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COMMONWEALTH



OF AUSTRALIA

Commonwealth Scientific and Industrial Research Organization

Division of Fisheries and Oceanography

REPORT 44

DISPERSAL OF PULP MILL EFFLUENT IN
HOSPITAL BAY, TASMANIA

By B. S. Newell

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TOTAL TRANSPORT AND FLUSHING TIMES
IN THE LOWER TAMAR RIVER

By B. S. Newell

Marine Laboratory
Cronulla, Sydney
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PART 1

INTRODUCTION

The pulp mill of Australian Paper Manufacturers Ltd, situated at Port Huon, Tasmania utilises a neutral sulphite process. The chipped wood (size about 1" x 1" x $\frac{1}{4}$ ") is digested under pressure in a liquor containing sodium carbonate and sodium sulphite. This serves to dissolve most of the natural cement substance in the wood, releasing the cellulose fibres. The effluent from the digester is black in colour, has a pH range 7-8 and a temperature range of 100-130°F at the point of discharge.

Traces of unused sulphite remaining in the effluent liquor produce a short term oxygen consumption when the effluent mixes with uncontaminated water. Microbial decomposition of the extracted organic materials creates a further long term oxygen consumption. Oxygen consumption is expressed as a composite of these, called the "5 day B.O.D.", viz the consumption of oxygen in a given volume of effluent over 5 days at 20°C. In general, the production of 1 ton of pulp creates a demand for 220/260 lb of oxygen, measured as "5 day B.O.D.". The current production rate of the mill (some 200 tons of pulp per day) therefore corresponds to a demand for about 48,000 lb of oxygen per day. If the effluent were discharged into a natural environment having a dissolved oxygen content of about 10 p.p.m., then theoretically an influx of uncontaminated water at the rate of 900 cusec would be sufficient to satisfy the oxygen demand. However, since the dispersal of the effluent depends not on a constant influx of diluting water, but on eddy diffusion and tidal movements, a gradient of oxygen diminution would be expected, with possible localised areas denuded of oxygen.

The Tasmanian Health Department has laid down a statutory requirement that at no place in the River Huon shall the effluent reduce the dissolved oxygen concentration below 5 p.p.m. Measurements of oxygen content made by the mill chemist, in the river since the construction of the mill, have never shown oxygen values below this level.

At the request of A.P.M., a survey with the following aims was carried out on September 23-26, 1968. Firstly it was proposed to plot the dispersion pattern of the mill effluent by means of natural fluorescence or the use of a fluorescent dye. Secondly, levels of dissolved oxygen were to be measured throughout the area to assess the effect of effluent discharge. Thirdly, the distribution of salinity and temperature with depth over the area was to be measured in order to calculate flushing rates, i.e. the availability of uncontaminated water to dilute the effluent.

Personnel

The survey was carried out by B. Newell with the assistance of two members of the Mill staff. Assistance was also given by Mr R. Winstanley of the Tasmanian Department of Fish and Game. Dr R.M. Crossett and Mr Z. Charash of Australian Atomic Energy Commission, Lucas Heights were present as observers.

METHODS

Dissolved oxygen was measured with an E.I.L. Model 15 A meter (Mackereth 1964) fitted with 10 m of cable. Readings were taken at surface and bottom (or 10 m where depth exceeded this) at the positions shown in Figures 1 and 2.

Chlorinity and temperature were measured with a CSIRO meter (Hamon 1956), at the positions shown in Figure 3. Readings were taken at 1 m intervals of depth.

Fluorescence was measured in a Turner Model 111 fluorometer. Surface samples were taken directly into 100 ml plastic bottles on September 23 and 25, at the positions where surface oxygen readings were made (Figs. 1 and 2). Bottom samples were collected in a vacuum operated sampler, on the 25th, at the positions where bottom oxygen readings were made (Fig. 2).

RESULTS

1. Oxygen levels

Distribution of low oxygen water was patchy, and the values shown in Figures 1 and 2 are the most constant reading at any place or depth. As a guide to interpreting the values, 100% saturation at the salinities and temperatures encountered would represent 9 p.p.m. for the saline bay water and 10.7 p.p.m. for the brackish surface water. The legal minimum of 5 p.p.m. would therefore be 55% saturation in the saline bay water and 44% in the brackish layer.

During the two days of the survey (September 23 and 25) a fault in the effluent screen mechanism required all effluent to be diverted down the hillside onto the mud flats and shallows at the western end of the bay. Figure 1 therefore shows the oxygen distribution pattern under the worst circumstances, i.e. with warm effluent flowing into restricted water at low tide. Despite this, no saturation value of lower than 59% was found. Most values, for surface and bottom, were over 80%. The pattern of dispersal of the effluent at low tide would seem to be in a general south-east direction along the bottom, thence into the deep channel off Whale Point.

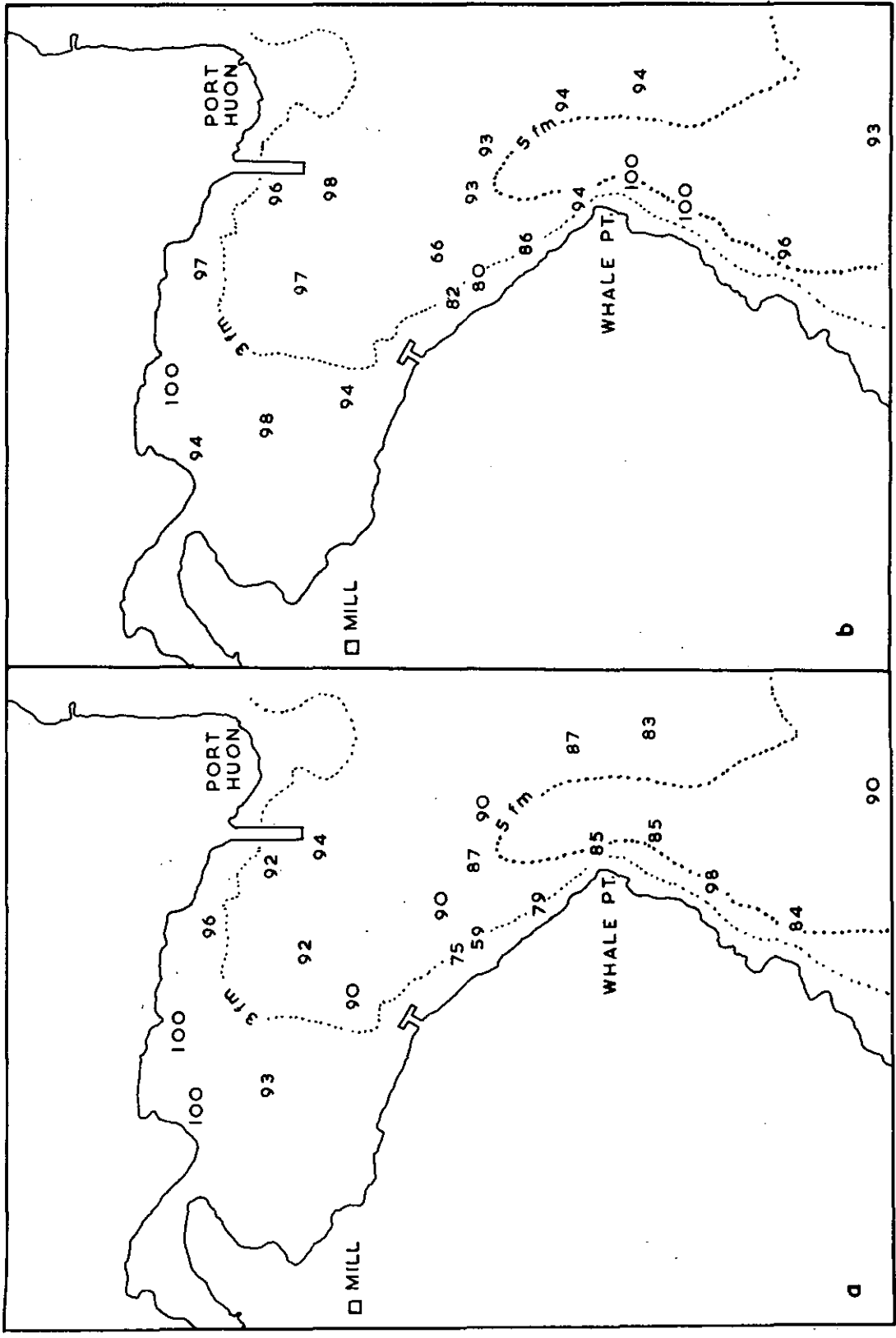


Fig. 1.- Distribution of dissolved oxygen (% saturation) in Hospital Bay on 23 September 1968. (a) Bottom (b) Surface.

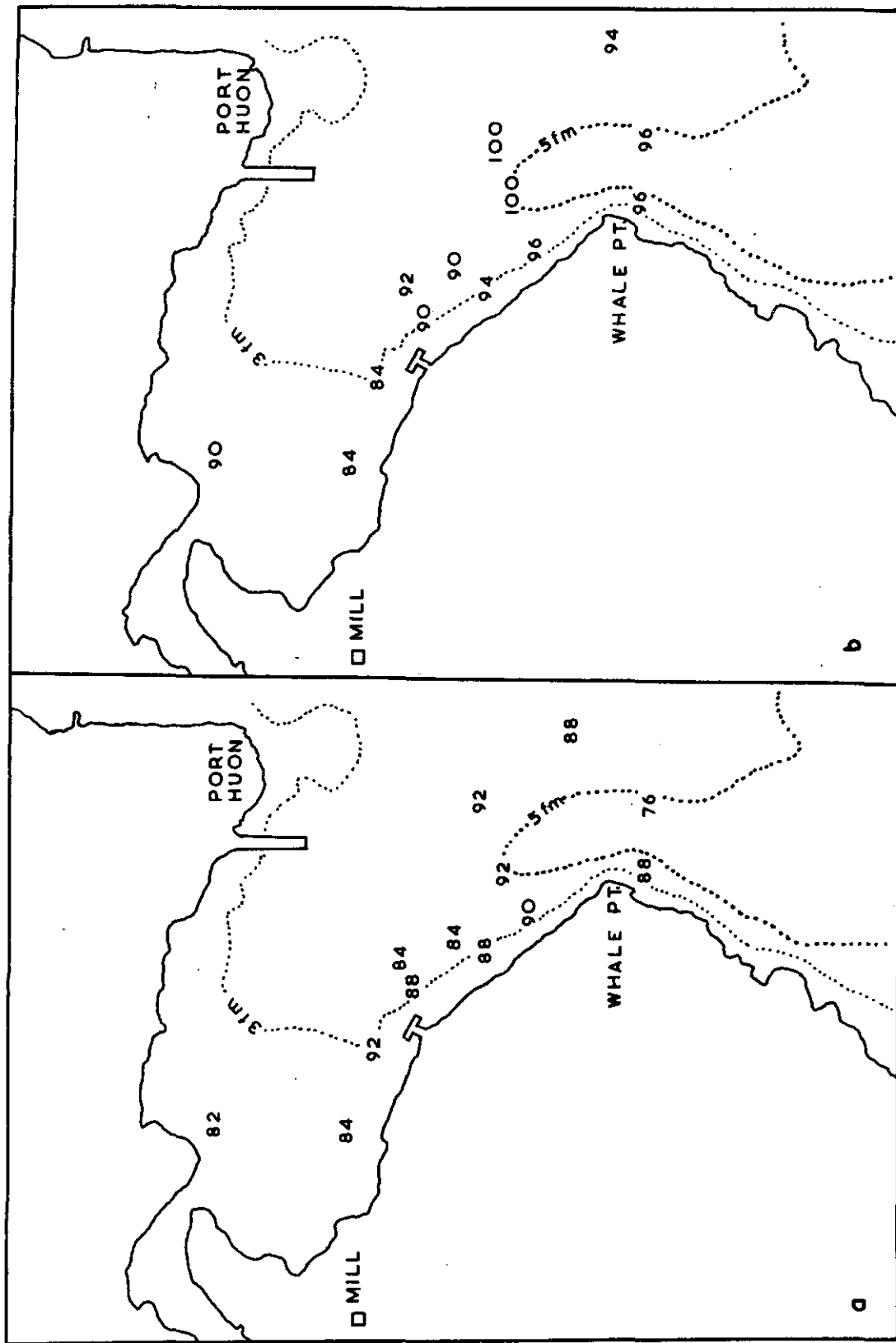


Fig. 2.- Distribution of dissolved oxygen (% saturation) in Hospital Bay on 25 September 1968. (a) Surface (b) Bottom.

Figure 2 gives the situation at high water. Heavy rain on September 24 had produced a layer of brackish water (chlorinity 3-10‰, temperature 8-9°C) some 1-2 m deep over the whole bay, overlying the uniform saline water (chlorinity 19.1‰, temperature 11.6°C) found throughout the bay on the 23rd. However, the flood tide had apparently flushed out the bay, raising oxygen saturation values, especially at the bottom.

2. Natural fluorescence

Since mill effluent had previously been tested and found to emit radiation at wavelengths over 595 nm when excited by light from a low-pressure cold cathodemercury lamp, samples collected from the surface of the bay on the 23rd and from both surface and bottom on the 25th were compared against distilled water in the Turner 111 fluorometer.

The results obtained are plotted against oxygen saturation in Figure 4. Interpretation of the results is difficult in that Kermadec River water is itself fluorescent (maximum 70 units) and the effluent is self-quenching at less than about 150 times dilution, giving a maximum also of 60-70 dial units. However, chlorinity levels in the superficial brackish layer indicate that this layer contained 56-70% of river water, so that fluorescence levels without effluent contamination should have been only 35-50 units. There seems also no reason for the river water to be unsaturated with oxygen (in fact 100% saturation was found at the mouth of the river on the 23rd, Fig. 1). The most reasonable explanation is that effluent discharged at the head of the bay (see earlier) mixed rapidly in the brackish layer and spread throughout the bay and into the main channel. The pattern of dispersal on the 25th was therefore quite different from that on the 23rd, when the effluent escaped mainly along the bottom. Only two samples of saline water showed lowered oxygen with increased fluorescence (Fig. 4).

3. Chlorinity and temperature

On September 25, chlorinity and temperature measurements were carried out between 1020 and 1210 h, i.e., from approximately high water to over two hours of ebb flow. Measurements were continued at the eastern end of the jetty until 1600 h in order to observe conditions at low water. Results are shown in Table 1. The pattern emerging from the latter observations was that of a simple fall in level of the whole water column, with fluctuating values at 2 m depth (the boundary between the brackish surface layer and the underlying saline water). Such fluctuations suggest internal waves, providing energy for vertical mixing across the halocline.

The stations occupied formed two longitudinal sections, one from the Kermantie River mouth and one from just up-river of Shipwright Point, downstream to Petchey Bay (Fig. 3). The vertical profiles of six stations are shown in Figure 5. All 18 stations showed similar vertical profiles, with in general, a brackish water layer diminishing in depth downstream, separated by a mixing gradient from an underlying saline layer, uniform in chlorinity and temperature to the bottom.

Such a situation falls into Bowden's "two layer system" of estuary classification, with the outflowing river water receiving an admixture of deeper saline water, so that the total seaward transport in the upper layer increases with distance downstream. Calculation of the Froude interfacial number gave a value of 0.78 at Bullock Point, with decreasing values up-river as the density difference between the layers and the depth of the brackish layer increased. The Froude number was calculated from the formula

$$F' = \frac{u^2}{\delta g D}$$

where u = velocity in the upper layer (cm sec^{-1}),

$$\delta = \frac{\rho_2 - \rho_1}{\rho_2},$$

D = Depth of upper layer (m),

ρ_2 = Density of lower layer,

ρ_1 = Density of upper layer,

g = 978 cm sec^{-2} .

D was assumed to be 1 m, and u was calculated from the cross-sectional area of the estuary and an estimated transport (T) of 16,400 cusec in the upper layer on the 25th. Such a value of F' (0.78) is consistent with the two layer hypothesis.

In such a system, the transport seawards in the upper layer through any cross-section is given by

$$T = \frac{S_2}{S_2 - S_1} \cdot R$$

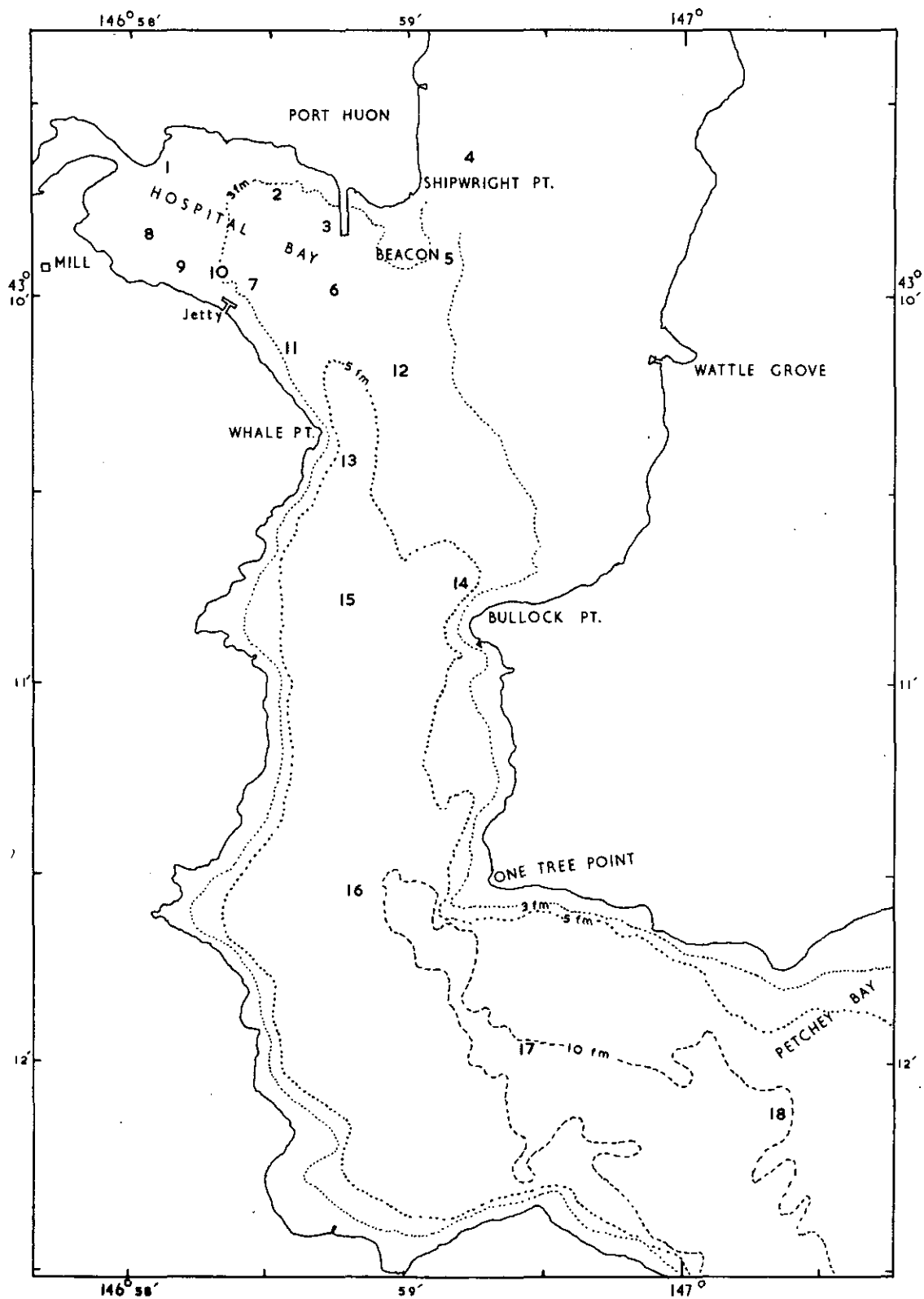


Fig. 3.- Chart of area investigated, showing positions at which chlorinity and temperature measurements were made (1-18).

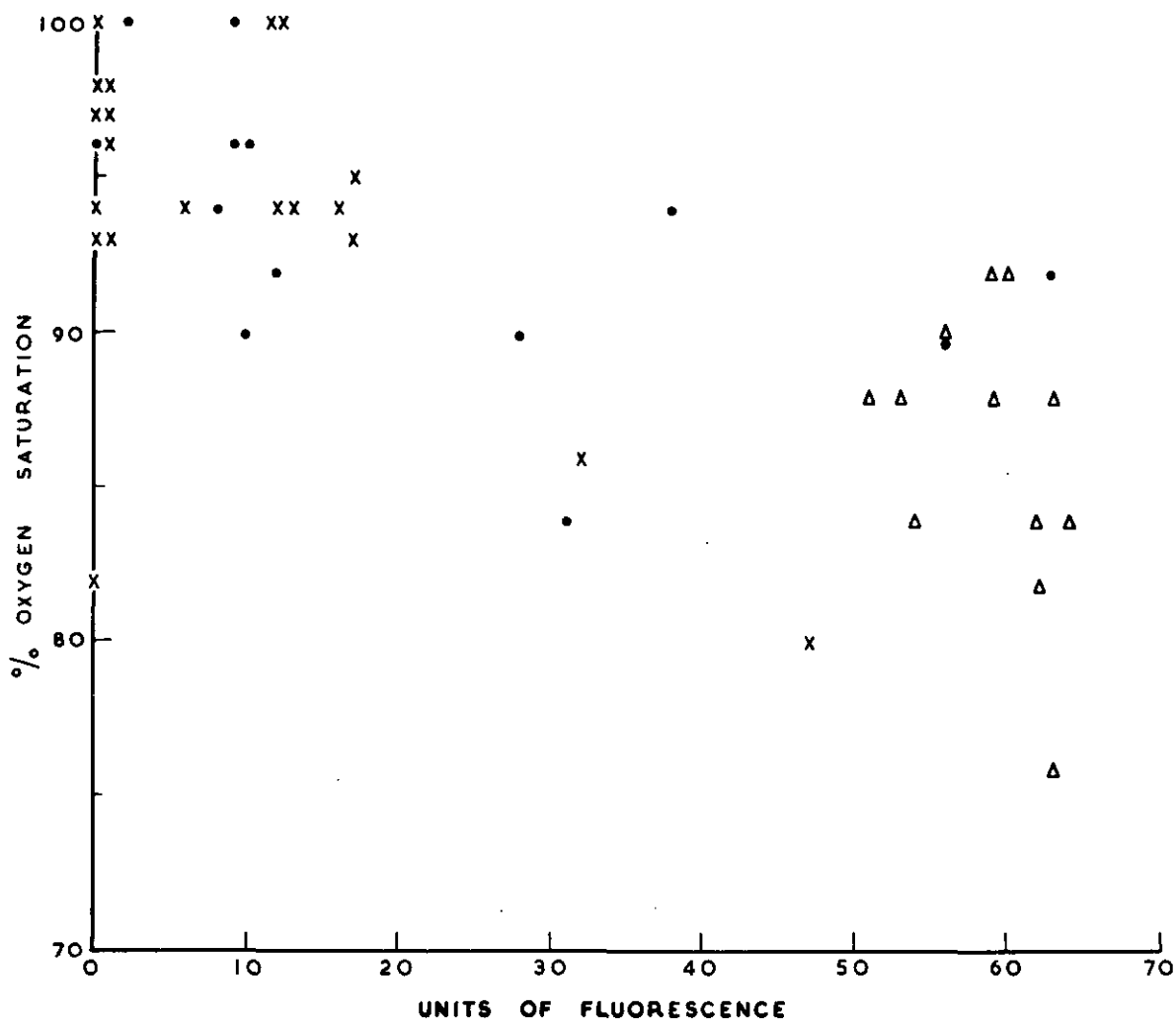


Fig. 4.- Fluorescence of water samples from Hospital Bay plotted against % oxygen saturation, showing increase of fluorescence with diminution of oxygen.
 X Surface 23.9.68 ● Bottom 25.9.68 Δ Surface 25.9.68

where T = transport seawards in upper layer (cusec),

R = volume of river flow into system (cusec),

S_2 = salinity of deeper layer (‰),

S_1 = salinity of upper layer (‰).

(Salinity = $0.03 + 1.805 \times \text{chlorinity}$)

At Bullock Point, $T = 1.4 R$, whilst at Petchey Bay $T = 2.1 R$. (The increase in seaward transport in the upper layer is compensated for by an increase in upstream transport in the lower layer.) The river flow was exceptionally high on September 24 (12,000 cusecs) and still high (8,500 cusecs) on September 25th so that there was abundant seaward flow to disperse effluent provided it were introduced into the main Huon Channel. This was not the case on September 23, when the Kermantie flow was negligible and the effluent tended to flow from the mud flats along the bottom, where it would probably, on the flood tide, be transported up-river with the deep compensating flow. Without measurements of velocity profiles over at least one tidal cycle, no calculation can be made of subsequent dispersal. On September 25, the Kermantie River flow was adequate to mix and disperse the effluent from the mud flats throughout the brackish layer, but this resulted in generally low surface oxygen in the bay (Figs. 2 and 4). It is therefore important that the effluent be directed down the pipe line, taking it as close as possible to the main channel.

4. Rhodamine B studies

Partial flow of effluent down the pipe line had been restored by the afternoon of the 25th, and observations with the oxygen probe from the jetty in the vicinity of the outlet showed transient occurrences of poorly oxygenated water (as low as 34% saturation) in the zone of the salinity gradient between 1 and 2 m from the surface. This suggested a rapid convective rise of the warm effluent. Experiments in a glass vessel confirmed that warm effluent (40°C) taken directly from the pipe line sank rapidly through samples of the brackish surface layer, but floated indefinitely on top of samples from the deeper saline layer.

On September 26, when pipe line flow was fully restored, small quantities of Rhodamine B dye were dispersed into the vertical leg of the pipe line through an inspection cover. However, samples collected from the jetty, initially at 1-2 m depth, and then throughout the water column (by means of a hand pump and hose) showed no sign of dye. The remaining portion of dye, about 40 lb, was therefore tipped into the

pipe line and a watch kept from the top of the loading tower over the jetty. After a few minutes, a patch about 20 ft in diameter of darker hue than the surrounding water became visible and moved rapidly along the jetty in a generally north-east direction. In 15 minutes, the patch, now about 50 ft in diameter, reached the end of the jetty and moved off toward Port Huon. Our intention of following the dispersion of dye therefore had to be abandoned, since the dye patch could not be seen at sea level through the brown surface layer and movement in such a "cloud" fashion makes sampling an erratic and misleading process.

Dye patches in the surface layer moved in a clockwise fashion round the bay, passing from the jetty north-west to the beacons, thence across to the north shore and then south-east past the town jetty. This occurred on the falling tide. On the 25th, at high water, higher salinities were found along the southern fringe of the bay than along the northern shore, so that it seems probable that a clockwise circulation cell exists in the surface layer of the bay at all states of the tide, powered by entrainment in the River Huon flow at the north-east corner, deflection at Whale Point, and flow of the Kermadie River along the northern edge. Local residents claim to have observed such a clockwise circulation.

5. Dissolved organic matter

None of the samples collected from the deep saline layer showed any discolouration due to the presence of wood-extractives. (All brackish layer samples were brown with humus.) A sample of "black liquor" diluted 50 times with sea-water clouded slightly and remained stable for 28 days. It seems likely, therefore, that the organic semi-colloidal residues in the effluent would be dispersed in the same way as the dissolved materials. The deposits of black material along the foreshores are presumably an accumulation of material dried out at low tides and not redissolved at high tide.

CONCLUSIONS

The present system of effluent disposal seems effective, resulting in convective mixing with subsequent rapid movement away from the jetty. The flow pattern in the Huon Channel provides abundant reserves of oxygenated water and is likely to mix the warm effluent rapidly through the salinity gradient into an outflowing seaward surface layer.

No oxygen levels below the legal minimum were observed, even under least favourable conditions. However, it is suggested that any increase in effluent flow be accommodated by an adequate pipe line to take the effluent at least as far as the jetty, discharging about 6 ft below mean low water. This would assist mixing of effluent into the surface system of the estuary.

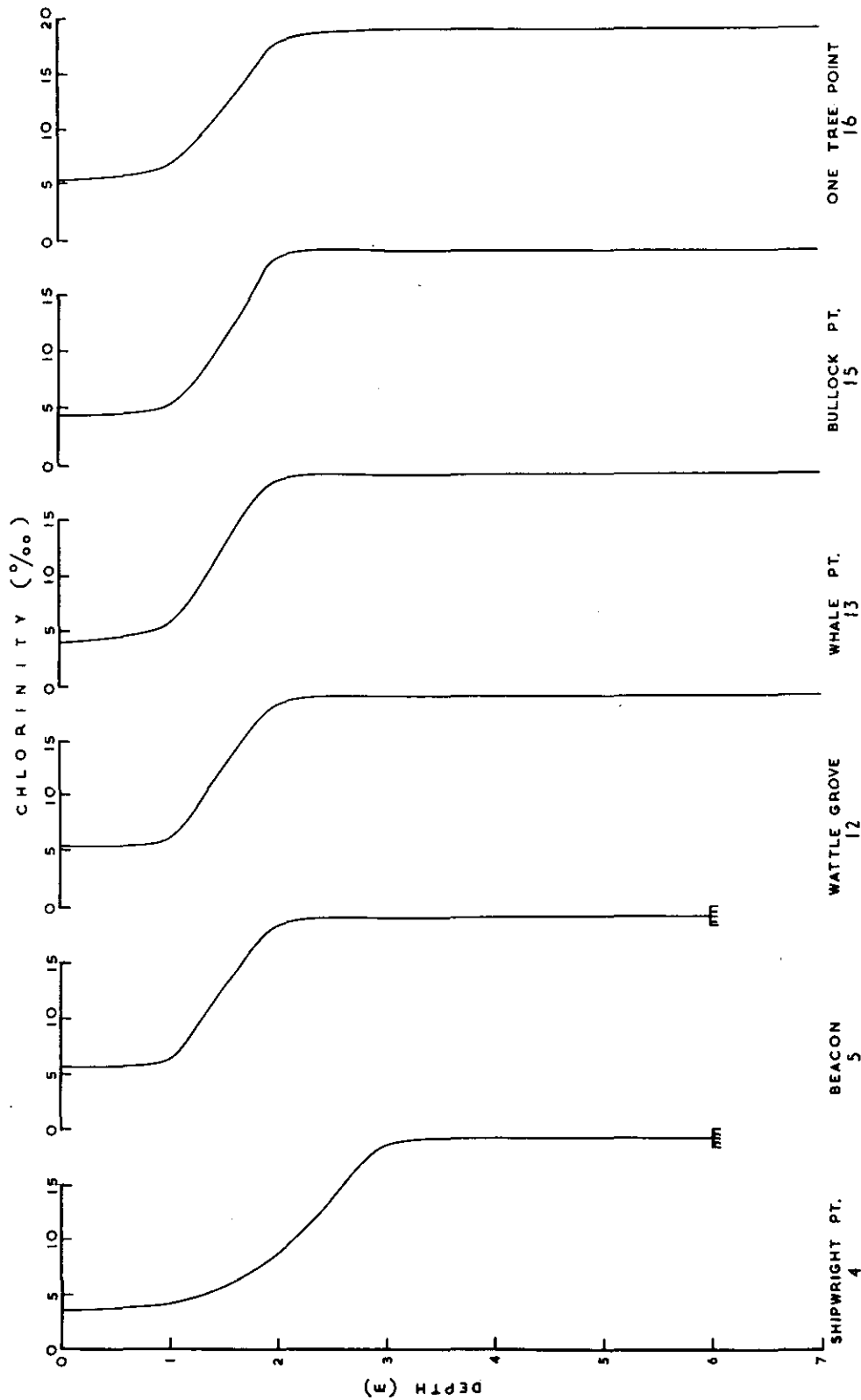


Fig. 5.- Chlorinity distribution with depth at six stations in River Huon main channel.

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- MACKERETH, F.J.H. (1964).-- An improved galvanic cell for determination of oxygen concentrations in fluids. J. scient. Instrum. 41, 38-41.

TABLE 1
Chlorinity and temperature

Station	Time h	Depth m	Temperature °C	Chlorinity ‰
1	1020	0	8.3	6.33
		1	8.3	7.08
		2	9.5	12.38
		3	11.4	18.18
		4	11.6	18.78
		5	11.6	19.01
		6	11.6	19.14
		7	11.6	19.14
2	1030	0	8.6	6.4
		1	8.6	6.4
		2	11.4	18.53
		3	11.6	18.98
		4	11.6	19.06
		5	11.6	19.11
		6	11.6	19.11
3	1037	0	8.4	6.38
		1	8.4	6.48
		2	11.6	18.41
		3	11.6	18.84
		4	11.6	19.02
		5	11.6	19.08
		6	11.6	19.11
		7	11.6	19.11
4	1045	0	8.3	3.68
		1	8.3	4.08
		2	11.0	8.58
		3	11.6	18.73
		4	11.6	19.04
		5	11.6	19.11
		6		
5	1050	0	8.5	5.48
		1	8.2	6.08
		2	11.5	18.00
		3	11.6	18.80
		4	11.6	19.04
		5	11.6	19.08
		6	11.6	19.08

Station	Time h	Depth m	Temperature °C	Chlorinity ‰
6	1055	0	8.5	6.38
		1	9.8	11.08
		2	11.6	18.08
		3	11.6	18.98
		4	11.6	19.06
		7	11.6	19.08
		8	11.6	19.10
		11	11.6	18.91
7	1100	0	8.6	6.68
		1	10.4	9.58
		2	11.6	17.38
		3	11.6	18.98
		4	11.6	19.05
		5	11.6	19.10
		8	11.6	19.10
		8	1107	0
1	9.8			9.48
9	1110	0	8.6	7.18
		1	8.6	7.98
		2	11.0	10.88
10	1115	0	8.7	6.28
		1	8.4	7.68
		2	11.5	18.03
		3	11.6	18.95
		4	11.6	19.06
		7	11.6	19.06
11	1120	0	8.6	4.38
		1	8.1	6.18
		2	11.6	18.35
		3	11.5	18.88
		4	11.5	19.05
		5	11.5	19.11
		10	11.5	19.11
12	1125	0	8.7	5.28
		1	8.9	5.88
		2	11.5	18.31
		3	11.5	18.98
		4	11.5	19.00
		5	11.5	19.05
		7	11.5	19.09
		8	11.5	19.12
		11	11.5	19.12

Station	Time h	Depth m	Temperature °C	Chlorinity ‰
13	1133	0	8.6	4.08
		1	8.6	5.68
		2	11.4	18.71
		3	11.6	18.95
		4	11.6	19.04
		5	11.6	19.05
		6	11.6	19.08
		9	11.6	19.13
14	1140	0	8.5	4.28
		1	8.4	4.48
		2	11.6	18.45
		3	11.6	18.84
		4	11.6	18.92
		5	11.6	19.04
		6	11.6	19.10
		7	11.6	19.12
15	1146	0	8.5	4.18
		2	11.3	18.42
		3	11.6	18.88
		4	11.6	19.03
		6	11.6	19.08
		7	11.6	19.12
		12	11.6	19.13
		15	11.6	19.13
16	1155	0	8.9	5.28
		1	9.4	6.68
		2	11.4	17.88
		3	11.6	18.88
		4	11.6	19.03
		5	11.6	19.05
		6	11.6	19.10
		10	11.6	19.12
		13	11.6	19.14
18	11.6	19.14		
17	1202	0	8.8	5.18
		1	11.0	17.78
		2	11.6	18.45
		3	11.6	18.92
		4	11.6	18.95
		6	11.6	18.98
		7	11.6	19.03
		9	11.6	19.05
		11	11.6	19.08

Station	Time h	Depth m	Temperature °C	Chlorinity ‰
18	1210	0	9.0	6.48
		1	11.2	17.13
		2	11.5	18.73
		3	11.5	18.75
		4	11.5	18.72
		5	11.5	19.00
		9	11.5	19.03
		13	11.5	19.04
		14	11.5	19.06
Jetty	1300	0	9.0	5.78
		1	8.9	7.38
		2	11.4	17.78
		3	11.6	18.86
		4	11.6	19.05
		5	11.6	19.12
		7	11.6	19.13
		8	11.6	17.95
		Jetty	1400	0
1	9.0			5.28
2	11.1			16.15
3	11.6			18.62
4	11.6			19.03
5	11.6			19.12
9	11.6			19.12
Jetty	1508	0	8.9	5.38
		1	8.9	5.68
		2	9.7	9.58
		3	11.7	18.18
		4	11.6	18.95
		5	11.6	19.08
		6	11.6	19.11
		8	11.6	19.12
		9	11.6	19.05
Jetty	1610	0	9.0	2.88
		1	9.0	3.48
		2	11.3	17.18
		3	11.8	18.51
		4	11.6	18.98
		5	11.6	19.11
		9	11.6	19.13

PART 2

INTRODUCTION

The investigations discussed in Part 1 of this report were made in winter, when flow in the Kermadie and Huon Rivers was high and mixing of at least the upper zone of the water was facilitated by strong winds and a negative temperature gradient in the water column. Whilst no serious deoxygenation of Hospital Bay or its environs was discovered, this reflected only the winter condition. The low river flow, high temperature gradient, and light winds of summer could be expected to reduce flushing, mixing, and natural aeration rates. Another survey was therefore planned for February 1969 and the results of that survey are described in this report.

Personnel

The survey was carried out by the author, with the assistance of Mr John Larkin, the chemist at Port Huon Mill.

METHODS

Measurements of chlorinity and temperature were made with a CSIRO S-T meter, as in Part 1.

Samples for dissolved oxygen determination were collected in a Nansen reversing bottle. Glass sample bottles (500 ml capacity) were filled from this by a plastic tube reaching to the bottom of the bottle. The sample bottle was withdrawn slowly when full with water still flowing. No air bubbles were present in the system. The standard Winkler reagents (manganous sulphate, sodium hydroxide, potassium iodide, and concentrated sulphuric acid) were added to samples within a few minutes of collection, except that the manganic hydroxide precipitate was allowed to settle before addition of the sulphuric acid. Sub-samples of 200 ml volume were titrated to a starch end-point with 0.025 N sodium thio-sulphate standardized against N/10 potassium iodate.

Measurements of current flow were made with a Pritchard vane as described by Foerster (1968). Strength of current flow is measured by the deviation from vertical of a cord attached to a vane composed of two metal planes intersecting at right angles.

The positions (1-11) at which readings of chlorinity and temperature and samples for dissolved oxygen were taken on February 18 are shown in Figure 6. A series of chlorinity, temperature, and current readings were taken at the end of the Port Huon pier (A, Fig. 6) over a 12 hour period from 0830 to 1945 h on February 19. On the 20th, chlorinity, temperature, and current readings and samples for dissolved oxygen were taken from 0900 to 2030 h at the A.P.M. jetty (B, Fig. 6).

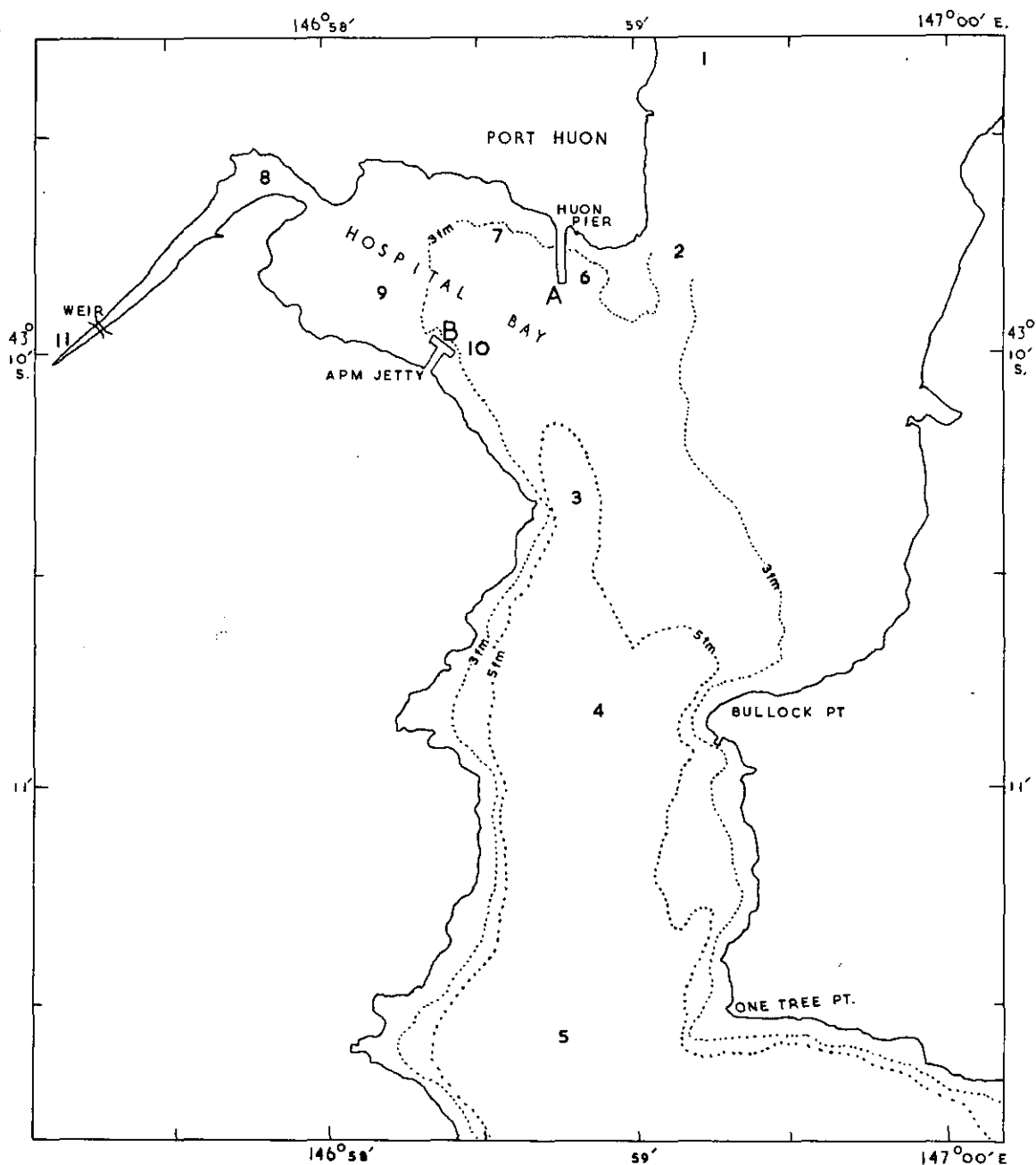


Fig. 6.- Positions (1-11) at which readings of chlorinity and temperature were taken, and samples collected for dissolved oxygen determination. Also positions at which temperature, chlorinity and current measurements were made over one tidal cycle. Station A, Huon Pier 19.2.69. Station B, A.P.M. Jetty 20.2.69.

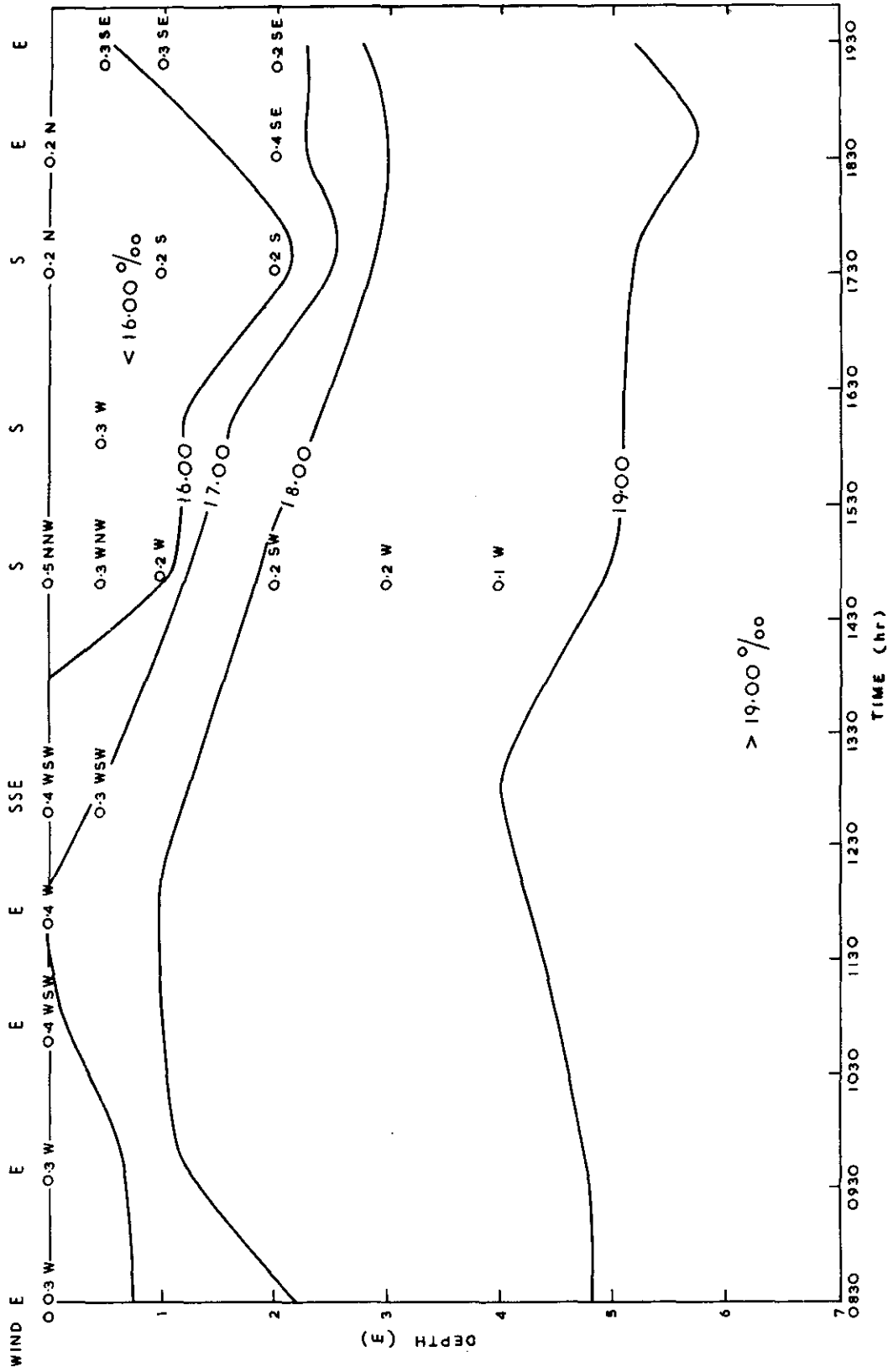


Fig. 7.- Rise and fall of isochlors, and changes in water movements over one tidal cycle at Station A. Current velocities in ft.sec⁻¹.

RESULTS

All data are given in tabular form in Tables 1-3. Graphical presentations of the observations from Port Huon pier and the A.P.M. jetty are also given in Figures 7 and 8.

The most obvious differences found in February as compared to September were decreased stratification of the water column and generally lower levels of oxygen saturation. Whereas the water column in September showed a cold brackish layer 1-2 m thick overlying a uniform warmer but more saline layer, the water column in February showed a positive gradient in both temperature and chlorinity. Confirmation of this mixing gradient was obtained by comparing the colour of the samples taken at various depths. In September the whole brackish layer was dark brown and the underlying saline layer quite clear (Fig. 4 shows only two bottom samples with low oxygen and high fluorescence caused by effluent). In February the colour of the samples diminished with depth from dark brown at the surface (almost black in the two samples of 2.00 and 2.45 p.p.m. dissolved oxygen content collected on the morning of the 20th) to clear at 3-4 m.

Given such a mixing gradient, the two-layer transport system described in Part 1 still applies. Taking Station 3 (Fig. 6) as representative of main river channel conditions, the water column may be divided into an upper portion of mean chlorinity 18.60‰ and a lower portion of mean chlorinity 19.20‰, separated by a zone of steepest chlorinity gradient at about 5 m (Fig. 9). Applying these values to the equation used in Part 1 it is found that total transport seawards in the upper layer is 32.5 R, where R is the river flow. The increased mixing of saline water from the lower layer upwards compensates for the lower river flow in summer. Even at the low river flows encountered during the survey (346 cusecs on February 18th) there existed ten times the required volume of advected water to satisfy the oxygen demand of the effluent. This flow approaches the minimum recorded over twenty one years (311 cusecs in February 1956). However, for this to apply, the effluent must find its way rapidly and continuously into the main river channel. The dissolved oxygen values (as low as 2 p.p.m.) found in Hospital Bay during this survey suggest that this condition is not satisfied, and that local accumulation of effluent occurs.

The measurements of temperature, chlorinity, and current flow carried out at the end of the Port Huon pier and A.P.M. jetty were an attempt to examine the pattern of flow in Hospital Bay.

The results were extremely complex, but can best be explained by wind changes, tidal effects being negligible. The amplitude of tide measured by sounding was only about 30 cm and high water occurred at about 1000 h on both days although the water structure was quite different at this time on each day (Figs. 7 and 8). Low water was

easily recognized between 1630 and 1730 h on the 19th, but on the 20th, at the A.P.M. jetty, water level remained almost constant from 1400 to 2030 h. Tidal fluctuations may therefore be masked by movement of water under wind stress. With such a low tidal amplitude compared to depth (1 in 20-30) tidal flushing alone would be extremely ineffective in removing effluent.

The changes in water structure shown in Figures 7 and 8 coincide with changes in wind direction. Taking the 19th (Fig. 7) it can be seen that with consistent east winds from 0830 to 1200 h the isochlors slowly ascended. No flow could be detected at depth, but a thin surface skin was moving steadily westward. With a sudden change of wind to the south-south-east and then south from 1300 h, the pattern altered. The isochlors descended, and a flow southwestward was observed to 4 m depth. Whilst measurable flow ceased after 1500 h the isochlors continued to descend until a backing of the wind to east at 1830. After this the isochlors began to ascend, and some flow south-eastwards was detected to 2 m depth. On the 20th (Fig. 8) the advent of a strong west wind from 1100 h coincided with detectable flow northwestward and ascent of the isochlors. A sudden change to strong south-east and east-south-east winds at 1900 h was accompanied by a descent of the isochlors and water movement northwestwards to 3 m depth. The pattern of change may be explained by the wind displacing water from the main river to Hospital Bay and vice versa. South winds tended to accumulate low-chlorinity water from the river against the northern shore of the bay (afternoon of the 19th). East winds moved river water towards the south-west side of the bay (evening of the 20th) with a compensating uplift of deeper, more saline water along the northern shore (morning of the 19th). West winds moved surface water out of the bay, giving an uplift of more saline water along the southern shore.

However, the net transport resulting from such wind induced movements might be negligible. The current velocities found were very low (0.1 to 0.5 ft sec⁻¹) and for much of the time no flow could be detected. If the movements were oscillating, with alternating wind direction, as observed in this survey, only small portions of bay water would occasionally be entrained in the river flow seawards.

An approximate check on the efficiency of circulation in Hospital Bay may be obtained by comparing the dissolved oxygen levels found to those expected if only natural atmospheric reoxygenation were occurring. A review of oxygenation by Hutchinson (1957) gives constants which may be used for calculating oxygenation rates. More recent work by Hanya and Hirayama (1964) substantially confirms the magnitude of these constants. Briefly, the rate of entry of oxygen from the atmosphere into a water surface is given by the relation:-

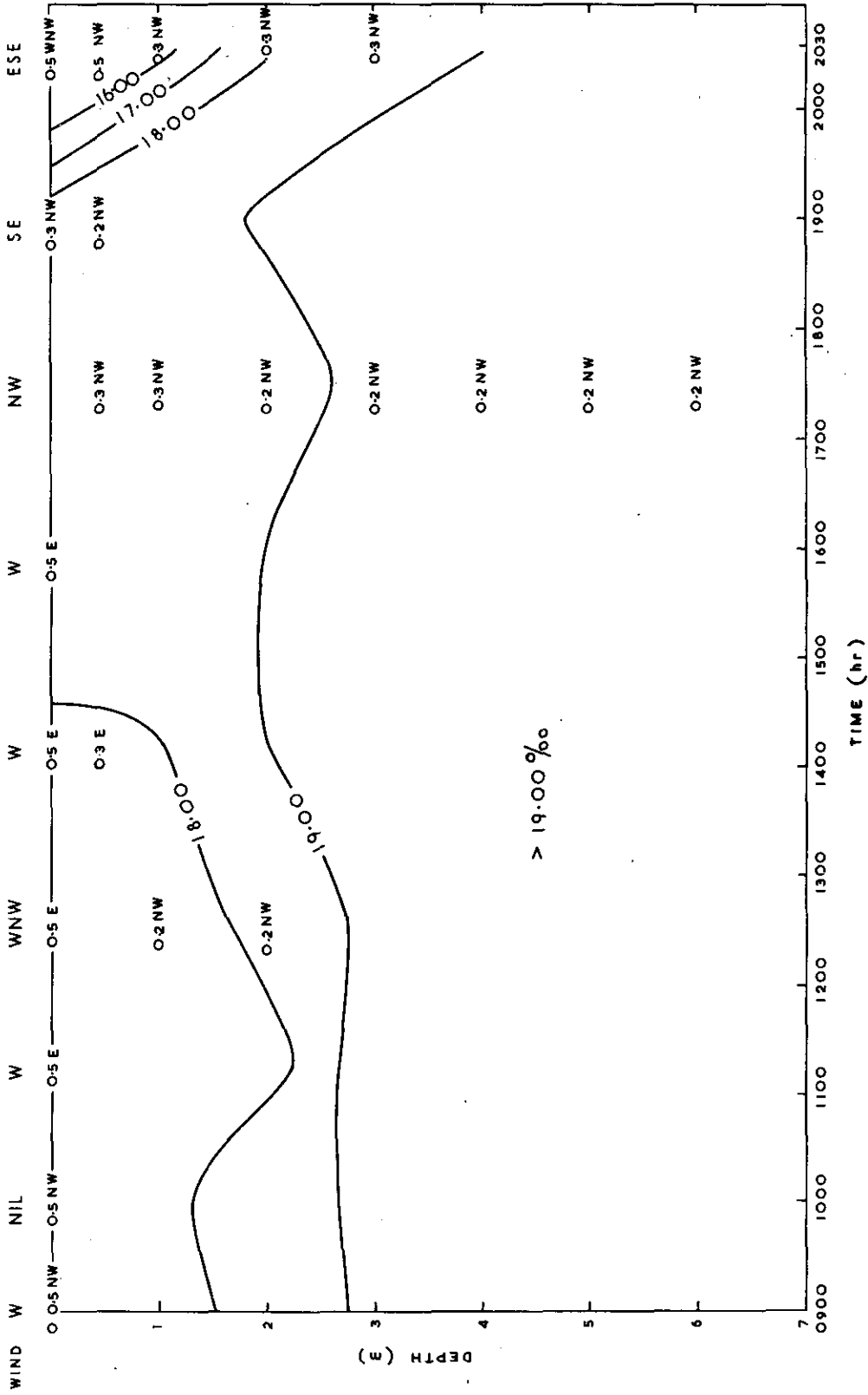


Fig. 8.- Rise and fall of isochlors, and changes in water movements over one tidal cycle at Station B. Current velocities in ft. sec⁻¹.

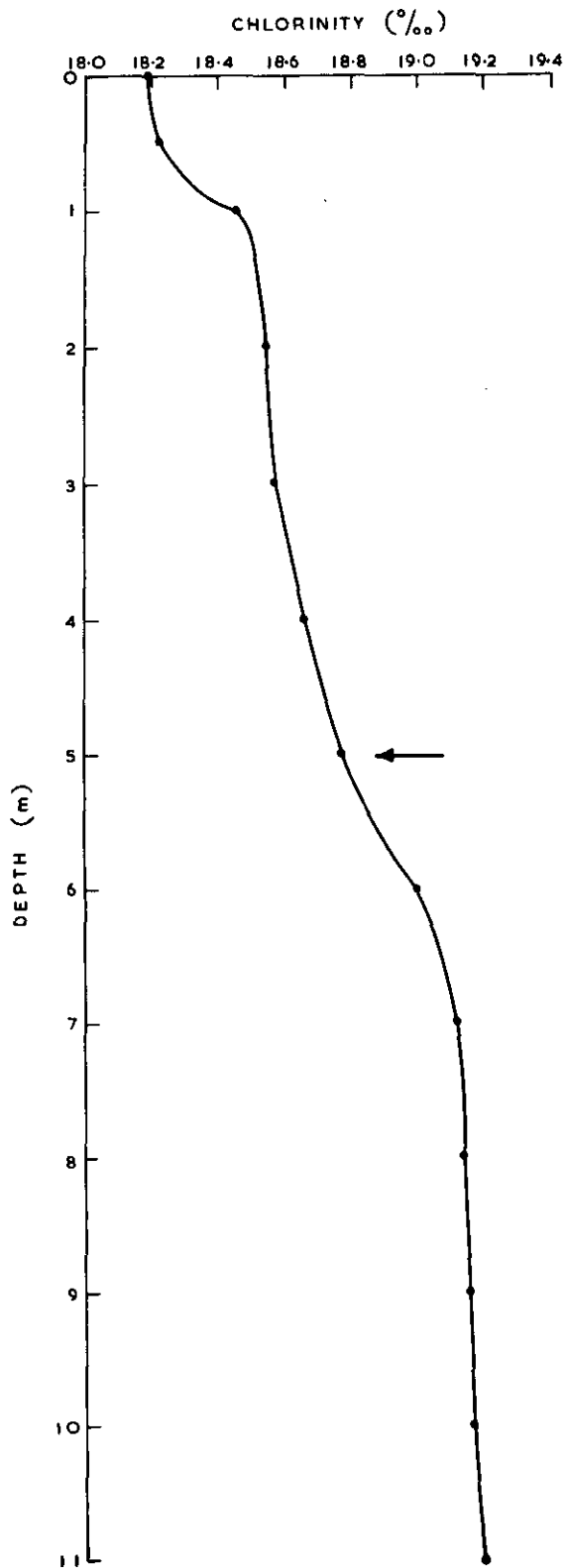


Fig. 9.- Chlorinity-depth profile at Station 3, 18.2.69.
Arrow indicates zone of maximum chlorinity gradient.

$$\frac{dO}{dt} = \alpha P_A \left(1 - \frac{P_W}{P_A}\right) = \alpha (P_a - P_w)$$

where $\alpha = 3.5 \times 10^5 \text{ mg O}_2 \text{ m}^{-2} \text{ day}^{-1} \text{ atmosphere}^{-1}$

P_A = Vapour pressure of oxygen in air in atmospheres

P_W = Vapour pressure of oxygen in water in atmospheres.

The rate of oxygen transfer therefore varies linearly with percentage oxygen saturation of a given body of water. On the assumption that the water surface is continually renewed by wind and wave action (which is likely to be true in Hospital Bay) and that the oxygen transferred is continually consumed by effluent material (which is also probable since the effluent is discharged continuously and mainly confined to the surface layers) then an equilibrium should exist between transfer and consumption.

Converting the constant α to $\text{lb O}_2 \text{ ft}^{-2} \text{ hr}^{-1} \text{ atmosphere}^{-1}$, assuming that the partial pressure of oxygen in air is 0.2 atmospheres, and estimating the surface area of Hospital Bay as $25.5 \times 10^6 \text{ ft}^2$, then a 10% deficiency in oxygen saturation results in a transfer rate of $1500 \text{ lb O}_2 \text{ hr}^{-1}$ across the surface of the bay. The effluent B.O.D. of 2000 lb hr^{-1} corresponds to a decrease in oxygen saturation by 13.3% in the bay.

The oxygen saturation of the Kermadie River surface water flowing into Hospital Bay is 81% (Station 11, Fig. 6, Table 1). Similarly, the oxygen saturation of main channel water (Stations 1-5, Fig. 6, Table 1) lies between 80 and 90%. If the bay water were originally composed of a mixture of these waters, and no flushing occurred, then the effluent should reduce the bay water to about 70% oxygen saturation. This was, in fact, approximately the level found (Stations 6-10, and B, Fig. 6, Tables 1,3). The occasional lower or higher values probably reflect unequal distribution of effluent in the bay.

Hence, a doubling in output of effluent could only be accommodated (at least in summer) by a decrease in oxygen saturation to less than 60% corresponding, in summer, to oxygen levels below 5 p.p.m.

CONCLUSIONS

In February 1969 seaward transport in the upper 5 m of the Huon River below Shipwright Point was more than adequate to disperse and oxygenate the effluent from the Port Huon Mill. However, the circulation

in Hospital Bay was slow and probably oscillating, so that effluent discharged into the bay was not reaching the river until most of its oxygen demand was satisfied. This resulted in generally low levels of oxygen in the bay. Several samples of bay water were discoloured, extending to about 3 m depth. The discolouration would greatly restrict the amount of light available for phytoplankton growth. Effluent diluted with sea-water throws down a brown precipitate after five months standing (but not when diluted with distilled water) and the foreshores of Hospital Bay are covered with a dark brown deposit. Continued discharge of effluent into Hospital Bay will worsen this situation.

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TABLE 1

Values of temperature, chlorinity and dissolved oxygen found in the Kermantie River, Hospital Bay and Huon River 18-2-69

Station	Time	Depth m	Temp. °C	Chlor. ‰	Oxygen p.p.m.	Oxygen % sat.
1	1000	0	17.5	14.70	6.15	75
		$\frac{1}{2}$	18.2	18.00		
		1	17.4	18.38		
		2	17.4	18.43	6.55	85
		3	17.2	18.46		
		4	16.7	18.54		
		5	16.7	18.61		
		6	16.4	18.61		
		7	16.1	18.70	5.70	70
		8	15.8	18.75		
2	1030	9	15.8	18.90		
		0	18.1	16.40	6.55	83
		$\frac{1}{2}$	17.5	18.14		
		1	17.5	18.36		
		2	17.2	18.46	6.70	85
		3	17.0	18.53		
		4	17.0	18.53		
3	1100	5	16.9	18.56	6.55	83
		0	18.5	18.20	6.60	86
		$\frac{1}{2}$	17.4	18.22		
		1	17.4	18.45		
		2	17.1	18.55		
		3	17.0	18.57		
		4	16.7	18.66		
		5	16.5	18.77		
		6	16.1	19.00		
		7	15.9	19.12		
		8	15.7	19.14	6.75	84
		9	15.4	19.16		
		10	15.3	19.17		
		11	15.2	19.20		
12	15.1	19.23				
13	15.1	19.23	6.20	76		
14	15.0	19.26				
4	1120	0	18.6	18.17	6.80	88
		$\frac{1}{2}$	18.5	18.14		
		1	18.0	18.37		
		2	17.5	18.47		

TABLE 1 - Continued

Station	Time	Depth m	Temp. °C	Chlor. ‰	Oxygen p.p.m.	Oxygen % sat.		
4	1120	3	17.4	18.50				
		4	17.1	18.59				
		5	16.2	19.00				
		6	16.2	19.10	7.20	90		
		7	16.2	19.12				
		8	15.9	19.15				
		9	15.8	19.15				
		10	15.7	19.15				
		11	15.6	19.15				
		12	15.5	19.15				
		13	15.1	19.26	6.70	82		
		14	15.0	19.30				
		15	15.0	19.30				
		16	15.0	19.30				
		5	1145	0	18.4	16.30	6.30	80
				$\frac{1}{2}$	18.4	16.40		
1	17.7			17.90				
2	17.3			18.50				
3	16.9			18.65				
4	16.7			18.73				
5	16.4			18.96				
6	16.5			19.14				
7	16.5			19.14				
8	16.2			19.16	7.70	96		
9	16.2			19.16				
10	16.2			19.16				
11	16.1			19.18				
12	16.1			19.18				
13	15.9			19.20				
14	15.3			19.25				
15	15.0			19.27				
16	14.8			19.33				
17	14.8			19.33	6.90	84		
18	14.8	19.35						
6	1225	0	19.3	15.60	6.40	82		
		$\frac{1}{2}$	19.2	15.90				
		1	17.5	16.70				
		2	17.4	18.50				
		3	17.3	18.50				
		4	17.1	18.54	6.45	82		
		5	16.2	18.95				
		6	15.6	19.06				
		7	15.5	19.10				
		8	15.4	19.15	5.65	72		
9	15.4	19.15						

TABLE 1 - Continued

Station	Time	Depth m	Temp. °C	Chlor. ‰	Oxygen p.p.m.	Oxygen % sat.
7	1245	0	18.6	18.34	5.85	76
		$\frac{1}{2}$	18.6	18.30		
		1	18.5	18.30		
		2	18.1	18.33	5.75	74
		3	17.5	18.44		
		4	17.3	18.44		
		5	16.5	18.75	5.00	62
8	1305	6	15.9	19.05		
		0	20.6	16.40	4.00	52
		$\frac{1}{2}$	20.2	16.50		
		1	18.0	17.96	5.30	67
9	1330	2	17.5	18.34		
		0	20.1	16.60	5.70	73
		$\frac{1}{2}$	19.9	16.70		
		1	19.8	17.00		
		2	19.7	17.72	5.40	71
10	1345	3	17.0	18.66		
		0	20.1	15.10	5.95	77
		$\frac{1}{2}$	20.0	15.10		
		1	19.8	15.80		
		2	19.2	17.60	5.15	67
11	1330	3	18.0	18.45		
		4	17.4	18.45	5.60	71
		0	22.0	0.00	7.10	81
		$2\frac{1}{2}$		0.00	2.50	

TABLE 2

Temperature, chlorinity and water movements from surface
to bottom at the Port Huon pier 19-2-69

Station	Time	Depth m	Temp. °C	Chlor. ‰	Current ft. sec. ⁻¹	Current Direction	Wind
Huon pier (A)	0830	0	18.5	16.20	0.30	W	E
		$\frac{1}{2}$	18.0	16.50	Nil		
		1	18.0	17.36	"		
		2	18.3	17.95	"		
		3	17.4	18.24	"		
		4	16.3	18.70	"		
		5	15.8	19.06	"		
		6	15.7	19.06	"		
		7	15.8	19.07	"		
		8	15.8	19.10	"		
		9	15.6	19.10	"		
	0940	0	18.8	16.30	0.30	W	E
		$\frac{1}{2}$	18.6	16.70	Nil		
		1	18.4	17.42	"		
		2	18.2	18.13	"		
		3	17.4	18.43	"		
		4	16.8	18.57	"		
		5	15.8	19.10	"		
		6	15.8	19.07	"		
		7	16.0	19.08	"		
		8	16.0	19.10	"		
		9	15.9	19.10	"		
	1100	0	19.4	16.60	0.40	WSW	E
		$\frac{1}{2}$	18.8	17.90	Nil		
		1	18.5	18.00	"		
		2	18.3	18.14	"		
		3	17.3	18.52	"		
		4	16.3	18.90	"		
		5	16.2	19.09	"		
		6	16.0	19.10	"		
		7	15.9	19.10	"		
		8	16.0	19.10	"		
		9	15.8	19.10	"		
	1200	0	20.0	17.00	0.40	W	E
		$\frac{1}{2}$	18.7	17.85	Nil		
		1	18.7	18.03	"		
		2	18.2	18.24	"		
		3	17.5	18.50	"		
		4	16.3	18.98	"		
		5	16.2	19.06	"		
		6	16.2	19.07	"		
		7	16.3	19.10	"		
		8	16.2	19.10	"		
		9	16.0	19.15	"		

TABLE 2 - Continued

Station	Time	Depth m	Temp. °C	Chlor. ‰	Current ft. sec. ⁻¹	Current Direction	Wind
Huon pier	1300	0	21.5	16.00	0.40	WSW	SSE
		$\frac{1}{2}$	19.1	17.92	0.30	WSW	
		1	19.0	17.92	Nil		
		2	18.2	18.25	"		
		3	17.6	18.48	"		
		4	16.2	19.00	"		
		5	16.1	19.11	"		
		6	16.2	19.07	"		
		7	16.2	19.12	"		
	8	16.1	19.14	"			
	9	16.0	19.10	"			
	1500	0	22.4	15.50	0.50	NNW	S
		$\frac{1}{2}$	22.2	15.50	0.33	WNW	
		1	20.3	15.50	0.23	W	
		2	18.8	18.28	0.20	W	
		3	18.3	18.25	0.20	W	
		4	17.0	18.74	0.10	W	
		5	16.2	19.00	Nil		
		6	16.1	19.11	"		
		7	16.1	19.11	"		
	8	15.9	19.11	"			
	1615	0	23.0	15.20	Nil		S
		$\frac{1}{2}$	23.0	15.20	0.33	N	
		1	23.0	15.30	Nil		
2		20.0	17.80	"			
3		18.7	18.30	"			
4		18.0	18.47	"			
5		16.6	18.98	"			
6		16.2	19.11	"			
7		16.2	19.10	"			
8	16.0	19.11	"				
1740	0	23.3	15.10	0.20	N	S	
	$\frac{1}{2}$	23.3	15.10	Nil			
	1	23.2	15.30) 0.23	S		
	2	22.4	15.20				
	3	18.4	18.32	Nil			
	4	18.2	18.32	"			
	5	16.6	18.97	"			
	6	16.2	19.12	"			
	7	16.2	19.10	"			
8	16.1	19.14	"				

TABLE 2 - Continued

Station	Time	Depth m	Temp. °C	Chlor. ‰	Current ft. sec. ⁻¹	Current Direction	Wind
Hoon pier	1840	0	23.0	15.00	0.20	N	E
		$\frac{1}{2}$	23.0	15.20	Nil		
		1	23.0	15.30	"		
		2	22.9	16.40	0.40	SE	
		3	20.6	17.95	Nil		
		4	17.6	18.80	"		
		5	16.8	18.76	"		
		6	16.1	19.07	"		
	7	16.1	19.11	"			
	8	16.0	19.11	"			
	1945	0	23.0	15.80	Nil		E
		$\frac{1}{2}$	23.0	15.80	} 0.33	SE	
		1	23.0	15.90		SE	
		2	22.9	16.10	0.23		
		3	18.3	18.50	Nil		
		4	17.5	18.60	"		
5		16.2	18.97	"			
6		16.0	19.12	"			
7		16.0	19.12	"			
8	15.8	19.12	"				
	9	15.7	19.12	"			

TABLE 3

Temperature, chlorinity and water movements from surface to bottom and dissolved oxygen at surface and bottom at the A.P.M. jetty 20-2-69

Station	Time	Depth m	Temp. °C	Chlor. ‰	Oxygen p.p.m.	Oxygen % sat.	Current ⁻¹ ft. sec.	Current Direction	Wind
A.P.M. jetty (B)	0900	0	19.8	17.08	2.00	26	0.50	NW	W
		½	19.5	17.35		Nil			
		1	19.3	17.59		"			
		2	18.0	18.41		"			
		3	16.1	19.18		"			
		4	16.0	19.15		"			
		5	16.0	16.16		"			
		6	15.9	19.16		"			
	7	15.8	19.17	5.70					
	8	15.8	19.15						
	1000	0	20.5	17.21			0.50	NW	Nil
		½	19.9	17.59			Nil		
		1	19.2	17.88			"		
		2	18.4	18.28			"		
		3	16.1	19.29			"		
		4	16.1	19.16			"		
	5	16.1	19.16			"			
	6	16.0	19.16			"			
	7	15.9	19.16			"			
	8	15.8	19.16			"			
	1120	0	21.1	17.83			0.50	E	W
		½	20.9	17.63			Nil		
		1	19.7	17.93			"		
		2	17.7	17.65			"		
		3	16.2	19.18			"		
		4	16.2	19.17			"		
		5	16.1	19.17			"		
		6	16.1	19.17			"		
		7	16.0	19.17			"		
		8	16.0	19.17			"		

TABLE 3 - Continued

Station	Time	Depth m	Temp. °C	Chlor. ‰	Oxygen p.p.m.	Oxygen % sat.	Current ⁻¹ ft. sec.	Current Direction	Wind	
A.P.M. Jetty	1245	0	21.6	18.03	2.50	34	0.50	E	MNW	
		½	21.4	17.65		Nil				
		1	21.4	17.73			} 0.23	NW		
		2	19.0	18.19						
		3	16.3	19.30			Nil			
		4	16.2	19.21			"			
		5	16.2	19.18			"			
		6	16.0	19.18			"			
	7	16.0	19.18	6.05						
	8	16.0	19.18							
	1415	0	20.4	17.98				0.50	E	W (strong)
		½	20.4	17.95				0.33	E	
		1	20.2	17.97				Nil		
		2	17.2	19.03				"		
		3	16.2	19.13				"		
		4	16.2	19.16				"		
5		16.2	19.16				"			
6		16.2	19.16				"			
7	16.0	19.16				"				
8	16.0	19.18				"				
1600	0	19.4	18.24	4.85	64	0.50	E	W (strong)		
	½	19.2	18.26			Nil				
	1	19.3	18.20			"				
	2	17.0	19.03			"				
	3	16.2	19.24			"				
	4	16.2	19.20			"				
	5	16.2	19.18			"				
	6	16.1	19.18			"				
7	16.1	19.17	6.00							
8	16.0	19.17								

TABLE 3 - Continued.

Station	Time	Depth m	Temp. °C	Chlor. %	Oxygen p.p.m.	Oxygen % sat.	Current -1 ft. sec.	Current Direction	Wind	
A.P.M. jetty	1730	0	20.0	18.13			Nil		NW	
		1	20.0	18.05			0.33	NW		
		2	19.7	18.07						
		3	17.1	18.73			0.20			
		4	16.4	19.19			0.20			
		5	16.2	19.19			0.20			
		6	16.2	19.16			0.20			
		7	16.2	19.16			0.20			
	8	16.2	19.16			Nil				
	1900	0	20.1	18.13	4.60	61	0.30	NW	SE (strong)	
		1	20.0	18.13			0.23	NW		
		2	19.3	18.28			Nil			
		3	16.5	19.18			"			
		4	16.2	19.15			"			
		5	16.2	19.15			"			
		6	16.1	19.18			"			
7		15.4	19.18	6.40	79	"				
8	15.4	19.18			"					
2030	0	22.1	14.10			0.55	WNW	ESE (strong)		
	1	21.9	15.10			0.55	NW			
	2	21.9	15.10			0.30				
	3	19.4	17.97			0.30				
	4	18.9	18.37			0.30				
	5	17.0	18.97			Nil				
	6	16.0	19.27			"				
	7	15.7	19.27			"				
8	15.2	19.27			"					
		15.2	19.27			"				

COMMONWEALTH



OF AUSTRALIA

Commonwealth Scientific and Industrial Research Organization

Division of Fisheries and Oceanography

REPORT 45

TOTAL TRANSPORT AND FLUSHING TIMES
IN THE LOWER TAMAR RIVER

By B. S. Newell

Marine Laboratory
Cronulla, Sydney
1969

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When citing this report, abbreviate as follows:
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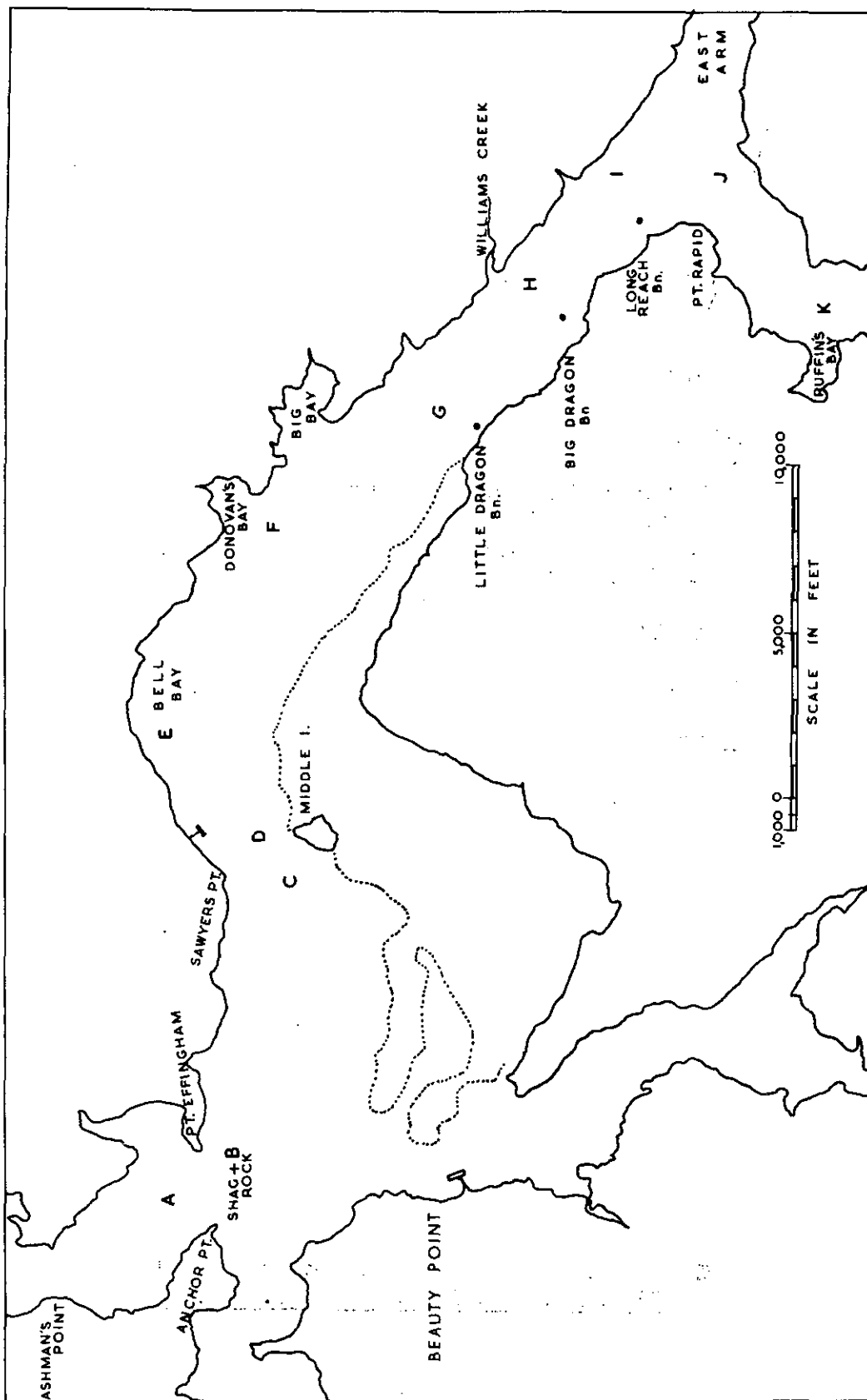


Fig. 1.- Area investigated showing position of stations occupied (A-K).

INTRODUCTION

The survey described in this report arose from a proposal by the Australian Pulp and Paper Manufacturing Co. Ltd to install a wood-chip plant on the east bank of the Tamar River, some 3 miles upstream from Bell Bay, Tasmania. The effluent from this plant would consist of freshwater washings containing soil, bark fragments, wood dust and some natural colouring matter. Of the solid material some 90% would be removed in settling ponds, giving a final effluent of about 1200 gal/min (3 cusec) containing a small amount of fine suspended solids and natural colouring material. A prediction was required of the probable rate of dilution of this effluent. Since a knowledge of chlorinity distribution is a prerequisite in determining the type of classification into which a particular estuary or river falls (Rochford 1951) a chlorinity-temperature survey was proposed. In the event, chlorinity distribution proved sufficient to calculate the dilution rates required.

Personnel

The survey was carried out by Mr A.L. Brown, assisted by Mr D. Wolfe of the Department of Agriculture (Fisheries Division), Tasmania, and Captain R.E.N. Barber of the Port of Launceston Authority. Mr W. Meadows of A.P.P.M. was present as an observer.

METHODS

Measurements of chlorinity and temperature were made from an Authority launch piloted by Captain Barber. Values were read at 1 m intervals from surface to bottom with a CSIRO meter (Hamon 1956). The 11 stations (Fig. 1, A-K) were occupied as nearly as possible in the deepest parts of the river channel but wind and current drift made exact positioning impossible. Similarly, when the 11 stations were re-occupied 6 hours (one half-tide) later, it was impossible to revisit exactly the same positions. Hence the depth differences between Figures 2 and 3.

RESULTS

1. Chlorinity and temperature

The distribution of chlorinity and temperature in vertical profile is given in Figures 2, 3, 4 and 5 respectively. It was intended to occupy one run of stations on the ebb tide and one on the flood tide, and direction of current alone puts the measurements during the morning of October 29th (Figs. 3 and 5) as ebb tide and those of the afternoon of the 28th and 29th (Figs. 2 and 4) as flood tide. However, the chlorinity distribution and tidal currents were out of phase, a common phenomenon in rivers where time of high and low water gets later upstream. Hence Figures 2 and 4 show a low water situation with

the isochlors beginning to move upstream at Station A whilst those at Station K are still in an ebb state. Figures 3 and 5 show an opposite situation. For simplicity, the isochlor distribution will be taken as indication of tidal state, and the situation in Figures 2 and 4 will be referred to as low water and Figures 3 and 5 as high water.

Results are given in Table 3.

2. Flushing times

Flushing times were calculated by the method of Bowden (1967). The proportion (f) of freshwater in the river at any point is given by:-

$$f = \frac{Cl_0 - Cl}{Cl_0}$$

where Cl_0 = Chlorinity at seaward end (assumed 19.5‰)

Cl = Chlorinity at chosen point (‰)

The mean chlorinity at each location was estimated from the tabulated data.

The freshwater volume at any point is given by fV where V is the total volume of water, and for a length of river the accumulated freshwater volume (F_w) becomes

$$F_w = \int_0^{\text{vol}} f d(\text{vol})$$

This expression may be evaluated by dividing the river into compartments by means of imaginary lines drawn equidistant between stations. Because stations A and B, and C and D were so close, they were counted as 2 stations only, giving 9 compartments in all. The water volume in each compartment was calculated from the product of the surface area and the mean sounding. (An attempt was made to measure cross-sectional areas by planimetry, but the irregular bottom made this tedious and unreliable. Soundings on Admiralty Chart 1080 were numerous and evenly distributed, so that the mean sounding probably gives a reliable enough measure of mean depth.)

The flushing time (T) is given by:-

$$T = \frac{F_w}{R}$$

where R = river flow.

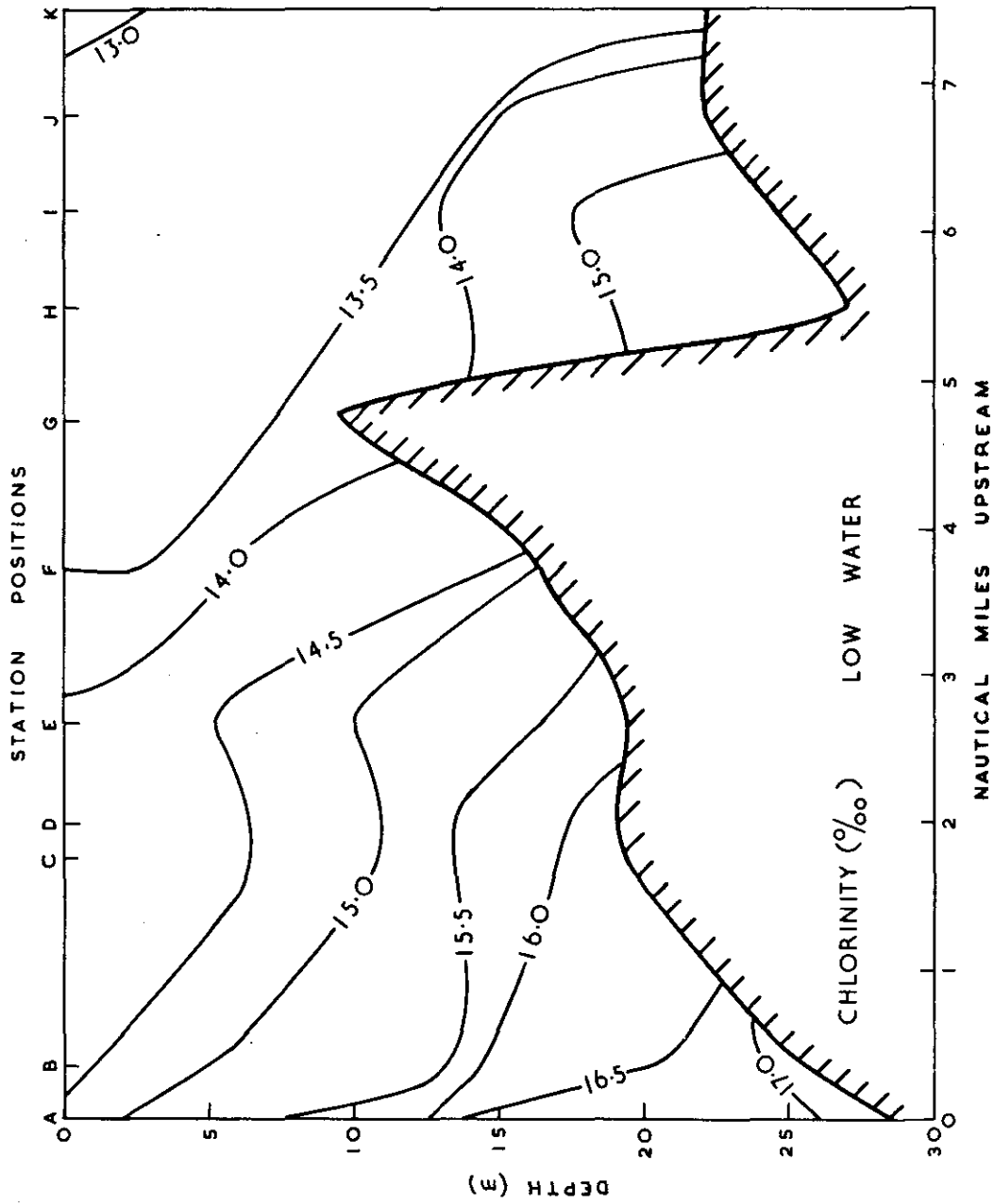


Fig. 2.- Longitudinal vertical distribution of isochlors (‰) at low water.

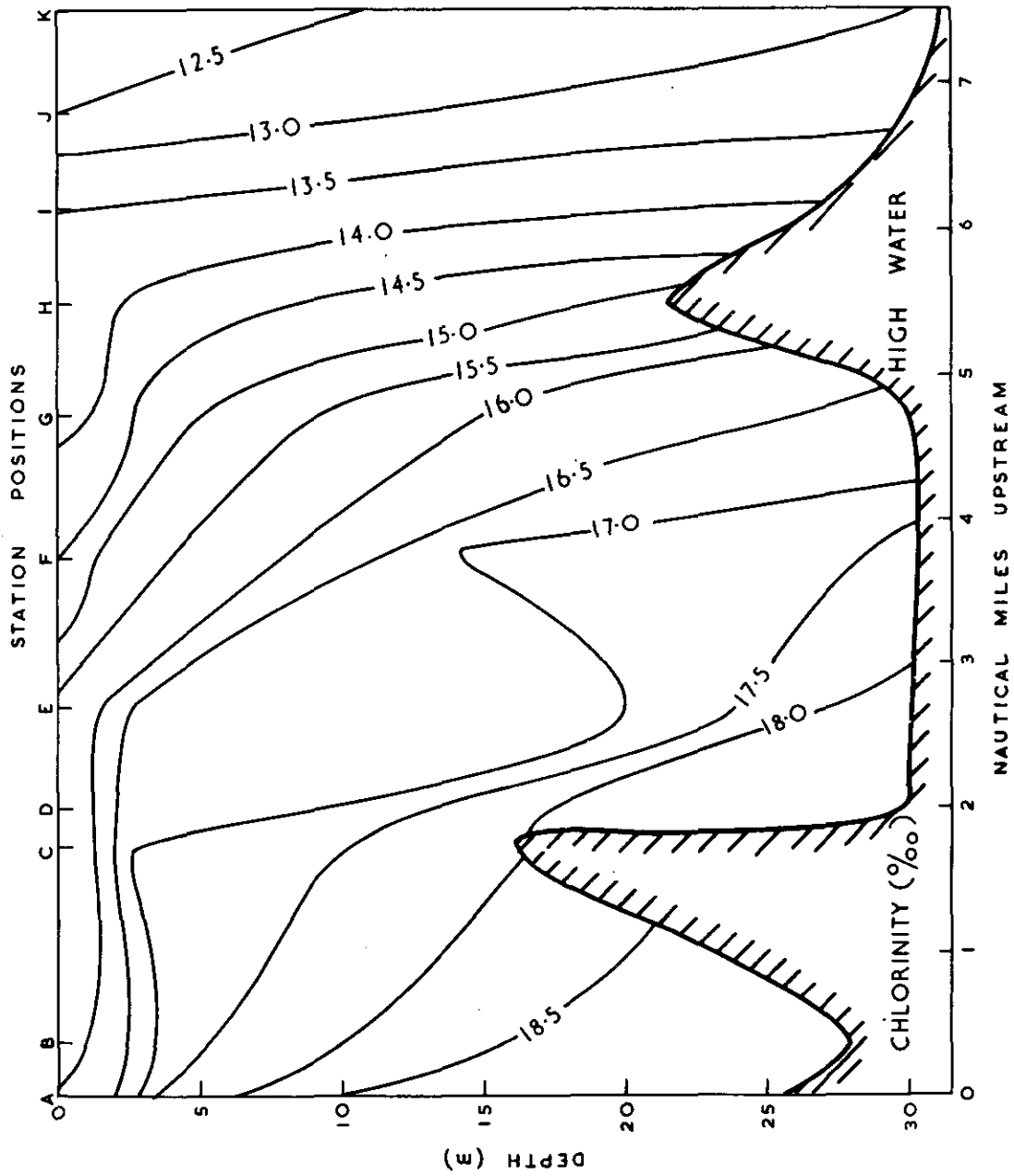


Fig. 3.- Longitudinal vertical distribution of isochlores (‰) at high water.

The results are given in Table 1, with the cumulative total volumes (V_T) and freshwater volumes proceeding upstream. The flushing time is therefore the time required to replace completely all the freshwater component between any compartment and Ashman's Point. River flow was assumed to be 2,000 cusec, the approximate discharge of the North and South Esk Rivers at Launceston before the period of the survey. Any contribution from other rivers or creeks downstream from Launceston has been neglected so that the calculated flushing times are probably slight overestimates. Change in river flow itself does not change flushing times proportionately, because the accumulated freshwater volume also changes, but an increase in river flow generally decreases flushing time, and vice versa.

3. Transport rates

The chlorinity distribution found during the survey (Figs. 2 and 3, Table 3) indicates that the Tamar River is uniformly mixed above Station I at low water and Station G at high water. The dilution of any continuous effluent introduced into the river upstream of these stations will therefore depend upon river discharge and the change in tidal volume. For practical purposes, river discharge volume would suffice to give a conservative estimate of dilution rates. Since the water column is uniform, mixing of effluent would be rapid and complete, and tidal exchange will enhance dilution.

Downstream of Station G at high water, and I at low water, the river forms a 2-layer system with a horizontal boundary (the halocline) at about 10 m depth. A vertical flux of salt water through this boundary greatly enhances seaward transport in the surface layer, and the total transport can be calculated from the distribution of chlorinity (Bowden 1967).

The transport seawards in the upper layer (T_1) is given by -

$$T_1 = \frac{Cl_2}{Cl_2 - Cl_1} \cdot R,$$

where Cl_1 = mean chlorinity of upper layer (‰),

Cl_2 = mean chlorinity of lower layer (‰),

R = river discharge (cusec).

Similarly, the transport up-river in the lower layer (T_2) is given by -

$$T_2 = \frac{Cl_1}{Cl_2 - Cl_1} \cdot R = T_1 - R$$

Table 2 gives the estimated values of Cl_1 , Cl_2 , T_1 and T_2 for each station at high and low water, assuming, as before, a value of 2,000 cusec for R. Contributions from rivers and creeks downstream from Launceston would increase T_1 and T_2 . Changes in river discharge, however, do not alter the transport rates proportionately because the chlorinity distribution and vertical flux rate are also changed. The transport rates are affected by the tides, and the differential flow may disappear at mid-tide when tidal velocities are greatest (Hughes 1958).

4. Tidal excursion

From the shift in position of the isochlors at the surface in Figures 2 and 3, an approximate measure of tidal excursion may be obtained. The 13‰ isochlor moved about 0.7 miles (KJ to JI) in $5\frac{1}{2}$ hr, the 13.5‰ isochlor about 2.4 miles (I to F) in $4\frac{1}{2}$ hr and the 14.5‰ isochlor about 3.6 miles (F to A) in 4 hr. The excursion for a dissolved substance in Long Reach would therefore be about 3.2 miles over one half tidal cycle.

Measurements of float drift in Long Reach made by the Port of Launceston Authority in June 1968 (information by courtesy of Captain R.E.N. Barber) indicated tidal velocities of about 2 kn at mid-ebb and 1 kn during late ebb or early flood. These velocities are higher than would be expected from the isochlor shift, but the latter includes mixing effects and is a minimum estimate of tidal excursion. The float measurements indicated uniform flow to 30 ft depth, which is consistent with the presence of a two-layer flow system with halocline boundary at about 10 m (33 ft).

CONCLUSIONS

Calculation of flushing times suggests that a single contamination of the River Tamar in Long Reach will take 5 to 7 days to clear past Ashman's Point.

Calculation of transport rates makes it clear that an abundance of flow exists to dilute the small volume of effluent from the proposed wood chip mill. If this effluent were released into the surface layer, transport seawards would be rapid, but isolated patches of effluent might become isolated in bays. On the other hand, if released into the lower layer (below 10 m depth) the effluent would be uniformly diluted but transported further upstream.

Movement of isochlors suggests that an effluent released in Long Reach will travel about 3 miles up-river on each flood.

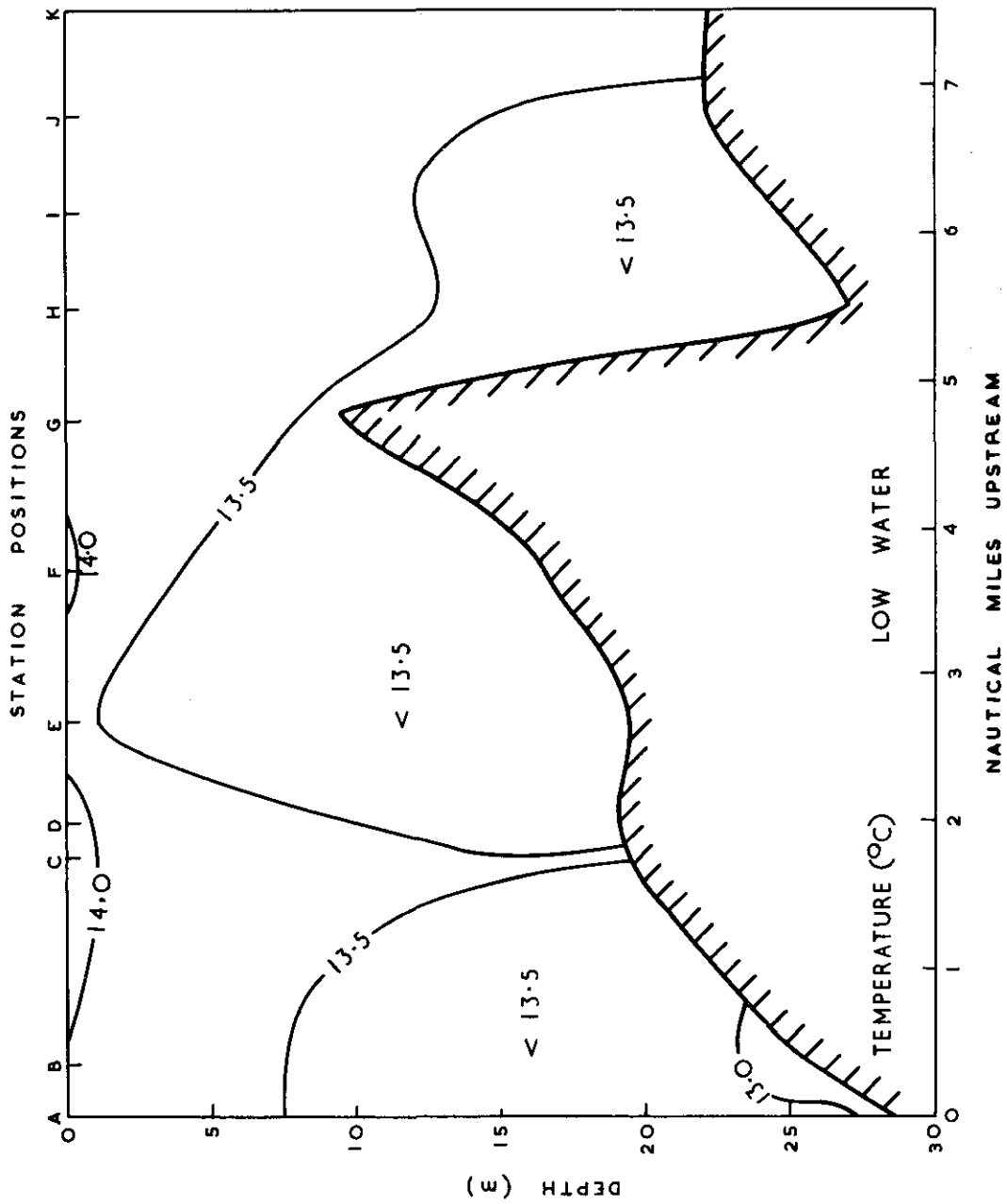


Fig. 4.- Longitudinal vertical distribution of isotherms (°C) at low water.

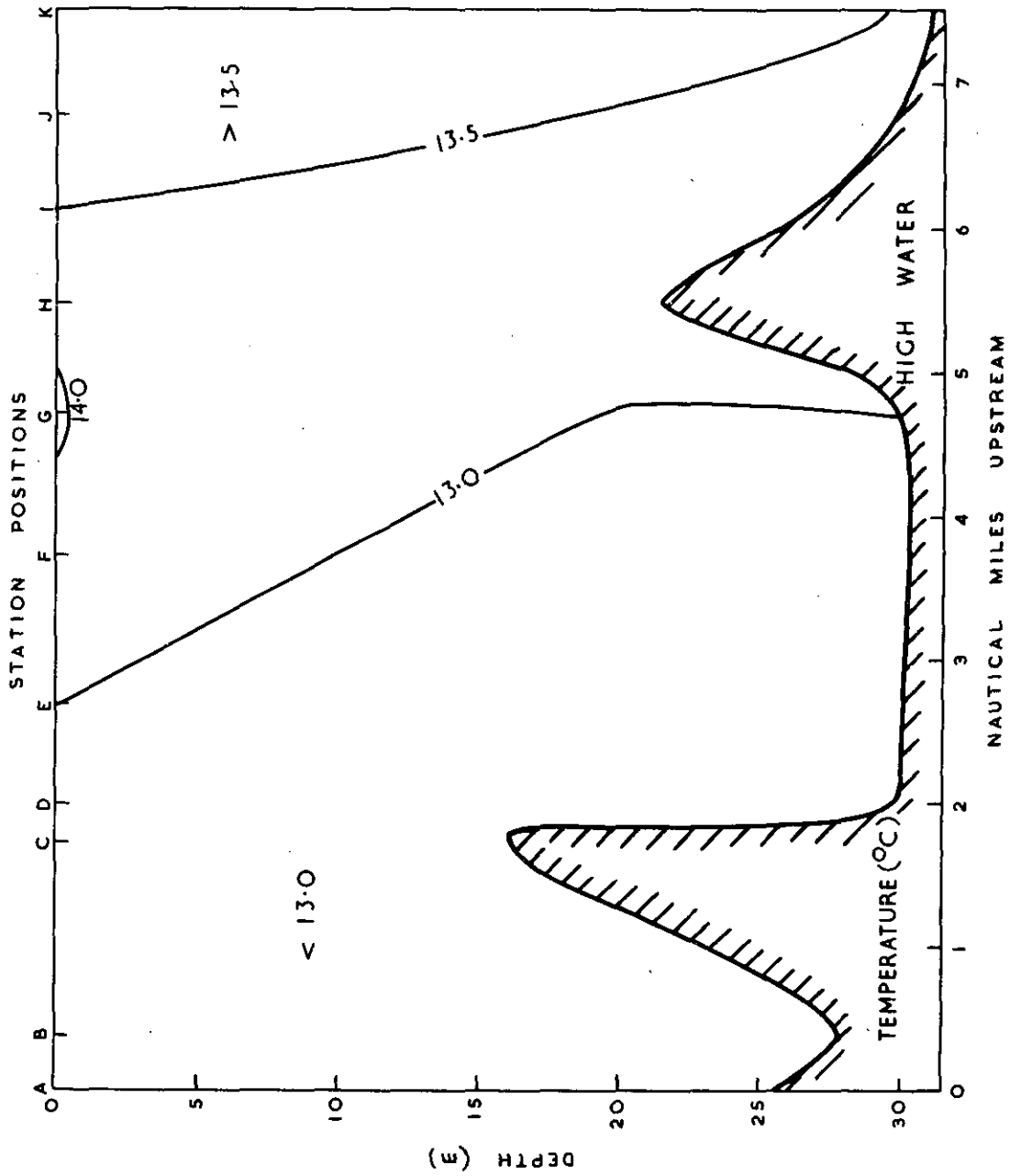


Fig. 5.- Longitudinal vertical distribution of isotherms ($^{\circ}\text{C}$) at high water.

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TABLE 1

Flushing times

(Time to displace total freshwater component between
Stations K and A-B)

Compartment	Mean Cl ‰	f	V_T 10^6 cu ft	F_w 10^6 cu ft	T days
A-B	17.0	0.13	3000	385	2.2
C-D	16.5	0.15	3850	515	3.0
E	16.0	0.18	4533	638	3.7
F	15.5	0.21	5328	802	4.6
G	15.0	0.23	5993	956	5.5
H	14.5	0.26	6473	1079	6.2
I	14.0	0.28	6998	1227	7.1
J	13.5	0.31	7798	1474	8.5
K	12.7	0.35	8428	1694	9.7

TABLE 2

Transport rates

The volume transport downstream in the upper layer (T_1) and upstream in the lower layer (T_2) at high and low water

LOW WATER						HIGH WATER					
Station	Time	Cl_1	Cl_2	T_1	T_2	Station	Time	Cl_1	Cl_2	T_1	T_2
		%	%	10 ³ cusec	10 ³ cusec			%	%	10 ³ cusec	10 ³ cusec
A	1300	15.5	17.0	22.6	20.6	A	0705	16.5	18.5	18.4	16.4
B	1316	15.0	16.5	22.0	20.0	B	0724	16.5	18.5	18.4	16.4
C	1345	14.0	15.5	20.6	18.6	C	0749	16.0	18.0	18.0	16.0
D	1357	14.0	15.5	20.6	18.6	D	0807	16.0	18.0	18.0	16.0
E	1420	14.0	15.5	20.6	18.6	E	0825	16.0	18.0	18.0	16.0
F	1445	13.5	15.0	20.0	18.0	F	0856	15.5	17.5	17.4	15.4
G	1500	NO DATA				G	0921	14.5	16.5	16.4	14.4
H	1515	13.3	15.0	17.6	15.6						
I	1535	13.3	15.0	17.6	15.6						

TABLE 3

Chlorinity and temperature

Station	Time h	Depth m	Temperature °C	Chlorinity ‰	
A	0705	0	13.0	16.22	
		1	13.0	16.30	
		2	13.0	16.50	
		3	12.8	17.12	
	29.10.68	0710	4	12.7	17.85
			5	12.6	17.86
			6	12.6	17.91
			7	12.6	18.16
			8	12.6	18.28
			9	12.6	18.58
			10	12.6	18.60
			11	12.6	18.65
			11 $\frac{1}{2}$	12.6	18.65
			12 $\frac{1}{2}$	12.6	18.65
			13 $\frac{1}{2}$	12.6	18.67
			14	12.6	18.67
			15	12.6	18.67
			16	12.6	18.66
			17	12.6	18.70
			17 $\frac{1}{2}$	12.6	18.75
			18	12.6	18.75
	19	12.6	18.75		
	20	12.6	18.75		
	21	12.6	18.75		
	22	12.6	18.75		
0716	0724	23	12.6	18.75	
		24	12.6	18.75	
		24 $\frac{1}{2}$	12.6	18.78	
25 $\frac{1}{2}$	12.6	18.78			
B	0724	0	13.0	15.50	
		1	13.0	16.00	
		2	13.0	16.31	
		3	12.9	16.77	
		4	12.9	17.06	
		5	12.8	17.34	
		6	12.8	17.70	
		7	12.8	17.80	
		8	12.8	17.81	
		9	12.8	17.87	
10	12.7	18.02			

TABLE 3 - Continued

Station	Time h	Depth m	Temperature °C	Chlorinity ‰
B	0724	11	12.7	18.12
		12	12.7	18.20
		13	12.7	18.24
		14	12.7	18.25
		15	12.7	18.44
		16	12.6	18.51
		17	12.6	18.58
		18	12.6	18.64
		19	12.6	18.70
		20	12.6	18.78
		21	12.6	18.78
		22	12.6	18.83
		23	12.6	18.83
C	0749	0	12.9	15.00
		1	12.9	16.44
		2	12.9	17.00
		3	12.8	17.13
		4	12.8	17.21
		5	12.8	17.28
		6	12.8	17.31
		7	12.8	17.34
		8	12.8	17.35
		9	12.8	17.35
		10	12.8	17.48
		11	12.8	17.58
		12	12.8	17.67
13	12.8	17.72		
14	12.7	17.79		
15	12.7	17.85		
16	12.7	17.95		
D	0807	0	12.8	15.00
		1	13.0	15.60
		2	13.0	16.21
		3	13.0	16.36
		4	13.0	16.49
		5	13.0	16.60
		6	13.0	16.63
		7	13.0	16.71
		8	13.0	16.75
		9	13.0	17.06
10	12.8	17.22		

TABLE 3 - Continued

Station	Time h	Depth m	Temperature °C	Chlorinity ‰		
D	0807	11	12.8	17.38		
		12	12.8	17.44		
		13	12.8	17.50		
		14	12.8	17.62		
		15	12.8	17.70		
		16	12.8	18.00		
		17	12.8	18.00		
		18	12.8	17.92		
		19	12.8	17.97		
		20	12.8	17.97		
		21	12.8	17.97		
		22	12.8	17.97		
		23	12.8	18.00		
		24	12.8	18.04		
		25	12.8	18.04		
		26	12.7	18.20		
		27	12.7	18.30		
		28	12.7	18.30		
		29	12.7	18.30		
		30	12.7	18.30		
		31	12.7	18.30		
		32	12.7	18.30		
		E	0825	0	13.0	15.70
				1	13.0	15.70
				2	13.0	16.38
				3	13.0	16.61
				4	13.0	16.70
				5	13.0	16.75
				6	13.0	16.80
				7	13.0	16.52
				8	13.0	16.46
				9	13.0	16.50
10	13.0			16.58		
11	13.0			16.40		
11 $\frac{1}{2}$	13.0			16.47		
12	13.0			16.47		
13	13.0			16.48		
14	13.0			16.55		
15	13.0			16.70		
16	13.0			16.67		
17	13.0			16.75		
18	13.0			16.79		
19	13.0	16.87				
20	13.0	16.96				

TABLE 3 - Continued.

Station	Time h	Depth m	Temperature °C	Chlorinity ‰		
E	0825	21	13.0	16.95		
		21 $\frac{1}{2}$	13.0	16.92		
		22 $\frac{1}{2}$	12.9	16.85		
		23 $\frac{1}{2}$	12.9	17.04		
		24 $\frac{1}{2}$	12.8	17.57		
		25 $\frac{1}{2}$	12.8	17.76		
		26 $\frac{1}{2}$	12.8	17.85		
		27 $\frac{1}{2}$	12.8	17.96		
		28	12.8	17.96		
		29	12.8	17.96		
		30	12.8	17.96		
		F	0856	0	13.2	14.50
				1	13.2	15.00
2	13.2			15.30		
3	13.2			15.30		
4	13.2			15.40		
5	13.2			15.80		
6	13.1			15.90		
7	13.1			15.90		
8	13.1			16.00		
9	13.1			16.28		
10	13.1			16.34		
11	13.0			16.50		
11 $\frac{1}{2}$	13.0			16.62		
12	13.0			16.86		
13	13.0			16.89		
14	13.0			17.05		
15	13.0			17.06		
16	13.0	17.13				
17	12.9	17.20				
18	12.9	17.27				
19	12.9	17.34				
19 $\frac{1}{2}$	12.9	17.34				
20 $\frac{1}{2}$	12.9	17.34				
21 $\frac{1}{2}$	12.9	17.35				
22 $\frac{1}{2}$	12.9	17.35				
23 $\frac{1}{2}$	12.9	17.35				
24 $\frac{1}{2}$	12.9	17.37				
25	12.9	17.41				
26	12.9	17.41				
27	12.9	17.44				
28	12.9	17.50				
29	12.9	17.50				
30	12.9	17.56				

TABLE 3 - Continued

Station	Time h	Depth m	Temperature °C	Chlorinity ‰
G	0921	0	14.4	13.80
		1	13.3	13.90
		2	13.3	14.30
		3	13.3	14.80
		4	13.3	15.00
		5	13.3	15.00
		6	13.3	15.00
		7	13.2	15.30
		8	13.2	15.40
		9	13.2	15.50
		10	13.2	15.60
		10 $\frac{1}{2}$	13.2	15.70
		11 $\frac{1}{2}$	13.2	15.80
		12	13.2	15.80
		12 $\frac{1}{2}$	13.2	15.70
		13 $\frac{1}{2}$	13.2	15.90
		14 $\frac{1}{2}$	13.2	16.00
		15	13.2	16.00
		16	13.2	16.00
		17	13.2	16.00
		18	13.2	16.00
		19	13.1	16.15
		20	13.0	16.26
		21	13.0	16.36
		21 $\frac{1}{2}$	13.0	16.40
		22 $\frac{1}{2}$	13.0	16.41
		23 $\frac{1}{2}$	13.0	16.42
		24 $\frac{1}{2}$	13.0	16.42
		25	13.0	16.45
26	13.0	16.46		
27	13.0	16.44		
28	13.0	16.52		
29	13.0	16.52		
29 $\frac{1}{2}$	13.0	16.52		
H	0950	0	13.4	13.90
		1	13.4	13.90
		2	13.4	14.00
		3	13.4	14.10
		4	13.4	14.20
		5	13.4	14.20
		6	13.4	14.25
		7	13.4	14.25
		8	13.4	14.40
		9	13.3	14.60
		10	13.3	14.60

TABLE 3 - Continued

Station	Time h	Depth m	Temperature °C	Chlorinity ‰
H	0950	11	13.3	14.60
		12	13.3	14.60
		13	13.3	14.80
		14	13.3	14.70
		15	13.3	14.70
		16	13.3	14.70
		17	13.3	14.70
		18	13.3	15.00
		19	13.3	15.00
		20	13.3	15.10
		21	13.3	15.10
I	1016	0	13.5	13.50
		1	13.5	13.50
		2	13.5	13.50
		3	13.5	13.50
		4	13.5	13.60
		5	13.5	13.60
		6	13.5	13.60
		7	13.5	13.60
		8	13.5	13.60
		9	13.5	13.60
		10	13.5	13.60
		11	13.5	13.60
		12	13.5	13.60
		13	13.5	13.60
		14	13.5	13.60
		15	13.5	13.60
		16	13.5	13.60
17	13.5	13.60		
18	13.5	13.60		
19	13.5	13.60		
20	13.5	13.60		
21	13.5	13.60		
22	13.5	13.60		
23	13.5	13.60		
24	13.5	13.60		
25	13.5	13.60		
26	13.5	13.60		
27	13.5	13.60		
J	1040	0	13.6	12.50
		1	13.6	12.60
		2	13.6	12.75
		3	13.6	12.80
		4	13.6	12.80
5	13.6	12.90		

TABLE 3 - Continued

Station	Time h	Depth m	Temperature °C	Chlorinity ‰		
J	1040	6	13.6	12.90		
		7	13.6	13.00		
		8	13.6	13.00		
		9	13.6	13.00		
		10	13.6	13.00		
		11	13.6	13.00		
		12	13.6	13.00		
		13	13.6	13.00		
		14	13.6	13.00		
		15	13.6	13.00		
		16	13.6	13.00		
		17	13.6	13.00		
		18	13.6	13.10		
		19	13.6	13.10		
		20	13.5	13.30		
		21	13.5	13.50		
		22	13.5	13.50		
		23	13.5	13.40		
		24	13.5	13.30		
		25	13.5	13.30		
		26	13.5	13.40		
		27	13.5	13.30		
		28	13.5	13.30		
		29	13.5	13.25		
		30	13.5	13.20		
		K	1100	0	13.8	12.00
				1	13.8	12.00
				2	13.8	12.00
				3	13.8	12.20
				4	13.8	12.20
5	13.8			12.20		
6	13.8			12.30		
7	13.8			12.40		
8	13.8			12.40		
9	13.8			12.40		
9 $\frac{1}{2}$	13.8			12.40		
10	13.8			12.40		
11	13.8			12.50		
12	13.8			12.50		
13	13.8			12.70		
14	13.7			12.75		
15	13.6			12.75		
16	13.6			12.75		
17	13.6			12.75		
18	13.6			12.75		
19	13.6			12.75		
20	13.6	12.75				

TABLE 3 - Continued

Station	Time h	Depth m	Temperature °C	Chlorinity ‰
K	1100	21	13.6	12.60
		22	13.6	12.70
		23	13.6	12.70
		24	13.6	12.70
		25	13.6	12.70
		26	13.6	12.70
		27	13.6	12.70
		28	13.6	12.70
		29	13.6	13.00
		30	13.5	13.40
A	1300	0	13.7	15.00
		1	13.7	15.00
		2	13.7	15.00
		3	13.7	15.00
		4	13.7	15.10
		5	13.7	15.10
		6	13.7	15.30
		7	13.6	15.40
		8	13.4	15.50
		9	13.4	15.60
		10	13.4	15.75
		11	13.4	15.75
		12	13.3	15.80
		13	13.3	16.38
		14	13.2	16.60
		15	13.2	16.70
		16	13.2	16.70
		17	13.2	16.70
		18	13.2	16.70
		19	13.2	16.74
		20	13.2	16.75
		21	13.2	16.76
		22	13.2	16.76
		23	13.2	16.77
		24	13.2	16.81
		25	13.2	16.85
		26	13.1	16.89
		27	13.1	17.05
28	13.0	17.17		
B	1316	0	13.9	14.40
		1	13.7	14.50
		2	13.5	14.80
		2½	13.5	14.80
		3½	13.5	14.80
		4½	13.5	14.90
		5	13.5	15.00

TABLE 3 - Continued

Station	Time h	Depth m	Temperature °C	Chlorinity ‰		
B	1316	6	13.5	15.10		
		7	13.5	15.10		
		8	13.5	15.10		
		8 $\frac{1}{2}$	13.5	15.20		
		9 $\frac{1}{2}$	13.4	15.20		
		10	13.4	15.25		
		11	13.4	15.25		
		12	13.4	15.25		
		13	13.4	15.30		
		14	13.3	15.80		
		15	13.2	16.22		
		15 $\frac{1}{2}$	13.2	16.30		
		16 $\frac{1}{2}$	13.2	16.20		
		17	13.2	16.20		
		18 $\frac{1}{2}$	13.2	16.22		
		20	13.2	16.30		
		21	13.2	16.65		
		22	13.1	16.75		
		22 $\frac{1}{2}$	13.1	16.85		
		23 $\frac{1}{2}$	13.0	17.20		
		C	1345	0	14.3	14.10
				1	14.0	14.00
				2	13.7	14.20
3	13.7			14.25		
4	13.7			14.30		
5	13.7			14.40		
6	13.7			14.50		
7	13.7			14.50		
8	13.7			14.50		
8 $\frac{1}{2}$	13.7			14.60		
9	13.7			14.90		
10	13.7			14.90		
11	13.7			14.90		
12	13.7			14.90		
12 $\frac{1}{2}$	13.7			15.00		
13 $\frac{1}{2}$	13.7			15.00		
14	13.7			15.00		
15	13.7			15.00		
15 $\frac{1}{2}$	13.7			15.00		
16 $\frac{1}{2}$	13.7	15.00				
17 $\frac{1}{2}$	13.7	15.00				
18	13.7	15.00				
19	13.7	15.00				

TABLE 3 - Continued

Station	Time h	Depth m	Temperature °C	Chlorinity ‰
D	1357	0	14.4	13.90
		1	13.8	14.00
		2	13.8	14.00
		3	13.8	14.00
		4	13.7	14.00
		5	13.6	14.10
		6	13.6	14.20
		7	13.6	14.25
		8	13.6	14.25
		9	13.6	14.30
		9 $\frac{1}{2}$	13.6	14.40
		10 $\frac{1}{2}$	13.6	14.75
		11 $\frac{1}{2}$	13.5	15.00
		12 $\frac{1}{2}$	13.4	15.25
		13 $\frac{1}{2}$	13.4	15.75
		14	13.4	15.75
		15	13.4	15.75
		16	13.3	15.80
		17	13.3	15.90
17 $\frac{1}{2}$	13.3	16.00		
18	13.3	16.19		
18 $\frac{1}{2}$	13.3	16.32		
E	1420 28.10.68	0	13.6	14.10
		1	13.6	14.20
		2	13.4	14.30
		3	13.3	14.50
		4	13.3	14.50
		5	13.3	14.50
		6	13.3	14.70
		7	13.3	14.75
		8	13.3	14.80
		9	13.3	15.00
		10	13.3	15.00
		11	13.3	15.10
		12	13.3	15.10
		13	13.3	15.10
		13 $\frac{1}{2}$	13.3	15.20
		14	13.3	15.20
		15	13.3	15.20
		16	13.3	15.40
		16 $\frac{1}{2}$	13.3	15.50
		17	13.3	15.60
17 $\frac{1}{2}$	13.3	15.60		
18	13.3	15.65		
19	13.3	15.75		

TABLE 3 - Continued

Station	Time h	Depth m	Temperature °C	Chlorinity ‰
F	1445	0	14.1	13.50
		1	13.8	13.50
		2	13.8	13.50
		3	13.8	13.50
		4	13.6	13.60
		5	13.4	13.80
		6	13.4	14.10
		7	13.4	14.20
		8	13.4	14.20
		9	13.4	14.20
		10	13.4	14.20
		10 $\frac{1}{2}$	13.4	14.20
		11 $\frac{1}{2}$	13.4	14.20
		12	13.4	14.30
		13	13.4	14.30
		14	13.4	14.30
15	13.4	14.40		
16	13.3	15.10		
G	1500	0	13.7	13.10
		1	13.7	13.10
		2	13.7	13.10
		3	13.7	13.10
		4	13.6	13.20
		5	13.6	13.30
		6	13.6	13.40
		7	13.6	13.50
		8	13.6	13.60
9	13.4	13.70		
H	1515	0	13.8	13.25
		1	13.8	13.25
		2	13.8	13.25
		3	13.8	13.25
		4	13.8	13.25
		5	13.8	13.30
		6	13.7	13.40
		7	13.6	13.50
		8	13.6	13.50
		9	13.6	13.50
		10	13.6	13.50
		11	13.6	13.60
		12	13.6	13.60
		13	13.5	13.80
		14	13.4	14.00
15	13.3	14.25		

TABLE 3 - Continued

Station	Time h	Depth m	Temperature °C	Chlorinity ‰		
H	1515	16	13.3	14.30		
		17	13.3	14.80		
		18	13.3	14.80		
		19	13.2	15.00		
		20	13.2	15.10		
		21	13.2	15.20		
		22	13.2	15.20		
		23	13.2	15.25		
		24	13.2	15.40		
		25	13.2	15.40		
I	1535	0	13.8	13.10		
		1	13.8	13.10		
		2	13.8	13.20		
		3	13.7	13.25		
		4	13.7	13.25		
		5	13.7	13.25		
		6	13.7	13.25		
		7	13.6	13.30		
		8	13.6	13.30		
		9	13.6	13.40		
		10	13.6	13.40		
		11	13.6	13.40		
		12	13.5	13.45		
		13	13.4	14.25		
		14	13.3	14.60		
		15	13.3	14.80		
		16	13.3	14.90		
		17	13.3	14.90		
		18	13.3	15.10		
		19	13.2	15.20		
		20	13.2	15.30		
		21	13.2	15.50		
		22	13.2	15.50		
		23	13.2	15.50		
		24	13.2	15.70		
		J	1555	0	13.8	13.30
				1	13.8	13.30
				2	13.8	13.30
				3	13.6	13.50
				4	13.6	13.50
5	13.6			13.50		
6	13.6			13.50		
7	13.6			13.50		
8	13.6	13.50				

TABLE 3 - Continued

Station	Time h	Depth m	Temperature °C	Chlorinity ‰
J	1555	9	13.6	13.50
		10	13.6	13.50
		11	13.6	13.50
		12	13.6	13.40
		13	13.6	13.40
		14	13.6	13.50
		15	13.6	13.50
		16	13.6	14.20
		17	13.4	14.20
		18	13.4	14.20
		19	13.4	14.00
		20	13.4	14.00
K	1610	21	13.4	14.00
		22	13.4	14.00
		0	13.6	12.90
		1	13.6	12.90
		2	13.6	12.90
		3	13.6	13.00
		4	13.6	13.00
		5	13.6	13.10
		6	13.6	13.10
		7	13.6	13.10
		8	13.6	13.10
		9	13.6	13.10
9 $\frac{1}{2}$	13.6	13.10		
10	13.6	13.10		
11	13.6	13.10		
12	13.6	13.10		
13	13.6	13.10		
14	13.6	13.10		
15	13.6	13.00		
16	13.6	13.00		
17	13.6	13.10		
18	13.6	13.00		
19	13.6	13.00		
19 $\frac{1}{2}$	13.6	13.00		
20 $\frac{1}{2}$	13.6	13.00		
21 $\frac{1}{2}$	13.6	13.30		
22 $\frac{1}{2}$	13.6	13.30		
23 $\frac{1}{2}$	13.6	13.30		

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