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**MANUSCRIPT REPORT SERIES
(OCEANOGRAPHIC and LIMNOLOGICAL)**

No. 197

**Current Observations in Cordova Bay
and
Predictions on Sewage Dispersal**

by

**C. J. Keenan, A. C. Kinnear, F. H. Sanders,
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**Pacific Oceanographic Group
Nanaimo, B.C.**

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C.J. Keenan¹, A.C. Kinnear², F.H. Sanders³, J.P. Tully⁴

M. Waldichuk⁵, S.O. Wigen⁶ and R.B. Young⁶

¹British Columbia Pollution Control Board, Victoria.

²Air Division, Surveys and Mapping Branch, Department of Lands, Forests and Water Resources, Victoria.

³Defence Research Board of Canada, Pacific Naval Laboratory, Esquimalt, (Now retired).

⁴Fisheries Research Board of Canada, Pacific Oceanographic Group, Nanaimo. (Now Headquarters, F.R.B. of C., Ottawa).

⁵Fisheries Research Board of Canada, Biological Station, Nanaimo.

⁶Canadian Hydrographic Service, Victoria.

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1. INTRODUCTION

Because of population growth and industrial expansion, it was becoming increasingly evident by 1964 that the four municipalities of the Greater Victoria area - Victoria, Esquimalt, Oak Bay and Saanich - required a joint program of sewerage development and sewage disposal, which should be coordinated by a central body. The British Columbia Pollution Control Board was receiving frequent applications from the different municipalities requesting approval for various schemes of sewage disposal in coastal waters. There was little information available concerning coastal currents on which to base any appraisal of these applications. Consequently, the B.C. Pollution Control Board appealed to the West Coast Working Group of the Canadian Committee on Oceanography for assistance in obtaining such information.

After preliminary meetings of representatives of a number of interested agencies early in 1964, it was agreed that aerial photography might answer the need for obtaining information quickly with limited resources. It was proposed, therefore, to seek the assistance of the Air Division, Surveys and Mapping Branch of the B.C. Department of Lands, Forests and Water Resources. During early discussions of the application of aerial photography in this project, it was agreed that the technique of photogrammetry (Cameron, 1962) might lead to extensive additional effort and various complications in interpretation. The Air Division of the B.C. Department of Lands, Forests and Water Resources and the Pacific Oceanographic Group (1950) already had some experience in photographing and interpreting water movements from aerial photographs of silty water taken at various stages of the tide in the Fraser River estuary and at the approaches to Vancouver Harbour (Fjarlie, 1950). It was decided, therefore, to apply the standard technique of time-lapse aerial photography of seeded targets to determine current vectors.

While the technique for obtaining the necessary current information had been agreed upon by early April, 1964, there were insufficient time and resources available in the remainder of the year for carrying out a full-scale current study in coastal waters adjacent to Greater Victoria. Hence, it was decided to carry out a pilot study in June, 1964, in a limited area for which current information was urgently needed. The area selected was Cordova Bay (Fig. 1), bordering on the municipality of Saanich, which had made application to the B.C. Pollution Control Board for sewage disposal from a new housing development. It was agreed that, while the primary immediate purpose of the

current data would be toward evaluation of different areas for sewage disposal, the longer-term need for general current information in navigation should not be ignored.

This report represents the joint efforts of a number of federal and provincial agencies which took an active part, contributing their specialized services toward gaining the required information. The B.C. Pollution Control Board provided the rolls of paper for targets. Four tugs of the Canadian Naval Auxiliary Vessel fleet, through the courtesy of the Queen's Harbour Master, Royal Canadian Navy, were used to lay the paper. The Air Division of the Surveys and Mapping Branch, B.C. Department of Lands, Forests and Water Resources carried out the aerial photography, using two aircraft flown during alternate periods. The Canadian Hydrographic Service conducted current measurements from C.G.S. Parry anchored in Cordova Bay and supervised the tracking of floats by theodolite from Mt. Douglas. The C.H.S. was also responsible for converting the data from the aerial photographs to charts showing the current vectors. The current data have been analyzed by staff of the Fisheries Research Board to determine suitable locations for sewer outfalls. A preliminary report on the project with recommendations on outfall sites was submitted to the Pollution Control Board at an earlier time (Waldichuk, MS 1964).

2. METHODS OF OBSERVATION

(a) Aerial Photography of Drifting Targets

(1) Target Material

After some preliminary consideration and testing of different target materials, it was agreed to use long strips of paper. A properly-selected paper could fulfil the necessary requirements for a suitable target material: (i) good visibility in aerial photographs taken at elevations of 6,000-12,000 ft with a scale of 1 in. = 1,000 ft; (ii) remain afloat for several hours for repeated photography; (iii) present no hazard to navigation; (iv) sink after about 12 hr and not be a potential pollutant on shore; (v) inexpensive. A number of different papers in $8\frac{1}{2}$ in. x 11 in. sheets were tested in water under laboratory conditions. The paper chosen was a $54\frac{1}{2}$ lb (3,000 ft² of paper weigh $54\frac{1}{2}$ lb) bond having good buoyancy and comparatively good endurance. It was manufactured by Island Paper Mills, Annacis Island, New Westminster (Division of MacMillan, Bloedel and Powell River Limited) and was provided in rolls 36 in. wide and 3,800 ft long.

(2) Laying the Targets

The roll of paper, with an axle through the core, was set on an A-frame mounted on the stern of a small tug so that it could rotate freely while the paper was spooled off into the water. A typical arrangement, with paper being released into the water, is shown in Figures 2A and 2B. Some difficulty was encountered in spooling the paper out evenly in the presence of wind, which would catch the edge of the paper and flip it upward. Combatting this problem

with two plywood sheets as guides between which the paper was supposed to slide from the A-frame to the water surface was unsuccessful, because the plywood became wet from the wake of the tug and caused the paper to stick. It was found that wind disturbance could be counteracted most effectively by a trimmer, in the shape of a large "T" or rake, manipulated by one person so that the crosspiece would hold the paper down near the water surface. In order to lay a flat layer of paper it was necessary to reduce the tug's speed to 4 knots or less. At greater speeds the paper tended to buckle in the tug's wake or collapse as the strain on the paper, due to the drag by the water, was suddenly relieved by cutting it. Care was necessary to lay the paper flat so that as much as possible of the area was visible to the camera.

The paper was released along four lines, running approximately normal to the coast of Vancouver Island (Fig. 3). Strips were torn off in about 40-ft lengths and seeded at 100-ft intervals. Floats attached by lines at 40 ft and 140 ft from the stern of the tugs were towed as guides for lengths of paper to be released and distances between them. The four lines were all seeded with paper by a tug on each line before the first flight of the photographing aircraft commenced at 0500 (P.S.T.)*. Following the initial seeding of the four lines, two of the tugs returned to base at Esquimalt and two remained for the purpose of reseeding those areas from which targets were drifting rapidly or were disappearing for other reasons. A grid system, as shown in Figure 3, was used to identify areas lacking paper. Instructions for reseeding target-free areas were given by an observer in the aircraft to the CNAV Heatherton via FM radio communication. The instructions were then passed on by the Heatherton, which acted as a control or mothership, to the particular tug nearest the area requiring more targets. In this way, an attempt was made to have as much of Cordova Bay covered with targets as possible throughout the entire period of photography.

(3) Aerial Photography

Aerial photography was carried out during the hours of daylight, commencing at 0500 hr with completion at 2000 hr. Twin-engined Beech 18 aircraft were used in the operation, flying at about 140 knots. Hourly flights were made along lines 1-3 in a north-south direction, with a 20% side lap between adjacent lines shown in Figure 1. Only occasional flights were made along line 4 and return flights frequently took photographs along line 1 to give data on short-period drift during the hour. Aerial photographs were taken at 6,000-ft elevation during the first and last parts of the day, and at 12,000 ft during the middle portion of the day in order to avoid the effect of the sun's glare when the sun was well above the horizon. In each case, however, the cameras were adjusted for a scale of 6 in. = 1 nautical mile or 1 in. = 1,000 ft (1/12,000). Cameras used were RC8 (No. 355) with a focal length of 6 in., when flights were made at the lower elevation, and an OSC (No. 330, Shutter No. 4) with a focal length of 12 in., at the higher elevation. Kodak Special XX film was used with the first camera and Kodak Plus X was used with the second camera, giving 9 in. x 9 in. photos in both series. The number and time of each photo were recorded by a picture of a

* All times reported herein given as Pacific Standard Time.

counter and clock accompanying each aerial photograph. Photographs were taken at about 15-sec intervals, giving a 60% overlap between successive shots. Typical aerial photographs, showing part of the shoreline of Cordova Bay with paper strips immediately following release and after a period of drift, are shown in Figures 4A and 4B.

(b) Anchor Station Current Measurements

Current meter measurements were carried out from CGS Parry anchored in the northern part of Cordova Bay, where she served also as a reference point for aerial photographs (Fig. 3). Neyrpic BBT current meters suspended at 12-ft and 36-ft depths recorded both direction and speed of the current at these depths. Part of the record taken from one of these current meters is shown with the reader in Figure 5. Surface currents were measured with a Neyrpic (H. Dumas) speed indicator. Visual observation of the orientation of the meter was used to give direction.

Currents were observed from 1500 hr, June 24 to 1800 hr, June 25, 1964. There was no usable record from the current meter suspended at 12-ft depth during approximately the first 24 hr of observations.

(c) Tracking of Floats from a Triangulation Station

The 739-ft height of land, known as Mt. Douglas (Fig. 6), makes an excellent observation point with a clear, unobstructed view of Cordova Bay. It is easily accessible by automobile and advantage was taken of its location for a triangulation station. Using a theodolite one could track moderate-sized floats throughout Cordova Bay and into contiguous waters. The triangulation system set up for these measurements is shown in Figure 6.

Floats used for this phase of the program consisted of 36-in., children's plastic swimming pools. They were partially filled with water in order to minimize the effect of the wind. Some of the floats were fitted with lights during the evening and tracking was continued until the floats drifted inshore at about midnight.

(d) Ancillary Observations

(1) Tides

Tide gauge stations were established in Oak Bay, Finnerty Cove and Saanichton Bay to supplement the permanent gauges at Victoria and Fulford Harbour. From tide predictions, the selected period of observations, June 25, was expected to be one of large tides.

(2) Winds

While it was recognized that winds can have a very marked effect on the surface current, no effort was made to take special wind observations. Rough estimates of wind were recorded by observers at the Mt. Douglas triangulation station.

lation station and by some of the surveyors on tugs. It was considered that meteorological data recorded at Victoria International Airport (Patricia Bay) and Victoria City (Gonzales Observatory) should suffice for the experiment. Fortunately, there was little wind during the course of the day, which not only meant that there was little wind to record, but it made the survey much more successful than it may have been otherwise.

3. COMMUNICATION AND CONTROL

CNAV Heatherton acted as a control or "mothership" for communication between the photographing aircraft and the tugs laying targets. FM radio transmitter-receiver sets on the aircraft and Heatherton were used to relay information from the observer in the aircraft to the tugs, concerning areas needing more targets. Communication between the Mt. Douglas observation station and the launch laying plastic floats was maintained with radio (walkie-talkie type) hand sets. CGS Parry could maintain radio communication with CNAV Heatherton on the standard frequency for government vessels and radio-telephone communication with shore installations through DOT radio or Northwest Telephone Company.

All crews, including tug captains, surveyors and target layers on tugs, and triangulation station surveyors received prior instructions for the operation. The field coordinator was either on the Heatherton or in the photographing aircraft. New instructions were issued by the coordinator as changing conditions demanded.

The waters were patrolled by an RCMP boat to prevent undue traffic from passing through the area during the experiment. A beach patrol made regular checks on foot of the beach for any targets washed up on shore.

4. TRANSLATING DATA FROM AERIAL PHOTOGRAPHS TO CURRENT CHARTS JUNE 25, 1964

Because no hydrographic chart was available to correspond precisely with the scale of the aerial photographs, it was necessary to draw up a suitable chart. From the largest hydrographic chart available, a shoreline was traced as accurately as possible on a plastic sheet on which was marked a polyconic grid with intervals of one minute of arc. A coastline traverse was run tying in all prominent and identifiable features such as houses, patios, rocky points and large boulders. The traverse was plotted on a plastic sheet with rectangular grid having intervals of one inch. The sheet with the traverse was superimposed on the sheet with the polyconic grid and coastline. When the sheets were found to fit perfectly, identification points were pinpricked and labelled. The detailed procedure for producing a chart of the same scale as the aerial photographs, suitable for plotting data from the latter, is given in the Appendix.

A total of 15 hourly sorties, from 0500 to 2000 by the photographing aircraft, yielded approximately 480 individual photographs and 15 nearly synoptic pictures of targets in the bay. Each succeeding pair of hourly

pictures produced a chart of hourly current vectors. Fourteen of these hourly current charts were obtained covering all phases of a large tidal cycle.

A number of incidental observations were also made from aerial photographs, concerning currents and surface water behaviour. "Tide lines", consisting of accumulations of debris along convergence zones where paper gathered, could be clearly seen in the photographs. These convergence lines were particularly common on stages of the tidal current when it was changing direction.

The orientation of boats moored near shore and the movement of other visible objects were used to provide data on the directions of nearshore currents.

(a) Ebb Currents

Currents observed during a large falling tide, when the set was from north to south, are shown in Figures 7 to 9. The speed of the ebbing current ranged from 0.5 kt at 0.5 n. mi. from shore to 1.3 kt at 1.5 n. mi. from shore in the northern part of Cordova Bay ($48^{\circ}32'N$). Currents decreased southward within the region of observations. The direction of the ebb current generally followed the trend of the coastline, shifting from a nearly southward set in the northern part of Cordova Bay to a southeastward set in the southern part.

There was a sustained period of about 5 hr of strong ebb with only a short-period decline in the current from maximum ebb to low-water slack. During the period approaching low-water slack, there appeared to be a great deal of variability in current direction and a reduction in speed to about 25% of maximum. The trend in the current direction was toward a westward set onto shore with the nearshore currents changing direction first, as the tide dropped near to its lowest level.

(b) Low-Water Slack

Currents deviated most from the basic pattern of a northwest-southeast flow during the turn of the tide. In the 6th hour of observations (1000-1100 hr), when low-water slack was ostensibly reached (Fig. 10), currents at 2 n. mi. from shore were still setting to the south and southeast, while those within 1 mile of shore were setting either to the northwest or west. This countercurrent near shore gave the effect of a clockwise circulation in the southern part of Cordova Bay. It was not until the 7th hour of observation (1100-1200 hr) that the currents 2 n. mi. from shore appeared to be turning from a southward to a northward direction, being fully developed in a flooding set on the 8th hour (1200-1300 hr).

There was a rather vague indication of a clockwise rotation in the direction of the currents in Cordova Bay, which became most evident during low-water slack. As the ebb in the southeastward direction approached slack

water, it would swing to a southward and then a southwestward set onto shore. Part of this rotational effect was associated with the difference in speed and direction between the nearshore and mid-channel current, the former changing direction before the latter.

(c) Flood Currents

A typical picture of current vectors during the flood is shown in Figure 11. The maximum flood ranged from 0.5 kt at a distance of 400 yd to 1.2 kt at 1.5 n. mi. from shore in the mid-section of observations ($48^{\circ}32'N$). Stronger currents were noted to the north of this section and in part of the channel offshore. Weaker currents generally prevailed on the flood in the southern part of Cordova Bay. There was not nearly as marked a relaxation in current speed, as the tide reached its new elevation, on the flood as on the ebb.

(d) High-Water Slack

Although data became rather sparse for the period of high-water slack, since targets were not as densely distributed as in previous hours and visibility was limited on this last run of the day, one set of vectors was obtained for a period near high-water slack (Fig. 12). For this stage of the tide, current vectors were deduced from aerial photographs taken on the 13th and 14th hours (1700-1900 hr). The first shift in current direction appeared to occur in the southern part of Cordova Bay, near Cormorant Point. In this region, the current set eastward at 0.3-0.4 kt, during the beginning of the ebb (1700-1800 hr), while the other currents continued setting quite strongly at about 0.5-1.0 kt to the north. On the 14th hour (1800-1900 hr), currents were turning to ebb everywhere, with a set eastward at 0.2-0.5 kt. It would appear that the current direction follows the same rotation in a clockwise direction at high-water slack as found at low-water slack.

5. CURRENT OBSERVATIONS AT ANCHOR STATION IN CORDOVA BAY

Currents were observed from CGS Parry, anchored in Cordova Bay, for a 50-hour period from June 24 to June 26. The data observed with current meters suspended at the surface, and depths of 12 ft and 36 ft are shown in Figure 13. The plot in the flood and ebb directions essentially separates the data into northwest and southeast components. For comparison, the predicted tidal current for Turn Point and the observed tide at Saanichton Bay are plotted.

Between the first and second 25-hour periods of current observations, Figure 13 shows a consistency of directions and velocities at the current meter station. This indicates that for the period of the survey the flow patterns in Cordova Bay were normal, and predictable. The consistency at the 3 depths shows that the flow patterns established from floating targets were not confined to surface water movements.

It is of interest to note that there was a distinctive semi-diurnal cycle in the observed currents which appeared to be in phase at all depths.

observed. However, there was a definite ebb bias in the currents at all depths. At the surface, there was a 0.254 kt ebb bias during the first 25 hr and a 0.352 kt ebb bias during the second 25 hr. At 12 ft and 36 ft, during the second 25 hr, there were ebb biases of 0.320 kt and 0.202 kt, respectively. There was in the surface current a diurnal velocity amplitude of 0.673 kt and semi-diurnal velocity amplitude of 1.099 kt, giving a ratio of diurnal to semi-diurnal velocity amplitudes of 0.612.

During the period of the survey the moon was at maximum southerly declination, and with the sun near maximum north, diurnal conditions were at a maximum. Fourier analysis for the period of observations during June 24-26, 1964, showed that although the current was still predominantly semi-diurnal the tide was strongly diurnal. For the 50 hours, the diurnal amplitude of the tide at Saanichton Bay was 4.0 ft, while the semi-diurnal amplitude was 1.7 ft, giving a ratio of diurnal to semi-diurnal amplitudes of 2.3. The average ratio of these amplitudes at Saanichton Bay over a month is 1.5.

Cordova Bay is in a region in which tides change rapidly over a short distance. The mean diurnal tide increases in range eastward through Juan de Fuca Strait and northward into Strait of Georgia. From Becher Bay, 13 n. miles south of Victoria to Fulford Harbour, 30 n. miles north of Victoria the mean diurnal constituents of the tide increase by 30% from 2.0 ft to 2.6 ft. The mean semi-diurnal tide reaches a minimum point of 1.1 ft south of Victoria, but is 2.0 ft at Fulford, an increase of amplitude of 80%. The rapid increase in tidal range is shown in Figure 14, illustrating the tide for June 25 at Oak Bay, Saanichton Bay and Fulford Harbour.

The diurnal component is generally less for currents than for tides in all the channels of the Gulf Islands. If currents exhibited a large diurnal effect, there would be a long period of no motion, such as shown by the predicted current for Turn Point in Figure 13. This does not appear to apply, at least for Cordova Bay.

A comparison of the surface current, measured at the anchor station in Cordova Bay, with those observed from aerial photographs of drifting targets, shows reasonably good agreement in the speeds, during the period when the tidal current was quite well developed. However, during the period around noon (low-water slack), the surface current at the anchor station was weak and variable and did not permit reliable recording with the current meter used. One must rely on drift observations for current data under those circumstances.

6. EXTRAPOLATION OF CURRENTS OBSERVED TO CONDITIONS OF DIFFERENT TIDES AND WINDS

In order to permit maximum use of data obtained, it would be desirable to have representative observations for all tidal and wind conditions. In a program limited by time and physical resources, such a complete coverage is virtually impossible. However, for the purpose of this study, which has as its primary goal an evaluation of coastal currents to provide a basis for selection of outfall sites, it may be possible to study only the critical periods relevant to the problem. From the point of view of beaches for recreation during the summer, any conditions which would cause sewage to wash back up on the beach could be considered limiting.

The low-water slack period appears to be the critical tidal stage, during which there may be a slow onshore movement of water as the tidal current shifts its direction. Whether this condition is accentuated during a tidal range that is smaller than that observed is a matter of speculation. It is highly probable that dispersion from any point along the shoreline would be slower under those circumstances, because of a longer period of slack water. However, at this time, there is no way of estimating how much slower this dispersion would be.

Observations on June 25, 1964, were carried out during a period of light and variable winds. The effect of wind on the surface current at that time could be considered as small or nearly negligible. It becomes necessary to examine the average prevailing winds over the course of the year in the area, in order to gain some appreciation of the influence that wind would have on the surface current. The percentage frequencies of winds, for Victoria International Airport (Patricia Bay) averaged over a 13-year period (1941-1954) and for Victoria City (Gonzales Heights) over a 15-year period (1939-1954), as obtained from Climatic Summaries (Department of Transport, 1959) are shown in Figure 15A. It is immediately evident from the wind roses that frequency of directions varies considerably between the two meteorological stations. Cordova Bay is located approximately midway between these stations, in the region of transition. However, because of the orographic effect and geometry of the coastline, winds in Cordova Bay are probably more closely allied to those at Patricia Bay than those at Gonzales Heights.

During the winter and autumn period, there is a high percentage (ca. 30%) of winds from the west. These winds are favourable for the transport offshore of sewage released in Cordova Bay. However, with the onset of spring, there is a strong component of southeasterly winds which reaches a frequency of 36%, during the recreational season in July and August. There is still a moderate amount of westerly winds (17-19%), during these months, which is partly compensated by winds from the northeast, the third-ranking wind direction (19%).

Wind speed can also be an important factor, in addition to frequency, in the effect of wind on surface water movement. The monthly mean wind speeds averaged over the years used for frequency given above, are shown in Figure 15B for the two important directions, east-west and southeast-northwest. In general, winds from the east and southeast have a greater average speed than those from the west and northwest at both the Victoria City and Patricia Bay meteorological stations. There is no strong seasonal variation in the wind speeds at Patricia Bay, although decrease of the southeast component from winter to summer amounts to about 30%. This decrease is more marked in Victoria City. The west and northwest wind components are quite uniform in monthly mean speed throughout the year, at about 5 miles per hr, at Patricia Bay.

It would appear, in summary, that the alongshore and onshore components of the wind are stronger than the offshore ones in Cordova Bay during the summer months. This would certainly lead to movement by wind of surface water onshore during the recreational period. The implication that must be accepted from this conclusion is that a substantial safety factor should be applied to any sewage disposal plans in order to allow for onshore wind effect in summer.

7. PREDICTED DISPERSION OF SEWAGE FROM A PROPOSED OUTFALL

(a) Dispersion Patterns

In order to depict the effect of the current system observed in Cordova Bay under different tidal conditions, effluent plumes were drawn for a proposed outfall discharging at a depth of 6 fath in the northern half of Cordova Bay. These plumes are somewhat diagrammatically portrayed in Figures 16 to 21 for effluent discharges commencing on different stages of the tide. Their purpose is mainly a graphic display of the effluent transport by observed currents along the bay, with an added effect of dispersion by diffusion.

To attach some meaning to the dispersion diagrams, a few words of explanation are necessary. It is assumed that the effluent released during 1 hr, as shown by the 1st-hr contour, spreads during the ensuing hours according to the distribution drawn for each succeeding hour. Although the plume is shown anchored at the end of the outfall during each successive hour, the effluent emerging after the first hour of discharge is not represented, in order to simplify the diagram. Dispersion longitudinally along the channel in a northwest-southeast direction has been plotted according to the current speed and set shown for the particular stage of the tide in the current diagrams. Some artistic license, however, has been used in depicting the lateral dispersion. There were instances of divergence in the current shown by the movement of paper. Unfortunately, there was an inadequate number of these cases to provide a complete picture of the lateral dispersion. Therefore, much guesswork entered into this aspect of estimating the shape of the plumes of sewage. Hence, the area covered by the plume should not be regarded as quantitative.

An opportunity was afforded in May, 1965, to observe the effect of the currents in Cordova Bay on dye released in solution and in packaged, powdered form. The diffusion of the dye solution suggests that the lateral dispersion of sewage depicted in the dispersion diagrams is somewhat exaggerated. The effect of convergence lines has been entirely ignored and this is known to markedly distort any regular plume-like distribution. Judging by the large number of convergence lines observed in the aerial photographs, and represented in Figures 7 to 12, this distortion by convergence lines can occur quite frequently over much of the area.

To summarize the information given in the dispersion diagrams, one might say that the most serious contamination of the shores would occur north of the proposed outfall with a release at low-water slack (Fig. 17) and on the last half of the ebb (Fig. 20). Contamination with dilute sewage might occur in the southern part of Cordova Bay with a release at high-water slack (Fig. 19) or on the last half of the flood (Fig. 21). An outfall terminating nearer shore than the one shown could cause greater contamination of the Cordova Bay beach area to the south, which might also be accentuated by an easterly or southeasterly wind.

In the foregoing discussion nothing has been mentioned regarding volumes of sewage or coliform concentrations. The dispersion shown is assumed

to be due to horizontal turbulence of the water acting on a nominal volume of sewage which in itself does not alter the diffusion characteristics of the surface water. A large volume of sewage can introduce a modifying effect through displacement action, as well as by turbulence created by the kinetic energy of sewage flowing into the sea water.

(b) Estimates of Dilution

It is not the purpose here to evaluate optimum length of outfall, minimum depth at which sewage can be safely discharged, and design characteristics for a diffuser. However, it might be of interest to compute the concentrations of coliforms reaching the shore from one possible outfall discharging different volumes of sewage. There are a number of empirical approaches that can be used to arrive at an estimate of these parameters.

Pomeroy (1960) described an empirical formula for calculating the number of coliforms, N per ml, at a given distance X from an outfall discharging a known volume of sewage Q at a known depth Y. Thus

$$N = \frac{KQ^2}{YX^2}$$

where K is a constant for a given location. For a possible outfall discharging at 6-fath depth 1,100 yd from shore, shown in Figures 16 to 21, X can be taken as 3,300 ft and Y as 36 ft. The value of Q might be estimated from the number of residents to be served by the sewer discharging via the outfall. For 5,000 residents at 100 Imp. gal per day, the daily volume of sewage released would be 500,000 gal. If a value of K is taken to be 10×10^6 , as evaluated by Pomeroy for outfalls off the coast of California, when distances are given in feet and sewage discharge in MGD (million gallons per day), then

$$N = \frac{10 \times 10^6 \times 0.5^2}{36 \times 3300^2} = 0.00638 \text{ coliforms/ml or } 0.64 \text{ coliform /100 ml}$$

A population of 10,000 residents would increase the value of N to 0.0255 col/100 ml or 2.55 col/100 ml and of 100,000 residents to 2.55 col/ml or 255 col/100 ml. The value for even the highest population is not far above the required minimum MPN (most probable number) of 240 col/100 ml for bathing beach standards in British Columbia.

Using the approach developed by Rawn and Palmer (1930) and extended by Pearson (1956), one obtains for 0.5, 1.0 and 10 MGD of sewage an initial dilution of 77, 53 and 27, respectively, with a 24-inch outfall line. With average coliform concentrations of about 50×10^6 col/100 ml in raw sewage, this initial dilution would lead to concentrations of 65.2×10^4 , 94.3×10^4 and 185×10^4 col/100 ml, respectively, at the surface in the area of the bubble. Initial dilution with the resulting coliform concentrations for different sewage flows and outfall sizes are given in Table I, as extracted from nomographs given by Pearson (1956). The data are given for a single-outlet discharge. A substantial improvement in initial dilution can be achieved with a multiple-port diffuser, as described by Rawn et al. (1960). While the concentrations in Table I are all considerably in excess of the prescribed

standard, their magnitude may not be too important from the health point of view, when present in an area well removed from bathing beaches.

The strip of coastal water between the outfall and the beach may be regarded as a buffer, whose effectiveness is dependent on the distance and the turbulent mixing in the water. Again the empirical equations developed by Rawn and Palmer (1930) can be used for an estimate of the extent of the sewage field. Pearson (1956, p. 58) gave a nomograph, based on the equations, for estimating the mean radius of the sewage field, and time, in which a 225-fold dilution of the sewage is reached. The value of 225 was used because Rawn and Palmer suggested it as the requirement to achieve a dilution at the periphery of the field, meeting the minimum standard for bathing beaches in California (MPN of 1000 E. coli/100 ml.*). For discharges of 5 MGD (9.3 c.f.s.) and 10 MGD (18.6 c.f.s.) through a 24-inch outfall, a 225-fold dilution is achieved at 520 ft from the outfall in slightly over one-half hour and at 920 ft in one hour, respectively. Distances and times for other outfall diameters are given in Table II; the values for the smaller discharges of 0.5 and 1.0 MGD were not determinable from Pearson's nomograph.

The foregoing estimations are all based on empirical approaches developed for sewage disposal along the coast of California with the particular characteristics of its coastal water. Waters along the British Columbia coast are generally much more stratified, receiving a considerably greater surface influence from freshwater runoff. However, in the Cordova Bay area, and generally in the coastal waters along Greater Victoria, the waters are all well mixed vertically to near homogeneity. Such a condition may provide this area with a better basis for comparison with the California coast than some of the other British Columbia coastal areas. However, the fact remains that data collected on transport and dispersion in a given area are more applicable to the problem of sewage disposal in that area than are the data collected elsewhere. In this respect, some of the dye information collected during the tests in May, 1965, may prove to be useful.

On May 18, 1965, a series of aerial photographs taken of various types of targets in Cordova Bay afforded an opportunity to estimate surface dilution due to horizontal diffusion. On a line extending in an easterly direction from the sample outfall site shown in Figures 16 to 21, batches of dye solution were released at approximately 1000-yd intervals to a distance of about 3 n. mi. from shore. Dye solutions were released on three stages of the tide: ebb, low-water slack and flood. These were photographed along the same lines and to the same scale as followed in June, 1964, immediately following release and one-half hour thereafter, with an additional flight during each half hour on the flight line closest to the coast.

The increase in size of the dye patches during the one half-hour intervals between flights can be estimated from the aerial photographs. These data are given in Table III for each stage of the tide. As in the survey of June, 1964, there was very little wind effect, with maximum wind being northeasterly at 6-7 m.p.h. The dispersion of the dye could be considered as primarily due to tidal turbulence.

* For bathing beach standards in British Columbia (240 col/100 ml), considering a raw sewage of 50×10^6 col/100 ml, a dilution of 2.1×10^5 , or 930 that given above, would be required.

Dilution factors given in Table III are only rough estimates, which are essentially minimum values. It is assumed in the estimates that: (a) all the diffusion takes place horizontally; and (b) the dye is all retained within the visible cloud in the aerial photographs. Neither of these assumptions is strictly true and, depending on the amount of deviation from them, the dilution would always be greater than that given. However, in the Cordova Bay area, it is anticipated that vertical mixing would be much less than horizontal mixing even though the waters are comparatively uniform in vertical salinity distribution. With respect to assumption (b), Gunnerson (1960) estimated that the measured width of a dye stream contains about 95% of the tracer. This may be somewhat high for the amount of resolution of dye boundaries obtainable with black and white film at the elevation that the present photographs were taken. Nevertheless, the clouds of dye seen in aerial photographs of Cordova Bay probably represent no less than 75% of the total dye within the first hour following release.

To obtain a measure of the effect of horizontal diffusion on dispersion of sewage during the critical tidal stage in Cordova Bay, one should consider discharge at low-water slack. From an outfall extending 1,000 yd from shore, at the outfall site used as an example in this report, the effluent would require about 1 hour to reach shore with the onshore current at low-water slack. The dilution obtained for dye patches 1-3 (Table III) during low-water slack averaged 1:10 in 1 hr. Assuming an initial dilution of 1:50 above the outfall, the total dilution for the sewage would be 1:500. With an estimated MPN of 50×10^6 col/100 ml in raw sewage, the concentration reaching shore would be about 10^5 col/100 ml. As pointed out previously, the dilution due to lateral diffusion is a minimum value, and, therefore, the calculated concentration is the maximum that can be expected. Nevertheless, there appears to be sufficient evidence from field data for the need to apply every scheme available for achieving high initial dilution of sewage.

8. SELECTION OF OUTFALL SITES

On the basis of the currents observed, it would appear that the period of low-water slack is most critical, insofar as effective removal of sewage from a shore outfall is concerned. During this period of approximately an hour, there is a prevailing onshore flow. Hence, it would be desirable in locating an outfall to carry it out far enough so that sewage would not be transported onshore during the period of low-water slack. Onshore currents had a maximum speed of about 0.4 kt. Therefore, assuming that this onshore flow persists for 1 hr, the outfall pipeline should extend at least 0.4 n. mi. (800 yd) from shore. To allow some factor of safety, particularly under the effect of easterly or southeasterly winds, the line should be taken 0.5 n. mi. or 1,000 yd from shore in the mid-section of observations ($48^{\circ}32.5'N$).

Because of the desirability of maintaining a clean beach in the recreational area of Cordova Bay, between Cormorant Point and a latitude of approximately $48^{\circ}32.5'N$, it would be inadvisable to locate a sewer outfall within these boundaries. This precaution is needed not only because of a threat to health due to potentially high bacteria counts from an outfall there,

but also as a matter of aesthetics. Waters receiving sewage tend to become unsightly from solid matter present in the sewage, as well as from turbidity created by plankton growth as a result of enrichment.

The strong currents in Cordova Channel and the headland projecting into the Channel at Cowichan Head combine to make this one of the better locations for a sewer outfall. The projection of the shoreline seaward would considerably reduce the length of pipeline needed to convey the sewage into the strong channel currents (Fig. 10). However, it appears that Cowichan Head is beyond the practical and economical reach of a trunk sewer line servicing the populated area and projected residential areas further to the south. Hence, an alternative outfall site would be the point south of Cowichan Head at about $48^{\circ}32.5'N$, shown on Figure 10. A pipeline extending 1,000 yd from shore at this point would reach approximately the 6-fath line. Substantial dilution could be achieved during the ascent of the sewage through this depth of water, provided a suitable diffuser was installed. Consideration should be given the installation of a multi-port diffuser which is now becoming common practice in ocean outfalls (Rawn et al., 1960).

One other possible behaviour of sewage released at the above point, which must be recognized, is the transport into shore in the southern part of Cordova Bay, at the beginning of the change from ebb to flood. While the current in the northern part of Cordova Bay was still setting quite strongly to the south and southeast, the current in the southern part of the bay began to shift westward. With a 0.5 kt current, sewage released at the proposed outfall could conceivably reach the shore in the southern part of Cordova Bay in 6 hrs. Although there is rapid die-away of sewage bacteria in sea water, any period of less than 12 hr for contact between sewage and sea water can still be considered as unsafe from the bacterial concentration point of view. Therefore, this adds strength to the argument for discharge at moderate depth, in order to gain a substantial initial dilution.

Currents in the vicinity of Cormorant Point indicated a frequent drift onshore into the southern extremity of Cordova Bay to the west, and into Margaret Bay to the east, both apparently popular beach areas. Therefore, this rules out Cormorant Point, and possibly Gordon Head, as satisfactory outfall sites. There is insufficient current information at present for the waters just south of Gordon Head, on which to base any opinions on sites for safe disposal of sewage.

9. SUMMARY AND CONCLUSIONS

Tidal currents in Cordova Bay generally flow parallel to the shoreline, setting to the north and northwest on the flood and to the south and southeast on the ebb. Deviations from this pattern occur during the changing tide, the current direction shifting to westward at low-water slack and to eastward at high-water slack. Currents are strongest (1.0-1.5 kt) at 1 to 2 n. mi. from shore in the northern part of Cordova Bay and in Cordova Channel. They tend to be considerably weaker nearshore and in the southern part of Cordova Bay, near Cormorant Point.

Although the effect of winds on surface currents was not measured, it can be expected to be quite strong during periods of sustained strong winds. Prevailing winds, as observed at the Victoria International (Patricia Bay) Airport, over a number of years, are southeasterly in spring and summer with a stronger westerly component in winter. This means that during the recreational season there is probably a greater onshore than offshore effect on surface currents due to winds. However, the strong tidal current in this area leaves wind as a modifying influence rather than a dominating one.

The critical period for sewage disposal is at low-water slack, when sewage would be transported toward shore with the onshore current. In order to prevent harmful concentrations of sewage from reaching the shore, near the mid-section of Cordova Bay, any sewer outfall should be extended to at least 0.5 n. mi. (1,000 yd) from shore, where the depth is about 6 fath (36 ft). A multi-port diffuser should be used for the discharge in order to provide maximum initial dilution. The decision will have to be made by planning engineers whether the investment should be made in a deeper outfall further from shore or in an efficient diffuser to obtain the necessary initial dilution.

The best site for an outfall, where the shoreline projects furthest seaward and alongshore currents are strongest, appears to be Cowichan Head. A depth of 6 fath can be reached at about 500 yd from shore and, therefore, the outfall here need not be as long as those further to the south. An alternative site, which is perhaps more practical and economical from the engineering point of view, is a point at the north end of the beach area south of Cowichan Head at about 48°32.5'N. There would obviously be a more urgent requirement for a higher degree of dilution in this area, because of the nearness to the recreational area.

In conclusion, it can be stated that Cordova Bay has a moderately strong current system and turbulent mixing, associated with the tides, which can be utilized for sewage dilution and dispersion. The coastal stretch of about 500-yd width is shallow (<3 fath) with a weaker alongshore current system and greater onshore drift. Waste disposal in this region would cause beach contamination. Because of rapid transport by strong currents further offshore, a substantial initial dilution is needed to prevent high concentrations of sewage bacteria from reaching the shores with the onshore current in the southern part of Cordova Bay, during the last of the ebb tide.

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Table I. Dilution of sewage above an outfall, discharging horizontally at a depth of 36 ft., with various sizes of outlet, and final coliform count, assuming an initial MPN of 50×10^6 col/100 ml. (Estimated from Pearson, 1956.)

Outlet diam. inches	Length ^a of rising plume, L feet	Initial diln. S ₀	Coliform concn. 10 ⁴ MPN/100 ml	Outlet diam. inches	Length of rising plume, L feet	Initial diln. S ₀	Coliform concn. 10 ⁴ MPN/100 ml
Population: 5,000 persons Sewage discharge: 0.5 MGD = 0.93 c.f.s.				Population: 10,000 persons Sewage discharge: 1.0 MGD = 1.86 c.f.s.			
12	40	88	5.68	12	42	61	8.20
15	39.5	85	5.88	15	41	59	8.47
18	39.0	81	6.17	18	40.5	58	8.62
21	38.5	79	6.33	21	39.5	54	9.26
24	38.0	77	6.49	24	39	53	9.43
30	37.5	73	6.85	30	38	50	10.00
36	37.3	70	7.14	36	37.5	48	10.42
48	37.0	68	7.35	48	37	46	10.87
Population: 50,000 persons Sewage discharge: 5 MGD = 9.3 c.f.s.				Population: 100,000 persons Sewage discharge: 10 MGD = 18.6 c.f.s.			
12	59	50	10.00	12	73	53	9.43
15	53.5	39	12.82	15	64	39	12.82
18	51	36	13.89	18	59	33	15.15
21	48	32	15.63	21	57	30	16.67
24	47	28	17.86	24	53	27	18.52
30	44	27	18.52	30	49	23	21.74
36	43	25	20.00	36	47	19.5	25.64
48	41.5	23	21.74	48	44	18	27.78

^a Represents the length of the centreline of the rising plume of sewage, as defined by Pearson (1956).

Table II. Distance and time required for sewage field to reach a 225-fold dilution of raw sewage or a coliform concentration of 2.22×10^5 /100 ml, assuming an initial count of 50×10^6 col/100 ml in raw sewage. (Estimated from Pearson, 1956.)

Sewage discharge: 5 MGD = 9.3 c.f.s.				Sewage discharge: 10 MGD = 18.6 c.f.s.			
Outlet diam. inches	Centreline length ^a , L feet	Distance to 225-fold diln. feet	Time to 225-fold diln. hours	Outlet diam. inches	Centreline length ^a , L feet	Distance to 225-fold diln. feet	Time to 225-fold diln. hours
12	59	160	0.2	12	73	170	0.2
24	47	390	0.4	24	53	560	0.5
36	43	520	0.6	36	47	920	1.0
48	41.5	600	0.75	48	44	1100	1.3

^aAs defined in Table I

Table III. Dispersion of dye in Cordova Bay, May 18, 1965.

Dye patch	t_0 hour	t_1 hour	A_1 10^4 feet ²	t_2 hour	A_2 10^4 feet ²	Δt min.	D
<u>EBB CURRENT</u>							
2	0758	0801	5.62	0830	30.24	29	11.14
3	0751	0806	5.75	0835	33.12	29	11.93
4	0746	0806	77.76	0835	285.12	29	7.59
5	0741	0812	15.65	0840:30	57.60	28.5	7.75
6	0736	0812	7.92	0840:30	34.34	28.5	9.13
1	0805	0817	10.08	0846	47.23	29	9.70
2	0758	0817	17.64	0846	30.24	29	3.55
EBB AVERAGE							<u>8.68</u>
<u>LOW-WATER SLACK</u>							
2	1157	1159	1.89	1229	31.62	30	33.46
2A	1156	1159	3.13	1229	19.80	30	12.67
3	1150	1203	24.30	1234	43.20	31	3.44
4	1143	1203	7.43	1234	49.30	31	12.84
5	1137	1208	29.07	1239		Not visible	
6	1132	1208	38.88	1239		Not visible	
1	1204	1213	4.32	1244	19.08	31	8.55
2	1157	1213	14.20	1244	56.30	31	7.68
2A	1156	1213	95.40	1244	45.90	31	9.31
LOW-WATER SLACK AVERAGE							<u>12.56</u>
<u>FLOOD CURRENT</u>							
1	1526	1600	18.65	1630	27.52	30	2.95
1A	1527	1600	53.82	1630	720.00	30	26.76
2	1531	1600	8.10	1630	41.95	30	10.36
2A	1532	1600	6.35	1630	23.40	30	7.37
2B	1533	1600	2.74	1630	25.20	30	18.42
3	1535	1605	24.95	1634	181.44	29	15.05
4	1540	1605	14.98	1634	38.02	29	5.25
5	1546	1611	20.59	1638:30	126.00	27.5	13.35
6	1552	1611	6.62	1638:30	41.47	27.5	13.66
7	1557	1611	3.46	1638:30	21.60	27.5	13.64
1	1526	1616	27.86	1643	115.92	27	9.25
1A	1527	1616	59.40	1643	97.92	27	3.66
FLOOD AVERAGE							<u>11.64</u>
OVER-ALL AVERAGE							<u>10.96</u>

continued.....

Table III (Continued)

Notation:

t_0 = time dye released.

t_1 = time of initial photograph of dye patch

A_1 = area of dye patch at time t_1

t_2 = time of second photograph of dye patch

A_2 = area of dye patch at time t_2

Δt = $t_2 - t_1$ = time interval between photographs

$D = \frac{A_2}{A_1} \times \frac{1 \text{ hr}}{\Delta t} =$ dilution in one hour

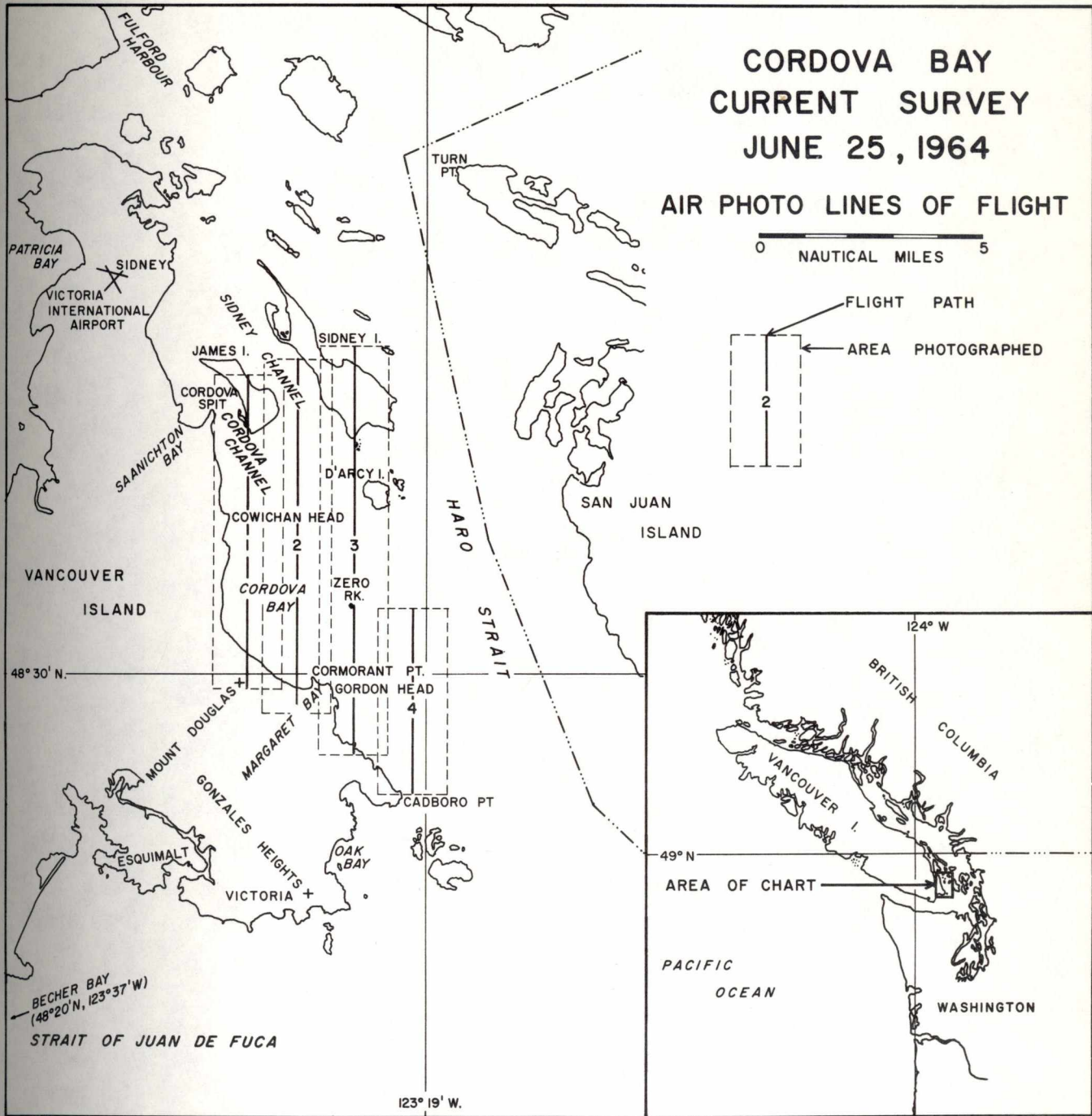


Fig. 1. Chart of Cordova Bay and adjacent waters, showing lines of flight and areas covered in aerial photography, June 25, 1964.

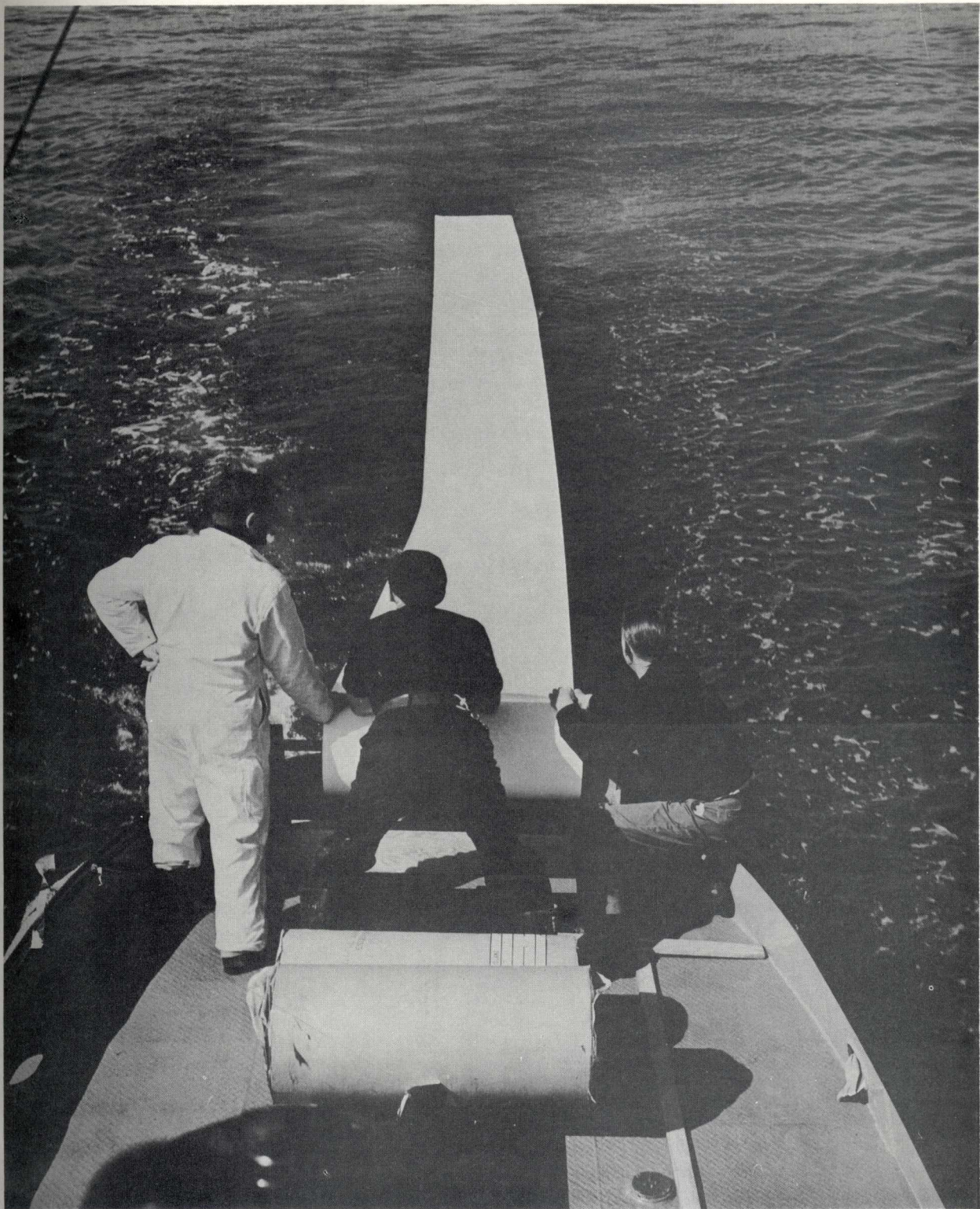


Fig. 2A. Photograph showing release of paper from a roll mounted on the stern of a tug.

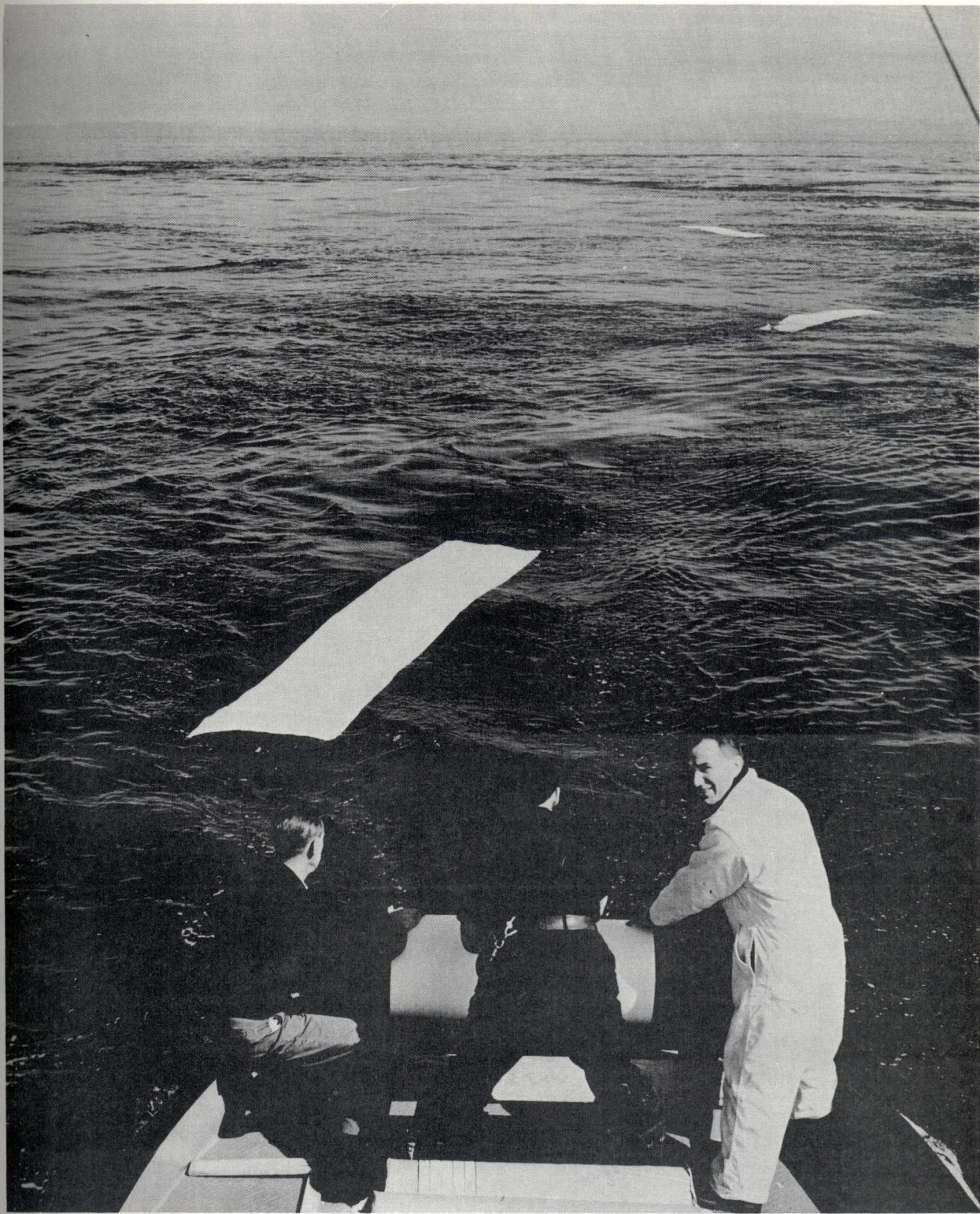


Fig. 2B. Photograph showing strips of paper floating on the water surface after being released from a tug.

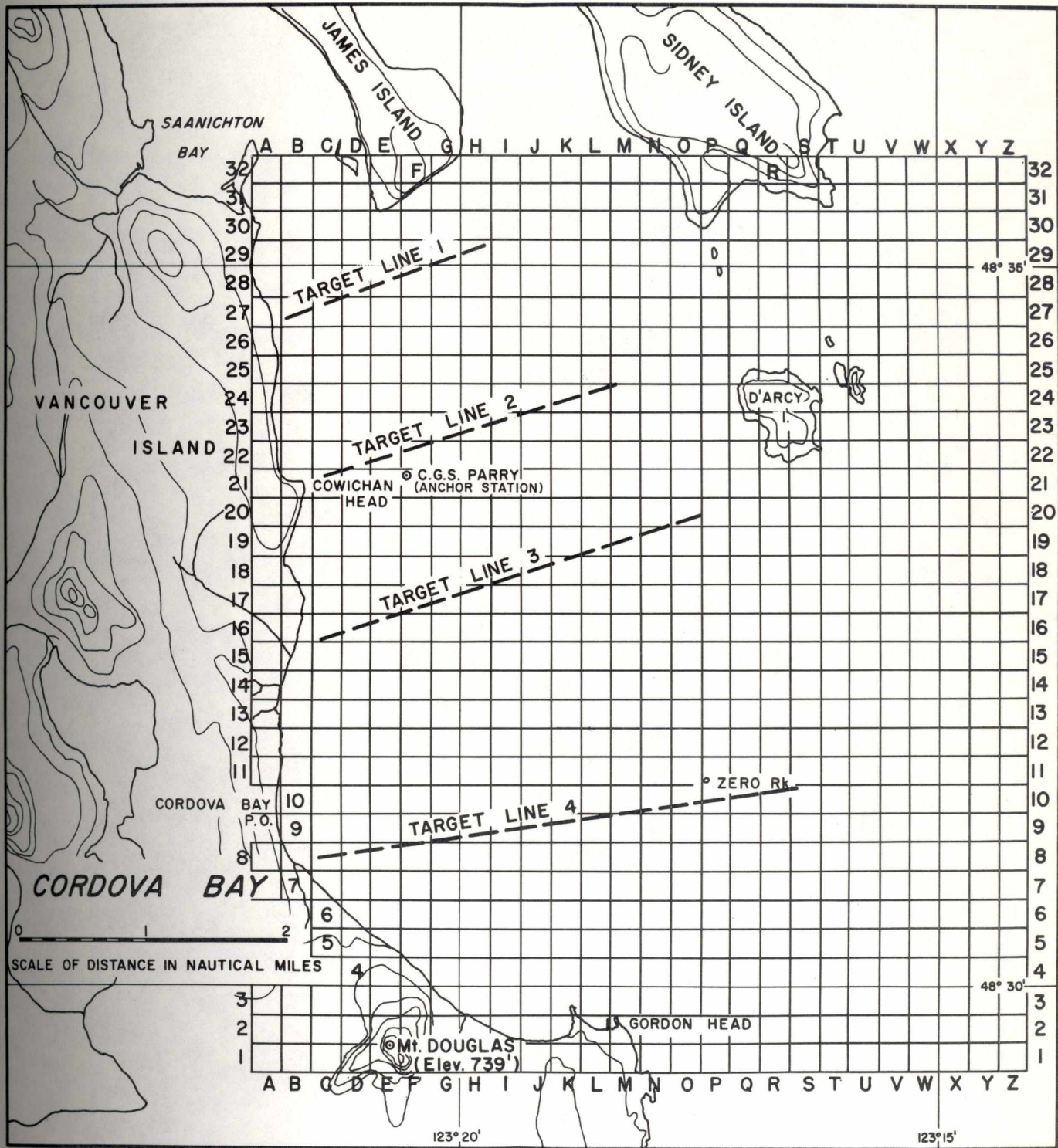


Fig. 3. Grid system for identification of areas, lines of targets laid in Cordova Bay, and location of current measurements at anchor, June 24-25, 1964.



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Fig. 4A. Typical aerial photograph of paper strips, immediately following release.

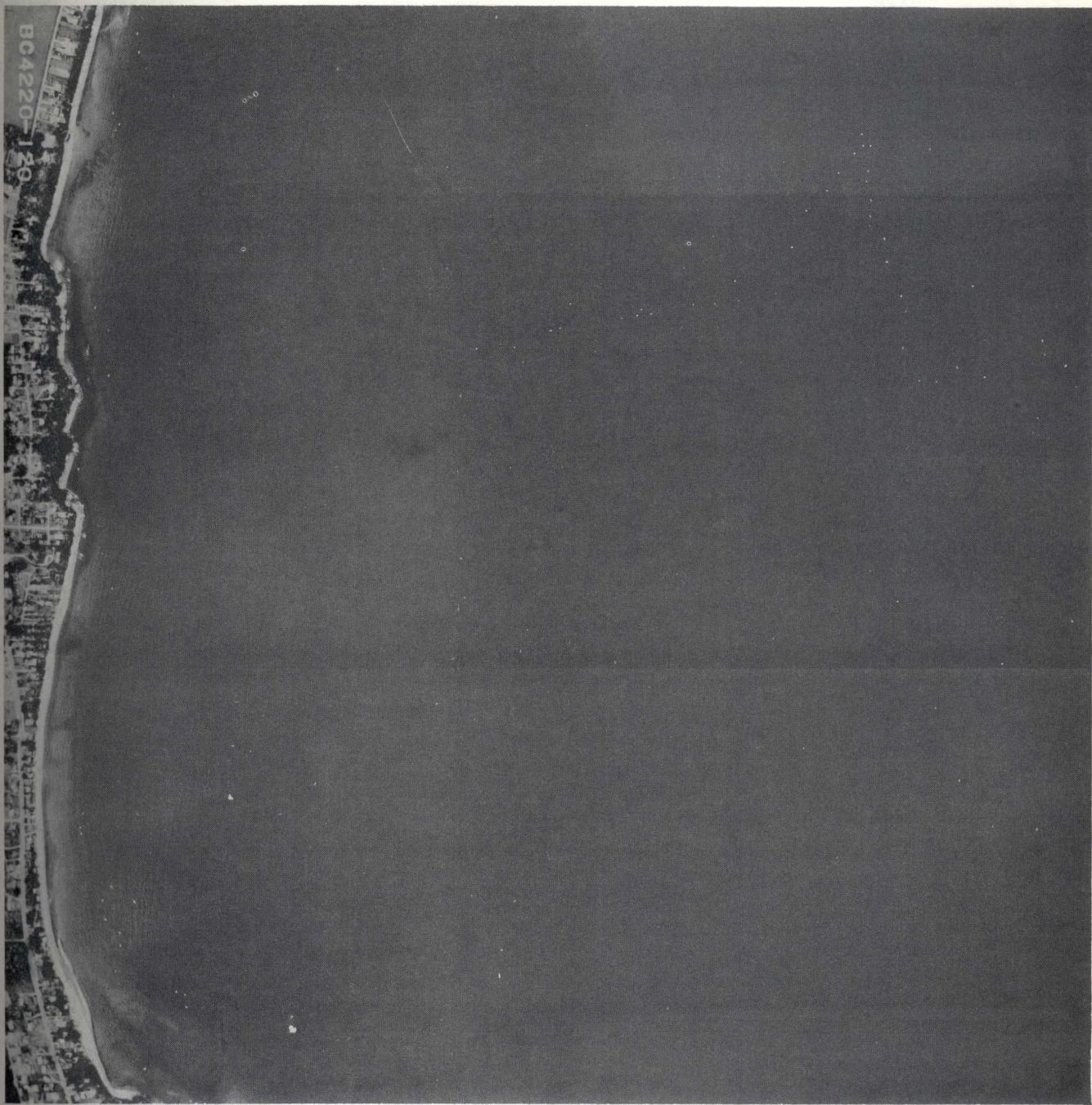


Fig. 4B. Typical aerial photograph of paper strips, after a period of drift.

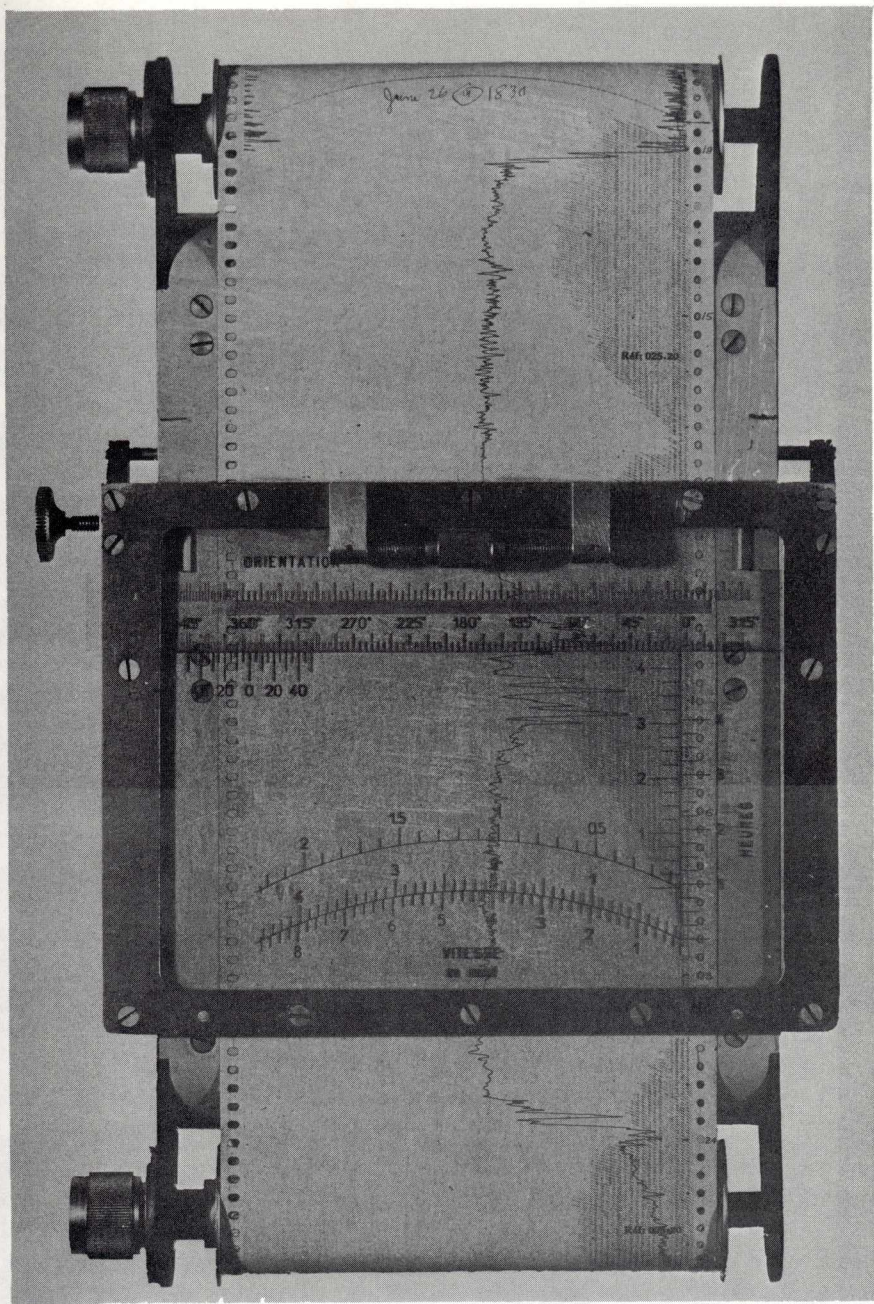


Fig. 5. Part of the Cordova Bay current record taken from a Neyrpic BBT current meter. The hatched portion gives the current speed as read on the upper "Vitesse" scale, while the solid jiggly line gives direction as read on the "Orientation" scale.

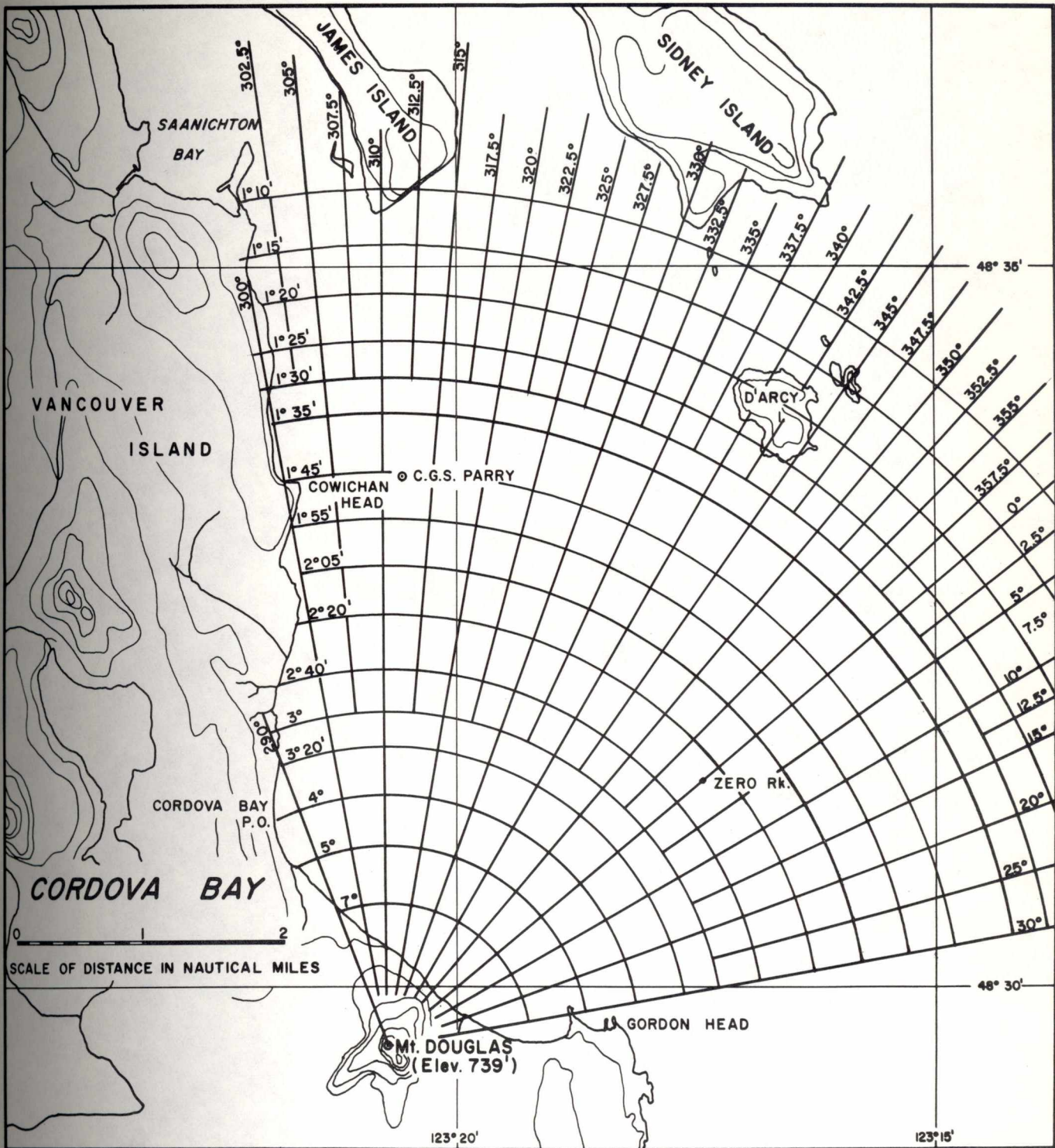


Fig. 6. Triangulation system for tracking floats by theodolite from Mt. Douglas.

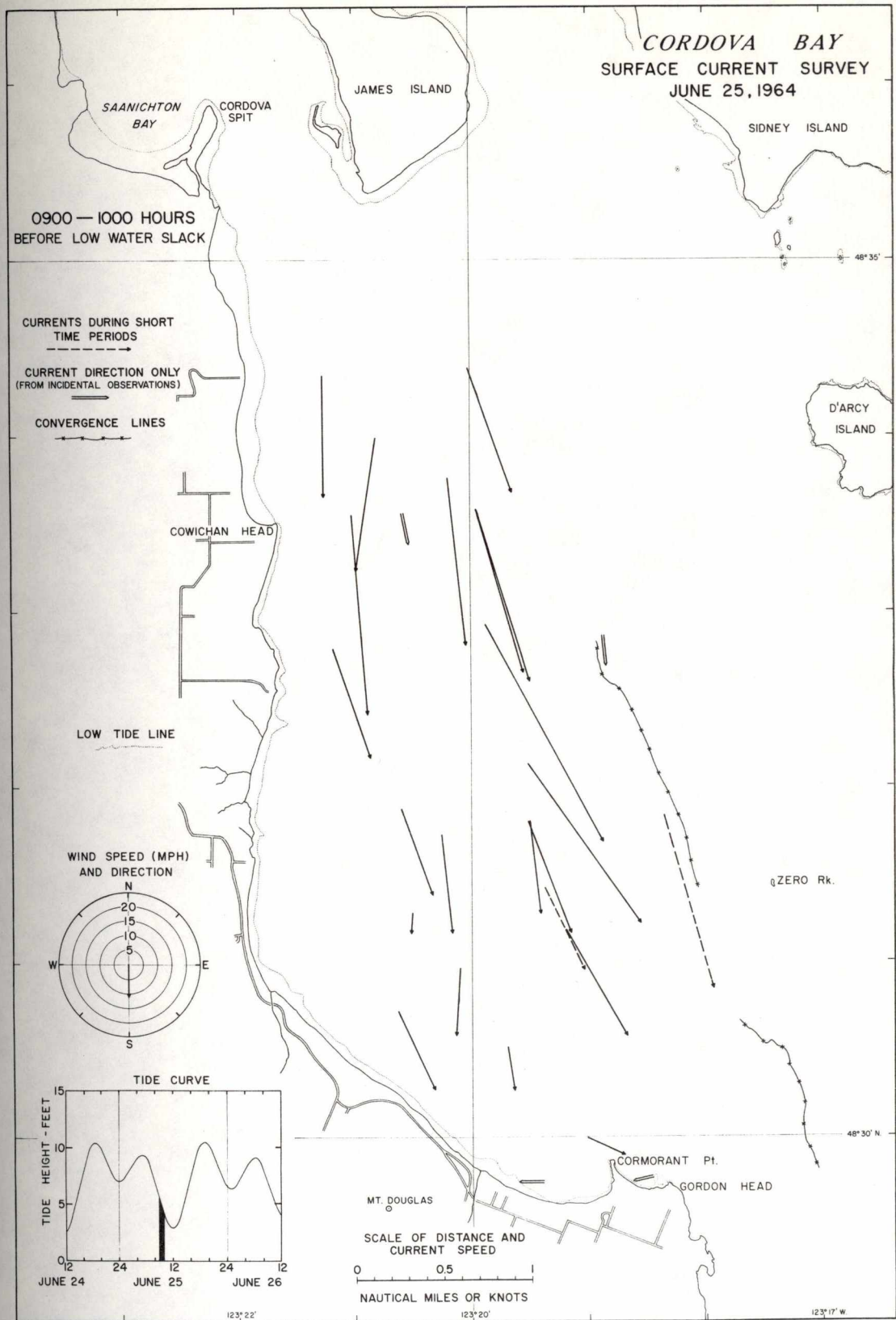


Fig. 8. Surface currents in Cordova Bay on the last half of the ebb, about 2 hours before low water slack, June 25, 1964.

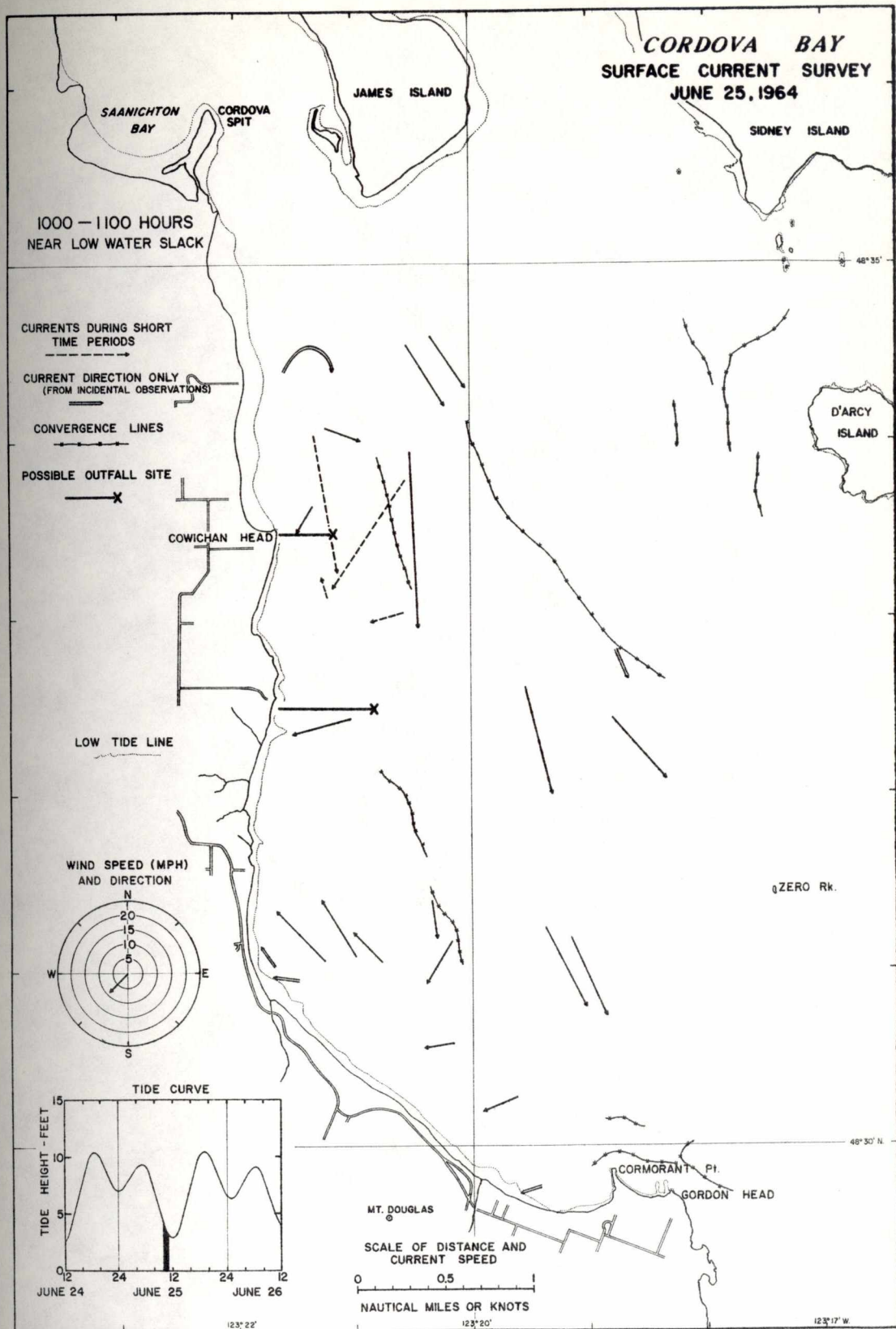


Fig. 9. Surface currents in Cordova Bay near the end of the ebb, June 25, 1964

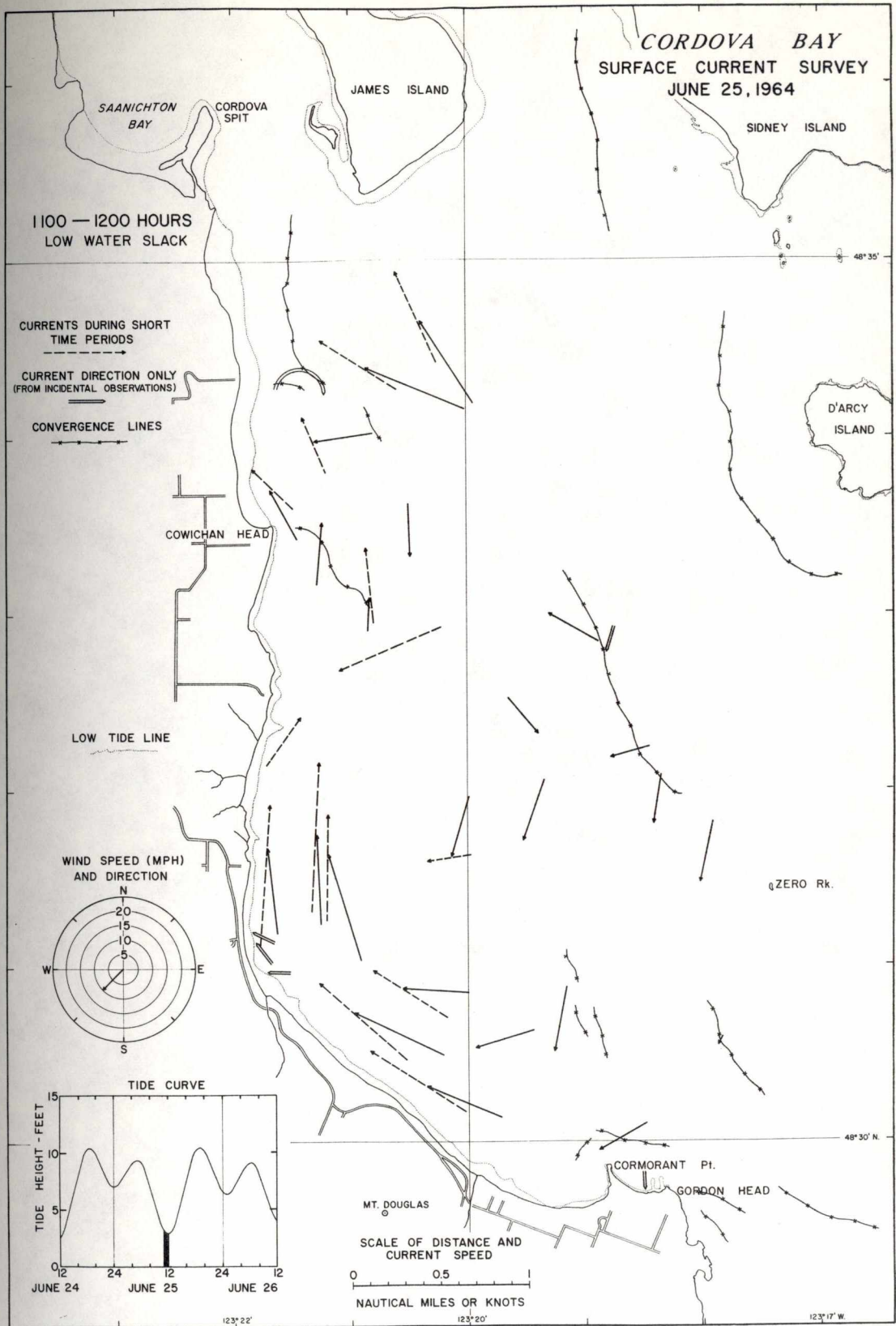


Fig. 10. Surface currents in Cordova Bay, at low water slack, June 25, 1964. Two possible outfall sites are shown for illustrating effect of currents on sewage transport during this critical period.

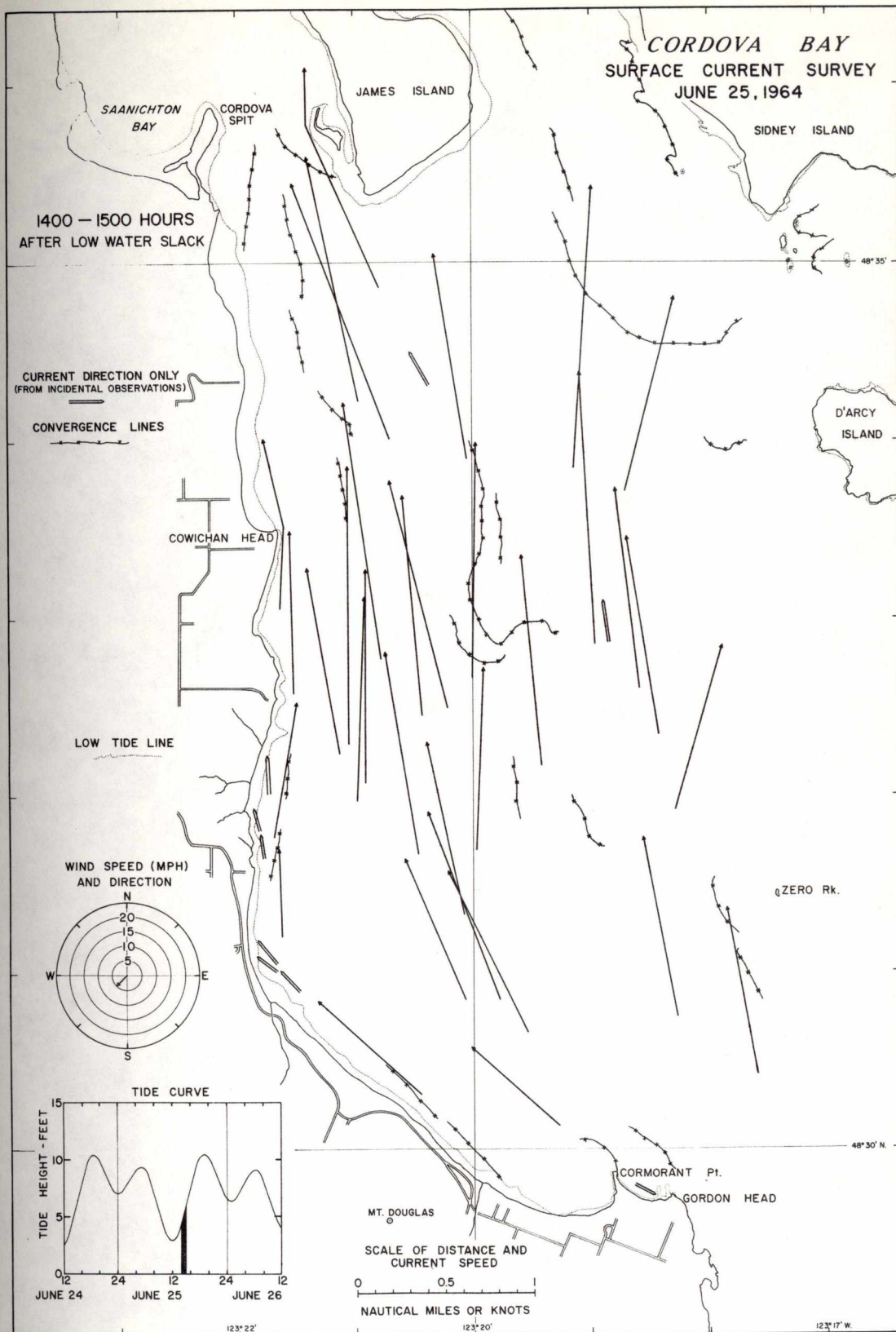


Fig. 11. Surface currents in Cordova Bay, at beginning of large flood, June 25, 1964.

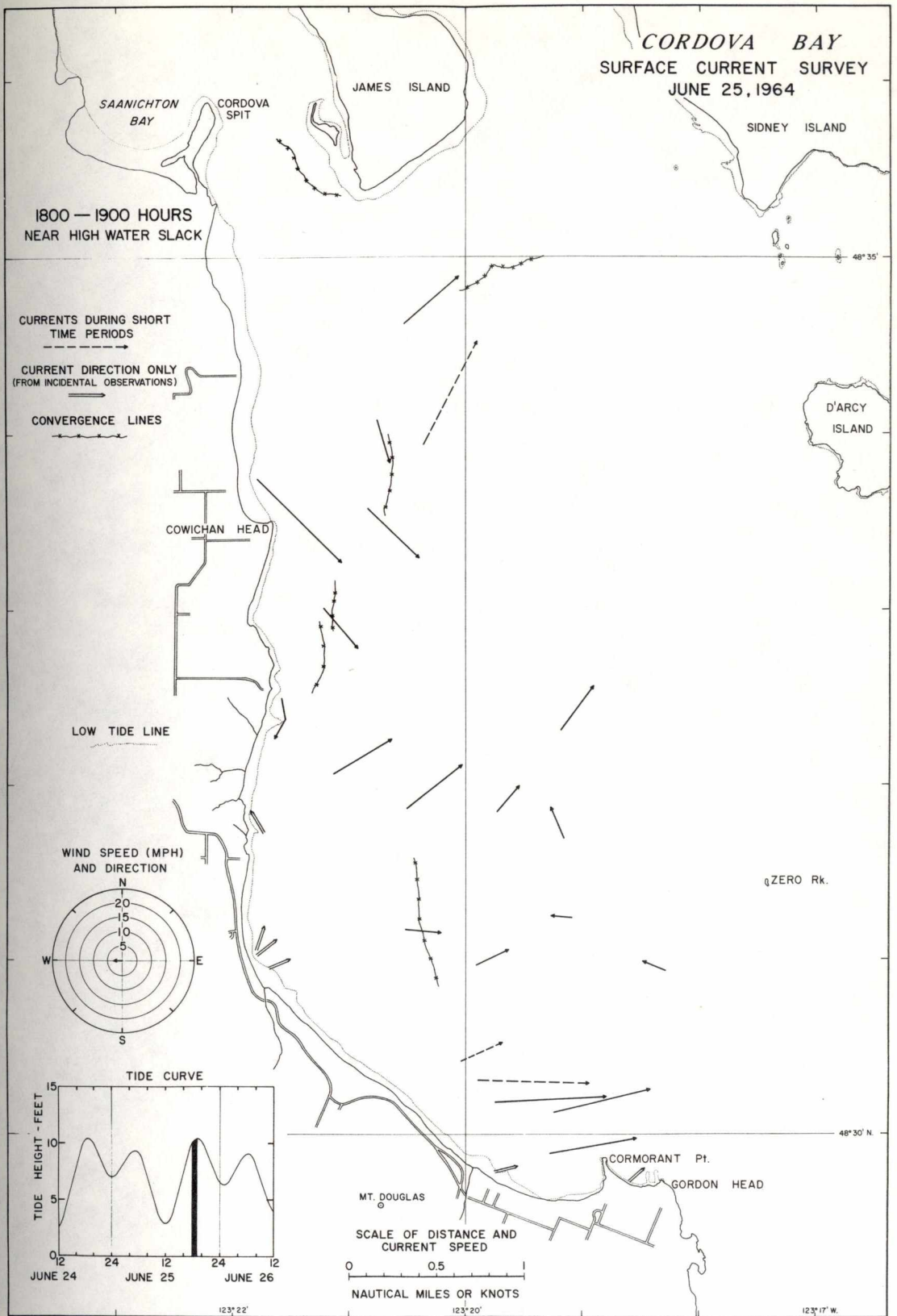


Fig. 12. Surface currents in Cordova Bay, near high water slack, June 25, 1964.

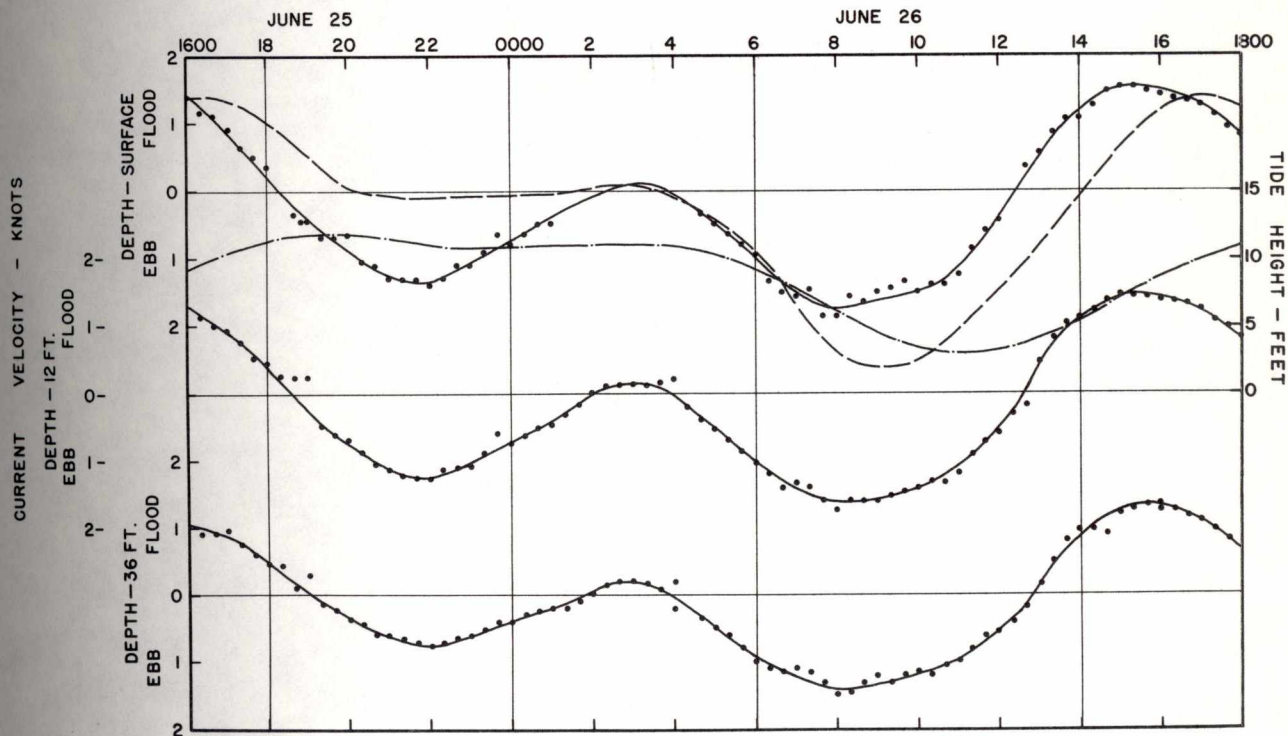
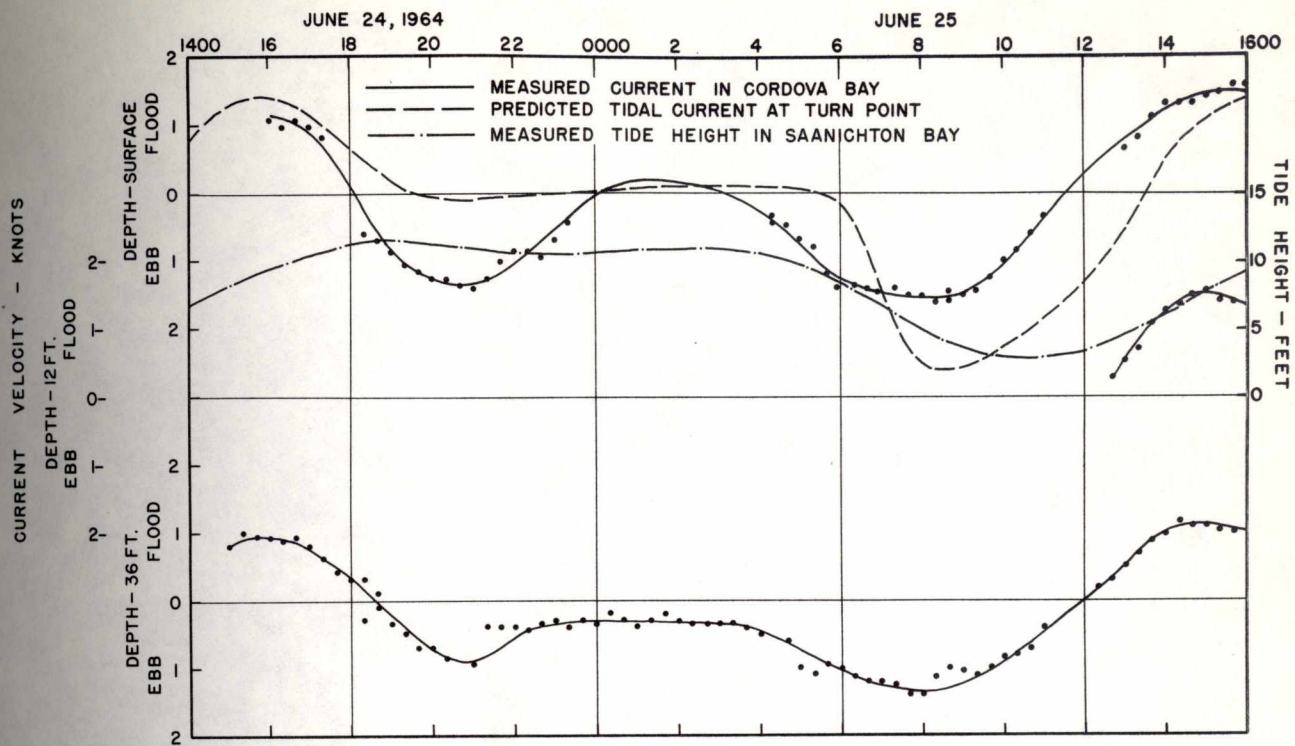


Fig. 13. Current data observed from CGS Parry at anchor in Cordova Bay (see Fig. 3), June 24-25, 1964.

JUNE 25, 1964 (PST)

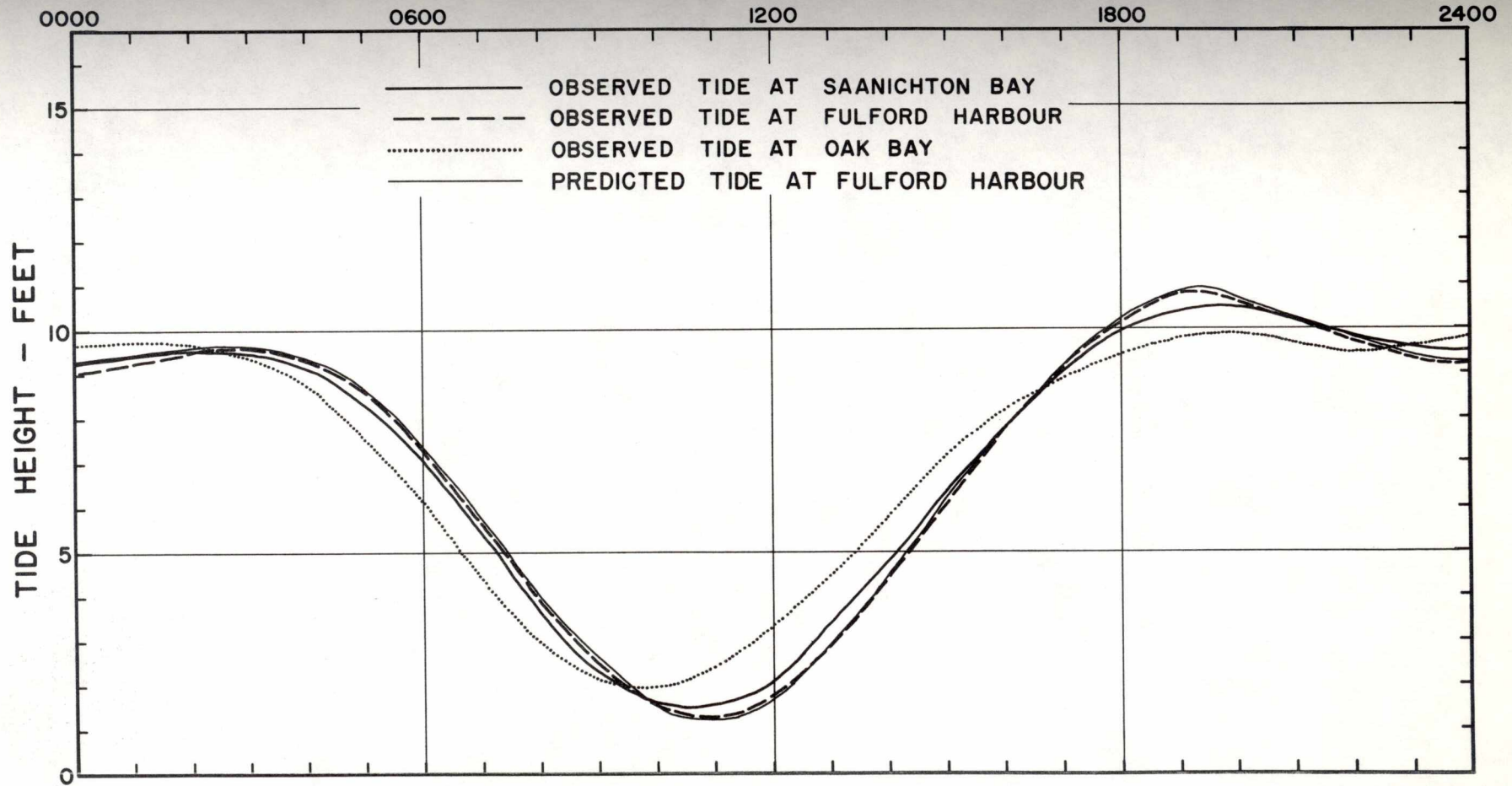
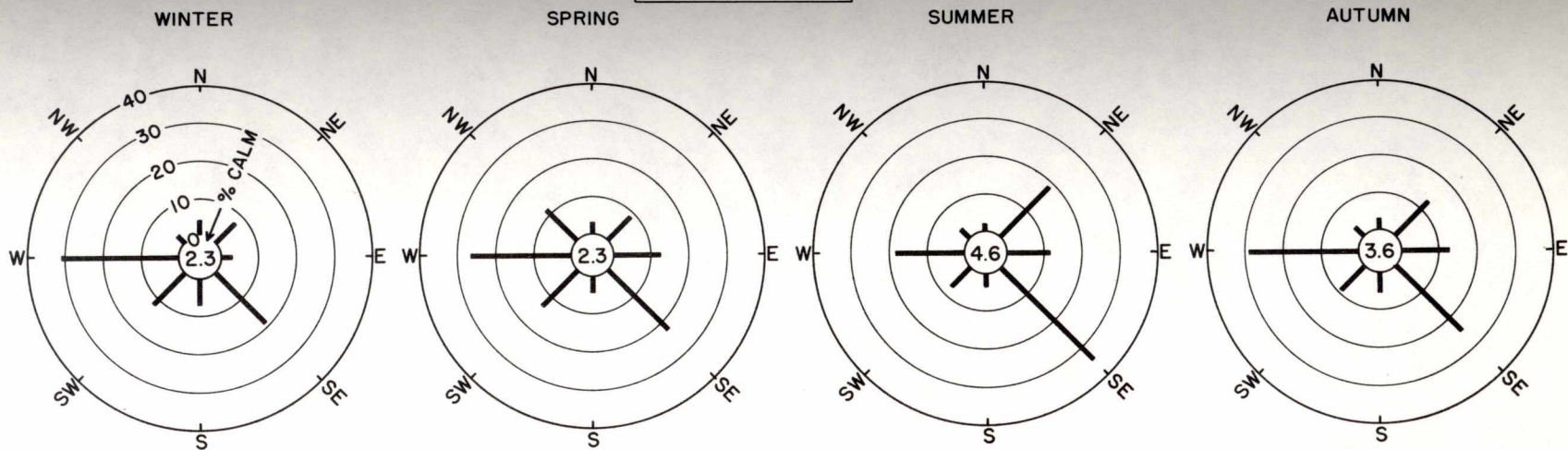


Fig. 14. Observed and predicted tides at different locations during the period of the survey, June 24-26, 1964.

PERCENTAGE FREQUENCY OF WIND BY DIRECTIONS

PATRICIA BAY



VICTORIA

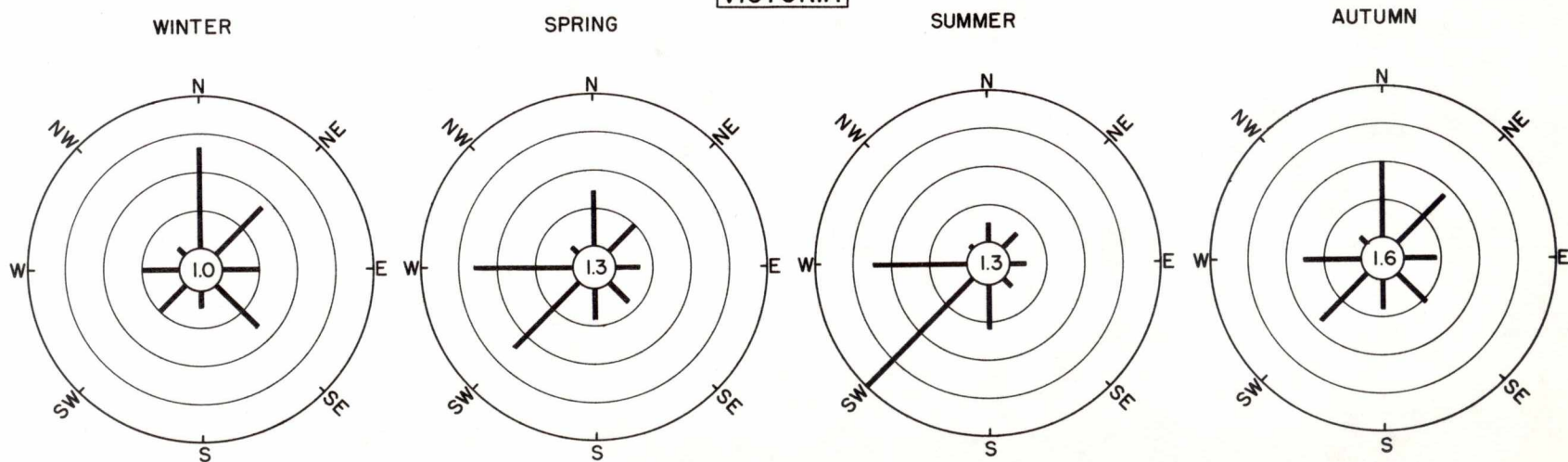
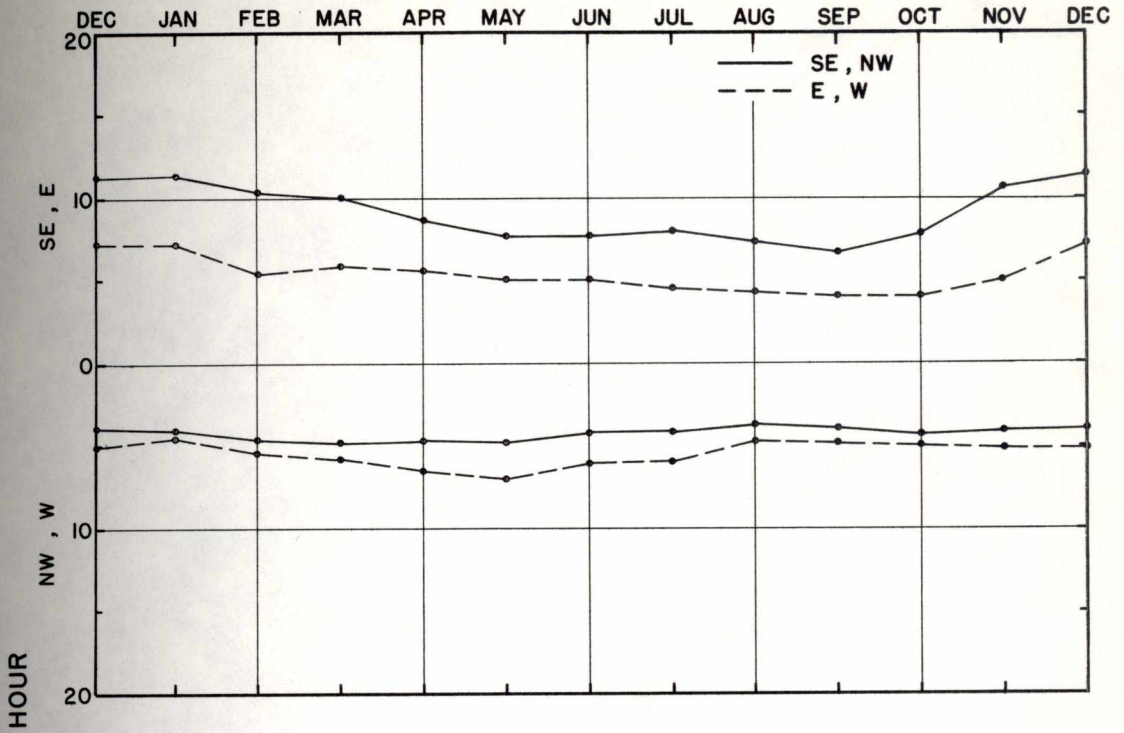


Fig. 15A. Percentage frequency of wind by direction, from long-term averages, at Victoria International Airport (Patricia Bay) and Victoria City (Gonzales Observatory).

AVERAGE WIND SPEED BY DIRECTIONS

PATRICIA BAY



VICTORIA

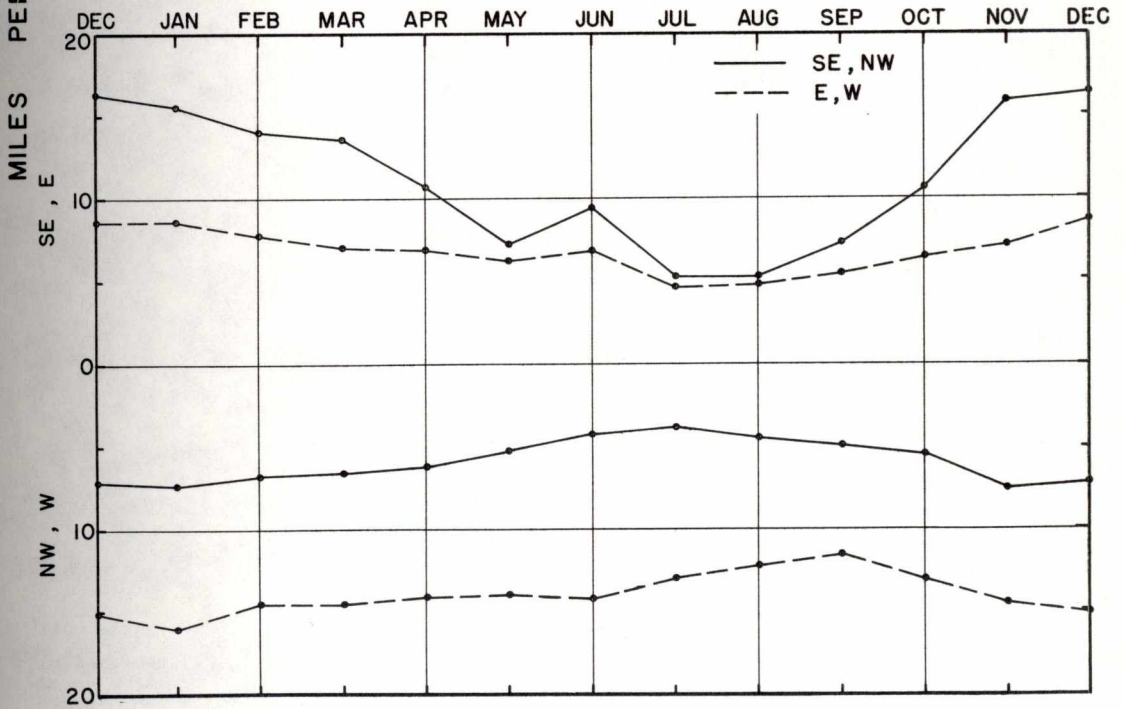


Fig. 15B. Monthly mean wind speeds, from long-term averages, in the southeast-northwest and east-west direction at Victoria International Airport (Patricia Bay) and Victoria City (Gonzales Observatory).

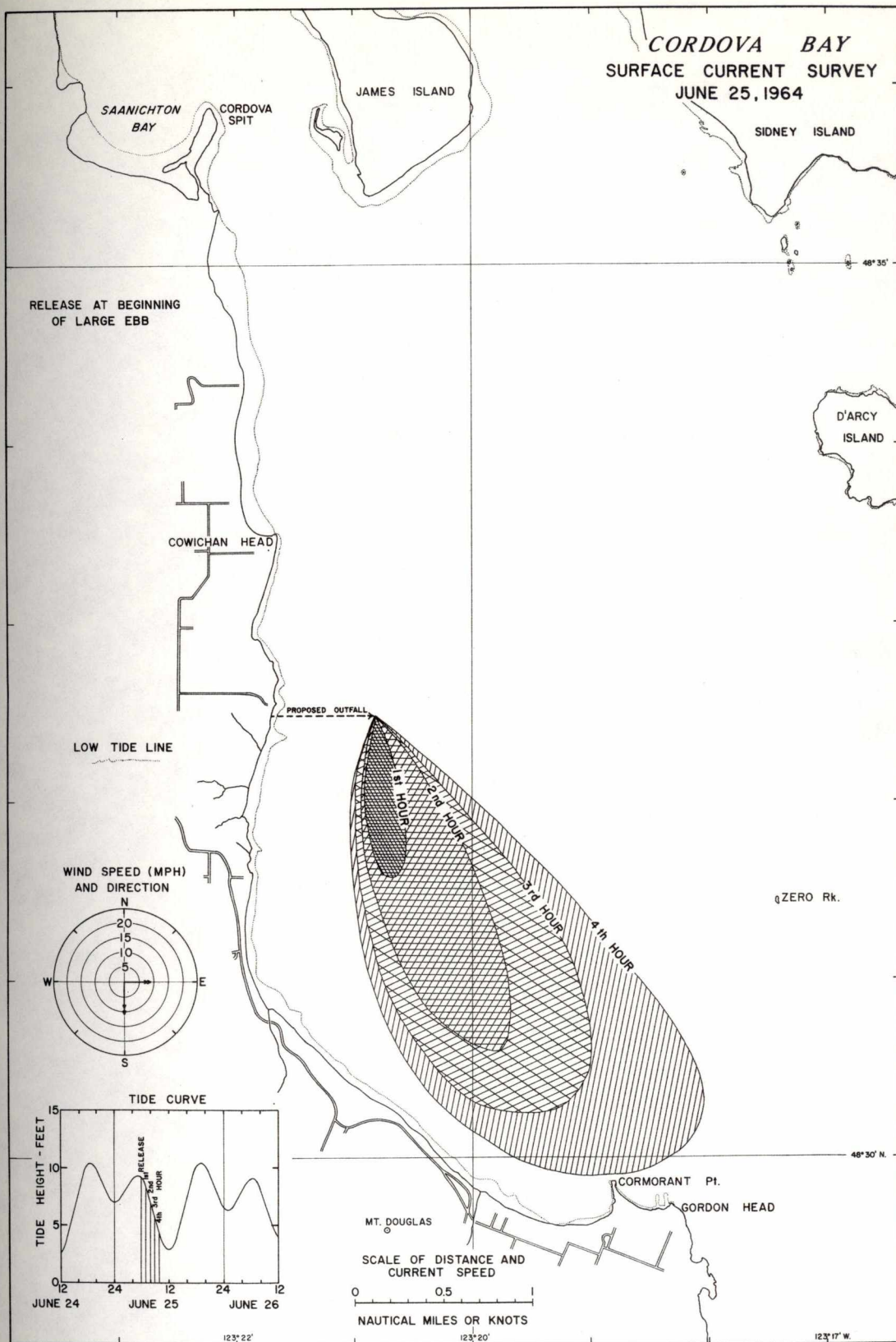


Fig. 16. Dispersion of effluent from a proposed outfall in Cordova Bay, with a release at the beginning of a large ebb. (Schematic, based partly on surface current data.)

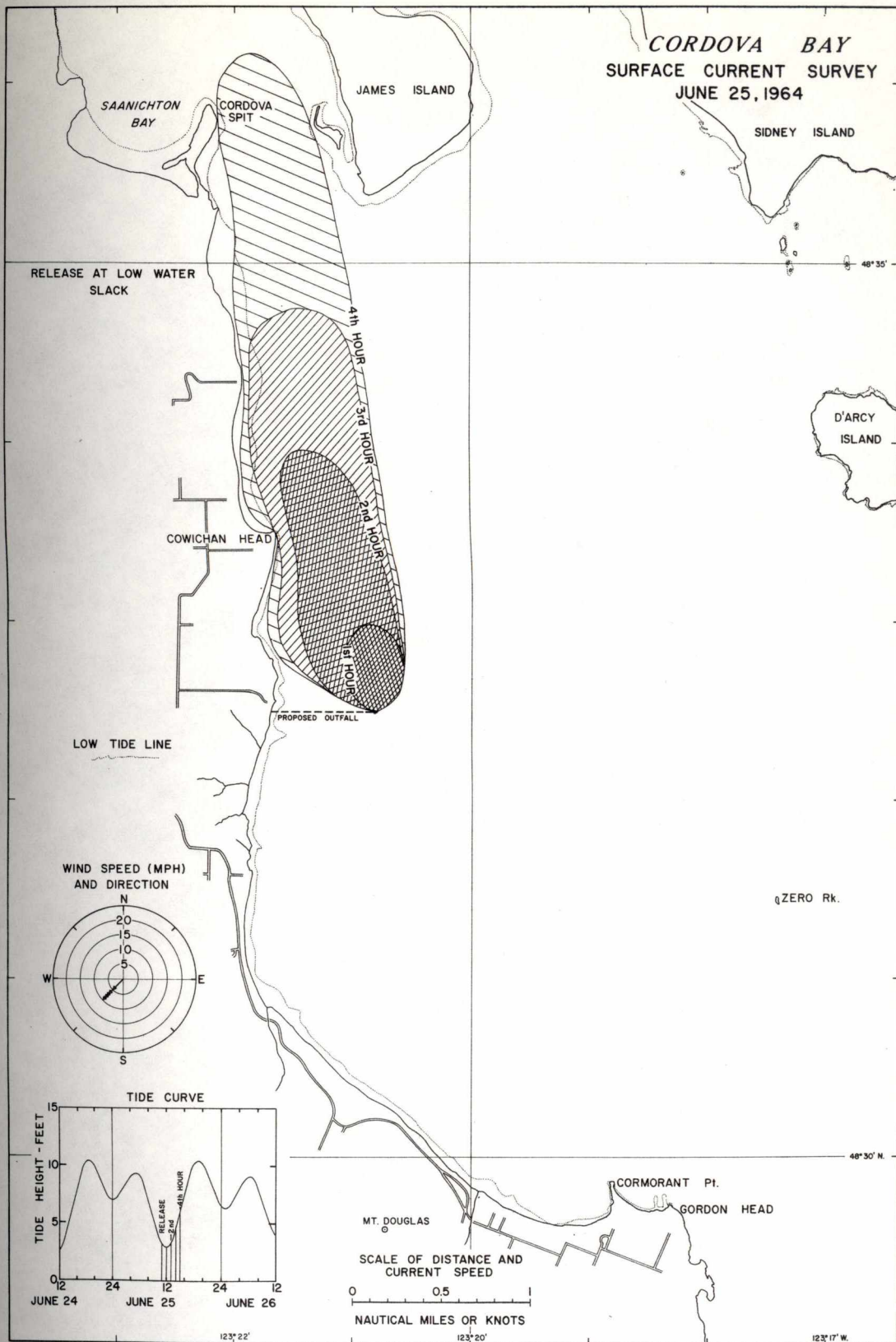


Fig. 17. Dispersion of effluent from a proposed outfall in Cordova Bay, with a release at low water slack. (Schematic, based partly on surface current data.)

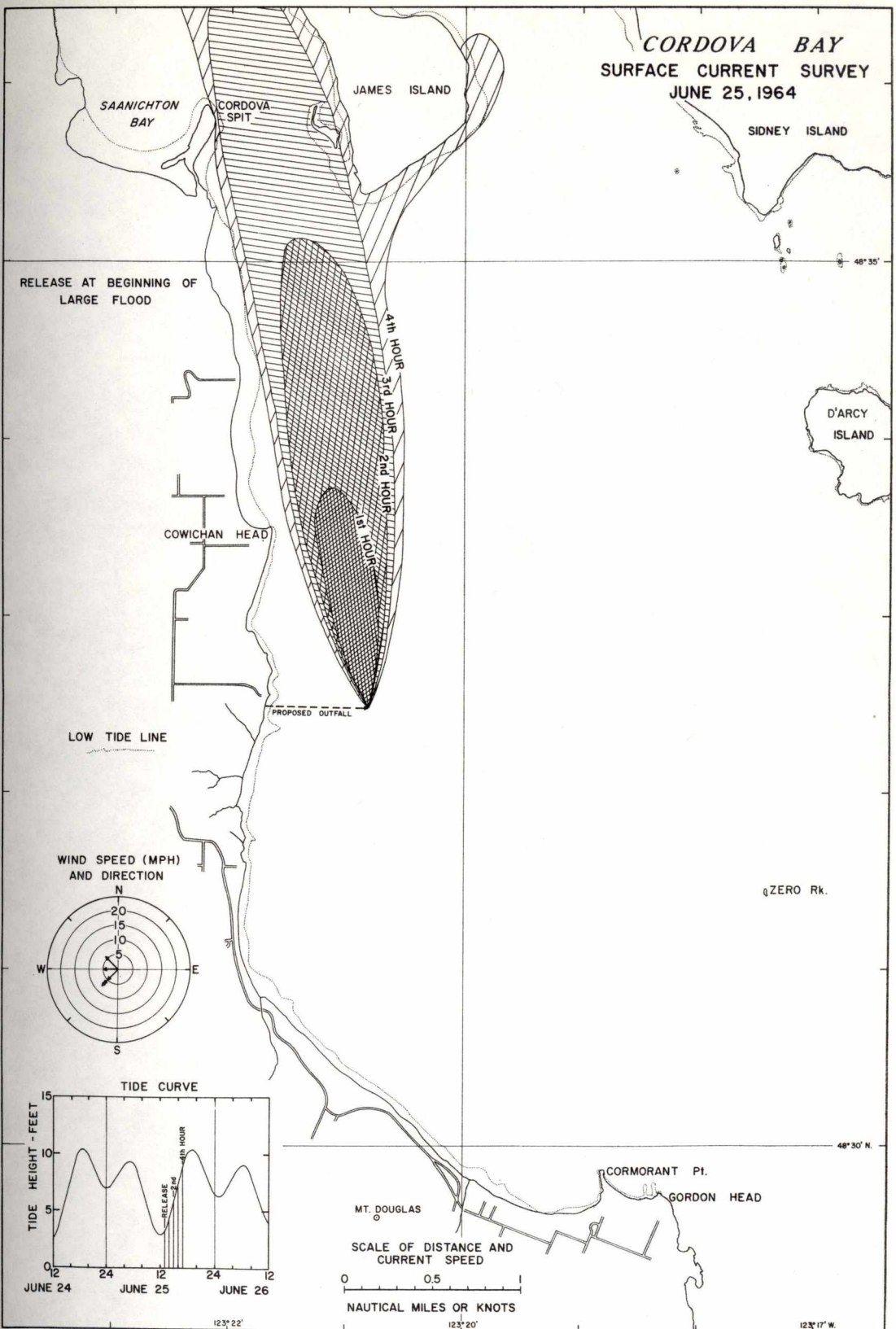


Fig. 18. Dispersion of effluent from a proposed outfall in Cordova Bay, with a release at the beginning of a large flood. (Schematic, based partly on surface current data.)

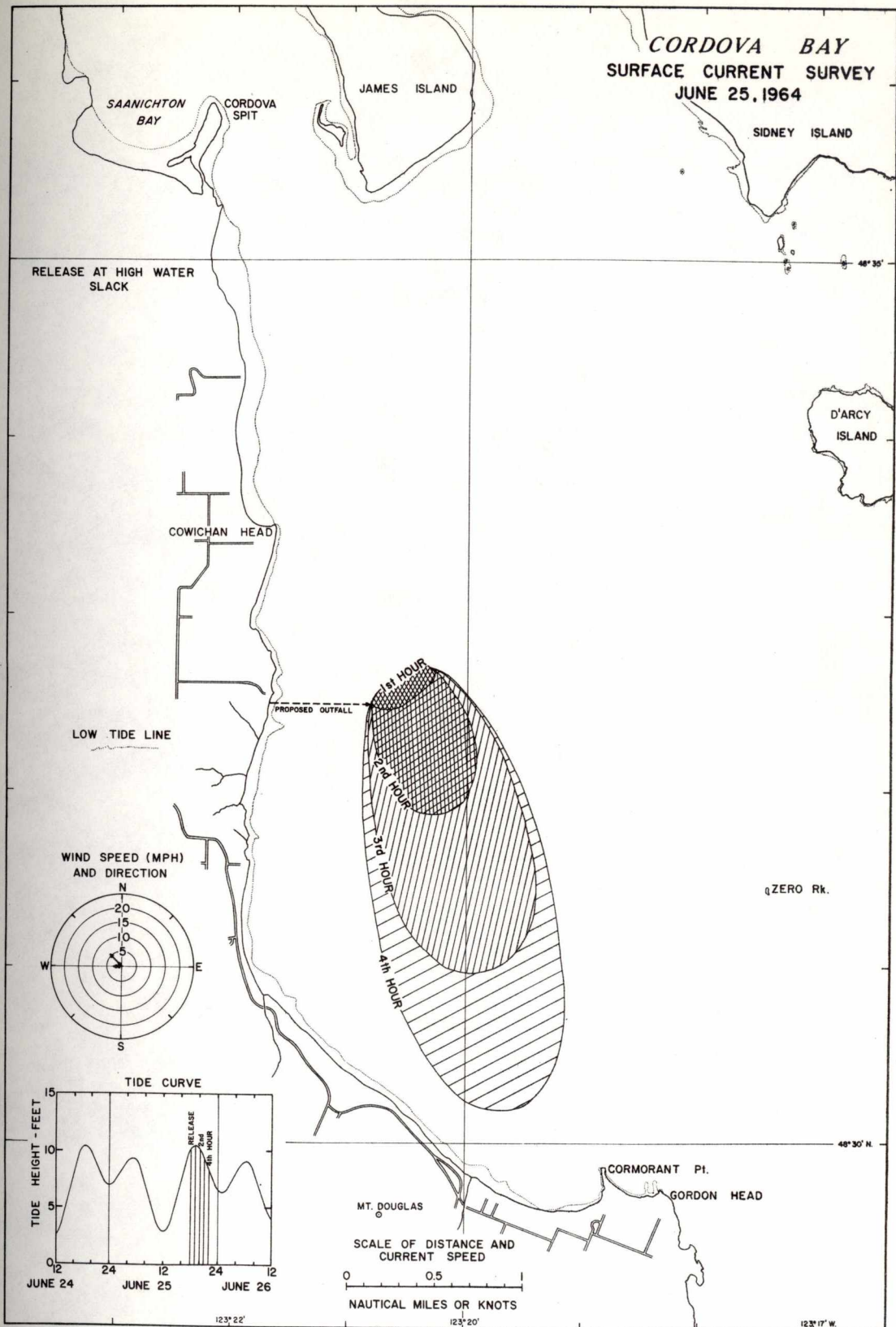


Fig. 19. Dispersion of effluent from a proposed outfall in Cordova Bay, with a release at high water slack. (Schematic, based partly on surface current data.)

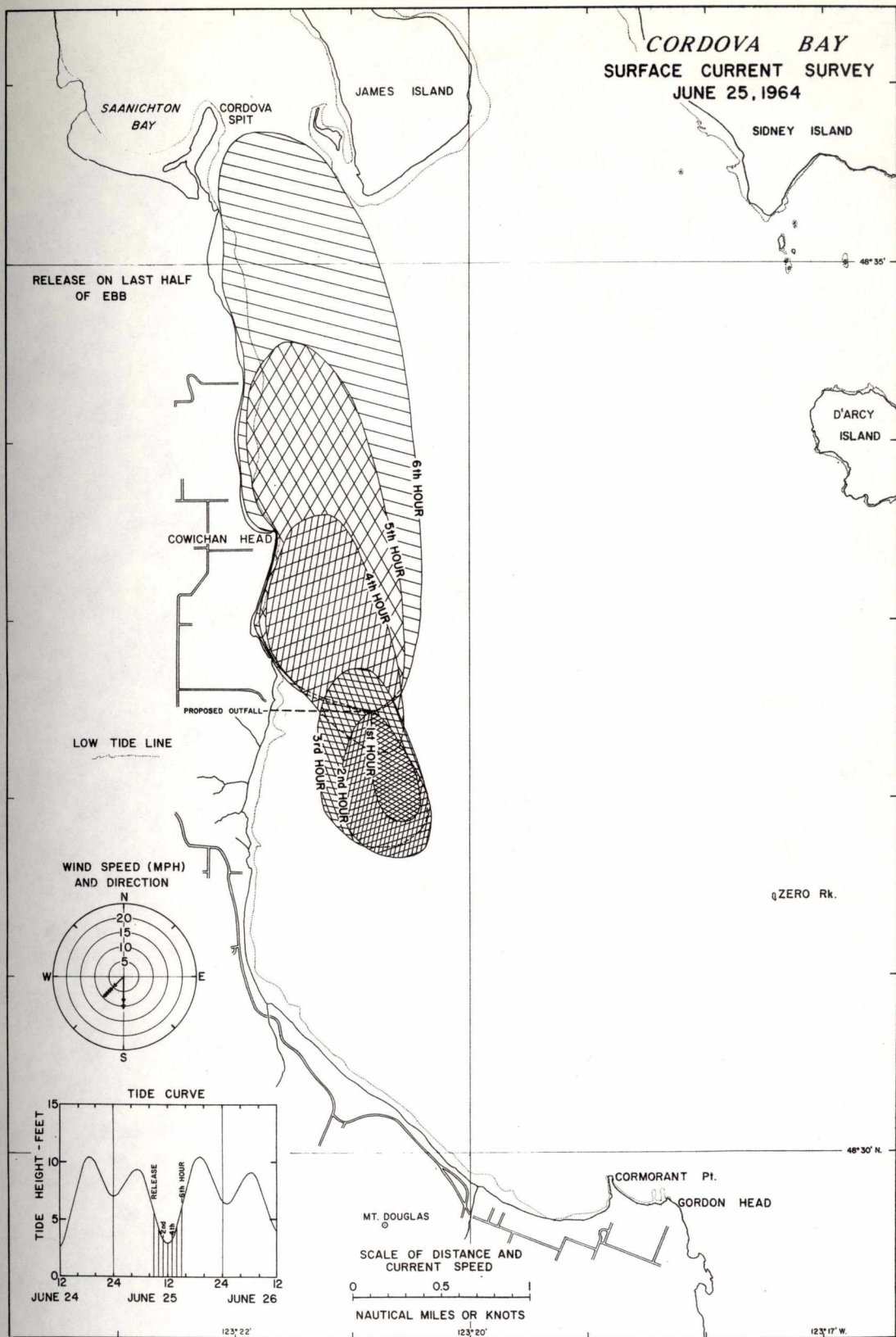


Fig. 20. Dispersion of effluent from a proposed outfall in Cordova Bay, with a release on the last half of the ebb. (Schematic, based partly on surface current data.)

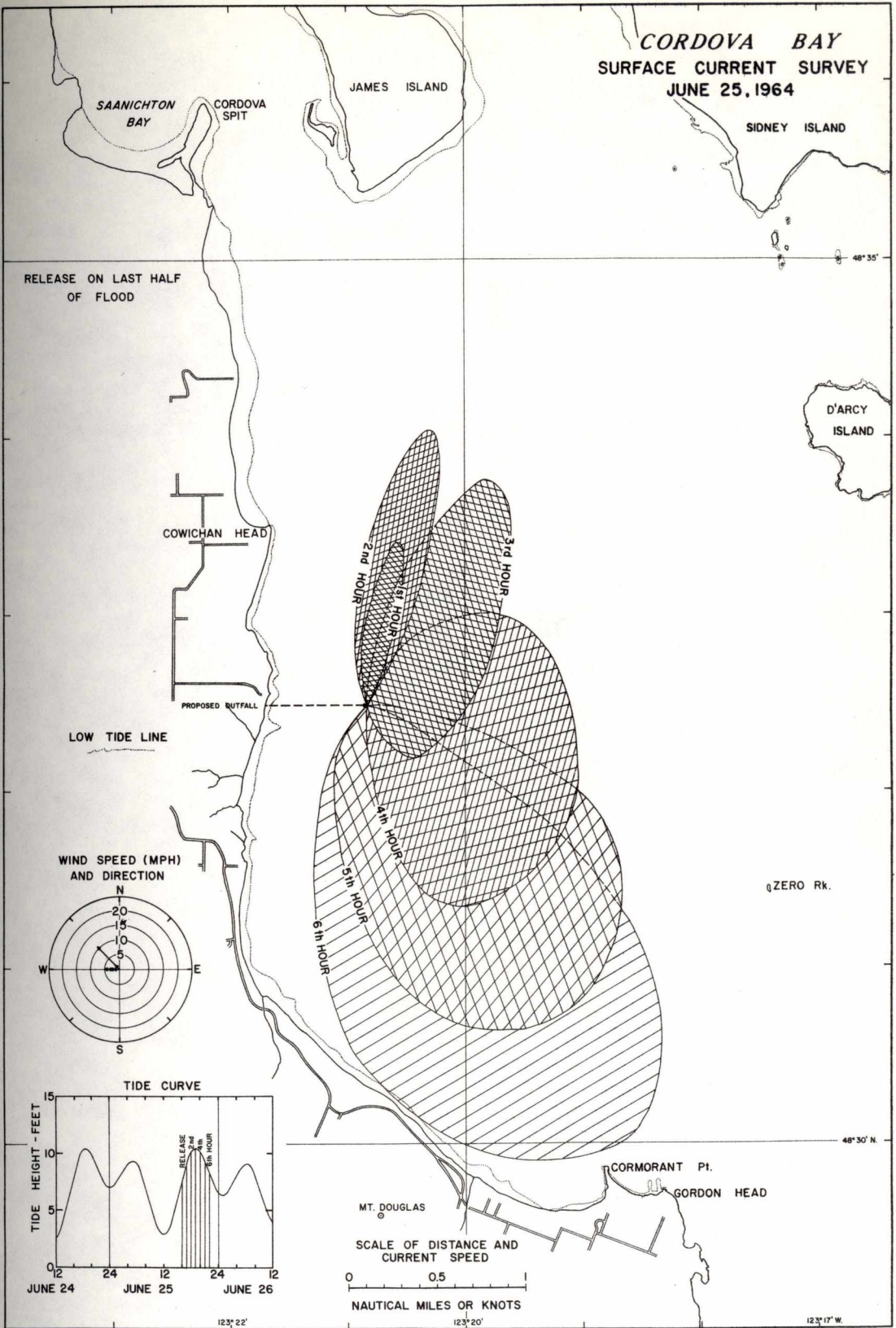


Fig. 21. Dispersion of effluent from a proposed outfall in Cordova Bay, with a release on the last half of the flood. (Schematic, based partly on surface current data.)

APPENDIX

Cordova Bay Survey - Target Tracking Phase

by

G. A. Tzvetcoff

Department of Mines and Technical Surveys

Marine Sciences Branch

Victoria, B. C.

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Cordova Bay Survey - Target Tracking Phase

Introduction

The Cordova Bay survey was undertaken in June, 1964, with the objective of determining the speed and direction of tidal currents. The survey was prompted by the development of new housing areas and the need for the safe disposal of an increasing volume of sewage to be discharged into the Bay. Representatives from the Provincial Pollution Board and the West Coast Working Group - Canadian Committee on Oceanography met several times to discuss the subject of pollution, and decided to carry out a survey of currents in Cordova Bay by means of aerial photography.

Procedure

The period of time covered by the survey was to be as long as practically possible so as to cover most of the tidal cycle. The period actually covered extended from dawn to dusk when the cameras failed because of lack of adequate light. Hourly flights were to be made from an altitude of 6,000 to 12,000 ft, covering the area with three overlapping strips of photographs. The photographs were to have 20% side lap and a 60% overlap. In order to track the displacement of water over the period of survey, four Navy tugboats were to seed the area with targets identifiable on aerial photographs. Each tugboat was to carry a roll of paper mounted on the stern and as the tug proceeded the paper was to be unwound and cut at appropriate intervals. The targets were to be strips of heavy paper, 3 ft x 40 ft. The paper was expected to stay afloat for several hours and the seeding of targets was to proceed regularly during the day to allow for targets sunk or swept out of the survey area to be replaced.

The Hydrographic Service was to run a limited experiment of its own by tracking targets consisting of floating wading pools, 3 ft in diameter and 12 inches high; the tracking was to be done with a transit set up on top of Mt. Douglas. A Hydrographic tidal ship, the Parry, was to be stationed in the area of the proposed sewer outlet, taking current velocity and direction readings with underwater current meters set at depths of 36 ft, 12 ft and surface.

Initial Work

The survey was carried out on the 25th of June with all phases running smoothly.

The first work on the photographs was done by the personnel of the Provincial Department of Lands and Forests. The photographs were marked with the time at which they were exposed, put in sequence, aligned and stapled together in strips. Approximately 480 photographs were taken during the survey;

these photographs were separated into 15 hourly flights which in turn consisted of 3 or 4 strips that covered the survey area. A polyconic grid at a scale of 1 inch to 1,000 ft was plotted on a sheet of transparent plastic together with a rough outline of the coast. At that stage all the photographs and the plastic sheet were transferred to the Hydrographic Service. The idea behind this work was to have a transparent sheet at the same scale as the photographs. Strips of photographs were to be fitted to the coastline and the positions of targets plotted onto the sheet; then hourly plots were to be made and resulting vectors computed.

An examination of stapled strips of photographs revealed that the alignment and positioning were inadequate. Some photographs were out of position by as much as half an inch and similar strips differed in length by up to 2 1/2 inches. The scale of the photographs being approximately 1 inch to 1,000 ft, the position of a target plotted from strips like this would have given an error of up to two-thirds of a knot. This error, however, would have not ended there. Because the survey area was covered by 3 strips, only 1 of which had enough shoreline to permit plotting, targets on the 2 offshore strips would have had to be positioned from previously plotted points; hence, any error in the first strip would have been magnified in the second strip and become even worse in the third. These considerations led to the conclusion that the stapled strips were not accurate enough. It was also noted that in recent surveys of current patterns in both Canada and the United States, results were obtained by stereophotogrammetric means with a standard of accuracy of 0.1 kt. It was, therefore, decided to try and keep the accuracy of the Cordova Bay Survey as close as possible to that standard.

Ground Control

The next step in the search for control was to find a more accurate coastline from existing charts. A new plastic sheet was prepared with a polyconic grid with intervals of 1 minute of arc. A chart of Cordova Bay at the largest scale available, was then obtained and a tracing of the shoreline was made with the best possible accuracy. When the coastline was traced and compared with the strips of photographs, it became apparent that the strips were hopelessly out of alignment. It also became evident that even if the strips were aligned properly, the coastline, which was magnified about 4 times, would have been much too nebulous for positioning. Another method was, therefore, necessary and it was agreed that a coastline traverse would have to be run, tying in all prominent and identifiable features such as houses, rocky points, patios and large boulders.

The proposed traverse was to run along the shore from Cordova Spit to Gordon Head. The problem of marked stations soon arose because only one plugged station was recovered, the geodetic station on Mt. Douglas. Other marked stations in the vicinity were two drilled holes, one of which was later found at station ASS. There was some doubt, however, as to its authenticity. Considering the few stations available, it was decided to use the drill hole at station ASS as a starting point for the traverse. The drill hole could not

have been more than 20 ft away from the original position of station ASS; any errors thus introduced into the traverse would have been reflected only in the azimuths, the length and configuration of the traverse remaining unaffected.

The stadia traverse was run from station ASS, north to the go-cart course at Island View Beach and south to Cormorant Point. Forty-four stations were built, most of them at prominent and easily identifiable points; a score of other features were also tied in along the way. In order to check the traverse, a tellurometer shot was taken across the water between Island View Beach and Cormorant Point. The total error in the length of the traverse was 40 ft, giving an acceptable accuracy of close to 1 in 1,800. The angular error was negligible. The traverse was then adjusted by distributing the errors according to the transit rule. At this stage, a check was made to see if a rectangular grid could be superimposed on a polyconic grid and it was found that the error would not be plottable. A plastic sheet with a rectangular grid of 1-inch squares was then prepared, and the traverse was plotted on it by the method of latitudes and departures. The sheet with the traverse was superimposed on the sheet with the polyconic grid and coastline. When the sheets were found to fit perfectly, identification points were pinpricked and labelled. About 20 copies of the sheet were then printed on the ozalid machine.

Identification of Targets

Identification of targets was the most troublesome part of the work because of the number of possibilities for errors. The photographs were in most cases clear and well detailed, and freshly laid paper targets showed up very well. However, after one or two hours, most of the targets sank and the few remaining ones were widely dispersed and about the size of dust specks on the photographs. A stereoscope was used to identify some targets, but it was of limited use. All dust specks on photographs were first deleted, then the targets were separated into vaguely identifiable patterns and compared over hourly intervals. In very few cases the shape of the patterns remained usable. In some cases the identification was through counting the targets from one end or the other of a line of targets or from some irregularity on the surface of the sea. Once the distance travelled by the water was determined, it became easier to compare target patterns. The lines were marked by one of four or five colours; for example, the first line was red and targets were identified as red one, red two, and so on. The next line was blue and its targets were numbered blue one, blue two; other lines were yellow, green, or some combination of colours. This colour scheme made it easier to track the same targets over long periods of time. The weakness of the system was that after some alterations in nomenclature due to the discovery of some mistakes, it became hard to tell which target was which. The problem was alleviated by the numerous targets that were swept out of the area or became indistinguishable in the shallow waters along the shoreline.

Plotting of Target Positions

The plotting of the targets in the coast strip was done with particularly great care because of decreasing accuracy as one progressed to the offshore strips of photographs. Some concern was also caused by the effects of tilt and variation of height of the aircraft. Variations in height caused no problems because distances to a target were scaled from only one photograph; these distances were, therefore, uniformly distorted and could be altered by a ratio. Tilt, however, produced an error. It was calculated that a 3-degree tilt would produce as much as 0.1-inch displacement, equivalent to approximately 100 ft on the surface of the water. This kind of tilt must have been rare, because ratios in most cases did not reflect such large displacements.

Plotting was done in the following manner: At least three identification points were selected from a photograph and the distances between them were scaled. Corresponding distances were scaled off the plotting sheet, and the ratios, between photograph and plotting sheet distances, were obtained. The ratios were then averaged, and those that deviated from the mean by more than two per cent were rejected. A ratio was thus obtained governing the distance relationships between the photograph and the plotting sheet. Distances from at least three identification points to a selected target were then measured, the ratio was applied and corresponding distances plotted. The intersections of the three lines pinpointed the position of the target on the plotting sheet. If the intersections produced a "cocked hat", a fourth section was used. The "cocked hat" was not allowed to deviate by more than 20 ft, except on two occasions when the coastline was notoriously poor and control points were impossible to locate by regular means.

The plotting of targets from the second strip was made more difficult by the lack of control points. The only controls were at the southern end of the Bay and were used as much as possible. However, away from the coastline, reliance was placed on previously plotted targets. Vectors had to be drawn from solidly positioned targets, an allowance had to be made for time lapse between exposures and the projected positions had to be used to plot outlying targets. Needless to say, the magnitude of errors increased, but it was kept within 100 feet. Plotting of targets from the third strip presented even further difficulties, because of the complete lack of solid control. In some cases the photographs were pinned to the table through common targets without regard to time lag, tilt of aircraft, or difference in ratios; plotting errors in these cases amounted to as much as 200 feet. In any event, the currents were relatively fast in this area and the number of tracked targets was small.

Problems of Identification

While identifying targets, use was made of several features which were not planned. Several logs were tracked for a considerable period of time; their identification was positive and they provided a good check on surrounding paper targets. Tide lines were sometimes very pronounced. Targets had a tendency to be segregated by tide lines which then provided a general outline

of the shift of the currents. Moored pleasure boats near beaches provided an excellent indicator for the direction of the current because mooring buoys and boats were visible in most cases. During changes of tide, the inshore current was often eddying and bore no relation to the direction of flow some distance offshore; it was then that moored boats best showed the direction of the current. There is a chance, however, that in some cases the 15 mph wind may have played a considerable role in shifting the boats. Anchored ships like the Parry, the Heatherton and the RCMP launch provided checks and additional data about the general direction of flow. An oil slick provided one spectacular case in tracking; it showed up immediately and kept its general shape until flushed outside the survey area. The oil slick was so pronounced that some oil base compound should perhaps be investigated for future use as marker fluid.

During the selection of targets there was a large incidence of chosen targets being wading pools used by the Mt. Douglas observers. This fact points out that targets need not be large, but rather stable and consistent of shape. Wading pools, logs and oil slicks were picked out and tracked correctly in most cases because they could be positively identified and because they stayed afloat; their presence in the area greatly facilitated the identification of paper targets. It may be mentioned here that had photographs been taken more often, for example every half hour, the problems of tracking would have been almost eliminated because the distortion of patterns and sinkings would not have been as pronounced as in the hourly intervals. Suffice it to say that whenever an extra flight was made, the tracking time was cut in half and much more reliable identification was obtained.

Tracking by Transit

Tracking of wading pools with a transit from the top of Mt. Douglas was conceived by the personnel of the Hydrographic Service. Mt. Douglas, with a height of 739.8 feet above sea level, offered a commanding view of the whole of Cordova Bay. It was reasoned that the sighting of a target from such a position would give its coordinates within close limits. The choice of wading pools over other targets was made because it was considered that pools would follow the currents, be stable and easily visible. Some problems of operation were expected - the visibility of pools of different sizes and colours was an unknown and it was apparent that a correction for dip and refraction would have to be applied and that longer sighting distances would have greater errors. Calculations showed, however, that at a maximum expected distance of 5 n. mi., an error of 12 sec in the vertical angle would produce an error of 100 ft in the horizontal distance; this compared favourably with the accuracy of plots from second and third strips. Furthermore, a reading of 12 sec was well within the capability of the transit and 5 miles was the very outside range. In the horizontal plane, no appreciable errors were expected since at 4 miles, an angle of 12 sec subtends only 18 inches.

Previous to the survey, a test was run from Mt. Douglas to check the feasibility of tracking the wading pools. The instrument was set up and white, blue and red wading pools were tossed in the water some 5 miles away. The wind was gusting to 30 mph and the Bay was covered with whitecaps. The instrument

was not protected against the wind and was vibrating badly. White and blue pools were very hard to see but the red pool was tracked in spite of difficulties. Later, results were checked against positions obtained by sextant fixes, and the two tracking methods tallied well. Several sightings were taken to anchored buoys and after reductions for dip and refraction, the positions obtained were almost identical with positions on the hydrographic chart. It was concluded that the system was feasible, but that a shelter should be provided and the tracking should be done at somewhat shorter distances.

Problems in Tracking by Transit

During the Cordova Bay survey, the instrument was set up on Mt. Douglas inside a sheltering booth, and a schedule was worked out whereby the instrument men relieved each other. A set of work sheets was issued of the survey area with a grid system showing areas covered by horizontal and depression angles. The sheets were supposed to facilitate the tracking and spotting of targets. A launch was sent into the survey area to drop red wading pools. The weather was clear and the visibility was good. The biggest problem encountered was in spotting the targets. Once a particular target was spotted with binoculars, it was easily tracked with the transit. Tracking sheets proved useless; but the presence, at one time, of a volunteer spotter with a good pair of binoculars, increased the number of tracked pools from two to eight. Altogether about 20 pools were used, some of which were fished out when they got outside the survey area and returned.

Tracking Results

The reduction of the collected data took a very short time because results could be tabulated. The paths of the wading pools proved to be of great value in checking velocity vectors of paper targets. The pools were frequently used to discover directions of the currents. In one instance a major error was averted when it was found that Mt. Douglas vectors pointed in a different direction from the paper targets. A closer examination of the photographs revealed that a large whirlpool action was taking place which was not until then apparent; the oversight was caused by the length of intervals between aerial photographs. At dusk, some pools were rigged with stiff wires which held a one-cell, war-surplus, waterproof light; these lighted pools were tracked until midnight. Although the vectors were of no practical value because of the few pools used, the results proved that perhaps with stronger lights and various colours, target tracking on a large scale is possible at night.

Conclusion

The survey of Cordova Bay took only one day to complete but the processing of the data took close to two months of work. Assuming that two men have been working continuously from start to finish, a rough breakdown of the work follows:-

- | | |
|--|---------|
| (a) Running of the stadia and tellurometer traverse | 3 days |
| (b) Balancing traverse, tracing coastline, plotting grids, testing for errors | 3 days |
| (c) Identifying, plotting, reducing Mt. Douglas readings, computing velocities | 28 days |

The total time for processing thus amounts to 68 man-days. This time does not include the work done by the personnel of the Department of Lands, Forests and Water Resources, who stapled the photographs in hourly sequences or of the oceanographers who interpreted the current vectors.

In conclusion, the following recommendations are made for future surveys:-

1. Flights should be more frequent.
2. With more frequent flights, paper targets will be adequate; otherwise, oil-like slicks or wading pools would be better.
3. Tracking from elevated positions on shore should be provided for checking purposes.
4. Better control system should be provided so that offshore features can be utilized.
5. Provisions should be made to have markers secured in shallow waters to provide additional information about the direction of inshore currents; such markers should be of low profile to decrease resistance to wind.
6. A target spotter should be stationed with the instrument man at the elevated shore station.

The survey of Cordova Bay can be considered a success for the following reasons:-

1. The objective of collecting enough information to analyse the currents was reached.
2. The work involving the co-operation of the B.C. Pollution Control Board, the Hydrographic Service, the Department of Lands, Forests and Water Resources, the Nanaimo Biological Station and the Navy was well co-ordinated.
3. The work was planned with a minimum of fuss and few problems arose during the survey.
4. A successful new method of tracking currents was initiated through the use of paper targets.

5. An experimental method of tracking wading pools from an elevated position on shore proved to be feasible and of potential value for future surveys, and particularly for night-time operations.
6. The method of identification and plotting ran into some difficulties, but these were overcome without resorting to expensive methods or loss of accuracy.
7. The accuracy obtained compared favourably with accuracies achieved elsewhere by stereophotogrammetric means.

It should be pointed out in the end that the Cordova Bay Survey was carried out in fine weather and that many difficulties were avoided because of that fact. Bad weather still remains the greatest unpredictable obstacle for future aerial surveys of the currents.