2) Results and discussions

The distribution range for the TSS varied from 0.45 to 6.77 mg/l for the TM image of 12 October 1999. The results showed higher distribution values along the coastal regions (e.g., the 3.16 to 4.51 mg/l was most common in the shallow water inshore areas; Plate 9). TSS range of 1.36 to 3.15 mg/l was widely distributed in mostly the offshore area. Although there was a time lag between the TM images and sample collection for a few days, a satisfactory distribution was observed for the region.

(3) Chlorophyll Distribution

1) Methodology

The TM Band 4 (0.76 to 0.90 micrometer range, near infrared region) was image sliced and distribution values were determined. Laboratory analyzed results for the chlorophyll distributions were utilized by referring the GPS locations and selecting the DNs for the Band 4. Ten sample sites were selected for generating the correlation between chlorophyll concentrations and DNs, a significant relationship was showed ($r = 0.87$ and standard error of estimate = 0.6113), and this calibration was applied for the whole data. Color coding, recoding, mosaicking and statistical filtering were performed for the preparation of the final distribution map.

2) Results and discussions

The distribution was divided into five categories ranging from 0.00 to 1.52 microgram/l for Path/Row 164/041-042 and 0.00 to 1.24 microgram/l for Path/Row 163/043 TM data, respectively. The quantitative analysis showed good correlation between the parameters. Generally low chlorophyll concentration were found for most of the whole intensive study area (Plate 10). Higher concentrations were present very close to the coastal sites, such as the northeast of Tarut Bay, the northeast side of Tarut Island, and Al Azaziz. Medium range (0.47 to 0.64 microgram/l) was observed in the NE parts of the image.

(4) Coastal Area Distribution

Coastal area distribution map was generated to depict the existing situation of the nearshore regions of the intensive study area. This was done for the first time as far as the present study is concerned by utilizing the TM data.

1) Methodology

TM Bands 1 to 4 (visible to near-infrared wavelengths) were utilized to classify the coastal areas. Unsupervised (automatic) classification was performed and initial 40 classes were generated for the coastal regions of the intensive study area. Interpretation was done and existing habitat maps (Executive Summary, Saudi Aramco Sustaining Research Project: Environmental Studies, Phase II, 1994) were referenced for finalizing and reducing the number of the classes. Fifteen classes were established. The present analysis shows the latest (October 1999) situation of the coastal region of the intensive study area. However, this classification still requires more detailed ground information for improving the classification accuracy and to reduce the spectrall confusions among some of the classes.

2) Results and discussions

The classified image (Plate 11) shows that the largest distribution was the general "shallow water" followed by "very shallow" and "muddy/silty" areas. Most of the coastal areas (more than 50%) comprise modified habitats. The present classification shows the existing situation for the coastal areas, e.g., land fills, built-up areas, dredgged channels etc. Mangroves and coral reef occupied very small areas.

4.2.5 Conclusion for the Analyzed TM Data

Overall, TM data analysis appears to be a very effective means of assessing water quality. Due to repeated vast area coverage by the LANDSAT the whole study area was covered by the acquired TM images. The analyzed TM data have shown good results despite the lack of *in situ* information at the time of satellite flyby. The prepared distribution maps show variations for the suspended solids, chlorophyll and possible oil pollution and can be referenced for the assessment and monitoring reporting purposes.

Marine and coastal processes are complex, interrelated systems, and remote sensing data may not always provide sufficient information for the efficient monitoring purposes. In general amounts of *in situ* measurements are necessary to enhance and facilitate the interpretation of the synoptic remote sensing imagery. Further similar type of TM analysis is necessary utilizing the existing water quality data (e.g., October – November 1999) for preparing the distribution maps for the Intensive Study Area. Utilization of the project's water sampling results is proposed to be incorporated for preparing the distribution map for the Intensive Study area. Also, sea surface temperature distribution, coral reef and seashore mapping can be performed from the TM information. The assimilation of remote sensing data into coastal process models

will provide synoptic and more integrated monitoring capability for the Intensive Study Area.

4.2.6 Recommended Action for the Future Work

(1) Conclusion

The main conclusions are that the TM images were able to successfully detect the variation of the selected water quality parameters; and they provide a valuable source of information for the ongoing project. From the results obtained, it could be seen that TM provides useful information for identifying and studying regional patterns in the temperature, suspended solids, chlorophyll and coastal area distribution. The analysis indicated the effectiveness of the satellite data for providing a synoptic and quantitative overview of the water quality in the intensive study area. Local conditions including tides, coastal discharge, shallow areas with sedimentation and algae-mats always need to be considered in the analysis. Although there are certain limitations, orbital remotely sensed data could and should be used as a complementary tool when field data are scarce to obtain synoptic views for monitoring purposes.

(2) Necessity for MEPA to Construct the Continuous System for the TM Data Analysis

Decision-makers are confronted with complex issues such as pollution, wastewater discharge, oil spill and coastal developments in relation to the marine environment. The task of acquiring information for input to models and to support decision making, remains daunting. Satellite remote sensing provides a cost efficient means of gathering both historic and near real time information over the region. Satellites such as LANDSAT/ SPOT/IRS etc., are helping to improve our understanding of oceans and coastal processes.

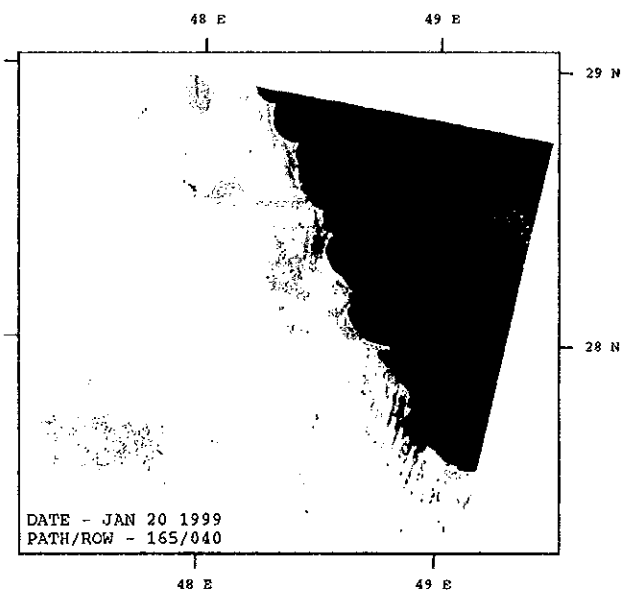
The detailed spatial distribution of water quality variables and coastal changes can be determined from the satellite images to an extent that can not be achieved by cost-effective Field Sampling campaigns alone.

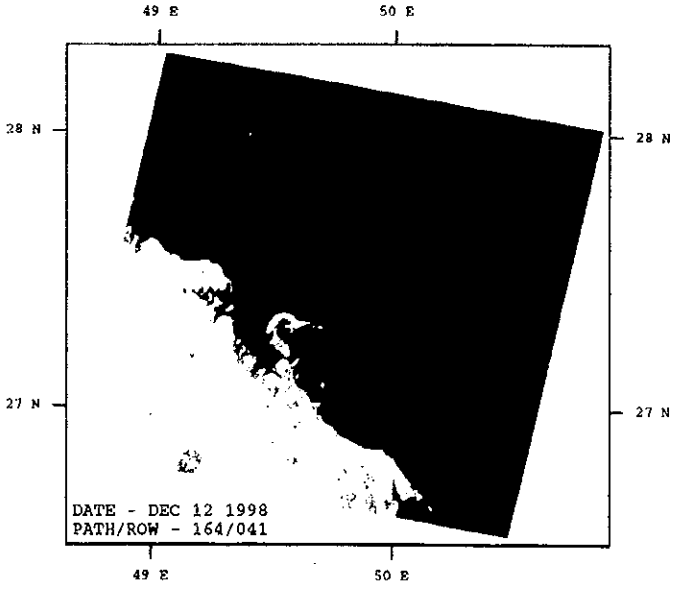
Utilization of satellite remote sensing can be a feasible means for regular monitoring on seasonal or temporal base.
Moreover, increased spatial and spectral resolution by suitable sensors of different satellites should be utilized to help expand the opportunities for monitoring the Arabian Gulf Environment.

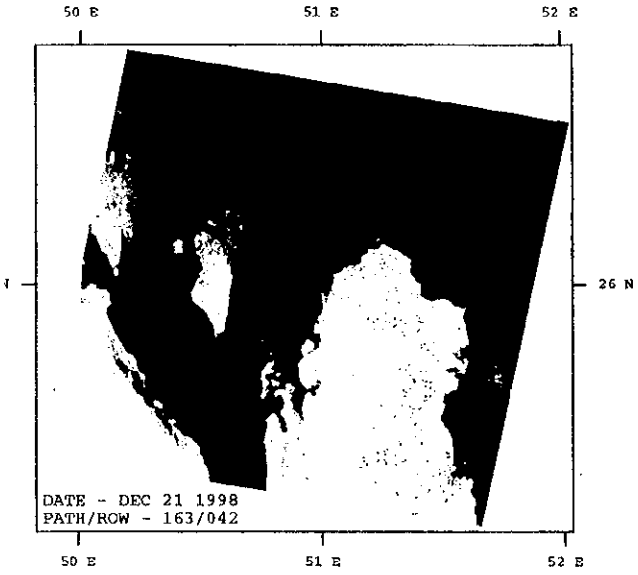
MEPA is actively engaged in monitoring of the coastal environment but lacks the satellite based monitoring system.

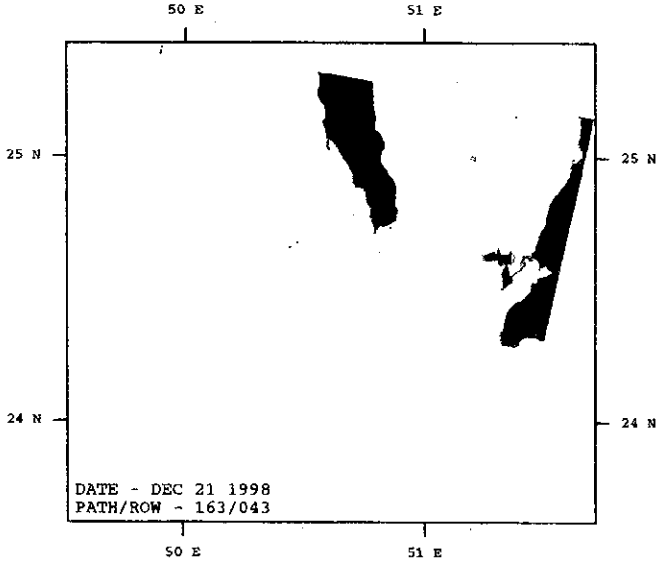
MEPA should have its own monitoring system utilizing the data from the earth observation satellites like LANDSAT or SPOT or IRS or RADARSAT etc., to improve the understanding of oceans and coastal processes. Also, MEPA should have a closer relationship with the organizations having the capability for the satellite data analysis.

In the near future MEPA is needed to have a couple of specialists with a background in satellite data analysis and its own well established image analysis system in combination with Geographic Information System (GIS). This will allow regional, real time and historic monitoring of activities such as continuing coastal developments and synoptic patterns of coastal, as well as disasters such as major oil spills in the coastal waters of the Arabian Gulf.

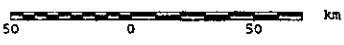








LANDSAT/TM Images
Bands - R:G:B :: 4:3:2



(for Path/Row-164/042)

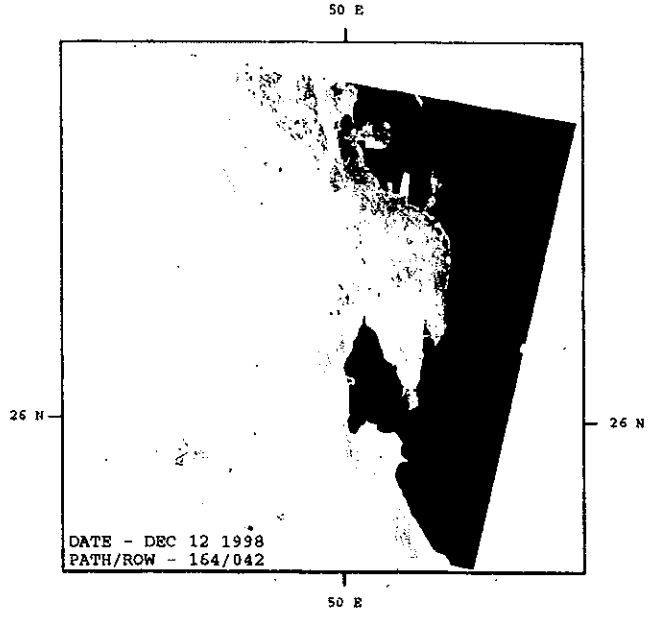


PLATE1 False Color Composite Images

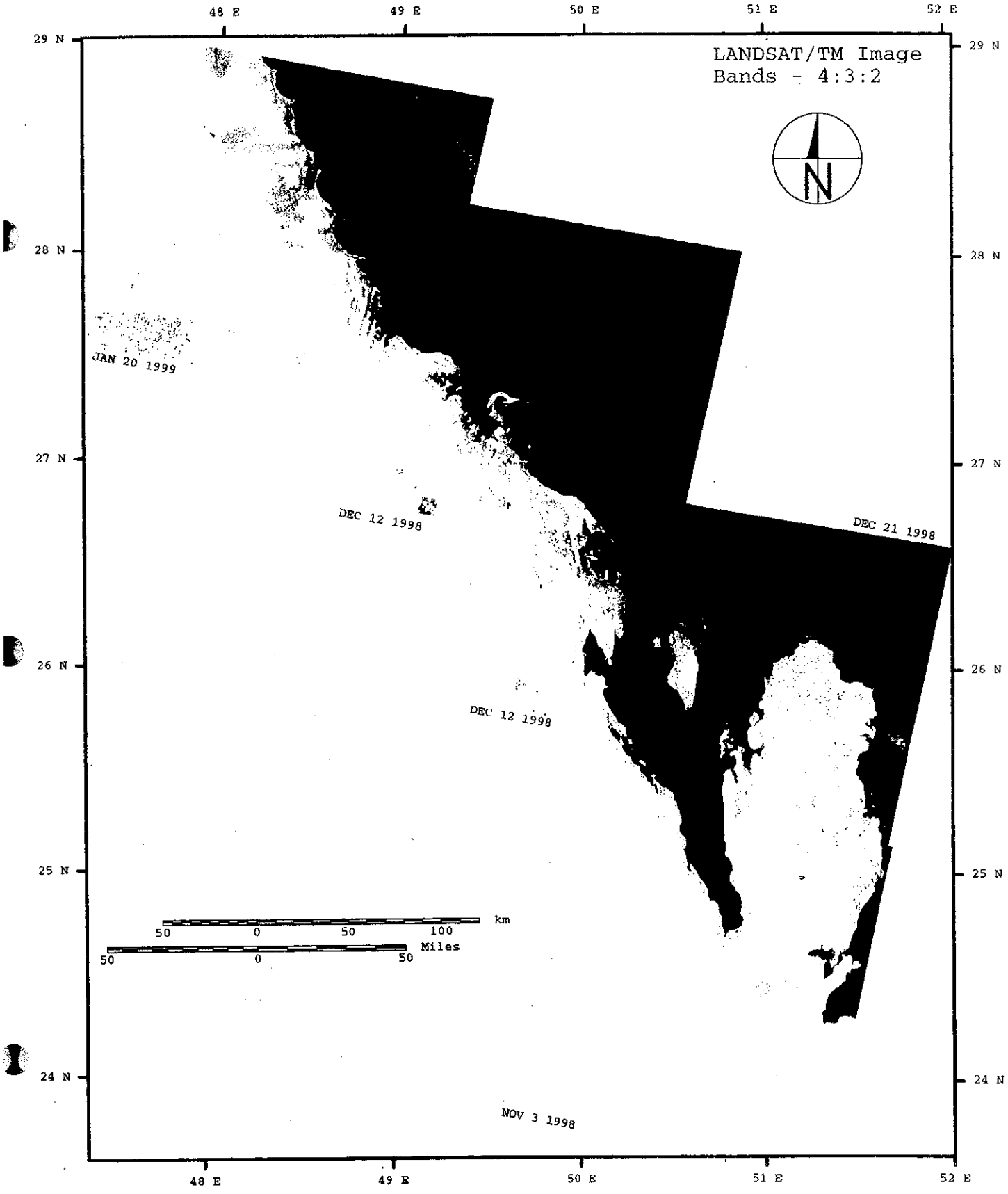


PLATE2 False Color Composite Image

PLATE3 Intensive Study Area

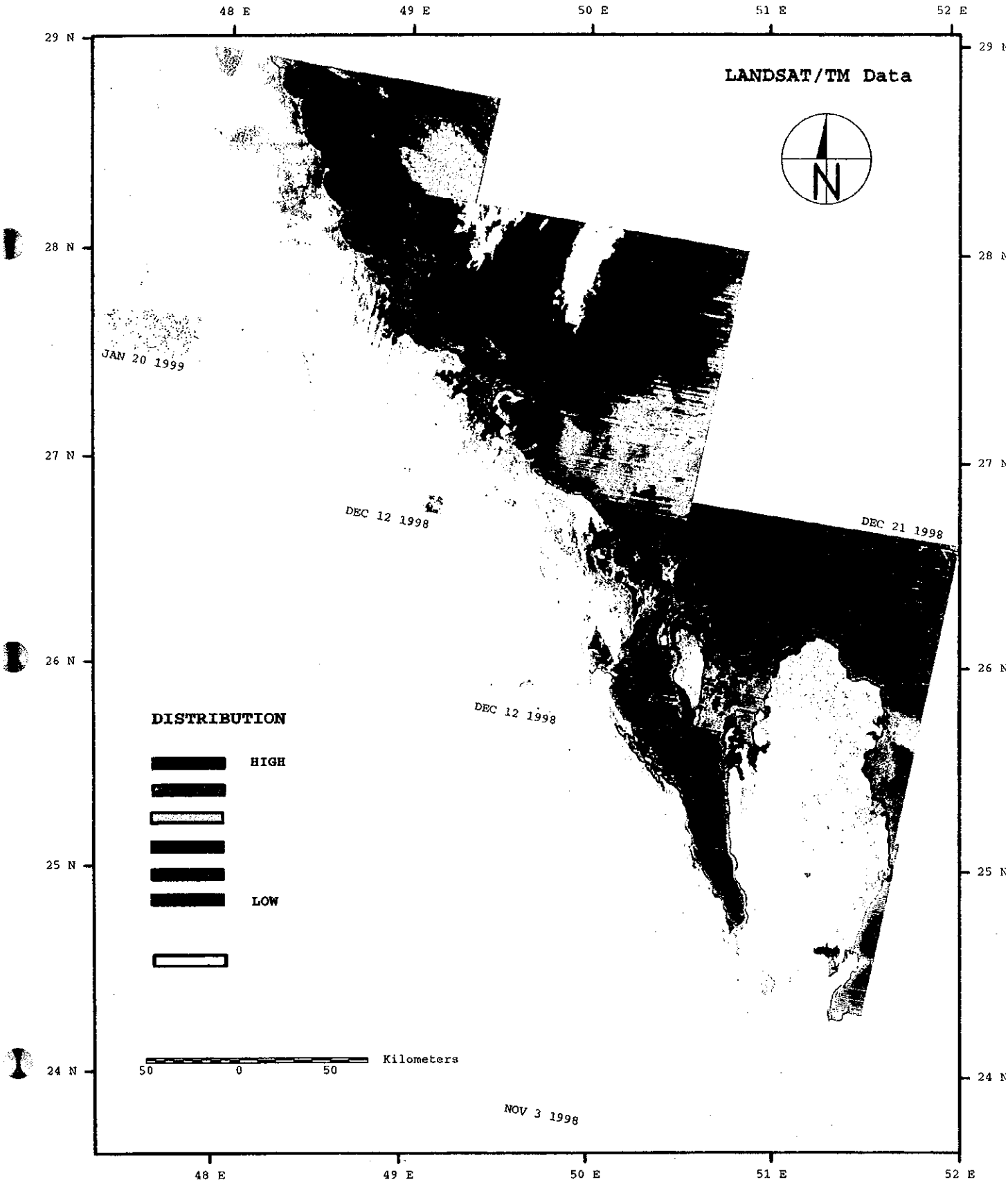


PLATE4 Suspended Solids Distribution Map

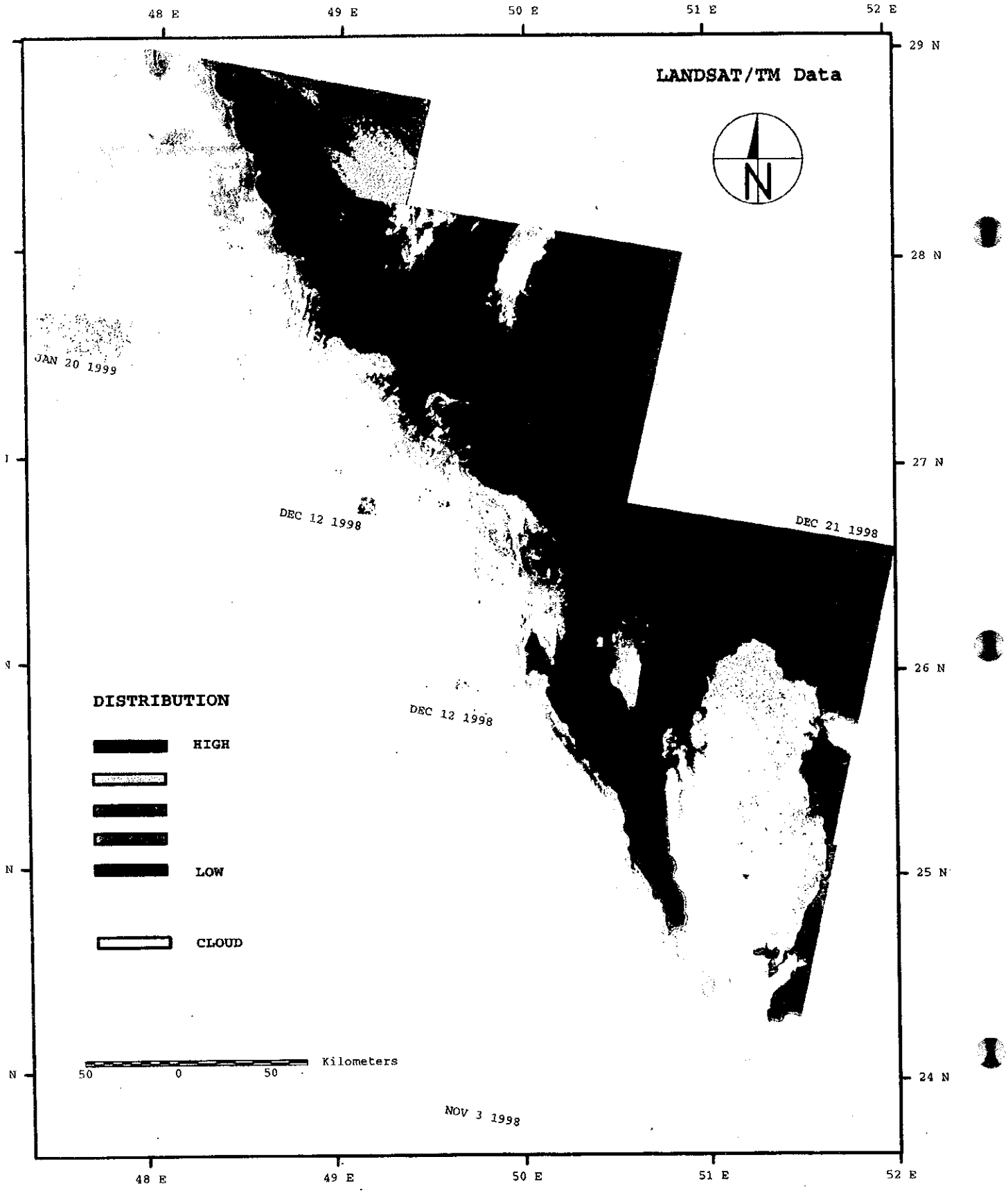


PLATE5 Chlorophyll Distribution Map

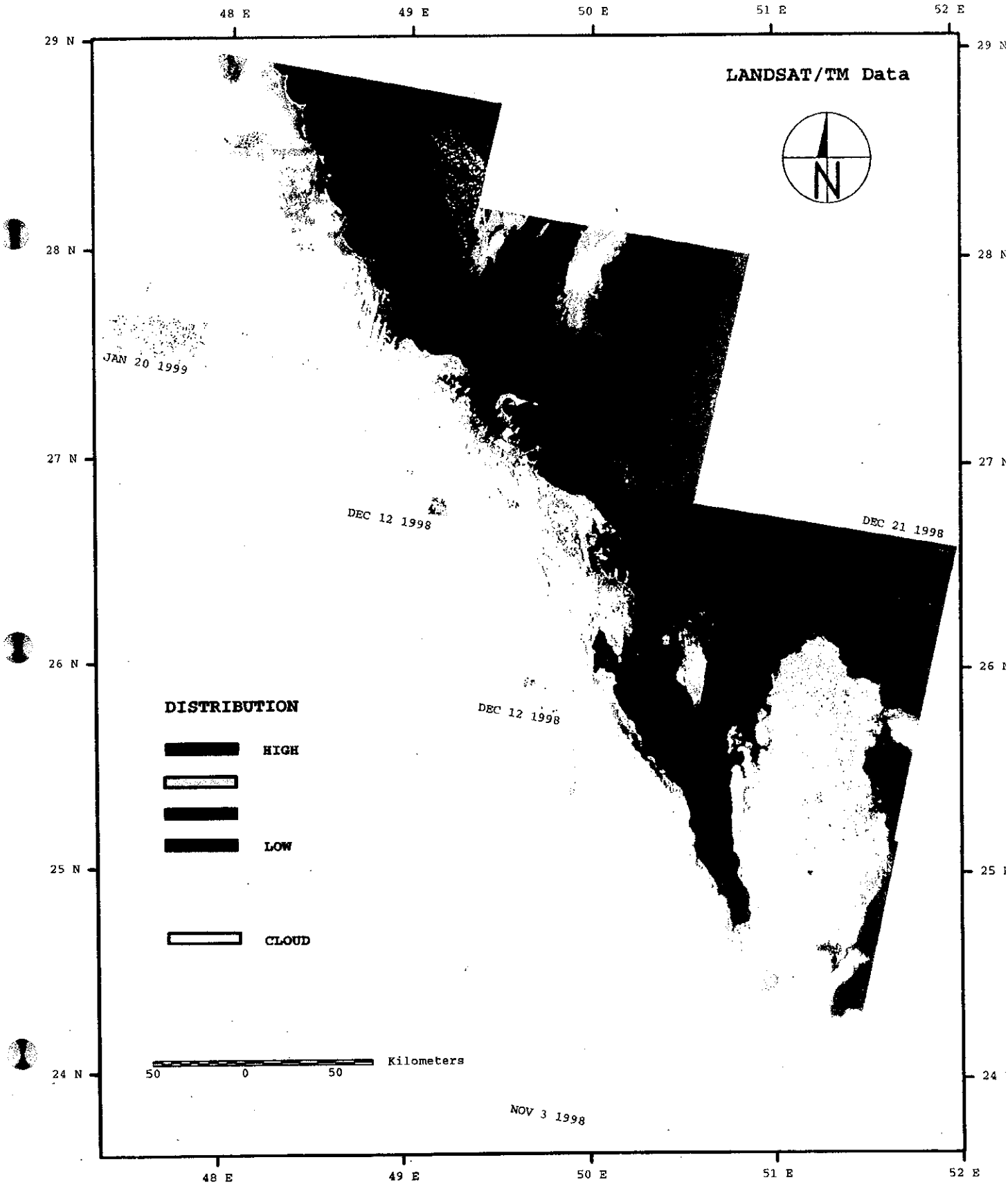


PLATE6 Oil Pollution Distribution Map

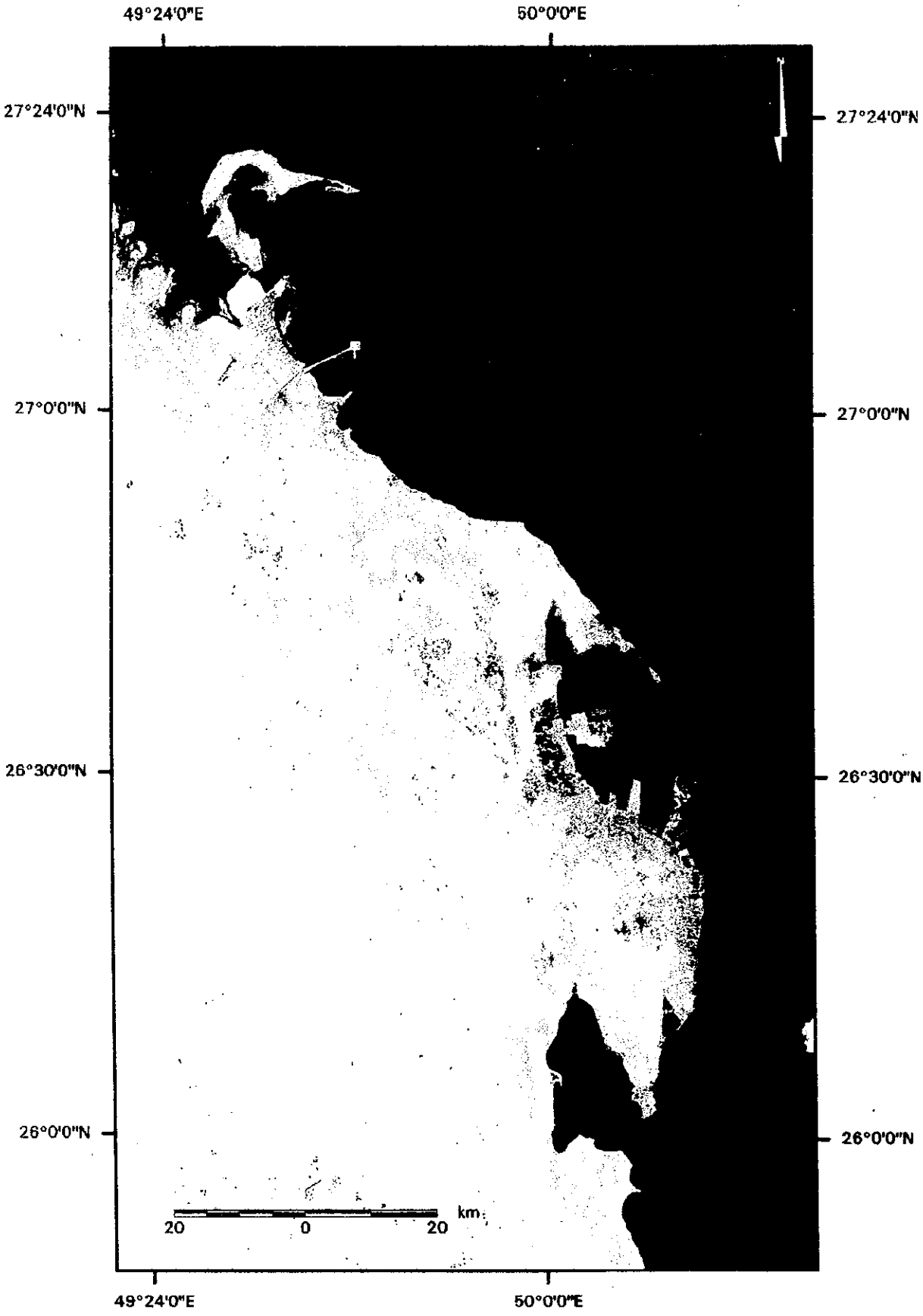


PLATE7 Intensive Study Area

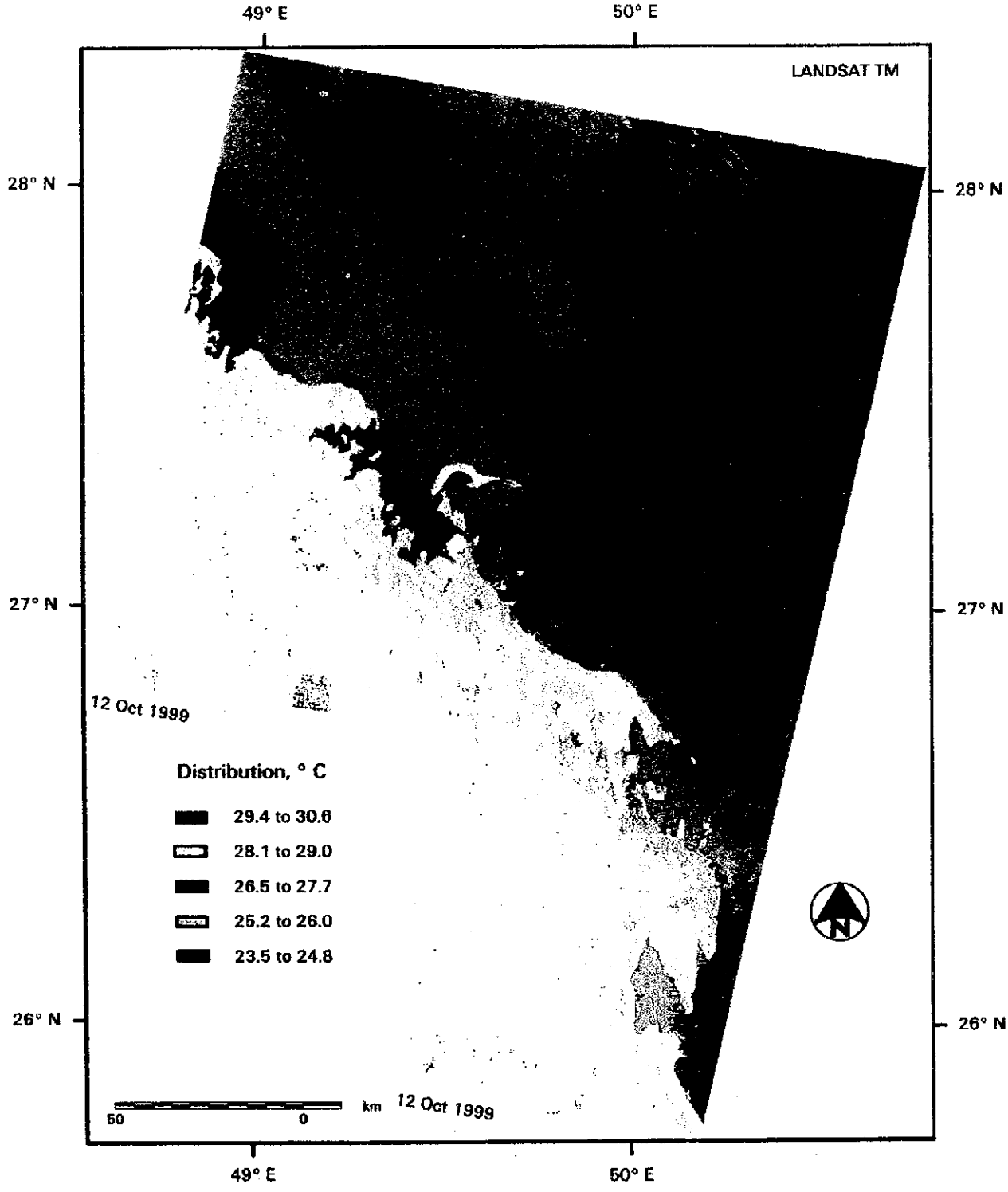


PLATE8 Thermal Distribution Map

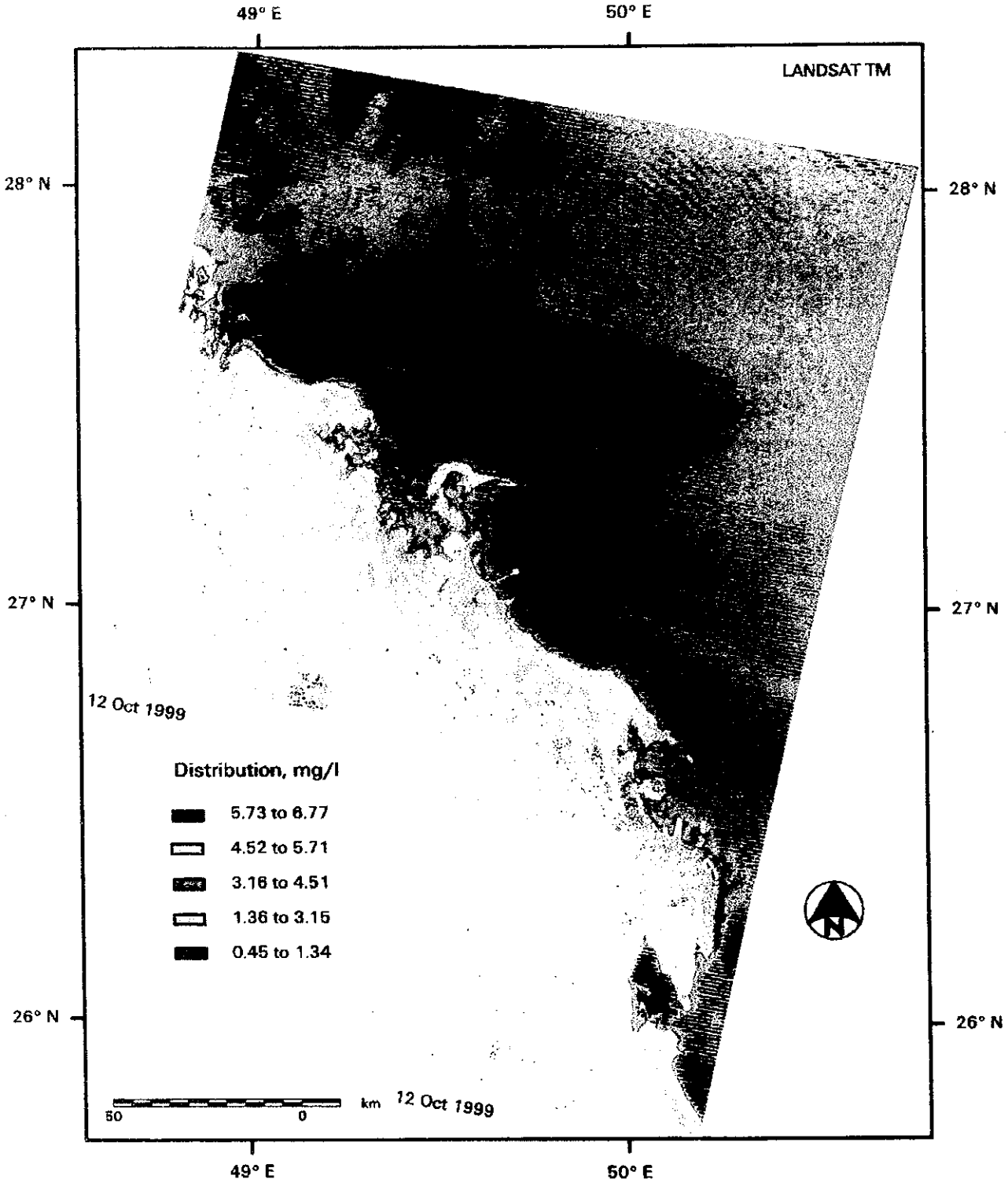


PLATE9 Suspended Solids Distribution Map

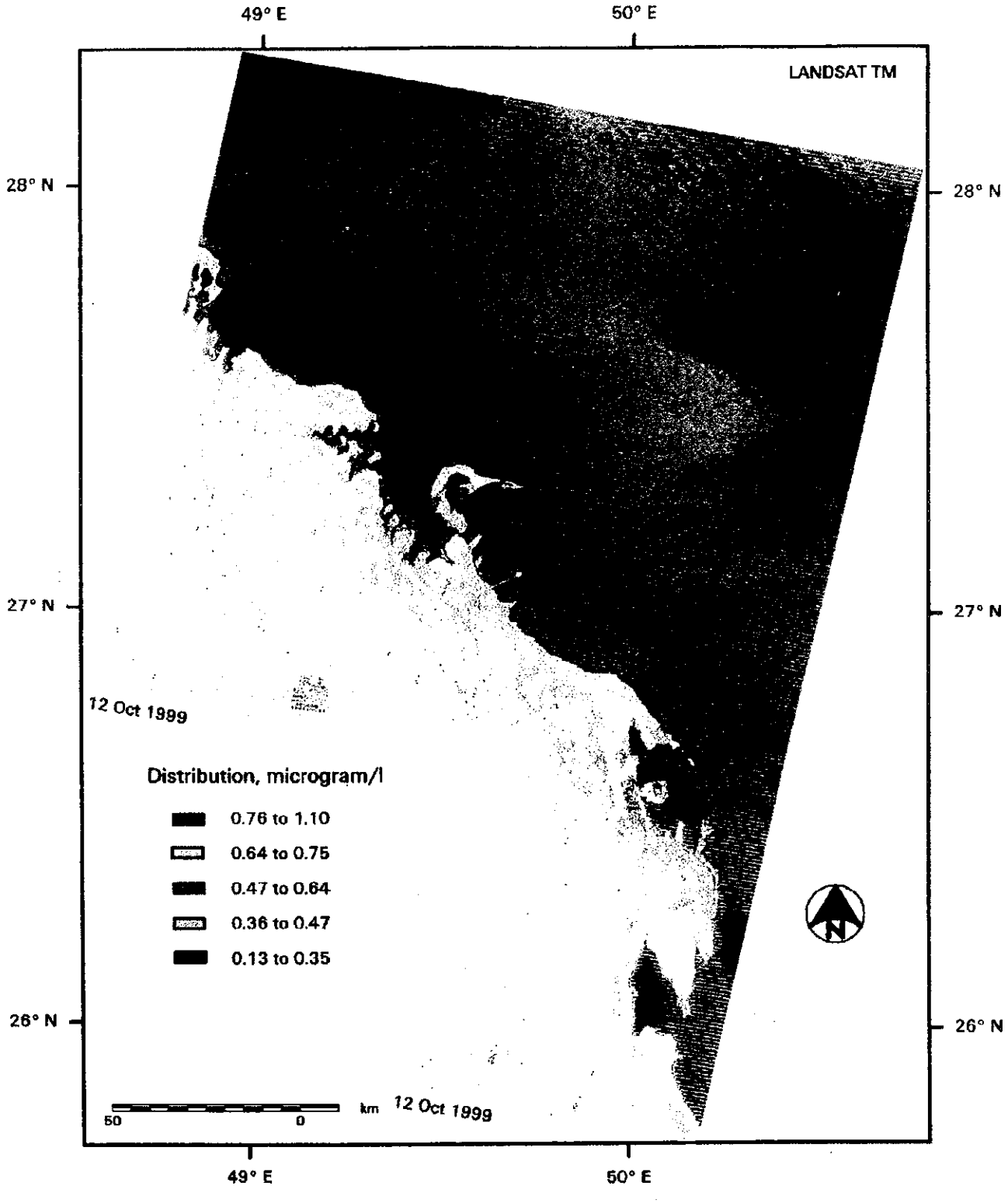


PLATE10 Chlorophylll Distribution Map

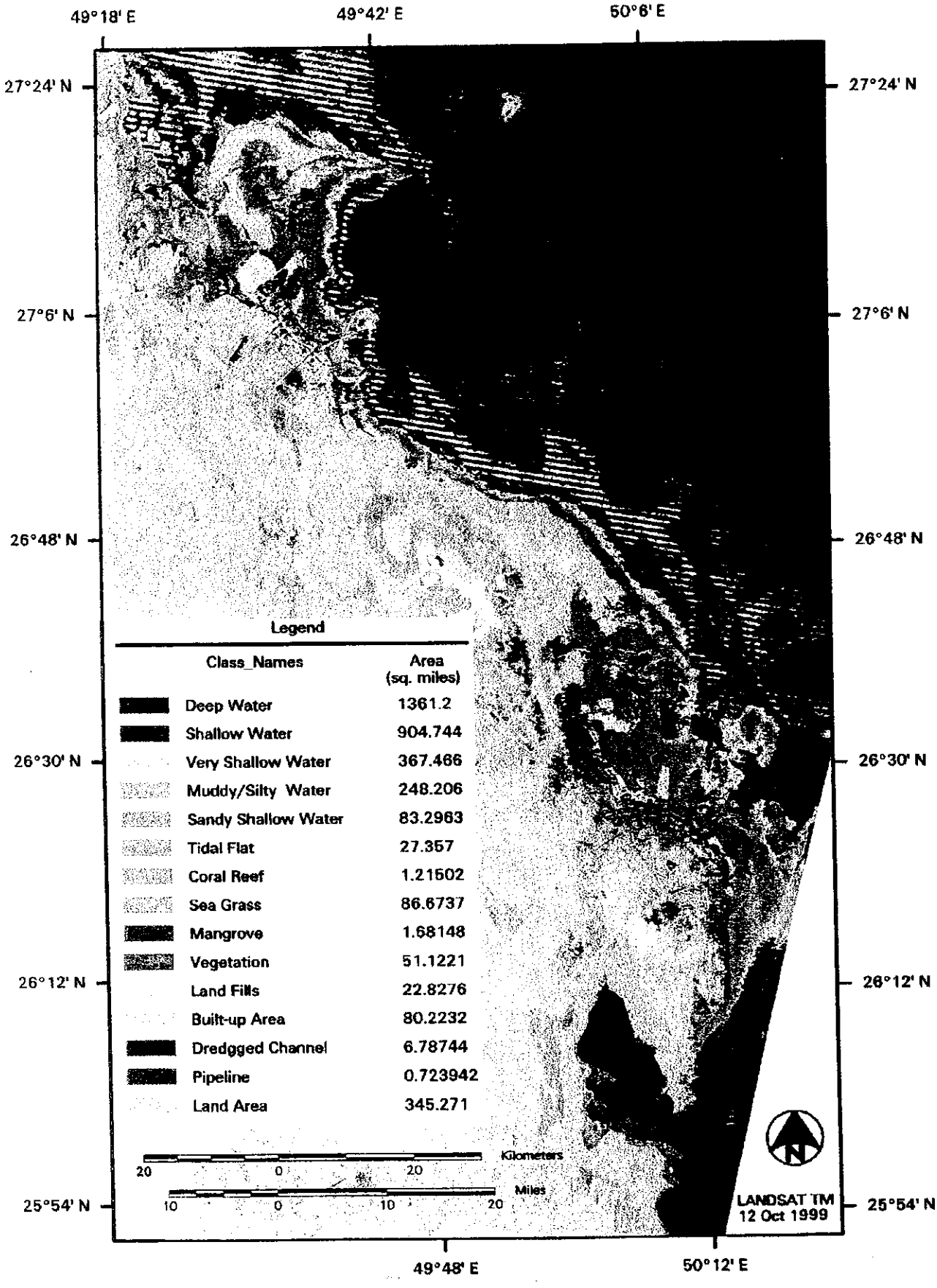


PLATE11 Coastal Araa Distribution Map

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4.3 Preparative Field Inspection

In order to understand the general characteristics of the environmental condition of the Intensive Study Area (ISA) and to collect information for monitoring plan preparation, field inspections were conducted.

For the purposes of both technology transfer and sampling location characterization, a total of 37 water/sediment samples were collected.

4.3.1 Objectives

The main objectives of the field inspection undertaken during the Second Stage (June-July 1999) were as follows.

- Study area familiarization and site inspections within the ISA.
- Identification of the range for suitable sampling sites for the future water quality monitoring at potential future sampling stations.
- To check the operational logistics, requirements, navigation constrains, boat characteristics and performance, facilities, communications and liaison / coordination requirements with the Coastguard vessels and their crews.

4.3.2 Sites and Schedule

Field inspections and water samplings were conducted during the period June 13 to June 27. Laboratory analysis was conducted during he period June 19 to 28, 1999. Total of 38 sites that represented the main characteristics of the Intensive Study Area was inspected. The location of each site is shown in Figure 4.3.1 and schedule of inspection survey is shown in Table 4.3.1.

Table 4.3.1 Site Inspection Schedule

Date	Region	Code of Inspected Site	Location Name
13.Jun.99	Al Jubail	J7A	ARAMCO South Terminal
	Al Jubail	J7B	Fanateera Island
	Al Jubail	J7C	Fanateera Marina
	Al Jubail	J9	Shared Industrial Outfall
	Al Jubail	J10	Jubail Harbour
14.Jun.99	Al Jubail	J11	Jubail Industrial Port Tank farm North
	Al Jubail	J3	Abu Ali North
	Al Jubail	J5	Berri Oilfield
	Al Jubail	J6	Outer Shoal
15.Jun.99	Al Jubail	J2B	Dawhat Dafi Bay
	Al Jubail	J8	Maduraigh Marina
	Al Jubail	C01	Storm outfall of Jubail Industrial City(1)
16.Jun.99	Al Jubail	C02	Storm outfall of Jubail Industrial City(2)
19.Jun.99	Ra's Tannurah	RD01	ARAMCO Oil Refinery Outfall
	Ra's Tannurah	RD02	Sea Island Termnl
	Ra's Tannurah	RD03	South Sand Spit
	Ra's Tannurah	RD03B	Platform reef (Almost dead)
	Ra's Tannurah	RD04	Marine coral reef (Najwah Island)
21.Jun.99	Tarut Bay	RA01	North side of Tarut Is
	Tarut Bay	RA02	Inshore north of Tarut
	Tarut Bay	RD8	Fishing Fleet jetty
	Tarut Bay	RD8B	South central Tarut
	Tarut Bay	RD9	Qatif Marina dredged
	Tarut Bay	RD9B	Qatif S/W drain
23.Jun.99	Dammam	RD10	Near ARAMCO Reclaim Island
	Dammam	RD11	SAFCO corner
	Dammam	RD12	Kaskus Island
	Dammam	RD4	Najwah Island
	Dammam	RD5	Dammam Harbour
	Dammam	RD7	Small boat Harbour
26.Jun.99	Al Khobar	RD14	Al Benhani Islet
	Al Khobar	RD14B	Sewage Outfall
	Al Khobar	RD15	Desalination intake
	Al Khobar	RD15B	Desalination outfall
	Al Khobar	RD15C	Residential marinas
27.Jun.99	HalfMoon Bay	RD17	Centre of HM Bay
	Al Qurayyah	RD18	Power station intake
	Al Qurayyah	RD18B	Power station outfall

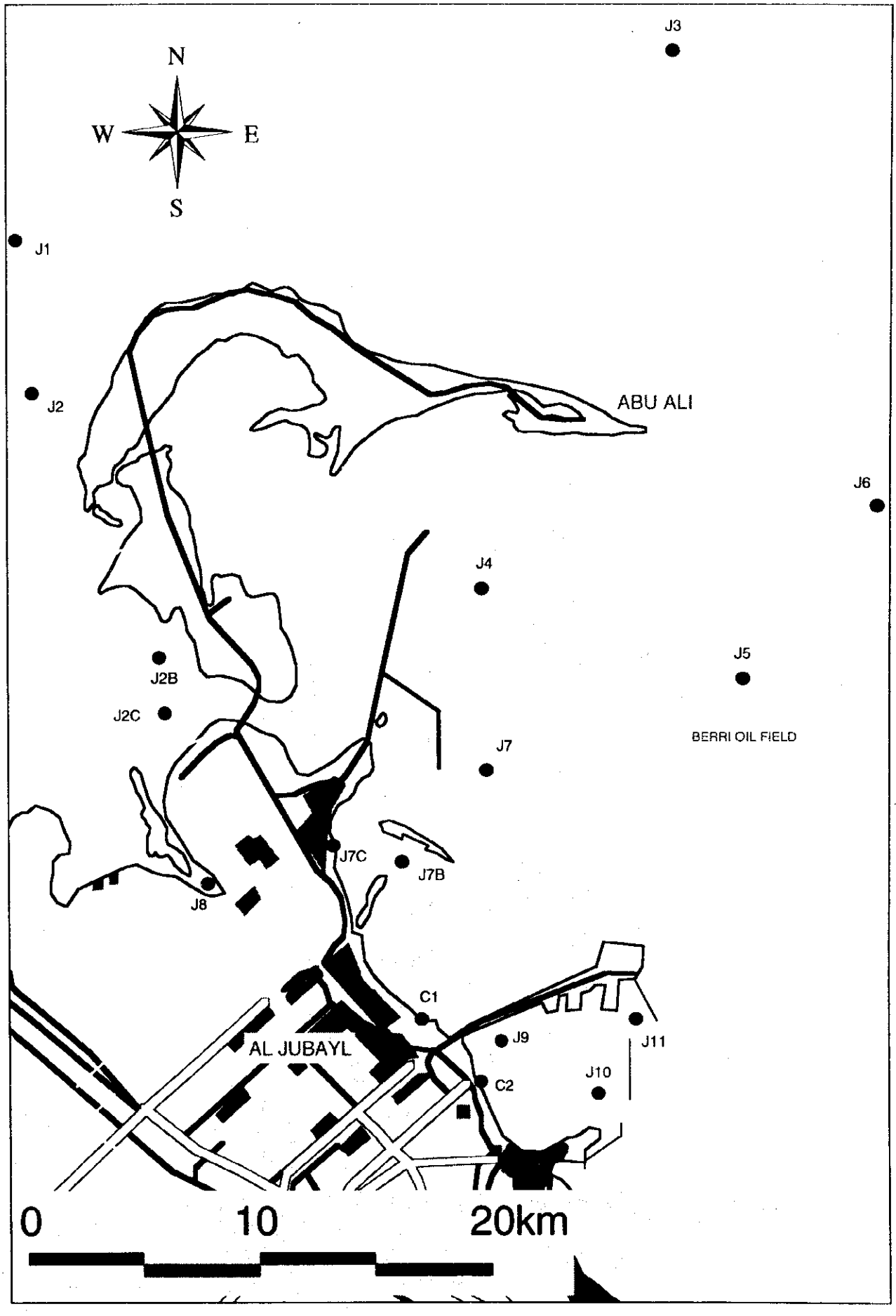

Figure 4.3.1 (1) Field Inspection Location

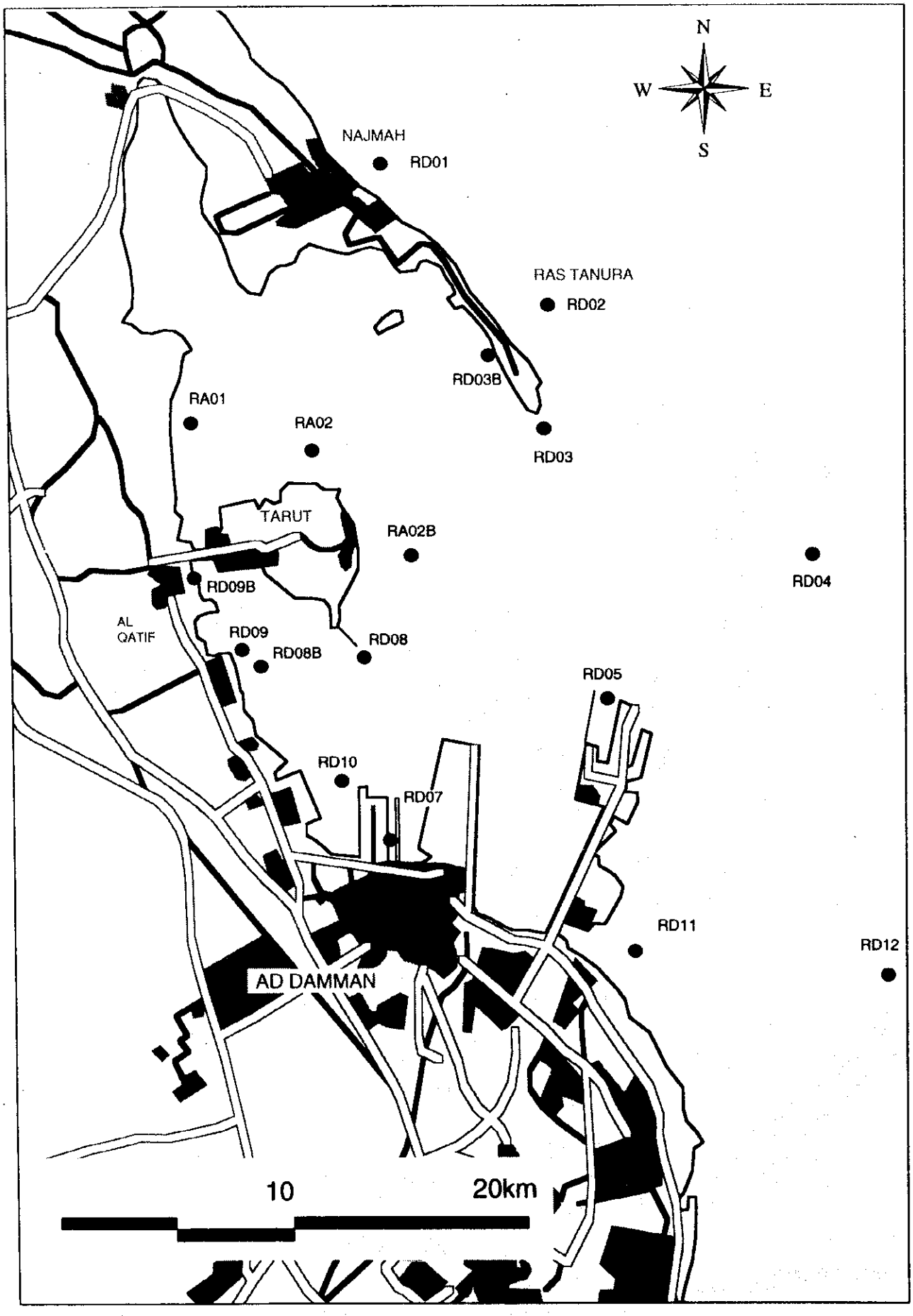

Figure 4.3.1 (2) Field Inspection Location

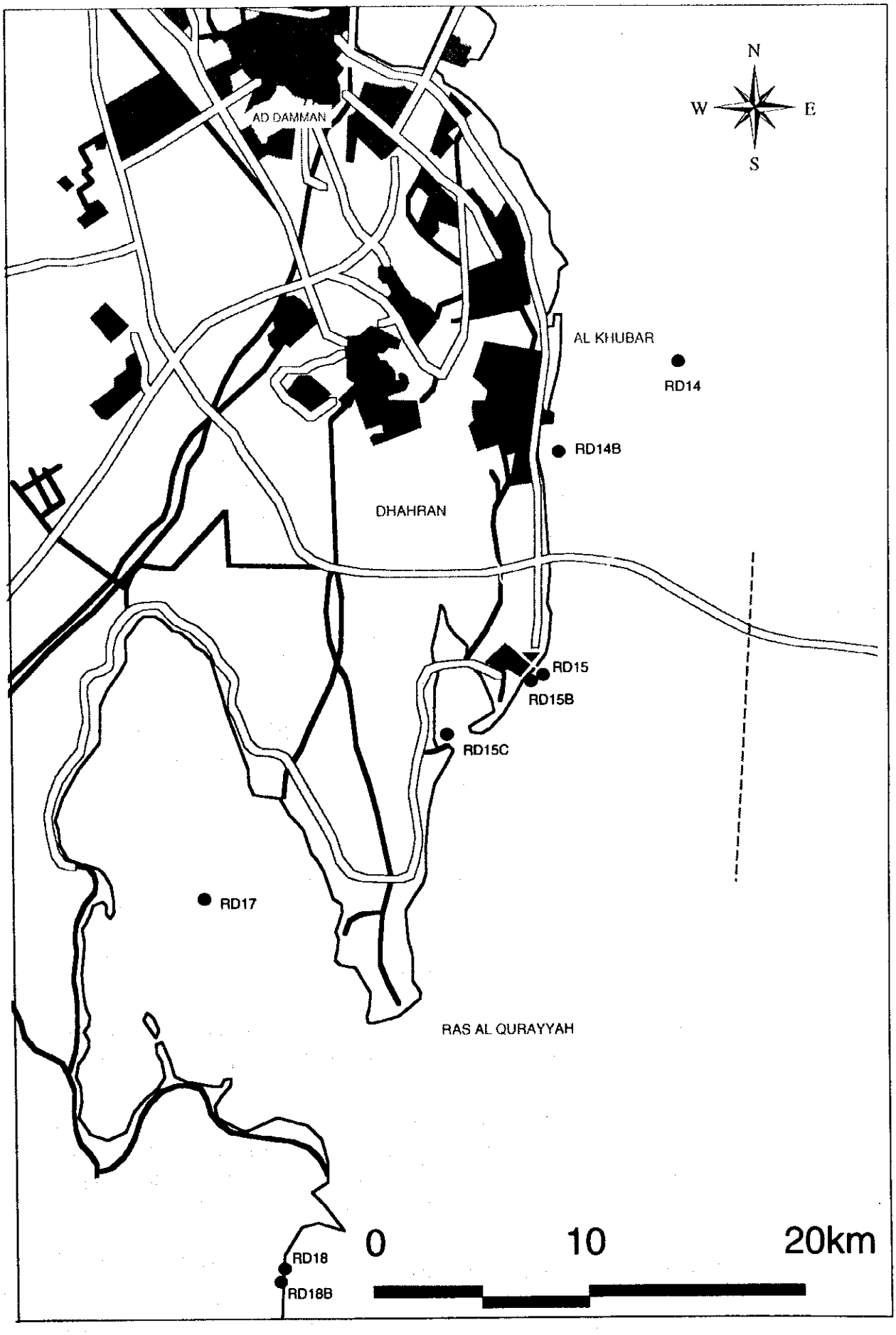

Figure 4.3.1 (3) Field Inspection Location

4.3.3 Water Quality Parameters and Methods

The following parameters were measured in the ISA during the inspection survey:

Table 4.3.2 List of Measured Parameters

Variable	Method
- Water depth (m)	: 20m&30m plastic tape and lead sinker
- Surface water current speed and direction	: Orange sub-surface floats and stopwatch
- pH	: Portable probe
- DO	: Portable probe
- Temperature	: Thermometer and portable probe
- Water clarity	: Secchi disc
- Water samples for MEPA laboratory training	: Vinyl bucket, 2 x 1L polyethylene sample bottles disposable sterile gloves, coolers and ice.
- Water Quality parameters	: TSS, COD_{Mn}, TS (number of samples: 37 sites)
- Seafloor inspections (for sites<5m)	: Snorkeling inspection, underwater photographs and hand-held seafloor sediment sampler.

The water quality analyses have been practiced as follows:

- Total Suspended Solids (TSS)

  The TSS analyses were carried out by common filtrate-gravimetry method. Samples were filtered with pre-weighting glass-filter and rinsed with distilled water. Filtered samples were dried at 105 °C.

- Chemical Oxygen Demand (COD_{Mn})

  The COD analyses were carried out by potassium permanganate method that is standardized in Japanese Industrial Standards. COD_{Mn} method is able to remove chloride ion influence. While the method provided by Standard Method or U.S. EPA, using potassium dichromate (COD_{Cr}), not enable to eliminate high chloride influence.

- Total Solids (TS)

  Chemical Oxygen Demand by potassium permanganate at The TS analyses was carried out by common evaporate-gravimetry method. Samples were dried at 105 °C

- TS consist of TSS and TDS (Total Dissolved Solids).

  In seawater, TDS is much greater than TSS. Therefore the TS results can be regarded as nearly equal to TDS or salinity for the samples taken

4.3.4 Results and Study Area Characterization

Based on both the above site observations and information gathered, the characterization of the Intensive Study Area was discussed.

(1) Field Measurements

The results of the field measurements are listed in Table 4.3.3. The field records provide no evidence for any gross water pollution, with Temperatures, pH, DO and Clarity values in the expected range for all areas, including most outfall mixing zones except for the Jubail industrial and Al-Khobar Sewage Treatment Plant (STP) outfalls.

(2) Laboratory Analyses

Results of the laboratory analyses undertaken at the MEPA Laboratory are shown in Table 4.3.4. Total Solids (TS), Total Suspended Solids (TSS) and COD values show the natural differences between the inshore and offshore areas of the Intensive Study Area, as well as the general north-south trend of increasing salinity, as can be expected with the predominance of the southerly flowing current. Overall, the laboratory values provide a consistent picture that matched the field observations and records.

(3) Seafloor Descriptions and Study Area Characterization

The descriptions made during the seafloor site inspections are listed in Table 4.3.5. Based on the survey field work, seafloor and shoreline site inspections and materials collated during June 1999 (including a biotope map of two sub-regions from Saudi Aramco and NCWCD publications), a preliminary characterization of the Intensive Study Area can be given as follows.

The ISA occupies a 180 km stretch of coastline from Dafi Dawhat (north and east of Abu Ali) to Half Moon Bay (south of Al-Khobar). This region can be divided into six convenient sub-regions or 'zones' based on the coastline shape, coastal morphology and the degree of human development. The six zones are briefly described, from north to south, as follows:

Zone D: Dawhat ad-Dafi Bay. This large and shallow bay lies within the Jubail Marine Wildlife Sanctuary, and it extends southward on the west side of Abu Ali until its southern termination at the recently developed Maguraih Marina. This shallow, evaporative and hypersaline embayment is relatively undeveloped except for reclamation works along the south-west shoreline, whilst its former entrance to Jubail

Bay (south of Abu Ali) was closed off during the Aramco causeway construction in the mid 1980's. The northern parts of the bay contain extensive seagrass meadows (primarily *Halodule uninervis*). In the south, it also contains Gurnah Island. This vegetated sand island supports an extensive stand of *Avicennia* mangroves, saltmarsh halophyte shrubs and high intertidal sabkhas. All these communities were oiled during the 1991 Gulf War, and are presently under continued monitoring by the Marine Studies Section of the KF University Research Institute. The bay forms an important fish nursery area, and is also popular for commercial and recreational fishermen.

At present there are no outfalls, industrial developments or significant residential developments. Therefore the potential value of this zone to the JICA/MEPA study is that it represents a reasonably unmodified area where seawater chemistry is modified by primarily by natural evaporitic events, whilst pollution is restricted to some areas which show the residual high intertidal effects from beaching of oil from the 1991 Gulf War spill. The zone also provides mangrove habitats that may be useful as a reference control for water quality and mangrove habitat conditions in the more eutrophic Tarut Bay (Zone 4).

Zone J: Al-Jubail: Jubail bay extends southward from Abu Ali island, past the new Jubail harbour, the old town of Al-Jubail and its fishing port, and terminates south of the KSA Navy base at the Gaslan power station. This area contains substantial developments and industrial activities, which include the offshore Berri oil field, the reclamation and dredging works associated with the Fanateera corniche, marina and artificial island development, the major new harbor and tank farm at Al-Jubail, the shared Jubail industrial outfall managed by the Royal Commission of Jubail, the commercial harbor, the fishing boat harbor, and the large SWCC desalination plant located 40 kms south near the Navy base. The sensitive habitats in this region include the extensive seagrass meadows which, in water depths of 1-3 m below LAT, extend from Fanateera Island (also an important tern breeding site) to the north. Zone J provides many examples of point source discharges, the ones of key interest to the study including (a) the shared industrial outfall, (b) the Berri oil field production platforms, and (b) the SWCC outfall.

Zone R: Ras Tanura Peninsula: This isolated and relatively exposed coastline extends southward from the Gaslan power station to the sand spit at the tip of Ras Tanura, and it includes the Saudi Aramco Sea Island Terminal and onshore refinery. The intertidal zone comprises linear sand beaches that are fronted by a sublittoral limestone pavement with variable veneers of coarse carbonate sands. These sand sheets, which are exposed to strong inshore southerly currents for much of the year support patches of seagrass that are interspersed by well developed macroalgae and

sponge beds in areas where the veneer is thin or non-existent. Inshore platform coral reefs are also present near the tip of Ras Tanurrah. This zone provides the best example of a major crude oil load-out terminal, refinery outfall and associated coastal infrastructure and facilities to the study.

Zone T: Tarut Bay: This large bay extends south and west from the tip of Ras Tanura to the commercial harbor at Dammam Port in the south. The bay is divided into northern and southern halves by the road and causeway that joins Tarut Island (which contains the substantial residential town of Tarut) to the adjoining coastal town of Al Qatif. This area provides a good example of diffuse groundwater and surface water nutrient pollution from older style residential areas that are not connected to reticulated sewage treatment works. A large urban storm water drain at Al-Qatif discharges into the mangrove area, and appears to be occasionally used for convenient disposal of urban and residential waste waters. The ecologically important habitats of Tarut Bay comprise: (a) the mangrove fringes which fringe the mainland coastline to north and south of Tarut Island; (b) the remaining offshore seagrass beds which occur in undisturbed shallow water areas to the north, south and east of Tarut Island; and (c) the coral reef at Nazwah Island. The inshore waters and coastal zone near Tarut Island and Dammam are the most heavily modified areas of the ISA, with major dredging, reclamation, corniche, harbor and marina works having being undertaken almost continuously over the past 20 years. Apart from the urban drain outfall at Al-Qatif, an STP outfall at Ramos (north of Tarut) and a refinery outfall to the north-east (now under decommissioning), Zone T also includes a significant and historic oil and transformer pollution source in the narrow fishing boat harbor immediately north of the Port of Dammam.

Zone K: Al-Khobar. This zone extends from the south side of Dammam Port to the Qurayyah peninsula in the south. It contains the major Al-Khobar/Dhahran urban area, and the principal outfalls of the SAFCO fertilizer plant, the Al-Khobar STP and the As-Azir desalination plants, all of which are important for the JICA/MEPA study. The zone also contains the new Al-Khobar corniche, the KSA-Bahrain International Causeway and the developing holiday marina and residential areas near the small embayment of As-Azir. It also contains offshore sand spits and seagrass meadows, such as those at Kascus Island, and popular fishery grounds. Further inshore, seagrass meadows extend from Dammam Port to the area offshore from the SAFCO plant.

Zone H: Half-Moon Bay and Agraiha Area: The southernmost zone of the ISA comprises a very large, evaporative embayment with a net inflow of water due to the evaporation rate. Salinities in the northern end exceed 60 g/kg. The area is fast becoming a popular holiday and fishing playground, with several holiday residential

areas being developed on both the east and west sides. The fine sediments in the center of the bay fall out of suspension due to the relatively sheltering of the bay from northerly winds, and these provide a 'sink' of suspended particulate contaminants and nutrients originating from the more northern zones. The southern end of this zone is marked by the large power station, complete with a large seawater cooling intake and outfall, at Al-Qurayyah.

Table-4.3.3 Field Inspection Results

Location Name	Site Code	Date	Latitude	Longitude	Depth (m)	Temp. (C°)	pH (-)	DO (mg/l)	Clarity (m)
Jubail Region									
Dawhat Dafi Bay	J2B	15.Jun.99	27°10.0'N	48°29.2'E	2.6	31.9	8.10	6.2	1.5
Abu Ali North	J3	14.Jun.99	27°22.6'N	49°45.5'E	35.0	30.8	8.12	6.6	15.0
Berri Oilfield	J5	14.Jun.99	27°12.5'N	49°43.0'E	16.0	31.4	8.16	6.6	11.0
Outer Shoal	J6	14.Jun.99	27°13.6'N	49°48.8'E	6.9	31.0	8.20	6.5	6.9
ARAMCO South Terminal	J7A	13.Jun.99	27°08.0'N	49°37.3'E	1.9	33.7	8.27	8.3	>1.9
Fanateera Island	J7B	13.Jun.99	27°07.0'N	49°35.1'E	1.1	33.0	8.20	8.2	>1.1
Fanateera Marina	J7C	13.Jun.99	27°07.1'N	49°33.1'E	4.6	31.2	8.18	8.3	2.4
Maduraigh Marina	J8	15.Jun.99	27°07.1'N	49°30.4'E	3.4	31.7	8.15	5.4	2.7
Shared Industrial Outfall	J9	13.Jun.99	27°03.6'N	49°37.8'E	4.5	41.0	8.14	7.5	2.4
Jubail Harbour	J10	13.Jun.99	27°02.5'N	49°41.8'E	5.0	32.3	8.20	6.5	3.3
Jubail Port Tank farm North	J11	14.Jun.99	27°04.5'N	49°42.5'E	20.0	31.7	8.17	6.6	8.2
Storm outfall of Jubail Ind. City(1)	C01	15.Jun.99	27°04.5'N	49°35.2'E	<1	32.1	8.21	6.8	-
Storm outfall of Jubail Ind. City(2)	C02	16.Jun.99	27°04.5'N	49°38.2'E	<1	30.6	8.31	7.1	-
Ra's Tannurah Region									
ARAMCO Oil Refinery Outfall	RD01	19.Jun.99	26°37.8'N	50°09.9'E	6.0	31.8	8.15	6.5	3.0
Sea Island Termnl	RD02	19.Jun.99	26°39.7'N	50°11.1'E	32.0	31.8	8.18	6.2	6.0
South Sand Spit	RD03	19.Jun.99	26°42.8'N	50°08.6'E	2.7	31.6	8.11	6.7	4.9
Platform reef (Almost dead)	RD03B	19.Jun.99	26°41.8'N	50°06.6'E	-	-	-	-	-
Tarut - Dammam Region									
North side of Tarut Is	RA01	21.Jun.99	26°35.8'N	50°00.8'E	0.7	30.5	8.07	5.7	0.6
Inshore north of Tarut	RA02	21.Jun.99	26°36.1'N	50°03.5'E	0.9	32.1	8.27	6.6	>0.92
Marine coral reef(Najwah Is)	RD04	19.Jun.99	26°33.0'N	50°15.3'E	0.8	32.7	8.21	8.6	>0.8
Dammam Harbour	RD5	23.Jun.99	26°28.2'N	50°13.8'E	8.5	30.1	8.15	7.4	3.2
Small boat Harbour	RD7	23.Jun.99	26°26.9'N	50°07.7'E	1.2	32.5	8.22	6.0	0.3
Fishing Fleet jetty	RD8	21.Jun.99	26°32.5'N	50°03.5'E	3.3	31.6	8.22	5.8	0.6
South central Tarut	RD8B	21.Jun.99	26°32.4'N	50°03.6'E	3.0	31.6	8.16	6.1	0.8
Qatif Marina dredged	RD9	21.Jun.99	26°32.8'N	50°01.7'E	8.2	30.6	8.22	5.8	0.9
Qatif S/W drain	RD9B	21.Jun.99	26°38.5'N	50°05.3'E	-	-	-	-	-
Near ARAMCO Reclaim Island	RD10	23.Jun.99	26°29.5'N	50°06.7'E	1.9	32.6	8.30	6.4	1.3
SAFCO corner	RD11	23.Jun.99	26°24.5'N	50°11.9'E	0.8	32.9	8.30	7.8	0.8
Kaskus Island	RD12	23.Jun.99	26°24.8'N	50°18.1'E	1.6	33.4	8.22	6.0	>1.6
Al Khobar Region									
Al Benhani Islet	RD14	26.Jun.99	26°15.2'N	50°19.6'E	>20	33.7	8.44	6.2	6.7
Sewage Outfall	RD14B	26.Jun.99	26°14.4'N	50°13.4'E	5.3	33.8	8.40	5.9	0.3
Desalination intake	RD15	26.Jun.99	26°10.4'N	50°12.8'E	-	33.5	8.42	5.8	2.7
Desalination outfall	RD15B	26.Jun.99	26°10.6'N	50°12.7'E	6.0	39.3	8.46	7.0	2.2
Residential marinas	RD15C	26.Jun.99	26°09.6'N	50°11.8'E	-	34.6	8.41	6.9	2.6
HalfMoon Bay									
Centre of HM Bay	RD17	27.Jun.99	26°04.0'N	50°03.0'E	3.5	32.6	8.25	5.6	>3.5
Al Qurayyah									
Power station intake	RD18	27.Jun.99	25°51.6'N	50°07.3'E	4.1	35.4	8.25	7.5	2.7
Power station outfall	RD18B	27.Jun.99	25°51.1'N	50°07.6'E	-	39.0	8.14	6.9	-

Table-4.3.4 Analysis Results of Field Samples

June, 1999

No.	Sample ID	Date Sampled	Time	Container	Q'ty	Note	COD mg/L	TSS mg/L	TS %
Jubail Region									
1	J 2B	15.Jun.99	10:08	1 liter, P	1		3	18	5.5
2	J 3	14.Jun.99	12:44	1 liter, P	4	control area	2	4	4.3
3	J 5	14.Jun.99	14:54	1 liter, P	2		1	5	4.4
4	J 6	14.Jun.99	14:00	1 liter, P	2		2	7	4.5
5	J 7	13.Jun.99	15:27	1 liter, P	2	seaweeds area	2	7	4.6
6	J 7B	13.Jun.99	16:25	1 liter, P	2	Fanateer Island	2	9	4.6
7	J 7C	13.Jun.99	17:08	1 liter, P	2	harbor	2	8	4.6
8	J 8	15.Jun.99	11:30	1.5 L, PET	2	Mardumah marina	4	9	5.7
9	J 9	13.Jun.99	11:35	1 liter, P	3	polluted area	2	7	4.5
10	J 10	13.Jun.99	10:10	1 liter, P	2	polluted area	2	6	4.3
11	J 11	14.Jun.99	16:15	1 liter, P	1		2	10	-
12	C1	16.Jun.99	9:30	1.5 L, PET	1		2	10	4.6
13	C2	15.Jun.99	17:50	1 liter, P	1		3	17	4.7
Ras Tannurah Region									
14	RD1	19.Jun.99	11:05	1 liter, P	2		2	7	4.4
15	RD2	19.Jun.99	11:55	1 liter, P	2		2	5	4.4
16	RD3	19.Jun.99	12:35	1 liter, P	2		2	6	4.6
Tarut-Damman Region									
17	RD4	23.Jun.99	14:30	1 liter, P	1		1	6	4.5
18	RD5	23.Jun.99	15:10	1 liter, P	2		2	8	4.5
19	RD7	23.Jun.99	11:00	1 liter, P	2	polluted area	4	21	4.5
20	RA1	21.Jun.99	10:00	1 liter, P	2		4	11	4.9
21	RA2	21.Jun.99	10:59	1 liter, P	2	polluted area	5	10	5.2
22	RD8	21.Jun.99	11:55	1 liter, P	2		3	11	4.8
23	RD8B	21.Jun.99	12:20	1 liter, P	1		-	7	4.7
24	RD9	21.Jun.99	12:50	1 liter, P	2		4	9	4.9
25	RD10	23.Jun.99	10:30	1 liter, P	2		2	8	4.6
26	RD11	23.Jun.99	12:20	1 liter, P	2		2	8	4.6
27	RD12	23.Jun.99	14:00	1 liter, P	2		1	7	4.5
Al Khobar Region									
28	RD14	26.Jun.99	11:50	1 liter, P	2		2	6	5.0
29	RD14B	26.Jun.99	10:50	1 liter, P	2	much suspended	3	24	3.6
30	RD15A	26.Jun.99	12:50	1 liter, P	2		2	15	5.7
31	RD15B	26.Jun.99		1 liter, P	2	desalination outlet	2	12	5.9
32	RD15C	26.Jun.99	14:30	1 liter, P	2		3	13	5.6
Half Moon Bay									
33	RD17	27.Jun.99	10:00	1 liter, P	2		2	6	6.4
Al Qurayyah									
34	RD18	27.Jun.99	12:00	1 liter, P	2	Power plant intake	2	7	6.0
35	RD18B	27.Jun.99		1 liter, P	2	Power plant out fall	2	7	5.9

COD: Chemical Oxygen Demand by Permanganate Method
TSS: Total Suspended Solids dried at 105 ℃
TS: Total Solids dried at 105 ℃ (nearly equal to TDS or Salinity for these samples)

Table 4.3.5 Seafloor description

REGION:	JUBAIL	DATES:	13-15 June 1999	REFERENCE:	KD-UW1
SITE	**DESCRIPTION**				
Site J10:	Outer Jubail Harbour: Sunday 13 June@1050. 4.8 m deep, near south end of outer breakwater. Coarse gravelly sand bottom with coral rubble. Some small colonies of yellow favid corals (5-10 cm in diameter; cf. *Goniastrea*). Black solitary sea squirts (7-10 cm high) on rubble. Bright red encrusting sponge on coral rubble (underside). Three crabs in rubble brought to surface. One fish seen. Currents in area at spring tide ebb (skipper; 1-1.5 knots). One photo.				
Site J9B:	Near outfall. 3 m deep. Burrow marks and fish feeding marks on soft fine to medium grained silty sands. Worth grab sampling for benthos. Thermocline at about 1.5 m, temp 31.8 on bottom, 39.2 on top. 3 photos. 1 shot of boat.				
Site J7A:	1.9 m deep. 800 m north-west of Aramco south breakwater coastal terminal (initially misnamed as Site 6 on water sample bottles). White sandy veneers (0.5-10 cm thick) over smooth carbonate platform, no rubble or rock. Thin veneer were colonised by green macroalgae with holdfast and bobbly stem ("Caulerpa" like but different?). No Sargassum. Bindweed (red or brown simple branching stem forming a network) was quite thick in this seaweed. Where sediment sheet was >5 cm, *Halodule uninervis* was very common. About 4 photos. South-east tip of south-east spit off Fanateer Island – boulders and rock spit, no live coral. Some reef fish.				
Site J7B:	1.1 m deep. Sand and seagrass beds (400 m diameter patch) on west edge of shallow bank, mid way between Fanateer Island and the other island to the south. Depth still shallow (1.6 m) until reaching the dredged area east of marina (7 m deep). One shot of the small boat, about four shots taken of seagrasses and seabed.				
Sites 3,5,6,11	No snorkelling at the four deepwater sites inspected on Monday 13 June.				
Site J2B:	Tuesday 14 June, 1000 am. North end of island ~8 km north of Maguraih Marina. Intertidal rocky platform on edge of steep sand slope to tidal channel (6 m deep). Sandy floor depths at the black post (1 km to the north) were 2.6 m. Six photos taken showing live barnacles, creepers, top shells and other gastropods. No sign of any coral in the intertidal or subtidal zone. Seagrass beds (*H uninervis*) relatively close because of large quantities of dead leaves washed up on the mangroves at Gurnah Island.				

REGION:	RAS TANURRA	DATE:	19 June 1999	REFERENCE:	KD-UW2
SITE	**DESCRIPTION**				
Site RD03B:	Platform coral reef, 1 km south-west off Ras Tannura spit, marked by two spit posts. Dived at south-west edge of intertidal reef. High tide. Depth 2-3 m. Old corals and coral rubble (cf. Stumps of branching *Acropora* or *Porites cylindrica* or branching type of *Montipora*?) all dead – maybe 3-5 years ago. Many long spined black sea urchins (*Diadema* sp). Sand taken for description on deck. 4 photos taken, then photo of boat. No WQ sampling.				
Site RD03A:	End of Ras Tannura spit – alongside the old spit post assembly, 30 m from beach. Shelley coarse white sands with small disc-like sandy tar balls (0.5-1.0 cm long). Description taken on deck. Large cods (Hamura) and other fish atr spit post. Depth 2-3 m. 4 photos taken of fish at spit post. Photo taken of boat from water showing spit.				
Site RD02:	Sea Island Terminal. 31 m deep. Too deep for inspection. UW photo of tanker departure operations and general scenes (3 photographs).				
Site RD01:	Ras Tannura Refinery – 200 m from refinery outfall. Water depth 2-2.5 m. Three photos taken of seafloor showing macroalgae (*Padina / Codium / Sargassum*) on carbonate plate rubble, covered with thin veneers (0.5-10 cm) of medium to coarse sands (description taken on deck). No seagrass observed (current too strong – seabed scoured to prevent sufficient sand build up). Three small crabs and *Scylla*-like crustaceans, plus 2 gastropod molluscs, and a green crunchy colonial sea squirt on underside of the rubble plates. Stored on ice ten in fridge (-4°C) before transfer to 70% methanol in the MEPA lab on Sunday a.m. (20 June 1999). Also a single coral polyp found under one rock, plus one single colony (bleached; 10 cm diameter; cf. *Cyphastrea*) seen on sand covered rubble on seafloor.				

Site RDO4:	Snorkelling inspection of coral fringing the sand spit immediately south of the Coastguard station jetty at Ras Tannura. Medium to fine white sands below coral level (~1 m below LAT), and medium to coarse sands on the rippled intertidal white sand spit above the coral level (MSL-MLW). Almost all the coral is dead – covered in fine white sediment and turfing algae – but maybe died last summer – bleaching event suspected. Very few living coral left (~25 parts of colonies just intact – all bleached or near bleached condition). No disease bands, no sedimentation event. Peculiar taste in water? (not felt by Ike-san). Possibility of minor local oil spill (there was thin tar layers from a 2-6 month old spill covering the intertidal rocks at base of sand spit). Also the reported possibility of Aramco's recent adoption to use dispersants routinely for oil spill combat (K. Al-Rasheed, pers comm). The corals were from MLW to 1 m below estimated LAT – and all were in same condition – no depth zoning. Coral colony size (0.2-0.8 typical diameter) indicated typical ages of 20-40 years. Coral types include cf. *Porites cylindrica*, thick branching Montipora spp., and several faviids (brains – *Goniastera/Plesiastrea* plus cf. *Cyphastrea*). No evidence/sign of *Acropora*. Also there were many dead clams and cup oysters – same death time. Some corals covered by caramel coloured encrusting sponge. A few medium grey branching sponges also found (10-20 cm long). Two live cone shells found. Short-spined and long-spined sea urchins (*Diadema*) plentiful everywhere. No algae or seagrass. Plenty of fish, including spotted cod and brown-banded cods (20-30 cm long), plus many blackspots and a few black damsel fish. Gastropod molluscs (cerithiid creepers) plentiful in the shallow intertidal, plus a small whelk with nobbly, ribbed shell (2-4 cm). Many empty shells – no hermit crabs or other crustaceans observed.

REGION:	TARUT	**DATE:**	21 June 1999	**REFERENCE:**	KD-UW3

SITE	**DESCRIPTION**
Site RA02:	Inshore low intertidal seafloor sampled near high tide (1030) (~1.0 m deep) about 500 m off the mangrove fringe to the north of the town of Al Qatif, and about 2.5 km north of the Tarut Island causeway. The seafloor comprised silty sands with live tube worm colonies forming 10-40 cm diameter limestone plates (10-20 cm high). The calcareous tube worm colonies (cf. Serpulid worms) provide a microhabitat for several crustacean and gastropod mollusc species, including 3-4 types of small crabs (cf. Xanthid family). Large numbers of creeper shells in the sediments (see field noes for description of molluscs). Sediment description recorded on field sheets. About 4 photos taken to show distribution of the tube worm colonies on the seafloor. Visibility was less than 2 m. Many small fishing boats in the area.
Site RA01:	Low intertidal site close to north side of Tarut Island, and immediately north-west of Zur. The site was inspected at about 1130 am, close to high tide. It was selected near an apparent STP plant on Tarut Island, based on the advice of local coastguard officers. The substrate comprised a thick multi-laminated BMC mat (1-4 cm thick) overlying sulphurous silty fine sands (dark grey). A sediment sample of the mat and sediments was taken for storage by freezing in the laboratory. The seawater was dark green, with clarity variable in the region (from very poor 500 m offshore) to about 1.5 m near the shore, a variation caused by the asymetrical displacement of turbid waters by the ingress of the clearer high tidal waters. About five photos were taken to show the edges of the BMC mat, plus many burrow marks and the tube worm colonies. The tube worm colonies were also present (in the same manner as RA03, but fewer and, on average, larger). The colour of the water (dark green hue) indicated the presence of nutrient inputs, but no outlet or outfall could be seen extending from STP, as viewed from the boats. A photo was also taken of the two boats.
Site RA01B:	This site was located in shallow subtidal waters (from LAT to 1 m below) on the east side of Tarut Island. A quick stop was made to determine the nature of the seabed. Water visibility was 2-3 m, and the area typical of the east coast. The substrate comprised coarse to medium sandy sediments with large and extensive patches of *Halodule uninervis* seagrasses, finely coated with sediment and some loosely attached epiphytic algae (colour was a milky pale brown due to sediment deposition). About 3 photos taken, followed by a surface photo of the boat. The seagrass was healthy when taken to deck (stirring action caused material to rinse off during ascent)with no signs of dieback or disease. However there was a large amount of recently detached floating seagrass wrack (still green-green/brown colour) in the whole Tarut region – probably seasonal and associated with summer temperature rise.
Site RD08A:	Tarut fishing jetty (1200-1215). Substrate was coarse to medium grey silty sands, recently dredged – no photos. Visibility (10 cm) and light low (~3 m) – no photos taken at this site.

Site RD08B:	South central side of Tarut Island, about 1 km from the shore; depth about 1.5-2 m. Inshore water normal pale green over sand, large area of outer waters show a strong yellow-brown tinge, with clear inshore demarkation line. Tide now on the ebb (1230), with surface current due south due to breeze, but near bottom current may be to the east – parallel to shore. No obvious source such as outfall. Substrate comprised bare and pale creamy colour sandy sediments – both in front of and within the west-east stained water area. May have been dredging operation in the marina to the east – but water colour or turbidity did not give obvious suggestion that suspended silt may be the cause (clarity no change??). So stained water emanating from deep dredged area? But no obvious increase in staining towards this area (but change of depth, and thermodensity may explain a bottom plume that becomes more visible in the shallower offshore areas....). See also site RA01 description. No photos taken.
Site RD03:	Beside entrance to new marina at Al Qatif (near coastguard jetty). Waters very deep (8-10 m) due to recent dredging. Drifted across marina mouth to overturned barge, and where depth shelved very rapidly to 2 m. Light and visibility was zero >5 m in the deep water area. Brown colour strong. This may well be the source of the brown stained water during the ebb tide. Substrate comprised limestone rubble and blocks due to recent dredging. Bottom of newly dredged area could not be reached (>6 m). No photos taken.
Site RD09B:	Shoreline Storm water discharge canal. Ebb tide. Visited by car on highway at about 1400. Dark green waters with weed. Current flowing at about 0.5-0.7 m per second, and enter mangrove creek on sea side of highway. No smell. No faeces, paper or other items indicating mixture with sewage discharge. However nutrient levels appear high due to dark green colouration of water (diatom or other phytoplankton bloom). No u/w photos taken.

REGION:	DAMMAM	DATE:	23 June 1999	REFERENCE:	KD-UW3

SITE	DESCRIPTION
Site RD10:	Aramco Reclaim sland used for Recreation – 0.8 km on east side in shallow water, seagrass beds – about 4 photos taken
Site RD07:	Dammam small boat fishing harbour and historic railway disposal site. Sediments taken (2 samples) but no photos – no light.
Site RD11:	SAFCO corner – inshore thin sediments on rock platform , with tube worm colonies. Further offshore sand sheets (with stingrays) getting thicker with seagrass beds – photos taken; Extensive seagrass beds stretching north to the Dammam Port and the refuse burning site.
Site RD12:	Kaskus Shoal; a linear ribbon sand spit, overlying a limestone platform with thick sand sheets and seagrass patches. Photos taken at sampling site. Plenty of fishing activity (including fishermen huts). Search made for coral – none found.
Site RD4:	Najwah Island – bare sand islet. Coral graveyard found on north-west corner of island. Extensive search found no live coral, all dead due to a 1-2 years old event – bleaching?? Small turf algae. No sign of significant eutrophication. Six photos taken.
Site RD5:	Inside Dammam Harbour – deep water site. No sediments or photos.

REGION:	AL-KHOBAR	DATE:	26 June 1999	REFERENCE:	KD-UW4

SITE	DESCRIPTION
Site RD14B:	Al Khobar sewage outfall – no sediments or photos taken due to health risks.
Site RD14:	Al Benhani Islet – a vegetated sand cay with well, on west side of the main channel passing southward to the Causeway. Seven photos taken of the 3 seagrass species and 7 algae species, plus pearl oyster bed. No corals or sign of corals nearby.
Site RD15:	Desalination Plant intake island – deepwater – no photos or sediments taken due to depth.
Site RD15B:	Desalination plant outfalls- deepwater – no photos or sediments taken due to depth.
Site RD15C:	Close inshore in the gap between the Sunrise and Sunset Marina – sediments taken – no photos taken due to depth.
Site RD16:	Site visit to this islet south of the main causeway and 6 km offshore was abandoned due to lack of

	petrol.				
REGION:	HALF-MOON	**DATE:**	27 June 1999	**REFERENCE:**	KD-UW4
SITE	**DESCRIPTION**				
Site RD17:	Centre of Half-Moon Bay – about 3.5 m deep. Less jellyfish and extensive seagrass beds comapred to northern end of bay. Mostly bare sands with small pearl shells (*Pinctada* and *Elatra*), grey sponges and occasional *Caulerpa* green macroalgae present at the sampling site. Silty sand sediments had a sulphur smell - fairly strong due to sulphate-reducing bacteria.				
Site RD17B:	Coastguard Marina at north end of Half-Moon Bay – water quality monitored and a sample taken – no photos or sediments due to time restriction.				
Site RD18:	Power station intake – no underwater photos or sediments (too dangerous to enter water). Artificial rock wall habitat.				
Site RD18B:	Power station outfall – no underwater photos or sediments (too dangerous to enter water – fast flow). Concrete raceway leading to shallow bay with local algal mat in shallows – all reachable by car.				

4.4 Monitoring Investigation

4.4.1 Objectives

Two seasonal monitoring surveys were conducted in the ISA following the preparative field inspection undertaken in June 1999 to check logistics, access points and provide initial field training (Section 4.3).

The objectives of these monitoring investigations are as follows.

1) To obtain baseline water and sediment quality information for the six zones of the ISA for each seasons.

2) To investigate the effects on water and sediment quality by sampling at key examples of the main pollution sources and activities within the ISA

3) To strengthen MEPA's capability for managing the environment particularly along the Gulf through technology transfer to counterpart personnel during the course of the Study

4.4.2. Selection of Sampling Sites and Site-Specific Monitoring Parameters

The Study was conducted in Dawhat ad-Dafi Bay area (Zone D; DD20), Al-Jubail area (Zone J; J1-J90), Ras Tanura area (Zone R; R1-R40), Tarut Bay area (Zone T; T1-T120), Al-Khobar-Dammam area (Zone K; K1-K9), Half-Moon Bay and Agraiha area (Zone H; H1-H50).

Based on the result of the preparative field inspection of these zones, which is described in section 4.3, a total of 34 sampling sites were selected.

The locations of the sampling sites are shown in Figures 4.4.1. The site co-ordinates (Latitude (N) and Longitude (E)) are listed in Table 4.4.1, together with a description of the location and purpose of each site.

Several sites were deliberately located in areas away from potential pollution sources to assess 'background' conditions. Other sites were located near examples of the main coastal industry activities and pollution sources in the ISA. These examples are listed as follows, together with the selected monitoring parameters:

- a major shared industrial outfall (for temperature, pH, salinity, clarity and dissolved oxygen [TPhSCDO], plus residual chlorine, metals, biostimulants [Nitrogen and Phosphorus], total petroleum hydrocarbons (TPH) and other organics).
- a large sewage treatment plant outfall (for TPhSCDO, coliform bacteria, biostimulants, eutrophication indicators, metals and Oil & Grease [OG]);
- an urban drainage canal (for TPhSCDO, biostimulants, eutrophic indicators, metals, TPH and other organics);
- a desalination plant outfall (for TPhSCDO plus residual chlorine and metals);
- an offshore oil production field (for TPhSCDO, TPH and metals);
- a crude oil load-out terminal (for TPhSCDO, TPH and metals);
- an oil refinery outfall (for TPhSCDO, TPH and metals);
- a power station outfall (for TPhSCDO, residual chlorine, metals and eutrophication indicators)
- a commercial work boat harbour (for TPhSCDO, TPH and metals)
- a fishing boat harbour (for TPhSCDO, biostimulants, metals and coliform bacteria)
- diffuse coastal pollution sources involving potential ground water contamination, residential marina developments, and/or waste disposal areas (for TPhSCDO, coliform bacteria, metals, biostimulants, eutrophication indicators and organics).

4.4.3. Survey Period

The monitoring investigations were conducted during the following periods;

- Stage 3 monitoring: October 16 - November 8, 1999
- Stage4 monitoring investigation: June 7 to June 28, 2000

The stage 3 monitoring and stage 4 monitoring are corresponding to autumn and summer season in KSA respectively.

4.4.4 Methods

1) Water and Sediment Sampling

a. Water

Water samples were collected using a Van Dorn Type water sampler or clean plastic buckets, depending on location and depth. Samples were poured into labeled bottles with added preservatives where required, and these were stored and transported in cooler boxes maintained at 4°C with crushed ice. The samples were transported to the laboratory to arrive within acceptable holding time limits.

Details of the various sample containers, preservatives and holding times associated with individual laboratory analyses are summarized in Table 4.4.2.
Water quality indicators and sample number for each site are summarized in Table 4.4.3.

For some sampling locations, Quality Assurance (QA) samples were collected to evaluate the accuracy of analytical results. QA samples were collected and handled with the same procedures as the primary samples. The QA samples were sent to an independent outside laboratory for the cross-check analyses.

b. Sediments

Subtidal sediment samples were obtained using a stainless steel Van Veen grab or by Ekman box grab, whilst intertidal sediments were obtained by using polycarbonate corer tubes.

Samples for sediment chemistry were always collected from the upper layer (0-5 cm surficial sediment layer). The collected sample was pooled and mixed in clean stainless trays and then sub-sampled to provide a series of composite sub-samples for each site. These were stored in sterile plastic Whirl-Pak bags, Ziplock bags and/or pre-cleaned glass jars depending on the analyses required. All sediment samples were stored and transported to the laboratory in cooler boxes maintained at 4°C by crushed ice. QA samples were also collected for the sediment.

Sediment quality indicators and sample number for each site are summarized in Table 4.4.4.

2) In-Situ Field Measurements

a. Water

Site locations were position-fixed using a portable, hand-held Magellan GPS unit. General parameters of site conditions and water quality were measured and recorded for

each site at the same time when water samples were obtained. Field parameters and methods are in Table 4.4.5.

Air speed and temperature were measured using a Silva airspeed meter and glass thermometer respectively. A portable Hydrolab multi-probe was deployed to measure pH, DO, temperature and salinity in both surface and deeper water layers (where depth permitted). Water clarity and depth were measured using a Secchi plate and sounding lead respectively.

To help understand water current characteristics of the ISA, water current velocity and direction was measured at each sites using an electromagnetic meter. Weather and meteorological / ocean conditions, including wind speed, wind direction (degrees from magnetic north), wave height, and tidal state (time versus predicted low and high tides) were also recorded.

b. Sediments

General parameters of sediment such as predominant grain-size, make-up, color, odor and oxidation-reduction potential were measured in the field immediately after the sediment samples had been obtained by grab or corer. Field measurement parameters and methods are summarized in Table 4.4.6.

3) Laboratory Analyses

a. Water

All water samples were stored at 4°C in a pharmaceutical refrigerator (range 2-9°C) following receipt at the laboratory. Each sample was analyzed within acceptable holding time limits, following methods according to USEPA and/or Japan Environmental Agency (JEA) methods. Water quality parameters and their analytical methods are described in Table 4.4.7.
Organo Chlorine (OCL) was analyzed in the outside laboratory because MEPA doses not have enough equipment to analyze this substance.

b. Sediment

Transported sediment samples were stored < -10°C in a chest freezer at the laboratory. Parameters and analysis methods for sediment sample are described in Table 4.4.7.
Analyses of PCB samples were subcontracted to the outside laboratory.

4) Plankton Survey

a. Sampling

Plankton samples were obtained by towing an NXX13 Kitahara plankton net (0.001 mm mesh size; 0.07m^2 mouth size area) vertically from the bottom to surface. The total towed distance was recorded to estimate the filtered volume. The filtered volume was calculated by using the following formula:

$V=A \times d \times Sw$

where, V = filtered volume;
A = area of plankton net mouth;
d = distance the net towed;
Sw = sea water filtering rate (82% for Kitahara Plankton Net).

Each sample obtained from standard net washing was placed in a labeled polyethylene bottle and immediately preserved with 10% buffered formalin. In addition to the net sampling, water-bottle sampling method was also undertaken, in which two liters (2L) of water were collected and topped up with formalin to achieve a 10% concentration for preservation.

b. Plankton Counting and Analysis

Laboratory methods for plankton sample analysis consisted of measuring the settling volume, identifying the taxonomic groups, and counting of the number of identified plankton. Details of each method are summarised as follows:

i) Measurement of the settling volume

Water-bottle samples were transferred to a measuring cylinder and settled for 24 hours. The precipitate was then recorded as the proportional quantity of the total volume.

ii) Taxonomic Identification of Plankton

Small (0.1ml) sub-samples were placed on glass microscope slides and placed under an optical microscope to permit identification of planktonic taxa at the level of order, family, genus or species, wherever possible.

The relative abundance (proportional frequency) of each identified taxon was recorded semi-quantitatively using the following method.

+	rare	(appearance rate, <10%)
++	uncommon	(appearance rate, 20-30%)
+++	common	(appearance rate, 40-60%)
++++	frequent	(appearance rate, 70-80%)
+++++	abundant	(appearance rate, >90%)

iii) Counting

Small sub-samples (0.1ml) were placed on 76×26 mm glass microscope slides with a 10 micron grid graticule, and examined under an optical microscope. The number of each plankton taxon was counted three times, and the total number of plankton per 1L of sample was calculated using the following formula:

$A=(a1+a2+a3)\times 10{,}000/3n$

where, A= number of units/ml
a1+a2+a3 = number of plankton counted by each trial (3)
n = concentration factor (= 1/dilution factor)

The results were used to calculate the Shannon-Weaver Diversity Index (D), which is as follows:

$$D= -\sum_{i=1}^{s} pi \log_2 pi$$

where, pi = Ni /N,
s= the number of species in a sample
N= the number of individuals in a sample
Ni = the number of individuals of species in a sample

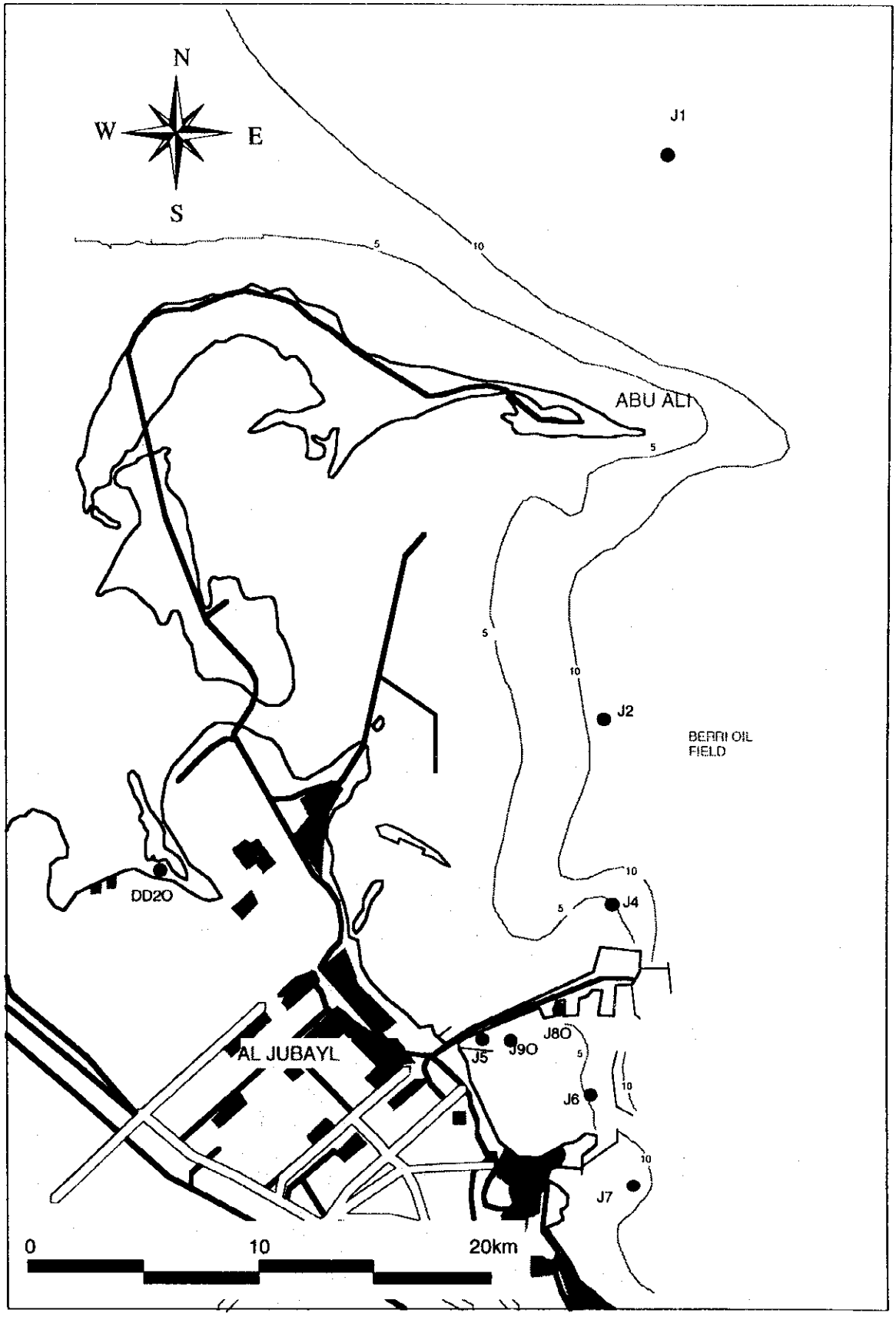

Figure 4.4.1 (1) Sampling Locations

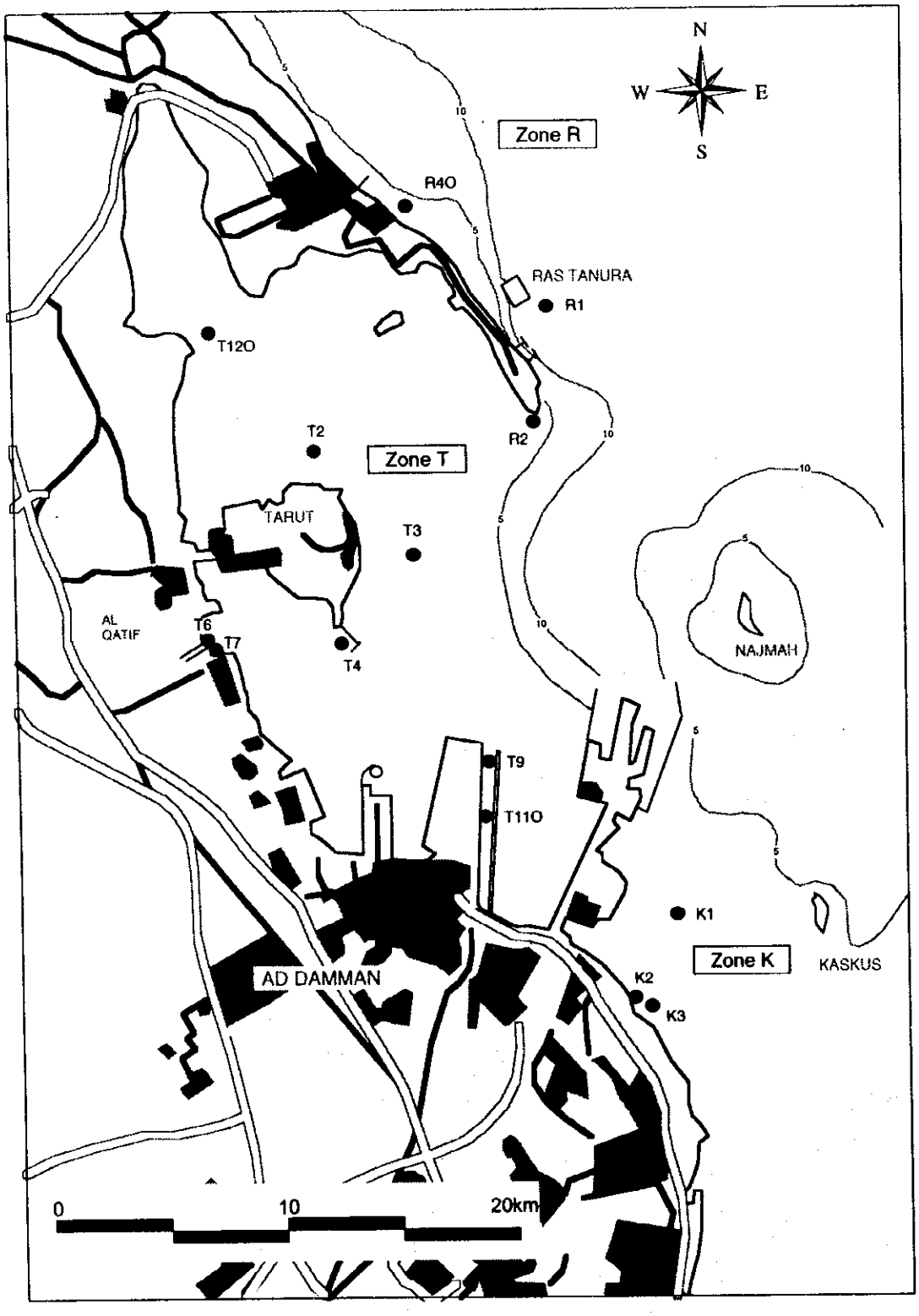

Figure 4.4.1 (2) Sampling Locations

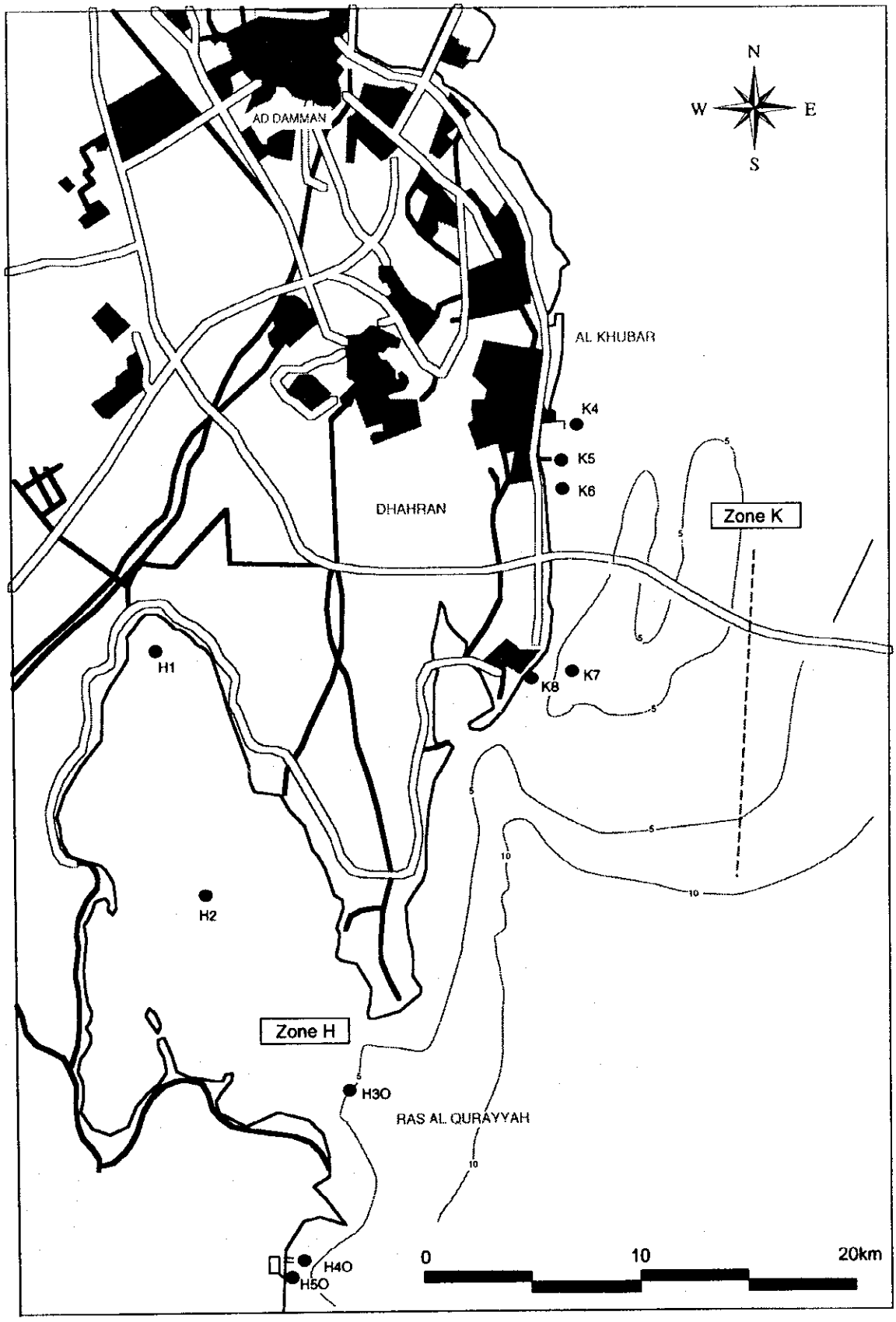

Figure 4.4.1 (3) Sampling Locations

Table 4.4.1 (1) Site Description and Purpose

Site Code	Region	Site Name	Type	Lat. (N)	Long. (E)	Purpose	Site Description
D2O	Dafi Dawhat	Gurnah Island	R	27° 07.92'	49° 29.22'	Zone D hypersaline southern zone background and mangrove reference	On the west side of Gurnah Island, where an extensive mangrove fringe is recovering from the 1991 spill.
J1	Jubail	Abul Ali North	B	27° 23.4'	49° 44.6'	Zone J Entry Level Water Quality Background	This will be a key regional baseline sampling point which is located about 5 km north from Abu Ali island (water depth ~ 25 m). The southerly current speed is high, particularly during the northerly summer winds. There are no pollution sources near this area.
J2	Jubail	Berri Oil Field	I	27° 10.5'	49° 42.1'	Offshore oil field	South end of Berri Oil Field. There are many oil platforms around the site. Water depth about 30 m and current speed is high enough to avoid the affect from the oil field. Sediment may be contaminated by oil spill derived from the oil field activity.
J3	Jubail	Fanateera	I	27° 07.0'	49° 35.1'	Affect of Coastal developmen on water and sediment quality near Fanateer Island.	About 2.5km from the north end of the tank farm of Jubail industrial port. Water depth about 2-5m. Water and sediment should not be affected from the point source.
J4	Jubail	North Jubail	B	27° 07.6'	49° 41.1'	Zone J Water Quality Background	Sensitive habitats are distributed around this island (Seagrass bed and Seabirdbreeding area etc.). Water depth about 1-2m. No pollution sources are recognized around the site.
J5	Jubail	Jubail Shared Outfall	I	27° 03.5'	49° 38.2'	Water quality of shared industrial outfall - point of discharge	Small boat marina in the Jubail Industrial Port. Water depth about 2m. Water and sediment quality should be affected by ship activity.
J6	Jubail	Jubail Harbour	I	27° 02.5'	49° 41.0'	Water quality in the outer mixing zone in harbour	The site in front of the shared industrial outfall of Jubail Industrial city. Water depth about 2m. High water temperature (>40C) that derived from the industrial outfall was measured in this site. Blue green algae mat is recognized around the site.
J7	Jubail	South Jubail	B	27° 01.0'	49° 42.2'	Zone J Water Quality Background (Exit Level)	Almost same as No.6. Sediment condition is more preferable than No.6 site.
J8O	Jubail	Jubail Boat Harbour	I	27° 04.9'	49° 40.1'	Option: Workboat harbour water & sediment quality	About 1.5km north from the Jubail commercial port. Water depth about 5m. Near the south entrance of Jubail port. Industrial effluent should be dilluted on the way to this site. Ship actifity of Commercial port should affect to this site.
J9O	Jubail	Near Jubail Outfall	I	27° 03.5'	49° 37.0'	Option: Water quality in the inner mixing zone	About 2.5km SE from the south entrance of the Jubail harbor. Water depth 7m. The pollutants from the Jubail harbor flows through this site.
R1	Ras Tan.	Sea Island Terminal	B/I	26° 39.0'	50° 12.0'	Zone R Background Water Quality	The site is in the shallow water area (<2m) . Salinity is obviously high (55). Some mangrobe vegitation is recognized near the site.
R2	Ras Tan.	Ras Tannura Spit	I	26° 37.0'	50° 11.0'	To assess oil pollution levels in sediments	Water depth about 20-25m. Deep water area. Water current flow through this site to Tarut bay.
R4O	Ras Tan.	Refinery Outfall	I	26° 41.8'	50° 06.4'	Option: Water and sediment quality near refinery outfall	West side of Coast guard small harbor. Water depth about 2m. Some (dead?) coral distributes in this area.
T1	Tarut Bay	North Tarut Bay	B	26° 38.5'	50° 09.0'	Zone T Background water quality at coral reef	Coral reef in very poor condition on the west side of the Ras Tannura peninsula - inside Tarut Bay.
T2	Tarut Bay	Tarut - Zur	I	26° 36.5'	50° 05.0'	To assess affect of diffuse residential groundwater discharges	About 1.5km north from the sewage treatment plant of tarut island. Water depth less than 2m. water and sediment are affected by sewage treatment plant effluent.
T3	Tarut Bay	Tarut - East	B	26° 36.5'	50° 05.1'	Zone T Water Quality Background (central area)	Site is East of Tarut Island where extensive seagrass beds occur in relatively clear water (depth 2-3 m).
T4	Tarut Bay	Tarut - Darin	I	26° 31.5'	50° 04.5'	To assess water & sediment quality in Fishing Boat harbour	Beside the Darin fishing jetty. Water depth 2-3 m. Water and sediment may be affected by raw sewage, cleaning and maintenance activities
T6	Tarut Bay	Qatif/Anik urban drain	I	26° 30.5'	50° 02.1'	To assess water quality at mouth of major urban drainage channel	Small channel in the Anik city. Some of the pollutants from the diffuse source run into the tarut bay through this channel. Sewage effluent is mingled.
T7	Tarut Bay	Qatif/Anik Drain Mouth	I	26° 31.2'	50° 02.3'	To assess effect of drain on nearby mangrove, water and sediment quality	Mangrove habitat to the south side of the outfall mixing zone
T9	Tarut Bay	Dammam Fishing Harbour - Entrance	I	26° 29.0'	50° 08.0'	To assess water quality exiting into Tarut Bay from the Dammam Fishing Boat marina	Long, narrow enclosed harbour used by fishing boats for maintenance purposes, lay-ups and repairs. Water depth about 2 m. PCB was also detected in the sediments in previous years.
T10	Tarut Bay	Dammam Fishing Harbour - End	I	26° 26.5'	50° 08.0'	To assess level of chronic water/sediment pollution inside harbour	Same as No.24 (T9)
T11O	Tarut Bay	Middle of Fishing Harbour	I	26° 27.5'	50° 08.0'	Option: to determine extent of chronic pollution	Same as No.24 (T9)

B = Background Site
R = Reference Site
I = Investigation Site

Table 4.4.1 (2) Site Description and Purpose

Site Code	Region	Site Name	Type	Lat. (N)	Long. (E)	Purpose	Site Description
TI2O	Tarut Bay	Swfwa	I	26° 38.9'	50° 01.1'	Option: to assess water & sediment quality in Tarut north	North of Tarut Island .Water depth less than 2m.
K1	Khobar	Dammam South	B	26° 22.5'	50° 15.0'	Zone K Water Quality Background (Entry Level)	About 5 km west of Kaskus island. Water depth 1-2m.Water clarity high. Seagrass beds present.
K2	Khobar	SAFCO outfall	I	26° 24.0'	50° 11.0'	To assess water quality of a fertiliser plant outfall	Close by SAFCO outfall.
K3	Khobar	SAFCO south	I	26° 23.5'	50° 11.1'	To assess water quality outside perimeter of fertiliser outfall mixing zone	200m south from the SAFCO outfall (Sediment Sampling site).
K4	Khobar	Khobar Central	B	26° 16.0'	50° 13.2'	Zone K Water Quality Background (Central Area)	About 2km north from the sewage outfall of khobar. Water depth about 5m.
K5	Khobar	Khobar STP Outfall	I	26° 14.0'	50° 13.2'	To assess water quality in the STP outfall mixing zone	Near the outfall of the sewage treatment plant of khobar. Water depth about 5m.Water clarity obviously low.
K6	Khobar	Khobar South	I	26° 13.0'	50° 13.2'	To assess water quality south of STP mixing zone	
K7	Khobar	Desalination Plant Intake	B	26° 10.5'	50° 13.5'	Zone K Water Quality Background (Southern Area)	About 2km south from the sewage treatment plant outfall. Water depth about 5m.
K8	Khobar	Desalination Outfall	I	26° 9.5'	50° 13.0'	To assess quality at the Desalination Plant discharge	Close to the desalination plant intake. Water depth about 4m.
K9	Khobar	Desalination Plant Sth	I			To assess water quality south of Desalination Plant	Near the desalination plant outfall.
H1	Half Moon	Half Moon Bay - North	B	26° 10.0'	50° 02.0'	Zone H Water Quality Background (North)	Innar part of the Halfmoon bay. Closed water body with high salinity (65). Water depth about 3-4m.
H2	Half Moon	Half Moon Bay - mid	B	26° 04.0'	50° 05.0'	Zone H Water Quality Background (Central)	Center of the Halfmoon bay. Closed water body with high salinity (65). Water depth about 3m.
H3O	Half Moon	Half Moon Bay - South	B	26° 00.0'	50° 10.0'	Zone H Water Quality Background (entrance area)	Mouth of the Halfmoon Bay. Open water
H4O	Half Moon	Power Station Intake	B			Zone H Water Quality Background (South)	
H5O	Half Moon	Power Station Outfall	I			To check water quality near Powerplant mixing zone	

B = Background Site
R = Reference Site

Table 4.4.2 Sample Containers, Preservatives and Holding Times

Analysis Parameter	Container	Volume (ml)	Preservation	Holding Time
Total Suspended Solid	Plastic	1000	Cool, 4°C	48hrs
Residual Chlorine	Plastic	1000	Cool, 4°C	Immediately
COD / TOC Ammonia, Total Kjeidahl Nitrogen Total Phosphorus	Plastic	2000	Cool, 4°C	48hrs
Cyanogen	Plastic	500	Cool, 4°C add NaOH, pH>12	14days
Metals	Plastic	500	add HNO_3, pH<2	28days (Hg) 6 months (others)
Phenols	Glass	500	Cool, 4°C add N2SO4, pH<2	28days
Oil &Greese, TPH	Glass	1000	Cool, 4°C add HCl, pH<2	28days
BTEX (Benzen, Toluene, Etylbenzen, Xylene)	Glass with teflon liner cap	250	Cool, 4°C add HCl, pH<2	14days
Chloropyll	Plastic	1000	Cool, 4°C	Immediately to filtrate 28days (Frozen)
Total Coliform	Plastic (sterilized)	100	Cool, 4°C	24hours

Table 4.4.3 Water Quality Parameters and Sampling Number

Site Code	Region	Site Name	Field Water Profiling					Planktn Samples	LABORATORY WATER QUALITY ANALYSES																		Extena Lab / OCL
			°C	pH	DO	Sal.	Clarity		TDS	TSS	TKN	T P	NH4	Chl.	TOC/ COD	As	Cr	Hg	Mg	Others	CN	Oil & Grse	TPH	BTEX	Phenol	Res. Cl	Total Coli.	
DD20	Dafi Dawhat	Gurnah Island	1	1	1	1	1	-			1	1																
J1	Jubail	Abul Ali North	1	1	1	1	1	3	1	1	1	1	1	2	2	1	1	1	1	1	1					1		
J2	Jubail	Berri Oil Field	1	1	1	1	1	-														1						
J4	Jubail	North Jubail	1	1	1	1	1	3		1	1	1		1														
J5	Jubail	Jubail Shared Outfall	1	1	1	1	1	-	1	1	1	1	1		1	1	1	1	1	1	1	1			1	1		1
J6	Jubail	Jubail Harbour	1	1	1	1	1	2	1	1	1	1		1	1	1	1	1		1	1							1
J7	Jubail	South Jubail	1	1	1	1	1	2			1	1		1	1													1
J8O	Jubail	Jubail Boat Harbour	1	1	1	1	1	-		1												1	1					
J9O	Jubail	Near Jubail Outfall	1	1	1	1	1	-		1																1		1
R1	Ras Tan.	Sea Island Terminal	1	1	1	1	1	2						1								1	1					
R2	Ras Tan.	Ras Tannura Spit	1	1	1	1	1	-																				
R4O	Ras Tan.	Refinery Outfall	1	1	1	1	1	-		1										1			1	1	1	1		
T1	Tarut Bay	North Tarut Bay	1	1	1	1	1	-																				
T2	Tarut Bay	Tarut - Zur	1	1	1	1	1	2		1	1	1	1	1	1												1	
T3	Tarut Bay	Tarut - East	1	1	1	1	1	-		1	1	1	1	1													1	
T4	Tarut Bay	Tarut - Darin	1	1	1	1	1	-		1	1	1	1		1												1	
T6	Tarut Bay	Qatif/Anik urban drain	1	1	1	1	1	-		1	1	1	1	1	1	1	1	1		1							1	
T7	Tarut Bay	Qatif/Anik Drain Mouth	1	1	1	1	1	-		1	1	1	1	1	1												1	
T9	Tarut Bay	Dammam Fish Entrance	1	1	1	1	1	-																				
T1IO	Tarut Bay	Dammam Fishing Harbour	1	1	1	1	1	-	1	1	1	1	1		1	1	1	1		1		1	1	2	1		1	
T12O	Tarut Bay	Swfwa	1	1	1	1	1	-		1	1	1	1	1														
K1	Khobar	Dammam South	1	1	1	1	1	2		1	1	1		1														
K2	Khobar	SAFCO outfall	1	1	1	1	1	-	1	1	1	1	1		1	1	1			1	1	1						
K3	Khobar	SAFCO south	1	1	1	1	1	2		1	1	1		1	1													
K4	Khobar	Khobar Central	1	1	1	1	1	2		1	1	1			1				1								1	
K5	Khobar	Khobar STP Outfall	1	1	1	1	1	-	1	1	1	1	1		1	1	1			1		1				1	1	
K6	Khobar	Khobar South	1	1	1	1	1	-		1	1	1	1		1							1					1	
K7	Khobar	Desalination Plant Intake	1	1	1	1	1	2											1	1						1		
K8	Khobar	Desalination Outfall	1	1	1	1	1	2								1	1		1	1						1		
H1	Half Moon	Half Moon Bay - North	1	1	1	1	1	2	1		1	1		1														
H2	Half Moon	Half Moon Bay - mid	1	1	1	1	1																					
H3O	Half Moon	Half Moon Bay - South	1	1	1	1	1	2						1														
H4O	Half Moon	Power Station Intake	1	1	1	1	1	-	1																			
H5O	Half Moon	Power Station Outfall	1	1	1	1	1	-	1	1					1					1		1				1		

Table 4.4.4 Sediment Quality Parameters and Sampling Number

					LABORATORY SEDIMENT ANALYSES										External Lab
Site			Field Sediment Profiling		Ign			Metals					HC		
Code	Region	Site Name	ORP	°C	PSA	Loss	TOC	As	Cr	Hg	Vn	Others	TPH	BTEX	PCB
D2O	Dafi Dawhat	Gumah Island	1		1	1	1	1	1		1	1	1		
J1	Jubail	Abul Ali North	1		1	1	1	1	1	1	1	1	1	1	
J2	Jubail	Berri Oil Field	1	1					1		1	1	1		
J4	Jubail	North Jubail	1	1	1	1		1	1		1	1			
J5	Jubail	Jubail Shared	1	1	1	1	1	1	1	1	1	1	1		1
J6	Jubail	Jubail Harbour	1	1	1	1	1	1	1	1	1	1	1		
J7	Jubail	South Jubail	1	1	1							1			
J8O	Jubail	Jubail Boat	1	1	1				1			1	1	1	
R1	Ras Tan.	Sea Island	1	1	1	1	1				1	1	1	1	
R2	Ras Tan.	Ras Tannura Spit	1	1	1				1		1	1	1		
R4O	Ras Tan.	Refinery Outfall	1	1	1			1	1	1	1	1	1	1	
T2	Tarut Bay	Tarut - Zur	1	1	1	1	1					1			
T3	Tarut Bay	Tarut - East	1	1											
T4	Tarut Bay	Tarut - Darin	1	1	1		1					1	1		
T6	Tarut Bay	Qatif/Anik urban	1	1											1
T7	Tarut Bay	Qatif/Anik Drain	1	1	1		1	1	1			1	1		
T9	Tarut Bay	Dammam Fishing	1	1											1
T11O	Tarut Bay	Dammam Fishing	1	1	1	1	1	1	1	1	1	1	1	1	1
T12O	Tarut Bay	Swfwa	1	1											
K1	Khobar	Dammam South	1	1	1	1	1	1	1			1			
K2	Khobar	SAFCO outfall	1	1	1		1	1	1			1			
K3	Khobar	SAFCO south	1	1	1	1	1	1				1			
K4	Khobar	Khobar Central	1	1	1		1								
K5	Khobar	Khobar STP	1	1	1	1	1	1	1			1	1		
K6	Khobar	Khobar South	1	1	1	1	1	1	1			1			
K8	Khobar	Desalination	1	1	1	1	1	1	1			1			
H1	Half Moon	Half Moon Bay -	1	1											
H2	Half Moon	Half Moon Bay -	1	1											
H3O	Half Moon	Half Moon Bay -	1	1											
H4O	Half Moon	Power Station	1	1											
H5O	Half Moon	Power Station	1	1								1			

Table 4.4.5 Parameters and Measurement Methods at Field (Water)

Parameters	Measurement Methods
Water Color	Observation with naked eyes
Odor	Performed by Personal sense of smell
pH	Portable multi-probe meter
DO	Portable multi-probe meter
Clorine	Portable Clorine meter
Temperature	Thermometer or Portable multi-probe meter
Salinity	Portable multi-probe meter
Water clarity	Secchi plate
Water depth	Sounding lead

Table 4.4.6 Parameters and Measurement Methods at Field (Sediment)

Parameters	Measurement Methods
Temperature	Portable probe meter
Color	Observation with naked eyes
Odor	Performed by Personal sense of smell
Oxidation-reduction potential	Portable probe meter

Table 4.4.7 List of Analysis Procedure

Analysis Item	Method	Standared No.	
Water Analysis			
Residual Chlorine	Titratmetric/DPD Colorimetric	K 0102 33.3	4500-Cl G
TOC	TOC analyzer	K 0102 22.1	5310 B
TSS	Gravimetric	JEA 59-8	2540 D
NH_3	Spectrophotometric	K 0102 42	4500-NH_3 B,F
TKN	Spectrophotometric	K 0102 44	4500-N_{org} B
Total Phosphorus	Spectrophotometric	K 0102 46	EPA 365.3
Cyanogen	Spectrophotometric	K 0102 38	EPA 335.2
Magnesium	AAS	K 0102 51.2	3500-Mg B
Cd, Pb, Zn, Cu, Co, Ni	solvent extraction - AAS	K 0102 52.2	3500 B
Chromium	solvent extraction - AAS	K 0102 65.1	3500-Cr B
Mercury	vapor generator - AAS	JEA 59-1	3500-Hg B
Arsenic	hydride generator - AAS	K 0102 61.2	3500-As B
Phenols	Spectrophotometric	K 0102 28	EPA 420.1
Oil & Grease	Oil contents meter	JEA 64-4	EPA 413.2
TPH	solvent extraction - oil contents meter	K 0102 26	EPA 418.1
BTEX	headspace - GC/FID	K 0125	EPA 602
Chlorophyll	Spectrophotometric	MHW VI-20.2	10200 H
Total Coliform	membrane filtration	MHW VIII-5.4	9222 B
Sediment Analysis			
Ignition Loss	Gravimetric	JEA II 4	-
TOC	Titratmetric	-	Moopam IV.4
Cr, Cd, Pb, Zn, Cu, Co, Ni, V	acid decomposition - AAS	JEA II 6-12	EPA 3050-B
Hg	acid decomposition - AAS	JEA II 5.1	
As	acid decomposition - AAS	JEA II 13	
TPH	solvent extraction - oil contents meter	-	5520 E,F
BTEX	headspace - GC/FID	K 0125	EPA 5021

4.4.5 Monitoring Results and Discussion

(1) Stage 3 monitoring results

1) Water Quality Indicators

Result of the field measurement (in-situ measurement) conducted in Stage3 monitoring is summarized in Table4.4.8. The result of chemical analysis for water is shown in Table 4.4.9. Water quality condition of each area is described as follows;

[Zone D:Dawhat ad-Dafi Bay]

Dawhat ad-Dafi Bay lies inside the Jubail Marine Wildlife Sanctuary. This large coastal embayment contains many productive natural habitats including supratidal to high tidal salt marshes (sabkha), mid-tidal mangrove forests, low intertidal sand and mud flats, and shallow subtidal seagrass beds. These habitats also form an important fish nursery area. There are no remarkable pint sources of pollution within the area but much of the bay was heavily oiled during the 1990-1991 Gulf War.

The sampling site selected for the water and sediment sampling (site DD20) was positioned in the lower intertidal zone on the west side of Gurnah Island, close to plots of mangroves whose recovery since the Gulf War oil spill has been monitored by the King Fahd University (Dhahran).

Results from the *in-situ* field measurements and laboratory analyses showed no evidence of marked water quality degradation, although water clarity was relatively low. This turbidity was a normal brown colour and not associated with signs of eutrophication such as green algal bloom and elevated chlorophyll *a*. The poor water clarity can be related to the fine sediments that readily mobilised from the shallow banks in this region by tidal currents and wave action.

[Zone J: Al -Jubail]

The Jubayl region contains several potential pollution sources including the offshore Berri oil field and the large shared seawater cooling canal used by industries in Jubayl Industrial City. The canal intake is located outside the large King Fahad Industrial Port and Commercial Port and the shoreline outfall discharges into the north-west part of the main basin.

As background water quality monitoring site, J1 and J2 were located in offshore of Al-Jubail area. Also, Site J4 was set as a background water quality monitoring site in the inshore of Al-Jubail.

The major industrial activities in the Jubail Industrial City region include oil refining and petro-chemical production, electricity generation, seawater desalination, fertilizer production and a growing plastics industry. There is also a large waste disposal area that receives solid and liquid waste from industrial and municipal sources. Although contaminants such as metals, petroleum hydrocarbons and other petrochemicals may be present in waste streams from these industries, none of these contaminants were found in water samples above laboratory detection limits at sites close to the outfall (J5, J90) or other parts of King Fahad port (sites J80, J6).

In the monitoring site near outfall (J5), remarkably higher water temperature of 34.8°C, which suspected to be caused by thermal effluent, was found. The temperature of the monitoring sites which have no influence from the outfall, for example siteJ7, recorded around 29°C, so that the increase in temperature of the effluent can be estimated about 6°C.

In J90, which located in the area influenced by thermal effluent, surface water temperature was 34.2°C, whereas bottom water temperature was 31.0°C. This result indicates that thermal effluent diffuses mainly in surface layer.
Also, mach alga scum was observed in siteJ5.

Water quality degradation was not recorded in King Fahad Industrial Port, including the monitoring sites for Jubail Boat Harbor (J8) and Commercial Port area (J6).

The background water quality of J1 and J2, which are located in offshore area, and in J4, located in coastal area, showed good water quality condition. Site of J2 also had a function as a monitoring site for oil contamination that derived from oil mining activity because it was located in Barri Oil Field.

According to the monitoring result, no oil/petroleum contamination was detected in the water of J2 and it should suggest that the oil mining activity doesn't affect water quality so much.

[Zone R: Ras Tanura]

Ras Tanura as the largest petroleum refinery and oil export terminal in Kingdom of Saudi Arabia. Selection of Ras Tanura monitoring sites and parameters during the

planning stage therefore focussed on the need to monitor petroleum hydrocarbons and related substances.

Sites R1 and R2 were located to investigate the influence of the 'Sea Island' oil tanker terminal, while site R40 was positioned in front of the refinery's small shoreline outfall to investigate the potential effect of this small discharge.

Regarding the hydrodynamic features, the exposed eastern shoreline of the Ras Tanura peninsula is exposed to wind waves and high tidal current speeds, so it was also expected that pollutants are rapidly diluted and dispersed in the region of the 'Sea Island' tanker terminal. It was therefore not unexpected that, apart from one exception, no water quality degradation was detectable in the samples taken from R1, R2 and R40.

According to the monitoring result, any noticeable water quality degradation was not detected in R1 and R2. Oil related indicators including Oil and Grease, TPH, BTEX and phenol, which should be derived from tanker activities, was also not detected.
In R40, no water quality degradation was occurred, same as R1 and R2. Oil related indicators and heavy metals, which should be possibly discharged form oil refinery, were also not found. However, relatively high concentration of residual chlorine (0.11mg/l) has detected in R40, which may be derived from anti-biofouling chemicals applied on the drainpipe.

[Zone T: Tarut Bay]

The waters of Tarut Bay are vulnerable to pollution because of its enclosed shape, shallow depths, weak tidal currents and major shoreline reclamation works, all of which act to prevent rapid dilution/dispersal of contaminants and promote their accumulation in sediments and biota. The practice of dredging inshore sediments to provide fill for reclamation projects has also produced deepwater pockets and 'dead' areas that act as sediment traps and pollutant sinks. Also, there are many kinds of possible pollution sources that may affect the water quality around the bay.

Al-Quatif is an old town and may not equipped water treatment system with enough ability. Some discharge is discharged to Tarut bay without treatment. In some place, treatment of effluent may be done by subsurface waste disposal, which has possibility to cause contamination into sea water through groundwater. Sewage treatment located in Tarut Zur is also may affect water quality of Tarut bay.

The activities of boats and vessels in Dammam port may be one of the possible pollution sources in the Tarut bay. Water quality degradation caused by waste dumping, reclamation of waste and dredging has also become a problem.

As the sites to assess the background water quality in Tarut Bay, T3 and T120 were positioned in central area and northern area of the bay respectively. T6 was located at the Al Quatif urban drain in order to detect the influence from domestic effluents. T7 was located in the diffusion area of T6.

In order to investigate the water quality condition of fishing port, T4, T9 and T110 were positioned. T2 (Tarut-Zur) was located about 1.5km north from a sewage treatment plant in which water body may be influenced from effluent of the sewage treatment plant and groundwater.

The concentration of chlorophyll in Tarut Bay ranged from 0.1ug/l to 54ug/l. The concentration was much higher than another monitoring point ranging from <0.1ug/l to 1.3ug/l. Chlorophyll is the indicator of phytoplankton increase rate and, therefore, the monitoring result seems to indicate that eutrophication has happened in whole Tarut Bay area. Remarkable water quality degradation was seen in T6 and T7. Especially, eutorophication indicating parameters, such as, TOC, Total Kjeldahl nitrogen (TKN), Ammonium (NH_4) and Total phosphorus showed very high value. Weak odor of sewage was also detected. It seems to indicate that the water body in this area has affected by sewage from towns.

Not only concentration of Chlorophyll, but TOC concentration showed relatively high value in T2 seemed to be affected by effluent from the sewage treatment plant. Nevertheless, the concentration of TKN, NH_4 and P showed relatively low value of 1mg/l, <2mg/l and 0.02mg/l respectively.

TSS and TOC were high in T4 and T110 located near fishery port. Relatively high value of TSS (10mg/l) in T120 seemed to be influenced by reclamation activity in nearby area.

[Zone K: Al-Khobar-Dammam]

Zone K is a topographically open water area and its rapid tide may help smooth diffusion of pollutants. Whereas, effluent from fertilizer production factory (SAFCO fertilizer factory; K2), sewage treatment plant (Al Khobar Sewage Treatment Plant; K5) and desalination plant (Aziziyah desalination plant; K8) has possibility to affect water quality condition. Monitoring sites were selected in order to know the influence from

these effluent discharge facilities. Site K1 was located further offshore and 3 km from Dammam to enable monitoring of the 'local background' condition of water entering the Zone K coastal strip from the north.

Water quality degradation was not detected in K1 except for little higher value of TSS.

High concentration of TOC, TKN and NH4 was monitored in K2 located at the outfall of fertilizer factory. High concentration of TSS, TOC and chlorophyll was monitored in K3 located near the outfall from fertilizer factory. These data indicate that the water body is influenced by effluent from fertilizer plant.

The monitoring result of K5 located in sewage treatment plant outfall showed high concentration of eutrophication indicate parameters, i.e., 8mg/l in TSS, 5mg/l in TOC, 8mg/l in TKN, 0.4mg/l in NH_4 and 1.03mg/l in P. High concentration of TOC and P was monitored in K4 which was located at downstream of the outfall based on the tide condition at the monitoring time. These results indicate that the effluent from the sewage treatment plant has influenced surrounding water body.

Water quality condition of K5 located in desalination plant outfall and K7 located in desalination plant intake seemed to be not affected by effluent, except for higher surface water temperature (neary by 5℃). Metals discharged from desalination plant were also not detected except for Mg which was normally existing in sea water.

[Zone H: Half-Moon Bay and Agraiha]

Half-Moon Bay is becoming an increasingly popular recreation area and many holiday home and resort facilities are being developed along its coastline, some of which may be causing significant quantities of eutrophication-causing biostimulants to enter this enclosed and highly evaporative basin which has limited tidal exchange.

Monitoring sites were positioned in mouth area (H3), central area (H2) and interior area (H1) of the bay in order to clarify general pollution condition. Al-Qulayyah power plant is located in Agraiha area. Water quality monitoring was conducted in H40 located at the intake of the plant and in H50 located at the outfall of the plant, respectively. The monitoring result indicated that degradation had not occurred in Half-Moon Bay.

The water quality condition of H50 and H40 seemed not to be affected except for higher surface water temperature by nearly 5℃ than others.

Table 4.4.8 (1) Results of Field Measurement

Site Code	Site Name	Location (GPS)		Sampling		MET-OCEAN CONDITIONS								FIELD WATERT PARAMETERS											
		Lat.	Long.	Date	Time	Air Temp.	Cloudiness	Wind Direction	Wind Speed	Wave Height	Depth (m)	Water Current Direction	Water Current Speed	Water Temp.	Salinity	pH	DO	Turbidity	Water Clarity	Water Color	Odor	Sheen	Rubbish	Res.Cl as Total	Res.Cl as Free
						(°C)	(%)	(o)	(m/s)	(m)		(°)	(cm/s)	(°C)	(g/L)		(mg/L)	(NTU)	(m)					(mg/L)	(mg/L)
DD20	Gumah Island	27° 07.92'N	49° 29.16'E	30.Oct.99	16:00	32.0	0	52.5	2-3	<0.05	5.2	52.5	14	27.5	52	8.15	5.6	-	2.25	Green	no	no	no	0.04	0.01
J1	Abul Ali North	27° 23.49'N	49° 44.59'E	31.Oct.99	11:30	33.5	40	35.4	3-4	<0.5	32	290(surf.) 310(5m)	6-9(surf.) 21(5m)	29.7	40	8.4	5.9	-	5.75	Geen	no	no	no	0.07	0
J2	Berri Oil Field	27° 10.54'N	49° 42.07'E	31.Oct.99	15:50	30.3	70	70.5	4-5	<0.5	25	-	-	29.7	40	8.22	5.4	-	11.5	Green	no	no	no	0.02	-
J4	North Jubail	27° 07.56'N	49° 41.33'E	31.Oct.99	16:15	30.5	40	123.6	4-5	<0.3	6.8	-	-	25.5	40.2	8.3	5.3	-	>6.9	Green	no	no	no	0.02	-
J5	Jubail Shared Outfall	27° 03.36'N	49° 37.22'E	1.Nov.99	12:30	35.5	0	298	5-6	<0.3	9.3	30	25	34.8	40.4	8.24	5.29	-	4.1	blue	no	no	algae	0.01	-
J6	Jubail Harbour	27° 02.54'N	49° 40.97'E	1.Nov.99	10:25	33.0	20	206	2	<0.3	6	350(surf.) 90(5m)	7(surf.) 8(5m)	28.9	40.6	8.26	5	-	>6.0	blue	no	no	little from fertilizer	0.07	0.05
J7	South Jubail	27° 00.98'N	49° 42.24'E	1.Nov.99	9:35	29.0	20	174	3	<0.3	10.3	260(surf.) 260(5m)	6(surf.) 4(5m)	29	40.4	8.23	5.2	-	9.2	blue	no	no	no	0.03	0.02
J8O	Jubail Boat Harbour	27° 05.08'N	49° 40.92'E	1.Nov.99	13:35	32.5	20	24.6	5-6	<0.1	5	-	-	29.3	40.3	8.01	5.01	-	>5.0	Geen	no	no	no	0.05	0.03
J9O	Near Jubail Outfall	27° 03.54'N	49° 37.70'E	1.Nov.99	11:30	36.3	10	350	5	<0.2	5.5	90(surface) 260(4m) 70(3m) 100(2m)	15(surf.) 4(4m) 20(3m) 6(2m)	34.22(S) 31.0(B)	40.3(S) 40.7(B)	8.27(S) 8.32(B)	4.95(S) 4.43(B)	-	3.3	Geen	no	no	little algae	0.04	0.02
H1	Half Moon Bay - North	26° 12.00'N	50° 02.24'E	6.Nov.99	11:50	29.5	0	S	5	<0.5	4.45	-	-	27	61	8.08	5.15		>4.45	Green	no	no	no	0.10	0.0
H2	Half Moon Bay - mid	26° 04.05'N	50° 04.94'E	6.Nov.99	10:35	30.0	0	225.3	1	<0.1	5.7	86(S) 233(3-4m) 227(B)	7.5(S) 6(3-4m) 3-5(B)	25.8(S) 25.7(B)	56.3(S) 59.3(B)	8.0(S) 8.1(B)	5.18(S) 4.73(B)		>5.7	Dark Green	no	no	no	0.07	0.05
H3O	Half Moon Bay - South	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.4.8 (2) Results of Field Measurement

Site Code	Site Name	Location (GPS)		Sampling		MET-OCEAN CONDITIONS								FIELD WATERT PARAMETERS										
		Lat.	Long.	Date	Time	Air Temp. (°C)	Cloudiness (%)	Wind Direction (o)	Wind Speed (m/s)	Wave Height (m)	Depth (m)	Water Current Direction (°)	Water Current Speed (cm/s)	Water Temp. (°C)	Salinity (g/L)	pH	DO (mg/L)	Turbidiy (NTU)	Water Clarity (m)	Water Color	Odor	Sheen	Rubbish	Res.Cl as Total (mg/L)	Res.Cl as Free (mg/L)
R1	Sea Island Terminal	26° 39.73'N	50° 11.04'E	8.Nov.99	12:35	31.0	0	159.1	6	<1	26.85	175	36	27.7(S) 27.6(B)	41.3(S) 41.4(B)	8.20(S) 8.12(B)	5.52(S) 5.69(B)		9.7	Dark Green	no	no	no	0.07	0.07
R2	Ras Tannura Spit	26° 37.60'N	50° 09.81'E	20.Oct.99	11:10	31.5	0	42.7	6	<0.5	6.7	215(S) 223(B)	45(S) 20(B)	29.8(S) 29.5(B)	40.8(S) 40.6(B)	8.15(S) 8.15(B)	5.2(S) 5.2(B)		6	Dark Green	no	no	no	0.08	0.07
R4O	Refinery Outfall	26° 41.86'N	50° 06.48'E	8.Nov.99	13:50	32.0	0	130	4	<0.5	1.9	170	11	28.5	41.2	8.13	6.85		>1.9	Pale Green	no	no	no	0.11	0.04
T1	Tarut - Zur	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	Tarut - Zur	26° 36.52'N	50° 04.94'E	18.Oct.99	13:21	30.5	0	51.9	4	<0.2	1.3	85	17	29.6	43.5	8	5.32	-	-	Pale Green	no	no	no	0.06	-
T3	Tarut - East	26° 33.83'N	50° 06.67'E	18.Oct.99	14:30	30.0	0	42.7	5	<0.2	1.36	120	3	29.5	43.1	8.2	8.2	-	>1.36	Pale Green	no	no	no	0.07	-
T4	Tarut - Darin	26° 32.43'N	50° 05.11'E	18.Oct.99	15:20	28.5	0	42.7	42.7	<0.2	2.76	140	3	29.1	42.4	8.15	5.65	-	-	Pale Green	no	no	no	0.06	-
T6	Qatif/Anik urban drain	26° 30.55'N	50° 02.11'E	17.Oct.99	14:40	26.0	0	64	3	-	40-60	-	33	31.9	3.9	7.4	2.2	-	<0.3	Dark Green	weak sewage smell	no	no	0.1	-
T7	Qatif/Anik Drain Mouth	26° 30.53'N	50° 02.57'E	17.Oct.99	15:50	29.5	0	58.3	5	<0.1	0.5	-	-	30	12.5	8	9.2	-	<0.3	dark green	sewage smell	no	no	0.05	-
T9	Dammam Fishing Harbour - Entrance	26° 29.46'N	50° 08.14'E	23.Oct.99	13:05	32.5	0	30.9	5	<0.5	4	256	31	27.9	41.7	8.02	5.5	-	2.2	green	no	no	no	0.14	0.08
T11O	Dammam Fishing Harbour	26° 27.55'N	50° 08.00'E	23.Oct.99	11:55	30.0	0	26.6	5	<0.1	1.3	0	0	27.5	41.6	8.3	5.63	-	0.72	Pale Green	no	no	no	0.07	0.03
T12O	Swfwa	26° 38.95'N	50° 01.15'E	17.Oct.99	12:30	32.7	0	102.4	5	<0.2	0.5	40	2	30.4	45.3	8.1	5.3	-	>0.5	blue / green	no	no	no	0.12	-

Table 4.4.8 (3) Results of Field Measurement

Site Code	Site Name	Location (GPS)		Sampling		MET-OCEAN CONDITIONS								FIELD WATERT PARAMETERS										
		Lat.	Long.	Date	Time	Air Temp. (°C)	Cloudiness (%)	Wind Direction (o)	Wind Speed (m/s)	Wave Height (m)	Depth (m)	Water Current Direction (°)	Water Current Speed (cm/s)	Water Temp. (°C)	Salinity (g/L)	pH	DO (mg/L)	Turbidiy (NTU)	Water Clarity (m)	Water Color	Odor	Sheen	Rubbish	Res.Cl as Total (mg/L)	Res.Cl as Free (mg/L)
K1	Dammam South	26° 25.14'N	05° 01.26'E	23.Oct.99	15:00	32.7	0	27.8	6	<0.4	1.7	220	18	28	42	8.08	5.74	-	>1.7	Pale Green	no	no	no	0.08	0.01
K2	SAFCO outfall	26° 24.52'N	50° 11.42'E	16.Oct.99	13:40	34.0	0	42.5	4.5	-	-	-	-	37.5	-	-	-	-	-	little milky	little smell	-	-	0.13	-
K3	SAFCO south	26° 24.47'N	50° 11.90'E	23.Oct.99	15:43	30.7	0	332.8	6	<0.5	1.2	0	0	27.2	42.7	8.2	6.31	-	>1.2	Pale Green	no	no	no	0.04	-
K4	Khobar Central	26° 14.94'N	50° 13.37'E	7.Nov.99	11:25	32.1	0	171.2	4-5	<0.1	4.1	0	25	26.7	47.3	8.04	5.73		1.3	pale green	no	no	no	0.12	0.05
K5	Khobar STP Outfall	26° 14.45'N	50° 13.41'E	7.Nov.99	12:10	30.3	0	171.8	5	<0.2	4.9	5	50	29.14	31	7.84	6.35		0.7	pale green	no	no	no	0.17	0.09
K6	Khobar South	26° 14.33'N	50° 13.50'E	7.Nov.99	10:45	31.0	0	SSE	4-5	<0.1	7.85	0	75(S) 50(B)	26.26	47.6	8.17	5.8		1.6	pale green	no	no	no	0.08	0.02
K7	Desalination intake	26° 10.40'N	50° 13.02'E	7.Nov.99	9:17	30.2	0	178.6	4-5	<0.2	6.9	10(S) 360(B)	30(S) 25(B)	26.3(S) 26.1(B)	49.0(S) 49.7(B)	8.10(S) 8.15(B)	5.90(S) 5.0(B)		1.7	pale green	no	no	no	0.09	0.02
K8	Desalination Outfall	26° 10.58'N	50° 12.70'E	7.Nov.99	9:47	30.0	0	170.9	4	<0.2	4.85	40(S) 50(B)	30(S) 24(B)	30.93(S) 27.6(B)	50	8.09	5.05(S) 5.2(B)		2.2	pale green	no	no	no	0.13	0.05
H4O	Power Station Intake	25° 51.62'N	50° 07.31'E	25.Oct.99	12:10	37.5	0	250.2	4	<0.1	4.5	-	-	29	54.1	7.98	5.7	-	>4.5	Dark Green	no	no	no	0.18	0.06
H5O	Power Station Outfall	25° 51.23'N	50° 07.57'E	25.Oct.99	12:35	37.0	0	224.2	3	-	1.9	-	-	34.3	53.6	8	4	-	-	pale green	little smell	no	no	0.13	0.12

Table 4.4.8 (4) Results of Field Measurement

Site Code	Site Name	Location (GPS)		Sampling		SEDIMENT PARAMETERS					Observation and Comment
		Lat.	Long.	Date	Time	Color	Odor	Texture	Sediment Temp. (°C)	ORP (mv)	
DD20	Gumah Island	27° 07.92'N	49° 29.16'E	30.Oct.99	16:00	glay	no	sandy	-	24	*Sediment is little oily. (Extra sample)*
J1	Abul Ali North	27° 23.49'N	49° 44.59'E	31.Oct.99	11:30	glay	little (H_2S)	muddy	27.7	-	
J2	Berri Oil Field	27° 10.54'N	49° 42.07'E	31.Oct.99	15:50	glay	no	sandy	-	-	
J4	North Jubail	27° 07.56'N	49° 41.33'E	31.Oct.99	16:15	-	-	-	-	-	Sediment sampling was impossible because sediment was rocky.
J5	Jubail Shared Outfall	27° 03.36'N	49° 37.22'E	1.Nov.99	12:30	dark glay	little (H2S)	sandy	-	-40	Water sampling point was 50-100m far from outfall. sediment point was 300m.
J6	Jubail Harbour	27° 02.54'N	49° 40.97'E	1.Nov.99	10:25	slight glay	no	sandy	-	-	
J7	South Jubail	27° 00.98'N	49° 42.24'E	1.Nov.99	9:35	clay	no	sandy	-	-	
J8O	Jubail Boat Harbour	27° 05.08'N	49° 40.92'E	1.Nov.99	13:35	glay	no	sandy	-	-34	
J9O	Near Jubail Outfall	27° 03.54'N	49° 37.70'E	1.Nov.99	11:30	-	-	-	-	-	
H1	Half Moon Bay - North	26° 12.00'N	50° 02.24'E	6.Nov.99	11:50	-	-	-	-	-	
H2	Half Moon Bay - mid	26° 04.05'N	50° 04.94'E	6.Nov.99	10:35	-	-	-	-	-	Extra water sample for H3O
H3O	Half Moon Bay - South	-	-	-	-	-	-	-	-	-	Sampling was not conducted because of petro shortage. Substitute sample was taken at H2

Table 4.4.8 (5) Results of Field Measurement

Site Code	Site Name	Location (GPS)		Sampling		SEDIMENT PARAMETERS					Observation and Comment
		Lat.	Long.	Date	Time	Color	Odor	Texture	Sediment Temp. (°C)	ORP (mv)	
R1	Sea Island Terminal	26° 39.73'N	50° 11.04'E	8.Nov.99	12:35	gray	no	Sandy silt	27.5	-30	Very Small tarball was observed in the sediment.
R2	Ras Tannura Spit	26° 37.60'N	50° 09.81'E	20.Oct.99	11:10	creamy	no	Silty sand	29	84	Old tarballs was observed in the sediment.
R4O	Refinery Outfall	26° 41.86'N	50° 06.48'E	8.Nov.99	13:50	creamy	no	Sandy	28.9	-55	
T1	Tarut - Zur	-	-	-	-	-	-	-	-	-	No sample site. Just coral reef condition check
T2	Tarut - Zur	26° 36.52'N	50° 04.94'E	18.Oct.99	13:21	creamy	no	shelly coarse	-	56	Shally sediment. Hermit crab was observed.
T3	Tarut - East	26° 33.83'N	50° 06.67'E	18.Oct.99	14:30	-	-	-	-	-	
T4	Tarut - Darin	26° 32.43'N	50° 05.11'E	18.Oct.99	15:20	gray	little smell	silty sand	28.5	-56	Soft fine Sediment
T6	Qatif/Anik urban drain	26° 30.55'N	50° 02.11'E	17.Oct.99	14:40	-	-	-	-	-	Drain channel, flesh water
T7	Qatif/Anik Drain Mouth	26° 30.53'N	50° 02.57'E	17.Oct.99	15:50	-	-	-	-	-	Near the sewage outfall
T9	Dammam Fishing Harbour - Entrance	26° 29.46'N	50° 08.14'E	23.Oct.99	13:05	dark gray	no	Silty sand	27	124	
T11O	Dammam Fishing Harbour	26° 27.55'N	50° 08.00'E	23.Oct.99	11:55	dark gray	weak smell	silty sand	27	16	
T12O	Swfwa	26° 38.95'N	50° 01.15'E	17.Oct.99	12:30	-	-	silty sand	-	-	Mongrove area. New mangrove is growing. Plenty of aminal life, fish, shrimp

Table 4.4.8 (6) Results of Field Measurement

Site Code	Site Name	Location (GPS)		Sampling		SEDIMENT PARAMETERS					Observation and Comment
		Lat.	Long.	Date	Time	Color	Odor	Texture	Sediment Temp. (°C)	ORP (mv)	
K1	Dammam South	26° 25.14'N	05° 01.26'E	23.Oct.99	15:00	mediam gray	no	shilty course sand	28	16.4	Sgrass was obserbed on the bottom.
K2	SAFCO outfall	26° 24.52'N	50° 11.42'E	16.Oct.99	13:40	dark glay	little smell	sticky and clayee	-	-212	Hashim can smell ammonia clearly. Birds are drinking. Surface sediment (0-10cm) is glay, below 10cm is dark. Biology activity Is low.
K3	SAFCO south	26° 24.47'N	50° 11.90'E	23.Oct.99	15:43	mediam gray	no	silty medium sand	26	98	Bottom condition: 50% of algae mat. 30% Rock, 20% sand.
K4	Khobar Central	26° 14.94'N	50° 13.37'E	7.Nov.99	11:25	dark gray	no	silty sand	26.5	-37	
K5	Khobar STP Outfall	26° 14.45'N	50° 13.41'E	7.Nov.99	12:10	gray	no	gravelly sand	27.1	-41	Sediment:Silty coarse gravelly sand
K6	Khobar South	26° 14.33'N	50° 13.50'E	7.Nov.99	10:45	creamy	no	coarse	26.3	-51	
K7	Desalination intake	26° 10.40'N	50° 13.02'E	7.Nov.99	9:17	-	-	-	-	-	
K8	Desalination Outfall	26° 10.58'N	50° 12.70'E	7.Nov.99	9:47	dark gray	no	silty coase sand	28.5	-40	
H4O	Power Station Intake	25° 51.62'N	50° 07.31'E	25.Oct.99	12:10	-	-	-	-	-	
H5O	Power Station Outfall	25° 51.23'N	50° 07.57'E	25.Oct.99	12:35	dark gray	no	Sandy shilty course sand	30	53	

Table 4.4.9 Analysis Result of Seawater Samples

WATER

Site ID	TSS mg/l	TKN mg/l	NH_3 mg/l	T-P mg/l	Chlor ug/l	TOC ppm	Metals										CN mg/l	Oil& Grse mg/l	TPH mg/l	BTEX mg/l	Phenol mg/l	Res. Cl (mg/L)	Coliform pcs (x100)	OCL mg/l
							As mg/l	Cr mg/l	Hg mg/l	Mg g/L	Cd	Co	Cu	Ni	Pb	Zn								
DD20	-	1.5	-	<0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
J1	2	1.5	<0.2	<0.01	1.3	2	<0.01	<0.1	<0.005	1.5	<0.01	<0.05	<0.05	<0.05	<0.1	<0.01	<0.01	-	-	-	-	<0.5	-	-
J2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.2	-	-	-	-	-	-
J4	1	1.5	-	0.01	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
J5	3	1.5	<0.2	0.01	-	2	-	<0.1	<0.005	1.5	<0.01	<0.05	<0.05	<0.05	<0.1	<0.01	<0.01	<0.2	-	-	<0.005	<0.5	-	<0.01
J6	2	1	-	0.01	0.3	1	<0.01	<0.1	<0.005	-	<0.01	<0.05	<0.05	<0.05	<0.1	<0.01	<0.01	-	-	-	-	-	-	<0.01
J7	-	0.8	-	0.01	0.2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.01
J8O	<1	-	-	-	-	-	<0.01	-	-	-	-	-	-	-	-	-	-	<0.2	<0.1	-	-	-	-	-
J9O	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	-	<0.01
R1	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	<0.2	<0.1	-	-	-	-	-
R2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
R4O	1	-	-	-	-	-	-	-	-	-	<0.01	<0.05	<0.05	<0.05	<0.1	<0.01	-	-	<0.1	<0.01	-	<0.5	-	-
T1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	<1	1	<0.2	0.02	2.6	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52	-
T3	1	<0.1	<0.2	0.01	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25	-
T4	9	1	<0.2	0.04	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21	-
T6	7	5	4.2	0.88	54	12	<0.01	<0.1	<0.005	0.17	<0.01	<0.05	<0.05	<0.05	<0.1	0.03	-	-	-	-	-	-	150	-
T7	12	3.6	2.7	0.64	26	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	70	-
T9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T11O	3	1	<0.2	0.04	-	5	<0.01	<0.1	<0.005	-	<0.01	<0.05	<0.05	<0.05	<0.1	<0.01	-	<0.2	0.2	<0.01	<0.005	-	55	-
T12O	10	1	<0.2	0.01	3.8	-	<0.01	<0.1	<0.005	1.7	<0.01	<0.05	<0.05	<0.05	<0.1	0.03	-	-	-	-	-	-	-	-
K1	4	0.8	-	<0.01	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K2	3	130	90	0.20	-	48	<0.01	0.2	<0.005	0.13	<0.01	<0.05	<0.05	<0.05	<0.1	0.2	<0.01	0.6	-	-	-	3.5	340	-
K3	5	1.5	-	0.01	0.3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K4	3	1.5	<0.2	0.10	-	2	-	-	-	-	-	-	-	-	-	-	-	<0.2	-	-	-	-	168	-
K5	8	2.5	0.4	1.03	-	5	<0.01	<0.1	-	-	<0.01	<0.05	<0.05	<0.05	<0.1	0.02	-	<0.2	-	-	-	16	80	-
K6	4	1	-	0.02	-	2	-	-	-	1.8	-	-	-	-	-	-	-	-	-	-	-	-	100	-
K7	-	-	-	-	-	-	-	-	-	1.8	<0.01	<0.05	<0.05	<0.05	<0.1	<0.01	-	-	-	-	-	<0.5	-	-
K8	-	-	-	-	-	-	<0.01	<0.1	-	1.9	<0.01	<0.05	<0.05	<0.05	<0.1	<0.01	-	-	-	-	-	<0.5	-	-
H1	1	1.5	-	<0.01	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H2	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H3Oa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H3Ob	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H4O	<1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H5O	<1	-	-	-	-	2	-	-	-	-	<0.01	<0.05	<0.05	<0.05	<0.1	<0.01	-	-	-	-	-	-	-	-

2) Sediment Quality Indicators

The analytical result of sediments in the Stage 3 monitoring is shown in Table 4.4.10. The pollution distribution conditions of sediments are almost same as that of water. Nevertheless, some locations in which water quality degradation was not detected had polluted sediments. It is because water pollution is easier to diluted and diffuse compared with that of sediments. Therefore, sediment quality condition is understood to indicate long term history of accumulation of pollutants whereas water quality condition shows relatively short-term pollution fluctuation.

Sediment quality condition of each area is described as follows;

[Zone D]

High concentration of TOC and TPH was detected from sediment at Dawhat ad-Dafi Bay (DD20). This site was polluted by oil leaking event of Gulf War in 1991. The high concentration of TOC and TPH may be derived from it.

[Zone J]

No significant water quality degradation was found in J1 that was a background monitoring site of Zone J. Nevertheless, in sediment, Nickel concentration at J1 showed remarkably high value of 71mg/kg. Sediment at J2 also showed high concentration of Nickel as 28mg/kg. Nickel is known as an indicator of the pollution discharged by oil mining activity so that these high concentrations of Nickel may be related to it. Vanadium and Barium are also pollutants derived from oil mining activity. Therefore, these metals may have accumulated into sediment. TPH concentration in sediment showed relatively high value of 15mg/kg and 17mg/kg at J1 and J2, respectively. It means the possibility of accumulation of oil pollution into sediment.

In coastal area, 3mg/kg of Cadmium (Cd) was detected at J80 (Jubail Boat Harbor) and J7 (out of Jubail Harbor). The source of Cd did not confirmed in this study but may not be derived from land-base sources because of the location of monitoring site.

[Zone R]

At site R1, relatively high concentration of Copper (Cu) and Zinc (Zn) were detected from the sediment as 20mg/kg and 70mg/kg, respectively. Besides, 3mg/kg of Cd was detected in sediment at R1 and R40. TPH concentration, that was an indicator of oil

contamination, was 38mg/kg at R40 unless TPH value was under detection limit at R1 and R2. The high concentration of TPH at R40 may possibly to be derived from oil refinery.

[Zone T]

Conspicuously high concentration of Zn was detected from sediment at Darin Jetty (T4). In this site, concentration of Cu, Ni and TPH was also high. It seems to have been caused by oil leaking from vessel's activity and metal contamination from paint used for ship bottom coat. High concentration of TPH of 96mg/kg was detected from sediment at Quatif/Anik Urban drain (T6).

The highest concentration of Mercury (0.28mg Hg /kg) among all monitoring sites was detected in sediment at fishery port in Dammam (H110). Analysis of PCB was conducted for this site because MEPA had reported PCB pollutionin of this area. No PCB contamination was found from sediment samples collected.

[Zone K]

Serious pollution was found in sediment at outfall of fertilizer plant (K2) that belongs to Zone K. Especially, concentration of TOC, Chromium (Cr) and Zn showed much higher value than other monitoring sites, i.e., 4.1%, 570mg/kg and 2,100mg/kg, respectively. Hg concentration was also high (0.16mg/kg) at this site. Among these pollutants, TOC seemed to be derived from fertilizer plant. Nevertheless, Cr, Zn and Hg are usually discharged from chemical industry, steel industry, metal industry and electrical machinery industry, and having nothing to do with the fertilizer plant. The identification of source of these metals requires further discussion.

[Zone H]

No noticeable pollution was found in sediment at Half-Moon bay (H1) and Al-Qulayyah power plant (H50) unless high ignition loss which derived from rich organics substances was observed in sediment at H50. Dead body of plankton, that impinged to the power plant, may cause this organic rich sediment around the diffusion area of power plant outfall.

Table 4.4.10 Analysis Result of Sediment Samples

SAMPLE DETAILS		LABORATORY RESULTS - SEDIMENT SAMPLES																	
Site Code	Site Name	Ign. Loss %	COD	TOC %	As mg/kg	Cr mg/kg	Hg mg/kg	V mg/kg	Cd mg/kg	Co mg/kg	Cu mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg	TPH mg/kg	Benzene mg/kg	Toluene mg/kg	Ethylene mg/kg	Xylene mg/kg
DD20	Gumah Island	13.4		3.2	1.6	<50	-	<100	<1	19	12	31	35	16	19	-	-	-	-
J1	Abul Ali North	18.9		2.1	0.48	<50	<0.05	<100	<1	24	21	71	40	22	15	<2	<2	<2	<2
J2	Berri Oil Field	5.1		-	-	<50	-	<100	<1	20	14	28	43	11	17	-	-	-	-
J4	North Jubail				-	<50	-	<100	-	-	-	-	-	-	-	-	-	-	-
J5	Jubail Shared Outfall	2.7		0.36	-	<50	<0.05	<100	<1	11	6	25	21	13	-	-	-	-	-
J6	Jubail Harbour	4.0		1.2	1.03	<50	<0.05	<100	<1	15	9	20	31	<10	10	-	-	-	-
J7	South Jubail	3.1		-	-	-	-	-	3	16	<5	20	30	<10	-	-	-	-	-
J8O	Jubail Boat Harbour	-		-	-	<50	-	-	3	17	14	20	35	10	9	<2	<2	<2	<2
R1	Sea Island Terminal	6.7		1.5	-	-	-	<100	3	20	20	35	48	70	<5	<2	<2	<2	<2
R2	Ras Tanaura Spit	2.7		-	-	<50	-	<100	<1	17	6	21	26	16	<5	-	-	-	-
R4O	Refinery Outfall	2.9		-	1.3	<50	<0.05	<100	3	17	7	21	36	<10	38	<2	<2	<2	<2
T2	Tarut - Zar	3.1		0.36	-	-	-	-	3	17	6	19	35	<10	-	-	-	-	-
T4	Tarut - Darin	11.7		3.4	-	-	-	-	<1	22	40	51	57	110	31	-	-	-	-
T6	Qatif/Anik urban drain	2.3		0.61	0.68	<50	-	-	2	11	8	19	27	24	96	-	-	-	-
T11O	Dammam Fishing Harbour	2.7		0.15	1.1	<50	0.28	<100	<1	10	6	29	24	23	<5	<2	<2	<2	<2
K1	Dammam South	26.4		0.56	0.83	<50	-	-	3	19	7	22	39	13	-	-	-	-	-
K2	SAFCO outfall	10.7		4.1	1.1	570	0.16	<100	<1	16	41	48	56	2100	-	-	-	-	-
K3	SAFCO south	4.7		1.1	0.93	-	-	-	3	17	9	22	42	130	-	-	-	-	-
K4	Khobar Central	5.2		1.5	0.98	<50	-	-	3	18	14	28	36	19	-	-	-	-	-
K5	Khobar STP Outfall	4.3		1.2	1.01	<50	-	-	3	17	10	25	36	13		-	-	-	-
K6	Khobar South	-		0.86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K8	Desalination Outfall	2.7		0.34	1.3	<50	-	-	1	9	10	23	21	11	-	-	-	-	-
H1	Half Moon Bay - North			0.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H5O	Power Station Outfall	1.2		-	-	-	-	-	<1	<5	<5	10	<20	<10	-	-	-	-	-

3) Plankton Analysis

The result of Plankton analysis is shown in Table 4.4.11.

The density and species composition of plankton were different between Al-Jubail area (Zone Z) and other areas. In Al-Jubail area (J1, J4, J6 and J7), plankton density was relatively high and phytoplankton concerning red tide, such as *Trichodesmium eryhraem* and *Thalassiothrix frauenfeldii,* were dominant. Zooplankton were mainly composed of species belongs to Copepoda Class, such as, *Acartiidae, Paraccalamus, Calanidae* and *Oithonidae.*

There was no remarkable difference of plankton species composition among Zone R, Zone T, Zone K and Zone H. The species of phytoplankton belong to family *Ceratiaceae*, such as, *Ceratium fuses* and *Ceratium tripos*, and *Rhizosolenia eryhraem* were dominant in these area . These species were known as a red tide organism. *Trichodesmium eryhraem*, which dominate in Al-Jubail area, was found at only K6, K8 and H2 with lower density than Al-Jubail area. Zooplankton species composition in these areas was almost same as that of Al-Jubail area.

Table 4.4.11 Results of Plankton Survey (1)

Pytoplankton

Site Code	Class	Order	Family	*Speices*	No. of Individuals (/L)	Frequency
J1	Dinophyceae	Peridiniales	Ceratiaceae	*Ceratium tripos?*	9	+
	Bacillariophyceae	Centrales	Coscinodiscaceae	*Coscinodiscus asteromphalus*	1	+
	Dinophyceae	Peridiniales	Peridiniaceae	*Peridinumu depressum*	1	+
	Bacillariophyceae	Soleniineae	Rhizosoleniaceae	*Rhizonosolenia alata*	5	+
	Bacillariophyceae	Pennales	Fragilariaceae	*Thalassiothrix frauenfeldii*	517	++
	Cyanophceae	Oscillatoriales	Oscillatoriaceae	*Trichodeswmium eryhraem*	1,740	++++
J4	Dinophyceae	Peridiniales	Ceratiaceae	*Ceratium fusus*	11	+
	Dinophyceae	Peridiniales	Ceratiaceae	*Ceratium tripos*	26	+
	Bacillariophyceae	Pennales	Nitzchiaceae	*Nitzcchia sp.*	4	+
	Dinophyceae	Peridiniales	Peridiniaceae	*Peridinum dpressum?*	4	+
	Bacillariophyceae	Pennales	Fragilariaceae	*Thalassiothrix frauenfeldii*	13,156	+++++
	Cyanophceae	Oscillatoriales	Oscillatoriaceae	*Trichodeswmium eryhraem*	9	+
J6	Cyanophceae	Oscillatoriales	Oscillatoriaceae	*Trichodeswmium eryhraem*	77,770	+++++
J7	Dinophyceae	Peridiniales	Ceratiaceae	*Ceratium tripos?*	40	+
	Bacillariophyceae	Biddulphiineae	Chaetoceraceae	*Chaetoceros affinis*	30	+
	Cyanophceae	Oscillatoriales	Oscillatoriaceae	*Trichodeswmium eryhraem*	55,443	+++++
K1	Bacillariophyceae	Pennales	Nitzchiaceae	*Nitzchiaceae sp.*	15	+++++
R1	Dinophyceae	Peridiniales	Ceratiaceae	*Ceratium tripos*	131	++++
	Bacillariophyceae	Biddulphiineae	Chaetoceraceae	*Chaetoceros affinis*	65	++
	Dinophyceae	Peridiniales	Peridiniaceae	*Peridinium depressum?*	7	+
T2	Bacillariophyceae	Centrales	Coscinodiscaceae	*Coscinodisus stellaris*	58	++
	Spirotricha	Titinnida	Ptychocylidae	*Epiplocylis sp.(nauplius)*	46	++
	Bacillariophyceae	Soleniineae	Rhizosoleniaceae	*Rhizosolenia alata*	232	++++
K6	Bacillariophyceae	Pennales	Nitzchiaceae	*Nitzchia sigma*	10	++
	Bacillariophyceae	Soleniineae	Rhizosoleniaceae	*Rhizosolenia alata*	6	++
	Cyanophceae	Oscillatoriales	Oscillatoriaceae	*Trichodeswmium eryhraem*	14	+++
K8	Bacillariophyceae	Pennales	Nitzchiaceae	*Nitzchiaceae sp.*	9	++
	Cyanophceae	Oscillatoriales	Oscillatoriaceae	*Trichodeswmium eryhraem*	21	++++
H1	Bacillariophyceae	Soleniineae	Rhizosoleniaceae	*Rhizonosolenia alata*	23	++
	Cyanophceae	Oscillatoriales	Oscillatoriaceae	*Trichodeswmium eryhraem*	105	++++
H2	Bacillariophyceae	Centrales	Coscinodiscaceae	*Coscinodisus stellaris*	13	+
	Bacillariophyceae	Pennales	Nitzchiaceae	*Nitzchia sigma*	13	+
	Bacillariophyceae	Pennales	Fragilariaceae	*Thalassiothrix frauenfeldii*	39	+++
	Cyanophceae	Oscillatoriales	Oscillatoriaceae	*Trichodeswmium eryhraem*	52	+++

Table 4.4.11 Results of Plankton Survey (2)

Zooplankton

Site Code	Class	Order	Family	*Speices*	No. of Individuals (/L)	Frequency
J1	Copepoda	Calanoida	Acartiidae	*Acartia erythraea*	1	+
	Copepoda	Calanoida	Paracalanus	*Acrocalanus gracilis*	1	+
	Copepoda	Calanoida	Pseudocalanidae	*Clausocalanus furcatus?*	1	+
	Crustacea	Mysidacea	Mysidae	*Neomysis sp.*	1	+
	Copepoda	Cyclopoida	Oithonidae	*Oithona sp.(nauplius)*	1	+
	Copepoda	Cyclopoida	Oithonidae	*Oithona tenuis*	2	+
	Sarcodina	Foraminifera	*Globrigorinidae*	*Orbulina universa*	12	+++
	Sarcodina	Foraminifera	*Globrigorinidae*	*Globrigorinidae sp.*	2	+
	-	-	-	*Fish egg?*	3	+
J4	Copepoda	Calanoida	Acartiidae	*Acartia erythraea*	42	++
	Copepoda	Calanoida	Calanidae	*Caranus minor?*	39	+
	Copepoda	Cyclopoida	Oithonidae	*Oithona sp.(Nauplius).*	25	+
	Copepoda	Cyclopoida	Oithonidae	*Oithona tenuis.*	30	+
	Sarcodina	Foraminifera	*Globrigorinidae*	*Globrigorinidae sp.*	106	+++
	-	-	-	*Fish egg?*	21	+
J6	Copepoda	Calanoida	Calanidae	*Calanus sp.*	15	+
	Copepoda	Cyclopoida	Oithonidae	*Oithona sp. (nauplius)*	54	+++
	Copepoda	Cyclopoida	Oithonidae	*Oithona sp.(nauplius)*	54	+++
J7	Copepoda	Calanoida	Acartiidae	*Acartia erythraea?*	40	++
	Copepoda	Calanoida	Paracalanus	*Acrocalanus gracilis?*	10	+
	Copepoda	Calanoida	Pseudocalanidae	*Clausocalanus arcuicornis?*	30	++
	Copepoda	Cyclopoida	Oithonidae	*Oithona tenuis*	40	++
	Copepoda	Cyclopoida	Oithonidae	*Oithona sp.(nauplius)*	35	++
	Sarcodina	Foraminifera	*Globigerinidae*	*Globigerinidae sp.*	50	++
R1	Copepoda	Calanoida	Acartiidae	*Acartia erythraea*	9	+
	Crustacea	Balanidae	Balanidae	*Balanus sp.(Nauplius)*	9	+
	Copepoda	Calanoida	Calanidae	*Calanus sp.*	254	+++
	Copepoda	Calanoida	Calanidae	*Calanus sp.(Nauplius)*	14	+
	Copepoda	Calanoida	Calocalanidae	*Calocalanus pavo*	42	+
	Copepoda	Cyclopoida	Oithonidae	*Oithona furcatus*	106	++
	-	-	-	*Fish egg?*	21	+
T2	Spirotricha	Tintinnida	Ptychosylidae	*Epiplocylis sp.*	23	+
	Copepoda	Cyclopoida	Oithonidae	*Oithona sp. (nauplius)*	58	++
	Copepoda	Cyclopoida	Oithonidae	*Oithona sp.(nauplius)*	23	+
	Copepoda	Cyclopoida	Oithonidae	*Oithona tenuis*	23	+
	Copepoda	Cyclopoida	Oithonidae	*Oithona tenuis.*	46	++
	Copepoda	Calanoida	Temoridae	*Eurytemora sp.*	46	++
	Copepoda	Calanoida	Temoridae	*Temora sp.*	35	+
K1	Branchiopoda	Ostracoda	Halocypridae	*Archiconchoecia sp.*	15	+
	Copepoda	Calanoida	Calanidae	*Calanus sp. (a)*	31	++
	Copepoda	Calanoida	Calanidae	*Calanus sp. (b)*	38	++
	Copepoda	Cyclopoida	Oithonidae	*Oithona sp. (nauplius)*	23	++
	Malacostraca	Decapoda	Sergestidae	*Sergia sp.(nauplius)*	15	+
	Copepoda	Calanoida	Temoridae	*Temora sp. (nauplius)*	15	+
	Copepoda	Calanoida	Temoridae	*Eurytemora sp.*	15	+
K3	Copepoda	Calanoida	Calanidae	*Calanus sp (a).*	39	+++
	Copepoda	Calanoida	Calanidae	*Calanus sp.(nauplius)*	77	++++
K6	Copepoda	Calanoida	Acartiidae	*Acartia erythraea?*	18	+
	Copepoda	Calanoida	Paracalanus	*Acrocalanus sp.*	10	+
	Copepoda	Calanoida	Augapdastilidae	*Euaugaptilus hecticus*	6	+
	Copepoda	Cyclopoida	Oithonidae	*Oithona sp.(nauplius)*	57	+++
	Copepoda	Cyclopoida	Oithonidae	*Oithona tenuis*	16	+
	Crustacea	Mysidacea	Mysidae	*Neomysis sp.*	4	+
	Annelida	Archiannelida	Sarcocirridae	*Sarcpcorris sp.*	6	+

Table 4.4.11 Results of Plankton Survey (3)

Zooplankton (Continue)

Site Code	Class	Order	Family	*Speices*	No. of Individuals (/L)	Frequency
K7	Crustacea	Balanidae	Balanidae	*Balanus sp.(nauplius)*	11	++
	Copepoda	Calanoida	Calanidae	*Caranus sp.*	26	+++
	Copepoda	Calanoida	Calanidae	*Caranus sp.(nauplius)*	4	+
	Polychaeta	Polychaeta	Sarcocirrus	*Sarcocirrus sp.*	2	+
K8	Copepoda	Calanoida	Acartiidae	*Acartia sp.(nauplius)*	18	+
	Copepoda	Calanoida	Paracalanus	*Acrocalanus sp.*	27	++
	Crustacea	Balanidae	Balanidae	*Balanus sp.(Nauplius)*	12	+
	Sarcodina	Foraminifera	*Globrigorinidae*	*Globrigorinidae sp.*	6	+
	Crustacea	Balanidae	Balanidae	*Balanus sp.(Cypriform larva)*	18	+
	Copepoda	Cyclopoida	Oithonidae	*Oithona tenuis.*	33	++
H1	Heteropoda	Pteropoda	Cavoliniidae	*Limacina inflata?*	23	+++
	Copepoda	Cyclopoida	Oithonidae	*Oithona sp. (Nauplius)*	12	++
	Copepoda	Cyclopoida	Oithonidae	*Oithona tenuis.*	23	+++
H2	Copepoda	Calanoida	Calanidae	*Calunus sp.*	17	++
	Copepoda	Cyclopoida	Oithonidae	*Oithona sp. (Nauplius)*	39	+++
	Copepoda	Cyclopoida	Oithonidae	*Oithona tenuis.*	35	+++

+	appear very rarely	(appearance rate, 10% or less)
++	appear rarely	(appearance rate, 20 to 30%)
+++	appear commonly	(appearance rate, 40 to 60%)
++++	appear frequently	(appearance rate, 70 to 80%)
+++++	appear very frequently	(appearance rate, 90% or more)