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VOLUME II-2

ADDENDUM TO

SYNOPTIC STUDIES OF THE PLUME OF SONGS
UNITS 2 AND 3

Submitted to: Marine Review Committee
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INTRODUCTION

This addendum to ECO-M's Volume II-2, "Synoptic Studies of the Plume of SONGS Units 2 and 3", reports our results and conclusions from the two latest dye studies.

2.6 An Overall Description of Surface Water Movement at SONGS
on April 7, 1987

2.7 Dilution Estimates from the Dye Study of May 22, 1987

2.6 An Overall Description of Surface Water Movement at SONGS on April 7, 1987

The area of study is hydrodynamically complex; its currents and circulation patterns are governed by the interaction of the discharge from the cooling system, local currents, and the north and south kelp beds.

This study is aimed towards a better understanding of the interaction of the above parameters. A fluorescent dye was used to trace water masses in the vicinity of the cooling system, both inside and outside the kelp beds. All the dye releases described here were point or line releases of rhodamine dye.

Figure 1 displays the starting locations of various dye patches (22) with a circle. The trajectory for each dye patch has been indicated at half hour intervals by a small dark circle. Arrows indicate that patches have continued to move in the same direction at about the same speed.

In addition to the dye patches, we released two line injections of dye. We will refer to the dye stripe released upcoast of the north SOK kelp bed as Stripe 1 and the second stripe released on the inshore boundary of the south SOK kelp bed as Stripe 2. Figure 2 shows the starting locations of Stripe 1 and Stripe 2.

The patches were observed from 12:52 P.M. to 5:30 P.M. Aerial photographs were taken every 20 minutes throughout the study. Fixes were made with a Motorola Mini-Ranger III system at release points and also at the end of the study for the patches still visible. We also anchored three buoys (markers) with known positions to aid us in determining the location of patches with time. Table 1 lists the dye patch release times.

Prior to the study, we deployed three current meters in three locations at 3 m below the water surface. Inter-Ocean S4 instruments were used for the current measurements. The current meter locations are also shown in Figure 2. Measurements of the currents are displayed in Figure 3. On this day, all pumps were operating and the power levels for Units 1, 2 and 3 were 92%, 98% and 100% respectively.

Following are several important conditions and observations pertaining to the study.

1. Measurements from current meters indicate that the current pattern is steady throughout the study (see Figure 3).
2. The discharge water from Units 2 and 3, together with the ambient current, formed a plume front (see Figure 1).
3. Patch 4 moved offshore to the plume edge and remained along the plume front as it travelled downcoast.
4. Patches 5, 6, 7, 8, 11, and 12, located offshore and south of the SOK kelp bed, moved approximately parallel to the shore. They demonstrate no offshore velocity.
5. Patch 9 moved slowly along the inshore side of the south kelp bed, then offshore more quickly through a less dense channel of the kelp bed, indicating the effect of the kelp in deflecting the flow.
6. Patches 13, 14, 15 and 17 displayed an offshore velocity in the vicinity of the diffuser system. This indicates that SONGS' cooling system directs the flow towards the south kelp bed. Notice the offshore and longshore components of the current near the diffuser line decreased as the patches moved further from the diffuser line.

7. Patch 16 never moved appreciably from its release point, indicating a stagnation area caused by the interaction of the discharged water, entrained water, make-up flow, and the local currents. (Patch 16 dispersed somewhat by the end of the day).

8. Dye patches A, B, C, and D demonstrate clearly that the surface upcoast water moved inshore and downcoast towards the diffuser line of Unit 3. The movement of these patches towards the Unit 3 diffuser line, but not towards the Unit 2 diffuser line, indicates that Unit 2 entrained water from levels lower than the surface.

9. At the end of the study, patches 1 through 8 had moved approximately 4000 meters from their release points.

The two dye stripes released during the study show the following:

1. The north SOK stripe moved inshore and downcoast towards the diffuser line of Unit 3 and was deflected by the north SOK kelp bed.

2. The south SOK stripe first moved quickly as it entered the kelp bed at about 18 cm/sec and then slowed down substantially inside the kelp bed to a speed of about 7 cm/sec.

From the aerial photo collection, we have chosen a representative series (see Figures 2-6-1 through 2-6-10). These photos demonstrate the above points. With each photo, we have included a description of various events.

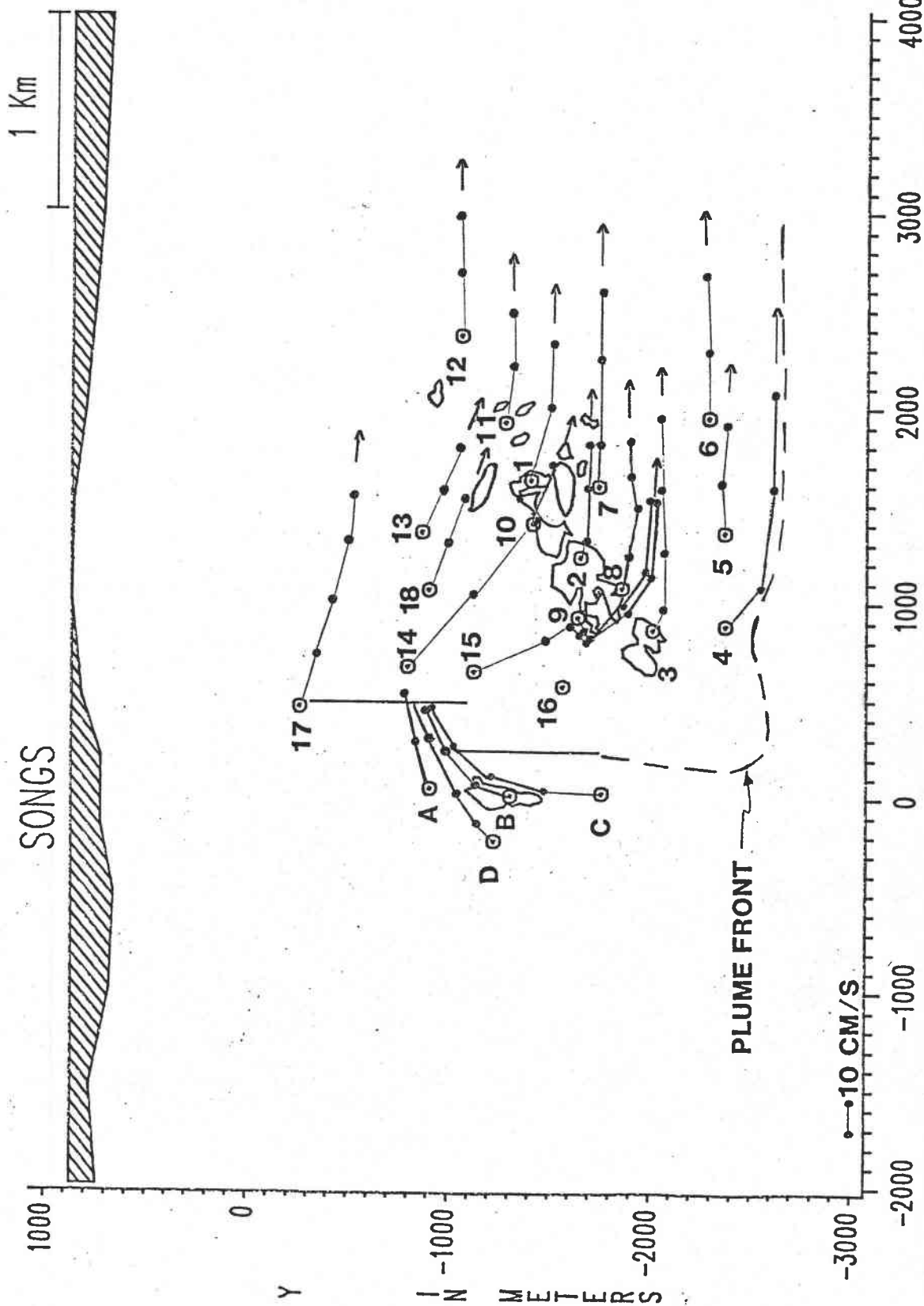
TABLE 1

Release Time of Various Dye Patches

<u>Patch</u>	<u>Release Time</u>	<u>Patch</u>	<u>Release Time</u>
1	12:30	13	13:20
2	12:33	14	13:24
3	12:37	15	13:26
4	12:42	16	13:30
5	12:45	17	14:05
6	12:48	18	14:40
7	12:54	A	13:43
8	12:58	B	13:45
9	13:02	C	13:51
10	13:05	D	13:54
11	13:09	Stripe 1	14:14
12	13:12	Stripe 2	14:31

DYE STUDY

07APR87



Note

Patch 16 never moved appreciably from its release point.

X IN METERS

Figure 1 Starting locations and trajectories for 22 dye patches. Dark circles represent half hour intervals.

DYE STUDY

07APR87

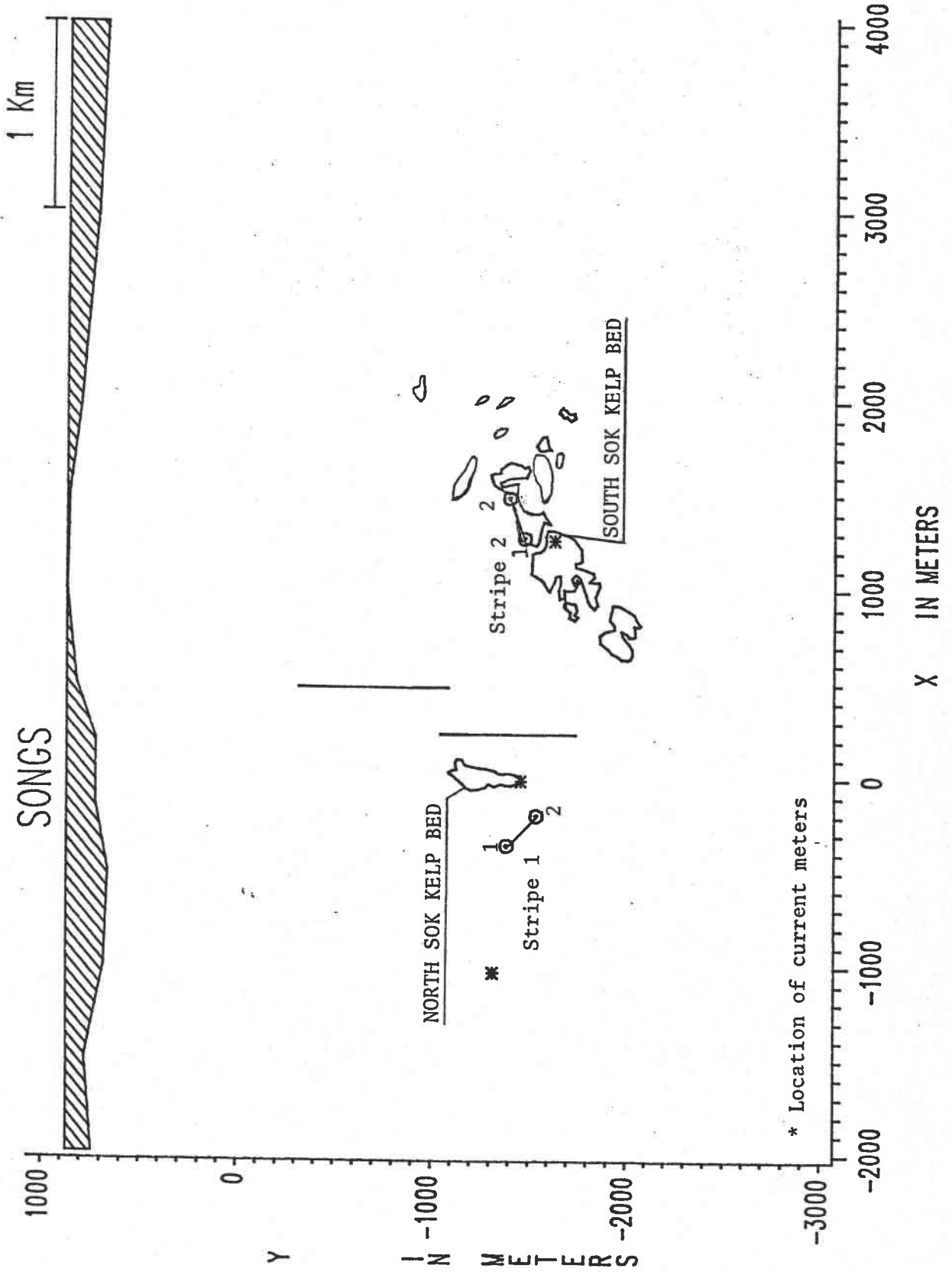
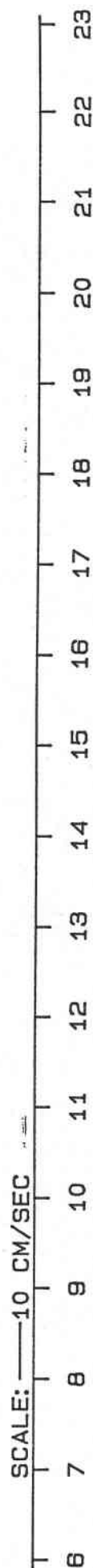
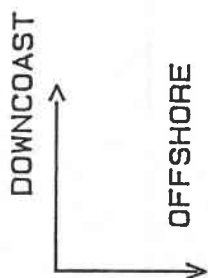


Figure 2 Starting locations of Stripe 1 and Stripe 2, and current meter locations.

HOURLY CURRENT (CM/SEC)

AT 3 METERS BELOW SURFACE



HOUR

Figure 3 Vector representations of current on 07apr87. Ambient current (out of kelp bed) shows a steady onshore/downcoast flow. Note that the flow in the south kelp bed is greatly reduced. 07APR87



Figure 2-6-1: Starting locations of dye patches 1 through 6. Time: 12:52.



Figure 2-6-2: Dye patches 1 through 12. Notice dye patch 4 moving offshore and downcoast. Time: 13:18.



Figure 2-6-3: Dye patches 1 through 16. Notice the plume front, the movement of dye patch 4 along this front, and the slight movement of dye patch 9 from its release position. Time: 13:43.



Figure 2-6-4: Dye patches A, B, C, D, 17 and Stripe 1. Notice dye patches 14 and 15 have already reached the south SOK kelp bed and dye patch 16 has not moved from its release location. Time: 14:28.



Figure 2-6-5: Starting location of Stripe 2 at the inshore part of the south SOK kelp bed. Notice dye patch A is on the Unit 3 diffuser line, dye patch 15 has joined the tail of dye patch 9, both deflecting into the less dense part of the kelp bed, dye patch 16 is still in the same location and dye patch 17 has moved downcoast. Time: 14:38

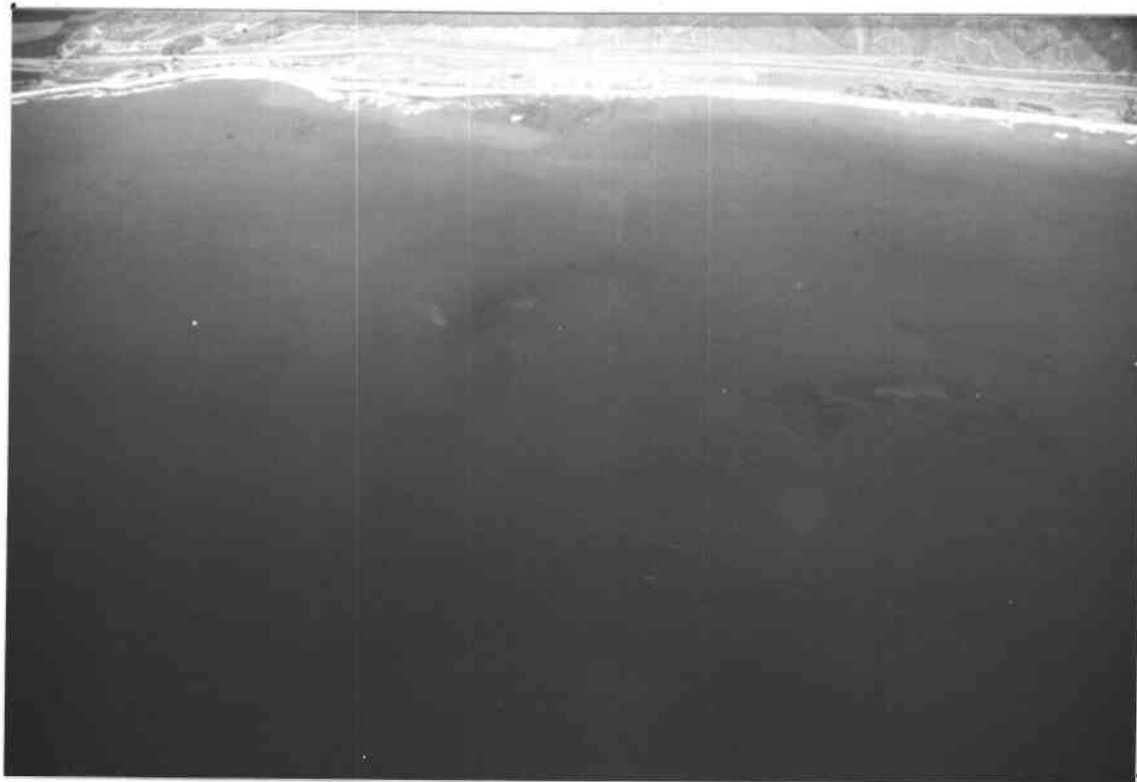


Figure 2-6-6: Starting location of dye patch 18. Notice that the dye patches north of SONGS have moved towards Unit 3 diffuser line, and Stripe 2 has quickly moved into the south SOK kelp bed. Time: 14:52.

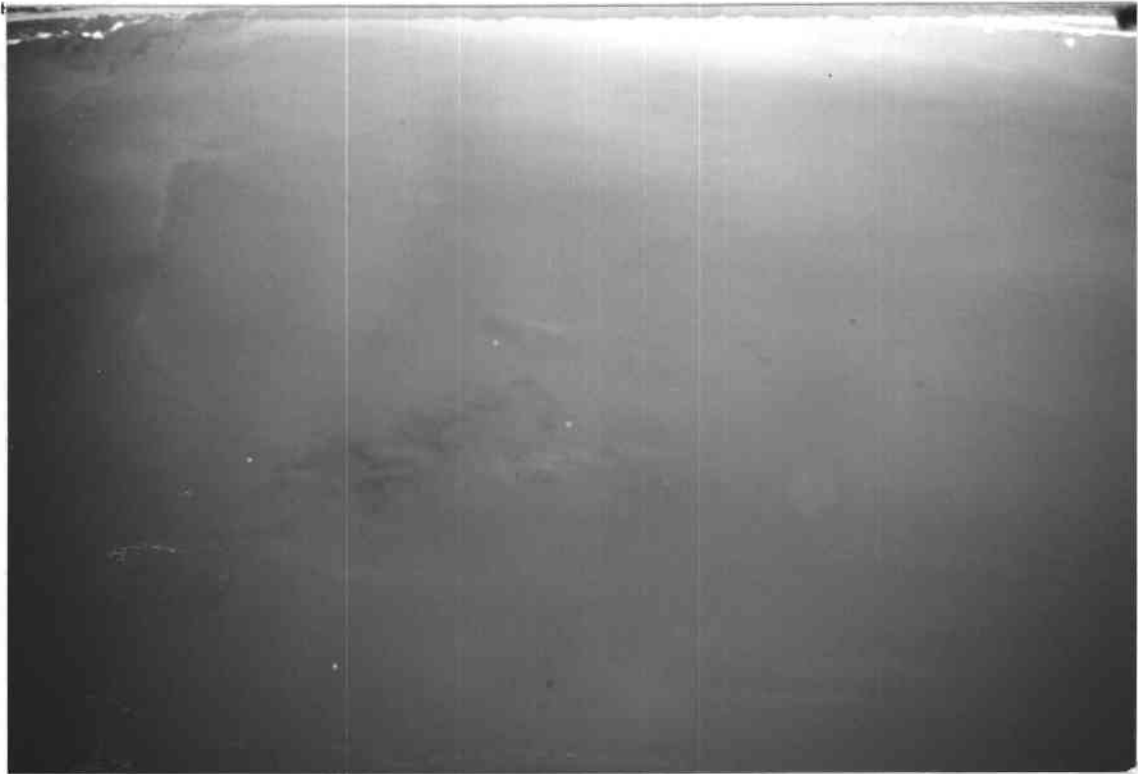


Figure 2-6-7: Stripe 2 is still in the south SOK kelp bed, moving offshore and downcoast. Notice dye patch 17 continuing downcoast and parallel to the shoreline. Time: 15:41.



Figure 2-6-8: Dye patch D is on the Unit 3 diffuser line, dye patch 16 is still in the release vicinity, and Stripe 2 is slowly advancing out of the SOK kelp bed. Time: 15:44.

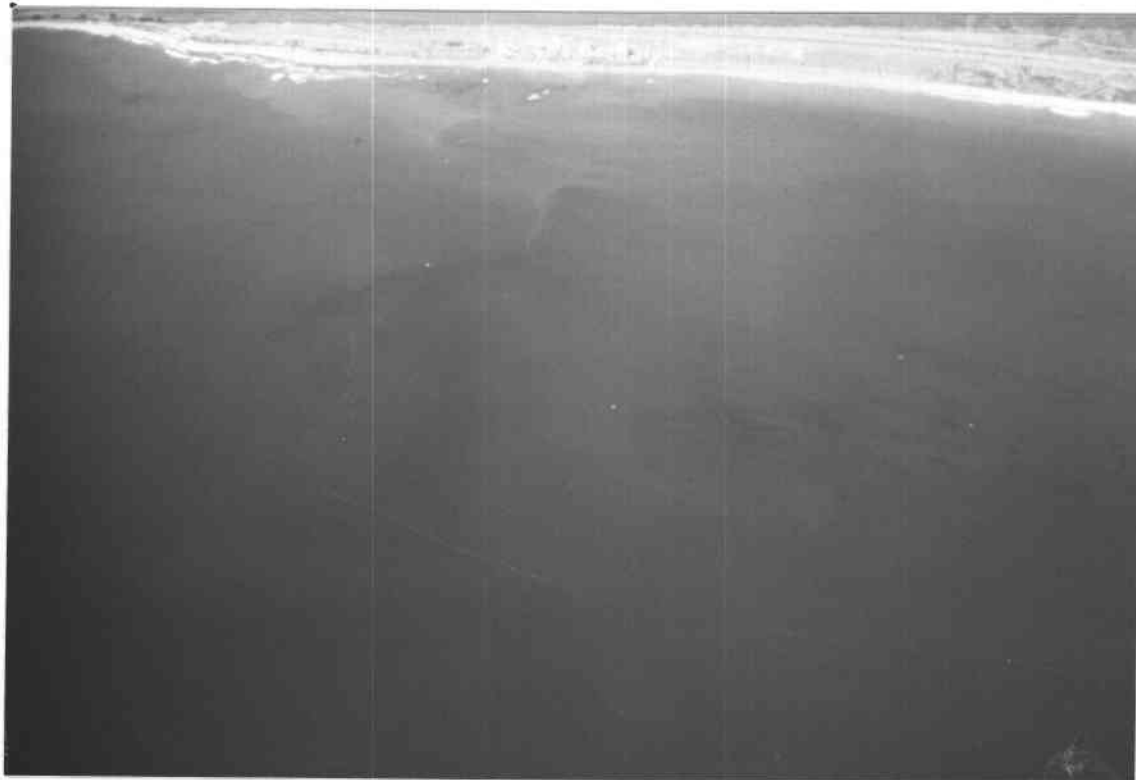


Figure 2-6-9: Stripe 1 is moving downcoast and inshore towards the Unit 3 diffuser line. Patch 16 is dispersing, and Stripe 2 is slowly moving to the offshore boundary of the south SOK kelp bed. Time: 15:55.



Figure 2-6-10: Stripe 1 is moving towards the Unit 3 diffuser line.
Dye patch 16 is still visible. Time: 16:17.

2.7 Dilution Estimates from the Dye Study of May 27, 1987

The dye study of May 27, 1987, was designed as a repetition of the dye study of November 25, 1986, to be carried out when the current was directed upcoast instead of downcoast. The general method was similar. A charge of dye was injected over eight minutes into the intake of Unit 3, and dilutions were estimated at fixed points by recording the history of dye concentration as the dyed stripe from the diffusers passed by the anchored boat. Observed concentrations at eight-minute intervals were added to estimate what the quasi-steady concentration would have been if all the discharge were dyed.

In this experiment, the emerged dye formed a broad stripe that moved upcoast from the Unit 3 diffuser. We estimated the current velocity at the Unit 3 intake to be 10 cm/sec upcoast based on the movement of a dye patch released at the start of the experiment. Figure 2-7-1 shows the shape of the SONGS plume prior to study, and Figure 2-7-2 shows the dye stripe immediately after it emerged from the ports of the Unit 3 diffuser, both indicating upcoast current. Two hours after the start of the experiment, the current reversed to downcoast.

In Table 2-7-1 we have summarized the parameters of this experiment. The recorded dye concentrations at positions 1 through 4 (see Figure 2-7-3) have been used to construct the quasi-steady concentrations by adding up instantaneously recorded concentrations at 8-minute intervals. The results are shown in Figure 2-7-4 and Table 2-7-2.

The result from the first recording position (nearest the diffuser) poses a problem for us, since the estimated dilution of 1.36 at this point is implausibly low by a factor of two or three at the least. An individual discharge jet would normally have entrained 1.36 times the original volume flow at about seven diameters or 3.5 meters along its axis (See Fischer, et al, 1979, p.326), much less than the distance at which entrainment would start to be limited by

interaction of the jet with other jets or with the surface. (In a discussion with Dr. J. List, he indicates that this result is not in line with his findings). To believe the estimated dilution, we have to suppose that entrainment stopped at a few meters from the discharge ports for no evident reason.

We have examined the assumptions and conditions of the experiment carefully, in search of errors large enough to explain this very unlikely result, but we have found none. The two fluorometers used in this study were calibrated before and after the experiment. The one used at the first position agreed with the other in several comparisons through the whole course of the experiment. The calibrations were done with known dilutions of dye solution of the same strength as the injected solution, so the measured concentrations and the estimated concentration emerging from the jets are both relative to the original concentration of the injected solution; an error in this original concentration would cancel out. The assumed discharge rate of $52 \text{ m}^3/\text{sec}$ was confirmed by SCE and was also approximately confirmed by the transit time of the dye from the intake to its emergence at the diffusers. A remaining possibility of error is that the boat dragged the anchor, lengthening the passage time of the stripe past the boat; there is no direct evidence that this happened, and a correction for drift would at best reduce the estimated dilution to about 3 to 1.

The search for error is not completely closed, but our present position is that we can neither accept the result from the first position with confidence nor reject it for an assigned reason related to the experiment itself. We report the result with this warning, and a recommendation that the MRC consider what further observations may serve either to verify or discount this result. The dilutions at other positions relative to the dilution near the diffusers are similar to the comparable relative dilutions observed in the study of November 25, 1986. See Table 2-2-1 (Reitzel, et al, 1987, p.6) and Table 2-7-2.

Table 2-7-3 gives the maximum observed dye concentrations at various positions for the two dye studies carried out on November 25, 1986 and May 27, 1987. ΔT is the time difference between maximums and position 1's maximum. Columns 4 and 7 in Table 2-7-3 show the agreement between the two experiments.

In the May 27, 1987 study it appears to us that the dye was visible for a longer period compared to earlier dye studies. The dye concentration and the temperature profiles at Positions 1 through 4 are shown in Figure 2-7-5.

There are several points worth noting in this study. These points are listed below.

1. As the dye stripe reached the Unit 2 diffuser line, it split into two dye stripes. The offshore part of the stripe moved further offshore and downcoast while the inshore stripe continued to move upcoast (see Figure 2-7-6). The offshore part of the dye stripe has been given further offshore momentum from entrainment into the Unit 2 diffuser line. The movement of this offshore part of the dye stripe downcoast can be explained by the current reversal at this position.
2. Figure 2-7-7 indicates that the north kelp bed slowed the flow through it.
3. At position 4 (see Figure 2-7-8), the dye stripe reversed its direction to downcoast before it passed the boat. We have taken this reversal into consideration when we estimated the quasi-study dye concentration at position 4. Therefore, our estimate for the dilution at this position given in Table 2-7-2 is an approximation.
4. As the current reversed direction, an offshore downcoast plume front was formed (see Figure 2-7-9).
5. The offshore stripe, mentioned in point 1, moved offshore and downcoast until it reached the plume front and then it spread out and

moved along the front in the downcoast direction. We have measured the dye concentration along this front at 1 m below the surface. The measurements indicate that this stripe was diluted 5-10 times since it emerged from the diffuser system. Figure 2-7-10 shows the dye-concentration and temperature profiles inside this dye stripe (position 5) and along the edge (position 6).

Figures 2-7-11 and 2-7-12 show the reverse of the movement of the inshore stripe towards the Unit 2 diffuser line.

In Conclusion, this dye study demonstrates the following points:

1. The interaction of the plumes of Units 2 and 3.
2. When the current reversed direction, the plume shape changed quickly.
3. As the current reversed from upcoast to downcoast, the upcoast water quickly cleared and the downcoast water became more turbid.



Figure 2-7-1: Shows upcoast plume at the beginning of May 27, 1987 dye experiment. Time: 11:56

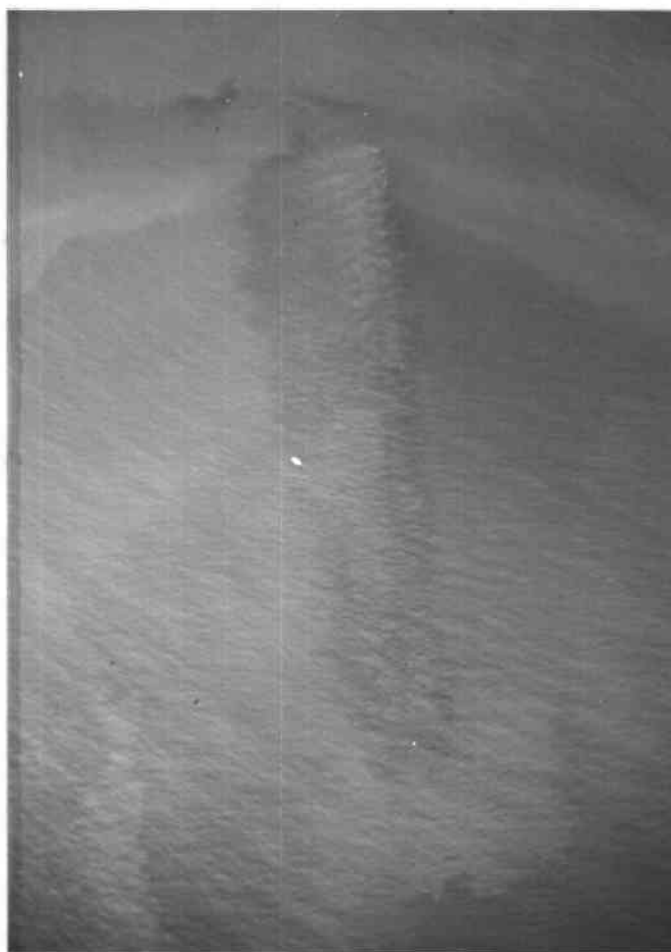


Figure 2-7-2: Dye from Unit 3 diffuser. White spot in the photo depicts the boat which is anchored at position 1. Time: 12:36.

TABLE 2-7-1

May 27, 1987 Dye Study Parameters

PARAMETER	VALUE
Location of release	Into Unit 3 intake
Amount of release	9.1 kg
Dye injection start	12:41 P.M.
Dye injection period	8 minutes
Dye Concentration as emerged from ports	360 ppb
Rate of water discharge from Unit 3.	52 m ³ /sec
Number of pumps operating; Unit 2	4
Number of pumps operating; Unit 3	3.992
Power level; Unit 2	100%
Power level; Unit 3	86%
Number of times boat anchored and dye stripe passed the boat; measurements were taken at 1 m below water surface	4 (See Figure 2-7-3; positions 1, 2, 3, & 4)
Number of times vertical profiles of dye concentration and temperature were carried out	6 (See Figure 2-7-3; positions 1, 2, 3, 4, 5, and 6)

DYE STUDY

27MAY87

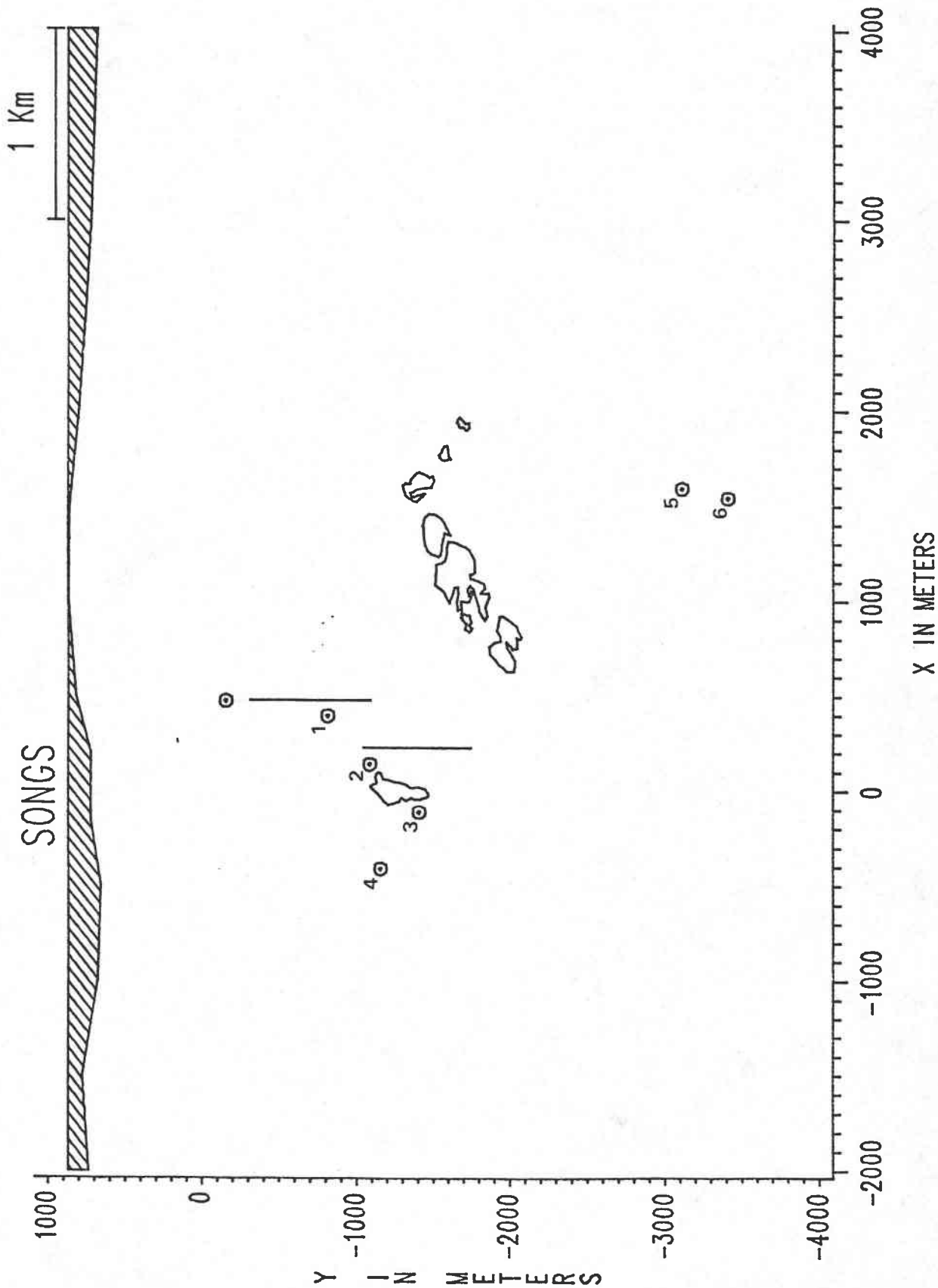


Figure 2-7-3: Location of positions 1 through 6 at 27May87 dye study

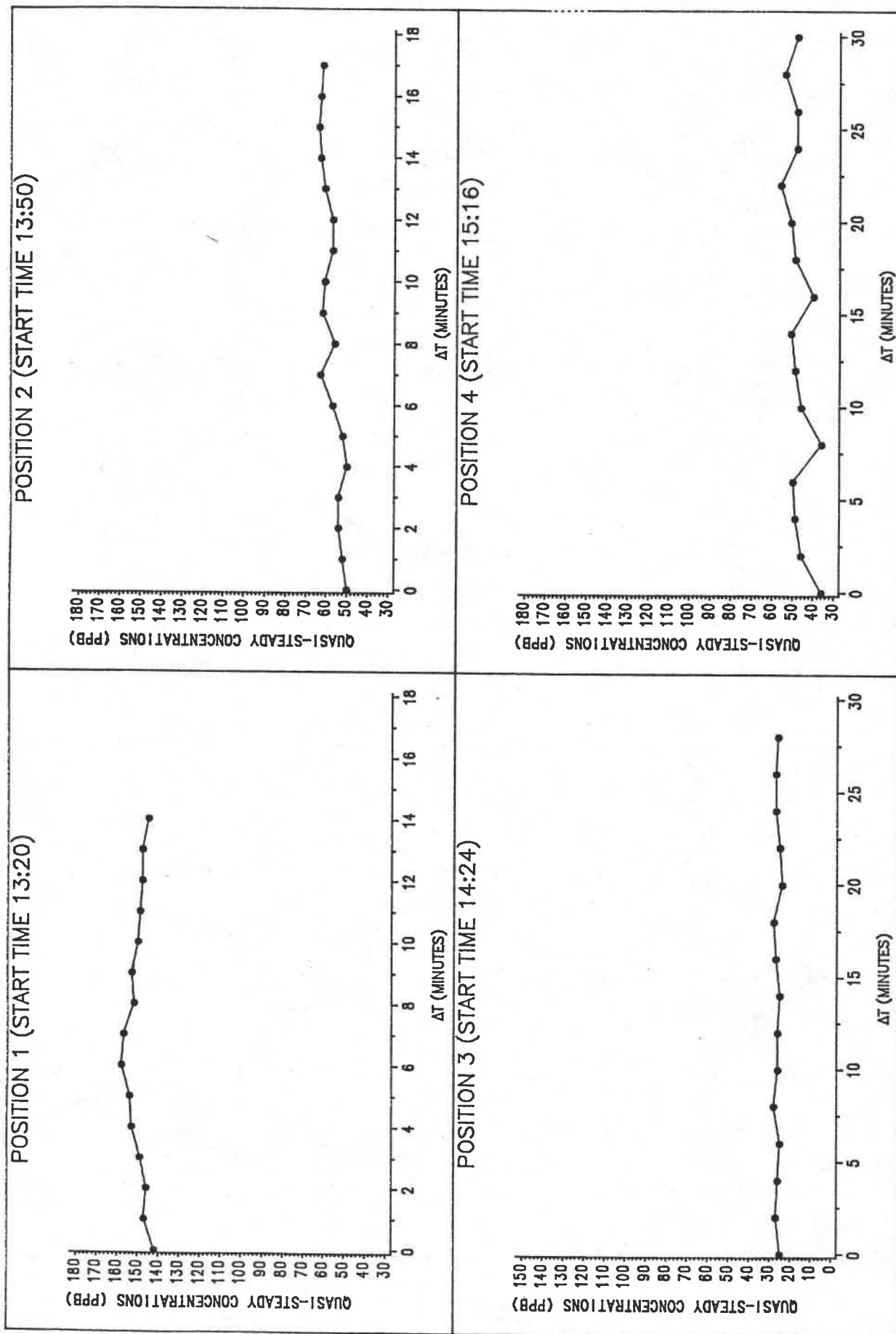


Figure 2-7-4: Quasi-study of dye concentration C_g for various positions during 27May87 dye study

TABLE 2-7-2
May 27, 1987 Dye Study Results

POSITION	CONCENTRATION C_S	DILUTION (360/ C_S)-1	DISTANCE FROM DIFFUSER LINE	WATER DEPTH
1	152 ppb	1.36	75 m	10.6 m
2	62 ppb	4.8	400 m	12.1 m
3	27 ppb	12.33	700 m	13.6 m
4	46 ppb	6.82	1000 m	13.6 m

TABLE 2-7-3
Maximum Observed Dye Concentrations at Various Positions

Position	25Nov86 Study			27May87 Study		
	ΔT mins	Maximum value (ppb)	Maximum/ maximum at Position 1	ΔT mins	Maximum value (ppb)	Maximum/ maximum at Position 1
1	0	40	1	0	90	1
2	30	24	1.7	34	47	1.9
3	75	10	4.0	75	12*	7.5*
4	120	7	5.7	125	14	6.4

*Position 3 for this study is on the lee side of the north San Onofre kelp bed.

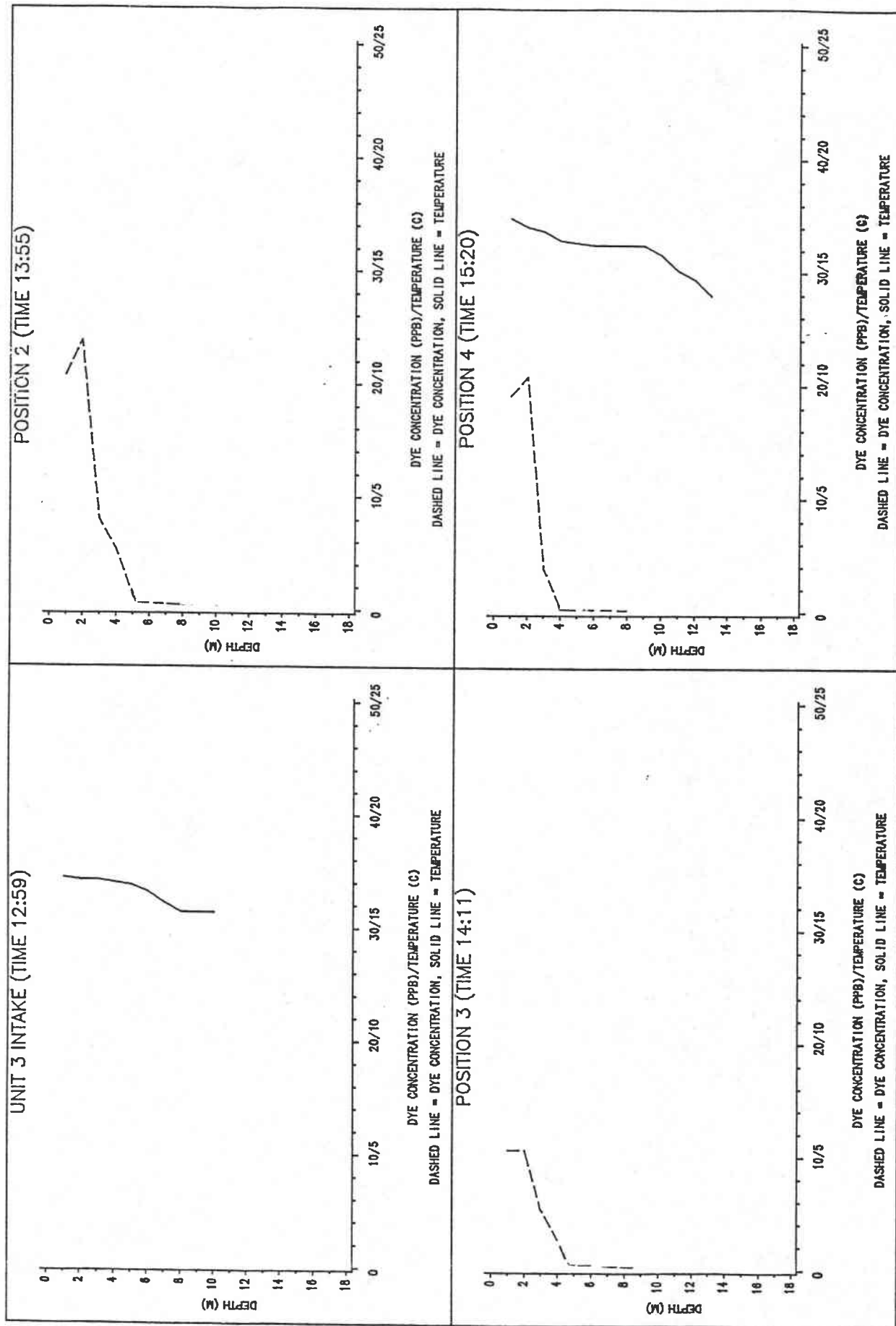


Figure 2-7-5: Dye concentration and temperature profiles for 27May87 dye study. Positions 1 through 4.

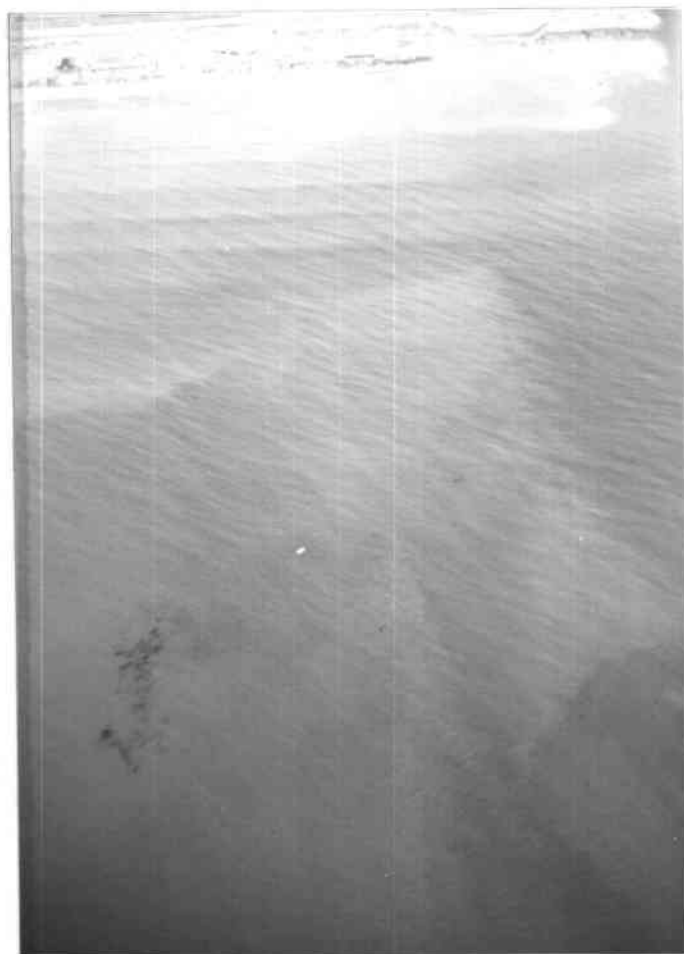


Figure 2-7-6: Notice the split of the dye stripe. The offshore stripe is moving offshore and downcoast while the inshore stripe is moving offshore and upcoast. Boat is anchored at position 2. Time: 14:05



Figure 2-7-7: Interaction of the inshore stripe with the north SOK bed. Boat is anchored at position 3. Time: 14:22



Figure 2-7-8: Notice the start of the change of plume shape due to current reversal. Boat is in position 4. Time: 15:56.

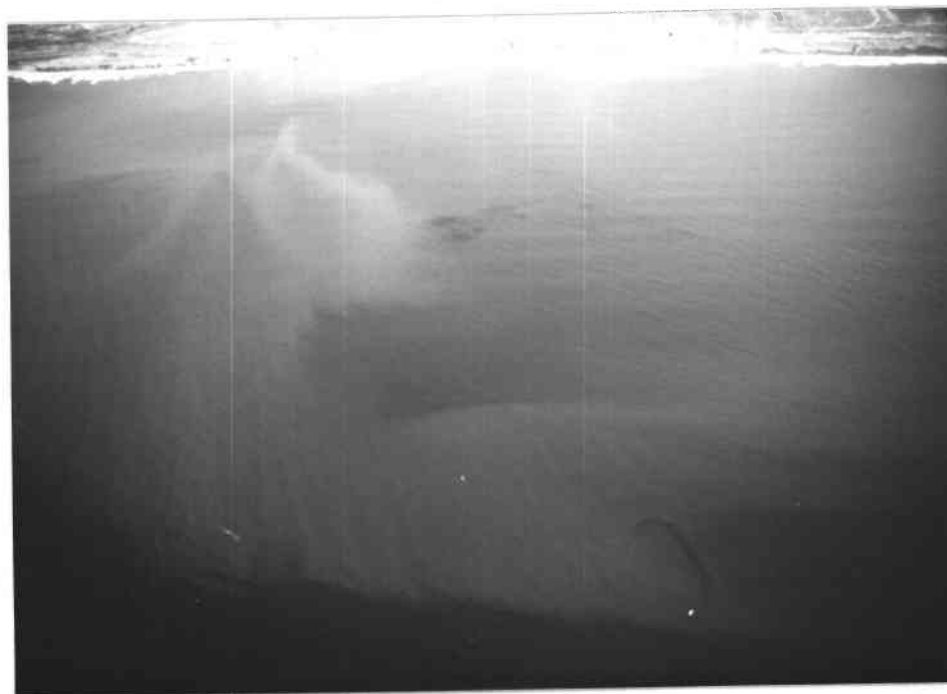


Figure 2-7-9: Notice the plume front; the movement of the offshore stripe to this front and the turbidity of the downcoast water due to current and plume reversal. Time: 16:44.

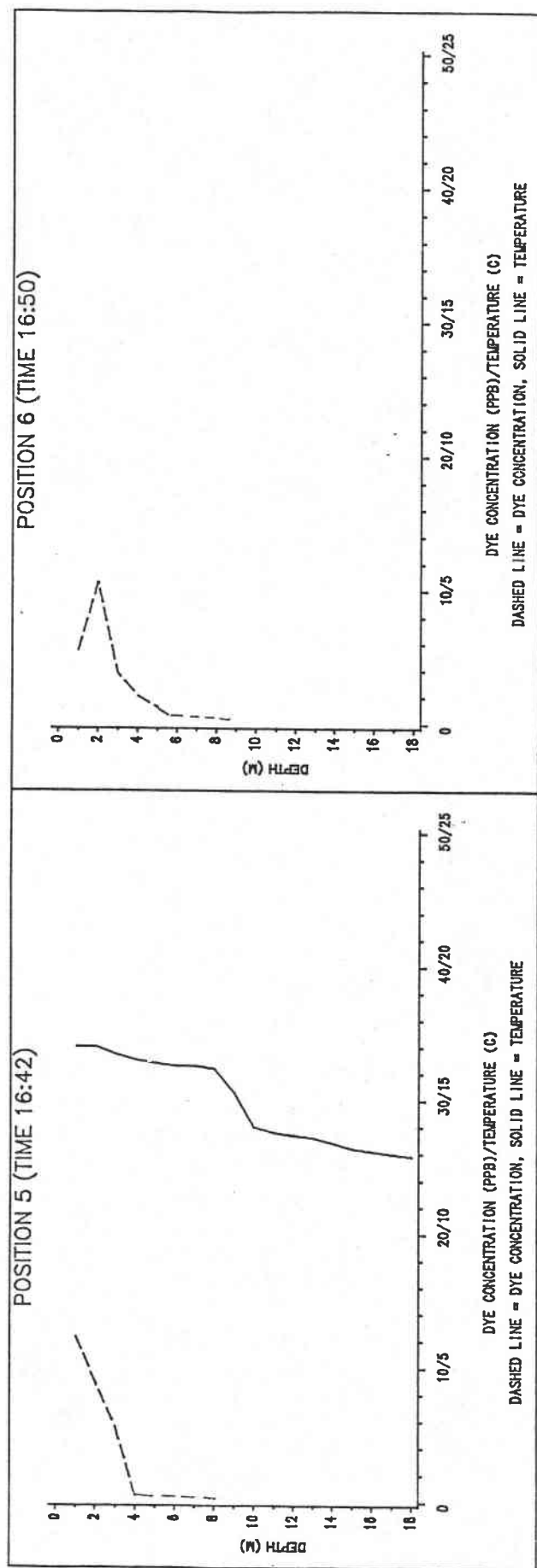


Figure 2-7-10: Dye concentration and temperature profiles at positions 5 and 6 for the 27May87 dye study



Figure 2-7-11: The reverse of the movement of the inshore stripe towards Unit 2 diffuser line. Time: 17:01.



Figure 2-7-12: Notice the deflection of the inshore stripe with north SOK kelp bed during the movement of the stripe towards Unit 2 diffuser line. Time: 17:22.

REFERENCES

Fischer, H.B., E.J. List, R.C.Y. Koh, J. Imberger and N.H. Brooks, 1979. Mixing in Inland and Coastal Waters. Academic Press, New York, p. 326.

Reitzel, J., M.H.S. Elwany, M.R. Erdman and K. Zabloudil, 1987. SONGS Physical and Chemical Oceanography, Final Report Vol. II-2. Submitted to the Marine Review Committee, INC., April 30, 1987, p. 6.