Chapter 5

Countermeasures against Prevention of Oil Contamination and Their Evaluation

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Chapter 5 Countermeasures against Prevention of Oil Contamination and Their Evaluation

5.1 Numerical Calculation on Oil Dispersion

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

Therefore, in order to predict the flow routes and the arrival time of spilled oil, current conditions around the Abu Dhabi Island should be estimated by way of numerical calculations. Based on these calculations on current conditions, movement of the oil is traced using Lagrangian particle instead of the oil itself.

The program of numerical calculation is shown in Fig. 5.1.1

(1) Object

The object of this section is to obtain the basic data necessary for the selection of the monitoring points and of the construction locations of oil.

As for the examination of the oil contamination monitoring system and the oil preventive system, it is important to obtain information about the routes and the arrival times of the spilled oil. The condition of the currents around the area of the Abu Dhabi Island and around the intake facilities of Umm Al Nar Station is the predominant factor in the movement of the oil.

Therefore, in this section, current conditions will be examined from the results of site surveys and prediction models will be selected so as to reproduce the current conditions of the subject area, thus enabling the current conditions to be predicted.

(2) Current Conditions of Subject Sea Area

The most important item regarding the routes and arrival times of inflowing oil is to grasp the current conditions of the subject sea area fully, and to reproduce the current features of the sea area.

The following is the summary of survey results.

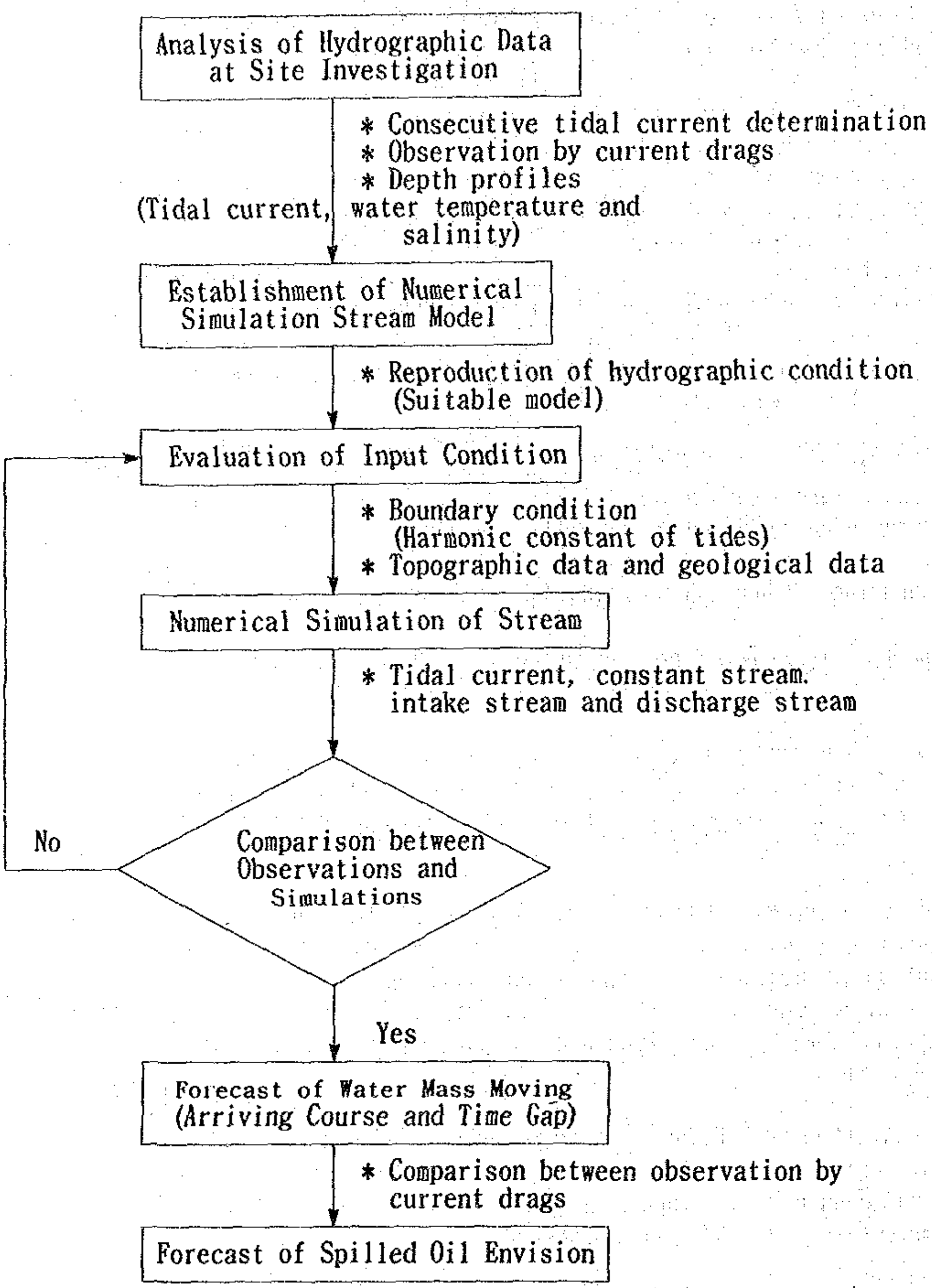


Fig. 5.1.1 Flow Chart of Numerical Calculation

1) Component of Tidal Current

A tidal current caused by an up-down motion of tide is predominant among currents inside the lagoon. Its current speed and current direction vary constantly from one time to another. The variations of the current around this area will be examined at Site 9 located on Baghal Channel at a strong current site.
The current is a composite tidal current consists of 4 tidal components Tide M_2 and Tide S_2 having about a 12 hour period, and Tide K_1 and Tide O_1 having about a 24 hour period. The above 4 tidal components are called the principal four tidal components and most of the tidal current conditions in subject sea area can be reproduced by them. The fluctuations of the four tidal components are as shown in Fig. 5.1.2 in comparison with the observed data.

According to this figure, (M_2 + S_2) shows a composite current of tides M_2 and S_2, (K_1 + O_1) shows composite current of tides K_1 and O_1, and (K_1 + O_1 + M_2 + S_2) shows a composite current of the principal 4 tidal components. Each composite current varies for 15 days per one period. The lowest figure is from raw data observed at the actual site, which indicates that the composition of the 4 principal tidal components reproduces an observed value well. However, (M_2 + S_2) for a 12 hour period is also enough to reproduce the rate of a current velocity.

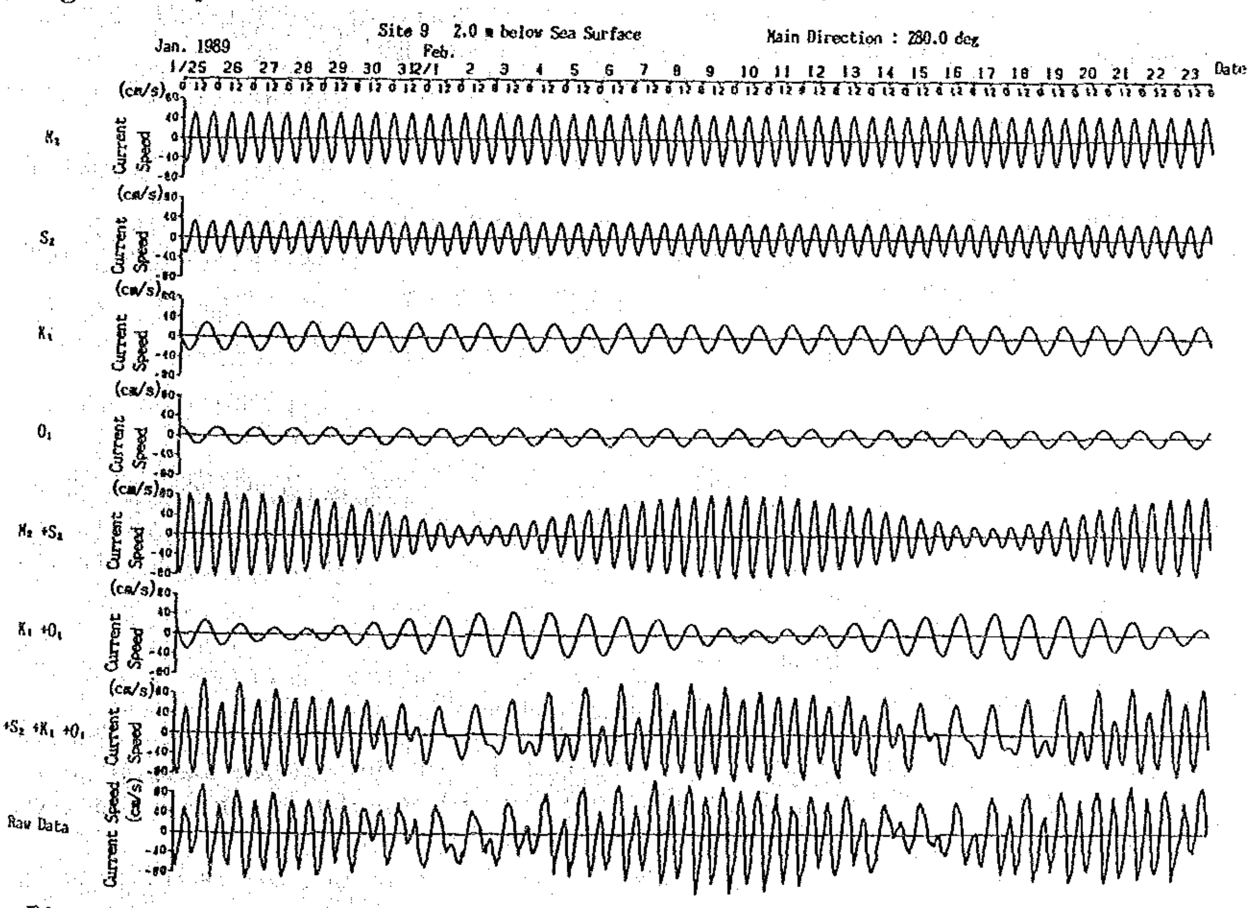


Fig. 5.1.2: Current Velocity Fluctuation of Each Tidal Component at Site 9

Due to the above reasons, in order to reproduce the tidal current of the subject sea area, it is appropriate to consider the four principal tidal components; Tide M_2, Tide S_2, Tide K_1 and Tide O_1.

2) Constant Flow of Ocean Current around Abu Dhabi Island

In this survey, a long term scaled constant flow, which is considered as a term average current, was hardly observed. However, outside the offshore area at Site 15, a SW current of 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 at the offshore area was recognized according to the analysis.

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

As the result of the 25 hour moving average of the raw data to find a constant flow for a shorter time than the term average current, a current of 5 to 10 cm/s flowing in the same direction for several days was recognized. Considering the wind at the time, the varying conditions of the wind and of the current were both quite similar, which indicates that the constant flow for several days in the lagoon was caused by the wind.

(3) Abstract of Causal Elements of Current

As mentioned above, the current of the subject sea area is considered a composite current of a very prominent "tidal current", "a current by wind" and "a constant flow at the offshore area".

In this part, causalities of these 3 elements shall be examined.

1) Tidal Current

Tidal currents are caused by the rise/fall of tides according to time, whereby the variation period of the current corresponds to the variation period of the tide. Table 5.1.1. shows the rate of tides at the site of Mina Zayed in the subject area.

2) Current due to Wind (Drift Current)

When wind blows, a tangential stress by the wind gets on the sea surface, and its stress affects the current. Especially in the closed bay, a circulating current occurs due to the constant blows of seasonal wind or land and sea breezes, indicating a complicated current.

Table 5.1.1: Harmonic Constants of Tide at Mina Zayed

Tidal Component	Period (h)	Amplitude (cm)	Lag (o)
Tide M_2 (Principal Lunar Semi-Diurnal Tide)	12.45	40.53	26.8
Tide S_2 (Principal Solar Semi-Diurnal Tide)	12.00	15.42	83.8
Tide K_1 (Luni-Solar Diurnal Tide)	23.93	25.64	170.9
Tide O_1 (Principal Lunar Diurnal Tide)	25.82	20.05	111.8

Analysis Period: February 1987 - December 1987
Analysis Method: Harmonic analysis by the minimum squared method

To see the conditions of the wind and current in the subject area, Fig. 5.1.3 shows current velocity except tidal currents (25 hour moving average value) and wind vectors at Site 19 and Site 23.

The figure indicates that the varying conditions of the two are quite similar and that current due to wind exists. However, a changing ratio from wind to current (coefficient of wind force) and the direction of the current are flexible according to the surrounding topography or the depth of water in the area, so that they show complicated conditions.

3) Constant Flow at Offshore of Abu Dhabi Island

The current due to wind (drift current) indicated in (2) is also one of the constant flows. However, in this section, "a constant flow at the offshore area" is defined as a constant flow caused by an ocean current in the offshore of the Abu Dhabi Island, and shall be separately used from a "drift current".

Detailed information on the ocean current of Arabian Gulf are not available. However, according to the navigation guide on the channels of Arabian Gulf published by the Maritime Safety Agency, Japan, its ocean current clearly flows into the Arabian Gulf, changing to the prevailing westerly current through the Hormuz Channel during most months of the year. In the offshore of the Abu Dhabi Island, a fair current or a counter-current of the prevailing westerly current is said to exist.

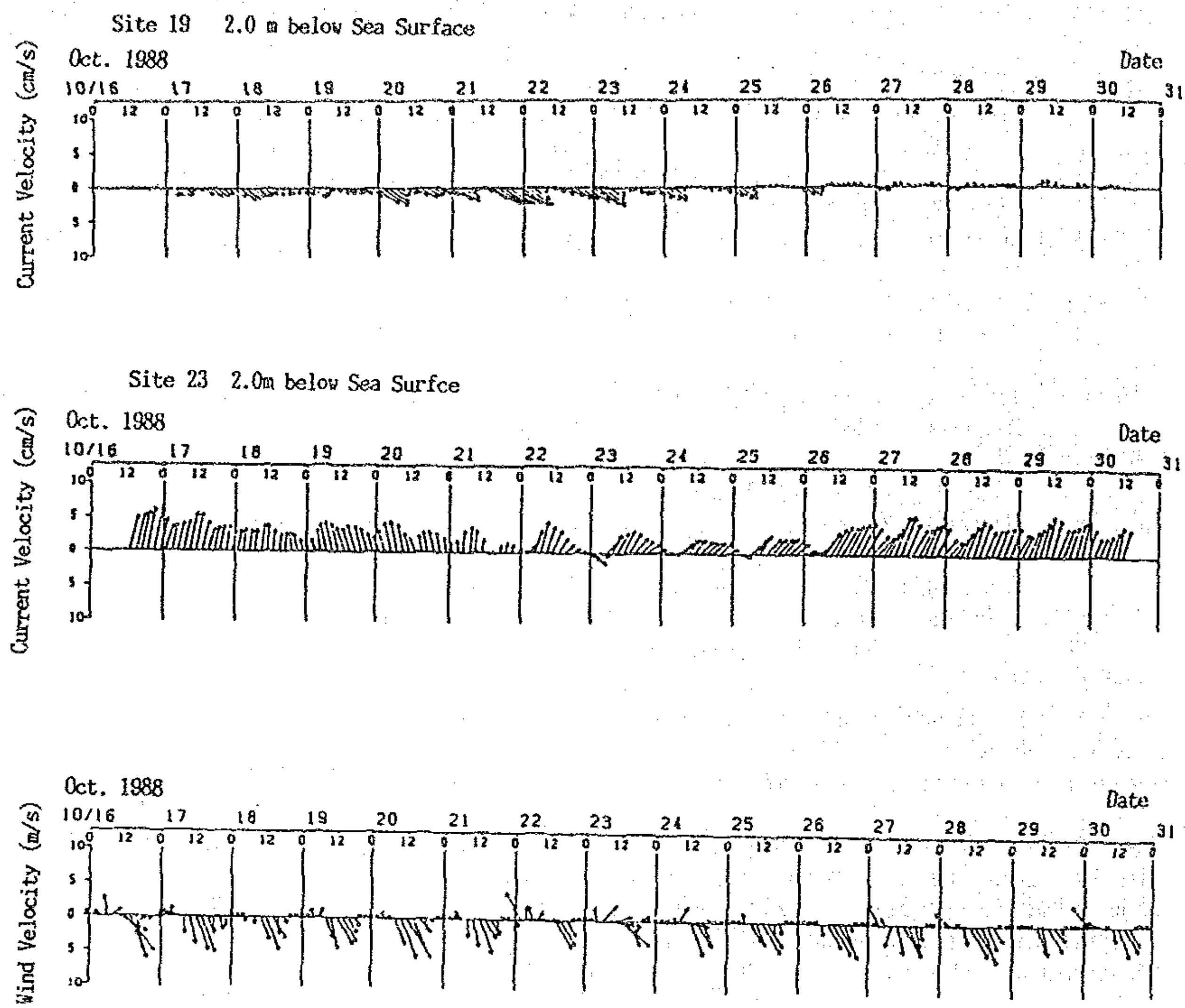


Fig. 5.1.3: Comparison between Current (25 Hour Moving Average Current) and Wind (Surveyed in October, 1988)

During the survey period of that time, October 14 to 20, 1988, the existence of a SW current of about 5 cm/s was recognized as shown in Figs. 5.1.4 and 5.1.5. Even though the existence of "constant flow" was recognized, it is hard to define it as a separate current from the above mentioned ocean current.

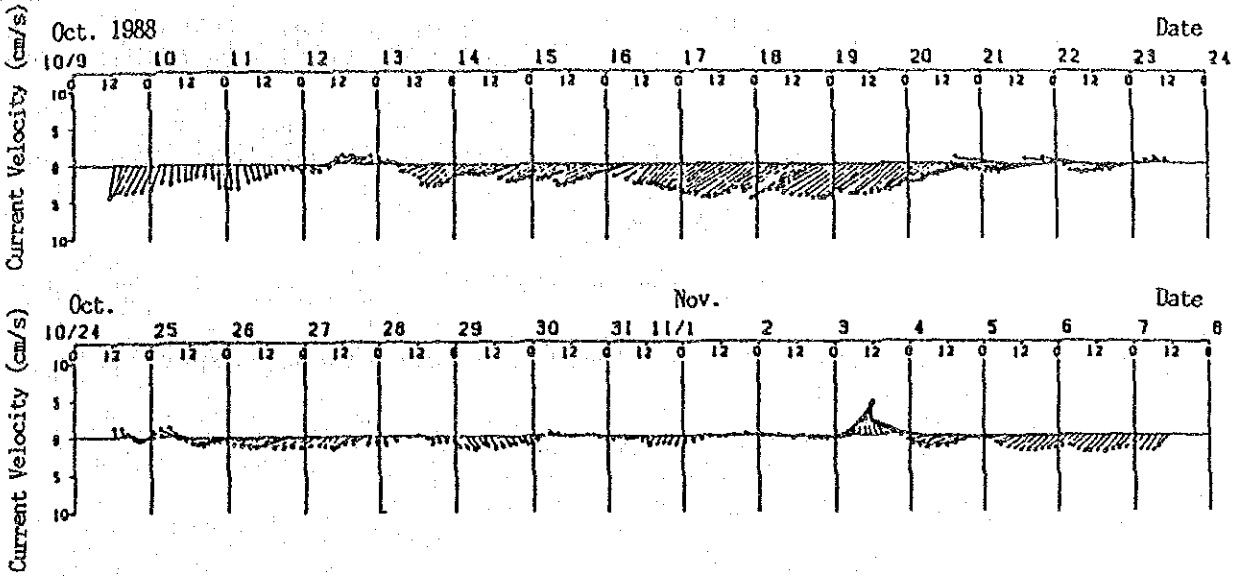


Fig. 5.1.4: 25 Hour Moving Average Current at Site 15
(Surveyed in October, 1988)

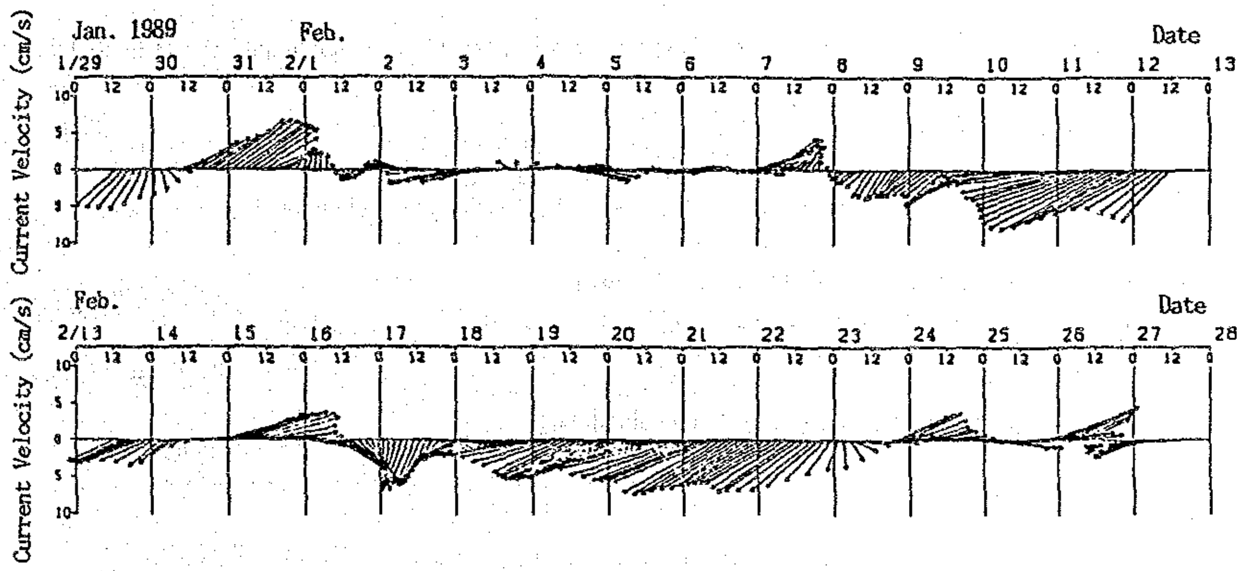


Fig. 5.1.5: 25 Hour Moving Average Current at Site 15
(Surveyed in February, 1989)

(4) Predicted Model of Current Conditions

As mentioned above, the current of the subject sea area has largely three big elements, and causal outer stresses are guessed to be "a tide-generating force", "a tangential stress by wind" and "a branch of ocean current outside the lagoon". A current with such different causal outer stresses has to be predicted in reproducing current conditions.

Though the causalities of the currents are different, the phenomena are the same, in terms of a dynamics problem to solve the motional equations of Navier-Stokes with conditions such as pressure on sea water, friction on the sea bottom and on the sea surface, and the effect of the topography.

The motion formula of Navier-Stokes and continual equations are shown below.

Equation

Where,

u, v:	Average current velocity of x, y directions respectively
ζ:	Water level
h:	Depth of water
f:	Coriolis coefficient (= 2 V sin ϕ)
ω:	Rotation speed of the earth
ϕ:	Latitude
ρ_w:	Density of sea water
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 surface are respectively:

Equation

Where,

Wx: 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

(5) Prediction Cases

Prediction will be carried out on cases as shown in Table 5.1.2.

Table 5.1.2: Prediction Case

Item	Content	Remarks
A-1 Tidal Current	Max. spring tide period (M_2 + S_2 + K_1 + O_1)	Note 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	Note 2
C-1 Drift Current	Wind direction N, velocity 5 m/s	Note 3
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	Note 4
E-1	Discharged vol. at power st. 123.3 m^3/s	

(Note 1)

As the tidal current is a composite current of each tidal component as mentioned above, periodic conditions of the tidal current of the subject sea area vary in a 15 day period. In this section, due to the reasons below, some tidal periods were proposed and predicted in 15 days.

<Maximum spring tide period>

This tide is a composite tide composed of the principal four tidal components, and it has the fastest current velocity. Therefore, the oil slick movement distance can vary the most, and it can be an important factor in selecting monitoring points in a remote area.

<Average spring tide period>

This tide has the fastest velocity period in the semi-diurnal tide. The maximum movement distance of an oil slick, or fluctuation in movement time can be established when diurnal inequality does not occur.

< Middle tide period>

This tide is called an average tide, and shows an average flowing field in this sea area. It targets an average period while the other three cases are for a special period.

<Neap tide period>

It has the slowest current velocity for 15 days. As the current velocity is slow, the velocity of sea water intake and brine discharge exceeds the the velocity of the tidal current around the intakc, and those artificial loads clearly affect the current.

(Note 2)

As mentioned previously, from the result of the field survey, at Site 15, a south-west current is observable around the constant flow of ocean currents in the offshore area, and its velocity is about 5 cm/s. Therefore, its current is reproduced here.

(Note 3)

It is very important to consider the current due to wind, when considering the floating oil which spreads mostly near the sea surface. Also, in this sea area the current due to the wind was observed from the result of the field survey.

Therefore, the drift current, a current due to wind, is to be predicted. As for the setting of a wind direction and a wind velocity, the prevailing winds, obtained from the observation results at Abu Dhabi International Airport and Bateen Airport, were referred to Fig. 5.1.6. Moreover, the wind direction assumed to affect the floating of oil was established by considering topographical features of the subject sea area.

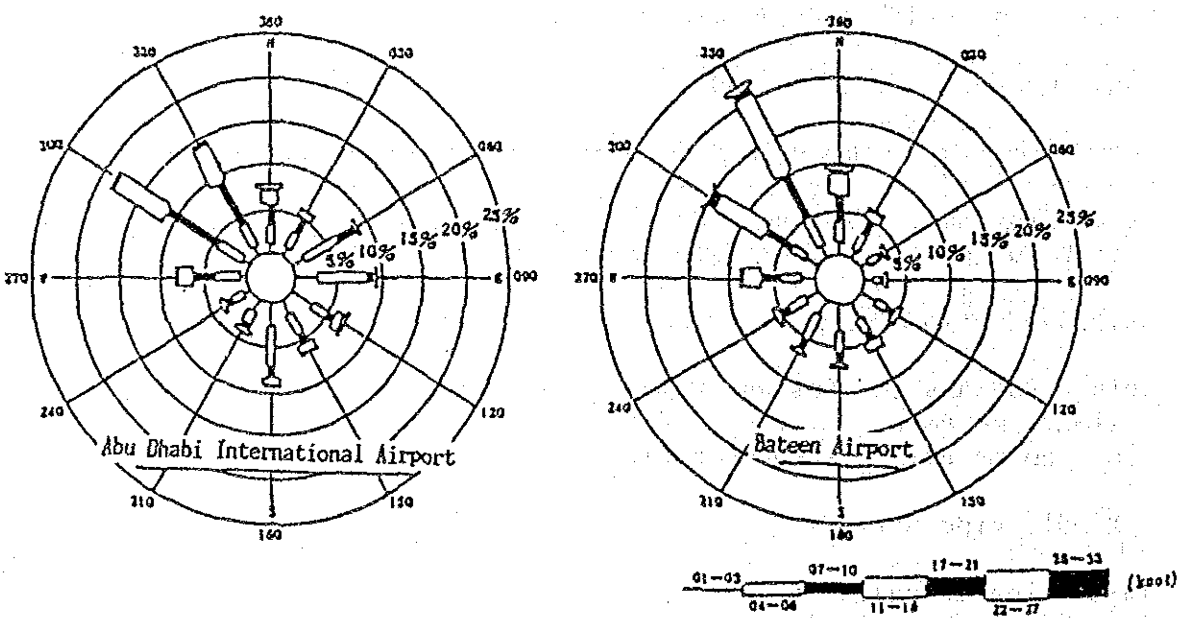


Fig. 5.1.6: Wind Rose at Abu Dhabi International Airport (1984)

(Note 4)

The above three currents are caused by natural external forces. Besides them, there is another large-scale intake and discharge of water into the subject sea area. Since the current flow is presumed to draw along the oil spill, the flow is also predicted.

Design quantities of each sea water intake and brine discharge facility are shown below.

Sea Water Intake Quantity		Brine Discharge Quantity	
Intake No. 1	220,000 m^3/h	Discharge No. 1	143,000 m^3/h
Intake No. 2	180,000 m^3/h	Discharge No. 2	178,000 m^3/h
Intake No. 3	55,000 m^3/h	Discharge No. 3	72,000 m^3/h
		Discharge No. 4	51,000 m^3/h
Total	455,000 m^3/h	Total	444,000 m^3/h
	= 126.4 m^3/s		= 123.3 m^3/s

(6) Subjective Range of Prediction

A subjective range of prediction is as shown in Fig. 5.1.7 considering the current conditions and the topography of the subject sea area. The range is as follows:

* Direction to coast (north-east, south-west)....22.8 km

* Direction to offshore (north-west, south-east)....26.6 km

Also, the area was divided into squares of 200 m each.

(7) Prediction Conditions

1) Open Boundary Condition

At the open boundary where the regions calculated adjoin the sea, the following conditions were given:

(a) Prediction of Tidal Current

A tidal variation is given with the following cosine function at the open boundary:

$$\zeta_b = h_{b2}\cos\{\omega_2 t - (\kappa_2 - \kappa_{m2})\} + h_{b1}\cos\{\omega_1 t - (\kappa_1 - \kappa_{m1})\}$$

Where,

ζ_b: Tide level at the open boundary (m)
Accompanying number: 2; Semi-diurnal tide,
1; Diurnal tide
h_b: Harmonic constant showing tidal amplitude (m)
κ: Harmonic constant showing tidal delay angle (°)

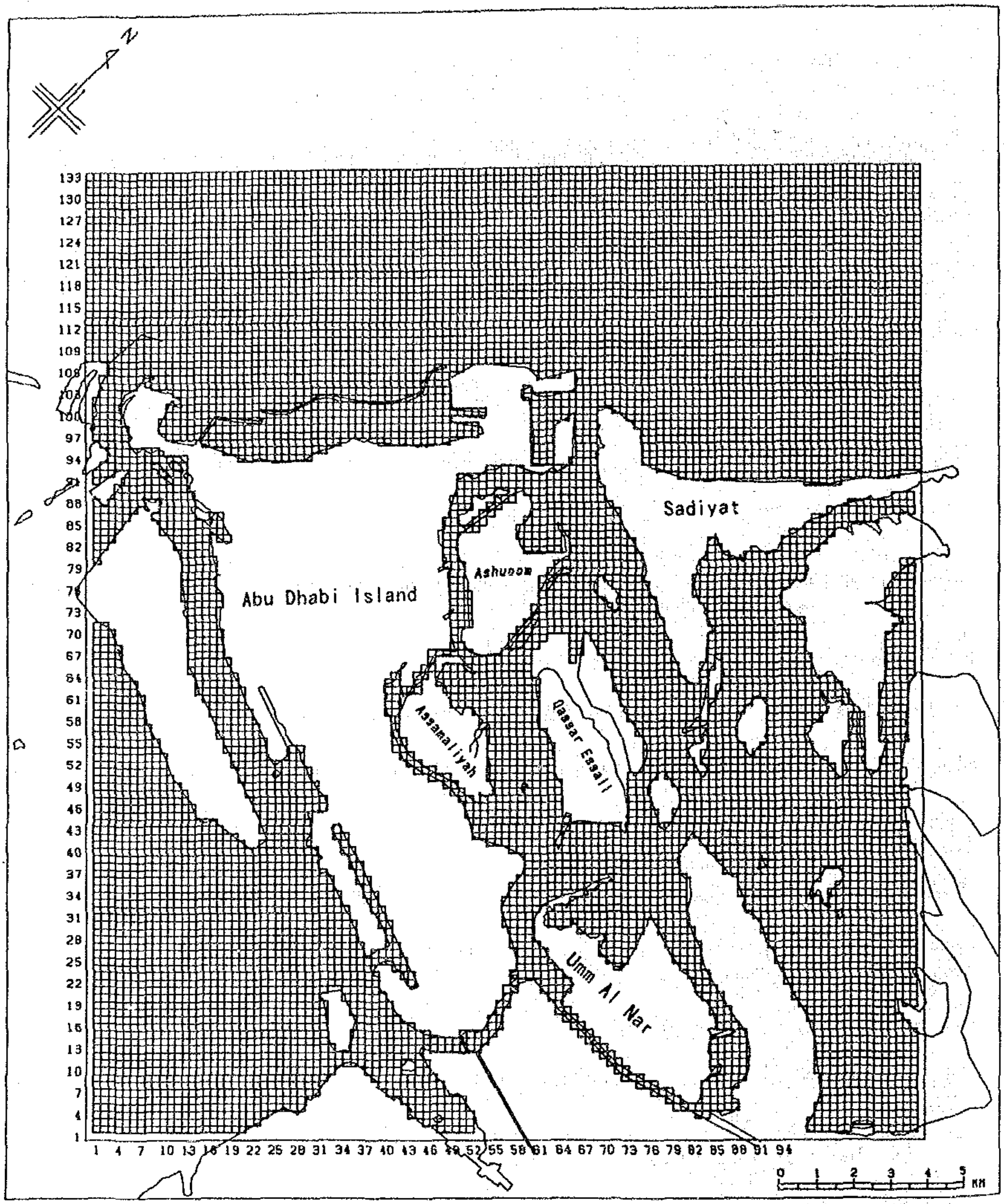


Fig. 5.1.7: Squared Nomogram (200 m x 200 m)

2) Closed Boundary Condition

The following is given considering that there is no flow through harbor structures such as land or breakwaters.

$$\frac{\partial M}{\partial n}=0 \quad \frac{\partial N}{\partial n}=0$$

Where,

M, N: Flow rate of x, y directions respectively
n: Normal direction of its current velocity direction

3) Natural Condition

The coastal topography and depth of the water were established with the following materials:

* Marine Chart No. 3170 published by Hydrographic Office, Maritime Safety Agency, Japan
* Marine Chart No. 3752, 3713 of WED
* Aerial photographs of WED

4) Calculating Coefficients

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

The viscosity coefficient of the horizontal vortex indicates the scatter of momentum accompanying the turbulent motion of sea water. Its value is not clear though it is generally said to be 10^4 to 10^7 cm^2/s. Therefore, in this item, the diffusion coefficient obtained from the flow observation result is referred to in the calculation.

The diffusion coefficients of the subject sea area are as shown in Figs. 5.1.8 and 5.1.9 and their values are 1×10^4 to 5×10^5 cm^2/s. So, an isotropy of $Ax = Ay = 5 \times 10^4$ cm^2/s is given in this item.

(b) Coriolis Coefficient (f)

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

$$f = 2\omega \sin\phi = 6.020 \times 10^{-5} \cdot s^{-1}$$

Where,

ω: Angle velocity of the rotation of the earth ($= 2\pi/(24 \times 3600)$)
ϕ: North latitude of the applied area ($= 24° 27'$)

ω: Angle velocity of tide (°/h)
ω_2 = 30.0
ω_1 = 15.0
$\varkappa_m$: Delay angle of time at standard port (°)
In this, Mina Zayed is set up as a standard point
t: Time (h)

For determining the harmonic constants, h_b and $\varkappa$, the tidal harmonic constants of the observed tide levels were referred to, and the following was proposed from the results of the trial and error testing of the conformity of the current.

An offshore boundary was searched for at the linear interpolation between the SW boundary and the NE boundary.

(b) Calculation of Constant Flow

A water level difference is given so as to have the postulated velocity (5 cm/s) at the offshore located 5 km out from Mina Zayed.

(c) Calculation of Drift Current

A wind velocity of 5 m/s is given as the established wind directions (N, NW and S).

An open boundary at this time is a free boundary.

Table 5.1.3 Condition of Open Boundary

Case	Tidal Period	Boundary at South-West		Boundary at North-East	
		h_b (m)	$\varkappa$ (o)	h_b (m)	$\varkappa$ (o)
A1	Max. Spring Tide Tide	h_{b1} 0.64 h_{b2} 0.45	$\varkappa_1$ 24.5 $\varkappa_1$ 141.5	h_{b1} 0.64 h_{b2} 0.45	$\varkappa_1$ 29.5 $\varkappa_1$ 151.5
A2	Ave. Spring Tide	0.64	24.5	0.64	29.5
A3	Middle Tide	0.41	24.5	0.41	29.5
A4	Neap Tide	0.15	24.5	0.15	29.5

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

The friction of the sea bottom is a horizontal force acting on the sea bottom. In a numerical prediction, the friction of the sea bottom is treated as the proportion of an absolute dimension of horizontal direction to a component of current velocity, on the other hand, a single stratum of ocean is for a long period wave. The proportion constant is the friction coefficient of the sea bottom. This is defined as below.

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

Where,

g: Gravity acceleration (= 9.8 m/s²)
c: Roughness coefficient of Chezy
$c = n^{-1} \times h^{1/6}$
n: Roughness coefficient of Manning(= 0.026 $m^{-1/3}$ s^{-1})
h: Depth of water (m)

(d) Coefficient Involving Friction of Sea Surface

<Resistance coefficient of the sea surface *1)	C^D = 0.0026
<Proportional constant *1	k = 0.25
<Air density *2)	ρ_a = 0.0012 g/cm³

Note: * The Port and Harbor Research Institute, Ministry of Transport: Numerical Simulation of Storm Surges by Alternating Direction Implicit Method:
Thchnical Note of the Port and Harbor Research Institute, No. 529, Sept. 1985

** Tokyo Astronomical Observatory: Chronological Table of Science, 1988

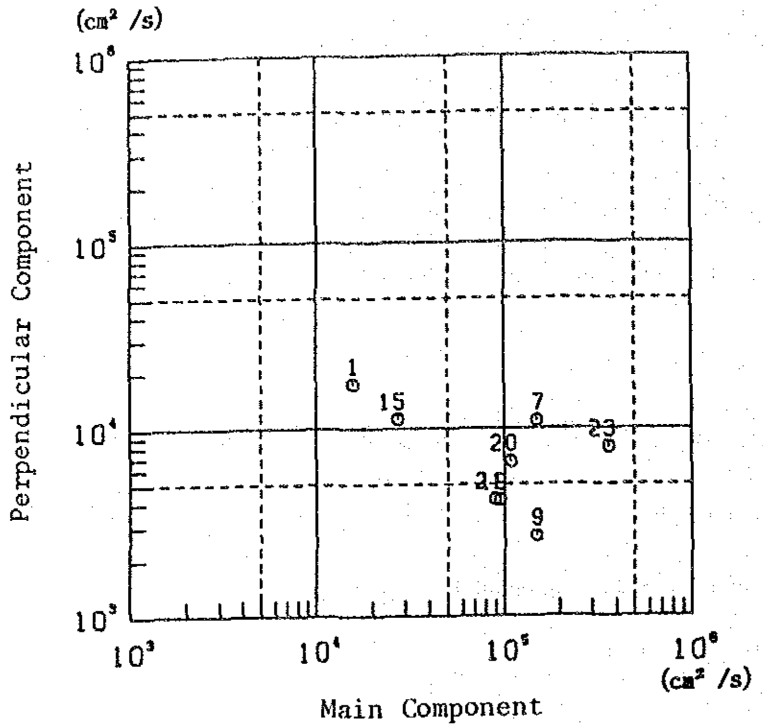


Fig. 5.1.8: Diffusion Coefficient (Surveyed in October, 1988)

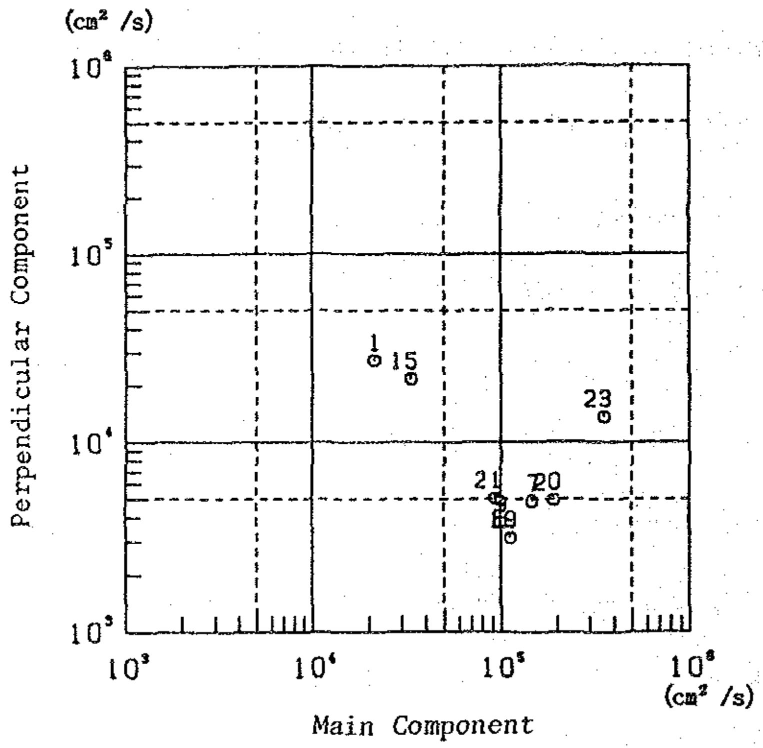


Fig. 5.1.9: Diffusion Coefficient (Surveyed in February, 1989)

(8) Conformity Examination of Predicted Value and Actual Value

1) Prediction of Tidal Current

As shown in Fig. 5.1.10, a tidal current observation was carried out at 8 sites altogether. Using these results, a tidal current ellipse were examined by the harmonic constant of tidal current and a tidal current hodograph of the predicted value.

"The inspection of current direction", can be obtained from the direction of the main axis of the tidal current ellipse, "the inspection of a current rate" from the current velocity of its main axis, and "the inspection of the time fluctuation of a current" from the tidal time, through examination.

The comparison between the tidal current ellipse of the actual values and the tidal hodograph of the actual values, at the period of average spring tide are shown in Figs. 5.1.11 and 5.1.12.

Moreover, the comparisons between the main axis directions and the value of current velocity of each site is shown in Table 5.1.4.

These results indicate that the predicted values of the current direction and the current velocity at Site 23, out of eight sites, do not accord to the actual values. Presumably the site is in a narrow channel and the 200 m of the square of prediction was not enough to reproduce the topography. As for the other seven sites, the predicted values generally accord to the observed ones. And the conformity of the prediction model to the subject sea area and the appropriateness of prediction conditions was confirmed.

2) Prediction of Constant Flow

A reproduction of the proposed "SW current, 5 cm/s at a 5 km point off the shore of Mina Zayed" will be shown with regards to the component of a constant flow offshore of the Abu Dhabi Island.

As for the current velocity at the 5 km point off from Mina Zayed, the current velocity proposed at "5.2 cm/s", and "current direction 225 degrees" were obtained, and the appropriateness of the 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 in the prediction. However, the result of the drift current prediction model and its condition were guessed appropriately, judging from the fact that the conformity at other sites was fully checked.

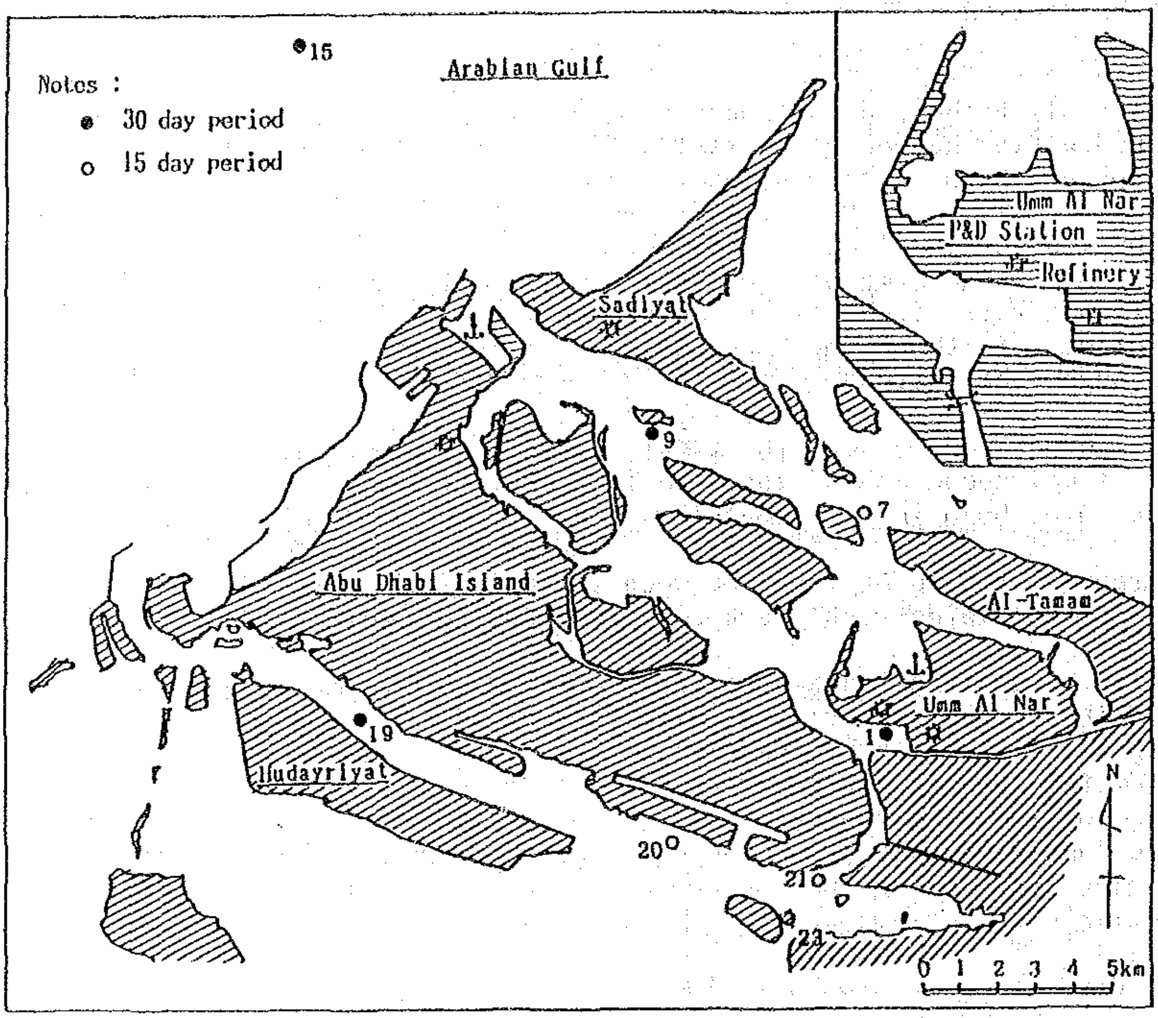


Fig. 5.1.10: Continual Survey Points of Proposed Current Condition

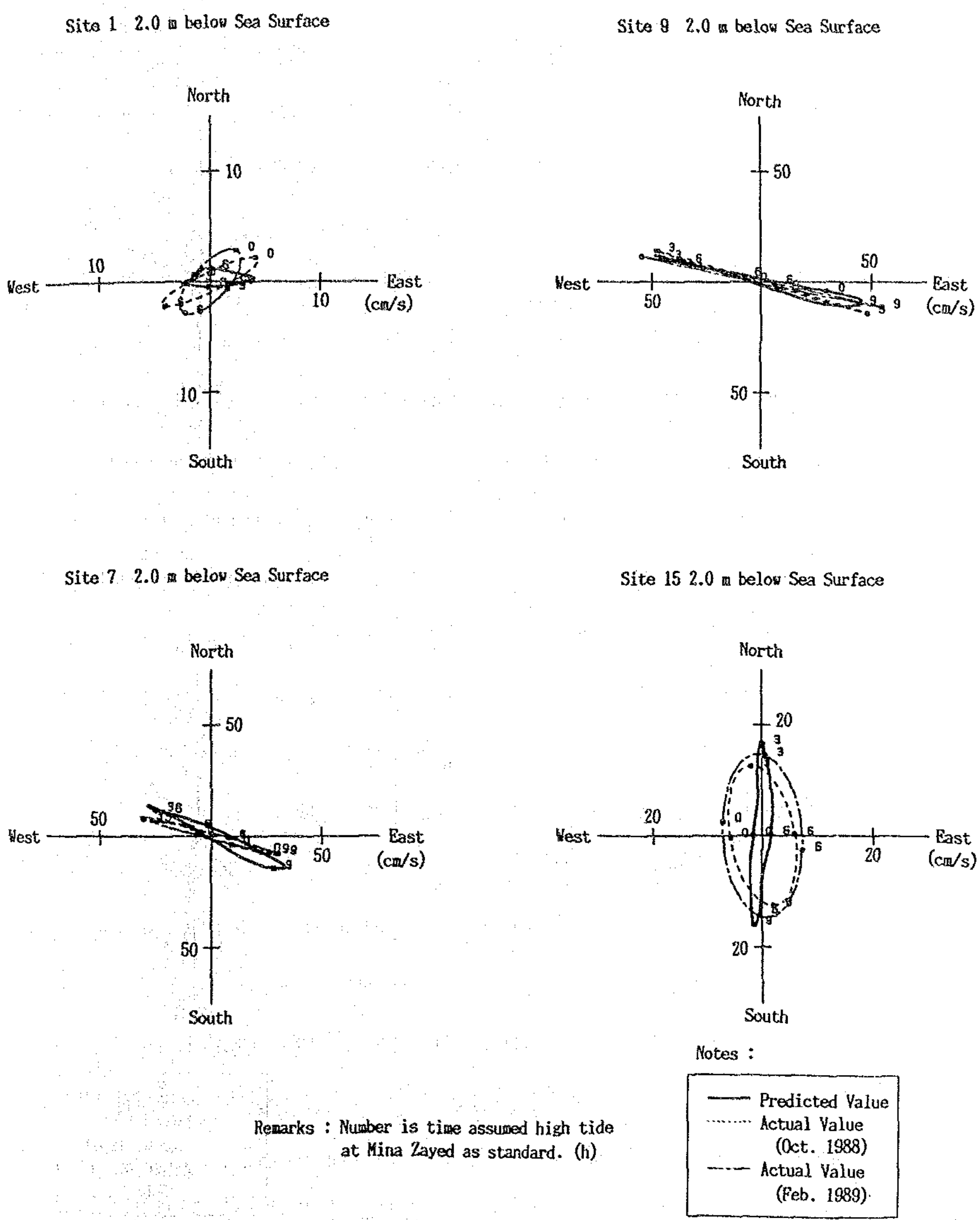


Fig. 5.1.11: Comparison between Actual Value (Tidal Current Ellipse) and Predicted Value (Tidal Current Hodograph)

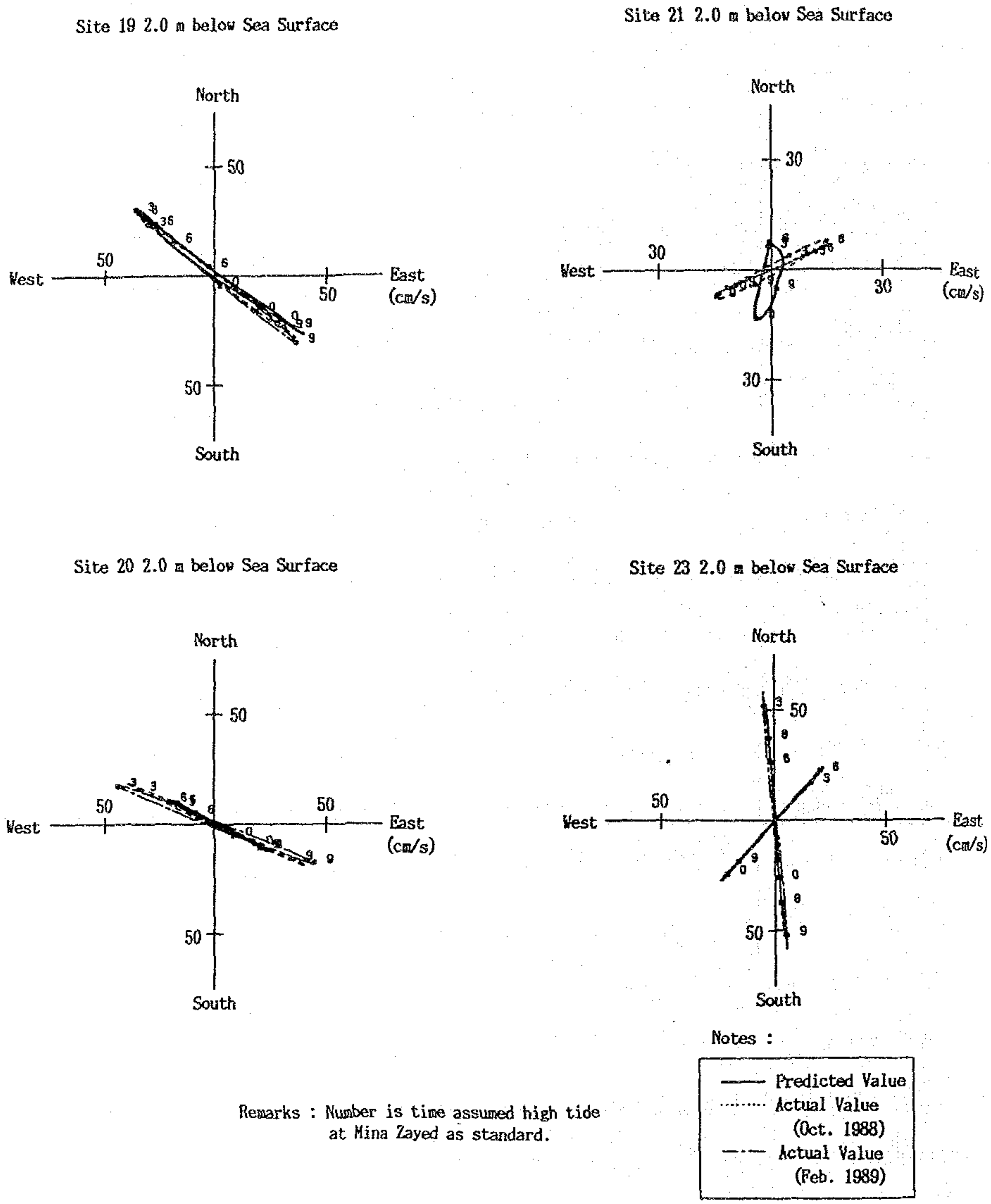


Fig. 5.1.12: Comparison between Actual Value (Tidal Current Ellipse)
and Predicted Value (Tidal Current Hodograph)

Item		Max. Spring Tide		Ave. Spring Tide		Middle Tide		Neap Tide	
		M Ax	CVel	M Ax	CVel	M Ax	CVel	M Ax	CVel
1	Act.	72	6	65	5	60	3	60	1
		70	7	54	5	44	3	44	1
	Pred	85	4	85	4	85	3	83	2
7	Act.	284	58	285	33	286	23	286	12
		285	44	284	28	286	20	286	12
	Pred	288	60	293	37	293	28	296	15
9	Act.	288	89	287	51	287	35	287	18
		284	802	284	54	282	35	282	14
	Pred	288	89	284	50	284	39	283	21
15	Act.	10	29	349	13	346	9	346	5
		11	30	347	14	357	9	357	3
	Pred	0	30	359	17	2	12	2	5
19	Act.	308	86	308	46	308	32	308	18
		310	72	311	46	311	31	311	15
	Pred	312	88	304	48	310	39	310	23
20	Act.	299	58	295	45	296	30	296	16
		297	58	296	39	292	33	292	18
	Pred	299	31	297	26	297	20	297	12
21	Act.	62	28	62	17	63	12	63	6
		67	24	67	16	67	11	67	6
	Pred	36	34	16	14	15	11	10	6
23	Act.	358	99	356	53	357	38	357	22
		358	95	357	62	355	38	357	18
	Pred	43	52	41	36	42	29	42	17

Remarks: CVel: Current Velocity (cm/s)
M Ax: Main Axis (degrees)
Act.: Actual Value
Pred: Predicted Value

Note: Upper of Actual Value is done in October 1988.
Lower of Actual Value is done in February 1989.

Table 5.1.4 Comparison between Predicted Value and Actual Value

Table 5.1.5: Figure Number List of Prediction Result

Prediction Item around Abu Dhabi Island		
Tidal Current	Max. Spring Tide Period	Figs. 5.1.14, 5.1.15
	Ave. Spring Tide Period	Figs. 5.1.16, 5.1.17
	Middle Tide	Figs. 5.1.18, 5.1.19
	Neap Tide	Figs. 5.1.20, 5.1.21
Constant Flow (Ocean Current)		Fig. 5.1.22
Drift Current	Wind Direction N	Fig. 5.1.23
	Wind Direction NW	Fig. 5.1.24
	Wind Direction S	Fig. 5.1.25

5.1.1 Current Conditions around Abu Dhabi Island

(1) Calculation Result

The result of current conditions around the Abu Dhabi Island is shown in Table 5.1.5.

(2) Summary of Current Condition

The prediction was carried out on each component of "tidal current component", "constant flow (ocean current) component", "drift current", and "intake and discharge water", which predominate over the current conditions of the subject sea area. The result is as follows:

1) Component of Tidal Current

(a) Rate of Current Velocity

The fastest current velocity at the entrance of the lagoon is about 1 to 1.5 m/s at the maximum spring tide and about 1 m/s at the average spring tide. This is presumably due to the fact that that area is the place where the entrance and exit of the water mass to the vast lagoon area occurs. An outline value concerning the current velocity will be calculated.

Q, the outflow and inflow of sea water at a certain cross section, as being equal to S x dh/dt, a variation of water capacity in the cross section, is expressed by the following formula:

$$Q = S \times \frac{dh}{dt} = S \times \frac{\pi \zeta}{T} \cos \frac{2\pi}{T}$$

Where,

ζ: Tide level
T: Tidal amplitude
h: Water level
S: Water surface area in cross section

Also,

ζ: 1.1 m (Average spring tidal period)
T: 12 x 3,600 = 43,200 s (12 hours period is applied)
π: 3.14
S: 60-80 x 10^6 m²
(Though being the water surface area, it is an outlined value since the affected waters through the entrance are not clear.)

Therefore, the volume at the fastest current velocity becomes;

Q=4, 800 - 6,400 m³/s

Also, the sectional area of the bay entrance being about 5,500 m² the outlined current velocity at the maximum becomes:

(4,800 - 6,400) / 5,500 = 0.87 - 1.16 m/s

In such cases the predicted value generally accords with the current velocity outline, and the current velocity at the bay entrance of the lagoon is assumed to be caused by the alternating current volume of sea water in the lagoon.

(b) Flow Conditions of Sea Water

Presumably there are two openings for the flow of sea water to the subject area from the open sea, that is, Mina Zayed and Khalidiya (about 12 km SE of Mina Zayed). The outline of routes and flows of sea water is as shown in Fig. 5.1.13, though they change according to the tide periods.
Summaries of observation results of current conditions around the Abu Dhabi Islands are as follows.

* The sea water flowing from Khalidiya goes up mostly around the S-most end of the Abu Dhabi Island.

* The sea water flowing from Mina Zayed is divided into one stream going up SE through Baghal Channel, and the other going up through the channel at the north side of Ashuum-Samliyah-Abu Dhabi Island.

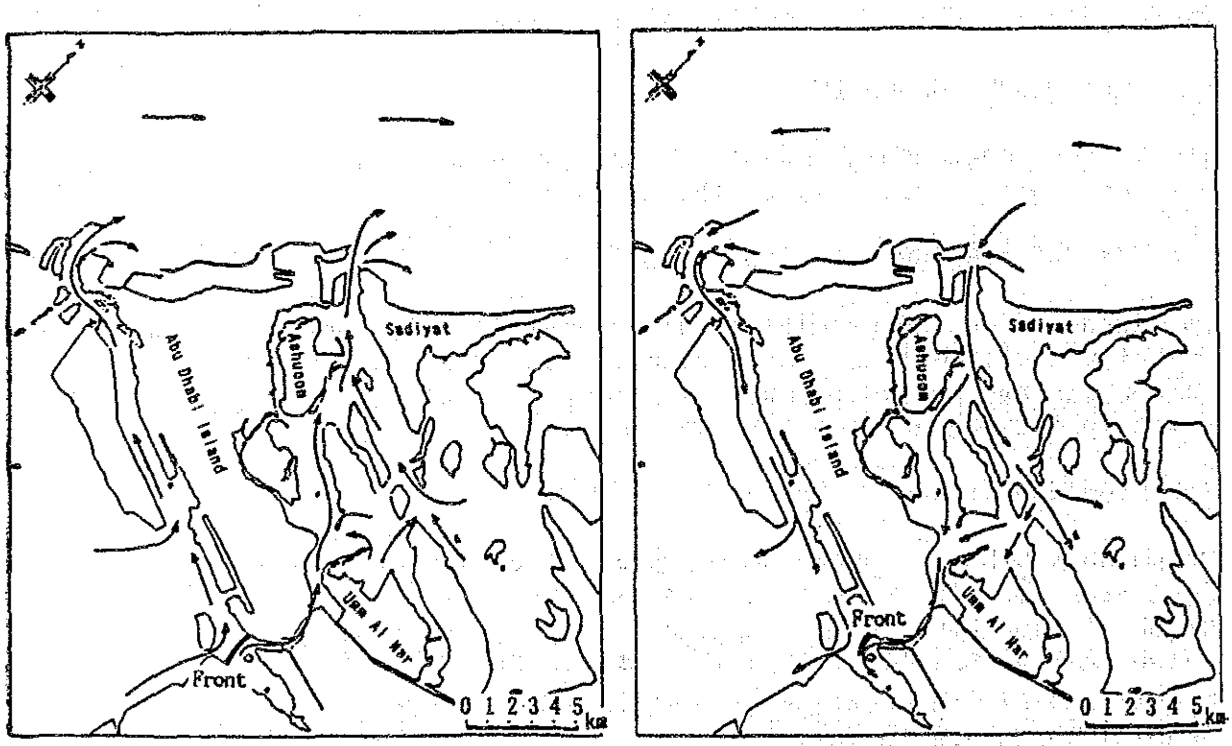
2) Component of Constant Flow

The SE current was assumed to be the constant flow of ocean currents in offshore of the Abu Dhabi Island. However, the component of this constant flow hardly affects the current in the lagoon.

3) Component of Drift Current

As for the drift current by constant wind blow, three wind directions (N, NW and S) were predicted. Reflecting the complexity of the topography of the subject area, a topographical whirlpool has developed very much.

Besides that, as is the general trend, the current direction becomes a fair current towards the wind direction in deep sea water, and its countercurrent occurs in shallow water. A horizontal circulation current is stressed since the prediction was based on a single stratum model.



Offshore Current

Inshore Current

Fig. 5.1.13: Flowing Condition of Sea Water

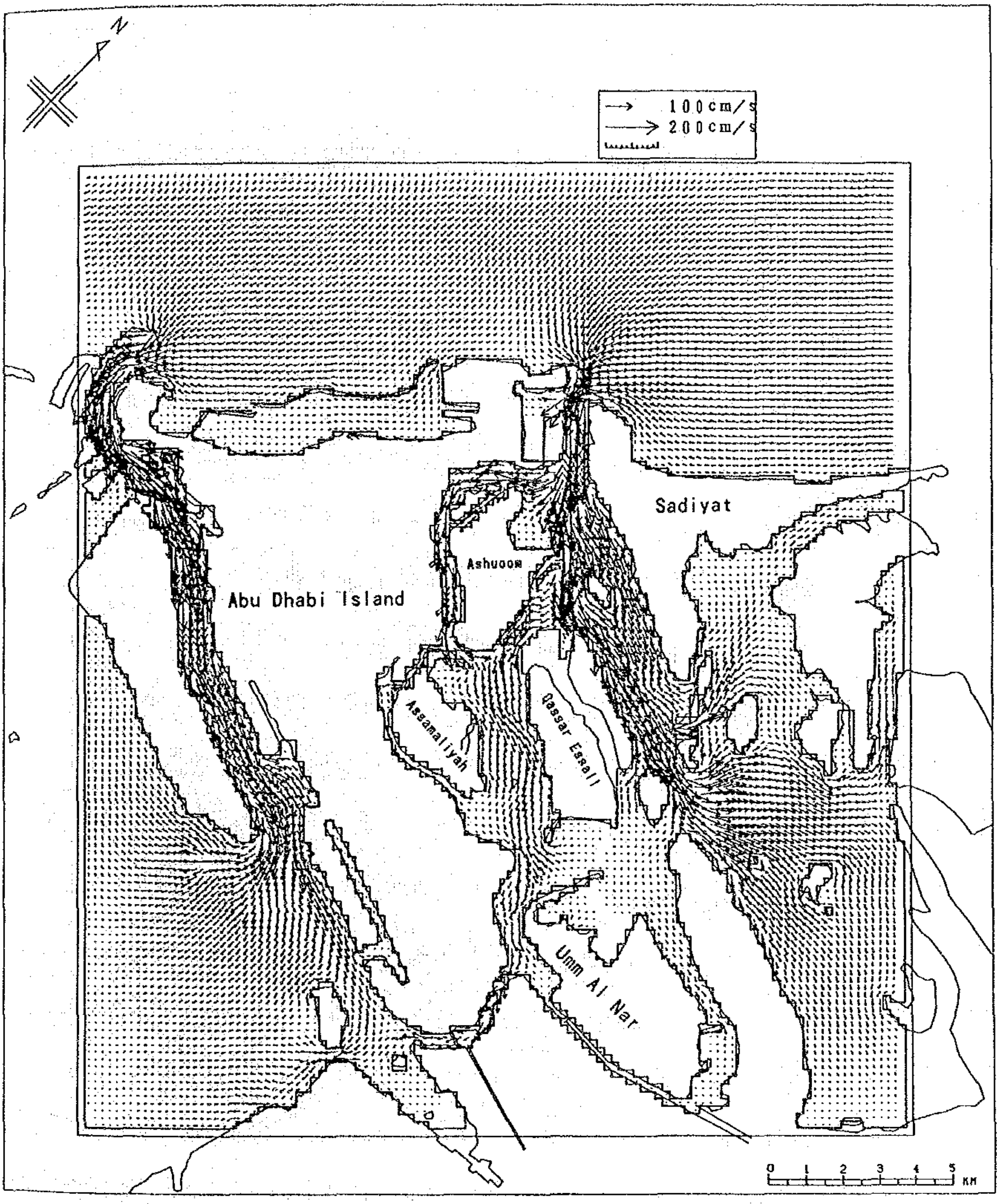


Fig. 5.1.14: Current Velocity Vector at Maximum Spring Tide
(Fastest Flood Current at Mina Zayed)

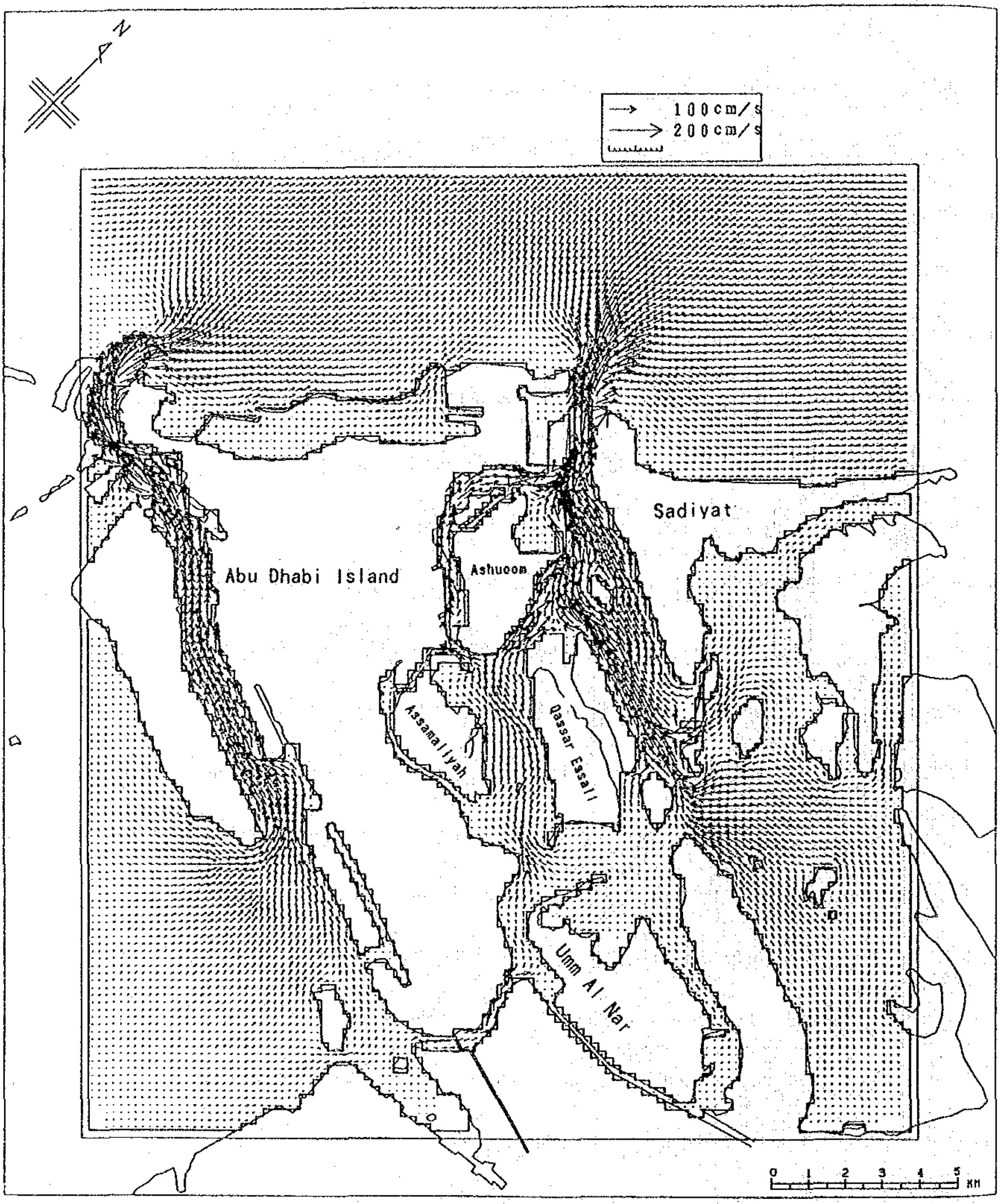


Fig. 5.1.15: Current Velocity Vector at Maximum Spring Tide
(Fastest Ebb Current at Mina Zayed)

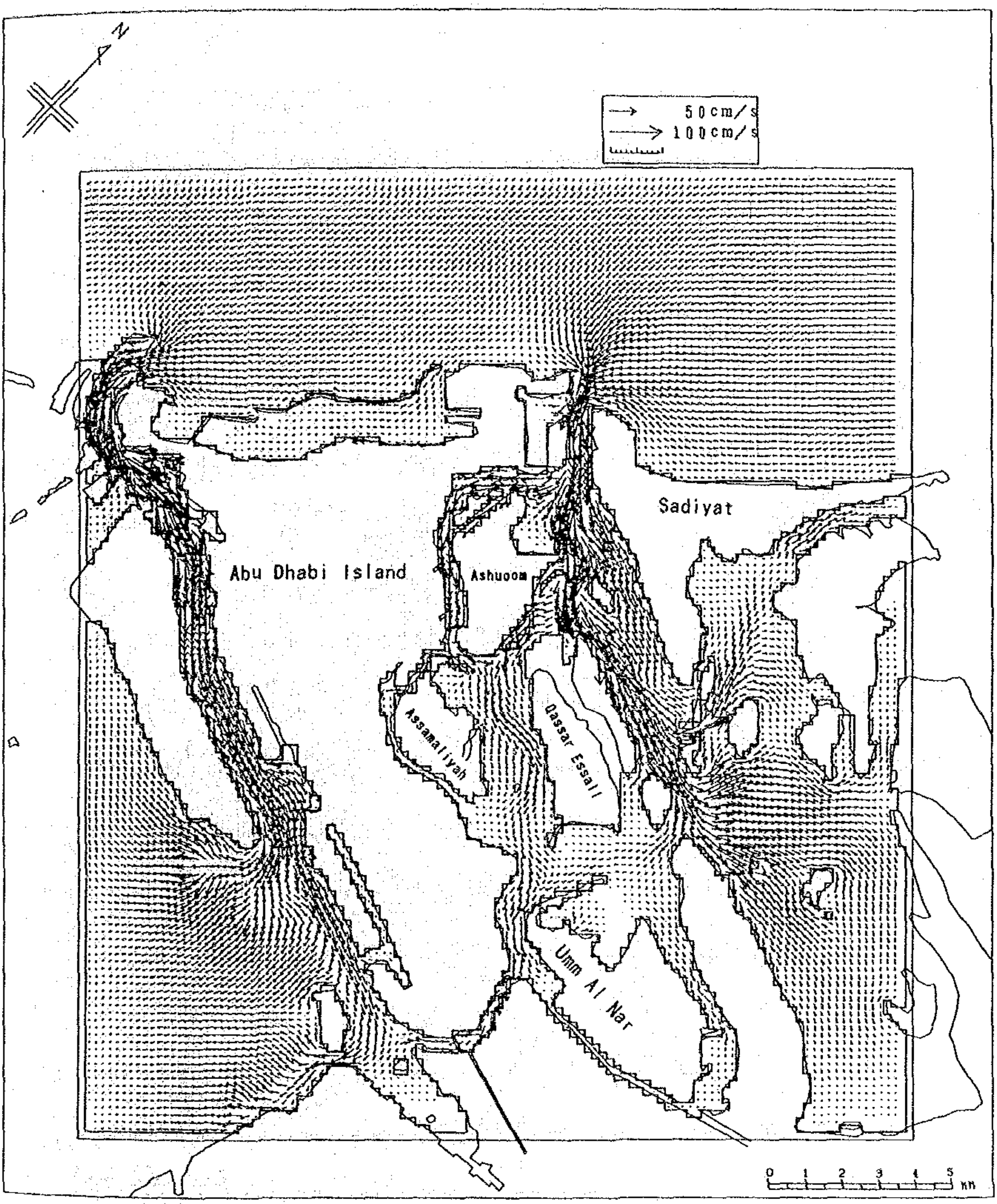


Fig. 5.1.16: Current Velocity Vector at Average Spring Tide
(Fastest Flood Current at Miza Zayed)

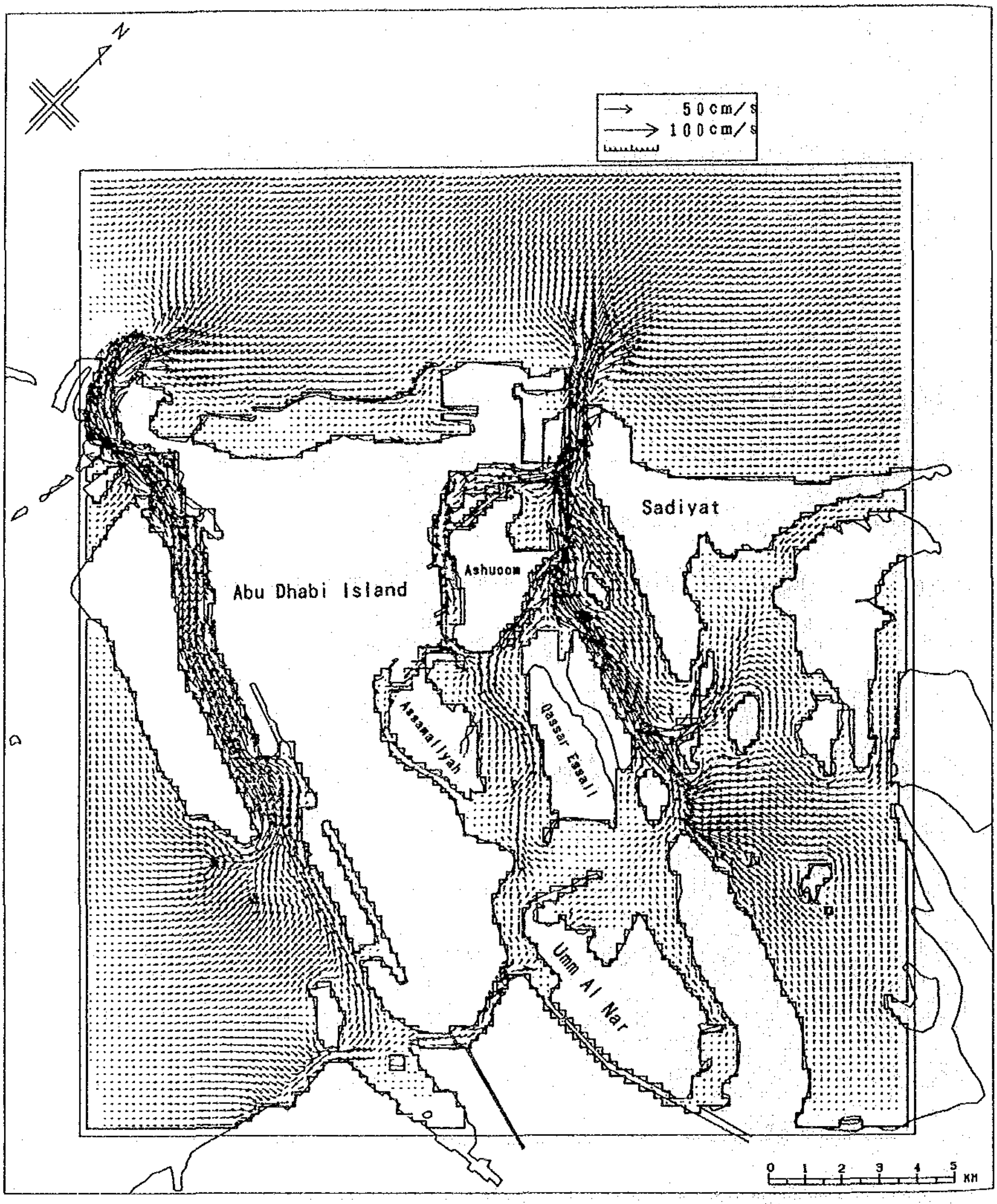


Fig. 5.1.17: Current Velocity Vector at Average Spring Tide
(Fastest Ebb Current at Miza Zayed)

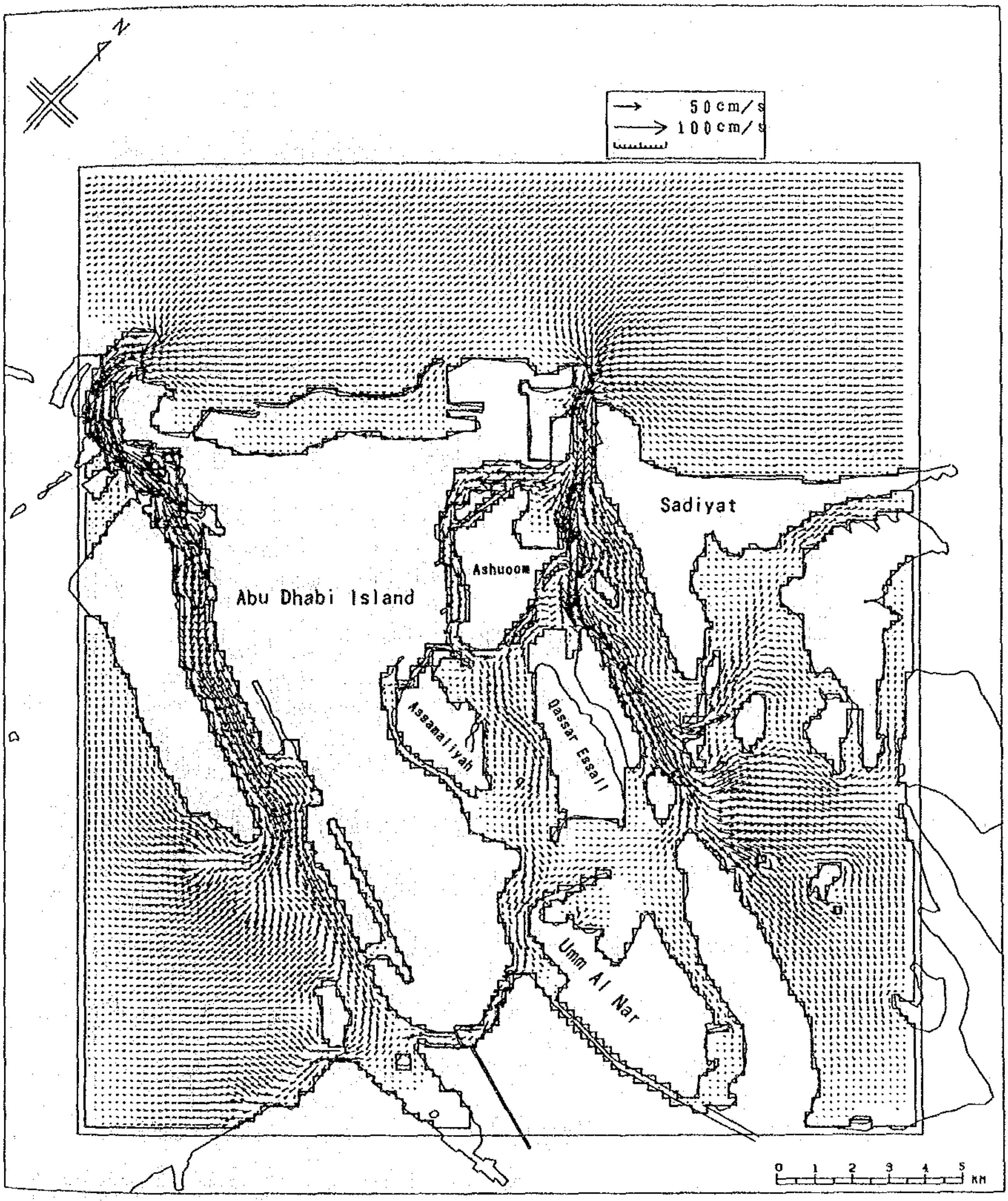


Fig. 5.1.18: Current Velocity Vector at Middle Tide
(Fastest Flood Current at Miza Zayed)

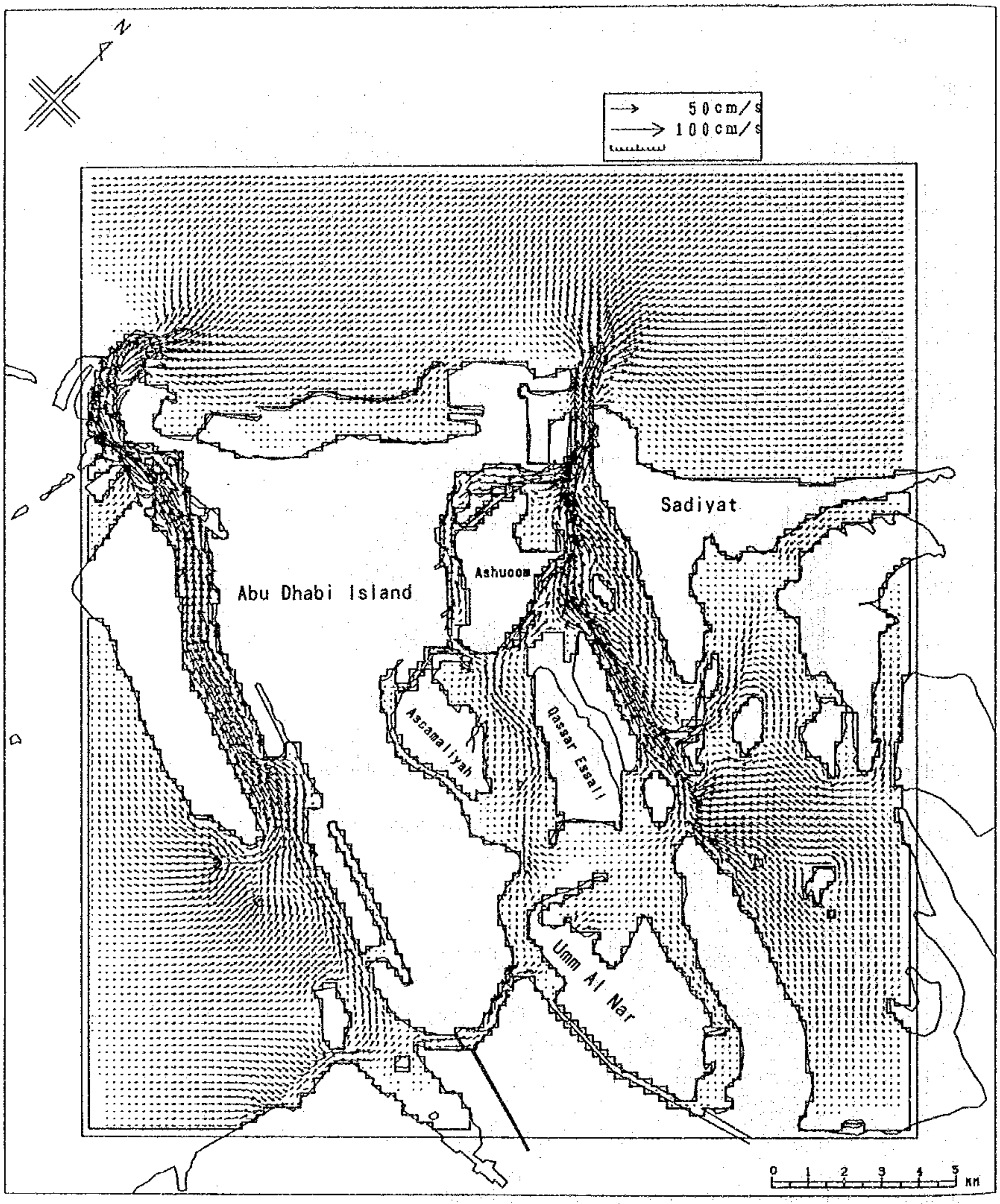


Fig. 5.1.19: Current Velocity Vector at Middle Tide
(Fastest Ebb Current at Miza Zayed)

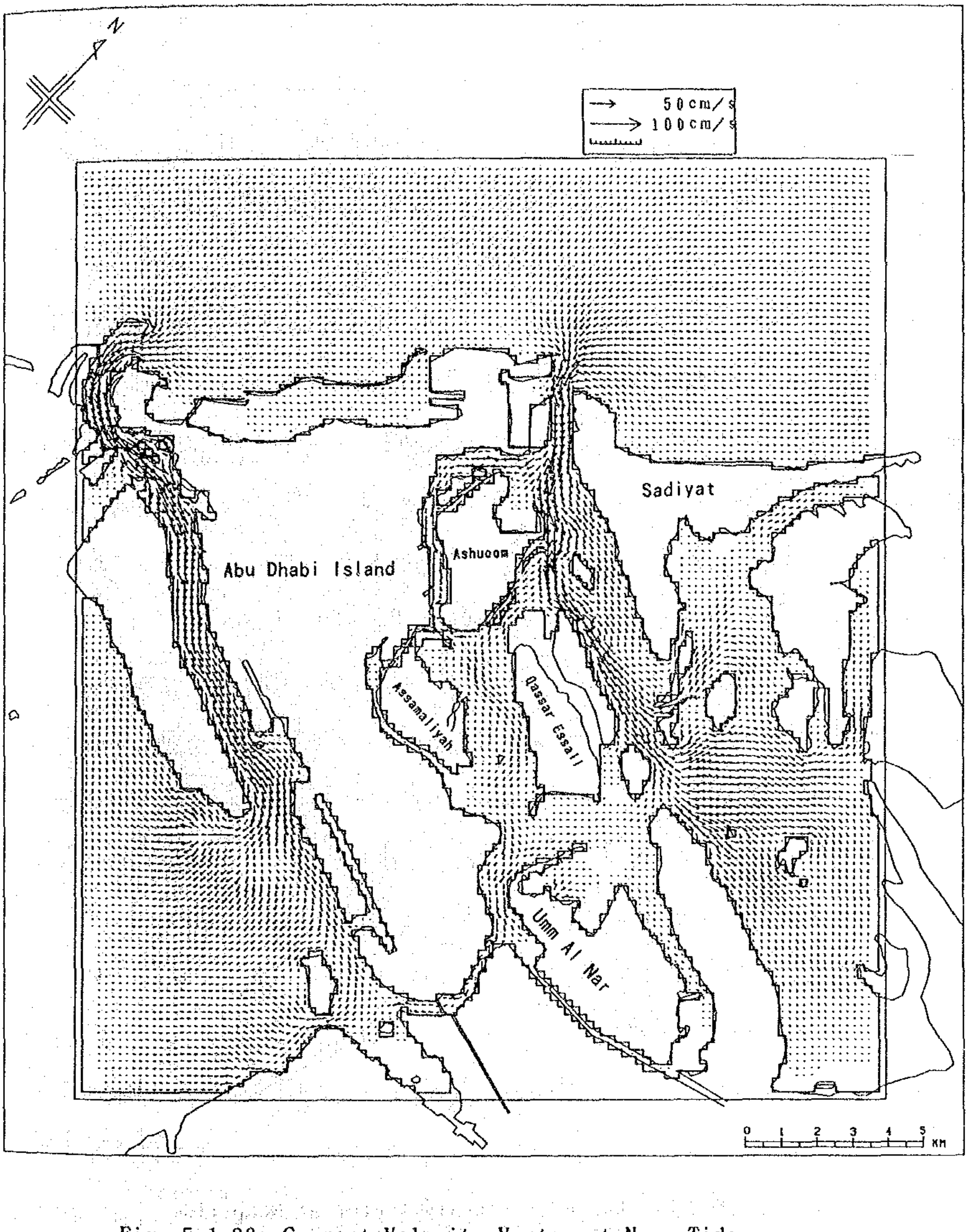


Fig. 5.1.20: Current Velocity Vector at Neap Tide
(Fastest Flood Current at Miza Zayed)

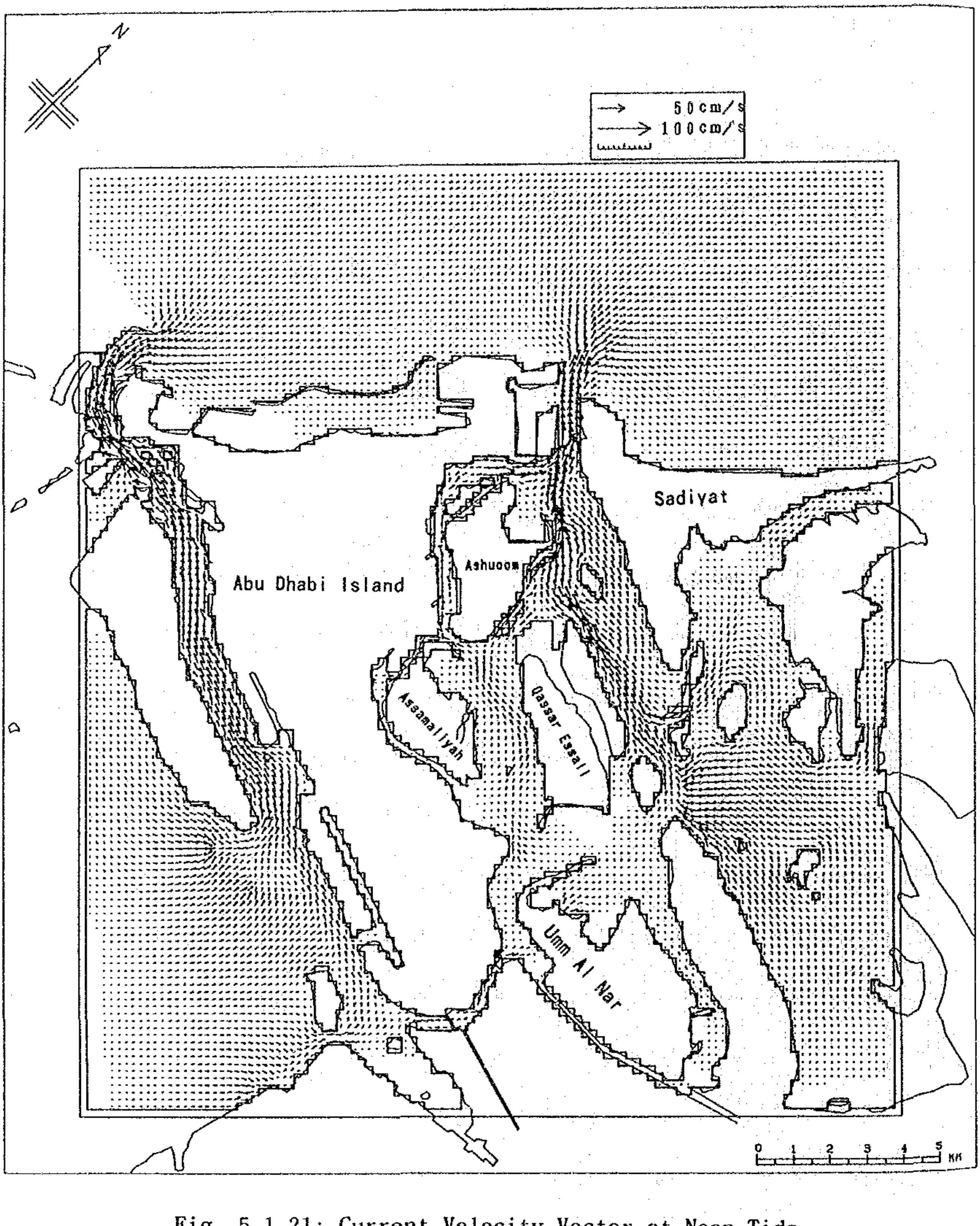


Fig. 5.1.21: Current Velocity Vector at Neap Tide
(Fastest Ebb Current at Miza Zayed)

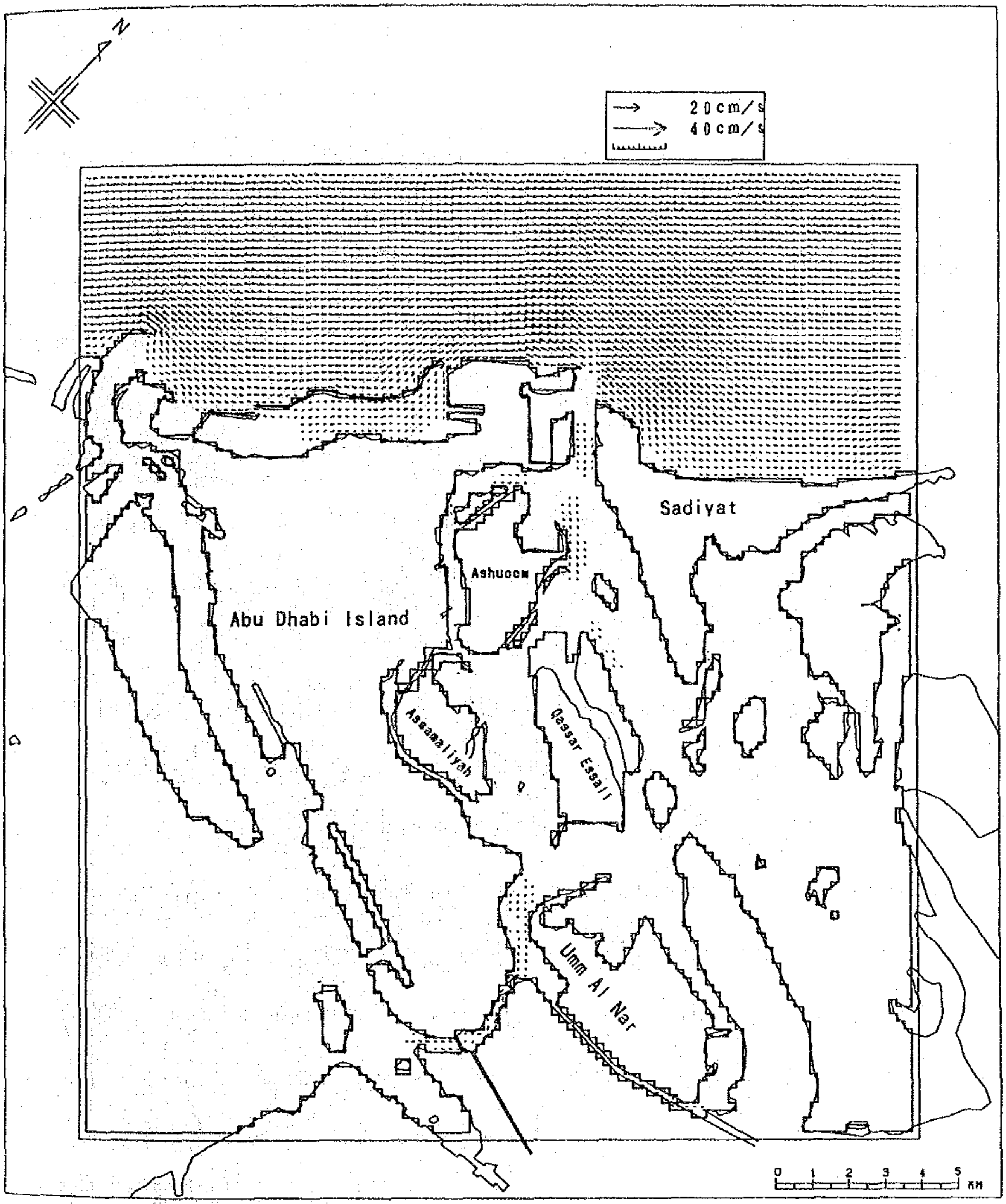


Fig. 5.1.22: Vector of Ocean Constant Flow (M.S.L.)

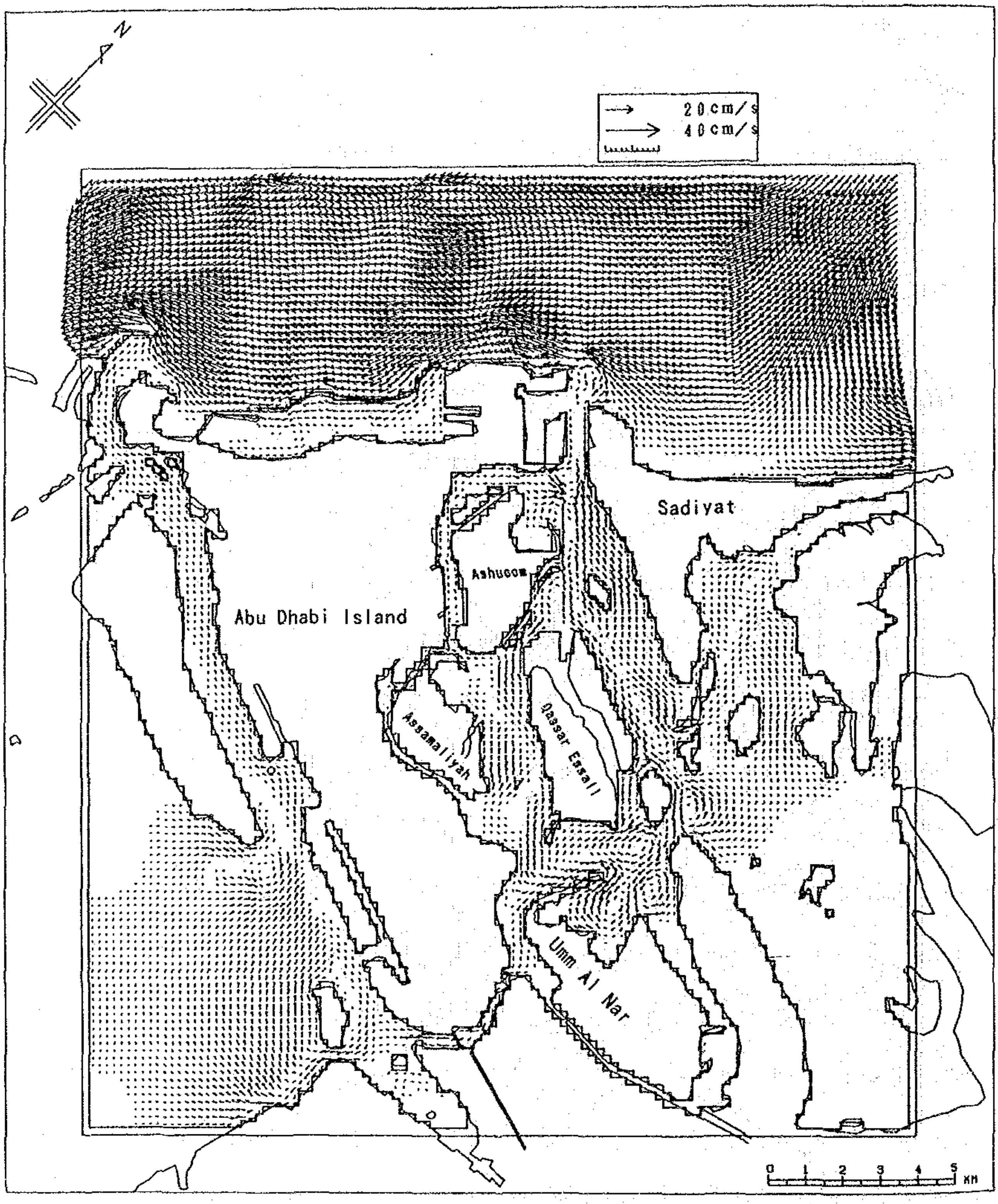


Fig. 5.1.23: Vector of Drift Current (M.S.L.)
(Wind Direction: N)

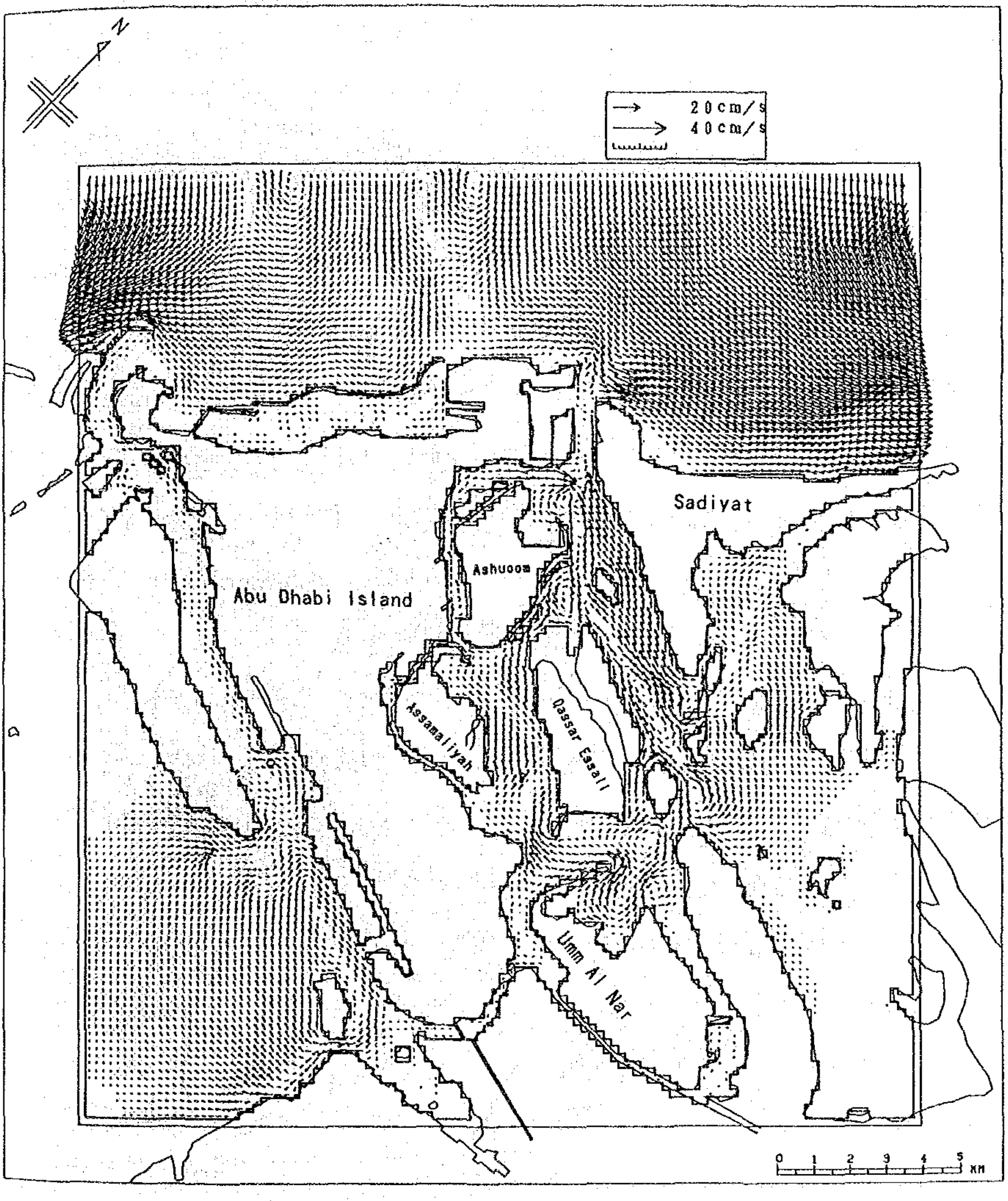


Fig. 5.1.24: Vector of Drift Current (M.S.L.)
(Wind Direction: NW)

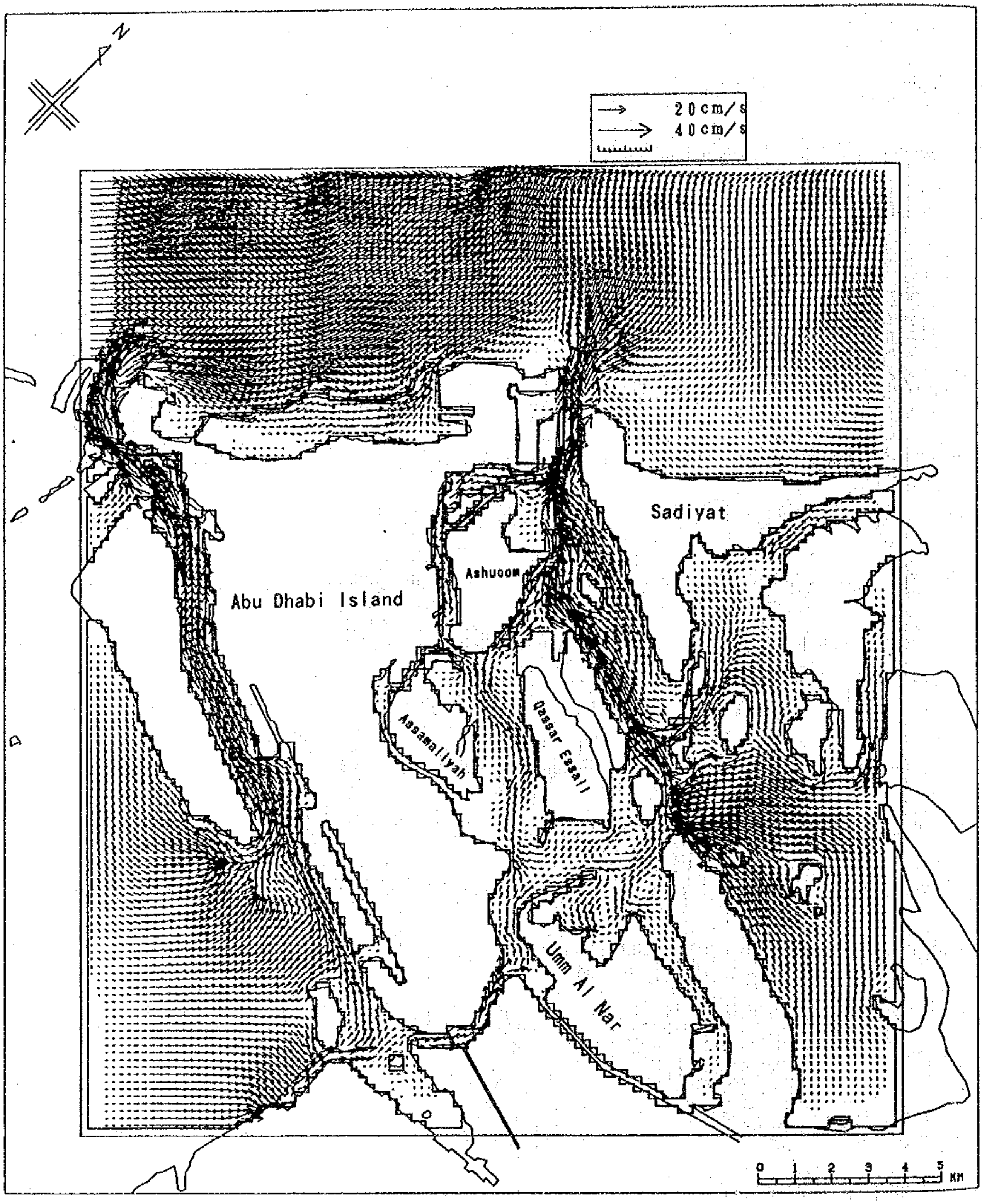


Fig. 5.1.25: Vector of Drift Current (M.S.L.)
(Wind Direction: S)

5.1.2 Current Conditions near Intake of Umm Al Nar Station

(1) Prediction Results

The current prediction results near the intake are shown figures listed in Table 5.1.6.

Table 5.1.6: Figure Number List of Current Prediction Results

Prediction Item		Near Intake
Tidal Current	Max. Spring Tide Period	Figs. 5.1.26, 5.1.27
	Ave. Spring Tide Period	Figs. 5.1.28, 5.1.29
	Middle Tide Period	Figs. 5.1.30, 5.1.31
	Neap Tide Period	Figs. 5.1.32, 5.1.33
Constant Flow (Ocean Current)		
Drift Current	Wind Direction N	Fig. 5.1.34
	Wind Direction NW	Fig. 5.1.35
	Wind Direction S	Fig. 5.1.36
Intake & Discharged Flow	Intake Flow	Fig. 5.1.37
	Discharged Flow	Fig. 5.1.38
	Intake & Discharged Composite	Fig. 5.1.39

(2) Summary of Current Condition

The prediction was carried out on each component of the currents, and the results are as follows.

1) Component of Tidal Current

(a) Rate of Current Tidal Velocity

The sea near the intake is influenced by the inflow and discharged water mass from Umm Al Nar. The current velocity declines to several cm/s near the intake, but has 20 to 30 cm/s for the maximum spring tide period at the inlet of South Basin where the channel closes.

(b) Flow Condition of Sea Water

The sea water flowing from Mina Zayed is divided into one stream going up SE through Baghal Channel, and the other going up through the channel of the N side of Assu-oom - Assamaliyah - Abu Dhabi Island. However, the water mass coming near the intake presumably goes through the both routes.

2) Component of Constant Flow

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

3) Component of Drift Current

Near the intake, the water mass moves along the coast from the north at the time of a northerly wind, and at the time of a southerly wind the water mass moves from the opposite direction. Therefore, as mentioned above, in view of the tidal current, though the sea water that flowed in from Khalidiya did not affect the area nearby the intake, the drift current sometimes works on the inflow of water from the south.

4) Component of Intake and Discharged Sea Water

The flows of the intake and the discharge of sea water of about 120 m^3/s were predicted. Their influences are limited to near the intake and the discharge facilities. But, the discharged sea water from Umm Al Nar Station might be recirculated because the intake and the discharge facilities are located relatively close.

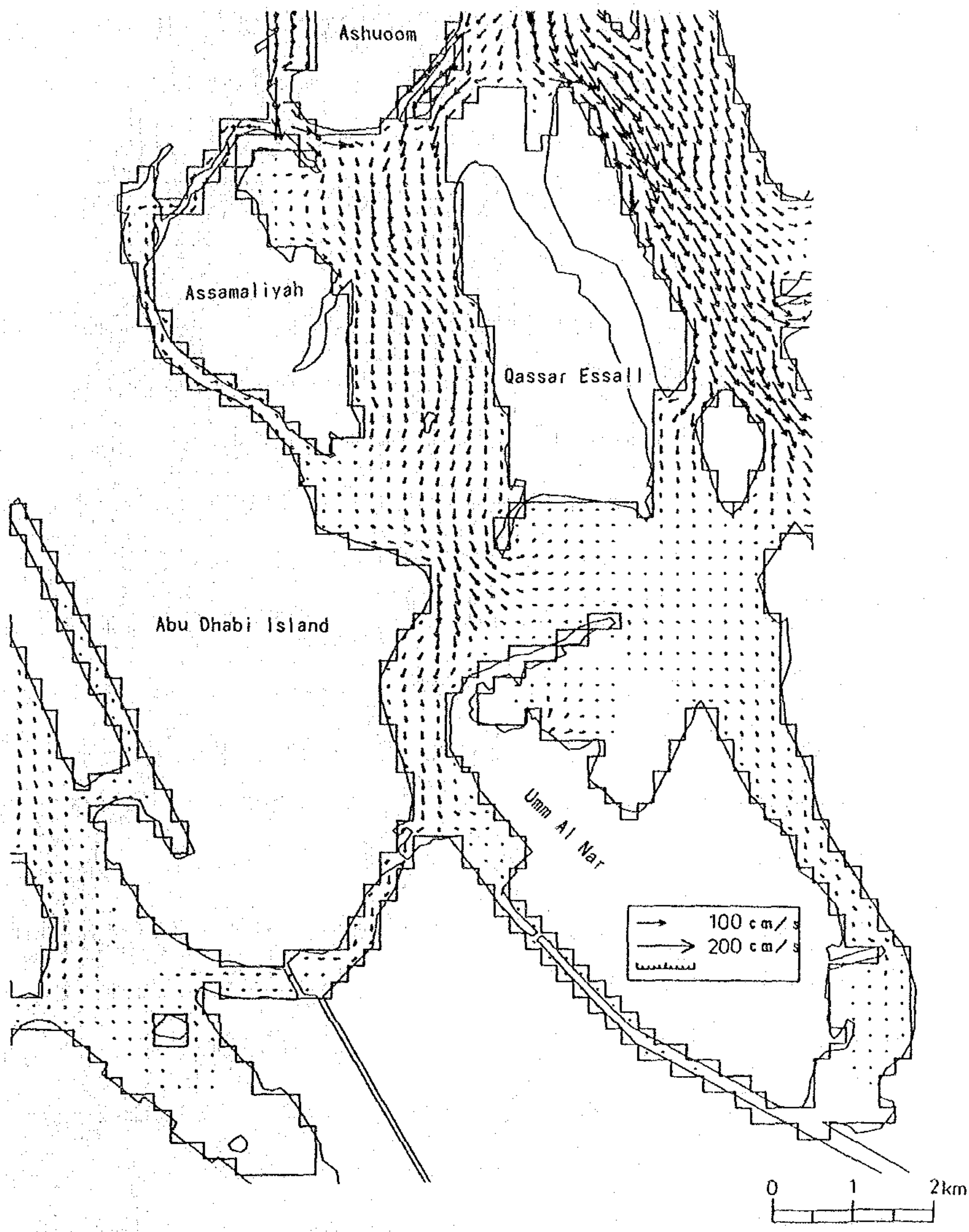


Fig. 5.1.26: Current Condition near Intake (Maximum Spring Tide, Fastest Flood Current at Miza Zayed)

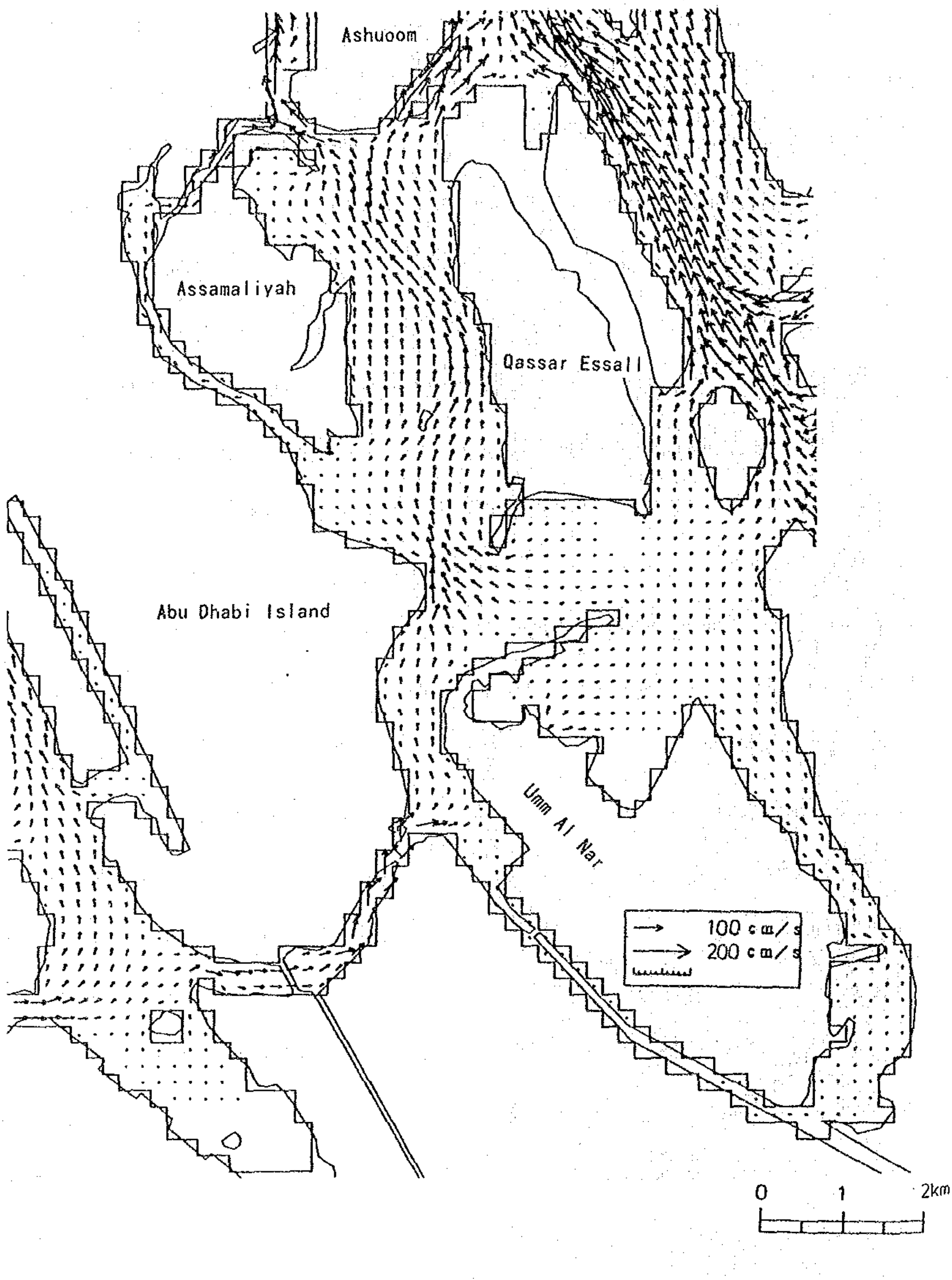


Fig. 5.1.27: Current Condition near Intake (Maximum Spring Tide, Fastest Ebb Current at Miza Zayed)

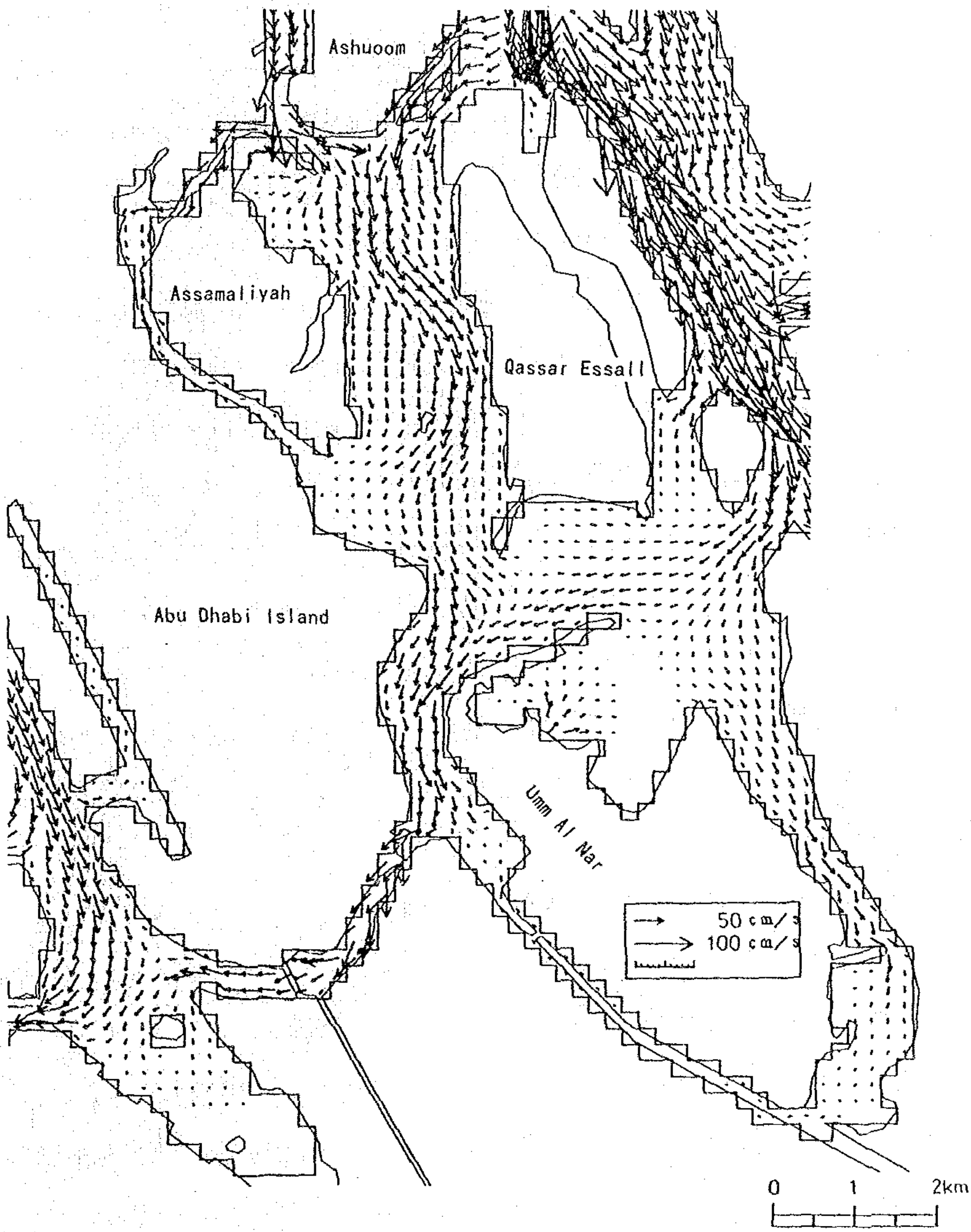
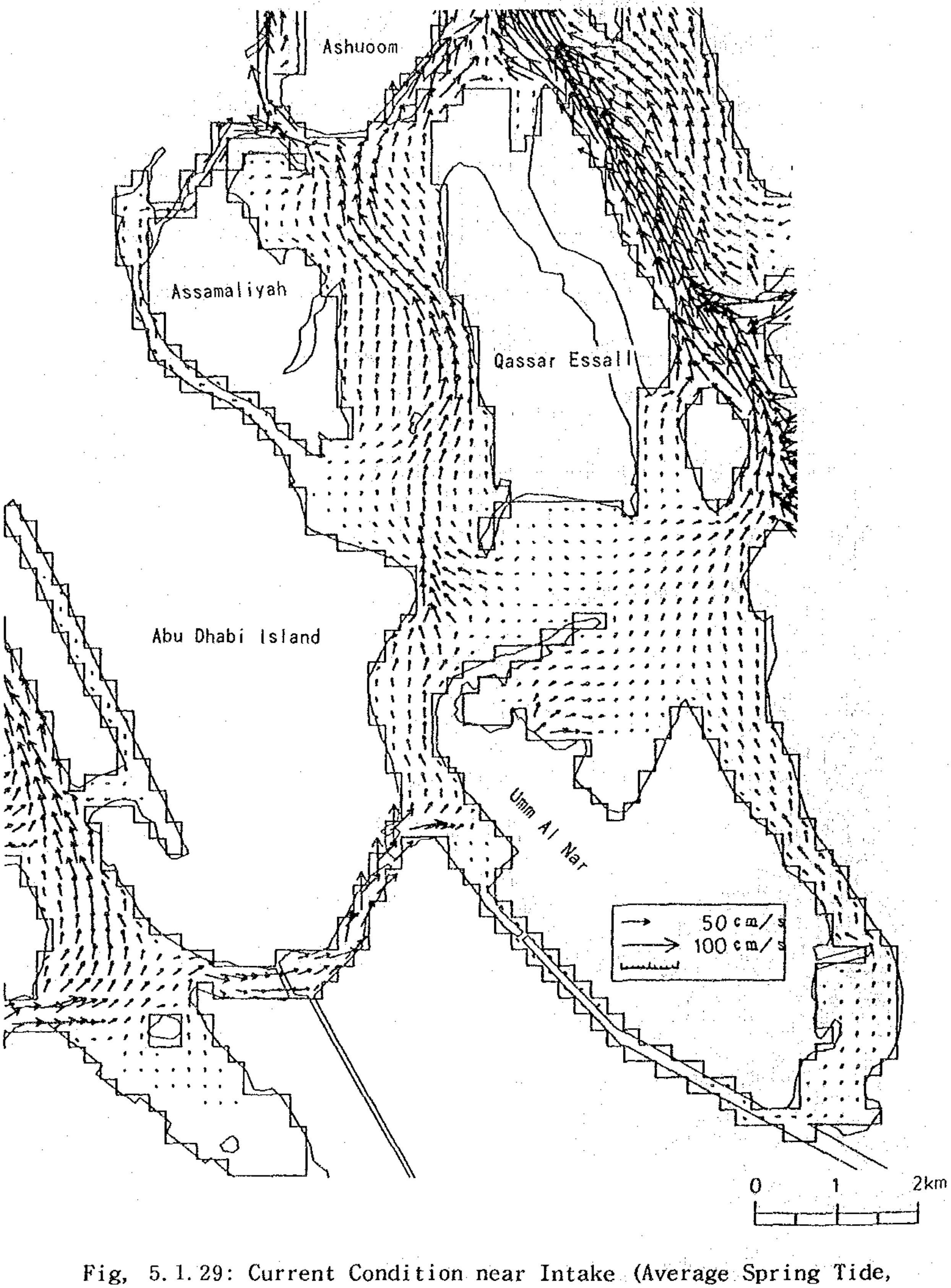


Fig. 5.1.28: Current Condition near Intake (Average Spring Tide, Fastest Flood Current at Miza Zayed)



Fig, 5.1.29: Current Condition near Intake (Average Spring Tide, Fastest Ebb Current at Miza Zayed)

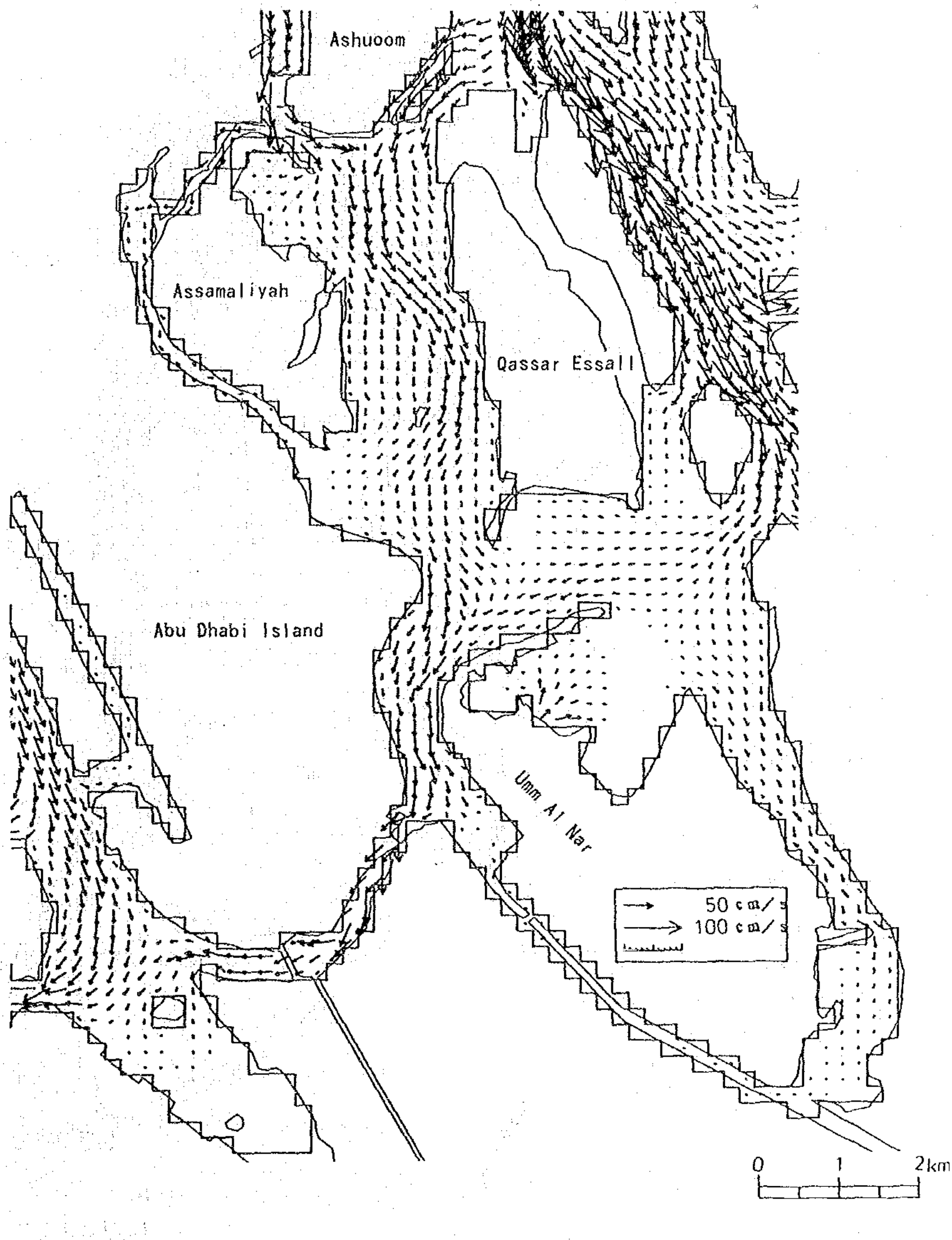


Fig. 5.1.30: Current Condition near Intake (Middle Tide, Fastest Flood Current at Miza Zayed)

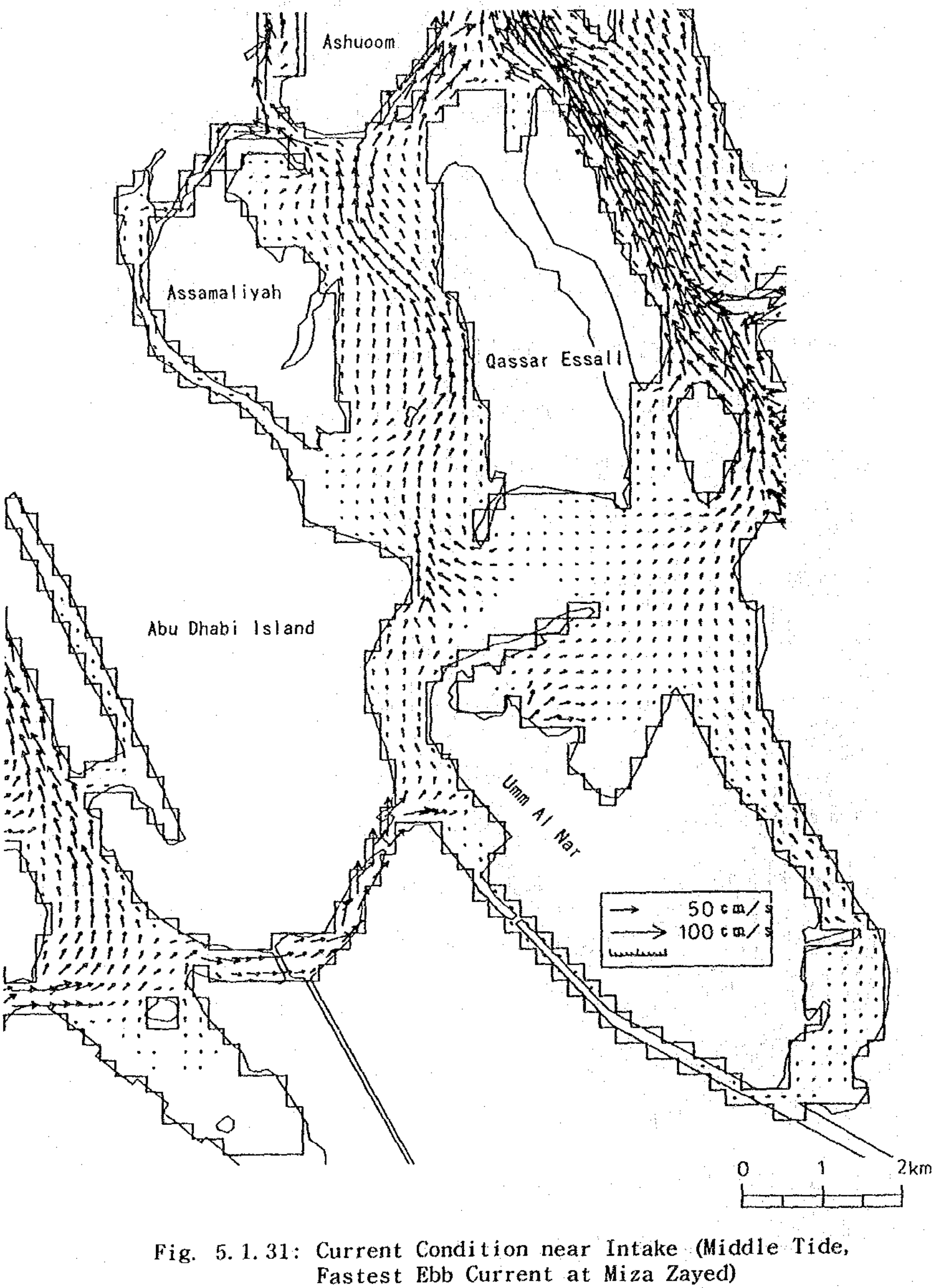


Fig. 5.1.31: Current Condition near Intake (Middle Tide, Fastest Ebb Current at Miza Zayed)

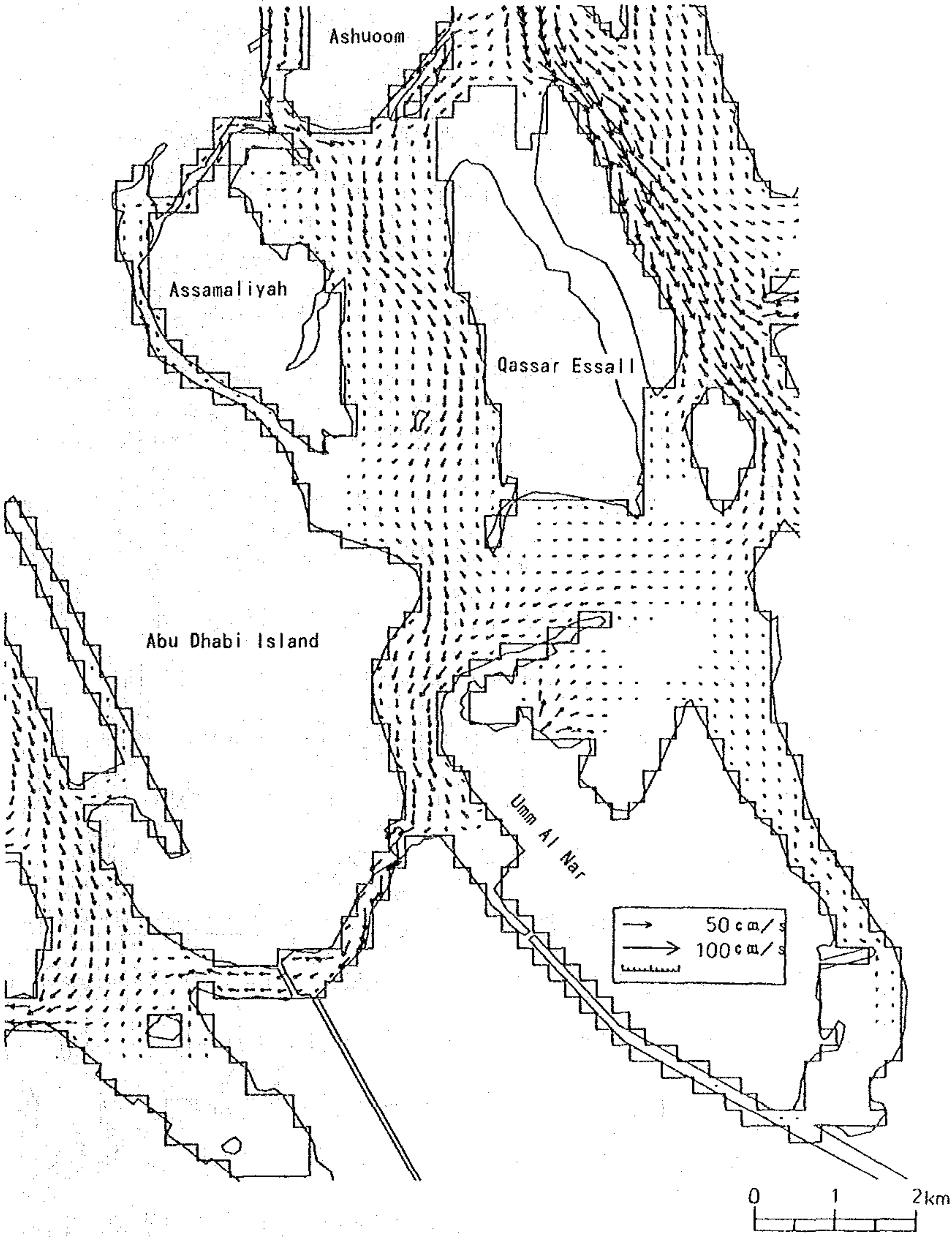


Fig. 5.1.32: Current Condition near Intake (Neap Tide, Fastest Flood Current at Miza Zayed)

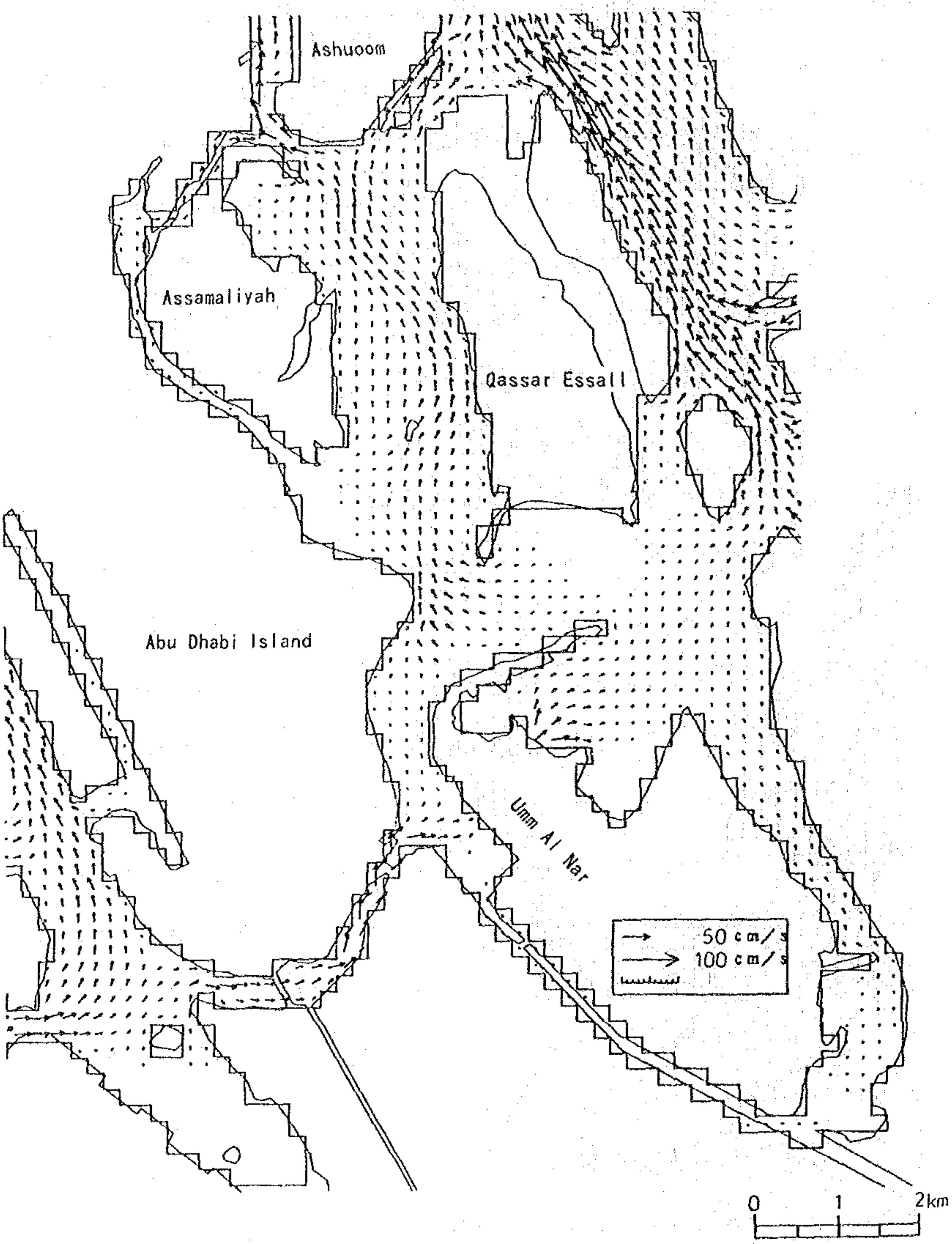


Fig. 5.1.33: Current Condition near Intake (Neap Tide, Fastest Ebb Current at Miza Zayed)

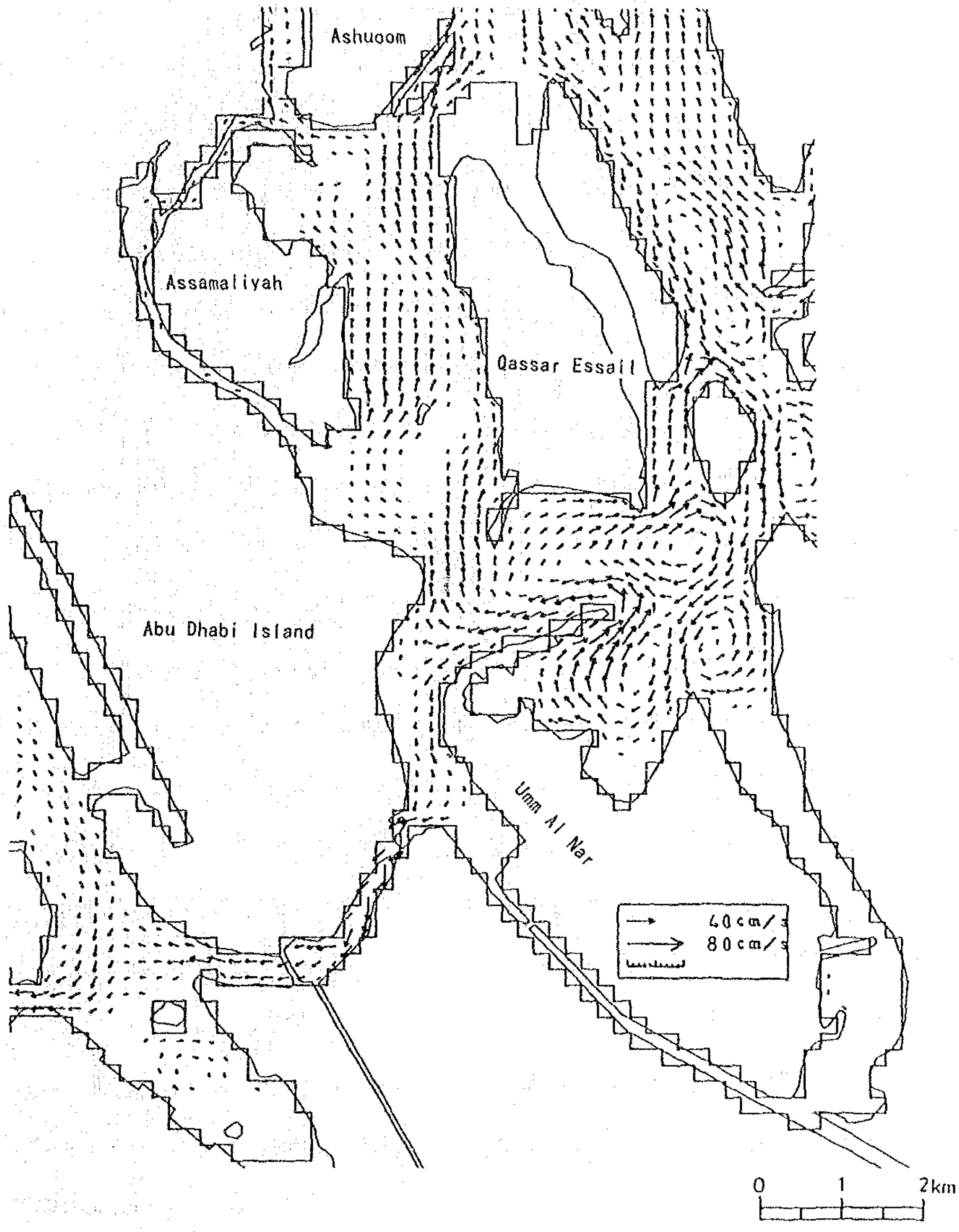


Fig. 5.1.34: Current Condition near Intake (M.S.L.)
(Drift Current, Wind Direction: N)

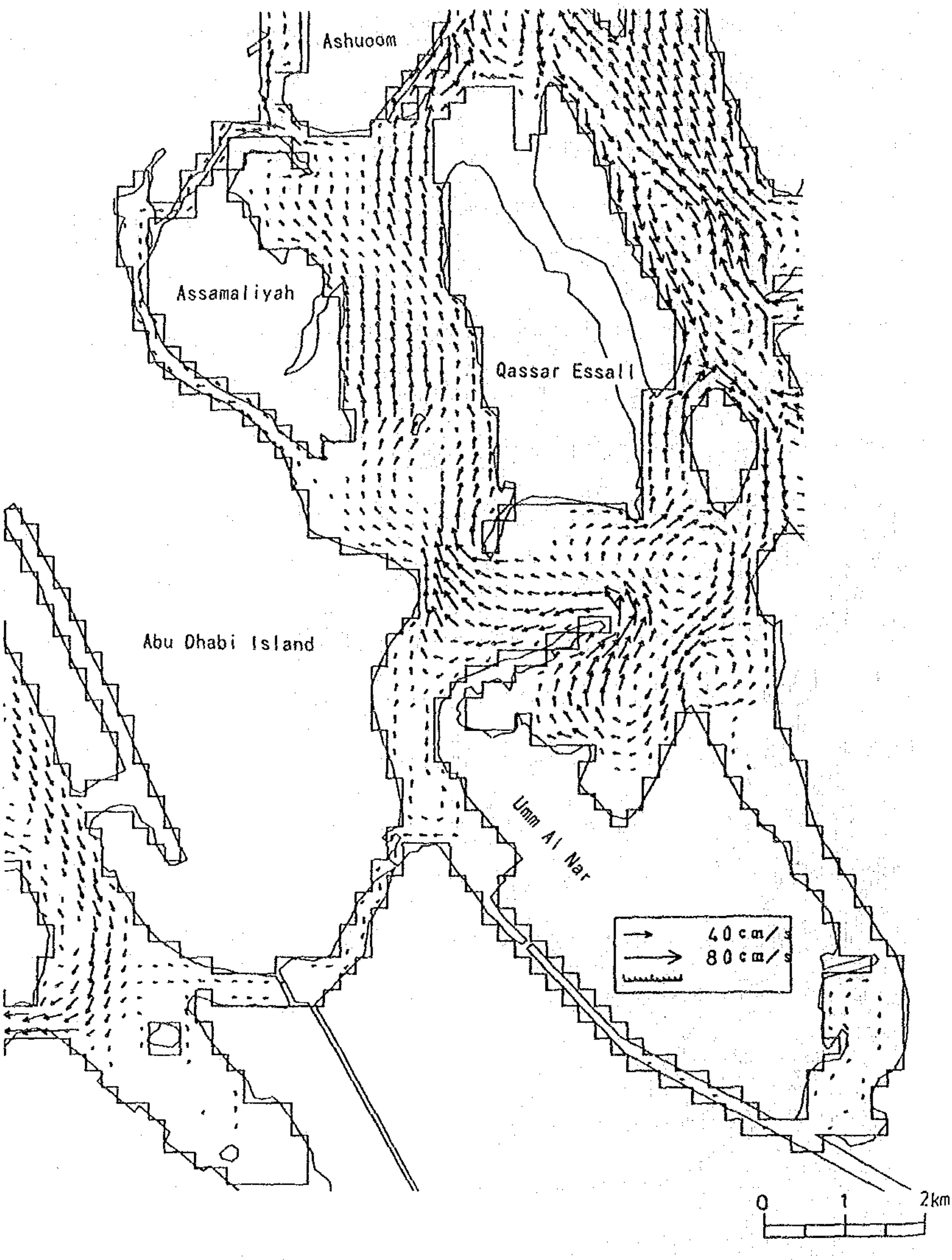


Fig. 5.1.35: Current Condition near Intake (M.S.L.)
(Drift Current, Wind Direction: NW)

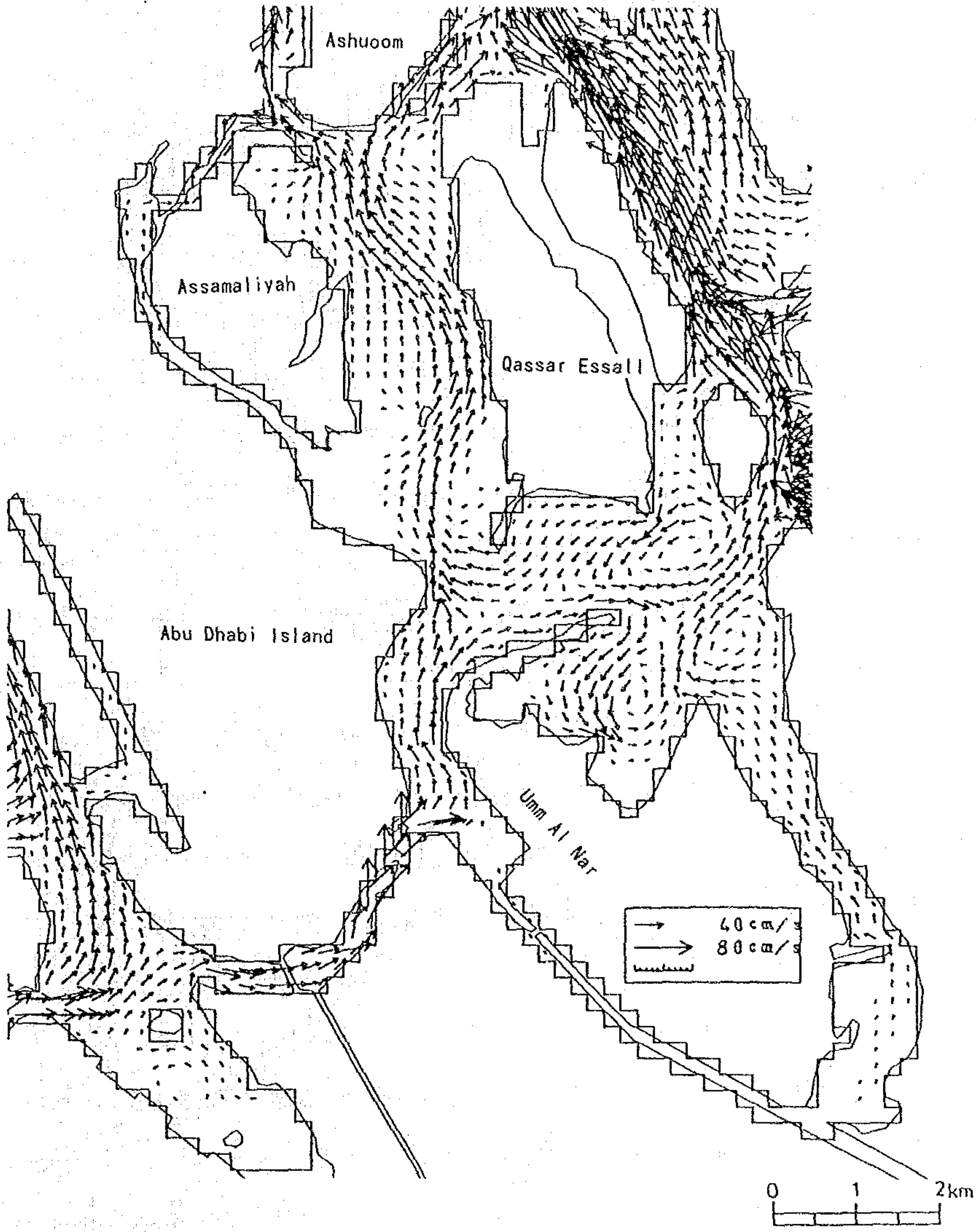


Fig. 5.1.36: Current Condition near Intake (M.S.L.)
(Drift Current, Wind Direction: S)

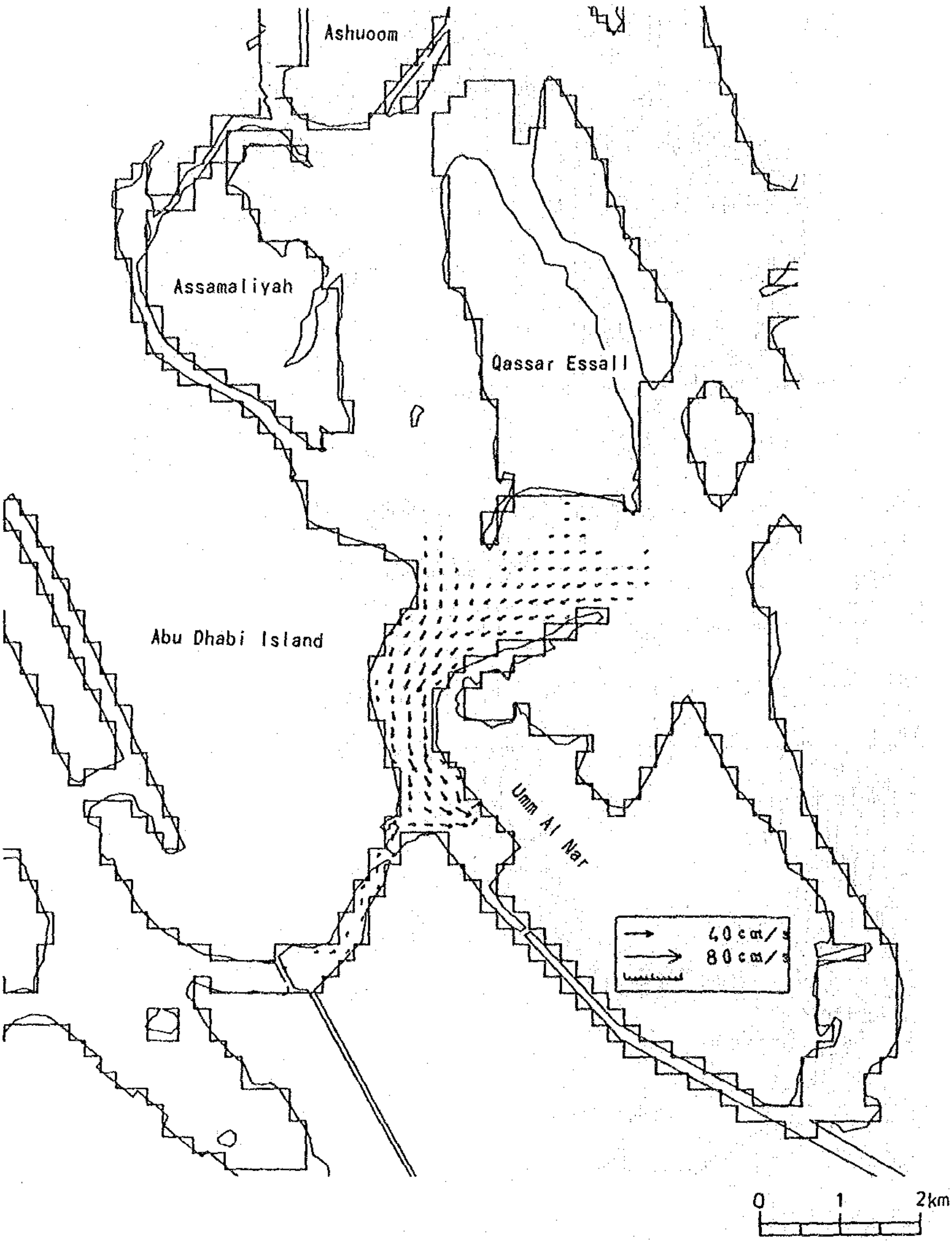


Fig. 5.1.37: Intake Flow Vector (M.S.L.)

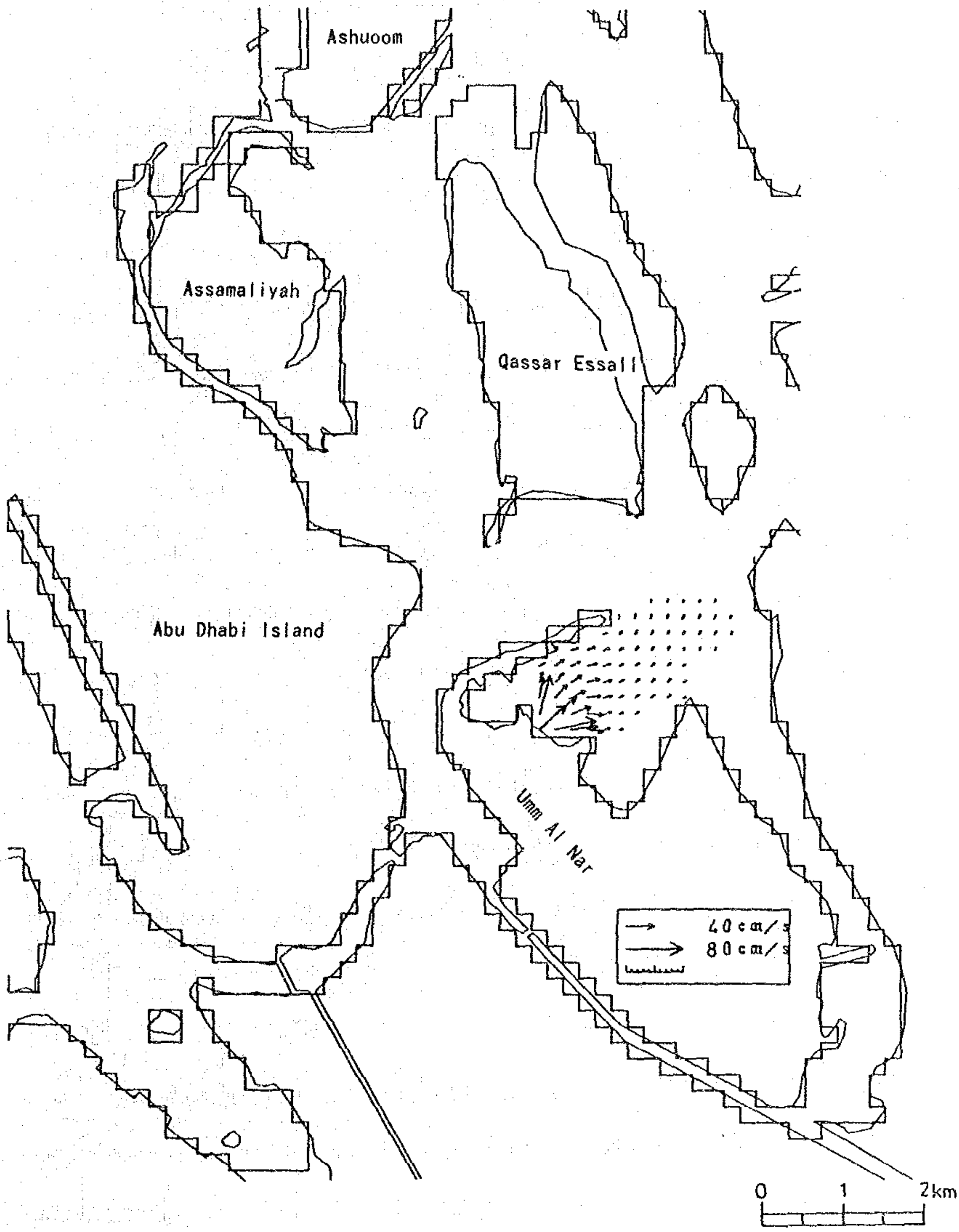


Fig. 5.1.38: Discharged Flow Vector (M.S.L.)

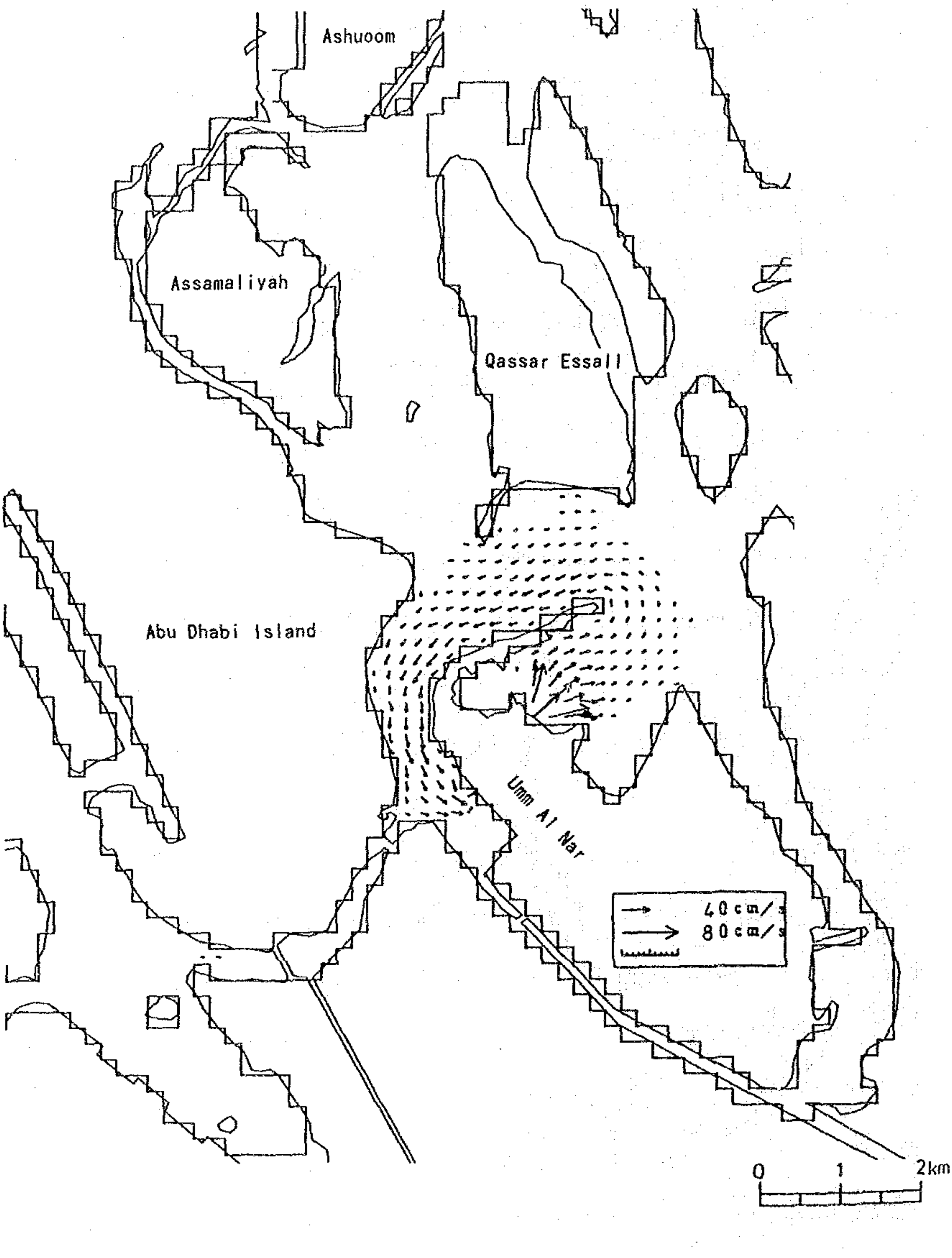


Fig. 5.1.39: Intake and Discharged Flow Vector (M.S.L.)

5.1.3 Case Study of Oil Contamination Accident

(1) Object

As a result of the prediction of current conditions around the Abu Dhabi Island and near the intake, the rates of velocity, its directions and the routes of the tide in the subject sea area were clarified in 5.1.1. Also, the outlined understanding was obtained to see how the currents, which are attributed to various external forces such as tidal currents, ocean currents, drift currents and intake and discharge flow, affect the dispersion of floating oil.

However, the results found in 5.1.1 were Eulerian currents on fixed coordinates, and the prediction results in the previous section by themselves are not complete enough to gain an understanding of the routes the oil takes, or the time taken, since the oil which flowed in the subject sea area moved with the currents which varied spatio-temporarily. That is, they could not be satisfactory base materials for the examination of an oil contamination monitoring system or an oil pollution protection system.

Therefore, in this section, a prediction will be done on how oil spilled at a certain location (this location is the subject of examination on setting the monitoring system or protection system) moves, and how long does it take to reach near the intake or the oil pollution protection system.

(2) Frame of Prediction

As clarified in the previous section, the current in the subject sea area is a composite of several current elements such as "tidal current", "ocean current", "drift current" and "intake and discharge flow". Moreover, "tidal current", out of the four elements, is considered to be the predominant factor in terms of the rate of current velocity.
This component of tidal current has a 12 hour period, and sea water flowing in during flood tide flows out during ebb tide in 6 hours, indicating simple to-and-fro motions. The oil flow returns to exactly the same position in 12 hours with this motion. In actuality, however, the oil does not return to the same position and describes complicated movements influenced by "tidal residual current" or "constant flows (ocean current, drift current, and intake and discharged flow".

Therefore, the object in this section is, by using the flowing Eulerian results obtained in 5.1.1, to search for the movement routes of markers (oil lump) and its movement time by using the Lagrangian method which spatio-temporarily traces the motion of oil thrown in at certain points.

(3) Condition of Prediction

1) Prediction Time

Monitoring points must be set in such positions as to fully ensure the time for plant superintendents to take emergency actions, principally during the time that the monitoring points sense the inflow of oil, and by the time that the oil reaches "the area near the intake" or "the setting positions of the oil protection system". Therefore, although prediction time must be set on the basis of "time to take various emergency actions", it cannot be decided unconditionally since its concrete time varies according to procedures.

Therefore, here, the prediction time will be set considering the current conditions of the subject sea area. The main current is a tidal current describing a to-and-fro motion. Seeing its movement routes as shown in Fig. 5.1.40, the oil thrown in at the start of the flood current at a certain position moves to where it was thrown in, in a half period (6 hours). So, if the movement routes in this period, from the start of the flood current to the start of the ebb current, are grasped, the object here will be attained. So, markers from the start of the flood will be traced for 6 hours.

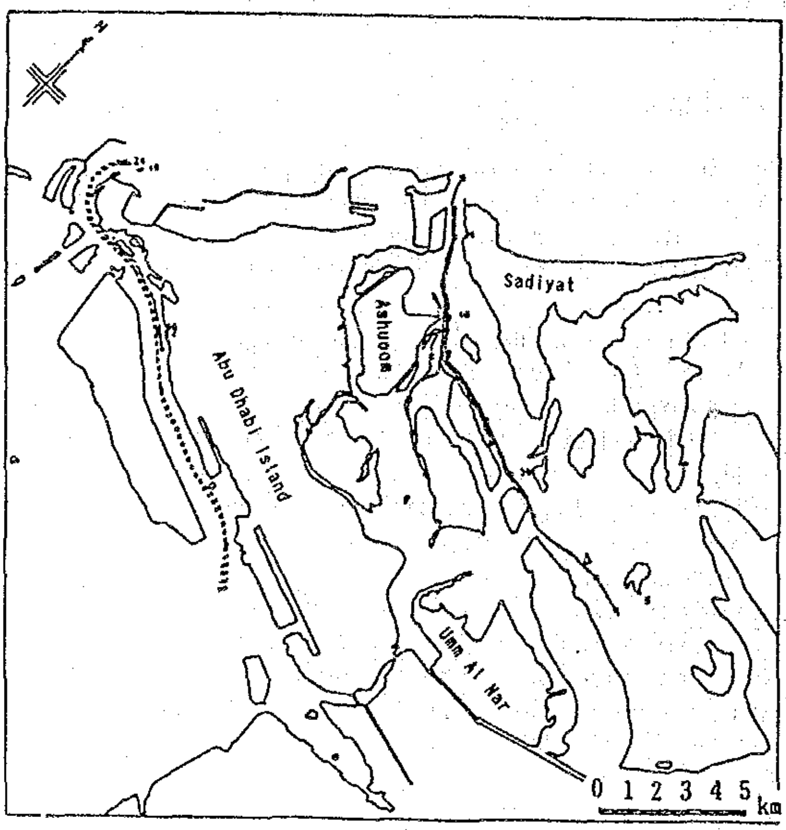


Fig. 5.1.40: Movement Route of Marker (Thrown at Start of Flood)

2) Thrown In Locations of Markers

13 lines in total were selected to throw in markers as shown in bold lines in Fig. 5.1.41. Lines 1 to 7 were remote from the intake, and Lines A to F were near the intake.

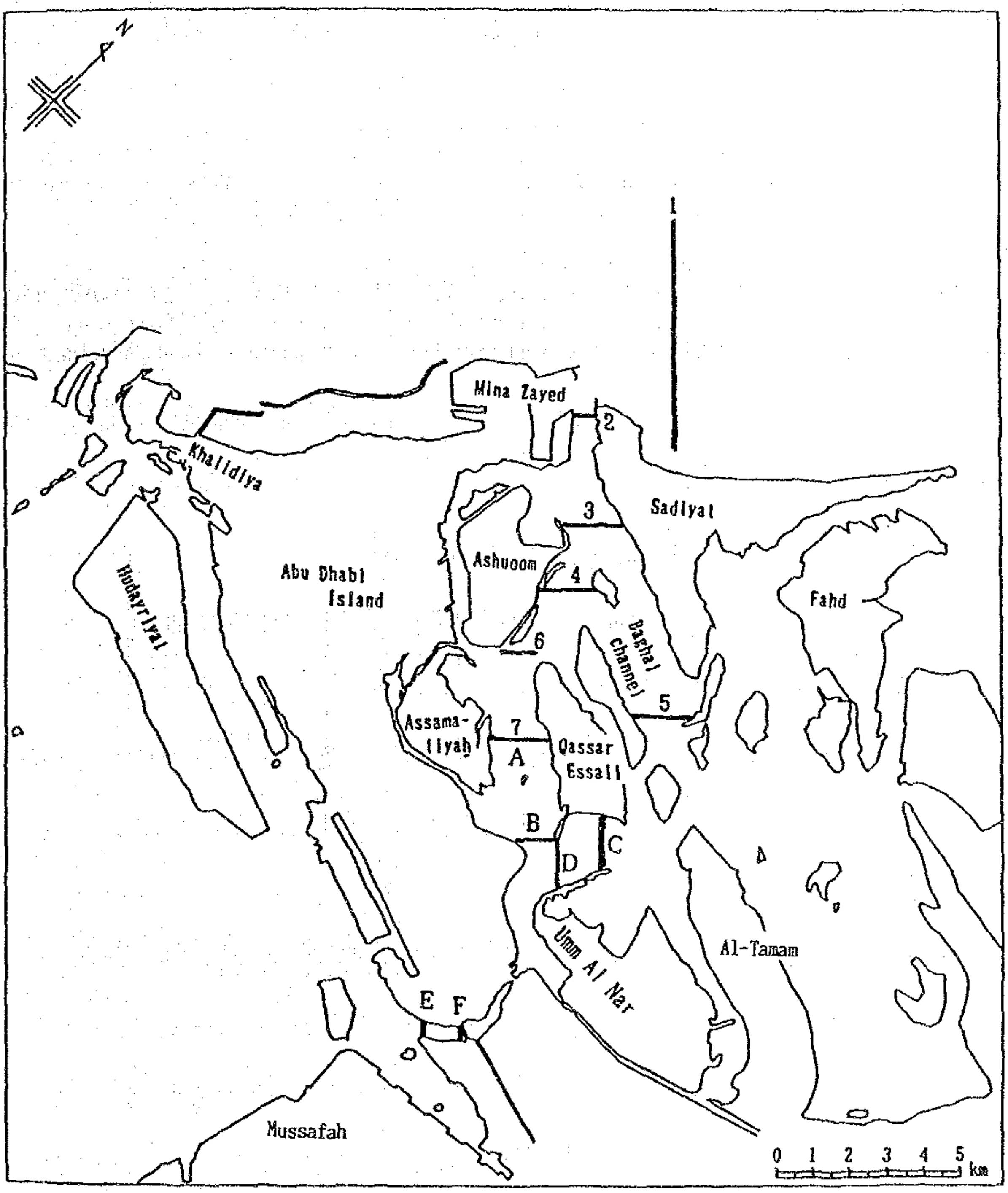


Fig. 5.1.41: Thrown In Locations Markers

3) Prediction Case

As mentioned in 5.1(2), it can be explained that the currents of the subject area are composed of 4 components. According to conditions of occurrence origins, they can be classified as follows:

* Constant elements

  Components of tidal current, and intake and discharged flow

* Temporal elements

  Components of drift current and ocean current

  Temporality means here, an uncertainty about its appearance frequency or continual time.

Therefore, to examine macrocscopically the whole subject sea area, the prediction will be done with "constant elements". However, as the route of oil flow near the intake may be greatly influenced by "temporal elements", both elements shall be considered for the prediction. Table 5.1.7 is a prediction case.

Table 5.1.7: Prediction Case

Tidal Curr.	I & D Flow	Drift Curr.	Ocean Curr.	Section Thrown In
MSTP ASTP MiTP NeTP	Intake 126.4 m^3 /s Discharge 123.3 m^3 /s			Total 7 Sections See 1-7
MSTP	Intake 126.4 m^3 /s Discharge 123.3 m^3 /s	WD : N WD : NW WD : S		Total 6 Sections See A-F
ASTP		WD : N WD : NW WD : S		
MiTP		WD : N WD : NW WD : S		
NeTP		WD : N WD : NW WD : S		
MSTP	Intake 126.4 m^3 /s Discharge 123.3 m^3 /s	WD : N WD : NW WD : S	SW Current	Total 6 Sections See A-F
ASTP		WD : N WD : NW WD : S	SW Current	
MiTP		WD : N WD : NW WD : S	SW Current	
NeTP		WD : N WD : NW WD : S	SW Current	

Where, MSTP: Maximum Spring Tide Period, ASTP: Average Spring Tide Period
MiTP: Middle Tide Period, NeTP: Neap Tide Period
Also, WD: Wind Direction

(4) Prediction Result

1) Movement Condition of Marker in Remote Area from Intake

(a) Line 1 (Fig. 5.1.42)

Markers thrown along the line 2.5 km NE from the entrance of the lagoon are moved into the bay with the water mass at the 5 km point of the Abu Dhabi Island at maximum spring tide. They moved into the bay up to a maximum of 14 km. At middle tide, an average tide with its water mass 1 km offshore is drawn in but the markers flow in only up to about 2 km from the entrance of the lagoon.

(b) Line 2 (Fig. 5.1.43)

Markers thrown in at 3 lines located the lagoon entrance moved along the coast of Baghal Channel and Ashuum Island. Some of the markers carried on a strong current area of Baghal Channel, have traces of about 16 km. In a middle tide, they moved in to about 9 km, but did not reach the intake for a semicycle period.

(c) Line 3 (Fig. 5.1.44)

Markers thrown in the channel moved SE along Baghal Channel. The movement route was same as the route of the markers thrown in along Lines 1 and 2.

(d) Line 4 (Fig. 5.1.45)

The movements of markers were divided into the one which moved up to Baghal Channel and the other moving to the channel between Essall and Ashuoom. The latter moved up to nearly 1 km from the intake in maximum spring tide.

(e) Line 5 (Fig. 5.1.46)

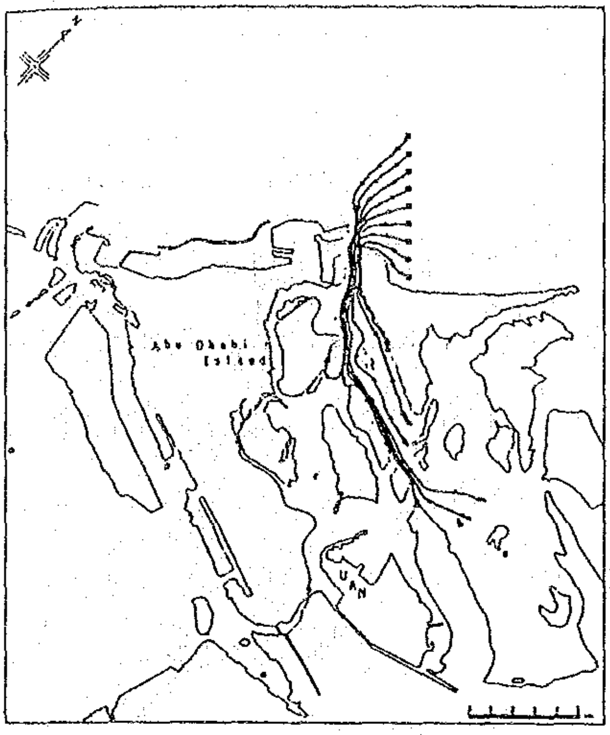
Some markers thrown in this Line moved into the channel leading to the intake, but most of them scatter toward Al Jubail or Umm Al Tamam, which indicates that some of the water mass flowing through Baghal Channel flows into the channel which leads to the intake, but is soon reversed at the channel due to a reversed current.

(f) Line 6 (Fig. 5.1.47)

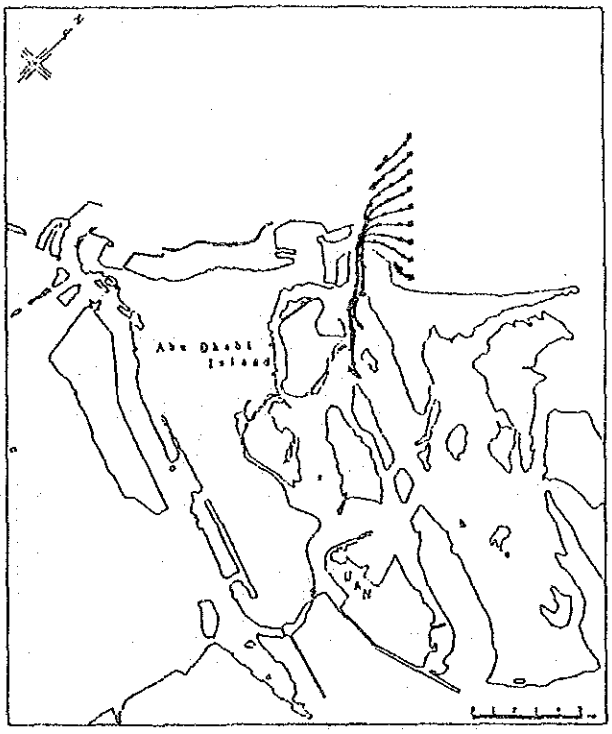
Markers reached the intake at maximum spring tide. This was probably due to the fact that the channel between Essal and Assamaliyah is a main current flow to the intake.

(g) Line 7 (Fig. 5.1.48)

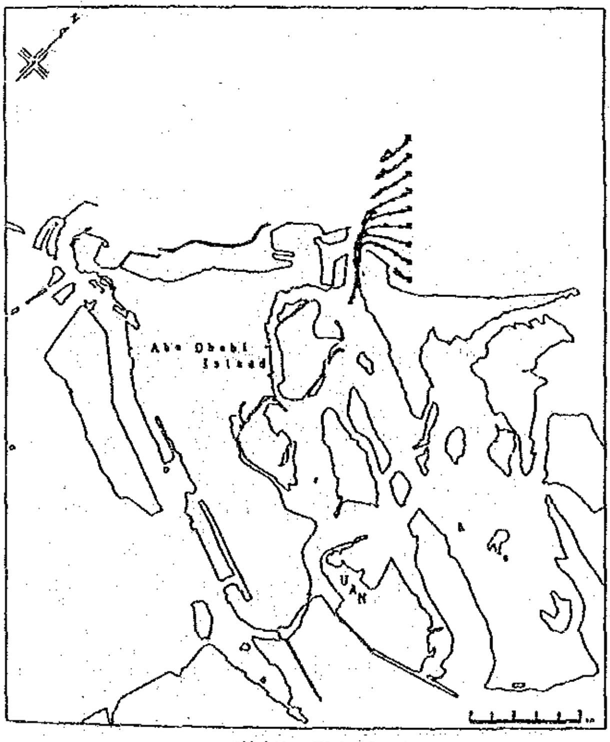
Markers reached the intake in 5 to 6 hours at the maximum spring tide. In other cases, they did not reach the intake.



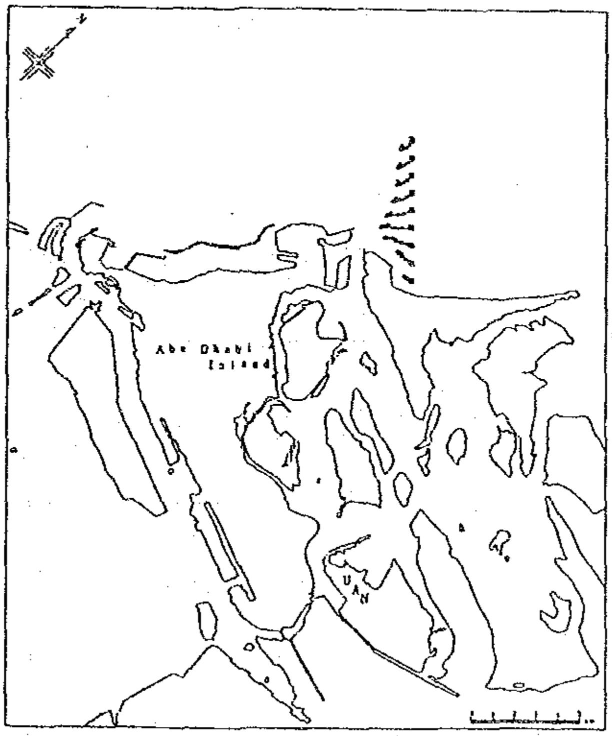
Maximum Spring Tide Period



Average Spring Tide Period



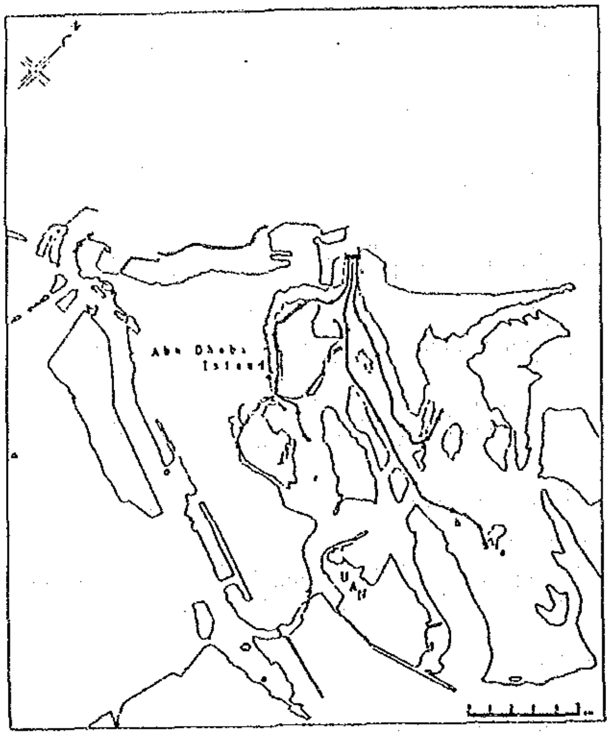
Middle Tide Period



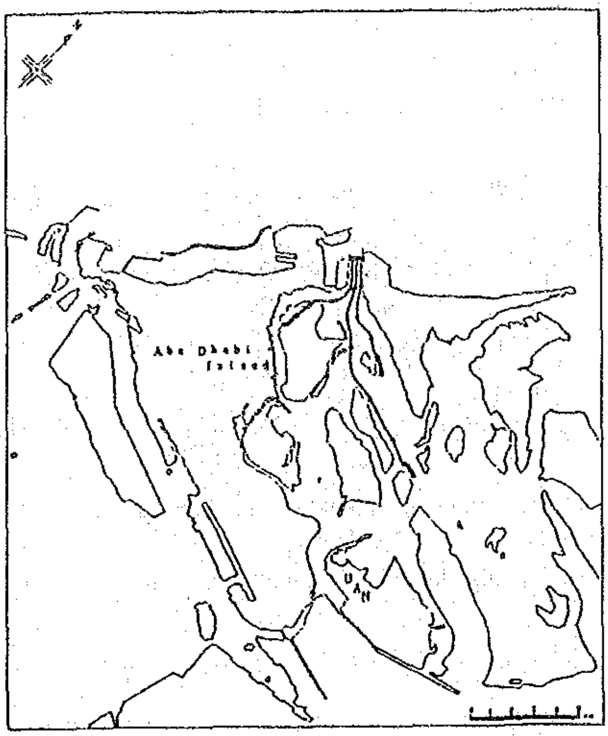
Neap Tide Period

Notes : * shows thrown location.
Mark is noted in every hour.

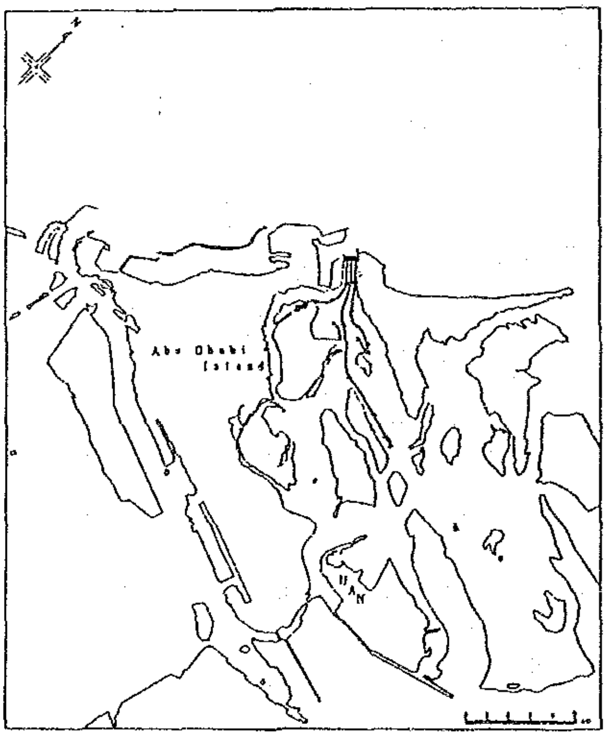
Fig. 5.1.42: Result of Marker Tracing (Thrown at Start of Flood Tide) <Line 1>



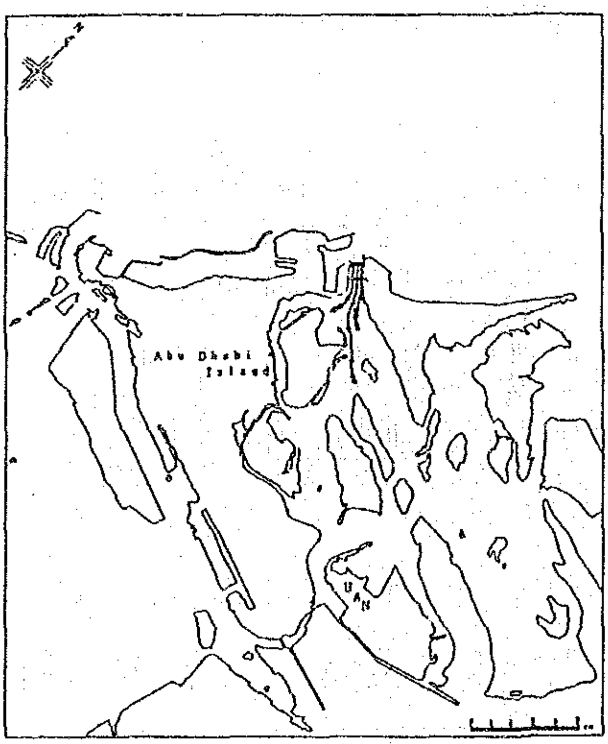
Maximum Spring Tide Period



Average Spring Tide Period



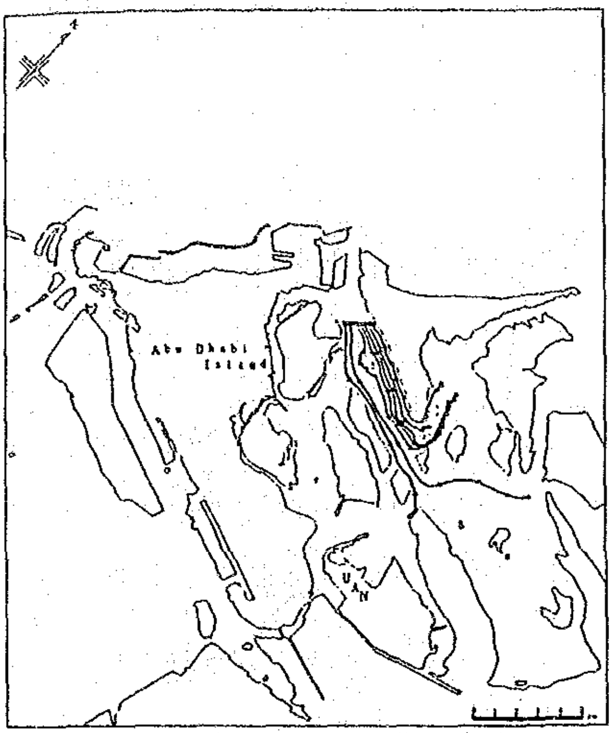
Middle Tide Period



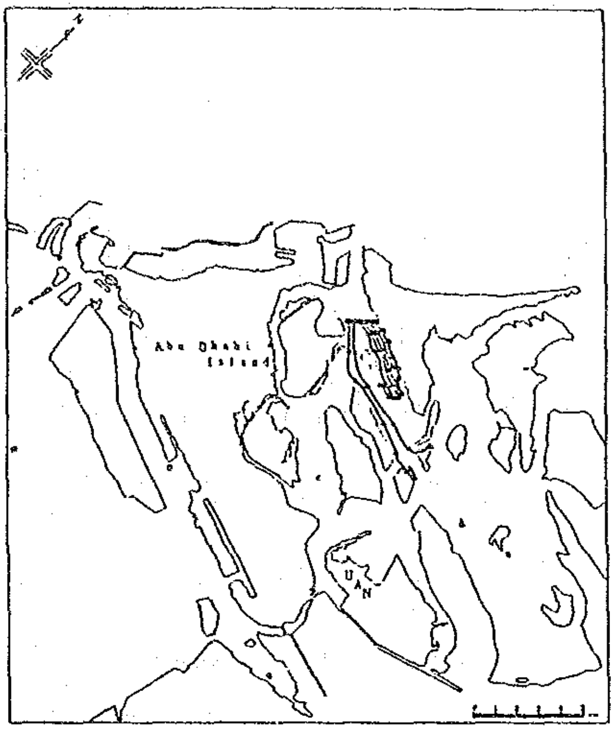
Neap Tide Period

Notes : * shows thrown location.
Mark is noted in every hour.

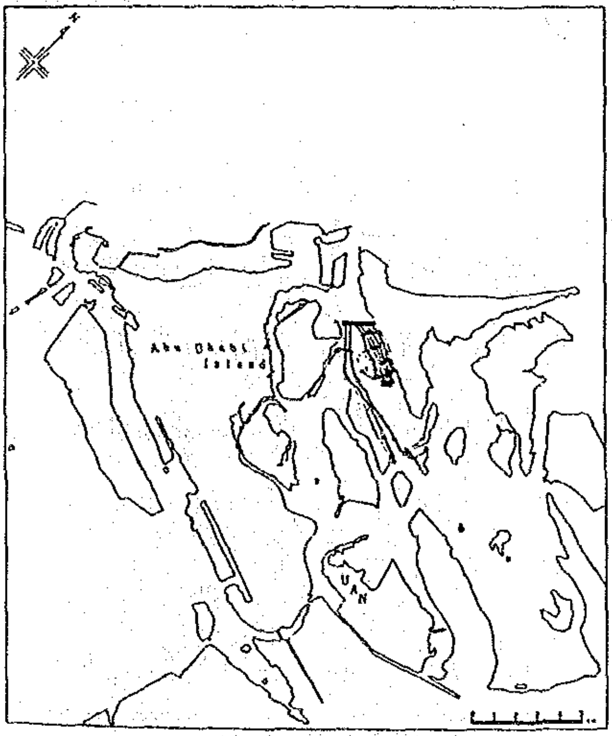
Fig. 5.1.43: Result of Marker Tracing (Thrown at Start of Flood Tide) <Line 2>



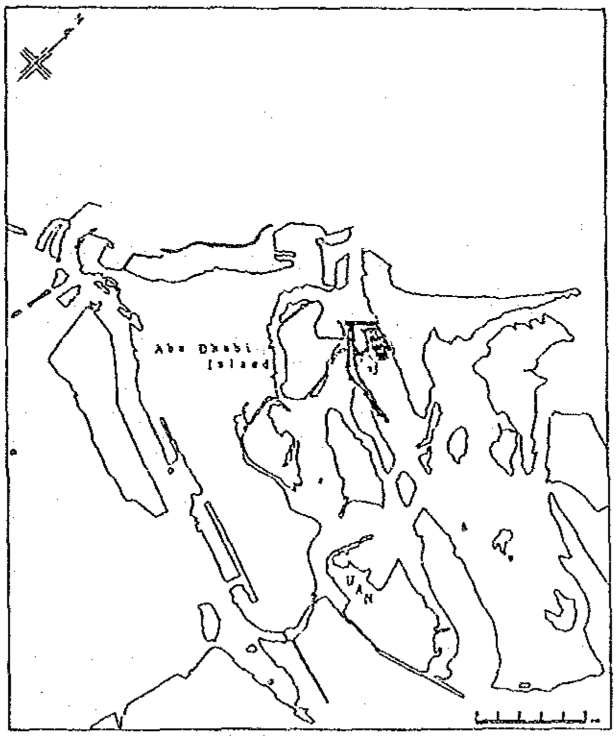
Maximum Spring Tide Period



Average Spring Tide Period



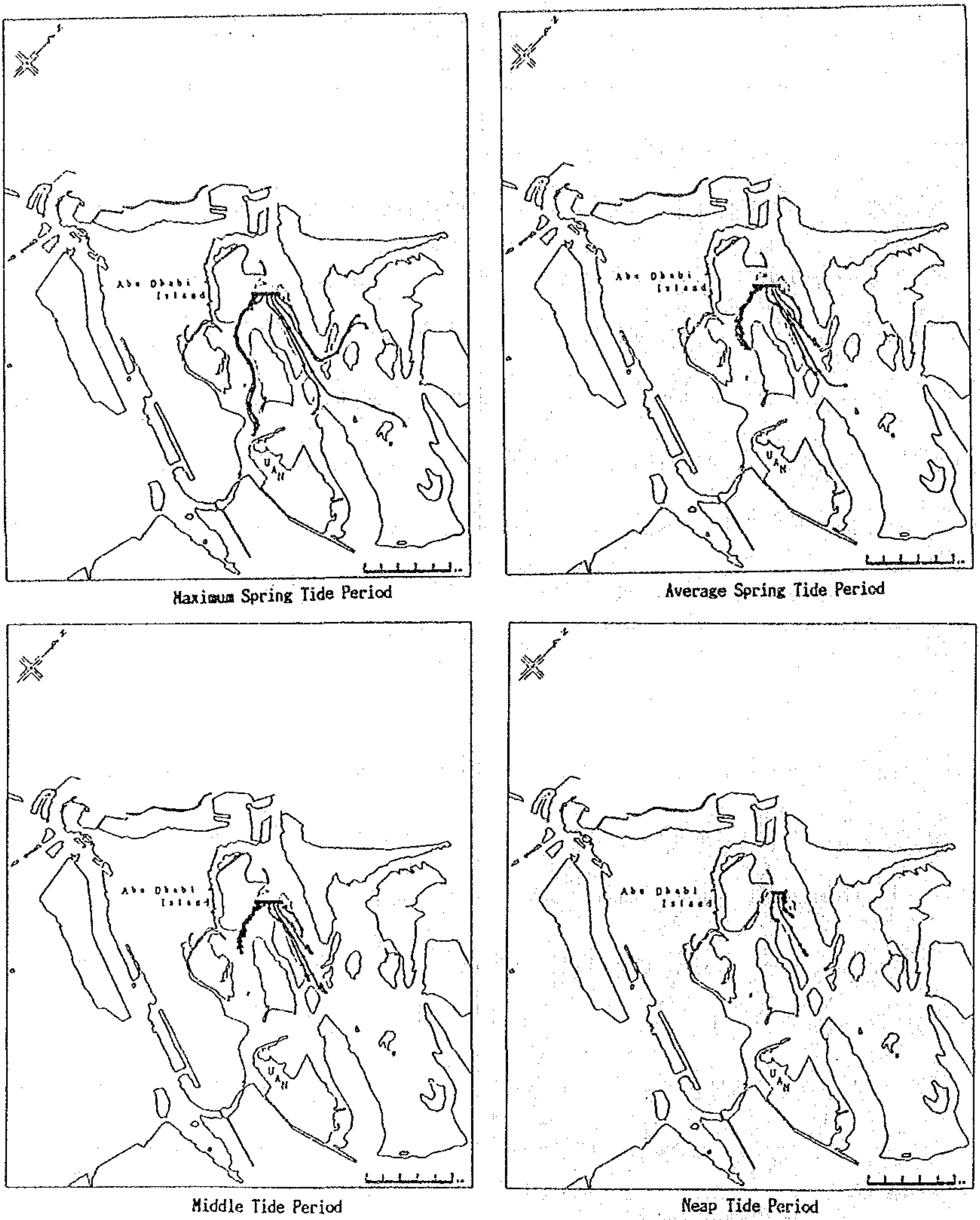
Middle Tide Period



Neap Tide Period

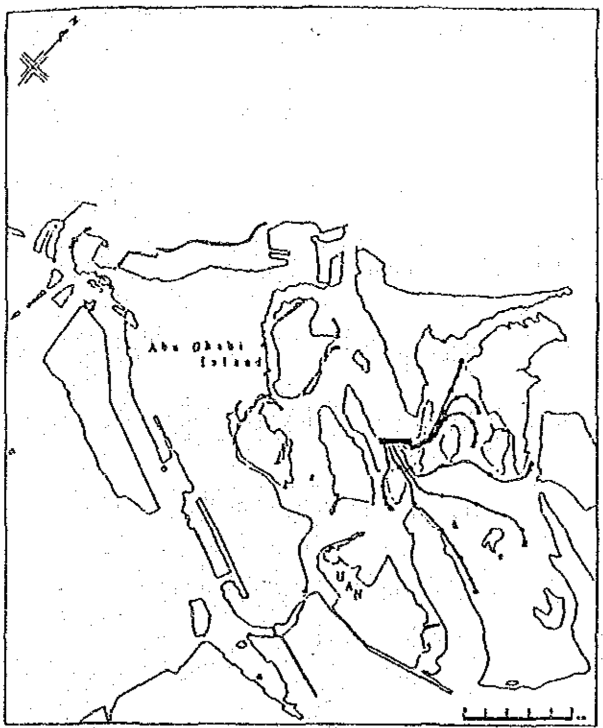
Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.44: Result of Marker Tracing (Thrown at Start of Flood Tide) <Line 3>

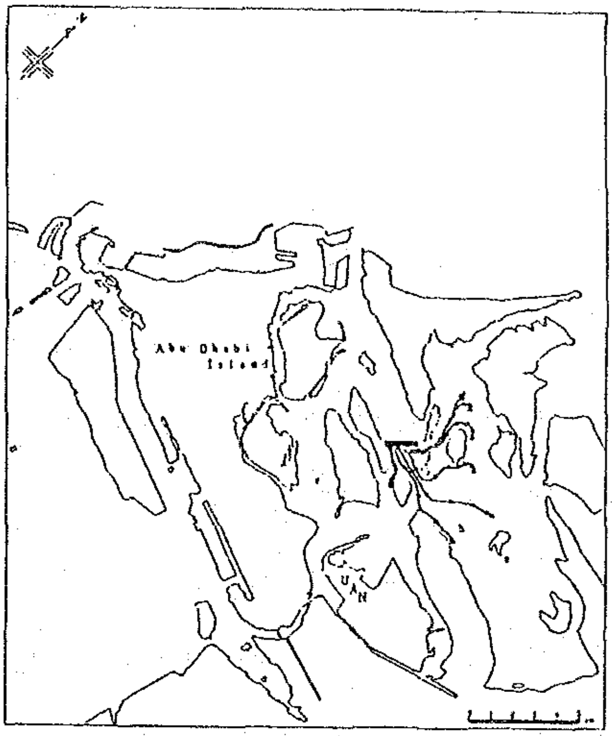


Notes : * shows thrown location.
Mark is noted in every hour.

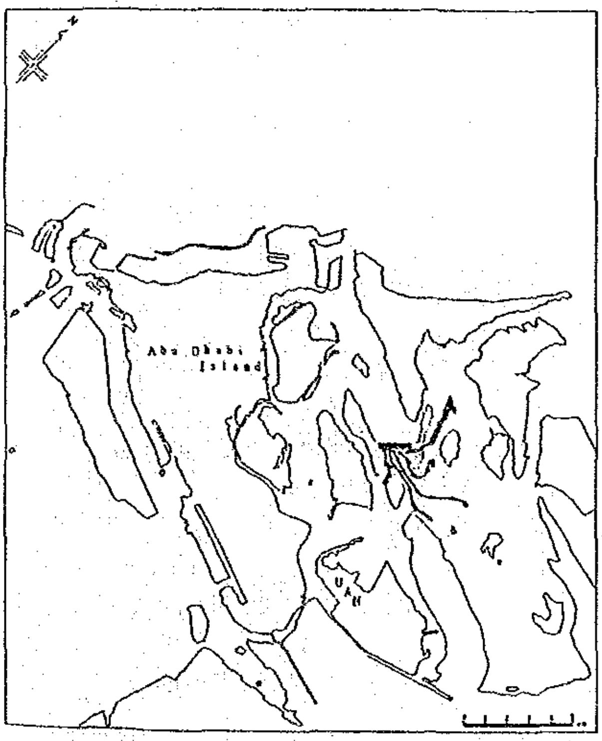
Fig. 5.1.45: Result of Marker Tracing (Thrown at Start of Flood Tide) <Line 4>



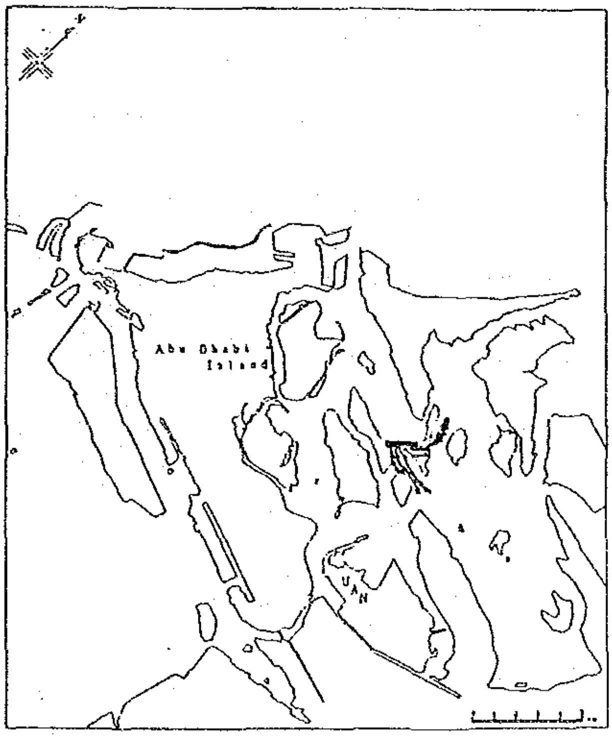
Maximum Spring Tide Period



Average Spring Tide Period



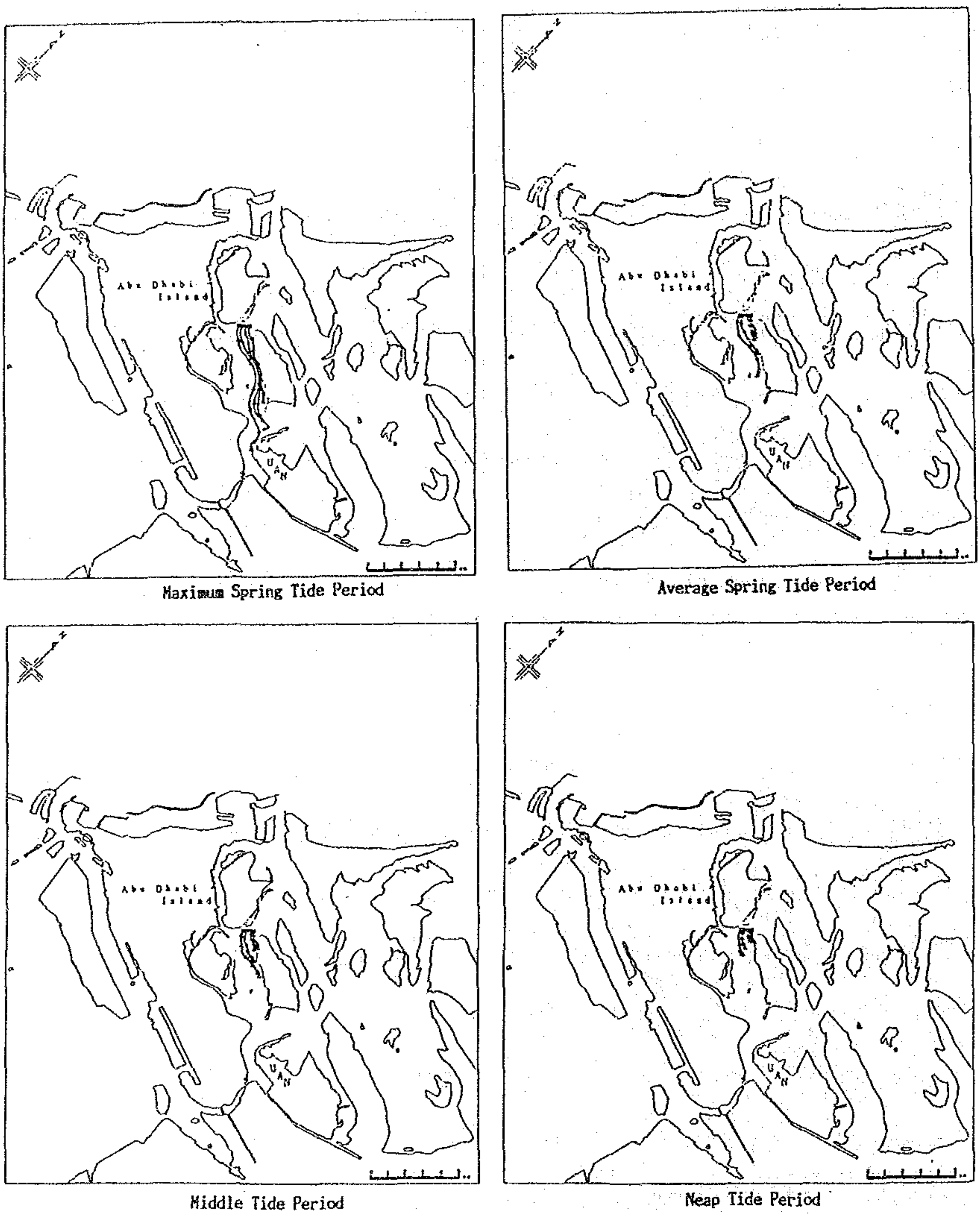
Middle Tide Period



Neap Tide Period

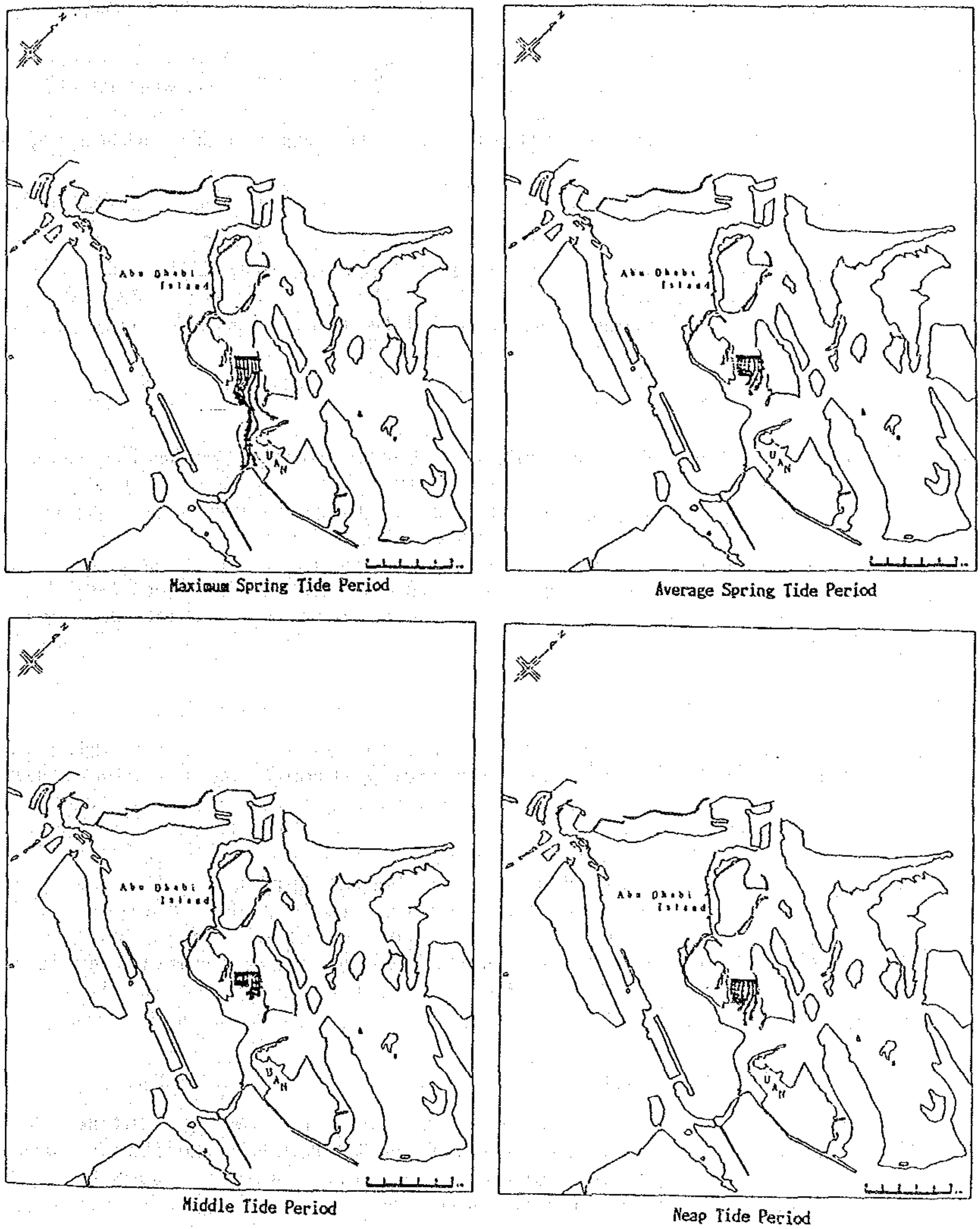
Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.46: Result of Marker Tracing (Thrown at Start of Flood Tide) <Line 5>



Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.47: Result of Marker Tracing (Thrown at Start of Flood Tide) <Line 6>



Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.48: Result of Marker Tracing (Thrown at Start of Flood Tide) <Line 7>

2) Movement Conditions of Markers near Intake of Umm Al Nar Station

Movement conditions of markers near the intake of Umm Al Nar Station were examined on a total of 6 lines from Lines A to Line F as shown in Fig. 5.1.41. The followings are the summeries of each line about movement conditions of markers. Markers were thrown in at the beginning of flood tide at each line.

(a) Line A (Figs. 5.1.49 to 5.1.52)

Markers reached the intake in 5 to 6 hours from the start of the flood current at maximum spring tide regardless the drift current caused by wind. In other tidal periods, they reached to a location 3 km away from the intake at most, even at average spring tide.

(b) Line B (Figs. 5.1.53 to 5.1.56)

At the maximum spring tide, the markers reached to the intake in 3 to 4 hours from the start of flood current. In other tidal periods, they would reach to 1 to 2 km from the intake, if there is no drift current (only a tidal current and an intake and discharge flow).
However, when there is a drift current, oil lumps would flow along a complicated route due to a complicated topographical whirlpool in the southern sea area of Qassar Essall. But, they would move rather NE, opposite of the intake.

(c) Line C (Figs. 5.1.57 to 5.1.60)

A large movement of the oil lumps was not observed as the Line C which is located at boundary between the current coming through Baghal Channel and that coming between Assamaliyah and Essall at the maximum spring tide.

Therefore, when a drift current occurs, it comes on the inside of the intake along the cape located on the of Umm Al Nar, but it does not reach the intake. On the other hand, during other tidal periods, oil lumps move along the peninsula because of the inflow of sea water coming through the Baghal Channel to the intake channel. When a drift current caused by a northern wind is added, they reach the intake in 4 to 6 hours.

(d) Line D (Figs 5.1.61 to 5.1.64)

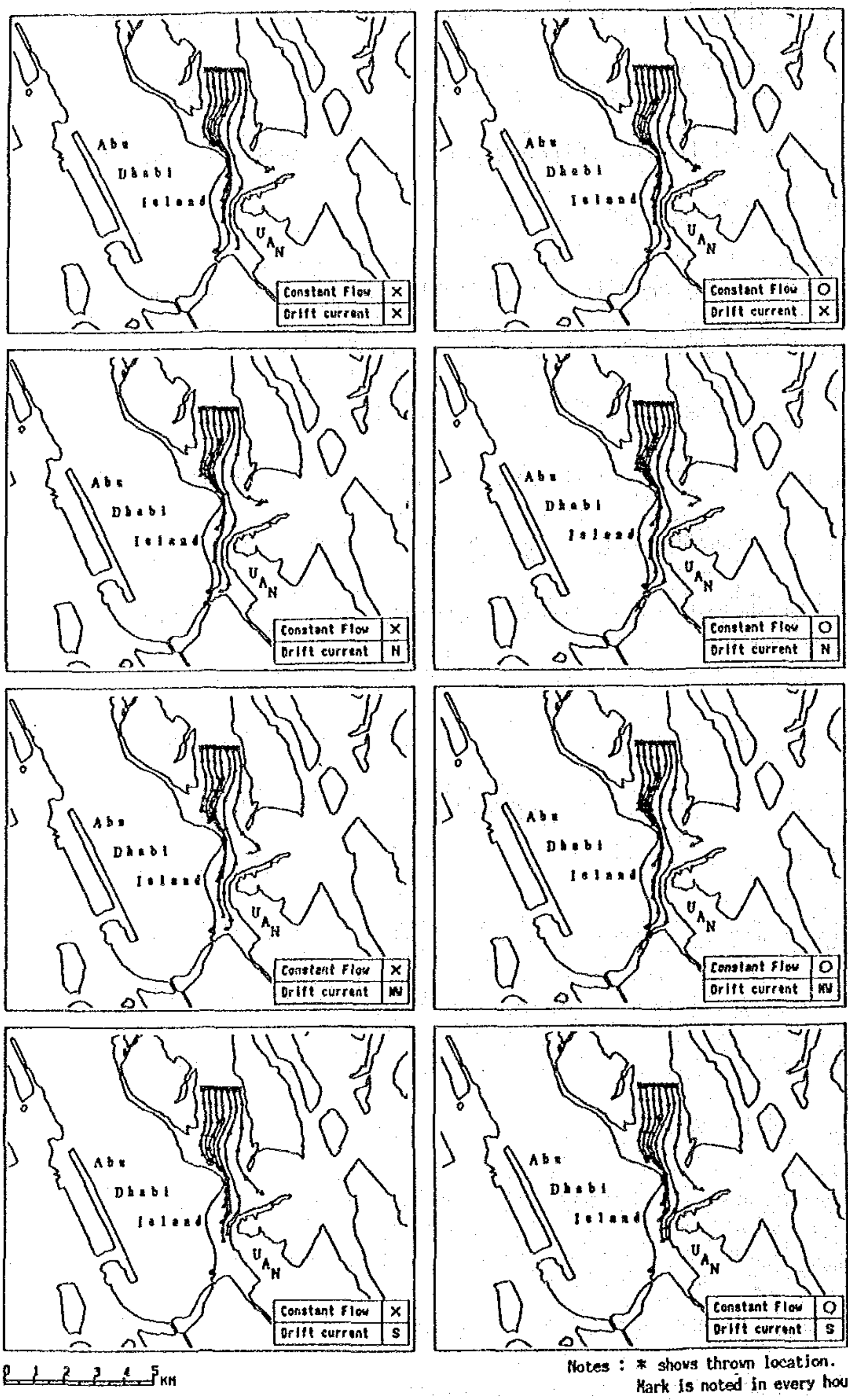
Line D is located in a sea area influenced by the flow of intake and discharge water. At the maximum spring tide, it reaches the intake in 3 hours. In other tidal periods, other than a drift current caused by a S wind, they reach the intake in 6 hours at the most.

(e) Line E (Figs. 5.1.65 to 5.1.68)

At the maximum spring tide, oil lumps reach the intake. At the other tidal periods, they only reach the intake with a drift current caused by southern winds. The minimum arrival time is about 3 hours at the maximum spring tide and in a drift current due to a southern wind.

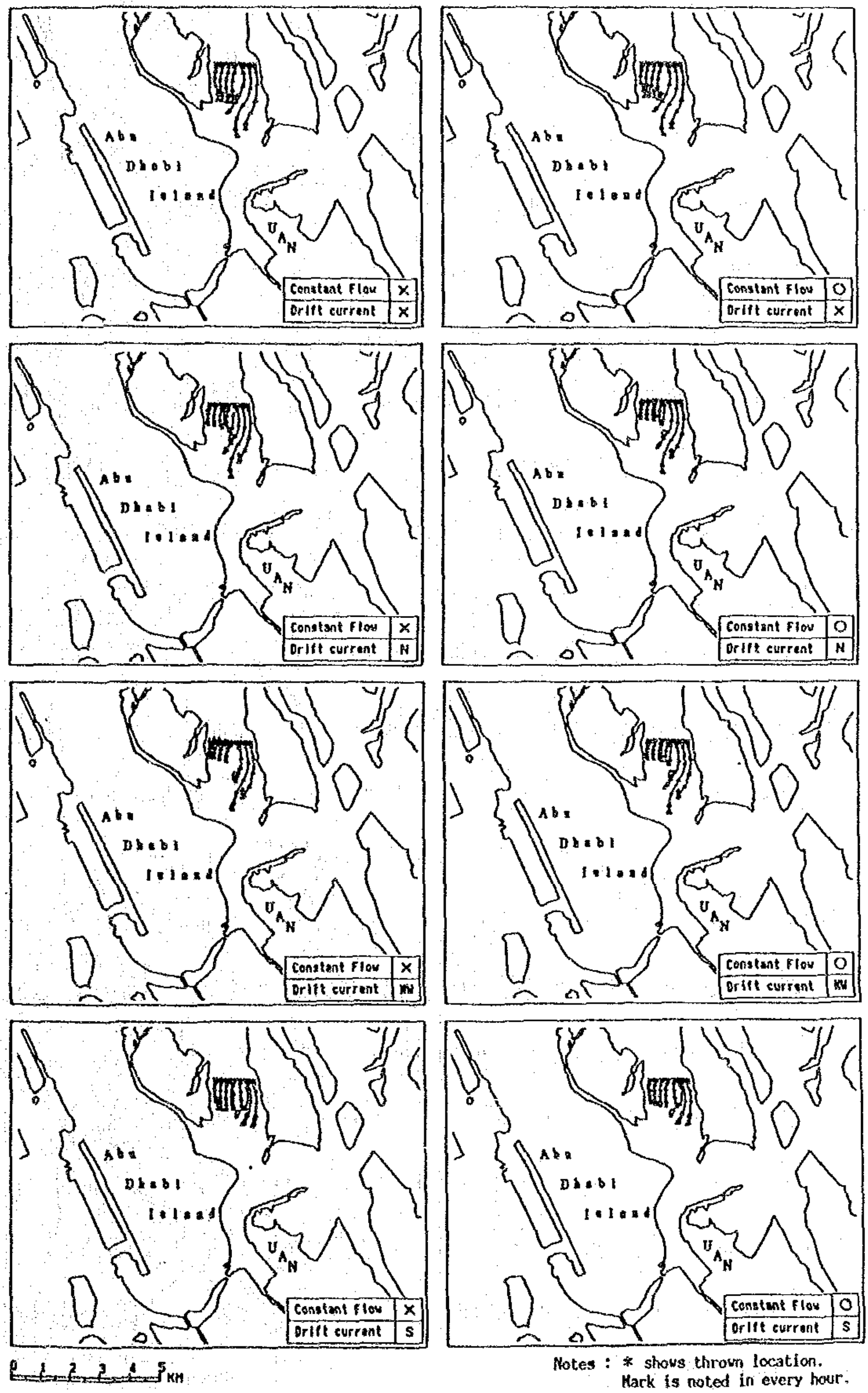
(f) Line F (Figs. 5.1.69 to 5.1.72)

The movement of oil lumps showed the same tendency as Line E since it was about 1 km apart from Line E, but the possibility of their flowing near the intake was greater than Line E since it was about 1 km closer to the intake.



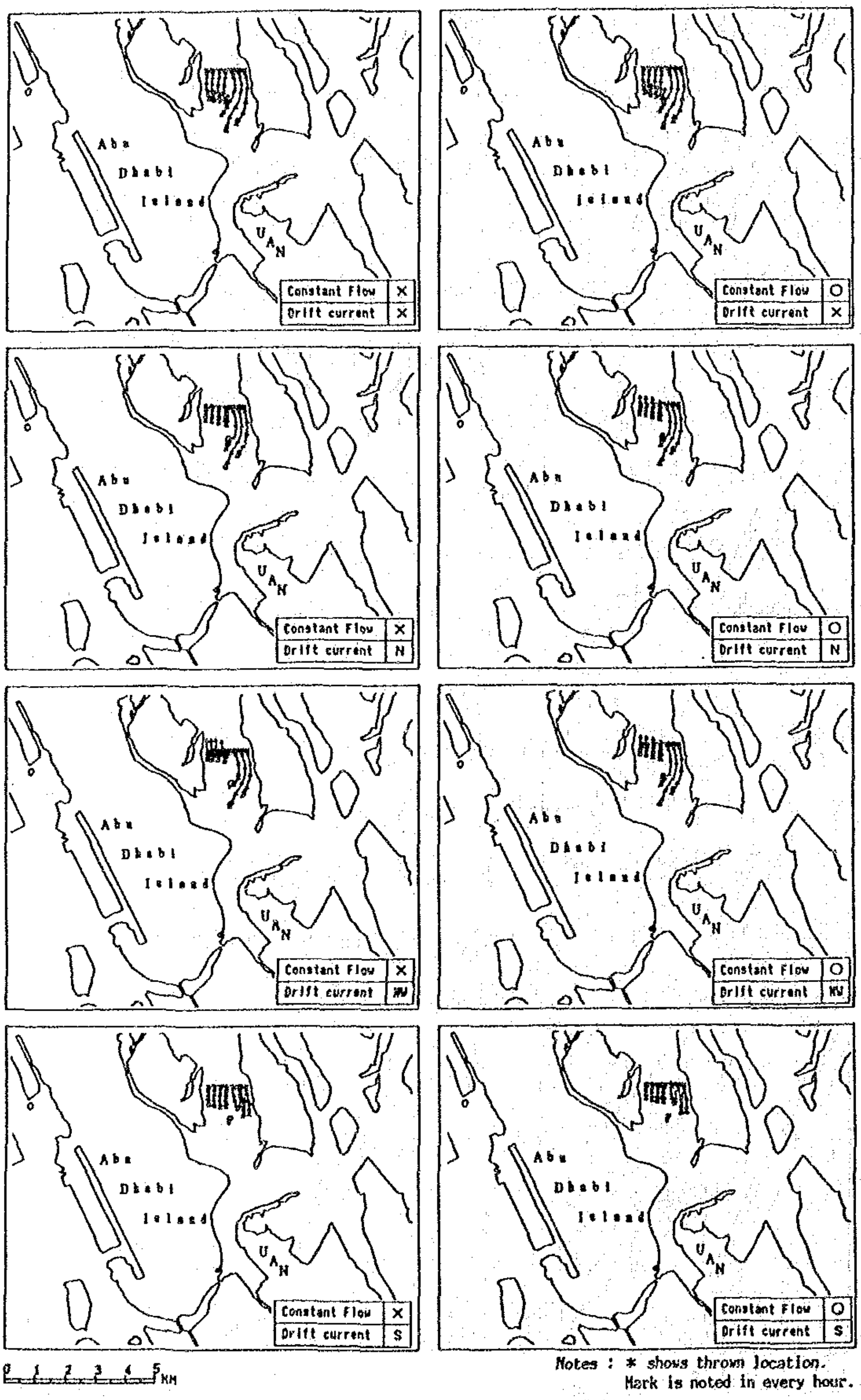
Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.49: Result of Marker Tracing (At Maximum Spring Tide + Intake and Discharge Flow) <Line A>



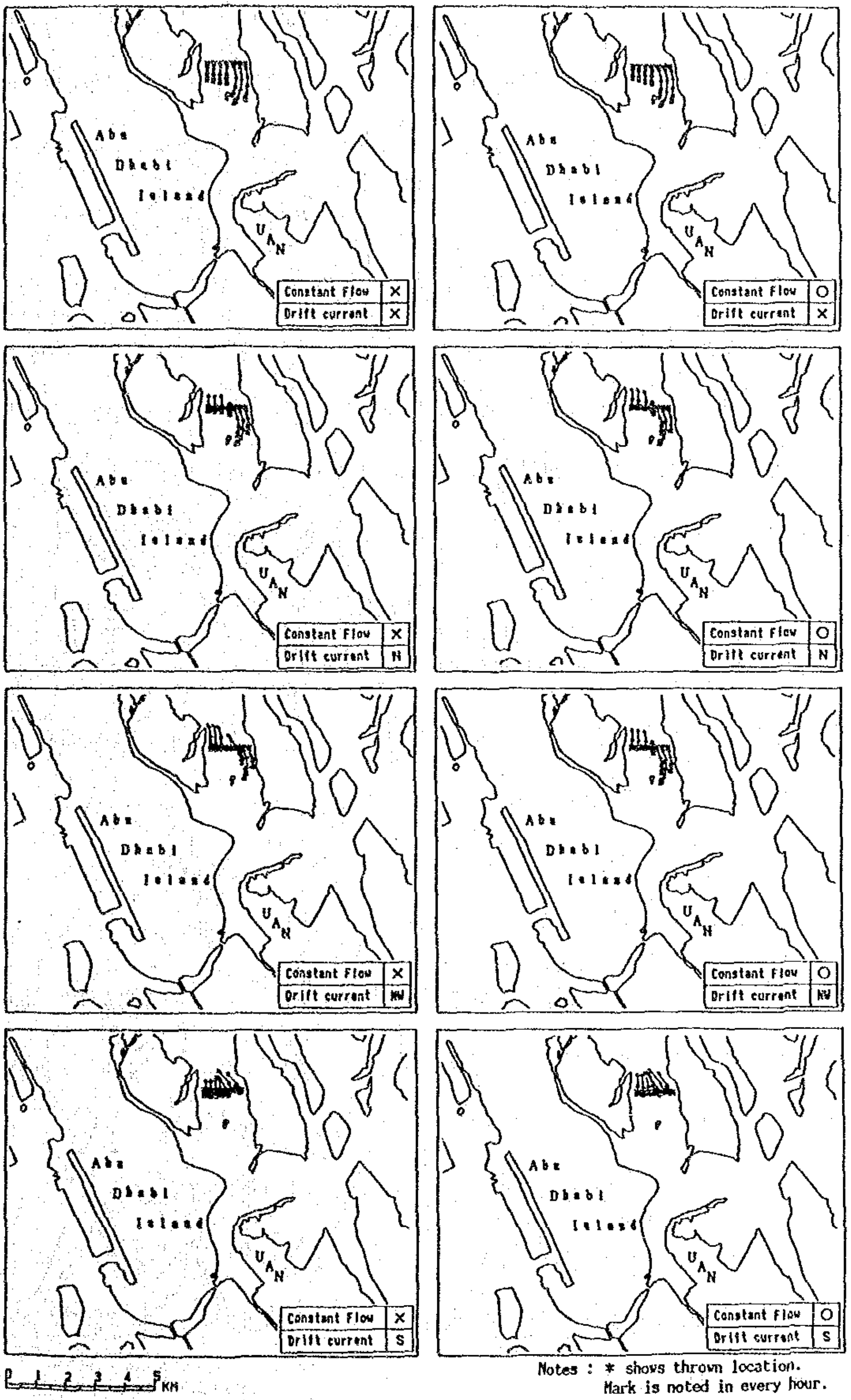
Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.50: Result of Marker Tracing (At Average Spring Tide + Intake and Discharge Flow) <Line A>



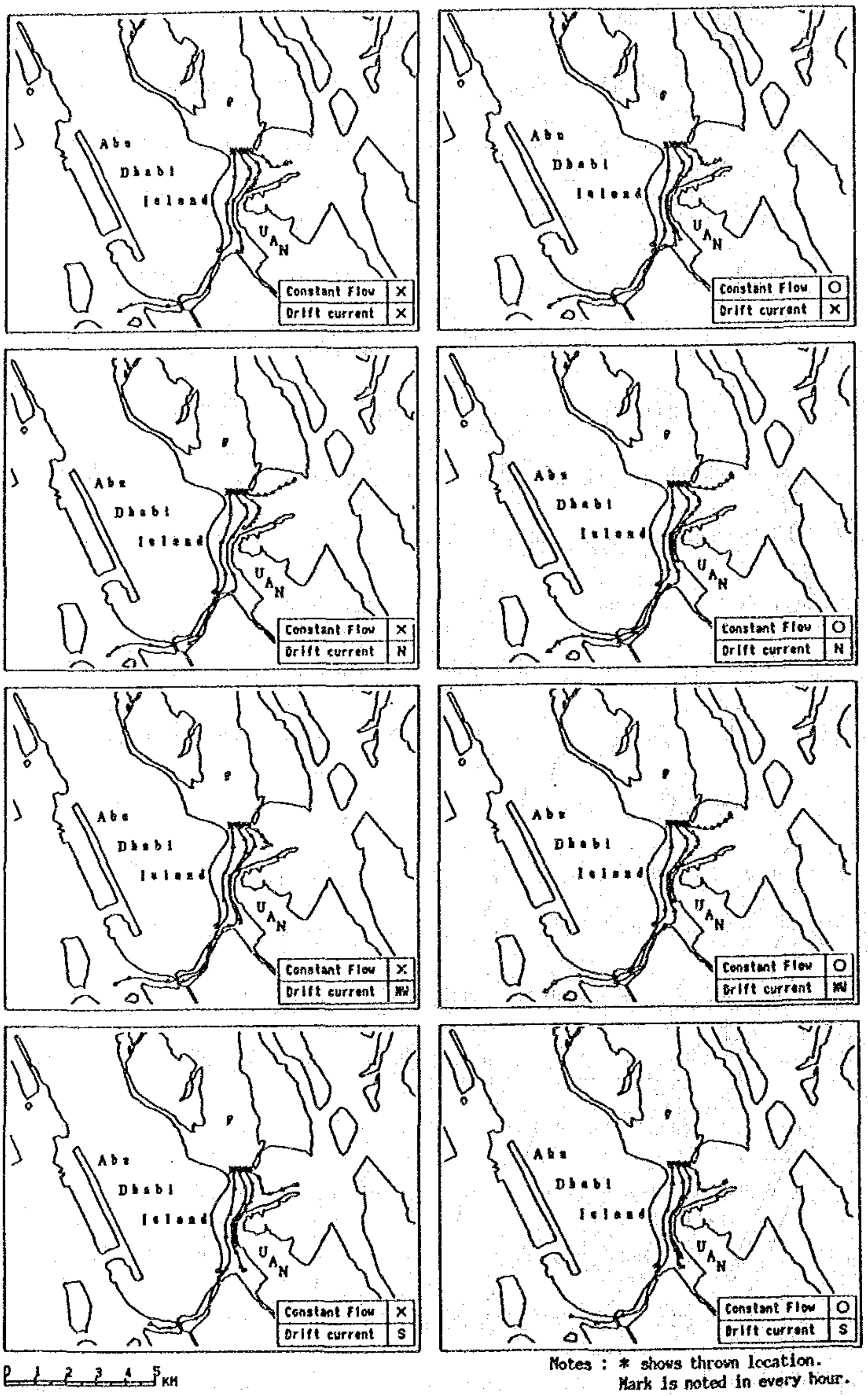
*Notes : * shows thrown location.*
Mark is noted in every hour.

Fig. 5.1.51: Result of Marker Tracing (At Middle Tide + Intake and Discharge Flow) <Line A>



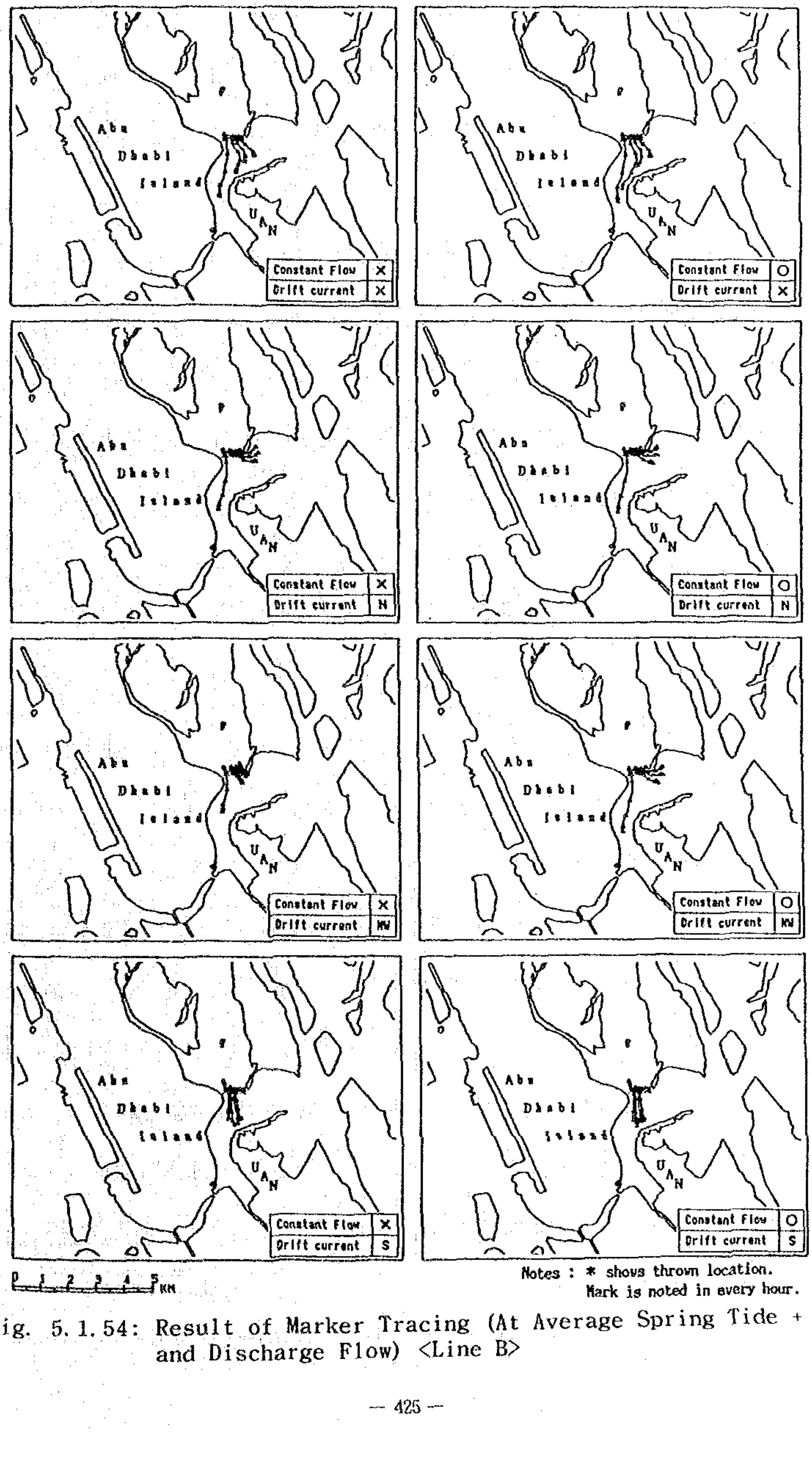
Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.52: Result of Marker Tracing (At Neap Tide + Intake and Discharge Flow) <Line A>



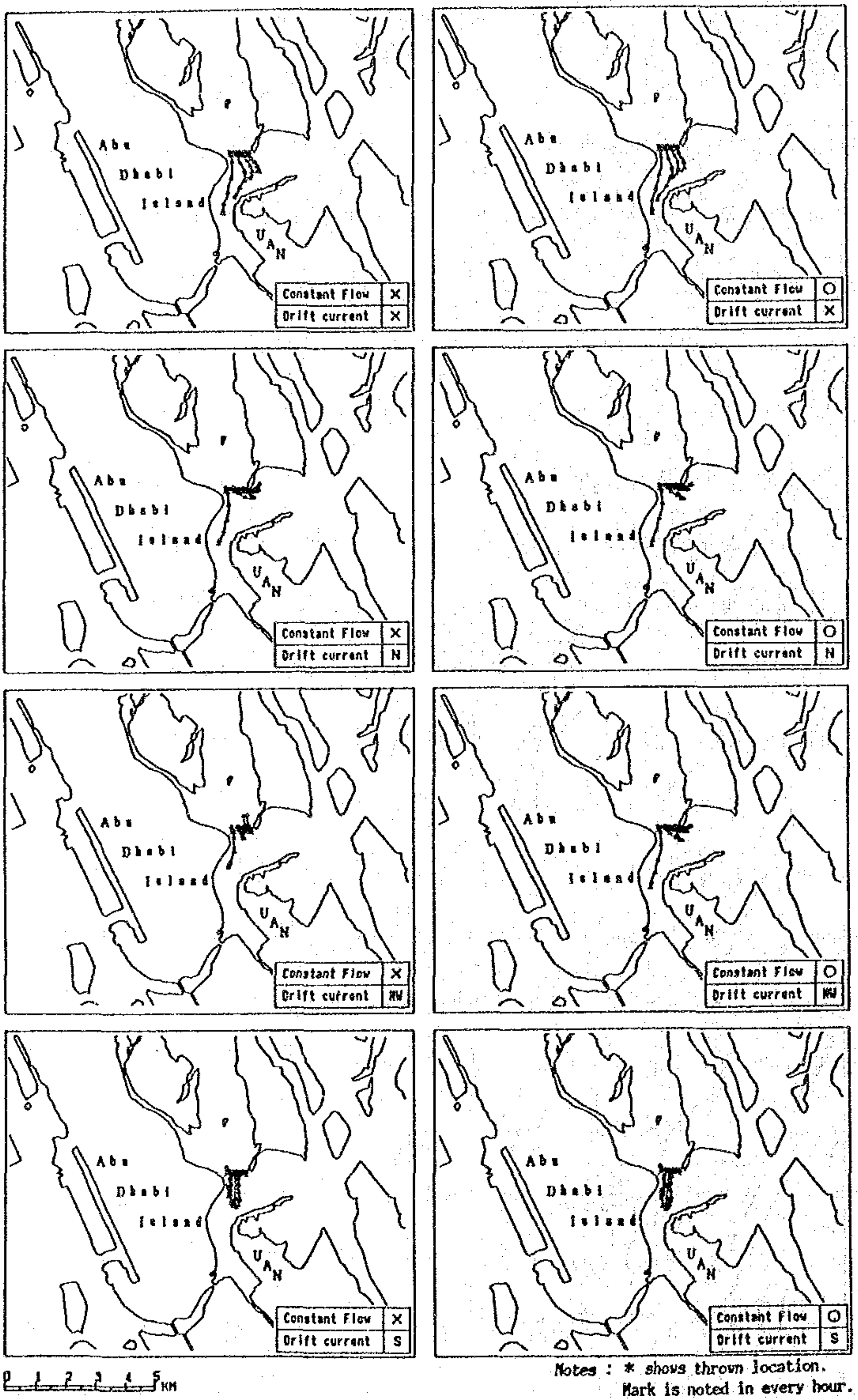
Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.53: Result of Marker Tracing (At Maximum Spring Tide + Intake and Discharge Flow) <Line B>



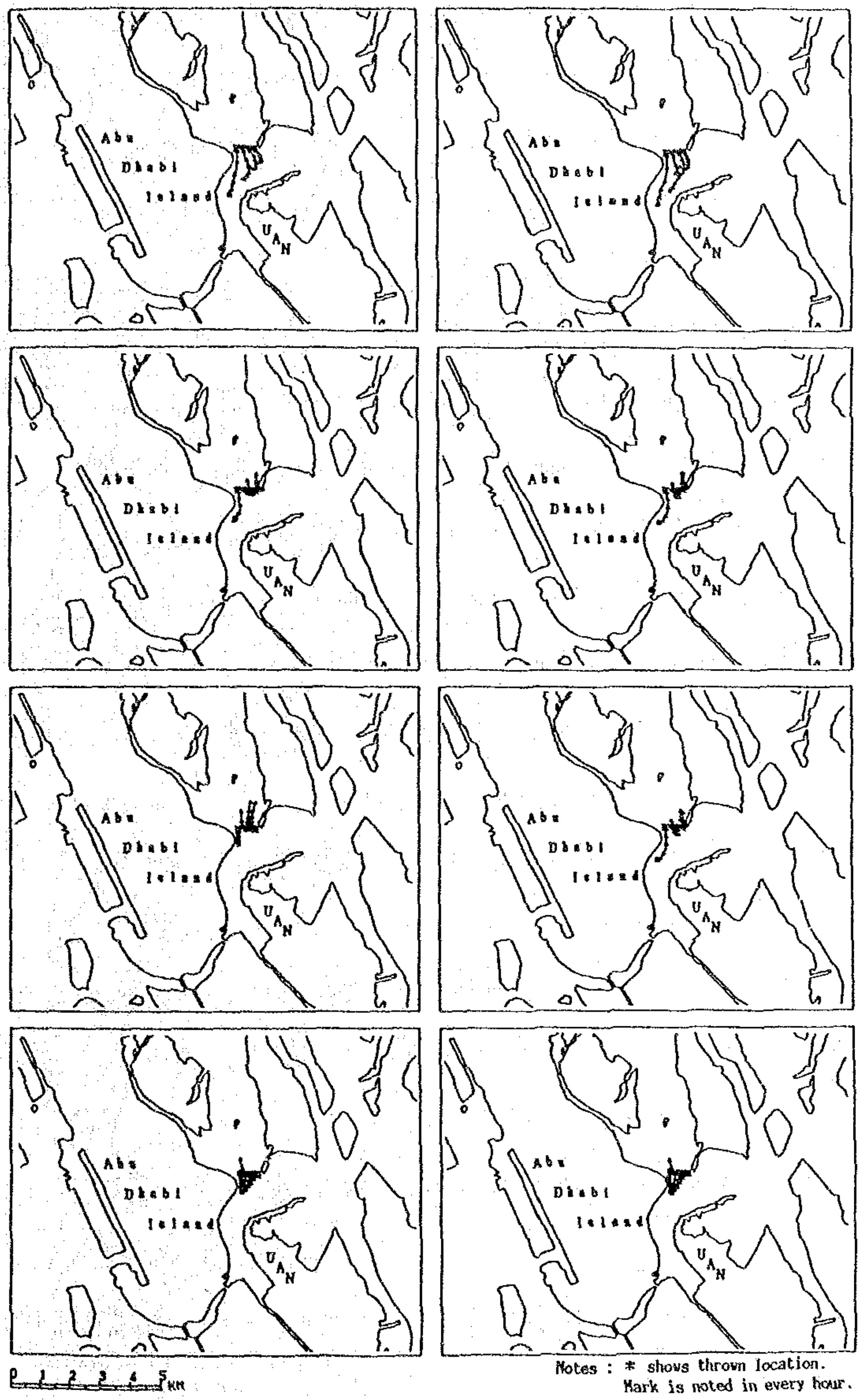
Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.54: Result of Marker Tracing (At Average Spring Tide + Intake and Discharge Flow) <Line B>



Notes : * shows thrown location.
Mark is noted in every hour.

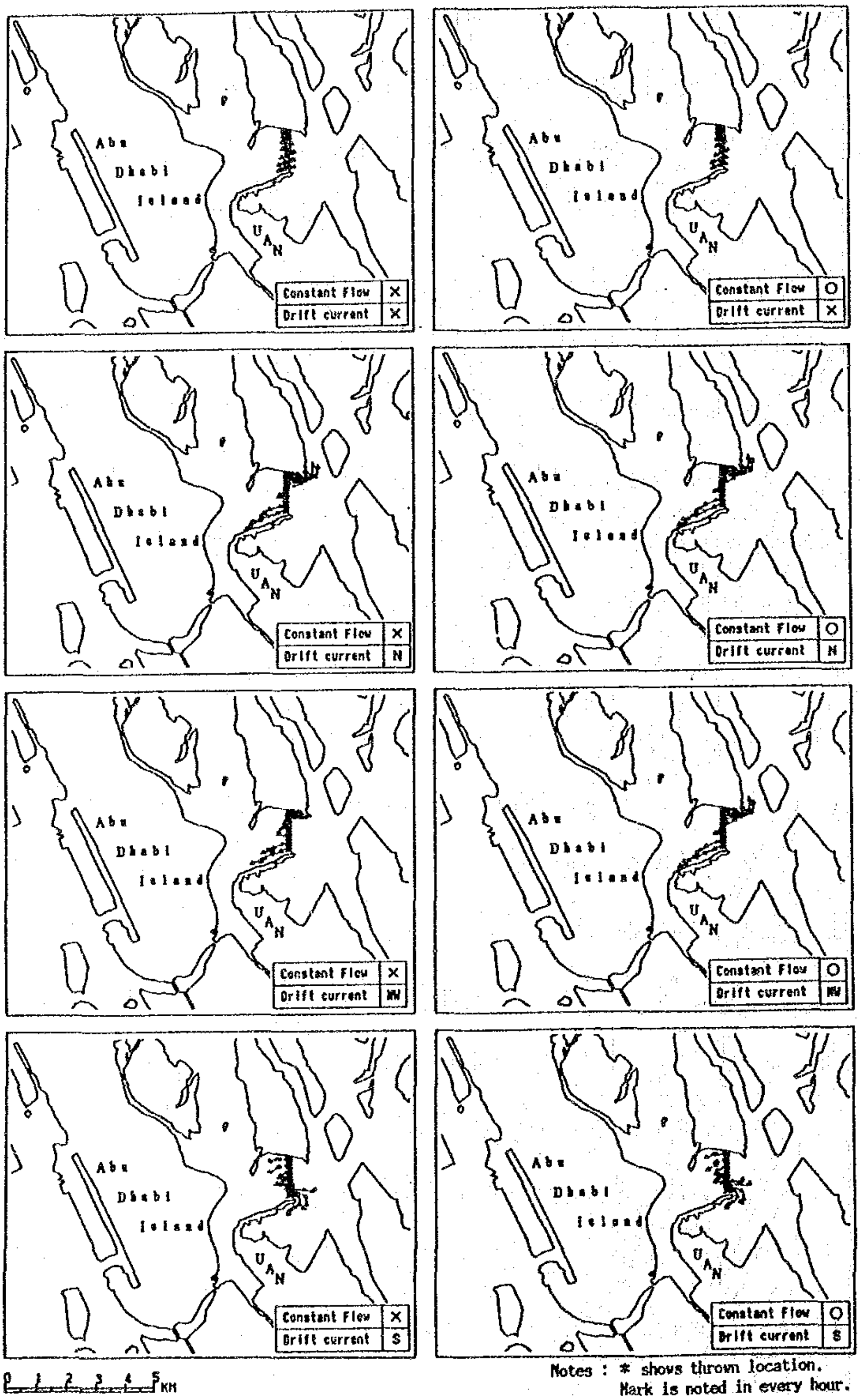
Fig. 5.1.55: Result of Marker Tracing (At Middle Tide + Intake and Discharge Flow) <Line B>



0 1 2 3 4 5 KM

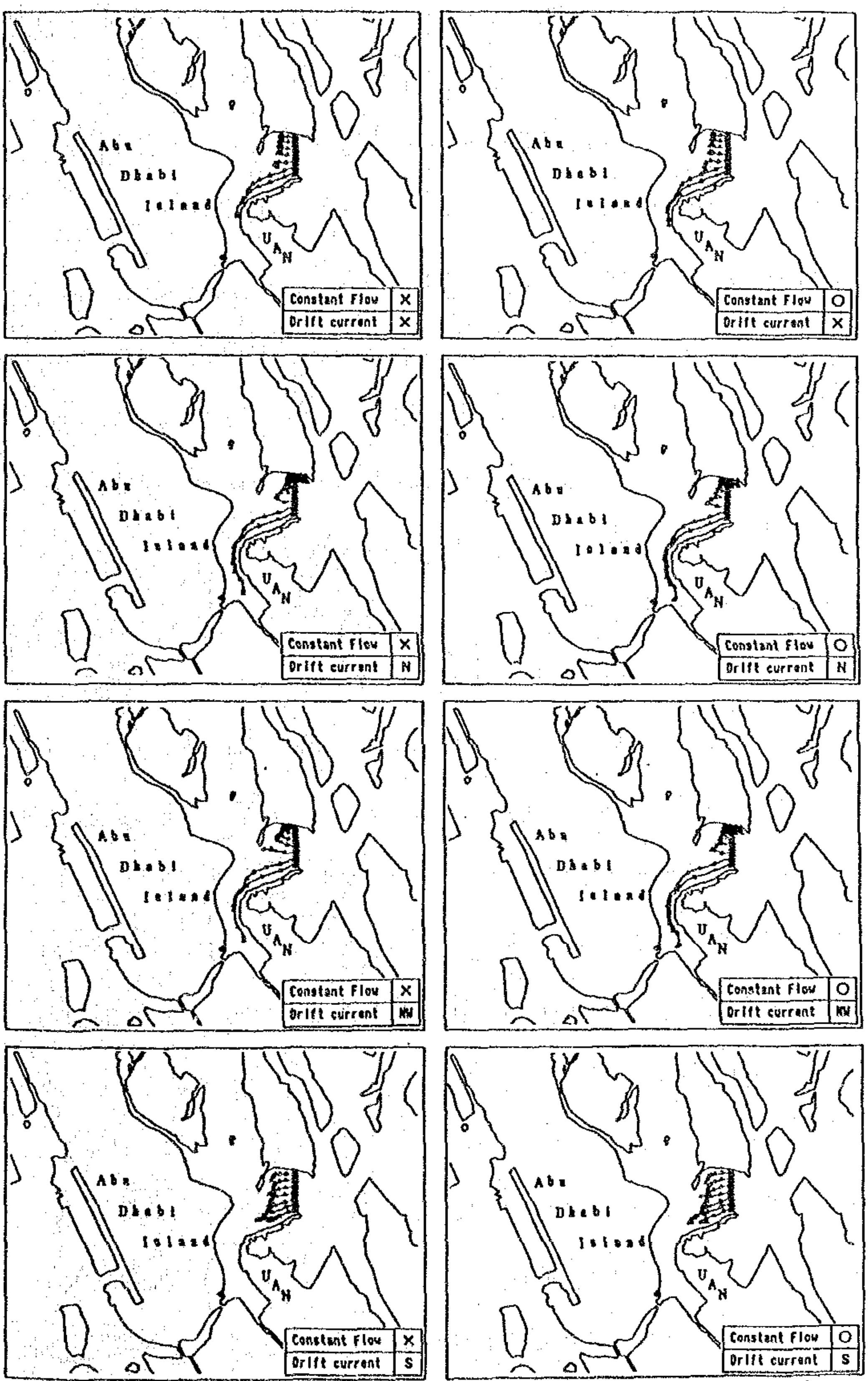
Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.56: Result of Marker Tracing (At Neap Tide + Intake and Discharge Flow) <Line B>



Notes : * shows thrown location.
Mark is noted in every hour.

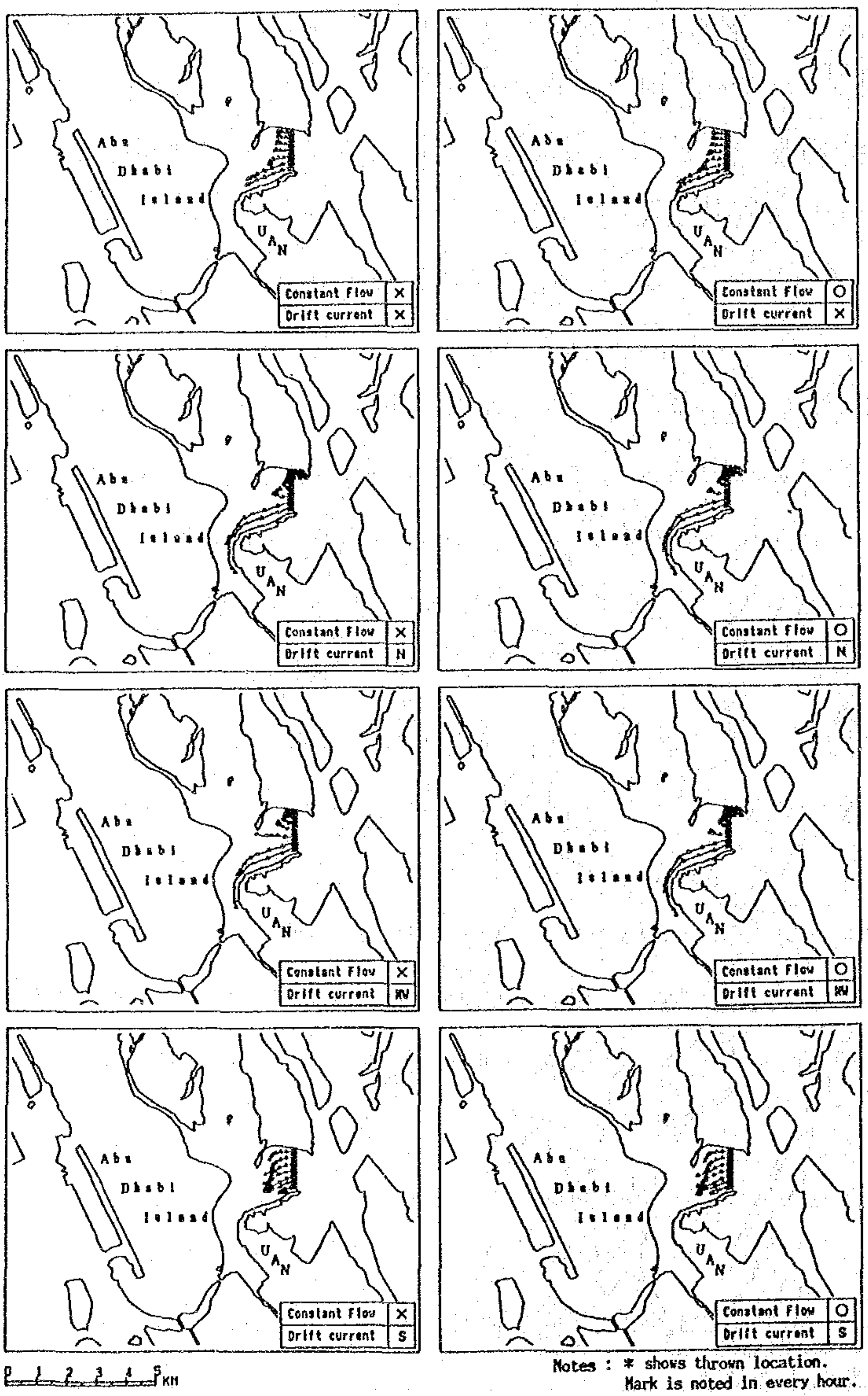
Fig. 5.1.57: Result of Marker Tracing (At Maximum Spring Tide + Intake and Discharge Flow) <Line C>



0 1 2 3 4 5 KM

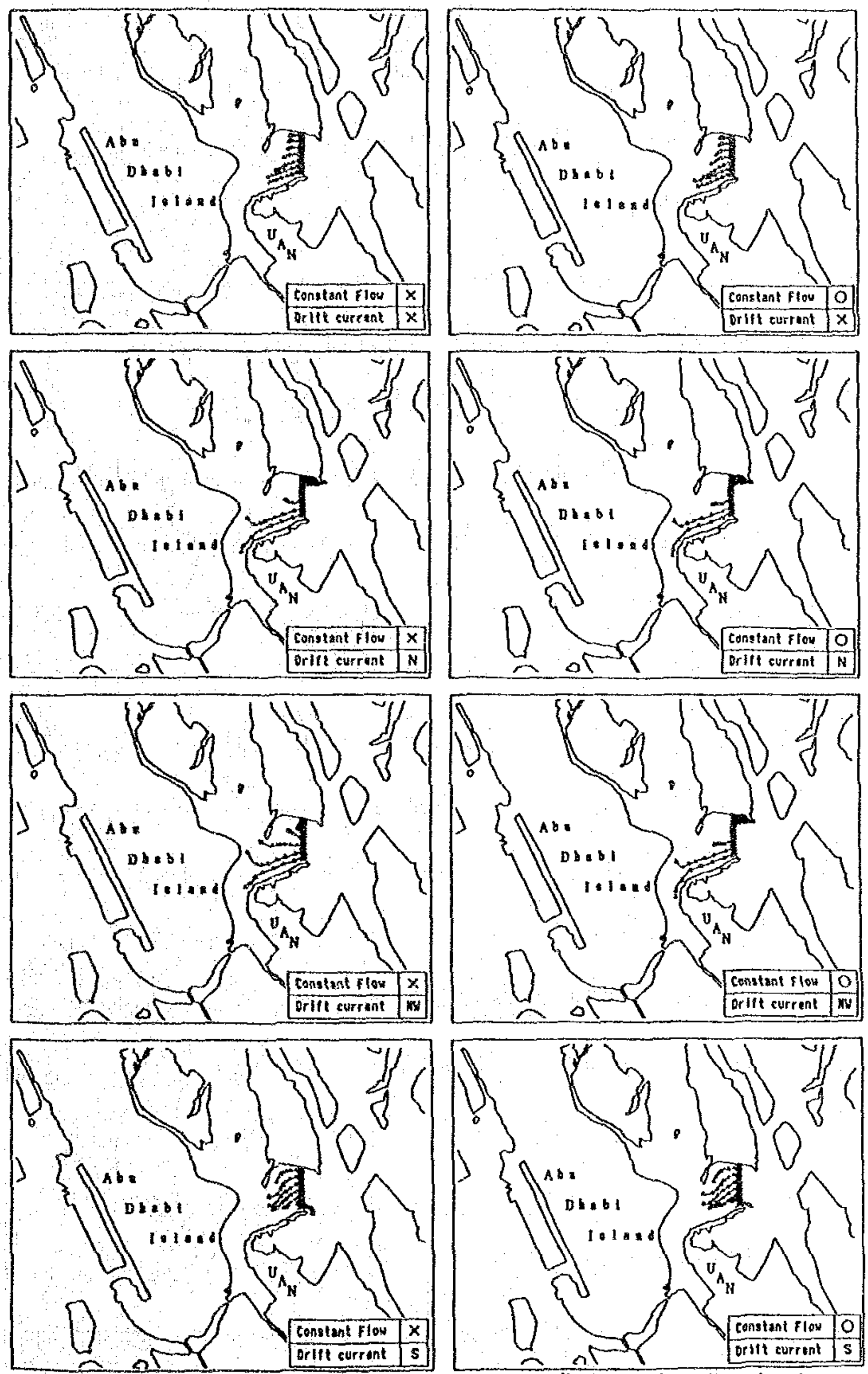
Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.58: Result of Marker Tracing (At Average Spring Tide + Intake and Discharge Flow) <Line C>



Notes : * shows thrown location.
Mark is noted in every hour.

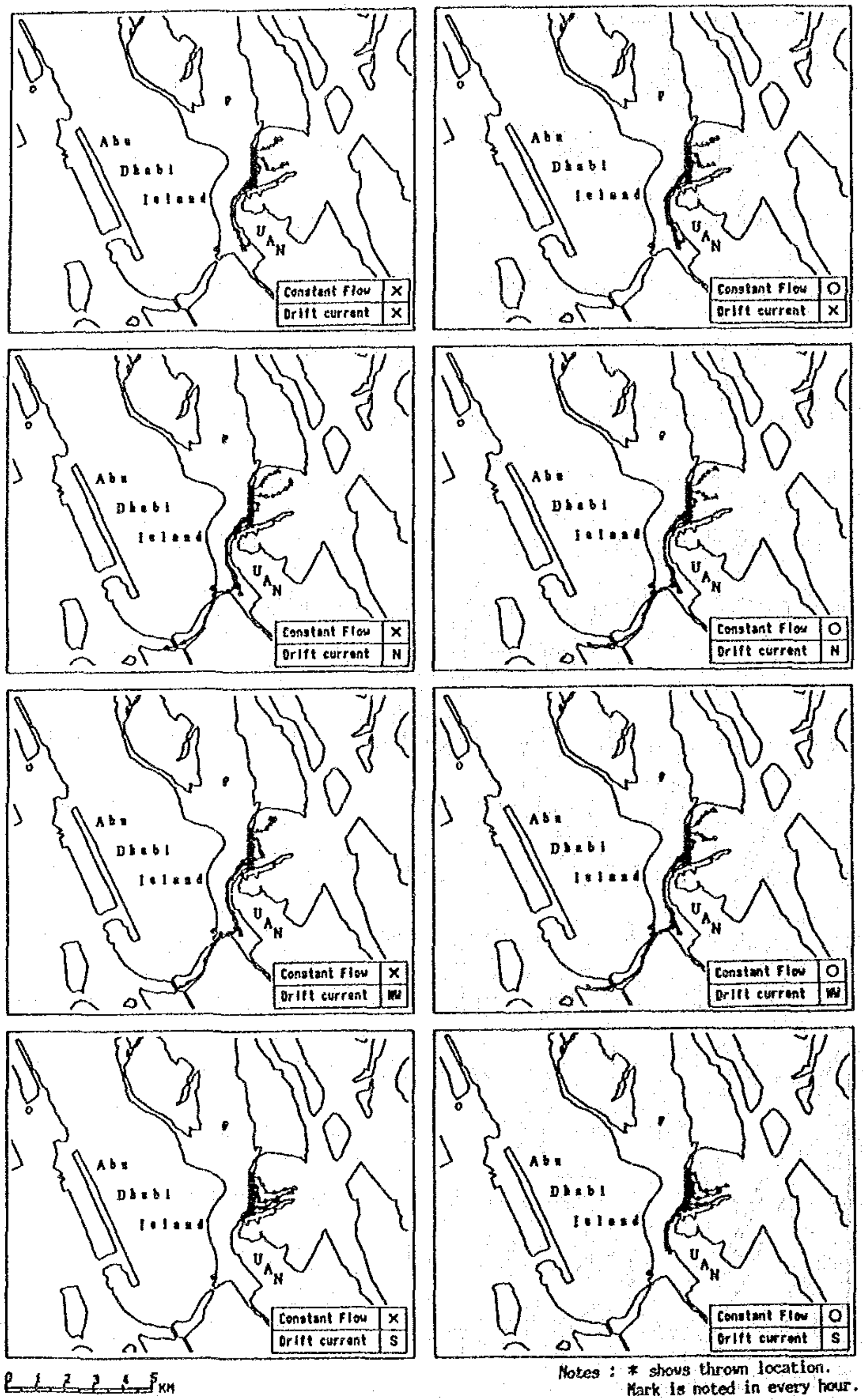
Fig. 5.1.59: Result of Marker Tracing (At Middle Tide + Intake and Discharge Flow) <Line C>



0 1 2 3 4 5 KM

Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.60: Result of Marker Tracing (At Neap Tide + Intake and Discharge Flow) <Line C>



Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.61: Result of Marker Tracing (At Maximum Spring Tide + Intake and Discharge Flow) <Line D>

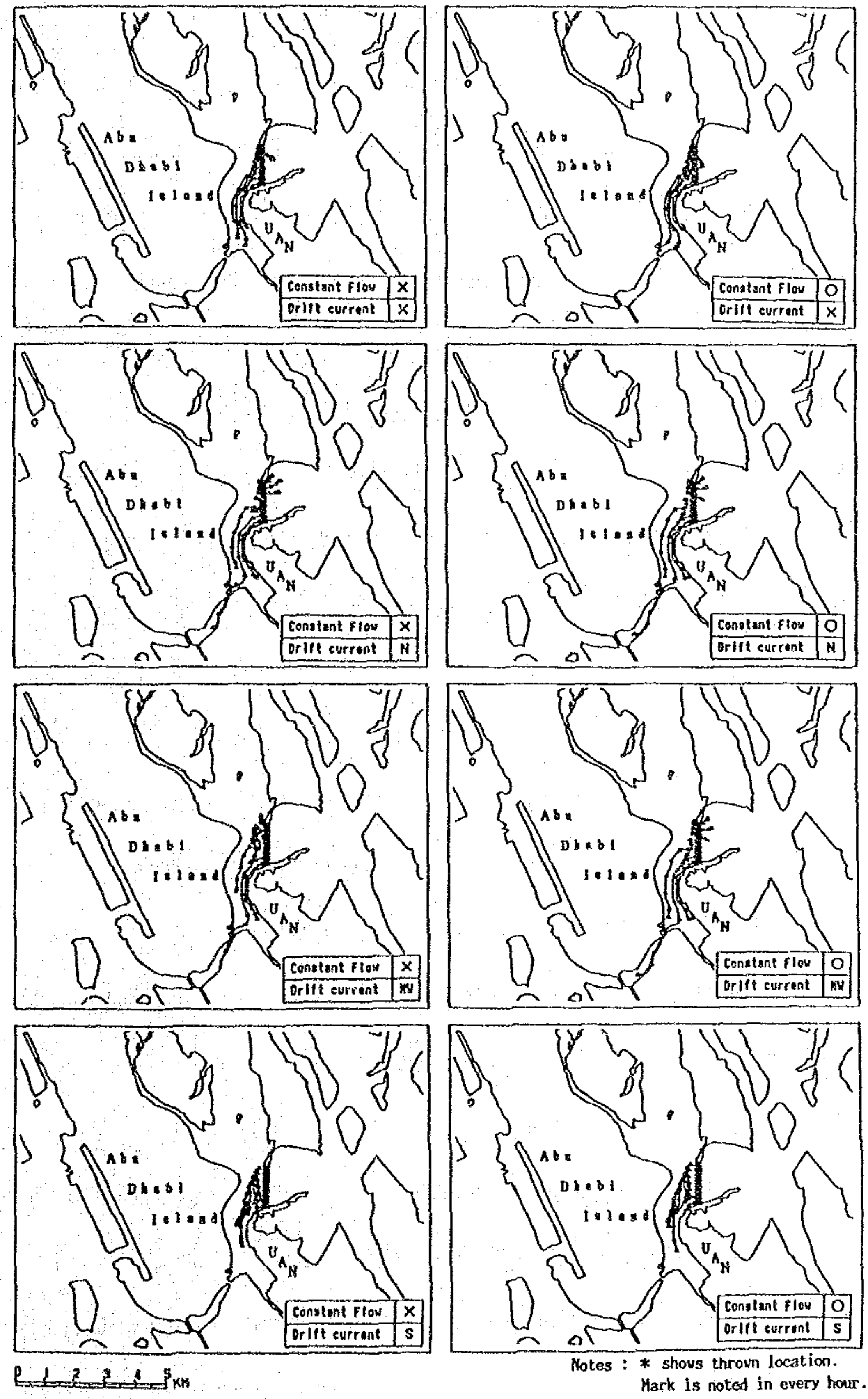


Fig. 5.1.62: Result of Marker Tracing (At Average Spring Tide + Intake and Discharge Flow) <Line D>

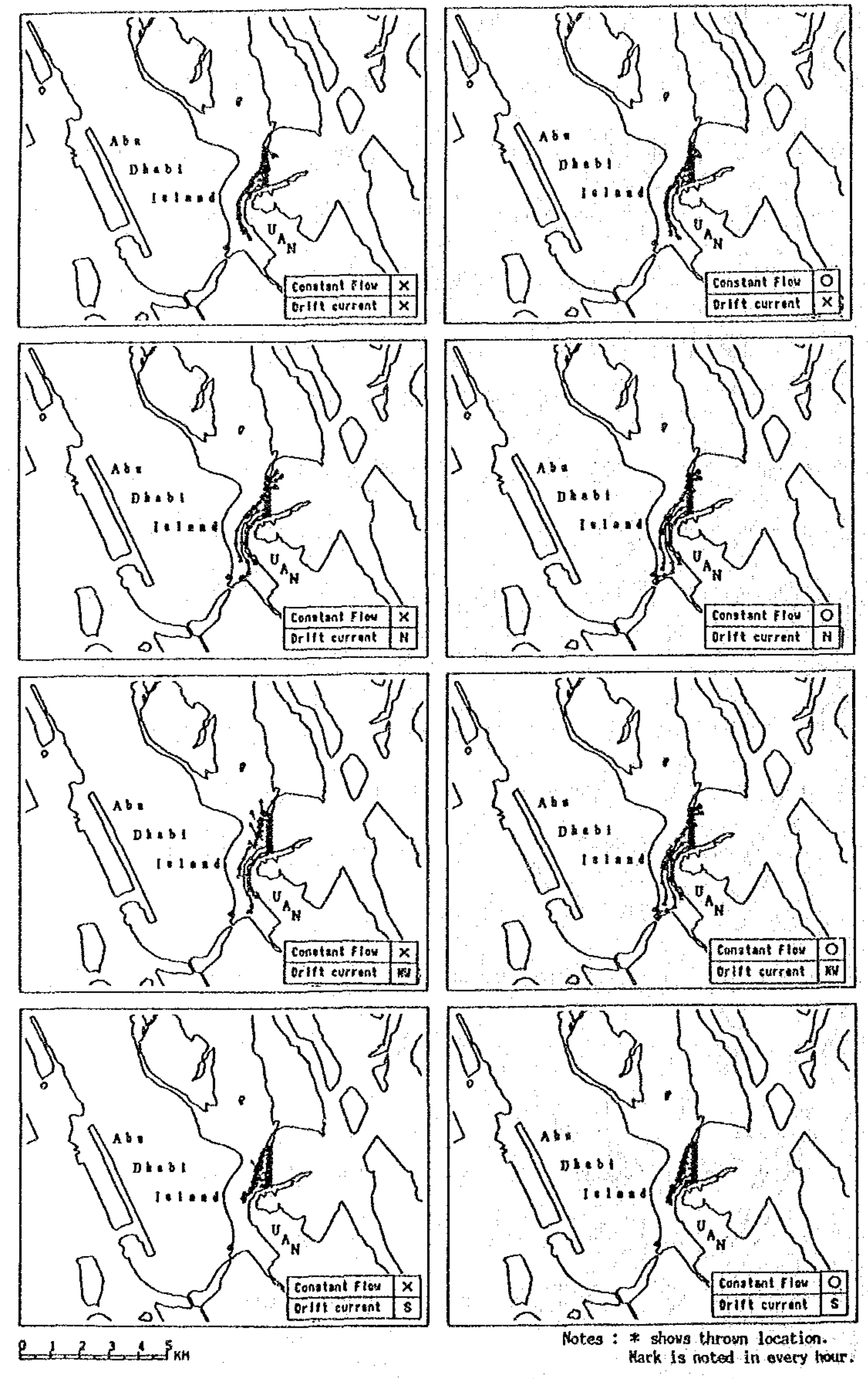
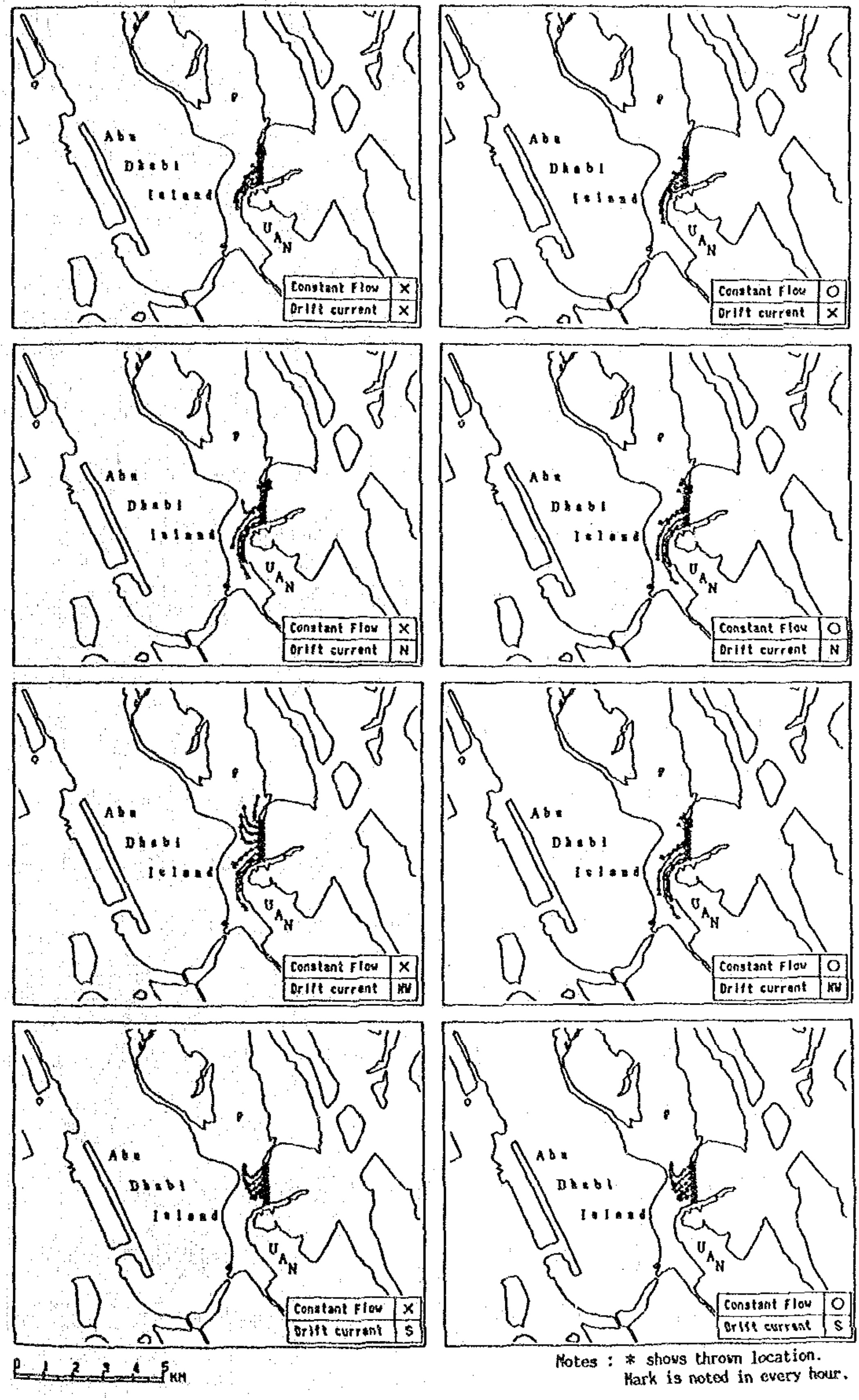
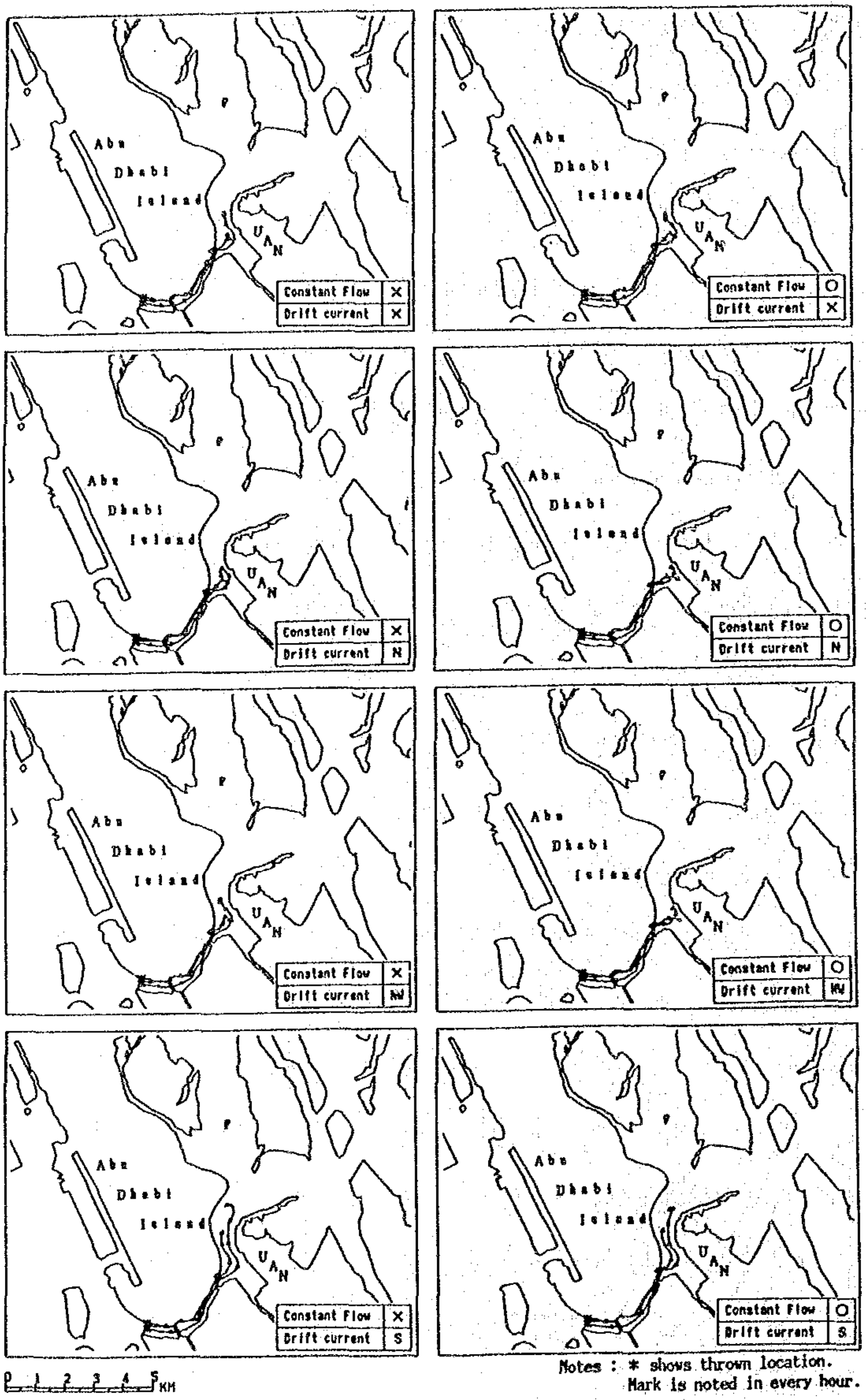


Fig. 5.1.63: Result of Marker Tracing (At Middle Tide + Intake and Discharge Flow) <Line D>



Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.64: Result of Marker Tracing (At Neap Tide + Intake and Discharge Flow) <Line D>



Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.65: Result of Marker Tracing (At Maximum Spring Tide + Intake and Discharge Flow) <Line E>

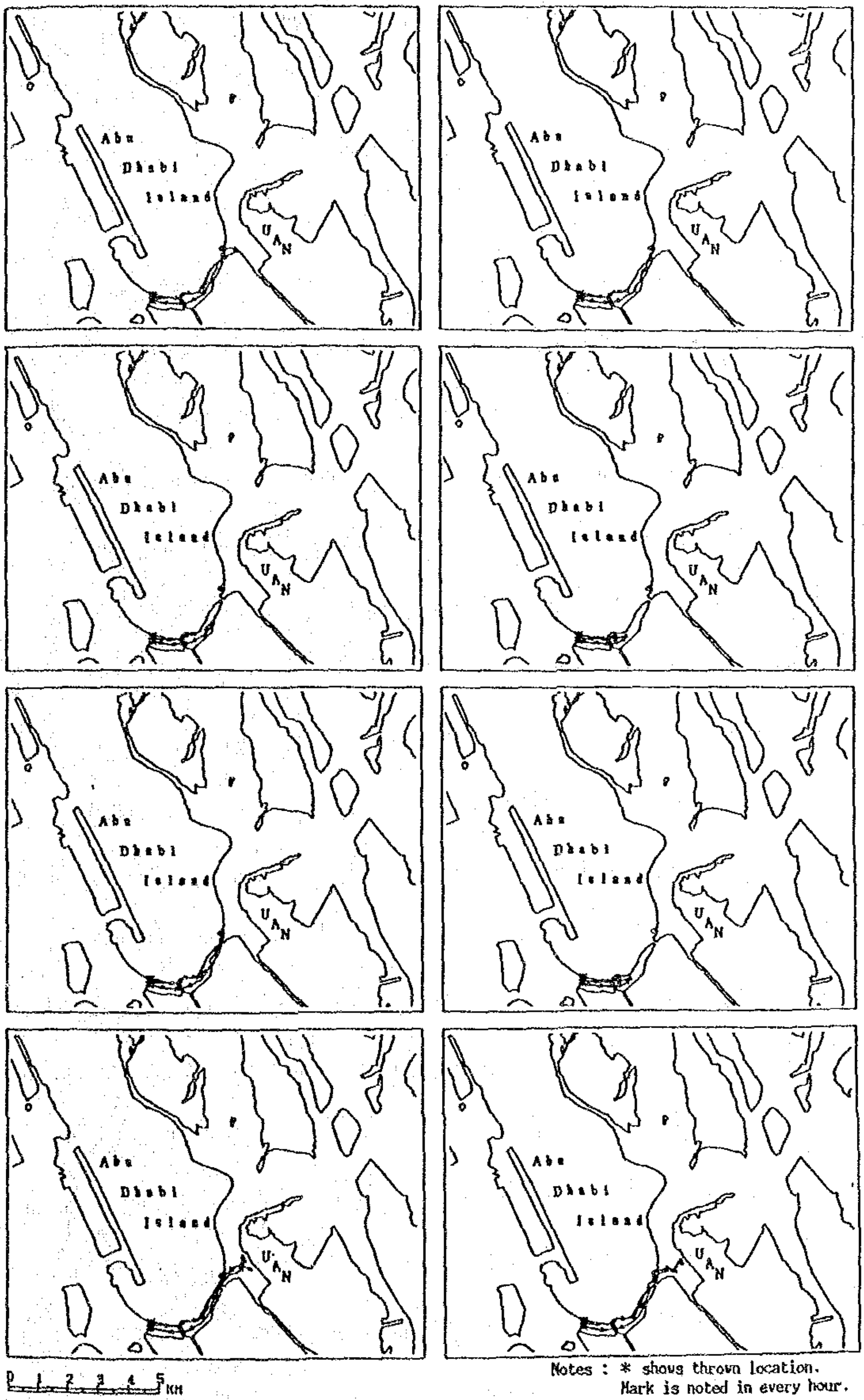


Fig. 5.1.66: Result of Marker Tracing (At Average Spring Tide + Intake and Discharge Flow) <Line E>

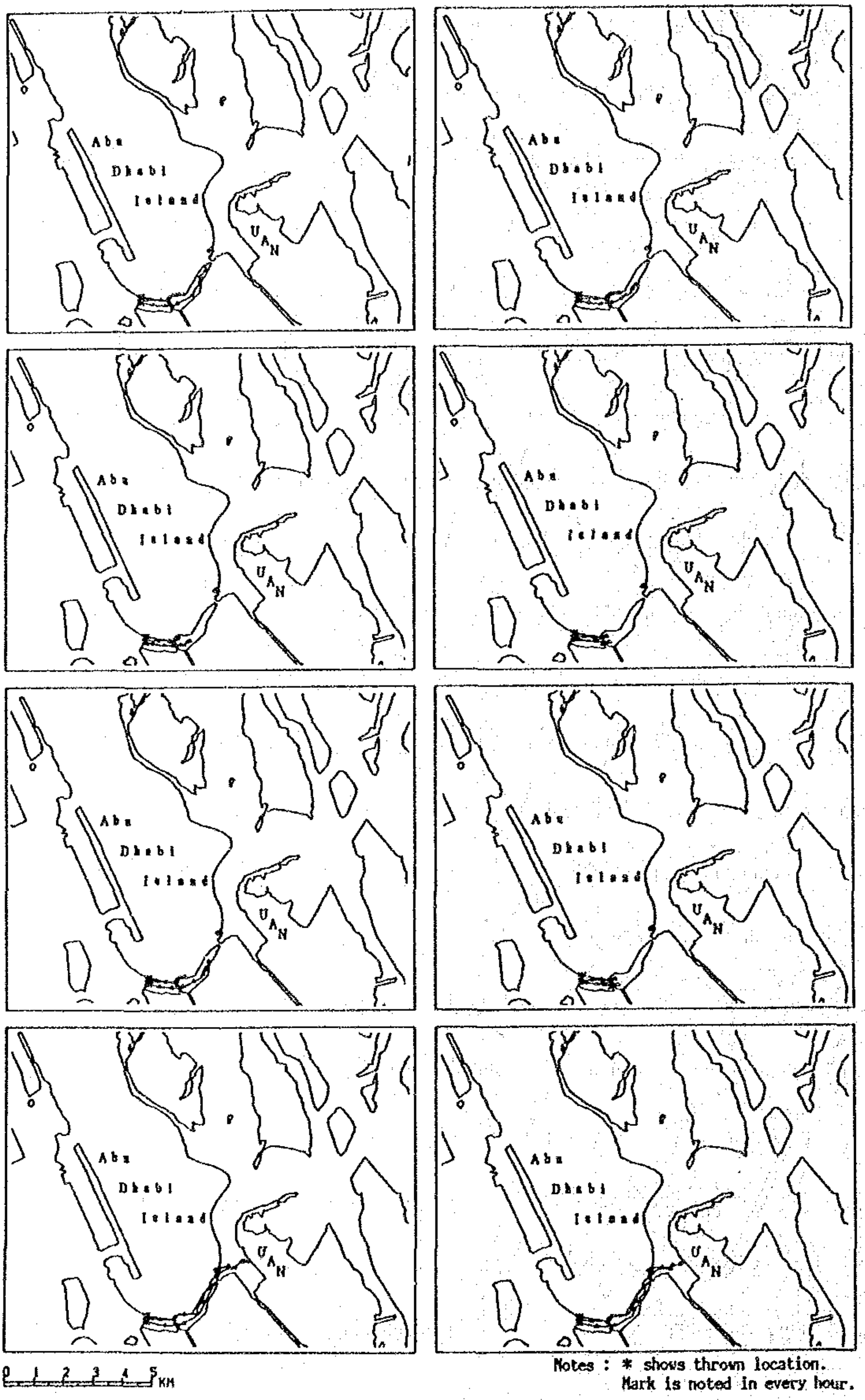
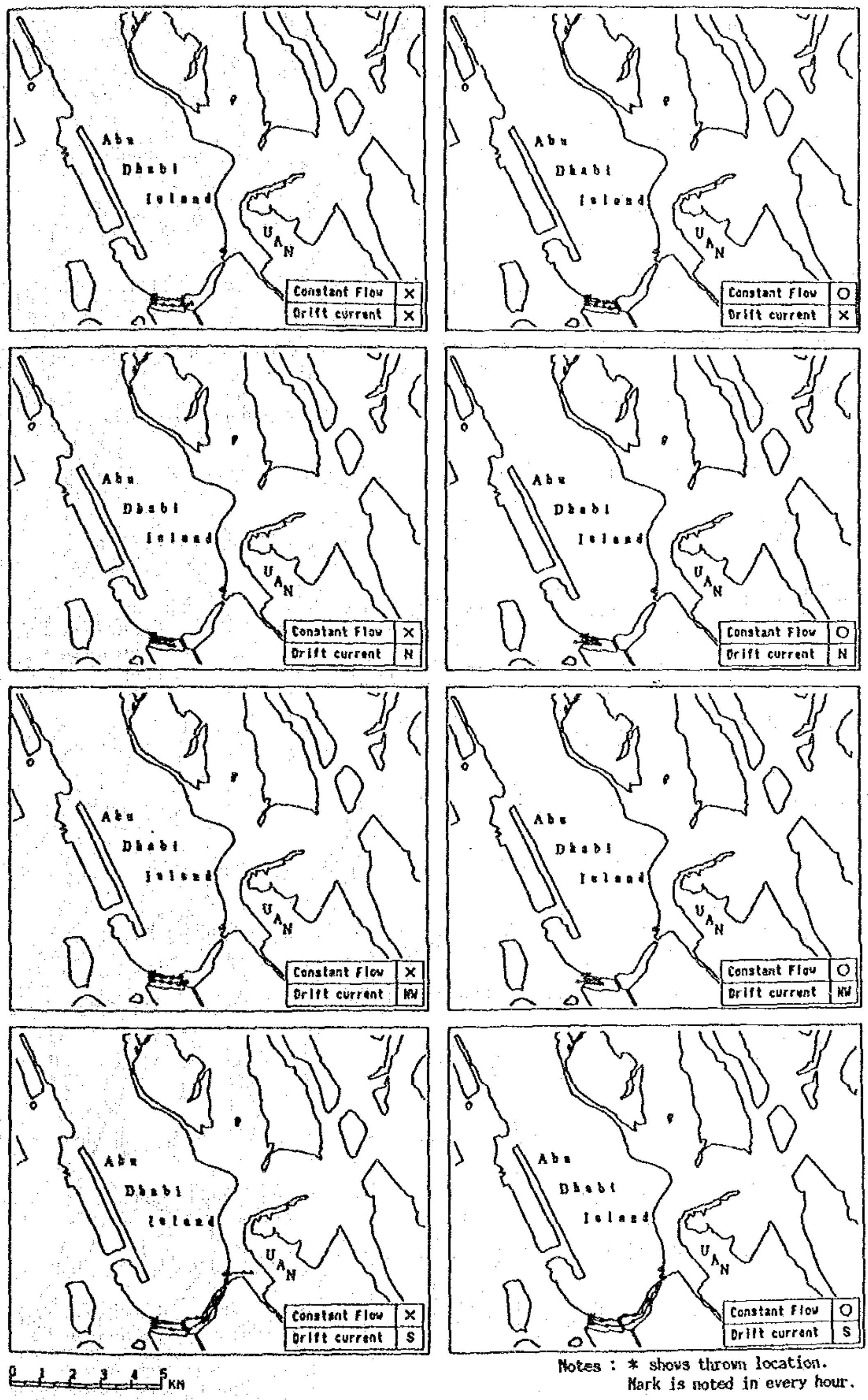
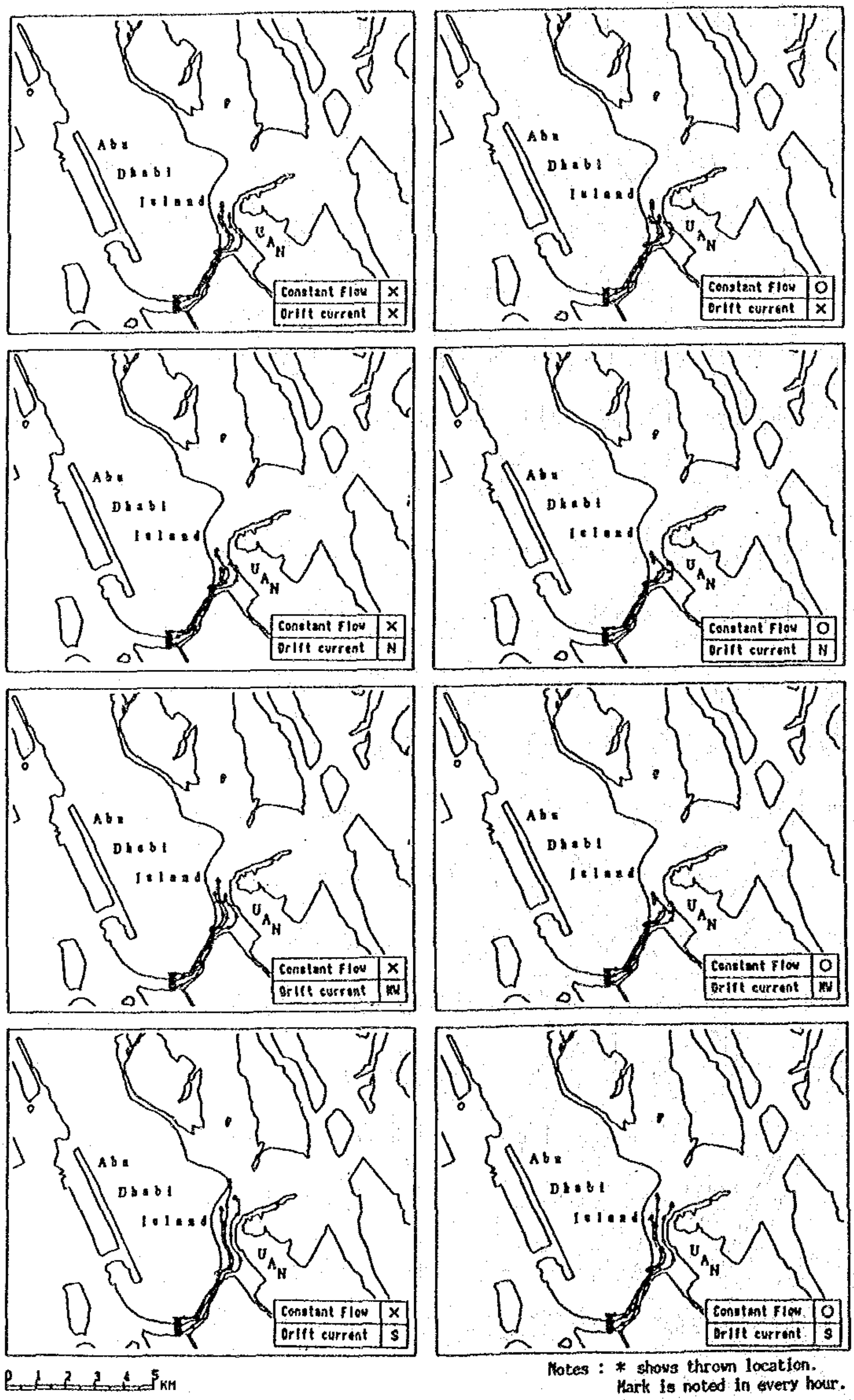


Fig. 5.1.67: Result of Marker Tracing (At Middle Tide + Intake and Discharge Flow) <Line E>



Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.68: Result of Marker Tracing (At Neap Tide + Intake and Discharge Flow) <Line E>



Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.69: Result of Marker Tracing (At Maximum Spring Tide + Intake and Discharge Flow) <Line F>

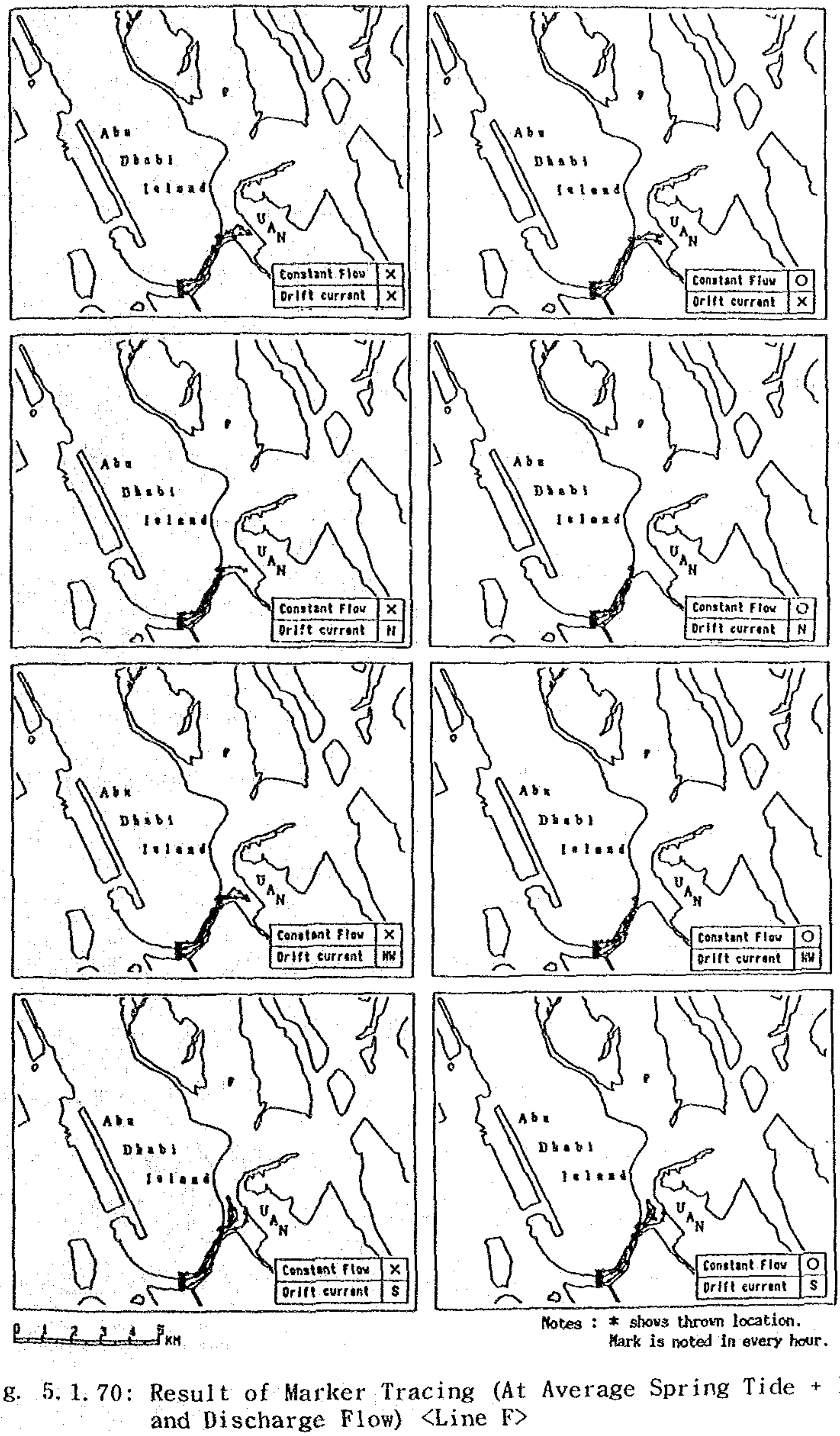
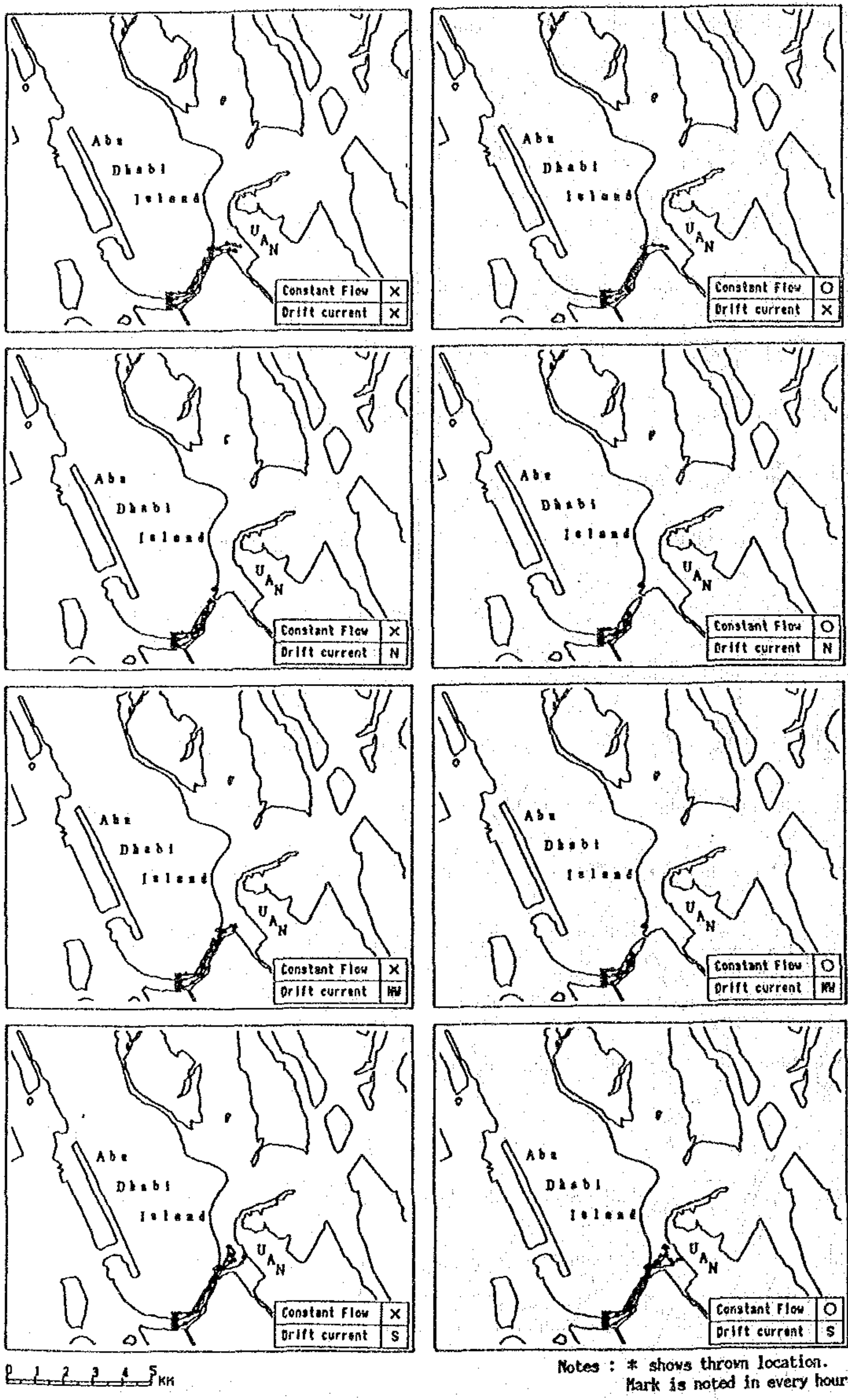
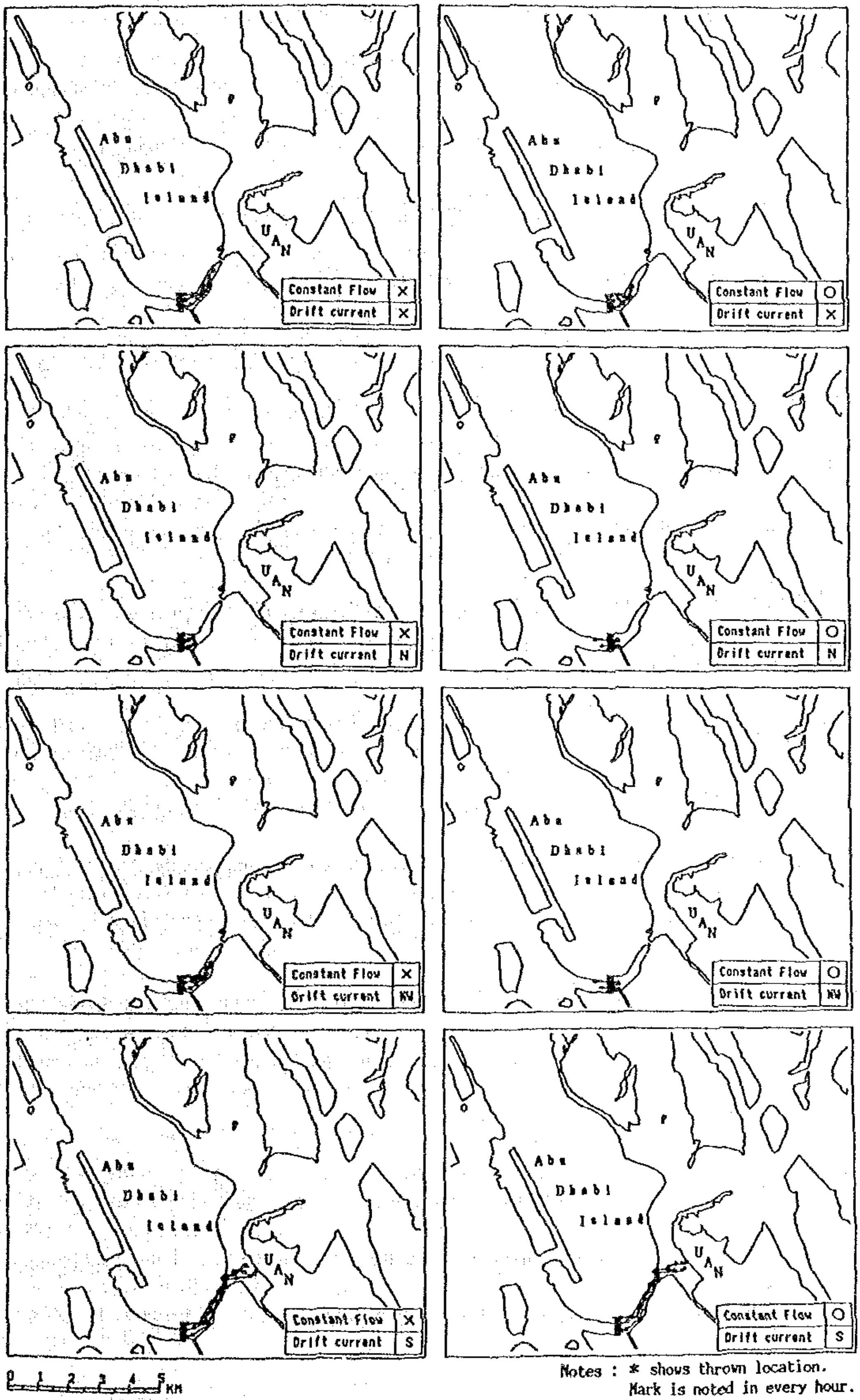


Fig. 5.1.70: Result of Marker Tracing (At Average Spring Tide + Intake and Discharge Flow) <Line F>



Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.71: Result of Marker Tracing (At Middle Tide + Intake and Discharge Flow) <Line F>



Notes : * shows thrown location.
Mark is noted in every hour.

Fig. 5.1.72: Result of Marker Tracing (At Neap Tide + Intake and Discharge Flow) <Line F>

(5) Summary

In this section, a prediction was performed in order to examine the protection system of oil contamination and the appropriate selection of positions for the monitoring system of oil contamination which senses the inflow of oil to the subject sea area. The summary is as follows.

1) Range of Oil Flowing into Lagoon

At the maximum spring tide, the water mass from the inlet of the lagoon to about 5 km offshore is taken into the lagoon. Its arrival time to the lagoon is about 2 to 5 hours.

2) The oil lumps near the lagoon inlet do not reach the intake in 6 hours (a semicircle period).

The oil lumps show a to-and-fro motion, so they do not reach the intake in 6 hours even in spring tide period when the flow of oil is the fastest and move to the lagoon entrance at the second ebb tide when the flow of oil is the fastest. Therefore, there is no need to install a monitoring point near the lagoon inlet.

But, if the oil accident could be considered to happen at night, it is necessary to set up a monitoring point near the entrance for more safety.

On the other hand, when the oil lumps flow in during a flood current period and drift ashore, they progress to the intake in the next flood current. From the inlet, they may possibly reach the intake in 18 hours (1.5 tides) at the shortest.

3) It is necessary to pay attention to the oil lumps coming through the channel between Assamaliyah and Qassar Essall (Lines A and B) rather than that coming through Baghal Channel, when selecting monitoring points.

4) The movement routes and arrival time of oil lumps were predicted near the intake at a total of 6 sections, Lines A to F. It is necessary to examine the installation points of a monitoring system, based on the setting positions of an oil pollution protection system and its method.

That is, when an oil fence is planned to be set up at the place shown below, as the first protection system of oil pollution near the intake, considering the time required for the oil fence extension or the instruction time to take up an emergency posture, the setting positions of a monitoring system of oil contamination should be Lines B, D and E, from where oil lumps would need more than 5 hours to reach the oil fence.

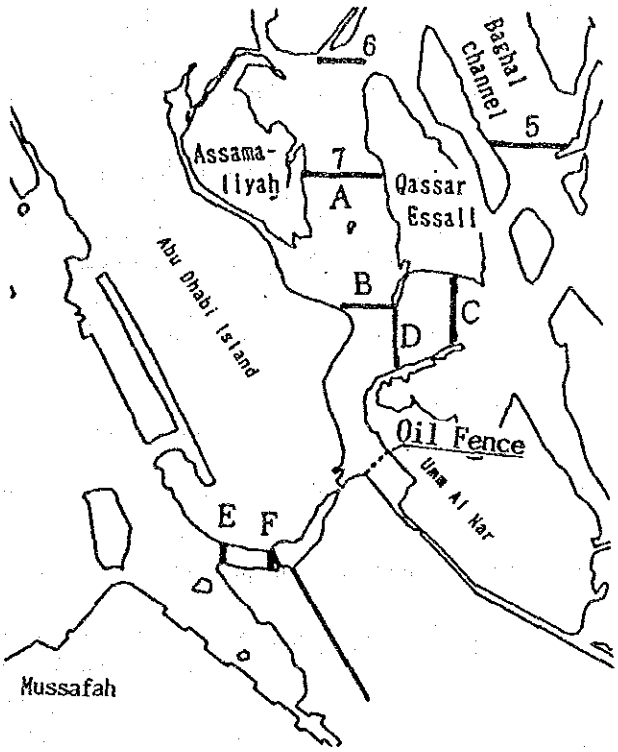


Fig. 5. 1. 73: Extension of Oil Fence Location