MEASUREMENTS OF INITIAL DILUTION OF A BUOYANT EFFLUENT

submitted to

WATER RESEARCH COMMISSION

WRC Report no. 160/1/88
ISBN 0-908356-99-4

HYDRODYNAMICS AND WATER QUALITY DIVISION
COASTAL ENGINEERING AND HYDRAULICS
NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY
COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

CSIR REPORT C/SEA 8766

Stellenbosch, South Africa
November 1987

THE NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY
WILL CEASE TO EXIST AS SUCH ON 31 MARCH 1988, AND
WILL BECOME PART OF THE NEWLY FORMED CSIR
DIVISION OF EARTH, MARINE AND ATMOSPHERIC SCIENCES
AND TECHNOLOGY ON 1 APRIL 1988

---oOo---

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY
COASTAL ENGINEERING AND HYDRAULICS
HYDRODYNAMICS AND WATER QUALITY DIVISION

MEASUREMENTS OF INITIAL DILUTION OF A BUOYANT EFFLUENT

SCOPE

Proposals for the discharge to sea of domestic and/or industrial wastes require thorough and cautious evaluation of environmental and engineering implications. In recognition of this and the increasing pressure of population and industry on South Africa's coastal resources, the Water Research Commission contracted the National Research Institute for Oceanology (NRIO) in 1984 to assist in the compilation of a "Guide for the Marine Disposal of Wastewater by Pipeline".

To support its contribution to the guide, the NRIO was requested to conduct several experiments at sea in order to test the validity of theoretical predictions of the initial dilution of buoyant effluent discharged at the sea bed by pipeline. These predictions form a vital link in the design process.

The NRIO conducted four experiments at sea, three on the existing Camps Bay outfall pipeline and a fourth on an experimental simulated discharge port in Hout Bay. This report describes these experiments and compares the full-scale initial dilution measurements with the corresponding theoretical predictions.

The report was compiled by Messrs W A M Botes and G Toms.

F P ANDERSON
CHIEF DIRECTOR

Stellenbosch
November 1987

CONTENTS

CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ρsea	Density of sea water (g/cc)
ρeff	Density of effluent (g/cc)
ρss	Density of sea water at the surface (g/cc)
ρsb	Density of sea water at the sea bed (g/cc)
ρa	$(\rho ss + \rho sb)/2$
$\Delta\rho$	$\rho sea - \rho eff$
b	Buoyancy flux/unit length of the diffuser (m^3/s^3)
Cpp	Peak concentration measured at pump
Cdp	Peak concentration measured at the diffuser
Cbp	Peak concentration measured in the effluent boil
dj	Port diameter (m)
Fa	Froude number to describe ambient flow
Fj	Froude number at jet
g	Gravitational acceleration (m/s^2)
g^1	Relative density parameter $= g\ (\frac{\rho a-\rho eff}{\rho a})$
G	Density gradient parameter $= \frac{g}{\rho sb} \cdot \frac{(\rho ss-\rho sb)}{h}$
h	Water depth (m)
L	Length of diffuser (m)
Q	Total discharge entering the diffuser (m^3/s)
qp	Port discharge (m^3/s)
Smin	Minimum dilution (plume centre line)
Sav	Average dilution (profile average)
Ua	Average ambient current velocity (m/s)
uj	Jet velocity (m/s)
y	Height above port (m)
Zm	Rise height (m)

1. INTRODUCTION

The initial dilution of a buoyant effluent is traditionally defined as the dilution that the effluent undergoes by virtue of its discharge momentum and its buoyancy relative to the surrounding sea water. In the case of a submerged discharge of effluent from an outfall port at the sea bed the discharge momentum usually plays a minor role in entraining uncontaminated sea water and hence in diluting the effluent compared to the buoyancy of the effluent relative to the surrounding sea water. Initial dilution, however, is significantly affected by properties of the surrounding sea water, notably the ambient current, flowing across the rising effluent plume and the vertical density differences in the sea water often present due to temperature differences with depth. The ambient current can dramatically enhance the mixing process while the density differences can inhibit these to the extent that the buoyant plume is prevented from surfacing. These effects are shown in Figure 1.

In view of the complications caused by the influence of currents and density gradients it is very convenient to use a standard comparative estimate of initial dilution when considering proposed or alternative designs for outfalls. Despite the trend in recent years of taking the dynamics of the discharge area into account and predicting initial dilution in moving stratified water (Roberts, 1977; Wright, 1984), designers and particularly licensing authorities often resort to the use of a standard prediction of initial dilution at the water surface above the diffuser in stagnant (zero current), uniform (zero density gradient) ambient sea conditions.

It was the purpose of the work described in this report to investigate the validity of the widely used initial dilution prediction techniques for stagnant unstratified sea conditions and to comment on their applicability to typical sea and outfall conditions.

During 1984 and 1985 the NRIO performed a series of prototype experiments in order to detect the initial dilutions achieved in the case of full-scale discharge conditions with ambient sea conditions as close as possible to those of stagnant and unstratified water. Three tests were conducted on an operating outfall at Camps Bay near Cape Town (Figure 2) and another test was subsequently done on a pilot experimental set-up at Hout Bay (Figure 3), where the discharge of fresh water could be accurately controlled through a horizontal single-port diffuser. The four experiments with Rhodamine-B as tracer material were conducted in near stagnant conditions with maximum current speeds (mid depth) of only 6 cm/s and very little stratification. Results showed consistent surface dilution values a factor of two to three times greater than predicted for stagnant uniform conditions. However, when ambient currents and stratification were taken into account the measured results compared well with theoretically predicted values.

The general conclusion is made that the assumption of stagnant-uniform sea conditions will result in the underprediction of surface dilutions during very calm conditions by a factor of two to three times. Considering this difference together with the fact that completely stagnant conditions do not occur at sea the applicability of the stagnant-uniform design condition is questioned.

Chapter 2 of this report contains a review of previous studies involving initial dilution measurements at sea reported in the literature. In Chapter 3 the experiments conducted by the NRIO in 1984 and 1985 are fully described. Chapter 4 presents a review of the theoretical prediction of initial dilution and provides theoretical predictions for the corresponding NRIO experiments at Camps Bay and Hout Bay. In Chapter 5 measurement is compared with theory and conclusions are given in Chapter 6.

In Appendix A the choice of and use of Rhodamine-B dye as tracer are discussed while Appendix B contains a report compiled by the

National Institute for Water Research (NIWR) of the CSIR. The NIWR took the opportunity to investigate faecal coliform counts after initial dilution and compare these with the NRIO-measured dilutions using the dye and tracer.

2. PREVIOUS STUDIES - LITERATURE REVIEW

Previous studies documenting actual dilution measurements at sea are fairly scarce because of the practical difficulties involved and the high cost per measurement. In reviewing these studies, however, considerable difficulty was experienced in interpreting the results obtained and the degree to which these are relevant for verifying the theory and contributing to the aims of the NRIO study. For example, Alam (1982) compared dilutions measured on the Alyeska outfall in Port Valdez, Alaska, with predictions made for a proposed outfall off Boston! Discussion and criticism of several aspects of this work was widespread (Abraham et al., 1983) and emphasized the importance of fully understanding the theory that is being compared, its limitations and its applicability to the outfall situation being measured.

A further difficulty in interpretation concerns sampling procedure and the relative merits of sample size, continuous or point sampling and types of tracer. Gibson (1978) reviews techniques employing artificial tracer such as dye and natural tracers which use effluent properties such as salinity, density and temperature to assess measured dilutions. He concluded that dye and salinity measurement tests were biased towards higher measurements of dilution and gave preference to dilution measurements based on density differences. In the sampling reviewed by Gibson (1978), which was conducted by the Southern California Coastal Water Research Projects (SCCWRP) laboratory on the Hyperion Outfall, California, a ratio of "about two times" was found between measured and predicted minimum dilution. Sample size and methods of sampling were also considered to play a significant role in the findings from any one experiment according to Gibson (1978). He explained that samples which are too large would contain an amount of uncontaminated sea water which would mean an overestimate of dilution. Averaging of results could also completely mask relevant tendencies because effluent fields are by no means homogeneous and contain a wide range of sizes of completely mixed, partially mixed and non-mixed pockets of tracer and ambient sea water.

The result that the predicted initial dilution is an underestimate of the measured initial dilution was confirmed by other researchers. Wallis (1980) reviewed measurements on four outfalls, namely Queensclift, San Francisco, Hyperion (Gibson, 1978) and West Point (Bendiner, 1976). These showed underprediction by a factor of 1 to 1,5 times (when using the Caldwell-Connell computer model).

Bennett (1981), who conducted measurements using dye as tracer on the Hastings Long sea outfall in Britain, examined the increase in dilution caused by currents and compared measured results to predictions by Agg and Wakeford (1972) and the Hydraulics Research Station (1977). Both these predictions were based on previous field studies. Bennett concluded that stagnant water dilutions were increased by a factor of 3 to 30 times for current speeds from 5 to 40 cm/s, indicating the extreme sensitivity of dilution to current speed. However, it is difficult to glean from these results the contribution to the increased measured dilution which was derived from currents and therefore did not provide an estimate of the performance of the stagnant water theory.

No specific publication could be traced which would provide a definitive comparison between actual measurement and theory of initial dilution in stagnant-uniform conditions. While measurements at sea would never be stagnant and rarely completely uniform it was felt that measurements in very calm conditions of initial dilution achieved by an operating outfall would be very useful to confirm or refute the general finding (based on the literature review) that measured initial dilutions greatly exceed predicted initial dilutions even in very calm conditions. (For further literature not quoted here see Bettes and Munro (1980), Caldwell-Connell Eng. (1979) and Hendricks (1977).)

3. INITIAL DILUTION MEASUREMENTS

3.1 Measurements at Camps Bay - An Operating Outfall

3.1.1 Test procedures

Three prototype tests were conducted on an operating outfall at Camps Bay near Cape Town. The Camps Bay outfall delivers about 2 800 m^3/d of macerated, screened raw sewage to a depth of approximately 24 m via a 1,3 km sea outfall with internal diameter of 354 mm which terminates in an eight-port diffuser. Port sizes vary from 102 to 115 mm. The ports discharge horizontally, and the spacing of 12,2 m avoids merging of adjacent plumes during their buoyant rise to the surface field. Thanks to the proximity of the NRIO offices to the Camps Bay site (approximately 60 km) the prototype experiments could be performed on selected calm days, as these would be closest to the stagnant-uniform conditions required. This was also important for diving operations, which were an essential part of the operation. The location of Camps Bay and the outfall location is shown in Figure 2.

The experimental procedures at Camps Bay are illustrated in Figure 4. For each of the three exercises similar procedures were followed for comparison and verification purposes. The effluent at Camps Bay runs from the shoreline pumphouse via an air-vessel (for the prevention of water-hammer) to the diffuser. The pumps, pumping intermittently on a cycle of about 5 minutes on and 15 minutes off, empty a reservoir of effluent at each cycle at a rate of about 70 ℓ/s. Rhodamine-B dye (20 ℓ), diluted to 1 in 5, was inserted into the line at the shoreline pumphouse during one of the pumping cycles. Two sampling vessels were used at the diffuser. One of these was a dinghy moored above the landward port of the diffuser. This landward port was blanked off by divers and a 12,5 mm hose was installed through the cover to sample the concentration of dye in the diffuser. The hose led from the diffuser up to the dinghy where 100 ml sample bottles were filled at 2 minute intervals.

As the absorption of the fluorescent tracer Rhodamine-B in the pumps and in the pipeline was an unknown factor, this operation was essential for dilution determination. It was decided to interpret measured dilutions as the ratio of the peak concentration of dye detected from the closed diffuser port to the concentrations of dye detected from all samples collected from the second sampling vessel.

The second vessel was used as a mobile sampling platform from which other operations such as current measurements could also be conducted. Accurate Tellurometer position-fixing equipment was installed on this vessel, thus allowing the position of each sample to be fixed and recorded for subsequent plotting. Sampling was again achieved with the use of 100 ml sampling bottles. Subsurface samples were obtained by inserting the bottle in a small frame fitted with a rubber ball on a hinge which closed off the bottle. The frame was lowered on a weighted rope and the bottle opened at the required depth by tugging on a nylon line attached to the hinge. Each sample bottle was then recovered on board, removed from its frame, labelled and stored in covered boxes for subsequent analysis on the laboratory fluorometer (Turner design). Sample bottles for surface sampling were attached to a similar frame on a long rigid pole. By using this technique each sample was retained and stored in its own labelled sample bottle so that contamination of consecutive samples was obviated. This technique also made it possible to re-analyse samples at a later stage. Time, sample number and sampling depth were manually recorded on observation sheets and in subsequent analysis at NRIO the exact position (Tellurometer data) and Rhodamine-B concentration were deduced for each sample.

During each exercise the current behaviour was determined by using surface and subsurface (-5 m) drogues. Profilers were used for measuring current, temperature and salinity profiles from which the stratification in the water column could be obtained.

About 80 minutes after dye had been injected at the pumphouse it was first detected at the landward diffuser port, and after a further two minutes dye appeared at the water surface. Samples were taken (employing two to three sampling teams) at various depths, from the surface to -20 m. In an attempt to detect the highest concentration and hence the lowest dilution as many surface samples as possible were taken in pockets of dye which appeared the brightest. Intense sampling at the boil was conducted during the initial surfacing of the dye. Subsequent sampling through sections of the growing surface field was conducted in order to determine the behaviour of the plume in time and space. At various times the perimeter of the dye patch was circled by the vessel and fixed in position with the aid of the Tellurometer.

Photographs were taken from:

(a) a light aircraft at heights of 300 and 1 000 m (see Figures 5 and 6);

(b) an oblique fixed high vantage point on land about 2 km away and 1 000 m high (Table Mountain upper cable station);

(c) a weather balloon tethered to the vessel from which a camera was suspended on a stabilizing frame and triggered by remote control at a height of 80 m (Figures 7 and 8), a technique which is described by Buirski (1985).

This monitoring of the dye patch provided useful information about the initial formation of the surface field and its subsequent behaviour. On impacting with the water surface, the individual plumes from each port were clearly visible as distinct circular patches as shown in Figure 5 for the exercise on 25 April 1985. Each of these patches rapidly spread horizontally to merge into a surface field that was obviously not homogeneous in terms of effluent (dye) concentration (Figure 8). Transport of the surface field at each of the three exercises was very slow because of slack currents, but it was observed to deform longitudinally, particularly during the last exercise (25 April 1985) when surface current speeds increased slightly to approximately 10 cm/s after the initial surfacing of the effluent. It was found that generally the front edge of the dye patch moved with the speed of a surface drogue and the trailing edge with the speed of a subsurface (-5 m) drogue. This indicated a significant longitudinal dispersion which was due to rapid decrease of current with depth in the direction of the wind.

However, use of the Camps Bay outfall to assess the applicability of the theoretical prediction of initial dilution had certain shortcomings, the most important being the fact that the pumping of the effluent was not continuous. Because of this the burst of dye inserted at the pumphouse was dispersed along the pipe, with dispersion being accentuated by the air vessel to such an extent that on release to the ocean the dye delivery was spread over several pumping cycles. The exact variation of the flow of effluent from the ports with time, therefore, was not clear and the assumption was made that no flow occurred outside pumping cycles. The validity of this assumption was not easy to assess and this largely motivated the need for the experimental study at Hout Bay as described in Chapter 3.2.

3.1.2 Test results

3.1.2.1 Weather and sea conditions

The Camps Bay field experiments were carried out only during relatively calm conditions. For the three experiments different types of current conditions (SW-, S- and N'erly) were encountered as listed below:

		1984/10/02	1985/02/13	1985/04/25
WIND:				
Before exp.	Speed (kn)	1	Calm	Calm
	Dir.	W	-	-
After exp.	Speed (kn)	4	Calm	Calm
	Dir.	SW	-	-
CURRENTS:				
Surface.	Speed (cm/s)	4 - 5	6	6 - 7
	Dir.	SW	S	N - NNE
-5 m.	Speed (cm/s)	5	5	5 - 6
	Dir.	WSW - SSW	S	N - NNE
-12 m.	Speed (cm/s)	6	6	6
-23 m.	Speed (cm/s)	9	5	4
TEMPERATURE (^{o}C):				
Before exp.	Surface	15,5	10,8	15,6
	Bottom	15,0	9,8	14,3
After exp.	Surface	16,0	11,5	16,1
	Bottom	14,6	9,8	15,4
SALINITY (^{o}/oo):				
Before exp.	Surface	35,15	35,16	35,15
	Bottom	35,18	35,16	35,19
After exp.	Surface	35,19	35,19	35,20
	Bottom	35,27	35,13	35,20

On all three occasions surface current velocities did not exceed 7 cm/s and mid-depth velocities were less than or equal to 6 cm/s. Wind speeds were less than 10 knots and there was no stratification in the water column. Thus a good comparison between most of the results of the three exercises could be obtained for the verification of the prototype measurements. While these conditions were by no means stagnant they were relatively calm (current speeds were only just above the zero threshold limit specified for the current meter used as 2-3 cm/s). One factor causing difficulty in full-scale tests such as these is the varying conditions during a test. This was certainly the case with temperature differences as seen above and, to a lesser extent, with currents.

3.1.2.2 Dye release details

Details of the injection and initial sampling of dye at the diffuser and in the boil for the three Camps Bay tests are summarized in the table below:

Remark	Date of test		
	1984/10/02	1985/02/13	1985/04/25
PUMPING OF RHODAMINE-B			
Vol. Rhodamine (ℓ)	35	20	20
Pre-dilution	1 in 5	1 in 5	1 in 5
Total vol. dye (ℓ)	175	100	100
Time of release	11h25	10h35	10h28
Duration of Rel. (s)	195	208	159
Pump discharge rate (ℓ/s)	78	86	81
Conc. at pump (Cpp)	$2,3 \times 10^{-3}$ (1 in 433)	$1,92 \times 10^{-3}$ (1 in 521)	*
Duration of the pumping cycles (s)	202 - 207	164 - 302	94 - 309
Intervals between pumping cycles (min)	11 - 15	11 - 20	4 - 9
Time of surfacing	13h13	11h55	11h24
Total travelling time in pipe (min)	108	80	56
AT DIFFUSER			
Highest conc. (Cdp)	$1,67 \times 10^{-3}$ 1 in 598	$1,85 \times 10^{-3}$ 1 in 540	$1,83 \times 10^{-3}$ 1 in 546
Conc. after 1 hr.	$6,7 \times 10^{-6}$	$4,5 \times 10^{-6}$	$4,6 \times 10^{-6}$
Conc. after 2 hr.	$2,6 \times 10^{-6}$	$5,4 \times 10^{-7}$	$9,0 \times 10^{-7}$
Conc. after 3 hr.	$6,8 \times 10^{-7}$	$5,0 \times 10^{-7}$	-

* Not measured accurately.

The highest concentration at the port (Cdp) was used to determine the minimum dilution (Smin) at the surface. The reduction in concentration that occurred between the pumphouse and the diffuser (Cpp-Cdp) was due to absorption and longitudinal dispersion in the pipeline.

The concentrations (Cdp) at the diffuser for the three experiments are plotted versus time in Figures 9 to 11 and listed in Tables I to III. From these figures it can be seen that the dye slug was not discharged from the pipeline in one pumping cycle, but partly remained in the pipe between two pumping cycles. In fact, dye continued to issue from the diffuser at higher than background levels for the rest of the exercise but at concentrations more than 1 000 times weaker than the duration peak when the values of Cdp were determined.

3.1.2.3 Measured initial dilutions

In order to determine the minimum surface dilutions (Smin) as many samples as possible were taken in the boil (surface to 5 m deep above the diffuser) where visually the highest concentration (Cbp) could be detected, and the relation Cdp/Cbp was taken as Smin. The values of all measured concentrations (in the plume) for the three experiments at Camps Bay are also plotted versus time in Figures 9 to 11 and listed in Tables IV to VI.

Minimum dilution in the boil (surface)			
No. of samples Highest conc. (Cbp) Time Dilution (Smin)	73 1,90 × 10^{-6} 13h34 880	70 2,58 × 10^{-6} 12h02 700	130 2,69 × 10^{-6} 11h35 680

3.1.2.4 Subsequent transport and dilution of effluent

The patch or surface field was monitored as it slowly moved away from the boil.

(a) 1984/10/02 (SW'ly current)

On two occasions the perimeter of the plume was determined. The plume forms are shown in Figure 12. The areas of the waste fields are listed below:

Time	Time after surfacing (min)	Area (sq. m)
14h15	62	25 000
15h00	107	43 000

The effluent dispersed in a SW'ly direction into a plume approximately 600 m long and 80 m wide, about two hours after the dye surfaced.

At 14h30 (72 min after surfacing) eight transects through the waste field were completed and samples taken at the surface in order to obtain contours of the surface concentrations. The results are shown in Figure 13. From this figure it can be seen that concentrations higher than 1 × 10^{-7} (1 in 10 mil.) covered an area of only 240 m long and 30 m wide. The highest concentration that could be detected at that time (14h30) was 2,7 × 10^{-7} (1 in 3,7 mil., representing a total dilution from the diffuser of over 6 000).

(b) <u>1985/02/13 (S'ly current)</u>

On three occasions the perimeter of the plume was determined. The plume forms are illustrated in Figure 14 and the areas of the waste fields were:

Time	Time after surfacing (min)	Area (sq. m)
12h35	70	23 600
13h20	115	39 600
14h20	175	46 700

The effluent dispersed in a S'ly direction into a plume approximately 350 m long and 190 m wide, about three hours after the dye surfaced.

Transects through the waste field were done at 13h00 and 14h00 (the results are shown in Figure 15). At 13h00 (65 min after the dye surfaced) concentrations higher than 1 × 10^{-7} (1 in 10 mil.) covered an area of approximately 175 m long and 50 m wide. The highest concentration that could be detected at that stage was 5,6 × 10^{-7} (1 in 1,8 mil., representing a total dilution from the diffuser of over 3 300).

(c) 1985/04/25 (N'ly currents)

Due to N'ly to NE'ly currents the surface waste field moved onto the rocks north of Camps Bay and therefore the perimeters of the dye patches could not be determined accurately and the exercise had to be aborted at 13h00. A sketch of the dye patch, illustrating the movement of the waste field, is given in Figure 16. Transects through the waste field were limited owing to the onshore movement of the dye and no results concerning the distribution of the concentrations in the waste field can be produced.

3.2 Measurements at Hout Bay - A Simulated Outfall

3.2.1 Test procedures

The primary purpose of this experiment was to conduct initial dilution measurements at full-scale during calm unstratified ambient sea conditions and to evaluate the findings of the three repeat tests at Camps Bay. The advantage of this experimental set-up as shown in Figure 17 was that good control on the burst-release of dye and the precise port discharge characteristics could be achieved. The location of Hout Bay and the experimental site are indicated in Figure 3. On the day of the experiment N'ly winds of up to 16 knots were recorded but did not hamper the field exercise. In spite of the stronger winds the surface currents in the bay were not more than 15 cm/s with subsequent slow transport of the surface waste field with mid-depth currents of below 4 cm/s.

The experiment was performed by pumping fresh water from the hold of a stationary vessel at sea through a horizontal 57 mm port mounted on a stand fixed on the sea bed. The rate of pumping and dye release was controlled, the dye being inserted just upstream of the pump. A second vessel sampled the surfacing plume of dye in exactly the same way as it had been done at Camps Bay. The experiment was repeated after two hours, but because of high background concentrations of Rhodâmine-B, as well as technical problems during the pumping and diving operation the quality of the results of the second exercise was not as good as that of the first trial. The analysis was also conducted in the same way as for Camps Bay. The findings of this experiment confirmed the results of the Camps Bay tests and indicated that those tests were not seriously affected by the problems associated with intermittent pumping and merging plumes. It is considered that the procedure used at Hout Bay could be very useful for future measurements of full-scale dilution under a broader variation of sea conditions, exit velocity, port orientation, port diameter and port depth.

3.2.2 Test results

3.2.2.1 Weather and sea conditions

The wind was moderate, N to NNE and the speed ranged between 7 and 16 knots. Currents were in a S'ly direction with almost no stratification in the water column. The weather and sea conditions are given in the Table below:

		Before the experiment (10h20)	After the experiment (14h30)
Wind:	Speed (kn)	8 - 16	7 - 10
	Dir.	N to NNE	NNE
Current:			
Surface	Speed (cm/s)	12	11
	Dir.	S	SSE
-5 m	Speed (cm/s)	3	4
	Dir.	S	SSE
-12 m	Speed (cm/s	3	4
	Dir.	SSE	SSE
Temperature: (^{o}C)	Surface	16,4	16,6
	Bottom	16,3	16,3
Salinity: (^{o}/oo)	Surface	35,62	35,71
	Bottom	35,75	35,77

While surface currents were slightly higher than during the Camps Bay tests (due to wind forcing), mid-depth currents to which the rising plume was exposed were almost negligible.

3.2.2.2 Dye release details

Rhodamine-B dye was released on two occasions (11h15 and 13h29). The second release at 13h29 was hampered by technical problems in the discharge mechanism and diving operation with the result that initial concentrations could not be measured. However, the concentrations which were recorded at a later stage of the release compared well with corresponding results during the first release as shown in Figure 18. The temperature of the freshwater in the hull of the pumping vessel was 16°C with no salinity reading. A prediluted solution of 1 in 20 (Rhodamine-B) was injected into the discharge pipe. The particulars of the pumping operation and initial sampling are listed below:

	First release	Second release
Pre-dilution	1 in 19,8	1 in 19,9
Volume of dye released (ℓ)	92	106
Time of release	11h15	13h29
Duration of release (s)	510	720
Rate of dye release (ℓ/s)	0,18	0,15(0,07-0,32)
Discharge rate Qp (m^3/s)	0,00292	0,00292
Vol. of freshwater released (ℓ)	1489	2102
Measured conc. downstream of pump (Cpp)	0,00342 (1 in 292)	0,00379 (last 6 min) (1 in 264)
Dilution downstream of pump	14,8	13,2
Time of surfacing	11h17	13h31

Samples were taken by divers near the outlet of the diffuser to confirm that there was no absorption in the pipe and that the concentration Cpp could be used as a basis for determining surface dilutions. Samples at different depths in the plume gave an indication of the dilutions in the rising plume. An attempt to take photos of the rising plume was not successful because of poor visibility. The results of the samples taken by the divers are given below:

Period after release (min)	Height above if (m)	Concentration ($\times 10^{-4}$)		Dilutions	
		1st release	2nd release	1st release	2nd release
2	0	27,6	22,3	1,2	1,7
3	0,5	6,1	2,9	5,6	*
4	1	5,9	1,1	5,8	*
5	2	2,5	0,34	13,8	*

* Owing to irregular pumping during the initial stage of the second release the relation between Cpp and the measured concentrations could not be determined.

3.2.2.3 Measured initial dilution

As for Camps Bay the strategy to obtain the minimum surface dilutions (Smin) was to take as many samples as possible in the boil where visually the highest concentrations could be detected. Initial sampling was hampered by the problems mentioned before and only the results of the first release are listed below:

No. of samples:	89
Highest concentration (Cbp):	$3,17 \times 10^{-6}$
Time:	11h18
Minimum dilution (Smin):	1080.

The measured concentrations for both releases versus time are illustrated in Figure 18 and listed in Table VII. The maximum measured concentrations after 20 minutes of the release were approximately 5×10^{-7} (dilution of 7 000).

3.2.2.4 Subsequent transport and dilution of effluent

The perimeters of the surface field were determined about 30 minutes after each of the releases and the surface areas of the plumes are listed below:

Release	Time	Period after release (min)	Area (sq. m)
No. 1	11h44	29	6 500
No. 2	14h02	33	7 800

The waste field in both experiments proceeded in a S'ly direction (with the currents), approximately 150 m long and 50 m wide, 40 minutes after the release.

For release No. 1 transverse and longitudinal transects through the plume were done between 11h51 and 12h02 and between 12h04 and 12h12, respectively. Surface samples were taken to describe the waste field concentrations after a certain time as illustrated in Figure 19a. Similar transects were done for release No. 2, with transverse and longitudinal sampling between 14h10 and 14h20 and between 14h23 and 14h28, respectively. The concentrations of the surface waste field are shown in Figure 19b. The highest concentrations that could be detected after approximately 40 minutes were $2{,}54 \times 10^{-7}$ and $2{,}45 \times 10^{-7}$ for release No. 1 and No. 2, respectively.

4. THEORETICAL PREDICTIONS

4.1 Review of Theories

4.1.1 General

A detailed review of the theory of initial dilution will not be given here as the subject is a very broad one. In this chapter we will briefly discuss the principles involved and highlight relevant theories for use in the comparison of theory to measurements for the tests reported in Chapter 3.

4.1.2 Stagnant-uniform theory

Roberts (1977) gives useful review of the fundamentals involved in initial dilution prediction theory. He shows by dimensionless analysis that the minimum dilution, Smin, in stagnant uniform sea conditions, on the centre line of a buoyant plume of effluent rising from a single round port of a diffuser at the sea bed is a function of two dimensionless groupings:

$$\frac{S_{min}}{F_j} = f\left(\frac{y}{d_j F_j}, \frac{1}{F_j}\right) \qquad \ldots (1)$$

where y = height above the jet exit where Smin is determined (m)

d_j = port diameter (internal) (m)

F_j = Froude number of the jet

$$= u_j / \left(g \frac{\Delta\rho}{\rho_{sea}} \cdot d_j\right)^{1/2}$$

and u_j = jet exit velocity (m/s)

g = gravitational acceleration (m/s^2)

$\Delta\rho$ = $\rho_{sea} - \rho_{eff}$

ρ_{sea} = density of surrounding sea water (g/cc)

ρ_{eff} = density of effluent (g/cc).

Figure 20 provides a definition sketch of a round buoyant plume rising in a stagnant uniform sea.

Roberts (1977) summarizes initial dilution prediction methods (Cederwall, 1967; Abraham, 1965; Fan and Brooks, 1969; Anwar, 1976). Fan and Brooks (1969) develop theoretical procedures solving simultaneous differential expressions for conservation of continuity, momentum, density difference and concentration and after inserting boundary conditions these are solved by numerical integration. Roberts (1977) further compares these with laboratory experiments (Hansen and Schroder, 1968; Cederwall, 1967; Liseth, 1970), as shown in Figure 21. The "plume solution" also shown in Figure 20 is valid only where the ratio (y/d_jF_j) is above 20. A general equation fitting the full curve was proposed by Roberts (1984) as follows:

$$\text{Smin} = 0{,}107F_j\left(1{,}6 + 5\left(\frac{y}{d_jF_j}\right) + \left(\frac{y}{d_jF_j}\right)^2\right)^{5/6} \qquad \ldots (2)$$

This is valid for all values of (y/d_jF_j) and reduces to the "plume solution" for high (>20) values as follows:

$$\text{Smin} = 0{,}107F_j\left(\frac{y}{d_jF_j}\right)^{5/3} \quad \left(\text{for } \frac{y}{d_jF_j} > 20\right) \qquad \ldots (3)$$

The Smin relates to centre line dilution. The plume is assumed to have a Gaussian (bell-shaped) distribution of concentration symmetrical about its centre line, and reference is more commonly made to Sav, the profile averaged dilution where:

$$\text{Sav} = 1{,}74\ \text{Smin} \qquad \ldots (4)$$

For purposes of comparison, as required for this report, equations (2) and (4) provide the best estimate of theoretical initial dilution at a height y above the outlet in stagnant uniform conditions.

4.1.3 Moving water - non-uniform sea theories

While the accuracy and applicability of the stagnant-uniform theory is the main topic of this report it is informative to examine the theoretical predictions of dilution prior to testing, taking the currents (non-stagnant moving water) and a vertical density gradient (non-uniform) that existed into account. To evaluate initial dilution, including the effects of ambient currents and vertical density gradients, theoretical computations become more complex. While a full description of the theories available and their development is beyond the scope of this report a brief description of three varying approaches is given.

The three theories used were those described in Roberts (1977), Wright (1984) and EPA (1985) (the first of these still assumes no vertical density gradient, that is, uniform sea).

(a) Roberts (1977)

In this approach laboratory testing was performed to provide empirically derived coefficients for relationships based mainly on dimensional analysis. The relationships in question related to 'slot plumes' which are equivalent to a curtain of buoyant effluent rising in a uniform sea. Such a curtain would be formed by closely spaced diffusers causing merging plumes close to the sea bed. In the Camps Bay case the plumes do not merge before impact with the sea surface and this is a drawback in applying this theory. However, the comparison was considered worthwhile.

Roberts (1977) makes use of a dimensionless Froude Number Fa to describe the relative strength of the ambient flow through the curtain (that is, over the diffuser):

$$Fa = \frac{Ua^3}{b} \qquad \ldots (5)$$

where Ua = average current velocity over the depth (m/s)

b = buoyancy flux per unit length of diffuser

$$= g \cdot \frac{\Delta \rho}{\rho sea} \cdot \frac{Q}{L} \qquad (m^3/s^3)$$

Q = total flow into the diffuser (m^3/s^3)

L = length of the diffuser (m).

A useful finding was that increased dilution is negligible for Fa below about 0,1.

The resulting expression for initial dilution after rigorous laboratory testing is given as:

$$Sav = 0,58 \cdot \frac{Ua \cdot h}{Q \cdot L} \qquad \ldots (6)$$

(current perpendicular to diffuser)

(b) Wright (1984)

This theory is more applicable to Camps Bay as it refers to individual rising plumes and makes provision for a linear, stratified environment.

The vertical density profile present in the ambient sea water, in this case due mainly to a temperature gradient, causes the plume to entrain denser water close to the bottom with the result that the density of the diluted plume could equal that of the surrounding sea water at some intermediate height before reaching the sea surface (refer Figure 1). Wright (1984) describes the intermediate height above the port at which the plume stops rising as zm where

$$zm = 2,3 \; (g^1 \; qp/u)^{1/3} \cdot G^{-1/3} \qquad \ldots (7)$$

and qp = port flow (m^3/s)

G = density gradient parameter

$$= \frac{g}{\rho sb} \cdot \frac{(\rho ss - \rho sb)}{h} \qquad (m/s^2/m)$$

ρsb = density of sea water at sea bed (g/cc)

ρss = density of sea water at surface (g/cc)

g^1 = relative density parameter

$= g \left(\frac{\rho a - \rho eff}{\rho a}\right) (m/s^2)$

ρa = average density of water column

$= \left(\frac{\rho sb + \rho ss}{2}\right)$

Having computed the value of zm then Wright derives the average dilution Sav as:

$$Sav = 0,25 \cdot Ua \cdot \frac{zm^2}{qp} \qquad \ldots (8)$$

However, after work by Chu (1979) and Roberts (1984) the coefficient of 0,25 was increased to 0,71:

$$Sav = 0,71 \cdot Ua \cdot \frac{zm^2}{qp} \qquad \ldots (9)$$

If zm is found to exceed the water depth then h can be substituted for zm in equation (9).

(Further explanation of the development of this approach can be found in Wright (1977-1), Wright (1977-2) and Koh (1984).)

(c) EPA (1985)

The US Environmental Protection Agency (EPA) have published standard computer programs which are recommended for use in the evaluation of initial dilution in a standard way in the design stage. These are designed to facilitate permit discussions.

Original programs published by Baumgartner _et_ _al_. (1971) were recently updated in EPA (1985). One of the programs presented, OUTPLM, computes rise heights and initial dilutions for moving water, non-uniform sea states. This program was applied to provide a third estimate of the predicted initial dilution taking the measured current and density profiles into account.

4.2 Application to Camps Bay

4.2.1 Stagnant-uniform theory

Using equations (2) and (4) the predicted value of initial dilution for all three tests was 300 with slight variation (± 10 per cent) when taking into account small differences in flow per port for each test as well as differences in port flows from port to port in any one test which are due to varying port sizes (102 to 115 mm). Also, the value of 'y' used in equation (2) is the average depth along the diffuser (23 m) less 3 m. This latter figure is due to the fact that surface samples were taken in the layer at 0 to 2 m depth and that the port is about 1 m from the sea bed. It was not felt justified to reduce y further to cater for a thicker surface field because initial surfacing of the dye on first release from the diffuser would cause mixing of dye over the entire travel distance to the surface.

According to Roberts (1977) the minimum current below which enhanced dilution is negligible (Fa = 0,1) was 3,2 cm/s indicating that currents above this very low value could have significantly increased dilution.

4.2.2 Moving water - non-uniform theories

When taking into account currents and density profiles on the days of sampling the problem arises that these were not stable throughout each measurement period. In view of the sensitivity of the three theoretical approaches to these ambient conditions "ranges" rather than precise values for initial dilution (Sav) were predicted to cater for measured variations in the sea conditions during each test:

	Roberts (1977) Equ. (7)	Wright (1984) Equ. (9)	EPA (1985) "OUTPLM"
2 Oct 1984	500-580	420-670	260-790
13 Feb 1985	680-910	570-780	470-900
25 Apr 1985	480-840	420-600	680-990

4.3 Application to Hout Bay

4.3.1 Stagnant-uniform theory

Using equations (2) and (4) the predicted value of initial dilution in the Hout Bay test was 480.

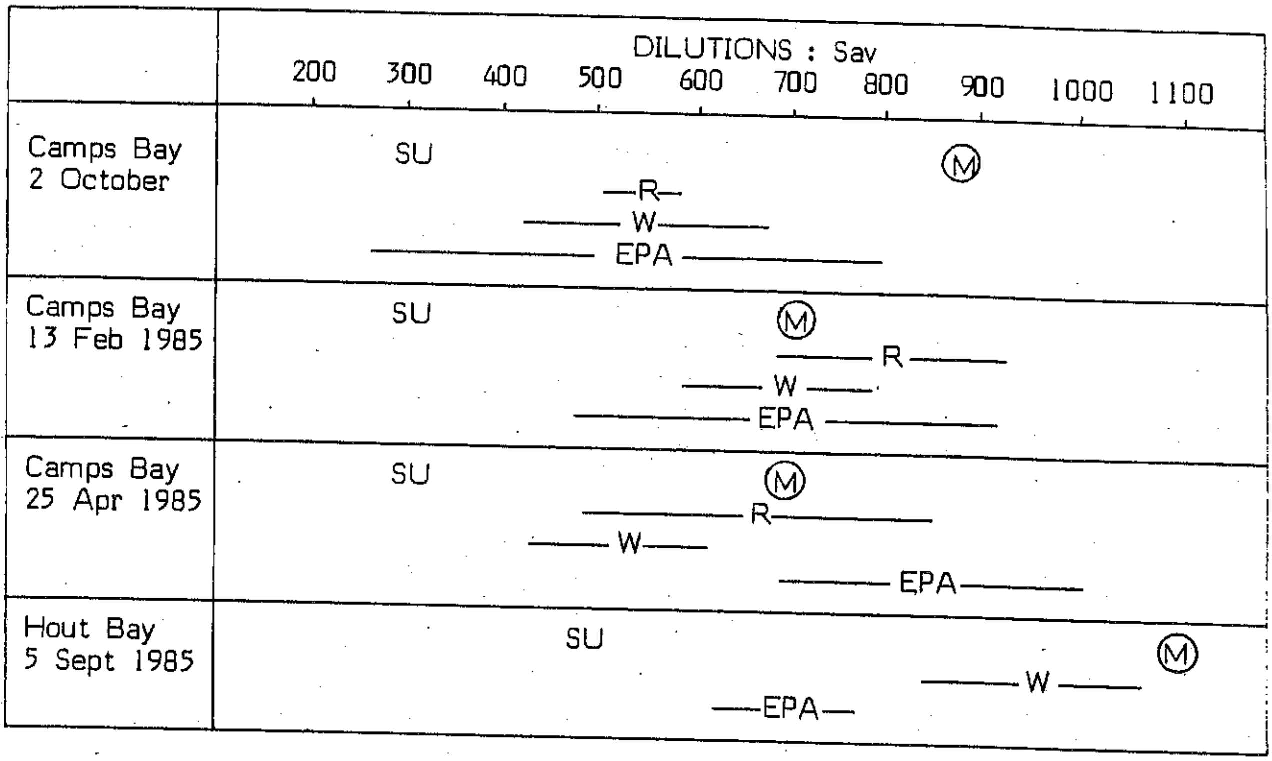
4.3.2 Moving water - non-uniform theories

Roberts (1977) is not applicable here because the effluent flows from a single port and not a diffuser which means that the line source or curtain approximation would be invalid:

	Wright (1984) Equ. (9)	EPA (1985) "OUTPLM"
5 Sept 1985	820-1 040	620-740

5. COMPARISON: MEASUREMENTS TO THEORY

The following representation summarizes the measured and predicted initial dilutions:



Where M. = measured value
SU = stagnant uniform theory prediction (Eq. (2), (4))
-R- = range predicted using Roberts (1977) (Eq. (7))
-W- = range predicted using Wright (1984) (Eq. (9))
-EPA- = range predicted using EPA (1985) (OUTPLM).

It can be seen that measured values are consistently much higher than predicted values when stagnant-uniform theories are used. This is despite the fact that the exercises were performed on selected calm days. The ratios:

$\frac{\text{Measured (M)}}{\text{Predicted (SU)}}$ have the values: 2,9 2,3 2,3 and 2,3 for the four tests conducted, thus indicating an average underprediction by a factor of about 2,5 times.

Possible reasons for this underprediction could be:

(i) Sampling inaccuracies.
(ii) Underestimation of entrainment in prediction.
(iii) The effect of currents.

Reference to the figures, particularly Figures 10 and 11, shows a strong consistency of concentrations sampled at the surface between successive samples thereby providing confidence in the sampling technique. Therefore (i) above is not thought to contribute to the underprediction.

Reference to Figure 7 (photographs of the surfacing patch of dye) shows intense variation in eddy sizes affecting entrainment. It seems that underprediction could be caused by underestimating the rate of entrainment at full scale by using scale laboratory tests which may not represent the full range of scales of entraining eddies.

The summarized representation above suggests that currents played the dominant role in causing high measured dilutions. Despite the fact that tests were done on selected calm days ambient currents present were (only just) above the threshold currents (predicted by the Roberts (1977) Fa = 0,1 value) required to enhance dilution. The extreme sensitivity of the moving water theories to these low currents increased predictions of dilution closer to the measured values, particularly for the second and third Camps Bay tests.

6. CONCLUSIONS

On the basis of three similar exercises for measurement of the dilution of a buoyant effluent released at the sea bed from an operating outfall it can be concluded that the actual surface dilution achieved was about 2,5 times greater than that predicted by the stagnant uniform theory. This finding was confirmed in a fourth test conducted on a simulated outfall port at full-scale, at sea. These tests were done in selected calm conditions with very low ambient currents. **This implies that a safety factor of 2 to 3 times is included in conservative estimates of dilution based on the assumption of stagnant-uniform sea conditions.** This conclusion concurs with that of other researchers, as reviewed in Chapter 2.

In investigating the reasons for the higher measured dilutions it appears feasible that even at very slack currents (that is, currents of approximately 5 cm/s, which are almost always present in the form of 'background' currents in the open sea at the surface) entrainment of clean sea water into the effluent plume enhances dilution significantly. Predictions made with due allowance for these slack currents showed closer agreement to measured values.

Taking these findings into consideration, the use of the stagnant-uniform theory in design is questionable. The extra cost involved in meeting a specific dilution requirement on the basis of calculations assuming stagnant-uniform sea conditions may be considerable and may be unjustified in view of the inherent safety factor revealed.

This work has served as a useful supplement to the NRIO's contribution to the WRC Guide and the above findings have been incorporated,

ACKNOWLEDGEMENTS

This project was financed by the Water Research Commission.

The NRIO would also like to express its sincere appreciation to:

- The City Engineer's Department of the City of Cape Town for the use of the Camps Bay outfall, with particular thanks to technical staff and divers who willingly participated in the sea experiments.

- The Steering Committee, as detailed below, for their able guidance and support throughout the research period.

STEERING COMMITTEE:

Mr J E McGlashan (chairman)	Water Research Commission
Mr F P Anderson (vice-chairman)	National Research Institute for Oceanology
Mr K S Russell	National Research Institute for Oceanology
Dr A D Connell	National Institute for Water Research
Dr J M Jordaan	Department of Water Affairs
Dr J A Lusher	Department of Water Affairs
Mr K O'H Murphy	Department of Environment Affairs
Mr N D Geldenhuys	Department of Environment Affairs
Mr A G S Moldan	Sea Fisheries Research Institute
Mr A E Thorne (observer)	City Council of Cape Town
Mr H Beekman (observer)	City Council of Cape Town
Dr G Tredoux (observer)	National Institute for Water Research
Mrs H Koch/Mrs L Ottervanger (Committee secretaries)	National Research Institute for Oceanology

REFERENCES

ABRAHAM, G, et al. (1983). Discussion of: evaluation of selected initial dilution models. Journal of Environmental Eng., ASCE, Vol. 190, No. 5.

AGG, A R and WAKEFORD, A C (1972). Field studies of jet dilution of sewage at outfalls. Institution of Public Health Engineers Journal, Vol. 71, pp. 126-149.

ALAM, A M Z, et al. (1982). Evaluation of selected initial dilution models. ASCE, Vol. 108, No. EE1.

BAUMGARTNER, D J, TRENT, D S and BYRAM, K V (1971). User's guide and documentation for outfall plume model. USEPA, Pacific Northwest Lab., Corvallis, Oregon, Working Paper No. 80.

BENDINER, W P (1976). Puget sound interim studies: dispersion of effluent from the West Point Outfall. Final Report, App. Phys. Lab., Univ. Washington.

BENNET, N J (1981). Initial dilution: A practical study on the Hastings Long Sea Outfall. Proc. Inst. Civ. Engrs., Part 1.

BETTESS, R and MUNRO, D (1980). Field measurements of initial dilutions at a sea outfall. Hyd. Res. Sta. Wallingford, Report No. II 198.

BUIRSKI, JJ (1985). Aerial photography from a tethered balloon. NRIO Memo. 8522, Stellenbosch, South Africa.

CALDWELL CONNELL ENG. (1979). Geelong Ocean outfall study. Caldwell Connell Eng. (Ltd), Melbourne, Australia.

CEDERWALL, K (1967). Jet diffusion. Review of model testing and comparison with theory. Chalmers Univ. of Technology, Div. of Hydraulics, Pub. No. 35, Göteborg, Sweden.

CHU, V H (1979). Fan's data on buoyant jets in crossflow. Jour. of Hyd. Div., ASCE, 105, pp. 612-617.

EPA (1985). Initial mixing characteristics of Municipal ocean discharges: Vol. 1. Procedures and Applications and Vol. 2 Computer programs. Environmental Res. Lab., Narragansett. Reports No. EPA/SW/MT-86/012a and b.

FAN, L N and BROOKS, N H (1969). Numerical solutions of turbulent buoyant jet problems. W M Keck Lab. Rep. No. KH-R-18, Calif. Inst. Tech.

GIBSON, C H (1978). Evaluation of initial dilution for ocean discharges. Final Rep. to State Water Resources Control Board from Dept. Applied Mech. and Eng. Sc., Scripps Inst. Oceanography.

HANSEN, J and SCHRODER, H (1968). Horizontal jet dilution studies by use of radio-active isotopes. Acta Polytechnica Scandinavia, Copenhagen, Pub. No. 49.

HENDRICKS, T (1977). Sea measurements of initial dilution. S. Calif. Coastal Water Research Project., Ann. Report.

HYDRAULICS RESEARCH STATION (1977). Horizontal outfalls in flowing water. Hyd. Res. Sta. Wallingford, Report No. Ex763.

KOH, R C Y (1983). Delivery systems and initial dilution. Ocean disposal of municipal wastewater: impacts on coastal environment. Mass. Insti. of Tech. Report Series: MIT Tech. Rep. MITSG83-33.

LISETH, P (1970). Mixing of merging buoyant jets from a manifold in stagnant receiving water of uniform density. Univ. of Cal., Berkeley, Hyd. Eng. Lab., Tech. Report HEL 23-1.

ROBERTS, P J W (1977). Dispersion of buoyant waste water discharged from outfall diffusers of finite length. W M Keck Lab., Calif. Inst. of Tech., Report No. KH-R-35.

ROBERTS, P J W (1984). Visit to NRIO (Stellenbosch). Pers. communication to G Toms.

WALLIS, I G (1981). Verification of ocean outfall performance predictions. Journ. of Env. Eng. Div., ASCE, 107 (EE2): 421-425.

WRIGHT, S J (1977-1). Effect of ambient crossflows and density stratification on the characteristic behaviour of round turbulent buoyant jets. W M Keck Lab., Calif. Inst. of Tech., Report No. KH-R-36.

WRIGHT, S J (1977-2). Mean behaviour of buoyant jets in a crossflow. Jnl. Hyd. Div., ASCE, Vol. 103(HY5) 499-513.

WRIGHT, S J (1984). Buoyant jets in density stratified crossflow. Jnl. Hyd. Div., ASCE, Vol. 110 (HY5).

TABLE I: RHODAMINE-B CONCENTRATIONS AT THE DIFFUSER ON 1984/10/04 AT CAMPS BAY

All concentrations × 10^{-6}

Time	Concentration
13h13	1 450
13h16	1 660
13h19	1 670
13h22	-
13h24	1 550
13h26	-
13h34	137
13h36	-
13h38	90,2
13h40	-
13h43	89,2
13h49	12,9
13h57	10,3
14h04	9,9
14h10	8,7
14h18	6,7
14h25	5,8
14h33	4,7
14h45	2,2
14h55	2,3
15h05	4,8
15h15	2,6
15h25	0,7
15h40	1,0
15h45	0,9
15h50	1,1
15h55	0,9
16h00	0,7
16h05	0,6
16h10	0,7
16h15	1,8
16h20	0,7

TABLE II: RHODAMINE-B CONCENTRATIONS AT THE DIFFUSER ON 1985/02/13 AT CAMPS BAY

All concentrations × 10^{-6}

Time	Concentration
10h45	0,0053
11h00	0,0053
11h15	0,0041
11h30	0,0068
11h45	0,0078
11h55	3,59
12h00	1 230
12h05	1 850
12h15	200
12h20	24,8
12h25	14,9
12h30	10,7
12h35	6,59
12h40	5,98
12h45	5,98
12h50	6,08
12h55	4,52
13h00	4,52
13h05	4,52
13h10	3,57
13h15	3,36
13h20	3,46
13h25	3,25
13h30	2,71
13h35	2,71
13h40	2,60
13h45	2,60
13h55	0,525
14h00	0,543
14h05	0,525
14h10	0,599
14h15	0,728
14h20	0,710
14h25	0,782
14h30	0,755
14h35	0,801
14h40	0,782
14h45	0,710
14h50	0,468
14h55	0,496
15h00	0,506
15h10	0,506
15h15	0,543

TABLE III: RHODAMINE-B CONCENTRATIONS AT THE DIFFUSER ON 1985/04/25 AT CAMPS BAY

All concentrations × 10^{-6}

Time	Concentration
11h18	68,4
11h20	937
11h23	1 730
11h24	1 830
11h26	1 810
11h28	426
11h30	70,3
11h32	19,7
11h34	15,6
11h36	11,7
11h38	11,1
11h40	7,25
11h45	4,90
11h50	4,15
11h55	3,63
12h00	3,09
12h05	3,36
12h10	2,95
12h15	3,09
12h20	3,36
12h25	4,59
12h30	4,28
12h35	1,29
12h40	1,04
12h45	1,01
12h50	1,01
12h55	1,03
13h00	0,987
13h05	0,945
13h10	0,914
13h15	0,903
13h20	0,881
13h25	0,903
13h30	0,903
13h35	0,881
13h40	0,871

TABLE IV: RHODAMINE-B CONCENTRATIONS IN THE BOIL ON 1984/10/04 AT CAMPS BAY

All concentrations × 10^{-6}

Time	Concentration
12h48	0
13h11	0
13h13	0
13h14	0
13h15	0
13h16	0
13h19	0,1
13h21	0
13h22	0
13h24	0
13h26	0,06
13h27	0,02
13h28	0
13h30	0,15
13h31	1,38
13h32	0,21
13h34	1,90
13h35	0,73
13h36	0,402
13h38	1,05
13h39	1,88
13h41	0,21
13h43	0,688
13h45	0,06
13h47	0,0212
13h48	1,34
13h50	0,865
13h51	0,053
13h52	0,0382
13h53	0,049
13h54	0,350
13h55	0,018
13h56	0,175
13h57	0,159
13h58	0,00227
13h59	0,159
14h00	0,0757
14h01	0
14h02	0,00267
14h03	0,376
14h04	0,012
14h05	0,067
14h06	0,0973
14h08	0,014
14h09	0,0525
14h10	0,007

TABLE V: RHODAMINE-B CONCENTRATIONS IN THE BOIL ON 1985/02/13 AT CAMPS BAY

All concentrations × 10^{-6}

Time	Concentration
11h54	0
11h56	0,147
11h57	0,000221
11h58	0,728
11h59	0,487
12h00	0,257
12h01	0,176
12h02	0,149
12h03	0,157
12h04	0,184
12h05	0,392
12h06	0,325
12h07	0,305
12h08	0,120
12h09	0,246
12h10	0,161
12h11	0,109
12h12	2,58
12h13	1,03
12h14	1,49
12h15	1,03
12h16	0,43
12h17	0,710
12h18	0,192
12h19	0,637
12h20	0,159
12h21	0,654
12h22	0,118
12h23	0,673
12h24	0,543
12h25	0,618
12h26	0,599
12h27	0,534
12h28	0,673
12h29	0,637
12h31	0,008

TABLE VI: RHODAMINE-B CONCENTRATIONS IN THE BOIL ON 1985/04/25 AT CAMPS BAY

All concentrations × 10^{-6}

Time	Concentration
10h54	0
10h55	0,0021
10h59	0,00529
11h02	0
11h22	0
11h24	0,089
11h25	0,28
11h26	0,139
11h27	0,41
11h28	0,224
11h29	0,466
11h30	0,32
11h31	0,231
11h32	1,05
11h33	2,5
11h34	2,54
11h35	2,69
11h36	0,838
11h37	0,795
11h38	0,58
11h39	0,784
11h40	0,107
11h41	0,849
11h42	0,740
11h43	0,784
11h44	0,806
11h45	0,773

Time	Concentration
11h46	0,373
11h47	0,773
11h48	0,751
11h49	0,729
11h50	0,706
11h51	0,717
11h52	0,740
11h53	0,684
11h54	0,000220
11h56	0,423
11h58	0,426
11h59	0,398
12h00	0,615
12h01	0,360
12h02	0,373
12h03	0,497
12h04	0,366
12h05	0,0108
12h06	0,273
12h07	0,246
12h08	0,125
12h09	0,153
12h10	0,239
12h11	0,12
12h12	0,166
12h13	0,294
12h14	0,208

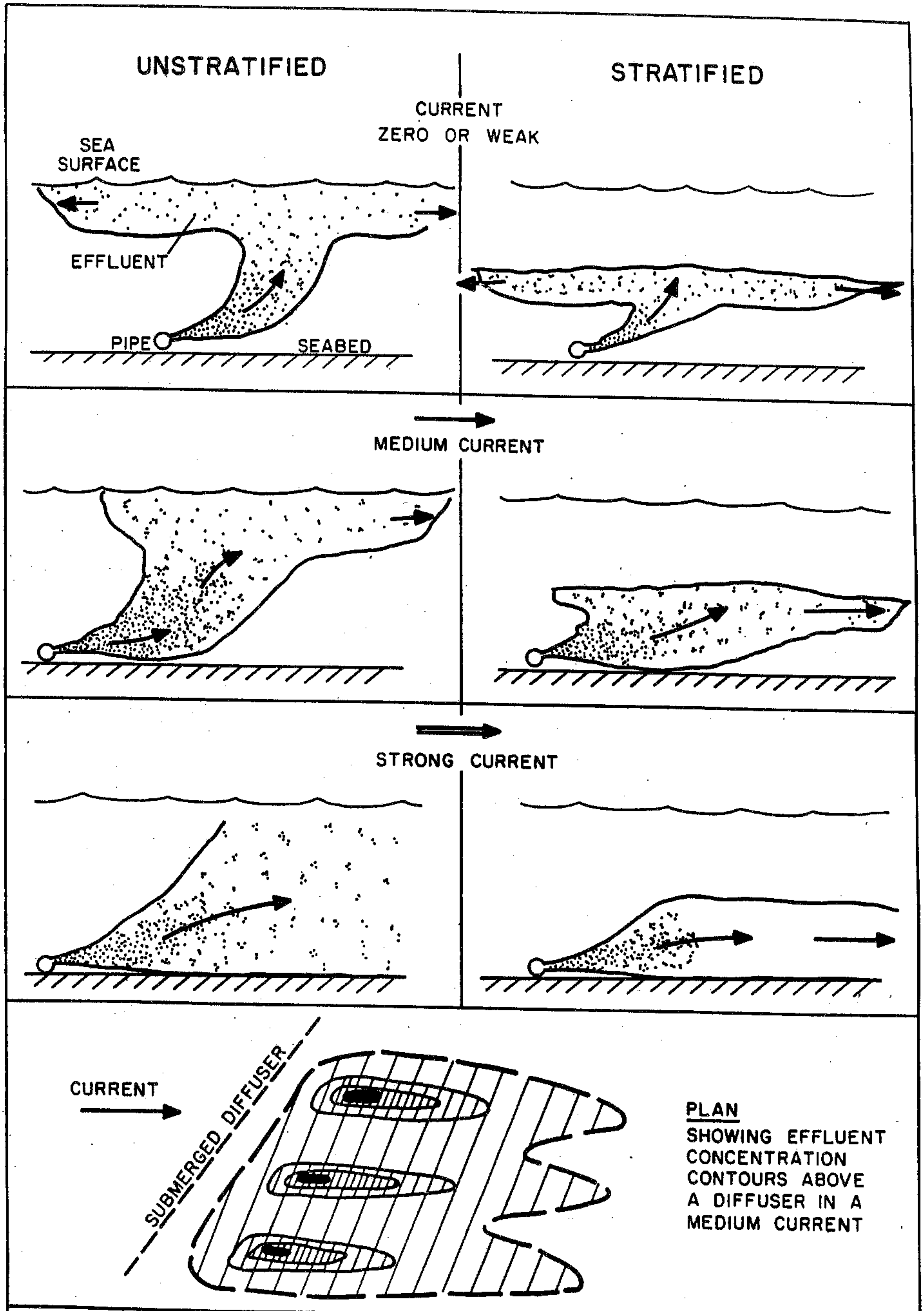
TABLE VII: RHODAMINE-B CONCENTRATIONS IN THE BOIL ON 1985/09/05 AT HOUT BAY

All concentrations × 10^{-6}

Time	Concentration
11h19	3,17
11h20	3,07
11h21	0,002
11h22	0,485
11h23	1,1
11h24	0,660
11h25	0,717
11h26	0,349
11h27	0,165
11h28	0,128
11h30	0,392
11h31	0,452
11h32	0,289
11h33	0,502
11h34	0,201
11h35	0,263
11h36	0,544
11h37	0,349
11h38	0,254
11h39	0,293
11h40	0,593
11h41	0,223
11h42	0,241
11h43	0,0345

Notes:

1. These are from the first release only.
2. Only samples at 1 minute intervals are listed, other samples taken in between are plotted in Figure 18.



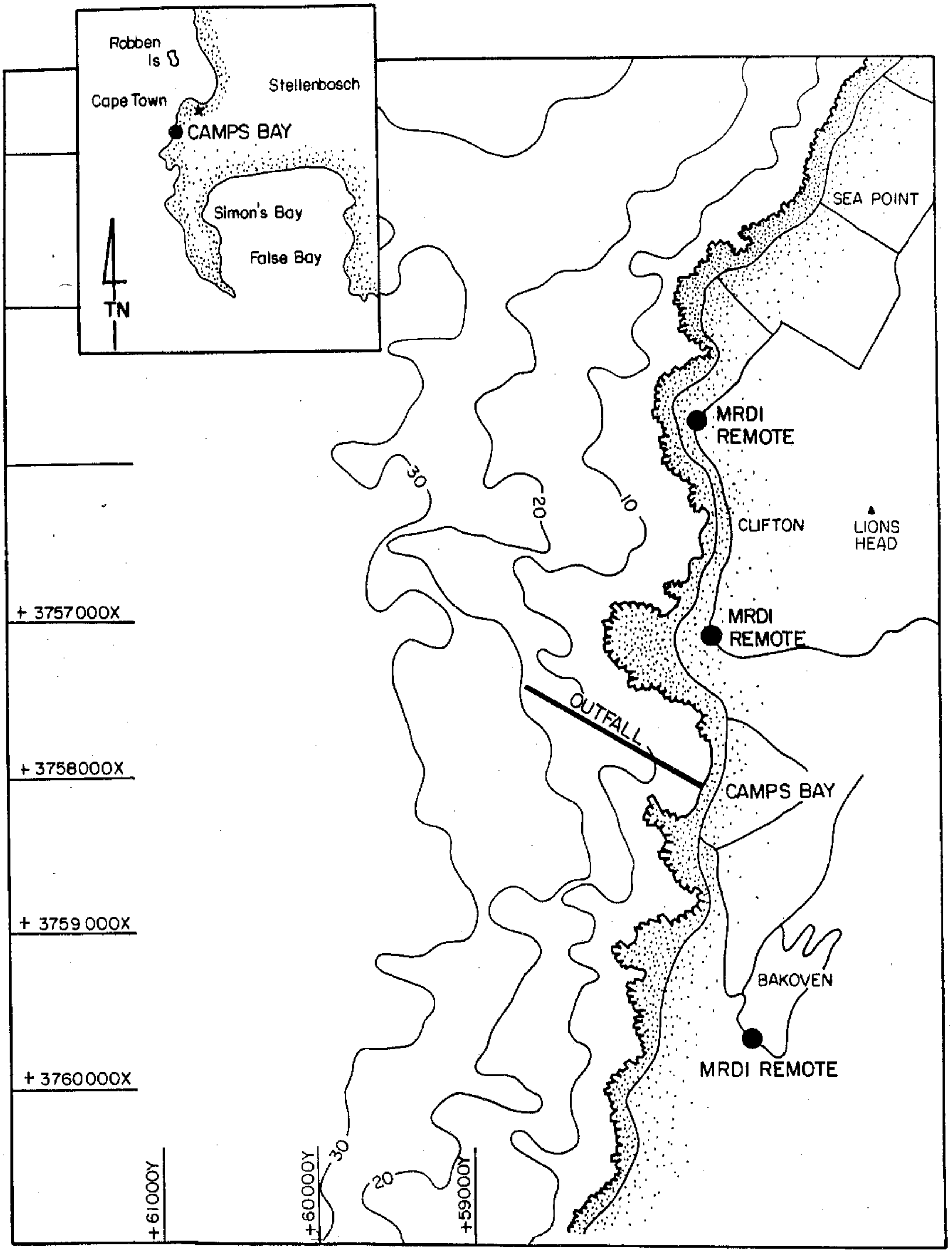
TRACED JM
CHECKED
DATE :
REF :

WRC OUTFALL STUDIES

GENERAL BEHAVIOUR OF BUOYANT EFFLUENT
DISCHARGED TO SEA
(INITIAL DILUTION)

FIGURE
1

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



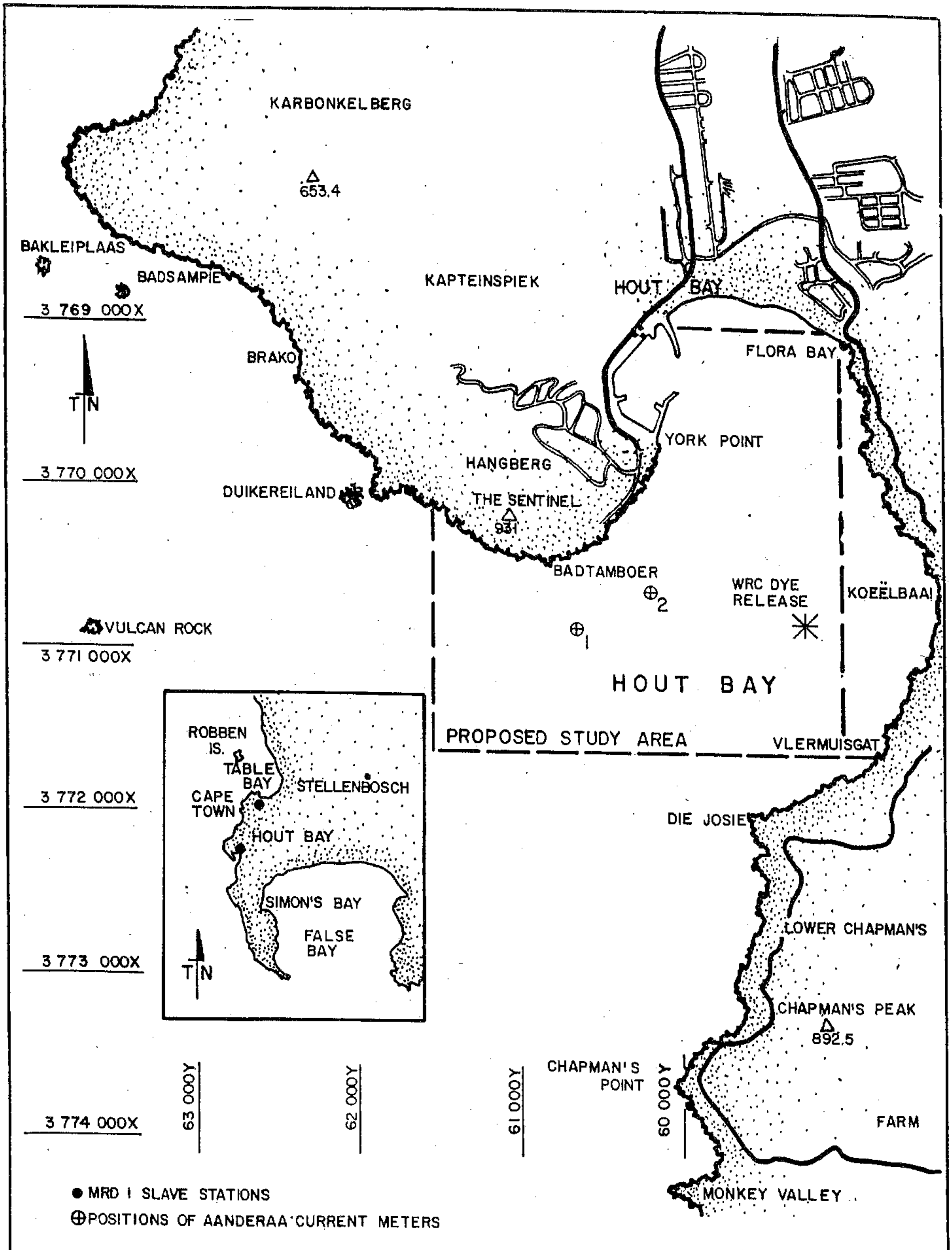
TRACED : HP7550
CHECKED : JJB
DATE : 86/10/29.
REF. :

WRC OUTFALL STUDIES

THE CAMPS BAY OUTFALL SITE

FIGURE
2

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY

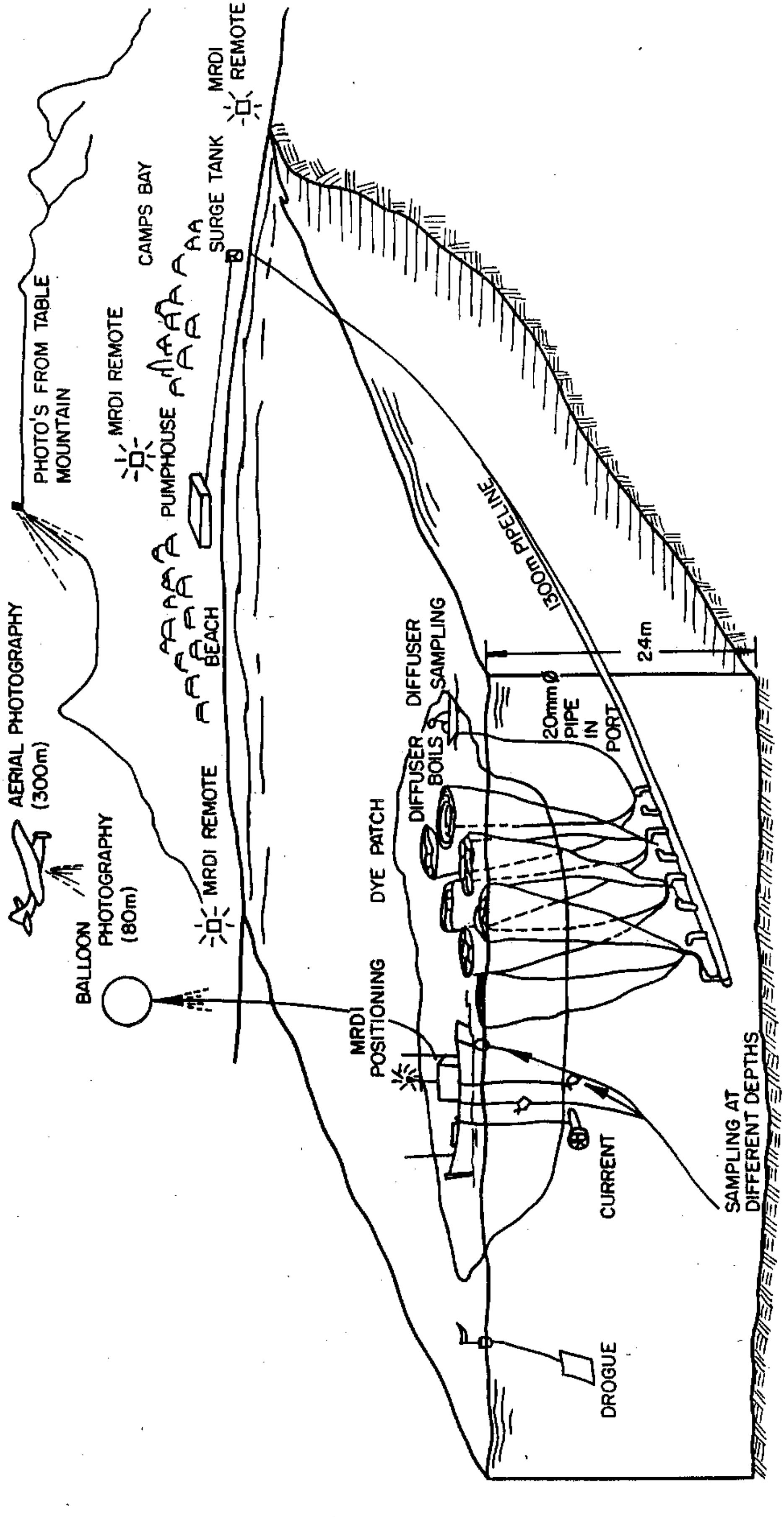


TRACED : HP7550
CHECKED : JJB
DATE : 86/10/29.
REF. :

WRC OUTFALL STUDIES
THE LOCALITY OF HOUT BAY AND
THE EXPERIMENTAL SITE

FIGURE
3

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



TRACED : HP7550
CHECKED : JJB
DATE : 86/10/29.
REF. :

WRC OUTFALL STUDIES
A SCHEMATIC REPRESENTATION OF THE
EXPERIMENTAL PROCEDURES AT CAMPS BAY

FIGURE
4

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY

12h45: 50 min after the surfacing of the effluent.

13h20: The waste field after 85 min from a height of 300 m. Samples were taken from the vessel while it transected the plume

13h31: After 96 min the waste field proceeded in a southerly direction with residual dye in the pipe still surfacing during pumping cycles.

14h48: After 173 min the waste field proceeded on the edge of an outflowing anti-clockwise eddy in the bay.

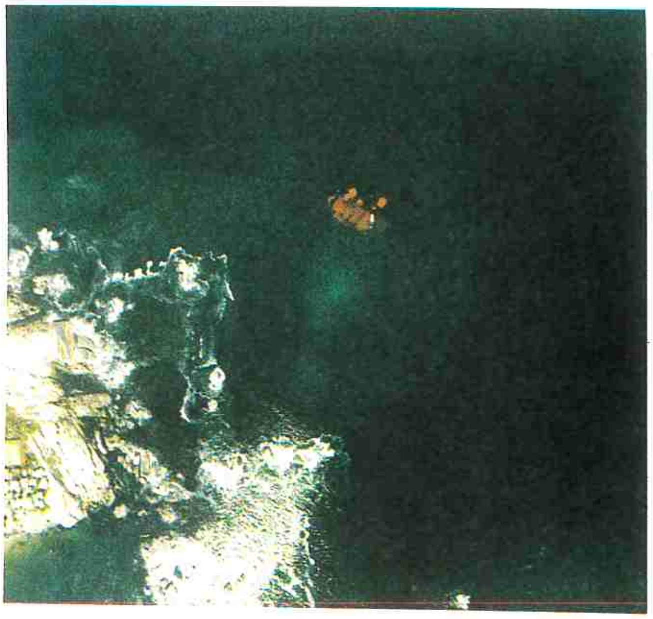
TRACED:
CHECKED:
DATE:
REF.:

WRC OUTFALL STUDIES

THE SURFACE WASTE FIELD
ON 1985/02/13 AT CAMPS BAY

FIGURE 5

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



11h31

The surfacing of the individual plumes of the seven diffusers. The two "releases" due to the intermittent pumping are clearly visible

12h37

The waste field approaching the rocky coastline north of Camps Bay. The directions of the surface and subsurface currents were northerly.

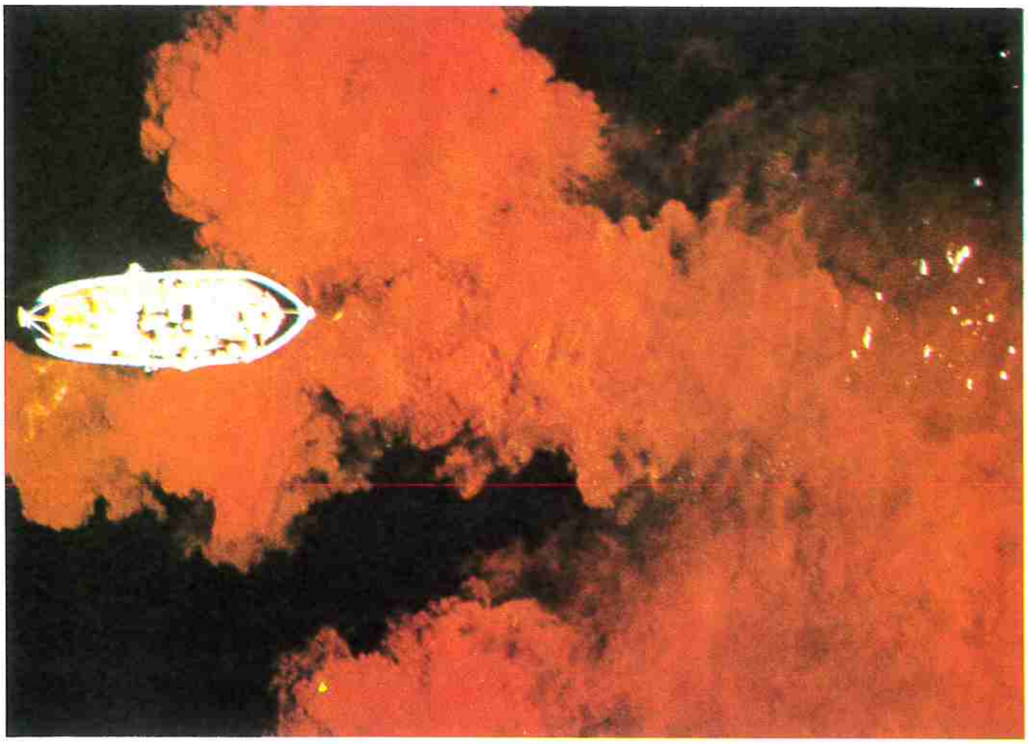
TRACED:
CHECKED:
DATE:
REF.:

WRC OUTFALL STUDIES

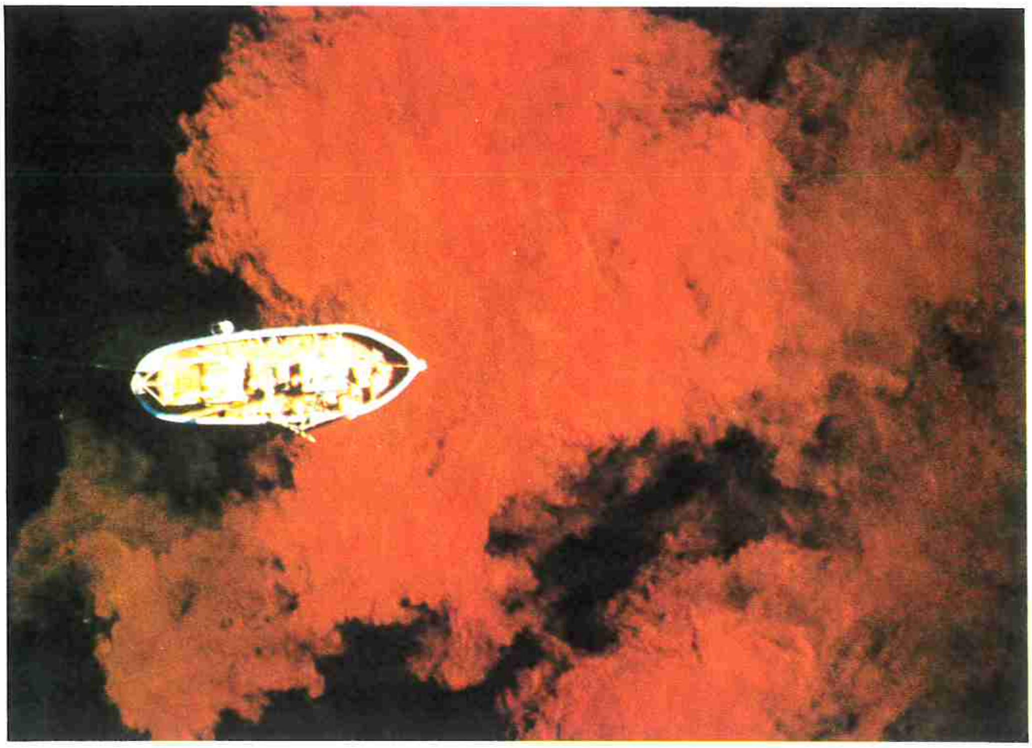
AERIAL PHOTOS OF THE DYE RELEASE
ON 1985/04/25 AT CAMPS BAY

FIGURE
6

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



11h20



11h33

TRACED: CHECKED: DATE: REF.:	WRC OUTFALL STUDIES A CLOSE-UP PHOTO OF THE SURFACING PLUMES ON 1985/04/25	FIGURE 7

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY

12h10

12h47

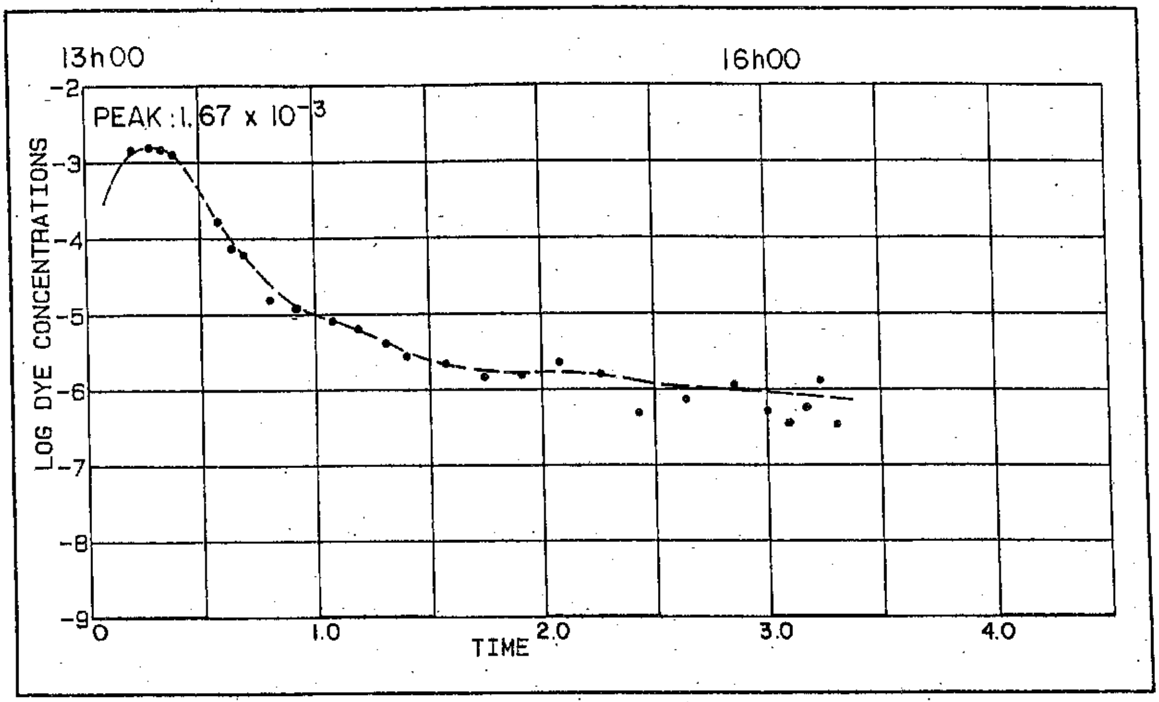
TRACED:
CHECKED:
DATE:
REF.:

WRC OUTFALL STUDIES

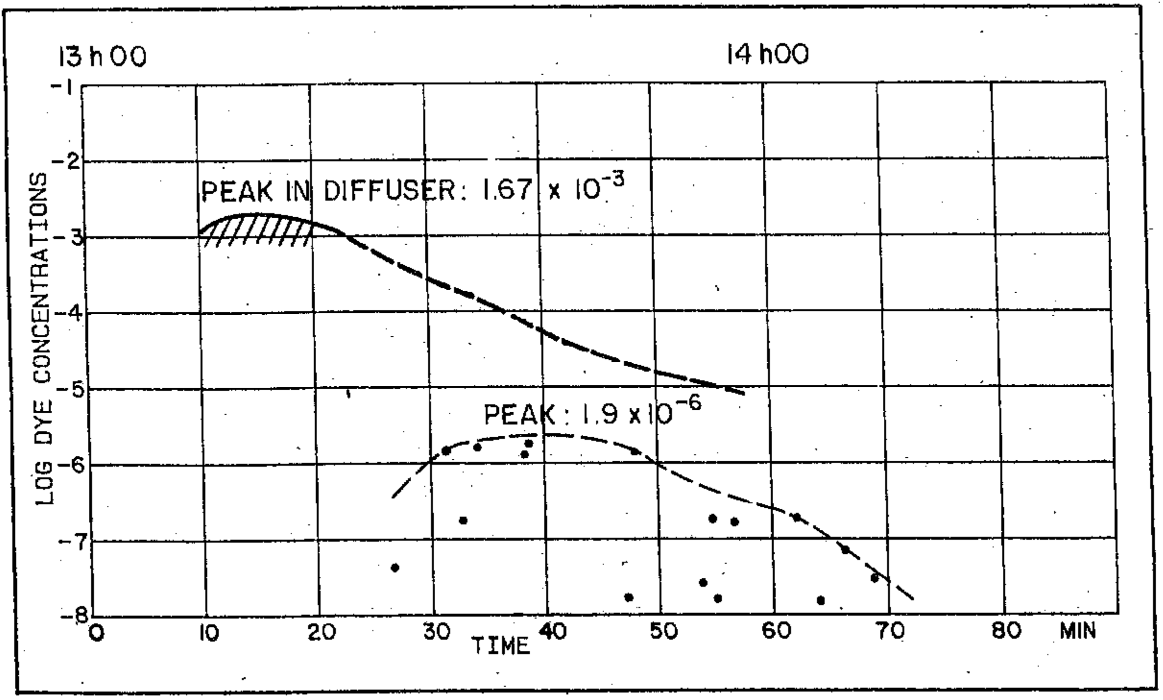
PHOTOS INDICATING THE NON-HOMOGENEOUS NATURE OF THE WASTE FIELD AT CAMPS BAY.

FIGURE 8

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



(A) DYE CONCENTRATIONS WITHIN THE DIFFUSER (13H13 — 16H20)



(B) DYE CONCENTRATIONS MEASURED AT THE WATER SURFACE (0 TO 2M DEEP) COMPARED WITH THOSE IN THE DIFFUSER (13H20 - 14H10)

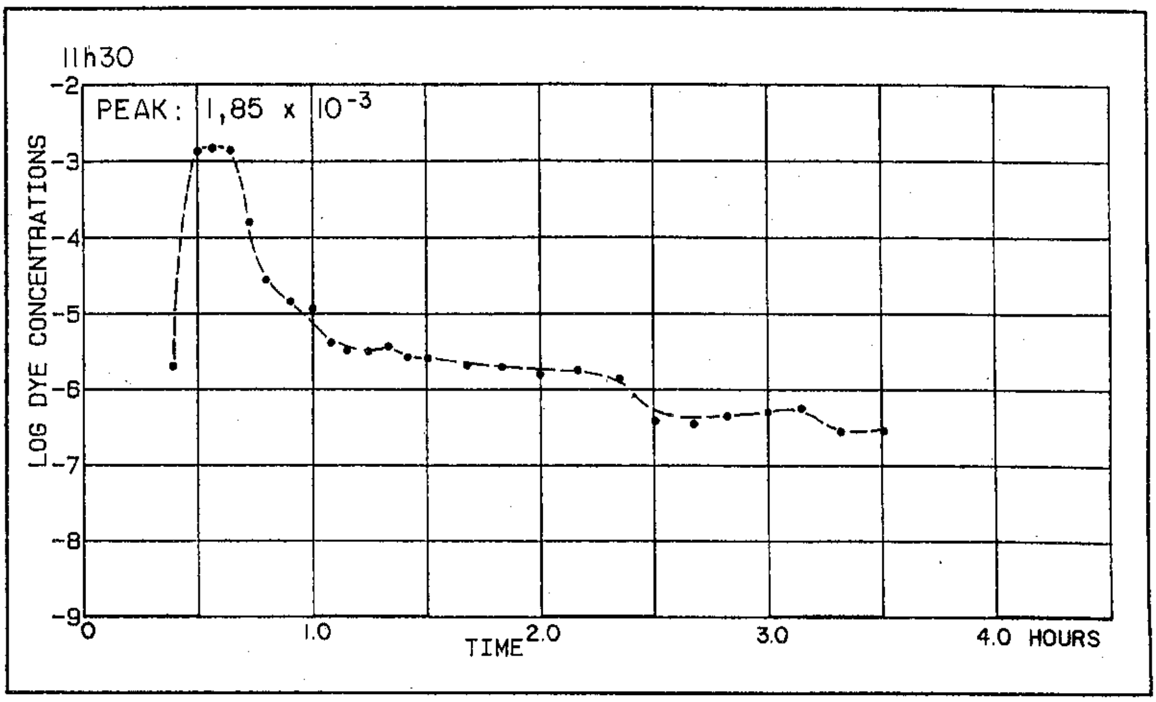
TRACED : HP7550
CHECKED : JJB
DATE : 86/11/03.
REF. :

WRC OUTFALL STUDIES

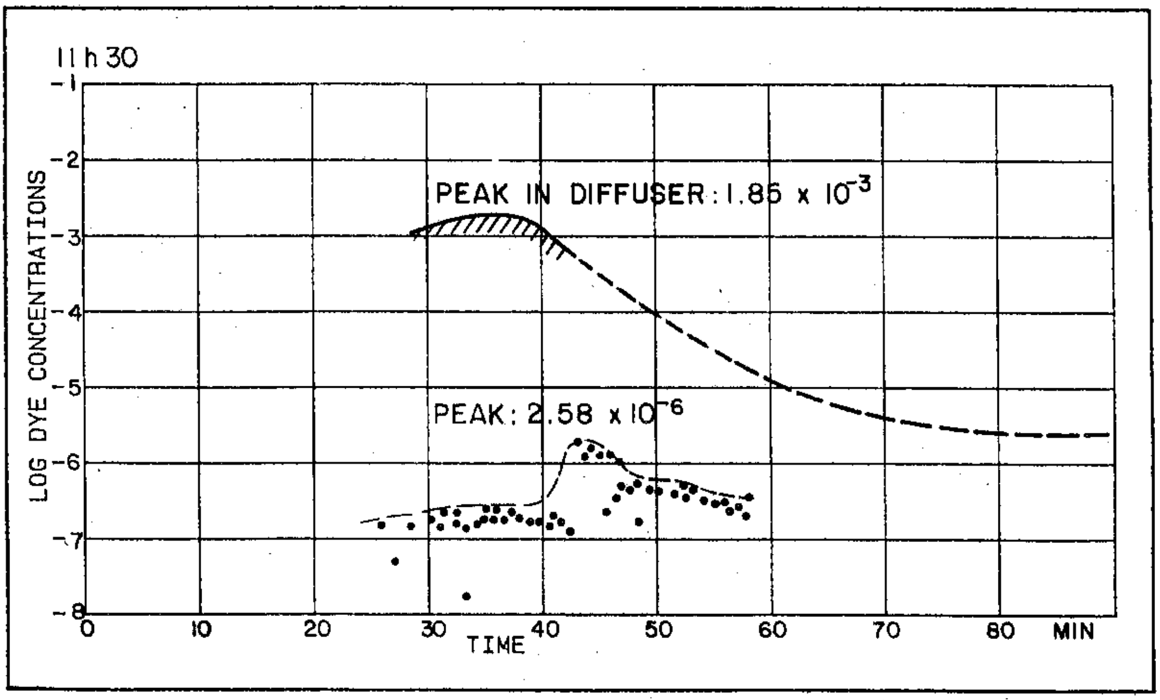
CONCENTRATIONS AT THE DIFFUSER
AND IN THE BOIL ON 1984/10/04
AT CAMPS BAY

FIGURE
9

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



(A) DYE CONCENTRATIONS WITHIN THE DIFFUSER (11H30 – 15H15)



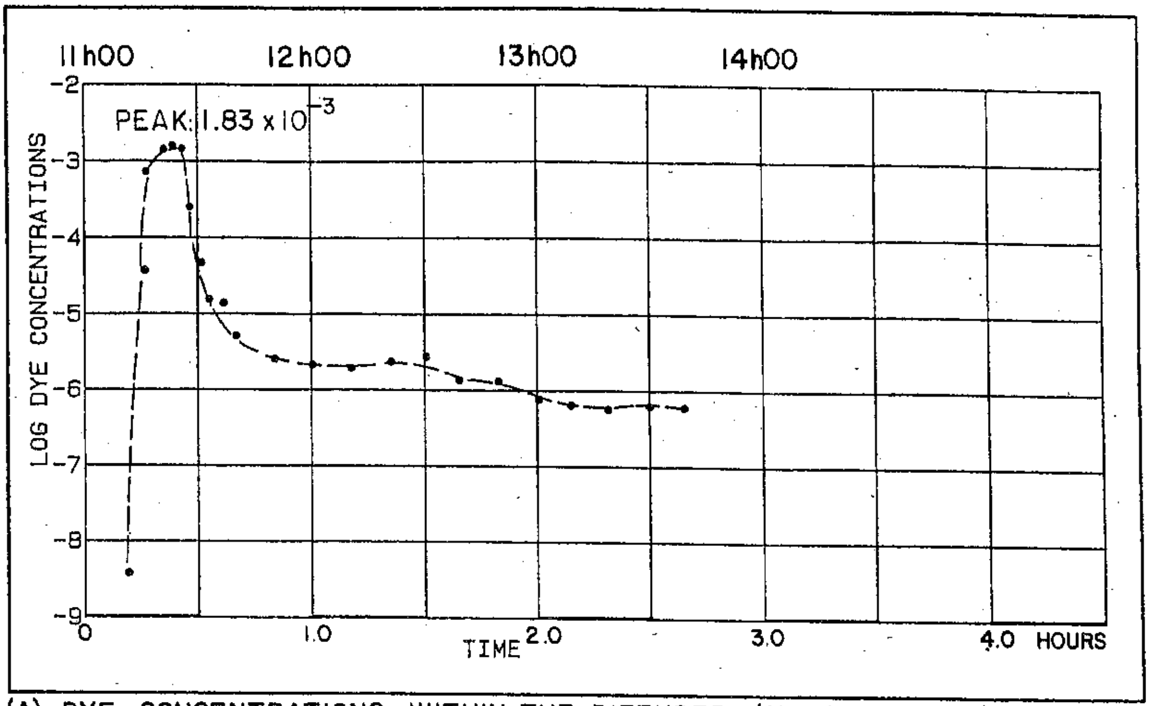
(B) DYE CONCENTRATIONS MEASURED AT THE WATER SURFACE (0 TO 2M DEEP) COMPARED WITH THOSE IN THE DIFFUSER (11H30 – 12H30)

TRACED : HP7550
CHECKED : JJB
DATE : 86/11/03.
REF. :

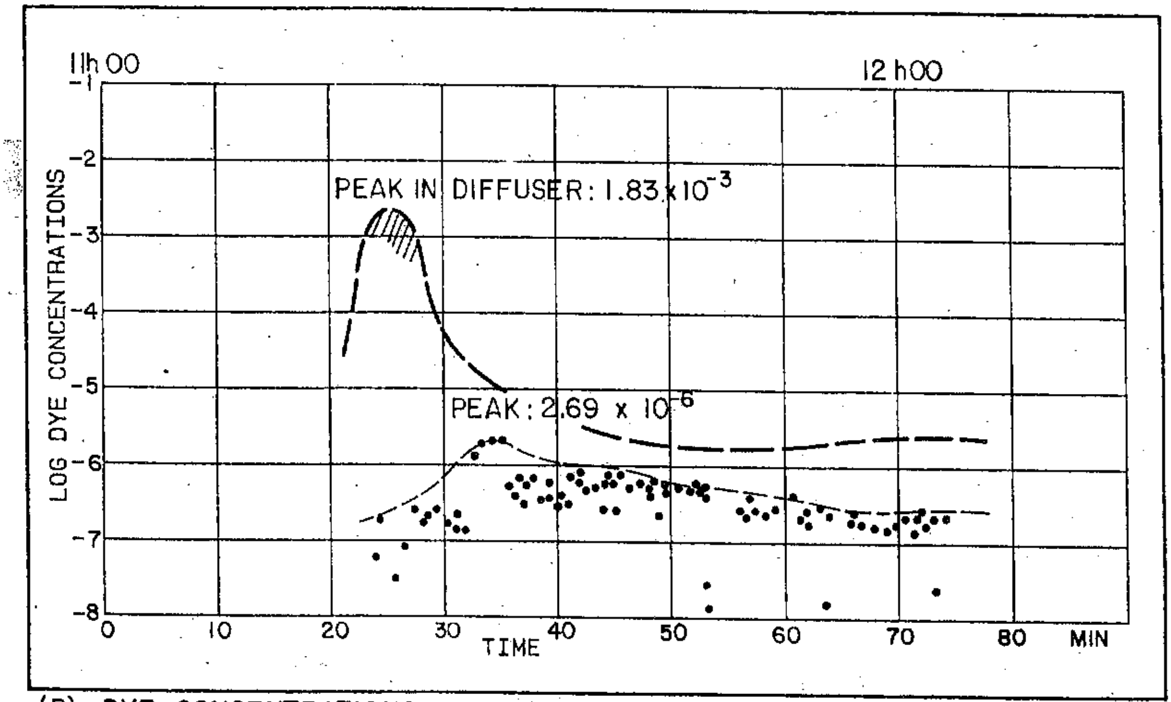
WRC OUTFALL STUDIES
CONCENTRATIONS AT THE DIFFUSER
AND IN THE BOIL ON 1985/02/13
AT CAMPS BAY

FIGURE
10

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



(A) DYE CONCENTRATIONS WITHIN THE DIFFUSER (11H14 – 13H40)



(B) DYE CONCENTRATIONS MEASURED AT THE WATER SURFACE (0 TO 2M DEEP) COMPARED WITH THOSE IN THE DIFFUSER (11H00 – 12H19)

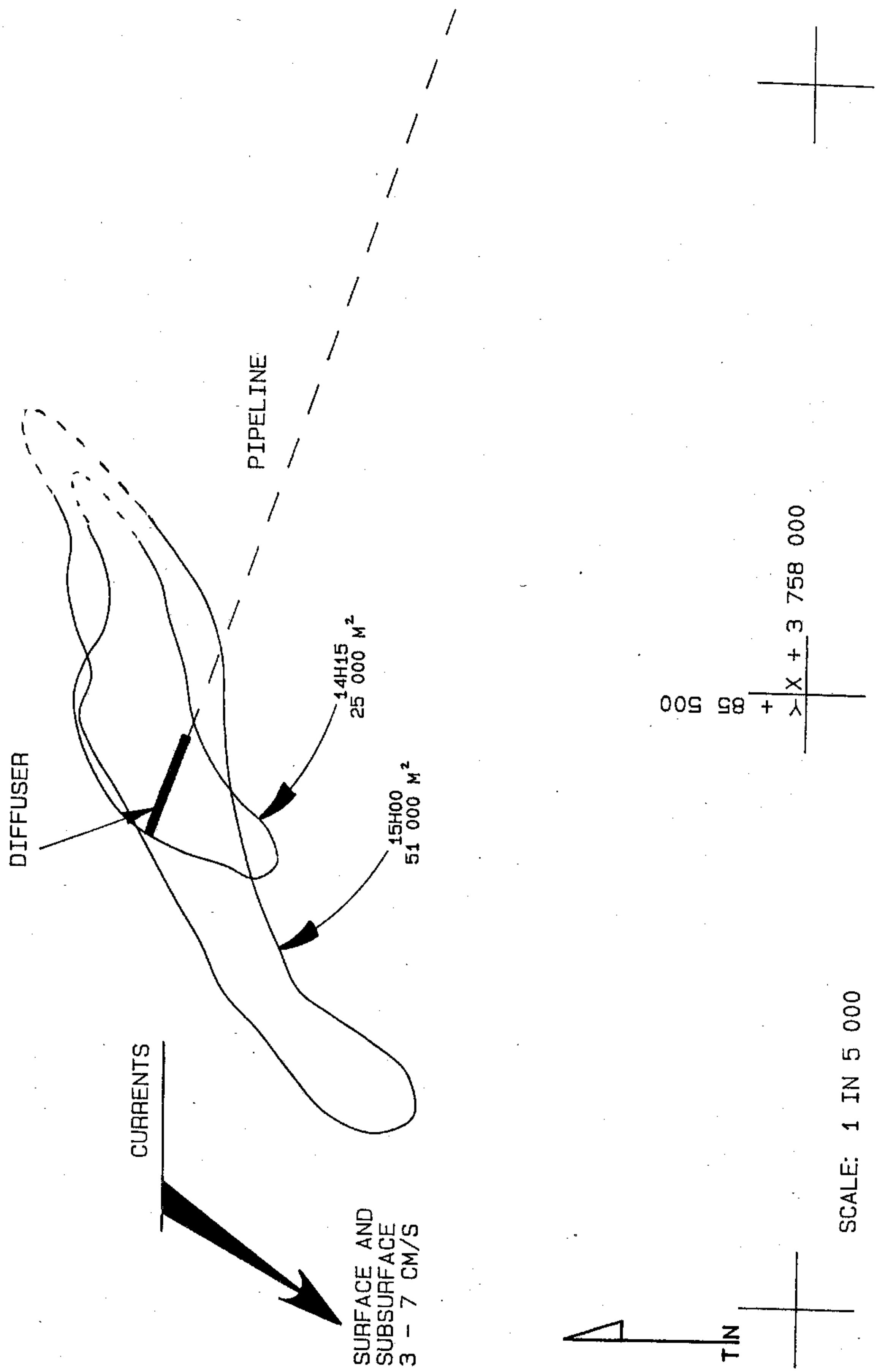
TRACED : HP7550
CHECKED : JJB
DATE : 86/11/03.
REF. :

WRC OUTFALL STUDIES

CONCENTRATIONS AT THE DIFFUSER
AND IN THE BOIL ON 1985/04/25
AT CAMPS BAY

FIGURE
11

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



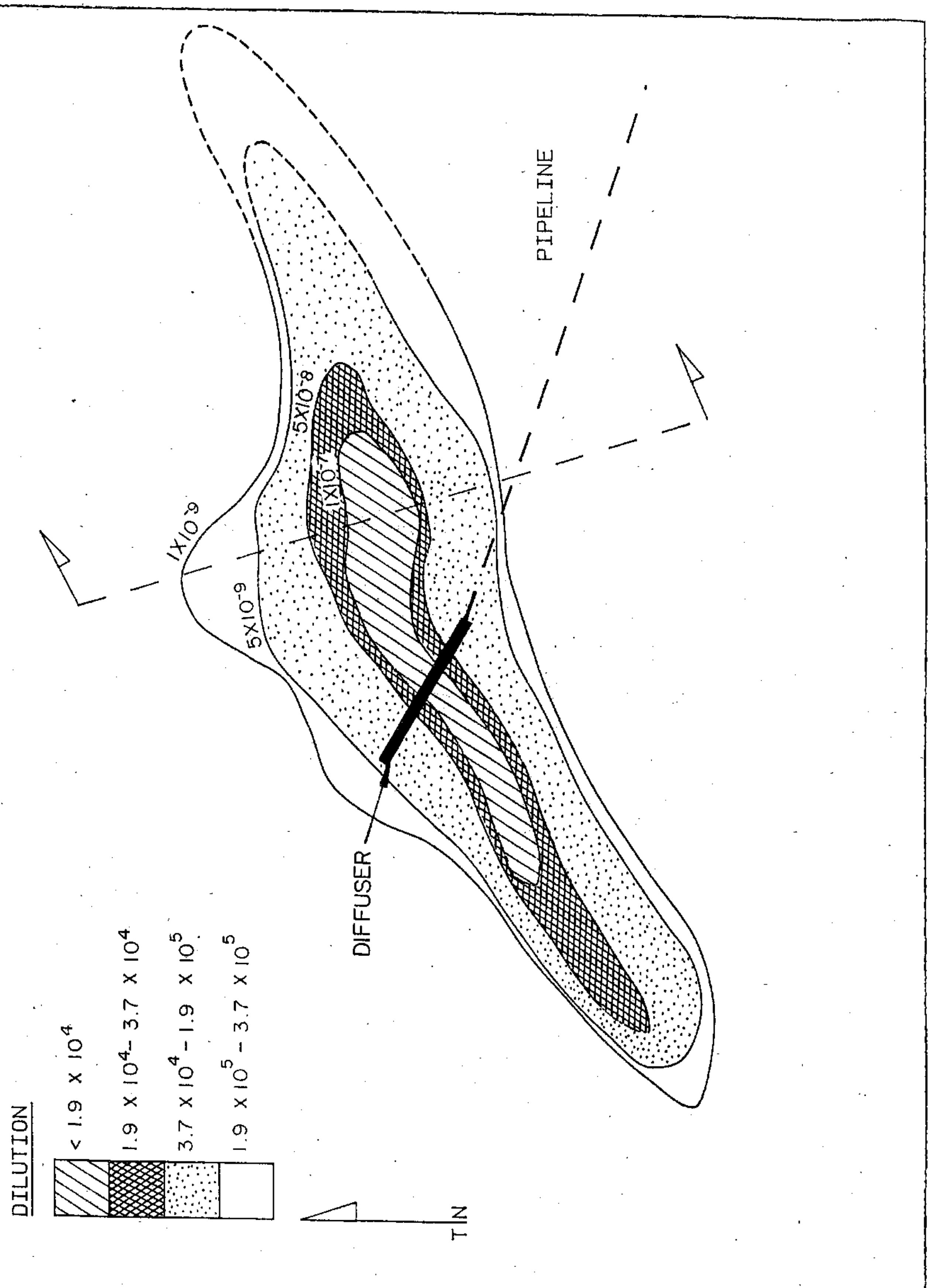
TRACED : HP7550
CHECKED : JJB
DATE : 86/11/04.
REF. :

WRC OUTFALL STUDIES

THE SPREADING OF THE WASTE-FIELD ON 1984/10/02 AT CAMPS BAY

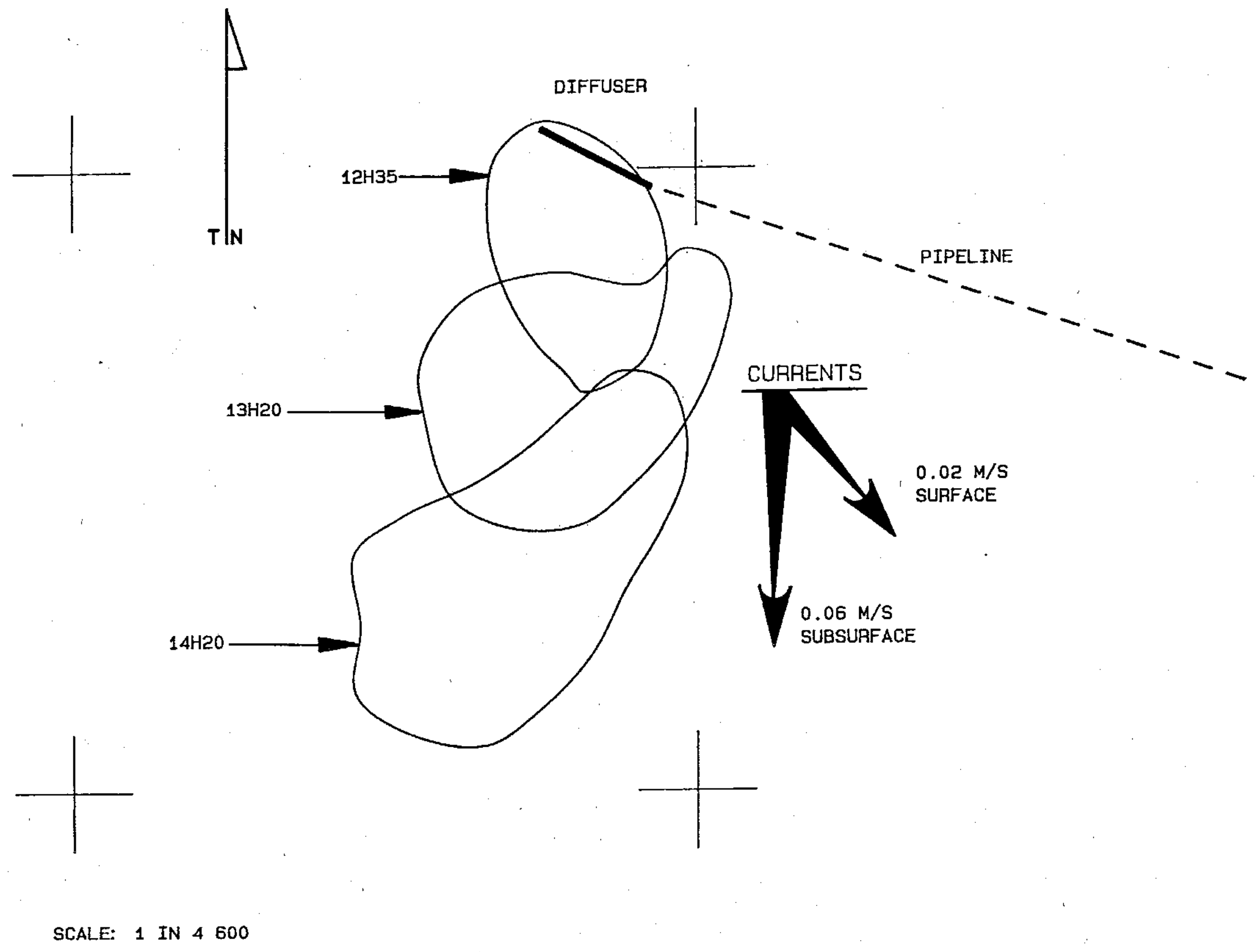
FIGURE
12

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



TRACED : HP7550 CHECKED : JJB DATE : 86/11/04. REF. :	WRC OUTFALL STUDIES DISTRIBUTION OF CONCENTRATIONS 3 HOURS AFTER RELEASE ON 1984/10/02 AT CAMPS BAY	FIGURE 13

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



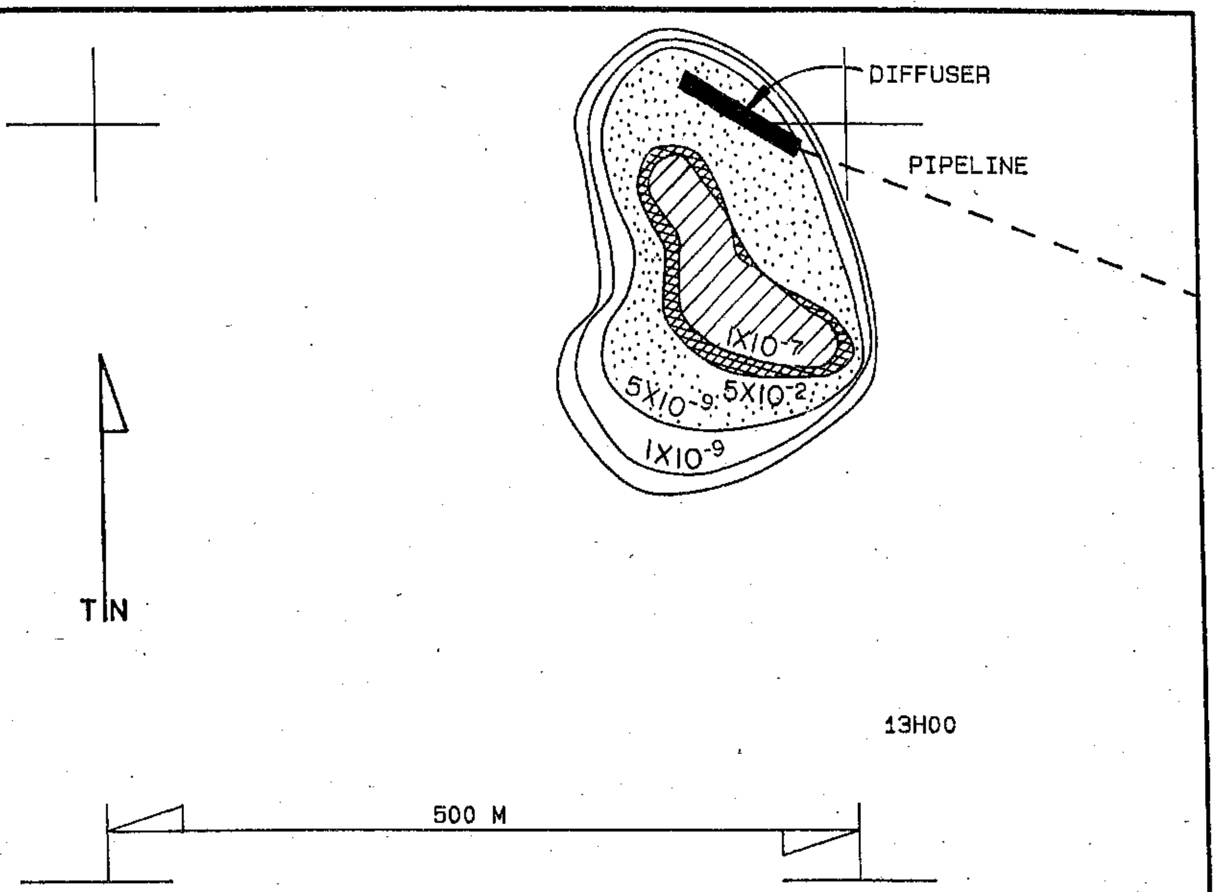
WRC OUTFALL STUDIES

THE SPREADING OF THE WASTE-FIELD
ON 1985/02/13 AT CAMPS BAY

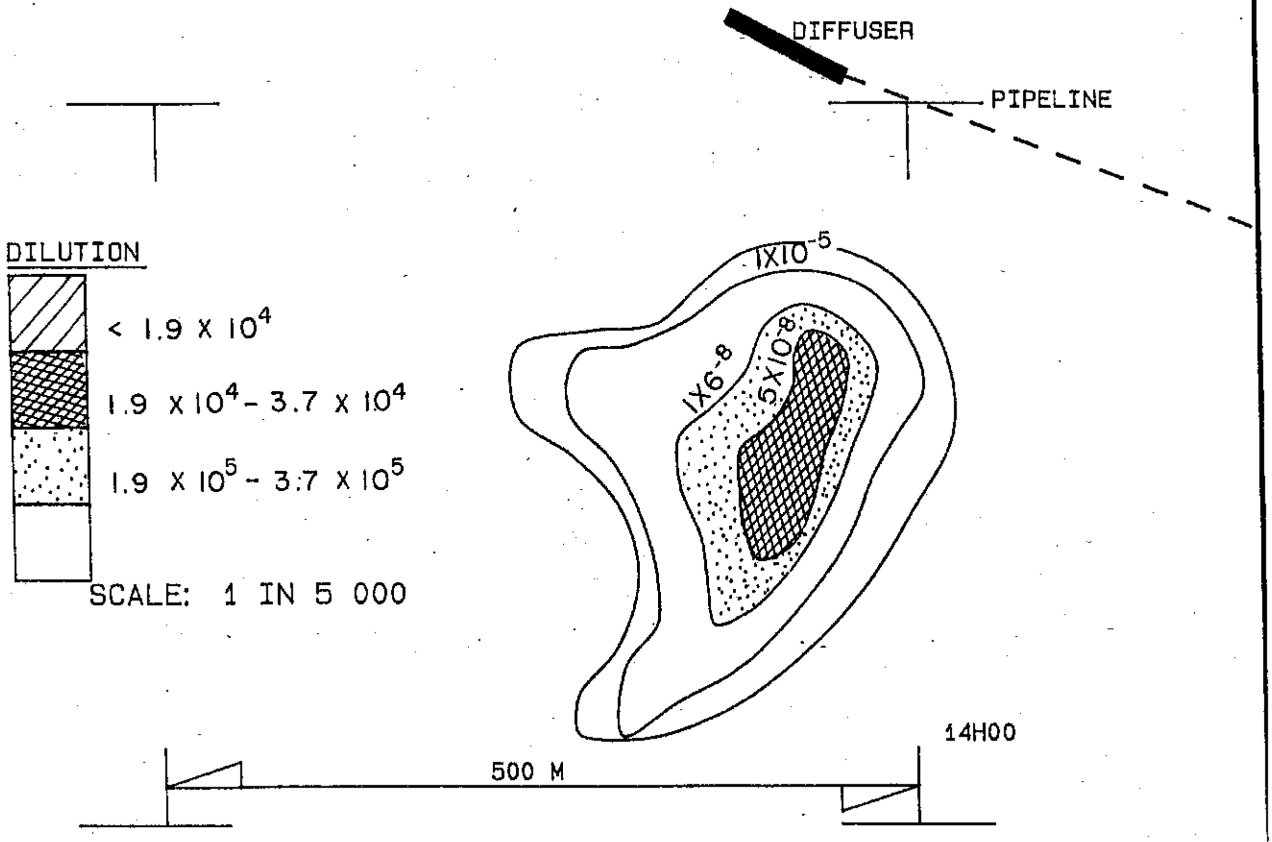
FIGURE
14

TRACED : HP7550
CHECKED : JJB
DATE : 86/11/05.
REF. :

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



A) THE CONCENTRATIONS 60 MIN AFTER SURFACING OF THE DYE



B) THE CONCENTRATIONS 120 MIN AFTER SURFACING OF THE DYE

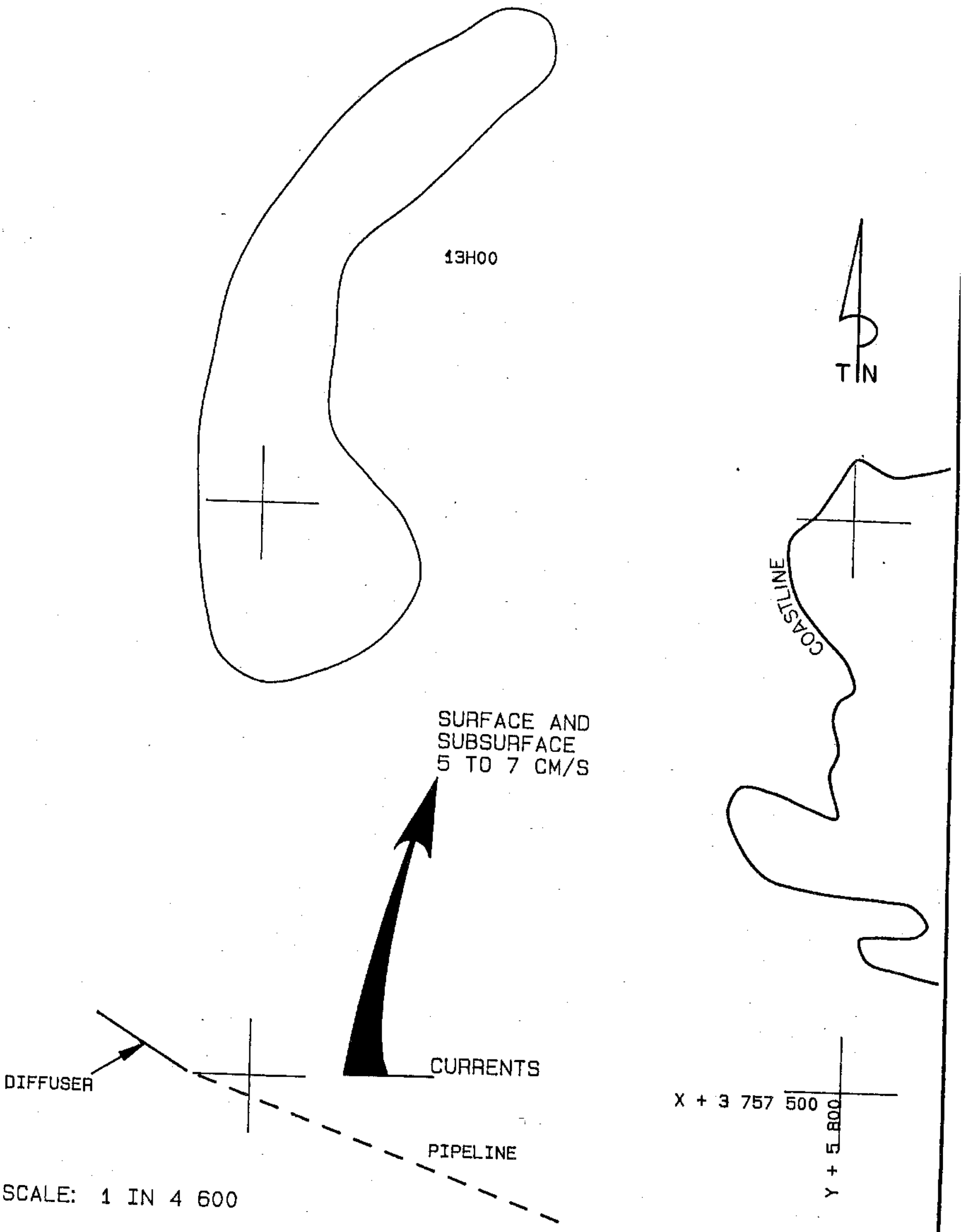
TRACED : HP7550
CHECKED : JJB
DATE : 86/11/05.
REF. :

WRC OUTFALL STUDIES

DISTRIBUTION OF CONCENTRATIONS 60 MIN AND 120 MIN AFTER SURFACING ON 1985/02/13 AT CAMPS BAY

FIGURE 15

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



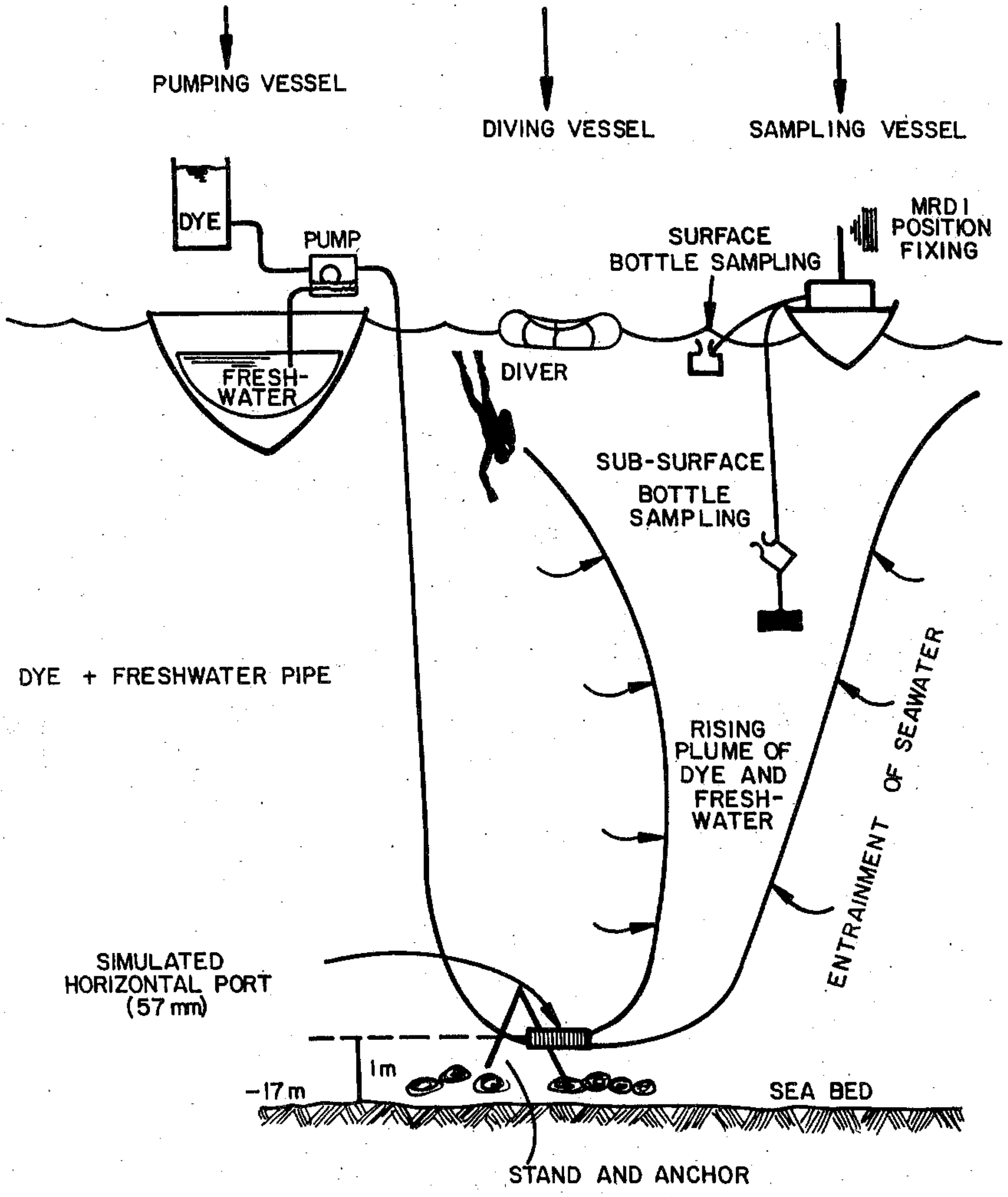
TRACED : HP7550
CHECKED : JJB
DATE : 86/11/05.
REF. :

WRC OUTFALL STUDIES

THE SPREADING OF THE WASTE-FIELD ON 1985/04/25 AT CAMPS BAY

FIGURE 16

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY

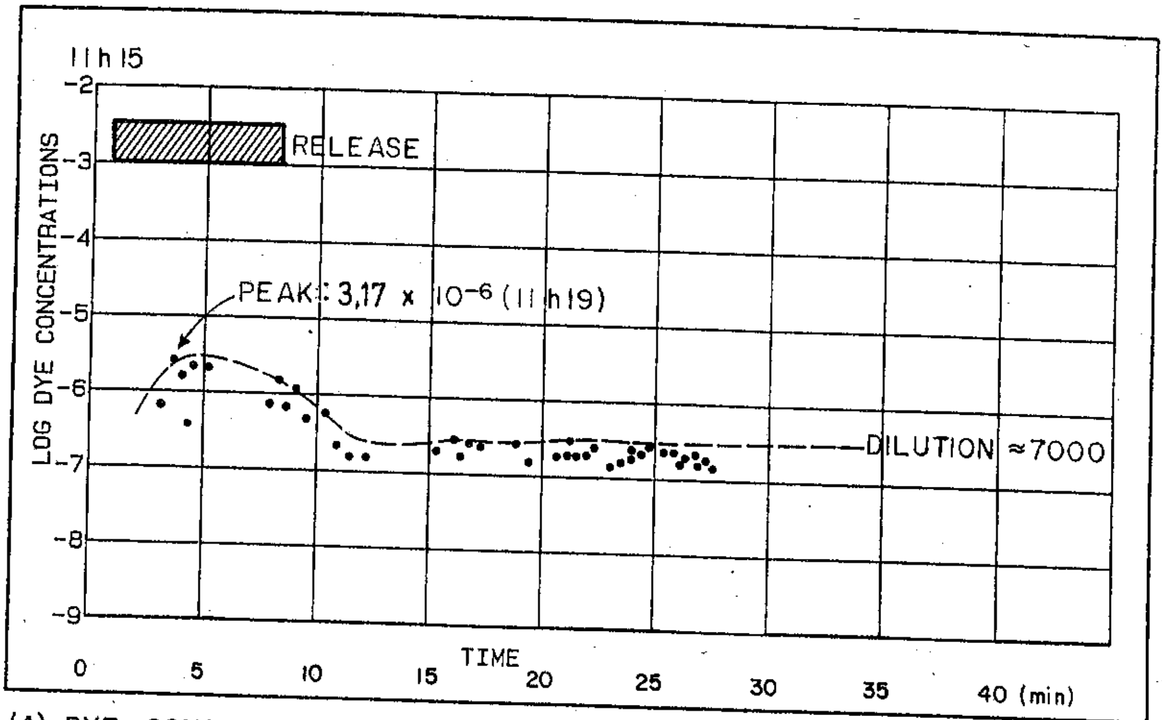


TRACED : HP7550
CHECKED : JJB
DATE : 86/10/29.
REF. :

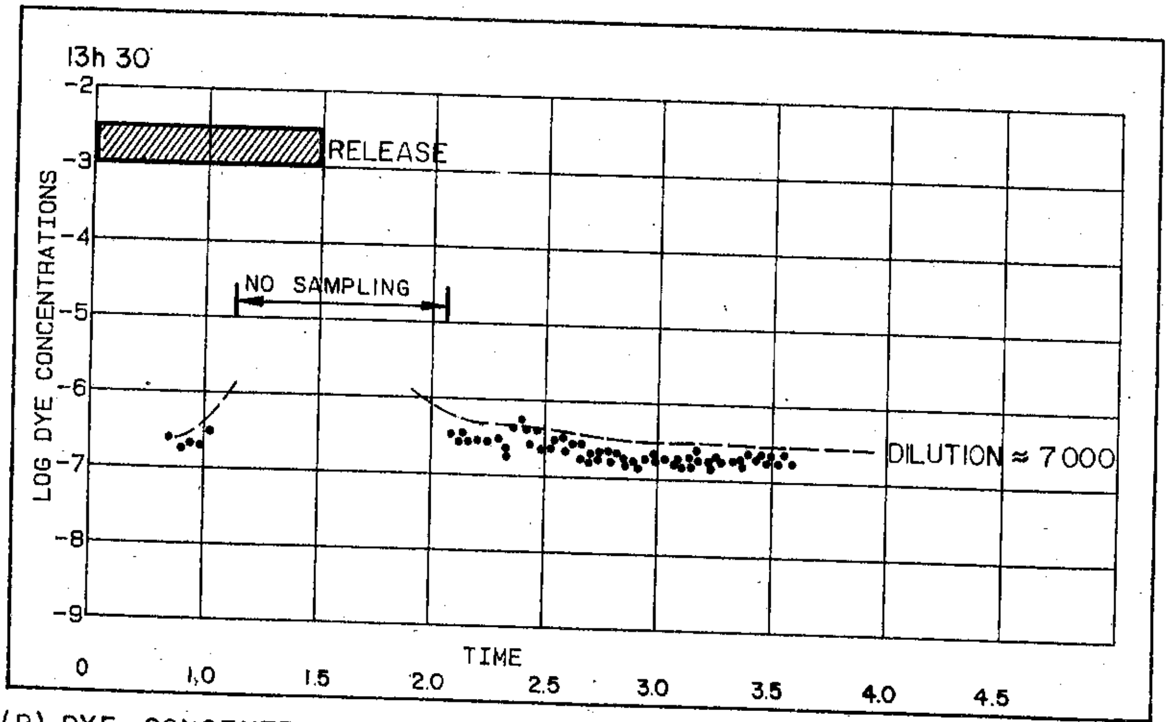
WRC OUTFALL STUDIES
A SCHEMATIC REPRESENTATION OF THE
EXPERIMENTAL PROCEDURES AT HOUT BAY

FIGURE
17

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



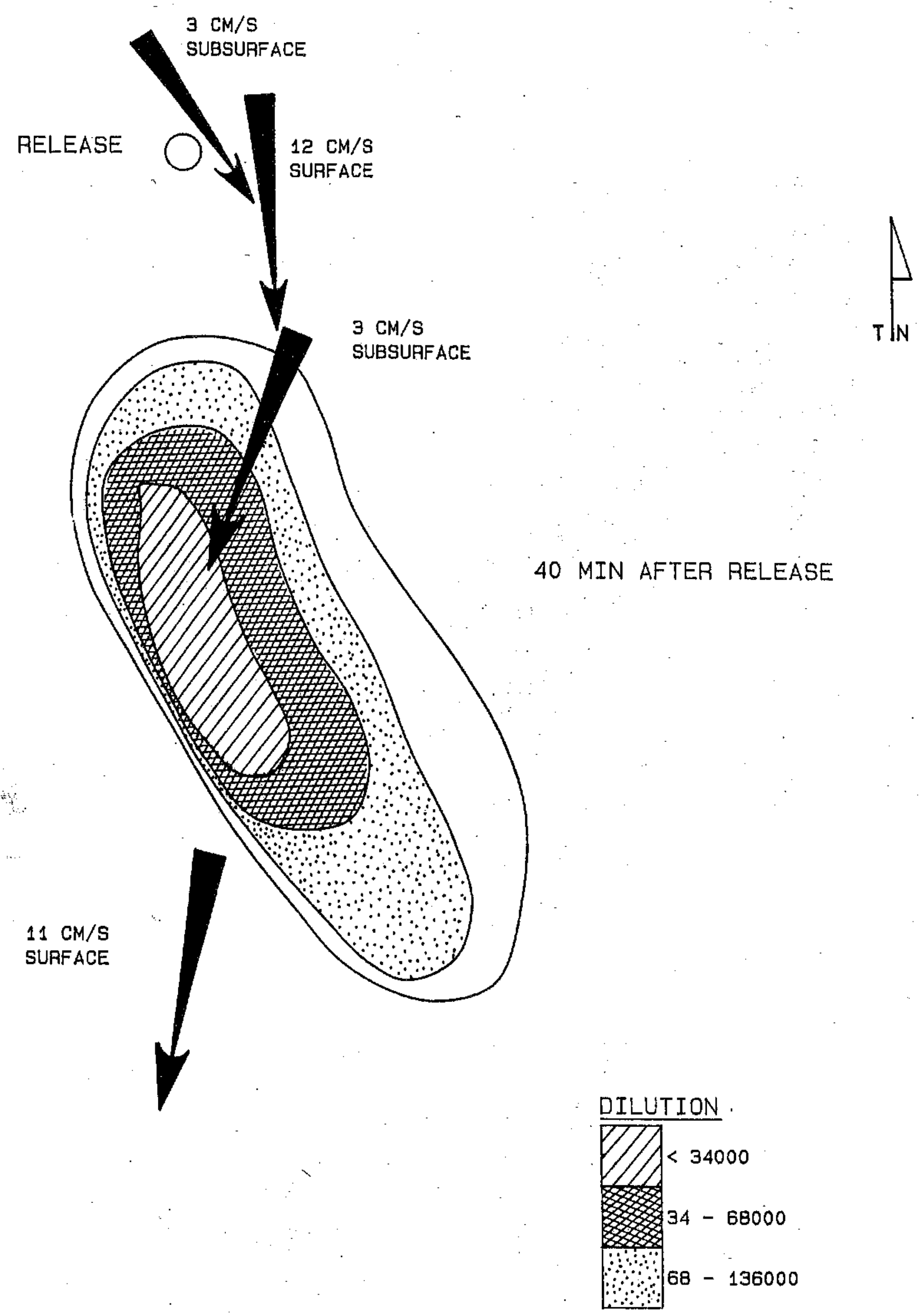
(A) DYE CONCENTRATIONS MEASURED AT THE WATER SURFACE (0 TO 2M DEEP) FOR THE FIRST RELEASE AT 11H15



(B) DYE CONCENTRATIONS MEASURED AT THE WATER SURFACE (0 TO 2M DEEP) FOR THE SECOND RELEASE AT 13H30

TRACED : HP7550 CHECKED : JJB DATE : 86/11/03. REF. :	WRC OUTFALL STUDIES CONCENTRATIONS IN THE BOIL ON 1985/09/05 AT HOUT BAY	FIGURE 18

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



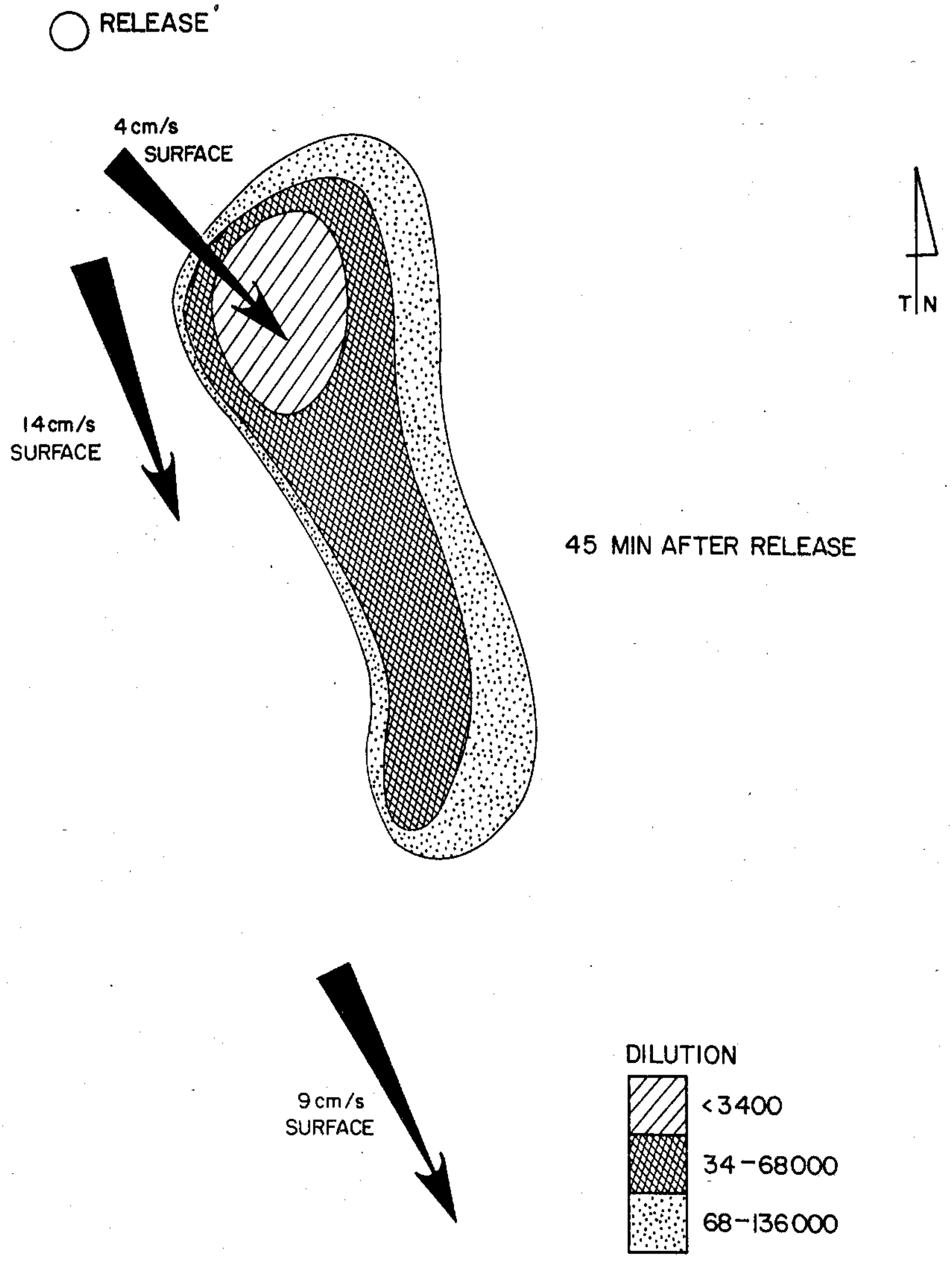
TRACED : HP7550
CHECKED : JJB
DATE : 86/11/10.
REF. :

WRC OUTFALL STUDIES

DISTRIBUTION OF CONCENTRATIONS 40 MIN AFTER THE FIRST RELEASE ON 1985/09/05 AT HOUT BAY

FIGURE 19a

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY

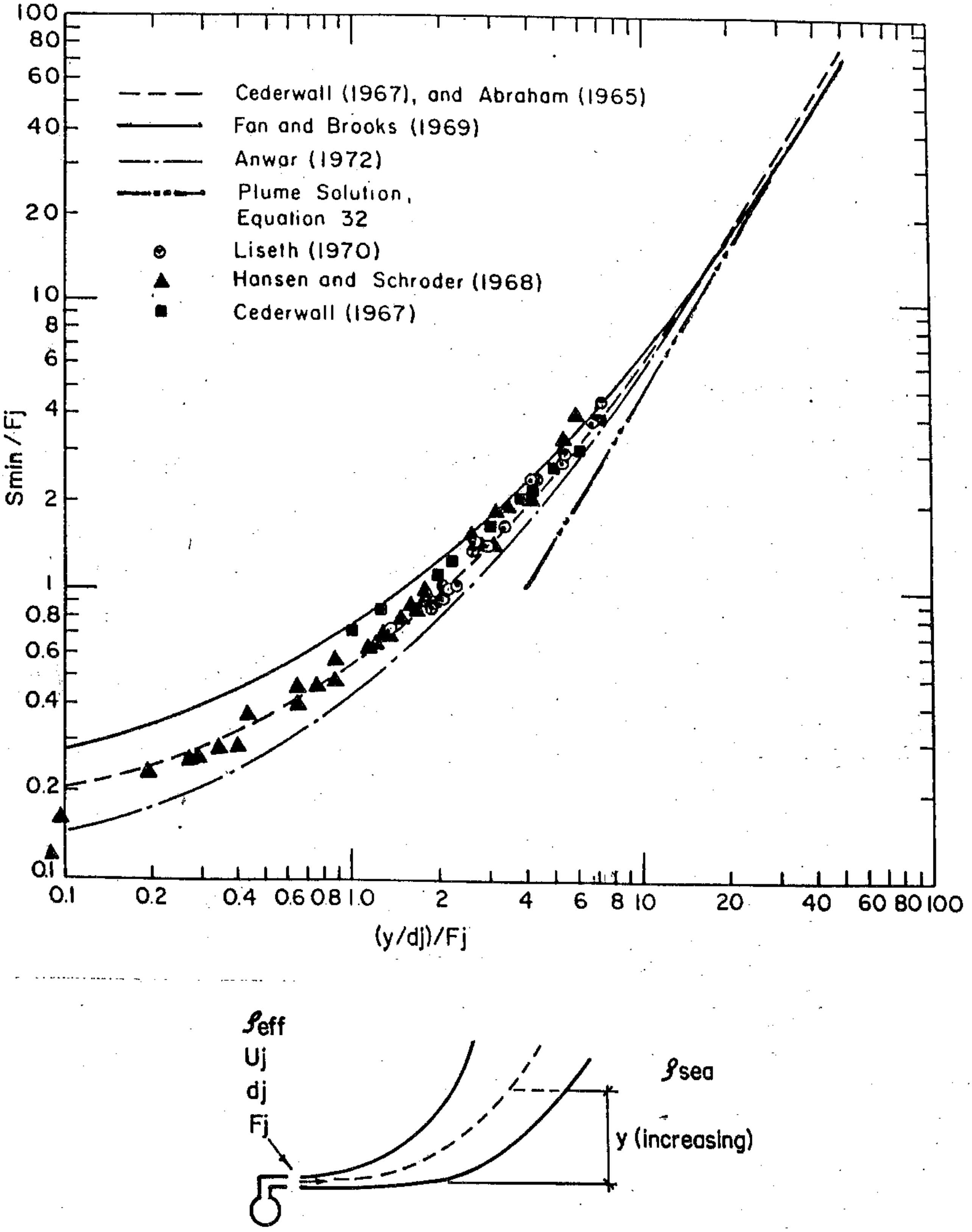


TRACED : HP7550
CHECKED : JJB
DATE : 86/10/29.
REF. :

WRC OUTFALL STUDIES
DISTRIBUTION OF CONCENTRATIONS 45 MIN
AFTER THE SECOND RELEASE ON 1985/09/05
AT HOUT BAY

FIGURE
19b

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



TRACED : HP7550
CHECKED : JJB
DATE : 86/11/11.
REF. :

WRC OUTFALL STUDIES

CENTRELINE DILUTION OF A HORIZONTAL, ROUND BUOYANT JET IN A STAGNANT, UNIFORM FLUID.

FIGURE 20

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY

APPENDIX A

DYE TRACERS FOR DILUTION MEASUREMENTS

Several types of tracer such as Rhodamine-B, Pontacyl Pink-B, sodium fluorescein and ammonia-base Orzan are available. Past experience excluded the use of radio-active tracers for this exercise owing to problems and costs of analysing procedures. According to Feuerstein and Selleck (1963) Pontacyl Pink is the ideal substance to use as tracer material, because of its characteristic of non-absorption in suspended solids and sediments. However, on the basis of availability and cost it was decided to use Rhodamine-B which, although it becomes more adsorbed onto solids than other tracers, has some very good characteristics compared with other materials, such as slow temperature effect, lowest measurable concentration by a Fluorometer, slow photo-chemical decay, and being non-toxic to coliforms.

An absorption of approximately 25 per cent was detected in the Camps Bay exercise between the pumphouse and the diffuser (over the length of the pipeline). However, samples were taken at the end of the pipeline and thus the problem was overcome when determining initial dilutions.

The following relations between Fluorometer readings and concentration were obtained for the four prototype experiments:

The relationship is expressed as a power curve:

$$c = aF^b$$

Where c = concentration

F = Fluorometer reading.

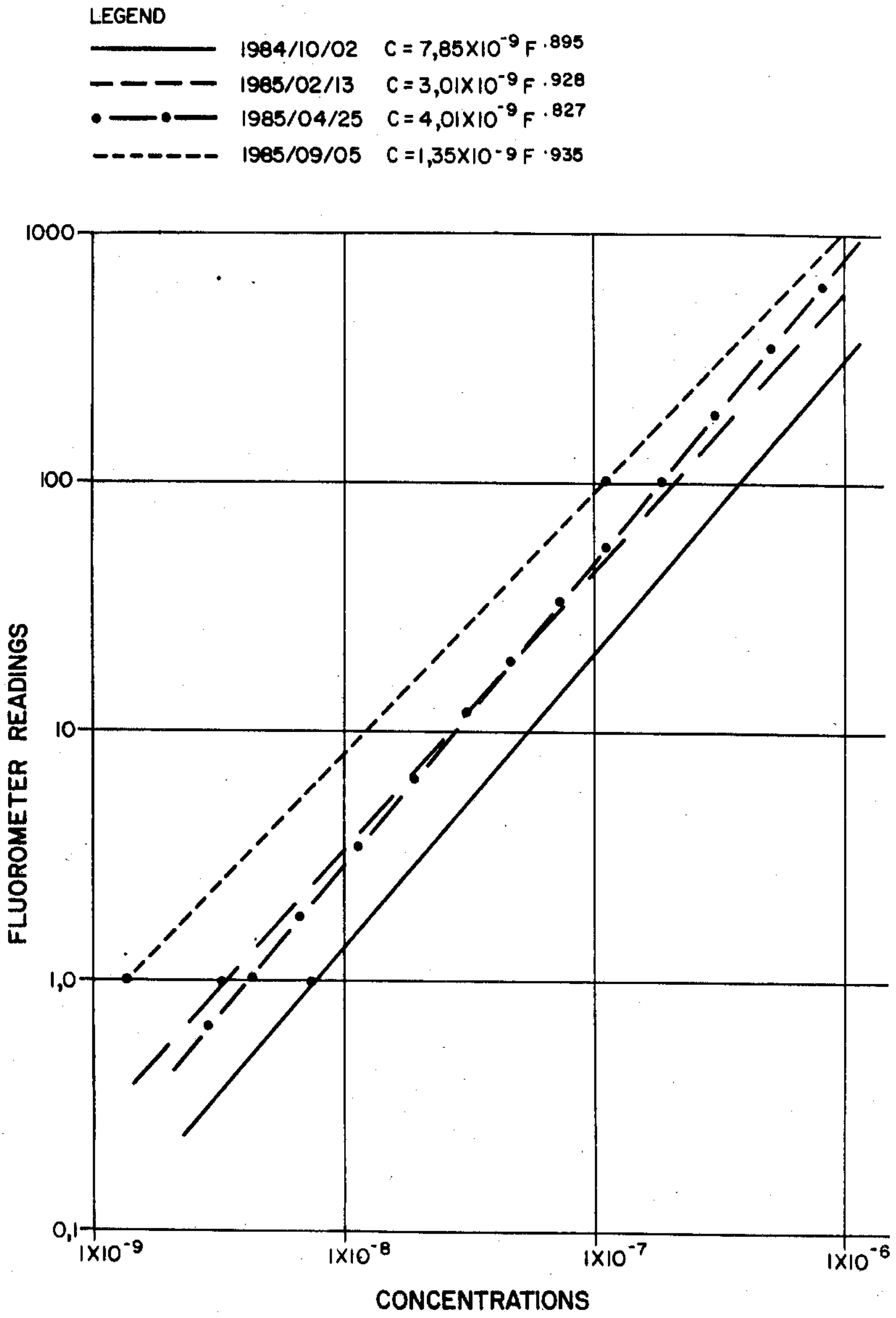
Date	Location	a	b
1984/10/02	Camps Bay	$7{,}85 \times 10^{-9}$	0,895
1985/02/13	Camps Bay	$3{,}01 \times 10^{-9}$	0,928
1985/04/25	Camps Bay	$4{,}01 \times 10^{-9}$	0,827
1985/09/05	Hout Bay	$1{,}35 \times 10^{-9}$	0,935

* The calibration curves (Fluorometer reading versus concentration) for the four experiments are shown in Fig ure A1.

The range of concentrations that the Fluorometer can measure accurately is between 1×10^{-10} mg/ℓ and 1×10^{-6} mg/ℓ. Concentrations higher than 1×10^{-6} mg/ℓ were diluted so as to fall within the measuring range.

REFERENCE

FEUERSTEIN, D L and SELLECK, R E (1963). Tracers for dispersion measurements in surface water. Eng. Res. Lab., Univ. of Calif., SERL Report No. 63-1.



TRACED:
CHECKED:
DATE:
REF.:

WRC OUTFALL STUDIES

FLUOROMETER CALIBRATION CURVES

FIGURE
A1

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY

APPENDIX B

AD HOC INVESTIGATION OF THE OCCURRENCE OF FAECAL COLIFORMS IN THE VICINITY OF THE CAMPS BAY MARINE OUTFALL

G Tredoux
J F P Engelbrecht
A Hon

COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH
NATIONAL INSTITUTE FOR WATER RESEARCH, BELLVILLE

1. INTRODUCTION

The Bellville Office of the National Institute for Water Research (NIWR) has for some time been undertaking programmes for monitoring the effect of marine sewage disposal on seawater quality. Emphasis was placed on health aspects and especially on seawater quality in the surf zone. In this way knowledge was gained concerning the behaviour of micro-organisms in the marine environment. This also led to closer collaboration with other institutions working in the marine field, especially the National Research Institute for Oceanology (NRIO).

During the course of the investigations the NIWR became aware of the discrepancies which arose between the expected die-off rates of micro-organisms in the marine environment based on modelling exercises, and the actual counts recorded under operational conditions. The NRIO suggested that the NIWR should take part in laboratory and pilot-scale experiments for determining the actual die-off rates during seawater dilution and also to investigate the effect of ultraviolet irradiation on micro-organisms suspended in seawater. Although the NIWR was interested in undertaking these studies, other commitments prevented the introduction of such a research programme. However, a preliminary literature survey was conducted and some of the findings are reported below. In the interim, it was decided to take part in tracer dilution studies at Camps Bay in order to establish faecal coliforms in a situation where the physical dilution rate is known from measured dye concentrations.

2. BACTERIAL DIE-OFF

From a literature survey Coetzee (1961) identified various factors influencing the survival of bacteria in seawater. Apparently seawater salinity has a detrimental effect on fresh water bacteria, but an additional "toxic factor" was needed to account for the observed die-off rates. Inorganic ions such as perchlorate, iodate (or other oxidized forms of iodine) and even sulphide are proposed in the literature as potentially toxic ions. Other factors of importance are: adsorption and sedimentation, ultra-violet radiation, temperature, aeration, and availability of nutrients.

According to Gameson (1985) microbial mortality is generally described mathematically by an equation related to first order chemical reaction kinetics. In such a reaction the rate of decrease in concentration (C) with time (t) is constant throughout the experiment. Therefore :

$$\frac{dC}{dt} = - kC \qquad (1)$$

where

k = rate constant for the reaction.

For describing microbial mortality the concentration, C, is replaced by the number of bacteria per unit of volume (i.e. bacterial concentration). It should be stressed that in the application of these principles, no variability of the rate constant should be allowed. Coetzee (1961) stated that in spite of what was claimed in the literature, the value of k varied depending on season of the year, temperature of the water, geographical location, availability of nutrients and experimental conditions. Provided that experimental conditions remain constant, and that the above limitations are taken into consideration, these principles could nevertheless be applied.

Integration of equation (1) yields:

$$N = N_o e^{-kt} \qquad (2)$$

where

N = bacterial population at time t
N_o = initial population at time t = 0
k = mortality rate constant.

If N_1 and N_2 are the bacterial populations at times t_1 and t_2 respectively, it follows from equation (2) that:

$$k = \frac{2,3 \log (N_1/N_2)}{t_2 - t_1} \qquad (3)$$

As the initial population is not always known, this equation is usually employed to determine the rate constant. Coetzee (1961) gives a value for k of 0,06 h^{-1} for the coliform group but does not indicate under what experimental conditions this was determined.

Another measure generally employed, is the T_{90} value which denotes the time required for the disappearance of 90 per cent of the organisms. For practical purposes the decrease in bacterial numbers is determined over a time interval and therefore T_{90} is defined as the time required for N_2 to be equal to 0,1 x N_1. By rearranging equation (3) it can be shown that T_{90} corresponds to a decrease of one order of magnitude in bacterial numbers. Coetzee (1961) give a T_{90} of 31,3 hours for the coliform group. In an investigation at the Geelong ocean outfall near Melbourne, Australia, a T_{90} varying from 2 to 60 hours was observed. The lowest values were obtained close to the middle of the day when solar radiation reached its highest intensity (Caldwell-Connell Engineers, 1979). Gameson (1985) confirmed the importance of radiation induced die-off but stated that lack of nutrients was the other principal factor. In another study Gameson and Gould (1985) came to the conclusion that the mortality rate of sewage coliform bacteria in seawater exposed to bright sunshine, is typically 100 times (i.e. two orders of magnitude) as great as in the dark at 20°C.

3. MODUS OPERANDI

The tracer studies were organized by the NRIO and included two staff members of the NIWR who accompanied the NRIO team for the collection of microbiological samples at sea. The number of microbiological samples was limited due to the requirement that analysis should commence within six hours after sampling. Approximately one third of the samples taken for determination of the dye concentration, was analyzed for faecal coliforms. In order to handle the maximum number of samples in the allotted time, a third staff member assisted with filtration and preparation of plates in the laboratory. In February and April 1985, a total of 107 and 102 samples respectively were analyzed for faecal coliforms.

The samples were taken aseptically and stored in cool boxes. The first sample was analyzed six hours after sampling, while the last one was analysed within five hours. Samples B05 and H73 were analysed repeatedly to determine whether an extended delay between sampling and analysis, from six to seven hours would cause a significant change in faecal coliform numbers. The results are tabled below.

Faecal coliforms were determined by the membrane filtration technique using m-FC agar as growth medium. The plates were incubated at 44°C for eighteen hours before enumeration.

Dye concentrations were determined by the NRIO team and results made available to the NIWR for the purpose of comparison.

4. RESULTS AND DISCUSSIONS

Individual results for each sample are given in Tables 2 and 3 for the two tracer studies carried out on 13 February and 25 April 1985 respectively. The results of replicate analyses on two samples at half-hourly intervals on 25 April 1985 are given in Table 1.

TABLE 1 : Replicate faecal coliform analyses (25 April 1985)

Sample ID	Sampling Time	Analysis Time	Time lapse since sampling (min)	Faecal coliforms per 100 mℓ
B05	11h25	17h17	352	3275
		17h54	389	3020
		18h22	417	3080
		18h47	443	2800
H73	12h12	18h15	363	12100
		18h45	393	11000
		19h15	423	10600

From the table it is evident that, apart from experimental fluctuations, faecal coliform counts decreased during storage. Mortality rate constants were calculated for the two samples using equation (3). For samples B05 and H73 the k-values were 0,10 and 0,13 h^{-1} respectively. The average mortality rate constant for faecal coliforms in seawater samples, stored in the dark for this ad hoc investigation, therefore amounted to 0,12 h^{-1}. The T_{90} was calculated to be 19,2 h. These values are in agreement with the data obtained from the literature.

Using the mortality rate constants determined on 25 April 1985, it was calculated that during the six hour time lapse between sampling and analysis, faecal coliform counts were reduced by 50 per cent. This is considerably less than one order of magnitude. These results are included merely to indicate the effect of storage on the samples. In future studies, more detailed investigation of this phenomenon will be required to derive a statistically more meaningful answer. Nevertheless, the studies of Gameson and Gould (1985) provided clear evidence that the mortality rate of faecal coliforms in bright sunshine was two orders of magnitude higher than in the dark. Therefore, even if all faecal coliform counts were to increase by 50 per cent, it would not cause a drastic change in the logarithmic representation. In the graphs and diagrams the original results are used without any correction factor for the effects of storage time.

On 13 February and 25 April twelve and six samples respectively were taken at the diffuser. The faecal coliform counts varied widely on the first occasion. For dilution calculations the geometric mean of the faecal coliform counts at the diffuser was used, while in the case of Rhodamine B, the maximum dye concentration at the diffuser was used.

Separate graphs were drawn for each depth due to the widely differing results obtained for the various depths. Comparatively few samples were taken at 15 m, necessitating a grouping with those from 20 m interval. Figures 1 and 2 give the set of graphs for each of the two studies. On these graphs, lines were drawn showing the values expected for equivalent dilution of the Rhodamine B concentration and the faecal coliform counts.

The dotted lines on either side give the expected minimum and maximum values calculated according to those determined at the diffuser. Points referring to samples taken within an hour after the first dye patch was spotted at the surface, are indicated by an encircled symbol.

Considering the encircled points, the data for February generally tend to follow the expected dilution pattern, especially for those points closer to the surface. With one exception (at 20 m), the faecal coliform counts are always lower than expected. In the case of the study during April the results are more clustered and do not show a definite trend. As in the case of the February exercise, faecal coliform counts, up to a sampling depth of five metres, are well below the expected values. At greater depths, the line indicating the expected dilution, appears to bisect the cluster of points.

When considering the difference in the dilution results at greater depths compared to the top five metres of seawater, it should be noted that, although both faecal coliforms and Rhodamine B serve as tracers for sewage in the marine environment, faecal coliforms are inherent constituents of sewage while only a "plug" of dye was introduced. It is therefore possible that newly introduced effluent could have mixed with already polluted seawater containing faecal coliforms. It would seem that this was indeed the case at depths greater than 5 m (in April, see Figure 2), where faecal coliforms were isolated from seawater which was apparently free of dye.

It is evident that in the top 5 m of seawater, faecal coliform counts were well below the expected values. This is clearly illustrated in Figure 3 where the dilution factors for faecal coliforms are compared with those for Rhodamine B in the same samples. Only in one case (at 13h21 on 13 February at a depth of 5 m, more than one hour after the first dye was spotted at the surface), the dilution according to the dye exceeded the dilution calculated according to faecal coliforms. This would mean that, despite the fact that faecal coliforms were being introduced continuously and practically stagnant conditions occurred, thereby limiting the quantity of unpolluted seawater available for dilution, faecal coliform counts were still well below expected values. Other die-off factors such as ultraviolet irradiation must, therefore, have become progressively more important closer to the surface.

Towards the final stages of the tracer experiment, various factors came into play. Low faecal coliform counts could have been the result of rapid die-off of organisms while the dye was relatively stable. On the other hand, high counts could have been due to new releases from the diffuser, containing no dye but high in coliforms entraining dye already present in the seawater.

The areal distribution of faecal coliforms around the Camps Bay diffuser is shown in Figures 4 and 5 for 13 February and 25 April 1985 respectively. On the first occasion a very slight southerly current was experienced while on the second occasion a somewhat stronger north-northeasterly current prevailed. The position of the marine outfall is indicated by a dotted line. Each of the dots on the various figures denotes a sampling position.

During February 1985, the occurrence of elevated faecal coliform counts at the seawater surface was restricted to a relatively small area within 100 m of the outfall. It should be taken into account that most of the samples were taken in the area where the dye was clearly visible. Therefore, most of the samples were related to recent emissions from the diffuser. Several samples were taken at 5 and 10 m depth. From the contours it is evident that higher counts extended over a somewhat larger area at greater depth. At 20 m the small number of samples preclude any conclusion. The fact is, however, that only one out of five samples exceeded 5000 faecal coliforms per 100 ml.

During April 1985, elevated counts at the seawater surface extended at least 400 m northwards from the outfall. At 5 and 10 m depth the area with high faecal coliform counts extended at least 200 m northwards. Only 9 samples were taken at 20 m but of these only two exceeded 5 000 faecal coliforms per 100 ml (i.e. 22 per cent as compared to 20 per cent in February).

Comparing the April with the February exercise the effect of the outfall apparently extended over a larger area. This is probably mainly due to the difference in strength of currents on the two occasions. An additional factor related to the movement of the tracer, is that sampling had to be abandoned sooner during April due to the fact that the "plume" was approaching an area where the boat was in danger of running aground. Therefore fewer effluent samples subjected to extended ultra-violet irradiation after surfacing were collected in April than during February. This fact probably contributed to the higher counts obtained during the former sampling run.

5. CONCLUSIONS

The tracer experiment proved that faecal coliform counts at the seawater surface are well below the values expected for a properly designed marine sewage outfall. This is also true during the initial stages of introducing sewage effluent into the marine environment and before natural die-off becomes significant.

Quantification of the conditions at depths greater than 5 m remains unresolved due to the possible entrainment of polluted seawater into the plume at these depths.

6. RECOMMENDATIONS

A scientifically sound basis for the prediction of faecal coliform counts to be expected around a marine outfall is essential for designing such outfalls to meet the water quality criteria drawn up for the marine environment. Laboratory and pilot-scale studies have to be carried out in order to determine the factors involved in the die-off of organisms during effluent discharge into the marine environment. It is recommended that such studies be undertaken in collaboration with the NRIO as they have the necessary facilities at their disposal for carrying out these tests, while the NIWR has the necessary microbiological expertise.

ACKNOWLEDGEMENTS

The invitation from the NRIO to take part in the tracer dilution studies is gratefully acknowledged.

Thanks are due to Ms M Franck for her assistance with the enumeration of faecal coliforms.

LITERATURE REFERENCES

CALDWELL-CONNELL ENGINEERS, 1979. GEELONG OCEAN OUTFALL STUDY, South Melbourne 3205, Australia, pp. 101-151.

COETZEE, O.J., 1961 The bacteriological problems of the discharge of waste water into the sea: A literature survey, 19th Annual Health Congress Inst. Public Health (CSIR Reprint RW 124). 8p.

GAMESON, A.L.H., 1985. Application of coastal pollution research: Part 5. Microbial Mortality. TR228, Water Research Centre, Medmenham, England, 28p

GAMESON, A.L.H. and GOULD, D.J., 1985. Investigation of sewage discharges to some British coastal waters. Chapter 8. Bacterial mortality, Part 2. TR222. Water Research Centre, Medmenham, England, 72p.

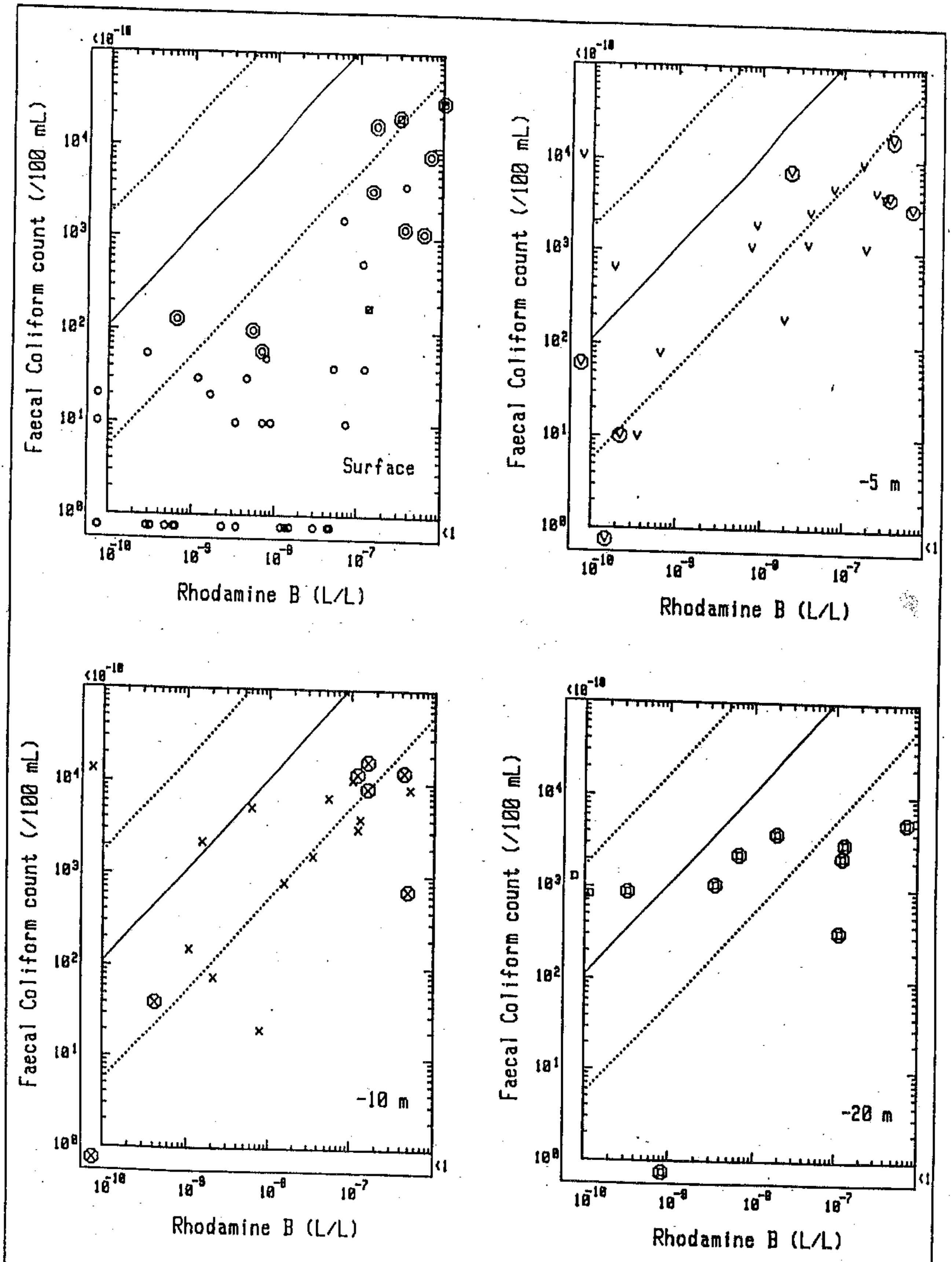


FIG. 1: CAMPS BAY MARINE OUTFALL TRACER DILUTION STUDY: DATA FOR VARIOUS DEPTHS (13 February 1985)

PLEASE NOTE:
1. Lines denote expected dilution ratio
2. Data points for first hour encircled

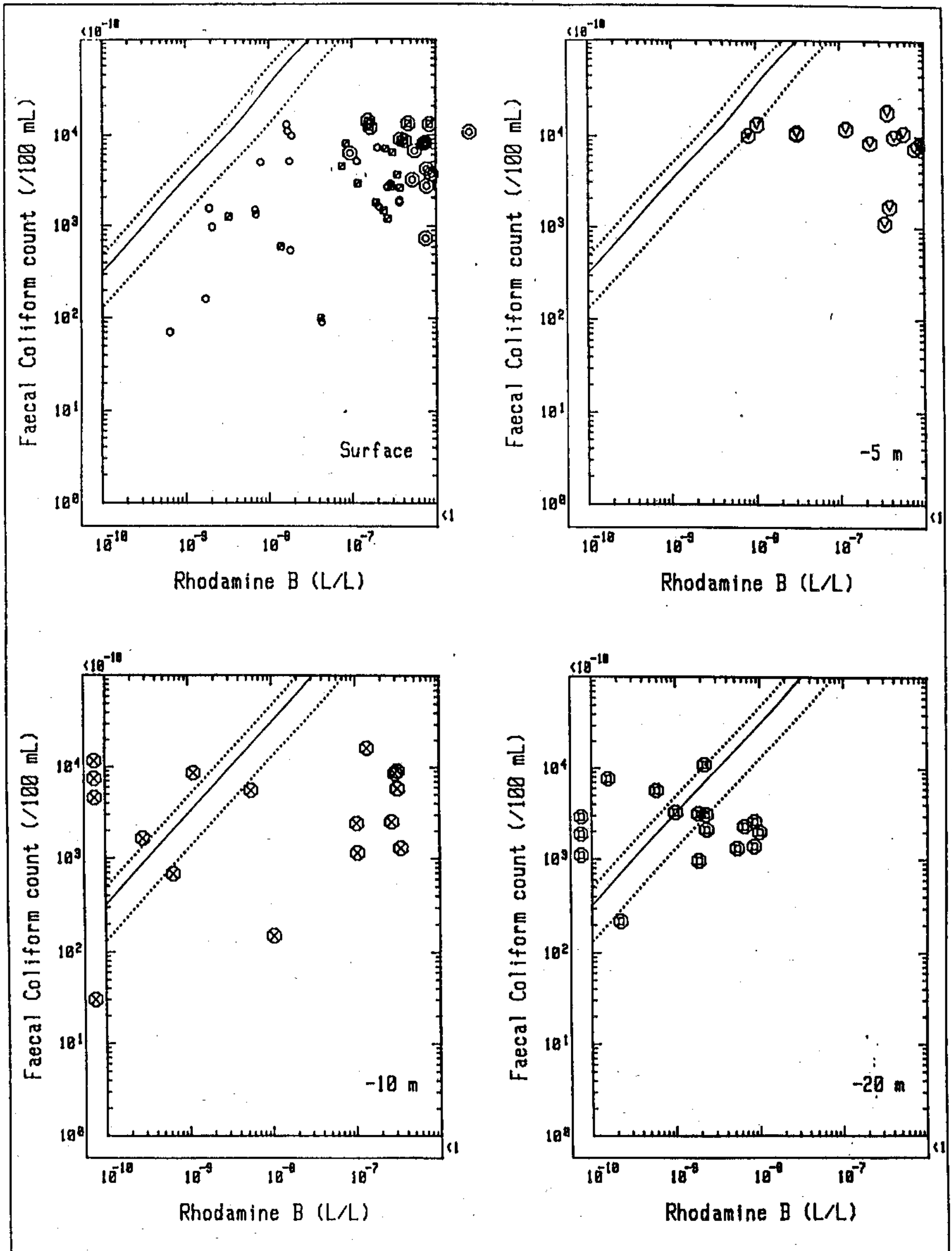


FIG. 2: CAMPS BAY MARINE OUTFALL TRACER DILUTION STUDY: DATA FOR VARIOUS DEPTHS (25 April 1985)

PLEASE NOTE:
1. Lines denote expected dilution ratio
2. Data points for first hour encircled

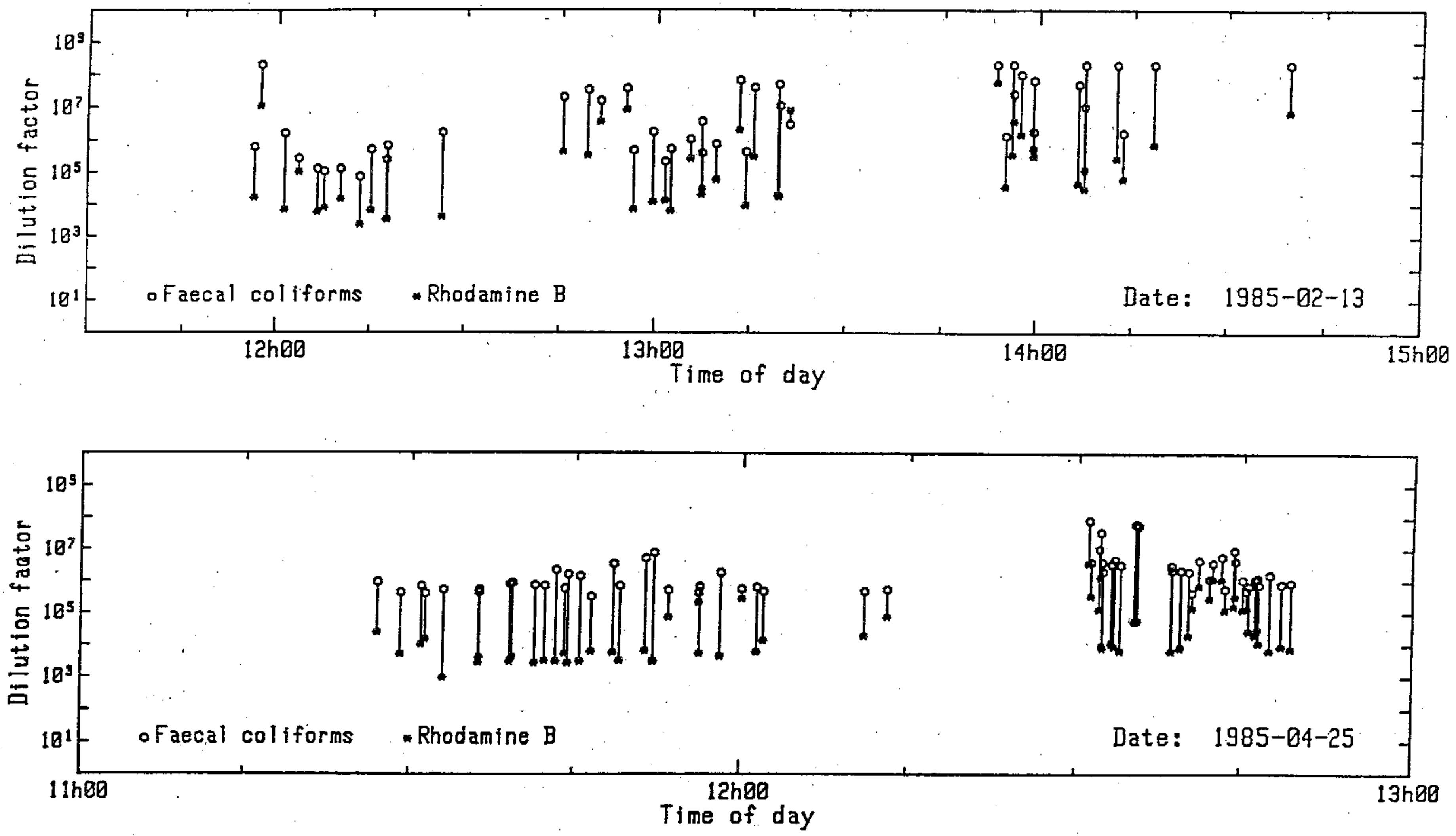


FIG. 3: CAMPS BAY MARINE OUTFALL TRACER DILUTION STUDY: COMPARISON OF CALCULATED DILUTION FACTORS (<10 m depth)

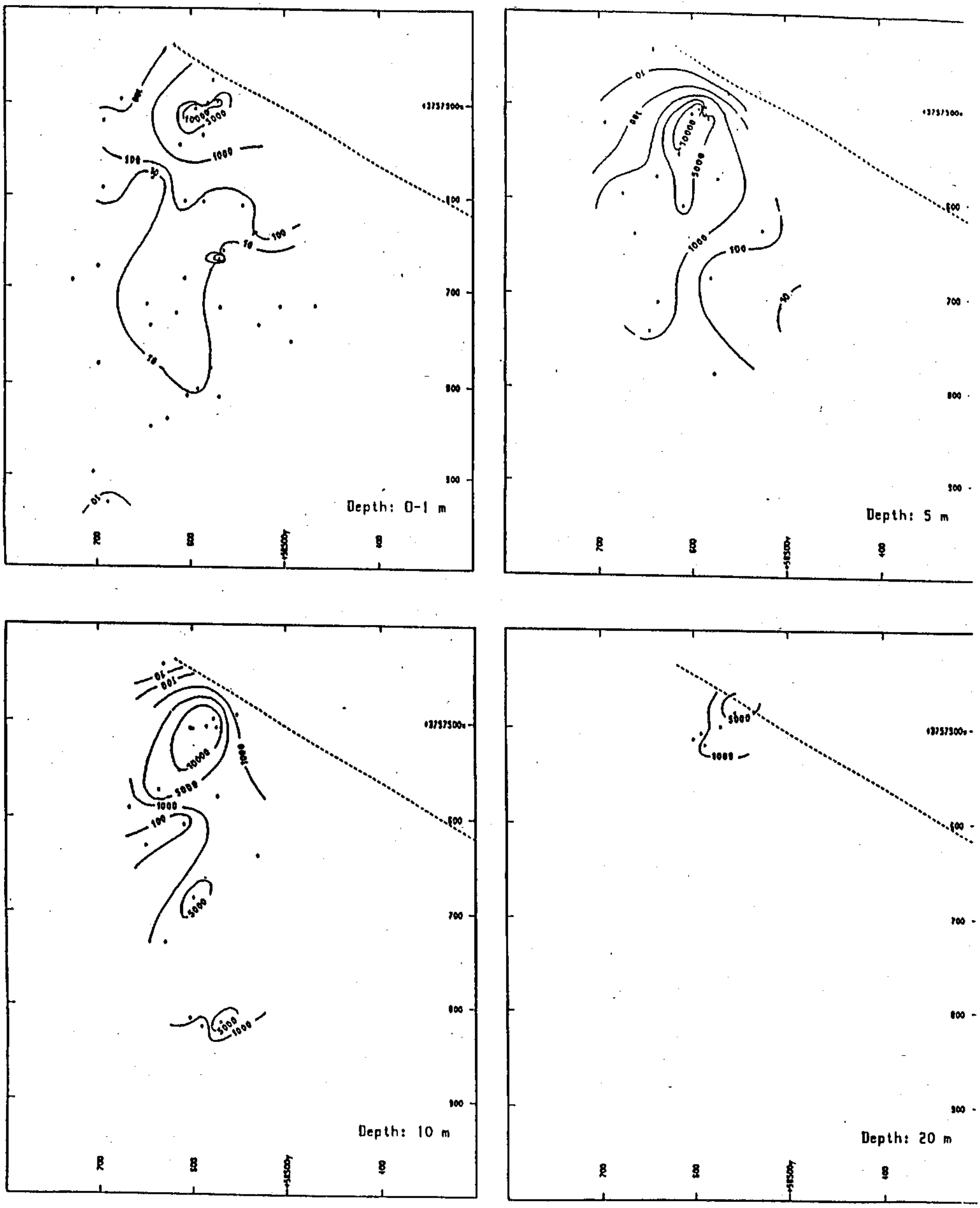


FIGURE 4 : Faecal coliforms (per 100 mL) in the vicinity of Camps Bay marine outfall : 13 February 1986

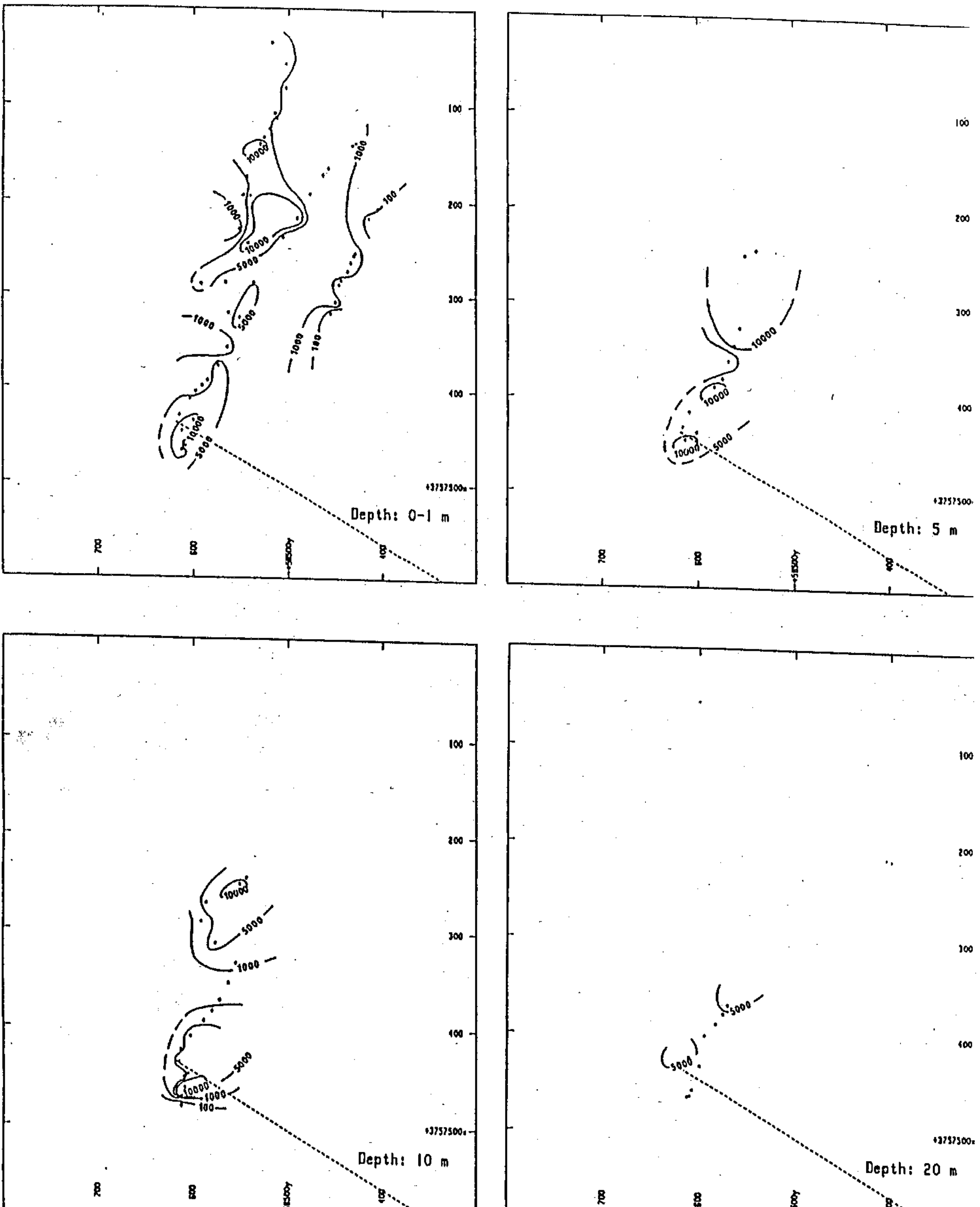


FIGURE 5 : Faecal coliforms (per 100 mL) in the vicinity of Camps Bay marine outfall : 25 April 1986

TABLE 2

CAMPS BAY MARINE OUTFALL TRACER DILUTION STUDY: 13 February 1985

ANALYTICAL RESULTS

Sample No	Time h m s	Source/ depth (m)	Coordinates X	Coordinates Y	Rhod.B (L/L)	F.C. No/100 mL	Dilution Rhod.B	Dilution F.C.
E01	10 45 00	Diffuser	-	-	5,30E-09	1,00E+09	-	-
E06	11 55 00	Diffuser	-	-	3,59E-06	1,40E+09	-	-
E09	12 10 00	Diffuser	-	-	1,67E-03	1,00E+08	-	-
E12	12 25 00	Diffuser	-	-	1,49E-05	1,00E+09	-	-
E15	12 40 00	Diffuser	-	-	5,98E-06	5,00E+08	-	-
E18	12 55 00	Diffuser	-	-	4,52E-06	2,80E+09	-	-
E21	13 10 00	Diffuser	-	-	3,57E-06	3,60E+09	-	-
E24	13 25 00	Diffuser	-	-	3,25E-06	2,60E+09	-	-
E27	13 40 00	Diffuser	-	-	2,60E-06	3,00E+09	-	-
E30	13 55 00	Diffuser	-	-	5,25E-07	3,12E+10	-	-
E33	14 10 00	Diffuser	-	-	5,99E-07	1,81E+10	-	-
E36	14 25 00	Diffuser	-	-	7,82E-07	1,60E+09	-	-
A50	11 51 00	20	3757511,6	58601,0	1,16E-10	8,25E+02	1,59E+07	2,42E+06
C04	11 52 00	5	3757510,3	58599,7	0,00E+00	1,04E+04	-	1,92E+05
A51	11 53 40	15	3757505,1	58602,6	0,00E+00	1,26E+03	-	1,59E+06
C05	11 54 00	10	3757506,6	58602,4	0,00E+00	1,33E+04	-	1,50E+05
G01	11 56 50	0	3757471,1	58575,9	1,47E-07	3,29E+03	1,26E+04	6,08E+05
C06	11 57 37	5	3757484,4	58560,7	2,21E-10	1,00E+01	8,37E+06	2,00E+08
A52	11 58 09	20	3757485,3	58556,9	7,28E-07	5,17E+03	2,54E+03	3,87E+05
C09	11 59 00	10	3757493,3	58551,9	4,87E-07	6,80E+02	3,80E+03	2,94E+06
A53	12 00 00	15	3757505,9	58563,3	6,52E-09	2,29E+03	2,84E+05	8,73E+05
G06	12 01 25	0	3757498,7	58581,6	3,54E-07	1,25E+03	5,23E+03	1,60E+06
C11	12 03 45	5	3757516,5	58582,0	2,31E-08	7,50E+03	8,01E+04	2,67E+05
C12	12 05 07	10	3757505,2	58584,6	1,61E-07	1,70E+04	1,15E+04	1,18E+05
A56	12 06 38	20	3757505,5	58592,7	3,22E-10	8,80E+02	5,75E+06	2,27E+06
C13	12 06 44	5	3757504,8	58592,3	4,11E-07	1,59E+04	4,50E+03	1,26E+05
C14	12 07 54	1	3757505,9	58594,6	3,05E-07	1,93E+04	6,07E+03	1,04E+05
C15	12 08 52	10	3757507,5	58599,7	1,20E-07	1,24E+04	1,54E+04	1,61E+05
G18	12 10 21	0	3757517,0	58595,1	1,61E-07	1,60E+04	1,15E+04	1,25E+05
C18	12 13 33	1	3757497,5	58570,9	1,03E-06	2,78E+04	1,80E+03	7,19E+04
A57	12 14 02	20	3757498,9	58572,2	1,26E-07	3,05E+03	1,47E+04	6,56E+05
C19	12 15 05	5	3757502,3	58584,5	3,73E-07	4,01E+03	4,96E+03	4,99E+05
A58	12 15 56	15	3757503,8	58574,2	1,09E-07	3,30E+02	1,70E+04	6,06E+06
C20	12 16 27	10	3757506,0	58573,9	4,30E-07	1,31E+04	4,30E+03	1,53E+05
G28	12 17 45	0	3757510,1	58580,8	7,10E-07	8,20E+03	2,61E+03	2,44E+05
C21	12 17 55	5	3757511,1	58584,4	7,28E-07	2,98E+03	2,54E+03	6,72E+05
C23	12 20 44	10	3757497,9	58577,1	1,59E-07	8,60E+03	1,16E+04	2,33E+05
A61	12 22 12	15	3757515,2	58584,1	1,18E-07	2,19E+03	1,57E+04	9,15E+05
A62	12 24 30	20	3757517,7	58588,8	1,88E-08	3,85E+03	9,84E+04	5,19E+05
G37	12 26 30	0	3757534,9	58586,9	5,99E-07	1,14E+03	3,09E+03	1,76E+06
A63	12 27 09	15	3757539,0	58585,6	3,43E-09	1,08E+03	5,39E+05	1,86E+06
G42	12 45 40	0	3757442,0	58628,1	5,33E-09	1,00E+02	3,47E+05	2,00E+07
A65	12 45 45	10	3757441,5	58630,2	0,00E+00	0,00E+00	-	-
A67	12 45 50	10	3757441,5	58630,2	4,21E-10	4,00E+01	4,39E+06	5,00E+07
A66	12 48 10	5	3757439,2	58641,9	1,52E-10	0,00E+00	1,22E+07	-
G43	12 49 33	0	3757495,4	58673,7	6,92E-09	6,00E+01	2,67E+05	3,33E+07
G45	12 51 30	0	3757520,6	58693,0	6,45E-10	1,30E+02	2,87E+06	1,54E+07
A68	12 51 38	5	3757521,8	58693,8	0,00E+00	6,00E+01	-	3,33E+07
C29	12 54 20	15	3757525,2	58704,4	8,32E-10	0,00E+00	2,22E+06	-
G47	12 55 31	0	3757590,6	58694,0	2,89E-10	5,50E+01	6,40E+06	3,64E+07
C30	12 56 53	5	3757594,3	58674,7	3,27E-07	4,09E+03	5,66E+03	4,89E+05
A70	12 58 11	10	3757590,2	58666,7	1,56E-08	8,05E+02	1,19E+05	2,48E+06
H51	12 59 37	0	3757579,1	58641,0	4,86E-10	0,00E+00	3,81E+06	-
A71	13 00 00	10	3757572,2	58636,2	5,10E-07	8,65E+03	3,63E+03	2,31E+05
C31	12 59 53	5	3757574,4	58637,7	1,94E-07	1,12E+03	9,54E+03	1,79E+06

CAMPS BAY MARINE OUTFALL TRACER DILUTION STUDY: 13 February 1985 (cont.)

ANALYTICAL RESULTS

Sample No	Time h m s	Source/ depth (m)	Coordinates X	Coordinates Y	Rhod.B (L/L)	F.C. No/100 mL	Dilution Rhod.B	Dilution F.C.
A72	13 01 41	10	3757551,3	58613,9	1,05E-07	1,07E+04	1,76E+04	1,87E+05
C32	13 01 49	5	3757551,3	58613,9	1,76E-07	9,31E+03	1,05E+04	2,15E+05
H57	13 02 38	0	3757544,7	58611,1	3,65E-07	3,76E+03	5,07E+03	5,32E+05
A73	13 06 06	10	3757578,5	58573,0	1,30E-07	4,04E+03	1,42E+04	4,95E+05
C33	13 05 49	5	3757576,9	58572,6	8,86E-09	1,89E+03	2,09E+05	1,06E+06
H63	13 07 28	0	3757606,1	58606,2	1,14E-07	5,42E+02	1,62E+04	3,69E+06
C34	13 07 35	5	3757607,0	58609,5	7,72E-08	5,07E+03	2,40E+04	3,94E+05
A74	13 07 42	10	3757607,3	58609,0	7,83E-09	2,00E+01	2,36E+05	1,00E+08
A75	13 08 53	10	3757630,2	58649,3	2,11E-09	7,50E+01	8,77E+05	2,67E+07
C36	13 09 55	5	3757638,1	58661,6	3,95E-08	2,67E+03	4,68E+04	7,49E+05
H71	13 13 12	0	3757716,9	58646,8	1,17E-09	3,00E+01	1,58E+06	6,67E+07
C38	13 14 24	5	3757708,2	58636,7	2,57E-07	4,67E+03	7,20E+03	4,28E+05
H74	13 15 41	0	3757690,0	58606,6	7,83E-09	5,00E+01	2,36E+05	4,00E+07
A78	13 16 15	10	3757685,1	58598,8	6,13E-09	5,20E+03	3,02E+05	3,85E+05
H78	13 19 26	0	3757642,9	58533,5	1,22E-07	4,00E+01	1,52E+04	5,00E+07
A79	13 19 48	10	3757640,5	58530,1	1,22E-07	3,15E+03	1,52E+04	6,35E+05
C40	13 19 49	1	3757640,5	58530,1	1,35E-07	1,80E+02	1,37E+04	1,11E+07
A80	13 21 03	5	3757633,2	58524,7	1,87E-10	6,50E+02	9,89E+06	3,08E+06
H83	13 51 07	0	3757692,8	58726,4	3,43E-09	0,00E+00	5,39E+05	-
H84	13 51 43	0	3757678,1	58699,1	0,00E+00	0,00E+00	-	-
H86	13 53 12	0	3757606,6	58586,3	0,00E+00	2,00E+01	-	1,00E+08
H87	13 53 55	0	3757610,9	58544,5	4,19E-11	1,00E+01	4,42E+07	2,00E+08
H88	13 54 38	0	3757660,4	58564,8	4,51E-08	0,00E+00	4,10E+04	-
A81	13 55 14	0	3757669,3	58569,8	6,63E-08	1,53E+03	2,79E+04	1,31E+06
H90	13 55 24	0	3757672,8	58570,0	3,02E-08	0,00E+00	6,13E+04	-
H92	13 56 10	0	3757681,0	58578,4	7,05E-09	1,00E+01	2,62E+05	2,00E+08
A82	13 56 30	5	3757683,7	58579,8	6,45E-10	8,00E+01	2,87E+06	2,50E+07
H95	13 57 39	0	3757726,0	58615,1	1,64E-09	2,00E+01	1,13E+06	1,00E+08
A83	13 58 16	10	3757733,3	58628,8	3,49E-08	1,60E+03	5,30E+04	1,25E+06
B01	13 59 32	0	3757739,6	58642,8	4,52E-09	3,00E+01	4,09E+05	6,67E+07
A84	13 59 37	5	3757739,6	58645,9	7,59E-09	1,10E+03	2,44E+05	1,83E+06
B03	14 00 28	0	3757780,4	58698,4	0,00E+00	0,00E+00	-	-
B05	14 02 11	0	3757896,6	58703,7	0,00E+00	0,00E+00	-	-
B07	14 03 31	0	3757847,4	58642,0	2,31E-09	0,00E+00	8,01E+05	-
A85	14 04 44	10	3757814,0	58603,2	1,52E-09	2,20E+03	1,22E+06	9,09E+05
B10	14 04 53	0	3757812,6	58603,0	4,85E-08	0,00E+00	3,81E+04	-
B12	14 06 10	0	3757804,8	58592,0	5,19E-08	4,00E+01	3,56E+04	5,00E+07
A86	14 07 12	5	3757784,2	58576,5	1,95E-08	1,90E+02	9,49E+04	1,05E+07
B14	14 07 15	0	3757784,0	58577,1	7,40E-08	1,00E+01	2,50E+04	2,00E+08
B16	14 08 16	0	3757738,4	58527,1	6,45E-10	0,00E+00	2,87E+06	-
B19	14 10 43	0	3757755,8	58493,0	3,22E-10	0,00E+00	5,75E+06	-
B20	14 11 53	0	3757813,5	58569,1	6,13E-10	0,00E+00	3,02E+06	-
A87	14 12 16	10	3757818,1	58570,5	5,41E-08	6,80E+03	3,42E+04	2,94E+05
B22	14 12 33	0	-	-	8,86E-09	1,00E+01	2,09E+05	2,00E+08
A88	14 13 40	5	-	-	3,72E-08	1,18E+03	4,97E+04	1,69E+06
B25	14 16 17	0	3757838,3	58624,5	1,22E-08	0,00E+00	1,52E+05	-
B29	14 18 21	0	3757929,2	58688,1	3,29E-09	1,00E+01	5,62E+05	2,00E+08
B31	14 38 41	0	3757716,8	58467,5	1,39E-08	0,00E+00	1,33E+05	-
A90	14 39 44	5	3757712,9	58506,1	3,55E-10	1,00E+01	5,21E+06	2,00E+08
B36	14 40 48	0	3757718,2	58504,2	1,54E-08	0,00E+00	1,20E+05	-
B39	14 42 50	0	3757719,9	58568,2	2,89E-10	0,00E+00	6,40E+06	-
A93	14 46 53	10	3757823,5	58590,6	1,08E-09	1,50E+02	1,71E+06	1,33E+07

TABLE 3

CAMPS BAY MARINE OUTFALL TRACER DILUTION STUDY: 25 April 1985

ANALYTICAL RESULTS

Sample	Time	Source/	Coordinates		Rhod.B	F.C.	Dilution	
No	h m s	depth (m)	X	Y	(L/L)	No/100 mL	Rhod.B	F.C.
A03	11 18 00	Diffuser	-	-	6,84E-05	8,20E+09	-	-
A09	11 28 00	Diffuser	-	-	4,26E-04	6,95E+09	-	-
A19	11 50 00	Diffuser	-	-	4,15E-06	7,80E+09	-	-
A22	12 00 00	Diffuser	-	-	3,09E-06	4,10E+09	-	-
A25	12 10 00	Diffuser	-	-	2,95E-06	2,40E+09	-	-
H01	-	Diffuser	-	-	-	8,90E+09	-	-
B06	11 22 58	10	3757480,6	58612,2	0,00E+00	3,00E+01	-	1,93E+08
B05	11 25 28	20	3757463,7	58609,2	1,01E-09	3,28E+03	1,81E+06	1,77E+06
B08	11 26 03	10	3757462,7	58608,5	1,39E-07	1,62E+04	1,32E+04	3,58E+05
B54	11 27 07	0	3757460,3	58608,2	9,50E-08	6,20E+03	1,93E+04	9,35E+05
B10	11 27 57	20	3757457,6	58606,9	2,30E-09	3,10E+03	7,96E+05	1,87E+06
B11	11 29 25	10	3757448,6	58604,7	3,00E-07	8,50E+03	6,10E+03	6,82E+05
B57	11 29 14	1	3757449,0	58604,6	4,66E-07	1,33E+04	3,93E+03	4,36E+05
B13	11 31 03	5	3757435,9	58601,0	2,31E-07	8,40E+03	7,92E+03	6,90E+05
B12	11 31 30	20	3757432,6	58599,3	6,51E-09	2,29E+03	2,81E+05	2,53E+06
B60	11 31 40	1	3757433,7	58600,4	1,55E-07	1,41E+04	1,18E+04	4,11E+05
B62	11 33 11	0	3757464,5	58612,3	2,50E-06	1,08E+04	7,32E+02	5,37E+05
B15	11 34 25	20	3757464,6	58612,0	8,55E-09	2,60E+03	2,14E+05	2,23E+06
B16	11 35 40	10	3757451,7	58609,3	3,47E-07	1,29E+03	5,27E+03	4,50E+06
B67	11 36 36	1	3757445,0	58612,1	8,38E-07	1,31E+04	2,18E+03	4,43E+05
B19	11 36 41	5	3757444,1	58612,9	5,80E-07	1,07E+04	3,16E+03	5,42E+05
B20	11 38 05	10	3757436,9	58614,8	3,20E-07	9,10E+03	5,72E+03	6,37E+05
B21	11 39 13	5	3757430,5	58615,5	7,84E-07	7,30E+03	2,33E+03	7,95E+05
B72	11 39 35	0	3757428,2	58614,8	5,57E-07	6,60E+03	3,29E+03	8,79E+05
B22	11 40 24	20	3757423,7	58610,2	5,97E-10	5,70E+03	3,07E+06	1,02E+06
B23	11 40 20	10	3757423,8	58612,9	1,07E-07	1,14E+03	1,71E+04	5,09E+06
B24	11 41 38	5	3757414,4	58608,7	8,71E-07	7,90E+03	2,10E+03	7,34E+05
B77	11 42 27	1	3757410,8	58603,9	7,40E-07	8,20E+03	2,47E+03	7,07E+05
B26	11 42 38	10	3757410,0	58602,7	3,20E-07	5,80E+03	5,72E+03	1,00E+06
B79	11 43 30	0	3757403,0	58598,0	7,73E-07	2,65E+03	2,37E+03	2,19E+06
B27	11 44 13	20	3757400,4	58594,4	1,88E-09	3,17E+03	9,73E+05	1,83E+06
B28	11 44 10	5	3757400,2	58595,7	4,48E-07	9,80E+03	4,08E+03	5,92E+05
B81	11 44 40	0.	3757396,8	58591,3	8,81E-07	3,60E+03	2,08E+03	1,61E+06
B29	11 45 10	10	3757393,2	58588,9	1,05E-07	2,40E+03	1,74E+04	2,42E+06
B83	11 45 50	0	3757391,2	58585,7	7,73E-07	4,10E+03	2,37E+03	1,41E+06
B31	11 46 50	5	3757387,5	58582,9	3,73E-07	1,76E+04	4,91E+03	3,30E+05
B30	11 46 46	20	3757387,6	58583,1	2,33E-09	2,10E+03	7,85E+05	2,76E+06
B32	11 47 38	10	3757383,5	58580,3	2,73E-07	2,50E+03	6,70E+03	2,32E+06
B88	11 49 02	1	3757375,9	58574,7	7,17E-07	8,00E+03	2,55E+03	7,25E+05
B34	11 48 44	5	3757378,7	58574,4	3,98E-07	1,66E+03	4,60E+03	3,49E+06
B33	11 48 50	20	3757377,5	58575,5	0,00E+00	1,10E+03	-	5,30E+06
B35	11 49 52	10	3757371,5	58572,4	1,05E-08	1,50E+02	1,74E+05	3,87E+07
B36	11 50 29	20	3757368,2	58571,0	1,58E-10	7,65E+03	1,16E+07	7,58E+05
B37	11 51 28	5	3757360,5	58567,7	3,47E-07	1,11E+03	5,27E+03	5,23E+06
B94	11 52 01	0	3757356,7	58565,3	7,40E-07	7,40E+02	2,47E+03	7,84E+06
B39	11 52 21	10	3757354,1	58563,2	6,46E-10	6,80E+02	2,83E+06	8,53E+06
B40	11 53 38	5	3757344,5	58561,3	3,13E-08	1,09E+04	5,85E+04	5,32E+05
B38	11 54 17	19	3757338,7	58559,4	2,20E-10	2,20E+02	8,32E+06	2,64E+07
B41	11 54 59	10	3757333,8	58555,6	2,80E-10	1,64E+03	6,54E+06	3,54E+06
B43	11 56 15	5	3757326,1	58555,5	1,05E-08	1,32E+04	1,74E+05	4,39E+05
H53	11 56 24	1	3757325,0	58552,5	4,23E-07	8,60E+03	4,33E+03	6,74E+05
H55	11 58 12	0	3757320,1	58563,9	5,21E-07	3,10E+03	3,51E+03	1,87E+06
B42	11 58 47	15	3757313,0	58575,1	0,00E+00	2,90E+03	-	2,00E+06
B44	11 58 50	10	3757313,2	58576,8	1,15E-09	8,60E+03	1,59E+06	6,74E+05
B45	12 00 02	5	3757302,6	58588,0	8,26E-09	1,02E+04	2,22E+05	5,69E+05

TABLE 3

CAMPS BAY MARINE OUTFALL TRACER DILUTION STUDY: 25 April 1985 (cont.)

ANALYTICAL RESULTS

Sample No	Time h m s	Source/ depth (m)	Coordinates X	Coordinates Y	Rhod.B (L/L)	F.C. No/100 mL	Dilution Rhod.B	Dilution F.C.
B46	12 00 42	15	3757295,9	58591,3	1,88E-09	9,65E+02	9,73E+05	6,01E+06
B47	12 01 21	10	3757290,8	58591,6	0,00E+00	4,56E+03	-	1,27E+06
H61	12 01 40	1	3757288,1	58592,3	3,79E-07	8,90E+03	4,83E+03	6,52E+05
B48	12 02 35	15	3757283,0	58590,2	0,00E+00	1,87E+03	-	3,11E+06
I54	12 04 09	10	3757271,1	58586,2	5,60E-09	5,50E+03	3,27E+05	1,05E+06
I55	12 07 38	15	3757262,3	58565,3	8,41E-09	1,39E+03	2,18E+05	4,19E+06
I59	12 09 29	15	3757253,4	58554,6	2,22E-09	1,10E+04	8,24E+05	5,27E+05
I60	12 09 45	10	3757251,3	58551,5	0,00E+00	1,16E+04	-	5,00E+05
I61	12 11 07	5	3757248,5	58550,0	1,20E-07	1,19E+04	1,53E+04	4,87E+05
I62	12 11 35	15	3757247,0	58544,8	5,29E-09	1,31E+03	3,46E+05	4,43E+06
H73	12 12 00	1	3757244,4	58543,5	1,66E-07	1,21E+04	1,10E+04	4,79E+05
I63	12 12 08	10	3757244,9	58544,0	0,00E+00	7,40E+03	-	7,84E+05
I65	12 13 15	5	3757242,7	58538,4	3,13E-08	1,05E+04	5,85E+04	5,52E+05
I64	12 13 19	15	3757241,4	58538,3	9,80E-09	1,99E+03	1,87E+05	2,91E+06
H76	12 31 06	0	3757319,7	58455,2	6,46E-10	7,00E+01	2,83E+06	8,29E+07
H77	12 32 07	0	3757288,2	58446,7	1,81E-08	5,45E+02	1,01E+05	1,06E+07
D01	12 31 31	0	3757307,0	58450,6	6,81E-09	1,46E+03	2,69E+05	3,97E+06
H78	12 32 36	1	3757273,4	58436,9	2,39E-07	1,46E+03	7,66E+03	3,99E+06
D02	12 32 16	0	3757283,4	58444,1	1,72E-09	1,60E+02	1,06E+06	3,63E+07
D03	12 32 44	0	3757273,4	58436,9	2,90E-07	2,80E+03	6,31E+03	2,07E+06
H79	12 33 26	1	3757263,9	58433,7	1,95E-07	1,76E+03	9,38E+03	3,30E+06
D04	12 33 23	0	3757264,5	58433,4	2,10E-07	1,60E+03	8,71E+03	3,63E+06
H80	12 33 50	1	3757256,9	58430,3	2,66E-07	1,20E+03	6,88E+03	4,85E+06
D05	12 34 05	0	3757254,3	58428,9	3,66E-07	1,78E+03	5,00E+03	3,27E+06
D07	12 35 33	0	3757217,3	58414,6	4,27E-08	9,00E+01	4,29E+04	6,44E+07
H83	12 35 57	1	3757206,8	58405,2	4,17E-08	1,00E+02	4,39E+04	5,80E+07
H87	12 38 57	1	3757143,0	58431,5	3,73E-07	2,53E+03	4,91E+03	2,29E+06
D11	12 38 53	0	3757140,5	58428,1	3,66E-07	1,84E+03	5,00E+03	3,15E+06
H88	12 39 35	1	3757166,4	58457,3	2,94E-07	2,60E+03	6,22E+03	2,23E+06
D12	12 39 40	0	3757173,0	58463,1	2,66E-07	2,58E+03	6,88E+03	2,25E+06
H89	12 40 10	1	3757192,0	58477,4	1,18E-07	2,83E+03	1,55E+04	2,05E+06
D13	12 40 41	0	3757217,3	58491,1	1,64E-08	1,30E+04	1,12E+05	4,46E+05
H90	12 41 03	1	3757238,0	58506,1	3,26E-09	1,25E+03	5,61E+05	4,66E+06
D15	12 42 03	0	3757287,2	58537,4	7,98E-09	4,90E+03	2,29E+05	1,18E+06
D16	12 42 33	0	3757286,8	58567,1	1,92E-09	1,52E+03	9,53E+05	3,83E+06
D17	12 43 15	0	3757229,5	58552,9	2,07E-09	9,65E+02	8,84E+05	6,01E+06
D18	12 43 48	0	3757194,3	58541,3	1,88E-08	9,80E+03	9,73E+04	5,92E+05
H93	12 44 26	1	3757193,6	58548,0	1,39E-08	6,00E+02	1,32E+05	9,67E+06
D19	12 44 36	0	3757193,9	58549,2	6,96E-09	1,32E+03	2,63E+05	4,41E+06
D20	12 45 06	0	3757175,3	58545,0	1,76E-08	5,00E+03	1,04E+05	1,16E+06
D21	12 45 41	0	3757142,4	58530,4	1,69E-08	1,10E+04	1,08E+05	5,27E+05
H94	12 45 57	1	3757134,9	58526,8	8,46E-08	8,00E+03	2,16E+04	7,25E+05
D22	12 46 13	0	3757125,5	58521,1	1,15E-07	5,00E+03	1,59E+04	1,16E+06
H95	12 46 32	1	3757113,8	58512,7	7,58E-08	4,40E+03	2,41E+04	1,32E+06
D23	12 46 44	0	3757108,2	58515,1	2,03E-07	7,20E+03	9,01E+03	8,06E+05
H96	12 47 34	1	3757082,7	58503,4	3,47E-07	3,53E+03	5,27E+03	1,65E+06
I01	12 48 33	1	3757057,9	58503,0	2,53E-07	7,00E+03	7,23E+03	8,29E+05
I02	12 49 15	1	3757034,9	58517,9	3,07E-07	6,34E+03	5,96E+03	9,15E+05