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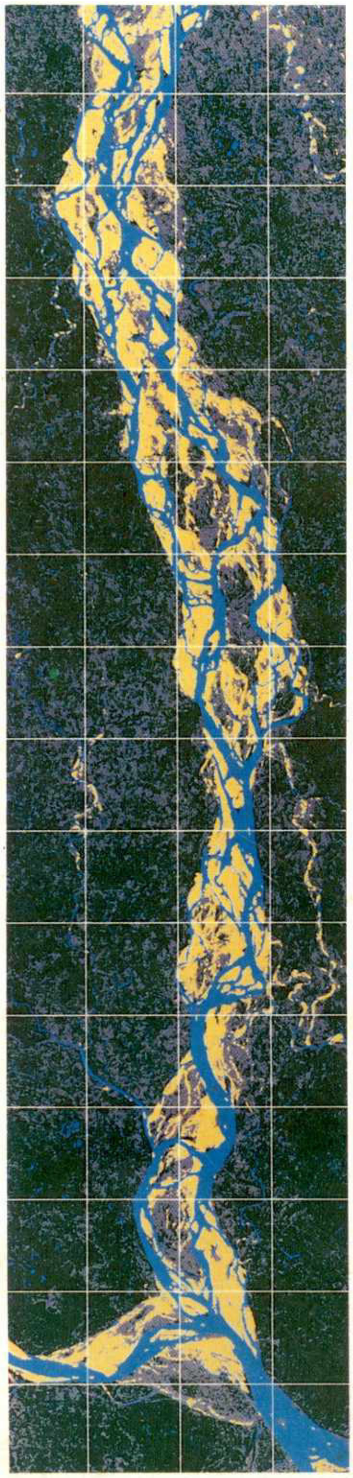


BANK PROTECTION AND RIVER TRAINING (AFPM) PILOT PROJECT FAP 21/22

TEST AND IMPLEMENTATION PHASE

CURRENT MEASUREMENTS AT KAMARJANI AND BAHADURABAD JULY AND AUGUST 1996

DECEMBER 1996

JAMUNA TEST WORKS CONSULTANTS, JOINT VENTURE
CONSULTING CONSORTIUM FAP 21/22

RHEIN-RUHR ING.-GES.MBH, DORTMUND/GERMANY

COMPAGNIE NATIONALE DU RHONE, LYON/FRANCE
PROF.DR. LACKNER & PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:

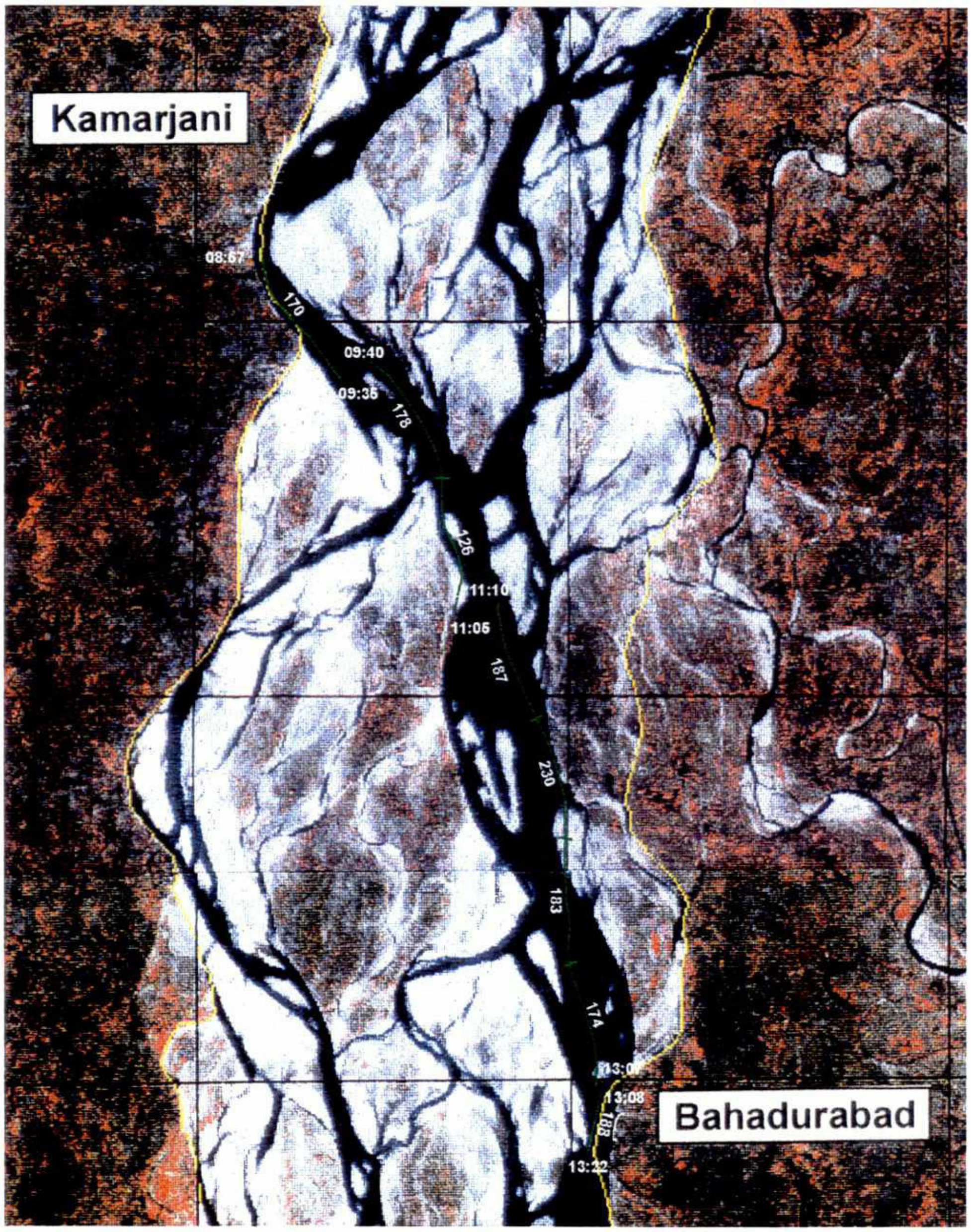
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD. (BETS)
DESH UPODESH LIMITED (DUL)

Current Measurements in the

Jamuna River

at Kamarjani and Bahadurabad

July and August 1996



Hochschule Bremen, Labor für Wasserbau

CURRENT MEASUREMENTS IN THE JAMUNA RIVER AT KAMARJANI AND BAHADURABAD

JULY AND AUGUST 1996

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CURRENT MEASUREMENTS IN THE JAMUNA RIVER AT KAMARJANI AND BAHADURABAD

JULY AND AUGUST 1996

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1 INTRODUCTION

The Jamuna River (Lower Brahmaputra) belongs to one of the largest river systems in the world. The Brahmaputra, which extends over China, Bhutan, Nepal, India and Bangladesh has a catchment area of approximately 560 000 km². The lower course flowing through Bangladesh, called the Jamuna River, has a length of about 240 km. The hydraulic gradient decreases from 8.5 cm/km at Bahadurabad to 6 cm/km at the mouth of the Ganges (fig. 1). The river discharges vary strongly depending on the season. During the dry season discharges lie between 5 000 m³/s and 10 000 m³/s. The bankfull discharge lies by over 44 000 m³/s and the maximum by over 100 000 m³/s (CONSULTING CONSORTIUM, 1993[1]). The Jamuna River is highly braided with up to five main channels and inumerous secondary channels and reaches an overall breadth of over 15 km in places.

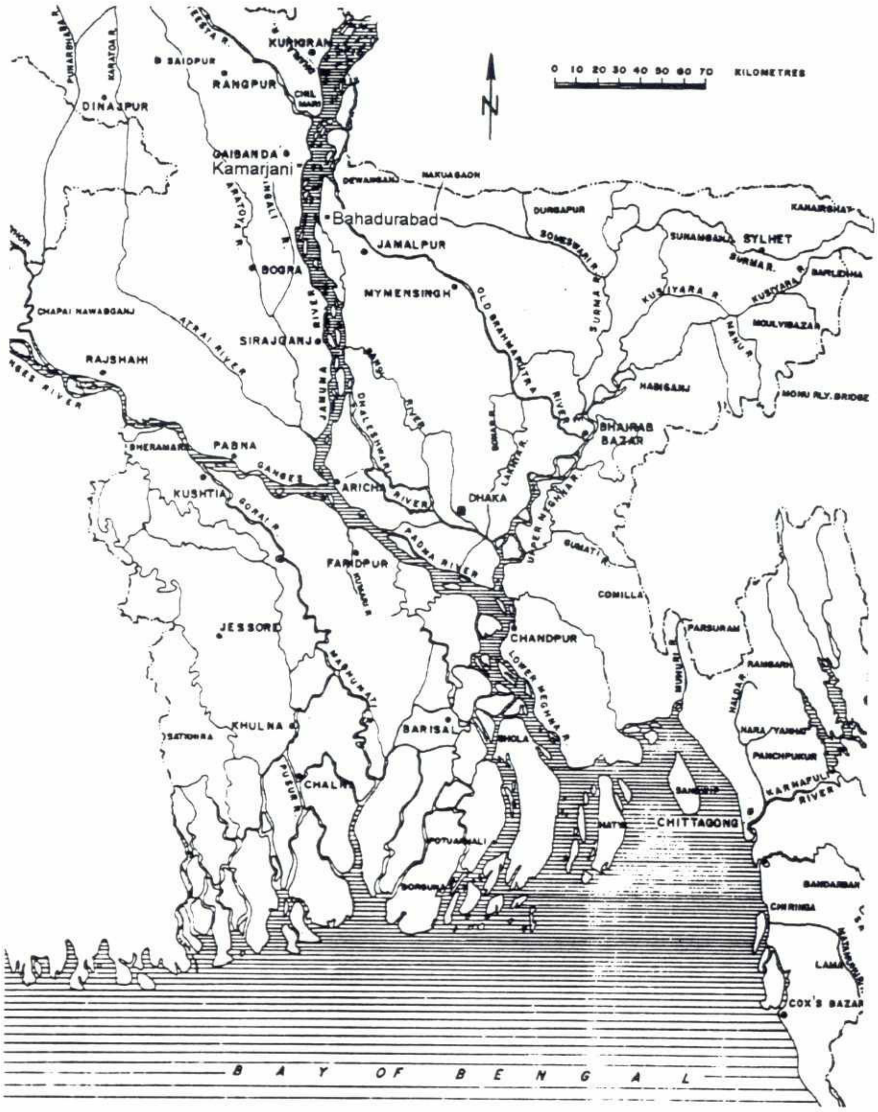

Fig. 1: Bangladesh with the Jamuna River and the Test Sites at Kamarjani and Bahadurabad

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[1] CONSULTING CONSORTIUM Final Report Planning Study, Executive Summary, June 1993

The bed and bank material consists of silt and fine sand with an average grain size of 0.2 mm, which leads to severe erosions of over one kilometre in some places during a single monsoon season. The vigorous morphologic activity of the Jamuna causes many problems for the population settled by the river. Within the frame of a Flood Action Plan (FAP) a Bank Protection and River Training Pilot Project (FAP 21/22) was raised with the objective to find means of improving the present situation. This project is jointly financed by the German „Kreditanstalt fuer Wiederaufbau“ (KfW) and the French „Caisse Française de Dévelopment“ (CFD) and is being carried out by " The Jamuna Test Works Consultants" (JTWC), a joint venture with Rhein-Ruhr Ingenieur Gesellschaft mbH as leading partner together with Compagnie Nationale du Rhône, Prof. Dr. Lackner & Partners and Delft Hydraulics in association with Bangladesh Engineering and Technological Services Ltd. (BETS) and Desh Upodesh Ltd. (DUL).

After careful assessment, sites at Kamarjani and Bahadurabad (fig. 1) were chosen to test prototype structures for bank protection. With a monitoring programme it is aimed to optimize design criteria under economic and functional aspects for future protection structures. Within the frame of the monitoring programme of the Bank Protection Pilot Project (FAP 21) the Hochschule Bremen, Labor fuer Wasserbau was engaged by the JTWC on the 28/02/1996 to carry out current measurements in the Jamuna River in the summer of 1996.

The current measurements were carried out with a newly developed system, which will be briefly described in the following.

2 CURRENT MEASUREMENTS WITH DGPS DRIFTER BUOYS

2.1 THE POSITIONING SYSTEM

The **G**lobal **P**ositioning **S**ystem (GPS) is based on satellite ranging and can be used world wide independent of the local geodetic datum.

It is known, that by telemetric measurements in one plane (two-dimensional), all points with the same distance from the transmitter lie on a circle with the transmitter as centre. As GPS is a three-dimensional system, all points with the same distance to a transmitting satellite lie on a sphere centred on that satellite. A measurement to a second satellite narrows down the position to somewhere on the circle where the two spheres intersect. A measurement to a third satellite leaves only two possible points, one in outer space and one on the Earth, for our location. In other words, in a three-dimensional system there are two positions which have the same distances to three "fixed" points. When these measurements are projected onto the Earth's surface we receive the following picture (fig. 2):

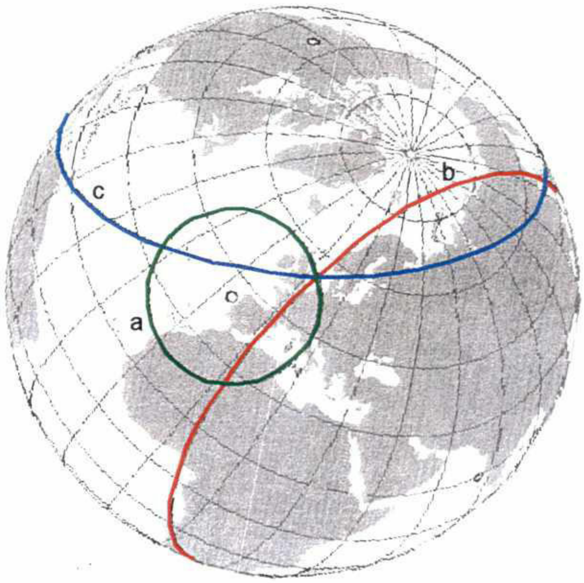

Fig. 2: Intersection of Measurements to three Satellites (KUMM, 1993[1])

The sphere with equal distances to a satellite A intersects the Earth's surface, giving a circle which describes all the possible points on the Earth's surface (green circle in fig. 2). The measurement to a second satellite B gives us a second circle (red circle in fig. 2) which results in two intersection points on the Earth's surface. A geometrically defined position is possible with a measurement to a third satellite (blue circle in fig. 2). The position lies where the three circles intersect. Theoretically a measurement to a fourth satellite is necessary to pinpoint the actual position in space. This, however, is not necessary in order to be able to define a position in latitude, longitude and altitude, as one of the two possible positions is a ridiculous result and can therefore be discarded. However, a fourth measurement is necessary for the following reasons:

This fourth measurement eliminates timing errors which occur in our satellite receivers and is important especially when a moving target has to be located.

In fig. 3 the intersection of the thin lines (X) is the true position resulting from true ranges. The intersection of the fat lines (XX, satellites A and B) results from offsets due to receiver clock errors, so called pseudo ranges. The diagrams are simplified to a two-dimensional system, but they are based on the same principle as a three-dimensional system (four satellites). By a measurement to a third

[1] KUMM, W. GPS Global Positioning System
Klasing, Bielefeld 1993

(fourth satellite in a three-dimensional system) the receiver registers that there is an error caused by an incorrect time in the receiver clock. Using an algorithm, the computer in the receiver calculates and corrects the clock offset.

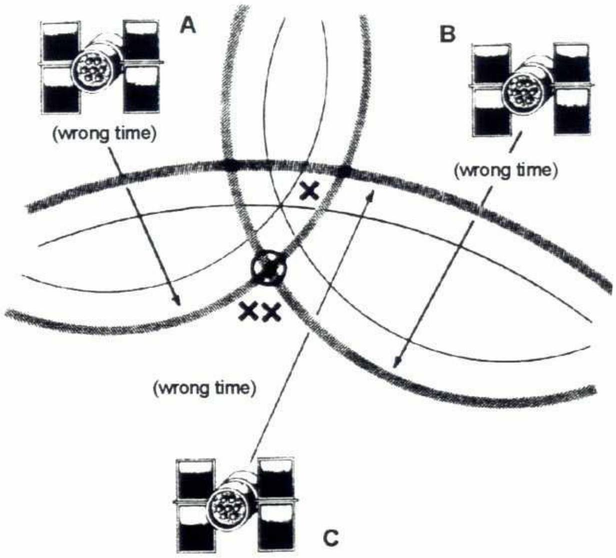

Fig. 3: Clock Offsets and Pseudoranges (HURN, 1989[1])

The measuring of distances to the satellites, which are equipped with highly accurate atomic clocks, works on the ranging of electromagnetic waves, which travel at the speed of light (300 000 km/s). An error of a 1/100 000 of a second would result in a ranging error of three kilometres. According to trigonometric rules, three perfect measurements can locate a position on the Earth, but as perfect measurements are not possible four imperfect measurements are necessary to eliminate any clock errors and to get an exact position. Therefore four satellites have to be in view at all times. There are 24 satellites orbiting the Earth at a minimum altitude of 20 000 km with an orbit time of 12 hours, which guarantees that there are always at least four satellites available. GPS positions are accurate up to 100 metres (KUMM, 1993). This is because civilian users only have access to the C/A code (**C**oarse **A**cquisition), the accuracy of which can be purposefully degraded by the American Department of Defense using an operation mode called "selective availability" or S/A. There is, however, a possibility to compensate S/A inaccuracies. By using a method called "**D**ifferential **G**lobal **P**ositioning **S**ystem" (DGPS) highly accurate positioning is possible.

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[1] HURN, J. GPS A Guide to the Next Utility
Trimble Navigation, USA 1989

2.2 DIFFERENTIAL GPS (DGPS)

With DGPS position accuracy of better than on metre can be achieved (HURN, 1989). The trick is to place a GPS receiver at a known position where it acts as a static reference point (fig. 4). The reference station instantly calculates differences (hence the name differential GPS) between the position it calculates from satellite ranging and its actual position. The resulting data is used to correct the positions collected and stored in the field receivers (drifter buoys).

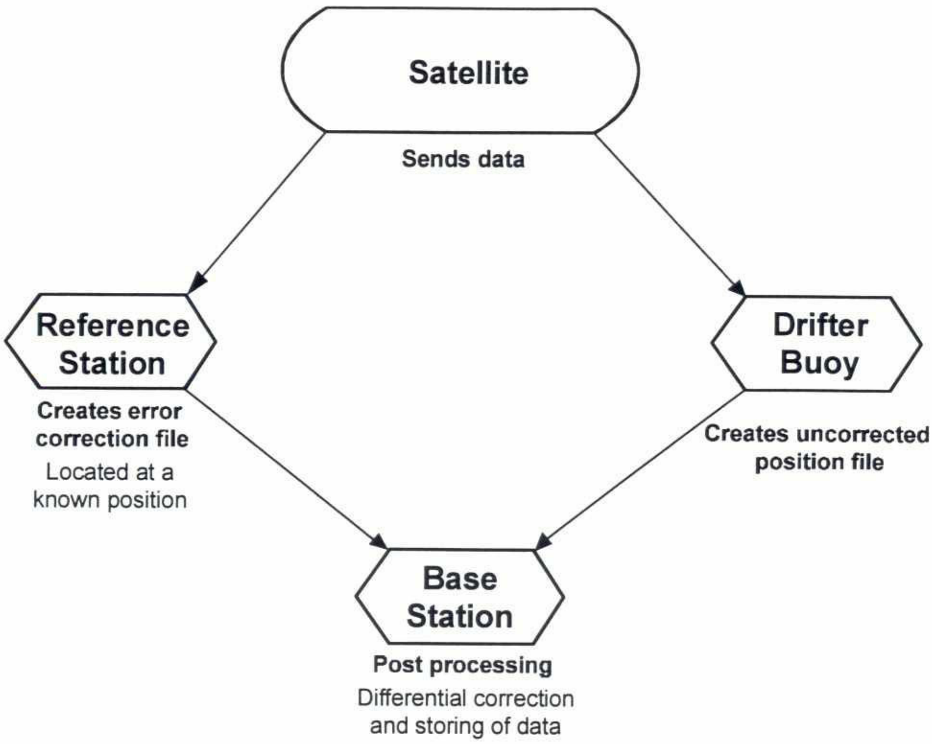

Fig. 4: The DGPS System

This concept works, because the satellites are so high up that the errors measured by the reference receiver are almost exactly the same as those measured by any other receiver within a range of about 500 kilometres of the reference receiver. This method eliminates all possible errors in the system up to a certain extent, whether they are from the receiver clocks, the satellite clocks, the satellite's position, S/A or of ionospheric or atmospheric nature.

Utilising DGPS, a system for monitoring current flow conditions was developed at the Hochschule Bremen by the Labor fuer Wasserbau with drifter buoys as floating survey stations.

2.3 THE DRIFTER BUOY

To record Lagrangian current flow patterns in various depths, the use of drifter buoys with drogues consisting of crossed sheet metal plates has been effective (fig. 5 & 6). The drogues can be hung to the drifter buoy with a rope at any required depth. The drag of the drogue is relatively high compared to that of the immersed buoy which allows an interpretation of the current conditions in the chosen depth. The buoy is a circular container made of aluminium with a diameter of 50 centimetres, a height of 12 centimetres and an immersed depth of 10 centimetres. It contains a GPS receiver/data logger as well as an electric power supply.

The receivers can track up to six satellites simultaneously in order to always have four satellites to calculate positions with, for one reason. The other reason has to do with geometry. As some satellite constellations (i.e. their relative positions to each other as well as their positions to the GPS receiver), are less suitable for accurate positions because of unfavourable angles as known in the terrestrial surveyance. Using a "geometrical dilution of precision" (PDOP, HDOP) the receiver selects the satellite constellation which is likely to give the best results.

The integrated data logger in the receiver can store up to 10 000 positions. The rate of positioning can be set at will. A rate of one position every two seconds allows a running time of about 5.5 hours.

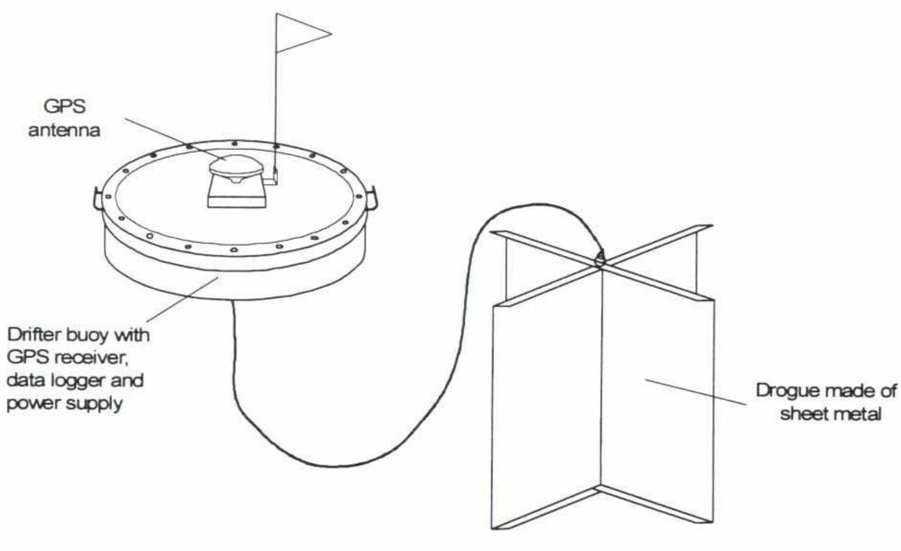

Fig. 5: DGPS Drifter Buoy with Drogue

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Fig. 6: Drifter Buoy in action

3 HYDROLOGICAL CONDITIONS

The water level of the Jamuna River is subject to strong seasonal changes. This is demonstrated by the water levels recorded at Kamarjani from January 1995 till the end of October 1996 (fig. 7). The water level until March 1995 lies below +15 m PWD (**P**ublic **W**orks **D**epartment). After the high water season it sank to +17 m PWD in November 1995. The high flow season lasts from June until October. The water level difference between the dry season and monsoon season is about 8 metres. The high water levels bring a significant increases in the cross section due to inundation.

The water level curves recorded at Kamarjani in 1995 and 1996 are generally similar. The peaks in the summer of 1995 were higher and the high flow period lasted longer. Water levels above +21 m PWD were first recorded in June until July and again in September. The highest water levels were recorded during July in both years. The highest water level in 1995 HW_{1995} = +22.38 m PWD was marginally higher than in 1996 with HW_{1996} = +22.11 m PWD.

With a water level frequency analysis carried out by the Consulting Consortium using available data the following design water levels were established (CONSULTING CONSORTIUM[1]):

- Standard low water level SLW	+15.2 m PWD
- Standard high water level SHW	+20.7 m PWD
- High flood level HW	+23.3 m PWD (100 years return period)
Design water level (SLW + 7.7 m)	+22.9 m PWD (25 years return period)

A comparison between these values and figure 7 shows that no unusually high water levels were recorded in 1995 and 1996 at Kamarjani. The current measurements by the Labor fuer Wasserbau of the Hochschule Bremen were carried out after the highest peak between 22/07 and 23/08/96.

The design wave height for the test site Kamarjani was calculated to Hs = 1 m with a period of T = 3 s.

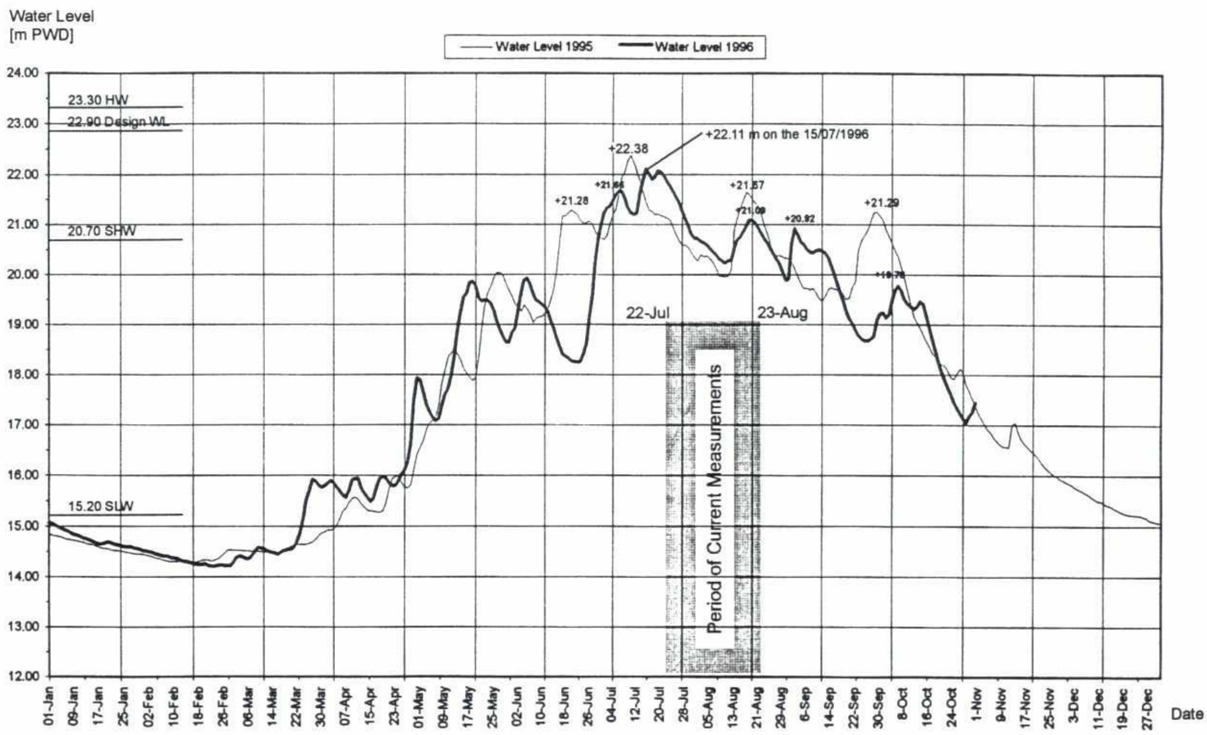

Fig. 7: Water Levels at Test Site Kamarjani from 1995 and 1996

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[1] CONSULTING CONSORTIUM, Draft Final Report Planning Study, Vol. VII, Annex 20, January 1993

4 CURRENT MEASUREMENTS AT TEST SITE KAMARJANI

4.1 AREA OF INVESTIGATION

Test Site Kamarjani consists of an embankment protected by groynes on the right bank of the River Jamuna upstream of the Manos Tributary (annex 1). The main components of the test fields are the partly permeable groynes G-1, G-2 and G-3. Upstream the two additional groynes, GB-1 and GB-2, are placed as a termination and protection against outflanking. The downstream termination consists of groyne GA.

During the high flow season in 1995 the test structures suffered damages. In early July 1995 (09/07/95) the impermeable part of G-2 broke shortly followed by the embankment downstream of G-2. About a month later the same happened to the impermeable part of G-3 and some of the inner piles were lost.

After the high flow season 1995 the part of the embankment between G-1 and G-3 was moved back. G-3 was extended to the new embankment with piles as a permeable structure. As the main attack during the monsoon season 1996 was expected in the area of the groynes G-3, GA and further downstream, a supplementary groyne, GA-2 was erected 200 metres downstream of GA. Groyne GA was extended and reinforced by an additional row of piles. Annex 1 shows the layout of the test site I as it was during the current measurements in July and August 1996. Figures 8 to 10 are photos taken on the 12/08/1996 at a water level in Kamarjani of +20.31 m PWD. The picture points are shown in annex 1. Figure 8 shows a view of G-1 from upstream. Figure 9 shows the remaining piles of G-2 and in the foreground the remains of the old embankment of 1995. Figure 10 shows also the old embankment and in the background the rebuilt groyne G-3 as a complete permeable structure. Figure 11 is a photo taken on the 22/07/1996 at a water level of +21.85 m PWD and shows the turbulences at the head of G-3. Figure 12 was taken during current measurements on the 15/08/1996. It shows a view of the inner part of GA with the cofferdam at a water level of +20.78 m PWD.

The vigorous morphologic activity of the Jamuna River is demonstrated by comparing the two bathymetric surveys carried out by the Consulting Consortium at the beginning (18/08 - 24/08/1996) and towards the end (11/08 - 15/08/1996) of the current measurements (fig. 13). The hydraulic cross section at Kamarjani lies between the embankment and a char some 1.8 kilometres west of the test site. Clearly visible is the natural scour on the undercut bank downstream of the Manos River. At the same time the stream flow is bundled by the groynes beginning at G-3 towards further downstream. The greater depths outside the groyne fields show the characteristic effect which the test structures

Fig. 8: View of Groyne G-1

Fig. 9: View of G-2 with the Remains of the old Embankment in the Foreground

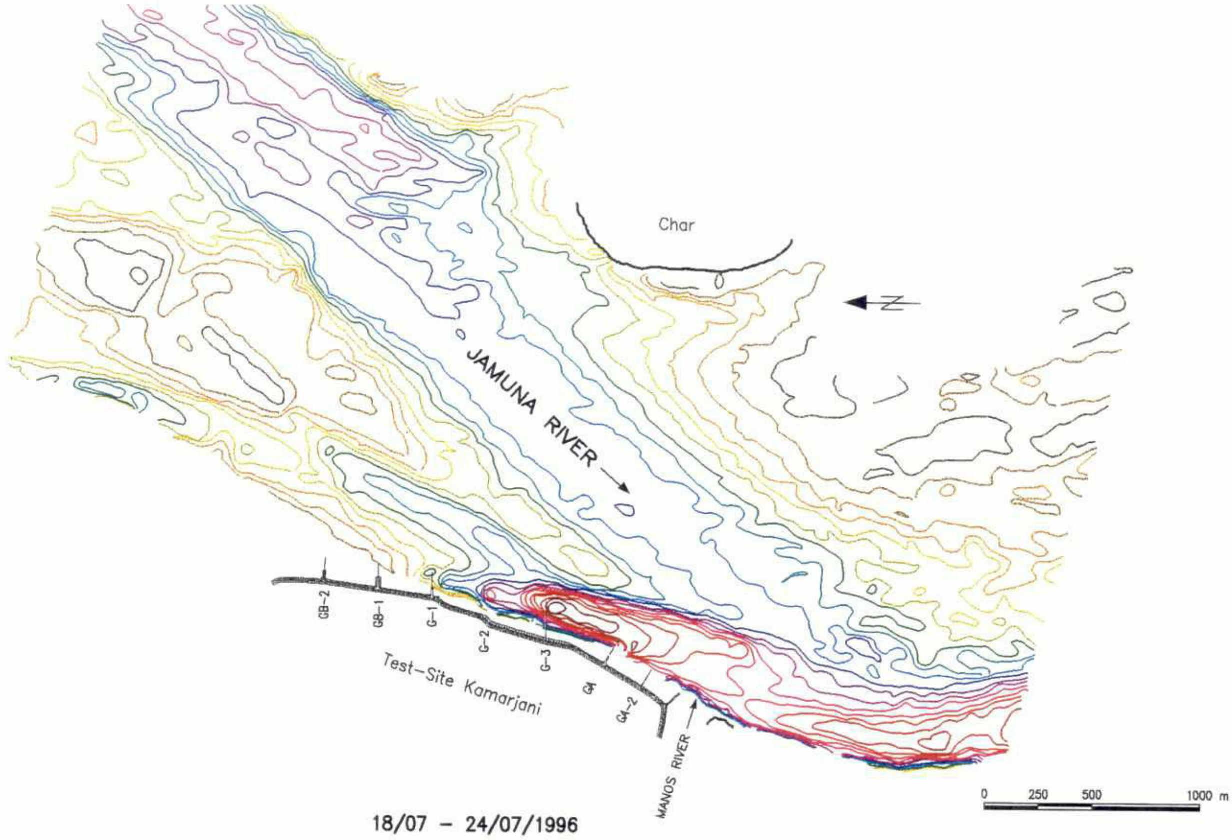
Fig. 10: View of Groyne G-3 and Remains of the old Embankment

Fig. 11: Photo of the Head of Groyne G-3

Fig. 12: View of Groyne GA

have on the flow directions in the river. In connection with this, it is interesting to note the changing morphology as shown in fig. 13. The deep water region due west of GB-1 and GB-2 and north of the char has extended itself southward in the period between late July and mid August. A comparison of the two bathymetric surveys shows how the main channel (margined by the blue 13 metre depth contours) has continued to scour from the deeper area north of the char across towards the right bank south of the Manos River. The erosion on the east side and the accretion on the west side upstream of the test site may be an indication whether the channel will move further eastwards pushing the escarpment south of the Manos River further downstream.

In alluvial rivers there is a tight connection between flow conditions and morphology. The brief discussion above about the bed behaviour in the Jamuna River ought to give a better understanding of the current measurement described in the following.



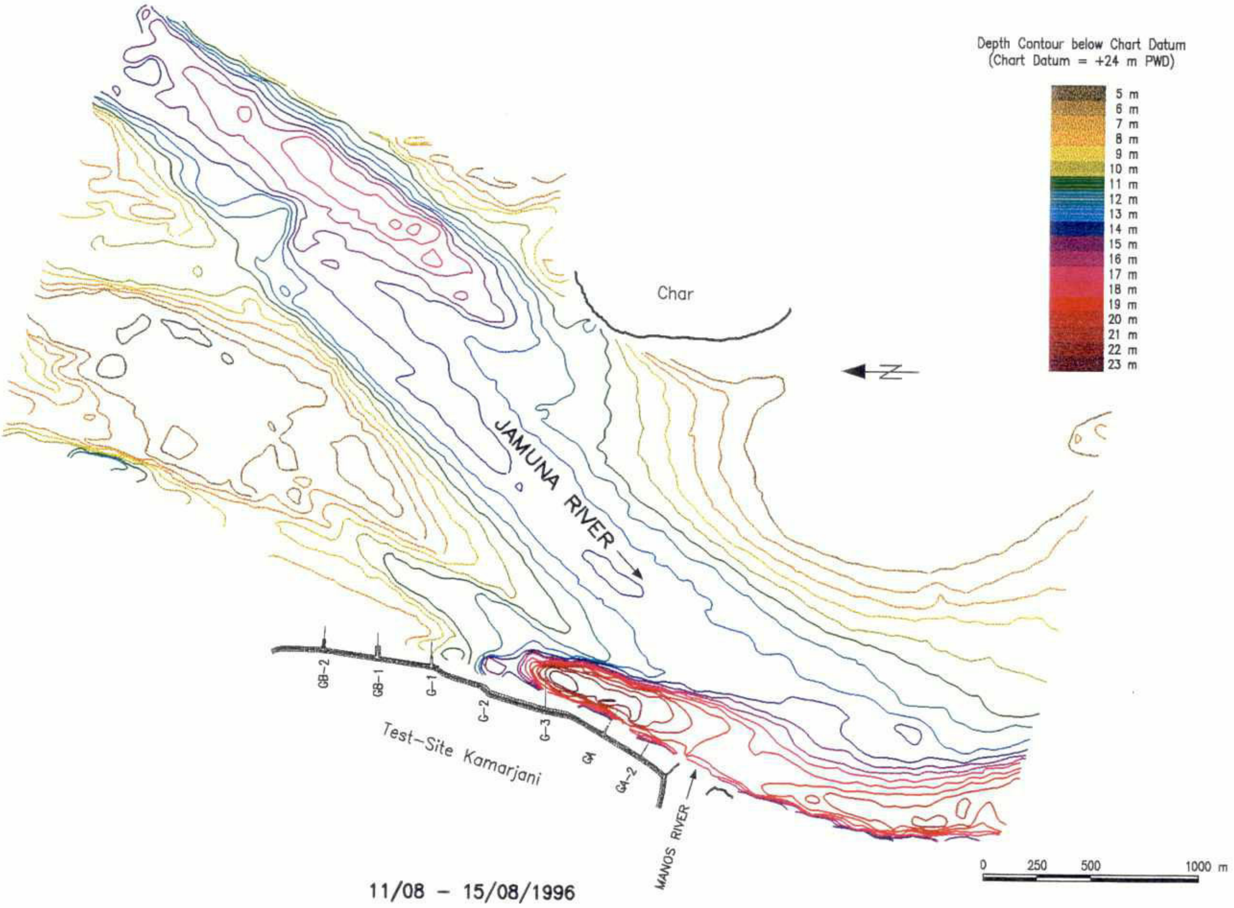


Fig. 13: Morphology at Kamarjani; Bathymetry Surveys from 18/07- 24/07/96 and 11/08 - 15/08/96

4.2 CURRENT MEASUREMENTS

4.2.1 Preliminary Remarks

All depth contours in the following plans are from bathymetric surveys carried out in August 1996. The chart datum (CD) for all the bathymetric surveys at Kamarjani are defined by the Consulting Consortium at +24 m PWD and +22 m PWD for the surveys at Bahadurabad.

4.2.2 Current Measurements in the River at Kamarjani

In the area of the test site at Kamarjani current measurements were carried out simultaneously in three different depths (surface, 1.5 metres and 3 metres depth) on the 10/08, 16/08 and 23/08 with water levels between +20.25 m PWD and 20.86 m PWD (annexes 2, 3 and 4). According to the water levels recorded at Kamarjani and Bahadurabad the surface gradient ranged between 0.079‰ and 0.083‰ (7.9 cm/km and 8.3 cm/km) and was therefore similar for all three measurements. Because of the similar hydraulic conditions the measurements can be discussed parallel.

In annex 2 are the surface current measurements from the 10/08 and 16/08. Owing to technical problems in the receiver there are no surface measurements from the 23/08.

It should be remarked that, as the depth contours are based on chart datum (CD) = +24.0 m PWD and that the water levels are based on PWD. That means the water surface lies between the 3 m and 4 m depth contours at water levels between +20 m and +21 m PWD. In other words, the actual water depth at the 6 m depth contour is 3 metres at a water level of +21m PWD at the gauge in Kamarjani. The exact water depths can be calculated with the aid of the water level diagram in the annexes.

In the upper (eastern) part in annex 2 it can be recognised how the flow tracks diverge around the char. To the west of the char the tracks are diverted into the deeper water where in the upper section naturally the highest current velocities of up to v = 2 m/s occur. Towards the west bank, where accretions can be observed, the flow velocities are reduced by more than half. This is because areas above 8 m below chart datum (+16 m PWD) fall dry outside the monsoon season and are therefore off the main stream. In the lower area downstream of groyne G-3 the deflection of the current flow caused by the groynes can be observed by the flow tracks towards the test structures. This leads to an increase of current velocities and therefore to greater scour depths. The test structures fulfil their purpose in deflecting the main current away from the embankment.

The current measurements in 1.5 metres depth in annex 3 show a complete picture of the current conditions, which can be assumed similar to those measured on the surface. The main attack lies by and downstream of groyne G-3. Upstream of G-3 current velocities of over v = 1 m/s were measured even in 6 metres water depth.

Outside the groynes the accelerating effect of the test structure leads to velocities of up to v = 140 cm/s. The velocities increase with growing distance to the char towards the deeper channel on the right bank. West of the 12 m depth contour the velocities are generally over v = 150 cm/s. Along the undercut bank some 800 metres downstream of the Manos tributary the velocities reached maxima of v = 180 cm/s.

The flow tracks in 3 metres depth in annex 4 show how the stream lines in the approximately 3 kilometre long stretch are bundled and accelerated as they pass groyne G-3. In the deeper channel the flow velocities are constantly high. This together with the local fine and non-cohesive bed material leads inevitably to erratic changes of the morphology as shown in fig. 13. The current velocities in areas of shallower depths are notably lower (annex 4 top and bottom left). The superposition of flow tracks on the depth contours in annex 4 demonstrates how the talweg progresses from the char to the right bank downstream of the Manos River. In accordance with the prevailing hydrodynamic and morphologic conditions the highest erosions occur on the undercut bank which has the tendency to shift further downstream.

4.2.3 Current Measurements in the Groyne Fields

Current measurements within the test site at Kamarjani were carried out in various depths between the 24/07 and 15/08/96 with the objective to get an insight into the prevailing hydrodynamic and morphologic conditions. The results are presented in the annexes 5 to 12. The depth contours are from the bathymetric survey taken on the 03/08/96 by the Consulting Consortium.

(1) Current Measurements on the Surface (Annexes 5 & 6)

Even after the passage of the high water in mid July relatively high current velocities were recorded between the 24/07 and 27/07/96 (annex 5). The water levels were +21.65 m PWD and +21.25 m PWD with a falling trend. The main flow attack was at the head of groyne G-3. Further upstream the velocities were generally about v = 2 m/s, depending on the varying turbulent velocities. This is the cause for the deep scour of 23 m depth (26 metres below CD; CD = 24 metres below PWD), located downstream of G-3. The continuously intensive flow attack holds the danger of receding scour action against the groyne head and threatening the stability of the structure. An evidence of this is the close succession of the depth contours downstream and parallel to G-3 (annex 5). In the upper region of the groyne field G-3/GA the current conditions are characterized by high turbulences which are indicated

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by the intersecting flow tracks and by the varying velocities in each track. These distinctive intersecting vortex trails leading away from the head of G-3 can be observed on location.

The grade of deceleration caused by groyne G-3 on the current velocities evidently depends on the grade of permeability (annex 5). It is important to note that no return currents occur downstream of the foot of G-3, owing to groyne G-3 being fully permeable. Return currents, however, can be observed downstream of the cofferdam at G-1 and downstream of the remains of the old embankment at G-2. These return currents are stable eddies of velocities up to v = 30 cm/s, which is enough to transport the fine non-cohesive bed material. Investigations by HJULSTRÖM (1935)[1] have shown that a current velocity of about v = 20 cm/s is sufficient to erode loose, fine sand with a grain size up to d = 0.2 mm (fig. 14).

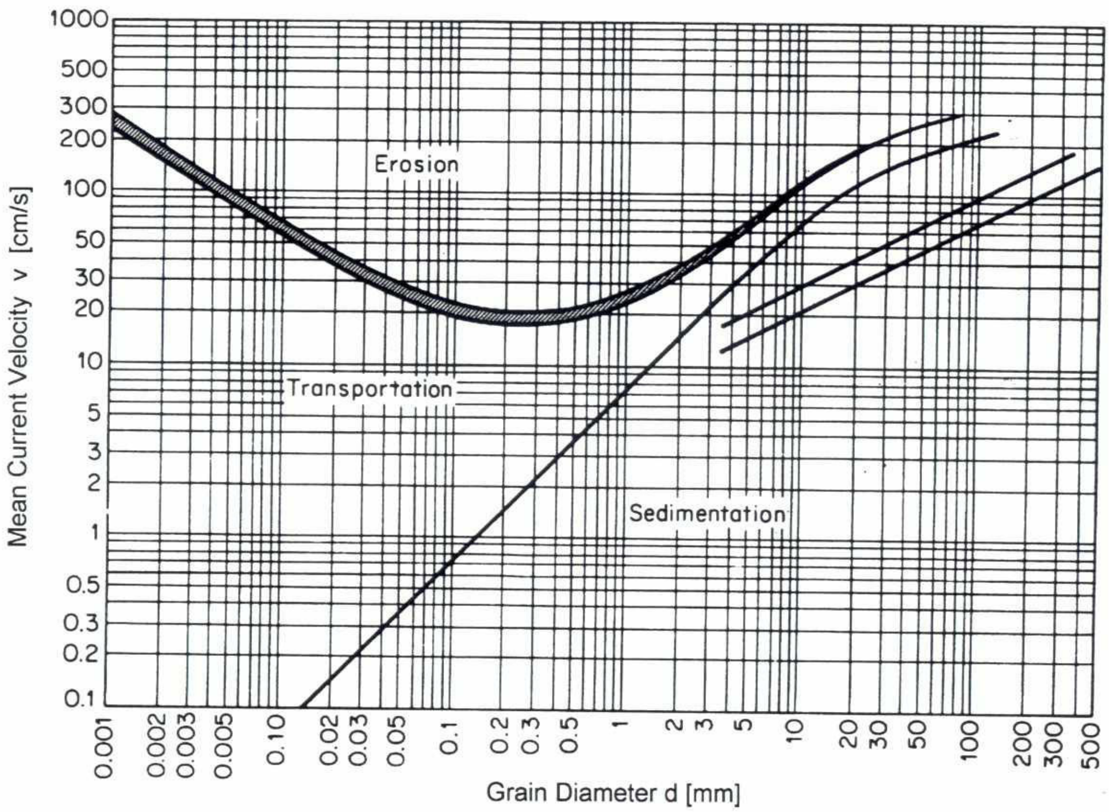


Fig. 14: Erosion-Deposition Criteria for uniform Particles (HJULSTRÖM, 1935)

As the grain size of the bank and bed material of the Jamuna River falls in this range, receding erosions can occur in areas of return currents at according water levels. This can be observed by the

[1] HJULSTRÖM, F. The Morphological Activity of Rivers as Illustrated by Rivers Fyries
Bull. Geol. Inst. Uppsala, vol. 25 (chap III)

bankline survey carried out by the Consulting Consortium on the 04/08/96 at a water level of about 3.5 metres below chart datum. The bankline downstream of the cofferdam at G-1 and GA runs parallel to the cofferdams whereas the bankline runs parallel to the embankment at G-3 (annex 5). However, owing to the low grade of permeability in the middle of groyne G-3, the formation of return currents cannot be ruled out downstream of G-3 at higher water levels than in July.

Return currents and scour are not the only responsible factors for the damages caused on the embankment. Owing to the vast breadth of the Jamuna, long wind fetches can cause wave heights of up to 1 metre. On the 26/07/96 winds of up to 11 m/s coming from east caused severe exudations on unprotected parts of the embankment. The damaged sections had to be hurriedly repaired with sand sacks. If immediate action is not taken accordingly during stormy periods the risk is too high that the embankment will take such damage that it will eventually burst. Figure 15, a photo taken on the 02/08/96 shows damages caused by wave erosion and figure 16, taken on 12/08/96 shows the extent of the damage to the unprotected slope.

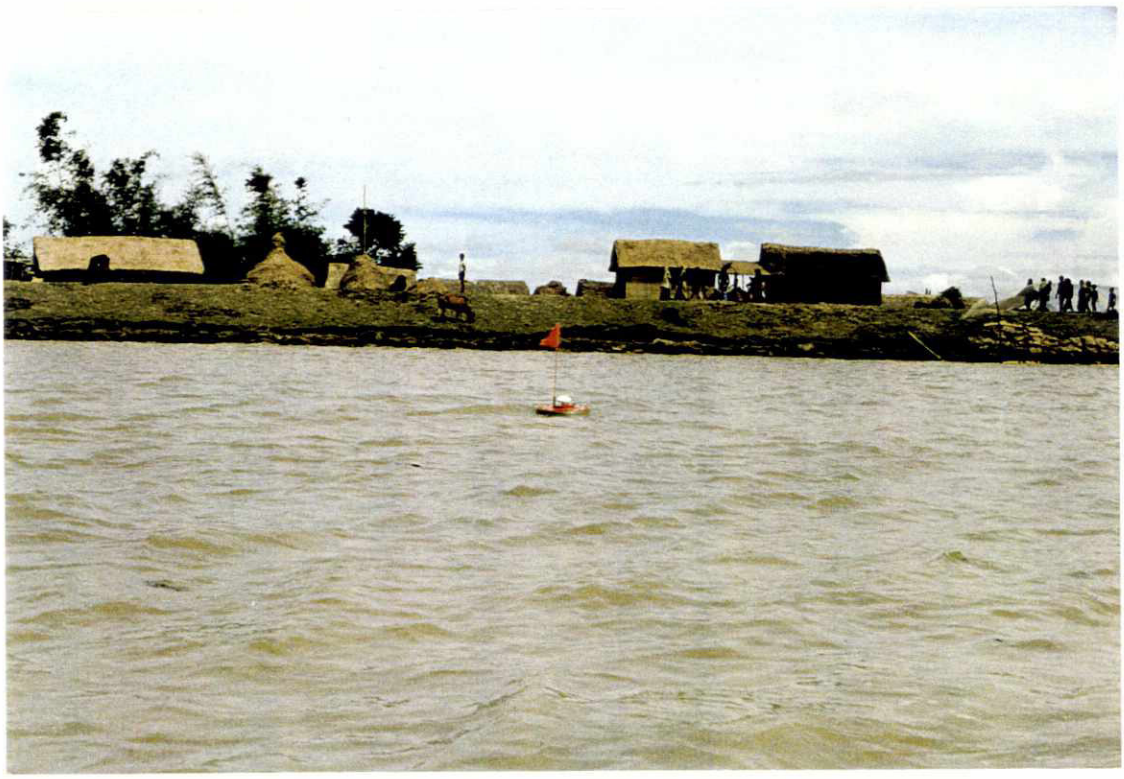


Fig. 15: Photo from the 02/08/96 of Wave Erosion on the Embankment after the Storm on the 26/07/96

Fig. 16: Photo taken on the 12/08/96 showing the Damage to the unprotected Embankment

The connection between water level and current intensity can be demonstrated by the measurements carried out in July compared to those carried out in August in the lower part of annex 5. The current velocities during lower water levels were significantly smaller.

On the 08/08/96 return currents leeward of GA were recorded (annex 6). Despite of the relatively low water level (+20.30 m PWD) the critical velocity for material transportation of v = 20 cm/s was exceeded. In the outer area of the groyne field turbulences are indicated by the intersecting stream lines and higher velocities.

The surface current patterns described above and in annex 5 are generally verified in annex 6 in a reduced manner. The velocities decrease notably the further the tracks are inside the groyne field. The most turbulent currents are found in the groyne field G-3/GA. The rapid changes of direction and velocity are demonstrated by the measurements carried out on the 15/08/96 (middle groyne field in annex 6). The four drifter tracks were recorded within half an hour, yet the successive velocities differ up to several decimetres. Of interest are also the return currents immediately downstream of the lesser permeable part of G-3.

Significantly calmer conditions can be found in the groyne field G-2/G-3. The stream lines are roughly parallel and hardly intersect. The stem of flow caused by G-3 can be seen by comparing the velocities immediately upstream to those immediately downstream of G-3. The slow and not clearly definable currents near the bankline at G-2 can be explained in connection with annex 5. Both upstream and downstream of the remains of the old embankment (fig 10) the formation of stable eddy currents lead to a calm zone as inbetween as is shown in annex 6.

(2) Current Measurement in 1.5 Metres Depth (Annexes 7 & 8)

The current conditions recorded on the 23/07, 27/07 and 30/07 in 1.5 m depth are shown in annex 7. Outside the groyne fields the current velocities shortly after the high water passed on the 23/07/96, were significantly higher than those recorded in August. To demonstrate this, selected drifter tracks from annexes 3 and 7 were compiled in figure 17. The main flow attack was on G-3 and downstream, where the highest current velocities were recorded.

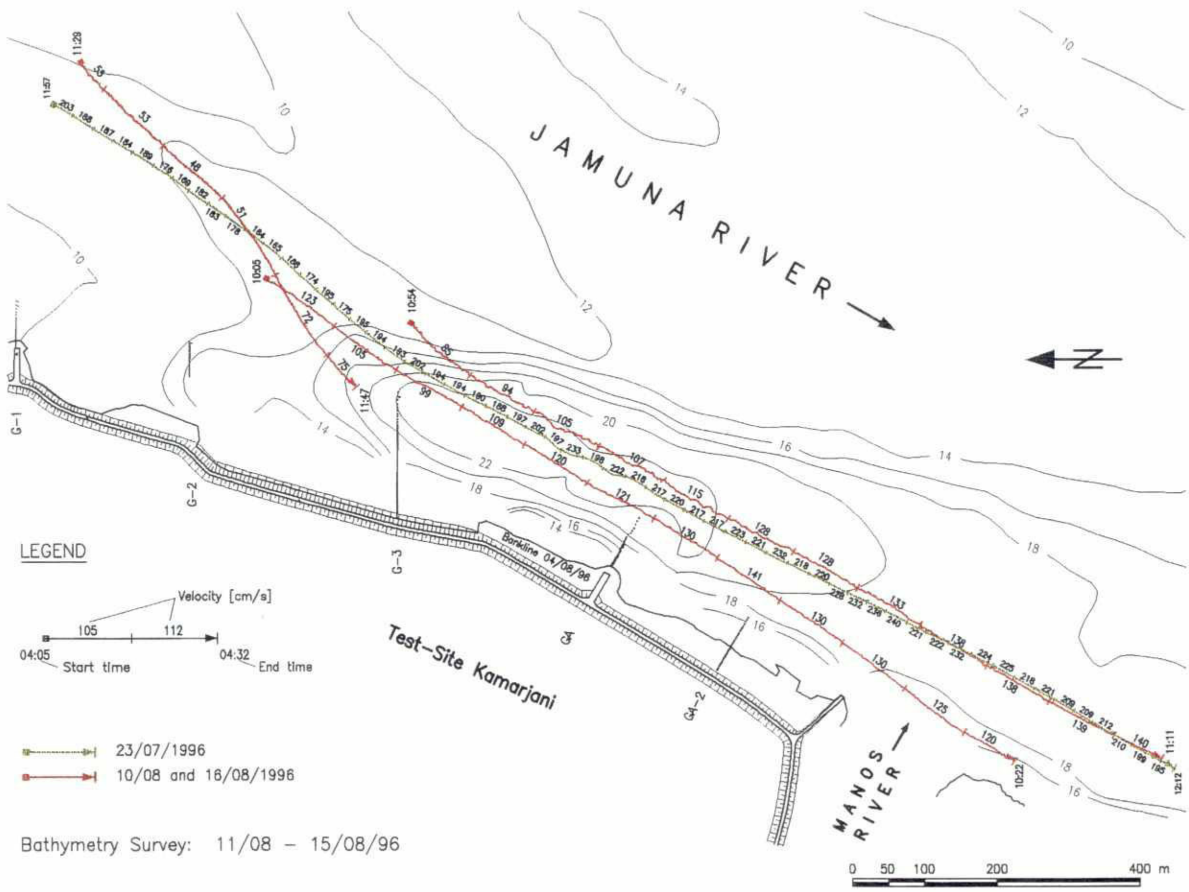


Fig. 17: Drifter Tracks measured in 1.5 m Depth in July and August 1996 at Kamarjani Test Site.

The current velocities were, despite of strong variations within single flow tracks, almost twice as high in July than in August. This causes multiple sediment transport which is according to hydrodynamic and physical laws stating a potential function between current velocity and drag force.

The current pattern in 1.5 m depth (annex 7) is similar to the currents on the surface (see annex 5). Drifters set out at the head of G-1 pass G-2 on the inside towards the embankment downstream of G-2 with decreasing velocities in a long sweeping bow. Return currents which can extend as far as downstream of G-2 were recorded in the groyne field G-1/G-2. The area where the tracks diverge most distinctively is downstream of G-3, as shown by the measurements from the 30/07/96. In the outer region of the groyne field G-2/G-3 the stream lines converge towards G-3.

Also during the generally calmer period in August 1996 short periodical changes in the current velocities and directions were observed (annex 8). Three drifters were set out downstream of G-2 within a time of 11 minutes. The middle track took a completely different path at a higher velocity compared to the other two. These sudden alterations in the current conditions show how difficult it is to describe them with numeric models. To be able to do this the mathematical and physical processes need to be registered in more detail, whereas model test suffer under the scale effects.

A further eddy with return current velocities up to v = 30 cm/s along the 10 metre depth contour was measured downstream of GA.

(3) Current Measurements in 3.0 Metres Depth (Annexes 9 & 10)

On the 22/07/96 stable eddy currents were measured in 3 metres depth downstream of G-1.The water depth along the 6 metre depth contour was 4 metres at a water level of almost +22 m PWD. From annex 9 it can be taken that there (1 metre above the bottom) return currents with velocities up to 38 cm/s were recorded. This confirms the above, that these return currents can, at higher water levels, reach velocities which are sufficient to erode the fine bed material and thus threatening to break groynes joined to the embankment with earth dams. Therefore return currents can be made responsible for the damage caused on G-2 and G-3 in the summer of 1995.

The eddy currents are subject to constant change. They are not centred on a specific point, but vary within a certain area. This is recognisable by the altering current directions in the outer area of G-1 (annex 9). The stream lines starting at the head of G-1 pass on the inside of G-2 into the lower groyne field with the trend to form return currents along the bankline.

On the 31/07/96 the highest and most turbulent currents were again measured in the lower part of the groyne field G-3/GA, as shown by the clear differences of velocity and direction of the flow tracks (annex 9). The highest velocities were recorded in the area of the head scour downstream of G-3. The part of G-3 with the closer pile distances stems the flow velocities upstream of G-3 and causes a calm zone leeward in which return currents can be observed.

On the 18/08/96 a drifter which was set out downstream of GA shows the eddy current (annex 10). The variable character of these eddy currents can be demonstrated by superpositioning the tracks measured on the 18/08/96 in 1.5 metres and 3 metres depth (see also annexes 8 & 10) and the track measured on the 08/08/96 on the surface shown in annex 6 (fig. 18).

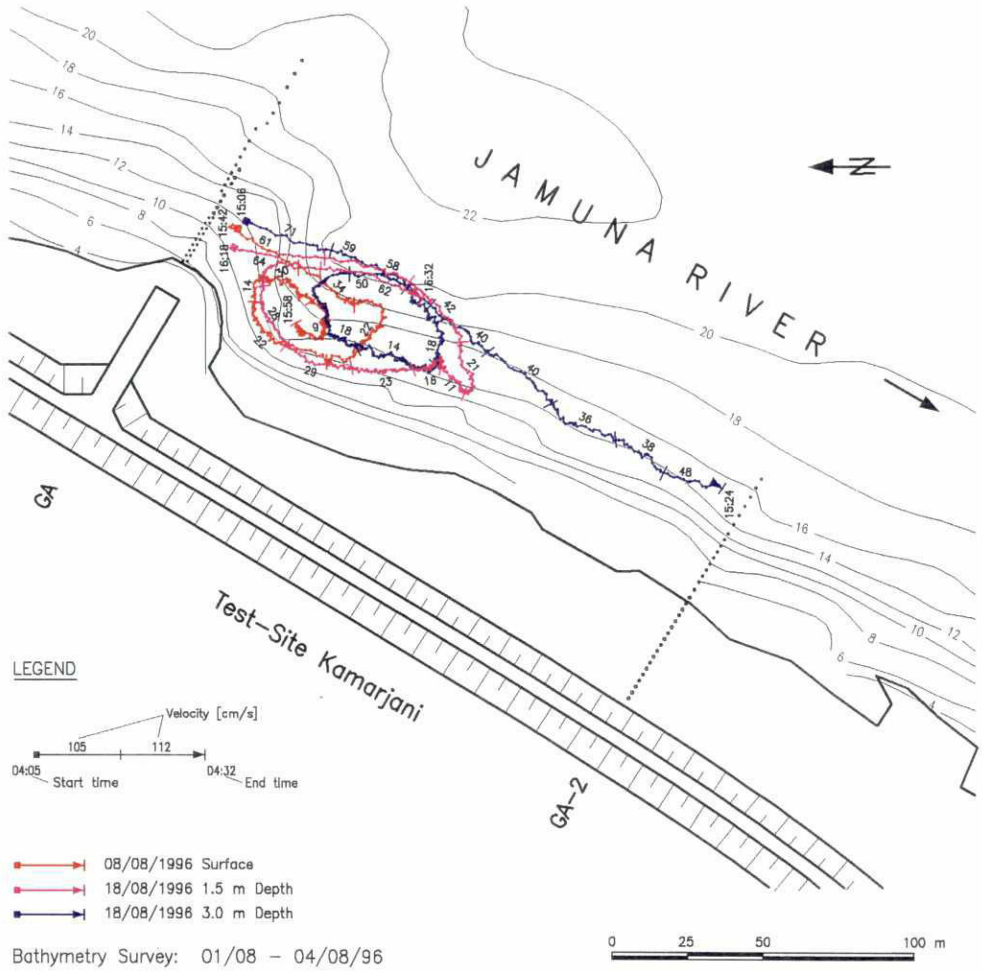


Fig. 18: Drifter Tracks recorded on the Surface (08/08/96), in 1.5 m and 3 m Depth (18/08/96).

The eddy current on the 08/08/96 was of lesser intensity and centred closer to GA than those recorded on the 18/08/96 at a 80 cm lower water level. This means that the return currents are intensified at higher water levels and exceed the critical velocity. This leads to leeward erosions threatening the structure's stability.

The tracks recorded on the 05/08/96 upstream of GA (annex 10) also demonstrate, compared with the tracks recorded in July, the connection between discharge and current conditions. The currents were generally less turbulent in August. The velocities were significantly lower and the tracks were more uniform in velocity and direction.

(4) Current Measurements in 6.0 Metres Depth (Annexes 11 & 12)

The above described current conditions at test site Kamarjani are confirmed by the measurements from the 02/08/96 and 11/08 & 12/08/96 (annex 12). The currents with strongly altering directions were also recorded downstream of groyne G-3 with slightly reduced intensity. The velocities are lower owing to the falling water level. A comparison of the absolute velocities of the tracks recorded outside the groyne field G-3/GA demonstrates this (annexes 11 & 12). The current attack must be accordingly higher during higher discharge periods, which would explain the scours extending from downstream of the head of G-3. In the groyne field G-1/G-2 there is a recognisable trend to form return currents along the bankline.

5 CURRENT MEASUREMENTS AT TEST SITE BAHADURABAD

5.1 PRELIMINARY REMARKS

The test site at Bahadurabad lies some 27 kilometres downstream of Kamarjani on the left bank of the Jamuna River. The water level curves between May and August 1996 from Bahadurabad and Kamarjani are similar (fig. 19). The surface gradient between the two test sites were established from the daily water level differences during this four month period. During the period of high water levels and discharges in July 1996 gradients of I = 0.1 ‰ were reached. The gradients were flattest at low water levels in May 1996 with values around I = 0.06 ‰. According to the instationary flow behaviour, the gradients are generally higher during phases of acceleration (during rising water levels) than during phases of deceleration (during falling water levels). The average gradient during the current measurements in August was about I = 0.08 ‰.

The Jamuna was very active at Bahadurabad also after the high water on the 15/07/1996. The bathymetric surveys carried out by the Consulting Consortium from the 30/07/96 and from the 21/08/96 show how the progressive bed and bank erosions have extended further south within just three weeks (fig. 20). The bed was deepened by more than 10 metres infront of the test site caused by the strong flow attack. This is demonstrated by the flow tracks described in the following.

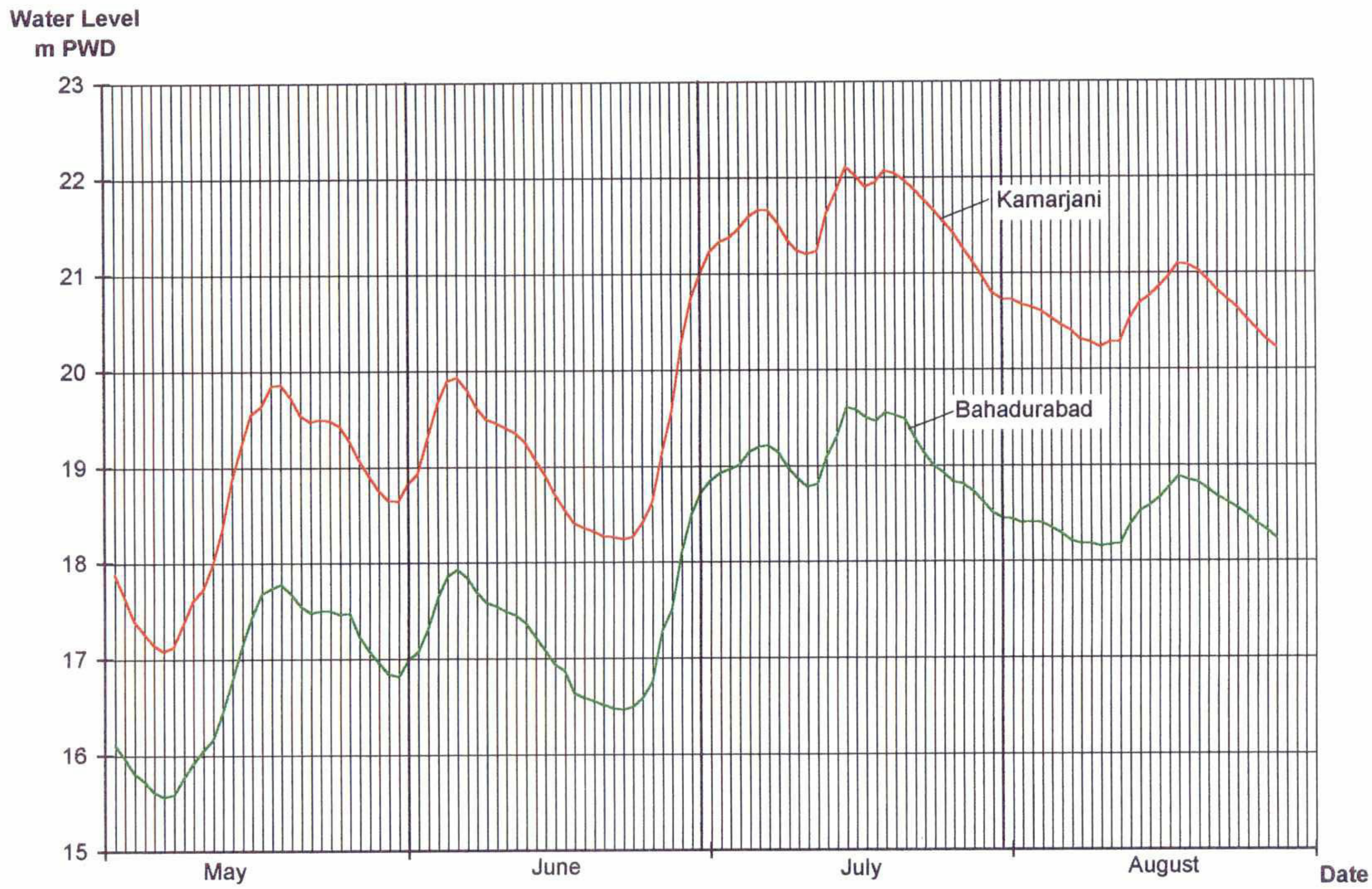


Fig. 19: Water Levels at Kamarjani and Bahadurabad from May until August 1996

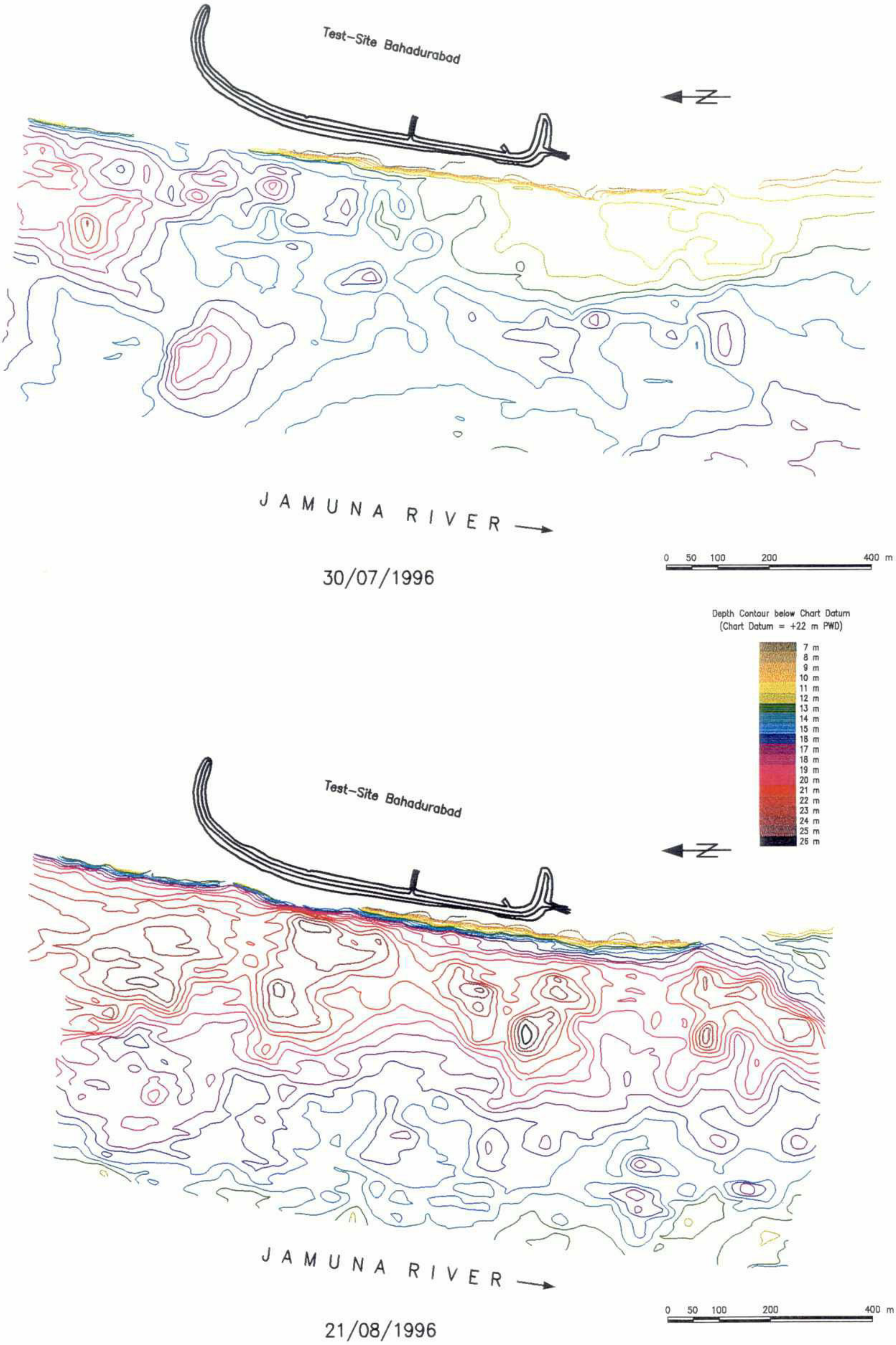


Fig. 20: Morphology at Test Site Bahadurabad; Bathymetry Surveys from 30/07/96 and 21/08/96

5.2 CURRENT MEASUREMENTS AT BAHADURABAD

At Bahadurabad current measurements were carried out on the 09/08, 14/08 and 20/08 simultaneously at the surface as well as in 1.5 metres and 3 metres depth. The measurements from the 09/08 have been attributed the bathymetric survey from the 30/07/96 (annexes 13 & 14), while the measurements from the 14/08 and 20/08/96 are presented with the soundings from the 21/08/96 (annexes 15 to 20).

On the 09/08/96 current measurements were carried out on the surface (annex 13) and in 3 metres depth (annex 14). The current velocities encountered at Bahadurabad were with over v = 3 m/s significantly higher than those at Kamarjani. High turbulences along the under water embankment have lead to the erratically changing velocities within the tracks recorded in close proximity of the embankment (annexes 13 & 14). The high velocity gradient is an evidence for the substantial transverse erosions towards the embankment, which occurred during this period. The concentration of the flow attack on the left bank is demonstrated by the decreasing velocities of the flow tracks furthest away from the embankment where velocities seldom reached or exceeded v = 2 m/s. The current patterns in annexes 13 & 14 demonstrate the cause for the drastic morphological changes which took place at Bahadurabad in August 1996.

The flow tracks recorded on the 14/08/96 indicate the high currents in the main channel compared to those further away from the embankment (annexes 15 to 18). The velocities on the surface and in 3 metres depth were similar. The turbulences just off the embankment were of permanently high intensity with current velocities of over v = 1 m/s which are multiples of the critical velocity of the local bank and bed material (annex 16).

Even after the high water from the 18/08/96 current velocities in 1.5 m and 3 m depth remained unaltered high with over v = 3 m/s (annexes 19 & 20). Distinctive are the relatively high current velocities near the embankment compared to the previous measurements. This underlines the fact that at that time the left bank of the Jamuna was subject to strong erosions. The morphologic and hydrologic conditions at Bahadurabad in August 1996 are further clarified in figure 21.

The comparison of the cross sections from the soundings from the 30/07/96 and 21/08/96 documents the extremely high bed erosions on the left bank. The highest vertical erosions reached over 10 metres at the profile 3-3 through the lower stretch of the test site. The highest horizontal erosions of about 30 metres within three weeks were encountered at cross section 1-1.

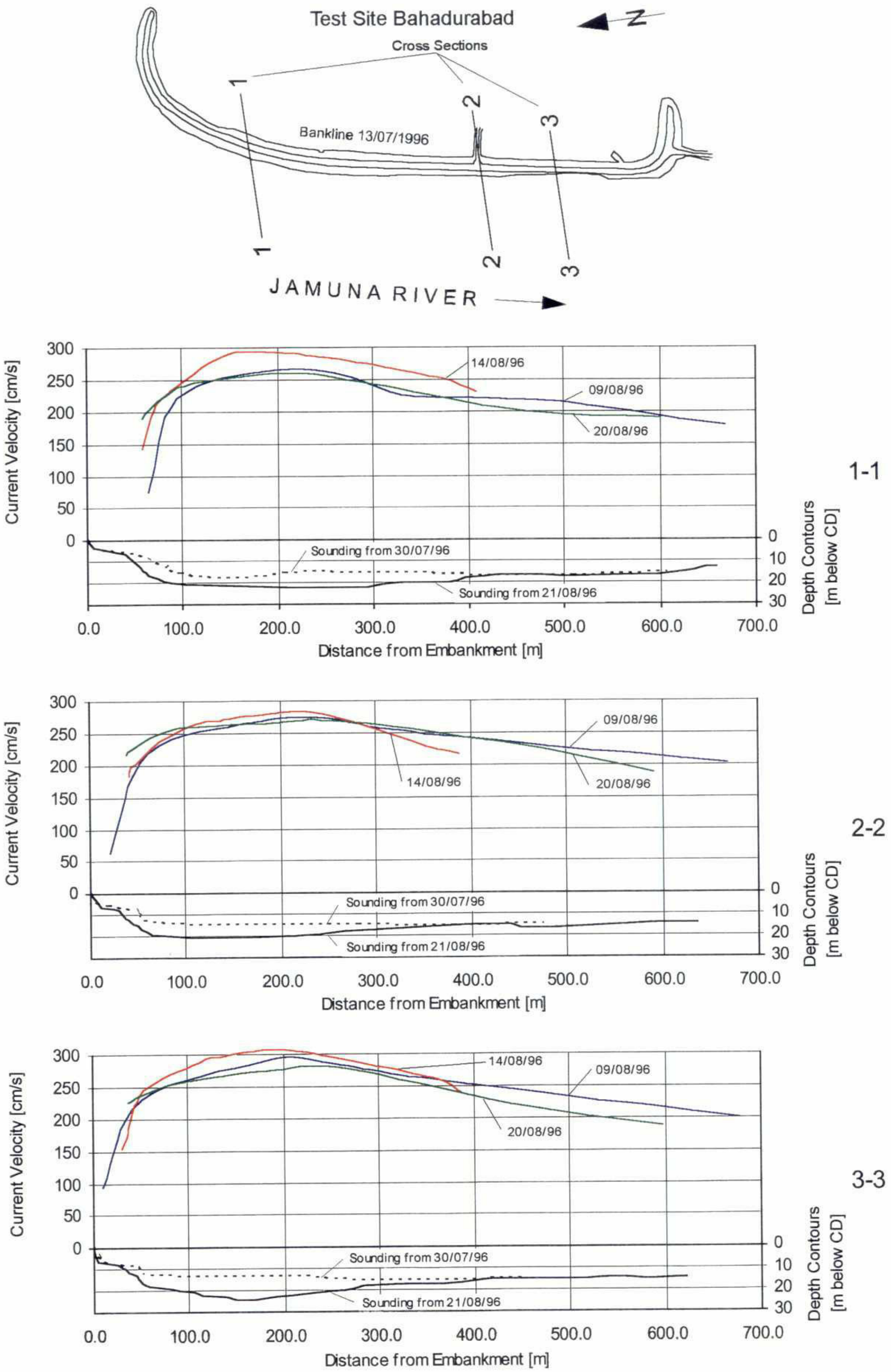


Fig. 21: Distribution of Current Velocities through Cross Sections 1-1, 2-2 and 3-3

The distribution of the current velocities of the flow tracks recorded in 3 metres depth on the 09/08, 14/08 and 20/08/96 through the cross sections based on the soundings are plotted in figure 21. The strongest flow attack was on the 14/08/96 during the short period of rising water levels (red lines in fig. 21). The highest velocities of over v = 3 m/s were reached in profile 3-3 where also the highest bed erosions took place. With the help of the velocity profiles it is recognisable how the currents on the 09/08 near the embankment (blue lines) have shifted eastwards towards the embankment by the 20/08 (green lines). Such high velocities cause severe transverse bed and bank erosions and lead to substantial bank losses because of the fine bed material at the test site Bahadurabad

Finally it can be stated that the test site Bahadurabad was exposed to much higher currents than the protected embankment at Kamarjani

6 CONCLUDING REMARKS

During the period between the 22/07 and the 23/08/96 current measurements were carried out by the Labor fuer Wasserbau of the Hochschule Bremen in the Jamuna River at the test sites Kamarjani and Bahadurabad. The objective was to obtain detailed information about the prevailing hydrodynamic and morphologic conditions in the areas of the test sites.

The complexity of the highly braided river system is documented by the satellite picture from January 1996 (fig. 22). On the 19/08/96 a DGPS drifter buoy following the talweg in 3 metres depth was tracked from Kamarjani to Bahadurabad. The flow track is shown in figure 22. The high velocities (in cm/s) indicate the vigorous morphologic activity of the Jamuna River during the monsoon season.

The analysis of the current measurements in the river at Kamarjani (annexes 2 to 4) in connection with the morphologic conditions during the high flow period (see fig. 13, p. 13) has shown that the talweg progresses from north-east to south-west in the region of the test site. The right undercut bank was situated downstream of the test structures in summer 1996.

The measurements in the groyne fields have shown that the main current attack took place in the environment of groyne G-3 (annexes 5 to 12). Also after the high water from the 15/07/96 current velocities of up to 2 m/s were recorded even during periods of falling water levels. This is the cause for the deep scour downstream of groyne G-3 with a depth of over -2 m PWD. The development of such scours requires special attention. Rapid and unpredictable morphologic changes can threaten the stability of the structure.

The concentration of the stream lines towards the groynes has caused the scour to extend as far as to the mouth of the Manos River (see also fig. 13, p. 13). This scour, caused by the test structure adjoins the natural scour on the undercut right bank. It can be assumed that if the course of the river does not change drastically, the main attack will in future be further south.

Fig. 22: Drifter Track from Kamarjani to Bahadurabad in 3 m Depth on the 19th August 1996; Satellite Picture from January 1996

Downstream of the impermeable dams at G-1 and GA eddy currents were repeatedly recorded. The return currents reached velocities which are sufficient to erode the fine bed and bank material. Recedeing erosions at higher water levels and high current velocities threaten the stability of earth dams, like it was the case in 1995 when the earth dams at G-2 and G-3 failed.

During the measurements it was observed that wind generated waves over long fetches can cause severe damages to unprotected earth dams. The wind velocities on the 26/07/96 reached 11 m/s and generated wave heights of up to 1 metre, which caused severe bank erosions which had to be secured with sand sacks.

The flow attack on the left bank of the constricted channel at Bahadurabad was in 1996 very much stronger than the flow attack at Kamarjani. Far higher current velocities were encountered reaching maxima of $v = 3$ m/s as late as one month after the high water peak on the 15/07/96. The discharges in August have lead to severe bed and bank erosions on the test site at Bahadurabad (fig. 20 and fig. 21, p. 24 and p. 26). Within a period of three weeks the bed was deepened by more than 10 metres with horizontal erosions of about 30 metres towards the left bank. Regarding these developments it can be assumed that the test site at Bahadurabad will be subject to the greater attack during the next monsoon season.

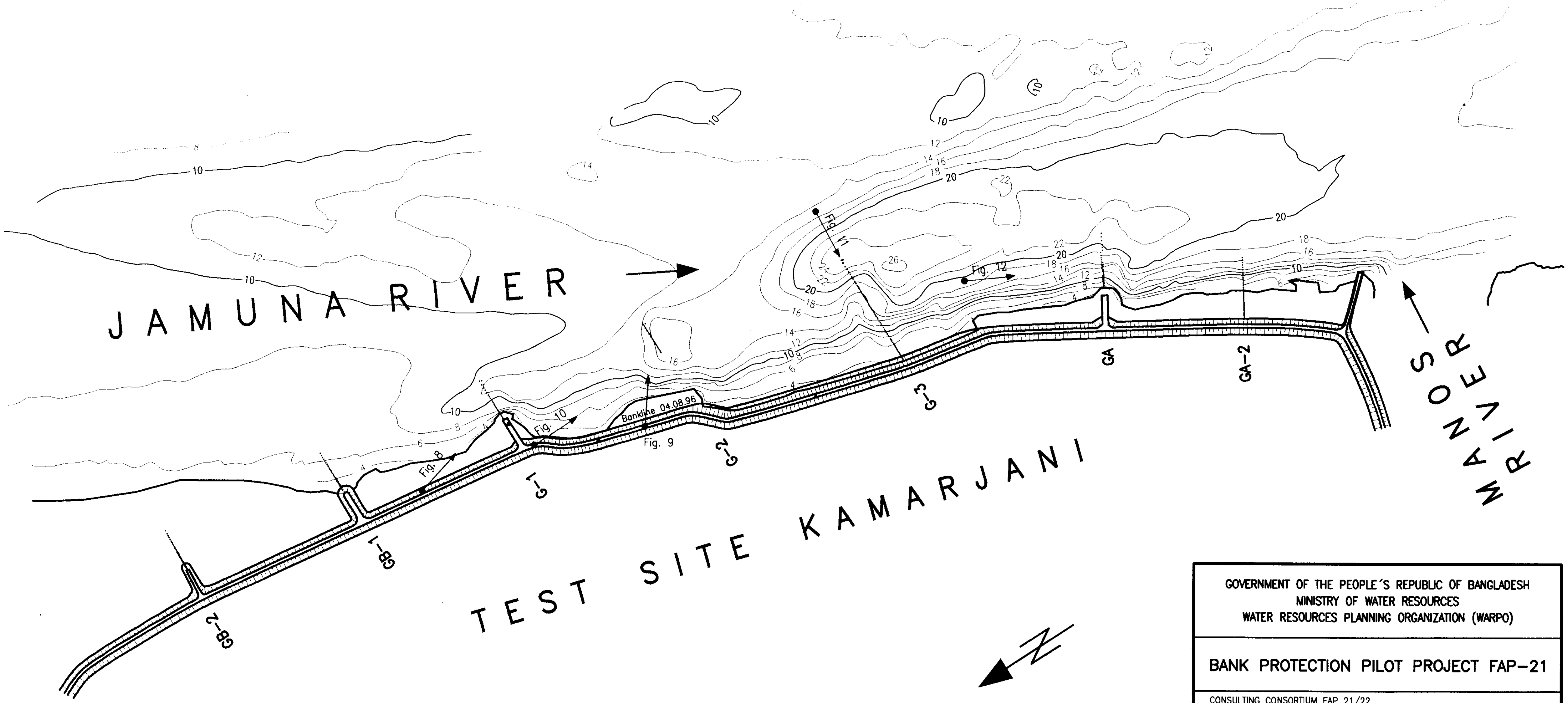
H. Nasner .... (Prof. Dr.-Ing. H. Nasner)

R. Pieper .... (Dipl.-Ing. R. Pieper)

P. Torn .... (Dipl.-Ing. P. Torn)

Bremen, 20/12/1996

ANNEX 1 - 20



GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
WATER RESOURCES PLANNING ORGANIZATION (WARPO)

BANK PROTECTION PILOT PROJECT FAP-21

CONSULTING CONSORTIUM FAP 21/22

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PROF.DR. LACKNER&PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.(BETS)
DESH UPODESH LIMITED (DUL)

TEST SITE I – KAMARJANI
GENERAL LAYOUT

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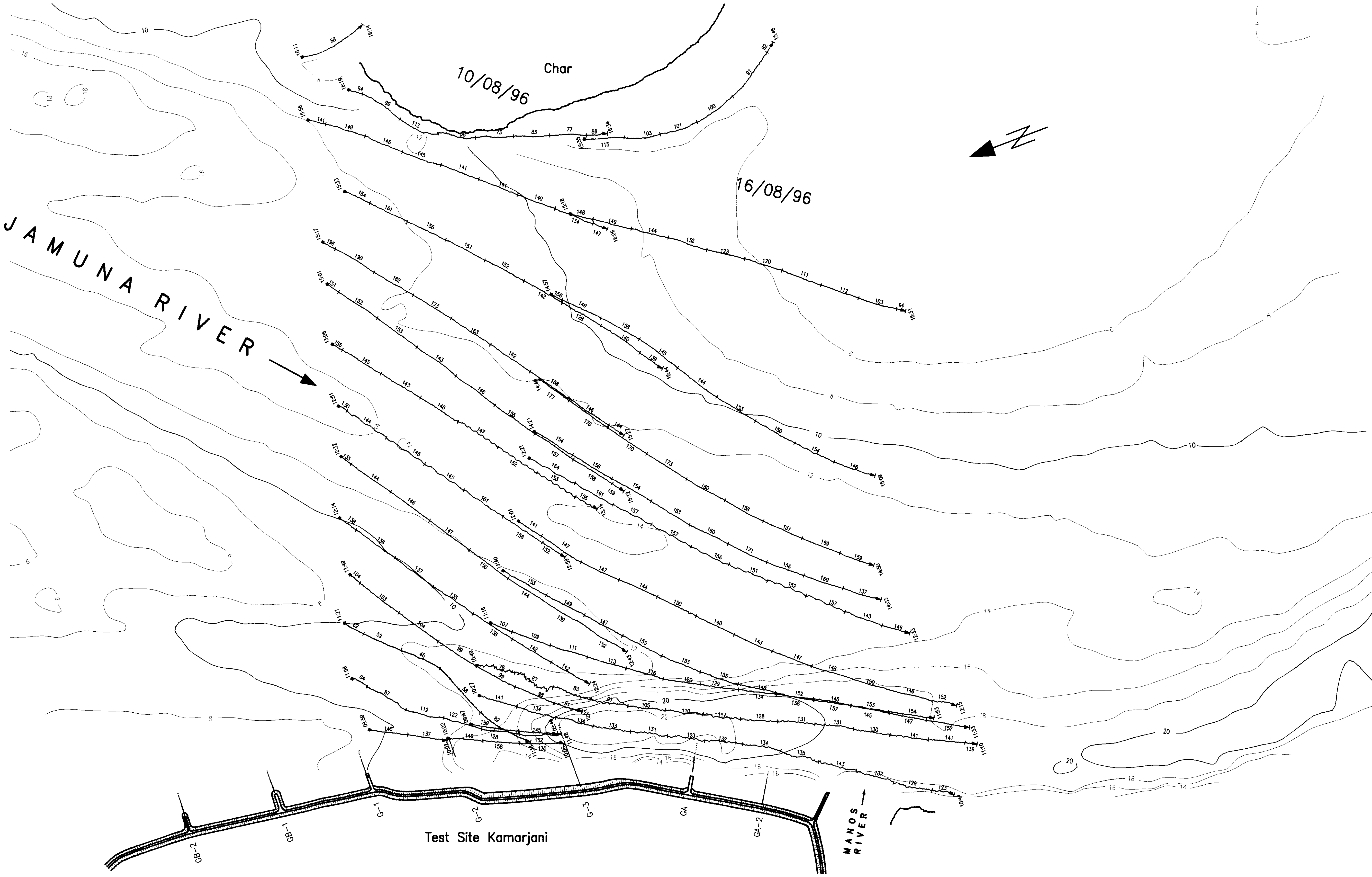
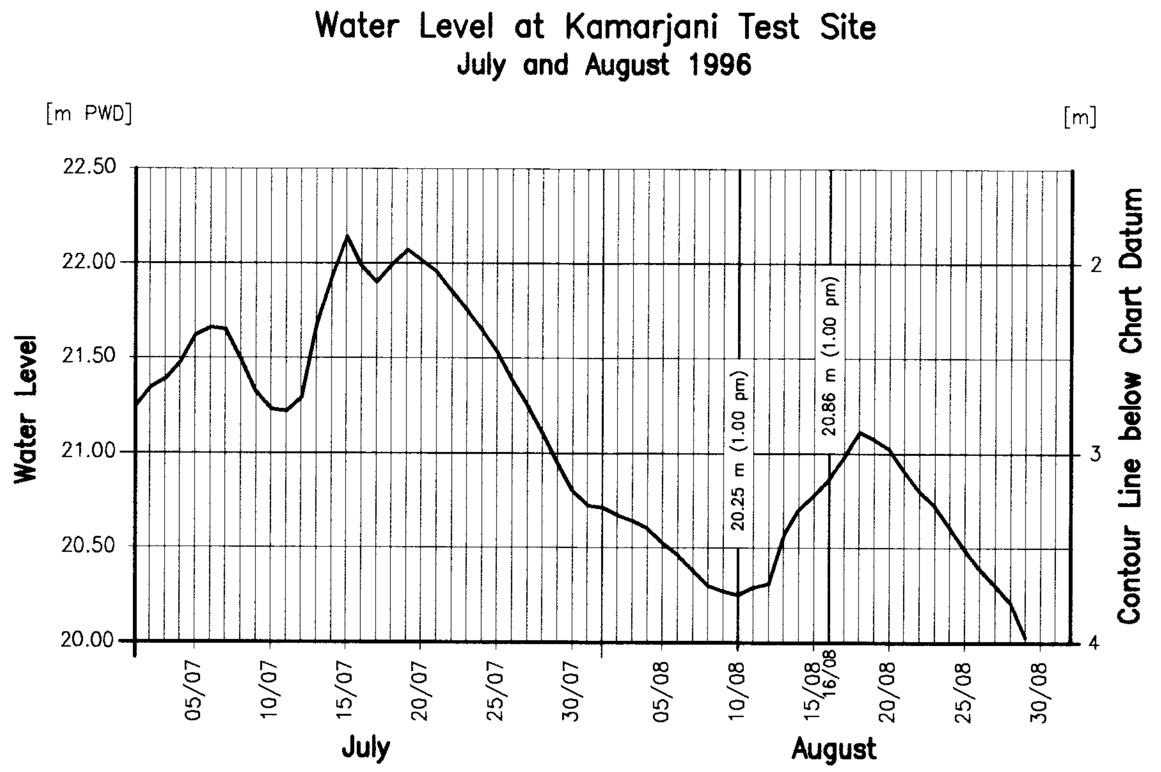
Bathymetric Survey: 01/08 – 04/08/96
Chart Datum: 24 m above Public Works Department (PWD)

ANNEX 1





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TEST SITE I - KAMARJANI
CURRENT MEASUREMENTS ON THE SURFACE

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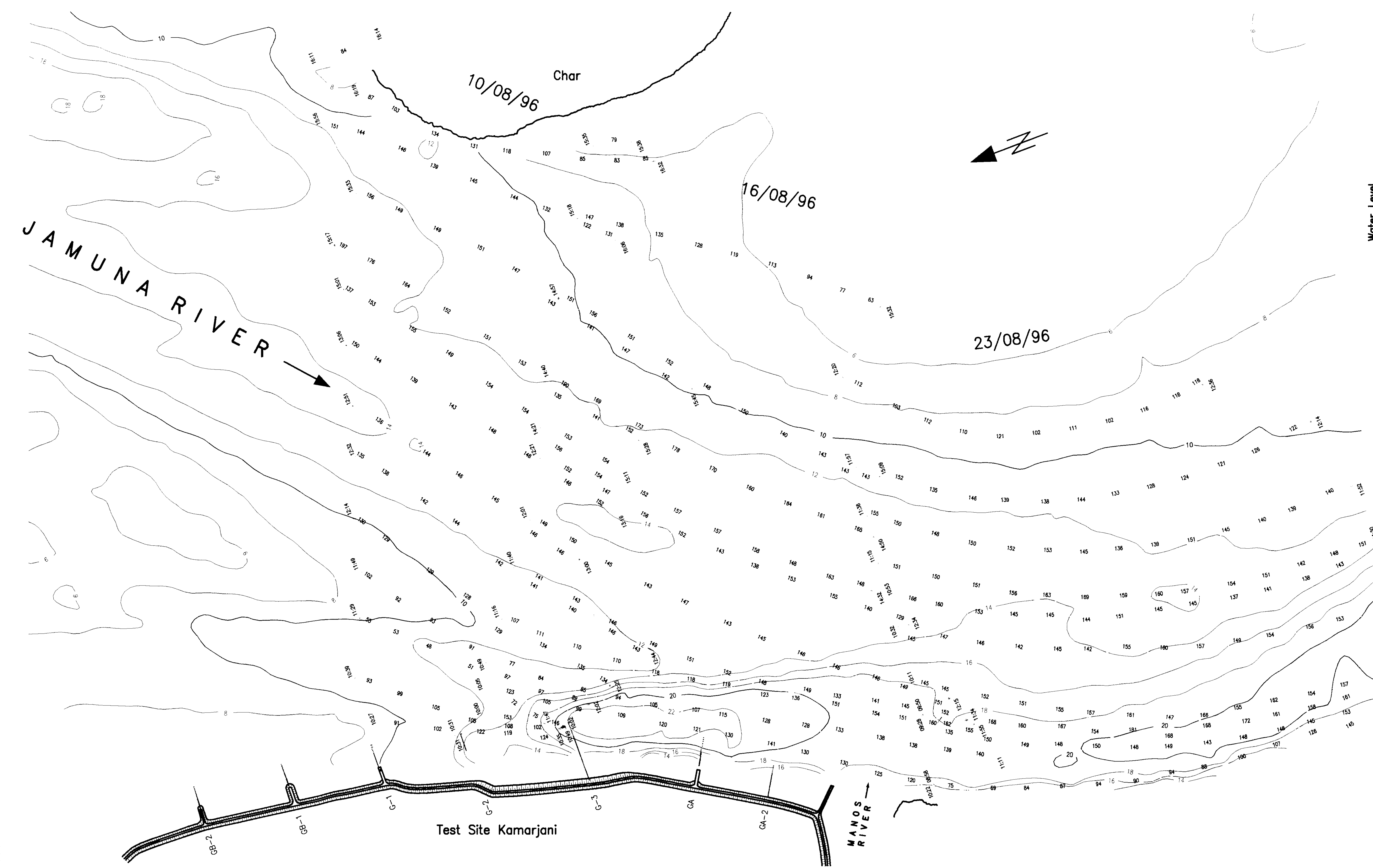
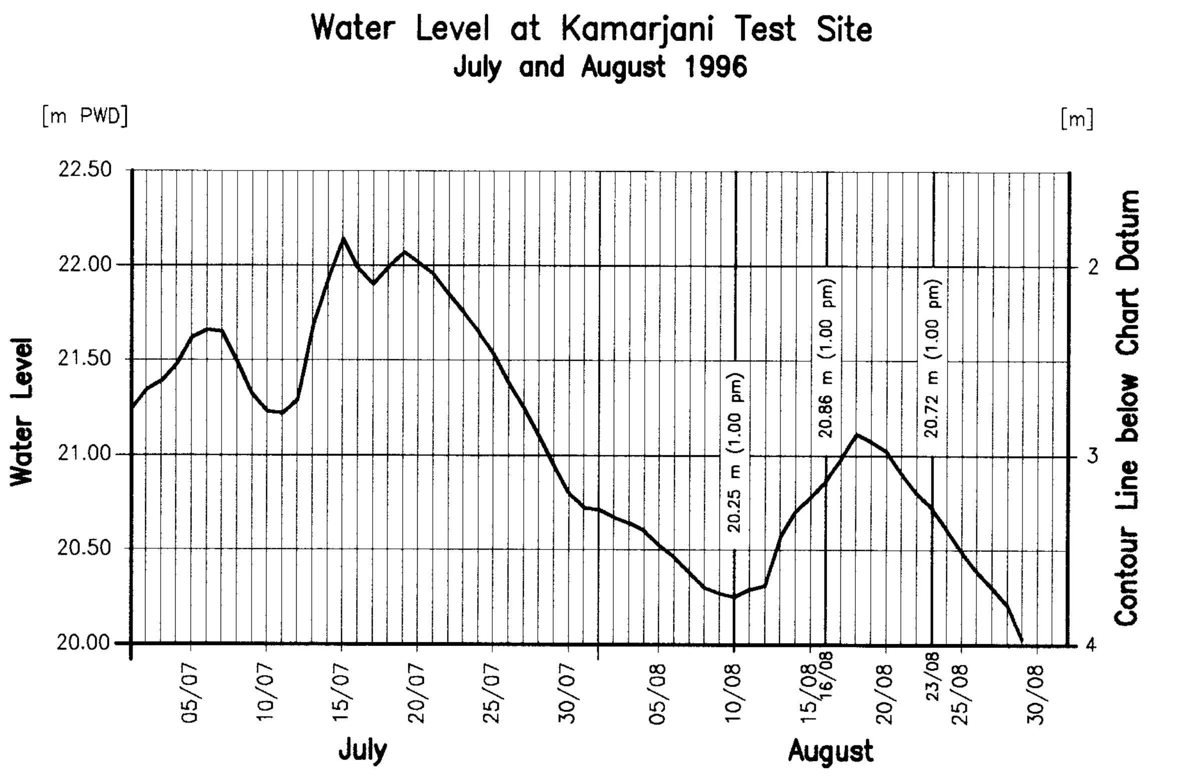
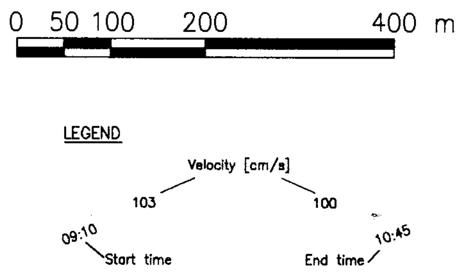
Current Measurements: 10/08/96, 16/08/96
Bathymetric Survey: 11/08 - 15/08/96
Chart Datum: 24 m above Public Works Department (PWD)

ANNEX 2







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BANK PROTECTION PILOT PROJECT FAP-21

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TEST SITE I - KAMARJANI
CURRENT MEASUREMENTS IN 1.5 & 6.0 METRES DEPTH

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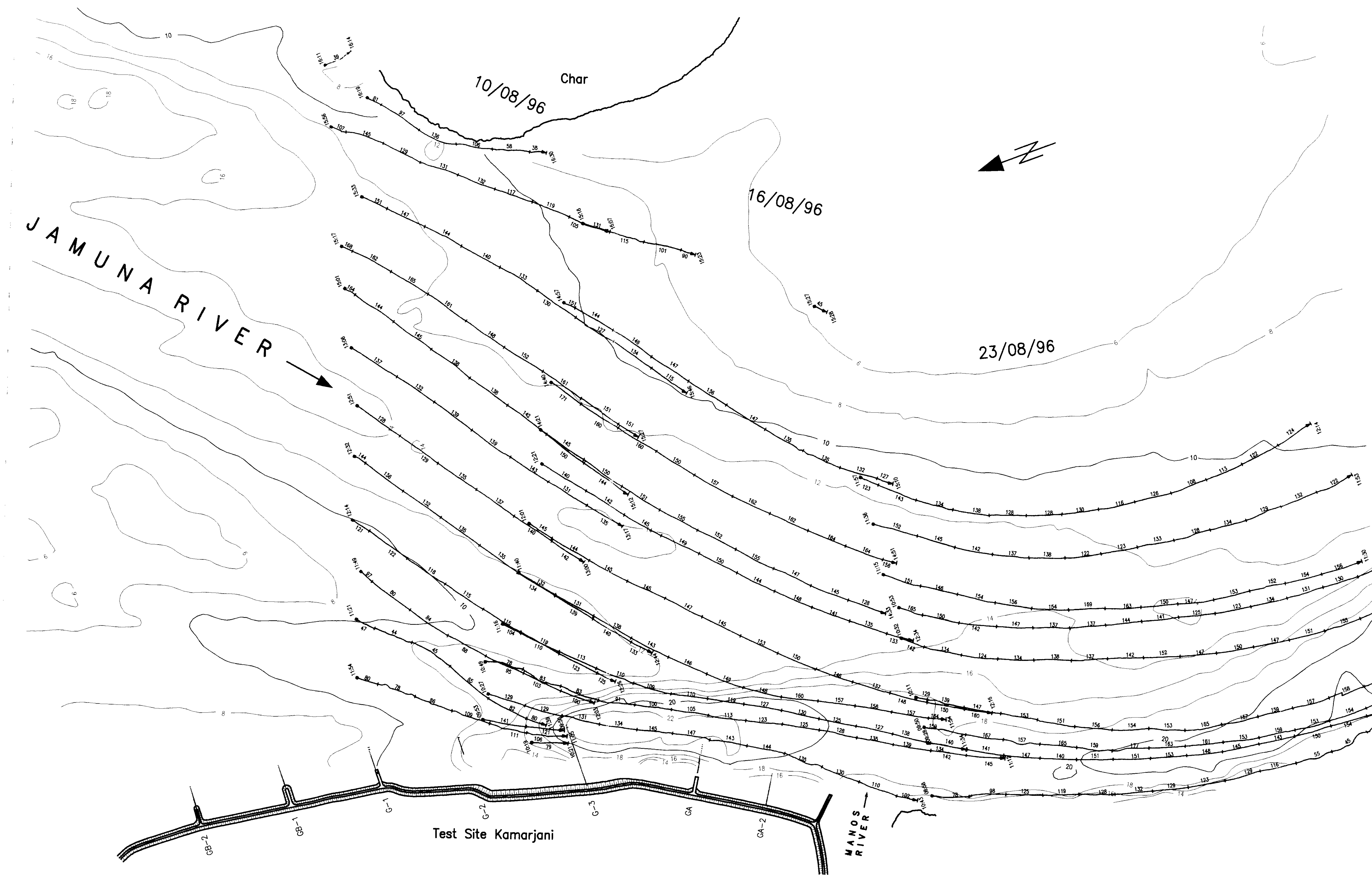
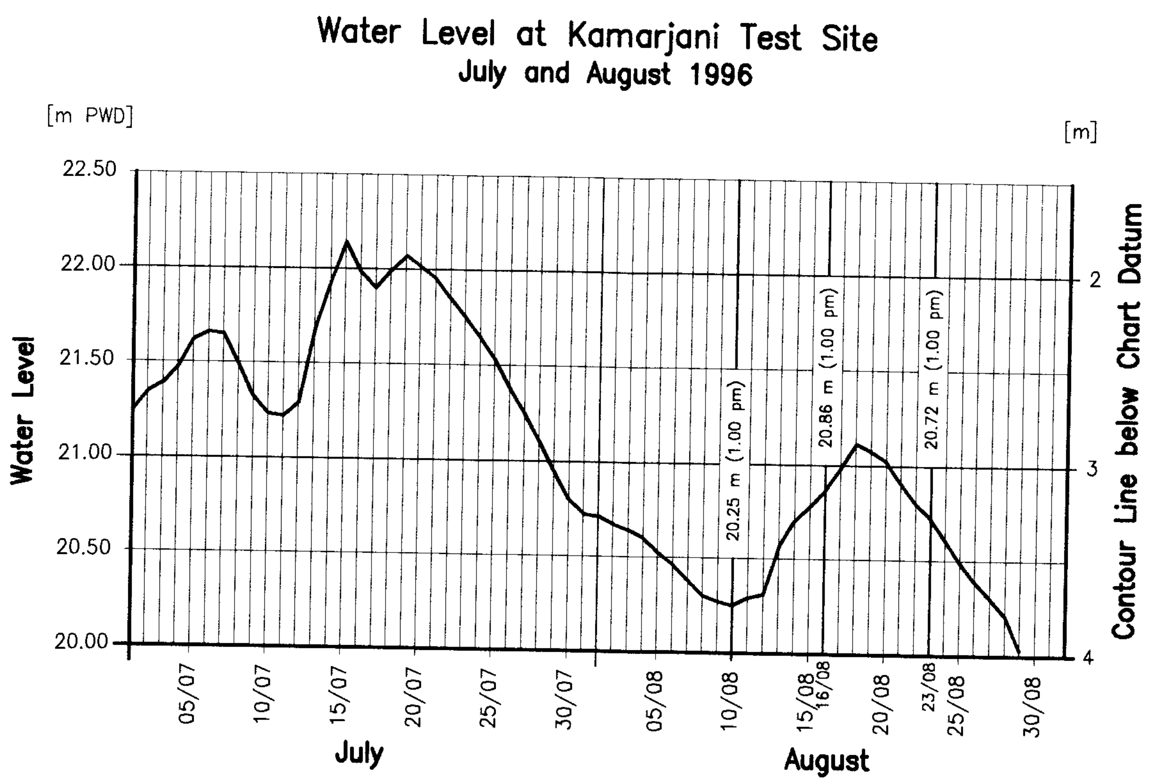
Current Measurements: 10/08/96, 16/08/96, 23/08/96
Bathymetric Survey: 11/08 - 15/08/96
Chart Datum: 24 m above Public Works Department (PWD)

ANNEX 3





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TEST SITE I – KAMARJANI
CURRENT MEASUREMENTS IN 3.0 METRES DEPTH

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Current Measurements: 10/08/96, 16/08/96, 23/08/96
Bathymetric Survey: 11/08 – 15/08/96
Chart Datum: 24 m above Public Works Department (PWD)

ANNEX 4

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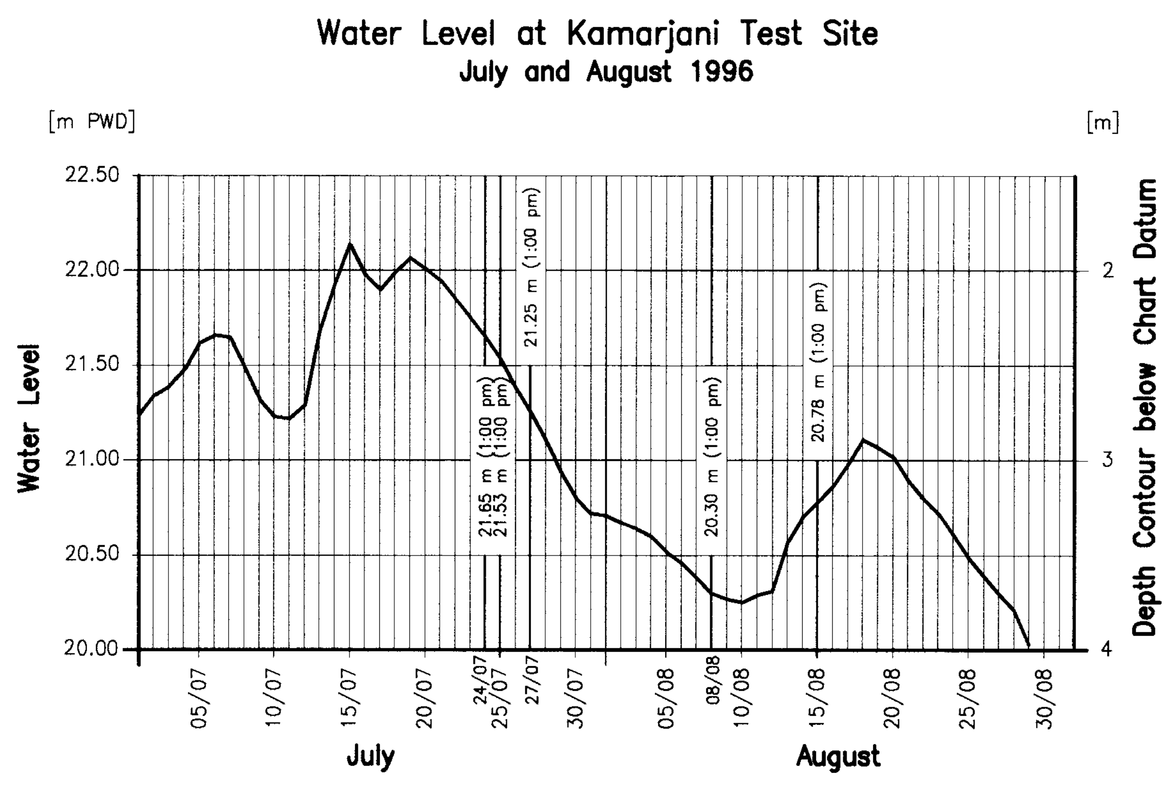

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TEST SITE I - KAMARJANI
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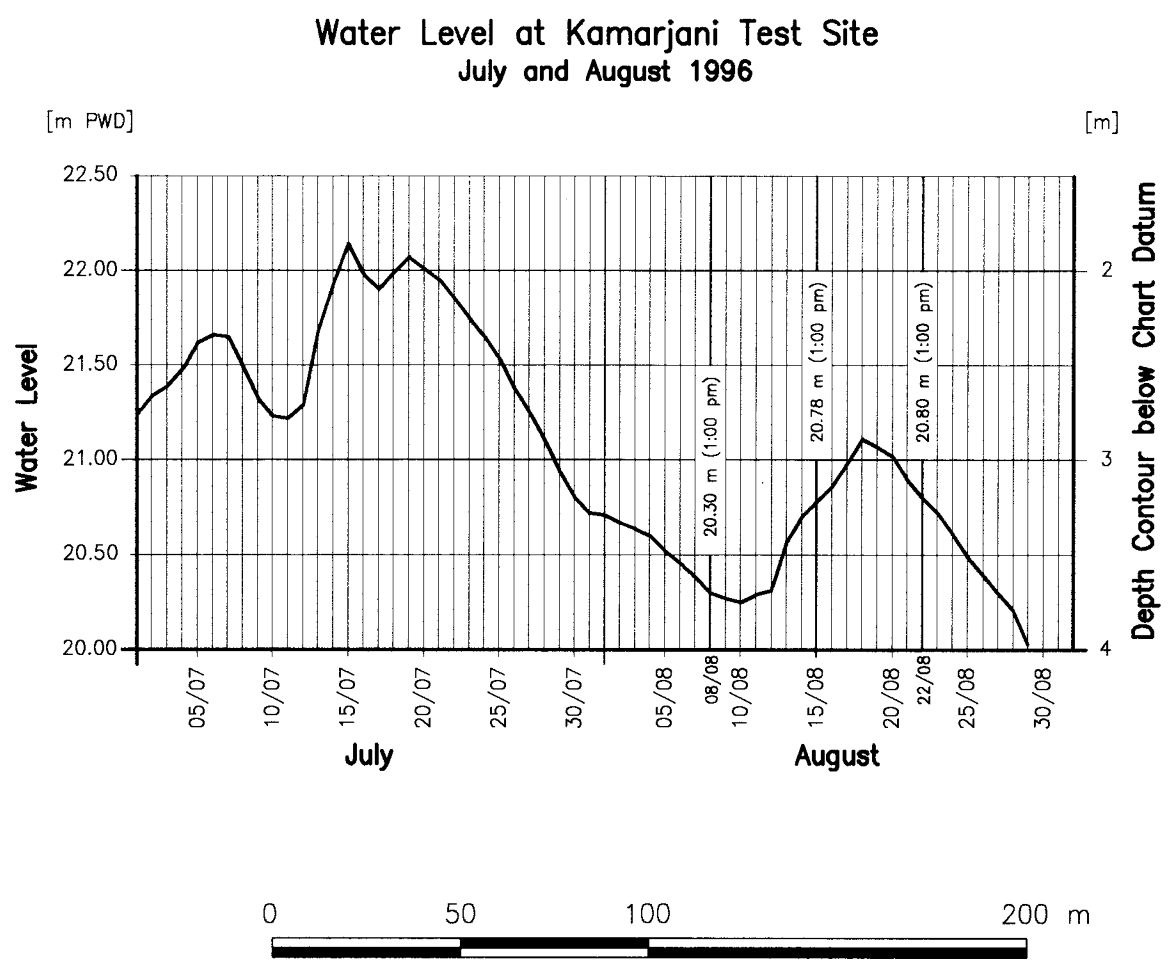
Current Measurements: 24/07, 25/07, 27/07, 08/08 & 15/08/96
Bathymetric Survey: 01/08 - 04/08/96
Chart Datum: 24 m above Public Works Department (PWD)

ANNEX 5



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Current Measurements: 08/08, 15/08 & 22/08/96
Bathymetric Survey: 01/08 - 04/08/96
Chart Datum: 24 m above Public Works Department (PWD)

ANNEX 6

GOVERNMENT OF THE PEOPLE´S REPUBLIC OF BANGLADESH
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TEST SITE I – KAMARJANI
CURRENT MEASUREMENTS IN 1.5 METRES DEPTH

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Current Measurements: 23/07, 27/07 & 30/07/96
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ANNEX 7

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Current Measurements: 03/08 & 18/08/96
Bathymetric Survey: 01/08 - 04/08/96
Chart Datum: 24 m above Public Works Department (PWD)

ANNEX 8

GOVERNMENT OF THE PEOPLE´S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
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CURRENT MEASUREMENTS IN 3.0 METRES DEPTH

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Current Measurements: 22/07 & 31/07/96
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ANNEX 9

GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
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CONSULTING CONSORTIUM FAP 21/22

RHEIN-RUHR ING.-GES.MBH, DORTMUND/GERMANY
COMPAGNIE NATIONALE DU RHONE, LYON/FRANCE
PROF.DR. LACKNER&PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.(BETS)
DESH UPODESH LIMITED (DUL)

TEST SITE I – KAMARJANI
CURRENT MEASUREMENTS IN 3.0 METRES DEPTH

HOCHSCHULE BREMEN
Prof. Dr.-Ing. H. Nasner

Labor fuer Wasserbau
Neustadtswall 30
D-28199 Bremen
Germany

Tel.: ++49-421-5905313
Fax: ++49-421-5905346

Current Measurements: 05/08 & 18/08/96
Bathymetric Survey: 01/08 – 04/08/96
Chart Datum: 24 m above Public Works Department (PWD)

ANNEX 10

GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
WATER RESOURCES PLANNING ORGANIZATION (WARPO)

BANK PROTECTION PILOT PROJECT FAP-21

CONSULTING CONSORTIUM FAP 21/22

RHEIN-RUHR ING.-GES.MBH, DORTMUND/GERMANY
COMPAGNIE NATIONALE DU RHONE, LYON/FRANCE
PROF.DR. LACKNER&PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.(BETS)
DESH UPODESH LIMITED (DUL)

TEST SITE I - KAMARJANI
CURRENT MEASUREMENTS IN 6.0 METRES DEPTH

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Germany
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Fax: ++49-421-5905346

Current Measurements: 02/08/96
Bathymetric Survey: 01/08 - 04/08/96
Chart Datum: 24 m above Public Works Department (PWD)

ANNEX 11

GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
WATER RESOURCES PLANNING ORGANIZATION (WARPO)

BANK PROTECTION PILOT PROJECT FAP-21

CONSULTING CONSORTIUM FAP 21/22

RHEIN-RUHR ING.-GES.MBH, DORTMUND/GERMANY
COMPAGNIE NATIONALE DU RHONE, LYON/FRANCE
PROF.DR. LACKNER&PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.(BETS)
DESH UPODESH LIMITED (DUL)

TEST SITE I – KAMARJANI
CURRENT MEASUREMENTS IN 6.0 METRES DEPTH

HOCHSCHULE BREMEN
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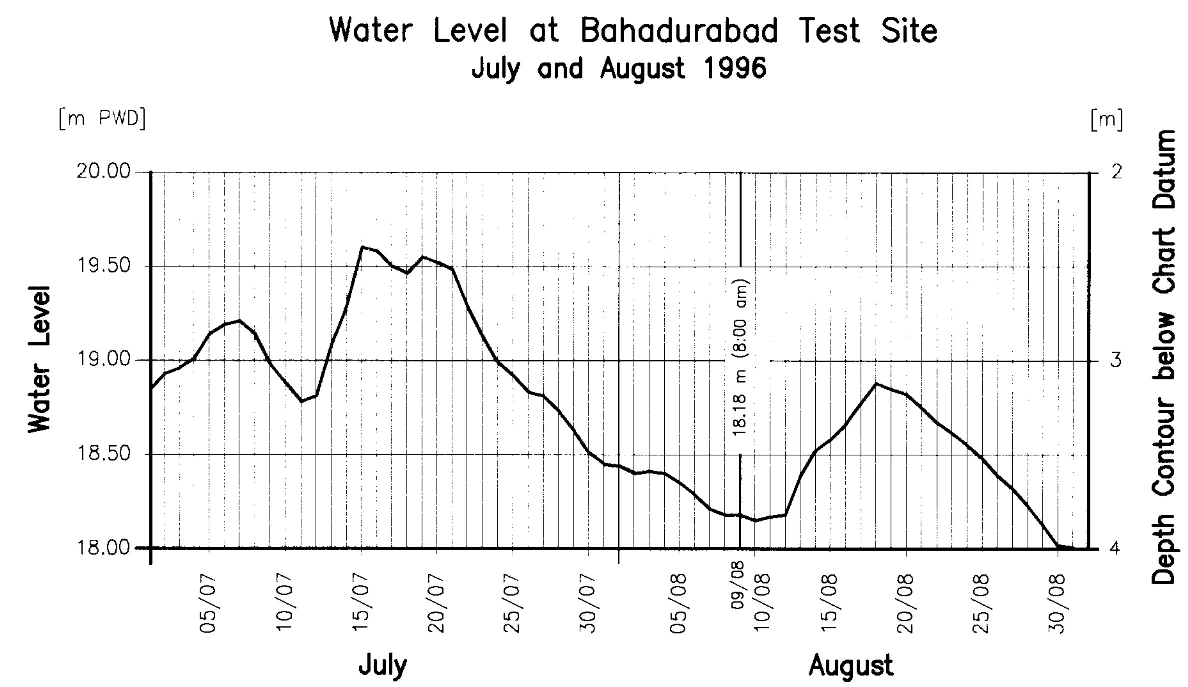
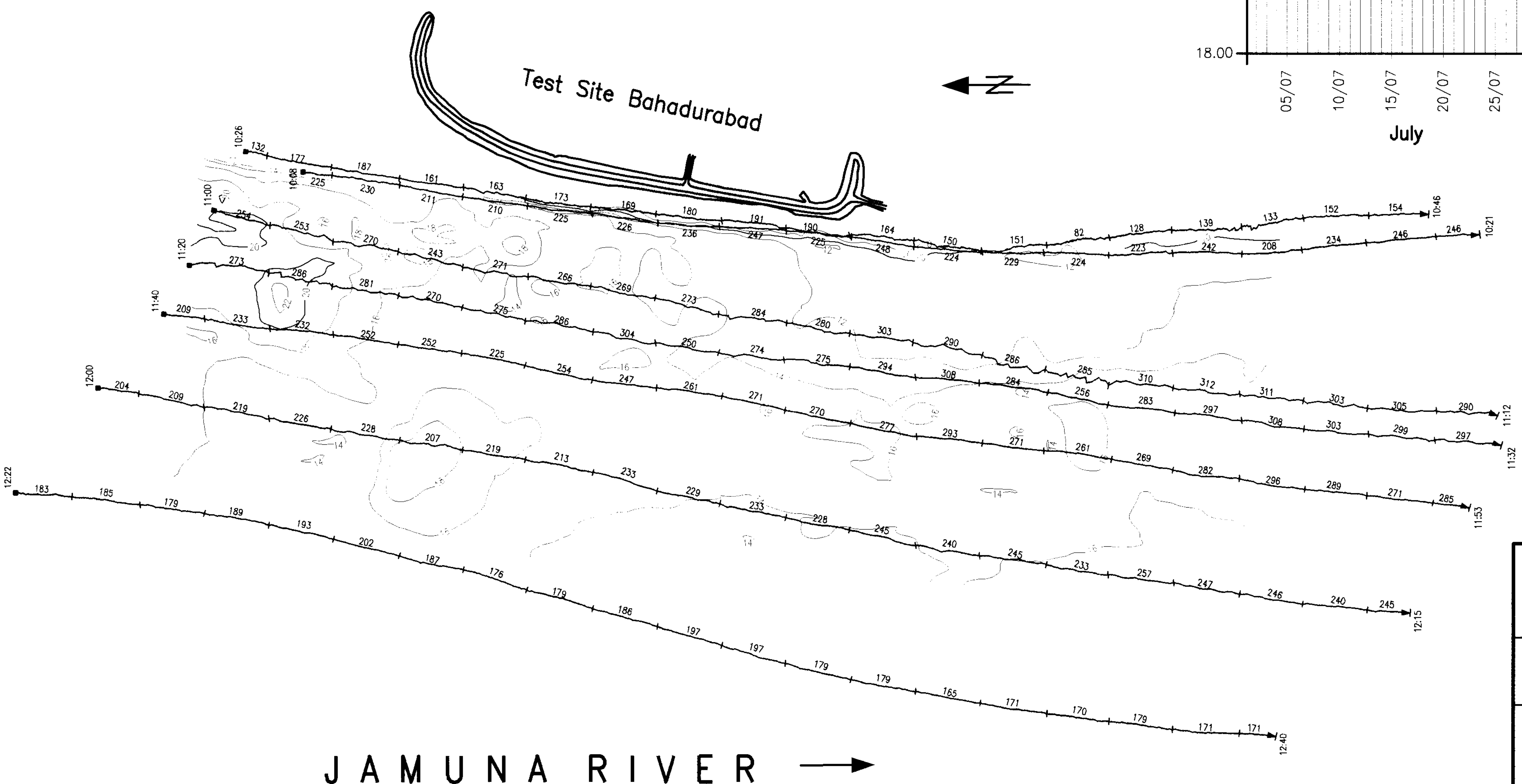
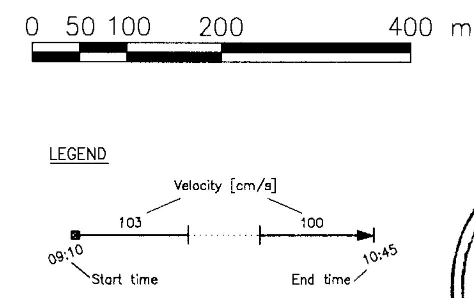
Current Measurements: 11/08 & 12/08/96
Bathymetric Survey: 01/08 – 04/08/96
Chart Datum: 24 m above Public Works Department (PWD)

ANNEX 12







GOVERNMENT OF THE PEOPLE´S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
WATER RESOURCES PLANNING ORGANIZATION (WARPO)

BANK PROTECTION PILOT PROJECT FAP–21

CONSULTING CONSORTIUM FAP 21/22

RHEIN–RUHR ING.–GES.MBH, DORTMUND/GERMANY
COMPAGNIE NATIONALE DU RHONE, LYON/FRANCE
PROF.DR. LACKNER&PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.(BETS)
DESH UPODESH LIMITED (DUL)

TEST SITE II – BAHADURABAD
CURRENT MEASUREMENTS ON THE SURFACE

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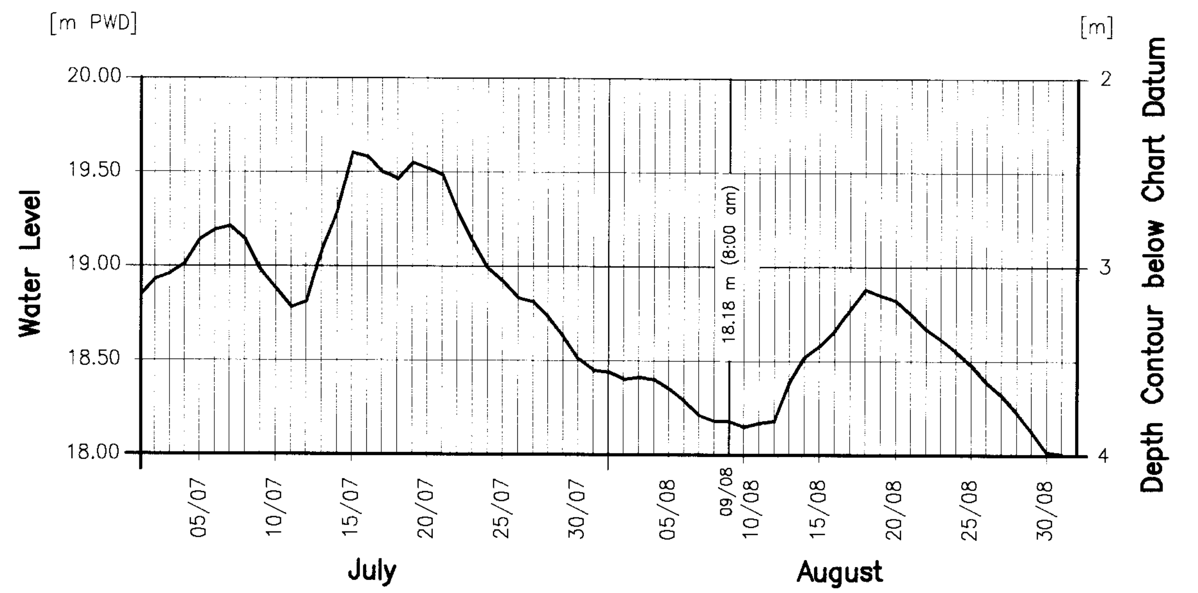
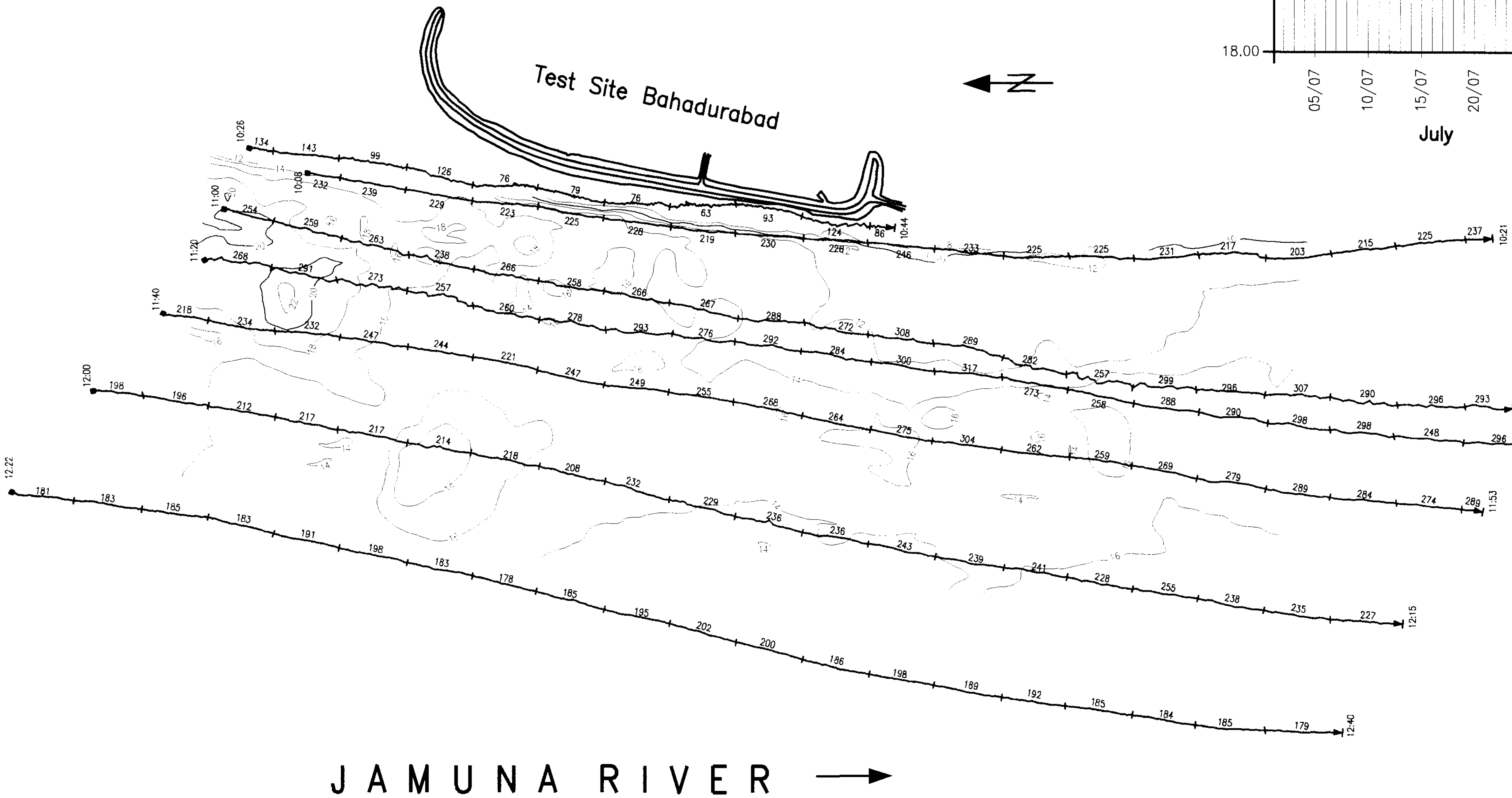
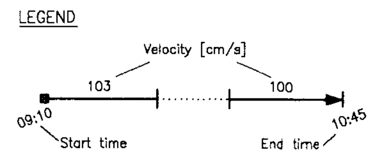
Current Measurements:	09/08/96	ANNEX
Bathymetric Survey:	30/07/96	13
Chart Datum:	22 m above Public Works Department (PWD)	

8∂

Water Level at Bahadurabad Test Site
July and August 1996







GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
WATER RESOURCES PLANNING ORGANIZATION (WARPO)

BANK PROTECTION PILOT PROJECT FAP–21

CONSULTING CONSORTIUM FAP 21/22

RHEIN–RUHR ING.–GES.MBH, DORTMUND/GERMANY
COMPAGNIE NATIONALE DU RHONE, LYON/FRANCE
PROF.DR. LACKNER&PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.(BETS)
DESH UPODESH LIMITED (DUL)

TEST SITE II – BAHADURABAD
CURRENT MEASUREMENTS IN 3.0 METRES DEPTH

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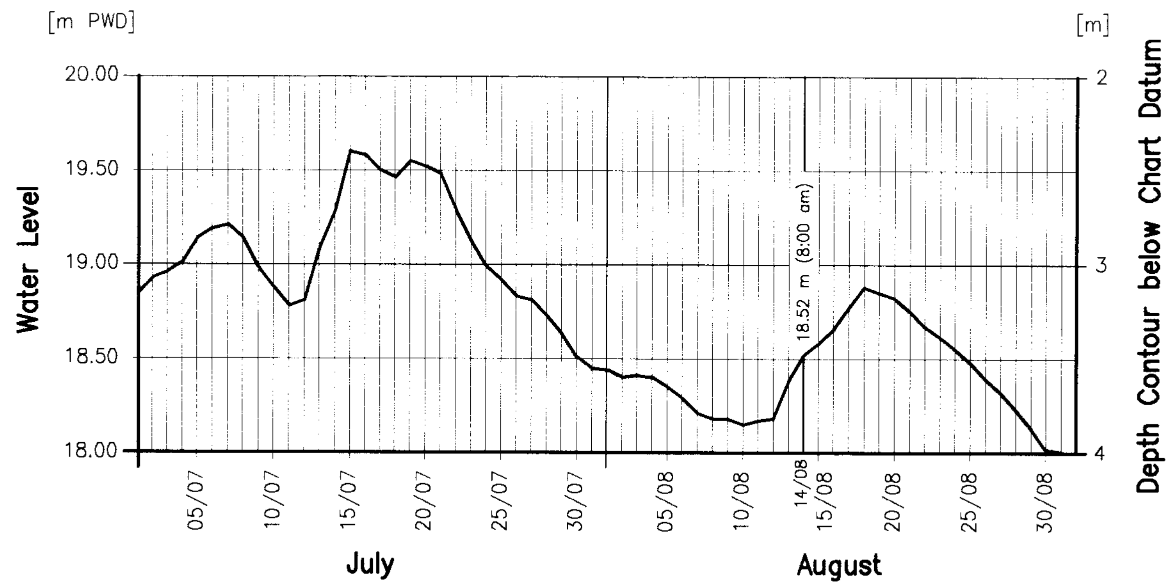
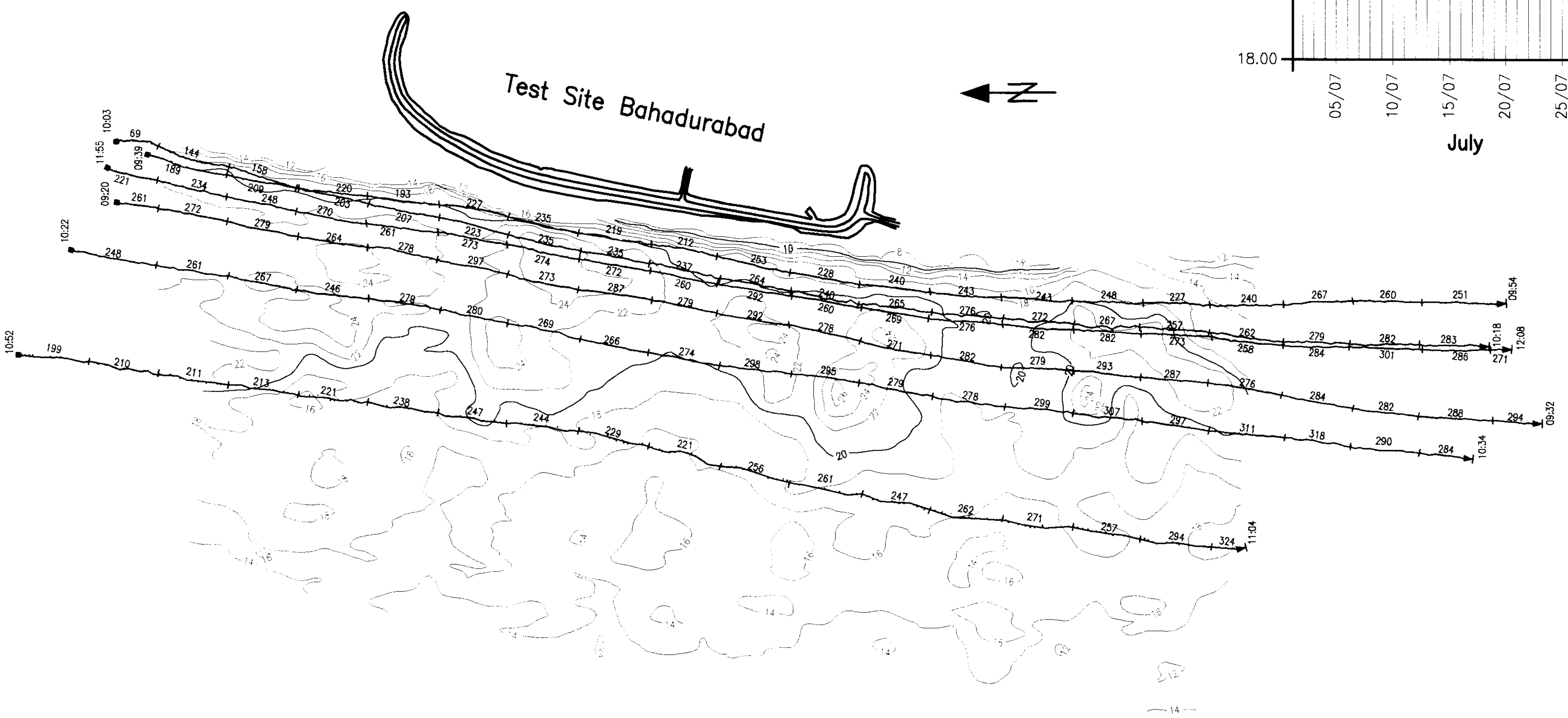
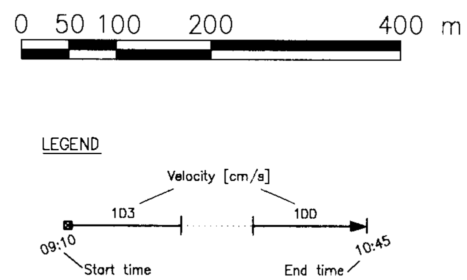
Current Measurements: 09/08/96
Bathymetric Survey: 30/07/96
Chart Datum: 22 m above Public Works Department (PWD)

ANNEX
14

Water Level at Bahadurabad Test Site
July and August 1996







JAMUNA RIVER →

GOVERNMENT OF THE PEOPLE´S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
WATER RESOURCES PLANNING ORGANIZATION (WARPO)

BANK PROTECTION PILOT PROJECT FAP–21

CONSULTING CONSORTIUM FAP 21/22

RHEIN–RUHR ING.–GES.MBH, DORTMUND/GERMANY
COMPAGNIE NATIONALE DU RHONE, LYON/FRANCE
PROF.DR. LACKNER&PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.(BETS)
DESH UPODESH LIMITED (DUL)

TEST SITE II – BAHADURABAD
CURRENT MEASUREMENTS ON THE SURFACE

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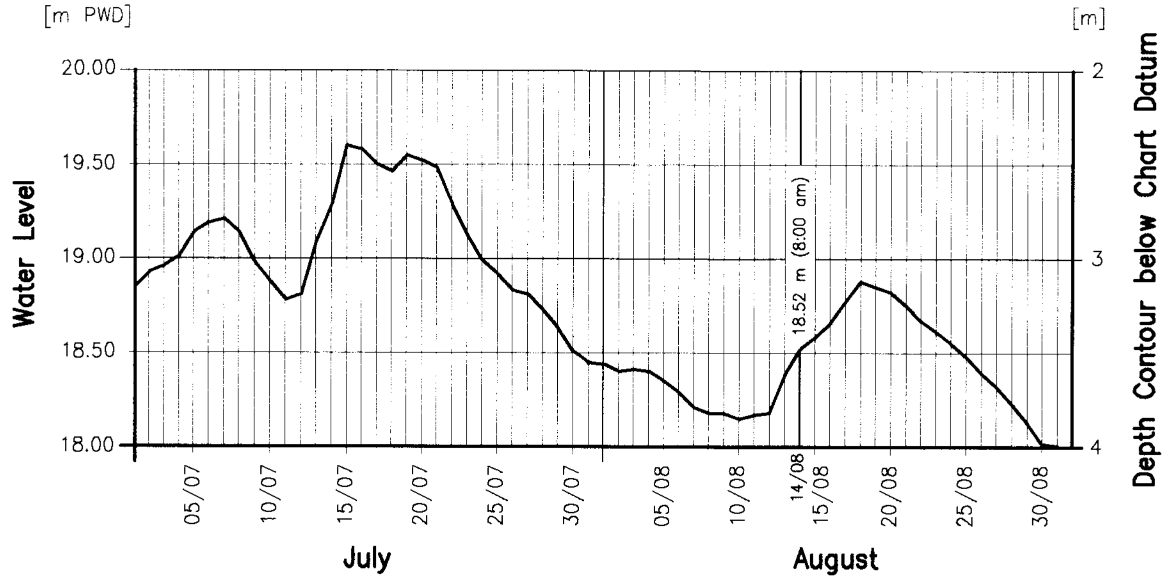
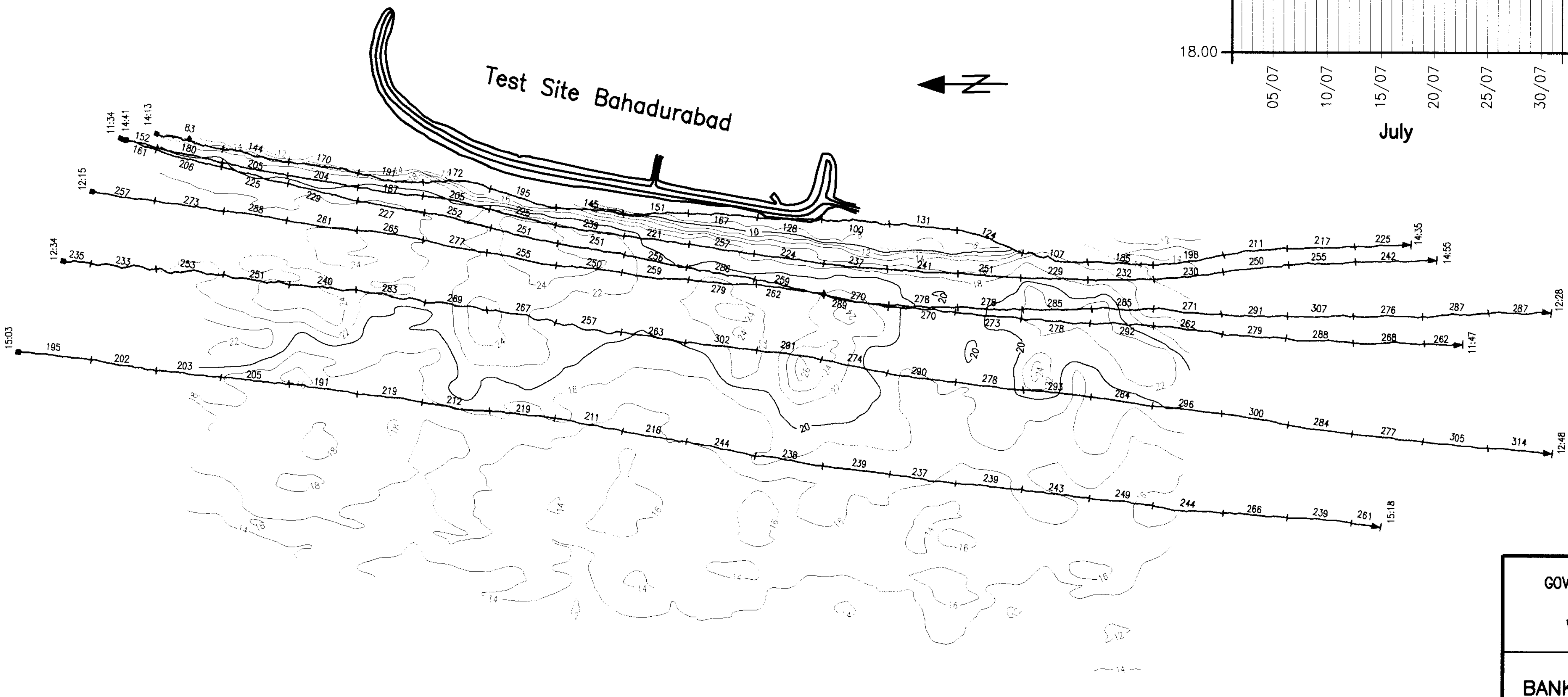
Fax: ++49–421–5905346

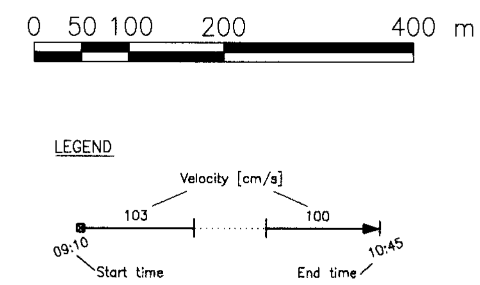
Current Measurements: 14/08/96
Bathymetric Survey: 21/08/96
Chart Datum: 22 m above Public Works Department (PWD)

ANNEX
15

Water Level at Bahadurabad Test Site
July and August 1996







JAMUNA RIVER →

GOVERNMENT OF THE PEOPLE´S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
WATER RESOURCES PLANNING ORGANIZATION (WARPO)

BANK PROTECTION PILOT PROJECT FAP–21

CONSULTING CONSORTIUM FAP 21/22

RHEIN–RUHR ING.–GES.MBH, DORTMUND/GERMANY
COMPAGNIE NATIONALE DU RHONE, LYON/FRANCE
PROF.DR. LACKNER&PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.(BETS)
DESH UPODESH LIMITED (DUL)

TEST SITE II – BAHADURABAD
CURRENT MEASUREMENTS ON THE SURFACE

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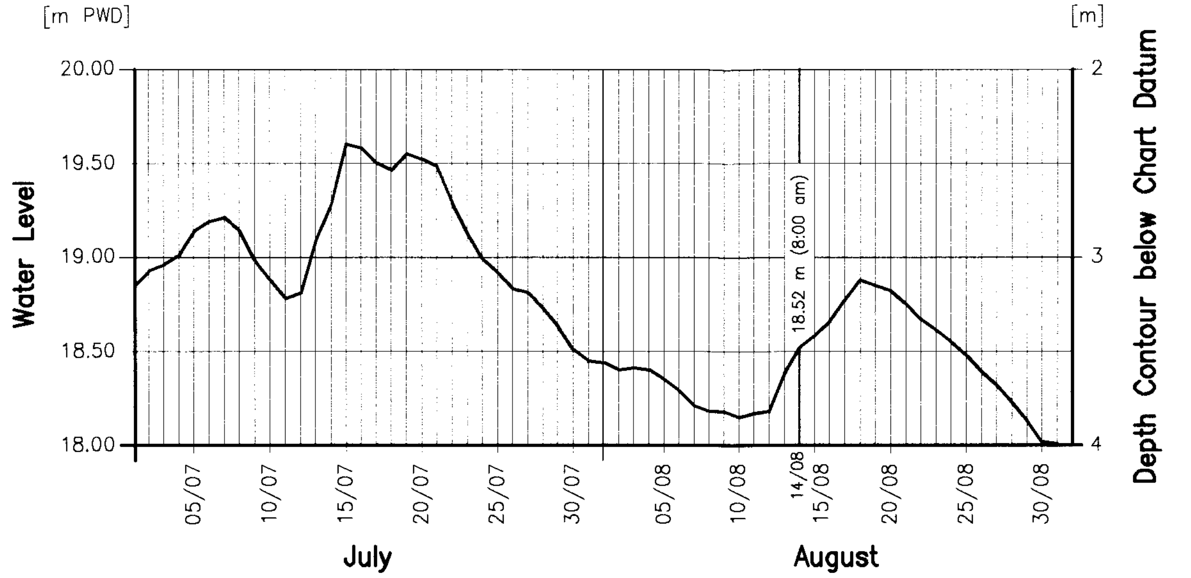
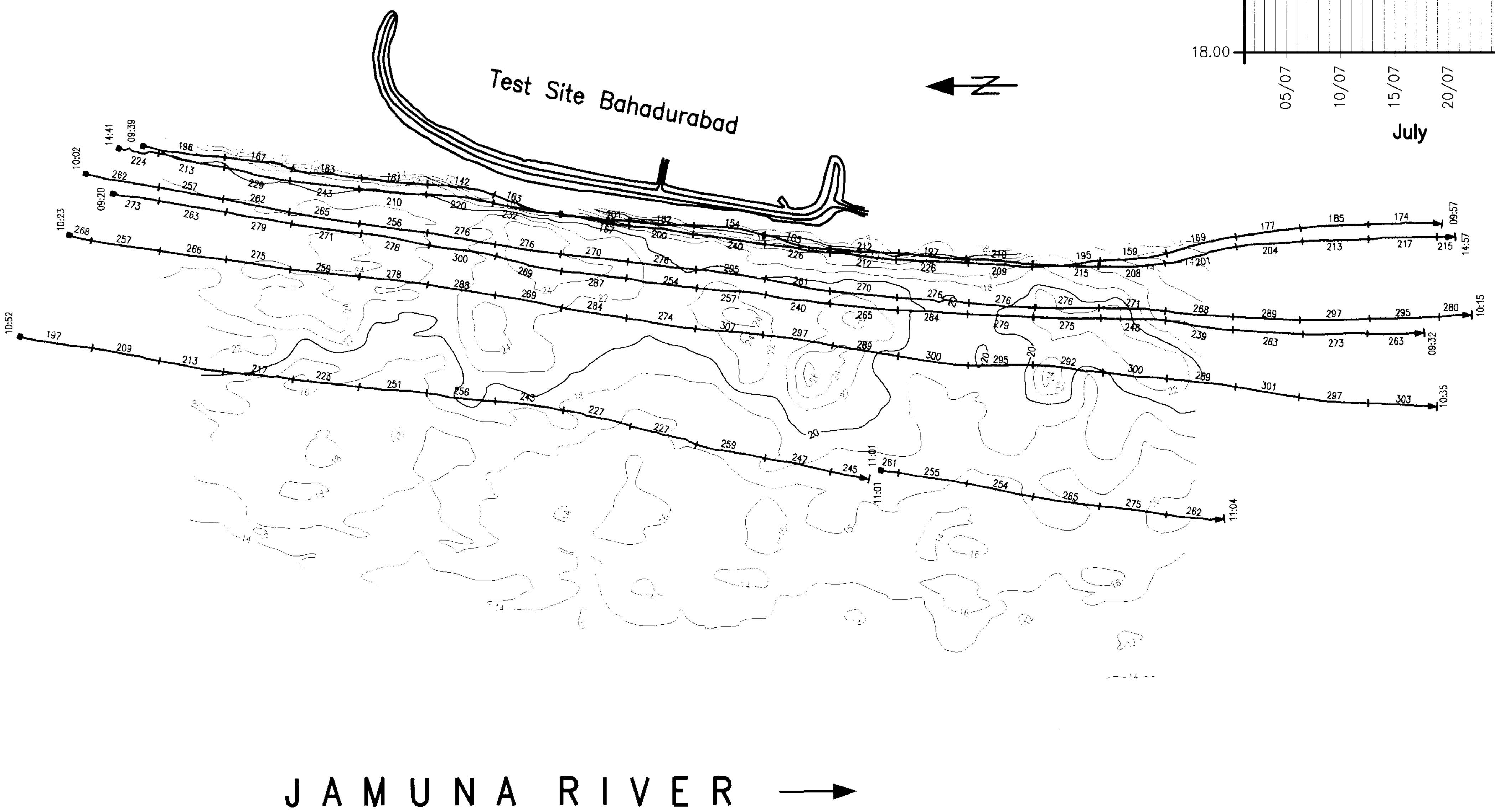
Germany
Tel.: ++49–421–5905313
Fax: ++49–421–5905346

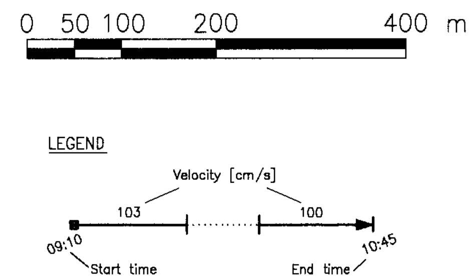
Current Measurements: 14/08/96
Bathymetric Survey: 21/08/96
Chart Datum: 22 m above Public Works Department (PWD)

ANNEX
16

Water Level at Bahadurabad Test Site
July and August 1996







GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
WATER RESOURCES PLANNING ORGANIZATION (WARPO)

BANK PROTECTION PILOT PROJECT FAP–21

CONSULTING CONSORTIUM FAP 21/22

RHEIN–RUHR ING.–GES.MBH, DORTMUND/GERMANY
COMPAGNIE NATIONALE DU RHONE, LYON/FRANCE
PROF.DR. LACKNER&PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.(BETS)
DESH UPODESH LIMITED (DUL)

TEST SITE II – BAHADURABAD
CURRENT MEASUREMENTS IN 3.0 METRES DEPTH

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Germany

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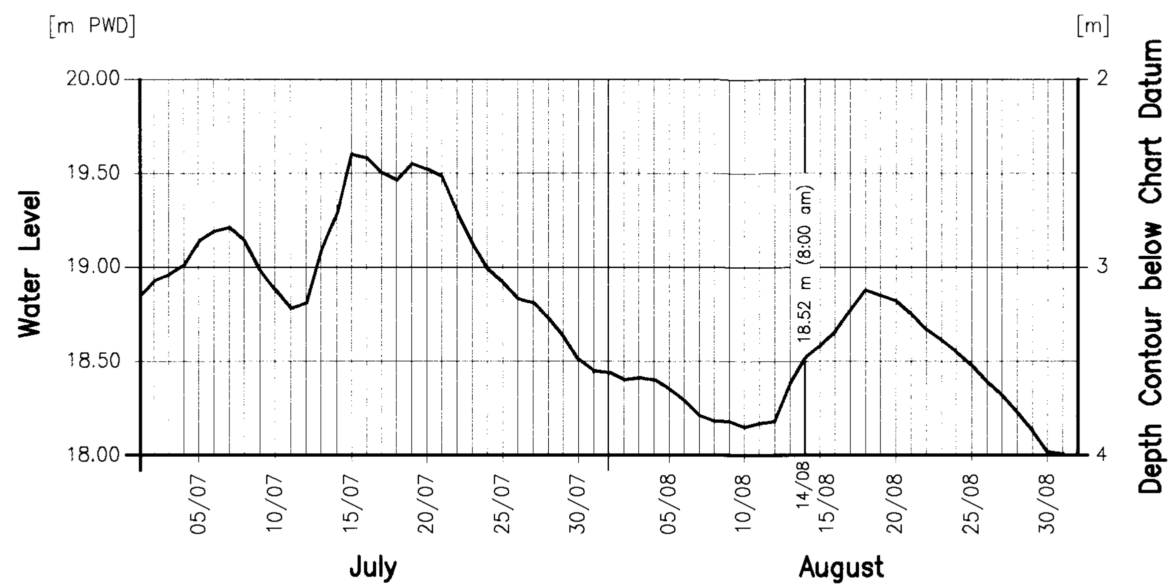
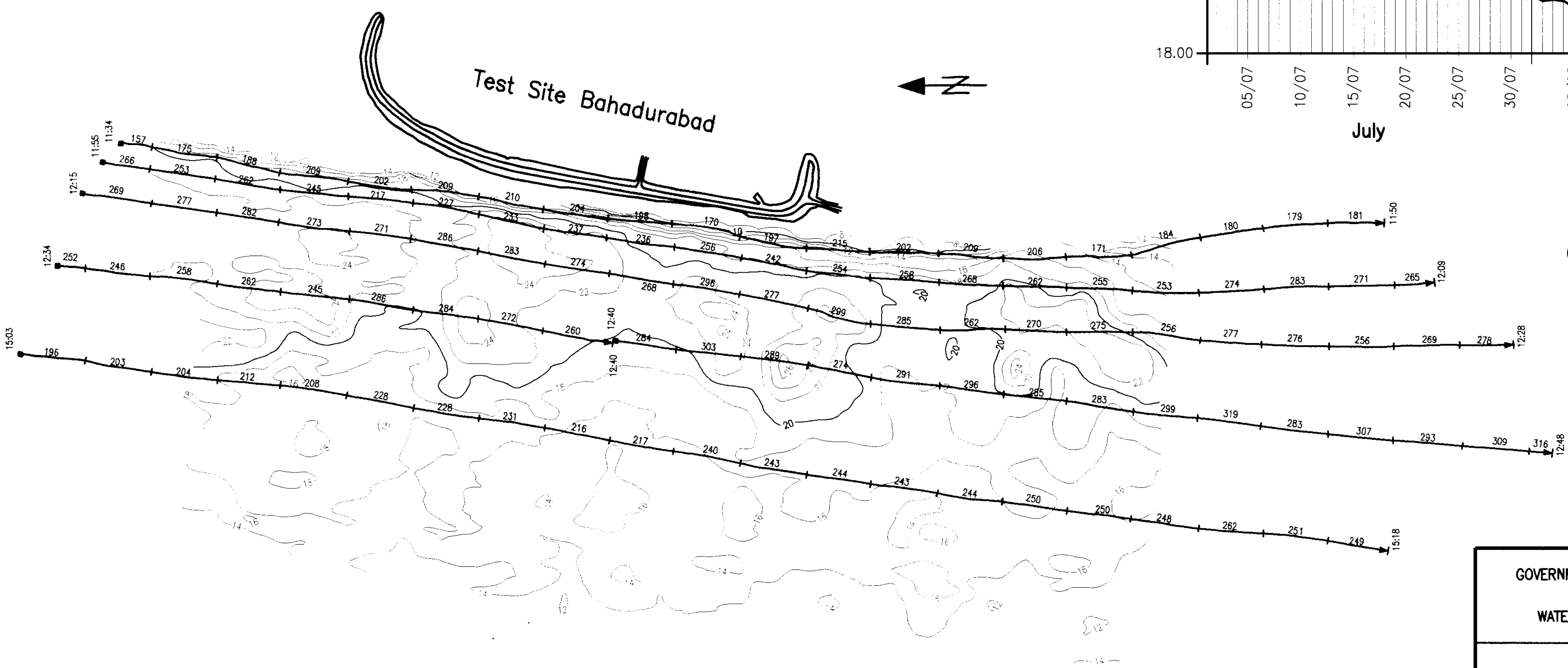
Fax: ++49–421–5905346

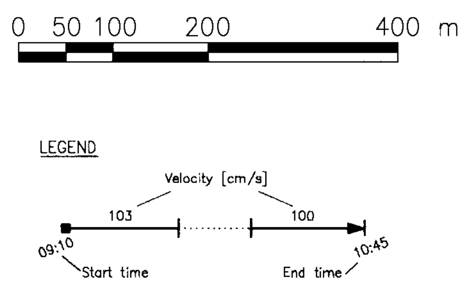
Current Measurements: 14/08/96
Bathymetric Survey: 21/08/96
Chart Datum: 22 m above Public Works Department (PWD)

ANNEX
17

Water Level at Bahadurabad Test Site
July and August 1996







GOVERNMENT OF THE PEOPLE´S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
WATER RESOURCES PLANNING ORGANIZATION (WARPO)

BANK PROTECTION PILOT PROJECT FAP–21

CONSULTING CONSORTIUM FAP 21/22

RHEIN–RUHR ING.–GES.MBH, DORTMUND/GERMANY
COMPAGNIE NATIONALE DU RHONE, LYON/FRANCE
PROF.DR. LACKNER&PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.(BETS)
DESH UPODESH LIMITED (DUL)

TEST SITE II – BAHADURABAD
CURRENT MEASUREMENTS IN 3.0 METRES DEPTH

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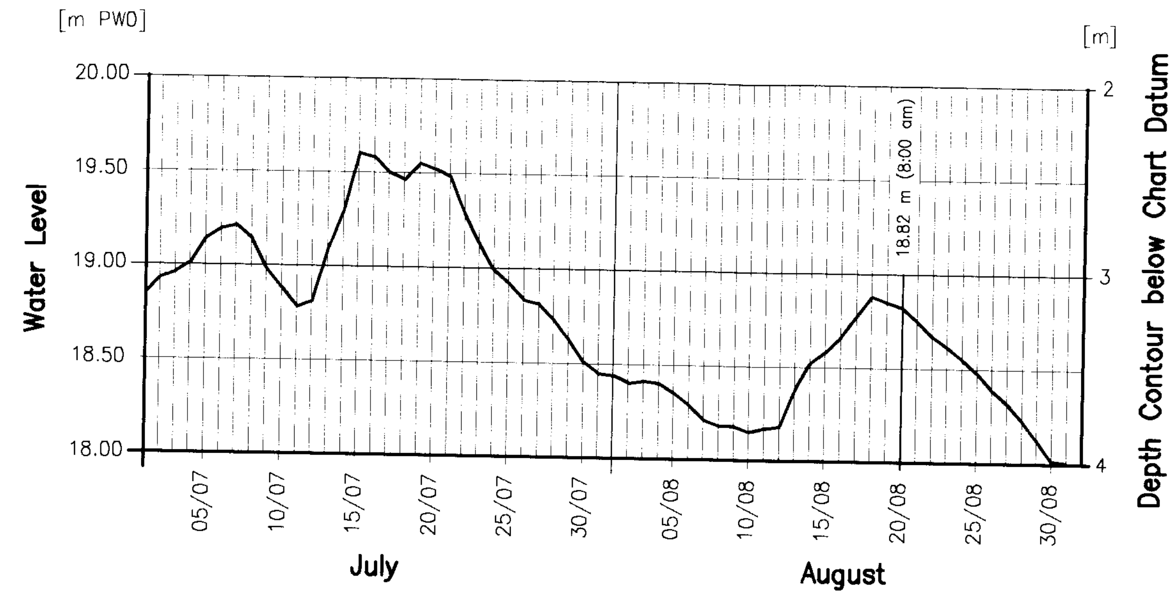
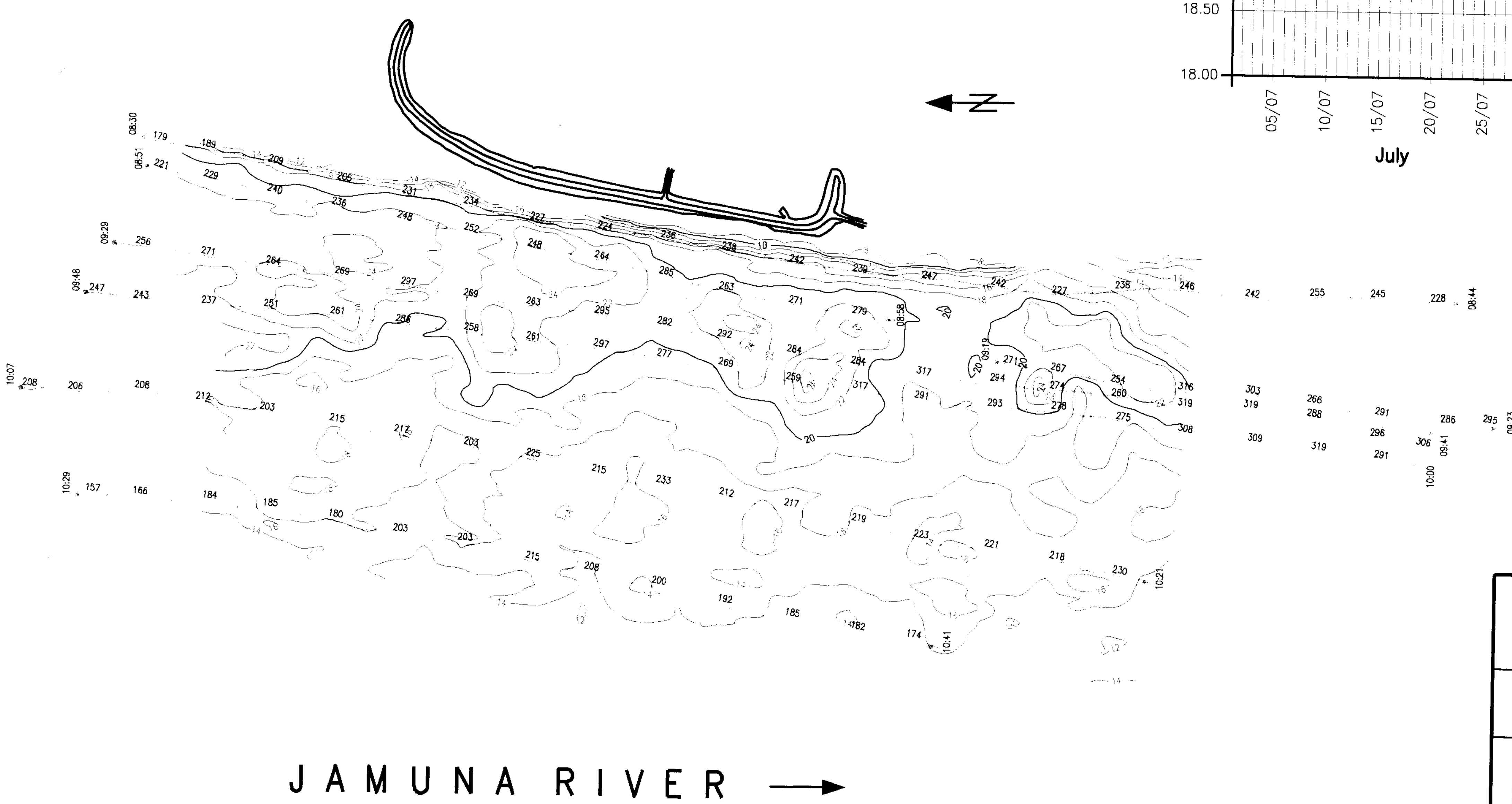
Tel.: ++49-421-5905313
Fax: ++49-421-5905346

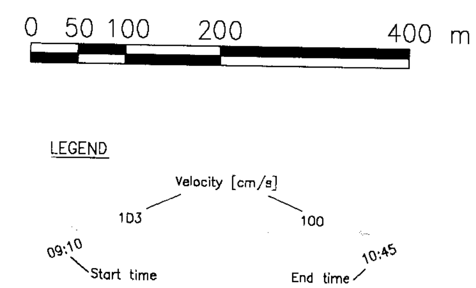
Current Measurements: 14/08/96
Bathymetric Survey: 21/08/96
Chart Datum: 22 m above Public Works Department (PWD)

ANNEX 18

Water Level at Bahadurabad Test Site
July and August 1996







GOVERNMENT OF THE PEOPLE´S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
WATER RESOURCES PLANNING ORGANIZATION (WARPO)

BANK PROTECTION PILOT PROJECT FAP–21

CONSULTING CONSORTIUM FAP 21/22

RHEIN–RUHR ING.–GES.MBH, DORTMUND/GERMANY
COMPAGNIE NATIONALE DU RHONE, LYON/FRANCE
PROF.DR. LACKNER&PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.(BETS)
DESH UPODESH LIMITED (DUL)

TEST SITE II – BAHADURABAD
CURRENT MEASUREMENTS IN 1.5 METRES DEPTH

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Germany
Tel.: ++49-421-5905313
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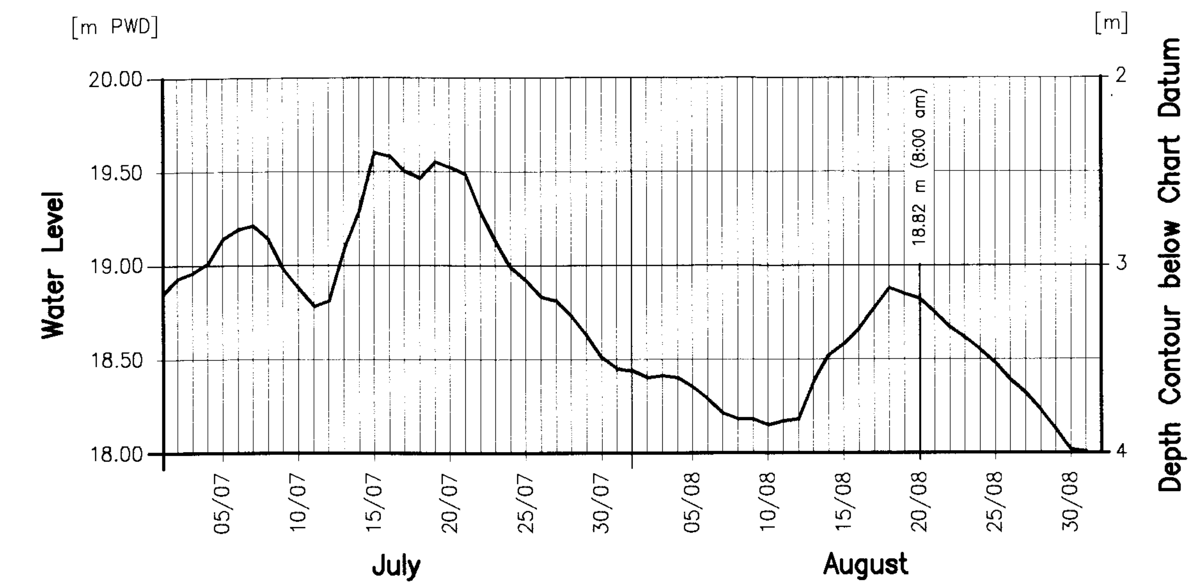
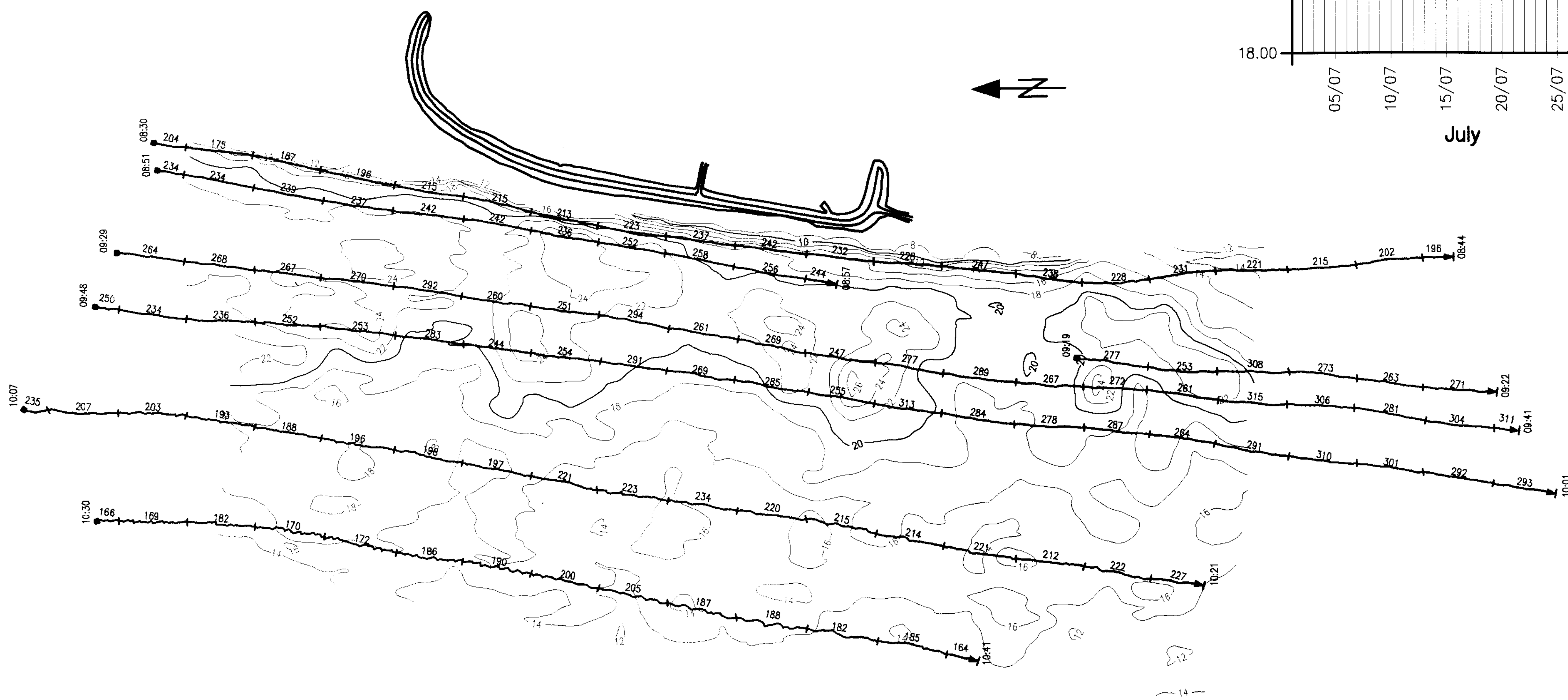
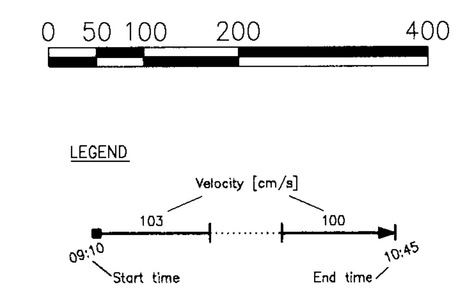
Current Measurements: 20/08/96
Bathymetric Survey: 21/08/96
Chart Datum: 22 m above Public Works Department (PWD)

ANNEX
19

Water Level at Bahadurabad Test Site
July and August 1996







J A M U N A   R I V E R →

GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
WATER RESOURCES PLANNING ORGANIZATION (WARPO)

BANK PROTECTION PILOT PROJECT FAP-21

CONSULTING CONSORTIUM FAP 21/22

RHEIN-RUHR ING.-GES.MBH, DORTMUND/GERMANY
COMPAGNIE NATIONALE DU RHONE, LYON/FRANCE
PROF.DR. LACKNER&PARTNERS, BREMEN/GERMANY
DELFT HYDRAULICS, DELFT/NETHERLANDS

In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.(BETS)
DESH UPODESH LIMITED (DUL)

TEST SITE II – BAHADURABAD
CURRENT MEASUREMENTS IN 3.0 METRES DEPTH

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Germany

Tel.: ++49-421-5905313
Fax: ++49-421-5905346

Current Measurements: 20/08/96
Bathymetric Survey: 21/08/96
Chart Datum: 22 m above Public Works Department (PWD)

ANNEX 20