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PHYSICAL EXPERIMENTS IN THE CENTRAL BASIN
PROPOSAL AND EXPERIMENT PLAN

by
F.M. Boyce

National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario
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1. INTRODUCTION

Recent work by Charlton (1979) has forced a re-examination of the apparent historical trend towards more severe late-summer hypolimnetic oxygen depletion in the Central Basin of Lake Erie (Dobson and Gilbertson, 1971). The conventional wisdom links rapid depletion with increased nutrient loading and upper layer productivity. Charlton's view is that the trend may be more apparent than real when physical factors such as mean hypolimnion temperature and mean epilimnion thickness are properly accounted for. In any case, it seems clear that the year-to-year variability in depletion is strongly influenced by physical factors and that these, at the present moment, are poorly known.

Oxygen depletion to the point of anoxic conditions seems to be a very touchy and ephemeral business. It occurs late in the summer at a time when a major storm might destroy the remnants of the summer stratification. At this time too, a curious "reverse entrainment" process has been observed wherein the hypolimnion increases in volume through incorporation of the thermocline water directly above it. (Burns and Ross, 1972). This process adds substantially to the reserves of dissolved oxygen available to the hypolimnion and may help to delay or to stave off the anoxic conditions. Blanton and Winklhofer (1972) point out that the timing of wind events seems critical to the appearance of the "reverse entrainment" phenomenon. A "relaxation period" between wind events is needed to weaken the very strong thermal gradients encountered in the main thermocline before "reverse" entrainment" can commence.

The observations which we possess so far, are of an integrated nature where entrainment rates have been deduced from basin-wide EBT surveys. We have yet to observe this phenomenon as it develops at a point in mid-basin. Furthermore, although we have models of thermal structure at our disposal which enjoy reasonable success in predicting the average characteristic of the thermal structure (Lam and Schertzer, 1980) these models are integrative in that they subsume a variety of processes into an effective eddy diffusion coefficient and they assume too, that the driving mechanical energy source is the wind.

We are thus ill-equipped, both observationally, and theoretically to predict the occurrence of late summer anoxia or to use past data to assess the variability of this phenomenon, particularly as it may depend on physical processes.

There are two main experimental approaches to this question. One takes advantage of the closed nature of the basin and forms basinwide averages of parameter distributions, or budget approach. This approach requires extensive sampling over wide areas and is correspondingly coarse in time resolution. The results are all the more useful if we have some physical theory into which they can be fitted, such as models of the formation and deepening of wind mixed layers.

The second approach is to try to make dense observations in time and space in a limited region where the phenomenon is thought to occur in the clearest form. Direct observation may provide some insight as to what is actually happening as opposed to inferences drawn from the process's signature on a lakewide budget. The direct approach seems better suited to the somewhat will-o-the-wisp prelude to late summer anoxia.

2. BASIC PHYSICAL EXPERIMENT - GOALS AND CONSTRAINTS

In the following paragraphs we shall develop a plan for an experiment designed to witness at firsthand some of the physical processes connected with the late summer oxygen budget of the Central Basin hypolimnion. A similar attempt was made in 1979 (see Boyce, 1980) and we are drawing on that experience to refine our experimental techniques.

The theoretical underpinning of the experiment is the momentum equation for horizontal motion. Written in words we have

(1)

Local Horizontal acceleration of fluid particle

(2)

= Advection terms (Horizontal flux of momentum) +

(3)

(Vertical flux of momentum due to wind stress on surface interfacial and bottom friction at boundaries, buoyancy flux.) +

(4)

(Pressure gradient forces due to free surface tilts and barometric pressure) +

(5)

(Pressure gradient forces due to tilting of isopycnals)

(6)

(Horizontal turbulent fluxes of momentum (diffusion)) +

(7)

(Coriolis force)

Term (3), the vertical flux of momentum within the fluid, is of particular significance to the dissolved oxygen transfer problem since the turbulence which exchanges momentum also exchanges chemical and biological species. It is possible in principle to measure this term directly using the underwater equivalent of cross-wire anemometers. This is a delicate measurement however, and not suited for long periods of data gathering. Moreover, the measurement of this term in isolation of the others rules out the possibility of developing useful parameterizations of the turbulent exchanges in terms of the more accessible mean flow variables.

The broad strategy then, is to measure all the accessible terms in the momentum equation (1,2,4,5,6, and 7). In principle, Term 3, the vertical flux term, will be available as a residual. A similar approach has been taken by Hamblin and Salmon (1975) who use observations of wind current and water level to infer vertical eddy diffusivities. In practice, the residual term may be small or masked by errors in estimating the other terms, but this need not imply failure of the whole experiment. In the attempt to define these terms, the ambient flow conditions are carefully measured and these in turn can be used with existing parameterizations - to verify them perhaps on a longer time scale. In the paragraphs below, we discuss the problems of measuring the different terms in the momentum balance equation.

Horizontal Velocity Field

Terms 1, 2, 6, and 7 require knowledge of the velocity field and in both time and space. Since we are interested in the vertical flux terms at specific levels, or more correctly, material interfaces such as the top of the thermocline, it makes sense to develop vertically integrated forms of the momentum equation over, say, the upper mixed layer. The problem then is how to estimate vertical averages of the velocity field given a maximum of four or five recording current meters in a vertical string.

Since the area in which we propose to work is located in mid basin in an area of very uniform depth, it seems reasonable to assume that the velocity profiles in a "small" area are self-similar; that if one knew the complete velocity profile at a central point, one could fit profiles of this general shape to fixed point current meter data at other locations in the neighbourhood and thus construct vertical averages. One could probably find objections to this approach, particularly when current profiles are compared across the node of an internal standing wave, but such cases would be readily spotted if one had two or more current meters located in the domain of vertical integration.

There is, therefore, a very strong case to be made for the inclusion of detailed measurements of the vertical distribution of horizontal velocity at the central point of the experimental array.

A second consideration which arises in the estimate of terms 2 and 6 (horizontally advected and diffused momentum) is the horizontal scale of the energy bearing eddies and the distinction we make between advection of momentum with the "mean" current field and the diffusion of it through random motions. Specifically, the evaluation of the advective component of momentum transport required knowledge of the local velocity gradient. This is estimated by comparing simultaneous velocity measurements separated in space. It is clear that a measured velocity difference is significant to a computation of advected momentum only if the two instruments are responding to a flow structure which is coherent across the distance which separates them. Thus the time averaging implicit in the formulation of the momentum balance equation is connected to the physical separation of the elements of the measurement array. It makes no sense to install an array on a 5 km grid and then to compute momentum balances at say 10-minute intervals - not unless the rms current velocities are something like 20 knots. Study of the spectrum of one-point velocity measurements can yield estimates of the length scales associated with the energetic water movements, but even better are data from a network of instruments which can be examined as spatial coherences over a series of increasing distances. Given an instrument separation, and the spatial coherence as a function of frequency, the proper averaging interval for the momentum balance can be formed.

In the 1979 experiments, with little *a priori* knowledge of the spatial coherence of mid lake water movements, we arbitrarily selected 5 km as a minimum separation for the mid lake array. Before designing the 1980 array in detail, we propose to examine some of the current meter data from the previous summer to make sure that the separations match the scales of water movements.

Surface Pressure Gradient

Term 4, the surface pressure gradient requires knowledge of the height of the free surface above a horizontal reference level as a function of time and space. The term itself is proportional to the gradient or slope of the surface. The gradient at a point can be estimated by the slope of the plane locally tangent to the curved water surface. Three water level measurement points centred about the point at which the slope is to be measured are sufficient in principle. The practical difficulties arise because of the differential nature of the measurement (the gradient is proportional to water level differences between adjoining instruments) and the finite resolving power of the instrumentation.

A rough estimate of the water surface slope produced by a wind stress τ is given by $\eta_{sx} = \frac{\tau}{\rho g h}$ where h is the total depth of the water. A typical value for τ for moderate winds is 1 dyne/cm^2 and h at the c-11 is about 24 m. Surface slopes are then of the order of 4×10^{-7} or 0.04 cm/km. Absolute changes in water level at the mid basin site over a storm cycle might be of the order of 5 cm. The Aanderaa tide gauge is capable of a resolution of 1 part in 10^5 and an accuracy of 1 part in 10^4 of the full range of the pressure transducer. For the C-11 site a 20 m pressure transducer is appropriate making the resolution of water level ±0.02 cm and the accuracy ±0.2 cm. The minimum <u>difference</u> in water level that a pair of gauges can detect is then about 0.5 cm. Assuming that the gradients are constant with a value of .04 cm/km, these instruments must be separated by distance in excess of 10 km in order to detect the slope of the water surface. The assumption of constant water surface slope over 10 km horizontal separations may be reasonable for quasi-steady wind setups in response to well defined wind forcing (major storms) but is much less certain for the time scales of the free surface modes of oscillation (14 hours or less). To put it another way, the use of an array of pressure gauges separated by 10 km or more is a means of estimating free surface slope is consistent with an averaging period for the dynamic balance computations of 14 hours or more.

Hamblin and Salmon (1975) fitted interpolating polynomials to both water level data and barometric pressure in order to estimate the net external pressure gradient field acting on Lake Ontario. By augmenting the network of shore-based water level gauges (Figure 1) with some open lake sites, the interpolating polynomial method can doubtless be improved. Again, since this is an extension of the fixed array method, the scales of motion which can be "caught" by the method and the attendant time averaging necessary to avoid aliasing are dependent on the separation of the instruments.

Another approach to the surface pressure gradient problem uses a numerical hydro-dynamical model of the storm surge variety in a hindcasting mode. The model inputs are wind stresses over the basin, barometric pressures, and observed water levels. The model is "tuned" to simulate the water level data in appropriate (least-squares?) fashion. The computed water level can then be used as input to the dynamic decomposition. Storm surge models themselves contain assumptions concerning the vertical transfers of momentum and, in particular, the loss of momentum through friction with the bottom. The virtue of the of the approach however, is that the horizontal resolution of the model does not depend on the spacing of control data points and the "interpolation" achieved by the model is dynamically correct.

A variant of this last scheme might be a form of objective analysis using both current meter data (vertically integrated mass transports) and water level data in order to form a dynamically consistent estimate of the surface slope.

The upshot of these arguments, insofar as the present experiment is concerned, is that the direct estimate of water surface slope is problematic but that moored water level gauges supplemented by shore stations will be necessary to make some kind of dynamic estimate of this term.

Internal Pressure Gradient

In a two layered water column, which is a good approximation to the Central Basin situation, the lower layer is acted upon by a pressure gradient due to the tilting of the thermocline from the horizontal. The gradient is given by

$$\frac{dp_i}{dn} = -\rho g\left(\frac{\Delta\rho}{\rho}\right)\frac{d\eta_i}{dn} = -g\Delta\rho\,\frac{d\eta_i}{dn}$$

where n is in the direction of the maximum slope of the thermocline (defined as the surface with height η_i above a horizontal reference surface) $\Delta\rho$ is the density difference between the two layers. As with the surface pressure term, the obvious way to measure the internal pressure gradient is by determining the height of appropriately chosen isopycnal (isothermal) surfaces as a function of time and space. This can be achieved in principal with a network of three or more moored thermistor arrays (FTP's). Again, in the absence of a priori knowledge of how the thermocline behaves, we can only guess at the instrument separations needed to give a useful result. During the 1979 campaign, we supplemented the mooring data with several launch surveys in the vicinity of the Central Basin array. These surveys provide a quasi-synoptic picture of thermocline topography in the area on which we may base some order of magnitude estimates.

The FTP locations and the launch sampling grid are shown in Figure 2. The separation of the four FTP locations is about 10.5 km while the nearest sample points to the central point (C-11) are separated by about 4.5 km. For each of the launch cruises a reference isothermal surface was chosen as representative of the main thermocline. The depth of this surface was estimated from profiles taken at each of the stations. This estimate is probably accurate to ±0.2 m. The mean slope of the thermocline is equated to the mean slope of the isothermal surface and is estimated in three ways.

(i) least squares fit to a plane surface using the four FTP positions;
(ii) least squares fit to a plane surface using the C-11 station and the four nearest points;
(iii) eyeball estimate from hand-drawn contours.

The average thermocline slope is about 6.5×10^{-5} for both the 10.5 km and the 4.5 km data points but the rms direction difference is ±68°. The slopes estimated from contours are about two and a half times as big on the average, but given the accuracy of the measurement, one should not insist too heavily on this point.

Looking at the contoured plots of thermocline depths, one observes that in the five early cruises, the topography of the thermocline surface is quite convoluted. The slope varies considerably in magnitude and direction from point to point. The last two cruises, on the contrary, show evidence of a more planar tilt of the surface with uniform gradient. In the first case we may be seeing internal waves of the Poincaré type with wavelengths of 10 km or so, while the later two cruises suggest a more uniform cross lake tilt. Of course the measurements may be aliased by a quasi-random short internal wave field (Boyce, 1979) but there is enough correspondence between the slope calculated from the 10.5 km grid and that calculated from the 4.5 km grid to suggest that a mean gradient does exist.

The mean observed thermocline slope is 6.5×10^{-5}. In dynamic terms the pressure gradient exerted on the lower layer by this slope is

$$g\Delta\rho \frac{d\eta_i}{dn} \text{ dynes/cm}^3 = 980 \times 1 \times 10^{-3} \times 6.5 \times 10^{-5} = 6.4 \times 10^{-5}$$

The pressure gradient exerted by the free surface slope in response to a 1 dyne/cm² wind stress is

$$g\rho \left(\frac{\tau}{\rho g h}\right) = g\rho \frac{d\eta_s}{dn} = \frac{1}{20 \times 10^2} = 5 \times 10^{-4} \text{ dynes/cm}^3$$

where h is the thickness of the upper layer (20 m).

The internal pressure gradient seems to be a relatively small term in relation to the surface slope pressure gradient, but more careful work is needed to settle this question.

The problem in hand at the moment is how to measure a thermocline slope of the order of 5 cm per kilometre. The FTP systems have been designed primarily for broad descriptive measurements; we have not had to insist heretofore on very precise control of sensor depth. The sensor spacing is approximately 1 m. How closely can we interpolate the depth of an isotherm which falls between the sensors. We have observed (Boyce, 1979) that the temperature gradients can become so compressed that almost the entire thermocline region is spanned in a vertical distance of 1 m. If this is the case, it is easy to show that the error in estimating the depth of an isotherm in the thermocline using a simple linear interpolation can be as large as the sensor spacing (1 m in this case). If however, one has some a priori knowledge of the temperature profile say from an EBT cast in the area and if one can assume a similarity of profile shape across the area of interest, then the interpolation procedure can be made more accurate, assuming of course that the thermocline zone is never much thinner than the sensor spacing. We assume that the displacements giving rise to isotherm tilts when the thermocline is very compressed are in the first mode - all isotherms are displaced in phase with one another.

An essential piece of information then is a suite of continuous temperature profiles in the middle of the FTP array.

The second problem associated with this measurement is to determine the depth of the sensors in each of the thermistor arrays. The usual mooring configuration is a semi-taut arrangement; the buoy has a limited vertical movement before the cable becomes fully taut. In heavy seas the buoy is at times submerged. We found (Healey et al, 1980) that the anchors tended to sink in the soft mud pulling the buoys down. Extra chain was added between the cable and the anchor in mid season.

One way of determining the "drift" due to anchor settling is to make EBT casts in the vicinity at regular intervals. A single EBT cast per session is not enough; a burst of 5 or 6 over a 5-10 minute period will be needed to average out any short period internal waves.

A second method would be to incorporate a pressure transducer in the system - locating the transducer about half way along the cable. If a potentiometric transducer were used (assuming the correct resistance range) it could be substituted for a thermistor at a mid-depth breakout.

If a 10 m (1 bar) pressure transducer were used with an accuracy of 1% full scale (garden variety), the depth precision might be kept to ±10 cm (not counting distortions in the cable shape caused by currents). Allowing an equal contribution from the vertical interpolation error, the best precision we might hope for is ±20 cm in the estimate of isotherm depth using an FTP. This means that we will not be able to distinguish true isotherm slopes from measurement error over distances which are much less than 10 km. The minimum baseline for measuring both the surface pressure gradient and the internal pressure gradient is about 10 km.

Measurements of Surface Windstress, Solar Radiation, Bottom Stress, and Internal Waves

Term 3, the vertical flux of horizontal momentum, responds primarily to surface fluxes at the top (wind stress) and bottom (bottom friction) of the water column. The vertical distribution of the momentum we know to be strongly influenced by the density field (turbulent "mixing" must do extra work to overcome the stability imposed by vertical density gradients). Since the density field is governed by the temperature field, we must then be concerned with the surface fluxes of heat as well as of momentum.

The wind stress vector may be estimated from the wind speed vector provided that the drag coefficient is known. The drag coefficient depends on the stability of the air column immediately above the water surface and the wave conditions (Donelan, 1979). The wind speed and direction as well as the temperature difference between the water surface and the air at anemometer height can be measured by the standard meteorological buoy. Wave characteristics are usually not available at unattended buoy sites. A waverider buoy located at the array centre could supply this information provided the receiving and recording equipment can be maintained close enough. This will limit the period during which wave records can be made to the anchor station experiment envisaged as an important part of this experiment (see below).

The surface heat flux can be approximated from data collected by a meteorological buoy which is equipped with a solar radiometer (air and water surface temperature, relative humidity, wind speed, incoming solar radiation). During the anchor station experiment, the radiation fluxes can be more accurately measured (total incoming radiation and incoming solar radiation). The subsurface distribution of the radiation can be determined during the anchor station period.

The bottom stress term is of particular interest in this experiment. During the transient episodes of reverse entrainment the hypolimnion must become turbulent enough to entrain some of the overlying thermocline water. The source of the turbulence may be interaction of mean hypolimnion flow with the bottom or with the thermocline (dynamic instability at large wave numbers). Earlier experiments (see Boyce, 1979) reveal the presence of short period (1-2 minutes) internal waves. The amplitudes of these waves appear to be coupled to wind events but not enough is known to say whether they arise from an interaction of surface wave trains, hypolimnion flow over an irregular bottom, or whether they extract their energy from the shear between the epilimnion and hypolimnion. The interaction of internal waves and mean current shear may be a source of enhanced vertical mixing (Woods, 1968).

It would be very exciting to measure the bottom stress with the eddy correlation method, however, I am not sure that we can put the necessary instrumentation together yet. A velocity profile is more easily obtained. We have developed the M-CATS system for this purpose (White, 1980) and look forward to the deployment of an improved version. Data from the continuously profiling G-VAPS system would be a valuable adjoint (Figure 3). The M-CATS system (Figure 4) samples the velocity at three levels (0.5 m, 1 m, and 4 m) above the bottom every 16 seconds over a 10 day period; the G-VAPS system has a design vertical resolution of 10 cm in velocity profile and a cycling time of perhaps 15 minutes. Assuming that the two systems can be placed close together, the data sets are complementary in time and space.

The thermistor array portion of the M-CATS system (Figure 4) is designed to measure the phase velocity and wavelength of the short period internal waves.

To test the hypothesis that internal waves may be involved in vertical mixing we need a means of measuring very small scale fluctuations of velocity and temperature near the bottom. An acoustic current meter and rapid response thermometer operated in a continuous mode would serve well (Kullenberg, 1979). Specifically we would look for bursts of high frequency activity correlated with the internal waves present. That is to say, the frequency of occurrence of the bursts of turbulence would be that of the internal waves. The high rate of sampling (five samples/sec., say) requires that this system be operated in short episodes and it would be convenient if the active periods could be chosen to suit the observed conditions. The current meter portion of Dr. Nriagu's bottom sampler looks to be ready-made for this purpose.

The foregoing has discussed the kinds of measurements to be made in order to establish a momentum balance via an Eulerian description of the flow field. A major goal is to establish the vertical momentum flux term primarily as a residual of the other terms in the momentun equation. Techniques more sophisticated than simple differencing may be used, such as objective analysis starting from various hypothetical models. The mainstay of this experiment is a network of individual autonomous moored instruments all of which yield time series data with fairly rapid sampling rates (six per hour).

3. ADDITIONAL GOALS: A SUPPORTING BIOCHEMICAL PROGRAM AND PHYSICAL MEASUREMENTS. USE OF LIMNOS AS ANCHORED SUPPORT PLATFORM. USE OF CSL ADVENT. NORTHSHORE CATS.

In the following paragraphs we propose some complementary work based on the presence of LIMNOS as an anchored platform in the centre of the mooring array and on the use of the ADVENT as a roving sampling platform.

Physical Experiments from an Anchored Ship

There have been several references earlier in this proposal to the presence of LIMNOS at the array centre and acting as a support platform for various physical activities. These are:

(i) reception of wave rider data;

(ii) support of "special" anchored systems;

(iii) MCATS and GVAPS

(iv) detailed temperature sampling.

One of the major problems in physical oceanography and physical limnology is the linking together of the two basic means of describing flow phenomena, Eulerian and Lagrangian. The Eulerian method describes the flow via the velocity field; each velocity component is expressed as a continuous function of the three space variables and time. An array of current meters produces a data set which may be interpolated to form an estimate of the velocity field and hence comprises a Eulerian flow measurement. The Lagrangian method of description specifies the instantaneous position of a "marked" fluid particle as a function of its initial coordinates and time. The tracking of a cluster of drogues furnishes an approximation to a Lagrangian flow description. The diffusion of a dye patch or the spreading of a soluble contaminant (tracking "marked" particles of water) is most easily measured and described in Lagrangian terms. However, information about water movements in a given locale are most easily provided by moored current meters (Eulerian measurement). The problem is how to describe the mixing properties of the flow field in terms of these Eulerian measurements. Can a description of the velocity at a number of fixed points be used to infer the paths taken by marked fluid particles in the vicinity of the measurement points? Many authors have attempted to define particle paths (statistically) from current meter data (Schott and Quadfarel, 1979). The relationship between Eulerian and Lagrangian descriptions being primarily empirically determined and possibly a function of the flow regime itself, opportunities to collect concomitant Eulerian and Lagrangian flow data are valuable. This point of view is widely shared and we know of several Eulerian-Lagrangian experiments either planned or in progress.

Drogues are favoured over dye patch experiments because they are inexpensive, data collection via radar tracking is straightforward and does not require special sampling and detecting gear. They are at some disadvantage because they move only horizontally and because their finite size "filters out" some of the motion at small scales.

One of the activities to be carried out from the anchored ship will be the radar-tracking of a cluster of drogues. During 1979 similar experiments were performed with a fair degree of success.

Additional experiments will broaden the data base for statistical purposes.

A further reason for using near surface drogues is the difficulty of obtaining current measurements at depths less than 10 m (wave contamination, ship damage). Surface drogue data collected in the vicinity of the current meter moorings is a valuable complement to the current meter data.

Dr. David Shonting of the Naval Underseas Systems Centre in Newport, Rhode Island, has developed instrumentation for measuring rapid current fluctuations (turbulence) at several levels. The support is a long (18 m) spar buoy. Very small (and sensitive) current meters are anchored to standoff arms located at intervals along the buoy. A recording package is carried on the buoy. The system is allowed to drift with the mean current and measures currents relative to the buoy. Data from this system would be very valuable and we have asked Dr. Shonting whether he is willing to participate. To date, the answer is affirmative.

Supporting Biochemical Program

The ultimate goal of the physical experiments is to determine what effects the physical processes may have on the biochemical ones. This interaction might be inferred later on if the vertical transports of momentum and heat could be expressed in terms of turbulent diffusion coefficients. It would be highly desirable though, to take advantage of the very thorough physical measurements and to plan a concurrent biochemical experiment. At the very least, closely spaced vertical profiles of some of the key parameters (dissolved oxygen, various phosphorus forms, nitrogen, carbon, optical properties, etc.) should be collected during the most intensive physical sampling at the centre of the current meter array. This work can be done from LIMNOS concurrently with the drogue experiment.

In the same way that a momentum balance must account for the possible horizontal advection of momentum, the chemical balance must allow for the possibility that an observed change may be due to horizontal movement of water of varying chemical concentrations as well as local transformation. The current meter network provides one-half of the information, the remainder, an assessment of the horizontal gradients of the chemical species must be provided by a special sampling program. In the absence of self-recording instrumentation, the sampling must be done from a surface vessel. We propose that the ADVENT be used for this purpose. A network of stations would be centred on the LIMNOS anchor position extending to distances of perhaps 10 km from the ship. Samples would be collected at these locations on a daily basis, and as rapidly as possible (quasi-symptotic). The analyses would be done onboard LIMNOS.

Northshore CATS Experiment

In 1979 an attempt was made to study the distributions of currents and temperatures on the northshore of the Central Basin in the vicinity of Pointe au Pins. The current meter data return was disappointing (Boyce, 1980) but the launch-based EBT survey showed a persistent upwelling and mixing within a few km of shore. The structure of horizontal currents in this narrow upwelling zone is particularly interesting. Are there, for example, persistent longshore currents? Can we detect onshore/offshore motions implied by the pattern of the isotherms?

We propose to install a few current meters on the northshore, much as we did in 1979, and to use the ADVENT to run local EBT surveys whenever possible. In addition, we propose to install the two CATS systems close to the shore where the upwelling was most evident.

4. EQUIPMENT AND RESOURCES

In the paragraphs below I have listed the various pieces of equipment needed for this experiment. This is a kind of worry list. For the sake of completeness, I have included items not strictly on the physics agenda but which have more to do with the biochemical aspects of the program. Exact geographical coordinates of moored instruments have not been finalized pending review of 1979 data.

4.1 Meteorological Buoys

Two meteorological buoys are the minimum requirement for this study. A third system would be highly desirable. One system should be equipped with a radiation sensor; it will be moored in the centre of the mid-lake array (near last year's C-11 site). The second system is to be moored near last year's C-9 site about 10 km from shore and midway between Point Pelee and Pointe aux Pins. The third system should be equipped with a radiation sensor as well and moored about 40 km east south-east of the C-11 site. All instruments should be rigged for 10 minute sampling (6 week endurance).

4.2 Conventional Current Meters (Plessey, Geodyne, RCM-12)

The total requirement is for about 30 current meters used in a one-shot deployment (10 minute sampling, 6 week endurance). The mix of meters should be about 18 Geodynes, 18 Plessey (or Grundy) and the remaining four could be RCM-12's (to continue the process of evaluating and upgrading these instruments). Most of the current meters will be located in the midbasin array. A few will be located on the north shore of the basin.

4.3 CAT Systems

Two CATS systems are proposed for the north shore of the basin between Point Pelee and Pointe aux Pins. In view of the problems in obtaining reliable turbidity measurements, we are relinquishing this option for the time being. We would like to equip the systems with thermistor staffs or cables, which would carry about 6 thermistors. The systems would be placed in 10-12 m of water about 1 km offshore. The thermistors should extend to a distance of 6 m above bottom (about 4-6 m below the water surface).

4.4 MCATS System

The MCATS system is being expanded to read more channels. The extra channels will be thermistors; the outrigger thermistors of 1979 have become outrigger arrays of 4 thermistors each and more thermistors have been added to the central staff. The acoustic current meter has beem replaced by an electromagnetic meter (see Figure 4). The system will be deployed in a fashion similar to that of the 1979 season; it will be set in place by LIMNOS at the beginning of the anchor station period and retrieved at the end. Required endurance is 9 full days and the sampling interval should be reduced to the smallest value yielding that endurance.

We have experienced difficulty in positioning the outrigger arrays relative to the main array. For a start, we propose that the markers for the main array and the outriggers be of the spar buoy type and that they be moored on taut wires (Figure 4). The marker buoys might conveniently be made of PVC or ABS tubing. With reasonable assurance that the markers lay close to or over the sensor strings, we could use the LIMNOS to estimate the direction of each arm of the triangle as well as the distance separating them. A scheme for doing this and which takes advantage of the accurate compasses and steadiness of the LIMNOS (compared with a Boston Whaler) is outlined in Figure 5 .

4.5 Rapid Sampling Bottom Current Meter

As a complement to the MCATS measurements there are several reasons (developed above) for wanting to measure horizontal currents at high sampling frequencies out to 5-10 samples/second and for periods of time of the order of 30 minutes (minimum). We anticipate on the basis of a recent paper by Kullenberg (1979) that the velocity fluctuations imposed on the mean current by bottom generated turbulence are of the order of 0.5 cm/s in a mean flow range of 5-10 cm/s. Velocity fluctuations imposed by breaking internal waves or shear instability may be larger. We do not know.

It would be useful to make measurements at at least two levels, close to the bottom (50 cm above) and close to the top of the hypolimnion (say, 2 m above the bottom). If the supporting vessel (LIMNOS) could be anchored fore and aft to reduce yawing, the sensors could be linked to the ship via a cable, with the recorder kept in the laboratory. By raising and lower the system and adjusting the height of the instrument, we could make successive runs of 30 minutes say at different elevations. I think we could assume that the environmental conditions are likely to remain fairly constant over the two hours or so it would take to make a pair of runs. A sketch (Figure 6) shows how this system might be configured.

We hope that the acoustic current meter (CMI) will be suitable for these measurements.

4.6 Drogues

The present design of drogues has some very good features both from the point of view of cost and hydrodynamic performance. The major difficulty we have encountered is the tendency for the radar echo to deteriorate when the wind and seas build up. In strong winds the surface pole "lies down" bringing the radar reflector close to the water surface.

The ability to track these drogues in rough weather could be improved by

1) setting the reflector higher up on the mast;
2) increasing the righting moment (more floatation, heavier ballast).

To achieve this will require a scaling up of the drogue, larger float, longer mast, increased sail area, heavier ballast. The new increase in size should not be so great that we are no longer able to launch and recover the drogues from a small boat. There are some further improvements which might be considered in order to make the units more robust. A sketch (Figure 7) summarizes these proposals. We will need 15 units for the August experiment.

4.7 GVAPS System

A concept sketch of the GVAPS system is given in Figure 3 . We count heavily on this system to provide details of the mean temperature and velocity profiles. At present the system is still under development. We plan to deploy it in the middle of the Central Basin array as soon as possible after the establishment of the current meter array and to maintain it until the removal of the array. Logistic constraints may limit us to the anchor station period when the LIMNOS can serve as a tending platform.

4.8 Electronic Bathythermodgraphs (EBT)

Two EBT systems will be in use during the experiment, one on LIMNOS and one on ADVENT. They are extremely important to the experiment and we therefore request that every precaution be taken to ensure reliability and accuracy.

4.9 Fixed Temperature Profilers (FTP)

Four systems are requested for this experiment, each with a nominal cable length of 21 m. Specifications as to thermistor distribution and mooring are identical to those of 1979. The exact locations of the systems will be defined at a later date.

Precise knowledge of the depth of the sensors is very important (see discussion above). We are proposing that a potentiometric pressure transducer be installed in each array in place of one of the upper thermistors (10 m nominally). The pressure signal, averaged over many readings to filter out wave induced noise, will reveal any tendency of the anchors to sink. Recall that we are particularly concerned about differential sinking among the four systems in the mid-lake array.

The systems are to be installed at the time of the main array (mid-July) and removed in early September. Ten minute sampling is required.

4.10 Shipboard Thermistor Array

During the anchor station period we intend to make detailed temperature profile measurements from the ship, in addition to those made by the other systems. One component of these measurements will be time series temperature data at 12 levels collected with a vertical thermistor array. The sampling rate is nominally one sample per second using thermistors with a 5-second time constant. A pressure sensor at the bottom of the array is used to determine sensor depths. This system has been successfully deployed in the 1979 field season (Boyce, 1979, 1980).

Experience with the very compressed thermocline in Lake Erie suggests that we should space most of the thermistors in the thermocline area, aiming at a spacing of 0.5 m in the zone of strongest gradients. The array should be raised or lowered from time to time to keep the closely spaced thermistors in the main thermocline. One of the thermistors in the dense part of the array should be of the 0.1 s time constant variety. It would be monitored at all times with the strip chart recorder in order to detect high frequency fluctuations possibly associated with shear instability.

4.11 Water Level Gauges

We intend to purchase four Aanderaa submersible water level gauges equipped with 0-20 m pressure gauges. Two more systems may be borrowed from Fisheries and Oceans. All groups will be installed in a bottom mounted configuration. Note that they must be about 5 m above the bottom in order to avoid overloads to the sensor or signal clipping. Data will be recorded every 10 minutes with the instrument integrating over seven minutes in order to filter out the surface wave signal.

4.12 Wave Rider System

We have arranged to borrow the wave rider buoy and receiver from Hydraulics Research Division for the duration of the experiment. The procedure will be exactly the same as in 1979. The antenna and receiver will be mounted aboard LIMNOS. The buoy will be moored at the beginning of the anchor station experiment and recovered at the end. The location will be close to the anchor station point. Recording of wave heights will be made for 40 minutes every three hours. In view of a loss of data experienced last year (Boyce, 1980) we feel it best to launch the buoy with the antenna and take the chance that the antenna may be damaged during the launch. For that reason a spare antenna should be carried aboard LIMNOS.

4.13 Radiation Sensor

As in 1979, we request that an incoming solar and an incoming allwave radiometer be mounted aboard LIMNOS during the active period of the experiment. (July 14 to September 5). Integrated totals and analogue chart recordings should be made of both sensor outputs.

4.14 Transmissometer and Spectral Irradiance Meter

The Martek system is not adequate for our purposes. We wish to use the new large-ship transmissometer during the anchor station experiment. This system contains a special winch. J. Jerome will provide technical details for both the transmissometer and the irradiance meter.

4.15 Water Sampling - Rosette, Bottles, Bottom Profiling Sampler

LIMNOS should be equipped with a Rosette system and spares. ADVENT should carry either a Rosette system if available or a complement of 6 Van Dorn bottles (and winch).

In 1979 we observed a high degree of variability in dissolved oxygen sampled one metre above the bottom. It is not known whether the variability was due to a combination of strong vertical DO gradients at the bottom and positioning error or uncertainty due to analytical error at very low DO values. It has been suggested that an optical or an acoustic triggering device could be used to close the sample bottle at a fixed distance above the bottom. Perhaps a simple mechanical device could be rigged to close a single Van Dorn bottle at a fixed (but to some degree unknown) distance above the bottom.

It has been proposed to use the profiling sampler developed by Dr. Nriagu to collect more detailed suite of samples above the bottom. The data would be interesting but the handling of the sampler and laboratory work is arduous. We are still making up our minds.

4.16 Underwater Oxygen Chambers

Dr. Snodgrass, of McMaster University, has requested assistance with a continuation of his experiments using bottom chambers to measure the sediment oxygen demand. This work is of considerable interest to other scientists at NWRI. The program will be similar to that of 1970; Dr. Snodgrass will supply the equipment and NWRI will install and retrieve it. There is a requirement for a diver to assist with the installation of some of the traps in order to avoid initial disturbance of the easily-suspended bottom material. A detailed experiment plan will be developed. This work will be done during the anchor station portion of the experiment.

4.17 U.S. Navy Undersea Systems Buoy

Although the details of this equipment are not known, we mention it for the sake of completeness. The device consists of a free floating spar buoy upon which is mounted a number of small, sensitive current meters. The buoy drifts with the mean current and is tracked by radar while the current meters record the water motion relative to the buoy at various levels. I have described the conditions of work aboard LIMNOS to Dr. Schonting, and I am assured that the equipment is manageable.

5. SCHEDULE OF OPERATIONS

Figure 8 shows a recent schedule for the major vessel, LIMNOS. The experiment begins on 14 July with the installation of the first moorings and ends on 5 Spetember when the last mooring is withdrawn. Total duration is 46 days. Most of the moored equipment will not require refurbishing during this interval. It is anticipated that CSL ADVENT will be based in Erieau and available to the experiment during this period.

5.1 Mooring Cruise 14-18 July

In this period LIMNOS will set out the elements of the array of moorings in the Central Basin. These are:

5.1.1 18 Plessey current meters (M021)
2,9021 current meters
17 - 20 Geodyne current meters
4 RCM-12 current meters
in approximately 12 moorings. All instruments should be set to record samples at 10 minute intervals. The Geodyne meters should be set to record an 80 second burst of compass-vane readings every 10 minutes.

5.1.2 Two or three meteorological buoys depending on availability, 10 minute sampling.

5.1.3 Four, 2 m FTP assemblies. The digitizers should be set for 10 minute samples.

5.1.4 Five or six tide gauges. Ten minute sampling, 7 minute integration period.

5.1.5 Depending on the results of the Lake Ontario trials, the GVAPS system may be installed by LIMNOS during this period. A final decision is postponed until the trials are completed.

5.1.6 During the week of July 14-18, the two CATS systems will be installed along the north shore of the basin. The ADVENT should be able to support the installations. Again, 10 minute sampling.

5.2 Small Scale Temperature and D.O. Surveys

In the interval between the mooring cruise and the anchor station period, and subject to the priorities of Item 6.3 below (July 21 to August 11 nominally), the ADVENT will make a series of local EBT surveys in the vicinity of the northshore CATS systems. This activity will be very similar to the 1979 northshore surveys, and will include surface and bottom dissolved oxygen samples. Although wind and weather will be the ultimate deciding factors, the aiming point is three mini surveys per week. This pattern of activity will change during the anchor station period, but will resume during the final operational week of 25 to 29 August.

5.3 Monitoring of Accessible Systems

Although the expected endurance of all the recording systems exceeds the 46 day experiment period, it may be advisable to monitor the MET buoys, the FTP's, and the CATS systems once. The best time for this would be during the week of 4-8 August to ensure that as many as possible of these systems are operating during the anchor station period.

5.4 Anchor Station Period, August 11-22

This period is the core of the experiment. It will undoubtedly be the most hectic. In anticipation of the final cruise plans for LIMNOS and ADVENT, I am attempting to define the sequence of activities as we now see it. As with the mooring array programs, there are three phases: installation, data collection, and recovery.

5.4.1. Installation

The order in which these tasks are done is not important except for the setting out of the drogues which should be done just before the LIMNOS anchors.

a) Zero speed test MCATS mooring and install. If weather permits, the outrigger thermistor arrays should be deployed with the Boston Whaler right away and the LIMNOS return to survey in the array on completion of step (b).

b) Install wave rider buoy and activate receiver/recorder.

c) Install biochemical mooring (see M. Charlton for details).

d) Install GVAPS system. To be confirmed.

e) Launch cluster of drogues including US Navy buoy.

f) Take up anchor position.

g) Install sediment D.O. chambers from Boston Whaler.

h) Put thermistor array overside.

5.4.2 Data Collection

Once on anchor station, a regular rhythm of sampling and measurement will be maintained with interruptions avoided if at all possible. If the weather during the installation phase does not permit deployment of the MCATS outriggers and their surveying then the first calm daylight opportunity should be taken to do this work.

Drogues. A radar sighting of the drogues is to be taken every 30 minutes (hours and half hours). Verification run with the Boston Whaler (or ADVENT) on an as-needed basis. When the cluster of drogues has moved to the limits of comfortable radar range they are to be recovered and reset close to LIMNOS again. The ADVENT should be used for this chore rather than LIMNOS if at all possible.

EBT Profiles. An EBT cast, surface to bottom, should be made every 30 minutes. For those made on the hour, an analogue trace (XYplot) and tracked temperature are required. For those made on the half hour, no trace is required. All EBT casts will be recorded digitally. Lowering speeds should not exceed 0.5 m/s.

Meteorological Data. Wind speed and direction, and (wet and dry) and water surface temperatures, cloud cover, barometric pressure should be recorded every hour. A full meteorological report should be made every three hours.

Dissolved Oxygen and Nutrient Sampling, Light Transmission Profiles. The basic rhytym of sampling will be once every four hours (0000, 0400, 0800, 1200, 1600, and 2000 EDT). At each sample time a bottle or rosette cast will be made for dissolved oxygen samples and nutrients. The sampling at 0400, 1200, and 2000 will be more extensive than at other times. At each sampling interval a profile of light transmission will be taken, and during daylight hours, measurements will be made of underwater irradiance.

Other Tasks of Non-Periodic or Occasional Nature.

- Servicing biochemical mooring
- Servicing bottom DO chambers
- Profiles with prototype dissolved oxygen probe.
- Detailed bottom water DO profiler with special sampler. (Maybe).
- High sampling rate records of bottom currents (maybe)
- Servicing GVAPS system.

Use of CSL ADVENT During Anchor Station Period. The ADVENT will be used to transfer personnel between Erieau and LIMNOS, to tend GVAPS system, and to retrieve drogues on an "as needed" basis. The major task for this vessel will be to extend the measurements of temperature profiles, dissolved oxygen and nutrients throughout the experiment area. A grid of between 6 and 10 stations will be selected in the vicinity of C-11. with the intention that the ADVENT should be able to run out from Erieau, collect samples over the pattern, leave the samples aboard LIMNOS for analysis, and return to Erieau within the span of one day. The north shore survey requirement will be dropped from three per week to one per week during the anchor station period. Subject to weather and other more pressing duties, the extended midlake sampling should be done as often as possible.

Recovery Phase. At the end of the anchor station experiment LIMNOS will recover the wave rider buoy, the MCATS system and the drogues. If the

GVAPS system is working well at this time, we will leave it until the mooring recovery period of 2-5 September. If no data is being collected, we may have to consider removing it at the end of the anchor station period.

5.5 Wind Down of Experiment. Removal of Moorings 2-5 September

During the LIMNOS mooring cruise of 2-5 September, all equipment will be removed from the lake. ADVENT will recover the two CATS systems.

6. SUMMARY

The foregoing has established the scientific rationale behind the experiments and outlined both the equipment needed and the timetable. There are several matters which have yet to be resolved.

- Exact locations of moorings (pending analysis of 1979 data).
- Detailed cruise plan for anchor station experiment (pending discussion with contributing scientists).
- Detailed cruise plans for ADVENT.

If there are other unresolved issues or matters which appear to have been overlooked please contact F.M. Boyce or J. Bull as soon as possible.

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APPENDIX A

F.M. Boyce

Government of Canada Gouvernement du Canada

MEMORANDUM **NOTE DE SERVICE**

F.M.Boyce/4277/NWRI/ns

SECURITY - CLASSIFICATION - DE SÉCURITÉ

OUR FILE/NOTRE RÉFÉRENCE

YOUR FILE/VOTRE RÉFÉRENCE

DATE April 9, 1980

TO À SEE DISTRIBUTION LIST

FROM DE
F.M. Boyce
Basin Investigation & Modelling Section
Aquatic Physics and Systems Division

SUBJECT OBJET Planning of Anchor Station Cruise, 12 - 21 August, 1980, LIMNOS, Central Basin of Lake Erie

On Wednesday, 12 March 1980, the following persons met to discuss and to begin the planning of the 1980 anchor station cruise:

F.M. Boyce, APSD, Chairman
J.A. Bull, APSD, Secretary
J. Jerome, APSD
N.M. Burns, AED
F. Rosa, AED
D.R.S. Lean, AED
M. Charlton, AED
E. Harrison, ESS
P. Healey, Tech Ops

The ship time has been requested by BIMS in support of their 1980 Lake Erie Physics program. The plan is similar to that of 1979; one ship is to be used as a fixed (anchored) mid lake platform from which to operate several physical experiments. We believe however, that it makes very good sense, and indeed presents a unique and valuable opportunity, to combine the physical experiment with chemical and biological studies related to the nutrient and oxygen budget of the Central Basin. In this spirit we have called together those whom we know to have an interest in working in the Central Basin at this time and those who may be able to contribute advice or guidance.

By this memorandum, I am recording the outline of the discussion and identifying the issues (most of them, I hope) which need to be resolved. The annotation "action-so-and-so" is to be read as a request that so-and-so provide missing information or details. Upon receipt of this information we will take it upon ourselves to draft preliminary scientific cruise plans which will serve as a working document for the next meeting.

..... 2

The shipboard activities envisaged for this cruise are listed in the accompanying table. The first six activities are very similar to those we conducted in 1979 with the difference that the optical measurements are more complete and involve the participation of the Spectro Optics Section (J. Jerome).

The EVAPS and O_2 profiler (7 & 8) activity involve new and different machinery and consequently a strong ESS input. The LIMNOS may be called upon to set out the GVAPS winch and anchor at the beginning of the cruise. The O_2 profiler will probably be the equivalent of a Rosette sampler in the matter of winches and deck space.

The turbulence buoy (9) is the creature of Dr. D. Shonting from the U.S. Navy Lab in Rhode Island. It is a free drifting spar buoy carrying velocity and temperature sensors. I have not seen this device but Shonting seems confident that it can be deployed from LIMNOS. It is allowed to drift freely, once deployed, and can be towed back into position with a Boston Whaler if required. I have obtained verbal assurance that Shonting would like to participate in this year's experiment. We'd like to have him since his data would be a valuable complement to the current meters and to GVAPS.

Activities 10, 11, and 12, are those contributed by D. Lean and M. Charlton. A moored "bottle holder" is installed at the beginning of the experiment and serviced thereafter by the ship's tender.

Activity 13, the bottom D.O. chamber measurements, would be similar to that occurring in 1979. We have yet to confirm the intent of Dr. Snodgrass to continue this project.

Activity 14 is a recent suggestion by N. Burns that the profilers developed by J. Nriagu might yield some useful data on near bottom DO_2 profiles. We will have to make up our minds about this one. The gear is bulky, a big winch is needed or else some cabling modifications are required, and the analysis of the samples is a substantial task.

Action Items

I am asking Tech Ops for comments on the feasibility of accommodating all the equipment in the available deck and laboratory space, as well as the problems of lowering and hoisting the equipment (winches, davits, etc.).

The experiment period spans a weekend, that of Saturday August 16, and Sunday, August 17. In order to maintain continuity of the time series measurements it will be necessary to work that weekend. Authorization is sought for the resulting overtime (Tech Ops to advise).

..... 3

Accommodation for scientific and technical personnel will be fully used. Everyone should be prepared to pitch in during "rush hours" in order to spread the overload around more equably.

Use of CSL ADVENT

The ADVENT will be stationed in Erieau during the experiment. She will serve as a tender for the LIMNOS and the EVAPS as and when required. When not not required as a tender she will be used to extend the water sampling to a 10 km circle about the anchored LIMNOS. Temperature profiles of nutrient samples, and dissolved oxygen samples will be collected at up to six depths for later analysis aboard LIMNOS. We would like to sample the outlying stations twice a day if possible.

Any conflicts, ommissions, additions, etc., should be communicated to the undersigned as soon as possible.

FMBoyce

F.M. Boyce

DISTRIBUTION

J.A. Bull, APSD
J. Jerome, APSD
N.M. Burns, AED
D. Lean, AED
M. Charlton, AED
E. Harrison, ESS
B. Taylor, Tech Ops
C.R. Murthy, APSD
F.C. Elder, APSD

ACTIVITY	DESCRIPTION	BODIES	SPECIAL CONSIDERATIONS
1. Wave rider	Moor & Recover, begin and end. Monitor receiver and change tapes	2 BIMS	
2. Drogue tracking	Launch, retrieve, and verify Boston Whaler half hourly radar plotting 10 drogues		
3. Thermistor array	Rig and dismantle. Monitor recorder and change tapes		
4. MCATS	Launch and recover at beginning and end.		
5. Water Sampling	EBT profile every 20 min. DO_2 samples every 3 hr. (6 samples/cast) Nutrient samples every 6 hr. filtering splits and analysis	1* W.O. female	* Water quality analyst (female)
6. Spectro optical measurements	Transmissometer profile every 3 hours Spectral irradiance profiler during daylight every 3 hours	1 S.O.	Transmissometer winch
7. EVAPS	Moore and recover at beginning and end. Daily visits via Boston Whaler for servicing	1 ESS	
8. O_2 profiler	Regular profiles with prototype DO profiler		Winch for profiler

	ACTIVITY	DESCRIPTION	BODIES	SPECIAL CONSIDERATIONS
9.	Turbulence buoy	Launch, tend with Boston Whaler, tack by radar, recover	2* USN	* to be confirmed
10.	Diurnal O_2	Regular sampling profiles for D.O. analysis		
11.	Insitu Mooring	Install and retrieve mooring. Servicing daily by Boston Whaler	4 AED (one female)	
12.	Laboratory analysis	Analysis of samples collected during 10 and 11. Tests with incubator.		
13.	DO chamber	Install and retrieve chambers - service at 3 day intervals		
14.	Bottom gradient profiler	Lower from ship, allow time for acclimatization, recover, drain and analyse samples. 2-3 times per day		Winch Deck space

T.B. Travel Directive as of April 1, 1980
#770506

Meal Rates	Canada		United States	
	New	Old	New	Old
Breakfast	4.25	3.70	4.75 US	4.20 US
Lunch	4.50	4.10	5.00 US	4.60 US
Dinner	10.50	10.25	11.50 US	11.25 US
Total Daily	19.25	18.05	21.25 US	20.05 US
Incidentals Hotel/Motel Accomodation	4.60	4.60	4.60 US	4.60 US
Composite Allowance	23.85	22.65	25.85 US	24.65 US
Incidentals Government accomodation or staying with friends	2.70	2.70	2.70 US	2.70 US
Private Accommodation	11.00	9.60		
Mileage Rates				
Employer Requested				
Miles	25¢	23.5¢		
Kilometers	15.5¢	14.5¢		
Employee Requested				
Miles	9.0¢	9.0¢		
Kilometers	5.5¢	5.5¢		

Additional Information to follow, when actual TB Minute arrives in the Finance Office

FIGURE CAPTIONS

Figure 1: Location of water level gauges in the Central Basin of Lake Erie.

Figure 2: 1979 FTP locations and sampling points for EBT survey in mid basin experiment area.

Figure 3: Concept sketch of GVAPS system configured for Lake Erie.

Figure 4: Concept sketch of MCATS systems for 1980 Lake Erie experiment.

Figure 5 Scheme for surveying in MCATS array.

Figure 6: Concept sketch of bottom current meter operable at 0.5, 2.5 and 4.5 m above the bottom.

Figure 7: Suggested improvements to drogues.

Figure 8: 1980 LIMNOS timetable.

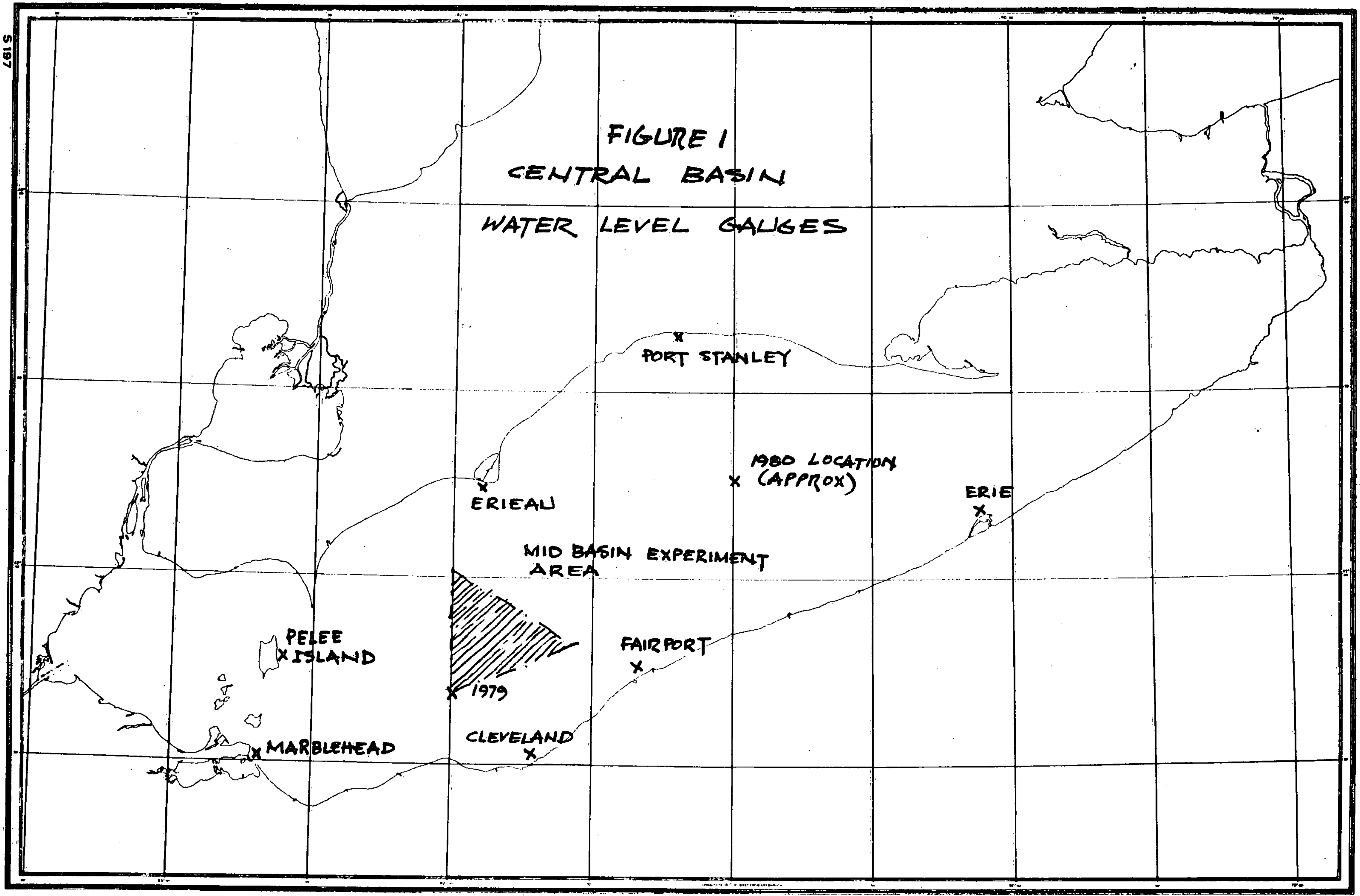


FIGURE 1
CENTRAL BASIN
WATER LEVEL GAUGES

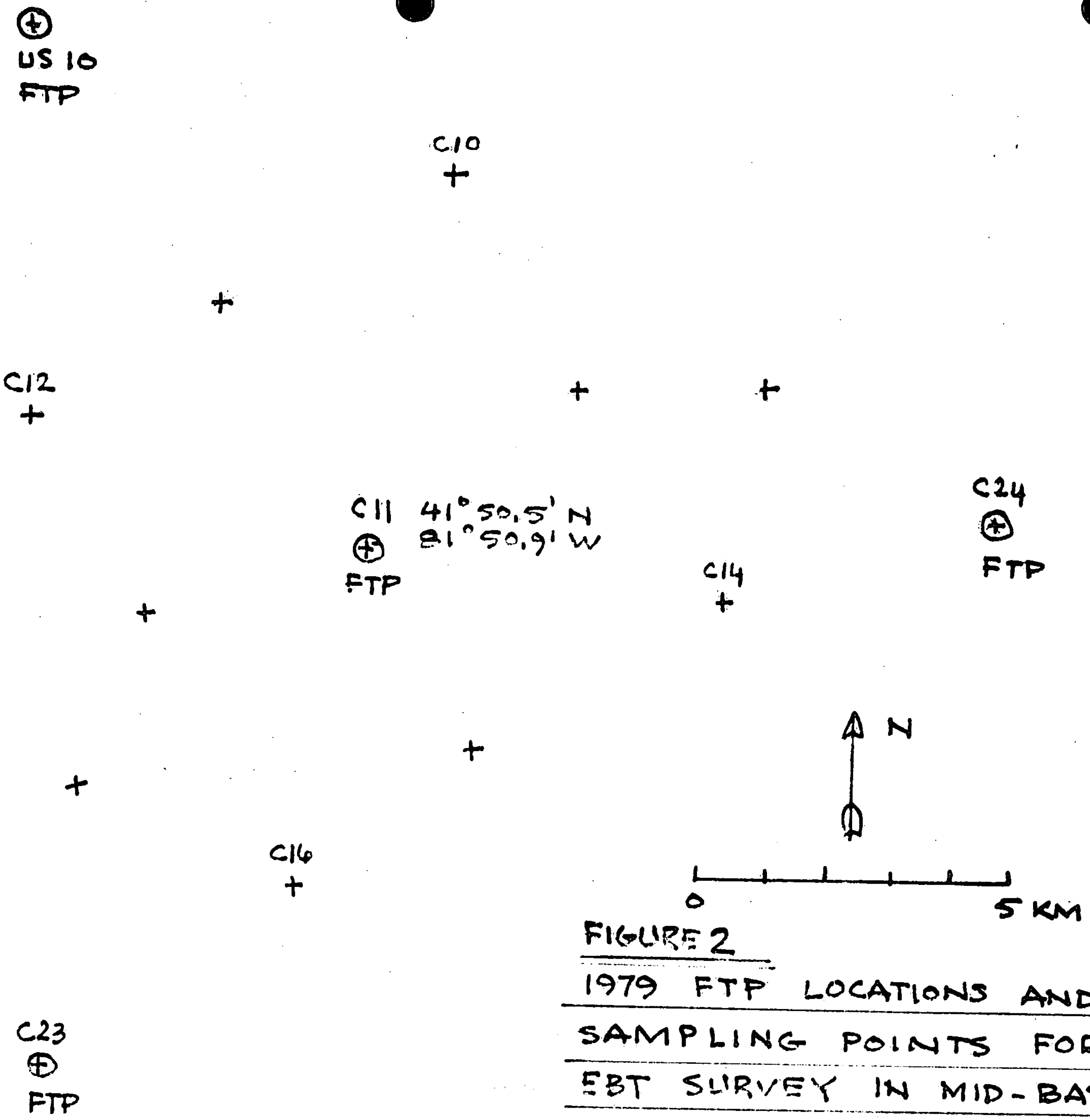


FIGURE 2

1979 FTP LOCATIONS AND SAMPLING POINTS FOR EBT SURVEY IN MID-BASIN EXPERIMENT AREA.

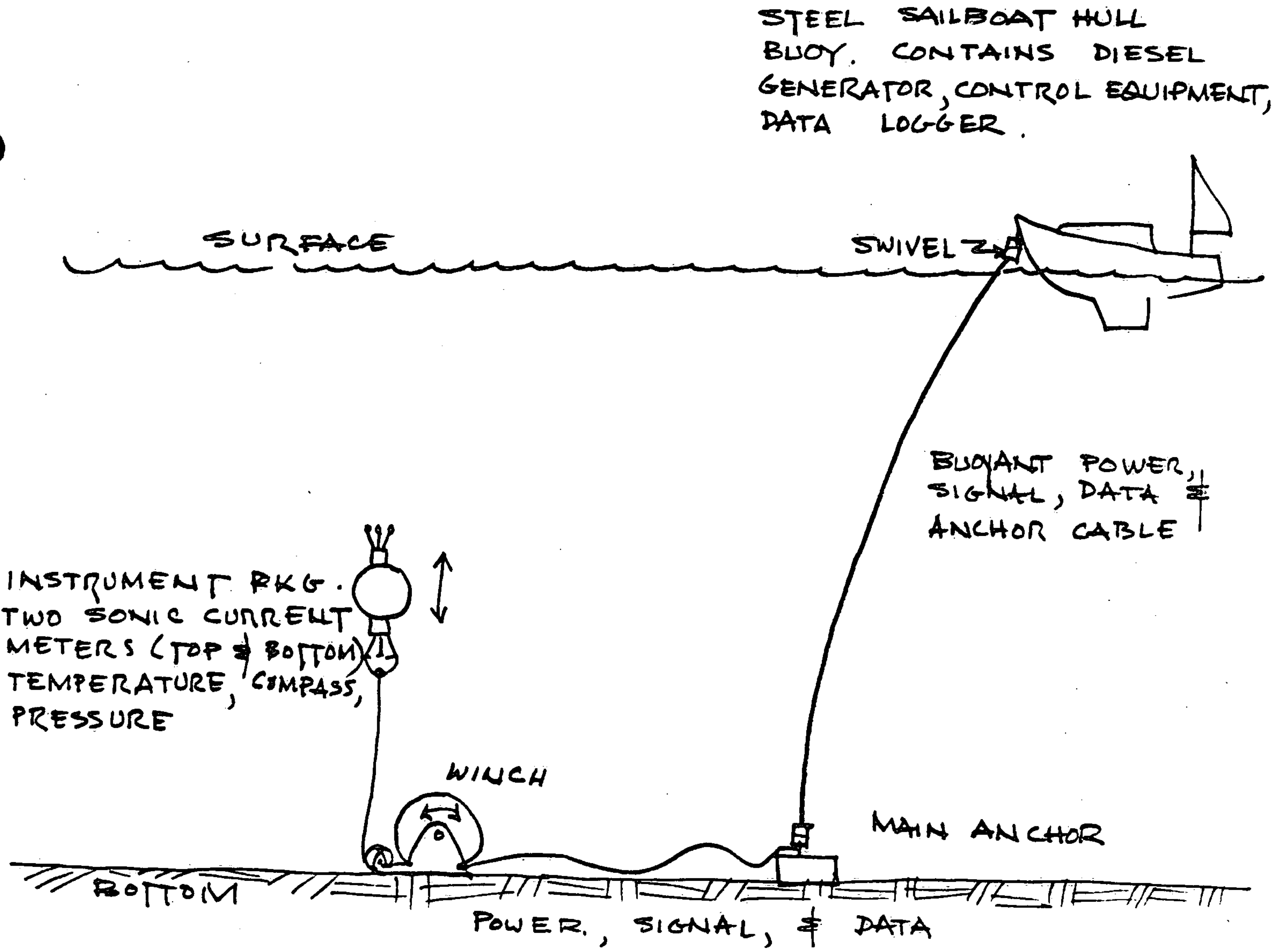


FIGURE 3
G-VAPS SYSTEM
(LAKE ERIE VERSION)

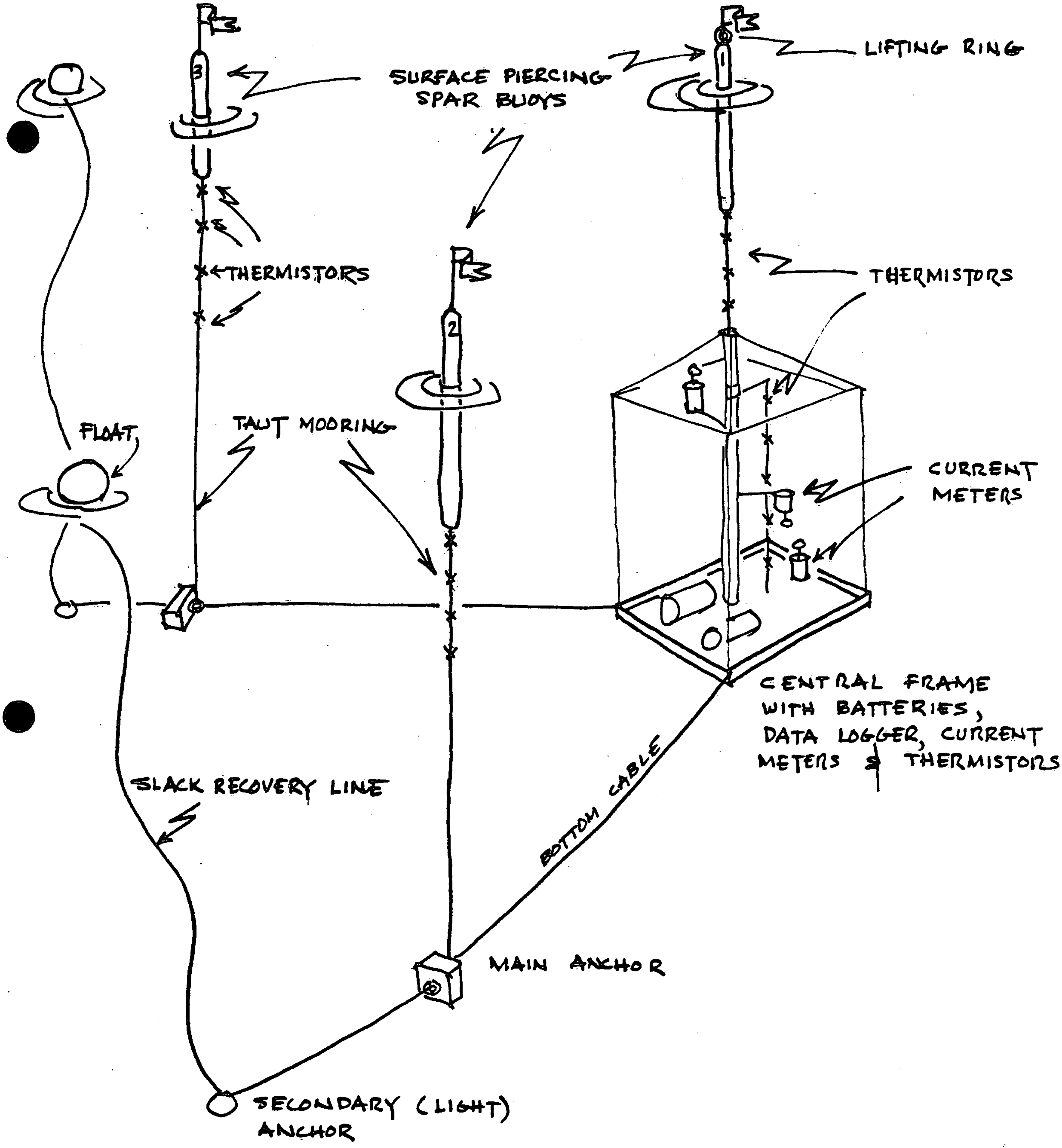
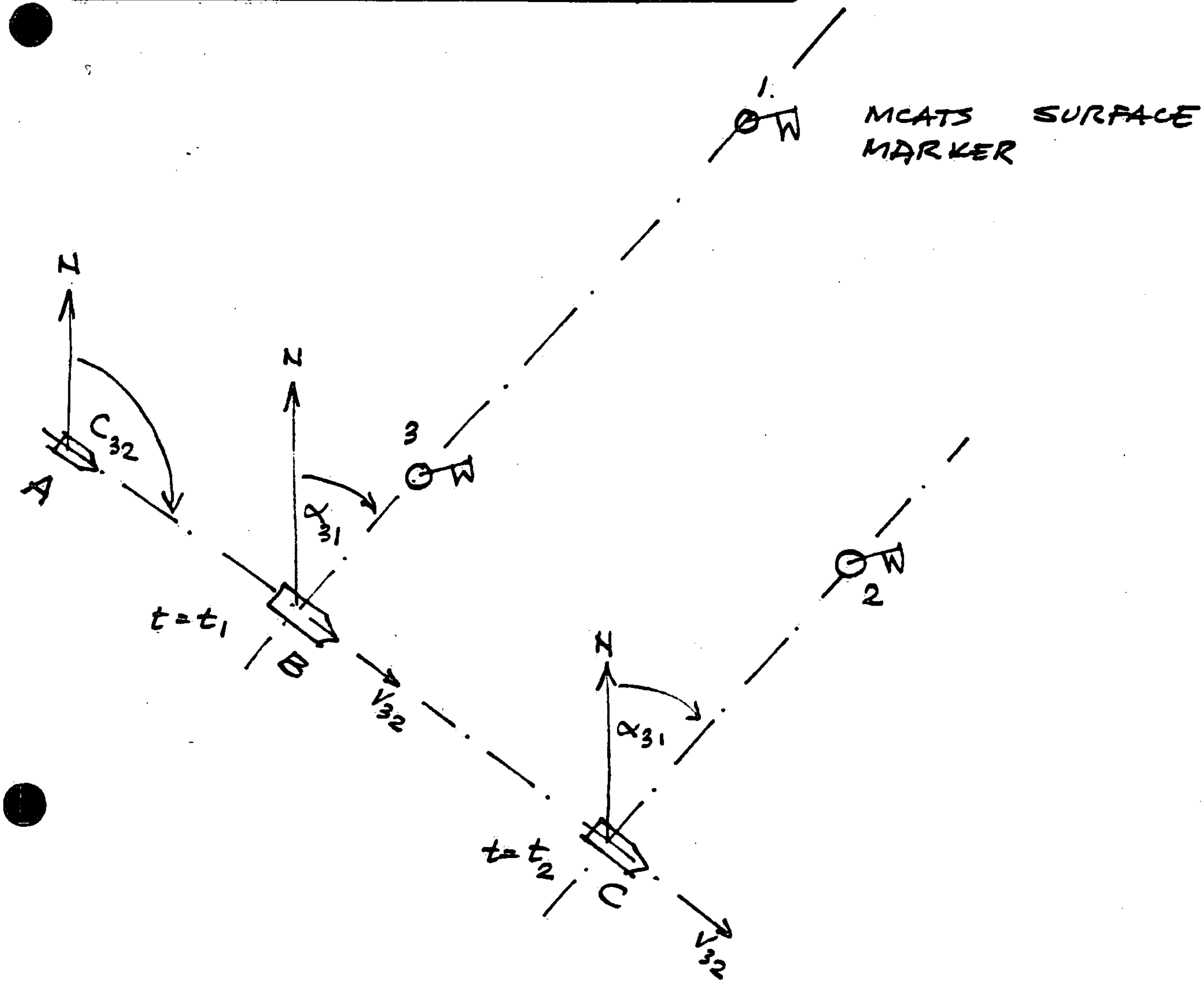


FIGURE 4

MCATS SYSTEM WITH OUTRIGGER THERMISTOR ARRAYS

FIGURE 5

SCHEME FOR SURVEYING IN MCATS ARRAY



SHIP STEAMS COURSE C_{32} AT CONSTANT SPEED V_{32}. CONTINUOUS BEARINGS TAKEN ON BUOY 3.

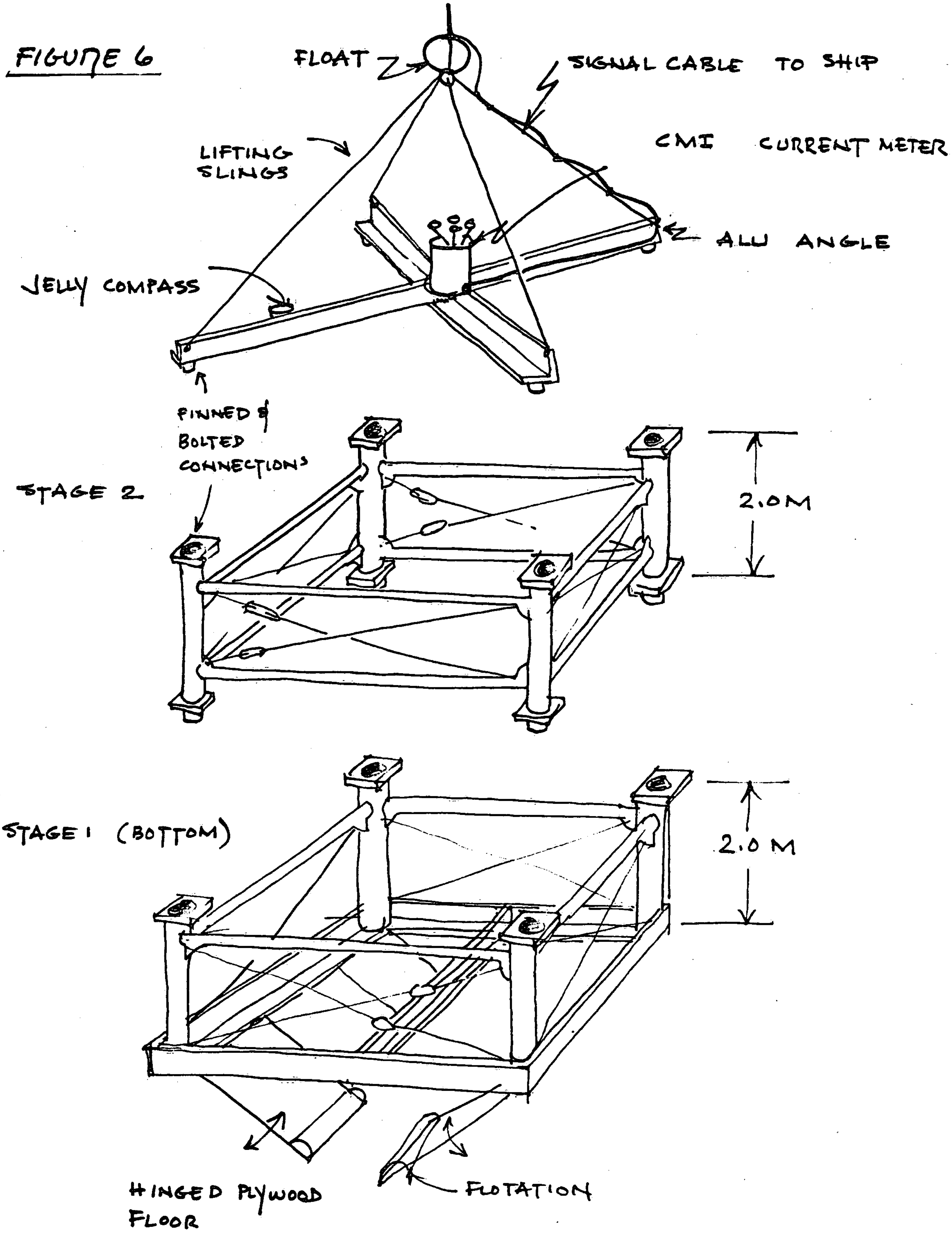
STOPWATCH STARTED AT $t=t_1$ WHEN BUOY 1 & BUOY 3 ARE IN LINE. COMPASS BEARING α_{31} IS NOT FURTHER CHANGED.

STOPWATCH STOPPED AT TIME t_2 WHEN BUOY 2 BEARS α_{31}

SHIP'S COURSE C_{32}, SPEED V_{32}, BEARING α_{31}, AND ELAPSED TIME t_2-t_1, ARE RECORDED.

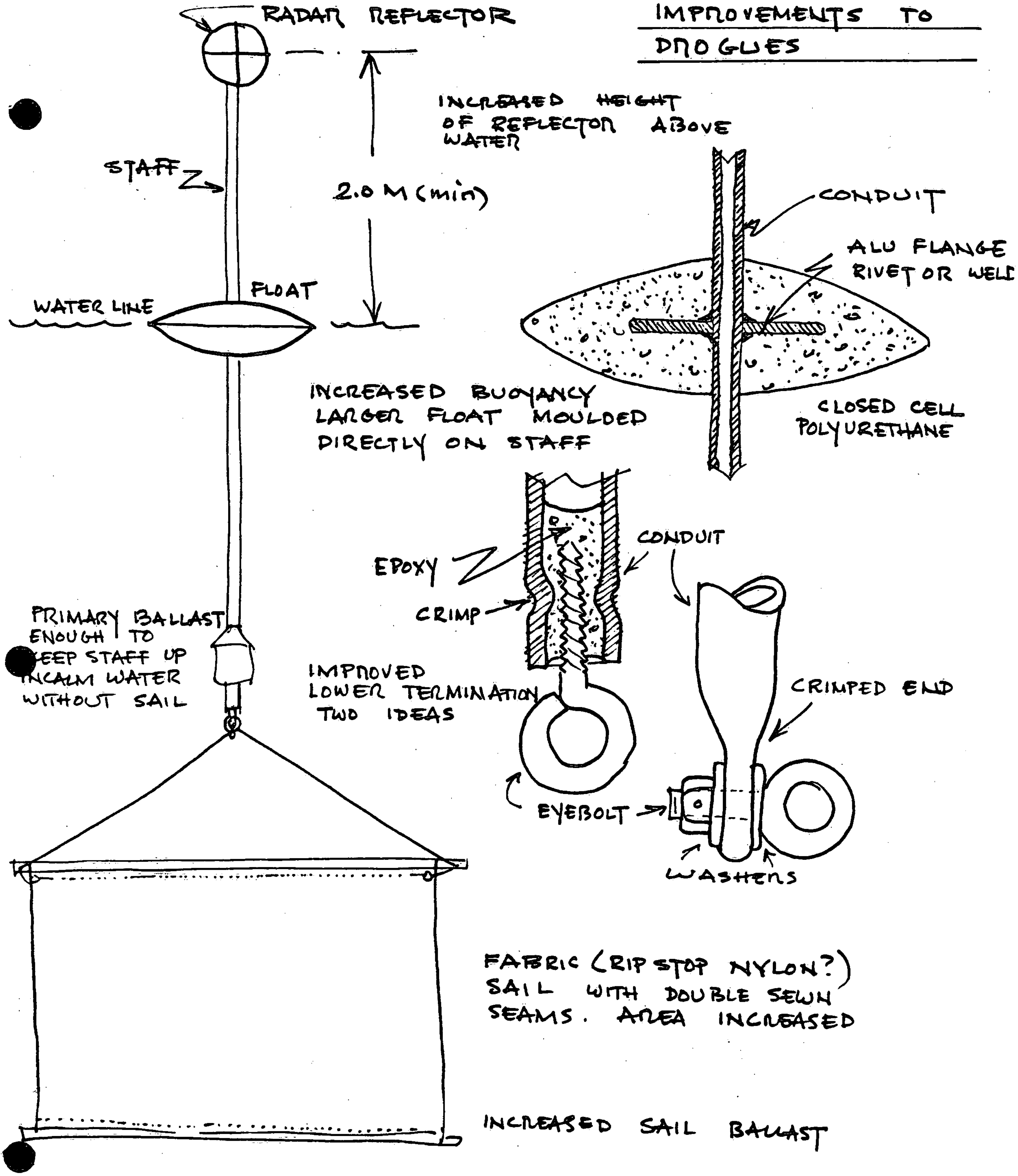
SIMILAR DATA COLLECTED FOR OTHER TWO LEGS.

FIGURE 6



BOTTOM CURRENT METER OPERABLE AT 0.5, 2.5, & 4.5M ABOVE BOTTOM. (FROM SHIP)

FIGURE7 IMPROVEMENTS TO DROGUES



"LIMNOS"

1980 JANUARY

SUN	MON	TUE	WED	THUR	FRI	SAT
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

FEBRUARY

SUN	MON	TUE	WED	THUR	FRI	SAT
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	

MARCH 1980

SUN	MON	TUE	WED	THUR	FRI	SAT
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17 SURVEILLANCE-ONT	18	19	20	21	22
23 30	24 31	25	26	27	28	29

APRIL

SUN	MON	TUE	WED	THUR	FRI	SAT
	MOORINGS-ONT	1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20 SURVEILLANCE-ONT	21	22	23	24	25	26
27	28	29	30			

MAY

SUN	MON	TUE	WED	THUR	FRI	SAT
				1	2	3
4	5	6	7	8	9	10
11	12 LUM - L. ONT	13	14	15	16	17
18	19	20 ENGINEERING	21	22	23	24
25	26 SURVEILLANCE - L HURON	27	28	29	30	31

JUNE

SUN	MON	TUE	WED	THUR	FRI	SAT
1	2 SURVEILLANCE - L. HURON	3	4	5	6	7
8 SURVEILLANCE - L. HURON	9	10	11	12	13	14
15	16 SEDIMENT BANK	17	18	19	20	21 *
22 LAKE HURON	23	24	25	26	27	28
29	30					

JULY

SUN	MON	TUE	WED	THUR	FRI	SAT
		1	2 LUM - L. ONT	3	4	5
6	7 LEAN - L. ERIE	8	9	10	11	12
13	14 MOORINGS - L. ERIE	15	16	17	18	19
20	21 GLBL - HURON &	22	23	24	25	26
27	28 SUPERIOR	29	30	31		

AUGUST

SUN	MON	TUE	WED	THUR	FRI	SAT
					1	2
3	4	5 DOWN TIME	6	7	8	9
10	11 BOYCE - ERIE	12	13	14	15	16
17	18 BOYCE/LEAN ERIE	19	20	21	22	23
24 31	25 LUM - ONT	26	27	28	29	30

SEPTEMBER

SUN	MON	TUE	WED	THUR	FRI	SAT
	1	2 MOORINGS - ERIE	3	4	5	6
7	8 SURVEILLANCE - HURON	9	10	11	12	13
SURVEILLANCE - HURON	15	16	17	18	19	20
SURVEILLANCE . HURON	22	23	24	25	26	27
28	29 LUM -	30				

OCTOBER

SUN	MON	TUE	WED	THUR	FRI	SAT
			1 L. ONT	2	3	4
5	6 SURVEILLANCE - ONT	7	8	9	10	11
12	13	14	15	16	17	18
19	20 SURVEILLANCE - HURON	21	22	23	24	25
26	27 SURVEILLANCE - HURON	28	29	30	31	

NOVEMBER

SUN	MON	TUE	WED	THUR	FRI	SAT
						1
2	3 SURVEILLANCE - HURON	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23 30	24	25	26	27	28	29

DECEMBER

SUN	MON	TUE	WED	THUR	FRI	SAT
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

* R.A. BOURBONNIERE - A.E.D.

FIGURE 8

Feb 6/80