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Mixing in the Surf Zone

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1 INTRODUCTION

Mixing in the surf zone, i.e. in the water between the line of breaking waves and the beach, is an interesting problem because of the many processes which can produce mixing. It is also of considerable relevance because many coastal discharges in Australia enter the ocean through an outlet in the surf zone, in many cases extending only to low water level.

A variety of empirical and theoretical approaches can be used to describe the mixing and subsequent dilution of these discharges. The empirical approaches involve making a summary of one or more experiments, without recourse to any particular theory. At the other extreme, the theoretical approaches involve using the results of experiments to obtain coefficients on constants in a selected diffusion formulation.

This paper leans towards the second approach with the variation that entrainment rather than diffusion is the theoretical approach which the analysis is based.

2 ENTRAINMENT

Essentially, the entrainment formulation states that the rate at which fluid enters a moving jet is proportional to the product of (1) interfacial area and (2) the relative velocity between the jet and the adjacent fluid. This formulation may be expressed as

$$\frac{dQ}{dS} = \alpha AV \qquad (1)$$

where Q is the volume flux in the jet; S is the distance along the axis of the jet; α is the entrainment constant; A is the interfacial area and V is the relative velocity. For a jet, the value of α typically is 0.06 (Refs. 1 and 2).

Effluent released in the surf zone quickly mixes over the depth and spreads over the area between the beach and the line of breaking waves. There is generally a longshore current in the surf zone which is significantly faster than the currents further offshore. Wind driven currents, variations in bottom topography and rip currents also have a significant role but, as an initial approximation, fluid can only be entrained across the breaker zone and thus the interfacial area is proportional to the depth of water (D) in which the waves are breaking. In this case, equation 1 becomes

$$\frac{dQ}{Ds} = \alpha DV \qquad (2)$$

3 RESULTS OF FIELD EXPERIMENTS

Values for the entrainment coefficient were derived from the results of four experiments carried out at Black Rock, Victoria, in which the discharge from the Geelong Waterworks and Sewerage Trust (GWST) outfall was labelled with dye. Two of these experiments were carried out by Caldwell Connell Engineers in 1979 (Ref. 3) and the other two by J. E. North with the assistance of GWST personnel in 1972 - 73. The details of these experiments are summarised in Table 1.

3.1 Experiment 1 - Outfall Dosing on 22 March 1979

In this experiment a moderate southeasterly wind held the sewage field close to the shore and the moderate southerly swell enhanced the eastward longshore current. Dye dosing commenced at 1330 hours and continued for 3.7 hours. Selected outlines of the dyed sewage field are shown in Fig. 1.

TABLE I

DETAILS OF DYE DIFFUSION EXPERIMENTS

Experiment	Date	Release	Dye	Duration of dosing	Tide	Monitoring[a]	Weather Conditions		
							Wind	Sea state	Swell state
1	22.3.79	Continuous in outfall	5 kg Rhodamine B	3.7 hours	Flood	A,Se,Sn,V	5 m/sec,SE	Moderate	Moderate
2	6.4.79	Continuous in outfall	5 kg Rhodamine B	3.0 hours	Flood	A,Sh	6 m/sec,SW	Moderate	Low
3[b]	29.11.72	Continuous in outfall	Fluorescein LT	3.0 hours	Flood	A,Sh,Se	5 m/sec,S	Slight	Low
4[b]	7.6.73	Continuous in outfall	Fluorescein LT	6.0 hours	Flood	Sh,Ch	5 m/sec,S	Smooth	Low

[a]Monitoring Code: A = aerial photography. Ch = shore sampling of coliforms. Se = dye sampling from boat.
Sh= shore sampling of dye. V = verticle profiles.

[b]North. J.E. "The Performance of Victorian Ocean Outfall Sewers" M.Eng. Sc. Thesis. Univ. Melbourne (1974).

The field moved eastwards at 0.11 m/s. In photographs, it was not visible east of East Point; however, it was detected by the fluorometer in water samples taken on the shore at locations further east.

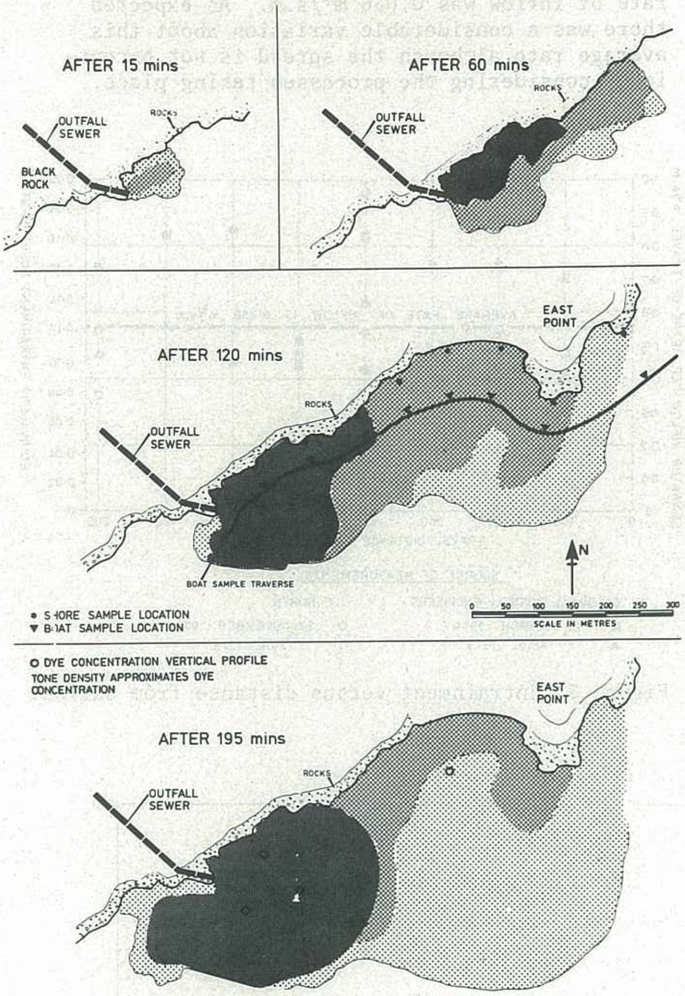

Figure 1 Positions of dyed sewage field during experiment 1 on 22 March 1979

Water samples were taken from the shore at stations shown in Fig. 1 and at sea in a longshore traverse path also shown in the figure. The steady state dye concentration profiles obtained from the boat and from shore sampling are presented in Fig. 2. The two profiles are generally similar except between 200 and 600 m. In this region, as shown in Fig. 1, the sewage field was confined in a narrow band inside the surf zone and the boat traverse could sample only the southern edge of the field thus accounting for the lower concentrations. The dilution ratio, based on the shore sampling, shown on Fig. 2 indicates that an initial dilution of about 13:1 was achieved within 50 m of the outfall. Over the next 250 m, dilution was rapid, a consequence of the intense vertical mixing produced by breaking waves on the rocky shore. Further east, dilution was less rapid, until 500 to 600 m east of the existing outfall, the dilution ratio increased rapidly as the field passed through a rip current and reached a value of about 150:1 at the eastern boundary of the Trust property.

Vertical profiles of dye concentrations were also made at locations shown in Fig. 1. The profiles indicate that the sewage field thickness increased with distance east of the outfall, and decreased with distance offshore. The vertical mixing rate was about 1 m for each 250 m of travel.

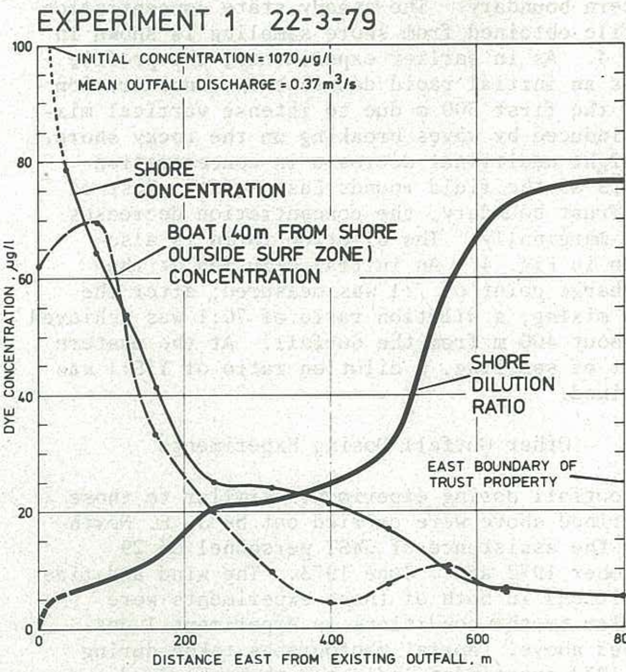

Figure 2 Dye concentration and dilution ratio for experiment 1

3.2 Experiment 2 - Outfall Dosing on 6 April 1979

This experiment was conducted on a flood tide with a moderate south westerly wind and a low swell. Dosing commenced at 1411 hours and continued for 3 hours. Selected outlines of the dyed field are presented in Fig. 3. The field moved rapidly eastwards under the influence of wind and tidal current at a speed of 0.17 m/s. It was visible as far as Thirteenth Beach.

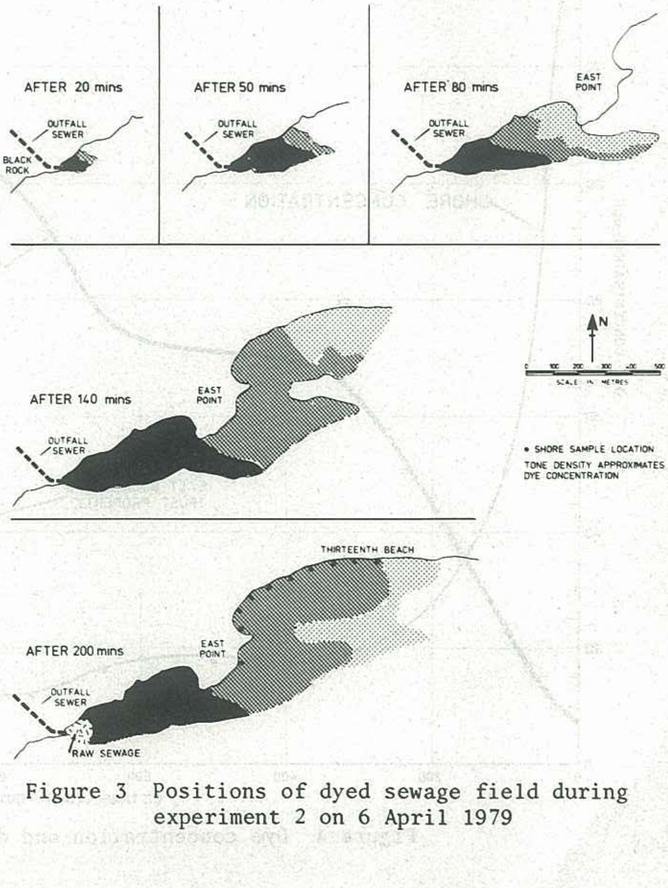

Figure 3 Positions of dyed sewage field during experiment 2 on 6 April 1979

Water samples were taken from shore at stations as far as 1500 m east of the existing outfall as shown in Fig. 3; this is 700 m east of the Trust's eastern boundary. The steady state concentration profile obtained from shore sampling is shown in Fig. 4. As in earlier experiments, the profile shows an initial rapid decrease in concentration over the first 300 m due to intense vertical mixing induced by waves breaking on the rocky shore. A slight additional decrease in concentration occurs as the field rounds East Point. East of the Trust boundary, the concentration decreases only marginally. The dilution ratio is also shown in Fig. 4. An initial dilution at the discharge point of 7:1 was measured; after the wave mixing, a dilution ratio of 70:1 was achieved at about 400 m from the outfall. At the eastern limit of sampling, a dilution ratio of 115:1 was obtained.

3.3 Other Outfall Dosing Experiments

Two outfall dosing experiments similar to those described above were carried out by J. E. North with the assistance of GWST personnel on 29 November 1972 and 7 June 1973. The wind and tide conditions in both of these experiments were similar to the conditions in experiment 1 described above. Aerial photographs taken during the 1972 experiment indicated that the dyed effluent field spread in the same manner as shown for experiment 1 in Fig. 1.

The results of North's experiments are generally similar tc the other experiments described above.

4 ENTRAINMENT COEFFICIENT

The rate of inflow of ocean water into dyed effluent plume which corresponds to the change in the dilution of the effluent was calculated for the four experiments and the results are shown in Fig. 5. It can be seen that the average rate of inflow was 0.056 $m^3/s.m$. As expected there was a considerable variation about this average rate although the spread is not exceptional considering the processes taking place.

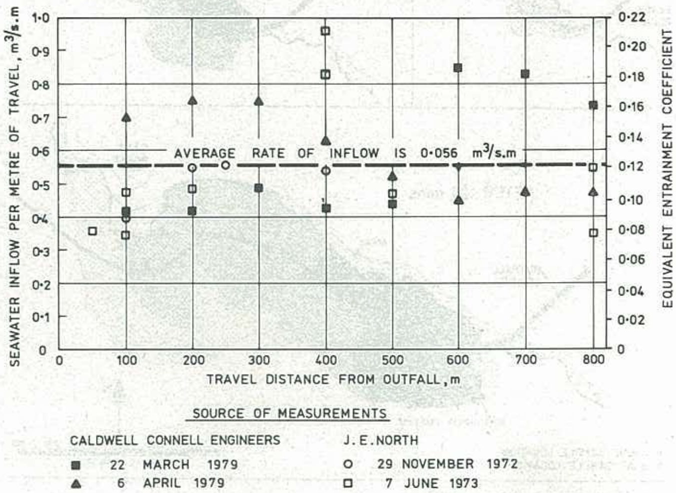

Figure 5 Entrainment versus distance from outfall

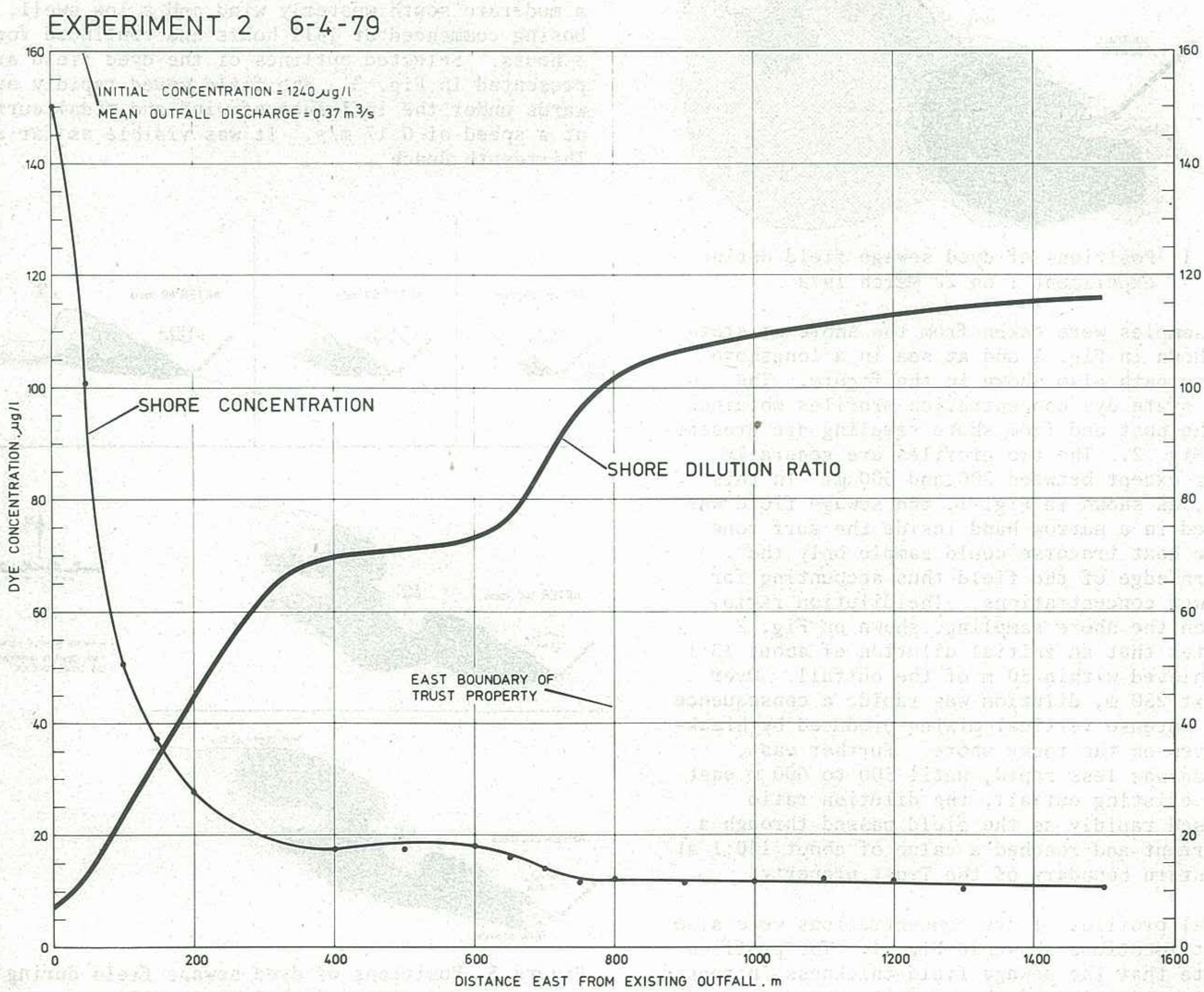

Figure 4 Dye concentration and dilution ratio for experiment 2

In the experiments, the average depth at the breaker zone was 6.5 m and the average velocity of the effluent field was 0.07 m/s. Substituting these values into equation 2 shows that the average value of the entrainment coefficient was 0.13. The range of values of coefficient is from 0.06 to 0.20, and it is interesting to note that no value was less than 0.06.

5 DISCUSSION OF ENTRAINMENT CONCEPT

The average entrainment coefficient of 0.13 is approximately twice that of a turbulent jet. This result indicates that the additional turbulence generated by the breaking waves increases the rate of entrainment by a factor of two.

It is apparent that the volume of water in the surf zone does not continually increase with time. Thus the entrainment must represent a circulation of water through the breaker zone. If this is represented as a two layer flow with inflow in the upper layer and outflow in the lower layer, the average current speed in these two layers would be 0.02 m/s - well within the feasible range.

Examination of Figs. 1 and 3 shows, however, that this simple model of compensating inflows and outflows was not dominating and that the rip currents have a major influence on the dilution in the surf zone. No doubt, wind and bottom topography are also significant variables. At present, the available data would not support a more complicated model of mixing in the surf zone and the entrainment model provides a useful first approximation to the processes taking place.

For example, the entrainment model is sufficient to reach the following conclusions about subsequent dilution of the effluent field (1) if the discharge is doubled subsequent dilution will be halved; (2) if the large initial dilution is achieved the contribution of mixing the surf zone to the total dilution will be extremely small. To illustrate these points, consider an existing discharge of 0.38 m^3/s which receives an initial dilution of 8:1. Thus the flow rate of the resulting effluent field is 3 m^3/s. With an entrainment of 0.056 m^3/s.m, the flow rate after 1 km of travel in the surf zone would be 59 m^3/s which corresponds to a total dilution of about 160:1. If the initial dilution were 150:1 then after 1 km of travel the total dilution would be about 300:1. In the first case the subsequent dilution would be 20:1 whereas in the second case it would be 2:1. This example illustrates the practical use of the entrainment model.

6 CONCLUSION

A simple entrainment model can be used to represent the mixing which takes place in the surf zone. In four experiments carried out at Black Rock, Victoria, an entrainment coefficient of 0.13 was established. This value is approximately twice that for turbulent jets, the difference being considered to be the contribution of the turbulence generated by the breaking waves.

The entrainment model is a considerable simplification of a complicated combination of processes but it can be used to provide an approximate estimate of mixing and subsequent dilution in the surf zone.

7 REFERENCES

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