OCEANOGRAPHIC CHARACTERISTICS OF COMOX HARBOUR AND APPROACHES IN RELATION TO SEA DISPOSAL OF SEWAGE

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Table of Contents

Page

1. Introduction 1

2. Oceanographic Survey Data and other Information 2

3. Geography 3

4. Flushing Forces 4

   (a) Tides 5

   (b) Runoff 5

   (c) Winds 7

5. Surface Circulation in Comox Harbour 8

6. Surface Circulation at the Approaches to Comox Harbour 9

   (a) Flood 10

   (b) Ebb 10

7. Subsurface Circulation 11

8. Currents Measured at Anchor Stations 11

9. Vertical Distribution of Properties 13

10. Characteristics of Domestic Sewage and its Behaviour in the Sea 15

11. Bacteriological Effects of Sewage Disposal in the Sea 16

    (a) Bacteriological Examination (The Coliform Test) 16

    (b) Results of Bacteriological Surveys in Comox Harbour 17

    (c) Discussion of Significance of Marine Bacteriological Data 19

12. Effects of Sewage on the Fishery 21

13. Selection of Outfall Site 23

14. Checks on the Safety of the Proposed Outfall 25

15. Some Problems in Submarine Disposal of Sewage 31

16. Summary and Conclusions 33

1. Introduction

Comox Harbour is located about halfway up the east coast of Vancouver Island on the northwest side of the Strait of Georgia. It is in the vicinity of the largest population centres, Courtenay and Comox, on the northern half of Vancouver Island. Courtenay is located a few miles inland on the Courtenay River, while the Village of Comox borders directly on the sea.

Comox was the site of considerable naval activity during World War II, and even now, the Royal Canadian Navy maintains a base on Goose Spit for cadet training and other purposes. A naval rifle range is located on the spit. An R.C.A.F. station, established a short distance from the Village of Comox, forms part of the West Coast defence system. The Federal Department of Transport also maintains a weather station there under its Meteorological Service in conjunction with the R.C.A.F. and the municipal airport.

Deep-sea docking facilities are available in Comox Harbour for merchant shipping that serves the rich agricultural area of Comox Valley and some of the logging industry of upper Vancouver Island. While it is not fully protected from winds, Comox Harbour does offer shelter against choppy seas behind a breakwater for fishing boats and other small craft.

A popular sport fishery for salmon and trout exists in Comox Harbour and contiguous waters. Substantial runs of spring and coho salmon and sea-run trout have been supported by the Courtenay River and Puntledge River system. Shellfish culture is practised on several leases in Comox Harbour and more extensively on shores nearby in Baynes Sound.

There are no significant industrial "establishments" in the area bordering on Comox Harbour. However, the growing population has necessitated revisions and improvements in the sewerage systems serving the communities.

By 1961, the new sewerage system for Courtenay was already being built, with a lagoon for settlement of solids and provision for discharge of effluent into the Courtenay River. The nearness of the sea has given promise for marine disposal to be relatively inexpensive and a practical solution to the sewage disposal problem in Comox. Planning a sewerage system in this village had been underway for some years during the latter half of the 1950-60 decade. The present study was undertaken to evaluate the circulation in Comox Harbour and adjoining waters with the purpose of determining a suitable marine site for an outfall from the Comox sewerage system*.

2. Oceanographic survey data and other information

An oceanographic survey specifically for the purpose of determining a suitable site for a sewer outfall in the Comox area was carried out during the week, 27 January to 1 February, 1958. This was a cooperative effort including, besides the Fisheries Research Board of Canada, the Provincial Department of Health and Associated Engineering Services Ltd. of Vancouver.

Water samples were taken at a number of depths on selected stations for chemical and bacteriological (<u>B</u>. <u>coli</u>) analysis. In addition, float observations were made using three vessels simultaneously. Surface floats consisted of pieces of wood 2" x 2" in cross-section, 18" long, and weighted at one end to float upright with about 2" exposed above the water. Drags for subsurface currents consisted of crosses made from 12" square plywood panels nailed to a 2" x 2"

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*The sewer by-law for the Village of Comox was passed by the rate-payers of the community in a plebescite held during September, 1961. The sewerage contract was awarded later in the year. The final selection of a sea outfall for the sewerage system was based largely on the studies incorporated herein.

centre piece. They were weighted to sink and suspended at 15 and 30-ft depths from 1-gallon can buoys, appropriately marked with penants. Current measurements were obtained with a C.B.I. (Chesapeake Bay Institute) drag at surface and with an Ekman current meter at a number of depths from an anchored ship on a station outside of Goose Spit and at one within Comox Harbour.

A subsequent survey of somewhat narrower scope was conducted in Comox Harbour and Baynes Sound during the week 23-27 May, 1961. Oceanographic data from this and the previous survey will be released in another report.

An earlier oceanographic survey during the autumn and winter of 1950-51 was carried out by the Pacific Oceanographic Group for the purpose of establishing relationships between the oceanographic conditions and the bottom fisheries in Baynes Sound. Data from this survey were reported in a manuscript report by Waldie (1951).

Float surveys and water sampling for bacteriological analysis have been carried out in the past by the Provincial Department of Health. These were conducted concurrently during 26 March and 3 September, 1943. Sampling for B. coli counts took place again on 12 April, 1949, and during June, 1957 in addition to the comprehensive coverage on 28 January, 1958.

Meteorological data have been drawn from published records of the Meteorological Division of the Department of Transport (Boughner and Thomas, 1948) and from unpublished records of the Meteorological Station at Comox Airport.

3. Geography

The area surveyed is at a latitude of 49°40' north bordering on the northwest shore of the "inside waters" of the Strait of Georgia. Comox Harbour can be classed as a semi-enclosed embayment (Fig. 1). It is essentially a northerly extension of Baynes Sound. Connected to the Strait of Georgia across

Comox Bar to the east and through Baynes Sound to the south, Comox Harbour is influenced in its circulation by currents in both the Strait of Georgia and Baynes Sound. Over the course of geological time, the action of currents in scouring and transporting sand has built up a projecting narrow neck of land, Goose Spit, extending in a southwestward direction. The Courtenay River, receiving runoff from the Puntledge and Tsolum Rivers, discharges into Comox Harbour from the northwest. In the channel connecting Comox Harbour with Baynes Sound, which will be referred to hereafter as Comox Channel, the Trent River contributes freshwater runoff entering the harbour from the west. Gartley Point at the mouth of this river is a low swampy projection of land opposite Goose Spit. Besides fresh water, these streams contribute a considerable amount of silt which deposits in the harbour to form extensive tide flats. The runoff is important from the point of view of flushing out the sewage discharged into the waters, and this will be dealt with more fully in a later section.

Comox Harbour is protected from heavy seas in the Strait of Georgia by Cape Lazo and Goose Spit. A salient headland with a flat summit, Cape Lazo is faced with cliffs of yellow clay on its seaward side. Being a rather low neck of land with no large forest cover, Goose Spit affords only incidental protection against winds from the south. Consequently, a fairly choppy condition may result during winter storms associated with strong southeasterly winds, as those fishing from small boats can attest.

4. Flushing forces

In an area such as Comox Harbour, there are essentially three forces in action which assist in flushing out any wastes -- tides, runoff and winds. These systems may work individually or in concert to provide flushing action in any marine area. In certain regions, one particular force may predominate while the others merely modify its effect. Usually in an area such as Comox Harbour, which is partially enclosed, the three forces mentioned above combine to give some net effect toward mixing and dispersion of sewage. Very seldom is any one of them very dominant to produce a particularly strong flushing effect. In areas like Osborn Bay (Crofton Harbour), Chemainus Harbour and Nanaimo Harbour, it is difficult to predict any type of consistent circulation, since it can vary from day to day depending on the interplay of winds, runoff and tides. A principal effect in Nanaimo Harbour appears to stem from the winds (Waldichuk and Tully, 1953). In Comox Harbour, there is a strong influence from all three forces, but the dominant one is probably due to the tide.

(a) Tides. Characteristic of all Pacific coast areas of North America, the tides in Baynes Sound are of the mixed type. This means that in one tidal day of 24 hours and 50 minutes, there are two tidal cycles, one with a large rise and fall and one with a smaller intertidal range. During every tidal cycle, a certain quantity of sea water, the intertidal volume, moves into and out of Comox Harbour. In an area where the water is completely mixed vertically, this intertidal volume is available for mixing with and diluting any wastes that might be present. However, such is not entirely the case in Comox Harbour, where vertical mixing is limited because the waters are highly stratified with light, freshwater at the surface and denser sea water below. The main effect of tides here, generally speaking, is to bring in seawater at depth on the flood and remove it on the ebb, raising and lowering the surface layer of brackish water in the process. Notwithstanding the lack of complete vertical mixing, there are strong tidal currents at the surface as well as in the deeper layer which have an important function insofar as pollution prevention is concerned. Wastes mixed with and diluted by seawater through tidal turbulence become rapidly dispersed and carried away by tidal currents. This effect is quite apparent at the approaches to Comox Harbour.

(b) Runoff. Receiving more fresh water from runoff and precipitation than it loses by evaporation, Comox Harbour is what is known as a positive estuary. There is always a flow of water out of the harbour into the sea. The Puntledge and Tsolum Rivers combine a few miles north of Comox Harbour to yield a substantial discharge in the Courtenay River. A smaller freshwater input is contributed by the Trent River. These rivers have a seasonal variation in discharge characteristic of coastal streams which fluctuate according to the local precipitation. Peak discharge occurs in winter, when rainfall is at a maximum, the ground is saturated, and there is a direct runoff from the coastal belt. The low in discharge takes place during the dry season of late summer (Fig. 2).

The effects of runoff vary seasonally. The Courtenay River is most effective as a flushing agent during the winter months. This, of course, is the season when there is least concern about pollution, because temperatures are low, wind mixing is prevalent, and flushing by local precipitation and runoff is quite marked. However, even the comparatively small river flow of late summer can contribute significantly toward removal of sewage.

The mechanism of movement of fresh water in the sea is as follows: Fresh water, being lighter than sea water, flows seaward at the sea surface. It picks up sea water from below by mixing and entrainment as it flows toward the open sea. Thus, the volume of sea water plus fresh water that ultimately reaches the open ocean is considerably larger than that of the fresh water originally entering the sea. In addition to providing a diluting medium, this freshwater-seawater mixture can be used as a vehicle for transporting away sewage and other wastes. To compensate for the sea water removed by the fresh water through entrainment, there is a counter-flow of deeper sea water into the harbour. This must occur if a salt balance is to be maintained and Comox Harbour is not to become progressively fresher. It is sometimes possible to measure with a current meter the inward flow at depth which may be in a direction opposite to that at the surface. The current crosses which were suspended at 15 and 30 ft depths in our survey in Comox Harbour drifted on some occasions in directions quite different from the drift of surface floats.

The subsurface inflow at the approaches to Comox Harbour was demonstrated by Dr. L. S. Anderson, when he suspended a sack of fluorescein dye at about 30 ft depth on the original site of the proposed outfall seaward of Goose Spit. By moving the sack up and down, he was able to inject dye into the near-bottom water. After some time (approximately 12 hours), the dye appeared rather dramatically along the waterfront in Comox Harbour.

The importance of subsurface inflow becomes apparent when we consider submarine discharge of sewage. It is important that sewage, or any other waste for that matter, is not allowed to pollute the deep layer of water and/or be transported onshore by bottom currents. This deep water would gradually accumulate wastes and transport them into the harbour to become a possible threat at a later time.

(c) Winds. Winds can be an important factor in diluting and dispersing sewage by mixing it with sea water and moving it seaward by direct transport at the surface. Shaw (1957) in his evaluation of factors affecting effluent disposal by submarine pipeline pointed out that winds play a prominent role in mixing effluent at an outfall. A critical wind speed for certain air-sea boundary processes has been shown to exist both in practice and in theory (Munk, 1947). These processes vary gradually with wind speed until it reaches about 15 miles per hour. Then there is an abrupt change with such manifestations as white cap formation and increased mixing. The presence of a critical or threshold wind speed, insofar as efficiency of waste dilution is concerned, was confirmed in studies of winds and their effects at the outfall from the nuclear reactor establishment at Windscale (Shaw, 1957). Mixing is considered very good at wind speeds greater than 15 mph and very poor at wind speeds less than 5 mph. It is one good reason why ends of outfalls should not be placed in sheltered waters.

Prevailing winds in the Comox area during summer are northwesterly, assisting mixing and movement of the surface water into Baynes Sound. In winter, southeasterly winds are dominant transporting surface water into Comox Harbour. The average frequency of winds during different seasons of the year at Comox Airport is shown in Figure 3(a).

The strongest wind effects occur from the southeast, because of the long, unobstructed stretch of the Strait of Georgia over which the wind can develop before it reaches Comox Harbour. Goose Spit affords little protection from southeast winds because of the lowness of the land and lack of heavy forest cover. Thus it can be expected that there will be considerable wind influence from southeast winds in mixing the deeper saline waters into the brackish surface layer and generally retarding the seaward flow of surface water contributed by runoff during the winter months. Northwest and west winds are not too well developed when they blow over Comox Harbour, because of the damping effect of the land topography. However, their influence in sewage dilution and dispersion is generally more favourable than that of southeast winds, inasmuch as they blow offshore and tend to move the sewage seaward. Thereby they augment the effect of runoff and ebb tidal currents. The seasonal variation of wind speed and frequency from northwest and southeast, averaged over a 4-year period at Comox Airport, is shown in Figure 3(b).

The proposed outfall location in the exposed area south of Goose Spit can take advantage of the comparatively strong winds available in that area for mixing purposes.

5. Surface Circulation in Comox Harbour

Currents within Comox Harbour are relatively sluggish. Generalized pictures of circulation in the harbour on flood and ebb tides are shown in Figures 4 and 5. There is a general net movement seaward in the surface water as a result of the discharge from the Courtenay River. Goose Spit inhibits the direct movement of water seaward and creates a slow-moving counter-clockwise eddy on the ebb tide in the eastern part of Comox Harbour. This slow eddy has probably caused the deposition of a relatively thick bed of silt in the inner part of the harbour marked by extensive tide flats.

Surface currents in the eastern sector seldom exceed 0.1 k, except perhaps under strong southeasterly winds, when surface water would be transported at speeds of 0.5 k or more toward the north and west. Movement of fresh water from the Courtenay River through Comox Harbour into Baynes Sound is generally on a fairly direct course through Comox Channel, except for that part of the flow which becomes caught behind Goose Spit to form a back eddy. Because there is a longshore current setting westward on the south side of Goose Spit during the flood tide, it can be expected that materials, such as flotsam in this area, can also be transported into Comox Harbour to become partially circulated in the harbour eddy.

During small flood tides in winter, the seaward movement of surface water appears to be considerably stronger than the inward-flowing current accompanying a small tidal rise. Consequently, during some of our observations in January 1958, floats drifted away from Comox Harbour in spite of a rising tide and relatively calm atmospheric conditions. During one particular day, even the current crosses suspended at 15 and 30 ft depth drifted seaward on a flooding tide. On the following day, however, the currents at 15 and 30 ft were evidently setting into the harbour, particularly along Goose Spit, while the surface current was setting seaward, judging by the opposing movement of the surface and subsurface floats.

6. Surface Circulation at the Approaches to Comox Harbour

While runoff is quite important to the flushing processes in Comox Harbour, probably the most important factor in transport of materials into and out of the harbour is the tide and its associated tidal currents. There is, on the average, a tidal range of 8 to 10 ft between lower low and higher high waters in Comox Harbour, as in other areas along the Strait of Georgia. Currents on the flood flow quite rapidly into Baynes Sound over the Comox Bar from the Strait of Georgia. This flow sweeps strongly as a longshore current along Goose Spit into Comox Harbour. The spit itself is the result of many thousands of years of strong currents scouring away sand from the sea bottom and the seashore along Cape Lazo and depositing it at the entrance to Comox Harbour. If this process were to continue for a few more thousand years without interference from man, the spit would probably extend toward the inner harbour, close off the eastern portion and transform it into a lagoon. Even now, there is a deeper basin in this eastern sector connected by a narrow channel through the tide flats to the main part of the harbour.

(a) <u>Flood</u>. From float observations in Comox Harbour and at its approaches during late January 1958 on different stages of the tide and from those made during July of that year and in September 1943, it has been possible to compile a general picture of circulation during flooding tides at the approaches to Comox Harbour (Fig. 4). In general, a strong flood tidal current moves westward from the Strait of Georgia into Comox Harbour.

While there is a strong set of current into the harbour along Goose Spit, there is perhaps a larger flow, if not as fast, which sets southwestward and then swings southeastward into Baynes Sound. This southward flow exists several hundred yards seaward of the harbour-bound flow. As it will be discussed later, herein lies the critical region of choice for an outfall location.

On a spring tide, currents flowing westward toward Comox Harbour on the south side of Goose Spit have speeds of 1.0 to 1.5 knots. Currents setting northward through Comox Channel have speeds ranging from less than 0.5 to 1.5 k.

(b) <u>Ebb</u>. On the ebb, the surface current flowing southward out of Comox Harbour is a little faster than that on the flood, being augmented by the seaward flow of runoff waters coming from the Courtenay River. Along the Vancouver Island shore, the ebb current generally sets southward; while further to the east, the ebb sets eastward toward the open Strait of Georgia across the Comox Bar (Fig. 5).

7. Subsurface Circulation

Currents at depths of 15 and 30 ft were observed using wooden crosses, adequately weighted and suspended from small can buoys at the surface. These drags were set free and their positions were plotted periodically during the 28 Jan - 1 Feb, 1958 survey.

There were insufficient data to provide reliable charts of water movements on both the ebb and flood stages of the tide. All observations have been collected and reproduced together in Figure 6. The picture represents essentially the subsurface circulation on the ebb stage of the tide. Sluggish and variable, the currents in Comox Harbour were quite unlike the stronger and more uniform currents in contiguous waters of Baynes Sound. The presence of a slow-moving eddy at a depth of 30 ft between Goose Spit and the Comox Village waterfront is suggested by some of the drags that drifted in a rough circle. Water leaving Comox Harbour appeared to be deflected from an east-southeasterly course to south-southwesterly at the Baynes Sound approach to the harbour.

Some of the subsurface currents in northern Baynes Sound approached a speed of 1 knot, but generally the currents ranged from 0.1 to 0.5 k. The set was predominantly southeastward into Baynes Sound. Some of the drags, however, drifted eastward toward the Comox Bar and Strait of Georgia.

8. Currents Measured at Anchor Stations

In order that the speed and direction of flow at a given point in the sea can be determined, currents are measured at various depths from an anchored ship. During the survey of 27 Jan to 1 Feb, 1958, current measurements were made at the surface with a drag and at a number of depths with an Ekman current meter.

The surface currents at anchor positions south of Goose Spit (Station A) and within Comox Harbour (Station B) are represented by vectors in Figure 6, giving current speed and direction at particular times of measurement. Tidal and wind variations during the periods of observations are given in the inset diagrams. The predominant flow eastward and southeastward at speeds of over 1.5 knots is in striking contrast to the relatively slow and infrequent currents setting into the N-W quadrant, on Station A. Currents at Station B were comparatively weak, with a large number of "zero current" observations. The tides exhibited a moderately large range between higher high and lower low waters. It is noteworthy that winds were generally weak during the first period of measurement (Station A) and predominantly southeast at 5 to 15 mph during the last period of measurement (Station B).

Currents measured at various depths with an Ekman current meter on anchor Station A are represented in Figure 8. In general, the subsurface currents were much smaller than the surface currents. The maximum speed was only about 0.5 knot, and the average current ranged from 0.1 to 0.3 k. There was a scatter of current direction at a depth of 15 ft, but the set was predominantly southward. At a depth of 30 ft, the current set mainly along the NE-SW line with the predominant flow southwestward. The same general picture prevailed at a depth of 60 ft, except that there was even a greater frequency of SW-setting current than at 30 ft. At a depth of 90 ft, currents set to westward more frequently than at 60 ft, and there were sometimes relatively strong currents setting southeastward.

The predominant set westward and southwestward of all subsurface currents, except those at 15 ft depth, is probably associated with the inflowing deep currents which compensate for removal of seawater by the seaward surface flow.

9. Vertical Distribution of Properties

The salt content of sea water is the chief property which distinguishes it from fresh water. A host of ancillary properties are associated with the salinity of sea water. A major effect of variation of salt content in sea water is manifested in density distribution. Pure water, being lighter than salt-containing water, will float on sea water. As fresh water from streams and local runoff discharges into the sea, it flows over the sea water. Even after mixing of sea water into the upper layer of fresh or brackish water, a density difference is maintained between the surface and deeper water for a considerable distance from shore.

Temperature has some influence on density of water, which increases as the temperature is lowered to the point of density maximum. Relative to the effects of salinity, however, temperature has only a minor influence on density. In the Strait of Georgia area generally, where runoff is so great, the effects of salinity are by far more significant than those of temperature in the density of the water. Essentially, the vertical density structure corresponds closely to the salinity structure.

The density variation from top to bottom in the sea has an important bearing on the amount of vertical mixing that can occur. A marked horizontal stratification in density requires strong turbulent mixing in order to stir deep water into surface water and vice versa. Fresh water literally puts a damper on vertical interchange of properties.

In waste disposal, the vertical density structure is an important factor influencing the rate of dilution and dispersion. Domestic sewage, which is mostly fresh water, will tend to flow over the surface of sea water and mix only with the upper layer of relatively fresh water, if it is released at the sea surface. On the other hand, sewage released in deep water may mix effectively only below the depth where there is an abrupt change in density (pycnocline).

The vertical distributions of physical and chemical properties at a station in Comox Harbour during late January are given in Figure 9. The effect of a large winter runoff into Comox Harbour from the Courtenay River is revealed in the low surface salinity. There was a rapid increase in salinity from nearly zero at the surface to about 27°/₀₀ at 10 ft. Below this layer of major freshwater influence, the change in salinity was rather small, increasing to about 29°/₀₀ at 90 ft.

At the time of year that the observations were made (late January), atmospheric cooling resulted in a relatively low temperature, 5°C (41°F), of the surface water. As with low salinity, the low-temperature water was confined to the upper 10 ft layer. Below that depth, the temperature remained fairly constant, around 7.5°C (45.5°F), all the way to the bottom.

The density lowering by fresh water was compensated only slightly by the lower temperatures in the surface layer. Density, as represented by the anomaly σ_t, was near the value for fresh water at the surface. At a depth of 6 ft, σ_t increased to 21 and below that there was only a small increase in density to the bottom with $\sigma_t = 22.5$ at 90 ft.

The non-conservative properties, i.e. those affected by biological processes, are shown in the right hand portion of Figure 9. Dissolved oxygen concentration was relatively high at all depths during these winter observations, varying from nearly 13 mg/l (milligrams per litre) at the surface to 8 mg/l at 90 ft. The highest oxygen concentrations were confined to the surface layer of maximum freshwater influence. Unlike oxygen distributions in water having a stagnant zone near the bottom, there was only a small drop from the average in dissolved oxygen concentration of the bottom layer, between depths of 60 and 90 ft. The profile of pH exhibited little variation from top to bottom. It was on the alkaline side at about 7.9, near the normal value for sea water, except at the surface, where a slight lowering of pH by the fresh water was evident.

The vertical distributions of properties in northern Baynes Sound, just outside Comox Harbour, are shown in Figure 10. They differ from the harbour distribution mainly in the upper 10-ft layer, where the effect of fresh water has diminished considerably. The deeper water exhibited a slightly higher salinity and consequently somewhat higher σ_t values than those in Comox Harbour.

10. Characteristics of Domestic Sewage and its Behaviour in the Sea

Sewage originating from private homes and from non-industrial sources in institutions is commonly referred to as domestic or sanitary sewage. It has two principal properties which characterize it as a pollutant. Firstly, and probably most important, it contains faecal bacteria of human intestinal origin. While these organisms are not necessarily dangerous in themselves, any pathogenic organisms that may have been excreted in the faecal matter could result in an epidemic if given the necessary transmittal. Hence, it is desirable to maintain the concentration of coliform bacteria, which are indicative of faecal contamination, as low as possible in waters with which humans may come into contact.

Secondly, sanitary sewage contains organic materials which, when present in large enough concentrations, will alter the aquatic environment in an unfavourable way. The organic material, dissolved and particulate, undergoes decomposition through the action of bacteria and other biological and chemical processes. These processes require oxygen and, therefore, the dissolved oxygen content of the water may become drastically reduced. Particulate materials, organic and inorganic, eventually settle to the bottom to form undesirable sludge beds in the waters where sewage is discharged. Although this sludge can be used as a source of food by certain bottom organisms, the original bottom fauna is usually eliminated or severely altered in species, composition and numbers. A progressive decomposition occurs in these sludges as more particulate material settles to the bottom, so that anaerobic conditions eventually arise. Not only does oxygen become non-existent in the sludge and in the water immediately above it, but toxic hydrogen sulphide becomes present in increasing abundance.

Sanitary sewage is made up, to a large extent, of fresh water. With the organic constituents that are present, sewage is of considerably lower density than average sea water. If discharged into the sea at the surface, sewage will tend to mix with water in the upper layer and flow seaward with any fresh or brackish water that might be present. It will undergo dilution by mixing with the surface water, which is of comparable density, as it flows to sea. If discharged into the sea by a submarine outfall, sewage will rise to the surface because of its buoyancy in sea water. Passed through a diffuser, the sewage will mix with sea water enroute experiencing considerable dilution before it reaches the surface. There are known circumstances under which sewage will actually entrain so much cold, saline sea water from near the bottom that it will reach the surface with a density somewhat higher than that of surface sea water. This sometimes happens when the effluent leaves a diffuser under great pressure as a result of gravitational drive from higher ground or by actual forced pumping. When this seawater-sewage mixture reaches the light surface water, it cannot remain floating there but sinks to a level where it meets water of a density comparable to its own. If this level happens to be at a depth where there is an inward flow, compensating for the seaward flow at the surface, then the sewage may be carried into the harbour at subsurface levels. The descent of an effluent-seawater mixture from the surface to a depth of equivalent density has been observed in some of our investigations of movement of effluent from a submarine outfall using a dye tracer.

11. Bacteriological Effects of Sewage Disposal in the Sea

(a) Bacteriological Examination (The Coliform Test). The important characteristics of sanitary sewage, from the health point of view, is the concentration of faecal bacteria. For analysis of the number of bacteria per unit volume of water in a given area, samples are taken and sent within 24 hours to the Division of Laboratories of the Department of Health. These samples are immediately made up in different dilutions with distilled water and cultured for an estimate of the bacterial density in each sample. Coliform bacteria, specifically denoted as _B_. _coli_* (_Bacterium_ _coli_), are regarded as a suitable index for contamination by sanitary sewage. These bacteria are normal inhabitants of the human intestinal tract and do not cause disease. Usually a series of 3 dilutions in geometric progression is made up with 5 portions in each dilution. Thus in the Division of Laboratories, the series of dilutions commonly used is 0.1, 1 and 10 ml made up to 100 ml in test tubes. Each one of the 5 portions in each dilution is examined, after a period of culture, to note whether the development of a bacterial population is positive or negative. From the number of positive developments in each dilution, the Most Probable Number (MPN) per 100 ml of water sample is taken from a standard table. The procedure is described in detail by experts in the volume "Standard Methods for the Examination of Water, Sewage and Industrial Wastes" (American Public Health Association, _et_ _al_., 1955).

(b) _Results of Bacteriological Surveys in Comox Harbour_. Bacteriological analyses of water samples taken in the Courtenay River estuary during late January 1958 gave high MPN values of _B_. _coli_ for all sampling areas, especially at the outlets of storm sewers (Fig.11). Many samples gave counts in excess of 2000 MPN per 100 ml of sample. The lowest count obtained in 8 samples taken at approximately equal intervals in a 3/4-mile stretch of the river east of the Courtenay bridge was 350 MPN/100 ml. Many of these high values were caused,

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*_B_. _coli_ index is regarded in most quarters as synonymous with _E_. _coli_ (_Escherichia_ _coli_), and reported data for both indices are comparable.

no doubt, by contamination from sewers and septic tanks discharging into the river upstream. A series of 8 samples taken at the outfall from the septic tank of the 100-home development and a few hundred feet downstream also exhibited MPN values from 500 to over 2000.

Counts were also relatively high in samples all along the waterfront of Comox Village with a number of samples at MPN's of 2000 or more in areas east and west of the Comox pier. Samples taken on the oyster leases yielded counts as high as 2000, but 3 out of 5 samples taken in that general area gave 920 and one nearest the Comox pier resulted in a count of 350. A surface water sample taken in mid-harbour gave a count of 1600 and even a surface sample, taken at the approaches to Comox Harbour, was at a fairly high MPN level of 220.

In June 1957, a sampling run similar to that of January 1958 had been made and counts were much lower. Only one sample gave an MPN value of over 250 and six samples were at zero. It is doubtful whether pollution had increased that much in the brief period of slightly more than 6 months. It was more likely that the active drainage resulting from the heavy runoff of mid-winter caused a greater input of sewage bacteria into the sea in January than in June.

High bacteria counts during the January 1958 survey occurred only in the surface water where the freshwater runoff is present in highest concentration. Water samples taken at 30 and 60 ft depth at five stations (C1 to C5 in Fig. 1) in the harbour and at the approaches failed to produce significant B. coli counts.

Samples taken in Comox Harbour at the height of military activity of World War II during March and September 1943, gave relatively low counts throughout the eastern half of the harbour. Only the area around the inner end of the Comox pier gave counts generally in excess of 100. A sample taken near the Elk Hotel in March 1943 yielded the highest value recorded for that sampling period, an MPN of 1600. Presumably the contamination was contributed by septic tank effluent.

(c) Discussion of Significance of Marine Bacteriological Data. In general, beaches are considered unsafe for bathing purposes when the B. coli count exceeds an MPN of 1000. According to standards of the U.S. Public Health Service, a class A beach or pool should have a count in the MPN range: 0 - 50; class B: 50 - 100; class C: 100 - 500; and class D: 500 - 1000. It is obvious that most of the waters in Comox Harbour would be unsafe for swimming under the bacterial contamination observed in January 1958.

A concentration of coliform organisms at median MPN greater than 70 per 100 ml is regarded by health authorities as sufficient for closure of oyster leases. It should be pointed out here, however, that oysters cultured by a commercial firm in Comox Harbour are transferred for fattening to the Henry Bay area on Denman Island before they are put on the market. Thus the oysters have an opportunity to cleanse themselves in unpolluted sea water of any bacterial contamination before they are marketed commercially.

It might be appropriate to mention here that recent samplings in the Nanaimo Harbour area have shown counts to be generally in the MPN range of 2 to 50 near the Nanaimo Yacht Club, where heavy pollution from a direct sewer gave extremely high counts in previous years. Since the new sewerage system has gone into operation, with sewage discharge outside of the harbour, samples taken at the outfall on the northeast side of Newcastle Island have repeatedly given MPN values of less than 10. The nearest beach at Kanaka Bay on Newcastle Island gave a count of 79, which may have been a result of contamination from some of the sewers still discharging into Nanaimo Harbour, inasmuch as a sample from Newcastle Island Beach on the harbour side resulted in an MPN of 240.

Judging by his findings of few or no coliform bacteria in marine materials collected at places remote from terrigenous or human contamination, Zo Bell (1960) concluded that coliform bacteria, such as Escherichia coli and allied enteric forms, are not normally present in the marine environment. While high concentrations of coliform bacteria have been found in the water and mud adjacent to the large sewer outfalls on the California coast, there is always a rapid decline in numbers with increasing distance from the outfall. This decline is much greater than can be accounted for by mere dilution. Not only do the bacteria fail to multiply, but they appear to suffer severe destruction through certain bacteriacidal effects of sea water.

Radioactive tracers (scandium-46) and dyes have been used to trace sewage fields in conjunction with counts for coliform bacteria. The T_{90} (time required for destruction of 90% of bacteria) has been found to be about 3 hours near the Hyperion Outfall in Santa Monica Bay for the first few hours following discharge (Rittenberg _et_ _al_., 1958). Some time after discharge, the T_{90} rises sharply to as much as 20 hours, presumably because of the greater resistance of bacteria that have already survived in the sea for several hours. The average range of survival time appears to be from 3 to 8 hours (Zo Bell, 1960). Although laboratory experiments on viability of coliform bacteria in sea water indicate that they can survive for 10 to 100 hours, field investigations indicate that other processes must be active in the sea to reduce the number of bacteria so drastically. It is believed that dilution, aggregation, flocculation, sedimentation, adsorption, antibiosis, action of sunlight, and other processes, which cannot be too easily simulated in the laboratory, effect a reduction of coliform organisms in the sea.

The work reported by Rittenberg _et_ _al_. (1958) demonstrated the presence of high concentrations of coliform organisms in the muds below the sewage field in the water. Sedimentation associated with dilution, flocculation or aggregation must be active in carrying down into the mud numerous living bacteria from overlying waters. It would seem also that the viability of the coliform bacteria is much higher in the muds than in the sea water to permit accumulation of such large numbers from waters having relatively low counts.

No data on survival time of coliform bacteria in marine muds are available. The question has been raised whether the aggregates of bacteria can be washed ashore from shallow waters to become a menace on beaches. It is not likely that such onshore movement of bacterial clumps can be possible from waters more than 10 ft deep in inside waters of the British Columbia coast, unless strong onshore bottom currents are present.

On the opposite end of the depth scale, there is evidence that higher concentrations of bacteria persist in the thin surface film of water than in waters immediately below (Zo Bell, 1960). This film of water may be only a millionth of an inch in thickness and presents technical difficulties in sampling for an actual count. However, bacteria are believed to be present there because of their buoyancy, surface tension and their association with low-density lipids and gases. Bacteria in surface films can be of public health significance for several reasons. (1) The surface film is moved more rapidly by the wind than the remainder of the water and may be blown ashore. (2) Dispersion of the film by diffusion into underlying water or by advection into surrounding waters is slow under normal ocean processes. (3) Concentration of these surface films often occurs through the convergence zones formed by wind, currents and internal waves.

12. Effects of Sewage on the Fishery

Sewage affects fish adversely mainly in a secondary way. The dissolved oxygen reduction, which results from decomposition of organic matter in the water, imposes a stress on the fish in mild cases and asphyxiation in severe cases. The oxygen required to stabilize the sewage from one person per day has been calculated as approximately 0.17 lb. For a population of 15,000, the maximum for which the proposed Comox sewerage system is designed, there would be an oxygen requirement of 2,550 lb/day. This amount of oxygen can be supplied by the excess over basic requirements for fish (5 parts per million is generally accepted as a minimum requirement for fish) in 10 million cubic feet of sea water having an average dissolved oxygen concentration of 9 ppm. This amounts to a flow of 116 cubic feet per second of sea water, which can be supplied by a small-sized river.

It is true that there are certain waters, particularly streams, which are so heavily polluted with domestic sewage that fish will not survive. For example, sewage from the city of London, England, has polluted the Thames River so completely over the years that dissolved oxygen is virtually non-existent in a large stretch of the river. Atlantic salmon have not been seen in this river for over 1 1/2 centuries. However, in areas where the water supply is plentiful and the amount of sewage is small, there is little to be concerned about in oxygen removal by organic constituents in the sewage. It is anticipated that in the Comox area, the small volume of sewage involved will do little more than fertilize the waters slightly and increase plankton growth. Deposition of sludge on the bottom is also not anticipated to create any serious problems.

The greatest threat of domestic sewage is in bacterial contamination of the waters and shore. Unless the volume of sewage is very large, the finfish such as salmon and trout, are not likely to be affected by bacteria. Since they are not scavengers, salmon and trout would pursue mainly food items from among other fish and plankton normal to their diet. Shellfish, on the other hand, being filter-feeders, can become seriously contaminated by faecal bacteria. However, by collecting in a sewer all the sewage now going into septic tanks or directly into the sea, the _B_. _coli_ count could be appreciably reduced in Comox Harbour. It is likely that areas, which now exhibit bacteria counts too high for safe oyster farming, could be used again without a health hazard.

13. Selection of Outfall Site

Three processes occur at an outfall in the sea and must be taken into consideration in evaluating the effectiveness of a particular site for sewage disposal.

(1) Initial dilution as effluent leaves the end of the pipe or diffuser and rises to the surface. This depends on depth and physical characteristics of the outfall. When sewage discharges from a single outlet near the bottom, mixing takes place as a result of two effects: (a) the jet action of sewage leaving the outlet, i.e., the kinetic energy of the jet, which is dependent on volume and velocity of flow; and (b) mixing by buoyant or gravitational forces, that are a net result of the difference in density of sewage and receiving waters. By increasing the number of jets, as in a diffuser, mixing can be intensified.

(2) Diffusion vertically and horizontally away from the outfall area. Dilution and dispersion by this process can vary from little more than molecular diffusion in calm waters with no mixing by currents and winds to large-scale eddy diffusion in turbulent waters.

(3) Transport by currents, tidal and non-tidal. The water movements in the Comox area are primarily tidal. Winds, of course, are instrumental in moving the surface water and any sewage that might be present therein.

Criteria for a suitable outfall site in sewage disposal are large initial dilution, strong horizontal and vertical diffusion, and rapid transport and dispersal of sewage away from the area used for recreation, commercial fishing or other purposes. These objectives must be balanced by cost and actual minimum requirements for safety.

It is obvious from what has been said in previous sections that proper sea disposal of sewage from the Village of Comox will depend on the location of the outfall. The object in efficacious disposal is rapid dilution and dispersion with as little return into the harbour by tidal currents as possible. There is little question that even a normal amount of sewage discharged directly into Comox Harbour would stagnate and create an intolerable condition in a relatively brief time.

It is generally agreed by the consulting engineers, the public health authorities and oceanographers that for adequate dilution and dispersal, sewage should be discharged outside Comox Harbour. The big question is how far beyond Goose Spit this sewage should be carried before release. If it is released too close to shore, it will be swept back into Comox Harbour in a relatively short time on the flood tide. One hour or slightly more would be required on a large flood tide for the sewage to round the spit and enter the harbour if the outfall were located on the shore about 1 mile from the western tip of Goose Spit. In two hours, the sewage could reach the waterfront of Comox.

The safe outfall location in the region lying to the south of Goose Spit will be determined by the distance from the Goose Spit shore, depth of water, and distance from the Comox Harbour waterfront. The deeper the discharge the greater the dilution, provided the sewage rises all the way to the surface. Thus only dilute concentrations of sewage bacteria will be present in the surface water overlying the outfall, if the discharge takes place in deep water. A large distance from Goose Spit will ensure that sewage is not transported onto the shore in relatively high concentrations by wind-driven onshore currents. The further eastward from the head of Goose Spit that the outfall can be practically maintained, the longer the period required for any sewage caught in a westward flowing current to be carried into Comox Harbour. The effectiveness of distance of the outfall from Goose Spit is reduced by the presence of tide flats. Hence more effective disposal can be achieved by laying the pipeline east of the broad bank located south of the Naval Rifle Range.

The outfall must be placed at some point where the current sets toward the south away from Comox Harbour. Separation of the westward-setting longshore current along Goose Spit and the flow to the southwest in northern Baynes Sound occurs roughly at a distance of 700 yd from the shore of the spit. It would be necessary to discharge at a point beyond this boundary if the sewage is to be maintained in the flow setting southward into Baynes Sound. To allow for any periodic fluctuation of the longshore current, 100 yd should be added to the distance of the boundary from the shore in order to allow a safety factor in the outfall location.

It appears that the minimum distance at which the outfall can be set is 800 yd from the bend in Goose Spit (location of butts of Rifle Range) at a depth of about 12 fathoms (72 ft). The bulk of the sewage released here will be carried southward into Baynes Sound. Undoubtedly, some sewage in a highly diluted form may enter into Comox Harbour. However, it is expected to be virtually undetectable. It is anticipated that the B. coli concentrations would be very low, probably little higher than the background count, in all areas of Baynes Sound outside the immediate vicinity of the outfall.

No doubt that the present high count of B. coli in Comox Harbour could be substantially reduced. If all the private dwellings and business establishments now contaminating the waterfront through septic tanks were to connect into the proposed sewerage system, there should be virtually no background counts in the harbour. Swimming, water skiing, and other aquatic recreation within the harbour could be pursued more safely from the health standpoint. Oyster culture within Comox Harbour should be safe bacteriologically.

14. Checks on the Safety of the Proposed Outfall

It is desirable in any sewage disposal plan to have recourse to some independent means of checking the safety of the particular outfall design. In problems dealing with ocean disposal of industrial wastes or sewage, there are many unknowns and variables which cannot be firmly established even with numerous surveys. Sewage itself is a variable sort of thing which can have daily lows and peaks as well as seasonal fluctuations in organic content and bacterial concentration. Marine conditions fluctuate with changing tides, winds, runoff, temperature, and any particular combination of these factors. Sewage may behave quite differently under a given set of conditions than under those which have been used as a yardstick to compute depth of outfall, distance from shore, diffuser characteristics, etc. In established sewer outfall areas along the California coast, monitoring for bacteria in the water and on the shore has shown periods of unexplained peaks in the coliform index (Pomeroy, 1960).

The objective in effective safe waste disposal should be adequate protection against the worst conditions that may be expected insofar as dilution and dispersal are concerned. Hence, it is not sufficient to satisfy only the average conditions. Safety factors must be applied to meet the most demanding situations, although freak instances of unusual water movements may occur once in several years, which may cause incidents of high coliform index even with this added protection.

There are mainly two ways in which a sea disposal scheme in the Comox harbour area can be harmful to the marine environment in its aesthetic, recreational and industrial values and to the aquatic life contained therein. (1) Oxygen depletion caused by decomposition of organic substances which accumulate from the sewage. (2) Buildup of high concentrations of enteric organisms. As shown in a previous section, the organic materials in the amount of sewage involved should have little effect on the dissolved oxygen concentrations in sea waters of the area. Certainly with the current and flushing action present in northern Baynes Sound, sewage is not expected to accumulate to any significant degree. The presence of enteric organisms in the water and on the shores nearby poses a definite public health problem both from the point of view of human contact and uptake by edible shellfish. The effectiveness of the outfall in dispersing the sewage to low levels of bacterial organisms must be carefully checked and rechecked.

The choice of an outfall site at least 800 yards from shore with a water depth of 12 fathoms is somewhat arbitrary, based mainly on the general circulation at the approaches to Comox Harbour. Hence, it is desirable to check these proposed figures by certain established methods. Early experimental work on submarine sewer outfall design was carried out by Rawn and Palmer (1930) off the coast of California. Data from these classical experiments have been used by engineers in more recent time to compute certain parameters for the typical type of outfall installation on the open coast of California. In a report of the State Water Pollution Control Board (Pearson, 1955), useful expressions and nomographs derived from the earlier data are given for evaluation of required depth of outfall, distance from shore and effect of multiple diffuser jets when such factors as volume of sewage, and size, shape, etc. of outlet are known.

It is estimated that the volume of sewage output per capita per day is 100 Imperial gallons. The maximum population that would be serviced by the proposed sewerage system has been given by the consulting engineers as 15,000. A maximum yield of sewage can be estimated as 1.5 million gallons per day or 2.8 cubic feet per second. Assuming a vertical discharge from a depth of 72 ft (12 fathoms), the initial dilution for sewage between the time it leaves a single-outlet jet and the time it reaches the surface is 150 (from Pearson, 1955, Fig. 14). If the outlet discharges horizontally, which is the more likely in a typical outfall, the sewage follows a curved path. The centreline length L of a rising column in such a discharge can be calculated according to the size of outlet pipe used. For a discharge of 2.8 c.f.s. at a depth of 72 ft, with different diameters of pipe D, L is given in the accompanying table.

Table I. Length of centreline of flow paths and initial dilution for a discharge of 2.8 c.f.s. at 72 ft depth.
(From Pearson, 1955, Fig. 13).

Diameter of Outlet D, inches	Centreline Length L, feet	Dilution So
12	85	225
15	83	210
18	79	185
24	78	180
30	77.5	177
36	77	175
42	76	170
48	75	165

From the computed values of L or from Pearson's nomograph (Pearson, 1955, Fig. 13), the dilution factor So can be obtained again from Pearson's graphical representation in his Figure 14 (loc. cit.).

The number of coliform bacteria present in sewage is extremely variable, depending on the amount of dilution that sewage receives at its source, age, treatment, etc. However, an average MPN value of 225,000 B. coli per 100 ml has been chosen by Pearson (1955) in his calculations on California sewage, and this value will be used here. Thus, in order to obtain a maximum safe MPN level of 1000 per 100 ml, a dilution of 225 must be achieved. As given in Table I, this amount of dilution occurs when a 12-inch pipe discharges horizontally at 72 ft depth. Even with a 4-ft diameter outlet, a substantial dilution of 165 can be obtained.

From Rawn and Palmer's (1930) data, Pearson (1955) also presented a graphical solution to the problem of obtaining the radius of a sewage field and the time from discharge required to achieve a dilution of 225 in terms of centre-line length L and sewage flow. For all cases of L given in Table I, dilution by 225 would occur in less than 100 ft from the centre of the "boil", a single outlet being used in the outfall. Less than 1/4 hour is required for the dilution to bring B. coli concentrations to safe levels. It was shown also that multiple outlets in the outfall pipe can lead to safe levels of B. coli concentration faster in a shorter distance than single outlets. For example, where a single outlet achieves 225-fold dilution at 150 ft, a double outlet provides the same dilution at 100 ft. Similarly, a 225-fold dilution is gained by single and quadruple outlets at 200 ft and 100 ft, respectively.

Another more empirical approach used by engineers in design of outfalls is that reported by Pomeroy (1960). An expression has been developed which states that the number of sewage bacteria N found at the shore station of highest pollution is directly proportional to the square of the sewage discharge Q and inversely proportional to the depth of the discharge Y and the square of the distance X of the outfall from shore. Stated in symbolic form:

$$N = \frac{KQ^2}{YX^2} \qquad (1)$$

where K is a constant dependent on general oceanographic conditions such as stratification of the water column, turbulence, wind mixing, and currents. For the southern California coast, it has been found to range from 1 to 2, when Q is given in cubic meters per second, X and Y is in metres and N is the most probable number of B. coli per 100 ml. As mixing increases, the value of K decreases. Although no attempt has been made to evaluate K for the Comox area, it is probable that a value considerably higher than those given for California would be obtained. Assuming that the higher value of K used by Pomeroy is applicable, we can calculate N for the proposed depth of outfall and distance from shore. Converting the volume and distances for the proposed outfall to the metric system,

$$N = \frac{2 \times (6.81 \times 10^3)^2}{22.0 \times (7.32 \times 10^2)^2} = 7.88 \qquad (2)$$

This value is considerably lower than a maximum permissible count (50 per 100 ml) for a grade A beach and very much lower than the recommendation of the California State Pollution Control Board for the value (1000 per 100 ml) not to be exceeded on the recreational beaches and bays along the coast of California.

From the foregoing checks, it might appear that the proposed plan for disposal should be not only very safe but that an unnecessary safety factor is being applied at considerable cost. There are several points that must be kept in mind in this analysis. The theoretical, experimental and empirical information for checking the outfall details has been drawn from work done in an area very different oceanographically from our own. The temperature and salinity regimes off the Southern California coast differ widely from those on the British Columbia coast, especially in the Strait of Georgia. Consequently, stratification in the two areas is not comparable. Accordingly, mixing characteristics are quite dissimilar. There is no doubt that the value of K for equation (1) is much larger for inshore waters along the British Columbia coast than for coastal waters of California. The currents in Baynes Sound and Comox Harbour are peculiar to that area alone. It would not be too valid to use data from other areas, which are different oceanographically, in order to evaluate the transport of sewage into Comox Harbour.

The question might be raised whether a check even to the extent that it was carried out here can be considered valid. We have field data from the submarine outfall at Crofton where pulp mill effluent discharges through a diffuser at a depth of 60 ft. Dilution of effluent at the surface in the "boil" has been measured to be about 20. This checks very closely with dilution predicted from Rawn and Palmer's data for a discharge of 45 c.f.s. at 60 ft depth (Pearson, 1955, Fig. 14). Mixing characteristics of sewage are probably not too different from those of pulp mill effluent. The diffuser with multiple jets on the end of the pulp mill sewer pipeline would be expected to give better dilution than that predicted from Pearson's graph, but it would not likely effect an improvement by more than a factor of 10.

15. Some Problems in Submarine Disposal of Sewage

There are certain characteristics of the marine environment which expose a submarine installation to problems not present in subaerial installations. These include wave action, currents, corrosion by sea water, fouling and boring by marine organisms, abrasion by water and suspended sand, shifting sediments and erosion caused by artificially changing the bottom topography. Some of the problems may be listed specifically for the Comox area as follows:

(1) Effects of currents near shore along Goose Spit. It is anticipated that the force of longshore currents setting perpendicularly to the effluent pipeline may have serious consequences on the pipeline's permanency by either shifting or breaking it. This could be at least partially avoided by suitably burying the pipeline on the tide flats and in the shallow water. Secure coupling of the pipe at the joints and firm anchoring to the bottom must be achieved along most of its length.

(2) Instability of bottom materials. The unconsolidated sediments consisting of sand and silt may shift with the wave and tidal current action and result in movement of the pipeline. The edge of a delta or bank, where suspended materials are being continuously deposited by stream discharge or currents, is particularly vulnerable to shifting. This unstable feature can be expected to occur along the tide flats bordering Goose Spit. A pipeline extended over the edge of the bank down a relatively steep slope would be subjected to considerable force if the bank "sluffed off" or shifted slightly. Separation at the joints, if they are not too securely fixed, can easily occur

in the critical lower end of the pipeline. Experience with such mishap has been gained in the submarine pipeline conducting waste effluent from the pulp mill at Crofton into Stuart Channel. Special anchoring devices were required to hold this pipeline in place following the initial break when discharge commenced from the pulp mill.

(3) Changes in natural erosional and depositional characteristics. Installation of an exposed, man-made structure in the waters along Goose Spit would likely lead to local changes in erosion and deposition of the shore sand. The natural equilibrium is disturbed and certain unwanted developments can occur such as those which have been observed along the coast of California where breakwaters and jetties have been installed. Avoidance of an undesirable shift in the natural erosional and depositional equilibrium can be most easily gained by burying the pipeline in the bottom sediments.

(4) Adverse effects of sea water and marine organisms on construction materials. Sea water, because of its salt content, is especially corrosive to ferric metals, except stainless steel. To avoid corrosion, submarine pipelines are sometimes made up of specially compounded mastic materials, fibre glass, synthetic materials such as polyvinal chloride, and treated wood staves bound with stainless steel bands. Reinforced concrete has also been used commonly. One or two instances of vitrified clay pipe in outfalls have been reported. Over 50% of the 140 outfalls examined by Pearson (1955) were made up of cast iron and wrought iron. The special advantage of these materials is that they can be welded to give solid, leak-proof joints and the assembled pipeline can be floated into position by barges and then sunk. They are attacked fairly heavily, however, by the corrosive action of sea water.

Marine organisms can bore into a large number of materials and will foul almost anything except perhaps copper-leaching substances. Wood used in submarine construction must be specially treated to prevent attack by the wood borers. There are certain clams that will bore into rock and concrete. Most of the synthetic materials used in pipes are fairly immune to attack by boring organisms.

(5) Diffuser design. Installation of a diffuser at an outfall effects a great deal more initial dilution than would be possible from a single outlet. Care should be taken in setting the spacing of the nozzles on the diffuser so that the maximum benefit can be gained in dilution by entrainment of sea water into each jet of sewage rising to the surface. Jets spaced too closely to each other interact so that sewage from one jet may be picked up by another.

16. Summary and Conclusions

Circulation in northern Baynes Sound is dominated by the tides with a strong current (1 - 2 knots) setting westward along Goose Spit on the flood and a much weaker current eastward on the ebb. The flood tidal current entering northern Baynes Sound over the Comox Bar from the Strait of Georgia diverges near the tip of Goose Spit to form one arm flowing northward into Comox Harbour and another that deflects southwestward away from the harbour. There is a marked tendency of the ebbing tidal current to flow southeastward into Baynes Sound. The circulation in Comox Harbour in surface and deep water is comparatively sluggish and erratic. Some evidence exists for the occurrence of slow-moving eddies in the eastern part of the harbour between Goose Spit and the Comox waterfront.

Vertical distributions of physical and chemical properties in Comox Harbour and northern Baynes Sound are characterized by a relatively thin surface layer of brackish water lying on a much thicker layer of sea water having higher and more uniform salinity from top to bottom. The surface layer varies in thickness and salinity seasonally according to the amount of runoff received from the Courtenay River. The influence of the river diminishes as the distance seaward from Comox Harbour increases.

Existing sewage disposal at the time of the January 1958 survey contributed to generally high coliform bacteria counts in Comox Harbour. This may have been an acute winter condition when seepage from septic tanks was high, inasmuch as B. coli counts from a previous summer's survey were much lower.

The fishery most seriously affected by the inadequate sewage disposal and consequent high bacteria counts in Comox Harbour was oyster farming. Aside from this, the aesthetic and recreational qualities of the water were seriously impaired by the uncontrolled discharge of raw sewage and/or sewage effluents.

From the survey data obtained it is obvious that sewage disposal into Comox Harbour is inadmissible from both a fisheries conservation and health point of view. Disposal into the deep, well-flushed waters of northern Baynes Sound offers a much safer scheme than harbour disposal and is less expensive than a treatment plant. The choice of a proper outfall site depends mainly on the location of the demarcation line between flood currents setting into Comox Harbour and those setting southwestward into Baynes Sound. This separation lay approximately 700 yards south of Goose Spit during the current survey. To allow a factor of safety for day-to-day variation of currents because of winds, runoff or peculiarities in the tide, an additional 100 yards should be given the length of the outfall pipeline. For further providing distance to the outfall from Comox Harbour, within economic reason, the outfall should lie as far eastward of the harbour entrance as possible. A reasonable point appears to be about 800 yards from shore approximately south of the "Butts" of the Naval Rifle Range. The depth here is about 12 fathoms (72 ft).

A check was made on the amount of dilution available at the proposed outfall by independent empirical methods developed elsewhere. For a sewerage system serving a population of 15,000, the proposed outfall location is reckoned to be entirely safe for fisheries and recreational uses of the waters of Comox Harbour and Baynes Sound.

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Dr. L. S. Anderson and his sanitary inspector, Mr. Hugh Hart, carried out most of the sampling for coliform counts; and the Division of Laboratories of the Department of Health made the analyses. I should like to extend to Dr. Anderson my gratitude for his stimulation in this study.

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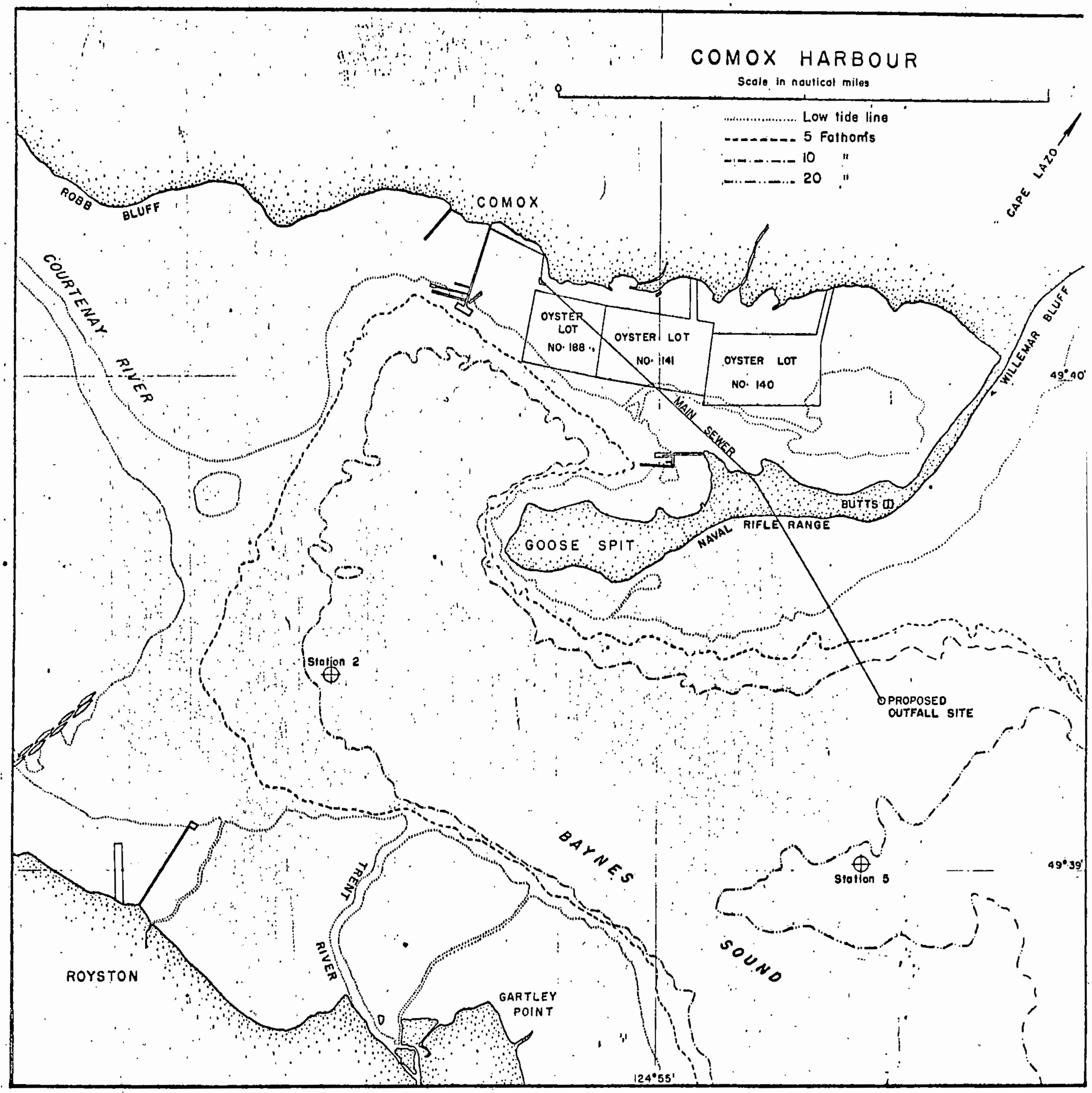


Figure 18: Chart of Comox Harbour and approaches, showing the location of the sewer outfall.

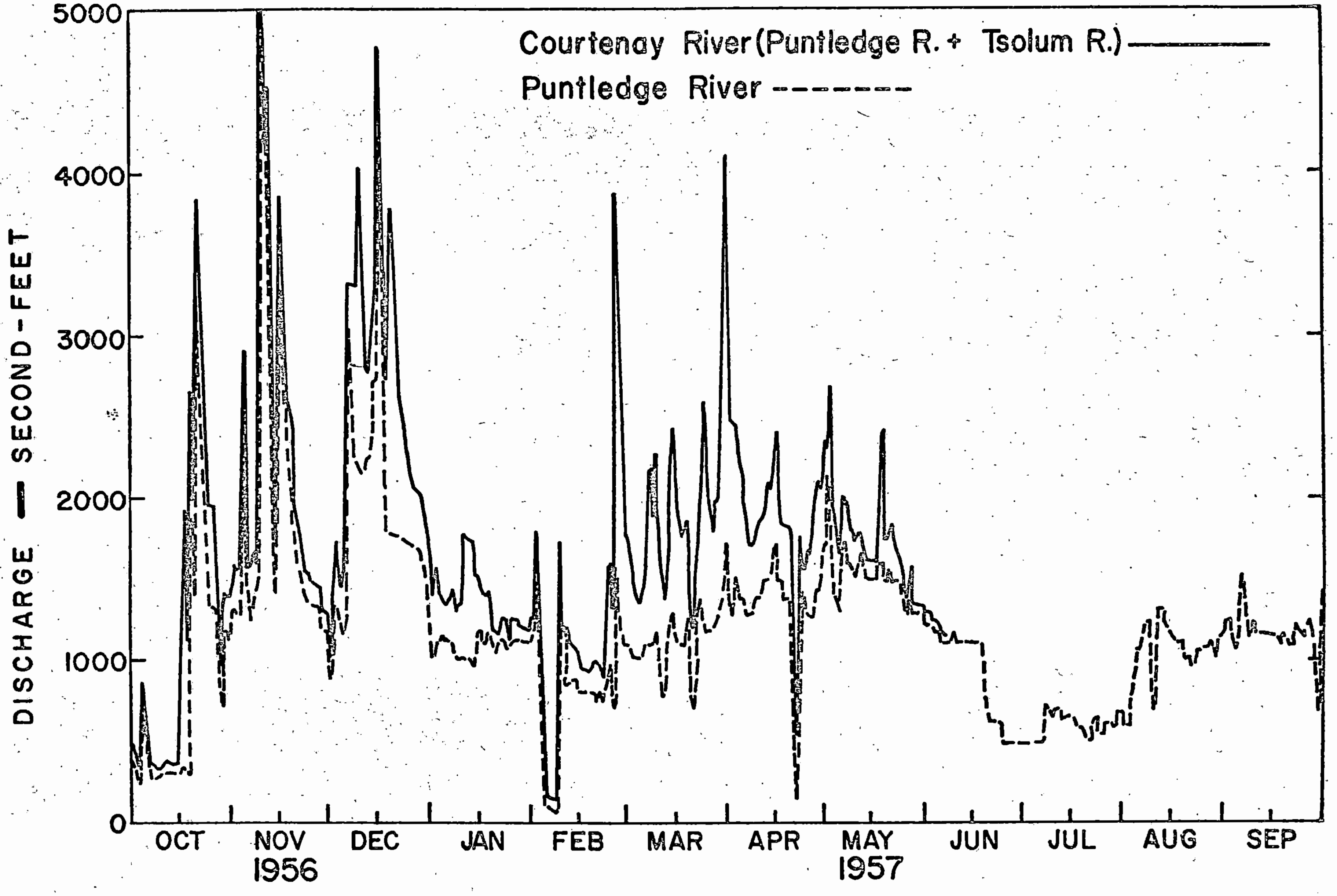


Figure 2. Seasonal variation of the Puntledge River and Courtenay River (Puntledge River and Tsolum River) discharge.

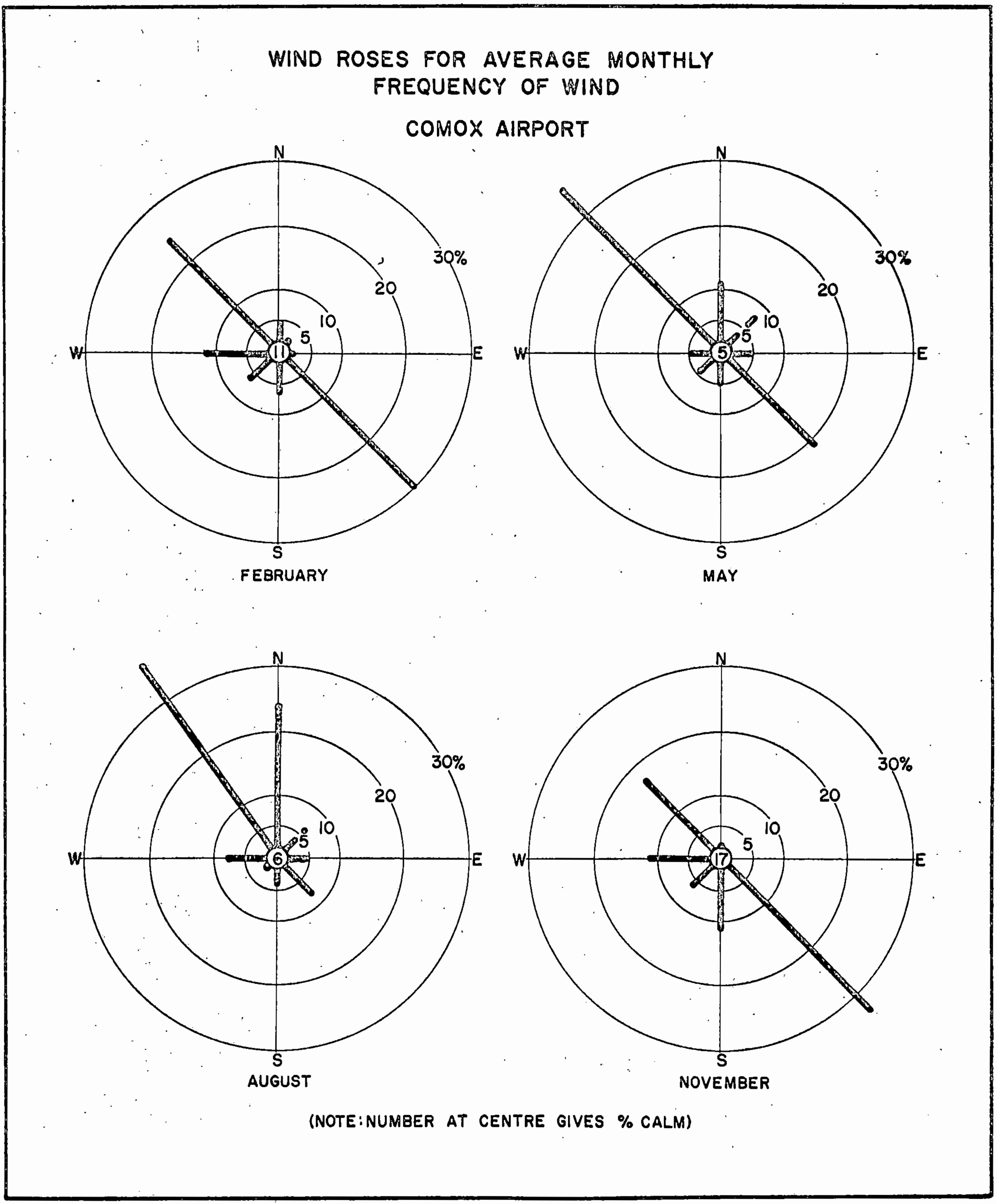


Figure 3a. Percentage frequency of winds from various directions during months of different seasons of the year at Comox Airport, averaged for the period 1944-1947.

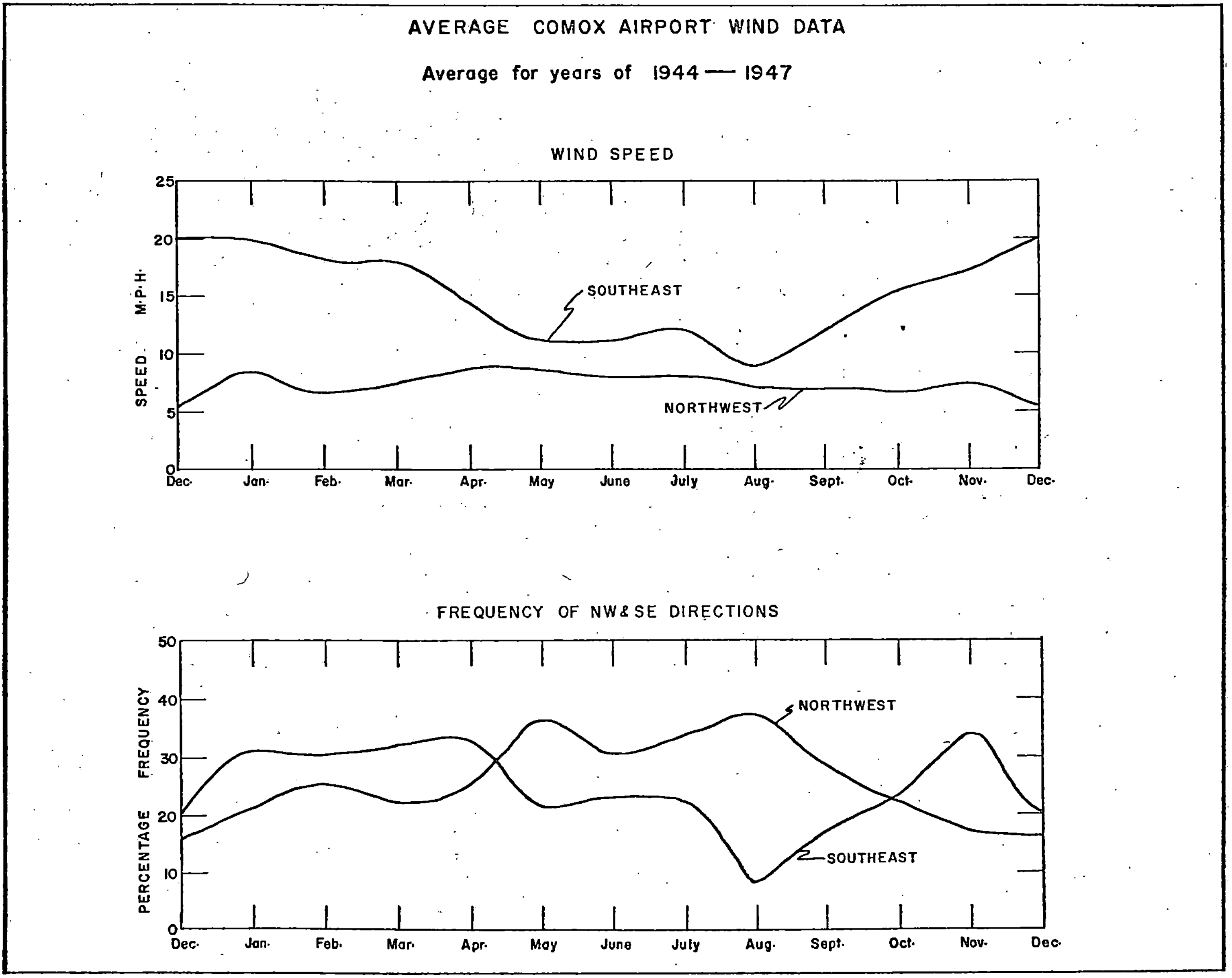


Figure 3b. Seasonal variation of wind speed and frequency from northwest and southeast directions at Comox Airport averaged for the period 1944-1947.

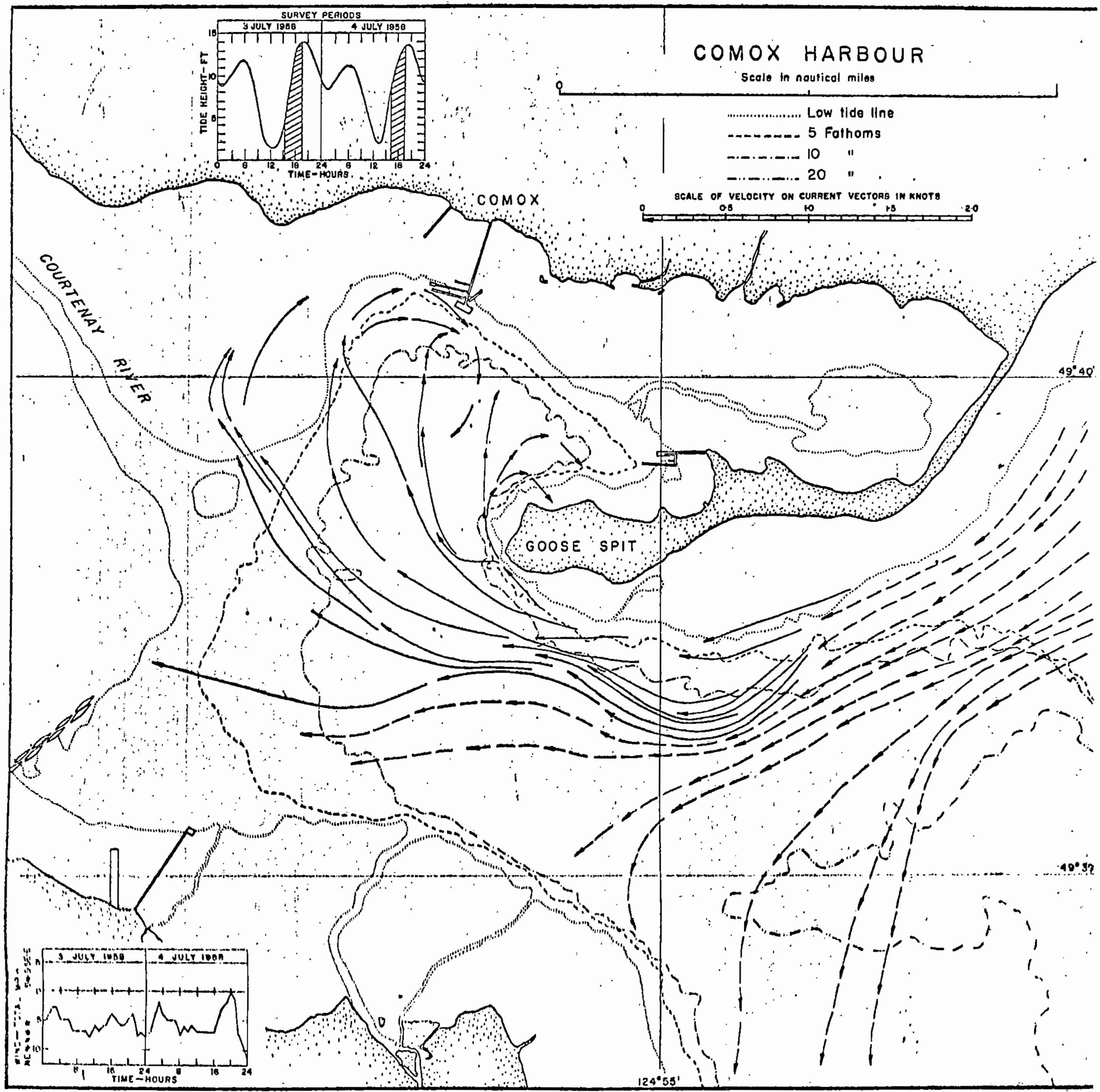


Figure 49: Generalized surface circulation in Comox Harbour and approaches during a flood tide. (Solid arrows give a composite picture of observations taken over a period of several hours on 3 July 1958. Dashed arrows give observed and estimated results for 4 July 1958.)

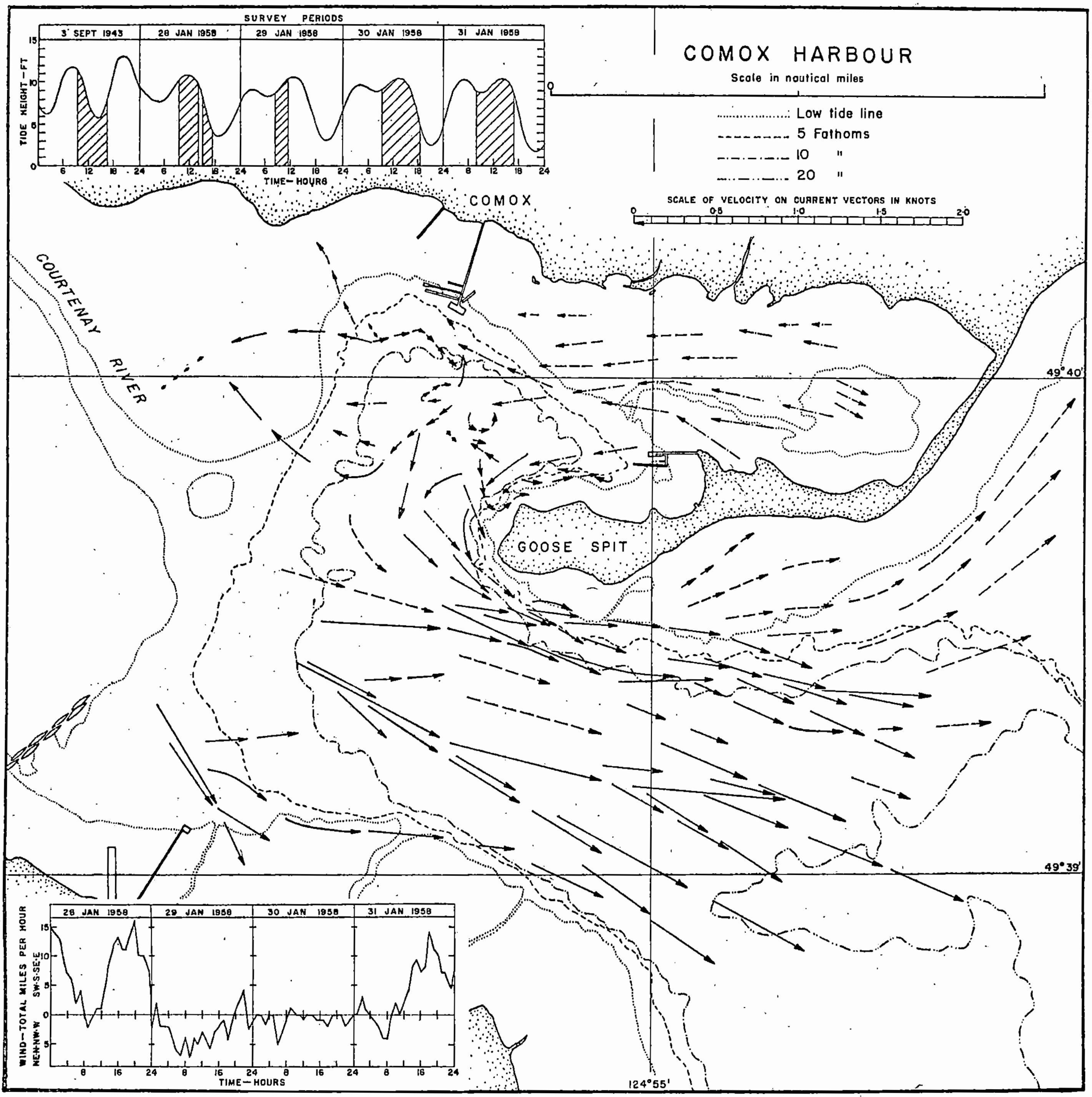


Figure 5. Generalized surface circulation in Comox Harbour and approaches during an ebb tide. (Solid arrows give a composite picture of observations taken over a period of several days, 28-31 January, 1958. Broken arrows give observations for 3 September, 1943. Dashed arrows are estimated currents.)

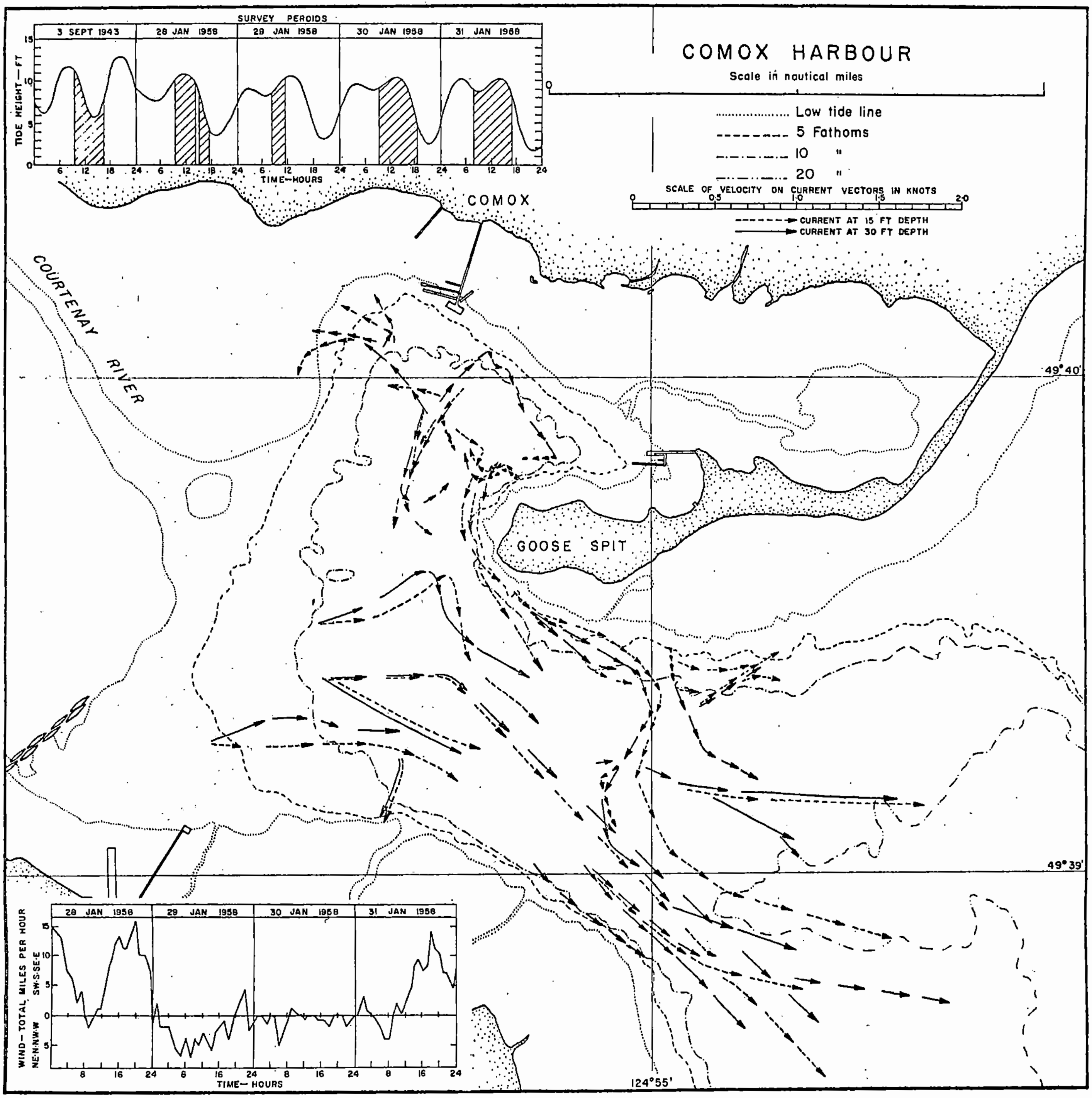


Figure 6. Observed circulation at 15-foot and 30-foot depth in Comox Harbour and approaches during the period 28-31 January, 1958.

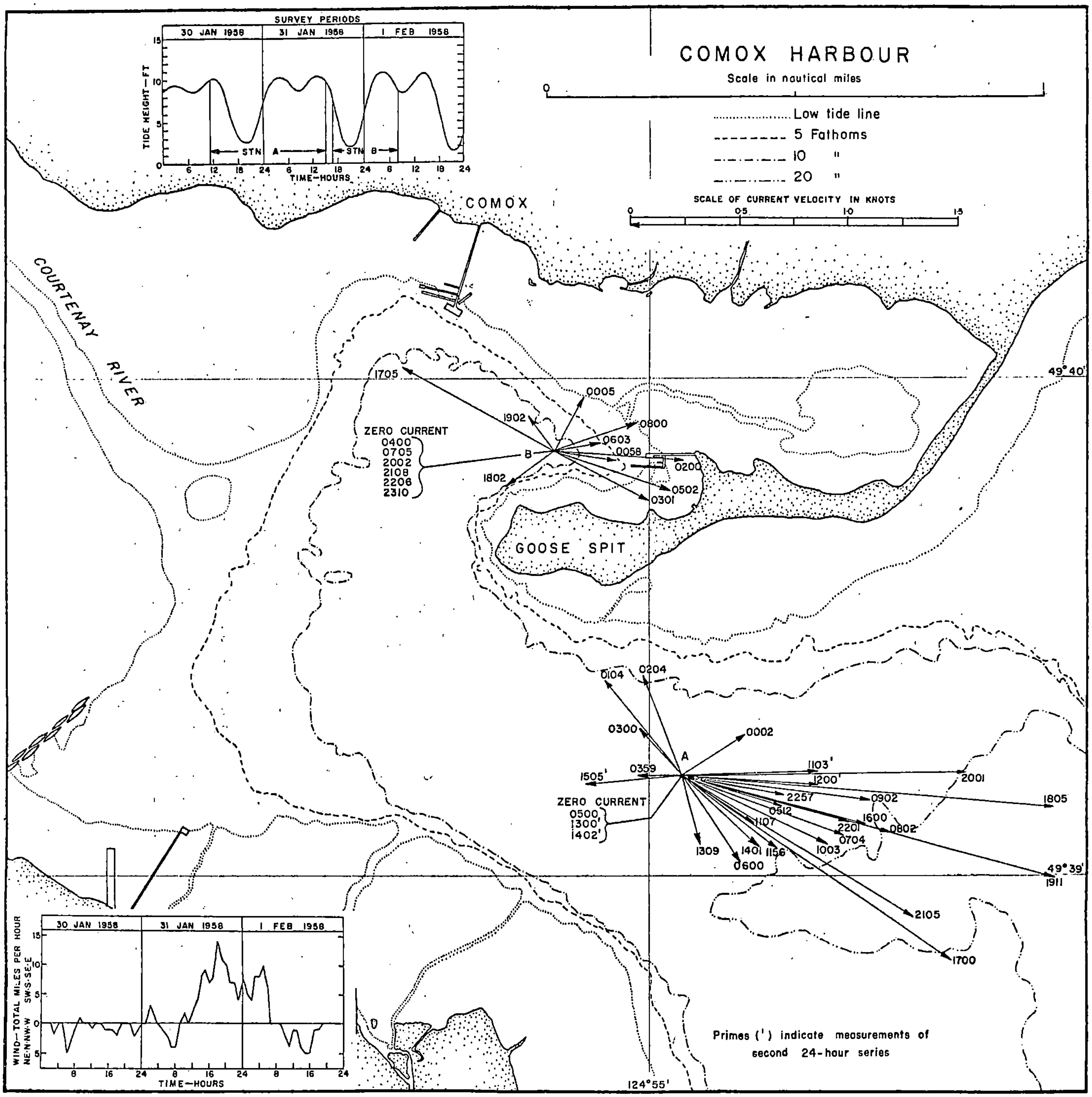
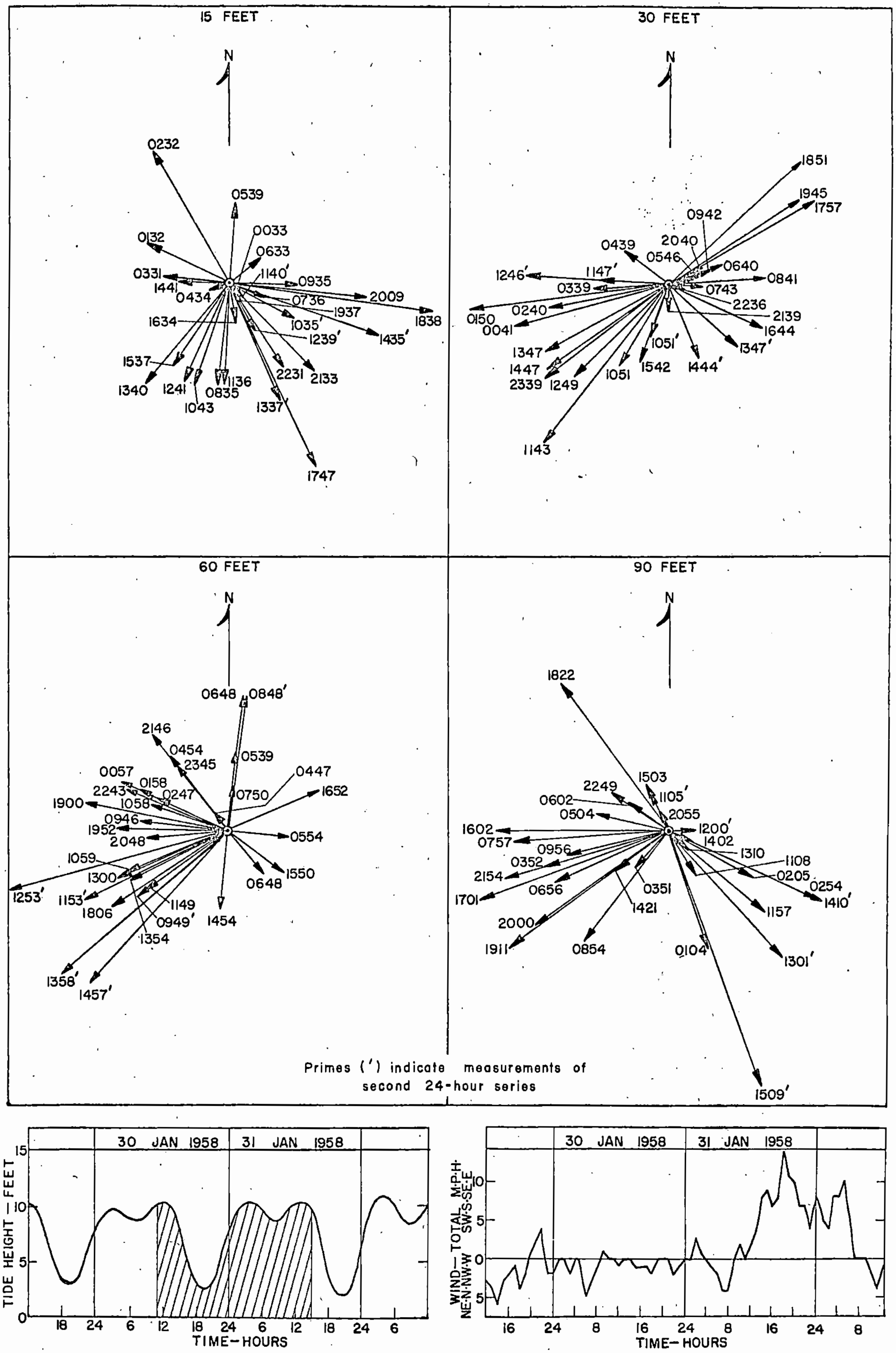


Figure 7. Variations of surface currents over a tidal cycle at anchor stations A, south of Goose Spit, and B, in Comox Harbour.



Primes (') indicate measurements of second 24-hour series

Figure 8. Variations of subsurface currents over a tidal cycle at anchor stations A, south of Goose Spit.

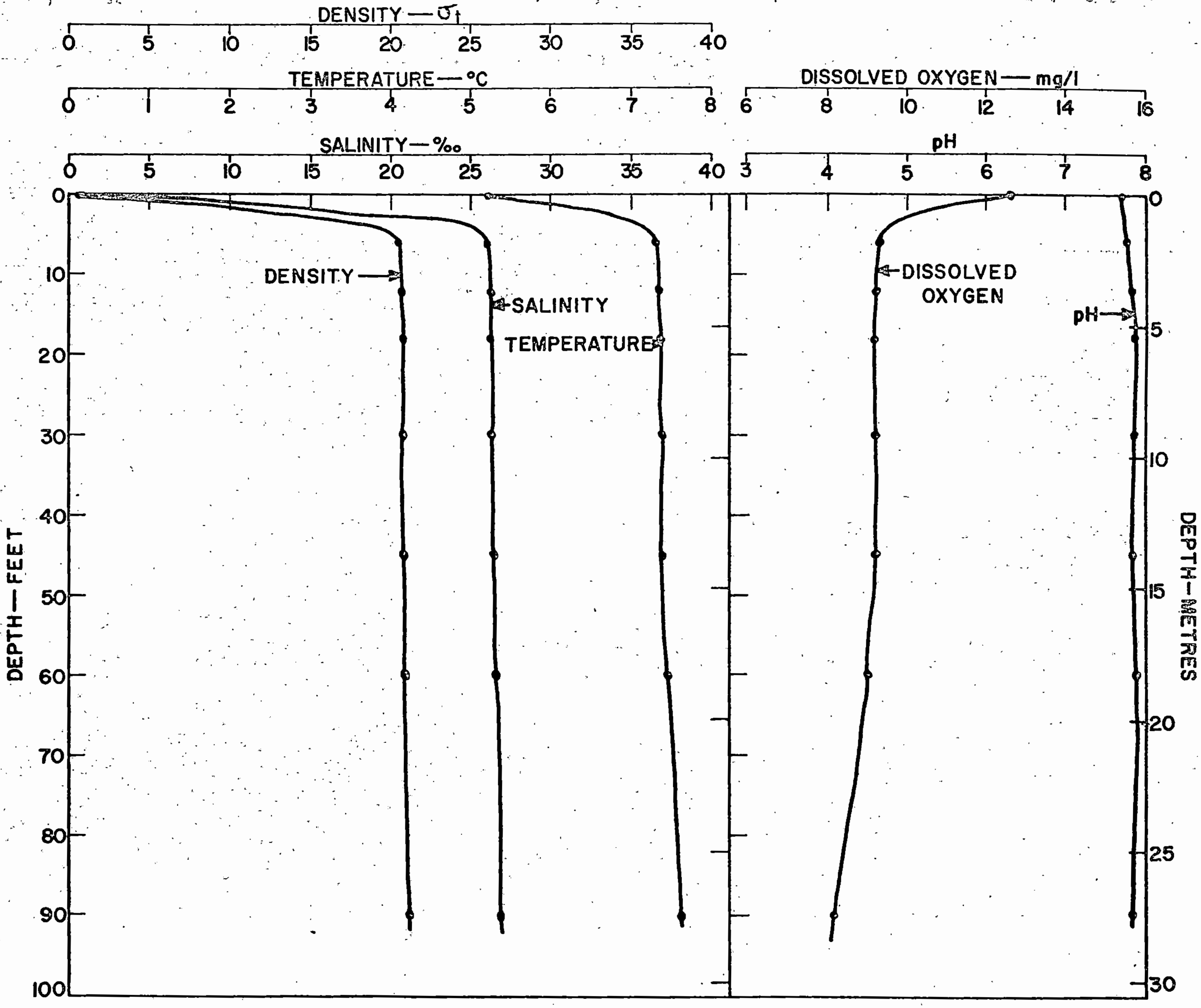


Figure 9. Vertical profiles of various physical and chemical properties in the water at Station 2 (see Fig. 1) in Comox Harbour, occupied 28 January, 1958.

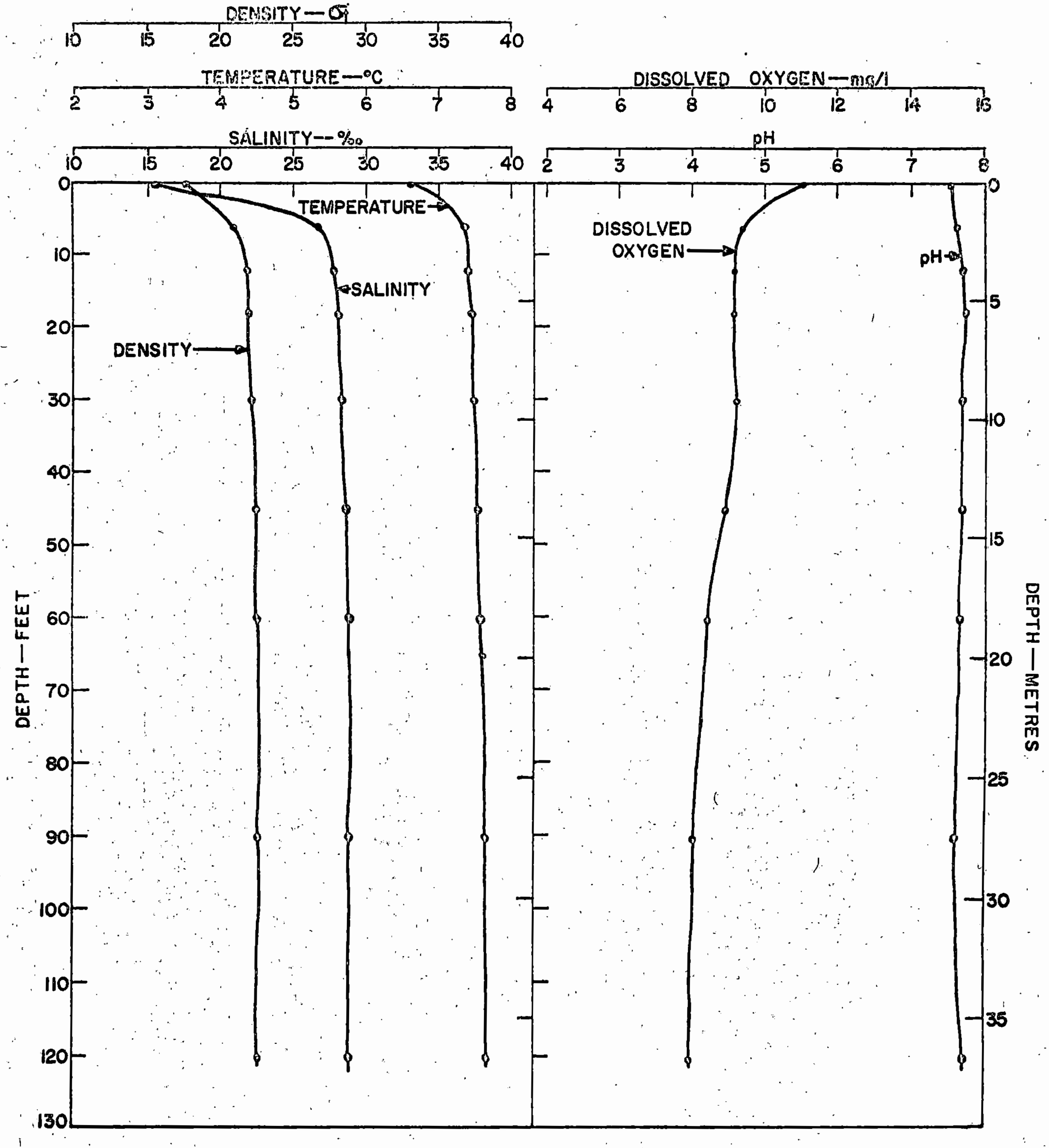


Figure 10. Vertical profiles of various physical and chemical properties in the water at Station 5 (see Fig. 1) in Baynes Sound, occupied 28 January, 1958.

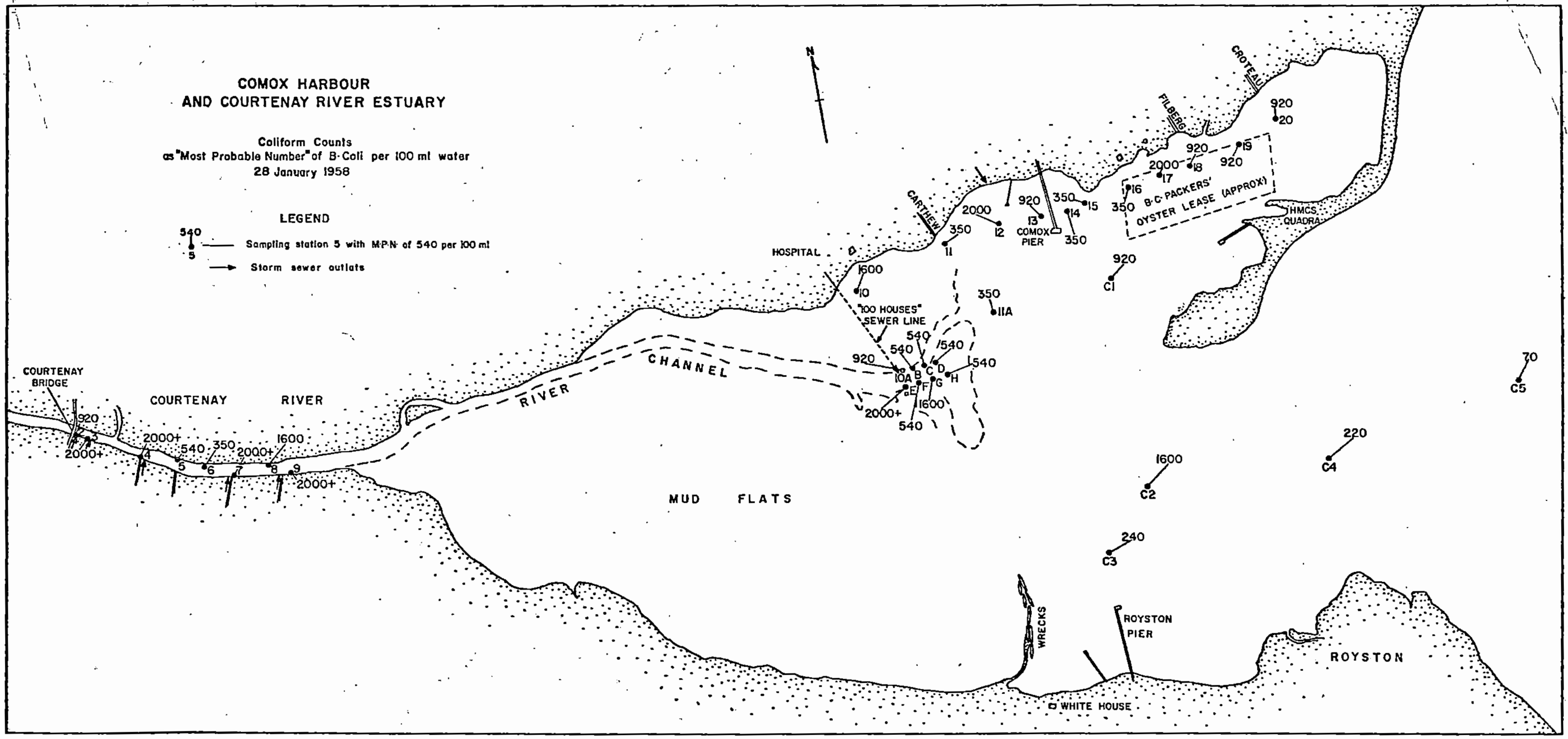


Figure 11. Distribution of B. coli in the Courtenay River estuary and Comox Harbour on 28 January, 1958. (Chart only approximate, traced from an aerial mosaic photograph.)