FINAL REPORT FOR STUDY ON MEASURES TO PREVENT OIL POLLUTION OF THERMAL ELECTRIC POWER STATIONS AND SEA WATER DESALINATION PLANTS IN UMM AL NAR, ABU DHABI THE UNITED ARAB EMIRATES

SUMMARY

OCTOBER 1989

JAPAN INTERNATIONAL COOPERATION AGENCY

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FOR
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Chapter 1 Introduction

1.1 Background of Study

All city water in Abu Dahbi, the capital of the United Arab Emirates, is supplied from the sea water desalination plants, and a part of the desalinated water is supplied to Al Ain through pipeline. Also, a large quantity of sea water is used as cooling water in the power plants.

In recent years, anxiety about pollution of sea water by effluent oil from tankers, oil wells and oil refineries is becoming more serious and, an urgent establishment of measures to prevent oil pollution of these plants has become an important matter.

If the present condition is left as it is, not only the decrease in production capacity of desalination plants due to fouling of equipment but also contamination of product water itself which leads to possible complete stop of city water supply will be caused.

Further, it will lead to possible decrease in power generating efficiency in the power plants. It is necessary, therefore, to establish effective measures to prevent such damages by oil for securing the stable power supply.

Under the circumstances, the Government of the United Arab Emirates has requested Japanese government in March 1987 to conduct the "Study on Measures to Prevent Oil Pollution of Thermal Electric Power Stations and Sea Water Desalination Plants". Japanese government has accepted the request and Japan International Cooperation Agency made a contract with Water Re-Use Promotion Center (WRPC). The study has been initiated in March, 1988 and completed in October, 1989.

1.2 Purpose of Study

The purpose of this study is to examine the influence of oil pollution of sea water and the necessary measures against oil pollution at the Umm Al Nar Thermal Power Station and Desalination Plant of the Water and Electricity Department, Abu Dhabi Emirate, United Arab Emirates.

This study covered No. 1 water intake system and the relevant facilities at the Umm Al Nar Power and Desalination Plant as well as the surrounding sea water area.

1.3 Contents and Implementation of Study

To implement this study, a study team has been organized mainly with the specialists from the WRPC as shown in Table 1.3.1, and the study was conducted by specialists in their respective field of expertise. List of the counterpart members is as shown in Table 1.3.2.

The procedures used in conducting the study are shown in Fig. 1.3.1.

Table 1.3.1: List of Japanese Study Team Members and Their Assignments

Name	Function	Assignment
Yoshio Murayama	Team Leader	Overall management Field work & home office work
Kunio Kikuchi	Deputy Leader	Control of technical works Home office work
Toshikazu Ishii	Engineer	Study on countermeasure of oil pollution Field work & home lofficе work
Yuzuru Naito	Engineer	Study on countermeasure of oil pollution Field work & home office work
Keiichi Ohta	Engineer	Study on water quality Home office work
Masaji Kanayama	Engineer	Study on desalination plant Home office work
Shizuo Hashimoto	Engineer	Study on oceanography Home office work
Masaru Sakai	Engineer	Study on oceanography Home office work
Isamu Kondou	Engineer	Study on Hydrology Home office work
Shigeru Suizu	Engineer	Study on Hydrology Field work & home office work
Hiroshi Kuboki	Engineer	Study on oceanography Field work & home office work
Akira Watanabe	Engineer	Study on oceanography Field work & home office work
Hisayoshi Taira	Engineer	Study on oceanography Field work
Shingo Itonaga	Engineer	Study on oceanography Field work
Shin-ichiro Nagai	Engineer	Study on oceanography Field work
Masafumi Okudaira	Engineer	Study on oceanography Field work

Table 1.5.1: Continued

Name	Function	Assignment
Hiroji Takahashi	Engineer	Study on monitoring system Home office work
Kenshiro Matsuzaki	Engineer	Study on monitoring system Field work & home office work
Tooru Nakao	Engineer	Study on monitoring system Home office work
Masanori Higashino	Engineer	Study on monitoring system Home office work
Noboru Kioka	Engineer	Study on power plant Field work & home office work

Table 1.3.2: List of Counterpart Members

Name	Function
Dr. A. M. Shams El Din Director Material Testing Laboratory	Team Leader
Mr. I. Money General Superintendent Umm Al Nar Station	Plant Engineer
Dr. Rasheed A. Arain	Plant Engineer
Mr. Samih Ammari	Plant Engineer
Mr. A. H. Hammoud	Plant Engineer
Mr. Showky Aziz	Plant Engineer
Mr. McGreger	Plant Engineer
Mr. Rizk A. Mohammed	Oceanographic Engineer
Mr. Tag El Din	Oceanographic Engineer
Dr. W. Falldorf	Oceanographic Engineer
Dr. R. Wundes	Oceanographic Engineer
Dr. R. Walker	Oceanographic Engineer

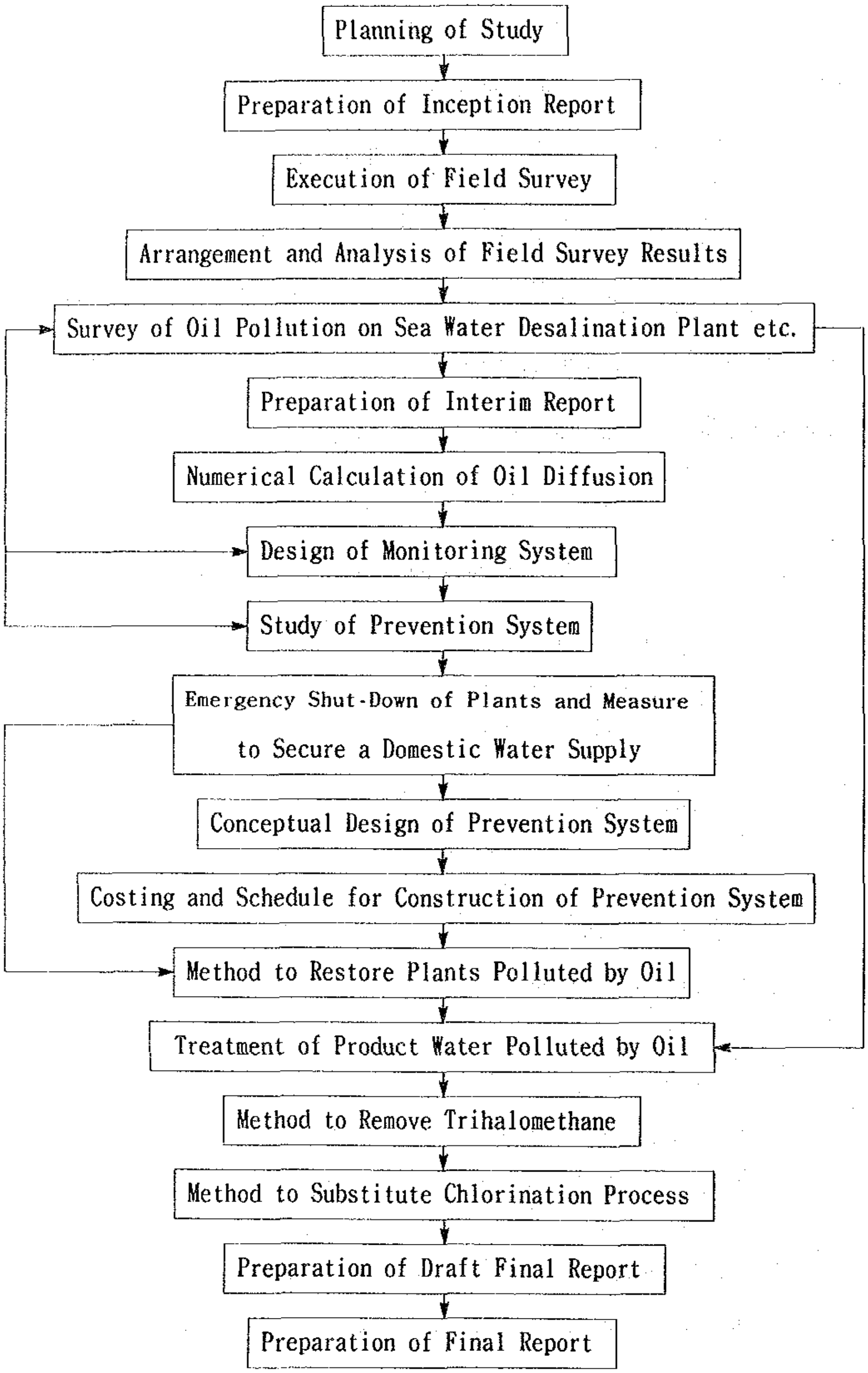


Fig. 1.3.1: Principal Procedures of Study

1.3.1 Marine Field Survey

Distribution characteristics of tidal current and others were investigated, and the collection of the basic date required for numerical calculation concerning distribution of oil diffusion and the grasp of present conditions of marine environment were conducted.

1.3.2 Study on Influence of Oil Pollution in Power and Desalination Plant

The influence on the plant caused by the oil pollution was investigated when oil, which was spilled out into the sea, flowed into the Plant.

1.3.3 Preventive Measures against Oil Pollution and their Evaluation

Based on the marine field survey, the numerical calculation of distribution of oil diffusion was carried out and, on the basis of this result, monitoring system and oil pollution preventive system against spilled oil were planned.

1.3.4 Countermeasures against Oil Contamination

Assuming that oil contamination cannot be preventive, the treating method of oil contaminated product and the re-starting method of the oil contaminated plant were studied.

Chapter 2 Present Status of Subject Plants and Environmental Conditions (Fundamental Principles and Condition for this Study)

Before carrying out the study, the premise such as the present status of power and desalination plant as well as the natural environment, etc. to be investigated was clarified.

2.1 Power and Desalination Plant

Umm Al Nar Power and Desalination Station comprises 10 units of thermal power plant, 4 units of gas turbine power plant and 16 units of multi-stage flash (MSF) type desalination plants, with total electric power generation capacity of 1,080 MW and desalination capacity of 77 MIGPD or 350,000 m3/d.

Heat source (steam) for desalination plants is supplied from the respective power plants. The plant is designed to be dual purpose plant taking into consideration the overall thermal efficiency.

The layout of the whole plant is shown in Fig. 2.1.1.

This study covers West No. 1 through No. 6 power and desalination plants and East No. 1 through No. 3 desalination plants which are supplied with sea water from No. 1 sea water intake system. These facilities are enclosed with line as shown in Fig. 2.1.1. Table 2.1.1 shows the outline of the plants covered by this study.

Table. 2.1.1 Outline of Umm AL Nar Power and Desalination Plants

Power Plant	West No.1 - No.6	East
Turbine Generator		
Manufacturer	SKODA (Chech.)	
Rated Output (kW)	60,000	
Units	6	
Boiler		
Manufacturer	Deutsche Babcock	
Type	Single Drum Radiant Natural Circulating	
Steam Pressure (Design)	86.4 bar	
Steam Production (Max.)	365 t/h	
Desalination Plant	West No.1 - No.6	East No.1 - No.3
Manufacturer	IHI (Japan)	SIDEM (France)
Number of Units	6	3
Capacity (MIGPD)	4	5
Type	MSF Cross Tube	MSF Cross Tube
Number of Stages	18	15
TDS of Product Water (ppm)	25	25
Max. Brine Temperature (°C)	90	90
GOR*	6	6

Remarks: * = Production/Steam Consumption

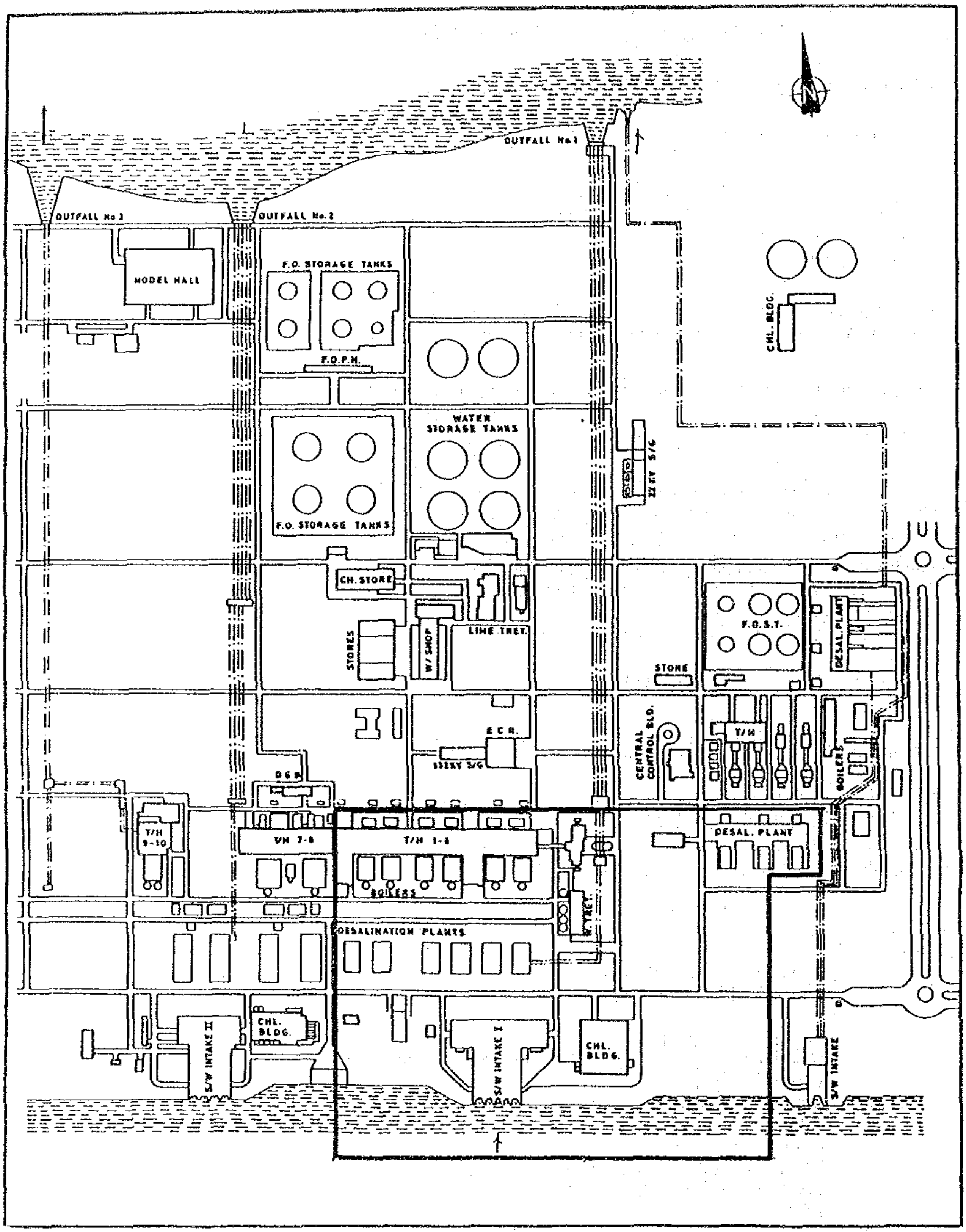


Fig. 2.1.1: General Arrangement of Umm Al Nar Power and Desalination Plants

2.2 Ancillary Equipment

The sea water used in the Umm Al Nar Plant is taken from the south seashore of the station and discharged to the north seashore. No. 1 sea water intake system covered by this study intakes approximately 220,000 m3/h of sea water.

This system is of submerged intake type made of concrete, with 5 intake gates and equipped with screen for preventing intrusion of foreign matters, sedimentation tank for sand and mud, chlorine gas injection device for prevention of fouling by marine organisms, etc. Air bubble system, oil fences and monitoring system using water surface conductivity sensors for prevention of oil pollution are also equipped.

2.3 Natural Environment

The United Arab Emirates is located on the west coast of Arabian Gulf in the desert hot weather zone where it is of high temperature and high humidity. The highest temperature reaches 45 °C and above in summer (April through October) while in winter (November through March), the climate is comparatively moderate at about 20 °C on the average.

In this region, it rains somewhat during January through March in winter, but it never rains in summer. Total amount of precipitation throughout the year is roughly 50 mm although it fluctuates drastically every year.

Abu Dhabi City is located in the Abu Dhabi Island facing Arabian Gulf and surrounded by tangled shallow lagoon. The Umm Al Nar Station is situated at the innermost location of the lagoon and facing the Abu Dhabi Island. Topographic map is shown in Fig. 2.3.1.

Sea water inside the lagoon is connected to the open sea mainly through narrow channels of south and north of the Abu Dhabi Island. Tidal current at these channels is rather high reaching 70 cm/s in some cases.

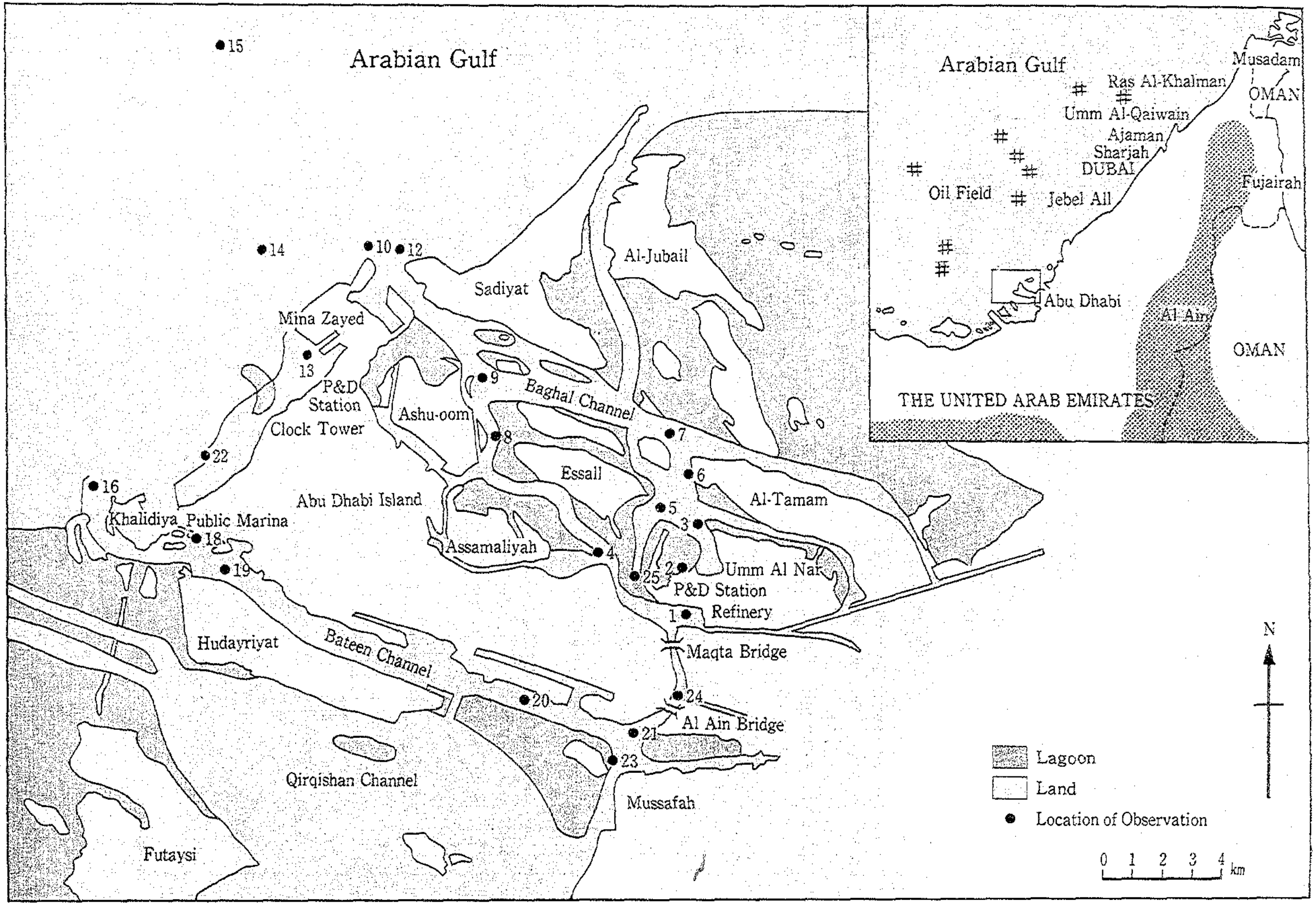


Fig. 2.3.1: Topographic Map of Abu Dhabi Island

Chapter 3 Marine Field Survey

3.1 Outline of Survey

3.1.1 Purpose of Survey

In order to predict and reduce the influence of oil pollution on the Umm Al Nar power and desalination plant, it is essential to install monitoring system and preventive system against oil pollution.

In this connection, characteristics of the surrounding sea area of the Abu Dhabi Island and the station should be clarified in order to plan such systems. Consequently, the marine field survey of the ocean conditions in such area was conducted concerning the following items:

(1) Collection of the necessary information required for the numerical calculation concerning oil diffusion in the surrounding area of the Abu Dhabi Island

(2) Clarification of the surrounding hydrographical conditions of the station required for planning oil pollution preventive system

(3) Clarification of the present conditions of the oil pollution in the vicinity of the station

(4) Clarification of environmental characteristics in the surrounding area of the Abu Dhabi Island which is required in planning the appropriate method of periodical environmental survey to monitor the oil pollution

Procedures for data analysis and numerical calculation are shown in Fig. 3.1.1.

3.1.2 Contents of Survey

The marine field survey is roughly divided into two categories i.e., survey on hydrographical conditions and survey on environmental conditions.

(1) Survey on Hydrographical Conditions

Water current conditions including tidal current and elevation of tide, etc. are determined by interactions of such factors as the gravitation of the moon and the sun, rotation and revolution of the earth and such natural conditions as physiographic features of the specific sea under survey and climate, etc.

In making predictions of water current conditions for the purpose of the above 3.1.1 (1) and (2), it is required to analyze how each factor interacts. For such purpose, the necessary data were obtained by various measurements as follows:

1) Tidal current

* Fixed point observation for a period of one month in summer and winter

* Observation by the current drag in the channels

* Observation of vertical distribution

2) Tidal elevation

* Continuous fixed point observation for a period of one month in summer and winter

3) Water temperature

* Continuous fixed point observation for a period of one month in summer and winter
* Vertical distribution at representative points in summer and winter

4) Salinity

* Continuous fixed point observation for a period of one month in summer and winter
* Vertical distribution at representative points in summer and winter

(2) Survey on Environmental Conditions

The following survey was conducted in order to clarify the present conditions of the oil pollution and to determine a method for the periodical survey.

1) Water quality at representative points in summer and winter

2) Bottom sediment at representative points in summer and winter

3) Planktons, benthos and coastal organisms at typical points in summer and winter.

3.1.3 Survey Schedule

The marine field survey was conducted in accordance with the following schedule:

1) The First Field Survey (Preliminary survey): March 20, 1988

2) The Second Field Survey (Summer season survey): September through November 1988

3) The Third Field Survey (Winter season survey): January through March 1989

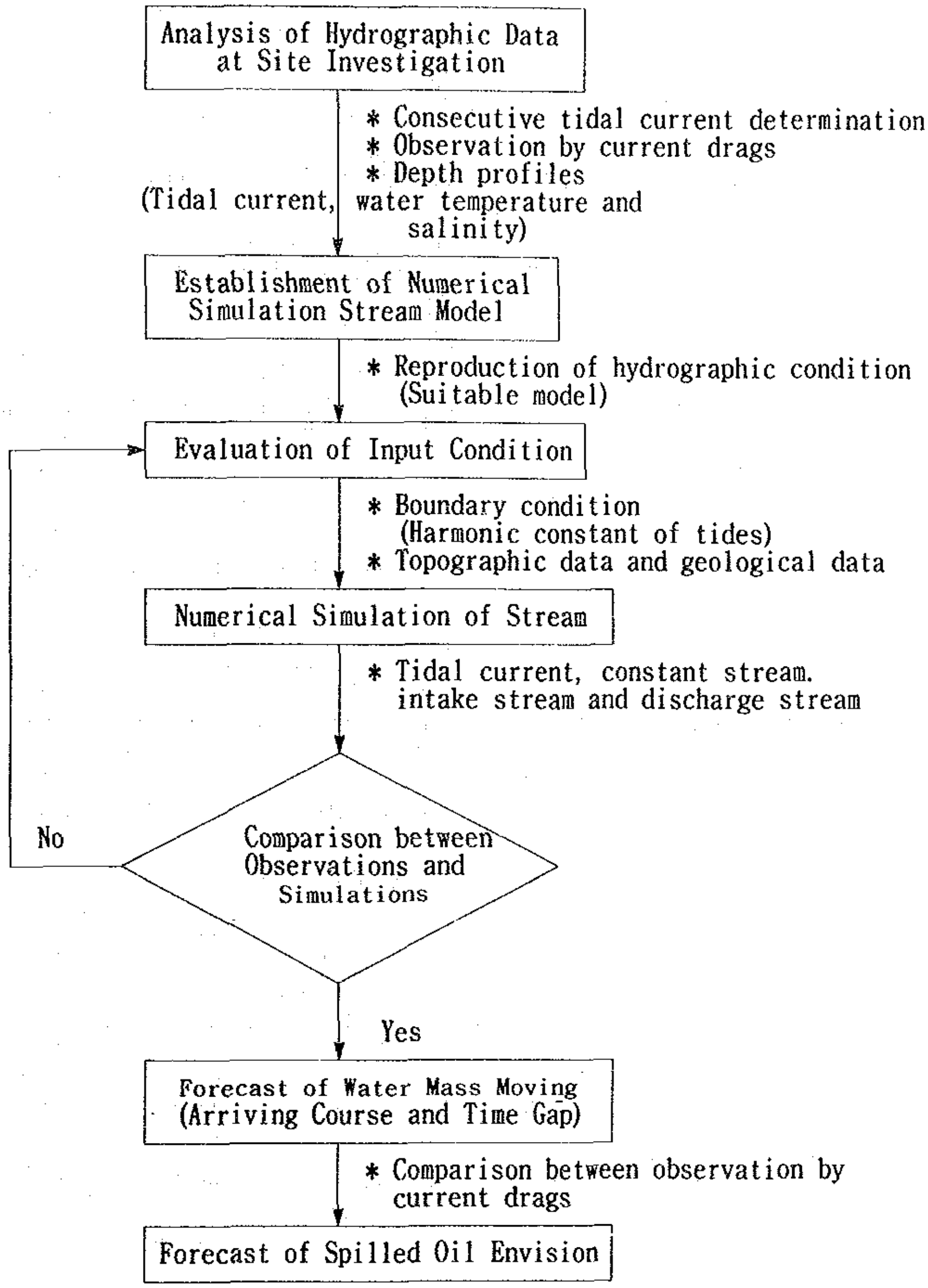


Fig. 3.1.1: Flow Chart of Numerical Calculation

3.2 Tidal Currents

The sea area around the Abu Dhabi Island was classified as a strong current zone in Baghal Channel and Bateen Channel, moderate current zone offshore the Abu Dhabi Island, and a light current zone in Umm Al Nar South Basin. Because of the physiographical factors that Baghal Channel and Bateen Channel have the features of shallow water depth and narrow channel width, the tidal current velocity in the both channels was very high at 90 to 100 cm/s during the strongest current time, and tidal current direction was parallel to each channel.

In the offshore area of the Abu Dhabi Island, there was no dominant direction. However, 10 to 20 cm/s tidal currents were observed and their direction were roughly NE-ward or SW-ward flowing back and forth in parallel to the coastal line.

In Umm Al Nar Station South Basin, the current speed was low at 0 to 10 cm/s and there was no direction in the tidal currents.

In order to determine a prediction model of water current conditions, a harmonic analysis was conducted. And, types of tidal currents (Note 2) were determined after obtaining disharmonic constants for major four (4) tidal components (Note 1).

Table 3.2.1: Disharmonic Constants Table of Tidal Currents in Second Field Survey (Oct. to Nov. 1988)

Site	Disharmonic Constants		F Value
	$M_2 + S_2$ (cm/s)	$K_1 + O_1$ (cm/s)	
1	4.7	4.0	0.85
7	33.1	25.8	0.78
9	50.5	41.1	0.81
15	11.9	18.8	1.58
19	45.7	43.5	0.95
20	45.0	30.1	0.67
21	17.2	13.9	0.81
23	52.8	44.7	0.85

Remarks:

$M_2 + S_2$: Semi-diurnal componebt current sum
$K_1 + O_1$: Diurnal component sum
F Value: $(K_1 + O_1)/(M_2 + S_2)$
Classification function of tidal types

Note 1: Major 4 tidal Components

M_2: Main lunar semi-diurnal tide
S_2: Main solar semi-diurnal tide
K_1: Solar and lunar composite diurnal tide
O_1: Main lunar diurnal tide

Note 2: Classification of tidal types (Judged values)

Semi-diurnal type:	$F < 0.25$
Mixed type:	$0.25 < F < 1.25$
Diurnal type:	$F > 1.25$

Types of tidal currents were judged as the mixed type at all points, except offshore Site 15 where the diurnal type was observed in summer season.

Table 3.2.1 shows judged values (F) for tidal currents at the second field survey.

According to the prediction of flow velocity for the maximum spring period as shown in Fig. 3.2.1, the time of the strongest ebb current which streams offshore, was 5 to 7 hours after high high water level at Mina Zayed. Current velocity becomes small as it approaches the interior of the lagoon.

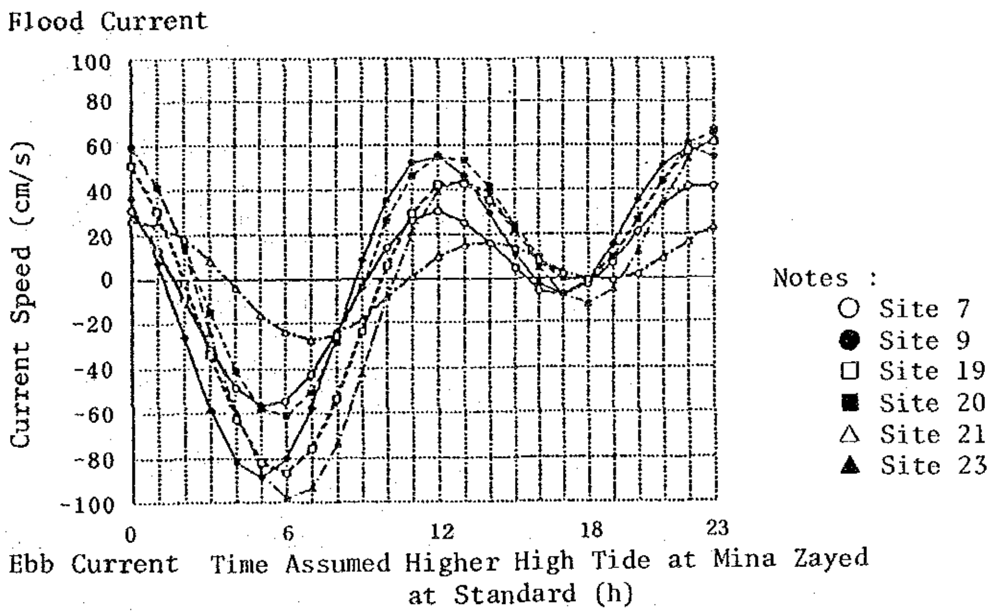


Fig. 3.2.1: Predicted Flow Velocity in Channels in Maximum Spring Tide Period in Second Field Survey (October to November 1988)

3.3 Tidal Elevation

As shown in Fig. 3.3.1, the variation of tidal elevation showed principally the semi-diurnal periodicity, but also the apparent diurnal periodicity was recorded, as shown in Fig. 3.3.2 in neap tide period.

According to the harmonic analysis results, 4 principal component tides of M_2, S_2, K_1 and O_1 occupied the larger part of all amplitudes at all the sites and the sum of 4 principal component tides was about 100 cm. The tidal types (Note 3) were the mixed type (Site 1) and the diurnal type (Site 10 and Site 18).

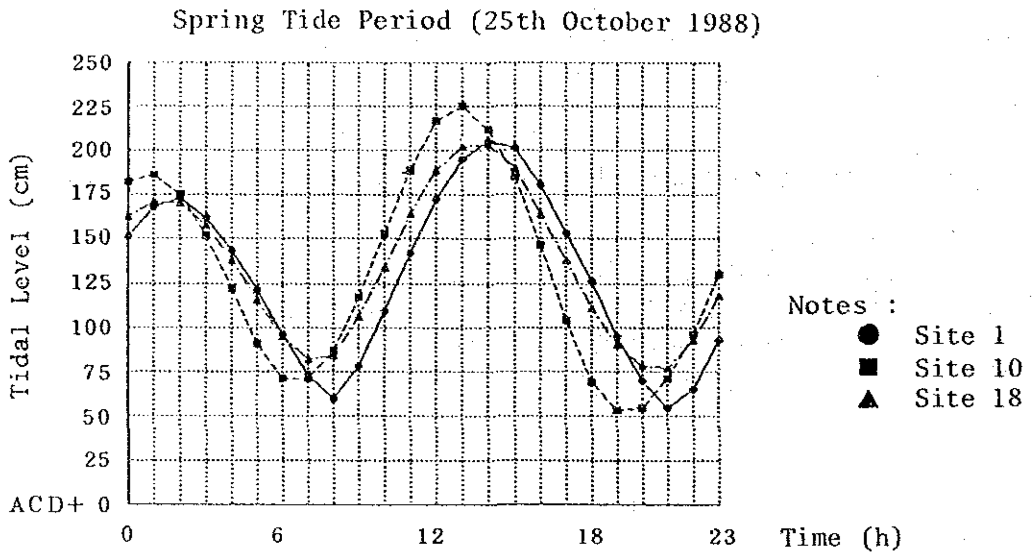


Fig. 3.3.1: Typical Tidal Level in Spring Tide Period

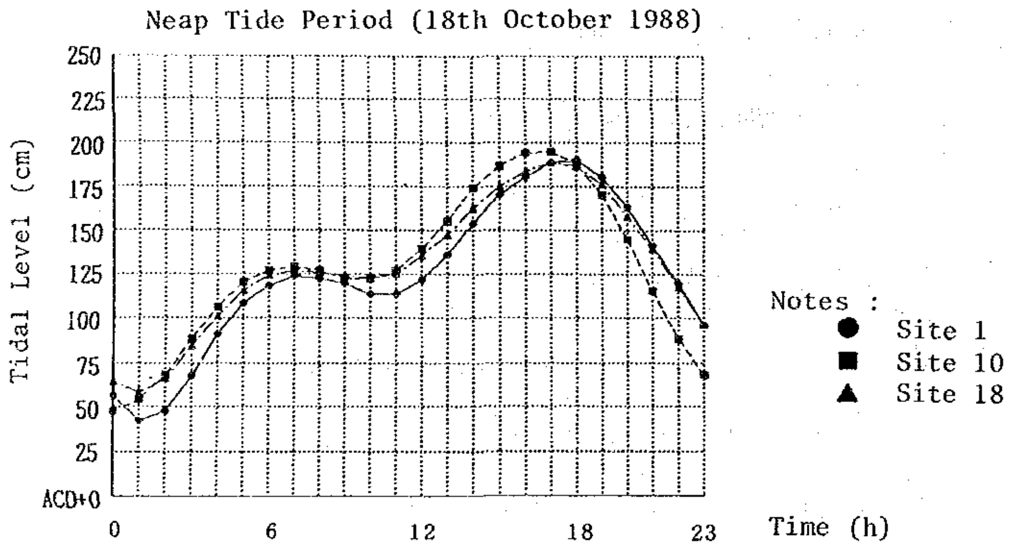


Fig. 3.3.2: Typical Tidal Level in Neap Tide Period

Table 3.3.1 shows values of classification function of tidal types.

Table 3.3.1: Disharmonic Constant and F Value of Tide

Site	Disharmonic Constants		F Value
	$M_2 + S_2$ (cm/s)	$K_1 + O_1$ (cm/s)	
1-1	53.4	60.0	1.12
1-2	55.0	58.3	1.06
10	45.7	60.2	1.32
18	43.0	55.8	1.30

Remarks:

$M_2 + S_2$: Semi-diurnal componebt current sum
$K_1 + O_1$: Diurnal component sum
F Value: $(K_1 + O_1)/(M_2 + S_2)$
Classification function of tidal types

Note 3: Type of tide

Semi-diurnal type: $F < 0.25$
Mixed type: $0.25 < F < 1.25$
Diurnal type: $F > 1.25$

3.4 Water Temperature

Observation results of water temperature at the typical points, based on continuous observations for a long period in summer and winter seasons, are shown in Tables 3.4.1 and 3.4.2. During the observation period, the water temperature recorded the highest of 34.1 °C in October and the lowest of 16.9 °C in January. The water temperature tends to rise from mid-February.

Cyclical change of water temperature was observed at each of measuring site at interval ranging approximately one full day to half day, as shown in Fig. 3.4.1. Near the Umm Al Nar Station (Site 1), the highest temperature was observed. Results of observations of vertical distribution of the water temperature is generally low between surface and bottom levels.

It is assumed that formation of thermocline is disturbed because water depth is shallow and flow speed is high.

The vertical range of water temperature was generally small. That is to say, the formation of thermocline might be very difficult in the sea area around the Abu Dhabi Island due both to the shallow water depth and to the relatively high current speed.

Table 3.4.1: Water Temperature at Each Site in Second Field Survey

Site	Max. (°C)	Min. (°C)	Ave. (°C)	Duration of Observation
1	34.1	29.3	31.1	Oct. 1 to Oct. 30, 1988
7	32.0	29.2	30.4	Oct. 16 to Oct. 30, 1988
9	32.9	29.8	30.7	Oct. 1 to Oct. 30, 1988
15	31.8	29.2	30.4	Oct. 9 to Nov 7, 1988
19	32.9	29.5	30.4	Oct. 1 to Oct. 30, 1988
20	32.6	27.6	30.3	Sept. 30 to Oct. 14, 1988
21	33.6	28.2	30.3	Sept. 30 to Oct. 14, 1988
23	30.8	28.5	29.6	Oct. 16 to Oct. 30, 1988

Table 3.4.2: Water Temperature at Each Site in Third Field Survey

Site	Max. (°C)	Min. (°C)	Ave. (°C)	Duration of Observation
1	23.6	17.7	19.6	Jan. 1 to Feb. 23, 1989
7	20.1	17.5	18.7	Jan. 25 to Feb. 8, 1989
9	22.4	17.8	19.7	Jan. 25 to Feb. 23, 1989
15	20.5	17.7	18.8	Jan. 29 to Feb. 27, 1989
19	20.8	17.6	18.7	Jan. 25 to Feb. 23, 1989
20	22.3	18.1	20.1	Feb. 11 to Feb. 26, 1989
21	22.8	18.3	20.1	Feb. 11 tl Feb. 26, 1989
23	22.6	16.9	19.4	Jan. 25 tp Feb. 23, 1989

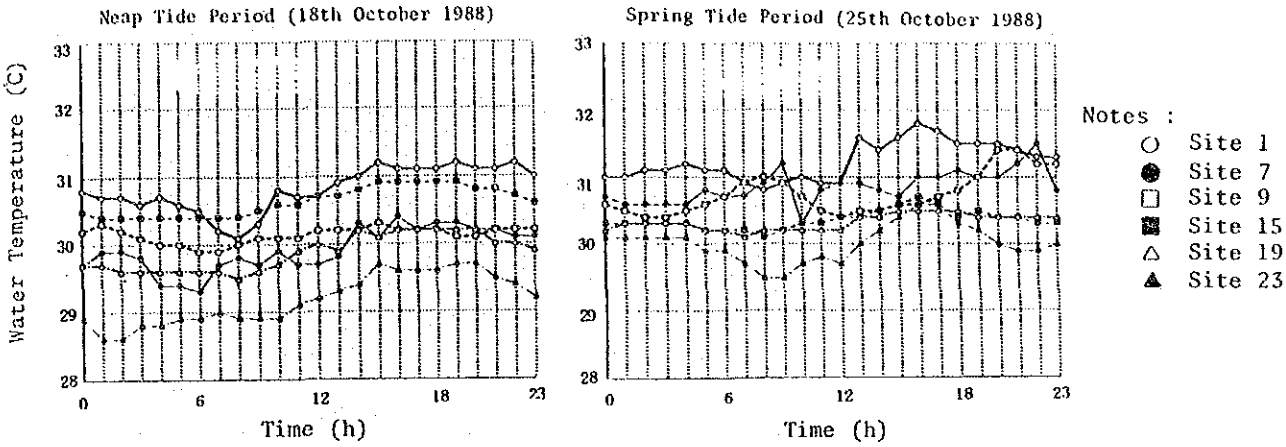


Fig. 3.4.1: Typical Daily Profile of Sea Water Temperature

3.5 Salinity

The salinity of the sea water is measured in accordance with practical salinity as defined by UNESCO in 1978. This salinity is determined by the electric conductivity ratio and is expressed nondimensionally.

The salinity was in the range of 41.42 to 47.22 in the summer, or in the range of 41.38 to 47.21 in the winter survey respectively, and all the observations had a higher salinity reading than 40 as shown in Tables 3.5.1 and 3.5.2.

The horizontal distribution of salinity showed a tendency that it was low offshore and high interior of the lagoon as seen in Fig. 3.5.1. The variations of salinity in the channels were diurnal or semi-diurnal, and ranged from 1 to 3.

According to the observation of vertical distribution of salinity, the vertical difference of salinity was small in both summer and winter for all the sites. However, higher temperature and salinity were observed in the lower layer during the ebb tide period at the site of brine discharge of Umm Al Nar Plant. This might be caused by discharged brine.

Table 3.5.1: Salinity at Each Site in Second Field Survey

Site	Max. (-)	Min. (-)	Ave. (-)	Duration of Observation
1	47.22	45.13	46.29	Oct. 1 to Oct. 30, 1988
7	46.50	41.91	44.43	Oct. 16 to Oct. 30, 1988
9	45.52	41.47	43.14	Oct. 1 to Oct. 30, 1988
15	42.51	41.42	42.02	Oct. 9 to Nov 7, 1988
19	44.84	42.09	43.28	Oct. 1 to Oct. 30, 1988
20	45.77	43.45	44.73	Sept. 30 to Oct. 14, 1988
21	46.37	45.00	45.71	Sept. 30 to Oct. 14, 1988
23	46.20	44.52	45.33	Oct. 16 to Oct. 30, 1988

Table 3.5.2: Salinity at Each Site in Third Field Survey

Site	Max. (-)	Min. (-)	Ave. (-)	Duration of Observation
1	47.21	45.82	46.37	Jan. 25 to Feb. 23, 1989
7	46.68	43.85	45.58	Jan. 25 to Feb. 8, 1989
9	46.72	42.87	44.85	Jan. 25 to Feb. 23, 1989
15	43.44	41.38	42.62	Jan. 29 to Feb. 27, 1989
19	45.64	43.20	44.03	Jan. 25 to Feb. 23, 1989
20	46.23	44.20	45.34	Feb. 11 to Feb. 26, 1989
21	46.63	45.41	46.06	Feb. 11 tl Feb. 26, 1989
23	47.13	44.78	45.82	Jan. 25 tp Feb. 23, 1989

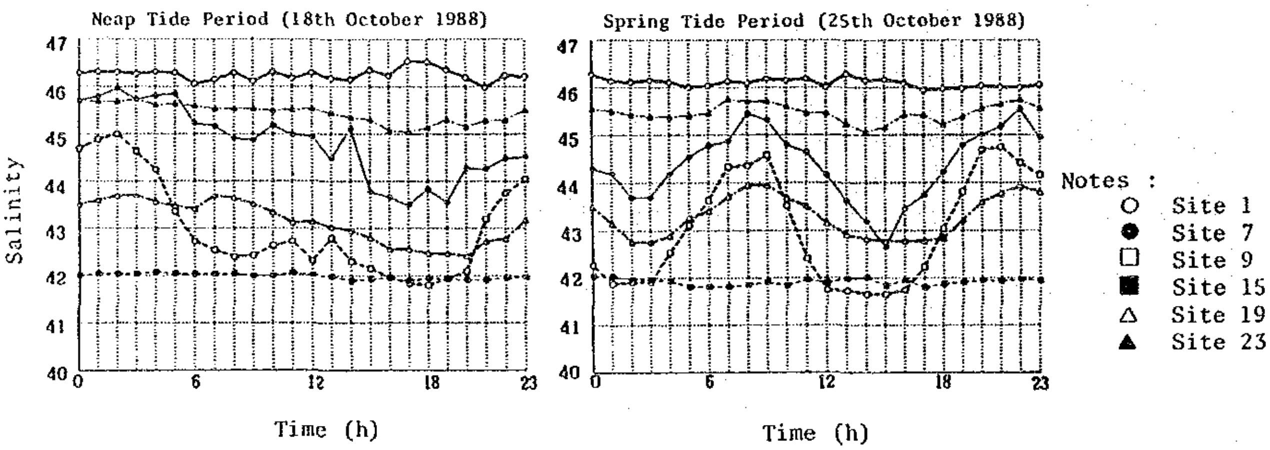


Fig. 3.5.1: Typical Daily Profiles of Salinity at Each Site

3.6 Water Quality

Around the Umm Al Nar Station, a high distribution of water temperature, salinity, turbidity and total organic carbon (TOC) was observed. This phenomenon might be caused by the fact that the sea water near Umm Al Nar Station cannot be easily replaced with the sea water from the open sea.

According to the principal analysis results of water quality, the marine area around Abu Dhabi Island can be classified into the three marine areas as shown in Table 3.6.1 and Fig. 3.6.1.

Table 3.6.1: Classification of Water Mass around Abu Dhabi Island According to Principal Component Analysis

Water Mass	Site	Characteristics
A	1-A 1-B 2	There is this type of water mass around sea water intake and brine discharge facilities of Umm Al Nar Station. Characteristics of water mass are high water temperature and salinity in particular, low transparency and relatively high turbidity and TOC.
B	3 7 20	There is this type of water mass in the interior of both Baghal Channel and Bateen Channel around the Abu Dhabi Island. Characteristics of water mass are not so apparent as A water mass, but are high salinity, turbidity and TOC and low transparency.
C	9, 12 13, 15 16, 19	There is this type of water mass near the inlet of Baghal Channel and Bateen Channel and off-shore area of the Abu Dhabi Island. Characteristics of the water mass are high transparency and low salinity, turbidity and TOC.

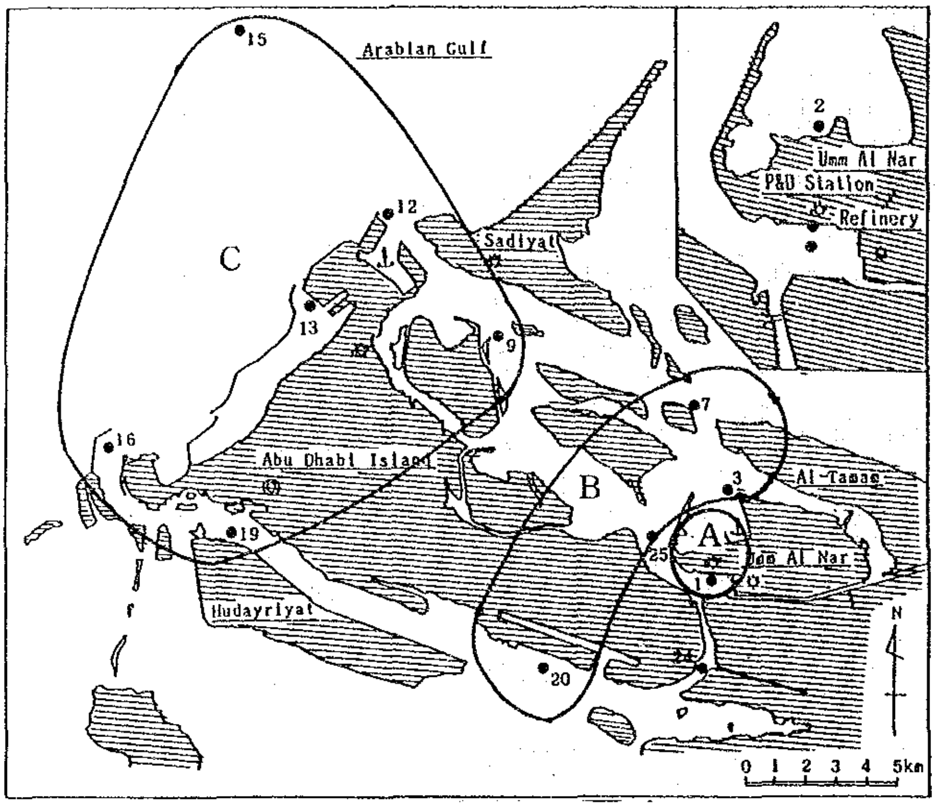


Fig. 3.6.1: Classification of Water Mass around Abu Dhabi Island According to Principal Component Analysis

3.7 Bottom Sediment

At the sites near the Umm Al Nar Plant intakes, the ratio of bottom sediments below the silty portion was large and the particle size distribution was fine. But in the offshore area of the Abu Dhabi Island and in entrance area of the channels, the bottom sediments contained many gravels and its distribution was coarse.

Sediment size at the edge of Baghal Channel and Bateen Channel was smaller than that at the center of channels.

The correlation coefficient between mercury, lead, copper, zinc or TOC, and the ratio below of very fine sand was 0.6 or more, showing a tendency for these contents to increase as the particle size distribution becomes finer.

The level of heavy metals and organic matter contents in the bottom sediments around Abu Dhabi Island was not much different from those normally found in rocks and soils. It can be considered that no remarkable marine pollution is caused by heavy metals and organic matter.

Observation at Site 13 and Site 14 have indicated respective oil content of 81 ppm and 83 ppm which are comparatively higher than other sites. However, no specific reason was found in this study.

3.8 Marine Organisms

3.8.1 Phytoplankton (Water Sampling Method)

Both the second field survey in summer and the third field survey in winter revealed greater numbers of occurrence kinds of Bacillariophyceae and Dinophyceaeas compared with other algae. Also, the number of occurrence kinds at all the sites was a little greater in summer.

The average number of occurrence cells, horizontally considered, was smaller around Umm Al Nar Station and larger in the offshore area of the Abu Dhabi Island.

The occurrence conditions of dominant kinds differed among the sites and between the tides. But, *Leptocylindrus danicus* was predominant in summer and Haptophyceae in winter.

Number of kinds indicating marine pollution was a little.

3.8.2 Zooplankton (Water Sampling Method)

Both in summer and in winter, the number of occurrence kinds of Ciliata and Copepoda were predominant. The occurrence conditions of dominant kinds differed according to the seasons. Naupius larvae of Copepoda were predominant in summer and Oligotrichida prevailed in winter.

Number of kinds indicating marine pollution was a little.

3.8.3 Zooplankton (Net Method)

In summer and in winter as well, the number of occurrence kinds of Copepodite of *Oithona* genus were predominant, and seasonal variation was not found in the number of occurrence kinds. Nauplius larvae of Copepodite were predominant in summer and winter.

Number of kinds indicating marine pollution was a little.

Copepodite and Appendiculata are considered effective as an index of marine pollution.

3.8.4 Benthos

Both the second field survey in summer and the third field survey in winter revealed a greater number of occurrence kinds of Annelida, Mollusca and Arthropoda. As for the main kinds near the Umm Al Nar Plant intakes, *Ophelina* sp. of Polychaeta, Apseudes family of Tanaidacea and *Grandidierella* sp. of Amphipoda were dominant in summer and winter. But, these kinds were scarcely observed at the other sites.

Polychaeta and Amphipoda are considered effective as an indicator of marine pollution.

3.8.5 Coastal Organisms

The basic distribution pattern through all the sites consisted of Littornidae, Chthamalus sp. and Isognomon sp. in the upper part of the tidal zone, and Balanus amphitrite, Pomatoleios kraussii and Siphonaria in the lower part of the tidal zone.

Number of kinds indicating marine pollution was a little.

3.9 Summary

3.9.1 Hydrographical Conditions

The Abu Dhabi Island faces the Arabian Gulf by the north coastal region and the other 3 directions are surrounded by the lagoon. Channels in the lagoon are shallow and narrow.

Due to such physiographic features and comparatively large variation of tidal level (maximum 2 m throughout the year), flow velocity in the waterway is very fast with return flow.

It is also noted that there is a time lag in variation of tidal current and height of tide between entrance and innermost portion of the lagoon and as a result, exchange of sea water between the open sea and the inner portion of the lagoon is not done well causing distribution of sea water with high temperature and high salinity in the vicinity of the Umm Al Nar Station which is considered to be affected by used sea water discharged from the Plant.

Results of the harmonic analysis show that major 4 tidal components are dominant.

Types of tidal currents are found to be diurnal tide offshore Abu Dhabi Island and mixed tide in the lagoon.

As a result of this survey, the water current conditions in the surrounding area of the Abu Dhabi Island and the Umm Al Nar Station are clarified and sufficient data were collected to enable numerical calculation relevant to the oil diffusion.

3.9.2 Survey on Marine Environment

As a result of this survey, present conditions of the marine environment in the surrounding area of the Abu Dhabi Island are revealed.

It was found that none of water quality, bottom sediment, planktons, benthos and coastal organisms show distinct indications of pollution.

Recommended items of survey on the marine environment in the future are shown in Table 3.9.1.

Table 3.9.1: Recommended Items of Survey on Marine Environment

Items	Water Quality	Bottom Sediment	Zooplankton (Net Method)	Benthos	Coastal Organism
Site No.					
1	○	○	○	○	○
9	○	○	○	○	–
13	○	○	○	○	○
15	○	○	○	○	–
19	○	○	○	○	–
23	○	○	–	○	–
25	○	○	–	○	–
Observation Layer	* 0.5 m below sea surface * 1.0 m above sea bottom	* Surface of sea bottom	* From 1 m above sea bottom to sea surface	* Surface of sea bottom	
Frequency	* Low tide period & high tide period * Every 3 months	* Summer period & winter period	* Low tide period & high tide period * Every 3 months	* Every 3 months	* Every 3 months
Observation Items	* Water temp. * Salinity * pH * Dissolved oxygen * Turbidity * TOC * Ammonic nitrogen * Oil content	* Particle size distribution * Specific gravity * TOC * Oil content * Mercury * Copper * Lead * Zinc	* Identification & calculation of Copepoda	* Identification & calculation of Polychaeta & Amphipoda	* Identification & calculation of kinds

Chapter 4 Influence of Oil-Contamination Sea Water and Desalination Plants

4.1 Properties of Effluent Oil which has Influence on Power and Desalination Plants

When crude oil is spilled into sea, low molecular components of oil evaporate at the beginning and a small amount of the components dissolved in sea water. After light components have been evaporated, the condensed oil been evaporated is tossed about by waves and allows the water to mix into, and a part of the oil forms water-in-oil emulsion and a part of the oil forms oil-in-water emulsion and both emulsions will disperse into sea water.

And a part of the heavy oil component forms oil balls and then whirls up to sea surface. A part of the heavy oil component, adhered sands and other solid particles, forms sludge and then goes down to the bottom.

Fig. 4.1.1 shows a general concept of process of natural change of spilled oil.

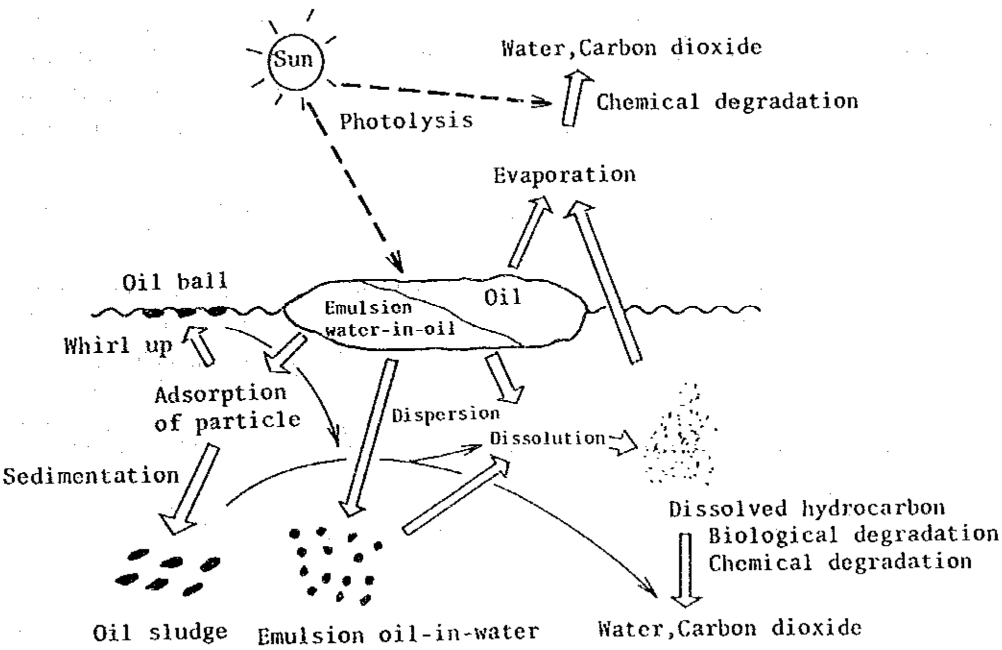


Fig. 4.1.1: Natural Changes of Spilled Oil

In the process, effluent oils oxidized and decomposed by oxygen in air or in sea water, and photochemical reaction by solar radiation promotes the oxidation. On the other hand, the oil dispersed to particles is digested and decomposed by bacteria in sea water to carbon dioxide and water.

According to a report, the following change is made in physical and chemical properties of effluent oil with the passage of time. The most outstanding change in physical properties is an increase of water content.

That is, the oil includes sea water drops and forms water-in-oil emulsion of high viscosity, and with the increase in water content, the specific gravity, viscosity and pour point of the emulsion also increase.

By evaporation of volatile components, the hydrocarbons with carbon number of around 15 or less in crude oil decrease or disappear, but little changes are seen on the hydrocarbons with carbon number of 16 or more. As a result the ratio of constituent substances of effluent oil changes greatly.

Crude oil dissolved in sea water at 40 to 100 mg/l, and the light weight component and the aromatic component dissolved easily in sea water. With passage of time, the ratio of resin component and residual carbon component increases. When about 1,000 hours have passed, rapid increase in total acid value is observed, which indicates chemical reactions such as oxidation, polymerization and hydrolysis are taking place.

The above change in properties varies according to the kind of oil, components, the state of out-flow and passage of time. Therefore, when studying the influence of oil-contaminated sea water on the power and desalination plants and measures to prevent contamination by oil, it is necessary to study in conformity with their respective circumstances.

4.2 Influence on Efficiency of Desalination Plant

While inflow of floating oil can be prevented to some extent by a preventive system, dissolved oil and emulsion state oil can flow into the plants. Since the maximum concentration of oil flowing in the plants can be estimated as 1,000 mg/l or less, a study was made under this condition on the performance and efficiency of each apparatus and equipment in the desalination plants.

The result of this study is as follows:

4.2.1 Pump

Oil emulsions in sea water are further crushed to smaller particles by the pumps, without attaching to the inner wall of the pumps and with- out affecting their performance.

4.2.2 Heat Transfer Tube

According to the experiments on adhesion of oil on inner wall of the tube, adhesion of oil particles to form cores takes place at first, then the cores grow and finally reach to equilibria. Quantity of adhered oil greatly differs depending on material of tube, physical properties of oil, concentration of oil and flow speed of sea water.

Calculation of overall heat transfer coefficient (U) by the following equation revealed that the decrease in the coefficient is only 0.5% when oil in deposition in 2 μm thickness on the inner surface of heat transfer tube in the evaporation chamber.

Also, the influence of change in viscosity of sea water due to mixing of oil on the inner wall heat transfer coefficient (h_i) and the outer wall condensation heat transfer coefficient (h_o) is extremely small.

$$\frac{1}{U} = \frac{1}{h_i\ r_i} + \frac{\ell n(r_o/r_i)}{\lambda_T} + \frac{1}{h_o\ r_o} + \frac{R_i}{r_i} + \frac{R_o}{r_o}$$

Where,

U	Overall heat transfer coefficient (per unit length)	(kcal/mh °C)
h_i:	Inner wall heat transfer coefficient	(kcal/m² °C)
h_o:	Outer wall condensation heat transfer coefficient	(kcal/m² °C)
r_i:	Inside radius of tube	(m)
r_o:	Outside radius of tube	(m)
λ_T:	Heat conductivity of tube	(kcal/mh °C)
R_i:	Fouling factor inside tube	(m²h °C/kcal)
R_o:	Fouling factor outside tube	(m²h °C/kcal)

4.2.3 Control and Measurement Apparatus

The temperature sensor in the control system of maximum temperature of brine is not affected because it is covered by a protective sheath made of stainless steel. There is no difference in indication of pressure before and after the orifice in the flow control system, even if some oil is intermixed into sea water to be measured.

Also, intermix of oil has almost no influence to the displacement of liquid surface in communicating tubes in the liquid surface control system. Since there are no problems in other measurement apparatus, in influence of oil polluted sea water on the control and measurement apparatus can be neglected.

4.2.4 Deaerator

Increase in viscosity of sea water by intermix of oil will change performance of the deaerator to slightly better direction. Even if a diameter of hole in the spray nozzle becomes smaller due to adhesion of heavy oil component in it, the effective height of deaerator becomes favorable if there is an allowance in pump capacity. However, if the adhesion exceeds the above or the deposit changes the shape of spray, performance of the deaerator will be dropped, but in actual application, the influence of viscous heavy oil component could be disregarded as the oil is removed before it reaches the nozzle.

4.2.5 Brine Heater

When the temperature rises, fluidity of sea water containing oil is improved owing to decrease in viscosity, and so it is thought that intermix of oil will not cause any bad effect on the heat transfer efficiency.

4.2.6 Vacuum System

In case of oil components of low boiling point are intermixed in the vacuum system and if cooling capacities of the vent condenser and the ejector condenser are not enough, the components are not condensed and are possibly discharged into air.

Also, since the subject plant is adapted to return condensed water produced in the bent and ejector condensers back to the condensation chamber of the evaporator, oil in the condensed water will be intermixed into production water, which results in deteriorating quality.

4.2.7 Evaporation Chamber

The oil separated from sea water is apt to deposit on the side wall of condensation chamber and contaminate the inside of the condensation chamber and product water.

As described in the above, it is considered that oil-polluted sea water (oil content 1,000 mg/l or less) will hardly decrease the efficiency of desalination plants or will not interfere their operation in a short time, except deterioration of coating material on the inner wall and that of quality of drain in the vacuum system and the product water.

4.3 Influence on Electric Power Plant Efficiency

In the Umm Al Nar West Power Plant, the following equipment use sea water. They are bound to undergo oil contamination.

(1) Surface condenser
(2) Water cooler
(3) Lubricating oil cooler for the steam turbine
(4) Air cooler for the generator

In these 4 equipment, the surface condenser serves for maintaining exhaust pressure at a low level by condensing exhaust steam from the turbine, which effects direct influence on the power generating efficiency.

The other 3 equipment are the auxiliary equipment to prevent and suppress heat in various equipment, which do not effect direct influence on the generator efficiency.

Therefore, examination on the surface condenser, to which influence from oil contamination is most likely was carried out, on condition of the degree of contamination around 1,000 mg/l on the same condition as described in 4.2.

The surface condenser is provided with 6,446 cooling tubes. Sea water flows within these tubes, while steam flows from top to bottom outside the tubes. Steam is cooled and condensed while flowing and temperature is elevated by several degrees.

Inside the tubes, heat is transferred from the wall to the sea water in turbulent condition. Outside the tubes, heat is transferred from steam to the tube wall through thin layer of the condensed water. Accordingly, when the sea water is polluted, only the flow of heat within the cooling tubes is influenced.

Taking this fact into consideration, it was examined how heat transfer in the surface condenser is effected by oil contamination, Besides, it is difficult to predict the form and values of physical properties of the spilled oil because they change naturally as the time elapses, as described in 4.1.

Therefore, as contamination was assumed spilled oil itself, the influence of contamination caused by it and of the change in properties of sea water with its dissolution were examined.

The performance of the condenser in an electric power generating plant, in other words, heat transfer efficiency is given by an overall heat transfer coefficient K expressed in the following equation.

$$K = \frac{\alpha w \cdot \alpha s}{\alpha w + \alpha s} \times F \quad (kcal/m^2h\ ^\circ C)$$

Where,

αw: heat transfer coefficient on the tube (sea water) side of condenser tube
αs: heat transfer coefficient on the shell (steam) side of condenser tube
F: cleanliness factor of condenser tube

Where sea water passing through the condenser cooling tubes is oil-coneqminated elements affected by oil pollution in above equation are αw and F. α_w changes by the sea water property changes due to their oil pollution and F changes by the cooling surface cleanliness decrease, due to oil particles adhesion in oil-in-water emulsion sea water.

Oil particles adhesion would presumably be less than 0.6% of total area inside the internally smooth tubes under turbulent oil-in-water emulsion flow with oil concentration of 1,000 mg/l and oil particle mean size of 20 microns. Due to the uneven internal surface of condenser steel tubes which have been caused by long time operation, F would be considered to be reduced less than 1 to 2% at the most, with more adhesion area increase.

α_w is expressed with the oil properties as follows:

$$\alpha w = 0.0338 \cdot \lambda w^{0.6} \cdot \gamma w^{0.8} \cdot C pw^{0.4} \cdot \eta w^{0.4}$$

λw : thermal conductivity of sea water (kcal/hm°C)
γw : specific weight of sea water (kg/m^3)
C_{pw}: specific heat of sea water (kcal/kg°C)
ηw : viscosity of sea water (kgh/m^2)

Where t (%) is an oil concentration rate in complete dissolution in sea water, the above equation is expressed by a function of t as follows:

$$aw = 6.99 \times 103 \times f(t)$$

$$f(t) = (1 - 0.00782t)^{0.67} \times (1 - 0.00118t)^{0.8} \times (1 - 0.0053t)^{0.4} \times (1 + 0.0122t)^{-1.2}$$

In case of t = 0.1, which means that the oil completely dissolved in sea water is 0.1%, αw decreases by 0.2% and K decreases by reduced 0.1% under F constant, when calculated by the above equation.

It is said that crude oil solubility in water would be approximately 100 mg/l, that is 0.01%. It would be very difficult to predict the relationship between changing properties and increasing solubility which would eventually occur during its dissipation process into sea water.

However, it would be sufficient in this study to estimate that the decrease of K due to the decrease of αw is less than 1% under F constant.

In conclusion, the reduction of overall heat transfer coefficient of thermal electric power plant would be less than 2% due to a combination of two factors, the decrease of heat transfer coefficient by dissolved oil and the decrease of cooling area by oil particle adhesion.

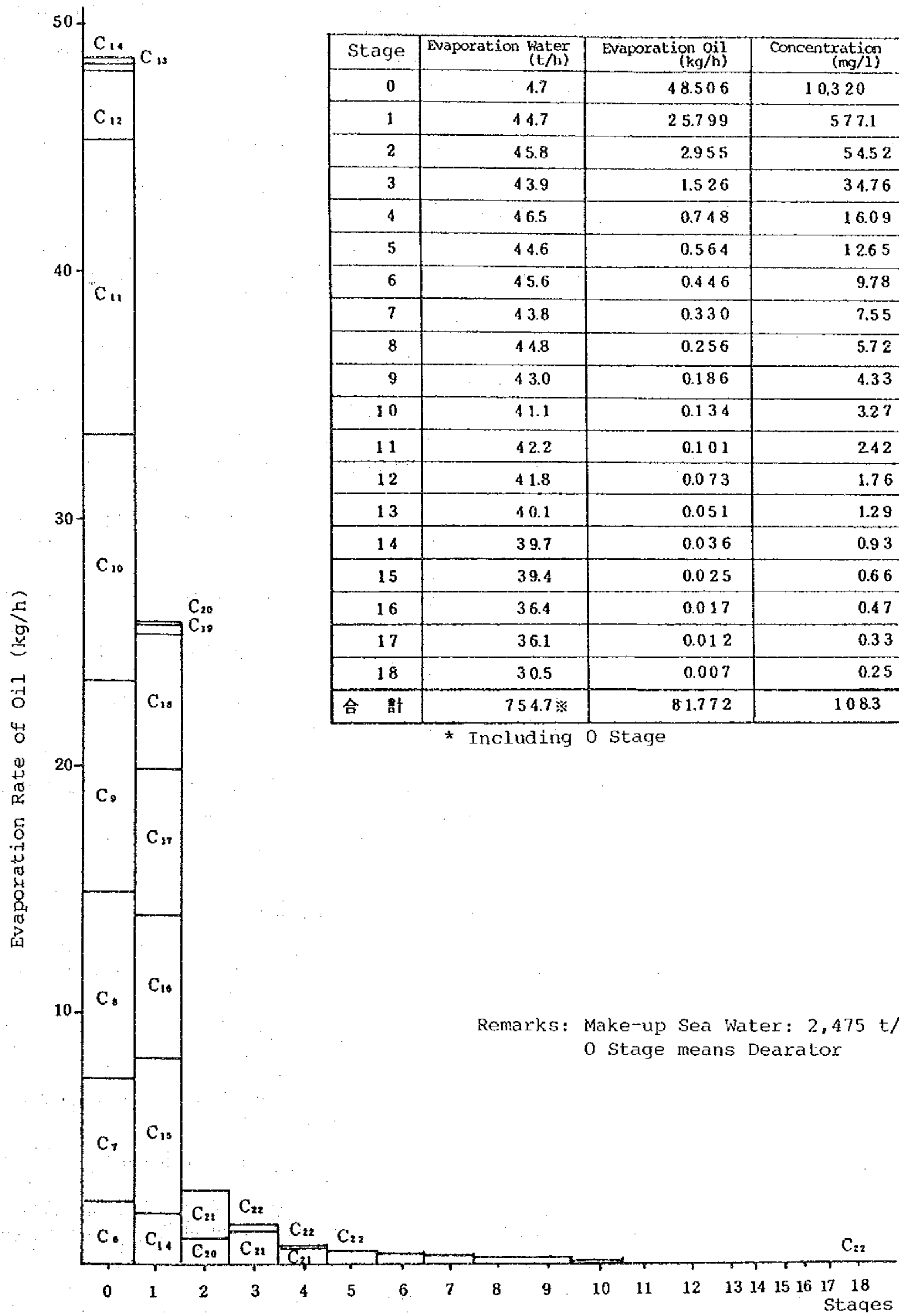
Consequently. the decrease in overall efficiency of power plant is expected less than 0.01%, considering the relations between efficiency of power plant and pressure in condenser.

4.4 Influence on Quality of Product Water

4.4.1 Intermix of Oil into Product Water

A computer program for simulation by a numerical model was prepared for behavior of hydrocarbons in the evaporation chambers of the plant when it is operated with seawater containing oil, and evaporation rates of oil components at each stage of evaporation chamber were calculated.

According to the results of simulative calculation (an example of 100 mg/l concentration of oil components in sea water is shown in Fig. 4.4.1) the oil contents distilled into fresh water from raw sea water is about 40% when oil concentration in seawater is 10 mg/l, and about 27% when oil concentration is 10,000 mg/l, and the remaining oil being left in the exhaust brine side.



Stage	Evaporation Water (t/h)	Evaporation Oil (kg/h)	Concentration (mg/l)
0	4.7	48.506	10,320
1	44.7	25.799	577.1
2	45.8	2.955	54.52
3	43.9	1.526	34.76
4	46.5	0.748	16.09
5	44.6	0.564	12.65
6	45.6	0.446	9.78
7	43.8	0.330	7.55
8	44.8	0.256	5.72
9	43.0	0.186	4.33
10	41.1	0.134	3.27
11	42.2	0.101	2.42
12	41.8	0.073	1.76
13	40.1	0.051	1.29
14	39.7	0.036	0.93
15	39.4	0.025	0.66
16	36.4	0.017	0.47
17	36.1	0.012	0.33
18	30.5	0.007	0.25
合 計	754.7※	81.772	108.3

* Including 0 Stage

Remarks: Make-up Sea Water: 2,475 t/h
0 Stage means Dearator

Fig. 4.4.1: Evaporation Rate of Oil at Each Evaporation Stage of Oil-Contaminated Sea Water

Case of 100 mg/l Oil Content in Sea Water (Oil Content 0.2475 t/h)

Assuming that all of distilled oil components are intermixed in product water, the oil concentration is product water becomes 12 mg/l in case of 10 mg/l oil concentration in sea water and 8,200 mg/l in case of 10,000 mg/l concentration in sea water.

It has been made clear that low boiling point compounds in crude oil, evaporate easily and transfer to the fresh water side. When the sea water is polluted by a small amount of crude oil (about 10 mg/l oil concentration), most of oil components evaporate in the deaerator. Even in case of 1,000 mg/l concentration, gasoline component evaporates into the deaerator, and most of kerosene and light oil components evaporate at 1 to 4 stages of high temperature side.

The vapor pressure of the components having relatively high carbon numbers (C20 or more) rapidly drops with decrease in temperature, and then only a small amount of the components shift to fresh water side at medium and lower temperature stages. On the other hand, even in case of sea water pollution by large quantity of crude oil (10,000 mg/l oil concentration), most of kerosene and light oil components evaporate at high temperature stages, while a small amount light oil and other components with higher boiling points than light oil shift bit by bit to fresh water side at medium and low temperature stages.

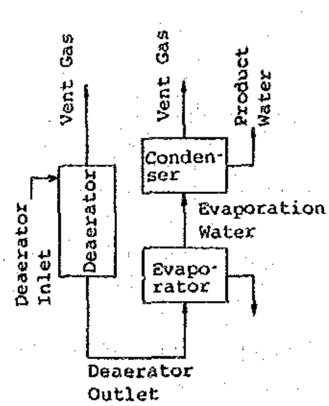
The above describes the behavior of oil content in liquid phase, and the behavior of dissolved oil in sea water can be considered as follows. As the result of calculation based on Henry's law, about 90% of aromatic hydrocarbons such as benzene, etc. shift to vent gas and exhaust brine in a MSF plant, and the rest dissolve in product water.

For example, if the concentration of benzene in raw sea water is 10 mg/l, 1.2 mg/l will shift to product water and the concentration of vent condensate will be about 5,000 mg/l.

Table 4.4.1 shows a calculation result in case of benzene.

Table 4.4.1: Calculation Result of Evaporation and Dissolution Behaviors of Benzene/Water

Temp. (°C)	Deacrator Inlet (mg/l)	Deaerator Outlet (mg/l)	Evaporation Water (mg/l)	Product Water (mg/l)	Removal Ratio (%)
35	10	1.9	6.3	1.2	88
50	10	1.9	6.3	1.2	88
60	10	1.9	6.3	1.2	88
70	10	1.9	6.3	1.3	87
80	10	1.9	6.2	1.3	87



Remarks:

$$\text{Removal Ratio} = \frac{\text{Deaeration Inlet} - \text{Product Water}}{\text{Deaeration Inlet}} \times 100$$

4.4.2 Standard Related to Oil Content in Product Water

Although there is no world-wide standard related to oil content for drinking water, there is a stipulation of WHO standard related to oil contamination, namely "10 $\mu g/l$ benzene" and "the taste and smell by which many consumers shall not feel unpleasant".

Although the content of benzene in the crude oil is only a little, benzene will be concentrated in water because its solubility in water is large. It is said that the limit of sensing odor of light oil is 0.22 mg/l by concentration in water. Under the condition of simulation (3.4.(1)), the oil concentration in product water far exceeds WHO standard.

4.5 Influence by Chlorination

4.5.1 Formation of Trihalomethane by Chlorination of Sea Water

In chlorination of sea water, trihalomethane (THM) is formed by reaction between humic existing in sea water and chlorine. Since bromide ion is contained in the sea water, most of the formed THM is bromoform and the rest is dibromochloromethane and the like. There is a survey report stating that the maximum concentration of total THM at the discharge water outlet in power/desalination plant was 90 $\mu g/l$.

For the rate of THM formation, the following equation has been proposed:

$$THM = 0.83 \times 10^{-3} (pH - 2.8)\ C\ Cl_2^{0.23}\ t^{0.35}$$

Where,

C: humic acid
: concentration of matter in mg/l
t: time in hour

According to this equation of reaction, THM will not be formed if free chlorine does not exist, but concentration of free residual chlorine does not give as much effect as that of humic acid, pH, or time factor. Consequently, control of chlorine addition is not very effective to decrease formation of THM.

4.5.2 Possibility of THM Formation by Chlorination of Oil-Contaminated Sea Water

Since there were no examples as to the formation of THM by chlorination of oil-containing sea water, a study has been made to find the possibility of THM formation based on the research on formation of chloroform by a reaction between organic compound and chlorine. The result of this study is as follows:

Reaction between benzene or toluene contained in crude oil and chlorine takes place a little; 15 to 19% of them become organic chlorine compounds whose 2 to 2.6% is chloroform and most of the rest are chlorinated organic compounds other than THM. In other words, the reaction with chlorine forms about 10 $\mu g/l$ of THM, which is only a small amount.

Also, with regard to naphthenic acid in naphthenic crude oil, in consideration of the fact that carboxylic acid which has similar properties as naphthenic acid forms a small amount of THM, it can be assumed that naphthenic acid also forms some THM.

The crude oil spilled into sea water is oxidized and decomposed to carboxylic acid, ketone and phenol. As for acetone, 55% of its chlorine consumption participates in formation of chlorinated organic compounds, about 20% of which becomes chloroform.

In case of phenol, about 9% of its chlorine consumption becomes chlorinated organic compounds, about 9% of which becomes chloroform. Therefore, it seems that more chloroform is formed in case of presence of a substance produced by oxidation and decomposition of the crude oil.

There is an experimental report saying that formation of bromoform was increased by chlorination of sea water to which water-soluble fraction of Kuwait crude oil was added, and so it can be thought that the presence of crude oil components increases formation of THM.

Since production of THM changes substantially depending on the various conditions such as composition of mixed oil, temperature condition and concentration of free chlorine, it is desirable to clarify phenomenon of THM production by reviewing various conditions of MSF type sea water desalting plant, by reviewing compounds possibly mixing into sea water in case of oil spills and to conduct a systematic experiment satisfying the foregoing conditions.

4.5.3 Possibility of THM Intermixing in Product Water

Henry' constant of bromoform is relatively large, and then assuming that 100 $\mu g/l$ of bromoform is intermixed in sea water, it is condensed to 202 $\mu g/l$ in product water according to calculation.

Since such precursors as humic acid, fulvo acid, etc. are macromolecular compounds, little volatility, and therefore, they could not be transferred to product water. However, if the raw sea water contains carboxylic acid, ketone and phenol which were formed by oxidation of crude oil, these are dissolved in product water after passing through evaporation and condensation stages. If such product water is chlorinated, there is considerable possibility to form THM.

4.6 Influence on Corrosion of Plant Materials

Since no example of the study could be found on corrosion of a desalination plant in oil-containing sea water environment, a study was made on the result of corrosion test which was conducted by installing specimens of various structural metals in the oil tank of a tanker, and also on the corrosion test of various metals conducted at the hydro-desulfurization facilities in an oil refinery plant, as examples of corrosion tests in similar environment.

Summary of the study result is as follows:

(1) Pitting by hydrogen sulfide in crude oil occurs in copper alloy and carbon steel.

(2) While corrosion-resistance of titanium is very good, there is possibility that stress corrosion by chloride occurs in stainless steel.

(3) Among non-metallic materials, epoxy resin, phenolic resin and synthetic rubber are subjected to severe deterioration.

(4) Heavy oil and heavy fuel oil have corrosion-proof effect by self-formed oil film against whole surface corrosion.

(5) When free surface boundary is formed by oil, corrosion of the part in gaseous phase is more severe than the part in liquid phase.

When studying corrosion of materials in the subject plants based on these study results, there is possibility that copper alloy will be attacked by hydrogen sulfide and corroded.

However, this will happen when the material is in direct contact with oil for many hours, and so the above result may not be applicable to the present case, that is, the material comes into contact with sea water containing oil content of 1,000 mg/l or less for a limited hours.

If the sea water is separated into two layers, sea water and oil, and the material is held in oil layer or in intermix of high concentration oil for a long period, it is fully possible that the material will be damaged by corrosion.

Also, it is quite possible that if environmental condition of the plants is the same as the above condition, deterioration of the epoxy resin used for coating of evaporation chambers in the subject plant will occur.

In order to make suitable evaluation on corrosion by oil-polluted sea water, it is necessary to conduct a systematic survey in the future.

Chapter 5 Countermeasures against Oil Pollution and Their Evaluation

5.1 Numerical Calculation on Oil Diffusion

A detection system of oil spills (an oil pollution monitoring) or a preventive system of oil pollution can be taken up as practical measure for the prevention of oil pollution. To select monitoring points, the flow routes and arrival time of oil, flowing from Arabian Gulf to the preventive system of oil pollution and to the sea water intake point of Umm Al Nar Power and Desalination Station, must be fully grasped since the monitors need to be set up at points which will allow the plant superintendents to have enough time to take emergency actions.

Therefore, in this chapter, current conditions from Abu Dhabi Island to the sea around Umm Al Nar are predicted by way of numerical simulations, and the movement of oil is to be traced in this sea area by using Lagrangian markers.

The object of these measures is, out of these results, to obtain the basic materials for the selection of the monitoring points in order to conduct measures for the prevention of oil pollution, and to the examine the preventive system of oil pollution, by calculating the arrival time and flow routes to the preventive system of oil pollution and to the area near the sea water intake point of Umm Al Nar Station.

5.1.1 Current Conditions of Designated Area

The most important factor in understanding the flow routes of oil and its arrival time is to fully grasp the current conditions of the designated sea area, and to be able to reproduce current characteristics of the sea area.

Summaries of the survey results for hydrographical conditions are as follows:

(1) Component of Tidal Current

The current is composed of various tidal components with Tide M_2 or S_2 having about a 12 hour period, or Tide K_1 and Tide O_1 having about a 24 hour period. The above four tidal components are called the principal four tidal components and most of them can be reproduced. The fluctuations of the four tidal components are shown in Fig. 5.1.1.

According to this figure, the data observed at an actual site is very similar to the composite currents of principal four tidal components. Therefore, in order to reproduce the tidal current of the designated sea area, it is appropriate to consider the principal four tidal components; Tide M_2, Tide S_2, Tide K_1 and Tide O_1.

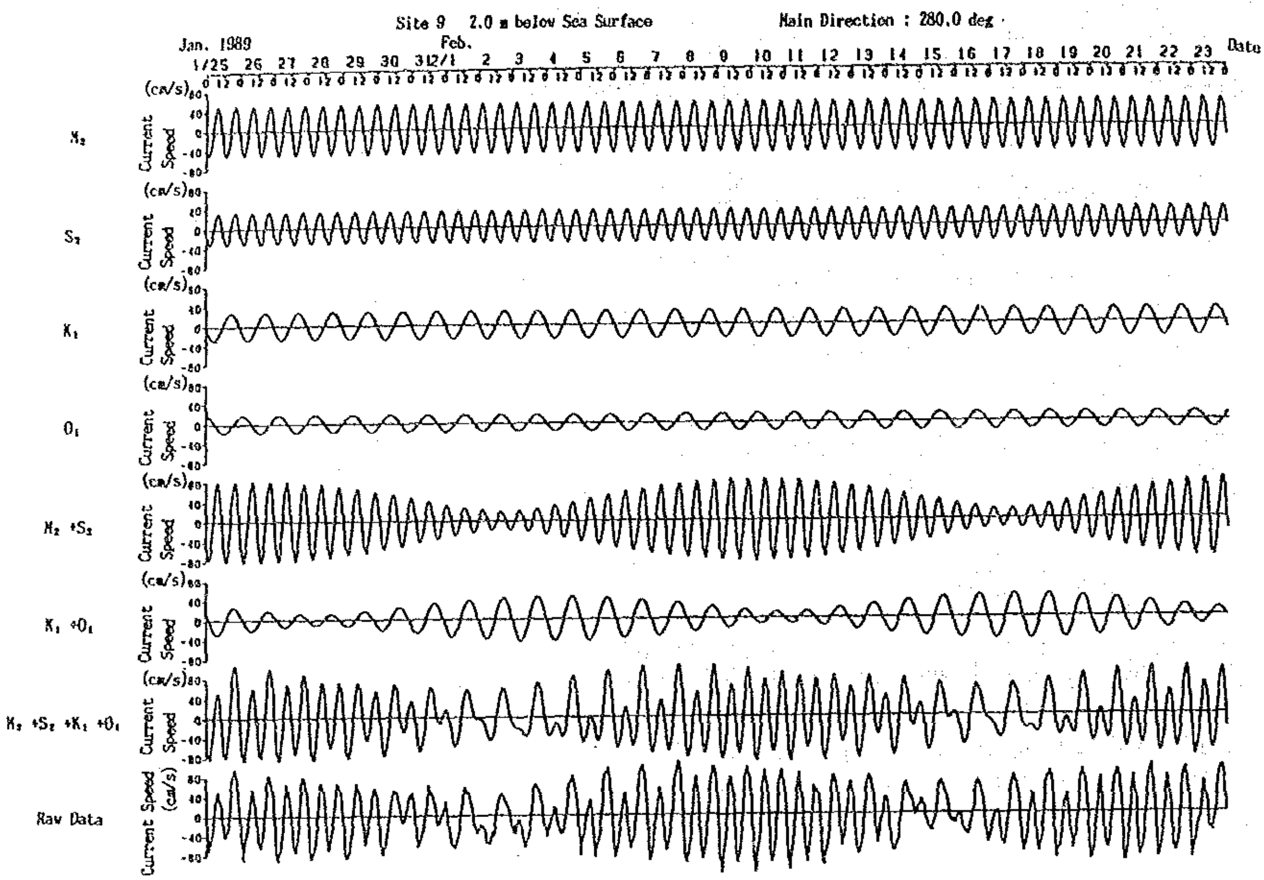


Fig. 5.1.1 The Principal Four Tidal Components and the Observed Data

(2) Constant Flow of Ocean Current in Arabian Gulf

Detailed information of the ocean currents in Arabian Gulf is not available. However, according to the navigation guide of Arabian Gulf published by the Maritime Safety Agency, Japan, its ocean current clearly flows into Arabian Gulf, changed to the prevailing westerly current through the Hormuz Channel in most months of the year. In front of the designated area, a fair current or a countercurrent of the prevailing westerly current is said to exist, though other points are uncertain.

From the results of site observations, at offshore site 15, a south-west current at about 5 cm/s was constantly flowing during October 10 to 14, 1988 and February 18 to 22, 1989, and the existence of a constant flow in Arabian Gulf was observed.

(3) Constant Flow in the Lagoon (Drift Current)

When the wind blows, a tangential stress by wind works on the sea surface, and its stress affects the current. In this chapter, drift currents which are conceivably an important factor in the diffusion of spilled oil, will be examined especially.

To see the conditions of wind and current in the designated area, a comparison is made between the current vectors of tidal currents (25 hour moving average value) and wind vectors at sites 19 and 23, and the fluctuating conditions of the two are revealed to be quite similar thus indicating that current by wind exists. However, a changing ratio from wind to current (coefficient of wind force) and a direction of current were not obtained from the observed data.

5.1.2 Predicted Model of Current Conditions

As mentioned in 5.1.1, the current of the designated sea area has largely three elements, and casual outer stresses are "an up and down motion of tide", "an element by ocean current outside the bay" and "a tangential stress by wind". A current with such different causal outer stresses has to be predicted in reproducing current conditions.

Though the causalities of current are different, the phenomena are the same in terms of being a dynamics problem solvable by the motional equations of Navier-Stokes with conditions such as pressure on sea water, friction on sea bottom and on sea surface, and effects of topography.

Motional equations of Navier-Stokes and continual equations are shown below.

$$\frac{\partial \zeta}{\partial t}+\frac{\partial[(h+\zeta)u]}{\partial x}+\frac{\partial[(h+\zeta)v]}{\partial y}=0$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial t}+v\frac{\partial u}{\partial y}-fv+g\frac{\partial \zeta}{\partial x}+\frac{1}{\rho_w}\frac{\partial P_0}{\partial x}$$

$$+\frac{\tau_x^b-\tau_x^s}{\rho_w(\zeta+h)}-A_h\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)=0$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+fu+g\frac{\partial \zeta}{\partial y}+\frac{1}{\rho_w}\frac{\partial P_0}{\partial y}$$

$$+\frac{\tau_y^b-\tau_y^s}{\rho_w(\zeta+h)}-A_h\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)=0$$

Where,

u,v	:	Average current velocity of x, y directions respectively
ζ	:	Water level
h	:	Depth of water
f	:	Coriolis coefficient (= $2\omega \sin\phi$)
ω	:	Rotation speed of the earth
ϕ	:	Latitude
ρ_w	:	Density of seawater
τ_x , τ_y	:	Friction stress at sea bottom
τ_x , τ_y	:	Share stress at sea surface
A_h	:	Viscosity coefficient of horizontal vortex
g	:	Gravitational Acceleration

The friction stress at the sea bottom and the share stress at the sea surface are respectively;

$$\tau_x^b = \frac{\rho_w g u \sqrt{u^2+v^2}}{C^2} - k\tau_x^s$$

$$\tau_y^b = \frac{\rho_w g v \sqrt{u^2+v^2}}{C^2} - k\tau_y^s$$

$$\tau_x^s = \rho_e C_D W_x \sqrt{W_x^2 + W_y^2}$$

$$\tau_y^s = \rho_a C_o W_y \sqrt{W_x^2 + W_y^2}$$

Where,

W_x	:	Wind velocity over sea surface
C_d	:	Resistance coefficient at sea surface
ρ_a	:	Density of air
C	:	Roughness coefficient of Chezy (= $n^{-1} h^{1/6}$)
n	:	Roughness coefficient of Manning
k	:	Proportional coefficient

(1) Prediction Cases

Prediction cases are shown in Table 5. 1. 1.

Table 5. 1. 1: Prediction Cases

Item		Content
A-1	Tidal Current	Max. spring tide period ($M_2 + S_2 + K_1 + O_1$)
A-2		Ave. spring tide period ($M_2 + S_2$)
A-3		Middle tide period (M_2)
A-4		Neap tide period ($M_2 - S_2$)
B-1	Constant Flow	South-west current 5 cm/s
C-1	Drift Current	Wind direction N, velocity 5 m/s
C-2		Wind direction NW, velocity 5 m/s
C-3		Wind direction S, velocity 5 m/s
D-1		Intake vol. at power st. 126. 4 m^3/s
E-1		Discharged vol. at power st. 123. 3 m^3/s

(2) Prediction Conditions

1) Subjective Range of Prediction

A subjective range of prediction is as is shown in Fig. 5. 1. 2 considering the current conditions and the topography of the designated sea area. Also, it is divided into square grid size of 200 m each.

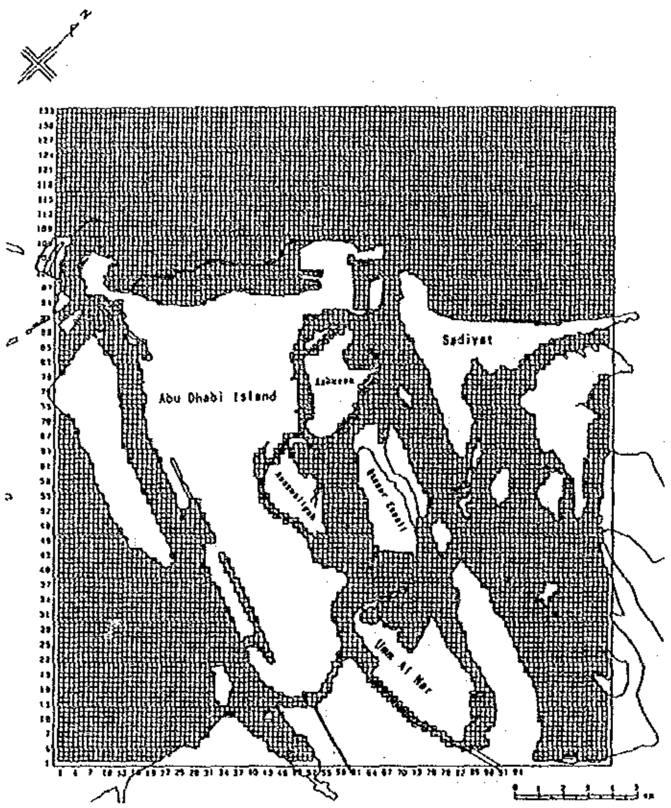


Fig. 5.1.2: The designated Sea Area

2) Open Boundary Condition

At the open boundary where calculating regions adjoin the sea, the following conditions are given.

(a) Calculation of Tidal Current

A tidal vibration is given with cos function at the open boundary. And, setting of harmonic constants, hb and κ is referred to the tidal harmonic constants observed tide-levels, and is carried out as the result of the trial and error of conformity of current.

Also, an offshore boundary was searched at the linear equation between the south-west and north-east boundary.

(b) Calculation of Constant Flow

A water level difference is given so as to have the set up velocity (5 cm/s, south-west) at the offshore 5 km point away from Mina Zayed.

(c) Calculation of Drift Current

A wind velocity is given at 5 m/s at the set-up wind directions (N, NW, and S). An open boundary at this time is a free boundary.

3) Closed Boundary Condition

It is considered that there is no flow through harbor structures such as lands or breakwaters.

4) Natural Condition

A coastal topography and a depth of water were set up with the following materials.

* Hydraulic Chart No. 3170 published by Hydrographic Office, of Maritime Safety Agency in Japan

* Hydraulic Chart No. 3752, 3713 by WED

* Aerial photographs by WED

5) Coefficient of Calculation

(a) Viscosity Coefficient of Horizontal Vortex ($A_x A_y$)

($A_x = A_y$) $5\times10^4 cm^2/s$ is in this item.

(b) Coriolis Coefficient (f)

Coriolis force is caused by the rotation of the earth, and expressed as follows:

$f = 2\omega \sin\phi = 6.020\times10^{-5}S^{-1}$
w = Angular velocity of the rotation of the earth
o = North latitude of the designated area

(c) Friction Coefficient of Sea Bottom (γ_b^2)

$\gamma_b^2 = g/c^{\ 2}$

C_D = Gravity Acceleration
ρ_a = Roughness coefficient of Chezy

(d) Coefficient Involving the Friction of Sea Surface

<Resistance coefficient of the sea surface>	Cd = 0.0026
<Proportional constant>	k = 0.25
<Air density>	ρ = 1.00g/cm³

5.1.3 Conformity Examination of Predicted Value and Actual Value

(1) Prediction of Tidal Current

In order to determine the conformity of predicted value and actual value, the examination was carried out using tidal current ellipses by harmonic constant of tidal current obtained by the site observation and the prediction.

The comparison at the period of average spring tide is shown in Fig. 5.1.3.

These results indicate that the predicted values of the current direction and the current velocity at eight survey points except Site 23, accord to the actual values. Site 23 is in a narrow channel and the 200 m of the square for prediction was not enough to reproduce the topography.

As for the other survey points, the predicted values generally accord to the observed ones. And the conformity of the prediction model to the designated sea area and the suitability of prediction conditions was confirmed.

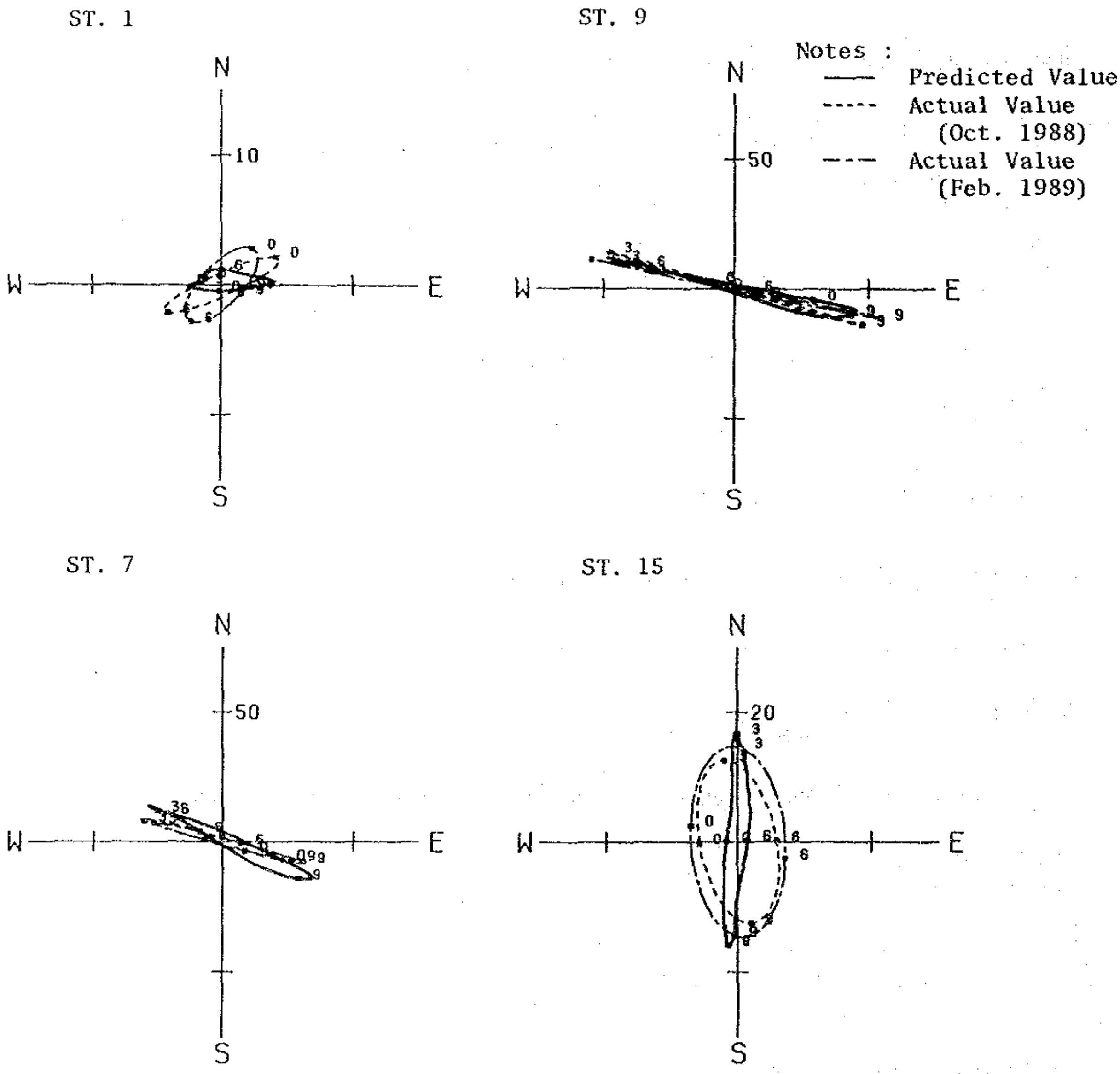


Fig. 5.1.3: Comparison with Actual Value (Tidal Current Ellipses) and Predicted Value Tidal Current Hodograph)

(2) Prediction of Constant Flow

An examination of the prediction was carried out with an example of the current velocity at a point 5 km offshore Mina Zayed.

As for the current velocity at the 5 km point offshore Mina Zayed, the predicted value is as "current velocity : 5.2 cm/s", "current direction : 315 degrees", the same as the value set up first. Therefore, the suitability of prediction conditions was confirmed.

(3) Prediction of Drift Current

As for the prediction of a drift current, the examination of the conformity between the actual value and the predicted value was not fully carried out since the wind condition at the observed time did not accord to the assumed wind on prediction. However, the result of the drift current prediction model and its condition are assumed to be appropriate, judging from the fact that conformity at other points was fully checked.

5.1.4 Prediction Results of Current Conditions

(1) Prediction Results of Current Conditions around the Abu Dhabi Island

Summary of the prediction results of current condition results around the the Abu Dhabi Island are as follows:

1) The sea water flowing from Mina Zayed is divided into two streams. One is going up south-east through Baghal Channel, and another is going up to south channel of the Abu Dhabi Island through the channel at the east side of Ashuoo and between Assumaliyah and Qassar Essal.

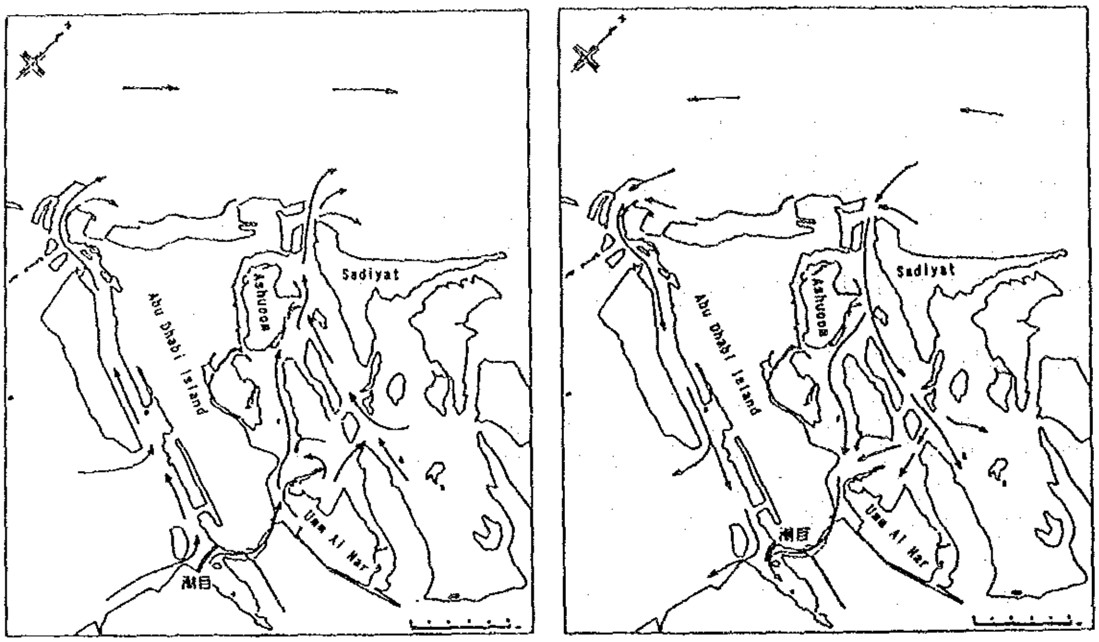
2) The sea water flowing from Assamaliyah goes up around the southernmost end of the Abu Dhabi Island.

3) The south-east current was assumed as the constant flow of ocean currents in Arabian Gulf. However, the component of this constant flow hardly affects the current around the Abu Dhabi Island.

4) As for the drift current caused by constant wind blow, three wind directions (N, NW, S) were predicted. Reflecting the complexity of the topography of the designated sea, a topographical vortex flow has developed to a great extent. Besides this it was observed that the current direction becomes a fair current in the same direction as the wind in the channel, but its countercurrent occurs in the shallow water as usual.

   It should be noted that a horizontal circulation current is stressed since the prediction was a single layer model.

5) The sea water flowing from Khalidia goes up to the observation Site 23, but does not go near Umm Al Nar Station.



Offshore Current　　　　　　　　Inshore Current

Fig. 5.1.4: Flowing Conditions of Sea Water

(2) Prediction Results of Current Conditions near the Sea Water Intake and Brine Discharge

1) The sea near the intake is influenced at points by the water mass from Mina Zayed. The current velocity declined to several cm/s quite near the sea water intake point, but the current velocity in the area where the channel adjoins was 20 to 30 cm/s during the maximum spring tide period.

2) There is almost no effect of the component of constant flow of the ocean current in Arabian Gulf to the recess of the lagoon.

3) As for the influence of drift current near the sea water intake facility, the water mass moves along the coast from the north at times of northerly wind, and at times of southerly wind the water mass moves from the other direction. Therefore, as mentioned above, the sea water flowing in from Khalidiya did not affect the vicinity of the sea water intake point, but the drift current sometimes works on the inflow of water from the south.

4) The influence of intake and discharge sea water is limited to near the area. Since the two of them which are in the recess of the lagoon, discharge sea water is assumed to be recirculated.

5.1.5 Examination of Countermeasures to Oil Pollution Accidents with Marker Tracing

The above mentioned results (refer to 4.1.4) indicate the variation of the current velocity and the direction at fixed points, since the oil flows in the designated sea water move on the currents from time to time, and the prediction results in the previous section are not full enough to grasp much information about oil routes or movement time. That is, they cannot be satisfactory as basic materials for the examination of an oil pollution monitoring system or a preventive system of oil pollution.

Therefore, in this section, a prediction will be done on how oil reaches a certain point (this point can be the subject of examination on setting the monitoring system or preventive system) moves, and how long it takes to reach the sea water intake point of Umm Al Nar Station or the preventive system of oil pollution.

(1) Prediction Time

The markers thrown at the start of flood current at a certain position reach the farthest point in a half hour period (6 hours), and returns to where it was thrown. Therefore, if the movement routes in this period, from the start of flood current to the start of ebb current, are grasped, the object here will be attained. Thus, markers for 6 hours from the start of flood current will be traced.

(2) Position of Marker Thrown

Positions of markers thrown will be shown at each section of 1 to 7 and A to F in Fig. 5.1.5.

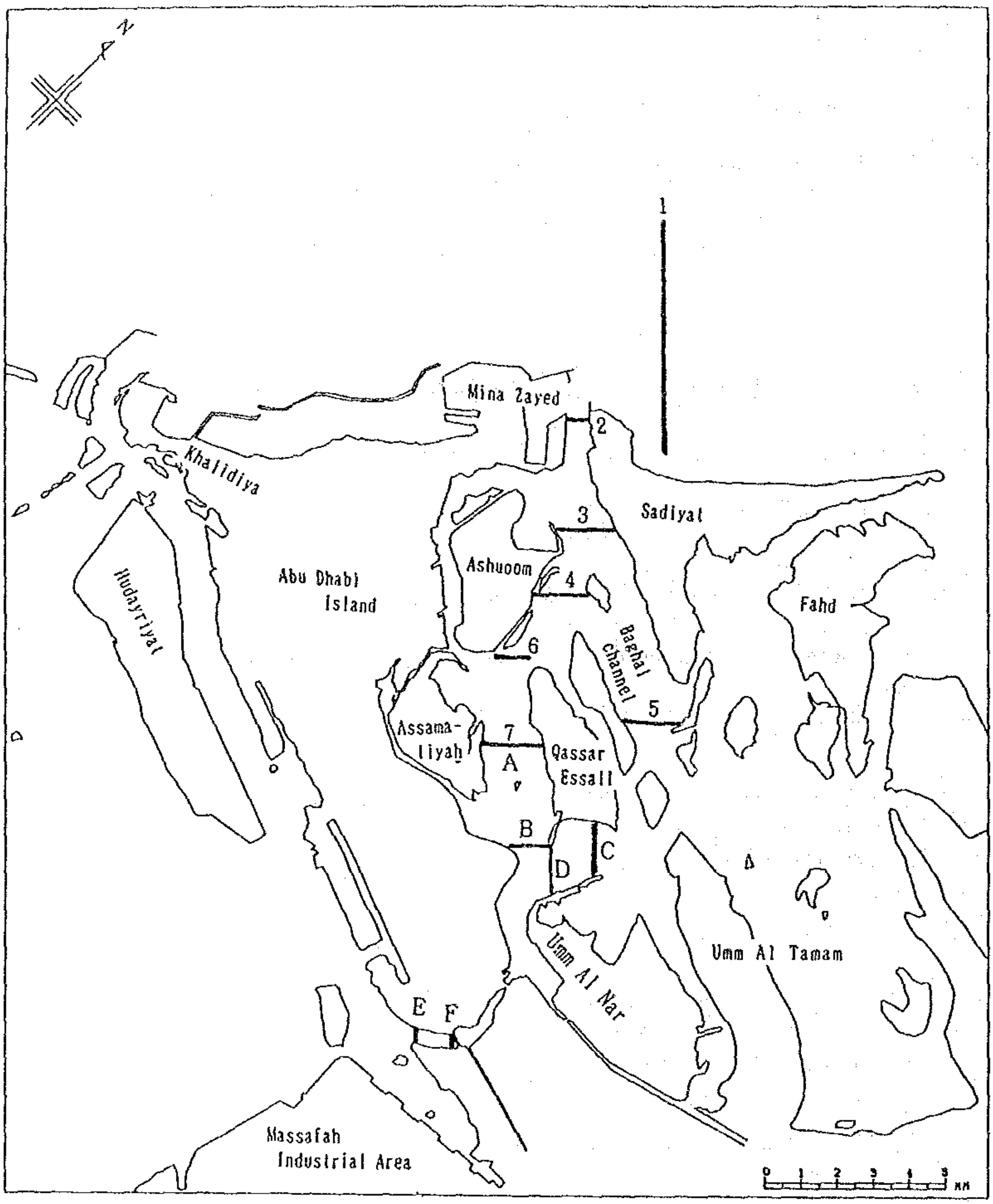


Fig. 5.1.5: Cross Section of Marker Thrown

(3) Prediction Case

As mentioned in the previous section (5.1.4), the current of the subject sea area is composite of 4 elements.

And those elements can be classified as follows:

* Permanent element ------Tidal current, Intake & Discharge current

* Temporary element ------Drift current, Marine current

Temporary element denotes the current with uncertain occurrence and continuation period.

Therefore, overall investigation of current of the subject sea area takes permanent element into consideration on the one hand, and the prediction of the current near the intake requires the 2 factors mentioned above, because there is possibility for the passage to be greatly influenced by both elements.

Cases are shown in Table 5.1.2.

Table 5.1.2: Prediction Case

Tidal Curr.	I & D Flow	Drift Current			Ocean Current	Section Thrown In
		N	NW	S		
MSTP ASTP MiTP NeTP	Intake 126.4 m³/s Discharge 123.3 m³/s	× × × ×	× × × ×	× × × ×	× × × ×	Total 7 Sections See 1 - 7
MSTP ASTP MiTP NeTP	Intake 126.4 m³/s Discharge 123.3 m³/s	○ ○ ○ ○	○ ○ ○ ○	○ ○ ○ ○	× × × ×	Total 6 Sections See A - F
MSTP ASTP MiTP NeTP	Intke 126.4 m³/s Discharge 123.3 m³/s	○ ○ ○ ○	○ ○ ○ ○	○ ○ ○ ○	SW Current SW Current SW Current SW Current	Total 6 Sections See A - F

Remarks : MSTP: Maximum Spring Tide Period
ASTP: Average Spring Tide Period
MiTP: Middle Tide Period
NeTP: Neap Tide Period
I & D: Sea Water Intake and Brine Discharge

(Note) Blanks in Table mean the current component is not added

(4) Prediction Results

1) Movement Conditions of Marker in Remote Area from the Sea Water Intake Point

(a) Section 1

Markers in the section 2.5 km north-east of the entrance of the lagoon are taken into the lagoon with a water mass at the 5 km point off the lagoon at the maximum spring tide. They flow up to a maximum of 14 km off the entrance of the lagoon. At middle tide, that is, an average tide, the water mass 1 km off the entrance of the lagoon is taken in but they flow in only up to about 2 km from the entrance of the lagoon. (Refer to Fig. 5.1.6)

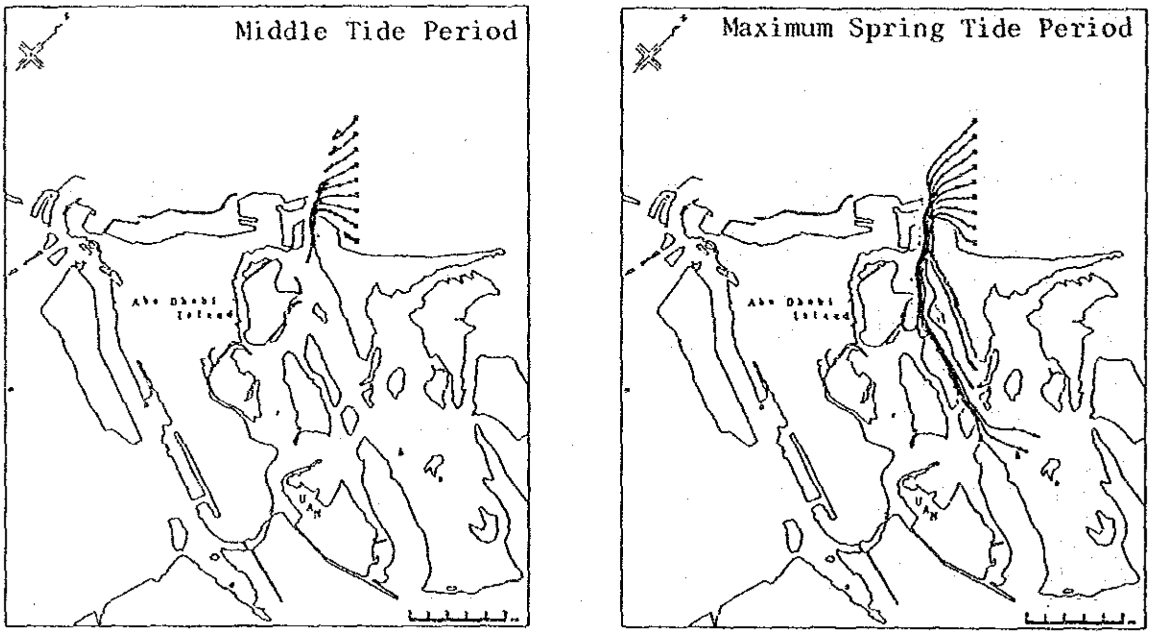


Fig. 5.1.6: Result of Marker Tracing (Thrown at Beginning of Rising Tide) <Section 1>

(b) Section 2

Markers thrown in at three positions in the lagoon flow along the coast of Baghal Channel and have traces of about 16 km. At middle tide they flow in up to about 9 km, but do not reach the sea water intake point for a semicycle period. (Refer to Fig. 5.1.7)

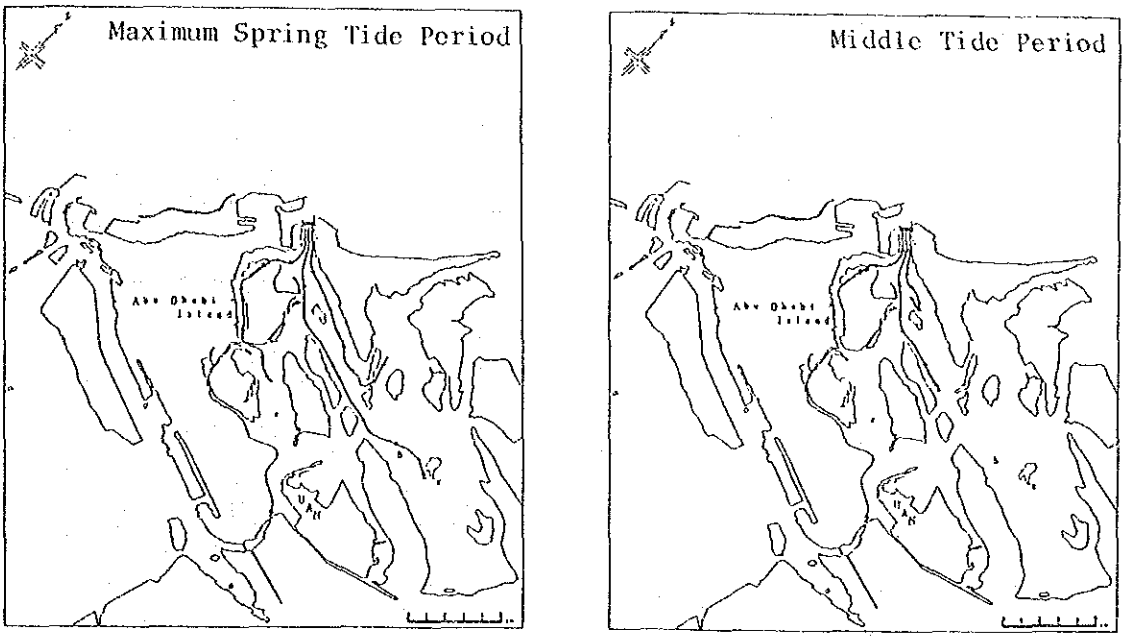


Fig. 5.1.7: Result of Marker Tracing (Thrown at Beginning of Rising Tide) <Section 2)

(c) Section 3

Markers thrown in the water lane go up to the south-east carried along Baghal Channel. The flow route shows the same case as those markers to Baghal Channel in Section 1. (Refer to Fig. 5.1.8)

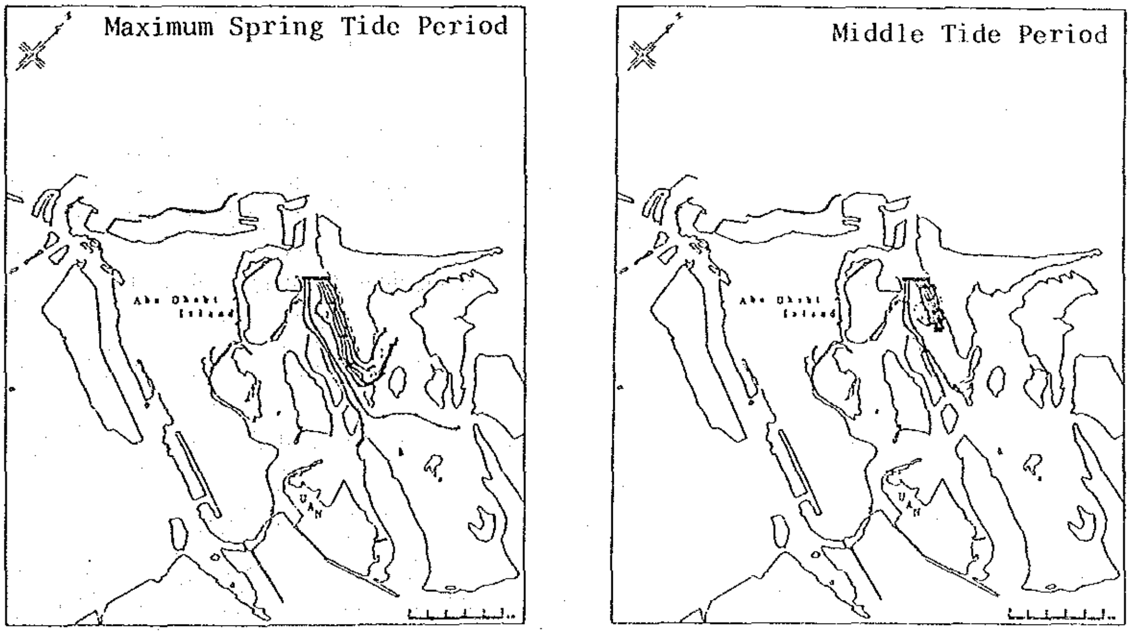


Fig. 5.1.8: Result of Marker Tracing (Thrown at Beginning of Rising Tide) <Section 3>

(d) Section 4

Markers thrown in are divided into the ones which go up to Baghal Channel and the others going to the lane between Assamaliyah and Qassar Essall. The latter goes close to 1 km near the sea water intake point at maximum spring tide. (Refer to Fig. 5.1.9)

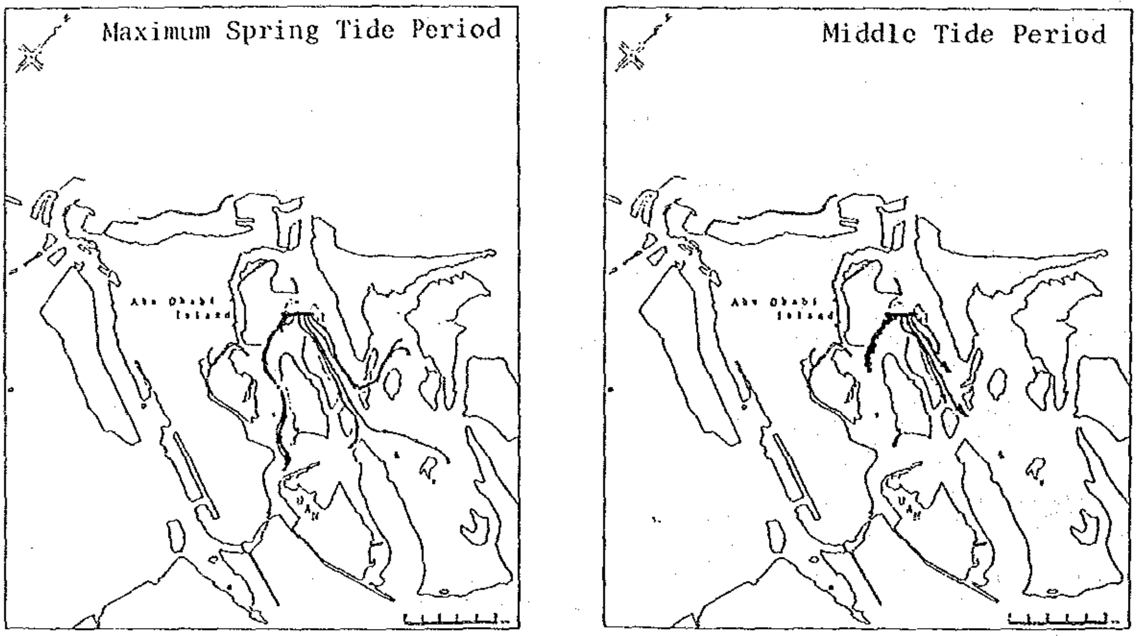


Fig. 5.1.9: Result of Marker Tracing (Thrown at Beginning of Rising Tide) <Section 4>

(e) Section 5

Some markers thrown in this section flow into the lane leading to the intake, but most of them scatter towards Fahd or Umm Al Tamam, which indicate that some of the water mass going through Baghal Channel flows into the lane which leads to the sea water intake point, but is reversed at the lane due to a reversed current. (Refer to Fig. 5.1.10)

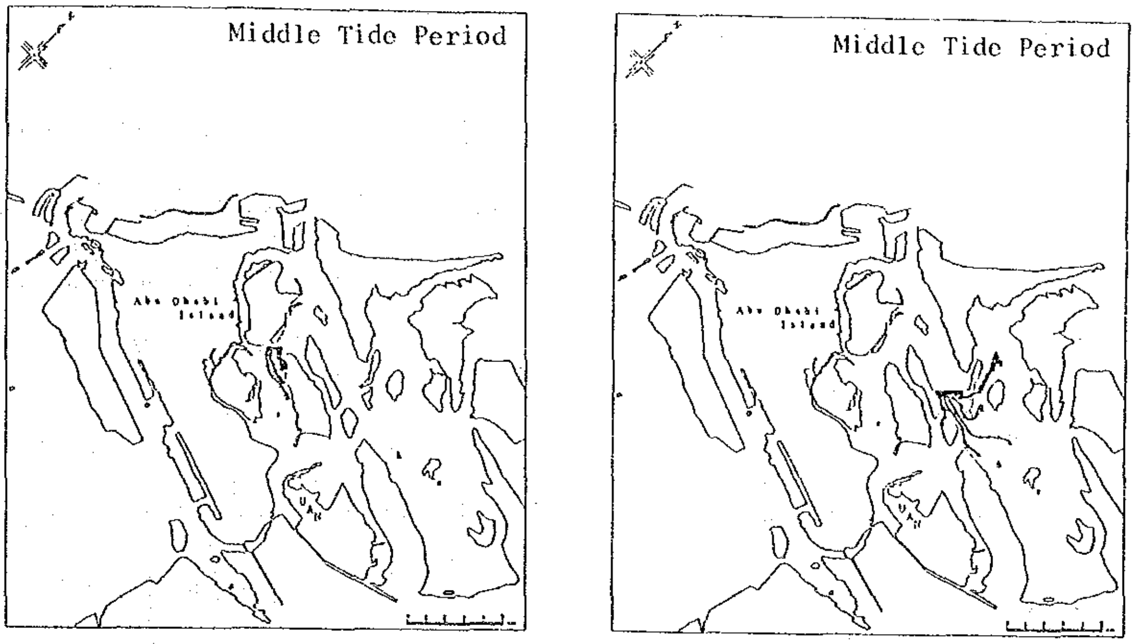


Fig. 5.1.10: Result of Marker Tracing (Thrown at Beginning of Rising Tide)
<Section 5>

(f) Section 6

Markers arrive near the sea water intake point at maximum spring tide. This is presumably due to the fact that the lane between Qassar Essall and Assamaliyah is a main current flowing to the sea water intake point. (Refer to Fig. 5.1.11)

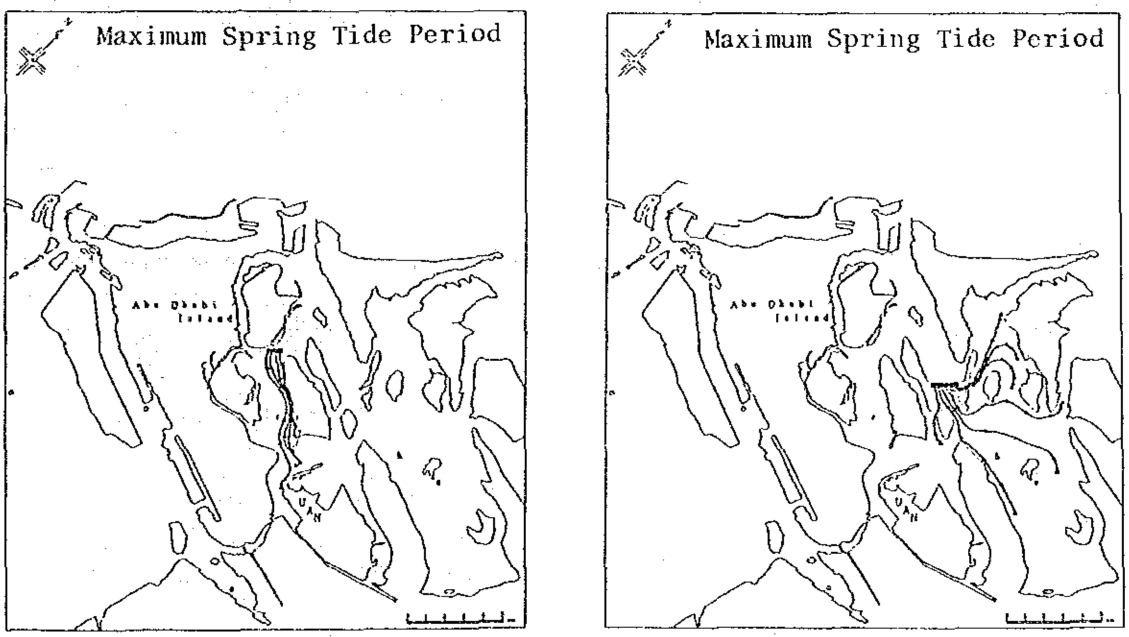


Fig. 5.1.11: Result of Marker Tracing (Thrown at Beginning of Rising Tide)
<Section 6>

(g) Section 7

Markers arrive near the sea water intake point in 5 to 6 hours at maximum spring tide. In other cases they do not reach the sea water intake point. (Refer to Fig. 5. 1. 12)

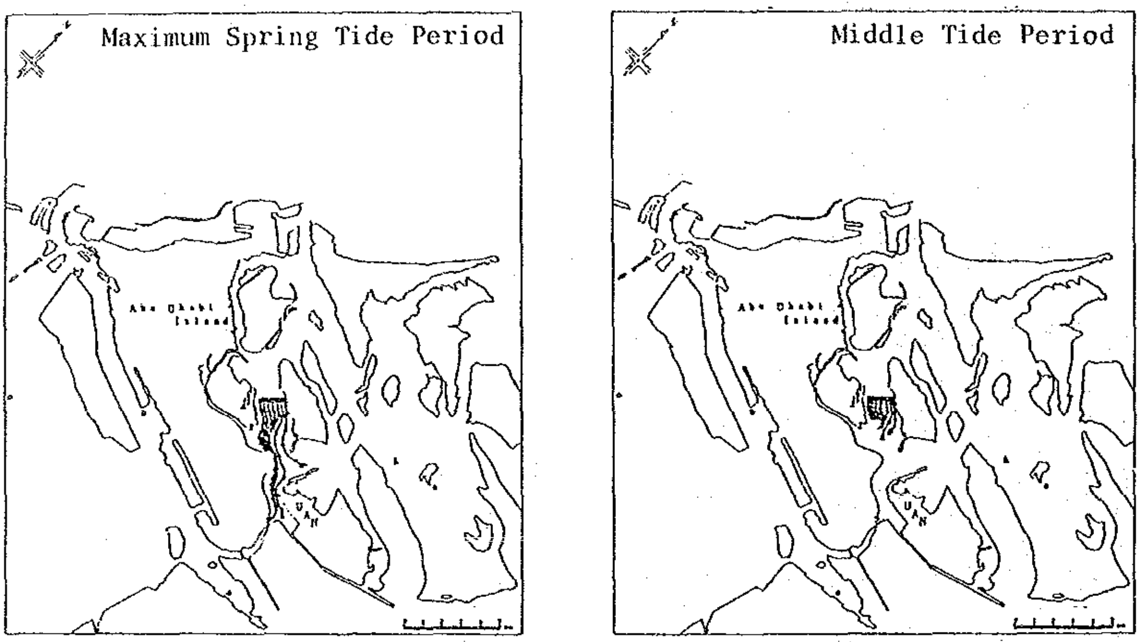


Fig. 5. 1. 12: Result of Marker Tracing (Thrown at Beginning of Rising Tide) <Section 7>

2) Movement Conditions of Marker near the Sea Water Intake Point

Movement conditions of markers near the sea water intake point were examined in 6 sections from Section A to F as shown in Fig. 5. 1. 5. Below is the summary from each section of the movement conditions of markers.

(a) Section A

Markers reach the sea water intake point in 5 to 6 hours from the start of flood current at maximum spring tide regardless of drift current by wind. In other tidal periods, they reach at the most 3 km away from the sea water intake point even at the average spring tide. (Refer to Fig. 5.1.13)

Maximum Spring Tide Period　　　　Average Spring Tide Period

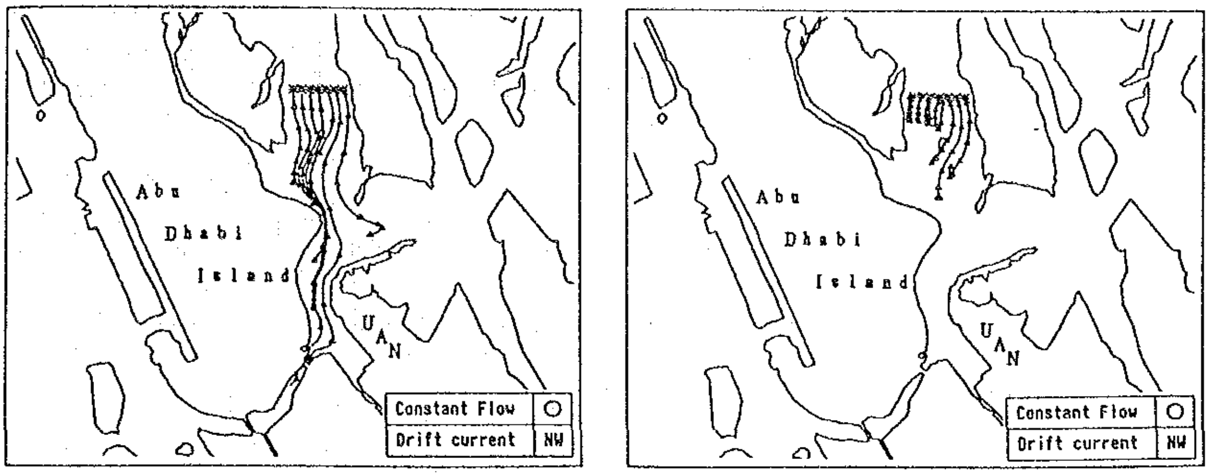


Fig. 5.1.13: Result of Marker Tracing <Section A>

(b) Section B

At maximum spring tide, they reach the sea water intake point area in 3 to 4 hours from the start of the flood current. In other tidal periods, they reach to 1 to 2km from the sea water intake point area in the case of no drift current (only a tidal current and an intake and discharge flow). However, when there exists a drift current, the movement of the oil lump shows a complicated route due to a complicated topographical whirlpool in the south sea area of Qassar Essall. But it moves rather north-eastwards, in an opposite direction to the intake. (Refer to Fig. 5.1.14)

Maximum Spring Tide Period　　　　Average Spring Tide Period

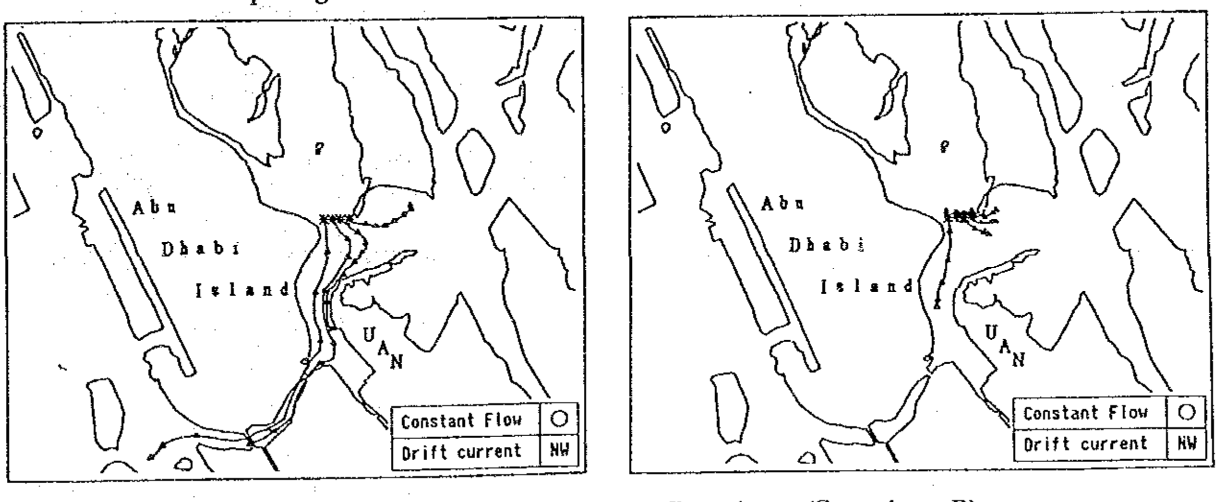


Fig. 5.1.14: Result of Marker Tracing <Section B>

(c) Section C

A big movement of oil was not recognized, as Section C is positioned between the sea water coming through Baghal Channel and that coming from between Assamaliyah and Qassar Essall at the maximum spring tide.

Therefore, when a drift current occurs, it comes on the side of the sea water intake point along the peninsula where there is a power plant, but it does not reach the sea water intake point. On the other hand, at other tidal periods, oil moves along the peninsula because of the inflow of sea water coming through Baghal Channel to the lane of the sea water intake point. When a drift current due to a northward wind is added, it arrives in 4 to 6 hours. (Refer to Fig. 5.1.15)

Maximum Spring Tide Period | Average Spring Tide Period

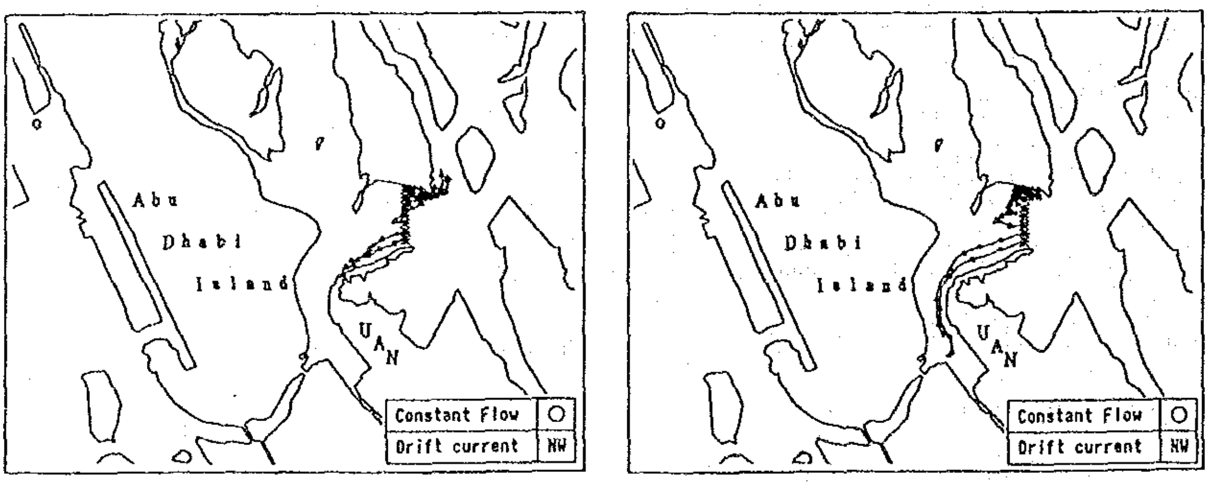


Fig. 5.1.15: Result of Marker Tracing <Section C>

(d) Section D

Section D is a sea area influenced by the flow of intake and discharge water. At the maximum spring tide, it reaches the sea water intake point in 3 hours. In other tidal periods, other than a drift current by a southward wind, it reaches the sea water intake point in at the most 6 hours. (Refer to Fig. 5.1.16)

Maximum Spring Tide Period　　　　Average Spring Tide Period

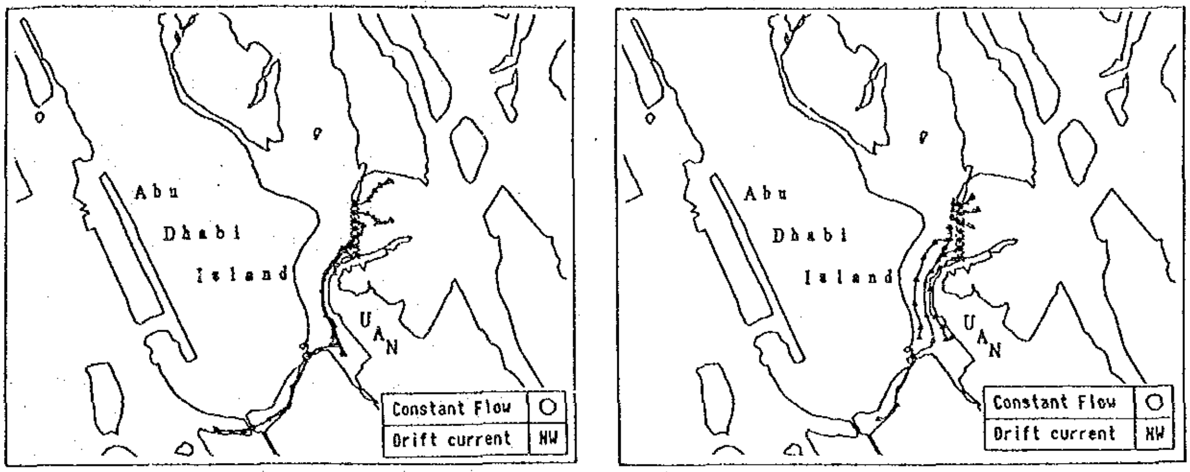


Fig. 5.1.16: Result of Marker Tracing <Section D>

(e) Section E

At the maximum spring tide, oil reaches the sea water intake point area. At other tidal periods, it reaches the sea water intake point area only with a drift current by a southward wind. Its minimum arrival time is about 3 hours at maximum spring tide with a drift current by a southward wind. (Refer to Fig. 5.1.17)

Maximum Spring Tide Period　　　　Average Spring Tide Period

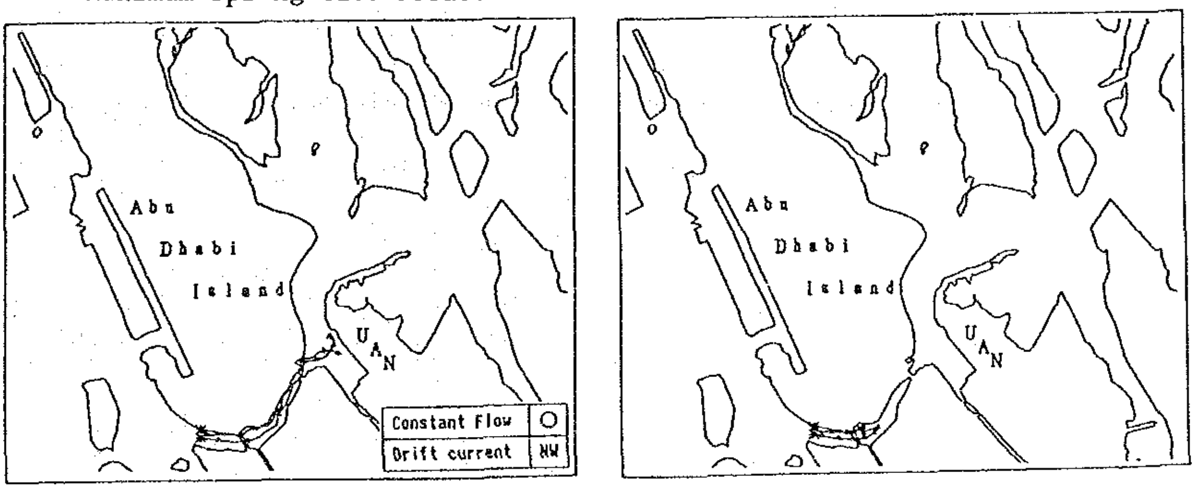


Fig. 5.1.17: Result of Marker Tracing <Section E>

(f) Section F

The movement of oil here, shows the same tendency as Section E since it is about 1 km apart from Section E, but the possibility for the oil to come near the sea water intake point is greater since it is about 1 km closer to the sea water intake point than Section E. (Refer to Fig. 5.1.18)

Maximum Spring Tide Period　　　　Average Spring Tide Period

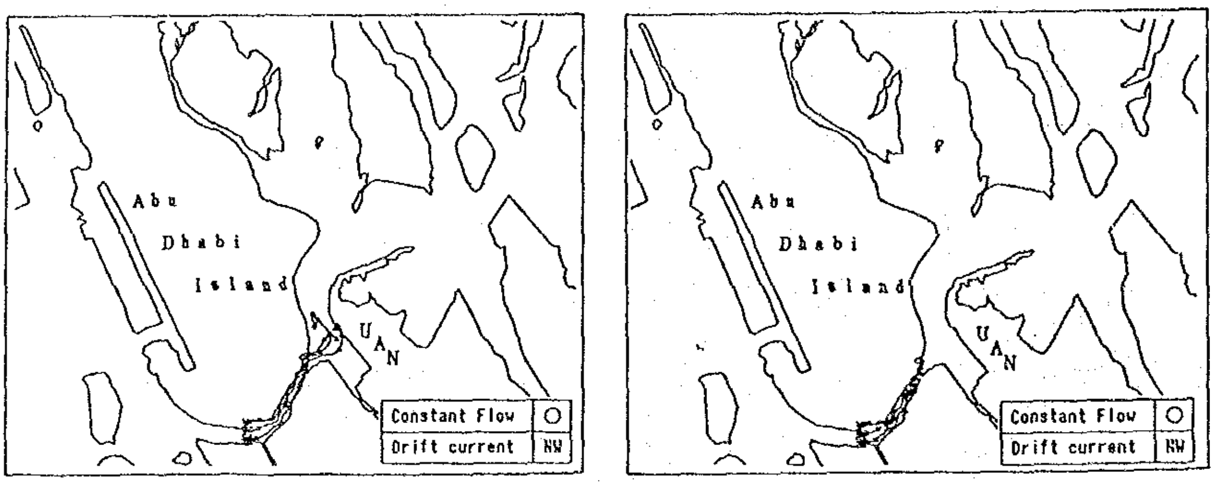


Fig. 5.1.18: Result of Marker Tracing <Section F>

5.1.6 Summary

In this Chapter, a prediction was performed in order to examine the preventive system of oil pollution and the appropriate selection of positions of the monitoring system of oil pollution which senses an inflow of oil into the designated area. The summary is as follows.

(1) Range of oil flowing into the lagoon from Arabian Gulf

At the maximum spring tide, a water mass from the Gulf to about 5 km offshore is taken into the lagoon. Its arrival time to the sea water intake point is about 2 to 5 hours.

(2) The oil near the entrance of the lagoon does not reach the sea water intake point area in 6 hours (a semicycle period).

The oil does not reach the sea water intake area in 6 hours even at the maximum spring tide when the flow of oil is the fastest. However, it has a possibility to reach the sea water intake point in 18 hours (1.5 tides) at the shortest.

(3) It is necessary to pay attention to the oil coming through the lane between Assamaliyah and Qassar Essall (Section A , B) rather than that coming through Baghal Channel, when selecting a monitoring point.

(4) The movement routes and arrival time of oil were predicted near the sea water intake point at a total of 6 sections, Sections A - F. It is necessary to consider, by way of the setting positions of a preventive system of oil pollution and its method, where to set a monitoring point.

That is, an oil fence is planned to be set at a place shown in Fig. 5.1.19 as the first preventive system of oil pollution near the sea water intake point. Considering the time of the oil fence extension or the time taken to assume an emergency posture, the setting positions of the monitoring system of oil pollution for the preventive system of oil pollution, at this point should be Sections B, D, and E, to where oil can reach in 3 to 5 hours.

By providing the monitoring system of oil pollution at Section D, monitoring oil pollution resulting from the drainage of oil refinery located in the north of Umm Al Nar Plant can certainly be achieved.

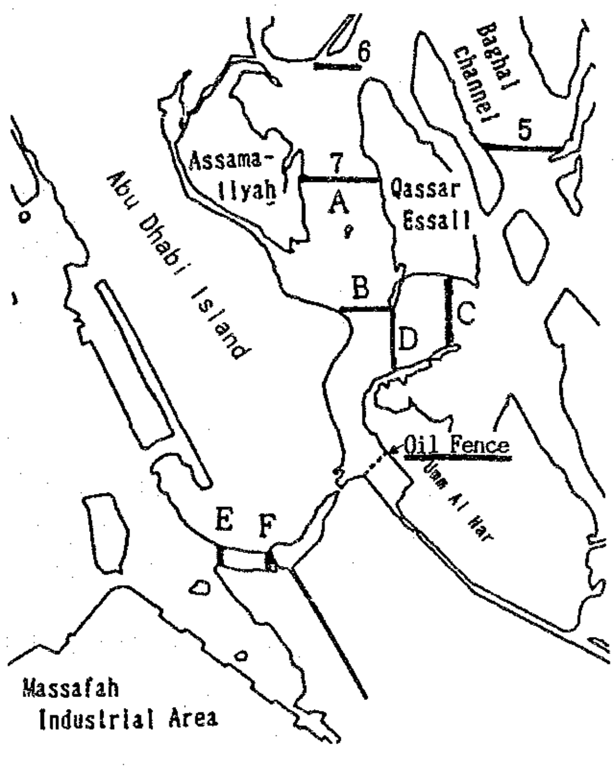


Fig. 5.1.19: Position of Oil Fence Extension

5.2 Design of Oil Monitoring System

5.2.1 Monitoring Requirements

The existing oil sensors at Umm Al Nar Plant are currently deployed only in the vicinity of intake No. 1. Therefore, they cannot effectively monitor the presence of oil over a wide area or detect oil in the water.

To provide an early warning system for the protection of the electric power and desalination plants from oil spills, it is necessary to not only detect the oil spreading on the sea surface and in the water column, but also to obtain information on the meteorological and oceanographic conditions for aid of preventive action procedures. In addition to monitoring, it is necessary to predict the trajectory of an oil slick once it is detected.

During evaluation of the recommended requirements, the following parameters were considered.

(1) Oil Pollution

* Oil slicks or films on the sea surface
* Oil in water

(2) Oceanographic and Meteorological Conditions

* Wind speed and direction
* Current speed and direction
* Wave height
* Tidal level

5.2.2 Selection of Sensors and Monitors

(1) Oil on the Sea Surface

Sensors developed for the detection of oil on the water surface are summarized in Tables 5.2.1 (1) and 5.2.1 (2). Each sensor was evaluated based on criteria for actual time response, continuous monitoring, day and night coverage, wave effects, environmental effects and experience in field operation.

As a result of the evaluation, the following sensors were selected:

* Remote sensor: Active infrared oil sensor
* In-situ sensor: Chemical fuse sensor

(2) Oil in Water

A summary table of measurement methods for oil in water detection is shown in Table 5.2.2.

Table 5.2.1 (1): Remote Sensors

Sensor	Principle	Sensitivity	Real Time	Continuous Sensing	Night Operation	Coverage Area	Operational Status
Side Looking Airborne Radar	Difference in radar reflectivity between the oil film and the surrounding water	Doubtful usefulness under calm and high wave conditions	Yes	Yes	Yes	Wide	Operating in maritime surveillance aircraft
Synthetic Aperture Radar	〃	〃	Yes	Yes	Yes	Wide	Experimental test flight
Microwave Radiometry	Difference of brightness temperature between the oil film & the surrounding water	Applicable in thick oil films	Yes	Yes	Yes	Wide	Currently under development
Passive Infrared Sensor	Temperature differences between the oil film and the surrounding water	May not detect thin oil films	Yes	Yes	Yes	Wide	Operating in maritime surveillance aircraft
* Active Infrared Sensor	Reflectance properties of oil and water	Applicable in wave conditions, based on experimental results	Yes	Yes	Yes	Medium	Operating in refineries and other manufacturing plants
Ultraviolet Sensor	Difference of reflected ultraviolet between the oil film and the surrounding water	Detects thin oil films under sufficient solar illumination	Yes	Yes	No	Wide	Operating with passive infrared sensor in maritime surveillance aircraft
Fluorescence Sensor	Fluorescence excited by ultraviolet lamp	Affected by atmospheric attenuation of ultraviolet from high altitude radiation	Yes	Yes	Yes	Medium	Operating in effluent stilling basins and sewers
Laser Fluorosensor	Fluorescence excited by ultraviolet pulsed laser	Applicable for oil classification	Yes	Yes	Yes	Medium	Extensively tested in laboratory measurements and experimental flights

Table 5. 2. 1 (1) continued

Sensor	Principle	Sensitivity	Real Time	Continuous Sensing	Night Operation	Coverage Area	Operational Status
Low Light Level Tele-vision	Difference in reflectivity of solar energy between the oil film & surrounding water	Applicable in low light conditions	Yes	Yes	No	Medium	Operated as supple-mentary sen sor of ultraviolet sensor

* Selected Sensor

Table 5. 2. 1 (2) : In-Situ Sensors

Sensor	Principle	Sensitivity	Real Time	Continuous Sensing	Night Operation	Coverage Area	Operational Status
Surface Conductivity Sensor	Change of conductivity by contact with oil	Applicable in thick oil films Affected by wave action	Yes	Yes	Yes	Narrow	Operating in oil sepa-rators, oil storage facilities
* Chemical Fuse Sensor	Dissolution of chemical fuse by oil	Depend on dissolution potential of oil	Yes	Yes	Yes	Narrow	Operating in Abu Dhabi Power Stati on
Vapor Sensor	Evaporated vapor detection from oil	Insufficient in open water environments	Yes	Yes	Yes	Narrow	Laboratory and field tests
Mechanical Torque Sensor	Increased shaft torque from oil coating	Inoperative in waves, clogging with debris	Yes	Yes	Yes	Narrow	Laboratory tests
Sonar Sensor	Acoustic impedance difference amongst water, oil and air	Applicable in thick oil films	Yes	Yes	Yes	Narrow	Laboratory tests
Differential Vapor Sensor	Temperature difference caused by evaporation pro-perties of oil and water	Only the detection technique has been demonstrated	Yes	Yes	Yes	Narrow	Prototype design

* Selected Sensor

Table 5.2.2: Measurement Methods for Oil in Water

Method	Principle	Real Time	Continuous Measurement	Application
Gravimetric	Extract oil to solvent. Evaporate solvent. Measure weight of remaining oil.	No	No	Laboratory use
*Infrared	Extract oil to solvent. Measure Infrared absorbance.	Yes	Yes	Monitoring of discharge water from ship and factory
Ultraviolet Fluorescence	Irradiate Ultraviolet. (UV). Measure UV absorbance or excited fluorescence.	Yes	Yes	Monitoring of discharge water from ship and factory
Turbidity	Measure turbidities of standing and emulsified condition.	Yes	Yes	Monitoring of discharge water from ship and factory
Laser Fluorescence	Irradiate laser. Measure excited fluorescence.	Yes	Yes	Outdoor use
Gas/Liquid Chromato-graphy	Separate to each com-ponent and measure its property.	No	No	Laboratory use Effective for micro analysis
*Acoustic	Emit acoustic wave. Measure scattered wave.	Yes	Yes	Laboratory use

* Selected Method

* Selected Measurement Methods:

These methods were evaluated based on criteria for actual time response, continuous monitoring and experience in field operation. The following methods were selected:

* Oil content : Ultraviolet-fluorescence method
* Oil particles in water : Acoustic method

However, as discrimination of oil from other suspended solids can not be made only by the acoustic method, a system combining the acoustic method with an oil content method was considered.

(3) Meteorological and Oceanographic Parameters

The following methods were selected considering the applicability of sensors and field conditions.

* Wind speed and direction:	Propeller type wind sensor
* Current speed and direction:	Numerical simulation based on hydrodynamic modeling
* Wave height:	Pressure wave gage
* Tidal level:	Result of harmonic analysis based on measurements of tide

5.2.3 Alarm Threshold for Oil Spill

Since there are no criteria or standards available regarding the allowable maximum contaminant levels for oil in sea water taken into the power and desalination plants, the following thresholds were set based on existing data, information on the behavior of spilled oil and the results of numerical simulations described in 4.4.

* Oil on sea surface: 1 μm of oil film thickness
* Oil in water: 10 mg/l

In addition to these thresholds, the following supplementary alarm criteria was established to reduce the probability of false alarms caused by noise in the output signal.

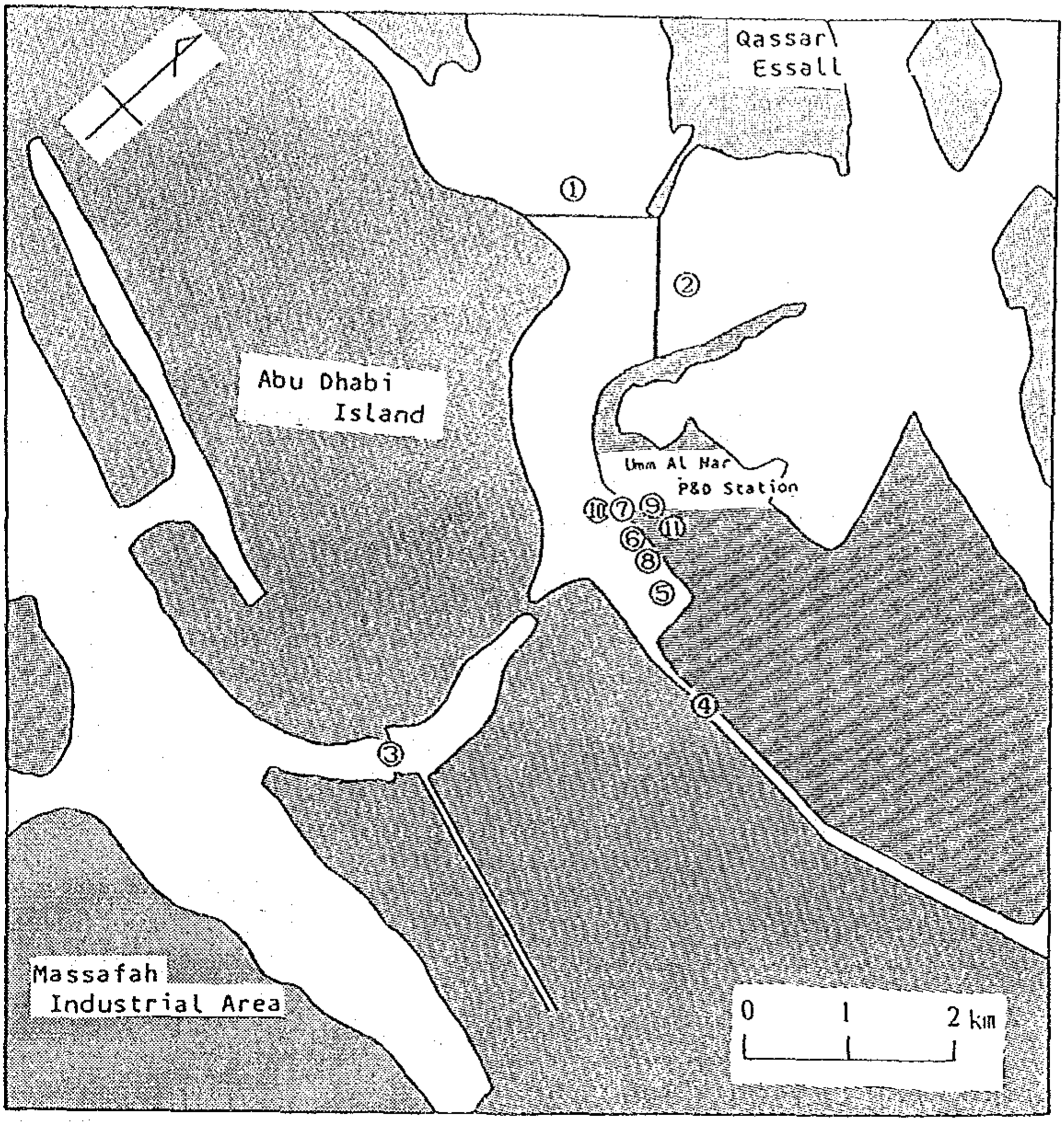
* An alarm signal is triggered only if the signal output from a monitor is continuously exceeded target figure for detecting oil in a present time period.

5.2.4 Selection of Monitoring Location

The location of the monitoring stations shown in Fig. 4.2.1 were selected after considering the following factors:

* Anticipated probability of drifting oil or an oil spill
* Proper sensor and monitor placement with respect to oil detection and accessibility for maintenance
* Stability of oceanographic conditions
* Minimum effects regarding obstructing vessel navigation
* Response when an alarm is activated

Selected monitoring location are shown in Fig. 5.2.1.



Legend:

(1) Section B (Active Infrared Oil Sensor)
(2) Section D (Active Infrared Oil Sensor)
(3) Al Ain Bridge (Active Infrared Oil Sensor)
(4) Waterway W (Active Infrared Oil Sensor)
(5) Pier (Active Infrared Oil Sensor)
(6) Intake No. 1 (Acoustic Sensor, Oil Content Meter)
(7) Intake No. 2 (Acoustic Sensor, Oil Content Meter)
(8) Intake No. 3 (Acoustic Sensor, Oil Content Meter)
(9) Turbine Building (Wind Sensor)
(10) Intake No. 2 (Wave Sensor)
(11) Control Room (Central Monitoring Station)

Fig. 5.2.1: Candidate for Monitoring Station

5.2.5 Data Transmission System

(1) Transmission Media

A direct wire link was selected for the wind sensor, and radio was adopted for the other sensors and monitors. Factors considered include: distance of transmission, existing transmission means, terrain, and reliability and installation cost.

(2) Transmission Method

The HDLC (High Level Data Link Control) procedure was adopted for the data transmission procedure after considering data transmission reliability and data transmission speed. The polling method of data acquisition used to transmit data from remote stations to the master station, was selected (the master station calls each remote station according to a predetermined sequence and only then receives data).

The polling method has been widely used for environmental monitoring, is capable of handling an increase in the number of remote stations, and has a low probability of failure regarding radio transmissions and system operation.

5.2.6 Design of Monitoring System

(1) Configuration of Total Monitoring System

The design of the monitoring system has been made by combining the system components selected in the above section. The result of study is shown in Table 5.2.3 and Fig. 5.2.2.

Table 5.2.3: System Configuration

Component	Function	Quantity
Oil Sensor	Detect oil on the sea surface	8
Oil Content Meter	Measure oil concentration in wate	3
Acoustic Sensor	Detect oil particles in water	3
Wind Sensor	Measure wind speed and direction	1
Wave Sensor	Measure wave height	1
Telemeter	Transmit a signal	17
Data Processor	Process the transmitted data	1
Data Display and Recording Device	Display and record the processed data	1 each
Floppy & Hard Disks	Record the processed date	1 each
Key Borad		1
Trajectory Prediction Program	Predict the movement of oil slick after detection	1
Data Base of Current Speed and Direction	Storage of current speed and direction	1
Tidal Level Forecast	Forecast tidal level based on the results of harmonic analysis	1

(2) Installation Process

The following 2 methods have been established for the process of installation of monitoring system.

1) Simultaneous Installation

In this option, installation of the total system takes place simultaneously. This approach requires a high initial investment cost but results in a short period (18 months) for the establishment of the total system.

2) Stepwise Installation

Because it has been generally observed that most spilled oil spreads and drifts on the sea surface, in this option the total system is established sequentially according to a priority related to the detection of oil spill. The stepwise installation sequence is:

* Detection system for oil on the surface,
* Detection system for oil in water,
* Measurement system for meteorological and oceanographic parameters and
* Trajectory prediction system.

It takes 48 months to establishment the system.

(3) Cost Estimation for Installation

The current cost estimated for establishment of the monitoring system is approximately 420 milion yen. However, this amount does not include the cost of data base preparation.

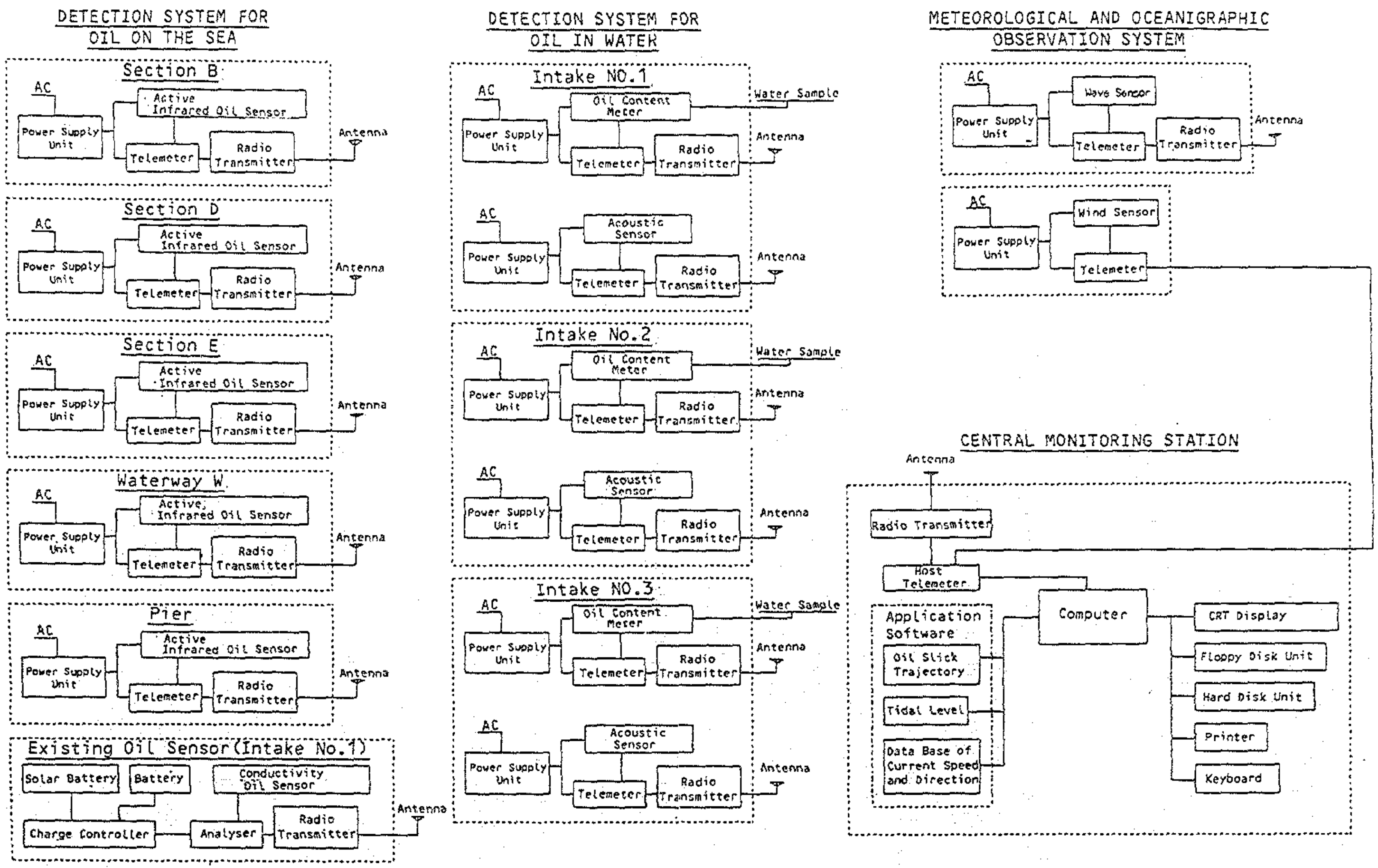


Fig. 5.2.2: Total Conceptual System

5.3 Conceptual Design of Oil Contamination Preventive System

5.3.1 Outline of Oil Contamination Preventive System

As described in Chapter 5.1, the following preventive method for oil contamination at Umm Al Nar Plant are considered to be effective:

1) Prevention of oil effluent from Arabian Gulf to Baghal Channel
2) Prevention of oil effluent from the entrance part of South Basin in Umm Al Nar to the sea water intake
3) Improvement work of the existing sea water intake facilities at Umm Al Nar Plant

5.3.2 Design Conditions

In this paragraph, fundamental design conditions are assumed as follows:

(1) Marine Conditions and Climatic Conditions

1) Tide

H.H.W.L. : ACD + 2.37 m
H.W.L. : ACD + 1.90 m
M.S.L. : ACD + 1.29 m
L.W.L. : ACD + 0.70 m
L.L.W.L. : ACD + 0.32 m

2) Tidal currents

Entrance part of Baghal Channel: 40 to 90 cm/s
Entrance part of Umm Al Nar South Basin: 20 cm/s

3) Wave

Negligible near Umm Al Nar Station

4) Wind Velocity

V = 15 m/s for oil fence design

5) Sea water temperature and salinity

According to investigation results obtained at the front of Umm Al Nar Station in October, 1988, sea water temperature, salinity and density are : 31°C, 46% and 1.0297 g/m^3 respectively.

(2) Chemical Component of Effluent Oil

Regarding the chemical components in effluent oil, they depend on the production place, effluent scale and marine conditions. The density of effluent oil is assumed as follows :

f = 1.00 g/m^3 (water content: 80 %)

(3) Intake Sea Water Quantity at Umm Al Nar Plant

* No. 1 sea water intake facilities Q1 = 61.0 m^3/s
* No. 2 sea water intake facilities Q2 = 50.0 m^3/s
* No. 3 sea water intake facilities Q3 = 15.3 m^3/s

5.3.3 Countermeasure against Oil Effluent from Arabian Gulf to Baghal Channel

According the numerical simulation results carried out lately, effluent oil near the seashore, which originates from an oil contamination accident in Arabian Gulf, will invade Baghal Channel and the lagoon which will be contaminated once the oil comes into the channel. Gradually the oil diffuses to the innermost part of the channel and at last arrives at nearby Umm Al Nar Station.

Therefore, it is necessary to execute a countermeasure against oil pollution in connection with prevention from oil pollution at not only Umm Al Nar Station, but also all facilities in the channel.

Countermeasures against oil effluent from Arabian Gulf to Baghal Channel are as follows:

* Extension of an oil fence at the entrance part of Baghal Channel
* Oil recovery in the Gulf by oil enveloping method

(1) Extension method of an Oil Fence at the Entrance Part of Baghal Channel

Based on the results of site investigation and numerical calculation, the extension method of an oil fence at Mina Zayed, where sea water inflow quantity is at a maximum compared with the other places, will be studied. Extension of an oil fence at Mina Zayed to prevent oil invasion into the channel is considered in 2 ways as shown in Fig. 5.3.1.

* Case 1 Complete Barrier at entrance of the lagoon
* Case 2 Extension of an oil fence in the offshore area

But, both cases are not practical from the viewpoint of preventive efficiency and economy.

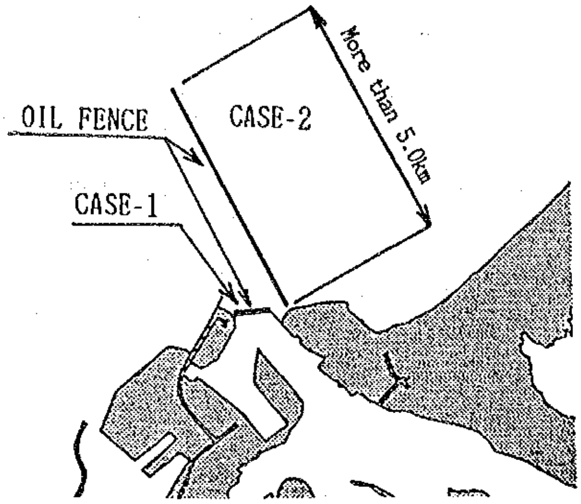


Fig. 5.3.1: Location of Oil Fence Extended (Entry to Lagoon)

The reasons are as follows:

1) The said area is the most important sea route connecting the inside and the outside of lagoon. Therefore, when the period of oil contamination becomes lengthy, a sea route blockade as in Case 1 is actually difficult to carry out.

2) According to the site investigation results, flow velocity at the said area is as fast as about 40 to 90 cm/s. The highest preventive efficiency of an oil fence is 20 cm/s, and sufficient preventive efficiency for oil inflow in this area cannot be expected.

3) According to the numerical simulation, markers flowing near the seashore are almost drawn into the channel from the offshore area 5 km from the embankment.

In Case 2, an oil fence must be extended up to more than 5 km.

(2) Encircling Oil Fence Method in the offing of Abu Dhabi Island

As mentioned above, utilization of semi-fixed oil fence at the said area is not practical from the view point of preventing effluence and economy.

Therefore, to minimize invasion oil into the said places and for prevention of a contamination accident in the Gulf, the best way is to provide an oil fence extension ship and an oil recovery ship which are always prepared nearby the said place, and the prevention of oil dispersion and oil recovery in the Gulf should be carried out by those ships.

1) Encircling oil fence extension ship

Generally, an oil fence ship drags a previously extended oil fence and goes to the site to prevent oil dispersion. But, as prompt action is necessary, an on-board oil fence ship which is able to carry, extend and rewind an oil fence is preferable.

2) Oil recovery ship

Generally, oil enveloped by an oil fence is recovered by an oil recovery ship. Although the on-board oil fence ship mentioned above has some kinds of oil recovery facilities, preparation of a professional oil recovery ship is preferable.

5.3.4 Prevention of Oil Inflow at Entry Part of South Basin of Umm Al Nar Plant

According to the results of numerical calculation, inflowing oil into lagoon will probably arrive at the sea water intake of Umm Al Nar Plant through the channel between Assamaliyah and Essall. Also, inflowing oil originated from an accident occurred in the vicinity of an intake will flow to the intake in all probability.

Considering marine and geographical conditions at the sea water intake point of Umm Al Nar Plant, influence of oil contamination shown in previous paragraph are considered as follows:

1) Inflow oil nearby the sea water intake has some tendency to gather nearby the No. 3 sea water intake of Umm Al Nar Plant.

2) Oil, once it passes into the sea water intake, seems to be recirculated in the plant by the influence of waste water nearby the sea water intake and/or brine discharge from Umm Al Nar Station. Theerefore, the influence of oil contamination in the plant would continue for a long time.

3) As the surface sea water is completely introduced into the plant by presently used sea water intake system at the time of lowering of tide level, any oil near the sea water intake system will be apt to be introduced into the plant together with the surface sea water.

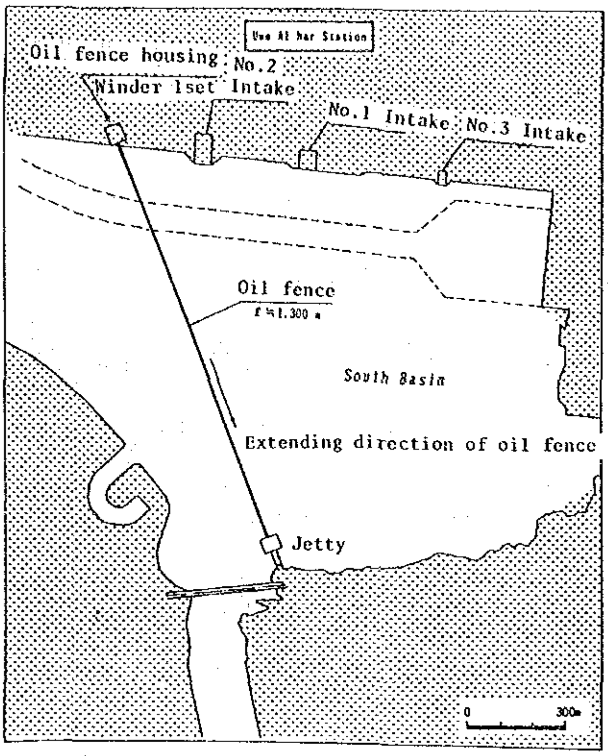


Fig. 5.3.2:Location of Oil Fence Extended (Umm Al Nar Station)

Therefore, regarding protection of station from oil pollution, it would be very effective to prepare an oil inflow prevention system at the entry of South Basin of Umm Al Nar Plant. Oil fence extension at this sea area is shown in Fig. 5.3.2. An oil fence is normally wound on a winder, located at Umm Al Nar Station side so as not to block the sea route. The oil fence will be extended from Umm Al Nar Plant side to the opposite side only when there is some fear of oil invasion.

Oil fence and accessories are described hereinafter.

(1) Oil Fence (length of 1,300 m)

Marine conditions at this area are as follows:

Tidal currents: 20 cm/s
Wave: negligible
Wind velocity: 15 m/s

According to the above mentioned marine conditions, a normal oil fence would be sufficient. But this time, a B-type oil fence having a long skirt, will be adopted. There are many kinds of B-type oil fences approved by the Ministry of Transport in Japan. One of the B-type oil fences is shown in Fig. 5.3.3.

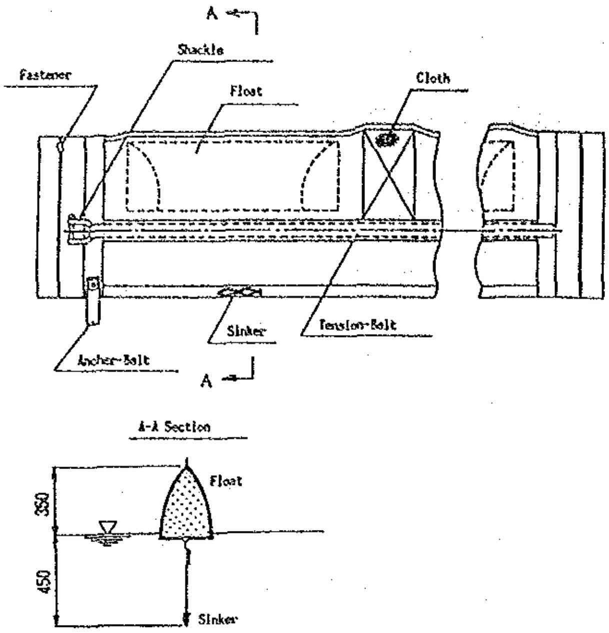


Fig. 5.3.3: B-type Oil Fence

(2) Oil Fence Winder

Installation of an oil fence winder at the embankment of Umm Al Nar Plant is necessary for the speedy extension and rewinding of the oil fence in cases of emergency. An oil fence winder is shown in fig. 5.3.4.

Fig. 5.3.4: Oil Fence Winder

(3) Oil Fence Extension Ship

An oil fence extension ship is necessary to use an oil fence winder effectively and also must always be prepared and ready nearby the winder in case of emergency. An oil fence winder and working extension ship is shown in Fig. 5.3.5.