

JOINT COMMITTEE ON OCEANOGRAPHY

**THE OCEANOGRAPHIC PHASE
OF THE
NANAIMO SEWAGE PROBLEM**

**Pacific Oceanographic Group
Nanaimo, B.C.
September 1, 1953**

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Nanaimo, B.C.

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SEWAGE PROBLEM

by

John P. Tully and Michael Waldichuk

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The Oceanographic Phase of the Nanaimo Sewage Problem

by

John P. Tully and Michael Waldichuk

SUMMARY

Wind is the all-important factor in the movement of surface water in the Nanaimo Harbour-Departure Bay area. Southeast winds move water northward into Nanaimo Harbour and Departure Bay and then out through Rainbow Channel. Northwest winds move the water southward from Departure Bay into Nanaimo Harbour and out through McKay Channel.

Currents measured at anchor showed little consistency in any regular pattern, except in the deep water where they conformed to the tidal picture. Bottom currents were observed to be stronger than the surface or intermediate currents in Nanaimo Harbour and the greatest movement was noted to be into the harbour from McKay Channel.

Regions of stagnation are mainly along the waterfront in Nanaimo Harbour and in the cove west of Pimbury Point in Departure Bay. The most rapidly moving water is by mid-channel in all areas studied, and in the deep channels outside the areas.

Bacteriological analysis shows virtually all areas in Nanaimo Harbour polluted beyond a safety limit. Departure Bay is still relatively free of pollution. It is demonstrated that a sewage outfall at Pimbury Point would completely pollute Departure Bay during southeast winds and under certain conditions of northwest winds. Extension of the sewer outfalls in Nanaimo Harbour into deeper waters might relieve some of the extreme inshore pollution but might pose a threat to the water of Departure Bay.

I. INTRODUCTION

Reason for the Survey

Three principal city sewers discharge into Nanaimo Harbour and Newcastle Island Passage at the positions shown in Figure 1. There is evidence of this sewage all along the City foreshore as far north as Pimbury Point, and some evidence of sewage on the Departure Bay beaches. These sewers are in need of repair, and it will soon be necessary to provide a sewerage system for the rapidly growing Brechin and Departure Bay areas.

The Townsite Beach and Newcastle Island Passage were formerly recreational areas, and Departure Bay is the only remaining sea front recreational beach in the Nanaimo District. It is desirable to reclaim the Townsite Beach, and of some importance to save Departure Bay for recreational purposes. It is also desirable to clean up the harbour for aesthetic and health reasons.

A plan of sewage disposal should be formulated into which repairs, alterations and new sewer construction can be fitted. Sewer outfalls can often be located to take advantage of sea currents to carry the sewage out of the area, or to keep finely divided sewage off the beaches for twelve hours, in which time it becomes harmless to bathers.

If the sea currents are unfavourable some degree of sewage treatment would be required. The choice depends on the currents and rate of flushing of the area. Hence a survey of the surface currents is prerequisite to any sewage disposal plan.

In addition, a knowledge of the currents is required for navigational purposes, particularly along the industrial waterfront, where the present information is obscure and conflicting.

Objective of the Survey

Nanaimo has a domestic sewage system whose discharge may be assumed to behave as fresh water. When it enters the sea it rises to the surface and is dispersed by the surface currents. Most storm water is carried in separate sewers and need not be considered since it is not a polluting agent.

In order to decide where sewer outlets should be placed, and the degree of treatment required, it is necessary to be able to trace the movement of the water throughout the area, and through the sequence of tidal phases.

In view of the local oceanographical and meteorological conditions it was decided to study only the surface currents by following series of free floats released at frequent intervals through the large and small tide cycles, and if possible during representative winds. In addition, surface and deep currents at fixed points were to be observed at frequent intervals to provide continuity in case the drift measurements failed, and to determine the dominant speed and direction of the flow. These concurrent observations provide the instantaneous character of the circulation as well as the movement and dispersion of a particular parcel of water over a period of time.

II. ORGANIZATION OF THE SURVEY

Community Effort

The need for the survey was recognized by the Provincial Department of Health, and the Nanaimo City Engineer, who approached the Pacific Oceanographic Group of the Fisheries Research Board of Canada, to undertake it. Although the Oceanographic Group had experience (Fjarlie, 1950; Tully, 1949) in such undertakings, and was willing to do the work within the limits of their personnel they could not provide funds for the whole operation. Neither the Health Department nor City could find sufficient money to implement the project.

In this dilemma the City turned to the Nanaimo Yacht Club to provide boats, and to the Sea Cadets to provide added manpower. The staff of the Oceanographic Group was augmented by volunteer surveyors from the Institute of Oceanography at the University of British Columbia, Pacific Naval Laboratory, the staff of the City Hall and several private citizens. The Ladies Auxiliaries of the Yacht Club and the Sea Cadets catered. The Pacific Oceanographic Group provided or enlisted all technical equipment, the Yacht Club provided boats and crews, and the Health Department made a contribution towards the floats.

Boats

The area was arbitrarily divided into seven sectors as shown in Figure 1. In each sector there was a SURVEY SHIP (a large yacht) and one or two PICK-UP boats (small open motor boats) provided by the Nanaimo Yacht Club. Groups of floats were released in each sector every two hours, their positions plotted periodically from the SURVEY SHIP and eventually they were recovered by the PICK-UP boats.

The survey ships were operated by their Master and crew, and carried a surveyor and one or two Sea Cadets. The Master was in full command of the ship. At the request of the surveyor, the crew or Sea Cadets set the bundles of floats, while the surveyor fixed the positions. Then the survey ship patrolled the groups of floats, coming alongside each group in turn, while the surveyor fixed and recorded the positions.

Each pick-up boat had its own operator and carried a surveyor, and was under the direction of the survey ship to which it was attached. In general, both the operator and surveyor picked up floats as directed by the survey ship; and the surveyor in the pick-up boat recorded the "pick-up".

A shipping wharf was provided at the Yacht Club, from which two fast tenders (speed boats) operated. The required bundles of floats were sent out to each survey ship every two hours, in anticipation of the next "set". Having delivered the floats, the tenders went to the pick-up boats and took the recovered floats back to the shipping wharf where they were sorted, re-numbered, re-bundled, and eventually re-issued.

Unless they were being relieved, the survey and pick-up boats remained on duty in their sector throughout the day. Supplies, and transfer of personnel and equipment were handled by the fast tenders.

Surveyors

In each sector there was one surveyor for the survey ship and one for each pick-up boat. Each surveyor was supplied with sextant, station pointer, and a chart of the area. The positions of the groups of floats were determined by sextant bearings to known marks ashore, and plotted by station pointer on a Hydrographic chart, or a suitable enlargement. Usually sextants were not necessary along the shore where the nearby landmarks ensured an accurate estimate of position. To facilitate recording of the "pick-up" a grid (400 by 600 feet) was superimposed on the chart.

The recruitment and training of surveyors is worthy of note. Prior to the survey there were only five people who had first-hand experience with this type of operation, and only two more were acquainted with the use of the sextant method of position finding. It was necessary to recruit a total of 29 people as surveyors.

People who had some experience with the use of any kind of survey or measuring instruments were sought, and volunteers were obtained from the City administration, private engineering offices, the Pacific Oceanographic Group, the Institute of Oceanography and the Pacific Naval Laboratory. The essential training and practice was given in two three-hour sessions.

The more experienced personnel were concerned with the disposition of supplies and supervision; while those with sextant training alone observed the drift of the floats.

Supervision

C.G.M.S. Investigator I (65 feet length) was anchored near the middle of Departure Bay and C.N.A.V. Enkoli (94 feet length) was anchored near the middle of Nanaimo Harbour, from Friday night to Sunday night of each week-end. A senior surveyor and assistant were assigned to each ship in addition to the regular complement.

As each drift of floats was completed and recorded, the survey ships reported to the mother ship, where their records were checked for completeness and legibility, and their chart taken aboard. A new chart was issued, and the surveyors were advised where to set the next drift. Any problems regarding the survey were clarified, and the movements of several surveys were coordinated.

Between conferences the senior surveyor collected the data of the last drift, from the several sectors reporting to him, on a tracing paper overlay, and constructed a synoptic current chart. Thus the results of the survey were being developed while in progress, and allowed adjustment of the procedure to obtain maximum efficiency.

The crew of each of these ships measured the speed and direction of the surface currents with a modified chip-log, and the deep currents with an Ekman current meter throughout the period. These data provided a continuous record of the currents at each fixed position.

Survey Instruments and Supplies.

Sixteen sextants were obtained on loan from private owners in Nanaimo and Vancouver. Towards the end of the survey ten modern sextants were obtained on loan from the Navy.

Station pointers are usually in the form of three-arm protractors which are very expensive and virtually unobtainable. A substitute was made from three strips of xylonite rivetted together at one end and free to be positioned at the other.

The Hydrographic Service supplied 100 charts of Nanaimo Harbour (No. 3581; 12 inches = 1 mile) and 65 charts of Departure Bay (No. 3509; 4 inches = 1 mile). After the first week-end it was found advisable to redraw the chart of Departure Bay on the larger scale, and Messrs. MacMillan and Bloedel provided 75 ozalid prints.

The Hydrographic Service also provided photographic enlargements of the area (24 inches = 1 mile) for use as control charts in the headquarters.

Other stationery such as shipping orders, pick-up records, and message forms were multilithed at the Pacific Oceanographic Group.

Communication

Six pack radio sets (1775 kc), two F.M. hand sets and three link (F.M.) sets were provided by Pacific Naval Laboratory, Esquimalt. Mr. Jack Bond of the Amateur Radio Relay League provided a set to monitor the pack radios. In all but one area (D) a pack radio set was provided to the survey vessels. Both mother ships had F.M. link sets, and two hand sets were used where needed. At headquarters both the pack sets and the link sets were monitored, providing direct communication with the survey and mother ships.

The radio was operated by the Sea Cadets of R.C.S.C.C. Amphion (Nanaimo). Two cadets were stationed at each ship and took turns on radio watch. When off watch they assisted with the survey, in the pick-up boats and on the shipping wharf. The sets were maintained in service by Mr. Marcel Pirart (ARRL) who travelled where required through the fleet.

Headquarters.

All phases of the project were directed from headquarters provided in the Nanaimo Yacht Club. The Oceanographer-in-Charge directed the survey operations through the radio link with the senior surveyors in the mother ships, and thence to the surveyors in the boats. A Despatcher, represented the Yacht Club and directed the movement of all boats, personnel and supplies. From information furnished by the Oceanographer-in-Charge he

shipped floats to the survey vessels. From information supplied by the Masters he shipped food, transferred personnel, or provided relief for boats. The communication's chief represented the Sea Cadets and the Amateur Radio Relay League. He provided communications and extra personnel.

These three chiefs of staff or their deputies were on duty at headquarters throughout the operation and resolved all problems between them.

Food

The Ladies Auxiliary of the Nanaimo Yacht Club and the Sea Cadets catered. Sandwich lunches were provided for all personnel, for three meals on each of the four days. The ladies prepared the lunches the evening previous to the operations. These were sent out with the boats in the morning. Hot coffee, and in many cases a hot dish was prepared in the survey boats to augment the lunches for their crew and those in the pick-up boats. A small committee of the ladies provided a similar service at the Yacht Club for the people working in the tenders, on the wharf and at headquarters.

Pollution Survey

Dr. E.W.R. Best, Director and Medical Health Officer, and Mr. A.E. Hill, Sanitary Inspector, of the Central Vancouver Island Health Unit took surface temperatures and water samples for a bacteria count at certain critical points in Nanaimo Harbour and Departure Bay on the two Sundays of the survey, May 24 and 31.

III. NATURAL CHARACTERISTICS OF THE NANAIMO HARBOUR-DEPARTURE BAY AREA

Geography

Nanaimo Harbour and Departure Bay are sheltered embayments on the west side of the Strait of Georgia. They are located on the northwest-southeast trending coastline of southeast Vancouver Island. The two regions are separated by Newcastle Island and connected by a narrow channel, Newcastle Island Passage. The area of Nanaimo Harbour is about one square statute mile at mean sea level, whereas that of Departure Bay is just a little greater at 1.1 square statute miles.

Bottom Topography

Although the two areas are closely adjacent they are of two different systems. Nanaimo Harbour is a shallow, somewhat closed region with its behaviour often governed by local conditions of wind and runoff. Departure Bay, on the other hand, is a more open and deeper system related in its behaviour to the Strait of Georgia.

Nanaimo Harbour has a depth at low water of around 30 feet in the main part and about 50 feet at the principal entrance at McKay Channel. Mud flats to the south of the harbour have resulted from the silting of the Nanaimo River and are almost always exposed at low water. Other mud flats are located at the mouth of the Millstone River but are not as

extensive. Shoals in the middle of the harbour, such as Beacon Rock and Satellite Reef, are hazards to navigation and are marked by numerous spar buoys, light buoys and fixed beacons. A secondary shallow entrance to Nanaimo Harbour exists between Protection Island and Newcastle Island, hereafter referred to as the "Gap". This is a tidal region which dries at low water and can be considered suitable for water exchange only at high tide. Newcastle Island Passage is shallow not exceeding 30 feet in depth. A sill exists about a third of the way up the passage from Nanaimo Harbour proper where the depth is less than 10 feet at low water.

Departure Bay is a much deeper embayment than Nanaimo Harbour with depths up to 150 feet near the middle. The entrance from the Strait of Georgia between Newcastle Island and Jesse Island is quite open with depths exceeding 120 feet at mid-channel. Shoaling areas are mainly restricted to the beaches of the west side of the bay and the rocks surrounding Brandon and Jesse Islands. More than a quarter of the area of the bay exceeds 120 feet in depth.

Runoff

The main stream of any significant discharge affecting Nanaimo Harbour is the Nanaimo River. It varies from a low of about 150 cubic feet per second in August and September to a high of almost 4,000 cubic feet per second in November and December. The discharge is extremely variable and changes according to the local rainfall. Some influence is imposed by the snows stored in the watershed area in the mountains of the interior of Vancouver Island. Increased discharge can be observed during the spring thaw in April and May.

Much of the water from the Nanaimo River, however, finds its way into the Strait of Georgia without entering Nanaimo Harbour. This is the result of the position of the river mouth on the edge of the harbour where the flow is partly directed west and partly east of Protection Island as shown in Figure 2.

Another source of fresh water into Nanaimo Harbour is the Millstone River. The discharge of this stream is relatively small, of the order of 10 cubic feet per second during the summer months and possibly 10 times as great during the heavy runoff period in December and January. It discharges directly into Nanaimo Harbour and probably exerts a considerable influence on the distribution of salinity in the upper layer. As a result of this fresh water inflow, a stratification in both salinity and temperature occurs particularly in summer. It is presumed that this stratification also provides a variation in current speed and direction with depth. Some movement in the surface water is supplied by the river water, as it flows out to sea.

There are no comparable streams entering Departure Bay and only a small brook (Keighley Creek) at the northwest end of the bay discharges fresh water into the area. The effects of this discharge can be considered as negligible. Water in Departure Bay is generally considered as much more homogeneous than that in Nanaimo Harbour.

Tides

Tides in the Departure Bay-Nanaimo Harbour area are of the mixed type characteristic of the Pacific Coast with a large diurnal inequality in the low waters. This means that there are two high tides and two low tides in a lunar day (24 hours, 50 minutes) and that the time interval and range between consecutive highs and lows may be quite different. The tidal range approaches a maximum of 16 feet during the period of spring tides (sun, moon and earth are in line).

There is a lag of 4 to 8 minutes between the tide in Departure Bay and corresponding stages in Nanaimo Harbour. This is due to the restriction to water movement into Nanaimo Harbour compared to Departure Bay.

Two distinctly different periods of tides were covered during the survey - neap tides, May 22-24, and spring tides, May 29-31 (see Figure 3).

Winds

Winds in the Strait of Georgia are generally either northwest or southeast due to the "channelling" effect of the mainland and Vancouver Island mountains. Winter winds are predominately southeast and are either accompanied or followed by rain and stormy weather. Prevailing summer winds are northwest bringing clear, warm weather into the area.

The land topography in the Nanaimo area maintains the direction of the local winds northwest-southeast or almost parallel to the waterfront. Winds in Departure Bay are diverted more to the east and west. There are fewer periods of calm in Departure Bay than in Nanaimo Harbour.

The survey period occupied a period of variability in the wind when both southeast and northwest winds were encountered. This is characteristic of the summer season. Effects of weak to moderate winds were observed in addition to some brief periods of complete calm.

IV. METHODS OF OBSERVATION

Free Float Measurements

The floats were green fir, 2" x 2" x 18", drilled at one end and loaded with a piece of 1/2" x 8" round iron rod, and adjusted with spikes to float upright with less than four inches showing. In preparation the floats were soaked for a week and were very wet when in use. The upper two inches of these floats were painted, by dipping, in yellow, orange, red, or white paint. The floats were assembled in bundles of twenty (later sixteen) all bearing the same number, marked with grease pencil.

The floats were released by laying the bundle on the stern of a cruiser, cutting the two cords with which they were tied, and pushing

them overboard. In the water they formed a compact group about five feet across. As they drifted they scattered in accordance with the water movements, and so provided a measure of the dispersion as well as tracing the speed and course of the drift. The group technique was employed for this reason, and because the group was much easier to find and follow than a single float. The numbers were recorded when the floats were set and again when they were picked up.

In each of the seven sectors several groups of floats were set out and their positions fixed and recorded from time to time as they drifted through the sector. The floats were picked up when they drifted out of the sector or went ashore, and these positions were also recorded. Fresh groups of floats were set every two hours so that the drift through the area was continually being observed. The laying of floats in all sectors was done at about the same time so that the observations were synoptic.

These float surveys were conducted on Saturday and Sunday, May 23 - 24, when neap tides prevailed, and again the following week-end, May 30 - 31, when the tides were spring. Light northwest winds prevailed the first Saturday, and light southeast winds the first Sunday. During the second week-end the wind conditions reversed with southeast winds on Saturday and northwest winds on Sunday. In consequence the gamut of tidal and wind conditions were observed.

Current Measurements at Anchor

In order to observe the variation of currents with the tide and wind at fixed points in Nanaimo Harbour and Departure Bay during the current survey, continuous current measurements were conducted from two anchored ships. C.N.A.V. Ehkoli was anchored at an appropriate point in mid-Nanaimo Harbour and C.G.M.S. Investigator I in mid-Departure Bay (Figure 1.). Current measurements were made during the regular week-end periods of the survey.

In addition, mid-week observations were made at the same position in Nanaimo Harbour and at a point just north of Newcastle Island Channel in Departure Bay (Table II).

During the first week-end, a drift pole (2" x 4" x 12") and a log line were used for surface current measurements in Nanaimo Harbour. The pole was weighted at one end and extended to a depth of about 10 feet. It did not appear too satisfactory in Departure Bay as its movement did not correspond to the surface flow and a drift bucket arrangement was assembled. This consisted of a bucket extending to a depth of 2 feet below the surface and buoyed up by a glass float. Its movement was checked with the drift of fluorescein dye and was found to be very similar. Throughout the subsequent measurements a drift bucket was used exclusively for surface currents in both Departure Bay and Nanaimo Harbour.

During the mid-week period, May 26 - 28, Ekman current meter measurements were made at 15 and 24 feet levels and were continued in Nanaimo Harbour the week-end of May 29 - 31. The Ekman current meter is a device for measuring the speed and direction of currents at depth. Observations made with it provide an indication of the behaviour of the deep water.

Wind Observations

Throughout the survey period winds were recorded every half hour at the anchored ships in Nanaimo Harbour and Departure Bay by visual observation. Records of wind every half hour in other parts of the Strait of Georgia - Vancouver Airport, Patricia Bay and Comox - were made by the Meteorological Division of the Department of Transport with wind measuring instruments.

In addition to the regular measurements, any unusual phenomena occurring in the water were recorded. Of particular concern were the occasional tide lines or accumulations of debris noted.

Water Sampling for Bacteriological Analysis

Samples were taken from the surface at depths of about 6 feet on Newcastle Beach, Black Ball pier, north end of Kin Park, south end of Kin Park and Departure Bay resort, at high, low and intermediate stages of the tide. These samples were placed in special containers and refrigerated to the appropriate temperatures. Analysis for the bacteria count was made in laboratories in Vancouver.

V. RESULTS

Summary of Free Float Results

May 23

The currents were very indefinite starting early in the morning but showed a general flow out of Departure Bay and Nanaimo Harbour. This would correspond to the direction of the ebb current; and since the atmosphere was calm and the stage of the tide was midway between HHW (higher high water) and LLW (lower low water) on a tidal range of 7.7 ft. the course of the flow was predominately tidal. Currents from a point half-way up Newcastle Island Passage to southern Departure Bay were very indefinite but those to the south in the passage were moderately strong and directed southward. With the rise and increase of the northwest wind the currents increased in the direction the wind was blowing to a maximum both in Departure Bay and Nanaimo Harbour during the two hour period, 0900-1100. The major change in currents for the rest of the day was in Departure Bay where they shifted from a southeast flow to almost due west at one stage and then varied back and forth. Currents in Nanaimo Harbour had a more defined pattern generally flowing southward becoming variable only on the last "set", 1900-2100 hours.

May 24

Wind was very lightly northwesterly until 0800 hours when it shifted to southeasterly and reached a maximum of southeast 10 mph (miles per hour) at about 1700 hours. The tide was between HHW and LLW on a tidal range of 8.6 ft. at the start of operations.

Currents showed a very strong flow into Nanaimo Harbour through McKay Channel and into Departure Bay through Rainbow Channel from 0500 to 1100 hours with a maximum flow into Departure Bay during the period, 0700 to 0900 hours. A convergence resulting from the northward flowing current in Newcastle Island Passage and the southward flowing current in Departure Bay was evident at Pimbury Point.

On the set 0900-1100 hours the current picture was becoming confused in Departure Bay with only small speeds and a variety of directions. A southeast wind up to 5 mph had developed by this time and currents already moving northwestward in Nanaimo Harbour were being helped along by the wind.

By 1100 hours, currents in Departure Bay had also shifted to northwestward and, in general, surface water everywhere was moving in the direction the wind was blowing. This general condition persisted for the remainder of the day except for a period, 1300-1500 hours, when currents were moving into Departure Bay, and off Gallows Point were directed more toward the Coaling Wharf and the Booming Ground.

May 30

Winds can be considered as having been essentially southeasterly all day. The tidal stages between HW (high water) and HHW were occupied on a spring tide of 14.4 ft. tidal range on the rise.

The general surface movement of water was northward throughout the day with some minor variations. Observations in Nanaimo Harbour in the early morning showed a very indefinite flow except east of Gallows Point where the movement was northward. The flow through Newcastle Island Passage was increasing northward. The set in Departure Bay was generally north and northeast with a tendency toward eddy formation on the west side of the bay. As the day advanced and the wind continued southeasterly up to about 4 mph the surface currents became more pronounced in the direction the wind was blowing until the northern entrance to Departure Bay was reached where the flow was eastward out of the bay. This regular trend in the flow pattern continued from 0900 until 1300 hours.

In the early afternoon with the increased southeasterly winds and the beginning of the flood, the flow pattern was becoming confused. Currents in Nanaimo Harbour continued a general northerly flow, but there were cross and counter currents. This situation persisted in the harbour for the remainder of the afternoon. Less evidence of such conflicting currents was seen in Departure Bay but there was a trend toward eddies and the flow was shifting to west.

May 31

This period of observations showed the least regular tendency in the current pattern over the four days of observations.

Winds were north to northwesterly all day varying in magnitude from calm to 7 miles per hour. Tidal stages covered were between HW and HHW of a spring tide with a tidal range of 14.5 ft. on the rise.

Currents were generally moving northward during the calm of early morning and a tidal stage at HW. A large counterclockwise eddy was evident in Departure Bay. This circulation became more pronounced by mid-morning when the currents in Nanaimo Harbour were undergoing a shift from north to south. The flow was mainly out of Nanaimo Harbour through McKay Channel and out of Departure Bay through Rainbow Channel. By noon a very distinct tide line had developed in Nanaimo Harbour as a result of currents converging from north and south on a line between the Gap and the Coaling Wharf. The set of currents in Newcastle Island Passage had shifted from north to south by 0900 hours and continued in that direction for the remainder of the period of observations. Departure Bay exhibited little change in the irregular counterclockwise circulation pattern until 1500 hours. The flow then shifted to a general westerly set resuming some of the earlier circulation pattern at about 1900 hours.

With the dispersion of the tide line in Nanaimo Harbour by 1300 hours the flow shifted to cross channel setting southwestward. Wind was decreasing from north 7 to north 5 mph and the tide was LLW. As the tide began to flood and wind was further reduced to north 2 mph the flow was into the harbour from McKay Channel and the Gap giving a clockwise flow with eddies in the center of the harbour. These eddies were apparent during surface current measurements at anchor when the drift bucket would move away from the ship, describe a large circle and then return. By 1900 hours the currents in the harbour had shifted to a southerly set with still small cross and counter currents apparent.

Results of Surface Current Measurements at Anchor

Nanaimo Harbour

The results of the first week-end, May 23-24, for the Nanaimo Harbour surface currents are shown in hodograph form in Figure 4. The position of the ship is represented by the center of the hodograph and a radial vector taken from the center to a particular point gives direction and speed of current at the particular time. There is much scatter in both direction and speed so that little pattern of rotary or simple reversing current can be recognized. Figure 5 shows variation of direction and speed over a period of time as related to the tidal height. The directions have been taken into or out of the harbour or roughly northwest-southeast, inflowing currents represented on the diagram by points above the line and outflowing currents by points below the line.

The midweek surface current picture for May 26-27 as measured with a drift bucket shows some indication of a clockwise rotary current during the first part of the measurements. But this is reversed during the following observations. There is a very distinct relationship with the tide. The maximum flood occurs at some intermediate point between low and high water and the maximum ebb occurs almost midway between high and low. During this period, wind speeds were quite small and the directions variable. It appears that the major influence was the tide, winds being mostly less than 5 mph.

The results of drift bucket and Ekman meter current measurements in Nanaimo Harbor during the second week-end, May 29-30, are shown in Figures 6 and 7. The scatter of points can be seen to be considerably less on May 30 than it was on the previous week-end. Current directions can be taken northwest-southeast without too much difficulty. On the diagram of current speed with time (Figure 7) a very distinct correlation can be shown between the current direction and the prevailing wind direction. During the daylight hours of May 30 strong southeasterly winds were effective in moving the surface water into the harbour from McKay Channel. From midnight to dawn during the night of May 30 the current showed a definite tendency to follow the tide. Winds were generally light, considerably less than 5 mph throughout these periods.

Departure Bay

The currents shown by the drift bucket measurements (Figure 8) in Departure Bay and substantiated by free float observations the first week-end were almost entirely into the bay and toward shore. Some very strong currents of about 1 knot were recorded during a period of weak winds. This mainly occurred on the falling tide when one would expect the water to be flowing out of the bay.

The plot of current velocity with time only shows up the relative speed of the current without too much correspondence with the tide.

During the midweek period of current measurements in Departure Bay May 27-28, a position was occupied closer to Newcastle Island Passage (Figure 1, position 3). This was a period of small winds. The surface currents, although generally quite weak, showed a distinct tidal influence with maximum ebb occurring at low water and maximum flood at high water. The flow was mainly northwest-southeast. It was generally observed that this region is one of very confused currents and considerable stagnation as it is in the convergence area of currents from Newcastle Island Passage as well as those coming from the Strait of Georgia through Rainbow Channel.

On the last anchor station in Departure Bay the Investigator I was moved westward toward Newcastle Island (Figure 1, position 2). During the first day, May 29-30, the currents were directed mainly northward. The second day, May 30-31, showed much more scatter with directions varying through the northern and southern quarters of the compass (Figure 10). Little correlation can be seen with the tide and the currents appear mainly as wind-driven (Figure 11).

Bacteria Count

The variation of the most probable number of bacteria (Coli-Aerogenes) in a water sample of 100 milliliters taken at specified points is given in graphical form in Figure 12. The relation of the concentration of these organisms to the tide and wind is also shown. A sharp increase in the count at the Black Ball Ferry pier and Departure Bay resort was observed with increasing southeast winds May 24. Other areas remain at much the same level of pollution except Newcastle Beach which exhibited an increase at 1000 hours (low tide) and a decrease by 1300 hours.

With increasing northwest winds on May 31 all areas except Newcastle Beach underwent a decrease in bacteriological contamination.

VI. DISCUSSION OF RESULTS

Surface Currents as Inferred from Free Float Observations.

Winds control the surface currents in Nanaimo Harbour and Departure Bay. Northwest winds 5 mph and over move the surface water west and southward into Departure Bay, through Newcastle Island Passage and southeastward out of Nanaimo Harbour (Figure 13). The reverse is true with steady southeast winds over 5 mph (Figure 14). This is a generalization which has its exceptions and which holds more closely for Nanaimo Harbour than for Departure Bay, partially due to the deeper water and smaller fresh water runoff in the latter.

A particular case of irregular flow where winds were shifting from northwest to northeast is shown in Figure 15A. A very well defined convergence or tide line was developed across the harbour as a result of currents moving towards each other. An indefinite current pattern can also be observed in Newcastle Island Passage where a divergence or flow in both directions away from a region existed. A counterclockwise circulation was becoming developed in Departure Bay with the net flow out of the bay through Rainbow Channel. The subsequent change in the current picture is shown in Figure 15B where the flow was weak and directed across Nanaimo Harbour into the waterfront facilities. The flow in Newcastle Island Passage was southward, while that in Departure Bay was variable with a net transport seaward through Rainbow Channel.

Periods of true calm were virtually non-existent, but relatively calm weather did occur during the brief transition periods when the wind was changing direction from southeast to northwest or vice versa. During these periods other factors than local winds may direct the water movements. Due to a sustained wind in one direction preceding the period of calm a "piling up" of water occurs and relaxation currents develop in an opposite direction to regain an equilibrium. Winds in remote areas of the Strait of Georgia often produce a surface flow of considerable speed. The latter is shown up very clearly in Figure 16A where the

current was observed to flow strongly in a direction opposite to the wind and presumed tidal flow. A reasonable solution to this anomalous current pattern can be found by examining the wind data from points along the Strait of Georgia. For about five hours preceding these measurements, winds had been blowing southeast 10 mph in the area of Vancouver Airport. This wind would tend to move the surface water across the Strait of Georgia toward Nanaimo and thus set up a current in that direction. At this time also a counterclockwise circulation was apparent in Departure Bay and a convergence between north and south-setting currents occurred at Pimbury Point. By what course the water from this convergence returned to the sea is uncertain, but it is presumed that the water sank at this point to return at a deeper level.

Figure 16B shows the confused current picture resulting from the combined effect of weak winds, tidal currents and probably relaxation currents. The counterclockwise circulation in Departure Bay is quite well defined at this time. The shift in current direction began during these measurements and continued in later observations finally resulting in a southward flow.

The response to a wind shift occurs first in Nanaimo Harbour and then advances into Departure Bay. With a change in wind direction from northwest to southeast the current direction changes from a southerly set to a northerly set in Nanaimo Harbour and Newcastle Island Passage followed by a later shift in Departure Bay. This lag causes a short-lived convergence at Pimbury Point between currents flowing southward in Departure Bay and northward in Newcastle Island Passage. With a change from southeast to northwest winds there is a corresponding lag in the current direction change between the two bodies of water and a divergence results at Pimbury Point.

Newcastle Island Passage acts almost as a valve to equilibrate the water levels between Departure Bay and Nanaimo Harbour. When the water level is higher in Nanaimo Harbour than in Departure Bay strong currents in the passage move water northward. This corresponds to the situation with southeast winds. The reverse is true with northwest winds.

Variation of Surface Currents Observed at Anchor

Surface currents in both Nanaimo Harbour and Departure Bay showed much scatter in speed and direction. This confused picture can be largely attributed to conditions as they actually existed. Gustiness in the wind pattern introduced surges into the surface current which consequently became erratic in magnitude and direction. Eddies observed at times gave a very indefinite current picture. However, some of the irregularity may be a result of the technique employed in current measurement. The unavoidable swing of the ship especially when fixed by only one anchor introduces errors into small current measurements.

Wind effect predominated at the surface with wind speeds of 5 mph or more particularly in Nanaimo Harbour. At wind speeds less than 5 mph the tide became important except where other factors contributed to the formation of eddies.

From the current picture it would appear that there must be a net circulation through the harbour from the southern approaches and out through Newcastle Island Passage. This is particularly true in the deep water, but can also be observed in the surface water.

Convergence Lines

These demarcation lines are variously designated as tide lines, interfaces or, in extreme cases, tide rips. They can readily be recognized from the accumulation of drift wood, flotsam and foam. Often distinct changes in the roughness of the water surface from one side of the line to the other can be observed. The cause of these convergences is usually the meeting of currents flowing towards each other from different directions. Although the water along these lines appears stagnant there is actually a subsidence as indeed there must be to relieve a "piling-up". Material which is lighter than the water, however, is buoyed up and tends to collect. Such convergences of small proportions are common in island regions where tidal and wind currents may move through various passages and on occasion oppose each other as they meet.

A considerable number of convergences were noted in Nanaimo Harbour and Departure Bay during the survey. Particularly of note were the lines encountered near Pimbury Point, where currents from Newcastle Island Passage and Departure Bay often met. Occasionally a convergence would move across Nanaimo Harbour when changing wind conditions introduced some variation in the currents.

Convergence lines are important from a sewage disposal point of view in that they accumulate sewage rather than disperse it. However, they are usually of short duration (1-3 hours) and do not normally remain in one area but themselves advance slowly in the direction of the strongest current.

Dispersion of Sewage from Three Main Sewer Outfalls in Nanaimo Harbour.

A study was made of sewage dispersion from three existing sewer outfalls under three different wind conditions in Nanaimo Harbour, as indicated by float drift and "pick-up" records. The results of this analysis are shown in Figures 17 to 25. The diagrams show cases of the introduction of sewer effluent into a pollution-free harbour over a six hour period starting at 0500 when winds were slight and generally increasing as the day advanced. It is considered that the bactericidal action of sea water renders the bacteria of domestic sewage virtually harmless after six hours. Primary pollution or that which was introduced in a particular 2-hour period is shown by heavy line hatching. Secondary pollution or that which was in the harbour between 2 and 4 hours is shown by light line hatching; and third order pollution or that which is 4 to 6 hours old is shown by dotted line hatching. The figures have been idealized to a certain extent, but the essential features are reasonably accurate. In drawing up the dispersion

patterns it was assumed, firstly, that sewage would follow the same course as floats used in the survey; and, secondly, that there is an accumulation of sewage in the discharge area for about six hours after which an equilibrium is reached and the sewage disperses at a constant rate. The density of the hatching lines in a particular diagram shows the relative concentration of pollution.

The case of northwest winds increasing over the six hour period under study is shown in Figures 17 to 19. There is a general southeasterly flow from all outfalls with a maximum trend in that direction from A. Outfall B shows a wider dispersion as some of that effluent was caught in the stronger currents of McKay Channel. Marked stagnation occurs at C with the sewage remaining in that area for some time. The waterfront from the C.P.R. Wharf to the Assembly Wharf suffers the combined effect of sewage from A and B as well as some from C.

With southeast winds the flow from all outfalls is northward (Figures 20-22), the most rapid dispersion being in Newcastle Island Passage and at its approaches from Nanaimo Harbour proper. In Departure Bay the surface water hugs the northwest shore of Newcastle Island from where it spreads into the middle of the bay and is swept rapidly toward Departure Bay beach by the counterclockwise circulation. The foreshore of Nanaimo undergoes the heaviest pollution from all outfalls. At outfall C virtual stagnation occurs for several hours until the effluent spreads to a point further out in the harbour and is then swept rapidly northward.

The effect of small variable winds is shown in Figures 23-25. Due to the shifting currents the flushing is relatively small, a state of stagnation results with considerable accumulation near all sewage outfalls and heavy pollution exists along the entire waterfront.

To summarize the whole two-dimensional flushing problem in Nanaimo Harbour the following points can be stressed. Northwest winds move the sewage quite rapidly southward with the exception of the effluent from C where stagnation occurs. Southeast winds move the sewage northward and calm or small winds tend to retain the sewage much longer along the foreshore. Inshore currents are small and have little dispersive effect, but once the sewage moves further offshore it is rapidly carried away by the fast mid-channel currents. In no case did the sewage appear to move completely out of the Nanaimo Harbour-Departure Bay area in a six-hour period.

Prediction of Pollution from the Proposed Brechin Sewer Outfall.

Similar conditions of wind were considered as in the previous section and the same approach was taken in predicting the dispersion.

In Figure 26 the effect of a northwest wind increasing from calm at 0500 hours up to 10 mph around 1000 hours is shown. The early discharge stagnated north of Pimbury Point but is soon moved toward Nanaimo Harbour as the currents in Newcastle Island Passage increase southward. It can

be considered that the waterfront along the passage and in the harbour up to the Coaling Wharf would be polluted by this outfall in a six hour period.

Southeast winds (Figure 27) would generally have the effect of completely polluting Departure Bay. The effluent moves out along the north shore of Newcastle Island, but as it spreads it is caught by westward flowing currents and is moved towards the beach in a counterclockwise circulation. The greatest intensity of pollution would be around Pimbury Point and just north.

The effect of small northwest winds on May 31 is shown in Figure 28 where the influence of both tide and wind can be observed. The tide was mainly ebbing throughout this period and the overall flow is tidal. A point worthy of note in this diagram is that the initial discharge (0500-0700 hours) moves out along a convergence formed between currents flowing northward from Newcastle Island Passage and southward along the west side of the bay. The dispersion is far greater over the entire period than in the other cases, the effluent being swept rapidly southward once it enters the strong currents of Horsewell and Rainbow Channels. The influence of a counterclockwise circulation is very obvious where a pollution-free cell is apparent in the southern bay.

Existing Bacterial Contamination

The bacteria count is reduced at all points checked except Newcastle Beach after sustained northwest winds. A general increase in contamination can be noted with southeast winds the same area excepted. Newcastle Beach probably comes under the influence of a diverging flow south of Bate Point and consequently suffers contamination from both north and south flowing currents. Waters off the Black Ball Pier exhibit extremely high contamination under certain conditions. This is probably a direct result of accumulation and stagnation in the area at certain times.

Little correlation can be established between the stage of the tide and the bacteria count found at the various points. Although tide would obviously have some effect, the big determining factor is the current picture which is mainly a consequence of the wind.

At times contamination exceeds the limit of tolerance at all points tested except that part of Departure Bay beach occupied by the Kinsmen's Park.

VII. CONCLUSIONS

It must, first of all, be emphasized that the water movements in Nanaimo Harbour and Departure Bay are wind dominated. That is, with southeast winds (prevailing winter winds) the surface water is directed northwestward and with northwest winds (prevailing summer winds) the surface water is directed southeastward. This is especially

true in Nanaimo Harbour and only partly so in Departure Bay. Thus with northwest winds there is a greater chance of flushing sewage out of Nanaimo Harbour as it will move directly out of the area with the exception of some which may land on the mud flats at the mouth of the Nanaimo River.

Southeasterly winds generally cause water to move toward the harbour facilities and into Newcastle Island Passage in Nanaimo Harbour. Any sewage discharged into this area will remain there much longer with southeasterly winds. For example, sewage discharged into the harbour at the C.P.R. Wharf will take approximately 3 hours to be moved out of the harbour into Departure Bay under a southeast wind of 5 mph. The sewage would spend an additional two hours or more in Departure Bay. With a northwest wind of similar speed the sewage would be moved completely out of the harbour within 1.5 hours.

Stagnant Areas

The section of the waterfront in the south end including the Coaling Wharf, the Booming Ground and the Government Assembly Wharf is one of extreme stagnation. Water movements tend to converge into this area and from the apparent debris and drift of floats it can be assumed that sewage would collect very noticeably there.

An area of smaller stagnation is that off Madill's Shipyard south of the breakwater. The existing sewer outfall there can be considered a major contributing factor to the pollution in this section of the waterfront. (Townsite Beach).

Mark Bay on Newcastle Island shows some evidence of very small currents and a considerable number of floats drifted in at various times. Pollution there would be of concern to the waterfront recreation indulged in during the summer season.

In Departure Bay the cove west of Pimbury Point (Black Ball Ferry terminal) shows a very marked stagnation under most conditions. Slow eddy movements tend to retain debris in the area for long periods of time. The whole southern section of Departure Bay usually exhibits a counterclockwise circulation and any refuse dumped into the bay may circulate for some time with a possibility of landing on the beach on the west side.

Generally speaking, the areas immediately along the waterfront have the slowest moving surface currents. This is particularly true in those parts where there are numerous docking facilities. Pilings and booms tend to cut down the surface flow drastically.

Regions of More Rapid Flow

Currents in mid-channel in both Nanaimo and Departure Bay are usually the fastest in the two areas. Those in Newcastle Island Passage frequently exceeded the others in speed and were generally with one set over a considerable period of time as determined by the wind direction.

It might be pointed out that in order to obtain maximum flushing, sewage should be discharged at some point in mid-channel. However, in the Nanaimo Harbour area this would mean spreading the pollution over a larger area in a less concentrated form and possibly endangering the beaches of Departure Bay.

From the few observations made in the channels just outside the Departure Bay-Nanaimo Harbour areas currents were found to reach relatively high velocities. Sewage discharged anywhere along the outer boundaries would undoubtedly undergo rapid dilution and dispersion.

Pollution Control

A pipeline across Nanaimo Harbour and through the Gap would almost completely eliminate pollution in the harbour and Departure Bay, but might contaminate the beaches on the east side of Newcastle and Protection Islands. The latter problem could be overcome as well if the outfall projected sufficiently far into the water.

Water exchange through the Gap is quite negligible and occurs only at high water. It can be assumed that effluent discharged on the east end of the Gap will generally find its way into the waters of Fairway and Northumberland Channels.

A corresponding sewerage plan could be introduced into Departure Bay. Here the pipeline could be extended to the north side of Nares Point. The general flow of water along the north end of Newcastle Island was found to be predominantly eastward so that sewage discharged in this region should be almost completely carried out to sea. There is a danger, however, that the westward flowing currents only slightly to the north would pick up some of the effluent and carry it back into Departure Bay.

By extending a sewer line across the Nanaimo River estuary mud flats to Jack Point and thence discharging the sewage into Northumberland Channel, the problem of local pollution could be completely eliminated. Currents in Northumberland Channel are strong and predominantly southeastward on both ebb and flood due to the restriction at Dodd and False Narrows which check the northward moving flood current from the south. Any effluent discharged here would be mainly moved southward with ample dilution.

An additional advantage to this plan is that the pipeline would run through an area unsuitable for navigation and would not have to be driven too far underground. A disadvantage is that it would necessitate a pipeline of at least 1.5 miles length from the Nanaimo waterfront.

An alternative plan for eradication of sewage pollution is complete sewage treatment right down to the chlorination of the effluent before discharge.

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APPENDIX I.

VOLUNTEER PERSONNEL

Executive Committee

George Muir	Mayor of Nanaimo
Arthur P. Leynard	Nanaimo City Engineer
Harold E. Snider	Rear Commodore, Nanaimo Yacht Club
R.S.K. Isaacson	Nanaimo Yacht Club
George T. Taylor	Commanding Officer, Royal Canadian Sea Cadet Corps, R.C.S.C.C. <u>Amphion</u>
John P. Tully	Pacific Oceanographic Group
Michael Waldichuk	Pacific Oceanographic Group
Mrs. H.E. Snider	Ladies Auxiliary, Nanaimo Yacht Club
Mrs. Wm. Stannard	Ladies Auxiliary, Royal Canadian Sea Cadet Corps, R.C.S.C.C. <u>Amphion</u>
<u>Oceanographer in Charge</u>	Dr. John P. Tully

Supervising Oceanographers

Departure Bay Area

Dr. G.L. Pickard
H.J. Hollister

Nanaimo Harbour Area

M. Waldichuk
A.J. Dodimead

Surveyors

J.T. Anderson

T. Anderson

B.J. Burns

N. Campbell

Ald. R.E. Fawdry

R. Foster

L.H. Hinton, B.C.L.S.

E.G. Hokonson

J. Kemp

Dr. M. Kirsch

A.P. Leynard

T. McDonald

H. Nicholson

R.A. Pollard

K. Riley

R. Rowledge

J. Sawyer

J.A. Shand

S. Tabata

R.W. Trites

S. Wilson

F.H.C. Taylor

Health Inspectors

Dr. E.W.R. Best

A.E. Hill

City Truck

J. Niven

Survey Cruisers and Masters

Belinda

Biker

(No Name)

Garfin

Viento

Mist

Playboy

Gypsy Lass

Wen-Lin

Wilberwin

Daway

Jas. Addison

S. Blackburn

J.G. Cowan

J. Espitalier

A.G. Guest

K.T. Guest

A.W. Harding

R.S. Isaacson

Wm. Low

W.W. Nash

Doug. Robinson

Survey Cruisers and Masters (Cont'd)

Ray-Mar

John Rayer

Loueda

H.E. Snider

Reverie

E. Madill

Nifty Girl

Walter Sorenson

Quandary

S.M. Saunders

Philomar

C.W. Swanson

Jim Bar

N.R. Thompson

Jo-Von II

J. Thompson

Kit-Gard

H.M. Wilson

Mother Ships

C.G.M.S. Investigator I

Pacific Biological
Station

C.N.A.V. Ehkoli

Royal Canadian Navy

Pick-up Boats - Owner-Operators

Jas. Allan

T. Jackson

J. Benny

N.E. Martin

W.F. Bennett

Gus Reimer

Ed. Dermott

Jas. Storey

Frank English

C.J. Whittaker

Frank Foster

A.M. Wilson

John Grassick

N. Wheatcroft

Additional Operators of Pick-up Boats

Bryon W. Jeeves

A.G. Paul

Robt. B. Jeeves

E.W. Stolzenberg

J.H. Stevens

W. Neave

Additional Operators of Pick-up Boats (Cont'd)

D.C. Stewart

J.S. Rees

G. Wilson

Tenders

M.G. Blunt

Earl Rowan

Despatchers

G.S. Lott

Capt. J.B. McGee

J.O. Godwin

Shippers

R.H. Herlinveaux

J.A. Stickland

L.H. McCracken

Royal Canadian Sea Cadets

Lt. Geo. T. Taylor

Commanding Officer

S/Lt. G.A. Black

Petty Officer D. Tayelor

Able Cadets

R. Bell

G. Payne

L. Green

J. Curran

A. Montgomery

A. Wilson

D. Field

R. Jeeves

Ordinary Cadets

D. Warner

J. Morley

M. Cross

R. Bryce

A. Rogers

P. Hiley

L. Sherry

D. Lindsay

D. Mackenzie

Ordinary Cadets (Cont'd)

L. Gallia	T. Bagley	R. Boulton
H. James	L. Blanco	D. Livingstone
L. Gallant	N. Stannard	W. Greenwood
E. Gallant		

Amateur Radio Relay League

J. Bond	M. Pirart
W.W. Emmerson	A. Thick

The Food Committee

Nanaimo Yacht Club Ladies Auxiliary

Mrs. C.E. Hirst	Mrs. H.M. Wilson
Mrs. Wm. Low	Mrs. E.B. Wilson
Mrs. C.W. McAllister	Mrs. R.F. Kaltenbach
Mrs. R.S. Isaacson	Mrs. J. Allan
Mrs. M.G. Blunt	Mrs. J.H. Stevens
Mrs. N.R. Thompson	Mrs. S.M. Saunders
Mrs. R.G. Good	Mrs. H.E. Snider
Mrs. C.W. Swanson	

Sea Cadet Ladies Auxiliary

Mrs. E.E. Rogers	Mrs. J. Bilton
Mrs. E. Rogers, Jr.	Mrs. D. Gallia
Mrs. W.J. Lindsay	Mrs. T.J. Montgomery
Mrs. E.G. Taylor	Mrs. L. Bestwick
Mrs. Wm. Stannard	Mrs. F.L. Jeeves
Mrs. Geo. Payne	

Additional Volunteer Help

Mrs. J.P. Tully

Analysis of the Data

J.P. Tully

R.A. Pollard

B.J. Burns

M. Waldichuk

S. Tabata

TABLE I. Schedule of Operations

May 11 to 22.	Preparation of floats, charts, books, etc. (10 days, 6 men per day).
May 19,21,22.	Evening courses in use of sextant and position plotting.
May 22,23,24.	C.G.M.S. <u>Investigator I</u> and C.N.A.V. <u>Ehkoli</u> anchor on positions (Figure 1) taking current measurements half-hourly from 2100, 22nd May to 2000 23rd May.
May 23,24.	Free float survey from 0430 to 2100 each day, all personnel.
May 24.	Pollution survey for bacteria count, Central Vancouver Island Health Unit.
May 26 to 29.	C.N.A.V. <u>Ehkoli</u> anchored in Nanaimo Harbour and Departure Bay taking half-hourly current measurements, 1300, 26th May till 0900, 29th May.
May 29,30,31.	C.G.M.S. <u>Investigator I</u> and C.N.A.V. <u>Ehkoli</u> anchor on positions (Figure 1) taking half-hourly current measurements from 2100, 29th May, till 2000 31st May.
May 30,31.	Free float survey from 0430 to 2100 each day, all personnel.
May 31.	Pollution survey for bacteria count, Central Vancouver Island Health Unit.

TABLE II. Current Measurements at Anchor

NANAIMO HARBOUR

C.N.A.V. Ehkoli

From	Date To	Position		How* Anchored	Depth	Method*	Hours of Observation
		Lat. N.	Long. W.				
	2130/22-1400/23/May	49°10.16'	123°55.50'	B	Surf.	D.P.	16.5
	1400/23-0700/24/May	49°10.15'	123°55.51'	B & S	Surf.	D.P.	17.0
	0700/24-1800/24/May	49°10.18'	123°55.55'	B & S	Surf.	D.P.	11.00
	1730/26-2200/26/May	49°10.16'	123°55.47'	B & S	Surf.	D.B.	4.5
	1730/26-2200/26/May	49°10.16'	123°55.47'	B & S	15'	E.M.	4.5
	2200/26-2000/27/May	49°10.15'	123°55.49'	B	Surf.	D.B.	22.0
	2200/26-2000/27/May	49°10.15'	123°55.49'	B	15'	E.M.	22.0
	1130/27-1930/27/May	49°10.15'	123°55.49'	B	24'	E.M.	8.0
	2030/29-2030/31/May	49°10.14'	123°55.47'	B & S	Surf.	D.B.	48.0
	0600/30-2200/30/May	49°10.14'	123°55.47'	B & S	15'	E.M.	16.0
	0600/30-2200/30/May	49°10.14'	123°55.47'	B & S	25'	E.M.	16.0
	0530/31-2030/31/May	49°10.14'	123°55.47'	B & S	15'	E.M.	15.0
	0530/31-2030/31/May	49°10.14'	123°55.47'	B & S	25'	E.M.	15.0

DEPARTURE BAY

C.G.M.S. Investigator I and C.N.A.V. Ehkoli

From	Date To	Position		How* Anchored	Depth	Method*	Hours of Observation
		Lat. N.	Long. W.				
	2130/22-1800/24/May	49°12.10'	123°57.18'	B	Surf.	D.B.	44.5
	2100/27-2200/28/May	49°11.76'	123°57.03'	B & S	Surf.	D.B.	25.0
	2100/27-2200/28/May	49°11.76'	123°57.03'	B & S	15'	E.M.	25.0
	0130/28-0930/28/May	49°11.76'	123°57.03'	B & S	24'	E.M.	8.0
	1900/28-2030/28/May	49°11.76'	123°57.03'	B & S	60'	E.M.	1.5
	2100/29-2000/31/May	49°12.04'	123°56.98'	B & S	Surf.	D.B.	47.0

* B = Bow
 S = Stern
 D.P. = Drift Pole
 D.B. = Drift Bucket
 E.M. = Ekman Meter

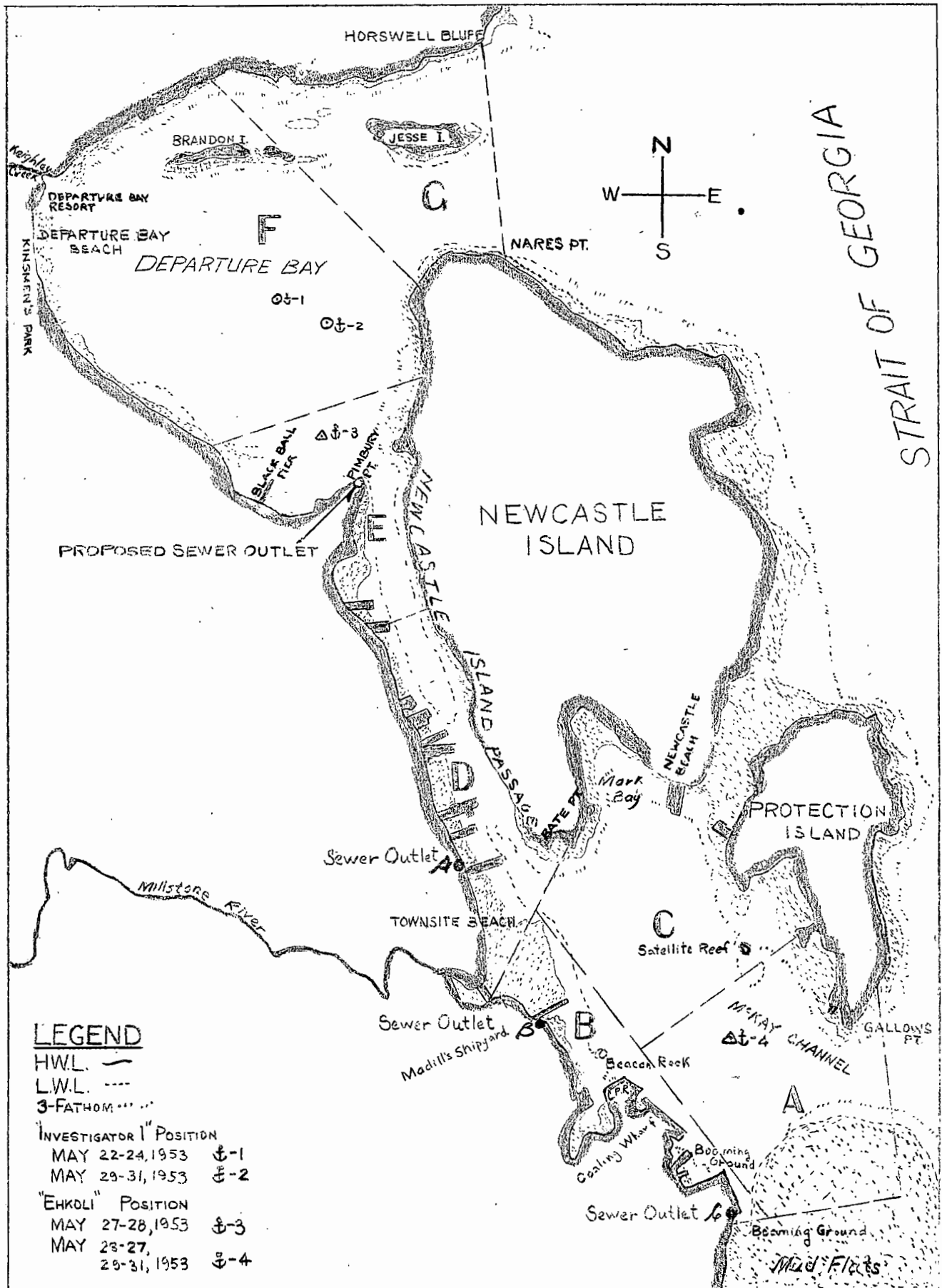


Figure 1. Nanaimo Harbour - Departure Bay showing survey sectors, anchor stations and sewer outfalls.

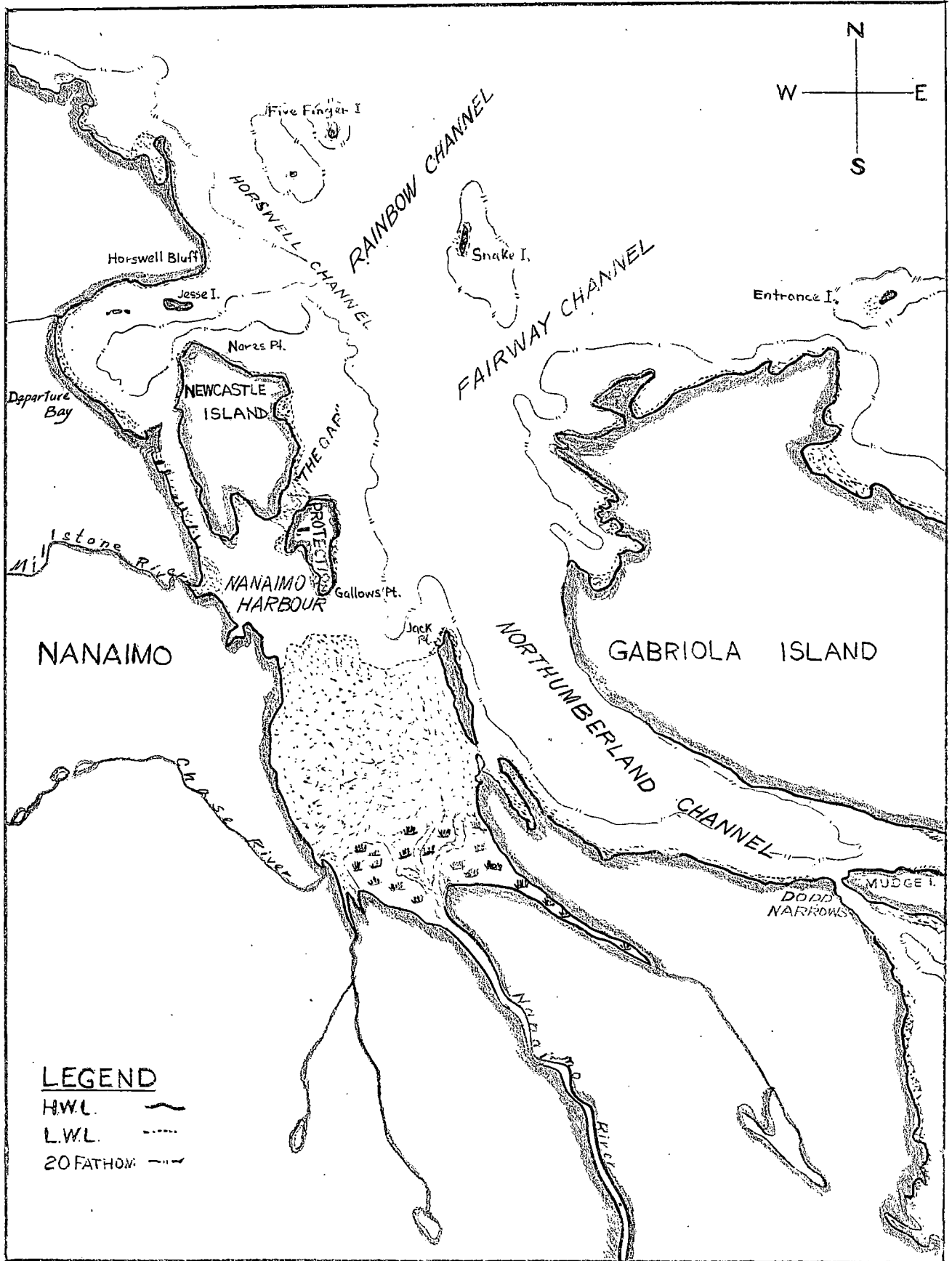


Figure 2. Chart of Nanaimo Harbour - Departure Bay and environs.

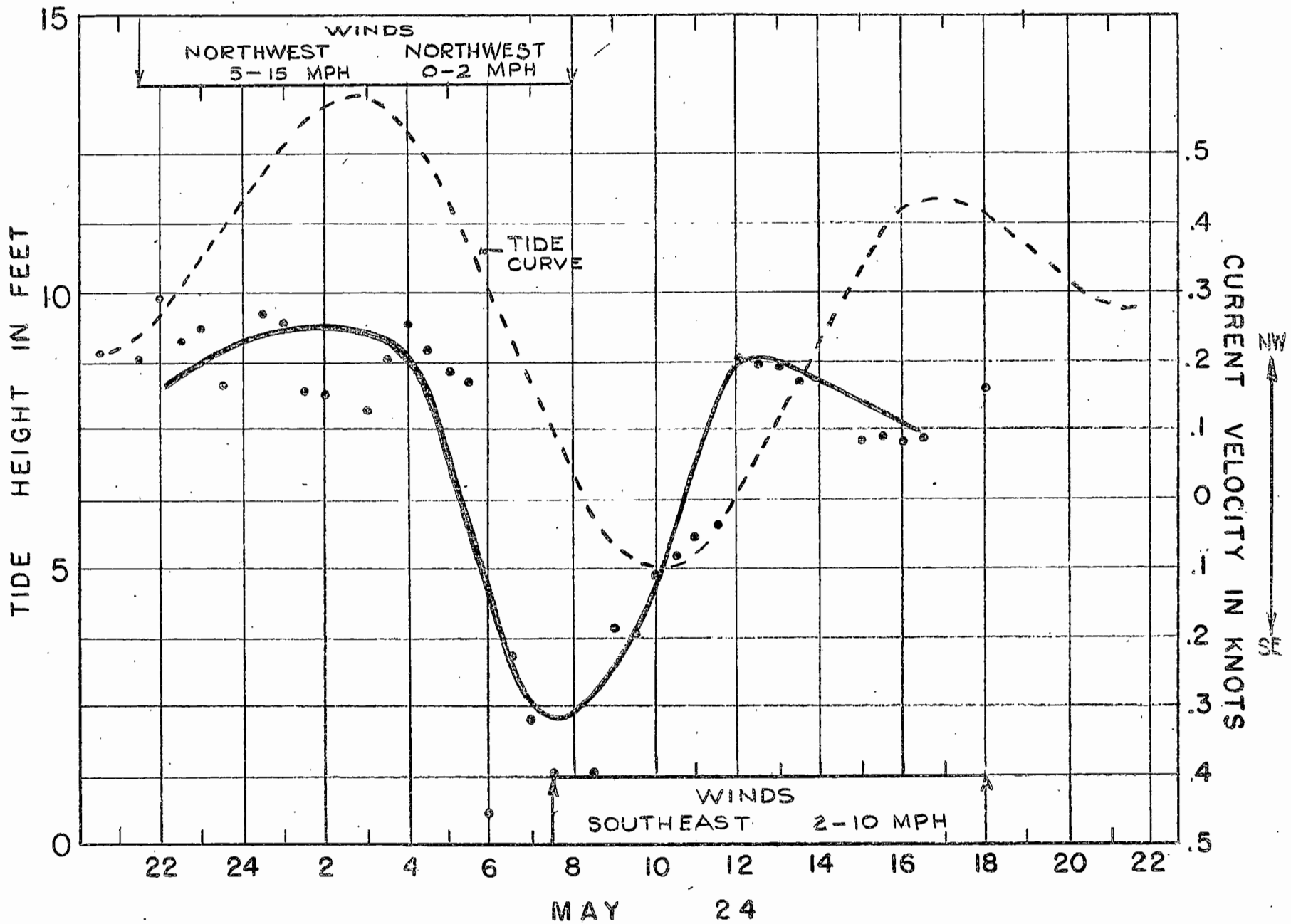


Figure 5. Variation of surface current velocity and relation to the predicted tide height in Nanaimo Harbour, May 23-24.

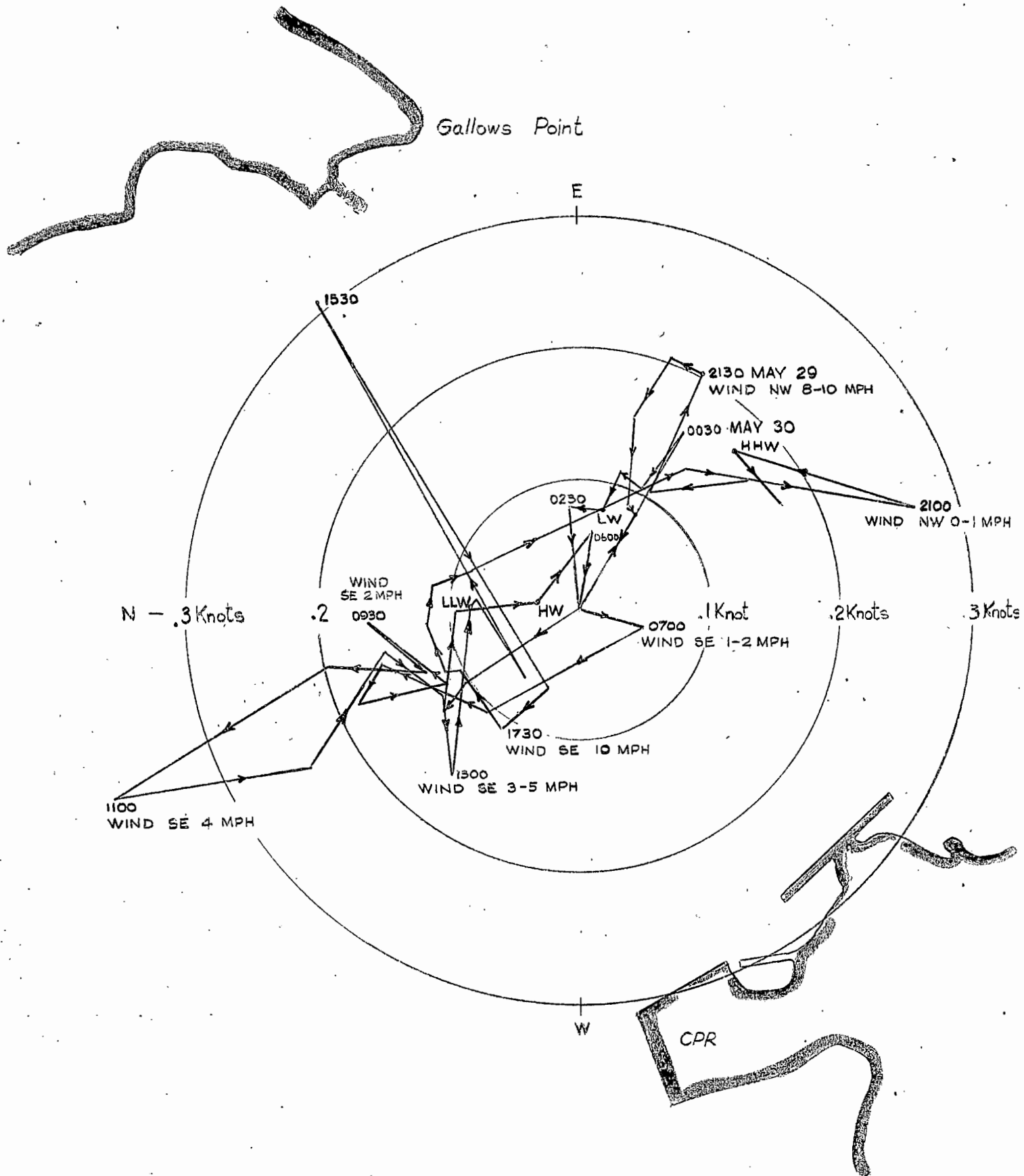


Figure 6. Hodograph showing surface current speed and direction at anchor station in Nanaimo Harbour, May 29-30.

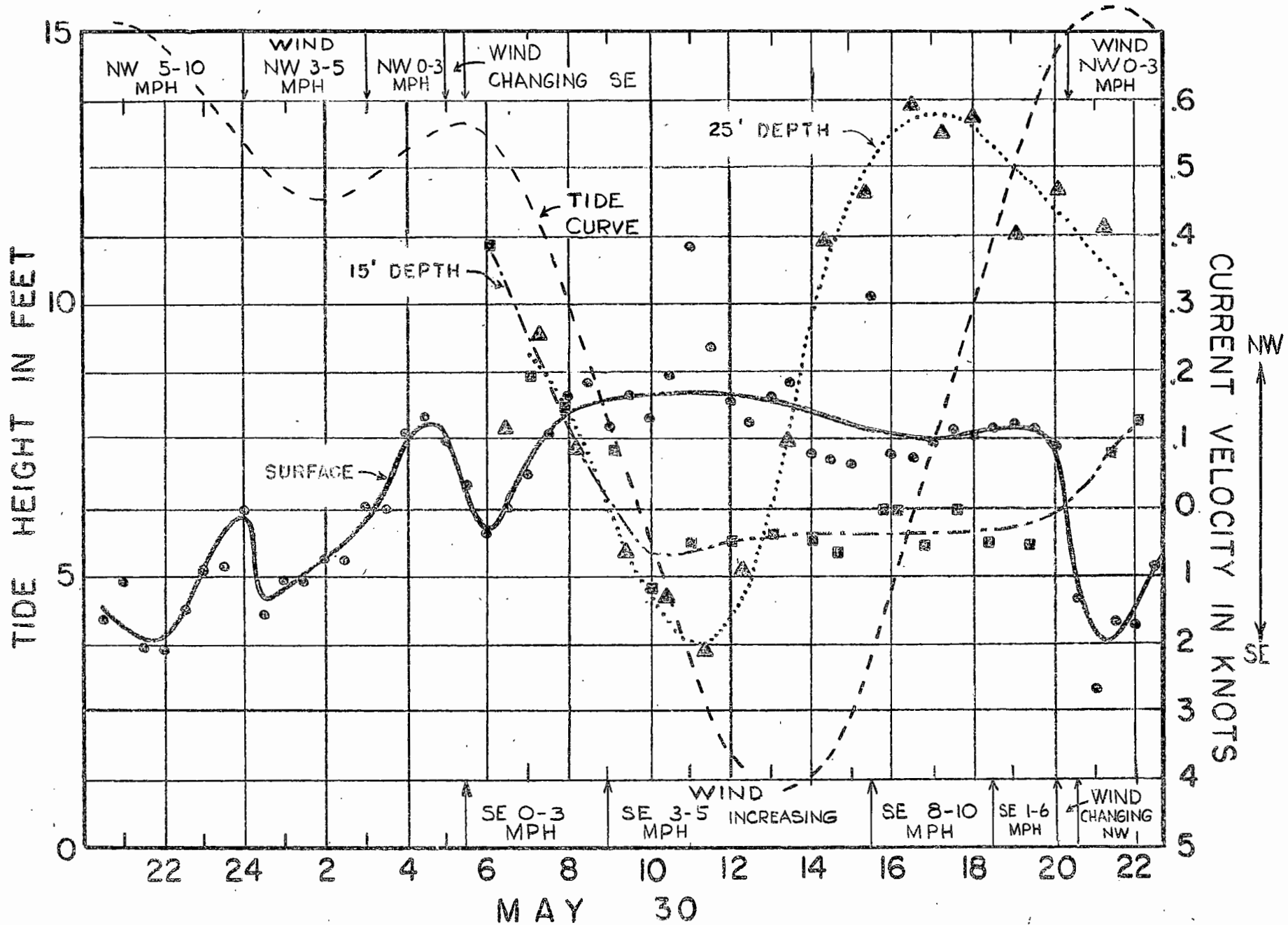


Figure 7. Variation of current velocities and relation to the predicted tide height in Nanaimo Harbour, May 29-30.

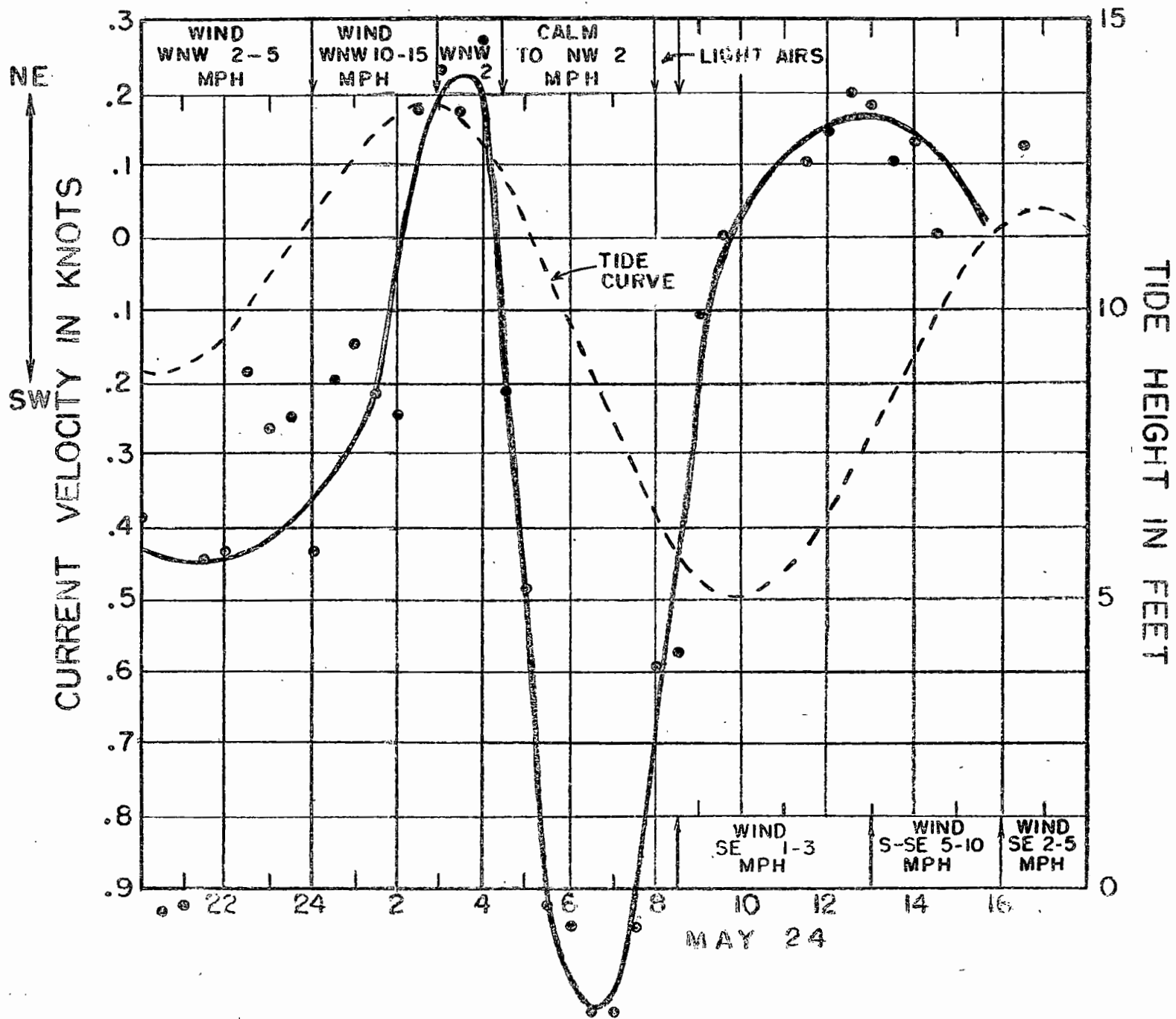


Figure 9. Variation of surface current velocity and relation to predicted tide height in Departure Bay, May 23-24.

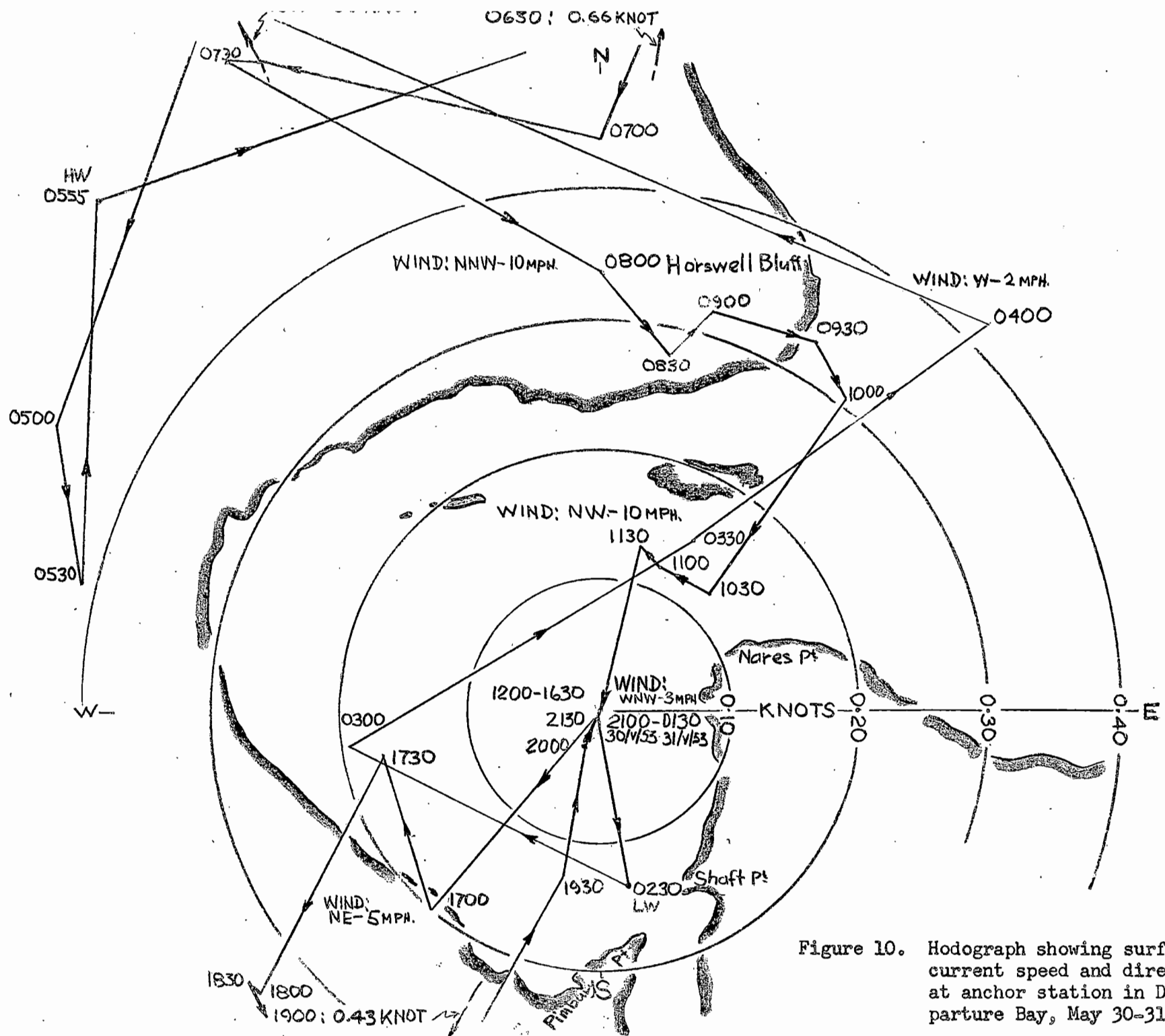


Figure 10. Hodograph showing surface current speed and direction at anchor station in Departure Bay, May 30-31.

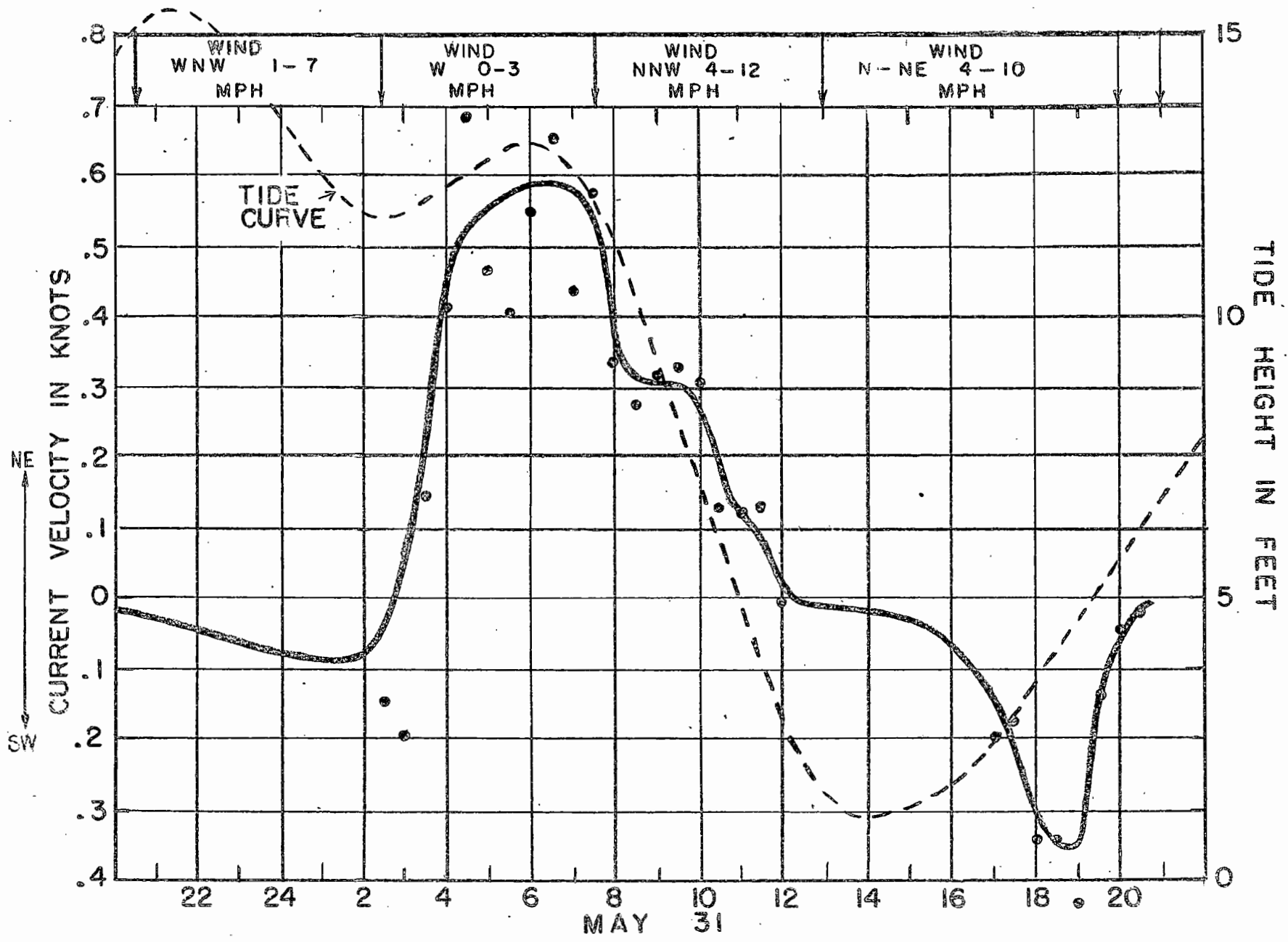


Figure 11. Variation of surface current velocity and relation to the predicted tide height in Departure Bay, May 30-31.

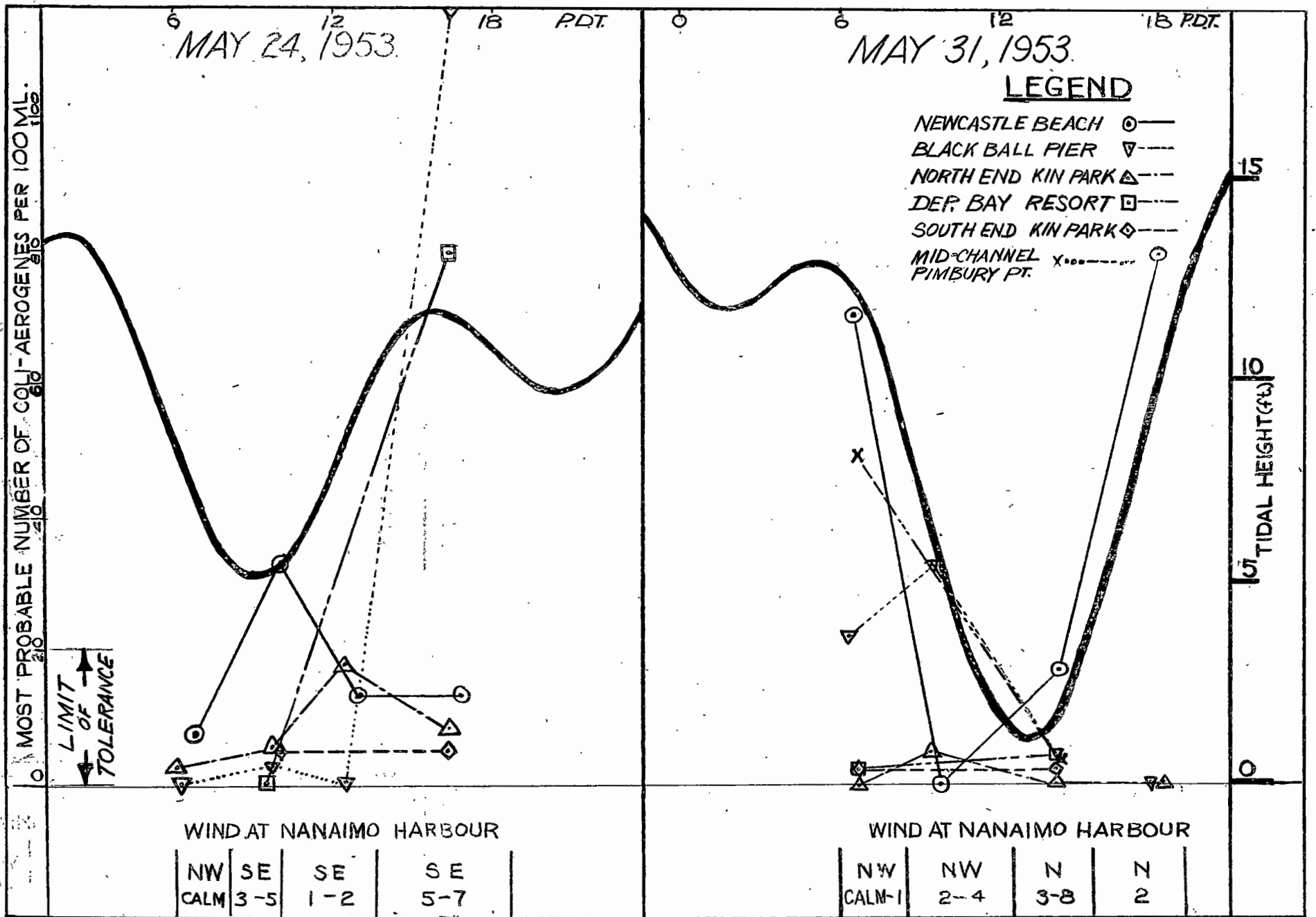


Figure 12. Variation of bacteria concentration at various sampling points under different tidal and wind conditions.

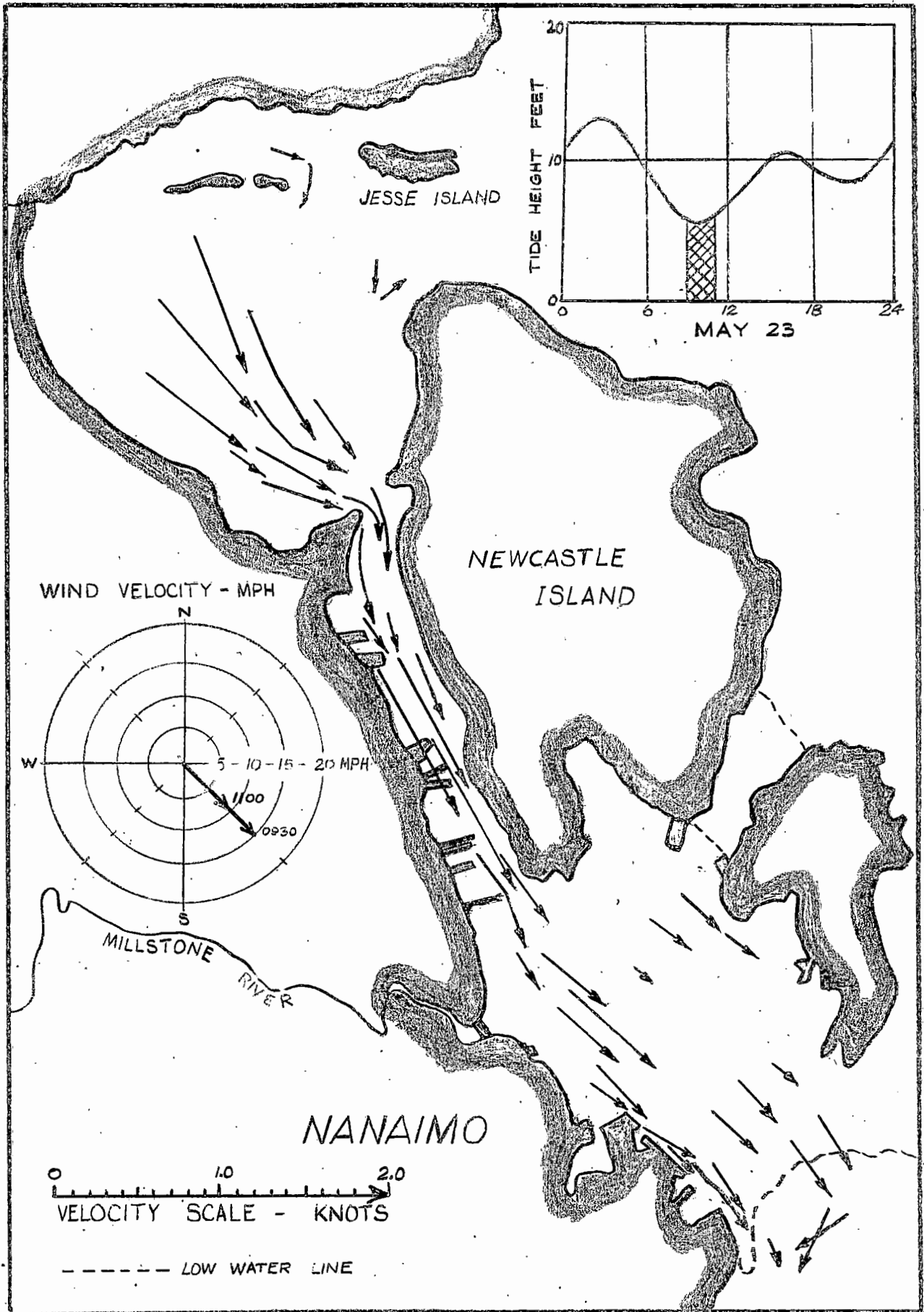


Figure 13. Typical surface current picture under conditions of a northwest wind.

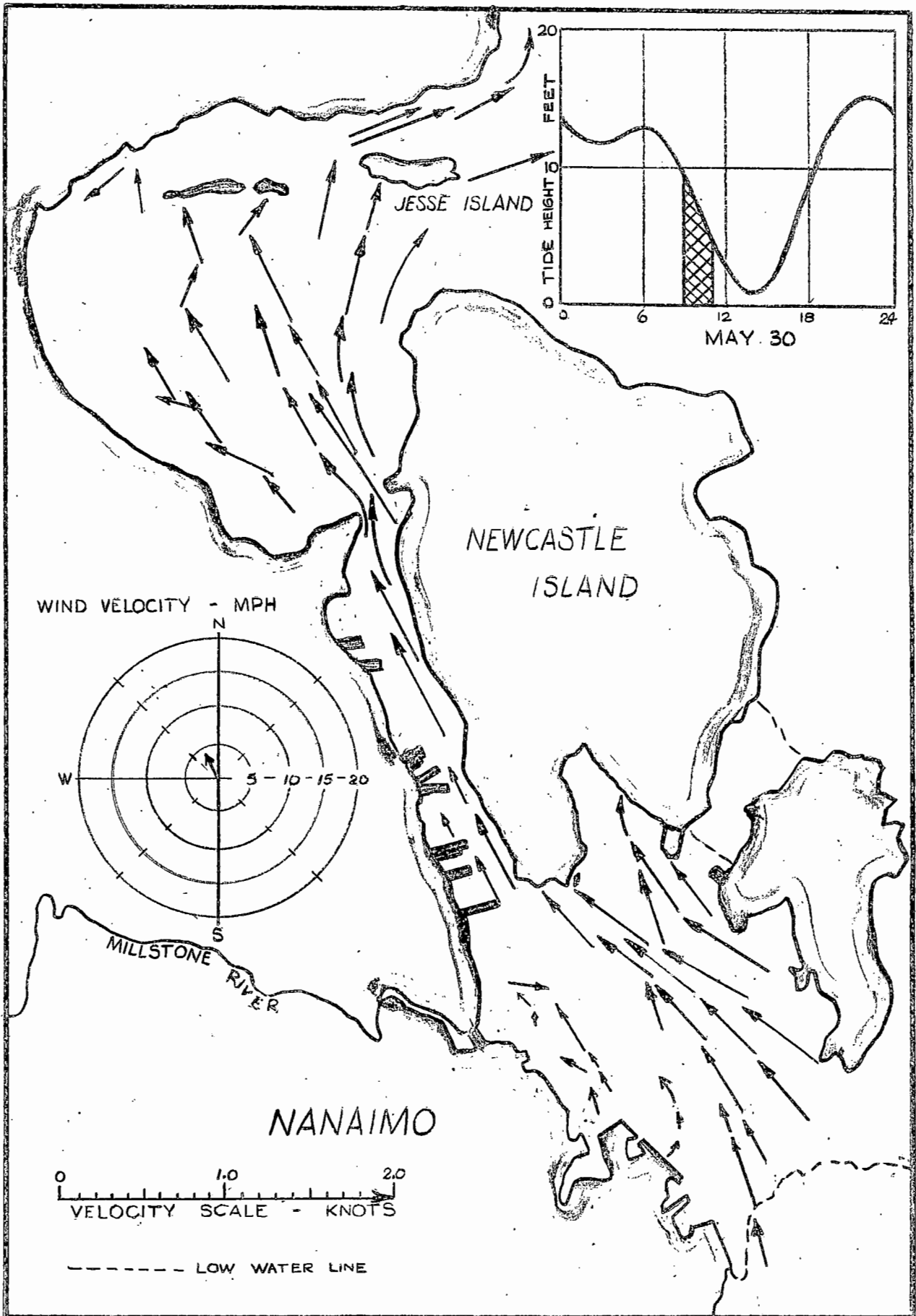


Figure 14. Typical surface current picture under conditions of a southeast wind.

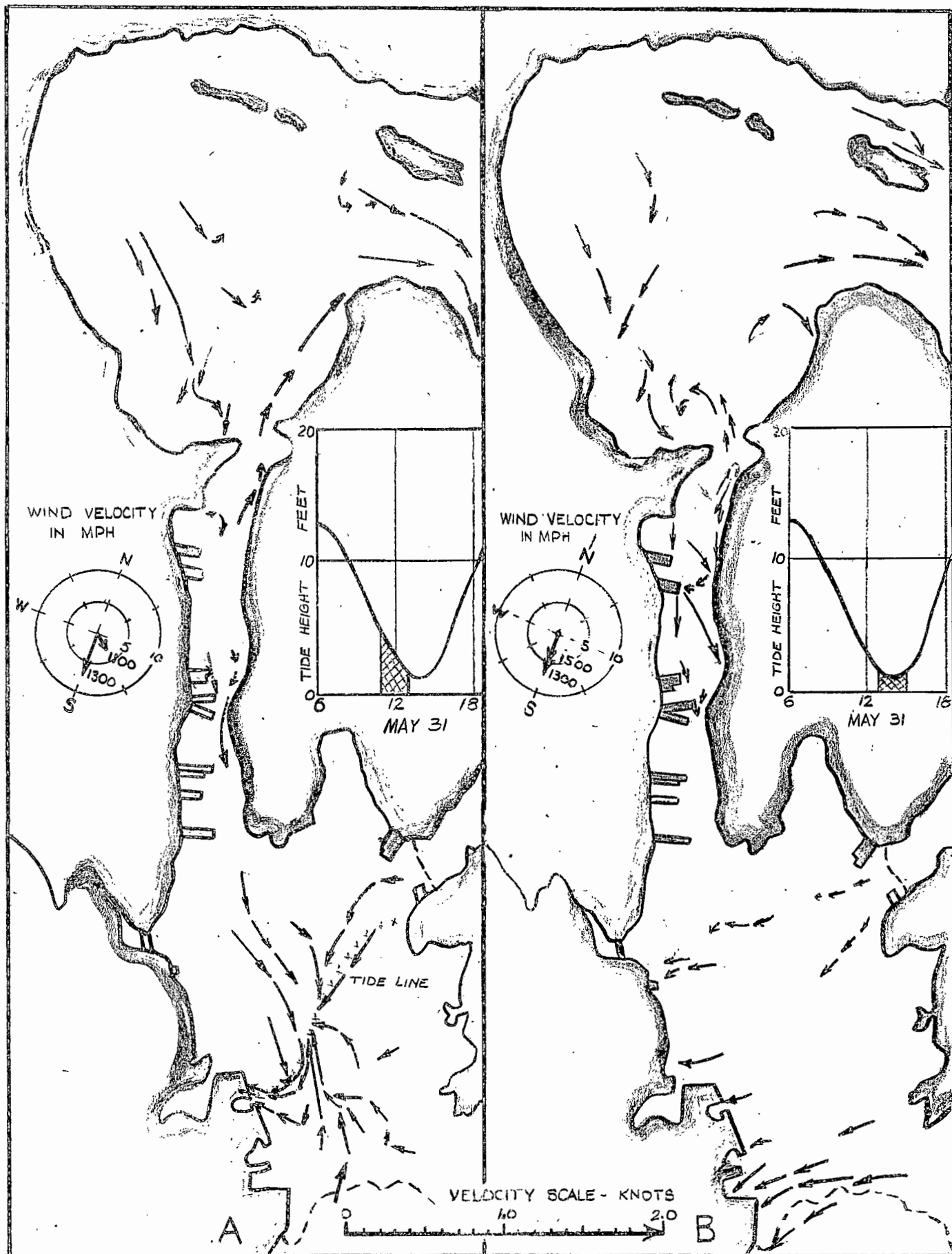


Figure 15. Surface current picture under variable wind conditions where the wind was shifting from northwest in A to north in B.

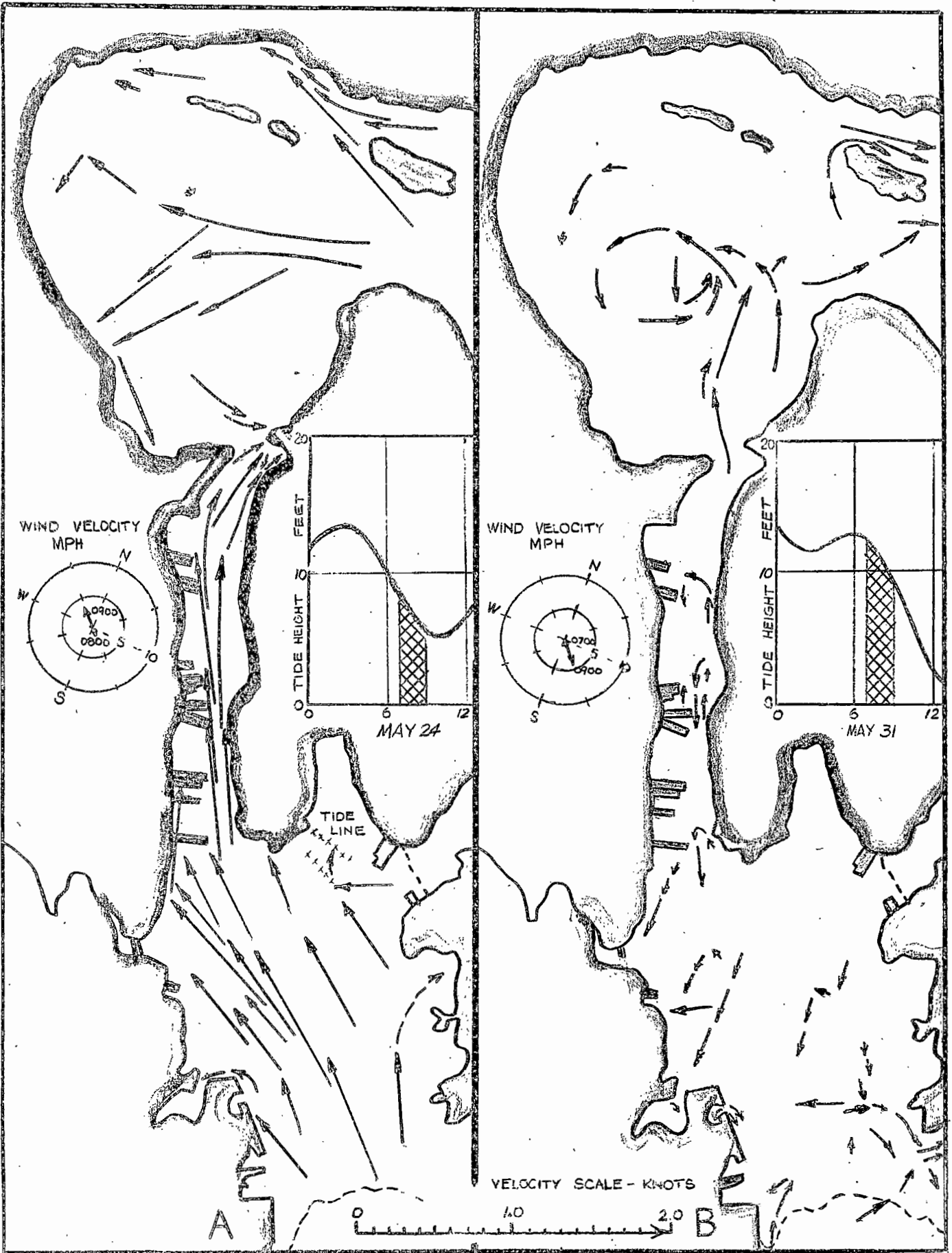


Figure 16. Variable and confused surface current pattern during calm to small local winds

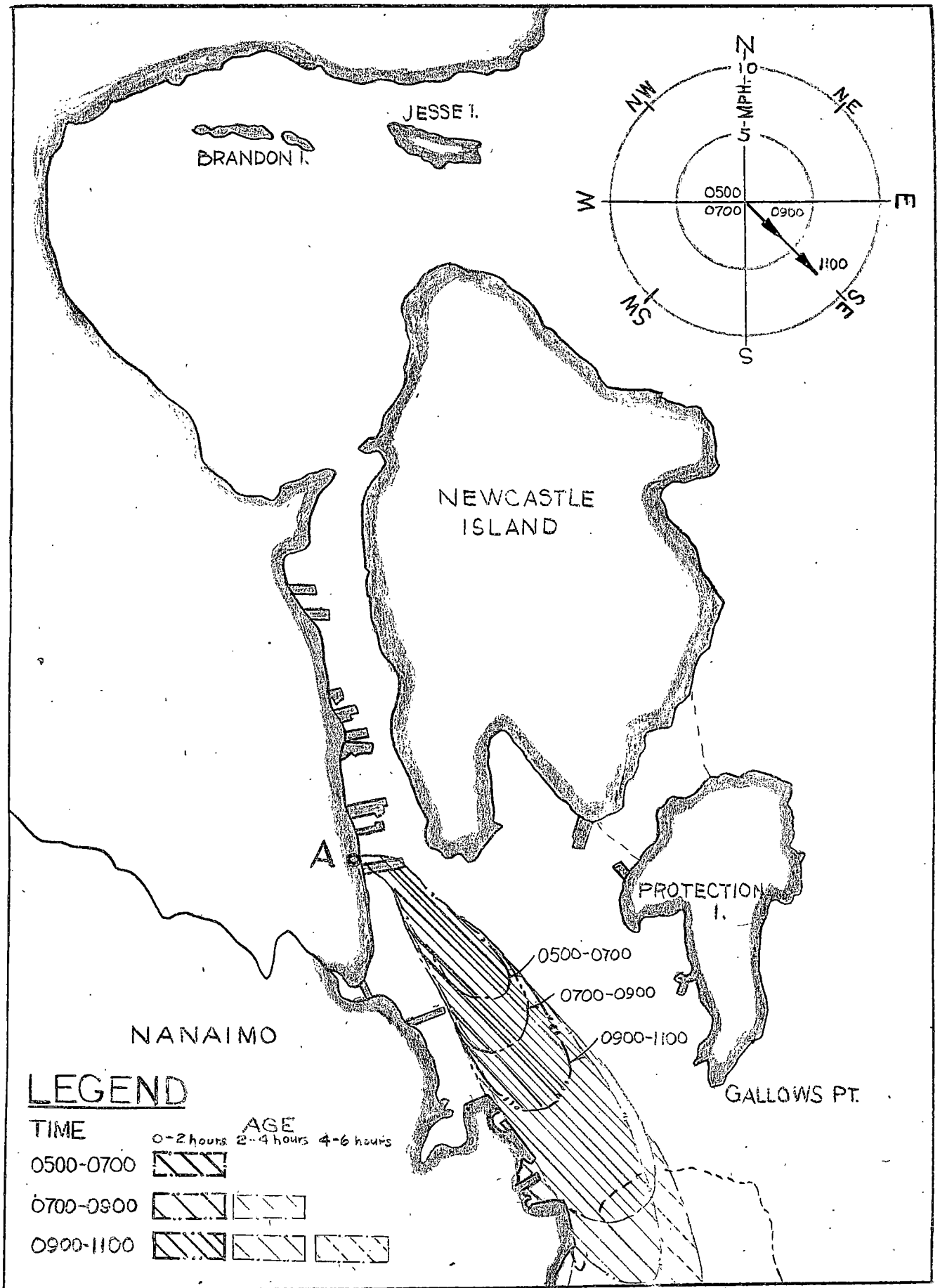


Figure 17. Dispersion from sewer outfall A under a northwest wind.

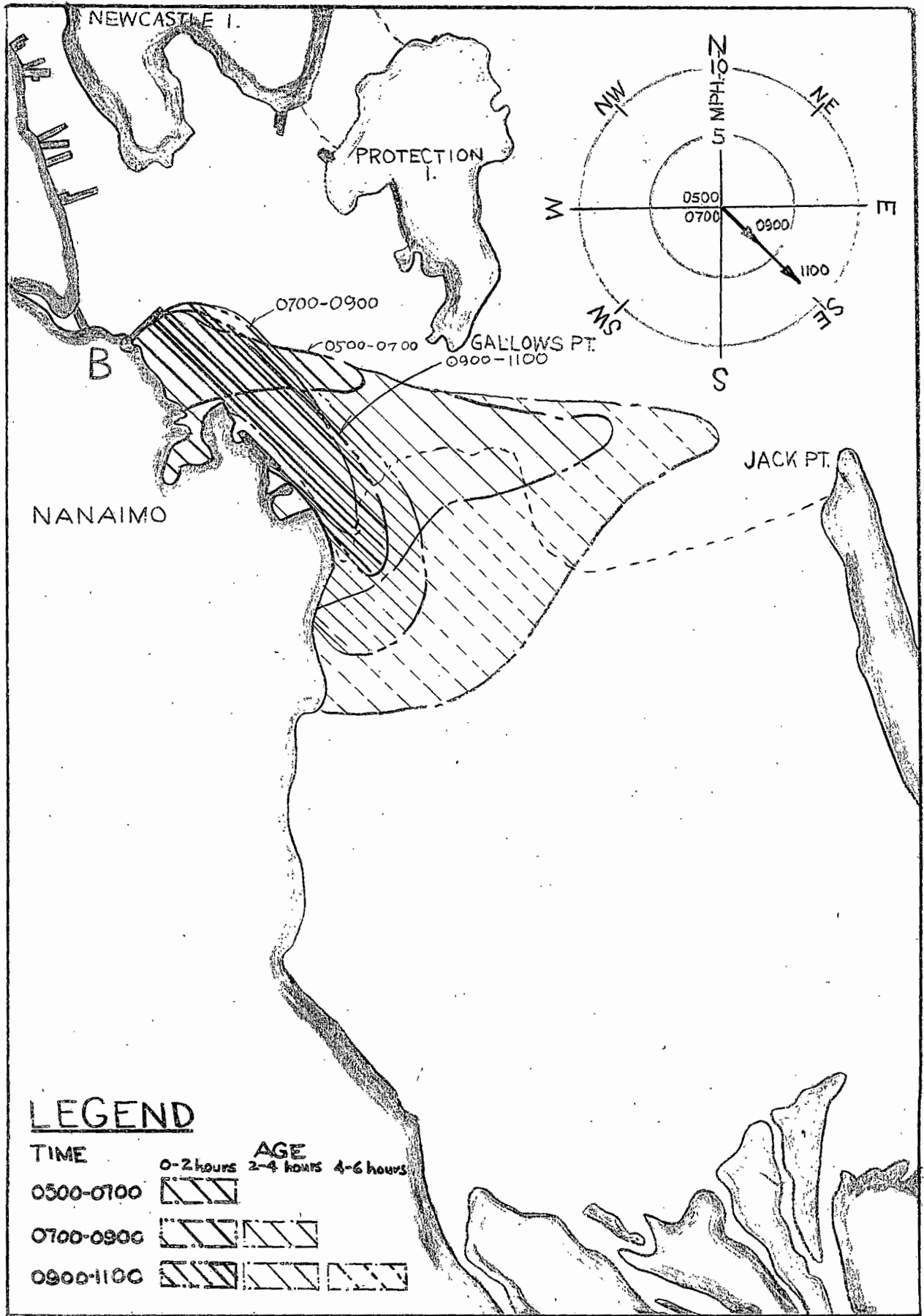


Figure 18. Dispersion from sewer outfall B under a northwest wind.

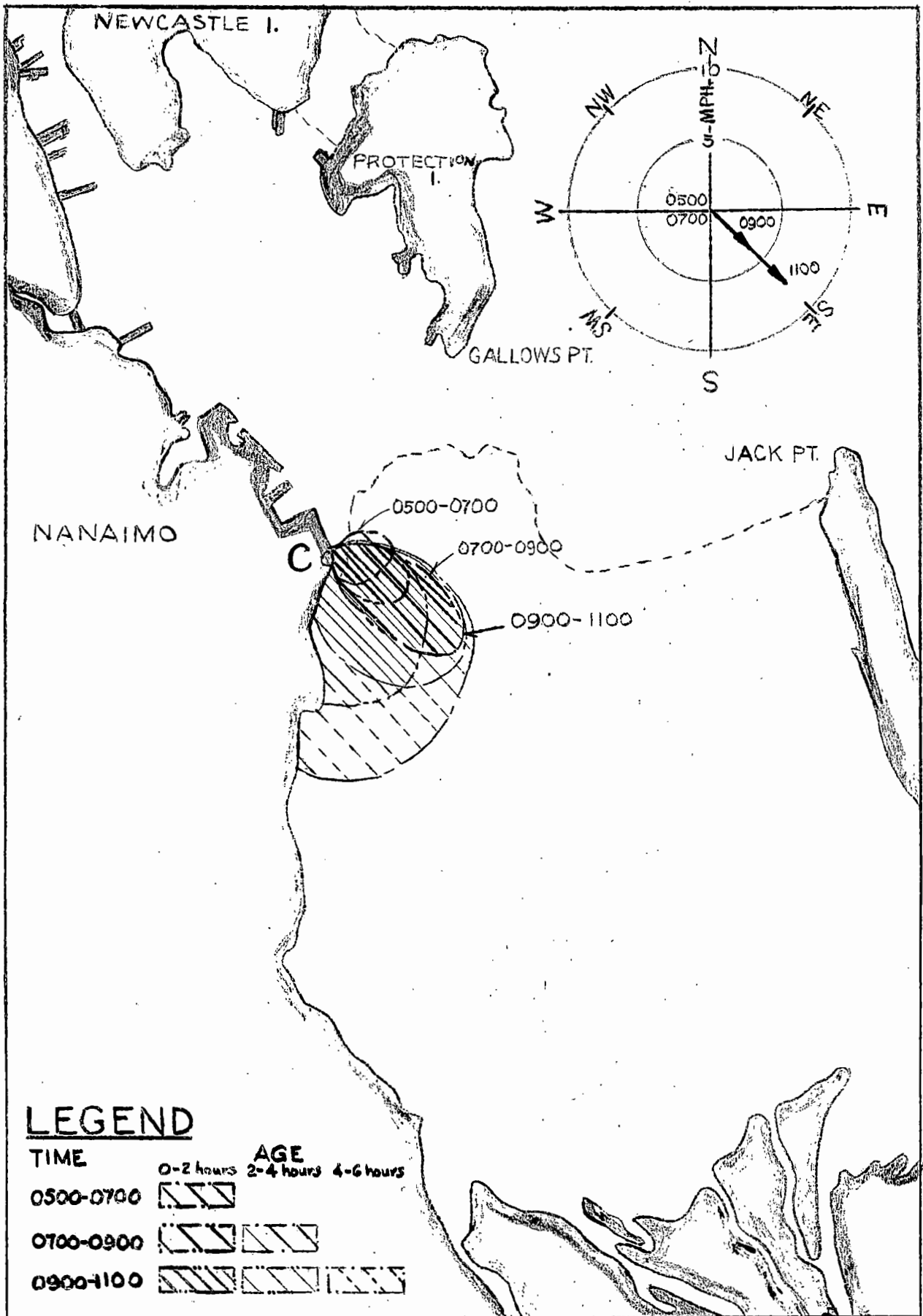


Figure 19. Dispersion from sewer outfall C under a northwest wind.

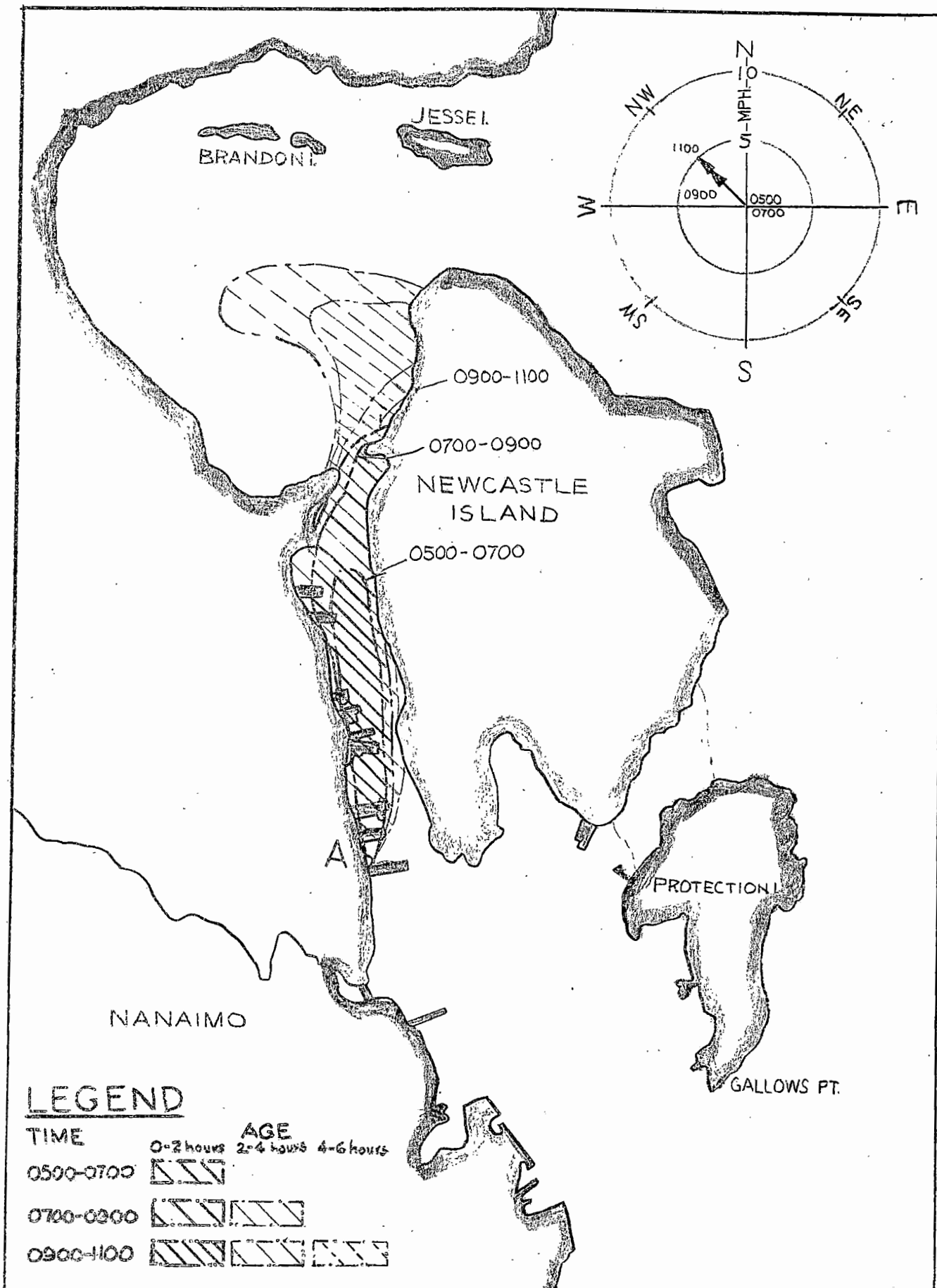


Figure 20. Dispersion from sewer outfall A under a southeast wind.

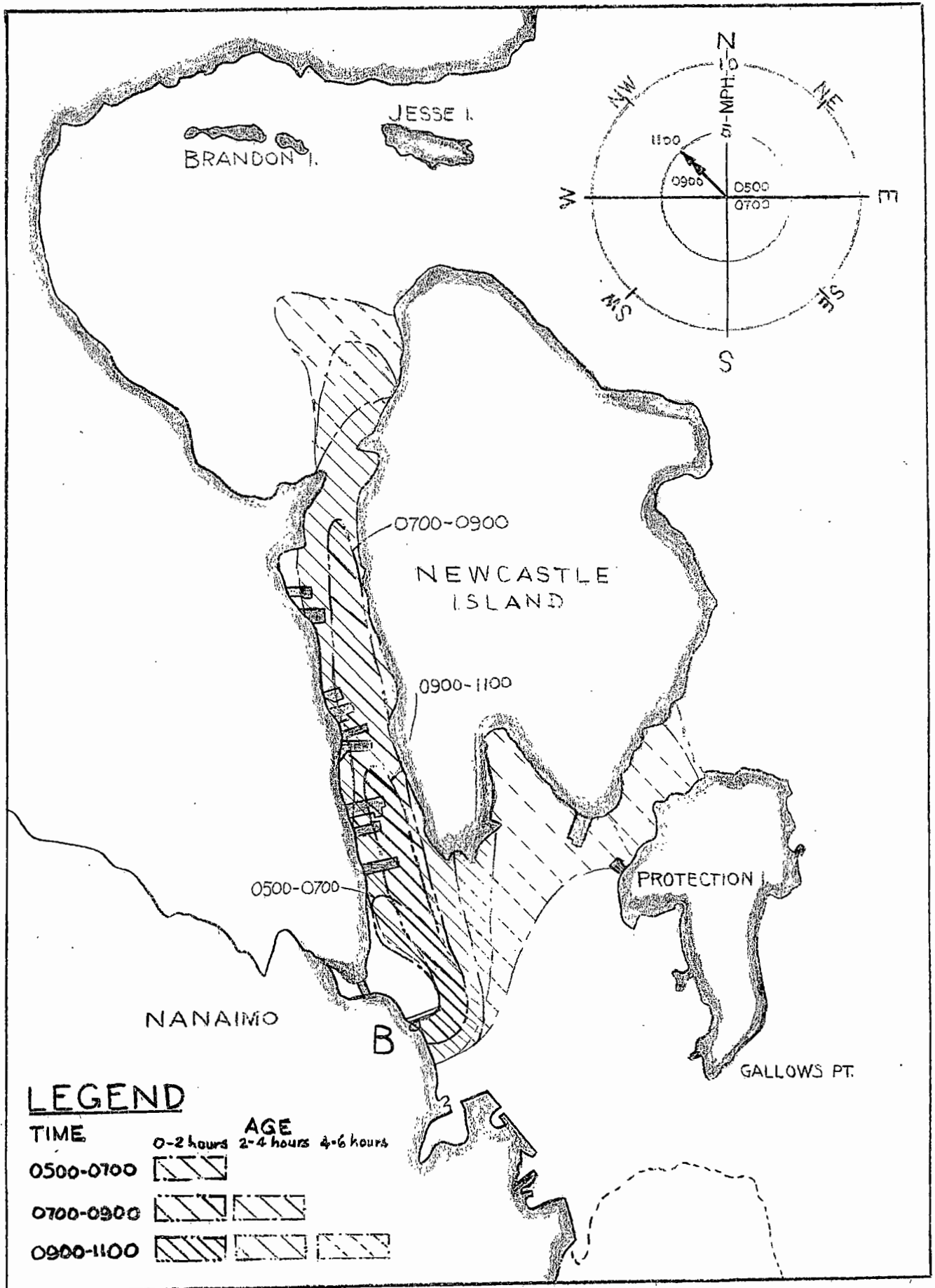


Figure 21. Dispersion from sewer outfall B under a southeast wind.

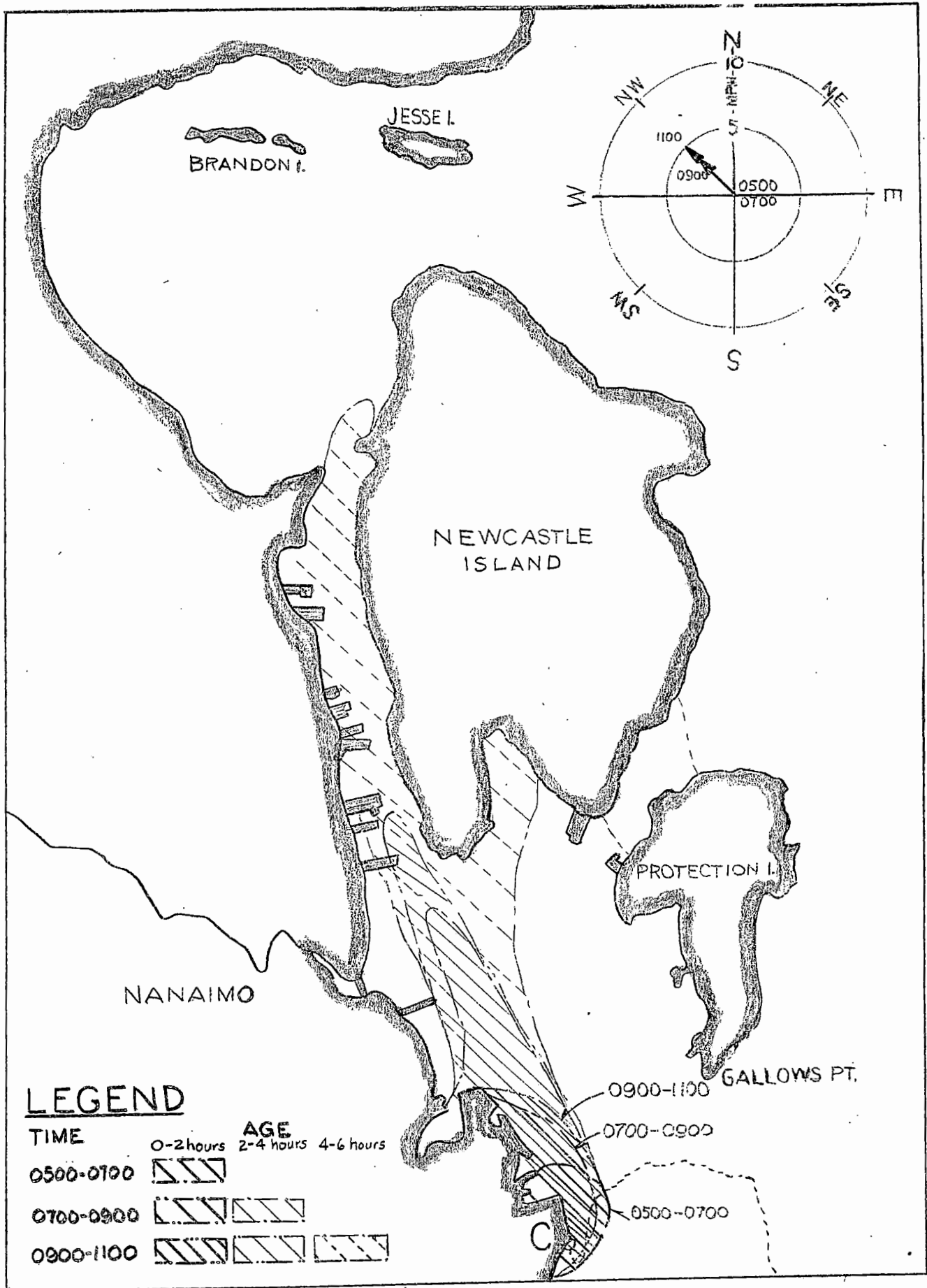


Figure 22. Dispersion from sewer outfall C under a southeast wind.

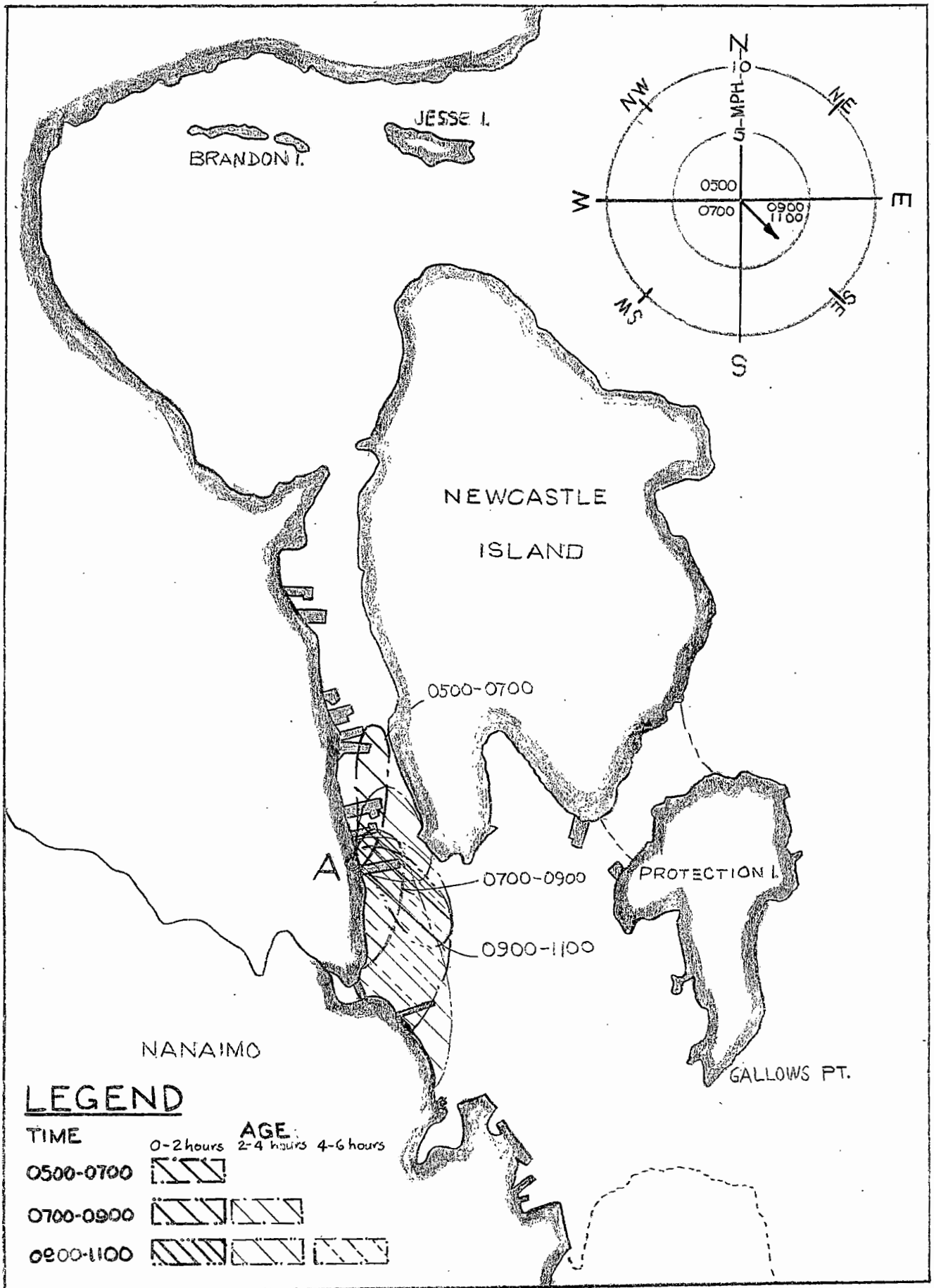


Figure 23. Dispersion from sewer outfall A under small variable winds.

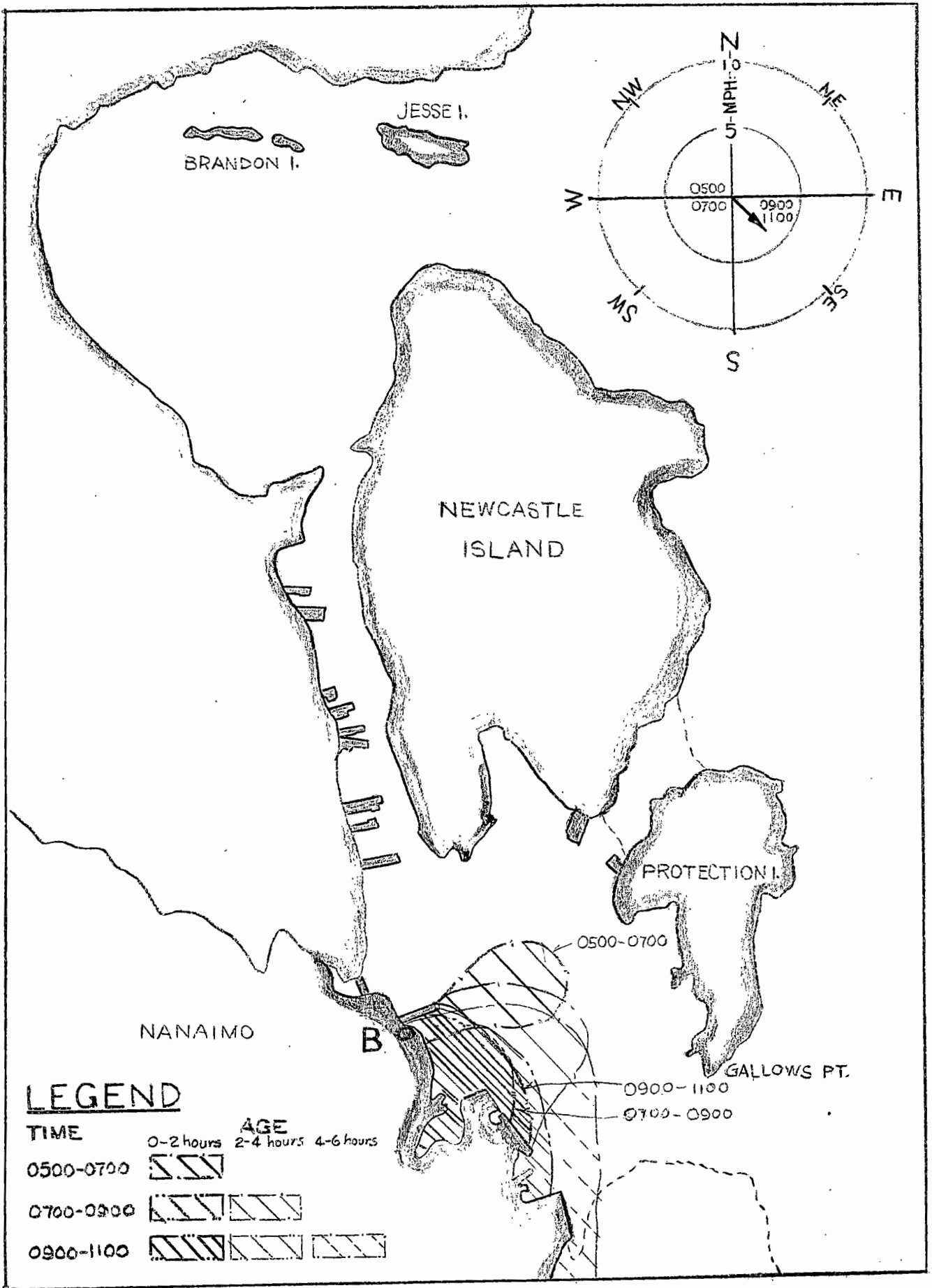


Figure 24. Dispersion from sewer outfall B under small variable winds.

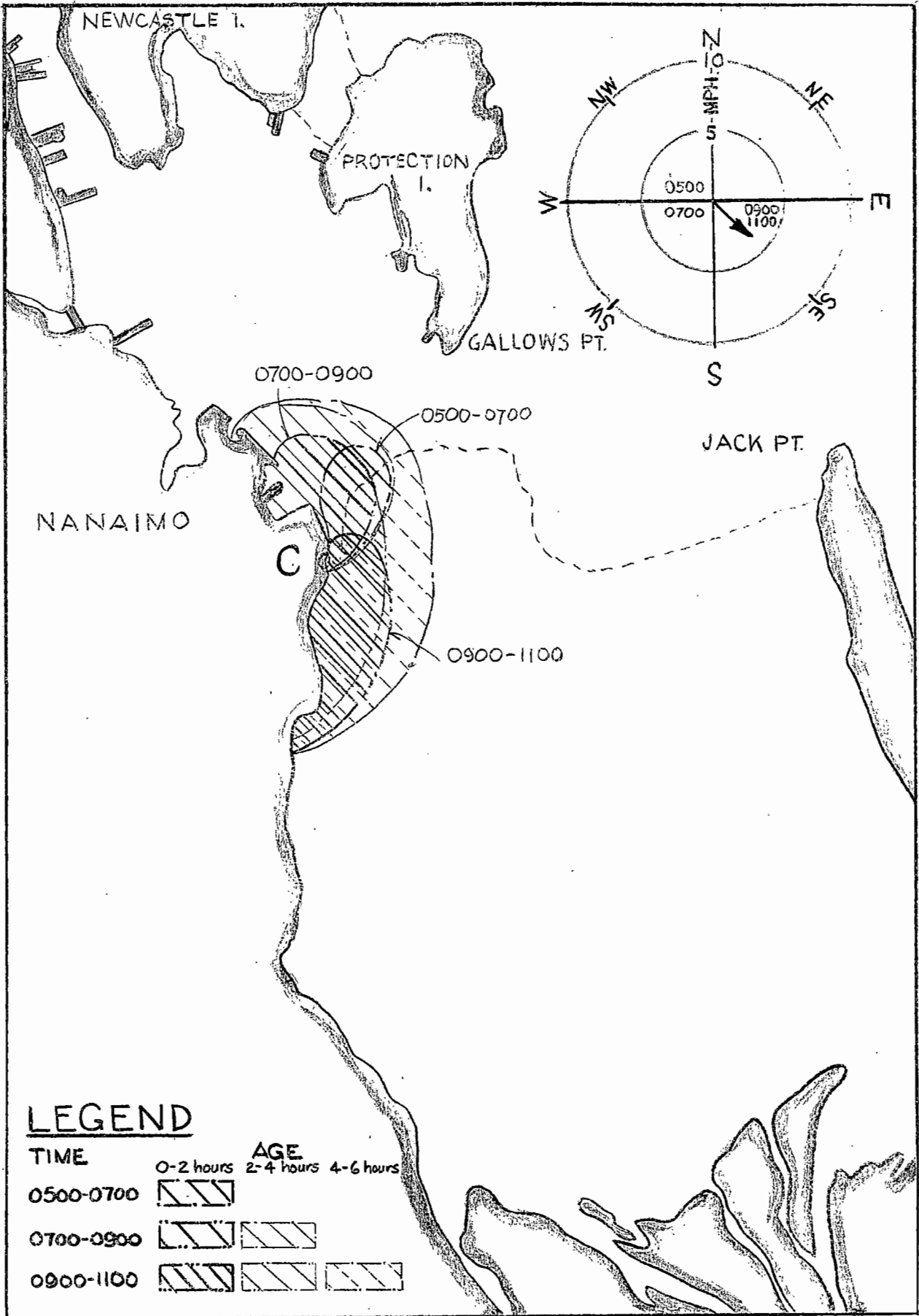


Figure 25. Dispersion from sewer outfall C under small variable winds.

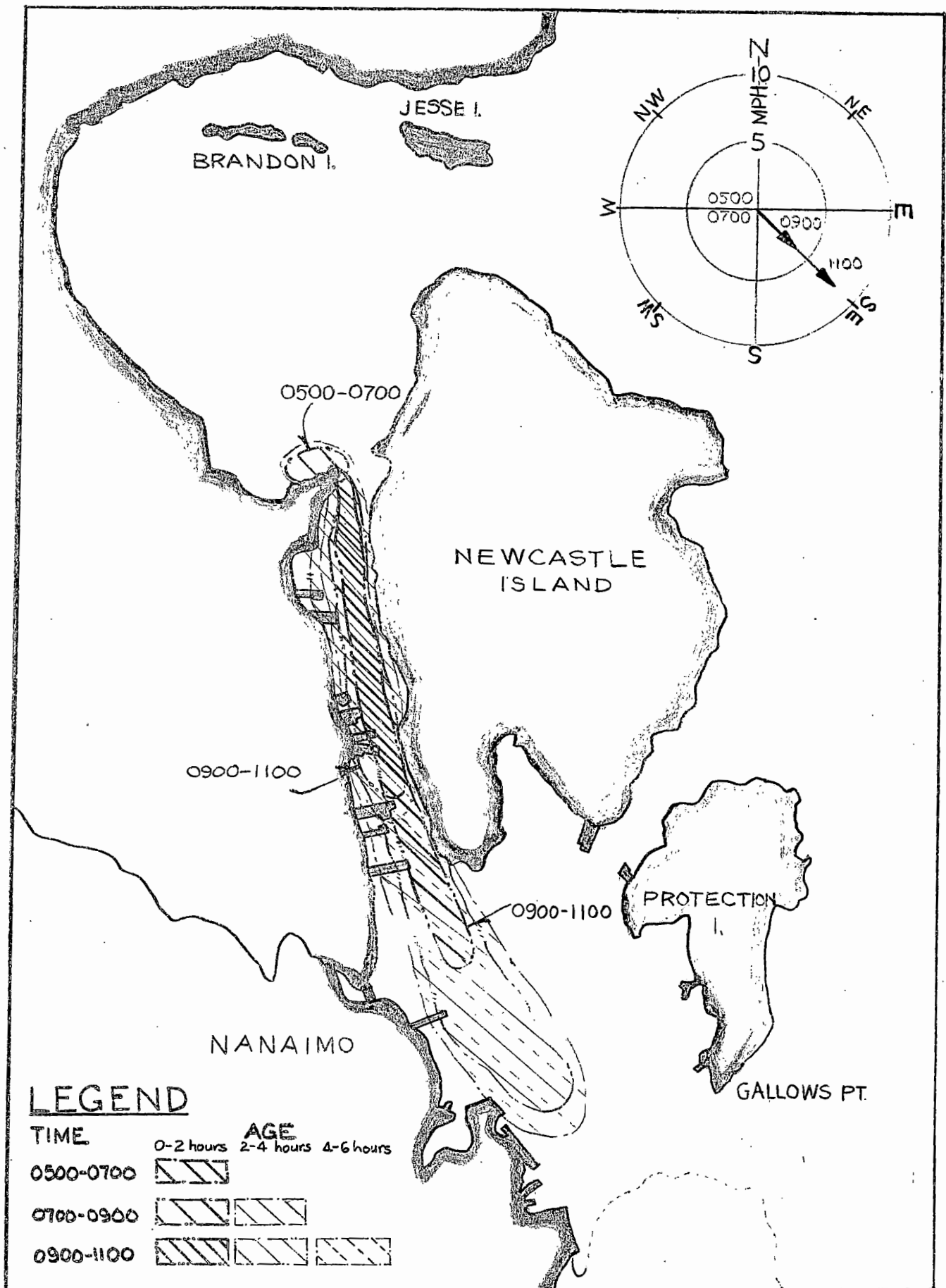


Figure 26. Predicted dispersion from proposed Brechin sewer outfall under northwest winds.

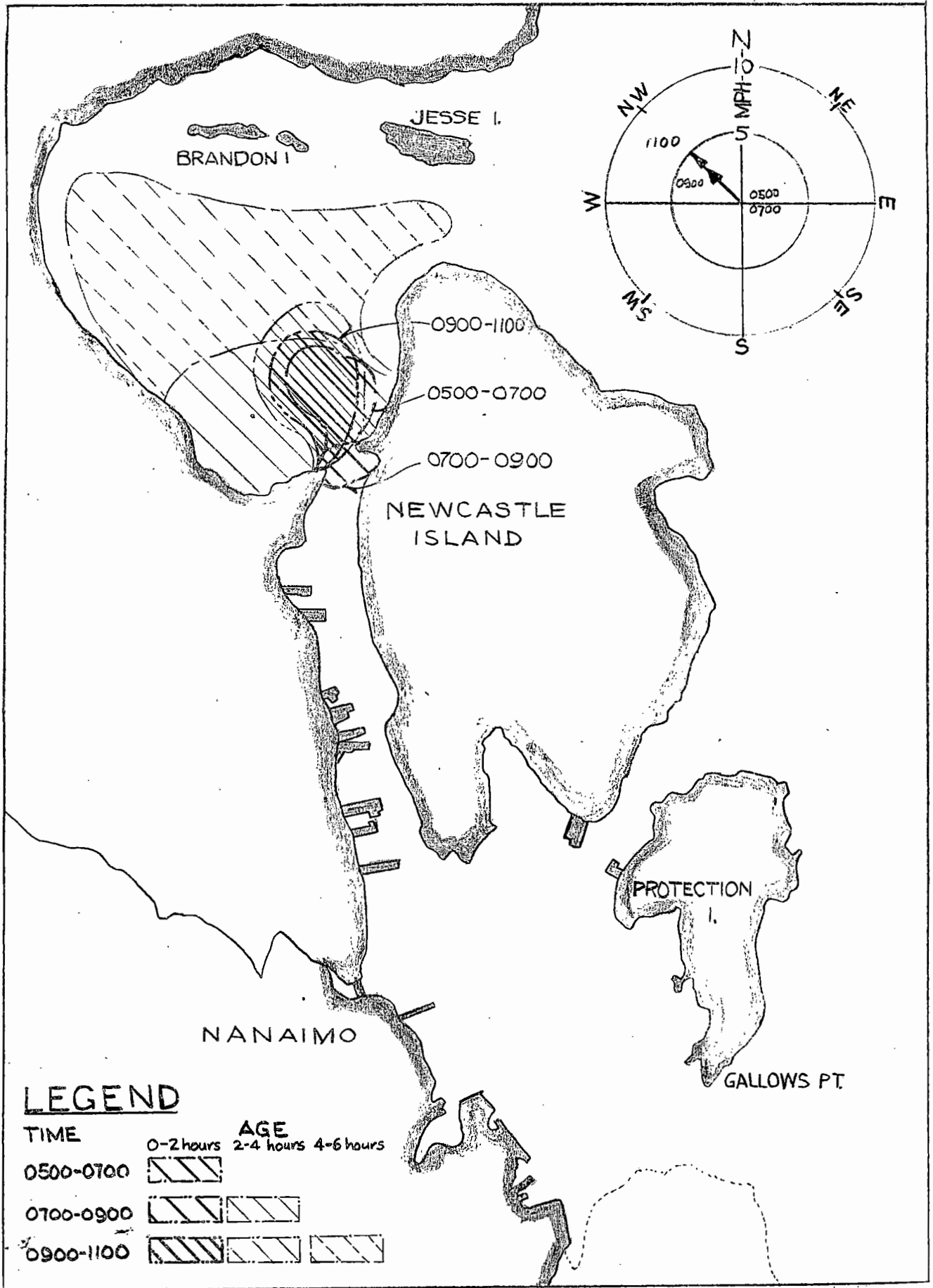


Figure 27. Predicted dispersion from proposed Brechin sewer outfall under southeast winds.

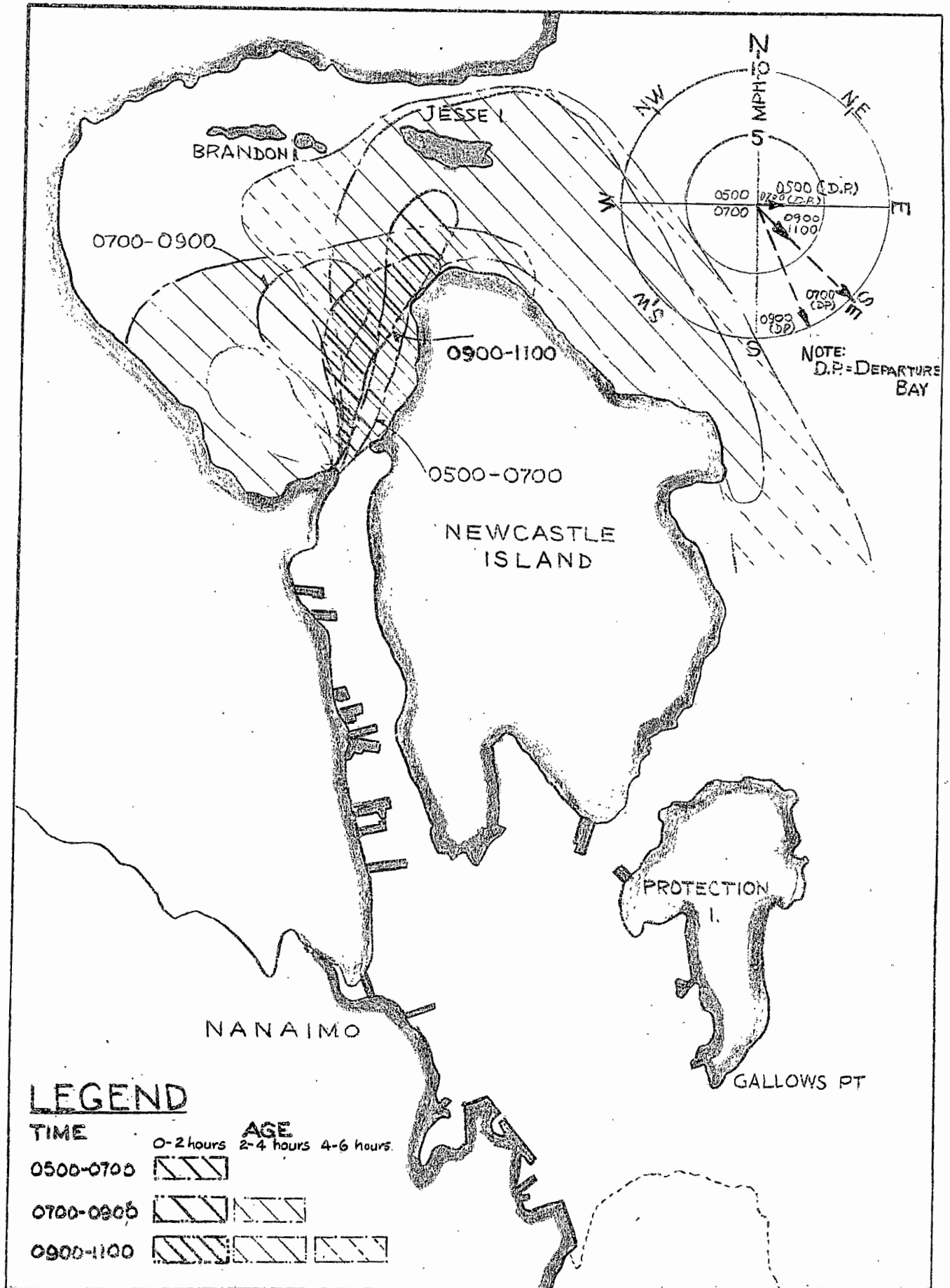


Figure 28. Predicted dispersion from proposed Brechin sewer outfall under small variable winds.