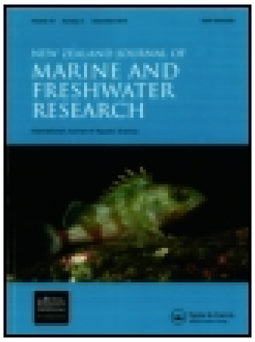

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SURFACE WATERS OF WAIMEA INLET AND NELSON HAVEN: A PRELIMINARY ASSESSMENT OF QUALITY

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ABSTRACT

Because of mounting inflows of sewage and organic industrial effluents in Nelson Haven, Waimea Inlet, and Tasman Bay, a water quality survey to obtain background information, on 17 parameters from 28 sites was made during 1975.

Some water samples collected near effluent discharges showed high levels of nitrate, total nitrogen, total phosphorus, volatile solids, ATP, heterotrophic potential, total bacteria, viable bacteria, and coliform bacteria. Measurements were also made of temperature, salinity, dissolved oxygen, pH, suspended solids, and chlorophyll *a;* counts were made for confirmed faecal coliforms and confirmed *Escherichia coli* (Type I).

Water from sites remote from effluent discharges showed characteristics of normal seawater: water turbulence and tidal flushing appeared to be rapidly degrading, diluting, and dispersing the organic contaminants.

INTRODUCTION

Estuaries and coastal inlets are very fragile ecosystems which can be greatly altered by the inflow of sewage and industrial effluents. Until recently, to many people the sea was a boundless reservoir into which all sewage and wastes could be dumped without serious adverse effects. It is now appreciated that the continuing productivity of commercially valuable species of fish, crustacea and molluscs can depend on relatively unpolluted, adequately oxygenated coastal waters. Many of the ecological implications are discussed in Olson & Burgess (1967) and Barnes & Green (1971).

However, the discharge of organic effluents into coastal waters may also have beneficial aspects. Sibert & Brown (1975) found high heterotrophic activity and ATP concentrations in a Canadian fjord where the BOD of the daily discharge of a pulp mill exceeded 1.59×10^4 kg; they suggested there were benefits to the food chain from the enhanced heterotrophic production. Gray (1975) states that a relatively innocuous group of pollutants includes sewage and agricultural fertilisers, and cites the example of the fishery off the Thames estuary receiving London sewage being better than others in the North Sea.

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Although water quality can be determined by physical, chemical, and biological measurements, in practice it has to be related to a specific end use. Thus natural sea water is excellent for fish production and for recreation, but is not used for drinking or for boiler feed. In establishing criteria for water quality, two general approaches can be made: standards may be set for the effluents, or for the receiving waters.

The New Zealand Water and Soil Conservation Act 1967, and Amendments, set five grades for seawater quality. The water classification scheme lists physical, chemical, and biological criteria: temperature, pH, colour, clarity; dissolved oxygen, suspended solids, grease, and oil; odour, aquatic life, coliform bacteria. Other measurements might be used and could be as significant: levels of ammonia, nitrite, nitrate, organic nitrogen, phosphorus, suspended solids, volatile solids, chlorophyll, ATP, heterotrophic potential, numbers of total bacteria, viable bacteria (plate count), coliform bacteria, faecal coliform bacteria, *Escherichia coli*, faecal streptococci, and enumeration of the biota.

During recent years the increasing disposal of wastes into coastal waters has caused concern to regional authorities, and the need for an assessment of the quality of the water in Waimea Inlet and Nelson Haven as well as in the larger encompassing area of Tasman Bay has become apparent. At several sites, one look was enough to see that the receiving water and adjacent intertidal seabed were affected by effluents, which produced discolouration or odour or diminished clarity. This paper records the results for 17 parameters from 28 sites around the shoreline and adjacent coastal waters from a survey made during 1975.

DESCRIPTION OF THE AREA

Tasman Bay's southern extremity is shown in Fig. 1. Heath (1973, 1976b) describes aspects of hydrology and water circulation. Tidal range reaches 4 m at spring tides and 2 m at neaps. The seabed has a gentle gradient with extensive shoaling at the southern end, where Nelson Haven and Waimea Inlet are located.

Nelson Haven (41° 15′ S, 173° 17′ E) is separated from Tasman Bay by the 13-km-long Boulder Bank, which encloses a 13 km^2 high water area which reduces to 2 km^2 at low water spring (LWS) tides. Heath (1976a) calculates the tidal compartment as containing 30×10^6 m^3 at high water and 13×10^6 m^3 at low water spring tide. The waters of Nelson Haven contact Tasman Bay through two narrow channels at the southern end of the Boulder Bank. Flowing into the haven is the Maitai River, with a daily average discharge of 1.4×10^5 m^3 and a minimum summer flow of 2×10^4 $m^3 \cdot d^{-1}$ (Nelson Catchment Board records). Nelson harbour installations, fish processing plants, and a municipal garbage dump border the haven, which also receives stormwater run-off from Nelson City. Information on Nelson Haven is recorded in studies by Davies (1931) and Doak (1931). Davies records marked changes in haven contours and sediment accretion between 1868 and 1930. An updated appraisal of changes over the past 46 y appears desirable.

Waimea Inlet (41° 18′ S, 173° 10′ E) is separated from Tasman Bay by the 8-km-long Rabbit Island. For this survey Waimea Inlet was demarked to the west by a line joining the foreshores of Rabbit Island and Ruby Bay, and to the east by a line between the eastern tip of Rabbit Island and Tahunanui Beach (Fig. 1). The total area to high water line is 33 km^2, but at LWS the water surface is reduced to about 10 km^2. Waimea River enters Waimea Inlet from the south about midway along the length of Rabbit Island and has an average daily discharge of 1.8×10^6 m^3 which reduces to a minimum of 1.1×10^5 m^3 during summer drought (Nelson Catchment Board records). Other streamlets contribute fresh water discharges of minor significance. River water and tidal interchange flush the inlet through a maze of sparsely-vegetated channels between sandbanks and islets (Bests, Bells, Rough). Recent observations indicate that at low tide as much as 70% of Waimea River water is diverted by channels towards the western end of Rabbit Island; however, as the channels are covered by the rising tide, an increasing proportion of river water flows eastward, possibly 70% at high water.

SAMPLING PROCEDURES

Many *in situ* field profiles for salinity were measured with a YSI salinity, conductivity, and temperature meter. Of these profiles, four sites (Sites 29–32 on Fig. 1) are mentioned in the discussion of salinity determinations. A smaller number of oxygen profiles were recorded with a Beckman dissolved oxygen sensor. All temperature readings were made *in situ* to the nearest 0.1°C.

Water samples for laboratory determinations were collected from a few centimetres below the surface at Sites 1–28 in Fig. 1. Five bottles of water were collected at each site for:

(i) nitrogen and phosphorus components,
(ii) solids and salinity,
(iii) pH, chlorophyll, ATP, and heterotrophic potential,
(iv) dissolved oxygen, and
(v) bacterial numbers.

Ten sites were the maximum that could be processed on a single occasion. The samples were collected over a period of 60–90 min in the early morning by three or four groups of personnel, and processing began within 2 h of collection.

Sites 1–8 were sampled by boat at 0.1 km to 6 km from shore. Two trips were made, the first near high tide on 25 March and the second near low tide on 30 April 1975, although not all sites were sampled on both occasions. Seas were moderately rough on both trips. Sites 20–23 were also sampled by boat near high water on 20 October 1975 in calm

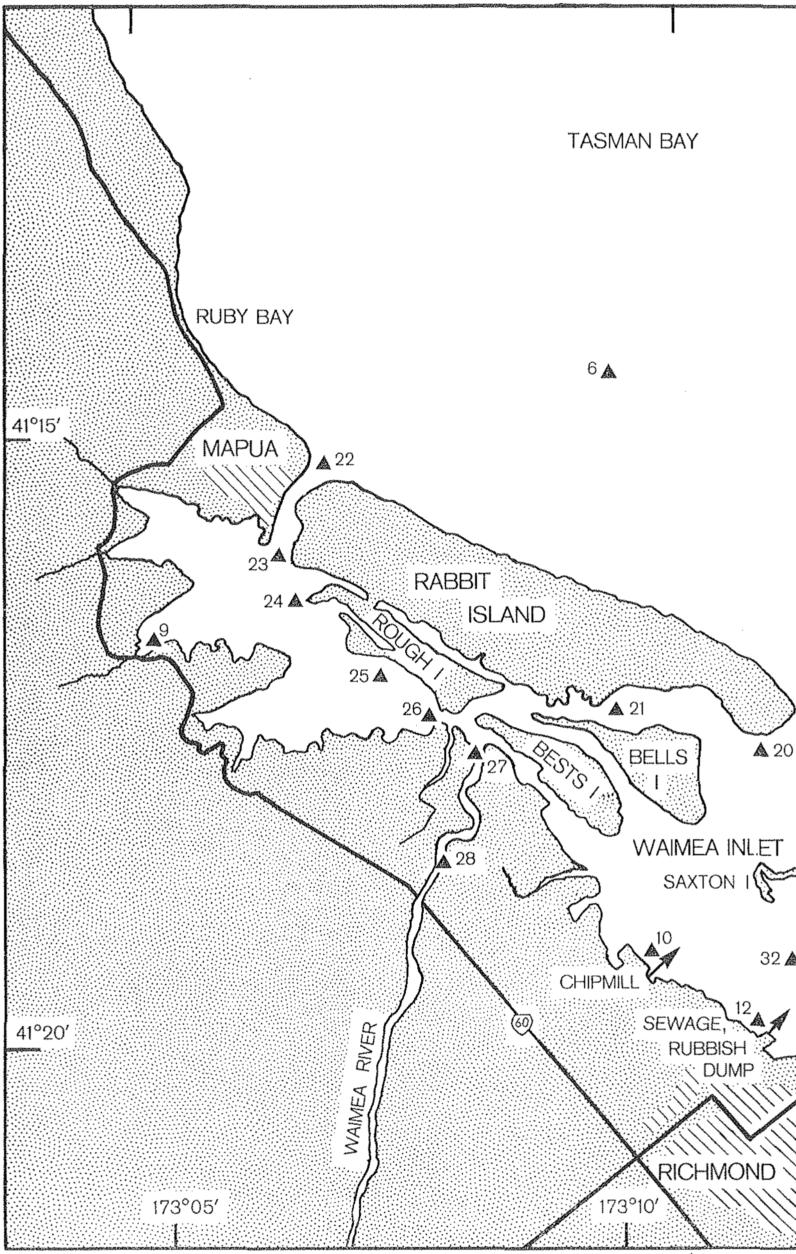
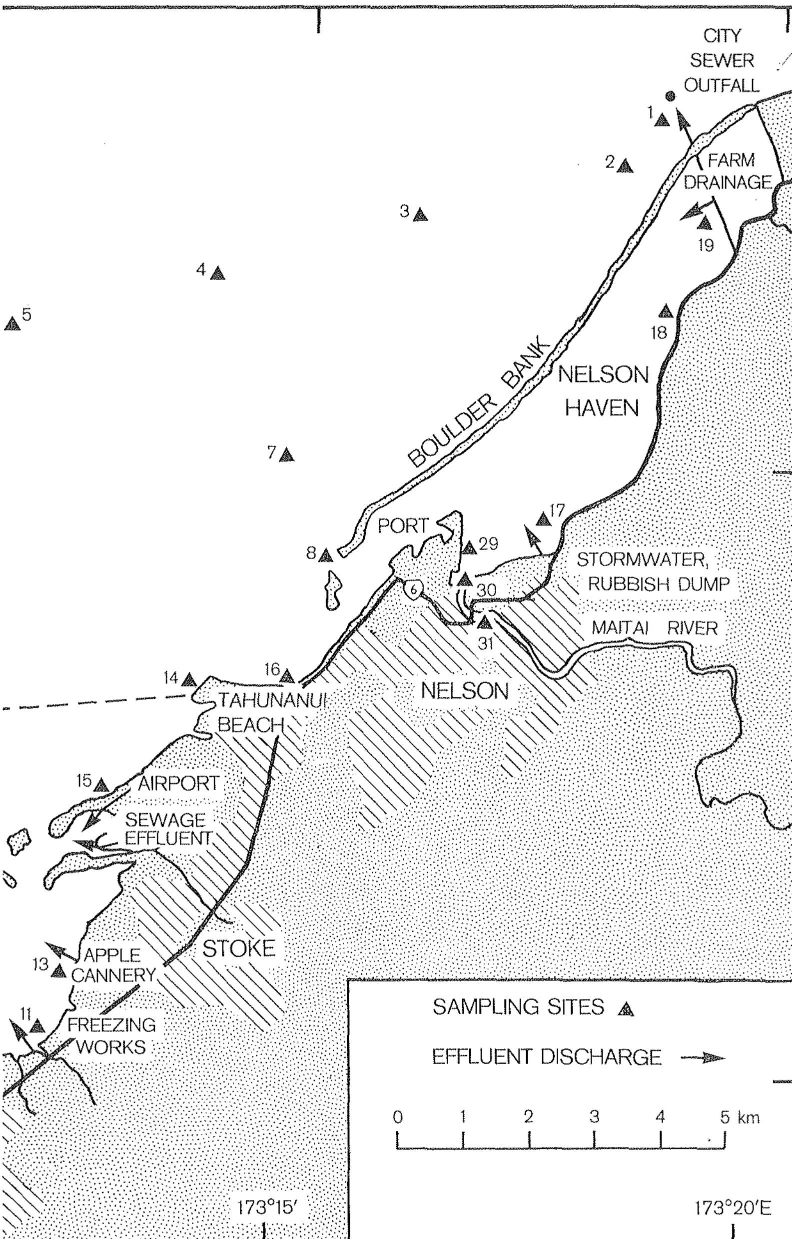


FIG. 1—Sketch map of Nelson Haven, Waimea Inlet, and Tasman Bay, South Is



land, New Zealand, showing sampling sites and regions of effluent discharge, 1975 sunny conditions, when there had been 26 mm of rainfall over the previous 2 d.

Samples from the other 16 sites were collected in calm sea by slowly wading from shore into water 0.4–0.6 m deep. Where effluent discharge was the feature of a site, samples were taken at least 50 m to the side of the discharge channel. At most sites, samples could be collected at HWS within a few metres of the shoreline. At other tidal periods it was necessary to wade an additional 50–150 m seaward to obtain suitable samples. Four sites, 11–14, were sampled on five occasions, Site 10 four times, Sites 9 and 15–19 twice, and the remainder once only. Samples were obtained near full tide on 10 June and 20 October, within the first two hours of ebbing tide on 8 April and 7 July and within the last two hours of flood on 12 May.

Major changes in water quality caused by effluents were anticipated near the following sites (effluents in parentheses): 1 (Nelson municipal sewage); 10 (wood-chip mill); 11 (freezing works); 12 (Richmond primary sewage treatment and garbage dump); 13 (apple cannery); 15 (Stoke primary sewage); 17 (Nelson municipal garbage dump and stormwater); and 19 (dairy farming). The other 20 sites were chosen to establish the distance over which these pollutants were causing changes.

LABORATORY PROCEDURES

Salinity was measured with a YSI salinity, conductivity, and temperature meter in both field and laboratory. This instrument could have been subject to minor errors, but was frequently calibrated against standard Copenhagen seawater (salinity 35.001‰) to reduce the error to less than 1%.

Dissolved oxygen was determined by the Winkler method (American Public Health Association 1971). pH measurements were made with a Radiometer meter and glass-calomel electrodes.

Nitrate was determined by the method of Kamm *et al.* (1965), and total nitrogen was obtained by addition of the nitrate figure to that for Kjeldahl nitrogen on the unfiltered sample (American Public Health Association 1971).

Total phosphorus was determined on unfiltered samples by the method of Hansen & Robinson as modified by Strickland & Parsons (1968).

Suspended solids were obtained by filtering 0.75–2.0 litres of sample through a preignited 47 mm Sartorius glass fibre filter, drying at 105°C and weighing; for volatile solids, the filter and residue were heated to 500°C for 15 min in a muffle furnace, cooled, and re-weighed.

Chlorophyll *a* was measured by the method of Strickland & Parsons (1968), and ATP by the method of Holm-Hansen & Booth (1966).

Heterotrophic potential (V_{max}) was determined with ^{14}C labelled glucose by the method of Hobbie & Crawford (1969). Incubation temperature was within 1°C of *in situ* temperatures.

Total bacteria were counted by staining with acridine orange as described by Jones (1974) or by filtering the water sample and staining with acridine orange just before viewing with a Leitz microscope with incident UV illumination. Viable bacteria counts were made by the pour-plate method on Marine agar 2216 (Difco).

Most probable number determinations for presumptive coliform bacteria were done by the 5-tube 3-dilution method (Ministry of Health *et al.* 1969) using Oxoid Minerals Modified Glutamate Medium incubated at 37 ± 0.5°C for 48 ± 2 h. Confirmatory media included lauryl tryptose (Oxoid) and 1% tryptone (Oxoid) at 44.5 ± 0.2°C for 24 ± 2 h. Definitions of terms and methods are given by the New Zealand Microbiological Society (1976).

RESULTS

Table 1 summarises physical, chemical, and biological data for 17 parameters from 28 stations during the period 25 March to 20 October 1975. If a site was sampled on more than one occasion, the records were averaged to give a simplified presentation.

DISCUSSION

SALINITY

With seasonal fluctuations, oceanic surface waters around central New Zealand show salinities close to 35‰ (Garner 1961). In March 1970, Heath (1973) found surface salinities of 35.0‰ for the centre of Tasman Bay.

Many salinities were measured in the field in addition to the determinations on the water samples. For offshore sites, recordings ranged from 34.0‰ to 35.0‰ indicating a very minor dilution of the sea water in this area of Tasman Bay, probably less than 3%.

For Nelson Haven, profiles measured at HWS in April around the entrances to Nelson Haven and through the shipping channel showed a salinity concentration of 34.0‰ or higher. Only in the Maitai River channel approaching the boat harbour was dilution obvious, with salinity dropping to 32.0‰ in the top 30 cm, although readings >34.0 were obtained at lower depths (Site 29). Site 31 was only 400 m below the furthest point of tidal influence: the top 30 cm gave salinity readings of 20‰ increasing to 34‰ on the bottom, at 130 cm below the surface. At this site, 31, 30 min of ebbing tide dropped the surface salinity to zero, but readings >30‰ were still recorded in 1 m of water in depressions of the river bottom after 1 h. Even at low tide, water near the boat harbour (Site 30) gave 15‰ salinity at 10 cm from the surface and 33‰ on the bottom at 1 m.

Salinity measurements were made in Waimea Inlet during May at low tide in the eastern approaches and channels. Even at the extremity of boat access (Site 32) in water 30 cm deep the minimum recorded salinity was 30.5‰. During July–August measurements were made from

ABLE 1—Averaged records of water quality at 28 sample sites in tidal waters in the Nelson area, 1975 (dates of sampling: a – 25 March, b – 8 April, c – 30 April, d – 12 May, e – 10 June, f – 7 July, g – 20 October; * = one record only, † = two counts only, ‡ = one extremely high value of 32 not included in averages, – = not analysed)

	TASMAN BAY E–W								WAIMEA INLET – EFFLUENT SITES				
	Sewer outfall 1	2	3	4	5	6	Harbour mouth 7	8	Mapua 9	Chip mill 10	Freezer 11	Tip 12	Cannery 13
ates of sampling	c	c	c	a c	a c	c	a c	a c	b d	bdfg	bdefg	bdefg	bdefg
umber of samples	1	1	1	2	2	1	2	2	2	4	5	5	5
mperature (°C)	15.0	15.0	15.4	19.0	18.5	16.0	18.6	19.9	13.2	11.8	10.8	11.0	11.4
$_2$ (g·m^{-3})	7.9	8.1	8.2	7.5	8.3*	8.1	11.1	10.2	7.5	8.6	7.6	8.4	8.2
I	7.10	8.11	8.10	8.10	8.09	8.10	8.02	8.00	7.95	8.05	8.01	8.05	8.03
linity (‰)	34.2	34.2	34.0	34.2	35.0	34.8	34.3	34.5	22.0	29.2	28.6	29.0	31.2
itrate-N (g·m^{-3})	0.012	0.013	0.012	0.005	0.005	0.013	0.009	0.009	0.060	0.167	0.126	0.094	0.091
itrogen total (g·m^{-3})	0.15	0.15	0.18	0.15	0.11	0.18	0.13	0.16	0.45	0.43	2.55	0.39	0.43
osphorus, total (g·m^{-3})	0.047	0.028	0.026	0.022	0.022	0.024	0.16	0.020	0.065	0.055	0.468	0.059	0.052
ispended solids (g·m^{-3})	6.4	4.0	5.2	4.5	5.8	4.8	8.0	6.5	28.7	24.5	35.1	21.7	29.6
latile solids (g·m^{-3})	1.0	0.9	1.1	0.9	1.2	1.0	1.1	1.1	3.6	2.5	11.7	2.4	2.6
lorophyll (mg·m^{-3})	1.24	1.79	1.96	1.69	2.08	2.41	1.80	1.55	6.40	2.35	22.80	2.71	2.52
TP (mg·m^{-3})	0.56	0.57	0.56	0.45	1.31	0.58	0.67	0.22	0.90	0.85	2.51	0.98	0.80
nax (mg·m^{-3}·h^{-1})	0.102	0.121	0.094	0.02*	–	0.067	0.141	0.101	0.452	0.849	0.342‡	0.632‡	0.153‡
tal bacteria (nos·ml^{-1} × 10^{6})	0.80	0.51	0.53	0.81*	0.42*	0.47	0.54*	0.59*	0.90	2.52	12.66	1.39	3.52
able count (nos·ml^{-1} × 10^{2})	2.40	3.50	2.80	1.93	4.80	6.30	2.50	6.05	8.8	22.6†	173†	13.5†	33†
liform bacteria (nos·ml^{-1} × 10^{2})	300	–	–	16*	350*	–	132	350*	125	4310	361000	6700	3200
nfirmed faecal coliform (nos·ml^{-1} × 10^{2})	170	–	–	0*	80*	–	10	14*	97	365	58800	1250	830
nfirmed *E. coli* (Type I) (nos·ml^{-1} × 10^{2})	50	–	–	0*	50*	–	7	9*	91	194	58500	918	428

TABLE 1—(*Continued*)

	TAHUNANUI			NELSON HAVEN			CHANNELS BEHIND RABBIT ISLAND							WAIMEA RIVER	
	West	Aero-drome	East	Tip	Mary-bank	North End	East side	Mapua to Rabbit Island Bridge							
	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
ates of sampling	bdefg	b d	b d	b d	b d	b d	g	g	g	g	g	g	g	g	g
umber of samples	5	2	2	2	2	2	1	1	1	1	1	1	1	1	1
:mperature (°C)	13.3	15.7	16.0	14.9	14.1	12.6	15.0	13.5	15.0	15.0	15.0	13.0	12.0	11.0	10.5
$_2$ (g·m^{-3})	8.5	7.7	7.7	7.6	8.0	8.7	8.1	8.2	8.2	8.2	8.3	10.6	9.9	10.9	10.9
I	8.20	8.21	8.25	8.18	8.16	8.11	8.22	8.20	8.25	8.23	8.21	7.79	8.00	7.85	7.22
ılinity (‰)	35.6	30.7	32.3	34.0	31.0	19.8	34.4	30.1	34.4	34.2	33.4	2.8	11.6	0.0	0.0
itrate-N (g·m^{-3})	0.015	0.034	0.014	0.008	0.017	0.140	0.029	0.059	0.001	0.001	0.005	0.112	0.074	0.153	0.198
itrogen total (g·m^{-3})	0.23	0.25	0.25	0.21	0.25	0.60	0.24	0.21	0.12	0.13	0.14	0.21	0.24	0.24	0.34
ıosphorus, total (g·m^{-3})	0.027	0.023	0.032	0.028	0.035	0.070	0.029	0.029	0.021	0.001	0.001	0.009	0.029	0.013	0.011
ıspended solids (g·m^{-3})..	13.7	18.0	27.2	11.2	17.0	26.8	20.5	9.7	13.3	13.6	9.0	6.5	13.3	1.7	1.4
olatile solids (g·m^{-3})	1.5	1.5	2.5	1.3	1.2	2.5	2.6	1.0	2.1	1.9	1.3	0.9	1.7	0.5	0.3
hlorophyll (mg·m^{-3})	2.61	2.07	5.04	1.92	2.20	3.26	3.60	1.87	2.20	1.30	1.40	0.49	1.65	0.26	0.39
TP (mg·m^{-3})	0.54	0.49	1.02	0.70	0.56	0.50	0.77	0.30	0.72	0.28	0.28	0.035	0.22	0.014	0.018
max (mg·m^{-3}·h^{-1})	0.094	0.452	–	–	0.162	–	0.032	–	0.083	–	0.094	–	0.265	–	0.077
otal bacteria (nos·ml^{-1} × 10^{6})	0.52	1.26	0.84	1.35	1.68	2.25	0.35	0.37	0.34	0.23	0.26	0.24	0.37	0.13	0.10
iable count (nos·ml^{-1} × 10^{2})	10.1†	7.7	11.5	21.0	3.8	118	–	–	–	–	–	–	–	350	550
oliform bacteria (nos·ml^{-1} × 10^{2}) ..	270	2550	105	725	62	2780	17	550	50	13	130	2250	1600	80	70
onfirmed faecal coliform (nos·ml^{-1} × 10^{2})	63	350	26	300	32	870	0	170	4	5	35	110	130	80	70
onfirmed *E. coli* (Type I) (nos·ml^{-1} × 10^{2})	48	177	5	300	24	860	0	110	4	2	25	20	130	–	–

the lower reaches of the Waimea River to the Mapua sea coast in the west and to the eastern extremity of Rabbit Island. At HWS, sea water was present 1 km downstream from the bridge on Highway 60 (Site 28): surface salinity was nil at 15 cm, 2.1‰ at 1 m, and 19.1‰ at 2 m (bottom). A further 1.5 km downstream at Site 27, readings were 12‰, 24‰, and 25‰ respectively. A further 2 km away in channels to east and west readings showed at least 95% seawater. At low tides the diluted seawater moved seaward, but at Sites 20 and 22 salinities indicated minor dilution at low tide.

At Sites 9–19 salinities were usually high (Table 1). There was appreciable dilution in only the series of samples collected on 8 April 1975, when salinities ranged from a low of 5.7‰ for Site 19 to a high 36.3‰ for Site 14. Nelson Airport recorded 46 mm rainfall on 1 April, but it is not known if this was responsible for the dilution.

Overall, from the salinity measurements for Nelson Haven and Waimea Inlet it appears that even in calm weather at neap tides the water is very well mixed. Even in shallow inshore areas the salinities were usually close to open sea values.

Water volumes in Waimea Inlet were calculated from the limited data available on tidal range, water area, and depth. For the 33 km^2 surface of the inlet it was estimated that at LWS the approximate volume of water remaining was 7×10^6 m^3 and that this was augmented by 60×10^6 m^3 at HWS. At low water neap (LWN) tide 10×10^6 m^3 was retained, and this was augmented by 23×10^6 m^3 at high water. These tidal flushings were very high in comparison with the daily average freshwater discharge of Waimea River, 1.8×10^6 m^3. Total daily discharge of urban and industrial effluent has been stated to be about 1.5×10^4 m^3 (Nelson Catchment Board records).

In Nelson Haven ratios of tidal flushing to freshwater discharge are similar to those for Waimea Inlet.

TEMPERATURE

Predictably, temperatures changed markedly with season, and ranged from a maximum of 23°C at Site 8 on 25 March 1975 to a minimum of 4.5°C at Site 11 on 7 July 1975. On five occasions Site 14 (Tahunanui Beach) was unusual in showing temperatures consistently higher than others taken on the same day – 0.5–3.5°C higher than nearby Sites 11, 12, and 13. Temperature changes have profound effects on biological activity; for example the uptake of ^{14}C-labelled glucose, used to measure V_{max}, is approximately doubled for each 10°C rise in temperature (M. J. Spencer, unpublished data).

pH

The pH of seawater is usually in the range 7.5 to 8.4 The only recording outside this range was Waimea River water, Site 28, pH 7.22.

DISSOLVED OXYGEN

Dissolved oxygen was close to saturation (6.7 mg.l^{-1} at 25°C and 10.0 mg.l^{-1} at 5°C in sea water at 760 mm pressure – Beckman Instrument Inc. 1973) in practically all samples. In some samples oxygen exceeded saturation, probably as a result of algal photosynthesis. In only three samples was oxygen appreciably below saturation, Sites 11 (freezing works) and 13 (apple cannery) on 8 April 1975 and Site 11 on 20 October, but on these occasions oxygen exceeded 60% of saturation, which is adequate for all marine life.

At many points where salinity profiles were measured, oxygen meter records were also taken. Values were always near saturation and there was little variation from surface to bottom.

NITROGEN

Ocean water contains very little nitrogen and this element is often the limiting nutrient for the growth of phytoplankton (Ryther & Dunstan 1971). Weast (1974) gives the ranges of concentration for the nitrogen components of seawater as nitrate-N 0.001–0.7 g.m^{-3}, nitrite-N 0.0001–0.05 g.m^{-3}, ammonia-N 0.005–0.05 g.m^{-3}, and organic-N 0.03–0.2 g.m^{-3}. Since nitrite and ammonia are usually found only in traces, this survey was confined to nitrate and Kjeldahl-N determinations.

The range of nitrate-N levels for offshore samples was 0.001–0.017 g.m^{-3}; inshore sites showed much higher levels, 0.01–0.29 g.m^{-3}.

The range of total nitrogen levels in the offshore samples was 0.09–0.24 g.m^{-3}, but increased markedly at some inshore sites (0.16–8.58 g.m^{-3}). The highest levels were found at Site 11, near the protein-rich freezing works effluent: five samples averaged 2.55 g.m^{-3}. Table 1 also shows enriched levels for Sites 9, 10, 12, 13, and 19. The much lower amounts of nitrogen found at sites remote from effluent discharge indicate effective denitrification, assimilation, or dispersion of the nitrogen compounds.

TOTAL PHOSPHORUS

Phosphorus is an extremely important nutrient in seawater, which normally contains 0.001–0.1 g.m^{-3} (Weast 1974), with open ocean levels at the lower end of this range. Phosphorus tends to have a weight ratio of approximately 1 to 10 with nitrogen and reaches high concentrations only where phosphorus is brought in by run-off from the land (Ryther & Dunstan 1975).

Values greater than 0.2 g.m^{-3} were recorded at Sites 10 and 13 once and four times at the freezing works, Site 11 (maximum 1.57, minimum 0.07, average of five samples 0.47 g.m^{-3}). Table 1 shows that Sites 9, 10, 12, 13, and 19 all gave indications of phosphorus enrichment with average levels exceeding 0.05 g.m^{-3}. Site 18 showed minor increase, but the other 13 inshore sites had phosphorus levels below 0.03 g.m^{-3}.

Tasman Bay samples, with a single exception (Site 1) were below 0.03 g.m^{-3}. The exception, taken within approximately 100 m of the sewer outfall, showed 0.047 g.m^{-3}. Unfortunately, further samples were not obtained from this site, but it can be assumed that these would show extreme variation depending on tidal flow, sea conditions, and direction and distance from the sewer outfall.

Where fresh and salt water mix, phosphate can be reduced by flocculation, precipitation, and entrainment into sediments (Poon 1976, Sharp 1975). From the 28 sampling sites, here recorded, 13 inshore and 7 offshore areas show low total phosphorus and indicate a rapid diminution of the high phosphate of several effluent sources.

SUSPENDED SOLIDS

Suspended solids were considerably higher for inshore samples than those from deeper water. Microscopic examination showed the bulk of the solids to be fine greyish brown mineral material.

The volatile fraction was much greater in samples from sites near effluents with rich organic components. Volatile solids showed a close relationship to nitrogen and phosphorus levels and to microbial parameters.

CHLOROPHYLL, ATP, AND V_{max}

These three parameters are considered together as they relate to a measure of biomass and microbial activity. Chlorophyll *a* (Chl *a*) measurements provide an indication of the total organic material produced by the phytoplankton and can give an index of productivity of a series of samples (Reid 1961). Adenosine triphosphate (ATP) is a constituent of all organisms, being produced through aerobic and anaerobic metabolism. Its determination provides a measure of the total biomass (including bacteria, phytoplankton, and zooplankton) which may be related to the heterotrophic population assuming that no ATP is associated with non-living material and that samples are taken such that autotrophic plants are precluded (Hamilton & Holm-Hansen 1967). V_{max} is the maximum velocity of uptake of a substrate, here ^{14}C-labelled glucose, of a sample when the system is saturated; V_{max} thus gives a measure of the potential heterotrophy.

Table 2 summarises the range and/or average values of these measurements according to appropriate groupings of sites by similar geographic, chemical and physical characteristics. As the levels of 22.8 mg.m^{-3} for chlorophyll *a* at the freezing works (Site 11) and 3.6 mg.m^{-3} for Rabbit Island (Site 20) were much higher than the other sites in their respective groups, these data were not included in Table 2. For a similar reason, the 2.5 mg.m^{-3} ATP value for Site 11 was also deleted. Undecayed, suspended vegetable detritus in some effluents probably contributed to high chlorophyll *a* levels, and redispersion of fine detritus may have caused increased ATP values.

For the effluent sites in Waimea Inlet (Sites 9–13) there was a considerable variation in the ATP values because of effects of tidal flow and the difficulty of obtaining exactly identical samples each time, but

TABLE 2—Summary of averaged values of chlorophyll *a* (Chl *a*), ATP, and V_{max} determinations made for discrete groups of sites in the Nelson area, 1975

Site No.	Area	Chl *a* ($mg.m^{-3}$)	ATP ($mg.m^{-3}$)	V_{max} ($mg.m^{-3}.h^{-1}$)
1–8	Tasman Bay	1.2–2.4	0.62	0.104
9–13	Waimea Inlet	2.5–6.4	0.90	0.489
15	Aerodrome	2.1	0.49	0 452
14 & 16	Tahunanui Beach	2.6–5.0	0.78	0.094
17–19	Nelson Haven	1.9–3.3	0.59	0.162
20–26	Rabbit Island	1.3–2.2	0.43	0.070
27 & 28	Waimea River	0.3–0.4	0.016	0.077

it is hoped the average reflects a justifiable figure for comparative purposes.

While it is difficult to compare the absolute values for these different groupings directly with other published results, their relative magnitudes can serve to differentiate the trophic status, compared with Tasman Bay as a base-line, and provides a basis for future reference. The average ATP/Chl *a* ratio for Tasman Bay samples (Sites 1–8) of 0.32 fits in well with the range of 0.22–0.36 for mixed populations in sea water reported by Brezonik *et al.* (1975).

The use of the heterotrophic potential technique to study the trophic status of lakes, rivers, and estuaries is well established in the literature (Gillespie 1976, Albright & Wentworth 1973, Wright & Hobbie 1966, Hobbie & Wright 1968). Carney & Colwell (1976) showed, after a 1-y study of a Chesapeake Bay sub-estuary, that microbial populations demonstrated greater heterotrophic potential with increased pollution loads, and concluded that V_{max} may provide a useful index of relative pollution in natural waters.

A major difficulty in this study was the wide variation in the samples taken. At several sites near effluent discharges, notably the freezing works, Richmond tip, and the apple cannery, the uptake kinetics sometimes approached the upper theoretical maximum (slope = zero), giving V_{max} values of $\geqslant$ 32 $mg.m^{-3}.h^{-1}$, far in excess of anything reported in the literature for the low substrate concentrations used in this study. Thus the averaged V_{max} values in Table 2 at these three sites take into account only the "less polluted" samples and are perhaps very much underestimated. It can be seen, however, that the average microbial activity for this grouping (Sites 9–13) is about sixfold higher than for the less polluted regions (Sites 1–8 and 20–28). Average chlorophyll *a* and ATP concentrations confirm this difference, except near Tahunanui Beach where values for both these parameters are higher than would be expected from the average V_{max} values.

TOTAL AND VIABLE BACTERIAL COUNTS

The mean values for the total numbers of bacteria (Table 1) varied between 0.23 and 1.68 millions per millilitre for 22 of the 26 seawater sites. The remaining four sites (10, 11, and 13 near effluent outfalls and 19 at the north end of Nelson Haven) had higher bacterial populations. Viable counts of bacteria represented only about 0.1% of the total population. They tended to show greater variation than the direct counts, but were also higher at the sites near the effluent discharges (Sites 10, 11, and 13) and at Site 19.

COLIFORM BACTERIA

The numbers of coliform bacteria and faecal coliforms and their ratios give more precise information about the source from which the bacteria originate. Effluents from a freezing works and two primary sewage installations discharge into the south-east corner of Waimea Inlet. Extremely high numbers of coliform bacteria were always found in water near the freezing works (Site 11), and relatively high numbers near the Richmond tip (Site 12), chipmill (Site 10), aerodrome (Site 15) and apple cannery (Site 13), also from farm drainage into Nelson Haven (Site 19). Numbers were usually low at off-shore sites.

SEDIMENTS

The zone of freshwater–seawater mixing can be one of active chemical and physical reactions and one where aggregation of soluble and insoluble organic compounds is promoted by micro-organisms. In this zone there is flocculation of water-borne clay, phosphate, and organic detritus, which settles in calm, shallow waters and accumulates in the sediment sink. Aspects of these reactions have been discussed by Dyer (1972), Jannasch & Pritchard (1972), and Poon (1976).

On the shallow, inshore flats of Waimea Inlet and Nelson Haven there are expanses of soft mud 5–30 cm deep, rich in organic matter. Beneath the surface, the mud is often black and smells of hydrogen sulphide. At Sites 10–13, 17, and 19, effluents continue to contribute rich organic material to some of these calm, shallow areas.

Coliform counts and viable plate counts on the sediments showed large numbers of bacteria in the mud. The numbers were very much higher at Sites 10–13 than at other areas (B. B. Bohlool, Cawthron Institute, pers. comm.).

INLETS AND ESTUARIES

Nelson Haven, and more particularly Waimea Inlet, have without delineation or definition often been referred to as "estuaries". Problems of "estuary" definition are discussed by Barnes & Green (1972). Inlets and estuaries are semi-enclosed coastal zones where seawater and freshwater meet and the water mass is mixed by many natural phenomena. The time normally required to "replace" or "flush" the water from the zone has been variously defined (Bowden 1967). For this paper, there was inadequate data for precise calculations of flushing time, but with up to 80% of the water leaving Waimea Inlet on each tidal cycle, rapid water exchange was indicated. Recent dye marker tests in the eastern half of Waimea Inlet by the Nelson Catchment Board showed that appreciable proportions of this water returned with the flooding tide.

CONCLUSIONS

In general, water samples collected from off-shore areas and from sites remote from effluent discharges showed values for all parameters which were characteristic of normal seawater. There was no significant evidence of oxygen depletion or of pH change within the period of the survey over the area sampled.

Many water samples collected near effluent discharges had high levels for nitrate, total nitrogen, total phosphorus, volatile solids, ATP, V_{max}, total bacteria, viable bacteria, and coliform bacteria. These sites were all in the upper intertidal zone, where they were flooded only at high water. In only three water samples, two from near the freezing works and one from near the apple cannery, was minor oxygen depletion recorded. Anaerobic muds, and water and muds with dense populations of micro-organisms, were present in the vicinity of some organic-rich effluent discharges.

These studies indicated that the outflowing eutrophic waters were causing little change in trophic status of surface water at remote and off-shore sites. Generally, the river inflows, tidal flushing, and water turbulence appeared to promote good oxidation, dilution, inactivation, and dispersion of the effluents. It is hoped that this assessment will provide background for future monitoring and further studies.

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