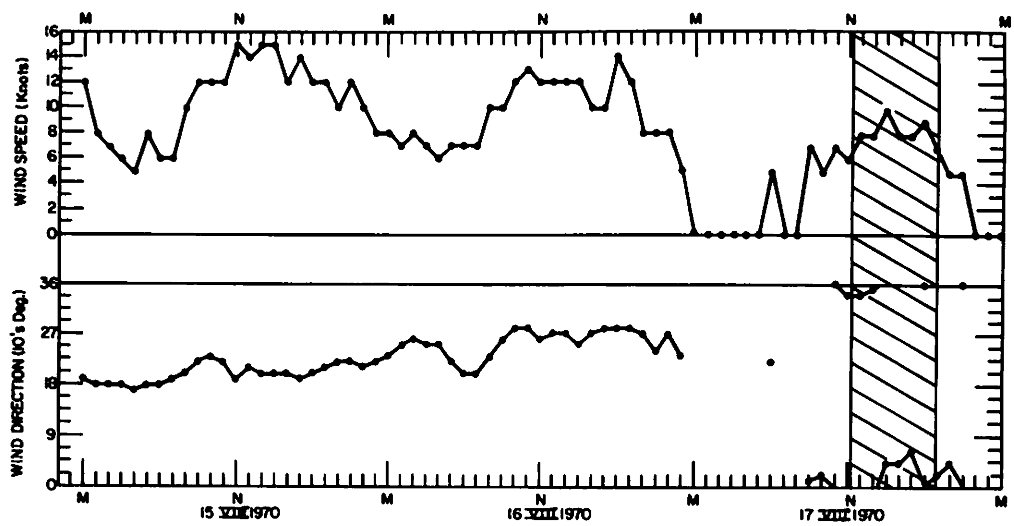

Hatches Crossing
Lookout Point
Cedar Lake
Cedar Creek
Greilickville
TV MAST
4 Vert Lts
2 Occ R 2 F R
R MAST (WTCM)
3 Vert Lts
Occ R 2 F R
R MAST
3 Vert Lts
Occ R 2 F R
R RELAY TR
2 Vert Lts
Occ R F R
R MAST
2 Vert Lts
R MAST
COAL PILE
CP MARINA
STACK
CUPOLA
TECH CENTER
Net Stakes

Figure 10

Drogue Pattern in West Arm Approximately 4 Miles North of Traverse City on 17 August 1970; Drogues 1 and 4 at 5 Meters Depth, 2 and 5 at 20 Meters, and 3 and 6 at 35 Meters


WIND SPEED (Knots)
WIND DIRECTION (10's Deg.)
M N M N M N M
15 VIII 1970
16 VIII 1970
17 VIII 1970

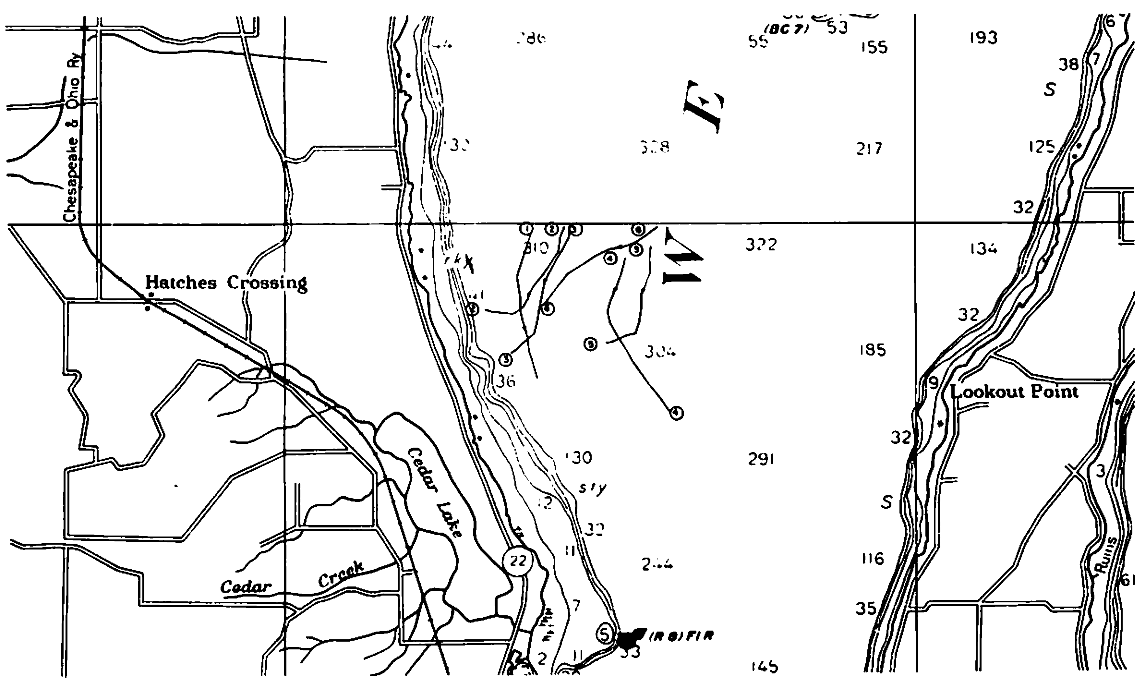
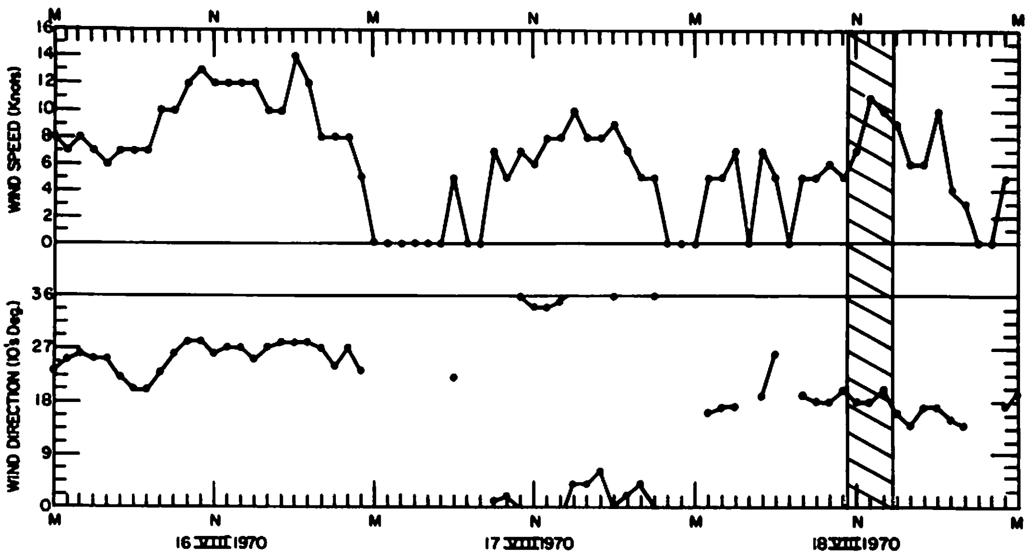

Chesapeake & Ohio Ry
Hatches Crossing
Cedar Lake
Cedar Creek
Lookout Point
Ruins

Figure 11

Drogue Pattern in West Arm South of Marion Island on 18 August 1970; Drogues 1 and 4 at 5 Meters Depth, 2 and 5 at 20 Meters, and 3 and 6 at 35 Meters


WIND SPEED (Knots)
WIND DIRECTION (10's Deg.)
M
N
16 VIII 1970
17 VIII 1970
18 VIII 1970

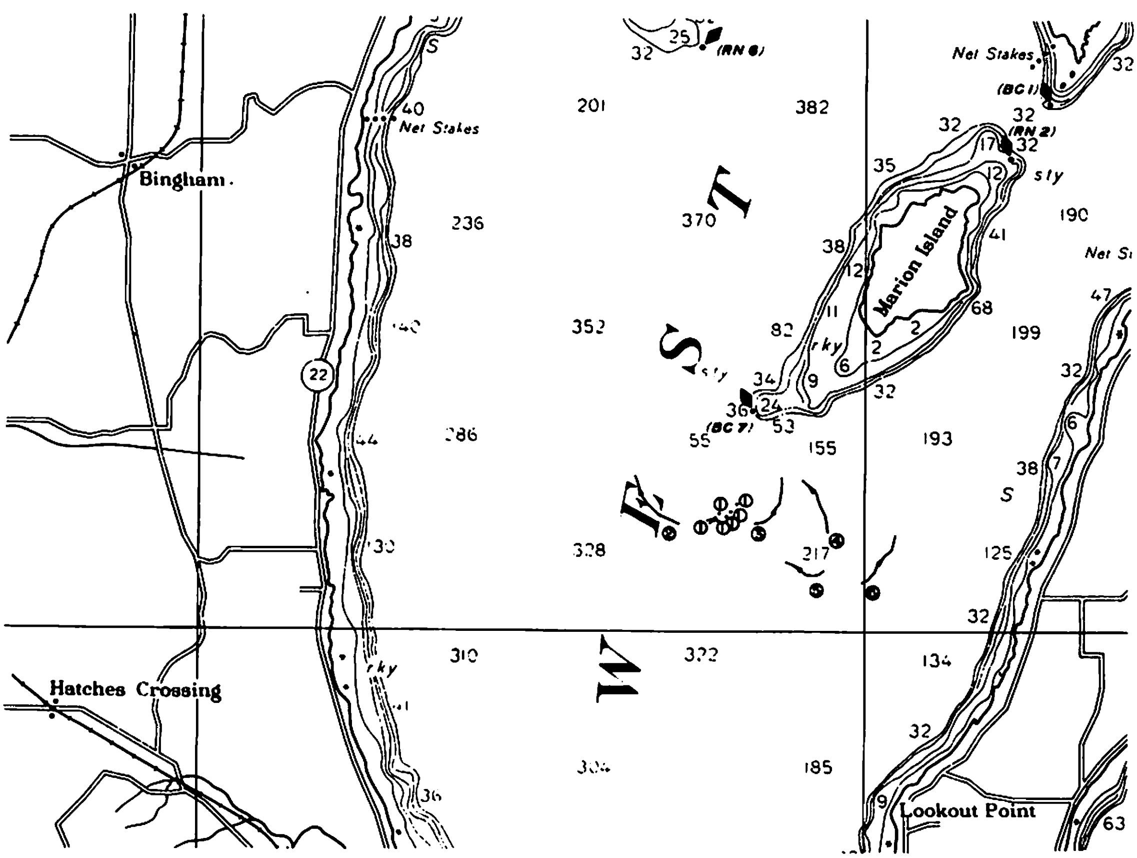
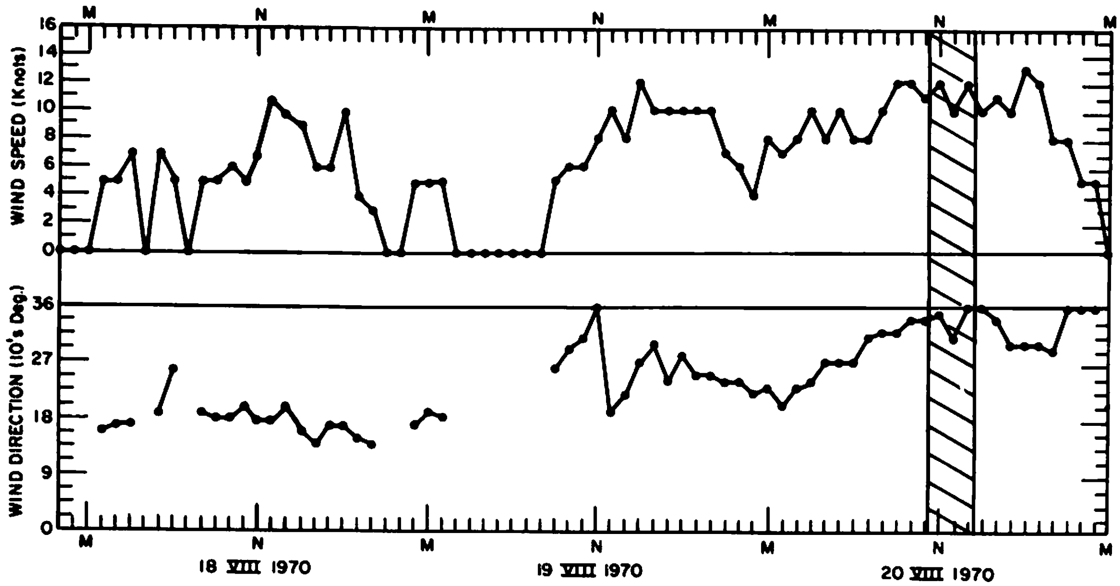

Bingham
Hatches Crossing
Lookout Point
Marion Island
Net Stakes
22
(RN 6)
(RN 2)
(BC 1)
(BC 7)
T
S
W

Figure 12

Drogue Pattern in West
Arm off Suttons Point on
20 August 1970; Drogue 1
at 35 Meters Depth, 2 at
20 Meters, and 5 at 5 Meters


WIND SPEED (Knots)
WIND DIRECTION (10's Deg.)
18 VIII 1970
19 VIII 1970
20 VIII 1970

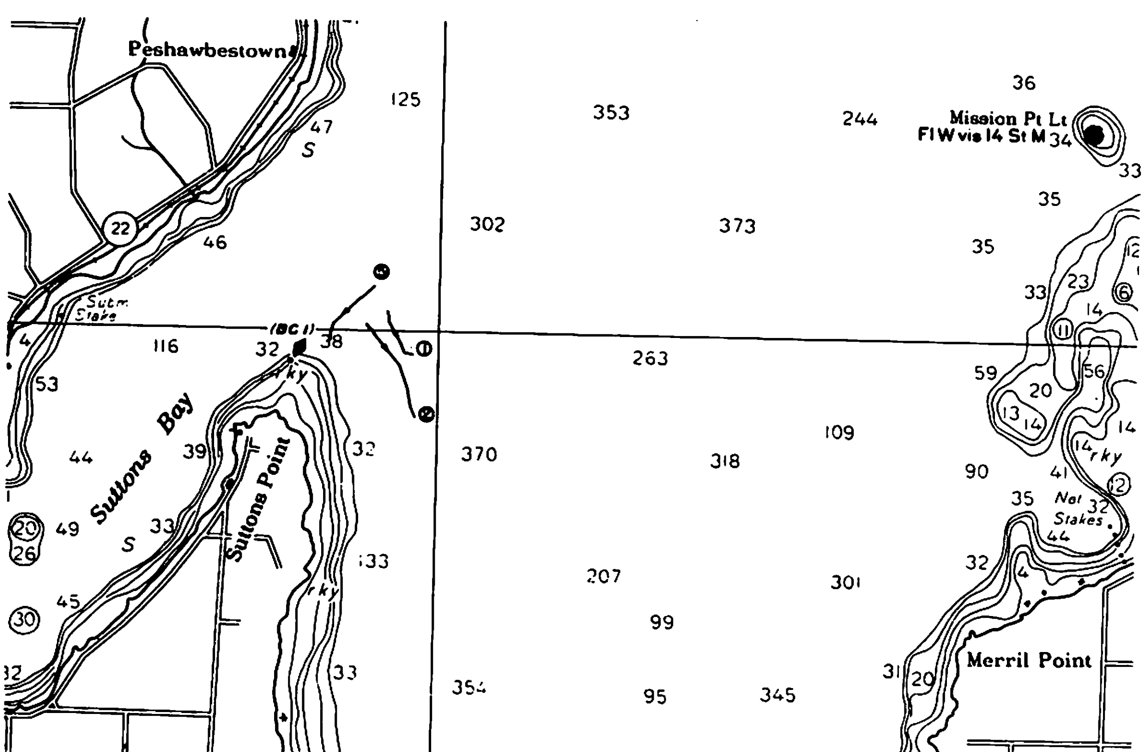
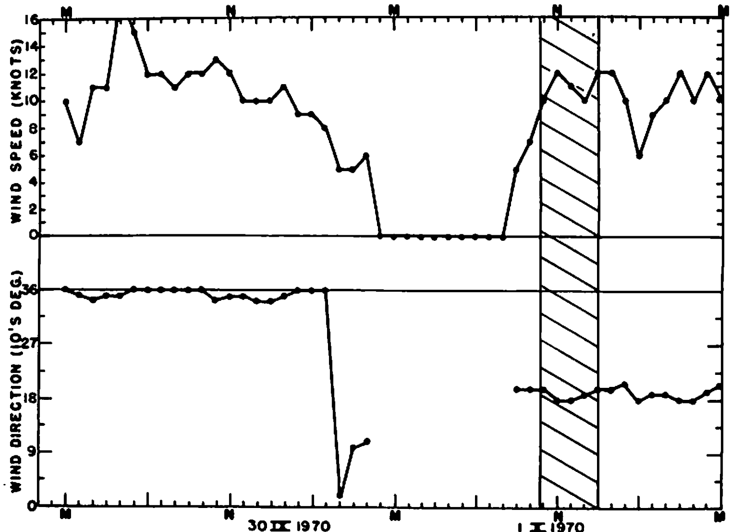
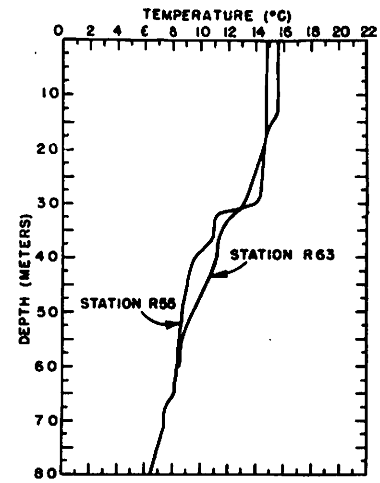

Peshawbestown
Suttons Bay
Suttons Point
Mission Pt Lt
Fl W vis 14 St M 34
Merril Point
Net Stakes
rky

Figure 13

Drogue Pattern in West Arm Approximately 2 Miles North of Traverse City on 1 October 1970; Drogues 1 and 4 at 5 Meters Depth, 2 and 5 at 20 Meters, and 3 and 6 at 35 Meters


WIND SPEED (KNOTS)
WIND DIRECTION (10'S DEG.)
30 IX 1970
1 X 1970


TEMPERATURE (°C)
DEPTH (METERS)
STATION R63
STATION R55

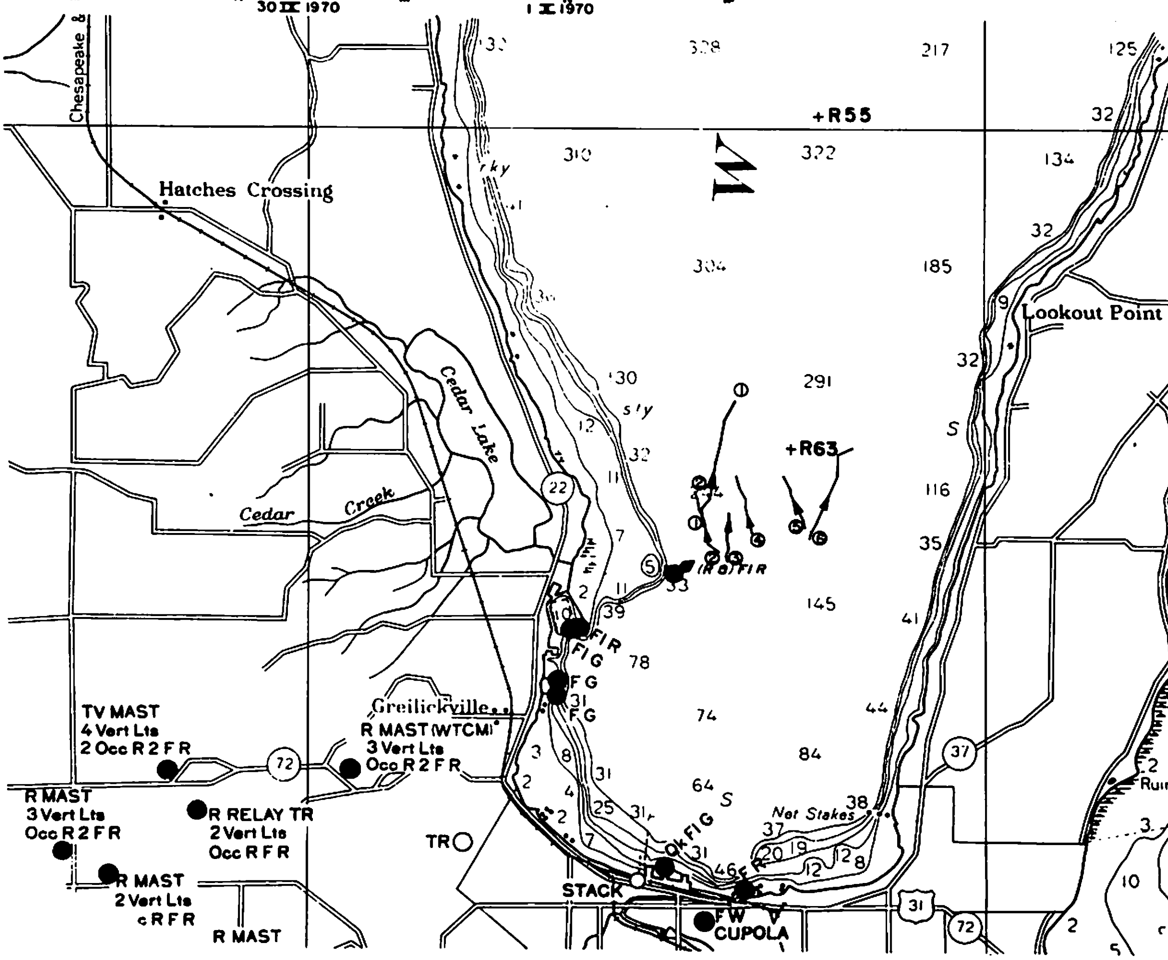

+R55
+R63
Hatches Crossing
Lookout Point
Cedar Lake
Cedar Creek
Greilickville
TV MAST
R MAST
R RELAY TR
STACK
CUPOLA
Chesapeake &
Net Stakes
Ruins

Figure 14

Drogue Pattern in West Arm Southwest of Marion Island on 6 and 7 November 1970; Drogues 1 and 4 at 5 Meters Depth, 2 and 5 at 20 Meters, and 3 and 6 at 35 Meters

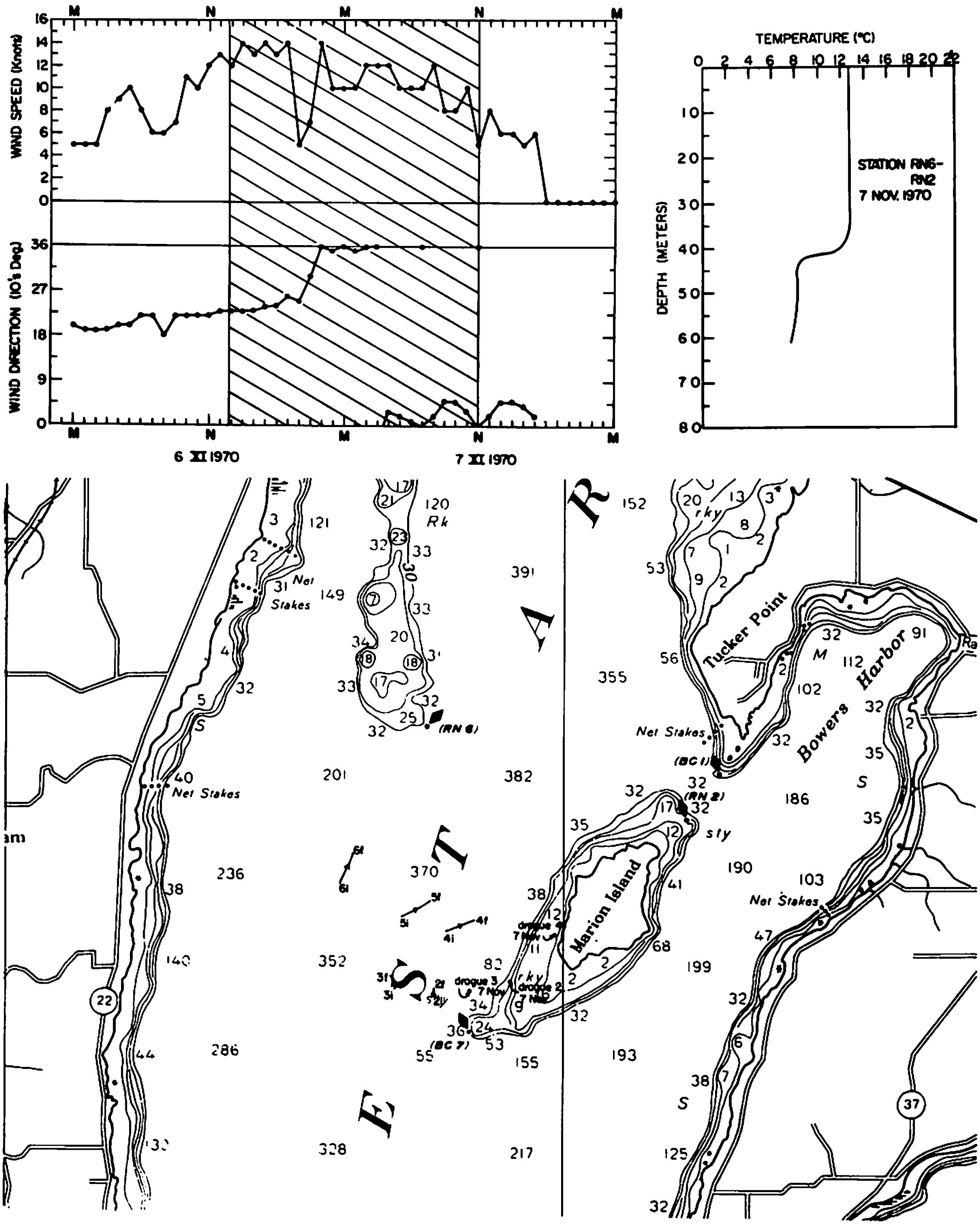
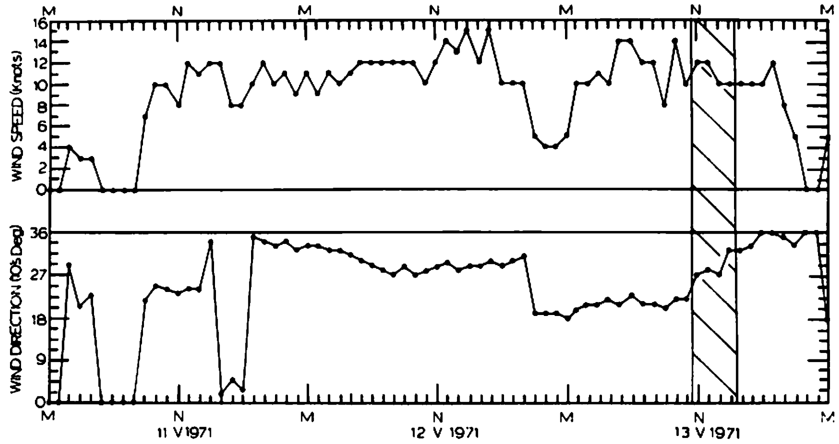

WIND SPEED (Knots)
WIND DIRECTION (10's Deg.)
M
N
6 XI 1970
7 XI 1970
TEMPERATURE (°C)
DEPTH (METERS)
STATION RN6-RN2
7 NOV. 1970
Tucker Point
Bowers Harbor
Marion Island
Net Stakes
(RN 6)
(RN 2)
(BC 1)
(BC 7)
drogue 3
7 Nov
drogue 2
7 Nov
22
37

Figure 15

Drogue Pattern in West Arm Immediately North of Traverse City on 13 May 1971; Drogue Depths as Indicated in the Figure


WIND SPEED (knots)
WIND DIRECTION (10's Deg)
M N M N M N M
11 V 1971
12 V 1971
13 V 1971

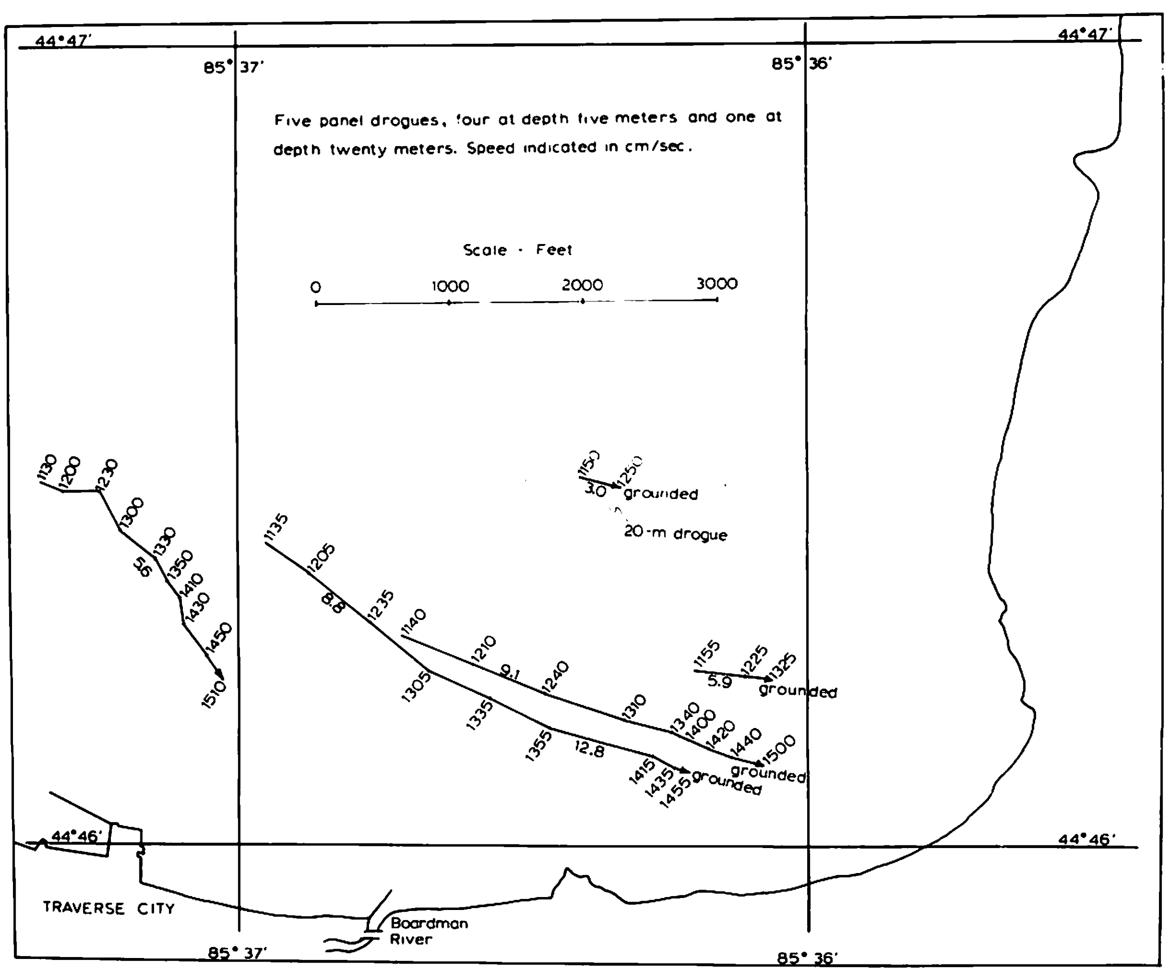
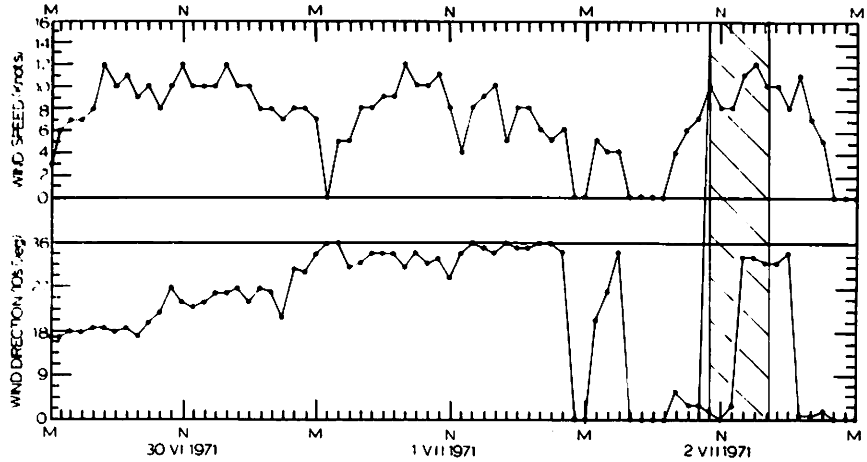

44°47'
85° 37'
85° 36'
Five panel drogues, four at depth five meters and one at depth twenty meters. Speed indicated in cm/sec.
Scale - Feet
0 1000 2000 3000
grounded
20-m drogue
grounded
grounded
grounded
44°46'
TRAVERSE CITY
Boardman River

Figure 16

Drogue Pattern in West Arm Immediately North of Traverse City on 2 July 1971; Drogue Depths as Indicated in the Figure


WIND SPEED (knots)
WIND DIRECTION (10's deg)
30 VI 1971
1 VII 1971
2 VII 1971

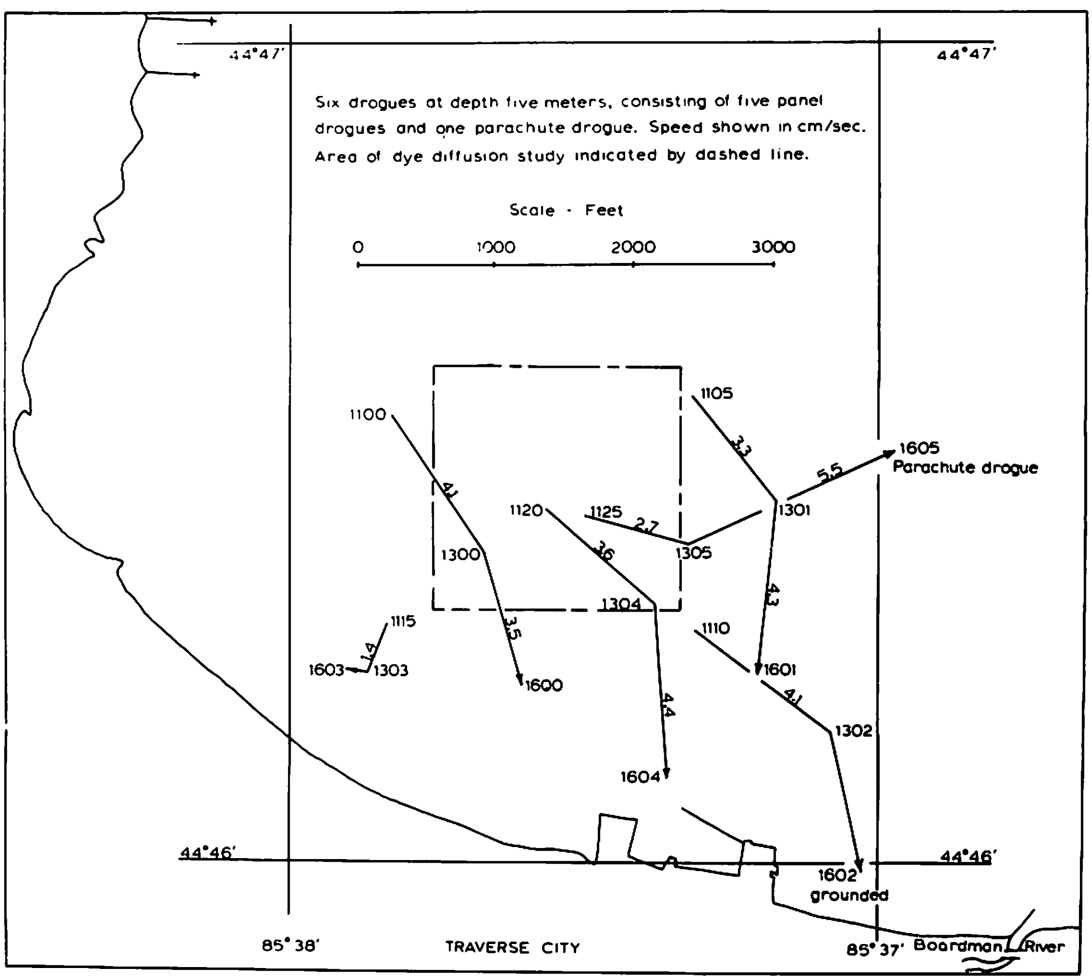

44°47'
Six drogues at depth five meters, consisting of five panel drogues and one parachute drogue. Speed shown in cm/sec. Area of dye diffusion study indicated by dashed line.
Scale - Feet
0
1000
2000
3000
1100
1105
1605
Parachute drogue
1301
1120
1125
1305
1300
1304
1115
1110
1603
1303
1600
1601
1302
1604
1602
grounded
44°46'
85° 38'
TRAVERSE CITY
85° 37'
Boardman River

Figure 17

Drogue Pattern in West Arm off Mission Point on 26 July 1972; All Drogues at 3 Meters Depth

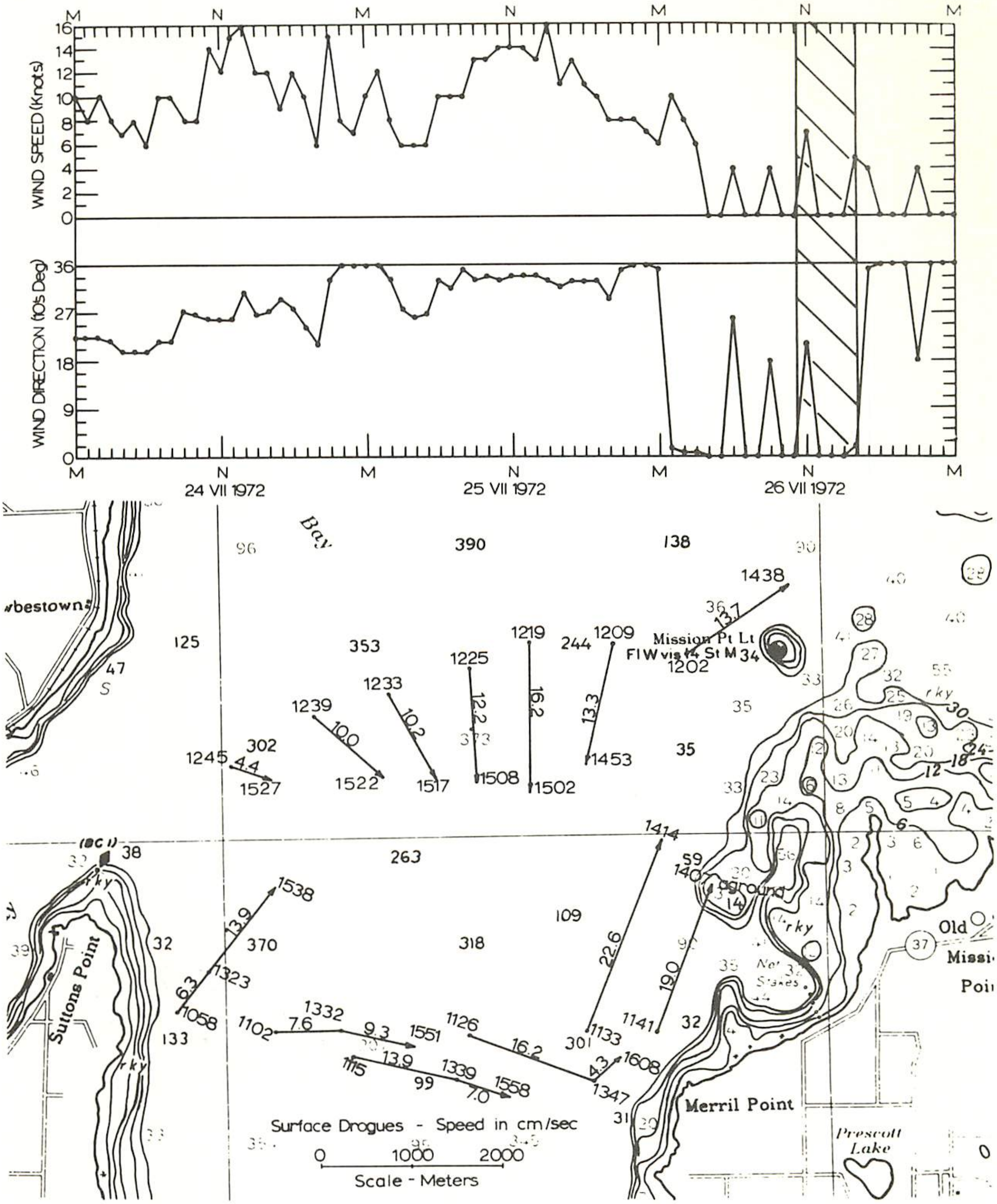
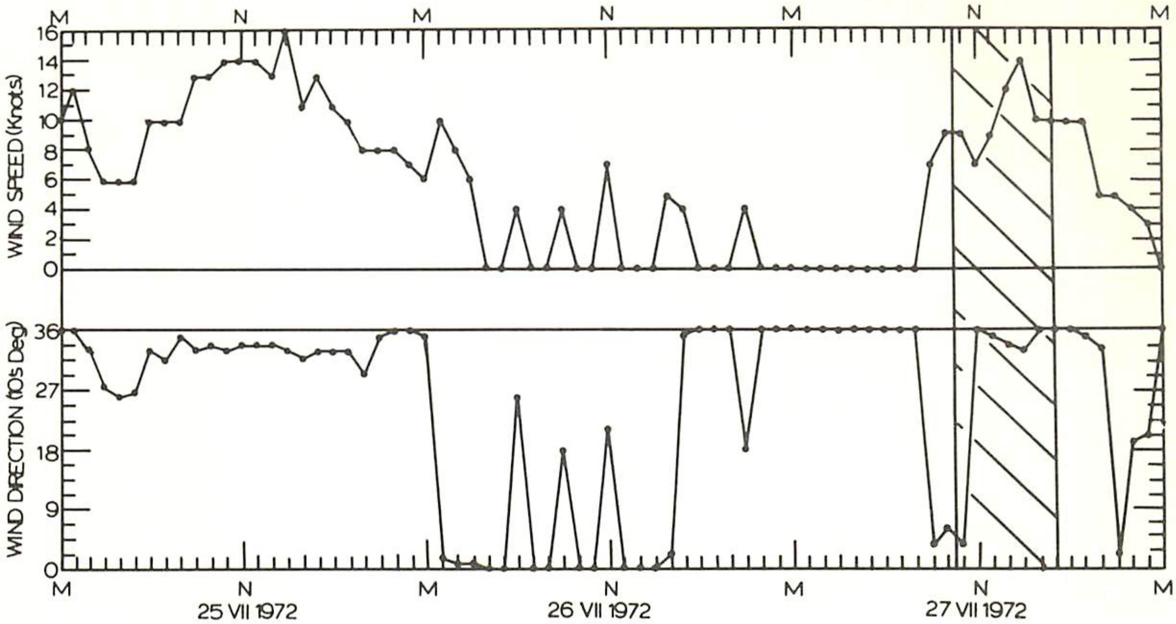

WIND SPEED (Knots)
WIND DIRECTION (10's Deg)
M
N
24 VII 1972
25 VII 1972
26 VII 1972
Bay
Suttons Point
Mission Pt Lt
Merril Point
Prescott Lake
Old
Surface Drogues - Speed in cm/sec
0
1000
2000
Scale - Meters

Figure 18

Drogue Pattern in West Arm off Mission Point on 27 July 1972; All Drogues at 3 Meters Depth


WIND SPEED (Knots)
WIND DIRECTION (10's Deg)
M
N
25 VII 1972
26 VII 1972
27 VII 1972

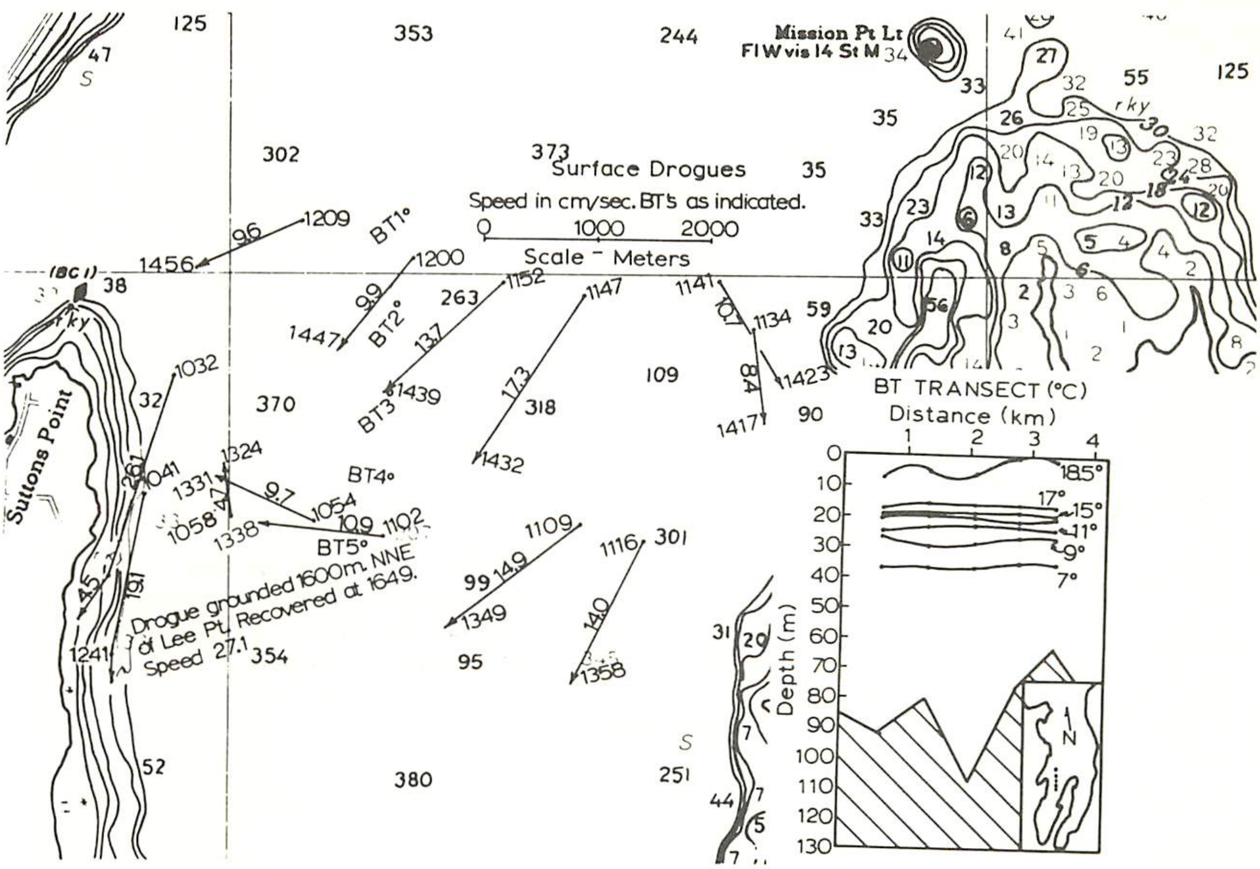
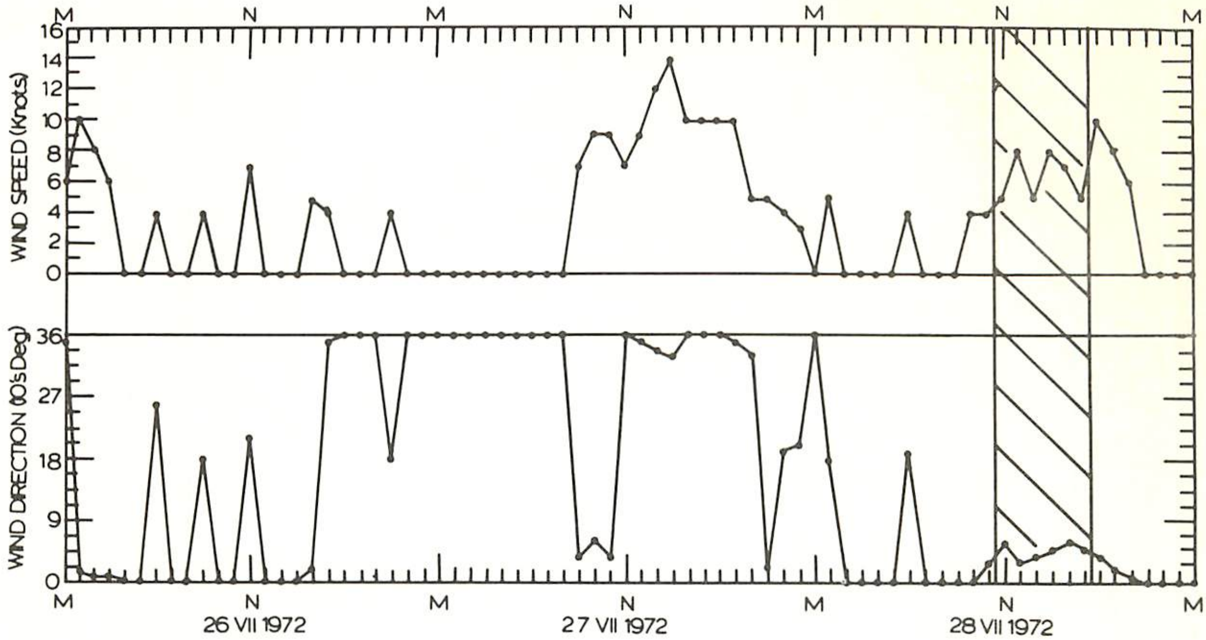

Surface Drogues
Speed in cm/sec. BT's as indicated.
Scale - Meters
Mission Pt Lt
Fl W vis 14 St M
Suttons Point
Drogue grounded 1600m. NNE of Lee Pt. Recovered at 1649. Speed 27.1
BT TRANSECT (°C)
Distance (km)
Depth (m)

Figure 19

Drogue Pattern in West Arm off Mission Point on 28 July 1972; All Drogues at 3 Meters Depth


WIND SPEED (Knots)
WIND DIRECTION (10's Deg)
26 VII 1972
27 VII 1972
28 VII 1972

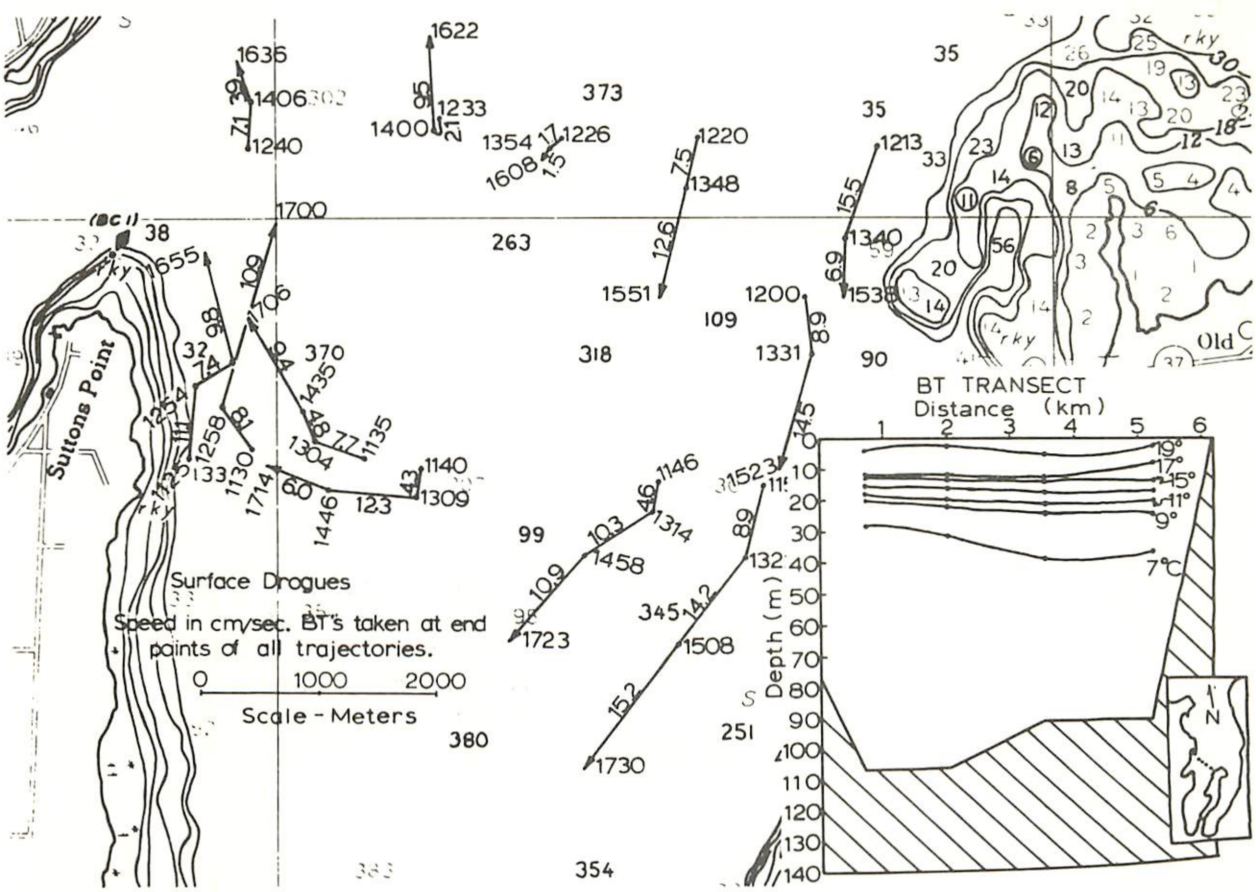

Suttons Point
Surface Drogues
Speed in cm/sec. BT's taken at end points of all trajectories.
Scale - Meters
BT TRANSECT
Distance (km)
Depth (m)

Figure 20

Drogue Pattern in West Arm off Lee Point on 15 August 1972; All Drogues at 3 Meters Depth

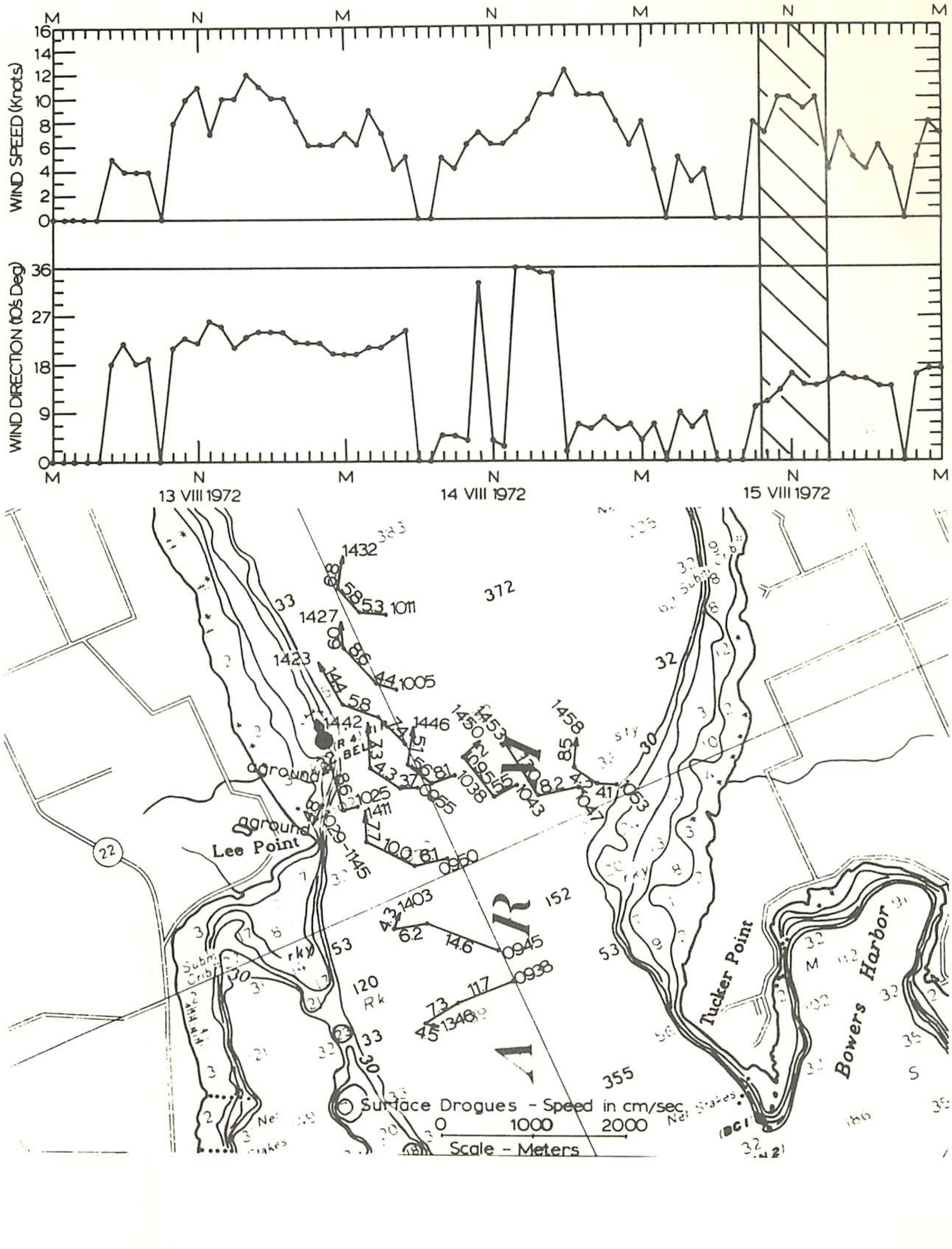
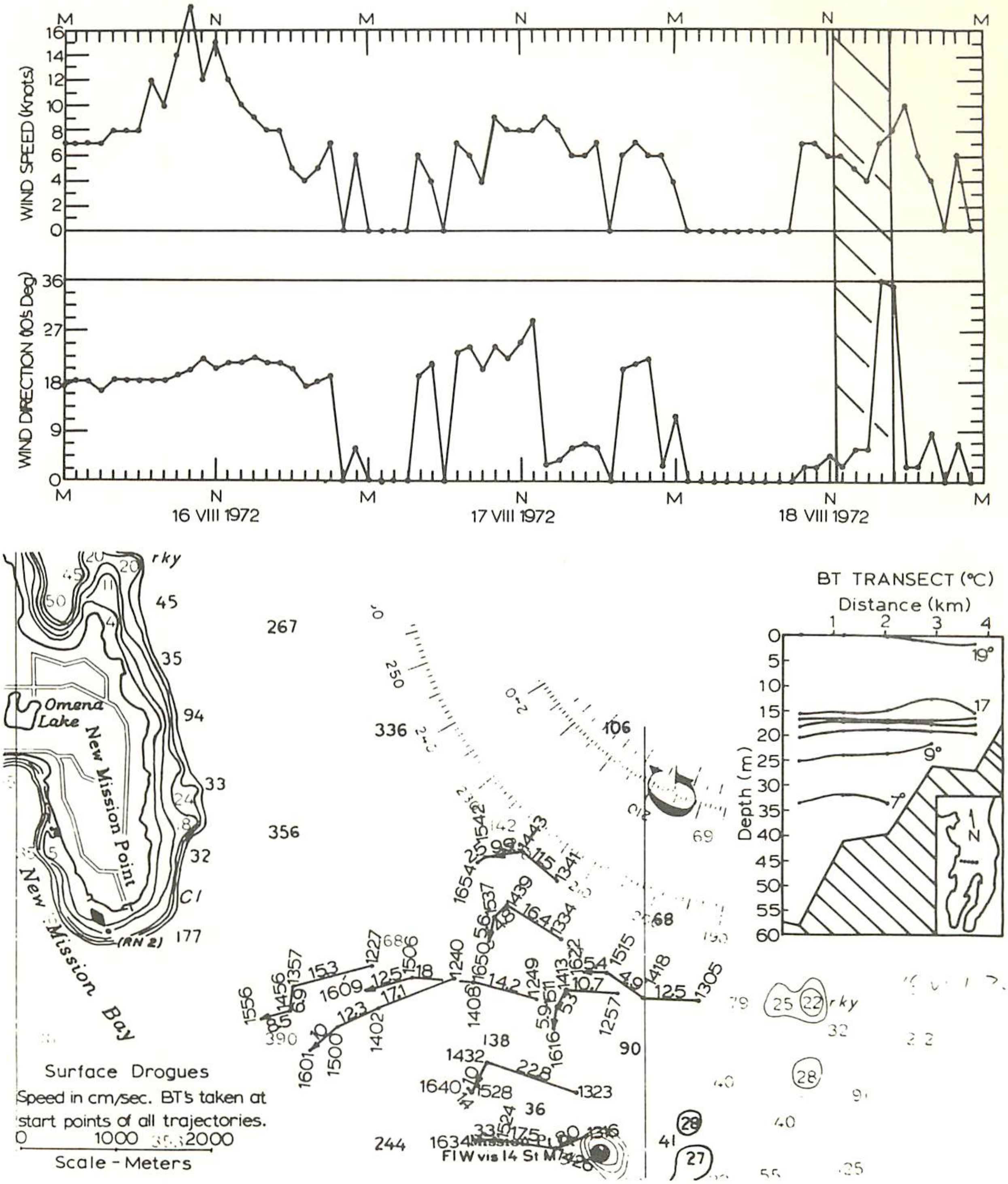

WIND SPEED (Knots)
WIND DIRECTION (10's Deg)
13 VIII 1972
14 VIII 1972
15 VIII 1972
Lee Point
Tucker Point
Bowers Harbor
Surface Drogues - Speed in cm/sec
0 1000 2000
Scale - Meters

Figure 21

Drogue Pattern East of Omena on 18 August 1972; All Drogues at 3 Meters Depth


WIND SPEED (Knots)
WIND DIRECTION (10's Deg)
M
N
16 VIII 1972
17 VIII 1972
18 VIII 1972
Omena Lake
New Mission Point
New Mission Bay
BT TRANSECT (°C)
Distance (km)
Depth (m)
Surface Drogues
Speed in cm/sec. BT's taken at start points of all trajectories.
Scale - Meters
0 1000 2000

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