

CHAPTER 4

SILTATION ANALYSIS OF THE ACCESS CHANNEL

Chapter 4 Siltation Analysis of the Access Channel

4.1 Analysis of Sounding Maps

Sounding survey maps utilized to analyze sedimentation characteristics of the Access Channel are shown in Table 4.1-1.

Table 4.1-1 Collected Sounding Survey Maps

Year/Month	Section	Surveyed by	Remarks
1989 / 2, 3	All Sections	BCA	Before Capital Dredging
1990 / 8, 9	All Sections	BCA	Immediately after Capital Dredging
1991 / 8, 9	All Sections	BCA	One year after Capital Dredging
1993 / 4, 5	A part of E4, E6, E7 and E12, E8, E9, E10, E11	EMODRAGA	
1993 / 10, 11	A part of E4 and E10, E6, E7	EMODRAGA	
1996 / 4	All Sections except E14	INAHINA	
1997 / 2	All Sections	This Study	
1997 / 7	All Sections	This Study	

4.1.1 Bottom Configuration of the Access Channel

(1) Bottom Configuration in April 1996

Figures 4.1.1-1 to 4.1.1-3 show contour lines along the Access Channel drawn basing on the survey map of April 1996, where the width of the Channel is indicated by two solid lines and its axis line by a dotted line between them. The boundary line of E4 and E6 can be seen in Figure 4.1.1-1, which is taken as the starting point for writing the distance along the axis line in intervals of 1,000 m.

Based on the figures, main features of the Channel is summarized below:

- (a) Shallower areas than 6.0 m below CDL appear in the vicinity of 4,700 m in Section E8 and in the part from 7,000 m of E9 to 11,000 m of E10,

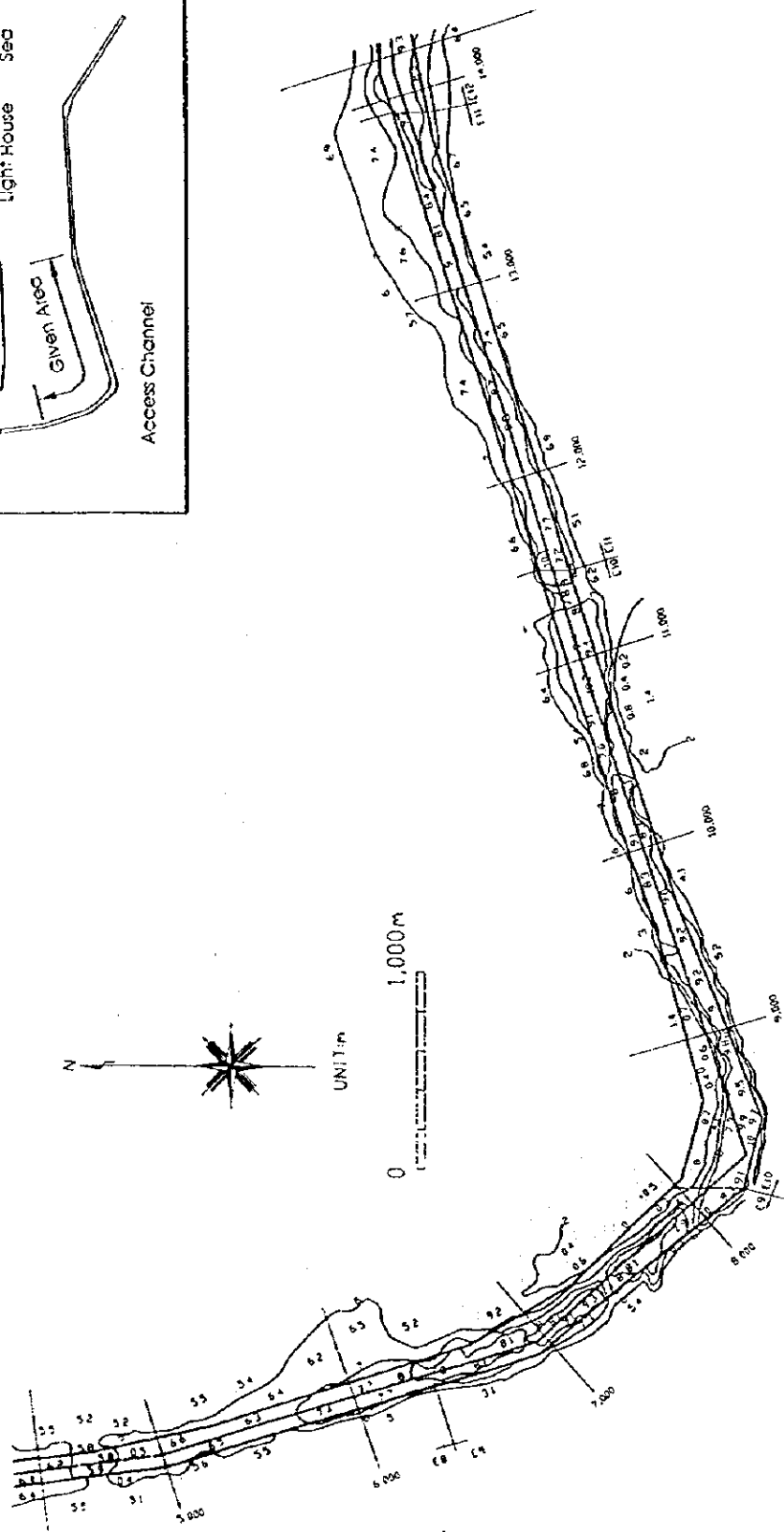
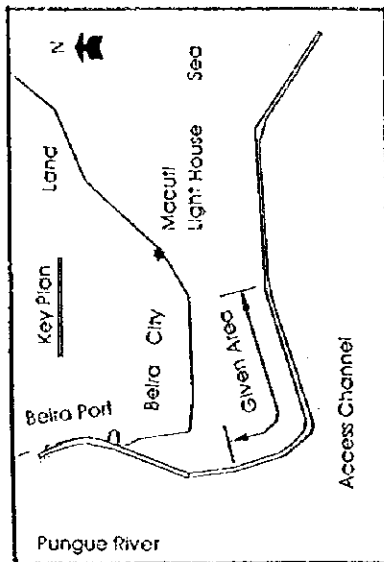


Figure 4.1.1-2 Contour Lines along the Access Channel in April 1996 (2)

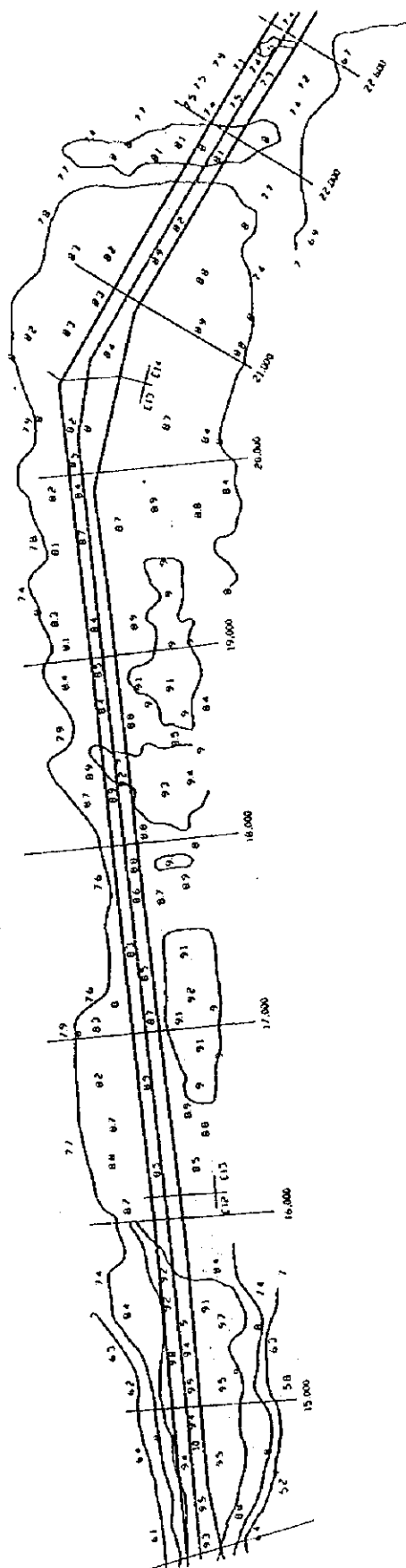
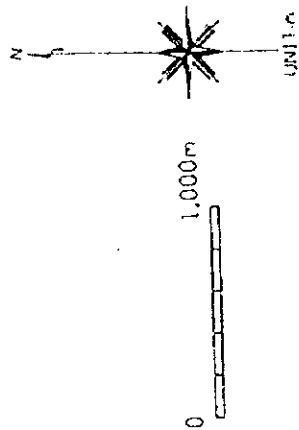
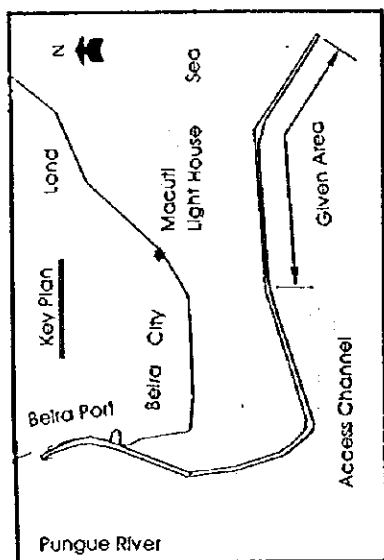


Figure 4.1.1-3 Contour Lines along the Access Channel in April 1996 (3)

- (b) Shallower areas than 7.0 m below CDL are seen in the vicinity of 2,000 m in E6 and 4,000 m in E7, in the part from the beginning to 5,700 m in E8 and the whole area of E9 and E10,
- (c) Area shallower than 8.0 m below CDL exists in almost all Sections from E6 to E11,
- (d) Area shallower than 2.0 m below CDL is seen in E9 and E10,
- (e) Water depth more than 10.0 m below CDL exists at the beginning of E6, in E9 and in E10,
- (f) In E12, E13 and E14, water depth is more than 8.0 m below CDL in almost whole area except the vicinity of 22,000 m in E14. This shallow part will be discussed later.

(2) Change of Cross Section along the Access Channel

Figure 4.1.1-4 shows time history of the cross section change of the Access Channel at the distance of 5,100 m in E8, 8,700 m and 10,700 m in E10 and 20,100 m in E14, where the distance is that measured from the boundary between E4 and E6 in Figure 4.1.1-1 and the land side corresponds to the side of the city of Beira. At the distance of 5,100 m, the channel shoaled up to about - 8 m during one year after the capital dredging carried out in 1990 when it was excavated to a depth of 9 m below CDL. Then, in April 1996 it was completely buried to the past configuration before the capital dredging.

At the distance of 8,700 m, the Access Channel shoaled from the land side by sand moved from the Macuti Shoal so that the slope invade the channel. But a part of 10 m deep still exists in the seaward side of the channel. At the distance of 10,700 m, it is buried in the same manner but from the sea side. These two sections correspond respectively to the points of advance of 0.0 m contour line towards the channel in the bending corner and in the vicinity of UFM Grid 694,500 E which have been mentioned in Section 3.5.2. At the distance of 20,100 m, where sea bottom was not excavated in the capital dredging, a part of the Channel shoaled very slightly as well as the neighboring sea bottom.

In the above mentioned cross sections, the cross sections surveyed in February and July 1997 are respectively deeper and shallower than the survey in April 1996.

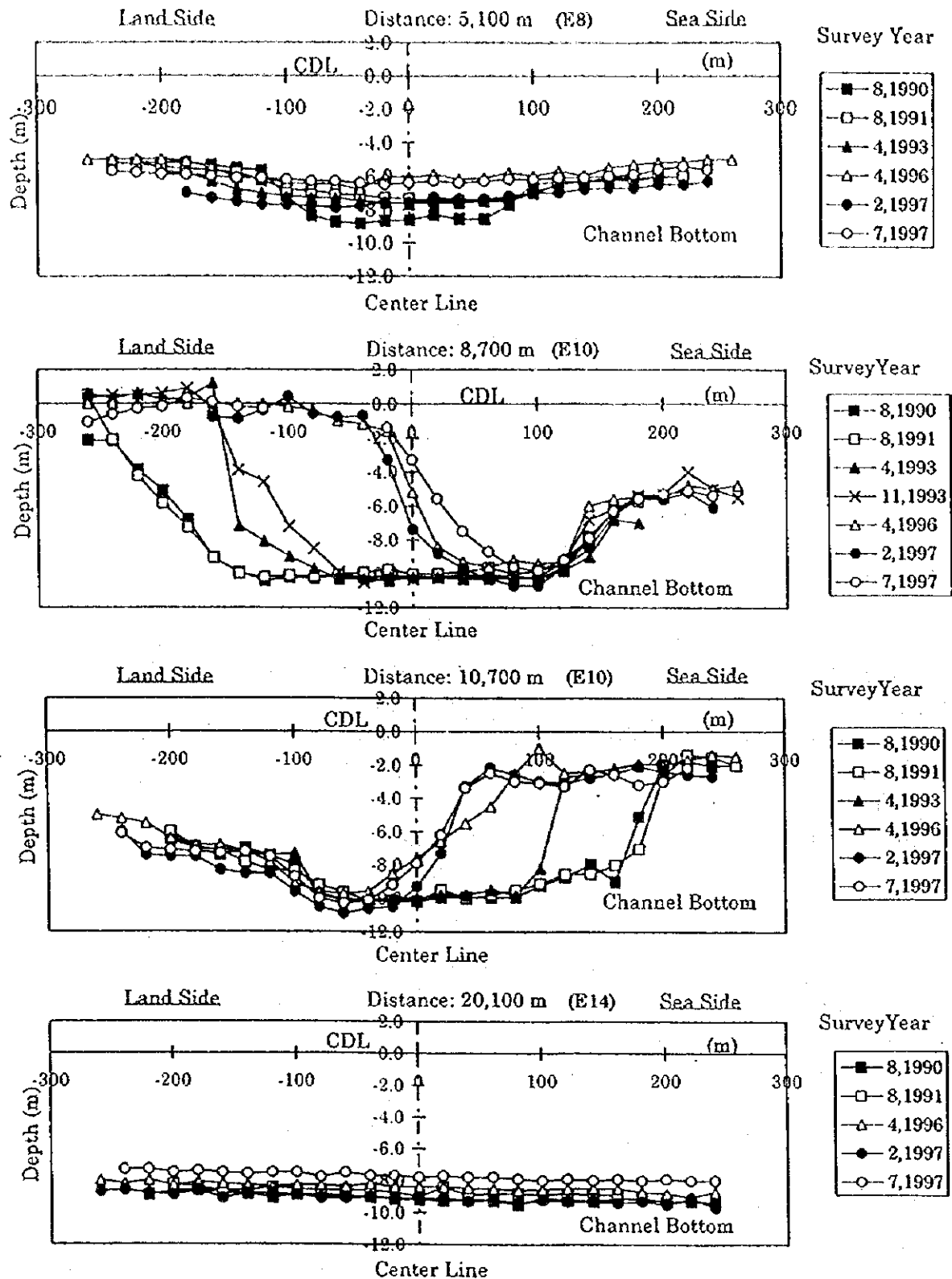


Figure 4.1.1-4 Change of Cross Sections of the Access Channel

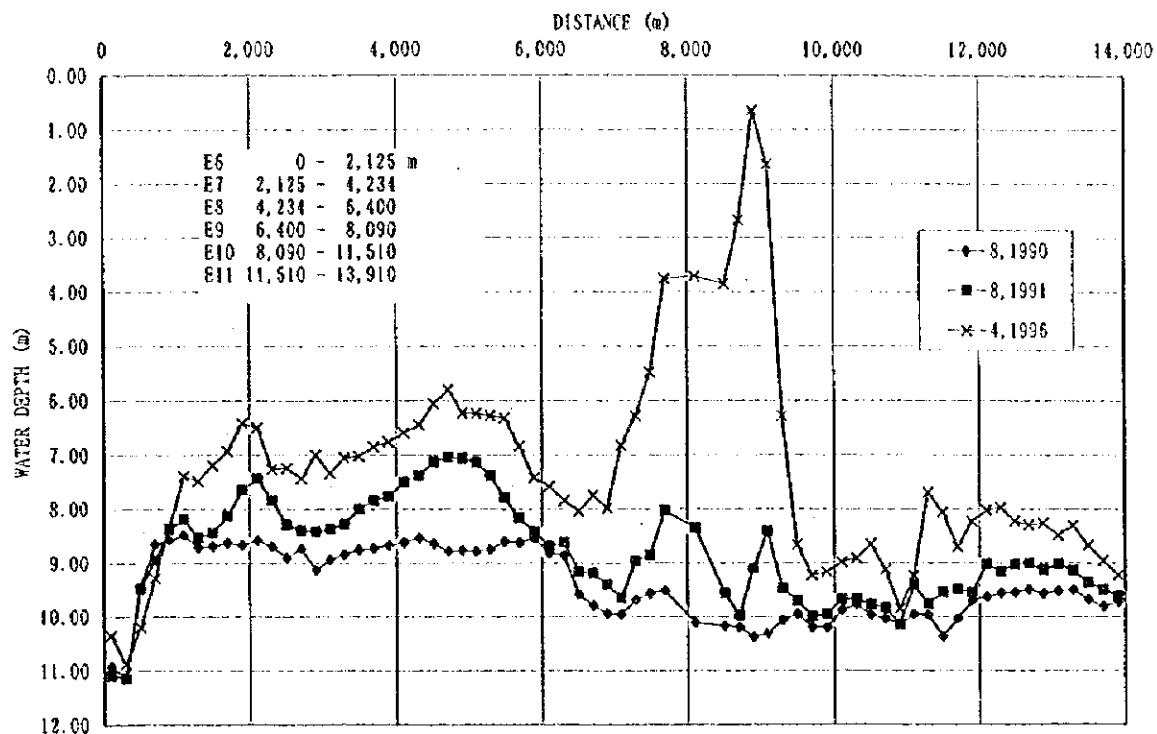


Figure 4.1.1-5 Change of Water Depth along the Access Channel of E6 to E11 (Land Side)

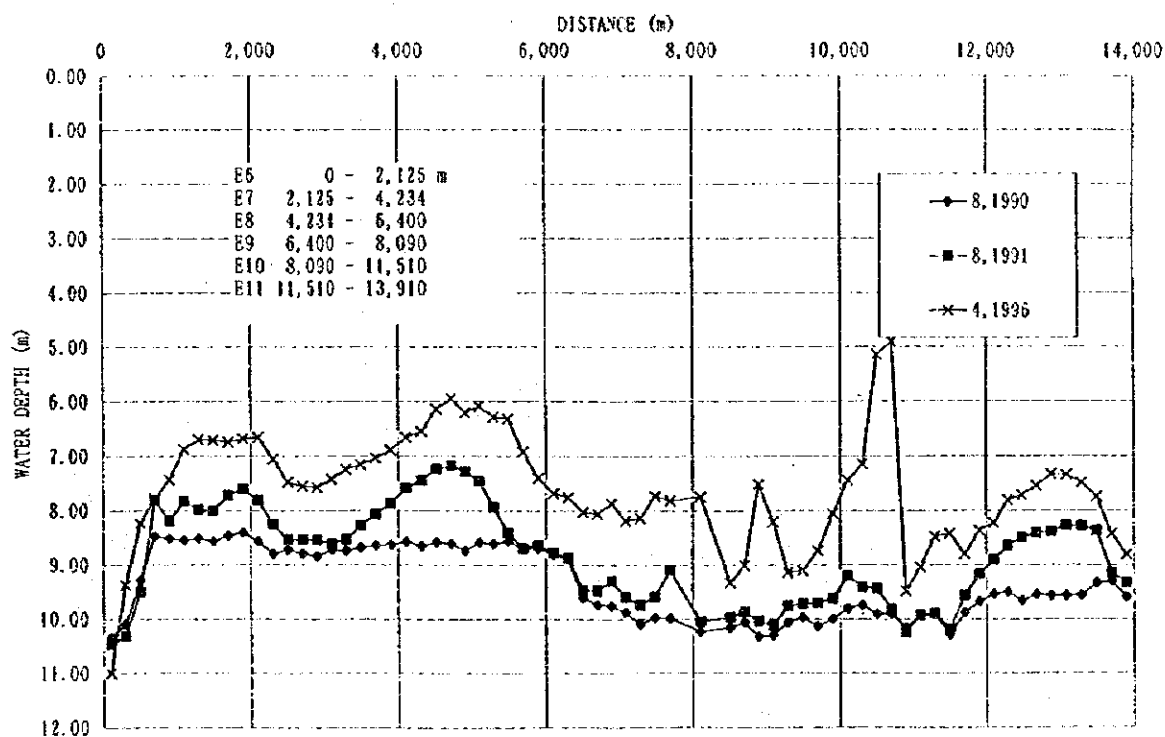


Figure 4.1.1-6 Change of Water Depth along the Access Channel of E6 to E11 (Sea Side)

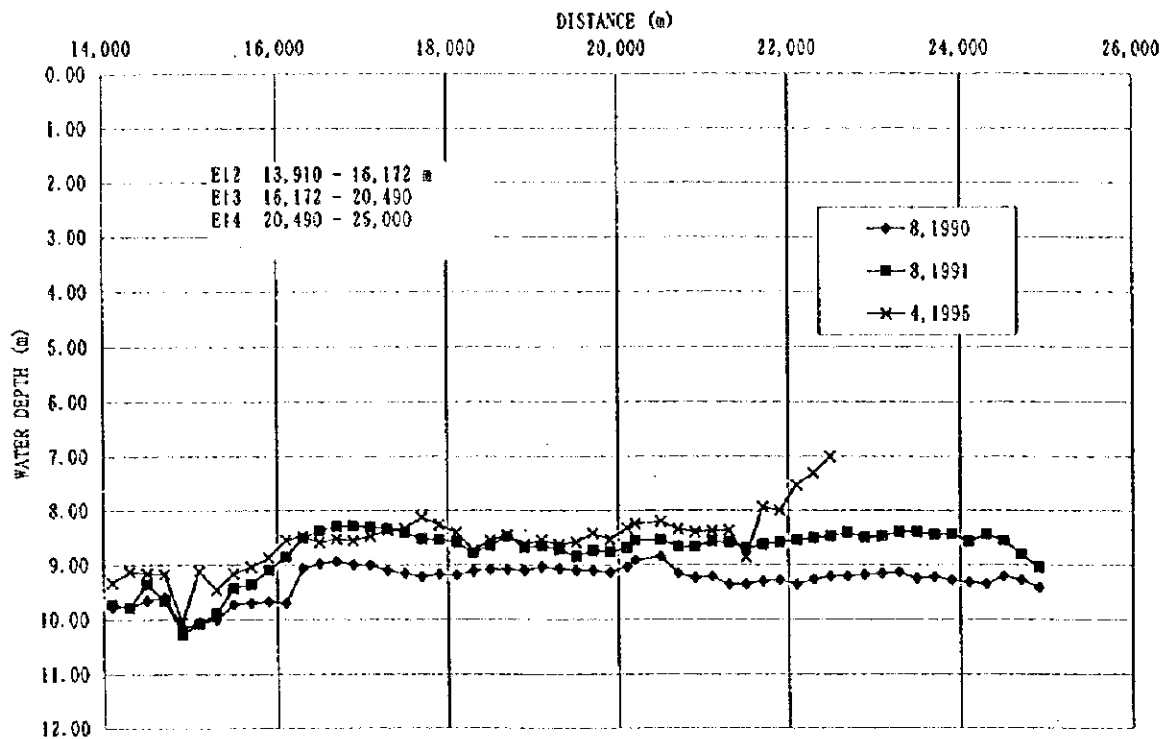


Figure 4.1.1-7 Change of Water Depth along the Access Channel of E12 to E14 (Land Side)

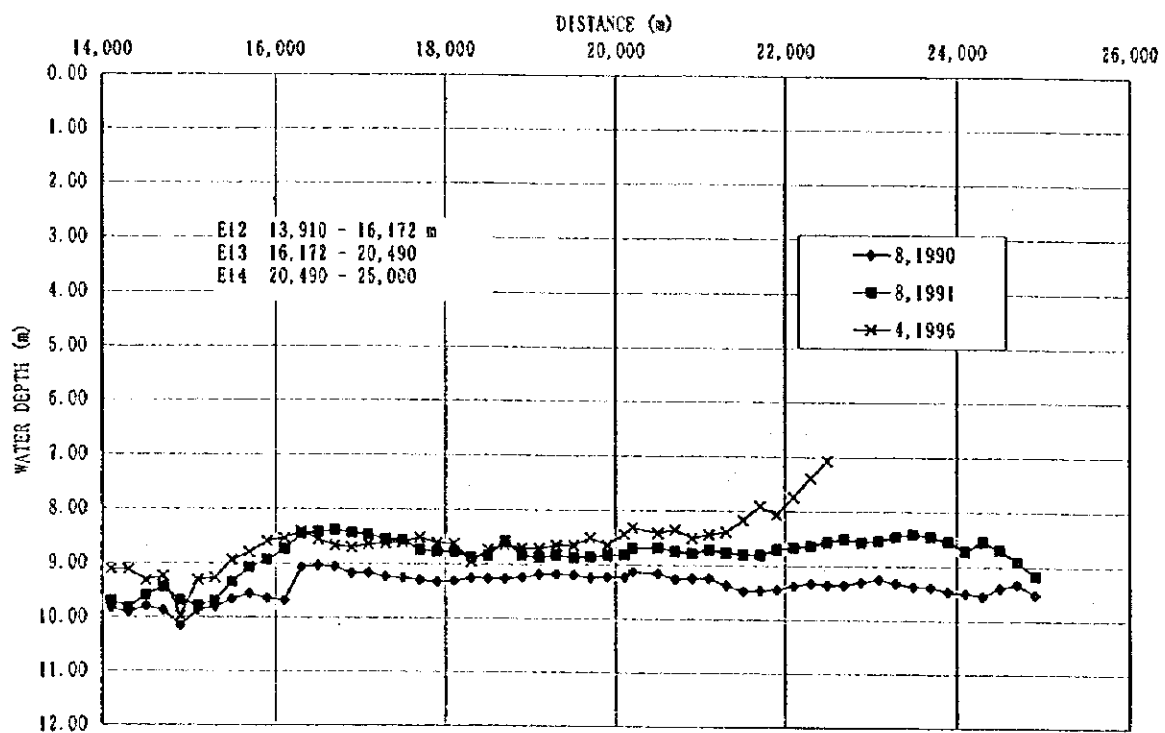


Figure 4.1.1-8 Change of Water Depth along the Access Channel of E12 to E14 (Sea Side)

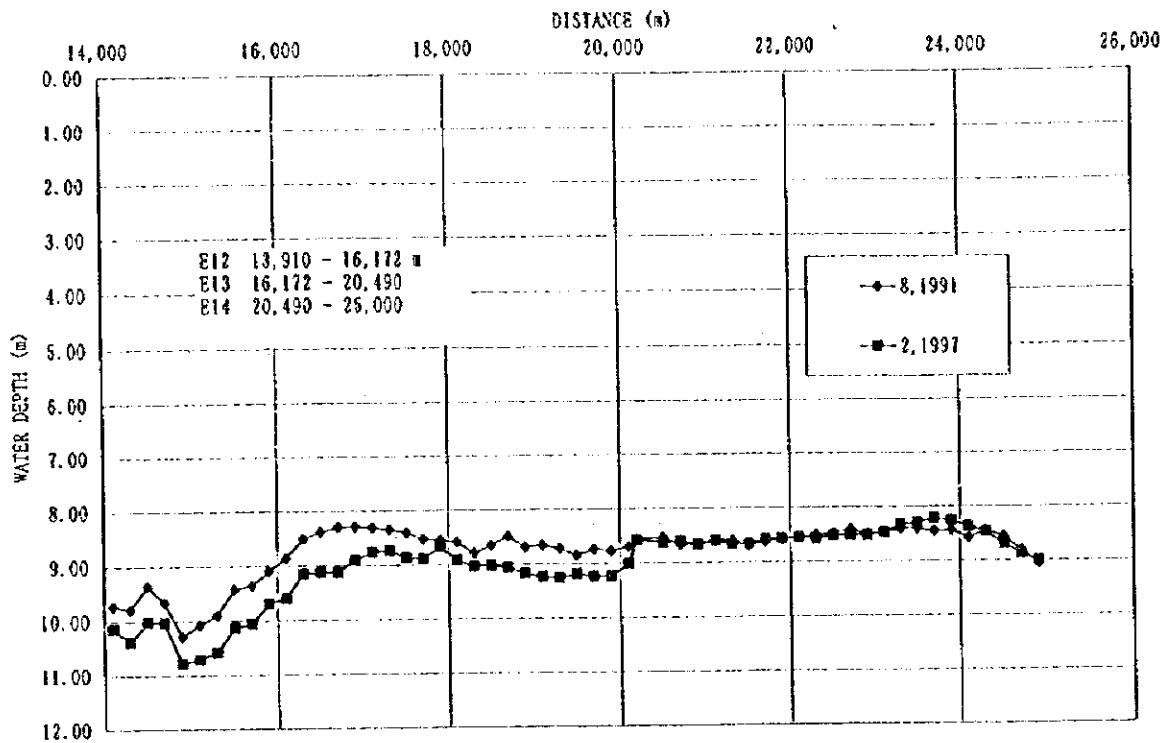


Figure 4.1.1-9 Change of Water Depth of E12 to E14 between August 1991 and February 1997 (Land Side)

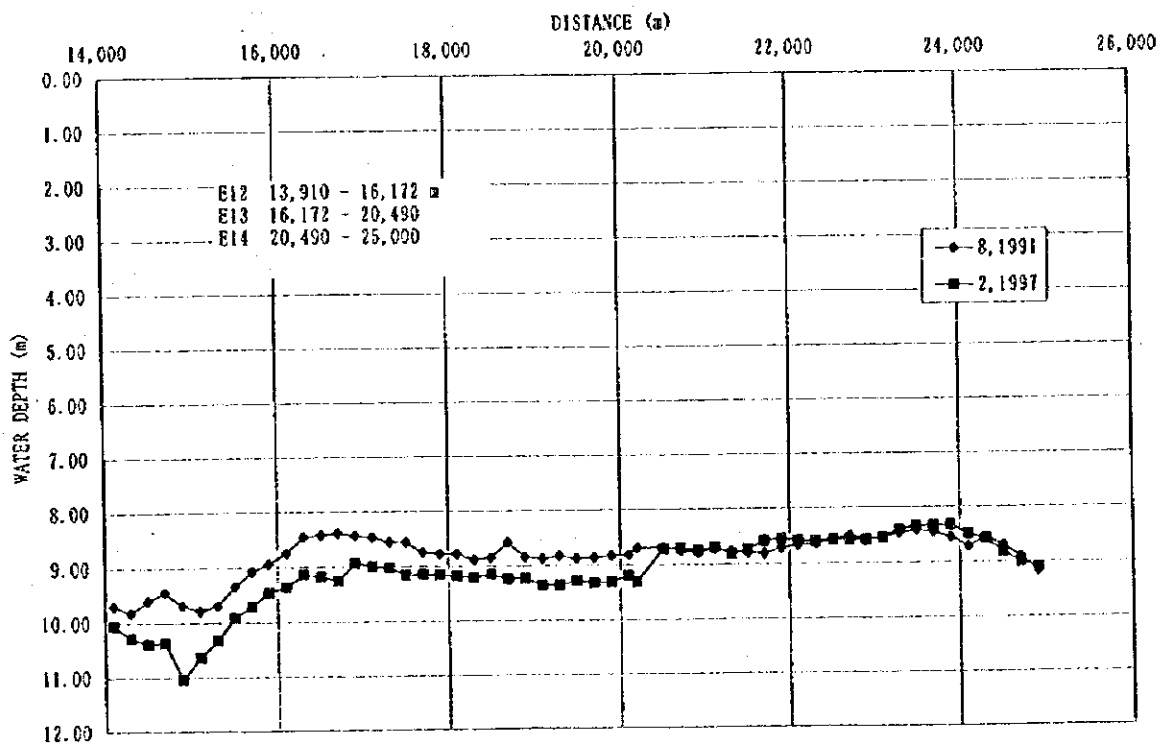


Figure 4.1.1-10 Change of Water Depth of E12 to E14 between August 1991 and February 1997 (Sea Side)

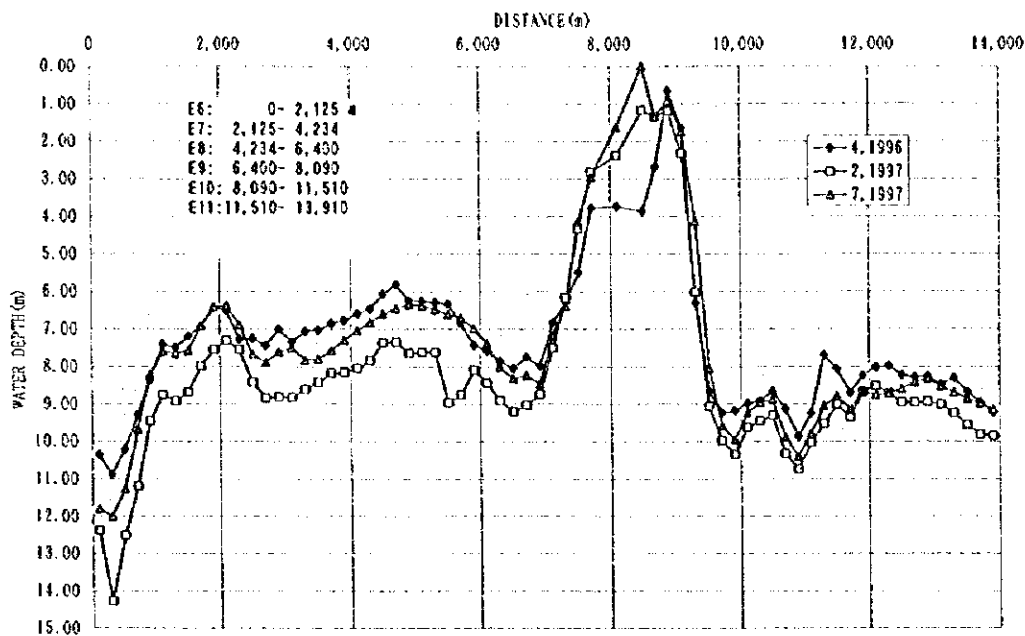


Figure 4.1.1-11 Change of Water Depth along the Access Channel of E6 to E11 during 1997 (Land Side)

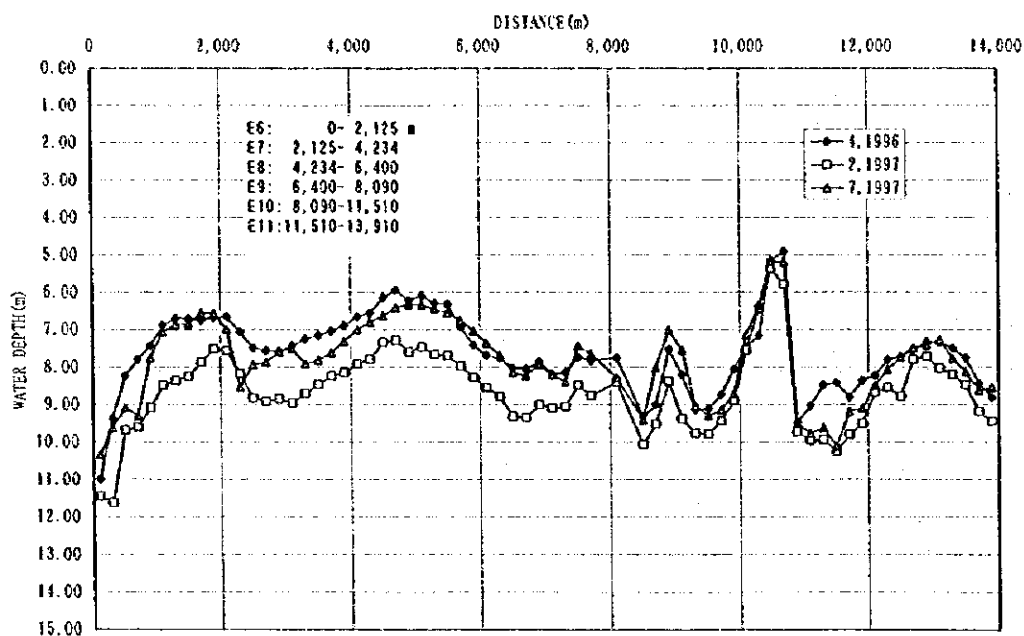


Figure 4.1.1-12 Change of Water Depth along the Access Channel of E6 to E11 during 1997 (Sea Side)

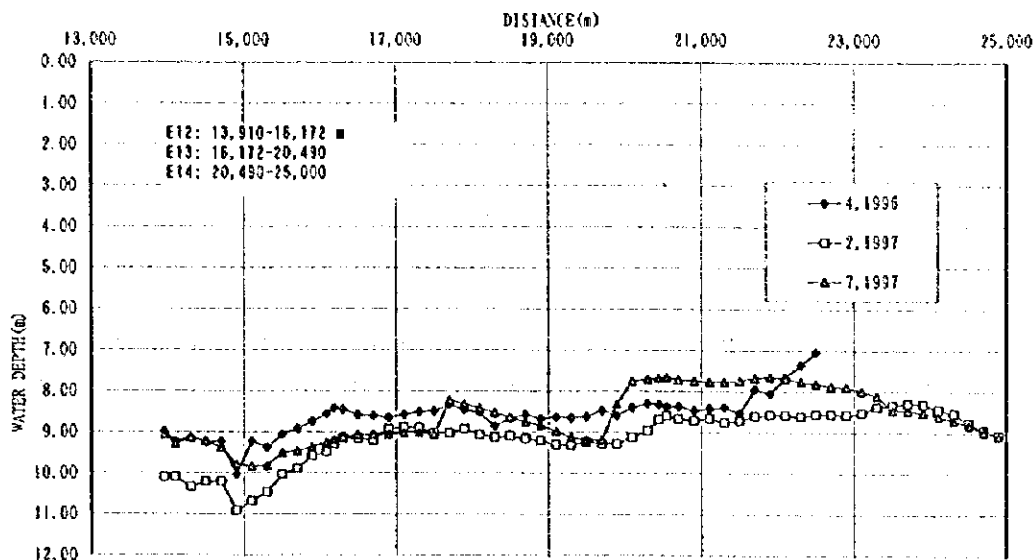


Figure 4.1.1-13 Change of Water Depth along the Access Channel of E12 to E14 during 1997

(3) Change of Water Depth along the Access Channel

Dividing the channel into the land and sea sides at the channel axis, the mean water depth of each segment length of 200 m in the direction of the Channel was calculated for each side. But, in the part near the boundary between E9 and E10, it was divided by a line connecting two channel axis points at the boundary between E9 and E10 and at the distance of 8,600 m owing to large deviation of the channel axis line from the center there. Figures 4.1.1-5 to 4.1.1-8 show the mean water depths plotted along the Channel based on the sounding maps surveyed in August 1990, August 1991 and April 1996.

Following observations are made based on the figures:

- (a) Remarkable sedimentation is seen in E9 and E10, to which E8 follows,
- (b) The most remarkable sedimentation appeared in the vicinity of 8,800 m in the land side and 10,600 m in the sea side in April 1996,
- (c) The trend of sedimentation in April 1996 is similar to in August 1991, excluding from E12 to E14.

Concerning Sections from E12 to E14, the water depth sharply decreases in the vicinity of 22,000 m in April 1996, as seen in Figures 4.1.1-7 and 4.1.1-8. On the other hand, such sharp shoaling does not appear in the survey of February 1997 as shown in Figures 4.1.1-9 and 4.1.1-10. Therefore, that of April 1996

seems to be a temporary phenomenon. If it is excluded, the whole Section from E12 to E14 shows a very little sedimentation since August 1991 and still now keeps deeper than 8 m below CDL in water depth, after an occurrence of nearly one meter of shoaling during one year after the capital dredging.

Figures 4.1.1-11 to 4.1.1-13 are the same depth change during 1997 after April 1996, though the Sections from E12 to E14 are plotted with the average water depth of the land and sea sides. In E6 to E12, the water depth in February 1997 is deeper than April 1996 in the most area and that of July 1997 is almost equal to April 1996, except the vicinity of 8,800 m in E10 where water depth is shallower with time. Concerning E13 and E14, the water depth shows so complicated changes with time that all available data are shown in Figure 4.1.14.

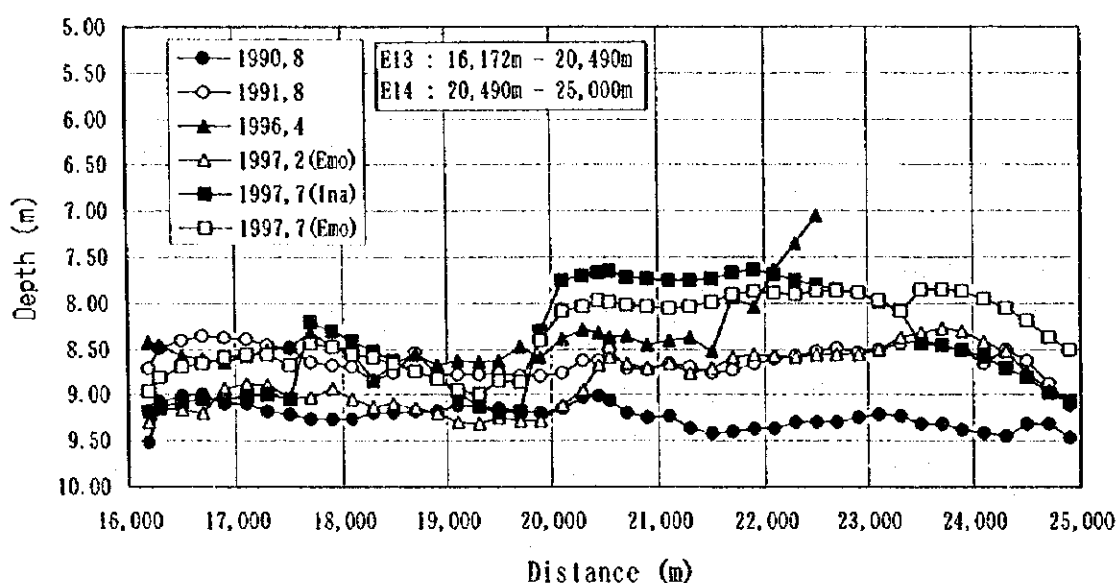


Figure 4.1.1-14 Depth Change in Sections E13 and E14

Referring to Figure 4.1.1-14, data marked by (Emo) and (Ina) in the figure are mutually different in the manner to take into consideration tide angles in drawing of sounding maps. (Emo) took changeable tide angles depending on the distance from the tide gauge station in the port. And (Ina) adopted a constant tide angle through the Access Channel in Macuti Coast. The depth difference is about 0.5 m at maximum between the both manners.

In the distance from 16,000 m to 19,500 m, water depths of April 1996 and July 1997 (Emo) in the dry season are nearly equal to August 1991, but it of February 1997 in the wet season is nearly equal to August 1990. Concerning the further distance, the depth of February 1997 (Emo) in the wet season is nearly equal to August 1991 and it of July 1997 in the dry season is shallower by about 1

m at maximum. At the distance from 23,500 to 25,000 m, February 1997 (Emo) and July of 1997 (Ina) have a equal depth to August 1991. Moreover, water depth sharply changes in July 1997 at the distance of about 20,000 m and in April 1996 at the distance of about 21,500 m. From these depth changes, it is seen that the vicinity of E14 has a tendency to become shallower in the dry season and to become deeper in the wet season. Namely, in the vicinity of E14, it would be supposed that fine sand and silt deposit from the offshore side owing to the decrease of currents at the entrance of the Channel in the dry season and are transported to the further offshore or toward the Macuti Shoal by severe waves and currents in the wet season.

Also, it seems that there exist a tendency of deepening in the wet season and shoaling in the dry season through all section of the Access Channel.

4.1.2 Sedimentation Volume of the Access Channel

(1) Calculation Method of Sedimentation Volume

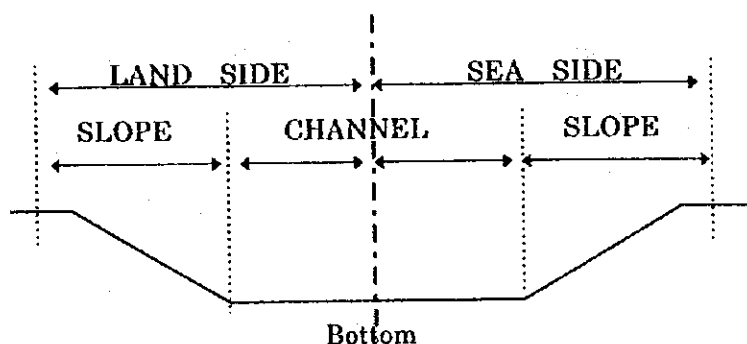


Figure 4.1.2-1 Section of the Access Channel

The method of calculation of the sedimentation in the Access Channel is as follows.

- (a) In each segment divided into every 200 m in length in the direction of the Channel, the mean depths of the slope and channel respectively were calculated in the land and sea sides. The land side means the side of the city of Beira when the cross section is divided at the centerline of the Channel as shown in Figure 4.1.2-1. That is, the cross section for each part of 200 m long is divided into four parts as shown in the figure.
- (b) The width of both slopes is taken as 100 m at Sections from E4 to E10 and as 50 m at E11, though in some parts, where there are not enough depth

data such as at the land side of E4 and the sea side near the bending corner of the Channel in E10, it is taken as 50 m,

- (c) In Sections from E12 to E14, the calculation of sedimentation volume in the slope was not conducted, because deepening of the sea bottom during the capital dredging was executed a little only in some parts and most parts were not excavated there,
- (d) The mean depth calculated in (a) was multiplied by its area to obtain the water volume in each part,
- (e) The difference between two survey maps of the above calculated water volume was taken as sedimentation in each part,
- (f) Finally, the sedimentation volume was summarized in each Section.

(2) Sedimentation Volume in August 1990 and August 1991

Table 4.1.2-1 shows the sedimentation volume of the Access Channel in the period from August 1990 to August 1991. The second column of the table is the sedimentation volume calculated by the Beira Corridor Authority (BCA). The third and forth columns respectively refer to the value of the sum of the slope and channel and to the value of the channel only, which are calculated by means of the above mentioned method. Comparing the third and forth columns, it is seen that sedimentation occurs more in the channel portion than in the slope portion. The fifth column is the sum of only accumulation parts excluding erosion parts of the channel and slope.*)

*) To check the adequacy of the calculation method applied here, the calculation by cross section as follows has been tried:

- (a) To calculate cross sections in intervals of 50 m in the direction of the channel using water depth of every 10 m long in the crossing direction of the channel.
- (b) To multiply each section of (a) by 50 m to obtain the water volume of an area of 25 m wide in both sides of the cross section.

The sedimentation volume calculated by using this method about the Section E9 in the items of Table 4.1.2-1 are as follows.

Basin	Channel and Slope	Channel	Total without erosion
E9	427,737 m ³	217,943 m ³	466,262 m ³

This calculated values show a small difference of only a few percents from the numbers indicated in Table 4.1.2-1.

Table 4.1.2-1 Sedimentation Volume between August 1990 and August 1991

(Volume in m ³)				
Calculated by	BCA	This Study		
Portion	Channel and Slope	Channel and Slope (w/erosion volume)	Channel (w/ erosion volume)	Channel and Slope (w/o erosion volume)
E4	507,799	471,638	442,339	491,879
E5	198,189	214,617	186,722	214,617
E15	314,409	333,099	233,414	333,099
E4+E5+E15	1020,397	1019,354	862,475	1,039,595
E6	115,825	99,247	93,507	159,401
E7	173,157	109,108	180,621	185,411
E8	286,990	249,591	268,401	283,540
E6+E7+E8	575,972	457,946	542,529	628,355
E9	451,275	394,506	220,806	448,641
E10	481,227	521,270	245,161	531,762
E11	258,550	271,439	227,170	290,739
E9+E10+E11	1,191,052	1,187,215	693,137	1,271,142
E12	81,915	81,023	81,023	83,783
E13	336,944	346,148	346,148	346,148
E14	529,027	502,050	502,050	502,050
E12+E13+E14	947,886	929,221	929,221	931,981
Total	3,735,307	3,593,736	3,027,362	3,871,073

From the table, it is clear that a severe sedimentation occurred in Sections E9 and E10 near the bending corner of the channel. Also, the sedimentation volumes indicated on the third and fifth columns are nearly equal to 3,735,000 m³ of the second column calculated by BCA.

Figures 4.1.2-2 to 4.1.2-4 show the depth difference along the Access Channel during the period, where CH. and SL. respectively correspond to the parts of the channel and the slope shown in Figure 4.1.2-1. Regarding the land side, heavy sedimentation occurred in the channel part of E8, E9 and E10 and in the slope part of E9 and E10, whereas in the sea side such heavy sedimentation appeared only in the channel part of E8 and E11. From E12 to E14, a uniform sedimentation is seen on both sides along the total length.

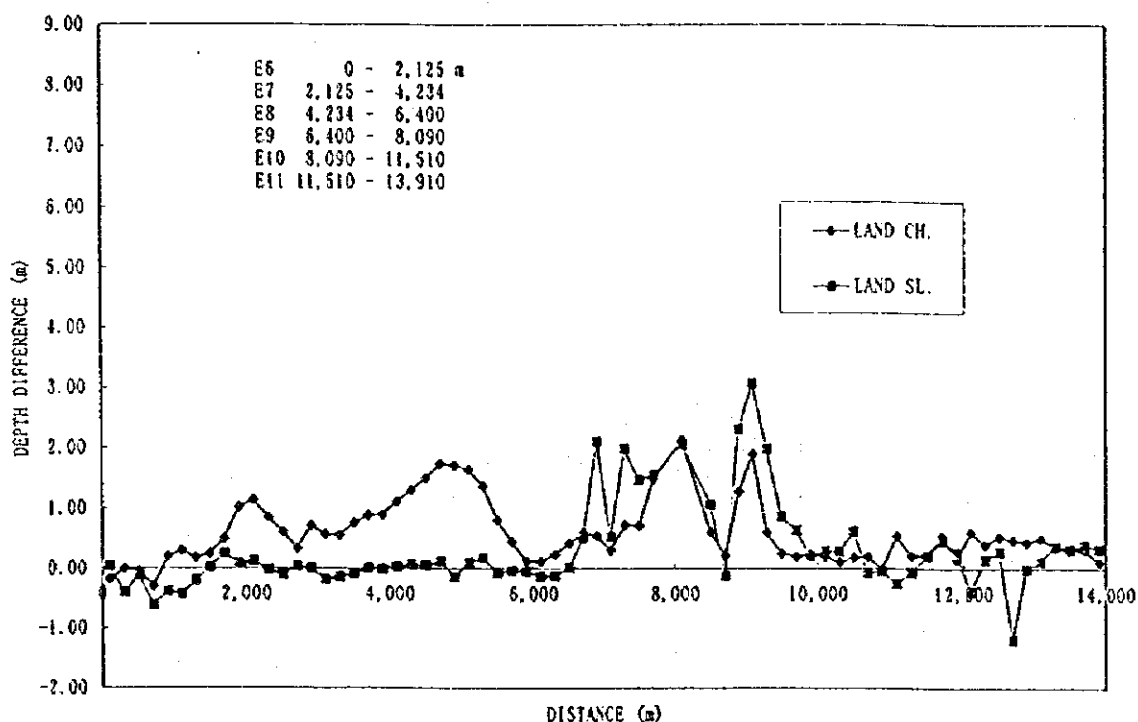


Figure 4.1.2-2 Depth Difference of E6 to E11 between August 1990 and August 1991 (Land Side)

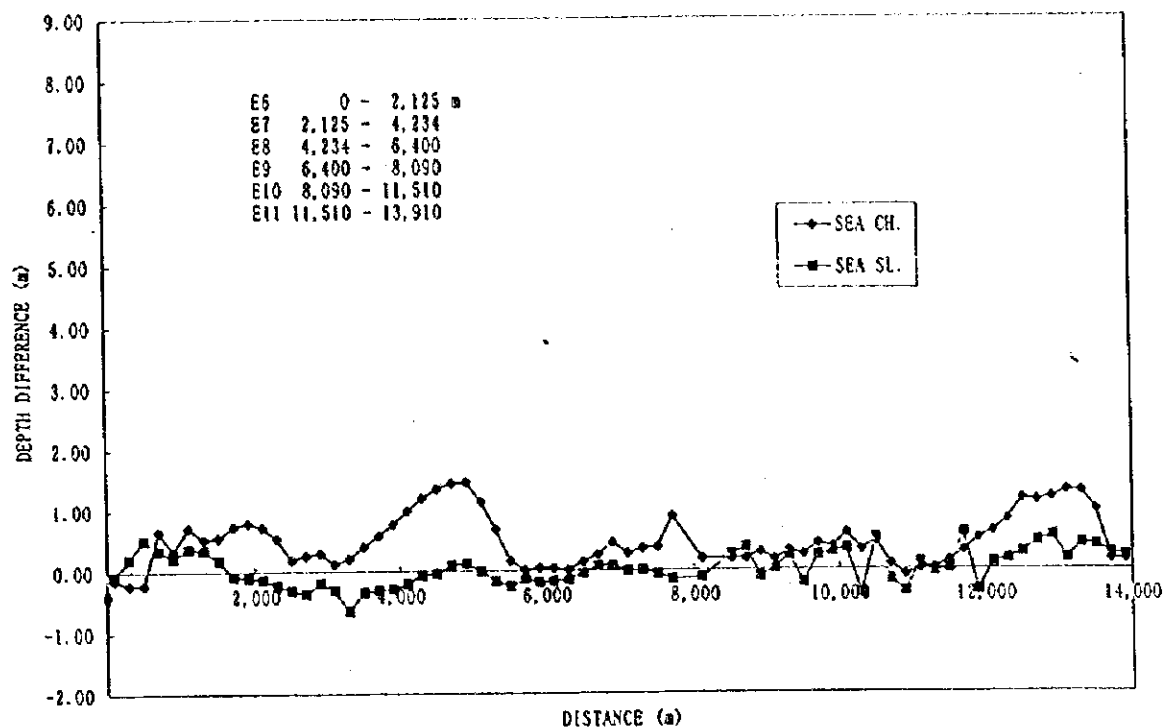


Figure 4.1.2-3 Depth Difference of E6 to E11 between August 1990 and August 1991 (Sea Side)

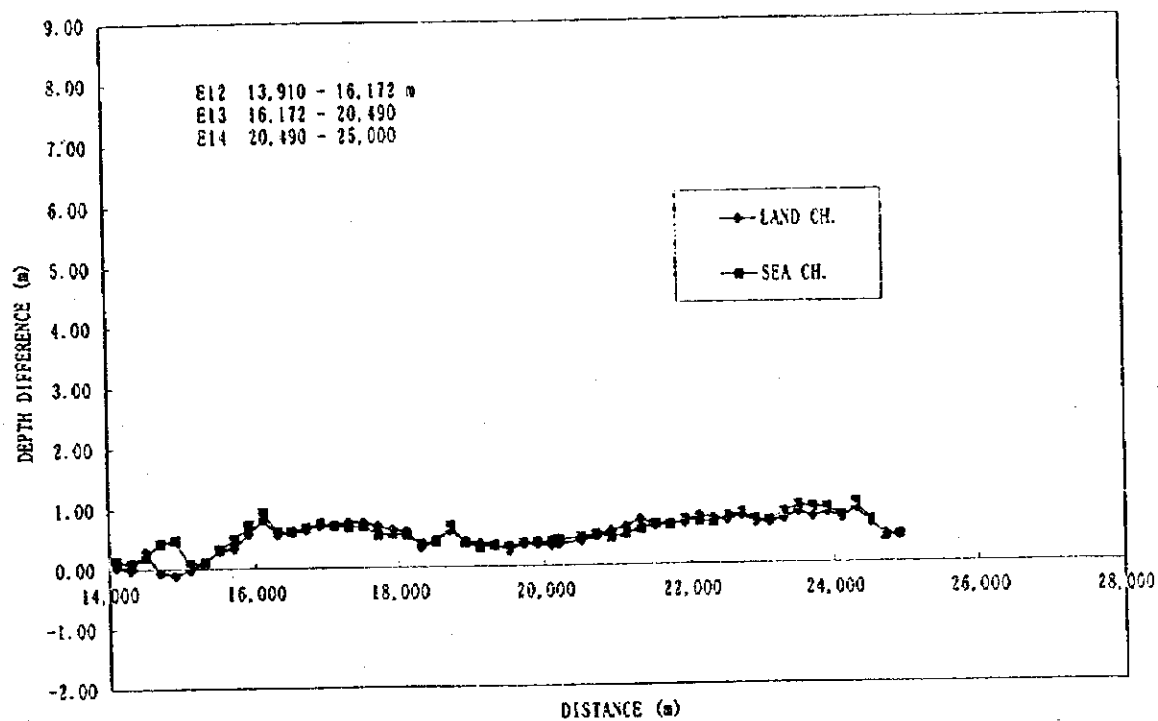


Figure 4.1.2-4 Depth Difference of E12 to E14 between August 1990 and August 1991

(3) Sedimentation Volume between August 1991 and April 1996

Table 4.1.2-2 shows the sedimentation volume in the period from August 1991 to April 1996 calculated excluding erosion parts in the same manner as the fifth column of Table 4.1.2-1. The sedimentation volume during the period from August 1990 to August 1991 in Table 4.1.2-1 is also contained in the table. Also the mean depth given in the table is merely the mean value of depths at respective two sounding maps, between which the sedimentation is calculated.

Table 4.1.2.-2 Sedimentation between August 1991 and April 1996

Section	August 1990 to August 1991		August 1991 to April 1996		
	Annual Rate (m ³ /yr.)	Mean Depth (m)	per 4.67 yr. (m ³)	Annual Rate (m ³ /yr.)	Mean Depth (m)
E4	491,879	8.65	-65,350		8.44
E5	214,617	5.91	-96,688		5.57
E15	333,099	6.92	-10,237		7.79
E4+E5+E15	1,039,595		-172,275		
E6	159,404	8.85	476,865	102,112	8.32
E7	185,411	8.41	542,827	116,237	7.56
E8	283,540	8.23	627,721	134,416	7.24
E6+E7+E8	628,355		1,647,413	352,765	
E9	448,641	9.42	1,213,996	259,956	7.98
E10	531,762	9.90	2,593,833	555,425	8.61
E11	290,739	9.37	426,223	91,268	8.70
E9+E10+E11	1,271,142		4,234,052	906,649	
E12	83,783	9.67	143,077	30,637	9.27
E13	346,148	8.90	102,472	21,943	8.56
E14	502,050	8.97	495,075	106,012	8.33
E12+E13+E14	931,981		740,624	158,592	
E6 to E14	2,831,478		6,622,089	1,418,005	
E4 to E15	3,871,073				

The sedimentation between August 1991 and April 1996 shows negative value in Sections E4, E5 and E15, which seems to depend on the deepening of the basin in front of the new oil terminal in 1994. Also, the sedimentation in the Section of E14 was calculated on the assumption that the ratio of sedimentation until 22,600 m point against that until 25,000 m point is the same as that during the period from August 1990 to August 1991, including the sharp shoaling in the vicinity of 22,000 m point described in Section 4.1.1(3). The sum from E6 to E14 is $1,400 \times 10^3 \text{ m}^3/\text{year}$ against $2,800 \times 10^3 \text{ m}^3/\text{year}$ between 1990 and 1991. The sedimentation volume of all sections are smaller than the volume calculated between 1990 and 1991 except Section E10.

Figures 4.1.2-5 to 4.1.2-7 show the same depth difference in the period as the previous figures. Concerning the land side of Figure 4.1.2-5, remarkable sedimentation occurred in the channel and slope of E9 and E10, especially at the distance of about 9,000 m in the bending corner of the channel. Erosion appears at the channel and slope at the beginning of E6 and at the slope in the vicinities of 6,500 m point in E9 and of 11,000 m point in E10. On the other hand, on the sea side of Figure 4.1.2-6, remarkable sedimentation is seen at the channel and slope of the distance from 10,500 to 11,000 m in E10 and it is also seen in the vicinity of 8,000 m located on the boundary between E9 and E10. Erosion appeared at the slope in the vicinity of 9,000 m of the bending corner. In Sections from E12 to E14 illustrated in Figure 4.1.2-7, a little sedimentation is seen at both channel sides.

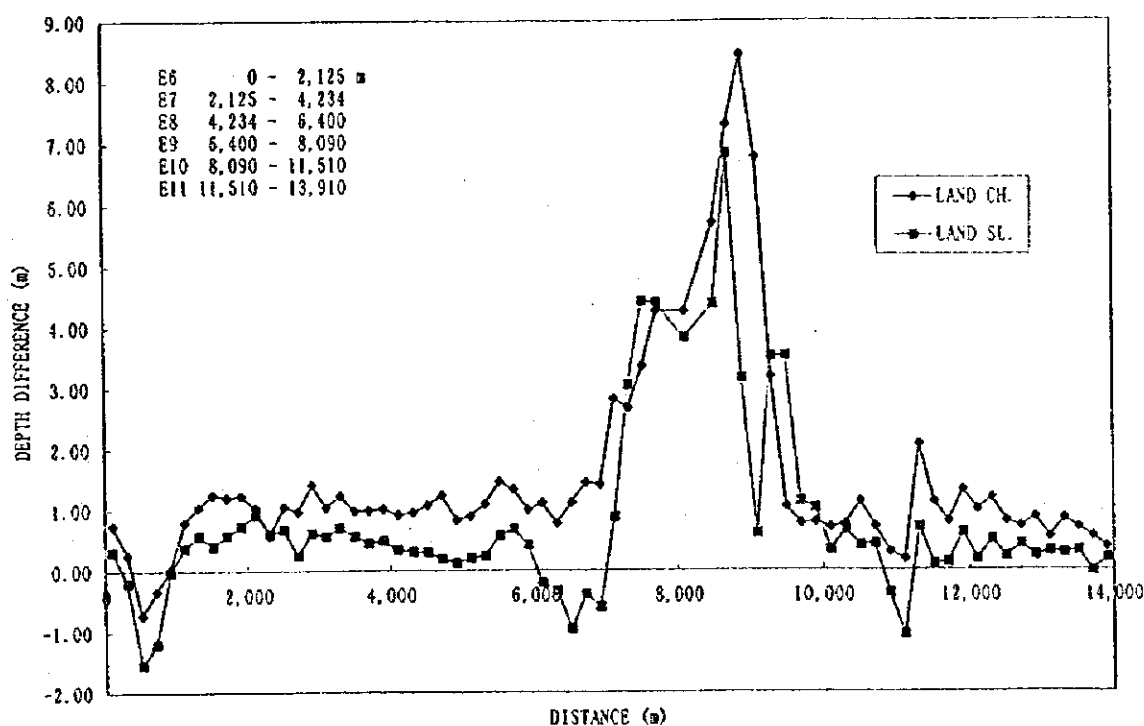


Figure 4.1.2-5 Depth Difference of E6 to E11 between August 1991 and April 1996 (Land Side)

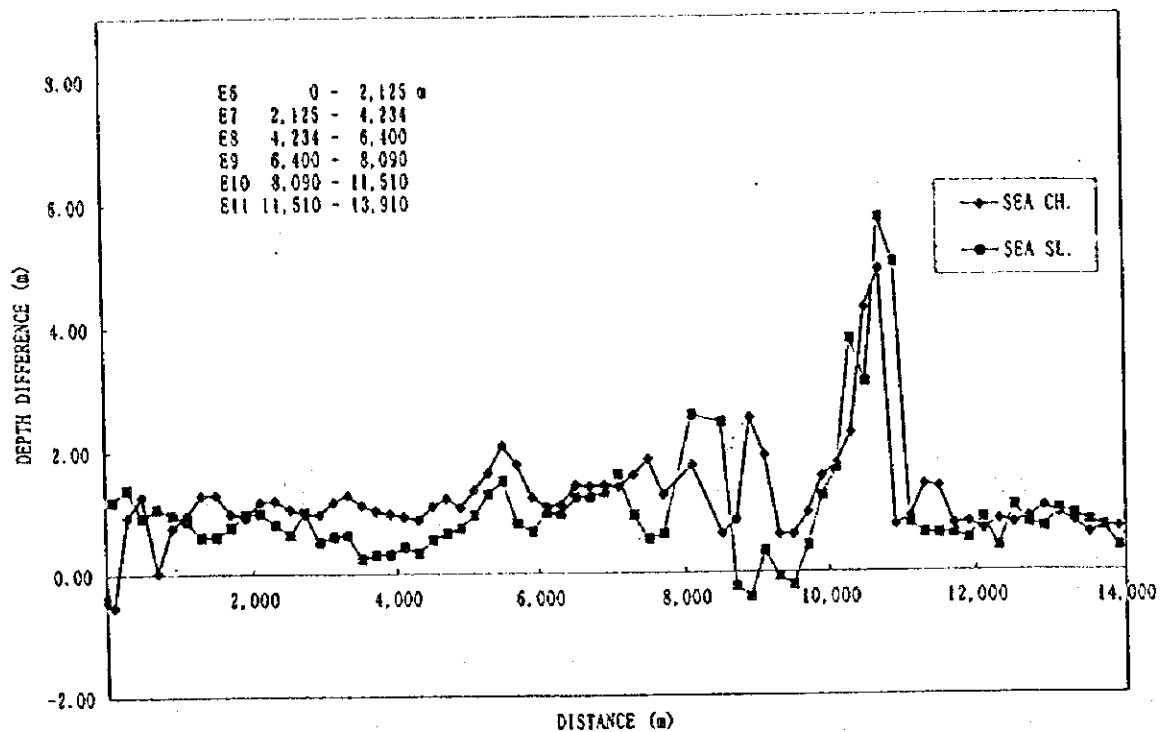


Figure 4.1.2-6 Depth Difference of E6 to E11 between August 1991 and April 1996 (Sea Side)

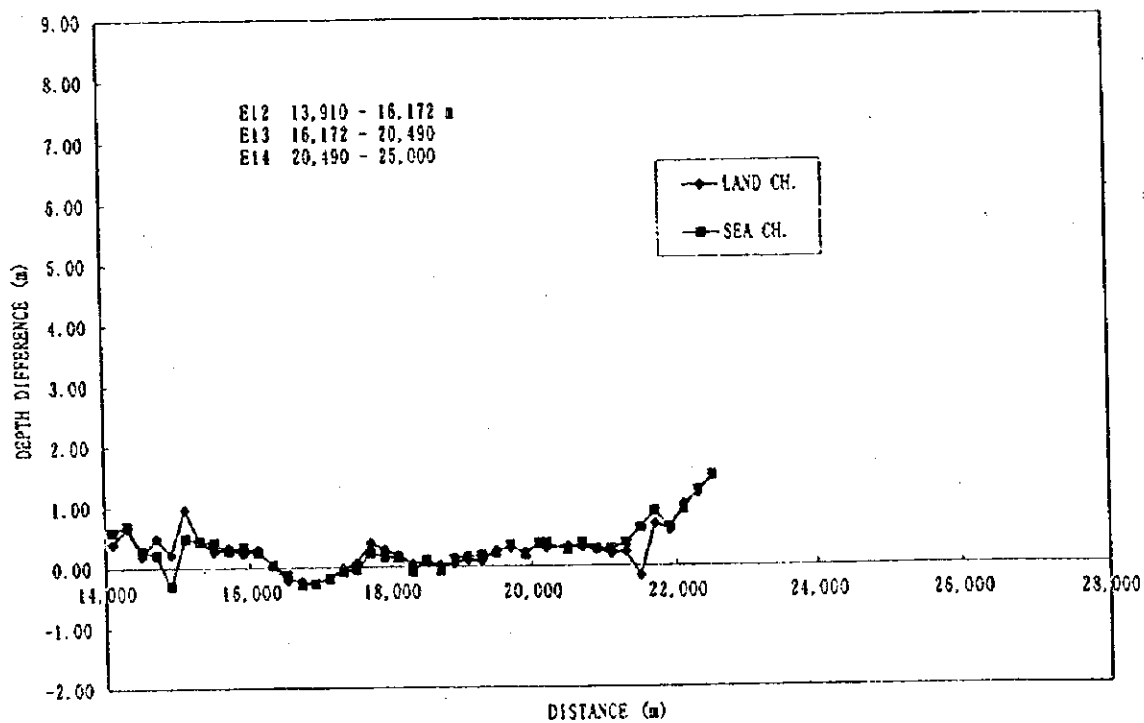


Figure 4.1.2-7 Depth Difference of E12 to E14 between August 1991 and April 1996

(4) Sedimentation of Other Periods

The same calculation is shown in Table 4.1.2-3 about Sections E9, E10 and E11 on the basis of the surveys carried out in August 1991, April 1993 and April 1996. In the table, the sedimentation between August 1991 and April 1996 is also tabulated with the same value as shown in Table 4.1.2-2.

In the table, the annual sedimentation volume is 724×10^3 and $1,059 \times 10^3$ m³/year respectively against the period from August 1991 to April 1993 and the period from April 1993 to April 1996. In general, the sedimentation rate decreases with the decrease of channel depth, therefore, it seems that the annual sedimentation rate during August 1991 to April 1993 should be greater than that during April 1993 to April 1996. Referring to the monthly rainfall in Table 3.2.3-1, the former period experienced the rainy season two times during 1.67 years and the latter period passed the more severe rainy season than the former period three times during 3.1 years. Moreover, referring to Table 3.2.5-1, no attack of heavy cyclones was recorded during the former period, whereas 3 heavy cyclones attacked during the latter period. Thus, it is understandable that the sedimentation volume is greatly influenced by rainfall and sea conditions.

Also, the sedimentation between April 1993 and November 1993 was calculated as 202×10^3 and 92×10^3 m³/year, respectively in E6 and in the distance from 8,090 to 9,800 m of E10.

Table 4.1.2-4 shows the sedimentation volume and the annual sedimentation rate calculated by sounding data of April 1996 and July 1997. Compared with the value of Table 4.1.2-3, the sedimentation volume of the Section E9+E10+E11 becomes smaller, which seems to depend on the decrease of channel depth. Also, the sedimentation occurring in the Section of E6+E7+E8 is very small, but that of E14 is a remarkable value though the channel of this section already had been buried. This seems to show that in the dry season fine sand and silt have a strong tendency to deposit in the vicinities of E14, as described about Figure 4.1.1-14. The calculation of sedimentation between February and August in 1997 is shown in Appendix A-3.

(5) General Characteristics of the Sedimentation

From the above mentioned, the follows would be supposed on the sedimentation of the Access Channel.

- (a) The annual sedimentation volume is greatly influenced by the river flow of the Pungue River and cyclones attacking Beira,

Table 4.1.2-3 Sedimentation of Section E9, E10 and E11

Period	August 1991 to April 1996	August 1991 to April 1993	April 1993 to April 1996
Years	4.67	1.67	3.1
Sedimentation Volume	(m ³)	(m ³)	(m ³)
E9	1,213,996	300,936	981,438
E10	2,593,833	805,513	1,888,475
E11	426,223	103,300	414,091
E9+E10+E11	4,234,052	1,209,749	3,284,004
Annual Sedimentation Rate (m ³ /year)			
E9	259,956	180,201	316,592
E10	555,425	482,343	609,185
E11	91,268	61,856	133,578
E9+E10+E11	906,649	724,401	1,059,356

Table 4.1.2-4 Sedimentation between April 1996 and July 1997

Section	Sedimentation Volume for 1.25 year.(m ³)	Annual Sedimentation Rate (m ³ /yr.)
E6	26,233	20,986
E7	15,530	12,424
E8	27,064	21,651
E6+E7+E8	68,827	55,062
E9	126,878	101,502
E10	326,794	261,435
E11	16,170	12,936
E9+E10+E11	469,842	375,874
E12	8,064	6,451
E13	100,741	80,593
E14	451,693	361,354
E12+E13+E14	560,498	448,398
Total	1,099,167	879,334

- (b) The most remarkable sedimentation occurs at E9 and E10 in the vicinity of the bending corner and E8 follows them. The sedimentation from E11 to E13 is smaller compared with the their vicinity area,
- (c) In the vicinity of 8,700 m and 10,700 m of E10, sedimentation occurs so that the slope of land side and the slope of sea side invade the Channel, respectively,
- (d) The Channel seems to have a tendency to be scoured in the wet season and shoaled in dry season. Therefore, in the wet season, sediment transported in the vicinity of the Access Channel from rivers and the northern coast seems to deposit at the shoal area around the Access Channel and to enter comparatively early in the dry season into the Channel.
- (e) In the vicinity of E14, a tendency of deepening in the wet season and shoaling in the dry season is very remarkable.

4.2 Computer Simulation

Numerical simulation has been carried out to evaluate the sedimentation volume in the Access Channel between Sections E6 and E11. Bijker's sedimentation model is applied for calculation of the sedimentation volume induced by tidal currents and waves. In order to provide input data for the sedimentation model, the distribution of current and wave in the study area as shown in Figure 4.2.1-1 was simulated.

4.2.1 Simulation of Tidal Current and Wave Propagation

As to external forces, the currents of spring tide and storm wave heights are calculated. The calculation conditions are shown in the following table.

Table 4.2.1-1 Calculation Conditions of Tidal Current and Wave

Study area	50 km(E)×54 km(N)	see Figure 4.2.1-1
Grid space	200 m (250×270)	see Figure 4.2.1-2
Sea side boundary condition	mean spring tide	$M_2 + S_2$ semi-diurnal tide
Tidal amplitude	2.80 m	
Tidal period	12.0 hr	
River upstream condition	No river flow	Closed boundary
Manning's roughness coefficient	0.02	MKS unit
Horizontal mixing coefficients	10.0 m ² /sec	
Offshore wave height	2.0 m	
wave period	10.0 sec	
wave direction	SE	
Current conditions in wave calculation	Results of tidal current simulation at every hours	

Figures 4.2.1-3 and 4.2.1-4 show calculated current distributions at flood and ebb tides. Figures 4.2.1-5 and 4.2.1-6 show calculated current distribution at high water level and low water level. The figures indicate that the current patterns and the maximum current velocities (about 2.0 m/s) measured in the field are well simulated.

Figures 4.2.1-7 to 4.2.1-10 show simulation results on the distribution of wave height and wave direction at flood and ebb tides. Figures 4.2.1-11 to 4.2.1-14 show wave height and wave direction distribution calculated at high water

level and low water level. These figures indicate no wave zone where wave can not propagate upstream against a strong opposing current existing at ebb tides and at low water level.

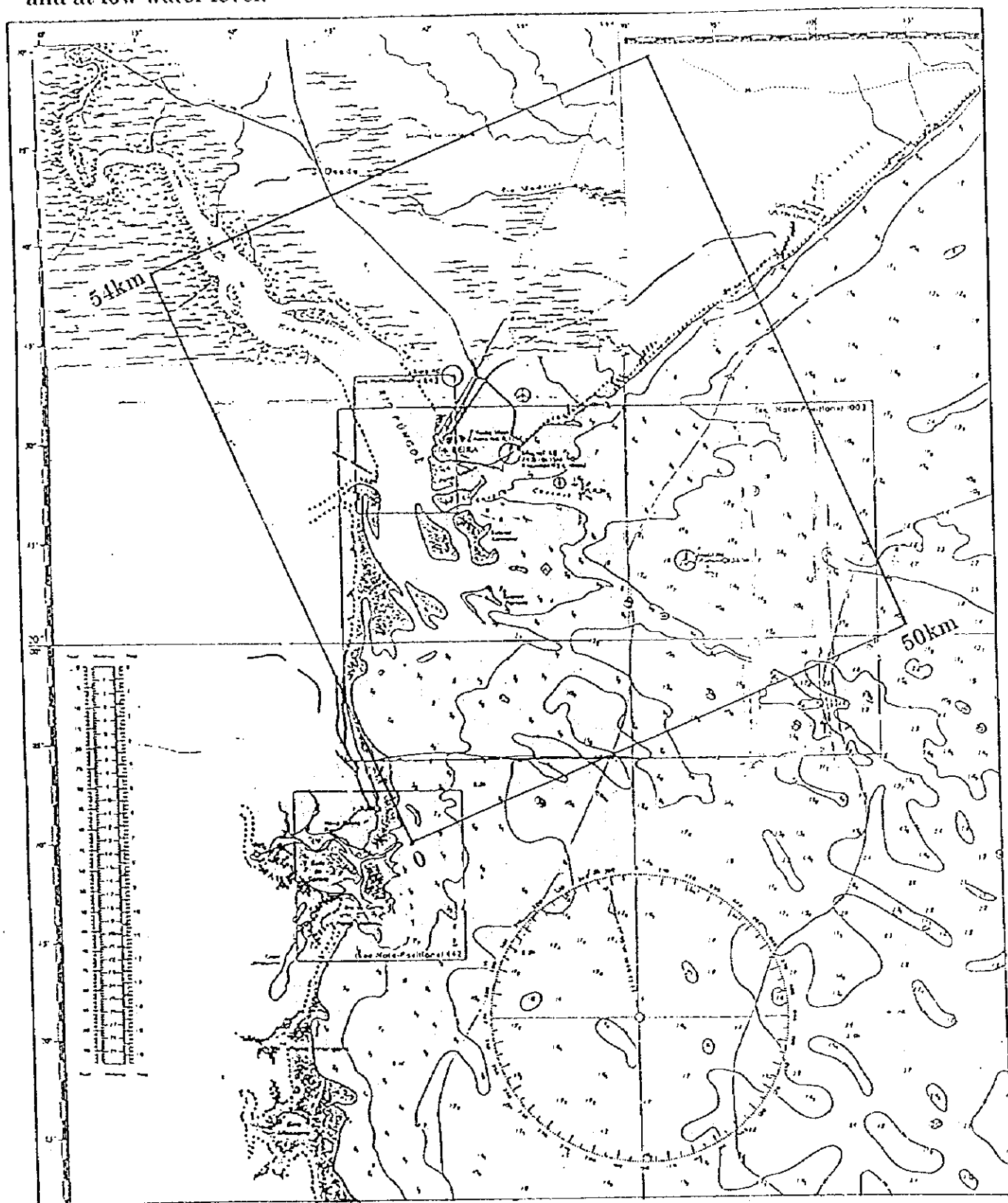


Figure 4.2.1-1 Area of Numerical Simulation

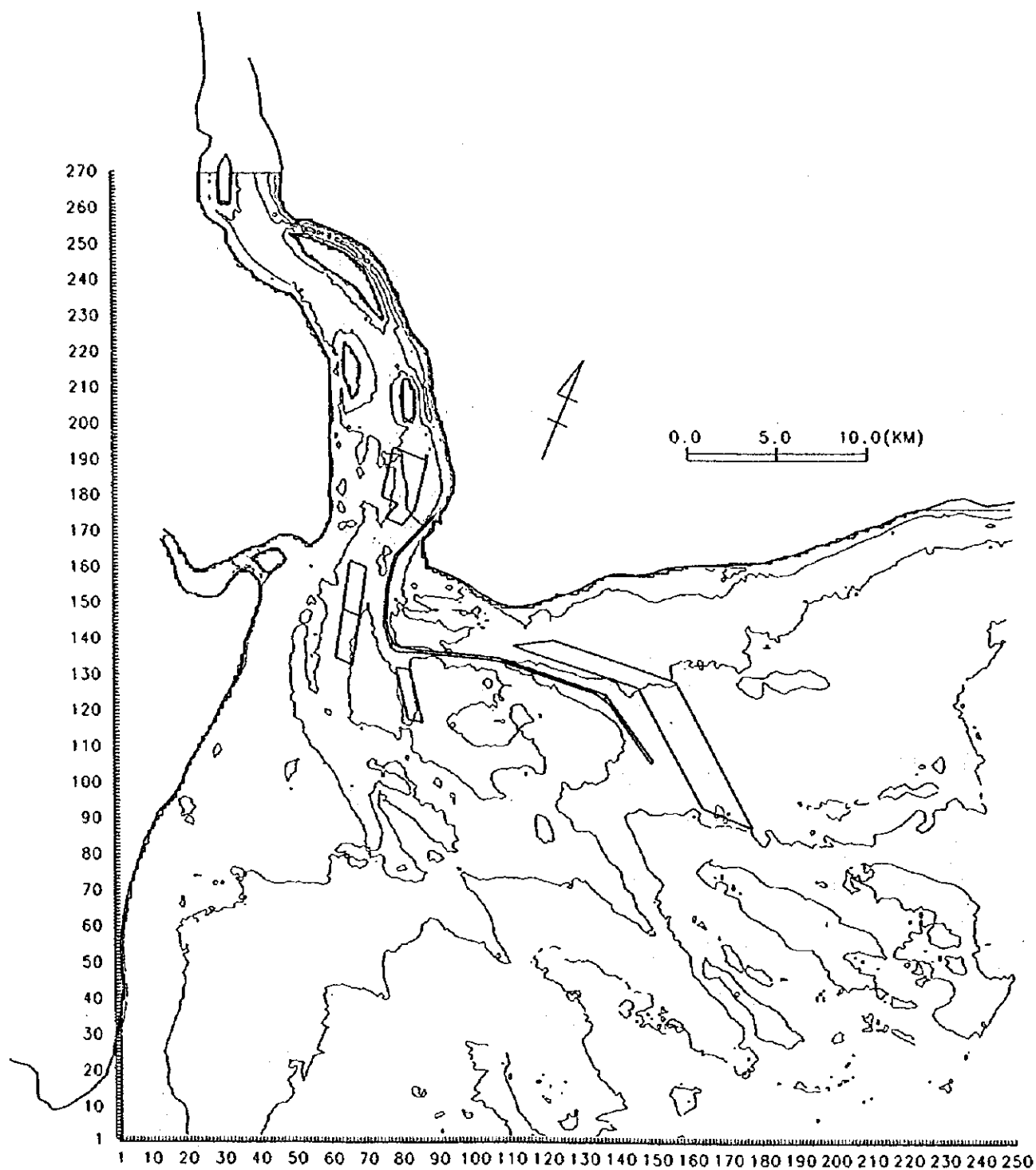


Figure 4.2.1-2 Grid Layout and Model Bathymetry

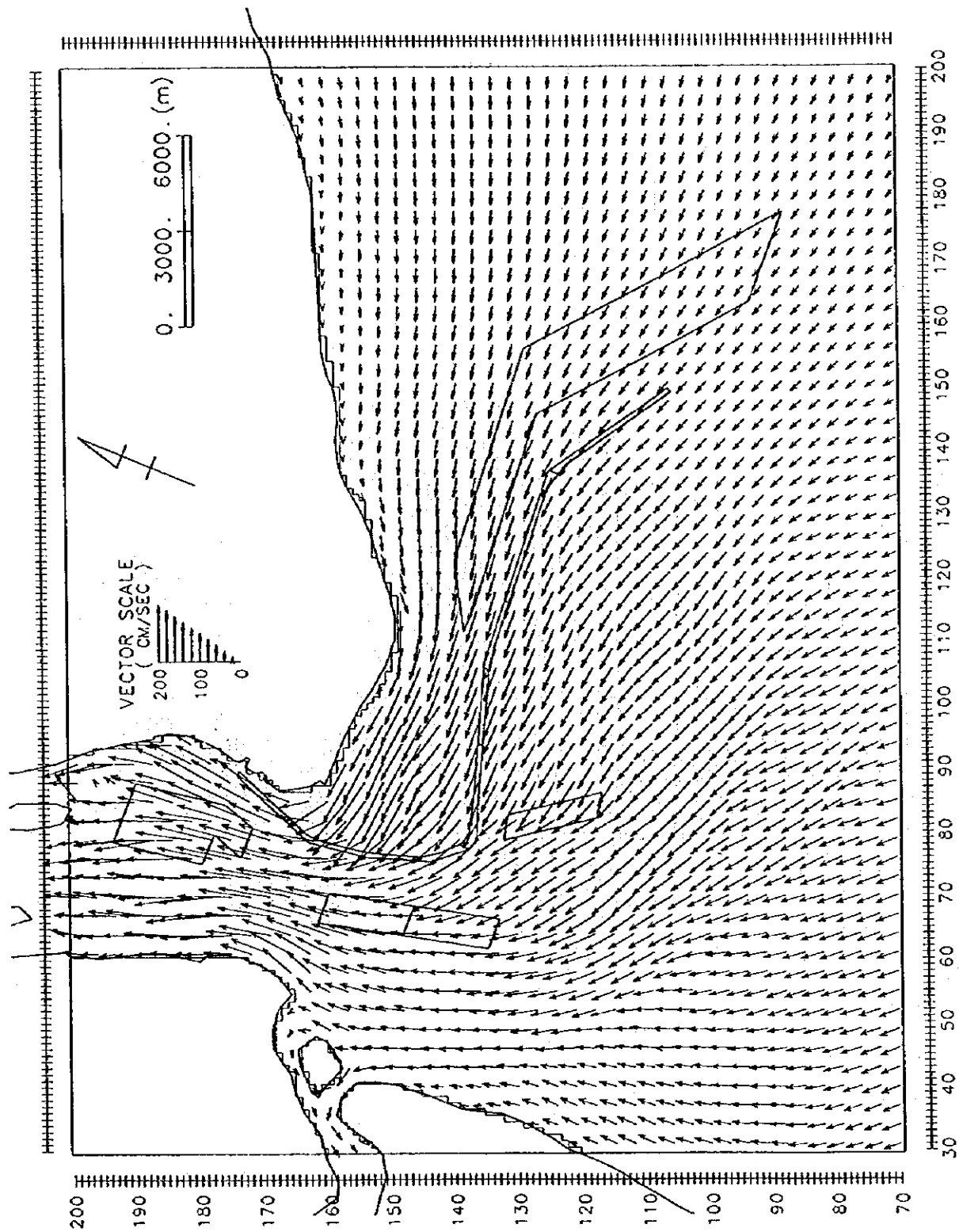


Figure 4.2.1-3 Calculated Tidal Current Distribution at Flood Tides

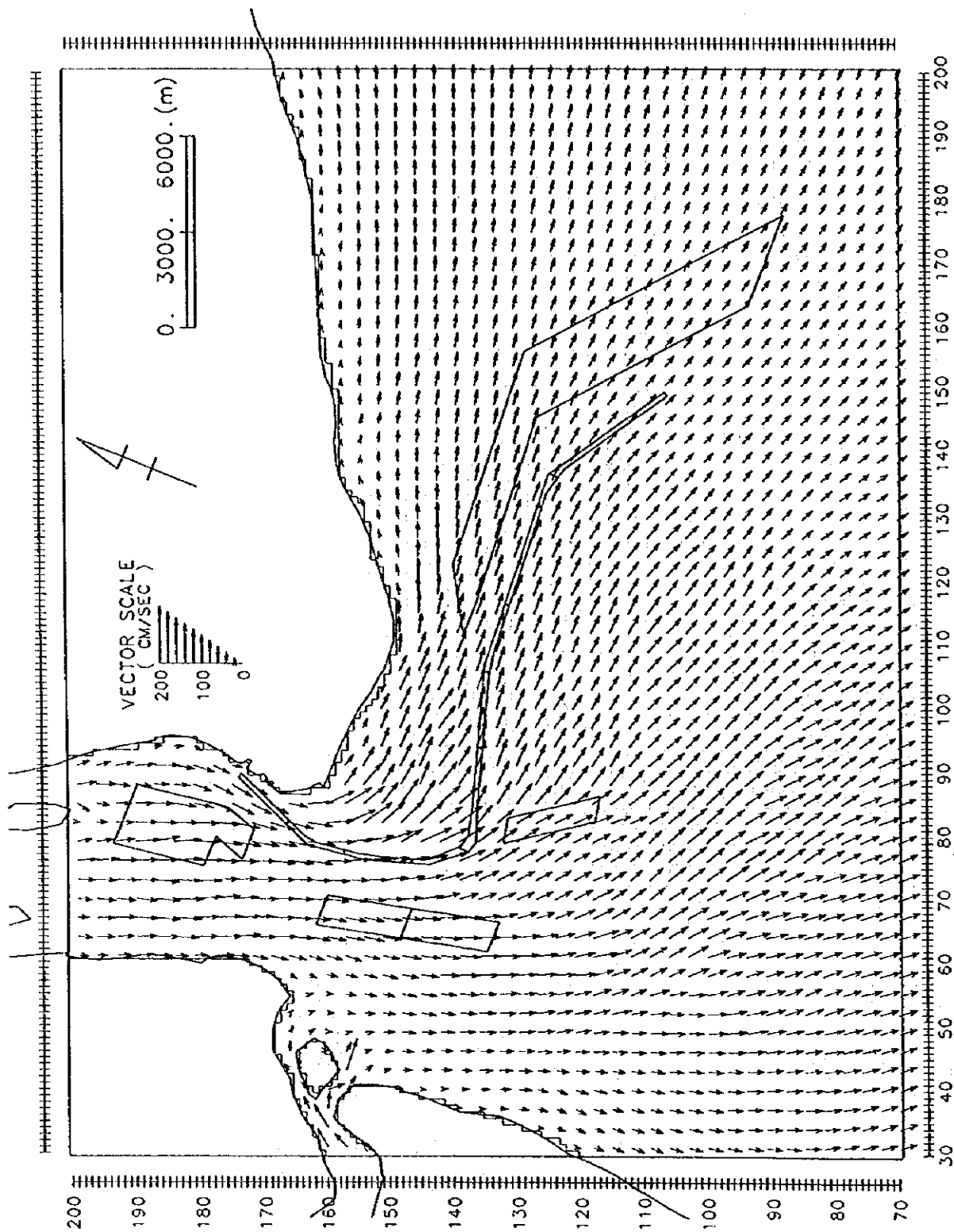


Figure 4.2.1-4 Calculated Tidal Current Distribution at Ebb Tides

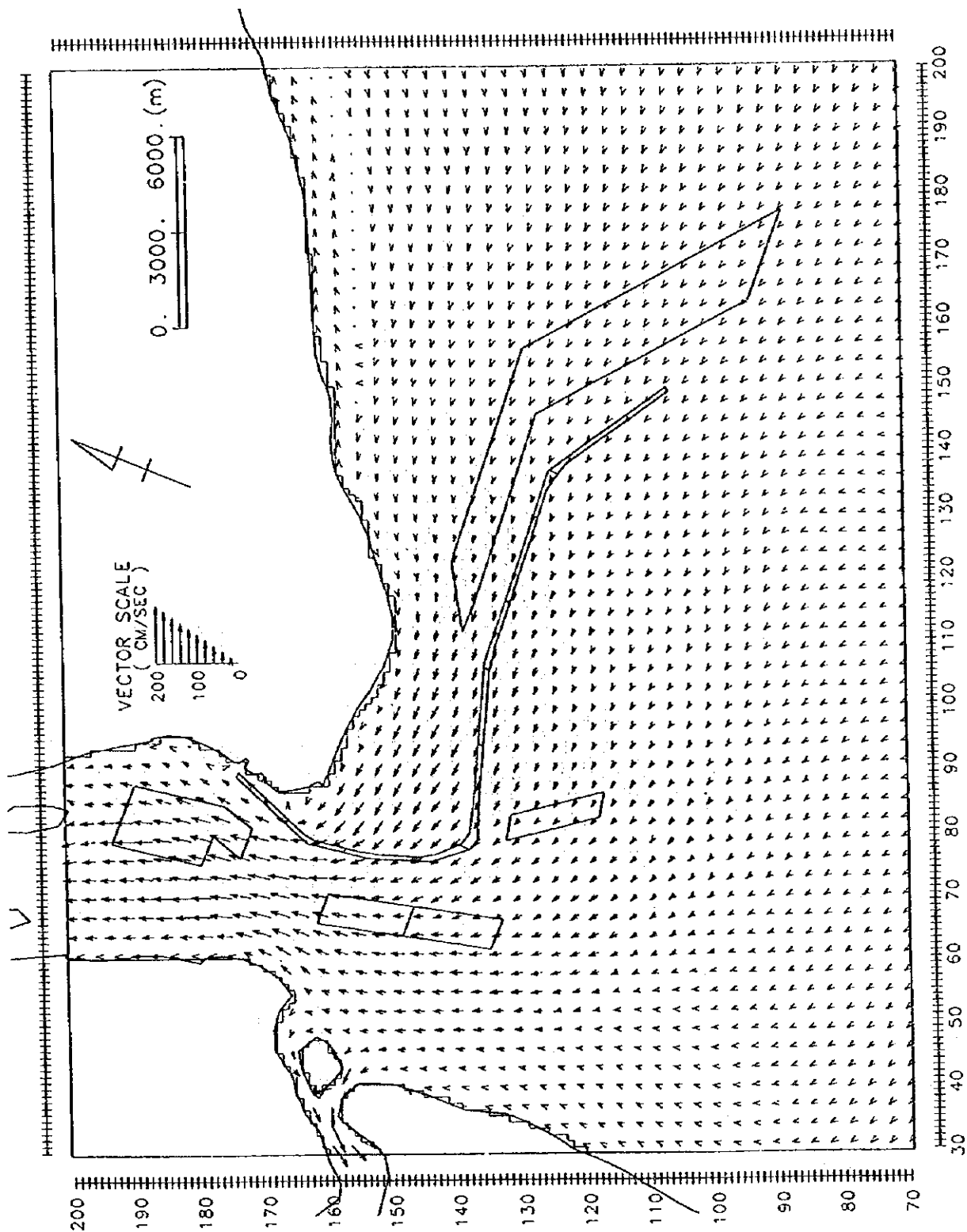


Figure 4.2.1-5 Calculated Tidal Current Distribution at High Water Level

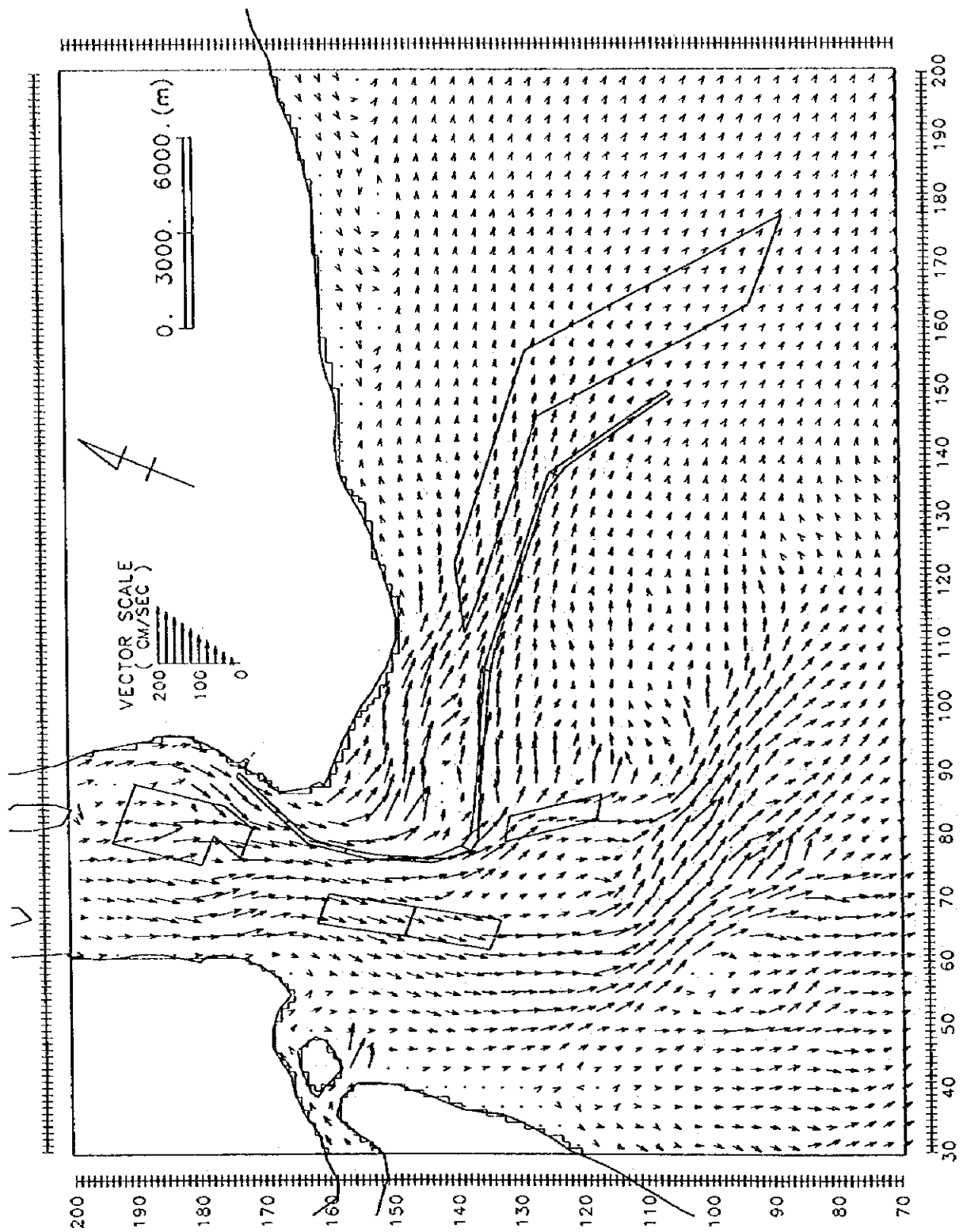
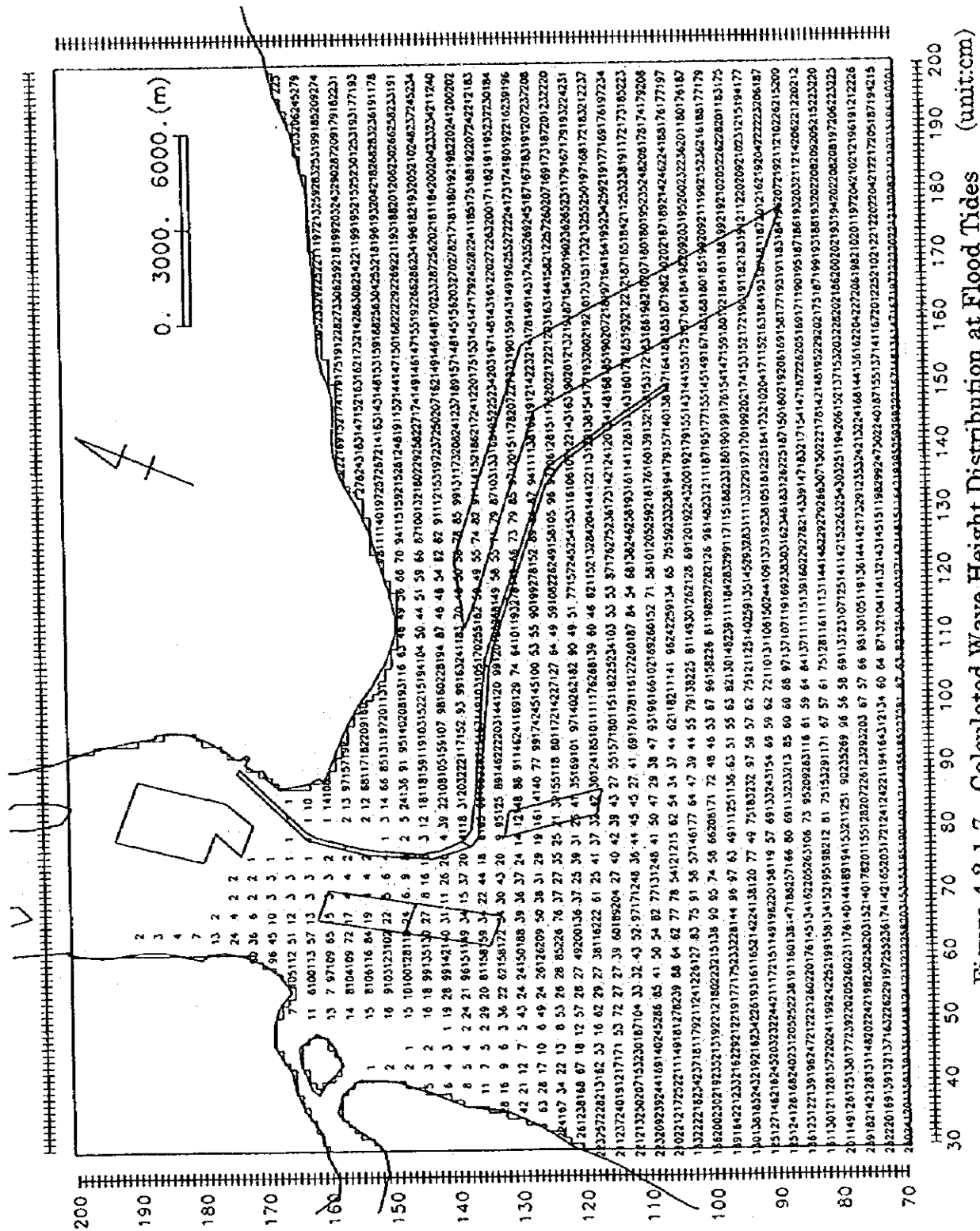


Figure 4.2.1-6 Calculated Tidal Current Distribution at Low Water Level



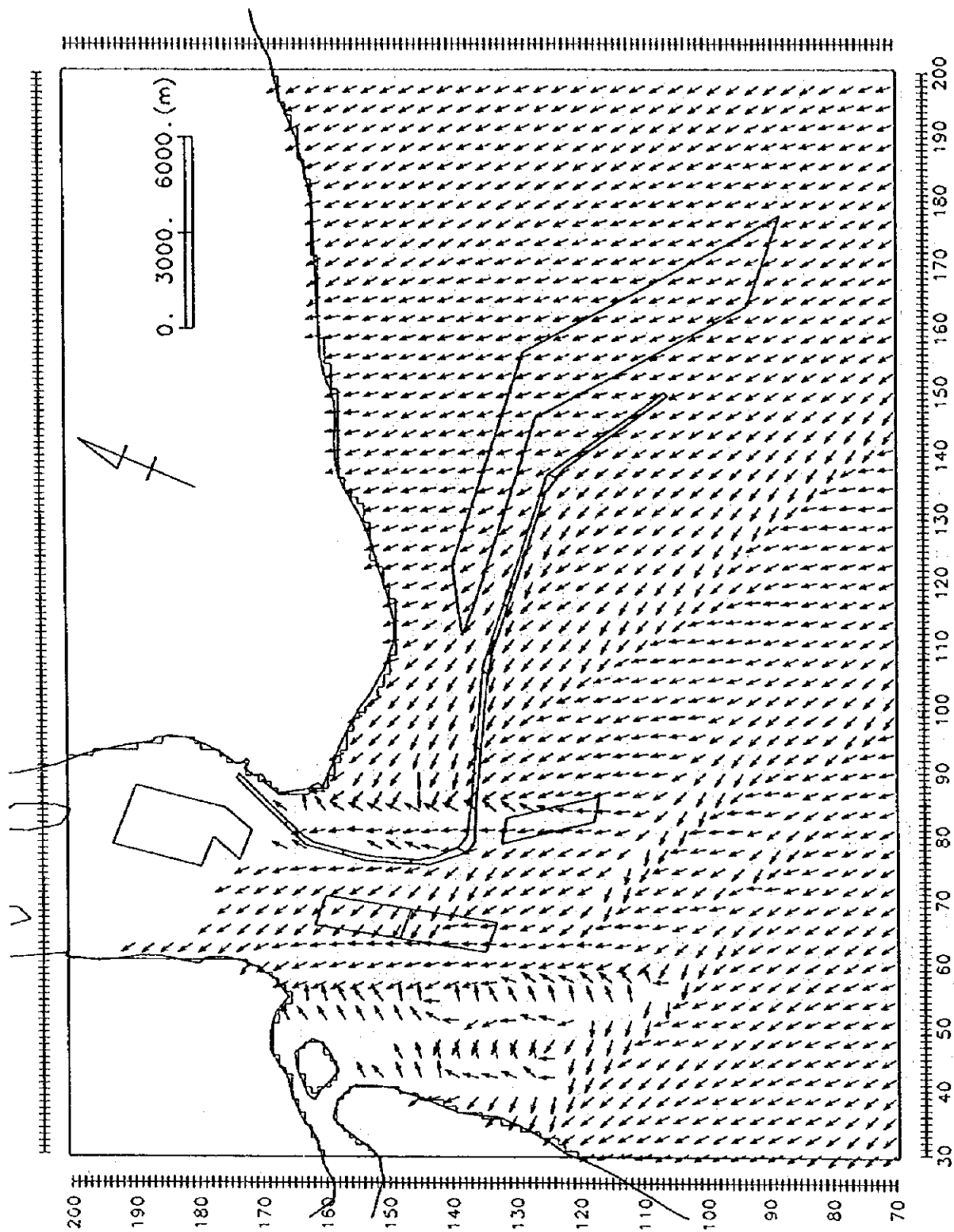
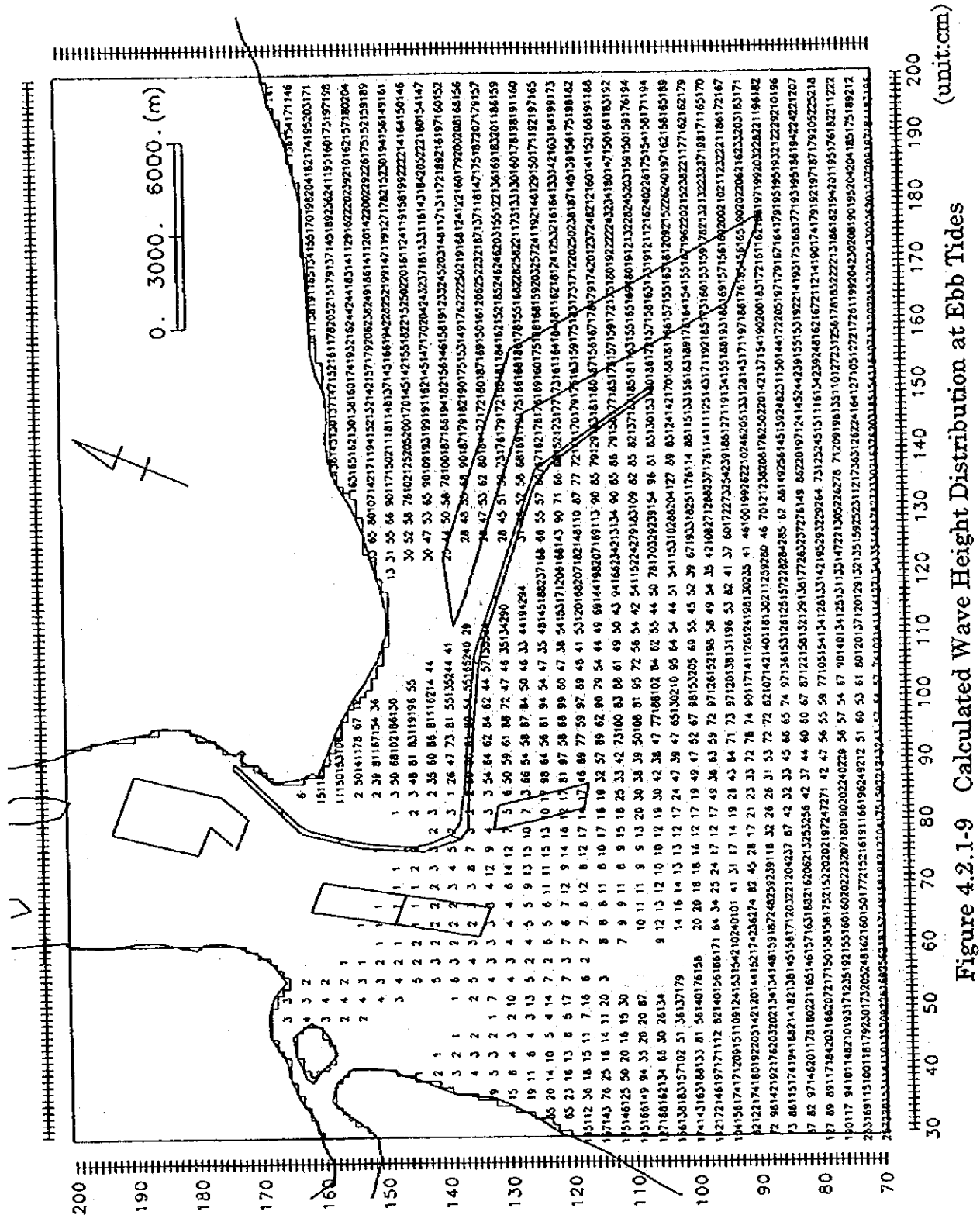


Figure 4.2.1-8 Calculated Wave Direction Distribution at Flood Tides



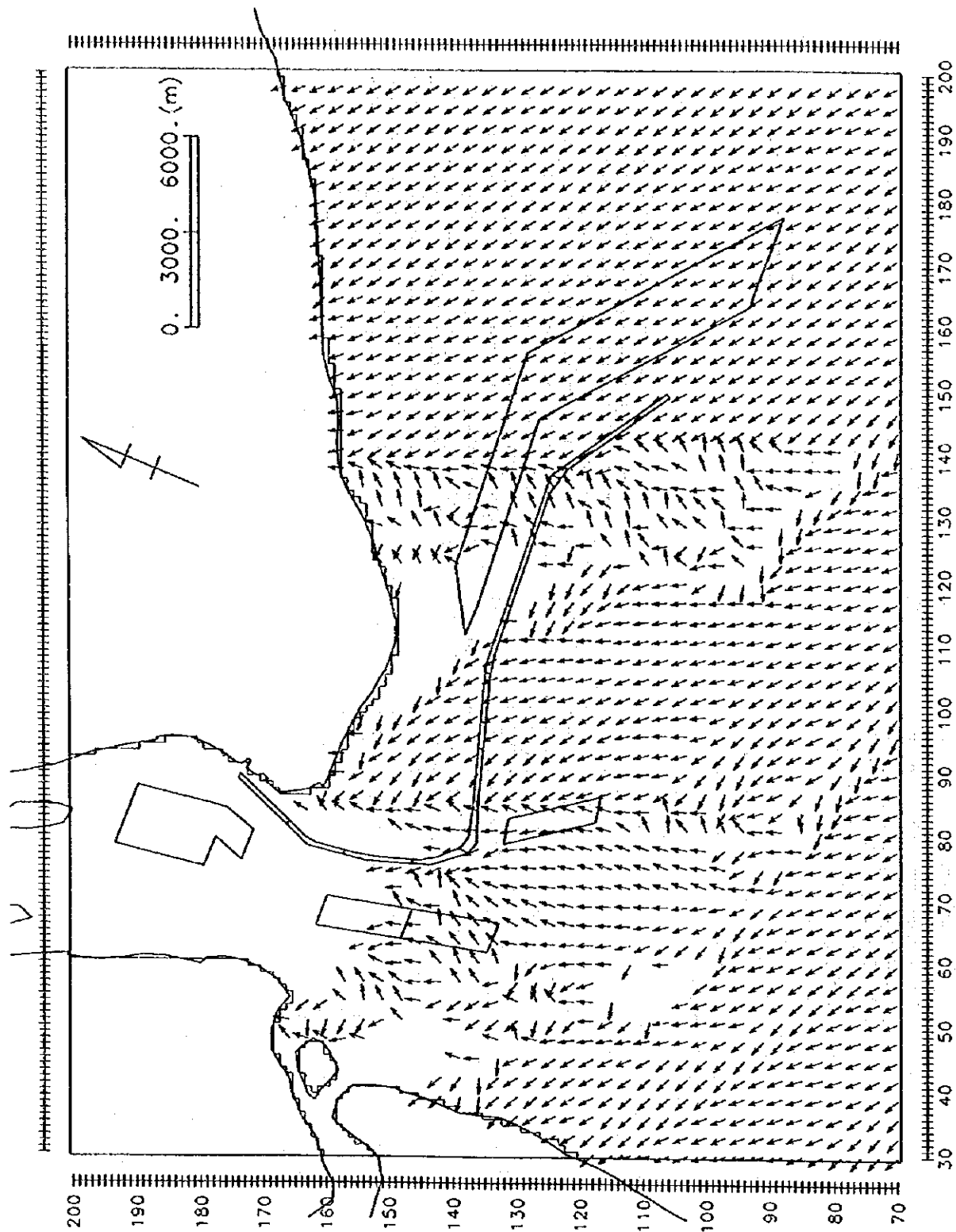


Figure 4.2.1-10 Calculated Wave Direction Distribution at Ebb Tides

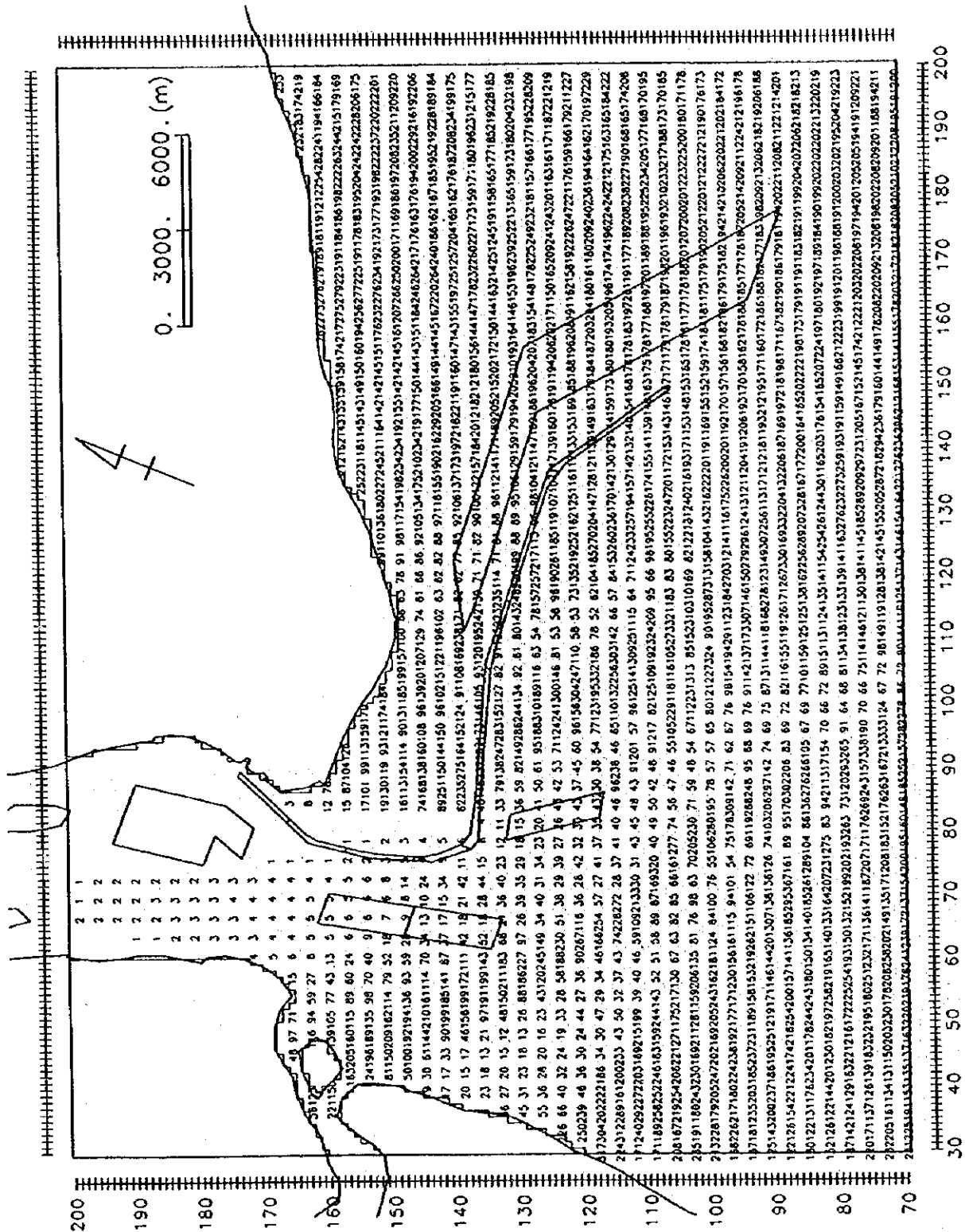


Figure 4.2.1-11 Calculated Wave Height Distribution at High Water Level (unit:cm)

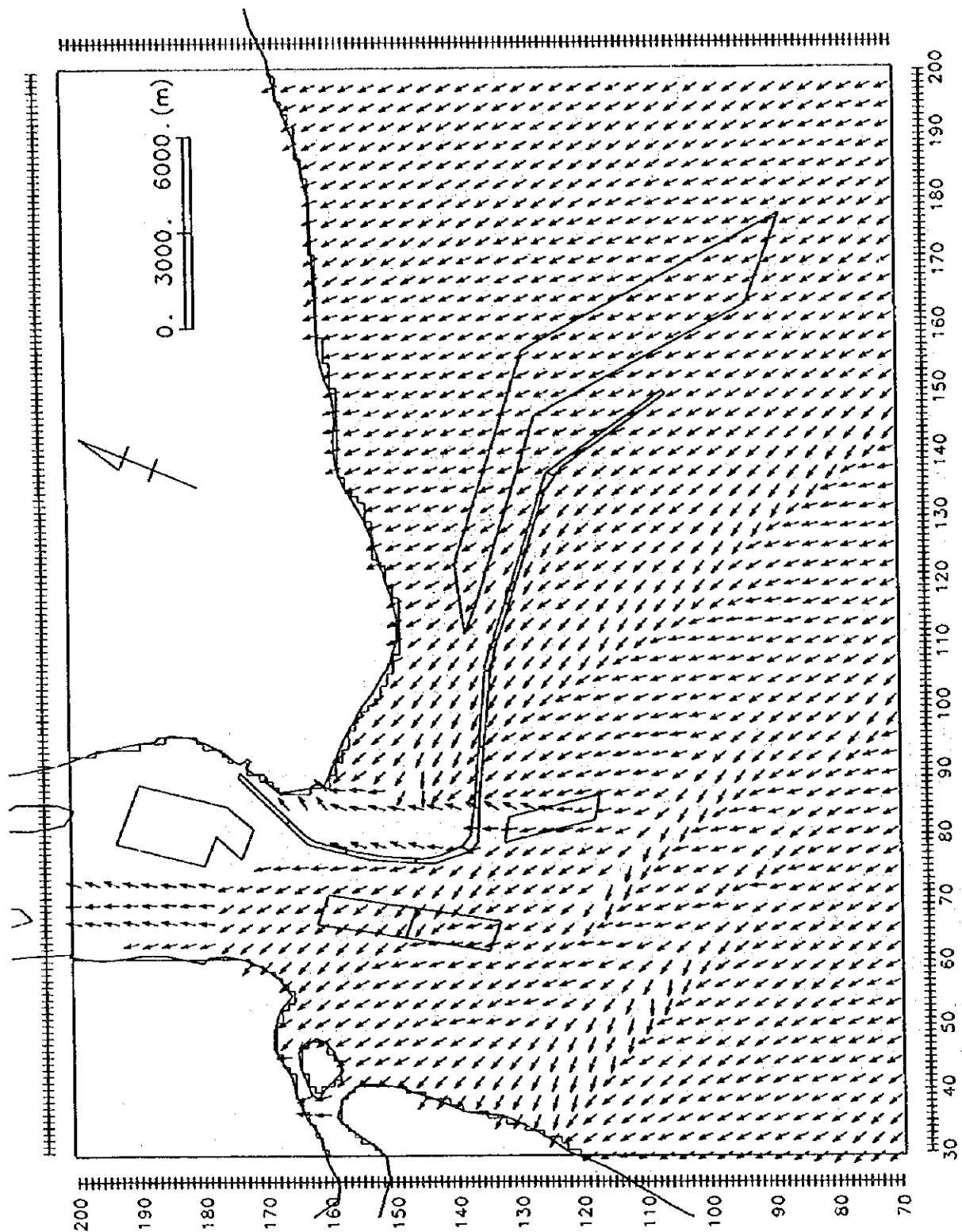
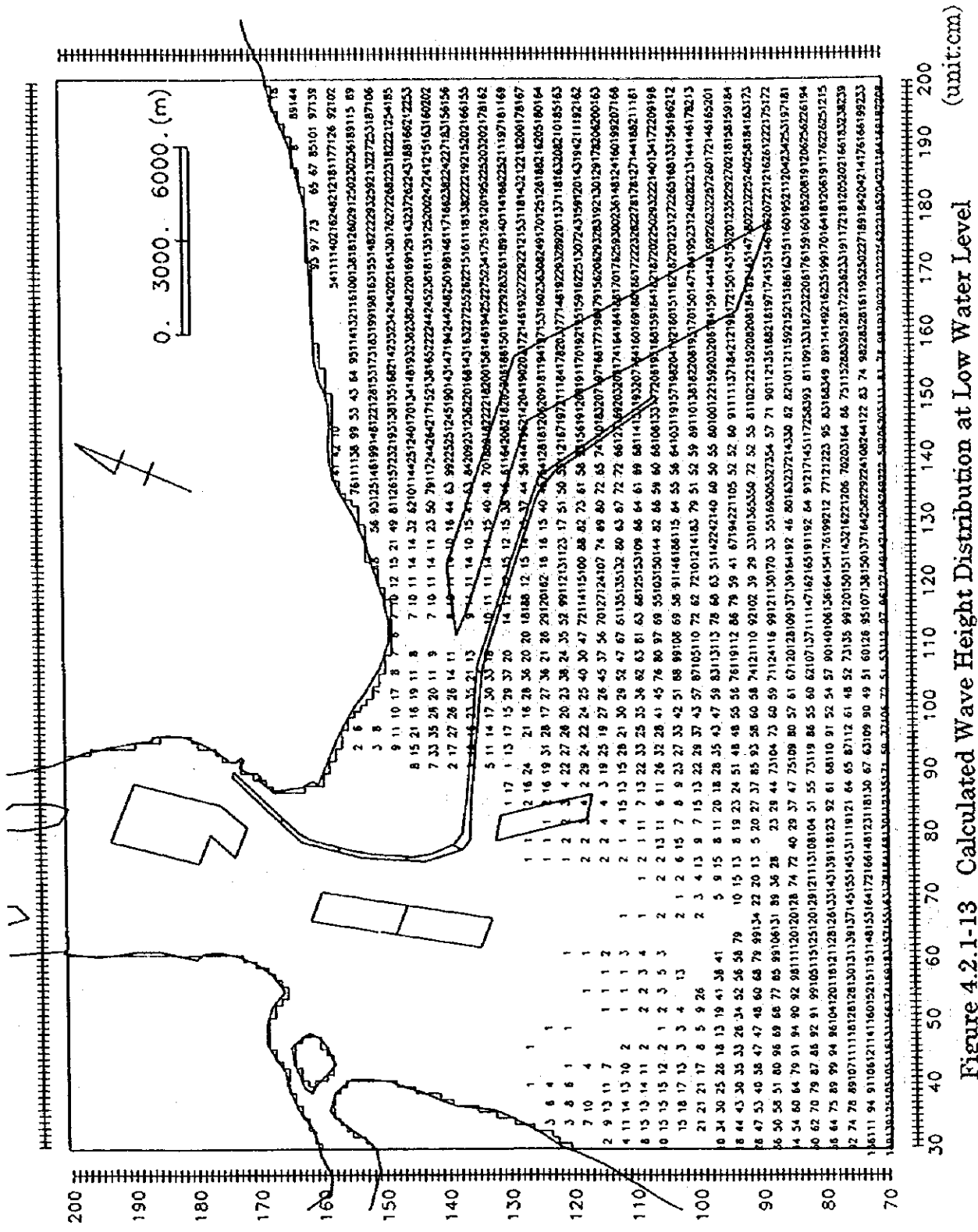


Figure 4.2.1-12 Calculated Wave Direction Distribution at High Water Level



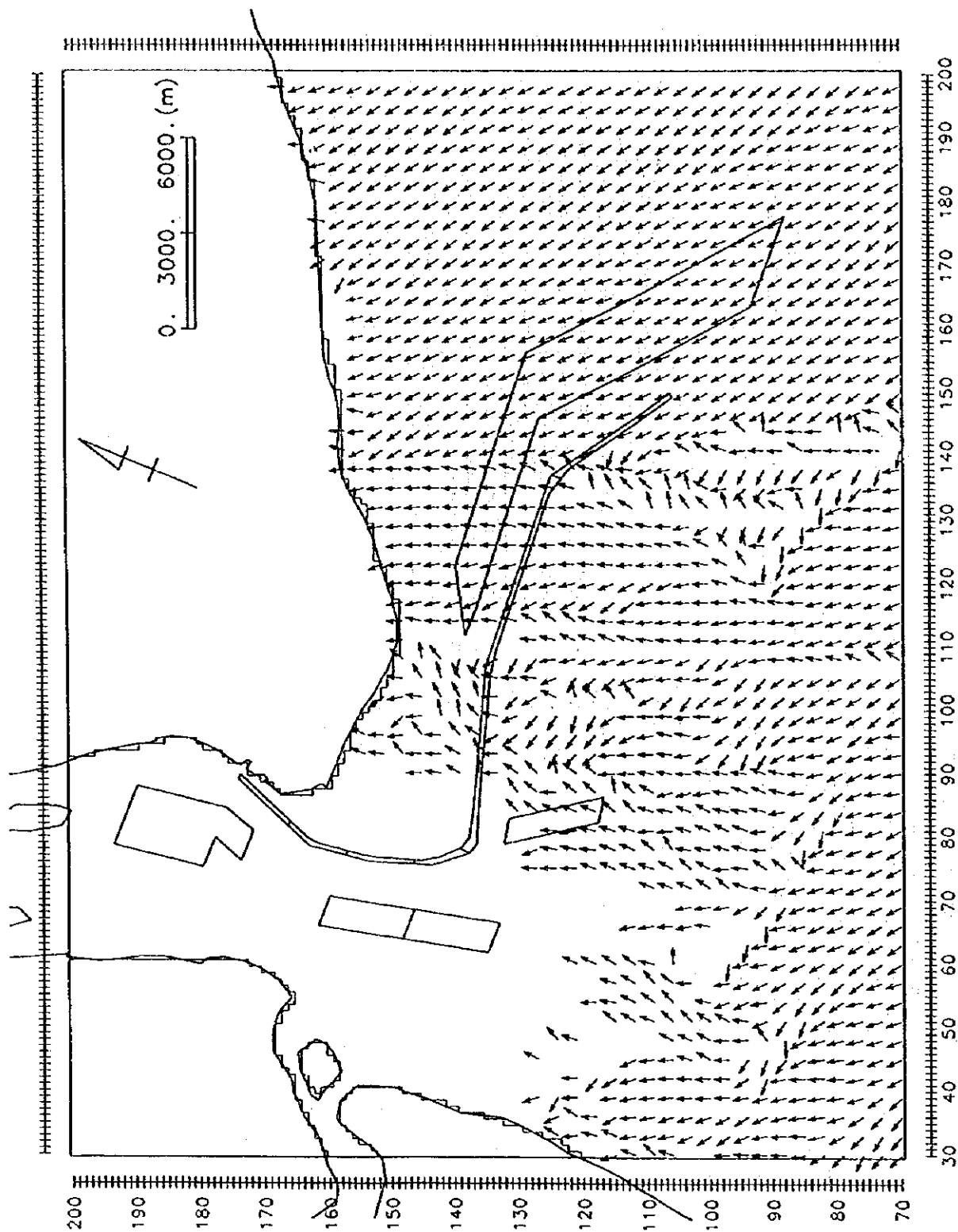


Figure 4.2.1-14 Calculated Wave Direction Distribution at Low Water Level

4.2.2 Simulation of Sedimentation in the Access Channel

(1) Simulation Model

In the Bijker's sedimentation model as shown in Figure 4.2.2-1, a horizontal sediment transport rate $S(x)$ and a siltation rate in the channel DS are expressed as follows.

$$S(x) = (S_0 - S_1) \exp(-\beta x) + S_1 \quad (4.2.2-1)$$

$$DS = [(S_0 - S_1) \{1 - \exp(-\beta B / \sin \alpha)\}] \sin \alpha \quad (4.2.2-2)$$

where

S_0 : horizontal sediment transport rate under equilibrium condition at upstream of the channel.

S_1 : horizontal sediment transport rate under equilibrium condition at depth of the channel.

α : angle between current direction and the channel

B : channel width

β : attenuation rate of horizontal sediment transport formulated as the function of local current, wave and sediment characteristics proposed

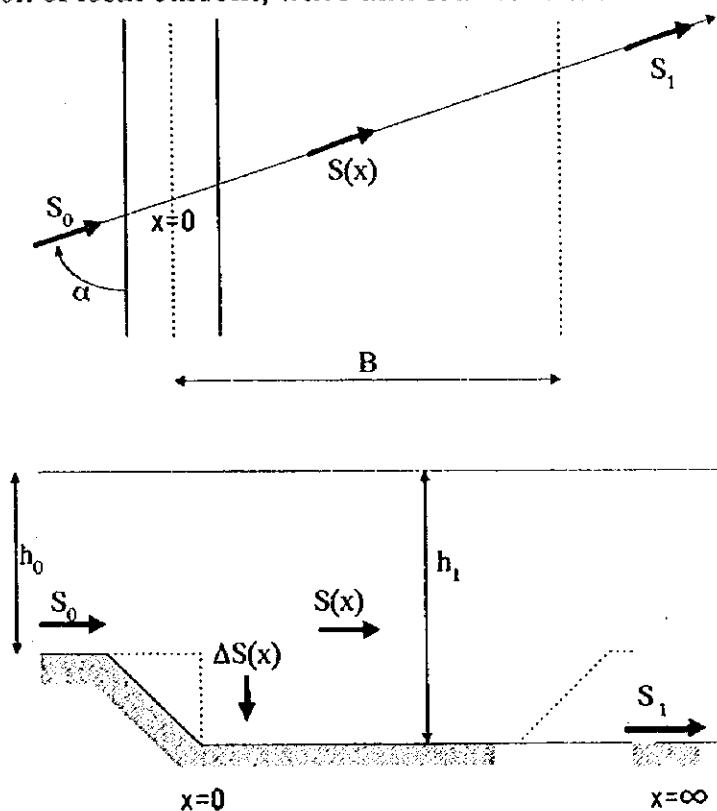


Figure 4.2.2-1 Definition Sketch of Sedimentation Model

In applying the Bijker's model to calculate the siltation rate in the channel, the channel between Sections E6 and E14 is divided into segments of 200 m in length along the channel and the siltation is calculated in each segment. As the first step in the calculation of the siltation at each segment during one tide cycle is calculated with current and wave, switching upstream depth (h_0) shown in Figure 4.2.2-1 according to current directions. Then the annual siltation rate against the siltation for one tide cycle calculation is estimated on the basis of the annual siltation volume obtained from the analysis of the sounding survey maps between August 1990 and August 1991. The reproducibility of the simulation model using the annual siltation rate is examined by comparing with the annual siltation volume obtained from numerical simulation and that obtained from the analysis of the sounding survey maps between August 1991 and April 1996. Then the annual siltation volume of six cases are predicted by using numerical simulation.

(2) Simulation Conditions

The annual siltation volume of eight cases tabulated in Table 4.2.2-1 are estimated by using numerical simulation.

Table 4.2.2-1 Channel Segments for Numerical Simulation

Case	Depth at downstream of channel (h_1)	Depth at upstream of channel (h_0)	Remarks
S-1	depth surveyed at 1990/8	depth surveyed at 1990/8	Calibration case (see Figure 4.2.2-2)
S-2	depth surveyed at 1991/8	depth surveyed at 1991/8	Hindcast case (see Figure 4.2.2-3)
Y-0	E6-E8 :8.0 m E9-E11:8.5 m	depth surveyed at 1996/8.	Prediction Cases (see Figure 4.2.2-4)
Y-1	E6-E11 :9.0 m		
Y-2	E6-E11 :8.0 m		
Y-3	E6-E11 :7.0 m		
Y-4	E6-E11 :6.0 m		
Y-5	E6-E11 :5.0 m		

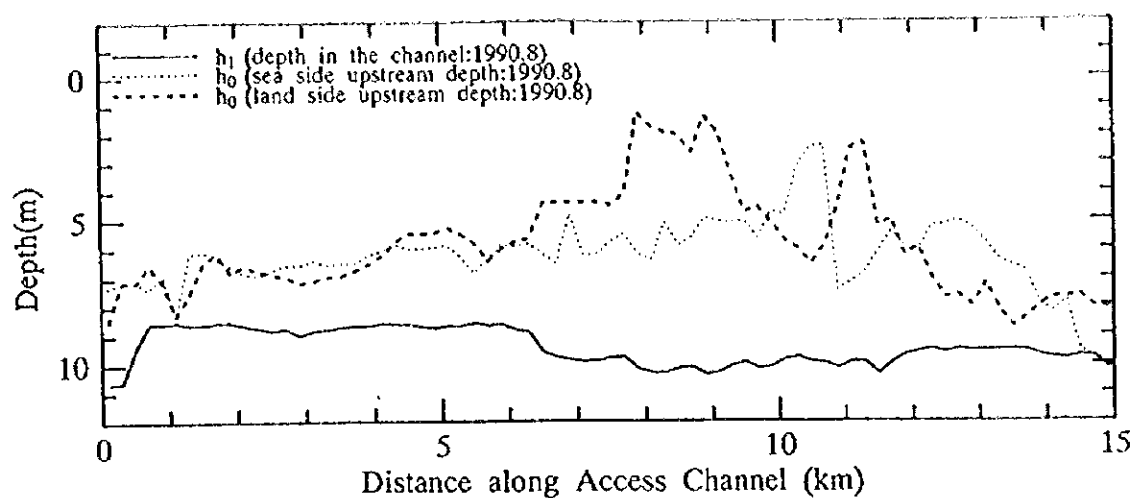


Figure 4.2.2-2 Depth along Access Channel (S-1:1990-1991)

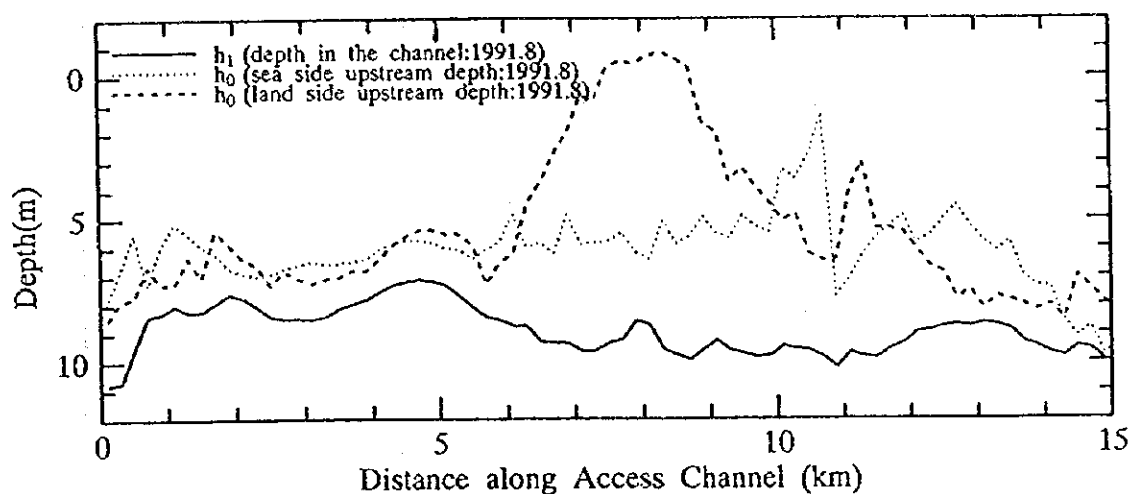


Figure 4.2.2-3 Depth along Access Channel (S-2:1991-1996)

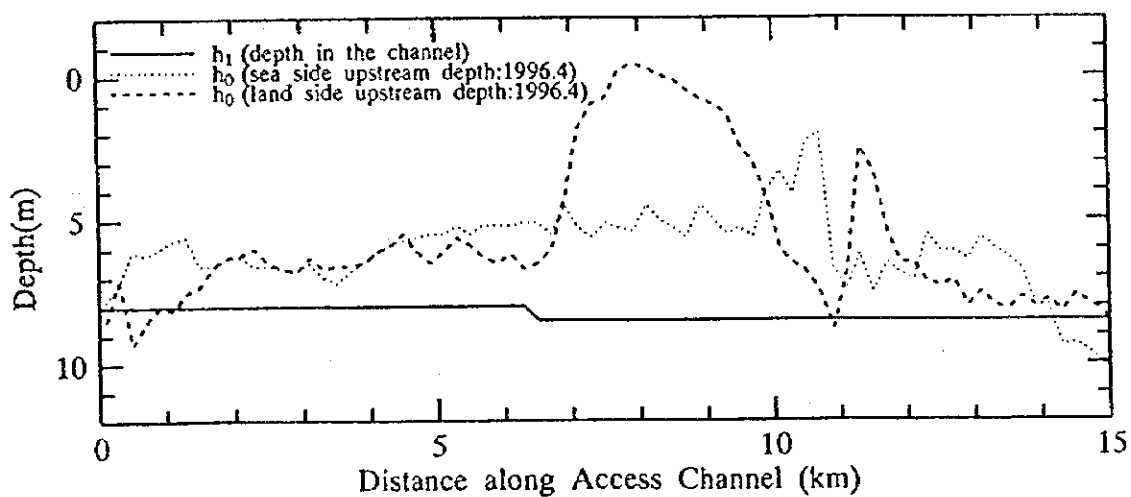


Figure 4.2.2-4 Depth along Access Channel (Y-0:1996-)

The mean diameter of sediments for each channel segment used as input data in the sedimentation model is given based on the results of the field survey as shown in Figure 4.2.2-5.

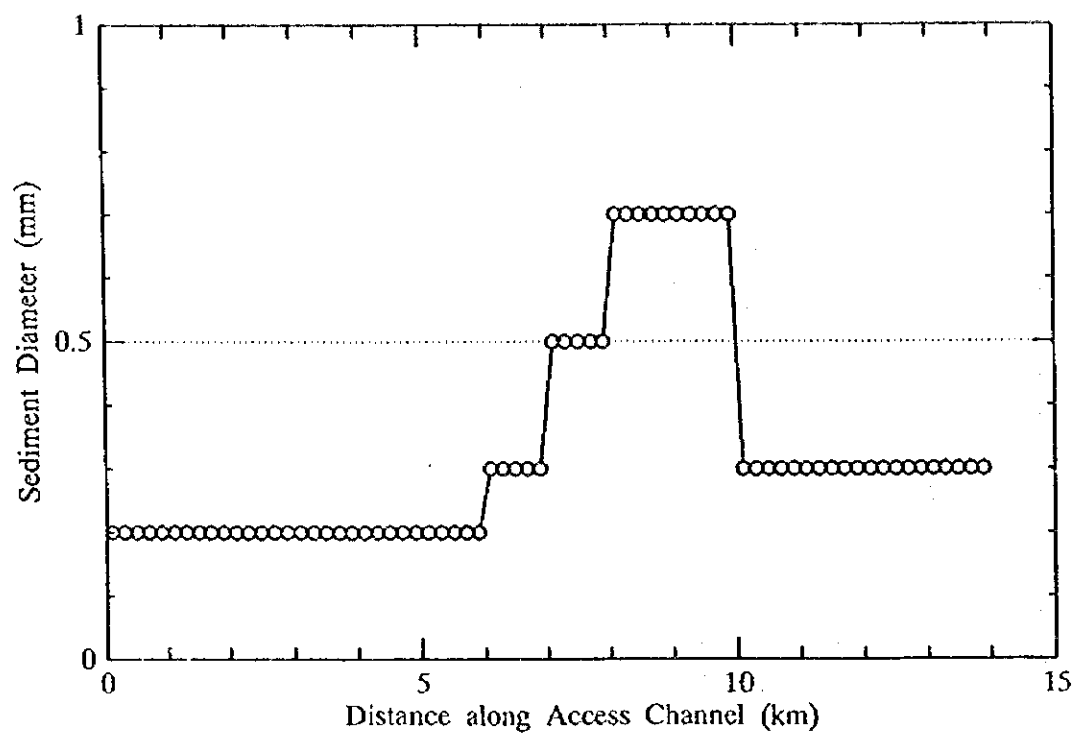


Figure 4.2.2-5 Diameter of Sediment along the Access Channel

(3) Simulation Result

1) Hindcast Case (S-1, S-2)

Figures 4.2.2-6 and 4.2.2-7 show the calculated and analyzed sediment rates along the channel between August 1990 and August 1991. Figure 4.2.2-8 shows the calculated and analyzed annual siltation volume along the Access Channel between August 1991 and April 1996. The annual siltation volumes of Sections E6 to E11 are shown in Table 4.2.2-2.

Table 4.2.2-2 Calculated and Analyzed Siltation Volume (unit: m³/y)

Section	Analyzed siltation volume (1990/8-1991/8)	Calculated siltation volume (1990/8-1991/8) case S-1	Analyzed siltation volume (1991/8-1996/4)	Calculated siltation volume (1991/8-1996/4) case S-2
E6	15.9	10.4	10.2	10.6
E7	18.5	17.7	11.6	12.3
E8	28.3	24.6	13.4	18.4
E6-E8	62.8	52.8	35.2	52.8
E9	44.8	47.9	25.9	35.2
E10	53.2	68.0	55.5	62.0
E11	29.1	21.3	9.1	18.5
E9-E11	127.1	137.2	90.7	115.7
E6-E11	190.0	190.0	125.9	157.1

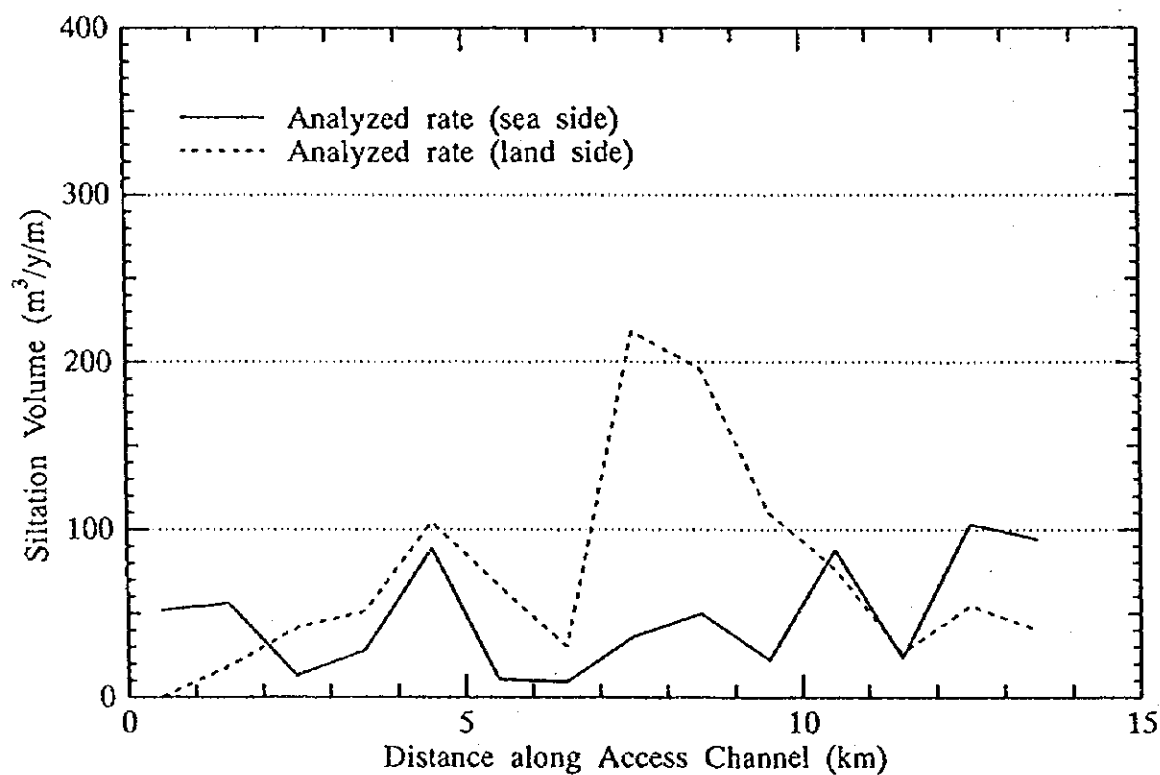
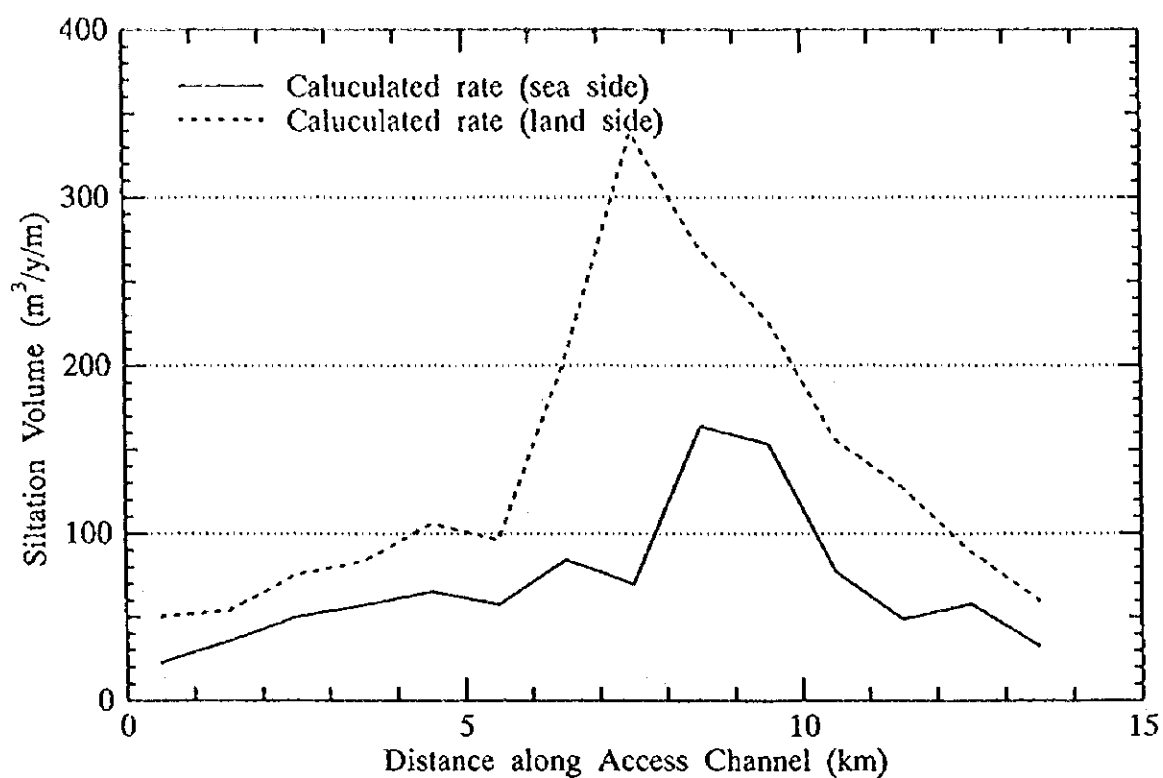


Figure 4.2.2-6 Calculated and Analyzed Annual Siltation Volume
(S-1: 1990/8-1991/8)

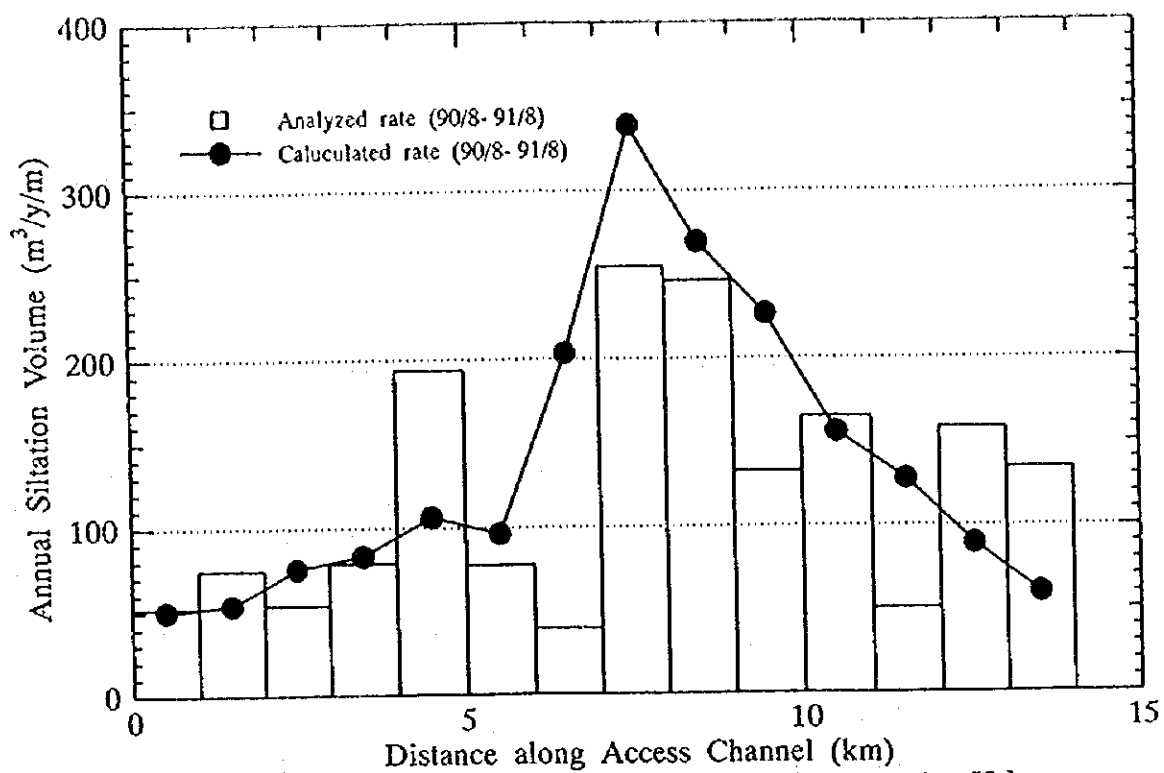


Figure 4.2.2-7 Calculated and Analyzed Annual Siltation Volume
(S-1: 1990/8-1991/8)

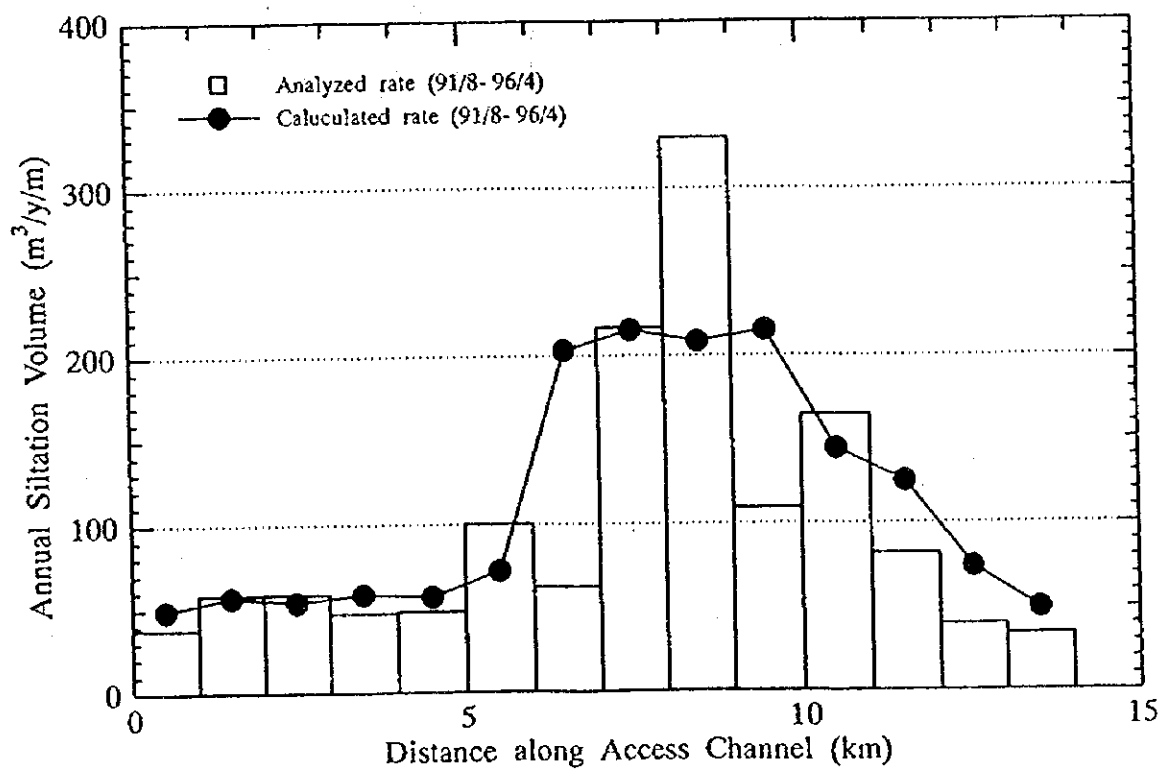


Figure 4.2.2-8 Calculated and Analyzed Annual Siltation Volume
(S-2: 1991/8-1996/4)

2) Predicted Case (Y-0, Y-1, Y-2, Y-3, Y-4, Y-5)

Figure 4.2.2-9 shows calculated annual siltation volumes along the Access Channel of case Y-0. Figure 4.2.2-10 shows calculated siltation rates along the channel of case Y-1, Y-2, Y-3, Y-4 and Y-5. Predicted siltation rates of Sections E6 to E11 are shown in Table 4.2.2-3.

Table 4.2.2-3 Predicted Siltation Volumes of the Access Channel

Case	Depth of channel	Siltation volume E6-E8(*10,000m ³ /y)	Siltation volume E9-E11(*10,000m ³ /y)	Siltation volume E6-E11(*10,000m ³ /y)
Y-0	E6-E8 :8.0 m E9-E11:8.5 m	38.7	99.8	138.5
Y-1	E6-E11 :9.0 m	58.3	108.8	167.2
Y-2	E6-E11 :8.0 m	38.7	90.1	128.8
Y-3	E6-E11 :7.0 m	18.5	70.6	89.1
Y-4	E6-E11 :6.0 m	4.3	52.7	56.0
Y-5	E6-E11 :5.0 m	0.0	36.1	36.1

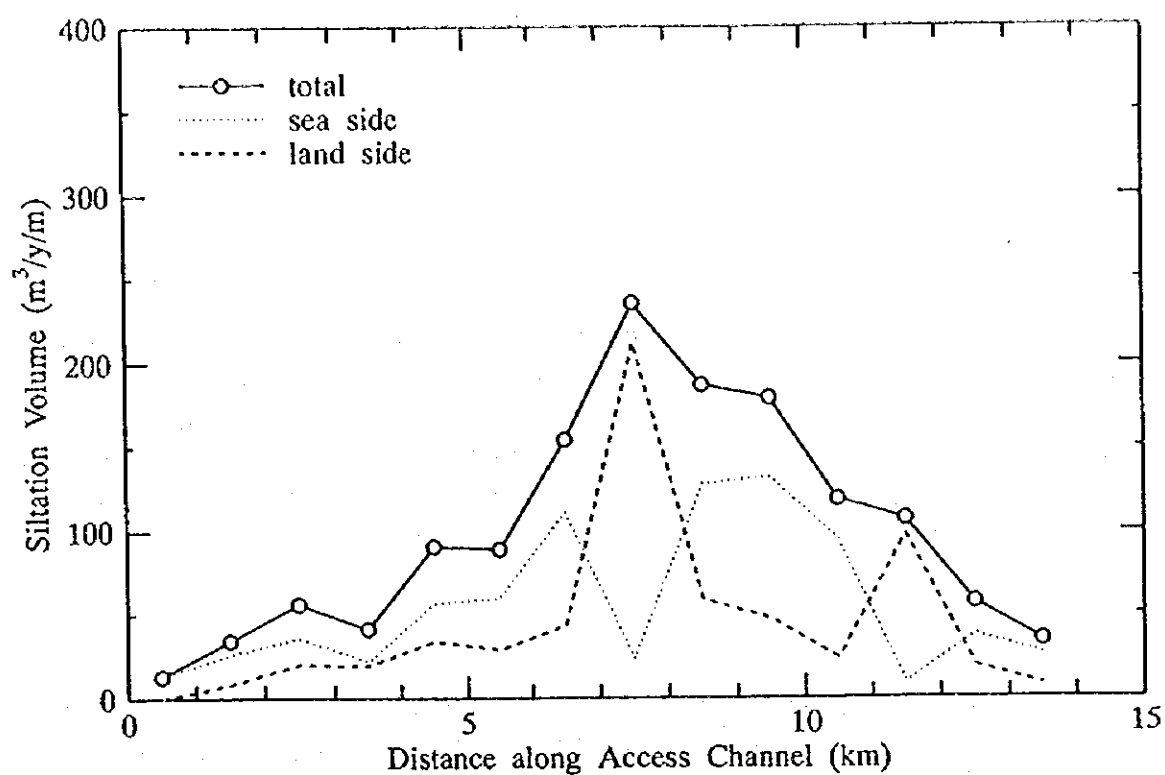


Figure 4.2.2-9 Calculated Annual Siltation Volume (Y-0:h=8.0,8.5m)

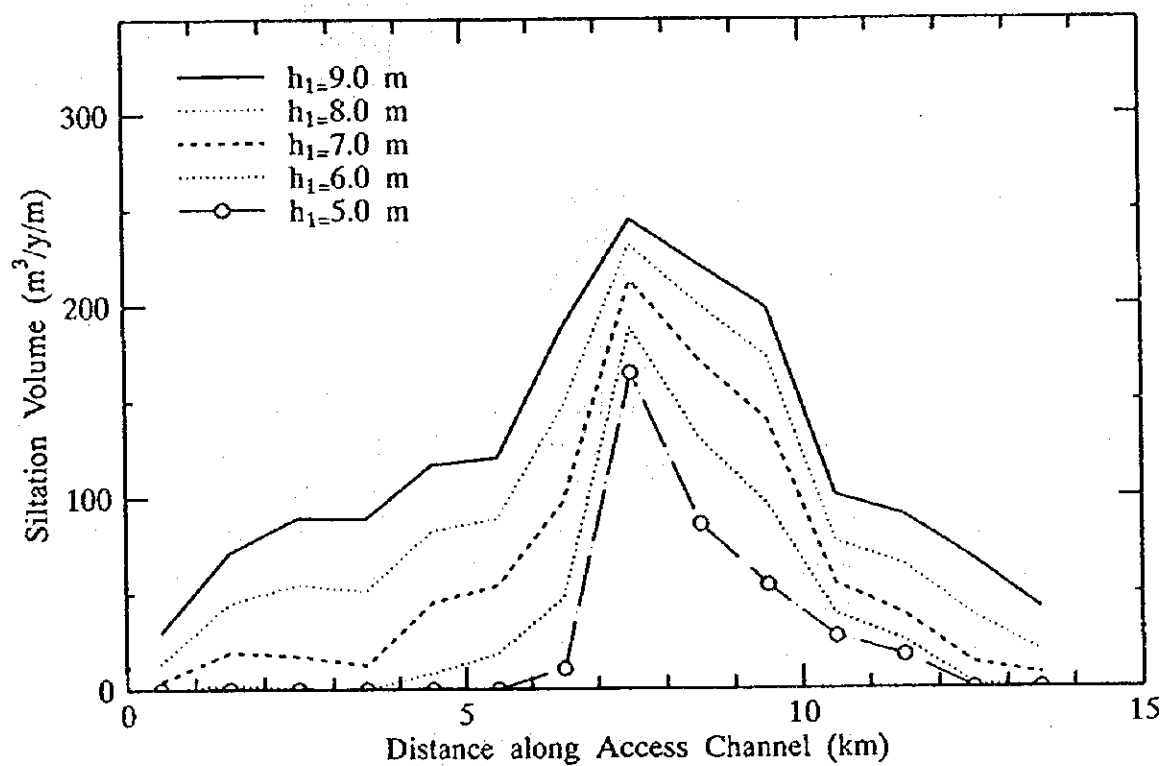


Figure 4.2.2-10 Calculated Annual Siltation Volume
(Y-1 to Y-5: h=9.0 to 5.0m)

4.3 Consideration on Maintenance Dredging Volume

4.3.1 Average Annual Maintenance Dredging Volume

Sections E12 to E14 of the Access Channel showed a very little sedimentation and have kept the channel depth deeper than -8 m below CDL from the second year after the capital dredging, though there was a remarkable seasonal change as described in Chapter 4.1.1. All Sections had a depth allowance of more than one meter against the design water depth at the completion stage of the capital dredging. Consequently, for the annual maintenance dredging volume for the channel of -8 m below CDL in water depth, which is called 8M Channel, it seems that the sedimentation volume of E12+E13+E14 would be able to be subtracted from the total value of 3,735,000 m³ calculated by BCA. That is:

$$3,735,000 - 948,000 = 2,787,000 \text{ m}^3 \quad (4.3.1-1)$$

On the other hand, on the sedimentation between August 1991 and April 1996 in Table 4.1.2-2, the negative value of E4+E5+E15 has been seen to depend on deepening of the area in front of the new oil terminal in 1994. Therefore, if the sedimentation ratio of E4+E5+E15 against E6+E7+E8 between August 1991 and April 1996 is assumed to be the same as that between August 1990 and August 1991 and the volume of dredging conducted in Sections E7 to E11 shown in Table 2.3.3-2 is added, the total annual sedimentation volume in this period is estimated as follows:

$$\begin{aligned} & 1,418,005 + 1,039,595 \times 352,765 / 628,355 \\ & \quad + (126,766 + 49,889 + 453,751) / 4.67 \\ & = 1,418,005 + 583,640 + 132,438 \\ & = 2,136,637 \text{ m}^3 \end{aligned} \quad (4.3.1-2)$$

The volume calculated by Equation (4.3.1-1) would be larger than the expected average annual maintenance volume for 8M Channel because it bases on the sedimentation volume during the first one year after the capital dredging. While, the volume of Equation (4.3.1-2) would be smaller than that because the water depth was shallower than -8 m below CDL in some parts of the Access Channel. After all, the average annual volume necessary to maintain 8M Channel seems to be between 2.2 to 2.7 million m³.

From the above consideration, the average annual maintenance dredging volume has been determined as 2,500,000 m³ which will be used to establish the dredging plan later. The maintenance dredging volume of 2,500,000 m³ was allocated in each section along the Access Channel as shown in Table 4.3.1-1.

In the table, the column by Equation (4.3.1-2) was calculated basing on the sedimentation volume during the period from August 1991 to April 1996 in Table 4.1.2-2 as follows.

- (a) The volume of 583,640 m³ in Equation (4.3.1-2) was divided in E4, E5, and E15 according to the ratio among them during the period from August 1990 to August 1991 in Table 4.1.2-2.
- (b) The average annual dredging volume of 132,438 m³ in Equation (4.3.1-2) was added to each sedimentation volume from E6 to E11 in the period from August 1991 to April 1996 after having been divided into the volume ratio among them.
- (c) As a result, the total volume of E4 to E15 is the same as Equation (4.3.1-2)

The column of Maintenance Dredging Volume has been obtained by adding the difference of 363,363 m³ between 2,500,000 m³ and 2,136,637 m³ to the values of E13 and E14 in the column of Equation (4.3.1-2) according to their ratio.

However, the actual maintenance dredging volume for each year would be expected to change in the order of more or less 50 % owing to the yearly fluctuation of river flow of the Pungue River and cyclones attacking Beira Port.

Table 4.3.1-1 Average Annual Maintenance Dredging Volume

Section	(Volume in m ³)	
	Sedimentation Volume by Equation (4.3.1-2)	Maintenance Dredging Volume
E4	276,146	276,146
E5	120,488	120,488
E15	187,005	187,005
E4+E5+E15	583,640	583,640
E6	113,057	113,057
E7	128,696	128,696
E8	148,823	148,823
E6+E7+E8	390,576	390,576
E9	287,820	287,820
E10	614,958	614,958
E11	101,051	101,051
E9+E10+E11	1,003,829	1,003,829
E12	30,637	30,637
E13	21,943	62,313
E14	106,012	429,005
E12+E13+E14	158,592	521,955
Total	2,136,637	2,500,000

4.3.2 Estimation of Maintenance Volume for Different Channel Depth

The annual sedimentation volumes by different channel depths for Sections E6+E7+E8 and E9+E10+E11 in Table 4.2.2-3 are again tabulated in Table 4.3.2-1 and are plotted in Figure 4.3.2-1.

Table 4.3.2-1 Annual Sedimentation Volume by Channel Depth

Channel Depth (m)	Sedimentation Volume	
	E6+E7+E8 ($\times 10^4 \text{ m}^3$)	E9+E10+E11 ($\times 10^4 \text{ m}^3$)
5	0.0	36.1
6	4.3	51.7
7	18.5	70.6
8	38.7	90.1
9	58.3	108.8
10	77.9	127.5

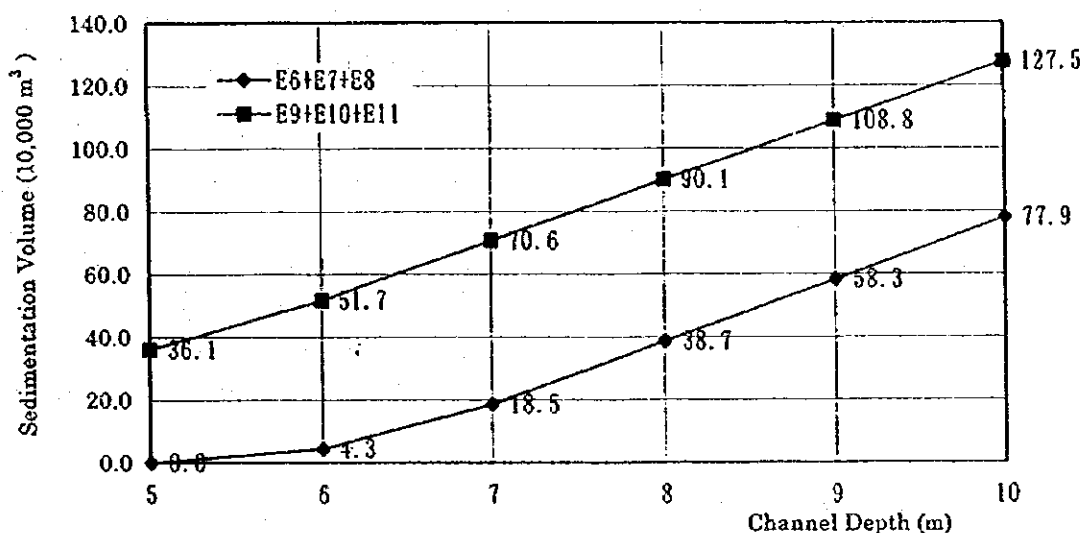


Figure 4.3.2-1 Annual Sedimentation Volume by Channel Depth

Annual sedimentation volumes of different channel depths in each section are calculated to estimate the maintenance dredging volume in the Access Channel. The 8M Channel is set at 8 m deep at Sections E6+E7+E8 and 8.5 m deep at Sections E9+E10+E11, and the 7M Channel is set respectively at 7.0 m and 7.5 m deep. The other channels also are set in the same way, that is, the water depth at E9+E10+E11 is set to be deeper by 0.5 m than that at E6+E7+E8.

Therefore, the annual sedimentation volumes in Sections E6 to E11 become as in Table 4.3.2-2 for each channel depth, in which the ratio is that of the sedimentation volume of each channel against 8M Channel.

Table 4.3.2-2 Annual Sedimentation Volume from E6 to E11 by Channel Depth

Channel	Sedimentation Volume					
	E6+E7+E8			E9+E10+E11		
	Depth (m)	Volume ($\times 10^4 \text{ m}^3$)	Ratio	Depth (m)	Volume ($\times 10^4 \text{ m}^3$)	Ratio
5M	5.0	0	0.000	5.5	43.9	0.441
6M	6.0	4.3	0.111	6.5	61.15	0.615
7M	7.0	18.5	0.478	7.5	80.35	0.808
8M	8.0	38.7	1.000	8.5	99.45	1.000
9M	9.0	58.3	1.506	9.5	118.15	1.188

On the other hand, in the maintenance dredging volume shown in Table 4.3.1-1, the volumes of Sections E6+E7+E8 and E9+E10+E11 are 39.1×10^4 and $100.4 \times 10^4 \text{ m}^3$, respectively, which are nearly equal to those of the 8M Channel in Table 4.3.2-2. It confirms that the annual maintenance volume of $250 \times 10^4 \text{ m}^3$ corresponds to that for the 8M Channel.

Basing on the annual maintenance volume of $250 \times 10^4 \text{ m}^3$ for the 8M Channel, the annual maintenance volumes for other channels are calculated using the ratios described in Table 4.3.2-2 and are shown in Table 4.3.2-3, where Ratio 1 and 2 are ratios of the Sections E6+E7+E8 and E9+E10+E11 against them of the 8M Channel, respectively. The total volume of each channel of the table are illustrated in Figure 4.3.2-2. In the table, the calculation for Sections E4+E5+E15 and E12+E13+E14 was made as follows.

(1) The calculation for E4+E5+E15 was executed using Ratio 1

(2) The calculation for E12+E13+E14 is ;

For the 5M and 6 M Channels:

The volume is zero, because the surrounding water depth is currently deeper than 7m deep.

For the 7M Channel:

Ratio 2 is used.

For the 9M Channel:

Dredging volumes are calculated from the volume of

E9+E10+E11 by the ratio of E12+E13+E14 against E9+E10+E11 of BCA in Table 4.1.2-1, because the depth change for 9M Channel is seemed to be the same as during the first one year after the capital dredging.

Table 4.3.2-3 Maintenance Dredging Volume by Channel Depth

Channel	Maintenance Dredging Volume (m ³)				
	9M	8M	7M	6M	5M
Ratio 1	1.506	1.000	0.478	0.111	0.000
Ratio 2	1.188	1.000	0.808	0.615	0.441
E4	415,876	276,146	131,998	30,652	
E5	181,455	120,488	57,593	13,374	
E15	281,630	187,005	89,388	20,758	
E4+E5+E15	878,962	583,640	278,980	64,784	
E6	170,264	113,057	54,041	12,549	
E7	193,816	128,696	61,517	14,285	
E8	224,127	148,823	71,137	16,519	
E6+E7+E8	588,207	390,576	186,695	43,354	
E9	321,783	287,820	232,559	177,009	126,929
E10	687,523	614,958	496,886	378,199	319,778
E11	112,975	101,051	81,649	62,146	52,547
E9+E10+E11	1,122,281	1,003,829	811,094	617,355	521,991
E12	77,201	30,637	24,755		
E13	317,553	62,313	50,349		
E14	498,582	429,005	346,636		
E12+E13+E14	893,336	521,955	421,740		
Total	3,482,786	2,500,000	1,698,509	725,493	521,991

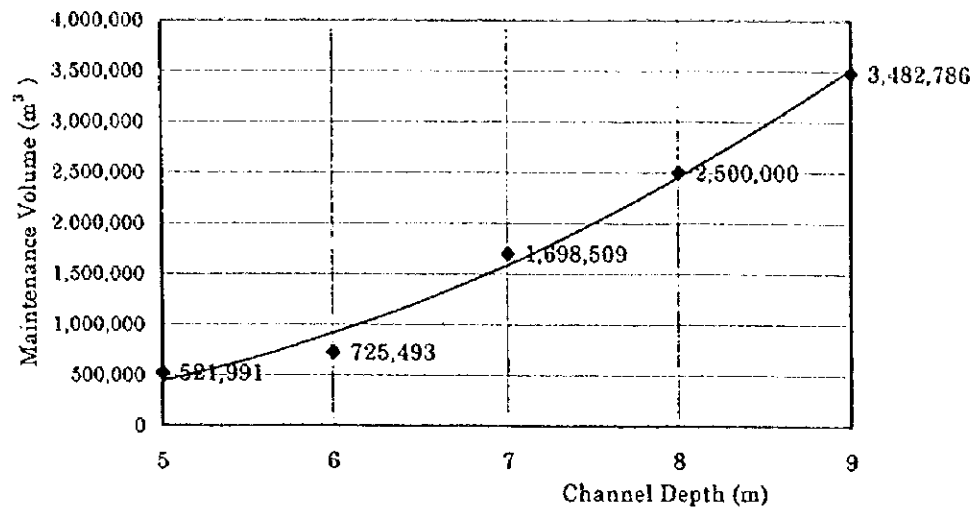


Figure 4.3.2-2 Annual Maintenance Dredging Volume