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PROGRESS REPORT OF 1981-82 INTERNATIONAL SEA GRANT PROGRAM. PHASE 1 OF REMOTE SENSING TASK: Water Quality Assessment of the Golfo de Nicoya, Costa Rica

$2.00

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Technical Report

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PROGRESS REPORT OF 1981-82 INTERNATIONAL SEA GRANT PROGRAM. PHASE 1 OF REMOTE SENSING TASK:

Water Quality Assessment of the Golfo de Nicoya, Costa Rica

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by

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PREFACE

In April of 1980, the University of Costa Rica and the College of Marine Studies, University of Delaware, began collaborative remote sensing investigations of the Gulf of Nicoya, Costa Rica as part of an International Sea Grant Program. The objectives of the program are to obtain much needed information pertaining to the physical characteristics of the Gulf, to train Costa Rican personnel in data gathering techniques and to transfer associated technology.

The remote sensing investigations may be divided into two separate phases, both of which deal with problems directly related to local fisheries. Phase 1 is an attempt to characterize various physical parameters within the surface and near-surface waters of the Gulf which include circulation, suspended sediment concentration, transmissivity, secchi depth, salinity, temperature and dissolved oxygen. Phase 2 is concerned with detecting changes within the numerous mangrove swamps surrounding the Gulf. Such changes may include both the size of individual swamps and species zonation. Both phases utilize remote sensing data collected from Landsat as well as aerial color and infrared photography. This report will present results obtained from Phase 1 whereas Phase 2 results will be the subject of a future report.

The results contained within this report are distilled from the efforts of many individuals associated with the University of Costa Rica and the University of Delaware. Dr. Manuel Murillo (UCR) was effective in the role of liason between both institutions. Jose Vargas (UCR) was instrumental in the implementation of field surveys and participated in all aspects of data acquisition within the Gulf of Nicoya. Other notable Costa Rican participants were Enrique Borrase, Luis Cruz, Gustavo Frenandez, Luis Elizodo and Ana Dittel. Rolando Hoffmeister proved to be a more than worthy ships captain, both in apprenticeship under Timothy Pfeiffer (UD) and upon promotion.

We would like to stress the point that the data contained herein is still in the process of being analyzed and that any interpretations or conclusions are preliminary. In the event that future researchers plan to cite this report, it would be greatly appreciated if the authors were contacted and given the opportunity to expound upon the data where necessary.

Vytautas Klemas and Steven G. Ackleson
December 1, 1981

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ABSTRACT

Beginning in April of 1980 and continuing until July of 1981, the University of Costa Rica and the College of Marine Studies, University of Delaware, collaborated in remote sensing studies of the Gulf of Nicoya, Costa Rica, as part of an International Sea Grant Program. Included in the investigations was an attempt to characterize the circulation of the surface waters of the Gulf and measurements of suspended sediment concentration, transmissivity, Secchi depth, salinity, temperature and dissolved oxygen. A total of three cruises were conducted throughout the Gulf with the majority of emphasis placed upon the area adjacent to the Rio Grande de Tarcoles. Results indicated a well defined plume of river outflow that was buoyant in nature and extended at least 6 km from the river mouth into the central and lower portions of the Gulf. Surface drogues released 2.4 km and 4.7 km offshore from the river mouth at low slack tide drifted north during the ensuing flood tide and in a shoreward direction.

LANDSAT imagery of the Gulf area adjacent to the Rio Grande de Tarcoles representing overpasses at four different phases of the tidal cycle were analyzed on an ERDAS 400 (Earth Resources Data Analysis System). Results provided further evidence of a well defined river plume extending into the central and lower portions of the Gulf as much as 10 km from the river mouth. The shape and orientation of the plume relative to the river mouth is shown to be tidal dependent, drifting north along the coastline during flood tide and south during ebb tide.

Additional enhancement of LANDSAT imagery indicated a rather strong front located in the central portion of the Gulf, east of Islas Negritos. The feature appears to be ebb tidal dependent and appears only in the imagery corresponding to large ebb tidal currents in the Gulf.

1.0 INTRODUCTION

The Gulf of Nicoya, located on the west coast of Central America, plays an indispensable role in the development of Costa Rica's marine resources. In addition to a well developed fisheries industry, it provides port facilities and serves as a major outlet for waste disposal. The conflicting nature of these exploits is amplified with the lack of environmental information to aid in marine policy decisions.

The Gulf of Nicoya encompasses an area of 1543 km^2 (eighty-four kilometers in length and varying in width from 55 km at its mouth to 9 kilometers at Puntarenas). Circulation throughout the gulf is tidal dominated with an average tidal range of three meters. Fresh water influx is largely seasonal, the majority of which enters the Gulf during the rainy season (May through December) from one of three major rivers; the Rio Tempisque at its head, the Rio Barranca just east of Puntarenas or the Rio Grande de Tarcoles on the east shore of the lower Gulf.

Fishery industries operate from the mouth of the Gulf to approximately San Lucas Island as depicted in Figure 1. Such fisheries include finfish, shrimp, lobsters and molluscs. An area extending from the Rio Barranca to Isla Chira is closed to fishery operations and serves as a nursery for shrimp.

Pollutants entering the Gulf have not only increased in the rate of input but diversified in terms of polluting sources. The Rio Tempisque, a major river entering the head of the Gulf, carries with it runoff from an extensive agricultural watershed. A major irrigation project involving the river provides unknown quantities of pesticides and other organic nutrients. On the east side of the Gulf is the port of Puntarenas (less

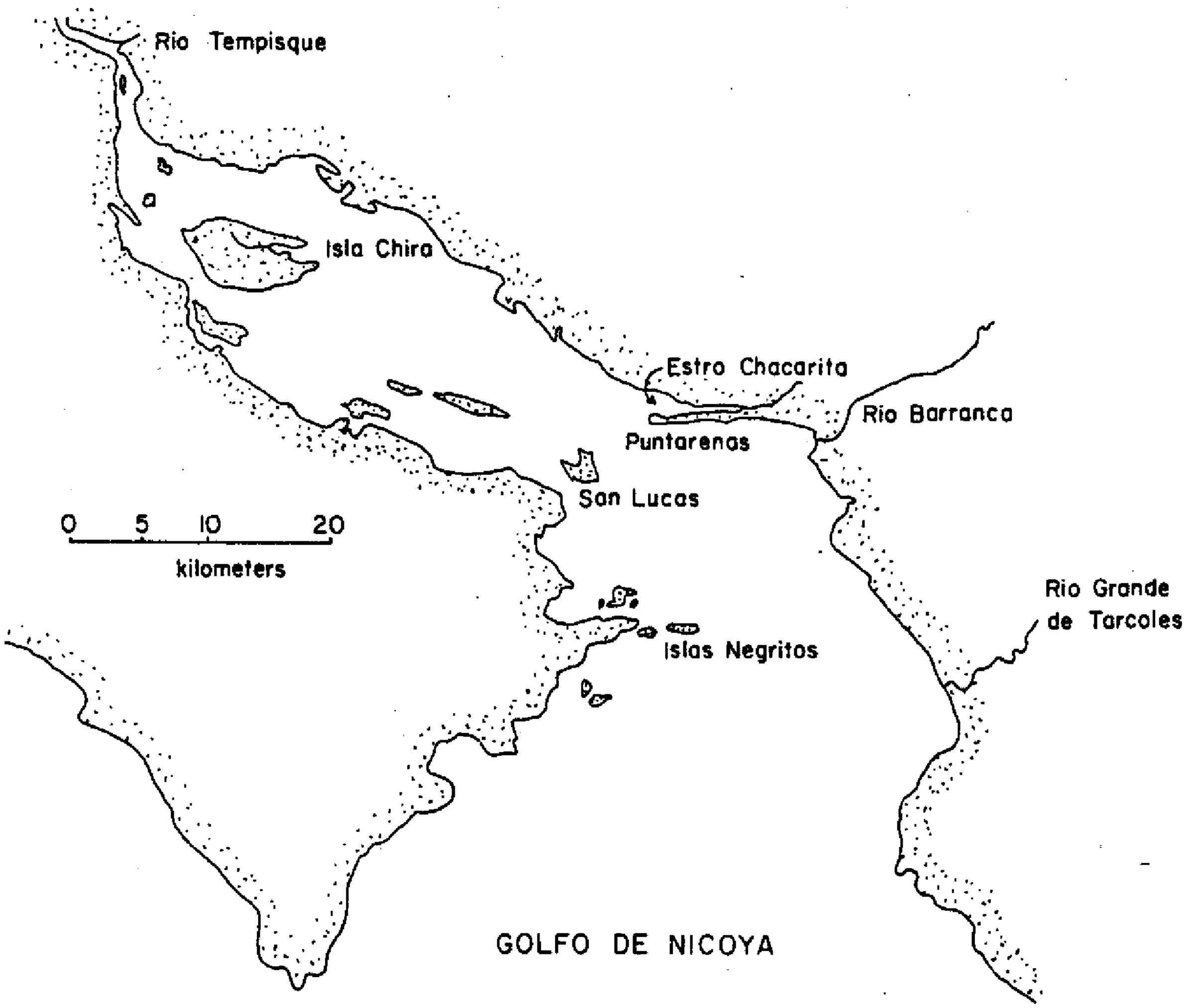

Figure 1: Chart of the Golfo de Nicoya indicating outstanding geographic features.

than 50,000 people) which is presently undergoing a high rate of development as a port city. Here, a central sewage system pumps untreated sewage into a small secondary estuary connected to the Gulf (Estero Chacarita). The Rio Grande de Tarcoles empties into the east side of the Gulf approximately 20 miles south of Puntarenas. It carries with it untreated sewage from the population centers on Costa Rica's central plateau. In addition to untreated human waste, agricultural and industrial chemicals are introduced to the Gulf via the Rio Tarcoles, the concentrations of which are unknown at present.

Contained within this progress report is a condensation of water quality investigations conducted in the Gulf of Nicoya between April 13, 1980 and July 28, 1981. Field measurements are combined with various remote sensing techniques to address the problem of urban pollutants entering the lower Gulf via the Rio Grande de Tarcoles and, to a lesser extent, agricultural pollutants entering to the upper Gulf from the Rio Tempisque.

2.0 LITERATURE REVIEW

Few physical oceanographic studies have been conducted in the Gulf of Nicoya, investigations conducted by Peterson (1958) are by far the most comprehensive. Temperature, salinity and dissolved oxygen measurements were performed on bimonthly hydrographic surveys during the period 1952 to 1957. The results of the hydorgraphic data were compared with meteorological observations and river discharges. Peterson concluded that the dynamic structure of the Gulf was principally controlled by salinity variations. Strong gradiants in temperature, salinity and dissolved oxygen were characteristic during the rainy season (May through November) resulting from very high runoff rates. With the decline of runoff during the dry season (December through April) temperature and dissolved oxygen gradients became negligible and the salinity structure emulated oceanic conditions.

Voorhis et al (1979) conducted hydrographic surveys of the Gulf during the dry season from January 29 to February 8, 1979 in an attempt to further define horizontal distributions of water properties, circulation (both tidal and subtidal) and the influence of vertical and horizontal tidal motions. Temperature, salinity and density were found to be well stratified in the lower Gulf while the stratification of temperature was reduced in the upper Gulf. Horizontal variations were found to be dominated by large vertical oscillations resulting from internal semidiurnal tidal motions. Average variations along the axis of the Gulf were found to be small. Vertical distributions along a traverse spanning the central portion of the Gulf from Islas Negritos (shown in Figure 1) were found to suggest strong frontal formation just to the east of the island.

Voorhis characterized the Gulf as a positive estuary. Fresh water input to the upper Gulf, mainly from the Rio Tempisque, mixed with more saline water from deeper levels, is transported down the Gulf through the narrow passage between Puntarenas and San Lucas Island in a shallow layer extending from the surface to an average depth of 20 meters. In the central portion of the Gulf, the layer is deflected eastward during ebb tide at the partial barrier created by Islas Negritos resulting in a strong frontal boundary. Finally, the layer proceeds seaware along the eastern side of the lower Gulf.

3.0 HYDROGRAPHIC SURVEYS

3.1 Surface Drifter Drogues

3.1.1 Materials and Methods

Drifter drogues were designed and constructed for the purpose of investigating the circulation of surface waters within the Gulf of Nicoya. The constraints placed upon drogue design and fabrication were:

(1) construction expenses: due to high shipping costs limited funding, drogues were to be constructed of inexpensive materials that were readily obtainable in Costa Rica;

(2) portable: limited storage space aboard the R/V Skimmer demanded the drogues be compact and easily assembled on station;

(3) high resolution: each drogue had to be visible enough so as to be resolvable on low to medium altitude (1000-3000 ft.) aerial photography.

The resulting drogue design consisted of a byplane frame constructed of 1.3 cm PVC and supported by a 2.5 cm PVC center post (shown in Figure 2). Fabric panels were secured to the PVC frame and pulled taut with accompanying ties (see Figure 3). No glue was needed to secure the PVC as each interlocking section was held in place by the resulting tension on the fabric panels. Each byplane constituted a cross-sectional area of 1.0 m^2. The top surface area of each drogue was 0.7 m^2 and was coated with a highly reflectant paint (day-glow red or florescent yellow).

A cluster of nine drogues was released in the Gulf adjacent to the Rio Grande de Tarcoles in the mornings of April 16 and 17, 1980. The deployment sites were located 2.5 km and 4.8 km offshore respectively. Drogue clusters consisted of eight secondary drogues and one master drogue. The master drogue was unique only in that a one meter length of 1.3 cm PVC extended

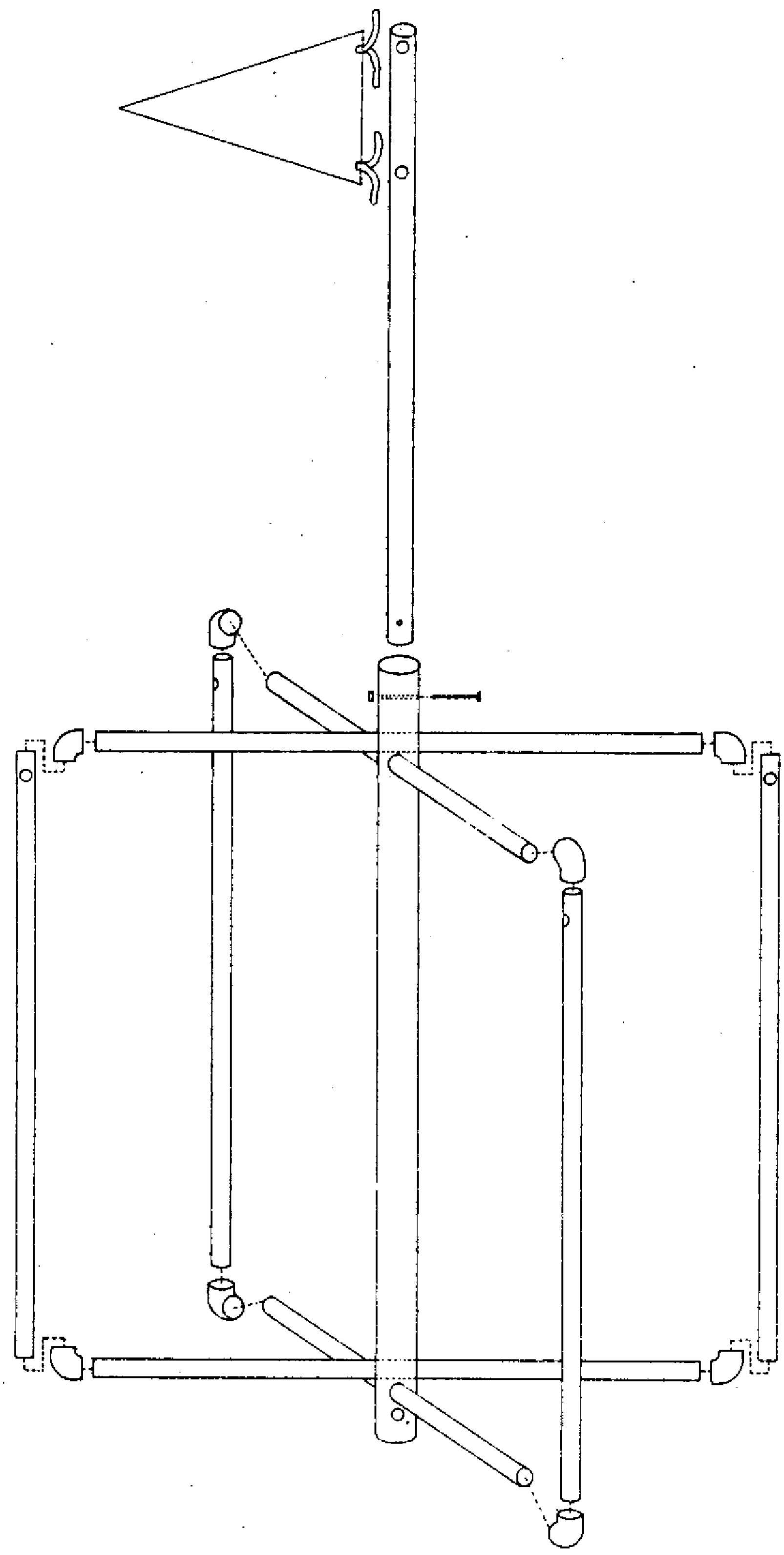

Figure 2. Drogue PVC frame assemblage

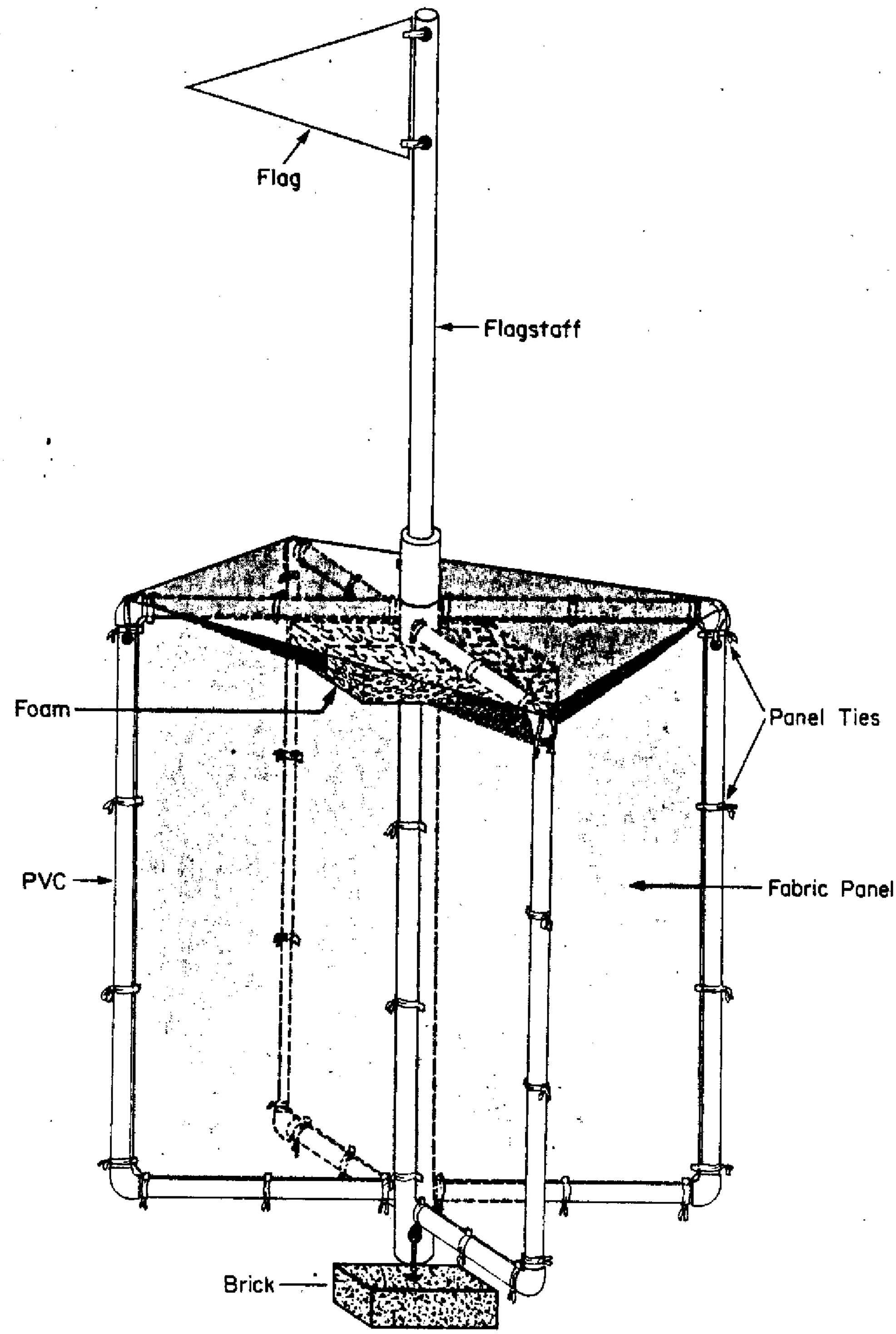

Figure 3. Assembled drogue with bouyancy system

above the water surface. This was painted florescent red to aid in sighting the drogue from the R/V Skimmer. At 30 minute intervals during each tracking operation the R/V Skimmer was maneuvered to within a few yards of the master drogue. Ship radar was then used to locate the ship position, and thus the master drogue. Drogue positions were then indicated on a nautical chart. Tracking operations were completed in the late afternoon of each day after which the drogues were retrieved.

Overflights of the drogue cluster were conducted during each tracking operation with a twin engine Beechcraft at an altitude ranging from 300 m to 800 m. During each overflight, the relative position of the deployment vessel and drogue cluster was photographed onto 9 inch color IR transparencies. For each photo mission, a scaling factor was calculated in order to convert photo measurements to ground distances. A rectangular coordinate system was arbitrarily assigned to each set of transparencies and individual drogue locations recorded; X_i, and Y_i, where i represents a specific drogue. A drogue cluster center was then calculated for each overflight as

$$\overline{X} = \frac{1}{N}\sum_{i=1}^{N} X_i \qquad (1)$$

$$\overline{Y} = \frac{1}{N}\sum_{i=1}^{N} Y_i \qquad (2)$$

where N represents the total number of drogues observed in each cluster. Finally, the average drogue distance from each cluster center was calculated as

$$\overline{D} = \frac{1}{N}\sum_{i=1}^{N} \left[(X_i - \overline{X})^2 + (Y_i - \overline{Y})^2 \right]^{1/2} \qquad (3)$$

3.1.2 Drogue Tracking Results

The results of the drogue tracking operations are shown in Figure 4. On both dates, the drogue cluster was released within 30 minutes of low slack tide. (All tidal phases were calculated from tide tables relative to Puntarenas.) The drogue cluster released on April 16, 1981 was found to drift in a north westerly direction throughout the entire $4^h\ 44^m$ tracking operation. The average rate of drift was calculated to be 30 cm/sec. The drift direction gradually brought the drogue cluster to within one kilometer of the shore, at which point concern for the drogues, as well as the R/V Skimmer, running aground prompted an early retrieval. Drogues tracked on April 17, 1981, although released twice as far offshore as those on the previous day, assumed a quite similar drift direction. The tracking operation lasted $5^h\ 32^m$ and an average rate of drift was calculated to be 38 cm/sec.

Drogue cluster dispersion rates were calculated from aerial photography for both tracking dates and are presented in Table 1. The column marked elapsed time represents the difference in hours between the time of each overflight and the time at which the drogue cluster was deployed. The mean of all drogue distances from the cluster center was calculated according to equation (3) and is reported in units of meters. Dispersion rates were calculated in units of cm/sec for each overflight and represent the mean rate of dispersion between consecutive overflights. The last column labeled mean dispersion rate is also given in units of cm/sec and represents the average rate of dispersion between each overflight and the time of deployment. Dispersion rates calculated from April 16 data ranged from a maximum of 0.72 cm/sec midway through the tracking operation to a minimum of 0.03 cm/sec immediately prior to retrieval with a mean

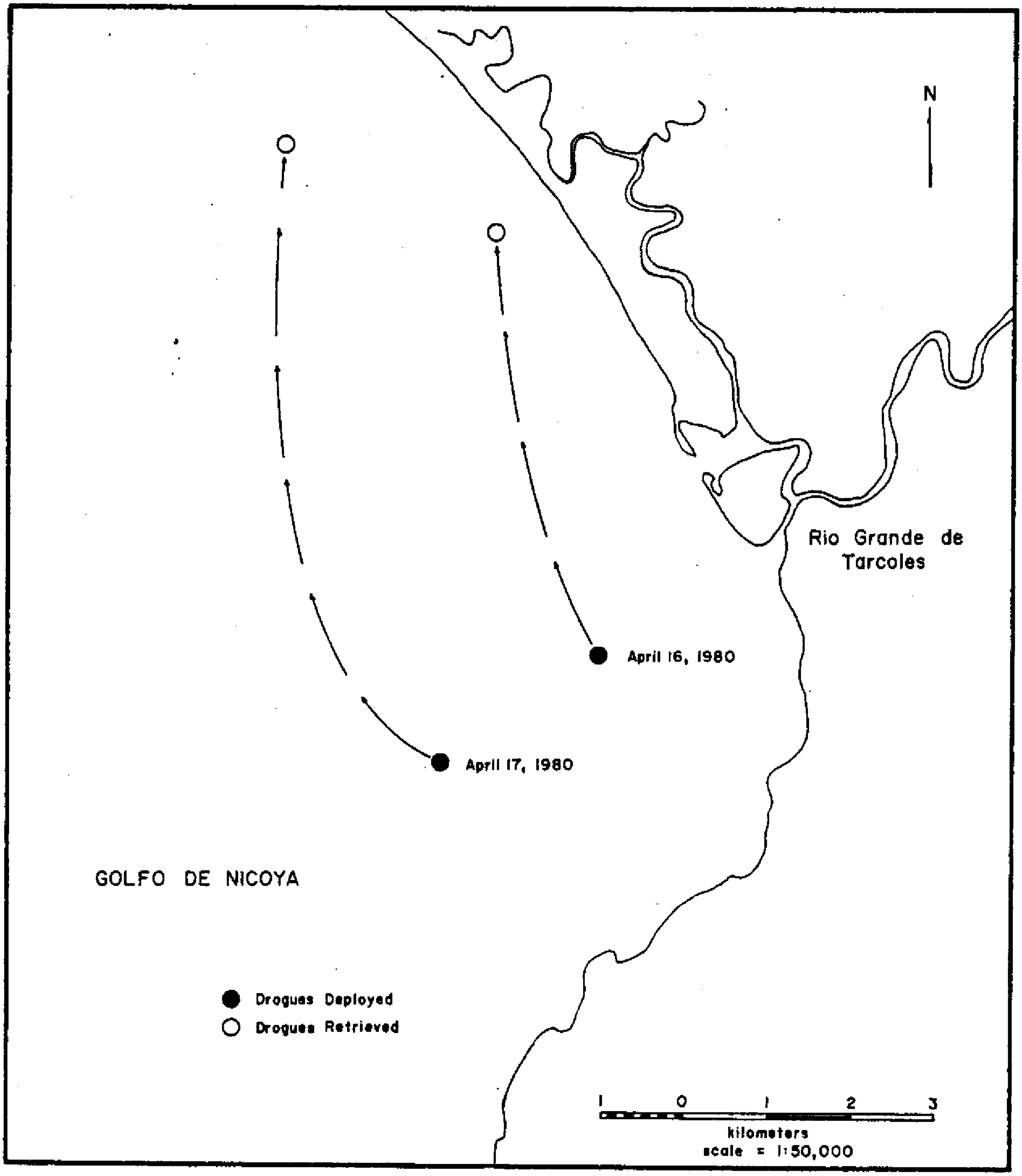

Figure 4: Results of surface drifter drogue tracking operations for April 16 and 17, 1980.

Table 1.

Dispersion rates for surface drifter drogues tracked on April 16 and 17, 1980.

Date	Time of Deployment	Time of Overflight	Elapsed Time (hours)	D (meters)	Dispersion Rate (cm/s)	Mean Dispersion Rate (cm/s)
April 16 1980	0924	1033	1.15	12.2	0.29	0.29
		1130	2.10	36.9	0.72	0.49
		1407	4.72	40.2	0.03	0.24
April 17 1980	1000	1111	1.18	34.6	0.81	0.81
		1404	4.06	111.2	0.74	0.76

dispersion rate of 0.24 cm/sec. Dispersion rates calculated from April 17 data were significantly higher ranging from 74 cm/sec to 81 cm/sec and a mean dispersion rate of 0.76 cm/sec.

3.2 Suspended Particulate Concentration

3.2.1 Materials and Methods

Water samples were collected from the surface and near surface waters of the Gulf of Nicoya and were analyzed for suspended particulate concentration. Samples representing the dry season were collected on February 4 and 5, 1981 at the station locations indicated in Figure 5. The latitude and longitude at each station is given in Table 2. Samples representing the rainy season were collected on July 25, 26, 27 and 28, 1981 at the station locations indicated in Figure 6. The latitude and longitude of each July station is given in Table 3. Surface samples were collected by lowering a clean plastic bucket to the water surface using an attached line. Subsurface samples were collected by lowering a Niskin bottle to the desired sampling depth which in most cases was the secchi depth. By doing this we attempted to obtain a mean suspended particulate concentration over an optically significant depth relative to an airborn sensor such as the Landsat MSS. When sampling conditions prohibited a secchi depth measurement (i.e. during evening hours) samples were collected between one and two meters of the surface.

Immediately after collection, samples were vacume filtered on board through preweighed 1.2μm Whatman GF/C microfiber filters which had previously been ignited at 500°C (932°F). After filtration, the filters stored in seperate petri dishes for the duration of the field work and taken to the University of Costa Rica for further analysis. In the laboratory, samples were dried at 75°C (167°F) and reweighed.

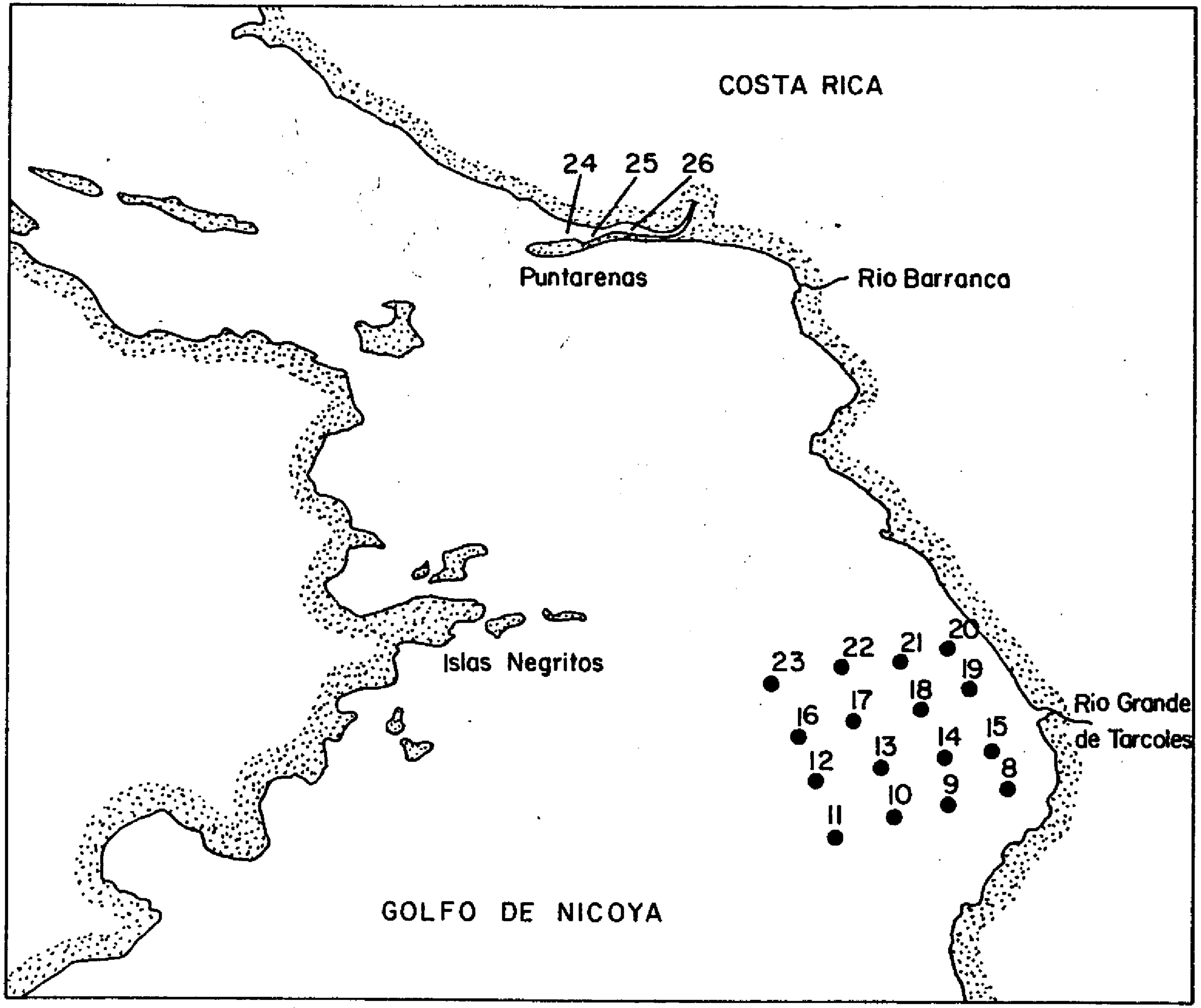

Figure 5: Locations of stations at which suspended particulate concentrations were measured in February, 1981.

Table 2.

Gulf of Nicoya Suspended Particulate Concentration Data

February 4-5, 1981

DATE	TIME	STATION	LATITUDE	LONGITUDE	SAMPLE DEPTH (m)	SUSPENDED PARTICULATE CONCENTRATION (mg/l)
02/04/81	12:06	8	09° 45' 10" N	84° 39' 00" W	Surface	3.8
02/04/81	12:06	8	09° 45' 10" N	84° 39' 00" W	2.0	3.1
02/04/81	12:30	9	09° 44' 40" N	84° 40' 30" W	Surface	2.0
02/04/81	12:30	9	09° 44' 40" N	84° 40' 30" W	3.0	2.0
02/04/81	13:05	10	09° 44' 30" N	84° 41' 50" W	Surface	1.2
02/04/81	13:05	10	09° 44' 30" N	84° 41' 50" W	2.0	1.3
02/04/81	13:25	11	09° 44' 05" N	84° 43' 22" W	Surface	1.3
02/04/81	13:25	11	09° 44' 05" N	84° 43' 22" W	4.0	1.3
02/04/81	13:42	12	09° 45' 25" N	84° 43' 50" W	Surface	3.0
02/04/81	13:42	12	09° 45' 25" N	84° 43' 50" W	3.5	1.4
02/04/81	14:10	13	09° 46' 00" N	84° 41' 50" W	Surface	3.6
02/04/81	14:10	13	09° 46' 00" N	84° 41' 50" W	3.0	3.3
02/04/81	14:27	14	09° 46' 00" N	84° 40' 45" W	Surface	1.6
02/04/81	14:27	14	09° 46' 00" N	84° 40' 45" W	3.0	3.1
02/04/81	14:44	15	09° 46' 05" N	84° 39' 20" W	Surface	2.4
02/04/81	14:44	15	09° 46' 05" N	84° 39' 20" W	2.5	3.6

Table 2. Continued

DATE	TIME	STATION	LATITUDE	LONGITUDE	SAMPLE DEPTH (m)	SUSPENDED PARTICULATE CONCENTRATION (mg/l)
02/05/81	09:33	15	09° 46' 05" N	84° 39' 20" W	Surface	10.5
02/05/81	09:33	15	09° 46' 05" N	84° 39' 20" W	Surface	****
02/05/81	09:33	15	09° 46' 05" N	84° 39' 20" W	2.0	3.9
02/05/81	09:33	15	09° 46' 05" N	84° 39' 20" W	2.0	3.6
02/05/81	10:12	14	09° 46' 00" N	84° 40' 30" W	Surface	6.5
02/05/81	10:12	14	09° 46' 00" N	84° 40' 30" W	Surface	5.1
02/05/81	10:12	14	09° 46' 00" N	84° 40' 30" W	2.0	1.7
02/05/81	10:12	14	09° 46' 00" N	84° 40' 30" W	2.0	4.8
02/05/81	10:32	F3	09° 45' 50" N	84° 40' 05" W	Surface	2.7
02/05/81	10:32	F3	09° 45' 50" N	84° 40' 05" W	Surface	****
02/05/81	10:32	F3	09° 45' 50" N	84° 40' 05" W	4.0	1.3
02/05/81	10:32	F3	09° 45' 50" N	84° 40' 05" W	4.0	1.4
02/05/81	10:40	F4	09° 45' 50" N	84° 40' 05" W	Surface	1.7
02/05/81	10:40	F4	09° 45' 50" N	84° 40' 05" W	4.0	1.5
02/05/81	11:04	13	09° 45' 45" N	84° 42' 10" W	Surface	2.0
02/05/81	11:04	13	09° 45' 45" N	84° 42' 10" W	Surface	1.4
02/05/81	11:04	13	09° 45' 45" N	84° 42' 10" W	5.0	1.0
02/05/81	11:29	12	09° 45' 25" N	84° 43' 50" W	Surface	1.6
02/05/81	11:29	12	09° 45' 25" N	84° 43' 50" W	Surface	****
02/05/81	11:29	12	09° 45' 25" N	84° 43' 50" W	3.5	0.9

Table 2. Continued

DATE	TIME	STATION	LATITUDE	LONGITUDE	SAMPLE DEPTH (m)	SUSPENDED PARTICULATE CONCENTRATION (mg/l)
02/05/81	11:48	16	09° 43' 30" N	84° 44' 10" W	Surface	2.7
02/05/81	11:48	16	09° 43' 30" N	84° 44' 10" W	4.5	0.8
02/05/81	12:04	17	09° 46' 50" N	84° 42' 50" W	Surface	1.1
02/05/81	12:04	17	09° 46' 50" N	84° 42' 50" W	3.5	1.3
02/05/81	12:20	18	09° 47' 10" N	84° 41' 05" W	Surface	1.4
02/05/81	12:20	18	09° 47' 10" N	84° 41' 05" W	3.8	1.3
02/05/81	12:38	19	09° 47' 40" N	84° 39' 50" W	Surface	2.7
02/05/81	12:38	19	09° 47' 40" N	84° 39' 50" W	2.0	3.4
02/05/81	12:56	20	09° 48' 35" N	84° 40' 30" W	Surface	2.4
02/05/81	12:56	20	09° 48' 35" N	84° 40' 30" W	2.5	1.4
02/05/81	13:12	21	09° 48' 25" N	84° 41' 30" W	Surface	1.7
02/05/81	13:12	21	09° 48' 25" N	84° 41' 30" W	4.0	1.1
02/05/81	13:30	22	09° 48' 15" N	84° 43' 05" W	Surface	1.8
02/05/81	13:30	22	09° 48' 15" N	84° 43' 05" W	4.0	0.4
02/05/81	13:50	23	09° 47' 55" N	84° 44' 50" W	Surface	1.1
02/05/81	13:50	23	09° 47' 55" N	84° 44' 50" W	3.0	1.0
02/05/81	15:50	24	08° 58' 40" N	84° 51' 20" W	Surface	6.0
02/05/81	15:50	24	08° 58' 40" N	84° 51' 20" W	1.5	6.6
02/05/81	16:05	25	08° 59' 00" N	84° 50' 32" W	Surface	6.3
02/05/81	16:05	25	08° 59' 00" N	84° 50' 32" W	1.5	6.9
02/05/81	16:20	26	Hotel Colonial	Dock	Surface	***
02/05/81	16:20	26	Hotel Colonial	Dock	1.0	6.7

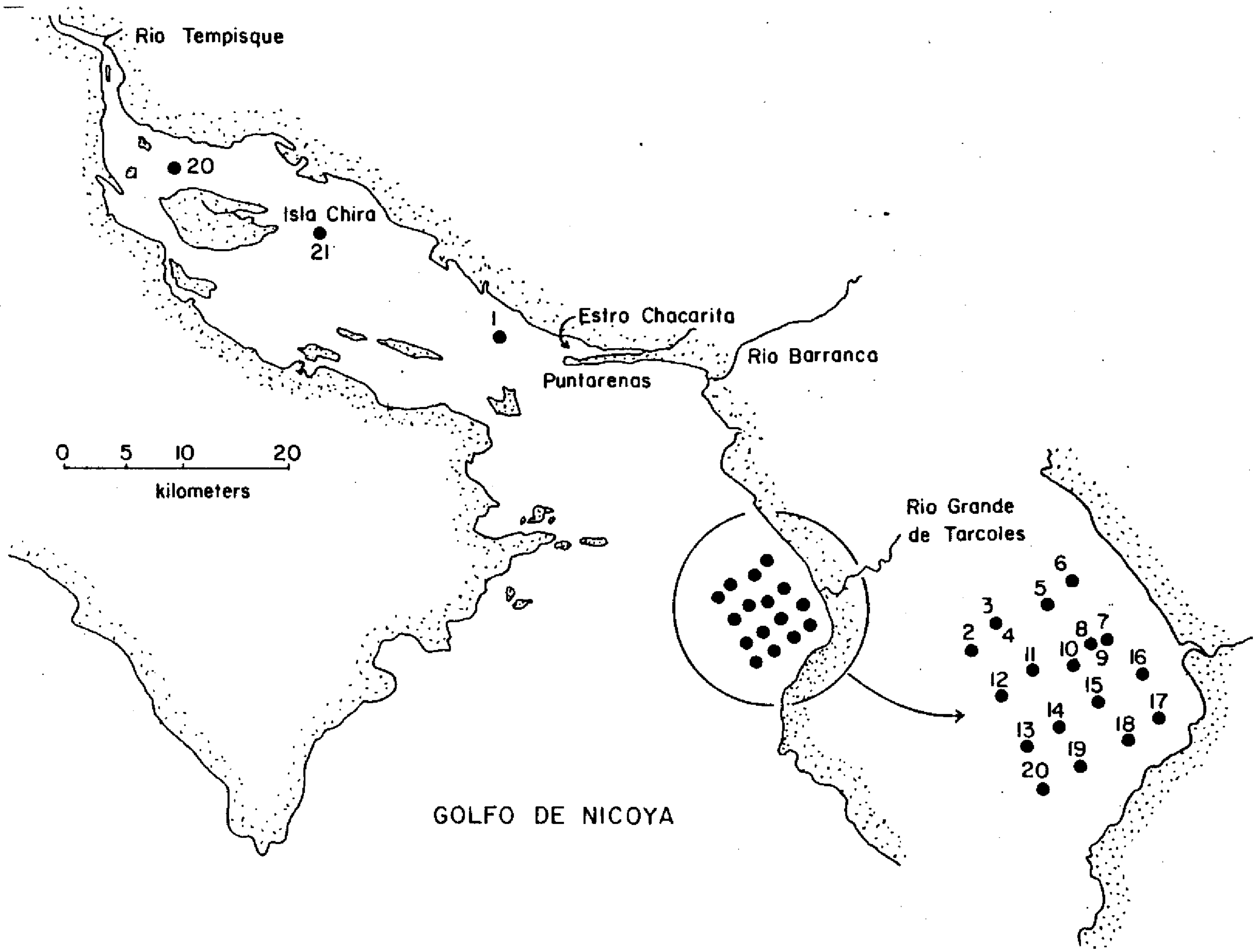

Figure 6: Locations of stations at which suspended particulate concentrations were measured in July, 1981.

Table 3.

Gulf of Nicoya Suspended Particulate Concentration Data

July 25 - 28, 1981

DATE	TIME	STATION	LATITUDE	LONGITUDE	SAMPLE DEPTH (m)	SUSPENDED PARTICULATE CONCENTRATION (mg/l)
07/25/81	15:06	1	10° 00' 00" N	84° 54' 40" W	Surface	3.0
07/25/81	15:06	1	10° 00' 00" N	84° 54' 40" W	Surface	4.5
07/25/81	15:06	1	10° 00' 00" N	84° 54' 40" W	1.3	5.3
07/25/81	16:30	1	10° 00' 00" N	84° 54' 40" W	Surface	3.4
07/25/81	16:30	1	10° 00' 00" N	84° 54' 40" W	1.3	3.5
07/25/81	17:30	1	10° 00' 00" N	84° 54' 40" W	Surface	3.6
07/25/81	17:30	1	10° 00' 00" N	84° 54' 40" W	1.0	4.1
07/25/81	18:30	1	10° 00' 00" N	84° 54' 40" W	Surface	4.5
07/25/81	18:30	1	10° 00' 00" N	84° 54' 40" W	1.0	5.0
07/25/81	19:30	1	10° 00' 00" N	84° 54' 40" W	Surface	3.5
07/25/81	19:30	1	10° 00' 00" N	84° 54' 40" W	1.0	3.1
07/25/81	20:30	1	10° 00' 00" N	84° 54' 40" W	Surface	3.7
07/25/81	20:30	1	10° 00' 00" N	84° 54' 40" W	1.0	3.0
07/25/81	21:30	1	10° 00' 00" N	84° 54' 40" W	Surface	1.9
07/25/81	21:30	1	10° 00' 00" N	84° 54' 40" W	1.0	2.9
07/25/81	22:30	1	10° 00' 00" N	84° 54' 40" W	Surface	2.2
07/25/81	22:30	1	10° 00' 00" N	84° 54' 40" W	1.0	1.8

Table 3. Continued

DATE	TIME	STATION	LATITUDE	LONGITUDE	SAMPLE DEPTH (m)	SUSPENDED PARTICULATE CONCENTRATION (mg/1)
07/25/81	23:30	1	10° 00' 00" N	84° 54' 40" W	Surface	2.9
07/25/81	23:30	1	10° 00' 00" N	84° 54' 40" W	Surface	3.1
07/25/81	23:30	1	10° 00' 00" N	84° 54' 40" W	1.0	2.6
07/26/81	00:30	1	10° 00' 00" N	84° 54' 40" W	Surface	3.0
07/26/81	00:30	1	10° 00' 00" N	84° 54' 40" W	1.0	2.7
07/26/81	01:30	1	10° 00' 00" N	84° 54' 40" W	Surface	3.2
07/26/81	01:30	1	10° 00' 00" N	84° 54' 40" W	1.0	2.8
07/26/81	02:30	1	10° 00' 00" N	84° 54' 40" W	Surface	2.8
07/26/81	02:30	1	10° 00' 00" N	84° 54' 40" W	1.0	3.4
07/26/81	11:24	2	09° 46' 50" N	84° 43' 55" W	Surface	1.4
07/26/81	11:24	2	09° 46' 50" N	84° 43' 55" W	Surface	1.9
07/26/81	11:24	2	09° 46' 50" N	84° 43' 55" W	1.0	0.6
07/26/81	11:45	3	09° 47' 30" N	84° 43' 15" W	Surface	1.9
07/26/81	11:45	3	09° 47' 30" N	84° 43' 15" W	Surface	2.4
07/26/81	11:45	3	09° 47' 30" N	84° 43' 15" W	5.0	3.2
07/26/81	12:00	4	09° 47' 30" N	84° 43' 15" W	Surface	2.8
07/26/81	12:00	4	09° 47' 30" N	84° 43' 15" W	5.0	2.4
07/26/81	12:15	5	09° 48' 05" N	84° 42' 05" W	Surface	2.4
07/26/81	12:15	5	09° 48' 05" N	84° 42' 05" W	4.5	2.8
07/26/81	12:30	6	09° 48' 40" N	84° 42' 15" W	Surface	3.0
07/26/81	12:30	6	09° 48' 40" N	84° 42' 15" W	4.5	2.1

Table 3. Continued

DATE	TIME	STATION	LATITUDE	LONGITUDE	SAMPLE DEPTH (m)	SUSPENDED PARTICULATE CONCENTRATION (mg/l)
07/26/81	12:45	7	09° 47' 10" N	84° 40' 20" W	Surface	2.6
07/26/81	12:45	7	09° 47' 10" N	84° 40' 20" W	3.0	1.8
07/26/81	12:45	7	09° 47' 10" N	84° 40' 20" W	3.0	0.6
07/26/81	13:00	8	09° 47' 05" N	84° 40' 40" W	Surface	2.6
07/26/81	13:00	8	09° 47' 05" N	84° 40' 40" W	2.5	1.5
07/26/81	13:15	9	09° 47' 05" N	84° 40' 40" W	Surface	3.2
07/26/81	13:15	9	09° 47' 05" N	84° 49' 40" W	2.5	2.0
07/26/81	13:30	10	09° 46' 30" N	84° 41' 10" W	Surface	1.9
07/26/81	13:30	10	09° 46' 30" N	84° 41' 10" W	2.5	1.4
07/26/81	13:45	11	09° 46' 20" N	84° 42' 10" W	Surface	1.1
07/26/81	13:45	11	09° 46' 20" N	84° 42' 10" W	3.0	1.4
07/26/81	14:00	12	09° 45' 40" N	84° 43' 00" W	Surface	1.4
07/26/81	14:00	12	09° 45' 40" N	84° 43' 00" W	4.5	0.9
07/26/81	14:15	13	09° 44' 20" N	84° 42' 20" W	Surface	2.9
07/26/81	14:15	13	09° 44' 20" N	84° 42' 20" W	Surface	2.3
07/26/81	14:15	13	09° 44' 20" N	84° 42' 20" W	3.0	1.8
07/26/81	14:30	14	09° 44' 50" N	84° 41' 30" W	Surface	3.6
07/26/81	14:30	14	09° 44' 50" N	84° 41' 30" W	2.3	2.5
07/26/81	14:48	15	09° 45' 30" N	84° 40' 30" W	Surface	3.4
07/26/81	14:48	15	09° 45' 30" N	84° 40' 30" W	2.0	0.9
07/26/81	15:01	16	09° 46' 20" N	84° 39' 20" W	Surface	2.6
07/26/81	15:01	16	09° 46' 20" N	84° 39' 20" W	2.0	18.9

Table 3. Continued

DATE	TIME	STATION	LATITUDE	LONGITUDE	SAMPLE DEPTH (m)	SUSPENDED PARTICULATE CONCENTRATION (mg/l)
07/26/81	15:15	17	09° 45' 10" N	84° 38' 55" W	Surface	3.8
07/26/81	15:15	17	09° 45' 10" N	84° 38' 55" W	1.0	2.8
07/26/81	15:32	18	09° 44' 30" N	84° 39' 40" W	Surface	2.8
07/26/81	15:47	19	09° 43' 50" N	84° 40' 55" W	4.5	1.4
07/26/81	16:02	20	09° 43' 10" N	84° 41' 50" W	Surface	6.4
07/26/81	16:02	20	09° 43' 10" N	84° 41' 50" W	3.5	3.0
07/27/81	13:45	21	10° 08' 15" N	85° 11' 35" W	Surface	3.9
07/27/81	13:45	21	10° 08' 15" N	85° 11' 35" W	2.0	8.1
07/27/81	14:45	21	10° 08' 15" N	85° 11' 35" W	Surface	7.3
07/27/81	14:45	21	10° 08' 15" N	85° 11' 35" W	1.0	7.4
07/27/81	15:45	21	10° 08' 15" N	85° 11' 35" W	Surface	14.8
07/27/81	15:45	21	10° 08' 15" N	85° 11' 35" W	Surface	16.8
07/27/81	15:45	21	10° 08' 15" N	85° 11' 35" W	1.0	17.2
07/27/81	15:45	21	10° 08' 15" N	85° 11' 35" W	1.0	10.9
07/27/81	16:45	21	10° 08' 15" N	85° 11' 35" W	Surface	10.0
07/27/81	16:45	21	10° 08' 15" N	85° 11' 35" W	0.5	60.8
07/27/81	17:45	21	10° 08' 15" N	85° 11' 35" W	Surface	35.2
07/27/81	17:45	21	10° 08' 15" N	85° 11' 35" W	0.3	38.4
07/27/81	18:45	21	10° 08' 15" N	85° 11' 35" W	Surface	97.2
07/27/81	18:45	21	10° 08' 15" N	85° 11' 35" W	Surface	32.4
07/27/81	18:45	21	10° 08' 15" N	85° 11' 35" W	1.0	24.8
07/27/81	18:45	21	10° 08' 15" N	85° 11' 35" W	1.0	26.4

Table 3. Continued

DATE	TIME	STATION	LATITUDE	LONGITUDE	SAMPLE DEPTH (m)	SUSPENDED PARTICULATE CONCENTRATION (mg/1)
07/27/81	19:45	21	10° 08' 15" N	85° 11' 35" W	Surface	6.0
07/27/81	19:45	21	10° 08' 15" N	85° 11' 35" W	2.0	10.0
07/27/81	20:45	21	10° 08' 15" N	85° 11' 35" W	Surface	9.0
07/27/81	21:45	21	10° 08' 15" N	85° 11' 35" W	Surface	6.8
07/27/81	21:45	21	10° 08' 15" N	85° 11' 35" W	2.0	5.9
07/27/81	22:45	21	10° 08' 15" N	85° 11' 35" W	Surface	2.8
07/27/81	22:45	21	10° 08' 15" N	85° 11' 35" W	Surface	16.6
07/27/81	22:45	21	10° 08' 15" N	85° 11' 35" W	2.0	17.6
07/27/81	22:45	21	10° 08' 15" N	85° 11' 35" W	2.0	12.0
07/27/81	23:45	21	10° 08' 15" N	85° 11' 35" W	2.0	14.8
07/28/81	00:45	21	10° 08' 15" N	85° 11' 35" W	Surface	2.5
07/28/81	00:45	21	10° 08' 15" N	85° 11' 35" W	2.0	29.7
07/28/81	02:05	22	10° 06' 10" N	85° 04' 10" W	Surface	6.1
07/28/81	02:05	22	10° 06' 10" N	85° 04' 10" W	2.0	4.6
07/28/81	03:00	22	10° 06' 10" N	85° 04' 10" W	Surface	1.6
07/28/81	03:00	22	10° 06' 10" N	85° 04' 10" W	2.0	4.8
07/28/81	04:00	22	10° 06' 10" N	85° 04' 10" W	Surface	2.6
07/28/81	04:00	22	10° 06' 10" N	85° 04' 10" W	2.0	2.2
07/28/81	05:00	22	10° 06' 10" N	85" 04' 10" W	Surface	4.1
07/28/81	05:00	22	10° 06' 10" N	85° 04' 10" W	Surface	4.7
07/28/81	05:00	22	10° 06' 10" N	85° 04' 10" W	2.0	8.6
07/28/81	06:05	22	10° 06' 10" N	85° 04' 10" W	Surface	1.0
07/28/81	06:05	22	10° 06' 10" N	83° 04' 10" W	2.0	3.4

Table 3. Continued

DATE	TIME	STATION	LATITUDE	LONGITUDE	SAMPLE DEPTH (m)	SUSPENDED PARTICULATE CONCENTRATION (mg/l)
07/28/81	07:05	22	10° 06' 10" N	85° 04' 10" W	Surface	8.9
07/28/81	07:05	22	10° 06' 10" N	85° 04' 10" W	2.0	8.3
07/28/81	08:05	22	10° 06' 10" N	85° 04' 10" W	Surface	5.4
07/28/81	08:05	22	10° 06' 10" N	85° 04' 10" W	1.5	11.6
07/28/81	09:05	22	10° 06' 10" N	85° 04' 10" W	Surface	4.4
07/28/81	09:05	22	10° 06' 10" N	85° 04' 10" W	1.5	9.8
07/28/81	10:05	22	10° 06' 10" N	85° 04' 10" W	Surface	4.7
07/28/81	10:05	22	10° 06' 10" N	85° 04' 10" W	2.0	3.7
07/28/81	10:05	22	10° 06' 10" N	85° 04' 10" W	2.0	4.2
07/28/81	11:05	22	10° 06' 10" N	85° 04' 10" W	Surface	5.0
07/28/81	11:05	22	10° 06' 10" N	85° 04' 10" W	1.5	5.5
07/28/81	12:05	22	10° 06' 10" N	85° 04' 10" W	Surface	4.0
07/28/81	12:05	22	10° 06' 10" N	85° 04' 10" W	2.0	5.1
07/28/81	13:05	22	10° 06' 10" N	85° 04' 10" W	Surface	6.3
07/28/81	13:05	22	10° 06' 10" N	85° 04' 10" W	Surface	8.4
07/28/81	13:05	22	10° 06' 10" N	85° 04' 10" W	2.0	2.5
07/28/81	13:05	22	10° 06' 10" N	85" 04' 10" W	2.0	1.6

The concentration of particulate material filtered from each sample was then calculated and recorded in units of mg/ℓ (Strickland and Parson, 1972).

3.2.2 Results of Suspended Particulate Analysis

The results of suspended particulate concentration analysis of samples collected on February 4 and 5, 1981 are shown in Table 2. Samples collected prior to 15:50 on February 5 represent stations 8 through 23 adjacent to the Rio Grande de Tarcoles. Values averaged over the secchi depth ranged from 1.1 mg/ℓ offshore at station 16 to 7.2 mg/ℓ inshore at station 15. The vertical distribution of suspended particulate concentration at a majority of stations adjacent to the Rio Grande de Tarcoles shows higher concentrations at the surface than at the secchi depth. Stations where both surface and subsurface concentrations are equal or where concentrations increase with depth were generally located 5.0 km or more offshore.

Samples collected between 15:50 and 16:20 on February 5 represent stations 24, 25 and 26 located in Estero Chacarita between Punturenas and the Hotel Colonial docks (see Figure 5). Suspended particulate concentrations averaged over the sechhi depth increased slightly from 6.3 mg/ℓ to 6.7 mg/ℓ between stations 24 and 26 respectively. The vertical distribution of concentrations exhibited a tendency to increase with depth.

Error analysis performed upon five replicates of samples collected in February indicated an error of ± 17.0% in the suspended particulate concentration values.

The results of suspended particulate concentration analysis of samples collected on July 25-28, 1981 are shown in Table 3. The data represents three 12 hour tidal stations located in the upper portion of the Gulf (Stations 1, 19 and 20) and a grid arrangement of 16 stations adjacent to the Rio Grande de Tarcoles similar to those sampled in February of 1981 (see Figure 6). Values averaged over the secchi depth representing samples collected at tidal station 1 were plotted against time and are shown in Figure 7. Maximum concentrations of between 3.5 mg/ℓ and 4.8 mg/ℓ were noted during the low tide portion of the tidal phase when a maximum influence from the Rio Tempisque would be expected. Minimum values ranging from 2.0 mg/ℓ to 2.4 mg/ℓ occured within an hour of high tide as less turbid water from the central and lower portion of the Gulf are carried northward with the flooding tide. Similar data representing tidal stations 21 and 22 are presented in Figure 8 and 9 respectively. At station 21, maximum concentration values were again recorded in the low tide portion of the tidal cycle while minimum values were noted at high tide. At station 22, maximum values were recorded approximately 3 hours after high tide and decreased as high tide approached. Trends in the data representing the low tide portion of the tidal cycle appeared less obvious than those representing stations 1 or 21 as values ranged between 2.2 mg/ℓ and 5.8 mg/ℓ.

Samples collected between 11:24 and 16:02 on July 26, 1981 represent stations adjacent to the Rio Grande de Tarcoles. Values averaged over the secchi depth range from 1.2 mg/ℓ offshore at station 11 to 10.8 mg/ℓ inshore at station 15 (see Figure 6). Similar to the February data, the vertical distribution of suspended particulate concentration at a majority of stations exhibited higher concentrations at the surface than at the secchi depth. Stations where concentration values increase with depth

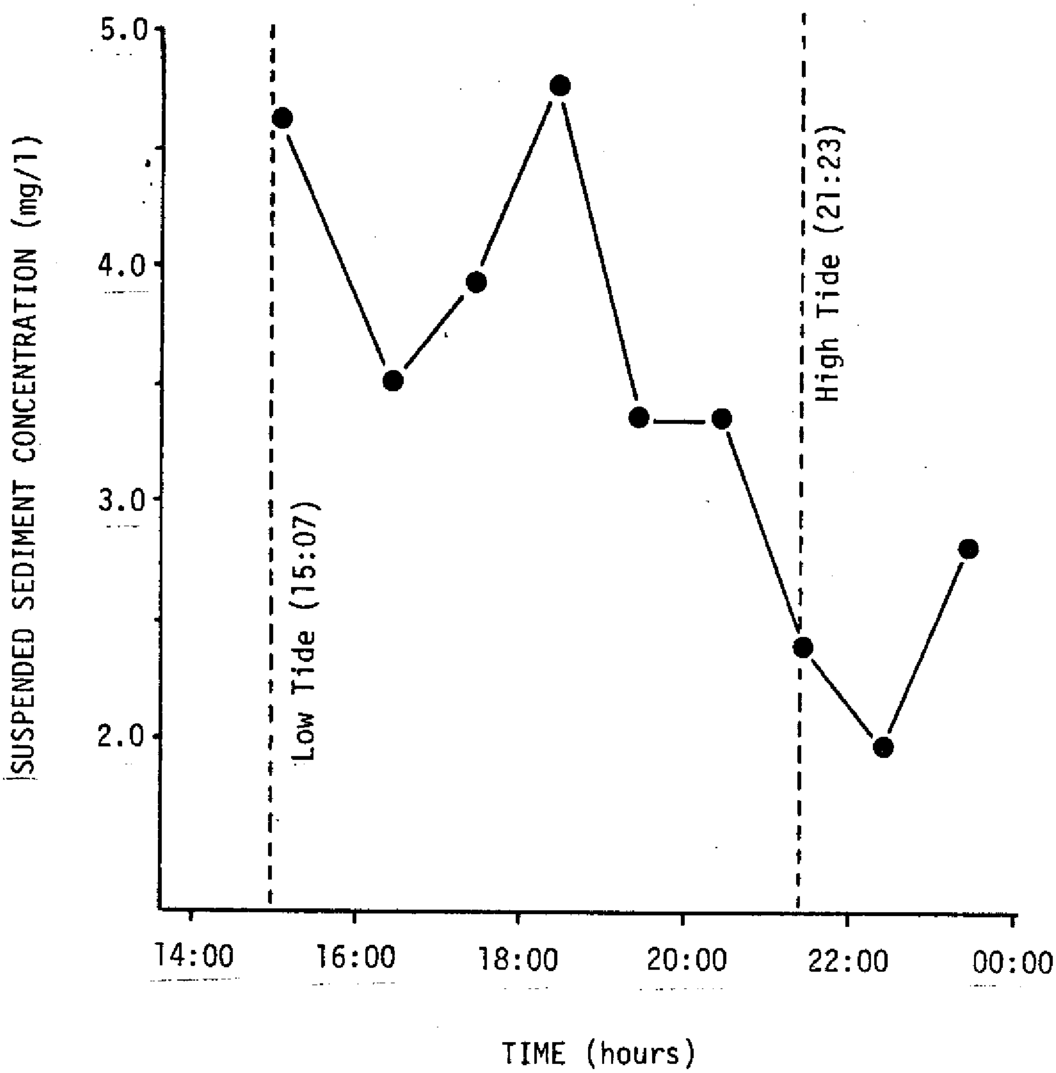

Figure 7: Plot of suspended particulate concentration versus time for station 1 sampled on July 25, 1981.

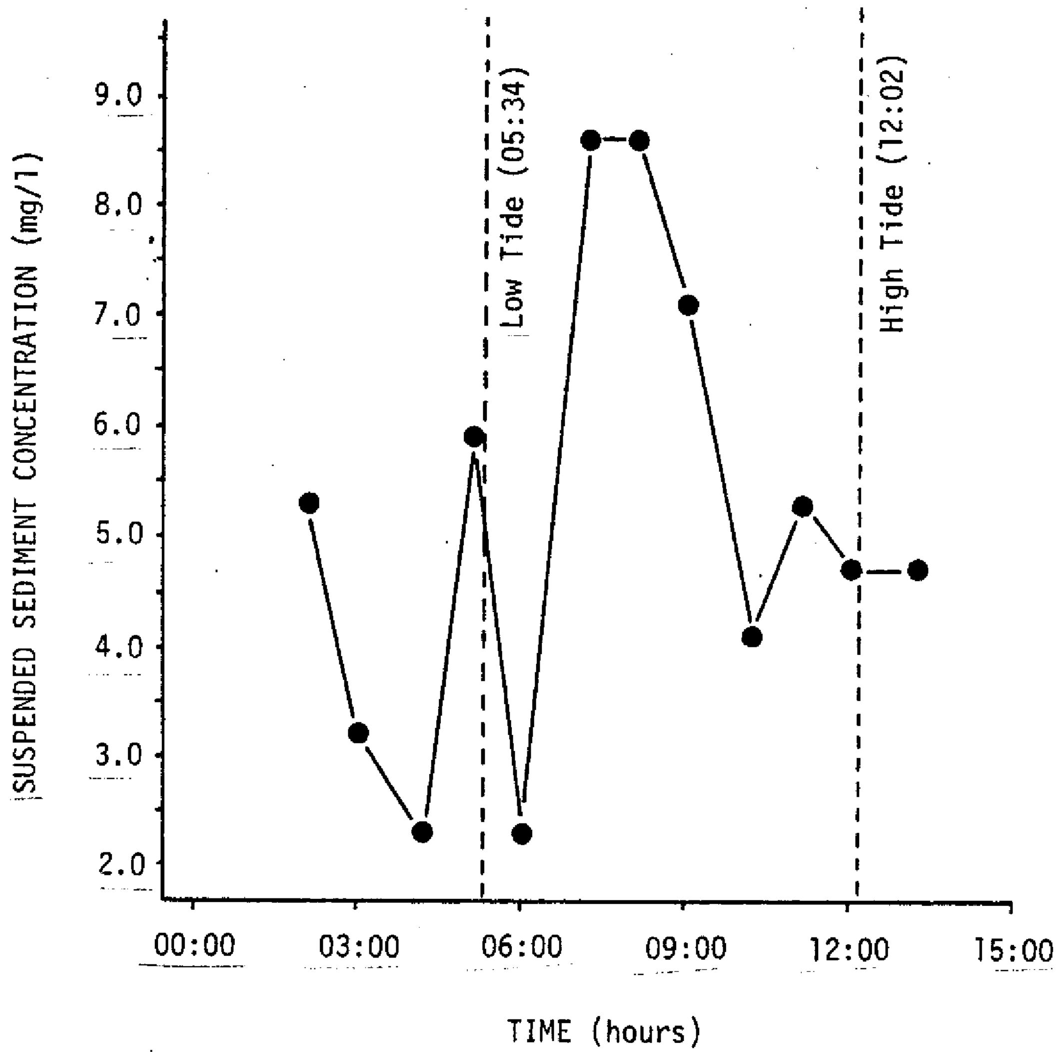

Figure 8: Plot of suspended particulate concentration versus time for station 21 sampled on July 27, 1981.

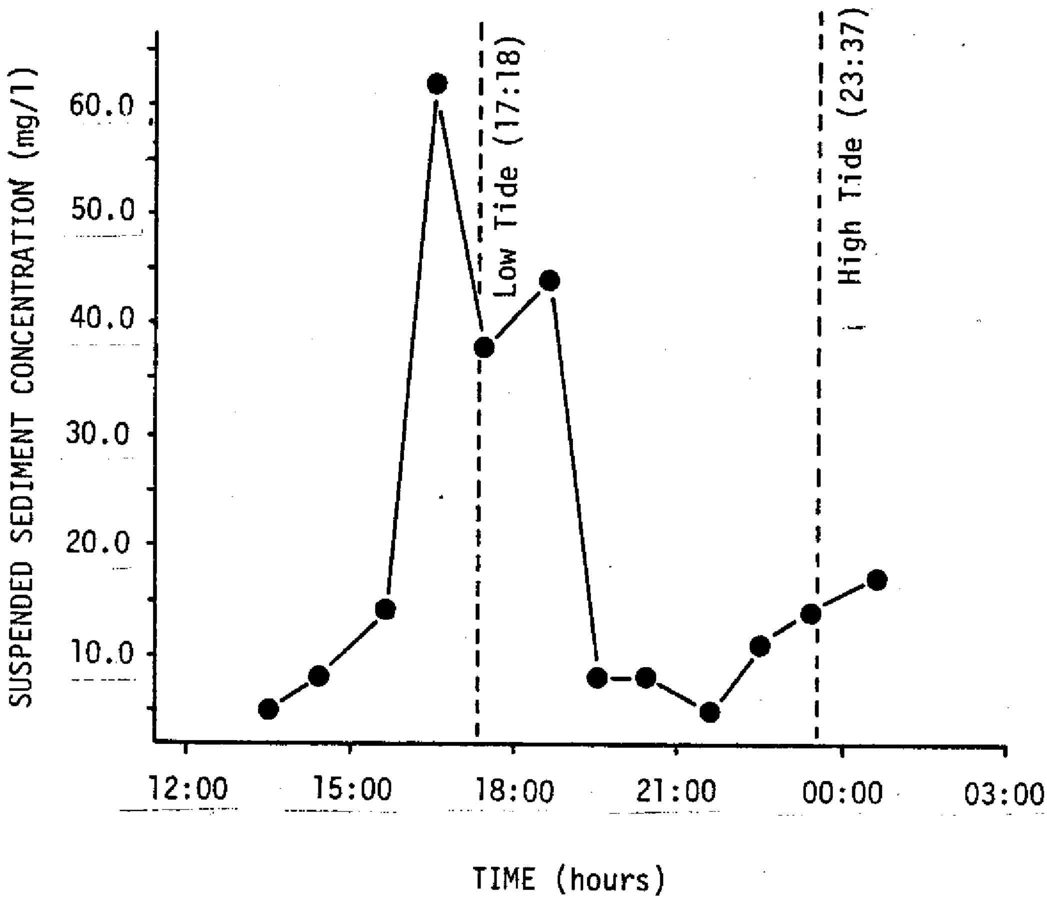

Figure 9: Plot of suspended particulate concentration versus time for station 22 sampled on July 28, 1981.

were located greater than 6.5 km from the river mouth.

Error analysis performed upon 16 sample replicates collected in July indicated an error of 20% in the suspended particulate concentration values.

3.3 Salinity, Temperature and Dissolved Oxygen

3.3.1 Materials and Methods

Measurements for salinity, temperature and dissolved oxygen were made throughout the Gulf of Nicoya on April 18, 1980, February 3-5, 1981 and July 25-28, 1981. The latitude and longitude of each station is given in Tables 4, 5 and 6 respectively. Station locations are shown for February and July sampling dates in Figures 10 and 11 respectively. Temperature and salinity were measured in situ throughout varying portions of the water column with an Interocean CSTD, Model 514. Dissolved oxygen measurements were also measured in situ using a YSI Model 51B oxygen meter. The oxygen meter was calibrated internally before each measurement and occasionally compared with standard Winkler titration of similar water samples (Strickland and Parsons, 1972).

At each station, vertical profiles of salinity, temperature and dissolved oxygen were obtained starting at the surface and continuing down through the water column to at least the secchi depth. In most cases, measurements were recorded at one meter increments. Occasionally during each of the sampling missions, strong fronts were encountered. When this occurred, vertical profiles of all three measurements were recorded on both sides of the front approximately 10-20 m from the foam line or color demarcation. The position of all fronts investigated are presented in Table 7 and are shown geographically for April and February in Figure 12 and for July in Figure 13.

TABLE 4.

Salinity, Temperature and Dissolved Oxygen Station Locations

April, 1980

STATION #	LATITUDE	LONGITUDE
1	09° 47' 00" N	84° 40' 45" W
2	09° 46' 50" N	84° 39' 30" W
3	09° 46' 50" N	84° 39' 30" W
4	09° 46' 50" N	84° 39' 30" W
5	09° 46' 45" N	84° 39' 32" W
6	09° 46' 37" N	84° 39' 20" W

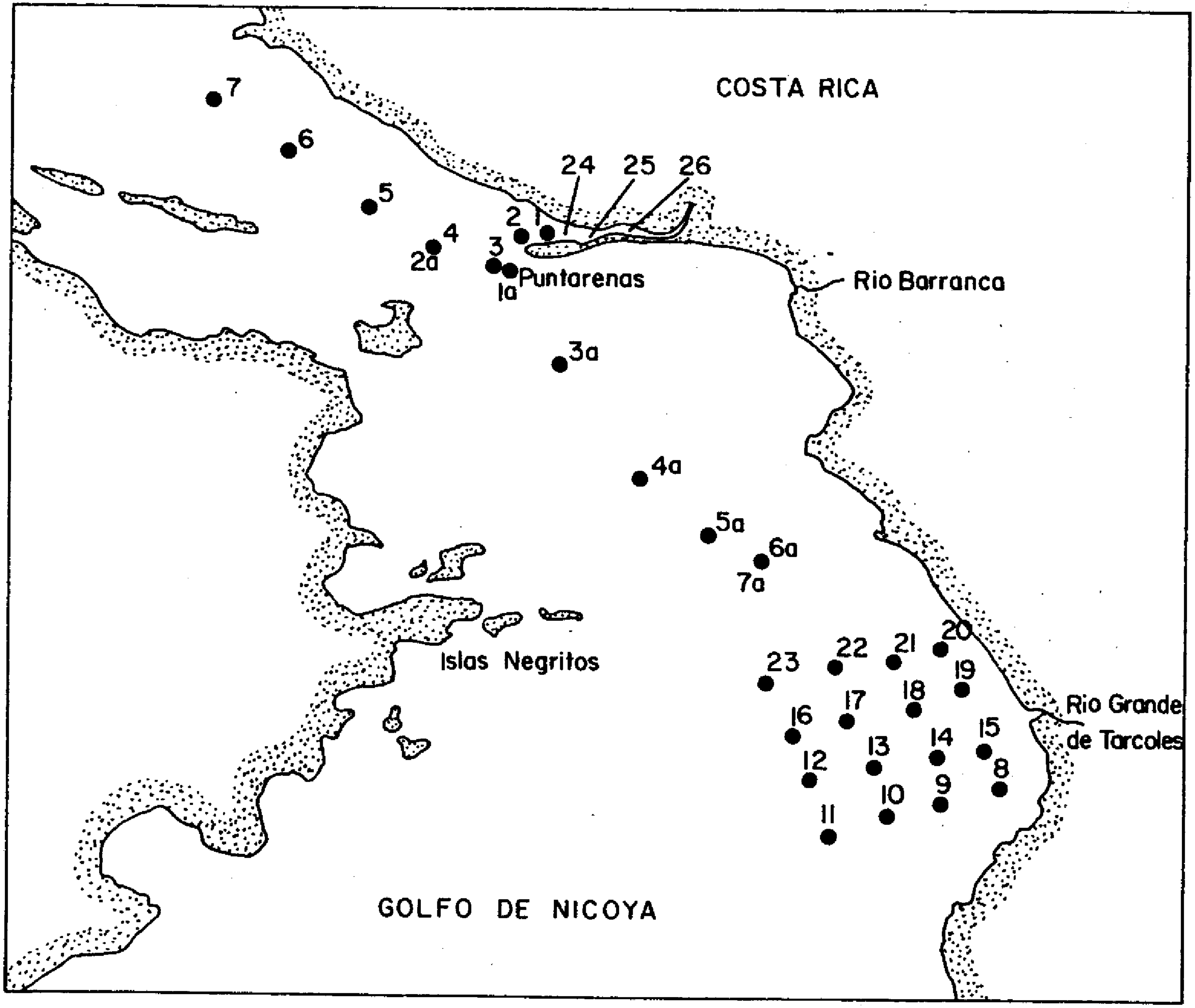

Figure 10: Locations of stations at which salinity, temperature, and dissolved oxygen was measured in February, 1981.

TABLE 5.

Salinity, Temperature and Dissolved Oxygen Station Locations

February, 1981

STATION #	LATITUDE	LONGITUDE
1	09° 59' 00" N	84° 59' 32" W
2	09° 58' 40" N	84° 51' 20" W
3	09° 58' 10" N	84° 51' 40" W
4	09° 58' 59" N	84° 53' 20" W
5	09° 59' 40" N	84° 55' 10" W
6	10° 01' 00" N	84° 57' 00" W
7	10° 02' 15" N	84° 58' 40" W
1a	09° 58' 40" N	84° 51' 20" W
2a	09° 58' 50" N	84° 53' 20" W
3a	09° 55' 50" N	84° 50' 10" W
4a	09° 53' 05" N	84° 48' 10" W
5a	09° 51' 30" N	84° 46' 15" W
6a	09° 50' 50" N	84° 45' 10" W
7a	09° 50' 50" N	84° 45' 10" W
8	09° 45' 10" N	84° 39' 00" W
9	09° 44' 40" N	84° 40' 30" W
10	09° 44' 30" N	84° 41' 50" W
11	09° 44' 05" N	84° 43' 20" W
12	09° 45' 25" N	84° 43' 50" W
13	09° 46' 00" N	84° 41' 50" W
14	09° 46' 00" N	84° 40' 45" W
15	09° 46' 05" N	84° 39' 20" W
16	09° 46' 10" N	84° 39' 00" W
17	09° 46' 50" N	84° 42' 50" W
18	09° 47' 10" N	84° 41' 05" W
19	09° 47' 40" N	84° 39' 50" W
20	09° 48' 35" N	84° 40' 30" W
21	09° 48' 25" N	84° 41' 30" W

TABLE 5 Continued.

STATION #	LATITUDE	LONGITUDE
22	09° 48' 15" N	84° 43' 05" W
23	09° 47' 55" N	84° 44' 50" W
24	09° 58' 40" N	84° 51' 20" W
25	09° 59' 00" N	84° 50' 32" W
26	Hotel Colonial Dock	
F1	09° 46' 40' N	84° 40' 40" W
F2	09° 46' 40' N	84° 40' 40" W
F3	09° 45' 50' N	84° 40' 05" W
F4	09° 45' 50" N	84° 40' 50" W

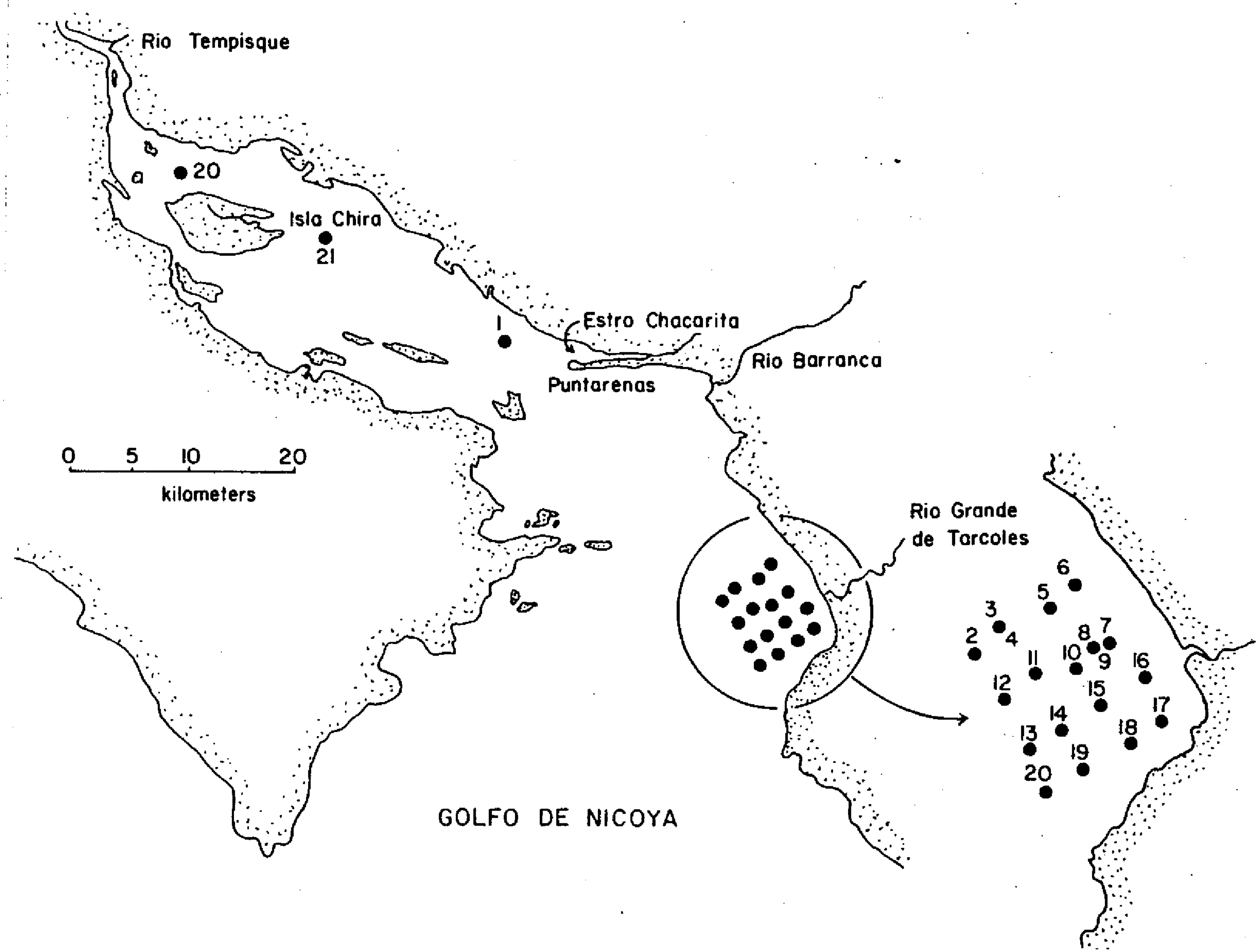

Figure 11: Locations of stations at which salinity, temperature, and dissolved oxygen was measured in July, 1981.

TABLE 6.

Salinity, Temperature and Dissolved Oxygen Station Locations

July, 1981

STATION #	LATITUDE	LONGTITUDE
1	10° 00' 00" N	84° 54' 40" W
2	09° 46' 50" N	84° 43' 55" W
3	09° 46' 30" N	84° 43' 15" W
4	09° 46' 30" N	84° 43' 15" W
5	09° 48" 05" N	84° 42' 05" W
6	09° 48' 50" N	84° 41' 15" W
7	09° 47' 10" N	84° 40' 20" W
8	09° 47' 05" N	84° 40' 40" W
9	09° 48' 05" N	84° 40' 40" W
10	09° 46' 30" N	84° 41' 10" W
11	09° 46' 20" N	84° 42' 10" W
12	09° 45' 40" N	84° 43' 00" W
13	09° 44' 20" N	84° 42' 20" W
14	09° 44' 50" N	84° 41' 30" W
15	09° 45' 30" N	84° 40' 30" W
16	09° 46' 20" N	84° 30' 20" W
17	09° 45' 10" N	84° 38' 55" W
18	09° 44' 30" N	84° 30' 40" W
19	09° 43' 50" N	84° 40' 55" W
20	09° 43' 10" N	84° 41' 50" W
21	10° 08' 15" N	85° 11' 35" W
22	10° 06' 10" N	85° 40' 10" W

TABLE 7.

Locations of Observed Fronts

DATA	TIME	STATIONS	LATITUDE	LONGITUDE
04/18/80	09:12	2,3,4	09° 46' 50" N	84° 39' 30" W
02/04/81	10:30	6a,7a	09° 50' 50" N	84° 45' 10" W
02/05/81	08:53	F1,F2	09° 46' 40" N	84° 40' 46" W
02/05/81	10:32	F3,F4	09° 45' 50" N	84° 40' 05" W
07/26/81	11:45	3,4	09° 46' 30" N	84° 43' 15" W
07/26/81	13:05	8,9	09° 47' 05" N	84° 40' 40" W

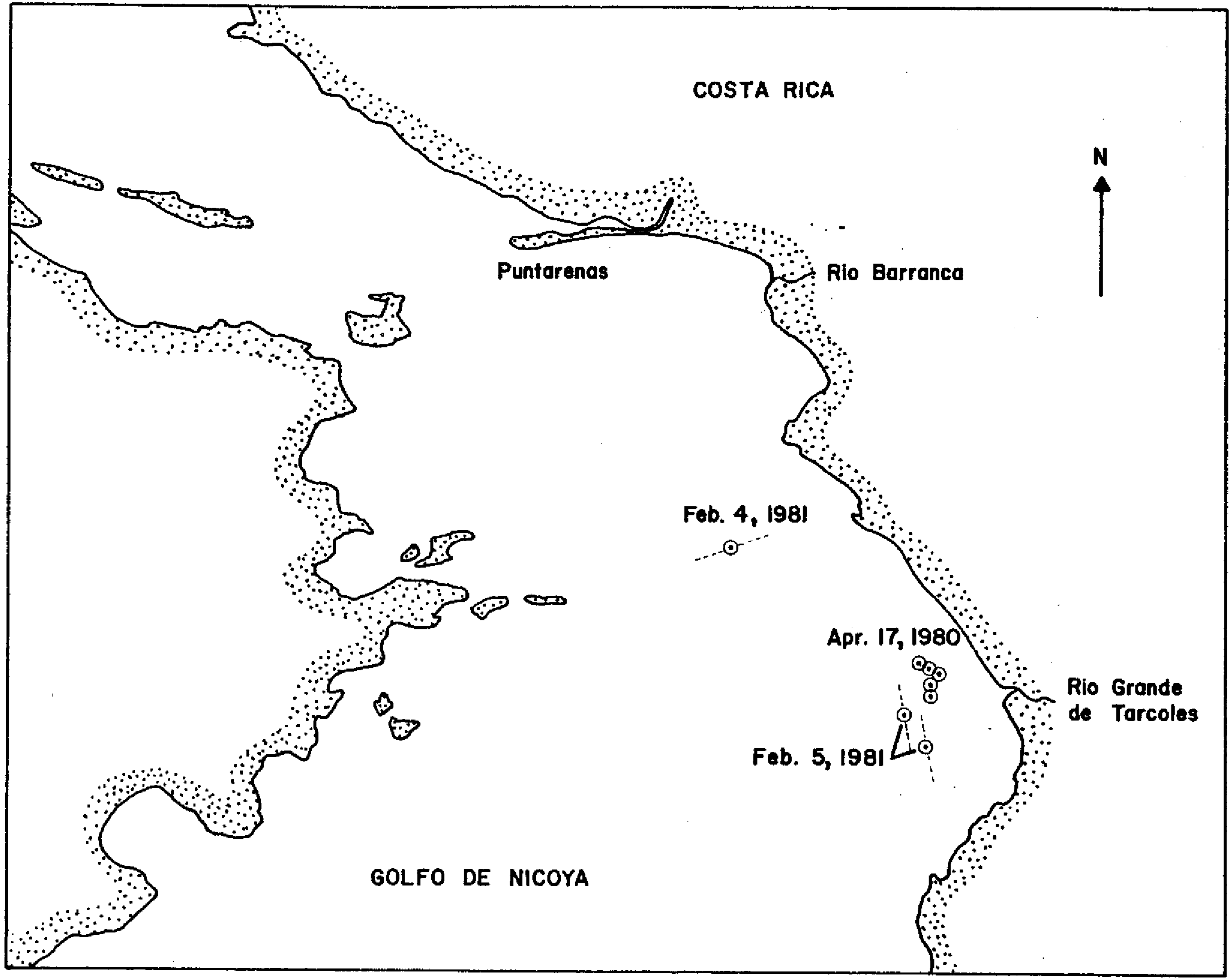

Figure 12: Locations of stations at which fronts were investigated in April, 1980 and February, 1981.

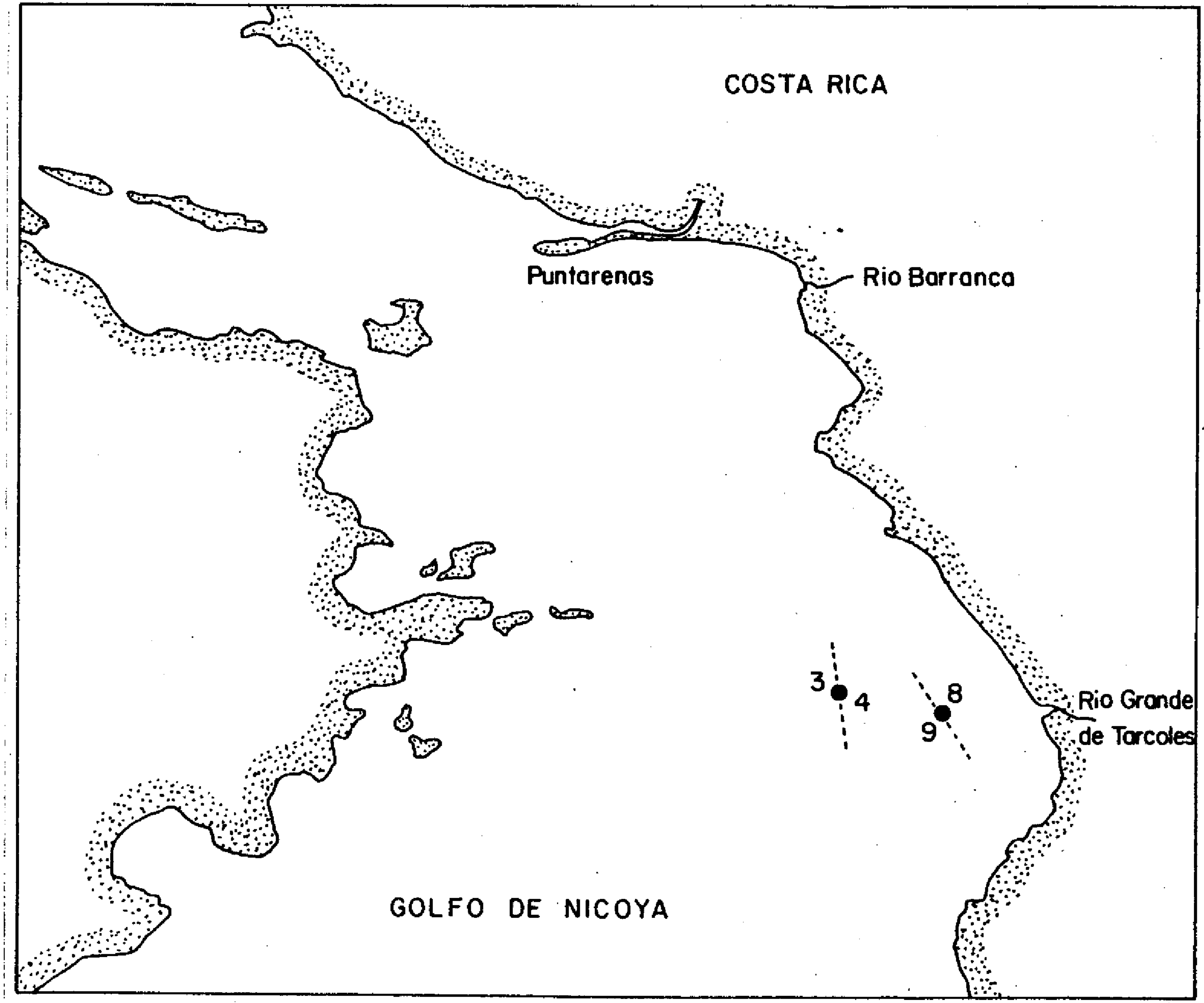

Figure 13: Locations of stations at which fronts were investigated in July, 1981.

3.3.2 Results of Salinity, Temperature and Dissolved Oxygen

Salinity, temperature and dissolved oxygen data collected in April, 1980 is presented in Table 8. Stations 2 through 6 were located along a strong front which was encountered adjacent to the Rio Grande de Tarcoles (see Figure 12). The front was believed to be the leading edge of the Rio Grande de Tarcoles River plume. Stations 2 and 6 were positioned outside of the plume (i.e. the ocean side of the front) while stations 3, 4 and 5 were positioned inside of the plume (20 to 100 meters from the front). Salinity values were found to range within the plume from 24.0 ‰ to 28.0 ‰. Salinity outside of the plume was slightly higher ranging from 26.0 ‰ to 30.0 ‰. Values were found to increase with depth on either side of the front. Water temperature was quite similar on both sides of the front and, in most cases, decreased with depth from 29°C - 30°C at the surface to 28°C at 8 meters. However, at two stations located within the plume (stations and 3 and 4), temperature increased slightly with depth from 30°C at the surface to 31°C at 8 meters. Dissolved oxygen values were high in most cases and ranged from 73% saturation to 113% saturation. No significant differences in dissolved oxygen was noted across the front.

Salinity, temperature and dissolved oxygen data collected in February and July, 1981 are shown in Tables 9 and 10 respectively. Data collected in February is representative of Costa Rica's dry season while the July data is characteristic of the rainy season.

In an attempt to monitor seasonal variations in salinity, temperature and dissolved oxygen, a grid of 16 stations were sampled in both February and July adjacent to the Rio Grande de Tarcoles (see Figures 10 and 11). Surface salinity values were found to average 2.5 ‰ higher during the

Table 8.

Gulf of Nicoya Salinity, Temperature and Dissolved Oxygen Data

April, 1980

DATE	TIME	STATION #	SAMPLE DEPTH (m)	SALINITY (°/₀₀)	TEMPERATURE (°C)	DISSOLVED OXYGEN (%)
04/18/80	08:36	1	Surface	29.0	30.0	82
04/18/80	08:36	1	4.0	29.0	29.5	87
04/18/80	08:36	1	8.0	28.9	31.0	91
04/18/80	09:12	2	Surface	27.0	30.0	105
04/18/80	09:12	2	4.0	26.0	29.0	113
04/18/80	09:12	2	8.0	29.0	28.0	109
04/18/80	09:22	3	Surface	27.0	30.0	***
04/18/80	09:22	3	4.0	****	30.0	***
04/18/80	09:22	3	8.0	27.0	31.0	***
04/18/80	09:30	4	Surface	24.0	30.0	90
04/18/80	09:30	4	4.0	24.0	30.0	106
04/18/80	09:30	4	6.0	25.0	31.0	106
04/18/80	09:30	4	8.0	27.0	31.0	108
04/18/80	09:40	5	Surface	26.0	29.0	78
04/18/80	09:40	5	2.0	27.8	****	***
04/18/80	09:40	5	4.0	28.0	28.5	92
04/18/80	09:40	5	6.0	27.5	****	***
04/18/80	09:40	5	8.0	27.5	28.0	86
04/18/80	09:53	6	Surface	29.0	29.0	73
04/18/80	09:53	6	2.0	30.0	29.0	86
04/18/80	09:53	6	4.0	28.0	28.0	79
04/18/80	09:53	6	8.0	28.0	28.0	79

Table 9.

Gulf of Nicoya Salinity, Temperature and Dissolved Oxygen Data

February, 1981

DATA	TIME	STATION #	SAMPLE DEPTH	SALINITY (°/₀₀)	TEMPERATURE (°C)	DISSOLVED OXYGEN (%)
02/03/81	08:35	1	Surface	26.0	28.0	84
02/03/81	08:50	2	Surface	34.0	28.0	101
02/03/81	09:00	3	Surface	34.0	28.0	104
02/03/81	09:13	4	Surface	32.0	28.0	114
02/03/81	09:29	5	Surface	31.0	27.8	121
02/03/81	09:45	6	Surface	32.0	27.6	121
02/03/81	10:04	7	Surface	30.0	28.2	115
02/03/81	10:34	7	Surface	32.0	28.3	111
02/03/81	11:00	7	Surface	33.0	27.8	126
02/03/81	11:30	7	Surface	33.0	27.6	123
02/03/81	12:00	7	Surface	33.0	28.0	119
02/03/81	12:35	7	Surface	33.0	27.9	119
02/03/81	13:00	7	Surface	33.0	27.6	121
02/03/81	13:30	7	Surface	34.0	27.5	114
02/03/81	14:00	7	Surface	34.0	27.5	114
02/03/81	14:30	7	Surface	34.0	27.4	112
02/03/81	15:00	7	Surface	34.0	27.4	116
02/03/81	15:30	7	Surface	33.0	27.2	112
02/03/81	16:00	7	Surface	33.0	27.0	117
02/03/81	16:30	7	Surface	32.0	26.2	114

Table 9. Continued

DATA	TIME	STATION #	SAMPLE DEPTH	SALINITY (°/₀₀)	TEMPERATURE (°C)	DISSOLVED OXYGEN (%)
02/03/81	17:00	6	Surface	30.0	26.0	107
02/03/81	17:15	5	Surface	32.0	27.0	120
02/03/81	17:30	4	Surface	32.0	27.0	115
02/03/81	17:45	3	Surface	32.0	27.5	114
02/03/81	17:54	2	Surface	32.0	28.0	116
02/03/81	18:05	1	Surface	28.0	28.0	126
02/04/81	08:45	1a	Surface	30.0	27.9	116
02/04/81	09:00	2a	Surface	33.0	27.9	121
02/04/81	09:18	3a	Surface	33.0	27.5	123
02/04/81	09:46	4a	Surface	33.0	27.6	121
02/04/81	10:10	5a	Surface	33.0	27.5	119
02/04/81	10:30	6a	Surface	32.0	28.4	119
02/04/81	10:30	6a	5.0	33.0	28.3	86
02/04/81	10:30	6a	15.0	34.0	27.3	80
02/04/81	10:40	7a	Surface	33.0	28.0	119
02/04/81	10:40	7a	5.0	33.0	28.0	111
02/04/81	10:40	7a	15.0	34.0	28.0	81
02/04/81	12:06	8	Surface	33.0	28.9	132
02/04/81	12:30	9	Surface	34.0	28.8	129
02/04/81	13:05	10	Surface	34.0	29.4	127
02/04/81	13:25	11	Surface	34.0	28.5	122
02/04/81	13:42	12	Surface	34.0	29.1	124

Table 9. Continued

DATA	TIME	STATION #	SAMPLE DEPTH	SALINITY (°/₀₀)	TEMPERATURE (°C)	DISSOLVED OXYGEN (%)
02/04/81	14:10	13	Surface	34.0	28.4	109
02/04/81	14:27	14	Surface	34.0	29.0	106
02/04/81	14:44	15	Surface	32.0	29.2	106
02/05/81	08:53	F1	Surface	34.0	28.5	91
02/05/81	08:53	F1	25.0	35.0	25.0	47
02/05/81	09:04	F2	Surface	34.0	28.8	96
02/05/81	09:04	F2	25.0	35.0	25.0	49
02/05/81	09:33	15	Surface	30.0	28.8	104
02/05/81	10:12	14	Surface	30.0	29.2	96
02/05/81	10:32	F3	Surface	34.0	29.2	94
02/05/81	10:40	F4	Surface	34.0	29.2	99
02/05/81	11:04	13	Surface	34.0	29.0	104
02/05/81	11:29	12	Surface	34.0	29.0	106
02/05/81	11:48	16	Surface	34.0	29.0	99
02/05/81	12:04	17	Surface	34.0	29.0	101
02/05/91	12:20	18	Surface	34.0	29.0	99
02/05/81	12:38	19	Surface	34.0	29.0	99
02/05/81	12:56	20	Surface	34.0	28.8	104
02/05/81	13:12	21	Surface	34.0	28.8	101
02/05/81	13:30	22	Surface	34.0	28.7	101
02/05/81	13:50	23	Surface	34.0	28.3	99
02/05/81	15:50	24	Surface	33.0	28.4	84
02/05/81	16:00	25	Surface	32.0	28.2	91
02/05/81	16:15	26	Surface	32.0	28.1	91

Table 10.

Gulf of Nicoya Salinity, Temperature and Dissolved Oxygen Data

July, 1981

DATA	TIME	STATION #	SAMPLE DEPTH	SALINITY (°/₀₀)	TEMPERATURE (°C)	DISSOLVED OXYGEN (%)
07/25/81	15:30	1	Surface	28.2	29.8	103
07/25/81	15:30	1	Surface	28.1	29.7	90
07/25/81	15:30	1	5.0	30.4	27.2	41
07/25/81	15:30	1	10.0	30.9	26.8	41
07/25/81	15:30	1	15.0	31.4	26.5	41
07/25/81	16:30	1	Surface	28.3	29.7	95
07/25/81	16:30	1	5.0	30.5	27.4	49
07/25/81	16:30	1	10.0	30.9	27.0	46
07/25/81	16:30	1	15.0	31.5	26.6	46
07/25/81	17:30	1	Surface	28.3	29.0	89
07/25/81	17:30	1	5.0	28.3	28.8	66
07/25/81	17:30	1	10.0	29.1	28.5	78
07/25/81	17:30	1	15.0	30.7	27.1	46
07/25/81	18:30	1	Surface	28.7	29.0	89
07/25/81	18:30	1	5.0	30.5	27.4	61
07/25/81	18:30	1	10.0	31.7	27.1	63
07/25/81	18:30	1	15.0	32.6	25.5	***
07/25/81	19:30	1	Surface	28.7	29.1	91
07/25/81	19:30	1	5.0	30.3	27.7	74
07/25/81	19:30	1	10.0	31.0	27.2	73
07/25/81	19:30	1	15.0	32.6	25.5	49

Table 10. Continued

DATA	TIME	STATION #	SAMPLE DEPTH	SALINITY (°/₀₀)	TEMPERATURE(°C)	DISSOLVED OXYGEN (%)
07/25/81	20:30	1	Surface	29.2	28.7	86
07/25/81	20:30	1	5.0	31.1	28.2	79
07/25/81	20:30	1	10.0	31.2	27.1	68
07/25/81	20:30	1	15.0	32.7	25.5	48
07/25/81	21:30	1	Surface	30.9	28.1	79
07/25/81	21:30	1	5.0	31.0	27.3	29
07/25/81	21:30	1	10.0	31.3	26.7	27
07/25/81	21:30	1	15.0	32.5	25.6	12
07/25/81	22:30	1	Surface	31.0	28.0	49
07/25/81	22:30	1	5.0	31.0	27.6	42
07/25/81	22:30	1	10.0	31.0	27.3	46
07/25/81	22:30	1	15.0	32.3	25.8	40
07/25/81	23:30	1	Surface	28.6	28.7	86
07/25/81	23:30	1	5.0	30.5	28.0	79
07/25/81	23:30	1	10.0	30.8	27.0	68
07/25/81	23:30	1	15.0	32.1	26.1	48
07/26/81	00:03	1	Surface	28.7	28.6	86
07/26/81	00:30	1	5.0	30.8	27.7	69
07/26/81	00:30	1	10.0	31.1	27.2	68
07/26/81	00:30	1	15.0	32.3	25.9	50
07/26/81	01:30	1	Surface	28.5	28.6	84
07/26/81	01:30	1	5.0	31.2	27.3	59
07/26/81	01:30	1	10.0	30.8	26.8	46
07/26/81	01:30	1	15.0	32.0	25.8	50

Table 10. Continued

DATA	TIME	STATION #	SAMPLE DEPTH	SALINITY (°/₀₀)	TEMPERATURE (°C)	DISSOLVED OXYGEN (%)
07/26/81	02:30	1	Surface	28.4	28.4	74
07/26/81	02:30	1	5.0	30.3	27.5	49
07/26/81	02:30	1	10.0	31.1	26.8	49
07/26/81	02:30	1	15.0	31.9	26.2	48
07/26/81	11:30	2	Surface	31.6	28.8	89
07/26/81	11:30	2	5.0	31.6	28.8	81
07/26/81	11:45	3	Surface	31.2	29.1	81
07/26/81	11:45	3	5.0	31.1	28.9	86
07/26/81	11:55	4	Surface	31.6	28.0	81
07/26/81	11:55	4	5.0	32.6	26.9	56
07/26/81	12:15	5	Surface	31.2	29.2	87
07/26/81	12:15	5	5.0	32.0	27.4	73
07/26/81	12:26	6	Surface	31.7	28.6	89
07/26/81	12:26	6	5.0	31.9	27.4	73
07/26/81	12:45	7	Surface	30.1	29.1	91
07/26/81	12:45	7	5.0	31.2	28.5	91
07/26/81	13:05	8	Surface	29.8	29.2	86
07/26/81	13:05	8	5.0	31.7	28.2	89
07/26/81	13:15	9	Surface	30.0	29.2	91
07/26/81	13:15	9	5.0	31.4	27.9	86
07/26/81	13:30	10	Surface	30.0	29.1	94
07/26/81	13:30	10	5.0	31.7	27.7	81
07/26/81	13:45	11	Surface	30.8	29.2	91
07/26/81	13:45	11	5.0	31.2	28.1	59

Table 10. Continued

DATA	TIME	STATION #	SAMPLE DEPTH	SALINITY (°/₀₀)	TEMPERATURE (°C)	DISSOLVED OXYGEN (%)
07/26/81	14:05	12	Surface	31.4	28.5	86
07/26/81	14:05	12	5.0	31.9	27.6	79
07/26/81	14:15	13	Surface	30.4	29.2	89
07/26/81	14:15	13	5.0	31.7	27.9	69
07/26/81	14:30	14	Surface	30.8	29.4	91
07/26/81	14:30	14	5.0	31.6	28.3	84
07/26/81	14:48	15	Surface	****	****	***
07/26/81	14:48	15	5.0	****	****	***
07/26/81	15:01	16	Surface	30.9	29.1	89
07/26/81	15:01	16	5.0	31.9	27.8	62
07/26/81	15:15	17	Surface	31.0	29.1	89
07/26/81	15:15	17	5.0	31.5	28.2	81
07/26/81	15:32	18	Surface	31.2	28.8	91
07/26/81	15:32	18	5.0	31.8	28.0	69
07/26/81	15:47	19	Surface	31.4	28.8	91
07/26/81	15:47	19	5.0	31.7	27.9	74
07/26/81	16:02	20	Surface	31.8	29.2	89
07/26/81	16:02	20	5.0	31.9	27.9	74
07/27/81	13:45	21	Surface	22.6	30.8	95
07/27/81	13:45	21	5.0	26.0	29.4	68
07/27/81	13:45	21	6.5	26.6	29.2	52
07/27/81	14:45	21	Surface	24.4	29.8	96
07/27/81	14:45	21	5.0	26.3	29.2	56

Table 10. Continued

DATA	TIME	STATION #	SAMPLE DEPTH	SALINITY (°/₀₀)	TEMPERATURE (°C)	DISSOLVED OXYGEN (%)
07/27/81	15:45	21	Surface	20.4	31.0	106
07/27/81	15:45	21	5.0	25.9	29.2	64
07/27/81	16:48	21	Surface	21.5	30.0	90
07/27/81	16:48	21	5.0	25.4	29.4	66
07/27/81	17:48	21	Surface	19.9	29.7	82
07/27/81	17:48	21	5.0	24.6	29.5	69
07/27/81	18:45	21	Surface	21.1	29.9	87
07/27/81	18:45	21	5.0	23.9	29.7	77
07/27/81	19:45	21	Surface	21.6	29.7	90
07/27/81	19:45	21	5.0	24.3	29.5	87
07/27/81	20:45	21	Surface	23.2	29.8	91
07/27/81	20:45	21	5.0	25.1	29.5	74
07/27/81	21:45	21	Surface	24.1	29.8	100
07/27/81	21:45	21	5.0	25.9	29.1	63
07/27/81	22:45	21	Surface	24.9	29.6	87
07/27/81	22:45	21	5.0	26.1	29.1	53
07/27/81	23:45	21	Surface	24.1	29.7	90
07/27/81	23:45	21	5.0	26.1	29.1	38
07/28/81	02:05	22	Surface	27.7	29.1	76
07/28/81	02:05	22	5.0	28.5	28.5	44
07/28/81	02:05	22	8.0	29.4	27.8	40
07/28/81	03:00	22	Surface	27.2	29.4	86
07/28/81	03:00	22	5.0	28.1	28.5	54

Table 10. Continued

DATA	TIME	STATION #	SAMPLE DEPTH	SALINITY (°/∘∘)	TEMPERATURE (°C)	DISSOLVED OXYGEN (%)
07/28/81	04:00	22	Surface	25.9	29.1	89
07/28/81	04:00	22	5.0	27.8	28.6	51
07/28/81	05:00	22	Surface	25.1	29.2	84
07/28/81	05:00	22	5.0	26.9	29.1	48
07/28/81	05:30	22	Surface	24.9	29.1	84
07/28/81	05:30	22	5.0	27.4	28.9	43
07/28/81	06:00	22	Surface	24.8	29.1	78
07/28/81	06:00	22	5.0	27.5	28.9	43
07/28/81	07:05	22	Surface	25.0	29.2	73
07/28/81	07:05	22	5.0	27.5	28.8	38
07/28/81	08:05	22	Surface	25.1	29.1	71
07/28/81	08:05	22	5.0	27.4	28.9	48
07/28/81	09:05	22	Surface	25.2	29.2	78
07/28/81	09:05	22	5.0	28.4	28.5	53
07/28/81	09:05	22	8.0	29.2	28.0	35
07/28/81	10:00	22	Surface	26.0	29.3	84
07/28/81	10:00	22	5.0	27.0	28.9	76
07/28/81	10:00	22	6.0	28.8	28.3	37
07/28/81	11:00	22	Surface	27.4	29.5	85
07/28/81	11:00	22	5.0	28.3	29.8	79
07/28/81	11:00	22	8.0	29.5	28.2	42

Table 10. Continued

DATA	TIME	STATION #	SAMPLE DEPTH	SALINITY(°/°°)	TEMPERATURE (°C)	DISSOLVED OXYGEN (%)
07/28/81	12:00	22	Surface	28.1	29.9	77
07/28/81	12:00	22	5.0	29.5	28.2	44
07/28/81	12:00	22	9.0	29.6	28.9	46
07/28/81	12:00	22	10.0	29.6	28.1	47
07/28/81	13:00	22	Surface	27.6	30.9	75
07/28/81	13:00	22	5.0	29.6	28.6	73
07/28/81	13:00	22	10.0	29.8	28.2	42

dry season than the rainy season as a result of the greatly decreased runoff. Dry season values ranges from 30.0 ‰ at the river mouth to 34.0 ‰ offshore. Rainy season values ranged from 29.8 ‰ at the river mouth to 31.8 ‰ offshore. Surface temperature was found to be slightly higher in the rainy season averaging 30.3°C over the entire grid. Dry season surface temperatures averaged 28.9°C. Unlike the distribution of salinity values, no clear trend was found correlating temperature with the river plume. Percent saturation of dissolved oxygen was found to be significantly higher in the dry season ranging from 99% to 132% as opposed to rainy season values which ranged from 81% to 91%.

Several fronts were investigated in both February and July, the locations for which are given in Figures 12 and 13 as well as Table 7. The only front encountered which was not believed to be connected with the Rio Grande de Tarcoles River plume occured in the central portion of the Gulf approximately 4.5 miles east northeast of Islas Negritos. The orientation of the front was accross the Gulf perpendicular to the Gulf axis. Salinity values increased with depth on both sides of the front to 33.0 ‰ at 5 meters and 34.0 ‰ at 15 meters. Surface salinity values differed only 1.0 ‰ across the front from 32.0 ‰ on the upper Gulf side to 33.0 ‰ on the ocean side. No significant changes in either temperature or dissolved oxygen were noted across the front.

A total of four fronts were observed in close proximity to the Rio Grande de Tarcoles, two in February and two in July. Fronts tended to be strongest in the rainy season with temperature being the most variable water property. Temperature decreased across the fronts in the rainy season an average of 0.9°C in a direction away from the river mouth. No temperature variations were noted across the fronts during the dry season and very small salinity variations were recorded in all four cases. Also in each case, salinity was noted to increase with depth on either side of the fronts while temperature decreased. No trends were observed in the distribution of dissolved oxygen.

3.4 Beam Transmittance and Beam Attenuation

3.4.1 Materials and Methods

Beam transmittance was measured in situ within the surface and near surface waters throughout the Gulf of Nicoya on February 3, 4 and 5, 1981. Station locations were the same as those at which salinity, temperature and dissolved oxygen were measured and are presented in Figure 10 and Table 7. Measurements were made with a Hydroproducts Transmissometer.

Vertical profiles of percent transmittance were obtained over various depths starting at the surface and continuing down through the water column to at least the secchi depth. Measurements were recorded at depth increments of 1.0 meter and, in a few cases, 0.5 meters. On several occasions, strong fronts were encountered. In these instances, vertical profiles were obtained on both sides of the front approximately 10-20 meters from the foam line or color demarcation. Beam attenuation coefficients were calculated for each beam transmittance value with the relationship

$$c = -\frac{1}{Z} \ln \left[\frac{L_z}{L_o} \right] \qquad (4)$$

where c = beam attenuation coefficient

Z = path length (0.1 meter)

$\frac{L_z}{L_o}$ = percentage of light transmitted through Z.

3.4.2 Results of Beam Transmittance and Beam Attenuation

Measured values of beam transmittance (T) and the associated calculations for beam attenuation coefficients (c) representing February, 1981 sampling operations are presented in Table 11. Beam transmittance values are given

Table 11.

Beam Transmittance and Beam Attenuation

February, 1981

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/03/81	08:35	1	Surface	27.0	13.09
02/03/81	08:50	2	Surface	70.0	3.57
02/03/81	08:50	2	1.0	71.0	3.42
02/03/81	09:00	3	Surface	75.0	2.88
02/03/81	09:00	3	0.5	77.0	2.61
02/03/81	09:00	3	1.0	76.0	2.74
02/03/81	09:00	3	1.5	75.0	2.88
02/03/81	09:00	3	2.0	76.0	2.74
02/03/81	09:13	4	Surface	85.0	1.63
02/03/81	09:13	4	1.0	86.0	1.51
02/03/81	09:13	4	1.5	86.0	1.51
02/03/81	09:13	4	2.0	86.0	1.51
02/03/81	09:13	4	2.5	86.5	1.45
02/03/81	09:13	4	3.0	86.5	1.45
02/03/81	09:13	4	3.5	86.5	1.45
02/03/81	09:29	5	Surface	77.0	2.61
02/03/81	09:29	5	0.5	77.0	2.61
02/03/81	09:29	5	1.0	77.0	2.61
02/03/81	09:29	5	1.5	77.0	2.61
02/03/81	09:29	5	2.0	76.5	2.68
02/03/81	09:29	5	2.5	76.5	2.68
02/03/81	09:29	5	3.0	76.0	2.74
02/03/81	09:45	6	Surface	77.5	2.55
02/03/81	09:45	6	0.5	78.0	2.48
02/03/81	09:45	6	1.5	78.0	2.48
02/03/81	09:45	6	2.0	78.0	2.48
02/03/81	10:00	7	Surface	79.5	2.29
02/03/81	10:00	7	0.5	78.5	2.42

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/03/81	10:00	7	1.0	76.5	2.68
02/03/81	10:00	7	1.5	75.0	2.88
02/03/81	10:00	7	2.0	74.5	2.94
02/03/81	10:00	7	2.5	73.5	3.08
02/03/81	10:00	7	3.0	73.5	3.08
02/03/81	10:00	7	3.5	73.5	3.08
02/03/81	10:00	7	4.0	74.0	3.01
02/03/81	10:30	7	Surface	75.5	2.81
02/03/81	10:30	7	0.5	74.5	2.94
02/03/81	10:30	7	1.0	75.0	2.88
02/03/81	10:30	7	1.5	75.5	2.81
02/03/81	10:30	7	2.0	76.5	2.68
02/03/81	10:30	7	2.5	76.5	2.68
02/03/81	10:30	7	3.0	75.5	2.81
02/03/81	10:30	7	3.5	75.5	2.81
02/02/81	10:30	7	4.0	75.5	2.81
02/03/81	11:00	7	Surface	76.5	2.68
02/03/81	11:00	7	0.5	76.5	2.68
02/03/81	11:00	7	1.0	76.5	2.68
02/03/81	11:00	7	1.5	76.5	2.68
02/03/81	11:00	7	2.0	76.5	2.68
02/03/81	11:00	7	2.5	76.5	2.68
02/03/81	11:00	7	3.0	76.0	2.74
02/03/81	11:00	7	3.5	76.0	2.74
02/03/81	11:00	7	4.0	75.5	2.81
02/03/81	11:30	7	Surface	71.5	3.35
02/03/81	11:30	7	0.5	72.0	3.29
02/03/81	11:30	7	1.0	71.5	3.35
02/03/81	11:30	7	1.5	71.5	3.35
02/03/81	11:30	7	2.0	72.0	3.29
02/03/81	11:30	7	2.5	72.5	3.22
02/03/81	11:30	7	3.0	72.5	3.22
02/03/81	11:30	7	3.5	72.5	3.22
02/03/81	11:30	7	4.0	72.5	3.22

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/03/81	12:00	7	Surface	76.0	2.74
02/03/81	12:00	7	0.5	76.0	2.74
02/03/81	12:00	7	1.0	76.0	2.74
02/03/81	12:00	7	1.5	76.0	2.74
02/03/81	12:00	7	2.0	76.0	2.74
02/03/81	12:00	7	2.5	76.0	2.74
02/03/81	12:00	7	3.0	76.5	2.68
02/03/81	12:00	7	3.5	76.0	2.74
02/03/81	12:00	7	4.0	76.0	2.74
02/03/81	12:30	7	Surface	72.5	3.22
02/03/81	12:30	7	0.5	72.5	3.22
02/03/81	12:30	7	1.0	72.5	3.22
02/03/81	12:30	7	1.5	72.5	3.22
02/03/81	12:30	7	2.0	72.5	3.22
02/03/81	12:30	7	2.5	72.5	3.22
02/03/81	12:30	7	3.0	72.5	3.22
02/03/81	12:30	7	3.5	73.0	3.15
02/03/81	12:30	7	4.0	73.0	3.15
02/03/81	13:00	7	Surface	77.0	2.61
02/03/81	13:00	7	0.5	77.0	2.61
02/03/81	13:00	7	1.0	77.5	2.55
02/03/81	13:00	7	1.5	77.5	2.55
02/03/81	13:00	7	2.0	77.5	2.55
02/03/81	13:00	7	2.5	77.0	2.61
02/03/81	13:00	7	3.0	77.0	2.61
02/03/81	13:00	7	3.5	77.5	2.55
02/03/81	13:00	7	4.0	77.0	2.61
02/03/81	13:30	7	Surface	75.0	2.88
02/03/81	13:30	7	0.5	75.0	2.88
02/03/81	13:30	7	1.0	74.0	3.01
02/03/81	13:30	7	1.5	74.5	2.94
02/03/81	13:30	7	2.0	74.5	2.94

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/03/81	13:30	7	2.5	74.5	2.94
02/03/81	13:30	7	3.0	74.5	2.94
02/03/81	13:30	7	3.5	74.0	3.01
02/03/81	13:30	7	4.0	73.5	3.08
02/03/81	14:00	7	Surface	73.0	3.15
02/03/81	14:00	7	0.5	73.0	3.15
02/03/81	14:00	7	1.0	73.0	3.15
02/03/81	14:00	7	1.5	72.5	3.22
02/03/81	14:00	7	2.0	72.0	3.29
02/03/81	14:00	7	2.5	71.5	3.35
02/03/81	14:00	7	3.0	71.0	3.42
02/03/81	14:00	7	3.5	70.5	3.50
02/03/81	14:00	7	4.0	64.0	4.46
02/03/81	14:00	7	4.5	60.0	5.12
02/03/81	14:00	7	5.0	59.0	5.28
02/03/81	14:30	7	Surface	77.0	2.61
02/03/81	14:30	7	0.5	77.0	2.61
02/03/81	14:30	7	1.0	77.0	2.61
02/03/81	14:30	7	1.5	76.5	2.68
02/03/81	14:30	7	2.0	76.5	2.68
02/03/81	14:30	7	2.5	76.5	2.68
02/03/81	14:30	7	3.0	75.5	2.81
02/03/81	14:30	7	3.5	75.5	2.81
02/03/81	14:30	7	4.0	74.0	3.01
02/03/81	15:00	7	Surface	73.5	3.08
02/03/81	15:00	7	0.5	73.5	3.08
02/03/81	15:00	7	1.0	73.5	3.08
02/03/81	15:00	7	1.5	73.0	3.15
02/03/81	15:00	7	2.0	72.5	3.22
02/03/81	15:00	7	2.5	72.0	3.29
02/03/81	15:00	7	3.0	72.5	3.22
02/03/81	15:00	7	3.5	71.5	3.35
02/03/81	15:00	7	4.0	72.0	3.29

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/03/81	15:30	7	Surface	69.5	3.64
02/03/81	15:30	7	0.5	69.5	3.64
02/03/81	15:30	7	1.0	69.0	3.71
02/03/81	15:30	7	1.5	69.5	3.64
02/03/81	15:30	7	2.0	69.5	3.64
02/03/81	15:30	7	2.5	69.5	3.64
02/03/81	15:30	7	3.0	69.5	3.64
02/03/81	15:30	7	3.5	69.5	3.64
02/03/81	15:30	7	4.0	69.5	3.64
02/03/81	16:00	7	Surface	63.5	4.54
02/03/81	16:00	7	0.5	64.0	4.46
02/03/81	16:00	7	1.0	66.0	4.19
02/03/81	16:00	7	1.5	65.0	4.31
02/03/81	16:00	7	2.0	65.5	4.23
02/03/81	16:00	7	2.5	65.5	4.23
02/03/81	16:00	7	3.0	65.5	4.23
02/03/81	16:00	7	3.5	65.5	4.23
02/03/81	16:00	7	4.0	65.5	4.23
02/03/81	16:30	7	Surface	71.5	3.35
02/03/81	16:30	7	0.5	71.5	3.35
02/03/81	16:30	7	1.0	71.5	3.35
02/03/81	16:30	7	1.5	72.0	3.29
02/03/81	16:30	7	2.0	72.0	3.29
02/03/81	16:30	7	2.5	72.0	3.29
02/03/81	16:30	7	3.0	71.5	3.35
02/03/81	16:30	7	3.5	72.5	3.22
02/03/81	16:30	7	4.0	72.5	3.22
02/03/81	17:00	6	Surface	73.5	3.08
02/03/81	17:00	6	1.0	73.5	3.08
02/03/81	17:15	5	Surface	78.5	2.42
02/03/81	17:15	5	2.0	78.5	2.42
02/03/81	17:30	4	Surface	97.0	0.30
02/03/81	17:30	4	3.5	97.5	0.25

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/03/81	17:45	3	Surface	71.0	3.42
02/03/81	17:45	3	2.0	73.0	3.15
02/03/81	17:54	2	Surface	50.0	6.93
02/03/81	17:54	2	1.0	48.0	7.34
02/03/81	18:05	1	Surface	39.0	9.42
02/03/81	18:05	1	1.0	40.0	9.16
02/04/81	08:45	1a	Surface	50.0	6.93
02/04/81	08:45	1a	1.0	54.0	6.16
02/04/81	09:00	2a	Surface	68.5	3.78
02/04/81	09:00	2a	2.0	67.5	3.93
02/04/81	09:18	3a	Surface	79.0	2.36
02/04/81	09:18	3a	4.0	75.5	2.81
02/04/81	09:46	4a	Surface	83.5	1.80
02/04/81	09:46	4a	4.0	84.0	1.74
02/04/81	10:10	5a	Surface	83.0	1.86
02/04/81	10:10	5a	5.0	83.5	1.80
02/04/81	10:30	6a	Surface	89.0	1.17
02/04/81	10:30	6a	1.0	89.5	1.11
02/04/81	10:30	6a	2.0	90.0	1.05
02/04/81	10:30	6a	3.0	89.5	1.11
02/04/81	10:30	6a	4.0	89.5	1.11
02/04/81	10:30	6a	5.0	90.0	1.05
02/04/81	10:30	6a	6.0	90.5	1.00
02/04/81	10:30	6a	7.0	90.5	1.00
02/04/81	10:30	6a	8.0	90.5	1.00
02/04/81	10:30	6a	9.0	90.5	1.00
02/04/81	10:30	6a	10.0	91.0	0.94
02/04/81	10:40	7a	Surface	91.5	0.89
02/04/81	10:40	7a	1.0	91.5	0.89
02/04/81	10:40	7a	2.0	92.0	0.83
02/04/81	10:40	7a	3.0	92.5	0.78
02/04/81	10:40	7a	4.0	93.0	0.73
02/04/81	10:40	7a	5.0	93.5	0.67

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/04/81	10:40	7a	6.0	94.0	0.62
02/04/81	10:40	7a	7.0	95.0	0.51
02/04/81	10:40	7a	8.0	95.0	0.51
02/04/81	10:40	7a	9.0	95.0	0.51
02/04/81	10:40	7a	10.0	95.0	0.51
02/04/81	12:06	8	Surface	73.5	3.08
02/04/81	12:06	8	1.0	73.5	3.08
02/04/81	12:06	8	2.0	74.5	2.94
02/04/81	12:06	8	3.0	74.5	2.94
02/04/81	12:06	8	4.0	75.5	2.81
02/04/81	12:06	8	5.0	79.5	2.29
02/04/81	12:06	8	6.0	80.5	2.17
02/04/81	12:06	8	7.0	81.5	2.05
02/04/81	12:06	8	8.0	82.0	1.98
02/04/81	12:06	8	9.0	80.5	1.92
02/04/81	12:06	8	10.0	83.0	1.86
02/04/81	12:30	9	Surface	81.5	2.05
02/04/81	12:30	9	1.0	81.5	2.05
02/04/81	12:30	9	2.0	81.5	2.05
02/04/81	12:30	9	3.0	81.5	2.05
02/04/81	12:30	9	4.0	82.0	1.98
02/04/81	12:30	9	5.0	82.0	1.98
02/04/81	12:30	9	6.0	83.0	1.86
02/04/81	12:30	9	7.0	84.0	1.74
02/04/81	12:30	9	8.0	85.0	1.63
02/04/81	12:30	9	9.0	86.5	1.45
02/04/81	12:30	9	10.0	89.0	1.17
02/04/81	13:05	10	Surface	88.0	1.28
02/04/81	13:05	10	1.0	88.5	1.22
02/04/81	13:05	10	2.0	88.5	1.22
02/04/81	13:05	10	3.0	88.5	1.22
02/04/81	13:05	10	4.0	88.5	1.22
02/04/81	13:05	10	5.0	88.0	1.28

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/04/81	13:05	10	6.0	88.0	1.28
02/04/81	13:05	10	7.0	89.5	1.11
02/04/81	13:05	10	8.0	89.5	1.11
02/04/81	13:05	10	9.0	91.0	0.94
02/04/81	13:05	10	10.0	91.0	0.94
02/04/81	13:25	11	Surface	90.0	0.95
02/04/81	13:25	11	1.0	90.0	0.95
02/04/81	13:25	11	2.0	90.5	1.00
02/04/81	13:25	11	3.0	90.5	1.00
02/04/81	13:25	11	4.0	91.0	0.94
02/04/81	13:25	11	5.0	91.5	0.89
02/04/81	13:25	11	6.0	91.5	0.89
02/04/81	13:25	11	7.0	91.5	0.89
02/04/81	13:25	11	8.0	91.5	0.89
02/04/81	13:25	11	9.0	91.5	0.89
02/04/81	13:25	11	10.0	91.5	0.89
02/04/81	13:42	12	Surface	85.0	1.63
02/04/81	13:42	12	1.0	85.5	1.57
02/04/81	13:42	12	2.0	85.5	1.57
02/04/81	13:42	12	3.0	85.5	1.57
02/04/81	13:42	12	4.0	85.5	1.57
02/04/81	13:42	12	5.0	85.5	1.57
02/04/81	13:42	12	6.0	85.5	1.57
02/04/81	13:42	12	7.0	85.5	1.57
02/04/81	13:42	12	8.0	85.5	1.57
02/04/81	13:42	12	9.0	85.5	1.57
02/04/81	13:42	12	10.0	85.5	1.57
02/04/81	14:10	13	Surface	90.0	1.05
02/04/81	14:10	13	1.0	90.0	1.05
02/04/81	14:10	13	2.0	90.0	1.05
02/04/81	14:10	13	3.0	90.5	1.00
02/04/81	14:10	13	4.0	91.0	0.94
02/04/81	14:10	13	5.0	91.5	0.89

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/04/81	14:10	13	6.0	91.5	0.89
02/04/81	14:10	13	7.0	92.5	0.78
02/04/81	14:10	13	8.0	93.5	0.67
02/04/81	14:10	13	9.0	94.5	0.57
02/04/81	14:10	13	10.0	95.5	0.46
02/04/81	14:27	14	Surface	85.0	1.63
02/04/81	14:27	14	1.0	85.5	1.57
02/04/81	14:27	14	2.0	86.0	1.51
02/04/81	14:27	14	3.0	87.0	1.39
02/04/81	14:27	14	4.0	87.0	1.39
02/04/81	14:27	14	5.0	88.0	1.28
02/04/81	14:27	14	6.0	88.5	1.22
02/04/81	14:27	14	7.0	89.0	1.17
02/04/81	14:27	14	8.0	90.0	1.05
02/04/81	14:27	14	9.0	90.5	1.00
02/04/81	14:27	14	10.0	92.0	0.83
02/04/81	14:44	15	Surface	84.0	1.74
02/04/81	14:44	15	1.0	84.5	1.68
02/04/81	14:44	15	2.0	85.0	1.63
02/04/81	14:44	15	3.0	85.0	1.63
02/04/81	14:44	15	4.0	84.5	1.68
02/04/81	14:44	15	5.0	83.0	1.86
02/04/81	14:44	15	6.0	82.5	1.92
02/04/81	14:44	15	7.0	81.5	2.05
02/04/81	14:44	15	8.0	81.5	2.05
02/04/81	14:44	15	9.0	80.5	2.17
02/04/81	14:44	15	10.0	79.5	2.29
02/05/81	08:53	F1	Surface	82.0	1.98
02/05/81	08:53	F1	1.0	83.0	1.86
02/05/81	08:53	F1	2.0	82.5	1.92
02/05/81	08:53	F1	3.0	83.0	1.86
02/05/81	08:53	F1	4.0	83.5	1.80
02/05/81	08:53	F1	5.0	83.5	1.80

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/05/81	08:53	F1	6.0	83.5	1.80
02/05/81	08:53	F1	7.0	85.0	1.63
02/05/81	08:53	F1	8.0	86.0	1.51
02/05/81	08:53	F1	9.0	87.0	1.39
02/05/81	08:53	F1	10.0	87.0	1.39
02/05/81	09:04	F2	Surface	75.0	2.88
02/05/81	09:04	F2	1.0	75.5	2.81
02/05/81	09:04	F2	2.0	80.0	2.23
02/05/81	09:04	F2	3.0	87.0	1.39
02/05/81	09:04	F2	4.0	87.5	1.34
02/05/81	09:04	F2	5.0	88.0	1.28
02/05/81	09:04	F2	6.0	88.5	1.22
02/05/81	09:04	F2	7.0	89.0	1.17
02/05/81	09:04	F2	8.0	91.0	0.94
02/05/81	09:04	F2	9.0	92.0	0.83
02/05/81	09:04	F2	10.0	92.0	0.83
02/05/81	09:33	15	Surface	55.0	5.98
02/05/81	09:33	15	0.5	65.0	4.31
02/05/81	09:33	15	1.0	72.0	3.29
02/05/81	09:33	15	2.0	73.0	3.15
02/05/81	09:33	15	3.0	73.5	3.08
02/05/81	09:33	15	4.0	73.5	3.08
02/05/81	09:33	15	5.0	71.5	3.35
02/05/81	09:33	15	6.0	47.0	7.55
02/05/81	09:33	15	7.0	55.0	5.98
02/05/81	09:33	15	8.0	56.5	5.71
02/05/81	09:33	15	9.0	63.0	4.62
02/05/81	09:33	15	10.0	75.0	2.88
02/05/81	10:12	14	Surface	56.0	5.80
02/05/81	10:12	14	0.5	60.0	5.11
02/05/81	10:12	14	1.0	60.0	5.11

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/05/81	10:12	14	2.0	83.5	1.80
02/05/81	10:12	14	3.0	84.5	1.68
02/05/81	10:12	14	4.0	86.5	1.45
02/05/81	10:12	14	5.0	87.5	1.34
02/05/81	10:12	14	6.0	81.5	2.05
02/05/81	10:12	14	7.0	75.0	2.88
02/05/81	10:12	14	8.0	75.0	2.88
02/05/81	10:12	14	9.0	76.0	2.74
02/05/81	10:12	14	10.0	83.0	1.86
02/05/81	10:12	14	11.0	86.0	1.51
02/05/81	10:12	14	12.0	88.5	1.22
02/05/81	10:32	F3	Surface	81.5	2.05
02/05/81	10:32	F3	1.0	81.0	2.11
02/05/81	10:32	F3	2.0	81.5	2.05
02/05/81	10:32	F3	3.0	85.0	1.63
02/05/81	10:32	F3	4.0	86.5	1.45
02/05/81	10:32	F3	5.0	88.0	1.28
02/05/81	10:32	F3	6.0	87.5	1.34
02/05/81	10:32	F3	7.0	87.5	1.34
02/05/81	10:32	F3	8.0	88.0	1.28
02/05/81	10:40	F4	Surface	87.0	1.39
02/05/81	10:40	F4	1.0	87.5	1.34
02/05/81	10:40	F4	2.0	85.0	1.63
02/05/81	10:40	F4	3.0	87.0	1.39
02/05/81	10:40	F4	4.0	89.0	1.17
02/05/81	10:40	F4	5.0	90.0	1.05
02/05/81	10:40	F4	6.0	90.0	1.05
02/05/81	10:40	F4	7.0	90.0	1.05
02/05/81	11:04	13	Surface	80.5	2.17
02/05/81	11:04	13	1.0	81.5	2.05
02/05/81	11:04	13	2.0	81.5	2.05
02/05/81	11:04	13	3.0	81.5	2.05

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/05/81	11:04	13	4.0	80.5	2.17
02/05/81	11:04	13	5.0	80.5	2.17
02/05/81	11:04	13	6.0	80.5	2.17
02/05/81	11:04	13	7.0	81.5	2.05
02/05/81	11:04	13	8.0	83.0	1.86
02/05/81	11:04	13	9.0	83.5	1.80
02/05/81	11:04	13	10.0	83.5	1.80
02/05/81	11:29	12	Surface	83.5	1.80
02/05/81	11:29	12	1.0	84.0	1.74
02/05/81	11:29	12	2.0	84.0	1.74
02/05/81	11:29	12	3.0	84.5	1.68
02/05/81	11:29	12	4.0	85.5	1.57
02/05/81	11:29	12	5.0	86.5	1.45
02/05/81	11:29	12	6.0	86.5	1.45
02/05/81	11:29	12	7.0	87.5	1.34
02/05/81	11:29	12	8.0	87.5	1.34
02/05/81	11:29	12	9.0	87.5	1.34
02/05/81	11:29	12	10.0	87.5	1.34
02/05/81	11:48	16	Surface	84.0	1.74
02/05/81	11:48	16	1.0	84.0	1.74
02/05/81	11:48	16	2.0	84.0	1.74
02/05/81	11:48	16	3.0	83.5	1.80
02/05/81	11:48	16	4.0	83.5	1.80
02/05/81	11:48	16	5.0	83.5	1.80
02/05/81	11:48	16	6.0	85.0	1.63
02/05/81	11:48	16	7.0	85.5	1.57
02/05/81	11:48	16	8.0	85.5	1.57
02/05/81	11:48	16	9.0	85.5	1.57
02/05/81	11:48	16	10.0	85.5	1.57
02/05/81	12:04	17	Surface	82.0	1.98
02/05/81	12:04	17	1.0	82.5	1.92
02/05/81	12:04	17	2.0	82.5	1.92

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/05/81	12:04	17	3.0	82.0	1.98
02/05/81	12:04	17	4.0	82.5	1.92
02/05/81	12:04	17	5.0	82.5	1.92
02/05/81	12:04	17	6.0	83.0	1.86
02/05/81	12:04	17	7.0	82.5	1.92
02/05/81	12:04	17	8.0	83.0	1.86
02/05/81	12:04	17	9.0	85.5	1.57
02/05/81	12:04	17	10.0	85.0	1.63
02/05/81	12:20	18	Surface	84.0	1.74
02/05/81	12:20	18	1.0	84.5	1.68
02/05/81	12:20	18	2.0	84.5	1.68
02/05/81	12:20	18	3.0	84.5	1.68
02/05/81	12:20	18	4.0	84.5	1.68
02/05/81	12:20	18	5.0	85.0	1.63
02/05/81	12:20	18	6.0	85.5	1.57
02/05/81	12:20	18	7.0	85.5	1.57
02/05/81	12:20	18	8.0	85.5	1.57
02/05/81	12:20	18	9.0	85.5	1.57
02/05/81	12:20	18	10.0	85.5	1.57
02/05/81	12:38	19	Surface	79.0	2.36
02/05/81	12:38	19	1.0	79.0	2.36
02/05/81	12:38	19	2.0	80.0	2.23
02/05/81	12:38	19	3.0	83.0	1.86
02/05/81	12:38	19	4.0	86.5	1.45
02/05/81	12:38	19	5.0	75.0	2.88
02/05/81	12:38	19	6.0	77.0	2.61
02/05/81	12:38	19	7.0	83.0	1.86
02/05/81	12:38	19	8.0	88.0	1.28
02/05/81	12:38	19	9.0	90.0	1.05
02/05/81	12:56	20	Surface	72.0	3.29
02/05/81	12:56	20	1.0	72.5	3.22
02/05/81	12:56	20	2.0	73.0	3.15

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/05/81	12:56	20	3.0	78.0	2.48
02/05/81	12:56	20	4.0	84.0	1.74
02/05/81	12:56	20	5.0	83.0	1.86
02/05/81	12:56	20	6.0	80.0	2.23
02/05/81	12:56	20	7.0	82.0	1.98
02/05/81	12:56	20	8.0	87.0	1.39
02/05/81	12:56	20	9.0	86.0	1.51
02/05/81	12:56	20	10.0	83.0	1.86
02/05/81	13:12	21	Surface	82.0	1.98
02/05/81	13:12	21	1.0	82.5	1.92
02/05/81	13:12	21	2.0	83.5	1.86
02/05/81	13:12	21	3.0	83.5	1.86
02/05/81	13:12	21	4.0	84.0	1.74
02/05/81	13:12	21	5.0	86.0	1.51
02/05/81	13:12	21	6.0	86.5	1.45
02/05/81	13:12	21	7.0	86.0	1.51
02/05/81	13:12	21	8.0	86.0	1.51
02/05/81	13:12	21	9.0	87.0	1.39
02/05/81	13:12	21	10.0	86.5	1.45
02/05/81	13:30	22	Surface	80.5	2.17
02/05/81	13:30	22	1.0	80.5	2.17
02/05/81	13:30	22	2.0	80.5	2.17
02/05/81	13:30	22	3.0	81.5	2.05
02/05/81	13:30	22	4.0	83.0	1.86
02/05/81	13:30	22	5.0	84.5	1.68
02/05/81	13:30	22	6.0	85.0	1.63
02/05/81	13:30	22	7.0	85.5	1.57
02/05/81	13:30	22	8.0	85.5	1.57
02/05/81	13:30	22	9.0	85.0	1.63
02/05/81	13:30	22	10.0	85.0	1.63

Table 11. Continued

DATE	TIME	STATION	SAMPLE DEPTH (m)	$\frac{L_z}{L_o} \times 100$	$C(m^{-1})$
02/05/81	13:50	23	Surface	81.0	2.11
02/05/81	13:50	23	1.0	81.5	2.05
02/05/81	13:50	23	2.0	81.5	2.05
02/05/81	13:50	23	3.0	81.5	2.05
02/05/81	13:50	23	4.0	84.0	1.74
02/05/81	13:50	23	5.0	83.5	1.80
02/05/81	13:50	23	6.0	84.5	1.68
02/05/81	13:50	23	7.0	84.0	1.74
02/05/81	13:50	23	8.0	83.0	1.86
02/05/81	13:50	23	9.0	83.0	1.86
02/05/81	13:50	23	10.0	83.0	1.86
02/05/81	15:50	24	Surface	65.0	4.31
02/05/81	15:50	24	1.5	65.0	4.31
02/05/81	16:05	25	Surface	62.0	4.78
02/05/81	16:05	25	1.5	61.5	4.86
02/05/81	16:20	26	Surface	50.0	6.93
02/05/81	16:20	26	1.0	59.0	5.28
02/05/81	16:20	26	2.0	60.0	5.10

as percentages ($\frac{L_z}{L_o}$ x 100) while beam attenuation coefficients are presented in units of inverse meters (m^{-1}). For the remainder of this section, results will be presented in terms of beam attenuation coefficients.

Beam attenuation coefficient values were found to range throughout the Gulf from 0.25 m^{-1} (97.5% transmittance), recorded at a depth of 3.5 meters at station 4 north of Puntarenas, to 13.09 m^{-1} (27.0% transmittance), measured in the Estero Chacarita adjacent to Puntarenas. It should be noted at this point that a beam attenuation coefficient is determined by the scattering characteristics of any material suspended within the water as well as absorption which may be a results of both particulate and dissolved material in the water column. The distribution of beam attenuation coefficient values throughout the Gulf may be generalized as follows:

1. Stations north of Puntarenas (5, 6 and 7) yielded values ranging from 2.29 m^{-1} to 5.28 m^{-1}.
2. Stations located in the central portion of the Gulf south of Puntarenas (4a, 5a, 6a and 7a) yielded values ranging from 0.25 m^{-1} to 1.86 m^{-1}. Values were found to consistantly decrease with depth.
3. Beam attenuation coefficients increased significantly at stations located in close proximity to areas of riverine and sewage outflow such as Puntarenas and the Rio Grande de Tarcoles.

Figures 14 through 17 represent vertical distributions of beam attenuation along four transects adjacent to the Rio Grande de Tarcoles. Each transect was oriented perpendicular to the shoreline. The first transect was composed of stations 8, 9, 10 and 11 and was located approximately 2 miles south of the river mouth (see Figure 14). The second transect was located less than

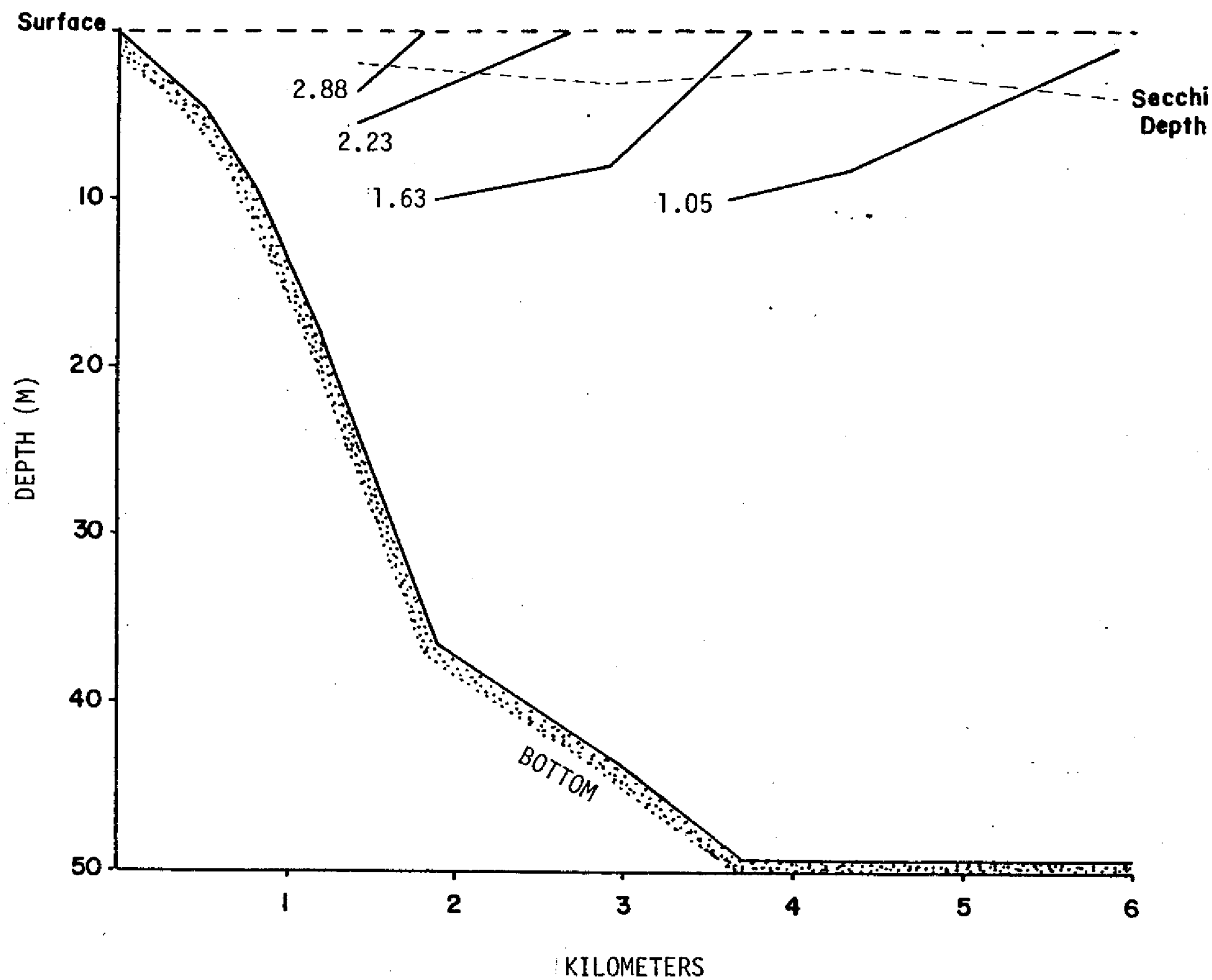

Figure 14: Vertical profile of beam attenuation coefficient values adjacent to the Rio Grande de Tarcoles representing stations 8, 9, 10 and 11 sampled on February 4, 1981.

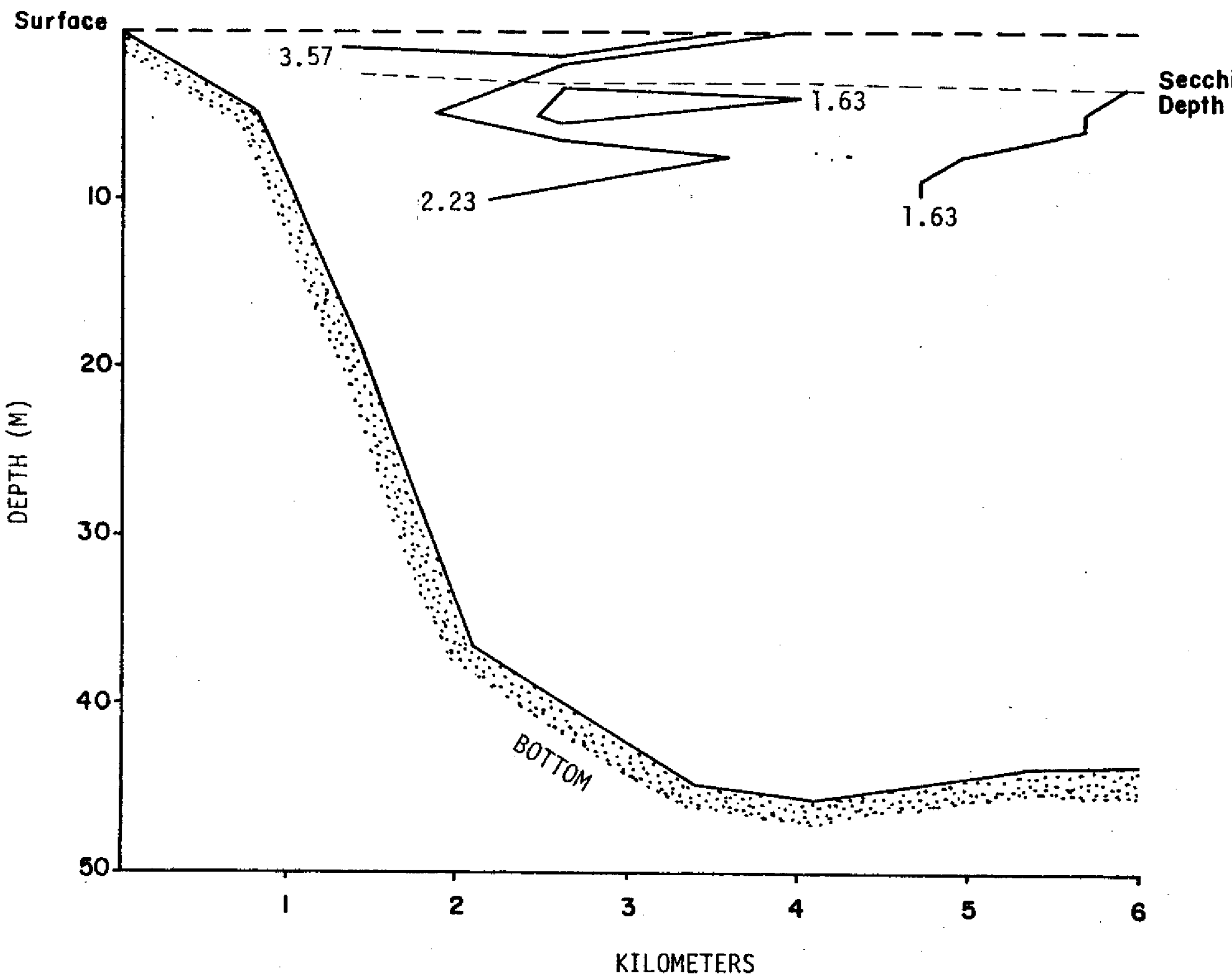

Figure 15: Vertical profile of beam attenuation coefficient values adjacent to the Rio Grande de Tarcoles representing stations 12, 13, 14 and 15 sampled on February 4, 1981.

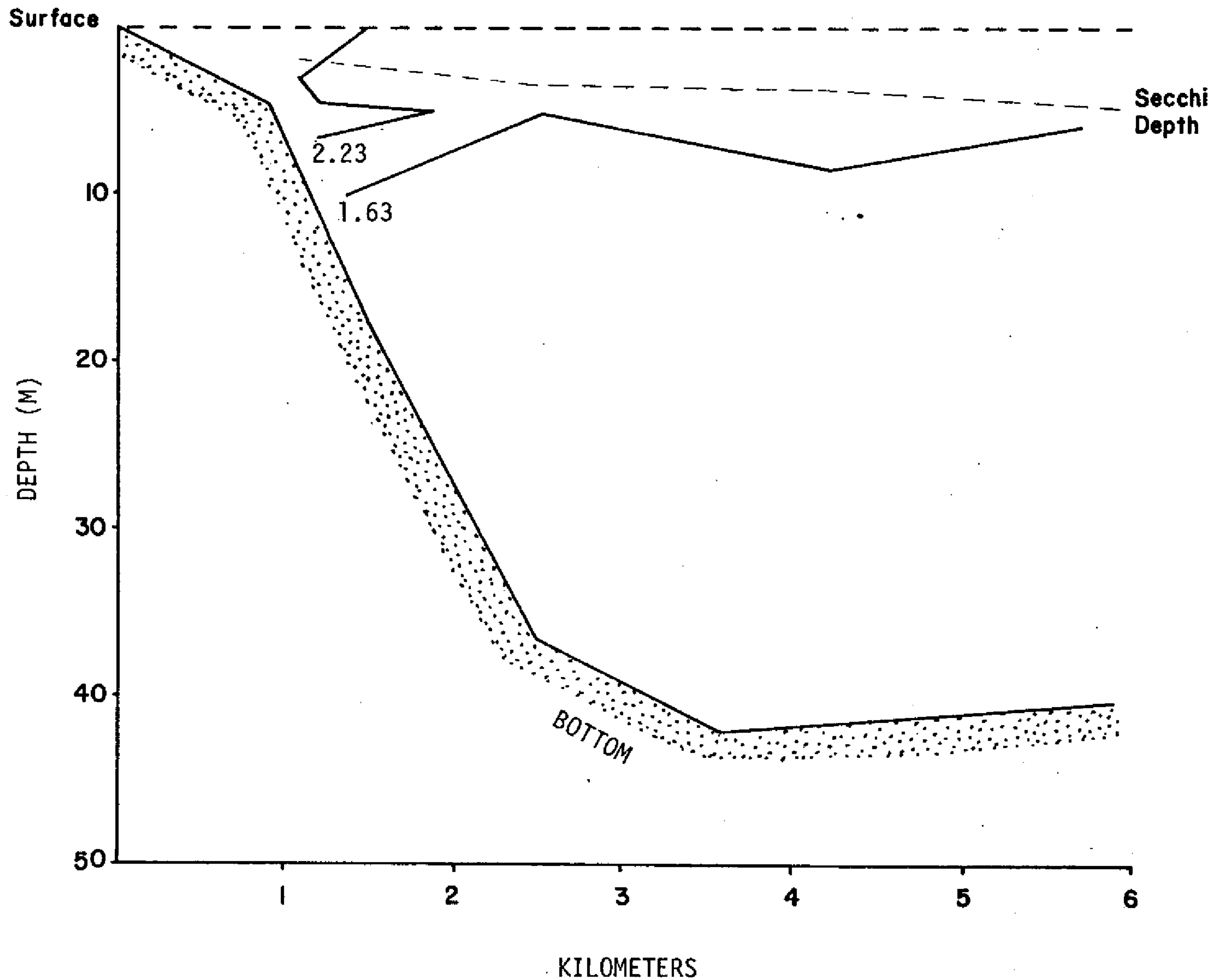

Figure 16: Vertical profile of beam attenuation coefficient values adjacent to the Rio Grande de Tarcoles representing stations 16, 17, 18 and 19 sampled on February 4, 1981.

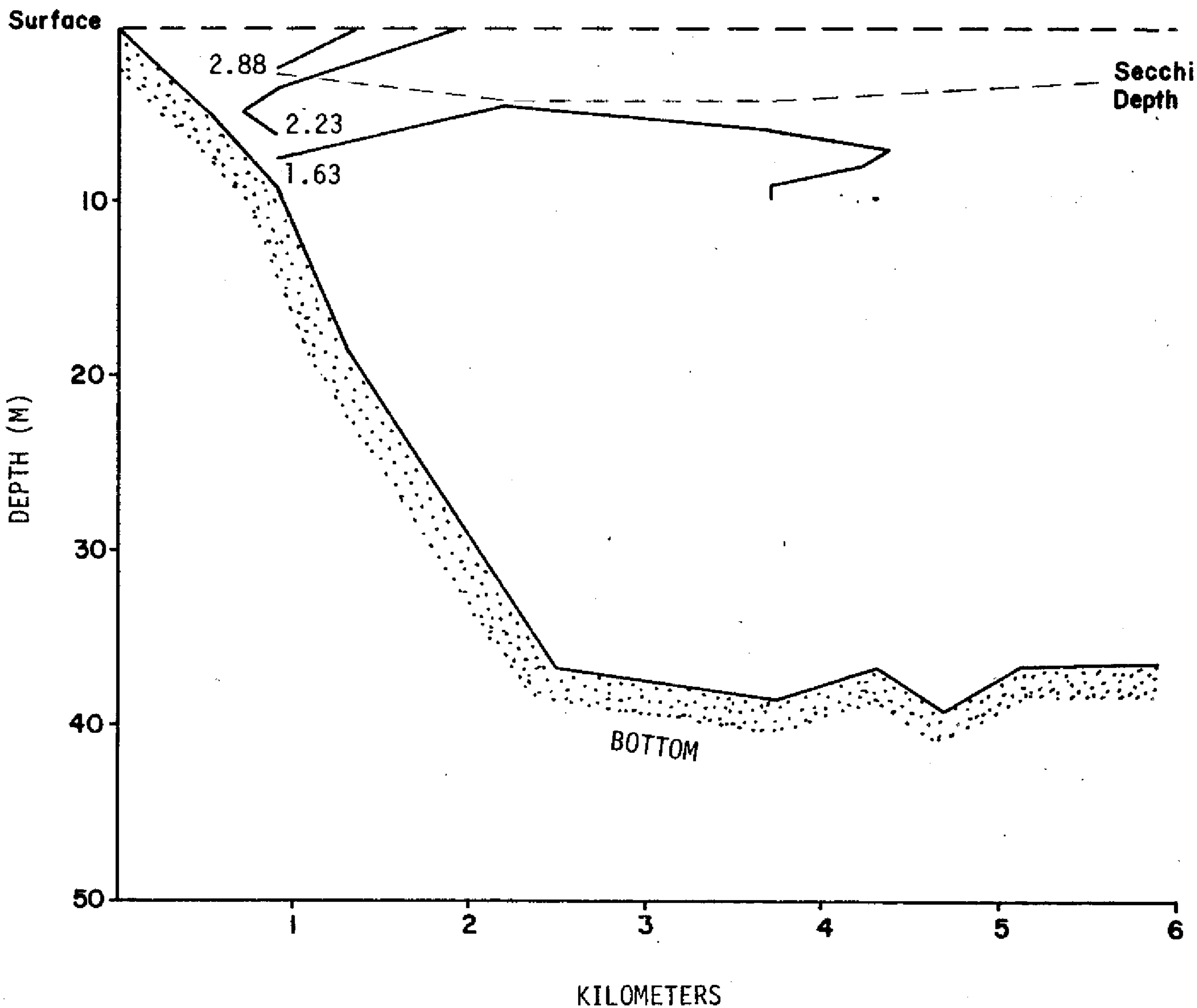

Figure 17: Vertical profile of beam attenuation coefficient values adjacent to the Rio Grande de Tarcoles representing stations 20, 21, 22 and 23 sampled on February 5, 1981.

one mile south of the river mouth and encompassed stations 12, 13, 14 and 15. The third transect representing stations 16, 17, 18 and 19 was located 1 mile north of the river mouth while the fourth and final transect represented stations 20, 21, 22 and 23 and was located 2 miles north of the river mouth. The following observations appear to be true of all four transects:

1. Beam attenuation values tended to increase towards the surface.
2. Values tended to increase in a shoreward direction, or more specifically, towards the river mouth.
3. The range in values over the water column increased in a shoreward direction.

Midway through the second transect, station 14 in particular which was located 2.6 miles offshore, four distinct layers were noted within the 12 meter sampling depth. High values for beam attenuation coefficients were found between the surface and 2 meters representing quite turbid water. Significantly lower values occurred between 3 and 5 meters. A second apparently turbid layer was found between 6 and 9 meters while the lowest values measured at the station occurred at 10 meters and below.

Figures 18, 19 and 20 represent the vertical distribution of beam attenuation coefficient values at stations bracketing each of the fronts encountered, during the February, 1981 sampling missions. The position of each front represented is shown in Figure 13. Figure 18 represents observations at a weak front located in the central portion of the Gulf approximately 4.5 miles east northeast of Islas Negritos. The front was oriented across the width of the Gulf, i.e., perpendicular to the Gulf axis. Although the shape of the coefficient profiles on either side of the front are similar, measurements on the ocean side of the front were

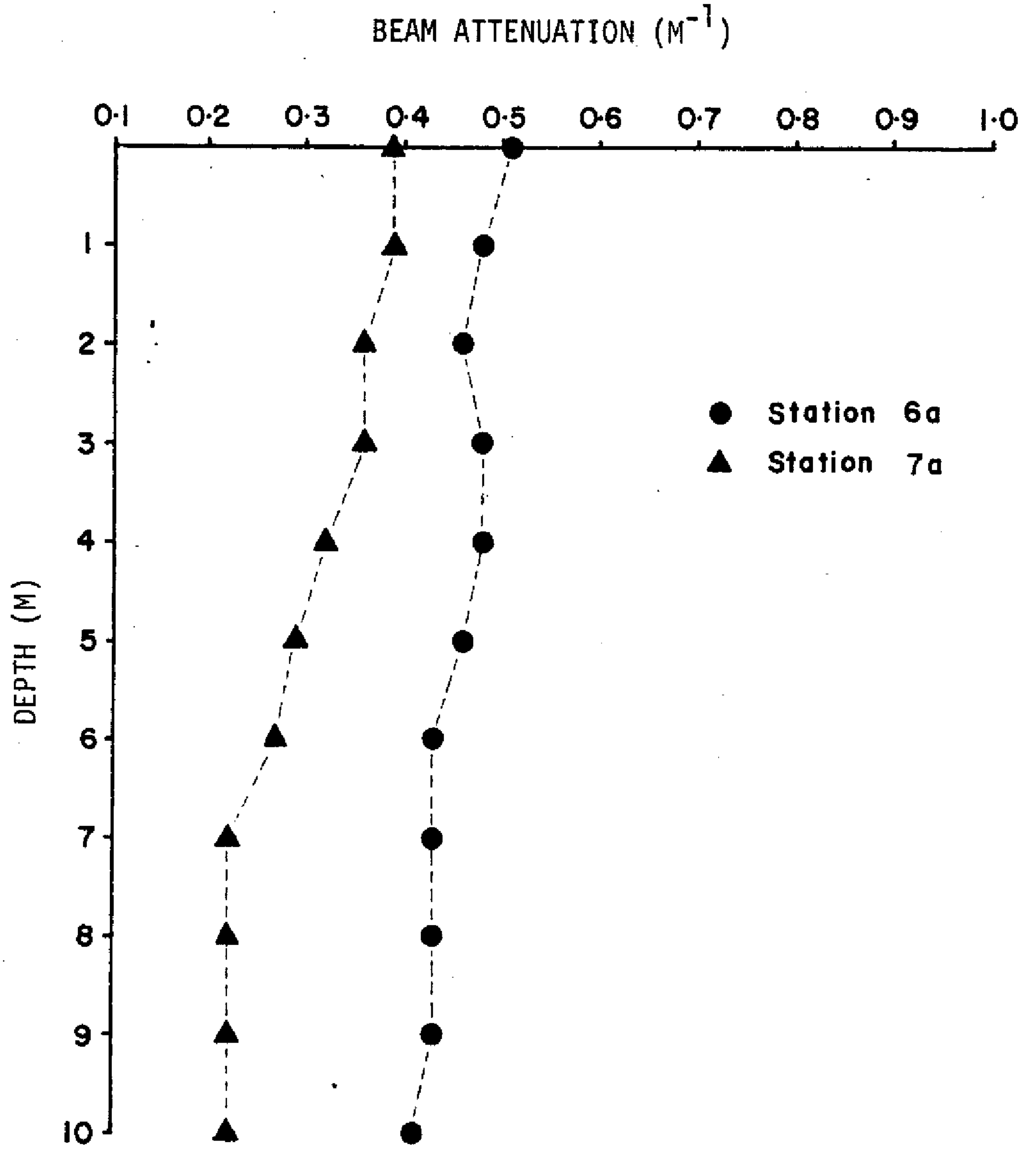

Figure 18: Vertical profile of beam attenuation coefficient values measured on both sides of a front (stations 6a and 7a) encountered east of Islas Negritos on February 4, 1981.

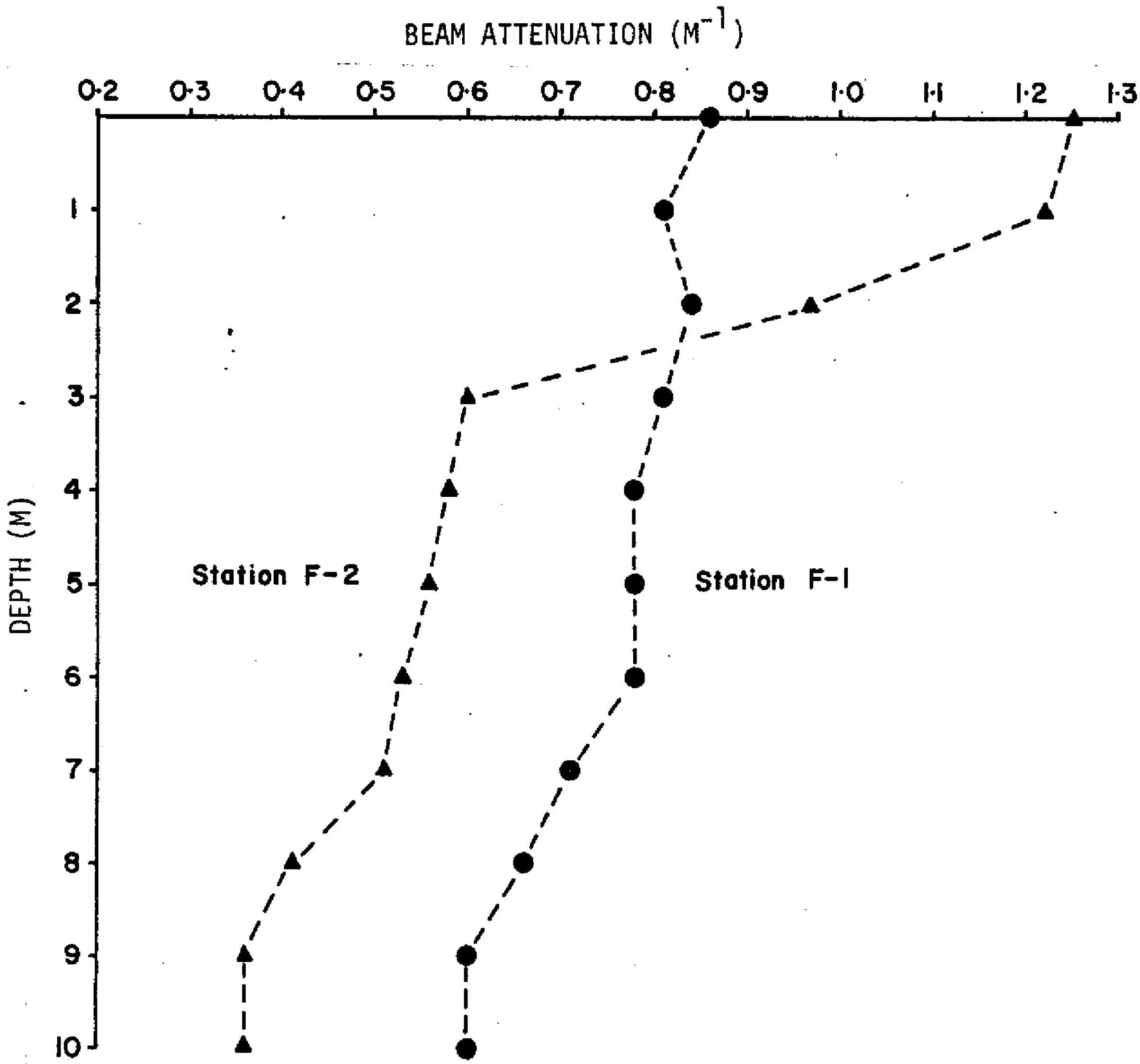

Figure 19: Vertical profile of beam attenuation coefficient values measured on both sides of a front (stations F-1 and F-2) encountered adjacent to the Rio Grande de Tarcoles on February 5, 1981.

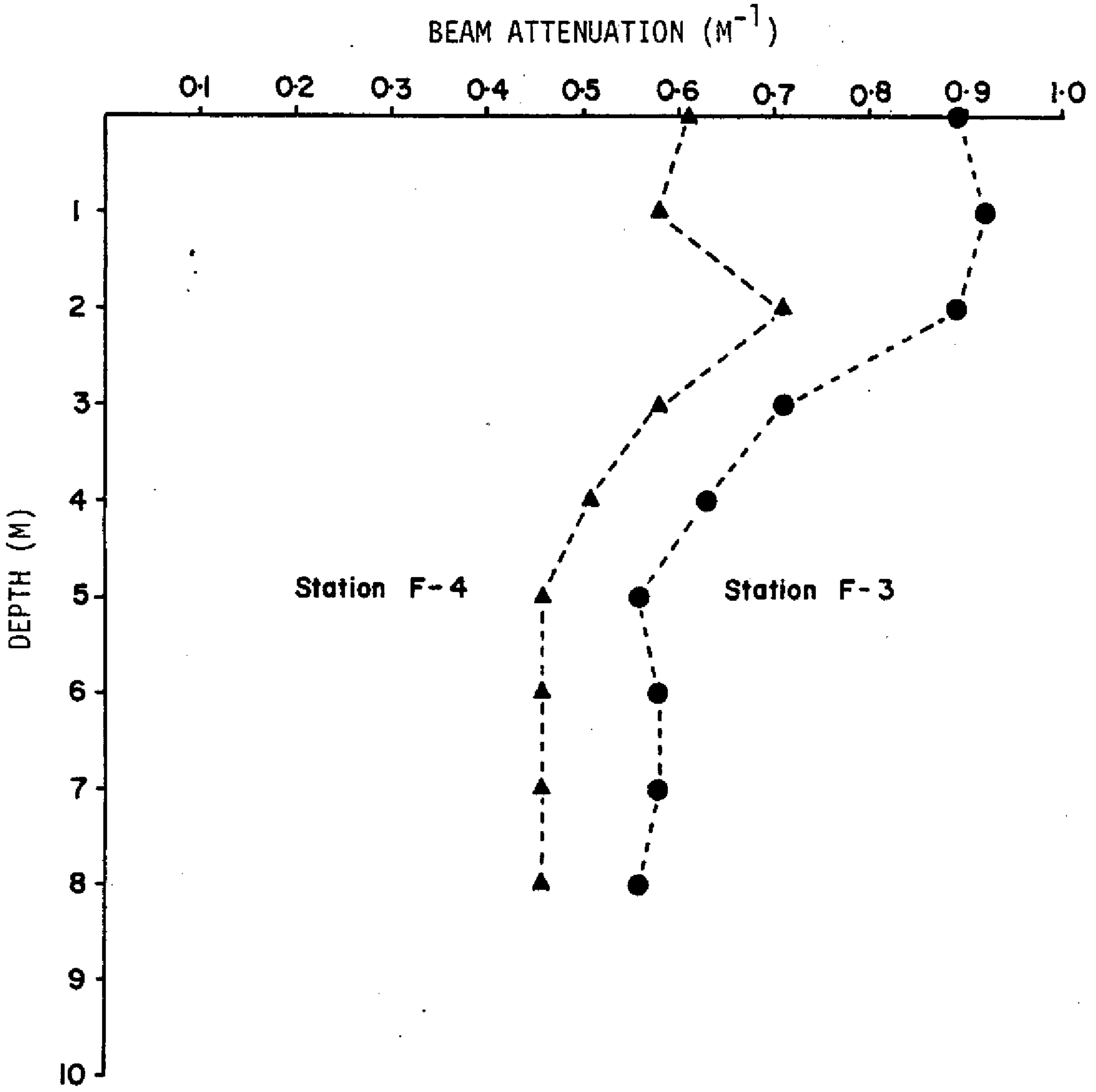

Figure 20: Vertical profile of beam attenuation coefficient values measured on both sides of a front (stations F-3 and F-4) encountered adjacent to the Rio Grande de Tarcoles on February 5, 1981.

consistantly smaller than those representing the upper Gulf side. Furthermore, the range of coefficient values, with depth conducted on the upper Gulf side appeared to be quite small while values representing the ocean side tended to decrease slightly more with depth.

Figures 19 and 20 represent fronts observed which were in close proximity to the mouth of the Rio Grande de Tarcoles (2.5 miles and 3.0 miles respectively). Both were oriented parallel to the shoreline. The vertical profiles representing the top 2 to 3 meters of both fronts were significantly different from those presented in Figure 18. While the coefficient values measured on the clear water side (the ocean side in both cases) tended to decrease gradually with depth, values representing the turbid side started out much higher at the surface and decreased rapidly. Below 3 meters, the profiles were again quite similar. In all cases, relatively clear water occurred at depth while increasingly turbid water occurred towards the surface.

4.0 LANDSAT IMAGERY ANALYSIS

4.1 Materials and Methods

Surface waters of the Gulf of Nicoya adjacent to the mouth of the Rio Grande de Tarcoles were investigated at a macroscopic scale utilizing historical Landsat imagery (see Figure 21). A total of four images were analyzed in which the Gulf area was completely cloud-free:

March 03, 1975
July 14, 1977
August 01, 1977
January 23, 1979

Two of the images, March and January, represent dry season conditions in Costa Rica while the July and August imagery is representative of rainy season conditions. Digital data in the form of CCT's (computer compatible tapes) was obtained for each overpass and analyzed on an ERDAS 400 (Earth Resources Data Analysis System) located in the College of Marine Studies, University of Delaware.

The ERDAS 400, shown in Figure 22, is a self-contained image processing system based upon a Z80 microprocessor. Multispectral imagery is stored on 8" double-sided/double-density floppy disks and displayed on a 13", high resolution, RGB color monitor. Each floppy diskette is capable of storing 1212 K of data. A total of 192K of active memory is available (128K within the image driver and 64K within the microprocessor). This permits the display of 3-band imagery with a maximum size of 256 by 240 pixels. In the case of Landsat imagery, bands 4, 5 and 7 are displayed. Imagery analysis is performed in an interactive mode which allows for rapid manipulation of the data. As shown in Figure 23, the ERDAS 400 is linked to a B7700 which is housed in the University of Delaware Computing Center. Typically, data is read from the CCT's onto the B7700 and transferred over phone lines to the ERDAS 400 and onto floppy disks.

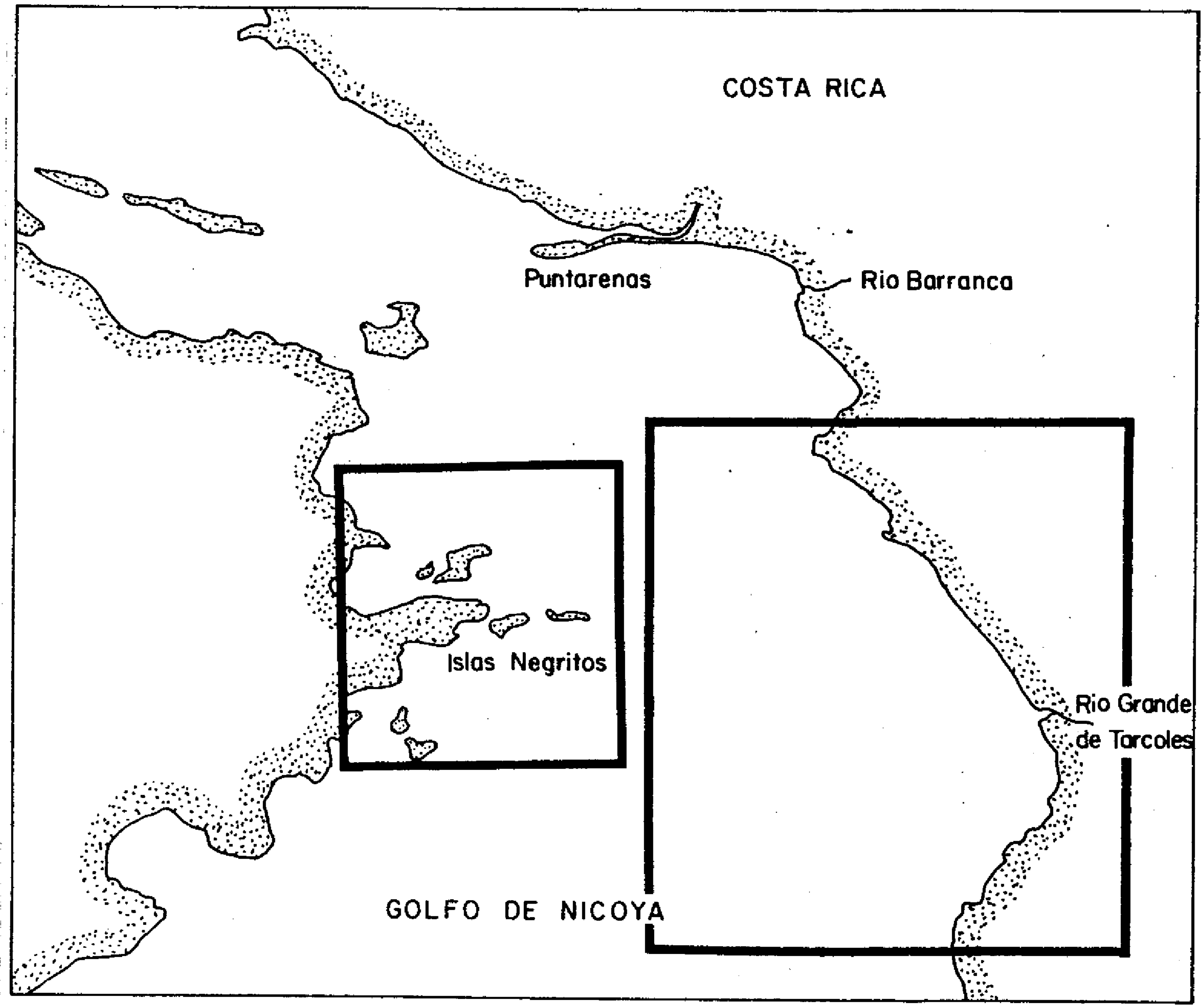

Figure 21: Areas of the Golfo de Nicoya for which LANDSAT imagery was analyzed. Water features were enhanced using an ERDAS 400.

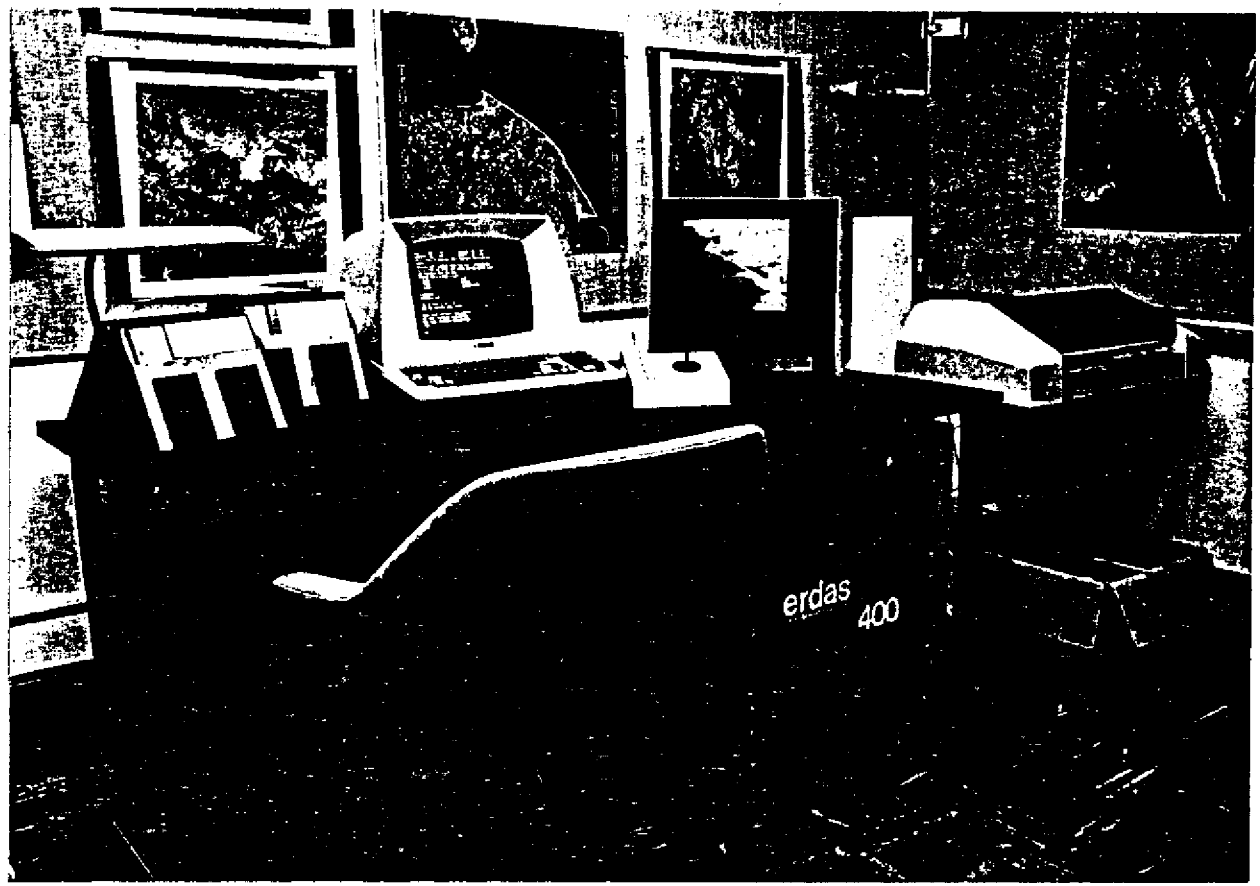

Figure 22: The ERDAS 400 image processing system composed of a Z80 microprocessor, a high resolution color CRT, a CRT monitor and two floppy/disk drives.

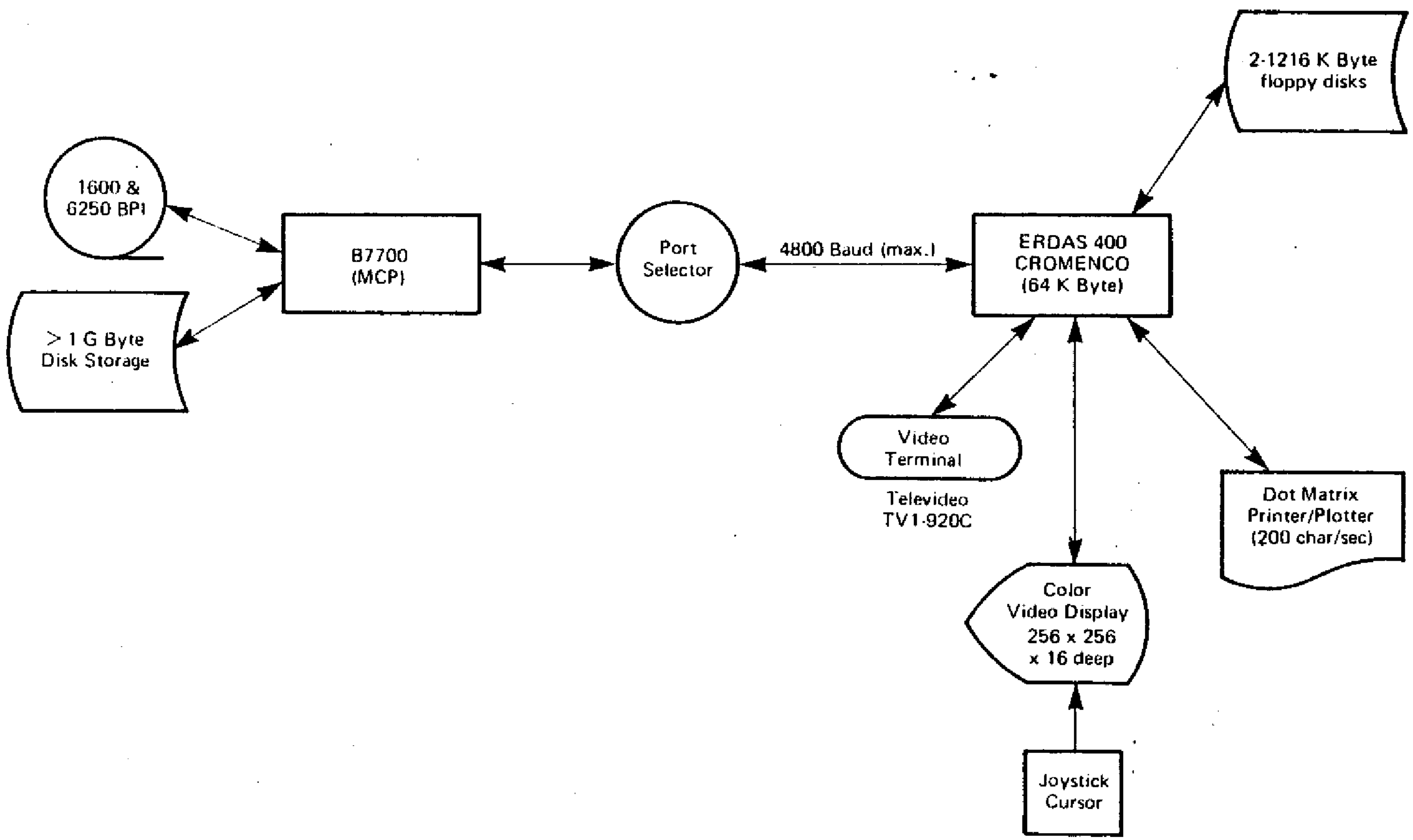

Figure 23: Schematic of the ERDAS 400 image processing system linked with the University of Delaware B7700.

After the transfer of Landsat data to the ERDAS system, a series of programs were used to enhance water features within the Gulf of Nicoya. Figure 24 is a schematic of the enhancement process. An image was first displayed on the color monitor and a frequency histogram of gray levels printed out for each band. From the frequency histogram, a range of gray levels was defined accounting for all of the water features within the scene. Water features displayed in band 4 of Landsat, for example, are normally depicted within a range of approximately 10 gray levels occupying the lowest portion of the frequency histogram. In general, the same is true for Landsat bands 5 and 7 except that in the latter case the range is very small (2 or 3 gray levels). This is because band 7 data is composed of reflected near infrared radiation (0.8 μm - 1.1 μm), nearly all of which is absorbed by the top few centimeters of the water column. After gray level ranges corresponding to water features were defined, the image was again displayed by stretching the gray level range in each band over the entire intensity range of the color monitor (255 intensities). The lowest value within a gray level range was assigned an intensity of 0 while the highest gray level was assigned the maximum intensity of 255. Intermediate values were defined linearly. Finally, a spatial filtering routine (essentially an edge enhancement procedure) was applied to increase contrast between water features.

4.2 Results of Landsat Imagery Analysis

Enhancements of Landsat data representing each of the four available dates show well defined plumes of relatively trubid water associated with outflow from the Rio Grande de Tarcoles. Variations in the orientation of each plume to the river mouth may be explained, at least in part, in terms of the local tidal regime. The March 03, 1975 imagery, shown in

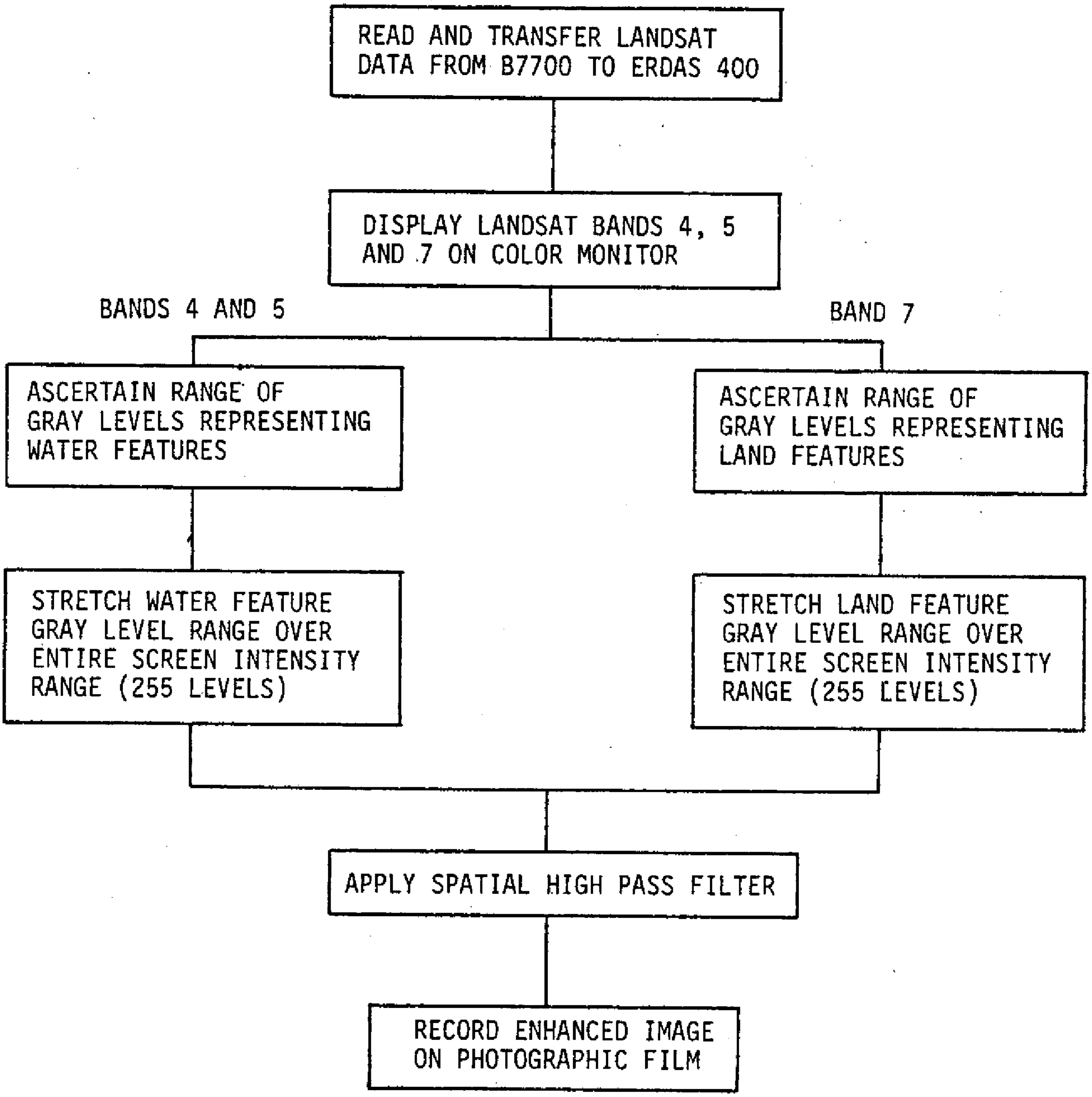

Figure 24: Block diagram of the enhancement procedure applied to LANDSAT imagery of the Golfo de Nicoya.

Figure 25, was generated 2.5 hours after high slack tide. The river plume is seen oriented to the north of the river mouth (up Gulf towards Puntarenas) and probably drifted north as a result of the previous flood tide. However, a slight curve southward increasing away from the shoreline may indicate the presence of small ebb tidal currents starting to force the plume in the direction of the Gulf mouth. A small intrusion of slightly less turbid water is seen in the northern portion of the plume and is further evidence of surface currents altering the plume shape and orientation.

The August 01, 1977 imagery, shown in Figure 26, was generated approximately 1 hour prior to low slack tide. The river plume is shown to be oriented almost directly offshore from the river mouth, presumably having been forced down Gulf from a more northern orientation at high tide by ebbing currents. A large eddy is shown to have formed slightly south of Punta Corralillo, probably a result of large ebb tidal currents flowing south past the point.

Imagery representing July 14, 1977 is shown in Figure 27 and was generated less than one hour after low slack tide. The river plume is shown to be positioned directly offshore from the river mouth and has apparently been forced as far south as the southern shoreline will permit. Sediment distributions appear to be more disperse and indicate no major flow patterns.

The January 23, 1979 imagery, shown in Figure 28, was generated less than one hour prior to high slack tide. Once again, the river plume has taken on a northern orientation relative to the river mouth. As was the case at low slack tide, sediment distributions yield very little evidence of major tidal currents.

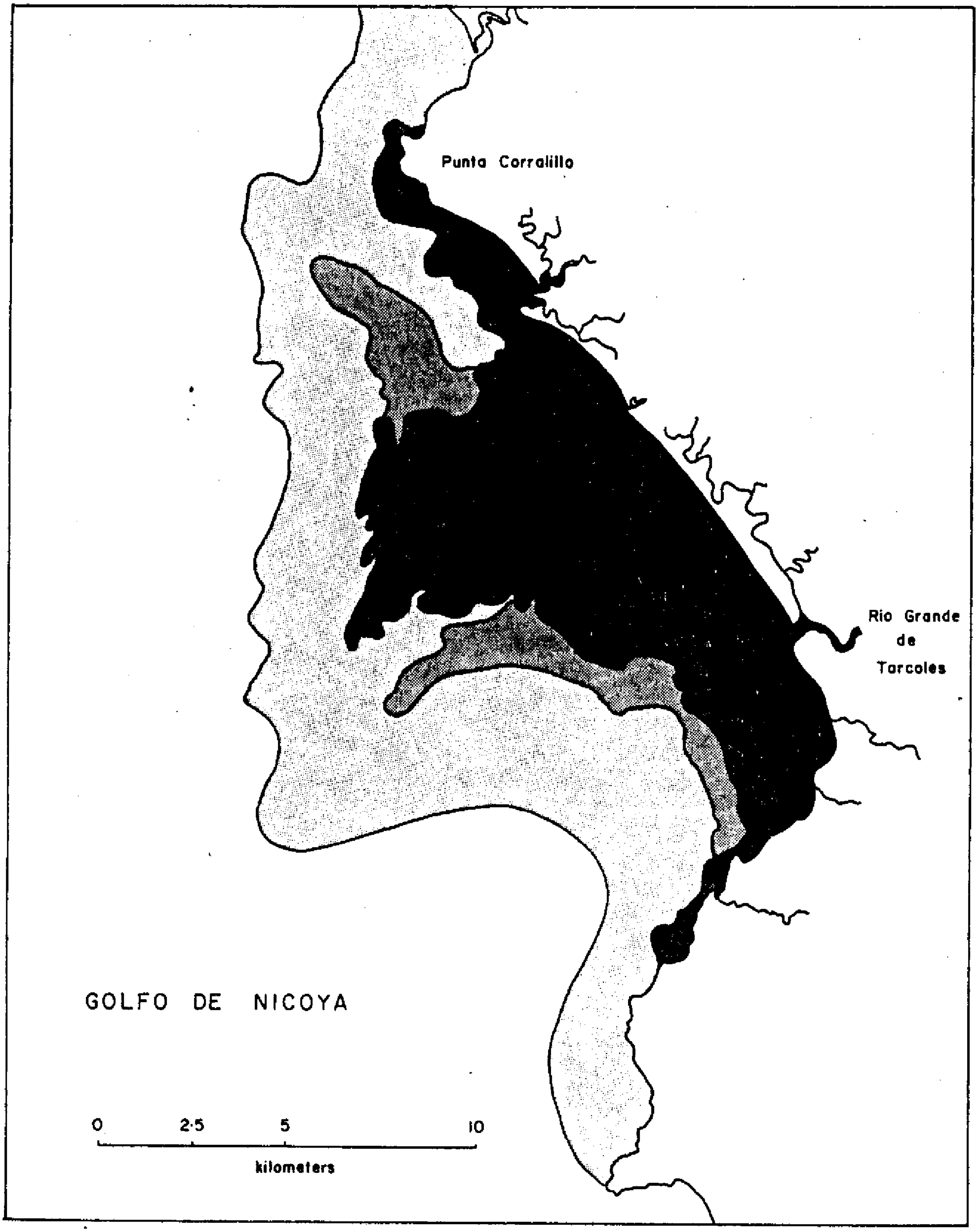

Figure 25: Enhanced LANDSAT imagery of the Gulf waters surrounding the Rio Grande de Tarcoles. The river plume is shown oriented north of the river mouth 2.5 hours after high slack tide.

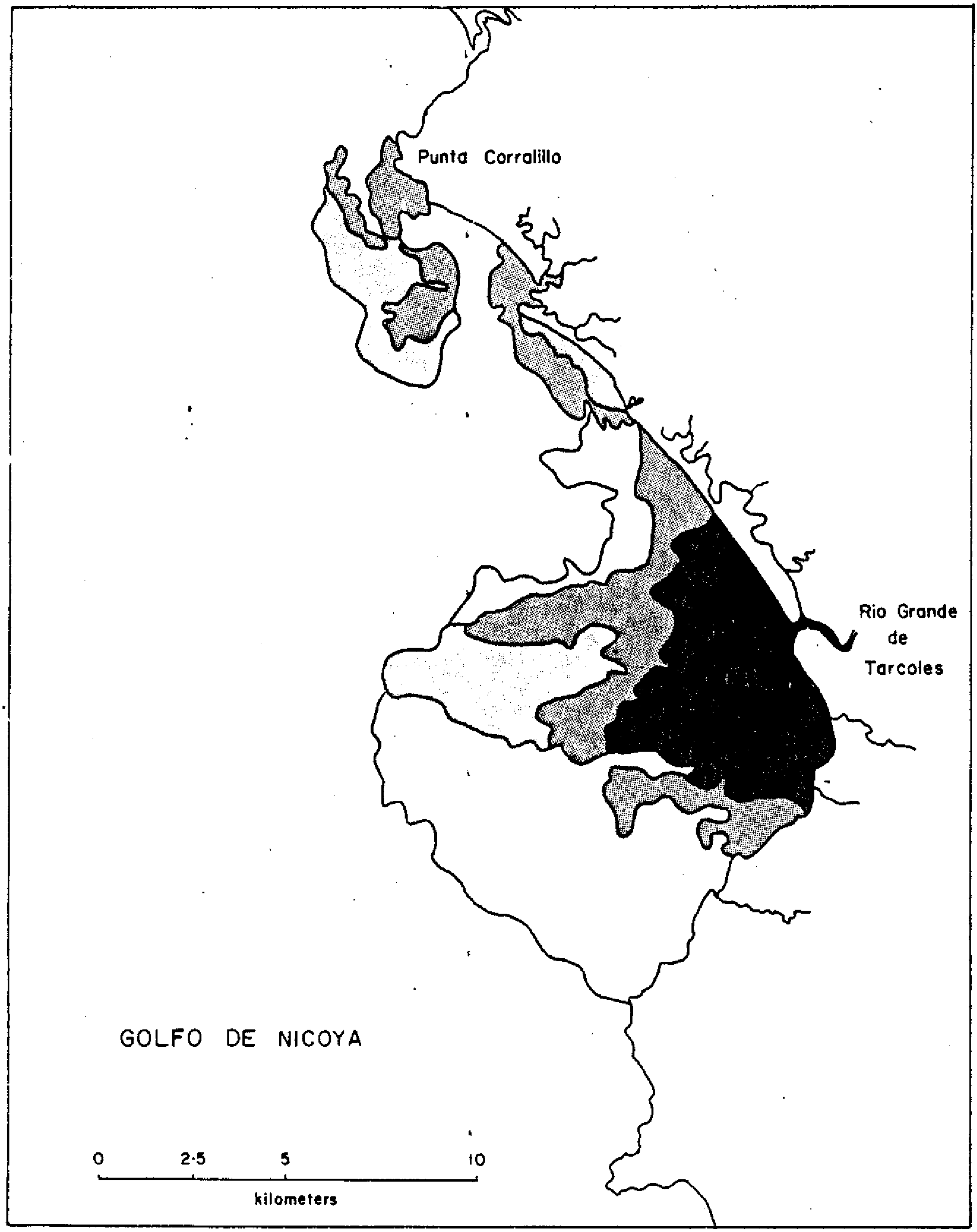

Figure 26: Enhanced LANDSAT imagery of the Gulf waters surrounding the Rio Grande de Tarcoles. The river plume is shown oriented directly offshore from the river mouth one hour prior to low slack tide.

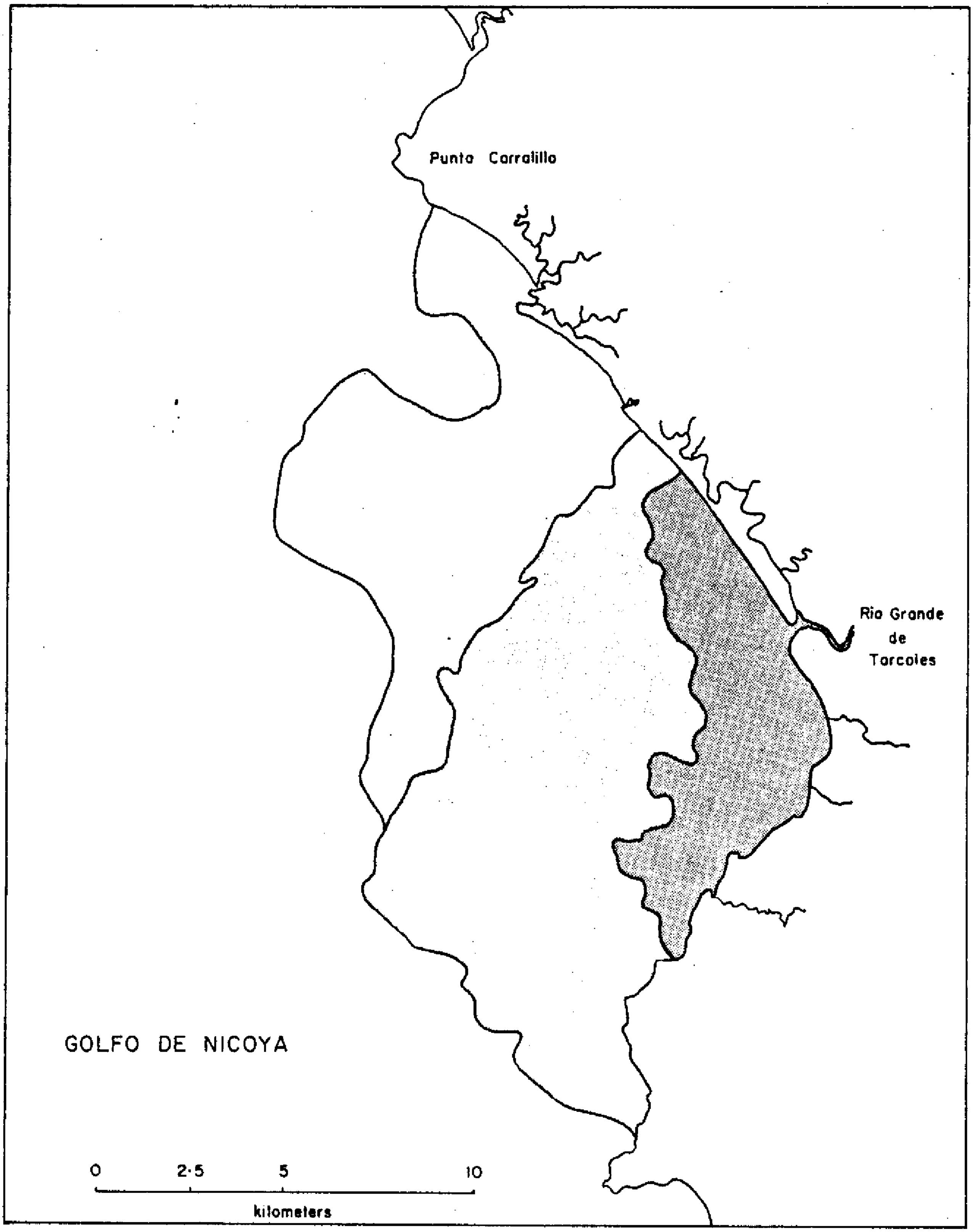

Figure 27: Enhanced LANDSAT imagery of the Gulf waters surrounding the Rio Grande de Tarcoles. The most intense part of the river plume is shown oriented south of the river mouth along the southern coastline less than one hour after low slack tide.

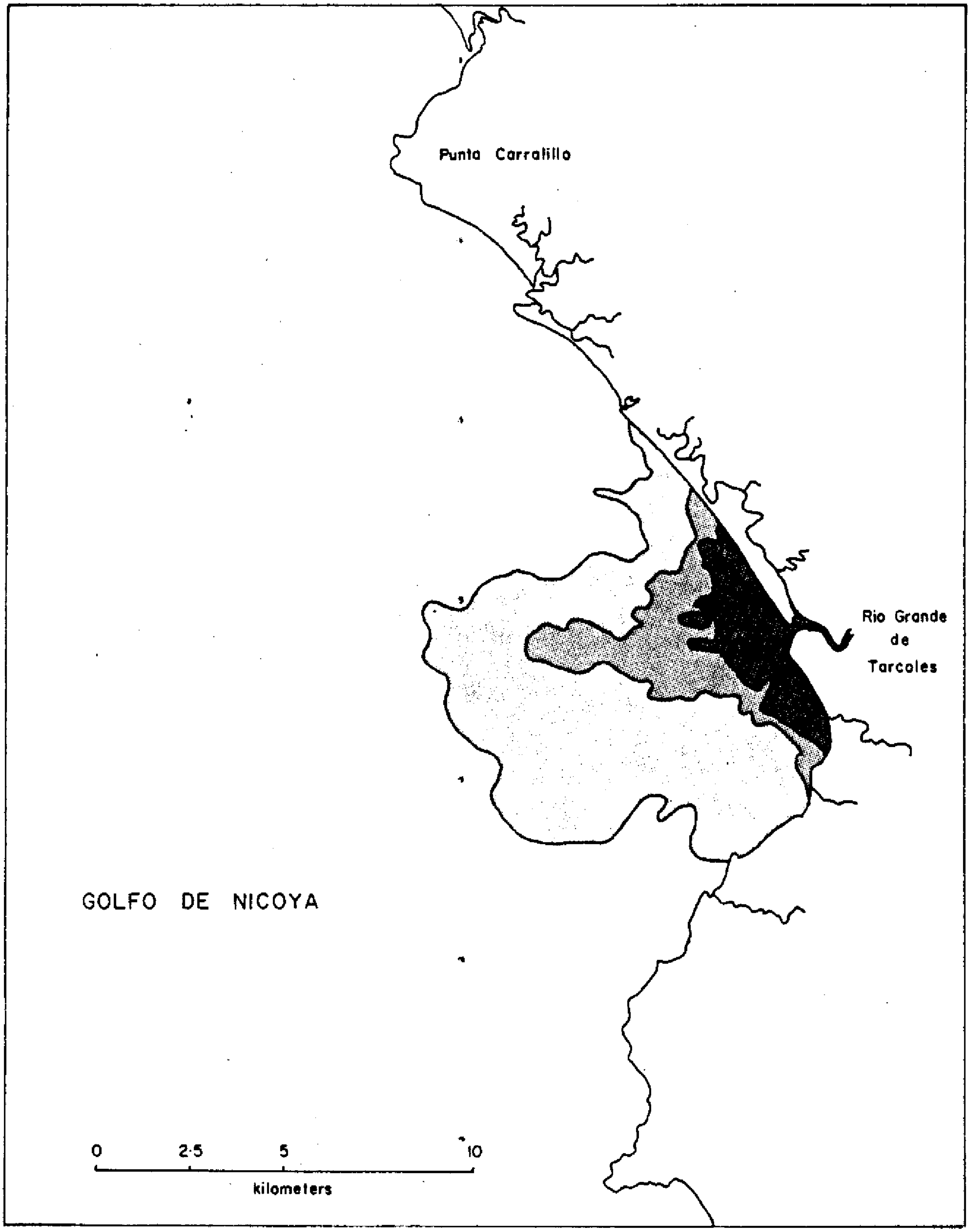

Figure 28: Enhanced LANDSAT imagery of the Gulf waters adjacent to the Rio Grande de Tarcoles. The river plume is shown oriented directly offshore from the river mouth one hour prior to high slack tide.

Maurer et al. (1980) reported the presence of a rather strong front east of Islas Negritos which was believed to be ebb tidal induced. Figure 29 is an ERDAS enhancement of Landsat imagery of the Islas Negritos area generated on March 03, 1975. Recall that the imaging took place 2.5 hours after high slack tide. As described by Maurer, a well defined jet of turbid water is apparently being funneled out into the central portion of the Gulf by the partial barrier formed by the islands. A smaller jet may also be seen emanating from the break in the two islands.

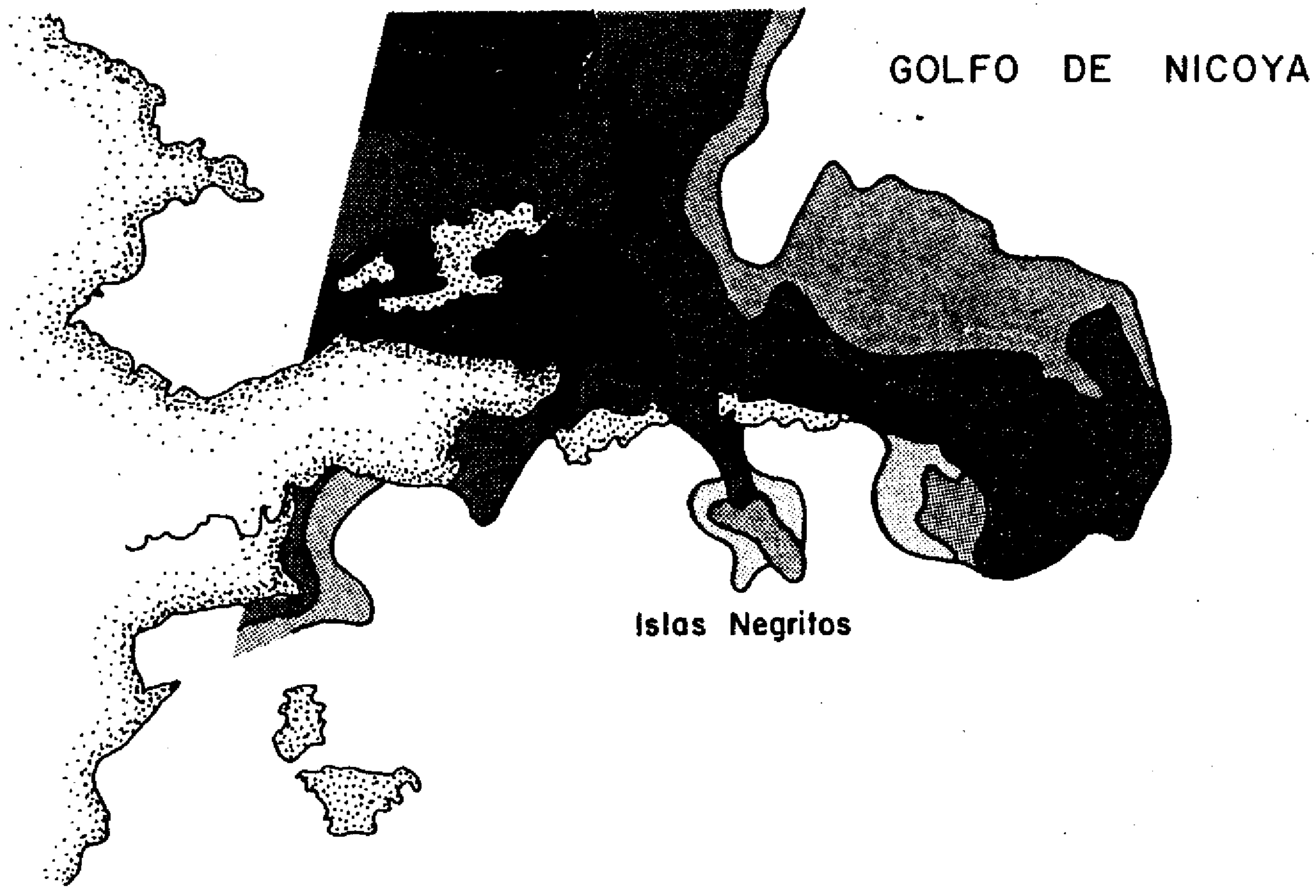

Figure 29: Enhanced LANDSAT imagery of the Gulf waters surrounding Islas Negritos. A strong frontal feature is shown east of the island chain as the partial barrier forces ebbing waters away from the west shore and into the central portion of the Gulf.

5.0 SUMMARY

Enhanced Landsat imagery of the Gulf of Nicoya indicated a rather well defined plume of river outflow emanating from the Rio Grande de Tarcoles. Although a detailed identification of suspended materials within the plume was not conducted, they are believed to include raw sewage and industrial waste carried downstream from the capital city of San Jose. The total concentration of suspended sediment within the plume, derived using vacuum filtration techniques, was found to range from 1.1 mg/ℓ offshore to 10.8 mg/ℓ inshore, close to the river mouth. The orientation of the plume appears to be tidal dependent, drifting as far north as Punta Loros (12 km from the river mouth) during flood tide. During ebb tide the plume was noted to drift south, eventually butting up against the coastline as far south as Punta Leona (10 km from the river mouth).

The circulation of surface waters adjacent to the Rio Grande de Tarcoles was further investigated for the case of a flooding tide by tracking drifter drogues. In all cases, the drift direction was north from the river mouth and slightly inshore. This supports the results of Landsat analysis which indicated a northerly orientated plume with respect to the river mouth during the same tidal phase. Drogues released 2.5 km offshore were found to drift with an average velocity of 30 cm/s and disperse at an average rate of 0.24 cm/s. Drogues released twice as far offshore (4.8 km) were found to drift with an average velocity similar to the inshore drogues (38 cm/s) yet exhibited a significantly higher dispersion rate of 0.76 cm/s.

Measurements of suspended sediment concentration, beam attenuation, salinity and temperature in the surface and near-surface waters adjacent to the mouth of the Rio Grande de Tarcoles also supports the results of Landsat analysis suggesting a well defined plume of river outflow. From the Landsat analysis, the plume was found to extend an average of 10 km offshore. Vertical profiles of the four physical parameters within 6 km of the river mouth indicated a bouyant plume occupying the top 10 meters of the water column. The plume may be characterized in terms of the measured parameters as:

1. suspended sediment concentration = 1.1 mg/ℓ - 10.8 mg/ℓ
2. beam attenuation coefficient = 0.46 m^{-1} - 5.28 m^{-1}
3. salinity = 2.69‰ - 34.0‰

No significant variation in temperature was found between the river plume and the clear offshore waters.

Seasonal variations (i.e. rainy season versus dry season) within the Rio Grande de Tarcoles river plume may be summarized as follows:

1. suspended sediment concentrations were found to be slightly higher during the rainy season (May through December)
2. water salinity increased as much as 2.5‰ during the dry season (January through April)
3. water temperature was found to be slightly higher during the rainy season
4. dissolved oxygen concentrations were found to be slightly higher during the dry season.

The concentration of suspended sediments within the surface and near-surface waters of the upper Gulf was found to range from 20.2 mg/ℓ at the mouth of the Rio Tempesque to 3.3 mg/ℓ just north of Puntarenas. These values were obtained in July of 1981 and, as such, represent rain season conditions.

Beam attenuation values representing surface and near-surface waters of the Gulf north of Puntarenas were found to range from 2.29 m^{-1} to

5.28 m^{-1}. Values recorded south of Puntarenas and north of Islas Negritos ranged from 0.51 m^{-1} to 1.86 m^{-1}.

Analysis of Landsat imagery of the Gulf area surrounding Islas Negritos during ebb tide (March 13, 1975 imagery) indicated the presence of a well defined frontal feature emanating from the northern side of the island chain and extending out into the central portion of the Gulf. Maurer _et al_. (1980) noted a similar feature and attributed it to ebbing waters flowing south along the western shore of the Gulf that were deflected out into the central portion of the Gulf by the islands which form a partial barrier.

6.0 REFERENCES

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