Northwest Hydraulic Consultants
Euroconsult Mott McDonald

Memo

To: Project Director FRERMIP

From: Saleh Adib Turash

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

Date: May 2019

Re: Site monitoring 2018/19

1 Introduction

This memo summarizes river changes in the Lower Jamuna and Padma river at Chauhali, Zafarganj, Harirampur, Chauhali upstream, Enayetpur, Koijuri and PIRDP during the flood season 2018, including a survey update at Chauhali in January 2019.

Regular monitoring and evaluation of river training facilities post-construction helps understanding the river behavior in response to protective works particularly any risk to the stability of the work and the need for adaptive protection. In more general terms, regular surveys support the understanding of the river response to new riverbank protection works as well as the performance of the works over time. In this context, FRERMIP conducts regular surveys since the end of 2015, which are annually reported.

The flood season monitoring 2018, during the third flood after construction, was defined to:

(i) Monitor the developments alongside the Project-1 riverbank protection with respect to flow velocity and scour developments (float track and bathymetry surveys), and identify potential adaptation needs for sustaining the work.
(ii) Conduct flow and discharge measurements (float tracking and ADCP transects) in 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 and Project-2. Key focus is on (a) the larger scale flow distribution between the eastern and western channels, which determines the level of attack on existing and future planned works, and (b) local river changes that determine (future) flow pattern at a specific site.
(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 2017/8 memo included, multibeam survey results from Chauhali and Koijuri which demonstrate geobags launching, and documenting launching of the apron requiring adaptation works. In total the BWDB implemented 3.8km of adaptation works in early 2018, 2km through variation of work packages W6 and W7 and 1.8km work through a new package W7. During the 2018 flood season, additional launching occurred in some areas. Adaptation work strengthens the existing work and introduces a step in the launched slope that acts as a berm, improving the geotechnical stabilities (Figure 1-1).

After a multitude of damages of the upper slope in 2017 and 18, no damages occurred in areas with adaptation works.

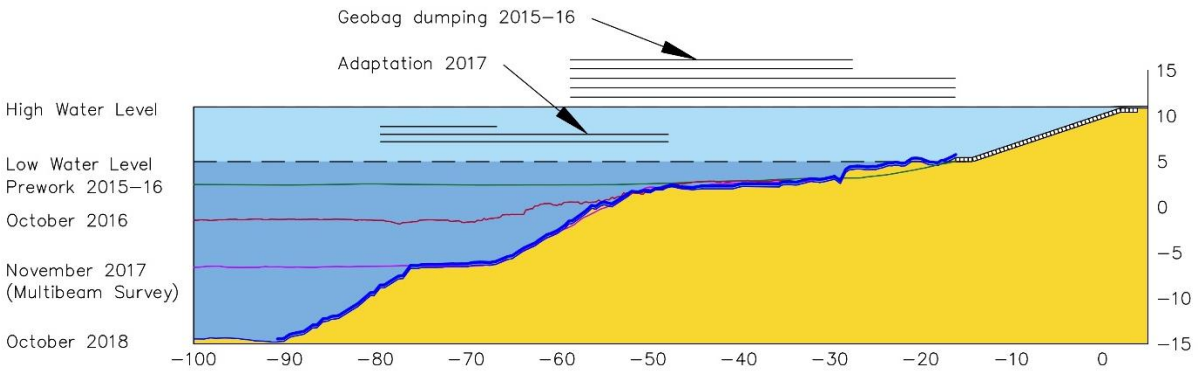


Figure 1-1 Chauhali periodic apron development

While the scour at Chauhali progresses in downstream direction alongside the implemented works and has reached its downstream end, upstream new erosion took place over a length of more than 10km. No significant erosion has been observed in Zafarganj since the implementation of the Project 1 work. The reasons for this are larger scale changes in the flow pattern, moving away from the riverbank. At Harirampur the movement of a sand bar splitting the main channel limits erosion alongside the protected riverbend. Here, new erosion occurred upstream of the implemented work.

To implement the survey work, the ISPMC retained the services of the Survey and Data Consultants with approval of the Project Director (reference PMO-FRERMIP/C-2/68 dated 30 July 2018). The Survey and Data Consultants conducted bathymetry and float track survey, reallocating ADCP survey resources for additional bathymetry surveys. In additoin, the BWDB surveyed the Chauhali site on January 29, 2019.

2 General River Monitoring

2.1 Purpose

General river monitoring surveys are designed to provide specific information about general flow patterns alongside protected sites and in different reaches, especially for works implemented during Project 1 in the lower Jamuna and upper Padma and in addition for earlier works built under JMREMP as well as for planned future works. General monitoring surveys support the following specific tasks:

(i) Morphological analysis and development of the Lower Jamuna and Upper Padma rivers, particularly with respect to stability and distribution of flow at the bifurcation into eastern and western brach about 20km downstream of the Bangabandhu (Jamuna) Bridge.

(ii) Assess the impact of the Chauhali revetment on the downstream channel pattern and the potential for reclaiming land, with special consideration of the flow diversion into the Solimabad Channel downstream of Chauhali.

(iii) Assess the morphology alongside the right protected bank from Koijuri to Koitola including erosion of yet unprotected riverbanks.

(iv) Assess the impact of morphological changes on potential navigation routes through the Lower Jamuna as well as the Upper Padma River, particularly alongside the Harirampur works.

(v) Provide input for numerical (Delft 3-D) modelling supporting future morphological prediction also with respect to proposed Project 2 work locations.

2.2 Monitoring Plan

The general river survey (Figure 2-1 and Figure 2-2) focused on float tracking and bathymetric survey, The bathymetric survey was conducted with 500m interval survey lines in the Lower Jamuna and 1,000m interval survey lines in Ganges and Upper Padma rivers. Normal float tracks were conducted to identify flow velocities and orientation in different channels of the lower Jamuna.

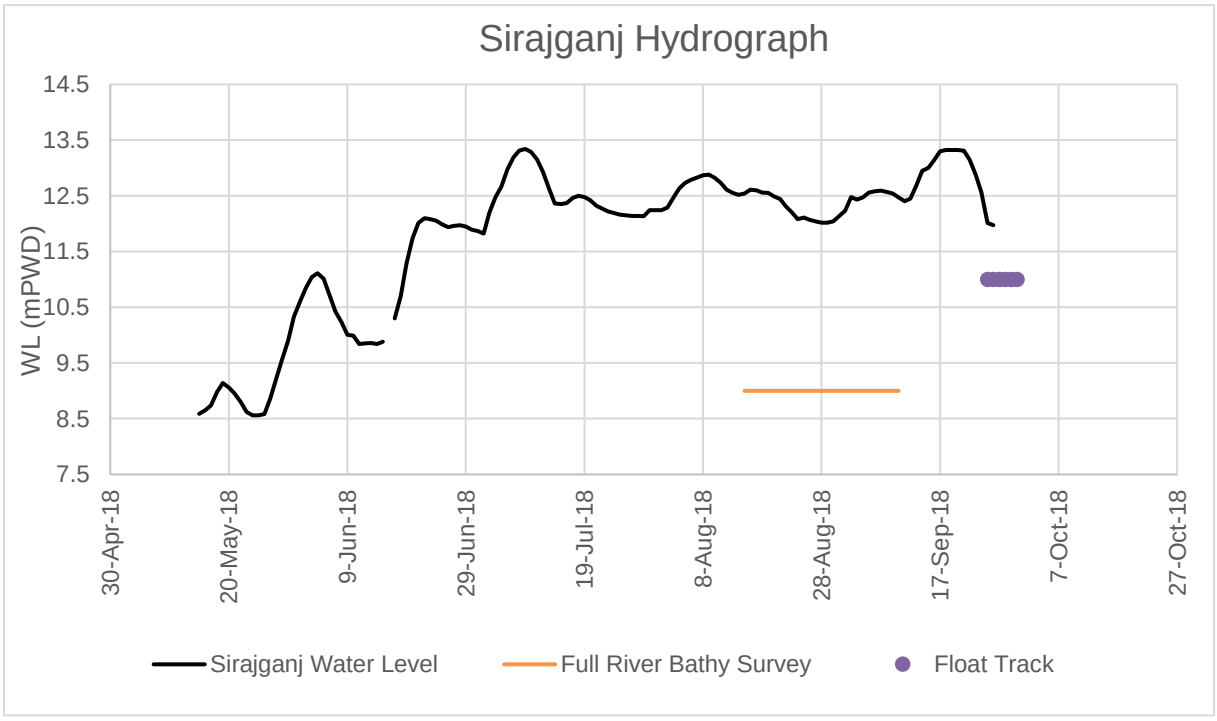


Figure 2-1 Full river survey and float tracks during the 2018 flood

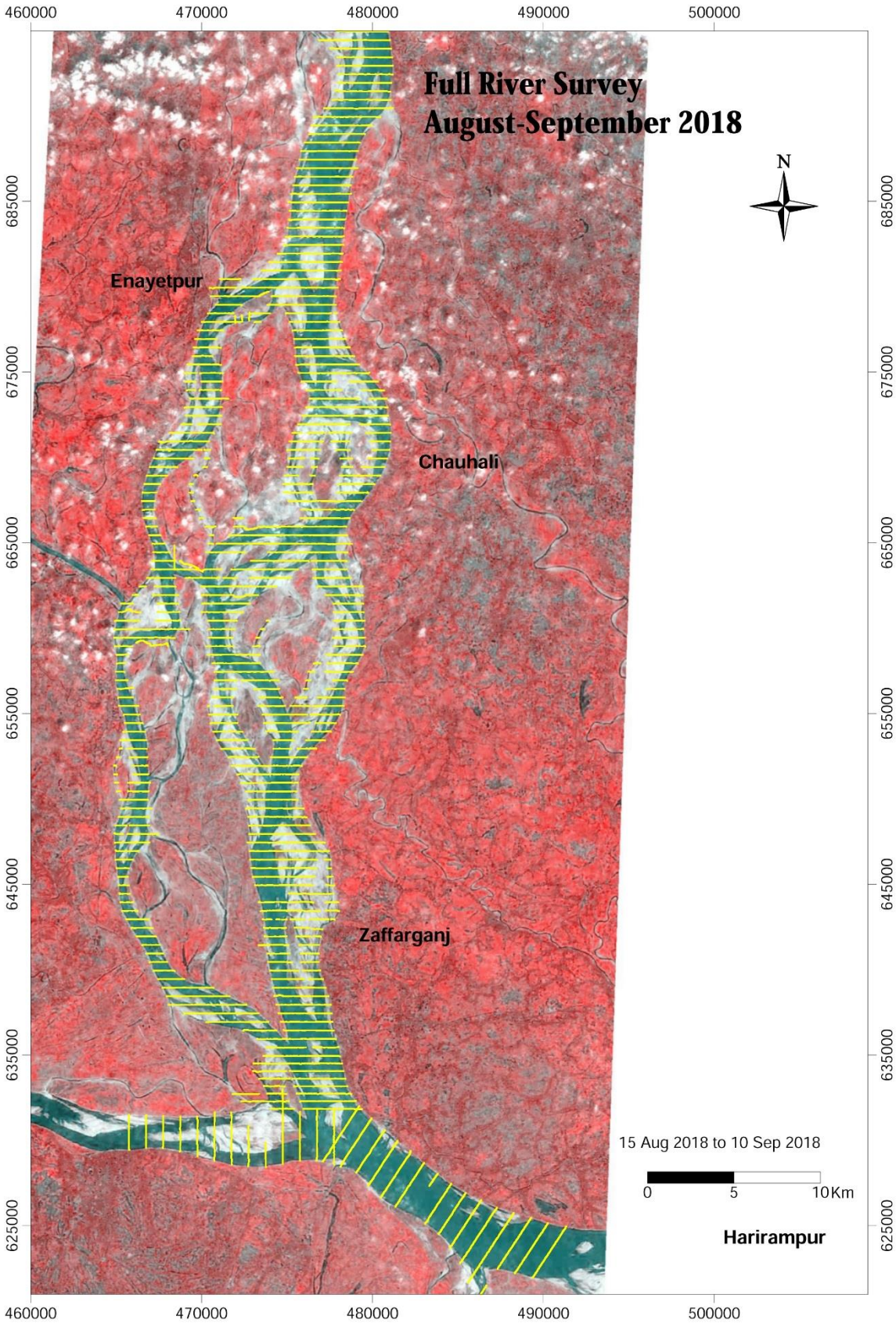


Figure 2-2 Flood season bathymetric survey of the Lower Jamuna

2.3 Monitoring Results

2.3.1 Lower Jamuna

The flood season survey (Figure 2-7) shows that despite the average flood substantial changes occurred in the Lower Jamuna:

(i) The differential survey map between 2017 and the 2018 shows the overall deepening of the lower Jamuna right and left channel as opposed to a more aggrading situation the year before (Figure 2-8).

(ii) Upstream of the Lower Jamuna bifurcation, the height of the mid-channel sand bars increased resulting in deeper channels at both banks (Figure 2-3 section 1). Deepening of section 2 indicates erosion of the left bank, which is planned to be addressed through 12 km of riverbank protection during Project 2.

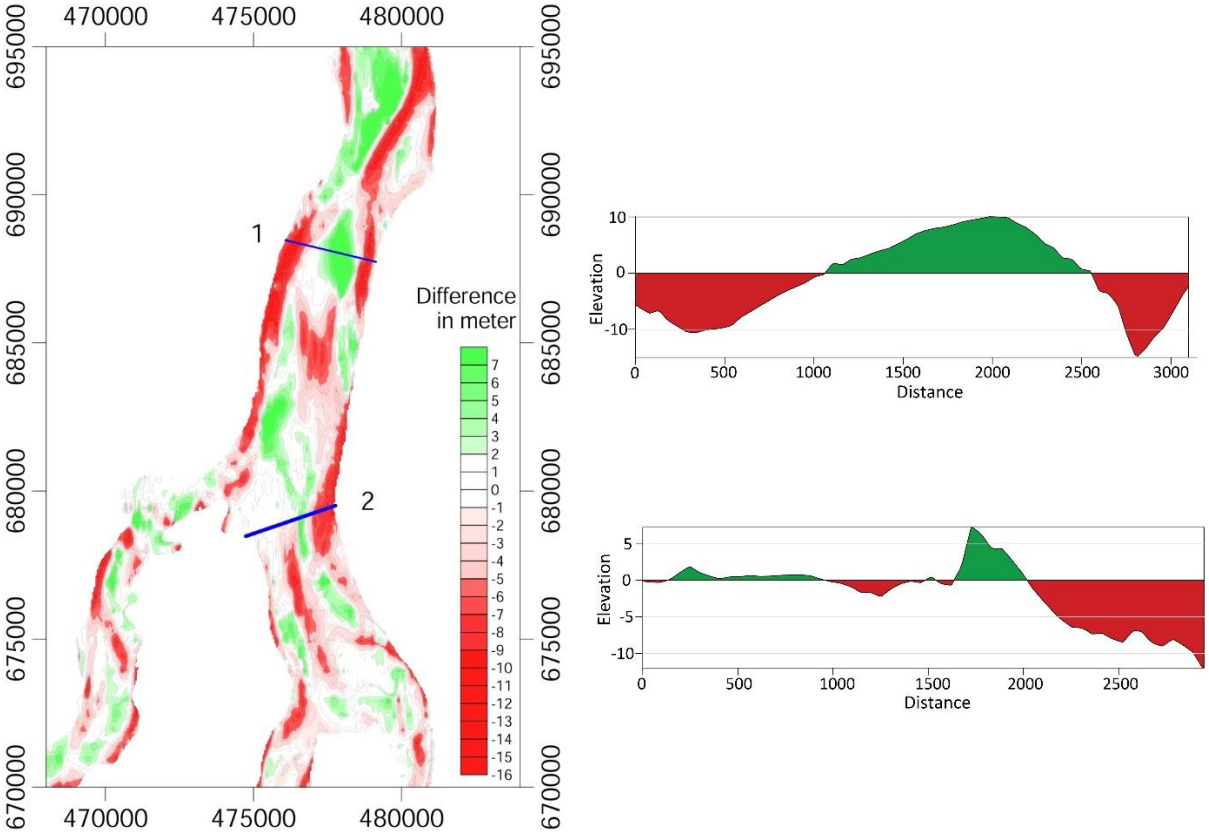


Figure 2-3 Increasing height of sandbar at section 1

(iii) Downstream of the lower Jamuna bifurcation, the 2018 flood season survey shows three cut off channels through the char opposite of the protected riverbank at Chauhali. A new channel has developed downstream of Chauhali forming a four channel junction (marked red in Figure 2-4).

(iv) The sandbar height splitting the offtake of the Solimabad channel (marked by a blue circle in Figure 2-4) and downstream opposite of Solimabad (marked by a blue ellipse in Figure 2-4) is increasing, narrowing the channel and increasing erosion on the left bank.

(v) The large sandbar opposite of Zafarganj, observed in 2017 starts eroding (Figure 2-5 black circle).

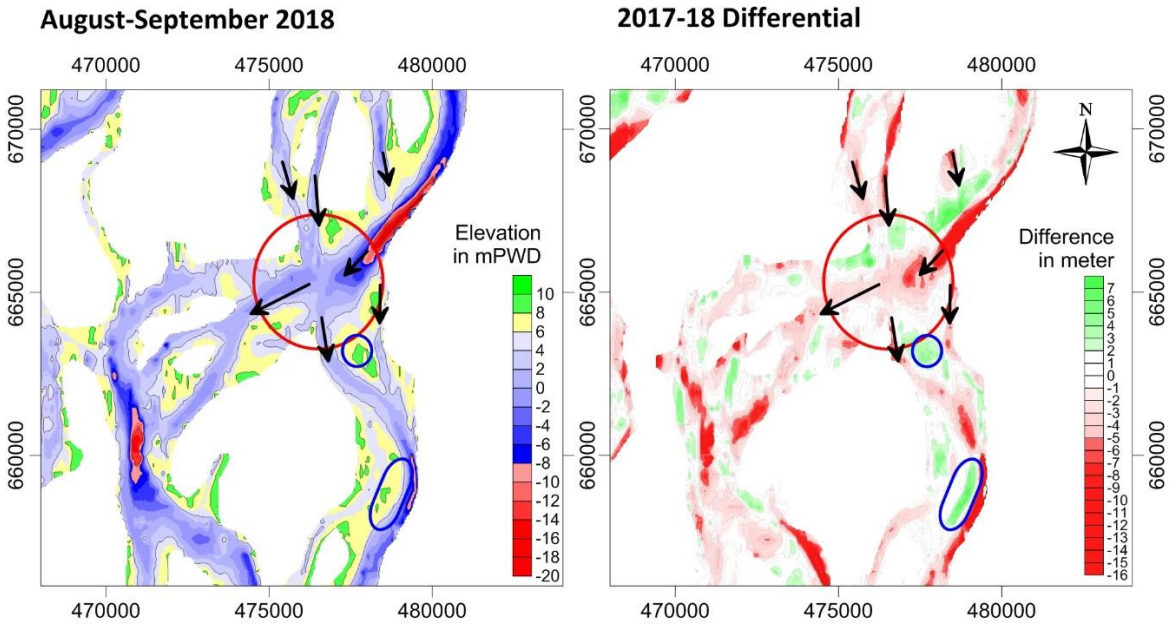


Figure 2-4 Downstream of Chauhali and Solimabad Channel

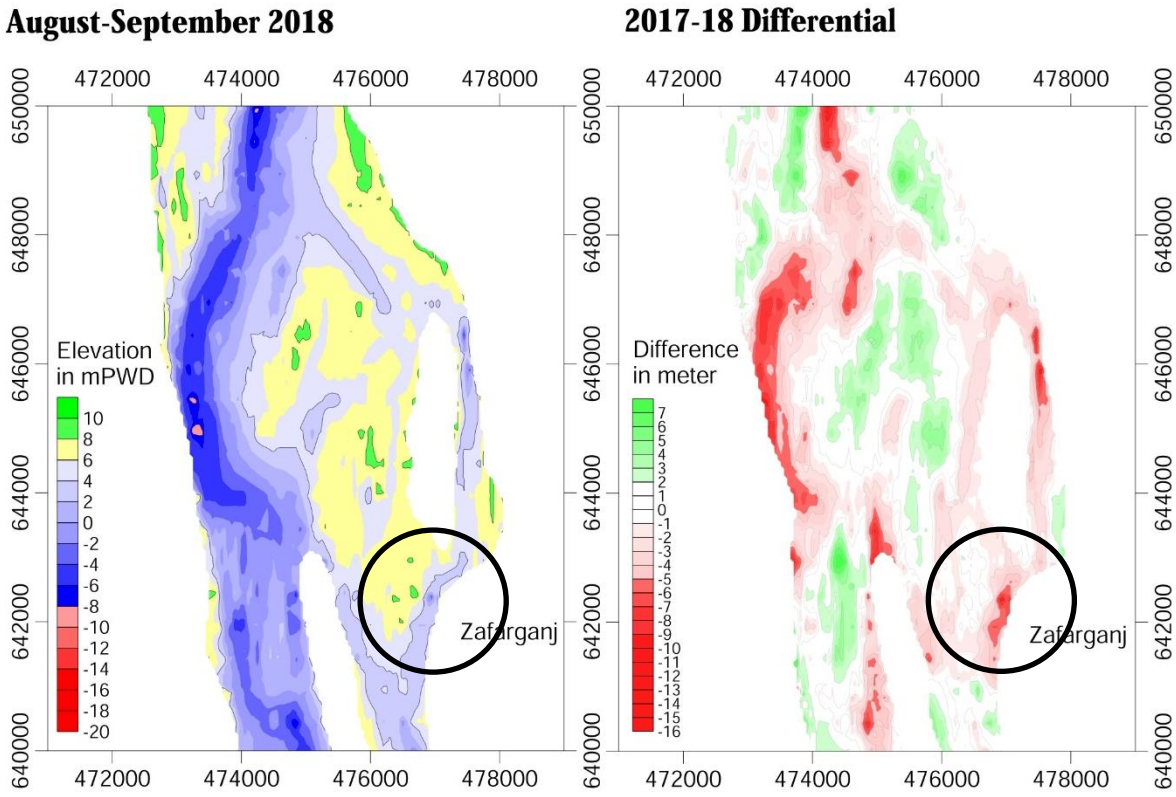


Figure 2-5 Large sandbar erosion beside Zafarganj

(vi) The right bank of the lower Jamuna channel is more stable and the bankline did not shift since the construction of 17km of riverbank protection works during JMREMP from 2004 to 2011.

(vii) Despite of some 32 km of riverbank protection on both banks, the Lower Jamuna remains a dynamic river, which is able to change its thalweg. Particularly, char movements remain difficult to predict. Figure 2-6 shows different flow paths downstream of the lower Jamuna bifurcation at Kaijuri (right bank) and Chauhali (left bank) over a period of one year.

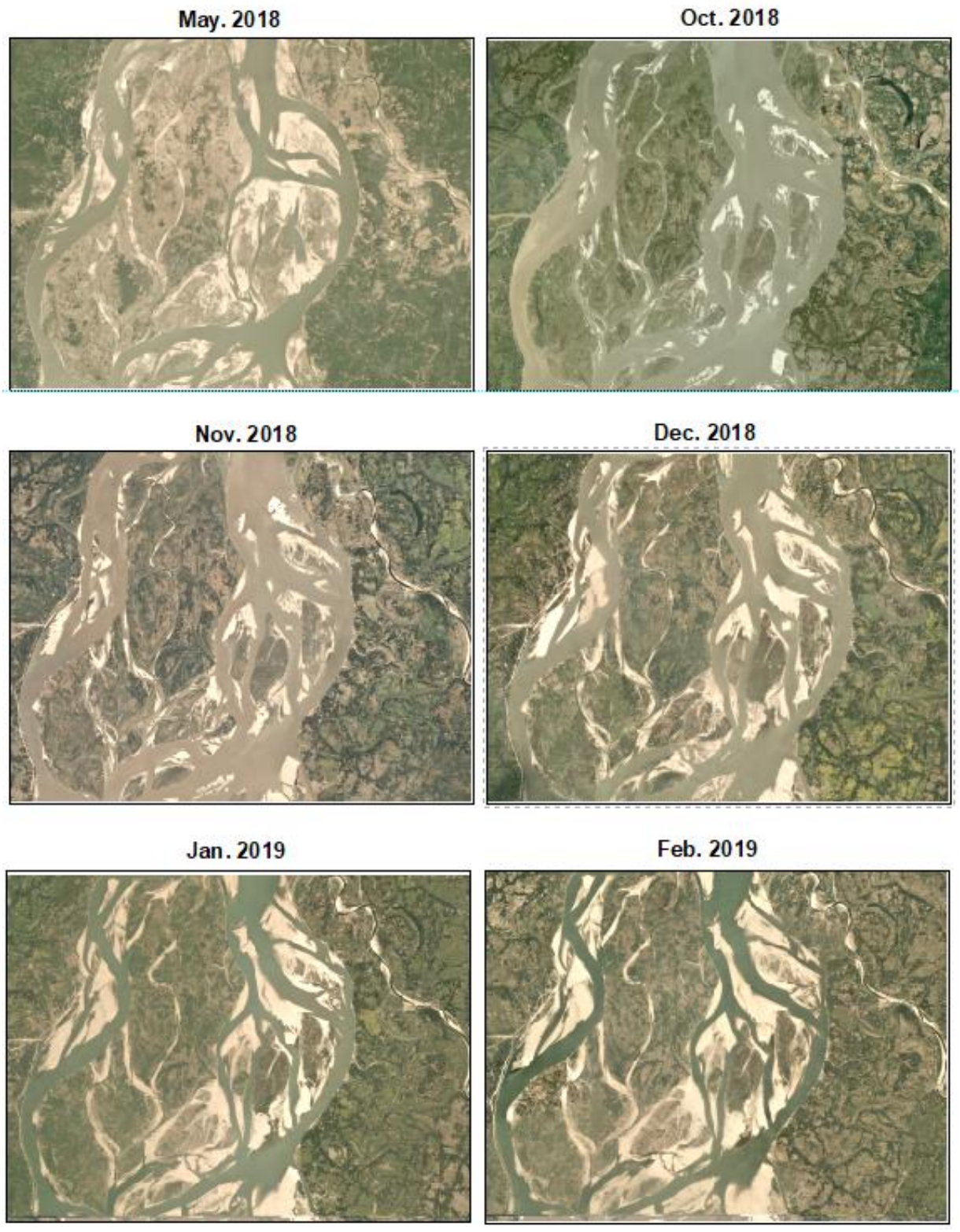


Figure 2-6 Aerial imagery of Lower Jamuna

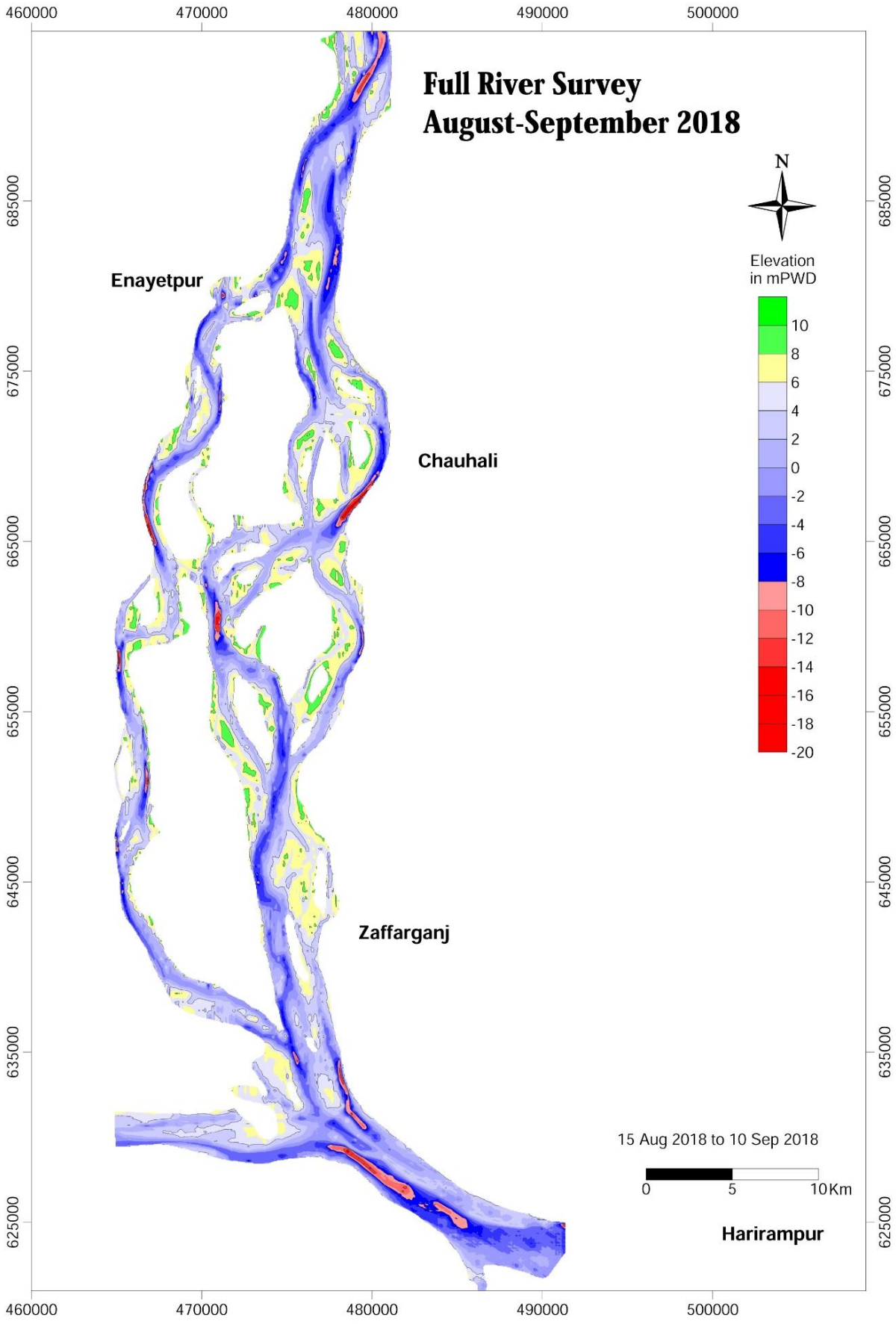


Figure 2-7 Full river bathymetry survey flood Season 2018

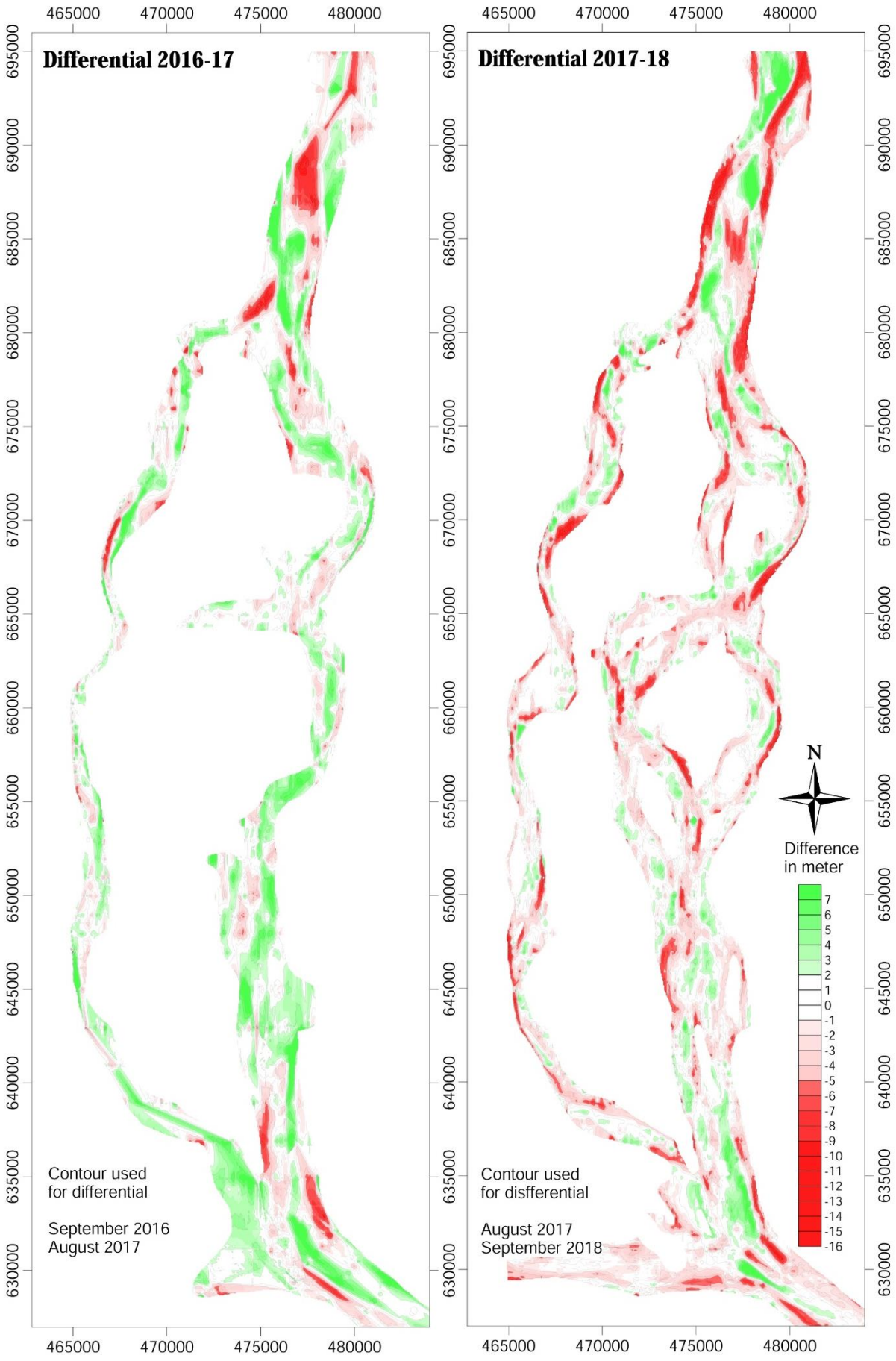


Figure 2-8 Differential map from 2016 to 17 and 2017 to 18

2.3.2 Upper Padma

The Upper Padma is dominantly influenced by the confluence dynamics of Ganges and Jamuna:

(i) The dominant influence of the Jamuna, particularly after its higher flood flows compared to the Ganges over the last years (since 2016) manifests in a gently curved channel (Figure 2-9). The deeper part of the channel is at the right bank near Goalando Ghat.

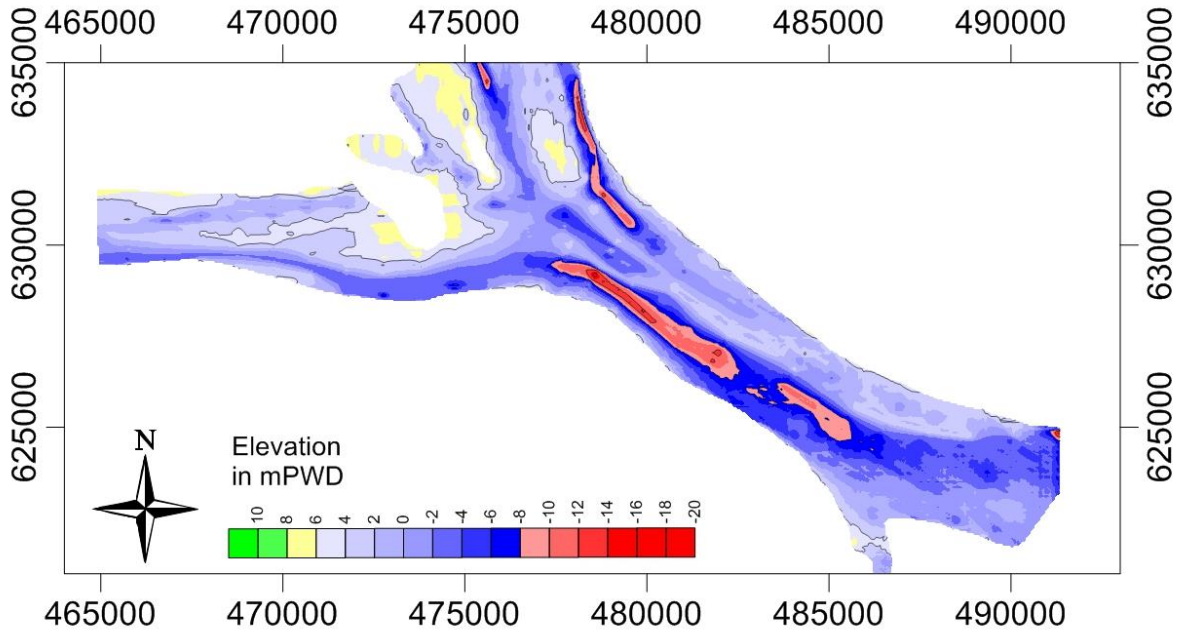


Figure 2-9 The Ganges and Upper Padma from 2016 until 2018

(ii) The thalweg is moving towards Harirampur which leads to some bank erosion upstream of the protected bank (Figure 2-10).

Figure 2-10 Differential maps showing changes from 2016 – 17 and 2017 - 18

3 Site Monitoring

3.1 Purpose

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

(i) the scour development alongside the launching aprons of the newly built Project-1 works; (Section 3.4)
(ii) the development of the JMREMP works at the PIRDP and Kaijuri, and
(iii) the design assumptions of past and future works.

3.2 Monitoring Plan

Site monitoring depends on regular (around three to four times between June and September) bathymetric surveys compared with the as-built condition (Appendix 6 and 7). In addition to documenting apron development and slope instability issues, the site (as well as general) surveys provide information about flow direction and surface flow velocities along the works.

Table 3-1 provides an overview of the 2018/19 site survey activities. Appendix 3 provides a summary of the survey work at the three sites from 2016 to 2018. Figure 3-1 to Figure 3-3 show the amalgamated as-built surveys, typically combining two to four surveys from different times, depending on the completion of different sections of work.

Table 3-1 Summary of survey activities at the sub-project sites

Survey Item	Site	Aug 18	Sep 18	Oct 18	Dec 18	January 19
Bathymetry Survey	Chauhali	8-9	1. 7 to 8 2. 24 3. 29 4. 30	1. 3 2. 7		29
	Zafarganj	10	9			
	Harirampur	11 to 12	10 to 11			
	Chauhali upstream			8		
	Koijuri			6 to 7		
	Enayetpur			5		
	PIRDP			7		
	Full River	15 Aug to 10 Sep				
Float track	Full River (flood season)		25-30			
	Chauhali		29	7		

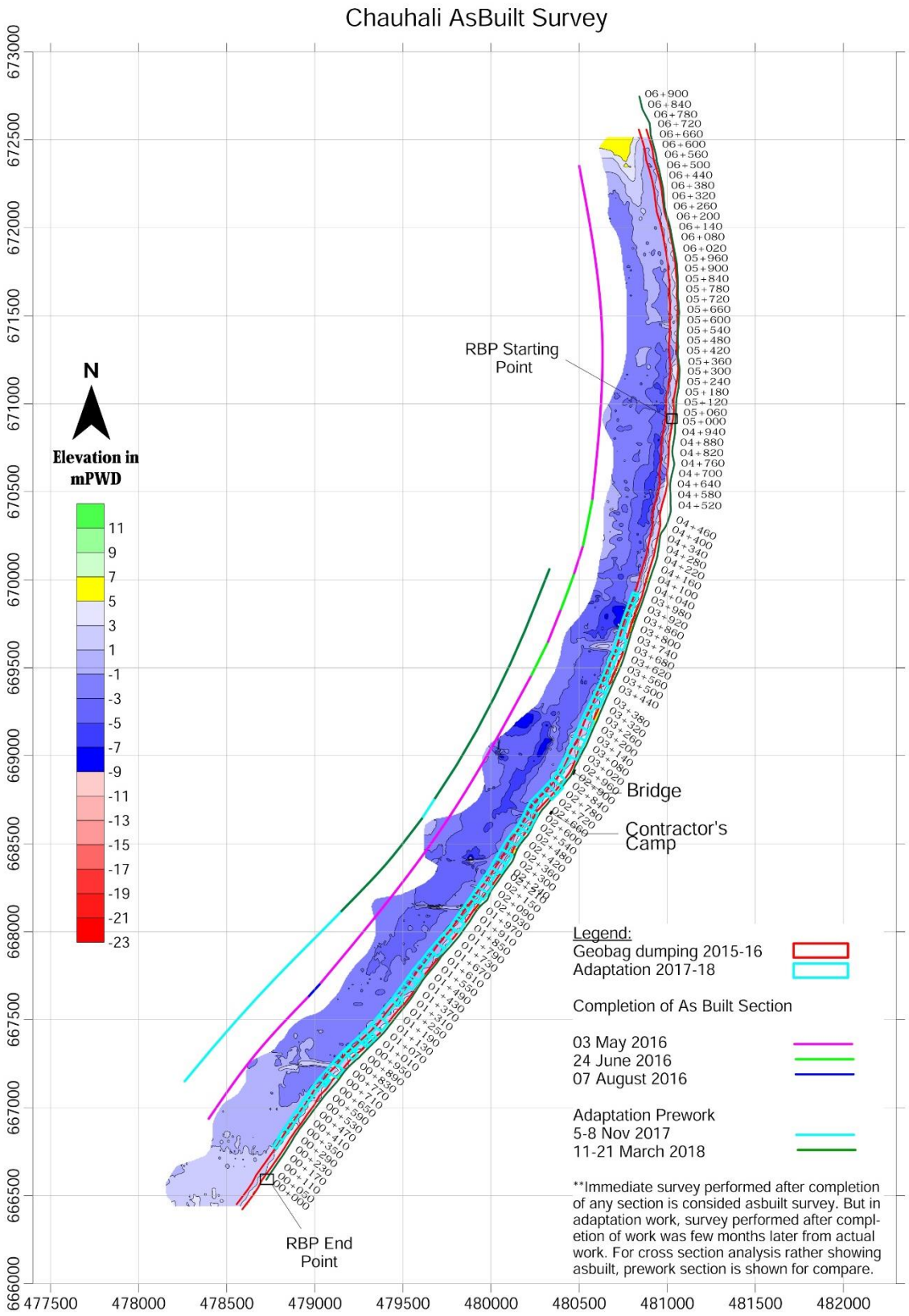


Figure 3-1 2016 AsBuilt survey and adaptation prework at Chauhali

Zafarjang AsBuilt Survey

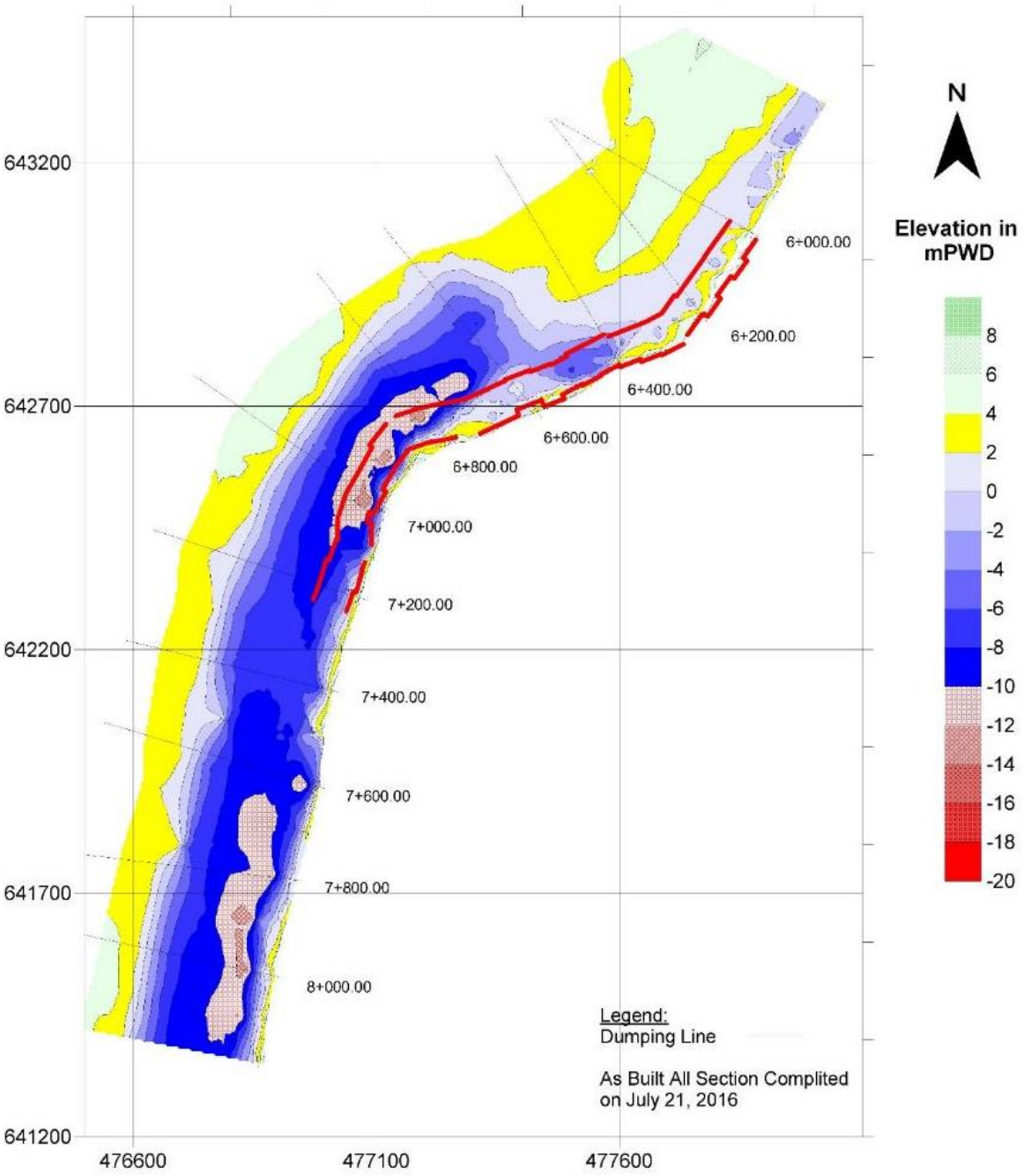


Figure 3-2 2016 AsBuilt survey at Zafarganj

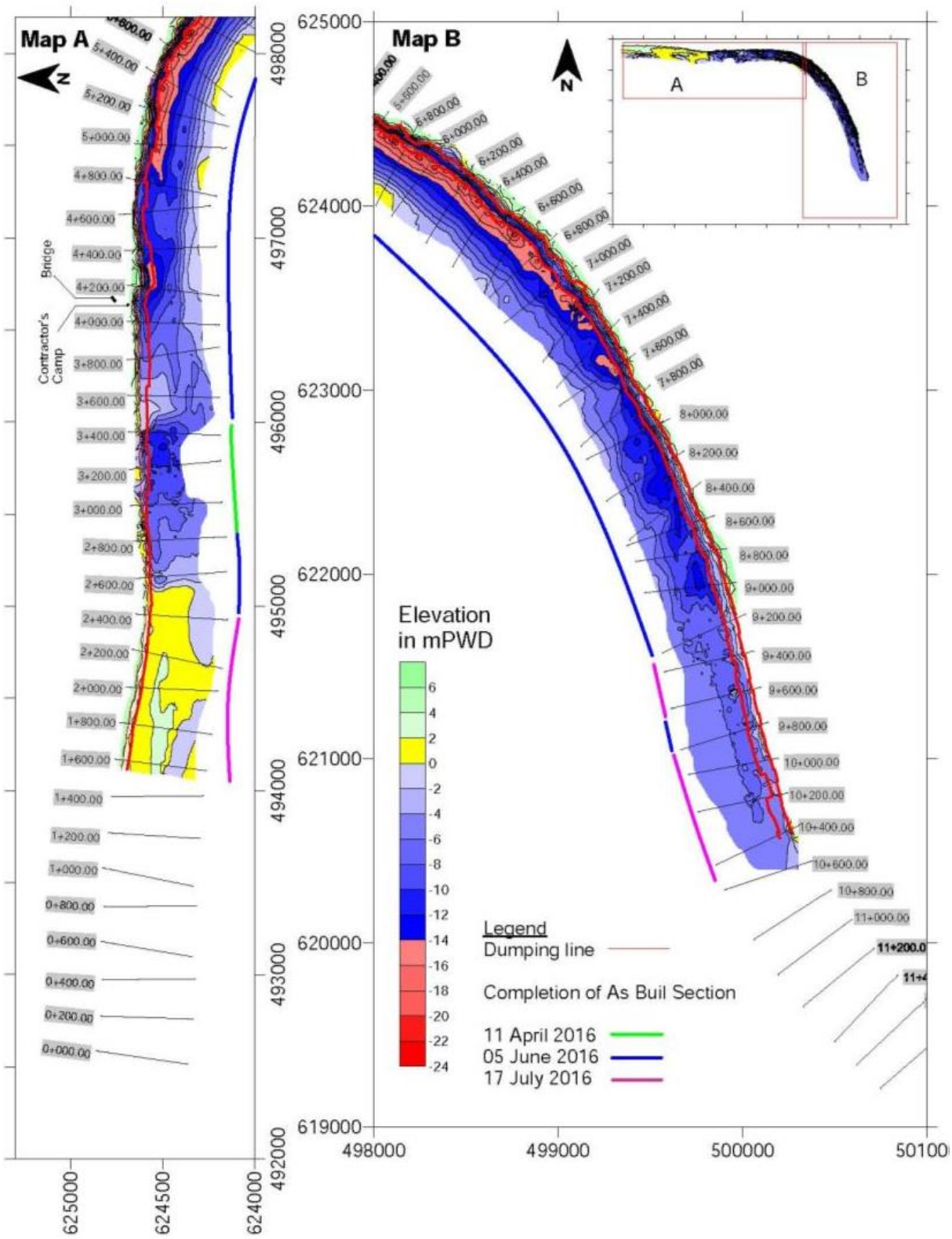


Figure 3-3 2016 AsBuilt survey at Harirampur

3.3 Survey Methodology

3.3.1 Procedure

Bathymetric survey:

Single Beam Echo Sounder: The Survey and Data Consultants used an Teledyne Odom Hydrotrac 1 single beam duel frequency echo sounder that recorded data at 1 second interval. For geo-referencing, two Trimble 750 RTK units operated at a frequency of 0.1 seconds were used, of which the base station was placed on the river bank and the rover on the moving survey boat.

Boat surveys do not follow a straight line, as the boat navigates perpendicular to flows of changing intensity. Therefore, some points on each sounding line deviate from the ideal base line (Figure 3-4). Given the good navigational skills of the boat driver, no point deviated by more than 1m from the target line.

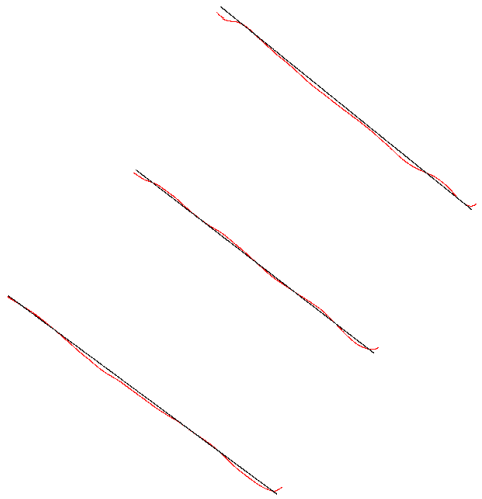


Figure 3-4 Reference (black) and surveyed line (red)

Float track: The river surface flow velocity was recorded with float tracks. These are floats equipped with a cross plate at 0.8m depth and a handheld GPS that are dropped in the river and follow the main current (thalweg). Data were recorded every 3 seconds.

3.3.2 Chauhali

At Chauhali, seven bathymetric surveys were conducted: three full site surveys of 7km length and a survey section interval of 100m, and four special (limited) surveys conducted in response to the failure of 24 September 2018. The special surveys were used for determining emergency dumping and consequently surveyed at 50m interval.

3.3.3 Zafarganj

At Zafarganj, two bathymetric surveys were conducted in August and September 2018 using a dual frequency single beam echo sounder with 100m cross section intervals.

3.3.4 Harirampur

At Harirampur, two surveys were conducted in August and September 2018 also using a dual frequency single beam echo sounder with 100m cross section intervals.

3.3.5 Chauhali Upstream

Around 18km survey was conducted from the upstream end of the Chauhali bank protection to the Dhaleswari offtake mouth, situated downstream of Bangabandhu (Jamuna) Bridge in 4th October 2018. This survey is located alongside the proposed 12km long bank protection, which will be implemented in Project-2. The survey interval was 200m.

3.3.6 Enayetpur

At Enyetpur 4km survey was conducted alongside proposed Enayetpur bank protection on 5th October 2018. The survey section interval was 200m. This site is located between Enayetpur spur and the lower Jamuna bifurcation.

3.3.7 Koijuri

At Koijuri 10km bank protection was implemented between 2009 and 2011. To monitor the underwater situation, 10km survey works were conducted from 6 to 7th October 2018. The survey section interval was 200m.

3.3.8 PIRDP

To monitor the PIRDP underwater situation, 8km of survey works were conducted on 6 and 7 October 2018. The survey section interval was 200m.

Detailed descriptions of the surveys are found in Appendix 6.

3.4 Scour and sedimentation

3.4.1 Introduction

Understanding deep scouring along the riverside toe but also sedimentation are key interests to the monitoring program. The first is relevant for the geotechnical stability of the stabilizing revetment and defines the required amount of adaptation works for reliable construction to deeper levels. The latter influences the constructability of the adaptation works. It is, for example, not practical 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. In deep river channels (those surpassing 15m below low water level) adaptation works of launched aprons becomes necessary when the toe deepens by more than 5m. Sedimentation becomes particularly relevant when the bed level silts up to low water level. Key design 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 m+PWD	3.4 m+PWD	1.4 m+PWD
Deep scour level	-23 m+PWD	-10 m+PWD	-18 m+PWD
Design scour level (BWDB)	-21.58 m+PWD	-23.3 m+PWD	-28.39 m+PWD
Revised scour level (2016 monitoring report)	-22 m+PWD	-22 m+PWD	-25 m+PWD

Apart from the requirements for the adaptation works, monitoring also allows to assess the quality of the design. Here two aspects are of fundamental importance: (i) the width (or breadth) of the apron and its response to scouring, and (ii) velocities over the protection work. The first can be assessed from regular bathymetric surveys while the latter depends on flow measurements using an ADCP and float tracks. As stated previously an ADCP measures underwater velocities and float track reports surface velocities, typically close to the maximum velocity of the thalweg. Applying this velocity provides some safety as near bank velocities are typically only a fraction of the surface velocity.

3.4.2 Chauhali

In 2018 after the adaptation work Chauhali has experienced bank failures in two locations, however outside of the length strengthened by adaptation works. Chauhali's surficial failure of the upper slope may give a very bad impression about the protection work but systematic monitoring alongside the protected riverbank reveals the effectiveness of the underwater protection. Key changes of the local morphology are summarized in Table 3-3. The contractor's chainage is used.

Table 3-3 Findings alongside the protected riverbank at Chauhali (as per contractor's chainage)

Time period	Sedimentation (>+5 m+PWD)	Deep Scour (<-9 m+PWD)	Deep Scour length	Deepest scour location
8-9 August 2018		Stn. 2.84 to 0.35	2.49 km	Stn 2.66; -17
7-8 September 2018		Stn. 3.38 to 0.17	3.21 km	Stn 1.55; -21
24 September 2018 (Partial Survey)		Stn. 0.50 to 0.00	0.5 km	Stn 0.00; -11
29 September 2018 (Partial Survey)		Stn. 0.05 to -0.05	0.1 km	Stn 0.00; -11
03 October 2018 (Partial Survey)		Stn. 0.00 to – 0.2	0.2 km	Stn 0.00; -11
8 October 2018		Stn. 2.66 to 1.55 Stn. 1.19 to 0.23	1.11 km 0.96 km	Stn 2.30; 15
23 Nov 2018 (Partial Survey)		Stn. 0.00 to -0.15	0.15 km	Stn 0.00; -11

Key findings of the survey at Chauhali are:

(i) On 4th June 2018, the adaptation work was completed in Chauhali. Adaptation works increased the underwater apron's strength by two layers of bag on top of the initially launched single layer slope coverage followed by a three layer thick additional toe apron of variable length (depending on the distance to the design scour depth).The August and September 2018 surveys show additional launching in the downstream part of the adaptation works. The additional launching has produced a stepped underwater slope (Figure 3-5).

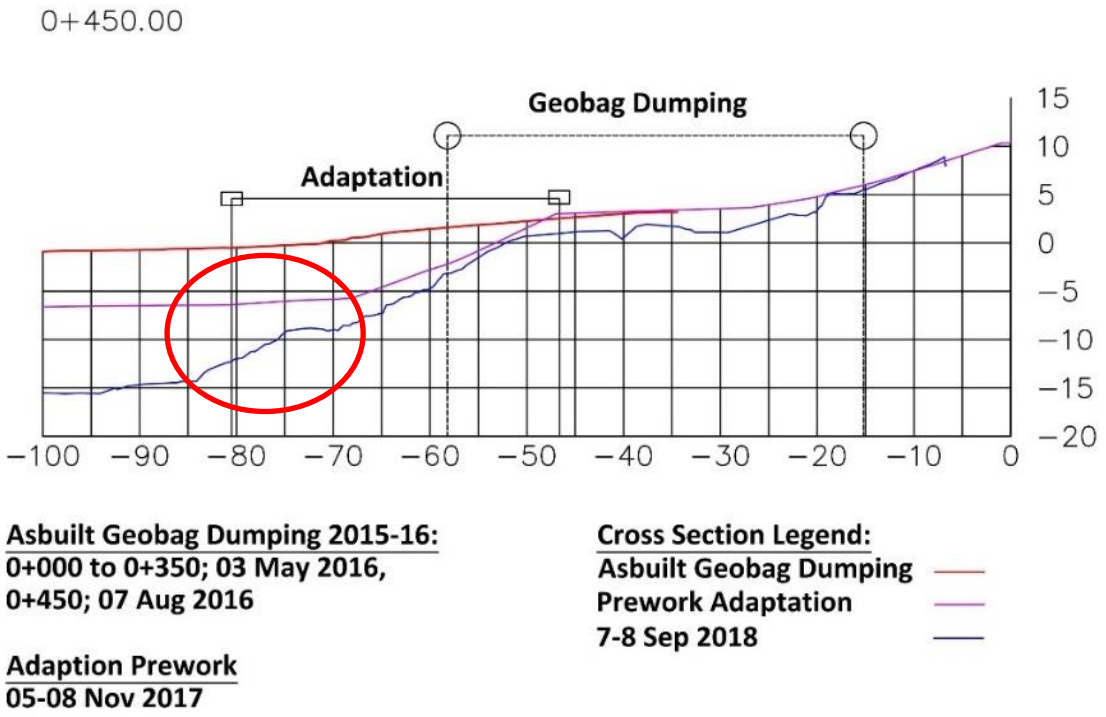


Figure 3-5 Additional launching at Chauhali after adaptation work

(ii) Differential maps for August 2018 with the November 2017 multibeam survey show sedimentation from stn 4.2 to 0.8. Again, from August to September this soft deposit eroded up to 5m.

(iii) There was erosion at the upstream end of the Chauhali work which destroyed some 100m slope upstream of station 6.7 (Figure 3-6).

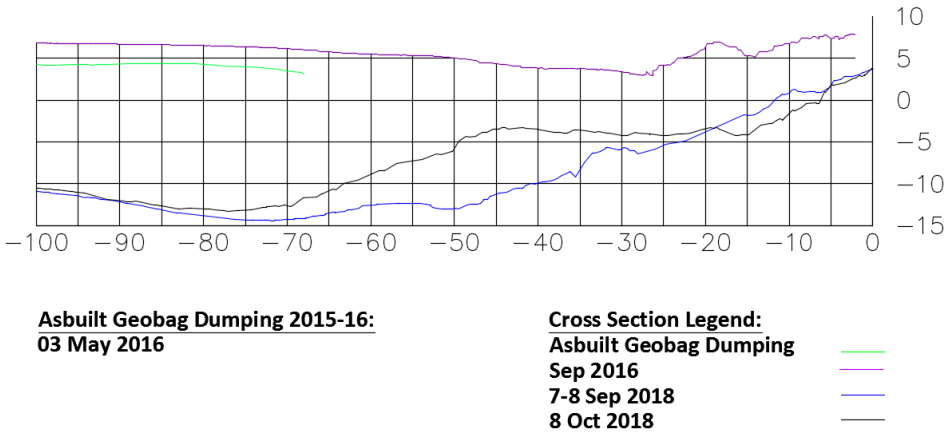


Figure 3-6: Upstream end of underwater apron

(iv) Adaptation works was completed between station 0.18 to 3.98 in early 2018 and no failure occurred in this area during the 2018 flood.

(v) Two failures were observed between station 0.0 to -0.25 and 4.8 to 5.04 due to angular flow attack described in more details in section 3.5.

(vi) 150m from the riverbank protection at station 0 a bed level of -23mPWD observed during the 8 to 9 August 2018 survey, which eventually increased to -33mPWD scour level on 24 September 2018. This is 11m below design scour level!

(vii) Upstream of station 4.0 the sandbar has started eroding. The apron placed during the construction season 2015-16 was buried under 10m sediment in November 2017 but may get expose during the 2019 flood season. These area needs to be monitored regularly to identify the need for future adaptation works.

Detailed maps for different surveys are included in Appendix 6.1 and in Appendix 7.1.

Long profiles along the deepest scour at end of the apron are provided in Appendix 9.1, documenting scour and sedimentation development during the 2018 flood season, compared with the as-built condition. The long profile was prepared based on 50m interval cross sections.

3.4.3 Zafarganj

Different from Chauhali and Harirampur, no erosion occurred in Zafarganj. The primary reason for this are large scale changes in the flow pattern, mowing away from the riverbank. Systematic monitoring alongside the revetment revealed key changes of the local morphology, summarized in Table 3-4.

Table 3-4 Findings alongside the protected riverbank at Zafarganj (with reference to the position along the works)

Time period	Sedimentation (>+2 m+PWD)	Deep Scour (<-9 m+PWD)	Deep Scour length	Deepest scour location
10 August 2018	From Stn. 6.4 to above in upstream and from Stn. 7.5 in downstream direction	6.9 to 7.1	Less than 200m	Stn 7; -10
09 September 2017	From Stan. 6.6 in upstream direction	6.9 to 7.2	300m	Stn 7; -12

Key findings of the Zafarganj survey are:

(i) The August 2018 survey shows that the upstream deposition, observed during the 2017 flood season, has started to erode.

(ii) Cross sectional analysis shows that the apron was placed during the deepest bed elevation in 2015/16. After that the apron was buried under sediment.

(iii) The maximum elevation was observed at stn 7 (Figure 3-7).

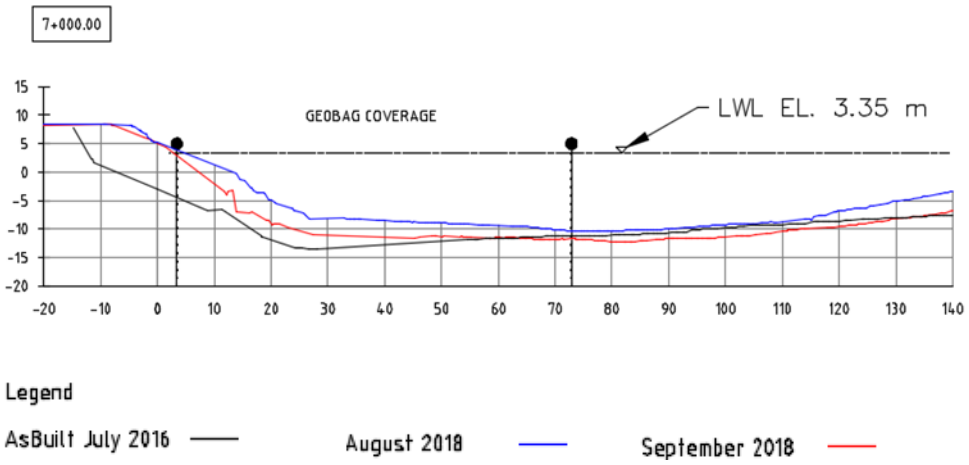


Figure 3-7 Periodic development of Apron launching and sedimentation

3.4.4 Harirampur

The Harirampur site situation was more stable than earlier. Key changes of the local morphology are, summarized in Table 3-5:

Table 3-5 Findings alongside the protected riverbank at Harirampur

Time period	Sedimentation (>+2 m+PWD)	Deep Scour (<-14 m+PWD)	Deep Scour length	Deepest scour location
11-12 August 2018	Stn. 3 to 5.2	Stn. 0 to 0.4; Stn. 9 to 10	1.4km	Stn 9.4; -20
10-11 September 2018	Stn. 3 to 5	Stn. 0 to 2.6; Stn. 9 to 10.4	4km	Stn 2.2: -20 Stn 9.4; -22

Key findings of the survey at Harirampur are:

(i) The sand bar which emerged in the upstream area of the protected riverbank during the 2017 flood season has moved downstream and fills most of the launched part in the bend area (station 4 to 7.6).

(ii) Upstream of the protection work bankline erosion has started (Figure 3-8).

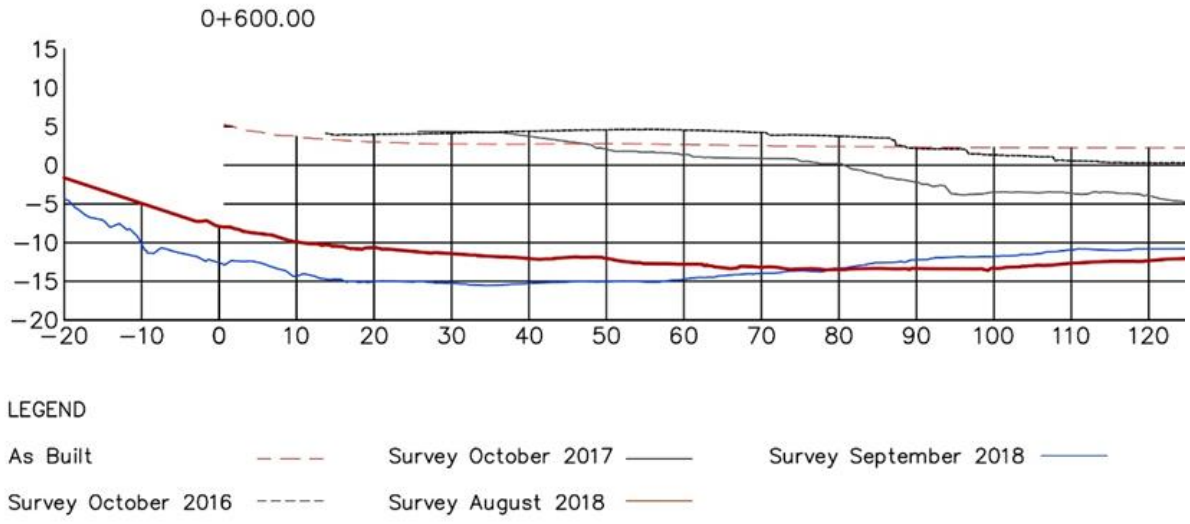


Figure 3-8 Underwater erosion at upstream of Harirampur site

(iii) The apron has launched significantly from station 1.6 to 2.8 in 2018. A 25m wide apron was dumped here. 10m to maximum 20m of the apron launched during 2018 flood season, as can be seen in the September 2018's survey (Figure 3-9).

(iv) From station 3 to 5.4 the apron is still buried under 5 to 10m of sediment.

(v) From station 9 to 10.4 apron launched 5 to 10m vertically.

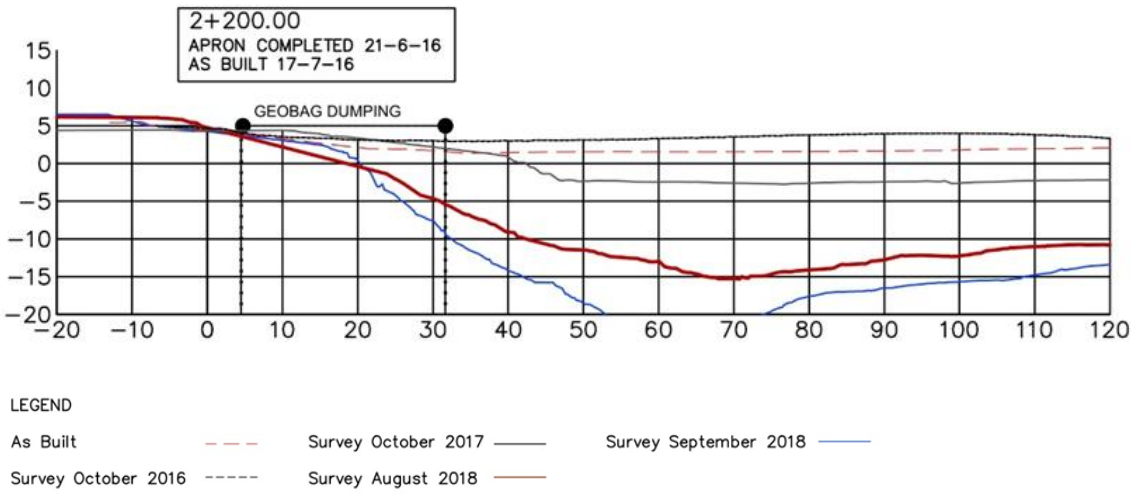


Figure 3-9 Launched section at station 2.2

Selected long profiles through the deepest scour at the end of the apron are provided in Appendix 9.2. The profile is based on simplified 200m interval cross sections that do not follow the exact paths of the dumping barges.

3.4.5 Chauhali Upstream

In Project-2, 12km of river bank protection work will be implemented upstream of Chauhali. One survey was carried out here in October 2018. The survey covers 18km length from the Dhawleshari offtake to the existing bank protection at Chauhali. This survey will be the basis for the design of Project–2 works and future river morphological analysis. Results are summarized in Table 3-6.

Table 3-6 Findings alongside the proposed 12km bank protection at Chauhali upstream

Time period	Sedimentation (>+2 m+PWD)	Deep Scour (<-9 m+PWD)	Deep Scour length	Deepest scour location
4th October 2018	Stn. 8.3 to 9.7 Stn. 10.7 to 13.7 Stn. 17.1 to 19.3 Stn. 22.7 to 25.7	Stn. 15.7 to 16.7	1km	Stn 16.1; -9

Key findings of the survey upstream of Chauhali are:

(i) The maximum scour was observed near the outer bend between station 17 and 13.

(ii) The full river survey of 2018 shows that the thalweg has shifted towards the left bank, where velocities up to 1.8m/s were observed during the September 2018 float track survey.

(iii) The reach upstream the outer bend area from station 14 to 17 is vulnerable to bank erosion.

3.4.6 Koijuri

In October 2018, the SDC conducted a bathymetric survey at Koijuri bankline to monitor and observe the performance of the underwater protection. Under JMREMP 10km of riverbank protection works was implemented there between 2009 and 2011. The results are summarized in Table 3-7.

Table 3-7 Findings alongside the bank protection area at Koijuri

Time period	Sedimentation (>+6 m+PWD)	Deep Scour (<-8 m+PWD)	Deep Scour length	Deepest scour location
6-7th October 2018	Stn. 8.5 to 11	Stn. 1.9 to 3.4 Stn. 3.9 to 6.1	8.1km	Stn 2.8; -18

Key findings of the survey in Koijiuri are:

(i) A char has formed between Stn. 8.5 to 11 with most of the area being not navigable. This char has shifted the main river thalweg 500m to 1km away from the bank protection works.
(ii) A deep channel is observed from station 1 to 8.
(iii) A multibeam survey was conducted at Koijuri between Stn. 8.4 and 2, from 9 to 11 November 2017. Differential maps from that survey show overall 2 to 6m sedimentation in this channel. Only at the downstream part from station 3.3 to 1.9, the channel has deepened up to 5 to 8m.
(iv) Cross section analysis does not show any underwater anomalies.

3.4.7 PIRDP

In October 2018, the SDC conducted bathymetry survey at the PIRDP for monitoring and observing 7km of riverbank protection built from 2004 to 2008. The results are summarized in Figure 3-8. Bathymetry map and long profile is added in Appendix 6.7 and 9.3.

Table 3-8 Findings alongside the proposed PIRDP site

Time period	Sedimentation (>+2 m+PWD)	Deep Scour (<-9 m+PWD)	Deep Scour length	Deepest scour location
7th October 2018	From Stn. 0.3 in upstream direction	Stn. 3.7 to 4.5	0.8km	Stn 4.3; -21

3.5 Chauhali failures

A technical committee was formed by BWDB on 4th July 2018, aimed to visit the site, investigate the reason behind the erosion by analyzing the data, and prepare a work proposal to strengthen the works. On the basis of preliminary investigations the ISPMC submitted a memo to the PMO (letter No ISPMC-FRERMIP-557) where after analyzing various aspects six reasons for the Chauhali failure were proposed (Table 3-9Table). All failures from 2016 to 19 are systematically listed in Appendix 5.

Initial lessons learned are as follows

1. Initial placement under water shall provide the widest possible apron to keep the scouring process away from the bank. To this end the conversion of 5 layers of geobags into three layers would have extended the initially placed protection by two thirds from 42 to 70m.
2. Launched aprons require adaptation with an additional toe apron and additional layers over the single launched layer, particularly when under angular attack.
3. Following the praxis of JMREMP, the contracts shall contain a provision to remove the temporary wave protection for additional dumping under water and excavating the final slope without any fill into the river.
4. No concrete key shall be built on loose deposits placed over the original geobag layer.
5. The concrete block key shall be designed with single layer coverage of underlying bags to prevent damage and not add massive surcharge destabilizing the slopes geotechnically.
6. The upper wave protection layer shall be anchored at the bottom with an anchor beam (see for example the Padma Bridge design) to avoid immediate sliding of the upper protection if the key is compromises.

7. The upper slope protection layer shall be designed to minimum thickness, following the JMREMP design (in accordance with wave loading depending on the water levels)

Table Failure causes table (updated from Chauhali Committee Report (ISPMC, 31 July 2018)

Failure cause	Failure Type	Design component			No of failures*
		Geotechnical stability	Hydraulic stability	Structural Stability	
Gaps in coverage from dumping	1	Erosion and slope instability		No toe support and slippage	2
Angular flow attack	2	Velocities above design velocity	Elements too small	Winnowing failure of launched single layer coverage	20
Localized slope instability	3	Slopes too steep for soil properties			13
Upper slope construction	4			Sloping into river resulting in loose deposit at low water level	23
Drainage	5	Upper slope instability through addl. seepage			1
Obstacles	6			Imperfect launching or gaps during dumping due to debris from buildings, vegetation	1

After implementing the adaptation work, which was completed in 11th July 2018, Chauhali has experienced no failures alongside the adapted length. However, two locations upstream and downstream failed. One failed on 23rd September 2018 from stn 0.05 to -0.250 and another one on 22nd February 2019 between stn 4.88 to 5.04. The ISPMC submitted two memo (reference ISPMC-FRERMIP-534 and ISPMC-FRERMIP-596) with detailed analysis. A summary is provided below.

21st September 2018

During the flood season 2018, only the downstream 250m experienced souring into a depth not reached earlier. The survey from early August shows, that the bed levels at the end of the flood season 2017, during the multi-beam echosounder survey in November 2017, were in a similar order than in August 2018 (Appendix 7.1). Both, the multi-beam survey of November 2017 as well as the cross sectional survey of August 2018 do not show any indications of underwater anomalies. The very gentle undulation of the bed in the maps is amplified by the color scheme of blue and red in Figure 3-10 (at around stn 290) and indicates the location of the anomaly.

The survey in early September 2018 shows an explicit, protruding triangular shape with its crest perpendicular to the riverbank at around stn 150. Two events happened that in combination encouraged the geotechnical slope failure:

(i) A part of the upstream approach flow bifurcating into the right Chauhali channel started shortcutting over the char opposite of the Chauhali riverbank and squeezing the flow along the downstream bank (Figure 3-11). This flow pattern was triggered as shortcut channels had formed over the char, which are still active during the dry season in November 2018.

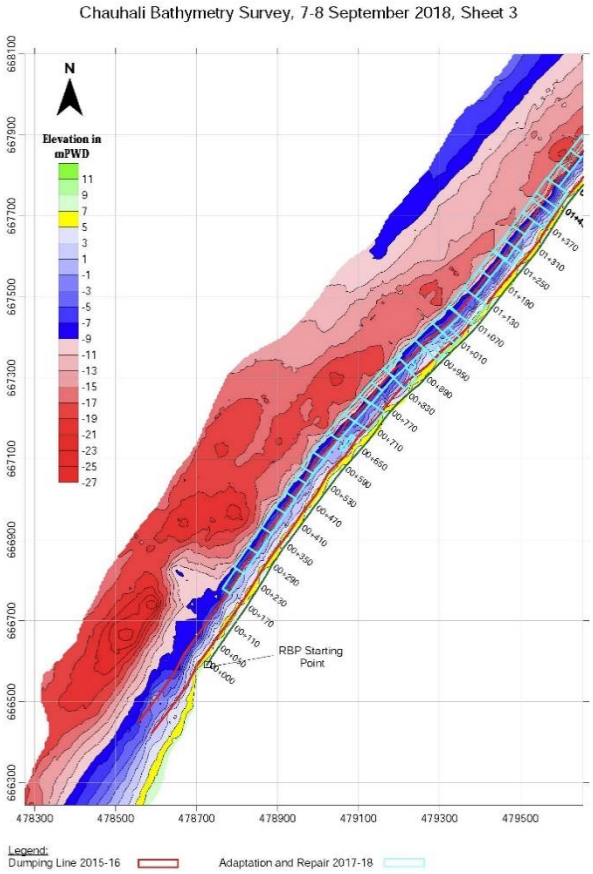


Figure 3-10 Chauhali 7 to 8 September 2018 survey

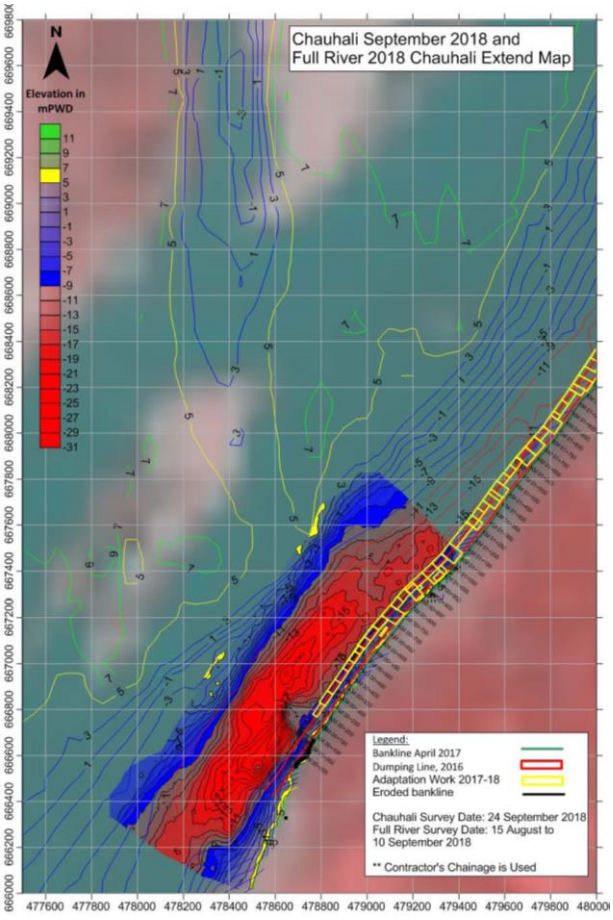


Figure 3-11 General river situation with shortcut flow at Chauhali squeezing the downstream flow at the bank

(ii) Another flood peak, with the highest water levels of 2018 stared scouring to great depth, reaching bed levels of around -33m+PWD about 100m from the end of the launched apron at stn -150. For comparison the computed design scour depth is -22m+PWD.

This combination of an anomaly (protrusion) in the river bed, acting like a submerged spur and the last peak flow being squeezed at the bank resulted in a deeper than normal bend scour – better explained as a combined bend and confluence scour acting on a protrusion.

Five emergency surveys were conducted between 23rd September to 23rd November 2018. Bathymetry maps are provided in Appendix 6.1.

In order to address the special situation at the downstream end of the work, the ISPMC suggested a three-step approach of which the BWDB Tangail division implemented step 1 and 2 between … and ….

(i) Step I: emergency repair: This consists of dumping two layers of geobags from country boats along the riverbank to prevent further erosion into the floodplain. The overall slope in the failure zone is very moderate (in the order of 1V:4H – see Figure 11 stn 0). This emergency coverage is required for around 25 m from the bankline. The total estimated number of bags is around 4,000. The work was completed after dumping 6000 geobags along the riverbank on 3rd October 2018.

(ii) Step 2: repair of the failed zone (Figure 17): This work consists of repairing the damage over the some 200m length and extending the work to the location of the deep scour hole using the remaining 27,000 geobags. The work ties in with the upstream adaptation work

to avoid discontinuities. The overall channel pattern explained in Figure 9 is likely to prevail during the next flood season, and at least at the beginning of the flood could result in further deep erosion. To this end we recommend to place three layers of geobags over an area of some 9,000m². The total number of bags required is around 27,000.

(iii) Step 3: strengthening the downstream end (Figure 17): The movement of the deep scour in downstream direction warrants further strengthening and extension of the downstream end of the Chauhali revetment. This strengthening work will cover a total area of some 65,000m² and require around 195,000 bags dumped from barges in 3 layers.

22nd February 2019

Two failures occurred between stn 4883 and 4915 km (32m) on 22nd February 2019 and stn 4938 and 5046 (108m) on 25th February 2019. The first failure was at previously placed concrete block wave protection whilst the second failure extended 42m into the temporary geobag wave protection, protecting the upstream end of the upper slope between stn 5,000 and 7,000.

Two failure mechanisms can be considered:

(i) As in previous cases, the berm consisting of weak soil has eroded and consequently the support for the upper slope has been lost, resulting in slippage of the placed concrete blocks.

(ii) The underwater apron has eroded, and the erosion has progressed through the whole width of the placed underwater apron (some 40m wide with 5 layers of geobags).

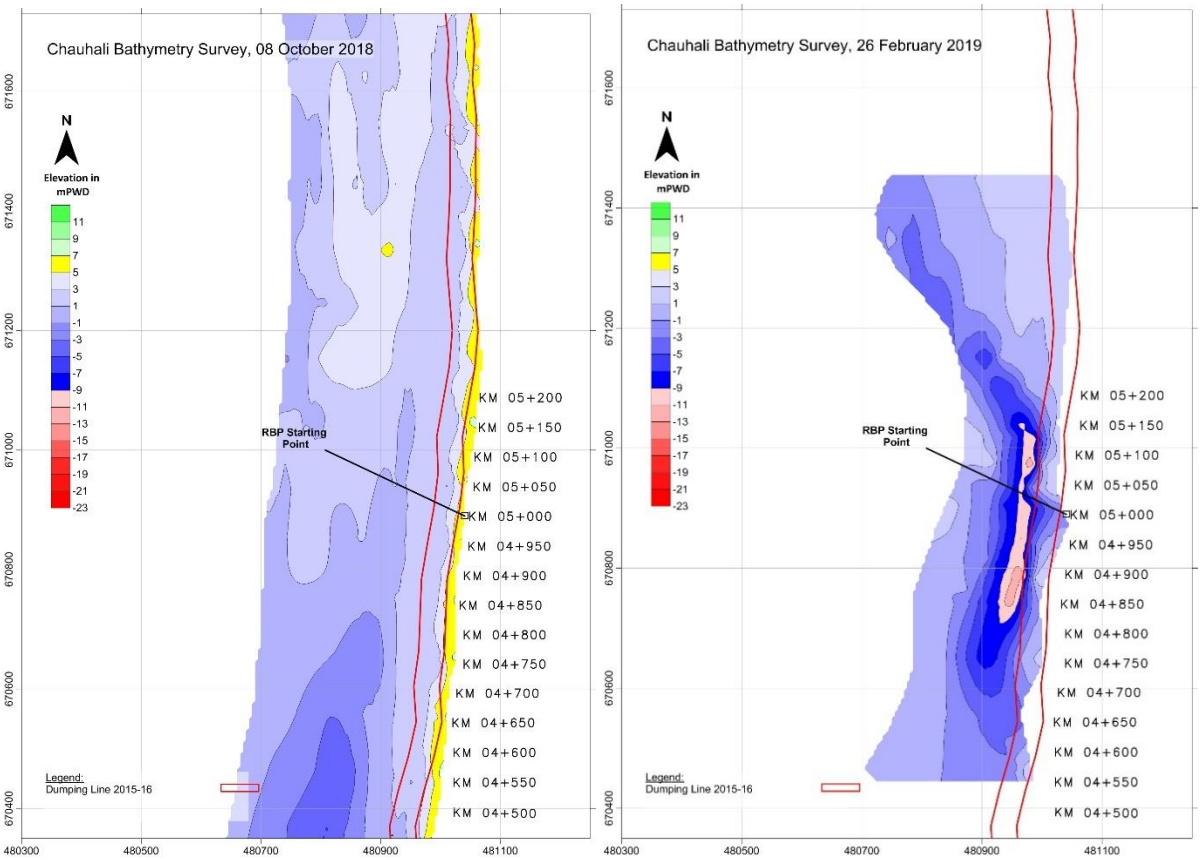


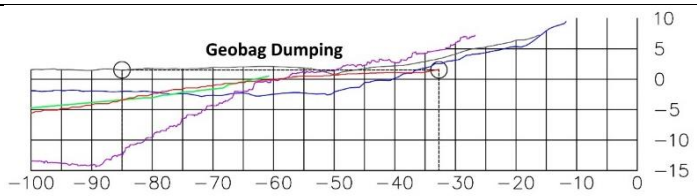
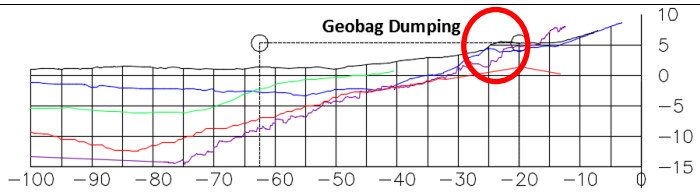
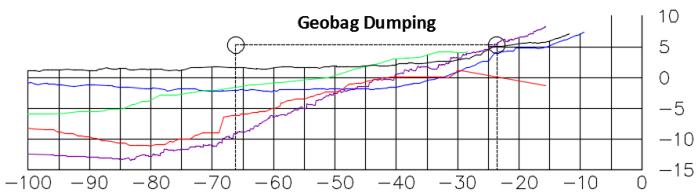
Figure 3-12 Comparison of October 2018 and February 2019 survey (February 2019 survey was carried out as a response to the failures and in the vicinity of the February 2019 failures only)

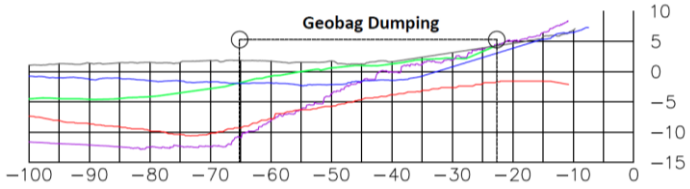
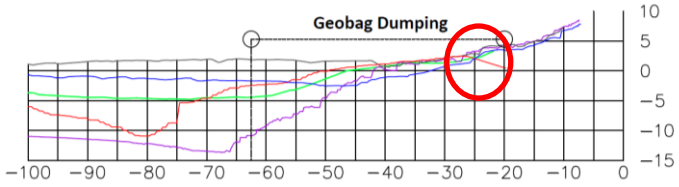
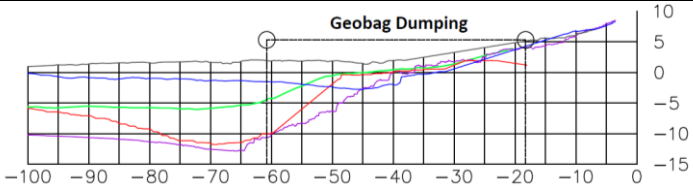
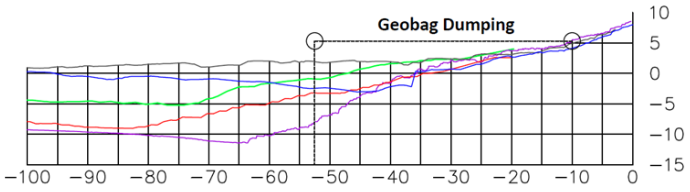
Analysis of the river survey and the cross sections shows:

(i) The erosion has occurred only during the dry season and is associated with the dry season channel pattern (Figure 3-12).

(ii) The underwater slope is mostly unaffected, as the apron, launched in 2016, has neither been reached nor eroded further than the maximum reached during the 2016 flood (Table 3-9).

Table 3-9 Survey Cross-Sections in vicinity of failures (ISPMC, 26th Feb 2019)

Stn	Cross-Section	Description
4750		No failures have occurred and the launched geobag apron has only been reached in the upper part above 1m PWD. Please note that the 26th February 2019 (red) line stops abruptly near the bank due to the presence of cc blocks preventing surveying any closer to the bank
4850		Failure of the upper slope up to 5m below low water level (5m PWD) can be seen in comparison to the September 2016 survey data immediately following apron launching At -5m PWD the lower slope has resisted angular flow attack and eroded only up to the geobag apron level. Below this a thin layer of sediment deposition remains above the launched geobag apron.
4950		Failure of the upper slope up to 4m below low water level can be seen in comparison to the September 2016 survey data immediately following apron launching At 0m PWD the lower slope has resisted angular flow attack and eroded only up to the geobag apron level. Below this a thin layer of sediment deposition

		remains above the launched geobag apron.
5000		Failure of the upper slope and lower slope up to -7m PWD can be seen in comparison to the September 2016 survey data immediately following apron launching. This appears to be a deep-seated slip failure.
5050		Failure of the upper slope up to 2m below low water level can be seen in comparison to the September 2016 survey data immediately following apron launching At just below the berm level therefore the lower slope has resisted angular flow attack and eroded only up to the placed geobag apron level. Below this the channel has not reached the launched geobag apron.
5100		Failure of the upper slope up to 4m below low water level can be seen in comparison to the September 2016 survey data immediately following apron launching Below this the launched geobag apron has resisted further erosion.
		No failures have occurred and the launched geobag apron has only been reached in the upper part above -3m PWD.

The failure is associated with the failure of the berm (cross sections 4800 to 5100). This is in line with earlier observed failures (see memo 31 July 2018 – ISPMC-FRERMIP-522), particularly as the concrete blocks were dumped on loose soil, bulldozed from the bank into the river to create a loose berm, expected to support the upper slope protection. Some cross sections even show steep upper slope of the loose material under the berm (red circles in cross sections 4850 and 5050) particularly in September 2016 after construction.

Only cross section 5,000 shows erosion into the launched apron. The assumption that this is a result of erosion through nearly 35m of placed apron is not supported by the typically low flow velocities. It is rather an indication of a geotechnical mass failure, which is the only mechanism that is able to displace the five-layer protection. Any failure of this kind indicates the weak subsoil composition, as further confirmed through additional boreholes conducted in the area in 2016 and 2017.

Stn 5,000 was in the location of the second failure that occurred 3 days after the first thereby supporting the theory that the upper berm failure triggered a deep-seated slip failure that caused this location to fail due to weak underlying soils rather than that this area of the bank suffered a failure mechanism that was unique amongst the remaining sections. The failure mechanism is therefore considered to be angular flow attack in a localized area combined with a geotechnical unravelling of the berm due to poor construction, a heavy berm due to the dumping of concrete blocks and weak underlying base soils.

These cross-sections show that the majority of the failures related to the upper slope only with the exception of stn 5,000 where a short length of the top of the lower slope failed alongside the upper slope. Cross-sections at stn 4,750 to 4,850 show that the underwater slope with previous geobag coverage remains both fully intact following erosion and higher than the post apron launching level following the 2016 flood season. Consequently, the failure is associated with the erosion of the berm, as observed in other places and consequently slippage of the concrete block slope protection.

It is understood from information collected by the ISPMC from the Tangail SO Jalal Uddin on 5th March 2019 that the following dumping was undertaken by BWDB Tangail using Non-Development Revenue (NDR) funds:

- Stn. 4.883 to 4.935, 5 layers of geobags, 15m wide apron
- Stn. 4.938 - 5.000, 5 layers of geobags (+ additional geobags to fill void), 15m wide apron
- Stn. 5.000 - 5.046, 5 layers of geobags (+additional geobags to fill void), 15m wide apron

3.6 Zafarganj and Harirampur failure

At Zafarganj there was no failure in 2018. Also, at Harirampur no failure was observed in the protected bank from station. But some bank erosion occurred upstream of the protected area from stn 0 to 1.6 which need to monitor regularly for any emergency action.

4 Adaptation Works

4.1 Chauhali

The BWDB successfully implemented 3.8km of adaptation works at Chauhali during the 2017-18 dry season. The adaptation plan was designed based on the November 2017 multibeam survey. The BWDB Tangail started implementing 1.54km adaptation work from stn 0.18 to 1.52 and 2.2 to 2.4 from the remaining geobags from work packages W6 and W7. After that due to lack of budget, leftover budgets from package W12 and 13 were adjusted with package W11 for implementing the rest length of around 1.96 km. The 1.96km adaptation design was revised considering the March 2018 bathymetry survey (Figure 4-2).

For adaptation and repair work, three different designs were proposed (Figure 4-1):

1. Repair of slope (three layer of bags – red color)
2. Strengthening of launched Apron (two layer of bags yellow color)
3. New toe apron (three layer of bags – green color)

For underwater slope failure repair works, three layers of geobags were dumped onto the damaged area. To strengthen the single layer after launching two layers of geobags were dumped on the launched apron followed by a new apron on the riverbed. The new apron is designed for the length required to reach to maximum design scour level and an additional residual length of 5m, which forms a berm following consecutive launching (stepped apron). A minimum 5 m apron will be provided where the apron has already reached to design scour level (Figure 4-1).

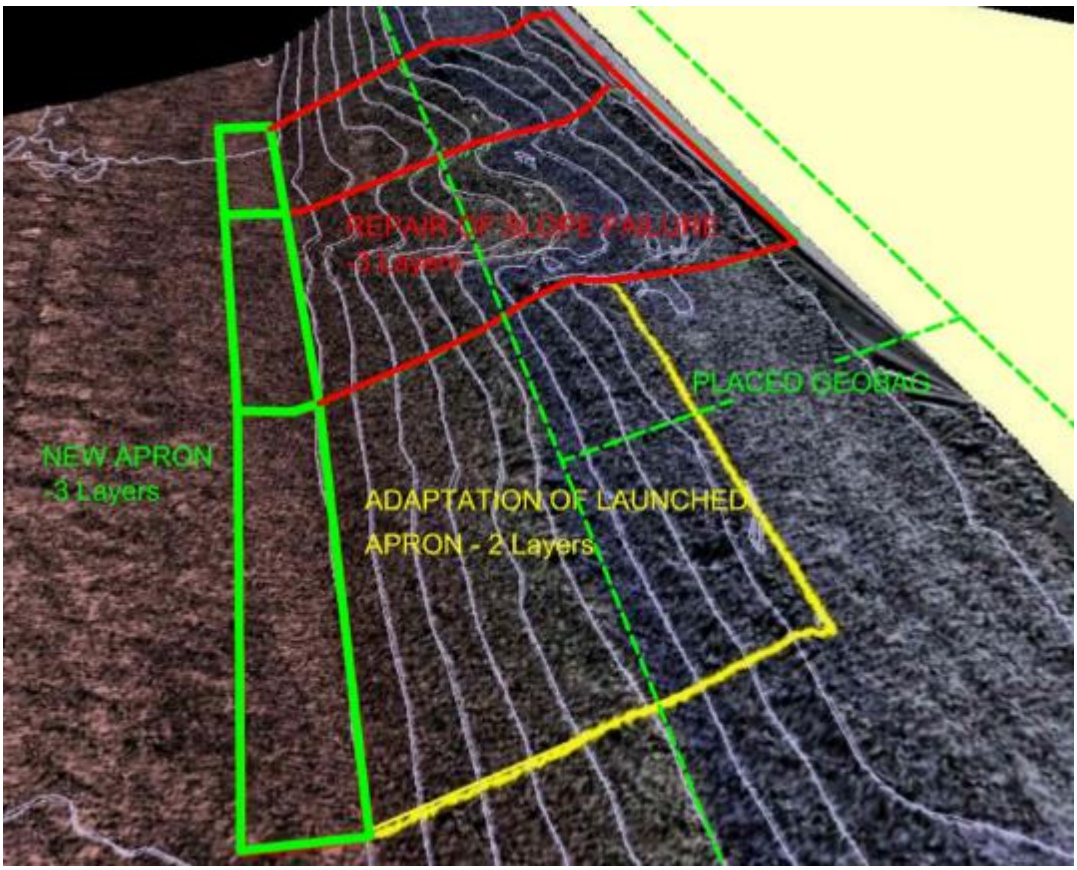


Figure 4-1 Adaptation and repair works design plan view

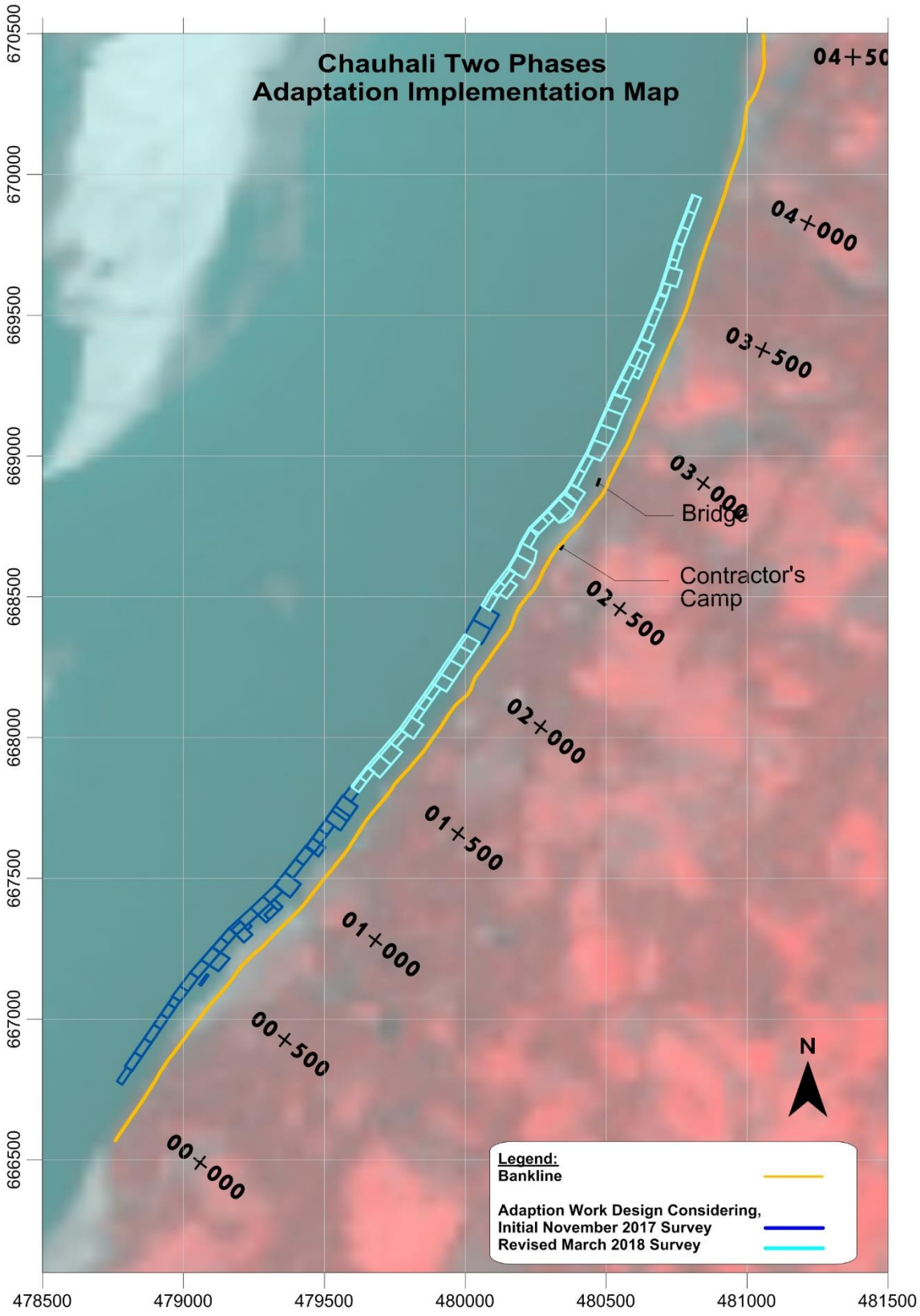


Figure 4-2 Plan view of two phases adaptation work

Figure 4-3 shows how adaptation actually works. The additional apron which was placed beside the initial launched apron referred in Figure 4-1, started launching newly and formed a stepped slope. This step launching was observed from stn 0.250 to 0.650. Further surveys during the future flood seasons are expected to reveal more details of the launching behavior of the new apron.

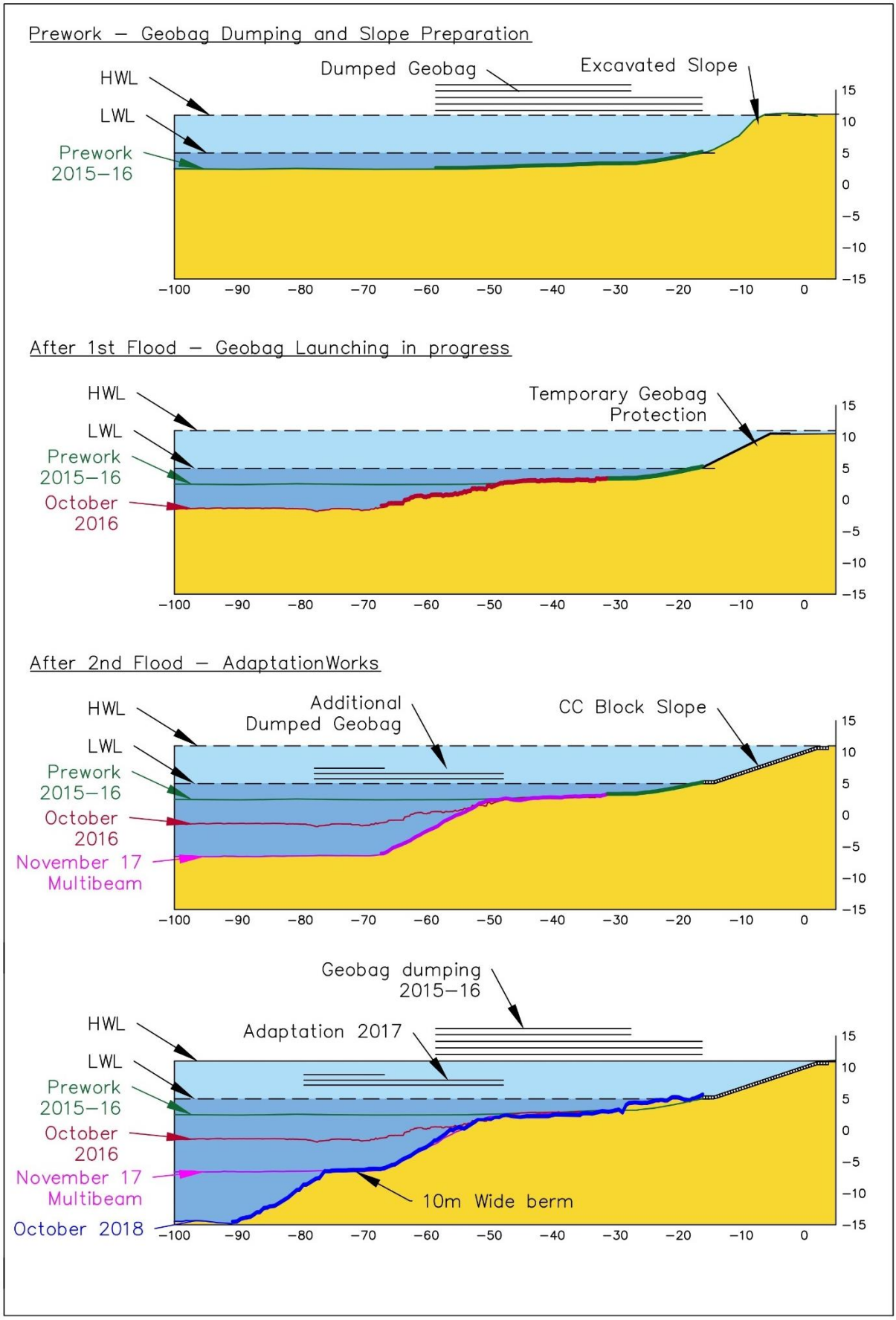


Figure 4-3 Steps of adaptation

Satellite imagery (Figure 2-6), a dry season survey from February 2019 (Appendix 6.1) and differential survey maps (Appendix 7.1) show that angular flow can affect the upstream part of Chauhali. Following the high degree of launching that had taken place up to September 2016 between stn 3.95 and 5.0, the launched slope was thereafter buried under 5 to 10m sediment which could again be exposed after the 2019 flood season. At that time adaptation work would be required to increase the apron from 1 layer of launched coverage to 3 layers post adaptation. Regular bathymetric surveys will be required to understand the necessity of adaptation work.

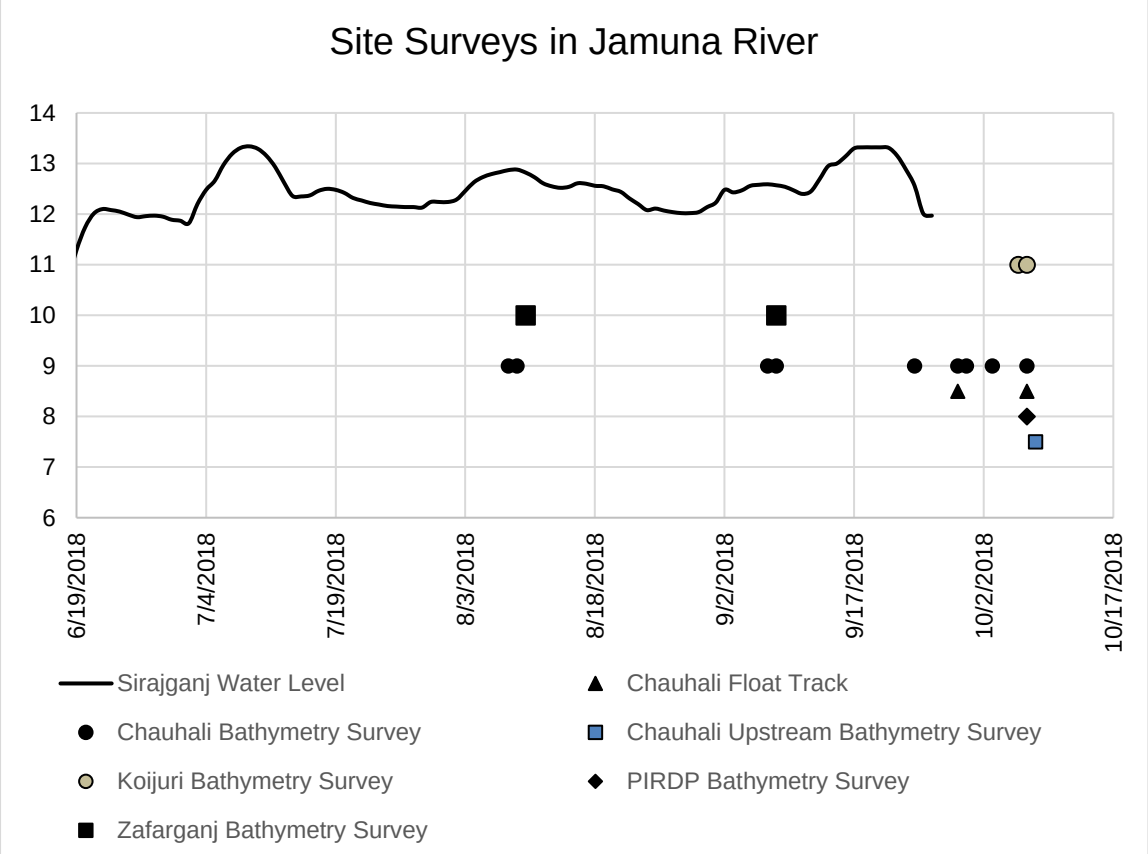
4.2 Zafarganj & Harirampur

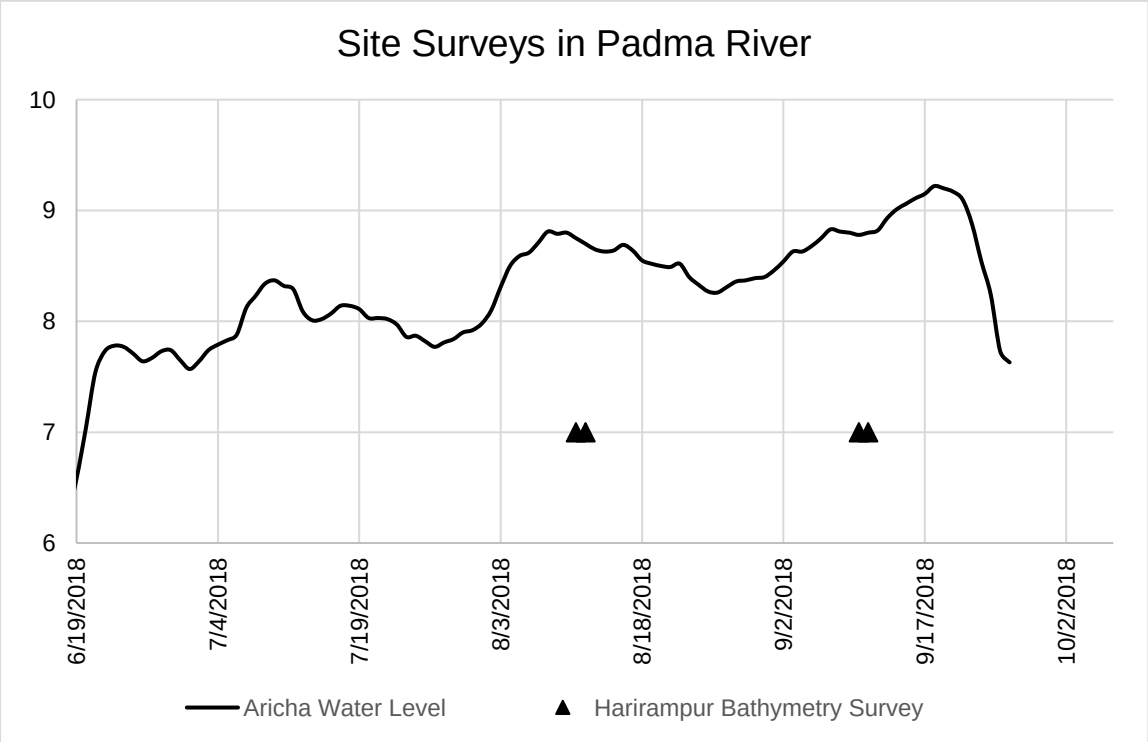
At Zafarganj no major erosion occurred in 2018. The school near the protective bank is vulnerable to future erosion. Also, at Harirampur no major erosion was observed alongside the protected bank. Some bank erosion occurred upstream of the protected area from stn 0 to 1.6.

Regular bathymetry survey will be required to identify changes and understand the necessity of future adaptation work at Zafarganj and Harirampur.

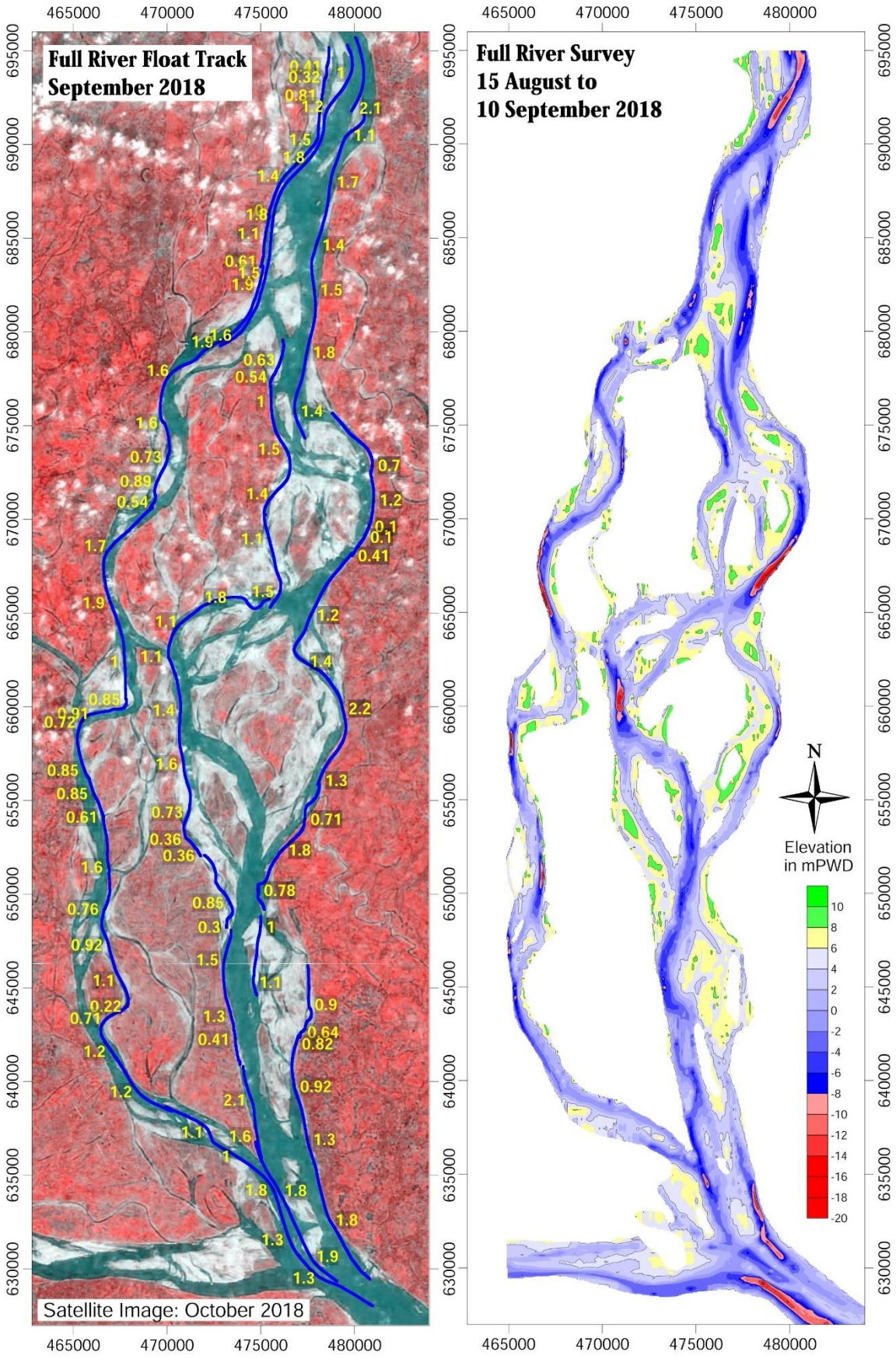
Appendices

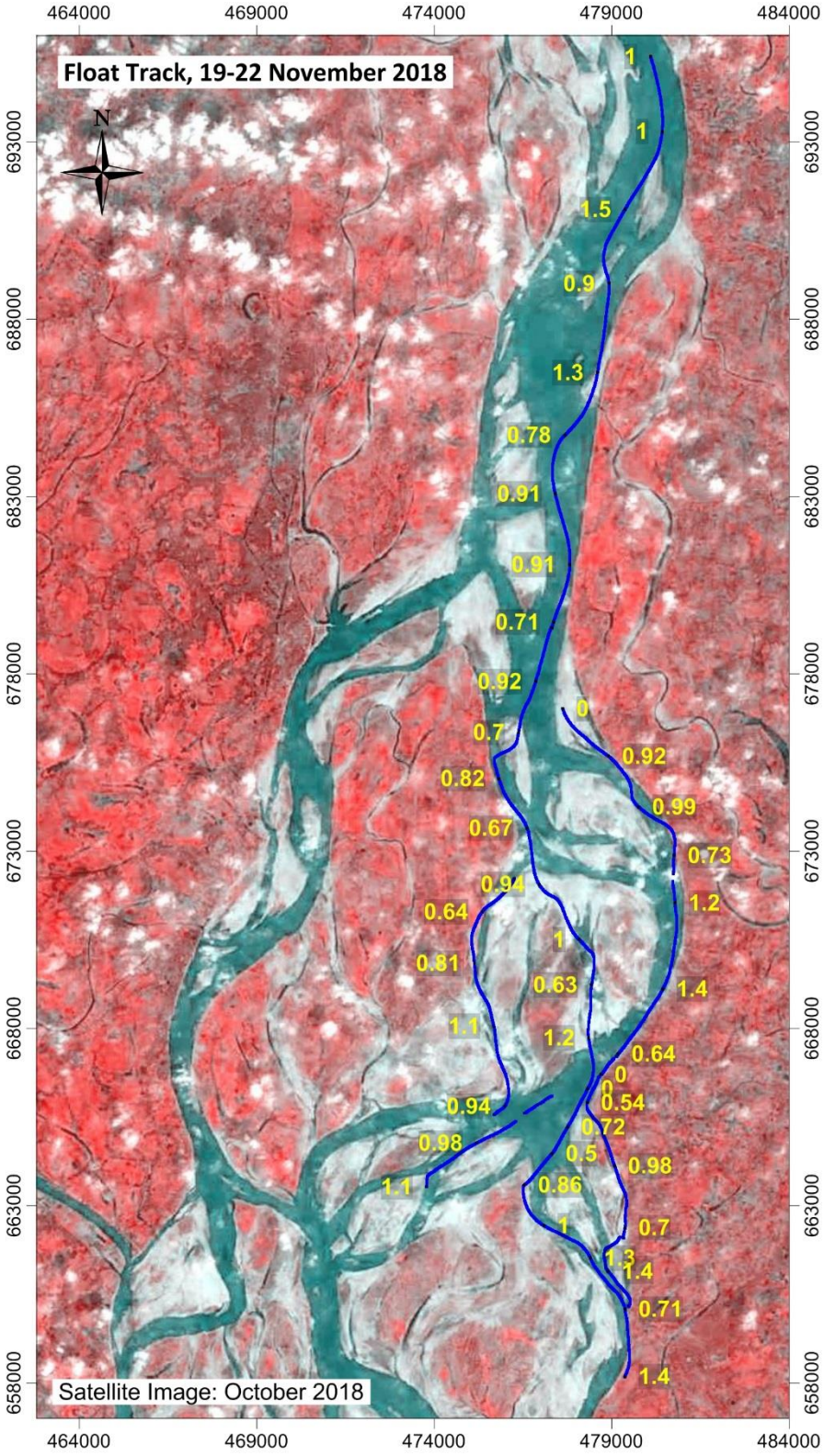
1 Summary Site Surveys





2 Float tracking




Float Track, 19-22 November 2018
N
Satellite Image: October 2018
464000
469000
474000
479000
484000
693000
688000
683000
678000
673000
668000
663000
658000
1
1
1.5
0.9
1.3
0.78
0.91
0.91
0.71
0.92
0.7
0.82
0.67
0.94
0.64
0.81
1.1
0.94
0.98
1.1
0
0.92
0.99
0.73
1.2
1
0.63
1.4
1.2
0.64
0
0
0.54
0.72
0.5
0.98
0.86
1
0.7
1.3
1.4
0.71
1.4

3 Survey quality

3.1 Chauhali

Survey Date	Parameter	Comments
August 8-9,2018	Status	Accepted
	Survey interval	100m
	Survey length	8km
	Survey coverage towards river	300m
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
September 7-8,2018	Status	Accepted
	Survey interval	100
	Survey length	8km
	Survey coverage towards river	300m
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
September 24,2018	Status	Accepted
	Survey interval	100m, 50m in eroded place
	Survey length	2km
	Survey coverage towards river	550m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
September 29,2018	Status	Accepted
	Survey interval	100m, 50m in eroded place
	Survey length	2km
	Survey coverage towards river	550m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
September 30,2018	Status	Accepted
	Survey interval	100m, 50m in eroded place
	Survey length	2km
	Survey coverage towards river	550m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
October 03, 2018	Status	Accepted
	Survey interval	100m, 50m in eroded place
	Survey length	2km
	Survey coverage towards river	550m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
October 08, 2018	Status	Accepted
	Survey interval	100m
	Survey length	8km
	Survey coverage towards river	300m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
November 23, 2018	Status	Accepted
	Survey interval	100m, 50m in eroded place
	Survey length	0.9km
	Survey coverage towards river	300m

Survey Date	Parameter	Comments
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency

3.2 Zafarganj

Survey Date	Parameter	Comments
August 10,2018	Status	Accepted
	Survey interval	100m
	Survey length	2.6km
	Survey coverage towards river	350m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
September 9,2018	Status	Accepted
	Survey interval	100m
	Survey length	2.6km
	Survey coverage towards river	350m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency

3.3 Harirampur

Survey Date	Parameter	Comment
August 11-12,2018	Status	Accepted
	Survey interval	100m
	Survey length	11.8km
	Survey coverage towards river	350m
	Data missing	No
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
September 10-11, 2018	Status	Accepted
	Survey data interval	100m
	Survey length	11.8km
	Survey coverage towards river	350m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency

3.4 Chauhali Upstream

Survey Date	Parameter	Comment
October 4, 2018	Status	Accepted
	Survey interval	200m
	Survey length	18km
	Survey coverage towards river	350m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency

3.5 Chauhali Upstream

Survey Date	Parameter	Comment
October 4, 2018	Status	Accepted
	Survey interval	200m
	Survey length	18km
	Survey coverage towards river	350m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency

3.6 Enayetpur

Survey Date	Parameter	Comment
October 5, 2018	Status	Accepted
	Survey interval	200m
	Survey length	4km
	Survey coverage towards river	350m to 400m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency

3.7 Koijuri

Survey Date	Parameter	Comment
November 09-10, 2017	Status	Accepted
	Survey interval	200m
	Survey length	12km
	Survey coverage towards river	350m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency

3.8 PIRDP

Survey Date	Parameter	Comment
October 7, 2018	Status	Accepted
	Survey interval	200m
	Survey length	7.4km
	Survey coverage towards river	350m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency

4 Chauhali Benchmarks

Sl No	Description	Northing BTM	Easting BTM	RL RTK	Adjusted RL	Remarks
1	BWDB BM			13.08	13.37	This BM Established by BWDB at Khokar Bridge Wheel Guard at Jotpara Bazar
2	BM01 NEW 2017	666548	478714	10.50	10.79	Established by RTK January 2017 after Flood 2016
3	BM01A NEW 2017	666458	478690	10.15	10.44	Established by RTK January 2017 after Flood 2016

4	BM02 NEW 2017	667439	479418	11.71	12.00	Established by RTK January 2017 after Flood 2016
5	BM02A NEW 2017	667542	479497	10.59	10.88	Established by RTK January 2017 after Flood 2016
6	BM03 NEW 2017	668263	480027	11.61	11.90	Established by RTK January 2017 after Flood 2016
7	BM03A OLD 2015	668380	480111	10.69	10.98	Established by RTK During Pre Work 2015 (BASE for 2017)
8	BM04 NEW 2017	669087	480588	9.65	9.94	Established by RTK January 2017 after Flood 2016
9	BM04A NEW 2017	669192	480723	10.25	10.54	Established by RTK January 2017 after Flood 2016
10	BM05 NEW 2017	669998	480918	10.60	10.89	Established by RTK January 2017 after Flood 2016
11	BM05A NEW 2017	669910	480888	10.96	11.25	Established by RTK January 2017 after Flood 2016
12	BM06 NEW 2017	670930	481064	11.61	11.90	Established by RTK January 2017 after Flood 2016
13	BM06A NEW 2017	670808	481065	10.78	11.07	Established by RTK January 2017 after Flood 2016
14	BM_01_NI16	672292	480994	13.32	13.61	BM installed by ISPMC surveyor during 2017 flood season survey
15	BM_02_NNRC	669605	480800	12.15	12.44	BM installed by ISPMC surveyor during 2017 flood season survey
16	BM_03_NNRC	666286	478708	10.99	11.28	BM installed by ISPMC surveyor during 2017 flood season survey

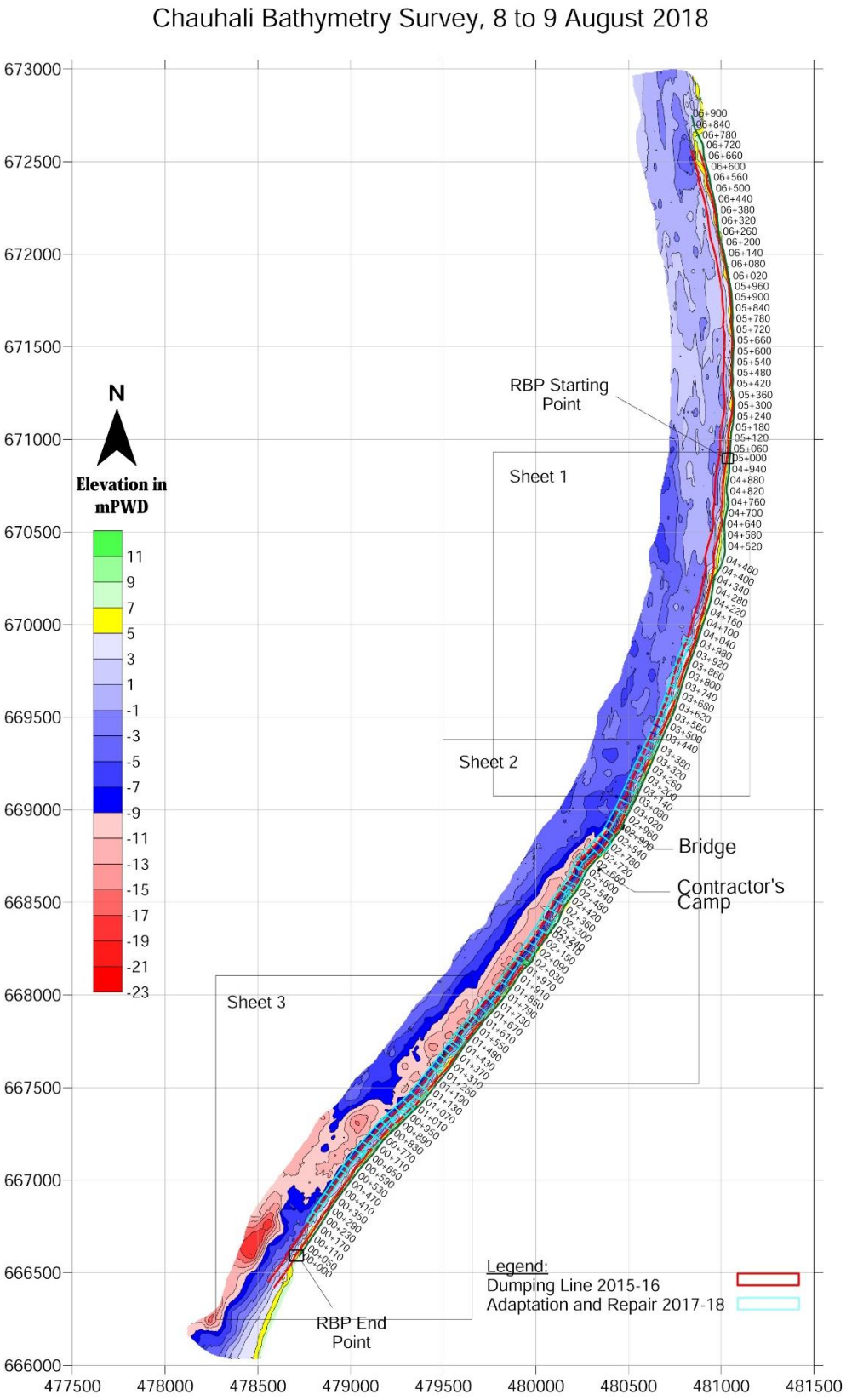
5 List of slope failures at Chauhali

Date	Erosion Code	Chauhali WL	Chainage		Length	Failure Description
			Start	End		
16/06/16	16-4.6	7.55	4600	4627	27	in temporary protection work
19/06/16	16-4.3	8.69	4335	4400	65	in temporary protection work
20/06/16	16-4.7	8.74	4740	4800	60	in temporary protection work
27/06/16	16-4.4	10.15	4410	4480	70	in temporary protection work
14/07/16	16-3.8	10.08	3800	3815	15	in temporary protection work
30/07/16	16-2.0		1990	2045	55	in temporary protection work
03/10/16	16-4.5		4505	4630	125	in temporary protection work
18/10/16	16-2.4		2480	2500	20	in temporary protection work
12/10/16	16-4.5		4560	4650	90	in temporary protection work
04/02/17	17-2.34	4.77	2340	2390	50	in temporary protection work
23/02/17	17-4.3	4.61	4365	4445	80	in temporary protection work
02/05/17	17-4.2	6.64	4270	4345	75	in permanent protection work.
07/05/17	17-2.5	7.57	2550	2570	20	in permanent protection work.
16/05/17	17-2.33	7.47	2330	2380	50	in permanent protection work.
03/06/17	17-2.0	7.84	2084	2112	28	in permanent protection work.

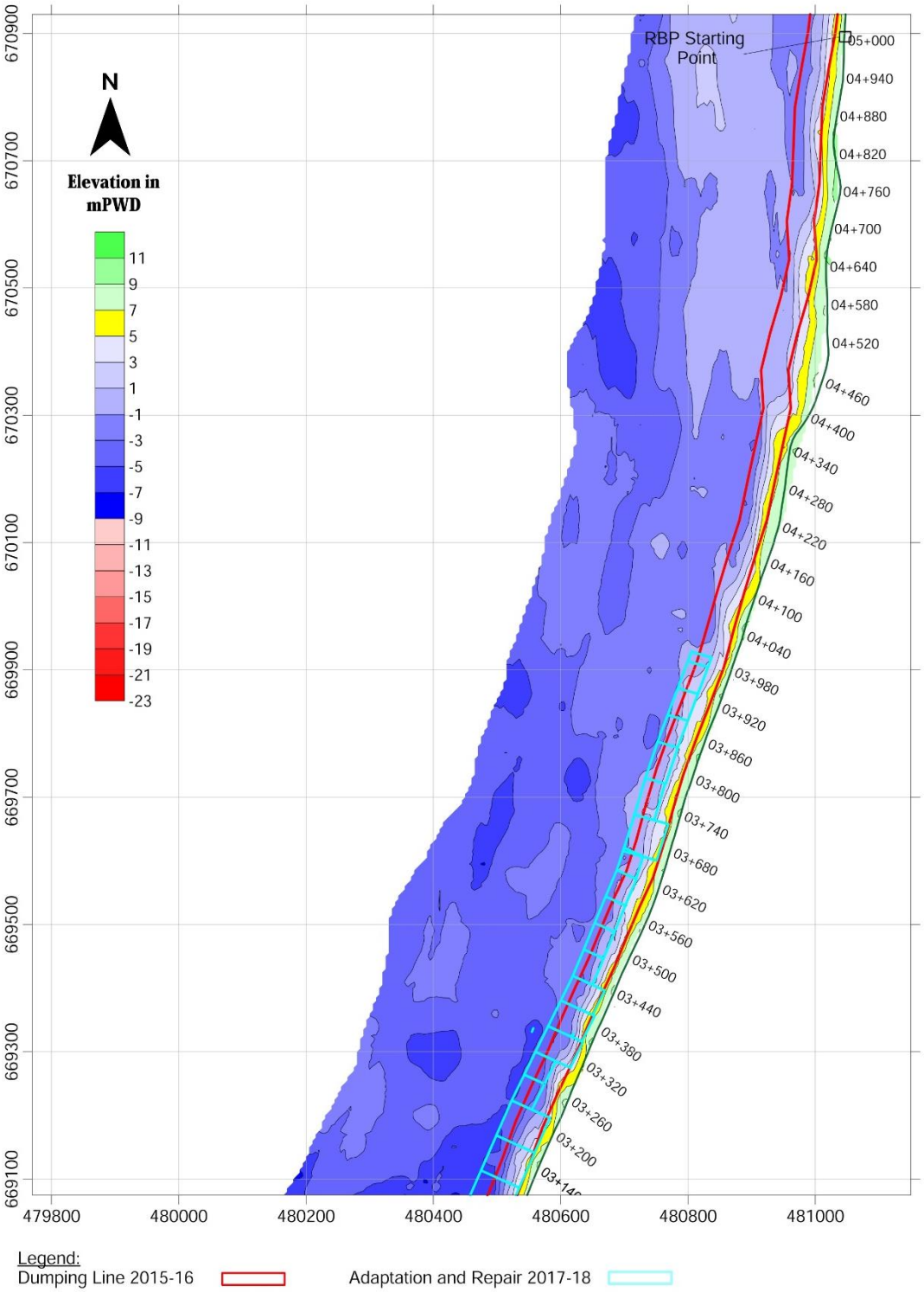
Date	Erosion Code	Chauhali WL	Chainage		Length	Failure Description
			Start	End		
08/06/17	17-1.7	9.04	1780	1857	77	in permanent protection work.
23/06/17	17-4.0	9.92	4070	4180	110	in permanent protection work.
23/06/17	17-0.8	9.92	833	863	30	in permanent protection work.
25/06/17	17-0.7	9.91	718	763	45	in permanent protection work.
27/06/17	17-2.7	9.92	2755	2785	30	in permanent protection work.
03/07/17	17-3.17	9.67	3170	3260	90	in permanent protection work.
07/07/17	17-2.8	10.37	2830	2915	85	in permanent protection work.
18/07/17	17-2.1	10.93	2120	2140	20	in permanent protection work.
19/07/17	17-2.9	10.74	2915	2935	20	in permanent protection work.
20/07/17	17-2.4	10.52	2490	2570	80	in permanent protection work.
21/07/17	17-2.05	10.20	2050	2100	50	in permanent protection work.
23/07/17	17-2.2	9.98	2205	2235	30	in permanent protection work.
25/07/17	17-3.0	9.98	3050	3080	30	in permanent protection work.
31/07/17	17-2.31	9.65	2310	2350	40	in permanent protection work.
31/07/17	17-3.11	9.65	3100	3150	50	in permanent protection work.
31/07/17	17-3.3	9.65	3300	3400	100	in permanent protection work.
13/08/17	17-2.78	10.81	2785	2820	35	in permanent protection work.
22/10/17	17-1.0		1070	1140	70	in permanent protection work.
08/12/17	17-0.9		960	1030	70	in permanent protection work.
17/03/18	18-2.2	4.72	2235	2286	51	Extension of 23rd July 2017 failure
27/03/18	18-2.7	4.67	2750	2770	20	Extension on 27th June 2017 failure
21/09/18	18-0.5		-0050	0000	50	In temporary protection
24/09/18	18-0.0		0000	0050	50	In permanent protection
27/09/18	18-2.55		-0250	0050	300	In temporary protection

6 Bathymetric Surveys

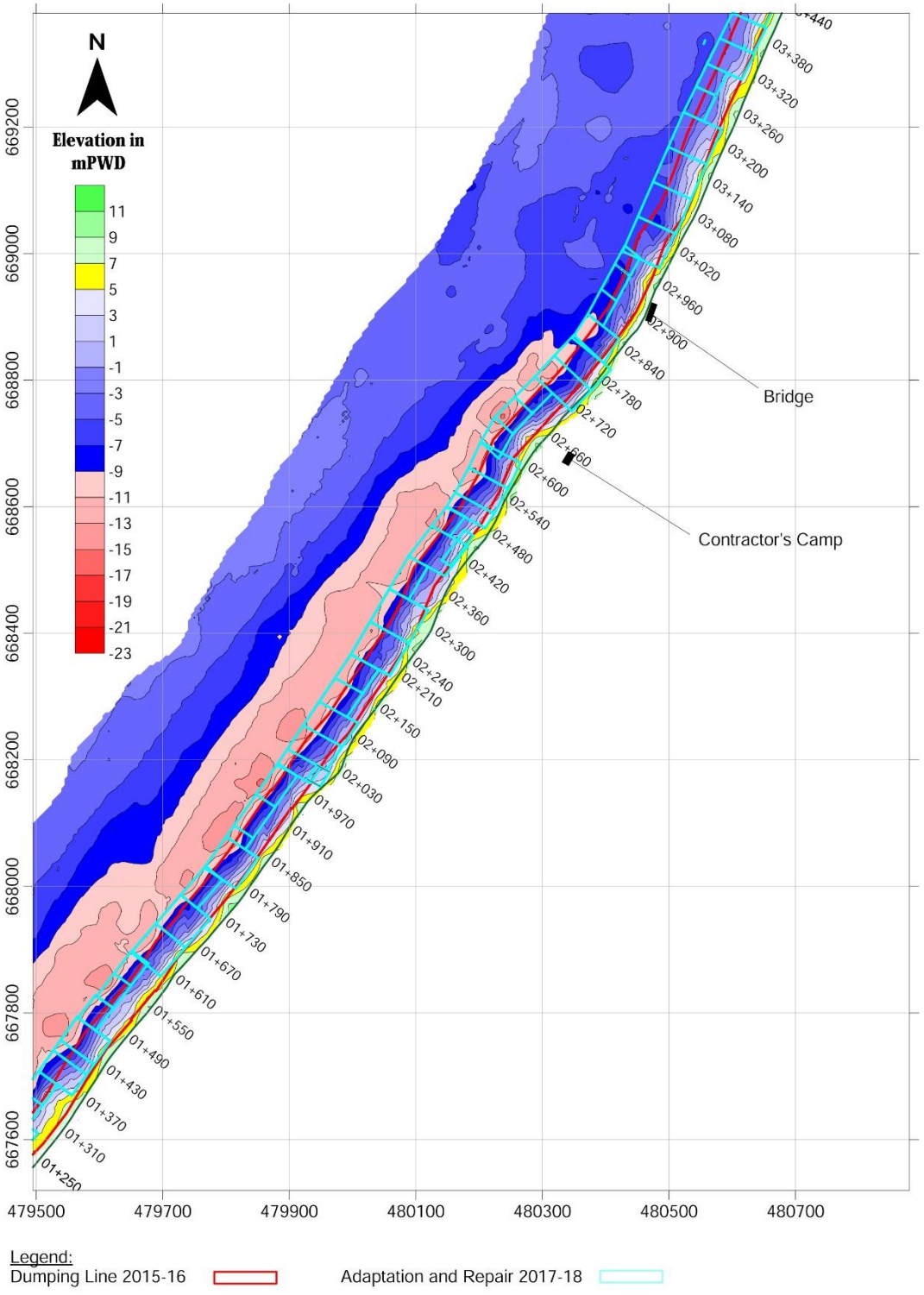
6.1 Chauhali



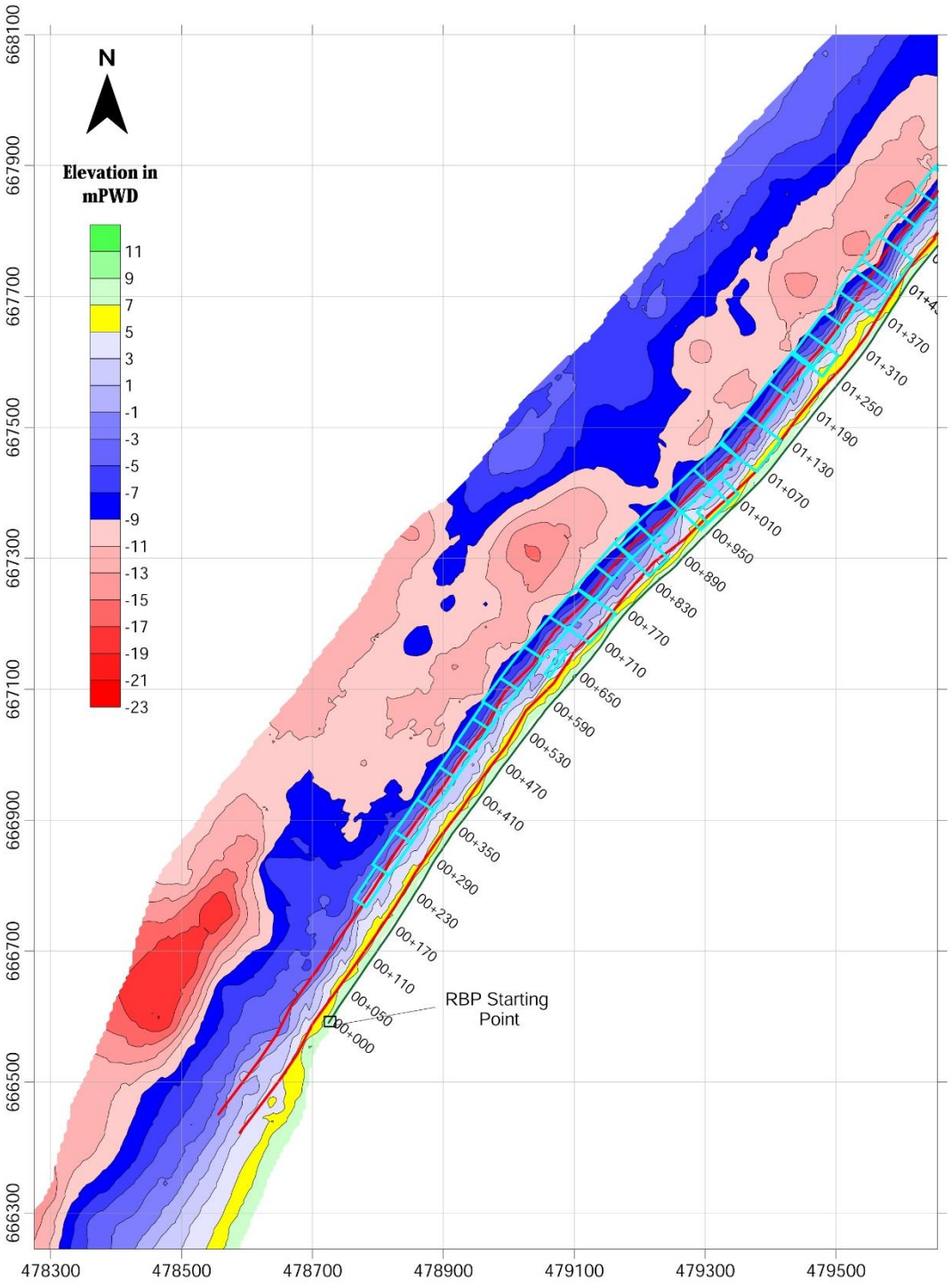
Chauhali Bathymetry Survey, 8 to 9 August 2018, Sheet 1



Chauhali Bathymetry Survey, 8 to 9 August 2018, Sheet 2

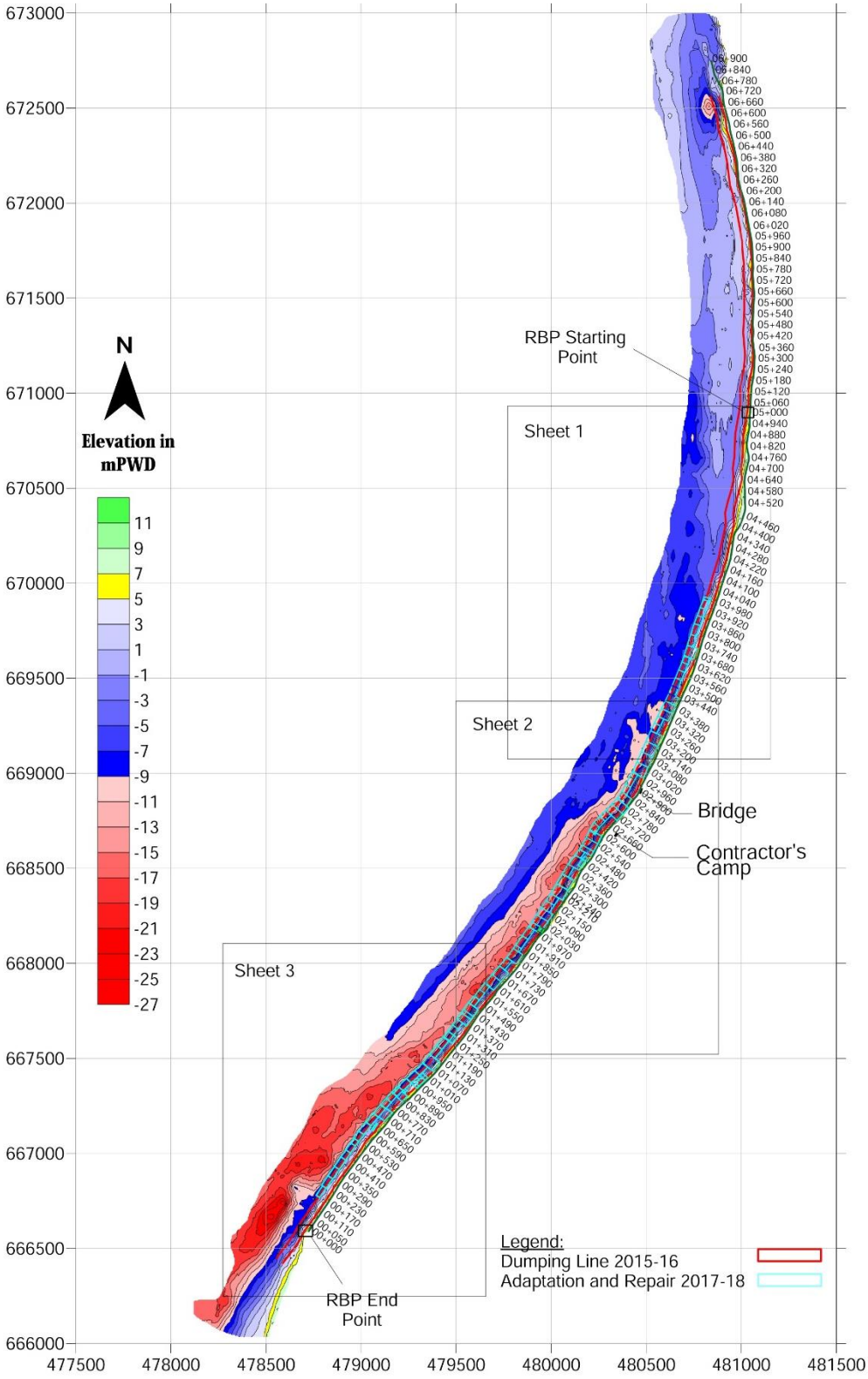


Chauhali Bathymetry Survey, 8 to 9 August 2018, Sheet 3

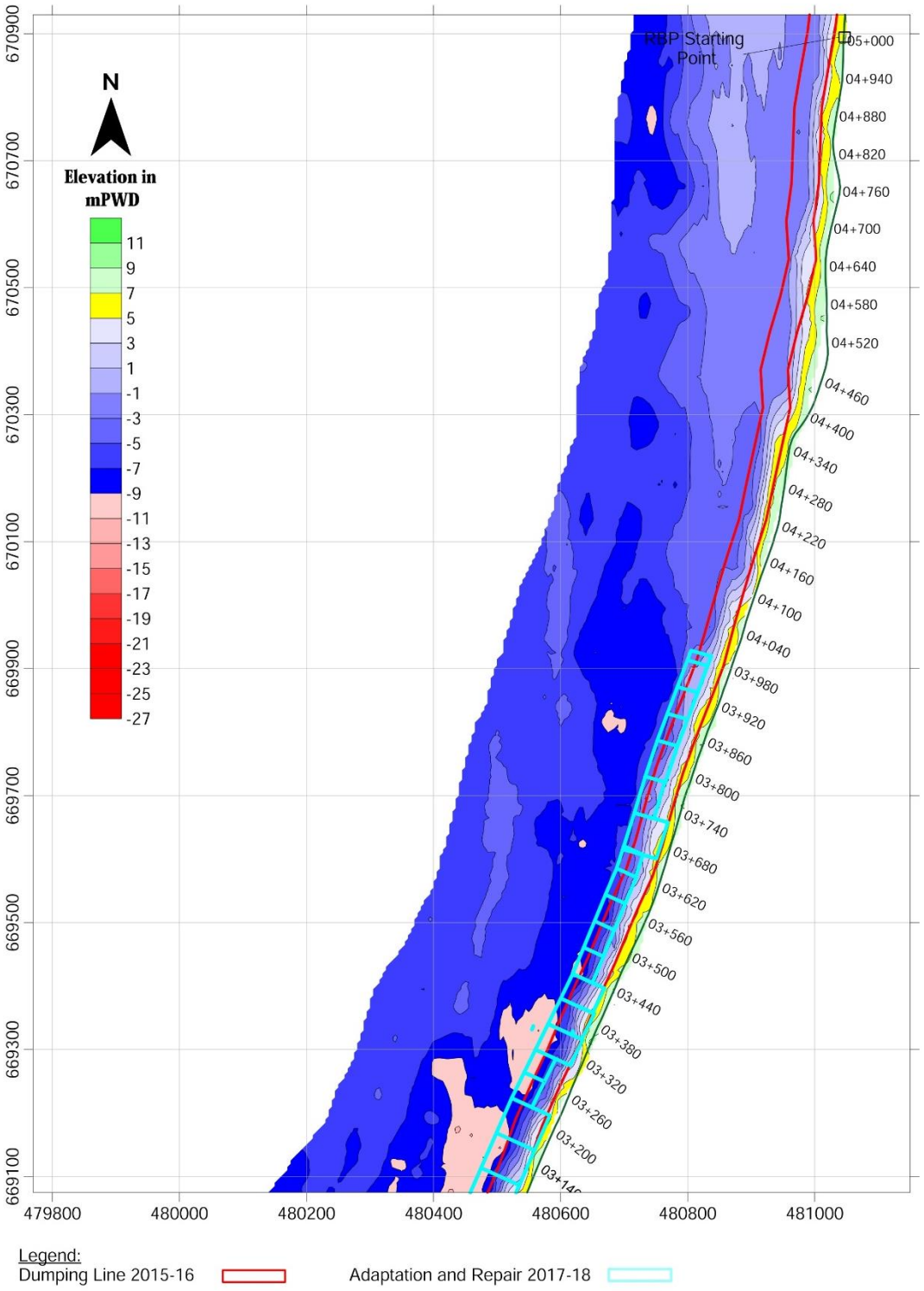


Legend:
Dumping Line 2015-16 Adaptation and Repair 2017-18

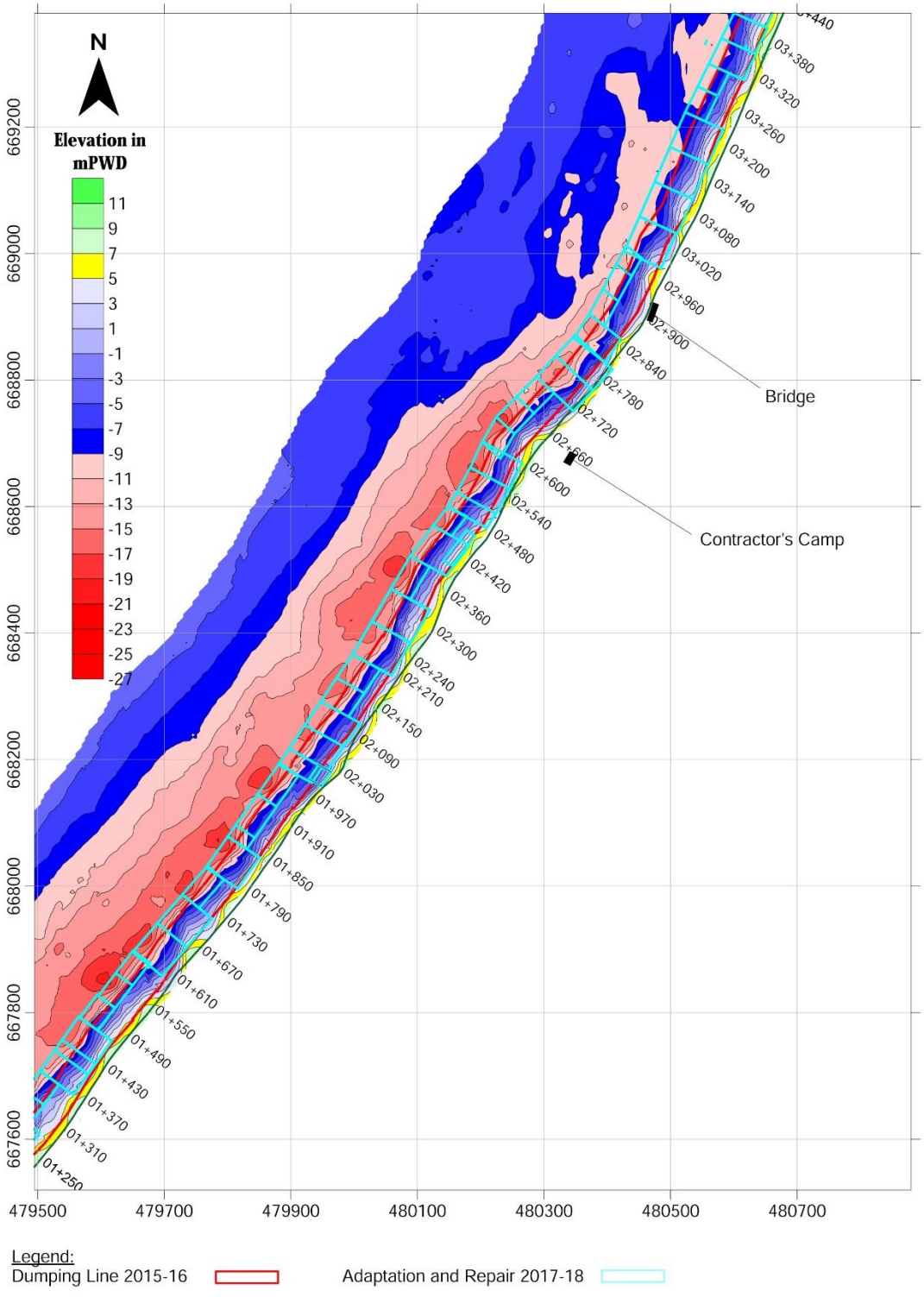
Chauhali Bathymetry Survey, 7 to 8 September 2018



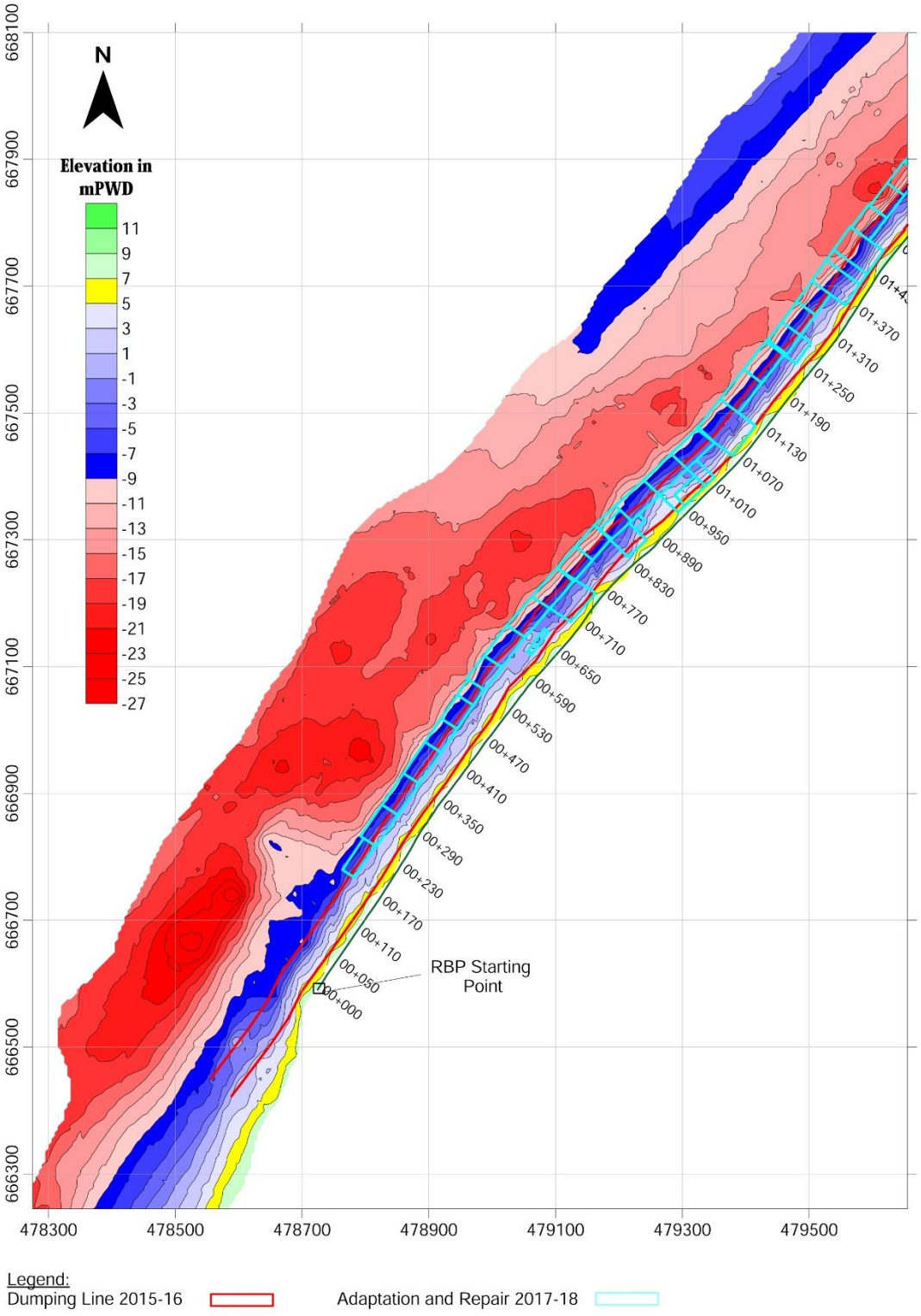
Chauhali Bathymetry Survey, 7-8 September 2018, Sheet 1



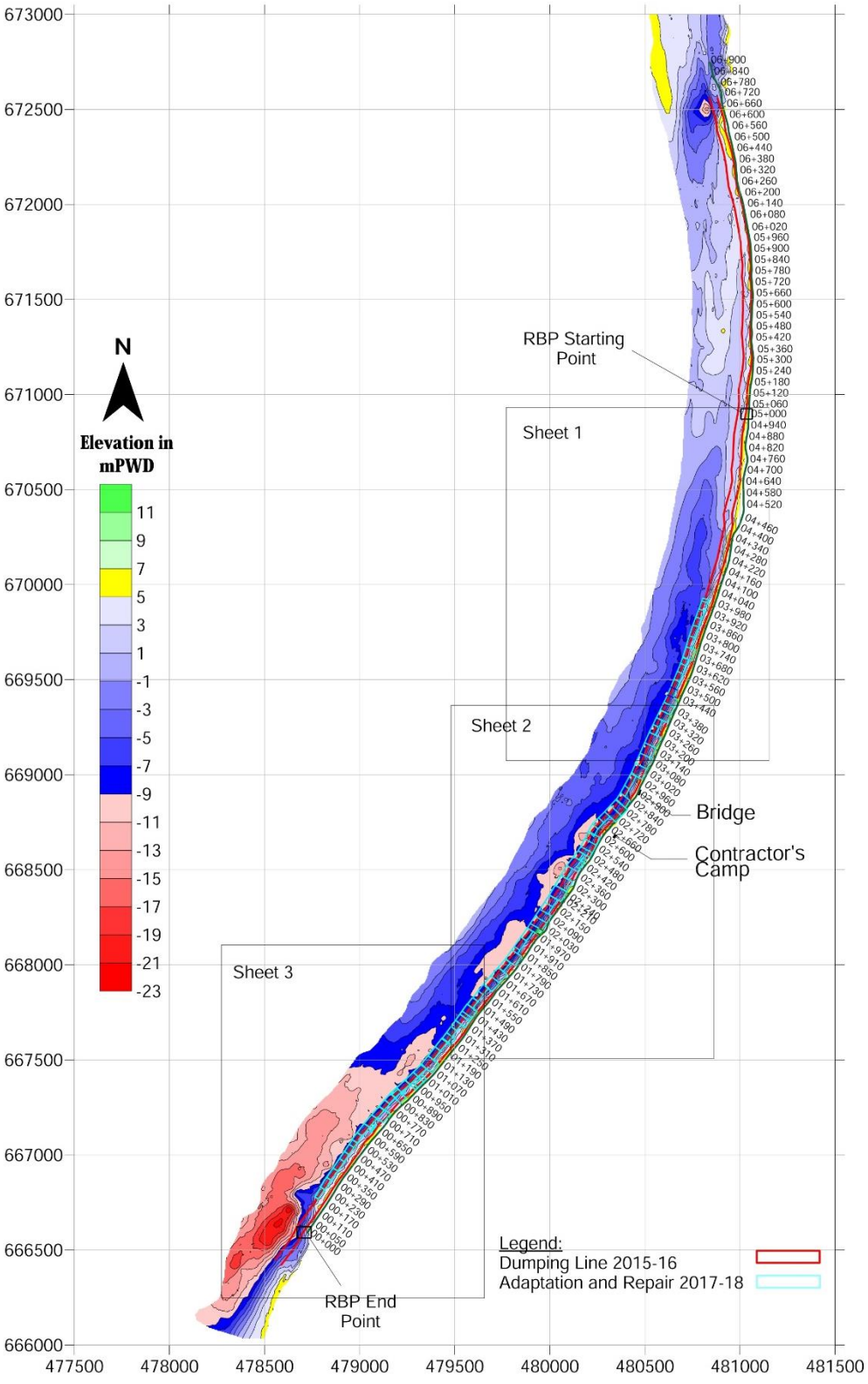
Chauhali Bathymetry Survey, 7-8 September 2018, Sheet 2



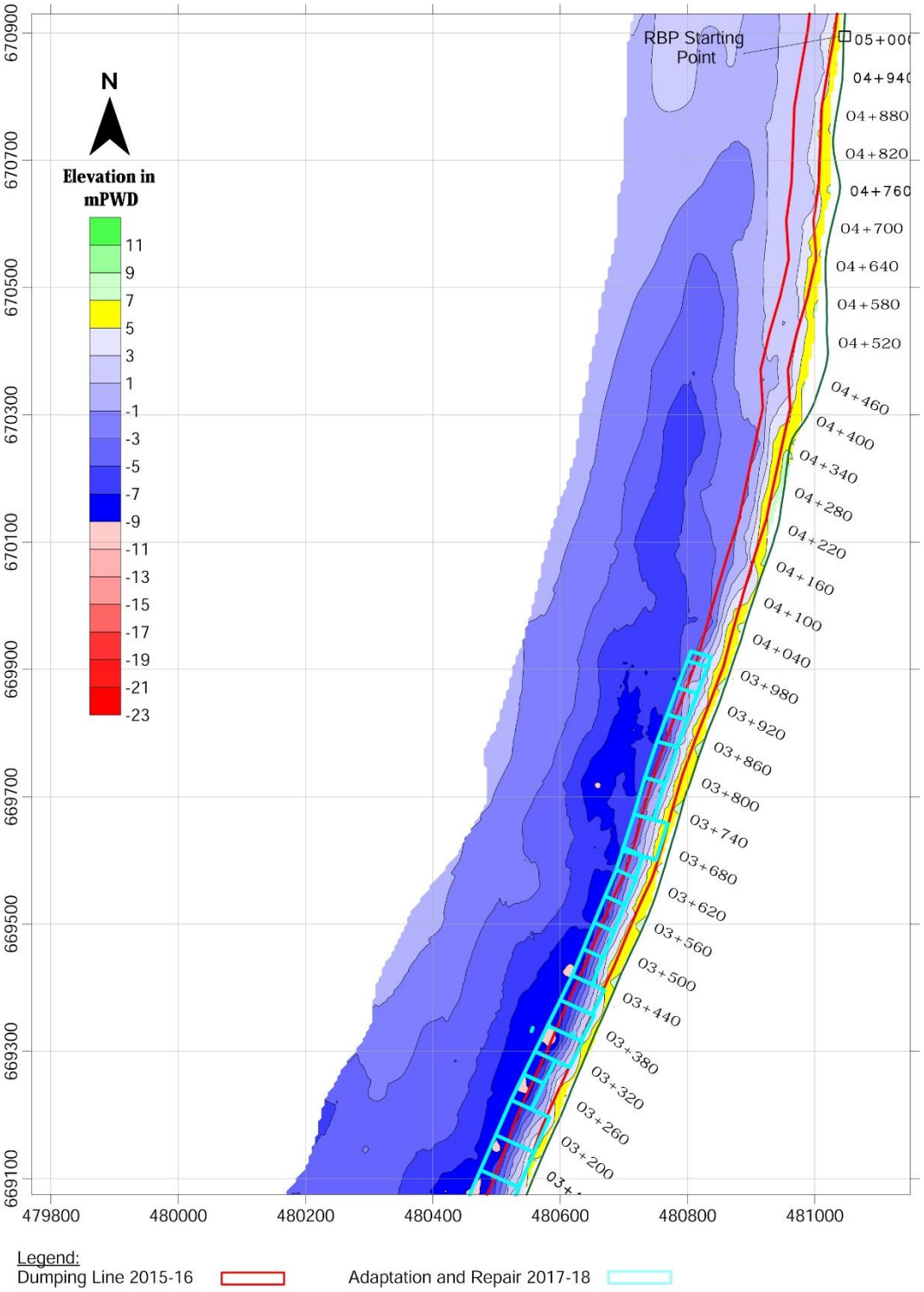
Chauhali Bathymetry Survey, 7-8 September 2018, Sheet 3



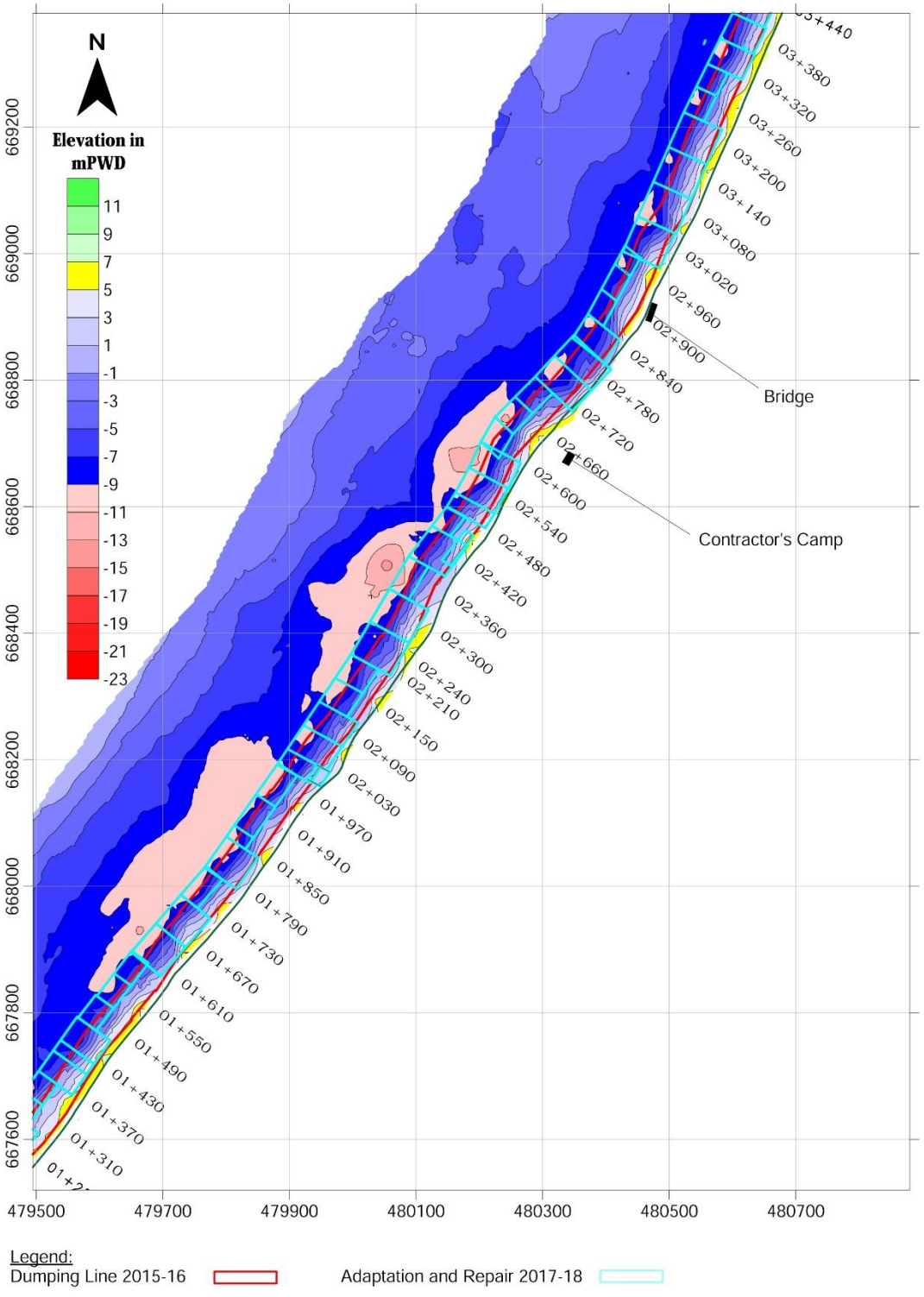
Chauhali Bathymetry Survey, 8 October 2018



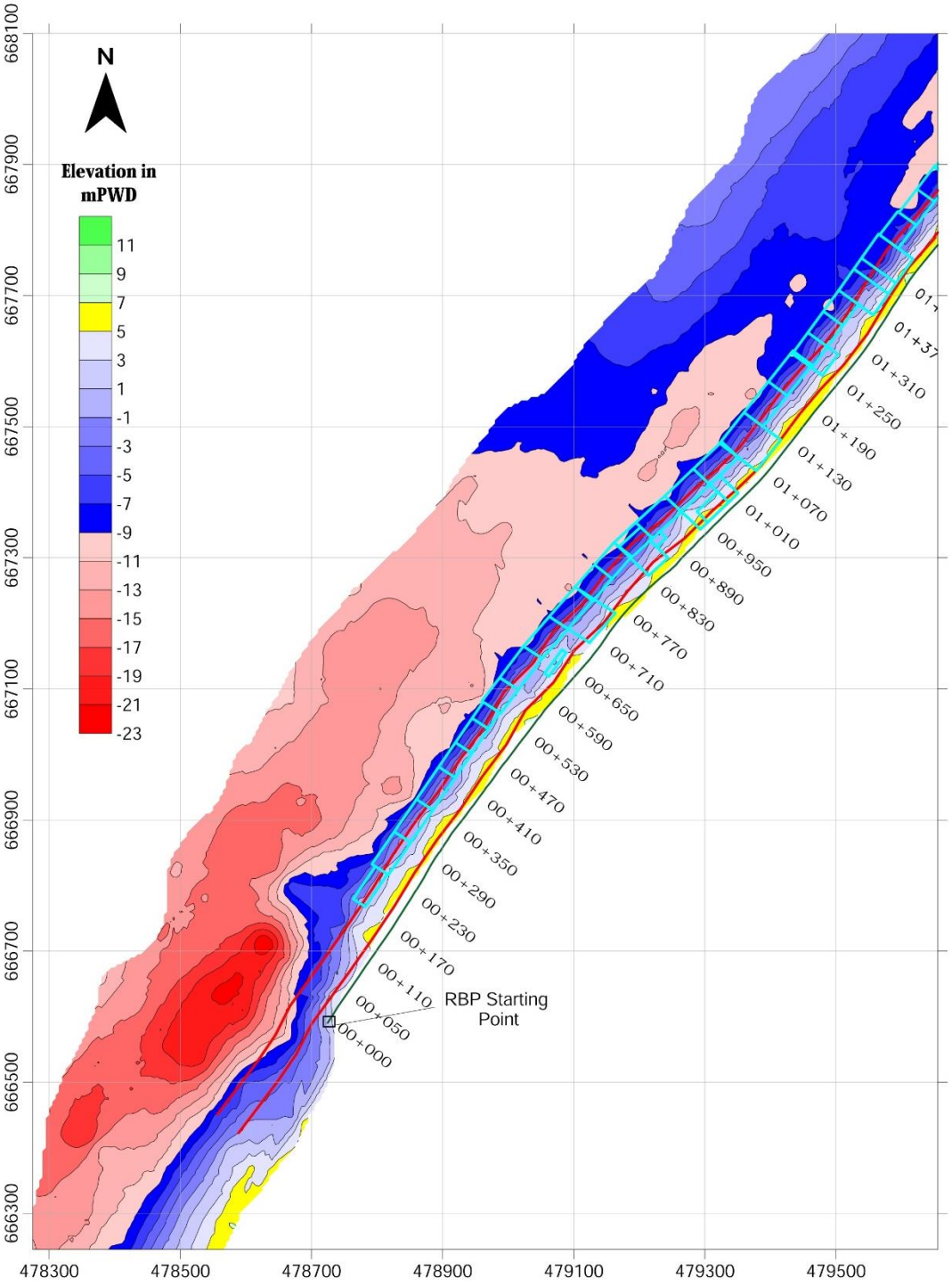
Chauhali Bathymetry Survey, 8 October 2018, Sheet 1



Chauhali Bathymetry Survey, 8 October 2018, Sheet 2

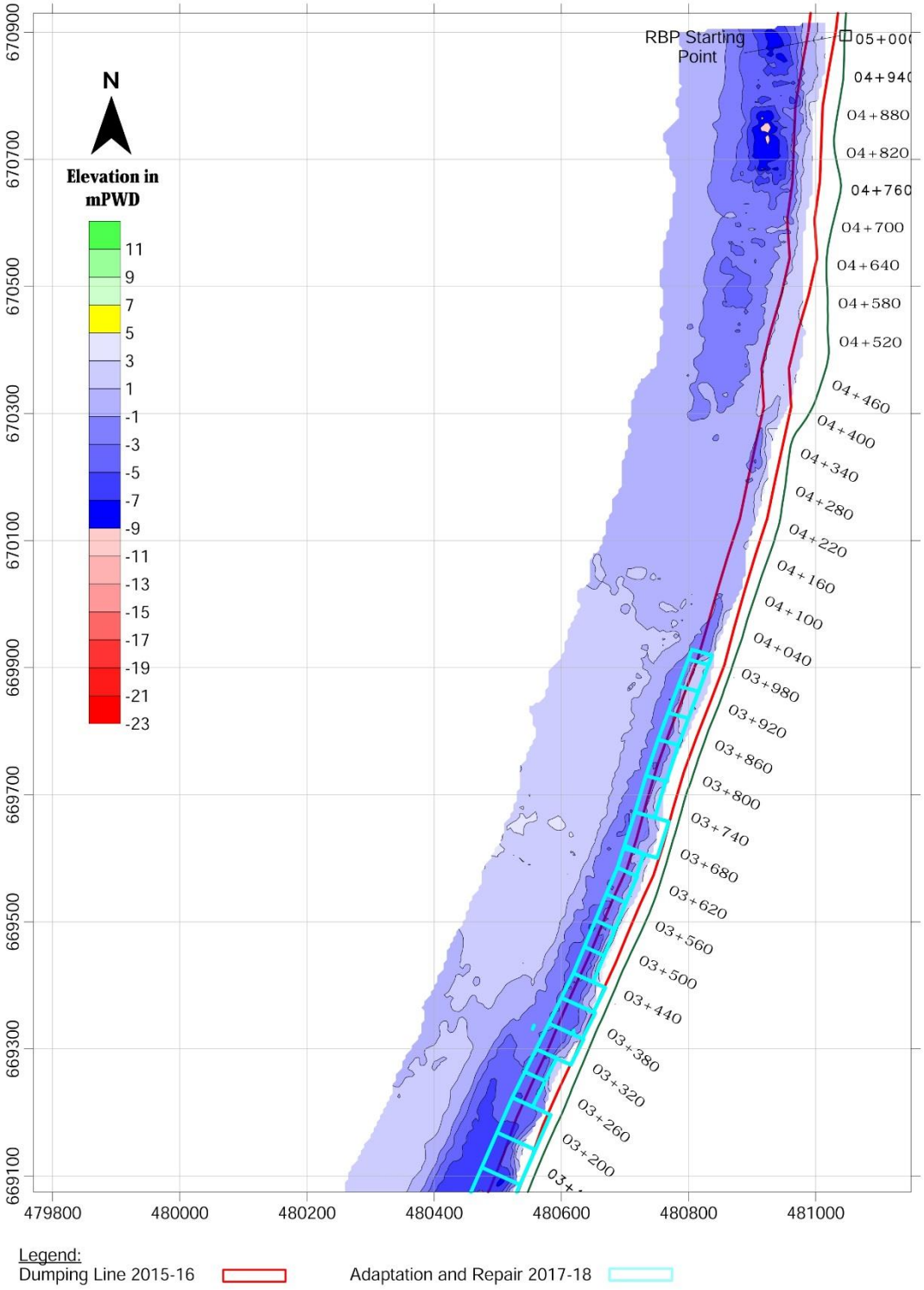


Chauhali Bathymetry Survey, 8 October 2018, Sheet 3

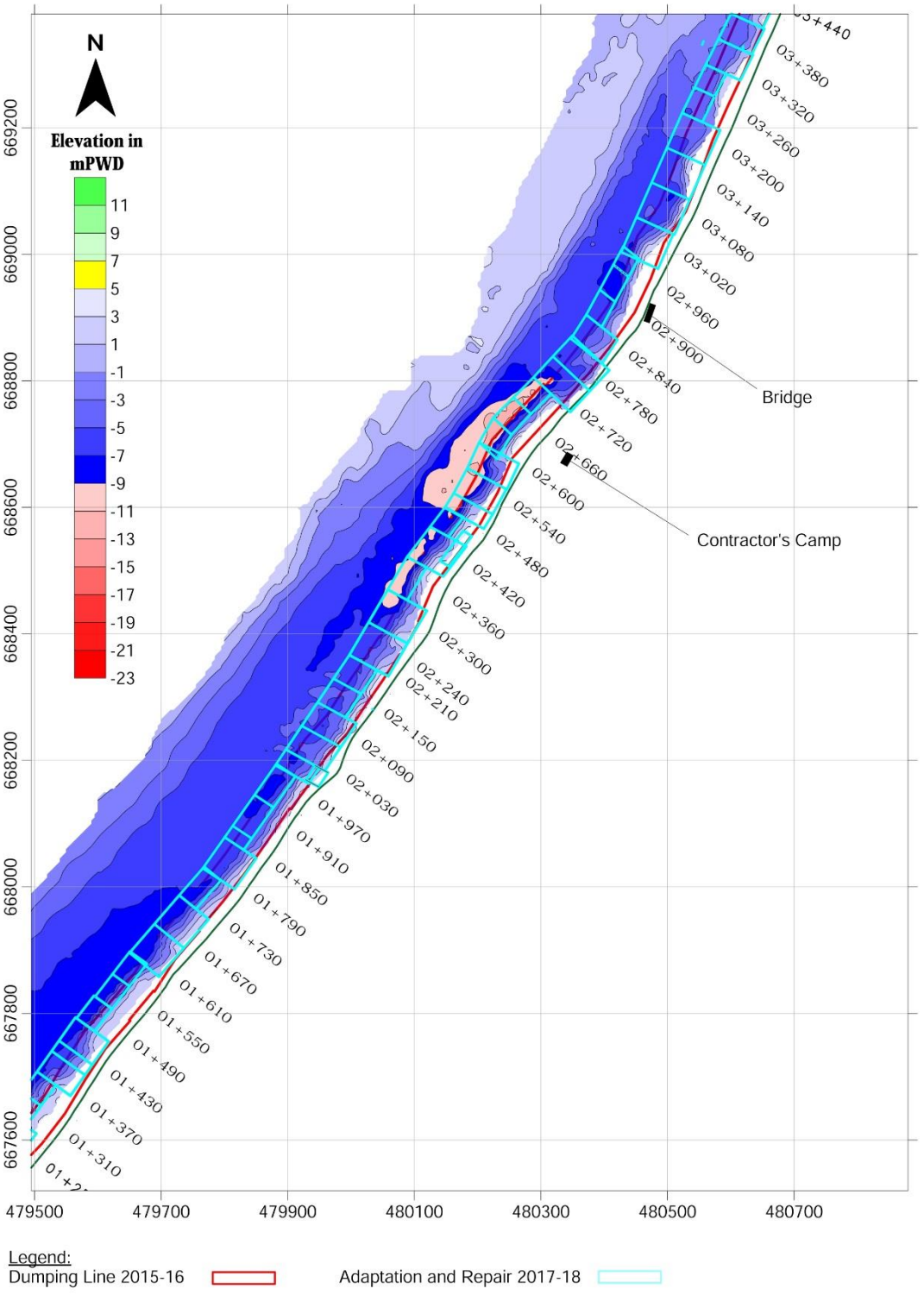


Legend:
Dumping Line 2015-16 Adaptation and Repair 2017-18

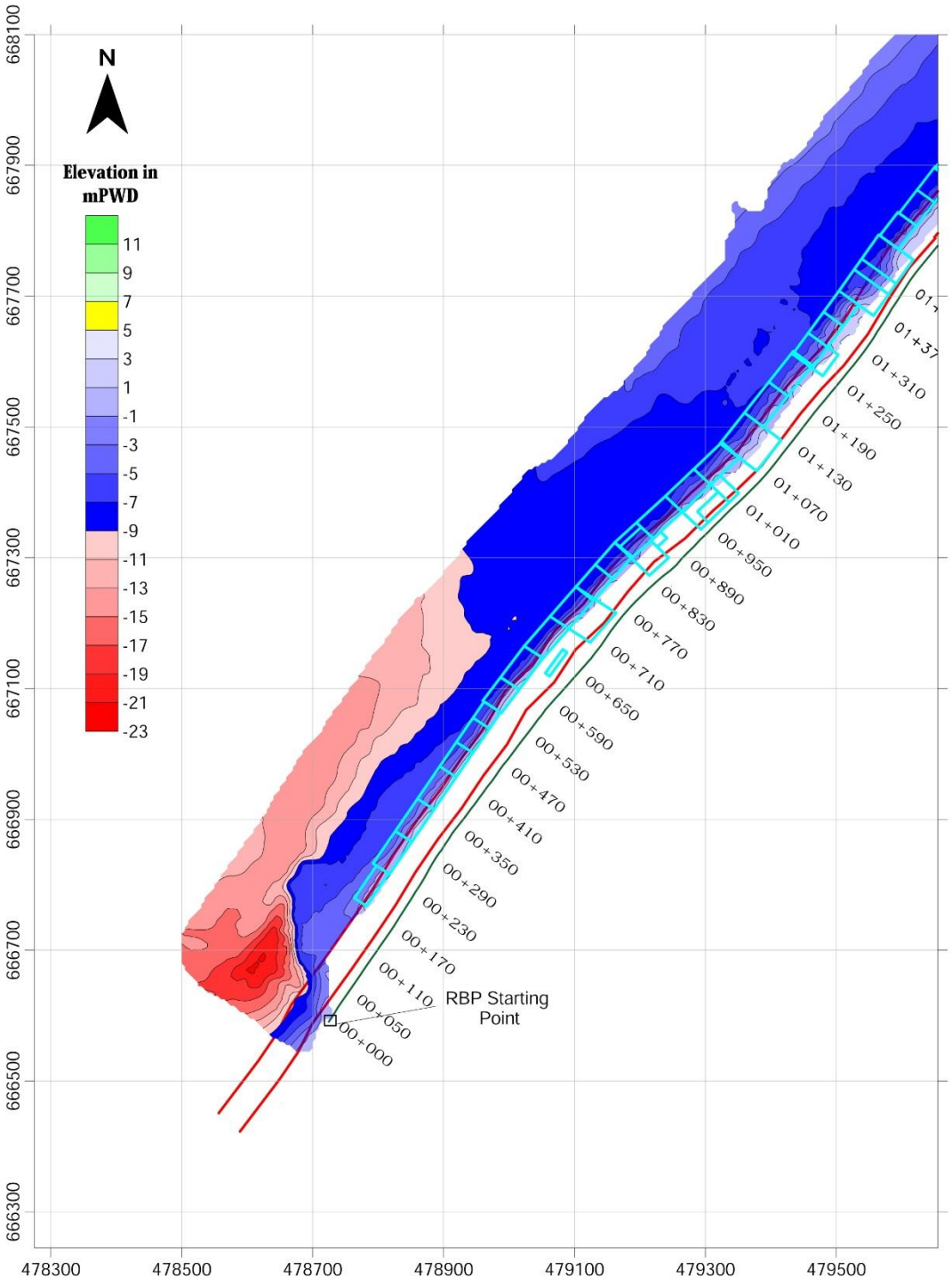
Chauhali Bathymetry Survey, 29 January 2019, Sheet 1



Chauhali Bathymetry Survey, 29 January 2019, Sheet 2

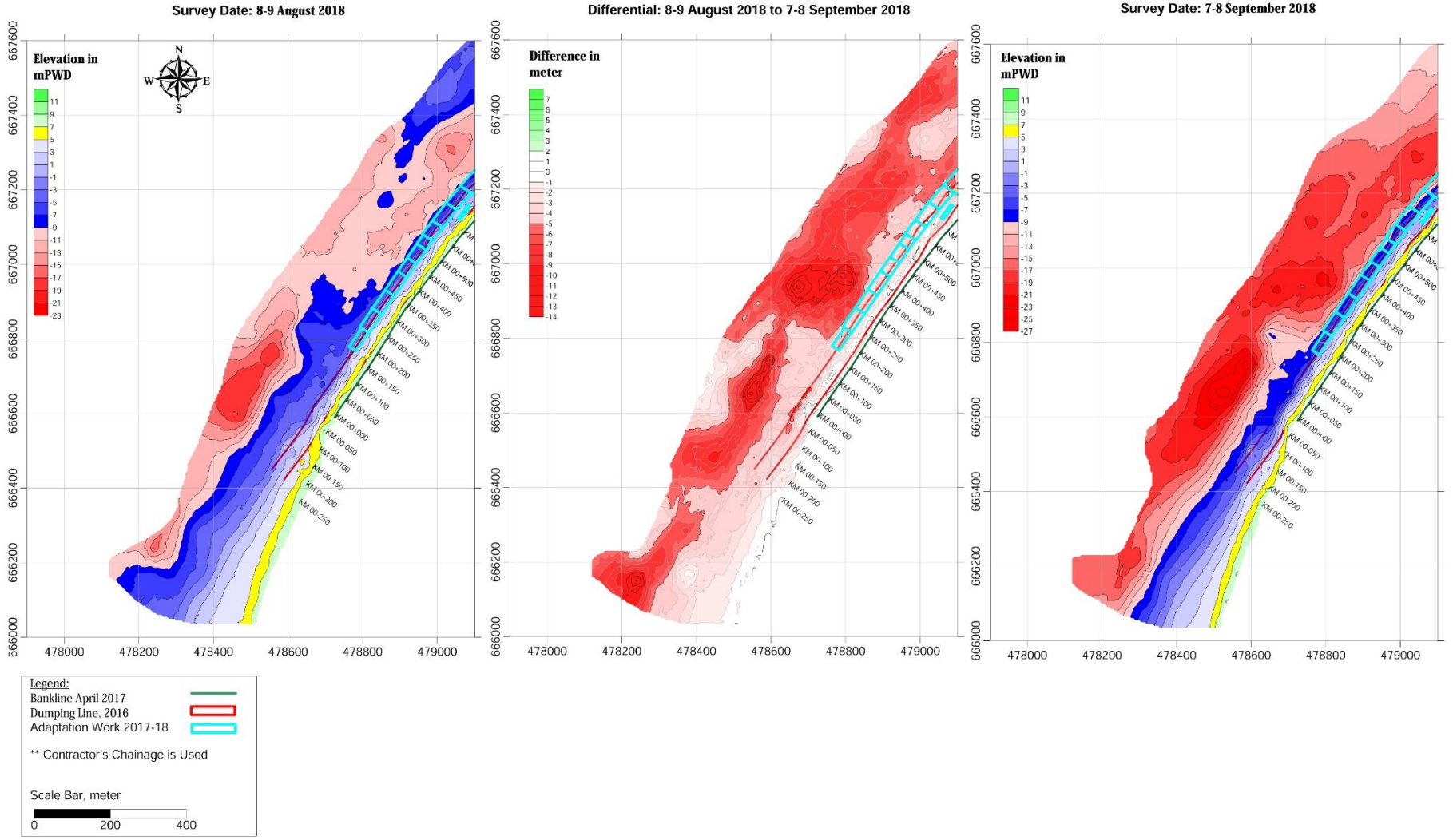


Chauhali Bathymetry Survey, 29 January 2019, Sheet 3



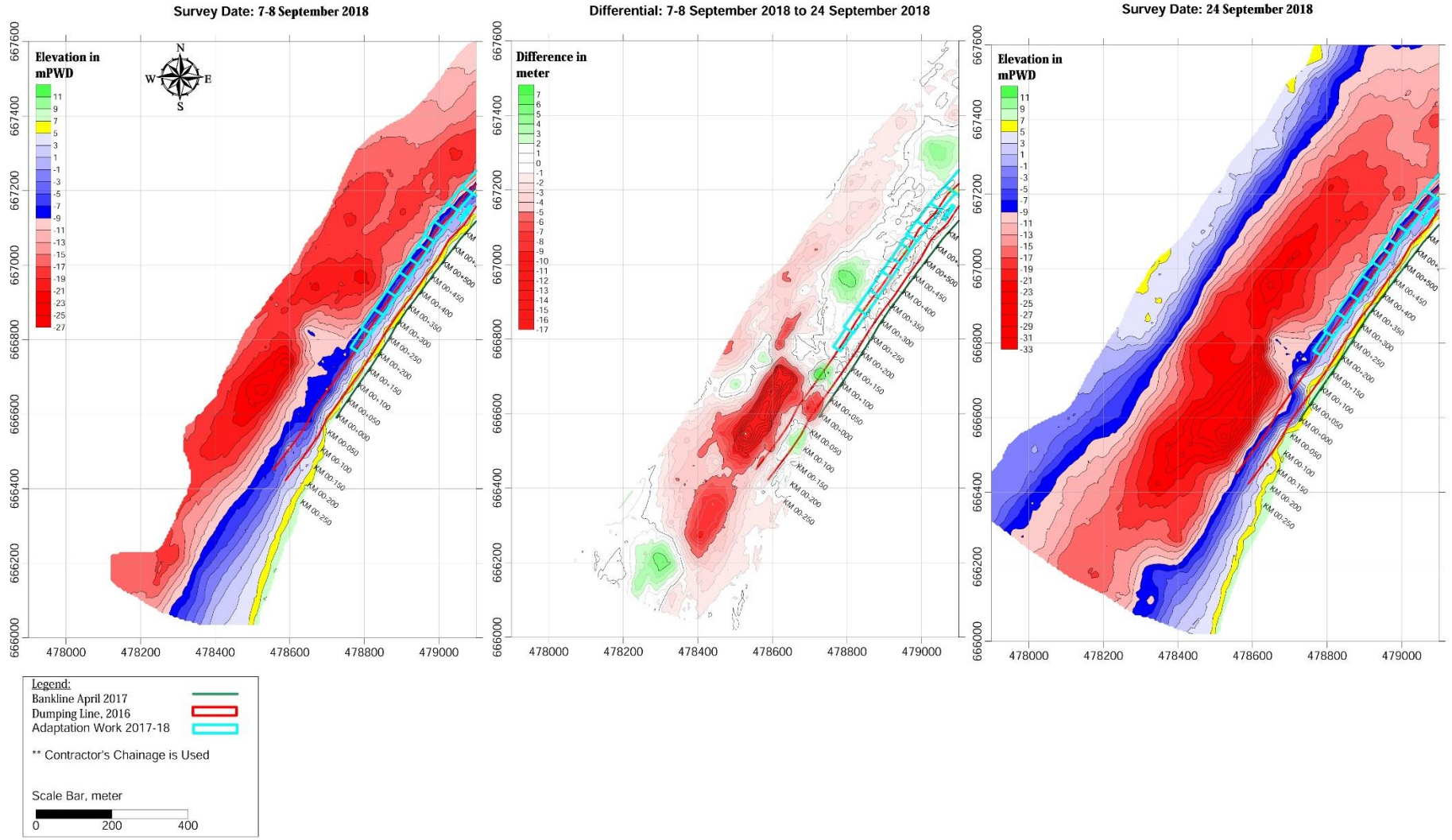
Chauhali Bathymetry Survey & Differential Map

Sheet 1

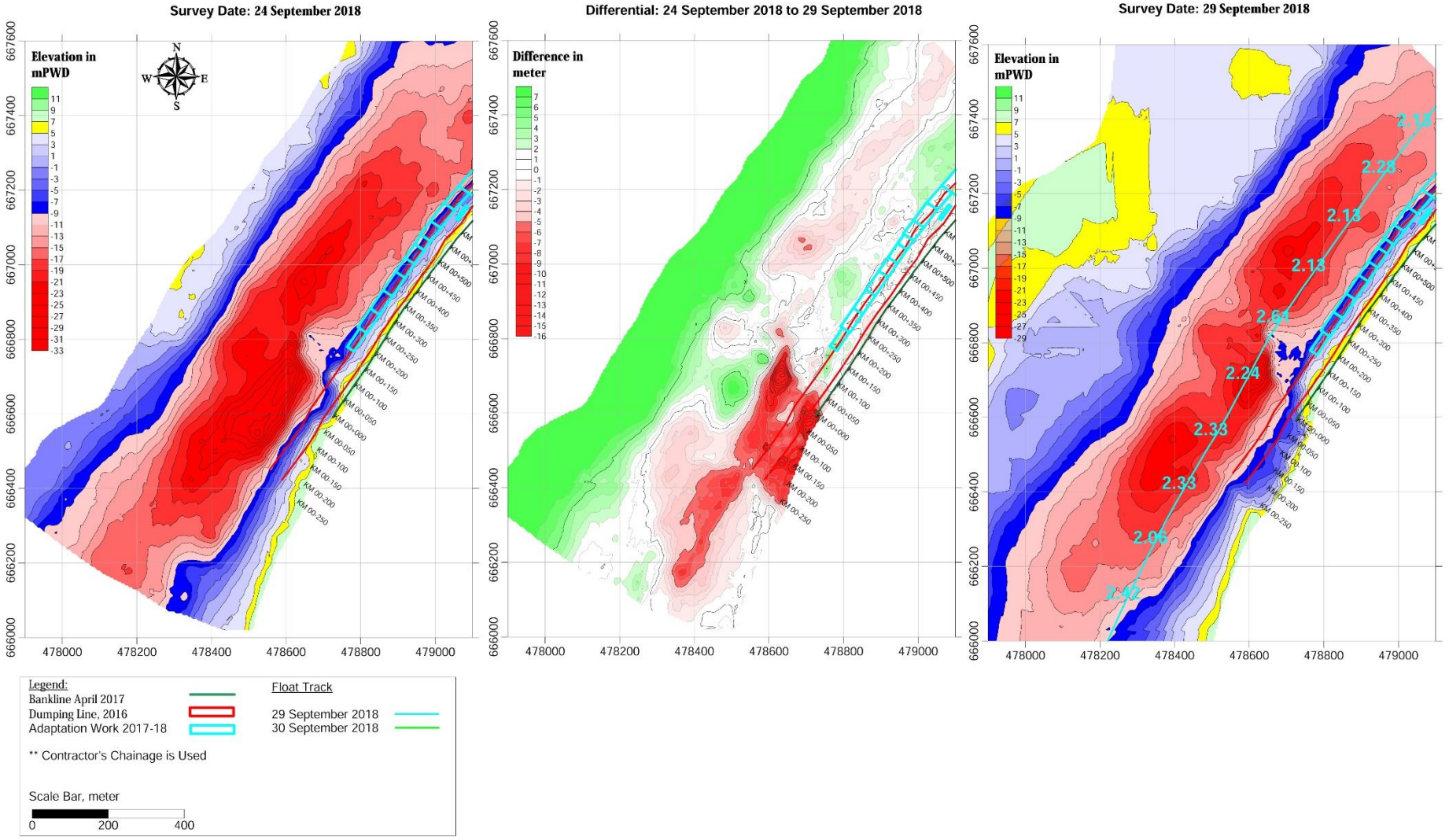


Chauhali Bathymetry Survey & Differential Map

Sheet 2

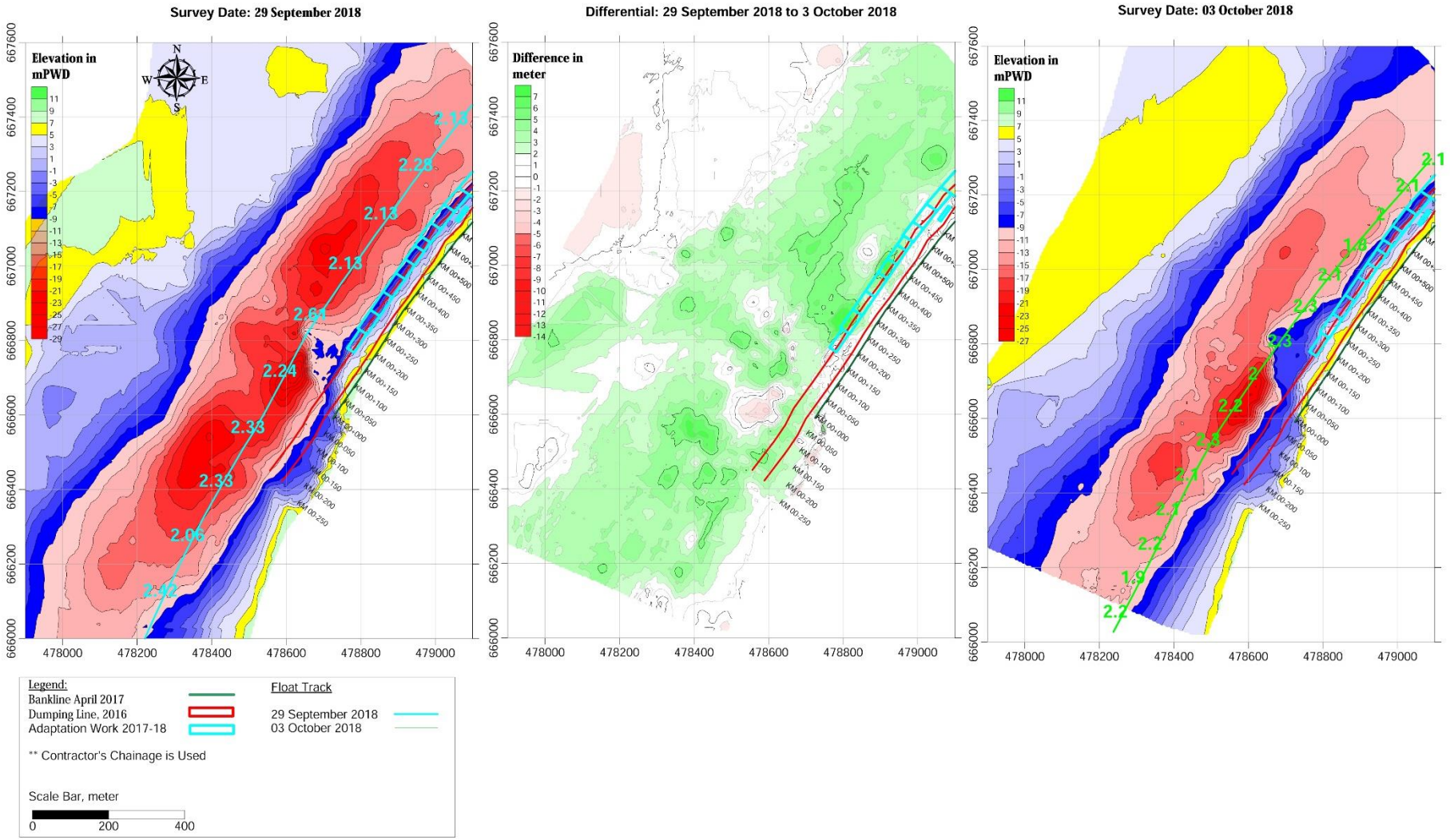


Chauhali Bathymetry Survey & Differential Map



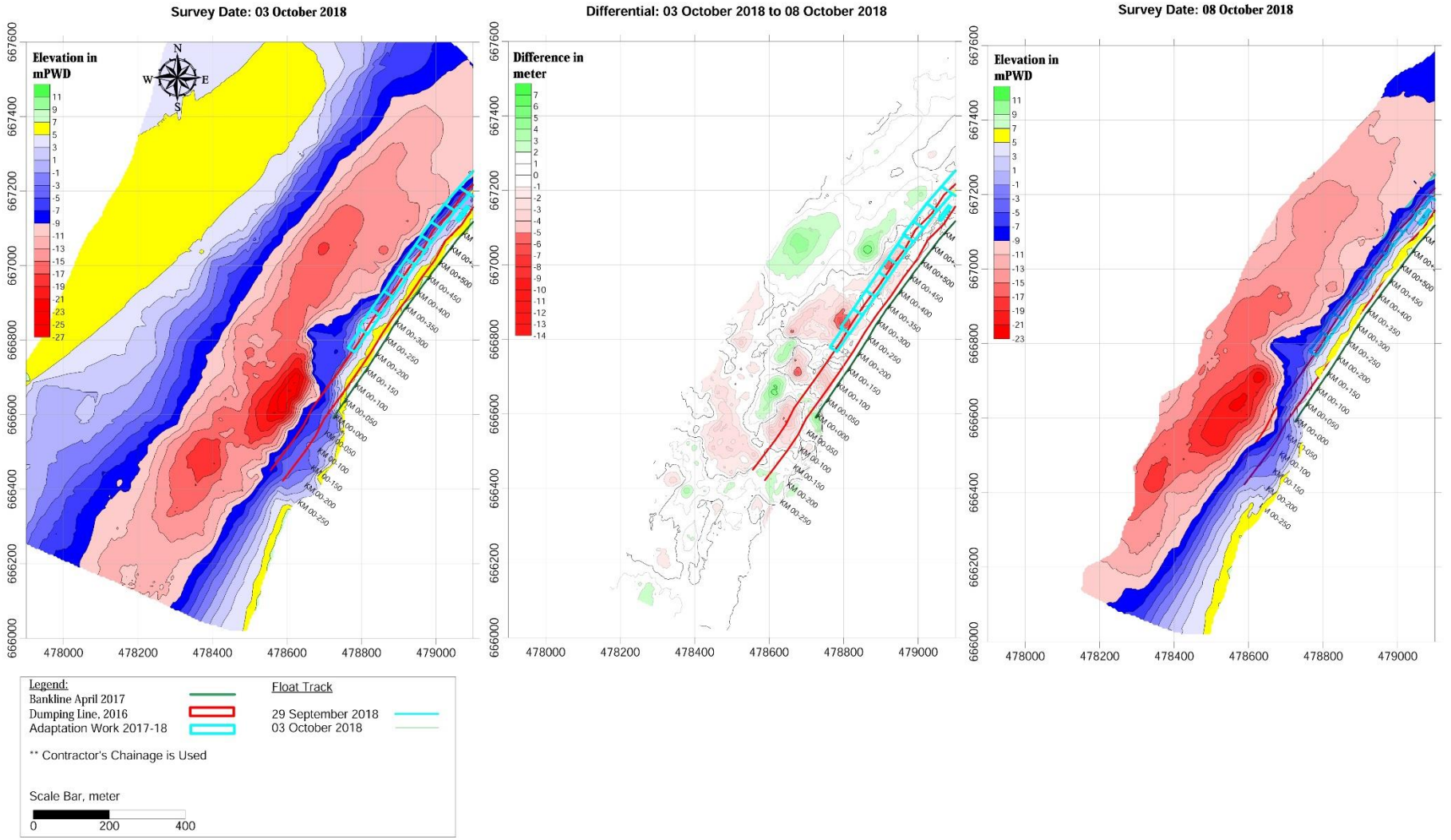
Chauhali Bathymetry Survey & Differential Map

Sheet 4



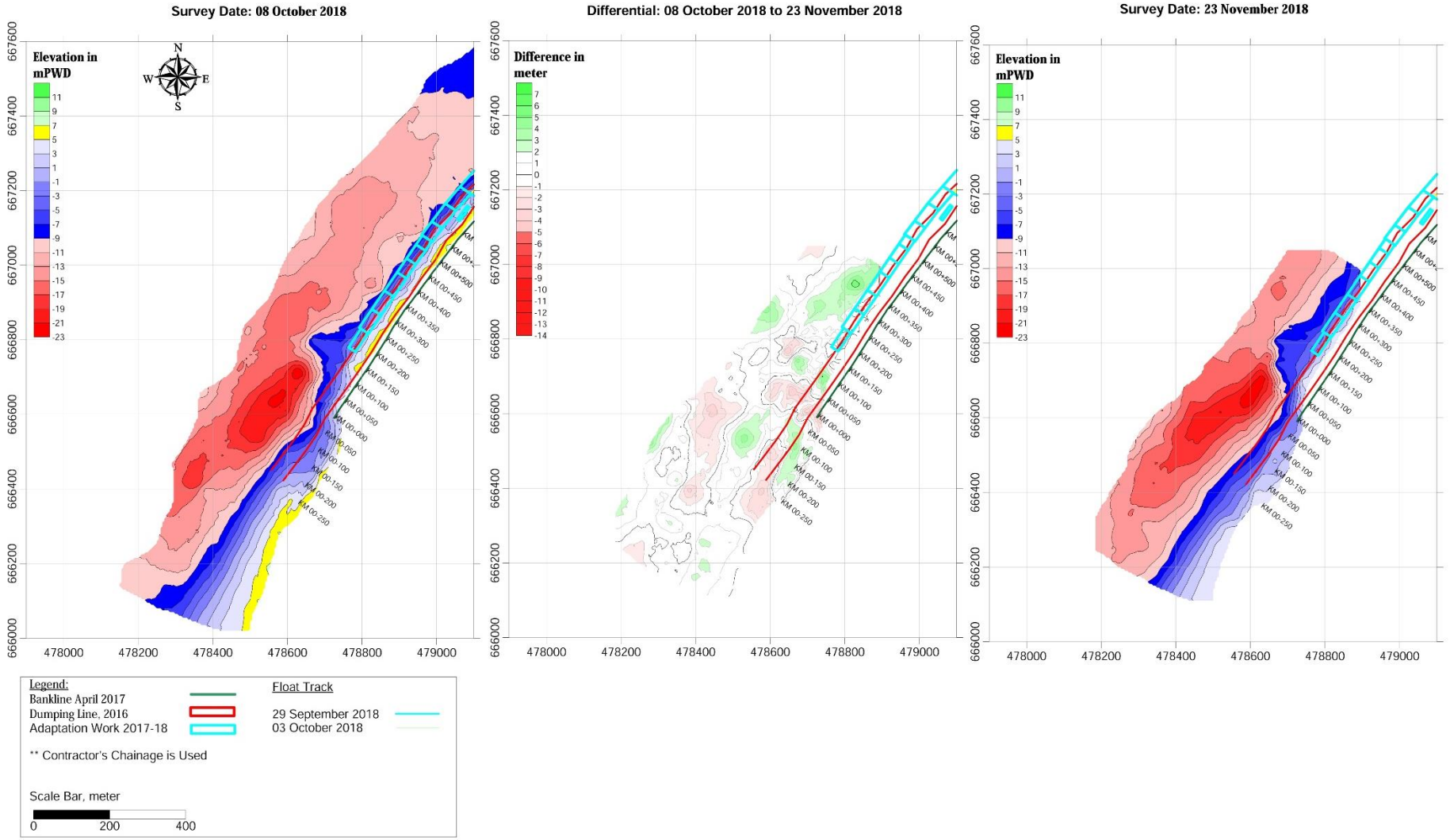
Chauhali Bathymetry Survey & Differential Map

Sheet 5

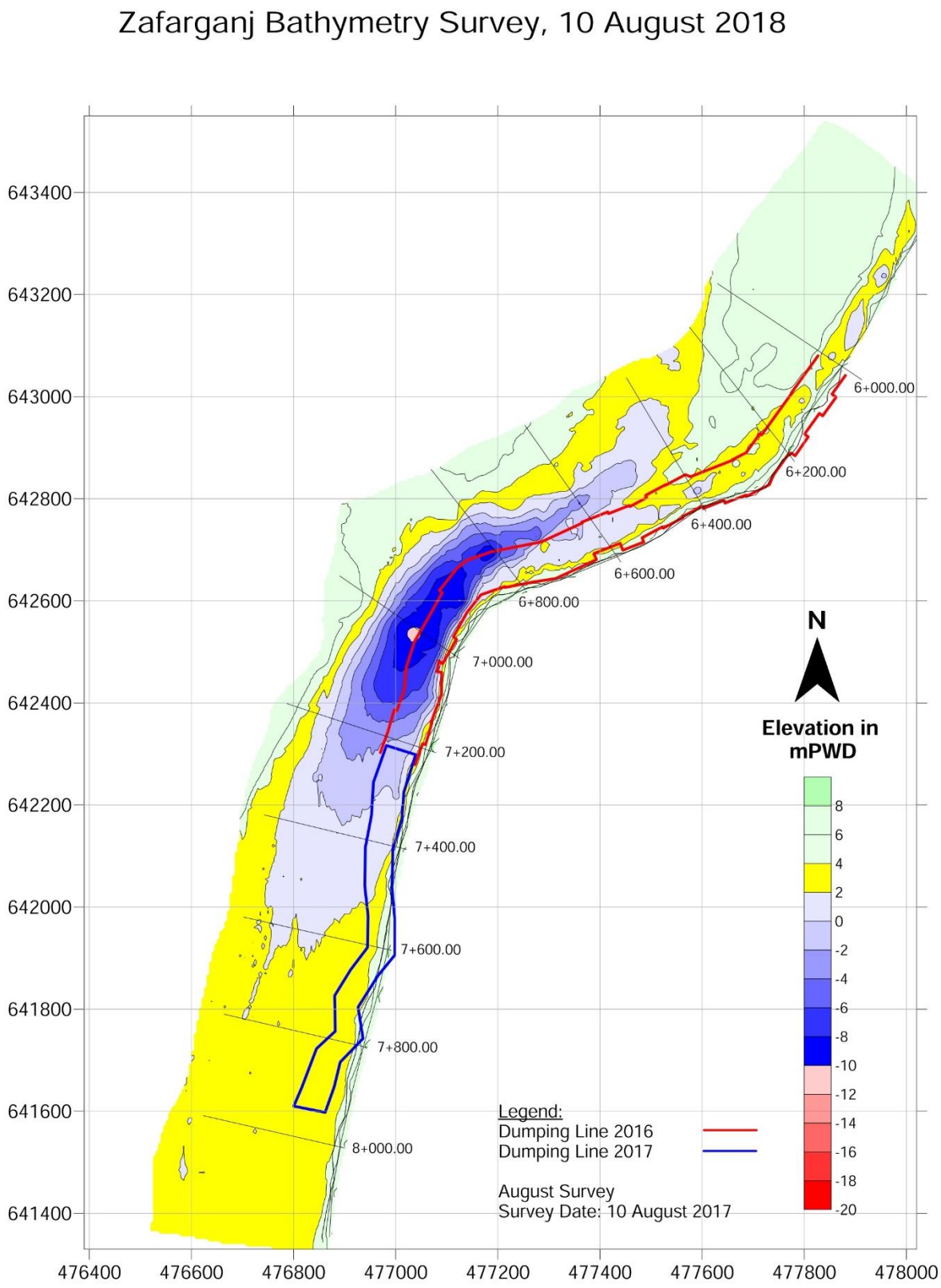


Chauhali Bathymetry Survey & Differential Map

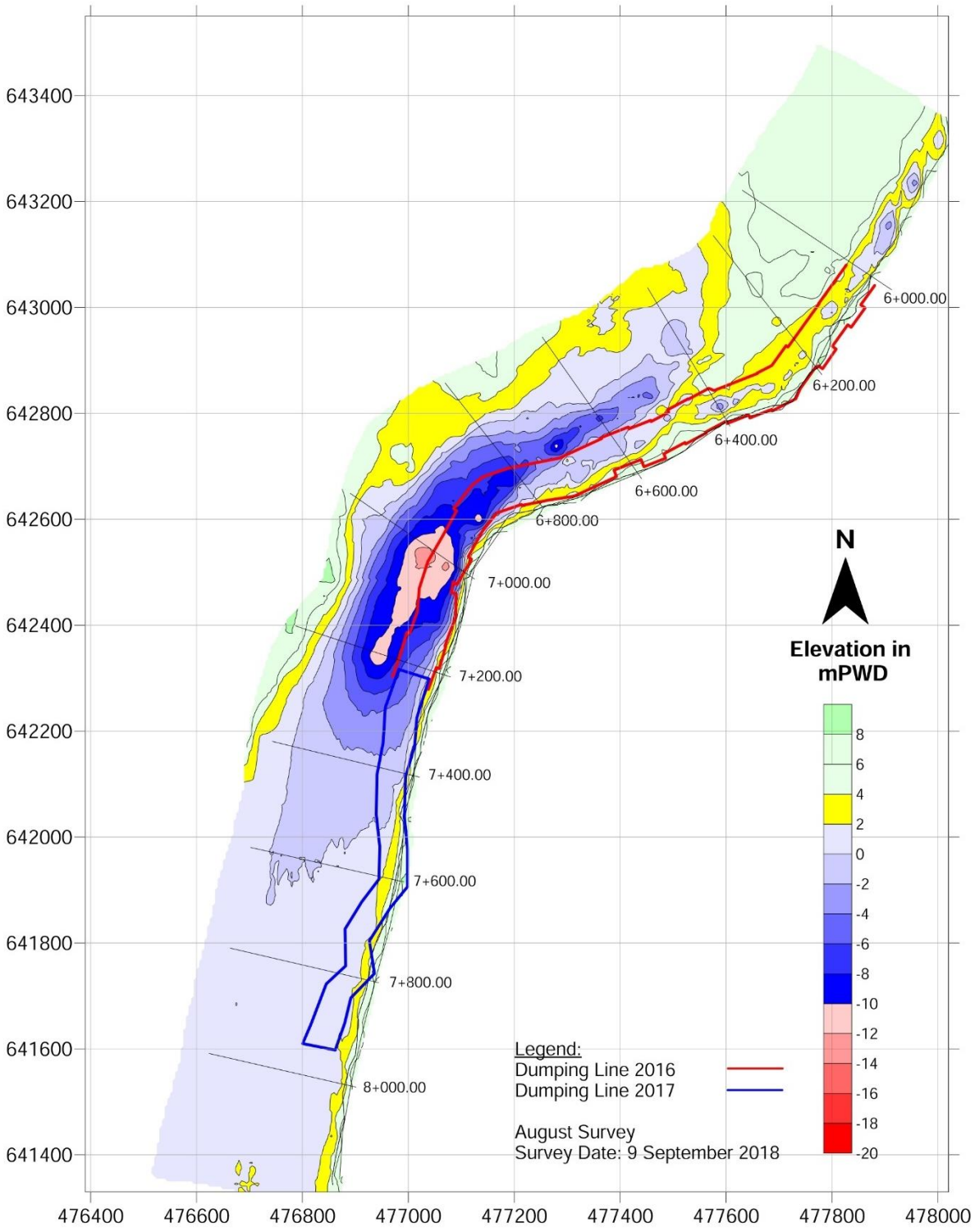
Sheet 6



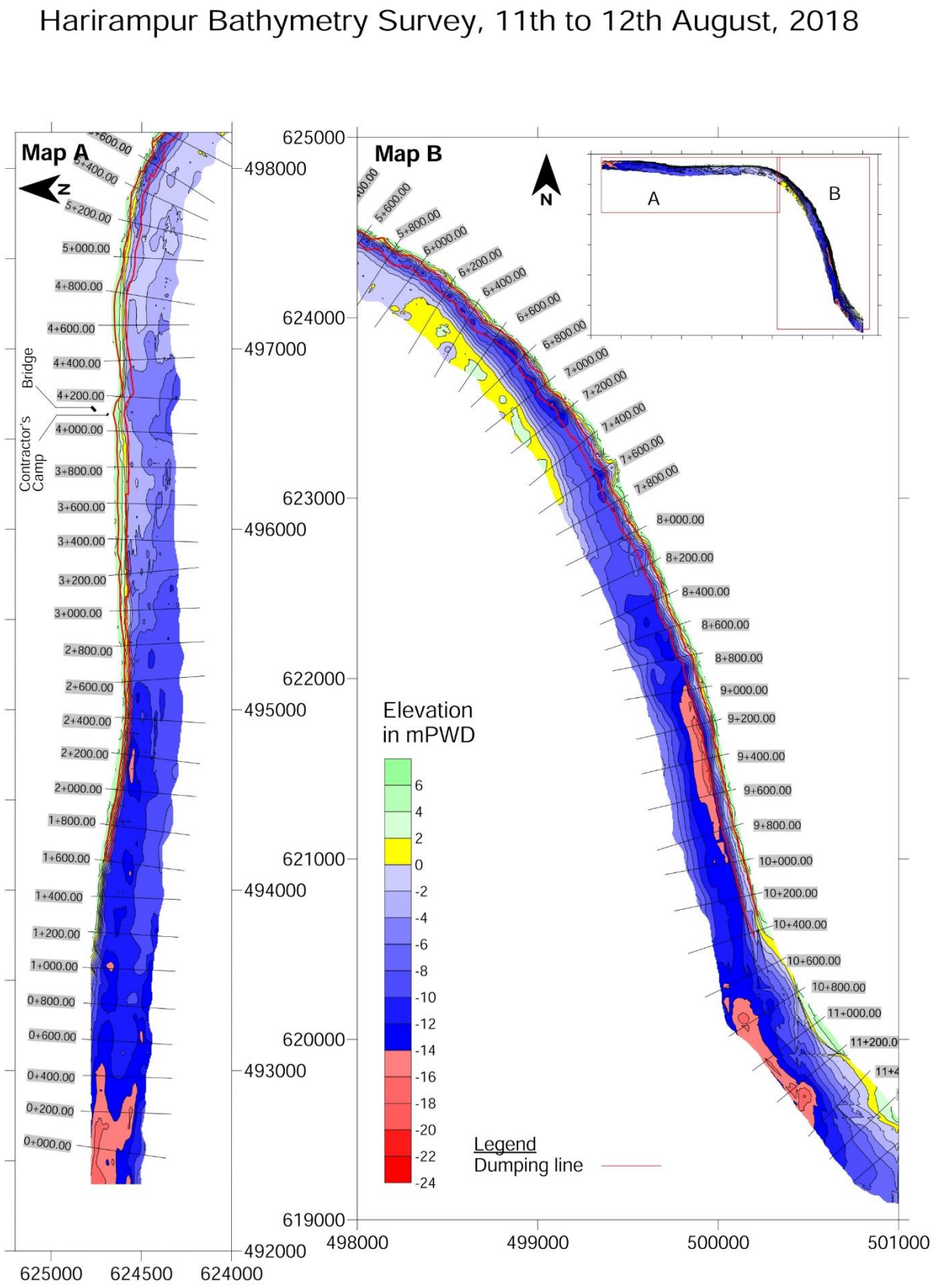
6.2 Zafarganj



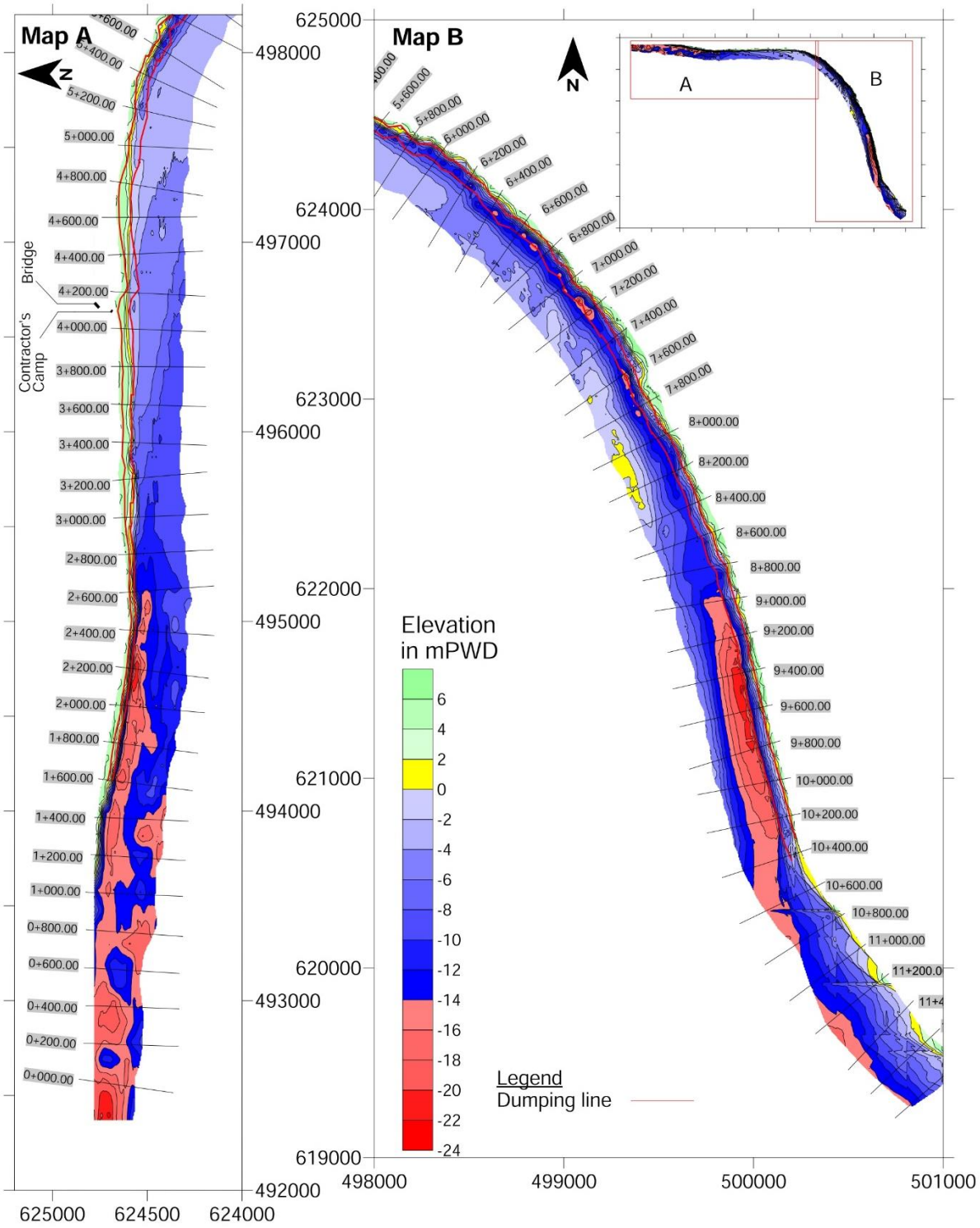
Zafarganj Bathymetry Survey, 9 September 2018



6.3 Harirampur

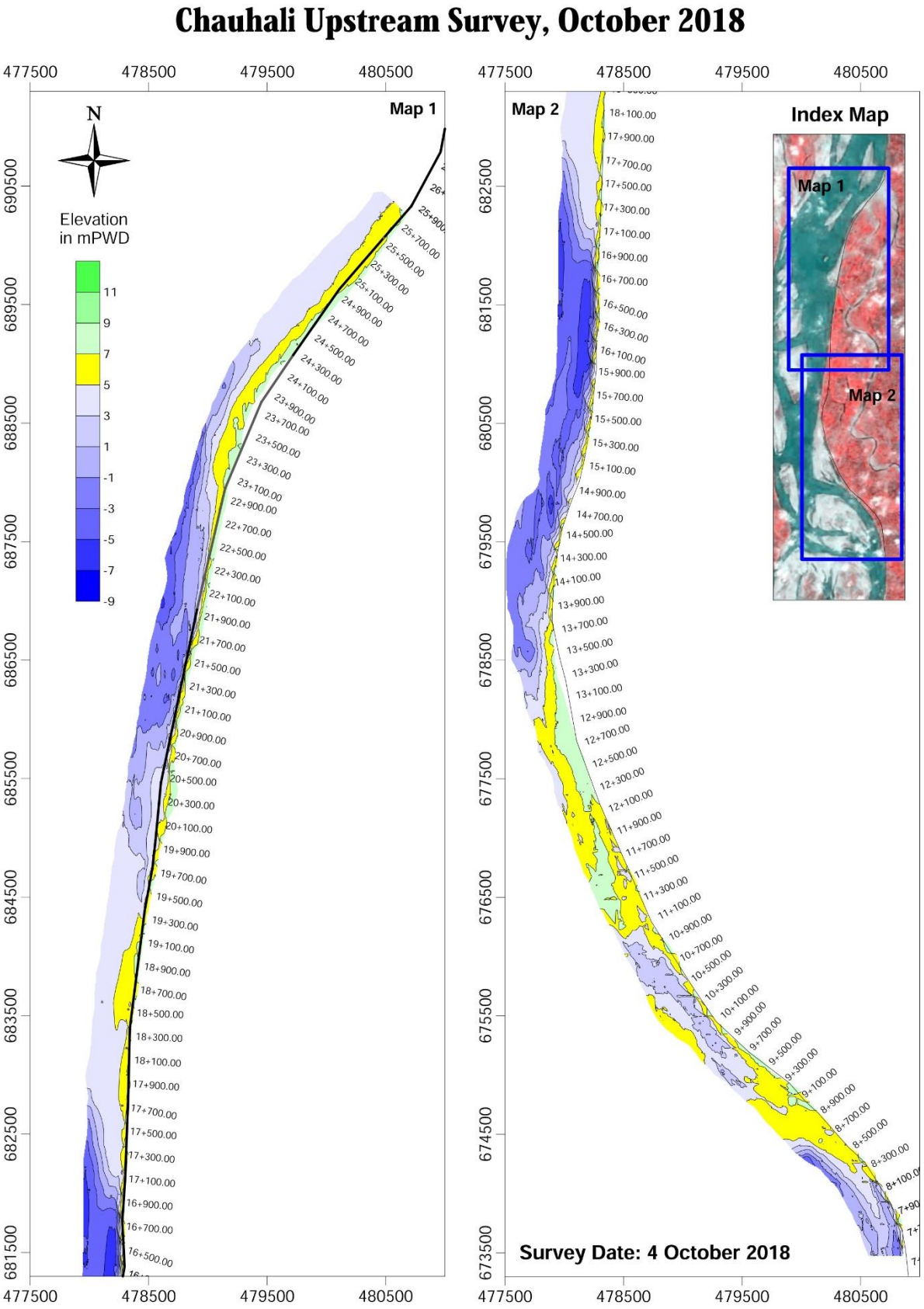


Harirampur Bathymetry Survey, 10th to 11th September, 2018

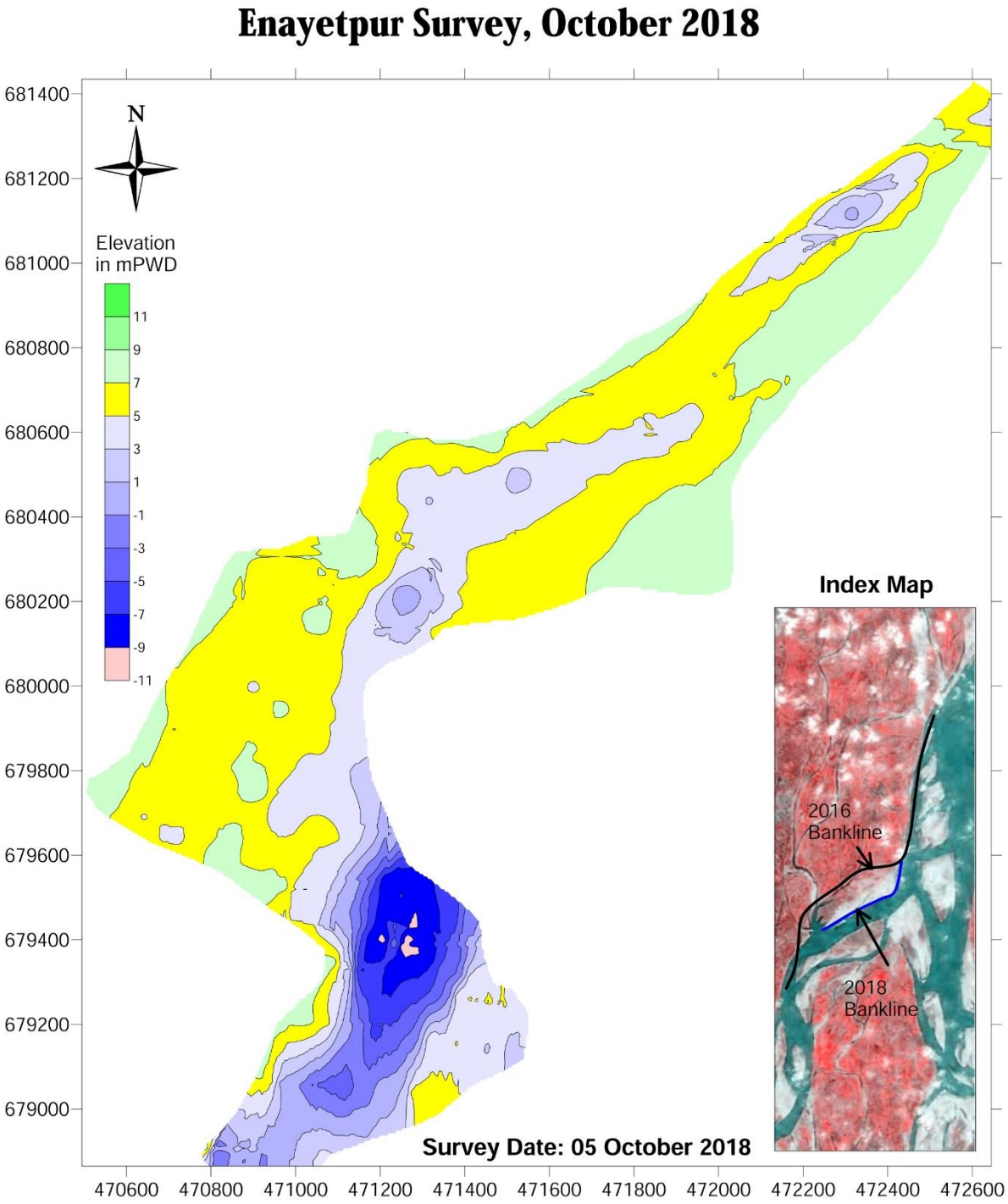


August Survey
Date: 10 to 11 September, 2018

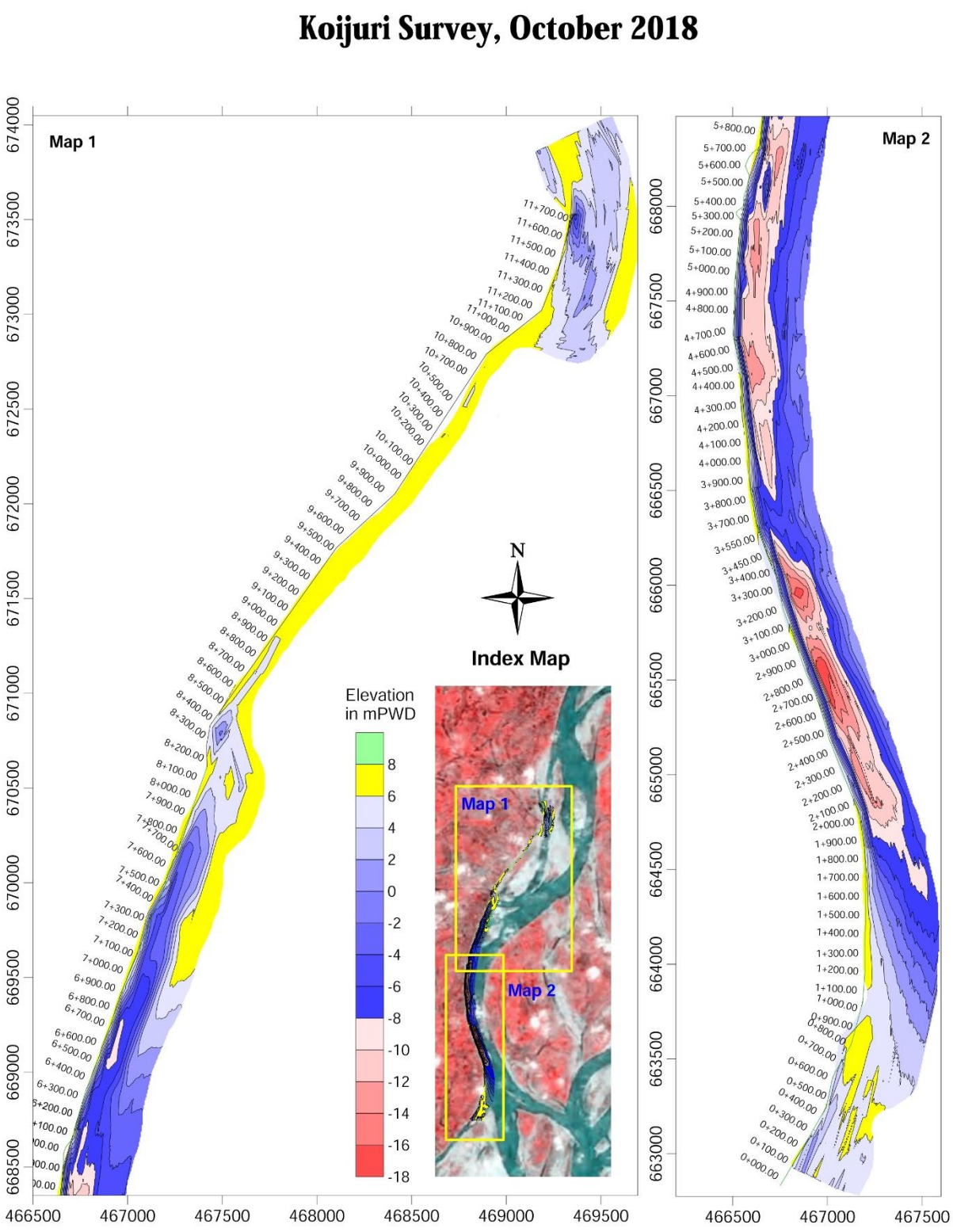
6.4 Chauhali Upstream



6.5 Enayetpur

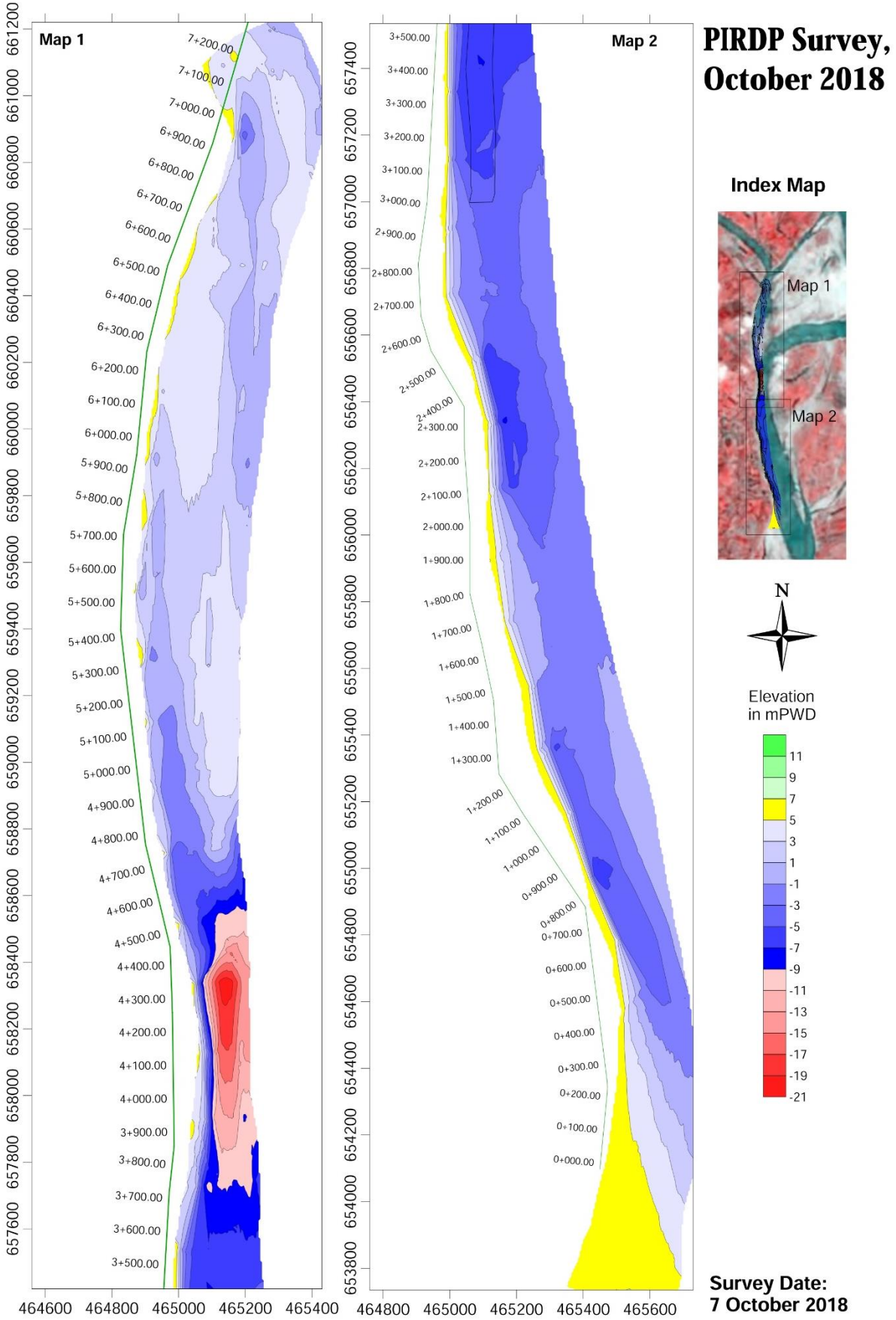


6.6 Koijuri



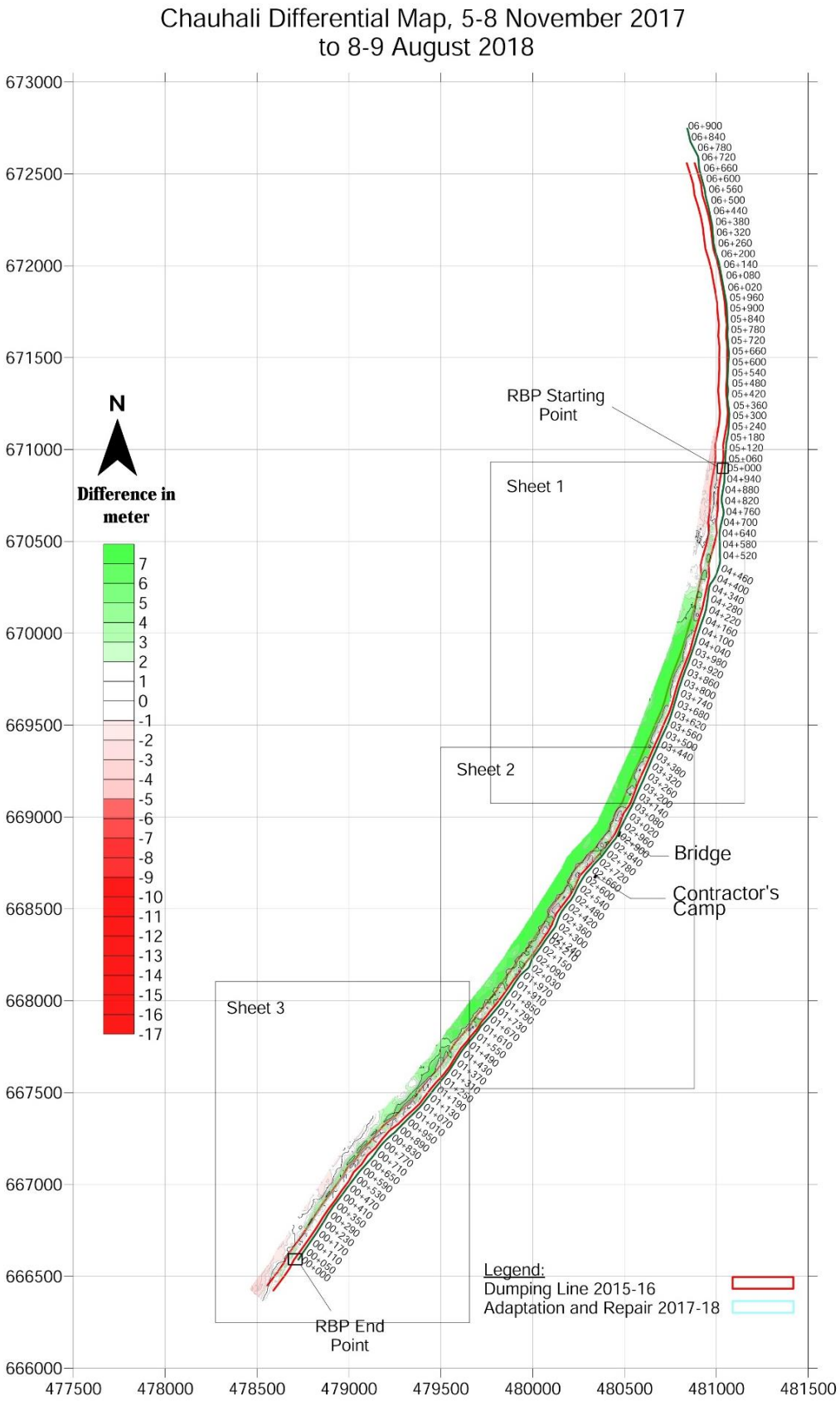
Survey Date: 6-7 October 2018

6.7 PIRDP

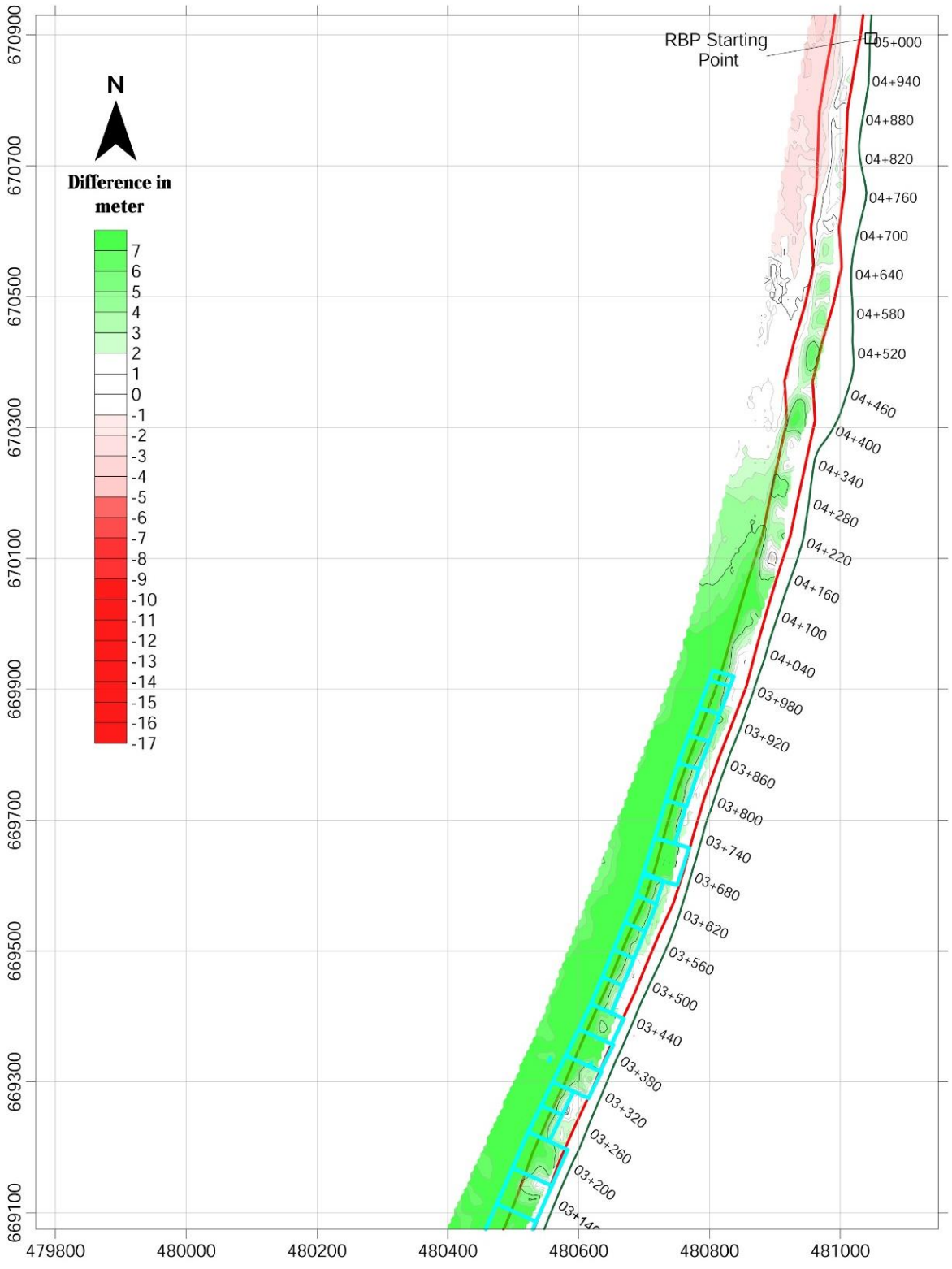

Map 1
Map 2
PIRDP Survey,
October 2018
Index Map
Map 1
Map 2
N
Elevation
in mPWD
11
9
7
5
3
1
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
Survey Date:
7 October 2018
464600
464800
465000
465200
465400
464800
465000
465200
465400
465600

7 Differential Models

7.1 Chauhali

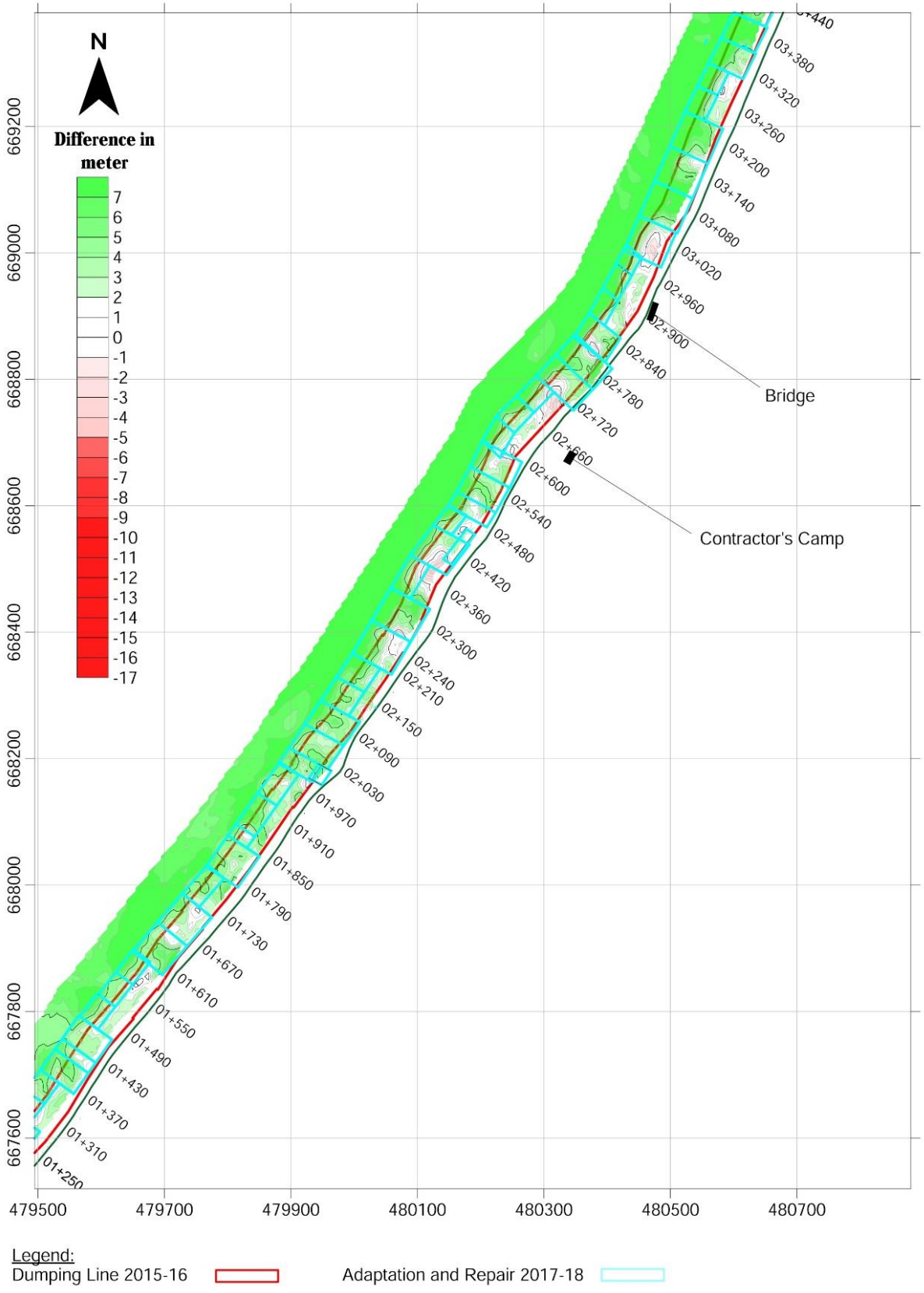


Chauhali Differential Map, 5-8 November 2017
to 8-9 August 2018, Sheet 1



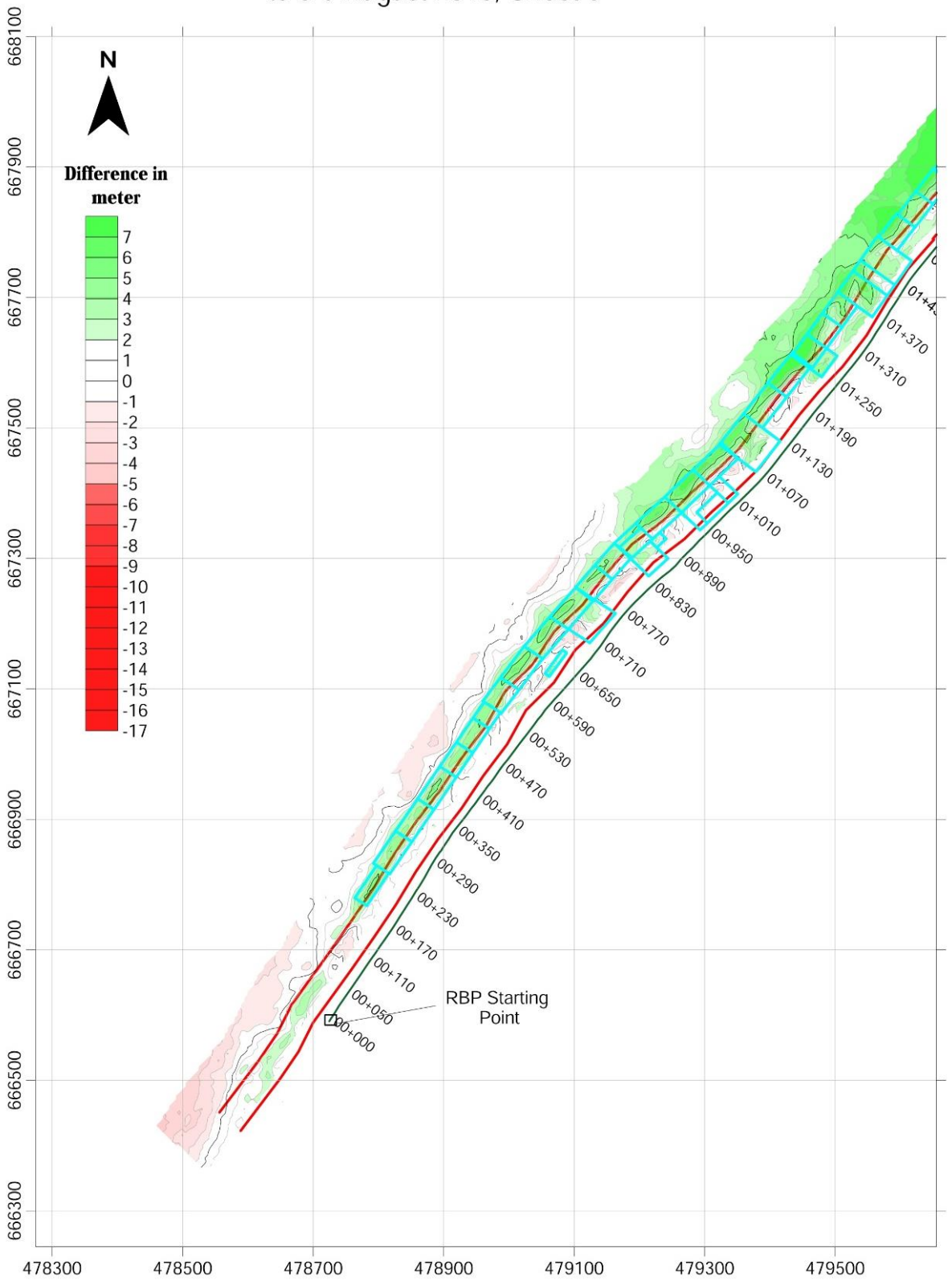
Legend:
Dumping Line 2015-16 Adaptation and Repair 2017-18

Chauhali Differential Map, 5-8 November 2017 to 8-9 August 2018, Sheet 2



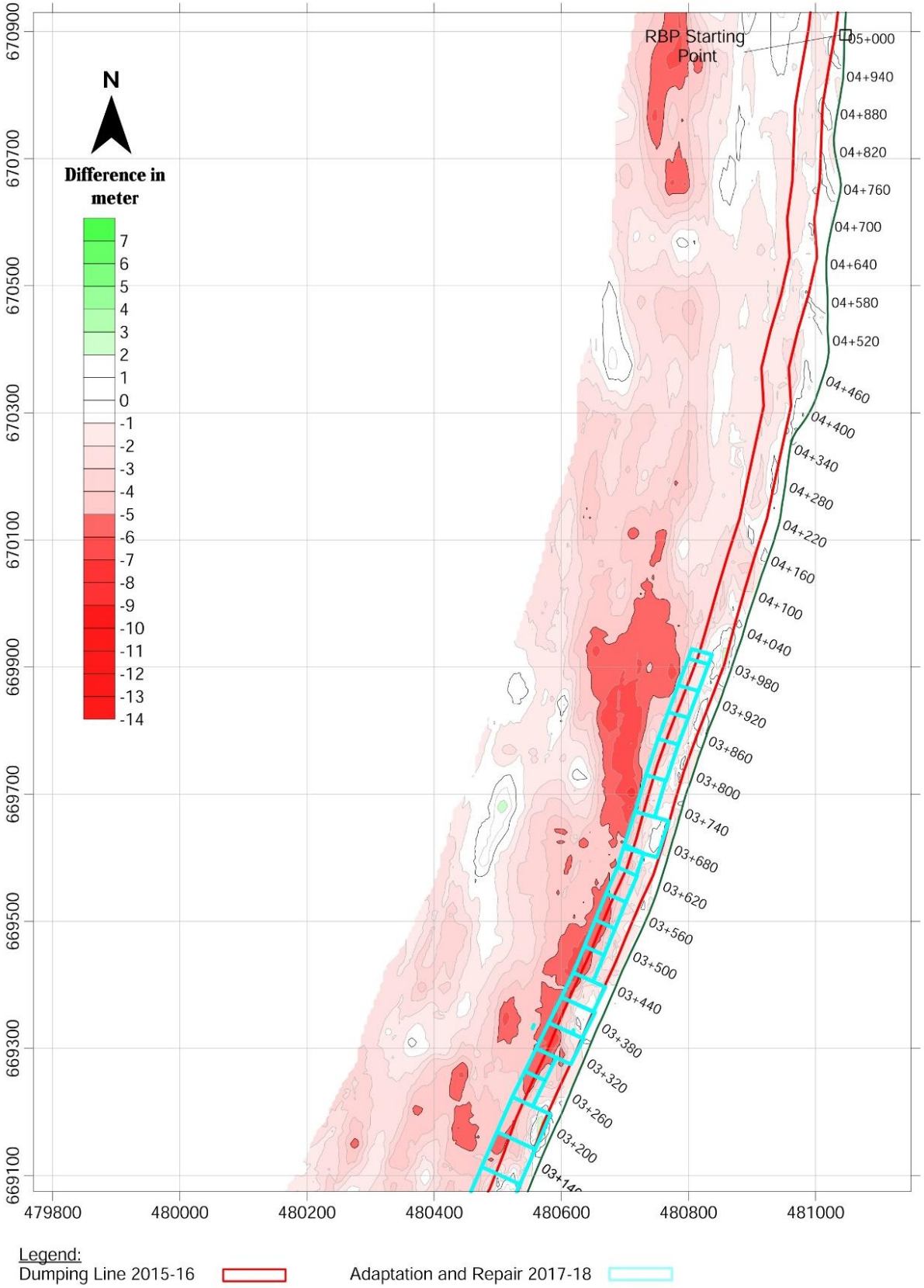
Legend:
Dumping Line 2015-16 Adaptation and Repair 2017-18

Chauhali Differential Map, 5-8 November 2017 to 8-9 August 2018, Sheet 3



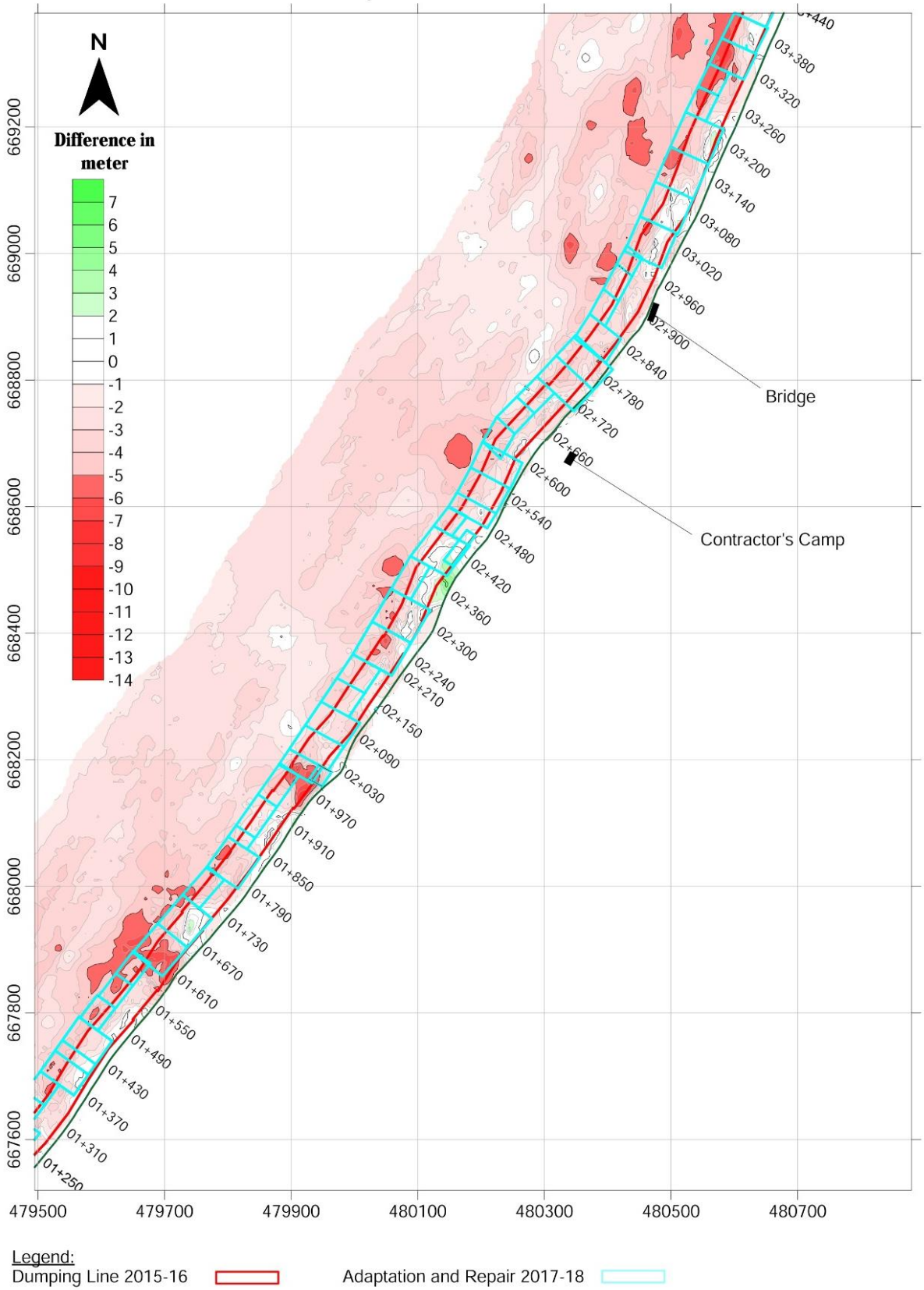
Legend:
Dumping Line 2015-16 Adaptation and Repair 2017-18

Chauhali Differential Map, 8-9 August 2018 to 7-8 September 2018, Sheet 1



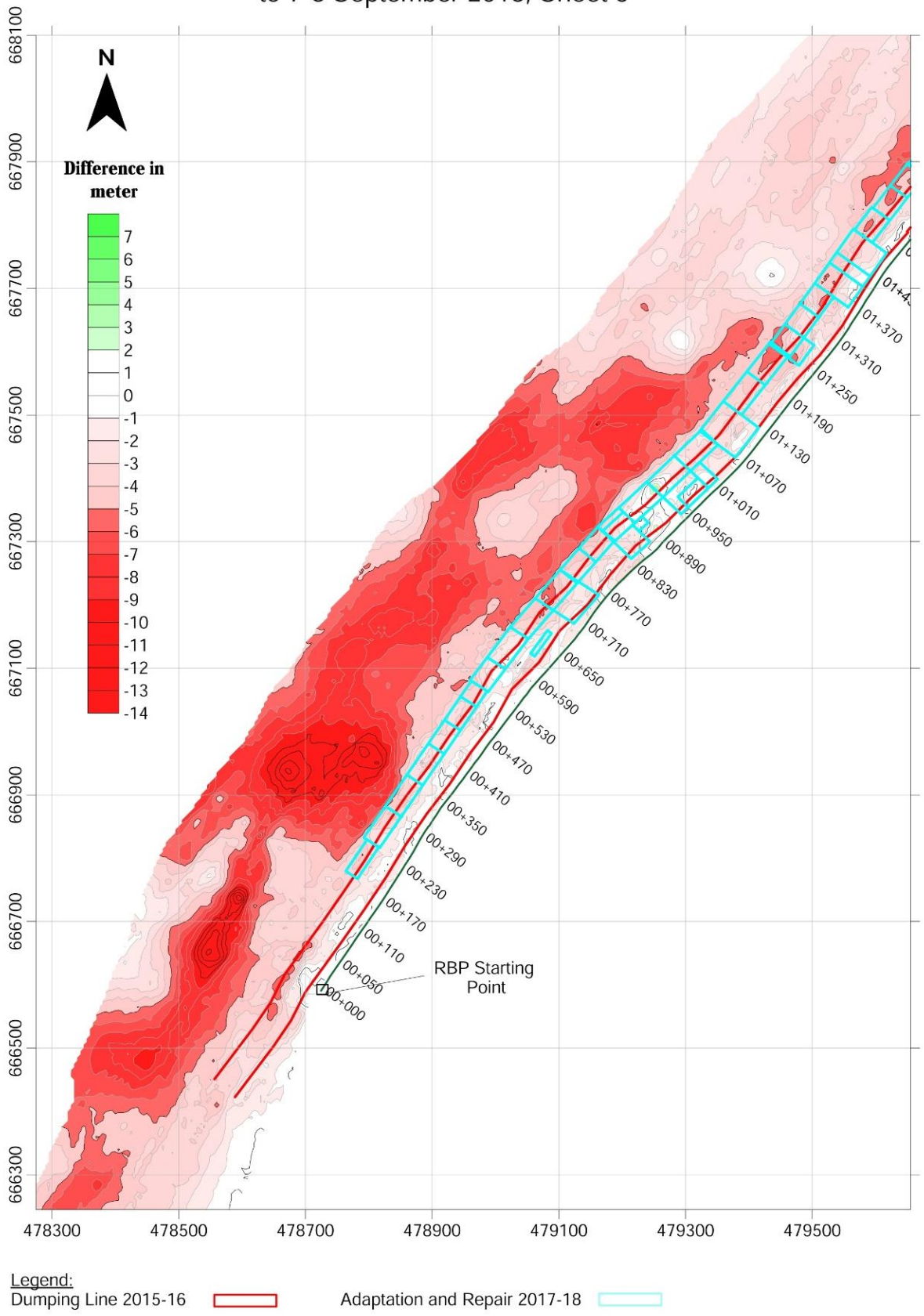
Legend:
Dumping Line 2015-16 Adaptation and Repair 2017-18

Chauhali Differential Map, 8-9 August 2018 to 7-8 September 2018, Sheet 2



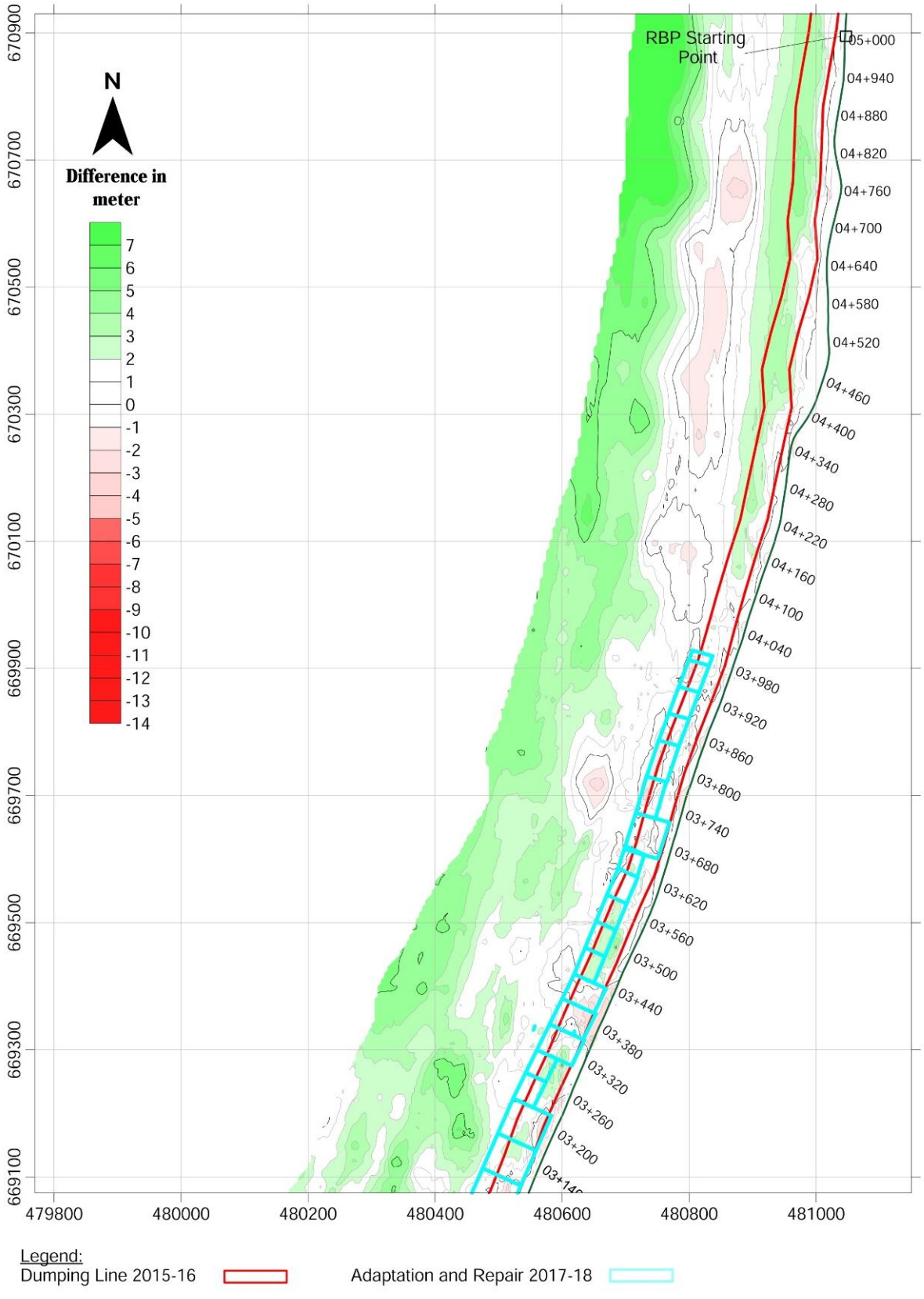
Legend:
Dumping Line 2015-16 Adaptation and Repair 2017-18

Chauhali Differential Map, 8-9 August 2018 to 7-8 September 2018, Sheet 3



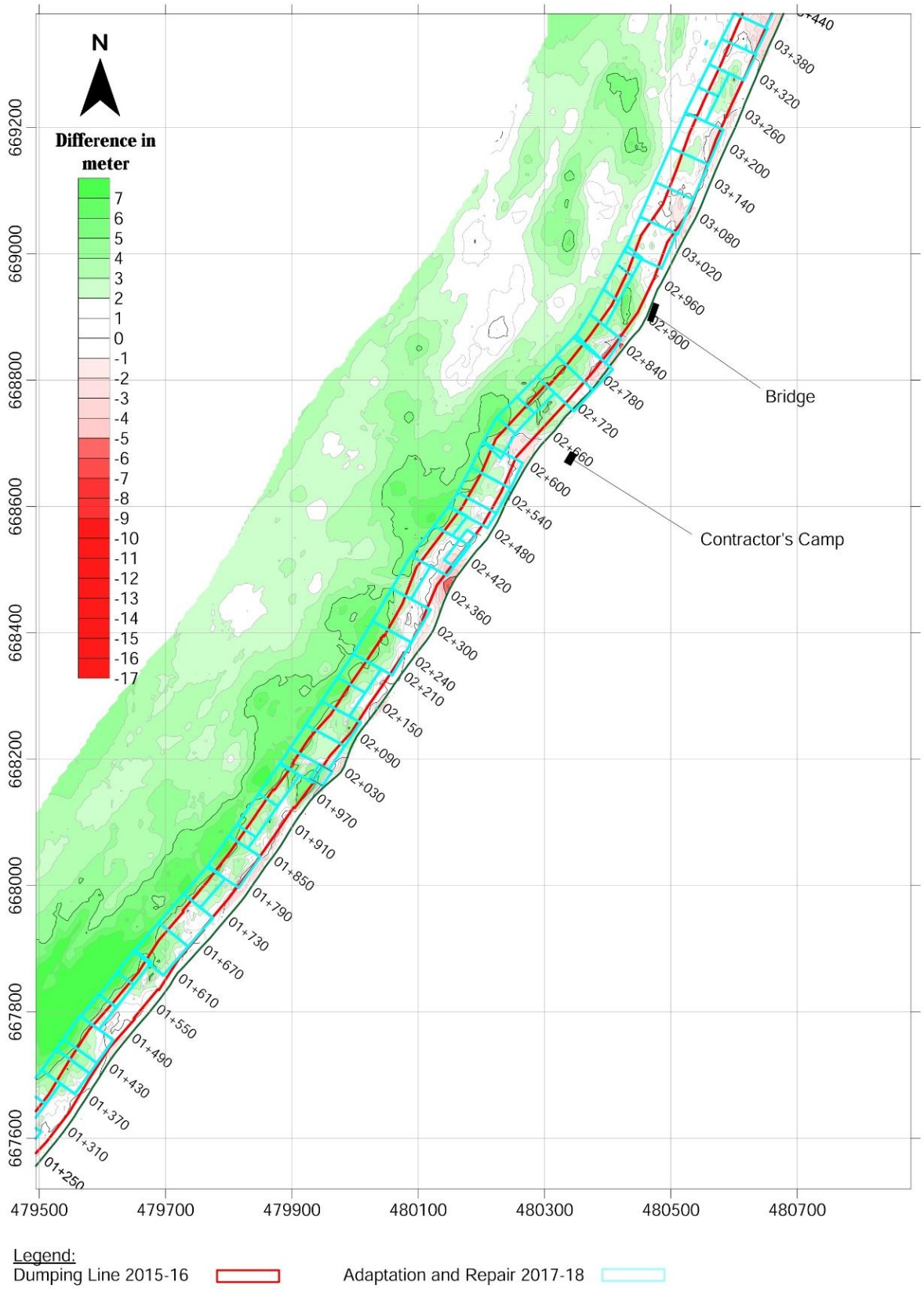
Legend:
Dumping Line 2015-16 Adaptation and Repair 2017-18

Chauhali Differential Map, 7-8 September 2018
to 8-9 October 2018, Sheet 1



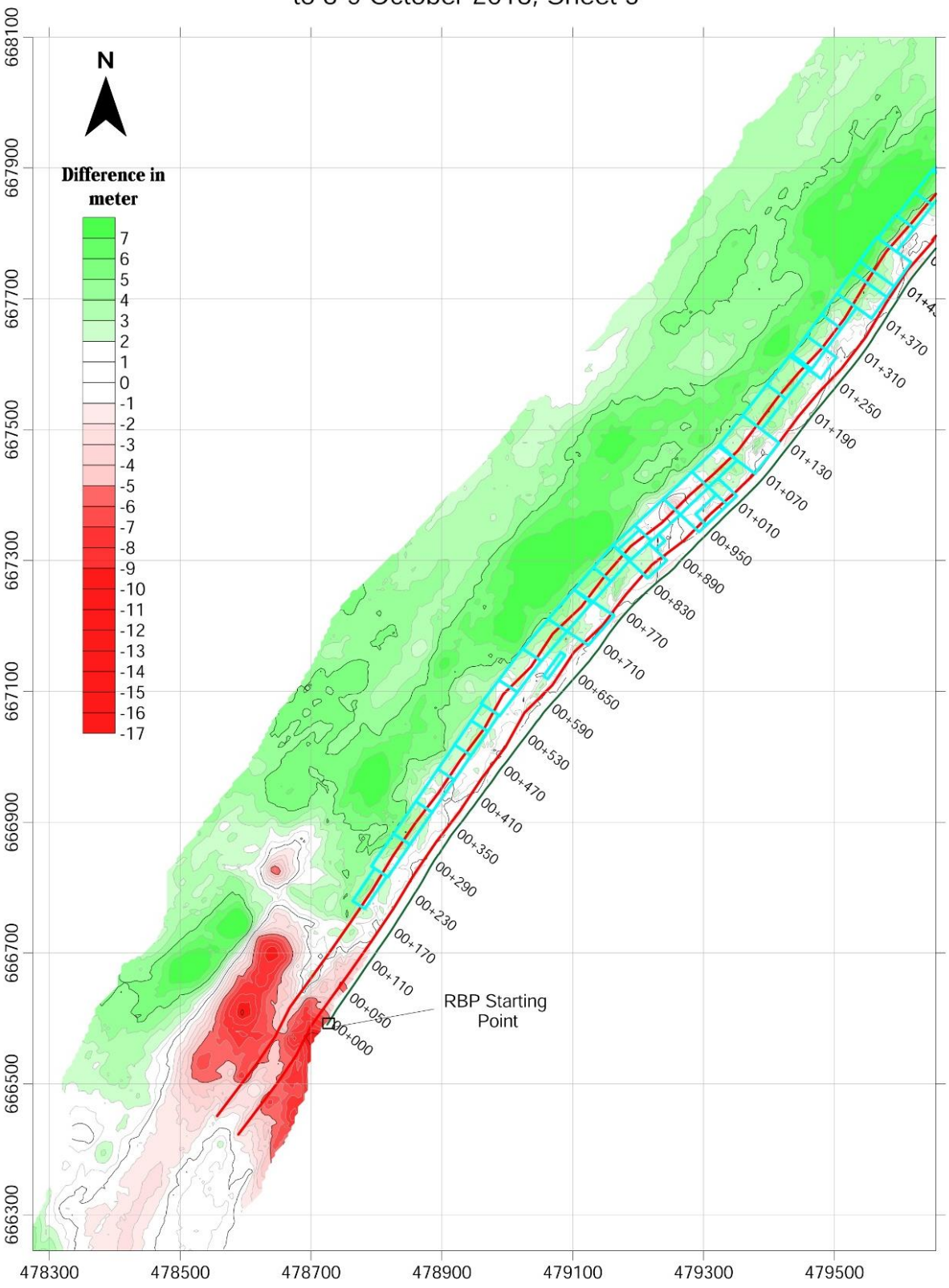
Legend:
Dumping Line 2015-16 Adaptation and Repair 2017-18

Chauhali Differential Map, 7-8 September 2018 to 8-9 October 2018, Sheet 2



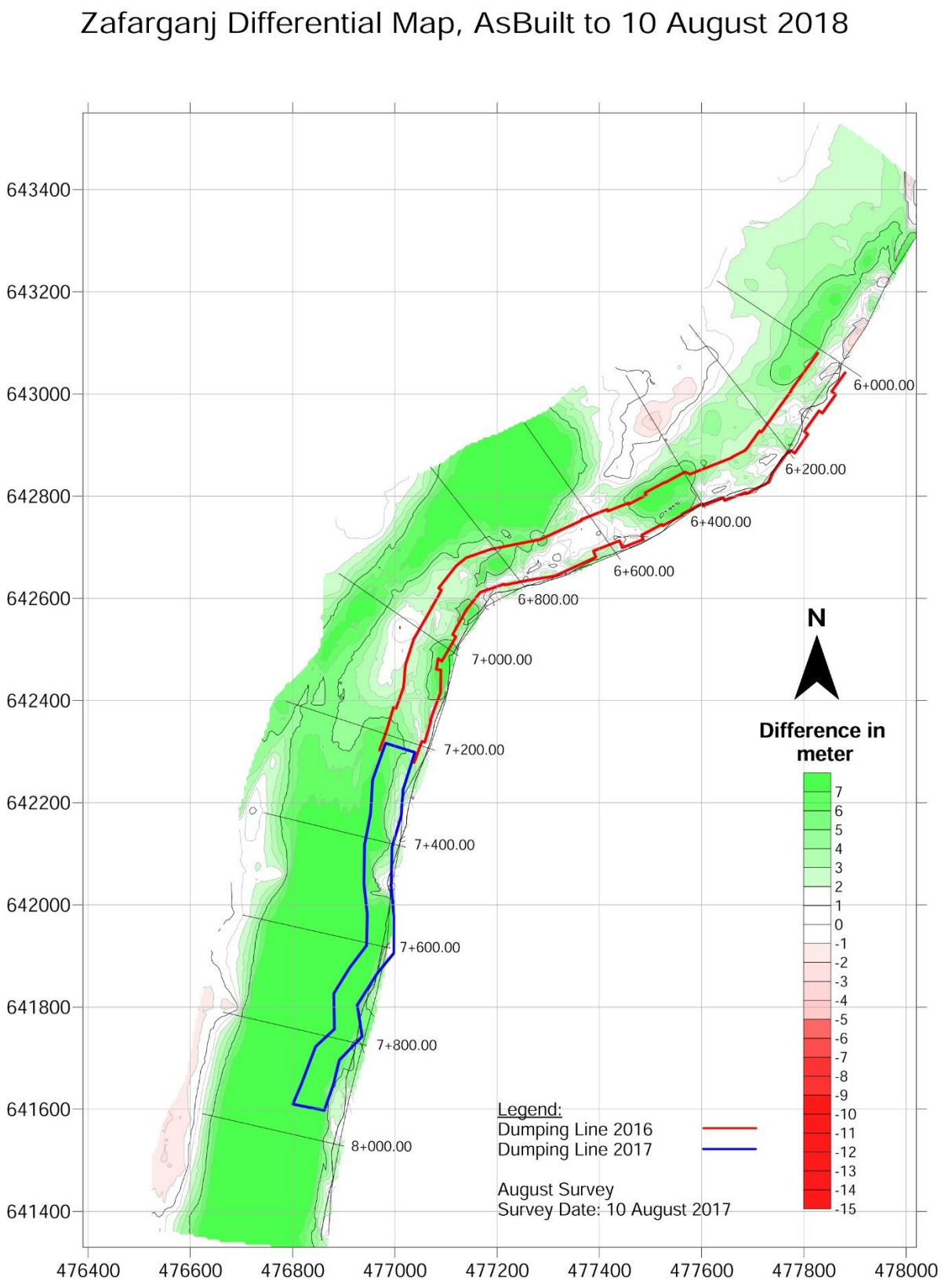
Legend:
Dumping Line 2015-16 Adaptation and Repair 2017-18

Chauhali Differential Map, 7-8 September 2018 to 8-9 October 2018, Sheet 3

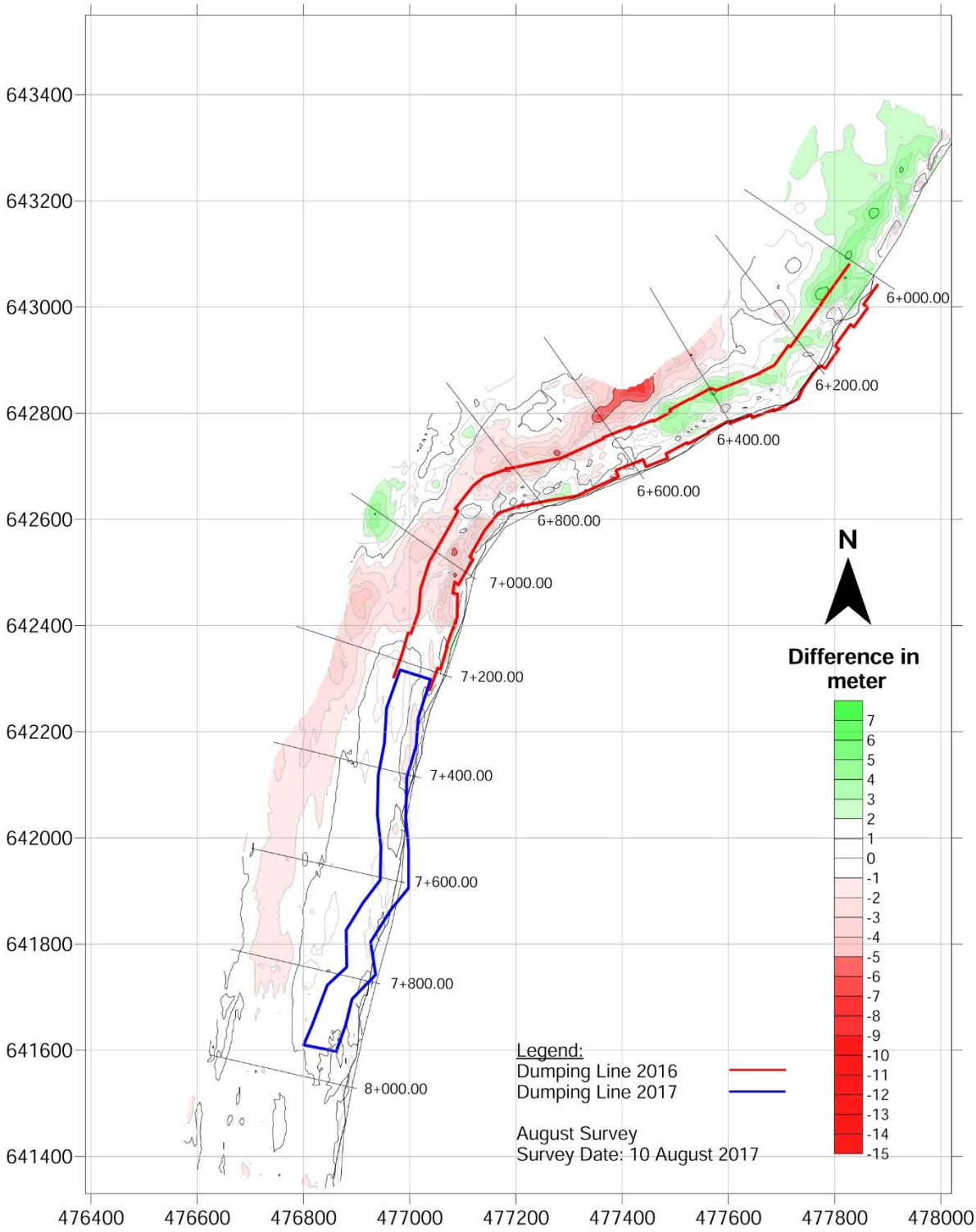


Legend:
Dumping Line 2015-16 Adaptation and Repair 2017-18

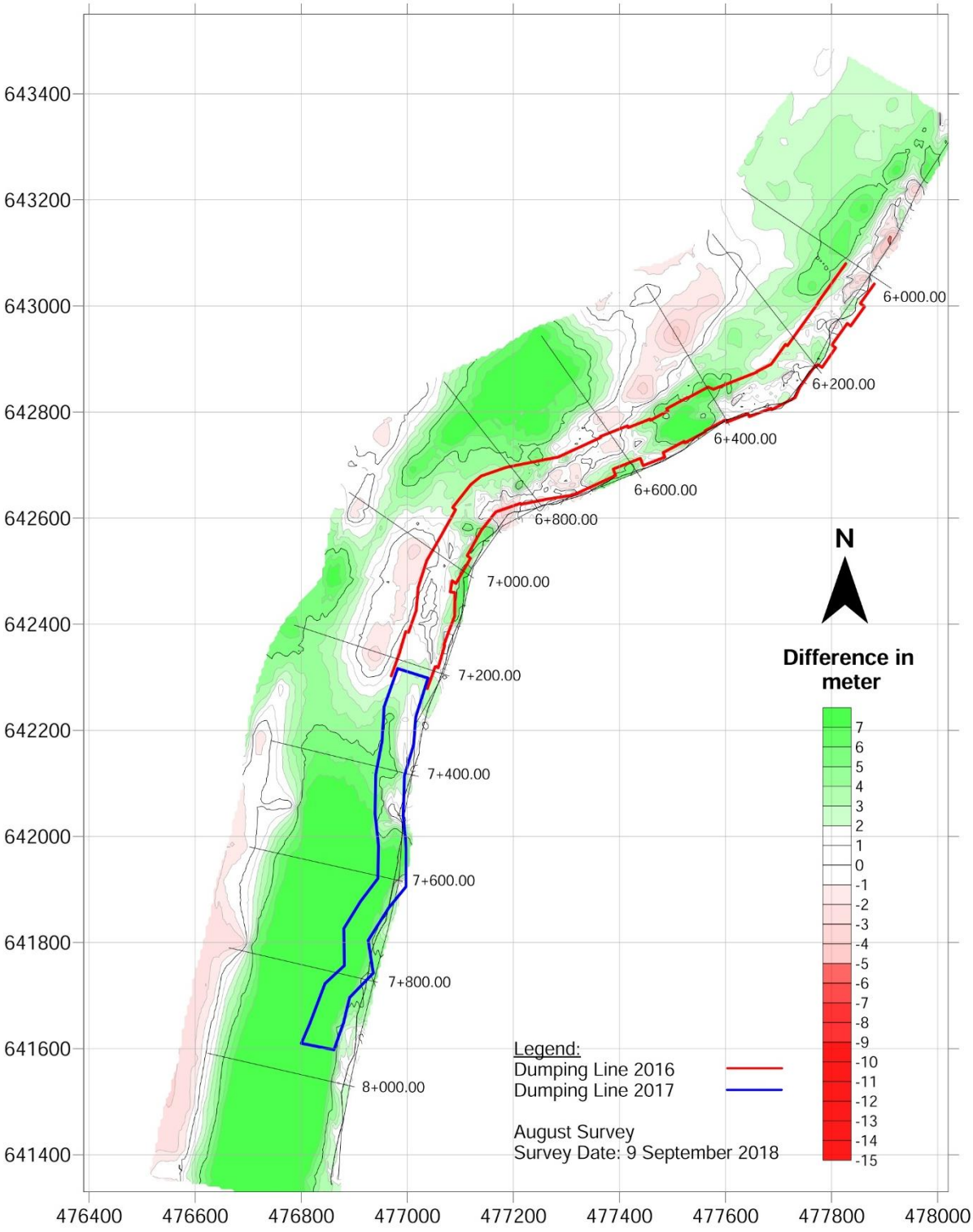
7.2 Zafarganj



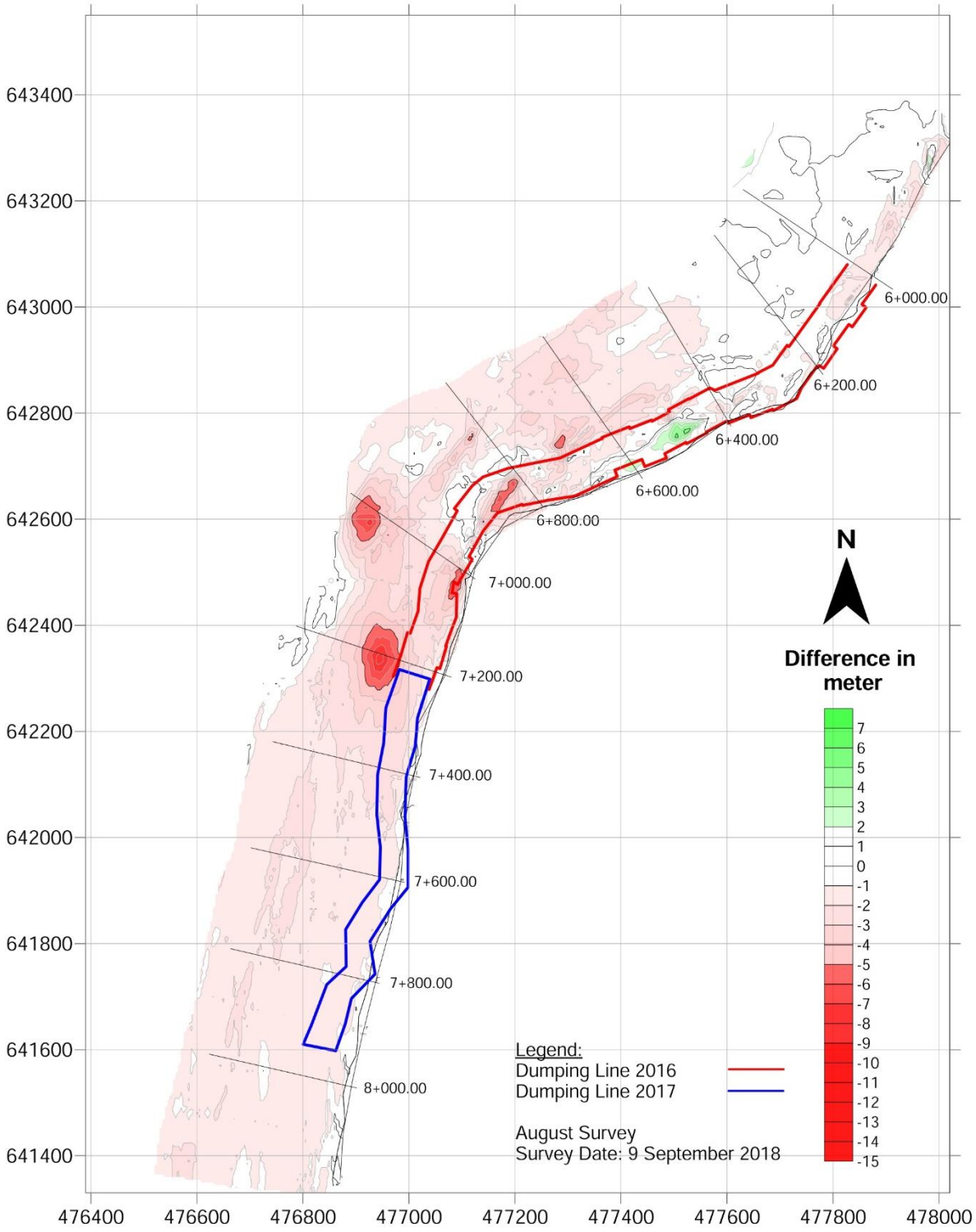
Zafarganj Differential Map, 14 October 2017 to 10 August 2018



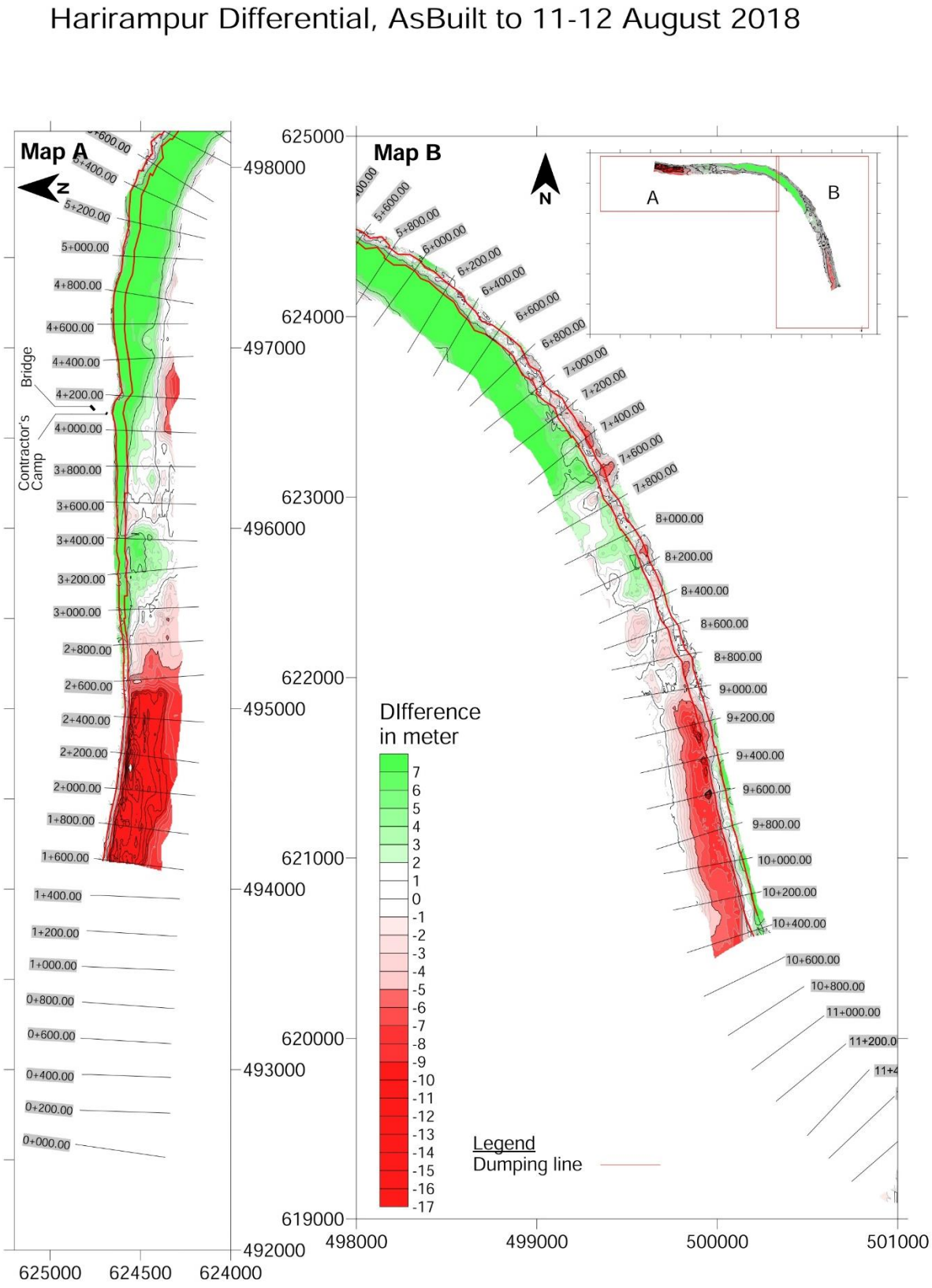
Zafarganj Differential Map, AsBuilt to 9 September 2018



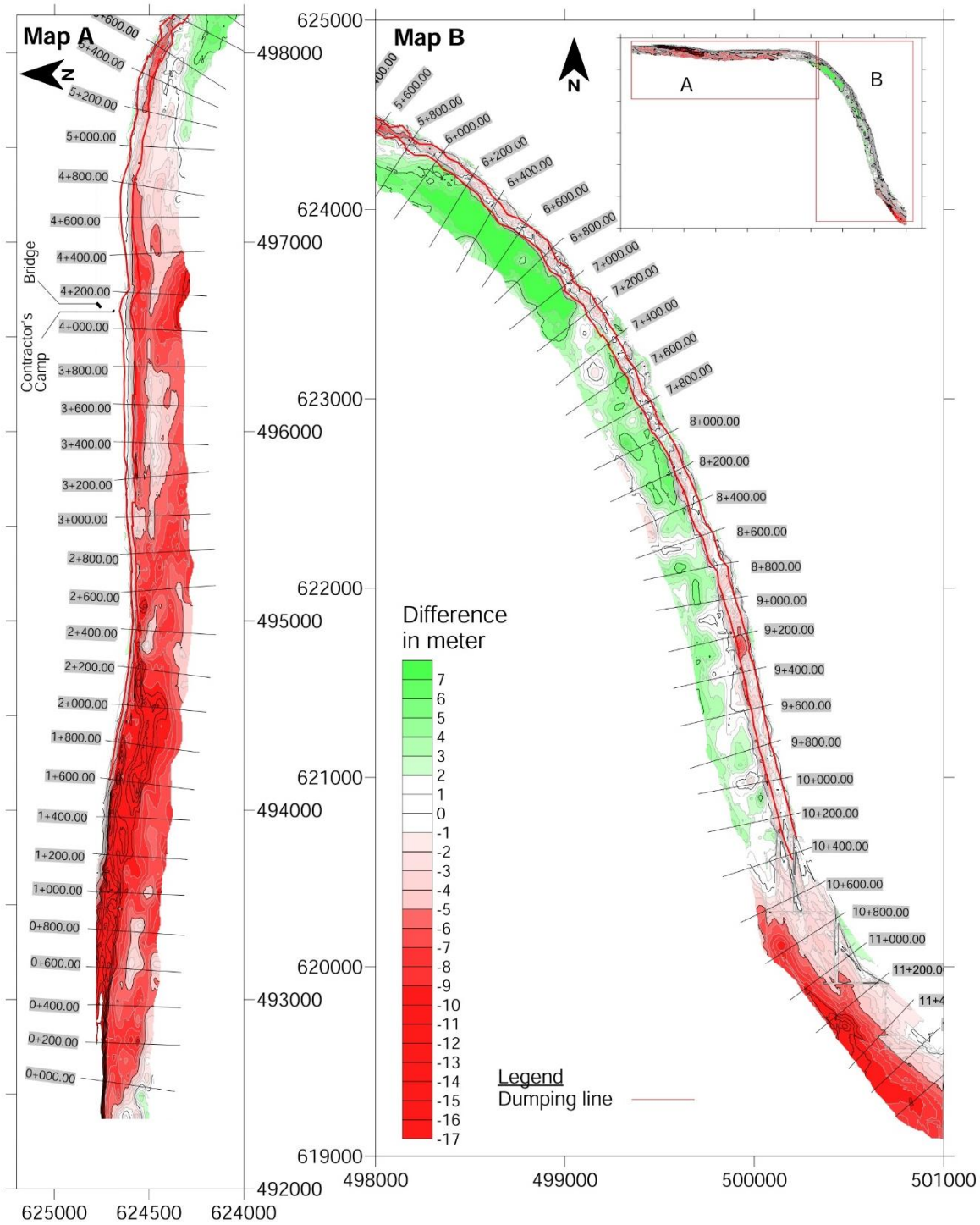
Zafarganj Differential Map, 10 August 2018 to 9 September 2018



7.3 Harirampur

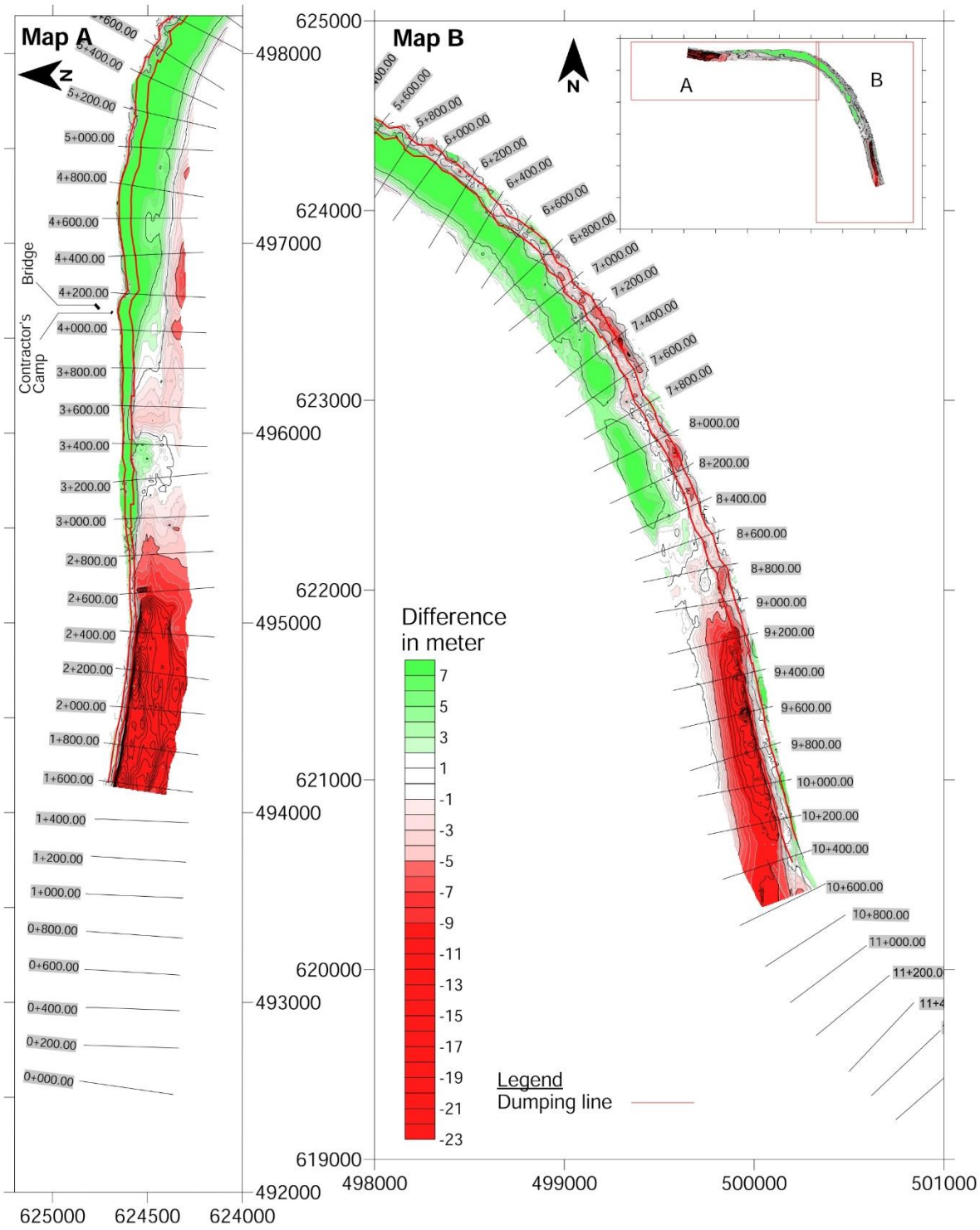


Harirampur Differential, 15-16 October 2017 to 11-12 August 2018



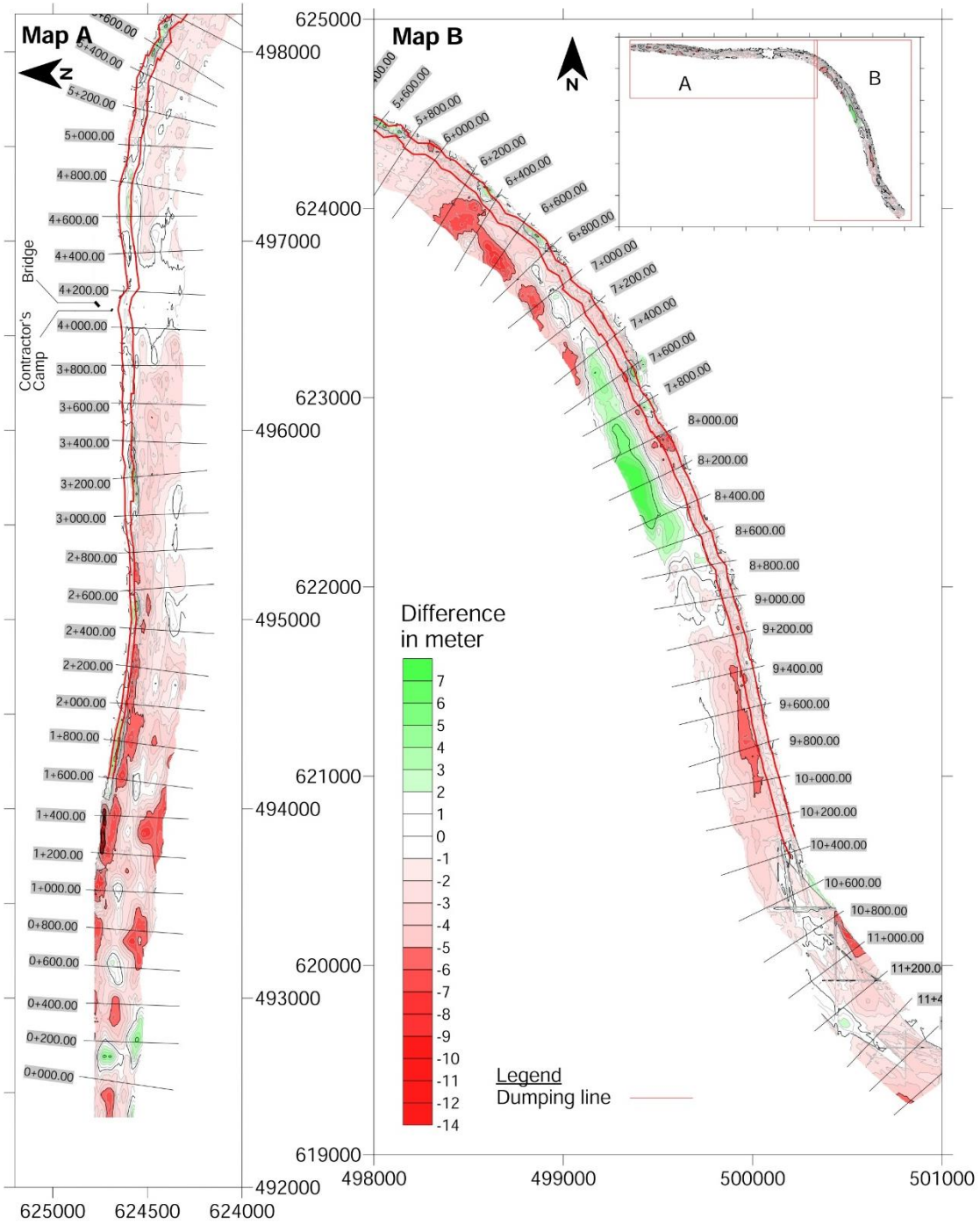
August Survey
Date: 11 to 12 August, 2018

Harirampur Differential, AsBuilt to 10-11 September 2018



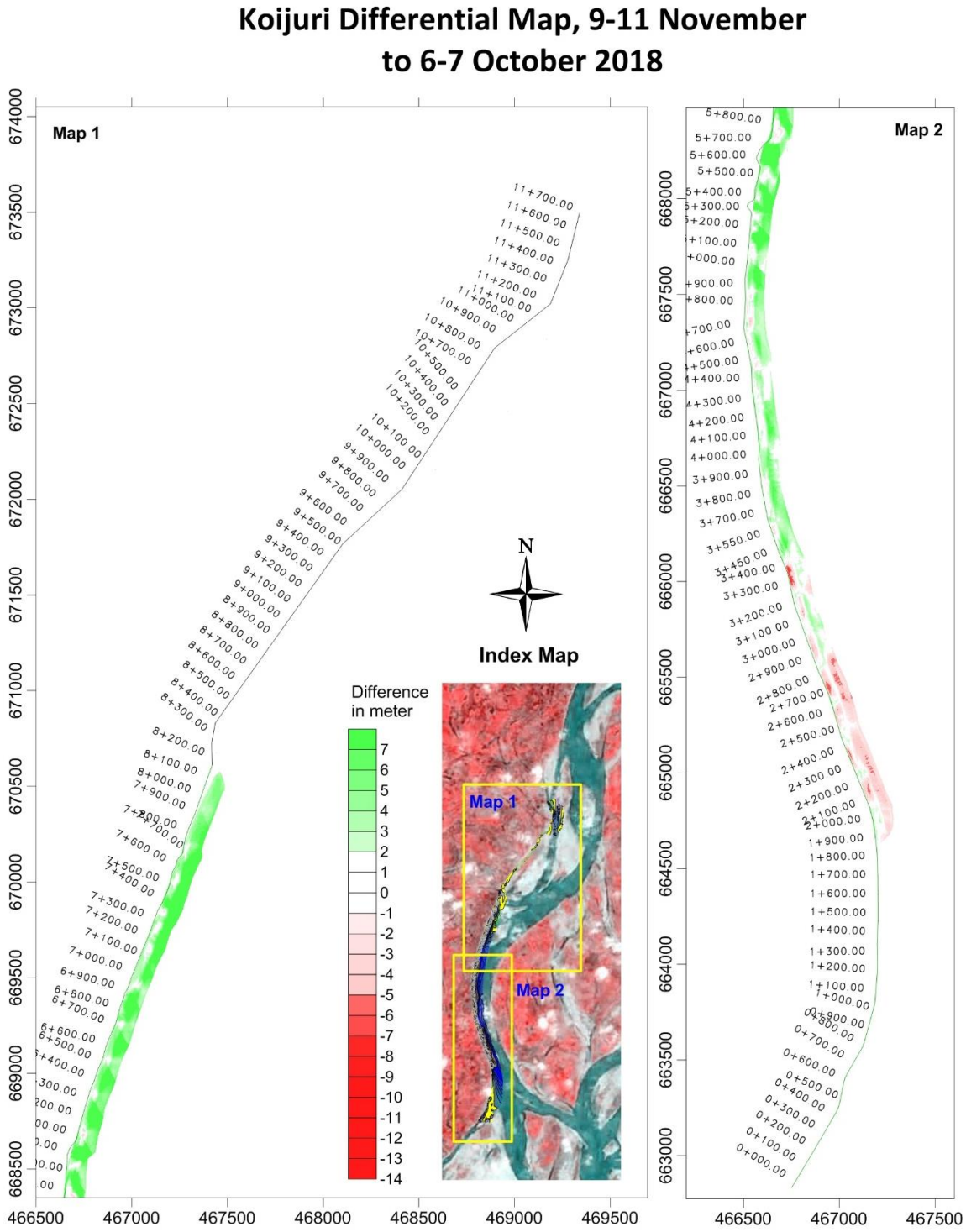
August Survey
Date: 10 to 11 September, 2018

Harirampur Differential, 11-12 August 2018 to 10-11 September 2018



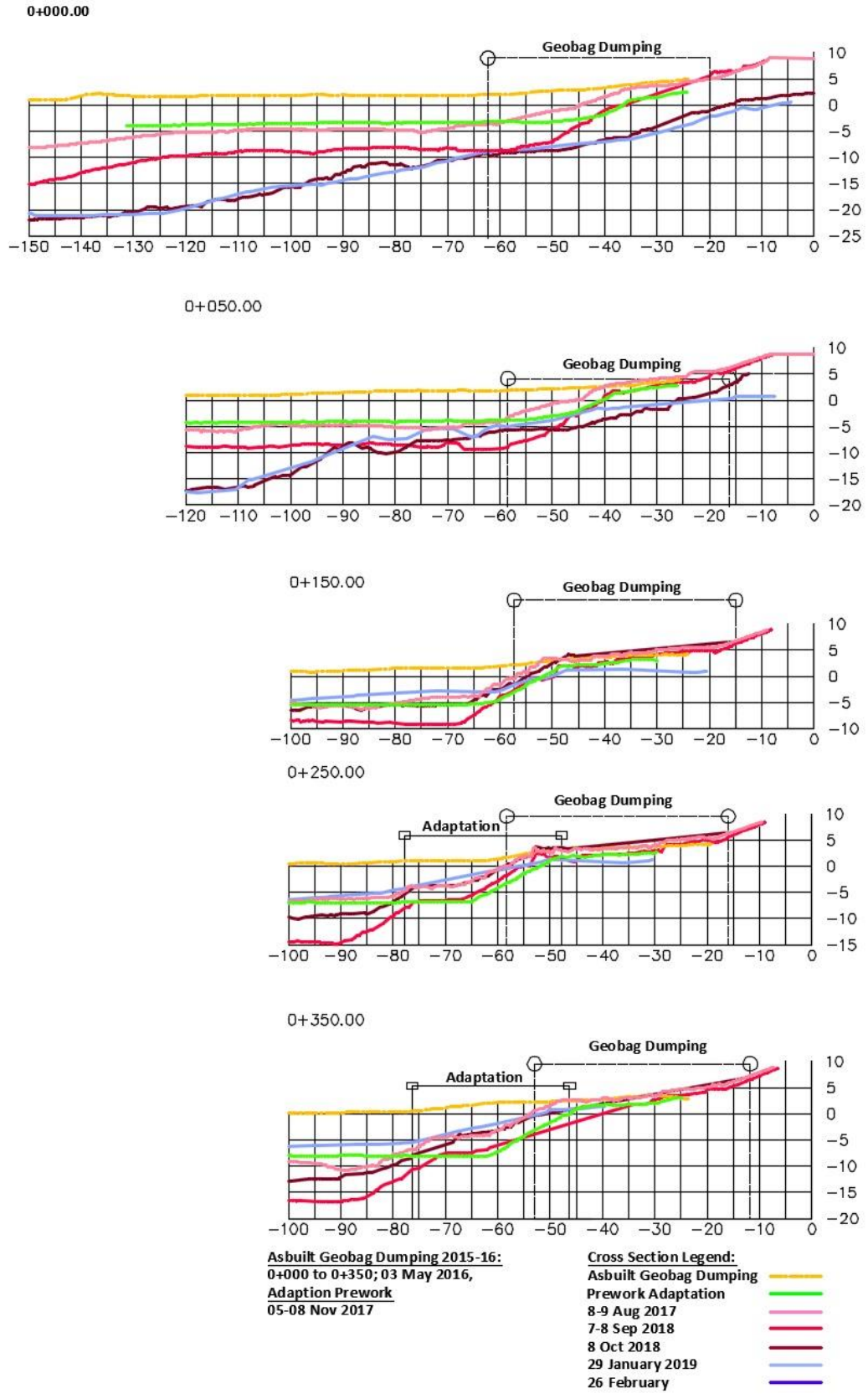
August Survey
Date: 10 to 11 September, 2018

7.4 Koijuri

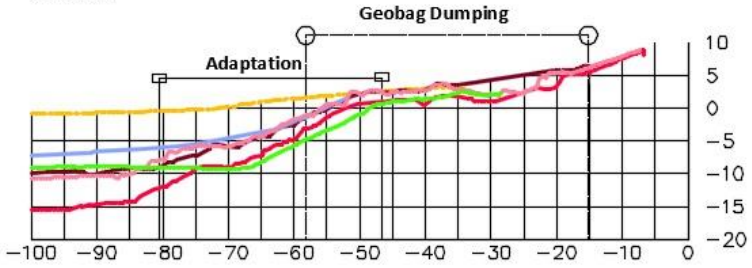

Koijuri Differential Map, 9-11 November to 6-7 October 2018
Map 1
Map 2
Index Map
N
Difference in meter
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
674000
673500
673000
672500
672000
671500
671000
670500
670000
669500
669000
668500
668000
667500
667000
666500
666000
665500
665000
664500
664000
663500
663000
466500
467000
467500
468000
468500
469000
469500

8 Cross section analysis

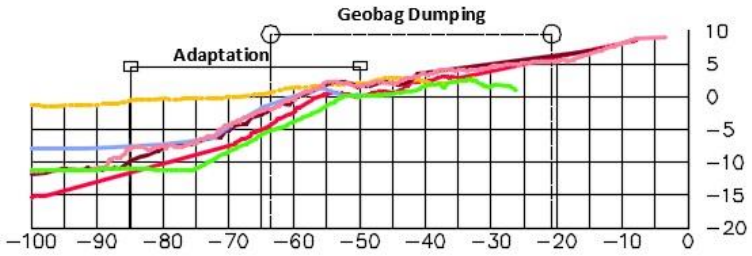
8.1 Chauhali



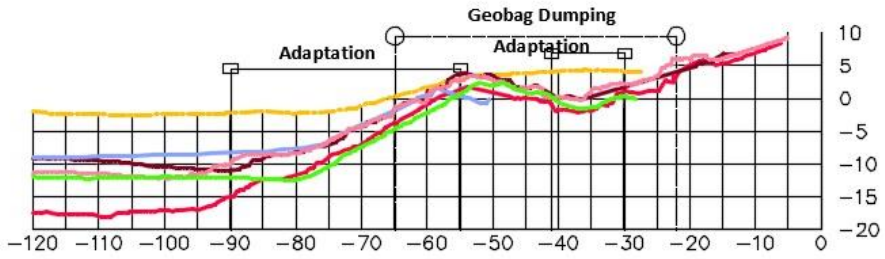
0+450.00



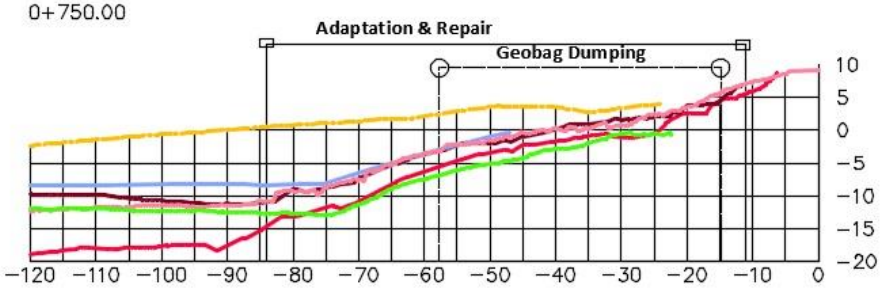
0+550.00



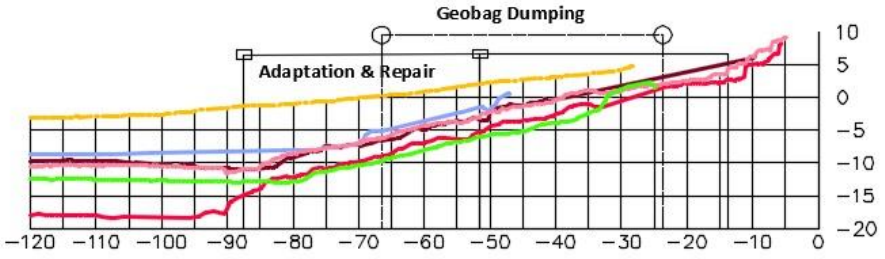
0+650.00



0+750.00



0+850.00

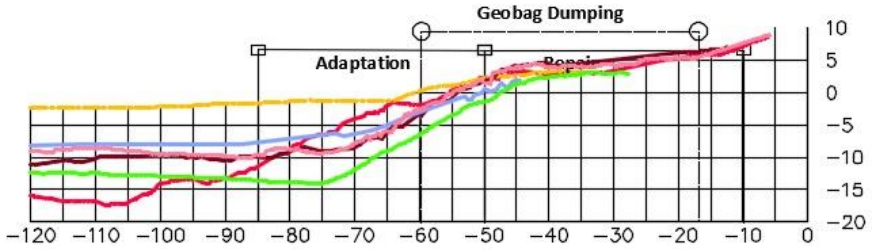


Asbuilt Geobag Dumping 2015-16:
0+450; 07 Aug 2016
0+550 to 0+850; 03 May 2016

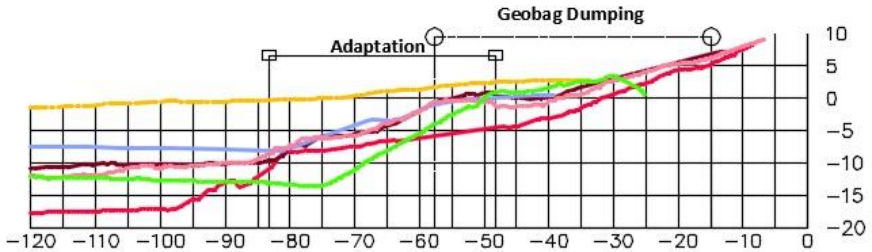
Adaption Prework
05-08 Nov 2017

Cross Section Legend:
Asbuilt Geobag Dumping
Prework Adaptation
8-9 Aug 2017
7-8 Sep 2018
8 Oct 2018
29 January 2019
26 February

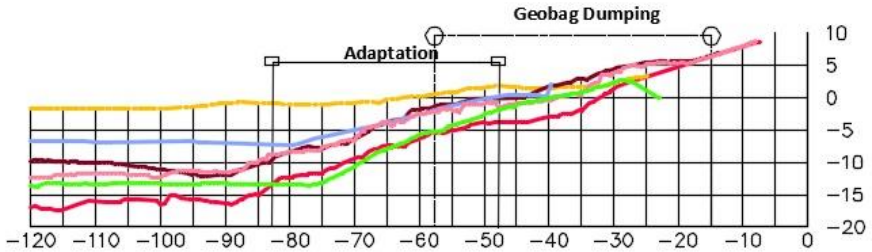
0+950.00



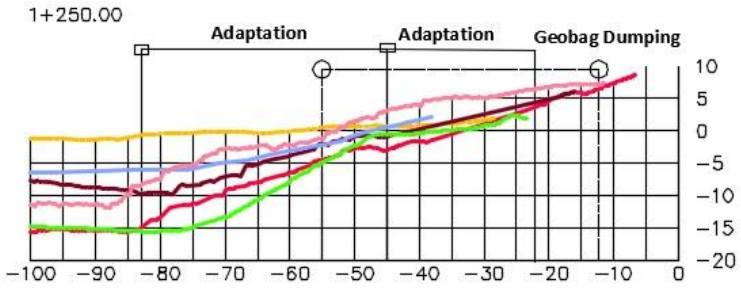
1+050.00



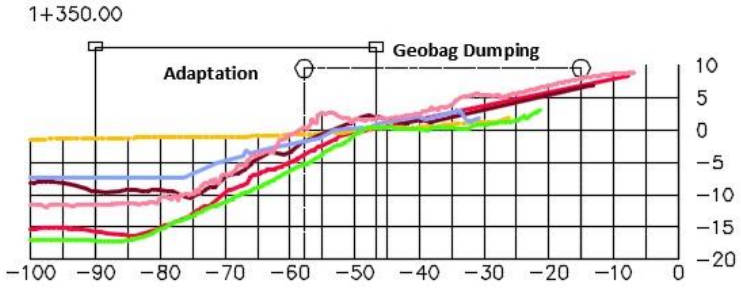
1+150.00



1+250.00



1+350.00



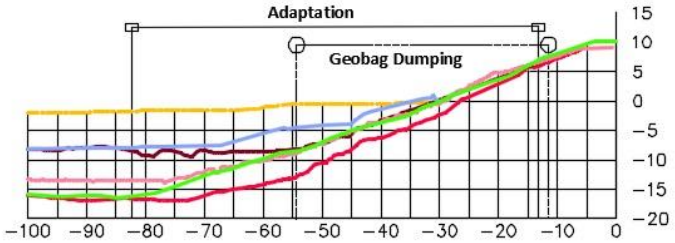
Asbuilt Geobag Dumping 2015-16:
03 May 2016

Adaption Prework
05-08 Nov 2017

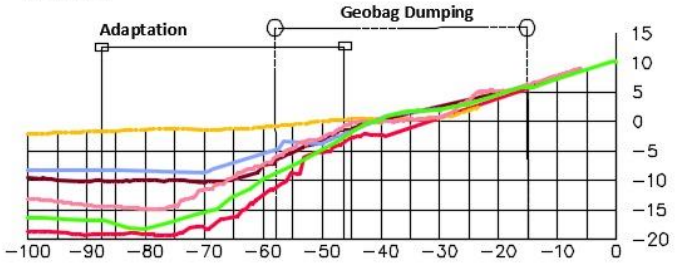
Cross Section Legend:

Asbuilt Geobag Dumping	
Prework Adaptation	
8-9 Aug 2017	
7-8 Sep 2018	
8 Oct 2018	
29 January 2019	
26 February	

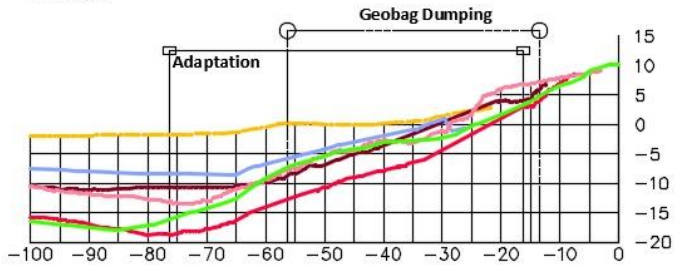
1+450.00



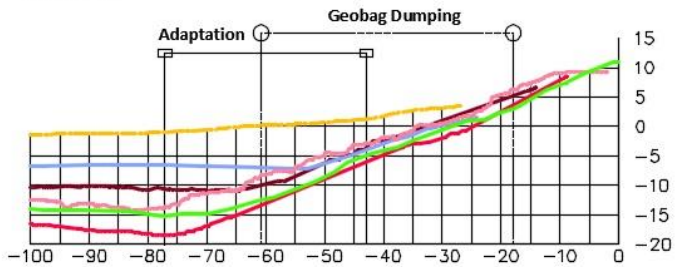
1+550.00



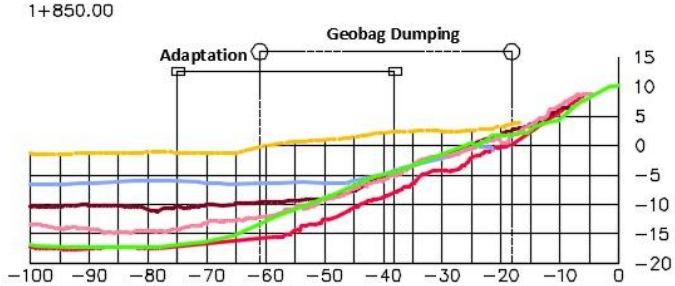
1+650.00



1+750.00



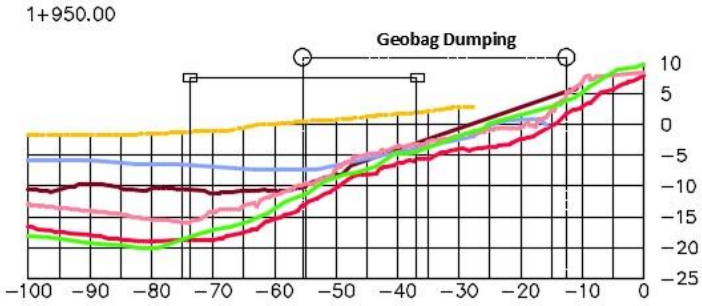
1+850.00

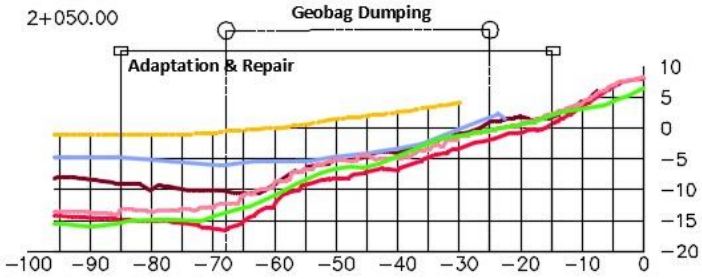


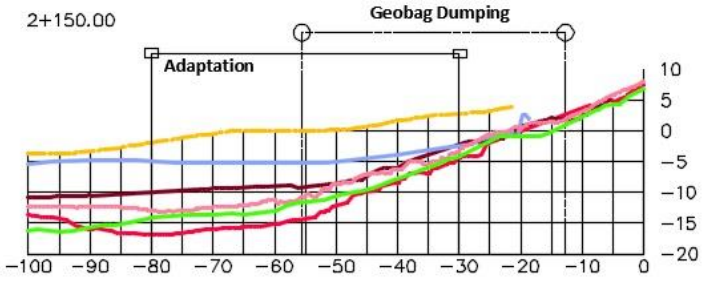
Asbuilt Geobag Dumping 2015-16:
03 May 2016

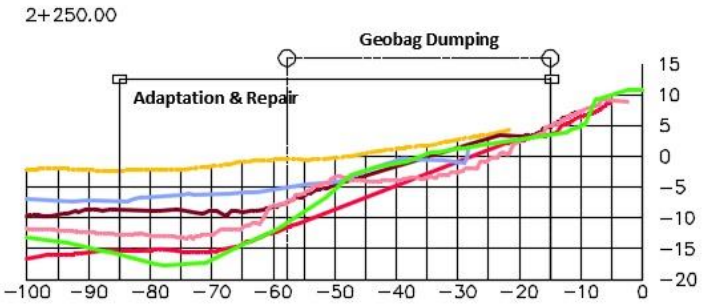
Adaption Prework
11-21 Mar 2018

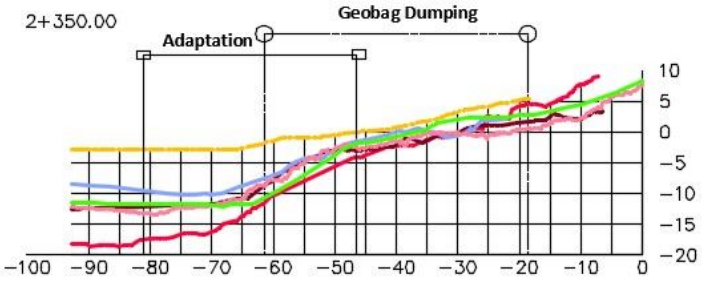
Cross Section Legend:
Asbuilt Geobag Dumping
Prework Adaptation
8-9 Aug 2017
7-8 Sep 2018
8 Oct 2018
29 January 2019
26 February







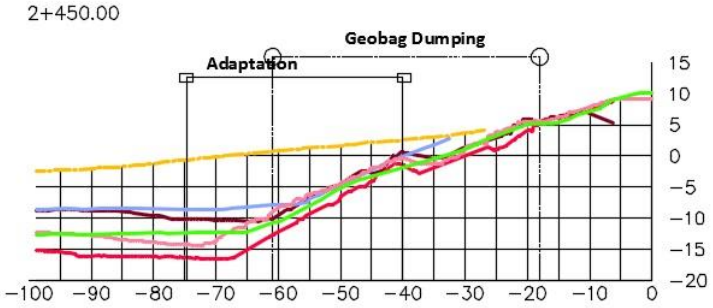


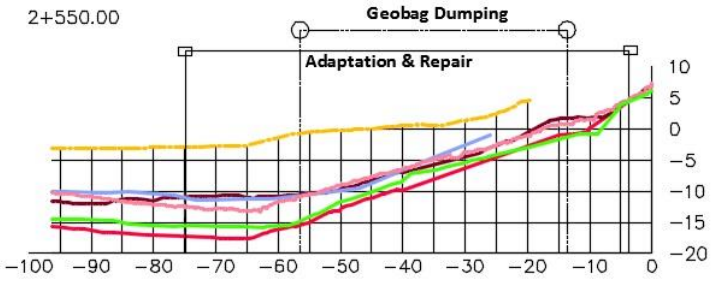


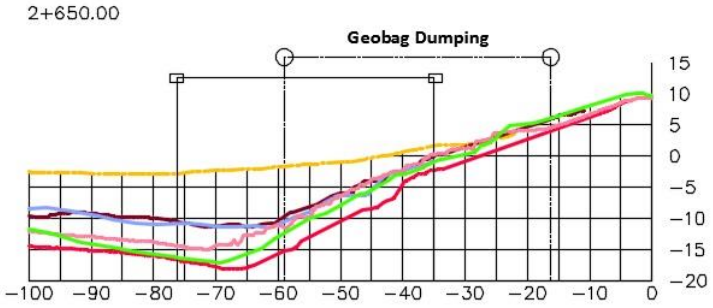
Asbuilt Geobag Dumping 2015-16:
03 May 2016

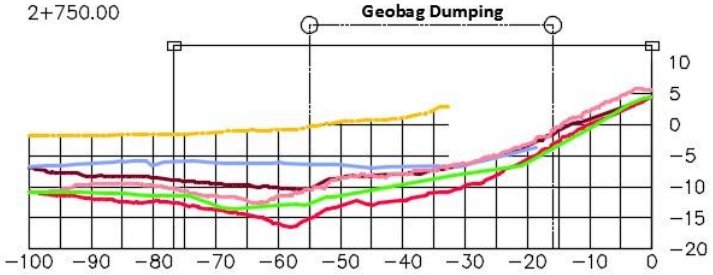
Adaption Prework
2+150 - 2+250; 05-08 Nov 2017
2+050, 2+350; 11-21 Mar 2018

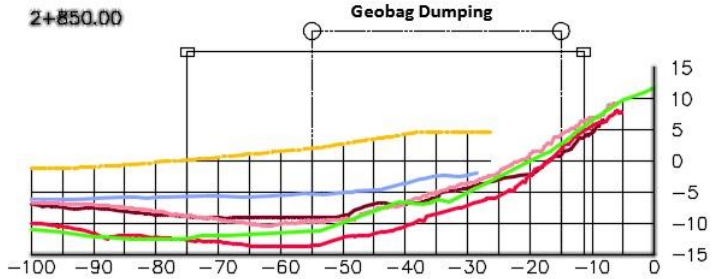
Cross Section Legend:
Asbuilt Geobag Dumping
Prework Adaptation
8-9 Aug 2017
7-8 Sep 2018
8 Oct 2018
29 January 2019
26 February







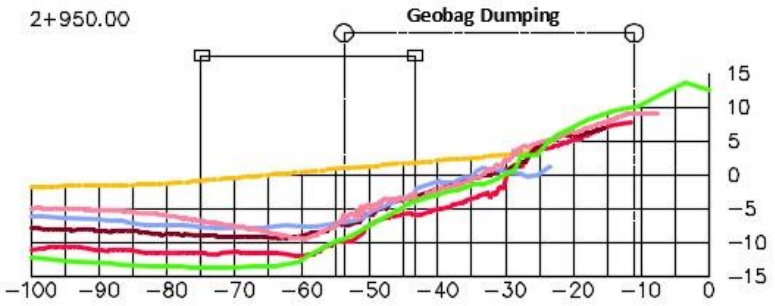


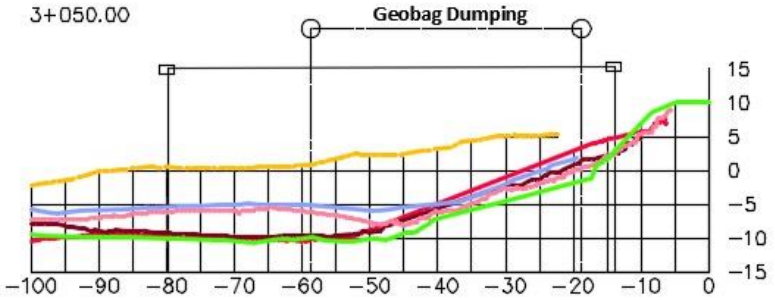


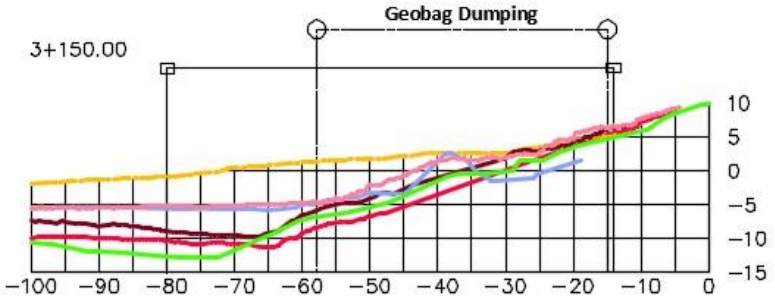
Asbuilt Geobag Dumping 2015-16:
2+550 - 2+850; 03 May 2016
2+950; 24 June 2016

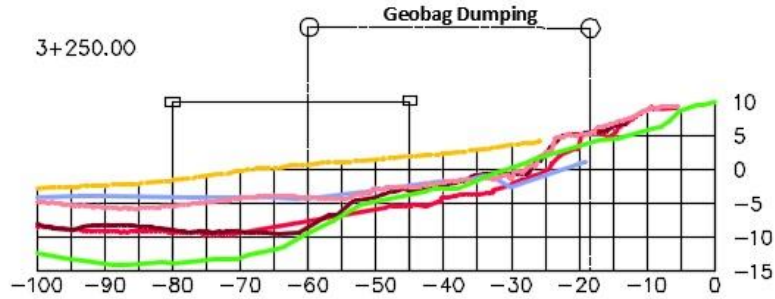
Adaption Prework
11-21 Mar 2018

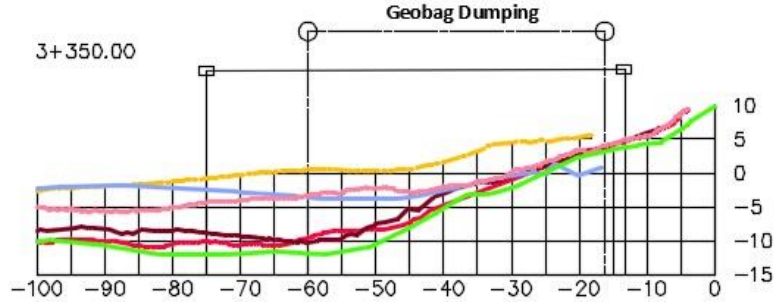
Cross Section Legend:
Asbuilt Geobag Dumping
Prework Adaptation
8-9 Aug 2017
7-8 Sep 2018
8 Oct 2018
29 January 2019
26 February







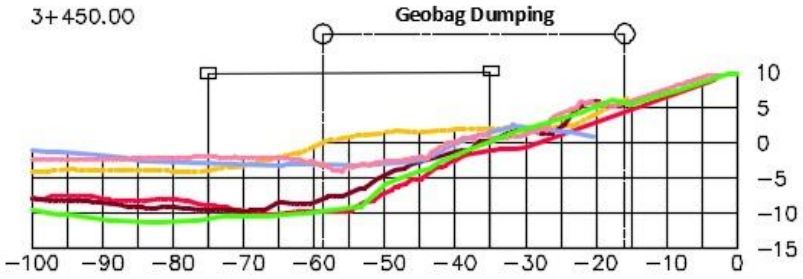


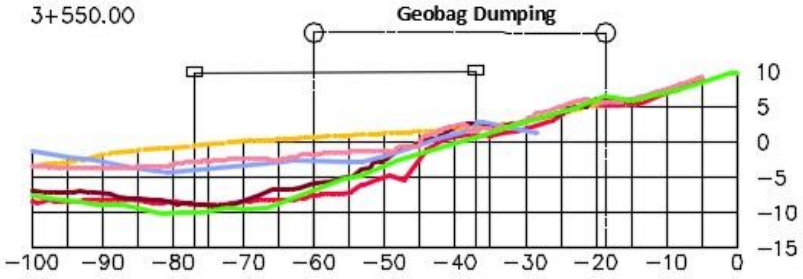


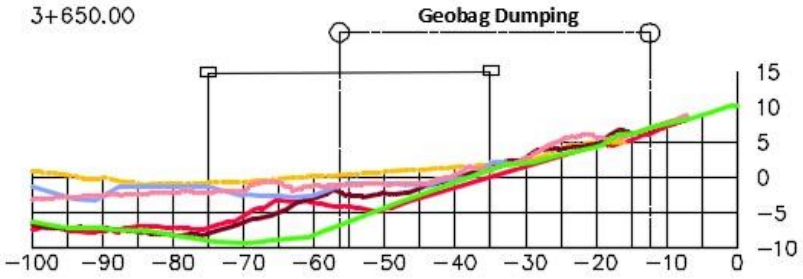
Asbuilt Geobag Dumping 2015-16:
3+050 - 3+250; 03 May 2016
3+350 - 3+450; 24 June 2016

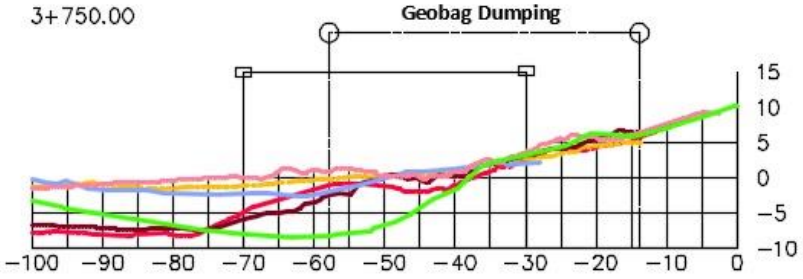
Adaption Prework
11-21 Mar 2018

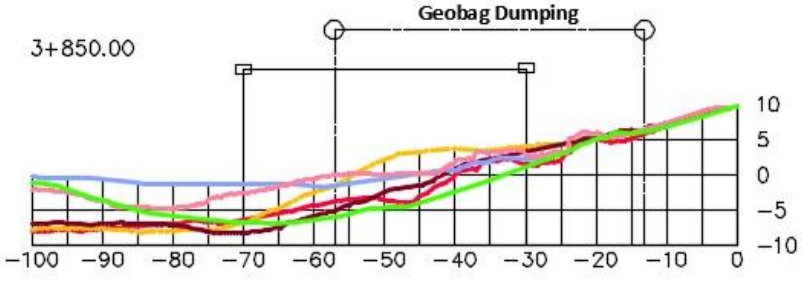
Cross Section Legend:
Asbuilt Geobag Dumping
Prework Adaptation
8-9 Aug 2017
7-8 Sep 2018
8 Oct 2018
29 January 2019
26 February 2019







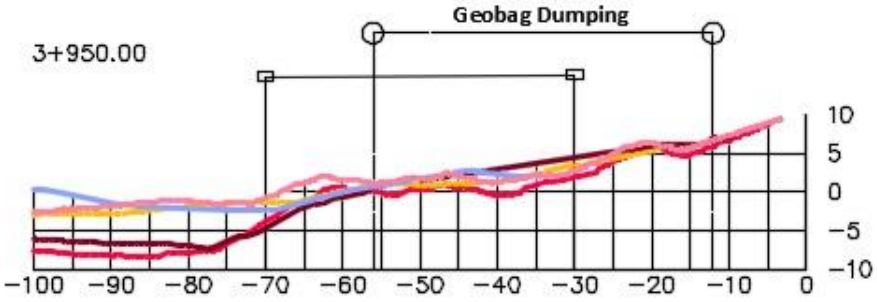


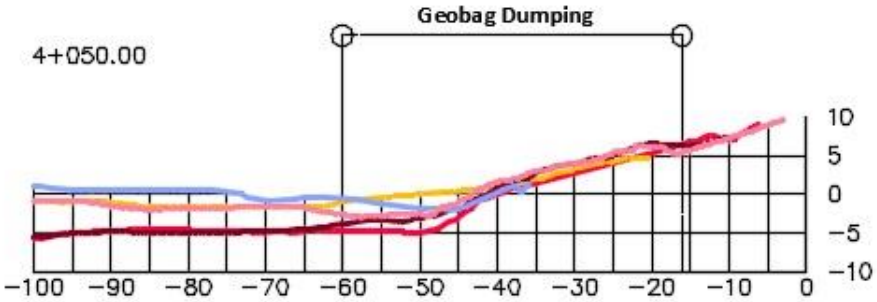


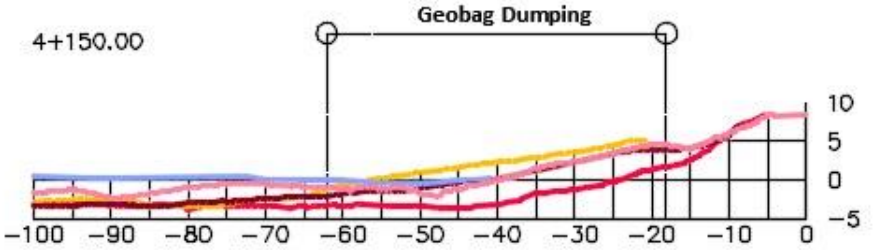
Asbuilt Geobag Dumping 2015-16:
3+550 - 3+750; 03 May 2016
3+850 - 3+950; 24 June 2016

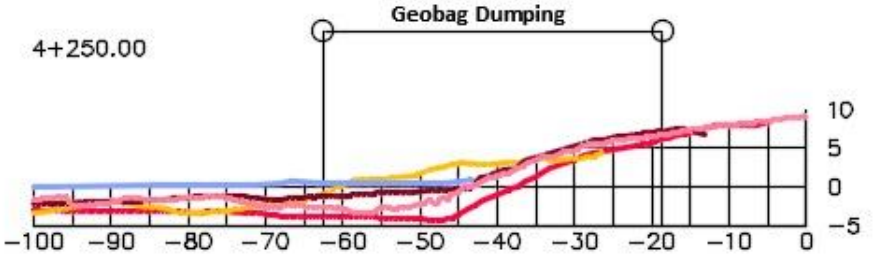
Adaption Prework
11-21 Mar 2018

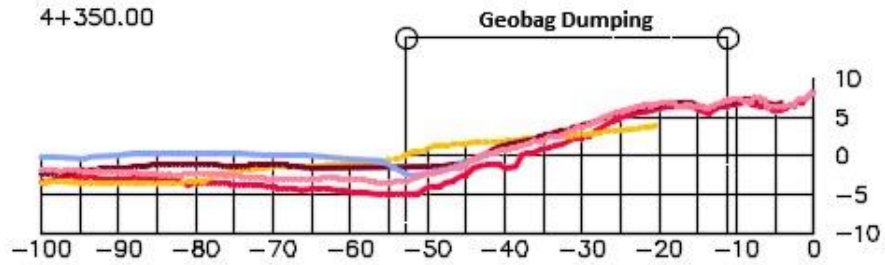
Cross Section Legend:
Asbuilt Geobag Dumping
Prework Adaptation
8-9 Aug 2017
7-8 Sep 2018
8 Oct 2018
29 January 2019
26 February 2019







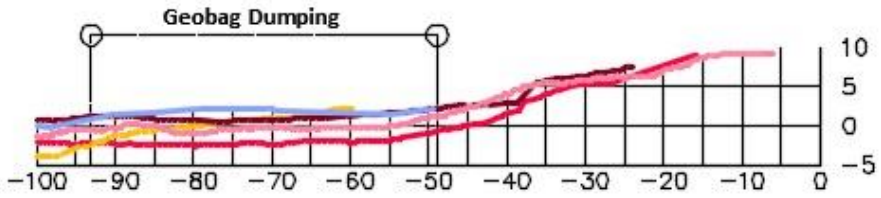




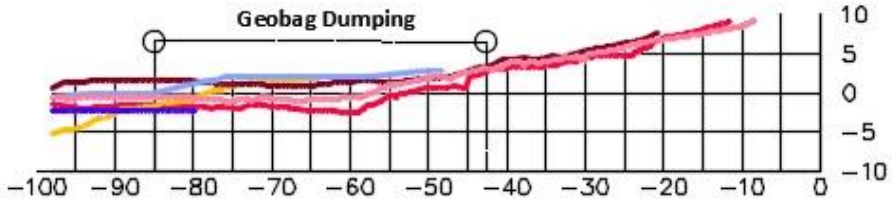
Asbuilt Geobag Dumping 2015-16:
4+050 - 4+150; 03 May 2016,
4+250 - 4+450; 24 June 2016

Cross Section Legend:
- **Asbuilt Geobag Dumping**
- **Prework Adaptation**
- **8-9 Aug 2017**
- **7-8 Sep 2018**
- **8 Oct 2018**
- **29 January 2019**
- **26 February**

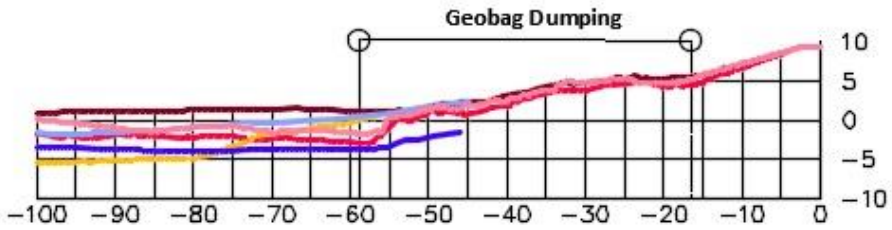
4+450.00



4+550.00



4+650.00



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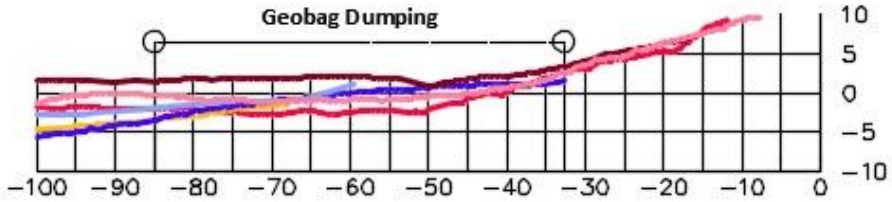
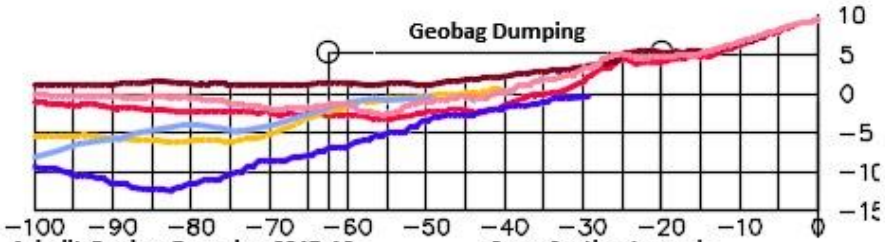


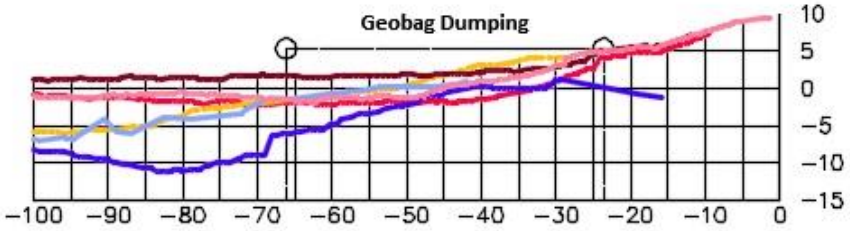
4+850.00



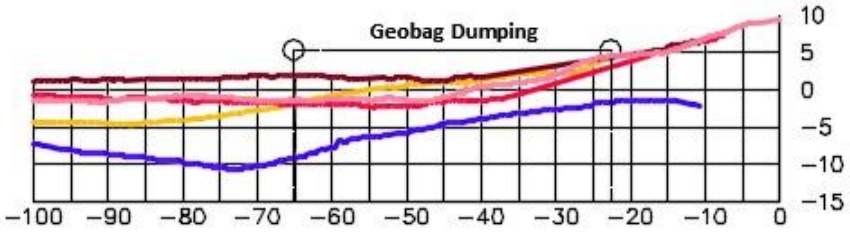
Asbuilt Geobag Dumping 2015-16:
03 May 2016

Cross Section Legend:
- Asbuilt Geobag Dumping
- Prework Adaptation
- 8-9 Aug 2017
- 7-8 Sep 2018
- 8 Oct 2018
- 29 January 2019
- 26 February

4+950.00



5+000.00



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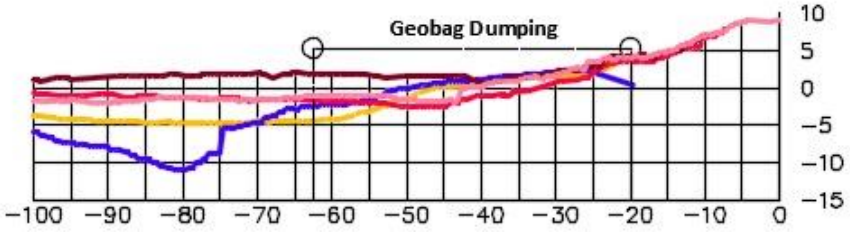
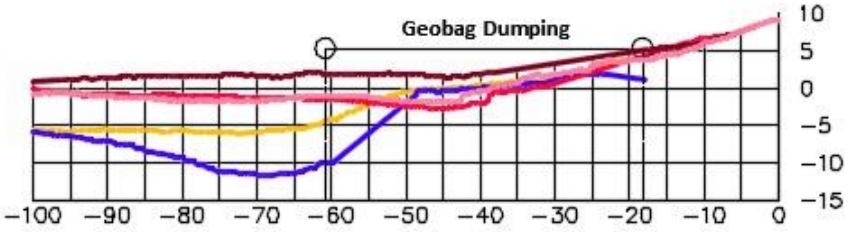
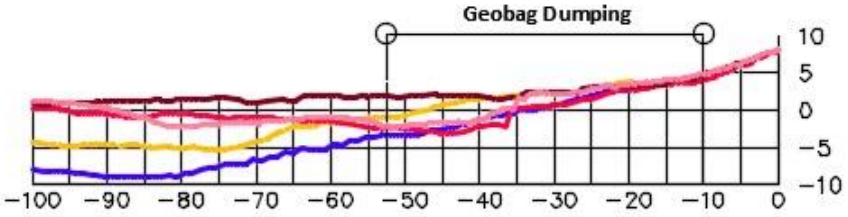


5+100.00



5+150.00

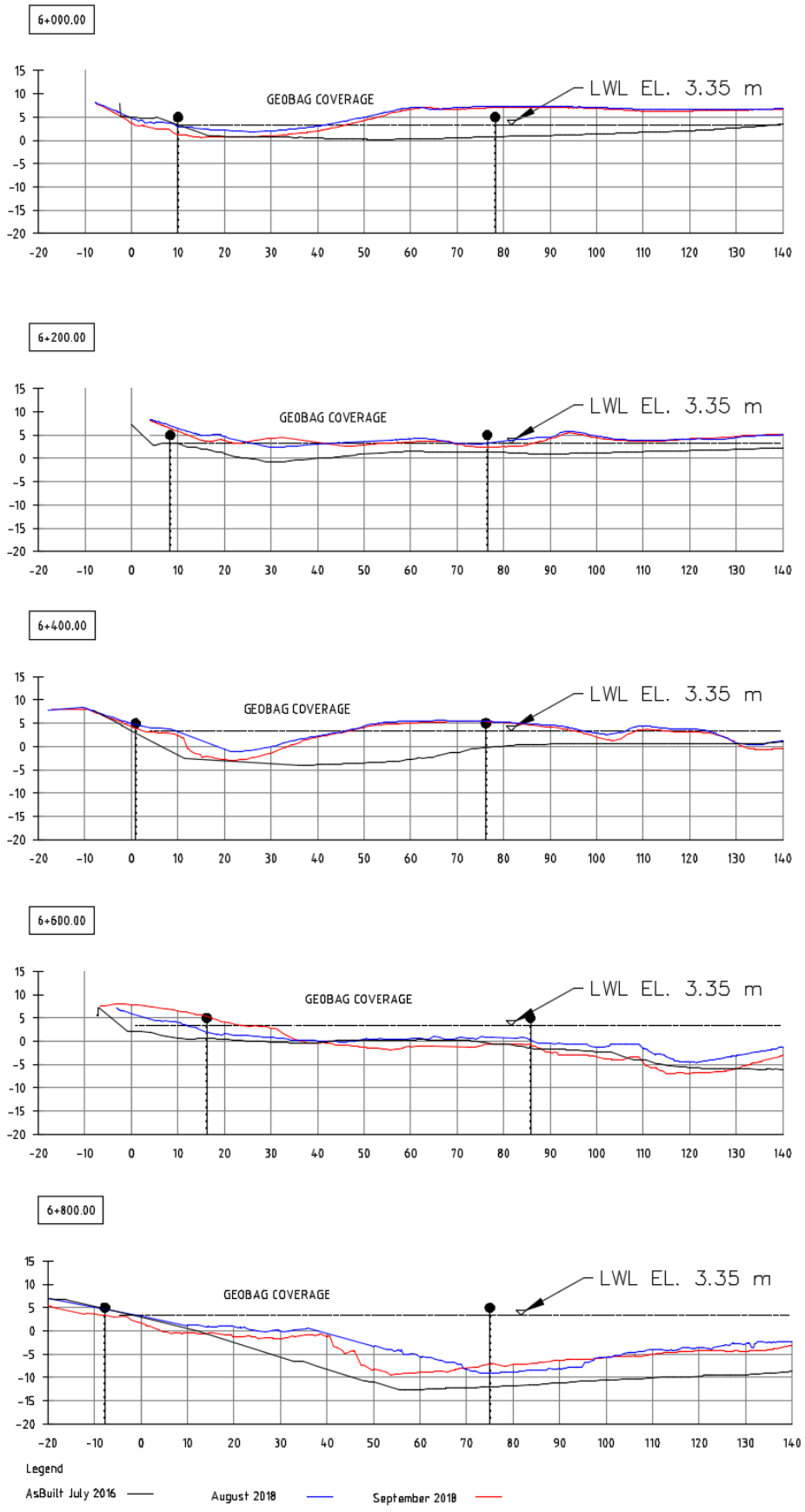


Asbuilt Geobag Dumping 2015-16:
03 May 2016

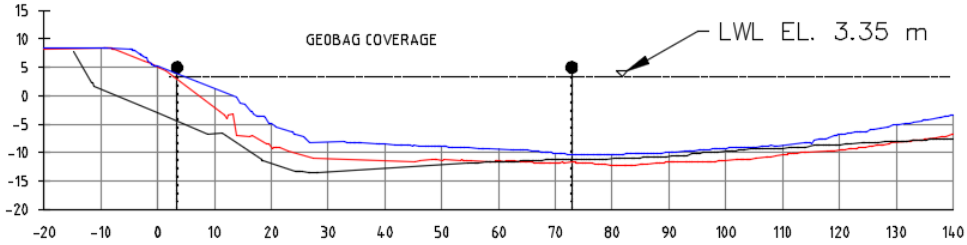
Cross Section Legend:

- Asbuilt Geobag Dumping
- Prework Adaptation
- 8-9 Aug 2017
- 7-8 Sep 2018
- 8 Oct 2018
- 29 January 2019
- 26 February 2019

8.2 Zafarganj



7+000.00



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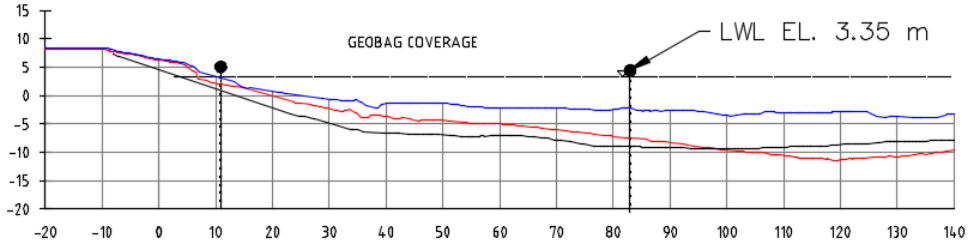

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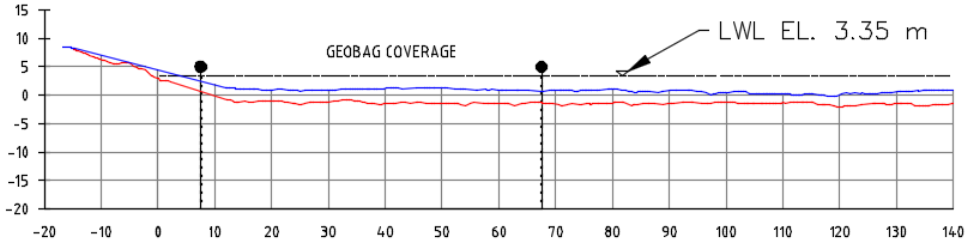

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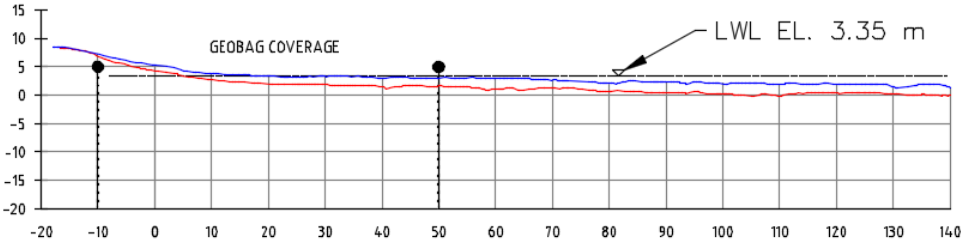
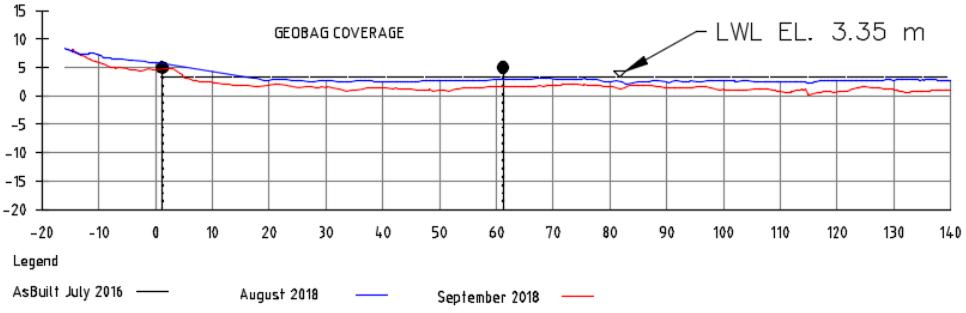
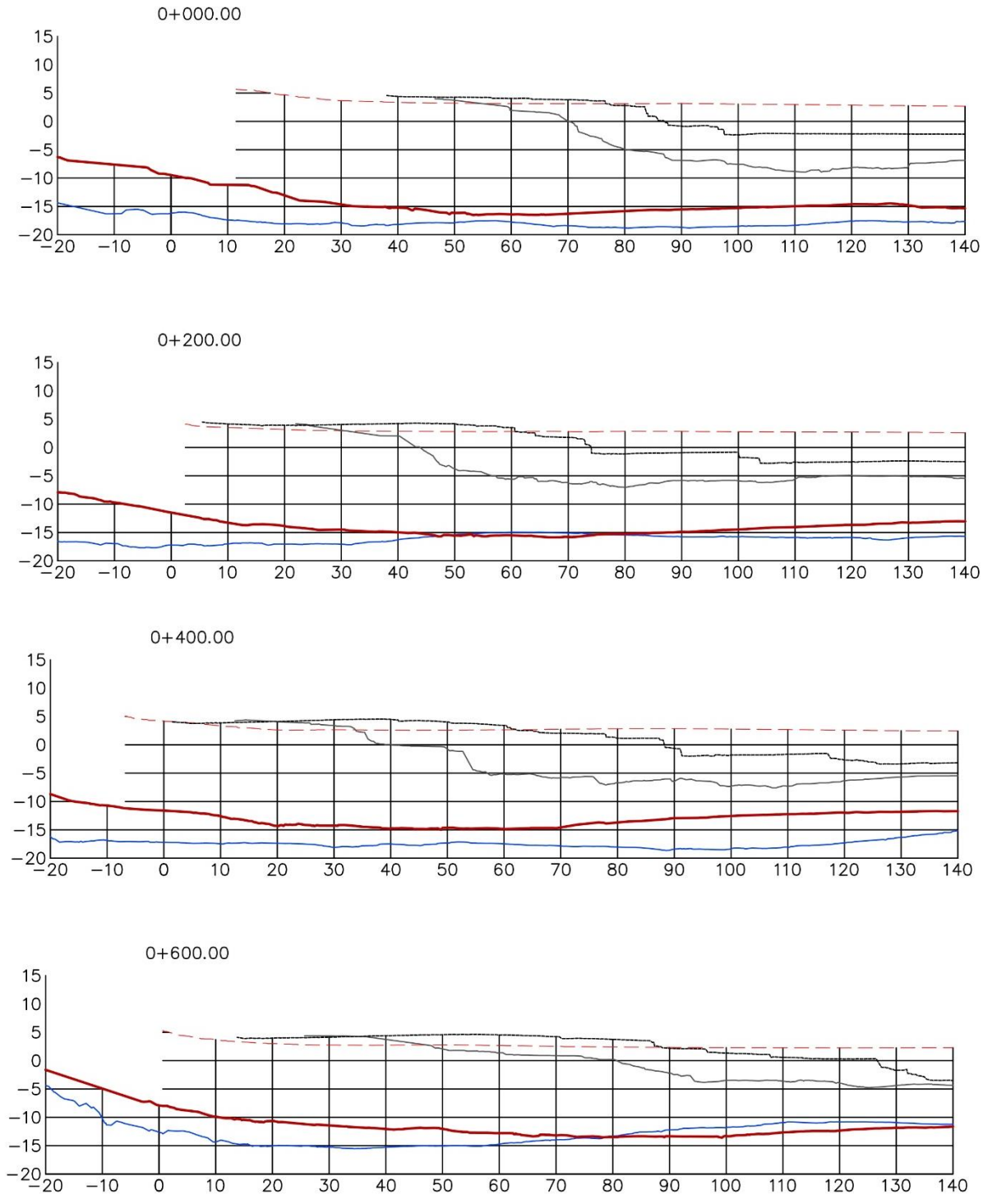
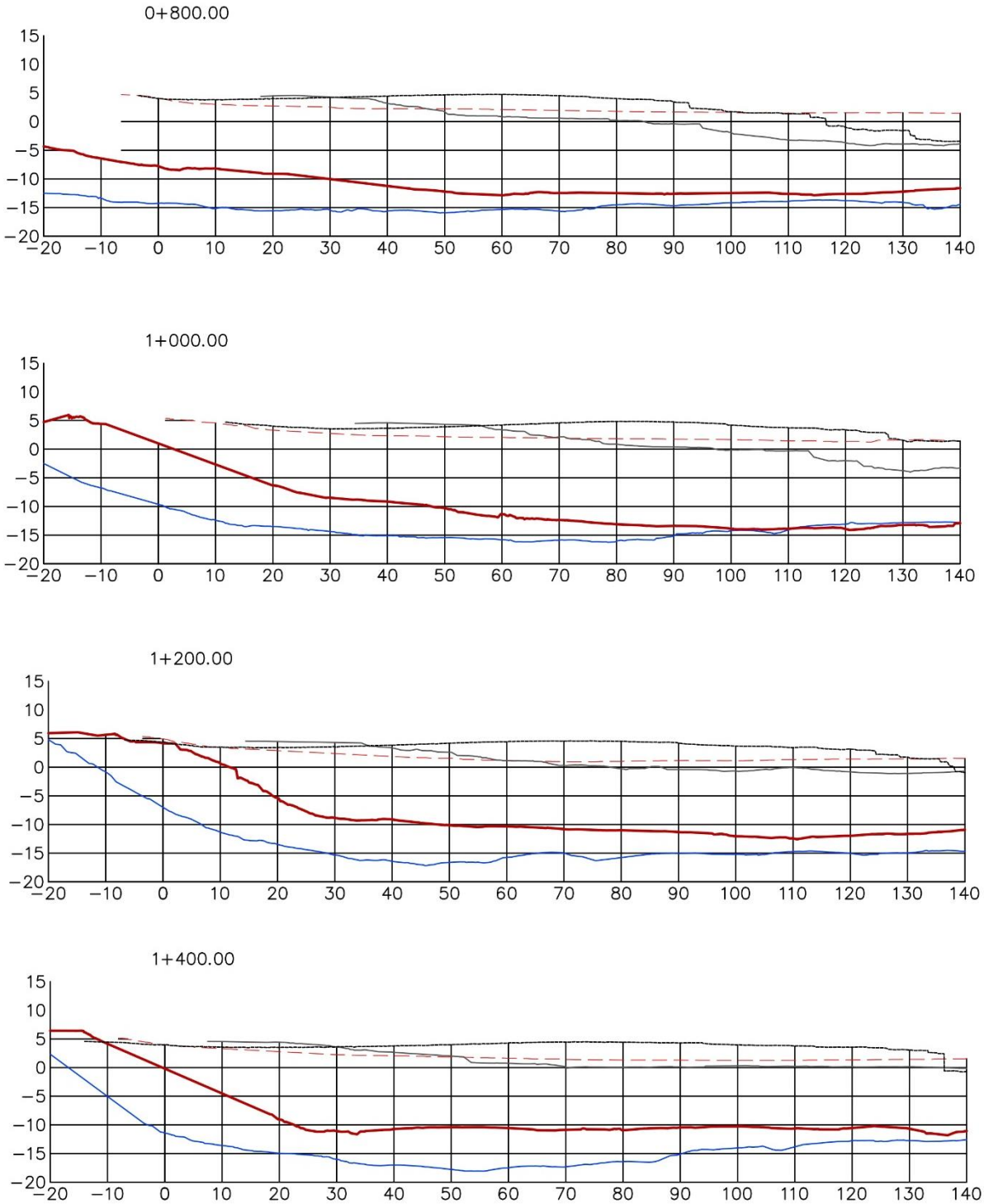


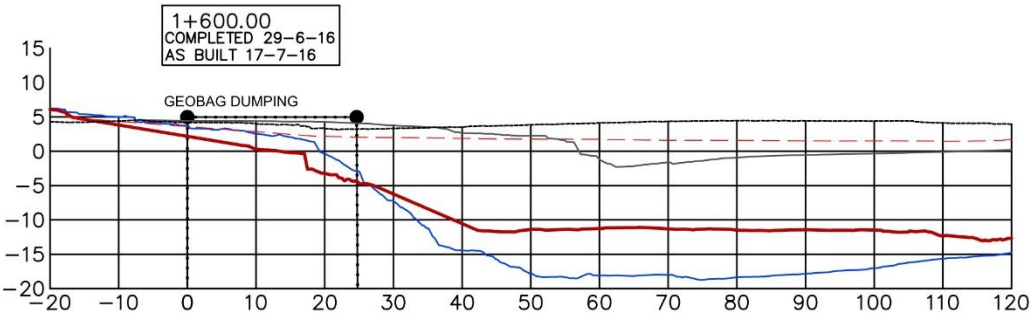
7+800.00

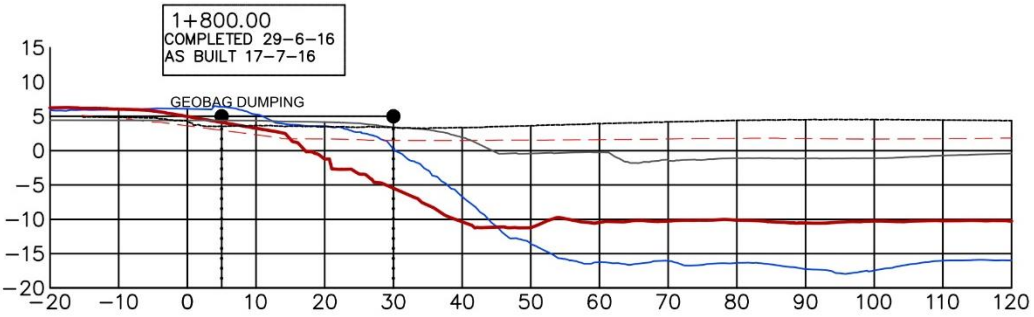


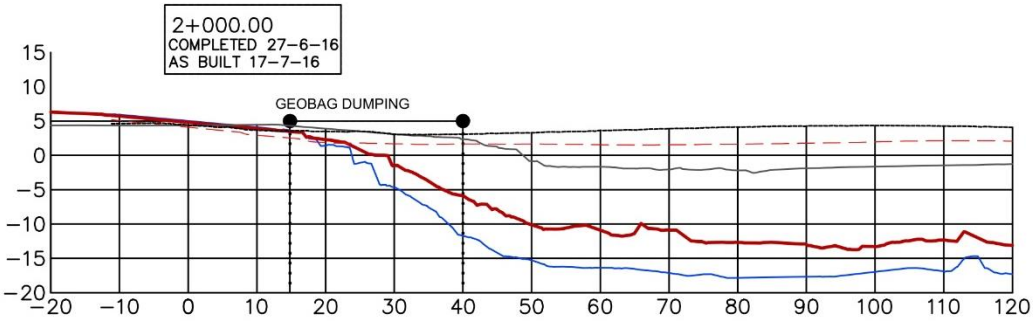
8.3 Harirampur

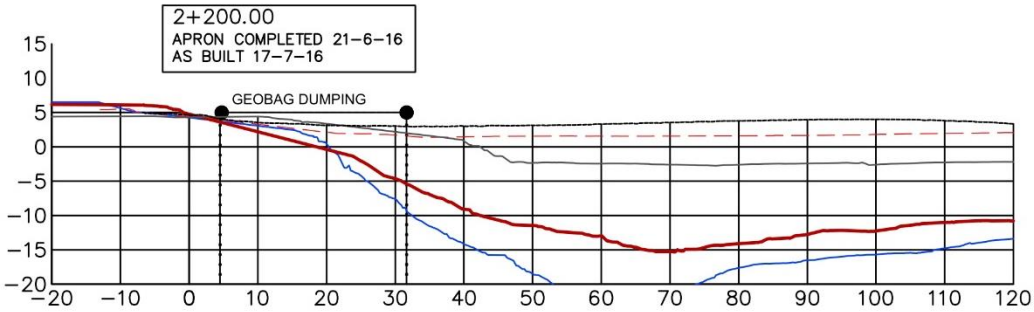


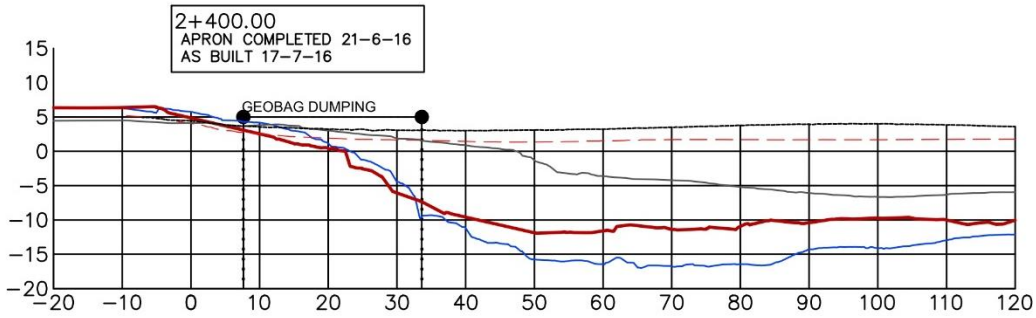

0+800.00
1+000.00
1+200.00
1+400.00
15
10
5
0
−5
−10
−15
−20
−20 −10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
LEGEND
As Built
Survey October 2016
Survey October 2017
Survey August 2018
Survey September 2018







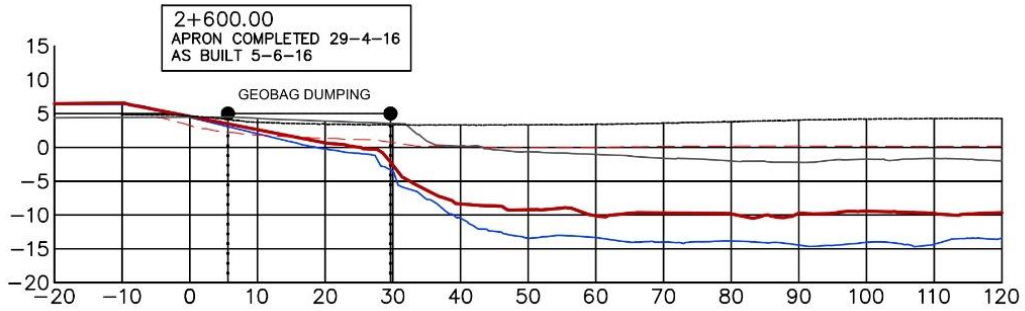


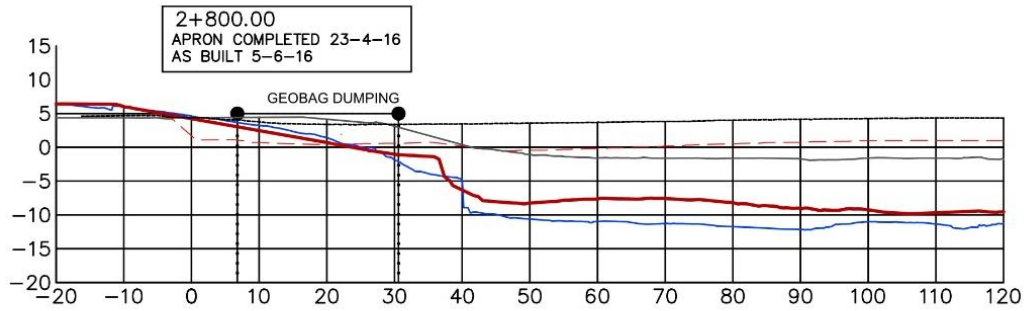


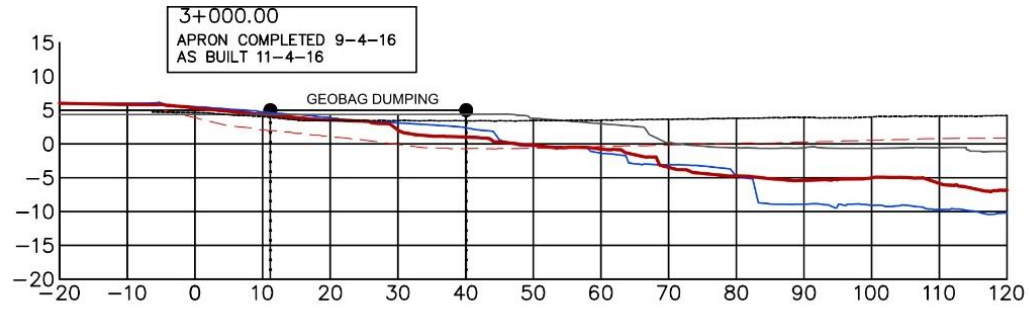
LEGEND

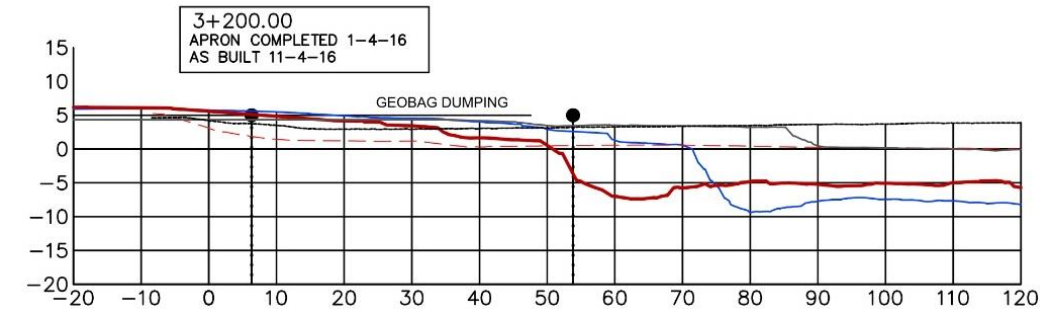
As Built — — — Survey October 2017 —— Survey September 2018 ——

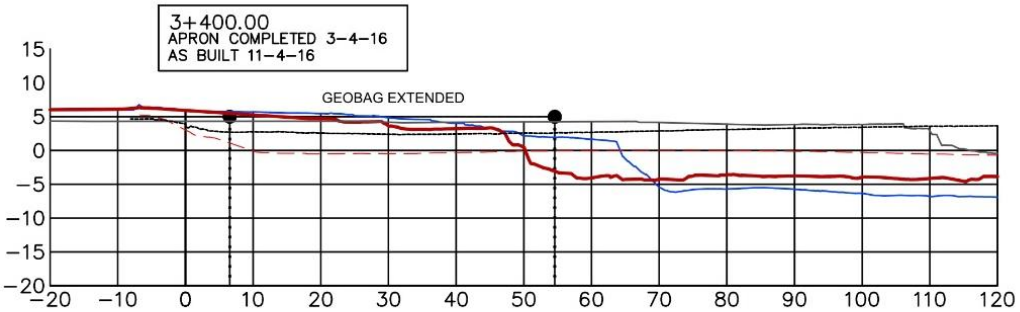
Survey October 2016 - - - - - Survey August 2018 ——







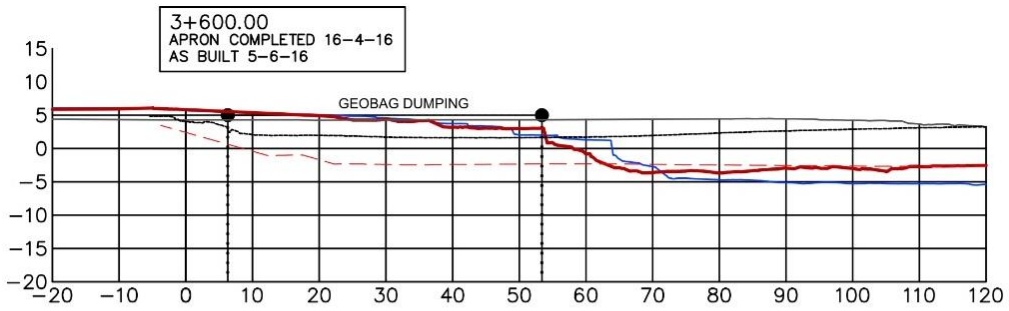


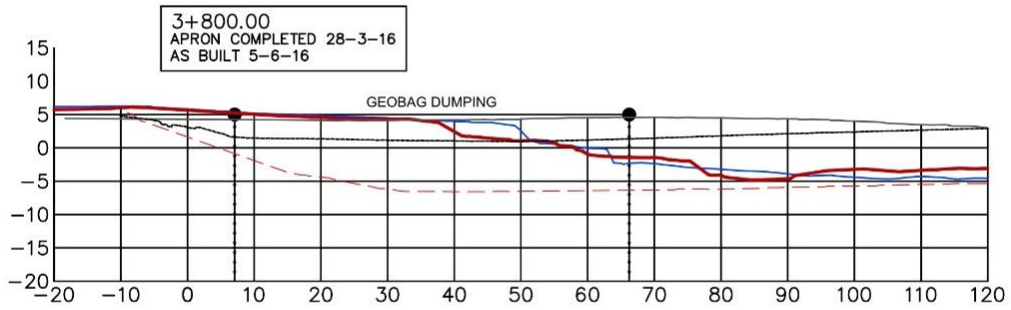


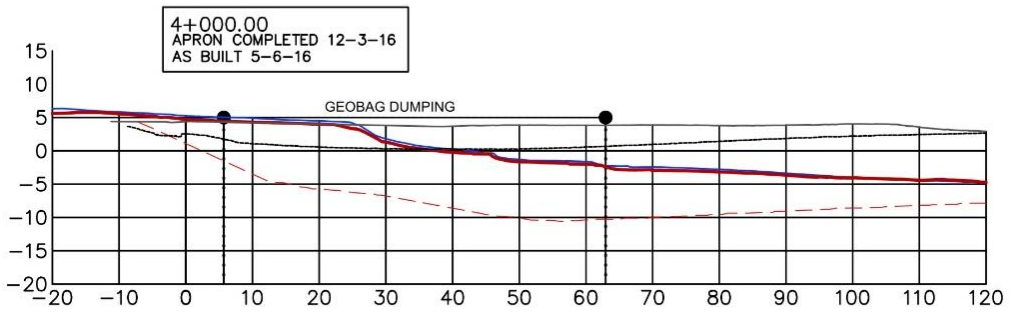
LEGEND

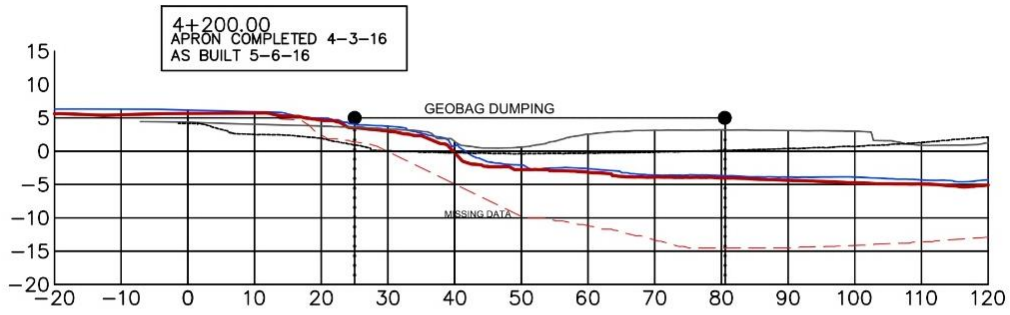
As Built — — — Survey October 2017 —— Survey September 2018 ——

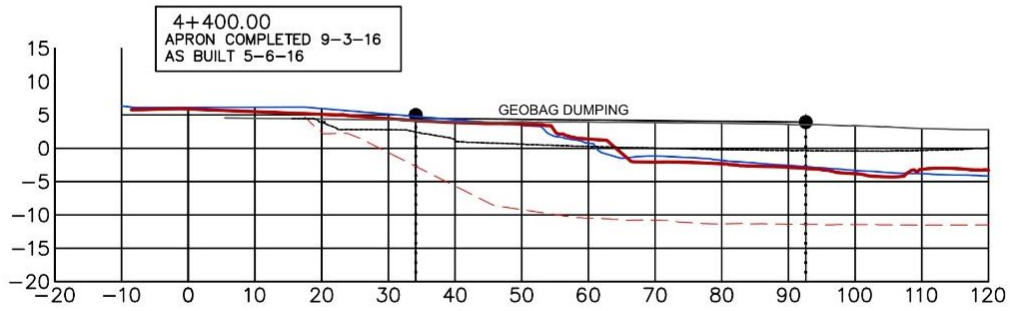
Survey October 2016 - - - - - Survey August 2018 ——







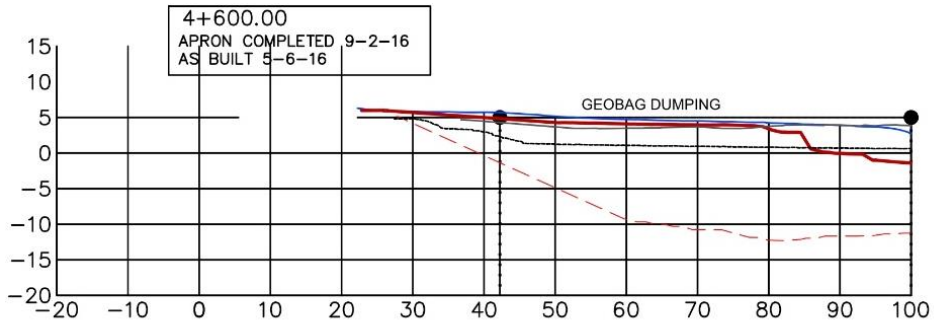


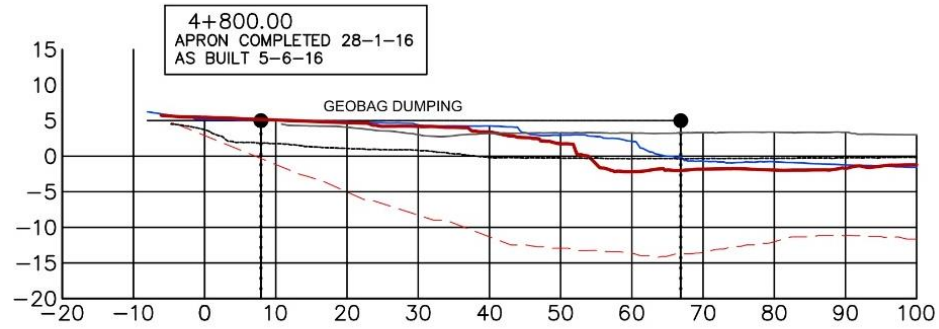


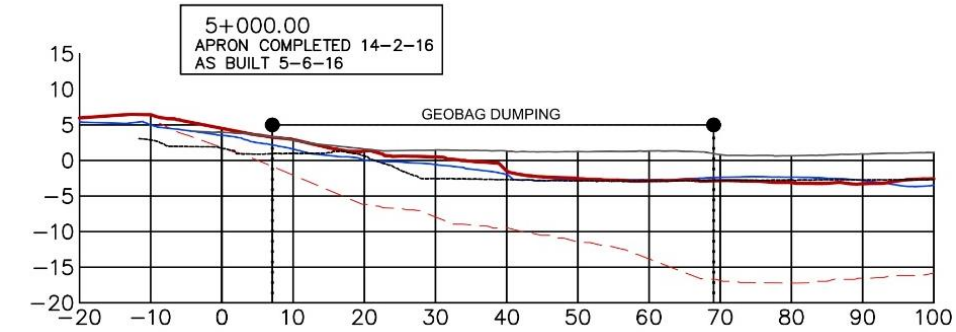
LEGEND

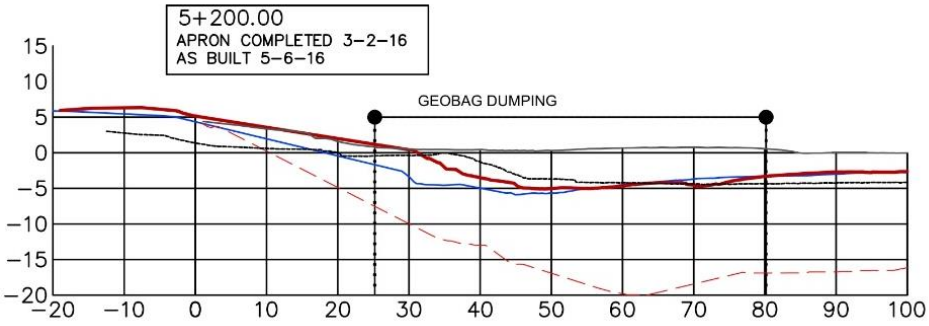
As Built — — — Survey October 2017 —— Survey September 2018 ——

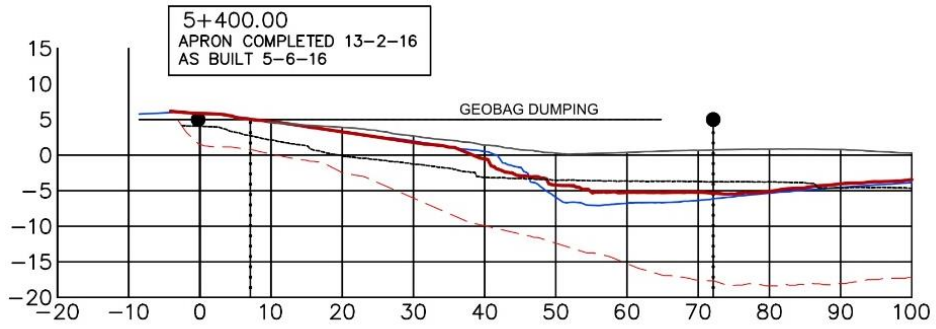
Survey October 2016 - - - - - Survey August 2018 ——







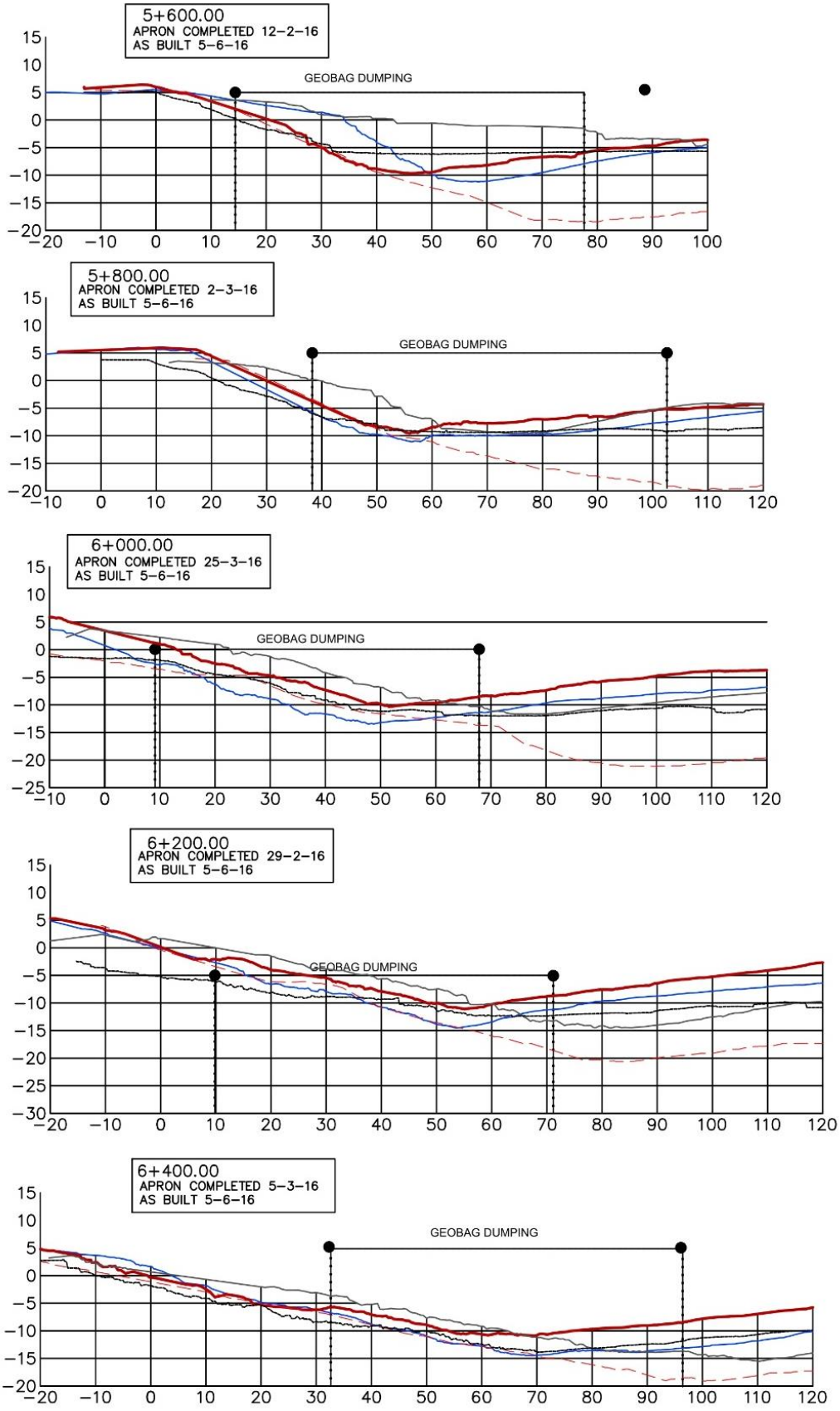




LEGEND

As Built - - - Survey October 2017 —— Survey September 2018 ——

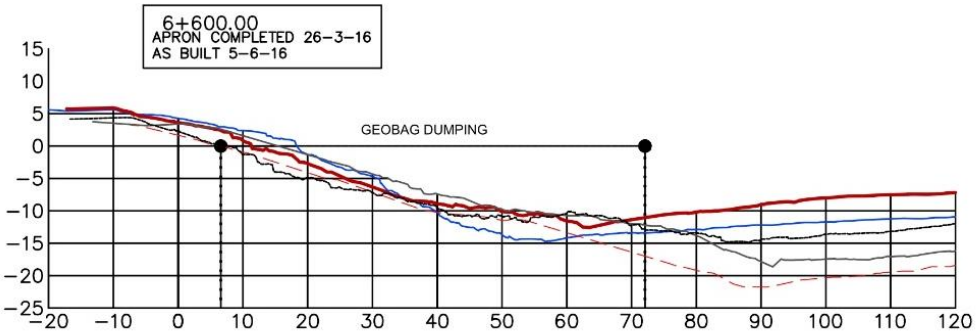
Survey October 2016 ----- Survey August 2018 ——

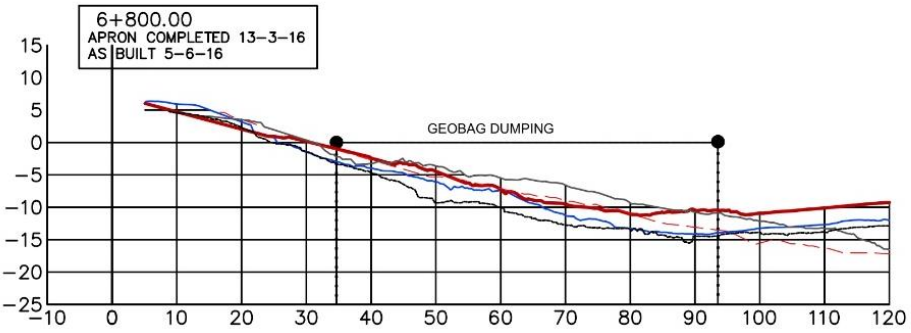


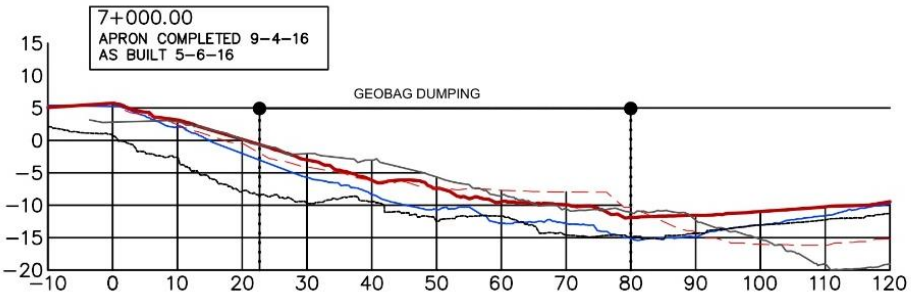
LEGEND

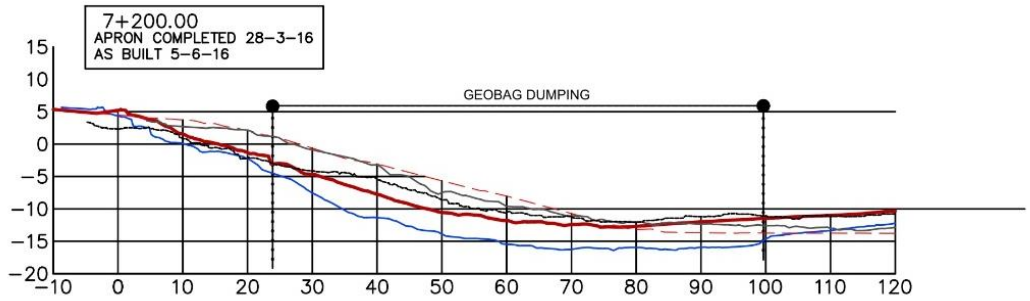
As Built — — — Survey October 2017 —— Survey September 2018 ——

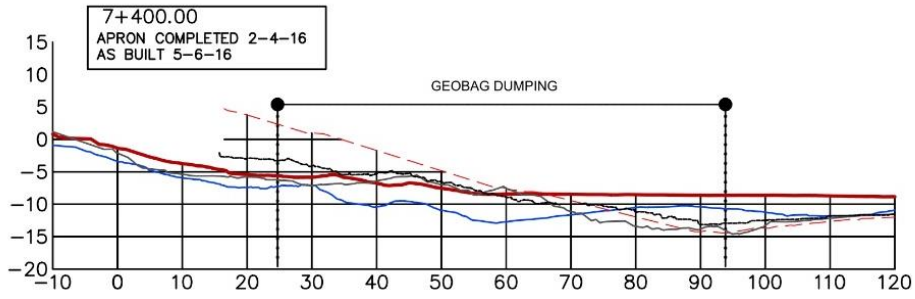
Survey October 2016 - - - - - Survey August 2018 ——







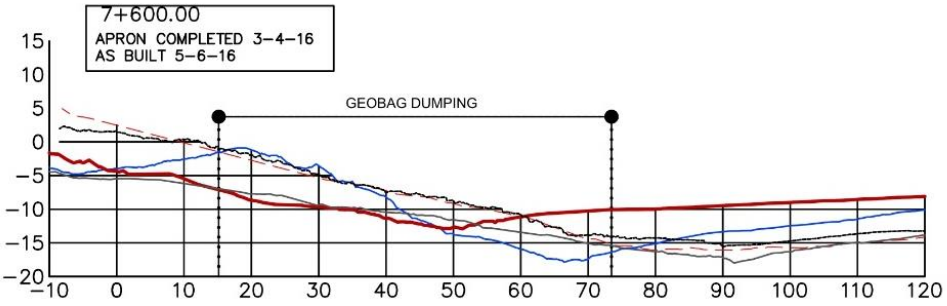


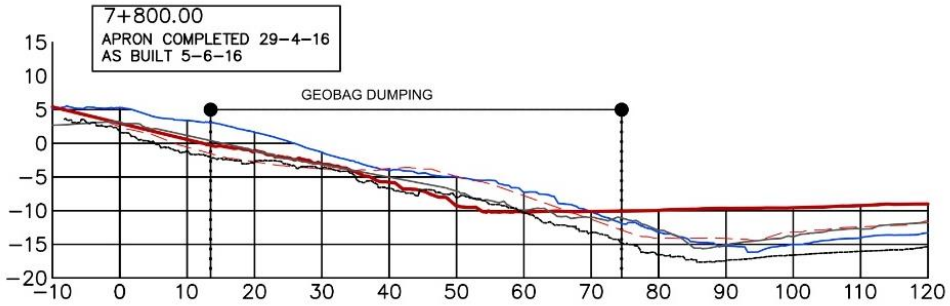


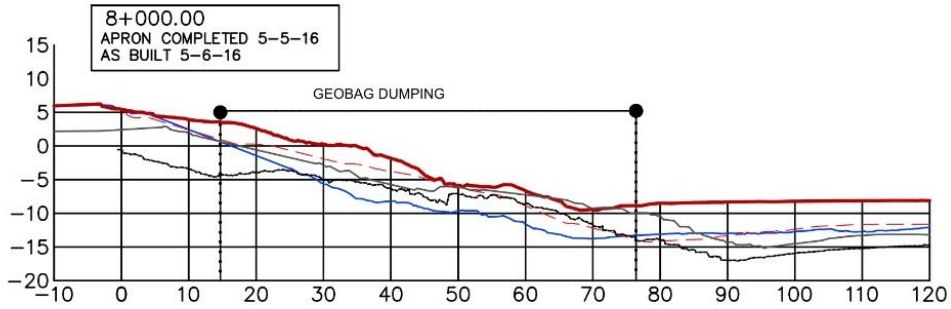
LEGEND

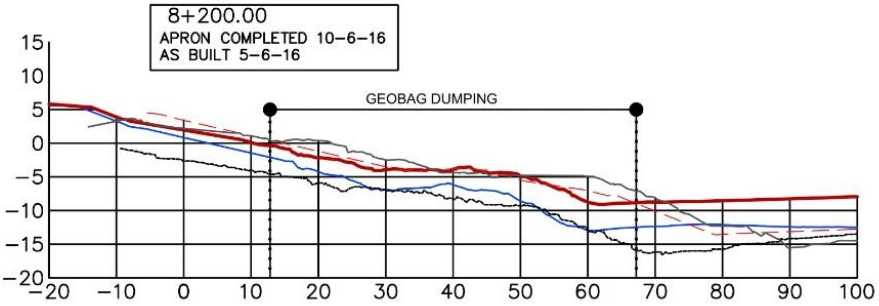
As Built — — — Survey October 2017 —— Survey September 2018 ——

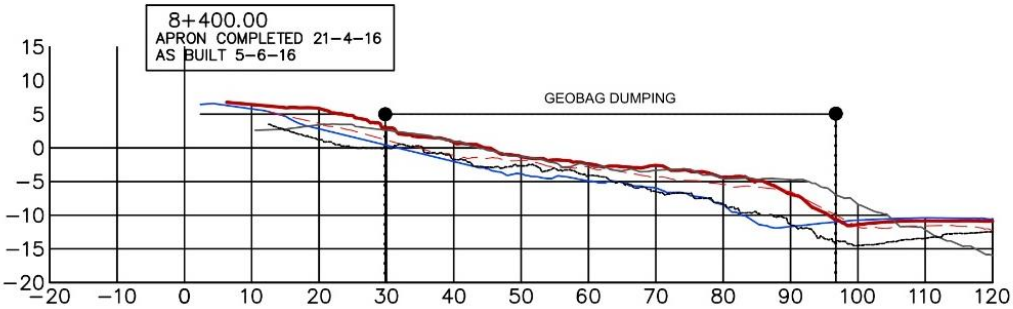
Survey October 2016 - - - - - Survey August 2018 ——







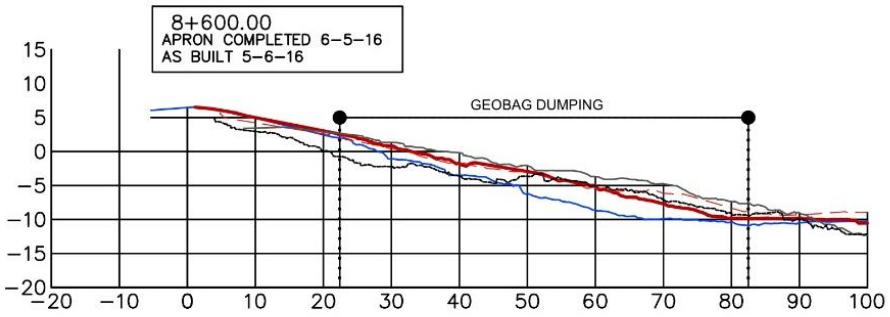


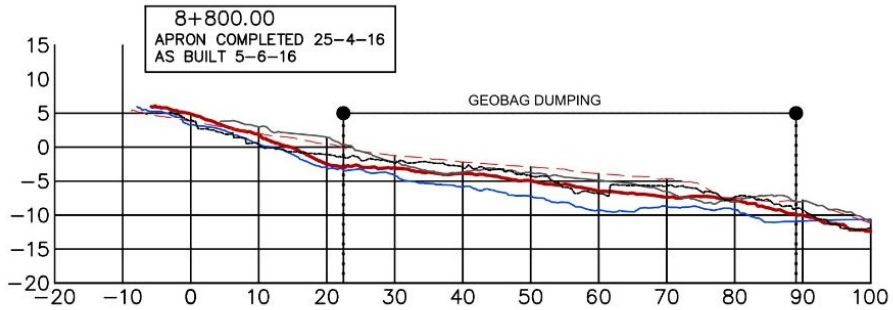


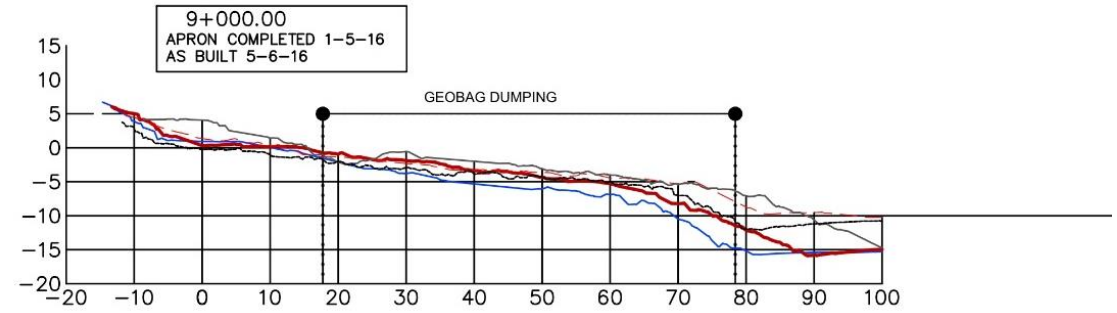
LEGEND

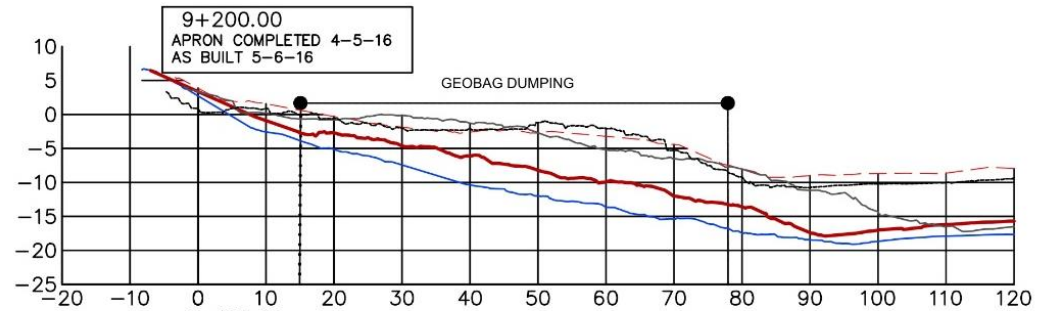
As Built — — — Survey October 2017 —— Survey September 2018 ——

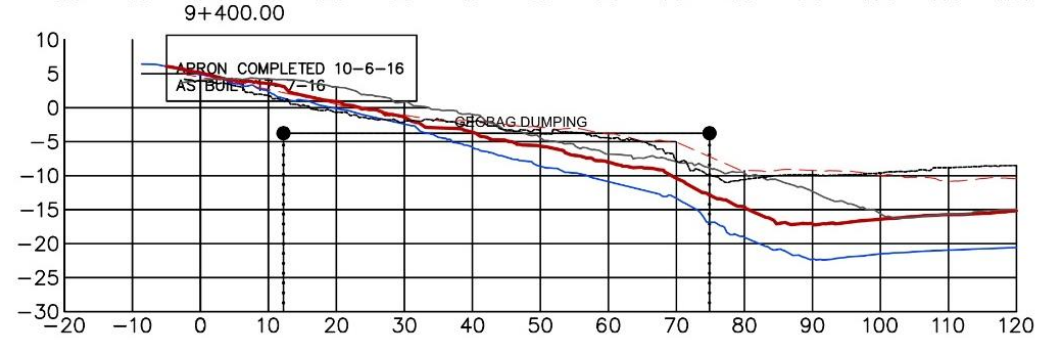
Survey October 2016 - - - - - Survey August 2018 ——







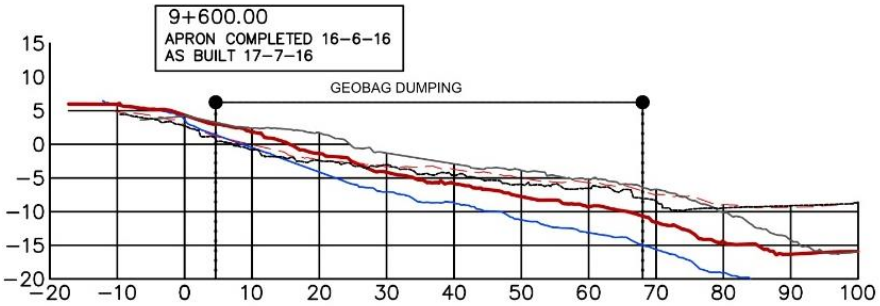


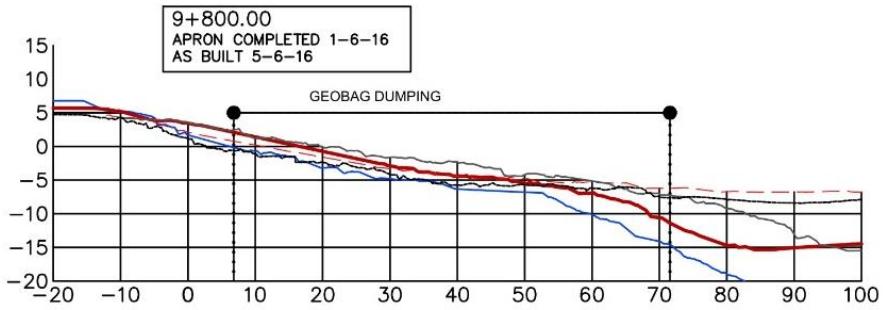


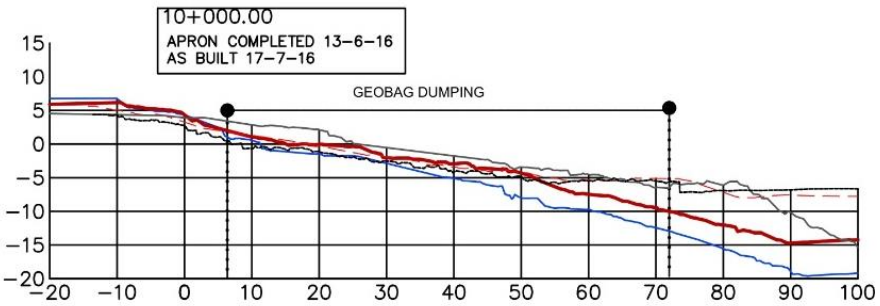
LEGEND

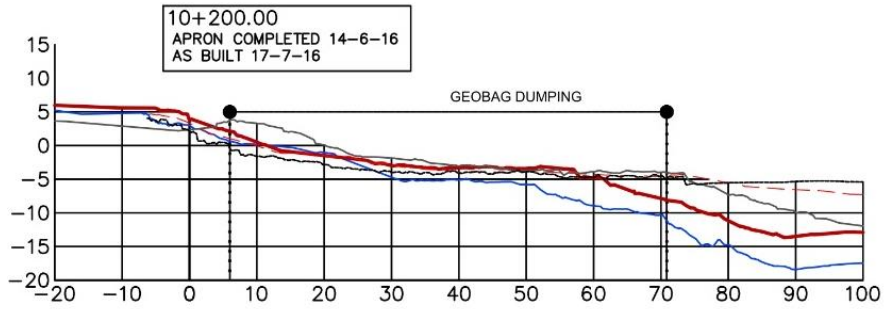
As Built — — — Survey October 2017 —— Survey September 2018 ——

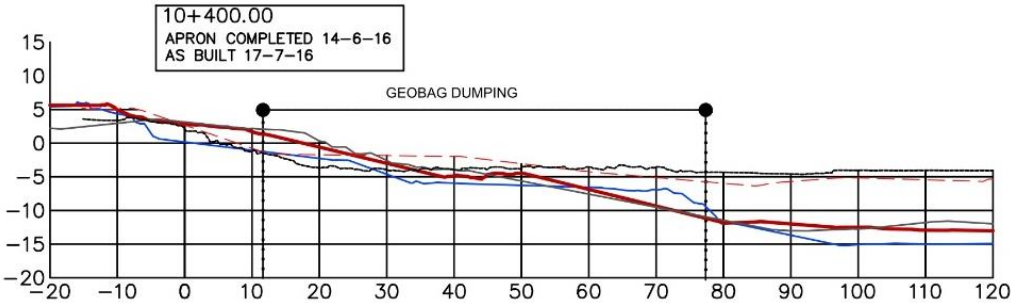
Survey October 2016 - - - - - Survey August 2018 ——









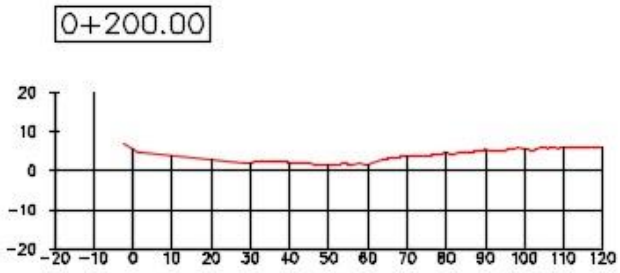


LEGEND

As Built — — — Survey October 2017 —— Survey September 2018 ——

Survey October 2016 - - - - - Survey August 2018 ——

8.4 Koijuri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0+600.00
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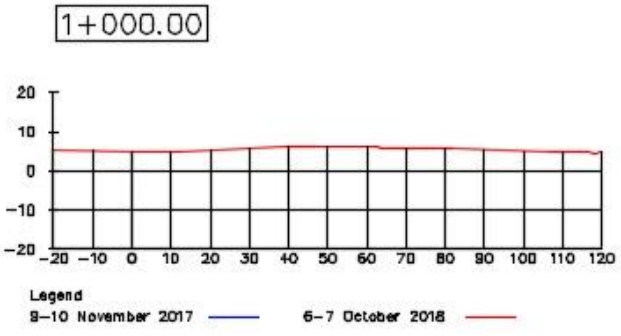
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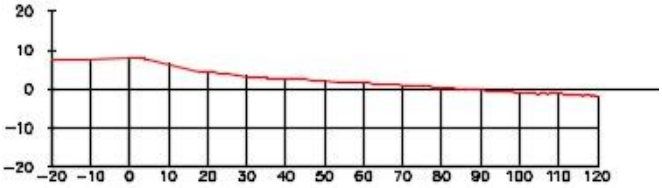
Legend
9-10 November 2017
6-7 October 2018

1+200.00

1+400.00

1+600.00



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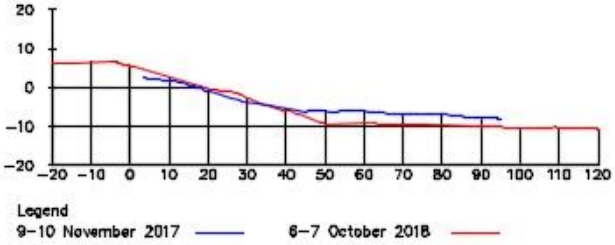

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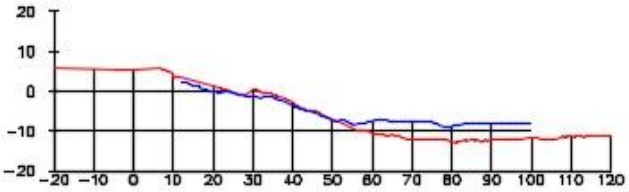

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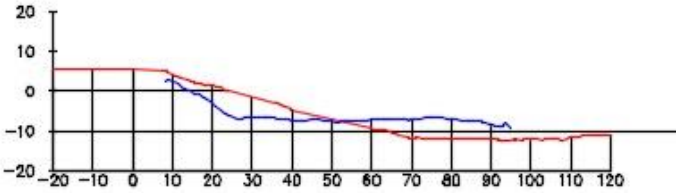

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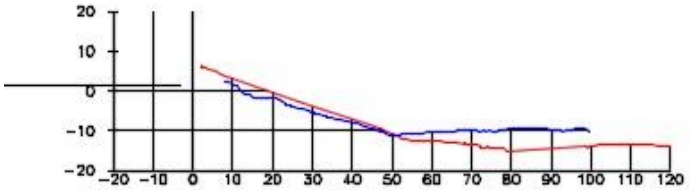

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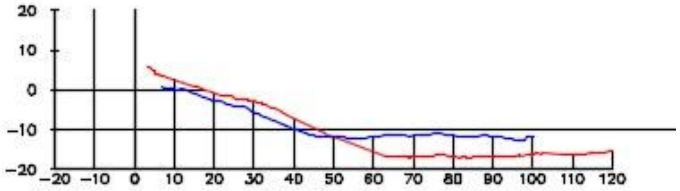

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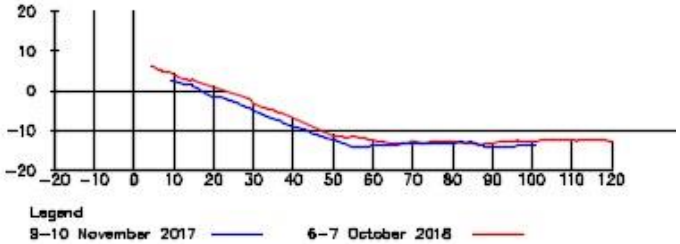

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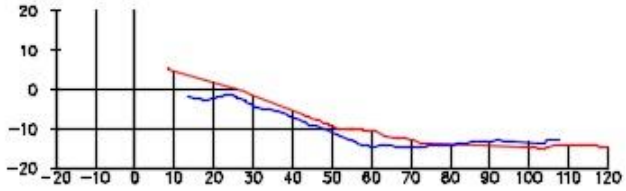

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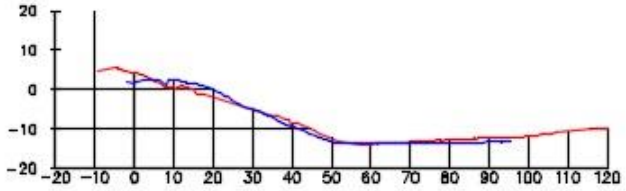

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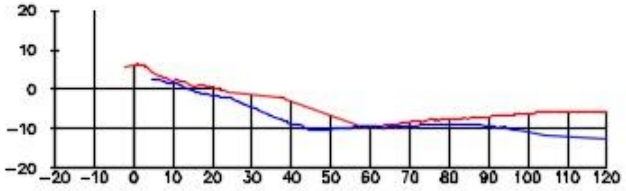

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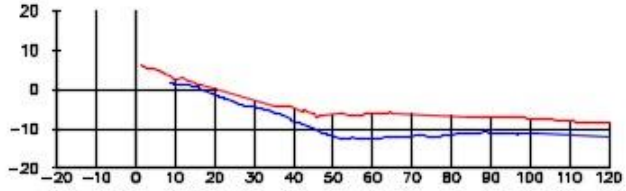

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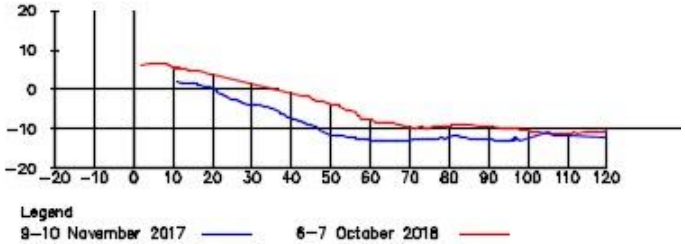

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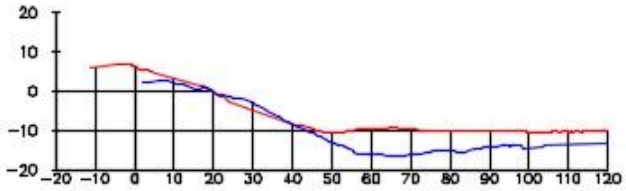

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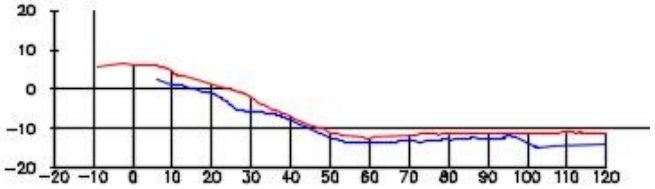

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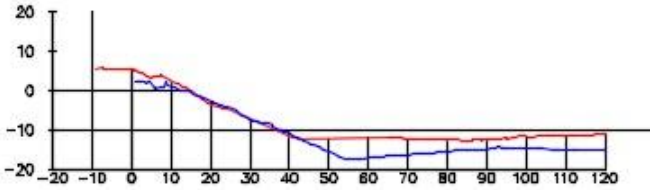

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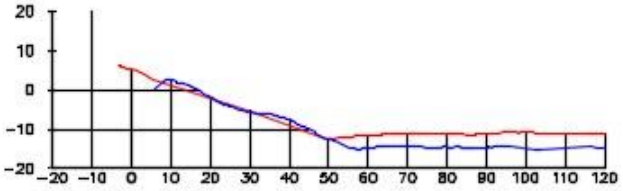

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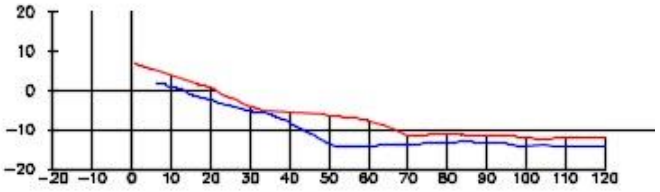
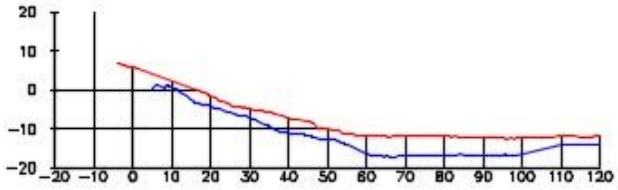


Legend
9–10 November 2017 —— 6–7 October 2018 ——

5+200.00



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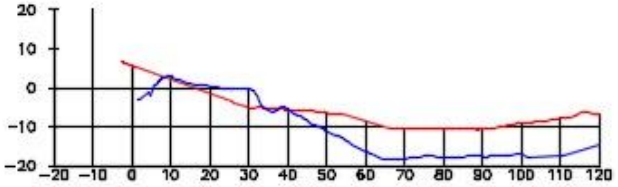

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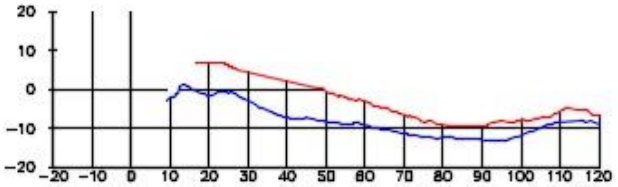

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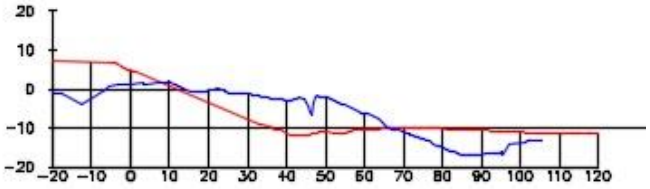

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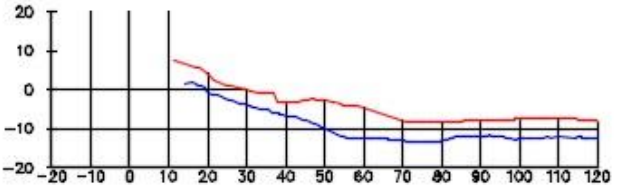

Legend
9–10 November 2017 —— 6–7 October 2018 ——

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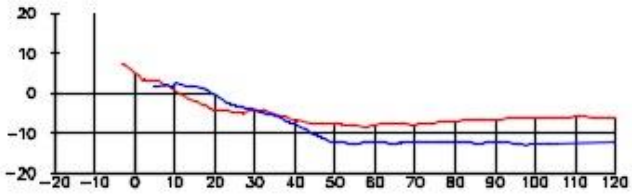

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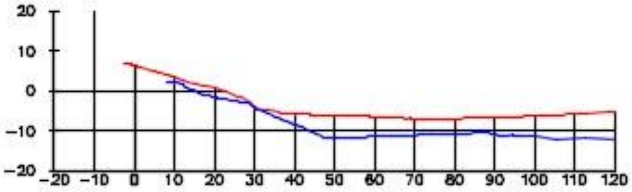

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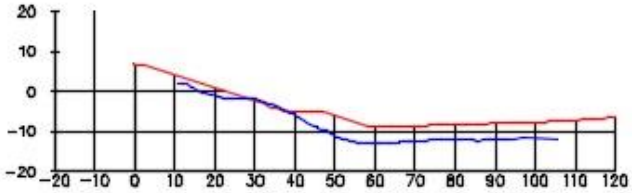

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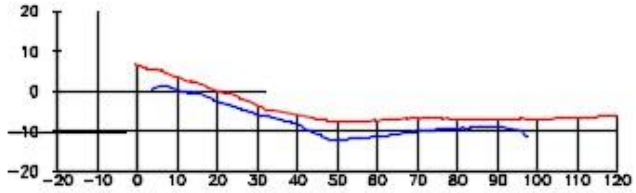

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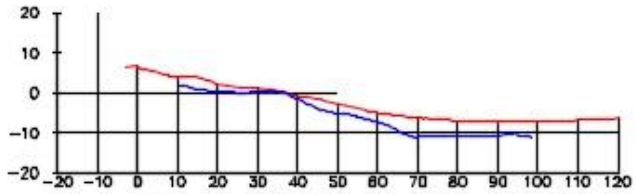

Legend
9–10 November 2017 —— 6–7 October 2018 ——

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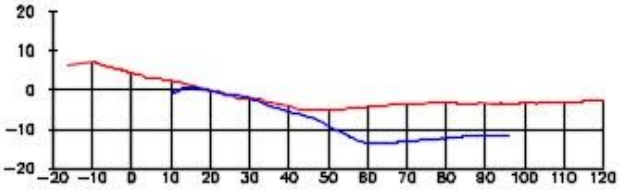

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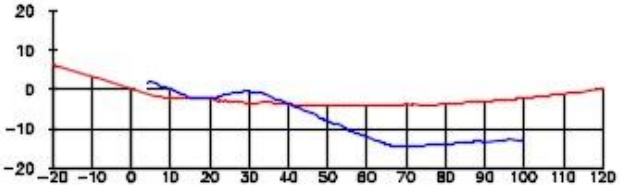

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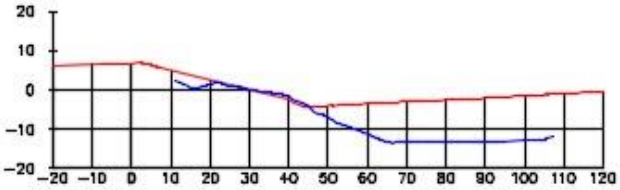

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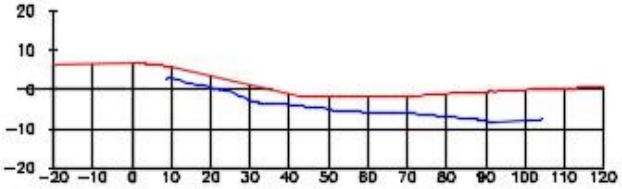

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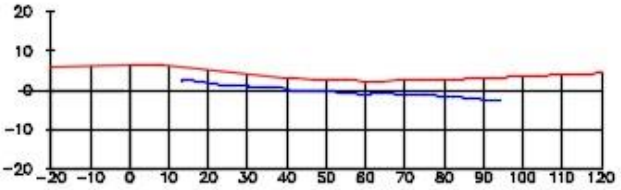

Legend
9–10 November 2017 —— 6–7 October 2018 ——

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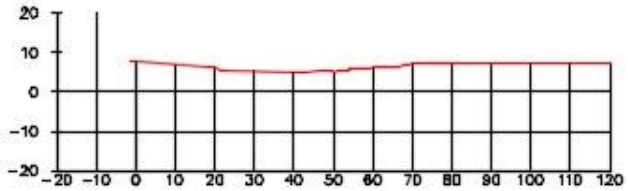
8+400.00

8+600.00



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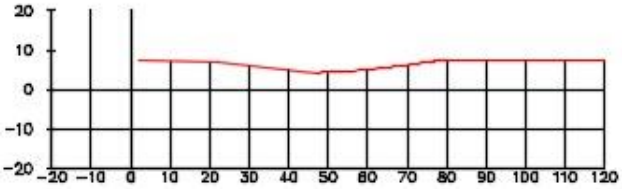

11+400.00

Legend
9–10 November 2017 ——— 6–7 October 2018 ———

11+600.00


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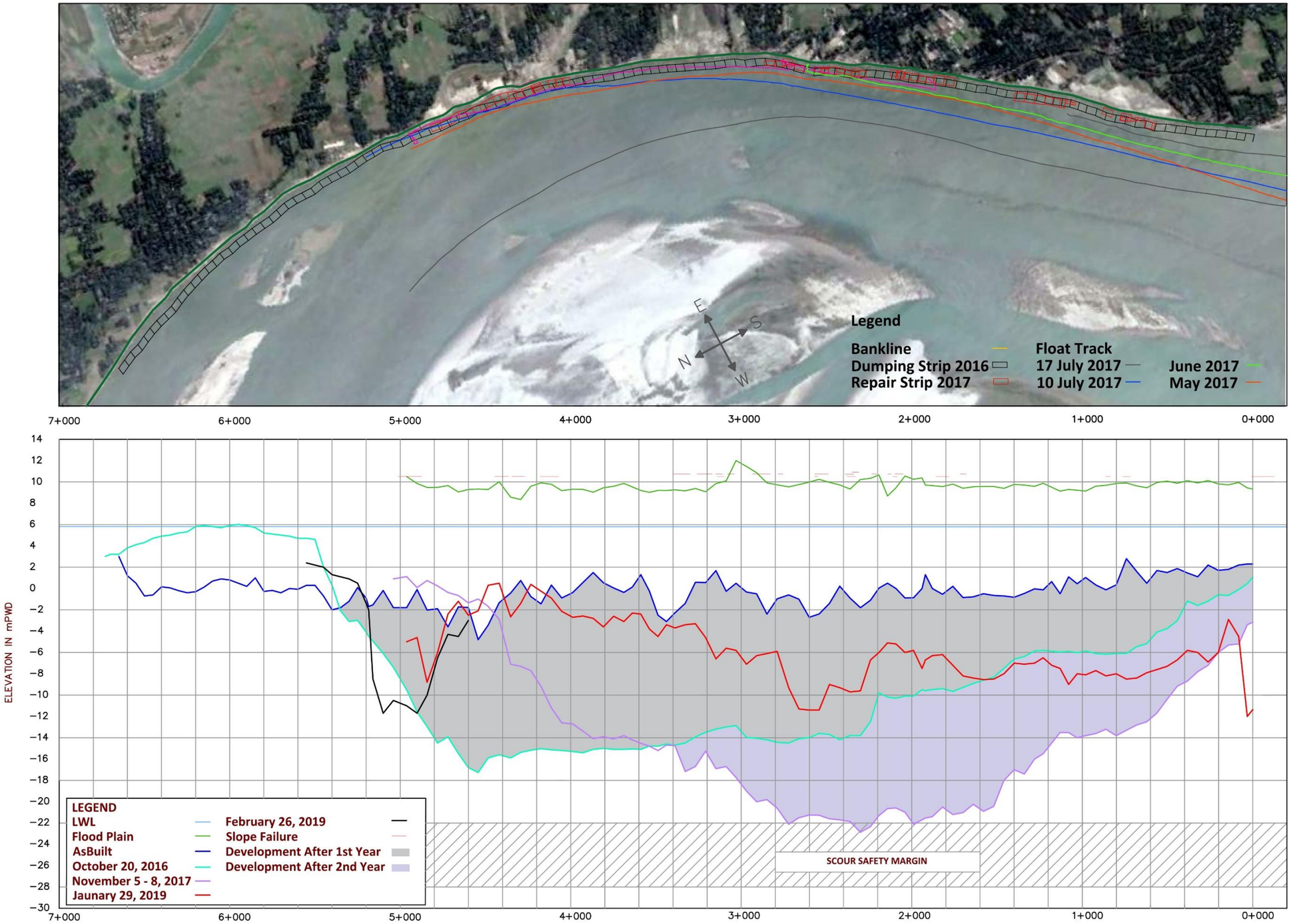
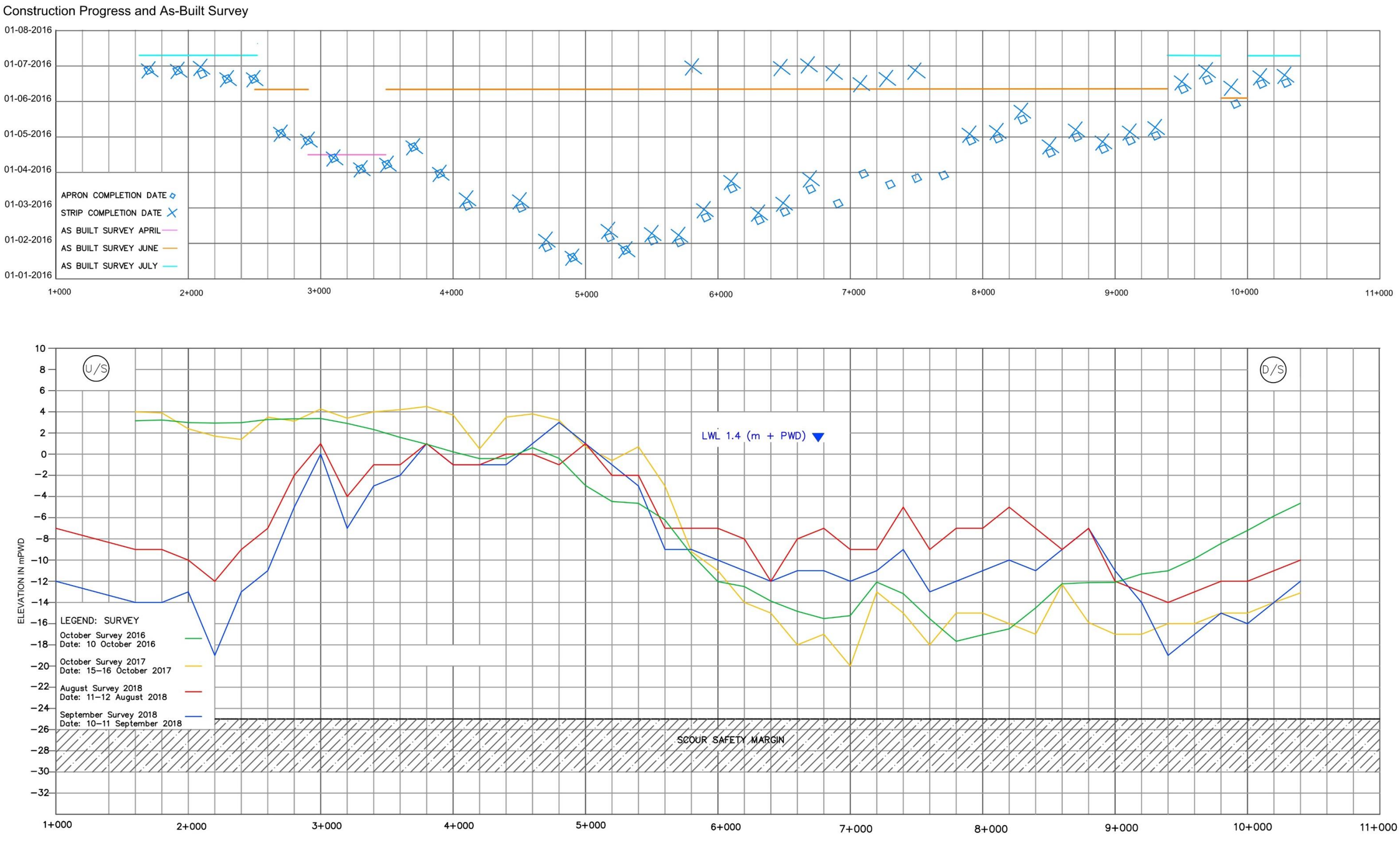
Legend
9−10 November 2017
6−7 October 2018

9 Longitudinal Section – Launching of Apron

9.1 Longitudinal Section of Chauhali



9.2 Longitudinal Section of Harirampur



9.3 Longitudinal Section of PIRDP