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MINISTRY OF WATER RESOURCES

BANGLADESH WATER DEVELOPMENT BOARD





# M E S II
# MEGHNA ESTUARY STUDY

TECHNICAL NOTE MES-032

## ANALYSIS OF BATHYMETRIC CHANGES IN THE MEGHNA ESTUARY

June 2001

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DHV CONSULTANTS BV

in association with

DEVCONSULTANTS LTD
SURFACE WATER MODELLING CENTRE

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# 1 INTRODUCTION

The Meghna Estuary is morphologically one of the most dynamic areas in the world. The enormous sediment load brought to the estuary by the Jamuna and Ganges Rivers and very strong flows in the estuary drive the process of a continuous reshaping of the estuary, migration of channels and banks, accretion and erosion.

Morphological development of the Meghna Estuary over the last decades has been analysed by the Meghna Estuary Studies (MES-project). The spatial extent of the study area is shown in Figure 1. The northern boundary is located just below the confluence of the Padma River and the Upper Meghna River, upstream of Chandpur. The southern boundary is drawn south of the islands in the mouth of the distributaries of the Meghna.

In the course of the study, MES carried out an extensive data collection. In 1997 and 2000, full-scale bathymetric surveys of the entire estuary were carried out. Besides these two large-scale surveys, also other small-scale surveys of pilot project areas were executed to monitor the morphological development of the bed and the impact of works. Bathymetric data from the Land Reclamation Project (LRP) from the period 1986 - 1993 LRP is also available.

In this report, changes to the bed forms of the Meghna Estuary are analysed. This is done for two time-scales:

- short-term: recent changes to bathymetry in the period 1997-2000 are analysed; and
- mid-term: changes to selected areas in the period of approximately 10-15 years

Areas of erosion and accretion are identified and movement of channels analysed. Also the change in volume of sediment in the study area is quantified.

Channel between Hatia and Nijhum Dwip in the south of the Meghna Estuary is an area of special interest of the MES project. This area has been chosen as a study location for a pilot project for promoting accretion. The area has been surveyed in detail many times in the past years. In this report, the morphological development of this area during the period 1988-2000 is followed.

# 2 METHODOLOGY

## 2.1 Data collection and processing

In this study, bathymetric data collected by MES in 1997 and 2000 surveys, and earlier data collected by the Land Reclamation Project (LRP) are used. The bed levels collected by the MES-project in 1997 and 2000 are determined by a combined use of echo sounding and RTK (Real Time Kinematics) positioning technology, which makes use of satellite information (GPS). Echo sounding determines the distance from the echo sounder onboard of the survey vessel to the seabed. The RTK positioning defines vertical and horizontal location of the echo sounder. RTK is based on GPS (Global Positioning System, a satellite-based positioning system) and global benchmarks to obtain a good estimate of the vertical position of the echo sounder. Under optimal circumstances, the technique can identify seabed variations of only a few centimetres. In practice, the accuracy of the obtained bed levels is estimated at 40 cm (ref. 2). The bathymetric data of Land Reclamation Project (LRP) is determined using echo sounder and Decca Navigator system for horizontal positioning and a water level gauge installed at the suitable location close to survey area for vertical positioning (ref. 3). No good estimates of accuracy are available, but it can be assumed that this accuracy will generally be less than in the measurements using modern RTK positioning.

Data processing 1997 survey

The data processing for 1997 comprised the following steps:

- Removal of spikes and steps in the field data records especially in echo sounding depth and real time kinematics (RTK) level from WGS84 ellipsoid surface
- Preparation of input files for Geoid model (Gravsoft geoid interpolation and transformation of ellipsoidal height to geoid height in terms of PWD datum)
- Linking of geoid input files
- Datum conversion by geoid model and
- Generation of XYZ (column of easting, northing and bed level) files for surveyed area.

Data processing 2000 survey

The data processing for 2000 consisted globally of the same steps as in 1997. However, methodology had to be adapted due to a bad quality or ever complete lack of RTK level during survey. Water levels from two-dimensional hydrodynamic model of the Meghna Estuary developed by SWMC were used for datum conversion of echo sounding depths. Simulated water levels were corrected using the actual water levels registered in the pressure cells deployed in the estuary during the survey (ref. 4). After conversion, final form of output bathymetric data is in XYZ format, with bed levels relative to PWD datum. The accuracy of obtained bed levels was estimated at 40 cm, same as when RTK positioning would be used.

Figure 2 shows the spatial extent of the 1997 and the 2000 survey that have been compared to analyse bathymetric changes.

Data processing LRP surveys

Data processing or datum conversion of bathymetric data for LRP was simple subtraction of echo sound depth from the gauge reading of water level collected during the survey period. Only data in the chart form as maps with bed level contours relative to PWD were available to MES.

## 2.2 Methods of analysis

### 2.2.1 Bathymetric change (Erosion / Accretion) Maps

For analysis of bathymetric change in the period 1997-2000, the project area has been divided into seven sub areas (see figure 3), which have been analysed separately. For purpose of presentation, an overlap of five kilometers of these areas has been introduced. The morphological change in the Meghna Estuary has been quantified by calculating the difference in bed levels obtained from two surveys. As the data were collected by vessels sailing along lines, and these lines were different during different surveys, a direct comparison of the data is not possible. A standard solution for this type of problems is to convert a scattered dataset to a structured dataset, with data points located on a grid (so-called gridding). The data in grid points are calculated by means of interpolation. The location of each grid point is the same for different datasets, so a direct comparison of these data is possible.

In the present study, bed level data in XYZ format were converted to grid data with a spacing of 250 m by using triangulation with linear interpolation technique of Surfer version 7 (grid-based contouring and 3D surface plotting graphics software). This method of interpolation has been selected after trying different interpolation techniques available in Surfer for a test area (Area 4). The methodology and results of this test are presented in Appendix 1. The grid points located on land have been removed (blanked) from the grid by superimposing land contour derived from satellite image. For the bathymetry of 1997 and 2000, bank lines derived from the 1998 and 2000 Landsat TM image with thirty meters resolution have been used.
LRP maps have been digitised and then gridded using Surfer software.

The bank lines in the Meghna Estuary are extremely movable as a result of erosion and accretion processes. Changes of more than 100 m per year are quite common. Using standard methods of calculation, only the areas, which were submerged both in 1997 and in 2000, would be included in the analysis, and a significant part of information regarding morphological dynamics would have been lost. This is solved by assigning a fake land value to all blanked (i.e. land) points, and then subtracting the grids. As land value, 1 m PWD is used for lower and mid estuary and 2 m PWD for the upper estuary (roughly the high water level), as the actual land level is unknown. It is assumed that the level of accreted land will in general be not much higher than the high water level. When two grids have been subtracted, the level difference in points marked as land in both grids became zero (=no change), while in the points which were submerged during one survey but not in both, either accretion or erosion is calculated. This method, although not very accurate, is considered much better than neglecting the difference.

Bed levels determined in for survey have a limited accuracy (40 cm for 1997 and 2000 survey, 50-100 cm for LRP surveys). In addition, interpolation of data introduces errors. It is estimated that the accuracy of change maps will be limited to approximately 1 m.

Bathymetric changes are quantified by means of change maps. For the generation of recent bathymetric change (erosion/accretion) maps, grids of 1997 have been subtracted from the grids of 2000. Mid-term change maps are generated by subtracting the LRP gridded data from the 2000 data. Bathymetric change is presented in change maps with an interval of 5 meters. To compensate for a limited accuracy of data, the region between -1 meter and +1 meter is considered as "no change".

### 2.2.2 Cross-section analysis

Fourteen cross-sections at different locations have been selected in the estuary (figure 4) to analyse the bathymetric change that occurred in this the 1997-2000 period. These cross-sections are selected as characteristic for areas of special interest. Out of the fourteen cross-sections, data for six cross-sections are taken directly from the bathymetric XYZ files, as these cross-sections were aligned with the survey lines, and rest of the cross-sections' data is extracted from Surfer grids of fifty meters grid spacing. The locations of the fourteen cross-sections are also shown in the bathymetric change maps. The changes to the cross-sections are analysed considering their shape, average and maximum depth, cross-sectional area, width and thalweg position.
For the detailed analysis of Nijhum Dwip area, five cross-sections have been chosen. One of these cross-sections is aligned with the envisaged cross-dam.

### 2.2.3 Volume calculations

The volume of actual erosion and accretion in each sub area within the period 1997-2000 and the volume of net change have been computed by the Surfer version 7 volume calculation method. In this method, the volume above and below a horizontal plane of fixed level (zero meter level) is calculated using trapezoidal integration method. This method has been applied to the change data (difference in bed levels between 2000 and 1997). The computed volume above plane indicates accreted volume and the volume below indicates eroded volume. To produce bathymetric change maps, an overlap between the subareas was introduced. Performing volume calculation on the overlapping subareas would mean that the calculated total change would be different from the actual change in the entire estuary. Therefore, the overlap between the subareas has been removed before calculating volumes.

The same method has been applied to calculate volume changes between the LRP-measured bed levels and 2000-bed levels.

# 3 RESULTS

## 3.1 Recent bathymetric changes

In this chapter, analysis of bathymetric changes in the period 1997-2000 is presented. The analysis is based on change maps and comparison of cross-sections. Each of the selected subareas (see figure 3) is discussed separately. Numerical comparison of hydraulic parameters in all cross-sections is given in Table A-1.

**Area 1 (northern reach of Lower Meghna)**

The bathymetric maps for 1997 and 2000 are presented in figures 5a and 5b. Figure 5c shows the bathymetric change map for this area.

At the level of Chandpur, the main channel moved to the west, causing some erosion of the west bank. However, going more south at the level of section 1 migration of the main conveyance (geometric properties of a channel, which determines the capacity of a channel to convey flow through it) channel towards east can be observed (see figure 5e). The thalweg (the line of maximum depth along a channel) shifted 2.7 km towards east bank. An overall tendency of shallowing can be observed, the area of this cross-section reduced by 26%, and the maximum depth decreased from 14 m to 8 m.

Largest changes are observed at the level of Hanarchar. A large char (Char Bhairabi) developed in the middle stream of the river, deflecting the flow. This char accretes distinctly to the west, towards Gosair Hat. Deep channels are located very close to both riverbanks. River widens, especially on the western side. Western channel moved to the west by 2-2.5 km over a distance of approximately 7 km along the river. Migration of this channel causes extensive erosion. Directly upstream of this zone, the western channel moved away from the west bank. Analysis of cross-sections 1, 2 and 3 (figures 5d and 5e) shows that the main conveyance channel migrates to the east. The cross-sectional area of the section 2 in the western branch decreased by 30%, while the cross-sectional area of the section 3 in the east branch increased by nearly 60%. The conveyance of the east branch, once lateral channel, is now nearly equal to the west branch (cross-sectional area is only 20% less, compared to 74% in 1997). Discharge measurements during 2000 monsoon indicate that approximately 60% of the flow is conveyed through the eastern branch (ref. 7). The thalweg in western branch shifted towards west by 1.7 km, but the depth of main conveyance channel decreased from 20 m in 1997 to 12 m in 2000. Shallow area along Char Bhairabi extended 1.5 km westward. The maximum depth of the eastern branch increased from 11 m in 1997 to 19 m in 2000, and its width increased from 1.3 km to 2.1 km. The thalweg position was in middle of the section in 1997 and shifted about 1 km towards east and is now very close to the riverbank. This also explains the heavy erosion of the river bank itself, which has occurred since then (see ref. 8).

Downstream of Hanarchar, some accretion occurred along the east bank. This is related to the migration of the channel to the west. The same is observed near Ramgati.

Cross-section 4 (figure 5e) is drawn just upstream of the Tetulia off-take. It shows very large change in the bed form. In 1997, one deep channel along the west bank was present. In 2000, three deep channels (along east bank, in the middle and along west bank) can be seen at this location. Erosion of the river bank towards west is observed. The thalweg shifted about 2.5 km eastwards. A moderate increase of cross-sectional area, average and maximum depth is observed.

**Area 2 (middle estuary)**

The bathymetric maps for 1997 and 2000 are presented in figures 6a and 6b. Figure 6c shows the bathymetric change map for this area.

North of Char Gazaria, migration of a deep channel towards Char Alexander is observed. This causes locally a significant erosion of the river bank. Erosion is also found at the upstream head of Char Gazaria. Large, very shallow flats west of Char Gazaria extended to the west. This is associated with the migration of the West Shahbazpur Channel, which moved very close to the bank of Bhola causing erosion of the river bank. Analysis of cross-section 5 (figure 6d) in the West Shahbazpur channel between Bhola and Char Gazaria shows migration of the main channel towards Bhola bank and accretion in the middle. The width of this section increased by 10% between 1997 and 2000. The maximum depth increased from 14 m to 18 m. The cross-sectional area increased by 17 percent. The thalweg position has shifted about 1.7 km to the south west. Cross-section 6 (figure 6d) in the East Shahbazpur channel between Char Gazaria and Char Alexander has undergone a very large change. Massive erosion on the Char Gazaria side can be seen. The maximum depth increased from 9m in 1997 to over 20m in 2000, and the width increased by 1.5 km. The cross-sectional area increased by 34%. The thalweg moved approximately 6.5 km south west direction. The ratio of cross-sectional area between the cross-sections on west and east side of Char Gazaria decreased from 40% to 20%, which shows the growing importance of the eastern channel. This also has resulted in heavy erosion of the river banks (see ref. 8).

Largest morphological change in this area is related to the migration of the Hatia Channel. At the level of North Hatia, extensive accretion is observed on the southern side (Noakhali mainland/ Boya Char), reducing the depth of the channel and forcing the main water flow towards the northern head of Hatia. This results in the migration and strong deepening of the Hatia Channel, and large-scale erosion of the head of the island. This can be clearly seen in cross-section 7 (figure 6d). In 1997, this section had a regular shape. The maximum depth was 11 m over most of its width. In 2000, a very deep channel (maximum depth 20 m) close to the bank of Hatia can be seen. Although the total width of the cross-section increased from 5.5 km to 6 km, most of the area is relatively shallow. The width of the main conveyance channel decreased from approximately 5 km to 2 km. The cross-sectional area increased by 16%. As this is combined with a spectacular increase in depth, the conveyance (transporting capacity) of this cross-section increased considerably. The thalweg shifted 2.4 km towards south-west. The increasing transport capacity of the Hatia channel is also in line with the increasing importance of the eastern channel along Char Gazaria.

**Area 3 (Hatia-Manpura)**

The bathymetric maps for 1997 and 2000 are presented in figures 7a and 7b. Figure 7c shows the bathymetric change map for this area.

Compared to Area 1 and 2, this area remained reasonably stable during the period 1997-2000. Erosion at the entrance to the West Shabhazpur Channel, between Bhola and Sonar Char can be seen. Alternating pattern of erosion and accretion in the longitudinal direction can be seen in the West Shabhazpur Channel between Hatia and Manpura. This is related to migration of the main conveyance channel. This can also be seen in figure 7d which shows cross-section 8 in the West Shahbazpur Channel. A pattern of transversal shifts of deep channels can be seen. The deepest part of the channel at the Bhola side shifted away from the bank, without changing its depth, while on the Manpura side the channel deepened from 12 to 14 m and moved closer to the river bank, causing erosion. Average depth of this cross-section decreased by 17%. This caused a decrease of cross-sectional area by 16%. The thalweg remained in the same position.

Accretion west / north west of Nijhum Dwip, and between Hatia and Nijhum Dwip occurred. Also accretion is observed around chars between Hatia and Manpura. This contributes to the overall shallowing of the East Shahbazpur Channel. In figure 7d, cross-section 9 in the East Shahbazpur Channel is presented. A bar at its west side, present in 1997, disappeared. A bar at the east side came up, with its top rising from –3 m PWD in 1997 to less than –2 m PWD in 2000. The main conveyance channel is located along Hatia. Its maximum depth remained unchanged. The cross-sectional area decreased by 10%. The thalweg shifted approximately 0.5 km towards Hatia. Cross-section 10 in a channel between Nijhum Dwip and Hatia illustrates the on-going process of shallowing of this channel. The width of this section decreased by 3 percent during the considered period but the cross-sectional area decreased by 93 percent. Maximum depth decreased from 4.8 m in 1997 to 3.2 m in 2000. The thalweg shifted by 300 meters towards Hatia.

**Area 4 (Urirchar-Sandwip)**

The bathymetric maps for 1997 and 2000 are presented in figures 8a and 8b. Figure 8c shows the bathymetric change map for this area. Due to a limited coverage during 1997 survey, the analysis is limited to only a small part of the total area. The areas left out are mostly very shallow and difficult for survey vessels to operate.

Vast accretion is observed at the northern head of Sandwip. Also some accretion is found along eastern bank of Sandwip, and between Sandwip and Char Piya. A narrow, deep channel along the west bank of Sandwip shows a tendency to migrate towards east, causing some erosion. A cross-section in the Sandwip Channel north of Urir Char (cross-section 11 in figure 8d) is available for analysis. A distinct tendency of migration towards Noakhali mainland can be seen. No significant change of the average depth is observed. The cross-sectional area decreased by 10%, which confirms the observation that the northern part of the Sandwip Channel tends to silt up.

**Area 5 (South-east)**

The bathymetric maps for 1997 and 2000 are presented in figures 9a and 9b. Figure 9c shows the bathymetric change map for this area. Also here, the analysis is limited to only a small part of the total area, as the shallow areas were not surveyed, and the south east part was not surveyed in 2000.
In this area, south of Sandwip and east of Hatia, no large bathymetric changes are found. Shallow areas north-east of Hatia extended to the east causing migration of the Hatia Channel to the north at the level of island's northern head, and to the east in the southern course of the channel. In figure 9d, a cross-section between Hatia and Char Piya is presented. Due to lack of data from 1997, it is not possible to show the change in the area close to Hatia. Erosion close to Char Piya due to migration of West Hatia Channel towards northwest and accretion in the south west part can be seen. The cross-sectional area, average depth and maximum depth increased by approximately 20%. The thalweg line remained at the same position the considered period.

**Area 6 (South-West)**

The bathymetric maps for 1997 and 2000 are presented in figures 10a and 10b. Figure 10c shows the bathymetric change map for this area. No comparison is possible for shallow areas in the west and east / north east of the area.

The area south of Char Montaz and Rangabali is very dynamic. Distinct bed forms have developed by the combined forces of waves, tidal flow and river flow. These bed forms are very movable. Deposition processes clearly exceed erosion processes.
In figure 10d, cross-section 13 is depicted. This cross-section is drawn between char Kukri Mukri to char Dhal in the southwest part of the estuary. No significant changes to this section are observed.

**Area 7 (Sandwip Channel)**

The bathymetric maps for 1997 and 2000 are presented in figures 11a and 11b. Figure 11c shows the bathymetric change map for this area.

Figure 11c shows that the northern part of the Sandwip Channel silts up. In the south of this channel, erosion is found. No patterns of migrating channels can be distinguished. Cross-section 14 in the Sandwip Channel (figure 11d) shows some accretion along both banks. No significant changes are observed.

### 3.2 Mid-term bathymetric changes

Four areas have been chosen for comparison of bathymetric changes over the period of approximately 10 years, utilising data of MES and LRP. The selected areas are:
East and West Shabhazpur Channel between Hatia and Bhola (comparison of 1987 and 2000 bed levels)

- Nijhum Dwip-Damar Char area (comparison of 1988 and 2000 bed levels)
- mid-estuary north of Char Gazaria (comparison of 1986 and 2000 bed levels)
- Sandwip Channel north of Urir Char (comparison of 1990 and 2000 bed levels)

Again, a series of 3 figures for each location is prepared. Figures denoted (a) show the bathymetry based on LRP data, figure denoted (b) show the 2000 bathymetry, and figures denoted (c) show the change map.

In figure 12c the morphological development of the West and East Shabhazpur Channel between Hatia and Bhola in the period 1987-2000 is presented. Generally, accretion in the East Shabhazpur Channel dominates, with bed level changes of more than 5m. In the west of this channel, large zone of erosion is found, suggesting that the deep section of the channel shifted from east to west. Only a small part of the West Shabhazpur Channel is covered by the LRP survey. Erosion of the east part of this channel with bed level changes of more than 5 m can be seen. Narrow zones of accretion along the Hatia bank, and also along the west bank of Manpura are considered to be an artefact caused by poor conversion from Decca to BTM coordinates, as according to satellite images, a retreat of these bank lines was observed.

Changes to the area Nijhum Dwip – Damar Char in the period 1988-2000 are depicted in figure 13c. Extensive accretion in the Nijhum Dwip channel can be seen. In particular, the western entrance to the channel and the eastern part accreted by more than 5 m. Erosion is found at the northeast of the channel. This agrees with the data from the satellite images. Between Nijhum Dwip and Damar Char, erosion is found along the eastern bank of Nijhum Dwip, which changes to accretion towards Damar Char. This indicates migration of the tidal channel towards west.

Figure 14c shows the bathymetric change in the Shabhazpur Channel north of Char Gazaria in the period 1986-2000. A longitudinal pattern of accretion in the west and erosion in the east indicates that the main conveyance channel moved towards the east bank. Once very deep western part is now very shallow, with bed levels not lower than –2m PWD. Zones of extreme erosion between Bhola and Char Gazaria, and near Char Alexander are clearly visible. Also the retreat of northern head of Char Gazaria can be observed.

Figure 15c shows the change map for the area in around Urir Char and Char Pir Baksh in the period 1990-2000. Very large movements of the bank lines occurred in this area, and the surveys give only a very fragmentary spatial coverage, therefore it has not been possible to produce a comprehensive change map. Accretion area west and north of Urir Char is associated with the migration of this island. Also a migration of the Sandwip Channel north and east of Urir Char is clearly visible. The shift of the channel towards Noakhali mainland amounts to about 1.5-2 km. Large erosion areas can be seen in the north-east of the Sandwip Channel.

### 3.3 Changes in the Nijhum Dwip pilot project area

For the detailed analysis of the Nijhum Dwip pilot project area, the following bathymetric data have been used:

- LRP map of 1988
- MES data of March 1997
- MES data of July 1999
- MES data of June 2000
- MES data of November 2000

The LRP map is based on cross-sections with spacing of approximately 1000 m. MES data have a much higher resolution; they been collected using line spacing of 100-200 m.

Analysis is based on a global comparison of bathymetric maps, and on a comparison of changes to the shape and hydraulic parameters (area and average depth) in the selected cross-sections.

<u>Period 1988 - 1997</u>
Comparison of LRP map of 1988 (Figure 16) with the map of 1997 (Figure 17) shows that a very large change in the bathymetry occurred in this period. Figure 16 shows a rather shallow, funnel-shaped channel becoming deeper and narrower towards east. In Figure 17, a large char in the western entrance to the channel can be seen. A considerable change in the position of the banks can be seen, particularly in the east of the area. Both banks shifted towards north. A deep gully (deepest section below -10 m PWD) developed on the Hatia side. This is clearly related to the constriction of the flow due to narrowing of this part of the channel. Deepening occurred also in the west, on the Nijhum Dwip side of the new char. This process can also be seen in the change map (Figure 21). The migration of the channel can be seen in the cross-sections (Figures 25 and 26). Cross-sectional area in sections 2 and 3 (mid part of the channel) increased in this period1Xthis period by 40% due to an increase in depth (Table A-2). The alignment of the envisaged cross-dam is close to cross-section no. 2 (Figure 26). In this location, the channel is very shallow. In 1988, bed level in the deepest part was about 2.5 m below PWD. In 1997, development of a char (still below MSL) can be seen. Depth increased significantly, in particular on the Nijhum Dwip side, the bed level decreased to over 4.5 m below PWD. Cross-sectional area in the remaining cross-sections, closer to the both entrances to the channel, increased. In cross-sections 3 to 5 in the east part of the channel, accretion of the south bank and resulting migration of the bank can be seen. This bank moved by more than 500 m to the north.

<u>Period 1997 - 1999</u>
Bathymetry of 1997 and 1999 is presented in Figures 17 and 18, respectively. The change map for this period is given in Figure 22. Large accretion can be seen along the Nijhum Dwip side of the channel. At the east side, a deep gully continues to migrate towards north, eroding the bank of Hatia. This can be clearly seen in cross-sections 4 and 5 (Figures 25 and 26). The migration of the banks in these sections is about 50-100 m/year. Compared to 1988, the cross-sectional area in these sections decreased by 30% and 55%, respectively (Table A-2).
The considered period 1997-1999 comprises heavy 1998 monsoon, associated with high sediment discharge from the river system and extreme erosion in the upper estuary. This sediment is clearly deposited in the southern area, including Nijhum Dwip Channel.

<u>Period July 1999 - June 2000</u>
Bathymetry of 1999 and June 2000 is presented in Figures 18 and 19, respectively. The change map for this period is given in Figure 23.
The char in the west of the channel extended further towards east, and the channels on both sides of this char silted up. This can be clearly seen in cross-sections 1 and 2. The area of cross-section 1 in 1999 was reduced by 50% compared to 1988. The gully at the tip of the char deepened. The trend of erosion of Hatia bank reversed in the western part of the channel, where accretion of this bank is observed. In all cross-sections, silting up of the channel can be seen. In the east, migration towards

north associated with accretion of Nijhum Dwip bank and erosion of Hatia bank continued. Similar to the western entrance to the channel, the area of cross-section 5 reduced by 50% compared to 1988. The depth of the deep gully along Hatia bank in the east of the channel slightly decreased.

Period June - November 2000

Bathymetry of June 2000 (pre-monsoon) and November 2000 (post-monsoon) is presented in Figures 19 and 20, respectively. The change map for this period is given in Figure 24. These figures illustrate the changes that occur during the monsoon period. In general, accretion occurred in the whole area. The char in the western entrance to the channel continued to grow and extended eastward. At the tip of this char, some deepening of the gully can be seen. Area of cross-sections 1, 4 and 5 (at both ends of the channel and in the constriction area) continued to decrease, and was reduced to 50-60% of the value in 1988. The strong reduction in the depth during the monsoon period is most probably related to high sediment load from the river system during this period.

The changes to cross-sectional area and average depth in cross-sections are presented graphically in Figure 27. It can be concluded that the cross-sectional area in the west (sections 1 and 2) decreased between 1988 and 1997, and increased since 1997. The area of cross-sections 3, 4 and (middle and east side) shows a nearly continuous decrease, indicating that the channel gradually silts up from east. The average depth in cross-sections 1 to 4 increased till 1997, and decreased strongly since that year. The average depth in cross-section 5, at the eastern entrance to the channel, decreased nearly continuously during the considered period. Cross-sectional area and average depth in all sections in 2000 were less than in 1988. Some seasonal influences can also be seen: most of the deposition takes place during or directly after monsoon, and the deposited sediments are partly eroded by tidal currents during dry period. The number of observations is, however, too low to ascertain this conclusion.

### 3.4 Changes in sediment volume

For the long-term development of the coastal area it is of utmost importance to know how large portion of the fluvial and marine inflow of sediment is retained in the Lower Meghna Estuary area. These net quantities are relatively small compared to the total quantities transported.
Part of the sediment carried by the flow can be deposited in the channels and on the tidal mud flats, mangroves and salt marshes, in this way reducing depth; on the other hand erosion of the bottom can also develop, with sediment being picked up and transported.

Available bathymetric data have been used to calculate the change in sediment volume. The whole area of the Meghna Estuary has been divided into 7 areas (see Figure 3). In each area, the volume of sediment, accreted and eroded between 1997 and 2000 has been calculated. The calculations are based upon interpolated depth values using 250x250 m grid squares. The results are shown in Table 2. It appears that in the considered period accreting processes have been more dominant than the erosive processes. Calculated net accretion amounts to approximately 306 millions $m^3$ during three years. The net change is small compared to the actual erosion and accretion volumes: it is about 6% of the total erosion and also 6% of the total accretion. This indicates large dynamics of the estuary, with large displacements of deep channels. The largest erosion is found in the northern part of the estuary (Area 1) and in the middle estuary (Area 2). In these areas also large-scale morphological changes, characteristic for a braided river, are observed: river widens, chars develop in the main reach of the river, deep channels develop along the banks causing extensive erosion. In the southern and north-eastern part of the estuary, accretion dominates: in Area 3 (area between Bhola and Hatia), Area 4 (area between Urir Char, Sandwip and Noakhali mainland) and in south-west (Area 6) accretion distinctly exceeds erosion. In the area east of Sandwip (Area 7) no significant change is observed. In Area 5 (south-east of the estuary), no significant change was found. However, large shallow areas between Hatia and Sandwip were not extensively surveyed due to insufficient water depth, therefore the accretion in that area is probably underestimated.

Period 1997-2000 includes the 1998 monsoon, which was associated with severe floods of duration longer than normal. High flow velocities in the river distributary system may be the reason of high erosion in these areas. The net accretion in three years is calculated at 306 million cubic meter, which is approximately 100 million cubic meter per year. The total sediment discharge per year is estimated on 1 to 1.5 billion cubic meter per year (see ref. 9) this means that the trapping capacity of the estuary of sediment is very low six to ten percent only.

**Table 1: Short-term Net Accretion Rate in the Meghna Estuary**

| Area | Accretion $[10^6\ m^3]$ | Erosion $[10^6\ m^3]$ | Total area $[km^2]$ | Net change $[10^6\ m^3]$ | Net change [m/yr] |
|---|---|---|---|---|---|
| Area 1 (north) | 1.055 | 1.198 | 448 | -143 | -0.11 |
| Area 2 (middle) | 1.279 | 1.537 | 749 | -259 | -0.12 |
| Area 3 (Hatia-Manpura) | 884 | 628 | 953 | 256 | 0.09 |
| Area 4 (Urir Char-Sandwip) | 581 | 286 | 473 | 295 | 0.21 |
| Area 5 (South-east) | 596 | 612 | 931 | -16 | -0.01 |
| Area 6 (South-West) | 767 | 585 | 933 | 182 | 0.07 |
| Area 7 (Sandwip Channel) | 263 | 272 | 399 | -9 | -0.01 |
| Total | 5.426 | 5.120 | 4.885 | 306 | 0.02 |

Hydrographic surveys of 1997 and 2000 give a good coverage of most of the study area, yet a 3 years period is rather short for analysis of morphological development. Earlier bathymetric data of LRP, available for four selected areas have therefore been used to analyse sediment budget over the period of more than 10 years. The results of calculations for shorter periods (3-4 years) in Table 1 are consistent with the calculations over a period of over 10 years, and agree with the values in Table 2. All selected areas except for area North Bhola – Char Gazaria show a distinct long-term trend of sedimentation. Net change is small compared to the total amount of erosion and accretion.

**Table 2: Long term Net Accretion Rate in Four Selected Areas**

| Area (....) = negative value | Period | Accretion $[10^6\ m^3]$ | Erosion $[10^6\ m^3]$ | Total area $[km^2]$ | Net change [m/yr] |
|---|---|---|---|---|---|
| North Bhola – Char Gazaria | 1986 – 1992 1) | 131 | 272 | 68 | (0.4 - 0.3) |
| | 1986 – 2000 | 599 | 651 | 253 | (0.1 - 0 ) |
| Manpura – South Hatia | 1987 – 1997 | 197 | 115 | 139 | 0 - 0.1 |
| | 1987 – 2000 | 235 | 168 | 157 | 0 - 0.1 |
| Nijhum Dwip – Damar Char | 1988 - 1993 1) | 41 | 22 | 33 | 0.1 - 0.2 |
| | 1990 –1993 | 32 | 12 | 28 | 0.1 - 0.3 |
| | 1988 – 2000 | 50 | 34 | 31 | 0 - 0.1 |
| Urir Char – Char Balua | 1990 -1994 1) | 302 | 157 | 247 | 0.1 - 0.2 |

1) Results of volume calculations from (ref. 1)

The change in the bathymetry of Urir Char area between 1990 and 2000 has been so large that a reliable volume calculation is not possible. Urir Char has extended to the north with about two kilometers while a new channel developed north of it.

**Table 3: Net Accretion Rate in the Nijhum Dwip Channel**

| Period | Accretion $[10^6\ m^3]$ | Erosion $[10^6\ m^3]$ | Total area $[km^2]$ | Net change [m/yr] |
|---|---|---|---|---|
| 1988 – 1997 | 12.1 | 13.3 | -1.2 | -0.1 |
| 1997 - 1999 | 8.9 | 4.9 | 4.1 | 0.5 |
| 1999 - 2000 | 9.2 | 2.2 | 7.0 | 0.8 |

Table 3 shows the changes to the sediment volume in the Nijhum Dwip Channel. These changes have been calculated from detailed bathymetric maps of this pilot project area. The results in Table 3 fully agree with the analysis of cross-sections described Chapter 3.3. In the period 1988-1997, a very small net erosion occurred in the channel. Recently, significant accretion is observed. It seems to be a lasting trend. It is not clear when the trend reversed from almost stable to accretion. The quality of 1993 bathymetric chart of LRP was found to be too poor for a detailed analysis.

# 4 CONCLUSIONS AND RECOMMENDATIONS

Comparison of results of bathymetric surveys from 1997 and 2000 shows that deposition processes in the study area exceed erosion processes. Largest erosion is found in the upper reach of the estuary, in the Lower Meghna between Chandpur and Char Gazaria. There, river widens, chars appear in the middle of the river section. Flow in these areas is deflected towards the banks, which suffer severe erosion as the deep channels come very close to bank. A dominant erosion trend at North-Hatia and North-Bhola is observed. An overall sedimentation trend can be seen near the edge of the delta front where new island and intertidal areas are. The morphology of the Upper Tetulia River is relatively stable compared to the Lower Meghna Estuary. Alternate erosion and sedimentation patterns along the Lower Meghna River, in particular in the area between Chandpur and north-Bhola, might indicate that the channel is very mobile and sensitive to river discharge and tidal conditions. The East-Shahbazpur Channel is, compared to the West-Shahbazpur Channel, relatively stable. In both channels a tendency of silting up, associated with development of deep channels along the bank can be seen. Similar development is observed in the North-Hatia Channel. The Sandwip Channel east of the Sandwip Island remains quite stable, but north of Urir Char it continues to migrate northwards. A slight tendency of silting up in the northern part and erosion in the southern part is observed. On the west side of Sandwip, a deep, narrow channel causes erosion of the west bank. The east side and southeast side of Hatia tend to silt up slowly. Sedimentation is dominant in the shallow areas around Nijhum Dwip and the area around Rangabali - Kukri Mukri. Excessive sedimentation and forming of large mudflats and new land south of Noakhali mainland is observed.

Detailed analysis of the pilot project area Nijhum Dwip shows that it was experiencing some erosion in the early 90's but in recent years, a very distinct trend of accretion is observed in the Nijhum Dwip Channel. The cross-sectional area near both ends of this channel decreased in 2000 by 50-60% compared to 1988, and the channel is silting up rapidly. Still some erosion on the Hatia side is observed in the astern part of the channel.

Analysis of change in sediment volume in the study area over the period 1997-2000 indicates that the deposition processes exceed the erosion processes. Net accretion during this 3-year period amounts to approximately 300 million $m^3$. However, the net change in the sediment volume is small (about 6%) compared to the total accretion and erosion. Erosion dominates in the northern part of the river system. Erosion in the Lower Meghna from the northern end down to northern head of Hatia is about 0.1 - 0.2 m/yr. High rate of accretion (approximately 0.2 m/yr) is found in the northeast of the estuary, between Noakhali mainland, Urir Char and Sandwip. Also the area between Bhola and Hatia, and the south-west end of the estuary are accreting, with an accretion rate of 0 - 0.1 m/yr. In other areas in the estuary, erosive and depositing processes are more or less in balance. Recent bathymetric data shows that the Nijhum Dwip Channel silts up steadily, with a net accretion rate of 0.5-0.8 m/yr.

## Recommendations

It is recommended to continue full-scale surveys of the whole estuary. Fixed cross-sections should be defined, and echosouned at regular intervals. In general, one cross-section does not give sufficient information about the area. Is therefore recommended to determine depths along 3 lines spaced 100 m from each other. To avoid interpolation errors, cross-sections should be taken along surveyed lines. Wherever possible, new cross-sections should be aligned with the LRP cross-sections. Information from the LRP cross-sections should be included in the analysis to obtain longer timeseries.

Migration of channels should be followed. This can be done by keeping track of the thalweg position. Cross-sections in the Lower Meghna should be drawn every 2 km, and the position of deepest point determined. Positions of these points should be drawn on a map to visualise the thalweg. Sometimes also a secondary channel in a cross-section will be found (e.g., north of Char Gazaria, where the Shabhazpur Channel splits in the west and the east part). In that case, deepest points in two channels in a cross-section should be marked and included in the analysis.

For the analyses of morphological development, the 2000 bathymetry can be taken as reference, as it has a nearly complete coverage of the area. New bathymetric information can be compared with the reference situation.

Changes in sediment volume should be calculated. Each time, the same areas should be compared. If this is done on a yearly basis, it should be possible to link the observed changes to the intensity of the monsoon discharge in a particular year.

Future analyses of bathymetric changes should comprise the following activities:

- analysis of change maps (change between bathymetries from two subsequential surveys, change between the reference bathymetry and the newest bathymetry)
- analysis of channel migration for predicting purpose of erosive attack on river banks
- analysis of cross-sections; this should include analysis of the form, and of the following parameters: cross-sectional area, average and maximum depth, thalweg position
- calculation of change in sediment volume.

## 5 REFERENCES

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5. Burrough P.A., McDonnel R.A.: Principles of geographical information systems. Oxford University Press, 1998
6. Doug Keckler, 1997, Surfer for Windows; Users Guide, Golden Software, Golden USA
7. Meghna Estuary Study, Float tracking and ADCP measurements 2000 monsoon; Technical Note MES-0030, June 2001
8. Meghna Estuary Study, Analysis of Shoreline Changes in the Meghna Estuary; Technical Note MES-0031, June 2001
9. Meghna Estuary Study, June 2001, Hydro-Morphological Dynamics of Meghna Estuary

# APPENDIX 1. Choice of interpolation technique

## 1. Interpolation techniques

Interpolation is the prediction of values of unsampled points within the range of sampled locations. This means that no prediction will be made outside the spatial extent of the sample locations. Many different interpolation techniques exist. The following techniques have been tried within the scope of this research:

- Block kriging
- Minimum curvature
- Linear interpolation

### 1.1 Kriging

Kriging is an exact optimal interpolation method. Optimal in the sense that that the variance at the unsampled location is minimal. Exact in the sense that the grid value at a sampled location is the same as the value for the sample.
Basic assumption is that the spatial variation Z can be divided in three components:

$$Z(x) = m(x) + \gamma(h) + \varepsilon''$$

Deterministic variation that can be modelled separately m(x). Spatially correlated variance, which is physically difficult to explain, the semi variance $\gamma(h)$ and noise $\varepsilon''$, spatially uncorrected variance.

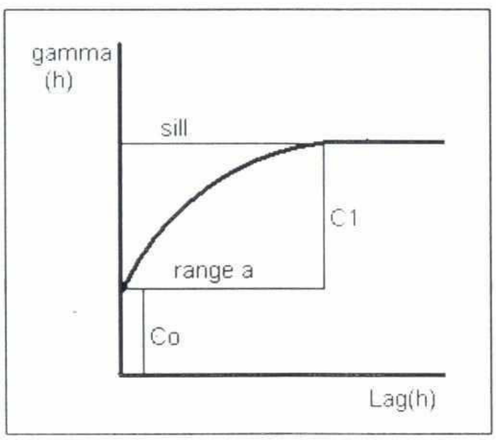
Restriction for the use of kriging is the intrinsic hypotheses consisting of two parts:

1. Stationarity of difference: The average and variance are constant over the location and the support
2. Variance of difference: The semi variance is only depending on distance

The value of the semi variance can be determined in the following way:

$$\lambda(h) = \frac{1}{2n}\sum_{i=1}^{n}\{z(x_i) - z(x_i + h)\}^2$$

The semi variance plotted against distance is called an experimental semi variogram.



**The semi variogram**

The semi variogram is built up from three components, see above:
The cross point with the y-axes is called the nugget. This indicates the amount of noise. The value of the semi variance where no more increase is found with a increasing distance is called the sill. The distance at which this occurs is called the range. The range of the model gives the spatial length over which spatial correlation is present. Modelling the variogram is very important because the influence on the resulting grid is great. Use of default values is no good practice.

1.2 Ordinary point kriging

The variogram can be used to determine the weight factors $\lambda_i$ for the local interpolation using:

$$\hat{z}(x)_0 = \sum_{i=1}^{n} \lambda_i * z(x_i)$$

This is done by solving the matrix form of the next equation:

$$\sum_{i=1}^{n} \lambda_i * \gamma(x_i, x_j) + \varphi = \lambda(x_i, x_0) \text{ for all j}$$

in which

| | |
|---|---|
| $z(x_0)$ | = Attribute value at unsampled point |
| $\lambda_i$ | = Weighting factor |
| $\gamma(x_i, x_0)$ | =Semi variance between sampled and unsampled location |
| $\gamma(x_i, x_j)$ | =Semi variance between two measured points |

In this way the variance at the unsampled location is minimal. For a detailed description of the matrix calculations, refer to Burrough en McDonnell (1998).
With ordinary point kriging no extra information is being used. The variogram is made using points in all directions (isotropic).

1.3 Ordinary block kriging.

Using ordinary block kriging the predicted value is related to the value if the support. The support is the physical extent of the sample that has been analysed. A small support can lead to a grid containing many spikes. The cause for which is the large noise of many natural phenomena. Block kriging is a way to resolve this problem. The kriging equations are modified in such a way that the predictions are being made for a support of an extent can be determined. The variance of the prediction also becomes smaller, because the variance within the block is subtracted from the value generated by ordinary point kriging. Block kriging can always be combined with other methods.

1.4 Anisotropic kriging

Using anisotropic kriging, the semi variogram is modelled looking more or less in one direction. This is particularly useful in a surface that has longitudinal features like scour

holes. The variance will be much larger in one direction than in the other, so the semi variogram will also be much different for the directions along and perpendicular to the scour hole.
When the predictions are being made, again only points from an ellipsoidal search radius will be used (Burrough en McDonnell (1998)).
In Surfer, a graphical software package that also contains options for interpolation, it is however not possible to model the semi variogram for the different directions. The search radius is ellipsoidal so the effect of the anisotropy can be seen in the interpretation, but the kriging is not performed properly.

### 1.5 Minimum curvature

The interpolated curvature from minimum curvature is analogous to a thin, linearly elastic plate passing through each of the data values as closely as possible. This generates as smooth a surface as possible, but it is not an exact interpolator (ref. 4).
Minimum curvature produces a grid by repeatedly applying an equation over the grid, attempting to smooth the grid. The grid nodes are recalculated until the successive changes in the values are below a specified value.
It is not possible in Surfer to specify a direction for this gridding method.

### 1.6 Triangulation with linear interpolation

The triangulation method in Surfer uses the optimal Delauney triangulation. The algorithm creates triangles by drawing lines between data points. The original data points are connected in such a way that no triangle edges are intersected by other triangles. The result is a patchwork of triangular faces over the extent of the grid. This method is an exact interpolator (ref. 4).
Each triangle defines a plane over the grid nodes lying within the triangle, with the tilt and elevation of the triangle defined by the three original data points defining the triangle. All grid nodes within a given triangle are defined by the triangular surface. Because the original data points are used to define the triangles, the data is closely honoured. Triangulation works best when the data are evenly distributed over the area. Sparse data results in distinct triangular features.
Both anisotropy and direction can be specified using this gridding method.

### 1.7 Choice of best interpolation method

In order to choose the best interpolation method the following steps have been taken. A sub sample of the estuary has been chosen to perform different interpolation techniques. The area around Urirchar in the east of the estuary has been taken, because this was known to be a difficult area. The survey lines were less than 600 m. apart in this area and cell length of the grid was 250 m, because the whole MES area has to be gridded with this cell length. So in order to limit computational and storage capacity demands a rather large cell size has been chosen.

The following gridding methods and options were tried:

| | |
|---|---|
| Block kriging | No anisotropy |
| | Anisotropic: ratio1.5, angle 45 degrees |
| | Anisotropic: ratio1.5 , angle -45 degrees |
| Triangulation | No anisotropy |
| | anisotropic: ratio 1.5, angle 45 degrees |
| | Anisotropic: ratio 1.5, angle -45 degrees |

Minimum curvature.

To assess the quality of the interpretation the grids were inspected visually and cross-section were analysed. The interpolated cross-sections were compared with the original data. The last criterion for the choice to make is the computation time required for the gridding.

First the different types of interpolation and options will be assessed for a small area of the estuary. Based on this assessment the best interpolation technique will be used for the whole estuary. The results of the bathymetric changes, changes to cross-sections and sediment volume will be described in following paragraphs

## 2. Assessment of different interpolation techniques

From the cross-sections and the grids it can be concluded there is some difference between the various gridding methods. The spacing of the survey lines (600m) in relation to the grid cell length (250) causes none of the grid nodes to be further away from a survey line then two cell lengths. The influence of the different interpolation techniques therefore is small. The best method for an area with various directions of the main channel is triangulation by linear interpolation with no anisotropy. This is based on the fact that it is a very fast method and the difference in grid node values is very small compared to more sophisticated methods like kriging. For areas with a clear direction of the main channel it is advised to use anisotropy with the same angle as the direction of the main channel and a ratio resembling the proportions of the scour holes. Also anisotropy can be specified relatively easy. Kriging is also a good method, but the lack of possibilities to model the anisotropic variogram makes it less attractive.

TABLES

**Table A-1 : Analysis of cross-sectional charecteristics of selected cross-sections in the Meghna Estuary**

| Section no. | Avg. depth(below PWD) | | Change | Max. depth(below PWD) | | Change | Area (sq. meter) | | Change | Width (kilometer) | | Change | Shifting of thalweg | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1997 | 2000 | % | 1997 | 2000 | % | 1997 | 2000 | % | 1997 | 2000 | % | Distance (km) | Direction |
| Section 1 | 6.74 | 5.27 | -28.00 | 14.37 | 7.92 | -81.47 | 38960 | 30947 | -25.89 | 5.8 | 5.85 | 0.85 | 2.65 | East-ward |
| Section 2 | 6.72 | 4.19 | -60.60 | 20.44 | 12.41 | -64.65 | 27060 | 21038 | -28.63 | 3.82 | 5.00 | 23.60 | 1.72 | West-ward |
| Section 3 | 5.19 | 7.55 | 31.23 | 11.18 | 18.80 | 40.53 | 7159 | 16964 | 57.80 | 1.28 | 2.10 | 39.05 | 1.17 | East-ward |
| Section 4 | 5.92 | 5.58 | -6.12 | 14.8 | 15.85 | 6.61 | 42012 | 43044 | 2.40 | 7.11 | 7.71 | 7.78 | 2.50 | East-ward |
| Section 5 | 5.71 | 6.42 | 11.00 | 14.34 | 17.81 | 19.46 | 39908 | 48178 | 17.17 | 6.78 | 7.50 | 9.60 | 1.66 | South-west |
| Section 6 | 4.43 | 5.14 | 13.76 | 9.11 | 20.25 | 55.01 | 24758 | 37374 | 33.76 | 5.55 | 7.27 | 23.66 | 6.46 | South-west |
| Section 7 | 7.50 | 5.60 | -33.99 | 11.45 | 20.29 | 43.58 | 40240 | 34699 | -15.97 | 5.31 | 6.17 | 13.94 | 2.37 | South-west |
| Section 8 | 5.98 | 5.13 | -16.63 | 12.29 | 14.29 | 14.00 | 64509 | 66100 | 2.41 | 11.80 | 12.00 | 1.67 | - | - |
| Section 9 | 5.13 | 4.76 | -7.68 | 7.33 | 7.24 | -1.31 | 33705 | 30676 | -9.87 | 6.55 | 6.42 | -2.02 | 0.46 | South-east |
| Section 10 | 3.28 | 1.70 | -93.55 | 4.84 | 3.27 | -47.81 | 4499 | 2333 | -92.86 | 1.36 | 1.32 | -3.03 | 0.31 | North-east |
| Section 11 | 8.62 | 7.93 | -8.77 | 11.27 | 10.87 | -3.71 | 20371 | 18402 | -10.70 | 2.37 | 2.31 | -2.60 | - | - |
| Section 12 | 5.77 | 6.93 | 16.82 | 10.13 | 12.40 | 18.26 | 45510 | 54713 | 16.82 | 7.87 | 7.87 | 0.00 | - | - |
| Section 13 | 8.35 | 8.72 | 4.30 | 14.08 | 14.56 | 3.30 | 48146 | 47513 | -1.33 | 5.55 | 5.45 | -1.83 | - | - |
| Section 14 | 11.34 | 10.95 | -3.59 | 14.49 | 14.70 | 1.41 | 118383 | 113859 | -3.97 | 10.42 | 10.42 | 0.00 | - | - |

( - ) indicates no change of thalweg position

Change (%) = (Z2000 - Z1997)/Z2000*100)

Table A-2. Cross-sections Nijhum Dwip channel

| | cross-sectional area (m2) | | | | |
|---|---|---|---|---|---|
| | section 1 | section 2 | section 3 | section 4 | section 5 |
| Jan-88 | 4608 | 3036 | 2984 | 4253 | 5329 |
| Mar-97 | 4020 | 4292 | 4206 | 3809 | 3129 |
| Jul-99 | 3718 | 3350 | 2588 | 3002 | 2278 |
| Jun-00 | 2315 | 2702 | 2937 | 2564 | 2707 |
| Nov-00 | 1834 | 1892 | 2615 | 2246 | 2369 |

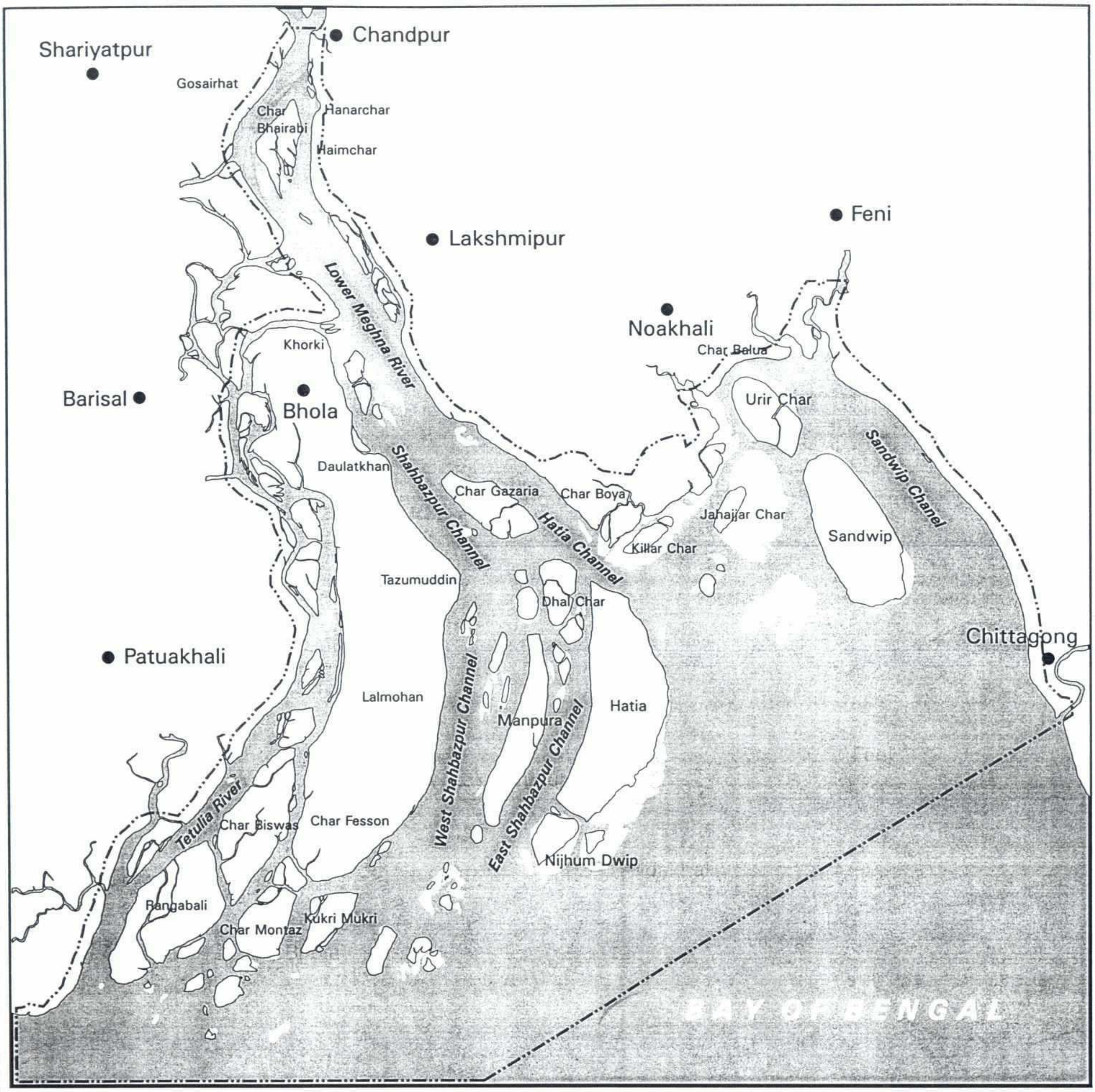
| | change in cross-sectional area relative to 1988 | | | | |
|---|---|---|---|---|---|
| | section 1 | section 2 | section 3 | section 4 | section 5 |
| Jan-88 | 0% | 0% | 0% | 0% | 0% |
| Mar-97 | -13% | 41% | 41% | -10% | -41% |
| Jul-99 | -19% | 10% | -13% | -29% | -57% |
| Jun-00 | -50% | -11% | -2% | -40% | -49% |
| Nov-00 | -60% | -38% | -12% | -47% | -56% |

| | average bed level (m, PWD) | | | | |
|---|---|---|---|---|---|
| | section 1 | section 2 | section 3 | section 4 | section 5 |
| Jan-88 | -1.86 | -2.09 | -2.33 | -4.10 | -5.59 |
| Mar-97 | -2.20 | -2.75 | -4.33 | -5.97 | -3.58 |
| Jul-99 | -2.33 | -1.91 | -2.44 | -4.33 | -2.43 |
| Jun-00 | -1.71 | -1.89 | -2.94 | -4.06 | -2.95 |
| Nov-00 | -1.47 | -1.50 | -2.59 | -3.79 | -2.58 |

| | change in average depth relative to 1988 | | | | |
|---|---|---|---|---|---|
| | section 1 | section 2 | section 3 | section 4 | section 5 |
| Jan-88 | 0% | 0% | 0% | 0% | 0% |
| Mar-97 | 18% | 31% | 86% | 46% | -36% |
| Jul-99 | 25% | -9% | 5% | 6% | -57% |
| Jun-00 | -8% | -10% | 26% | -1% | -47% |
| Nov-00 | -21% | -28% | 11% | -8% | -54% |

# FIGURES

**Figure 1: Meghna Estuary Study Area**




**Legend:**

- Land of 2000
- Mudflat
- Water body
- Study boundary
- District HQ

Meghna Estuary Study - II

MES II

10 0 40km

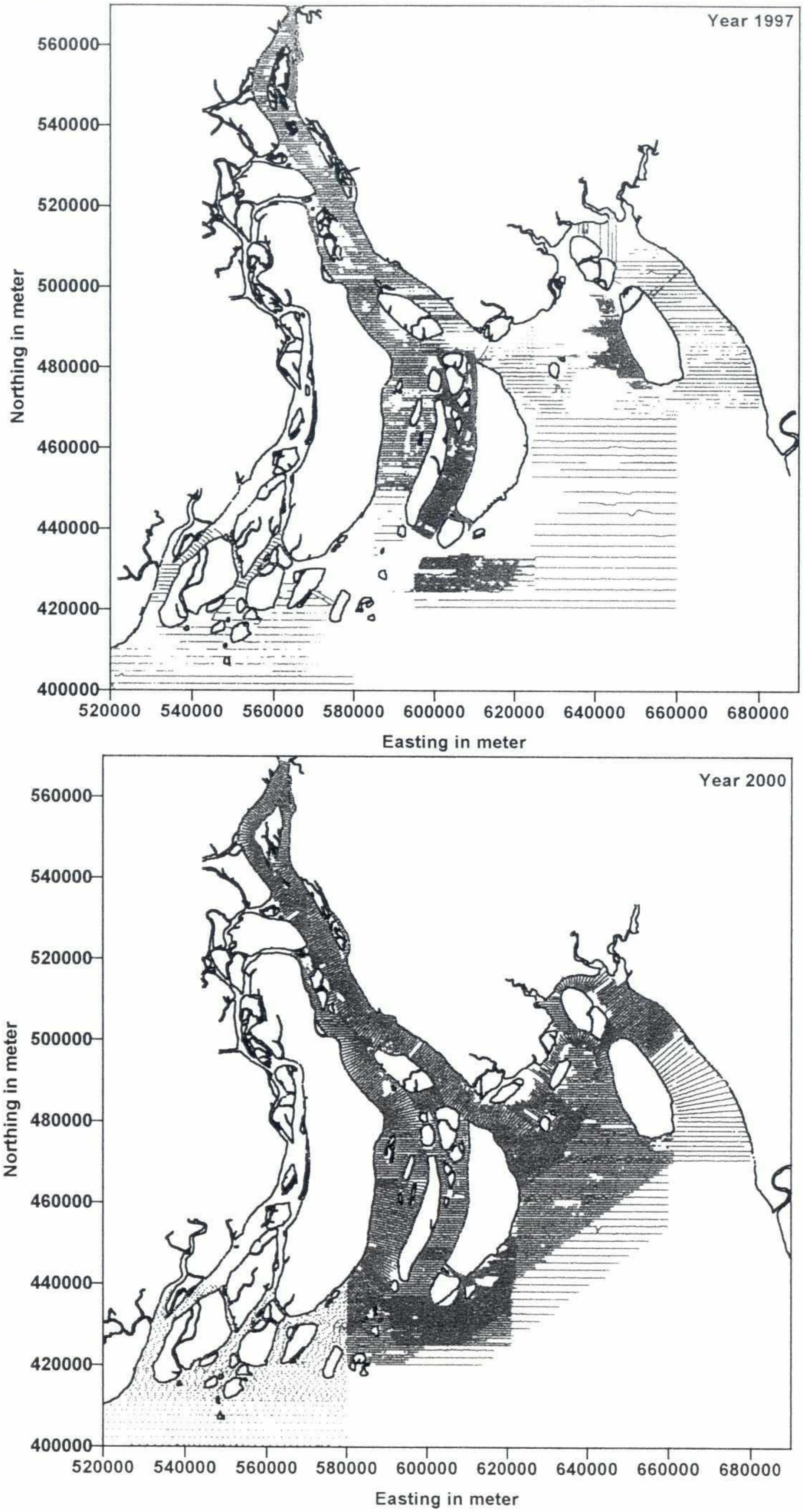
SCALE

Prepared by: GIS/RS/CAD Section of Meghna Estuary Study II

Note: Bankline were digitized from the Landsat TM imagery of January 2000

File- E:\Marius\MES-base00.cdr

Figure 2 **Spatial extent of survey in 1997 and 2000 for comparison of bathymetric change**



# Figure 3 : Division of study area into seven subareas

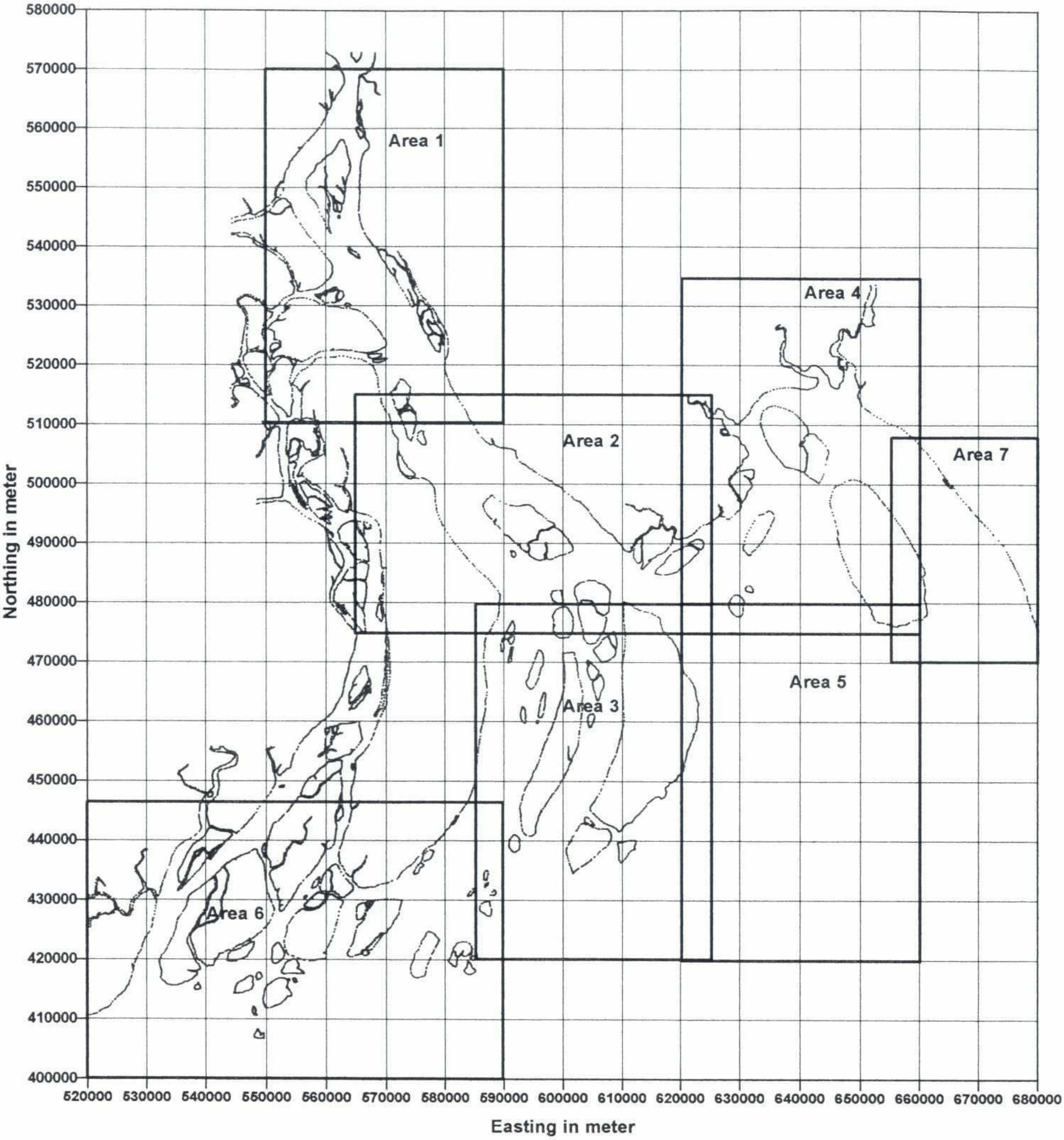


**Figure 3 (a) Contour map of bathymetry (1997) for the Meghna Estuary**

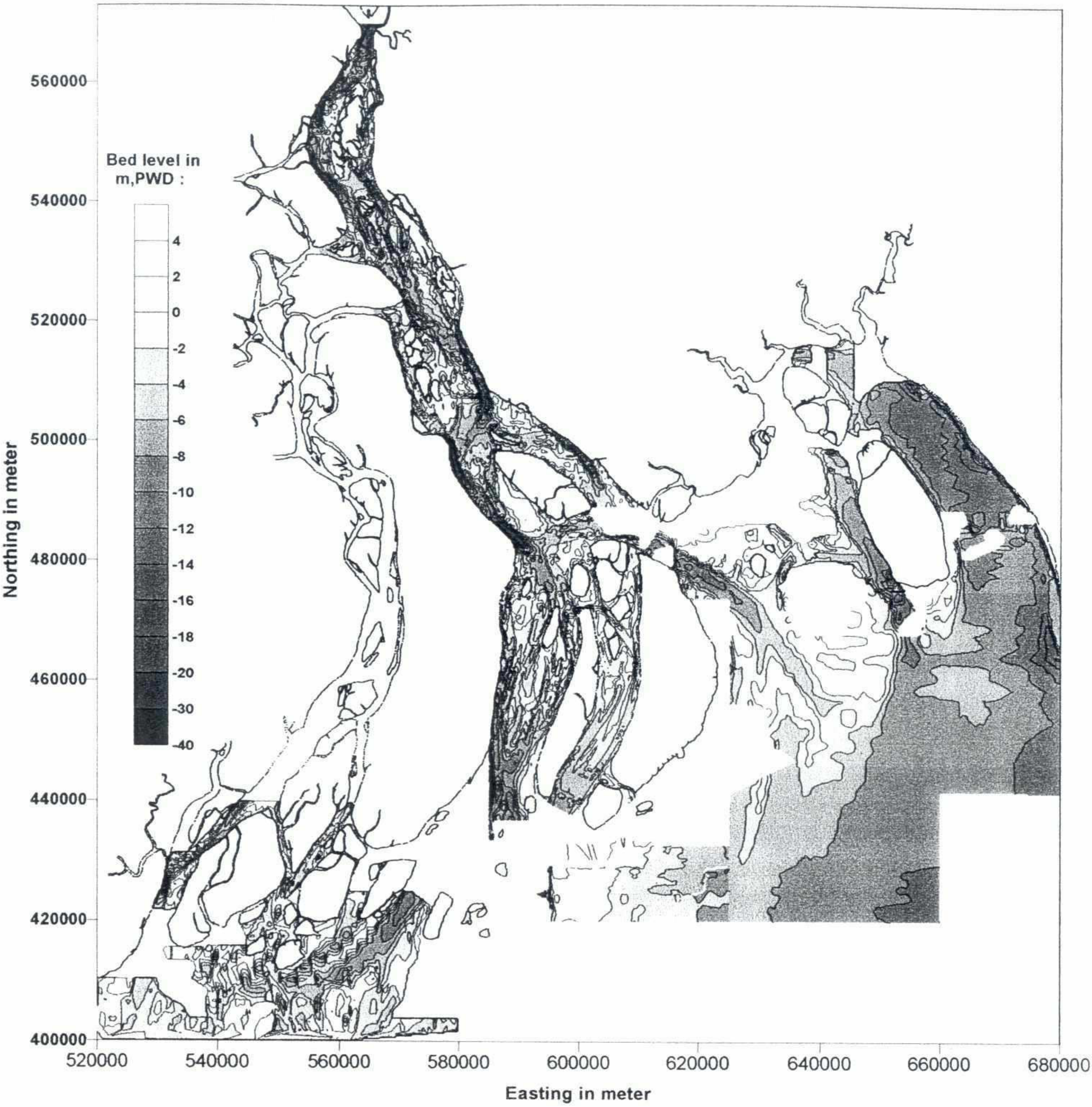


**Figure 3 (b) Contour map of bathymetry (2000) for the Meghna Estuary**

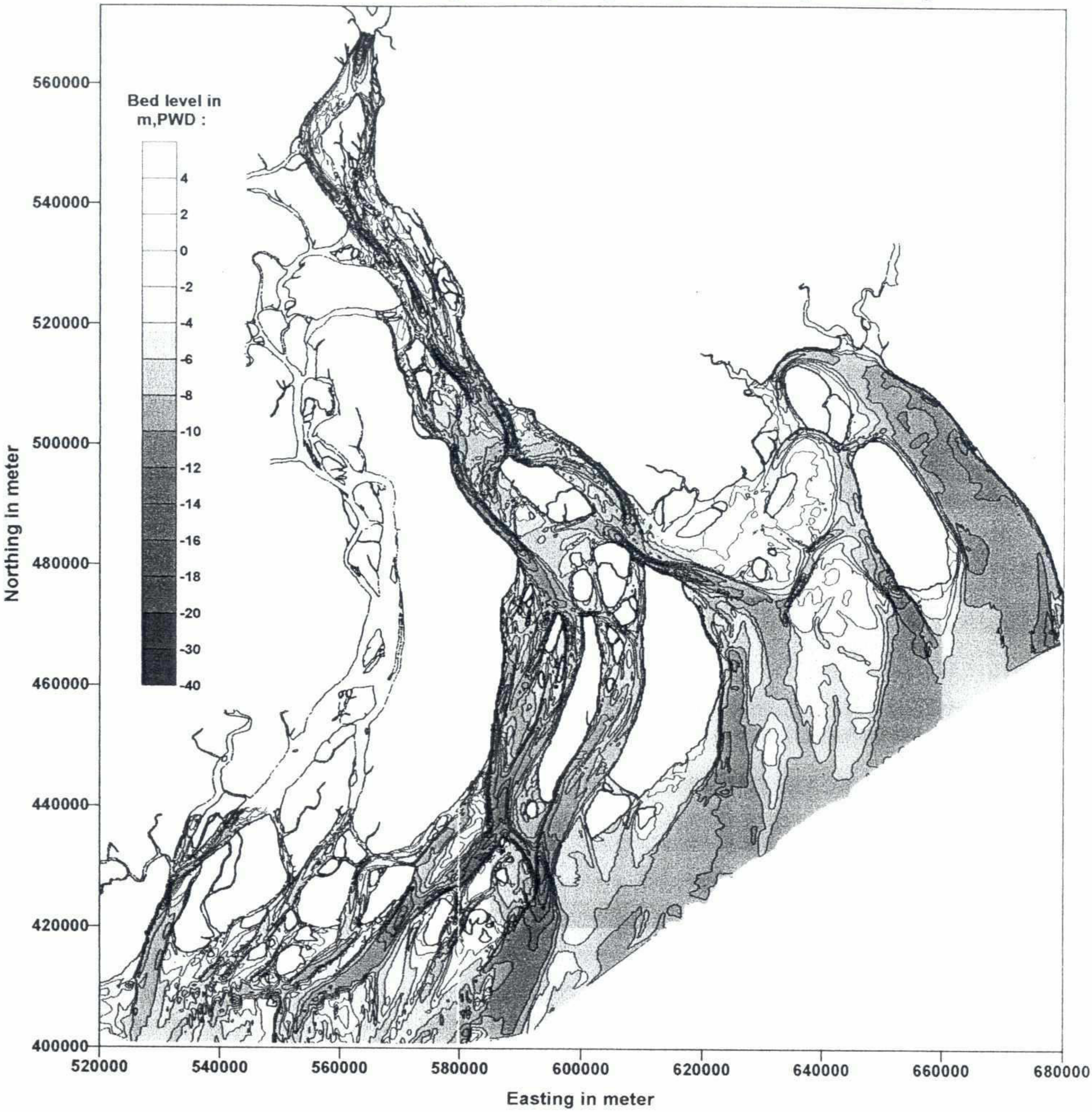


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**Figure 3 (c) Accretion/erosion (bathymetric change) map for the Meghna Estuary**

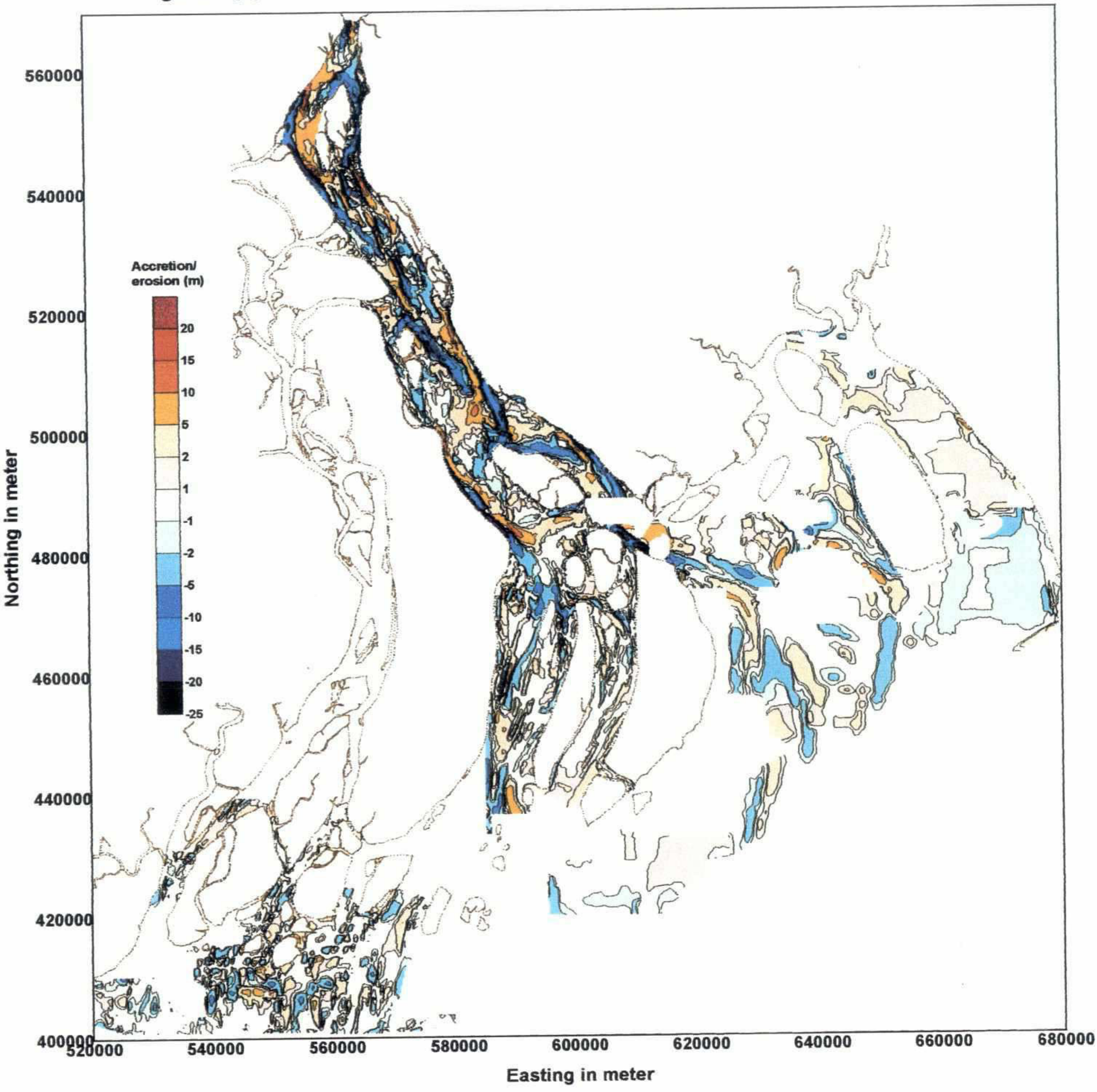
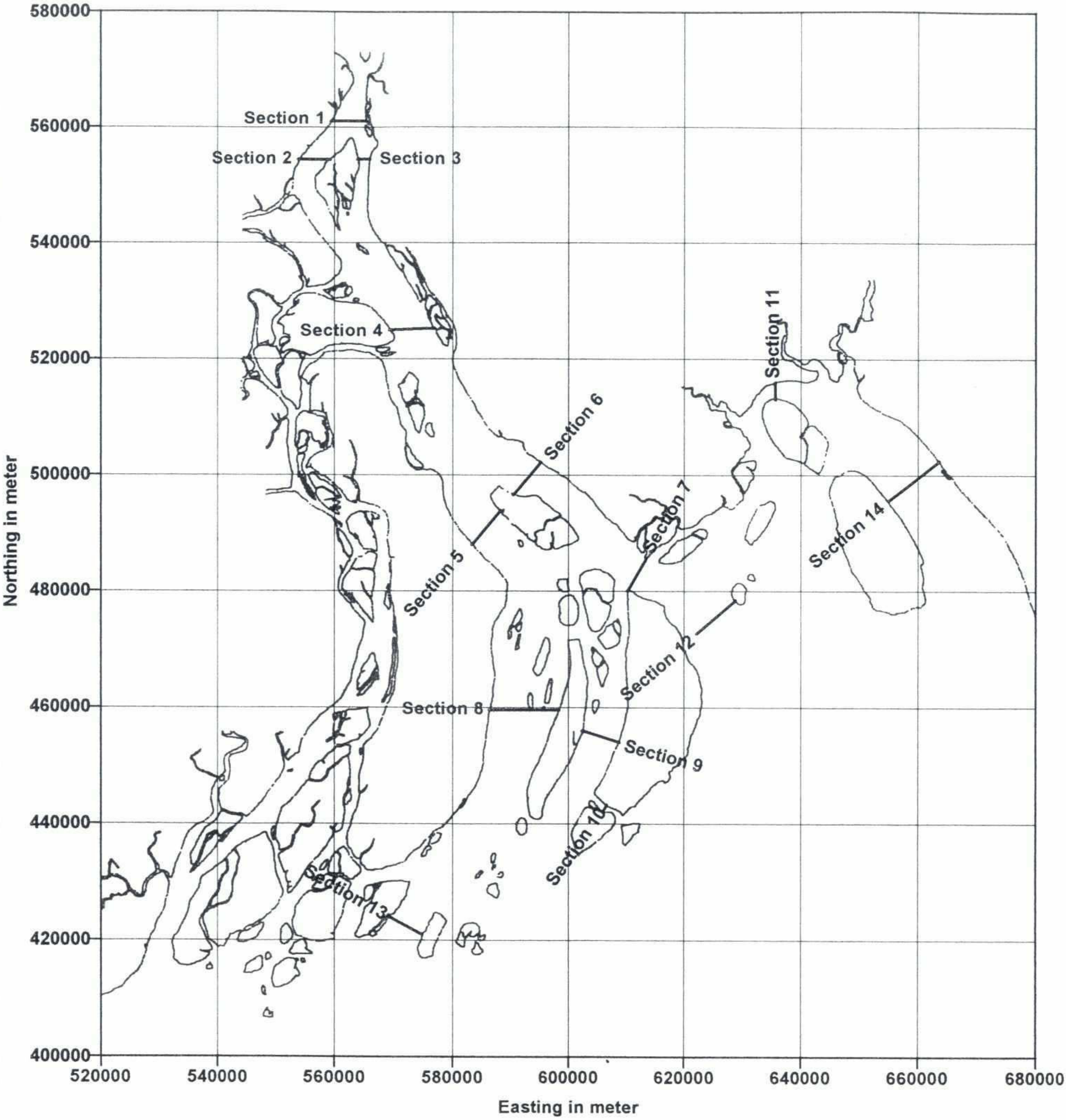


Figure 4 : Locations of the fourteen cross-sections in the study area



O1

## Figure 5 (a) Contour map of bathymetry (1997) for Area 1

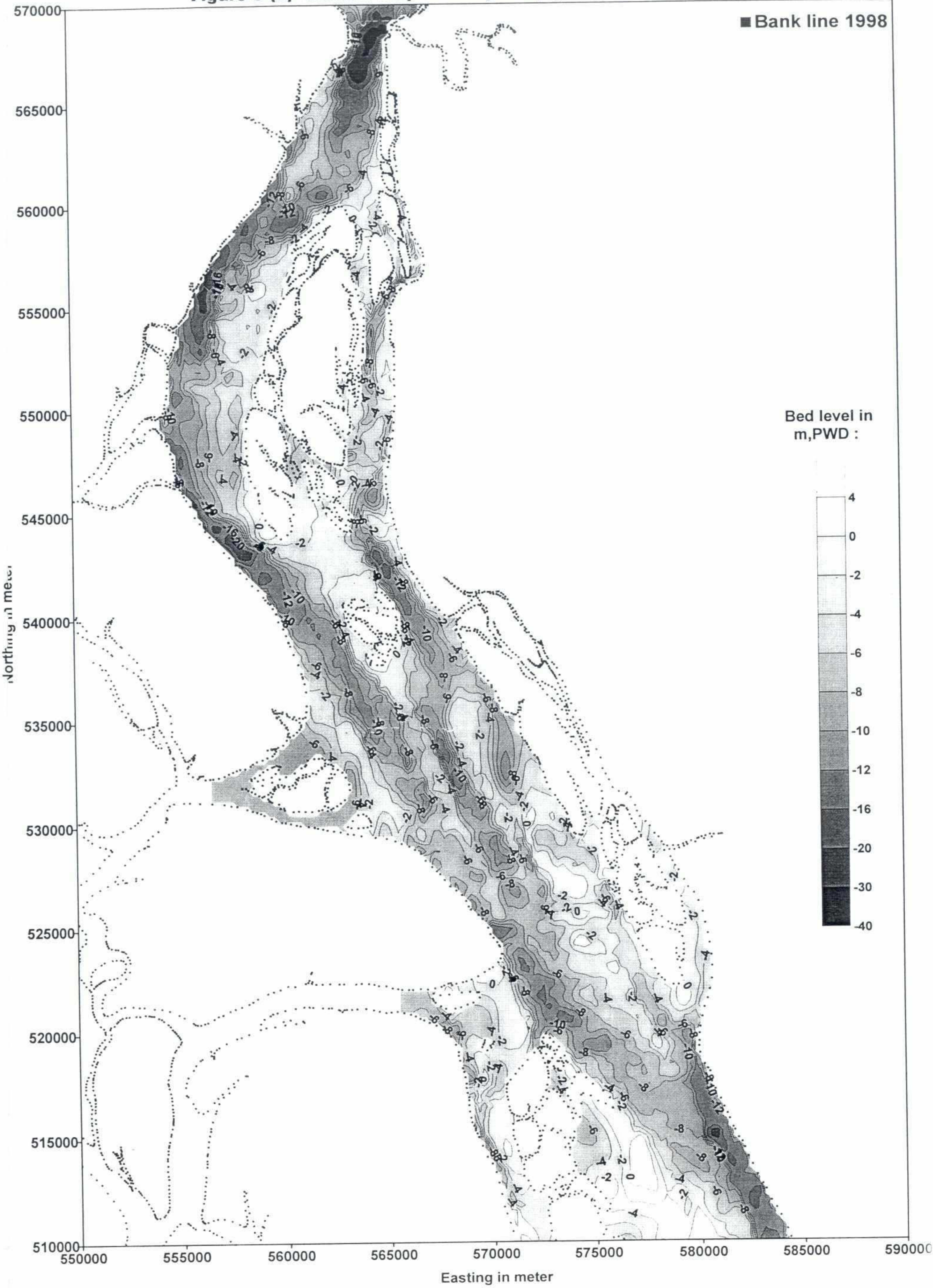


Figure 5 (b) Contour map of bathymetry (2000) for Area 1

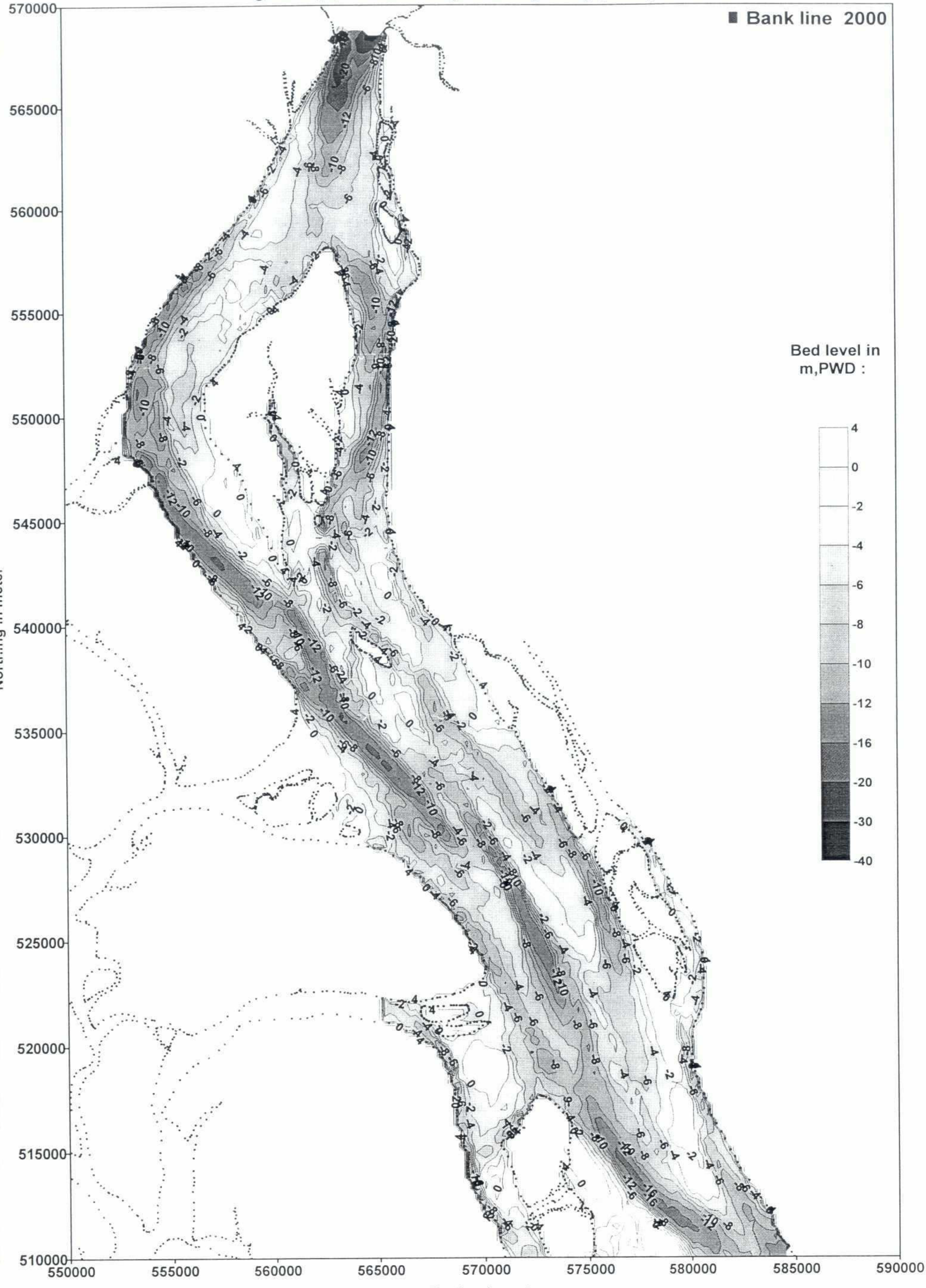


Figure 5 (c) Accretion/erosion (bathymetric change) map for area 1

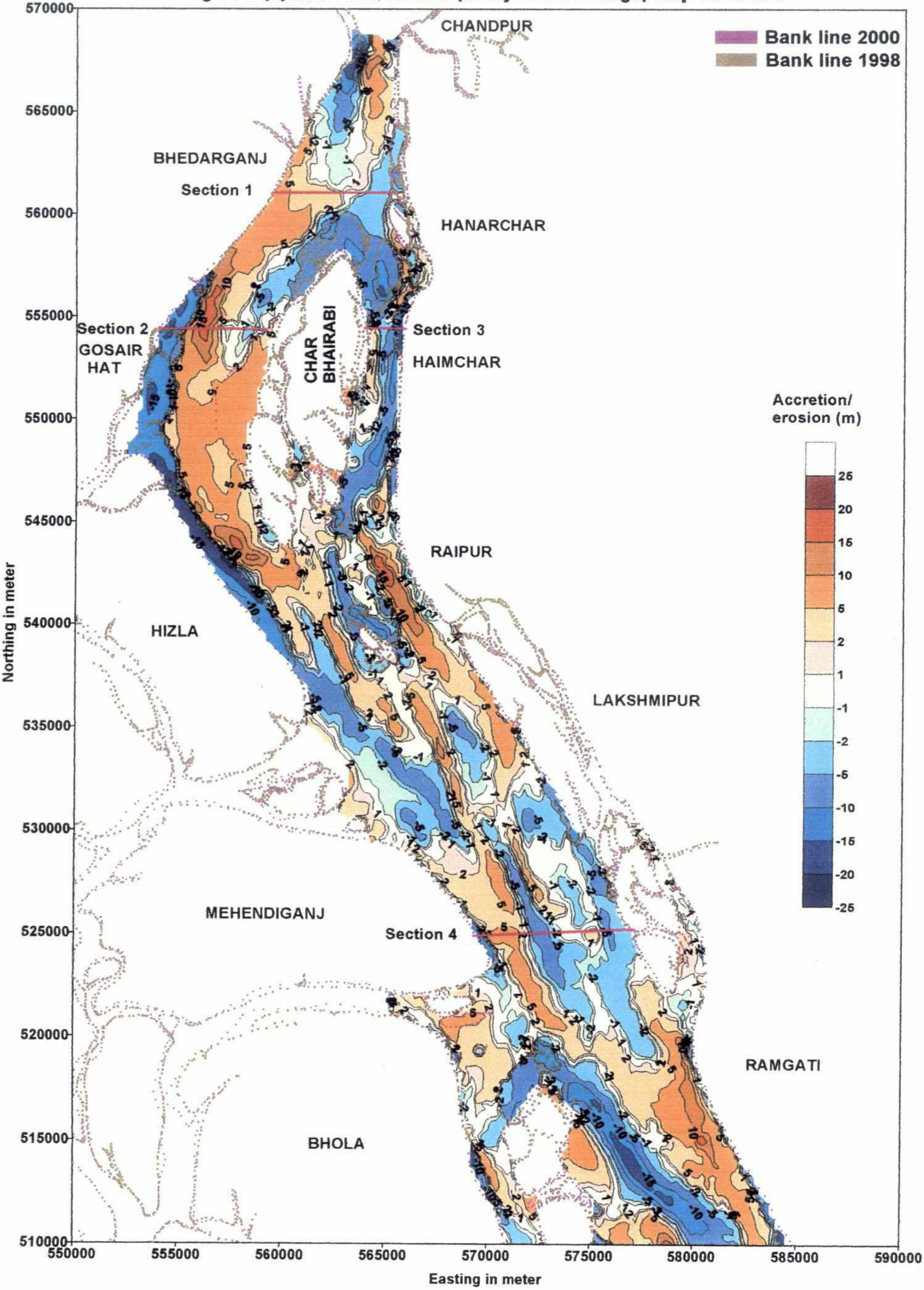


Figure 5(d) : Cross sections at locations in 1997 and 2000

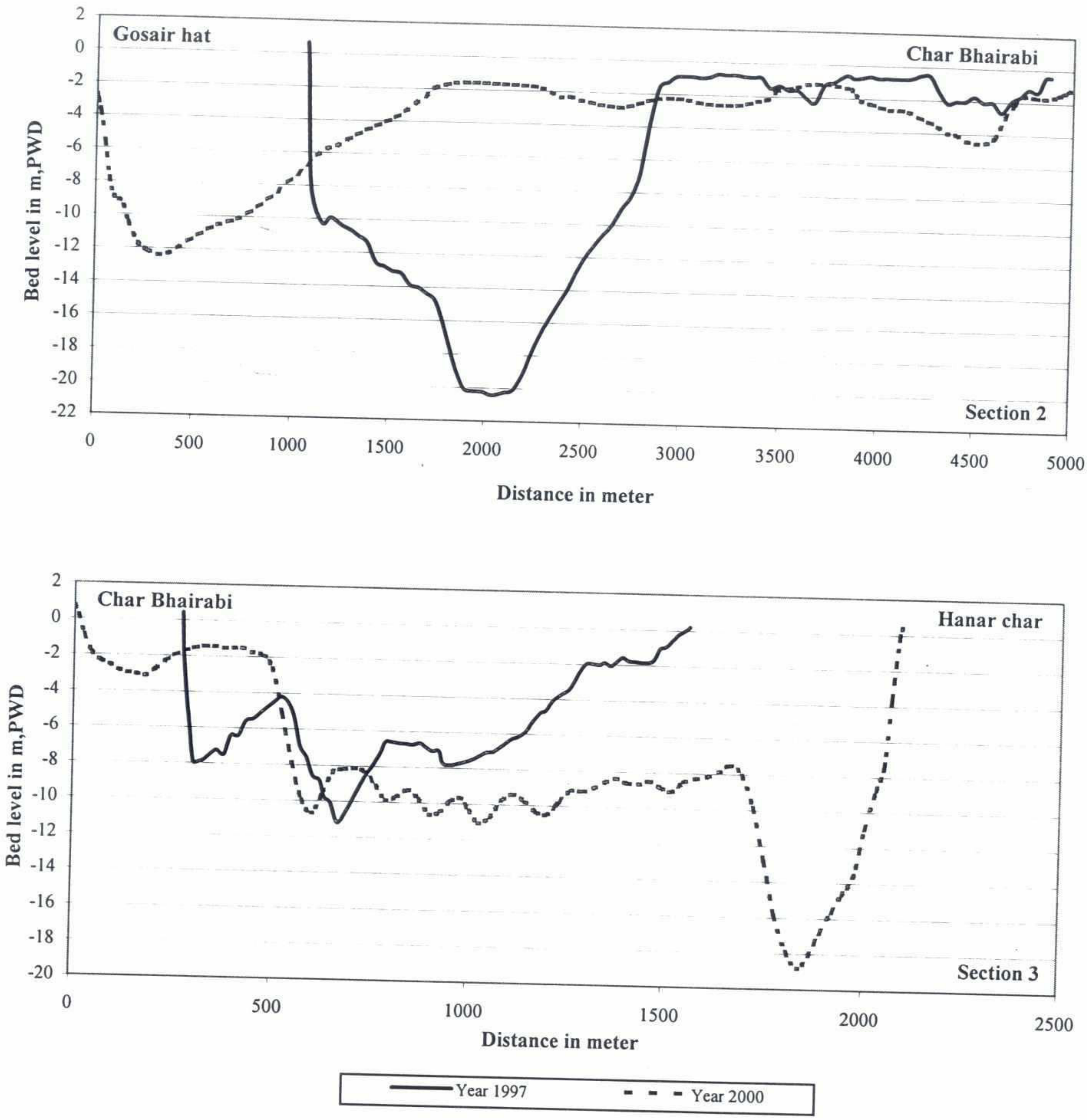
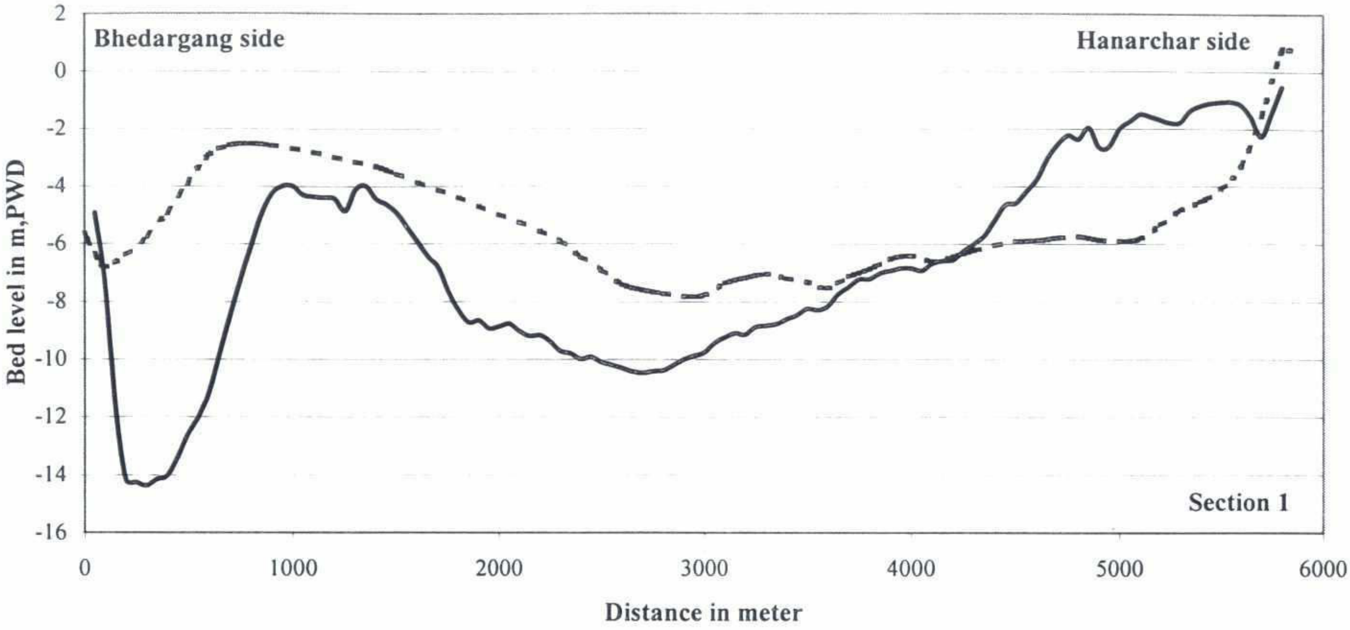


Figure 5(e) : Cross sections at locations in 1997 and 2000



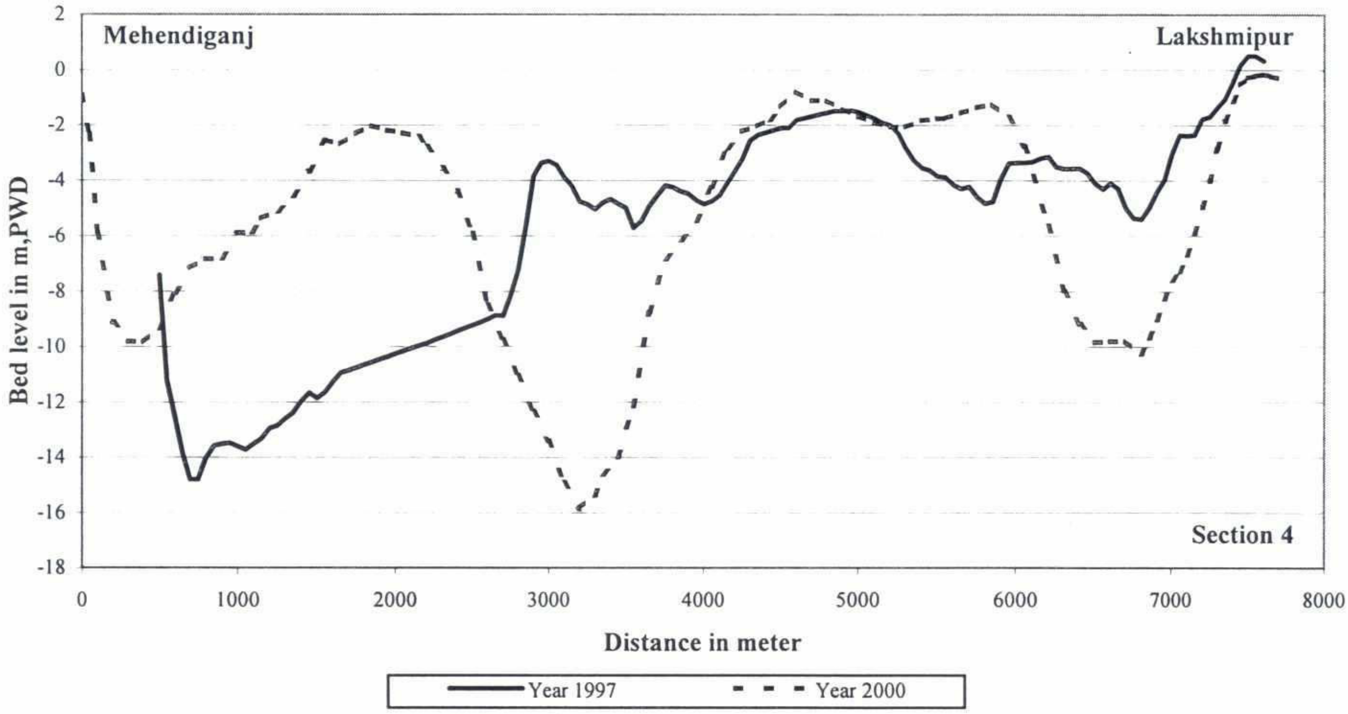



Figure 6 (a) Contour map of bathymetry (1997) for Area 2

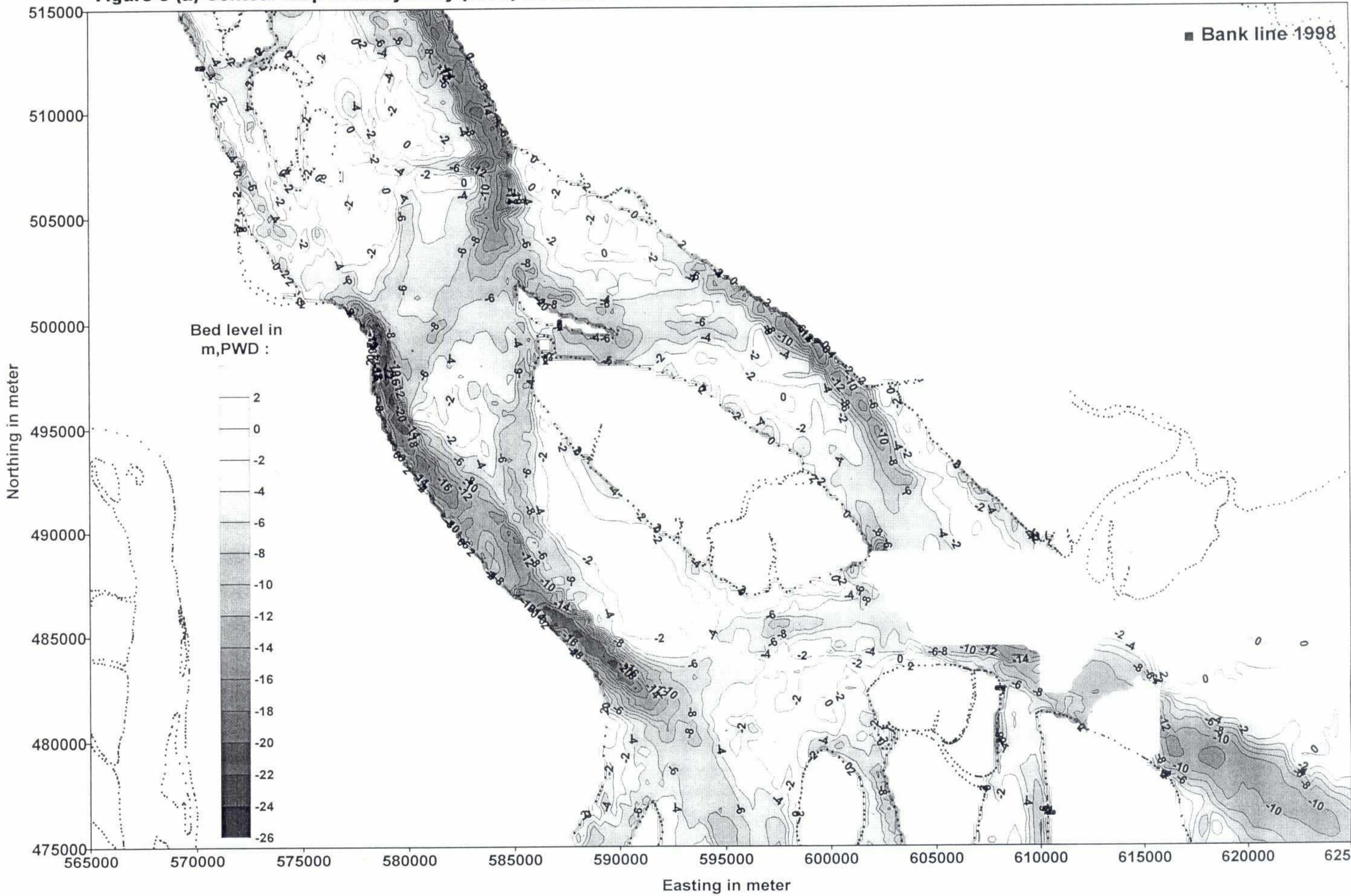



Figure 6 (a)

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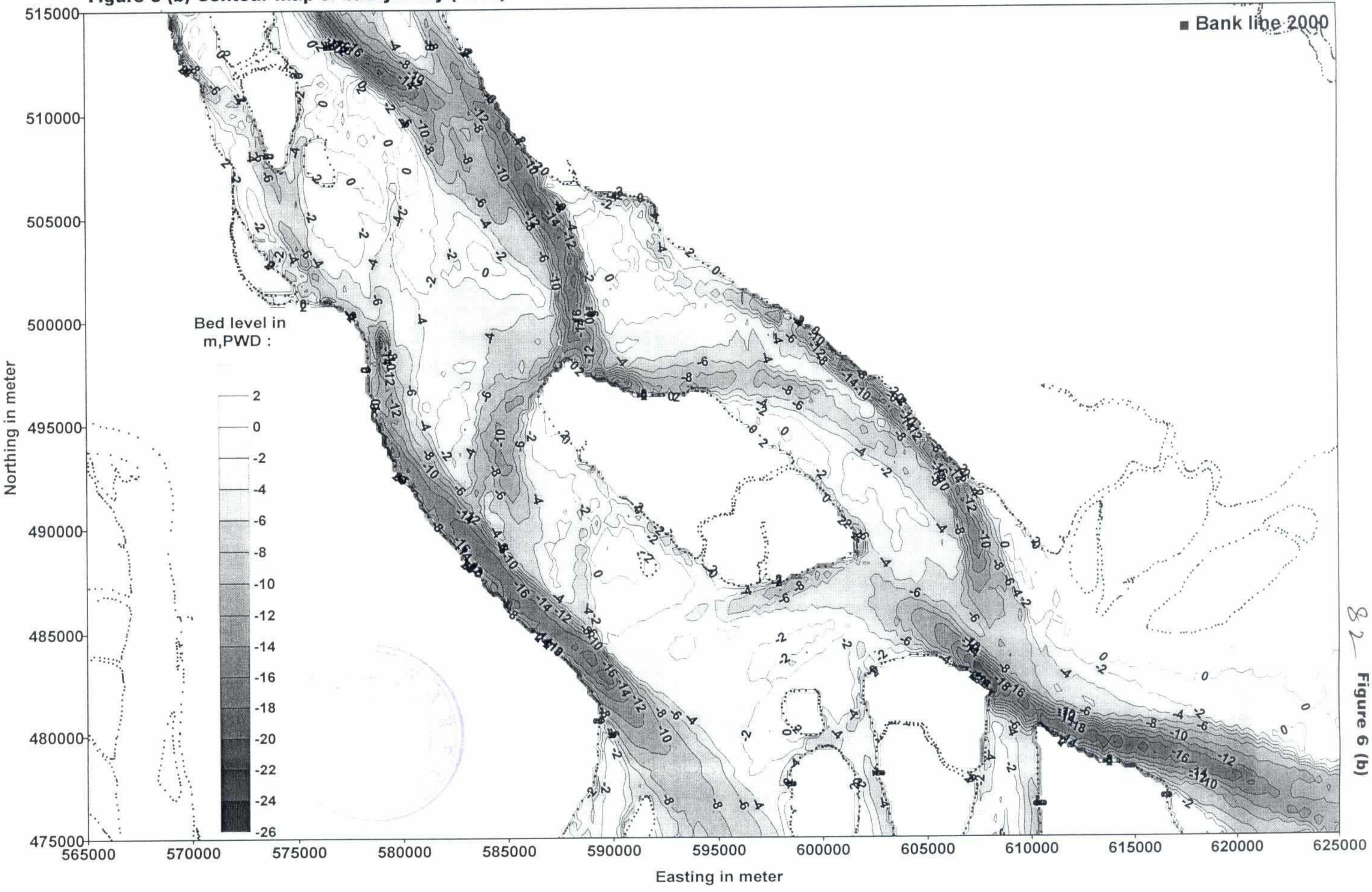
**Figure 6 (b) Contour map of bathymetry (2000) for Area 2**




82 Figure 6 (b)

**Figure 6 (c) Accretion/erosion (bathymetric change) map for area 2**

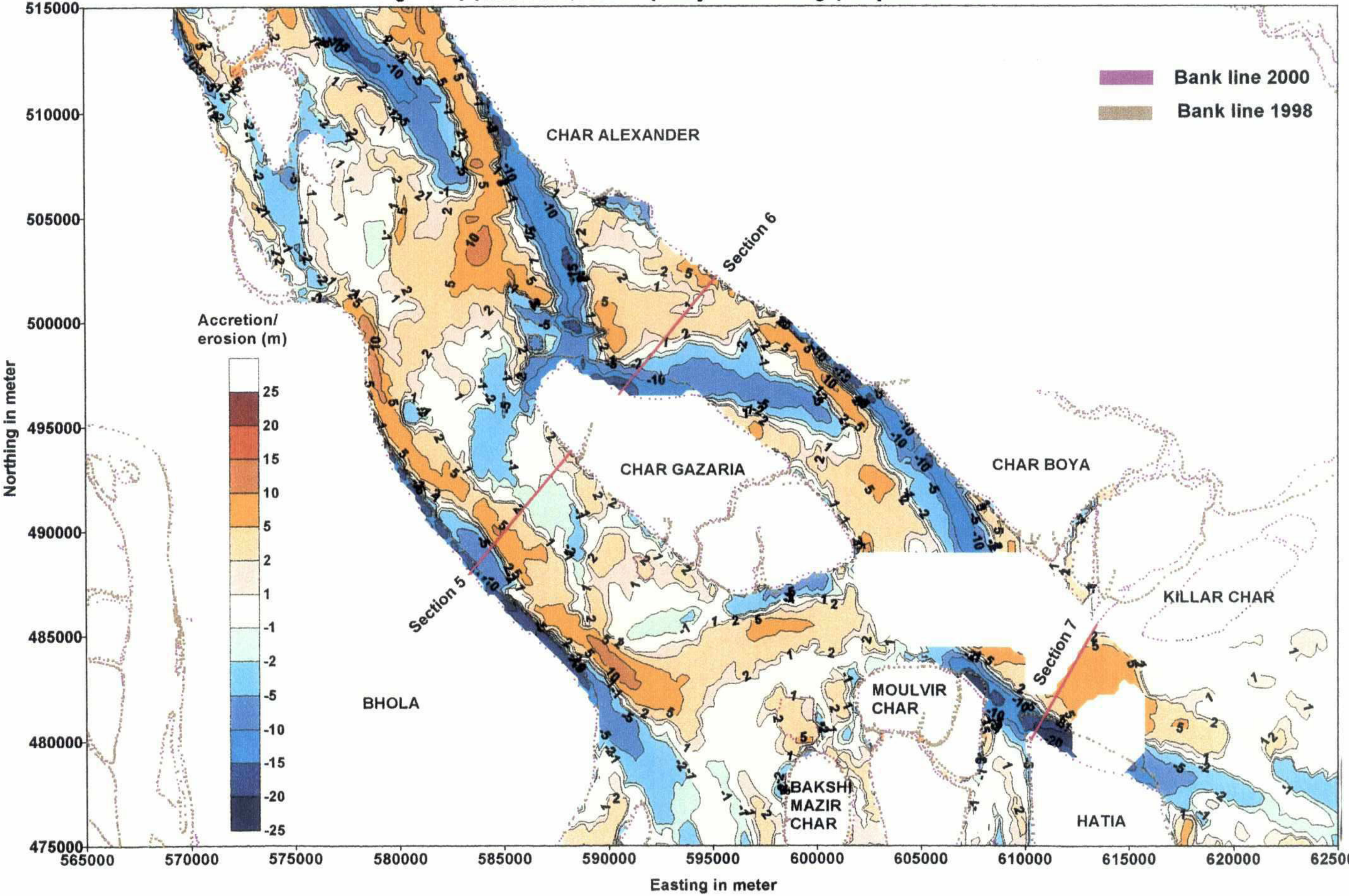
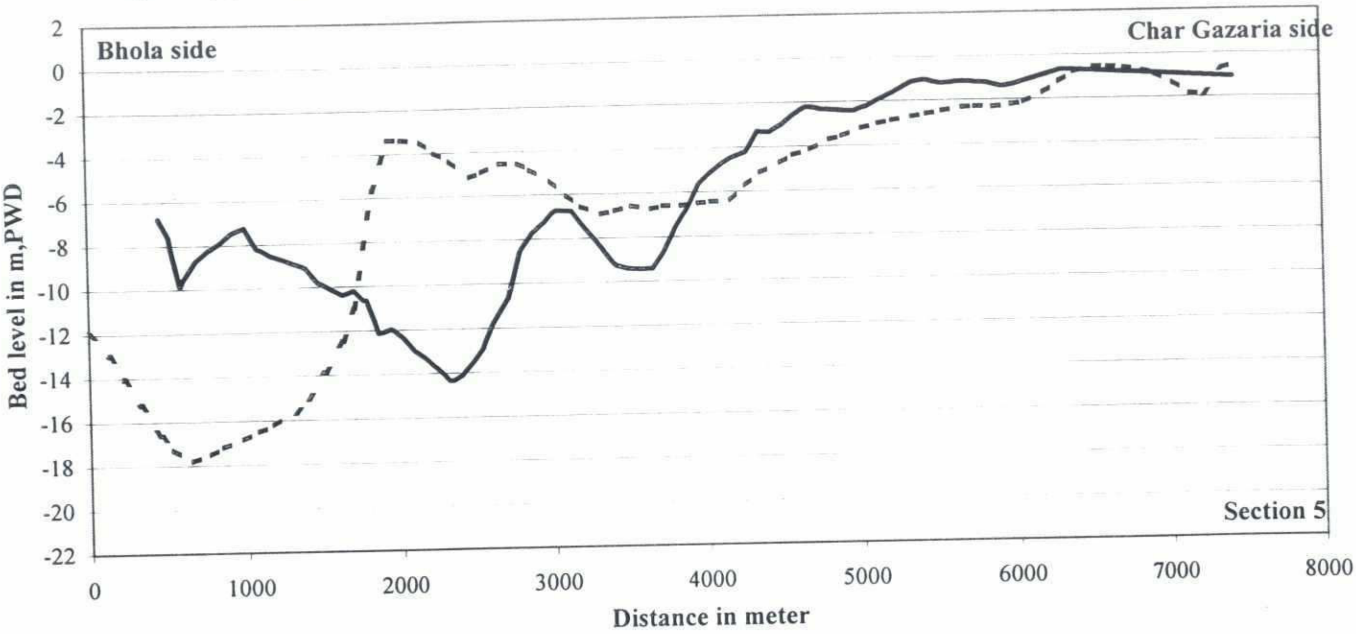
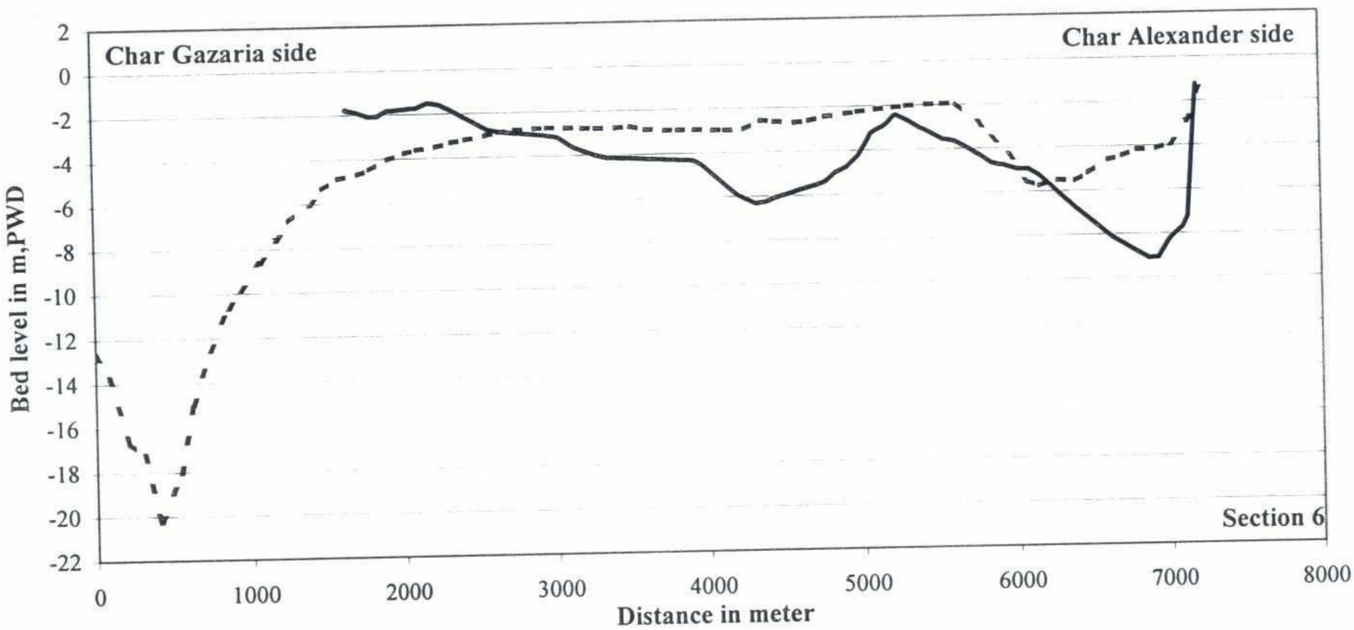



Figure 6 (c)

Figure 6(d) : Cross sections at locations in 1997 and 2000



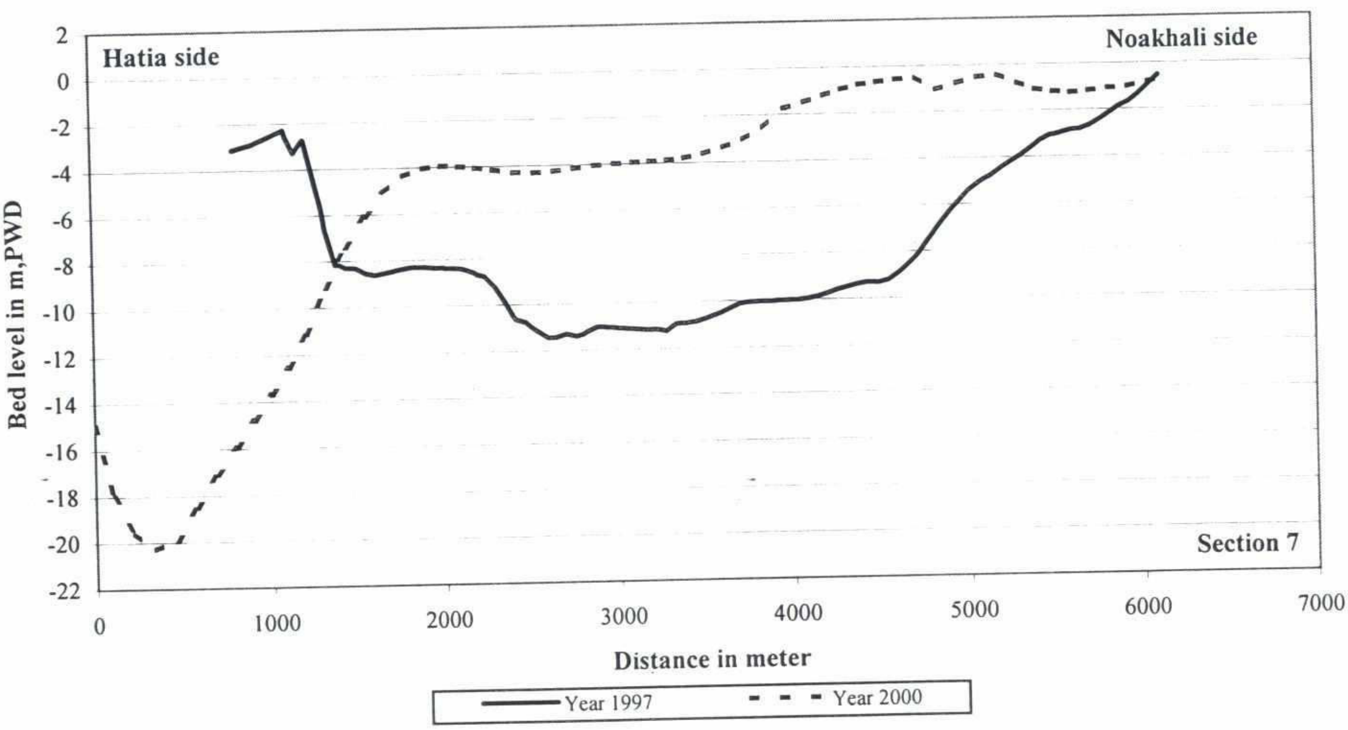



**Figure 7 (a) Contour map of bathymetry (1997) for Area 3**

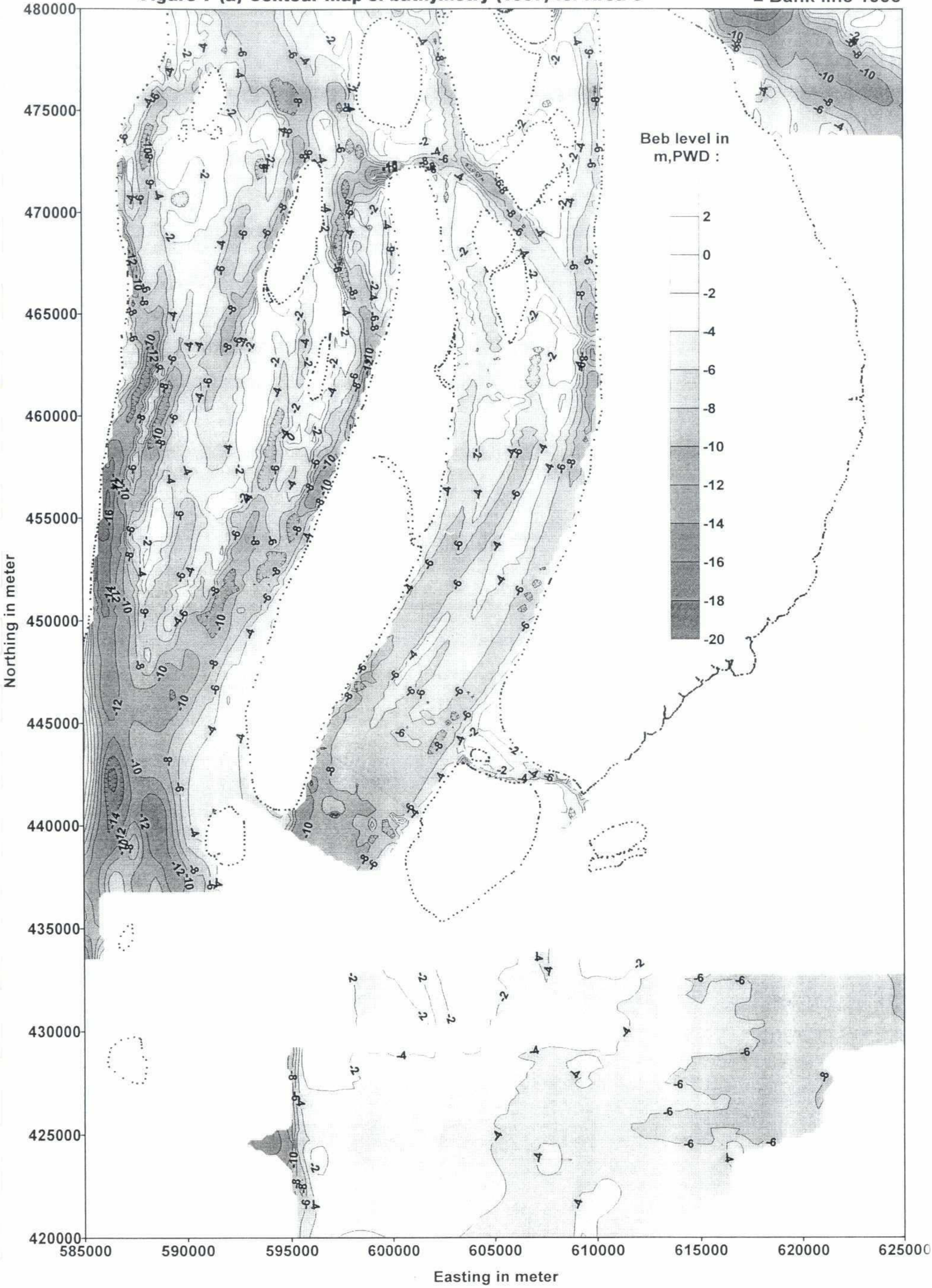


**Figure 7(b) Contour map of bathymetry (2000) for Area 3**

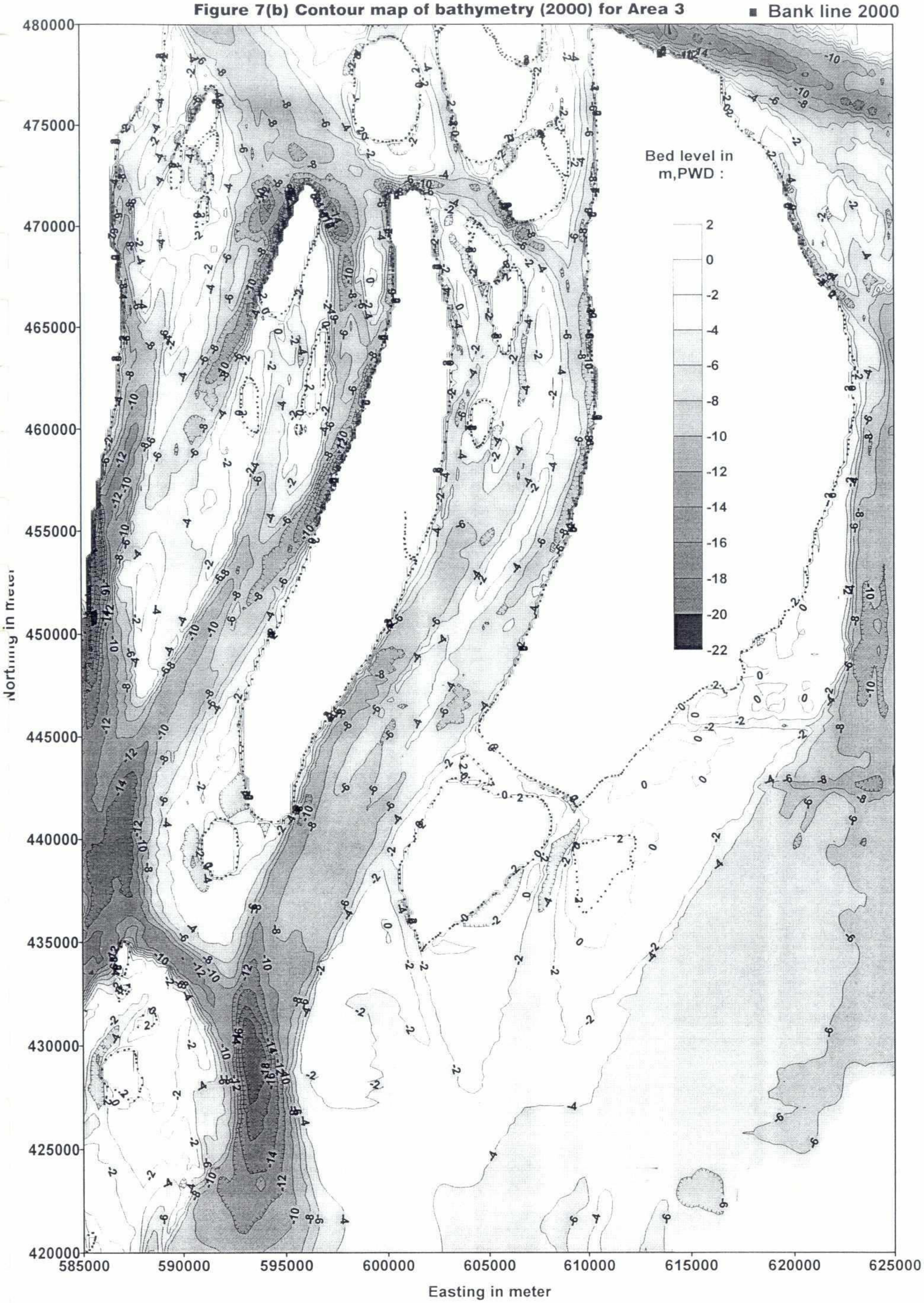


**Figure 7 (c) Accretion/erosion (bathymetric change) map for area 3**

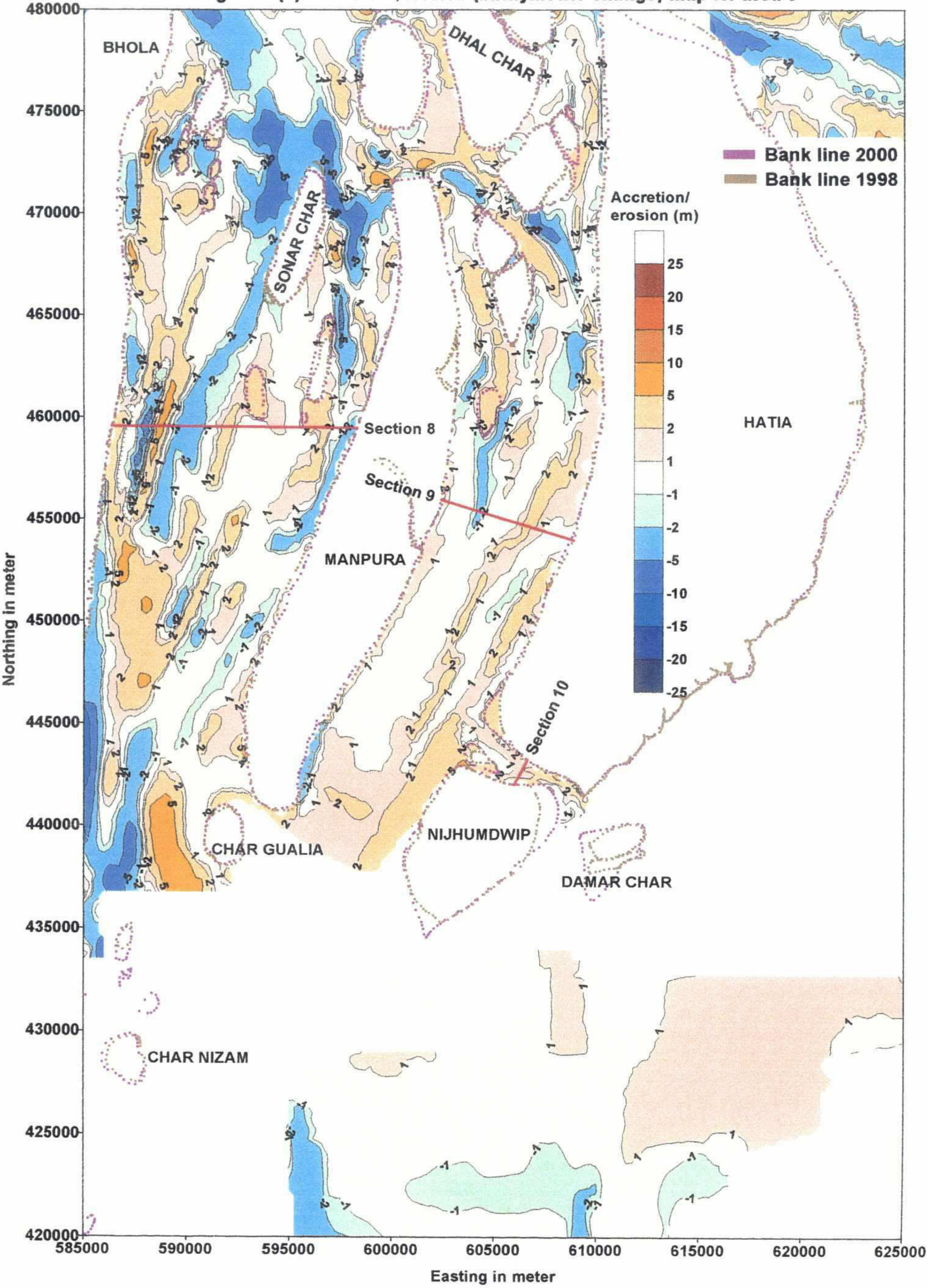
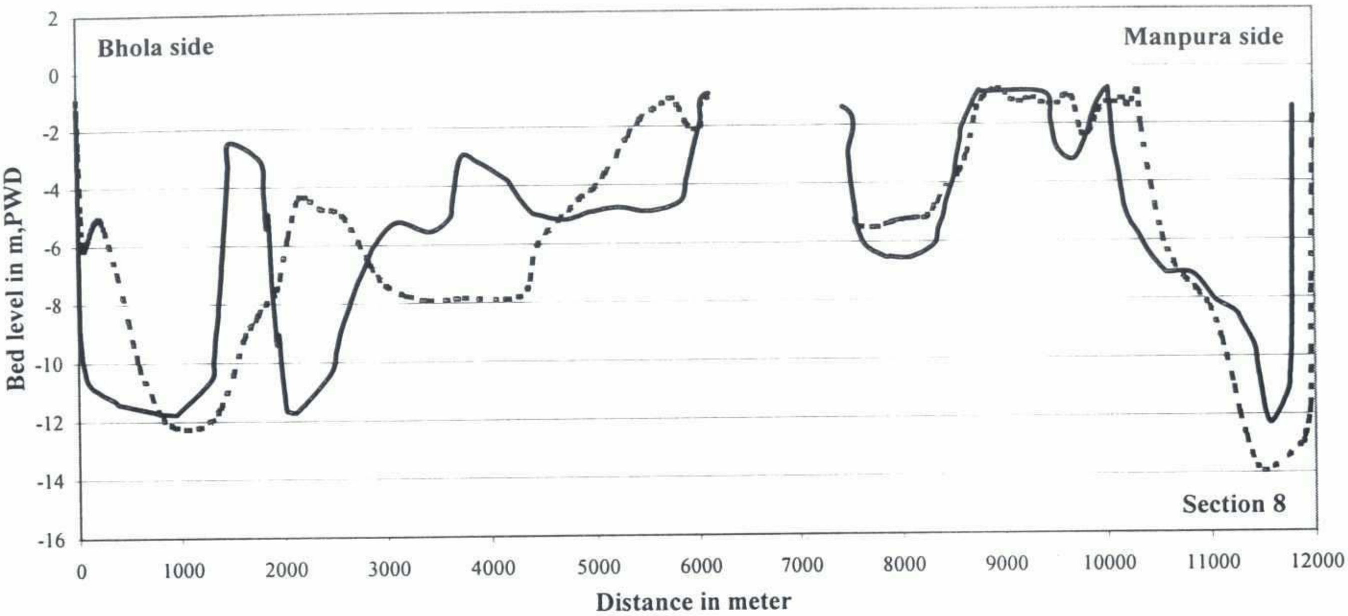
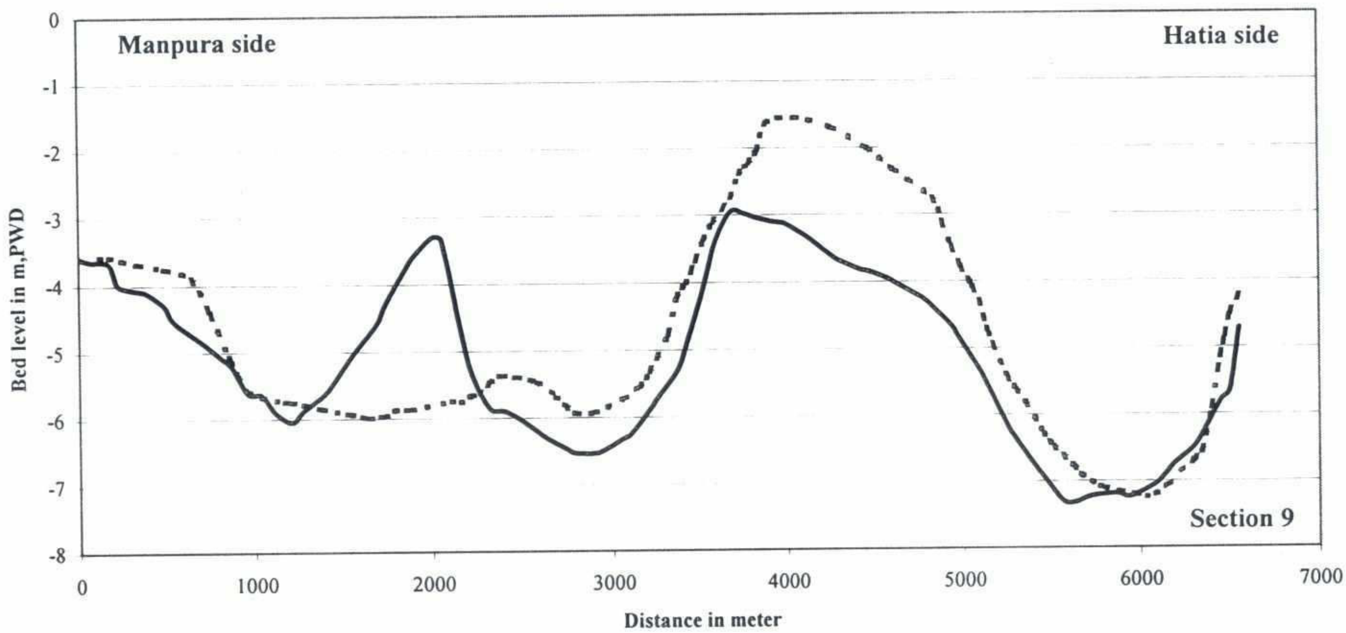


Figure 7(d) : Cross sections at locations in 1997 and 2000



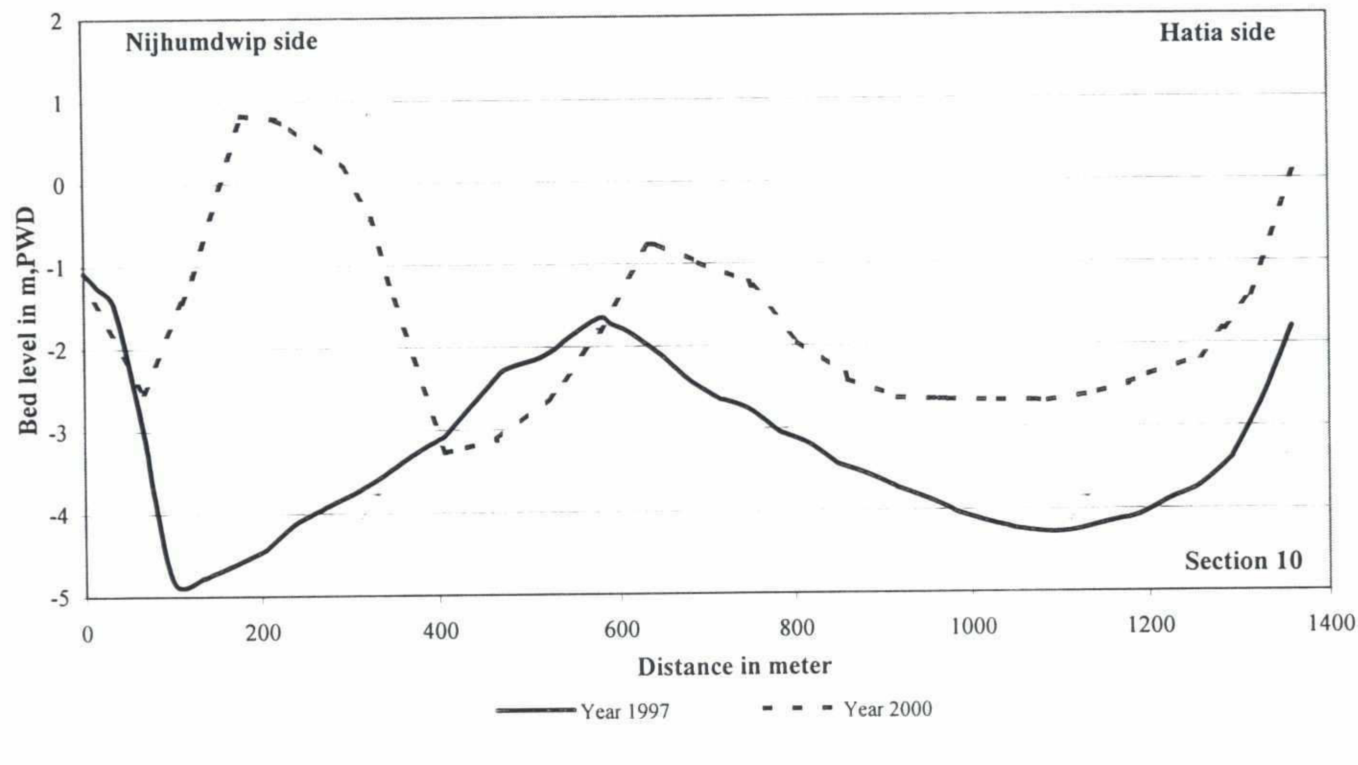



**Figure 8 (a) Contour map of bathymetry (1997) for Area 4**

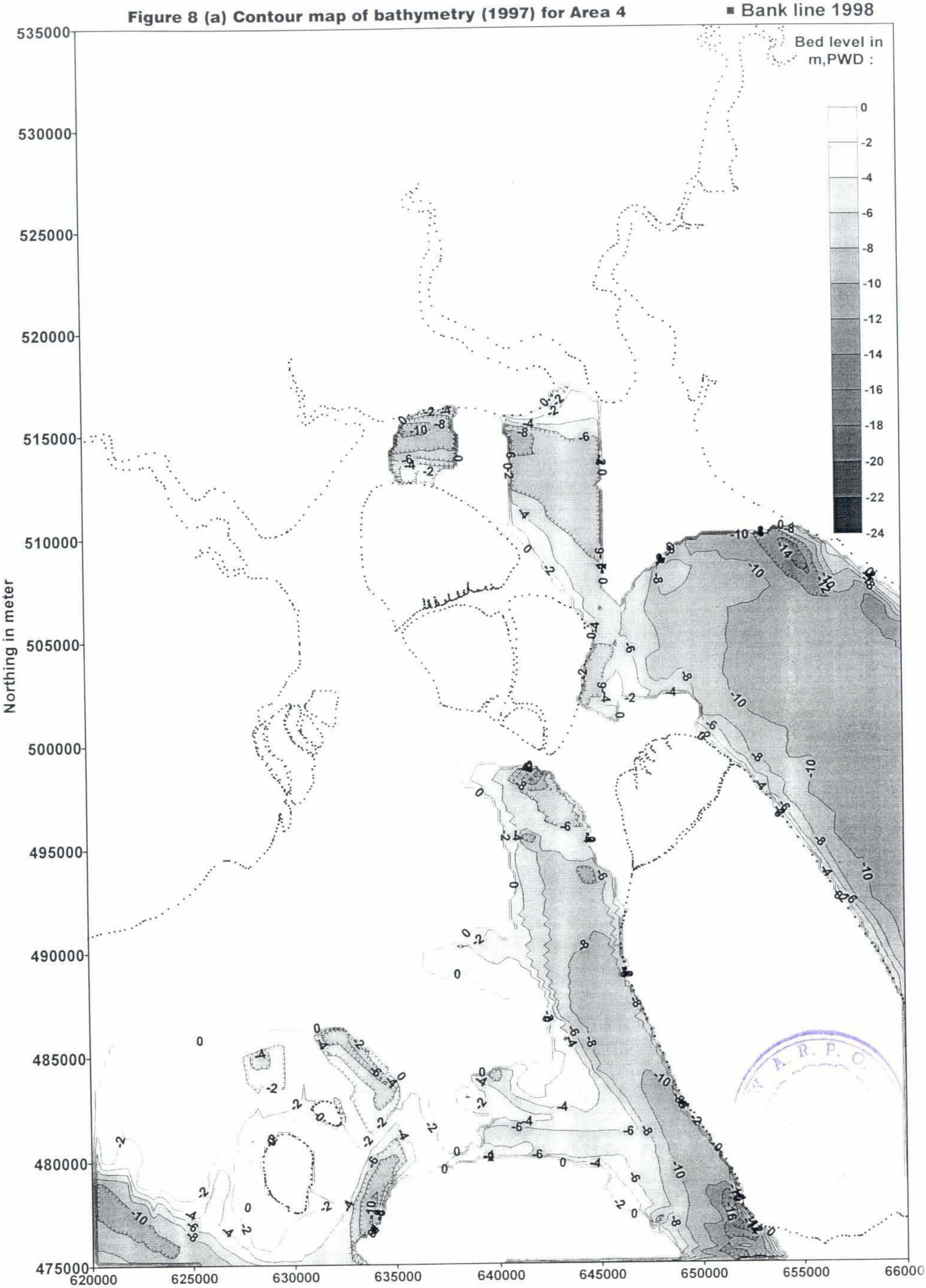


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**Figure 8 (b) Contour map of bathymetry (2000) for Area 4**

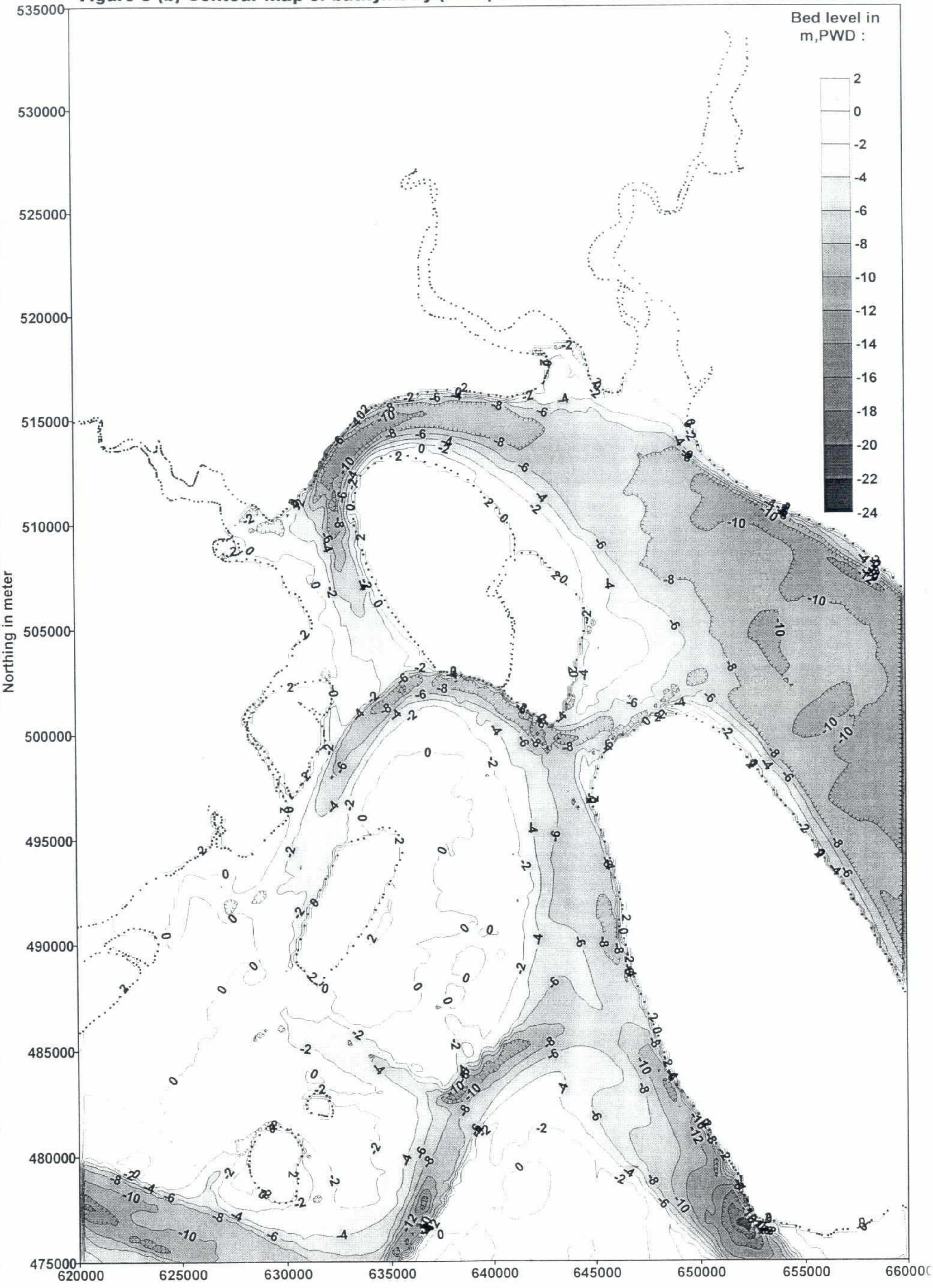


Figure 8 (c) Accretion/erosion (bathymetric change) map for area 4

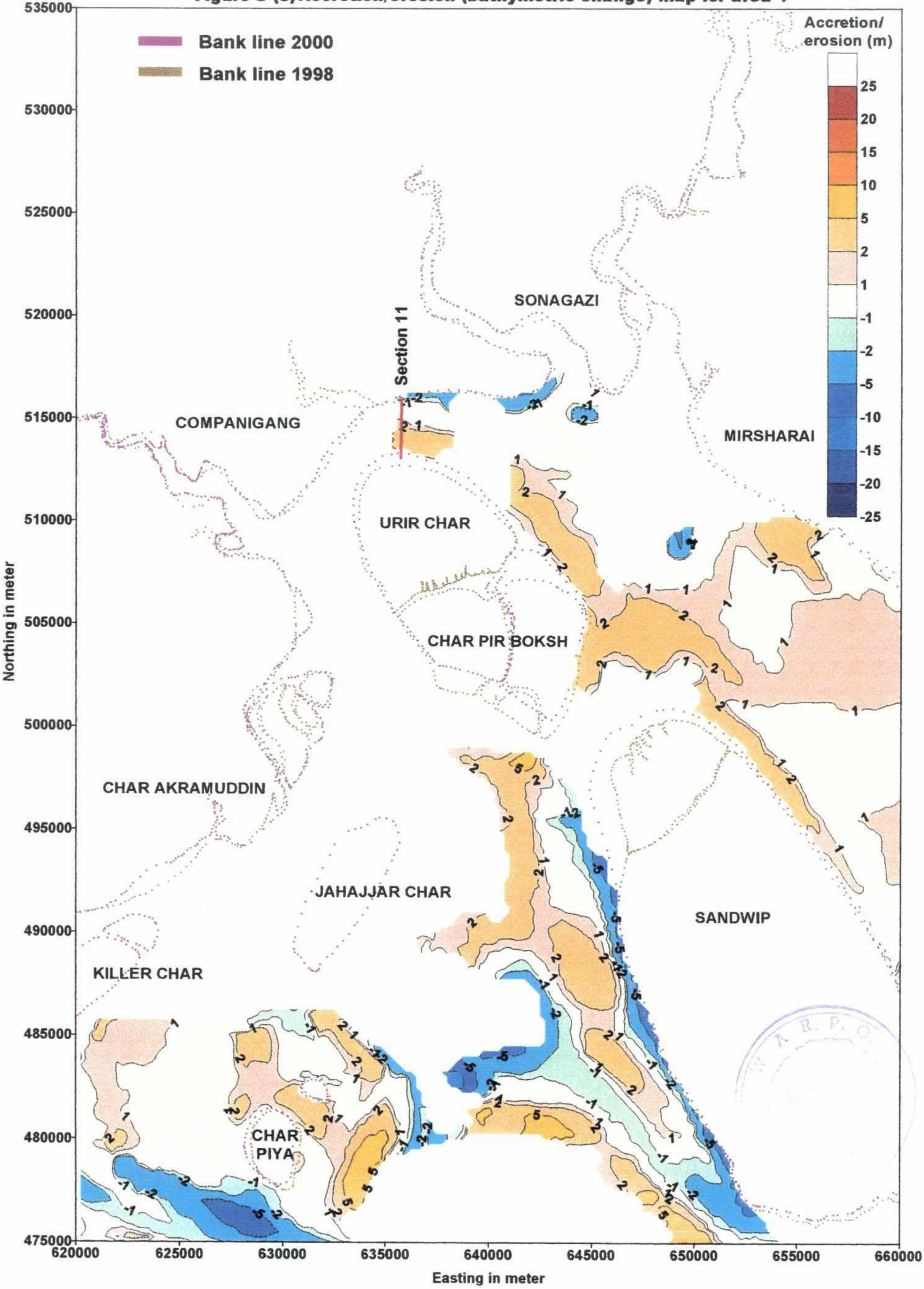
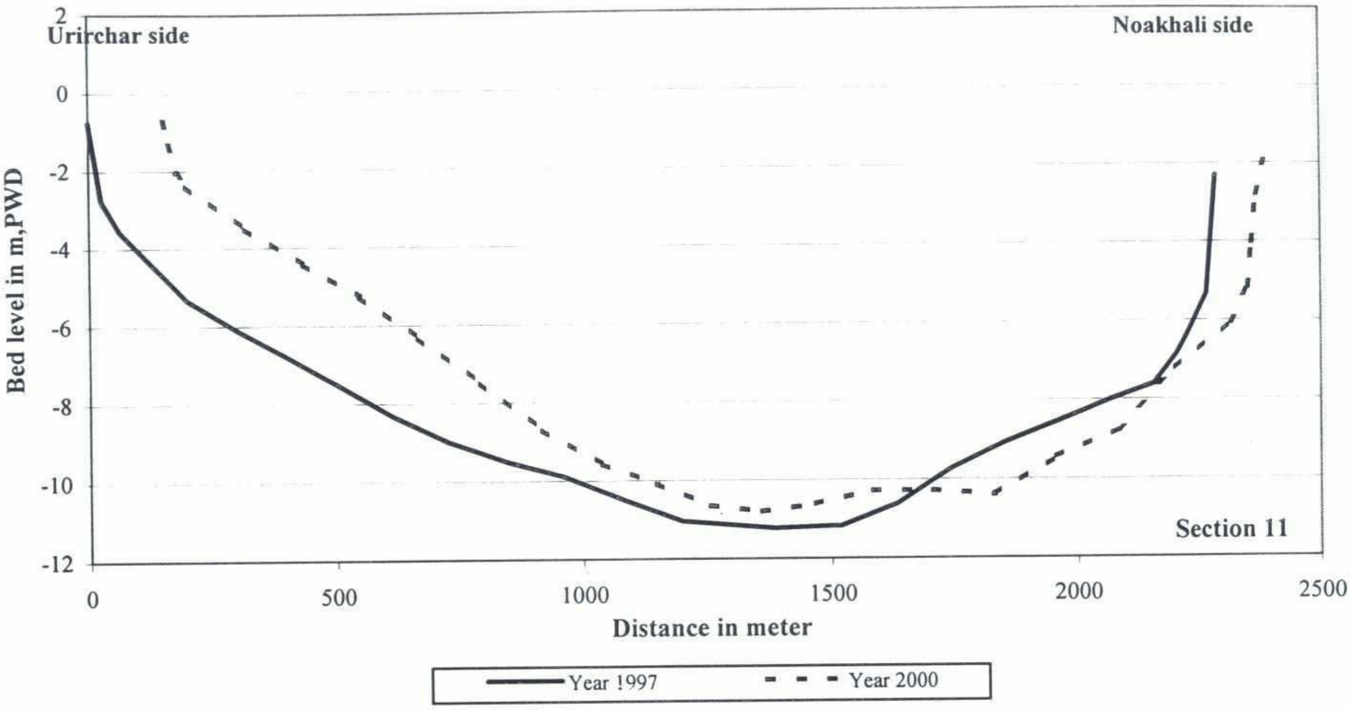


Figure 8(d) : Cross section at locations in 1997 and 2000



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# Figure 9 (a) Contour map of bathymetry (1997) for Area 5

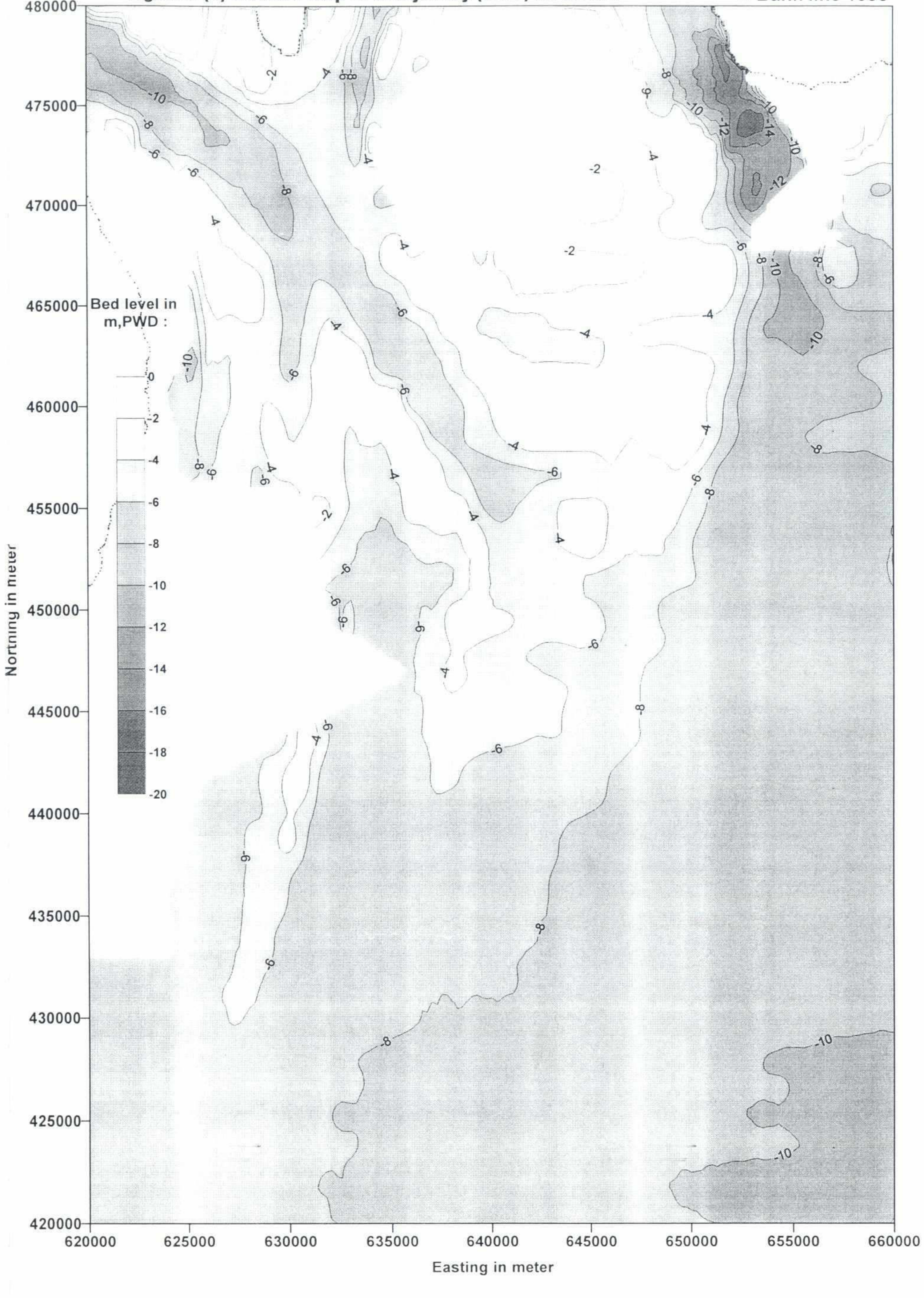

Figure 9 (b) Contour map of bathymetry (2000) for Area 5

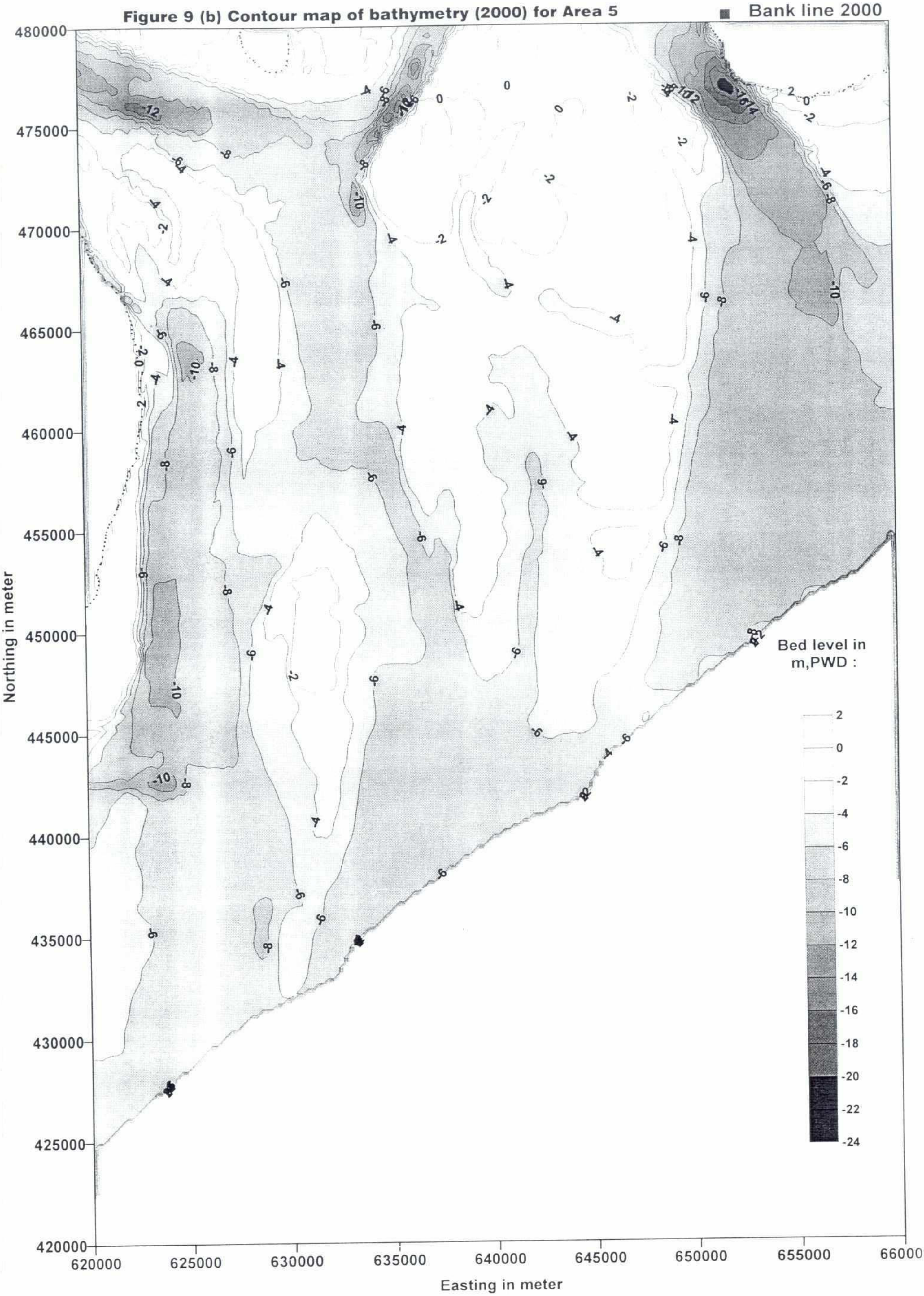

**Figure 9 (c) Accretion/erosion (bathymetric change) map for area 5**

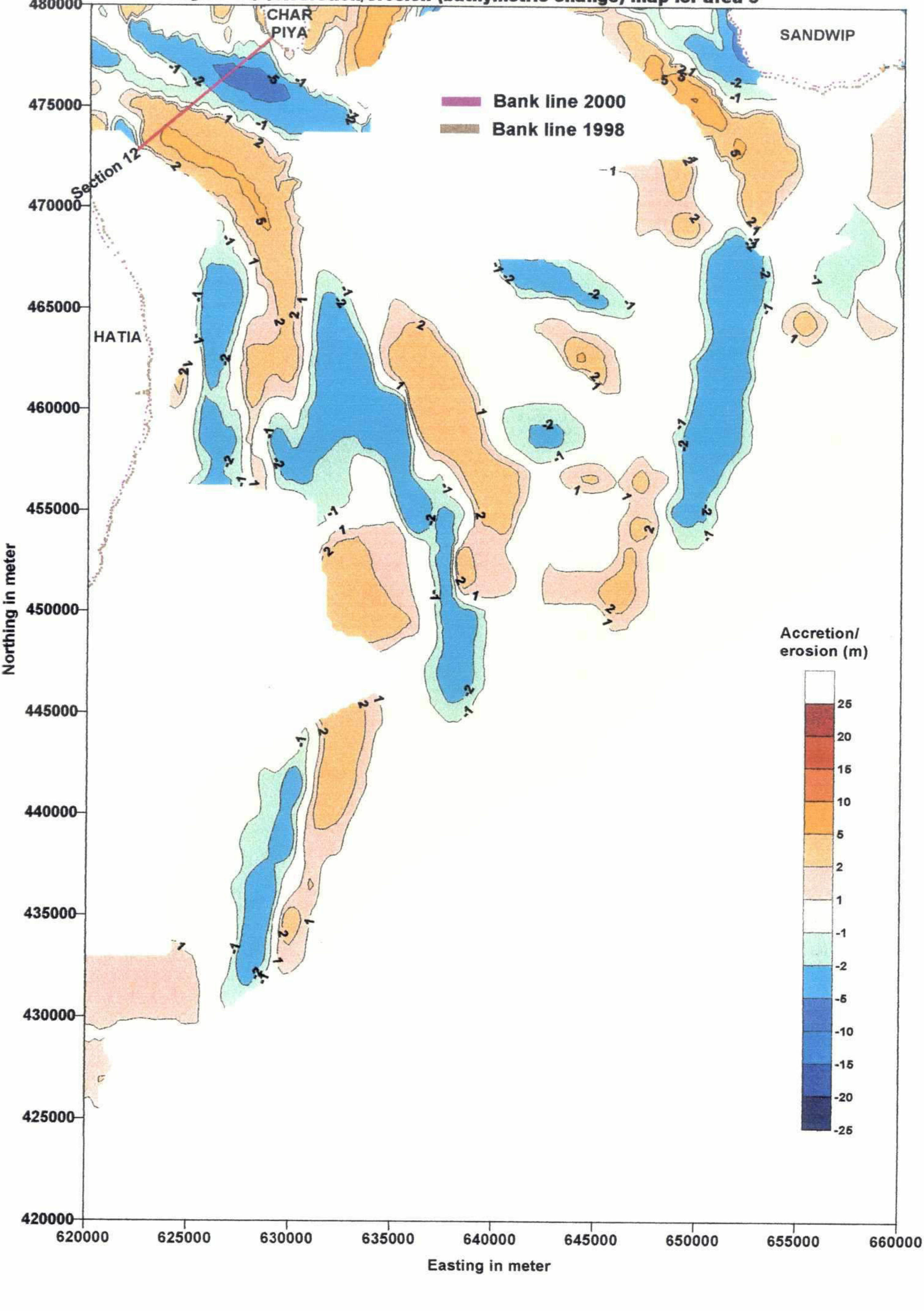

Figure 9(d) : Cross section at locations in 1997 and 2000

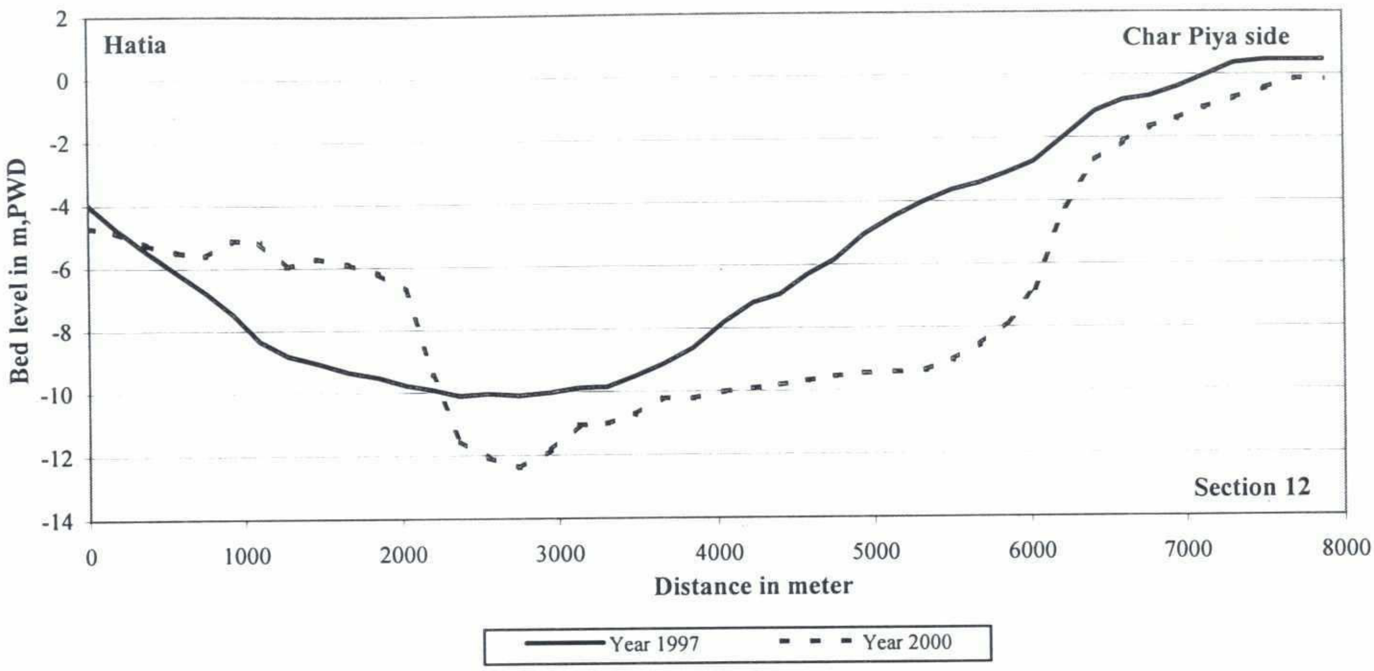

Figure 10 (a) Contour map of bathymetry (1997) for Area 6

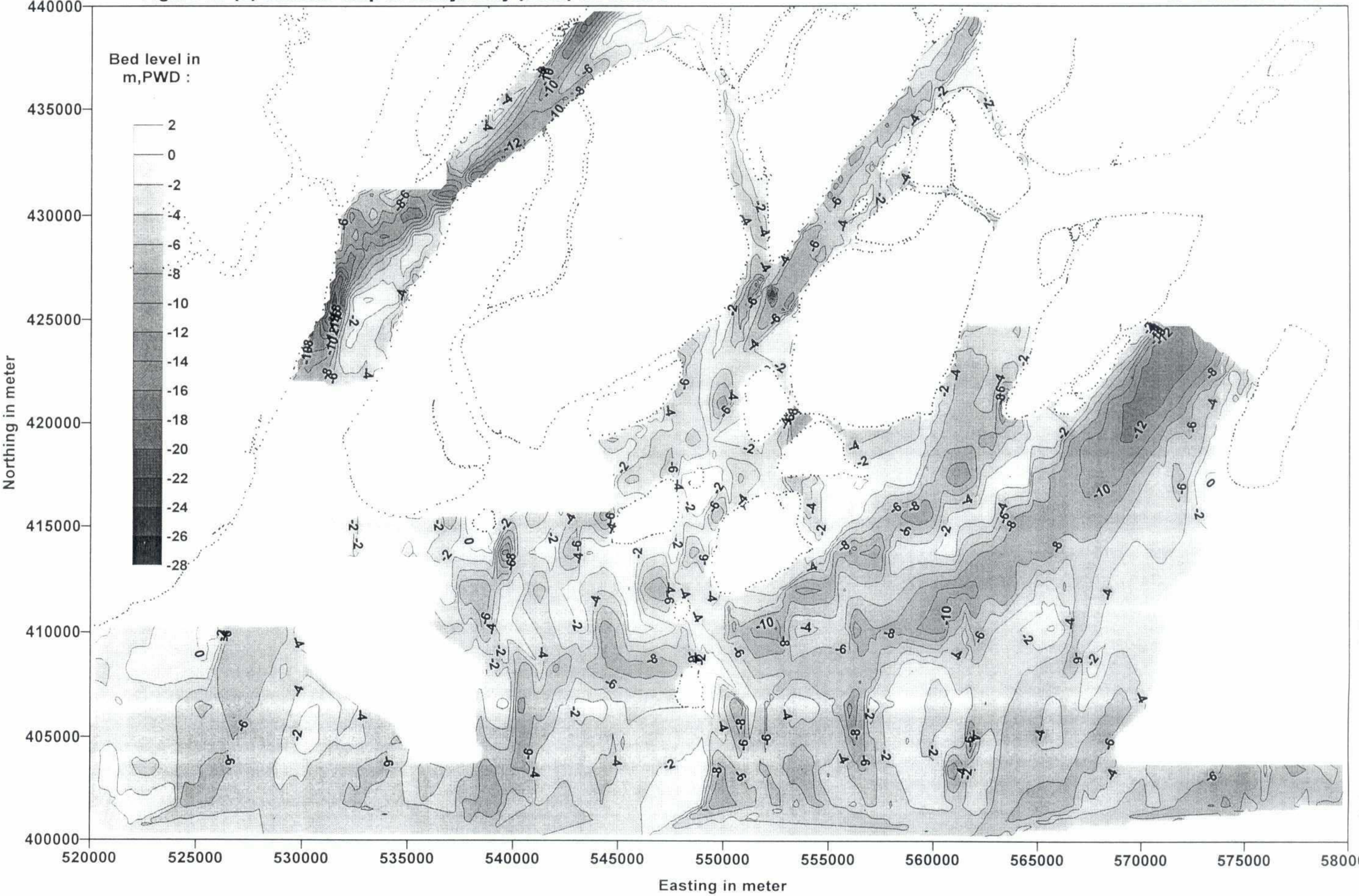

Figure 10 (b)

## Figure 10 (b) Contour map of bathymetry (2000) for Area 6

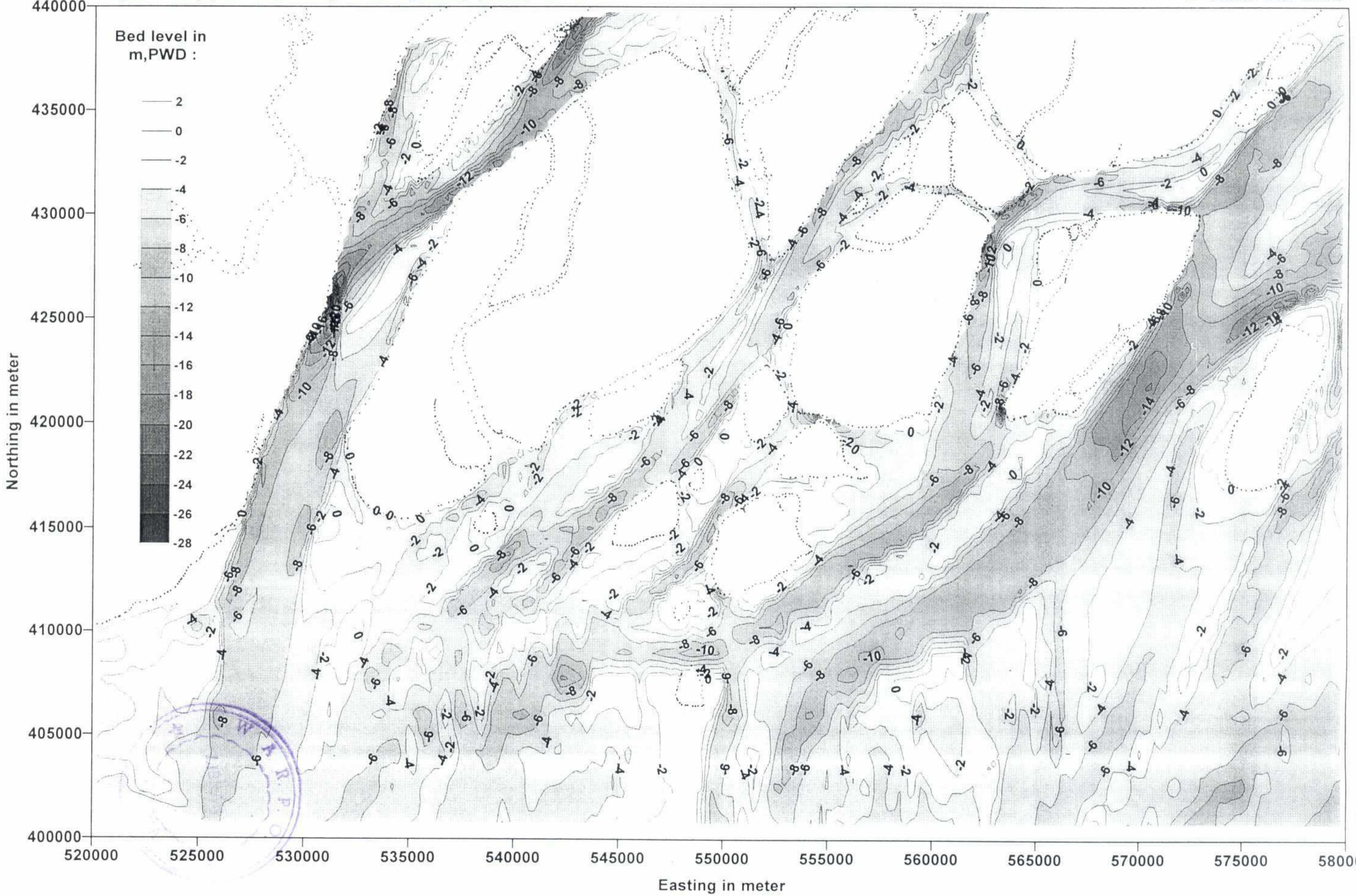

Figure 10 (c)

**Figure 10 (c) Accretion/erosion (bathymetric change) map for area 6**

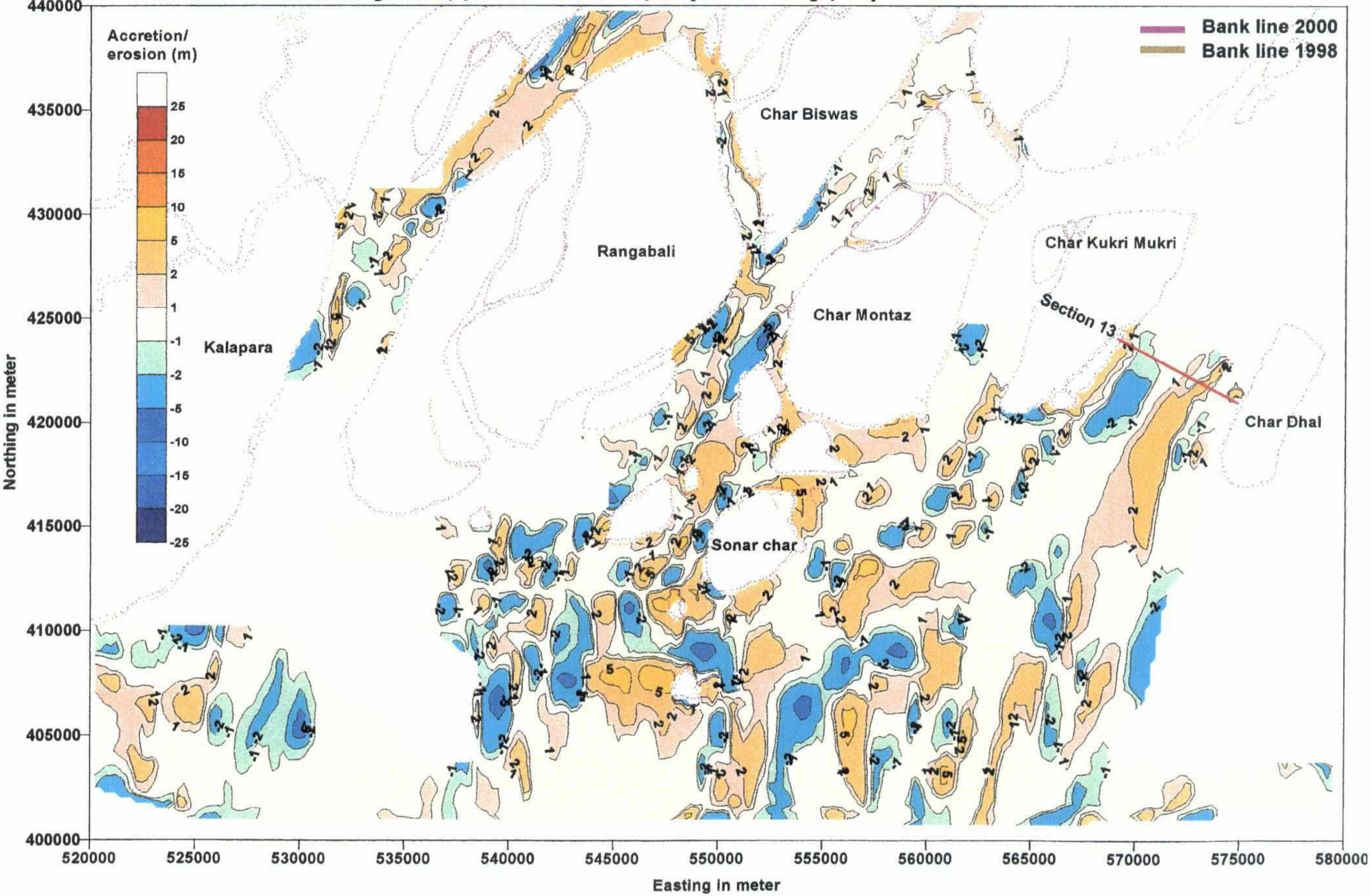

Figure 10(d) : Cross section at locations in 1997 and 2000

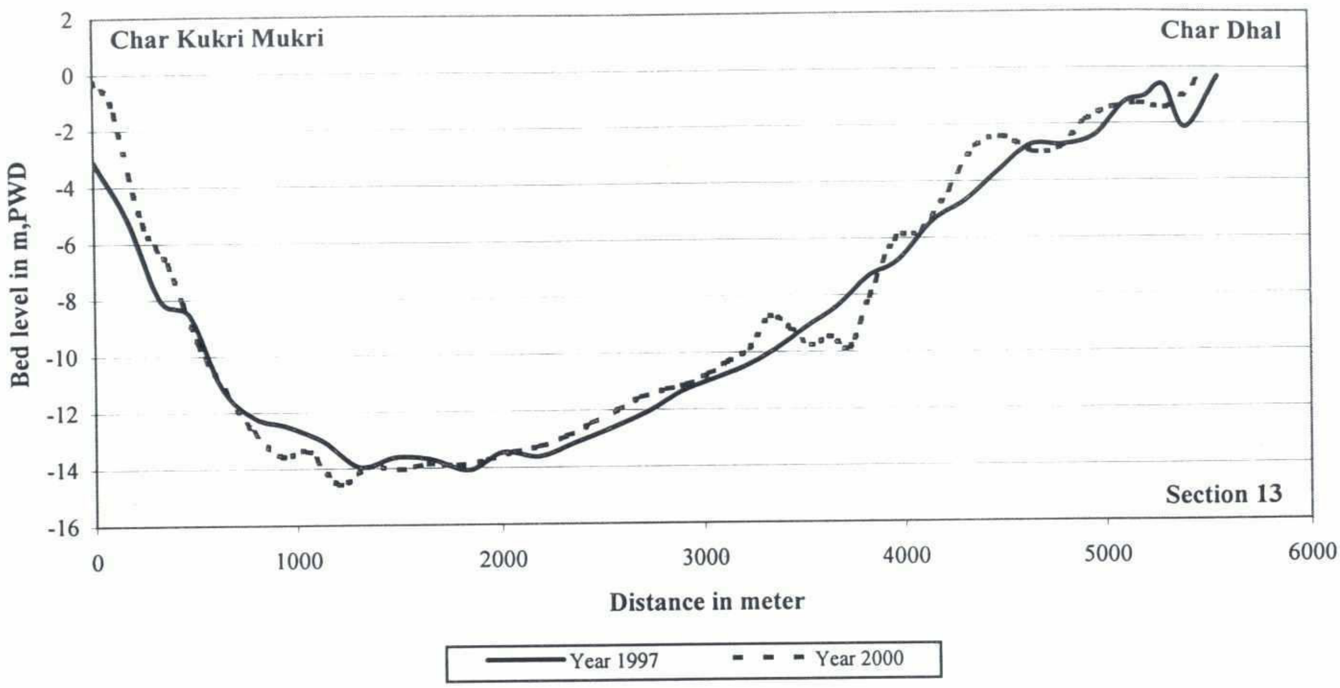

**Figure 11 (a) Contour map of bathymetry (1997) for Area 7**

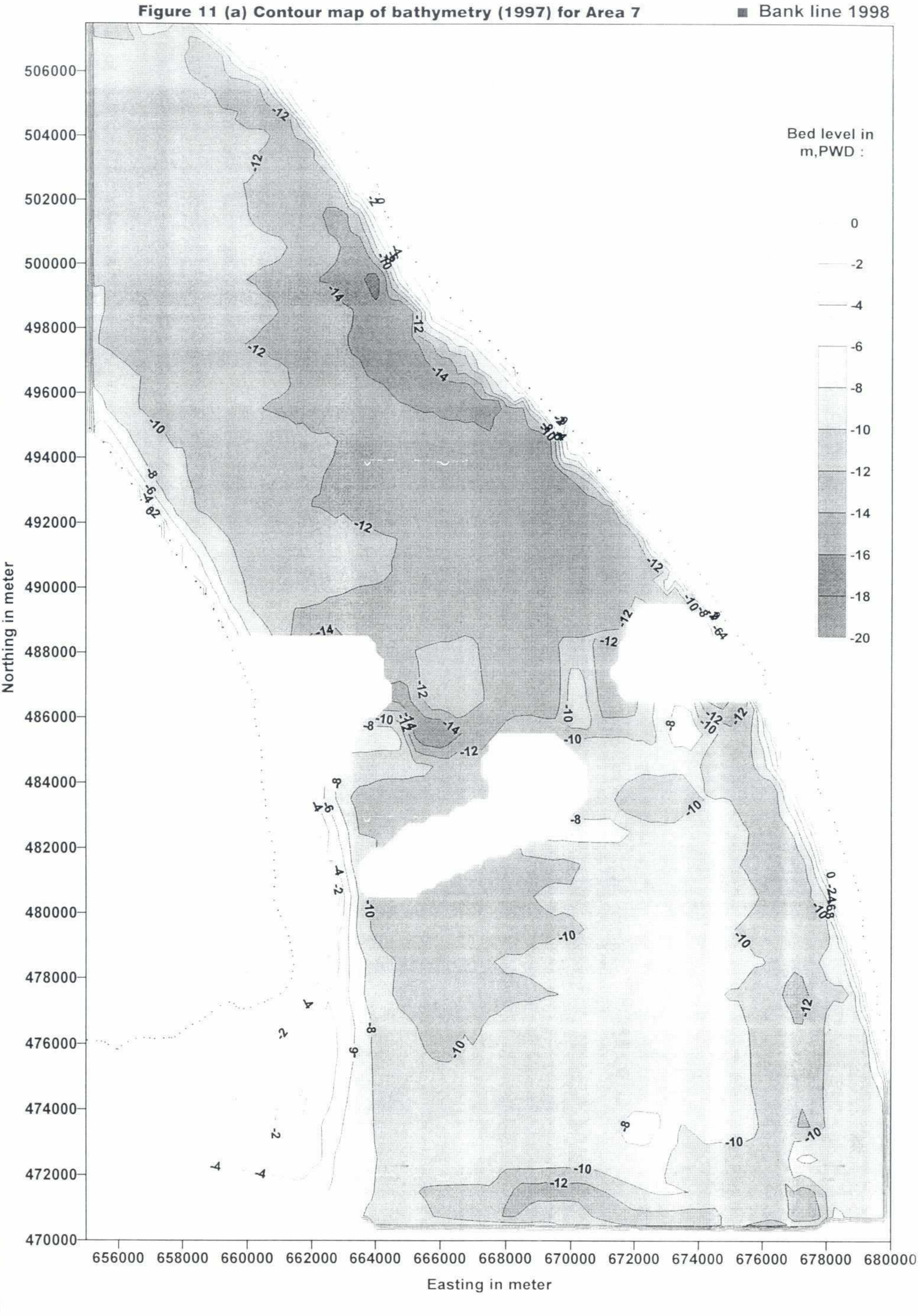

**Figure 11 (b) Contour map of bathymetry (2000) for Area 7**

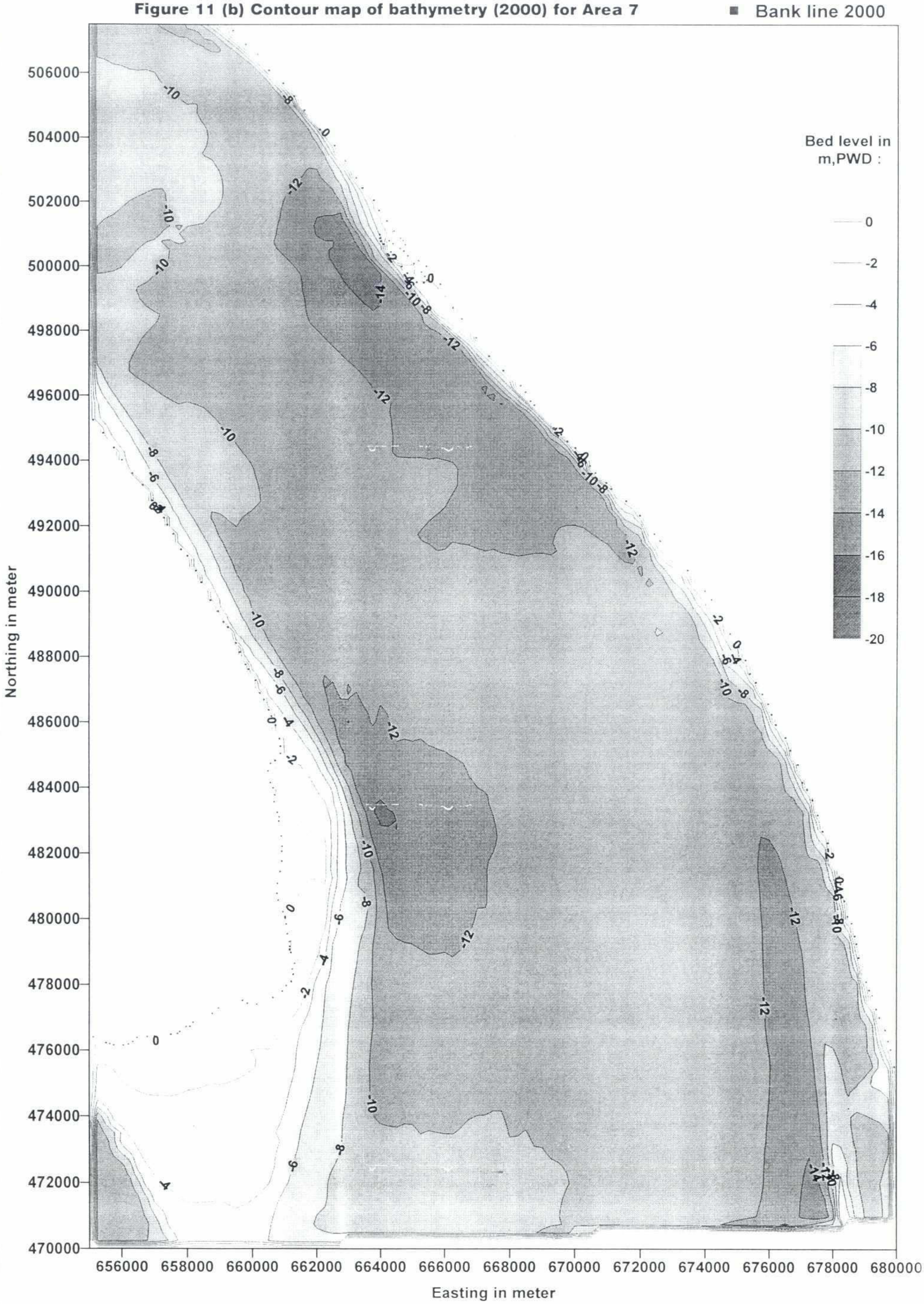

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**Figure 11 (c) Accretion/erosion (bathymetric change) map for area 7**

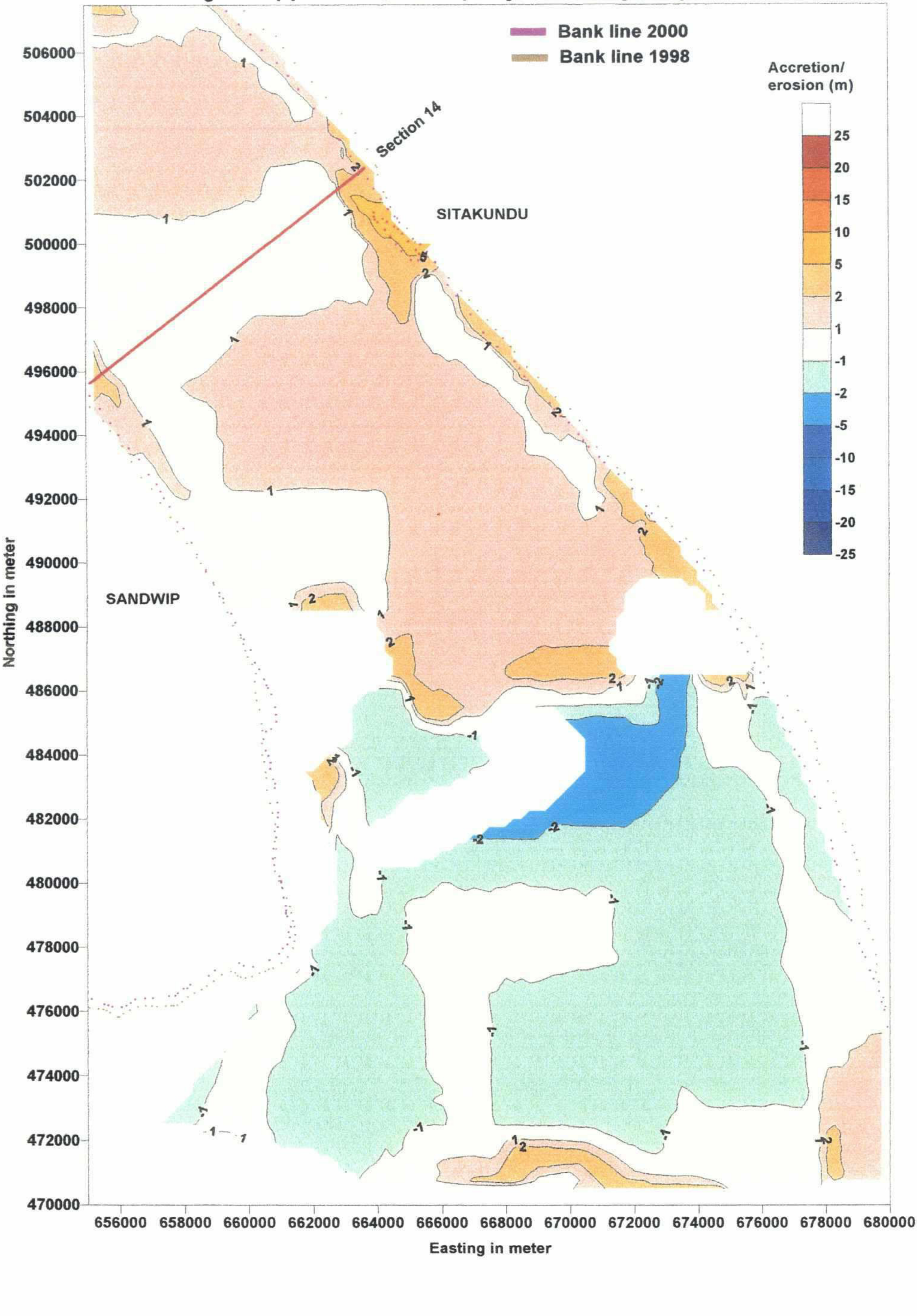

Figure 11(d) : Cross section at locations in 1997 and 2000

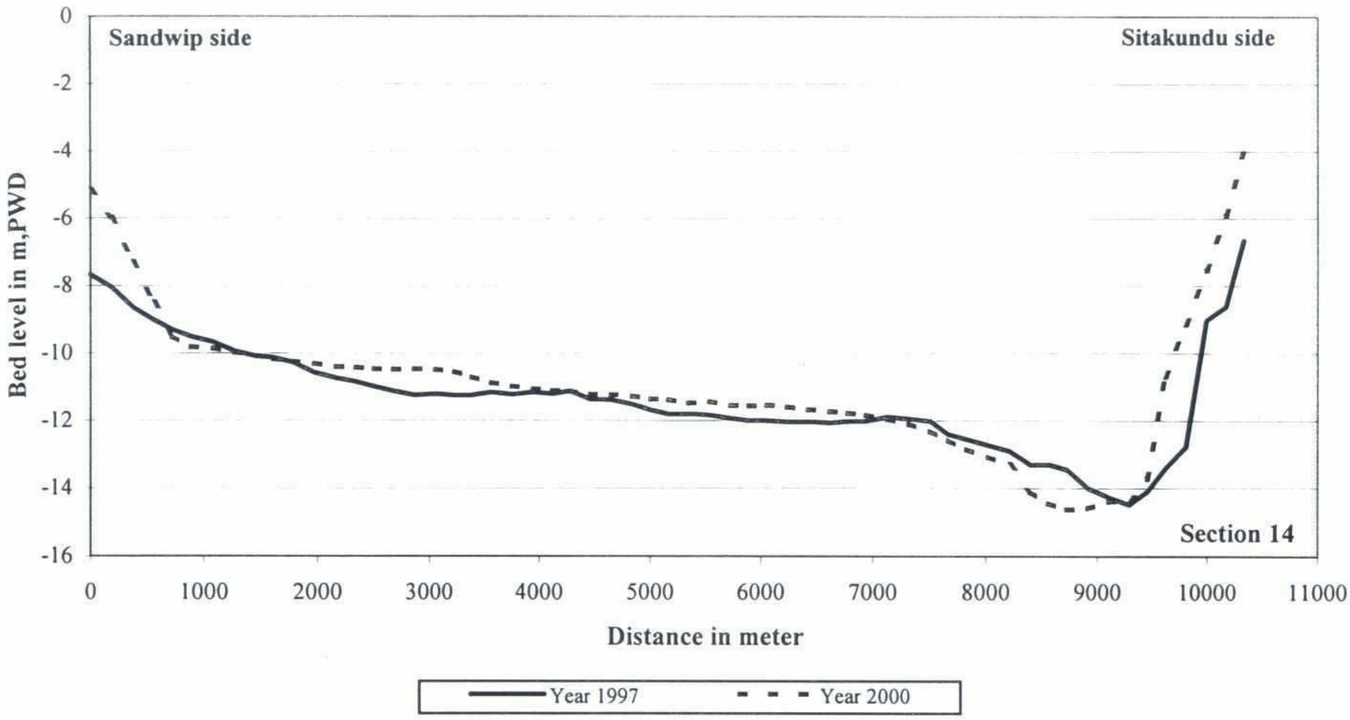

Figure 12 (a) Contour map of bathymetry (1987) around Manpura

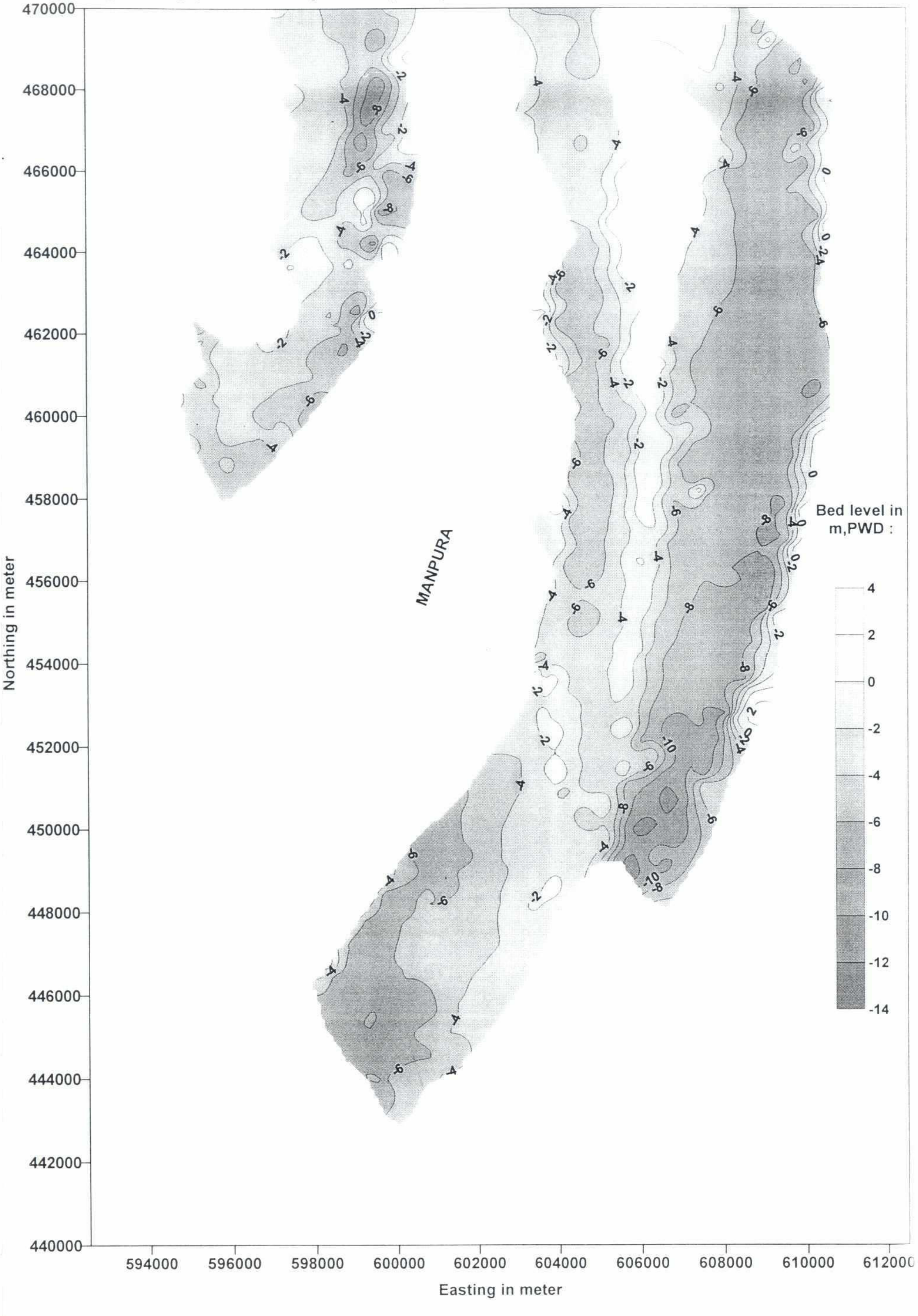

Figure 12 (b) Contour map of bathymetry (2000) around Manpura

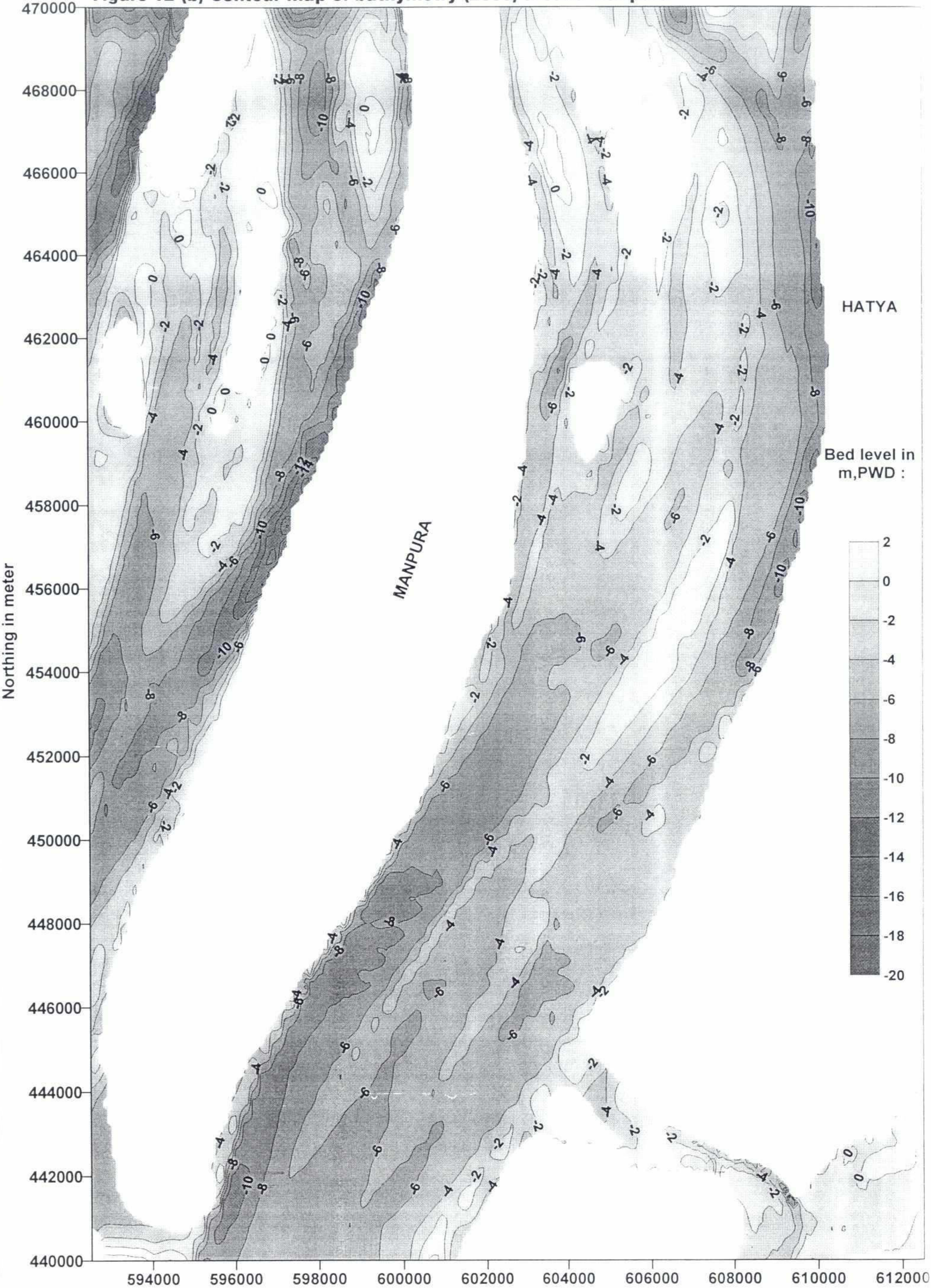

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**Figure 12 (c) Accretion/erosion (bathymetric change) map around Manpura (1987 to 2000)**

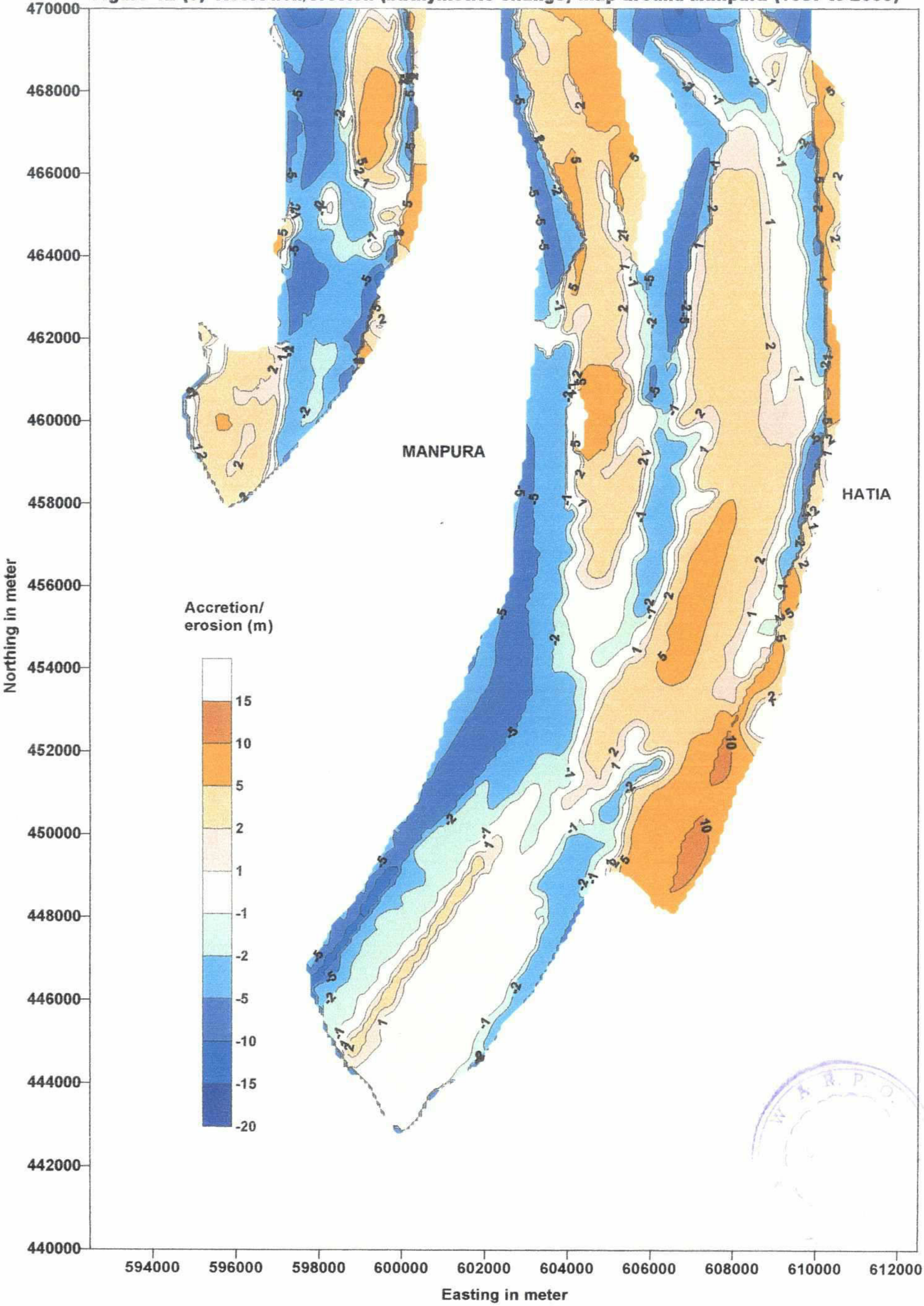

**Figure 13 (a) Contour map of bathymetry (1988) around Nijhumdwip**

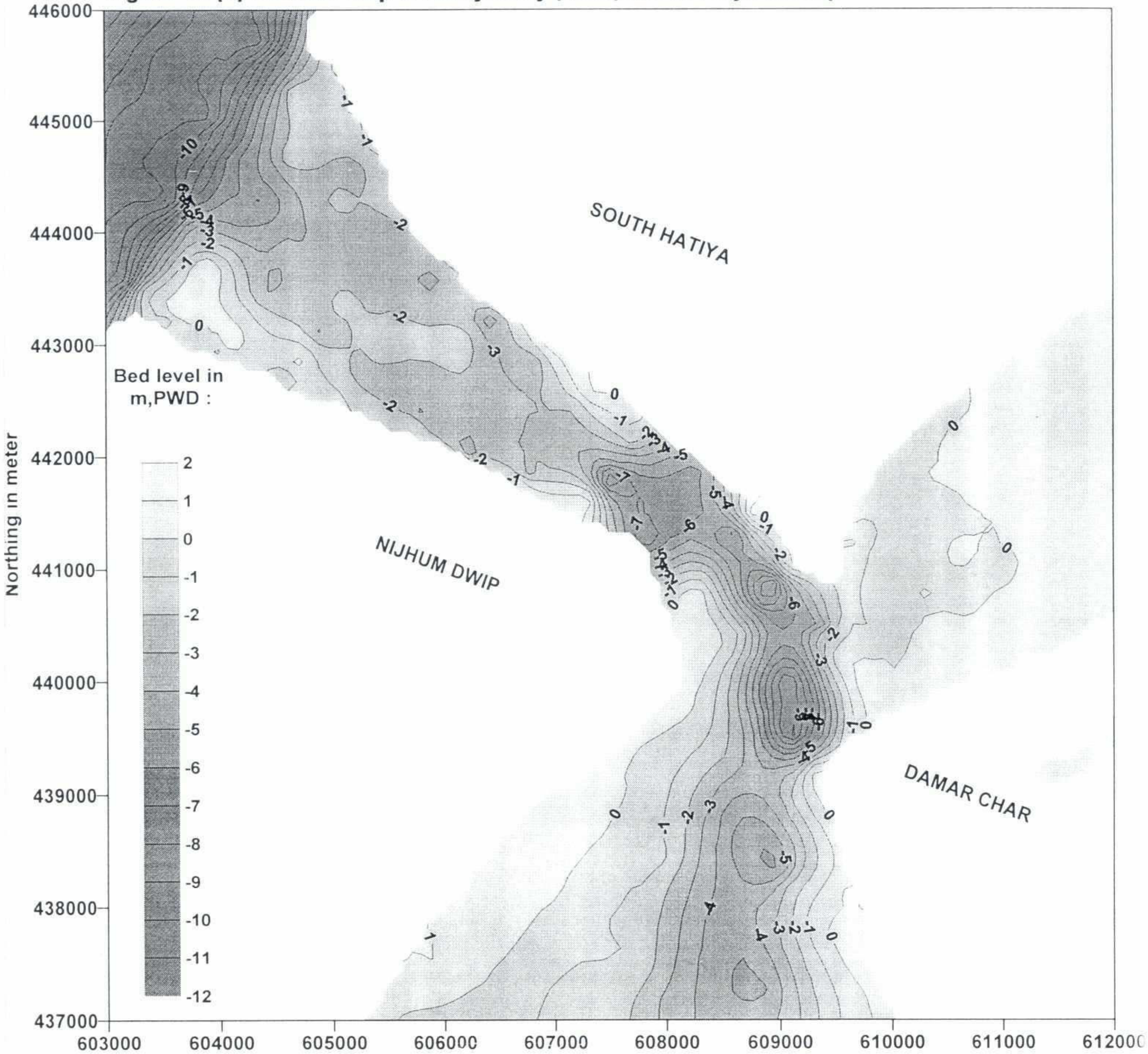

**Figure 13 (b) Contour map of bathymetry (2000) around Nijhumdwip**

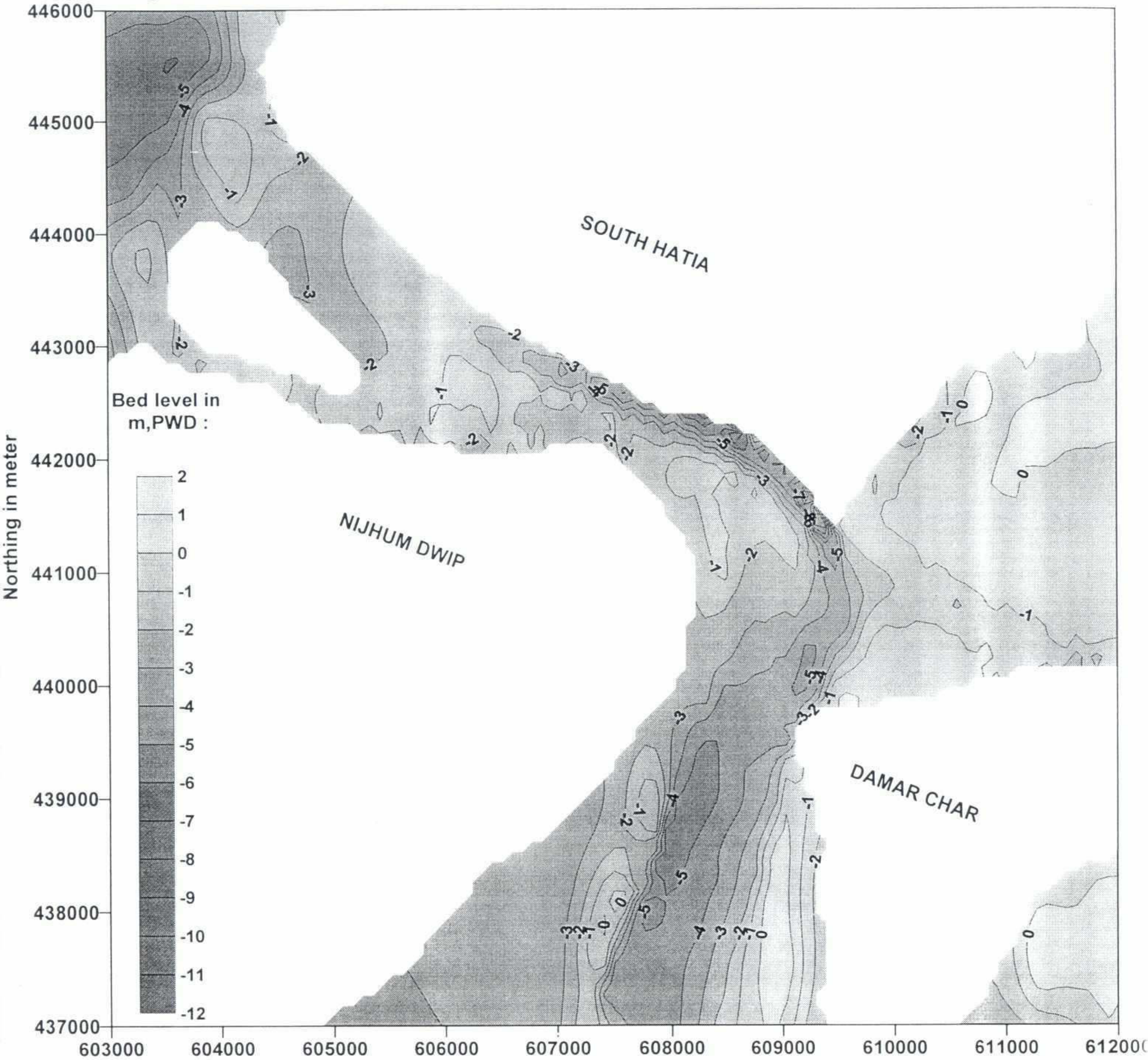

**Figure 13 (c) Accrtion/erosion (bathymetric change) map around Nijhumdwip (1988 to 2000)**

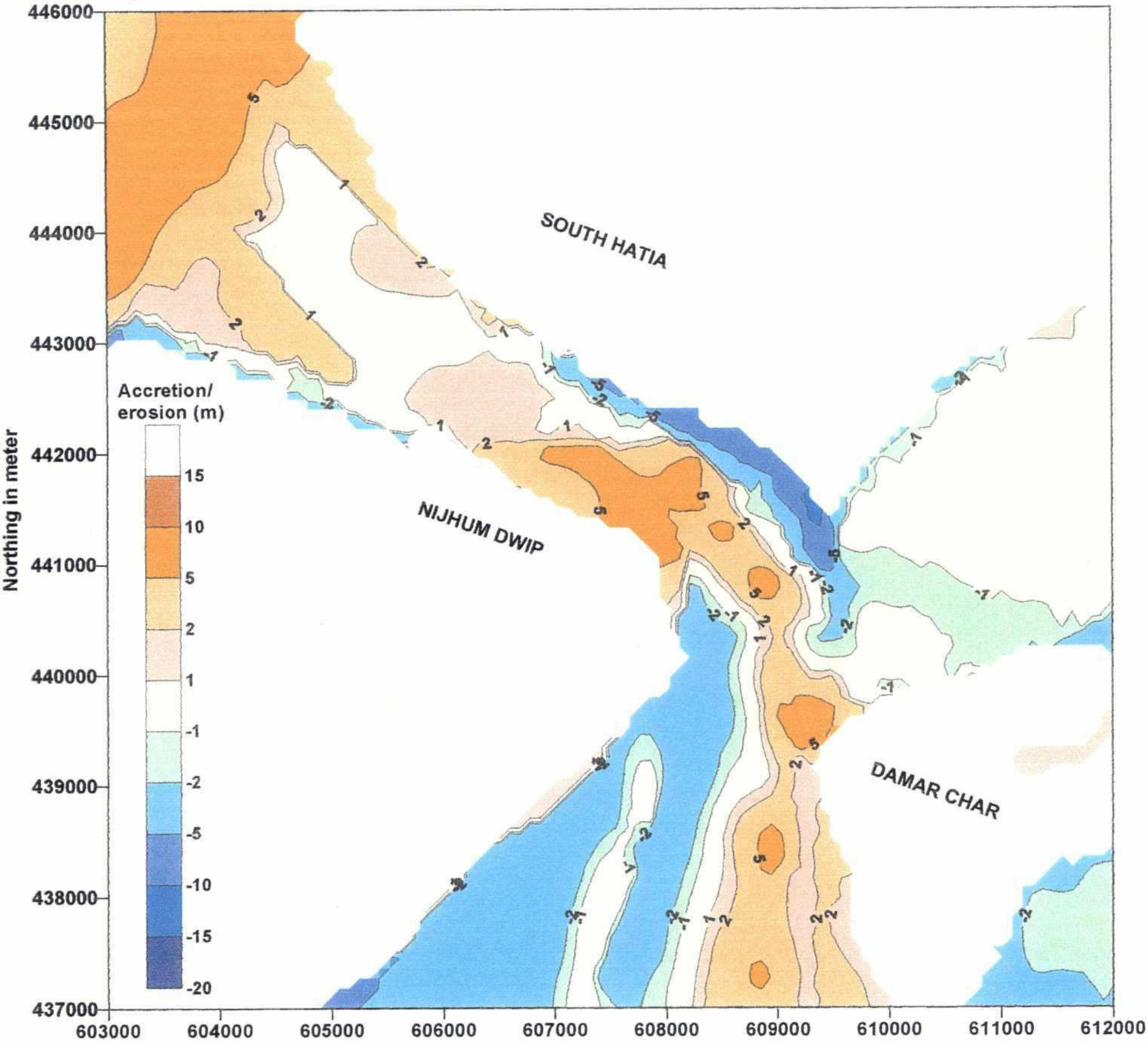

Figure 14 (a) Contour map of bathymetry (1986) around Northeast of Bhola

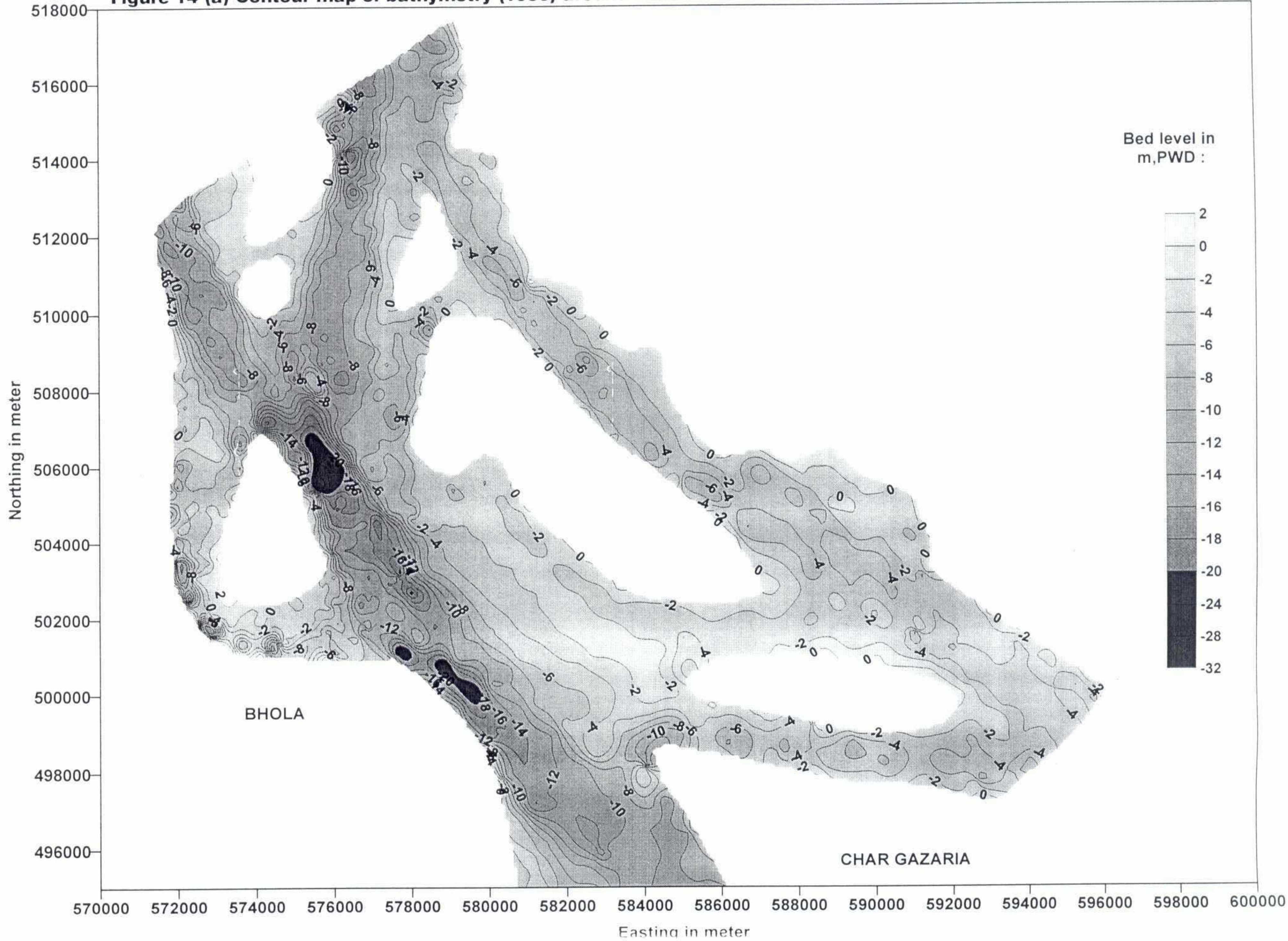

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**Figure 14 (b) Contour map of bathymetry (2000) around Northeast of Bhola**

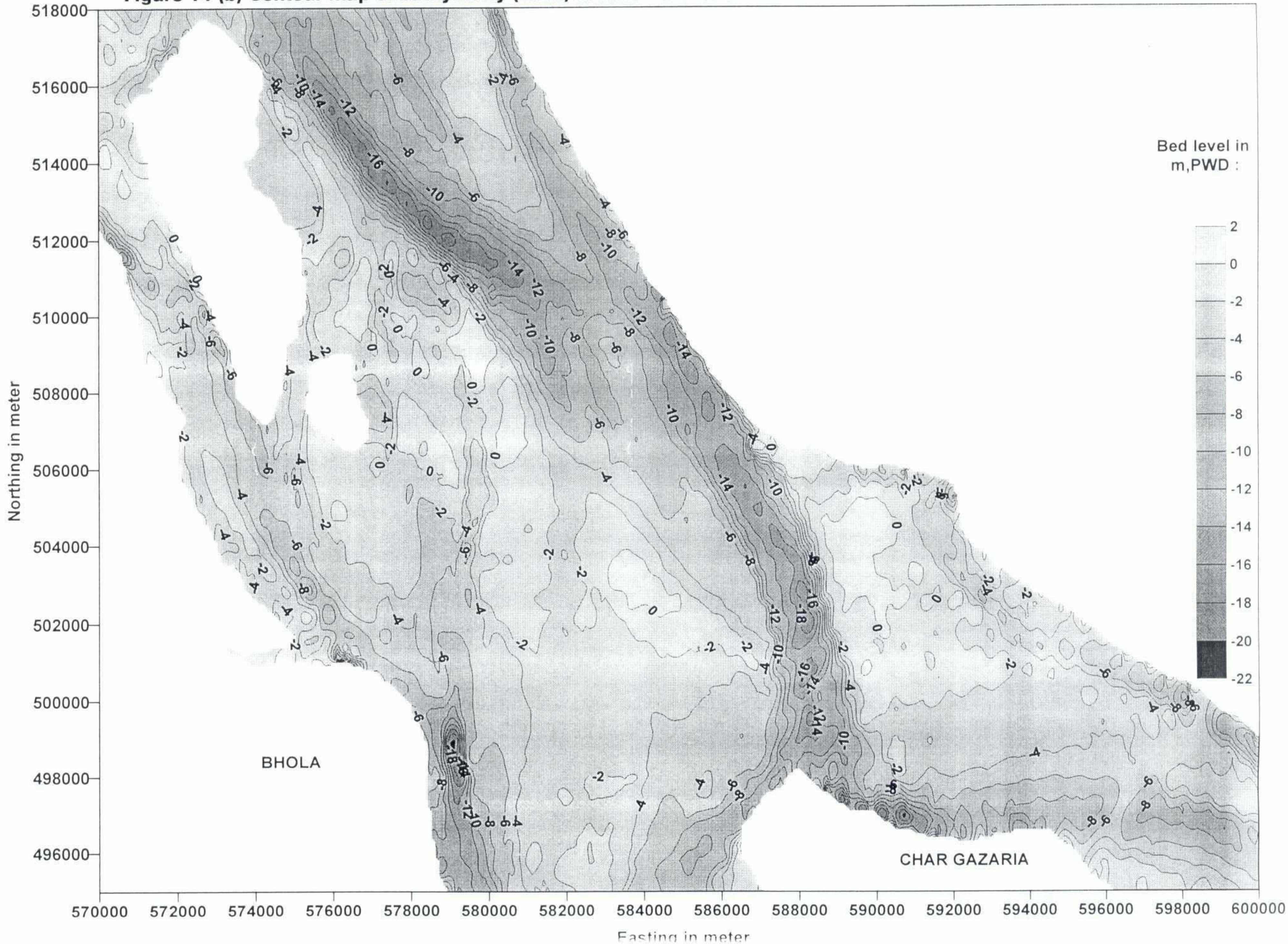

Figure 14(c) Accretion/erosion (bathymetric change) map around Northeast of Bhola (1986 to 2000)

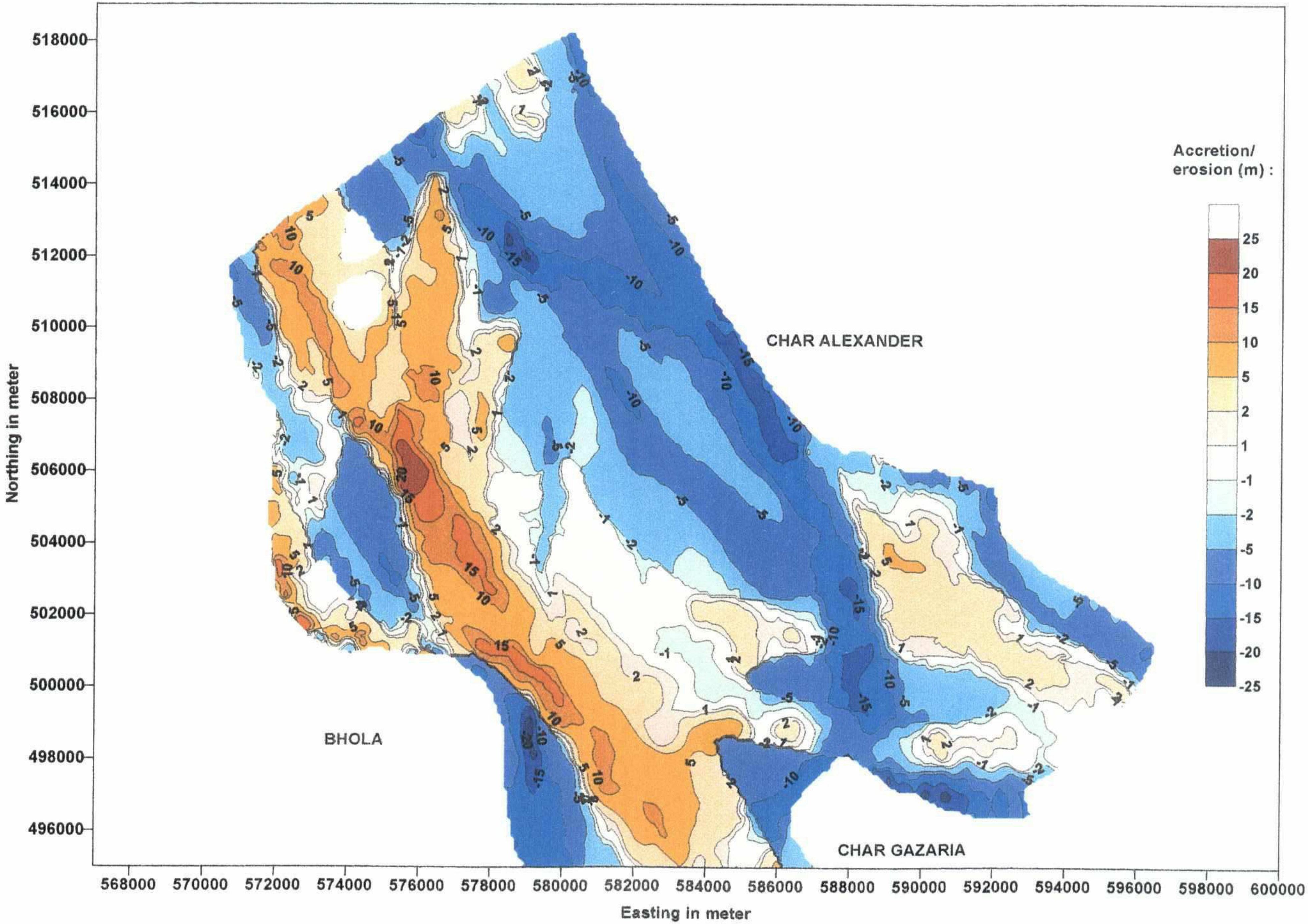


Figure 14 (c)

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**Figure 15 (a) Contour map of bathymetry (1990) around Urir Char**

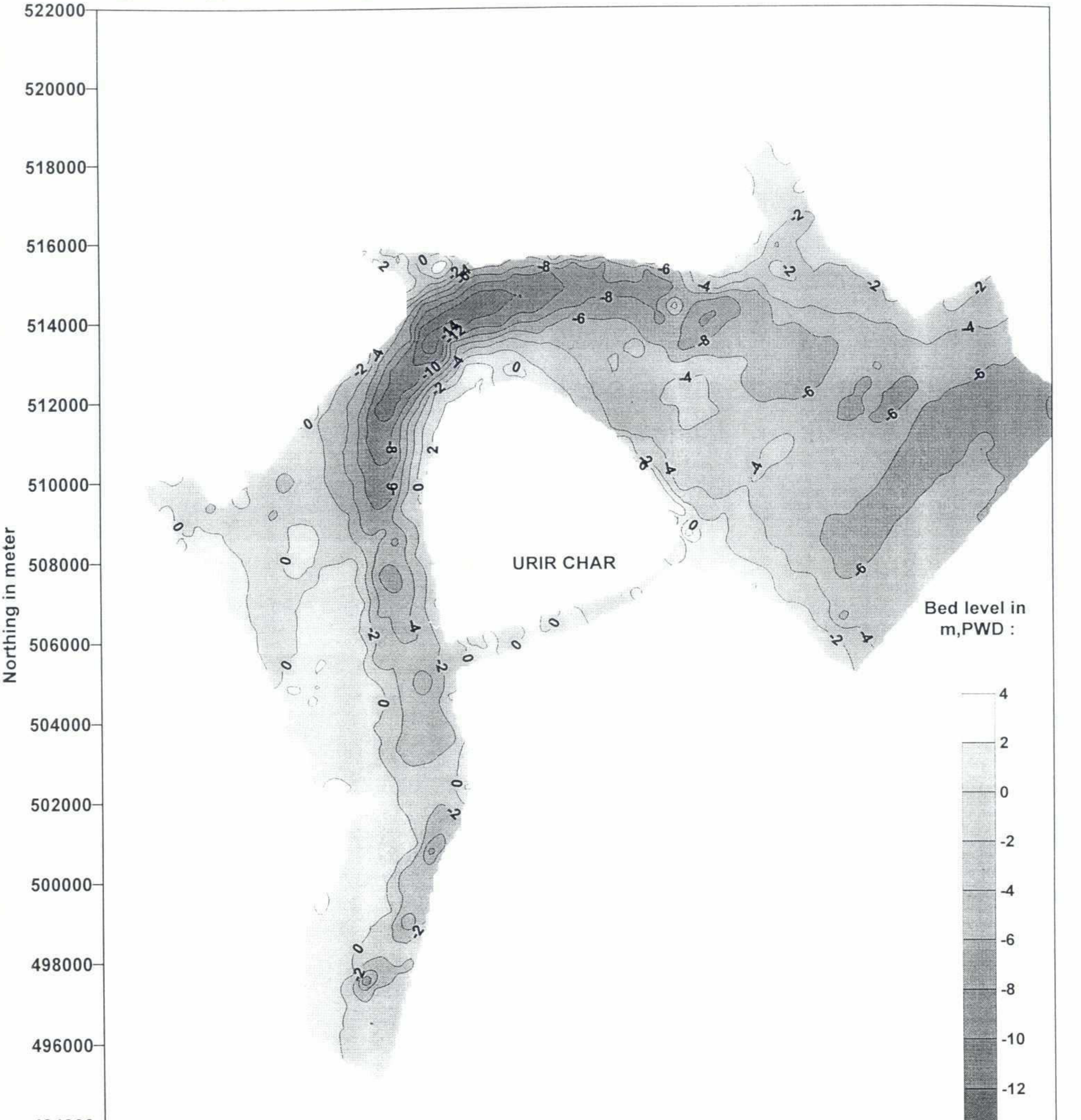

Figure 15 (b) Contour map of bathymetry (2000) around Urir Char

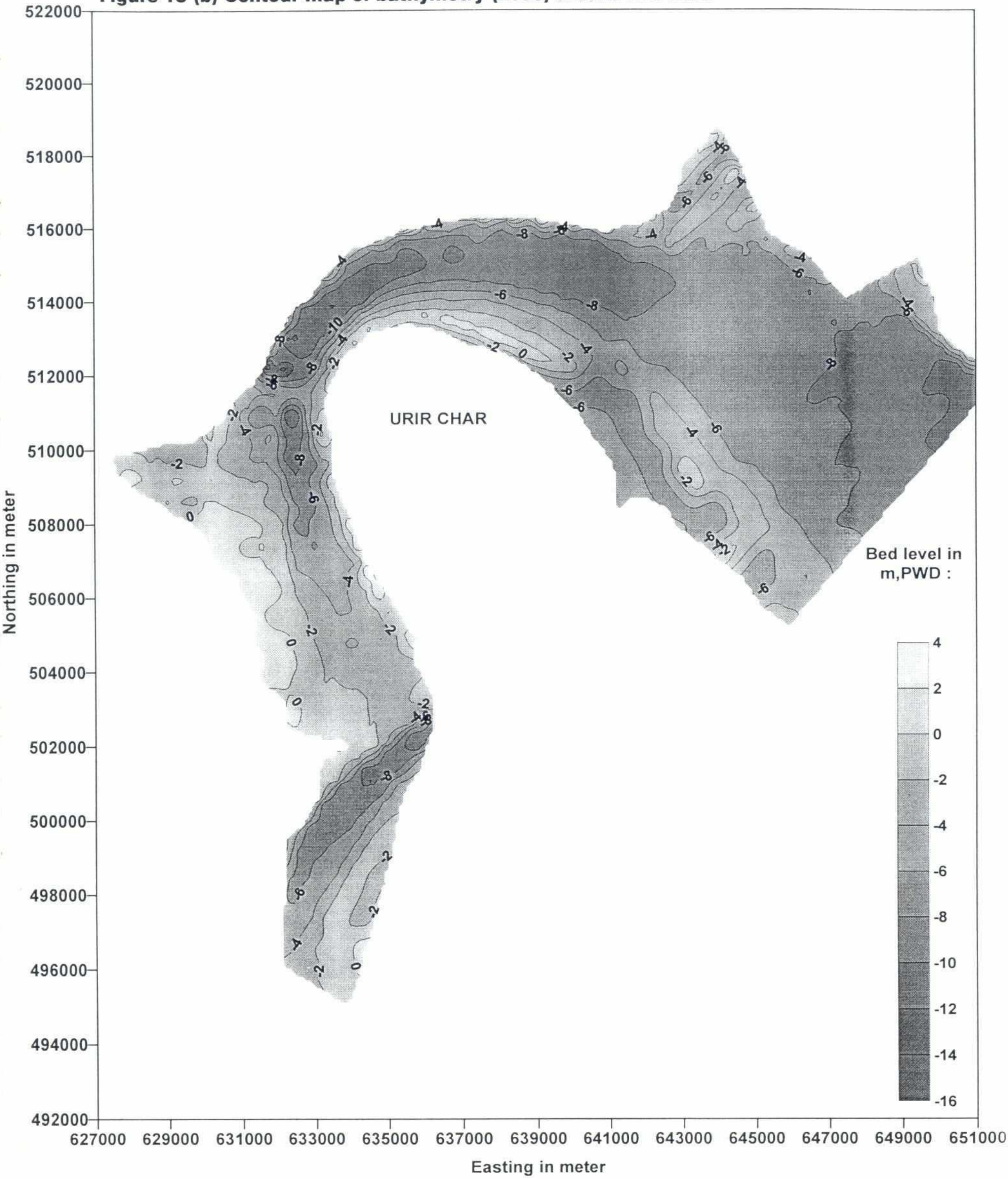

Figure 15 (c) Accretion/erosion (bathymetric change) map around Urirchar (1990 to 2000)

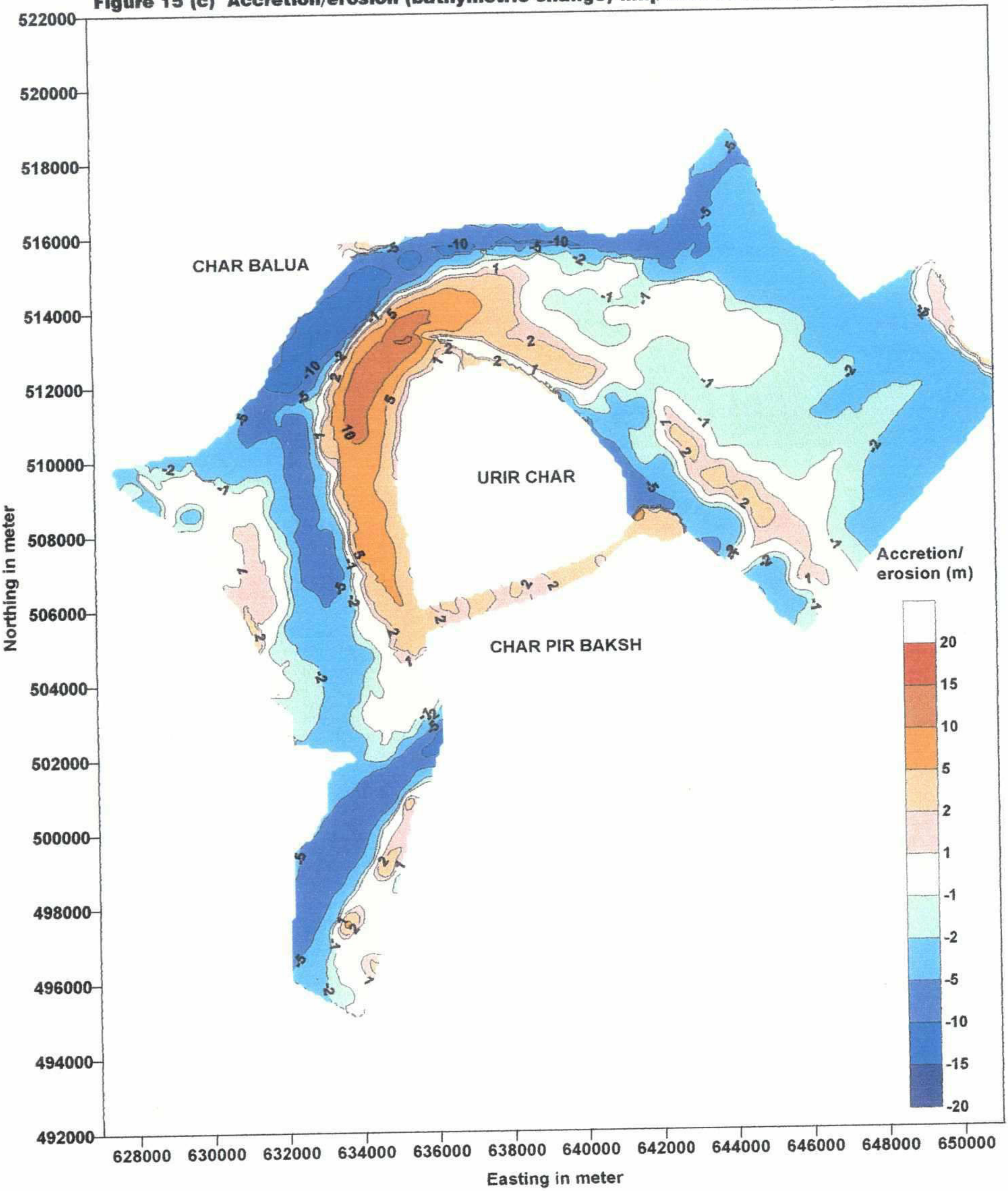

**Figure 16 : Contour map bathymetry (January 1988) for Nijhumdwip channel**

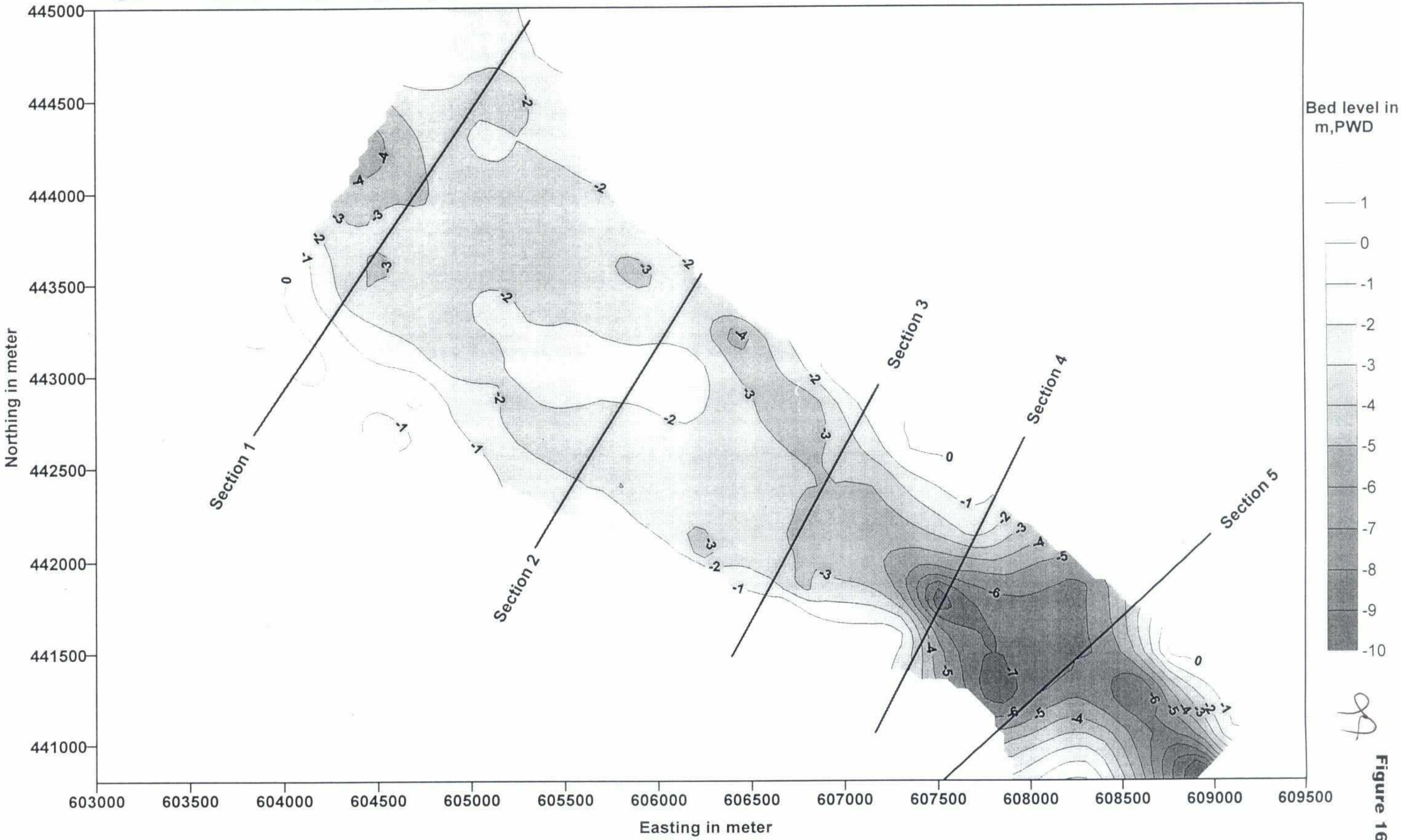


Figure 16

**Figure 17 : Contour map of bathymetry (March 1997) for Nijhumdwip channel**

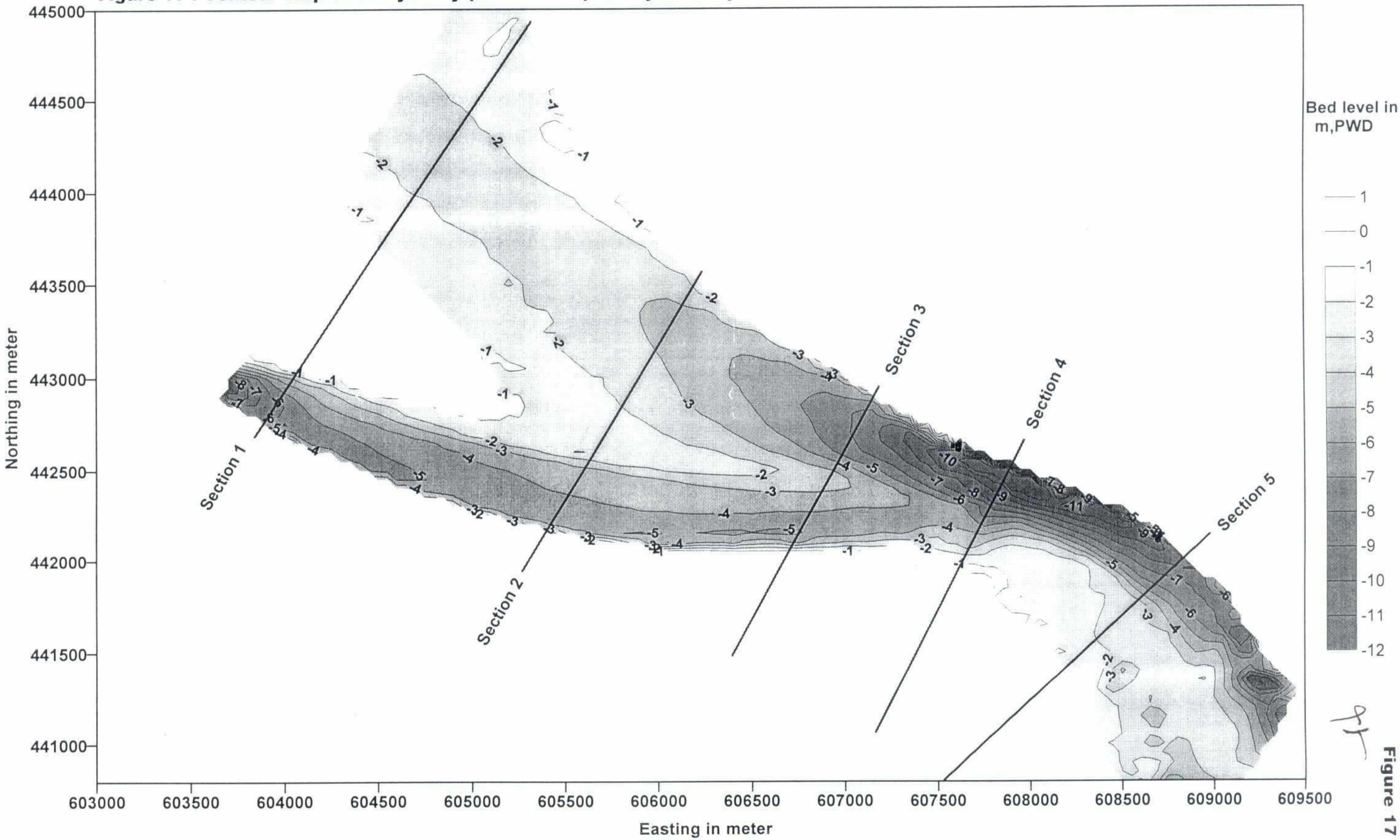

**Figure 19 : Contour map of bathymetry (June 2000) for Nijhumdwip channel**

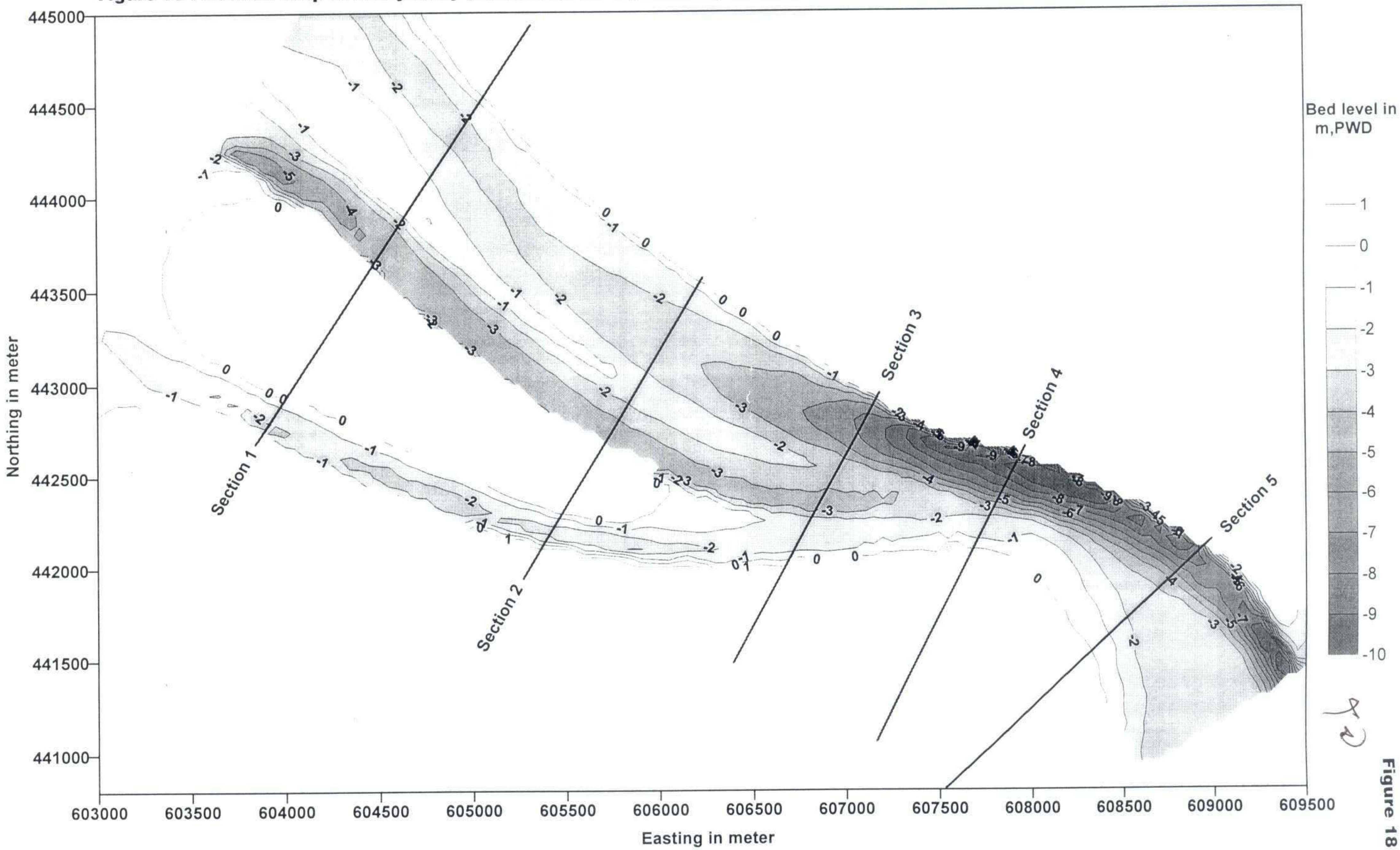

**Figure 18 : Contour map of bathymetry (July 1999) for Nijhumdwip channel**

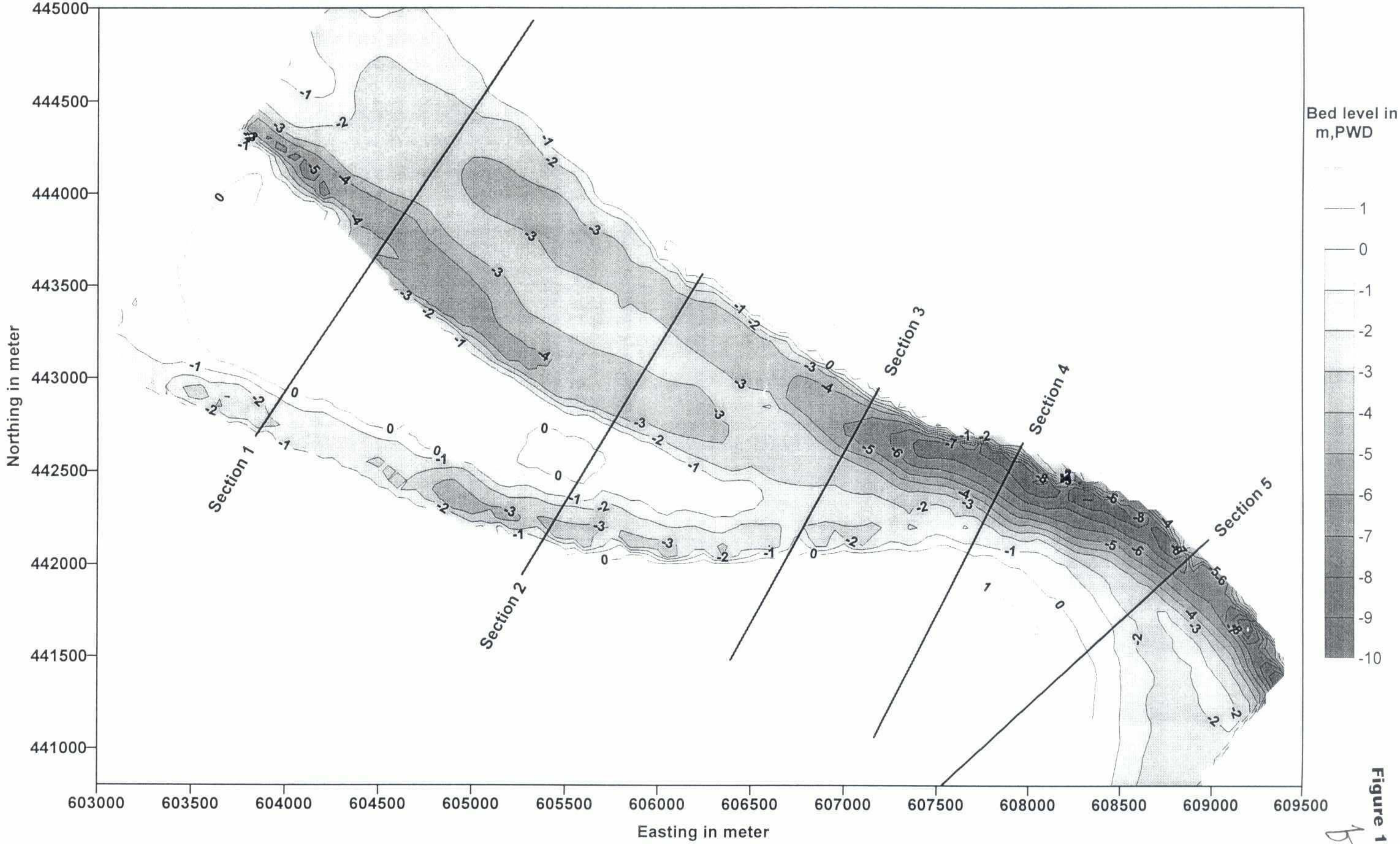


**Figure 19**

Figure 20 : Contour map of bathymetry (November 2000) for Nijhumdwip channel

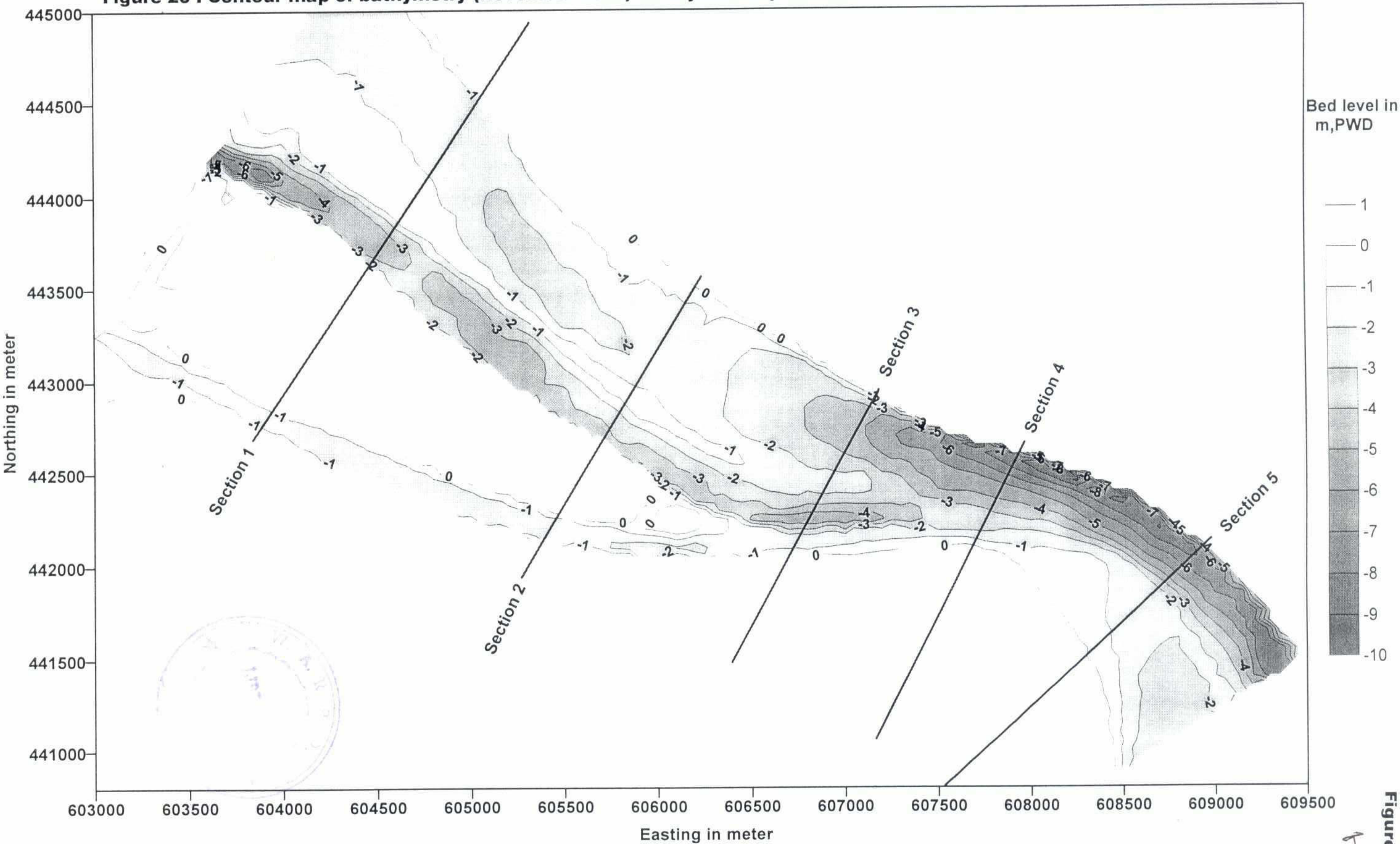


Figure 20

**Figure 21 : Accretion/erosion (bathymetric change) map for Nijhumdwip channel (1988 to 1997)**

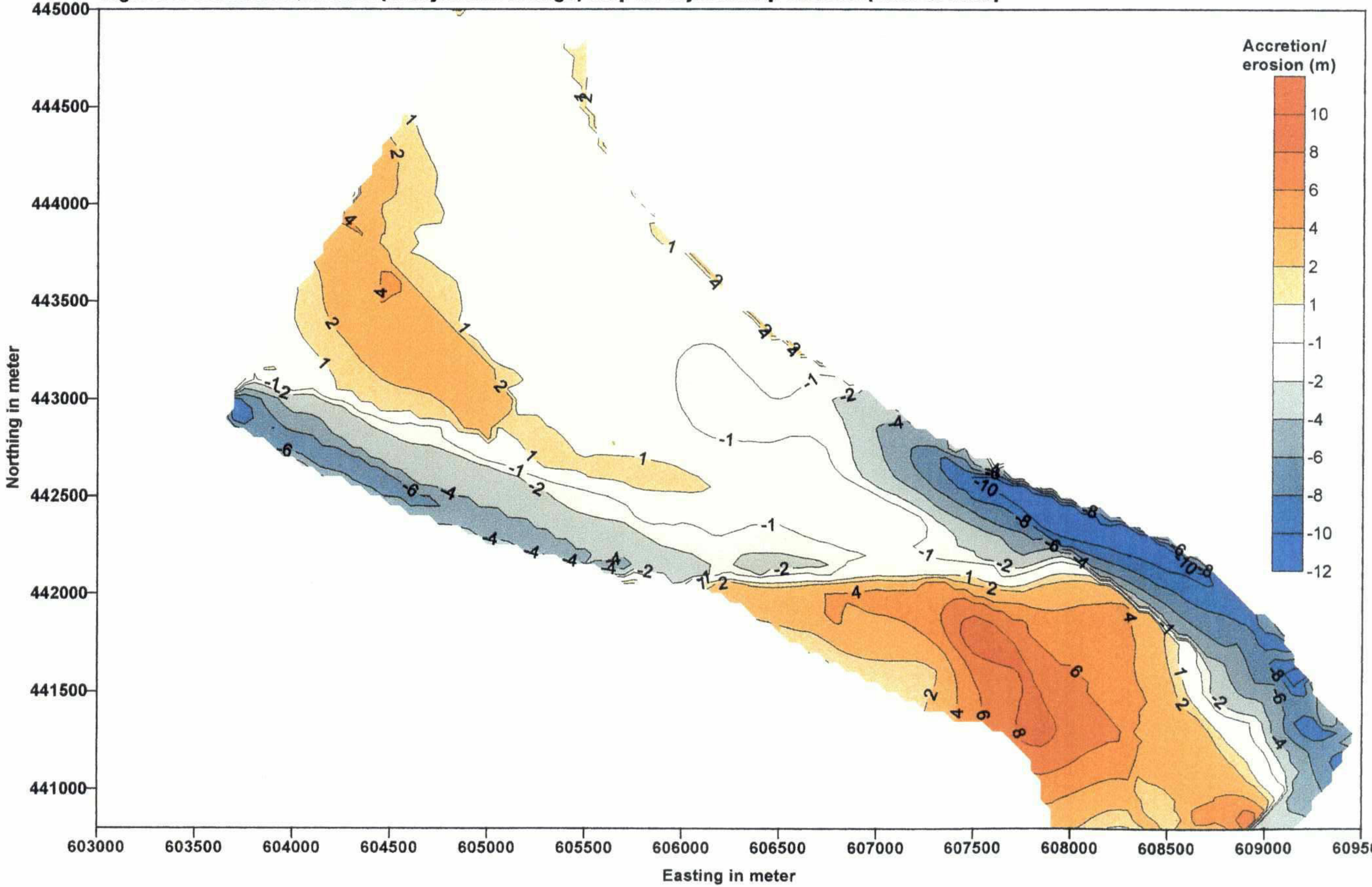

Figure 22 : Accretion/erosion map (bathymetric change) for Nijhumdwip channel (1997 to 1999)

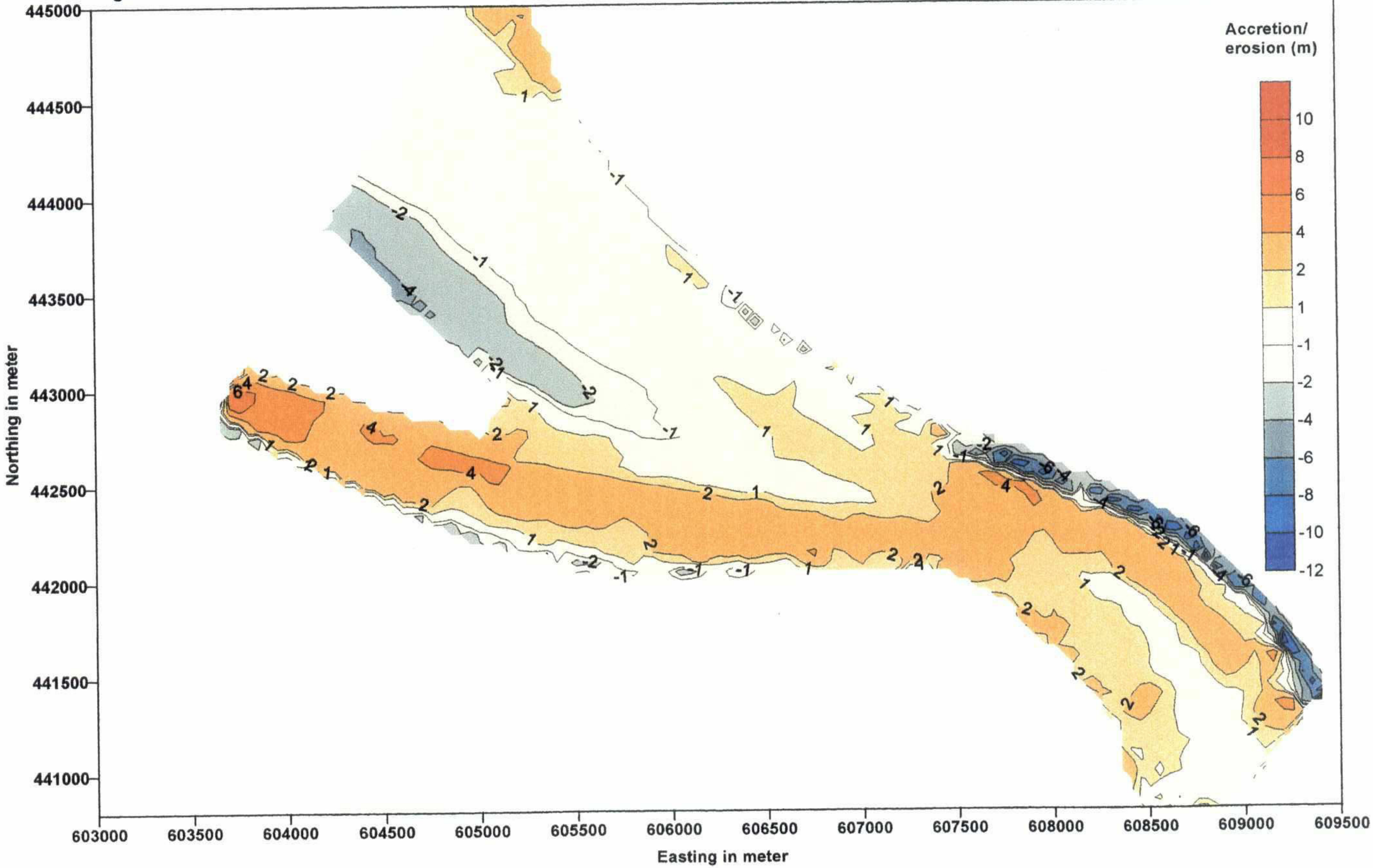

Figure 23

**Figure 23 : Accretion/erosion (bathymetric change) map for Nijhumdwip channel (1999 to 2000)**

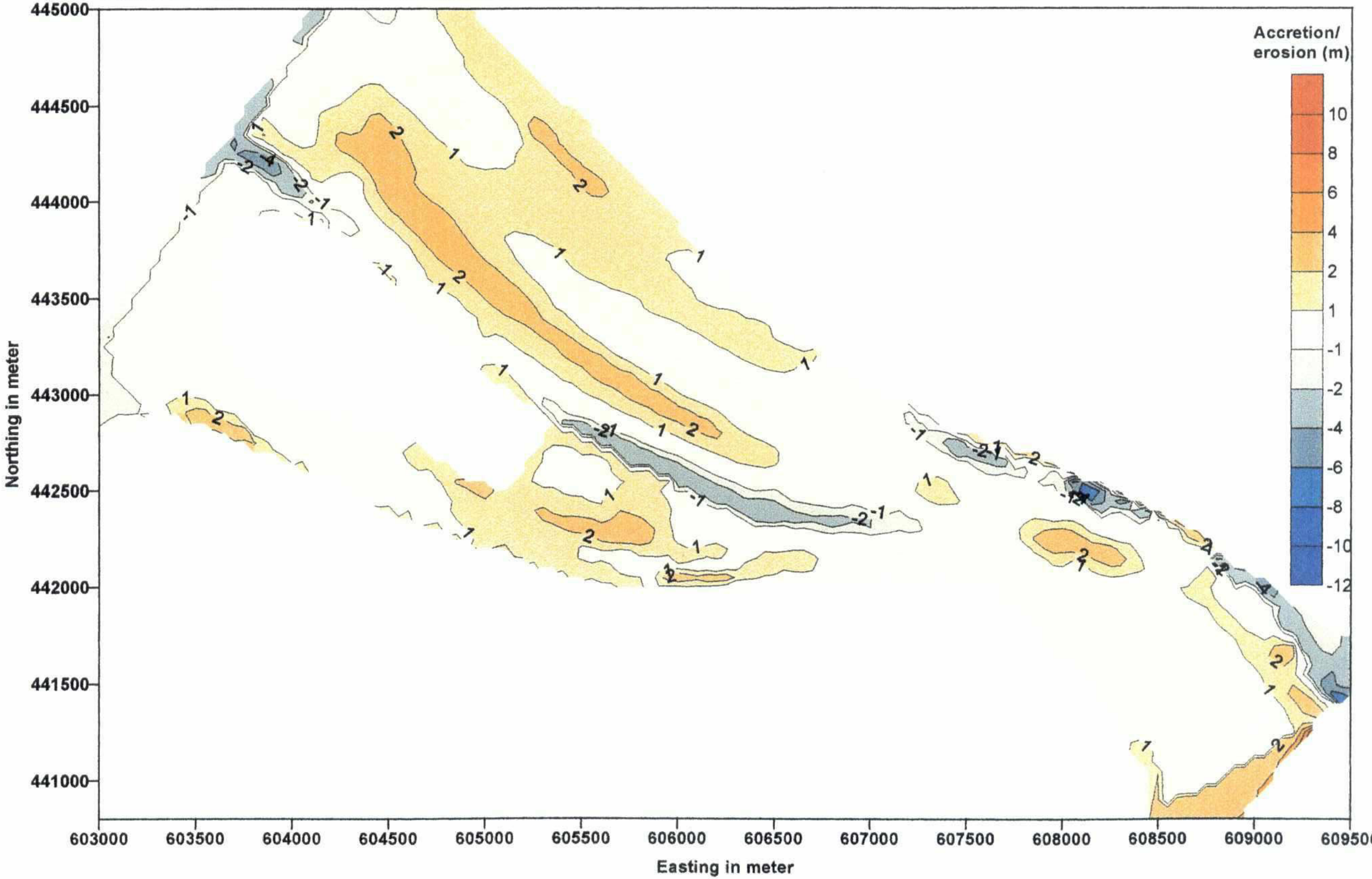

Figure 24

Figure 24 : Accretion/erosion (bathymetric change) map for Nijhumdwip channel (June to November 2000)

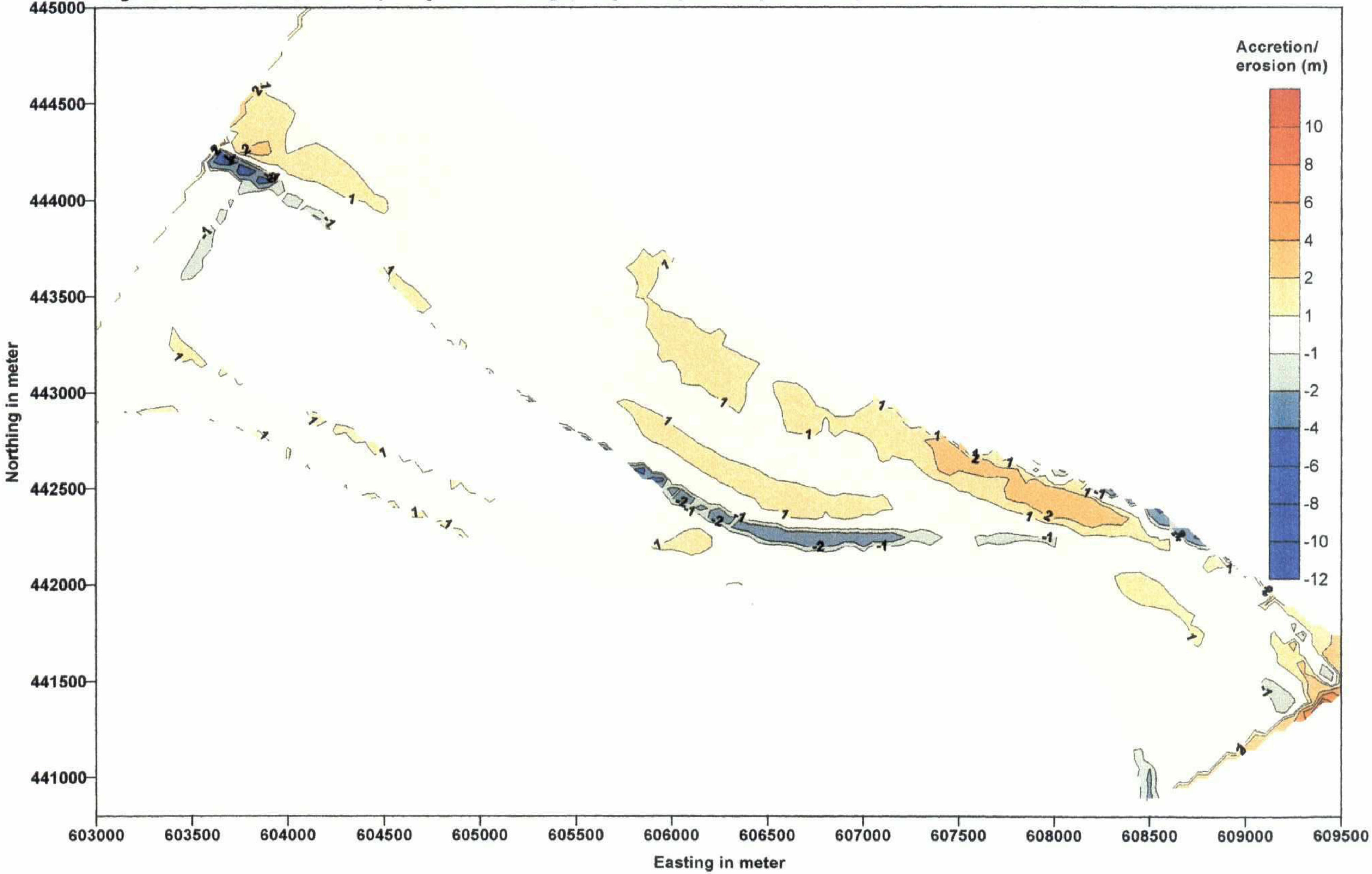

**Figure 25 : Cross-sections in Nijhumdwip channel**

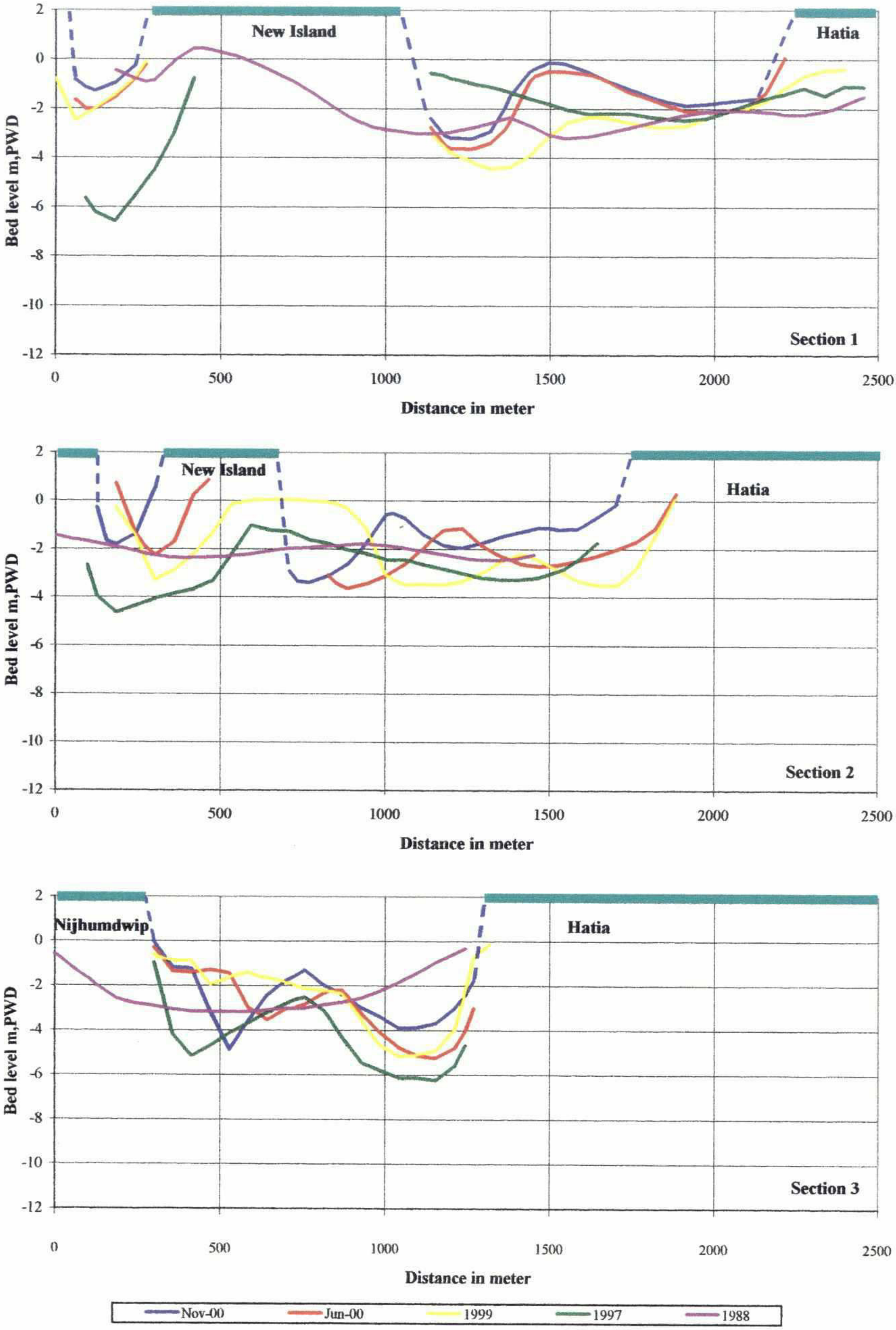

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**Figure 26 : Cross-sections in Nijhumdwip channel**

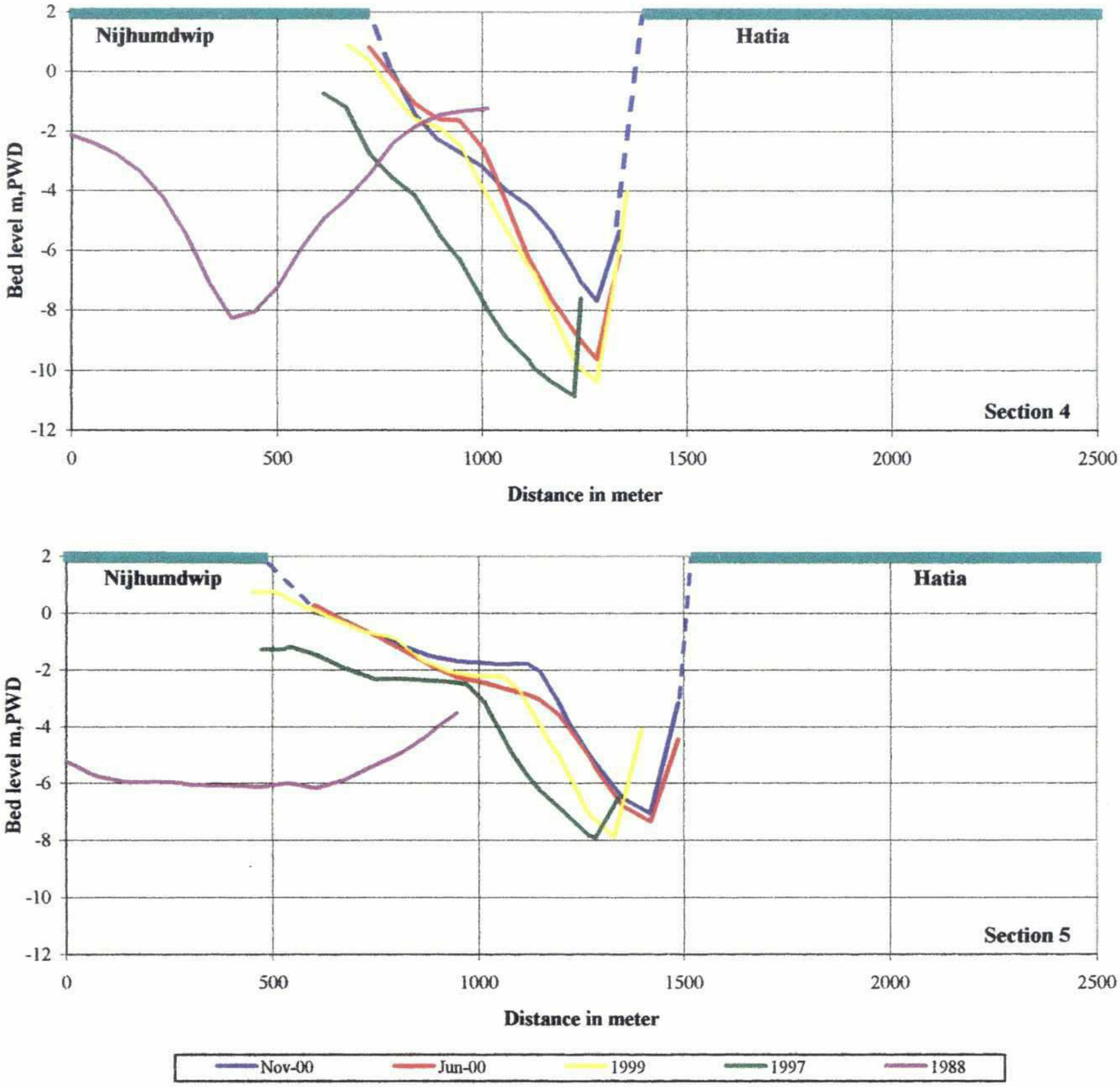

**Figure 27 : Changes of cross-sectional area and average bed level in Nijhumdwip channel cross-sections**