The Circulation of the Effluent from the Okanagan River as it Enters Lake Skaha

by

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ABSTRACT

The circulation of Okanagan River water as it enters Lake Skaha has been examined by tracking the diffusion of rhodamine B dye and tracking drogues. Results are based on a set of experiments conducted in Spring 1971 and September 1971.

Results showed that the north shore of Lake Skaha west of the river inlet was influenced the greatest by the Okanagan River. To a lesser degree, this zone extended down the west shore for several kilometers. The extent is probably governed by the strength of northerly winds. River water becomes rapidly diluted as it mixes out in the lake away from the northwestern corner. Evidence from one experiment suggests that southerly winds "trap" the effluent in the shore zone west of the inlet.

The basic circulation pattern in the northern half of Lake Skaha consists of a well-defined southerly current along the west shore whose strength correlates well with the magnitude of winds from the north. The southerly current along the west shore is undoubtedly present even when winds blow from the south. In this case, the current represents a large part of the flow deflected by the northern shore. This basic pattern was qualitatively the same for spring data when river discharge was 28 m^3/sec and for fall data when discharge was only 8 m^3/sec. Aerial photographs describing the distribution of ice in winter also confirm the basic circulation pattern.

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INTRODUCTION

The purpose of this report is to assess the influence of the Okanagan River on Lake Skaha as it enters the lake (Fig. 1). The study was conducted under the terms of reference of Task No. 120, and the results are thought to be useful in predicting the fate of Okanagan River water in Lake Skaha. The regimes that predominantly influence this problem are meteorological, hydrological and limnological in nature.

The pertinent meteorological regimes in the study area are fairly simple: The wind stress is the overriding factor and results basically from persistent north or south winds. The principal hydrological factor is the magnitude of the discharge of the Okanagan River. Based on 49-year means (B.C. Water Resources Service, 1970), the average monthly rate of discharge varies from about 6 m^3 sec^{-1}* (January) to nearly 20 m^3 sec^{-1} (June). Another important variable is the temperature of the river water as it enters the lake because this temperature relative to the lake water temperature governs whether the river water sinks or floats on or near the lake surface. The principal lake variable is the degree of stratification based on the heating rate of Lake Skaha. The variation of these variables with month were important considerations in the design of the experiments for this study.

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* 1 m^3 = 35.3 ft^3

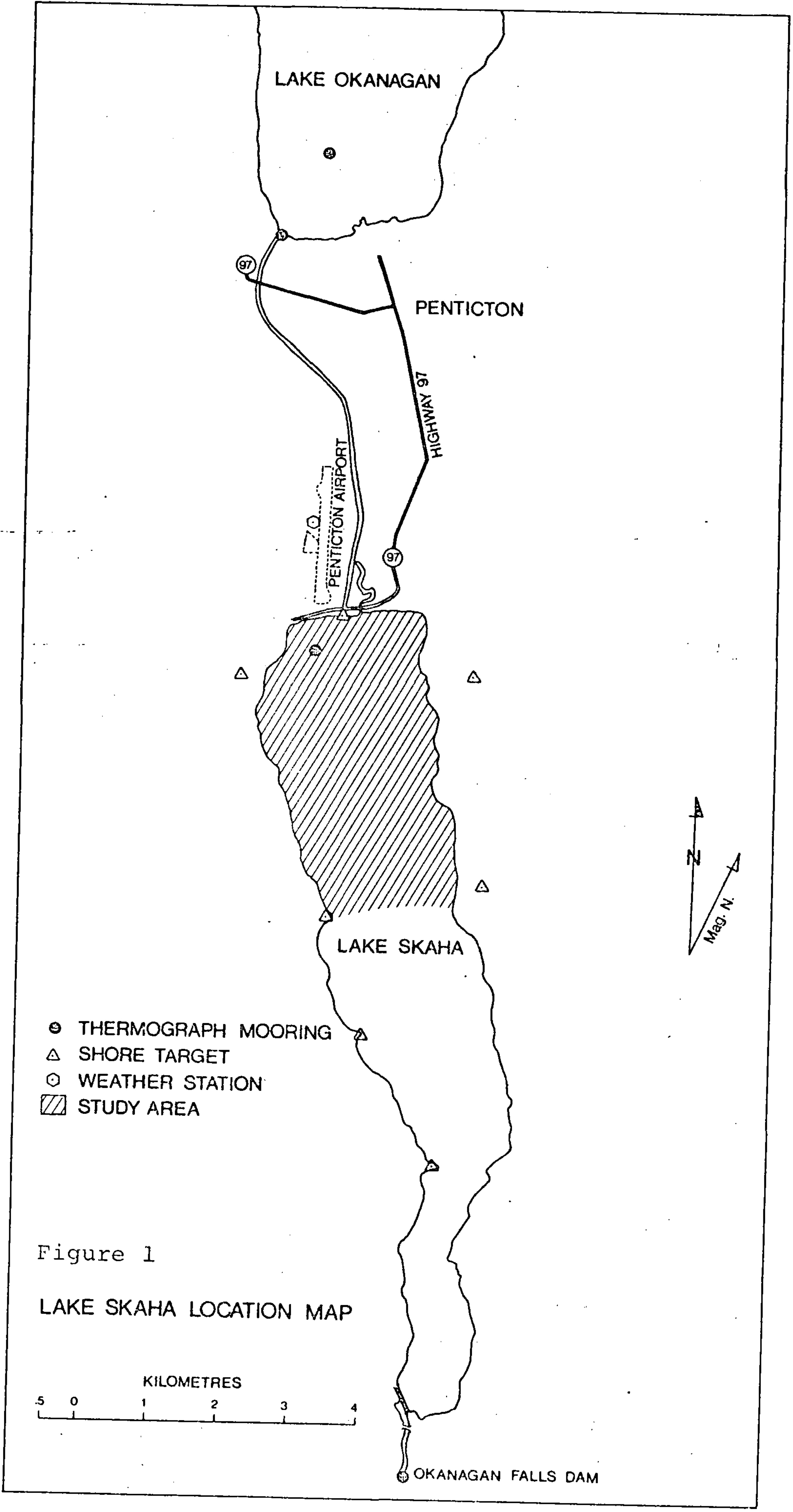

Figure 1

LAKE SKAHA LOCATION MAP

Factors affecting the effluent circulation

Generally speaking the winds vary in direction between north and south. During winter and spring when we find the lake well-mixed from top to bottom, the south winds are usually more frequent in occurrence (Fig. 2). Even when the lake is weakly stratified in late spring, the density changes with depth only slightly at such low temperatures, so that vertical mixing throughout the water column takes relatively little energy when compared with that necessary to vertically mix a strongly stratified lake. In summer and early autumn, the lake becomes highly stratified and warm river water will be confined predominantly above the thermocline. During this period, winds are most frequently from the north.

The discharge of the Okanagan River can be highly variable even though in the average, the discharge curve looks quite simple (Fig. 2). For example, the discharge during 1971 in spring and early summer was often more than twice the mean for this period (Water Survey of Canada, 1971). Moreover the actual dispersion of the river water will vary with the variation in hydraulic head between the inflow at Penticton and the outflow at Okanagan Falls. During periods when outflow is less than inflow, the head is diminished compared with that established when outflow and inflow are balanced. Under

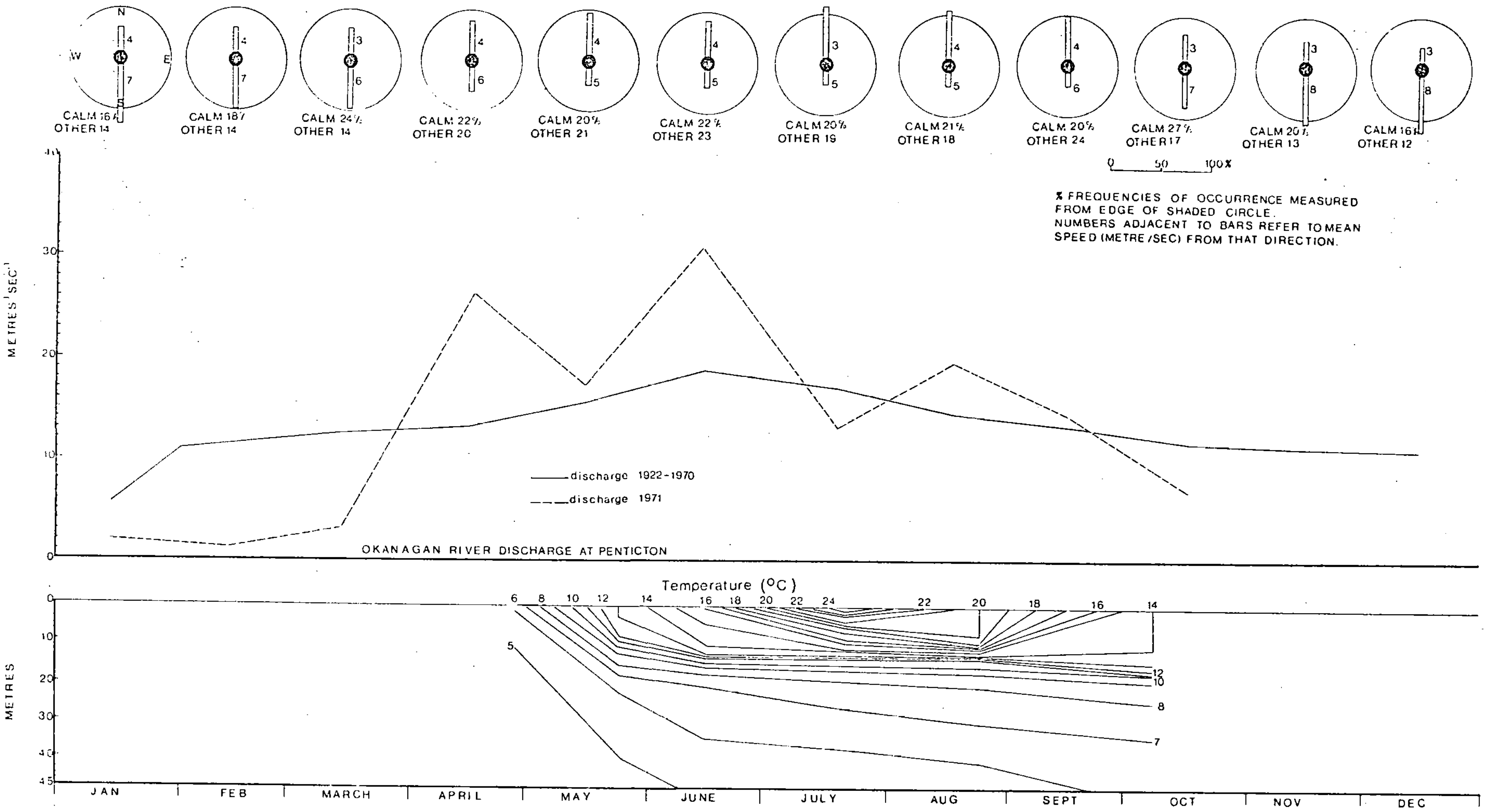

Figure 2: The principal meteorological, hydrological and limnological regimes affecting the circulation of the Okanagan River entering Skaha Lake. (Top): Monthly wind roses from wind data at Penticton Airport. (Bottom): Depth versus time of isotherms (°C) based on monitor cruises of the lake in 1971.

these conditions we would expect the flow-through time of river water to diminish.

A careful examination of Figure 2 will reveal that it was much beyond our scope and resources to examine all possible regimes that might have an important bearing on the circulation of the input of the Okanagan River. The deviations from the mean are simply too erratic for guess work. Therefore, our method of approach was quite simple. We selected two basic periods for study which might reflect major differences in behavior of the influent in the lake. The first period was in April-May 1971 during which the discharge would probably be quite high. There was also a good chance that we would sample during episodes of both north and south winds. The lake would be only weakly stratified in density. The second period was in September 1971. Discharge is usually low during this period and the winds are almost invariably out of the north (Fig. 2). The lake is also highly stratified. It was during these two periods that we made available man power and field equipment to carry out this study.

Scope of this study

The principal objective as stated in the terms of the Limnological Task Force was to ascertain by dye diffusion measurements within Lake Skaha the fate of nutrient input from the Okanagan River. We implicitly assume that dye concentrations and the gradients influencing the dispersion of the dye are identical to those of the nutrients. This assumption is far from realistic. The gradients for dye concentrations are likely to be several orders of magnitude greater than those for nutrient concentrations. Moreover the water motions which we follow with dye respond quickly to changing wind stress with response times measured in hours.

The actual fate of the input from the Okanagan River may be more accurately recorded in distributions which reflect averages over a longer time scale. Sediment-type distributions are good examples. Nevertheless, from the dye diffusion experiments and supplementary current information, much can be derived concerning the directions that dissolved and suspended nutrients take upon entering the lake and concerning the areas of Lake Skaha that are under large influence of the Okanagan River discharge.

Other limitations are briefly as follows: (1) no episodes during strong southerly winds were tested because they occurred either at night or they blew too hard for personnel to work safely on the lake; (2) the effect of varying discharge is not accurately known, but we suspect that the variations would not alter substantially the basic findings; and (3) our resources were limited to two boats, meaning that we sacrificed vertical sampling of dye in order to gain good horizontal sampling-using one boat. The other was used to track current-following devices (drogues).

RESULTS

During 1971, we performed four detailed experiments on the diffusion and advection of Okanagan river water into Lake Skaha. The general details of these experiments are outlined in Table 1.

Spring

Two experiments were performed in spring when the lake was virtually homogeneous as far as density variations are concerned (Fig. 3). Even though the second experiment had a weak thermocline, this variation would not significantly affect the vertical density changes. During Experiment I, light southerly winds generally prevailed in the morning and became moderate in the afternoon. North winds prevailed during Experiment II.

During both experiments, the river discharge changed rapidly from day to day (Fig. 4(a), (b)). These variations undoubtedly affected the areal distributions observed for the dye. The basic patterns, however, were consistant for the two experiments.

The horizontal distribution of dye measured in Experiment I showed that the dye patch exhibited rapid growth from the west and northwest shore in the area of Skaha Creek (Fig. 5). This pattern was basically the same at 1 and 3 metres. The spreading of dye was slower after 6 hours from release (Fig. 6). On comparing Figure 5 with

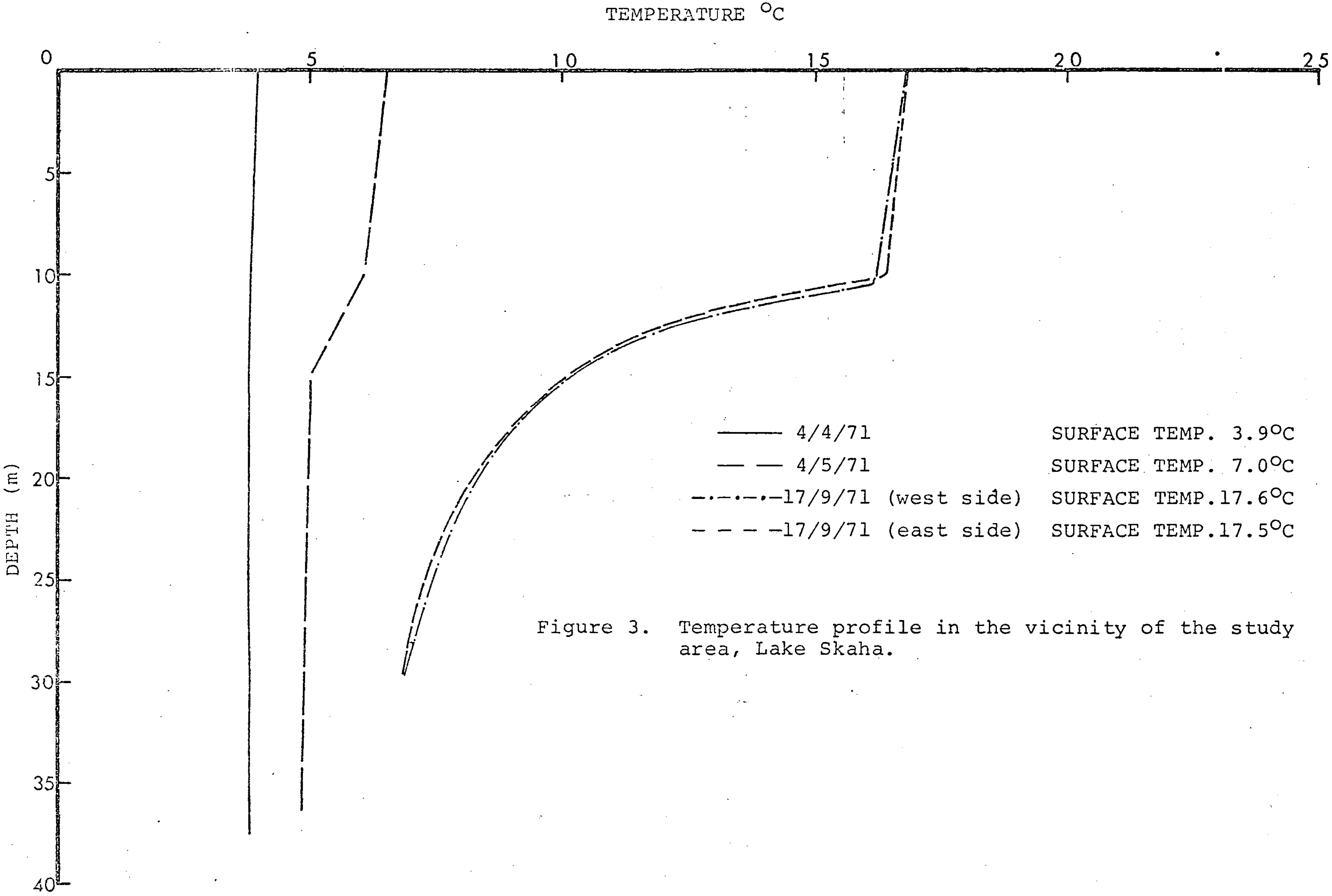

Figure 3. Temperature profile in the vicinity of the study area, Lake Skaha.

Table 1. General details of the diffusion experiments

Experiment	I	II	III	IV
Date	3/4/71	4/5/71	18/9/71	23/9/71
Type of dye source	Instantaneous	Continuous	Continuous	Continuous
Amount of dye released	67.5 Kg	9.0 Kg	34.0 Kg	169.0 Kg
Dimensions of plume measured	horizontal	horizontal	horizontal vertical	horizontal vertical
No. of realizations	3	1	2	2
Dates of realizations	3,4,6, April	4 May	18,19 Sept	23,24,25 Sept
Average time interval after dye released (hours)	6, 28, 72	2.5	3, 24	4, 36
Average sampling duration (hours)	6	3	4.5	4
Sampling depth (metres)	1, 2, 3	1, 2, 3		
Okanagan River discharge (m^3/sec)*	28	20	6	6
Okanagan Falls discharge (m^3/sec)*	28	22	11	11
Boat used	17-foot Runabout	17-foot Runabout	25-foot Flat Barge	25-foot Flat Barge
Initial conc. of dye (ppb) expressed as a ratio of dye discharge to river discharge	2.4×10^6	5	220	320
Wind during measurements (knots)	S 4.3	N 7.0	N 3.9	NE 4.2
Lake conditions	Homogeneous	Homogeneous	Thermocline at 10 m depth	Thermoline at 10 m depth

* 1 m^3/sec = 35.3 cfs

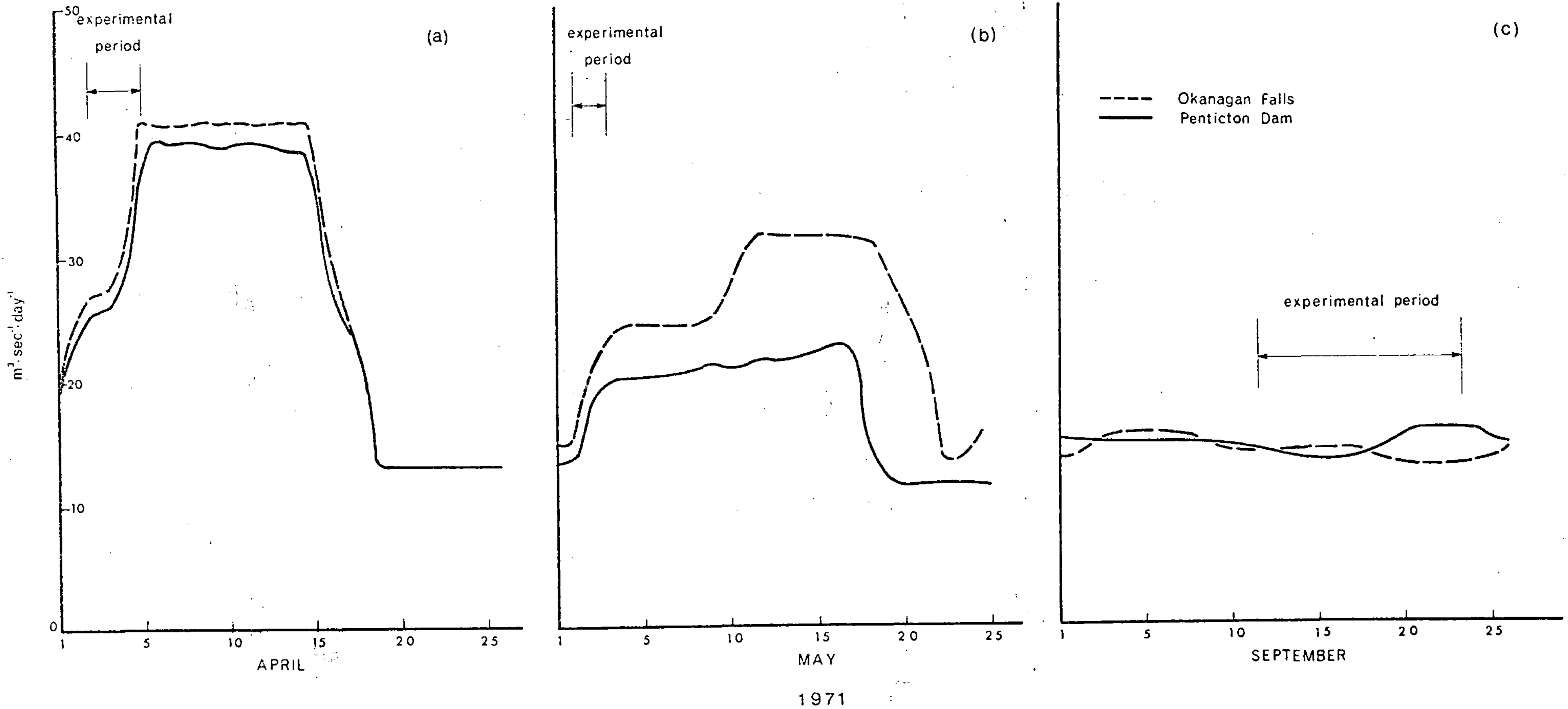

Figure 4. Daily discharge of Okanagan River at Penticton and Okanagan Falls dam at Okanagan Falls for the months of April, May, and September, 1971.

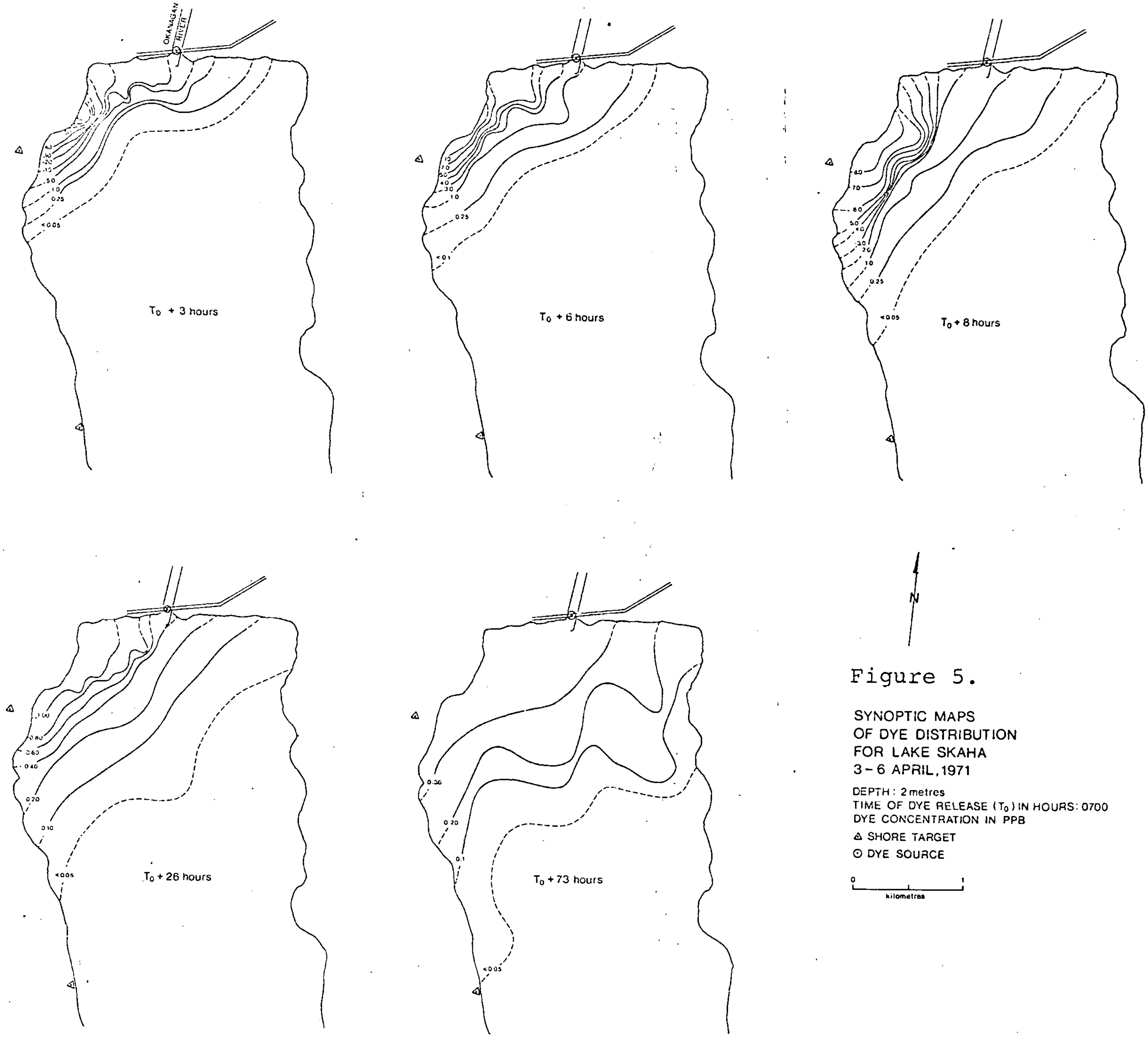

Figure 5.

SYNOPTIC MAPS
OF DYE DISTRIBUTION
FOR LAKE SKAHA
3-6 APRIL, 1971

DEPTH: 2 metres
TIME OF DYE RELEASE (T_0) IN HOURS: 0700
DYE CONCENTRATION IN PPB
△ SHORE TARGET
⊙ DYE SOURCE

Figure 6, one finds that the dilution rate of dye after 6 hours was quite rapid, even though the areal growth was relatively slow. Furthermore, Figure 5 indicated that the dye traveled more or less as a well-defined patch to the northwest corner with relatively little mixing with the lake. From this corner, the dye spread towards the southeast while simultaneously being carried southward along the west shore.

Much of the dilution observed is, of course, a function of the amount of vertical as well as horizontal mixing. We presume that the dye was mixed more or less uniformly with depth, but no check on this was possible. We do know that roughly 50% of the dye released was recovered after 3 hours. However, at 8 hours after release, only 20% was recovered in the horizontal sampling. Much of this loss must be attributed to vertical loss.

Experiment II was conducted with a continuous source (see Table 1). The injection rate of dye was 6 ml/min. The dye plume from the source was crossed several times at three different locations. An average cross-section dye concentration profile was calculated at each location. The centre of gravity of the profile was determined for each section (see Csanady, 1966). At the three locations, the point of the centre of gravity of the mean dye concentration profile was skewed towards the west shore of the lake, thus indicating

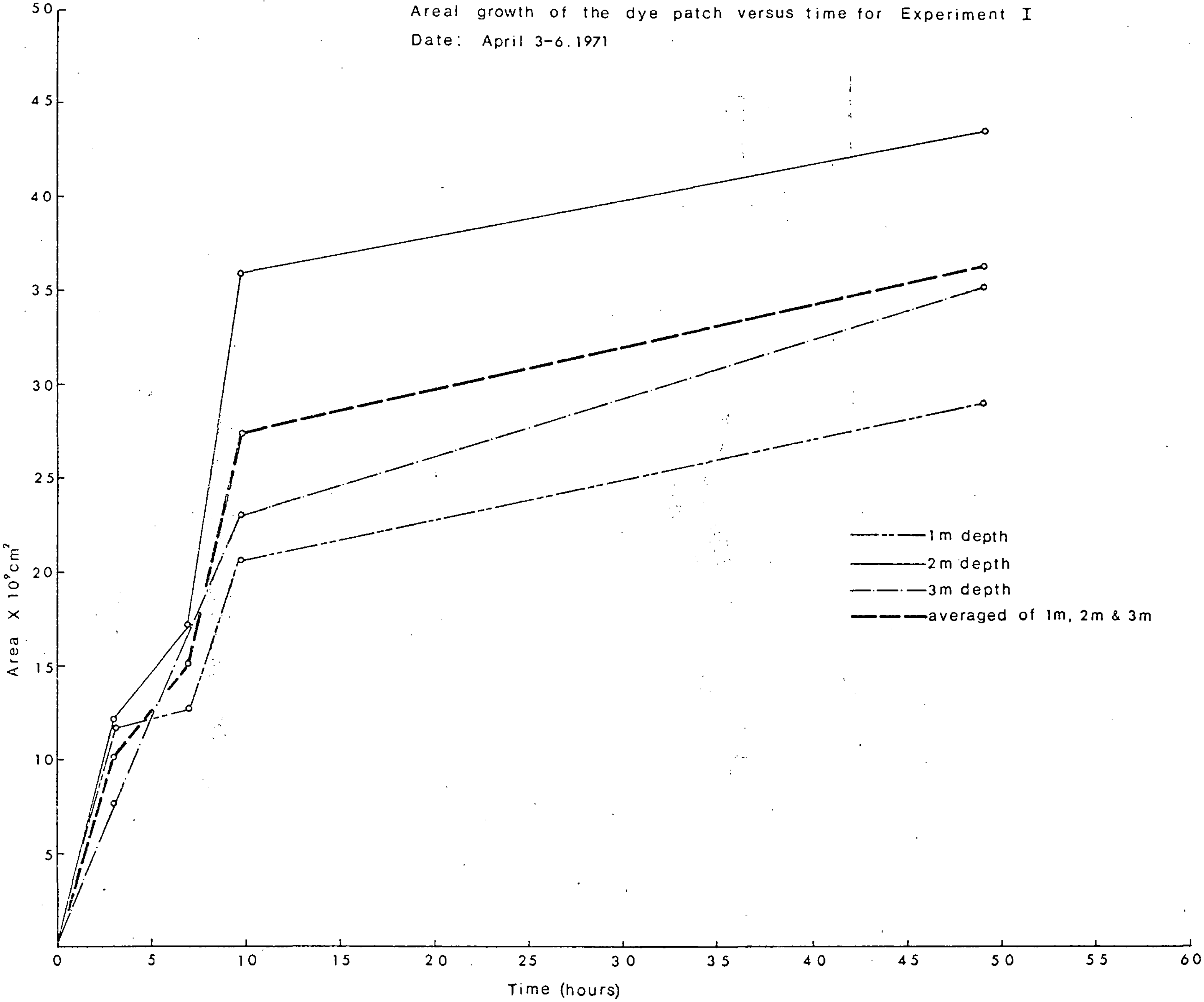

Figure 6.

Areal growth of the dye patch versus time for Experiment I

Date: April 3-6, 1971

a dispersion of dye towards that shore. There was less dispersion towards the eastern shore.

All drogues for the spring experiments were set at 1, 2 and 3 metres (Fig. 8). The drogues moved towards the southwest in this period. This result is quite consistant with the dye movements observed in the spring.

Fall

The details of the fall experiments are outlined in Table 1. These experiments were conducted under conditions quite different from those in the spring. The lake was highly stratified (Fig. 3), the river discharge was relatively low (Fig. 4(c)), the wind was predominantly out of the north (Fig. 7), and modification of the sampling gear allowed us to take vertical samples down to 20 metres. Boat facilities were considerably better than those in the spring, and an extensive drogue tracking program was conducted in parallel with the dye-diffusion experiments.

During Experiments III and IV, vertical samples were obtained in the northern end of Lake Skaha and particularly in the northwest corner. These samples showed negligible dye below the thermocline, a fact consistant with the observed densities of river water and lake water. The river water for Experiments III and IV was from 2°C to 4°C colder than the ambient lake

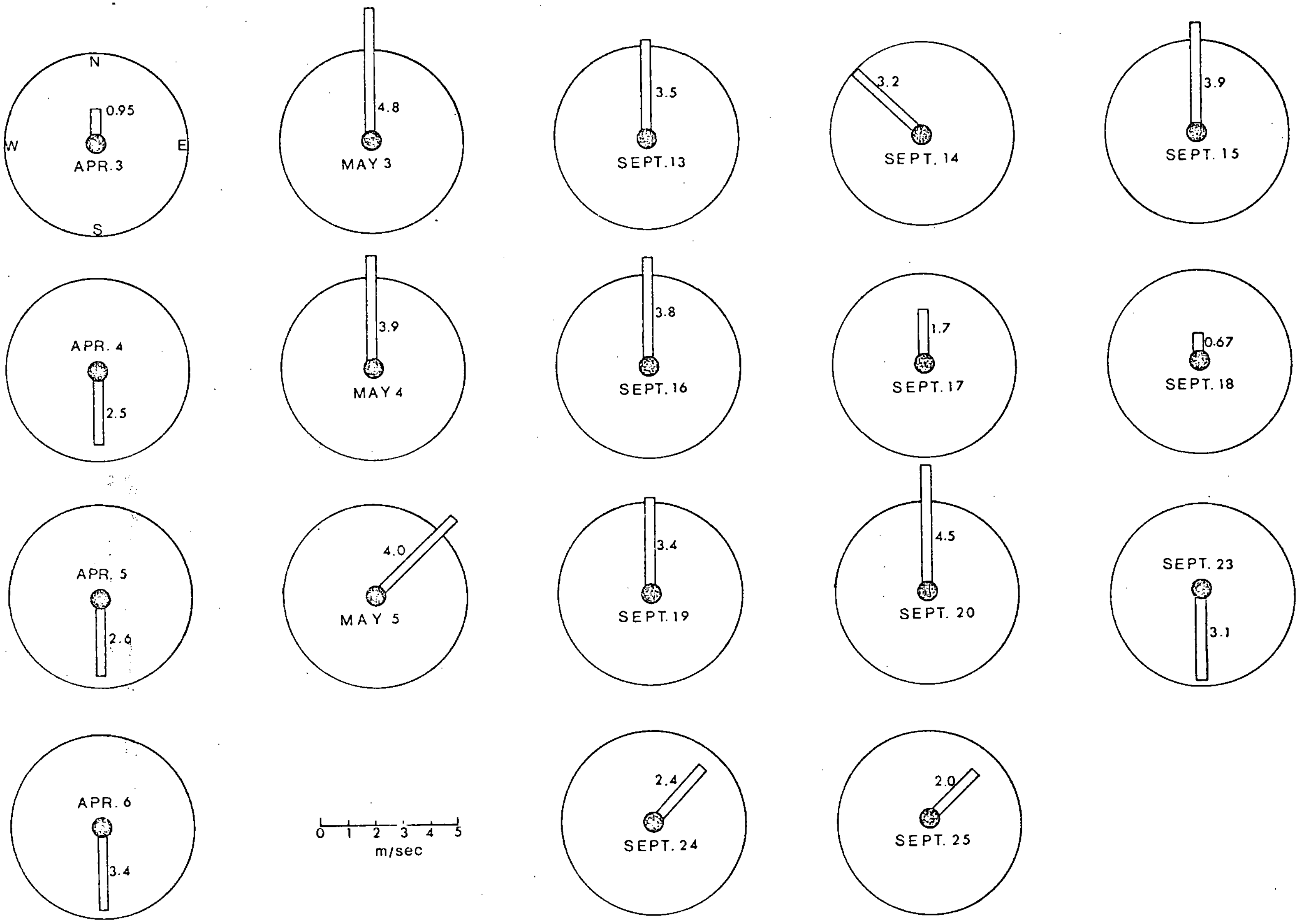

Figure 7. Daily wind speed and direction, 1971, at Penticton Airport during the experimental period. Numbers adjacent to bars refer to mean speed from that direction (m/sec) measured from the edge of the shaded circle.

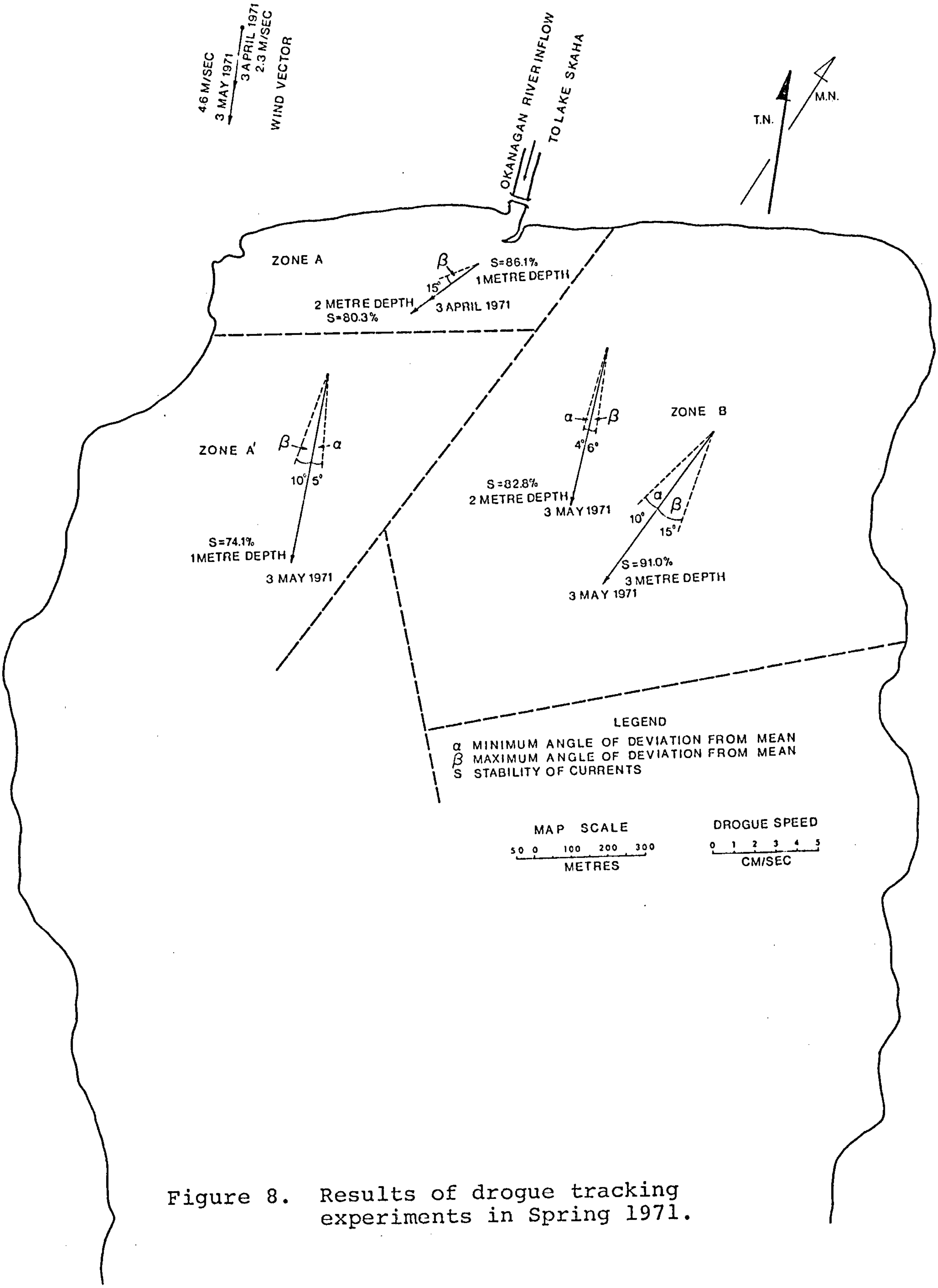

Figure 8. Results of drogue tracking experiments in Spring 1971.

temperature (Fig. 3). However, by the time the river water had spread into the lake and reached the region where the thermocline was present, mixing had raised its temperature. The river and lake water mixture always remained at depths between the surface and the top of the thermocline.

We have constructed maps of the horizontal distribution of dye at 2, 9 and 17 metres in Experiment III. No illustrations are presented because the essential details are similar to those for Experiment I (Fig. 5). There were large amounts of dye concentrated in the northwest corner which were spreading southward along the west shore. There was less-rapid spreading of the dye in the southeast and east directions.

Similar horizontal distribution maps were constructed for Experiment IV at 2, 5, and 12 metres. None are shown here for the same reason given for Experiment III. Essential features were that the strongest dye concentrations were found in the northwest corner. The dye spread rapidly to the south along the west shore and less rapidly in a southeast direction offshore. It was during Experiment IV that we have some indications of the effect of south winds as opposed to north winds. We have calculated the speed of advance of the leading edge of the dye patch along two directions on a distance versus time plot (Fig. 9). As found in previous experiments, the speed of spreading from the northwest corner was greater southward than southeastward. More interesting, however, is the abrupt change in speed along both directions after 13 hours. This change will be discussed in the Discussion section.

All fall data from the tracking of drogues at 2 metres are combined in Figure 10. (See the Appendix for a discussion of the data reduction techniques). While the drogue trajectories exhibit the expected variability over the mean (compare α and β for each mean*), a clear pattern emerges. Under prevailing northerly winds, there is a predominant flow towards the west shore (Fig. 10) in the epilimnion. This is clearly consistent with the observed spreading of the dye. Only in zone D are the currents very erratic as indicated by the low stability.

The pattern at 17 metres (Fig. 11) was quite regular as all drogues moved basically towards the south. Since movement occurs below the thermocline, it probably

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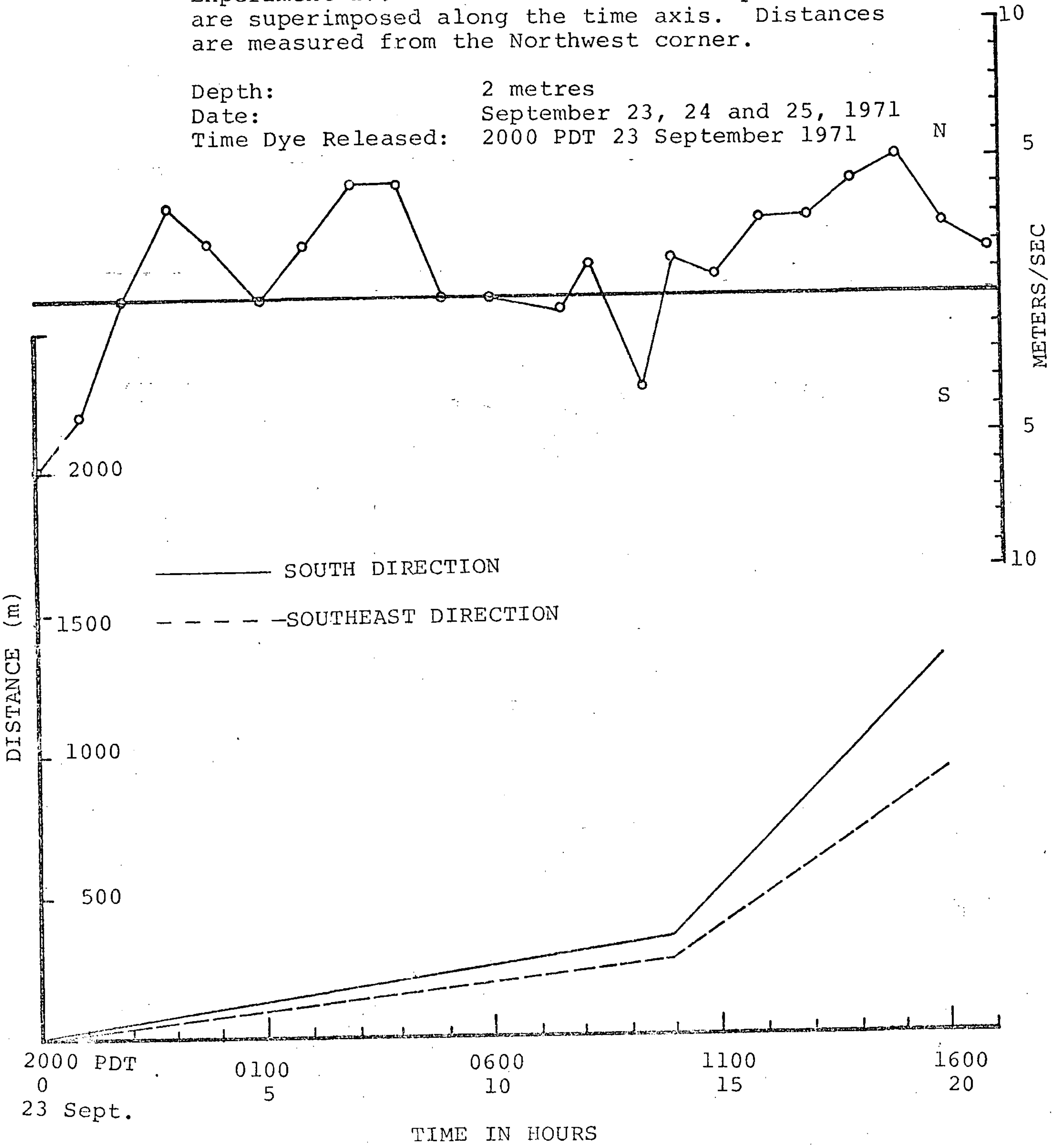
*The means apply to all drogues in a particular zone. α and β are geographical deviations, not statistical ones, since the daily drogue vectors are scattered over a given zone.

Figure 9. Speed of the leading edge of the dye patch for Experiment IV. North - South wind components are superimposed along the time axis. Distances are measured from the Northwest corner.

Depth: 2 metres
Date: September 23, 24 and 25, 1971
Time Dye Released: 2000 PDT 23 September 1971



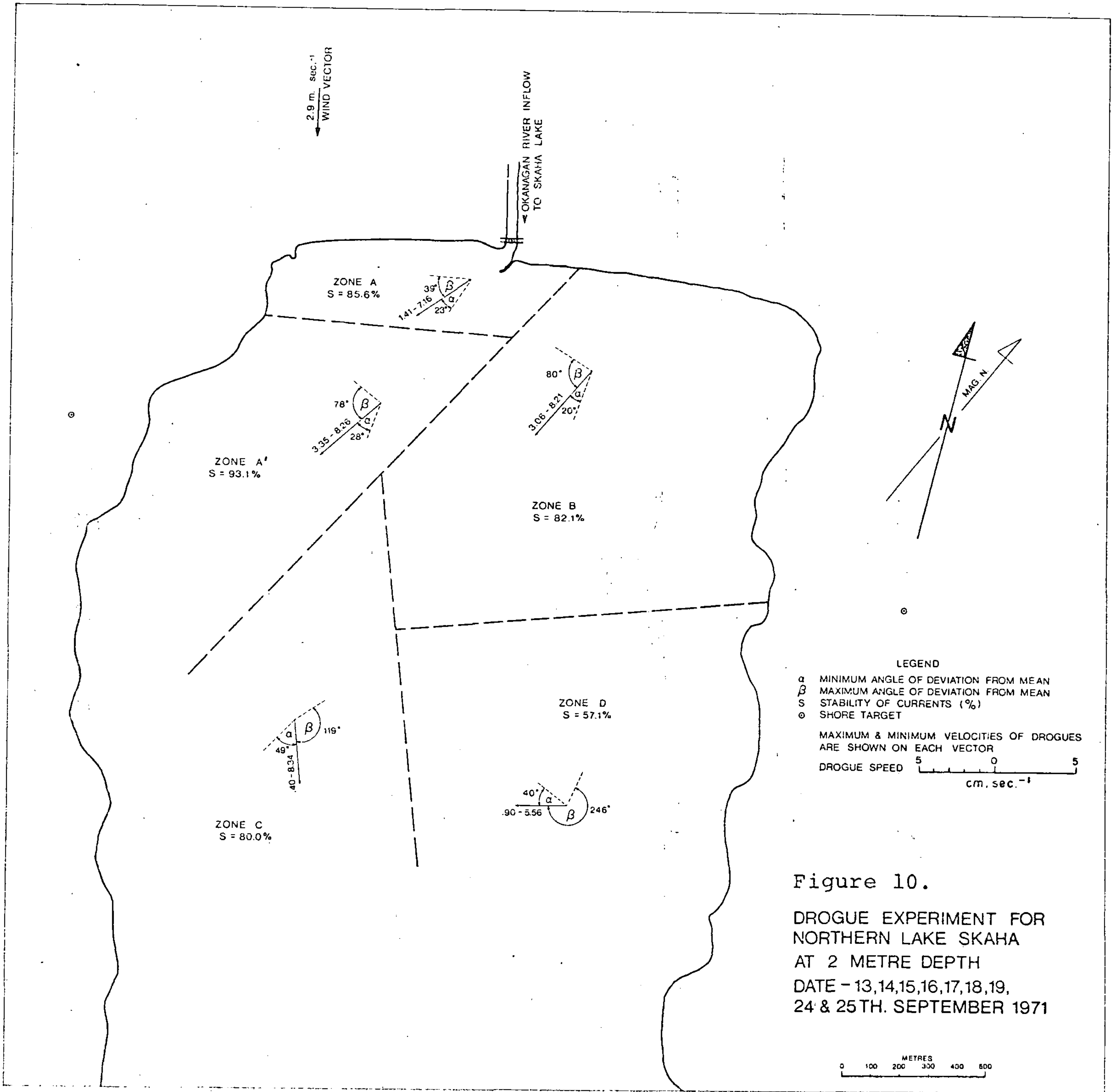


Figure 10.

DROGUE EXPERIMENT FOR NORTHERN LAKE SKAHA AT 2 METRE DEPTH

DATE – 13,14,15,16,17,18,19, 24 & 25TH. SEPTEMBER 1971

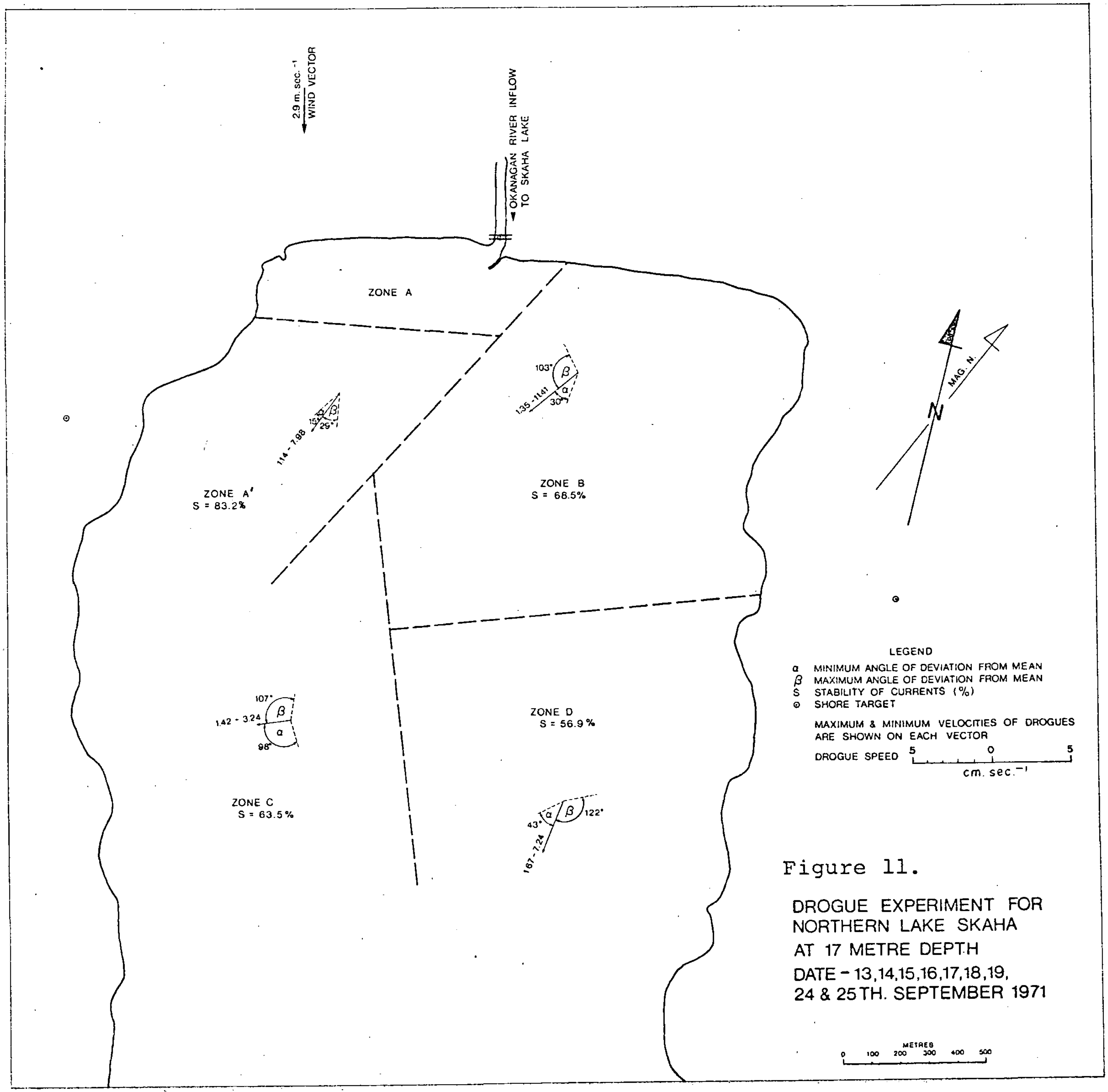


Figure 11.

DROGUE EXPERIMENT FOR
NORTHERN LAKE SKAHA
AT 17 METRE DEPTH
DATE - 13,14,15,16,17,18,19,
24 & 25TH. SEPTEMBER 1971

does not reflect the movement of any mixtures of river water and lake water because we suspect that only rarely does this water sink below the thermocline. The slopes of the regression lines of drogue speeds at 17-metres versus wind speeds were so low that we concluded that there was negligible coupling between winds and water movements at that depth.

For each average drogue speed within each zone, we correlated that speed with the mean wind speed (Table 2). The wind speed was averaged over the same duration in which the drogues were tracked. The correlations tabulated are not essentially different for winds averaged for an additional 2 hours prior to the tracking. Except for zone D, there was a reasonably good correlation between wind speed and drogue speed. The differences in correlations between zones A, A', B, and C are probably insignificant.

DISCUSSION

The results of the spring and fall experiments can be summarized as follows:

(1) The river effluent is carried along the north shore to the northwest corner where it then proceeds southward along the west shore. Slower mixing offshore to the southeast is observed.

Table 2. Least squares regressions of drogue speeds to wind speed

Depth = 2 metres

Zone	Drogue versus wind			Significance of correlation	Number of observations
	r	m	c	At 95% of confidence	
A	0.78	0.011	1.00	0.75	7
A'	0.73	0.009	3.52	0.75	7
B	0.80	0.005	6.55	0.81	6
C	0.91	0.015	4.49	0.88	5
D	0.46	0.002	4.97	0.95	4

r: coefficient of correlation

m: slope of regression line

c: intercept

(2) This pattern is consistant with the circulation measured with drogues.

These results are further interpreted below.

We believe that southerly winds do not essentially alter this basic pattern. However, during Experiment IV, we have some indications of the modifications imposed by brief episodes of southerly winds (Fig. 9). (There were no variations in river discharge for this experiment). The abrupt shift in the speed of both leading edges of the dye patch can probably be attributed to a switch to steady north winds at that time. When the dye was released on 23 September, the winds were moderately strong from the south, and remained so until almost midnight. After that there were still episodes of fluctuating northwinds which did not become steady until about 1000 PDT on the 24th of September. The southerly winds probably retarded the spread of the dye thereby trapping it adjacent to the northwest shoreline. The rapid spreading did not occur until after southwinds had ceased.

It should be pointed out that wind correlation is fairly high in zones A, A' and C (Table 2), so that the water speeds appear to correspond well with wind speeds. This fact is consistant with the rapid spreading of dye in those zones during northerly winds.

CONCLUSIONS

All four experiments have shown the basic features of Figure 7 as outlined in the first paragraph on the Discussion section. We conclude therefore that the northern portion of Lake Skaha can be divided into zones of river influence (Fig. 12).

The river zone is located along the north shore, west of the river inlet, and extends to the northwest corner. This zone is more or less directly influenced by the Okanagan River discharge. The magnitude of the influence probably increases with increasing river discharge and increasing southwind component. The effect of lake stratification and the river-lake density differences are unknown.

The next zone extends along the western shore beginning in the vicinity of the northwest corner. Advection by the strong southerly currents near the shoreline carries the mixture of river and lake water southward. The extent of this zone probably increases with increasing northerly winds and increasing river discharge. Again, the effects of stratification are unknown, but there is no evidence to suggest that stratification alters this regime.

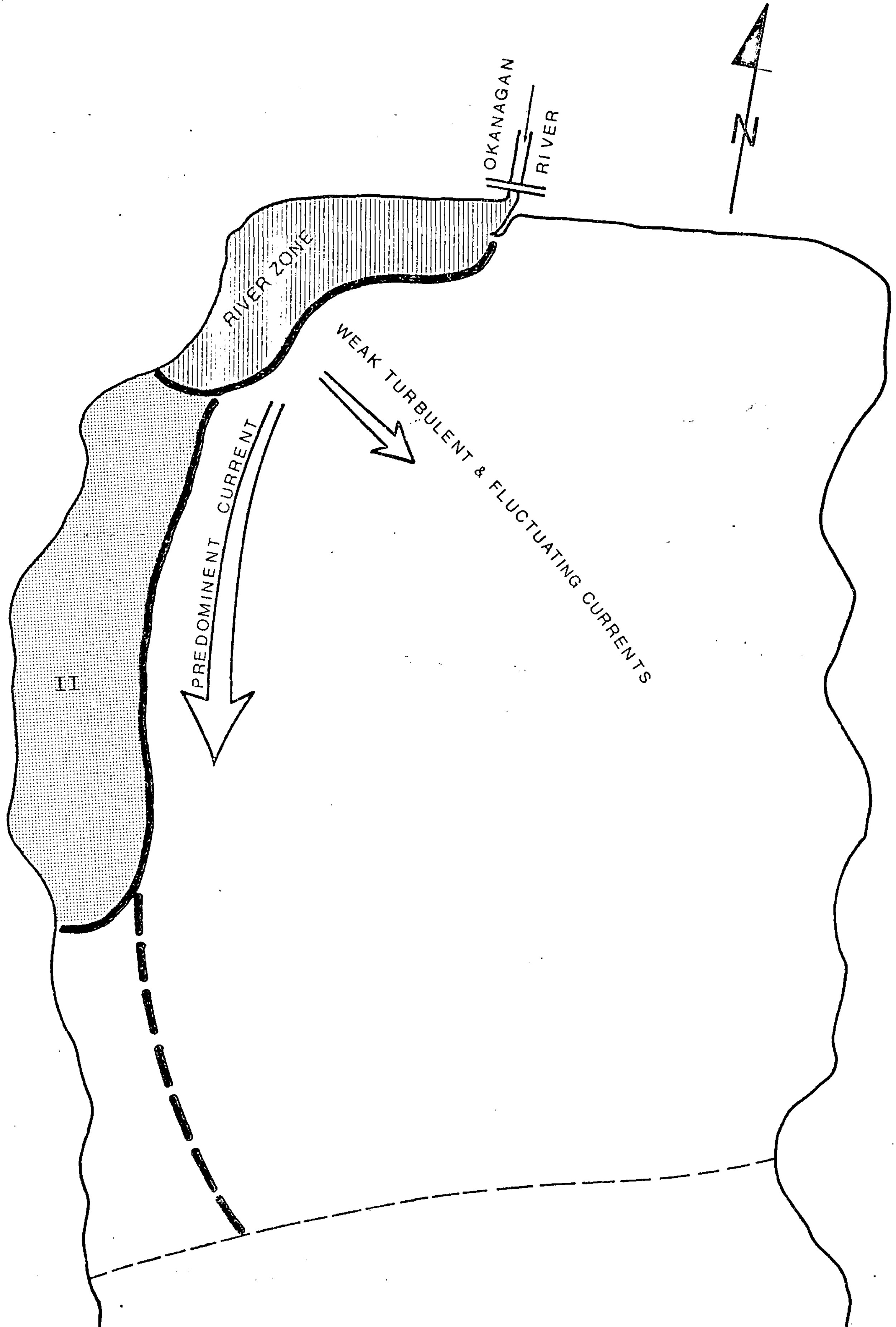


Figure 12. Schematic zones of influence by the Okanagan River as it enters Lake Skaha.

Apart from the above two zones, there is a mixing zone where the river-lake mixture spreads relatively slowly offshore, away from those zones. Dilution is very rapid, so that the northeastern shore of the lake is comparatively free of river influence.

Mr. Gordon Koshinsky kindly made available to us some aerial photographs taken in February, 1972 (Fig. 13). The lake was ice covered except for the zone influenced by the Okanagan River. This ice fill area plus the patterns of the ice fissures along the western side of the lake confirm the circulation patterns described in this study. We conclude that the schematic zones (Fig. 12)* probably reflect the main circulation throughout the year.

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* It is noteworthy that Figure 12 was completed and drafted before the ice photograph (Fig. 13) was made. This fact places quite a bit of credibility to the drogue and dye techniques employed in this study.

Figure 13. Aerial photograph of the northern end of Lake Skaha, 21 February, 1972. Note that the ice-free area and the fissure patterns in the ice correspond to the zones depicted in Figure 12.

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APPENDIX

EXPERIMENTAL EQUIPMENT AND FIELD METHOD

Field equipment and instrumentation

Water soluble Rhodamine B was used to tag the river water. The dye may be obtained from the manufacturer in a 40% acetic acid solution. The dye is a vivid red, non-toxic to human and aquatic life, identifiable or separable from naturally occurring substances, and is detectable at concentrations lower than one part per billion. The dye tracer method has been widely used by hydrologists and limnologists to investigate the time of travel and discharge in streams, and the diffusion characteristic in lake and in ocean. Thus, because of the ease of handling, this fluorescent dye has proven to be an excellent and low cost tracer.

Fluorescent tracers have been carefully studied, for example, by Fenerstein and Selleck (1963) and the fluorometric procedures for dye tracing has been described in detail by Wilson (1968). Following the above 2 references, we determined the natural degradation of Rhodamine B in Skaha Lake Water under different concentrations. Five different dye solutions were prepared by diluting with lake water. Such that the concentrations ranged from 12.4 ppb to 0.21 ppb. All five samples were at room temperatures of 19^{o} near a window so that the samples could receive sunlight during day light time. The fluorescence levels of each sample over the test were expressed as a fraction of its initial level. Higher fluorescence levels degraded faster than the lower ones for the 5-day period. A normalized fluorescence level of 2.48 ppb has been plotted against time (days) (Fig. 1A). The 50% degradation is about 16 days.

For releasing dye into the river a wooden platform was suspended beneath the Highway 97 bridge (Fig. 2A) at Penticton about 400 feet (122 m) from the end of the Lake Skaha break water. The platform was close to the centre of the Okanagan River, and the point of release was positioned approximately in the highest velocity region. A 45-gallon barrel, equipped with a constant head siphon, (Fig. 2A) placed on the platform. The siphon could be adjusted to a desired rate of flow. The dye was released 30 cm (1 ft) below the water surface from a copper pipe connected to the barrel through the siphon. The barrel and siphon apparatus delivered a continuous source of dye over a period dependent upon the desired flow rate. For an instantaneous release of dye, a plastic bag 26" x 36" (64 x 92 cm) was filled with dye solution. When sunk below the water from the platform, the dye emptied from the plastic

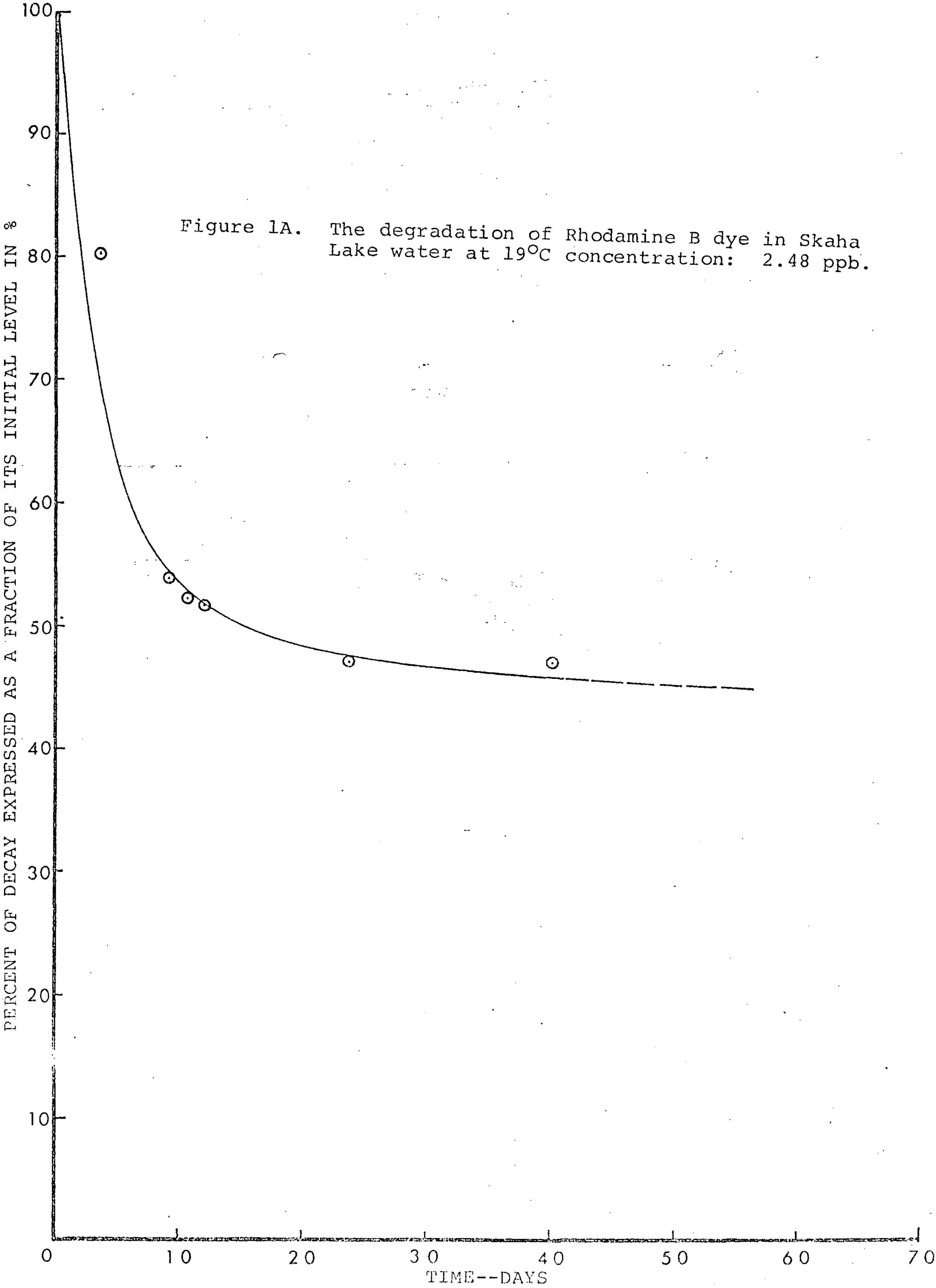


Figure 1A. The degradation of Rhodamine B dye in Skaha Lake water at 19°C concentration: 2.48 ppb.

bag in less than 5 sec. The dye solution was adjusted to a specific gravity of 1.00 by pre-mixing with methanol in the ratio 3:1.

In order to continuously track dye diffused in the lake, a system was designed that could be mounted on any suitably sized boat. The basic system consisted of (1) a sampling boom, (2) plastic garden hose (1/2"-ID), (3) submersible pumps and (4) fluorometers. Intakes were mounted along the sampling boom (a commercial, aerofoiled shaped aluminum extrusion) at one-metre intervals. The pumps were mounted along the boom at each intake, and tubing was extended from each intake. The water was pumped up through the inside of the boom. The intake tubings were each connected to fluorometers whose outputs were recorded on a Hewlett-Packard strip chart recorder. The pumps were manufactured by Little Giant Pump Co., Oklahoma City, U.S.A. (Model 2E-38N) and the fluorometers by Turner Associates, Pala Alto, U.S.A. (Model III). The entire system was powered by a 5 hp. portable gasoline generator (AC 115 V, 60 cycles, 1500 watts). A voltmeter was required to stabilize the output from the generator.

For the Skaha Lake experiments, the boom was designed to sample at depths of 1, 2, and 3 metres simultaneously. During fall, when the dye sank to greater depths, one pump and associated sampling tubes were detached from the boom and towed at depths as great as 12 metres. We could sample vertically as great as 20 metres with the boat stationary.

At the three meter depth, the minimum flow rate was 91 cm^3/sec, and 22 seconds was required for the water to pass up the tubing and into the fluorometer. At the shallower intakes, flow rate is higher, and response time is shorter. For deeper sampling the reverse is true. Boat speeds were maintained at 1 or 2 metres/sec (2-4 knots), depending upon depth of sampling.

During the spring experiments, only one 17-foot boat was available. When the sampling system plus 3 or 4 personnel were on board, safety was marginal under all but flat calm conditions. For the fall experiments, we obtained a 25-foot flat barge the "Sea Truck" (Fig. 3A). This provided ample stability and working space for the experiments. The 17-foot boat was used to track drogues when the Sea Truck became available. Both boats were furnished to us by the Marine Sciences Branch, Canada, Department of the Environment.

Figure 2A. Platform used to release dye into the Okanagan River at the Highway 97 bridge. Barrel with the constant head siphon is mounted on the platform.

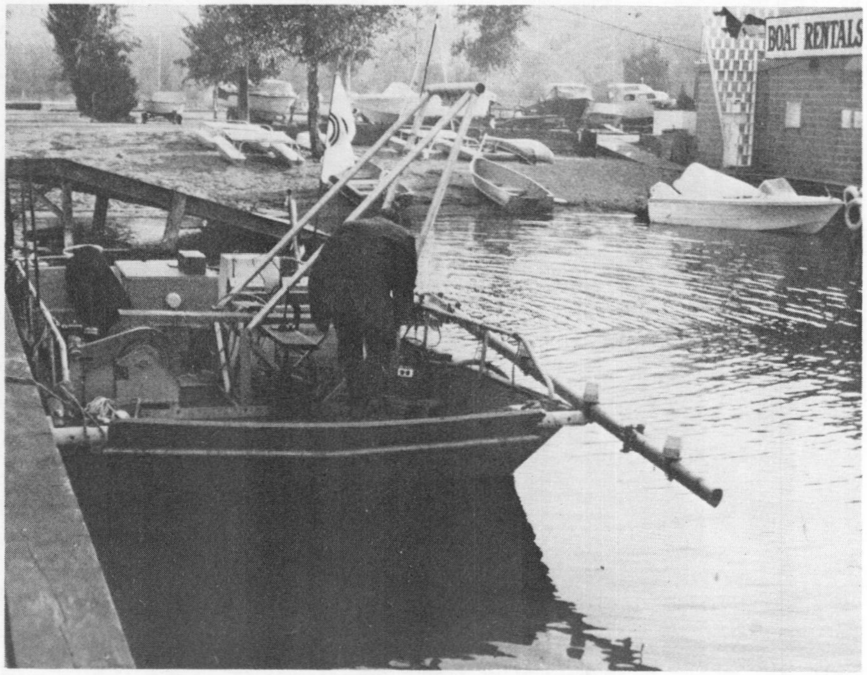


Figure 3A. The "Sea Truck" with dye sampling system mounted.

A Brunton's Pocket Transit or compass was used to fix the positions of boats and drogues by referring to known shore targets (Fig. 1). All the compass bearings were recorded in a deck log. The actual positions were obtained by plotting the bearing of each fix on a scaled map of Lake Skaha. The boat speeds were determined, by dividing the distance by the time intervals from one location to the other.

Position markers were anchored during dye plume sampling at times when multiple crossings of the plume were to be made at one location. The markers were 12-in. cubed styro-foam floats painted bright red-orange. A flag was mounted on the float by a pole, and the float was anchored with a 12" x 6" x 6" concrete block.

All current measurements were obtained by tracking drogues set at predetermined depths and marked on the surface by an easily identifiable target. This method of current measuring has been used by many investigators (Knauss 1963), and has been proved to be quite successful and relatively inexpensive. The two types of drogues used in this study are shown in Figure 4A. There were no essential differences in performance in the two types of drogues. Supplementary wind data

(a)

(b)

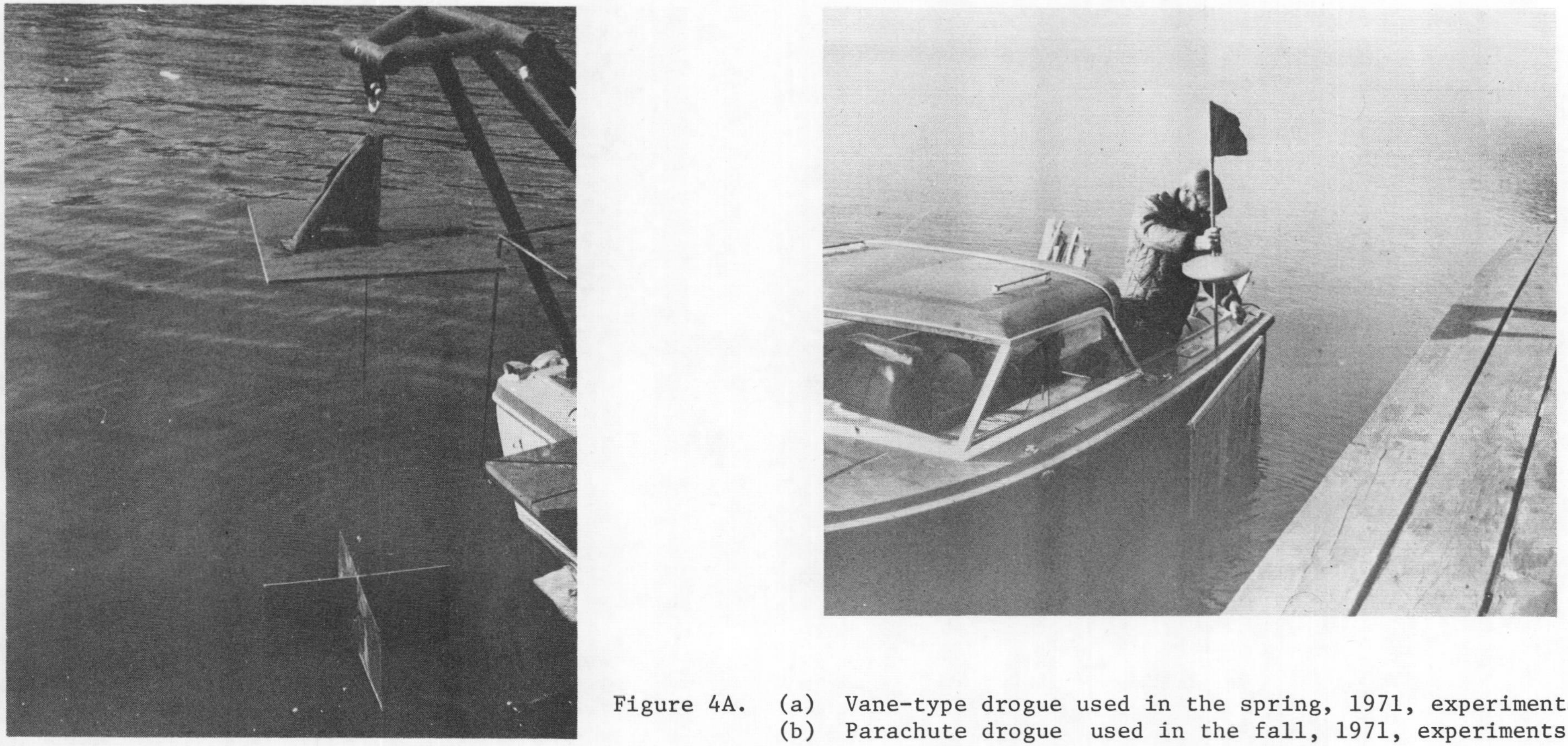


Figure 4A. (a) Vane-type drogue used in the spring, 1971, experiments.
(b) Parachute drogue used in the fall, 1971, experiments.

were obtained from the Penticton Airport (Fig. 1). Temperature profiles were obtained from a bathythermograph and mooring array of Ryan Recording Thermographs (Blanton and Ng, 1972). Unfortunately, there are no aerial photographs available for these experiments.

Experimental procedure: Spring

The field work was divided principally into two basic periods: spring, April-May and fall, September. In each of these periods, one detailed dye diffusion experiment was performed, supplemented by several shorter-termed experiments. The detailed measurements lasted for 48 to 72 hours while the shorter-termed ones were only day-to-day. Obviously the longer term experiments were most useful and we will describe the details of these.

During April 3, 1971, at 0700 local time a slug (67.5 Kg) Rhodamine B dye was released instantaneously at the Highway bridge (Fig. 1). Beginning one hour later, the boat began mapping the spreading dye patch criss-crossing it several times at different locations. Positioning of the boat was done as described above. Dye samples were obtained continuously at 1, 2, and 3 metres. For the next 72 hours, it was possible to obtain 5 maps at the three levels. No sampling was done on 5 April due to strong winds from the south. Some drogues were tracked during this period when the tracking did not interfere with the dye sampling.

Experimental procedure: Fall

On the 23rd of September, 2000 local time, 168 Kg of dye was released over a period of 12 hours. Beginning early the 24th, the boat began tracking the dye in order to obtain synoptic maps as in the spring. Due to the fact that deep sampling gear had to be towed, boat speed was reduced and only three maps were obtained during the experiments at levels of 2-5 metres and 12 metres. Extensive drogue measurements were made during this experiment because we had an additional boat.

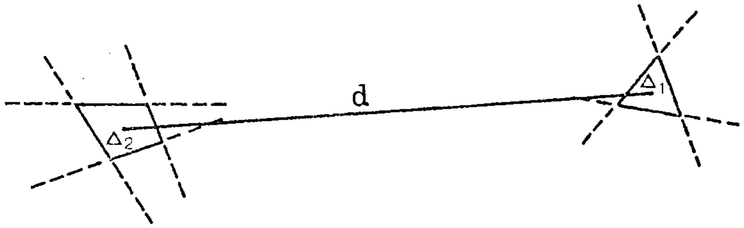
During daylight hours, drogues were tracked at 2 metres and 17 metres from 13-19th September and from 23-25 September. The 17-metre drogues were located in the hypolimnion about 2 metres below the thermocline for the entire fall study period. In spring, all drogues were set at 1 and 2-metre depths.

Data analysis

The fluorometer output as recorded on strip-chart paper was converted to fluorometer units (Murthy 1969 and 1970). These units were picked off the charts at 0.1 inch intervals and, using the boat speed to chart speed ratio, the values were plotted onto a scaled map of Lake Skaha. Equal concentration lines were then contoured on the map after which the fluorometer units were converted to parts per billion.

Some of the dye concentration data for the above described experiments plus data from the shorter-termed experiments are quite adequate for the calculation of eddy diffusivities of the dye (see Csanady, 1966). These parameters have very little value in describing the distribution of Okanagan River water, which is our basic aim here. Therefore, no attempt has been made to calculate eddy diffusivities.

The positions and times of each drogue were plotted on a scaled map of Lake Skaha, each map containing the positions of one day of tracking. A minimum of three shore targets were used for each positioning. The actual position of the drogue was chosen from the centroid of the bounded area by the target alignments.



The size of the bounded area (the "cocked hat") is dependent on the precision with which one can determine the compass bearings to each target. In addition, the alignment of the targets relative to the drogue affect the precision. The error in the velocity is determined by the uncertainties, Δ_1 and Δ_2 of the positions of the drogue at the times of the first fix and second fix respectively.

$$V = (d + \Delta_1 + \Delta_2)/t$$

where V, d, and t are velocity, distance and time respectively.

Most, however, have dimensions of less than 40 metres which means our accuracy for current speeds are about ±1 cm/sec for positions fixed hourly. The overall pattern of the circulation, however, is quite clear because we had many drogues and many position fixed throughout the course of the study. For example, each day in September when drogues were tracked, approximately 10 drogues were set simultaneously, and three or usually four hourly fixes were made on each drogue.

For each drogue on each day, two speeds were determined. One speed was the average distance covered between each fix, C_S. The other speed was determined as the distance between the first fix and the last fix, divided by the total time elapsed between the fixes, C_V. C_S is a scalar average, while C_V is a vectoral average. The current stability, S, was then calculated for each drogue as

$$S = \frac{C_V}{C_S} \times 100$$

The stability can thus vary between 0 and 100%, and the number may be thought of as an index of the variability drogue track during the day (Neumann, 1968). For each day, we also determined the vectoral average of the wind as measured at the Penticton Airport by averaging the hourly vectors from 2 hours before drogue tracking commenced until the tracking was completed on that day.