Northwest Hydraulic Consultants
Euroconsult Mott McDonald

Memo

To: Project Director FRERMIP

From: Jesper Mathiesen, Knut Oberhagemann, Saleh AdibTurash, Nasrin Jahan

cc: SE FRERMIP, DTL, River Engineers, Morphologists, and Modeling Team

Date: March 2017

Re: Site monitoring from 2015 to 2017

1 Introduction

The analysis of the river behavior after construction of riverbank protection fundamentally depends on regular monitoring and evaluation. This helps understanding the river response to new riverbank protection works as well as the performance of the works itself. It also provides indications about the adaptation works, without which there is no guarantee of sustainable riverbank protection. Apart from the pre-work bathymetries conducted by the contractors, regular monitoring was conducted during the 2016 flood season, followed by contractor surveys during the early dry season of 2017. The flood season monitoring during the first flood after construction is of specific important and its purpose was defined to:

(i) Conduct flow and discharge measurements (float tracking and ADCP transects) for the lower Jamuna to identify major changes relevant for the sustainability of the existing work (adaptation), and the planning of future works for Project-1 but also Project-2. Key focus is (a) on the a larger scale flow distribution between eastern and western channel, which determines the level of attack on existing works, and (b) on local river changes that determine the future flow pattern at the specific sites.

(ii) Monitor the developments alongside the newly constructed riverbank protection with respect to flow velocity and scour developments (ADCP and bathymetry surveys), and identify potential adaptation needs for sustaining the work until end of Project-1.

(iii) Provide background data relevant for future developments, more specifically (a) the improvement of the prediction tool, and (b) the development of a stable lower Jamuna.

The ISPMC retained the services of the survey company Survey and Data Consultants on 12 July 2016 based on the clearance of the Project Director (reference PMO-FRERMIP/C-2/614, dated 28 June 2016). The Survey and Data Consultants conducted Site Monitoring (Section 2) and General River Monitoring (Section 3) from July to October 2016:

This memo includes latest dry season site surveys taken before March 2017 in order to estimate the adaptation requirements. Adaptation works will be finally confirmed by the responsible BWDB design office. The nine Appendices contain detailed information about the different surveys.

2 General River Monitoring

2.1 Purpose

The purpose of the general river monitoring was to provide specific information about the general flow patterns alongside the protected sites and in different reaches especially of the lower Jamuna:

(i) The flow through Jamuna Bridge, with special attention to the riverbank alongside the Dhaleswari, which started eroding heavily as a consequence of the capital dredging pilot project;
(ii) The flow at the bifurcation about 20km downstream of the bridge, specifically with respect to the stability of the location of the bifurcation and the amount of flow into the different channels.
(iii) The impact of the Chauhali revetment on the downstream channel pattern and the potential of reclaiming land.
(iv) The exposure of Zafarganj to future flows,
(v) The potential navigation route alongside the Harirampur works.

2.2 Monitoring Plan

The general river monitoring focused on monthly discharge measurements and float tracking, which provided indications about the flow distribution to eastern and western channel and the flow fields changing over time and with different discharges (Figure 2-1, Figure 2-2, and Appendix 1 to 3). In addition, one larger scale bathymetric survey was conducted in September, to provide relevant bed topography, also allowing more detailed numerical modelling (Figure 2-3).

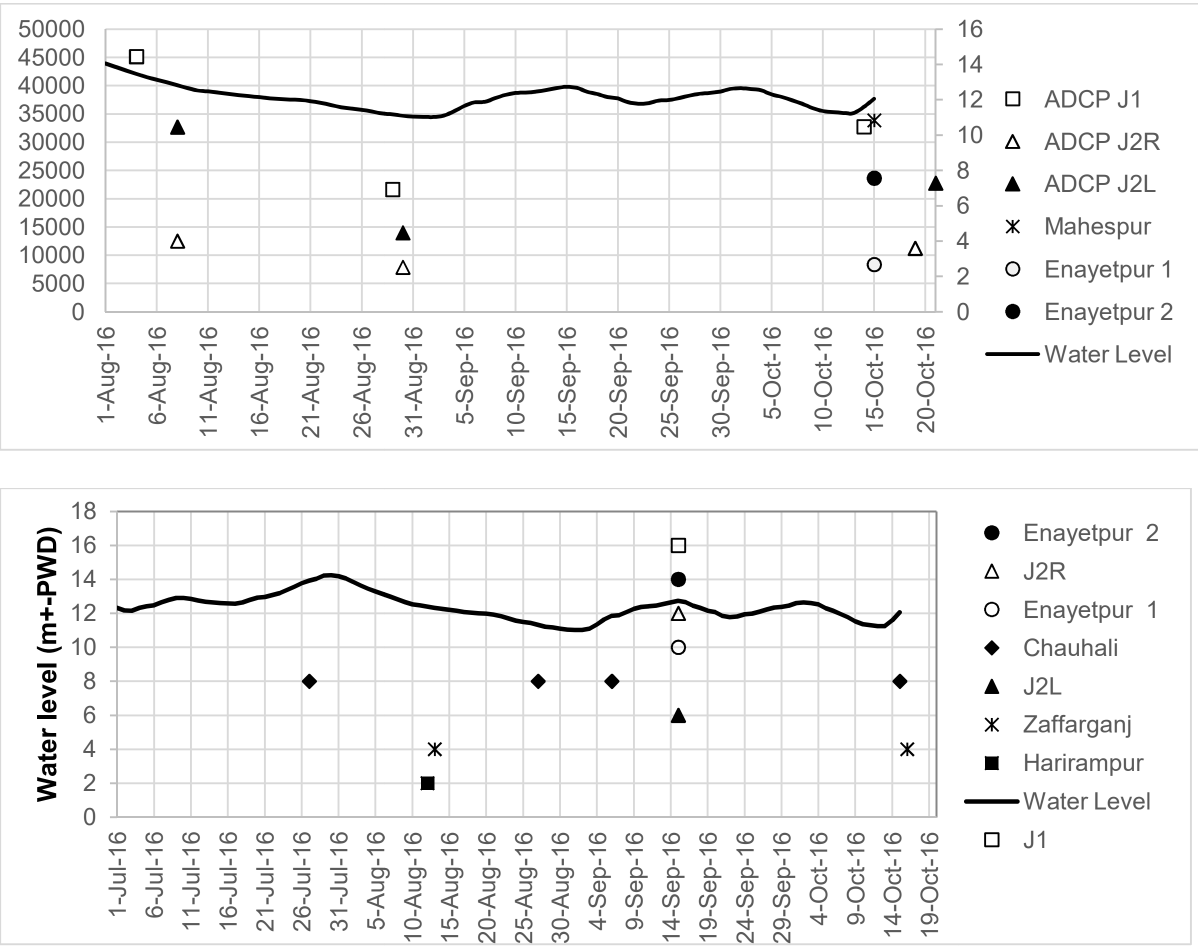


Figure 2-1 Discharge measurements and float tracks during different times of the 2016 flood

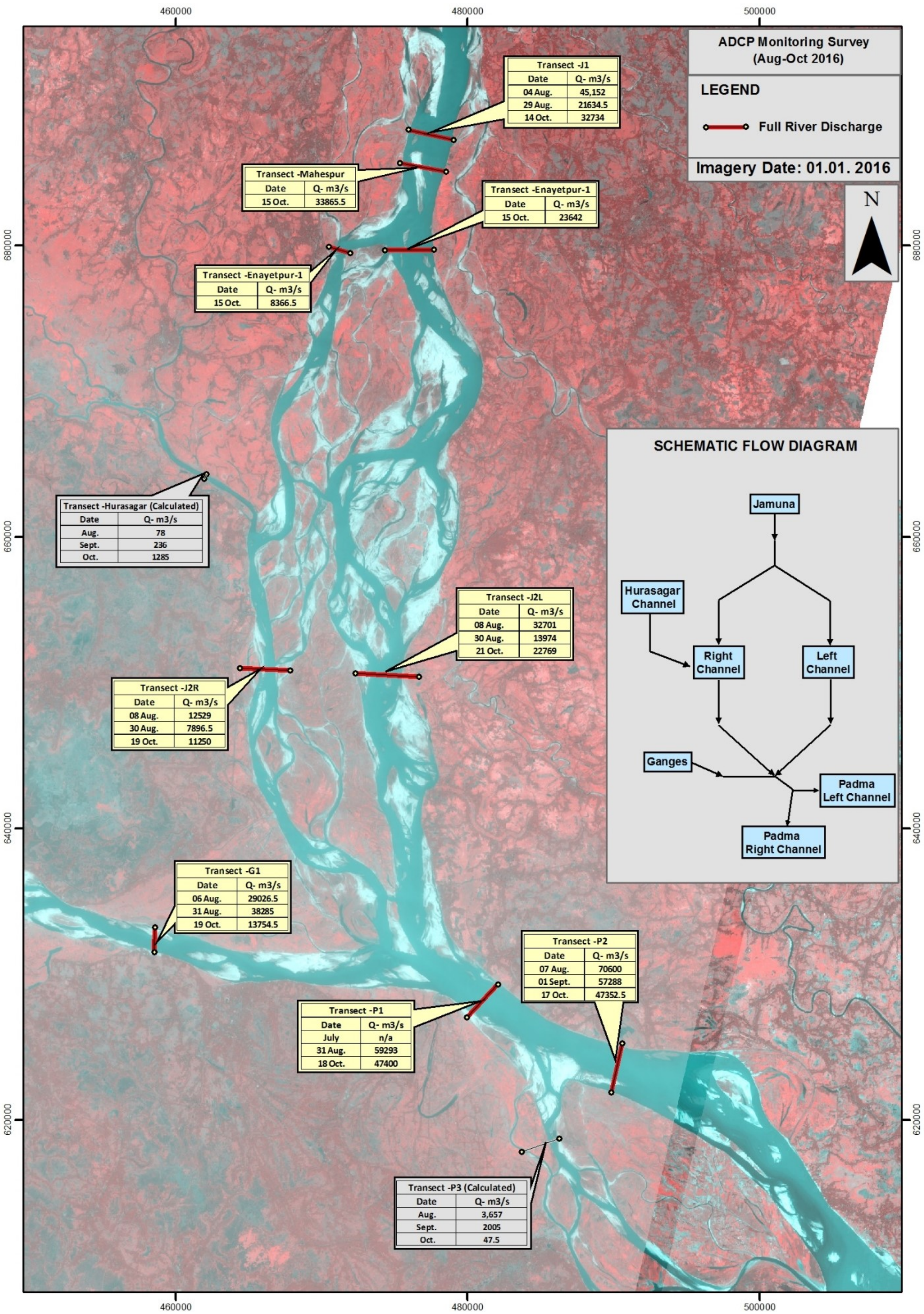


Figure 2-2 General River monitoring coverage area

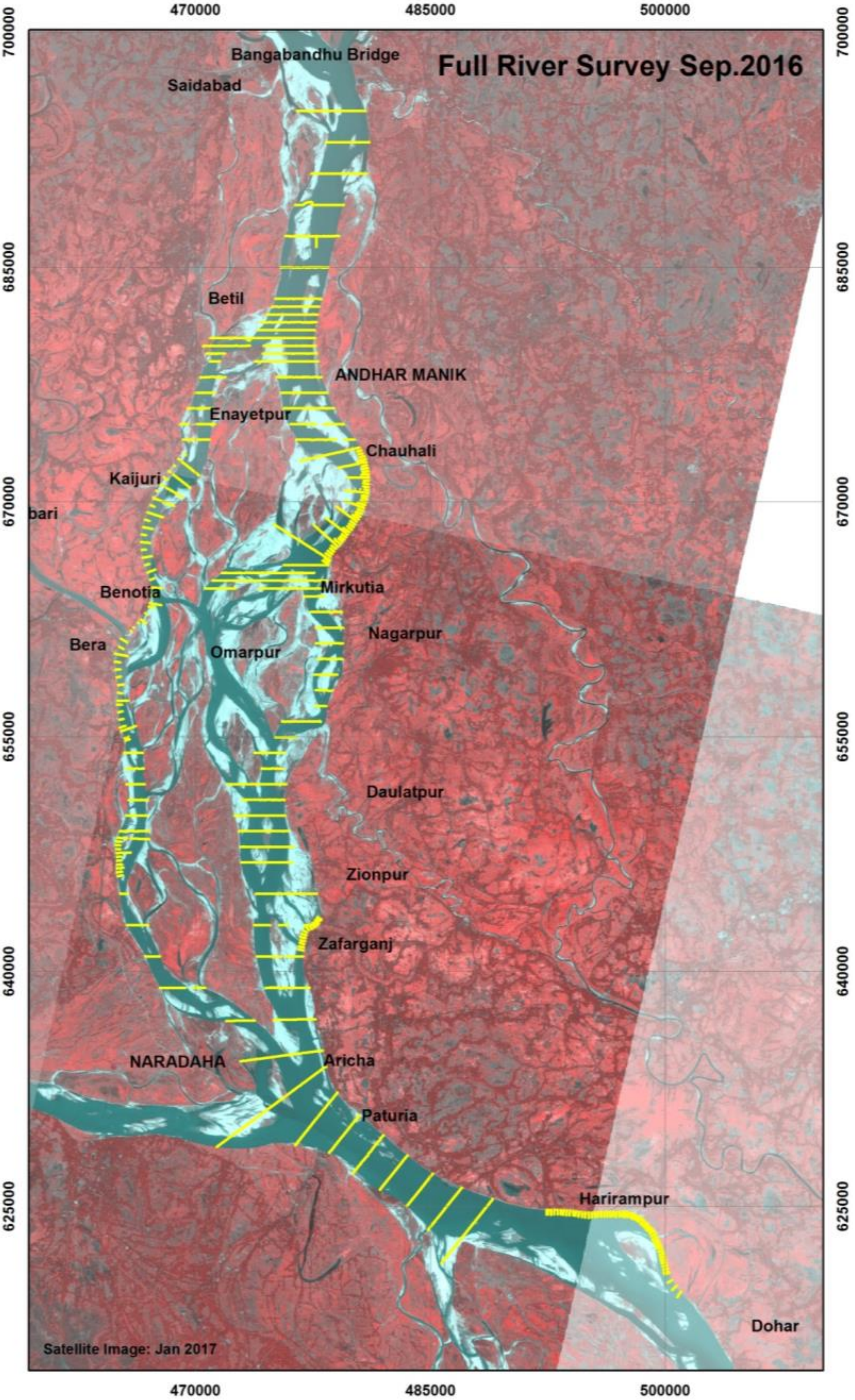


Figure 2-3 Large-scale bathymetric survey of the Lower Jamuna

2.3 Monitoring Results

2.3.1 Jamuna

The river has changed over the flood season

(i) The comparison of float tracks from August and September (Appendix 2) underlines the common understanding that faster flow at higher water levels during the flood season follows a straighter north-south alignment than flows at lower water levels.

(ii) It appears that the impact of the capital dredging pilot project at Jamuna Bridge wears off. The float track from September shows that there is flow alongside the western guide bund, which appears to be again acting as attractor at least during higher flows. The flow along the eastern guide bund does not deflect much into the downstream eastern bankline, indicating a potential future declining effect of the dredged channel that ran diagonally across the braided belt from Sirajganj towards the offtake of the Dhaleswari River.

(iii) Importantly, the straighter flow during higher water levels in August bifurcated more into the eastern channel towards Chauhali, while the later flow in September appears to be more attracted to the western channel towards Enayetpur and Kaijuri even though the total discharge was only around half of the one in August. Even though the bifurcation was quite stable over the last years, the flood season development underlines the instability of the flow distribution and a more dominant right (western) channel cannot be ruled out per se, although the probability of this has decreased over the last years. The discharge measurements at Transect Jamuna, Jamuna Right (West), Jamuna Left (East) are provided in Table 2-1 and Figure 2-4. With respect to river training, reduced flow in the western channel would support a higher degree of channel curvature, more closely to the imposed bend at Chauhali and potentially downstream.

Table 2-1 Jamuna flow bifurcation to the left and right channel

Transect	Aug [m³/s]	Sep [m³/s]	Oct [m³/s]
Jamuna	45,152	21,634	32,734
Jamuna Right (western) Branch	12,529	7,896	11,250
Jamuna Left (eastern) Branch	32,701	13,974	22,769

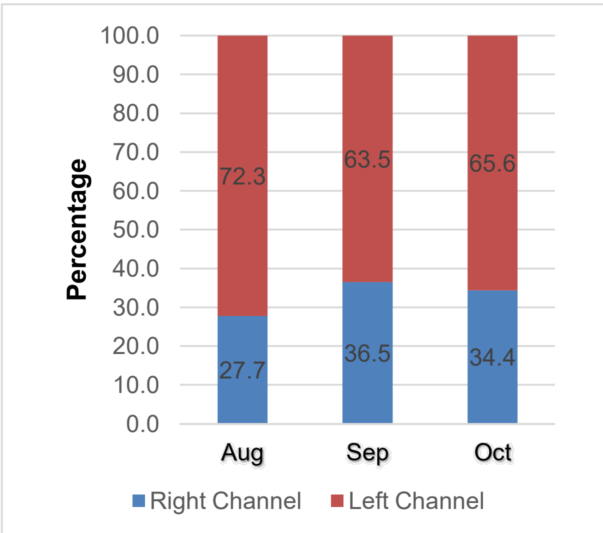


Figure 2-4Percentage flow distribution in the lower Jamuna

(iv) During larger discharges and higher water levels the Jamuna shows a straighter path with about one-third of the total flow in the left channel following a straighter cut-off channel (Figure 2-5), while still two thirds of the flow follow the Chauhali bend. The development of this cut-off led to substantial erosion alongside the central char but not leaving a dry season channel. While the cut-off formation reduces the pressure on Chauhali it poses new problems for the downstream river. This development indicates the need to stabilize the bifurcation point over time, with initial work along the central char during Project-2.

(v) Downstream of Chauhali the higher August flow bifurcated more to the south into the bankline channel (Figure 2-5), while the later September flow had a tendency to move away from the bankline with declining flow into the bankline channel. The bifurcation appears to be located more downstream during flood flows forming an about 90 angle with the main flow, while the deep dry season channel is located immediately downstream of the protection works. The flood flows have been able to erode only somewhat through the large sand bars, north of the char downstream of Chauhali (Figure 2-5). This starting development confirms the potential of developing a meandering planform from the bifurcation to Zafarganj and reclaiming about 5,000 ha of land downstream of Chauhali after closing the bankline channel. This channel is currently opening and the main flow is shifting towards the bank and will be monitored during the 2017 flood. However, it underlines the importance of the closure of the channel.

(vi) There is no indication that Zafarganj remains under heavy flow attack. In September the flow appears to be not moving towards Zafarganj, but stay away from the upstream bankline and flows fairly straight to the south, parallel to the riverbank downstream of Zafarganj. The dry season image shows that Zafarganj is sheltered by large sand bars (Figure 2-5).

The dry season situation is depicted in Figure 2-5.

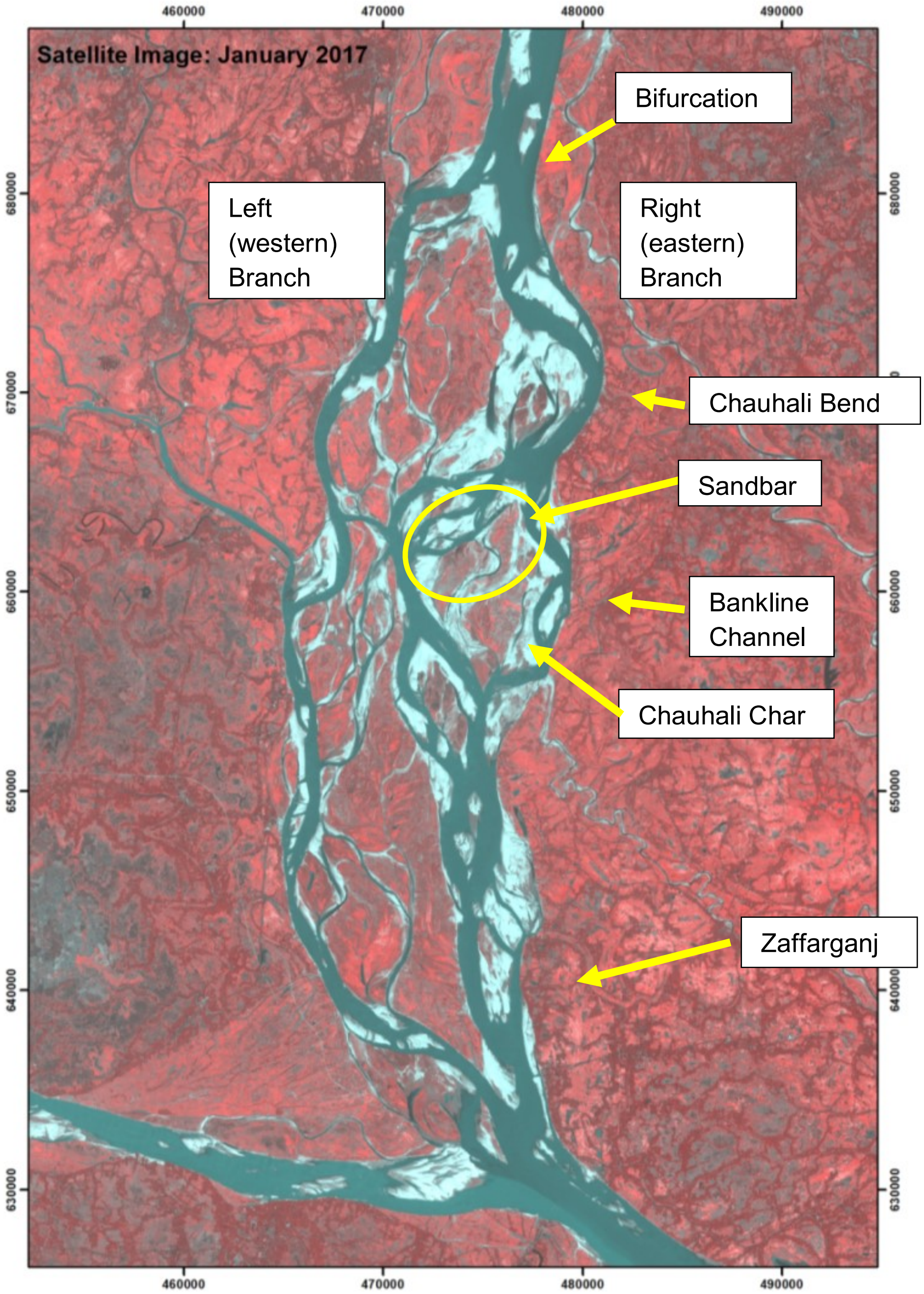


Figure 2-5 Dry season channel pattern of the Lower Jamuna River, January 2017

2.3.2 Padma

The North Padma Channel in the area of the works at Harirampur is characterized by the movement of sand bars:

(i) A low lying bar attached to the bankline is moving along the riverbank. The offtake of the Old Ichamatty River (labelled as chainage 0 for the work - Figure 2-6) was inaccessible during the 2016 dry season. At that time the char extended around 2.5km in downstream direction. This char has moved around 2km downstream and filled in a deep scour hole at chainage 4.2 of the works.

(ii) The North Padma Channel is split by a larger char in the river (Figure 2-6). The movement of this char has contributed to riverbank erosion. After protecting the river bank this char has moved into the bend, around 1.5km to the west and 1km to the south. The available channel width alongside the bankline declined from 700 to 400m at the narrowest point and the narrowest point moved downstream along the protected riverbank. The sedimentation process of this bankline channel started during the end of the flood season, after initial erosion, and continued until January 2017 with between 4 and 18m vertical accretion.

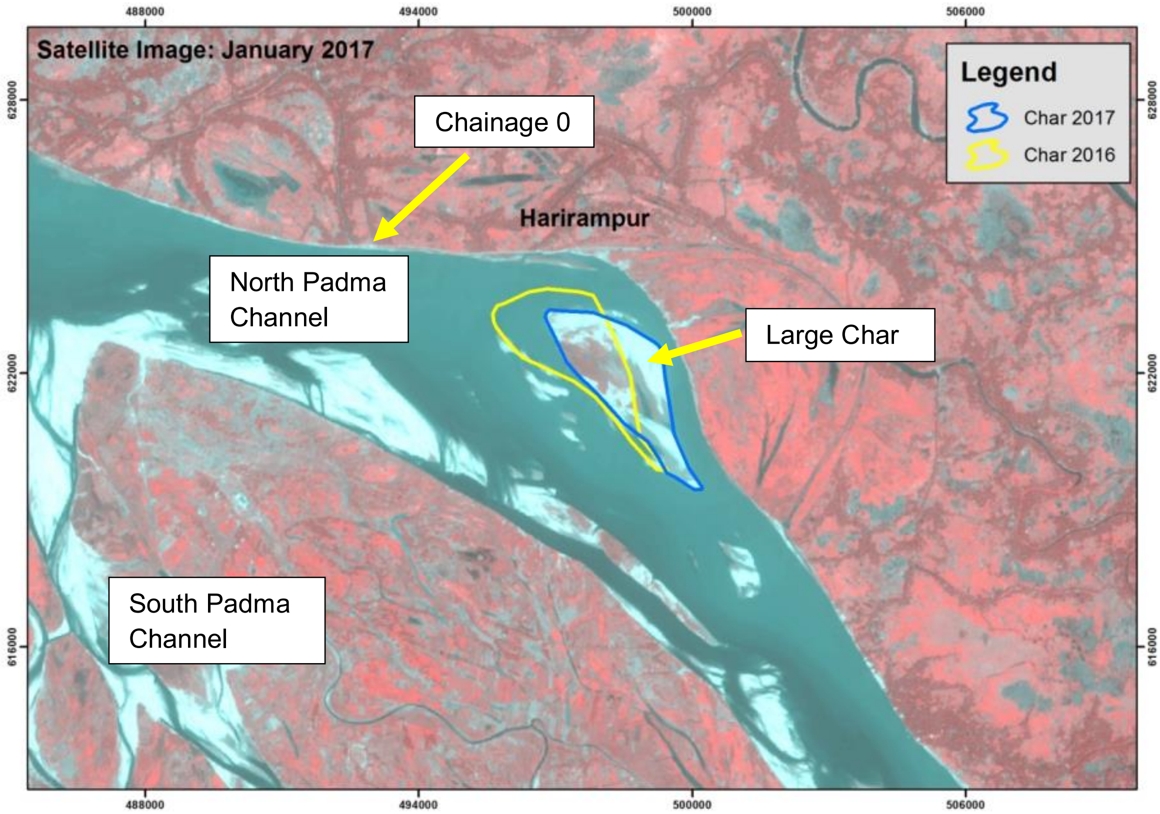


Figure 2-6 Changes in the Padma between 2016 and 2017

3 Site Monitoring

3.1 Purpose

The purpose of the site monitoring was to provide specific information about:

(i) the scour development alongside the falling aprons of the newly built works; (Section 3.4)
(ii) flow velocities over the newly built work (Section 3.7)
(iii) parameters for design formulae (Section 3.8)

3.2 Monitoring Plan

The site monitoring depends on a set of regular bathymetric surveys compared with the as-built situation (Appendix 5 and 6). The contractors conducted most parts of the as-built survey work between April and June at the different sites. However, as the work ended only in July, the flood season surveys of July constitute the as-built survey for those areas completed after the last contractor's survey in June.

In addition to the apron development and the detection of slope instability issues, the flood season survey provided information about the flow fields and resulting flow forces over the placed revetments. Consecutive ADCP measurements along three cross sections at each site contribute to the data set improving future designs (Appendix 8). Float tracking provides additional flow information about surface velocities along the whole river, but also at the three work sites (Appendix 2).

Table 3-1 and Appendix 1 provide a summary of the survey work at the three sites. Figure 3-1 to Figure 3-3 show the amalgamated as-built survey, typically combining two to four different survey periods.

Table 3-1 Summary of survey activities at the three sub-project sites
*(*not accepted by consultant)*

Types of survey	Site	Pre work	April	May	June	July	August	September	October	Post work
Bathymetric survey	Chauhali	29/10/15 - 3/11/15		4/4/16 - 5/5/16	24/06/16	(22/7/16 - 23/7/16)*	7/8/16 - 8/8/16	21/09/16	08/10/16	19/2/17 – 23/2/17
	Zafarganj	26/1/16		05/5/16		21/7/16	10/08/16	24/9/16	04/10/16	21/12/16 – 28/12/16
	Harirampur	28/12/15 - 30/1/16	11/4/16		05/06/16	17/7/16 - 19/7/16	11/8/16 - 13/8/16	25/9/16 - 26/9/16	17/10/16 - 18/10/16	24/1/17 – 31/1/17
ADCP Survey	Chauhali					27/7/16 - 28/7/26	4/8/16 - 5/8/16		20/10/16	
	Zafarganj						5/8/16,8/8/16 and 30/8/16		21/10/16	
	Harirampur						07/8/16		17/10/16	
Flow Track	Chauhali					27/7/16 - 28/7/26		06/9/16	15/10/16	
	Zafarganj						13/8/16		16/10/16	
	Harirampur						12/8/16			
Topographic Survey	Chauhali	29/10/15 - 23/12/15								
	Zafarganj	26/1/16								
	Harirampur	29/12/15 - 1/2/16								

In addition to the pre-work surveys from 2016 at all three sites, an additional set of pre-work surveys was conducted in late 2016 and early 2017 prior to the completion of the unfinished underwater works in Zaffarganj (Figure 3-5) and before adaptation works in Chauhali and Harirampur (Figure 3-4 and Figure 3-6).

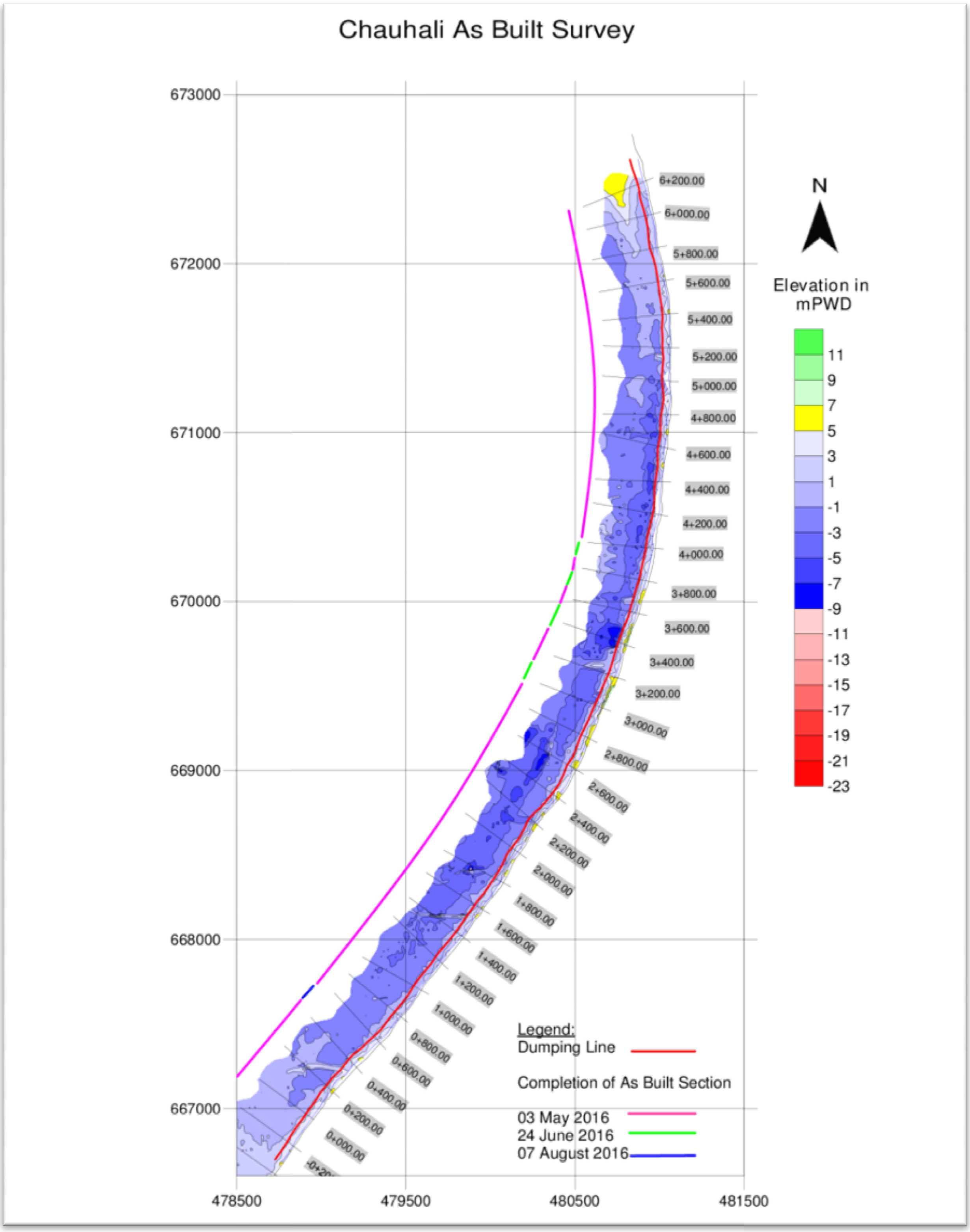


Figure 3-1 2016 as-built survey Chauhali

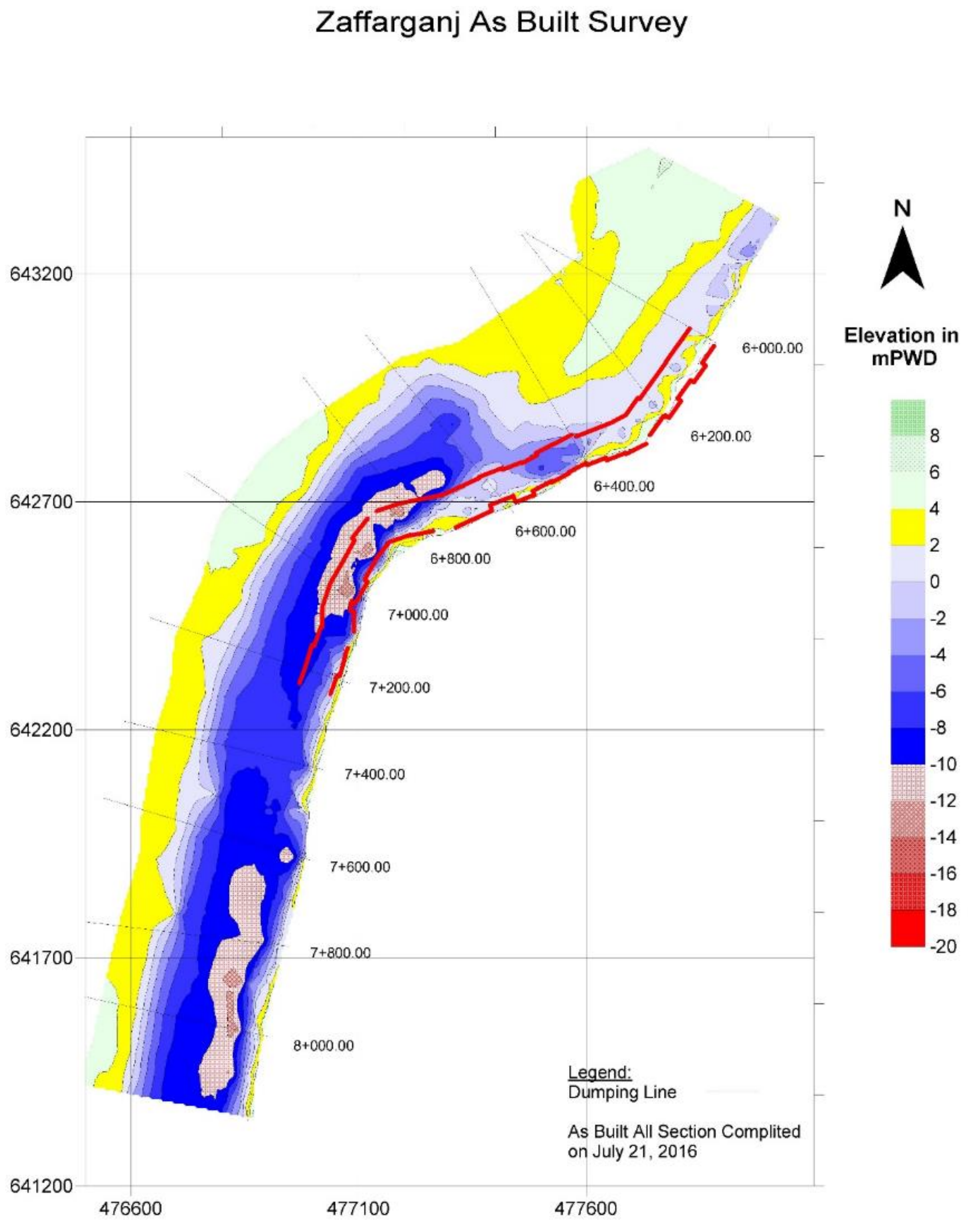


Figure 3-2 2016 as-built survey at Zafarganj

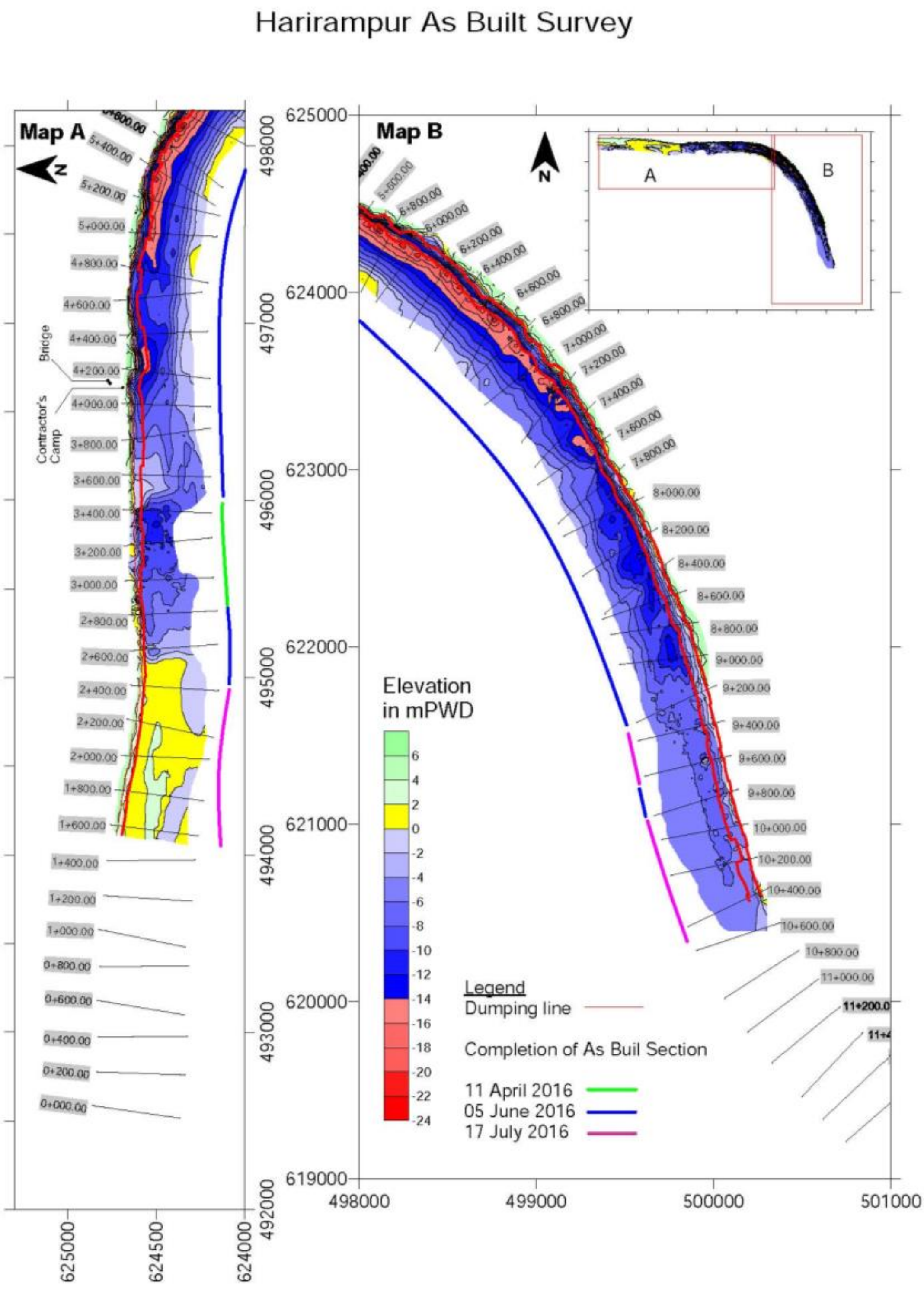


Figure 3-3 2016 as-built survey at Harirampur

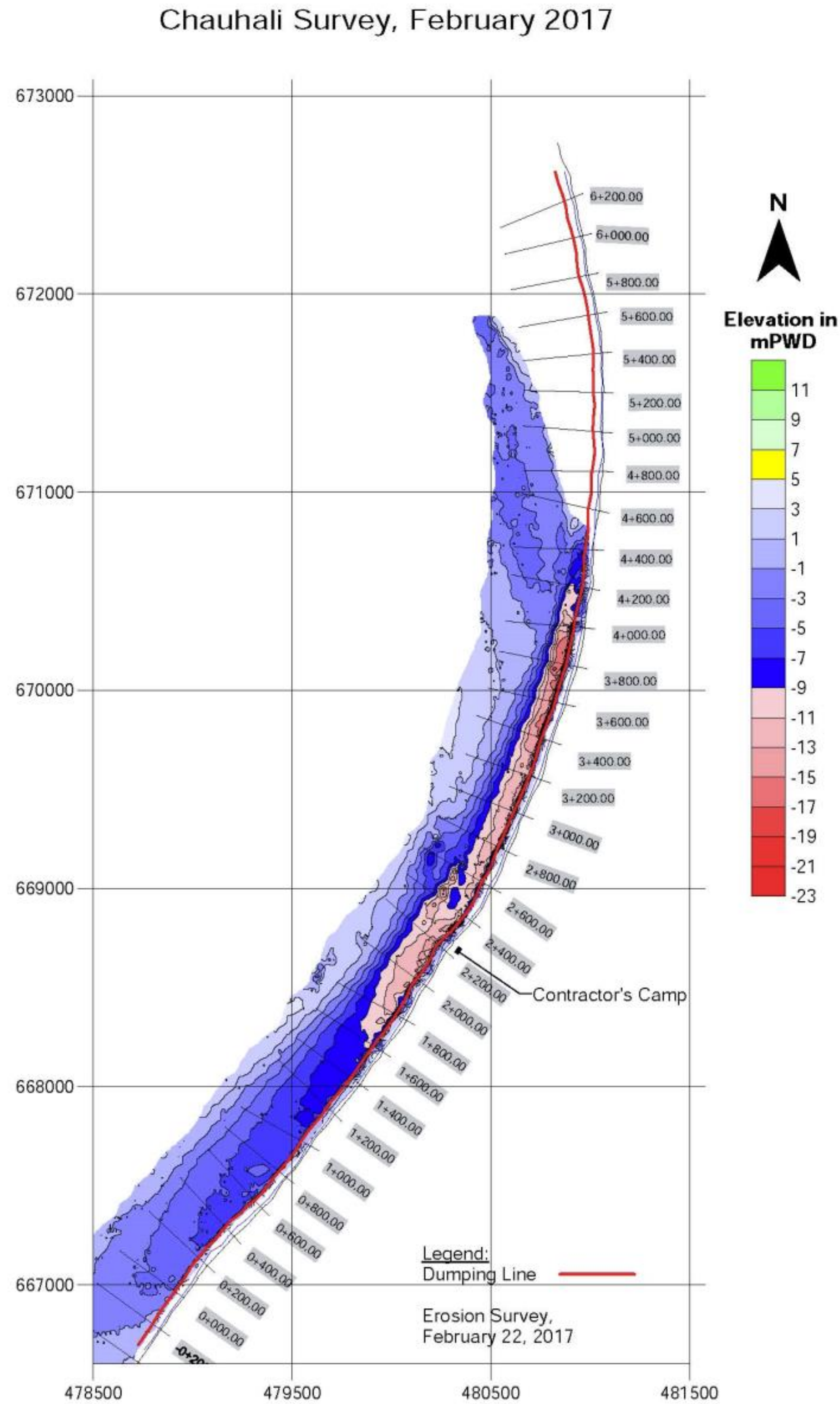


Figure 3-4 Chauhali February 2017 pre-work survey for adaptation works

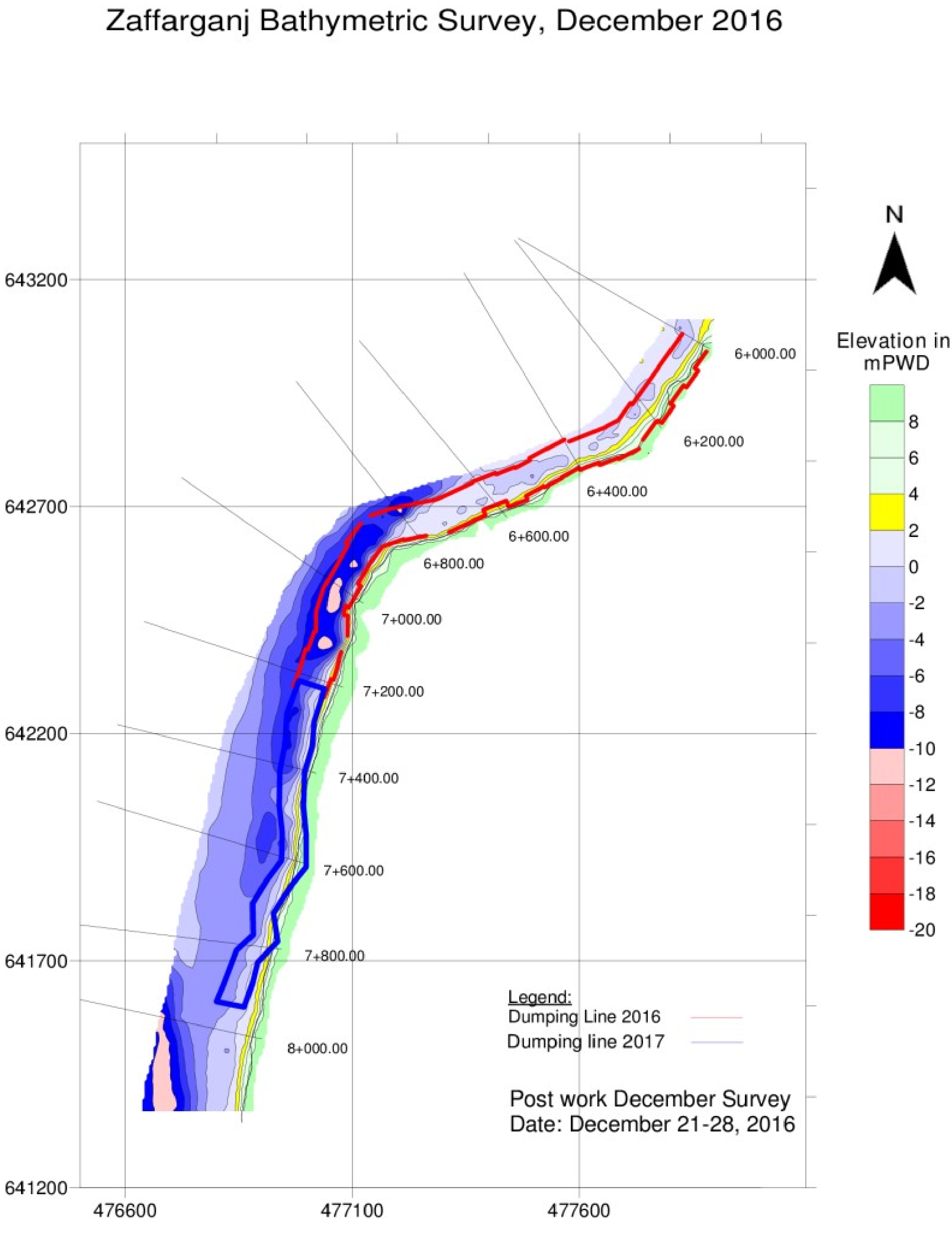


Figure 3-5 Zafarganj December 2016 pre-work survey, for 2016/17 works (shown in blue)

Harirampur January 2017

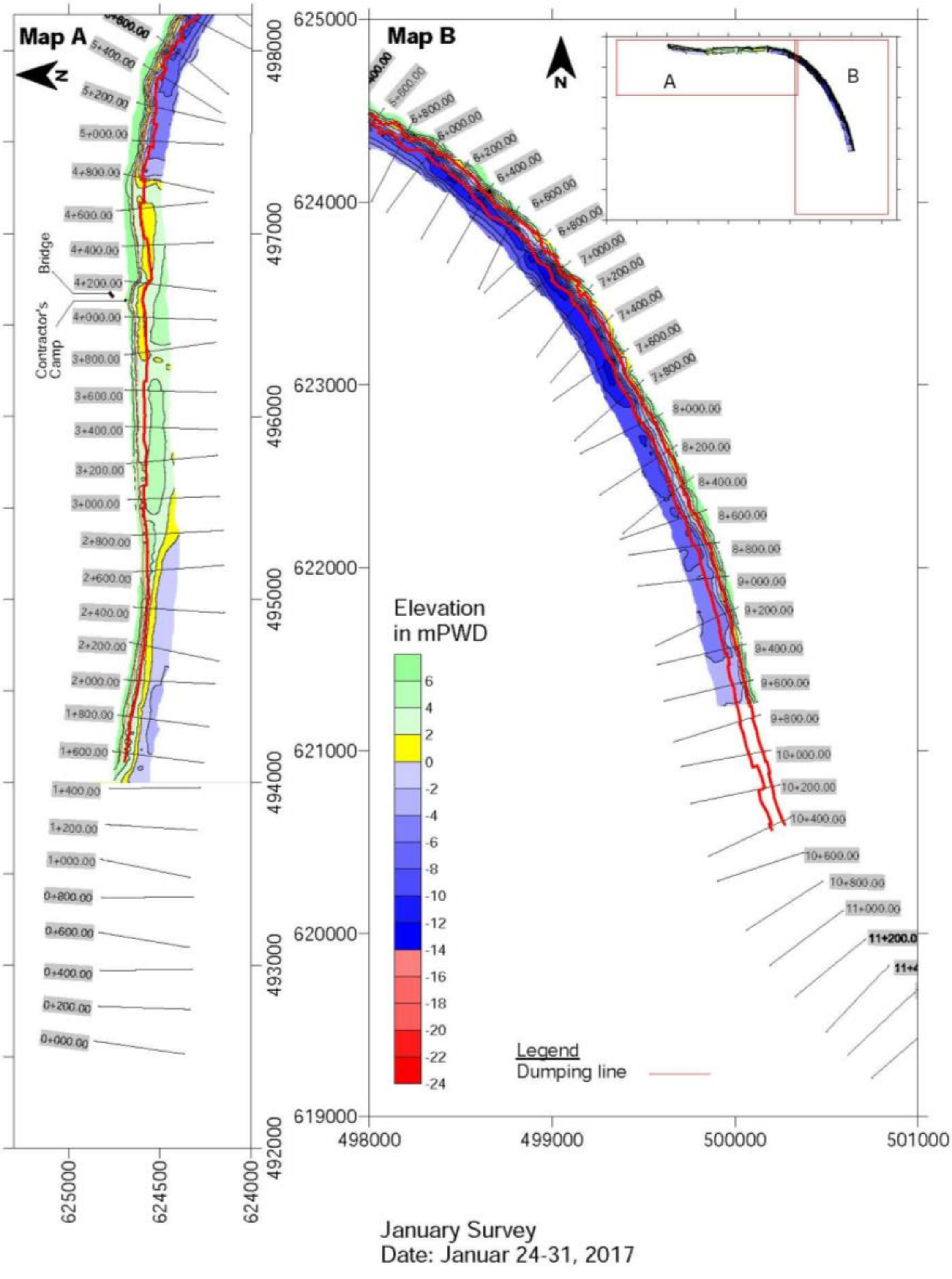


Figure 3-6 Harirampur January 2017 survey, used as baseline survey for 2016/17 adaptation works

3.3 Survey quality

3.3.1 Procedure

Bathymetric survey: The bathymetry at all work sites was conducted with single beam echo sounders. These were switched to dual-frequency echo sounders, (Echotrac CVM) after the July survey in Chauhali showed large data gaps. For geo-referencing, two RTK units (Trimble 750), were used, of which the base was placed on the river bank and the rover on the moving survey boat. Points were recorded with a frequency of 0.1 seconds.

The surveys from a moving boat do not follow a straight line, as the boat navigates perpendicular to flow of changing intensity. To mitigate triangulation errors during data processing, some points of each cross section were manually shifted to the ideal base line. This reduces the triangulation errors and allows to create an accurate surface. Figure 3-7 provides an example for the shifting of the points. No point was moved by more than 1m.

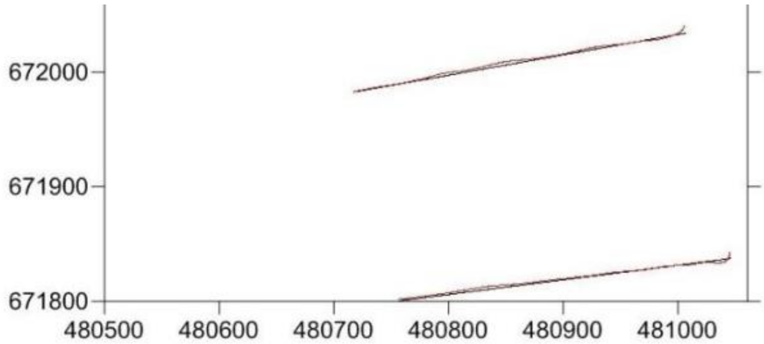


Figure 3-7 Reference (black) and surveyed line (red)

ADCP survey: The flow over the bank protection works was recorded with an acoustic Doppler current profiler (Riogrande 620), which was set on a boat and which position was determined using a RTK unit. The ADCP gives a detailed current profile in different depth over the bank. Points were taken with a frequency of 1 second.

Float track: To assess surface flow velocity, floats equipped with a cross plate at 0.8m depth and a handheld GPS device at the surface were dropped in the river to float along the main current (thalweg). Data were recorded every 3 seconds.

3.3.2 Chauhali

In Chauhali, a total of seven bathymetric surveys were conducted, including the pre-work survey, which also included a topographic survey of the bankline and parts of the floodplain land. The interval between the cross sections varied between 15m during the pre-work survey and 200m in September and October. Until July a single frequency, single beam echo sounder was used; thereafter a dual-frequency single beam echo sounder. The dual frequency echo-sounder mitigated the large data gaps observed in July and likely associated with substantial bed material transport over the protected slope.

The September survey was conducted on cross sections every 200m, which were not in line with the cross sections of other months, but shifted by 100m, so that a direct comparison between the cross sections is not possible. However, the survey data provide useful information as contour and differential maps for a larger scale assessment of the bathymetry development at the site.

3.3.3 Zafarganj

In Zafarganj, a total of six bathymetric surveys were conducted between January and October 2016. The cross section interval varies from 50m in January to 200m in October and the echo sounder used was a single-frequency single beam model up until July, after that a dual-frequency single beam echo sounder was used.

The May 2016 survey was rejected, because the survey references on land were lost, which made it impossible to accurately position the surveyed data and superimpose cross sections. All other surveys were in order. An additional survey was conducted in December 2016 prior to recommencing the remaining dumping activities, which represents the post-work, post-flood condition.

3.3.4 Harirampur

In Harirampur, a total of seven bathymetric surveys were conducted between December 2015 and October 2016. The interval between surveyed cross sections varied between 50m and 200m and the equipment used were single frequency, single beam echo sounders until July followed by a dual frequency model. The December, pre-work, survey covered the whole length of the site. In April a 2.1km long stretch was surveyed before the start of the work. All surveys were accepted and no problems occurred during date processing.

A more detailed description of the survey parameters can be found in Appendix 4.

3.4 Scouring and sedimentation

3.4.1 Introduction

Key interest are deep scouring along the riverside toe and sedimentation. The first is relevant for the geotechnical stability of the work and defines the amount of adaptation works for reliable construction to deeper levels, while the latter influences the constructability of the adaptation works. It is for example not possible to place additional layers of material and aprons on very thick deposits as this, after renewed scouring, would result in complicated three dimensional shapes that increase the turbulence and risk of slope failure. Deep river channels are those surpassing 15m depth below low water level, adaptation works of launched aprons becomes necessary when the toe deepens by more than 5m, while sedimentation becomes particularly relevant when the bed level silts up to low water level. Corresponding levels at the three sites are shown in Table 3-2.

Table 3-2 Low water and scour level definition at the three sites

Reference Level	Chauhali	Zafarganj	Harirampur
High flood level	13.22 m+PWD	11.68 m+PWD	10.00 m+PWD
Low Water Level (= Sedimentation Level)	5.8 m+PWD	3.4 m+PWD	1.4 m+PWD
Deep scour level	-9 m+PWD	-12 m+PWD	-14 m+PWD
Design scour level (BWDB)	-21.58 m+PWD	-23.3 m+PWD	-28.39 m+PWD
Revised scour level	-22 m+PWD	-22 m+PWD	-25 m+PWD

Apart from the requirements for the adaptation works, monitoring data allows to assess the quality of the design. Here two aspects are of fundamental importance: (i) the width (or breadth) of the placed apron and its response to scouring, and (ii) the flow velocities measured over the protection work. While the first can be assessed from regular bathymetric surveys, the latter depends on flow measurements through ADCP and float tracks. While the ADCP measurements provide velocities in the vicinity of the covered underwater slopes, admittedly averaged over some area, the float track provides the surface velocities along the thalweg, typically close to the maximum velocity used in design formulae.

3.4.2 Chauhali

The amount of vertical erosion along the revetment work underlines that the work has protected the floodplain against serious erosion. The systematic monitoring alongside the protected riverbank revealed several key changes of the local morphology, summarized in Table 3-5.

Table 3-3 Site developments alongside the protected riverbank at Chauhali (as per local chainage)

Month	Sedimentation (>+2 m+PWD)	Deep Scour (<-9 m+PWD)	Deep Scour length	Deepest scour
Dec2015/Jan2016	6.0 – 6.2	NA	NA	NA
May 2016	6.2	NA	NA	NA
June 2016	NA	4.0 - 4.7*	0.8 km	Stn 4.0 - 4.8; -13
August 2016	6.0 – 6.2	1.8 – 4.8	3.0 km	Stn 2.0 – 4.4; -15
September 2016	5.4 – 6.2	1.8 – 4.8	3.0 km	Stn 2.0 – 2.4; -17
October 2016	5.0 – 6.2	1.7 – 4.5	2.8 km	Stn 1.9 – 4.2; -17
February 2017	u/s of 5.0	1.7 – 4.5	2.8 km	Stn 2.0 – 4.2; -16

Note: * Station 4.7 is the end of the survey

Key findings of the survey in Chauhali are:

(i) During the 2015/16 dry season, no scour is observed at Chauhali, but at the upstream end a sandbar has formed.

(ii) In June, a small scour develops between station 4.0 and 4.8 with a depth of up to 19m below LWL. By August, this scour reached an extend of 3.0km between station 1.8 and 4.8km with the deepest sections being 21m below LWL. Until October the scour migrated marginally downstream to station 1.7km and shortened to 2.8km. The depth remained the same. Diving in February 2017 at the contractor's camp (chainage 2500) indicated a bed level at about -13m+PWD, roughly corresponding with the bed level during the flood season and indicating that no sedimentation has happened. This was confirmed through a February 2017 survey. Figure 3-8 provides some examples of the site development during the flood season.

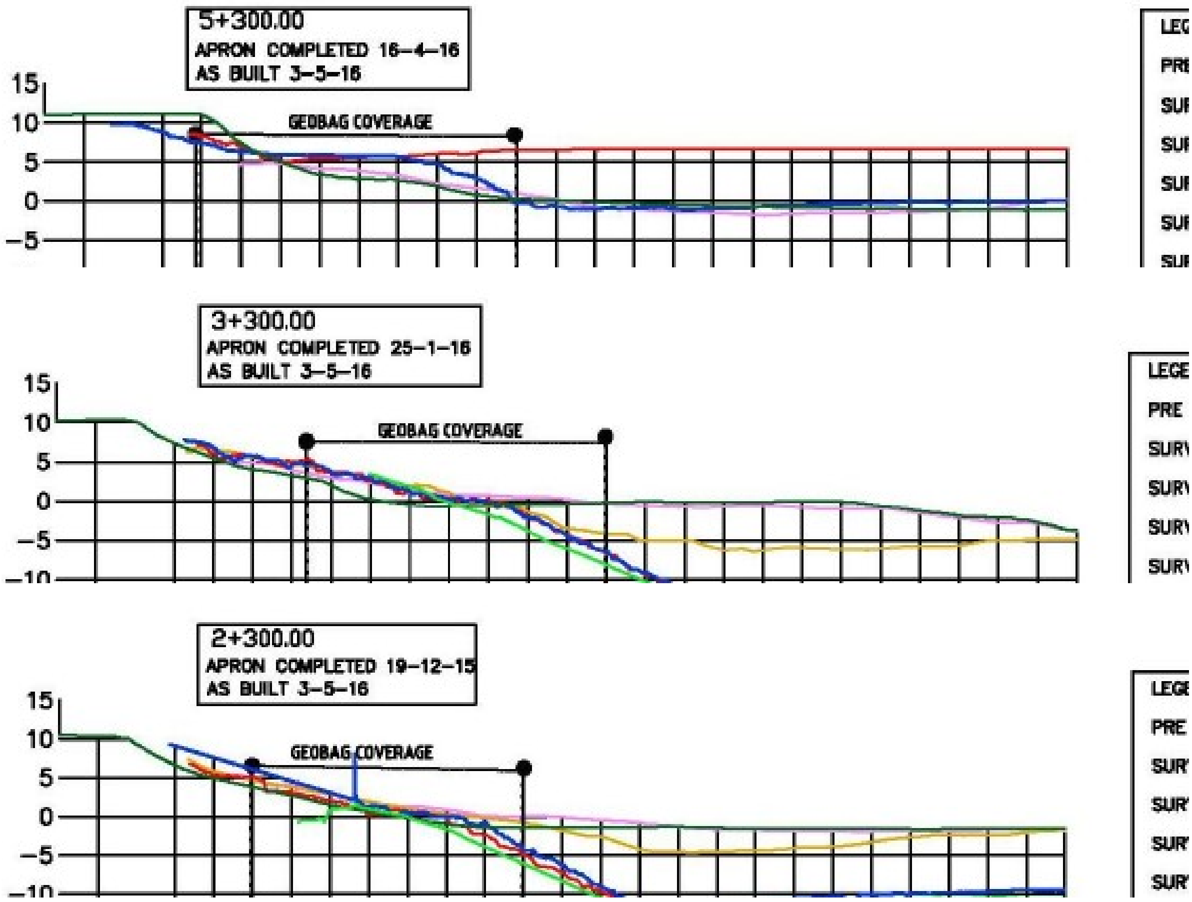


Figure 3-8 Bathymetry development during each survey period, compared to the as-built condition (August), Chauhali

(iii) The upstream sediment deposit has migrated downstream and reached station 5.0km by October. It is part of a 3km long char situated parallel to the left bank that has top elevations of 5-7m+PWD and is above LWL. This char is well visible in Figure 2-5.

(iv) At Chauhali some places near bank were eroded at 11 places during and at the end of this flood season. Those places were located from station 0.5 to 5. More than 5m apron launched from section 0.9 to 5.1.

3.4.3 Zafarganj

Different from the other two sites, the erosion situation at Zafarganj waned. The reasons for this are larger scale changes in the flow pattern, moving away from the riverbank. The systematic monitoring alongside the protected riverbank revealed several key changes of the local morphology, summarized in Table 3-4.

Table 3-4 Site developments alongside the protected riverbank at Zafarganj

Month	Sedimentation (>+2PWD)	Deep Scour (<-10PWD)	Deep Scour length	Deepest scour
January 2016	n/a	6.5 - 8	1.5km	Stn 6.5 : 16
July 2016	Beyond 6.5	7.1 – 6.7	0.4km	Stn 6.5 :-14
August 2016	Beyond 6.5	7.2 – 6.7	0.5km	Stn 7 :-17
September 2016	Beyond 6.5	7.1 – 6.9	0.2km	Stn 7 :-14
October 2016	Beyond 6.5	7.0	0.2km	Stn 7 :-14
December 2016	Beyond 6.5	7.0	0.2km	Stn 7 :-14

(i) The upstream deposition remained stable at Station 6.5 with a small near-bank channel active during the flood season. This channel caused some localized erosion upstream.

(ii) The deeper scour is situated at the protrusion between bazar and school at station 6.5 and has changed little in position. However, it reduced in size during the flood season but maintained the deepest point of around -17m+PWD locally.

(iii) The erosion alongside the downstream clayey riverbank, in extension of the protrusion scour at Zafarganj, has moved downstream. It is located outside the planned work area. Given the low erosion potential of the downstream riverbank, the main risk is wave erosion upstream in future.

(iv) No apron launching was recorded during this flood season (Figure 3-9)

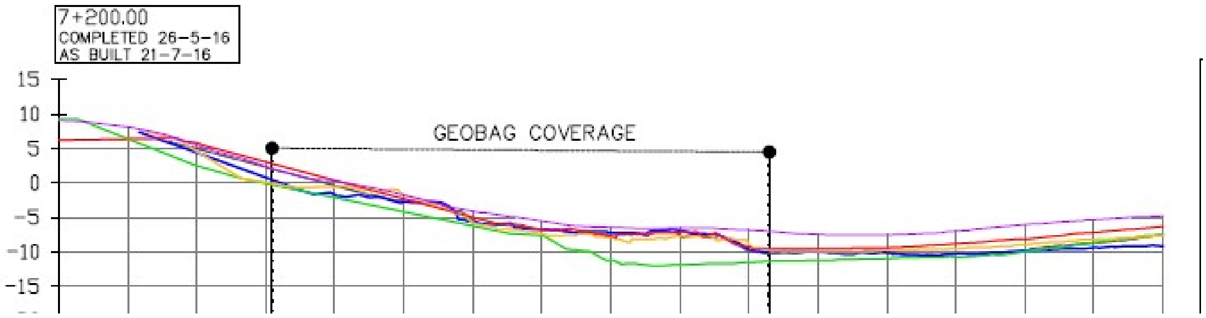


Figure 3-9 Bathymetry development during each survey period, compared to the as-built condition (July), Zafarganj

3.4.4 Harirampur

The amount of vertical erosion along the revetment work underlines that the work has protected the floodplain against serious erosion. Some cross sections are shown in Figure 3-10. The systematic monitoring alongside the protected riverbank revealed several key changes of the local morphology, summarized in Table 3-5:

Table 3-5 Site developments alongside the protected riverbank at Harirampur

Month	Sedimentation (>+2m+PWD)	Deep Scour (<-m-14PWD)	Deep Scour length	Deepest scour (m+PWD)
Nov/Dec2015	0.0 – 2.4	4.2 – 4.4	0.2km	Stn 4.3; –16
June 2016	0.0 – 2.4	3.6 – 5.6 5.9 – 6.7	2.0km 0.8km	Stn 4.1 – 4.5; -18
July 2016	0.0 – 0.6	4.2 – 4.4; 4.8 – 7.6	0.2km 2.8km	Stn 5.0 – 6.7; -18
August 2016	0.0 – 3.8	5.6 – 8.0	2.4km	Stn 6.2 – 7.3; -16
September 2016	0.0 – 3.7	6.2 – 8.1	1.9km	Stn 7.0 – 7.8; -16
October 2016	1.0 – 4.8	7.6 – 8.4	0.8km	Stn 7.7 – 8.0; -14
January 2017	3.4 – 5.5	na	na	na

(i) The upstream end is characterized by a large deposition that extended from station 0.00 to 2.4 during the 2015/16 dry season and had a lateral extend of about 400m away from the riverbank. Until June, the width increased to more than 500m, while the length of the sandbank remained the same. In July, most of the deposited sand eroded, leaving a 600 by 200m large sandbank behind. However, in August, the sandbank reached 3.8km length with a width of several hundred meters. In September, it narrowed down to 200m, expanding in length to 4.8km by October.

(ii) Pre-work, there was a small scour with a depth of about 18m and an extent of 200m at the river bend at station 4.2, which is associated with the abandoned concrete block revetment built by the BWDB. At the beginning of the flood season in June, this scour expanded to two kilometer length and deepened to 20m depth. At the same time, a second scour formed at station 5.9, which had an extent of 800m and a depth of 18m. In July and August, the upstream scour filled up, while the downstream scour expanded to 2.8km length with a depth of 22m. Over the next months, this scour mostly filled up, leaving a few scattered smaller scours over a length of 800m and a maximum depth of 16m around station 7.8. By January the scour had reduced to an about 1km long stretch from 7+400m to 8+400m, with an elevation of -11m+PWD and therefore not defined as deep scour.

(iii) At the downstream end of the protection the bed level has not changed during the 2016 flood season. The bed level remained fairly constant at around 5m below low water level. However, at the beginning dry season the bed levels have silted up and are now at about -3m+PWD.

(iv) At Harirampur near bank erosion resulted in apron launching during the 2016 flood season. Initially launching occurred from station 5.2 to station 7 by July. Then this area silted up, while erosion occurred downstream between station 7 and 9. More than 5m apron launched between chainage 5.8 to 9. However, most of this was covered with a more than 10m thick layer of sand at the end of the flood- and early dry season. A number of cross sections depict slopes flatter than 1V:3H, which indicates that static flow slides could have occurred. This will be confirmed through diving investigations prior to starting the adaptation works.

Long profiles along the deepest scour at the end of the apron, provided in Appendix 9, document the scour and sedimentation development between each survey period, compared to the as built, and 2017 dry season condition. For Chauhali, also numerical modelling prediction for potential scour movement during the 2017 flood has been shown. Long sections have been prepared for Chauhali and Harirmapur, where launching occurred. These sections are based on simplified 200m interval cross sections not following the exact length of the dumping barges, as the cross sectional data were taken every 200m.

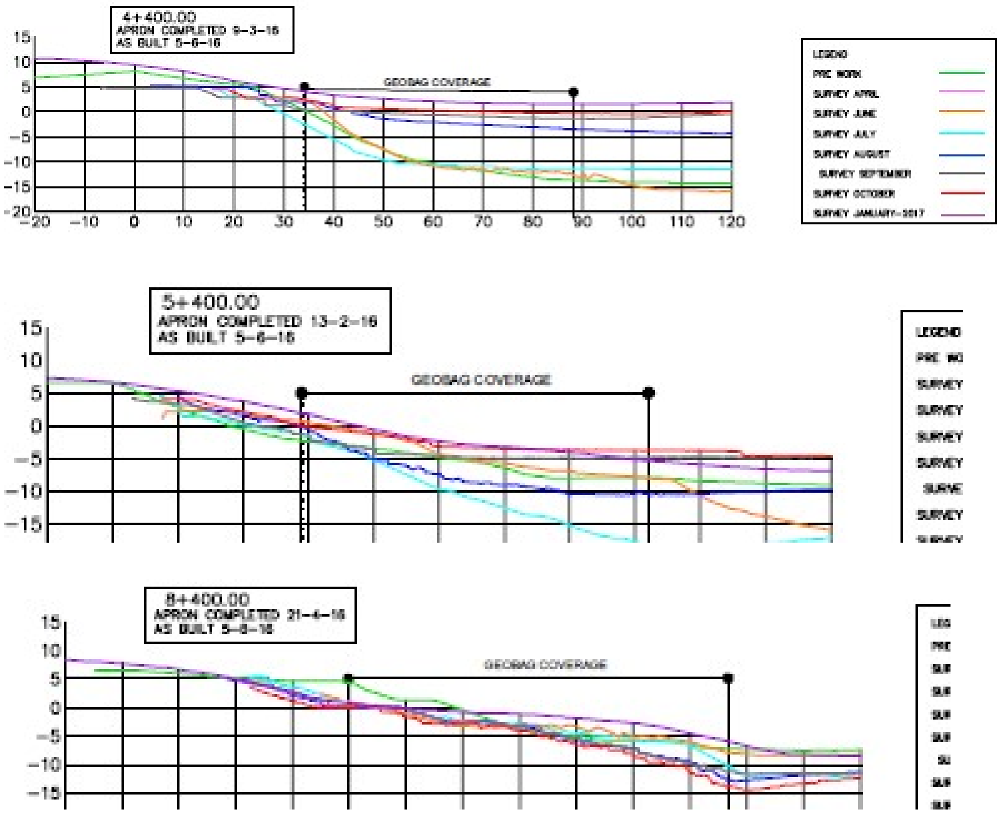


Figure 3-10 Development of the cross sections over time in Harirampur

3.5 Slope failures at Chauhali and Harirampur temporary protection

In Chauhali and Harirampur, the bank was protected during the last flood season by a temporary protection that generally followed the design as shown in Figure 3-11. However, during the first construction season only one layer of above water protection was placed, which proved insufficient in some places.

Figure 3-11 Temporary slope protection consisting of one layer of geobags

3.5.1 Chauhali

During the flood season, some local failures occurred at the Chauhali site, resulting in a loss of some 0.9ha of land alongside the riverbank. The locations of the erosion are shown in Table 3-6. There are two reasons for this failure:

(i) Destruction of the single layer temporary wave protection through concentrated high flow velocities (Figure 3-13), and

(ii) Geotechnical slope instability.

Table 3-6 Local bank failures in Chauhali

No	Chainage (km)	Length (m)
1	0.580 TO 0.69	110
2	1.970 T0 2.05	80
3	2.460 TO 2.510	50
4	2.650 TO 2.670	20
5	2.750 TO 2.790	40
6	3.220 TO 3.270	50
7	3.920 TO 3.960	40
8	4.210 TO 4.280	70
9	4.470 TO 4.670	200
10	4.780 TO 4.830	50
11	4.910 TO 4.950	40

While at least two failures were obviously due to geotechnical instability (confirmed by diving), the others were induced by winnowing failure of the single layer temporary wave protection. After the failure, the flow eroded the upper part of the bankline, resulting in the formation of a wide berm about 3 to 5m below low water level. The design of the temporary wave protection has underestimated the impact of waves and high flow velocities.

As can be clearly seen in Figure 3-13, all bank failures occurred where the flow lines are close to the bankline and exhibit relatively high velocities. This indicates that the design underestimated not only the risk of winnowing for the temporary wave protection but also of geotechnical failure by and large.

Figure 3-12 Bank failure in Chauhali

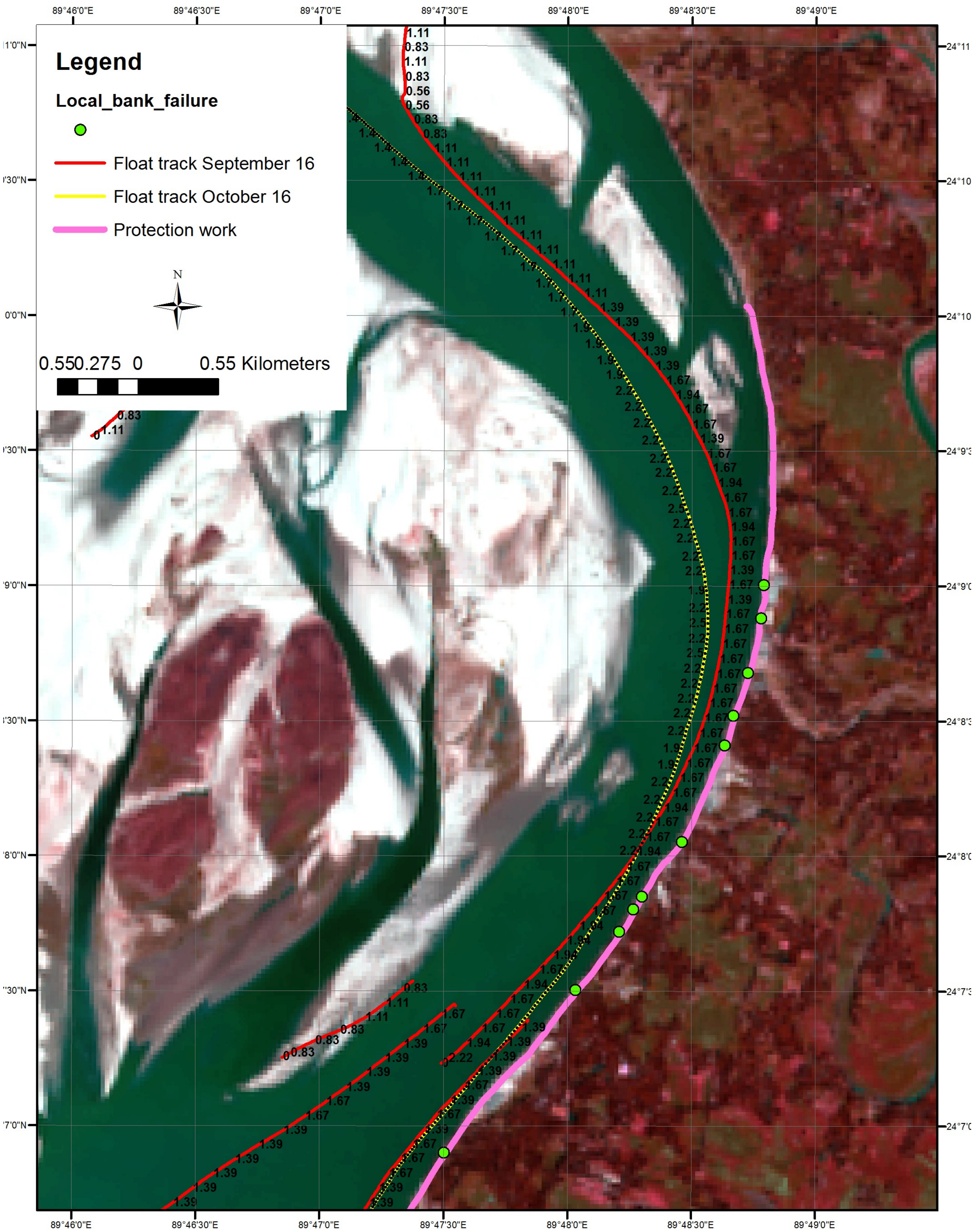


Figure 3-13 Location of slope failure with float tracks from September / October 2016 on 2017 satellite image

Following the Technical Advisory Committee decision from 4 February 2016, subsoil investigations were to be undertaken at the sites to establish the long-term stability of the protected riverbank slopes. The design office has made no information available pertaining to geotechnical design and confirmed verbally that no geotechnical analysis was conducted for the detailed design. Therefore this memo cannot provide further analysis based on detailed design investigations. During the PPTA study in 2013, a subsoil investigation study was conducted along the bankline of that time, which covered large parts of the 2016 work site (for the location of the boreholes see Figure 3-14). The responsible design office could use this information to confirm the subsoil conditions along the present bankline.

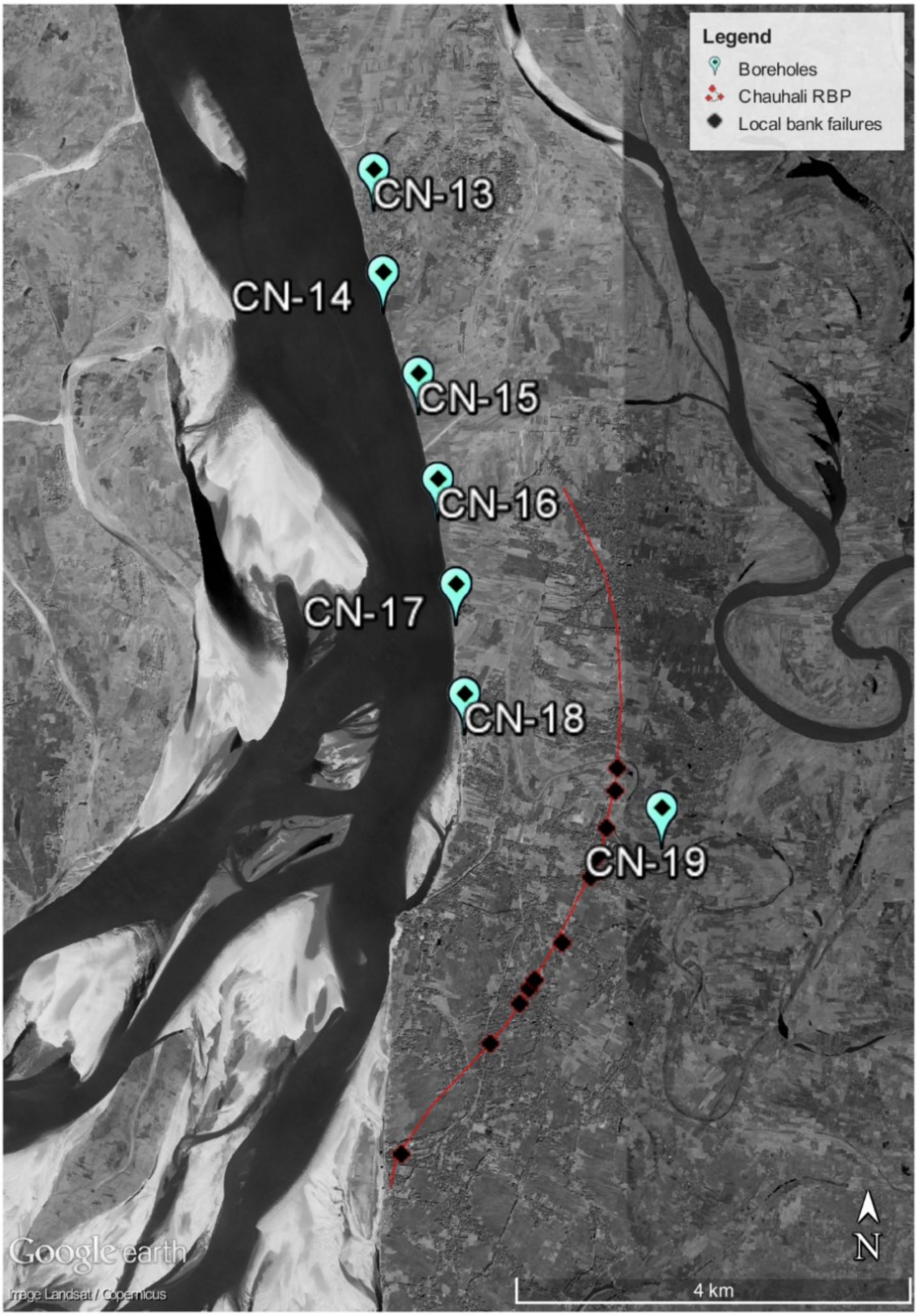


Figure 3-14 Borehole location of 2012 and local bank failure locations from 2017 on 2013 satellite picture

Although all borehole locations from 2013 were eroded by 2016, there could be relevant information from one borehole. Borehole CN-19 is the closest one to the 2016 bankline and also the only borehole location not eroded. By comparing the location of the bank failures with the location of the boreholes, it is noticeable that the majority of the failures are near or downstream of borehole CN-19 (Figure 3-14).

The plot of the soil distribution of the boreholes in Figure 3-15 shows that CN-13 to CN-18 have top layers of clay with a thickness of at least 4.0m, mostly more than 7m. At borehole CN-19, only a 2m thick clay layer is present and below that there is only fine sand. As a cohesive top clay layer improves the slope stability, it can be assumed that the lack of this caused the bank failures. The number of local failure points along the bank, indicates that the geotechnical stability plays a fundamental role in the design. In line with international best practice, we expect that the responsible design office will conduct a more detailed assessment as part of their detailed design and tender recommend to reassess this design accounting for the observed slope instability. It is clear that the present detailed design remains incomplete as long as the geotechnical slope stability is not included.

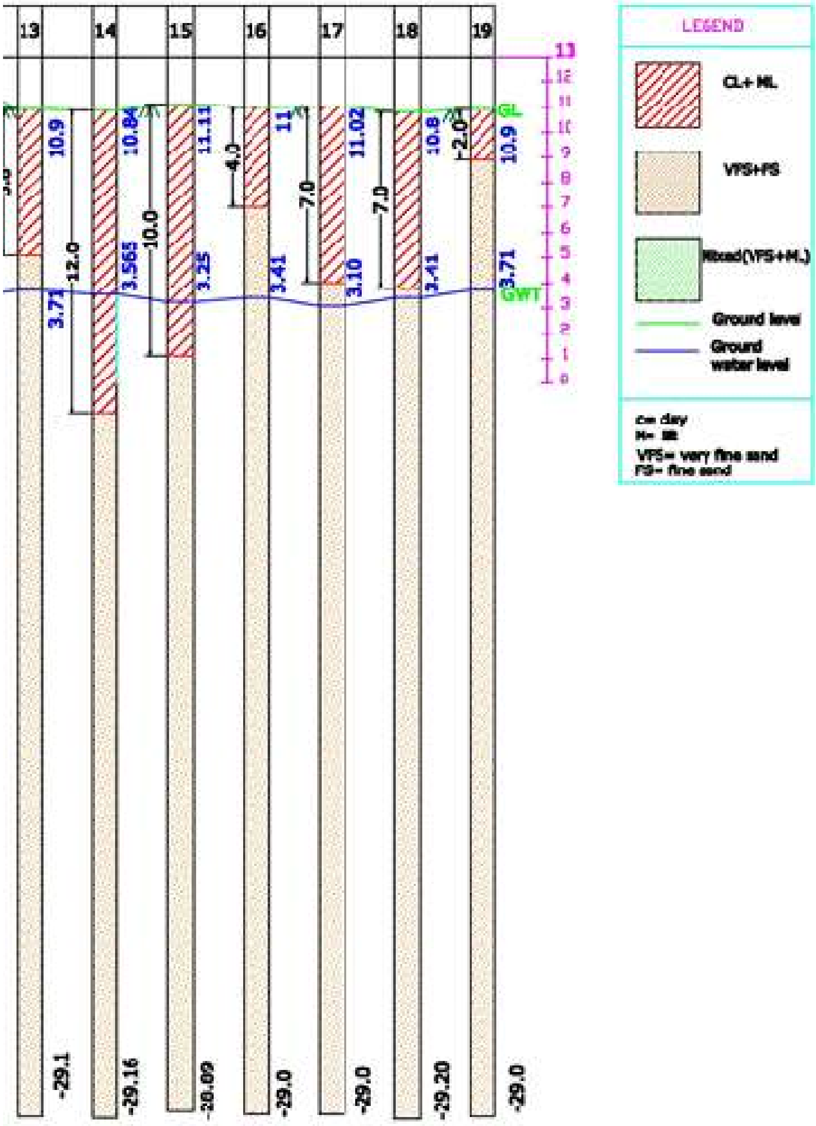


Figure 3-15 Results of subsoil investigation in Chauhali 2013

3.5.2 Harirampur

In Harirampur, winnowing failure also occurred, caused by the insufficient thickness of the temporary wave protection, leading to erosion of the riverbank in places, especially in the curved section. In total, about 700m of protection was completely destroyed and several kilometers have been partially damaged. The failures zones will be investigated more in detail to determine if static flow slides contributed to the failure of the wave protection as well.

Figure 3-16 confirms that the failure mostly occurred in the area, where the flow hits the bankline. This indicates that also here the impact of the high flow velocities and the waves were underestimated by the designers of the temporary wave protection.

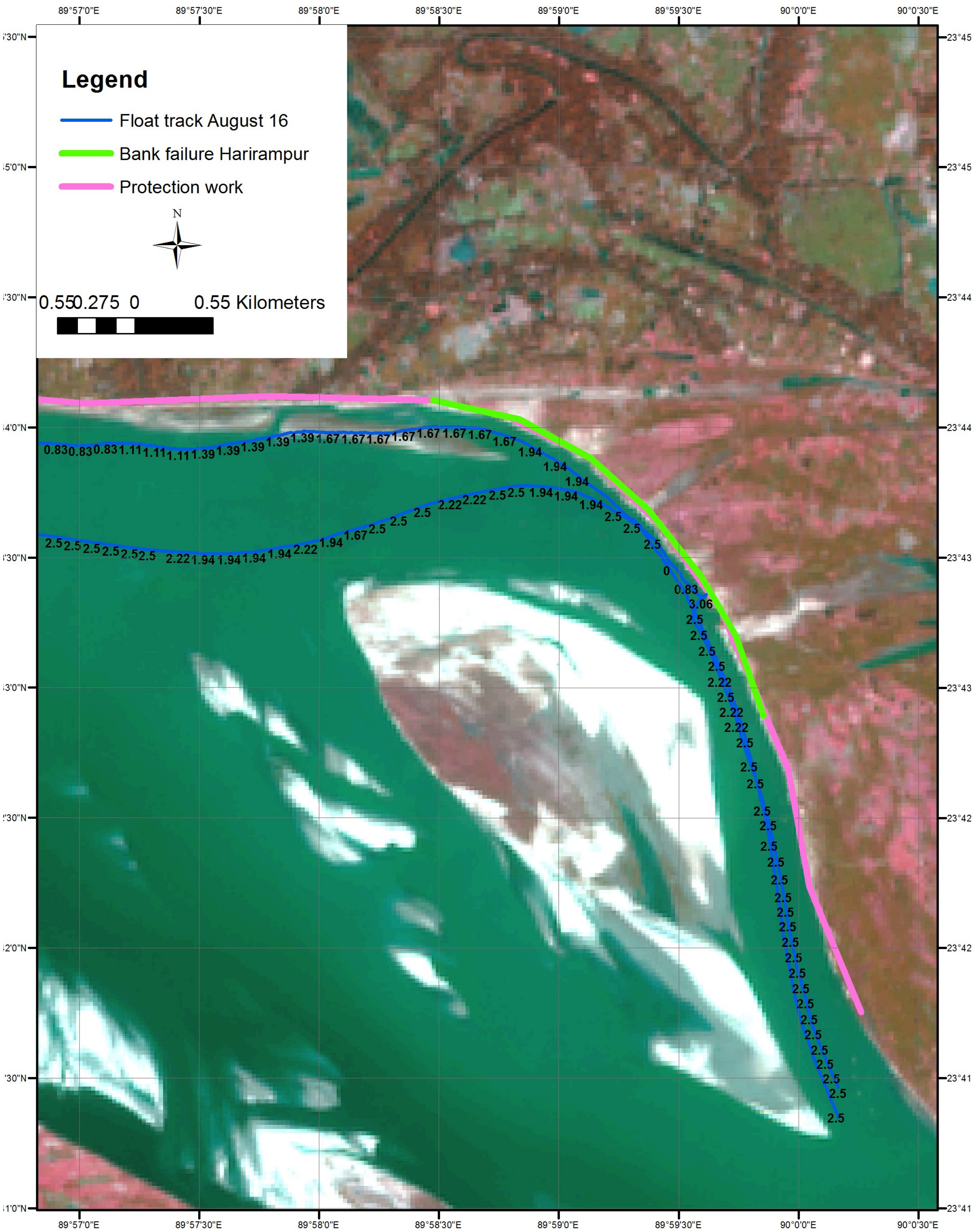


Figure 3-16 Location of slope failure with float tracks from August 2016

The winnowing failure mechanism is characterized by a gradual destruction of the wave protection and subsequently erosion of the riverbank in the area above the multi-layer underwater protection. Figure 3-17 and Figure 3-18 explain the process in detail. This failure mechanism is very similar to the gradual erosion of launched aprons, resulting in steepening slopes and eventual geotechnical failure, if not upgraded through adaptation works.

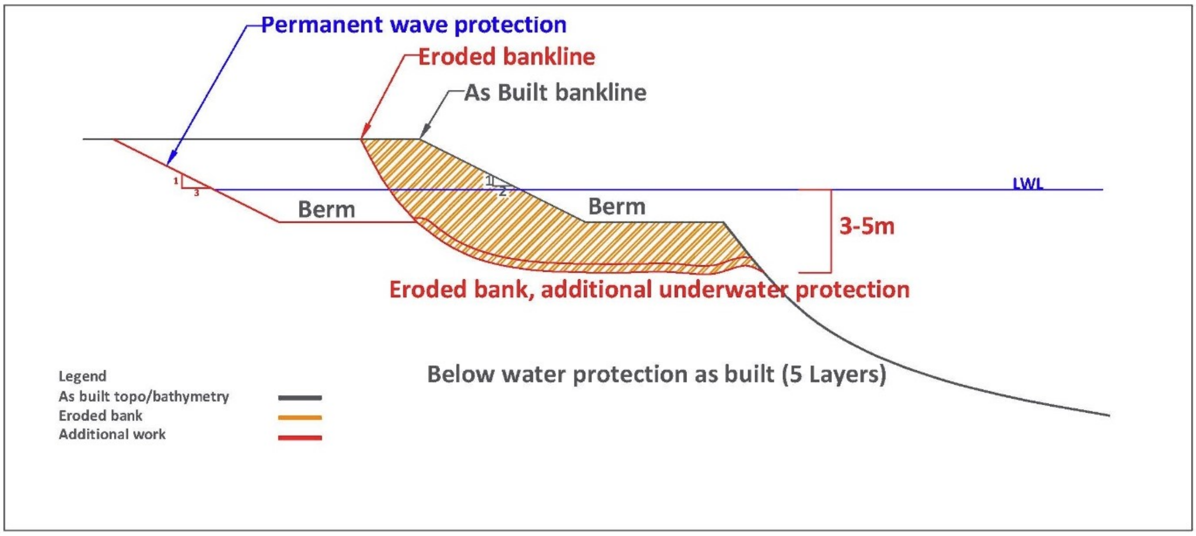


Figure 3-17 Schematic of slope erosion due to under-designed temporary wave protection

Figure 3-18 Progression of destruction of temporary slope protection: (1) surface protection disintegrates into elements (through high velocities or wave impact) (2) hole eroded in bankline with regressive erosion and deepens, but underwater protection is still in place (foreground at low water level)

3.6 Launched Quantities

The launching process of aprons is clearly visible on cross sectional surveys as very straight slopes at 1V:2H. The surveys also confirm the geometrical relationship of the length of the originally placed apron launched and the length of the launched slope. The ratio between both is defined by the number of layers of bags available for launching and the slope length after launching, and can be computed with the following formula:

$$L_S = \frac{D_S \cdot \sqrt{5}}{N}$$

Where:

L_S	Length of initially placed apron launched down the scoured slope [m]
D_S	scour depth [m]
N	Number of layers [no]

The launching results in a single layer coverage on a launched slope with a slope angle somewhat depending on the soil type. For well consolidated sandy soils without cohesion (along old floodplains) the slope is usually 1V:2H, while clayey soils might results in slopes as steep as 1V:1H. The launching process of the protected elements over the subsoil does not support slopes flatter than 1V:2H. The initial investigations at the site confirm the typically 1V:2H slopes under water. The survey precision does not allow to fully relate the launch length to the length of the underwater slope. This notwithstanding, diving investigations confirm the single layer coverage. Unconsolidated soil alongside chars exhibit much flatter slopes of about 1V:3.5H or less and do not support launching, as the launched slopes are geotechnically unstable and likely to collapse.

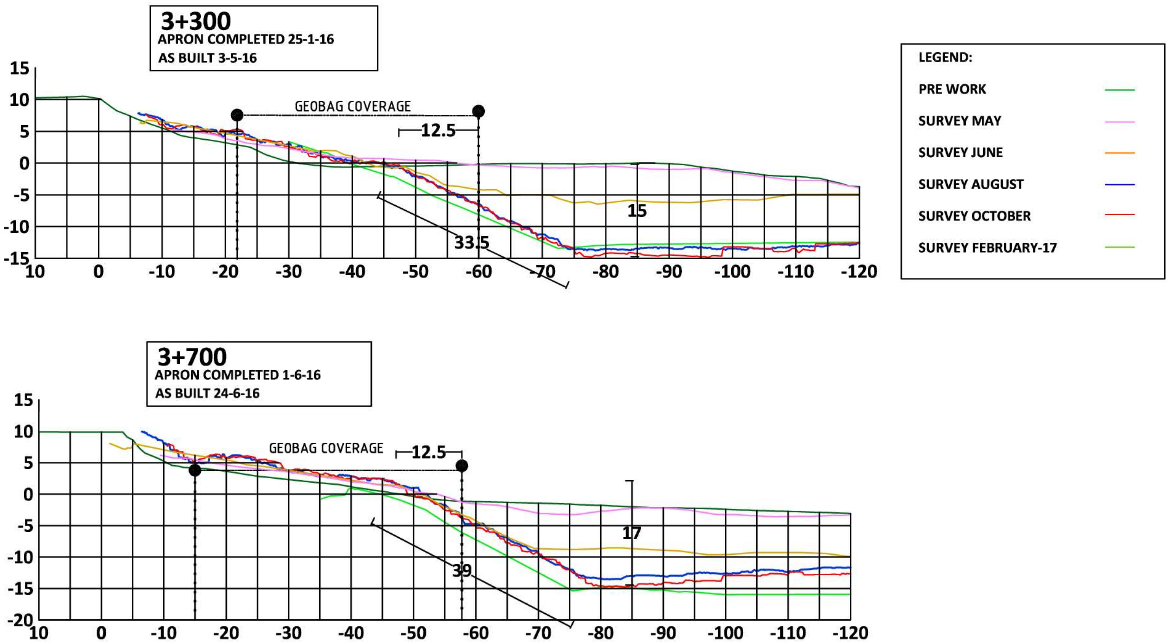


Figure 3-19 Examples of geometric relationship between launched length and launched slope length (Chauhali)

For a 5m deep scour, the launched length is about 11m at river bank lines on consolidated soils, requiring the bag number of a 4m wide, 3-layer thick apron. With a maximum expected launching of 15m (Table 3-7) vertical scouring in one season, creating a 34m long slope, a 12m wide, a minimum three layer thick apron is required.

Table 3-7 Comparison of scour rates for parallel (revetment) and protruding (spur) structures in the Jamuna River (reference BUET lecture note for BWDB staff from 12 and 18 February 2017)

Duration of Measurement	Revetment Scour	Protrusion/Spur Scour
2 days	2 m	5 m
7 days	7 m	10 m
14 days	9 m	15 m
30 days	11 m	21 m
60 days	13 m	29 m
90 days	15 m	33 m

3.7 Flow Velocities

Flow velocities and discharge were measured with an ADCP in August, September and October 2016 (for detailed locations and results refer to Figure 2-4 and Annex 8). The transects covered the river channel at Chauhali and between 300 and 850m wide sections in Zafarganj and between 350 and 2,000m wide sections in Harirampur. The section width varied with the width of the flow and the inundation of the near bank floodplain. Details are provided in Table 3-8:

Table 3-8 Length of transects in different month

Location	Transect	Aug	Sep	Oct
Harirampur	T 1-3	550	550	550
Chauhali	T1	2000	3900	500
	T2	2000	1200	500
	T3	350	3900	500
Zafarganj	T1	850	500	500
	T2	600	300	350
	T3	600	500	500

3.7.1 Chauhali

(i) In the channel at Chauhali, discharge and velocity were measured at three transects that are located upstream, in the center, and downstream of the protective works. The channel at this location carries around 44% of the total flow in the Jamuna (about 2/3 of the left channel flow, which is about 2/3 of the total Jamuna flow)

(ii) Discharges, average and maximum bed velocity are shown in Table 3-9. The average velocities were calculated over the 60m wide protected riverbank.

(iii) The average velocity was about 1.5m/s, with the lowest average velocity in the middle transect in the Chauhali bend.

(iv) The maximum bed velocity was about 2.4 m/s and occurred in September in the center of the bend.

Table 3-9 Discharge, average flow velocity, and near bed velocity development at Chauhali

Month	Aug			Sep			Oct		
	Discharge, m³/s/60m width	Av transect velocity, ms^{-1}	Velocity near bed, ms^{-1}	Discharge, m³/s/60m width	Av transect velocity, ms^{-1}	Velocity near bed, ms^{-1}	Discharge, m³/s/60m width	Av transect velocity, ms^{-1}	Velocity near bed, ms^{-1}
Transect-1	240	0.952	1.092	344	1.5	2.037	585	1.382	1.78
Transect-2	643	1.425	2.074	880	1.48	2.359	385	0.81	1.37
Transect-3	660	1.669	2.237	406	1.119	1.51	356	1.044	1.18

3.7.2 Zafarganj

(i) At Zafarganj, discharge and flow velocity were measured along three transects. Two transects were up- and downstream of the protective works, while transect no. 2 was at the location of the protrusion into the river.

(ii) The average flow velocities are around 1.4m/s and are highest at the location of the protrusion into the river.

(iii) The maximum near bed velocity of 2.85m/s was measured in October in transect 2 at the location of the protrusion into the river

Table 3-10 Discharge, average flow velocity, and near bed velocity development at Zafarganj

Month	Aug			Sep			Oct		
	Discharge, m³/s/60m width	Av transect velocity, ms^{-1}	Velocity near bed, ms^{-1}	Discharge, m³/s/60m width	Av transect velocity, ms^{-1}	Velocity near bed, ms^{-1}	Discharge, m³/s/60m width	Av transect velocity, ms^{-1}	Velocity near bed, ms^{-1}
Transect-1	274	0.79	1.3	347	1.06	1.86	447	1.05	1.49
Transect-2	651	1.08	1.85	1466	1.31	1.83	1530	1.81	2.85
Transect-3	869	1.53	2.35	435	0.93	1.31	344	0.9	1.38

3.7.3 Harirampur

(i) At Harirampur, velocity and discharge were measured along three transects, out of which two (up- and downstream) where outside of the protective works. Transect 2 was located in the bend.

(ii) The average flow velocities are relatively low, peaking at 1.5 m/s, but mostly below 1m/s.

(iii) The maximum near bed velocity was 1.3m/s and occurred in transect 1, upstream of the bank protection. The maximum near bed velocity in the bend was 1.15m/s.

Table 3-11 Discharge, average flow velocity, and near bed velocity development at Harirampur

Month	Aug			Sep			Oct		
	Discharge, m³/s/60m width	Av transect velocity, ms^{-1}	Velocity near bed, ms^{-1}	Discharge, m³/s/60m width	Av transect velocity, ms^{-1}	Velocity near bed, ms^{-1}	Av transect velocity, ms^{-1}	Average velocity, ms^{-1}	Velocity near bed, ms^{-1}
Transect-1	68	1.56	0.620	139	0.75	0.747	375	1.074	1.299
Transect-2	323	0.078	1.137	210	0.44	0.778	89	0.23	0.688
Transect-3	85	0.334	0.512	125	0.65	0.942	173	0.785	1.253

3.8 Comparison of Field Surveys and Scour Theory

The scour patterns at the three different sites that can be categorized into two different scour types:

1. Bend scour at Chauhali and Harirampur
2. Protrusion scour at Zafarganj

The development and the extent of the occurring scour depends on parameters such as curvature, flow depth, local soil characteristics etc., which have an influence on the flow and sediment transport.

For the estimate of scour extent and depth, a number of alternative formulae are available for each type of scour. In the following, the formulae are described, the results are compared to the observed scour development applying observed field parameters, and finally the design scour is checked.

3.8.1 Bend scour

For the calculation of the scour depth in a bend, Hoffman and Verheij, provide the following equation for radius/flow width ratios of between 2<R/B<22:

$$\frac{y_{m,e}}{y_0} = 1.07 - \log\left(\frac{R}{B} - 2\right)$$

Where:

ym,e	scour depth in bend [m]
y0	river depth upstream of the bend [m]
R	radius [m]
B	width of flow [m]

The BWDB design typically uses the Lacey formula, which reads:

$$y_{3r} = 0.47 * \left(\frac{Q}{f}\right)^{1/3}$$

Where:

y_{3r}	scour depth in bend [m]
Q	Discharge in river [m³/s]
f	silt factor [-] $f = 1.76 * \sqrt{D}$
D	grain size [mm]

To compare the results, and to assess whether the formulae over- or underestimate the observed scour depths, the calculated scour depths were compared with the BWDB design scour depth and the observed scour depths. The results are shown in the following. The BWDB uses the Lacey formula for the estimation of the design scour.

3.8.1.1 Observed and Computed Bend Scour Depth

The result of the comparison of the calculated with the observed scour depths in Harirampur, as shown in Table 3-12, show that the formula of Hoffman and Verheij slightly underestimates the scour depth by some 7%. The Lacey formula overestimates the scour depth by 20%.

Table 3-12 Observed and calculated scour depth at Harirampur

Symbol	Description	Unit	Lacey	Hoffman&Verheij	Observed
WL	Water level (August)	m+PWD	7.10	7.10	7.10
BL	Bed level	m+PWD	-1.80	-1.80	-1.80
Yel	**Scour elevation**	**m+PWD**	**-21.7**	**-16.8**	**-18.0**
Y	Scour depth (below bed level)	m	19.9	15.0	16.2
Y	Scour depth (below HFL)	m	28.80	23.9	25.1
Q	Discharge	m³/s	57,288		
f	Factor for grain size	-	0.25		
D	Grain size	mm	0.02		
R	Bend radius	m		2,530	2,530
B	Flow width	m		1,250	1,250
y0	Av. Water depth	m		8.90	8.90
R/B	Ratio of Radius to flow width	-		2.02	2.02

The comparison of observed and calculated scour depths in Chauhali is shown in Table 3-13. It shows that here the formula of Hoffman and Verheij matches the observed scour depth very closely, with a deviation of just 3%. The formula from Lacey shows significant differences of 17%. An explanation could be that the Lacey formula considers the flow in the whole channel, while the scour is mainly induced by near bank discharge, which can be very different, especially in braided rivers.

Table 3-13 Observed and calculated scour depth at Chauhali

Symbol	Description	Unit	Lacey	Hoffman&Verheij	Observed
WL	Water level (August)	m+PWD	10.50	10.50	10.50
BL	Bed level	m+PWD	0.20	0.20	0.20
Yel	**Scour elevation**	**m+PWD**	**-13.4**	**-15.5**	**-16.0**
Y	Scour depth (below bed level)	m	13.6	15.7	16.2
Y	Scour depth (below HFL)	m	23.89	26.0	26.5
Q	Discharge	m³/s	32,701		
f	Factor for grain size	-	0.25		
D	Grain size	mm	0.02		
R	Bend radius	m		3,500	3,500
B	Flow width	m		1,720	1,720
y0	Av. Water depth	m		10.30	10.30
R/B	Ratio of Radius to flow width	-		2.03	2.03

3.8.1.2 Reviewed Bend Scour Depth

To determine the design scour, the maximum – design – conditions have to be considered, which in this case equate to the selected design discharge and high flood level expected at this discharge. The results are shown in Table 3-14, which compares the expected design scour depths at Harirampur as calculated using the Lacey formula, with the Hoffman and Verheij formula, and the design scour depth provided by the BWDB Design Office. As the flow width increases in the event of a high flood, but the bend radius stays stable as it is protected by the provided protection, the Hoffman and Verheij formula cannot be used as the ratio of bend radius and flow width becomes too small. The design scour depth provided by the BWDB is about 16% deeper than the scour depth calculated with the Lacey formula. As we have seen at the comparison with observed data, the Lacey formula tends to overestimate the scour depth at Harirampur. Therefore, the BWDB design scour depth includes a safety factor.

Table 3-14 Design scour depth at Harirampur

Symbol	Description	Unit	Lacey	Hoffman&Verheij	BWDB (Lacey)
HFL	High flood level	m+PWD	10.00	10.00	10.00
BL	Bed level	m+PWD	-1.80	-1.80	-1.80
Yel	**Scour elevation**	**m+PWD**	**-24.7**	**Error**	**-28.4**
Y	Scour depth (below bed level)	m	22.9	Error	26.6
Y	Scour depth (below HFL)	m	34.68	Error	-18.4
Q	Discharge	m³/s	100,000		
f	Factor for grain size	-	0.25		
D	Grain size	mm	0.02		
R	Bend radius	m		2,530	
B	Flow width	m		2,000	
y0	Av. Water depth	m		11.80	
R/B	Ratio of Radius to flow width	-		1.3	

The comparison of the recalculated design scour data at Chauhali is shown in Table 3-15. It demonstrates that the BWDB estimates a much deeper level than the recalculated Lacey formula provides. The flow width is not expected to increase significantly, as the flow in the last flood season was relatively high, and the channel in this area is restricted by a large char. However, the scour depth calculated with the Hoffman and Verheij formula matches the BWDB design scour fairly well. As has been shown in the comparison with the observed data, the Lacey formula tends to underestimate the scour depth, while the Hoffman and Verheij formula delivers relatively close results. Therefore, the design scour should be adopted as calculated.

Table 3-15 Design scour depth at Chauhali

Symbol	Description	Unit	Lacey	Hoffman&Verheij	BWDB (Lacey)
HFL	High flood level	m+PWD	13.22	13.22	13.22
BL	Bed level	m+PWD	0.2	0.20	0.20
Yel	**Scour elevation**	**m+PWD**	**-17.0**	**-22.0**	**-21.6**
Y	Scour depth (below bed level)	m	17.2	22.2	21.8
Y	Scour depth (below HFL)	m	30.20	35.2	34.8
Q	Discharge (max)	m^3/s	66,000		
f	Factor for grain size	-	0.25		
D	Grain size	mm	0.02		
R	Bend radius	m		3,500	
B	Flow width	m		1,730	
y0	Av. Water depth	m		13.02	
R/B	Ratio of Radius to flow width	-		2.02	

3.8.2 Protrusion scour

All interventions in a river cause scouring due to flow diversions, which cause turbulences and higher flow velocities and resulting higher sediment transport capacity. The bank protection as a revetment does not pose as an obstacle, but still changes the flow near the river bank due to the smoother surface and resulting higher flow velocities. These scouring is called a protrusion scour as the mechanisms are the same as the ones causing scouring at spurs. A method for the estimation of the scour depth was presented in the Meghna Short Term Study, which is derived by Breusers and Raudkive and based on the works of Inglis.

Considering abutments as protrusion into the river, Simons and Senturk (cited in Meghna Short Term Study) derived for Mississippi conditions a scour equation that can be used for hard points:

$$\frac{y_{ps}}{y_a} = 4 * Fr^{0.33}$$

Where:

- yps depth of protrusion scour [m]
- ya average depth [m]
- Fr Froude number

Above mentioned theory can be used for assessing the expected scour depth in Zafarganj, which is, corresponding to different water depths, shown in Table 3-16. However, due to larger scale changes in the river morphology, no scouring has been observed in Zafarganj, which makes a comparison impossible.

Table 3-16 Protrusion scour depth at Zafarganj

Symbol	Description	Unit	Calculated	BWDB
yps	**Scour bottom elevation**	**m+PWD**	**-21.31**	**-23.3**
yps	depth of protrusion scour [m]	m	32.99	
MWL	Maximum water level	m+PWD	11.68	11.68
BL	Bed level	m+PWD	-2.00	
ya	average depth [m]	m	13.68	
Fr	Froude number	-	0.22	
u_0	average velocity [m/s]	m/s	2.5	

The expected scour depth for the design water level is 33m, with the bottom of the scour arriving at -35m+PWD.

3.8.3 Conclusion of Scour Comparison

The calculated design scour depth differs in all locations from the BWDB design scour depth. The calculated scour depth at Chauhali is deeper than the BWDB design, while Zaffarganj and Harirampur are less deep. Due to the lack of systematic scour assessment alongside existing riverbank protection works we recommend applying a safety factor of 5m.

Table 3-17 Design scour depth from BWDB and ISPMC

Design scour depth	HFL	Reassessed Scour Elevation	Calculated scour depth (below HFL)	BWDB design scour elevation	BWDB scour depth (below HFL)
	m+PWD	m+PWD	m	m+PWD	m
Chauhali	13.22	-22.0	35.2	-21.58	34.8
Harirampur	10	-24.7	34.7	-28.39	38.4
Zafarganj	11.68	-21.3	33.0	-23.3	35.0

3.9 Design Review of Geobags

Geobag sizes are determined using the stability coefficients and design conditions appropriate for the USACE and Pilarczyk approach for current velocities. The assumed sand bulk saturated density is 1,750 kg/m3.

The USACE equation reads (with the different variables explained in Table 3-18):

$$\frac{D_n}{y} = C_S S_f C_V C_T \left[\frac{v}{\sqrt{K_1 g y}} \cdot \left(\frac{\rho_w}{\rho_s - \rho_w} \right)^{1/2} \right]^{2.5}$$

The required geobag size for the design velocity is then solely depended on the water depth, as shown in Table 3-18. The size decreases with water depth, because of the lower flow velocities at higher water depths.

The design flow velocity was selected as 3.5m/s, which is the expected maximum flow velocity that occurs during extreme events. The highest velocity that was observed near bed was 2.8m/s in Zafarganj, where the bathymetric surveys showed no scouring and a generally stable protection. This indicates that the design of the geobags is safe.

Table 3-18 Required geobag dimensions

y	Water depth	m	1	1.5	2	2.5	3	3.5	4	4.5	5
W	Weight	kg	157	116	94	79	69	61	56	51	47
V	Volume	m^3	0.09	0.07	0.05	0.05	0.04	0.04	0.03	0.03	0.03
D	Diameter	m	0.49	0.44	0.41	0.39	0.37	0.36	0.35	0.34	0.33
v	Design velocity	m/s	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
S_f	Safety factor	-	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
C_s	Stability coefficient	-	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
C_v	Velocity distribution coefficient	-	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
C_T	Thickness coefficient	-	1	1	1	1	1	1	1	1	1
s	Relative density of sand	t/m^3	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Kl	Slope factor	-	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

4 Adaptation Works

4.1 The Purpose of Adaptation Works

Adaptation works is obligatory for sustainable riverbank protection. It consists of three elements (in the order of typical importance):

(i) Building existing work to deeper level and safeguarding the works from failure;
(ii) Extending existing works in upstream or downstream direction to prevent outflanking or downstream erosion, and
(iii) Repairing small damages, mostly damaged wave protection.

The key elements for safeguarding the existing work is to build riverbank protection to deeper levels. This is typically required after the first and second flood when the river responds to the new obstruction through deep scouring, but also after large floods that the works has not experienced earlier. Therefore, this adaptation element is the most fundamental to protect the substantial, new investment from immediate failure. Sadly, many and repeated collapses of riverbank protection in Bangladesh tell the story of neglected adaptation works. Building the works to deeper levels addresses two well-known weaknesses, both related to geotechnical instability:

(i) The single layer coverage of the launched apron has to be upgraded to reliable thickness (minimum three layers) as the slope would otherwise gradually steepen from winnowing and eventually fail due to slope instability (Figure 4-1). The construction in flowing water results in the dumping of three additional layers over the launched slope to arrive at consistent coverage. In stagnant or near stagnant water two layers can be dumped as the dumped material is not displaced. Upgrading of the launched apron can also be achieved through an additional apron launching from a higher deposit (Figure 4-1). In this way, at least two layer coverage will be achieved after renewed scouring.
(ii) A second or third toe apron at the end of the launched slope increases the geotechnical stability of the work. The deeper the river and higher the slope under constant angle, the smaller the safety factor and the higher the risk of total slope failure. The additional apron(s) assure a stepped slope down to design scour level, which is overall flatter than the directly launched slope at 1V:2H. As the sandy soils are at the borderline of stability, the designer naturally wants to avoid this precarious situation and attempts to attain higher geotechnical stability. The additional toe apron is designed to reach design scour depth in single layer coverage plus an added 5m safety margin that remains unlaunched and consists of three layers of dumped geobags to arrive at sufficiently dense coverage. If higher safety factors are desired a wider apron has to be placed, sufficient to withstand static flow slides typically resulting in failure slopes of 1V:3.5H to 1V:5H (for more details refer to the memo on the Harirampur work from February 2016).

Adaptation works are typically required for launching that exceeds 5m vertical bed erosion, resulting in 11m long slopes covered with single layer launched protection. It is well known that the amount of goebags typically stored on the underwater slope is still sufficient for launching to greater depth, however geotechnical instability governs the decision. This also means that the slope coverage only has to assure the minimum layer providing dense coverage (three layers) to arrive at economic designs. Any design asking for more wastes money, for example the designed five layer coverage is 66% overdesigned.

Largely different site conditions limit the adaptation works at the three FRERMIP sites to the followings:

(i) Building to deeper levels: In Chauhali and Harirampur parts of the revetment are required to be built to deeper levels due to systematic and expected repeated scouring.

(ii) Extension of works: At Chauhali the extension of the works in upstream and dcwnstream direction is indicated to prevent outflanking and protect important infrastructure further downstream. This work will follow the typical emergency work design proven repeatedly under JMREMP.

(iii) Erosion of temporary wave protection: At Chauhali and Harirampur surficial erosion destroyed the under-designed, temporary wave protection in parts causing local riverbank erosion. Under water, a wide shallow berm has formed, between some three and five meters below low water level. At Harirampur the temporary bank protection needs to be upgraded to survive another two flood seasons before Project-2 can provide permanent protection, while it is replaced in Chauhali, however requiring to protect a wider eroded underwater berm.

For the purpose of adaptation works the PMO has procured 864,500 geobags. The contract was awarded at the end of February 2017 and the bags will become available at the site from mid-March 2017. The contract can be extended by up to 15% to provide contingency material, prior to procure more geobags for dry season adaptation works in 2017/18.

The following subsections estimates adaptation work requirements based on the knowledge of the dry season situation in early 2017. The final work depends on the decision of the responsible BWDB design office and detailed site surveys, both shortly before placing and immediately after placing to arrive at as-built drawings:

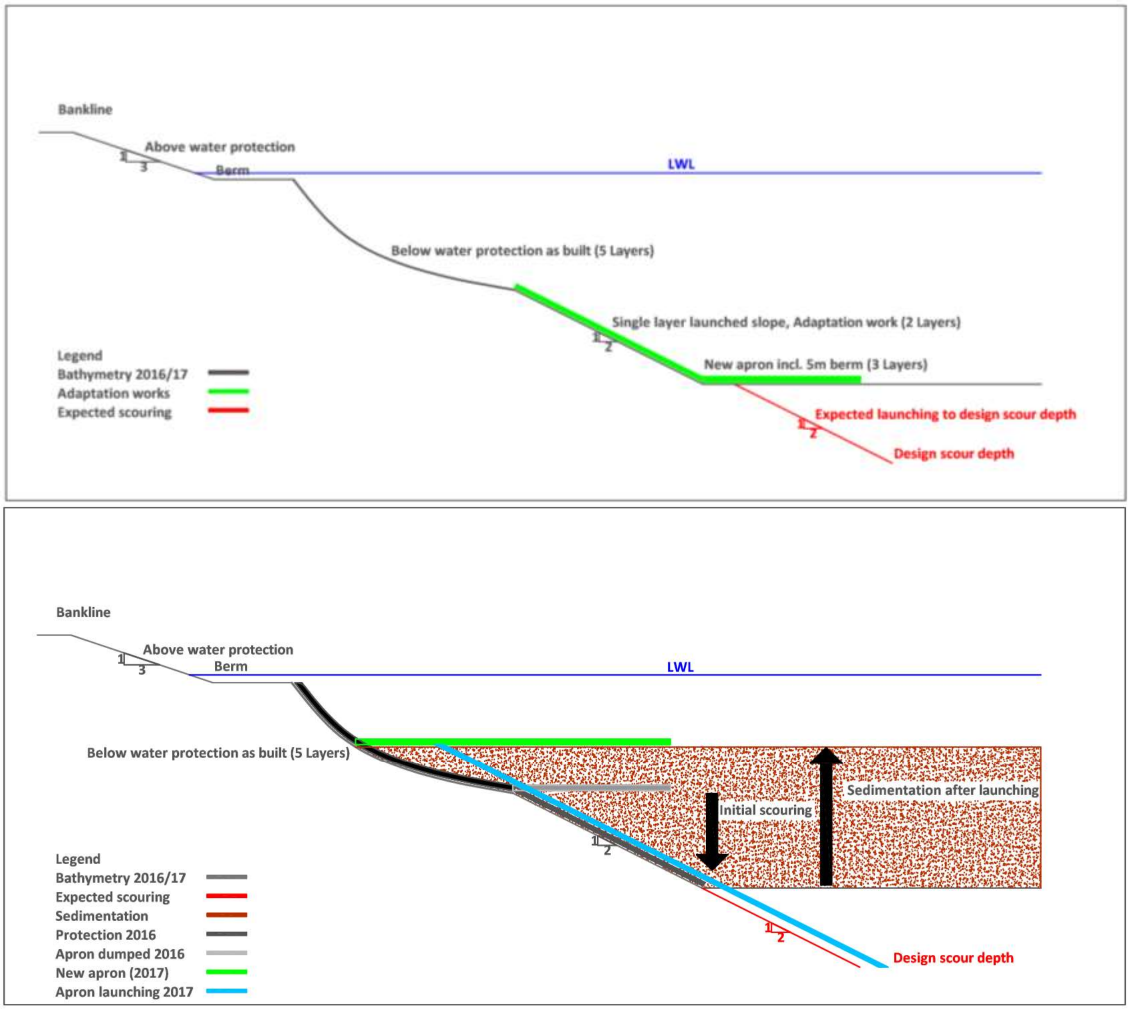


Figure 4-1 Adaptation work over launched apron (1) without later sedimentation and (2) with later sedimentation

4.2 Site Specific Adaptation of Works Built in 2016

4.2.1 Chauhali

The flood season surveys indicate that

(i) The apron has launched more than 5m vertically along a substantial part of the protected bankline except for the upstream and downstream end. In total, a length of 4.6km has launched between around 600 and 5,000m.

(ii) Along around 3km length, the bed has reached a relatively stable depth of -14 to -17m+ PWD, which is 10 to 13m above design scour (with safety margin).

(iii) The adaptation works includes provision of a new apron that would cover the slope to the design scour, while maintaining a safety-berm of 5m width.

(iv) The erosion of temporary wave protection in 11 locations causing a loss of around 0.9ha of the above water slope and floodplain requires protection of minimum three layers of geobags systematically dumped from barges onto the formed berm. The above water slope and berm are to be adjusted as per design. The situation is critical at the upstream end, where a major slope failure occurred at the end of February, which affected completed works (Figure 3-12).

(v) There is one large geotechnical failure (between contractor's camp and brick mosque), which, apart from additional geobag coverage, requires setting the riverbank back along a smoother alignment. Resettlement and land acquisition plans require updating.

Around 306,000 geobags are estimated to be required safeguarding the existing work by building it to greater depth (Table 4-1), based on available information. This includes the February survey, which indicates only small bed level changes compared to October 2016. Given that recent diving discovered more areas of geotechnical failure, where the underwater protection is completely destroyed, we recommend an additional allocation of 50,000 geobags.

The final work layout depends on the site situation established prior to dumping through a systematic river survey prior to and immediately after dumping (to establish precise as-built drawings). Some minor repairs that can be done from the remaining 30,000 geobags available on site.

Table 4-1 Adaptation works in Chauhali

Station	Av. Depth change	Length launched	No of Geobags
Underwater Works			
Km	m	m	No
0.0 – 0.9	4.8	200	9,600
0.9 – 4.9	10	4,000	169,400
4.9 – 6.1	4	1,200	46,800
Repair of eroded slope		Around .0.9	30,000
Contingency for underwater failures			50,000
Total			**305,800, say 306,000**

Example construction drawings can be found in Appendix 9.

4.2.2 Zafarganj

No section launched more than 5m during the 2016 flood season and consequently no adaptation works is necessary.

4.2.3 Harirampur

The flood season surveys indicate that

(i) The large sandbar that has moved into the worksite from the upstream end now covers about 5km of the riverbank. Another 2km have been silted in substantially (over several meters).
(ii) Along the char from around chainage 4,000 to chainage 8,400 there are indications that the slope has failed more substantially due to static flow slides. A number of cross sections in this area indicate initial launching followed by larger slope failures through static flow slides. However, as the flow slides settled on a slope of roughly 1:3.5, it can be expected that the geotechnical stability in these places is improved.
(iii) At station 7.6km, a scour hole is still present with an about 1,600m long section launched by more than 5m vertically, on average about 7m. Even though this is close to the 5m limit, the soft soil conditions in this area indicate the need for upgrading the underwater works and placing an additional apron.
(iv) The 1,000m long downstream end launched less than 5m vertically.
(v) During the dry season from October 2016 to January 2017 sedimentation continued and the channel filled in further.

Adaptation works would be required for the several kilometer length, especially in the curved section. After confirming that static flow slides destroyed the slope, the underwater protection needs to be rebuilt. The movement of the upstream bankline char with more than 10m of deposition and the available number of procured geobags for adaptation works will be largely insufficient for this reconstruction. In order to estimate the approximate amount of work, we recommend detailed diving investigations. Likely additional geobags have to be procured, for example 4km of riverbank protected by an 80m wide coverage with three layers will require around one milllion additional geobags. An example for the repair works is shown in Annex 9.

Table 4-2 shows the key work areas.

Table 4-2 Adaptation works in Harirampur provided no static flow slides have occurred

Station	Av. Depth change	Length launched	No of Geobags	Remarks
Km	m	m	No	
1.6 – 2.6	-4 (sedimentation)	0	0	No launching yet observed
2.6 – 4.0	-11 (sedimentation)	1,400	0	Full sandbank sedimentation height, original protection covered by up to 17m sand -> no adaptation works required as none of the protection has launched since it has been constructed
4.0 – 7.6	-11 (sedimentation)	3,600	As per diving survey	Full sandbank sedimentation height, original protection covered by up to 17m sand. Potential of static flow slides in this area to be checked.
7.8 – 9.0	6.6 (scour)	1,200	As per diving survey	Scour below deep scour level. Potential of static flow slides in the area to be checked
9.2 – 10.4	3.4	1,200	0	Some erosion, it can be expected that the scour is moving through this section during the next flood season. The potential of static flow slides indicates the need for further widening of the existing apron.
Total			**Depending on diving confirmation**	

Repair of above water protection

The wave protection above low water level constructed in Harirampur provides temporary protection until the time when the permanent protection will be built during Project-2. As the temporary works designed by the BWDB Design Office only consists of a single layer of geobags, it was damaged during the 2016 flood season especially in the central, curved area. The temporary wave protection has to be repaired to last for minimum two more flood seasons, until it is replaced by permanent protection during Project-2. While some works were only partially damaged, a stretch of about 700m was completely destroyed and has to be rebuilt including dumping of bags to cover the eroded underwater berm. In addition, some homesteads close to the riverbank require additional protection. To avoid repeated significant damage of the wave protection during the next flood seasons, a minimum two-layer protection shall be provided alongside about 3,000m of the most critical parts. This double layer might also be able to somewhat mitigate the fundamental design error to place geobag wave protection on flat slopes.

In addition to the repair of the wave protection, the eroded wide berm has to be covered. A detailed survey including diving investigation will provide the exact quantities and at this point only a lumpsum allocation of 50,000 geobags has been made.

Table 4-3 Overwater adaptation works in Harirampur provided no static flow slides have occurred

Site	**Chainage**	**Length (m)**	**No of bags**	**Remarks**
Scattered homesteads	1.6 – 4.5km	950	3,800	Protection for scattered homesteads
Partially damaged protection	1.6 – 4.5km	2,900	3,800	Repair of damaged wave protection
Partially damaged protection	4.5 – 10.3km	5,100	10,500	About 15% of geobags damaged
Fully damaged protection	4.5 – 10.3km	700	25,000	
Additional layer of protection under water	5.2 - 8.0km	3,000	36,000	
Berm repair			50,000	
Total		**9,650**	**129,100**	

Potential repair of below water protection

Underwater repair depends on the results of diving investigations to confirm if there are systematic or sporadic static flow slides having destroyed the placed protection. This was anticipated (refer to the Memo on Harirampur works from January 2016). Naturally, only wide aprons, proposed for Padma Bridge, but also the BWDB approved works of the River Bank Improvement Project can mitigate the situation. In all cases immediate reconstruction would be required, even though the situation at Harirampur indicates that the thick deposit layers provide a good chance of only limited erosion along parts of the riverbank.

Completion of protection as per design

We recommend to complete the work in the upstream area as per design, as the sandbar placed there in 2016 has shifted downstream and riverbank erosion could start during the 2017 flood season.

4.3 Extension of Work Location

4.3.1 Chauhali

Approach flow to the protected Chauhali bend has started eroding the upstream riverbank. The erosion is triggered by an about 3km long sandbar, which squeezes the flow along the unconsolidated riverbank (Figure 2-6). As this char is temporary in nature and will move over time, emergency protection consisting of a heap of geobags, dumped alongside the riverbank and supported above low water level through a double layer wave protection (Figure 4-2), will be suitable. This protection allows to be installed at comparatively small cost while observing the site development prior to deciding on more extensive works.

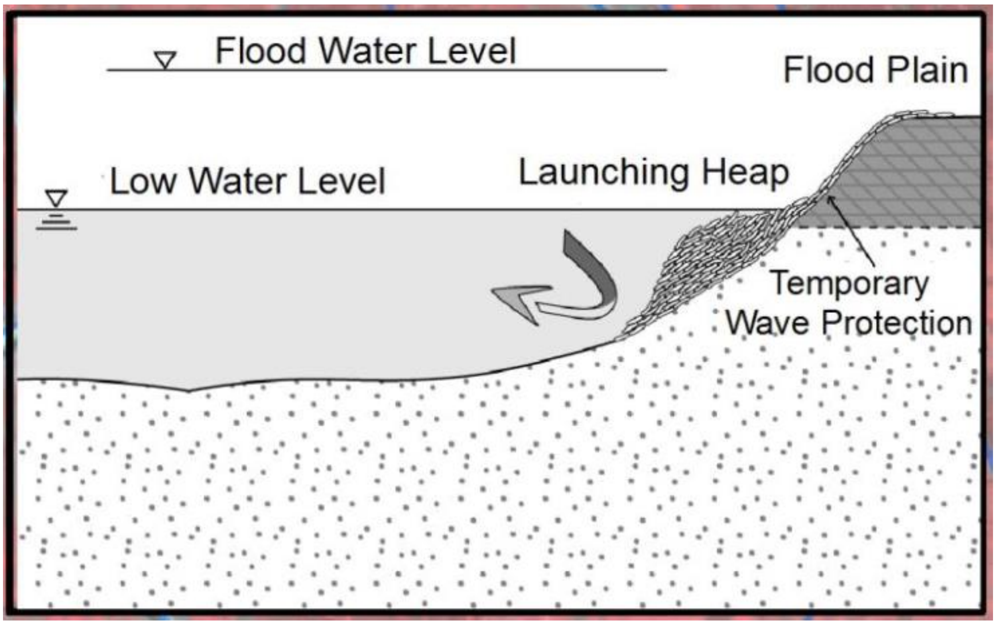


Figure 4-2 Emergency protection consisting of a heap of geobags dumped alongside the vulnerable riverbank

The proposed emergency protection needs to be able to cover the riverbank to the expected scour depth. Downstream, alongside the protected Chauhali bend, the bed level has deepened by around 10m after placing the protective works. Translating this knowledge to the upstream area indicates that about 20m water depth can be attained during the next flood season. To protect the underwater slope through an apron requires around 45 geobags of 250kg weight will become necessary, each covering 1m² of area (the slope length is 45m for a 1V:2H slope and 20m water depth). The above water slope, typically being 5m height requires around 15 bags for double layer coverage. The geobags are placed from the riverbank and built systematically out. The existing cross sectional survey shows that they will launch to the bed level (Figure 4-3) from where they would launch further, if further scouring occurs.

In total, the existing protective works has to be extended in upstream direction by around 3km. This translates into 152,000 geobags, including contingencies, 168,000. A detailed survey will be required to confirm the estimate.

Downstream of the protected Chauhali bend, a bankline channel exists that erodes the riverbank. This channel is likely to open more during the 2017 flood seasons, in parts due to the influence of the upstream Chauhali protection, keeping the deep channel along the protected bankline and reducing the inflow of sediment eroded from the riverbank. The increasing channel exhibits an increased erosion risk to the small remaining part of the Chauhali Upazilla, including the Solimabad growth center. In the more upstream area, BWDB has proposed 1.5km of riverbank protection, which will not be approved prior to the 2017 flood season. Temporarily helping the situation for some limited patchwork in line with the expected movement of the sand bars indicates the need to provide some 113,000 geobags in this area, 125,000 including contingency for around 2.5km of emergency protection. A specialist memo explaining the site situation and future potential developments has been provided to the PMO in mid-February. Figure 4-3 shows the typical design, consisting of mass dumping from the riverbank, a technology many times proven in JMREMP and very fast to implement.

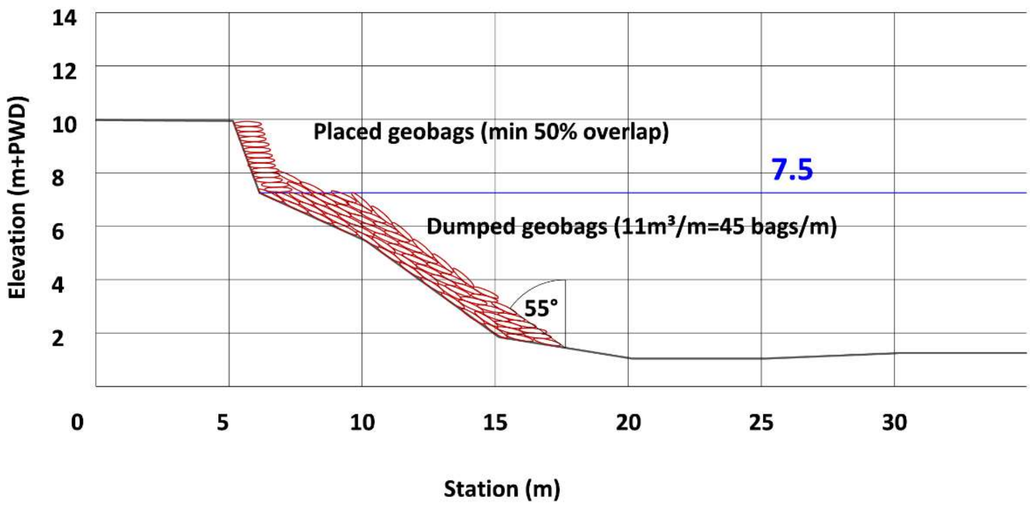


Figure 4-3 Typical emergency design for Solimabad

4.3.2 Zafarganj

Near the upstream end of the Zafarganj riverbank protection, the Ghoshbari khal opens into the Jamuna. The Khal has a top width of about 30m and a depth increasing from about 3m at a distance of 400m from the bankline to 5m at the bank line. The bed level of the khal is below low water level up to about 350m from the bank line. Because the depth and size of the khal, the standard drain notch cannot be applied, but a separate design is necessary.

The underwater protection needs to be extended by around 300m. This translates into around 45,000 geobags for a three layer coverage, 50m wide. This amount of geobags is still available at the site after completion of the underwater works.

The design for the bank protection of the khal follows the bank protection design of the main river. (see note on CC block design). The bed below LWL is protected by a layer of geobags with a supporting layer of dumped CC blocks with a dumped height of about 0.5m of 300x300x300mm blocks. The protection above LWL consists of placed 450x450x300mm blocks, including a crest protection of 5 blocks width and a sloped 5 block key up to 1m depth. The necessary quantities and cost are provided in Table 4-4.

Table 4-4 Concrete quantities and cost for Zafarganj, upstream extension

Part	Unit rate	Quantity	Cost	%
Crest	540	4,167	2,250,000	4%
Slope and bed	540	79,115	42,722,239	75%
Dumped	250	31,525	7,881,250	14%
Geotextile	150	18,252	2,737,779	5%
Sand layer	500	1,825	912,593	2%
Geobags	110	2,925	321,779	1%
Total (BDT)		**114,807**	**56,825,639**	**100%**
Total (USD)			**710,320**	

4.3.3 Additional Work at Kaijuri / Enayetpur to Protect the Brahmaputra Right Embankment

For the estimate of the scour depth at Enayetpur, the formula of Breusers and Raudkive was used, which was amended by Ahmad for the Meghna study.

$$y_0 + y_s = K * \left(y_0 * \frac{B}{B-b} * u_0 \right)^{2/3}$$

Where:

y_0	average river depth [m]
y_s	maximum scour depth [m]
K	constant 2.5 to 3.5
B	width influenced by structure [m]
b	protrusion [m]
u_0	average velocity

The computation results are shown in Table 4-5. The scour depth is estimated to be -27.8 m+PWD. The protection for this scour requires a 100m wide apron around the full length of the RCC structure. For this protection, a three-layer apron is provided, which covers a length of 220m on both sides of the 110m long structure. A total number of about 78,000 geobags is required for this work.

Table 4-5 Scour and Bank protection in Enayetpur

Scour calculation			
HFL	Maximum water level	m+PWD	13.00
BL	Bed level	m+PWD	-1.00
y_0	average river depth	m	14.00
y_s	maximum scour depth	m	26.8
Ye	Maximum scour elevation	m+PWD	-27.8
K	constant 2.5 to 3.5	-	2.5
B	width influenced by structure	m	1450
b	protrusion	m	680
u_0	average velocity	m/s	2.5
Bank protection			
RB	Riverbank	m+PWD	2.0
Sl	Slope	1:	2.0
Lsl	Slope length to bed level	m	6.7
Stoe	Present scour depth	m+PWD	-24.0
Luw	Slope under water to present scour	m	51.4
Lsc	Length of slope to design scour	m	8.5
Ltot,req	Total length calculated	m	66.6
SF	Safety factor	-	1.5
Ltot,sel	Total length required	m	99.9
Aw	Apron width selected	m	100.0
N	Number of layers	no	3.0
W	Width of protected structure	m	220.0
A	Area protected	m²	25,927
Ntot	Total no of bags	no	77,781

4.4 Summary and outlook

The adaptation works is summarized in **Error! Not a valid bookmark self-reference.** and

Table 4-7. The total quantities proposed exceed the presently procured. The final quantities will be confirmed by the design office after conducting detailed surveys, and are likely to change. It is advisable to procure more geobags immediately, also for timely implementation of further adaptation works after the 2017 flood season. Our tentative estimate includes 10% contingencies, but after all we recommend to extend the procurement of bags to 115% of the contracted quantities or 994,175 geobags.

Table 4-6 Adaptation works summary

Slope adaptation	**Exact**	**Selected**	**Contingency**	**Total**
Chauhali	225,800	226,000	10%	248,600
Harirampur (not including underwater works depending on further diving investigations)	113,200	114,000	10%	125,400
Zafarganj	0	0		0
Enayetpur	77,781	78,000	10%	85,800
Wave protection				
Harirampur	79,100	80,000	10%	88,000
Emergency work				
Harirampur bank failure repair	50,000	50,000	10%	55,000
Chauhali bank failure repair	30,000	30,000	10%	33,000
Chauhali upstream 3-4 km	152,000	153,000	10%	168,300
Chauhali downstream 2km	112,500	113,000	10%	124,300
Total		**844,000**		**928,400**

Table 4-7 Work site unit cost and quantities

Slope adaptation	**Unit cost for filling and dumping (Taka)**	**Number**	**Total (Taka)**
Chauhali	120	574,200	68,904,000
Harirampur (not including underwater works-depending on further diving investigations)	182	268,400	48,848,800
Zafarganj	110	0	0
Enayetpur	182	85,800	15,615,600
Total			**133,368,400**

The additional quantities will support the immediate adaptation of the downstream part of the Chauhali works, which numerical modeling shows will likely deepen substantially during the 2017 flood.

The adaptation works required after the 2017 flood can be estimated based on the development during the 2016 flood, which can be expected to continue in the same pattern.

Together with the model of the lower Jamuna, the estimates for the works in the 2017/18 dry season are shown in Table 4-8.

Table 4-8 Estimated quantities for adaptation works during 2017 - 18 dry season

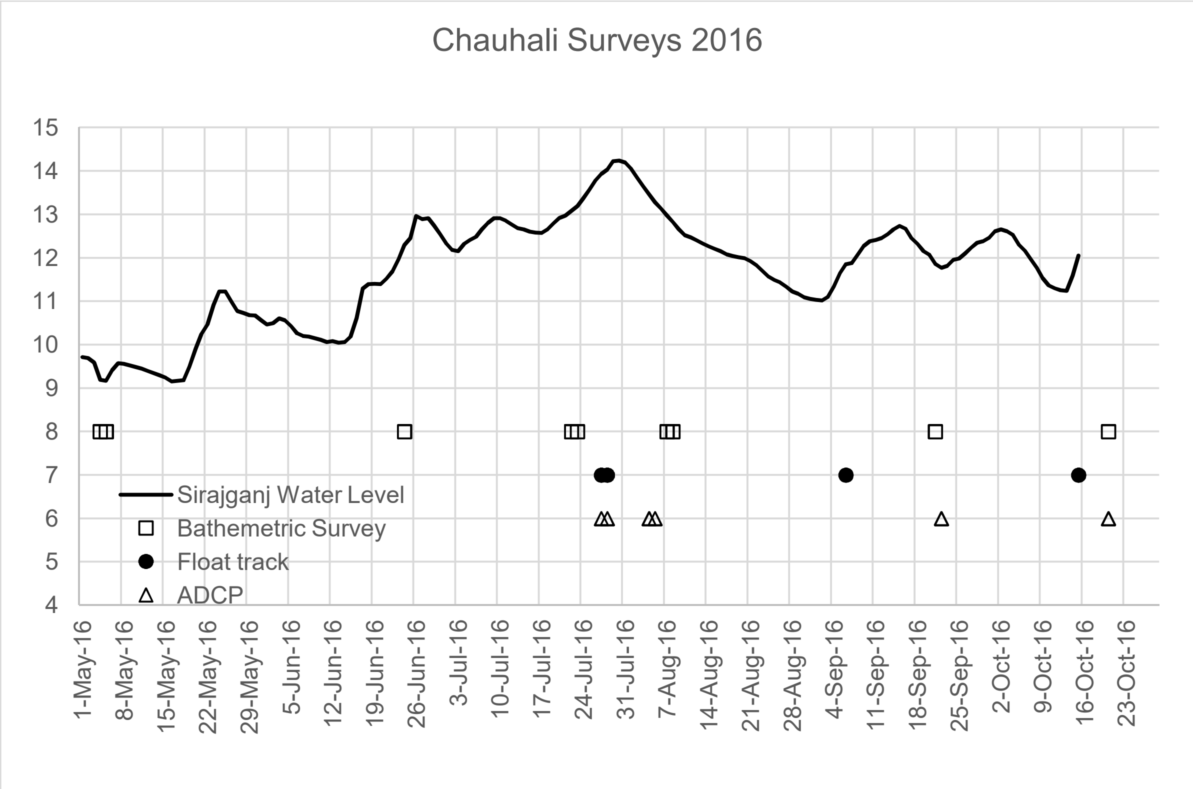
		2016/2017				2017/18		
		Launched		Not launched		Expected development		Required quantities
Site	Component	Launched length	Av. Launched height	Not launched length	Av. Bed elevation	Exp. Launching height	Exp. Launching length	Total
Chauhali	Work 2015/16	4,200	9.1	1,900	-1.5	13.5	1,900	237,500
	Upstream extension			4,000	-3	5	4,000	540,000
	Downstream extension			2,500	-3	7	2,500	320,000
Hariram pur	Work 2015/16	1,400	6.6	7,400	-4.2	10	7,400	984,200
Zafarganj	Work 2015/16	0	0	0	0	0	0	0
Total								**2,081,700**

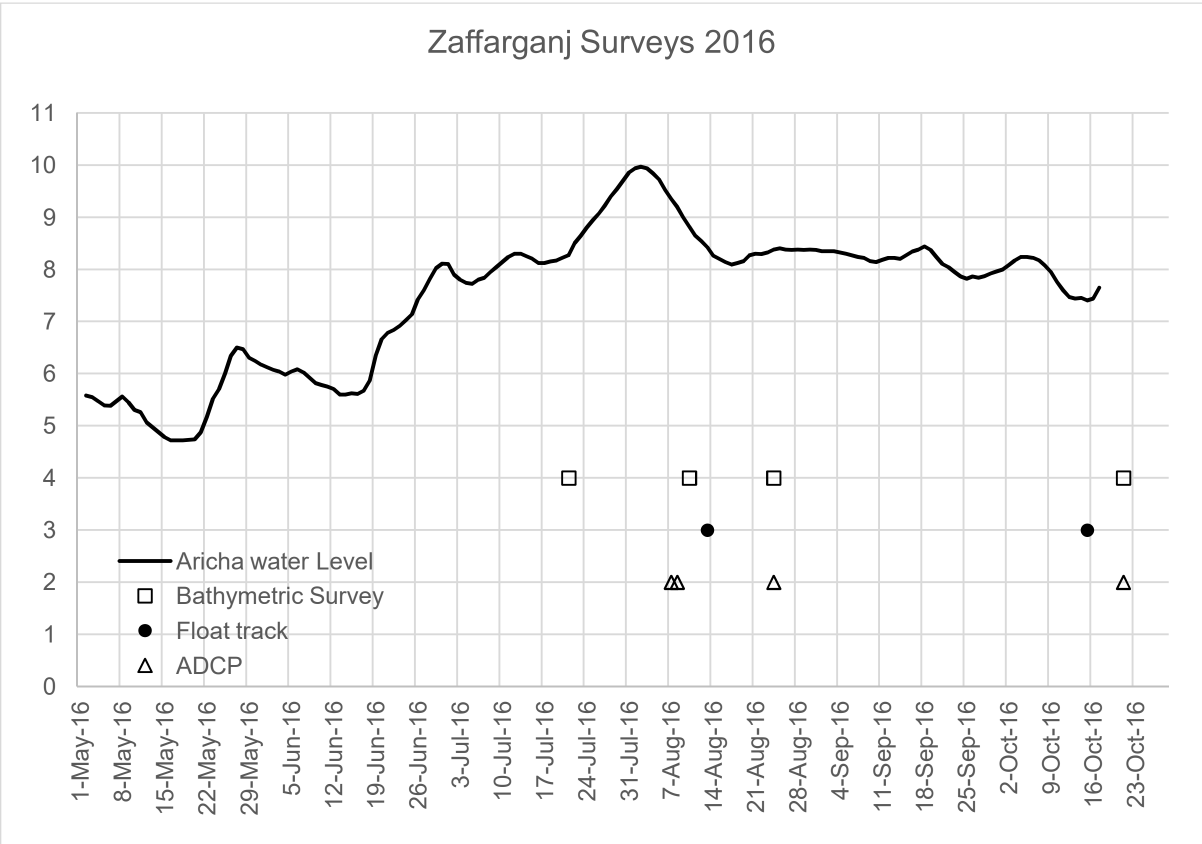
In Zafarganj, no launching was observed in 2016/17 and models show that the deep channel moves further away from Zafarganj, so no launching is expected in the next season.

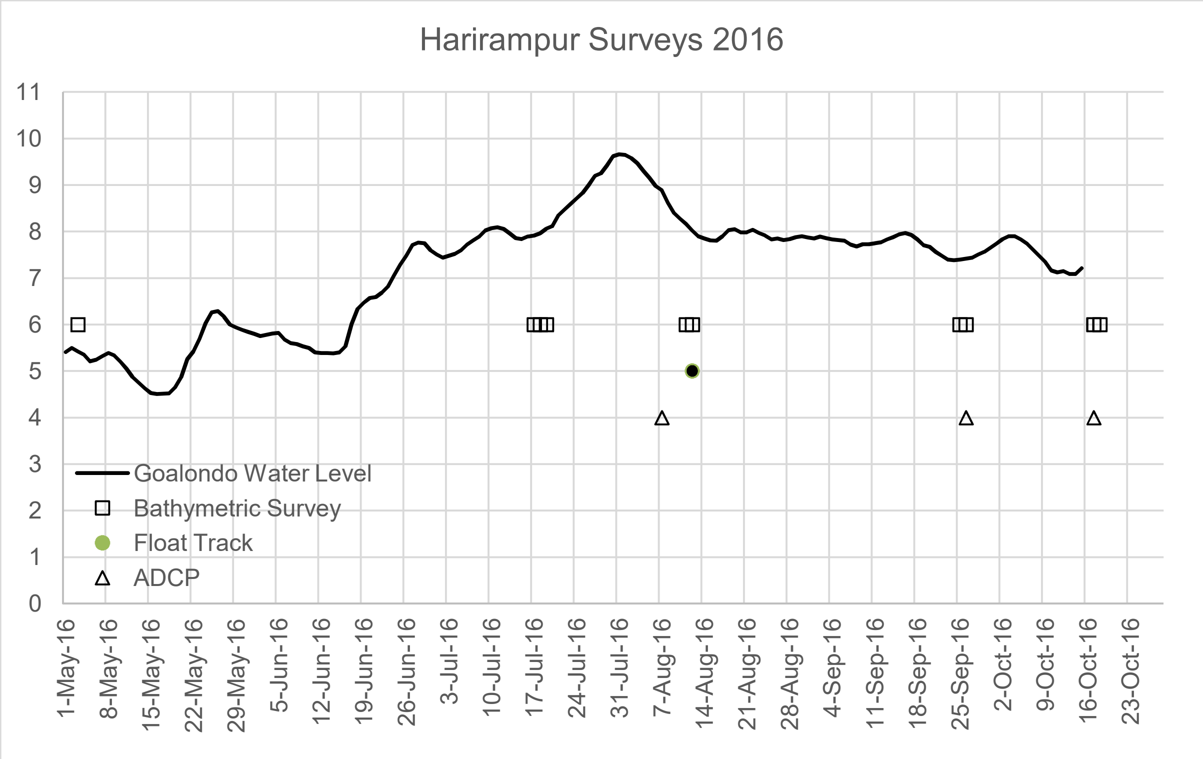
Depending on the 2017 flood, the required adaptation works may change.

Appendices

1 Summary Site Surveys






Harirampur Surveys 2016
11
10
9
8
7
6
5
4
3
2
1
0
Goalondo Water Level
Bathymetric Survey
Float Track
ADCP
1-May-16
8-May-16
15-May-16
22-May-16
29-May-16
5-Jun-16
12-Jun-16
19-Jun-16
26-Jun-16
3-Jul-16
10-Jul-16
17-Jul-16
24-Jul-16
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21-Aug-16
28-Aug-16
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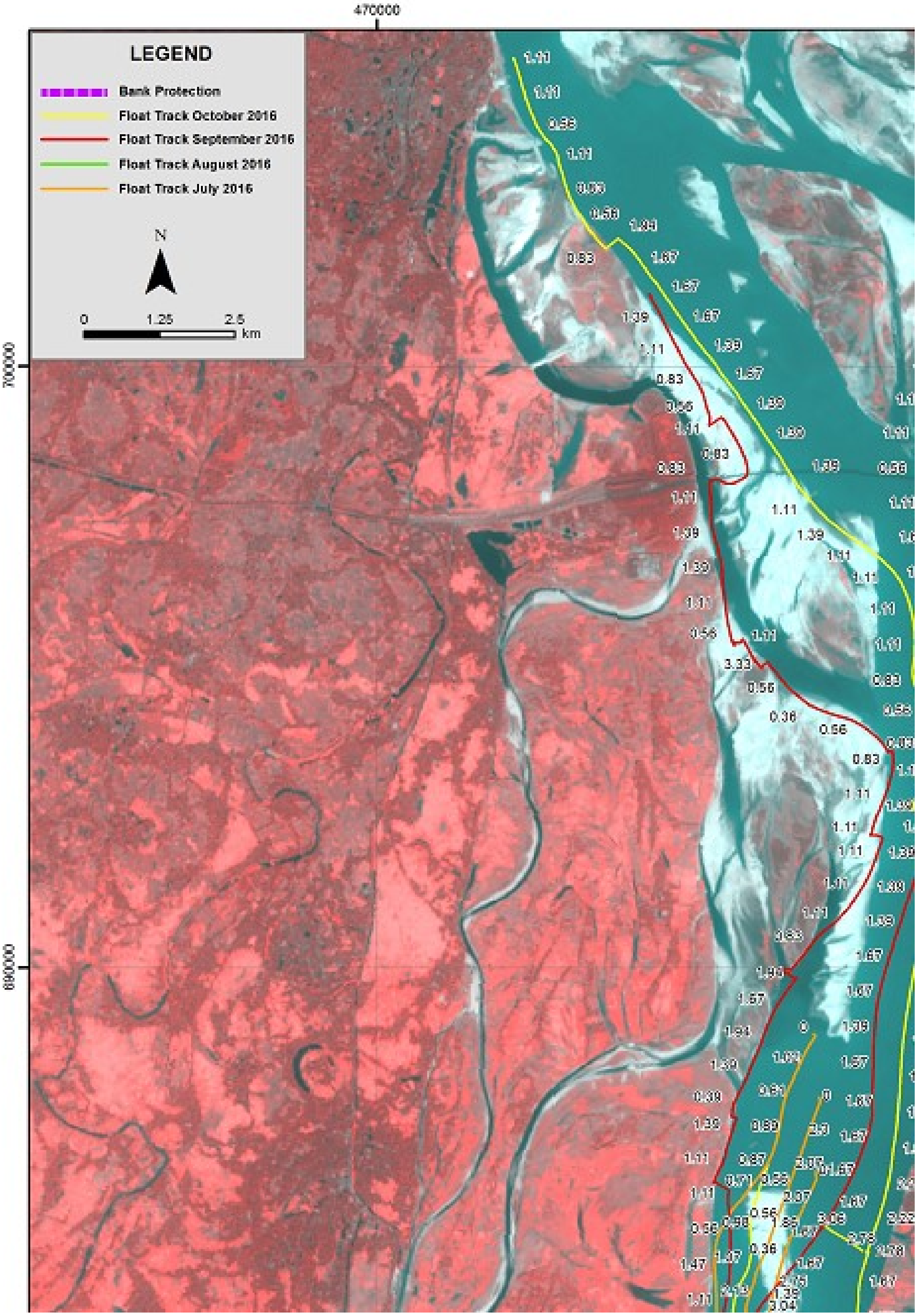
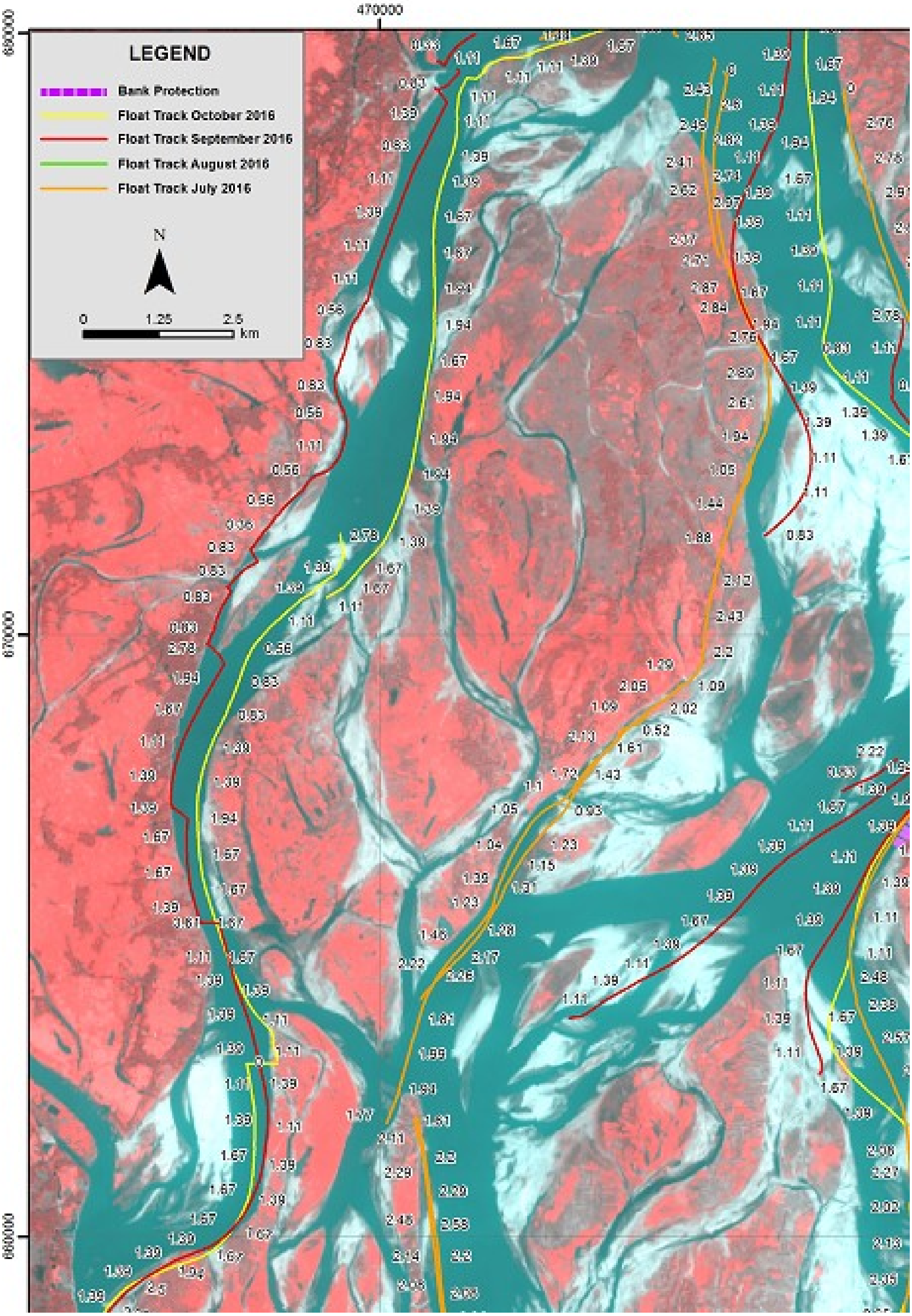
25-Sep-16
2-Oct-16
9-Oct-16
16-Oct-16
23-Oct-16

2 Float tracking




LEGEND
Bank Protection
Float Track October 2016
Float Track September 2016
Float Track August 2016
Float Track July 2016
N
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1.25
2.5
km
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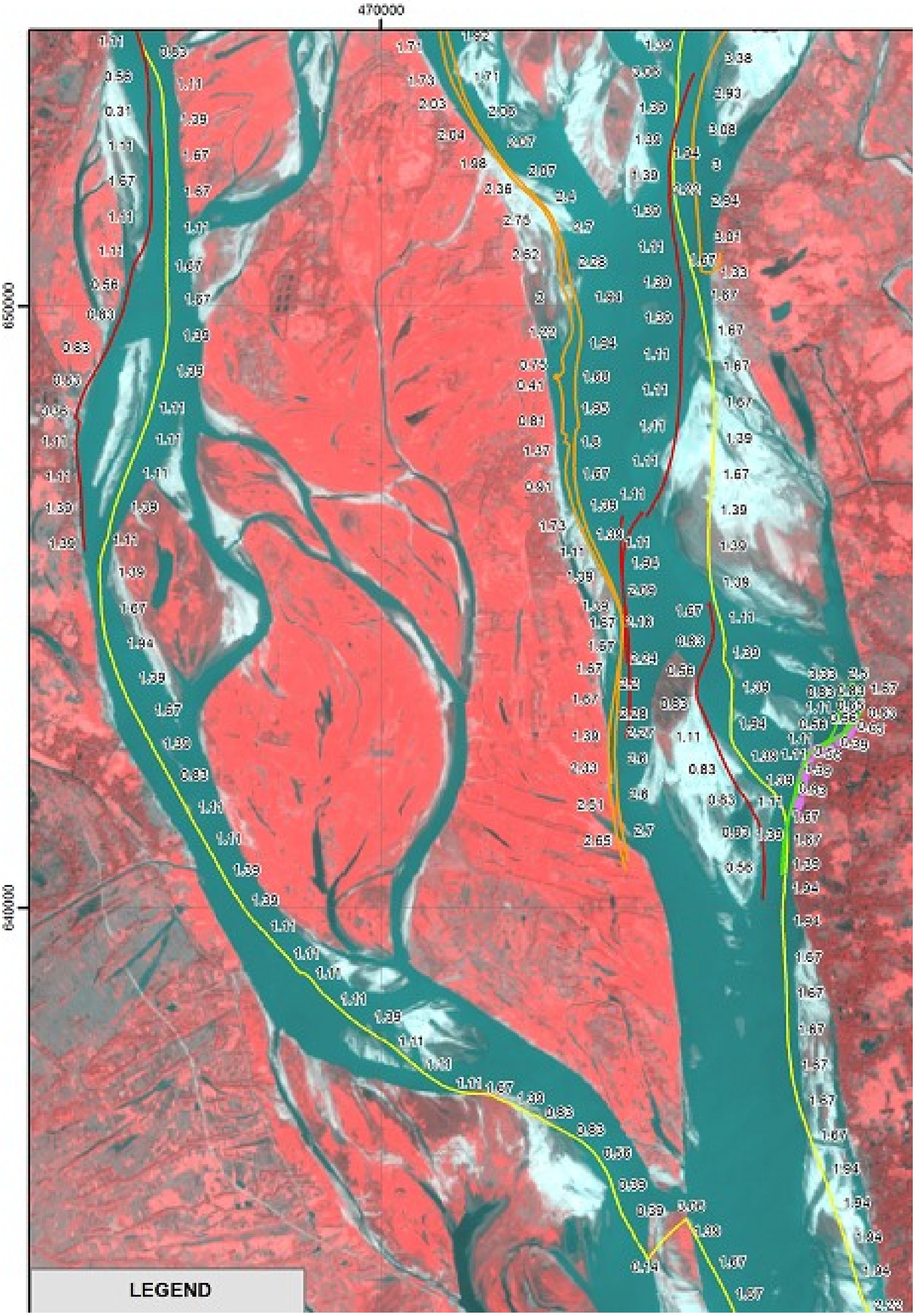
680000
670000
660000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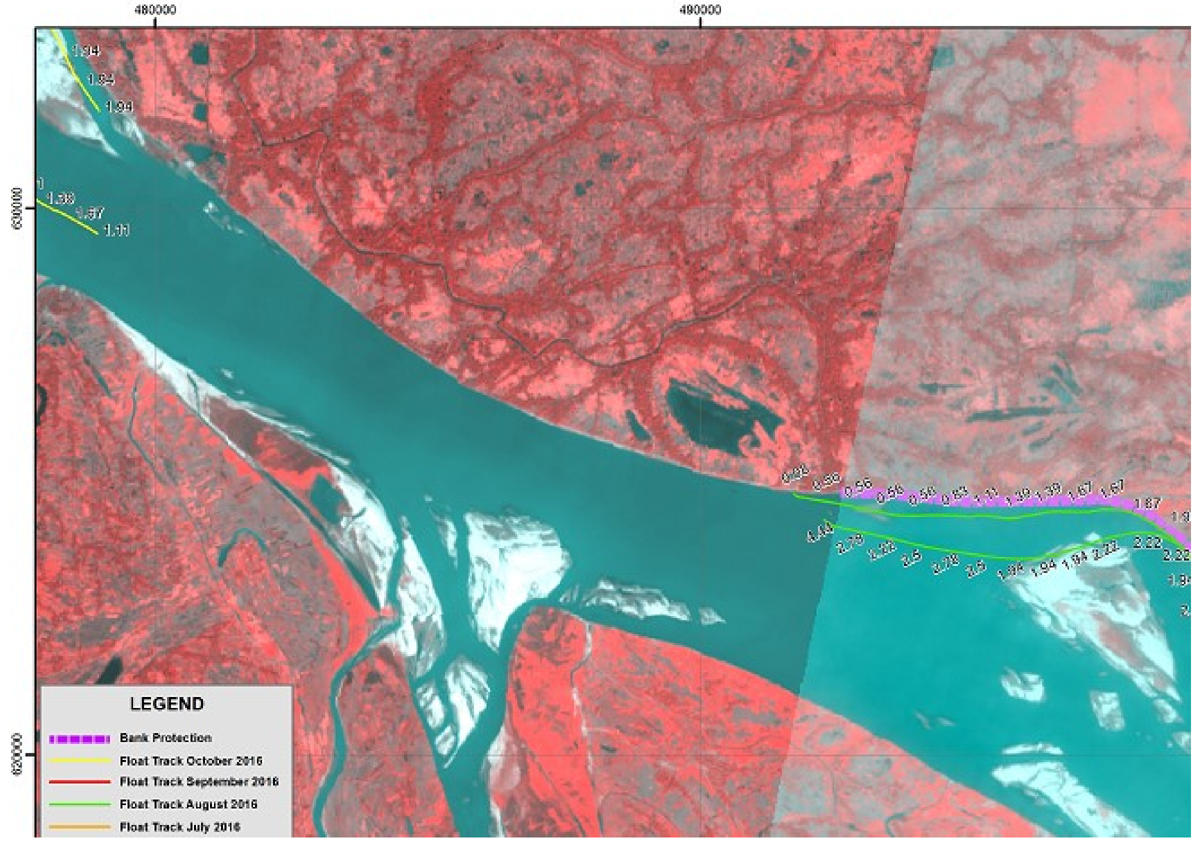
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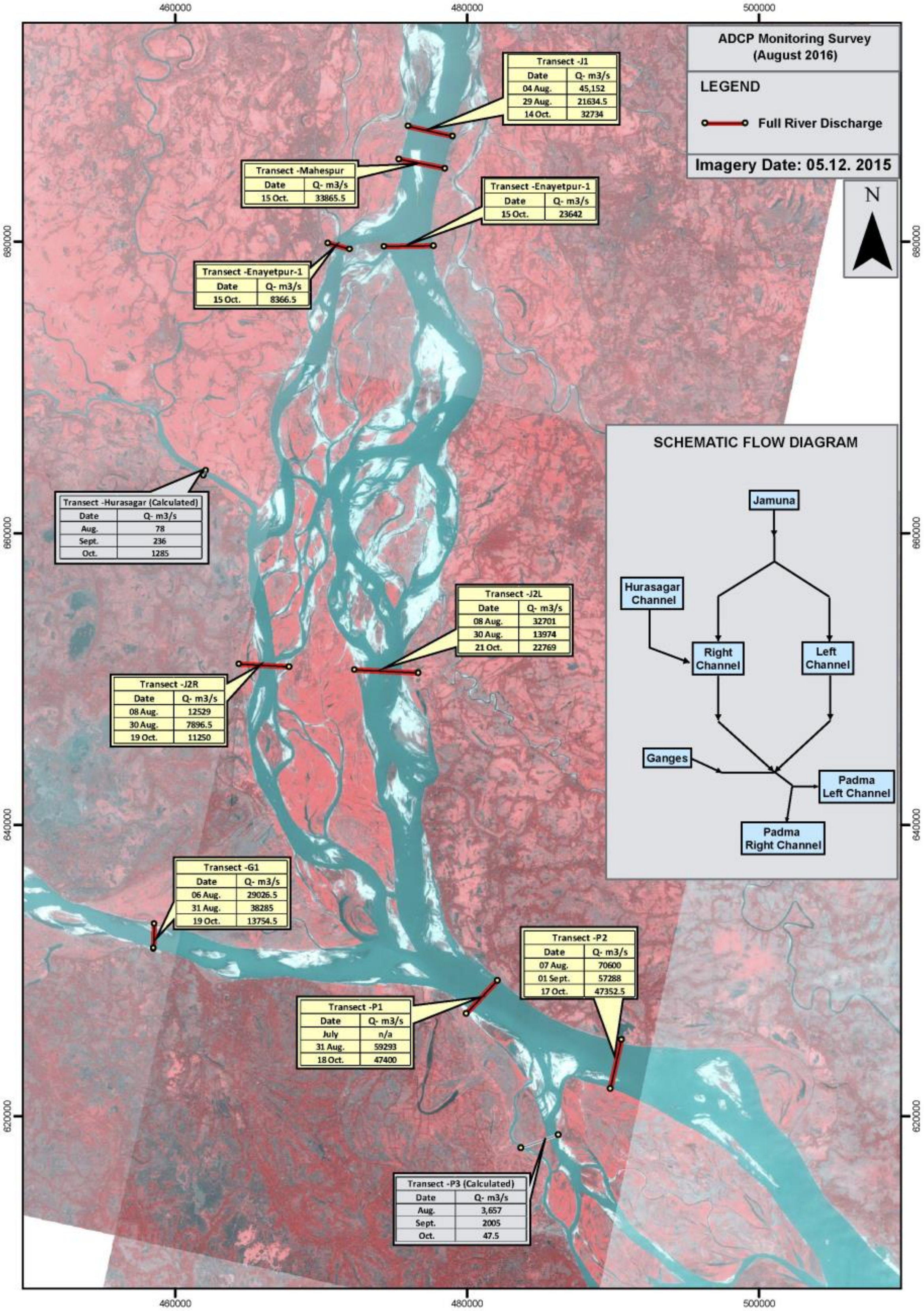
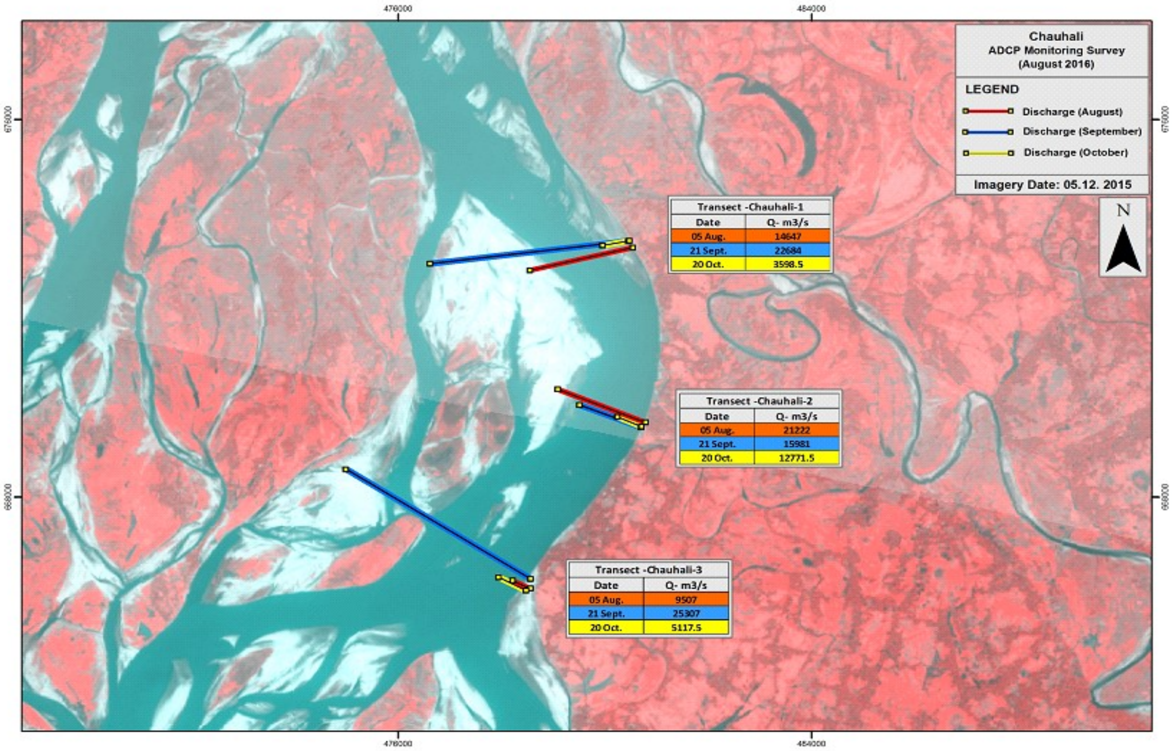
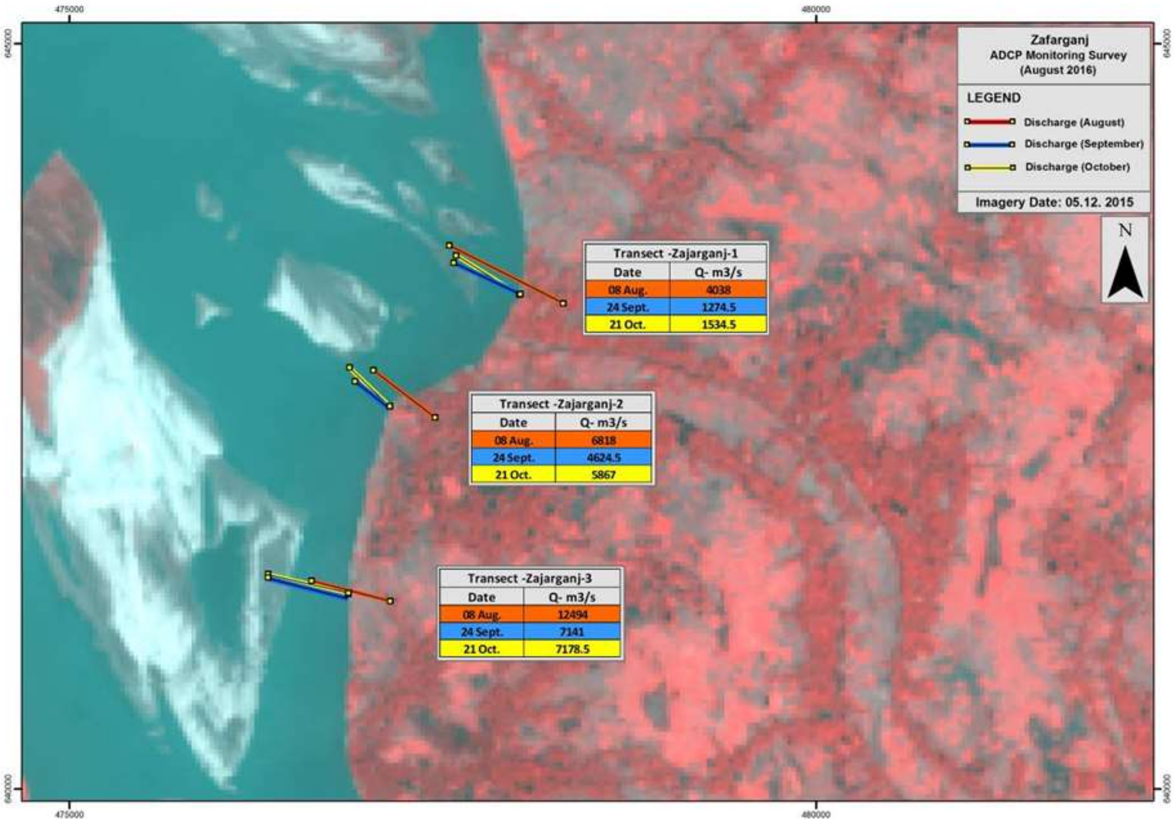
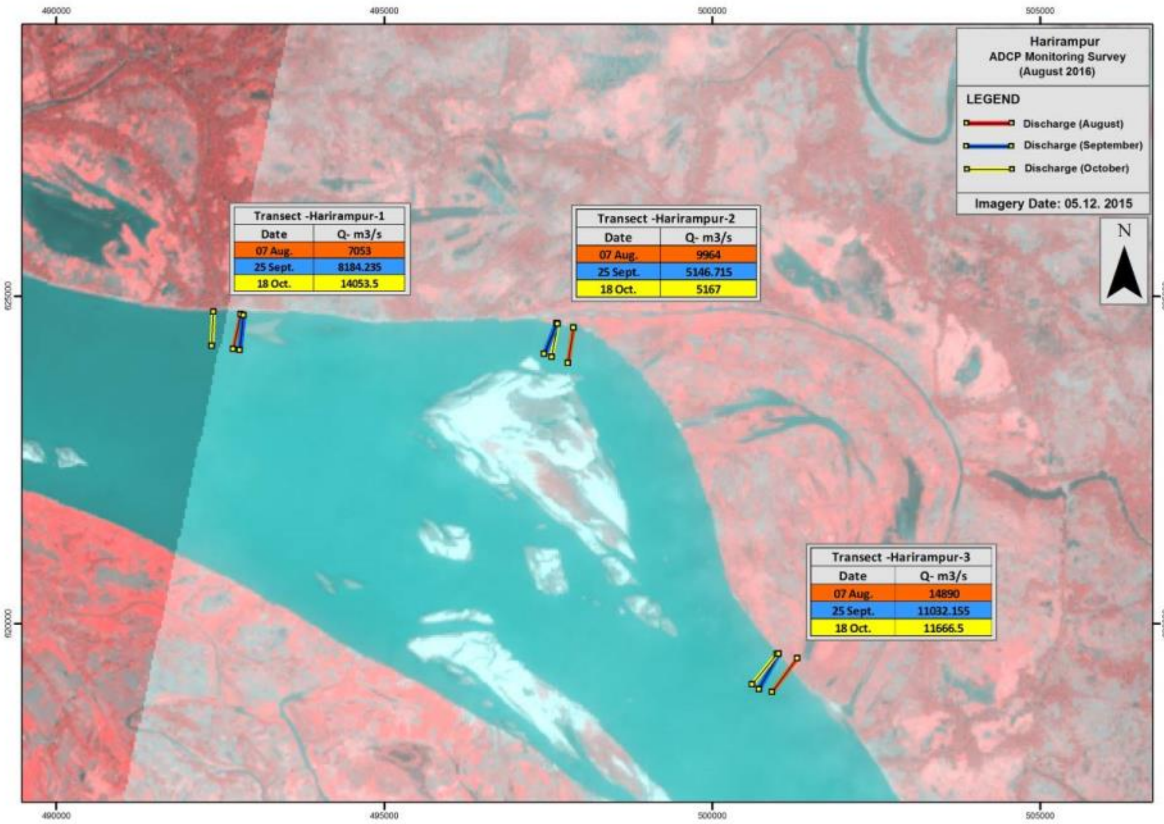
630000
620000
LEGEND
Bank Protection
Float Track October 2016
Float Track September 2016
Float Track August 2016
Float Track July 2016

3 Discharge Measurements




Chauhali
ADCP Monitoring Survey
(August 2016)
LEGEND
Discharge (August)
Discharge (September)
Discharge (October)
Imagery Date: 05.12. 2015
N
Transect -Chauhali-1
Date
Q- m3/s
05 Aug.
14647
21 Sept.
22684
20 Oct.
3598.5
Transect -Chauhali-2
Date
Q- m3/s
05 Aug.
21222
21 Sept.
15981
20 Oct.
12771.5
Transect -Chauhali-3
Date
Q- m3/s
05 Aug.
9507
21 Sept.
25307
20 Oct.
5117.5


Zafarganj
ADCP Monitoring Survey
(August 2016)
LEGEND
Discharge (August)
Discharge (September)
Discharge (October)
Imagery Date: 05.12. 2015
N
Transect -Zajarganj-1
Date
Q- m3/s
08 Aug.
4038
24 Sept.
1274.5
21 Oct.
1534.5
Transect -Zajarganj-2
Date
Q- m3/s
08 Aug.
6818
24 Sept.
4624.5
21 Oct.
5867
Transect -Zajarganj-3
Date
Q- m3/s
08 Aug.
12494
24 Sept.
7141
21 Oct.
7178.5



Harirampur
ADCP Monitoring Survey
(August 2016)
LEGEND
Discharge (August)
Discharge (September)
Discharge (October)
Imagery Date: 05.12. 2015
N
Transect -Harirampur-1
Date
Q- m3/s
07 Aug. 7053
25 Sept. 8184.235
18 Oct. 14053.5
Transect -Harirampur-2
Date
Q- m3/s
07 Aug. 9964
25 Sept. 5146.715
18 Oct. 5167
Transect -Harirampur-3
Date
Q- m3/s
07 Aug. 14890
25 Sept. 11032.155
18 Oct. 11666.5
490000
495000
500000
505000
625000
620000

4 Survey quality

4.1 Chauhali

Survey Date	Parameter	Comments
October 29,2015 to November 3, 2015	Status	Accepted
	Survey interval	15m
	Survey length	10.6km
	Survey coverage towards river	530m
	Data missing	Nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Single beam single frequency
	Data density	76 points per m^2
	Spikes	Nil
May 4-5,2016	Status	Accepted
	Survey interval	50m
	Survey length	7km
	Survey coverage towards river	300m
	Data missing	Nil
	Boat direction	R/S to C/S, C/S to R/S; meandering pattern
	Echo sounder & frequency	Single beam single frequency
	Data density	25 points per m^2
	Spikes	Nil
June 24,2016	Status	Accepted
	Survey interval	50m
	Survey length	3.5km
	Survey coverage towards river	200m
	Data missing	Nil
	Boat direction	R/S to C/S, C/S to R/S; meandering pattern
	Echo sounder & frequency	Single beam single frequency
	Data density	9.7 points per m^2
	Spikes	Nil
July 22-23,2016	Status	Not used
	Survey interval	na
	Survey length	na
	Survey coverage towards river	na
	Data missing	Over Apron area and bankline
	Boat direction	na
	Echo sounder & frequency	Single beam single frequency
	Data density	na
	Spikes	Nil
	Reason for rejection	Significant amount of data gap was observed over apron area and near bankline. During triangulation it generates wrong elevation.
August 7-8, 2016	Status	Accepted
	Survey interval	100m
	Survey length	7.8km
	Survey coverage towards river	380m
	Data missing	Nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Single beam dual frequency
	Data density	21 points per m^2
	Spikes	Nil
September 21,2016	Status	Used for Contour but not used in cross section
	Survey interval	200m along even no section

Survey Date	Parameter	Comments
	Survey length	8.4km
	Survey coverage towards river	390m
	Data missing	Nil
	Boat direction	R/S to C/S, C/S to R/S; meandering pattern
	Echo sounder & frequency	Single beam dual frequency
	Data density	35 points per m^2
	Spikes	Two spikes. One spike was observed near 4.6 to 4.0 station, distance from bankline was 250m. Another spike was near 3.6 to 3.4 station. Distance from bankline is 290m.
	Reason for rejection	Surveyor surveyed along even no section. But all other survey was conducted either 50 or 100m interval or along odd no section. So when we use this data in civil 3d cross section it gives a wrong elevation information with respect to other surveys. So not to confuse the viewer and as this data is not required for adaptation we did not include this survey in cross section but it is added in contour.
October	Status	Accepted
	Survey interval	200m along odd no station
	Survey length	8.4km
	Survey coverage towards river	390m
	Data missing	Nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Single beam dual frequency
	Data density	10 points per m^2
	Spikes	Nil

4.2 Zafarganj

Survey Date	Parameter	Comments
January 26,2016	Status	Accepted
	Survey interval	50m
	Survey length	3km
	Survey coverage towards river	360m
	Data missing	Nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Single beam single frequency
	Data density	14 points per m^2
	Spikes	Nil
May 5,2016	Status	Rejected
	Survey interval	na
	Survey length	3km
	Survey coverage towards river	na
	Data missing	na
	Boat direction	na
	Echo sounder & frequency	Single beam single frequency
	Data density	na
	Spikes	Nil
	Reason for rejection	Surveyor lost their ground reference. Maximum points near bend area were shifted

Survey Date	Parameter	Comments
		along 200 to 300m as they lost their ground reference they did not manage to provide us correct data.
July 21,2016	Status Survey interval Survey length Survey coverage towards river Data missing Boat direction Echo sounder & frequency Data density Spikes	Accepted 100m 3km 380m Nil R/S to C/S Single beam single frequency 13 points per m^2 Nil
August 10,2016	Status Survey interval Survey length Survey coverage towards river Data missing Boat direction Echo sounder & frequency Data density Spikes	Accepted 100m 3km 380m Nil R/S to C/S Single beam dual frequency 32 points per m^2 Nil
September 24,2016	Status Survey interval Survey length Survey coverage towards river Data missing Boat direction Echo sounder & frequency Data density Spikes	Accepted 200m 2.5km 370km na R/S to C/S Single beam dual frequency 17 points per m^2 Nil
October 4,2016	Status Survey interval Survey length Survey coverage towards river Data missing Boat direction Echo sounder & frequency Data density Spikes	Accepted 200m 2.4km 360km na R/S to C/S Single beam dual frequency 10 points per m^2 Nil

4.3 Harirampur

Survey Date	Parameter	Comment
December 28,2015 to January 03, 2016	Status	Accepted
	Survey interval Survey length Survey coverage towards river	100m 12km 300m

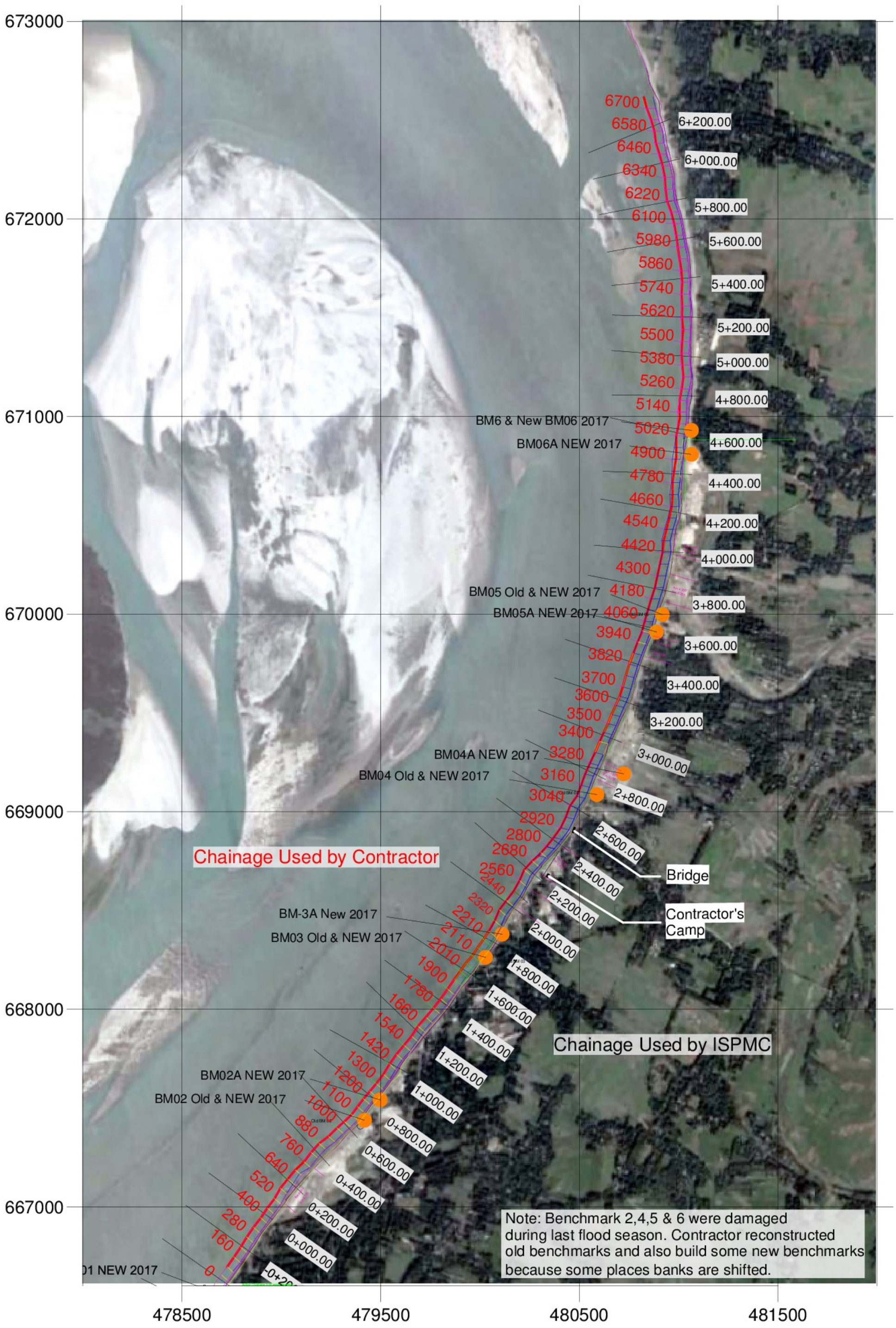
Survey Date	Parameter	Comment
	Data missing	Nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Single beam single frequency
	Data density	22 points per m^2
	Spikes	
April 11,2016	Status	Accepted
	Survey data interval	Average 50m
	Survey length	2.1km
	Survey coverage towards river	Average 250m
	Data missing	Nil
	Boat direction	R/S to C/S, C/S to R/S; meandering pattern
	Echo sounder & frequency	Single beam single frequency
	Data density	24 points per m^2
	Spikes	Nil
June 05,2016	Status	Accepted
	Survey interval	Average 50m
	Survey length	10.4km
	Survey coverage towards river	Average 350m
	Data missing	Nil
	Boat direction	R/S to C/S, C/S to R/S; meandering pattern
	Echo sounder & frequency	Single beam single frequency
	Data density	13 points per m^2
	Spikes	Nil
July 17-19,2016	Status	Accepted
	Survey interval	100m
	Survey length	11.8km
	Survey coverage towards river	390m
	Data missing	Nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Single beam single frequency
	Data density	26 points per m^2
	Spikes	Nil
August 11-12, 2016	Status	Accepted
	Survey interval	200m after chainage 0+100
	Survey length	11.6km
	Survey coverage towards river	380m
	Data missing	Nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Single beam dual frequency
	Data density	23 points per m^2
	Spikes	Nil
September 25-26, 2016	Status	Accepted
	Survey interval	200m after chainage 0+100
	Survey length	11.6km
	Survey coverage towards river	350m
	Data missing	Nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Single beam dual frequency
	Data density	16 points per m^2
	Spikes	Nil
October 17-18, 2016	Status	Accepted
	Survey interval	200m after chainage 0+100
	Survey length	11.8km
	Survey coverage towards river	340m

Survey Date	Parameter	Comment
	Data missing	Nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Single beam dual frequency
	Data density	8.9 points per m^2
	Spikes	Nil

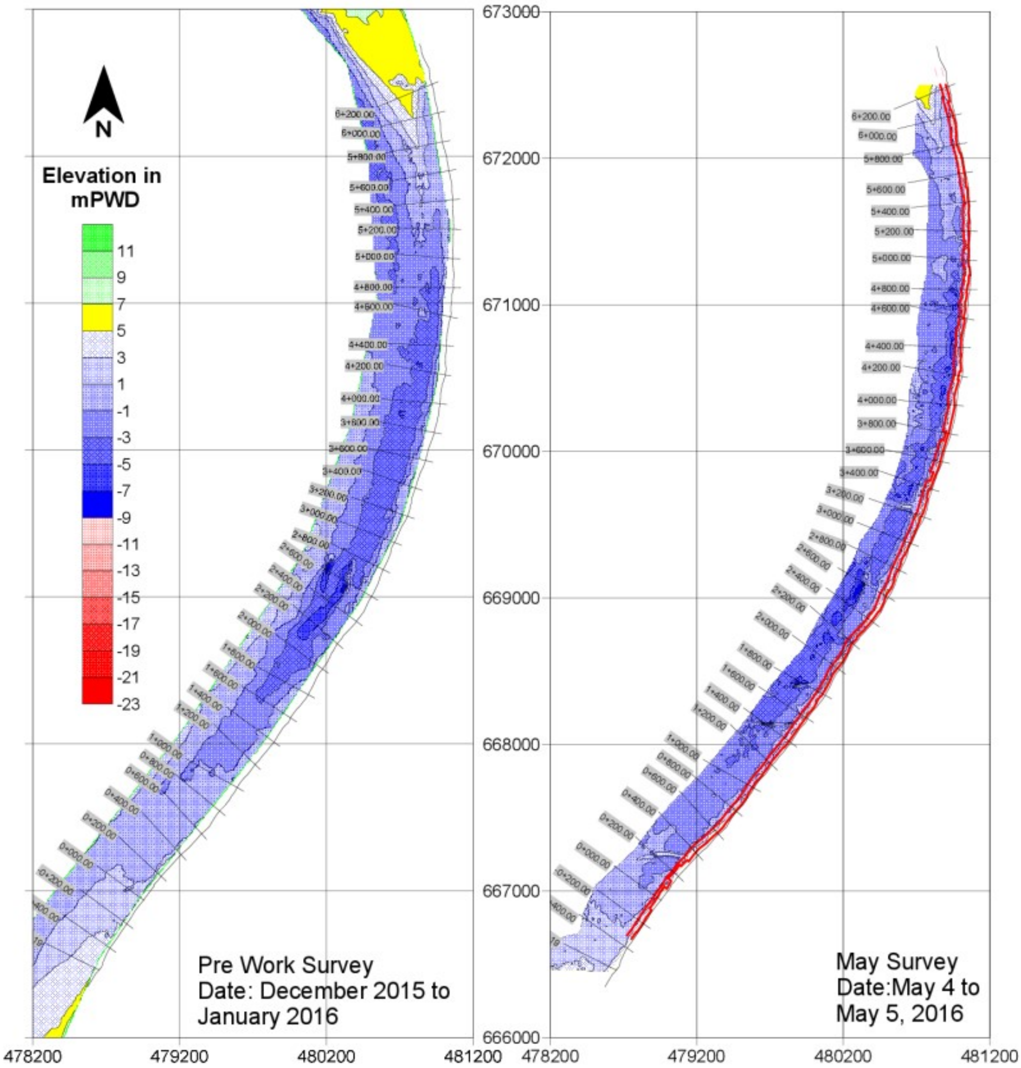
5 Bathymetric Surveys

5.1 Chauhali

Chauhali Benchmark & Chainage Location

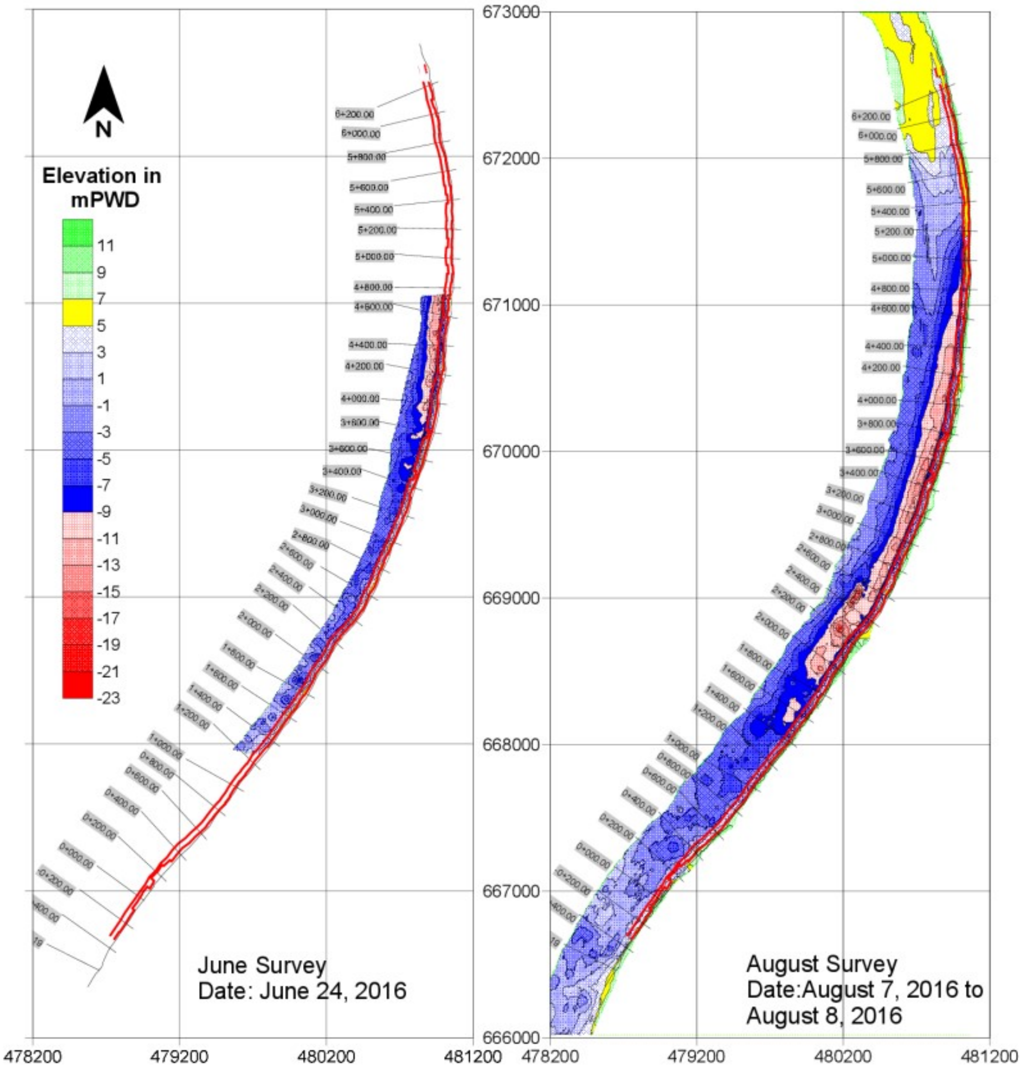


Chauhali Bathymetric Survey, Pre Work 2015-16 & May 2016



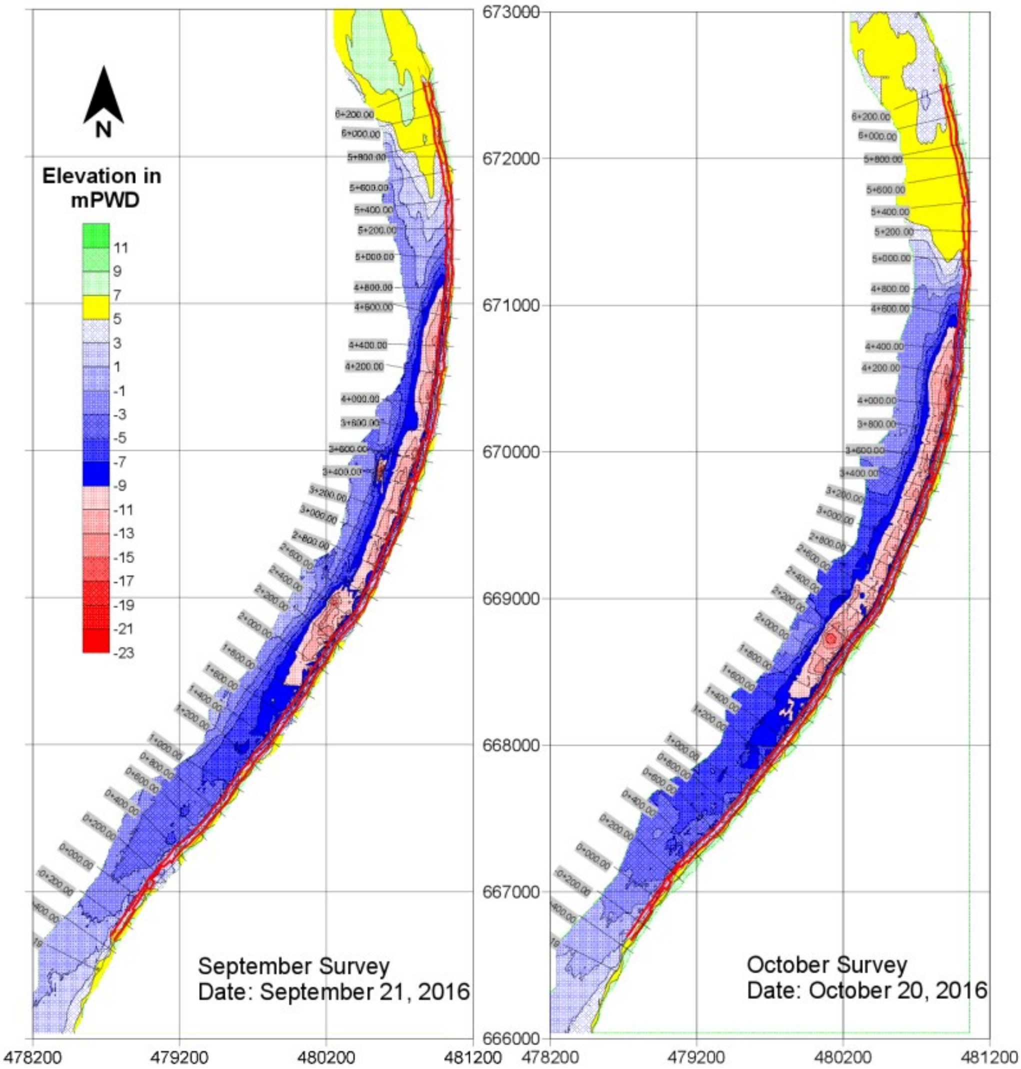
Legend:
Dumping Line

Chauhali Bathymetric Survey, June & August 2016



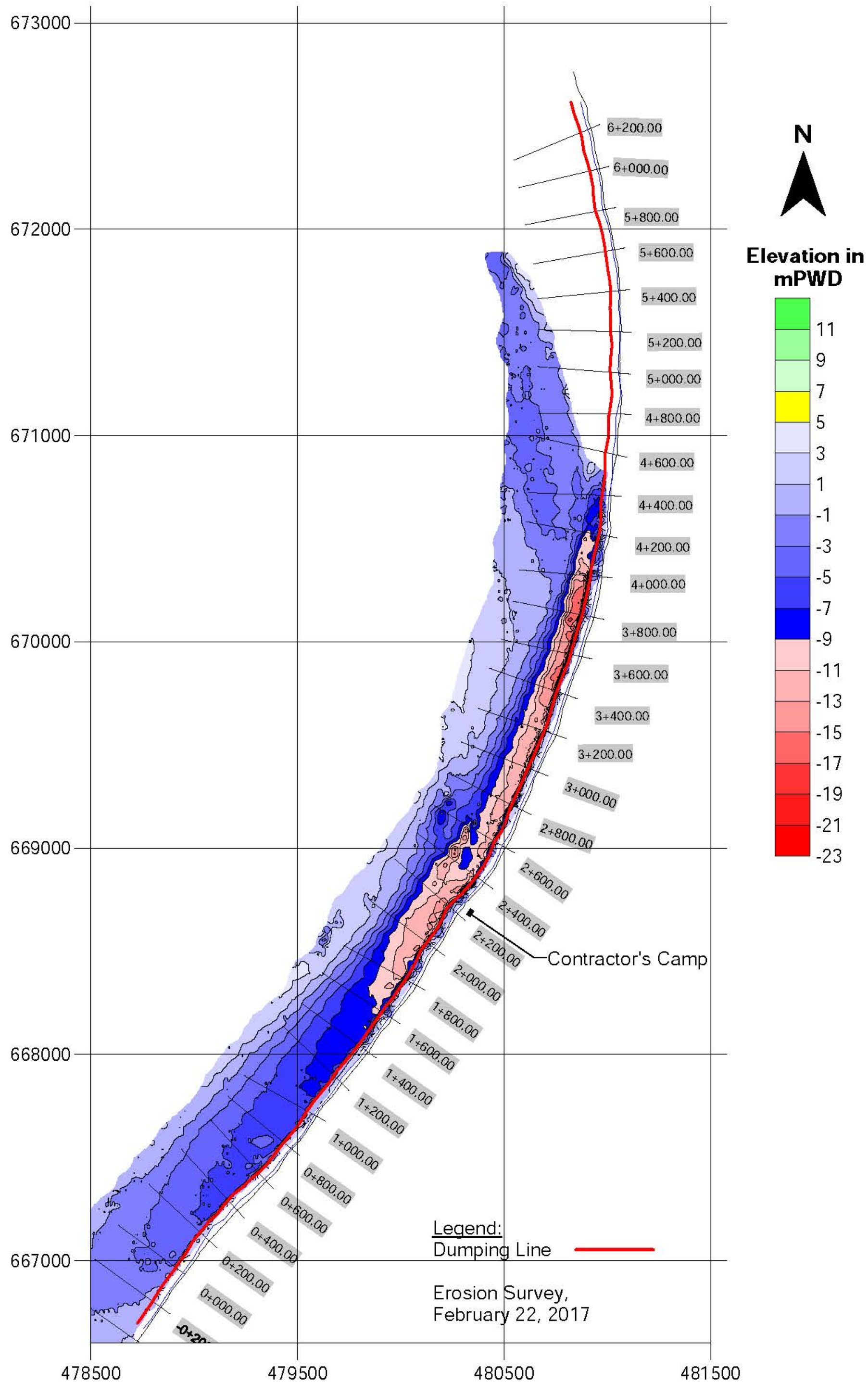
Legend:
Dumping Line

Chauhali Bathymetric Survey, September & October 2016

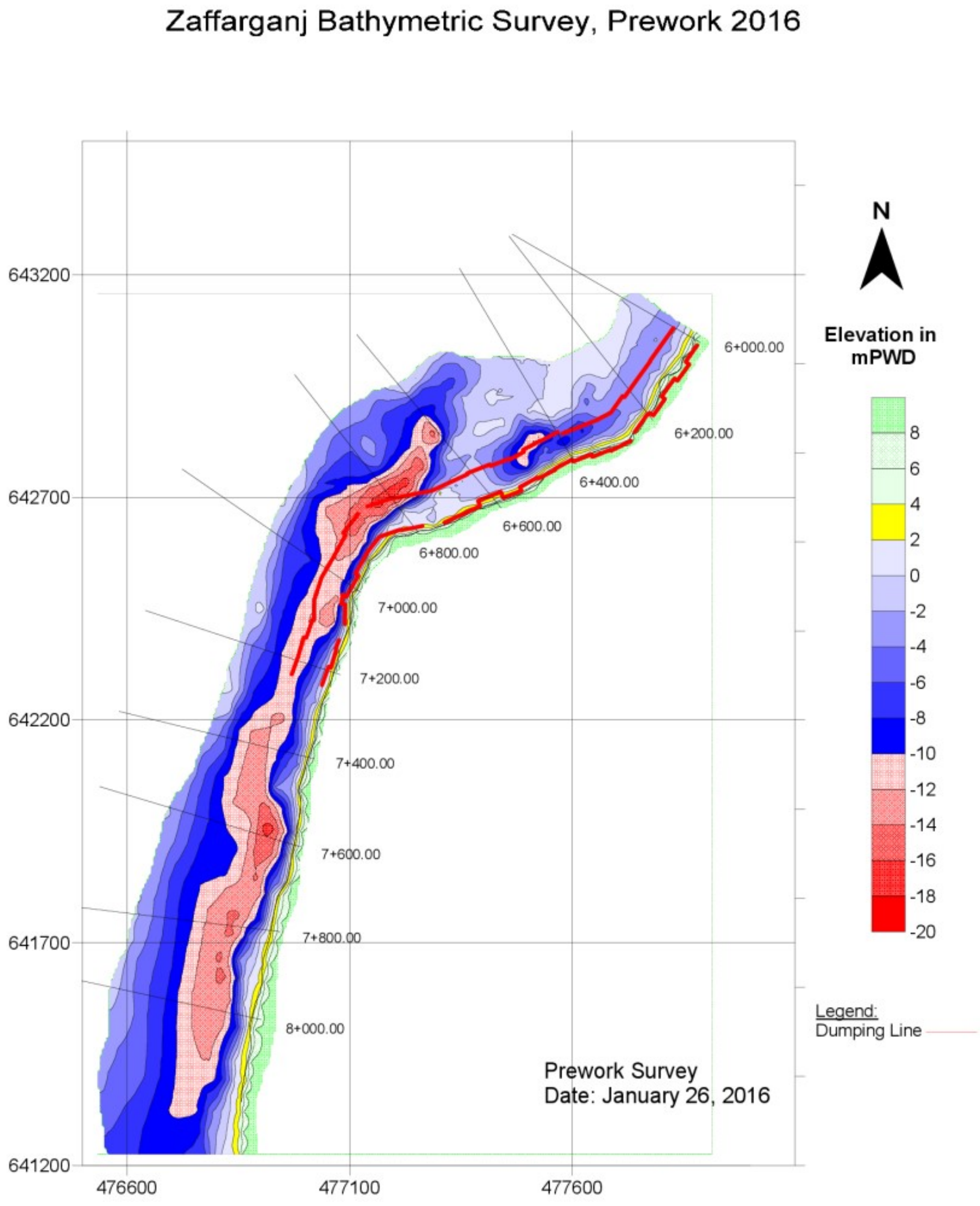


Legend:
Dumping Line

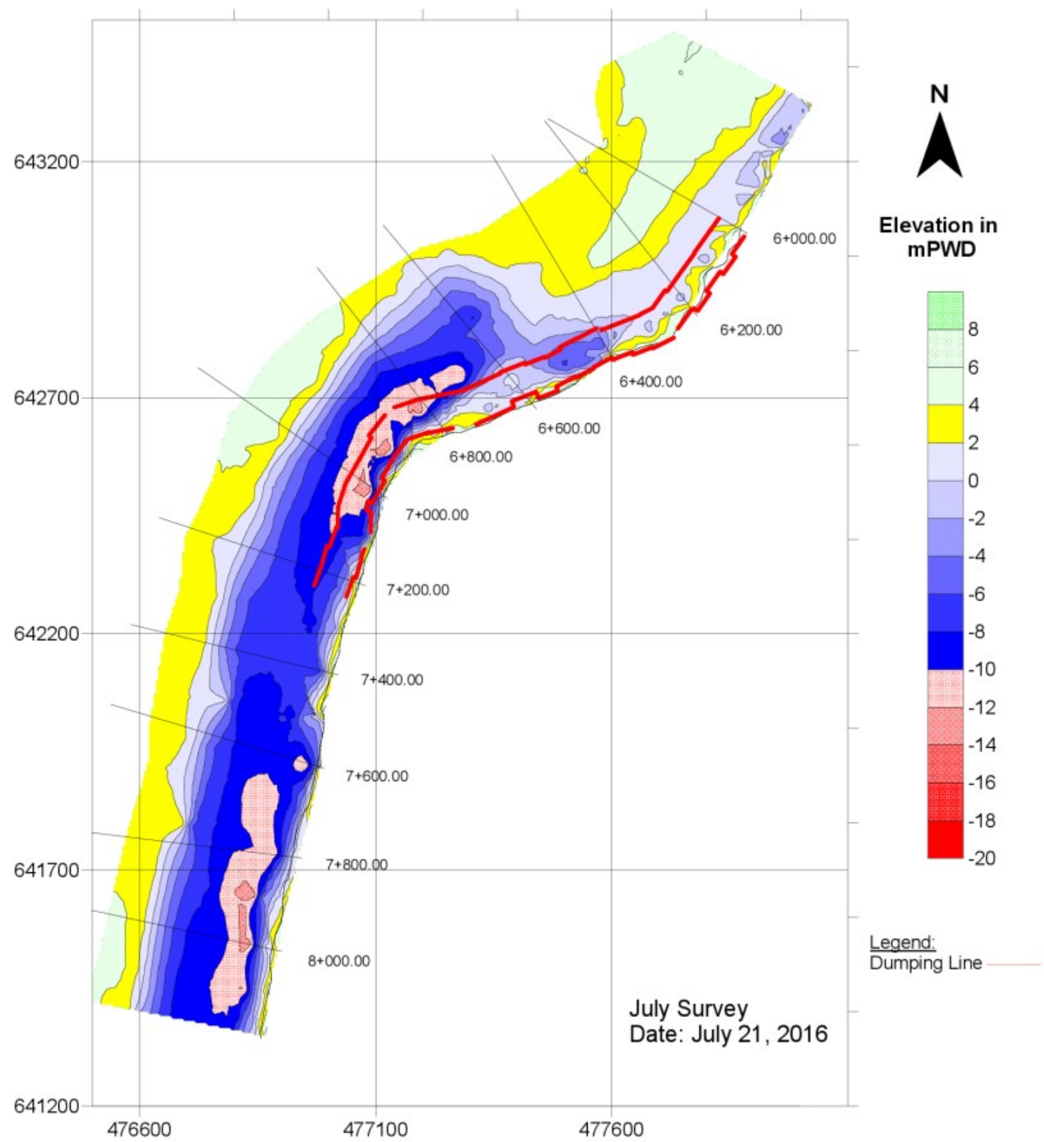
Chauhali Survey, February 2017



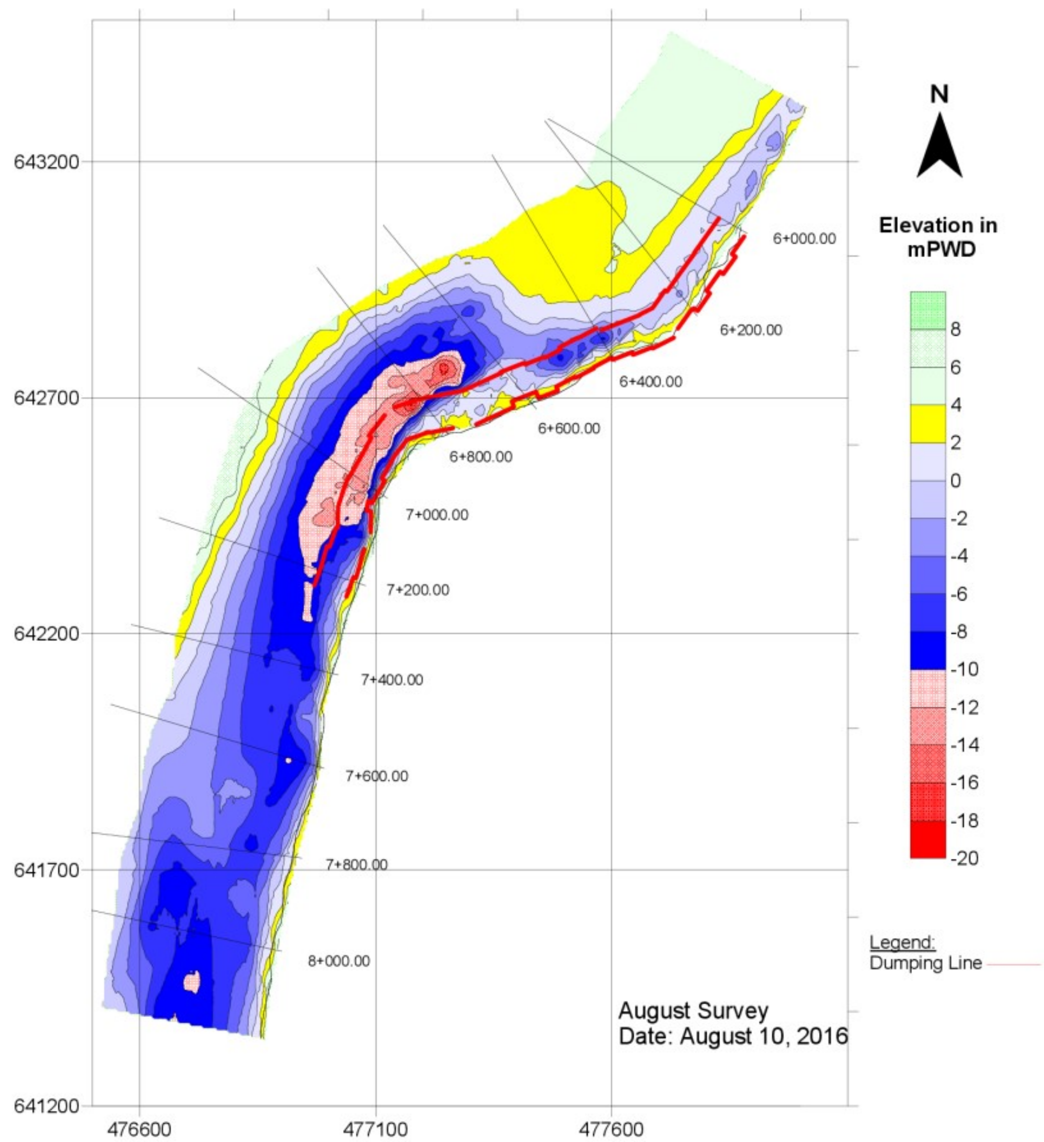
5.2 Zafarganj



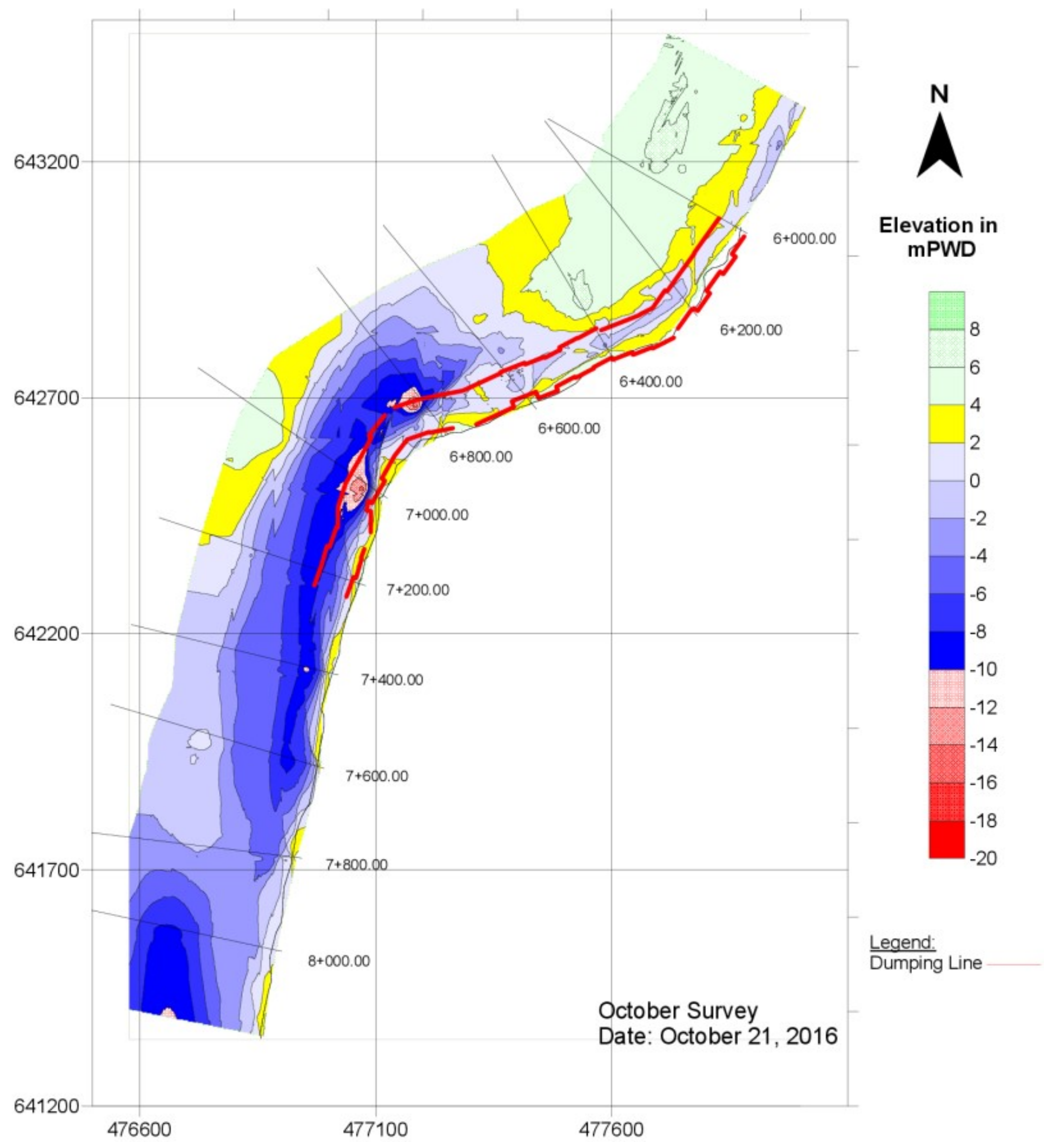
Zaffarganj Bathymetric Survey, July 2016



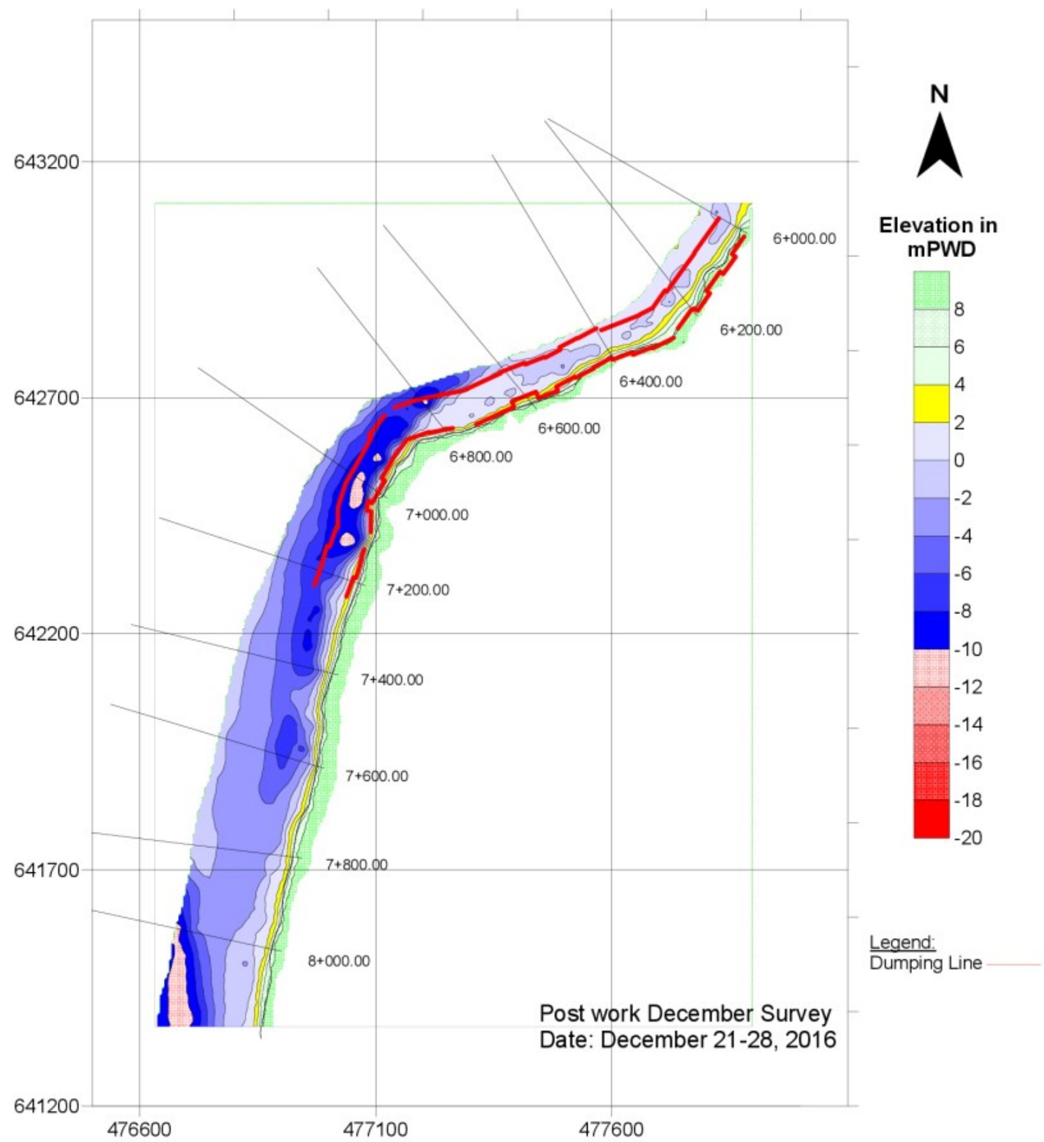
Zaffarganj Bathymetric Survey, August 2016



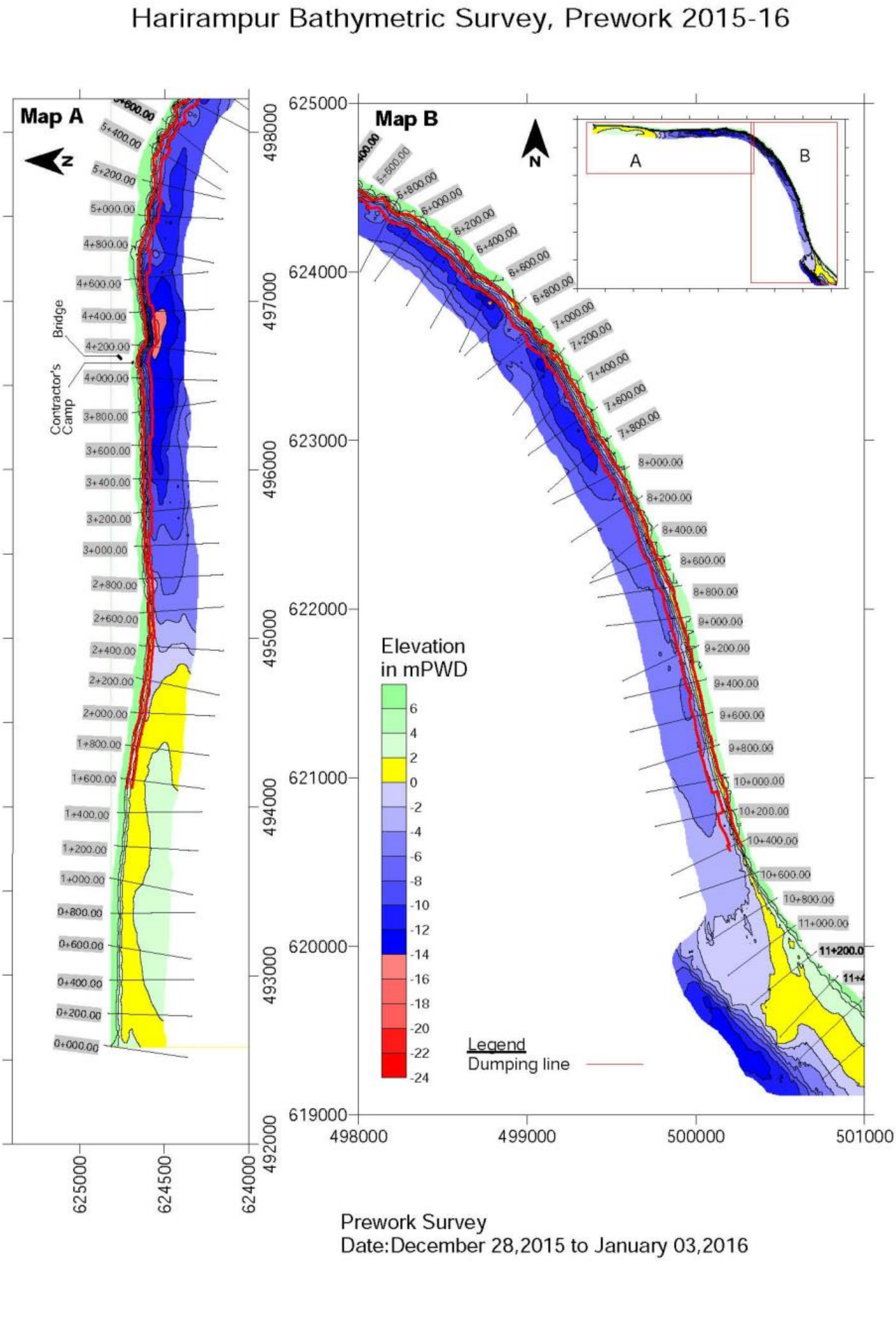
Zaffarganj Bathymetric Survey, October 2016



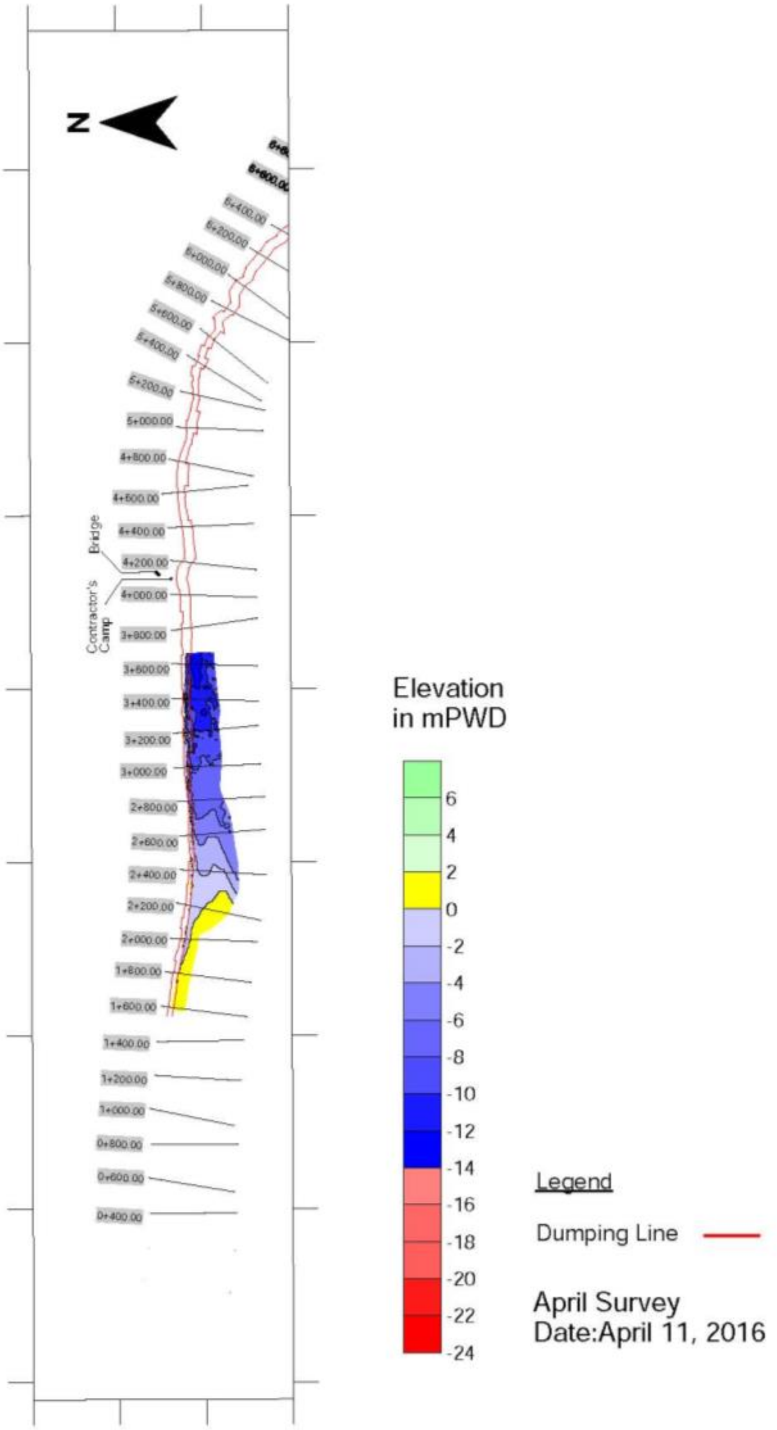
Zaffarganj Bathymetric Survey, Post work December 2016



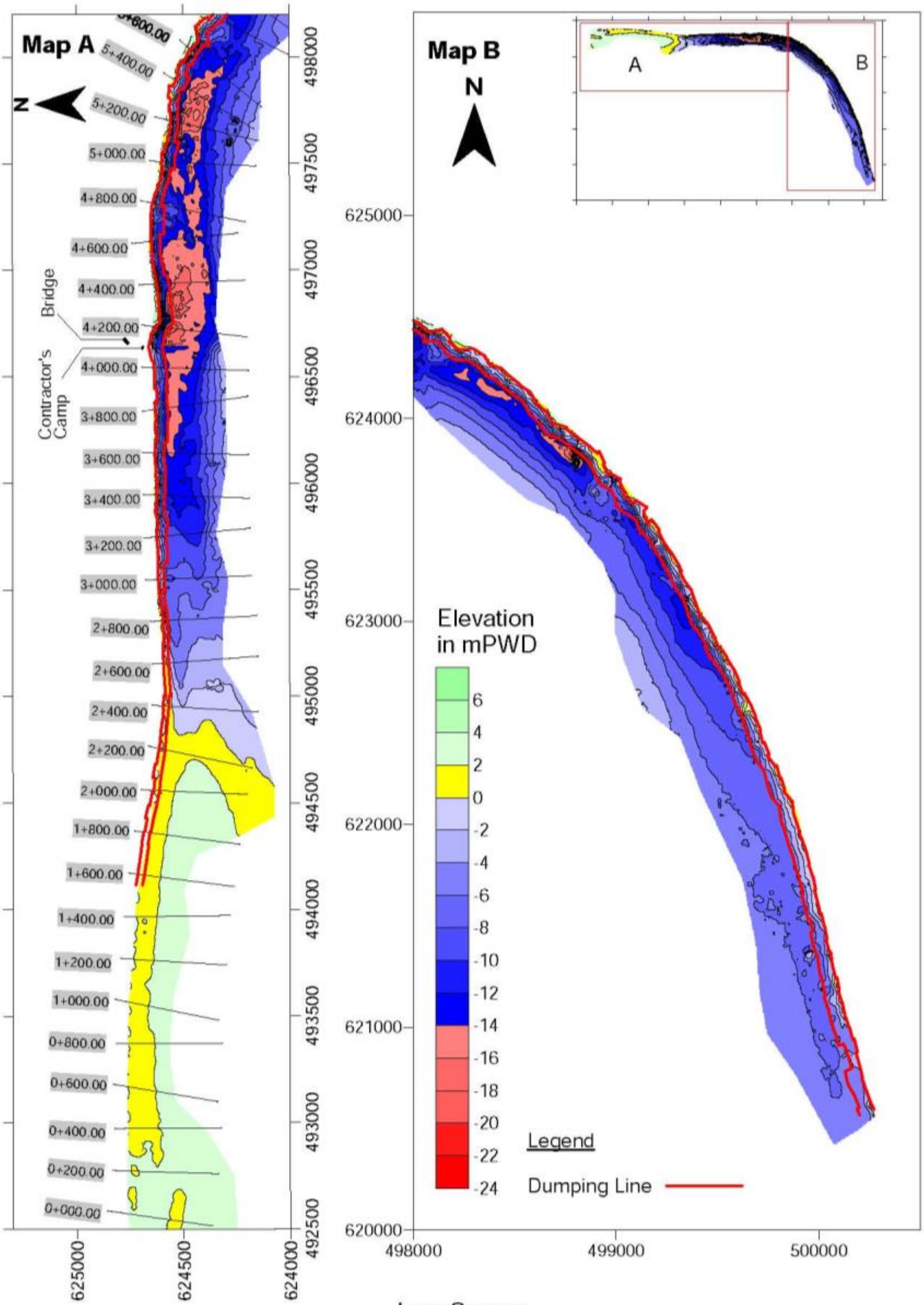
5.3 Harirampur



Harirampur Bathymetric Survey, April 2016 Survey

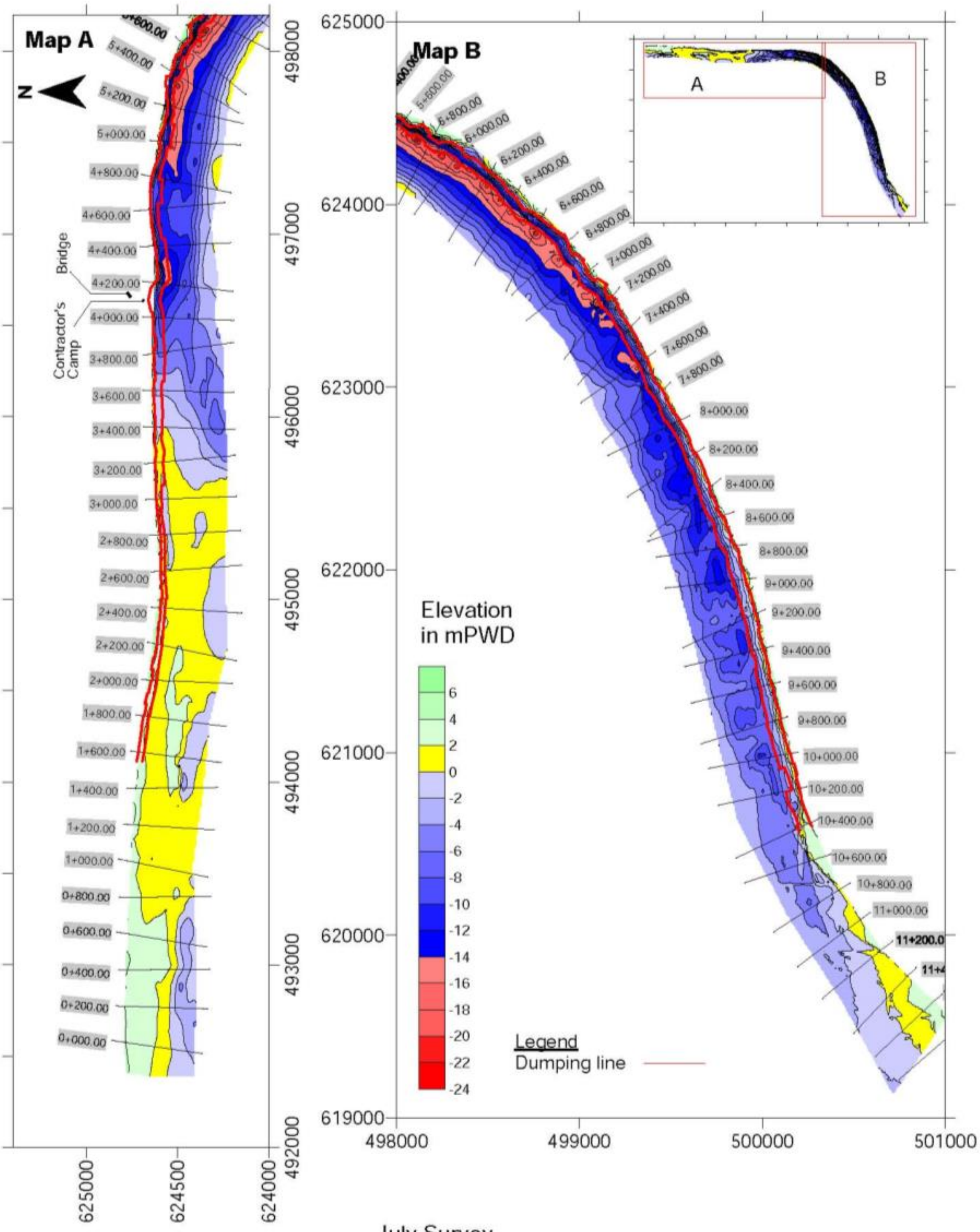


Harirampur Bathymetric Survey, June 2016



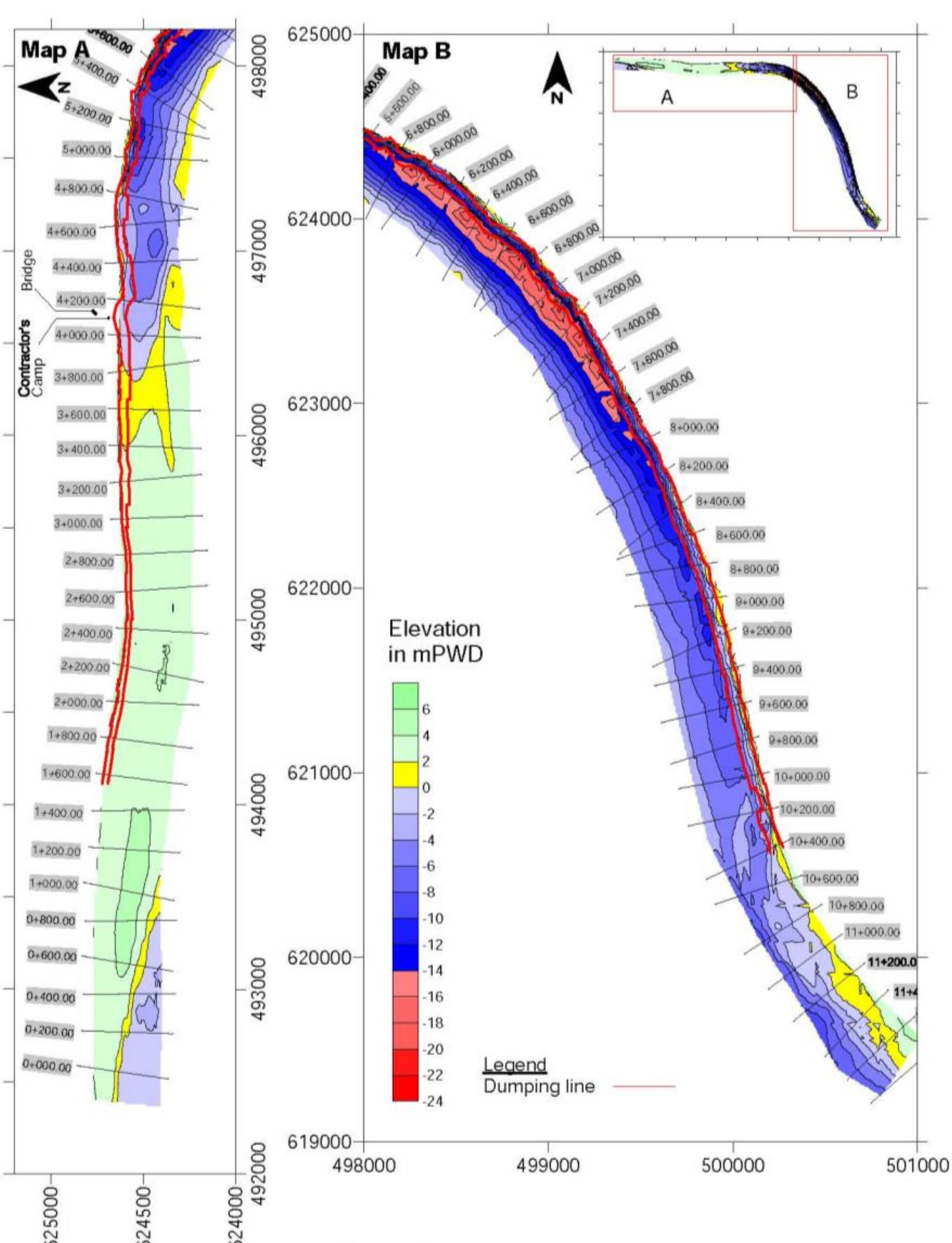
June Survey
Date:June 05, 2016

Harirampur Bathymetric Survey, July 2016



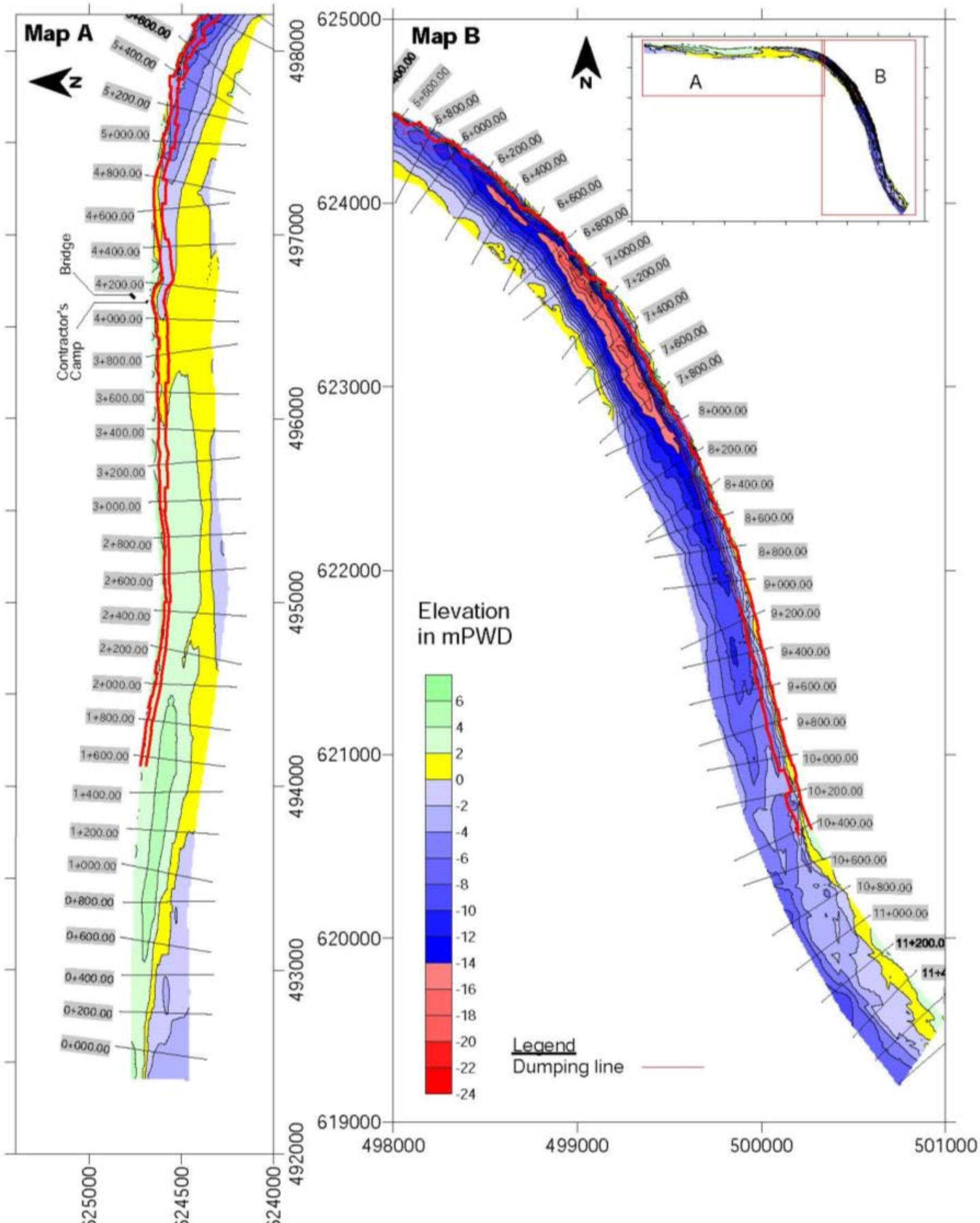
July Survey
Date:July 17, 2016 to July 19, 2016

Harirampur Bathymetric Survey, August 2016



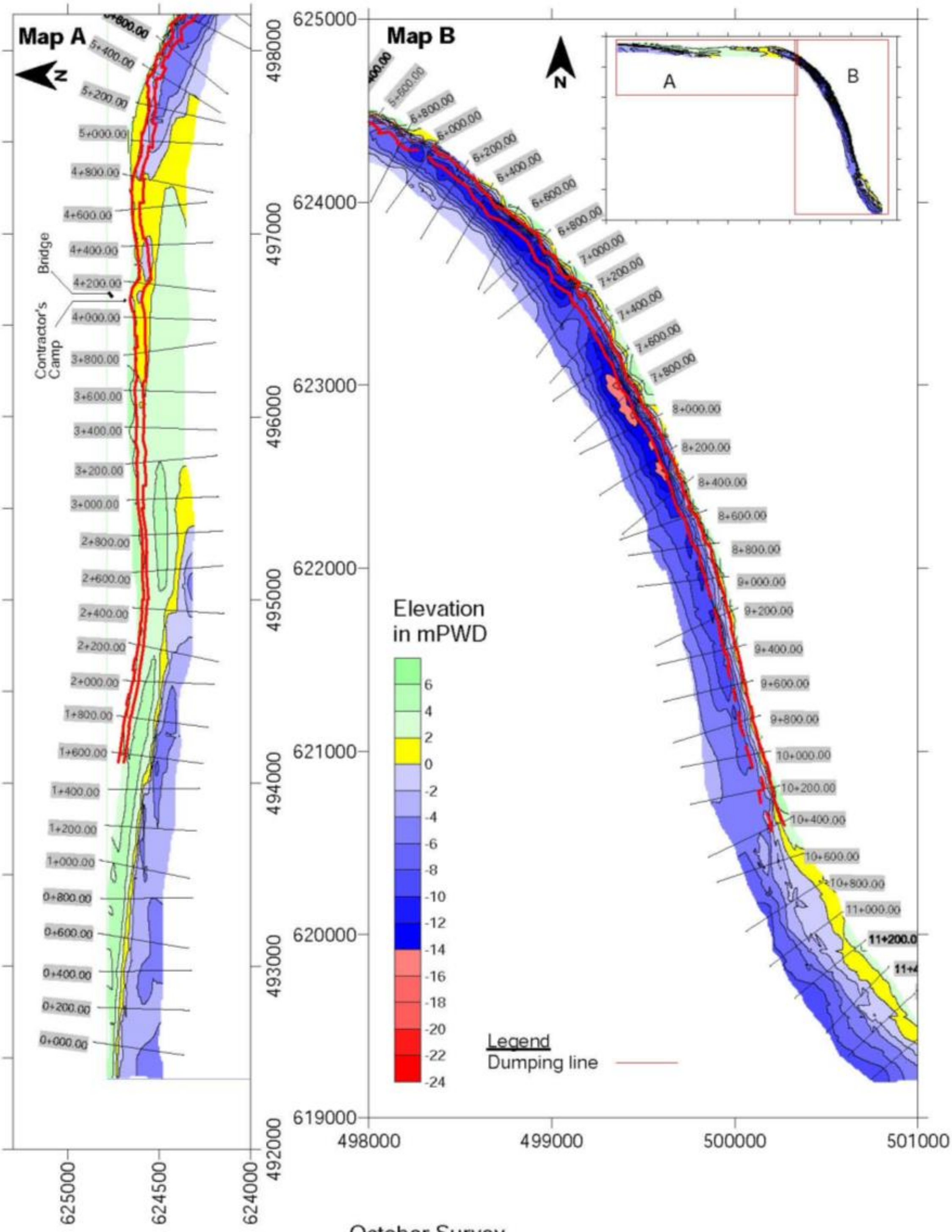
August Survey
Date:August 11, 2016 to August 12, 2016

Harirampur Bathymetric Survey, September 2016



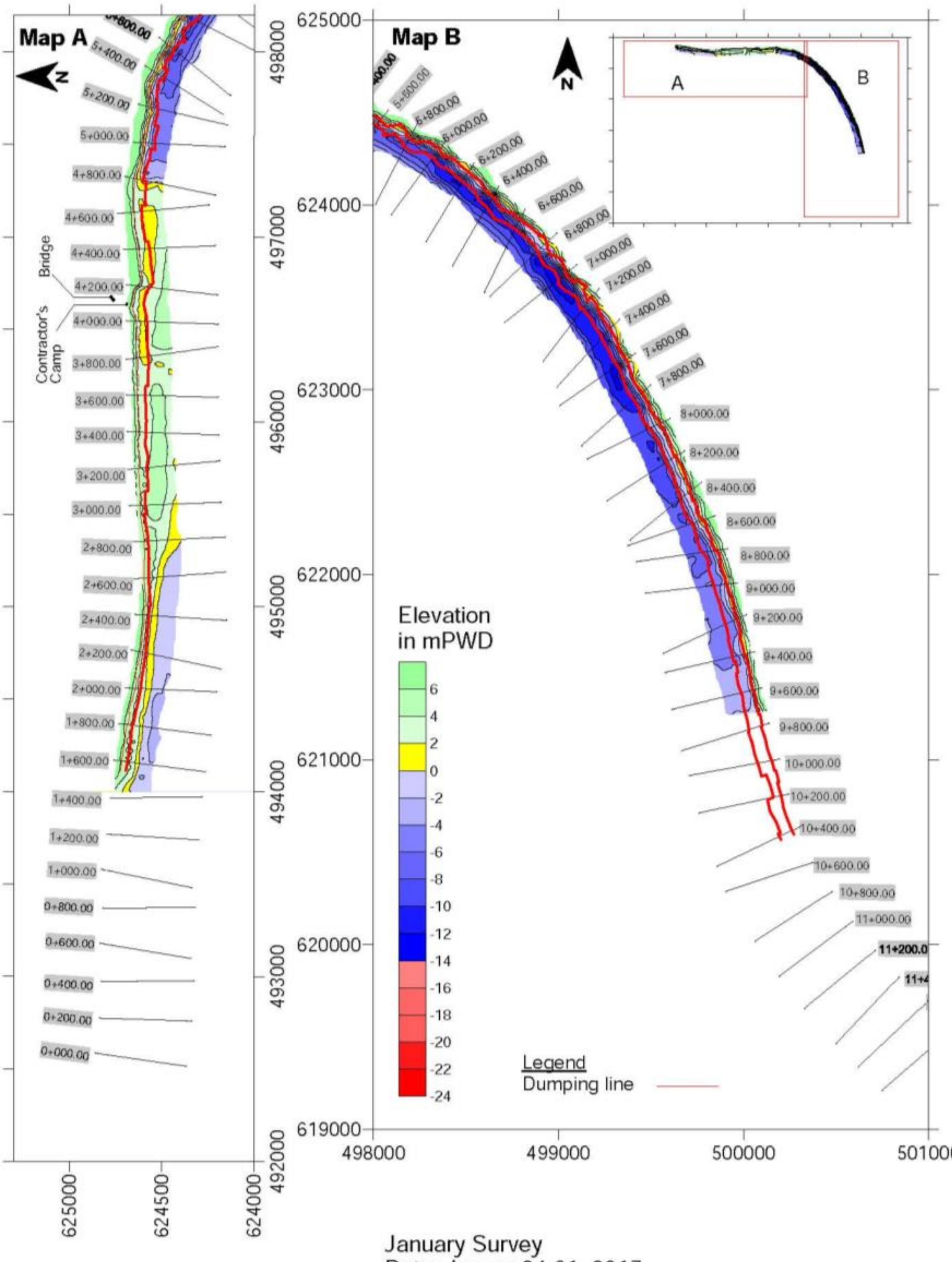
September Survey
Date:September 25, 2016 to September 26, 2016

Harirampur Bathymetric Survey, October 2016



October Survey
Date:October 17, 2016 to October 18, 2016

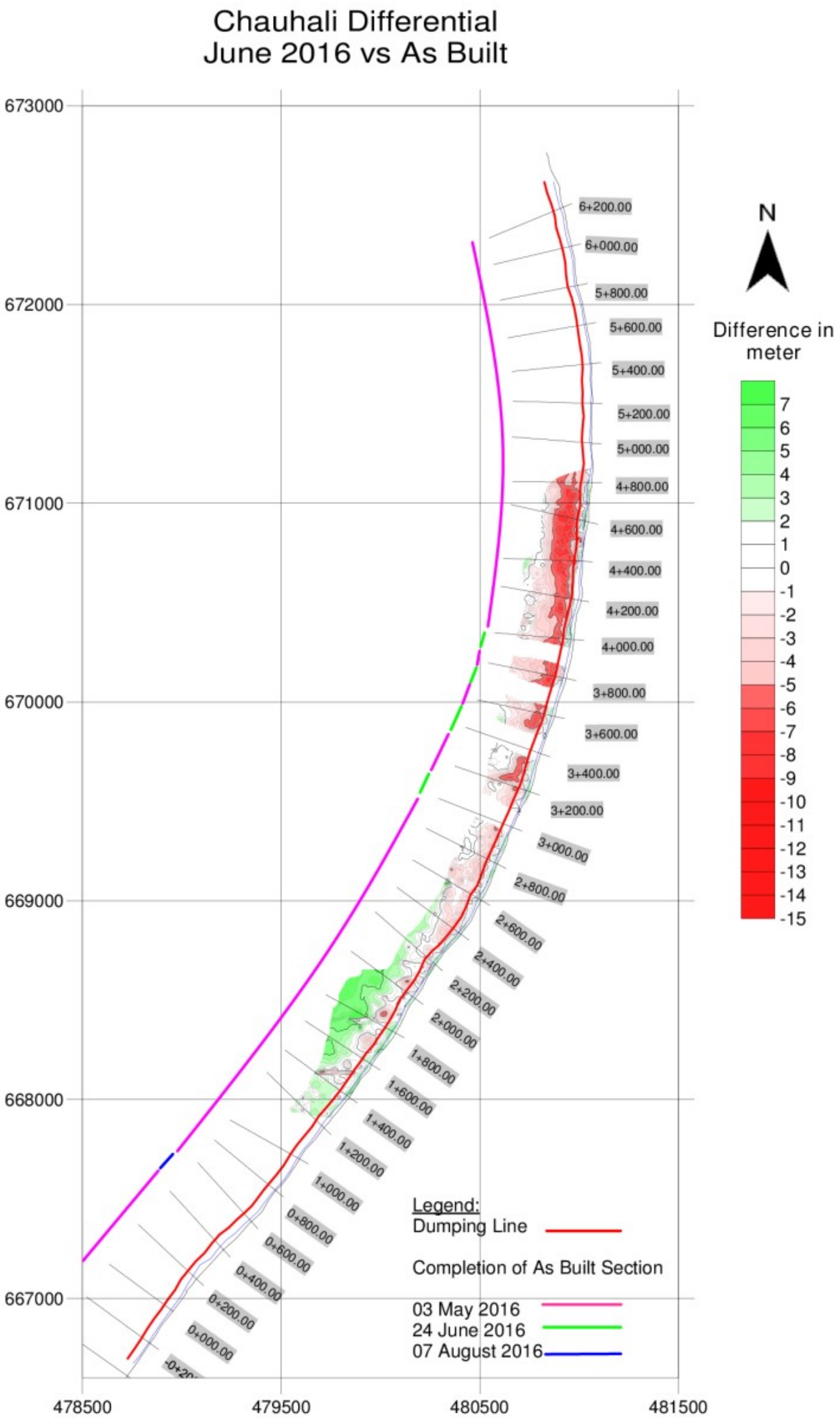
Harirampur January 2017



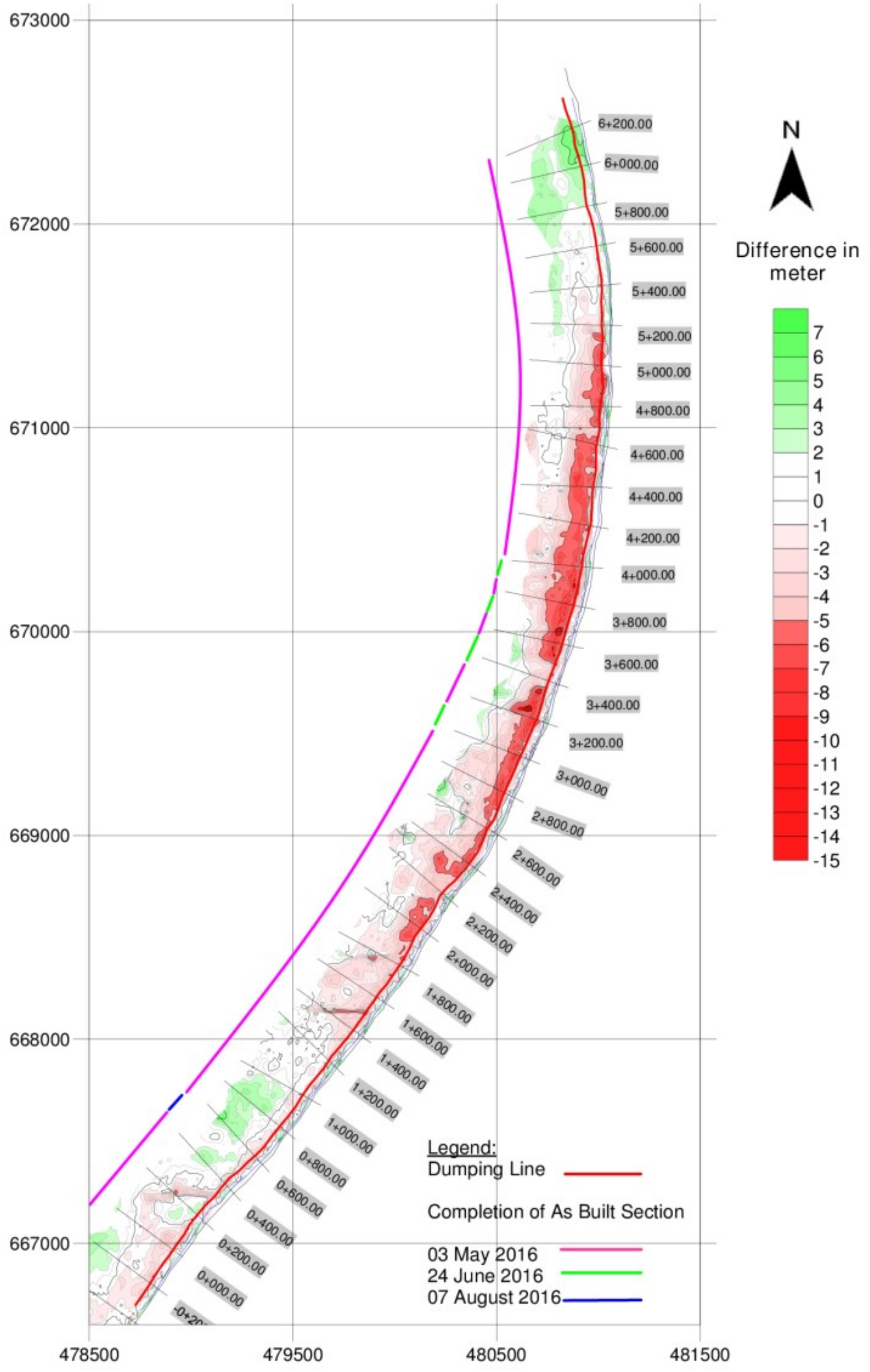
January Survey
Date: Januar 24-31, 2017

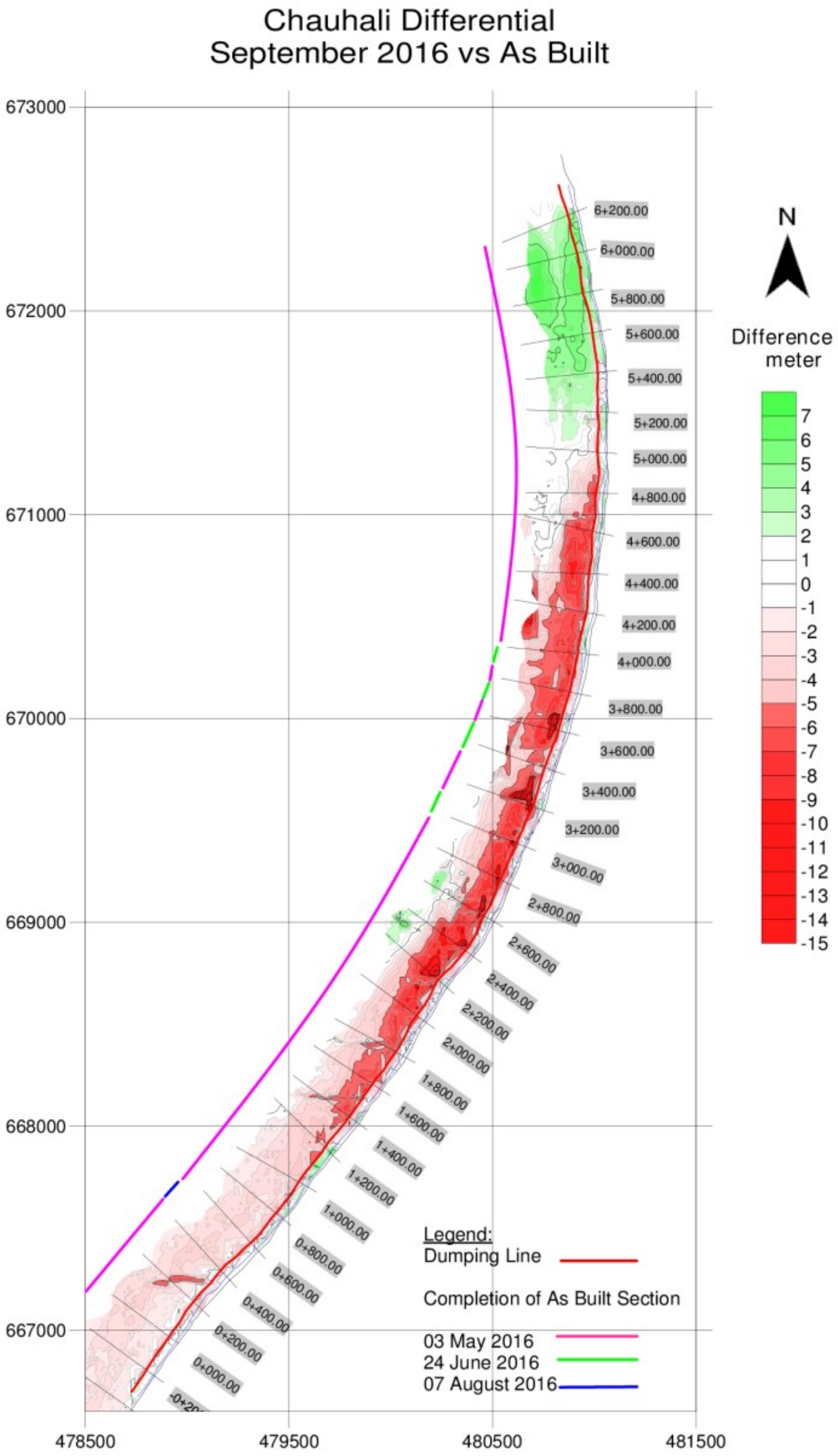
6 Differential Models

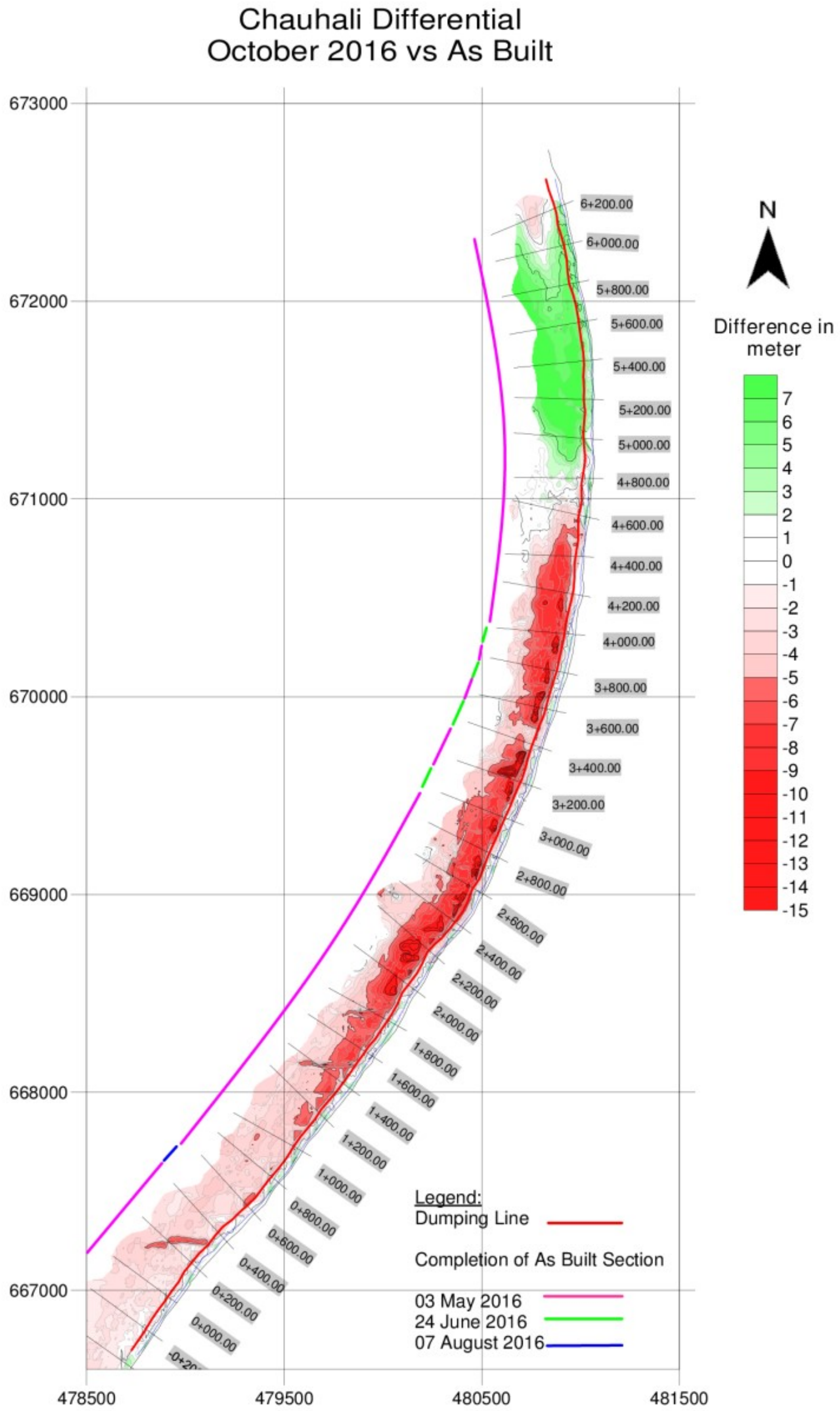
6.1 Chauhali

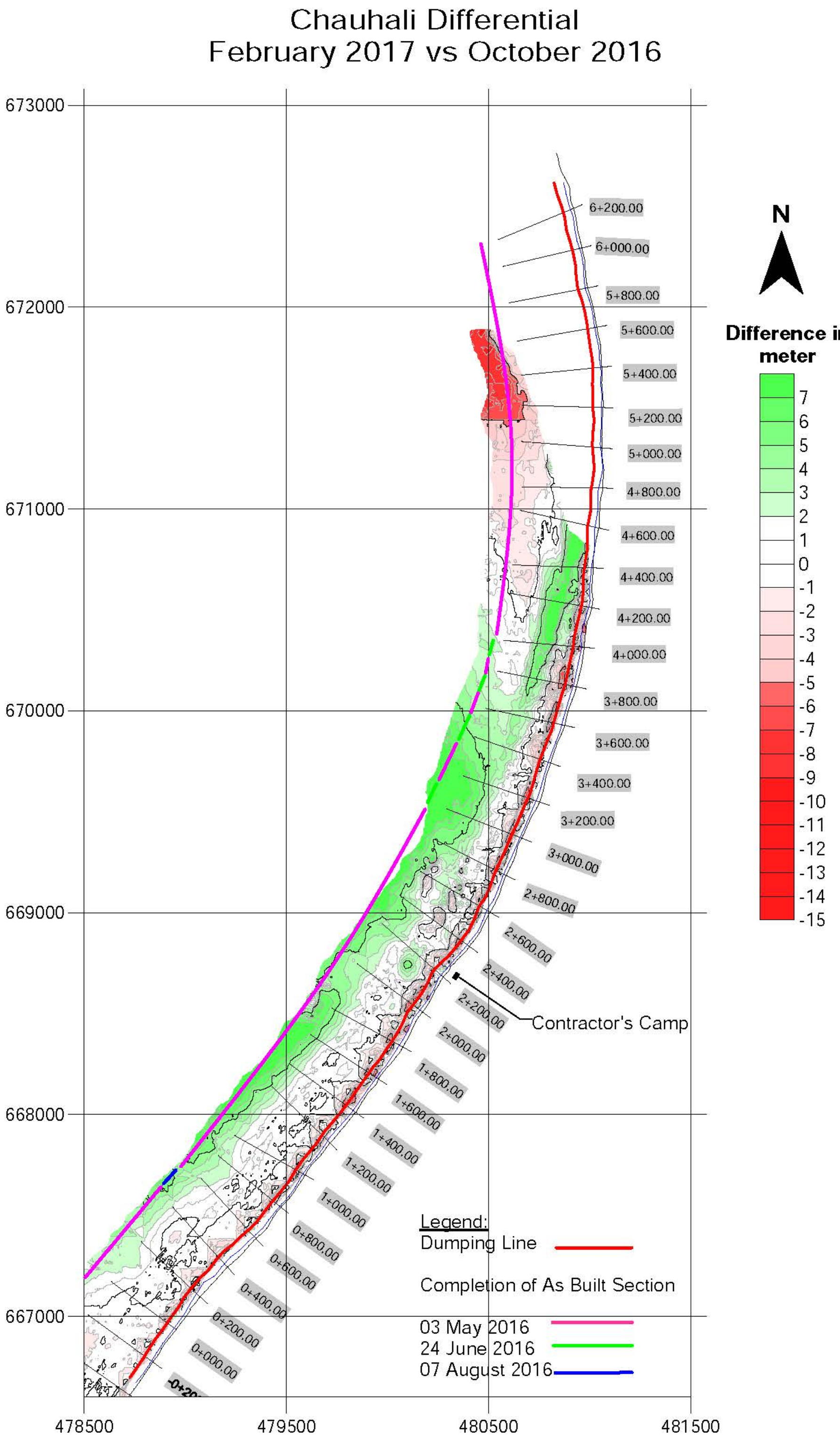


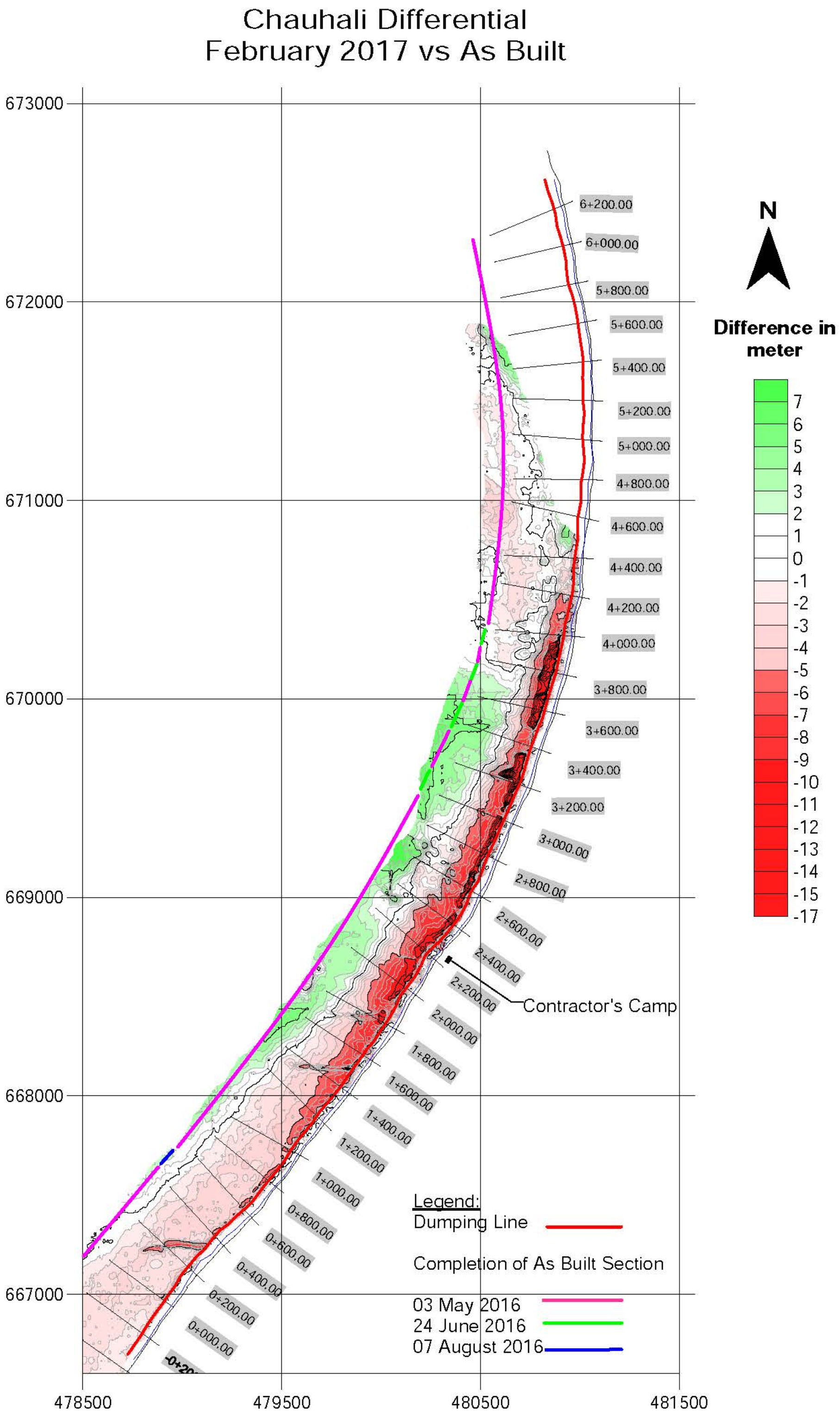
Chauhali Differential
August 2016 vs As Built




Chauhali Differential
September 2016 vs As Built
673000
672000
671000
670000
669000
668000
667000
478500
479500
480500
481500
6+200.00
6+000.00
5+800.00
5+600.00
5+400.00
5+200.00
5+000.00
4+800.00
4+600.00
4+400.00
4+200.00
4+000.00
3+800.00
3+600.00
3+400.00
3+200.00
3+000.00
2+800.00
2+600.00
2+400.00
2+200.00
2+000.00
1+800.00
1+600.00
1+400.00
1+200.00
1+000.00
0+800.00
0+600.00
0+400.00
0+200.00
0+000.00
N
Difference in meter
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
Legend:
Dumping Line
Completion of As Built Section
03 May 2016
24 June 2016
07 August 2016

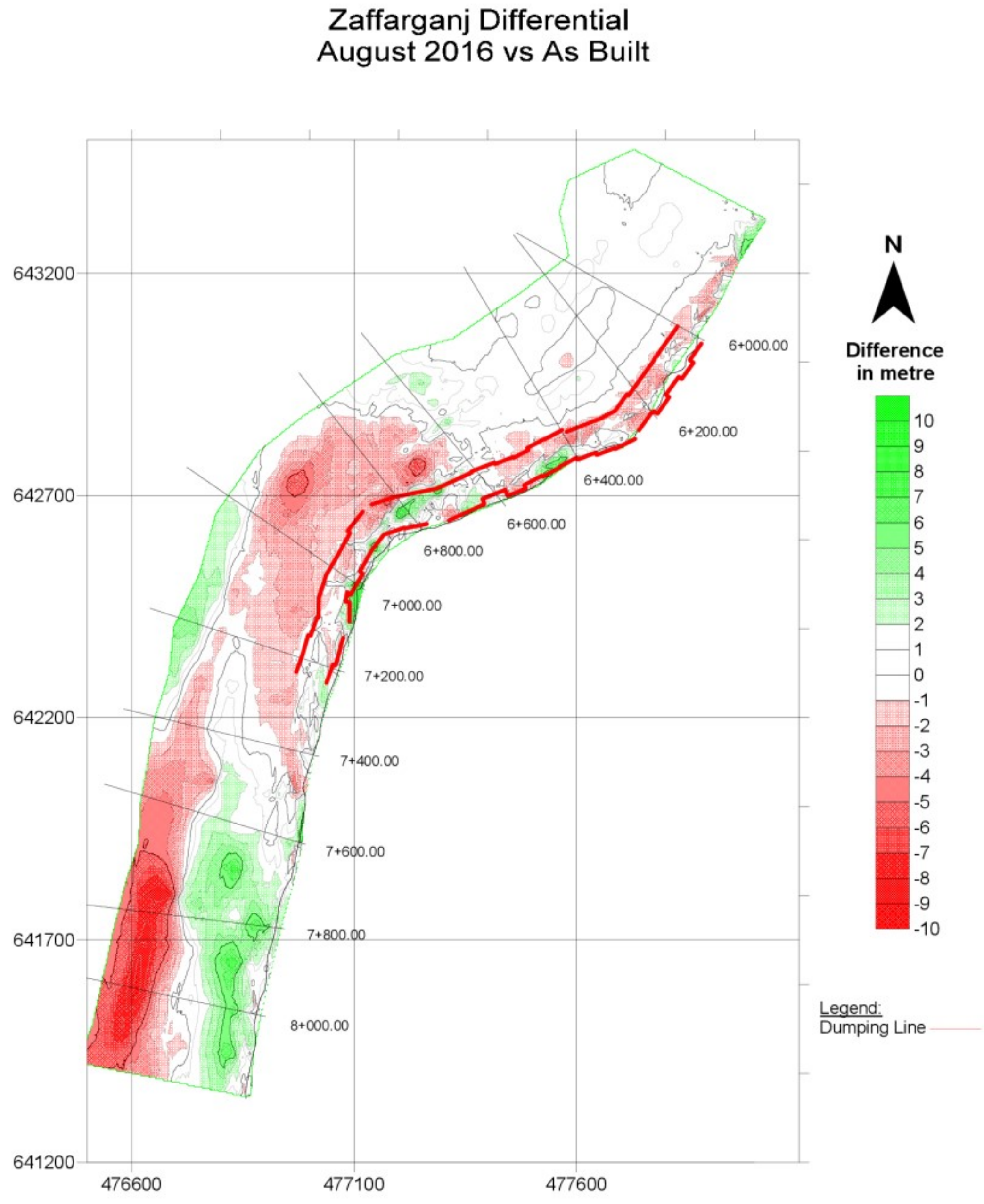

Chauhali Differential
October 2016 vs As Built
673000
672000
671000
670000
669000
668000
667000
478500
479500
480500
481500
6+200.00
6+000.00
5+800.00
5+600.00
5+400.00
5+200.00
5+000.00
4+800.00
4+600.00
4+400.00
4+200.00
4+000.00
3+800.00
3+600.00
3+400.00
3+200.00
3+000.00
2+800.00
2+600.00
2+400.00
2+200.00
2+000.00
1+800.00
1+600.00
1+400.00
1+200.00
1+000.00
0+800.00
0+600.00
0+400.00
0+200.00
0+000.00
N
Difference in meter
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
Legend:
Dumping Line
Completion of As Built Section
03 May 2016
24 June 2016
07 August 2016


Chauhali Differential
February 2017 vs October 2016
673000
672000
671000
670000
669000
668000
667000
478500
479500
480500
481500
6+200.00
6+000.00
5+800.00
5+600.00
5+400.00
5+200.00
5+000.00
4+800.00
4+600.00
4+400.00
4+200.00
4+000.00
3+800.00
3+600.00
3+400.00
3+200.00
3+000.00
2+800.00
2+600.00
2+400.00
2+200.00
2+000.00
1+800.00
1+600.00
1+400.00
1+200.00
1+000.00
0+800.00
0+600.00
0+400.00
0+200.00
0+000.00
Contractor's Camp
N
Difference in meter
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
Legend:
Dumping Line
Completion of As Built Section
03 May 2016
24 June 2016
07 August 2016

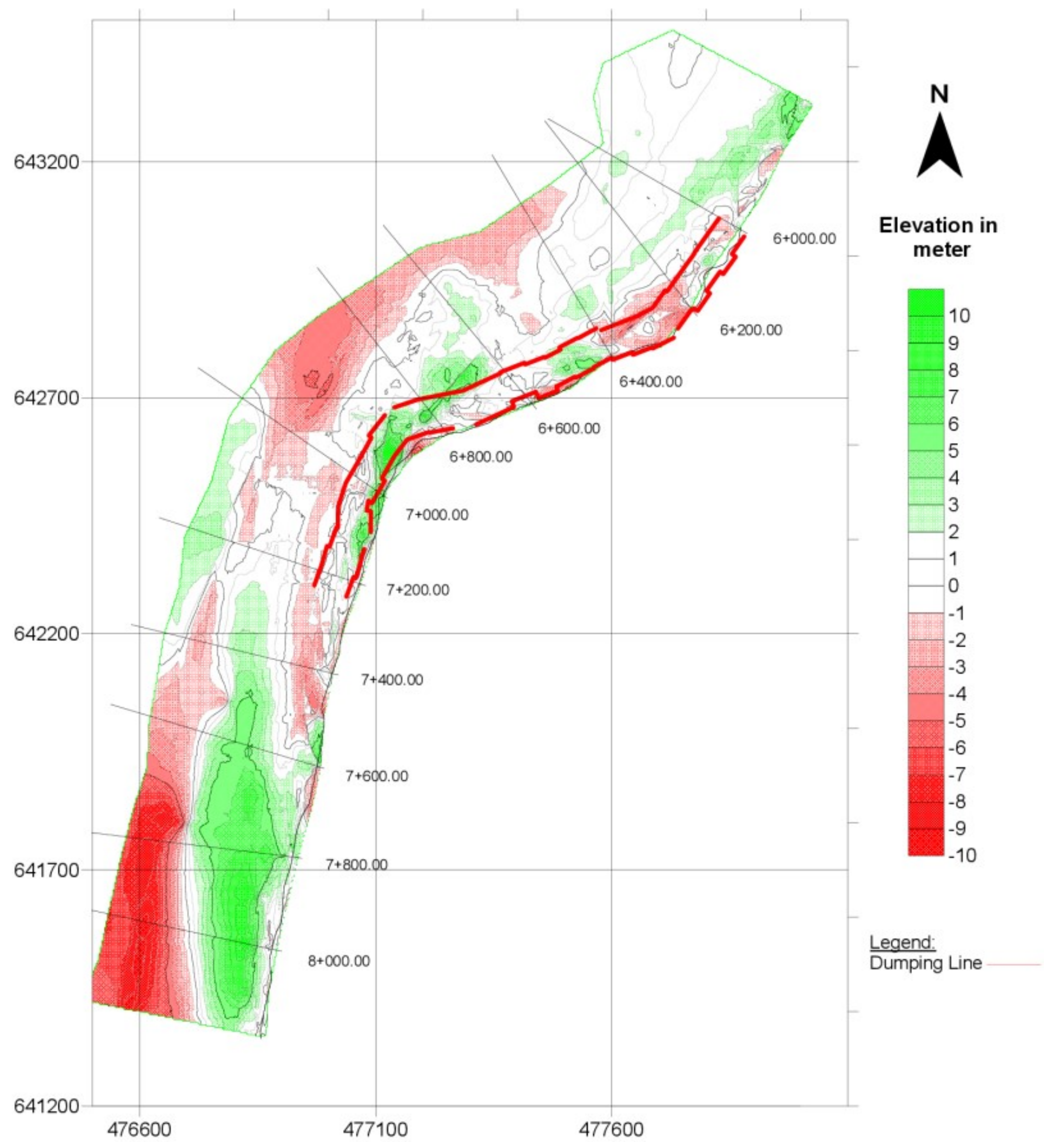


Chauhali Differential
February 2017 vs As Built
673000
672000
671000
670000
669000
668000
667000
478500
479500
480500
481500
6+200.00
6+000.00
5+800.00
5+600.00
5+400.00
5+200.00
5+000.00
4+800.00
4+600.00
4+400.00
4+200.00
4+000.00
3+800.00
3+600.00
3+400.00
3+200.00
3+000.00
2+800.00
2+600.00
2+400.00
2+200.00
2+000.00
1+800.00
1+600.00
1+400.00
1+200.00
1+000.00
0+800.00
0+600.00
0+400.00
0+200.00
0+000.00
Contractor's Camp
N
Difference in meter
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-17
Legend:
Dumping Line
Completion of As Built Section
03 May 2016
24 June 2016
07 August 2016

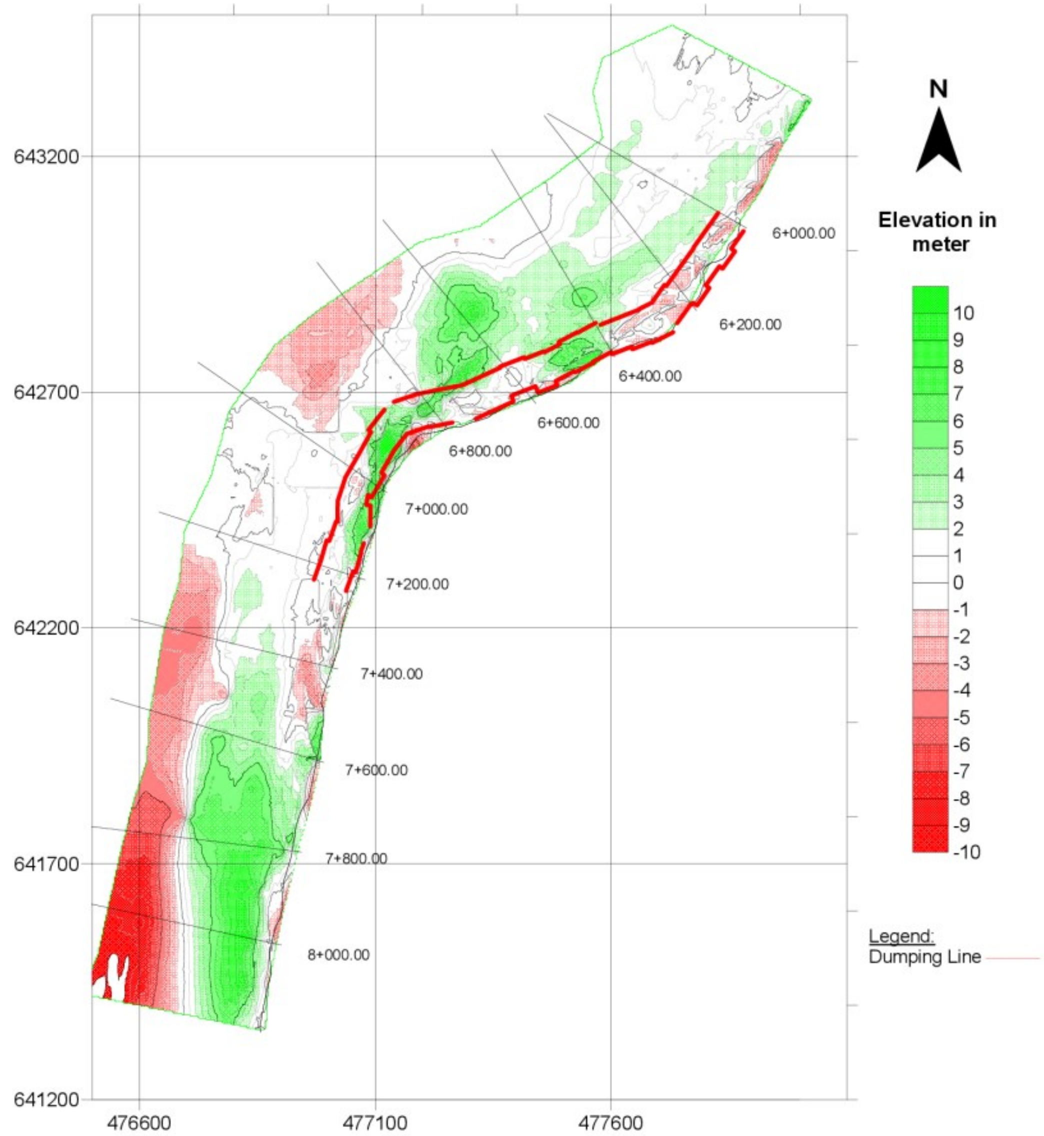
6.2 Zafarganj

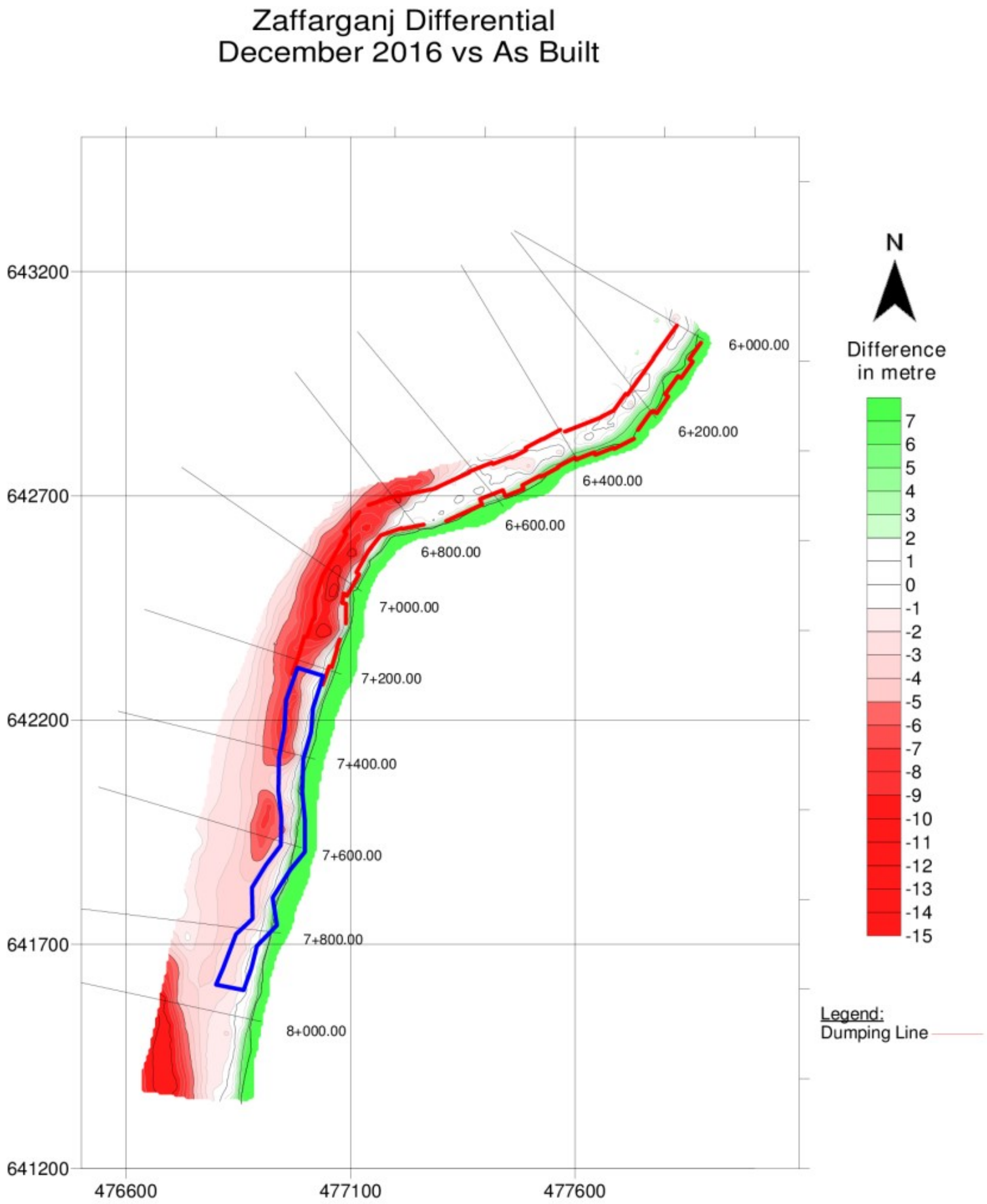


Zaffarganj Differential
September 2016 vs As Built

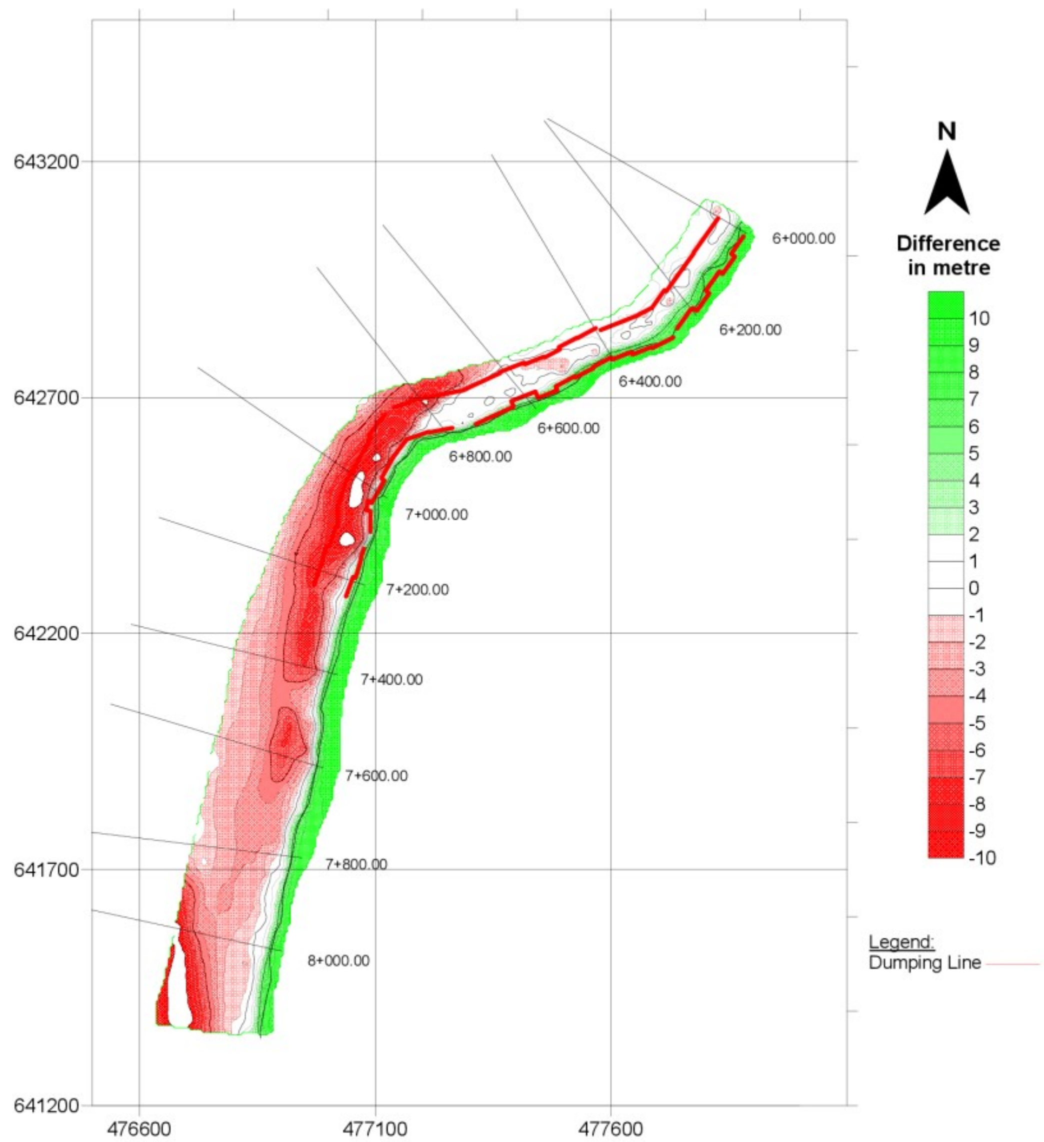


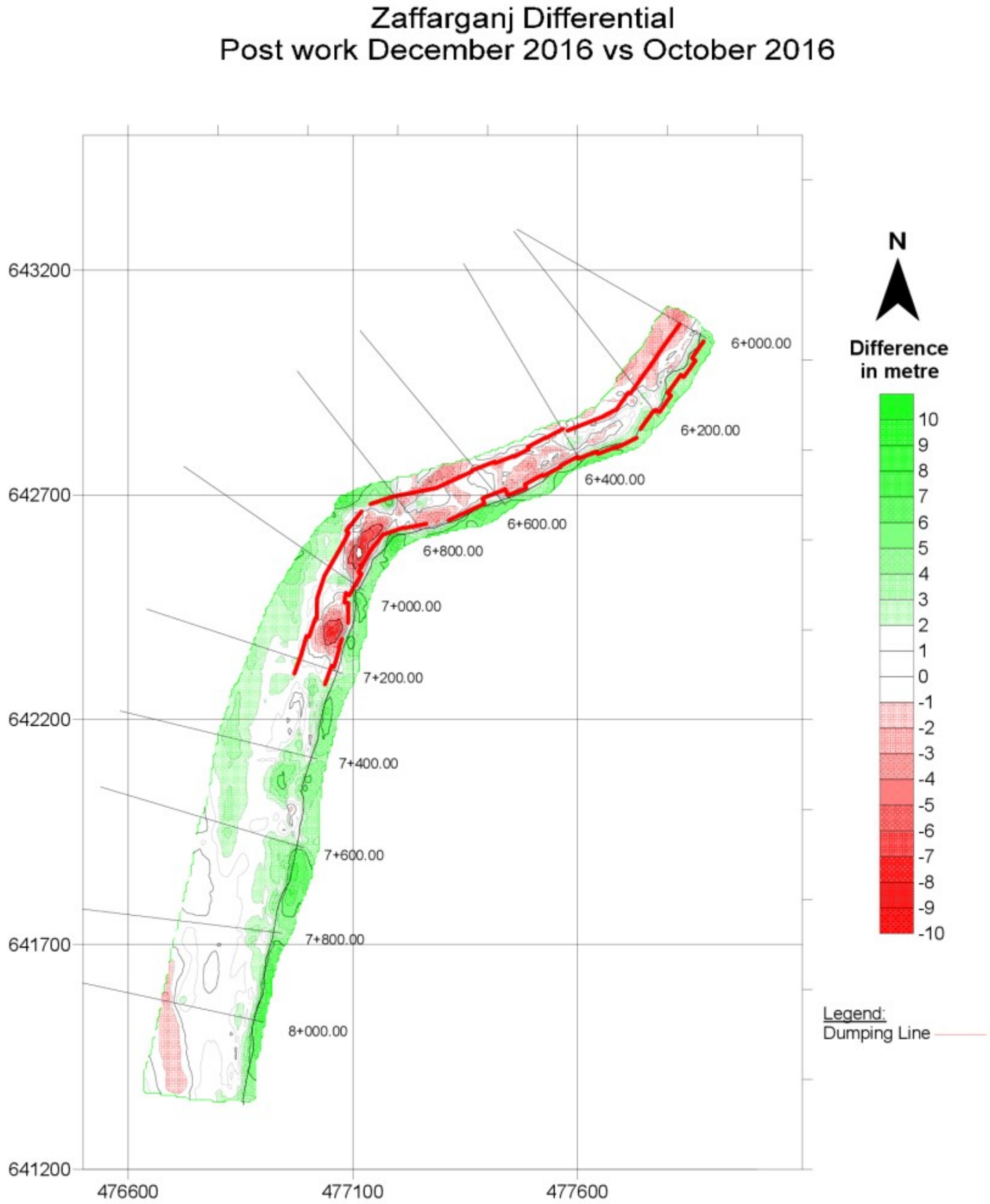
Zaffarganj Differential
October 2016 vs As Built




Zaffarganj Differential
December 2016 vs As Built
643200
642700
642200
641700
641200
476600
477100
477600
6+000.00
6+200.00
6+400.00
6+600.00
6+800.00
7+000.00
7+200.00
7+400.00
7+600.00
7+800.00
8+000.00
N
Difference
in metre
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
Legend:
Dumping Line

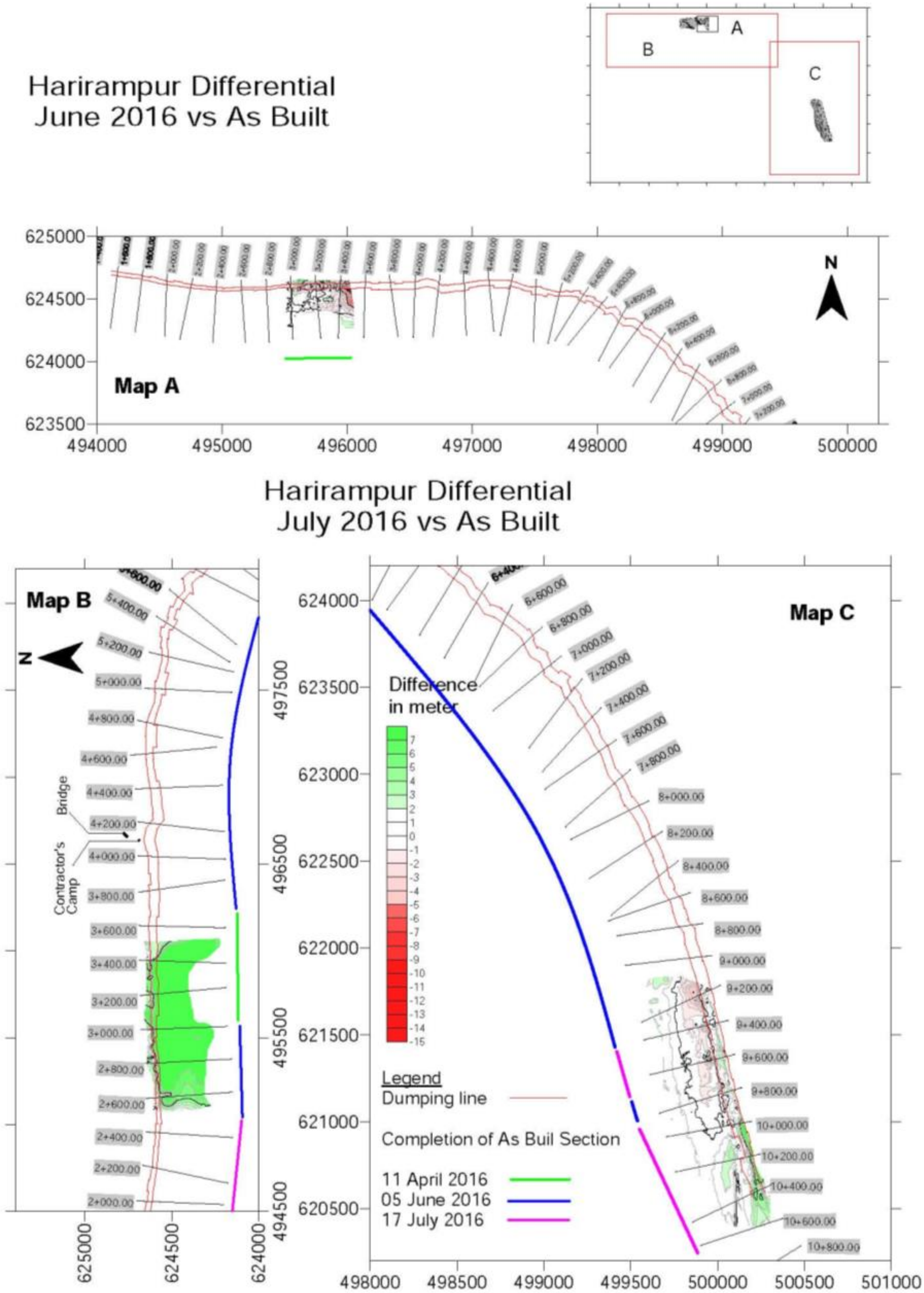
Zaffarganj Differential
Post work December 2016 vs As Built



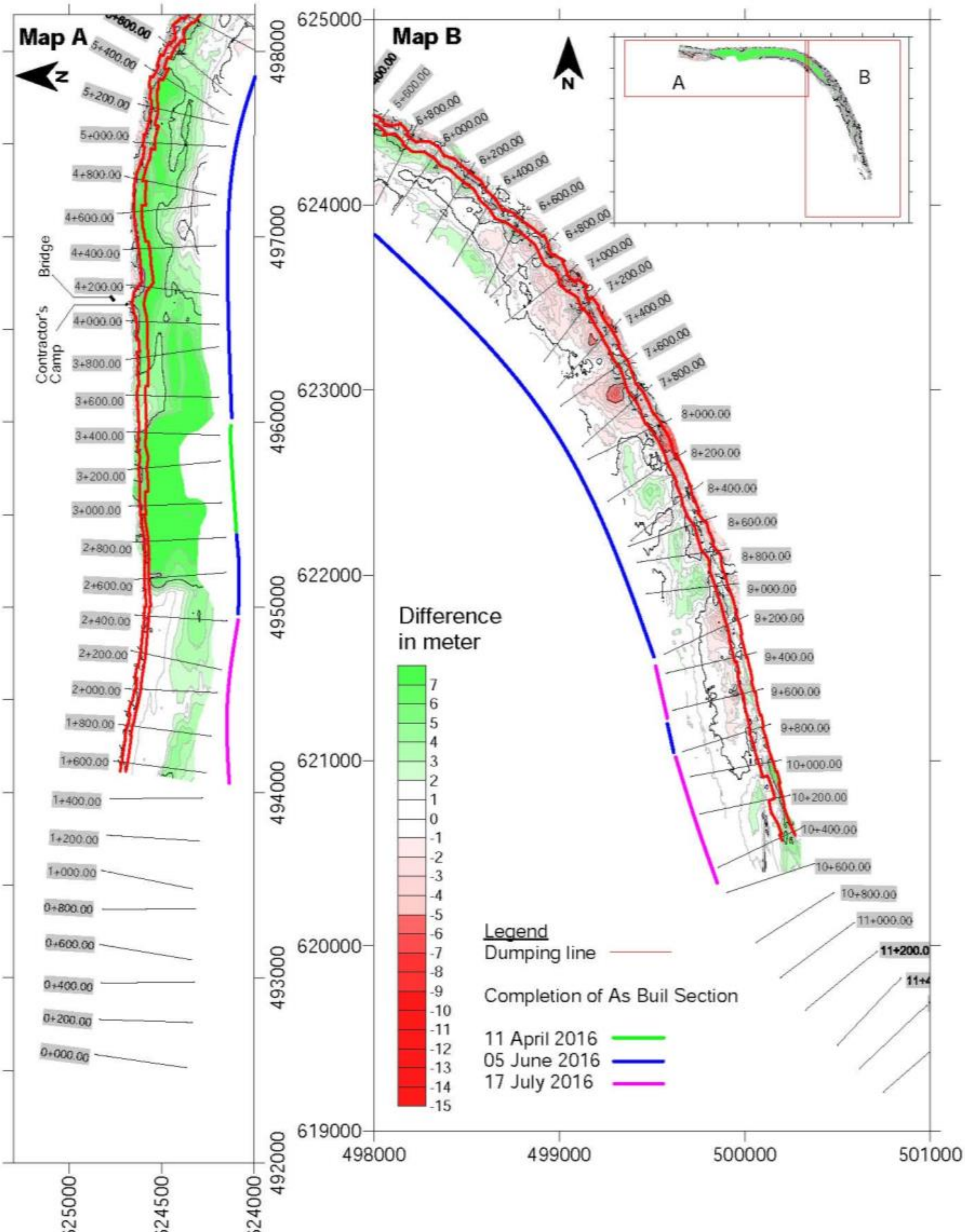


Zaffarganj Differential
Post work December 2016 vs October 2016
643200
642700
642200
641700
641200
476600
477100
477600
6+000.00
6+200.00
6+400.00
6+600.00
6+800.00
7+000.00
7+200.00
7+400.00
7+600.00
7+800.00
8+000.00
N
Difference in metre
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
Legend:
Dumping Line

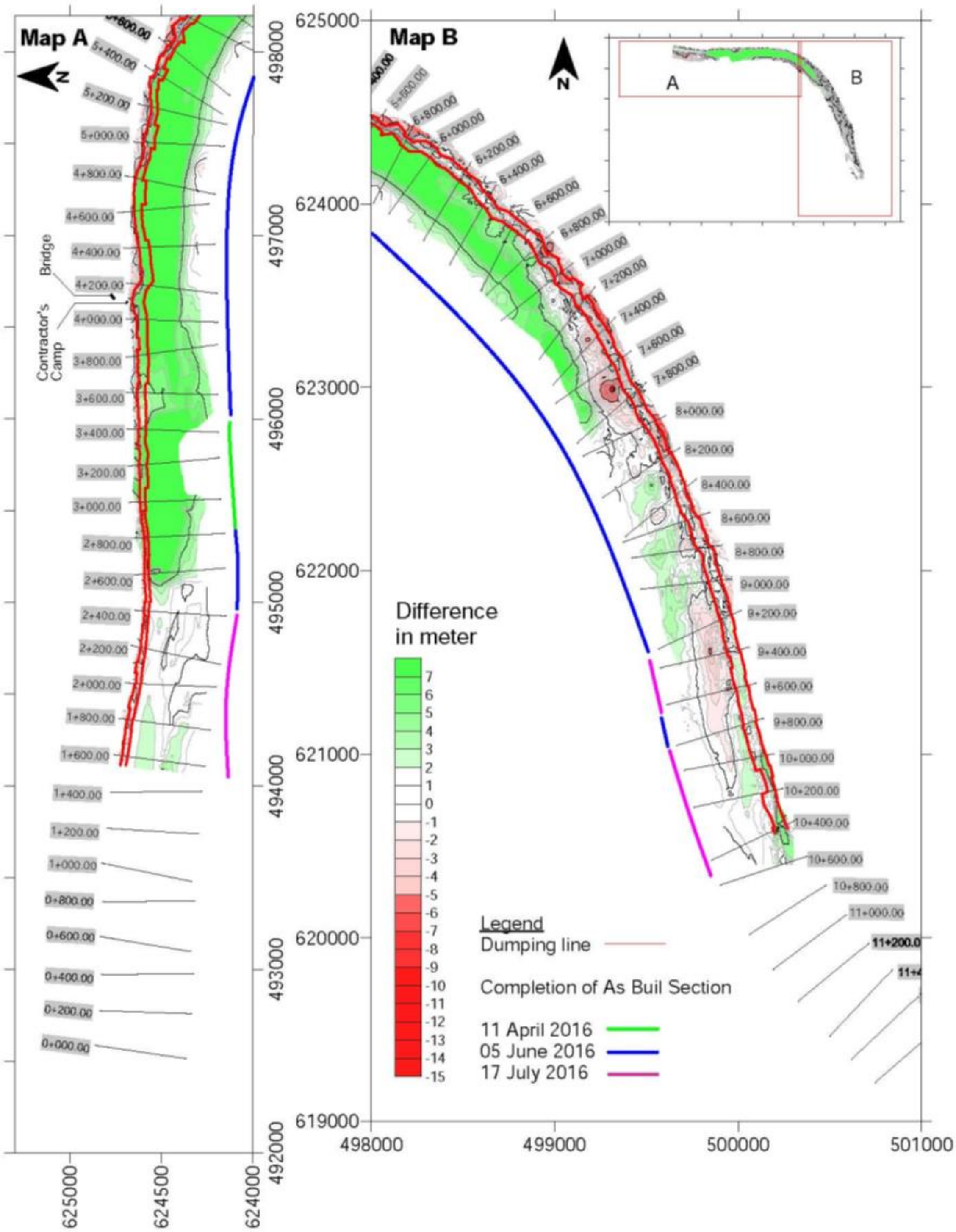
6.3 Harirampur



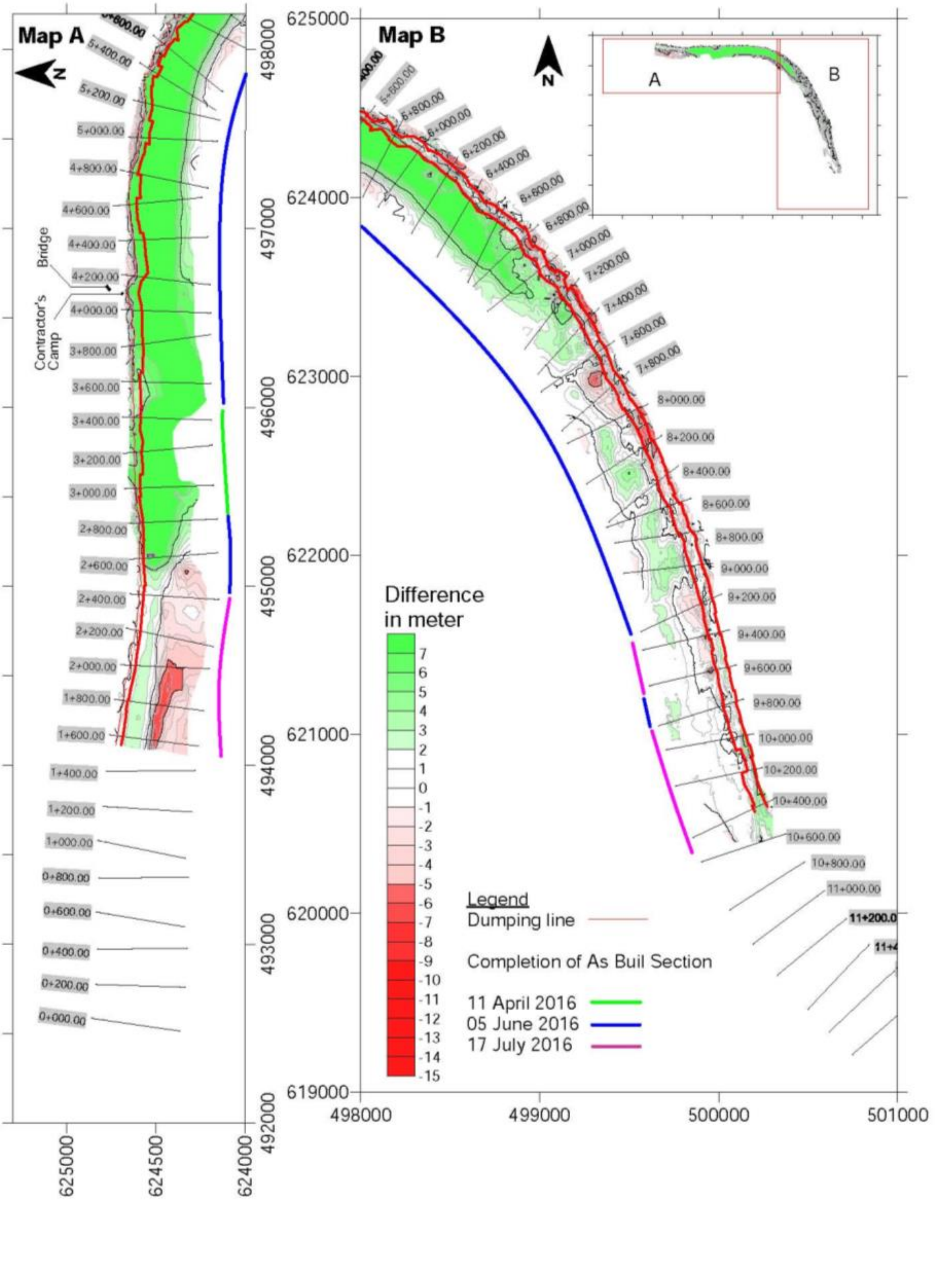
Harirampur Differential
August 2016 vs As Built



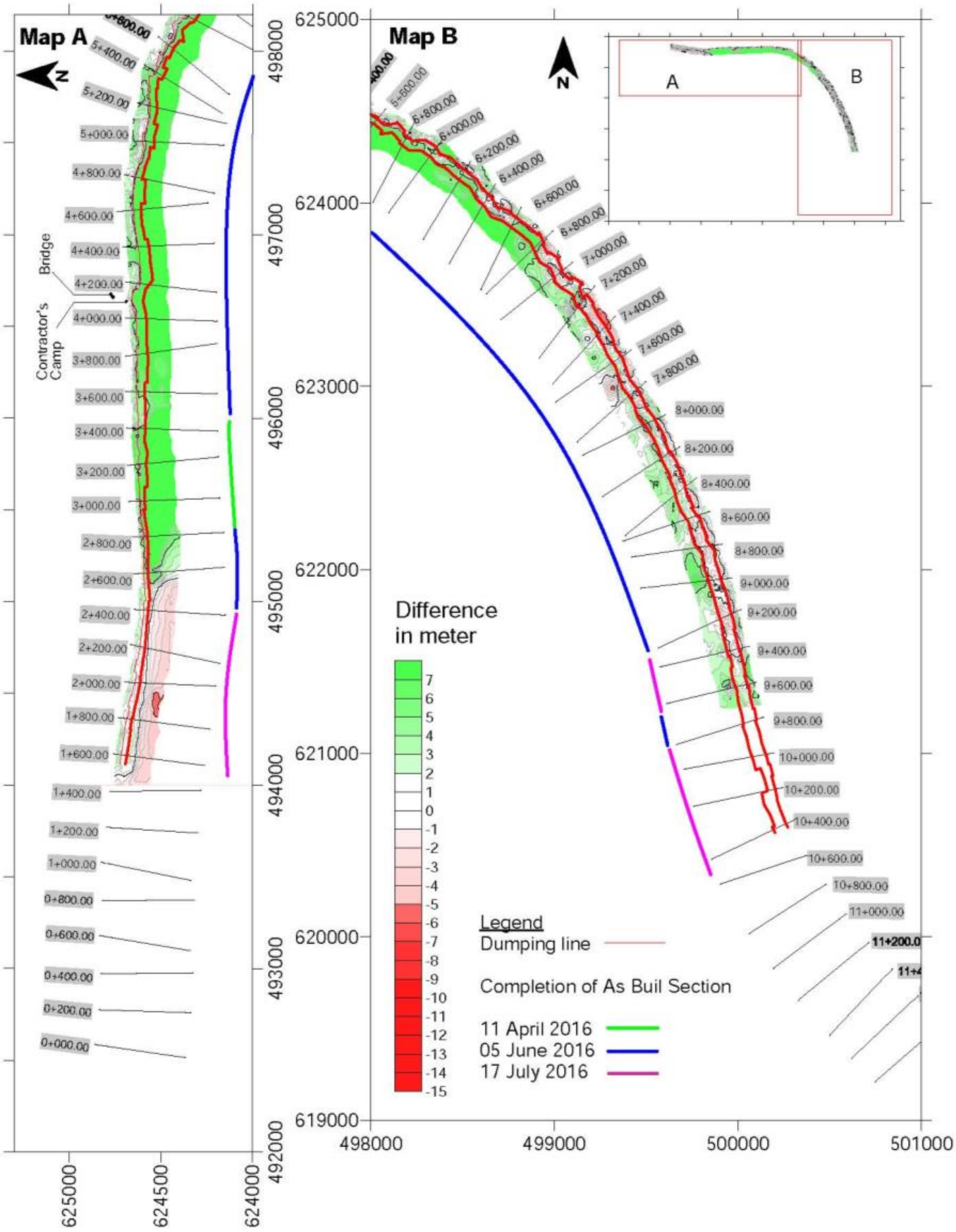
Harirampur Differential
September 2016 vs As Built



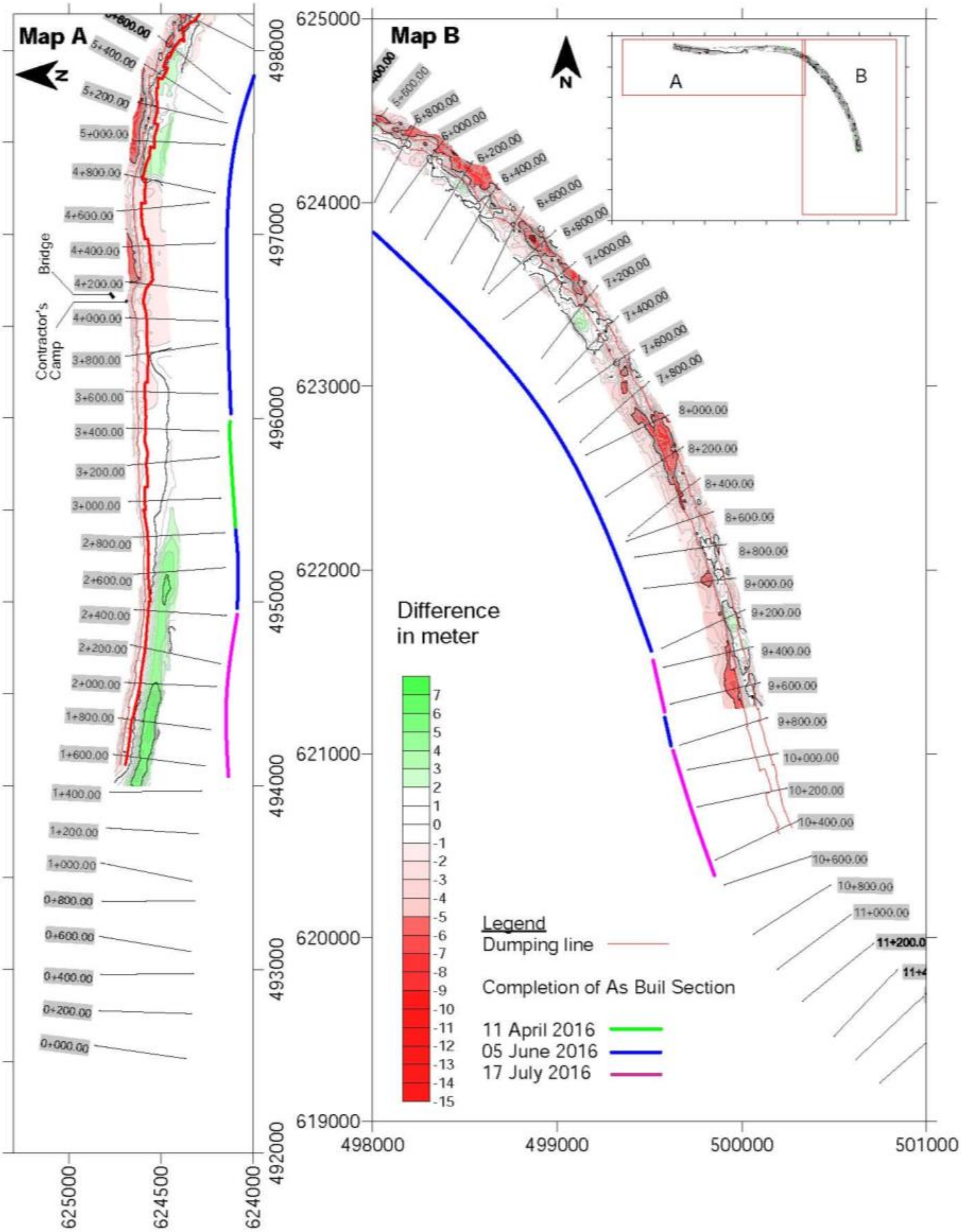
Harirampur Differential
October 2016 vs As Built



Harirampur Differential
January 2017 vs As Built

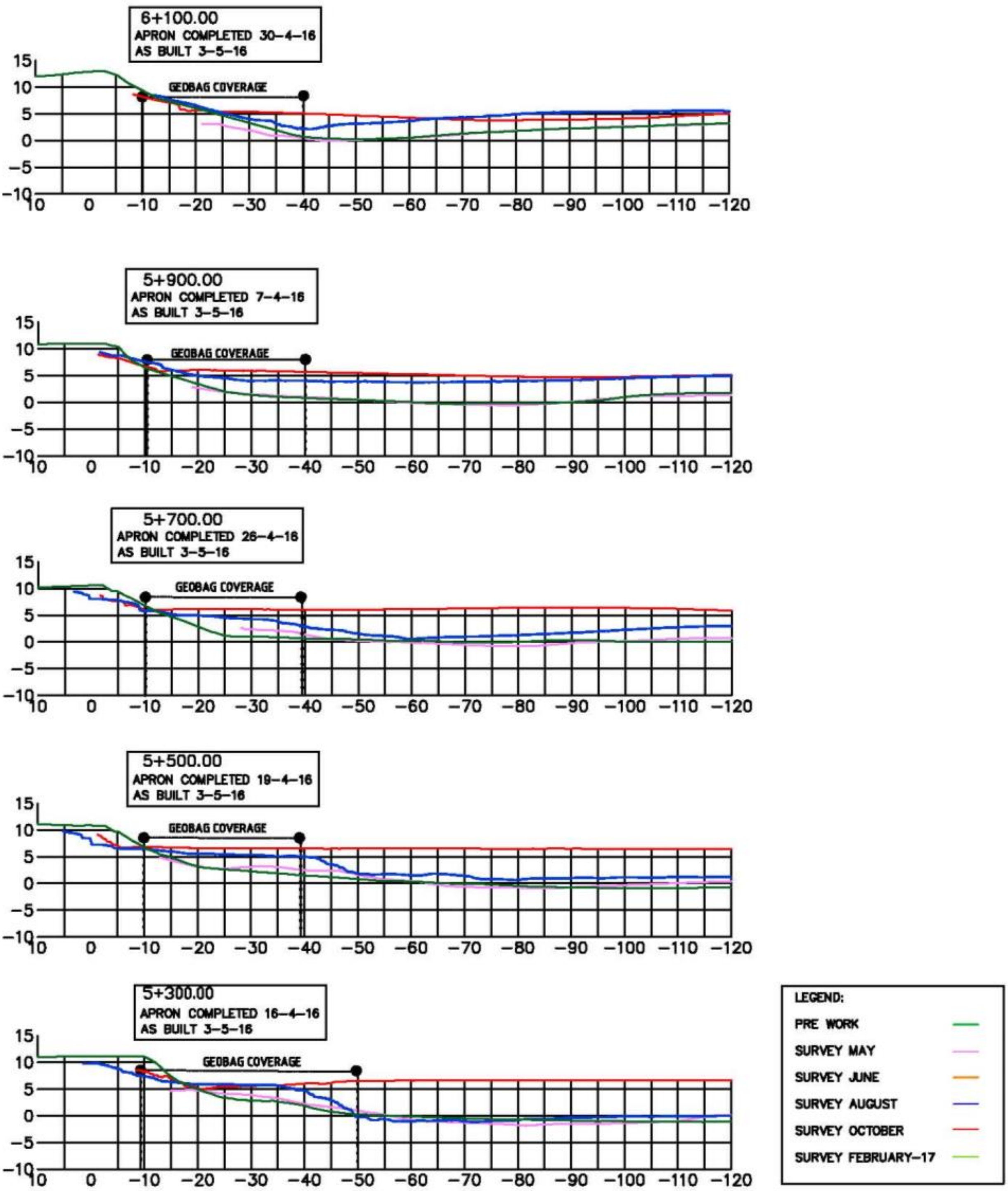


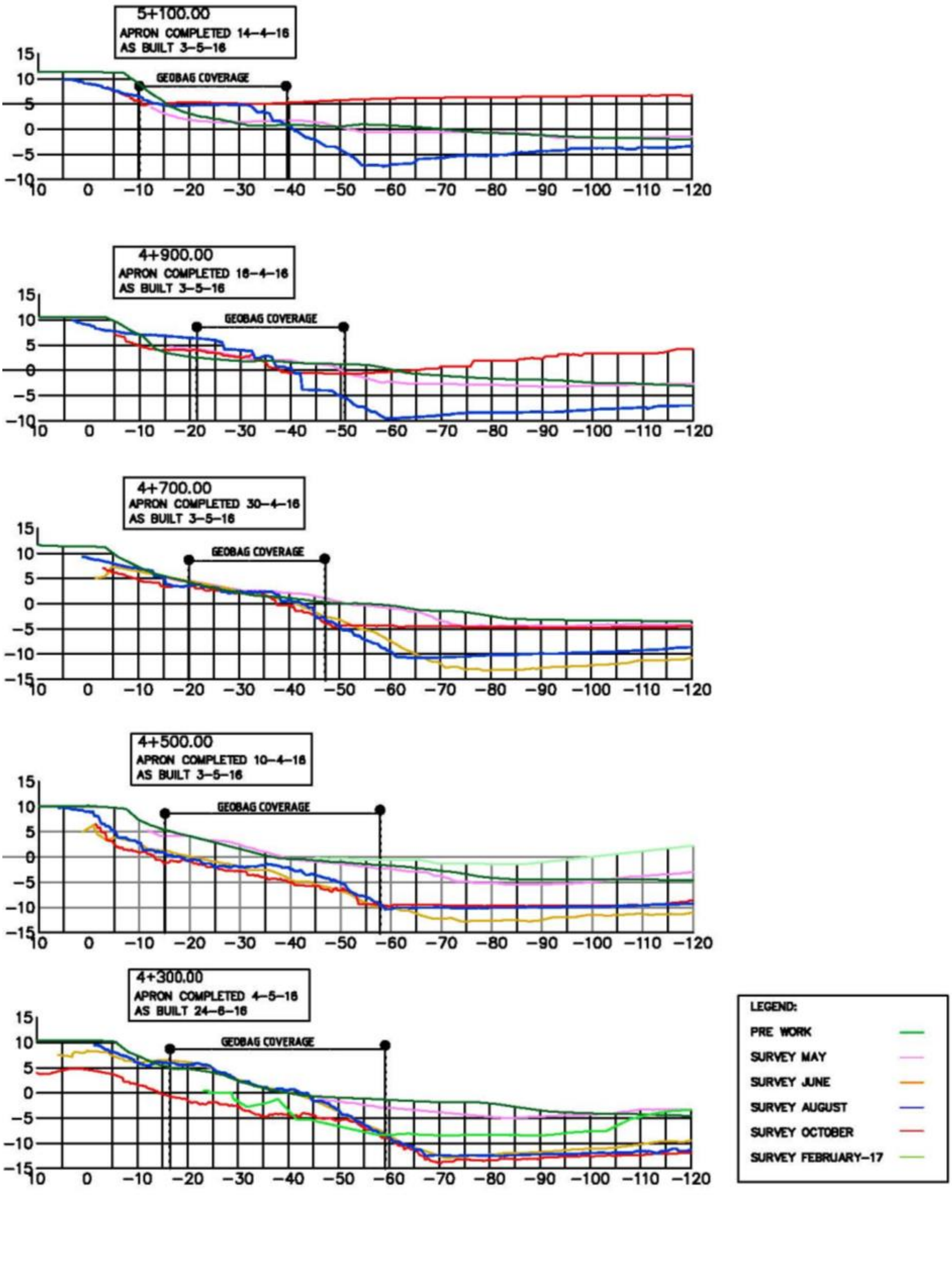
Harirampur Differential
October 2016 vs January 2017

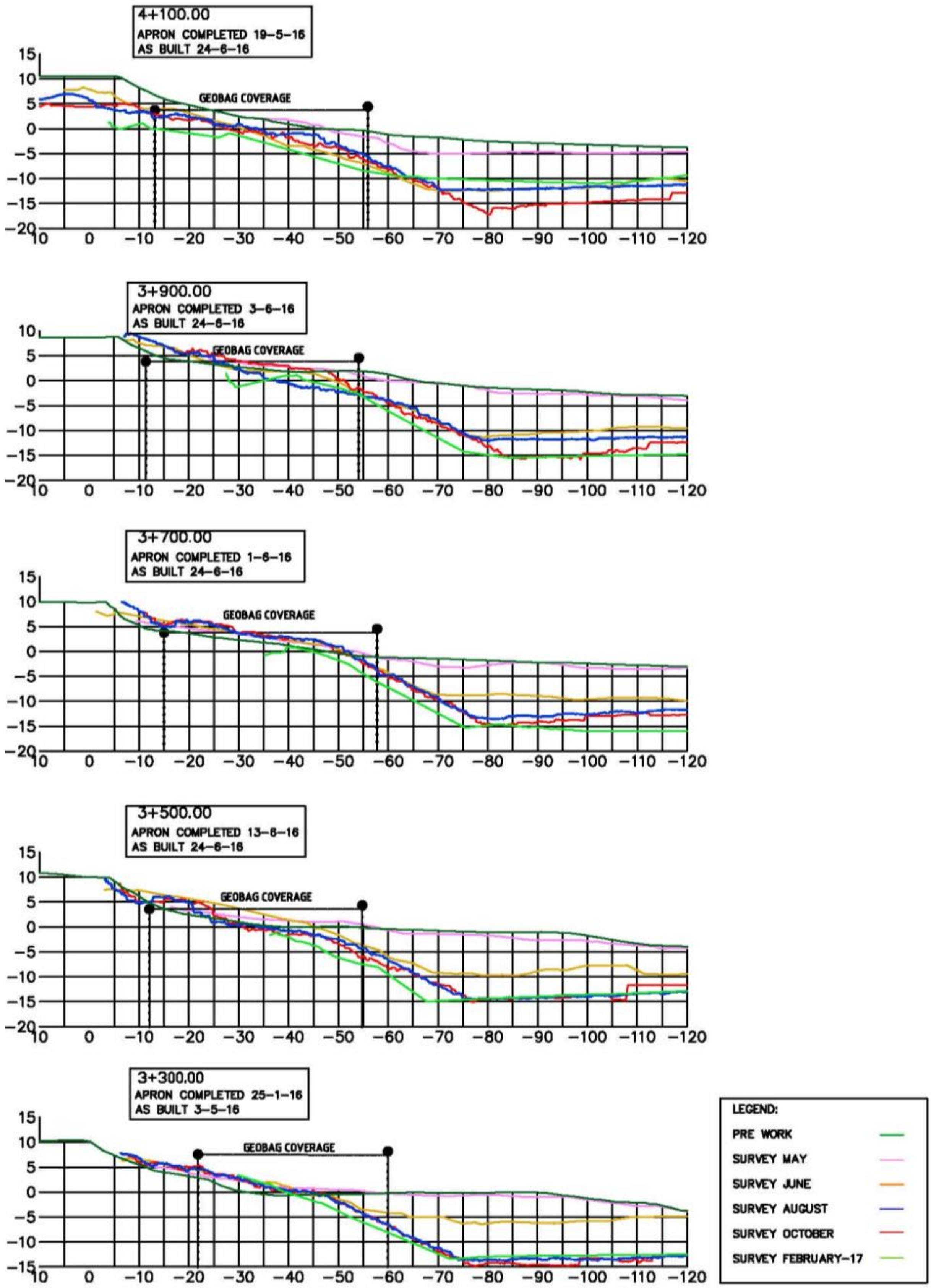


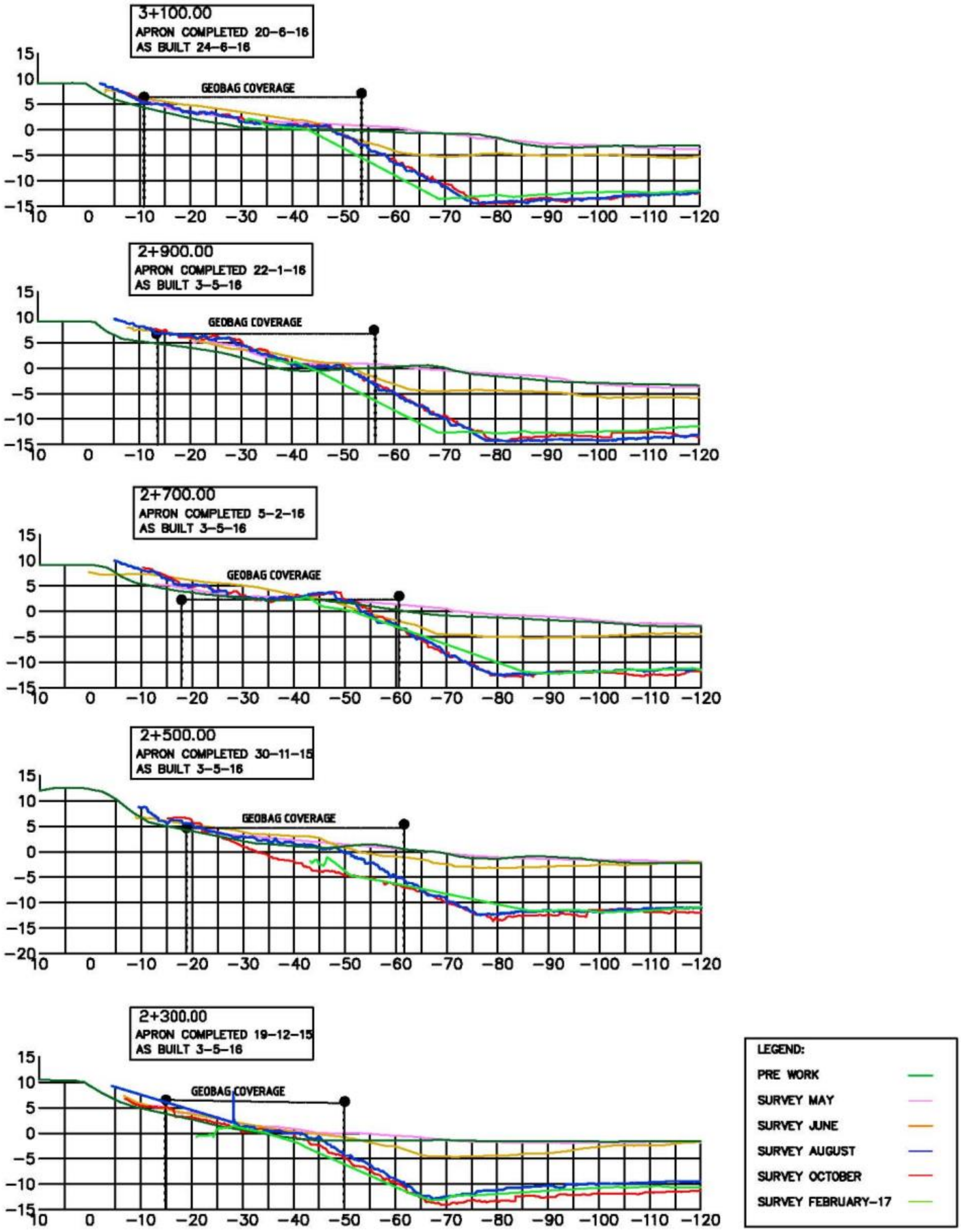
7 Cross section analysis

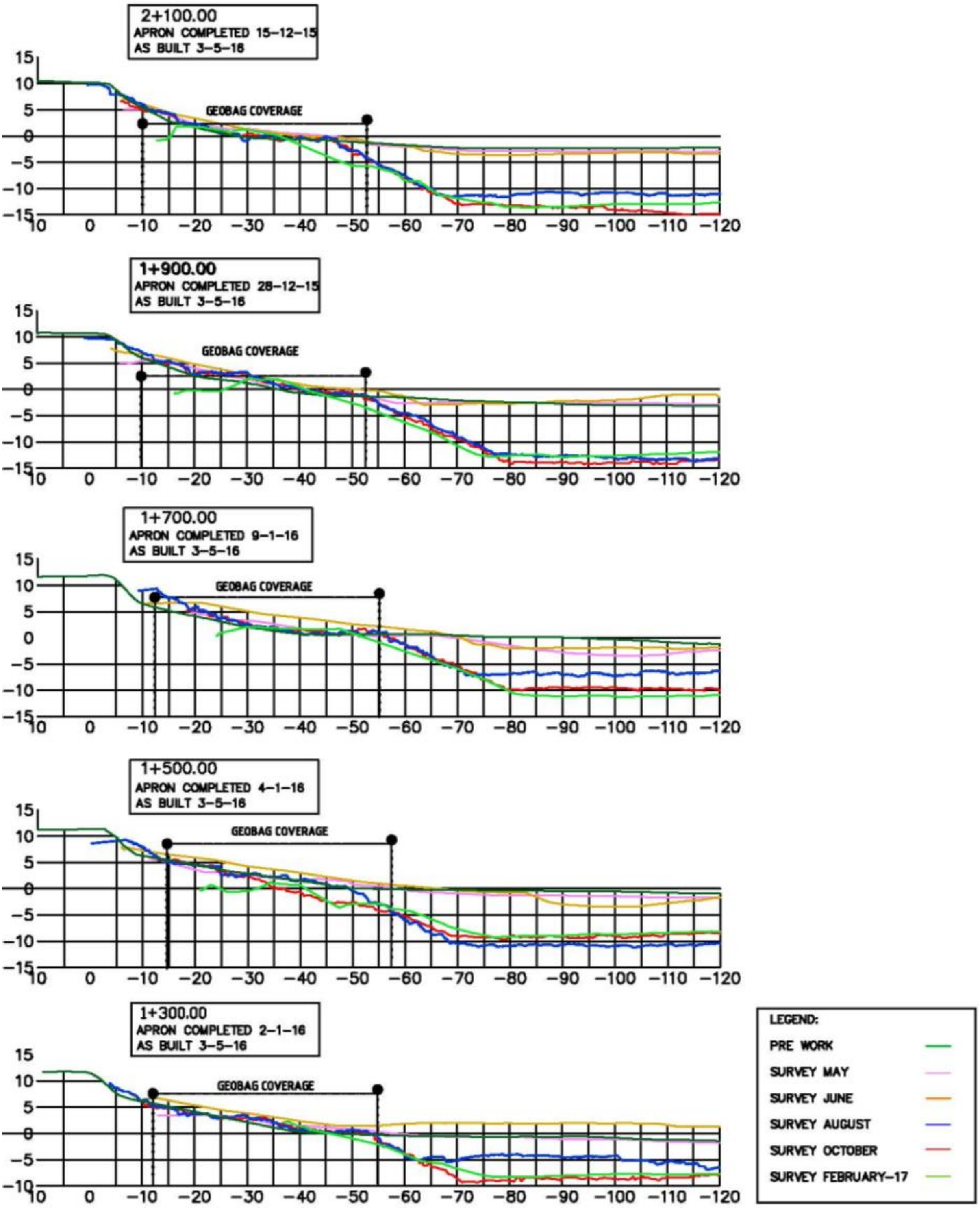
7.1 Chauhali

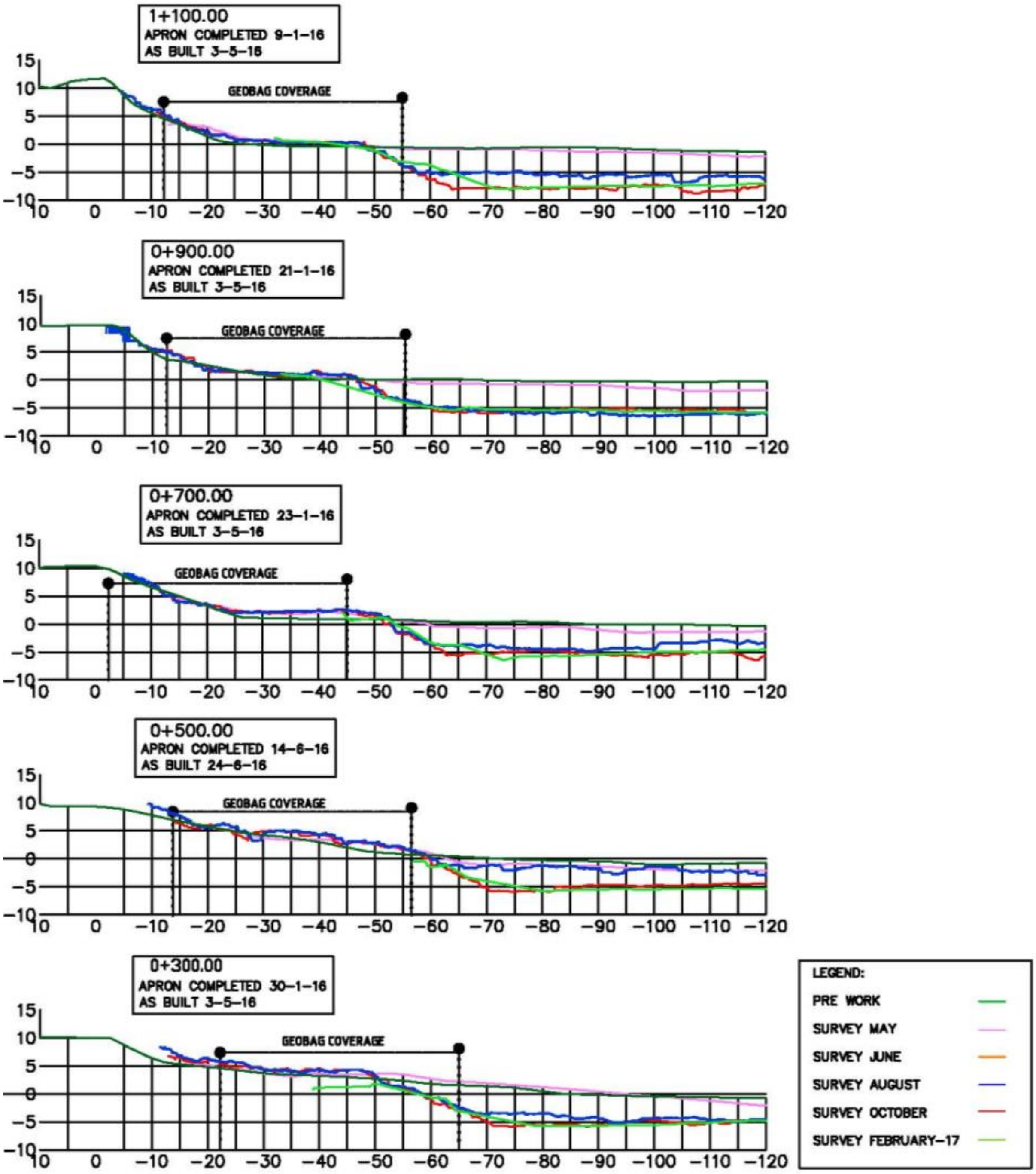


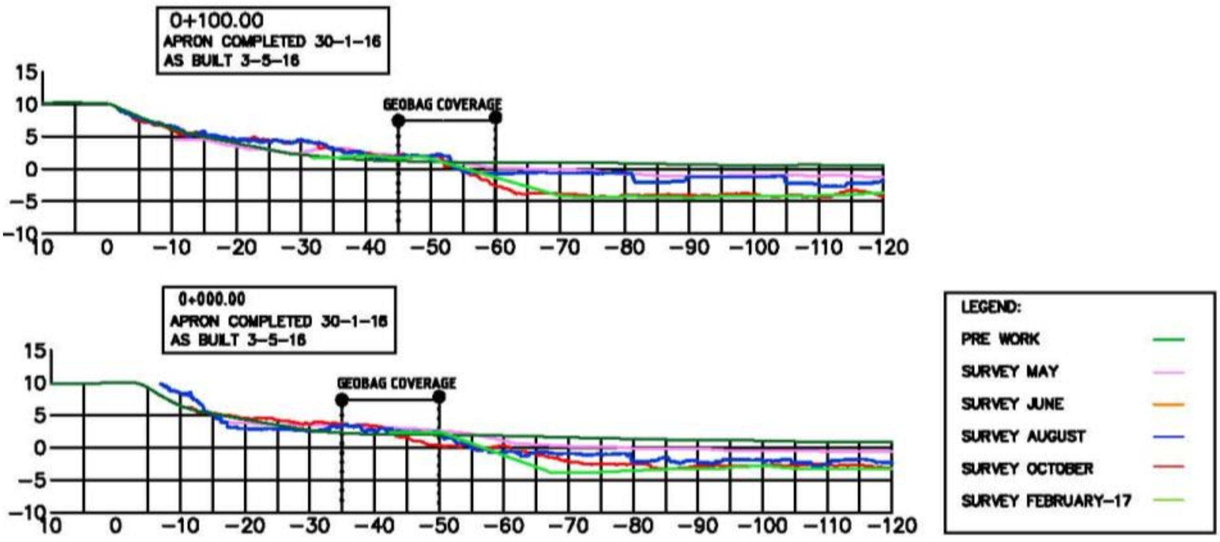

5+100.00
APRON COMPLETED 14-4-16
AS BUILT 3-5-16
GEOBAG COVERAGE
15 10 5 0 −5 −10
10 0 −10 −20 −30 −40 −50 −60 −70 −80 −90 −100 −110 −120
4+900.00
APRON COMPLETED 16-4-16
AS BUILT 3-5-16
GEOBAG COVERAGE
15 10 5 0 −5 −10
10 0 −10 −20 −30 −40 −50 −60 −70 −80 −90 −100 −110 −120
4+700.00
APRON COMPLETED 30-4-16
AS BUILT 3-5-16
GEOBAG COVERAGE
15 10 5 0 −5 −10 −15
10 0 −10 −20 −30 −40 −50 −60 −70 −80 −90 −100 −110 −120
4+500.00
APRON COMPLETED 10-4-16
AS BUILT 3-5-16
GEOBAG COVERAGE
15 10 5 0 −5 −10 −15
10 0 −10 −20 −30 −40 −50 −60 −70 −80 −90 −100 −110 −120
4+300.00
APRON COMPLETED 4-5-16
AS BUILT 24-6-16
GEOBAG COVERAGE
15 10 5 0 −5 −10 −15
10 0 −10 −20 −30 −40 −50 −60 −70 −80 −90 −100 −110 −120
LEGEND:
PRE WORK
SURVEY MAY
SURVEY JUNE
SURVEY AUGUST
SURVEY OCTOBER
SURVEY FEBRUARY-17


4+100.00
APRON COMPLETED 19-5-16
AS BUILT 24-6-16
GEOBAG COVERAGE
3+900.00
APRON COMPLETED 3-6-16
AS BUILT 24-6-16
GEOBAG COVERAGE
3+700.00
APRON COMPLETED 1-6-16
AS BUILT 24-6-16
GEOBAG COVERAGE
3+500.00
APRON COMPLETED 13-6-16
AS BUILT 24-6-16
GEOBAG COVERAGE
3+300.00
APRON COMPLETED 25-1-16
AS BUILT 3-5-16
GEOBAG COVERAGE
LEGEND:
PRE WORK
SURVEY MAY
SURVEY JUNE
SURVEY AUGUST
SURVEY OCTOBER
SURVEY FEBRUARY-17

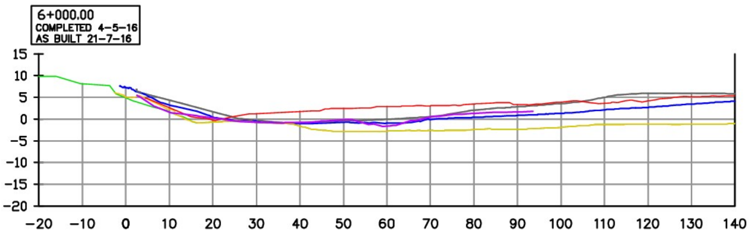

3+100.00
APRON COMPLETED 20-6-16
AS BUILT 24-6-16
GEOBAG COVERAGE
2+900.00
APRON COMPLETED 22-1-16
AS BUILT 3-5-16
GEOBAG COVERAGE
2+700.00
APRON COMPLETED 5-2-16
AS BUILT 3-5-16
GEOBAG COVERAGE
2+500.00
APRON COMPLETED 30-11-15
AS BUILT 3-5-16
GEOBAG COVERAGE
2+300.00
APRON COMPLETED 19-12-15
AS BUILT 3-5-16
GEOBAG COVERAGE
LEGEND:
PRE WORK
SURVEY MAY
SURVEY JUNE
SURVEY AUGUST
SURVEY OCTOBER
SURVEY FEBRUARY-17

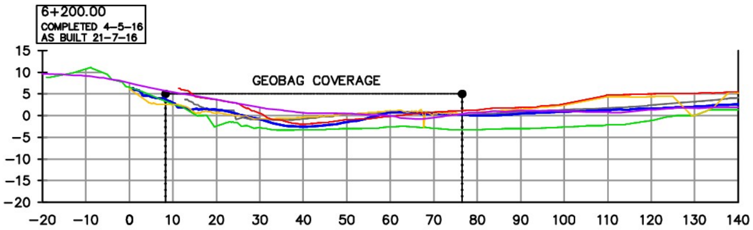

2+100.00
APRON COMPLETED 15-12-15
AS BUILT 3-5-16
GEOBAG COVERAGE
1+900.00
APRON COMPLETED 28-12-15
AS BUILT 3-5-16
GEOBAG COVERAGE
1+700.00
APRON COMPLETED 9-1-16
AS BUILT 3-5-16
GEOBAG COVERAGE
1+500.00
APRON COMPLETED 4-1-16
AS BUILT 3-5-16
GEOBAG COVERAGE
1+300.00
APRON COMPLETED 2-1-16
AS BUILT 3-5-16
GEOBAG COVERAGE
15
10
5
0
-5
-10
-15
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
LEGEND:
PRE WORK
SURVEY MAY
SURVEY JUNE
SURVEY AUGUST
SURVEY OCTOBER
SURVEY FEBRUARY-17

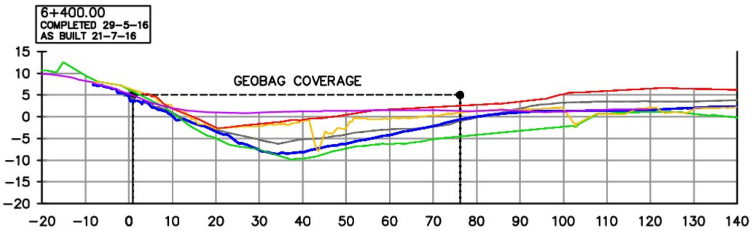

1+100.00
APRON COMPLETED 9-1-16
AS BUILT 3-5-16
GEOBAG COVERAGE
0+900.00
APRON COMPLETED 21-1-16
AS BUILT 3-5-16
GEOBAG COVERAGE
0+700.00
APRON COMPLETED 23-1-16
AS BUILT 3-5-16
GEOBAG COVERAGE
0+500.00
APRON COMPLETED 14-6-16
AS BUILT 24-6-16
GEOBAG COVERAGE
0+300.00
APRON COMPLETED 30-1-16
AS BUILT 3-5-16
GEOBAG COVERAGE
15
10
5
0
-5
-10
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
LEGEND:
PRE WORK
SURVEY MAY
SURVEY JUNE
SURVEY AUGUST
SURVEY OCTOBER
SURVEY FEBRUARY-17

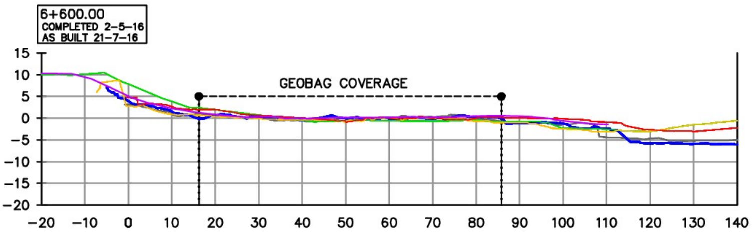

0+100.00
APRON COMPLETED 30-1-16
AS BUILT 3-5-16
GEOBAG COVERAGE
0+000.00
APRON COMPLETED 30-1-16
AS BUILT 3-5-16
GEOBAG COVERAGE
LEGEND:
PRE WORK
SURVEY MAY
SURVEY JUNE
SURVEY AUGUST
SURVEY OCTOBER
SURVEY FEBRUARY-17

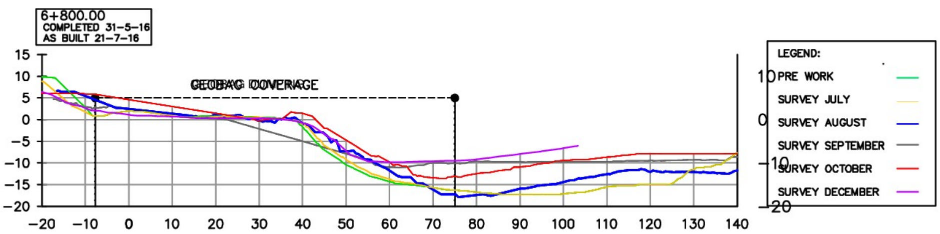
7.2 Zafarganj

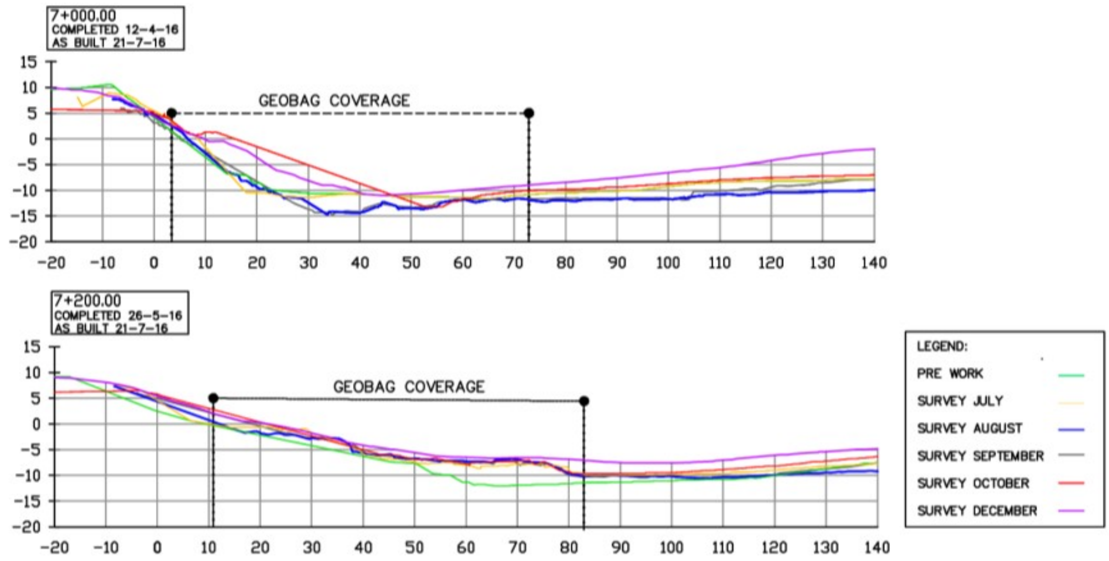






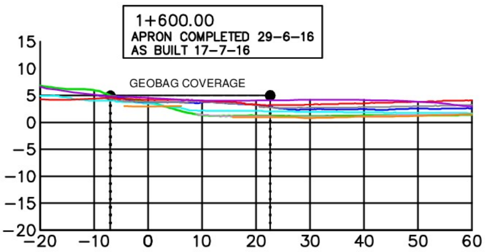


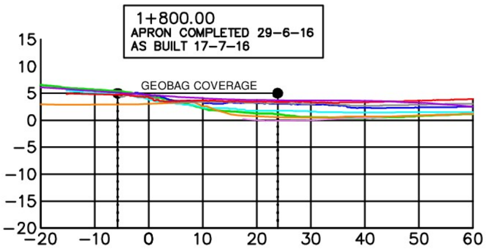


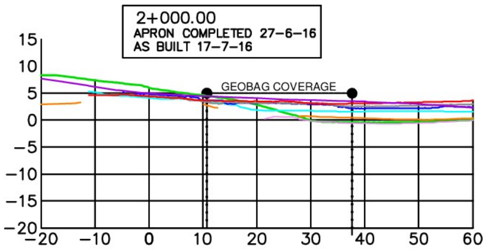


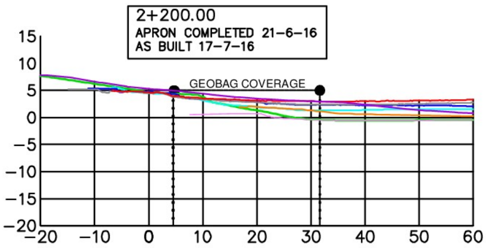
7+000.00
COMPLETED 12-4-16
AS BUILT 21-7-16
GEOBAG COVERAGE
7+200.00
COMPLETED 26-5-16
AS BUILT 21-7-16
GEOBAG COVERAGE
LEGEND:
PRE WORK
SURVEY JULY
SURVEY AUGUST
SURVEY SEPTEMBER
SURVEY OCTOBER
SURVEY DECEMBER

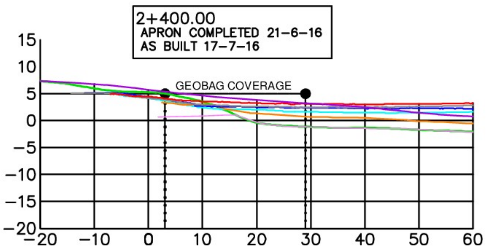
7.3 Harirampur

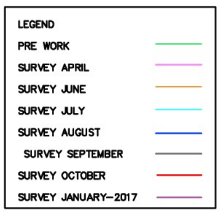


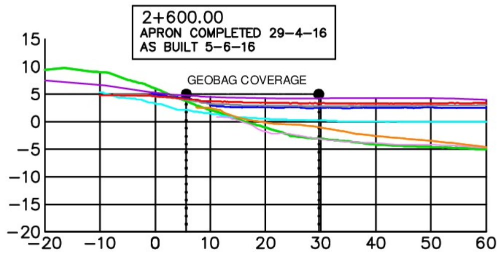


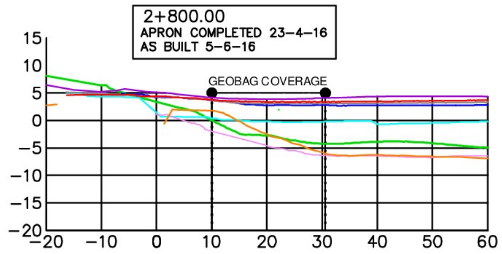


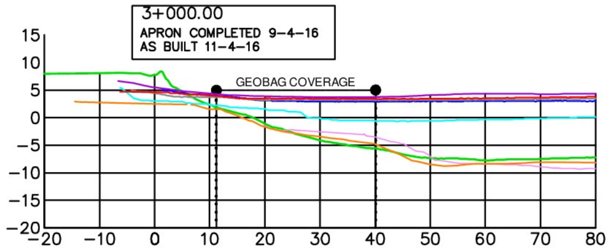


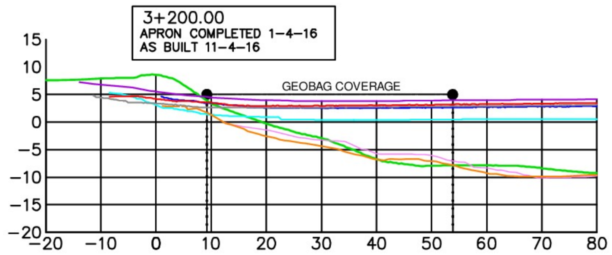





2+600.00
APRON COMPLETED 29-4-16
AS BUILT 5-6-16
GEOBAG COVERAGE
15
10
5
0
-5
-10
-15
-20
-20 -10 0 10 20 30 40 50 60


2+800.00
APRON COMPLETED 23-4-16
AS BUILT 5-6-16
GEOBAG COVERAGE
15
10
5
0
-5
-10
-15
-20
-20 -10 0 10 20 30 40 50 60


3+000.00
APRON COMPLETED 9-4-16
AS BUILT 11-4-16
GEOBAG COVERAGE
15
10
5
0
-5
-10
-15
-20
-20 -10 0 10 20 30 40 50 60 70 80


3+200.00
APRON COMPLETED 1-4-16
AS BUILT 11-4-16
GEOBAG COVERAGE
15
10
5
0
-5
-10
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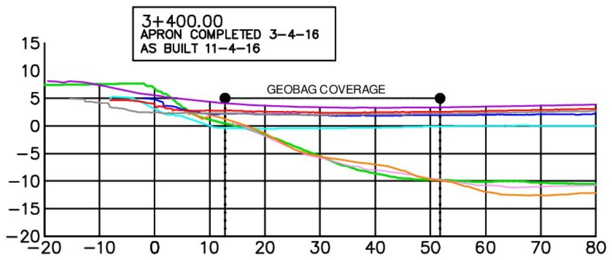
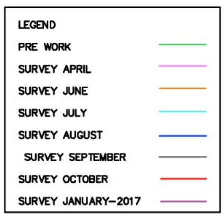
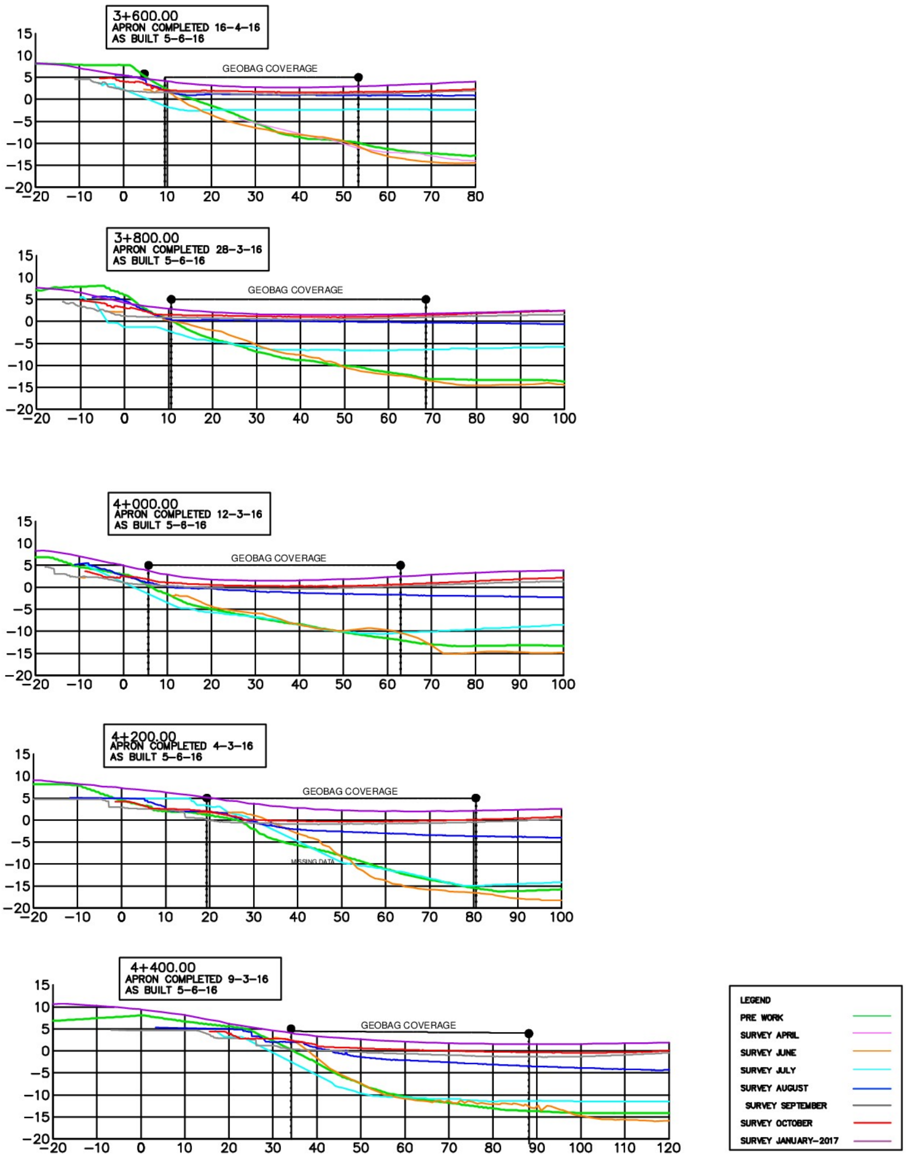
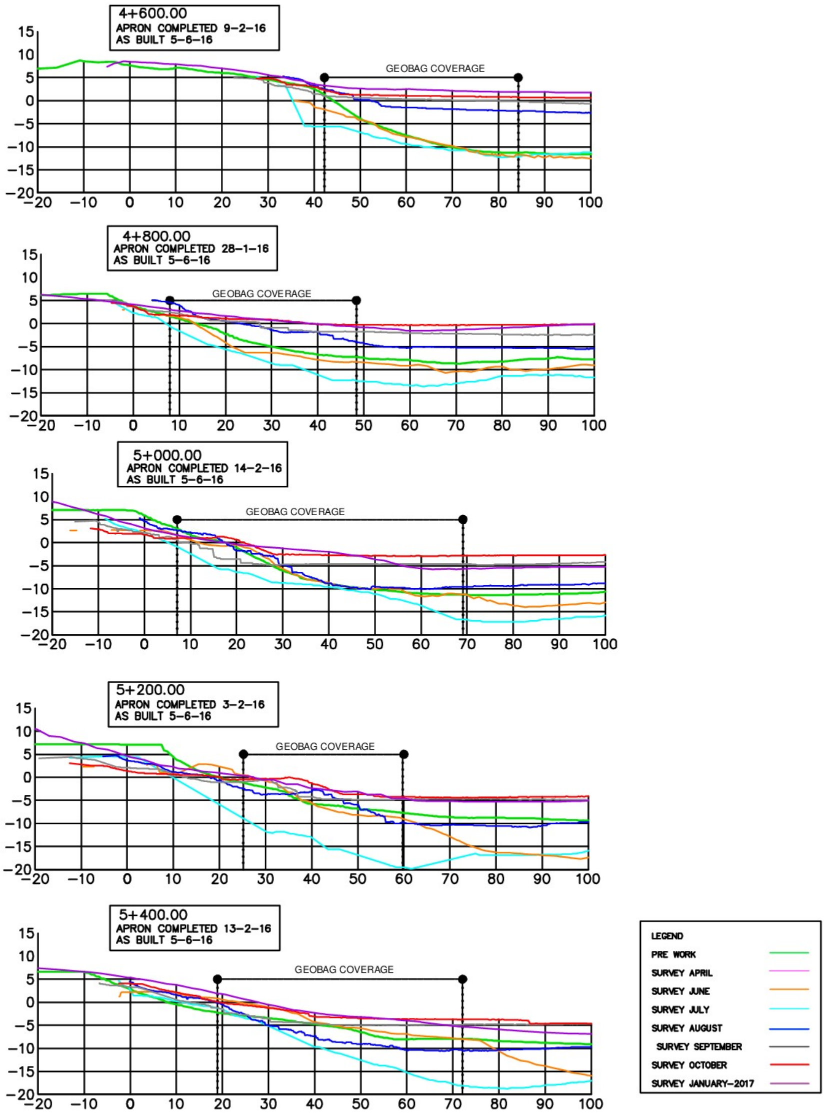
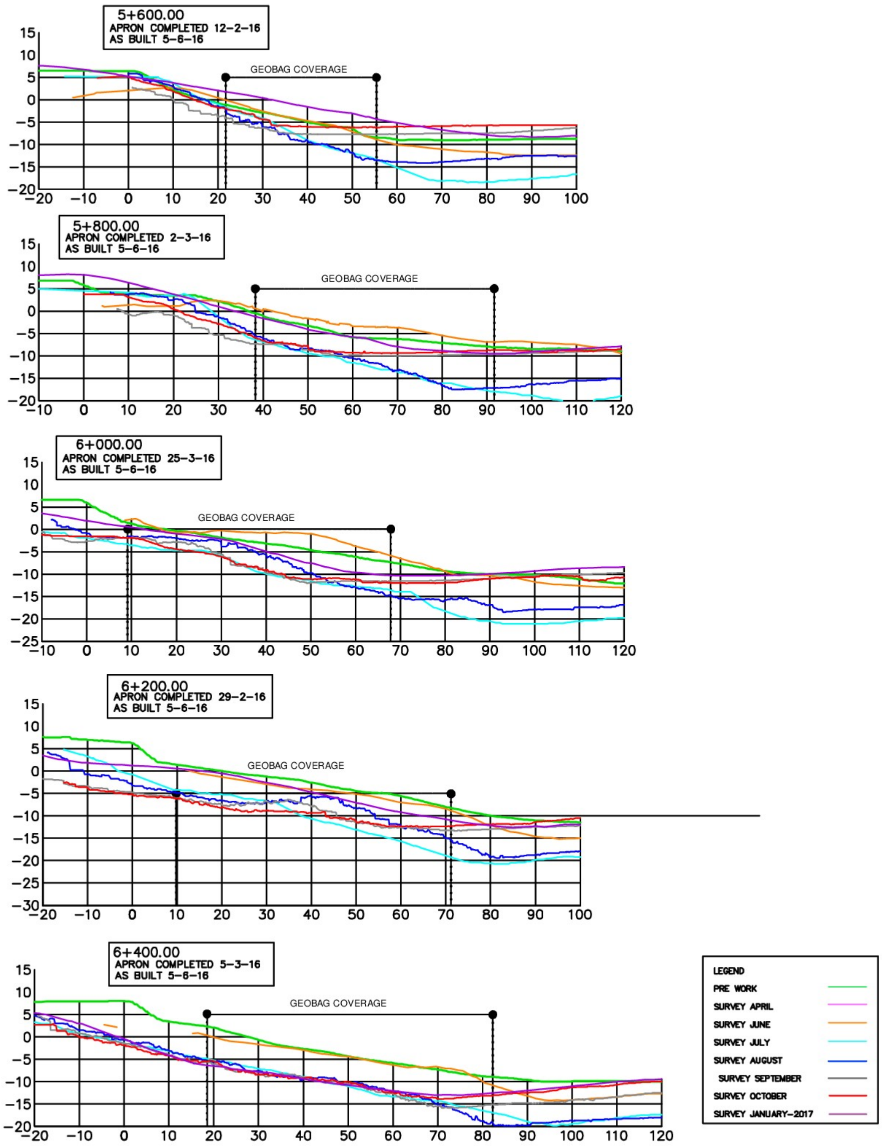
-20
-20 -10 0 10 20 30 40 50 60 70 80

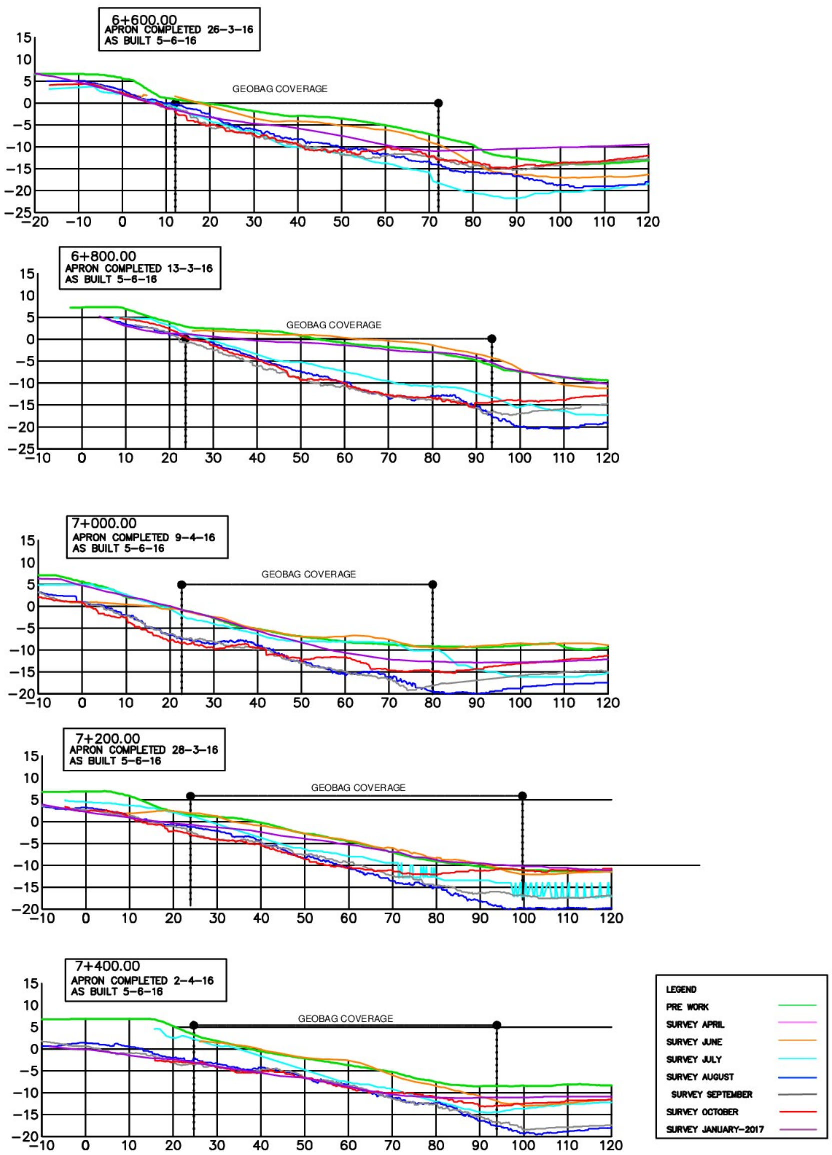

3+400.00
APRON COMPLETED 3-4-16
AS BUILT 11-4-16
GEOBAG COVERAGE
15
10
5
0
-5
-10
-15
-20
-20 -10 0 10 20 30 40 50 60 70 80


LEGEND
PRE WORK
SURVEY APRIL
SURVEY JUNE
SURVEY JULY
SURVEY AUGUST
SURVEY SEPTEMBER
SURVEY OCTOBER
SURVEY JANUARY-2017

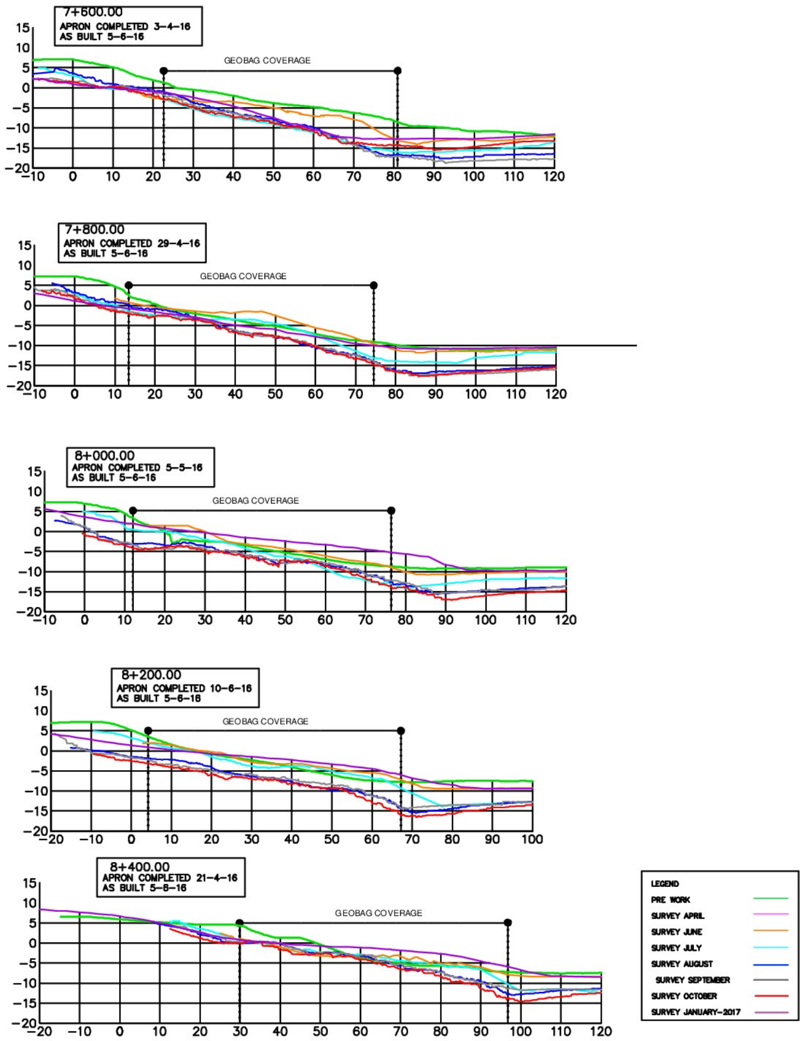

3+600.00
APRON COMPLETED 16-4-16
AS BUILT 5-6-16
GEOBAG COVERAGE
3+800.00
APRON COMPLETED 28-3-16
AS BUILT 5-6-16
GEOBAG COVERAGE
4+000.00
APRON COMPLETED 12-3-16
AS BUILT 5-6-16
GEOBAG COVERAGE
4+200.00
APRON COMPLETED 4-3-16
AS BUILT 5-6-16
GEOBAG COVERAGE
MISSING DATA
4+400.00
APRON COMPLETED 9-3-16
AS BUILT 5-6-16
GEOBAG COVERAGE
LEGEND
PRE WORK
SURVEY APRIL
SURVEY JUNE
SURVEY JULY
SURVEY AUGUST
SURVEY SEPTEMBER
SURVEY OCTOBER
SURVEY JANUARY-2017

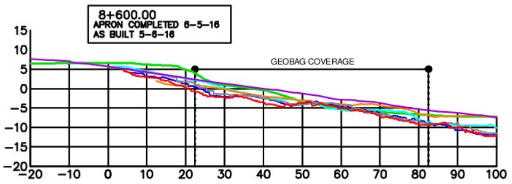

4+600.00
APRON COMPLETED 9-2-16
AS BUILT 5-6-16
GEOBAG COVERAGE
4+800.00
APRON COMPLETED 28-1-16
AS BUILT 5-6-16
GEOBAG COVERAGE
5+000.00
APRON COMPLETED 14-2-16
AS BUILT 5-6-16
GEOBAG COVERAGE
5+200.00
APRON COMPLETED 3-2-16
AS BUILT 5-6-16
GEOBAG COVERAGE
5+400.00
APRON COMPLETED 13-2-16
AS BUILT 5-6-16
GEOBAG COVERAGE
LEGEND
PRE WORK
SURVEY APRIL
SURVEY JUNE
SURVEY JULY
SURVEY AUGUST
SURVEY SEPTEMBER
SURVEY OCTOBER
SURVEY JANUARY-2017

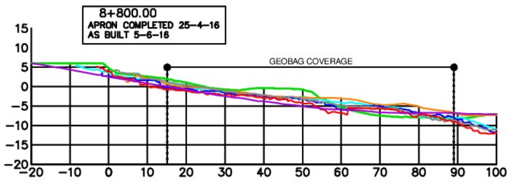

5+600.00
APRON COMPLETED 12-2-16
AS BUILT 5-6-16
GEOBAG COVERAGE
5+800.00
APRON COMPLETED 2-3-16
AS BUILT 5-6-16
GEOBAG COVERAGE
6+000.00
APRON COMPLETED 25-3-16
AS BUILT 5-6-16
GEOBAG COVERAGE
6+200.00
APRON COMPLETED 29-2-16
AS BUILT 5-6-16
GEOBAG COVERAGE
6+400.00
APRON COMPLETED 5-3-16
AS BUILT 5-6-16
GEOBAG COVERAGE
LEGEND
PRE WORK
SURVEY APRIL
SURVEY JUNE
SURVEY JULY
SURVEY AUGUST
SURVEY SEPTEMBER
SURVEY OCTOBER
SURVEY JANUARY-2017

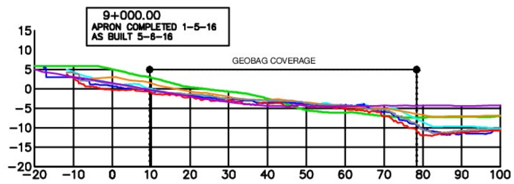


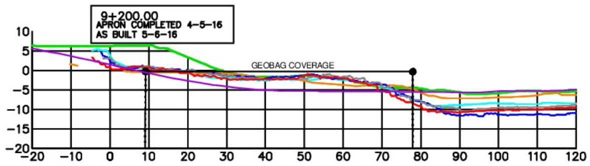
6+600.00
APRON COMPLETED 26-3-16
AS BUILT 5-6-16
GEOBAG COVERAGE
6+800.00
APRON COMPLETED 13-3-16
AS BUILT 5-6-16
GEOBAG COVERAGE
7+000.00
APRON COMPLETED 9-4-16
AS BUILT 5-6-16
GEOBAG COVERAGE
7+200.00
APRON COMPLETED 28-3-16
AS BUILT 5-6-16
GEOBAG COVERAGE
7+400.00
APRON COMPLETED 2-4-16
AS BUILT 5-6-16
GEOBAG COVERAGE
LEGEND
PRE WORK
SURVEY APRIL
SURVEY JUNE
SURVEY JULY
SURVEY AUGUST
SURVEY SEPTEMBER
SURVEY OCTOBER
SURVEY JANUARY-2017

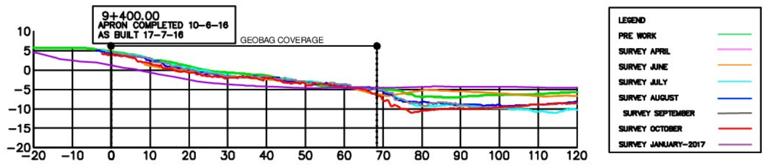

7+600.00
APRON COMPLETED 3-4-16
AS BUILT 5-6-16
GEOBAG COVERAGE
7+800.00
APRON COMPLETED 29-4-16
AS BUILT 5-6-16
GEOBAG COVERAGE
8+000.00
APRON COMPLETED 5-5-16
AS BUILT 5-6-16
GEOBAG COVERAGE
8+200.00
APRON COMPLETED 10-6-16
AS BUILT 5-6-16
GEOBAG COVERAGE
8+400.00
APRON COMPLETED 21-4-16
AS BUILT 5-6-16
GEOBAG COVERAGE
LEGEND
PRE WORK
SURVEY APRIL
SURVEY JUNE
SURVEY JULY
SURVEY AUGUST
SURVEY SEPTEMBER
SURVEY OCTOBER
SURVEY JANUARY-2017

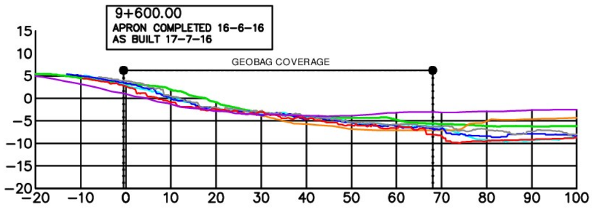

8+600.00
APRON COMPLETED 6-5-16
AS BUILT 5-6-16
GEOBAG COVERAGE

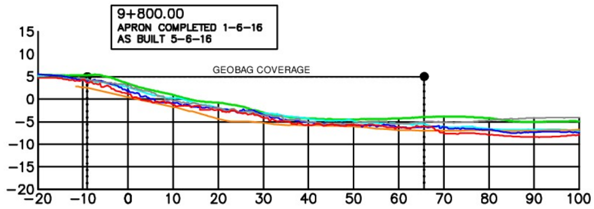

8+800.00
APRON COMPLETED 25-4-16
AS BUILT 5-6-16
GEOBAG COVERAGE

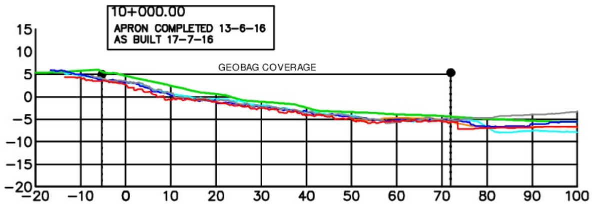

9+000.00
APRON COMPLETED 1-5-16
AS BUILT 5-6-16
GEOBAG COVERAGE

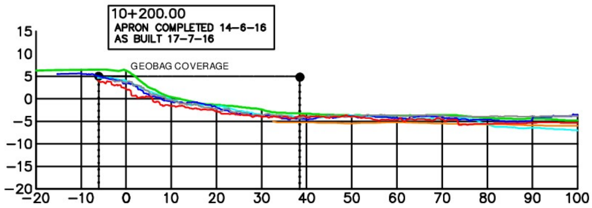

9+200.00
APRON COMPLETED 4-5-16
AS BUILT 5-6-16
GEOBAG COVERAGE

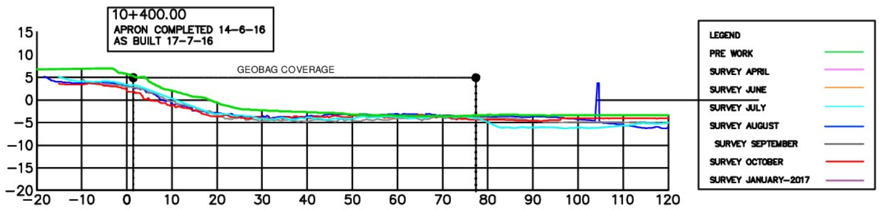

9+400.00
APRON COMPLETED 10-6-16
AS BUILT 17-7-16
GEOBAG COVERAGE
LEGEND
PRE WORK
SURVEY APRIL
SURVEY JUNE
SURVEY JULY
SURVEY AUGUST
SURVEY SEPTEMBER
SURVEY OCTOBER
SURVEY JANUARY-2017


9+600.00
APRON COMPLETED 16-6-16
AS BUILT 17-7-16
GEOBAG COVERAGE


9+800.00
APRON COMPLETED 1-6-16
AS BUILT 5-6-16
GEOBAG COVERAGE

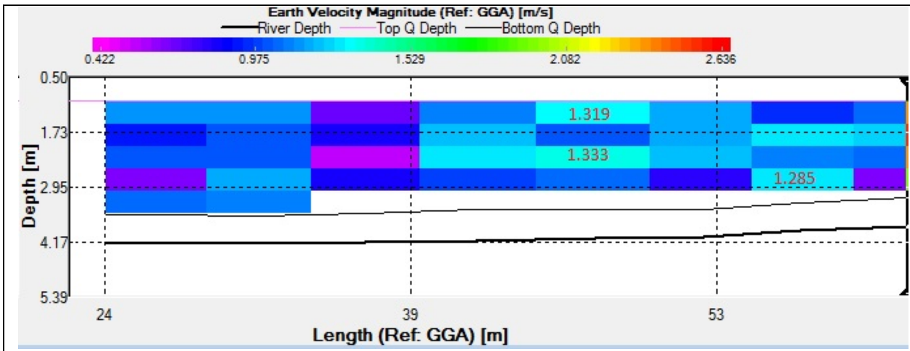

10+000.00
APRON COMPLETED 13-6-16
AS BUILT 17-7-16
GEOBAG COVERAGE


10+200.00
APRON COMPLETED 14-6-16
AS BUILT 17-7-16
GEOBAG COVERAGE

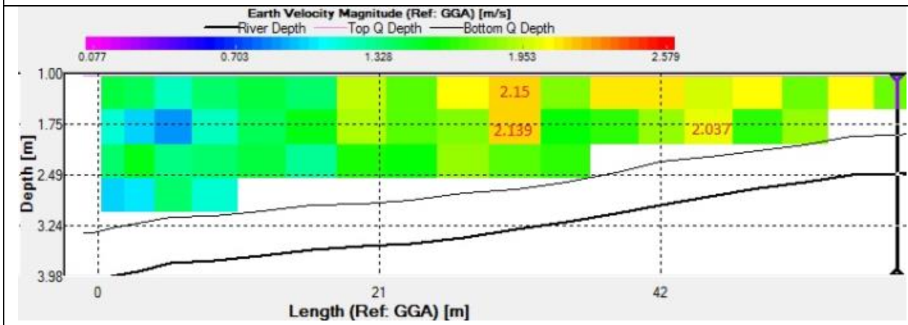

10+400.00
APRON COMPLETED 14-6-16
AS BUILT 17-7-16
GEOBAG COVERAGE
LEGEND
PRE WORK
SURVEY APRIL
SURVEY JUNE
SURVEY JULY
SURVEY AUGUST
SURVEY SEPTEMBER
SURVEY OCTOBER
SURVEY JANUARY-2017

8 Detailed flow measurements at the Sites

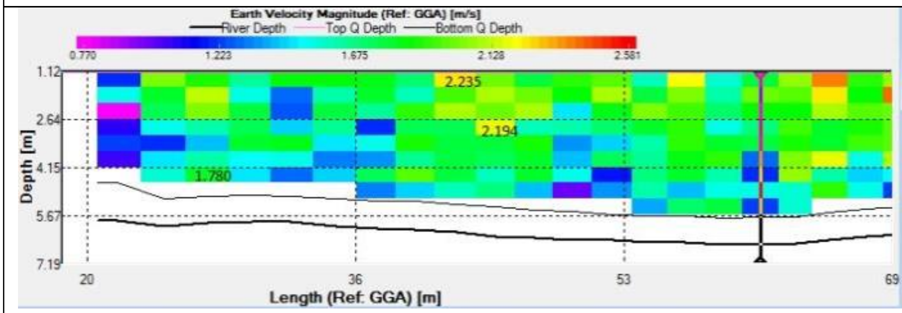
8.1 Chauhali



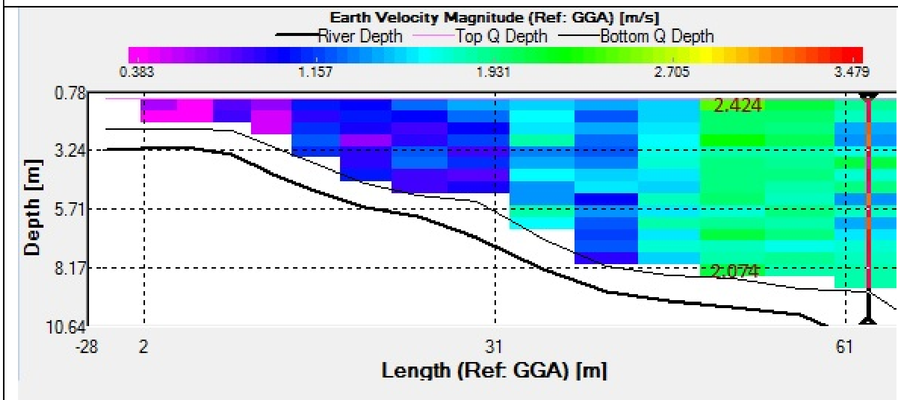
- **Site:** Chauhali Transect 1.
- **Month:** August 2016
- **Maximum velocity near bed:** 1.285ms^{-1}



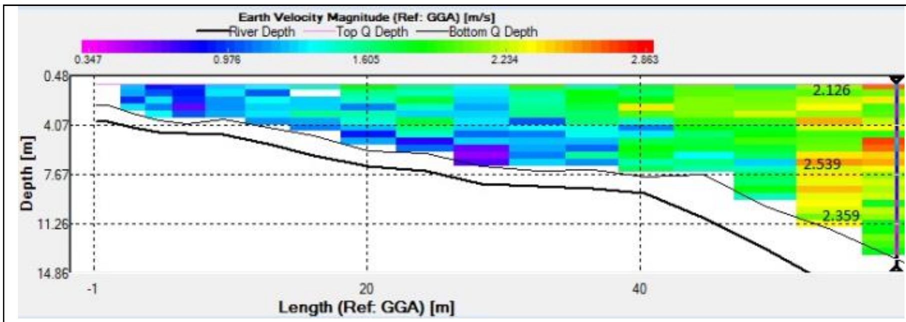
- **Site:** Chauhali Transect 1.
- **Month:** September 2016
- **Maximum velocity near bed:** 2.037ms^{-1}



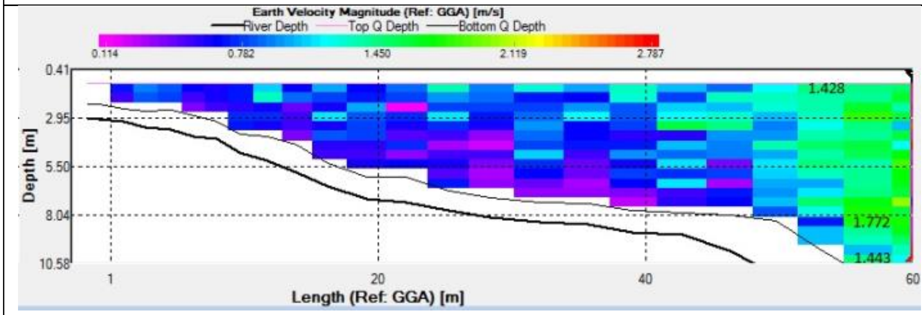
- **Site:** Chauhali Transect 1.
- **Month:** October 2016
- **Maximum velocity near bed:** 1.78ms^{-1}



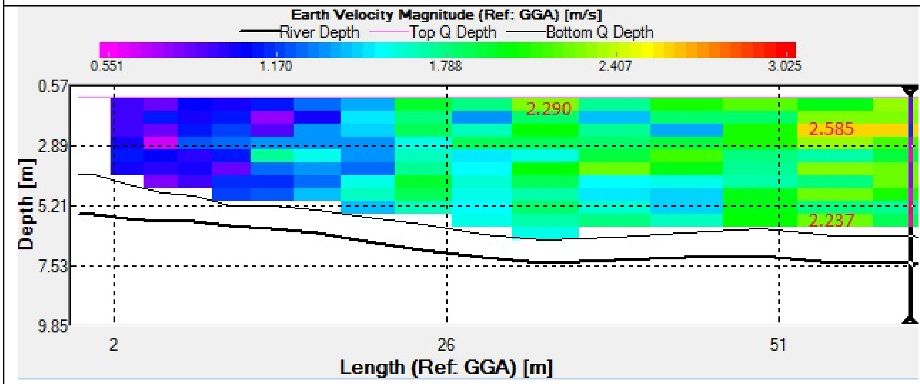
- **Site:** Chauhali Transect 2.
- **Month:** August 2016
- **Maximum velocity near bed:**2.07ms^{-1}



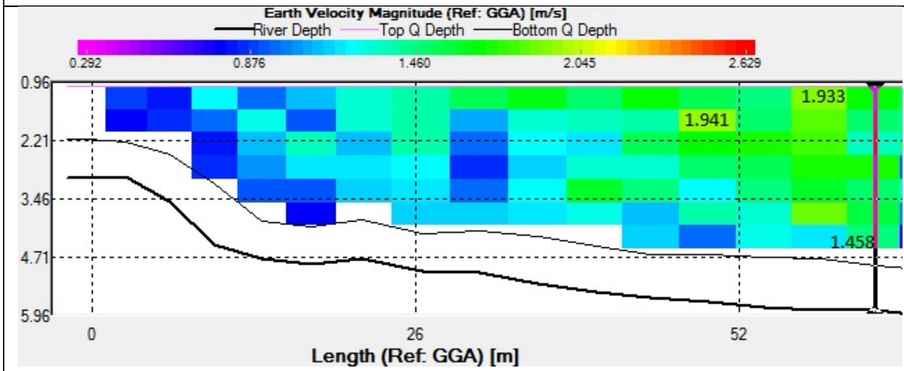
- **Site:** Chauhali Transect 2.
- **Month:** September 2016
- **Maximum velocity near bed:**2.35ms-1



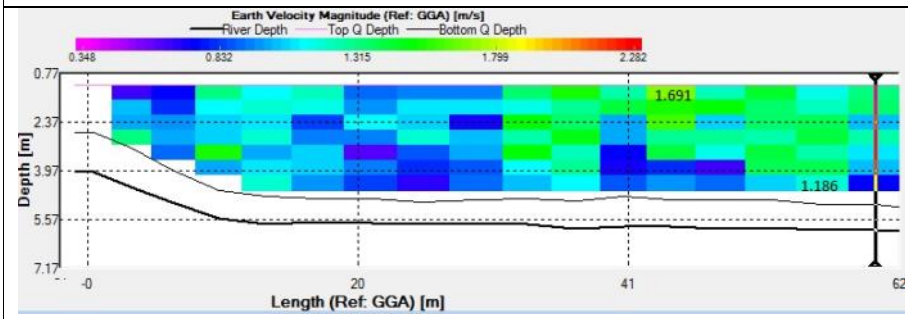
- **Site:** Chauhali Transect 2.
- **Month:** October 2016
- **Maximum velocity near bed:** 1.44ms-1



- **Site:** Chauhali Transect 3.
- **Month:**August 2016
- **Maximum velocity near bed:**2.237ms-1

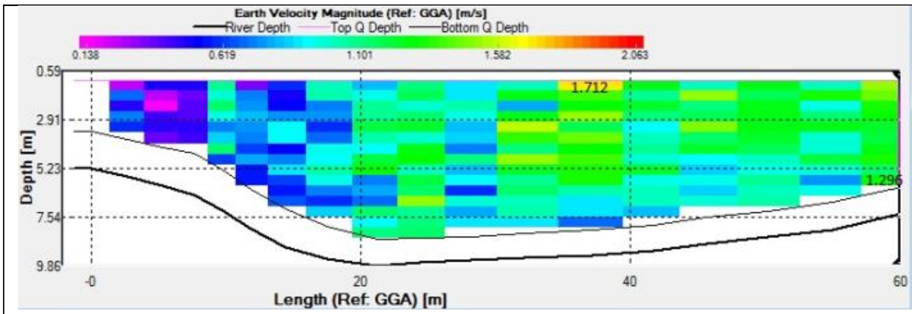
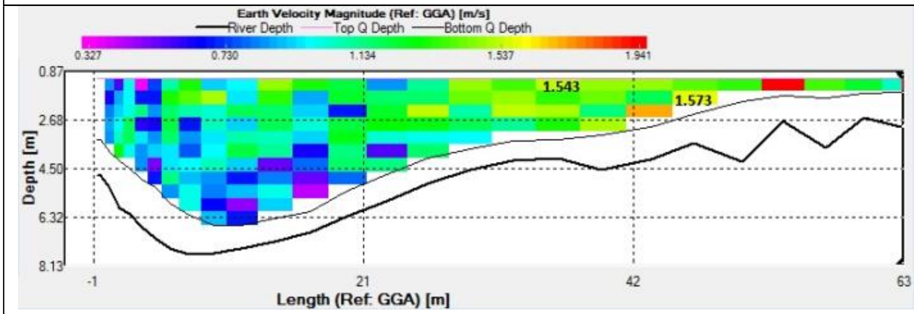
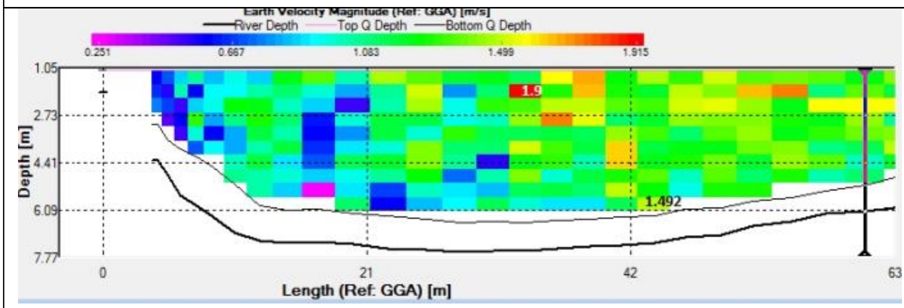
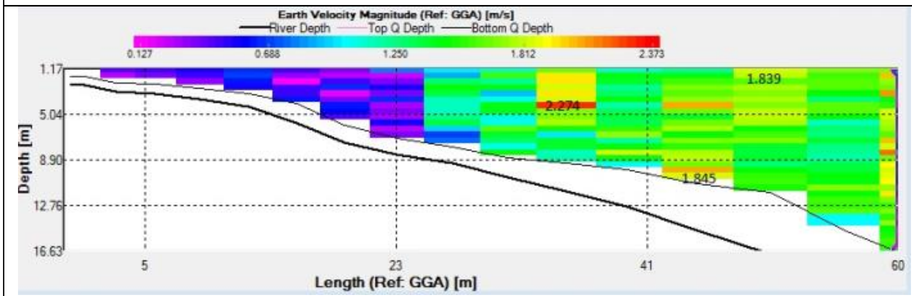
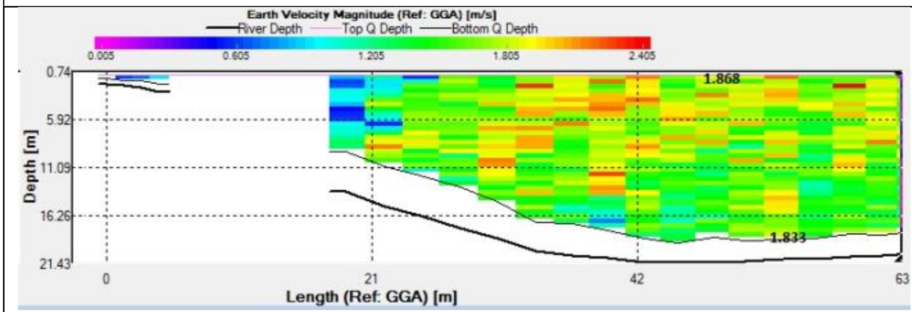


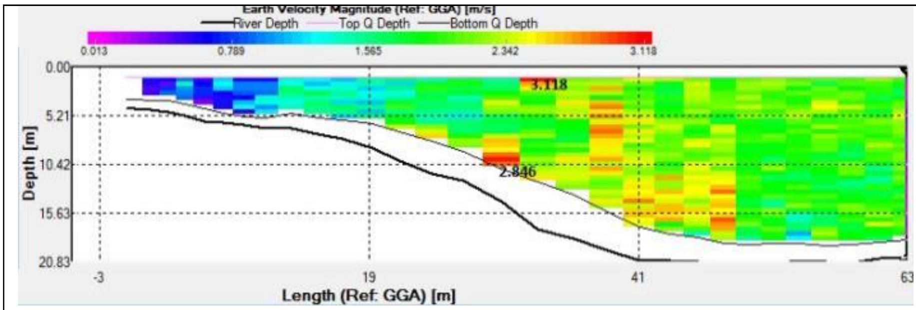
- **Site:** Chauhali Transect 3.
- **Month:** September 2016
- **Maximum velocity near bed:** 1.45ms-1



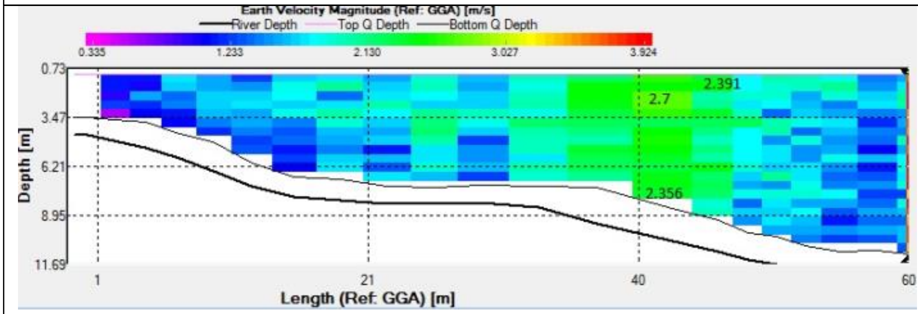
- **Site:** Chauhali Transect 3.
- **Month:** October 2016
- **Maximum velocity near bed:** 1.186ms-1

8.2 Zafarganj

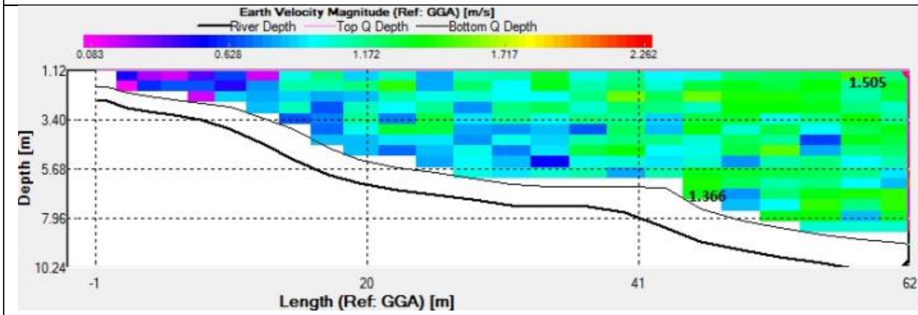
	• **Site:** Zaffarjanj Transect 1. • **Month:** August 2016 • **Maximum velocity near bed:** 1.2ms^{-1}
	• **Site:** Zaffarjanj Transect 1. • **Month:** September 2016 • **Maximum velocity near bed:** 1.57ms^{-1}
	• **Site:** Zaffarjanj Transect 1. • **Month:** October 2016 • **Maximum velocity near bed:** 1.4ms^{-1}
	• **Site:** Zaffarjanj Transect 2. • **Month:** August 2016 • **Maximum velocity near bed:** 1.84ms^{-1}
	• **Site:** Zaffarjanj Transect 2. • **Month:** September 2016 • **Maximum velocity near bed:** 1.83ms^{-1}



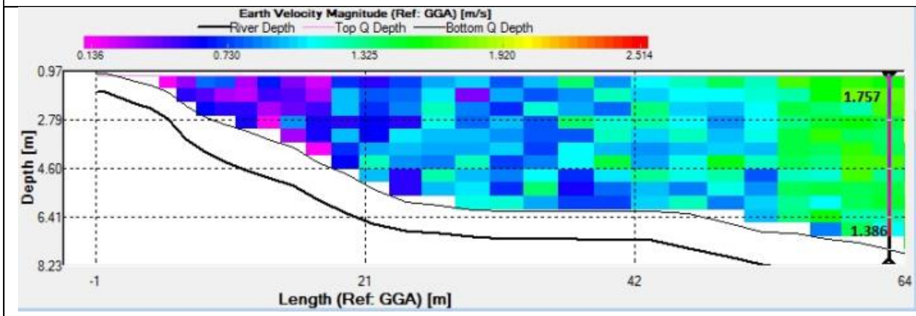
- **Site:** Zaffarjanj Transect 2.
- **Month:** October 2016
- **Maximum velocity near bed:**2.8ms^{-1}



- **Site:** Zaffarjanj Transect 3.
- **Month:** August 2016
- **Maximum velocity near bed:**2.3ms^{-1}

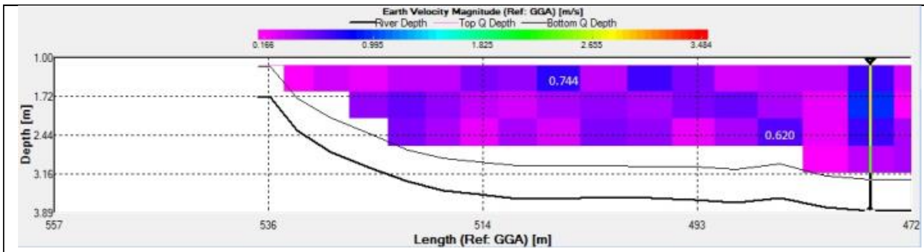
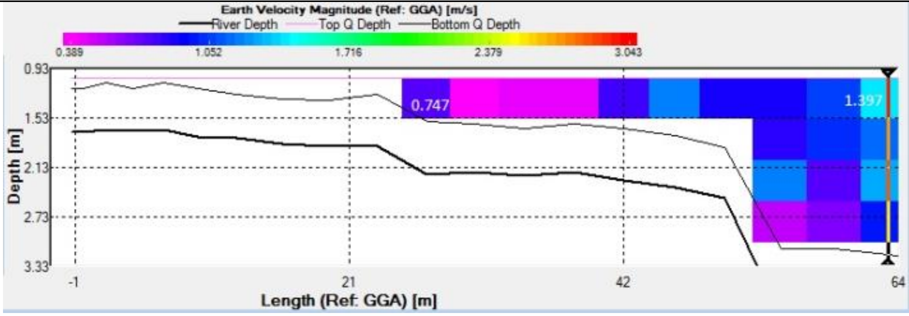
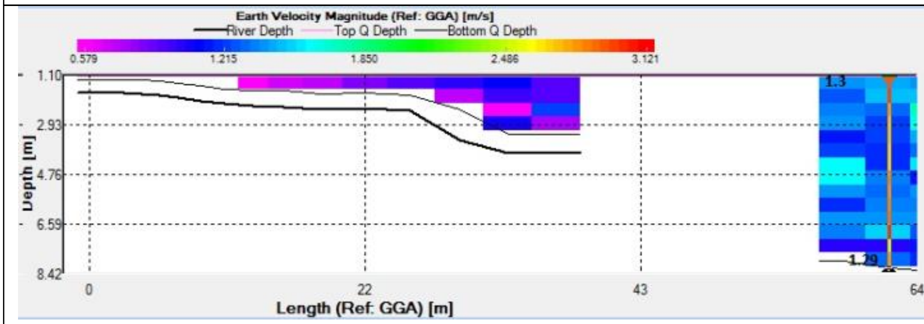
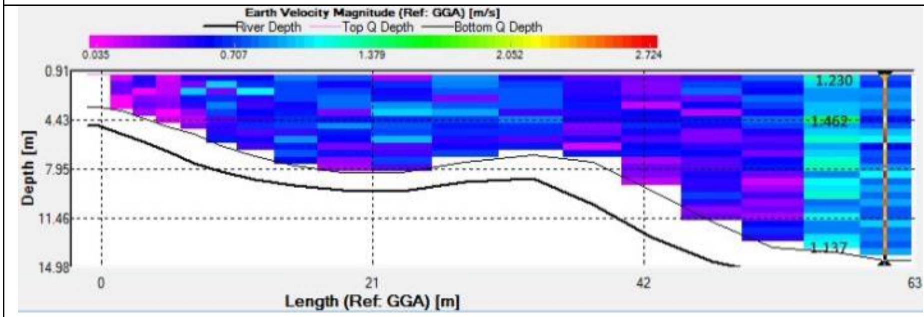
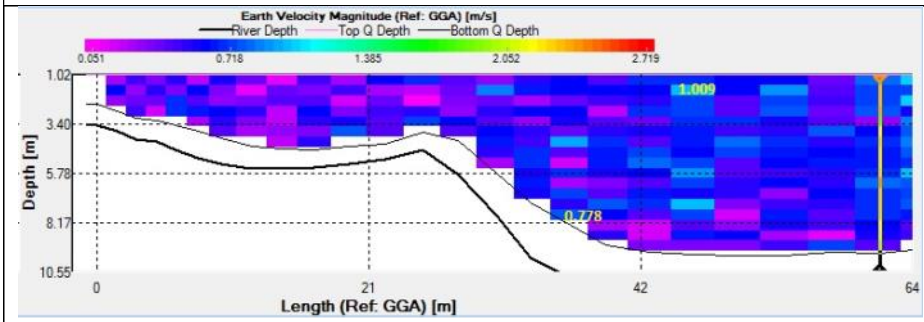


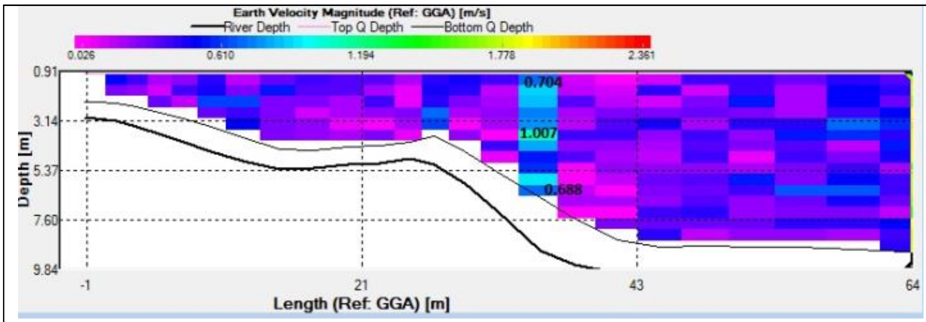
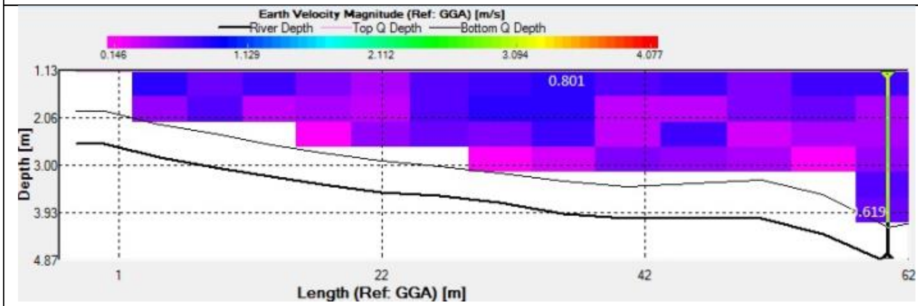
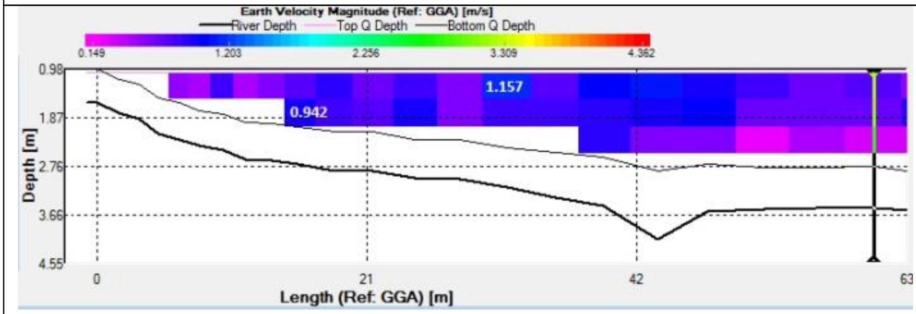
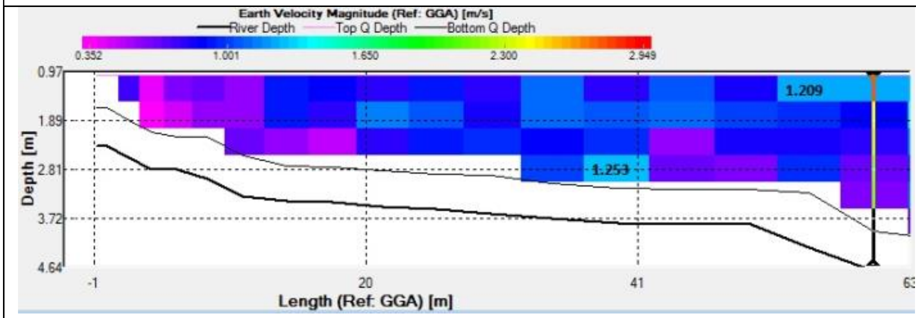
- **Site:** Zaffarjanj Transect 3.
- **Month:** September 2016
- **Maximum velocity near bed:** 1.3ms^{-1}



- **Site:** Zaffarjanj Transect 3.
- **Month:** October 2016
- **Maximum velocity near bed:** 1.386ms^{-1}

8.3 Harirampur

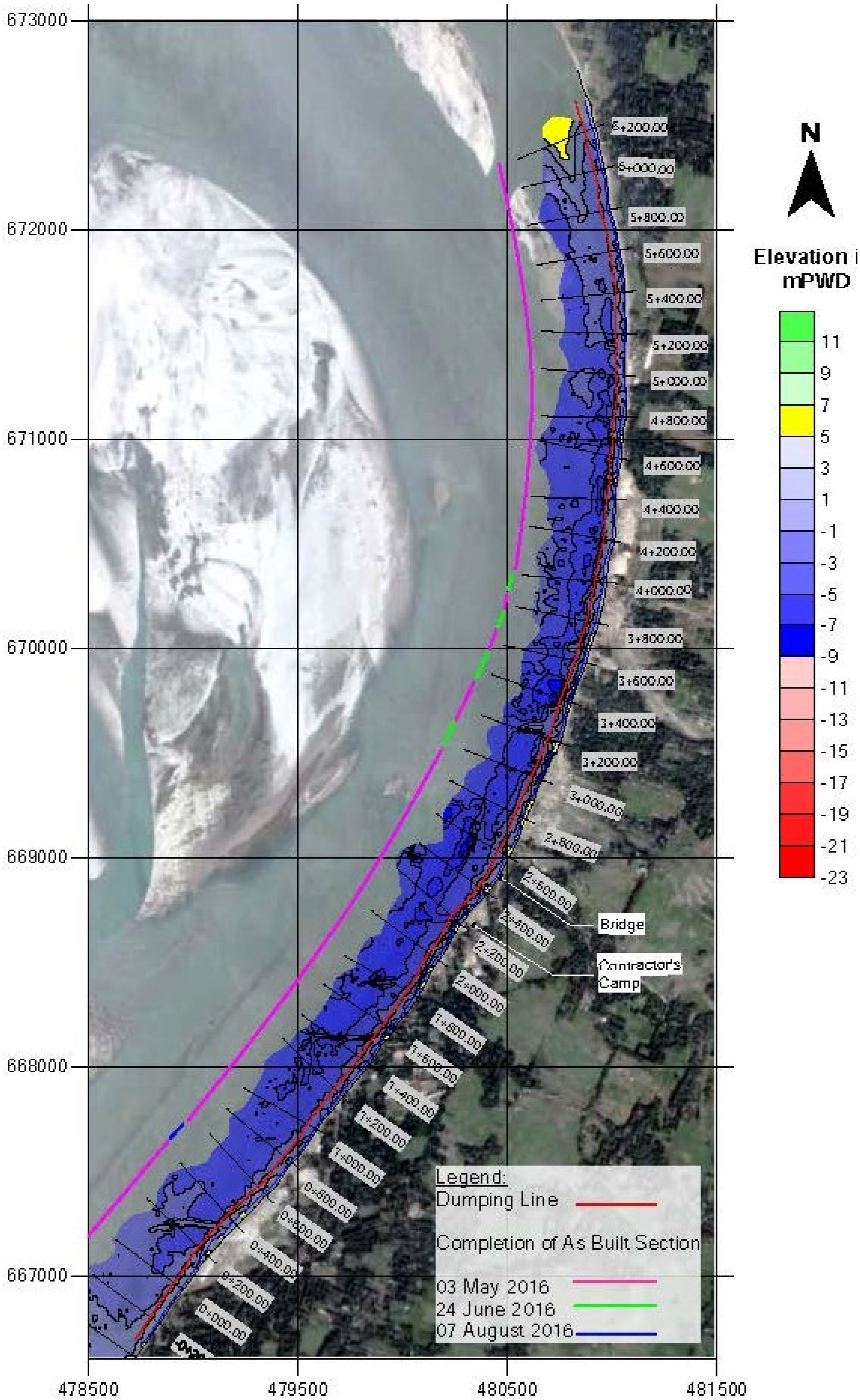
	• **Site:** Harirampur Transect 1. • **Month:** August 2016 • **Maximum velocity near bed:** 0.6ms^{-1}
	• **Site:** Harirampur Transect 1. • **Month:** September 2016 • **Maximum velocity near bed:** 0.747ms^{-1}
	• **Site:** Harirampur Transect 1. • **Month:** October 2016 • **Maximum velocity near bed:** 1.29ms^{-1}
	• **Site:** Harirampur Transect 2. • **Month:** August 2016 • **Maximum velocity near bed:** 1.13ms^{-1}
	• **Site:** Harirampur Transect 2. • **Month:** September 2016 • **Maximum velocity near bed:** 0.77ms^{-1}

	• **Site:** Harirampur Transect 2. • **Month:** October 2016 • **Maximum velocity near bed:**0.6ms^{-1}
	• **Site:** Harirampur Transect 3. • **Month:** August 2016 • **Maximum velocity near bed:**0.6ms^{-1}
	• **Site:** Harirampur Transect 3. • **Month:** September 2016 • **Maximum velocity near bed:**0.9ms^{-1}
	• **Site:** Harirampur Transect 3. • **Month:** October 2016 • **Maximum velocity near bed:** 1.2ms^{-1}

9 Provisional Adaptation Designs

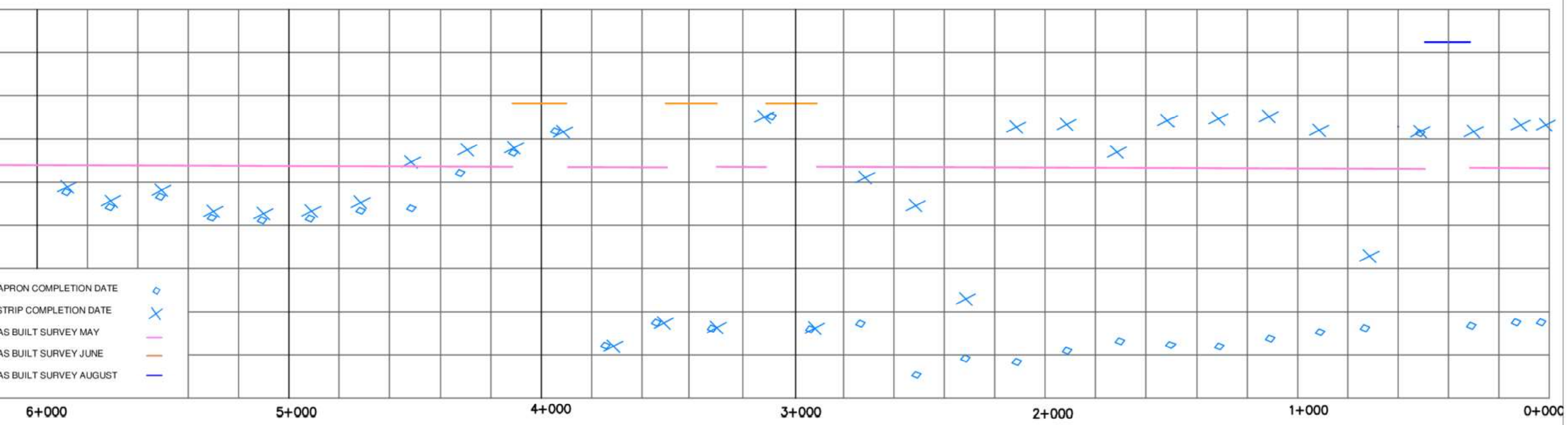
9.1 Chauhali

9.1.1 As-built with 2017 satellite picture

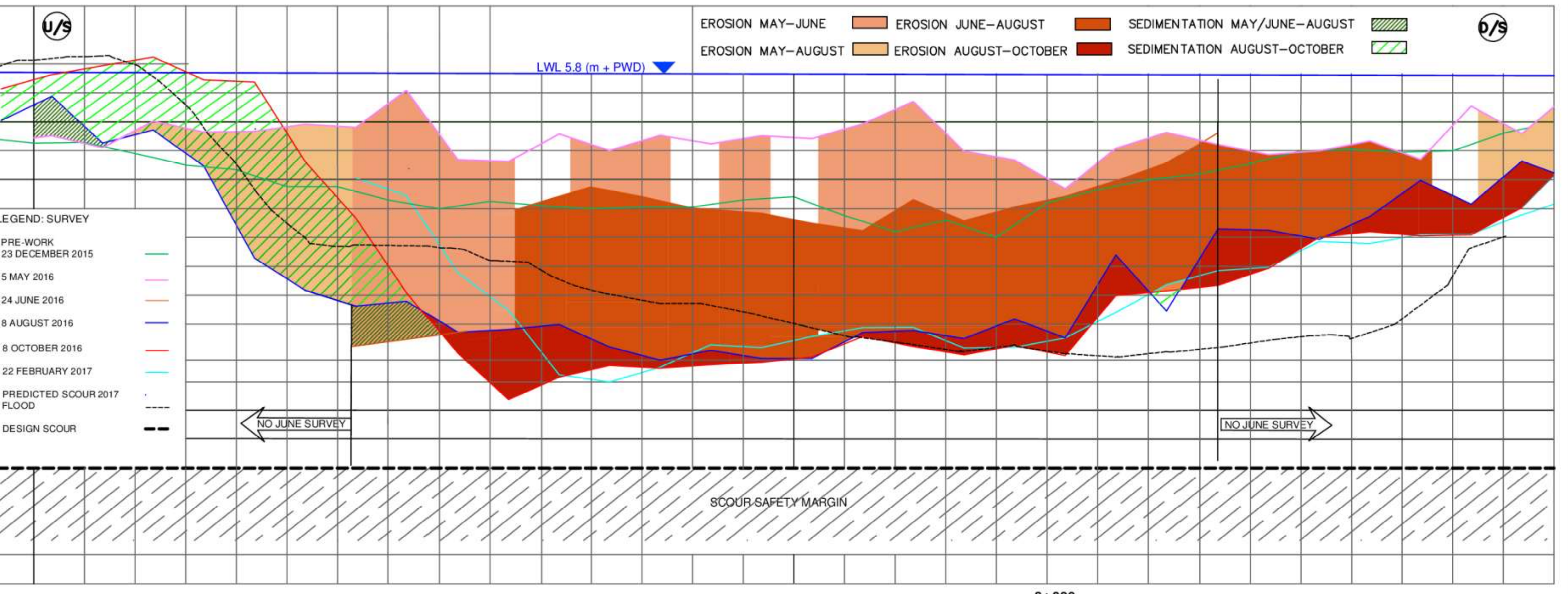


9.1.2 Longitudinal Section – Launching of Apron

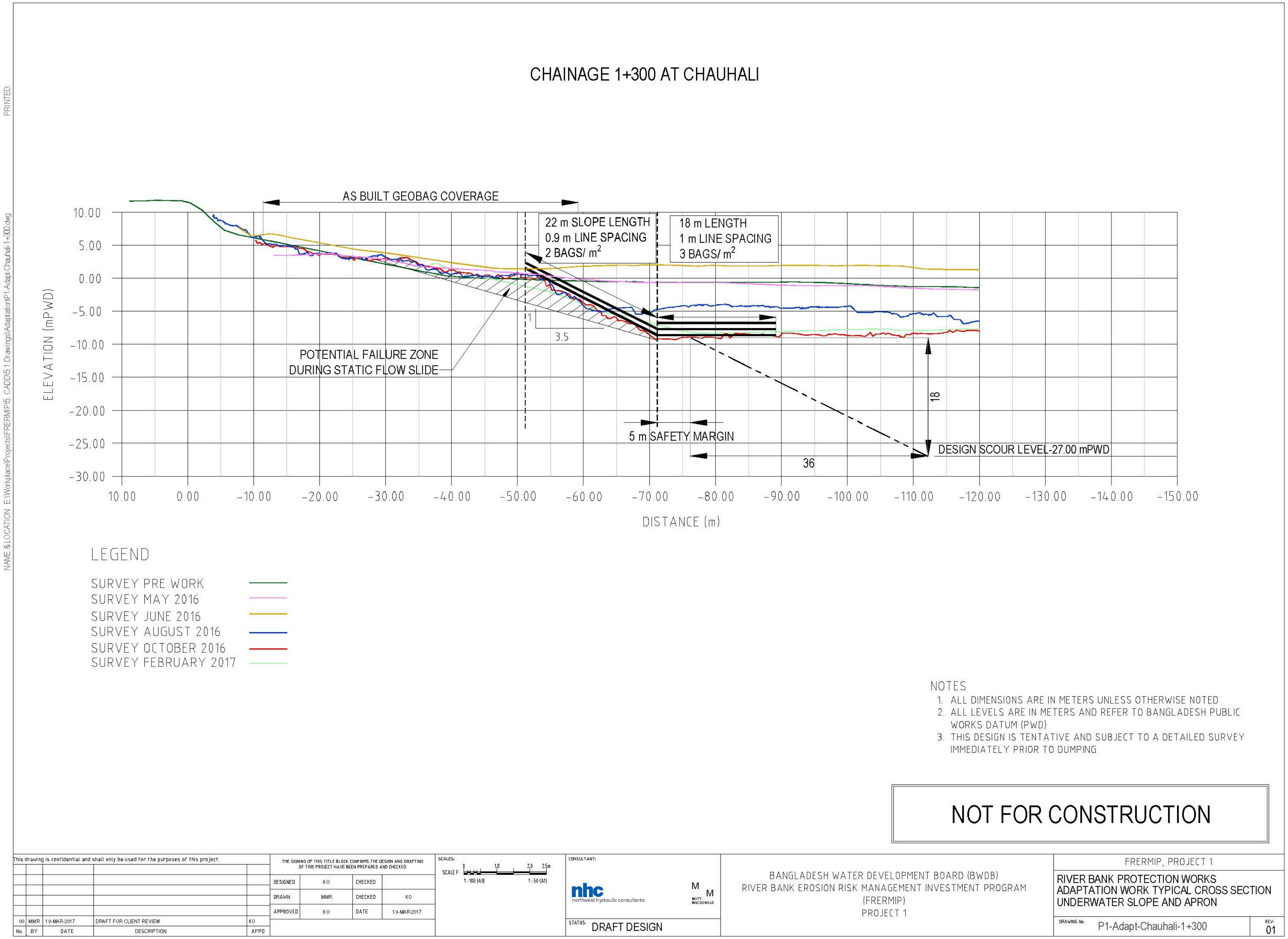
n Progress and As-Built Survey



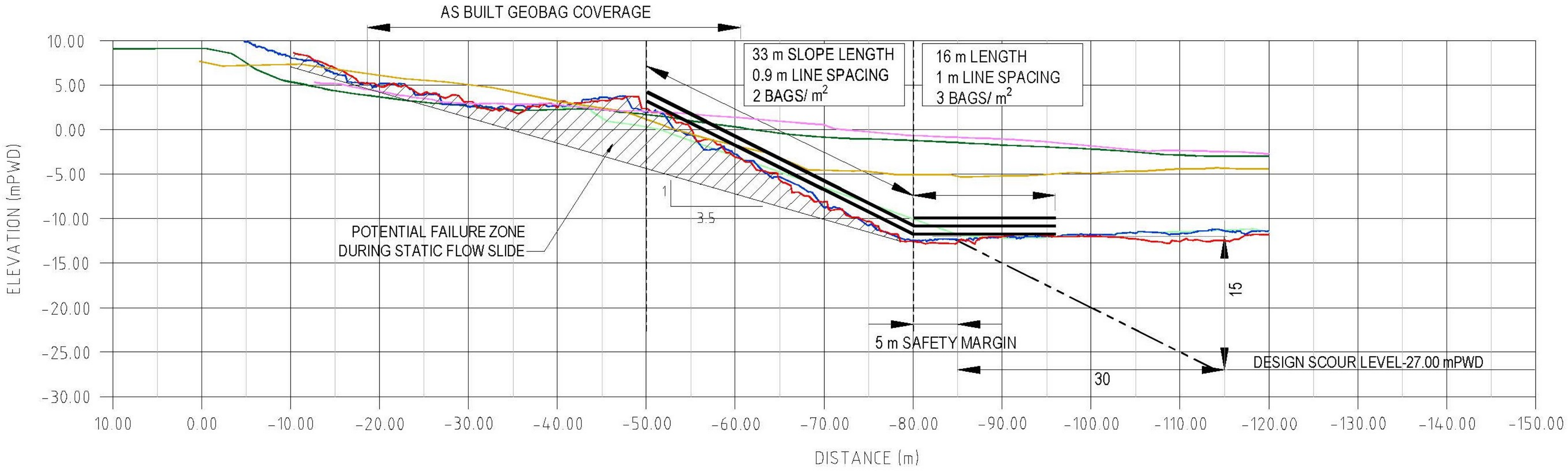
ron Development (2015 - 2017)



9.1.3 Cross Section – Example Provisional Adaptation Works



CHAINAGE 2+700 AT CHAUHALI



LEGEND

- SURVEY PRE WORK
- SURVEY MAY 2016
- SURVEY JUNE 2016
- SURVEY AUGUST 2016
- SURVEY OCTOBER 2016
- SURVEY FEBRUARY 2017

NOTES

1. ALL DIMENSIONS ARE IN METERS UNLESS OTHERWISE NOTED
2. ALL LEVELS ARE IN METERS AND REFER TO BANGLADESH PUBLIC WORKS DATUM (PWD)
3. THIS DESIGN IS TENTATIVE AND SUBJECT TO A DETAILED SURVEY IMMEDIATELY PRIOR TO DUMPING

NOT FOR CONSTRUCTION

PRINTED:
NAME & LOCATION: E:\Workplace\Projects\FRERMIP\5. CADD\5.1 Drawings\Adaptation\P1-Adapt-Chauhali-2+700.dwg

No.	BY	DATE	DESCRIPTION	APPD
00	MMR	19-MAR-2017	DRAFT FOR CLIENT REVIEW	KO

THE SIGNING OF THIS TITLE BLOCK CONFIRMS THE DESIGN AND DRAFTING OF THIS PROJECT HAVE BEEN PREPARED AND CHECKED

DESIGNED	KO	CHECKED	
DRAWN	MMR	CHECKED	KO
APPROVED	KO	DATE	19-MAR-2017

SCALES: SCALE F 0 1.0 2.0 2.5m 1 : 100 (A3) 1 : 50 (A1)

CONSULTANT: nhc northwest hydraulic consultants; MOTT MACDONALD

STATUS: DRAFT DESIGN

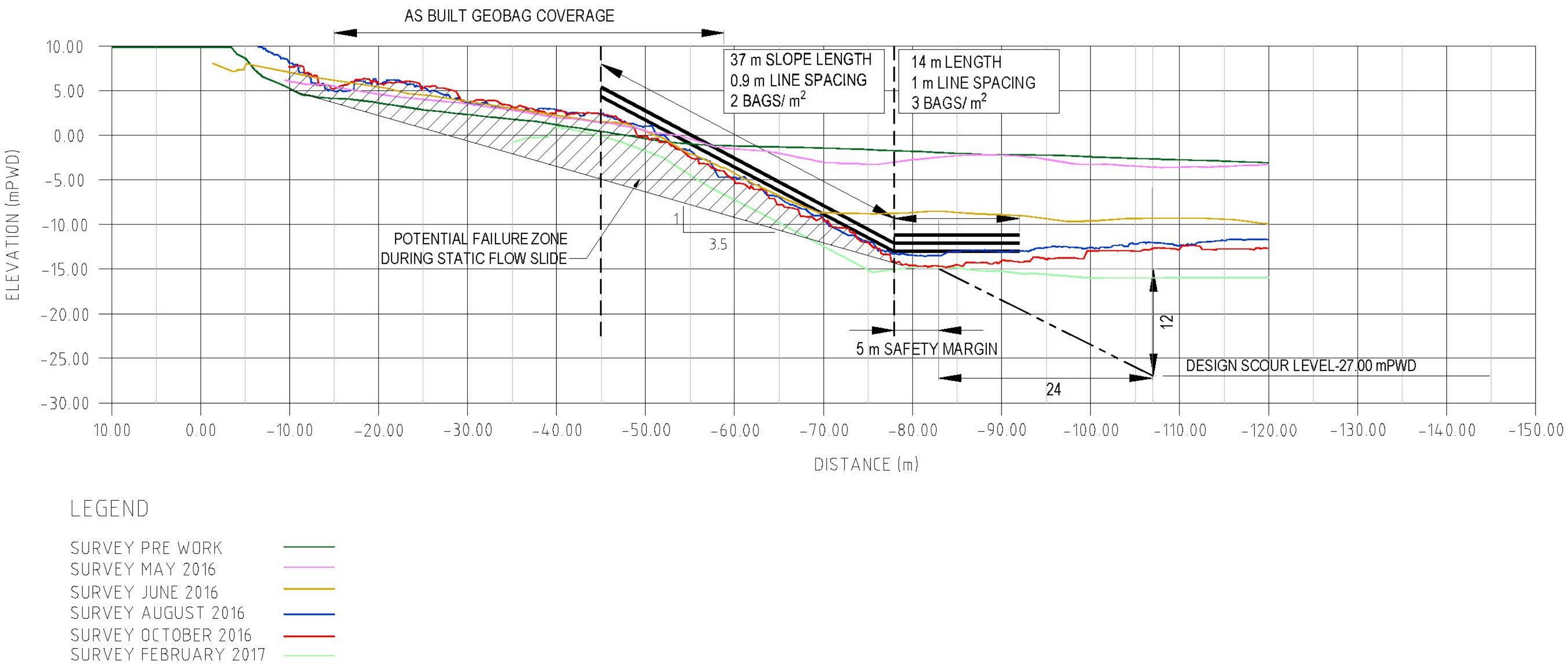
BANGLADESH WATER DEVELOPMENT BOARD (BWDB)
RIVER BANK EROSION RISK MANAGEMENT INVESTMENT PROGRAM
(FRERMIP)
PROJECT 1

FRERMIP, PROJECT 1

RIVER BANK PROTECTION WORKS
ADAPTATION WORK TYPICAL CROSS SECTION
UNDERWATER SLOPE AND APRON

DRAWING No. P1-Adapt-Chauhali-2+700 REV: 01

CHAINAGE 3+700 AT CHAUHALI



NOTES

1. ALL DIMENSIONS ARE IN METERS UNLESS OTHERWISE NOTED
2. ALL LEVELS ARE IN METERS AND REFER TO BANGLADESH PUBLIC WORKS DATUM (PWD)
3. THIS DESIGN IS TENTATIVE AND SUBJECT TO A DETAILED SURVEY IMMEDIATELY PRIOR TO DUMPING

NOT FOR CONSTRUCTION

No.	BY	DATE	DESCRIPTION	APPD
00	MMR	19-MAR-2017	DRAFT FOR CLIENT REVIEW	KO

THE SIGNING OF THIS TITLE BLOCK CONFIRMS THE DESIGN AND DRAFTING OF THIS PROJECT HAVE BEEN PREPARED AND CHECKED

DESIGNED	KO	CHECKED	
DRAWN	MMR	CHECKED	KO
APPROVED	KO	DATE	19-MAR-2017

SCALES: SCALE F 1:100 (A3) 1:50 (A1)

CONSULTANT: nhc northwest hydraulic consultants; MOTT MACDONALD

STATUS: DRAFT DESIGN

BANGLADESH WATER DEVELOPMENT BOARD (BWDB)
RIVER BANK EROSION RISK MANAGEMENT INVESTMENT PROGRAM
(FRERMIP)
PROJECT 1

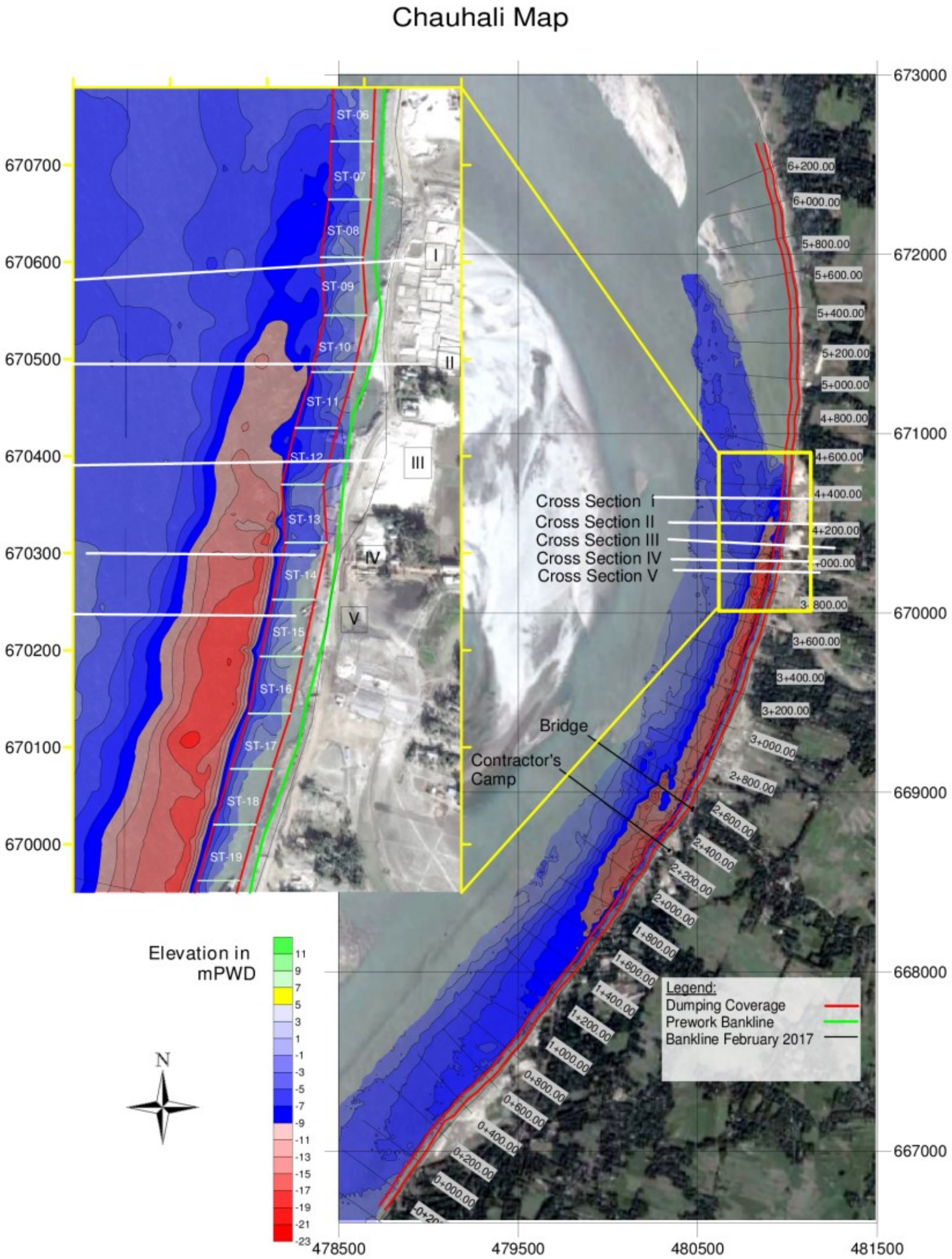
FRERMIP, PROJECT 1

RIVER BANK PROTECTION WORKS
ADAPTATION WORK TYPICAL CROSS SECTION
UNDERWATER SLOPE AND APRON

DRAWING No. P1-Adapt-Chauhali-3+700 REV: 01

9.1.4 Repair of Failed Wave Protection

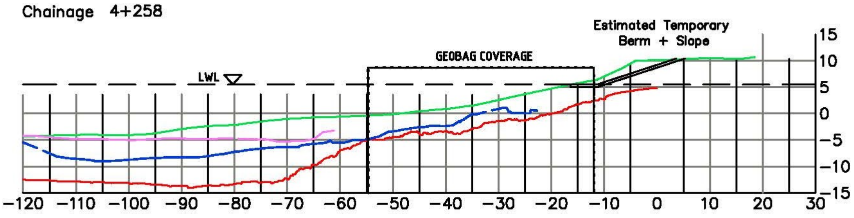
Example upstream



Note that the available survey data are not conclusive and do not allow a temporary design. The cross sections nevertheless indicate the need for filling in some areas. The final details have to be decided through diving investigation.

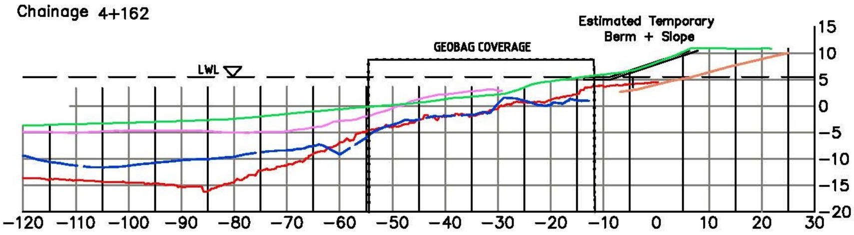
Cross Section I

Chainage 4+258



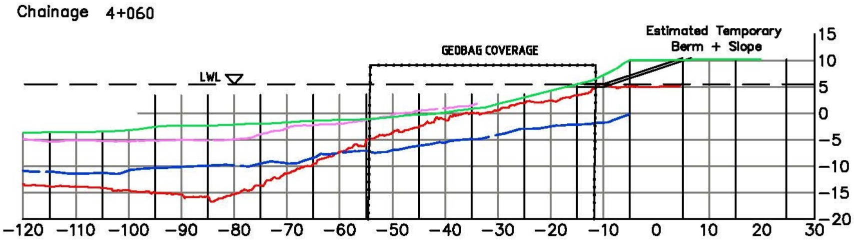
Cross Section II

Chainage 4+162



Cross Section III

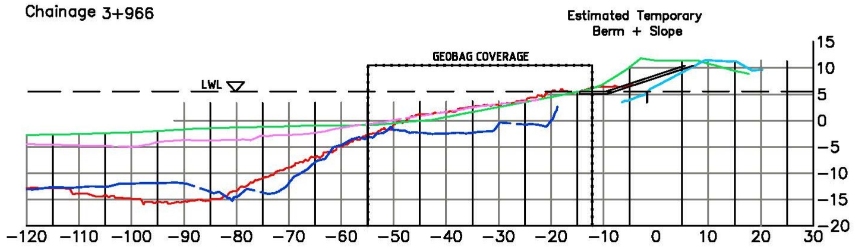
Chainage 4+060



LEGEND:
- Pre Work Survey
- As Built Survey
- October Survey
- January Topo Survey
- February Survey
- March Topo Survey

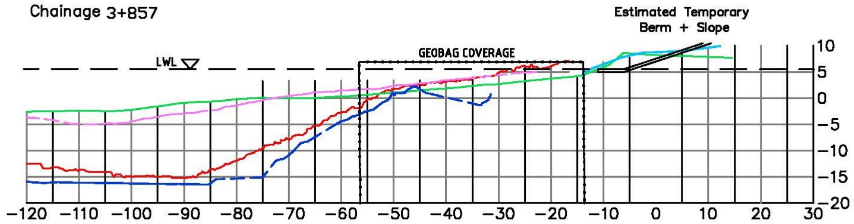
Cross Section IV

Chainage 3+966



Cross Section V

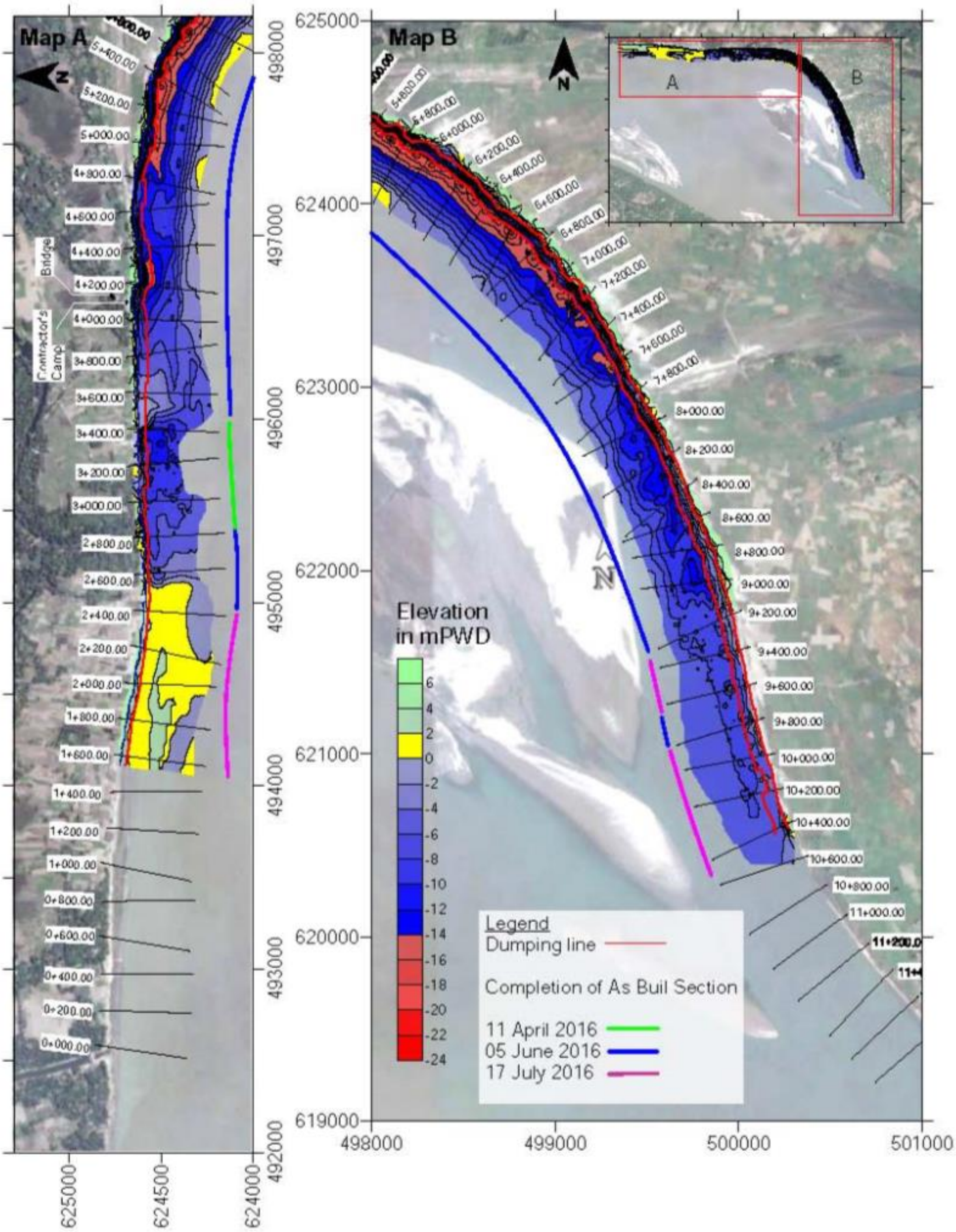
Chainage 3+857



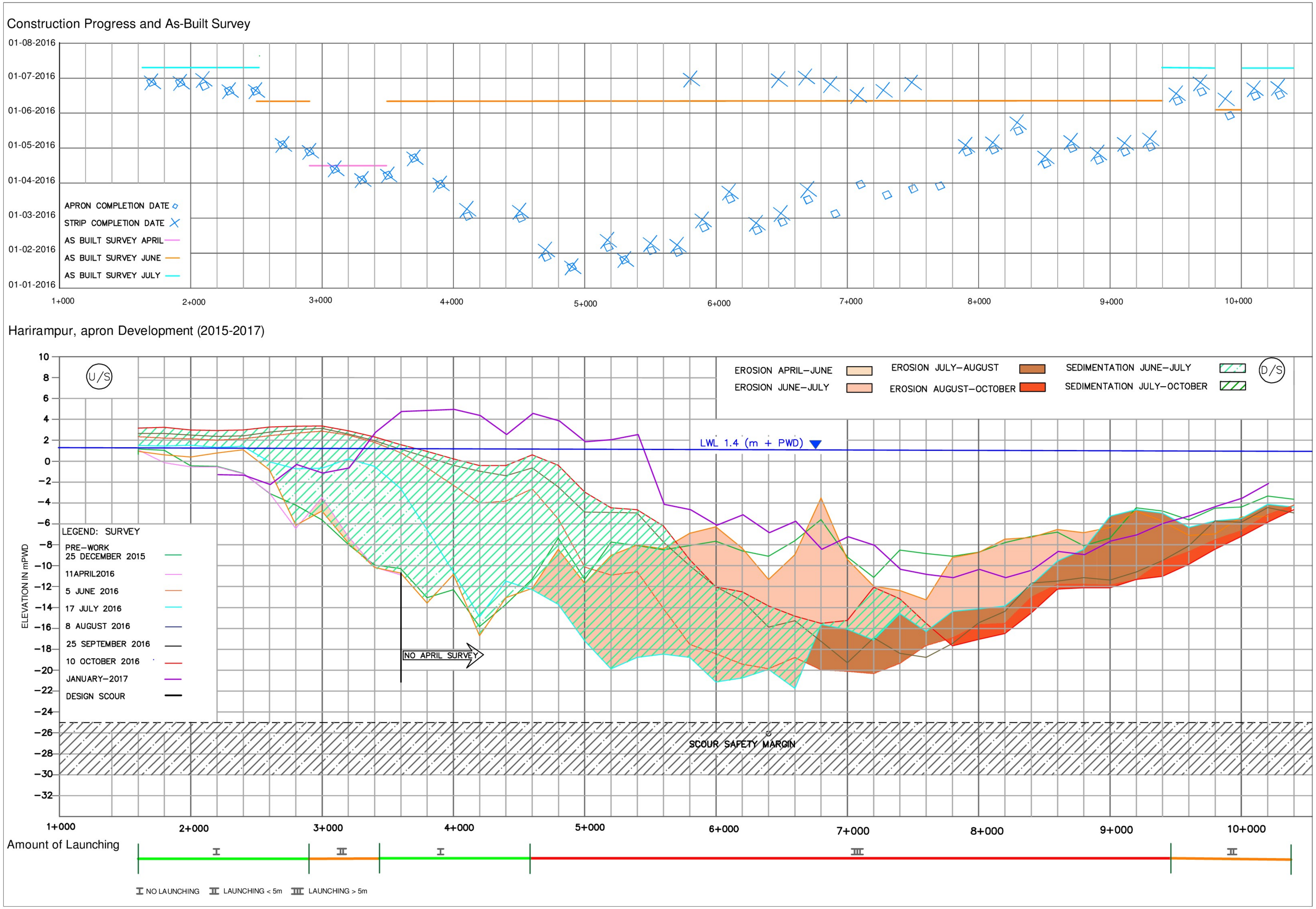
LEGEND:
- Pre Work Survey
- As Built Survey
- October Survey
- January Topo Survey
- February Survey
- March Topo Survey

9.2 Harirampur

9.2.1 As-built with 2017 satellite picture



9.2.2 Longitudinal Section – Launching of Apron



9.2.3 Cross Section – Example Provisional Adaptation Works