Northwest Hydraulic Consultants
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Memo

To: Project Director FRERMIP

From: Saleh Adib Turash, Jesper Mathiesen

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

Date: 30 June 2020

Re: Flood monitoring report 2019-20

1 Introduction

Since 2015, FRERMIP has successfully implemented about 18 km of riverbank protection works, planned for Tranche-1 at Chauhali, Zafarganj, and Harirampur. To guide the implementation and to ensure the sustainability of the works, regular surveys have been conducted to monitor the state of the works, identify potential damages, and allow planning of necessary repair and adaptation works. Till date, a total of six monitoring reports have been prepared:

(i) No 1-3 the site monitoring reports from July, August and September 2016 were prepared during implementation to document the as-build condition
(ii) No 4 the flood monitoring report 2016 documented the river response to the implemented works and the performance of the works during the first flood season after completion and provided an overview of the overall river morphology
(iii) No 5 the flood monitoring report 2017, along with the regular site and river monitoring, provided multibeam echosounder surveys for Chauhali and Kaijuri, leading to the development of adaptation works plan for Chauhali
(iv) No 6 the flood monitoring report 2018, along with the regular site and river monitoring, provided additional surveys of existing works at Kaijuri and PIRDP and potential Tranche 2 sites at upstream Chauhali and Enayetpur.

This is the seventh monitoring report, concluding the river monitoring during Tranche 1 and is expected to be continued through similar survey and reporting schedules in Tranche 2.

Scope of the flood season monitoring 2019 schedule, during the fourth flood after construction, was defined to:

(i) Monitor the developments at the Tranche-1 riverbank protection sites with respect to flow velocity and scour developments (float track and bathymetry surveys), and identify potential needs for adaptation works.
(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 Tranche-2. The key focus is on (i) the larger scale flow distribution between the eastern and western channels (right and left channel), which determines the level of attack on existing and planned works, and (ii) local river changes that determine (future) flow pattern at a specific site.

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

All surveys during the 2019 flood season from July to mid-November were conducted by IWM.

2 Summary of the development of river morphology during FRERMIP Tranche 1

This report marks the analysis of the final flood season survey conducted under FRERMIP Tranche 1. The river has been systematically surveyed over the past four flood seasons, during which parts of the overall river morphology have changed significantly and the protection works provided at Tranche 1 sites has adapted to the river response.

2.1 Full river

The full river surveys, covering the Lower Jamuna, Lower Ganges and Upper Padma rivers, were repeated annually providing detailed information regarding bathymetry, discharges and flow velocity. Key findings of these full river surveys over the course of the project are:

(v) Jamuna upstream of the bifurcation
- The left bank has come under attack, following the pilot capital dredging project, causing severe erosion near the Dhaleswari offtake
- The right bank at Enayetpur char shows erosion, with an overall tendency of river wideing in this part
- The left bank upstream Chauhali (downstream of Dhaleswari offtake) is eroding, widening the overall river
- The overall location of the bifurcation has remained stable

(vi) Jamuna left (eastern) channel
- The discharge into the Jamuna left channel has decreased over the years from 72% to 54%
- After construction of the protection works at Chauhali, a deep bank channel formed, which since is partially silted up while a straight channel is forming at Salura, eroding parts of the central char and impacting the Solimabad char
- The Solimabad channel had opened up but is partially filling in, however migration of the Chauhali scour into this channel is a possibility
- Downstream of the Solimabad channel is a confluence scour at the confluence between main Jamuna and Solimabad channel
- The area upstream of Zafarganj has been silted up, with only the protrusion being exposed to a minor channel of the Jamuna

(vii) Jamuna right (western) channel
- The right channel is eroding the area around the Enayetpur spur, which is not protecting the riverbank sufficiently
- The channel is largely following the bank protections build at Kaijuri and Nagarbari
- Downstream of the Hurashagar confluence, parts of the flood season flow flows over the char in several channels

(viii) Interconnection
- At Omarpur (between Kaijuri and Solimabad) a channel has opened up, which is now also open during the dry season

(ix) Jamuna-Ganges confluence
- There are confluence scours a the confluence of Jamuna right and left channel and at the confluence of the Jamuna and Ganges, these are sometimes connected
- The char protruding from the west into the confluence seems stable, this is likely to become more stable as the Ganges appears to shift to a right (southern) bank channel

(x) Lower Ganges
- The observed part of the Ganges has overall deepened significantly
- The thalweg appears to be shifting to the southern bank

(xi) Upper Padma
- The overall left (northern) bankline remained stable following the protection at Harirampur
- There is minor erosion upstream of Harirampur

- The thalweg appears to be shifting to the southern bank
- Erosion is occurring at the southern bank

2.2 Work sites and other existing works

Under FRERMIP Tranche 1, riverbank protection has been implemented at three sites, namely (i) Chauhali, (ii) Zafarganj and (iii) Harirampur. Performance of the works is:

(i) Chauhali
   a. The overall performance of the works is satisfactory as it achieved arresting ongoing erosion with no significant bankline shift since implementation, which followed a bankline shift of about 2km within two years
   b. The underwater works launched significantly during the first two seasons after implementation, resulting in a scour depth of up to 27m below low water level, with up to 17m scouring in the first year
   c. Adaptation works provided following the second flood season, achieved provision of a step in the launched apron and addressed some minor damages in the works
   d. Some minor erosion occurred at the upstream end of the works, which is planned to be addressed in Tranche 2
   e. Near the downstream end of the works, a clay formation was uncovered during the launching process, causing a local protrusion scour
   f. Most of the emerged scour has been filled in with sediment again

(ii) Zafarganj
   a. The main river channels were not near Zafarganj since implementation, consequently, the river has not deepened along the works
   b. The upstream half of the works is sedimented up with a char being close to the bankline
   c. The downstream half of the works silted up, but was under attack from the river in 2019, eroding most of the deposited sediment.

(iii) Harirampur
   a. The works at Harirampur successfully prevented erosion of the Harirampur char
   b. The launching apron launched to near design scour level over most of the work length, but has since been partially filled in
   c. Some erosion is occurring upstream of the work, which is planned to be addressed in Tranche 2

In addition ot the sites implemented in Tranche 1, other sites with existing works or potential future work sites have been surveyed.

(xii) Koijuri and Benotia
   - The works at Koijuri, implemented under JMREMP during 2010 show overall satisfactory performance
   - The apron has launched over most of the length of the works
   - Adaptation works is required
   - Some parts (upstream) are covered by a char
   - Downstream of the existing works, at Benotia, erosion occurred during 2019, surveys showing a emerging scour, which is planned to be addressed during Tranche 2

(xiii) PIRDP
   - Surveys show a launched apron with little damages. The works require adaptation

(xiv) Naharbari
   - Surveys show a launched apron with little damages. The works require adaptation

(xv) Sirajganj
   - Surveys show that most of the works are covered by sediment as the main river course has moved away from the site

(xvi) Enayetpur
   - Surveys show some erosion, requiring implementation of riverbank protection works

(xvii) Upstream Chauhali

- Surveys show some erosion, requiring implementation of riverbank protection works

2.3 Summary

The monitoring program of FRERMIP Tranche 1 has demonstrated that the implemented works largely performed satisfactory, while highlighting the need for adaptation works. The full river surveys proved useful for the determination of trends in changes in river morphology and identification of required future work sites.

3 General River Monitoring

3.1 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 Tranche 1 in the Lower Jamuna and Upper Padma, for earlier works built under JMREMP and other projects as well as for the planning of future works and to further understanding of launching behavior at different sites. 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 branch 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) modeling supporting future morphological prediction also with respect to proposed Tranche 2 work locations.

3.2 Monitoring Plan

The general river survey (Figure 3-1 and Figure 3-2) focused on ADCP, float tracks and bathymetric survey using single-beam echo sounders, 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. For details regarding the survey methodology, refer to section 4.3.

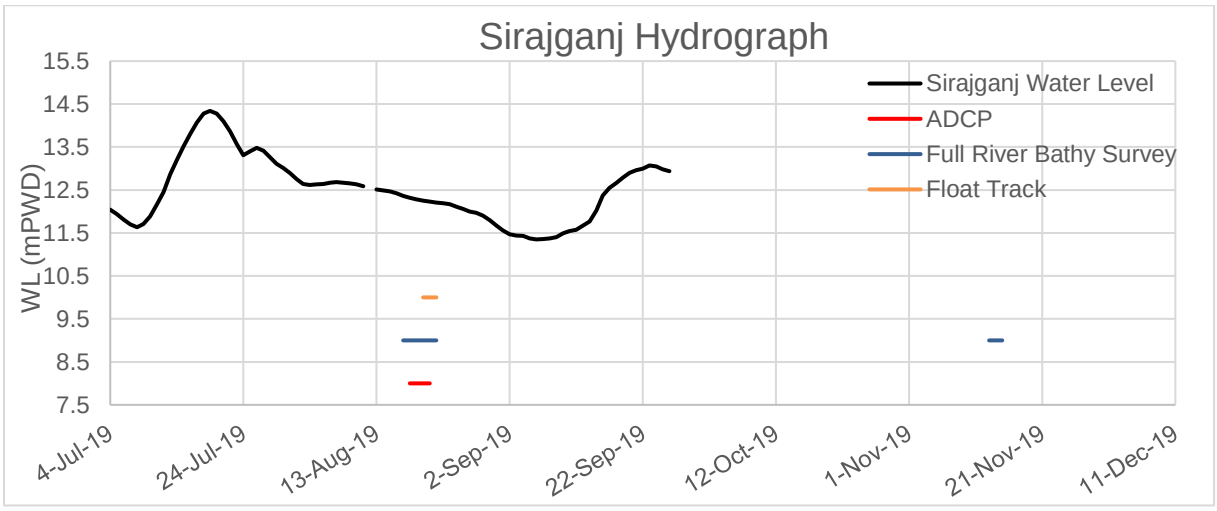


Figure 3-1 Full river survey and float tracks during the 2019 flood

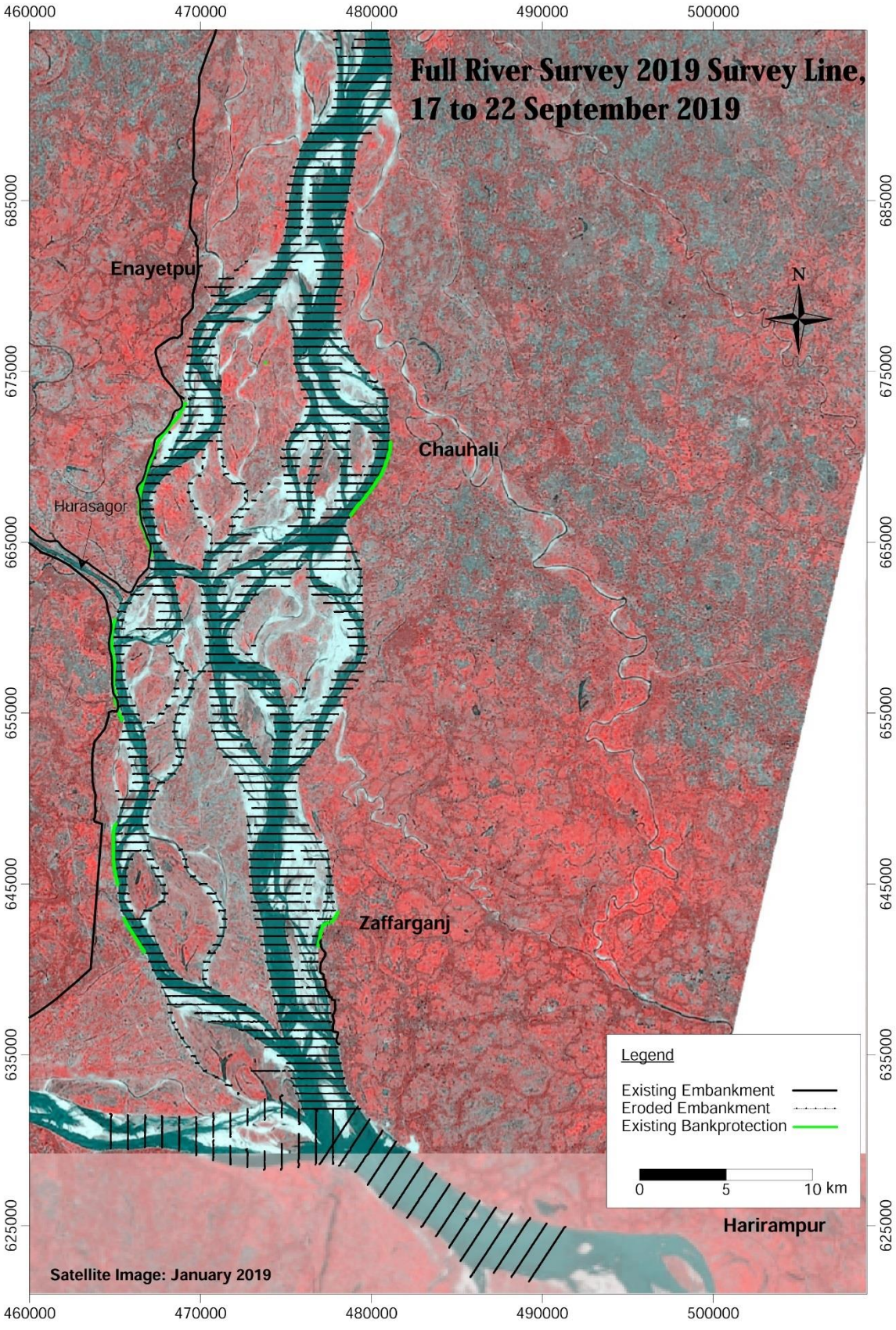


Figure 3-2 Flood season bathymetric survey of the Lower Jamuna

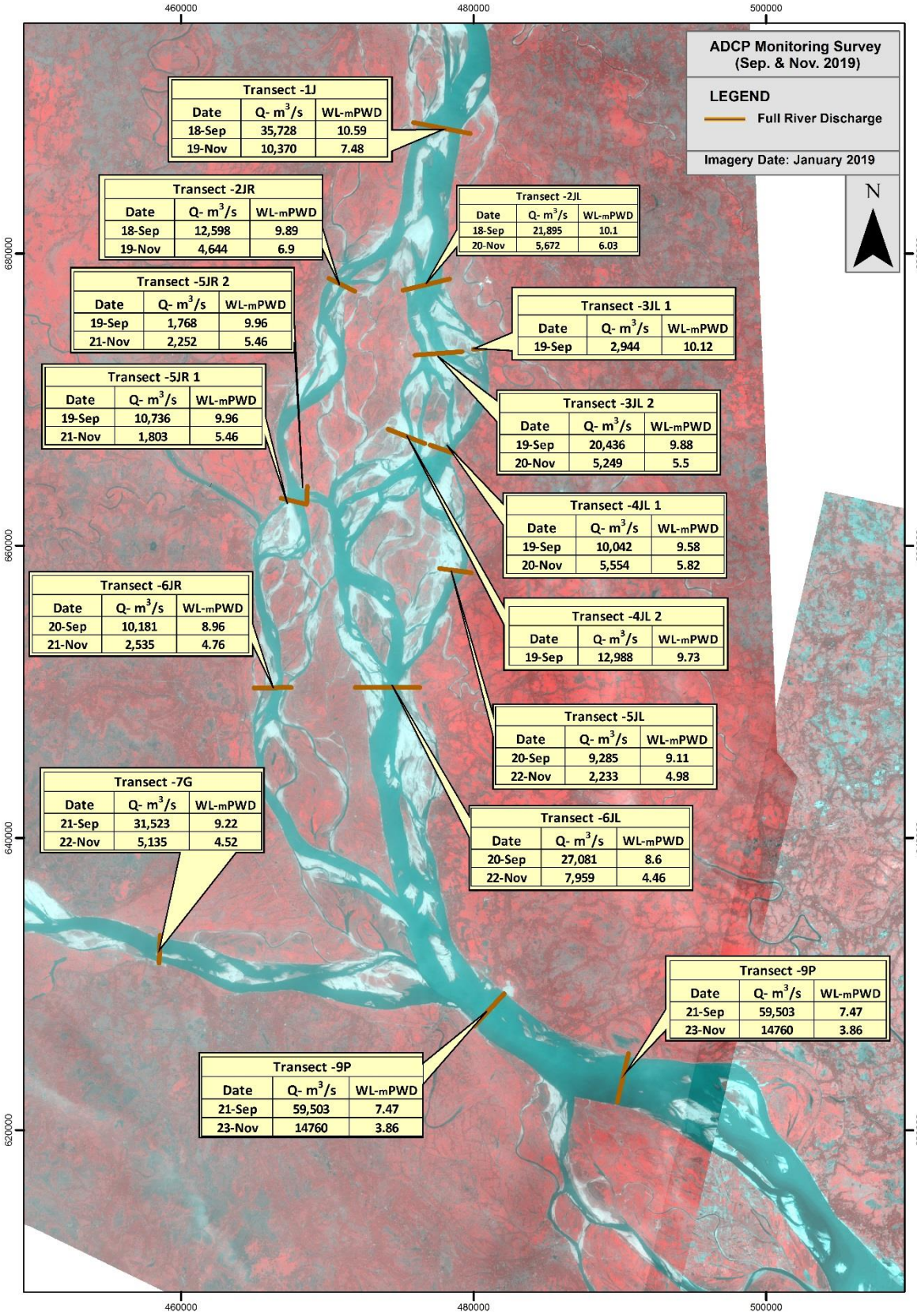


Figure 3-3 ADCP measurement 2019

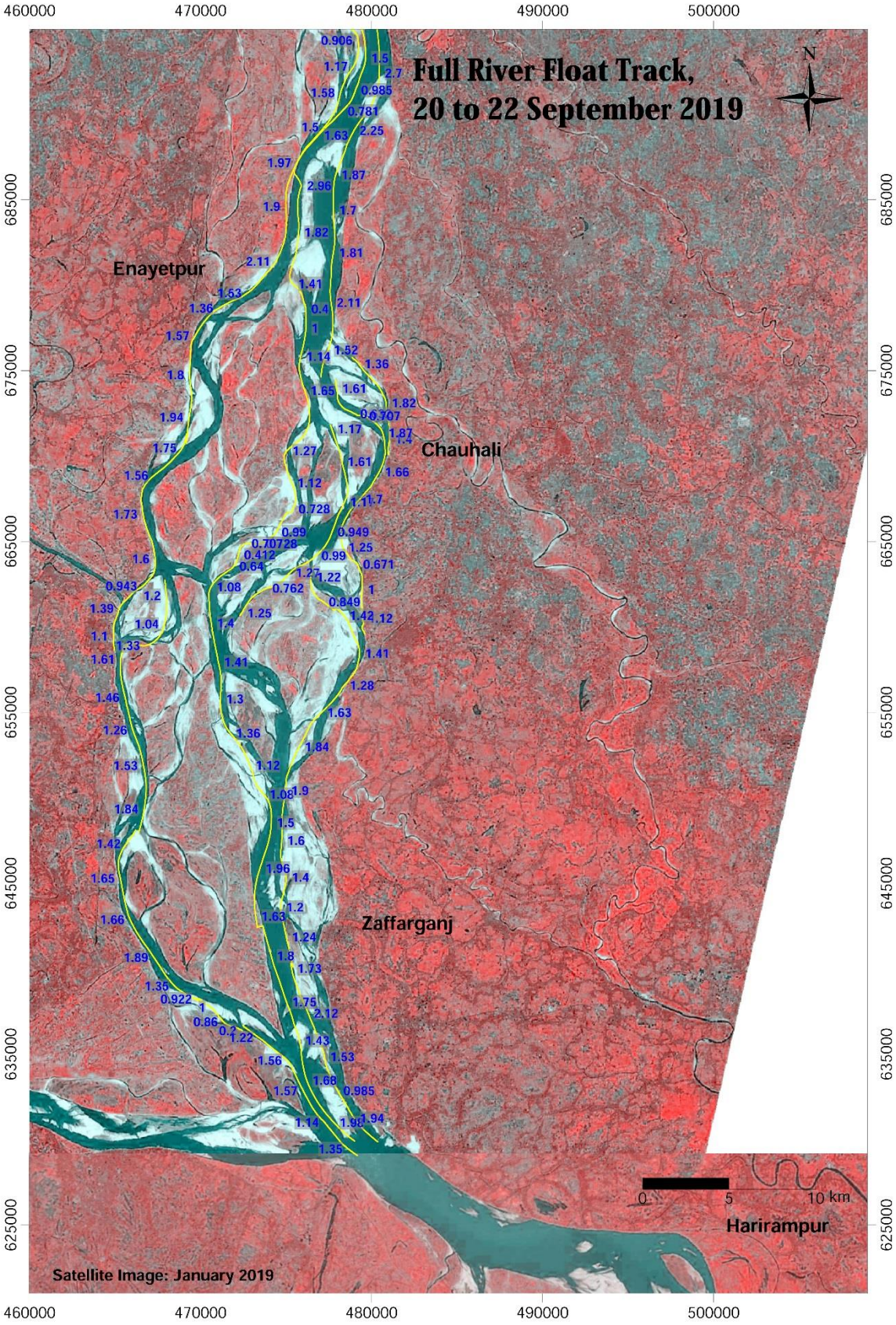


Figure 3-4 Float track survey 2019

3.3 Monitoring Results

3.3.1 Lower Jamuna

The changes in morphology in the Lower Jamuna were assessed based on the surveys conducted under FRERMIP (annual flood seasons surveys since 2016 and a dry season survey in 2017), as well as a flood season survey conducted by IWM in 2011. Following are the findings of these surveys:

i. The average bed level of the Lower Jamuna has decreased by about 1.5 m (Table 3-1), however, it is similar in 2019 and 2016. This may suggest periodic changes in the bed levels or be caused by the difference in magnitude of flooding. The development of maximum and minimum bed level reveals no clear trend.

Table 3-1 Average, maximum and minimum bed levels in the Lower Jamuna between 2011 and 2019

Year	Average bed level, mPWD	Maximum bed level, mPWD	Minimum bed level, mPWD
2011	3.53	9.57	-22.5
2016	2.02	10.17	-23.37
2017	4.05	10.84	-23.09
2018	2.25	10.45	-20.9
2019	2.08	9.6	-21.54

ii. The below graph in Figure 3-5 shows the river area by elevation. December 2017 survey was a dry season survey, having a corresponding low river area. Overall the area with an elevation between elevation -5mPWD to -10mPWD has increased significantly, while the area above +5mPWD has reduced. This may indicate the concentration of the river in fewer, deeper channels.

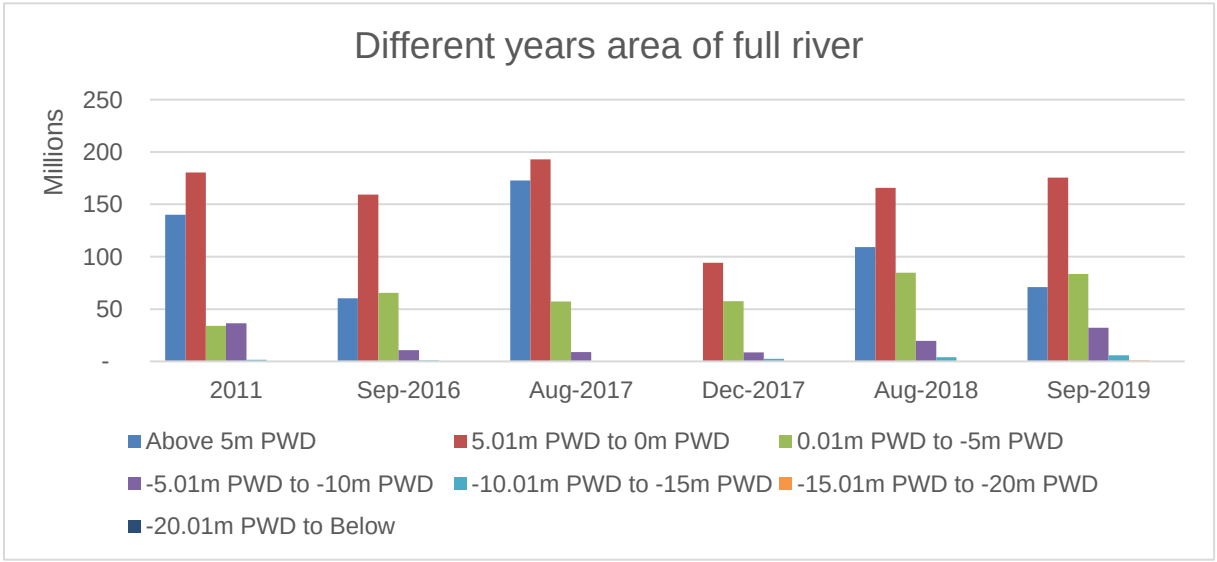


Figure 3-5 Area of different full river surveys

iii. Figure 3-6 shows the 2019 flood season survey contour map. Figure 3-7 and Figure 3-8 shows the differential map. The map shows deep channels at Chauhali, Kaijuri, and PIRDP, as well as deep confluence, scours at downstream Solimabad and the Jamuna and Ganges confluence. Inflow from the Hurashagar appears to have little influence on the further flow pattern of the Jamuna. The Solimabad bend (at the offtake of the Old Dhaleswari) appears to be silting up again following a deepening in 2017-2018.

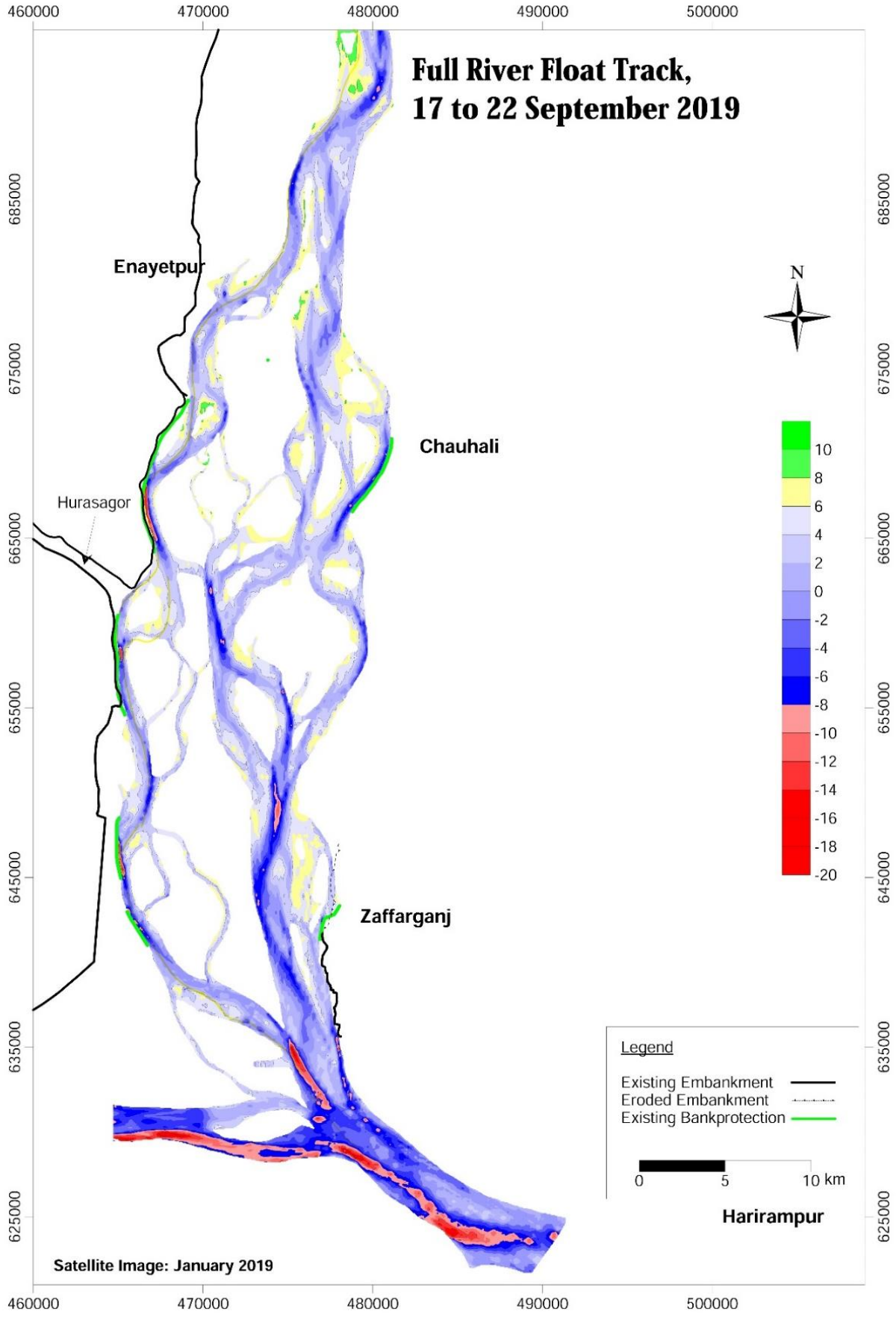


Figure 3-6 Full River Survey 2019

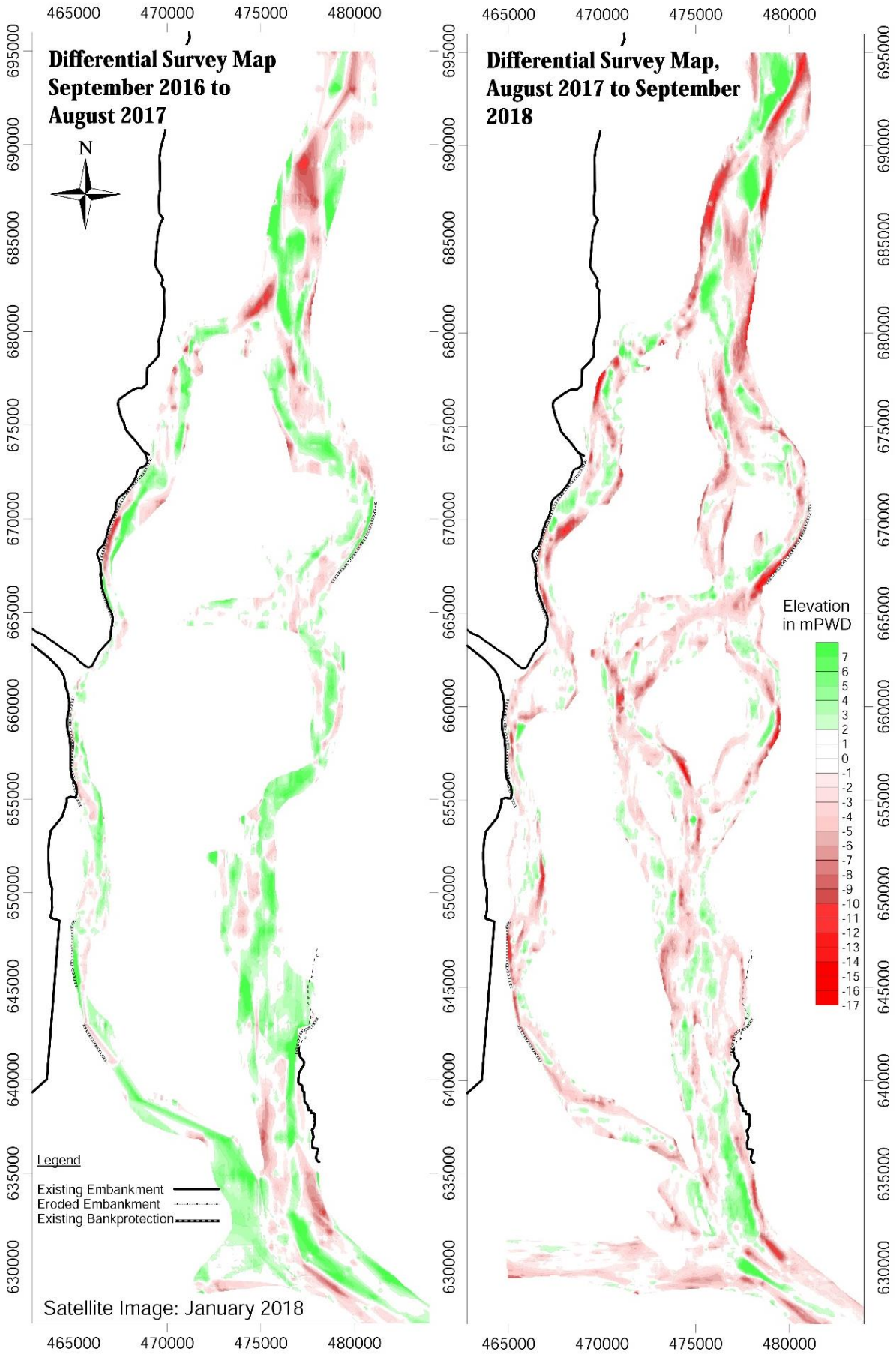


Figure 3-7 Differential survey from 2016 to 2017 and 2017 to 2018

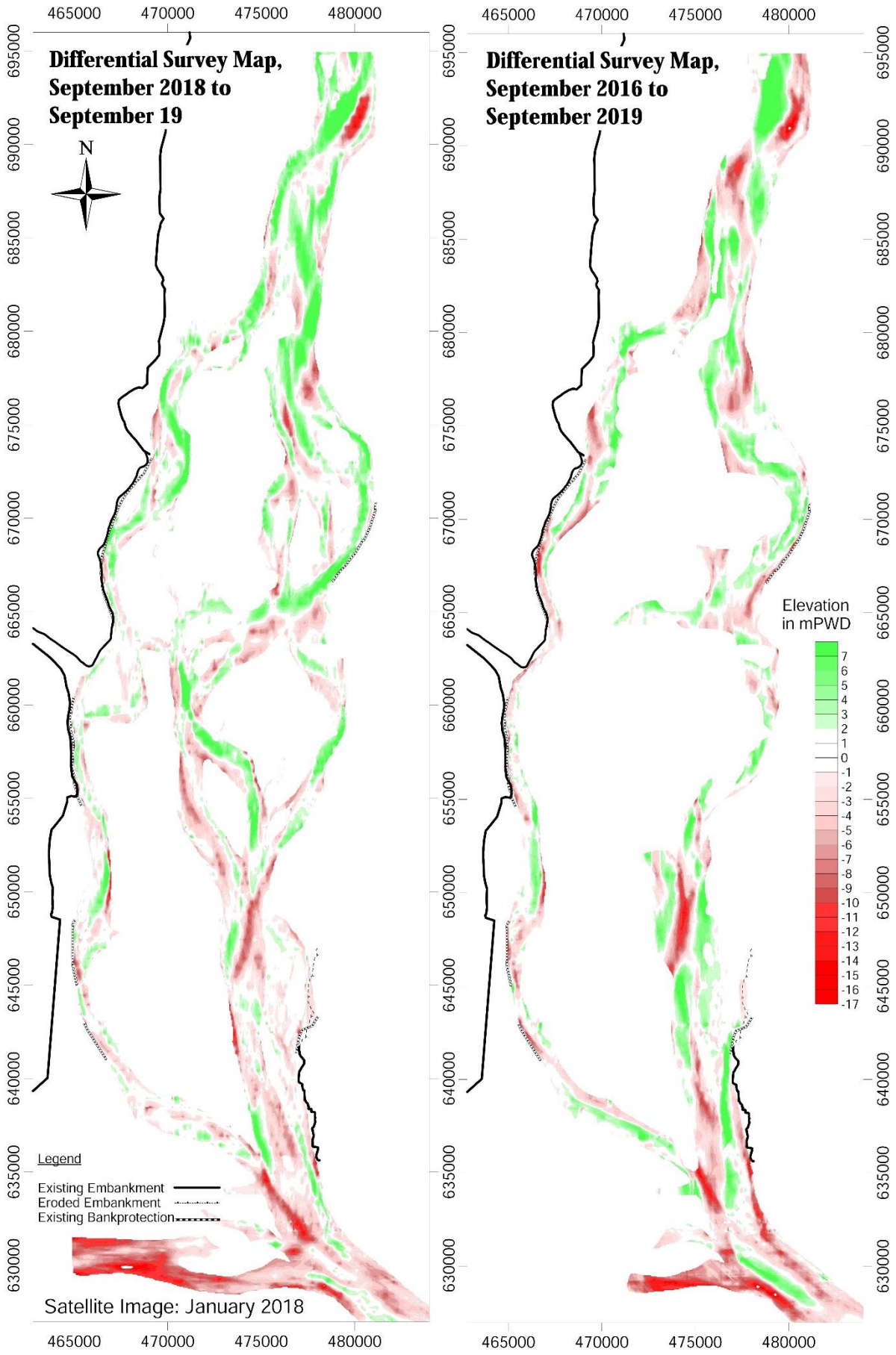


Figure 3-8 Differential survey from 2018 to 2019 and 2016 to 19

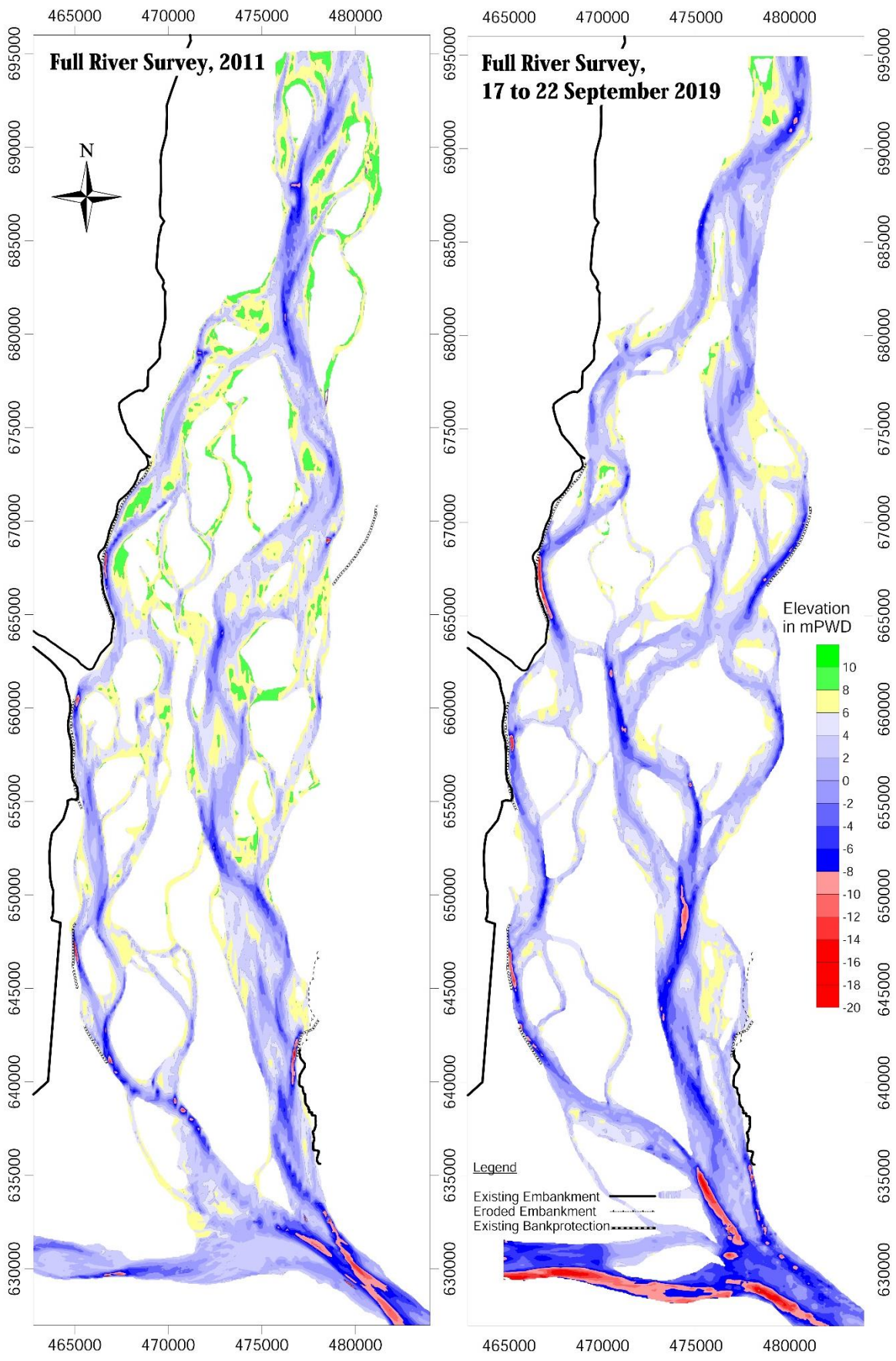


Figure 3-9 Full river survey 2011 and 2019

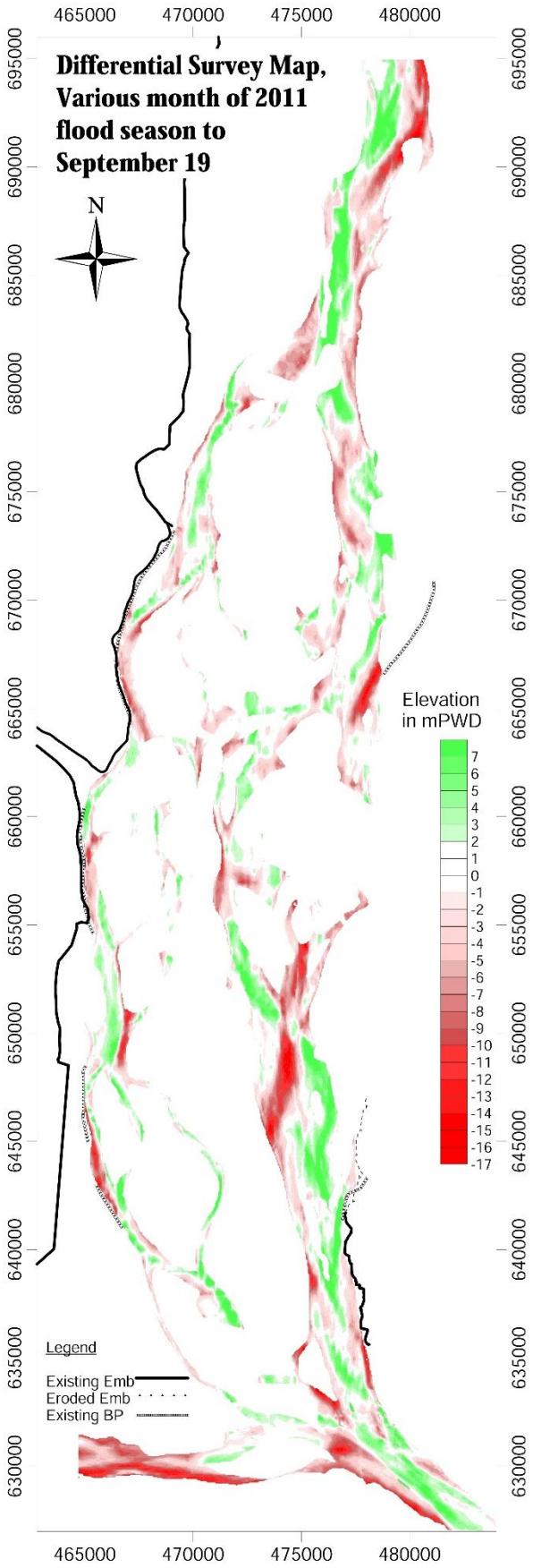


Figure 3-10 Differential survey from 2011 to 2019

iv. The flow distribution at the main Jamuna bifurcation (near Enayetpur) is that the western channel carries 46% and the eastern channel carries 54% discharge compared to the total discharge. ISPMC has conducted an ADCP survey from 2016 to 2019 and also collected 2012 discharge information from JMREMP. Figure 3-11 shows the development of the discharge distribution at the bifurcation. It shows that after years of dominance of the left (eastern) channel, the distribution is now almost equal.

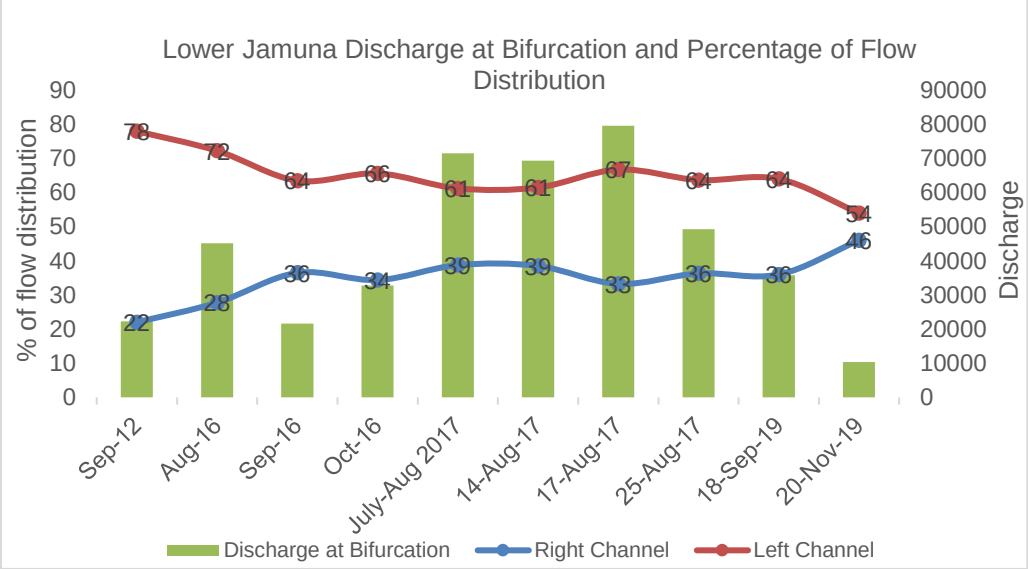


Figure 3-11 Yearwise discharge distribution at Enayetpur bifurcation

v. After the Enayetpur bifurcation opposite to the Chauhali bank protection site, three new channels were formed. From the September discharge measurement, it can be seen that the right two channels are carrying more then 50% of the discharge entering the eastern channel.

vi. The western channel near Benotia deepened during the 2019 flood season and is also taking more dry season discharge compared to the Bera channel (5JR 1). In September 2019, the Benotia channel carried 15% discharge and in November 2019 it carried 55% of the total discharge of the western channel.

vii. Beside Zafarganj, a big sand bar was formed which has started eroding. A tendency of a deep channel forming beside Aricha to Paturia is observed.

viii. The satellite image in Figure 3-12 shows

a. The river is in a single channel up until the bifurcation
b. The eastern (left) channel seems dominant
c. There are two channels at Chauhali, one straight and one along with the Tranche 1 works
d. There is a channel connecting the Jamuna at the Chauhali works with the Dhaleswari
e. The Solimabad channel appears to be relatively shallow
f. The eastern channel appears relatively straight downstream of the Solimabad char
g. The area protected by the Kaijuri (JRB-1) embankment implemented in Tranche 1 appears to be relatively dry
h. The western channel follows the protected banks and flows straight beyond the Hurashagar confluence after that multiple channels are crossing the char
i. There appears to significantly backlog of water in the Hurashagar upstream of Baghabari
j. The waters from the Hurashagar do not initially mix with the Jamuna waters

Figure 3-12 Lower Jamuna and Upper Padma rivers in October 2019 (source ESA Sentinel-2 mission)

3.3.2 Ganges and Padma

The differential map between September 2018 and September 2019 (Figure 3-13) shows:

i. The river bed of the Ganges has significantly deepened by up to 17m, resulting in a shift of the thalweg to the right side of the channel
ii. The char at the confluence appears to become more stable
iii. Bank erosion has been observed in some places at the left bank from Paturia to Harirampur.
iv. The right channel of the Padma is deepening, in particular just after the confluence and near Faridpur

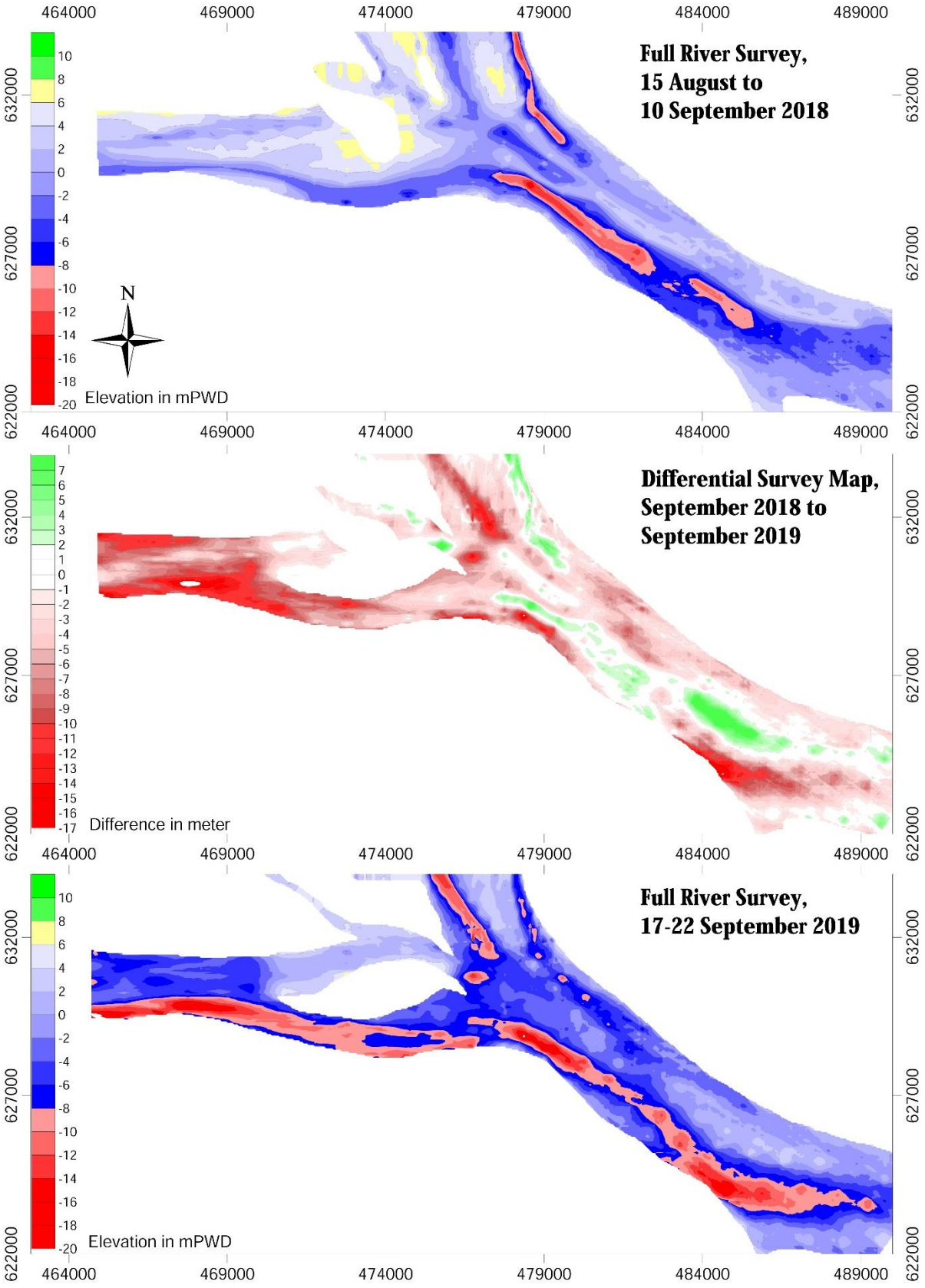


Figure 3-13 Differential from September 2018 to September 2019

4 Site Monitoring

4.1 Purpose

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

(i) the scour development alongside the Tranche 1 works; (Section 4.4)
(ii) the development of the JMREMP works at the PIRDP and Kaijuri,
(iii) detailed surveys of development using multibeam echo sounder at different sites

4.2 Monitoring Plan

Monitoring of implemented works is required throughout the lifetime of the works, but the required frequency and intensity of surveys vary corresponding to the response of the river, impact from the river, and situation of the works. Typically the first one or two flood seasons after implementation see the majority of the response of the river, resulting in large changes to the protection works, requiring adaptation works and potentially repairs. Therefore, the first survey cycles (2016 and 2017) included repeated surveys during the flood season (about two to four times between July and October) with bathymetric surveys, which were compared with the as-built condition (Appendix 5 and 6). Later surveys (2018 and 2019) have a lower frequency and concentrated on determining emerging threats to the protection by detailed analysis of placed and launched protection with multi-beam echo sounder surveys and determining changes in flow direction and flow velocities using float tracks.

In 2019, single beam, multibeam bathymetry survey, ADCP, and float track surveys were planned under W-16 contract. Initially, multibeam survey was considered for all Tranche 1 sites and for Kaijuri and PIRDP area. The full river survey and October survey reveal that the apron placed at Chauhali and Zafarganj has been buried under sediment, so multibeam surveys would not add any additional information regarding the condition of the launched slope. To allow a more detailed study of the launching behavior of different materials, the length of multibeam for Chauhali and Zafarganj was adjusted to cover sites at PIRDP, Nagarbari, Sirajganj hardpoint and Sirajganj crossbar.

Table 4-1 provides an overview of the 2019 site surveys. Appendix 2 provides a summary of the survey work at the all the sites in 2019.

Table 4-1 Summary of survey activities at the sub-project and othe sites

Survey Item	Site	July 19	Aug 19	Sep 19	Oct 19	Nov 19	June 20
Bathymetry Survey	Chauhali	25-27			26		23 (MB)
	Zafarganj	28			31		24 (MB)
	Harirampur		22	5		1. 2-3, 2. 13-14 (MB)	25 (MB)
	Koijuri				25-27	1.05-06 (MB) 2. 06 (MB) 3. 07 (MB) 4. 08 (MB)	22 (MB)
	Benotia	1. 18 2. 24-25			25-27		21 (MB)
	PIRDP				25-27	1. 07 (MB) 2. 10 (MB)	
	Nagarbari					1. 1 2. 12-15 (MB)	
	Sirajganj CB					17 (MB)	
	Sirajganj HP					17 (MB)	
	Full River			17-22			
ADCP	Full River			18-21		19-23	
Float Track	Full River			20-22			

**MB refers Multi Beam*

4.3 Survey Methodology

4.3.1 Procedure

Bathymetric survey:

Single Beam Echo Sounder (SBES): IWM did the SBES bathymetry survey using their survey speed boat. Survey track lines were provided in dxf and kml format for both full river and site surveys. For better comparison with the old survey data, the prescribed survey track line was strictly followed. Table 4-2 shows the list of the used instruments for the survey.

Multibeam Survey: Multibeam system consists of a sonar unit with an interface unit called Rack-mounted Sonar Processor. For effective hydrographic surveying, the system requires additional components for positioning, motion sending, collection of data, determining sound velocity in the water as well as a computer to run the operating software. Figure 4-1 shows an overview of the multibeam survey components. Surveyor used a speedboat for the survey work.

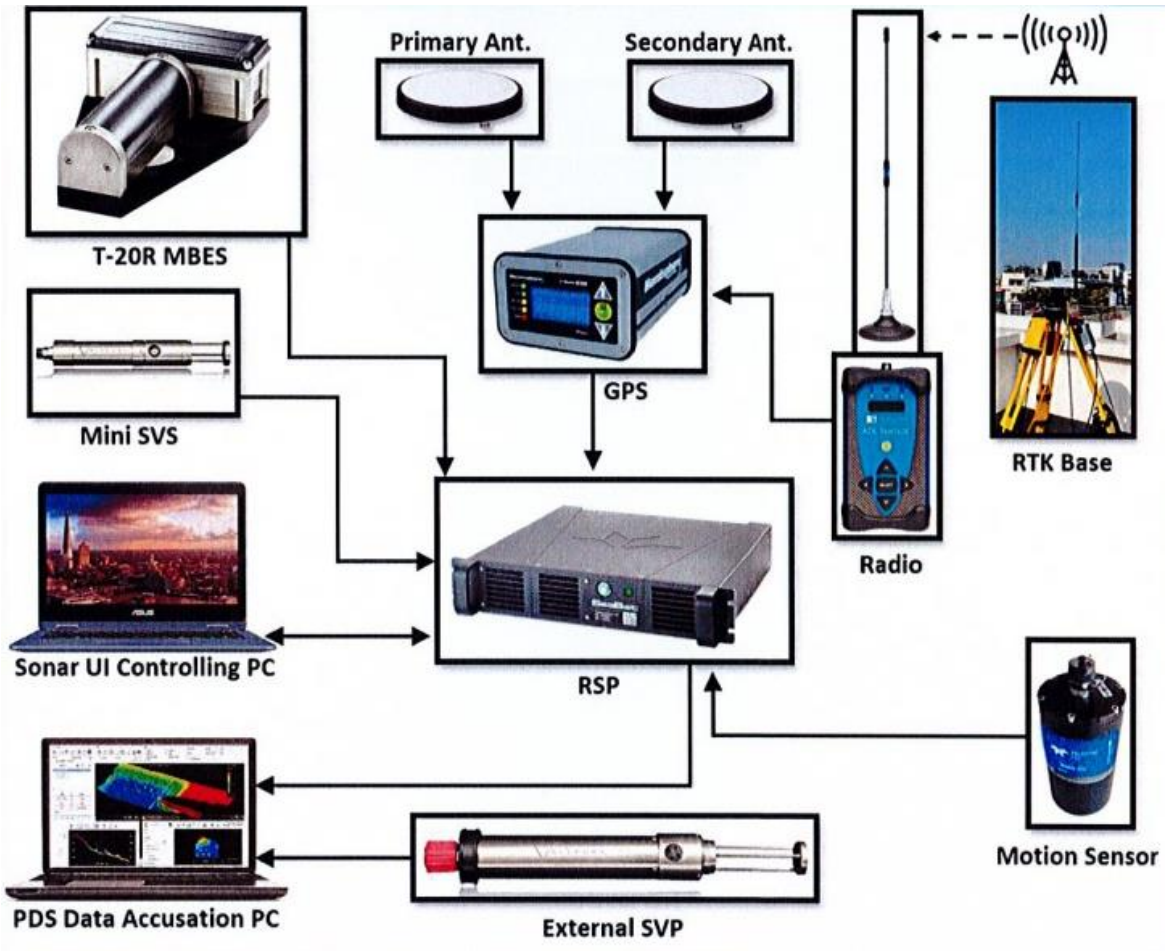


Figure 4-1 Multibeam system overview

ADCP: For discharge, the surveyor runs a survey boat along the prescribed line from one bank to the other bank and records velocity. To minimize errors, each line is surveyed bi-directional from one bank to the other and back. ADCP measurements were taken at 12 transects. Among them 9 transects were at Jamuna, one at Ganges and two were at Padma river.

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

List of the instruments for all surveys are given below.

Table 4-2 Equipment used for all surveys

Survey Type	Equipment	Equipment Model
Single beam echo sounder	RTK GPS	Hemisphere Vector H 321, Trimble SPS 855
	Optical level	Sokkia, Japan, B20
	Echosounder	Teledyne Odom Hydrotrac II CV 100
	Data collection and processing software	Trimble HydroPro
Multi beam echo sounder	Multibeam Echosounder	Teledyne RESON T20-R
	Motion Sensor	Teledyne TSS DMS 05
	Positioning/Heading	Trimble SPS 855, Hemisphere V330
	Sound velocity sensor/Profiler	Valeport Co. Mini SVS, Monior SVP
	Data collection and processing	Teledyne PDS, Beamworx AutoClean and AutoPatch, Hypack
ADCP	RTK GPS	Hemisphere Vector H 321, Trimble SPS 855, Vector VS 330
	Handheld GPS	Garmin
	ADCP	Teledyne RI Workhorse Sentinel (600KHz)
	Data Processing	Teledyne Win River II
Float Track	Handheld GPS	Garmin
	Float Device	Local workshape made floating platform

BM locations is provided in the appendix 3 section.

4.3.2 Chauhali

At Chauhali, two bathymetric surveys were conducted in July and October 2019. A 100m interval section was taken for the survey. IWM did one multibeam survey here during 23 June 2020.

4.3.3 Zafarganj

At Zafarganj, two bathymetric surveys were conducted in July and October 2019 using a dual-frequency single beam echo sounder with 100m cross-section intervals. July survey was conducted by the Survey and Data Consultant and IWM did an October survey. One multibeam survey was conducted here on 24th June 2020.

4.3.4 Harirampur

At Harirampur, three bathymetry surveys were conducted in August, September and November 2019 also using a dual-frequency single beam echo sounder with 100m cross-section intervals. 4.8km long multibeam survey was conducted from 13 to 14 November 2019 and another multibeam survey was conducted here on 25th June 2020.

4.3.5 Koijuri

At Koijuri, one bathymetry survey was conducted from 25 to 27 October 2019. The Survey interval was 100m. At this site, one 4km long multibeam survey was conducted from 5 to 6 November 2019. Additional 3 multibeam surveys were conducted to record the dune track on 6, 7, and 8 November. Another multibeam survey was conducted here on 22 June 2020.

4.3.6 Benotia

At Benotia three bathymetry surveys were conducted in July and October. In July two surveys were conducted by Survey and Data Consultant and IWM did survey in October. One multibeam survey was conducted here on 21th June 2020.

4.3.7 PIRDP

At PIRDP area one single beam bathymetry survey was conducted on 10th October 2019. At this site in two locations multibeam survey were conducted on 7th and 10th November 2019.

4.3.8 Nagarbari

At Nagarbari area one single beam bathymetry survey was conducted on 1st November 2019. Multibeam survey was conducted at two locations from 12 to 15 November 2019.

4.3.9 Sirajganj Hardpoint and crossbar

At Sirajganj hardpoint and crossbar area, one multibeam survey was conducted in 17 November.

Detailed descriptions of the surveys are found in Appendix 5.

4.4 Scour and sedimentation

4.4.1 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 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 a low water level. Key design levels at the three sites are shown in Table 4-3.

Table 4-3 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 assessing 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.

4.4.2 Chauhali

After the construction of this site, several damages, mainly to the wave protection above LWL, occurred during 2016, 17, and 18. Initially, bank erosion occurred at the temporary protection. Several places were eroded during and after the construction of permanent protection. That time several repairs works, repair dumping works were conducted. One multibeam survey was conducted to identify the underwater situation and based on 2017's monitoring report one adaptation dumping plan was prepared. Key changes of the local morphology are summarized in Table 4-4. The contractor's chainage is used.

Table 4-4 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
25-27 July 2019		Stn. 6.8 to 6.66	0.144 km	Stn 6.7; -11.5
		Stn. 4.4 to 3.7	0.7 km	Stn 3.95: -11.5
		Stn. 3.15 to 2.48	0.067 km	Stn 2.5; -13
23-26 October 2019		Stn, 2.7 to 2.3	0.4km	Stn 2.5; -11
		Stn, 3.9 to 3.7	0.2km	Stn 3.7; -11
23 June 2020		Stn, 5.7 to 4.7 Stn, 4.4 to 4.28	1km 0.2km	Stn5.1; -16

Key findings of the survey at Chauhali are:

(i) In this flood season, no erosion observed at Chauhali. The partial outflanking at the upstream end of the works that occurred in 2018 makes the upstream work vulnerable but has not resulted in significant additional outflanking in 2019.

(ii) the deep scour length has reduced from a total of 2.07 km at the end of the 2018 flood season to a total of 0.6 km in 2019

(iii) The maximum scour depth has reduced throughout the 2019 flood from -15 mPWD at the end of 2018.

(iv) After the Enayetpur bifurcation opposite to the Chauhali protection there formed three new channels.

(v) In the 2017-18 dry season, 3.8 km adaptation work conducted at Chauhali site from 180m to 3980m chainage. After that in September 2018 survey shows stepped launching at the downstream part of the protection area. Multibeam survey was planned there to reveal more information about additional launching. But those places were all sedimented during the 2019 flood season.

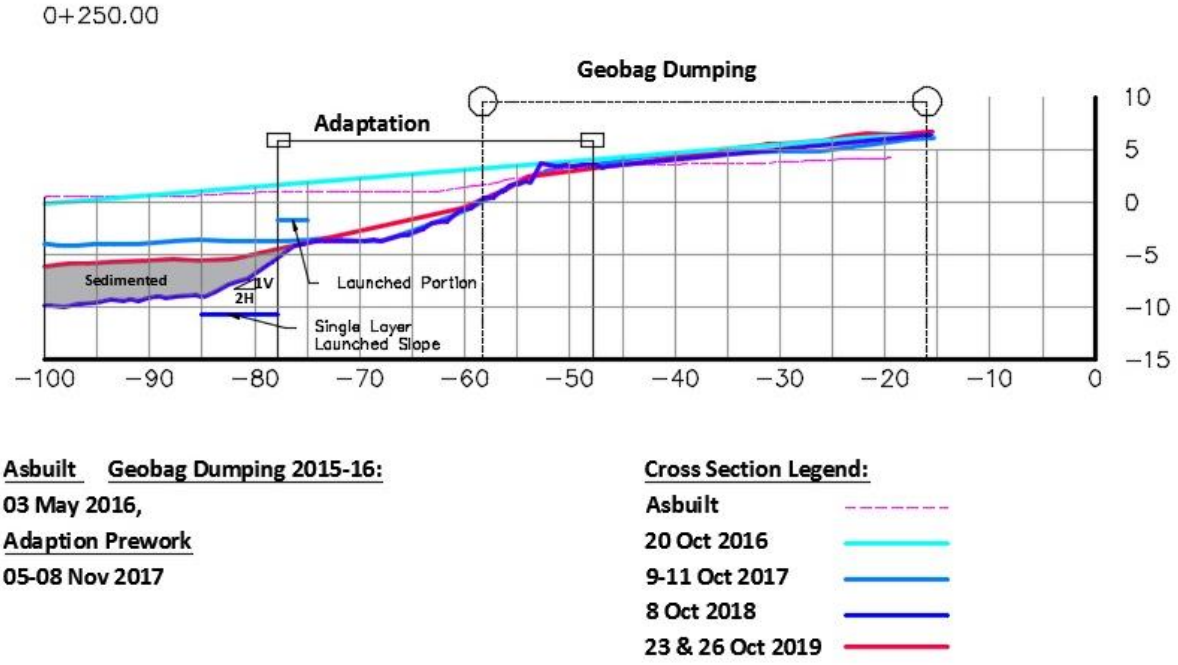


Figure 4-2 Chauhali adaptation work and present scenario

23rd June 2020 multibeam survey shows upstream portion of the Chauhali area which was sedimented during 2017 flood is now started scouring again. This section should be monitored regularly to identify need of adaptation. Detatil maps are provided in Appendix 8.1.

Detailed maps for different surveys are included in Appendix 5.1 and in Appendix 6.1. Long profiles along the deepest scour at end of the apron are provided in Appendix 9.1, documenting scour and sedimentation development during the 2019 flood season, compared with the as-built condition. The long profile was prepared based on 50m interval cross-sections.

4.4.3 Zafarganj

Different from Chauhali and Harirampur, no erosion occurred in Zafarganj. The primary reason for this is large scale changes in the flow pattern, moving away from the riverbank. Systematic monitoring alongside the revetment revealed key changes of the local morphology, summarized in Table 4-5.

Table 4-5 Findings alongside the protected riverbank at Zafarganj (with reference to the position along with the works)

Time period	Sedimentation (>+2 m+PWD)	Deep Scour (<-9 m+PWD)	Deep Scour length	Deepest scour location
28 July 2019	From Stn. 6.4 to above in upstream and from Stn. 7.5 in downstream direction	Stn. 6.95 to 7.2	Around 250m	Stn 7; -12.2
31 Oct 2019	From Stn 6.4 to above	Stn. 6.95 to 7.06	Around 160m	Stn 7; -13
24 Jun 2020		Stn. 7	20m	Stn 7; -11

Key findings of the Zafarganj survey are:

(i) It appears that the situation is overall stable and no large scour is emerging.

(ii) There is a small scour at the protrusion in about the middle of the works, which is slowly but gradually deepening. However, this scour is yet to significantly surpass the depth during implementation

(iii) Cross-section near the Primary school area shows that the initial apron was placed on a deep bed elevation and after that, that portion was sedimented. The overall progress of that place is shown in Figure 4-3

(iv) The slope near the primary school is ver steep (about 1V:1.5H see Figure 4-4), which is typical for slopes at protrusions like spurs and natural hardpoints. Steep slopes pose a significant geotechnical risk, in particular when the slope launches further, creating a longer slope at the same steepness

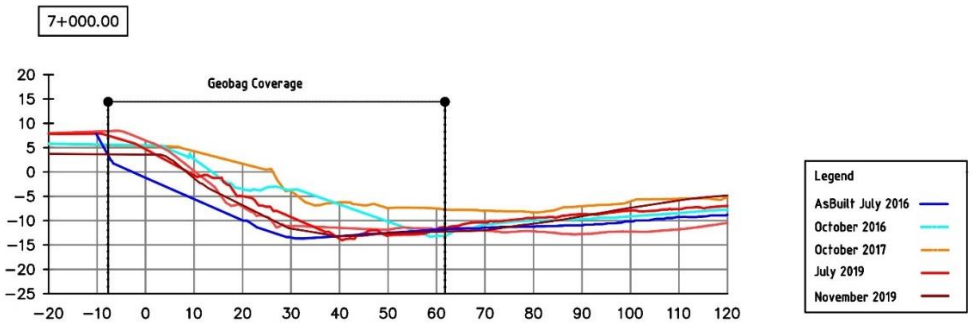


Figure 4-3 Riverbed development beside the Primary School at Zafarganj

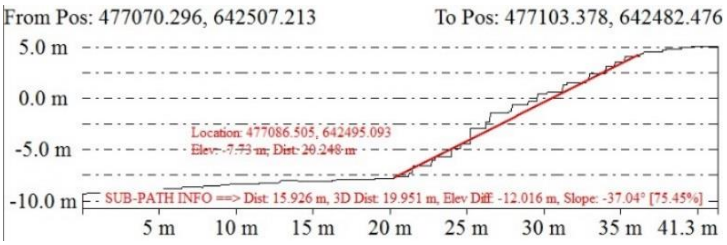


Figure 4-4 Cross section at primary school from multibeam echo sounder survey

Detailed maps for different surveys are included in Appendix 5.2, differentials are shown in Appendix 6.2 and detail multibeam survey map conducted on 24th June 2020 is provided in Appendix 8.2.

4.4.4 Harirampur

The Harirampur site situation in 2019 was more stable than in 2016-17, when some erosion occurred in the centre of the protection works. Key changes of the local morphology are, summarized in Table 4-6:

Table 4-6 Findings alongside the protected riverbank at Harirampur

Time period	Sedimentation (>+2 m+PWD)	Deep Scour (<-14 m+PWD)	Deep Scour length	Deepest scour location
5 September 2019	Stn 5.0 to 4.8			Stn 6.6: -12
2-3 November 2019		Stn. 6.5 to 6.6 Stn. 7.2 to 7.1 Stn. 7.6 to 7.8 Stn. 9.1 to 9.9	0.1km 0.1km 0.2km 0.8km	Stn. 6.6; -18 Stn 7.2; -16 Stn 7.6; -18 Stn 9.3; -18
13-14 November 2019 (MB)		Stn 6.0 to 5.9 Stn 7.2 to 6.4	0.1km 0.8km	Stn 6.0: -18 Stn 6.6; -18 Stn 7.2; -18

Key findings of the survey at Harirampur are:

(i) The scour hole is reducing in overall length and is separated into different smaller holes
(ii) The total depth of the scour hole has reduced slightly
(iii) Upstream of the placed protection, the riverbank came under increased attack since the 2018 flood season, which led to erosion over a length of about 3,000m, including damaging some part of the riverbank protection works. This erosion has the potential to outflank the protection works, despite the erosion rates being mitigated by the cohesiveness of the soil.
(iv) During the construction period there was a char at the upstream protion. That time from Stn 1600m to 3000m smaller apron was placed.After dumping that place was silted upto 5m during October 2016. During September 2018, after third year from the construction this portion started launching. Again in November 2019, this portion sedimented by roughly 10m.

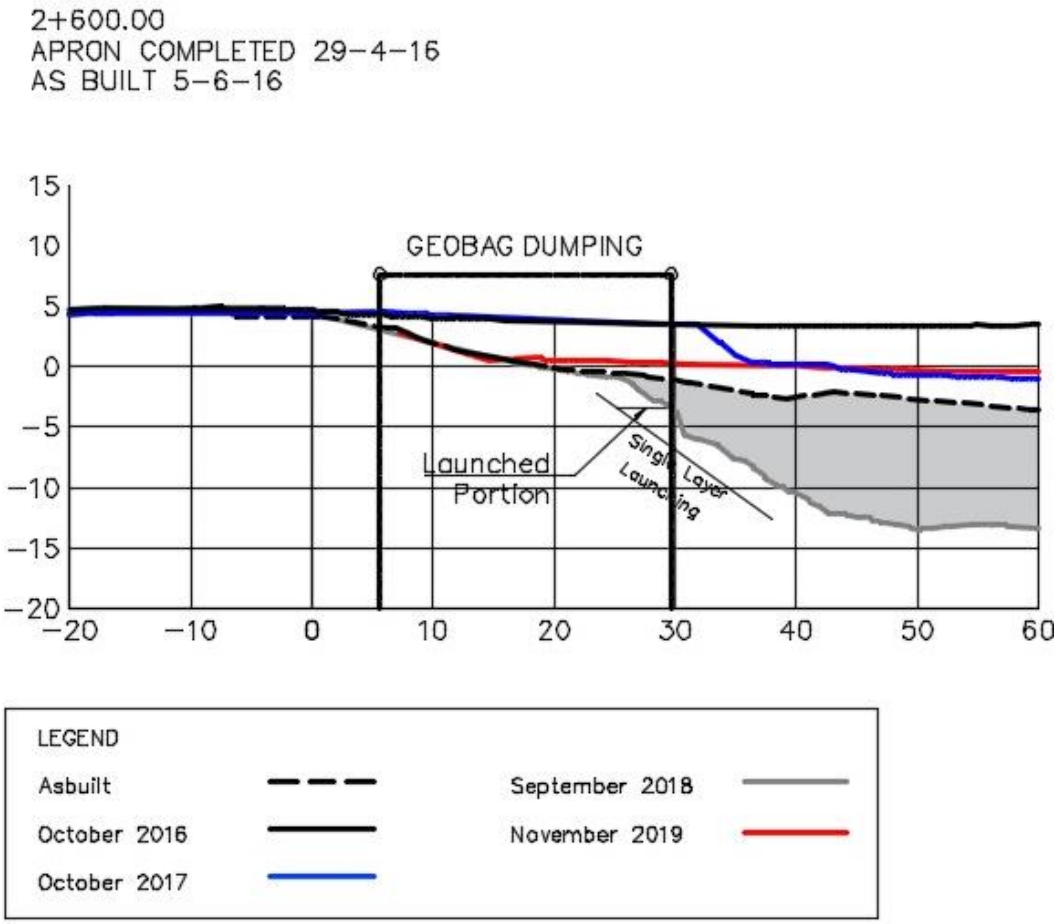


Figure 4-5 Riverbed development at upstream portion

(v) Additional bank protection and underwater protection will be required from 1600m to upstream to protect the existing work and mitigate upstream erosion.

(vi) During apron placement in 2015-16, there was a sandbar at the upstream potion. That time only 20m apron was placed. It launched in 2018 but again sedimented in 2019. This section needs to monitor during the 2020 flood season. Adaptation work would be needed to strengthen existing work.

Detailed maps for different surveys are included in Appendix 5.2, differentials are shown in Appendix 6.2 and detail multibeam survey map conducted on 24th June 2020 is provided in Appendix 8.2.

A multibeam survey was conducted on 05 to 06 November 2019 this site. Maps are provided in Appendix 8.3.

4.4.5 Koijuri

At Koijuri 10km bank protection work were implemented during JMREMP in from 2009 to 2011. This site is situated at downstream of the Enayetpur bifurcation along the Jamuna right channel. Historically, the main river flow went through this channel and before 2011 there was severe bank erosion at this bank. After completion of this bank protection work, no significant erosion occurred. The main purpose of this monitoring survey is to monitor the performance of underwater protection and identify the necessity for adaptation work. The results are summarized in Table 4-7.

Table 4-7 Findings alongside the proposed 12km bank protection at Koijuri

Time period	Sedimentation (>+5 m+PWD)	Deep Scour (<-9 m+PWD)	Deep Scour length	Deepest scour location
25-27 October 2019		Stn. 3.8 to 0	3.8km	Stn 2.4; -21

05-06 November 2019 (MB)		Stn. 3.2 to 0	3.2km	Stn 2.4; -21
22 June 2020		Stn 2.2 to 0.8	1.6km	Stn 1.6;

Key findings of the survey upstream of Koijuri are:

(i) Multibeam survey shows launched slope at different locations.
(ii) Deep channel found in both surveys
(iii) Old underewater erosion and holes at several location observed in the apron. Diving investigation is required to identify connection between placed cc blocks on riverbank slope and under water apron.

Detail bathymetry survey maps are provided in Appendix 5.4. Multibeam survey maps are provided in Appendix 8.4 and long profile is provided in Appendix 9.3.

4.4.6 Benotia

The embankment constructed in JRB-1 during FRERMIP Tranche 1 is in close proximity of the riverbank at Benotia, which is immediately downstream of the Kaijuri protection. In 2019, some parts of this bank came under attack from the river, leading to erosion and threatening the newly constructed embankment. To assess the condition and the severity of the erosion, surveys were conducted in Benotia and provision for the construction of 3.5 km of riverbank protection is included in the proposed works for FRERMIP Tranche 2. Table 4-8 summarises the key findings.

Table 4-8 Findings alongside the bank protection area at Benotia

Time period	Sedimentation (>+5 m+PWD)	Deep Scour (<-9 m+PWD)	Deep Scour length	Deepest scour location
24-25 July 2019	Stn. -1.3 to -0.5			Stn -3.4; -8
25-27 Oct 2019				Stn -3.4; -8
21 June 2020		Stn 3.15 to 3.25	100m	Stn -3.2; -10

Key findings of the survey in Benotia are:

(i) July and October 2019 both surveys shows 100m wide shallow deep thalweg which is close to the bank, results bank erosion.
(ii) Sandbar is forming after 100m from the bankline.

Detail bathymetry survey maps are provided in Appendix 5.4. Multibeam survey maps are provided in Appendix 8.5.

4.4.7 PIRDP

Bank protection work at the PIRDP was completed under JMREMP in 2008. During the construction period, erosion occurred at parts of the bank. A single beam and multibeam survey were conducted during 2019 to monitor the underwater condition of the provided works.

Table 4-9 Findings alongside the proposed PIRDP site

Time period	Sedimentation (>+2 m+PWD)	Deep Scour (<-9 m+PWD)	Deep Scour length	Deepest scour location
25-27 October 2019		Stn. 3.7 to 4.5	0.8km	Stn. 4.3; -21
07 November 2019		Stn. 3.6 to 4.2	0.6km	Stn. 4.0; -23

Key findings of the survey in PIRDP are:

(i) Jamuna right channel meets with the Bera channel at Stn 4. There a bend is formed and a deep confluence scour is observed.
(ii) Multibeam shows launching of the apron from Stn 4.1 to 3.6.
(iii) Towards the downstream end, the launched slope is buried with sediment. After Stn. 1.8 sand ripples can be seen close to the bank.

Detailed maps for different surveys are included in Appendix 5.6. Multibeam survey map conducted on 7 and 10 November 2019 is provided in Appendix 8.6. Long profile for this site is provided in Appendix 9.4.

4.4.8 Nagarbari

Around the Nagarbari ghat, two locations are provided with bank protection, for which geobags and CC blocks were dumped. One single beam and one multibeam survey were conducted to identify the state of the underwater works and the performance of the launching apron.

Table 4-10 Findings alongside the proposed Nagarbari site

Time period	Sedimentation (>+2 m+PWD)	Deep Scour (<-10 m+PWD)	Deep Scour length	Deepest scour location
1st November 2019		Stn. 0 to 1.8 Stn. 3.8 to 4.6	1.8km 0.8km	Stn 0.6; -18
12-15 November 2019 (MB)		Stn. 0 to 1.8 Stn.3.8 to 4.8	1.8km 1km	Stn. 0.4; -19 Stn. 4; -19

Key findings of the survey in Nagarbari are:

(i) Multibeam and single beam both survey shows a ratio of 1 vertical and 2 to 2.5 horizontal slope near the bank from Stn 0.4km to 1.8km and 4km to 5.2km. This slope indicates launching of apron material. Figure 4-6 shows a typical launched section at Nagarbari revetment and Figure 4-7 shows a 3D view of underwater launched slope.

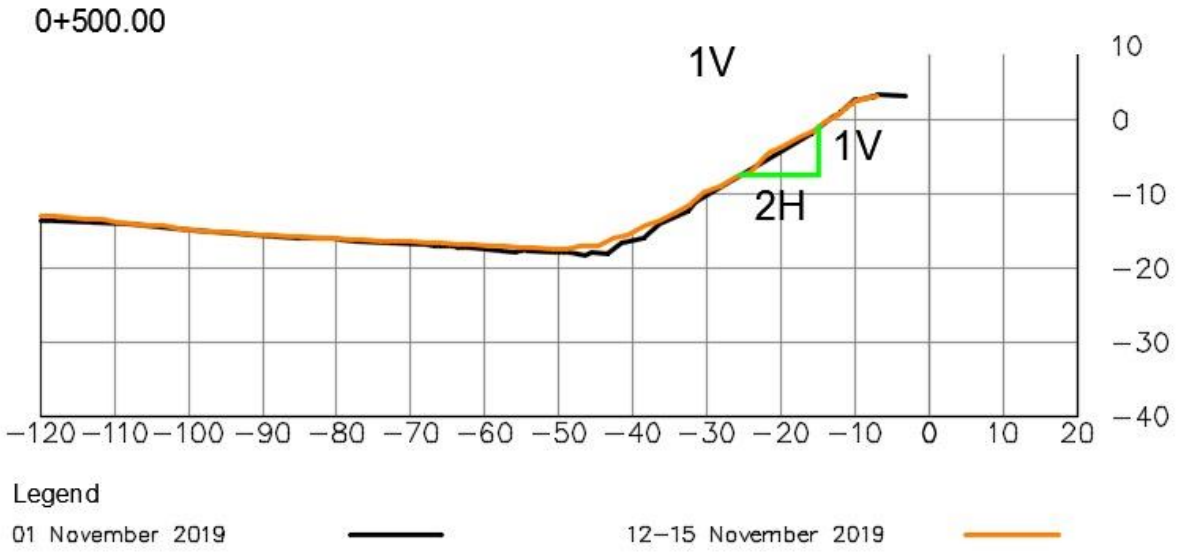


Figure 4-6 Launching at Stn. 0.5km

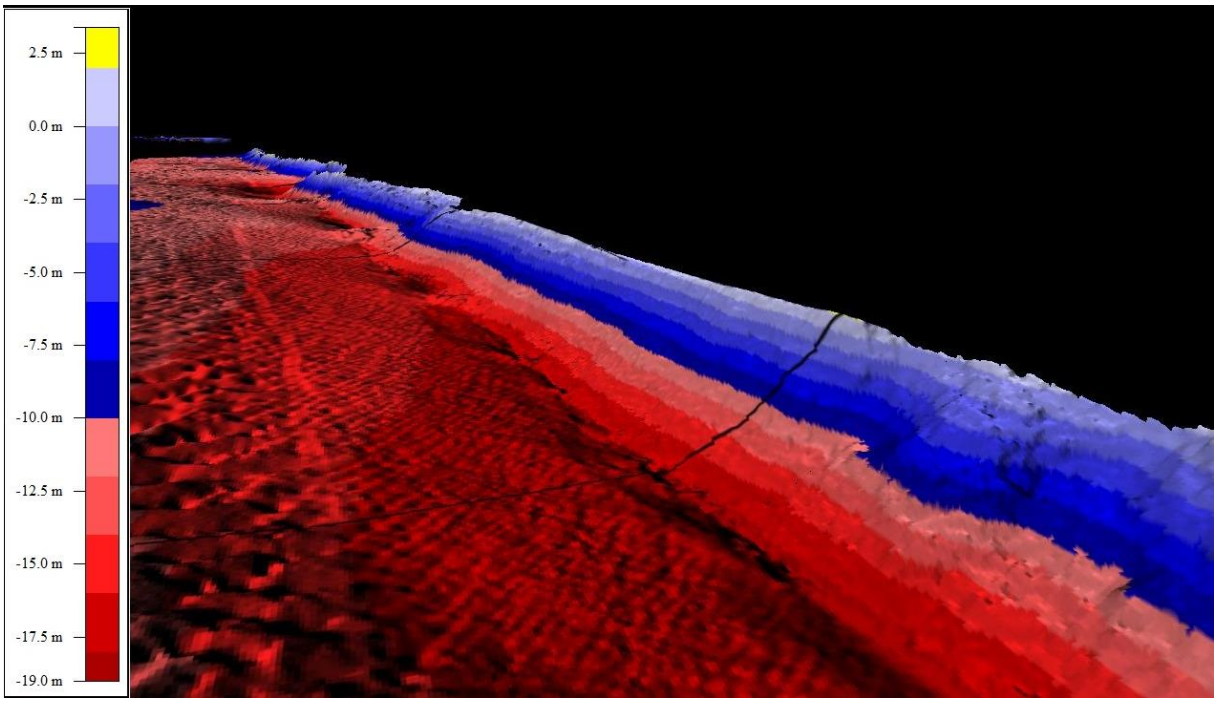


Figure 4-7 3D view of underwater lauched slope at Nagarbari

(ii) No anomalies were observed at either of the revetments.

Detail multibeam survey maps are provided in Appendix 8.7.

4.4.9 Sirajganj Crossbar

Sirajganj cross bar 3 is located downstream of Siranjganj town protection area.

Table 4-11 Findings alongside the proposed PIRDP site

Time period	Sedimentation (>+7 m+PWD)	Deep Scour (<-11 m+PWD)	Deep Scour length	Deepest scour location
17 November 2019		Stn. 0.25 to 1.0	0.75km	Stn 0.5; -21

Key findings of the survey at the Sirajganj crossbar are:

(i) At Stn 0.4, 150m from bankline an underwater spur shape dumping causes a deep scour at Stn 0.5. Satellite image shows heap of bolders dumped at that location. The point marking shows heap of boulders dumped in 2016, visible also in 2019. A detailed image is provided in Appendix 8.6.

Figure 4-8 Bathymetry near Sirajganj cross bar

(ii) Boulder's heap at stn 0.4km makes spur like erosion at downstream which results deep scour at stn 0.5km and this deep scour which is 100m far from the bankline affect underwater slope.

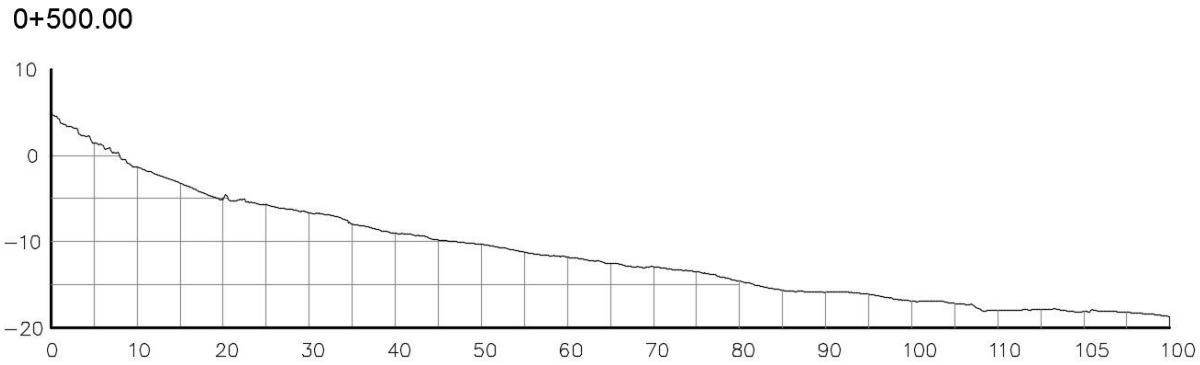


Figure 4-9 Deep scour at stn 0.5km

(iii) At this site stones are used for preparing the under water apron. Sample cross section at stn 0.6km shows 1V:1.2H steep underwater launched slope.

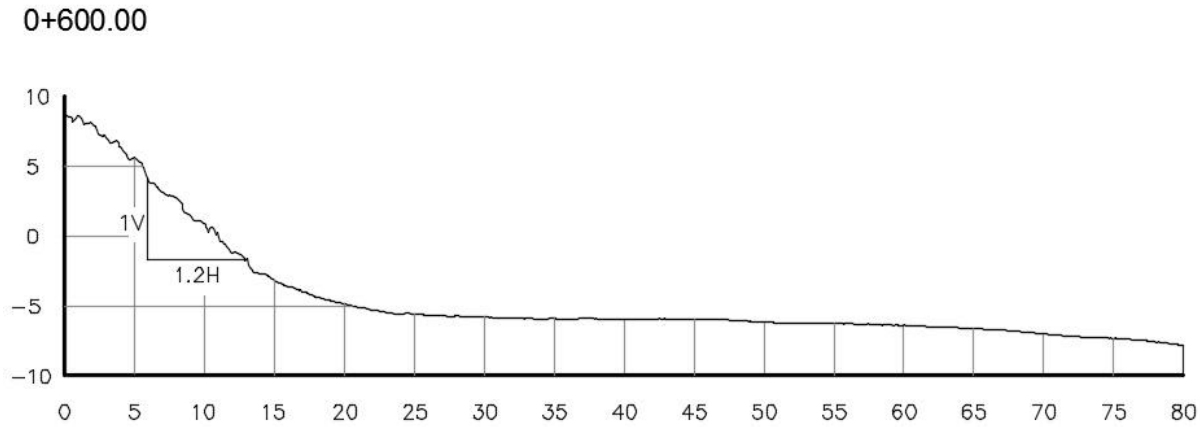


Figure 4-10 Step slop at stn 0+600

Detail multibeam survey maps are provided in Appendix 8.9.

4.4.1 Sirajganj Hardpoint

Sirajganj Hard-Point' has been built between 1995 and 1999 to protect Sirajganj town and adjacent areas from erosion. There were failures in 2009, 2010 and in 2011. The original revetment design was based on a scour depth of -11.00 mPWD; in the year 2009, the design of the launching apron was revised for a scour depth of -22.00 mPWD. MBE survey was conducted on 17 November 2019 to map the scour at the hard point. Key findings were:

(i) Deep scour in particular at the downstream end is -21mPWD at stn 0.5
(ii) At hardpoint site steep slope observes. Slope varies from 1V:1H to 1V:2H with most slopes being around 1V:1.5H. the steepest slopes occur at the head of the hardpoint

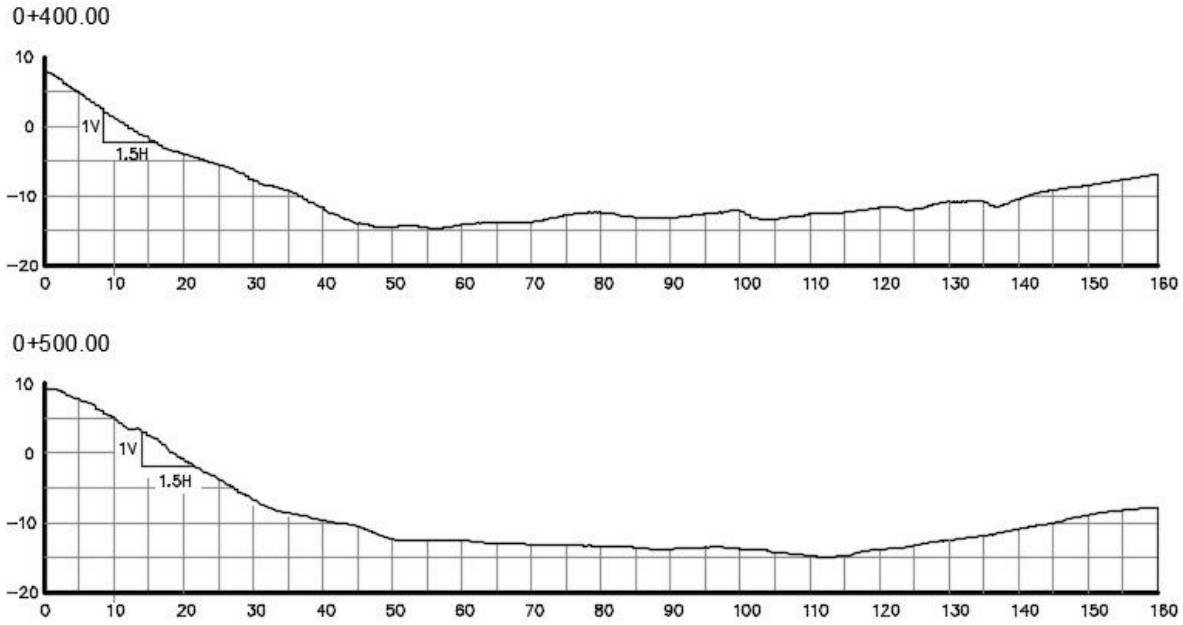


Figure 4-11 Steep slope at the hardpoint area

(iii) Distinct protrusion scour showing impact of eddy on downstream side.

Table 4-12 Findings alongside the Sirajganj Hardpoint

Time period	Sedimentation (>+7 m+PWD)	Deep Scour (<-11 m+PWD)	Deep Scour length	Deepest scour location
17 November 2019		Stn. 0.1 to 0.6	0.5km	Stn 0.5; -21

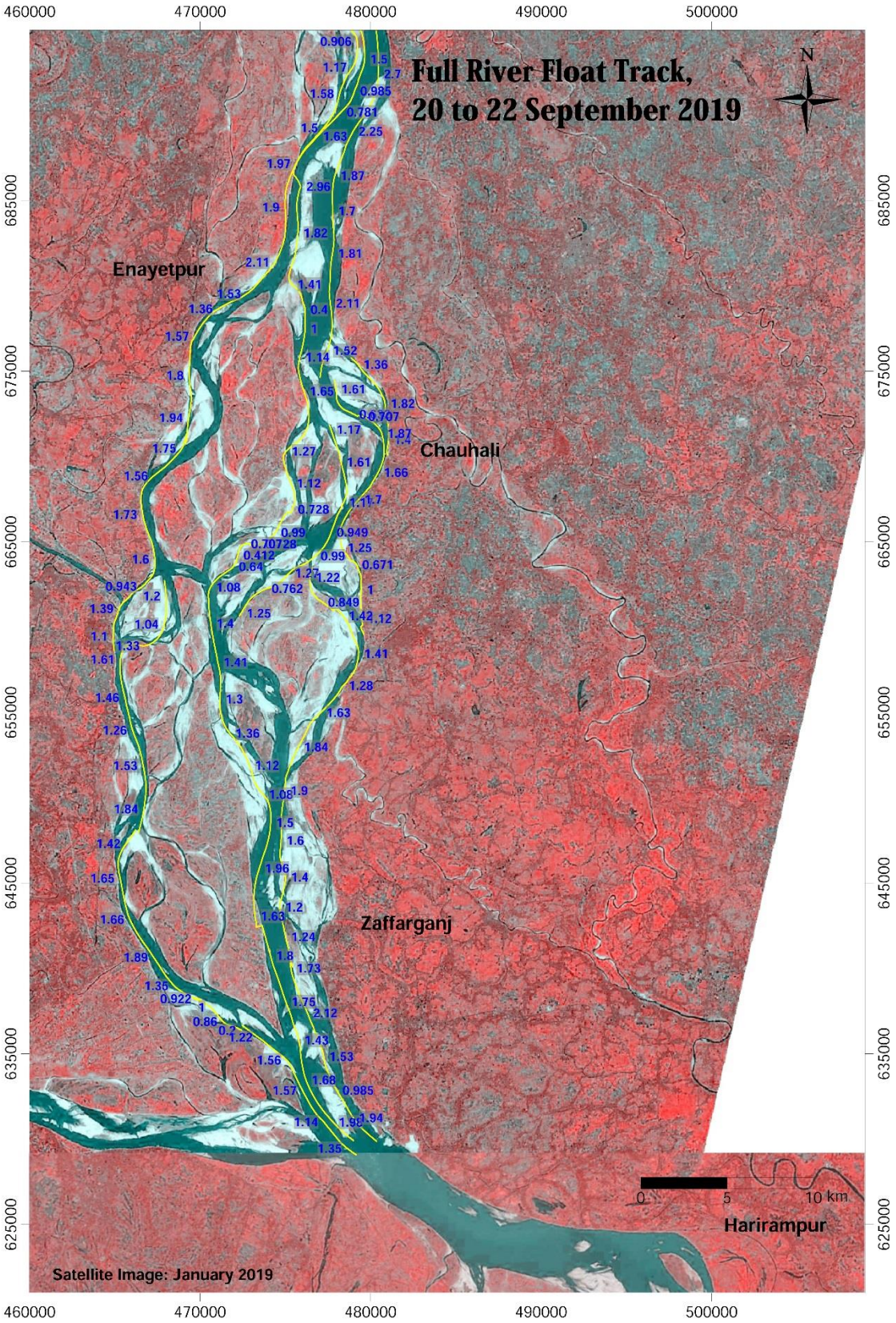
Detail multibeam survey maps are provided in Appendix 8.8.

4.5 All site failures

In 2019 flood season no failures were observed at any of the surveyed sites.

Appendices

1 Float tracking



2 Survey quality

2.1 Chauhali

Survey Date	Parameter	Comments
July 25-27,2019	Status	Accepted
	Survey Interval	50m interval 400m wide and 500m interval 1km wide section
	Survey length	8km
	Survey coverage towards river	400 to 1000m
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
October 26,2019	Status	Accepted
	Survey interval	100
	Survey length	8km
	Survey coverage towards river	350m
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency

2.2 Zafarganj

Survey Date	Parameter	Comments
July 28, 2019	Status	Accepted
	Survey interval	50m
	Survey length	3.3km
	Survey coverage towards river	300m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
October 31, 2019	Status	Accepted
	Survey interval	100m
	Survey length	1.8km
	Survey coverage towards river	300m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency

2.3 Harirampur

Survey Date	Parameter	Comment
August 22, 2019	Status	Accepted
	Survey interval	100m
	Survey length	1.2km
	Survey coverage towards river	250m
	Data missing	No
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
September 5, 2019	Status	Accepted
	Survey data interval	100m
	Survey length	2.7km
	Survey coverage towards river	200m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency

Survey Date	Parameter	Comment
November 2-3, 2019	Status	Accepted
	Survey data interval	100m
	Survey length	9.4km
	Survey coverage towards river	250m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
November 13-14, 2019 Multibeam Survey	Status	Accepted
	Survey data interval	50 percent overlapping line
	Survey length	5km
	Survey coverage towards river	150m

2.4 Koijuri

Survey Date	Parameter	Comment
October 25-27, 2019	Status	Accepted
	Survey interval	100m
	Survey length	9km
	Survey coverage towards river	350m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
October 05-06, 2019	Status	Accepted
	Survey data interval	50 percent overlapping line
	Survey length	4km
	Survey coverage towards river	150m

2.5 Benotia

Survey Date	Parameter	Comment
July 18, 2019	Status	Accepted
	Survey interval	50m
	Survey length	3km
	Survey coverage towards river	350m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
July 24-25, 2019	Status	Accepted
	Survey interval	50m
	Survey length	3km
	Survey coverage towards river	350m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency

2.6 PIRDP

Survey Date	Parameter	Comment
October 25-27, 2019	Status	Accepted
	Survey interval	100m
	Survey length	6.5km
	Survey coverage towards river	350m
	Data missing	nil
	Boat direction	R/S to C/S
	Echo sounder & frequency	Duel frequency
November 07, 2019	Status	Accepted

Survey Date	Parameter	Comment
	Survey data interval Survey length Survey coverage towards river	50 percent overlapping line 1km 150m
November 10, 2019	Status Survey data interval Survey length Survey coverage towards river	Accepted 50 percent overlapping line 2km 150m

2.7 Nagarbari

Survey Date	Parameter	Comment
October 25-27, 2019	Status Survey interval Survey length Survey coverage towards river Data missing Boat direction Echo sounder & frequency	Accepted 100m 4.3km 350m nil R/S to C/S Duel frequency
November 12-15, 2019	Status Survey data interval Survey length Survey coverage towards river	Accepted 50 percent overlapping line 4.3km 150m

2.8 Sirajganj Hardpoint

Survey Date	Parameter	Comment
November 17, 2019	Status Survey interval Survey length Survey coverage towards river	Accepted 50 percent overlapping line 0.7km 150m

2.9 Sirajganj Cross bar 3

Survey Date	Parameter	Comment
November 17, 2019	Status Survey interval Survey length Survey coverage towards river	Accepted 50 percent overlapping line 1km 150m

3 Benchmarks

Sl No	BM / TBM ID	Description	Easting (UTM)	Northing (UTM)	RL (MSL)
1	BM 2102	The pillar is situated in the south west corner of the compound of Belkuchi Upozila Parisad, Belkuchi, Sirajganj	773995	2689853	13.022
2	BM 2102 B	The pillar is situated in the compound of Thutia High School and College. It is in the Koijuri Hat (Market), Joypur, Shahajadpur, Sirajganj.	773523	2675894	12.374

3	BM 2301	The pillar is situated in the compound of Jhitka Pilot High School and College, Kalikapur, Harirampur, Manikganj	787018	2632145	8.866
4	GPS 5263	The pillar is situated in the compound of Diar Brahmandi Reg. Non-Govt Primary School, Kaji Sharifpur, Bera, Pabna	770455	2644588	10.626
5	GPS 5624	The pillar is situated in the north-east corner of Aladipur High School's playground, Aladipur, Rajbari.	770997	2625574	8.355

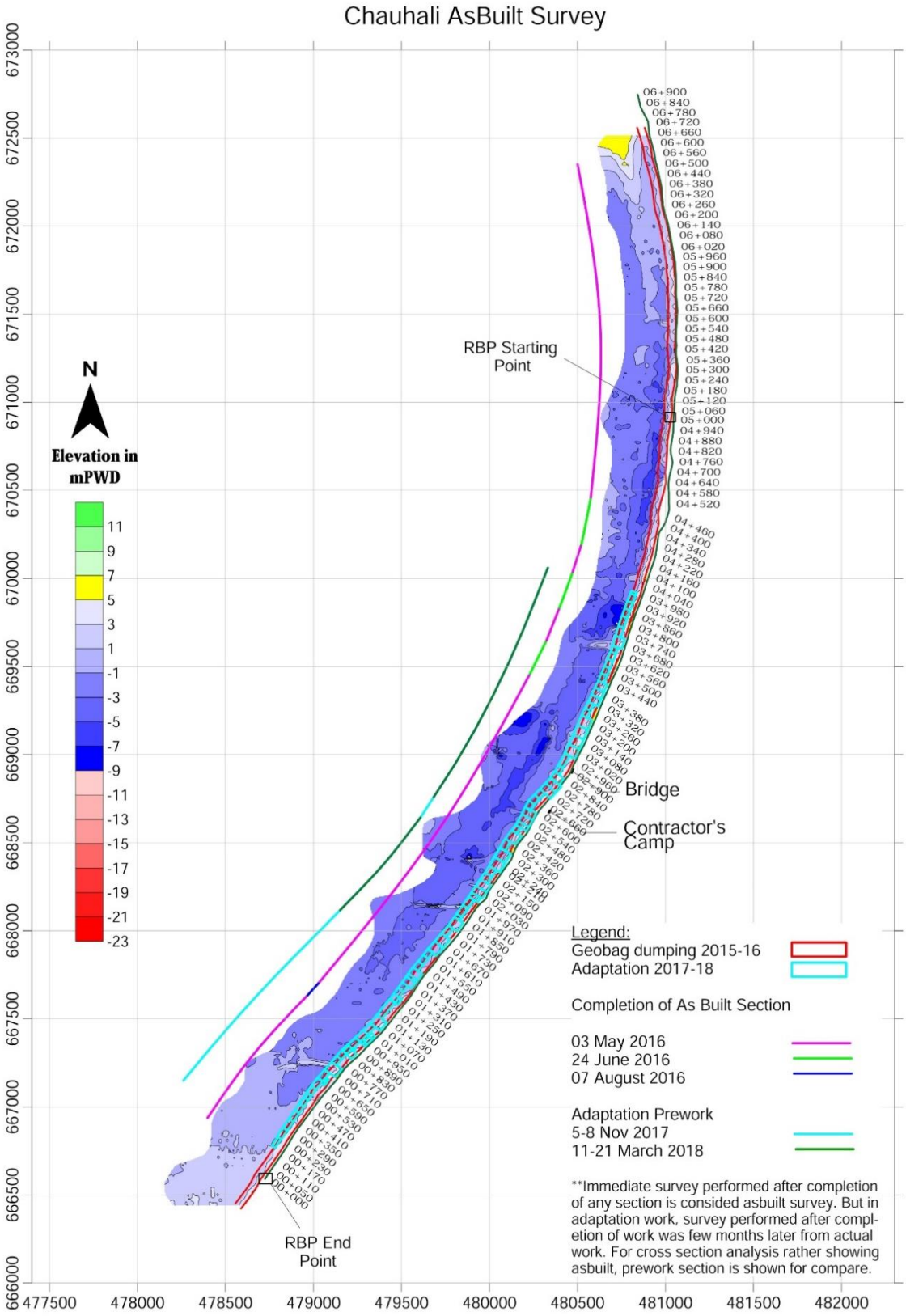
4 List of slope failures at Chauhali

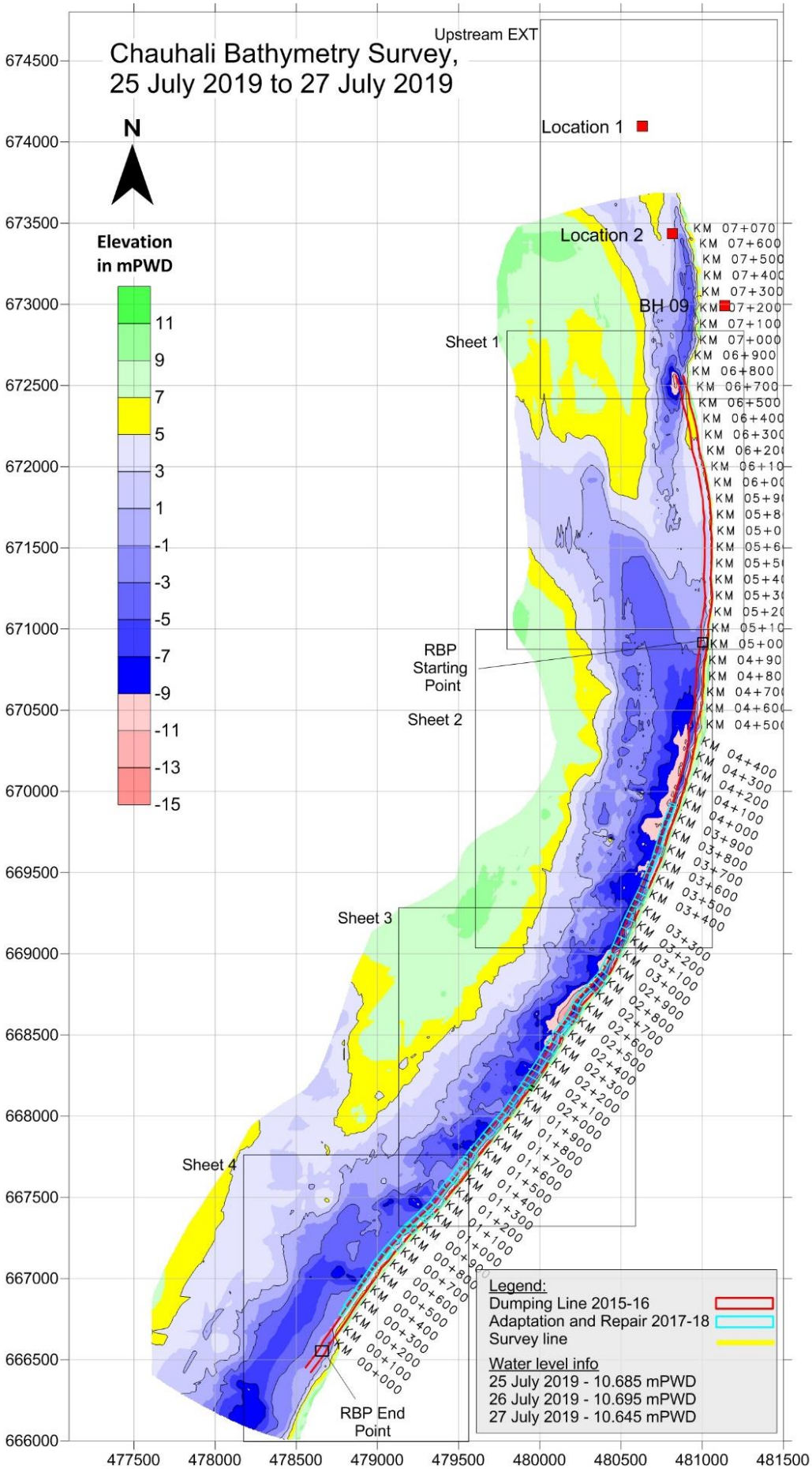
Date	Erosion Code	Chauhali WL	Chainage		Length	Failure Description
			Start	End		
16/06/16	16-4.6	7.55	4600	4627	27	in temporary protection work
19/06/16	16-4.3	8.69	4335	4400	65	in temporary protection work
20/06/16	16-4.7	8.74	4740	4800	60	in temporary protection work
27/06/16	16-4.4	10.15	4410	4480	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.
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.

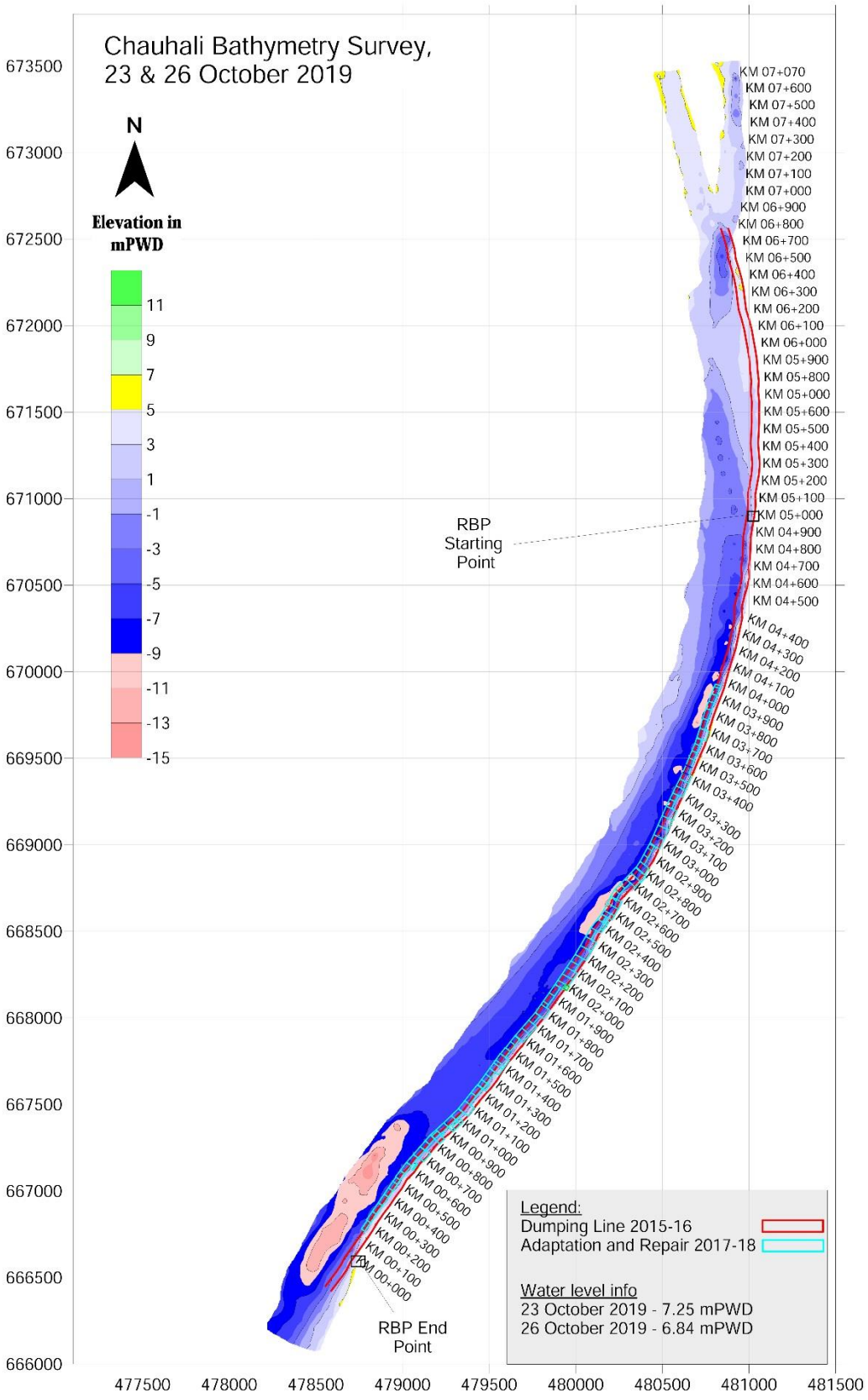
Date	Erosion Code	Chauhali WL	Chainage		Length	Failure Description
			Start	End		
23/07/17	17-2.2	9.98	2205	2235	30	in permanent protection work.
25/07/17	17-3.0	9.98	3050	3080	30	in permanent protection work.
31/07/17	17-2.31	9.65	2310	2350	40	in permanent protection work.
31/07/17	17-3.11	9.65	3100	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

5 Bathymetric Surveys

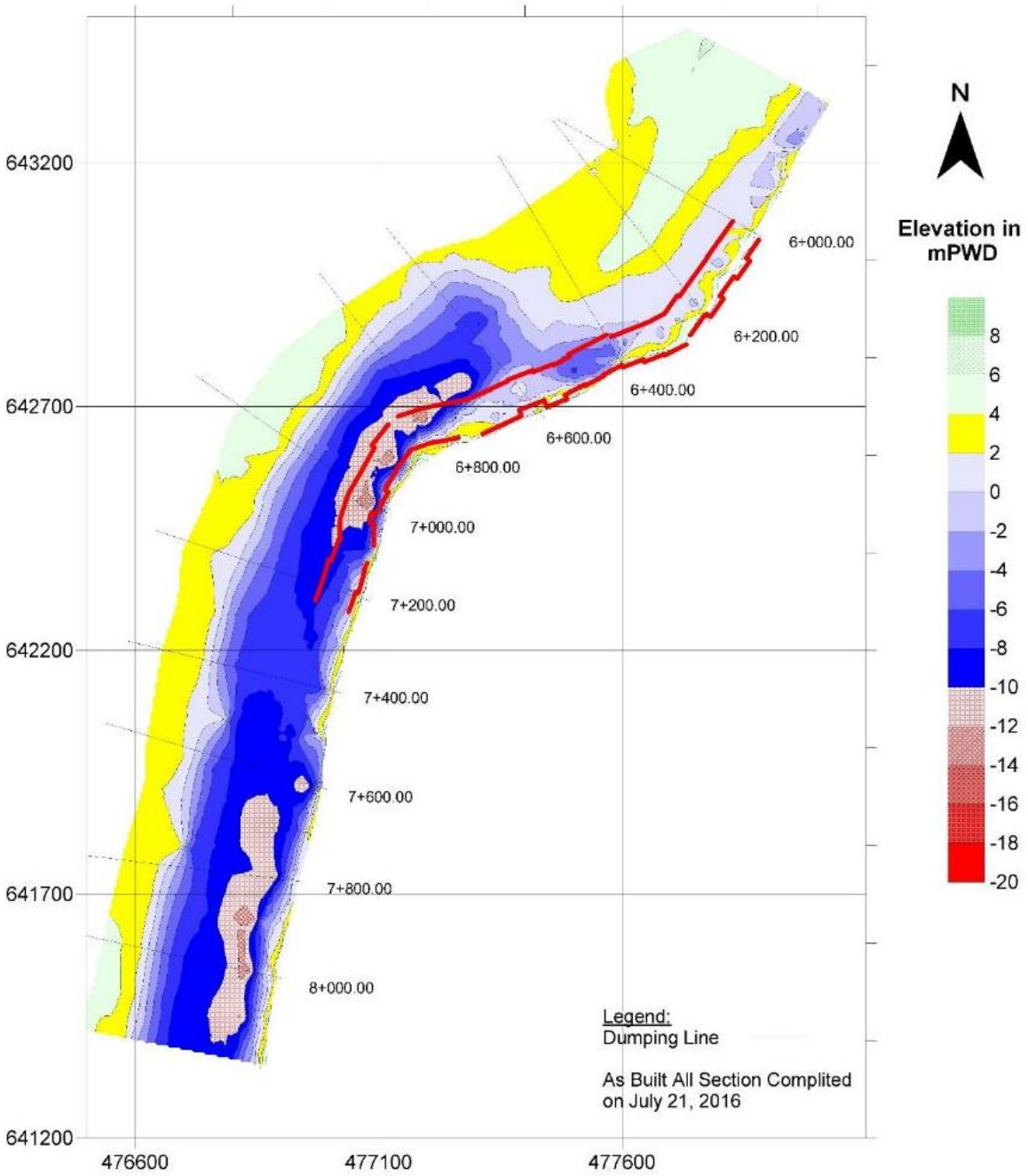
5.1 Chauhali

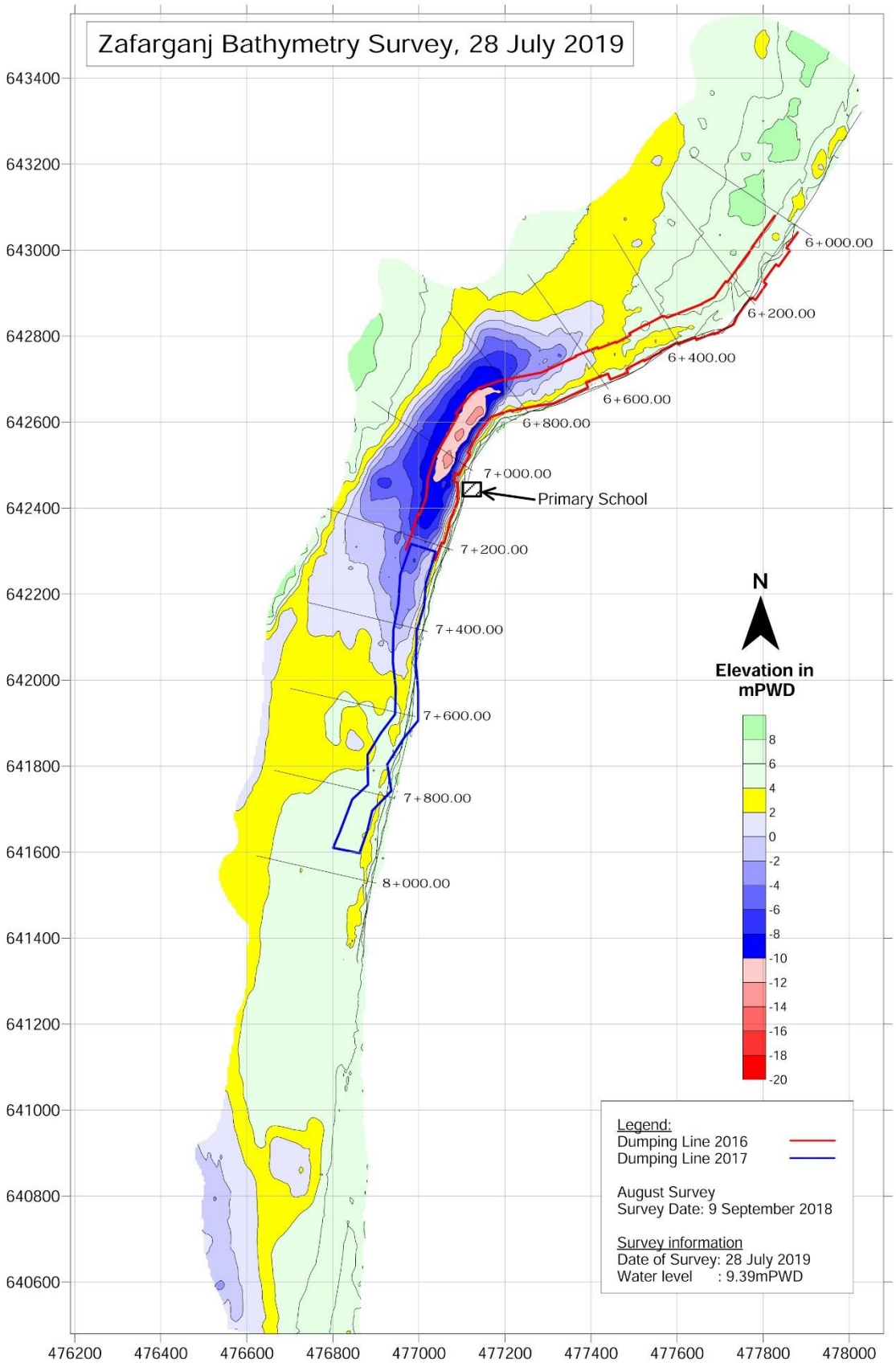


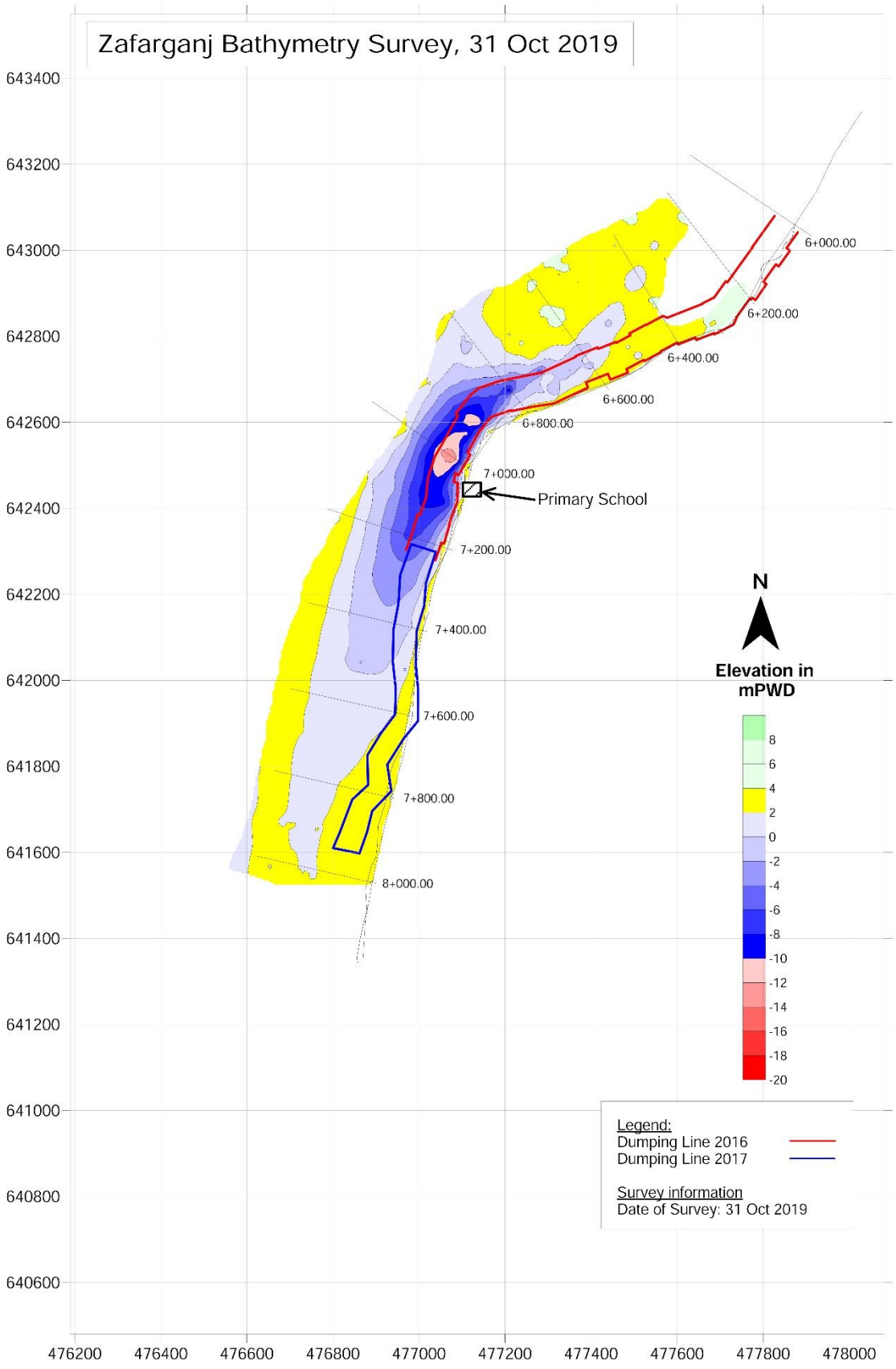

Chauhali Bathymetry Survey,
25 July 2019 to 27 July 2019
N
Elevation in mPWD
11
9
7
5
3
1
-1
-3
-5
-7
-9
-11
-13
-15
Upstream EXT
Location 1
Location 2
BH 09
Sheet 1
Sheet 2
Sheet 3
Sheet 4
RBP Starting Point
RBP End Point
Legend:
Dumping Line 2015-16
Adaptation and Repair 2017-18
Survey line
Water level info
25 July 2019 - 10.685 mPWD
26 July 2019 - 10.695 mPWD
27 July 2019 - 10.645 mPWD
674500
674000
673500
673000
672500
672000
671500
671000
670500
670000
669500
669000
668500
668000
667500
667000
666500
666000
477500
478000
478500
479000
479500
480000
480500
481000
481500


Chauhali Bathymetry Survey,
23 & 26 October 2019
N
Elevation in mPWD
11
9
7
5
3
1
-1
-3
-5
-7
-9
-11
-13
-15
RBP Starting Point
RBP End Point
KM 07+070
KM 07+600
KM 07+500
KM 07+400
KM 07+300
KM 07+200
KM 07+100
KM 07+000
KM 06+900
KM 06+800
KM 06+700
KM 06+500
KM 06+400
KM 06+300
KM 06+200
KM 06+100
KM 06+000
KM 05+900
KM 05+800
KM 05+000
KM 05+600
KM 05+500
KM 05+400
KM 05+300
KM 05+200
KM 05+100
KM 05+000
KM 04+900
KM 04+800
KM 04+700
KM 04+600
KM 04+500
KM 04+400
KM 04+300
KM 04+200
KM 04+100
KM 04+000
KM 03+900
KM 03+800
KM 03+700
KM 03+600
KM 03+500
KM 03+400
KM 03+300
KM 03+200
KM 03+100
KM 03+000
KM 02+900
KM 02+800
KM 02+700
KM 02+600
KM 02+500
KM 02+400
KM 02+300
KM 02+200
KM 02+100
KM 02+000
KM 01+900
KM 01+800
KM 01+700
KM 01+600
KM 01+500
KM 01+400
KM 01+300
KM 01+200
KM 01+100
KM 01+000
KM 00+900
KM 00+800
KM 00+700
KM 00+600
KM 00+500
KM 00+400
KM 00+300
KM 00+200
KM 00+100
KM 00+000
Legend:
Dumping Line 2015-16
Adaptation and Repair 2017-18
Water level info
23 October 2019 - 7.25 mPWD
26 October 2019 - 6.84 mPWD
673500
673000
672500
672000
671500
671000
670500
670000
669500
669000
668500
668000
667500
667000
666500
666000
477500
478000
478500
479000
479500
480000
480500
481000
481500

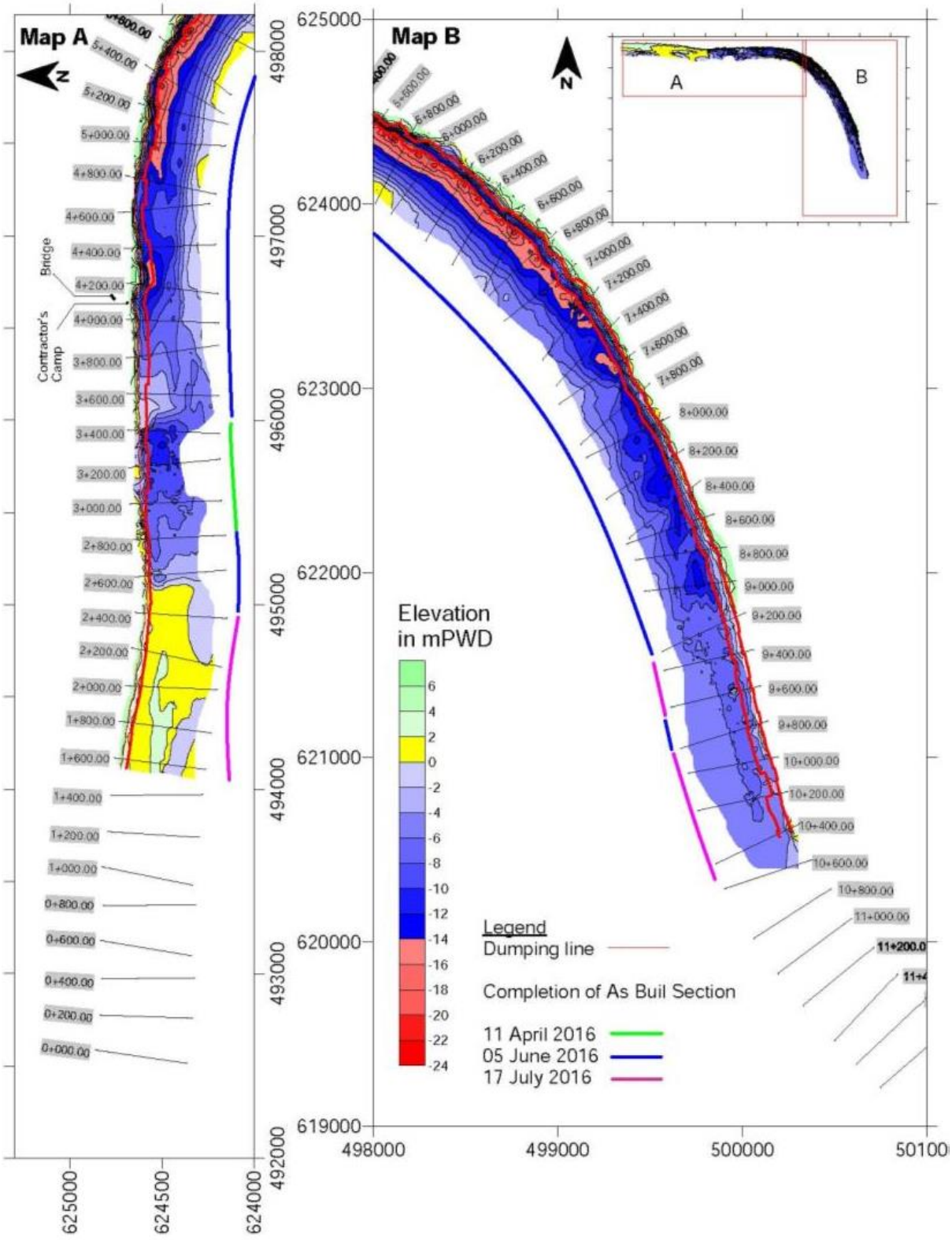
5.2 Zafarganj

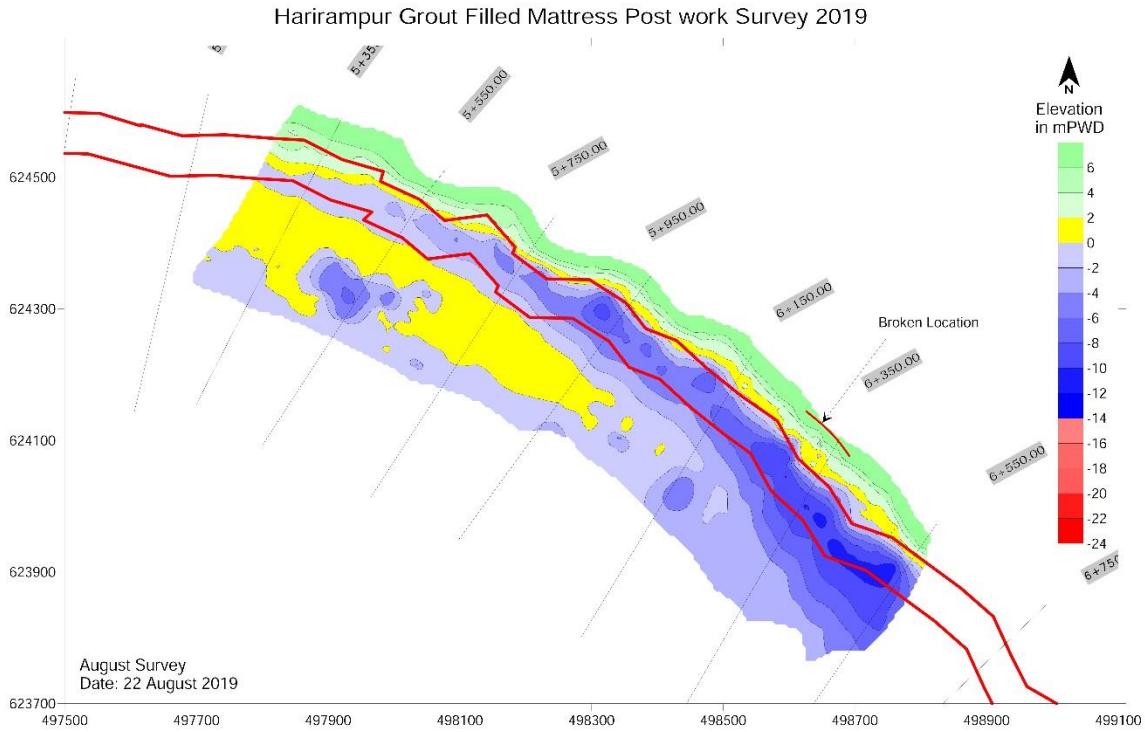



Zafarganj Bathymetry Survey, 28 July 2019
643400
643200
643000
642800
642600
642400
642200
642000
641800
641600
641400
641200
641000
640800
640600
476200
476400
476600
476800
477000
477200
477400
477600
477800
478000
6+000.00
6+200.00
6+400.00
6+600.00
6+800.00
7+000.00
Primary School
7+200.00
7+400.00
7+600.00
7+800.00
8+000.00
N
Elevation in mPWD
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
Legend:
Dumping Line 2016
Dumping Line 2017
August Survey
Survey Date: 9 September 2018
Survey information
Date of Survey: 28 July 2019
Water level : 9.39mPWD

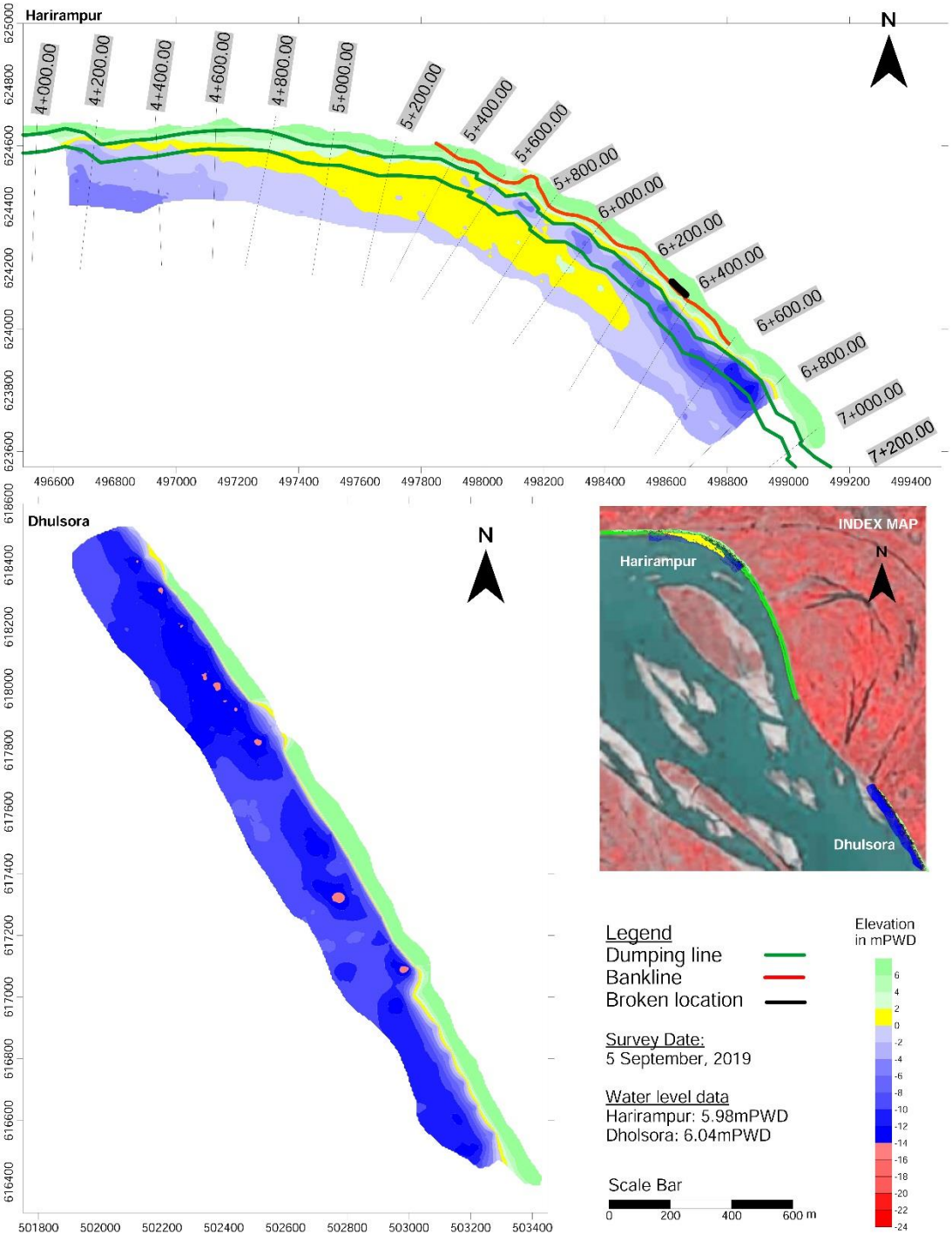

Zafarganj Bathymetry Survey, 31 Oct 2019
643400
643200
643000
642800
642600
642400
642200
642000
641800
641600
641400
641200
641000
640800
640600
476200
476400
476600
476800
477000
477200
477400
477600
477800
478000
6+000.00
6+200.00
6+400.00
6+600.00
6+800.00
7+000.00
Primary School
7+200.00
7+400.00
7+600.00
7+800.00
8+000.00
N
Elevation in mPWD
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
Legend:
Dumping Line 2016
Dumping Line 2017
Survey information
Date of Survey: 31 Oct 2019

5.3 Harirampur

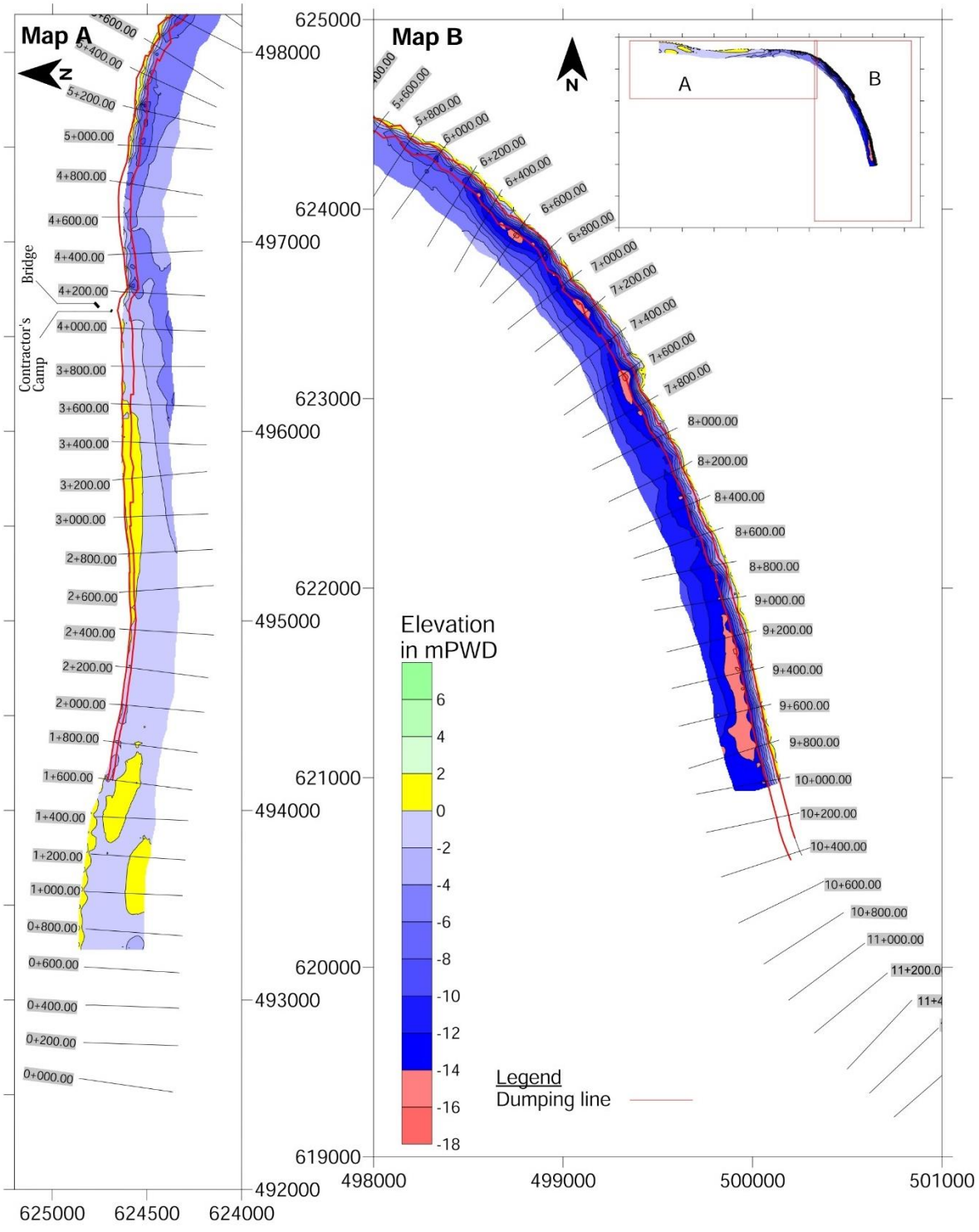



Harirampur Grout Filled Mattress Post work Survey 2019
N
Elevation
in mPWD
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
5+550.00
5+750.00
5+950.00
6+150.00
Broken Location
6+350.00
6+550.00
624500
624300
624100
623900
623700
497500
497700
497900
498100
498300
498500
498700
498900
499100
August Survey
Date: 22 August 2019

Harirampur Test Survey by IWM, 5 September 2019

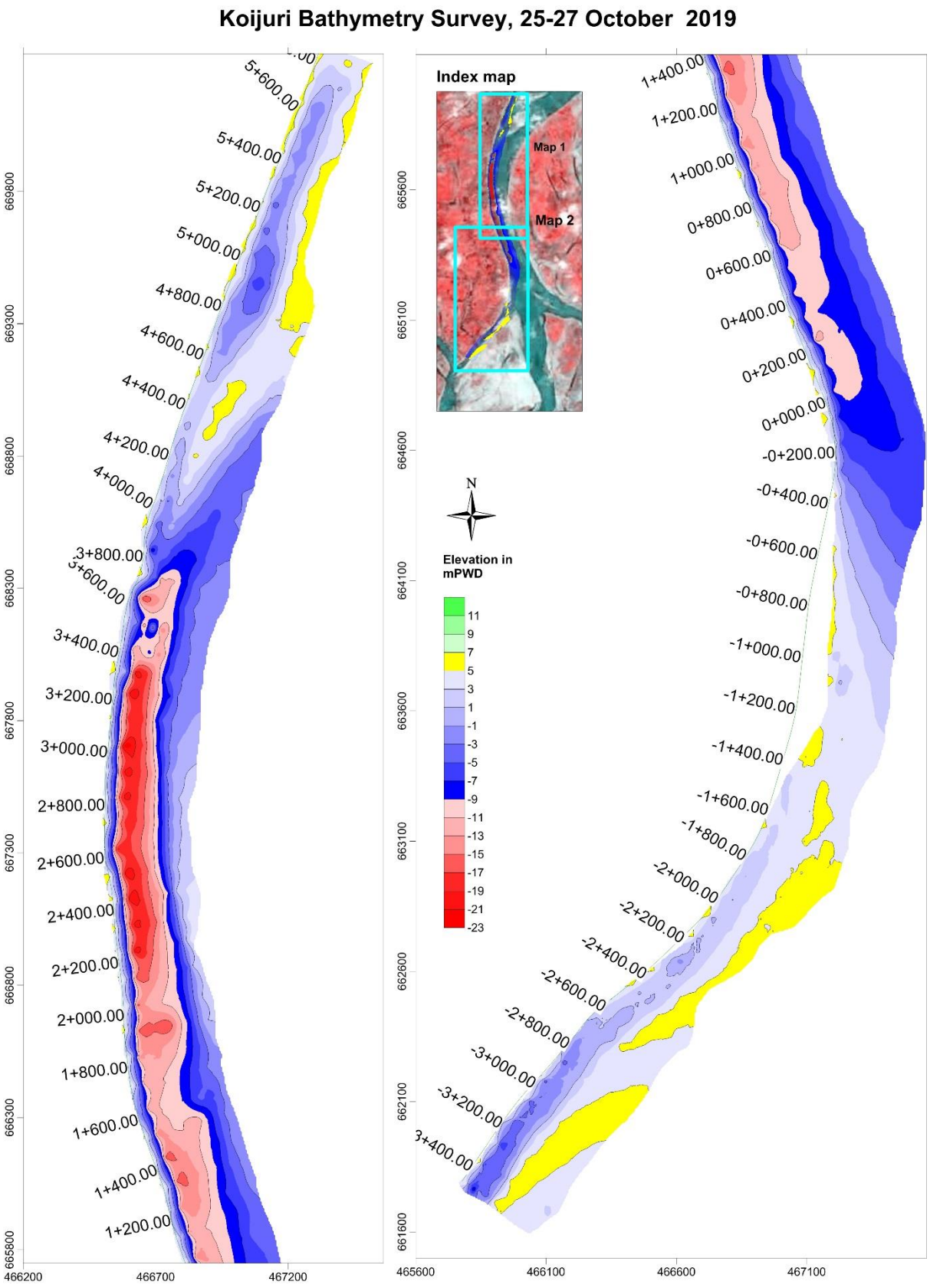


Harirampur Bathymetry Survey, 2 to 3 November, 2019

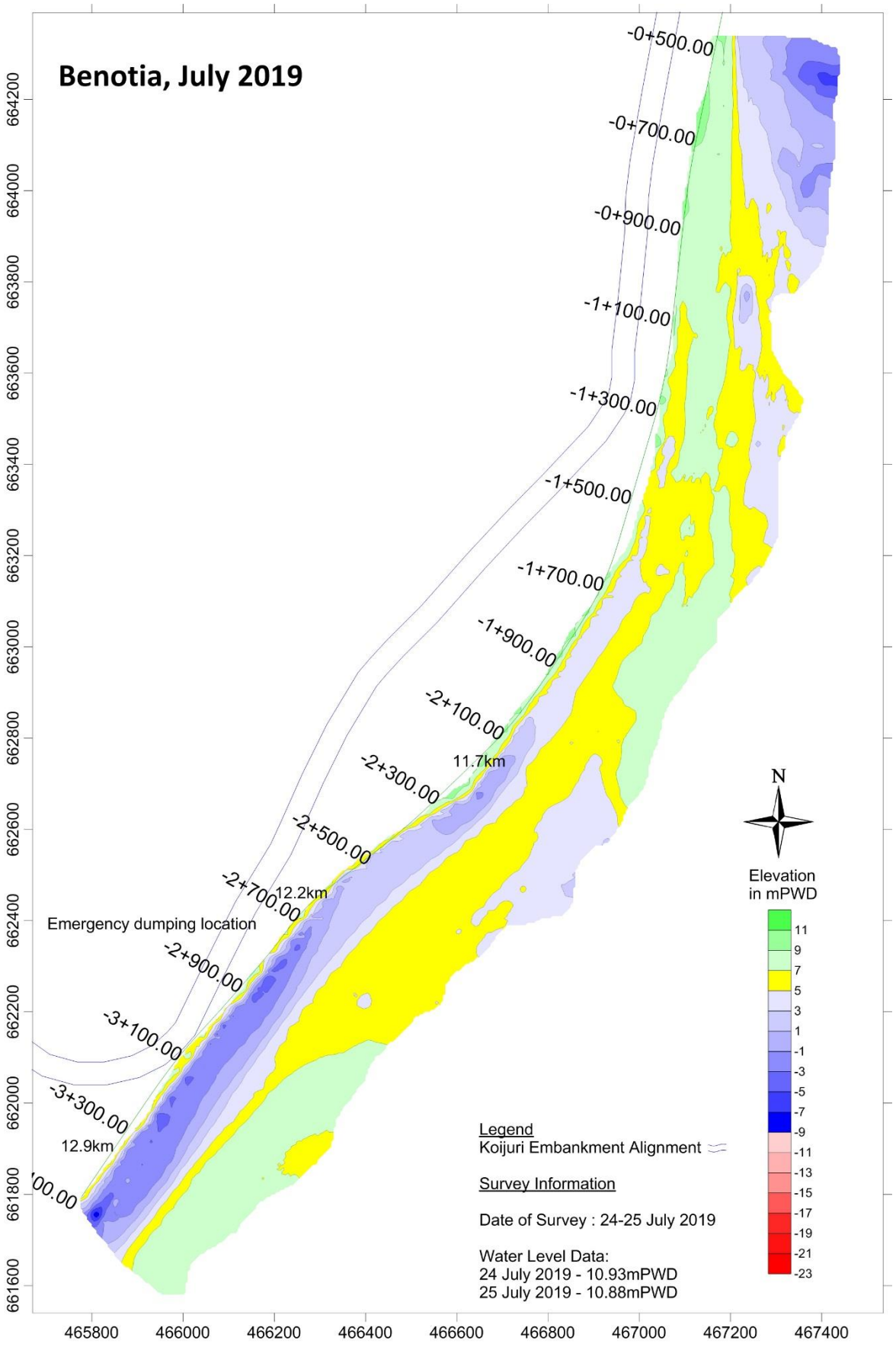


November Survey
Date: 02 to 03 November, 2019

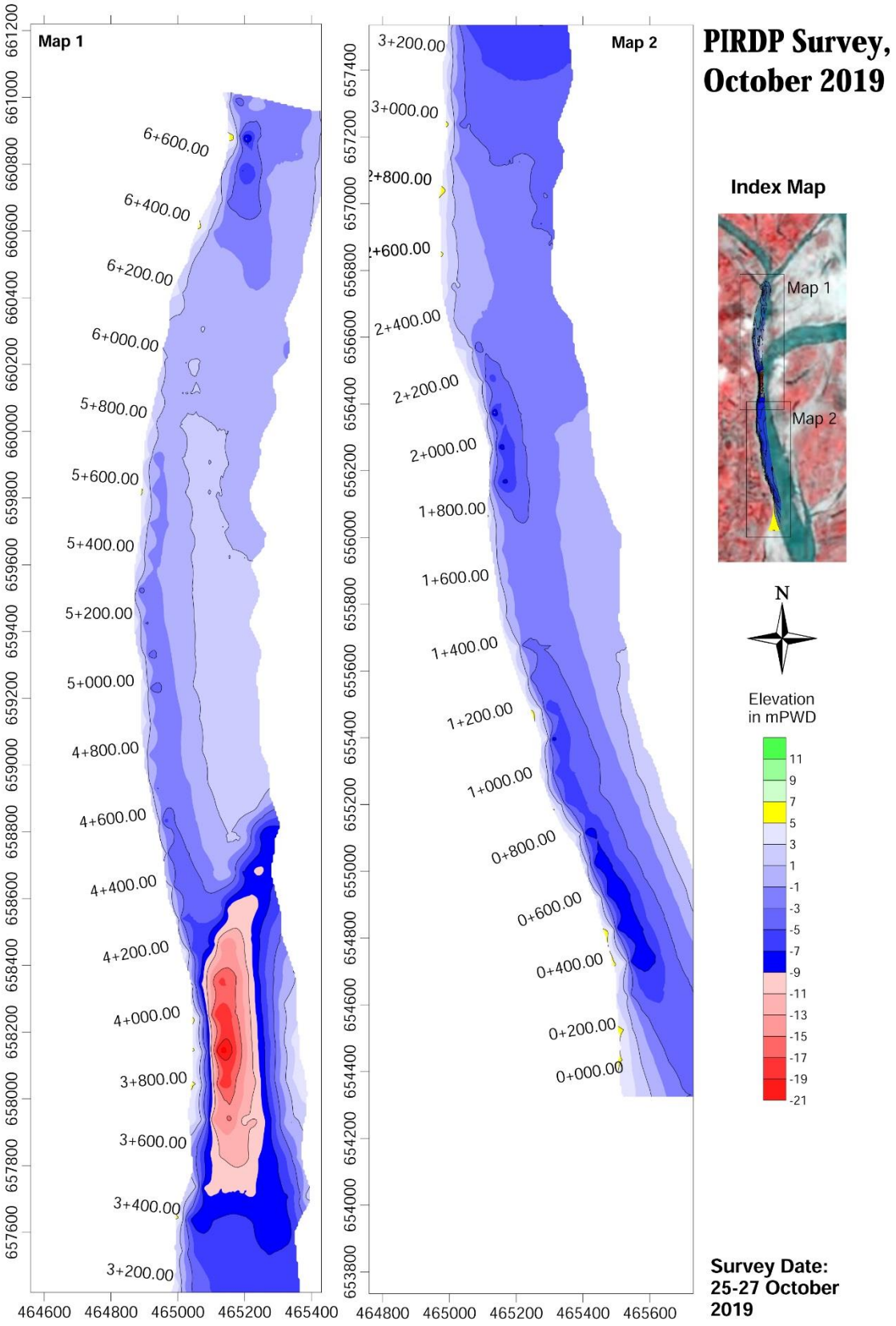
5.4 Koijuri


Koijuri Bathymetry Survey, 25-27 October 2019
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
-23
5+600.00
5+400.00
5+200.00
5+000.00
4+800.00
4+600.00
4+400.00
4+200.00
4+000.00
3+800.00
3+600.00
3+400.00
3+200.00
3+000.00
2+800.00
2+600.00
2+400.00
2+200.00
2+000.00
1+800.00
1+600.00
1+400.00
1+200.00
1+400.00
1+200.00
1+000.00
0+800.00
0+600.00
0+400.00
0+200.00
0+000.00
-0+200.00
-0+400.00
-0+600.00
-0+800.00
-1+000.00
-1+200.00
-1+400.00
-1+600.00
-1+800.00
-2+000.00
-2+200.00
-2+400.00
-2+600.00
-2+800.00
-3+000.00
-3+200.00
3+400.00
669800
669300
668800
668300
667800
667300
666800
666300
665800
466200
466700
467200
665600
665100
664600
664100
663600
663100
662600
662100
661600
465600
466100
466600
467100

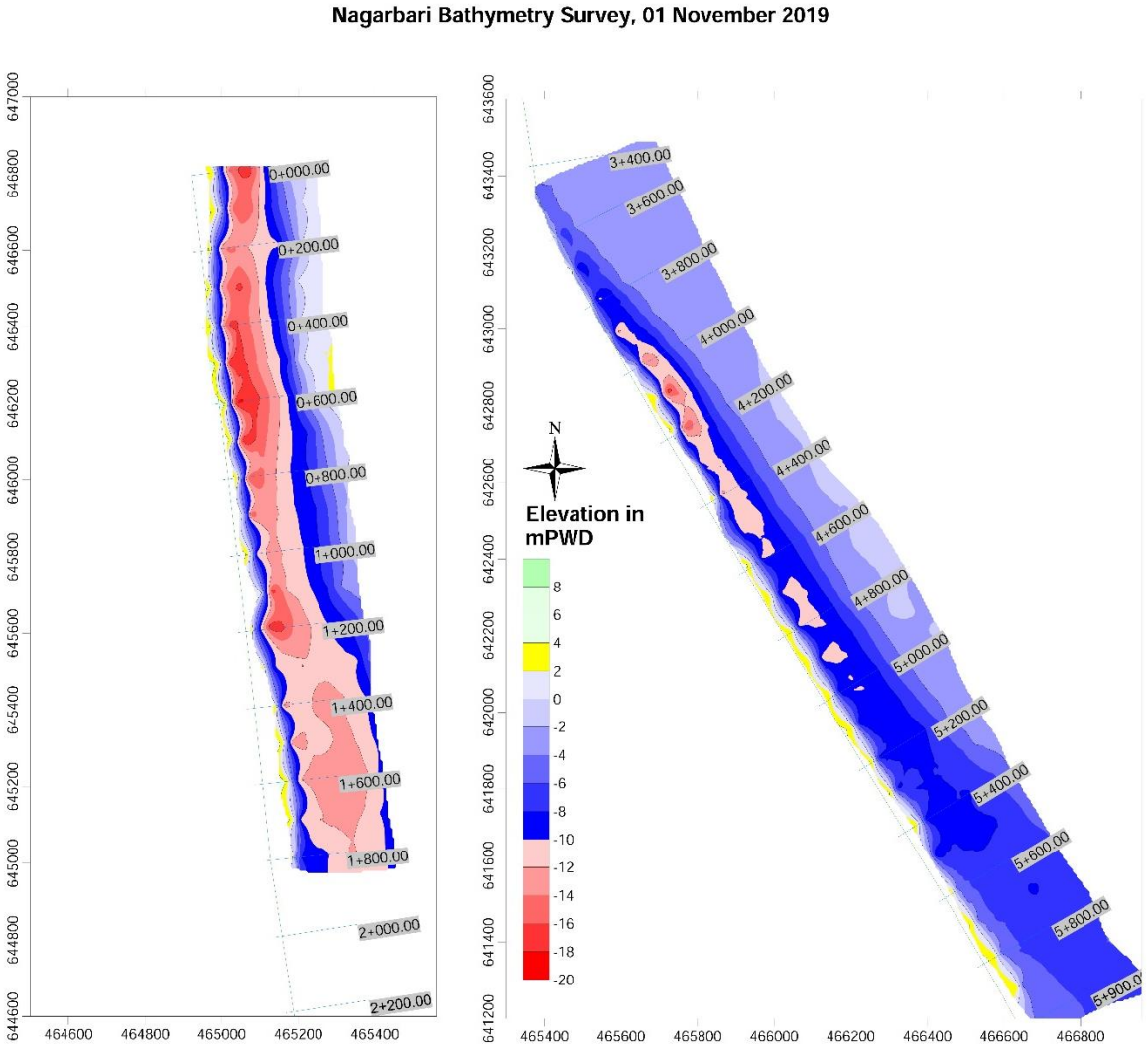
5.5 Benotia


Benotia, July 2019
-0+500.00
-0+700.00
-0+900.00
-1+100.00
-1+300.00
-1+500.00
-1+700.00
-1+900.00
-2+100.00
-2+300.00
-2+500.00
-2+700.00
-2+900.00
-3+100.00
-3+300.00
11.7km
12.2km
12.9km
Emergency dumping location
N
Elevation in mPWD
11
9
7
5
3
1
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
Legend
Koijuri Embankment Alignment
Survey Information
Date of Survey : 24-25 July 2019
Water Level Data:
24 July 2019 - 10.93mPWD
25 July 2019 - 10.88mPWD
664200
664000
663800
663600
663400
663200
663000
662800
662600
662400
662200
662000
661800
661600
465800
466000
466200
466400
466600
466800
467000
467200
467400

5.6 PIRDP

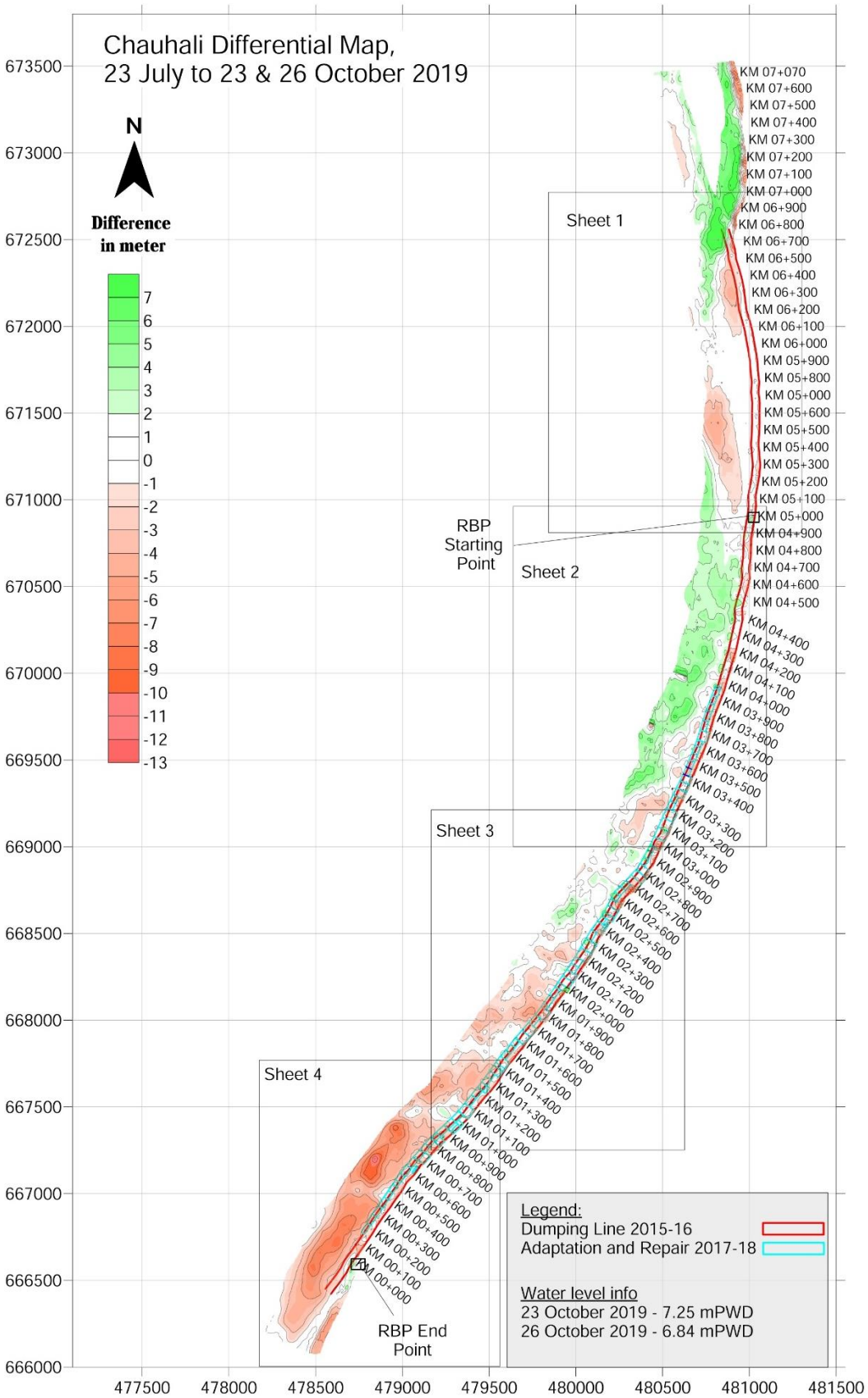

Map 1
Map 2
PIRDP Survey, October 2019
Index Map
Map 1
Map 2
N
Elevation in mPWD
11
9
7
5
3
1
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
Survey Date: 25-27 October 2019
6+600.00
6+400.00
6+200.00
6+000.00
5+800.00
5+600.00
5+400.00
5+200.00
5+000.00
4+800.00
4+600.00
4+400.00
4+200.00
4+000.00
3+800.00
3+600.00
3+400.00
3+200.00
3+000.00
2+800.00
2+600.00
2+400.00
2+200.00
2+000.00
1+800.00
1+600.00
1+400.00
1+200.00
1+000.00
0+800.00
0+600.00
0+400.00
0+200.00
0+000.00
464600
464800
465000
465200
465400
465600
653800
654000
654200
654400
654600
654800
655000
655200
655400
655600
655800
656000
656200
656400
656600
656800
657000
657200
657400
657600
657800
658000
658200
658400
658600
658800
659000
659200
659400
659600
659800
660000
660200
660400
660600
660800
661000
661200

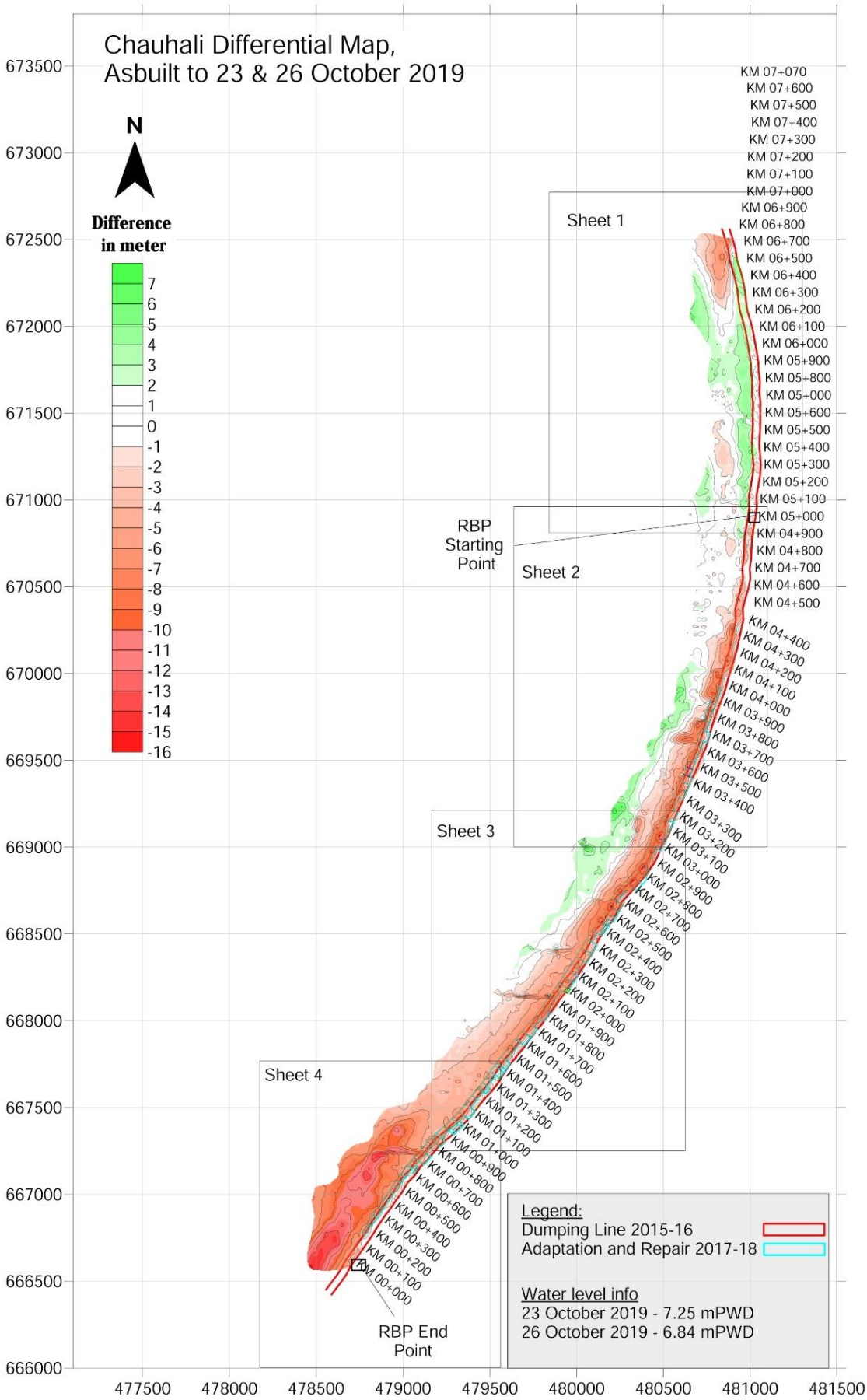
5.7 Nagarbari



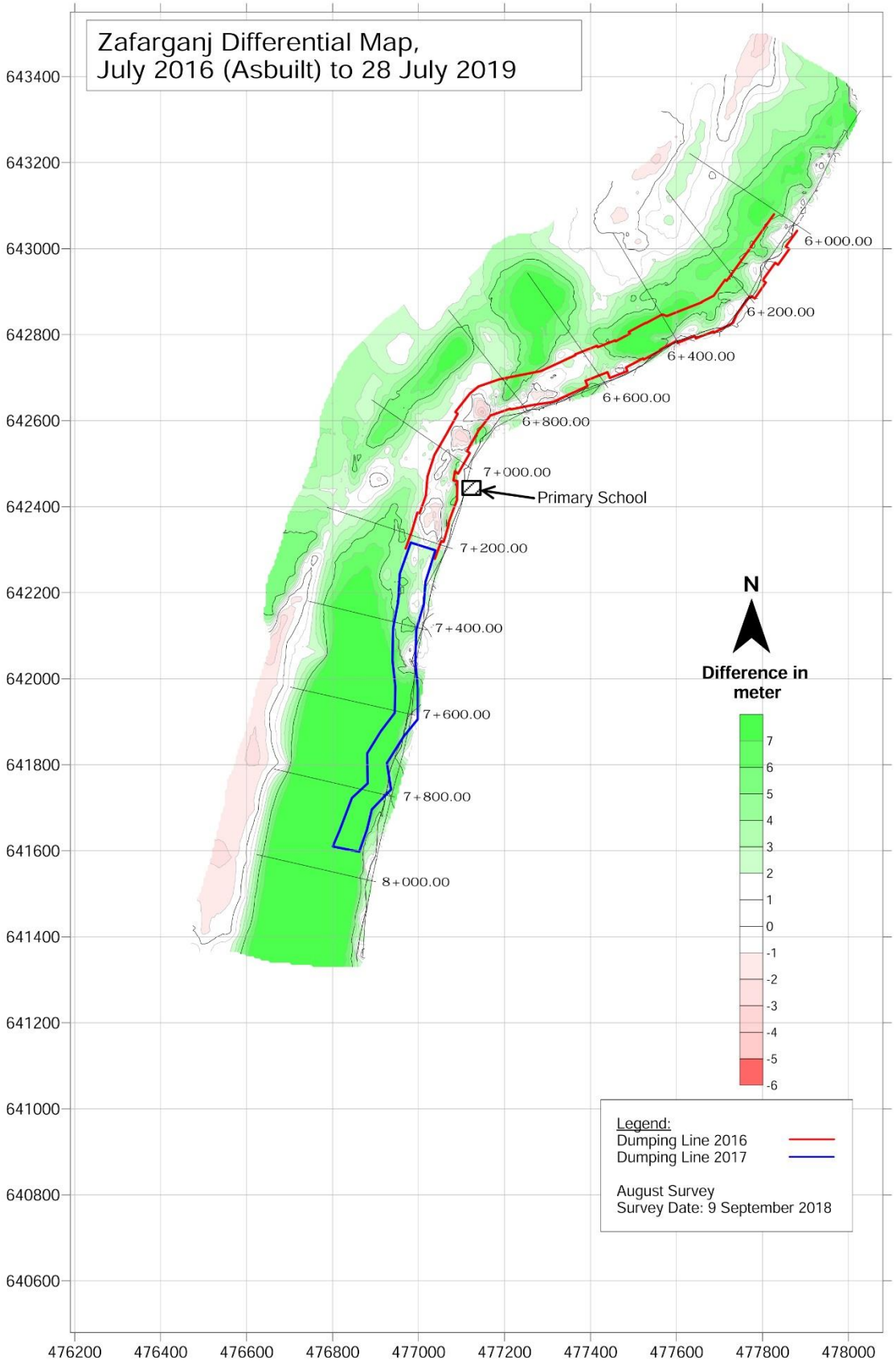
6 Differential Models

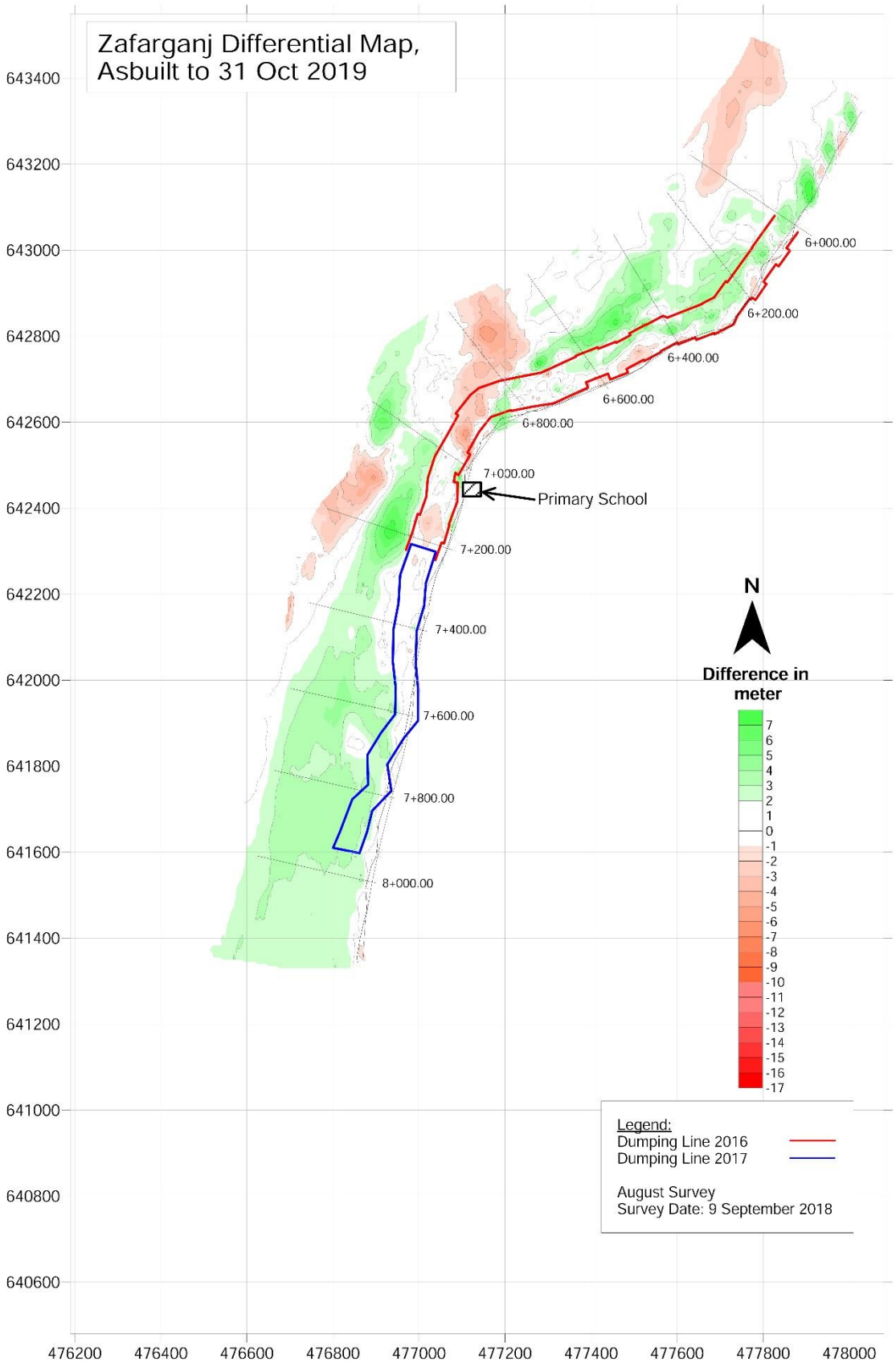
6.1 Chauhali



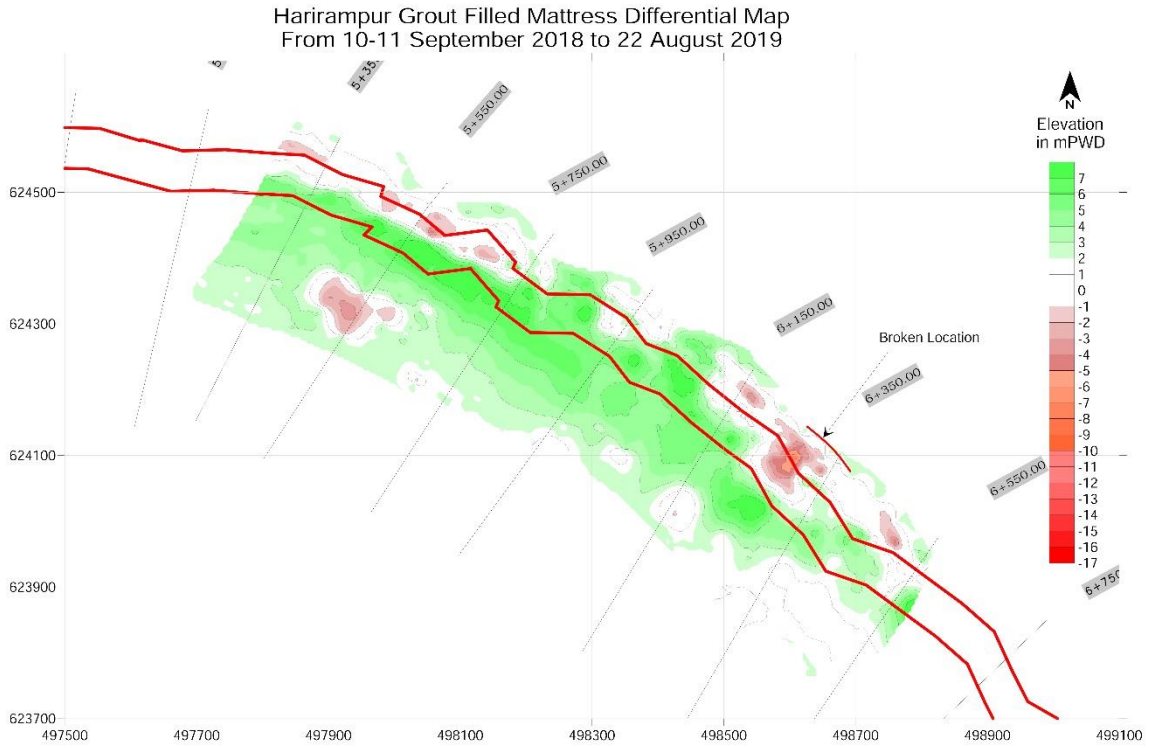

Chauhali Differential Map,
Asbuilt to 23 & 26 October 2019
N
Difference in meter
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
Sheet 1
Sheet 2
Sheet 3
Sheet 4
RBP Starting Point
RBP End Point
KM 07+070
KM 07+600
KM 07+500
KM 07+400
KM 07+300
KM 07+200
KM 07+100
KM 07+000
KM 06+900
KM 06+800
KM 06+700
KM 06+500
KM 06+400
KM 06+300
KM 06+200
KM 06+100
KM 06+000
KM 05+900
KM 05+800
KM 05+000
KM 05+600
KM 05+500
KM 05+400
KM 05+300
KM 05+200
KM 05+100
KM 05+000
KM 04+900
KM 04+800
KM 04+700
KM 04+600
KM 04+500
KM 04+400
KM 04+300
KM 04+200
KM 04+100
KM 04+000
KM 03+900
KM 03+800
KM 03+700
KM 03+600
KM 03+500
KM 03+400
KM 03+300
KM 03+200
KM 03+100
KM 03+000
KM 02+900
KM 02+800
KM 02+700
KM 02+600
KM 02+500
KM 02+400
KM 02+300
KM 02+200
KM 02+100
KM 02+000
KM 01+900
KM 01+800
KM 01+700
KM 01+600
KM 01+500
KM 01+400
KM 01+300
KM 01+200
KM 01+100
KM 01+000
KM 00+900
KM 00+800
KM 00+700
KM 00+600
KM 00+500
KM 00+400
KM 00+300
KM 00+200
KM 00+100
KM 00+000
Legend:
Dumping Line 2015-16
Adaptation and Repair 2017-18
Water level info
23 October 2019 - 7.25 mPWD
26 October 2019 - 6.84 mPWD
673500
673000
672500
672000
671500
671000
670500
670000
669500
669000
668500
668000
667500
667000
666500
666000
477500
478000
478500
479000
479500
480000
480500
481000
481500

6.2 Zafarganj



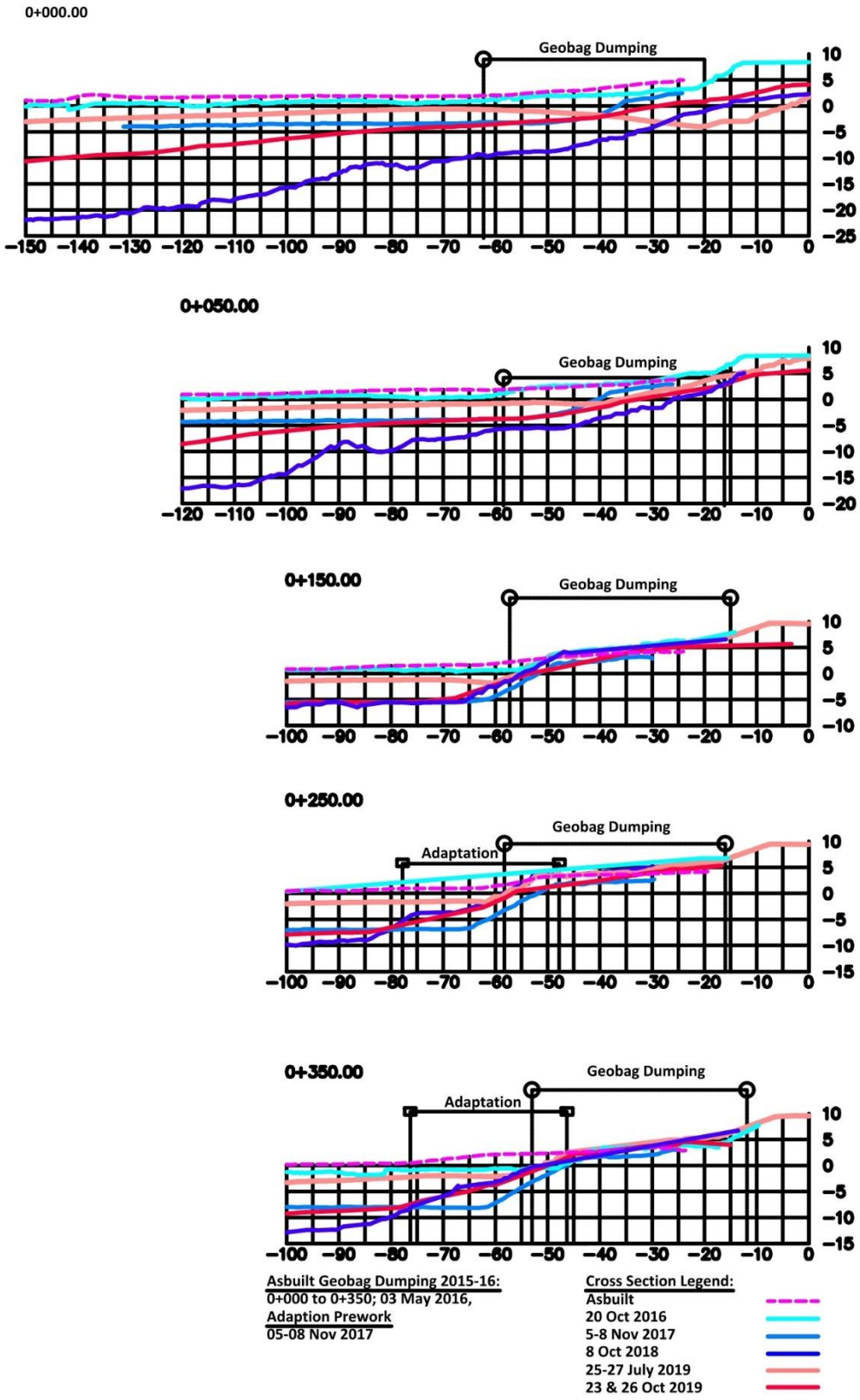

Zafarganj Differential Map,
Asbuilt to 31 Oct 2019
643400
643200
643000
642800
642600
642400
642200
642000
641800
641600
641400
641200
641000
640800
640600
476200
476400
476600
476800
477000
477200
477400
477600
477800
478000
6+000.00
6+200.00
6+400.00
6+600.00
6+800.00
7+000.00
Primary School
7+200.00
7+400.00
7+600.00
7+800.00
8+000.00
N
Difference in meter
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
Legend:
Dumping Line 2016
Dumping Line 2017
August Survey
Survey Date: 9 September 2018

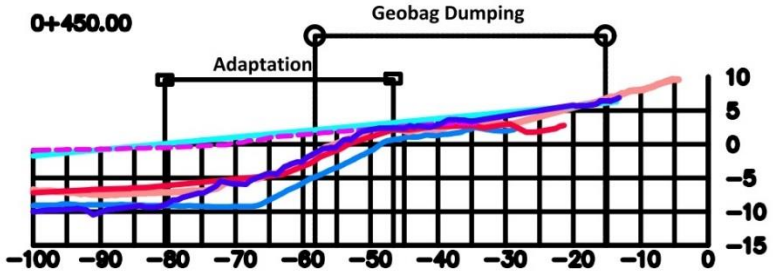
6.3 Harirampur

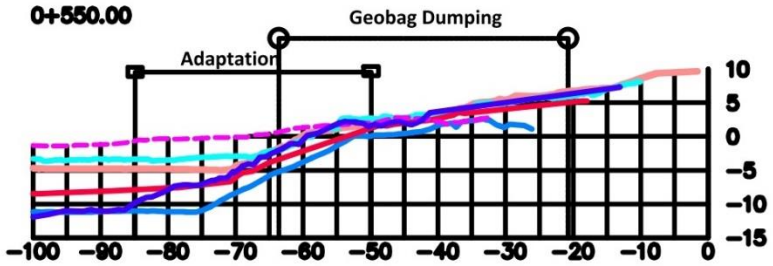


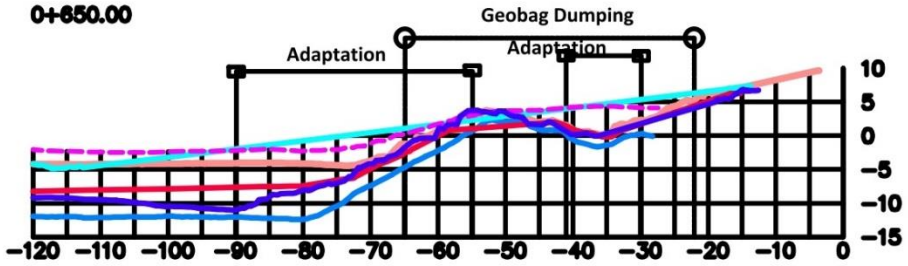
7 Cross section analysis

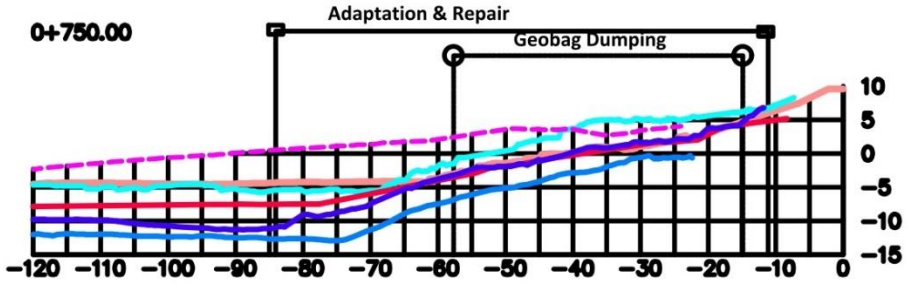
7.1 Chauhali

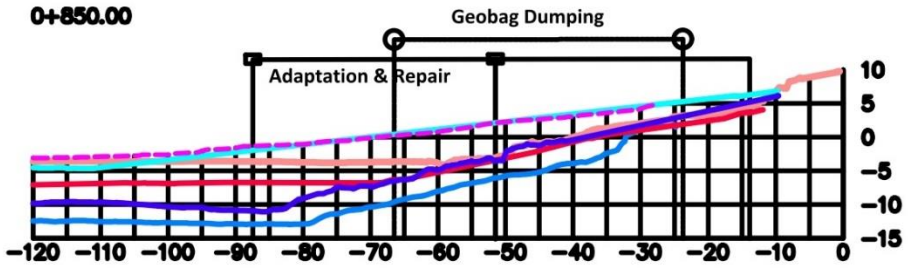








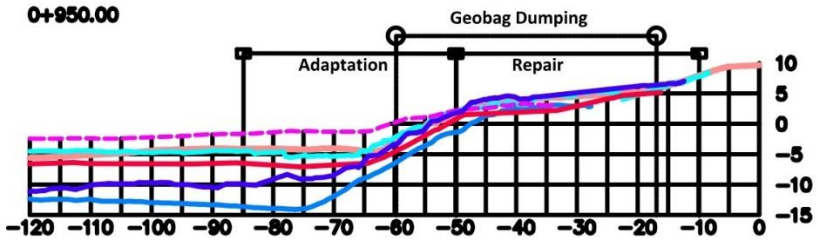


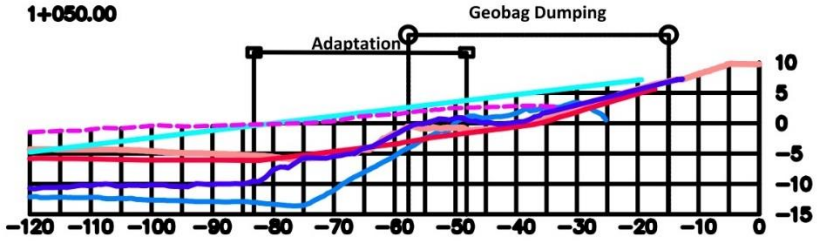


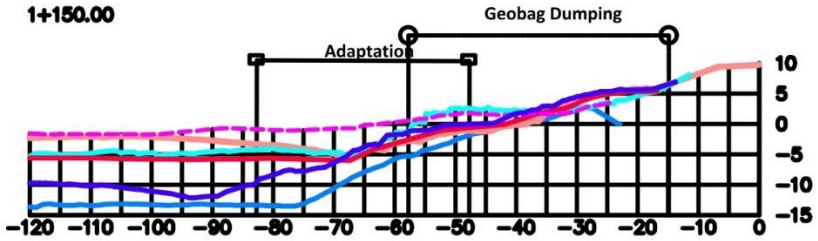
Asbuilt Geobag Dumping 2015-16:
0+450; 07 Aug 2016
0+550 to 0+850; 03 May 2016

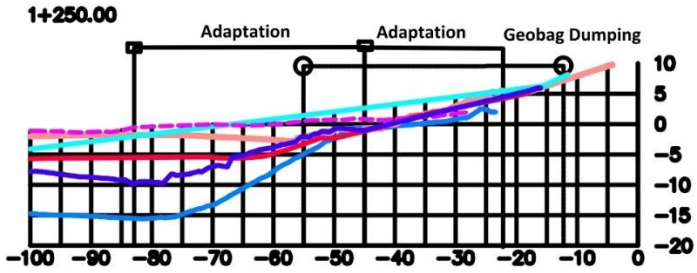
Adaption Prework
05-08 Nov 2017

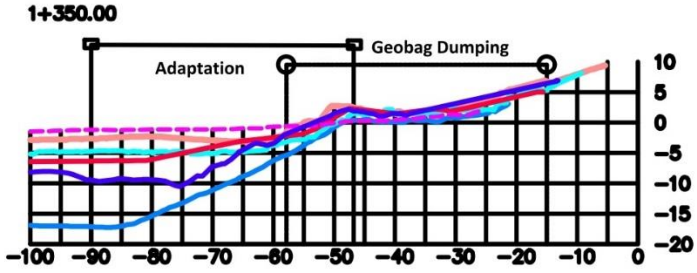
Cross Section Legend:
Asbuilt
20 Oct 2016
5-8 Nov 2017
8 Oct 2018
25-27 July 2019
23 & 26 Oct 2019







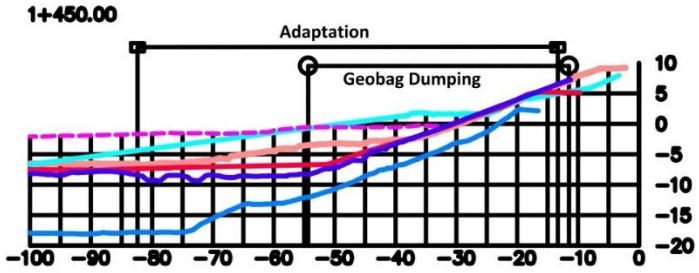


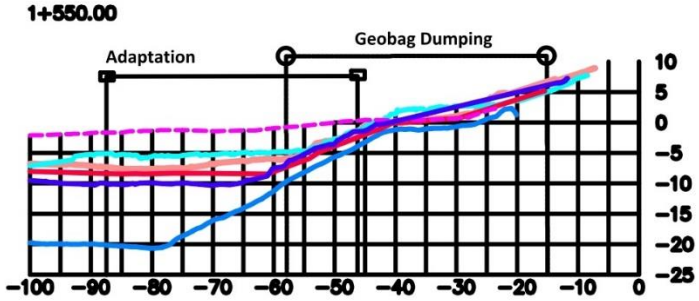


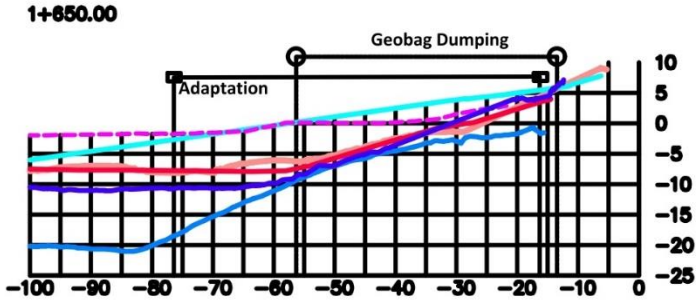
Asbuilt Geobag Dumping 2015-16:
03 May 2016

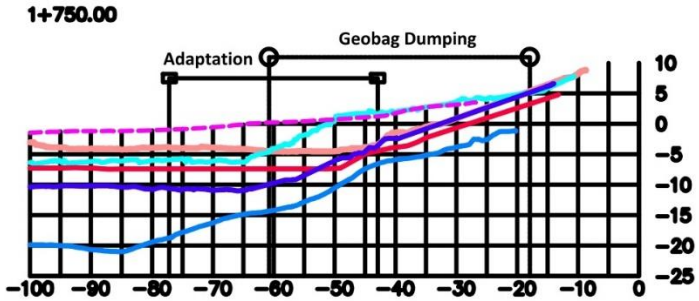
Adaption Prework
05-08 Nov 2017

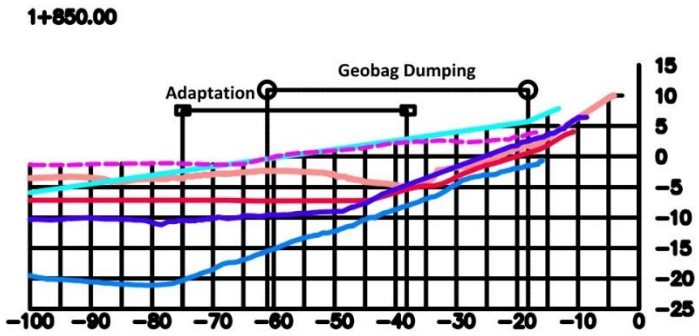
Cross Section Legend:
Asbuilt
20 Oct 2016
5-8 Nov 2017
8 Oct 2018
25-27 July 2019
23 & 26 Oct 2019











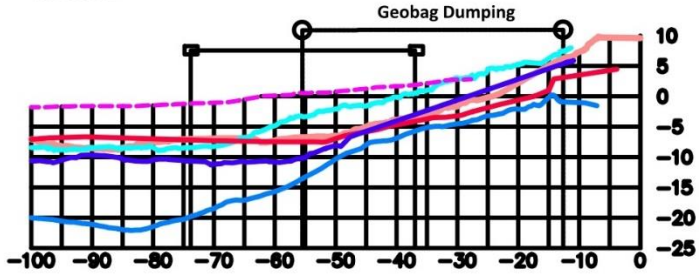
Asbuilt Geobag Dumping 2015-16:
03 May 2016

Adaption Prework
11-21 Mar 2018

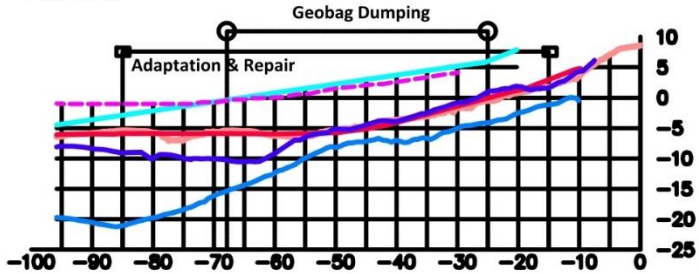
Cross Section Legend:

Asbuilt	
20 Oct 2016	
5-8 Nov 2017	
8 Oct 2018	
25-27 July 2019	
23 & 26 Oct 2019	

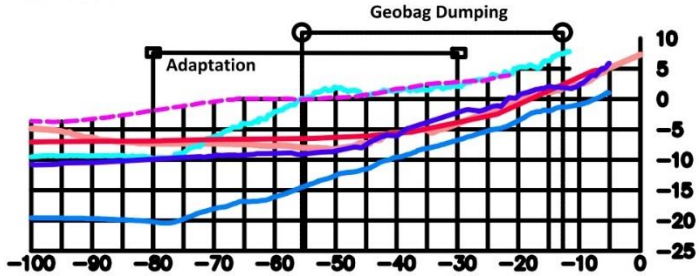
1+950.00



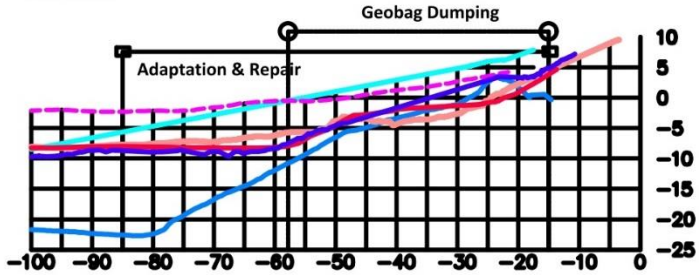
2+050.00



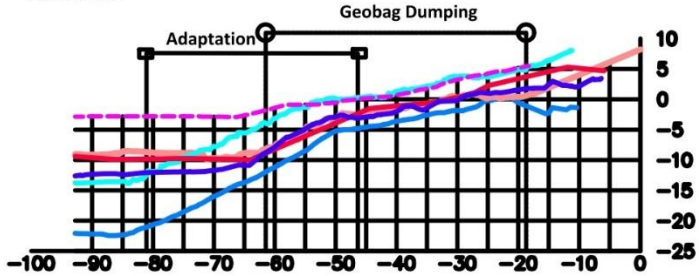
2+150.00



2+250.00



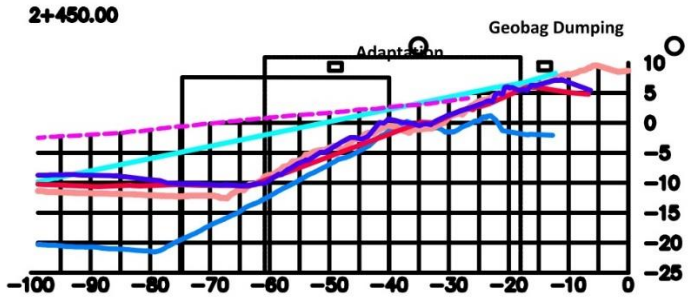
2+350.00

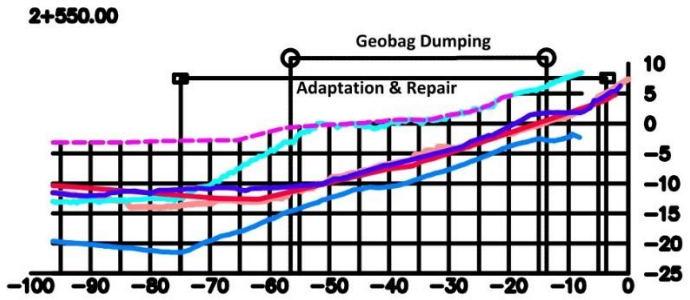


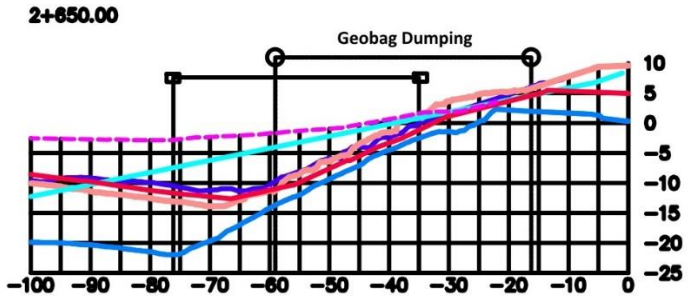
Asbuilt Geobag Dumping 2015-16:
03 May 2016

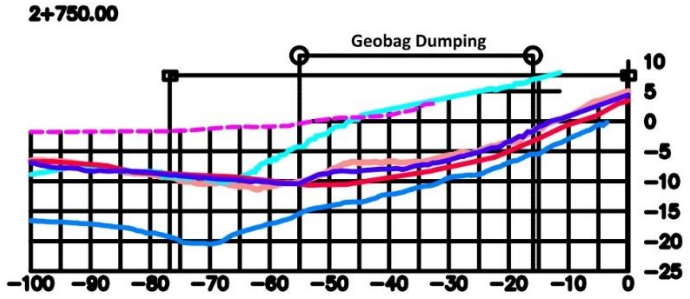
Adaption Prework
2+150 - 2+250; 05-08 Nov 2017
2+050, 2+350; 11-21 Mar 2018

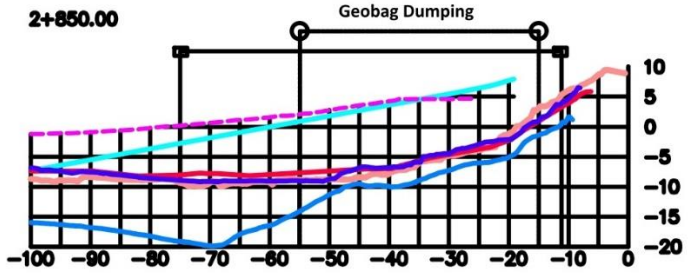
Cross Section Legend:
Asbuilt
20 Oct 2016
5-8 Nov 2017
8 Oct 2018
25-27 July 2019
23 & 26 Oct 2019







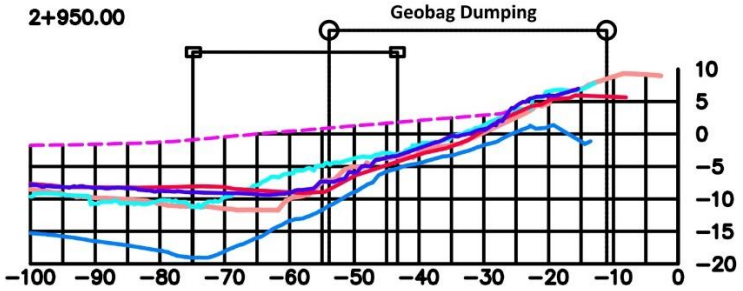


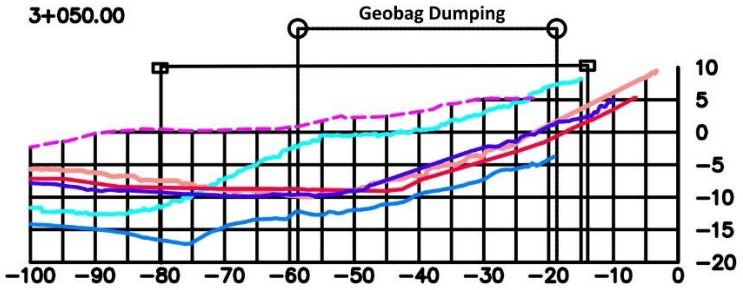


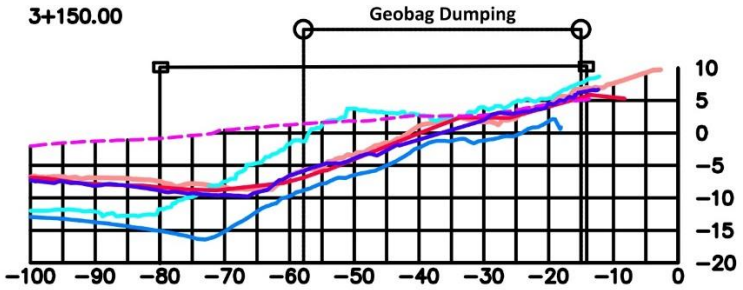
Asbuilt Geobag Dumping 2015-16:
2+550 - 2+850; 03 May 2016
2+950; 24 June 2016

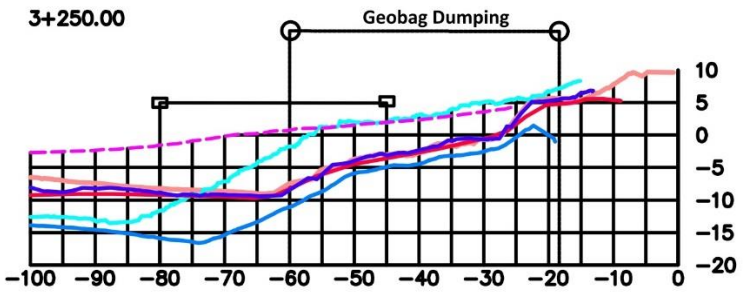
Adaption Prework
11-21 Mar 2018

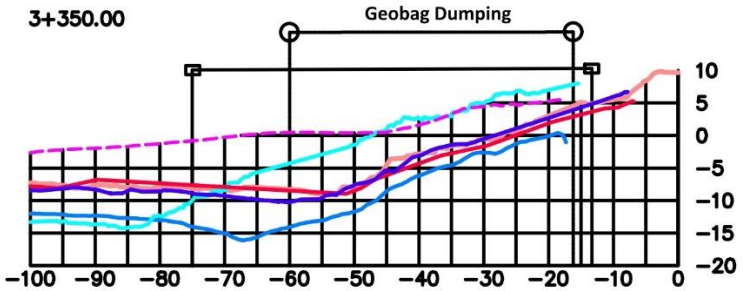
Cross Section Legend:
Asbuilt
20 Oct 2016
5-8 Nov 2017
8 Oct 2018
25-27 July 2019
23 & 26 Oct 2019







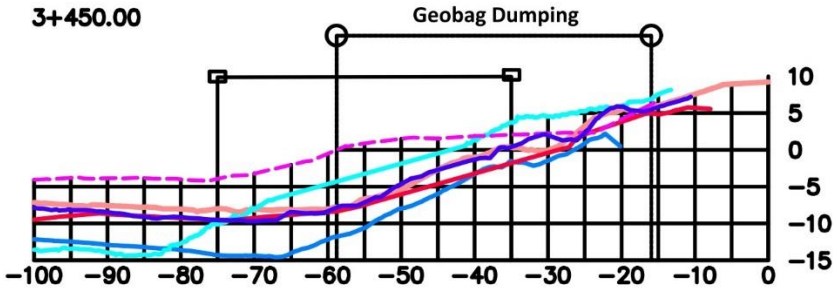


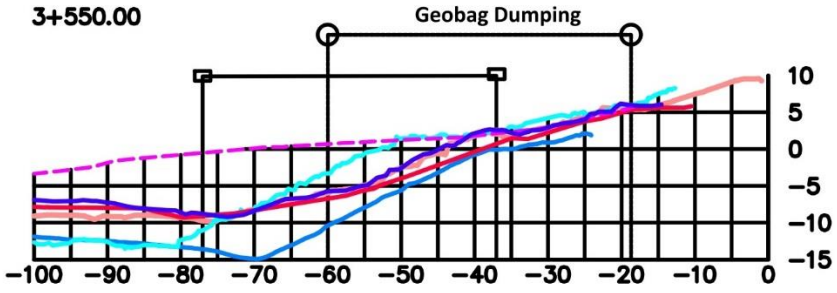


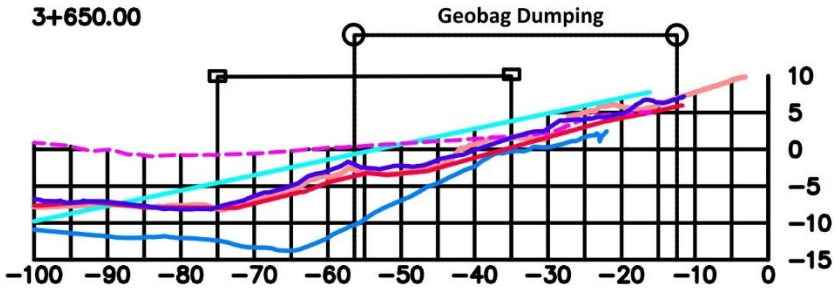
Asbuilt Geobag Dumping 2015-16:
3+050 - 3+250; 03 May 2016
3+350 - 3+450; 24 June 2016

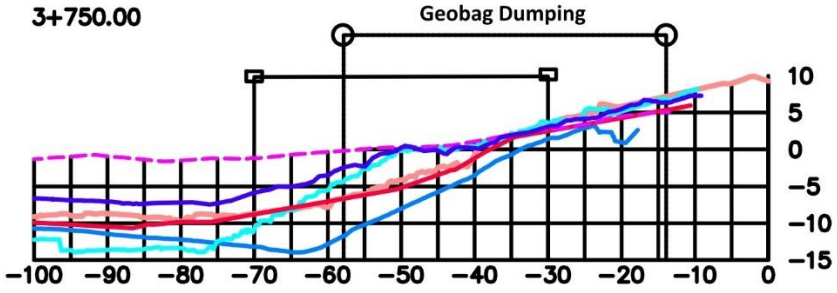
Adaption Prework
11-21 Mar 2018

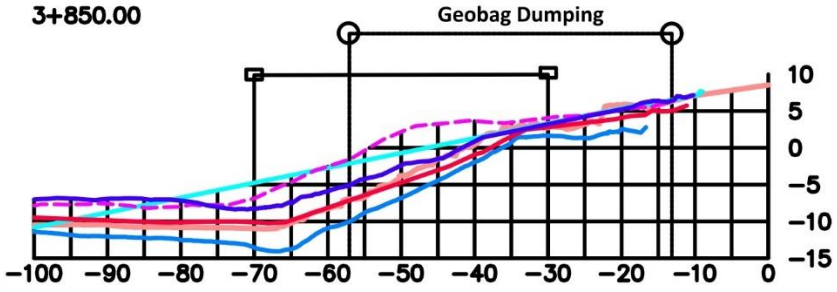
Cross Section Legend:
Asbuilt
20 Oct 2016
5-8 Nov 2017
8 Oct 2018
25-27 July 2019
23 & 26 Oct 2019







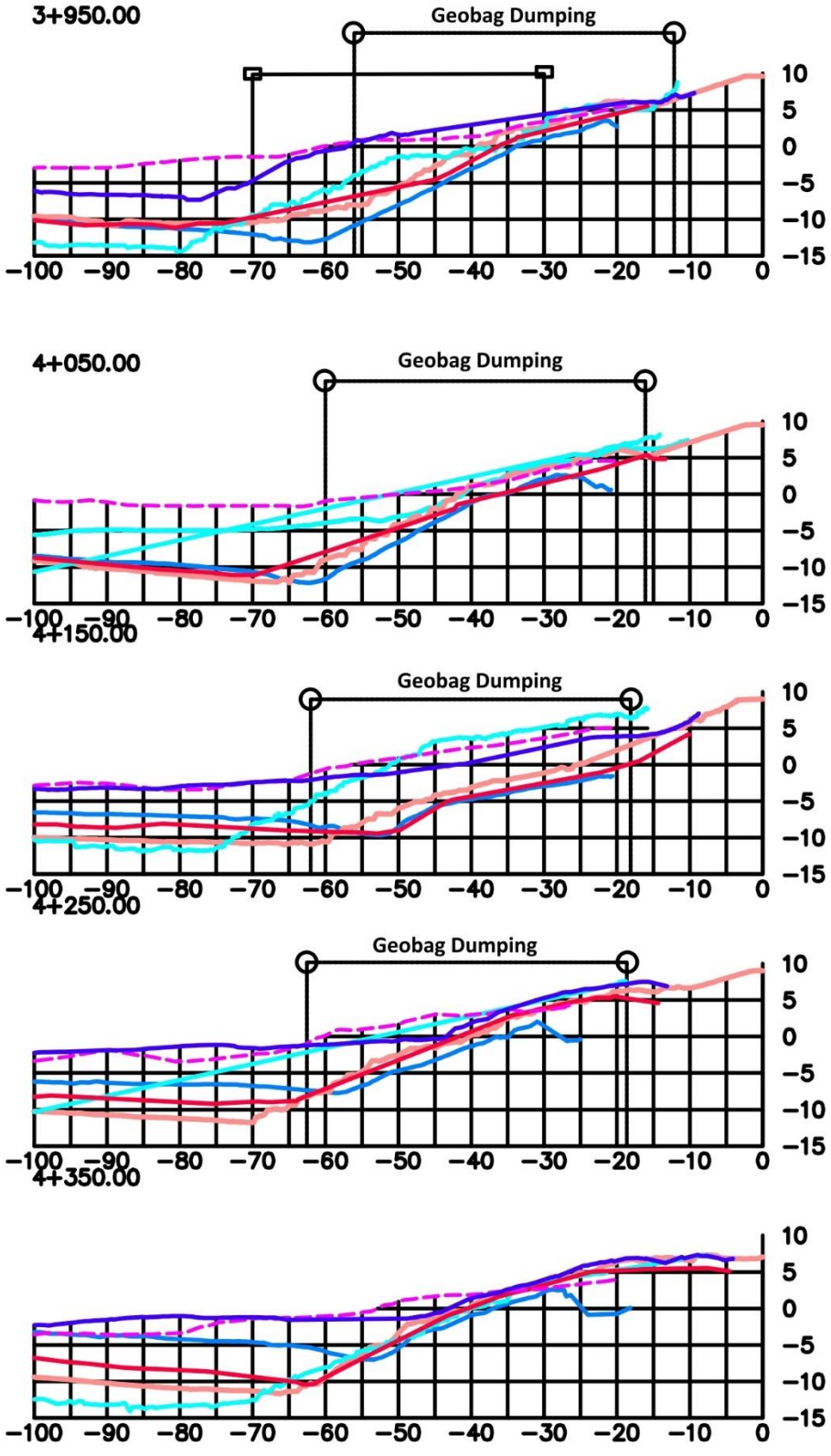




Asbuilt Geobag Dumping 2015-16:
3+550 - 3+750; 03 May 2016
3+850 - 3+950; 24 June 2016

Adaption Prework
11-21 Mar 2018

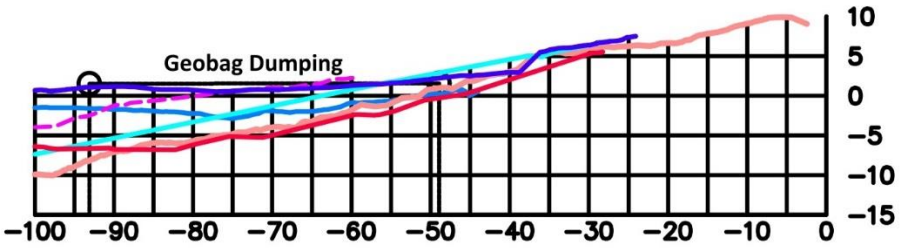
Cross Section Legend:
Asbuilt
20 Oct 2016
5-8 Nov 2017
8 Oct 2018
25-27 July 2019
23 & 26 Oct 2019



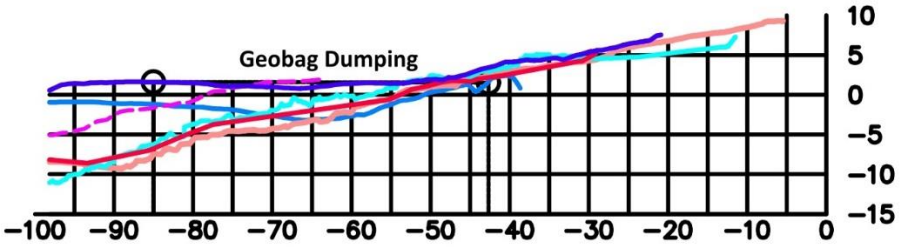
Asbuilt Geobag Dumping 2015-16:
4+050 - 4+150; 03 May 2016,
4+250 - 4+450; 24 June 2016

Cross Section Legend:
Asbuilt
20 Oct 2016
5-8 Nov 2017
8 Oct 2018
25-27 July 2019
23 & 26 Oct 2019

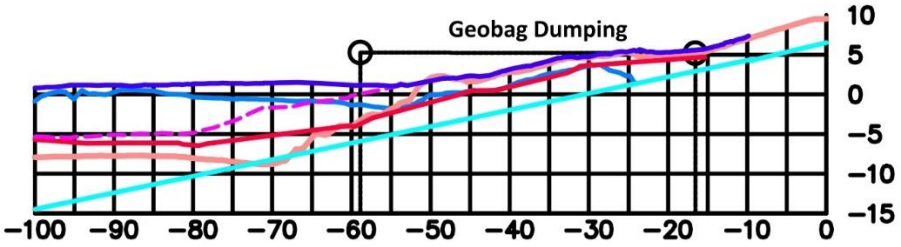
4+450.00



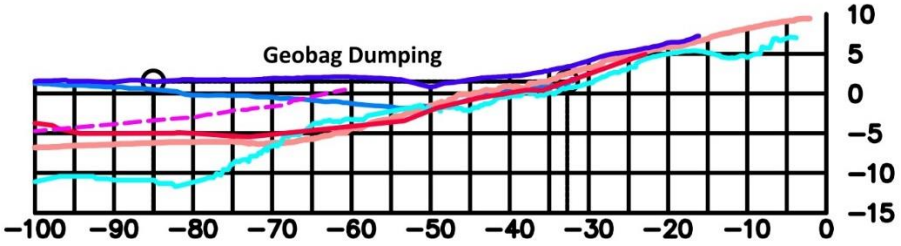
4+550.00



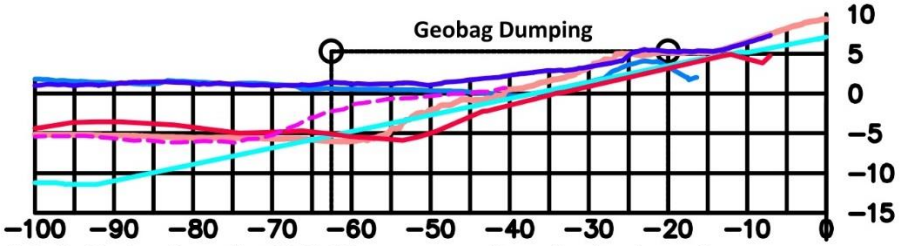
4+650.00



4+750.00



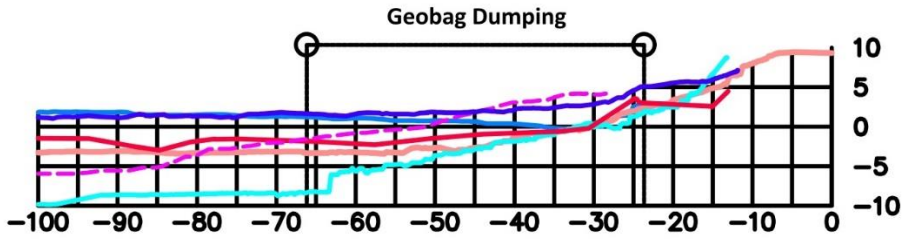
4+850.00



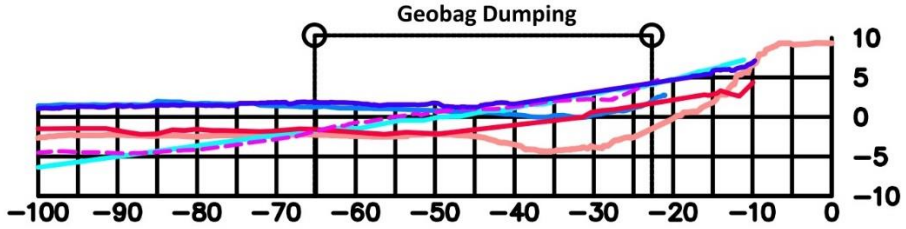
Asbuilt Geobag Dumping 2015-16:
03 May 2016

Cross Section Legend:
Asbuilt
20 Oct 2016
5-8 Nov 2017
8 Oct 2018
25-27 July 2019
23 & 26 Oct 2019

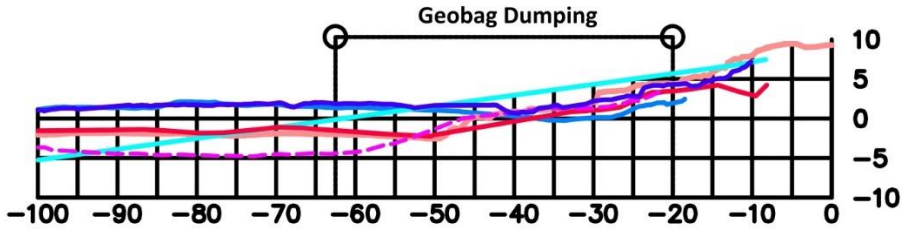
4+950.00



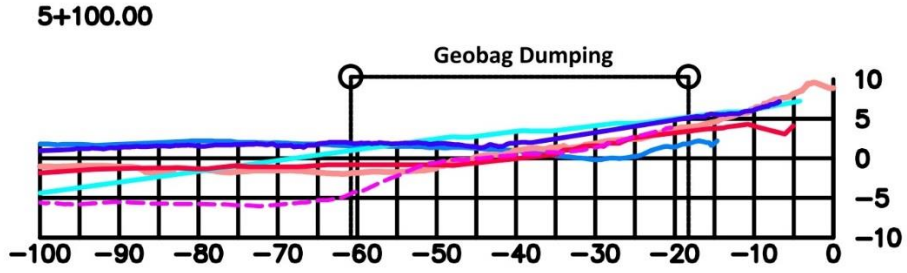
5+000.00



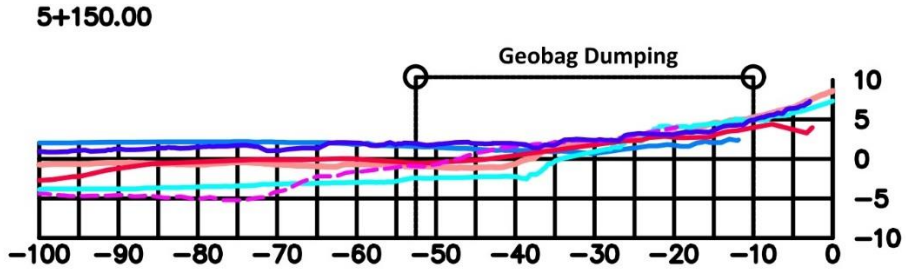
5+050.00



5+100.00



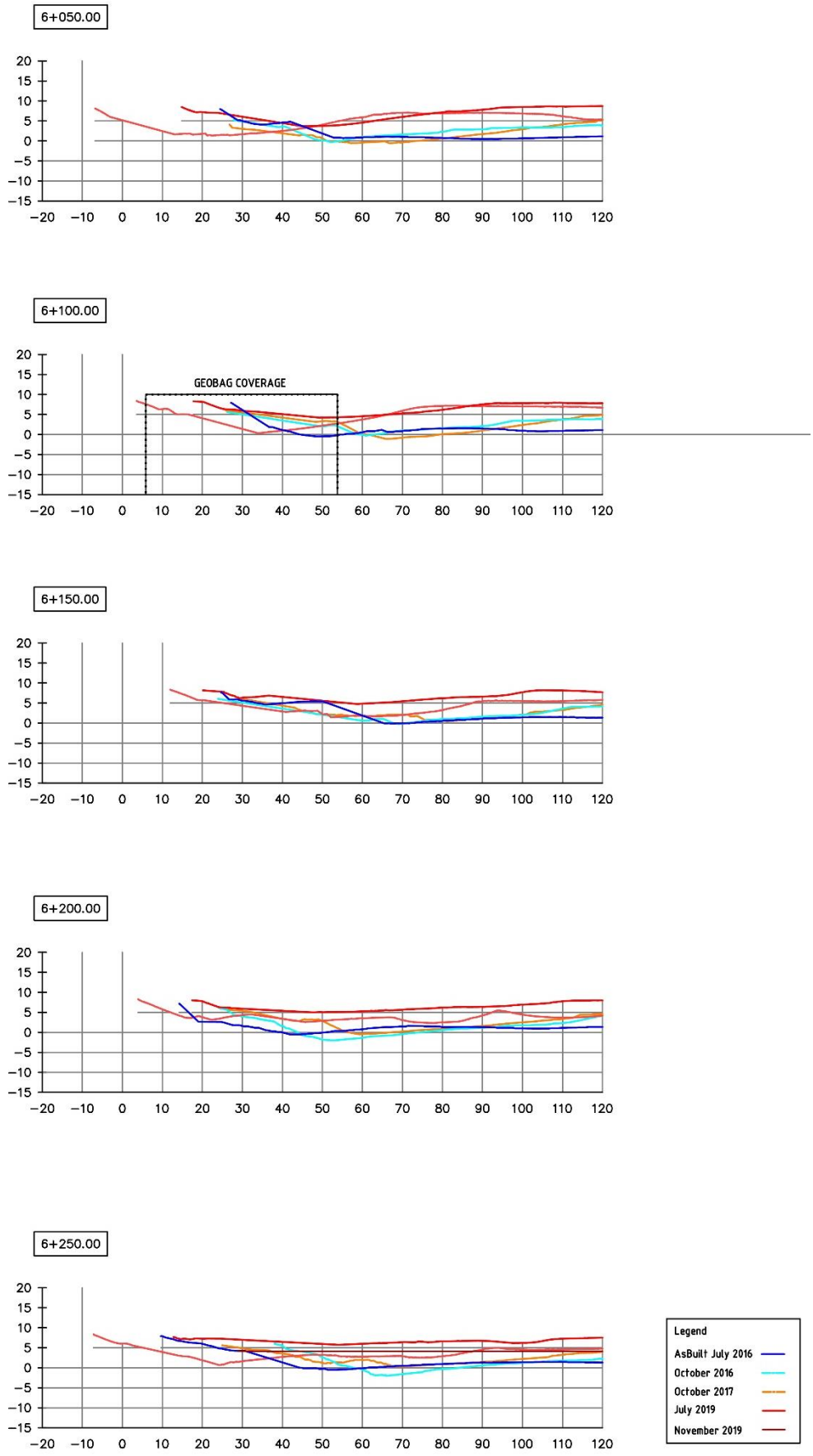
5+150.00



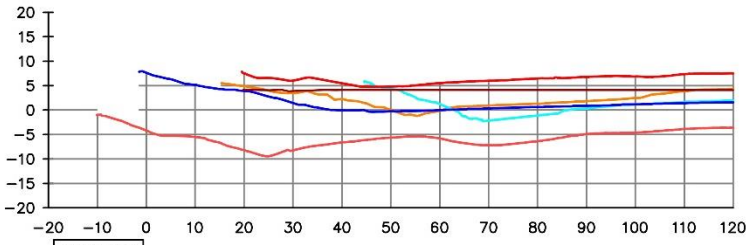
Asbuilt Geobag Dumping 2015-16:
03 May 2016

Cross Section Legend:
Asbuilt
20 Oct 2016
5-8 Nov 2017
8 Oct 2018
25-27 July 2019
23 & 26 Oct 2019

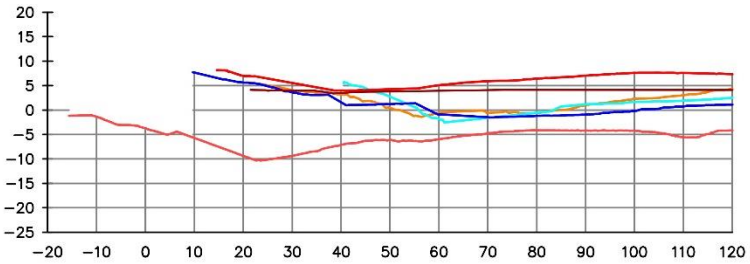
7.2 Zafarganj



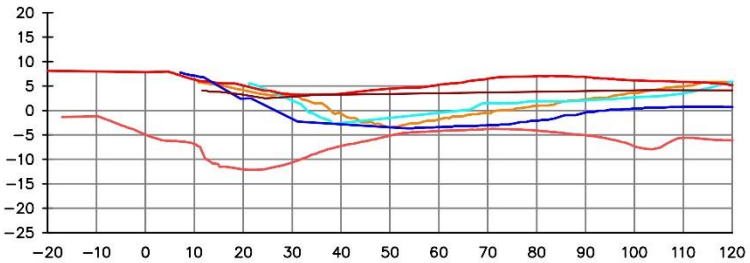
6+300.00



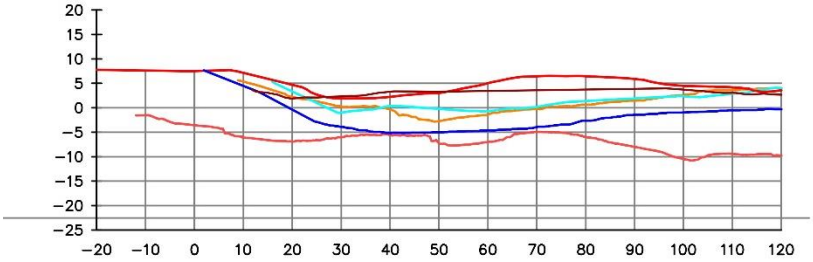
6+350.00



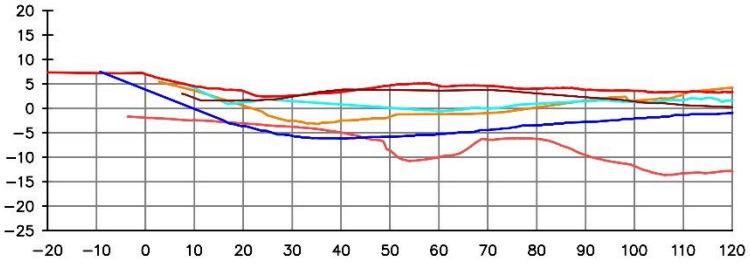
6+400.00

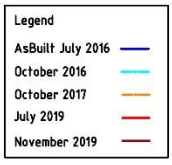


6+450.00

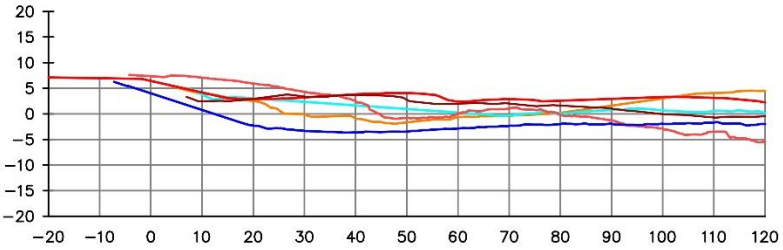


6+500.00

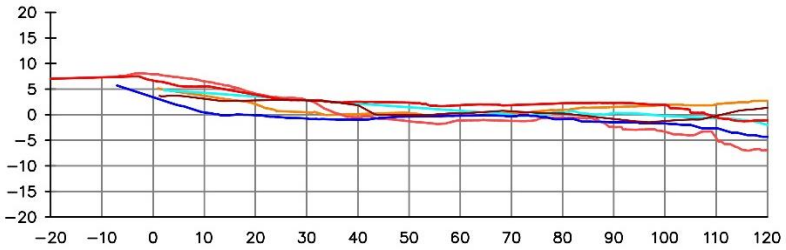




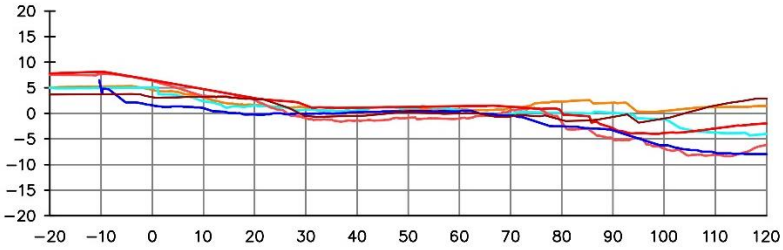
6+550.00



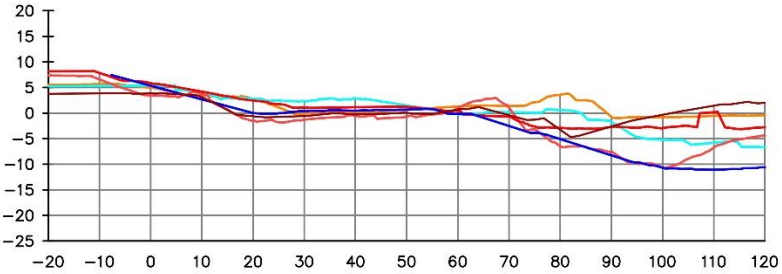
6+600.00



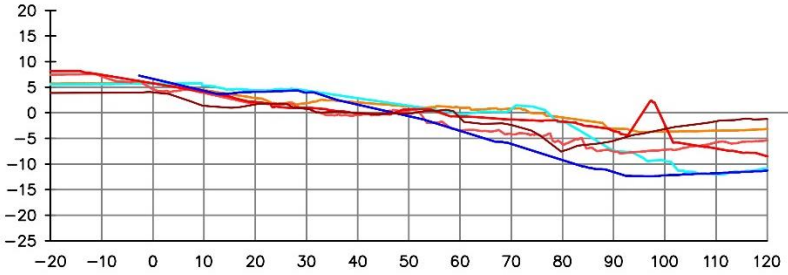
6+650.00



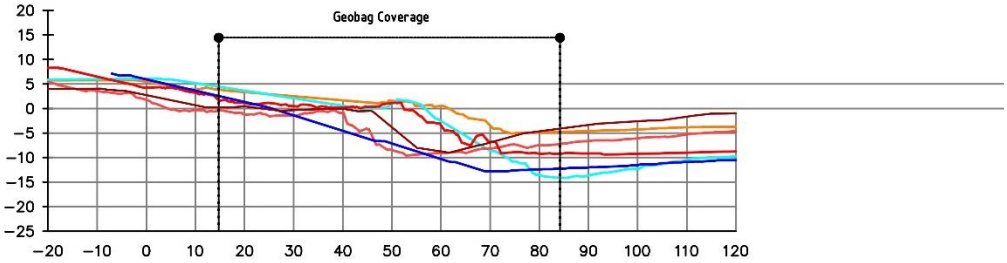
6+700.00



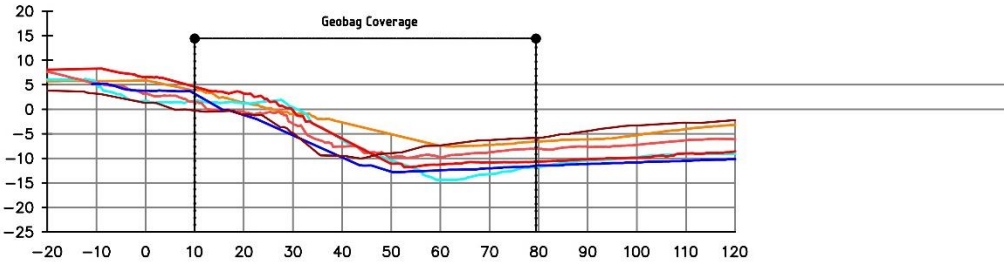
6+750.00



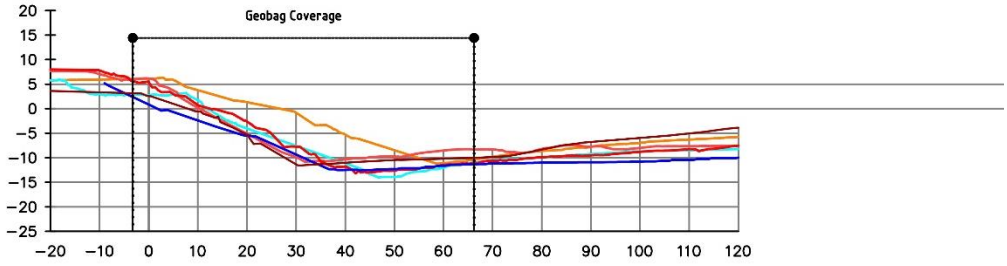
6+800.00



6+850.00



6+900.00



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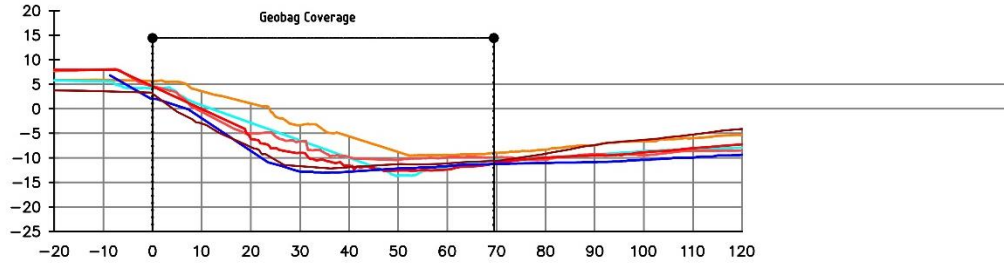
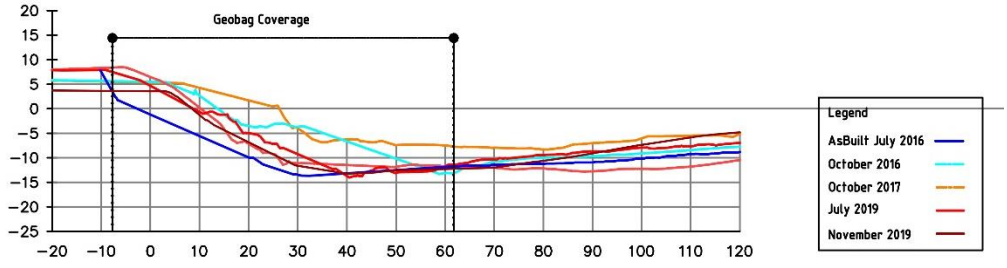
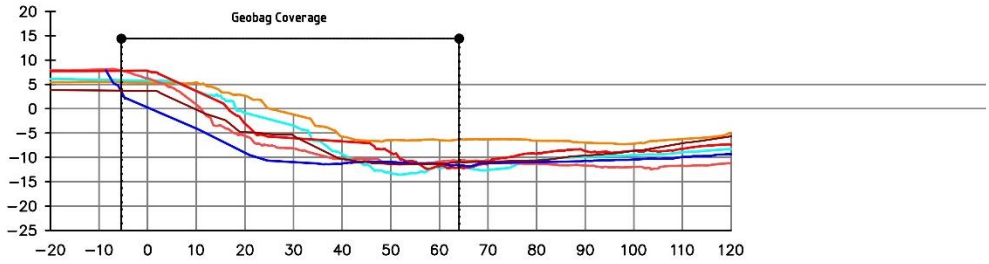


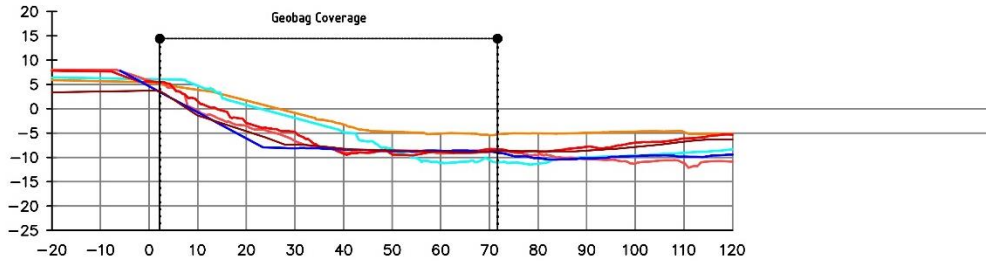
7+000.00



7+050.00



7+100.00



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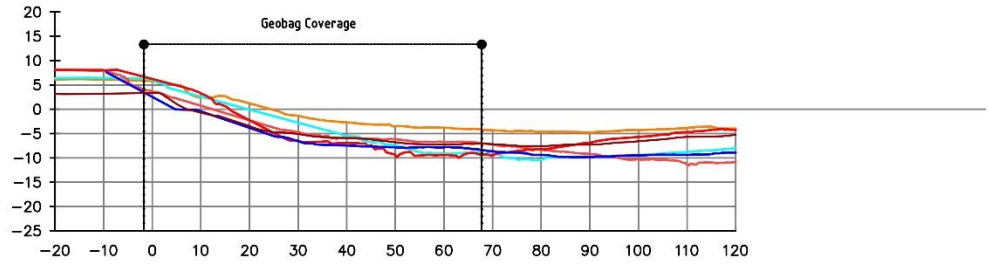

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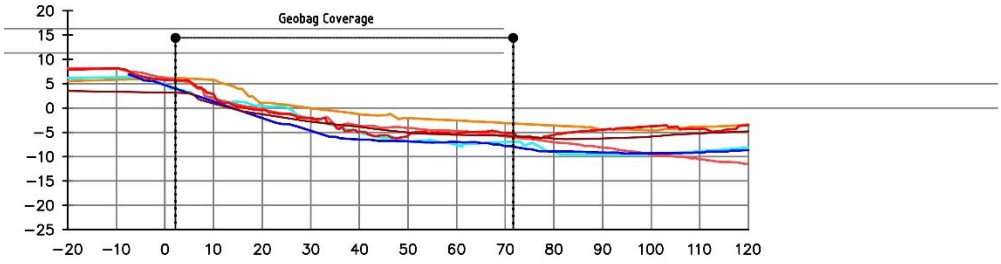

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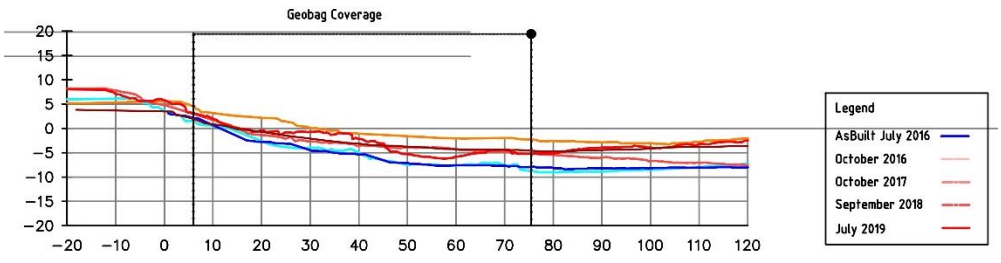
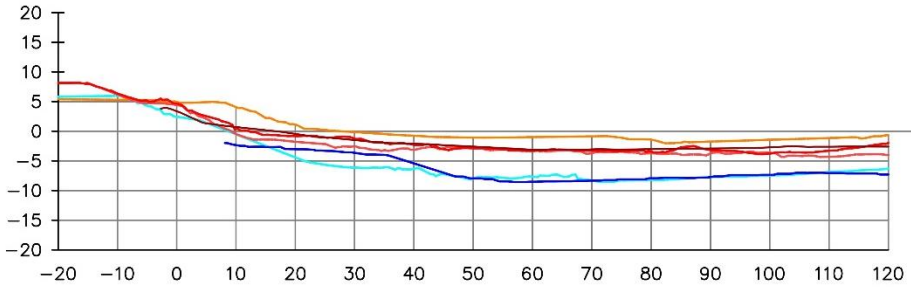
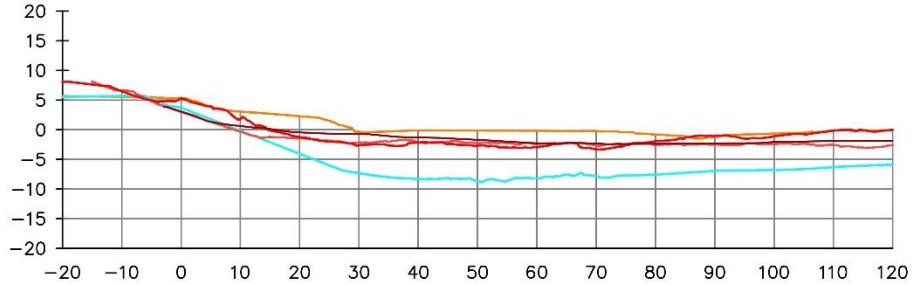


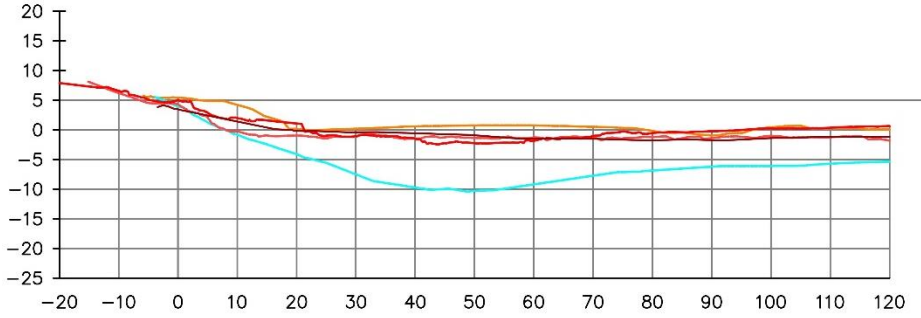
7+300.00



7+350.00



7+400.00



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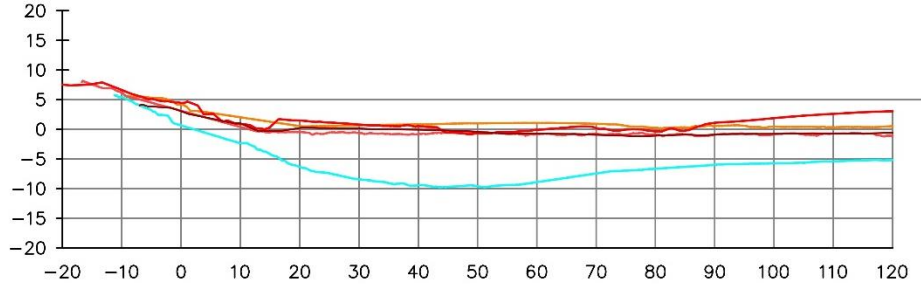

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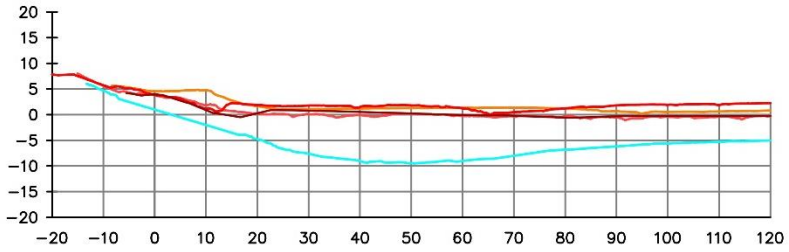
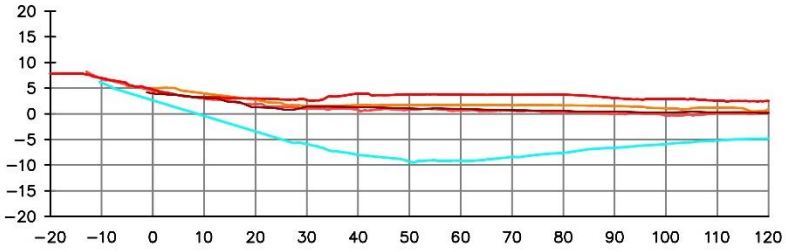
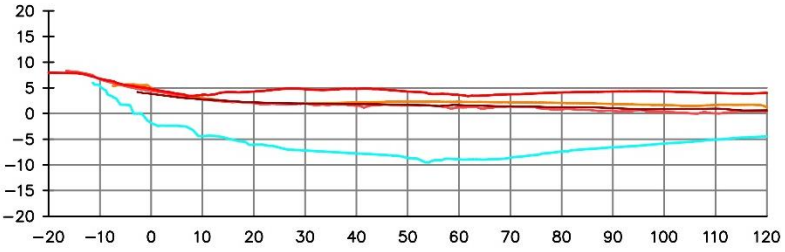


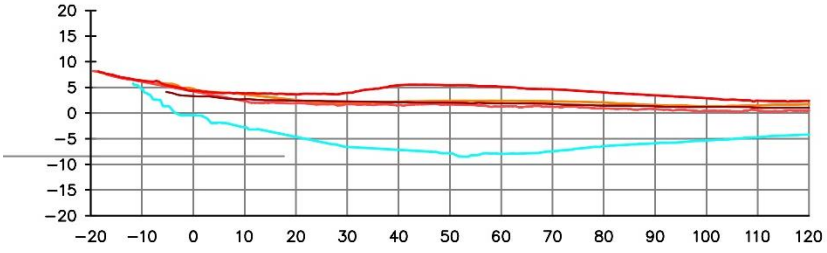
7+550.00



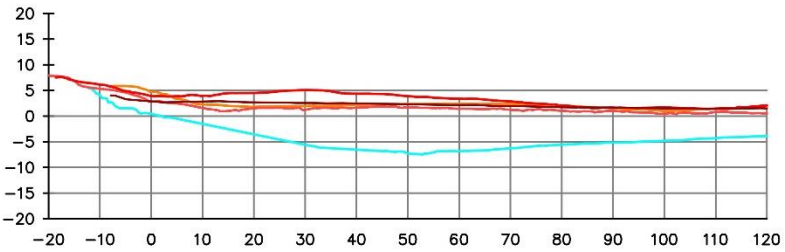
7+600.00

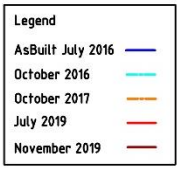


7+650.00

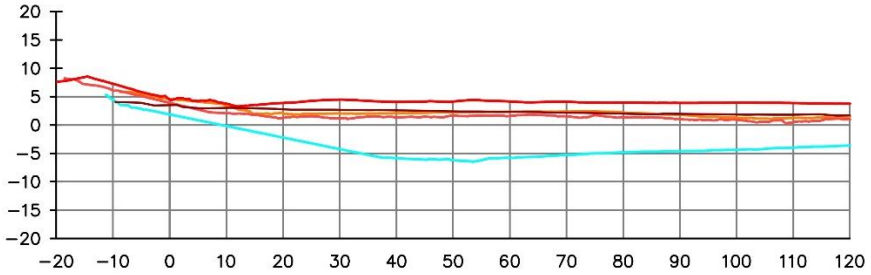


7+700.00

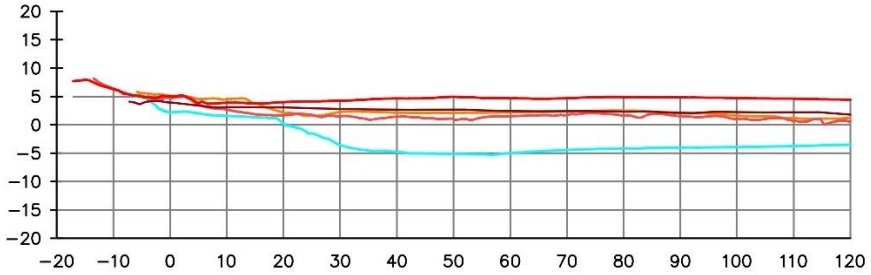




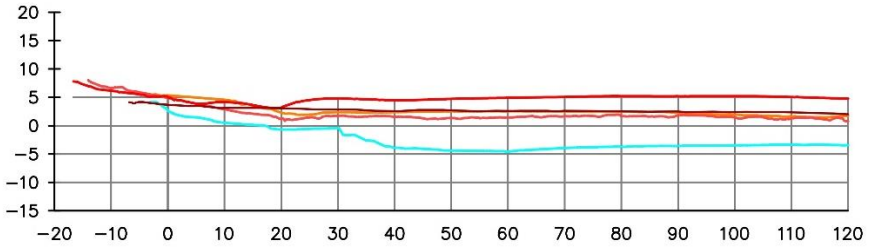
7+750.00



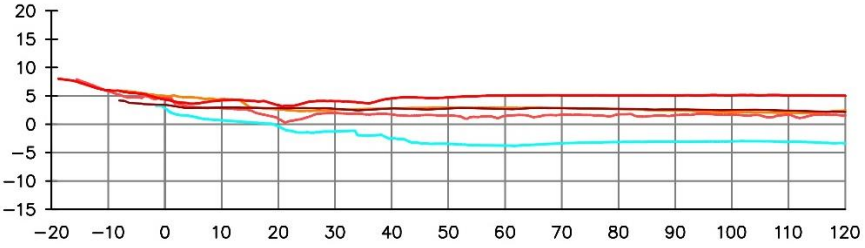
7+800.00



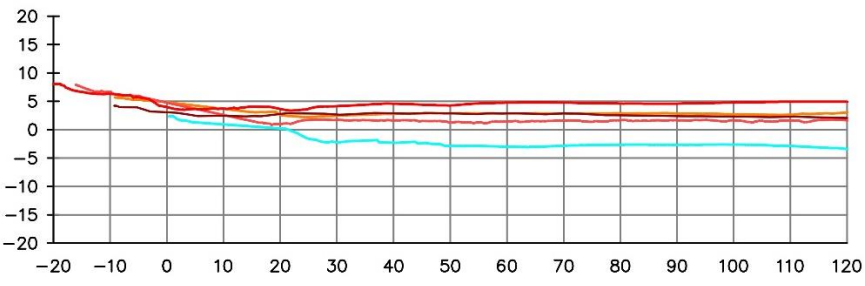
7+850.00

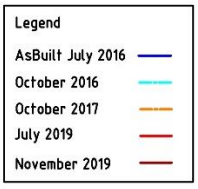


7+900.00

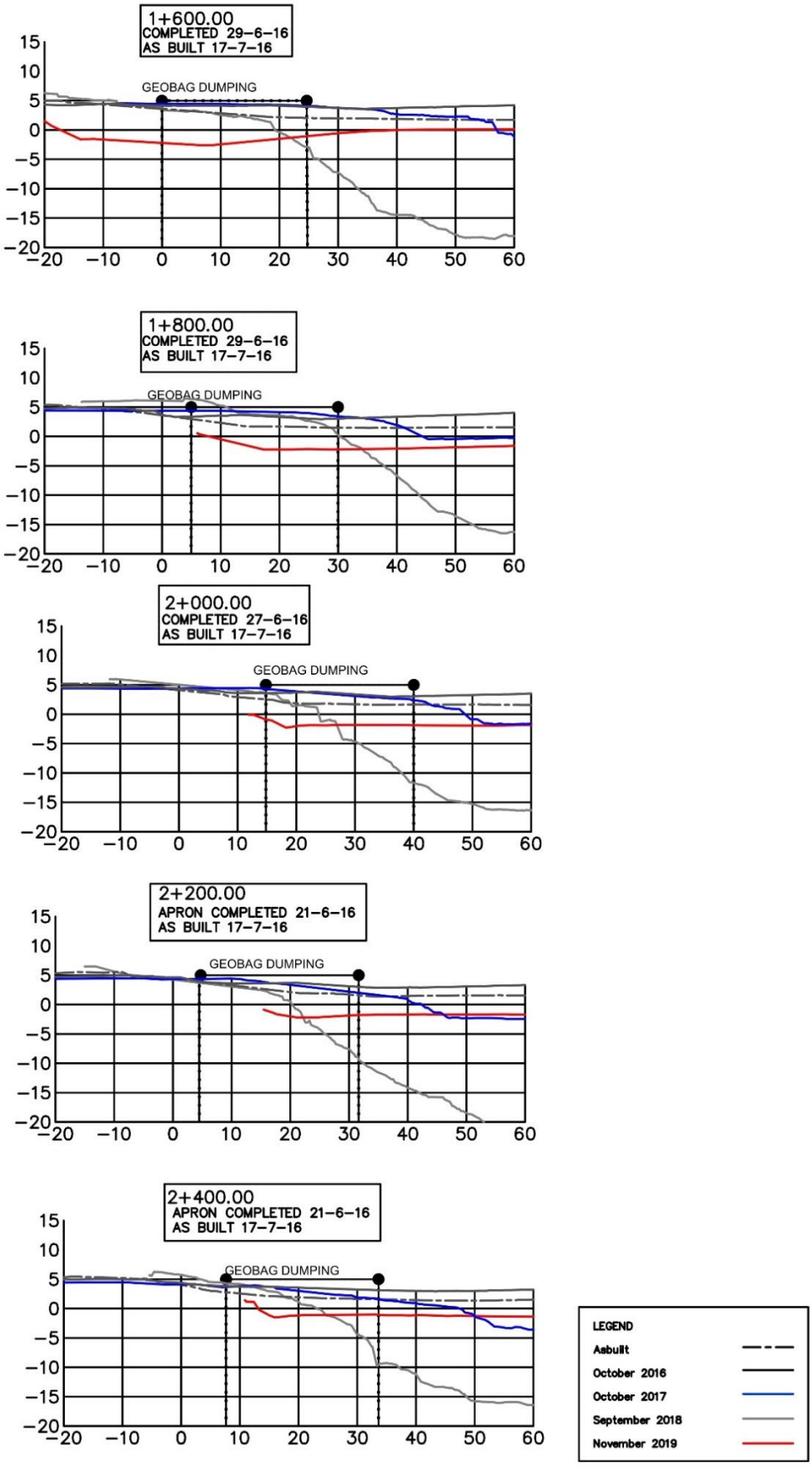


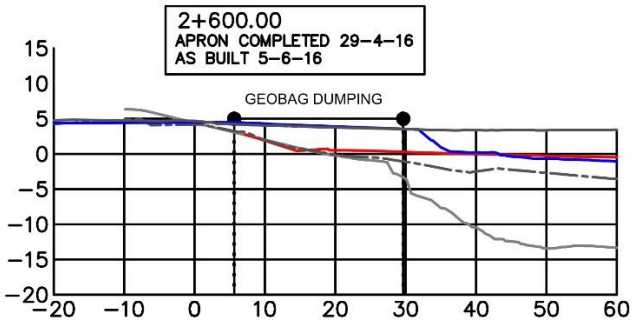
7+950.00

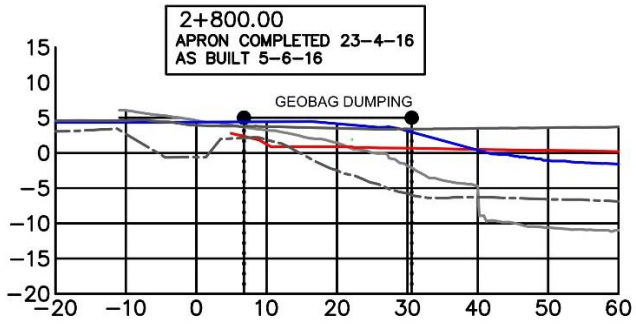


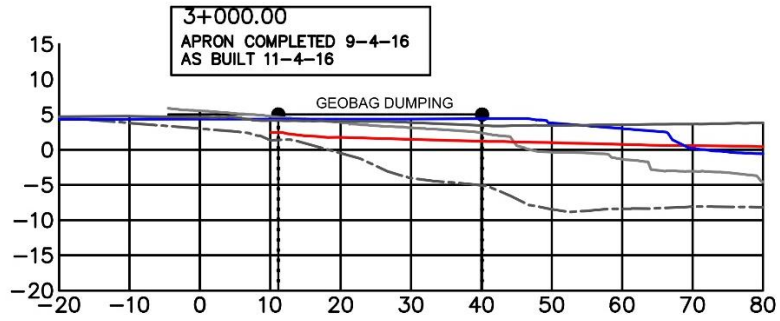


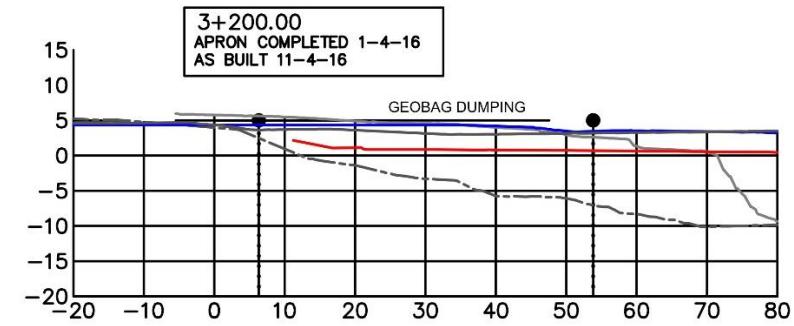
7.3 Harirampur

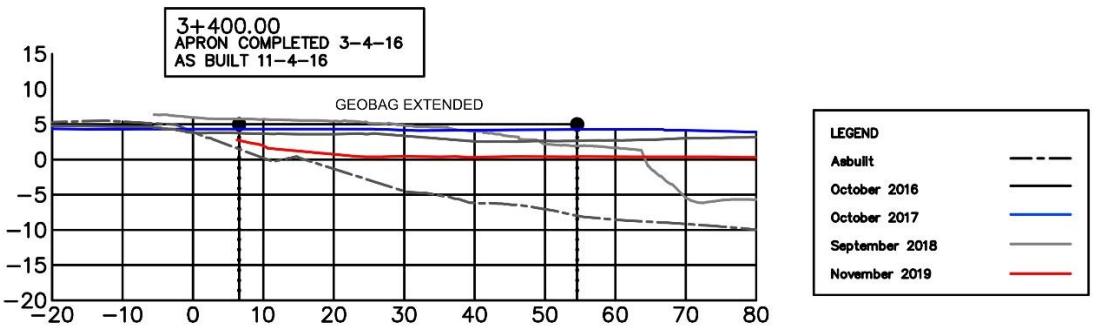


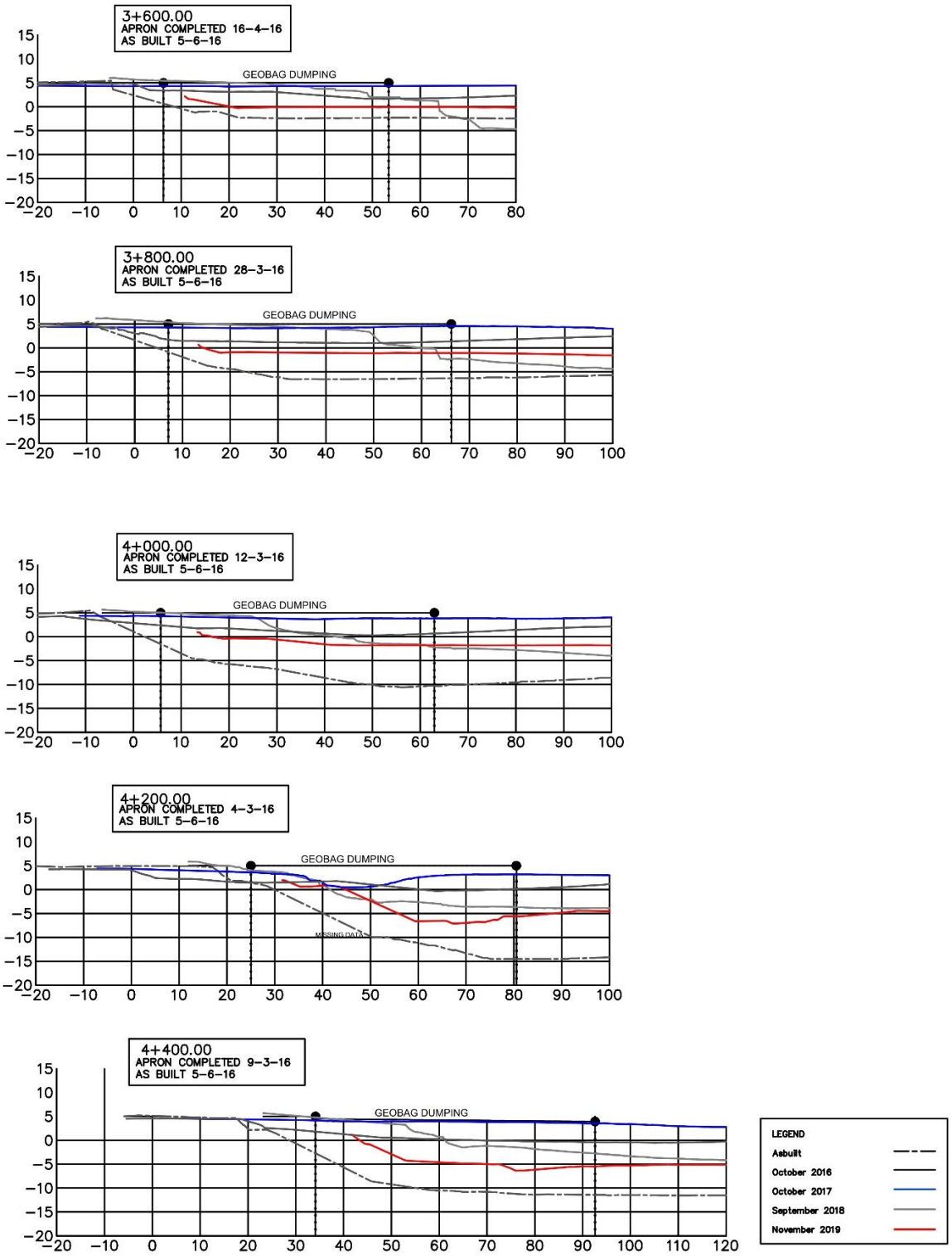

2+600.00
APRON COMPLETED 29-4-16
AS BUILT 5-6-16
GEOBAG DUMPING

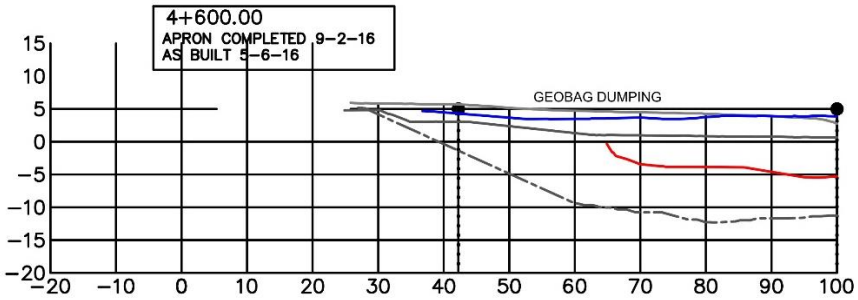

2+800.00
APRON COMPLETED 23-4-16
AS BUILT 5-6-16
GEOBAG DUMPING

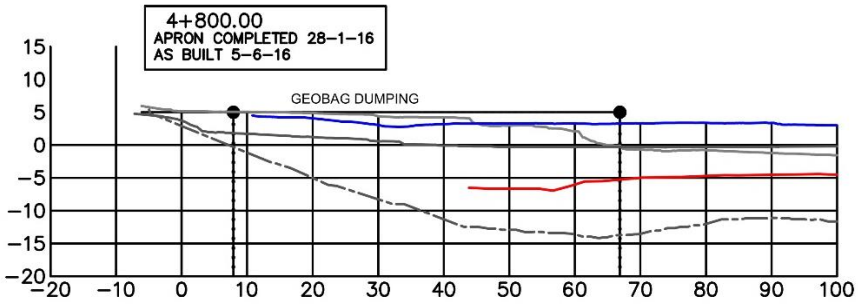

3+000.00
APRON COMPLETED 9-4-16
AS BUILT 11-4-16
GEOBAG DUMPING

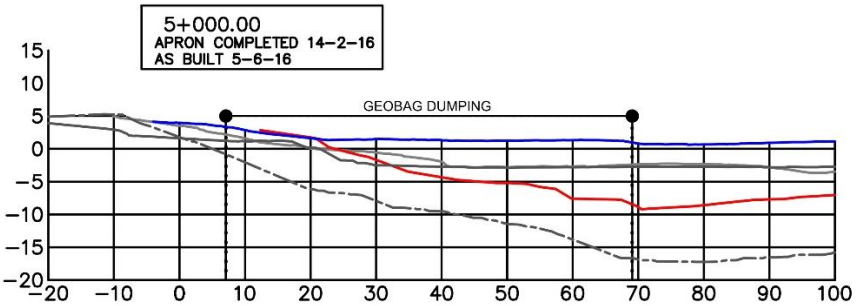

3+200.00
APRON COMPLETED 1-4-16
AS BUILT 11-4-16
GEOBAG DUMPING

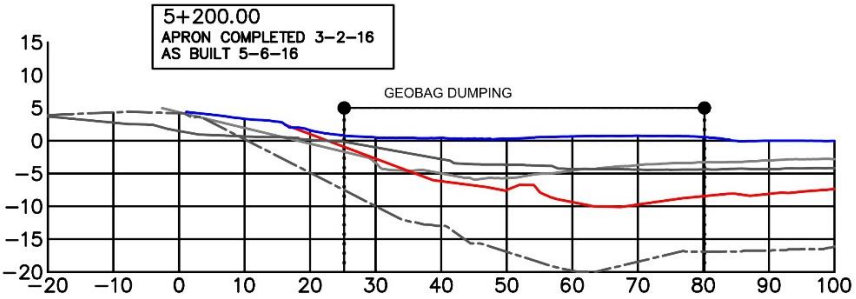

3+400.00
APRON COMPLETED 3-4-16
AS BUILT 11-4-16
GEOBAG EXTENDED
LEGEND
Asbuilt
October 2016
October 2017
September 2018
November 2019

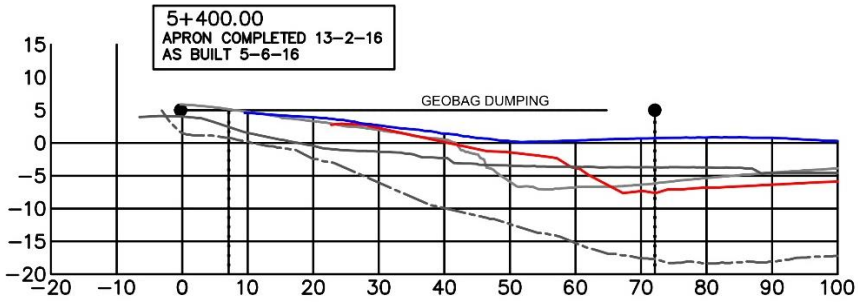

3+600.00
APRON COMPLETED 16-4-16
AS BUILT 5-6-16
GEOBAG DUMPING
3+800.00
APRON COMPLETED 28-3-16
AS BUILT 5-6-16
GEOBAG DUMPING
4+000.00
APRON COMPLETED 12-3-16
AS BUILT 5-6-16
GEOBAG DUMPING
4+200.00
APRON COMPLETED 4-3-16
AS BUILT 5-6-16
GEOBAG DUMPING
MISSING DATA
4+400.00
APRON COMPLETED 9-3-16
AS BUILT 5-6-16
GEOBAG DUMPING
LEGEND
Asbuilt
October 2016
October 2017
September 2018
November 2019

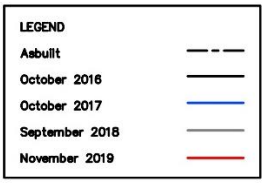

4+600.00
APRON COMPLETED 9-2-16
AS BUILT 5-6-16
GEOBAG DUMPING

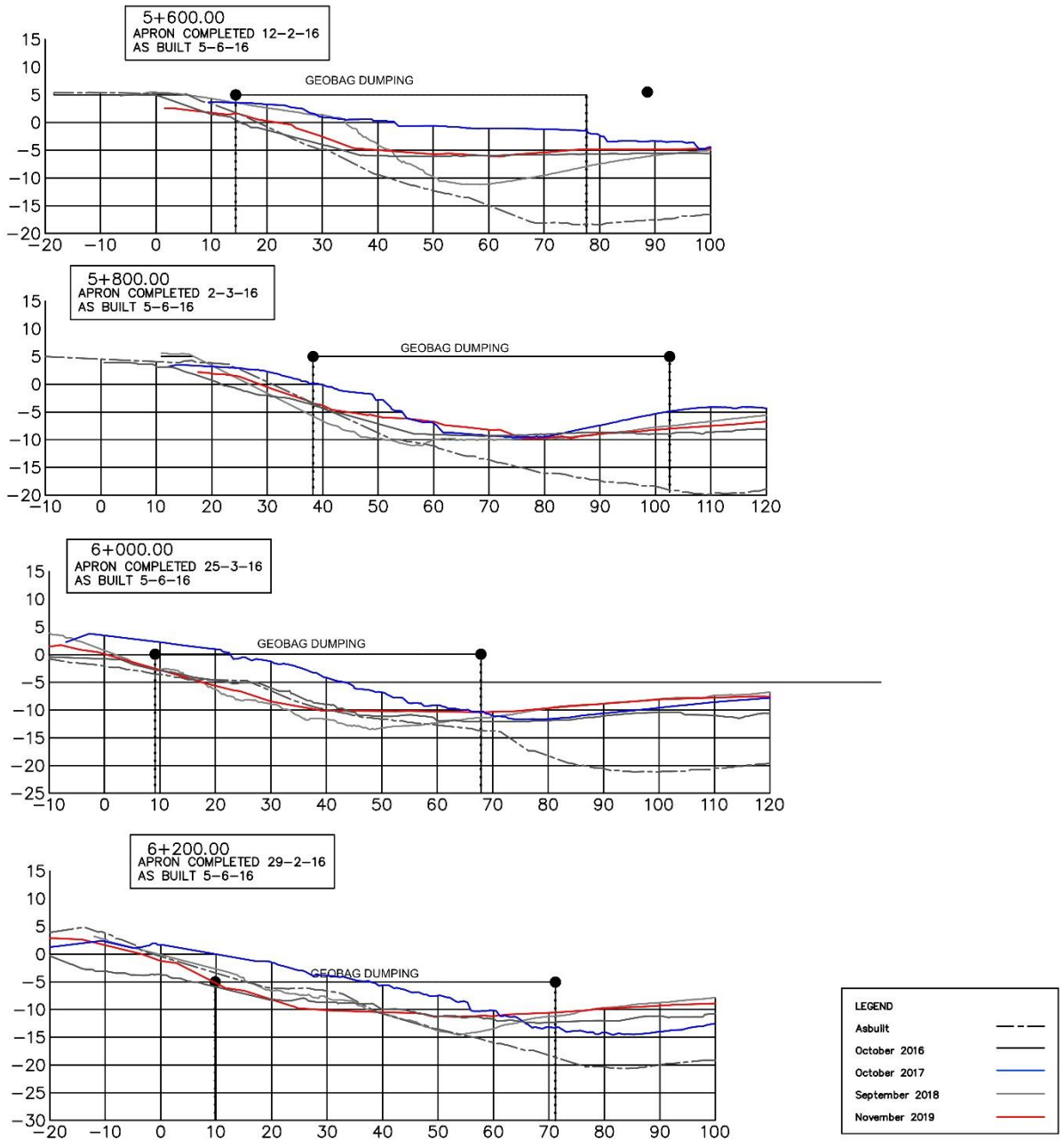

4+800.00
APRON COMPLETED 28-1-16
AS BUILT 5-6-16
GEOBAG DUMPING

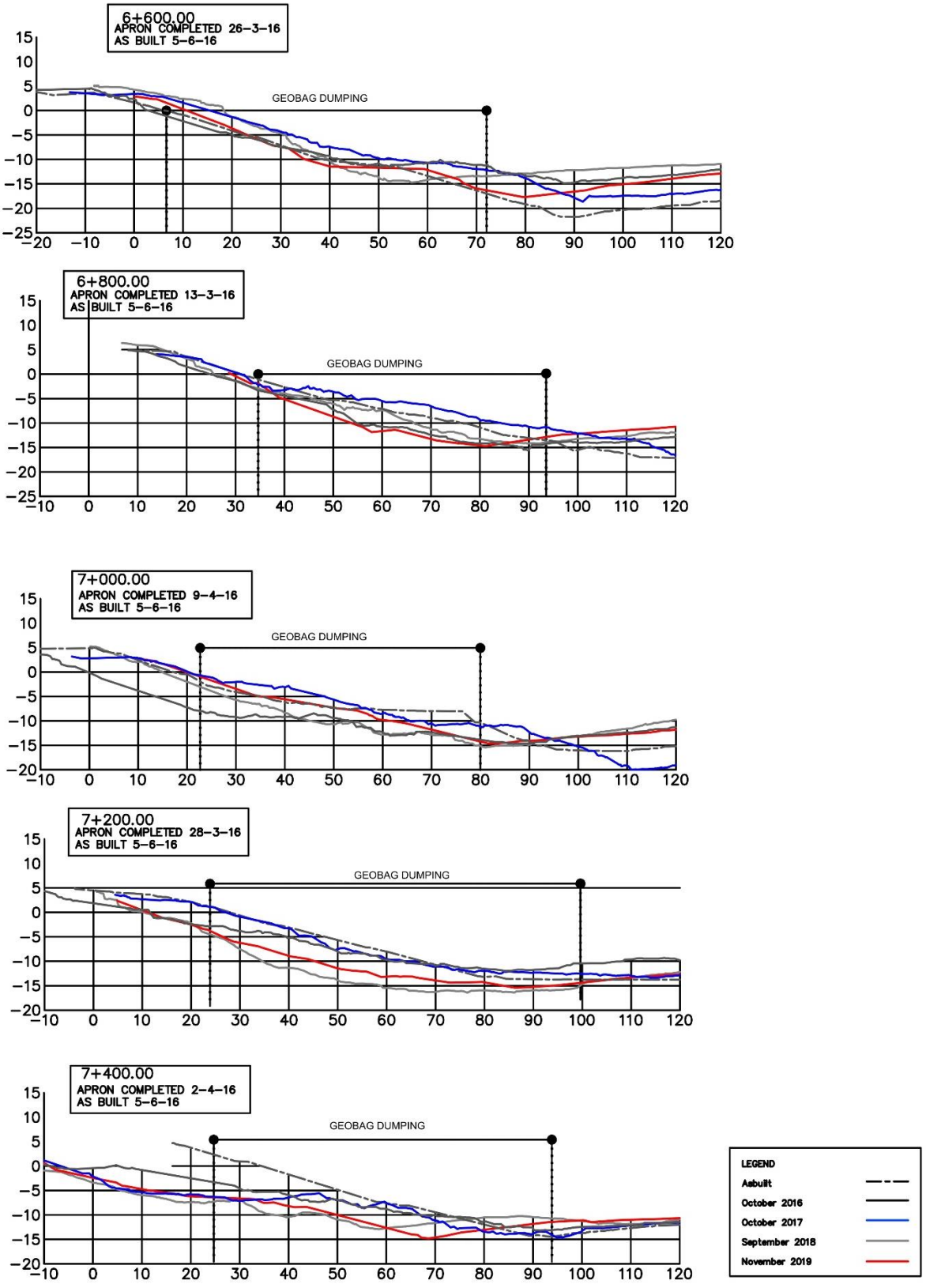

5+000.00
APRON COMPLETED 14-2-16
AS BUILT 5-6-16
GEOBAG DUMPING

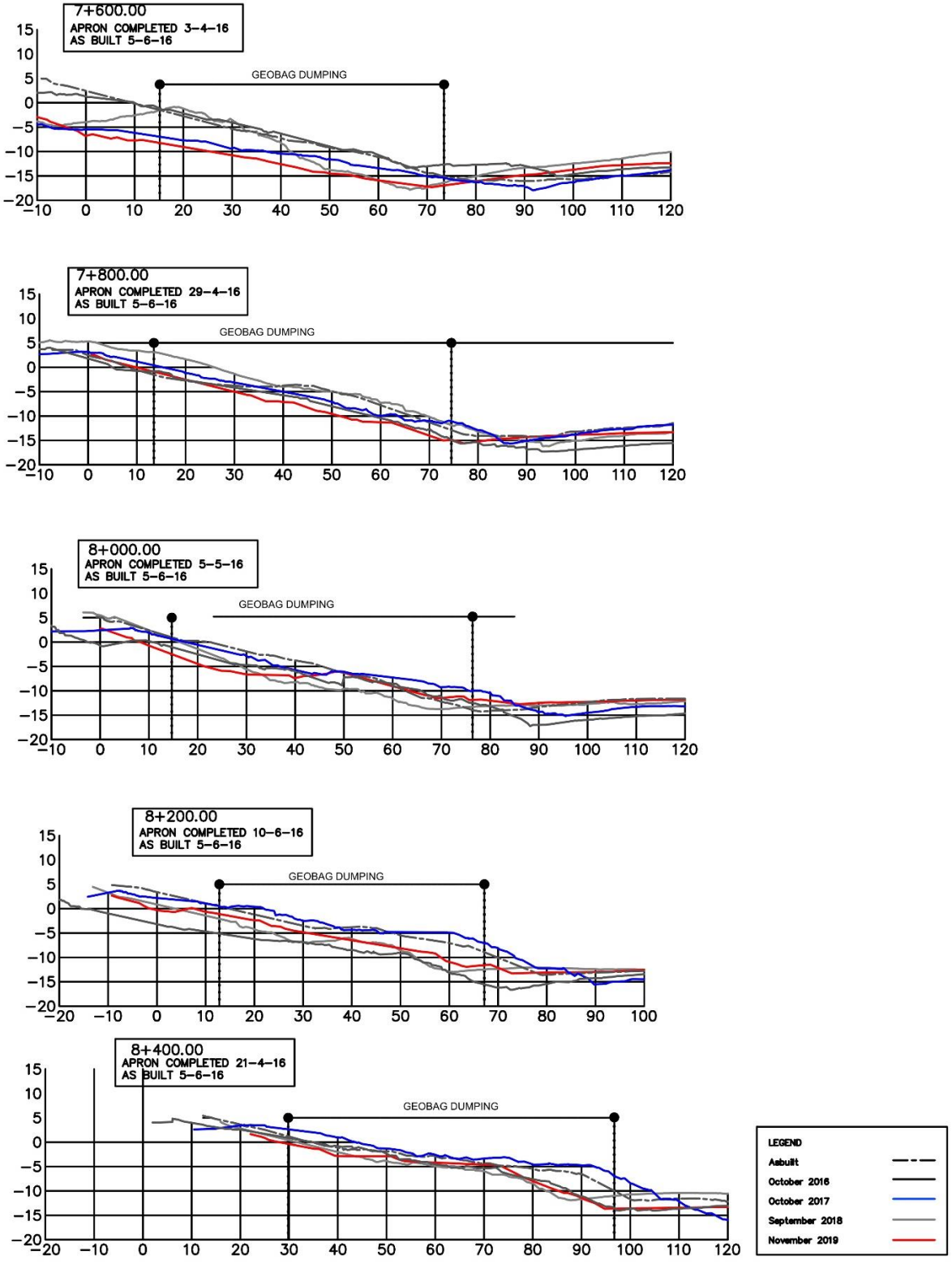

5+200.00
APRON COMPLETED 3-2-16
AS BUILT 5-6-16
GEOBAG DUMPING

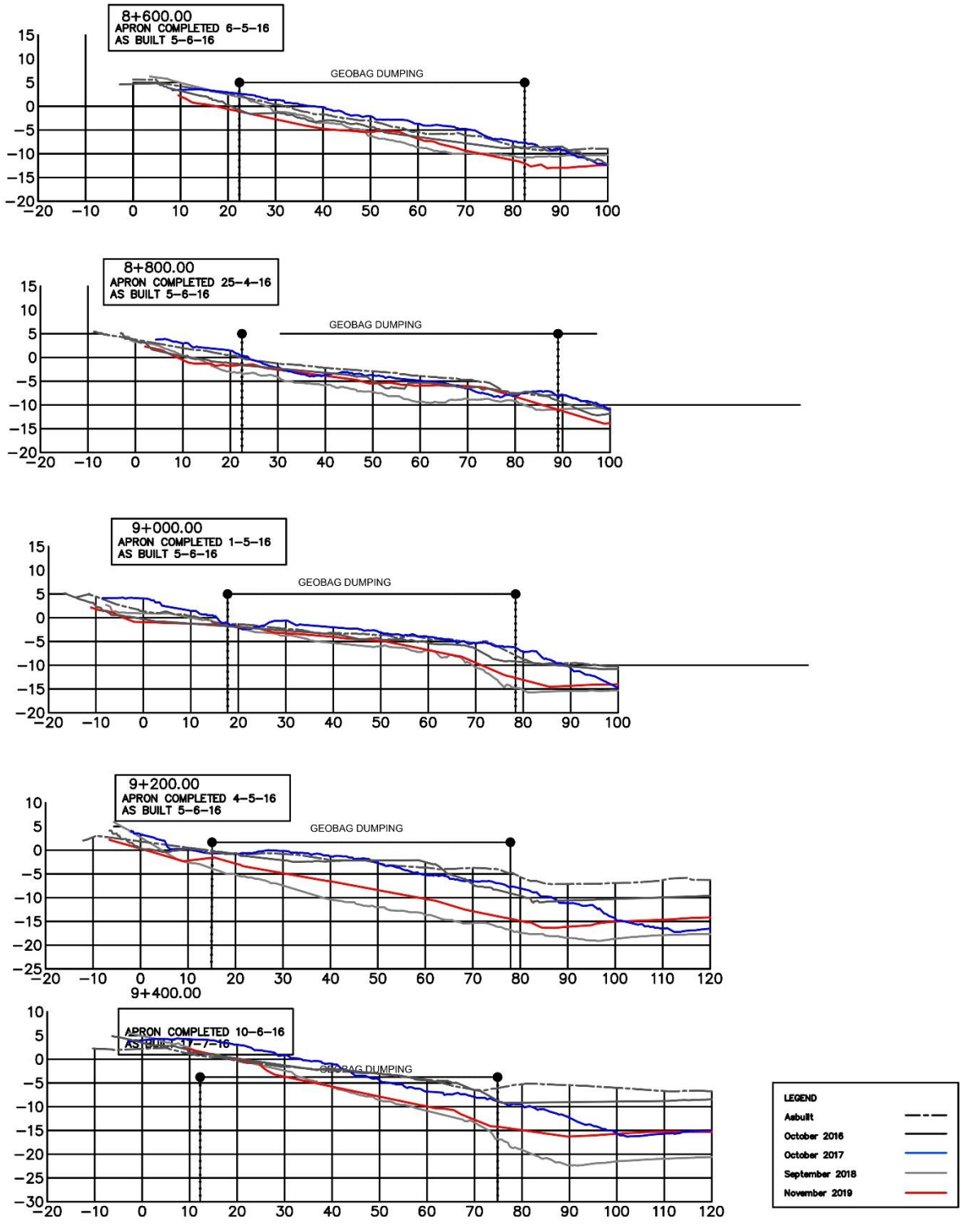

5+400.00
APRON COMPLETED 13-2-16
AS BUILT 5-6-16
GEOBAG DUMPING


LEGEND
Asbuilt
October 2016
October 2017
September 2018
November 2019

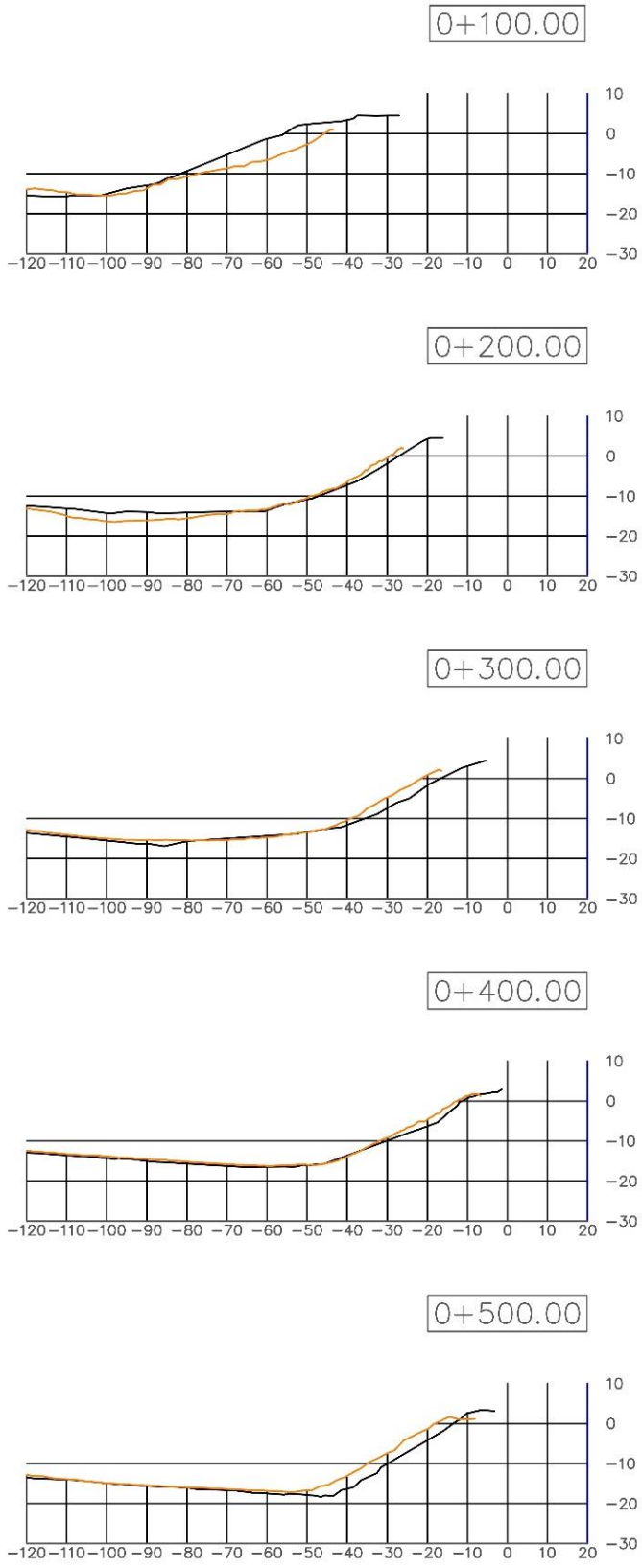

5+600.00
APRON COMPLETED 12-2-16
AS BUILT 5-6-16
GEOBAG DUMPING
5+800.00
APRON COMPLETED 2-3-16
AS BUILT 5-6-16
GEOBAG DUMPING
6+000.00
APRON COMPLETED 25-3-16
AS BUILT 5-6-16
GEOBAG DUMPING
6+200.00
APRON COMPLETED 29-2-16
AS BUILT 5-6-16
GEOBAG DUMPING
LEGEND
Asbuilt
October 2016
October 2017
September 2018
November 2019


6+600.00
APRON COMPLETED 26-3-16
AS BUILT 5-6-16
GEOBAG DUMPING
6+800.00
APRON COMPLETED 13-3-16
AS BUILT 5-6-16
GEOBAG DUMPING
7+000.00
APRON COMPLETED 9-4-16
AS BUILT 5-6-16
GEOBAG DUMPING
7+200.00
APRON COMPLETED 28-3-16
AS BUILT 5-6-16
GEOBAG DUMPING
7+400.00
APRON COMPLETED 2-4-16
AS BUILT 5-6-16
GEOBAG DUMPING
LEGEND
Asbuilt
October 2016
October 2017
September 2018
November 2019

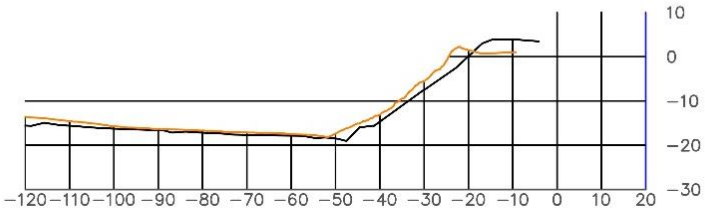

7+600.00
APRON COMPLETED 3-4-16
AS BUILT 5-6-16
GEOBAG DUMPING
7+800.00
APRON COMPLETED 29-4-16
AS BUILT 5-6-16
GEOBAG DUMPING
8+000.00
APRON COMPLETED 5-5-16
AS BUILT 5-6-16
GEOBAG DUMPING
8+200.00
APRON COMPLETED 10-6-16
AS BUILT 5-6-16
GEOBAG DUMPING
8+400.00
APRON COMPLETED 21-4-16
AS BUILT 5-6-16
GEOBAG DUMPING
LEGEND
Asbuilt
October 2016
October 2017
September 2018
November 2019


8+600.00
APRON COMPLETED 6-5-16
AS BUILT 5-6-16
GEOBAG DUMPING
8+800.00
APRON COMPLETED 25-4-16
AS BUILT 5-6-16
GEOBAG DUMPING
9+000.00
APRON COMPLETED 1-5-16
AS BUILT 5-6-16
GEOBAG DUMPING
9+200.00
APRON COMPLETED 4-5-16
AS BUILT 5-6-16
GEOBAG DUMPING
9+400.00
APRON COMPLETED 10-6-16
GEOBAG DUMPING
LEGEND
Asbuilt
October 2016
October 2017
September 2018
November 2019

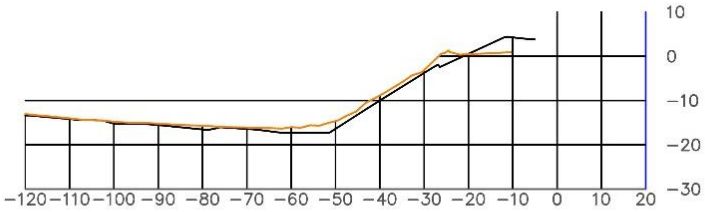
7.4 Nagarbari



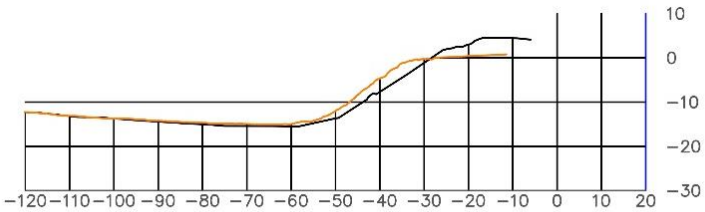
0+600.00



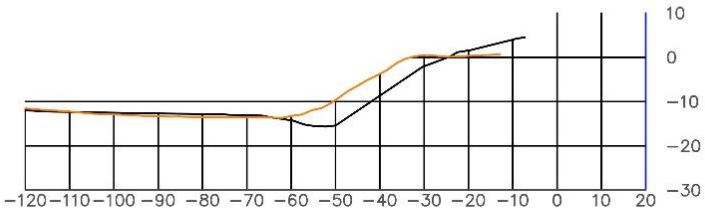
0+700.00



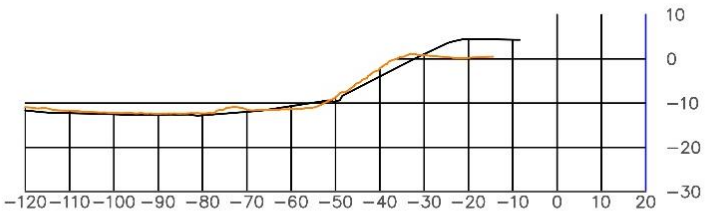
0+800.00



0+900.00



1+000.00

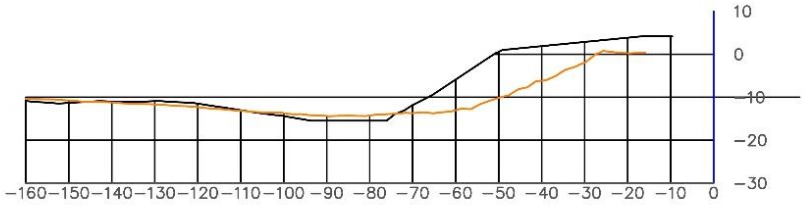


Legend

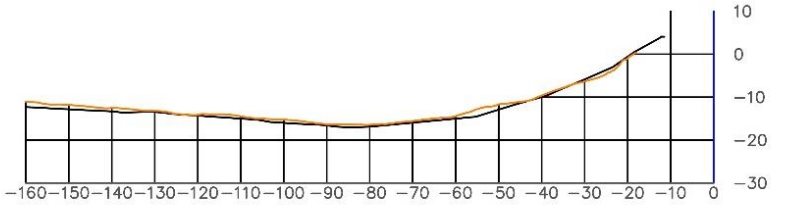
01 November 2019

12–15 November 2019

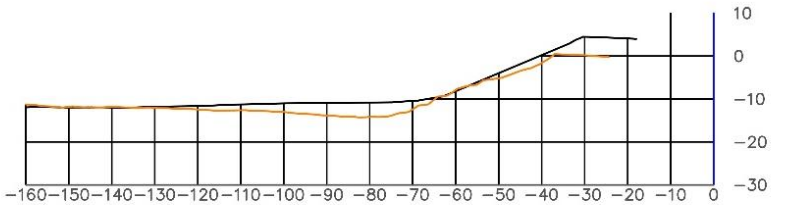
1+100.00



1+200.00



1+300.00



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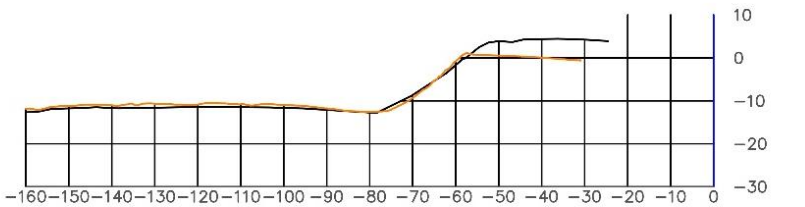

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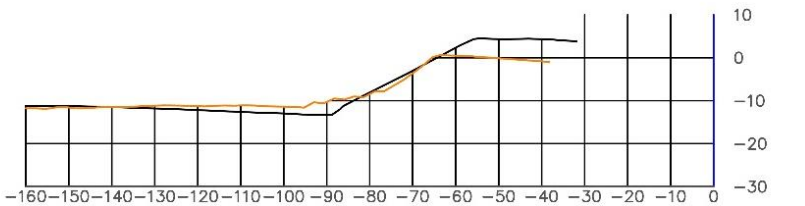
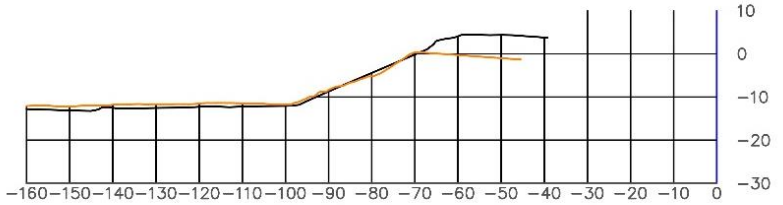


Legend

01 November 2019 ——

12–15 November 2019 ——

1+600.00



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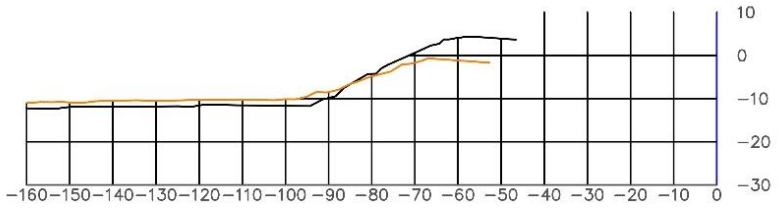

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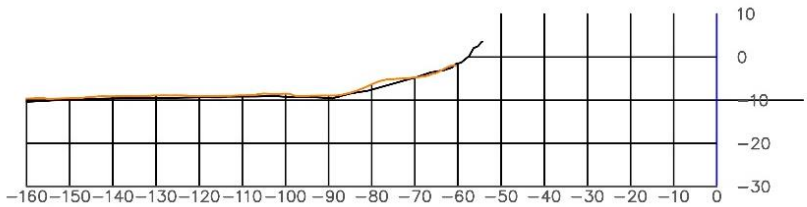

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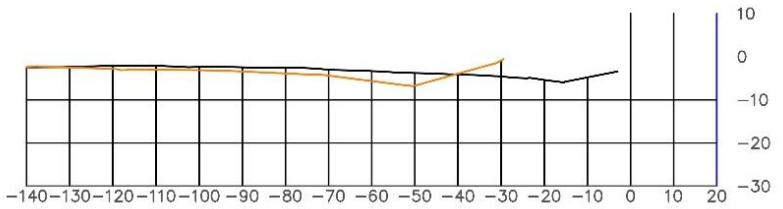

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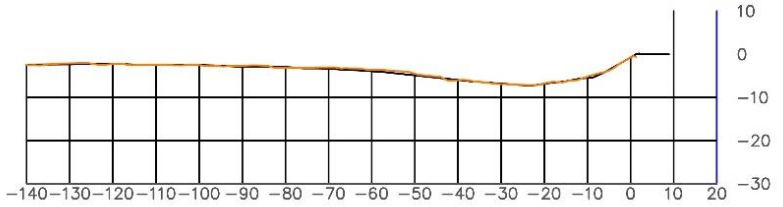

Legend

01 November 2019 ——

12–15 November 2019 ——

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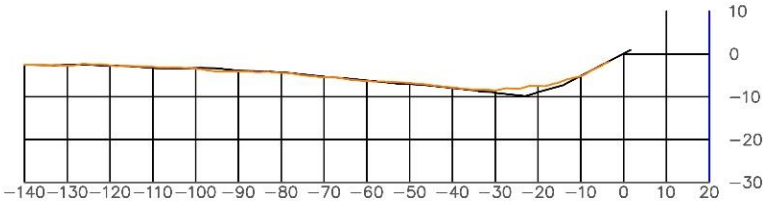

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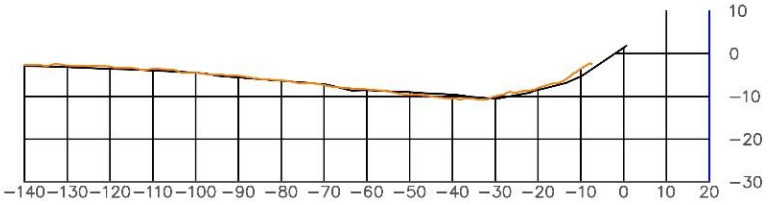

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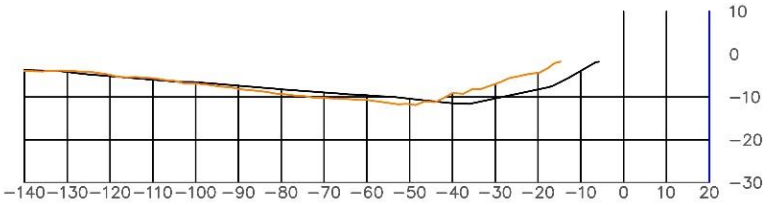

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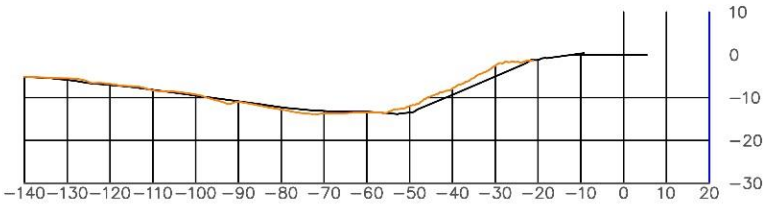

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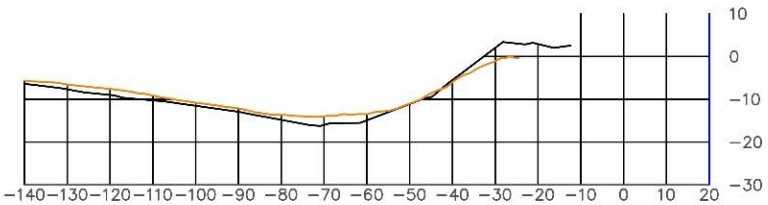
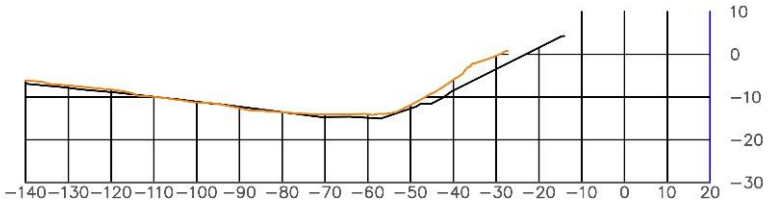


Legend

01 November 2019

12–15 November 2019

4+200.00



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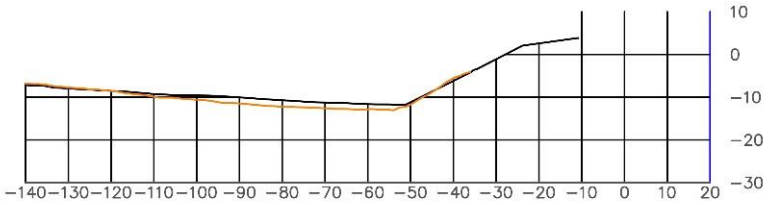

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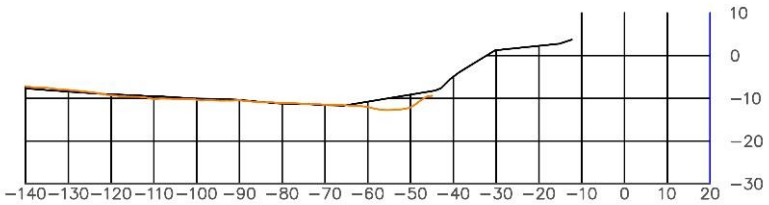
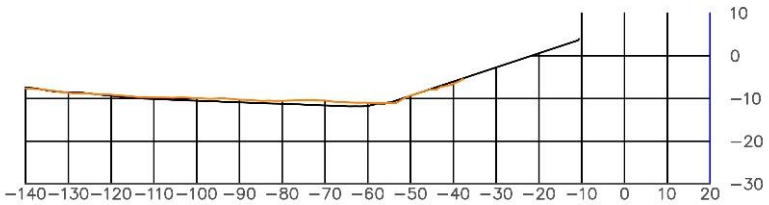


4+500.00



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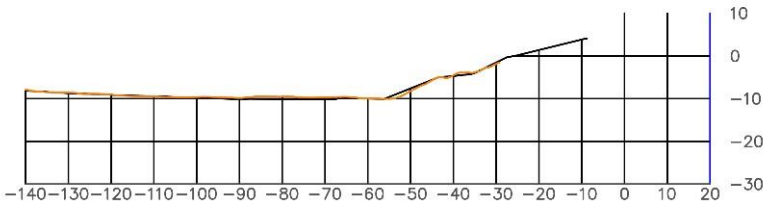

Legend

01 November 2019 ——

12–15 November 2019 ——

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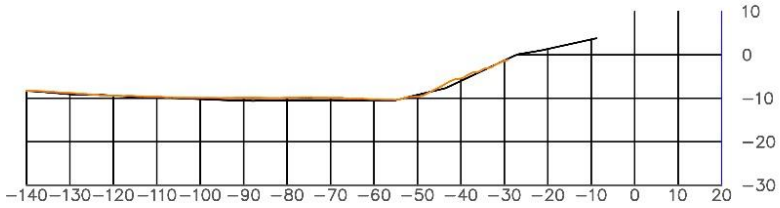
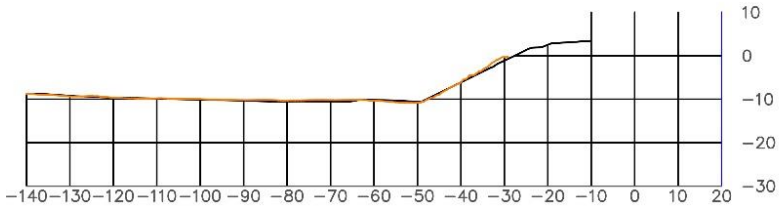
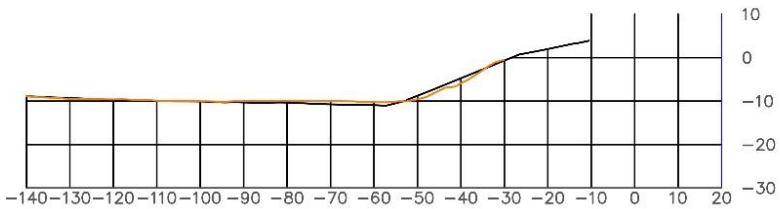


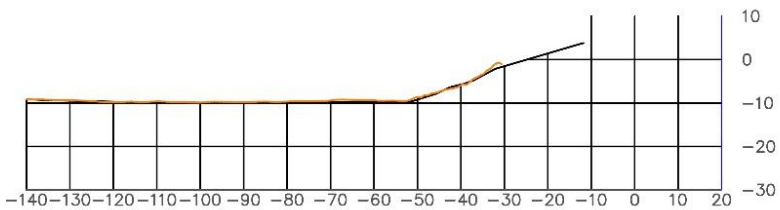
4+800.00



4+900.00



5+000.00



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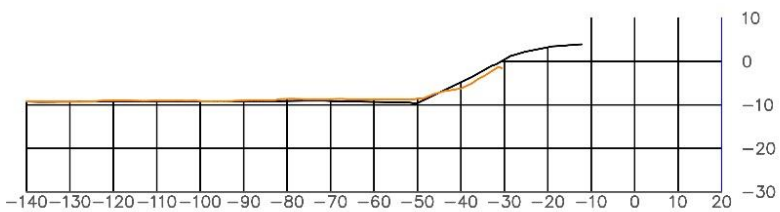
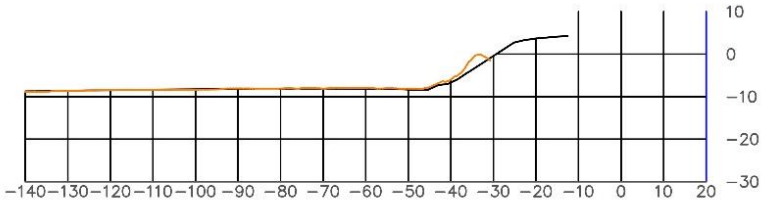


Legend

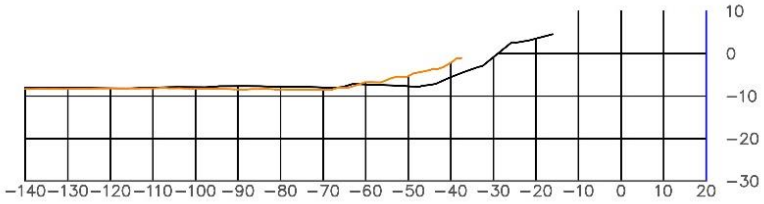
01 November 2019 ——

12–15 November 2019 ——

5+200.00



5+300.00



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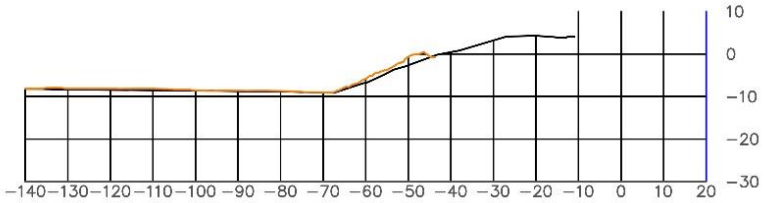

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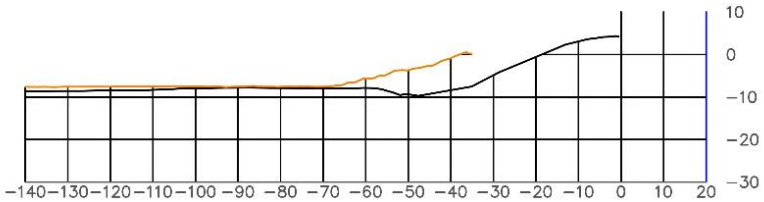
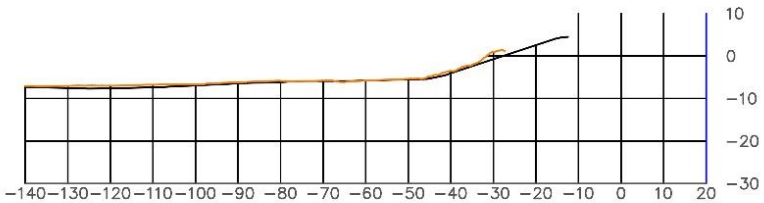


5+600.00

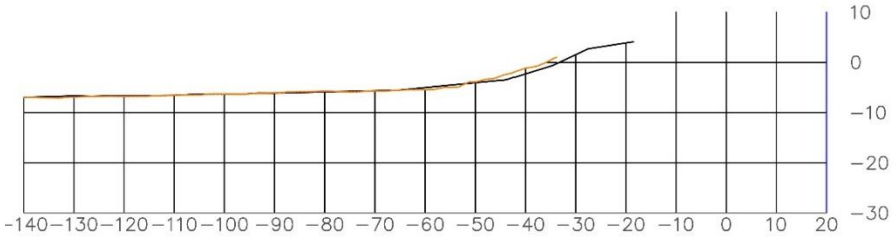


Legend

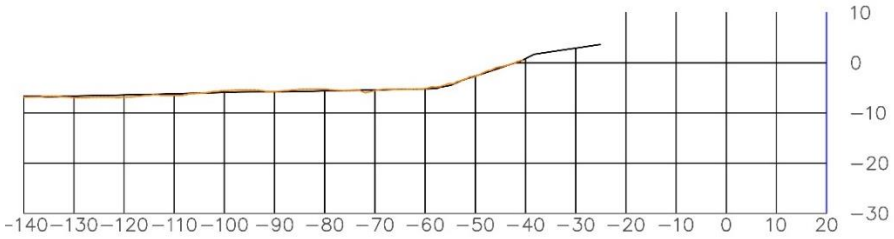
01 November 2019

12–15 November 2019

5+700.00



5+800.00



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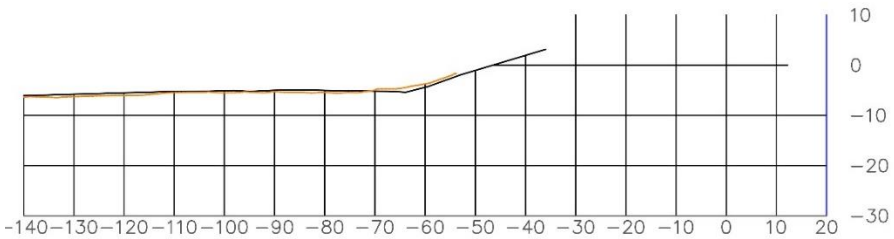


Legend

01 November 2019

12–15 November 2019

8 Multibeam Survey Maps

During November 2019 and June 2020 IWM conducted multibeam surveys at Chauhali, Koijuri, Benotia, PIRDP, Nagarbari, Zafarganj and Harirampur. Main objective and limitations of these multibeam survey were

- Identify underwater condition of the protected riverbank
- Identify performance of the launched apron
- Identify the need for adaption works
- Due to the low water level during the survey, the transition to the upper slope could not surveyed
- The survey coverage is 10 to 15m to the waterline.

Figure 8-1 shows location of the multibeam sites.

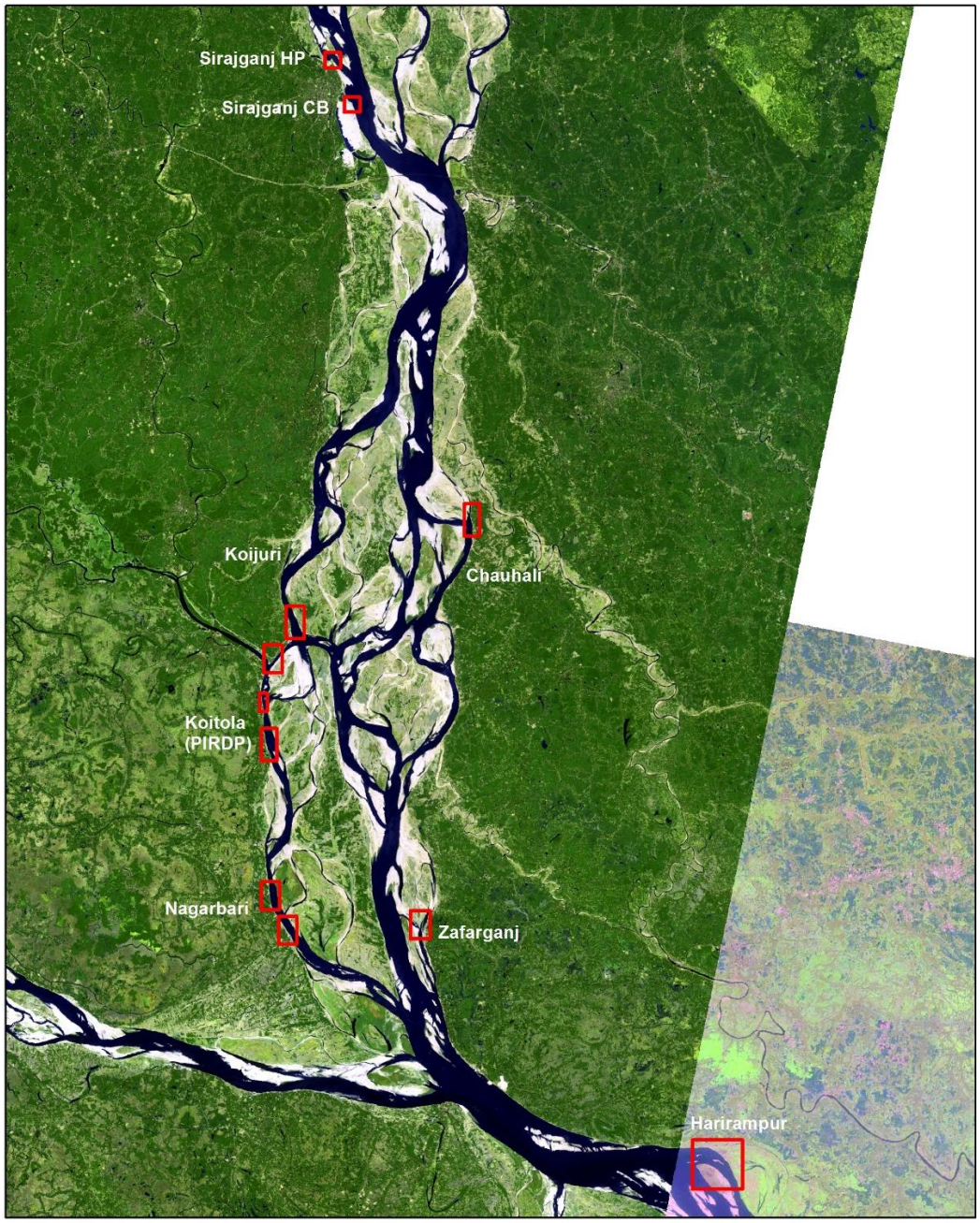
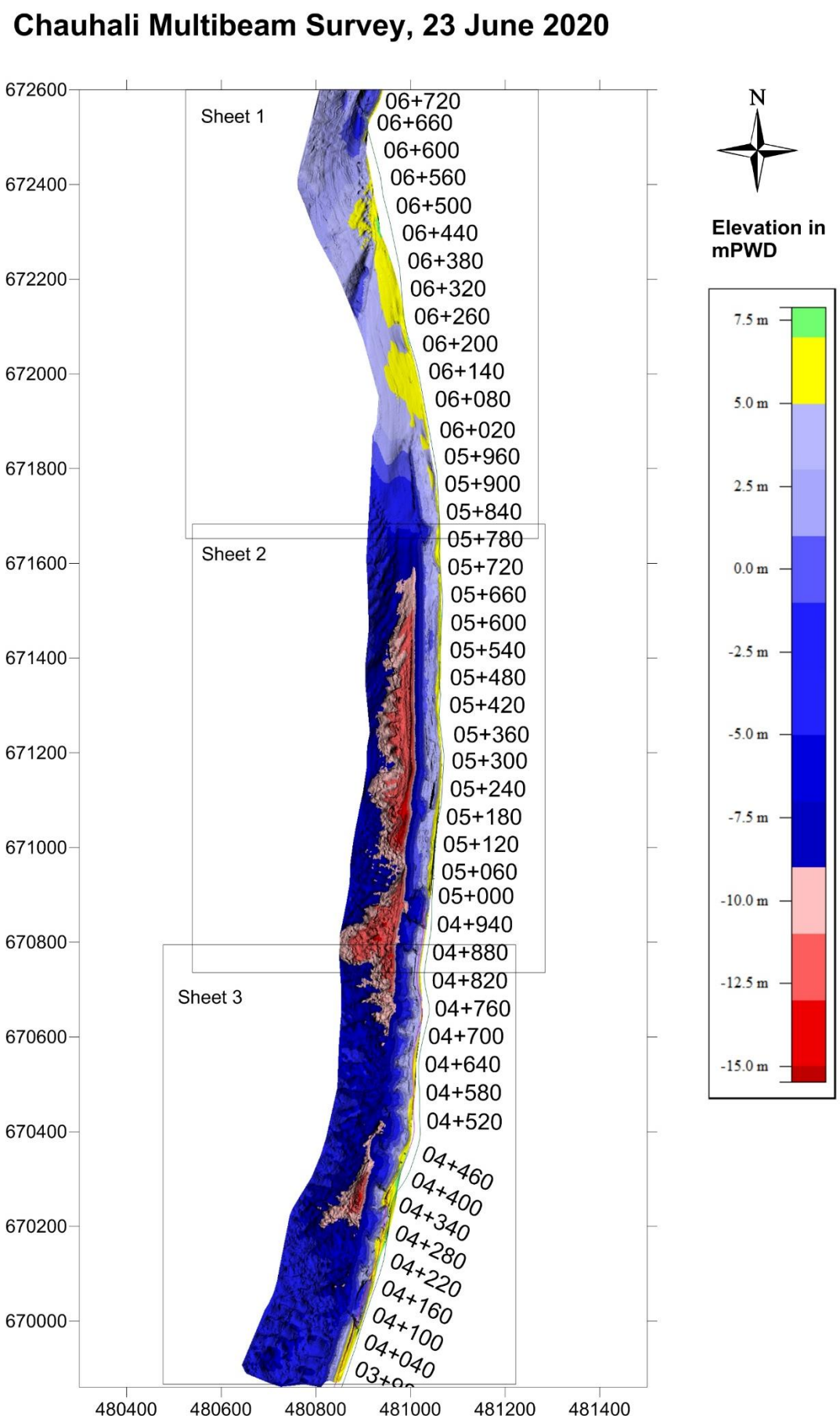
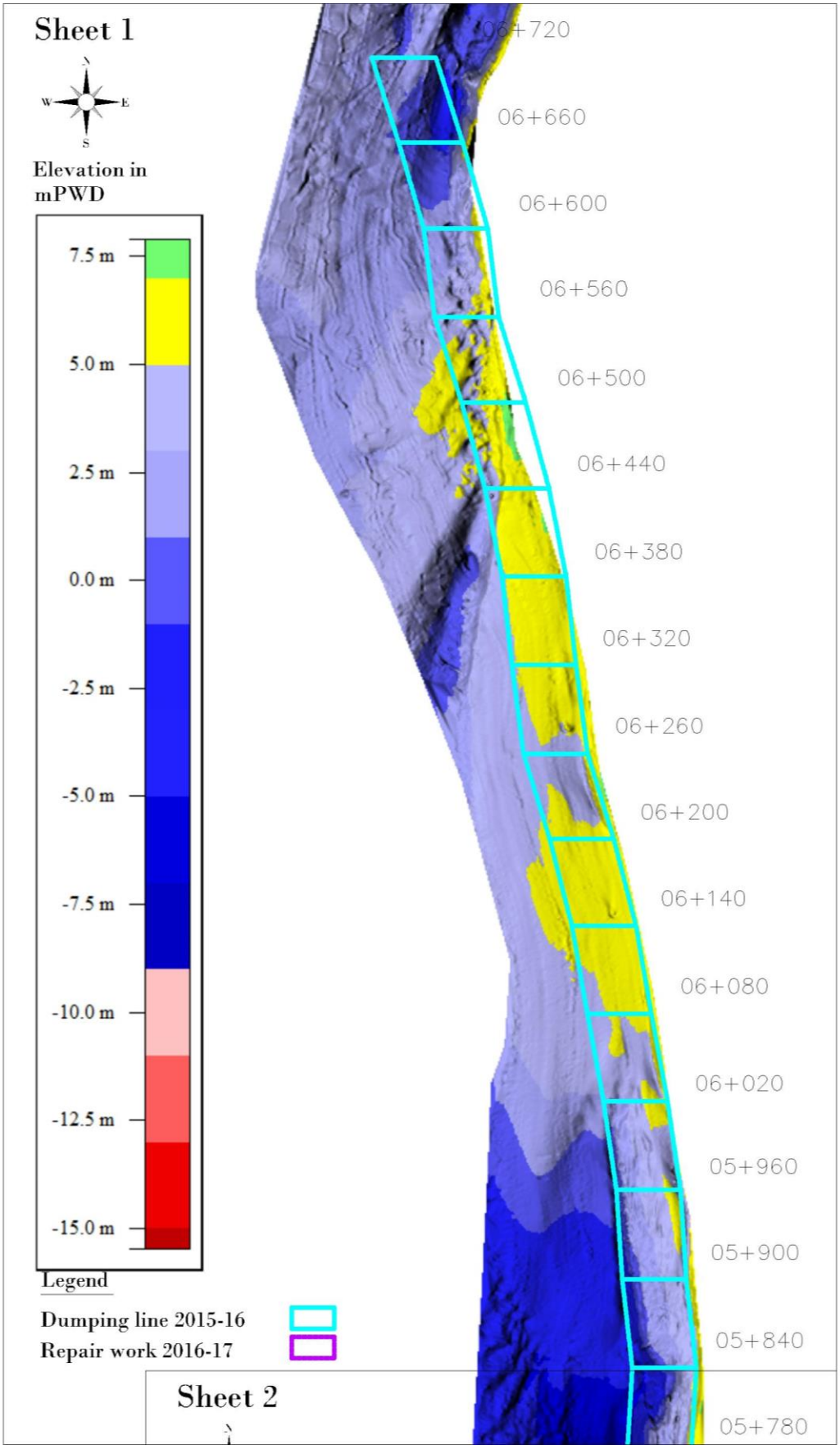


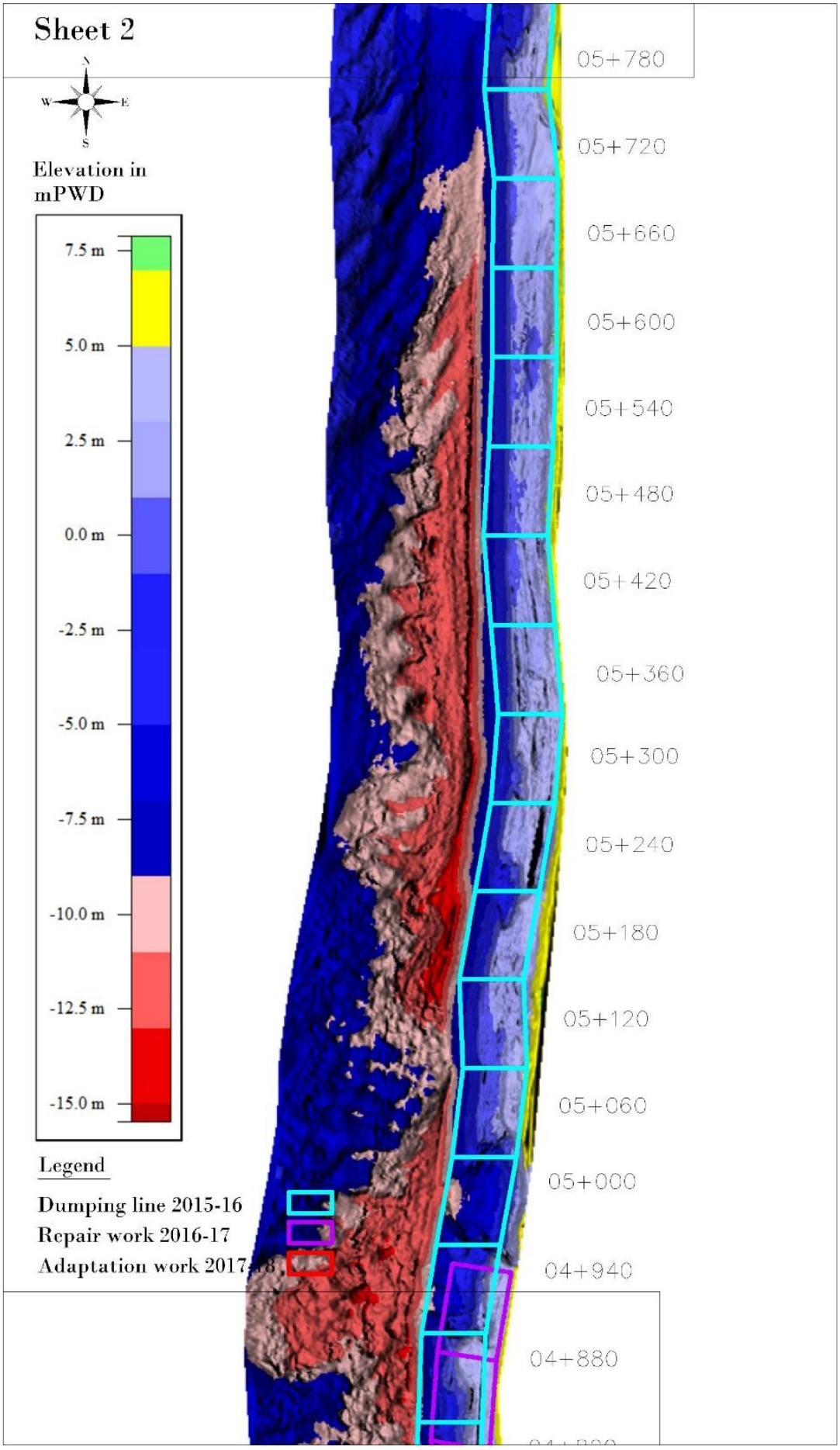
Figure 8-1 Location of multibeam survey

8.1 Chauhali


Chauhali Multibeam Survey, 23 June 2020
672600
672400
672200
672000
671800
671600
671400
671200
671000
670800
670600
670400
670200
670000
480400
480600
480800
481000
481200
481400
Sheet 1
Sheet 2
Sheet 3
06+720
06+660
06+600
06+560
06+500
06+440
06+380
06+320
06+260
06+200
06+140
06+080
06+020
05+960
05+900
05+840
05+780
05+720
05+660
05+600
05+540
05+480
05+420
05+360
05+300
05+240
05+180
05+120
05+060
05+000
04+940
04+880
04+820
04+760
04+700
04+640
04+580
04+520
04+460
04+400
04+340
04+280
04+220
04+160
04+100
04+040
N
Elevation in mPWD
7.5 m
5.0 m
2.5 m
0.0 m
-2.5 m
-5.0 m
-7.5 m
-10.0 m
-12.5 m
-15.0 m



There is a bankfailure and underwater erosion near the outflank at km 6+700. In this location apron is buried under sediment and except the outflank no other erosion observed.


Sheet 2
N
W
E
S
Elevation in mPWD
7.5 m
5.0 m
2.5 m
0.0 m
-2.5 m
-5.0 m
-7.5 m
-10.0 m
-12.5 m
-15.0 m
Legend
Dumping line 2015-16
Repair work 2016-17
Adaptation work 2017-18
05+780
05+720
05+660
05+600
05+540
05+480
05+420
05+360
05+300
05+240
05+180
05+120
05+060
05+000
04+940
04+880

. From plan view and 3D view it shows that the apron beside the protection upstream of 5+000 is in significantly better condition compared to the apron from km 4+000 to km 5+000.

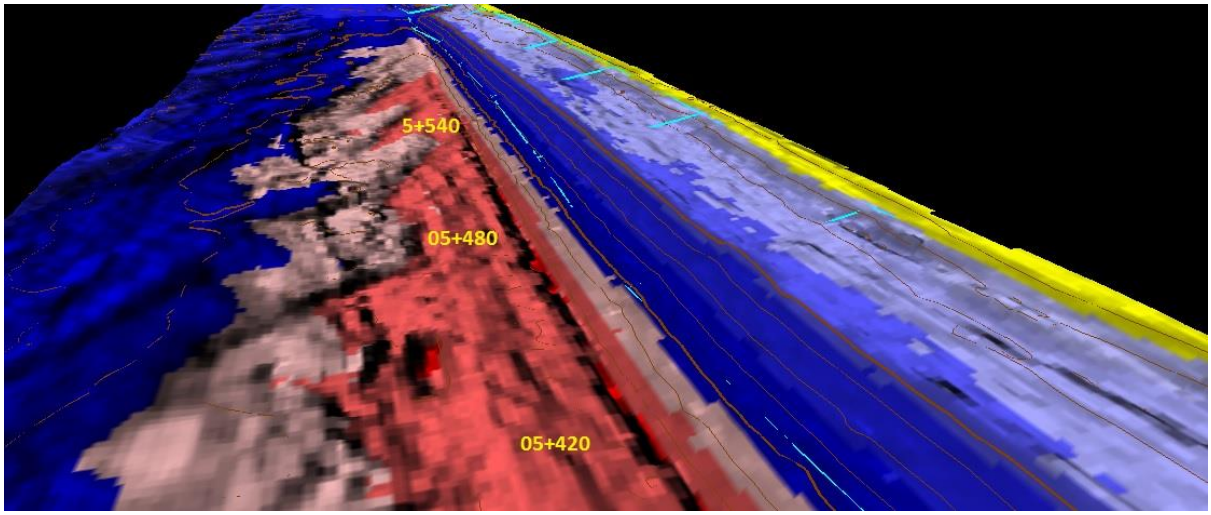


Figure 8-2 Underwater launched slope beside temporary protection

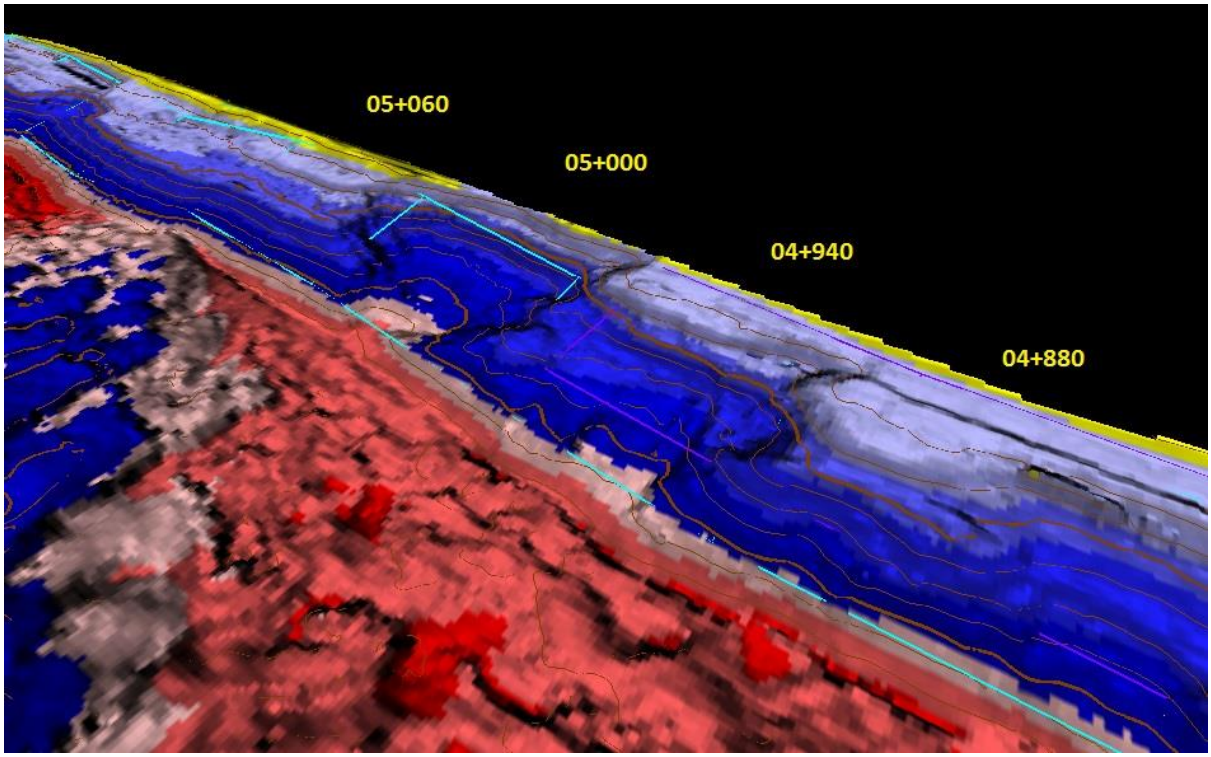
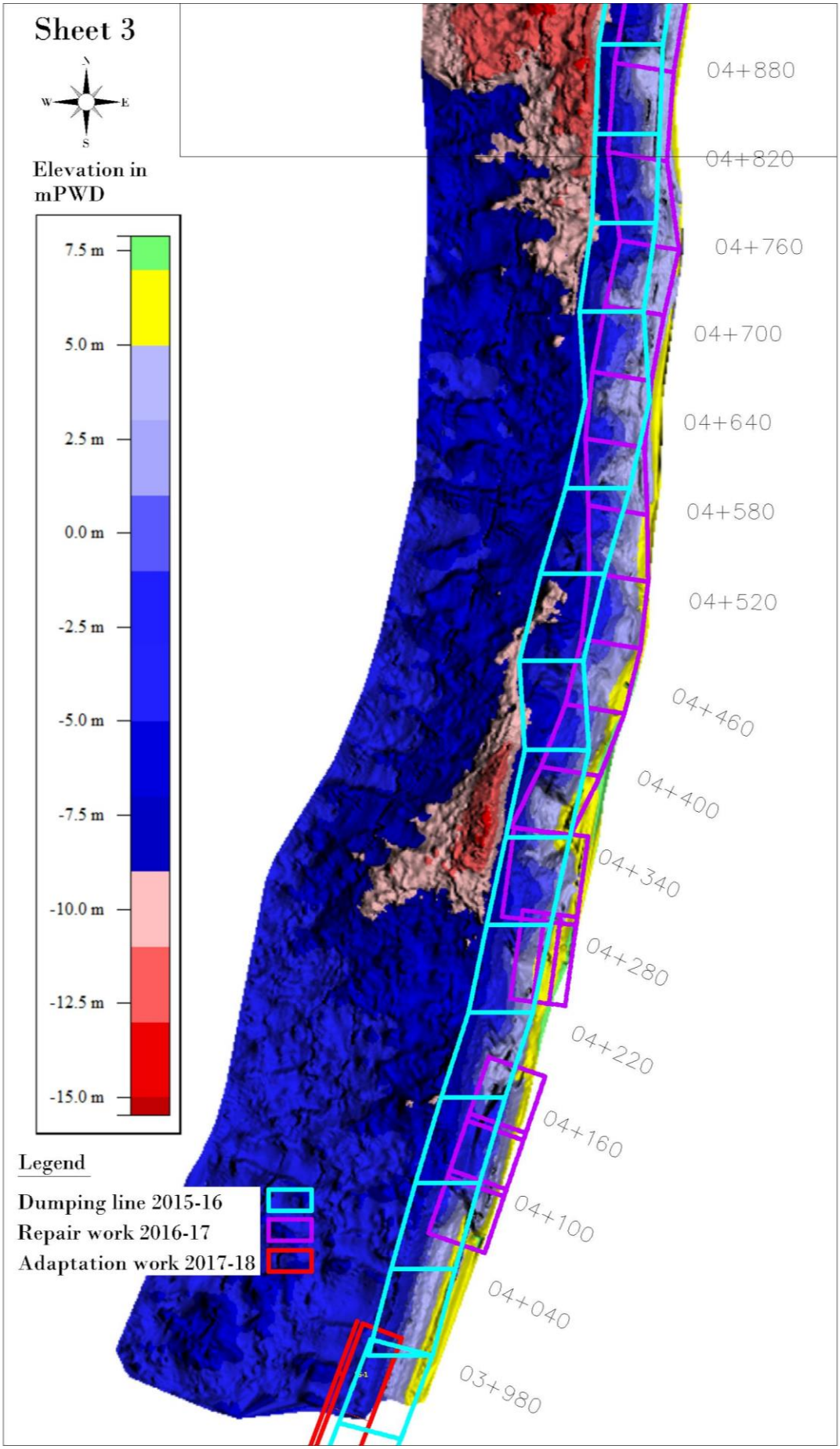


Figure 8-3 Underwater eroded location during February 2018 later repaired by geobag dumping using countryboat.


Sheet 3
N
W
E
S
Elevation in mPWD
7.5 m
5.0 m
2.5 m
0.0 m
-2.5 m
-5.0 m
-7.5 m
-10.0 m
-12.5 m
-15.0 m
Legend
Dumping line 2015-16
Repair work 2016-17
Adaptation work 2017-18
04+880
04+820
04+760
04+700
04+640
04+580
04+520
04+460
04+400
04+340
04+280
04+220
04+160
04+100
04+040
03+980

At this location erosion was observed during the 2016-17 flood season. After 2017 flood this location starts filling and recent survey shows new scour but still the launched slope is not completely exposed. From the plan view eroded location, dumping plan, repair strips and location of the adaptation work can be seen.

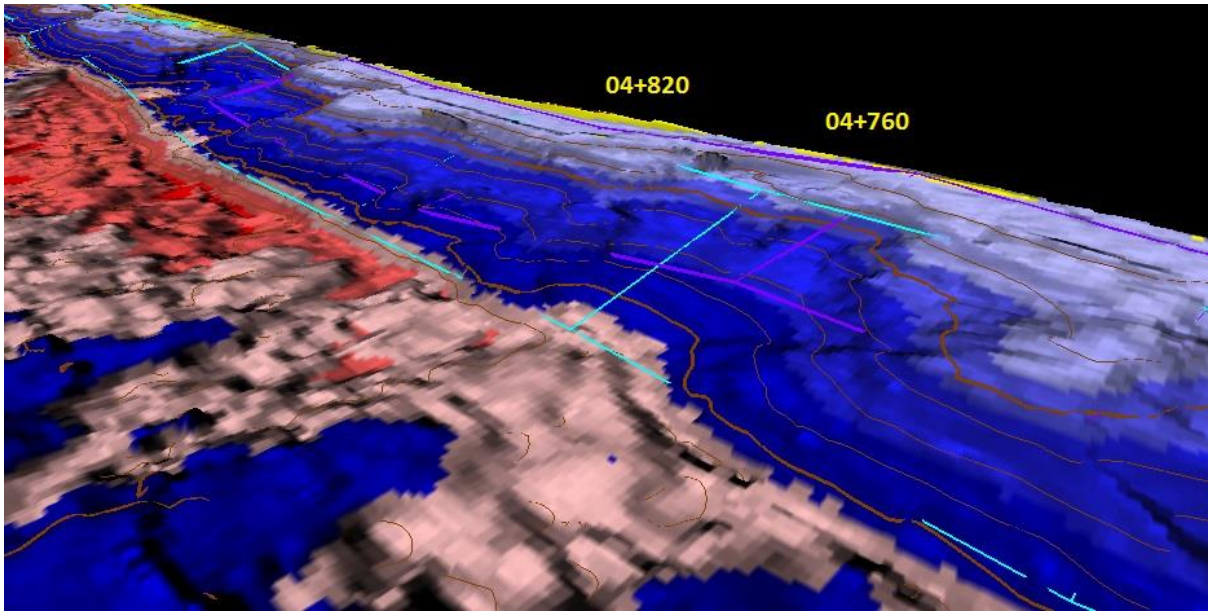
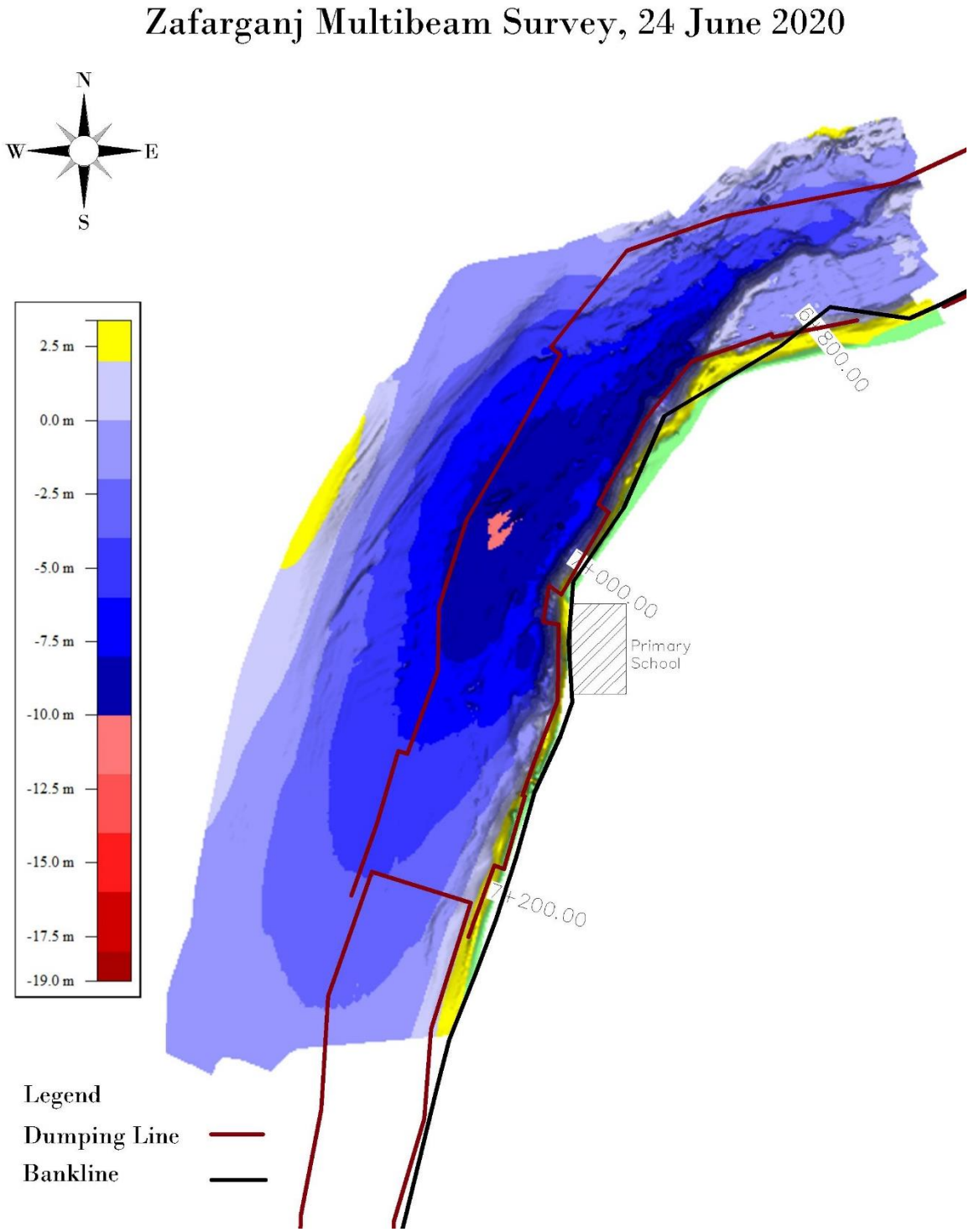


Figure 8-4 Under water erosion at km 04+760

8.2 Zafarganj



Beside the primary school at Zafarganj site, the underwater slope is very steep. 3D view shows the slope near the school and cross section shows roughly 1V: 1.5H underwater slope, which is typical for protrusion scours. The scour hole has not yet fully developed but it is likely that it will increase in depth and size over the next seasons.

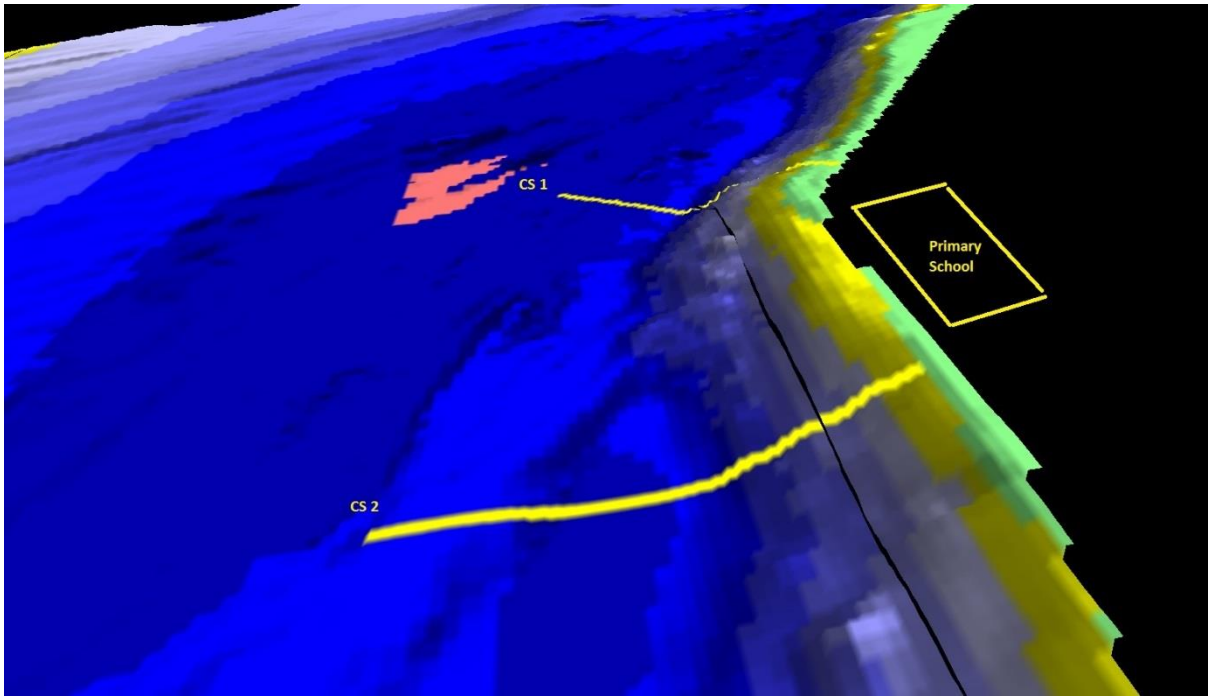


Figure 8-5 3D view of underwater situation near the primary school area

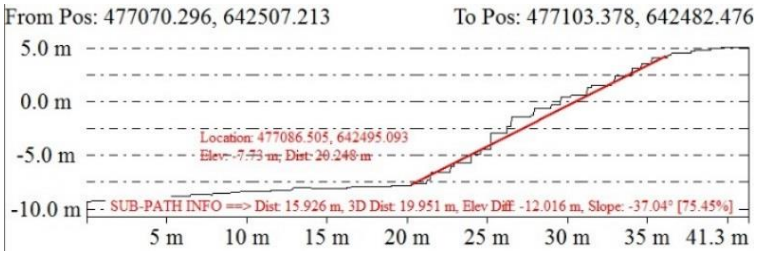


Figure 8-6 Cross section CS 01

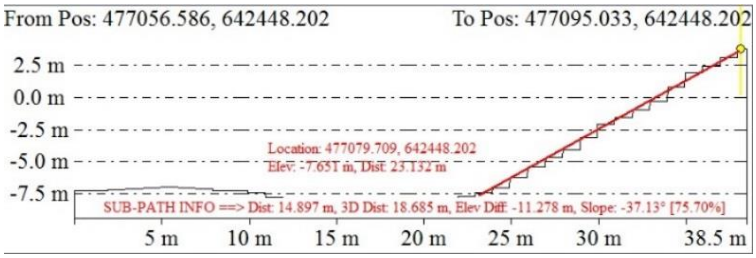
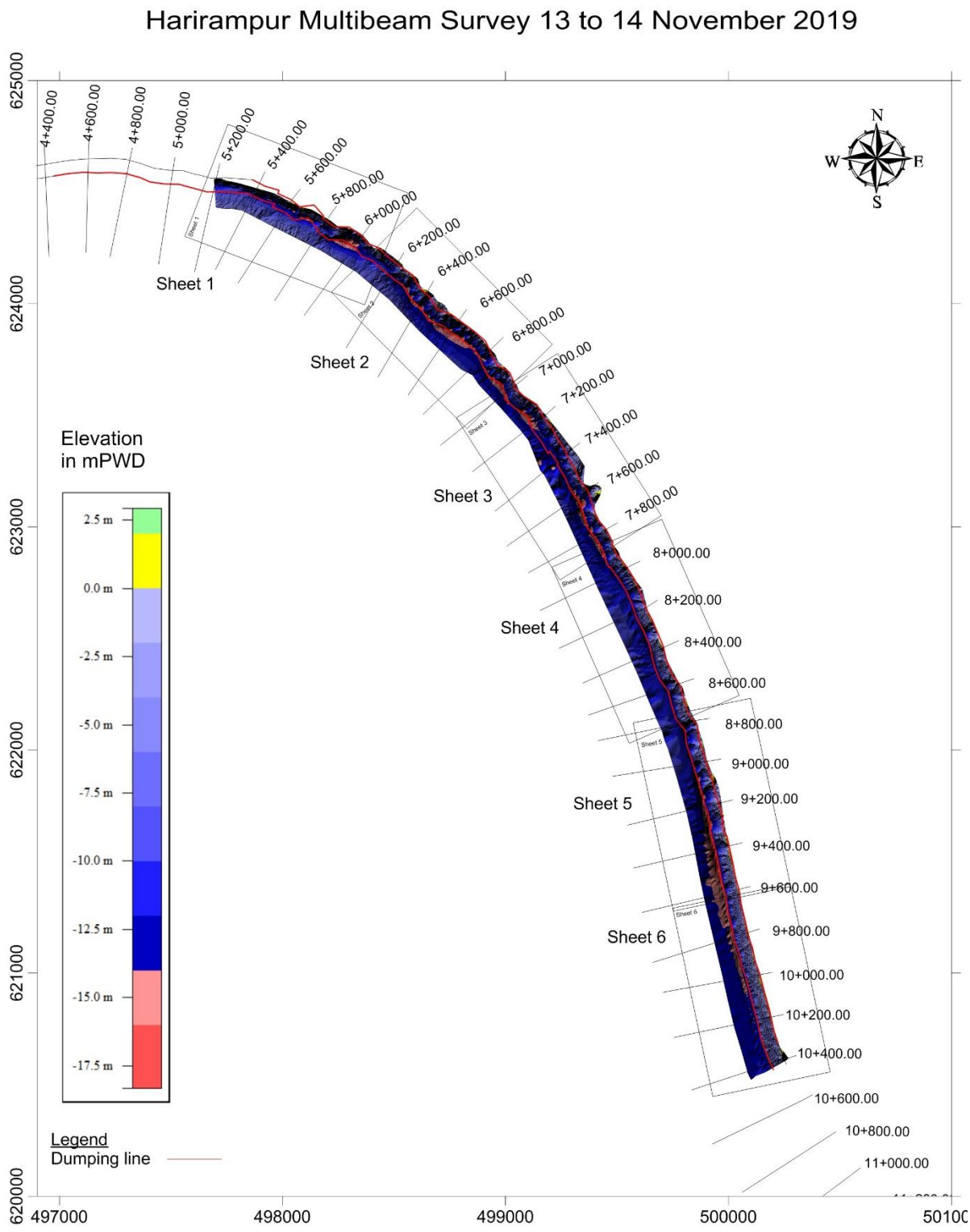
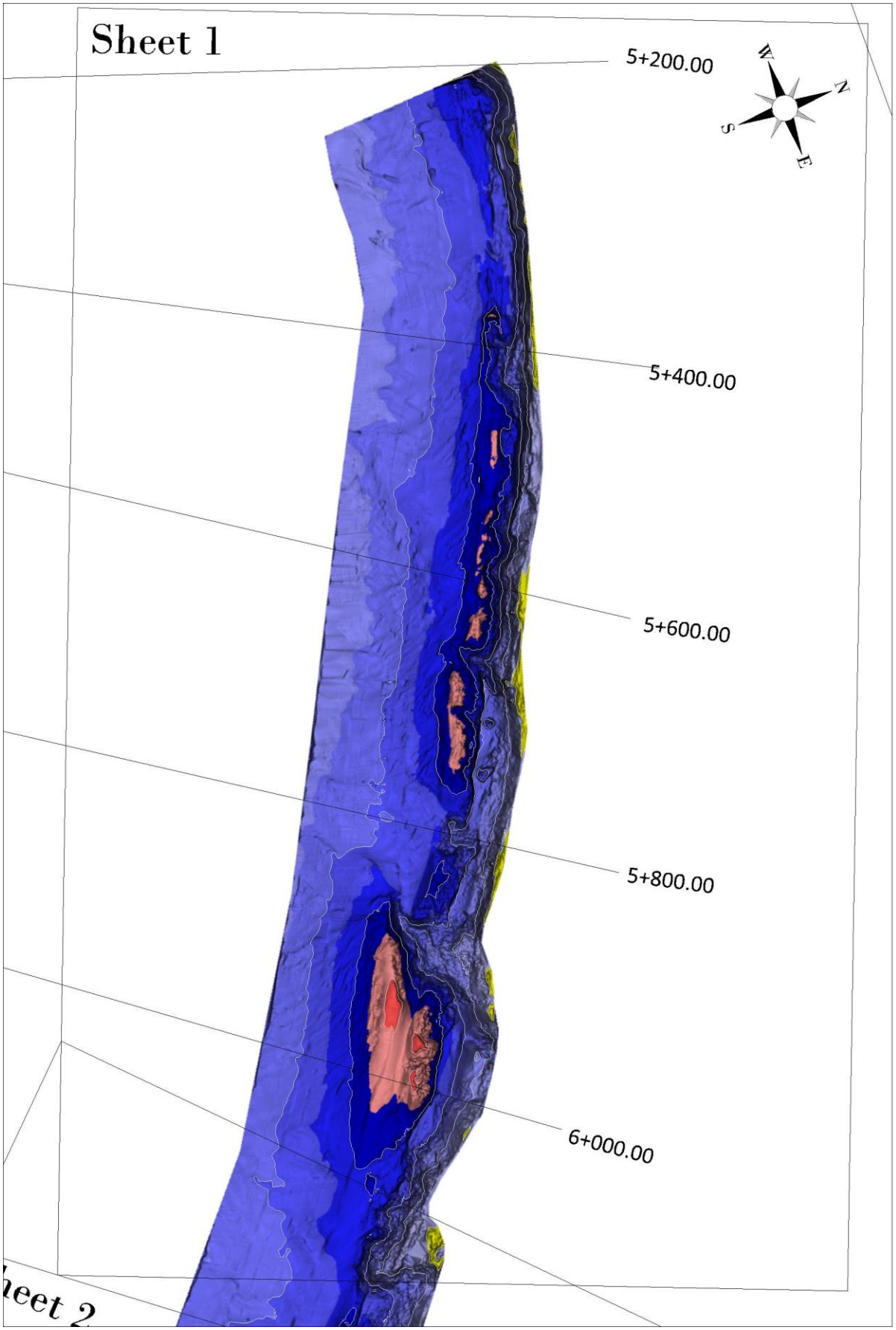


Figure 8-7 Cross Section CS 02

8.3 Harirampur




Sheet 1
5+200.00
5+400.00
5+600.00
5+800.00
6+000.00
N
W
E
S

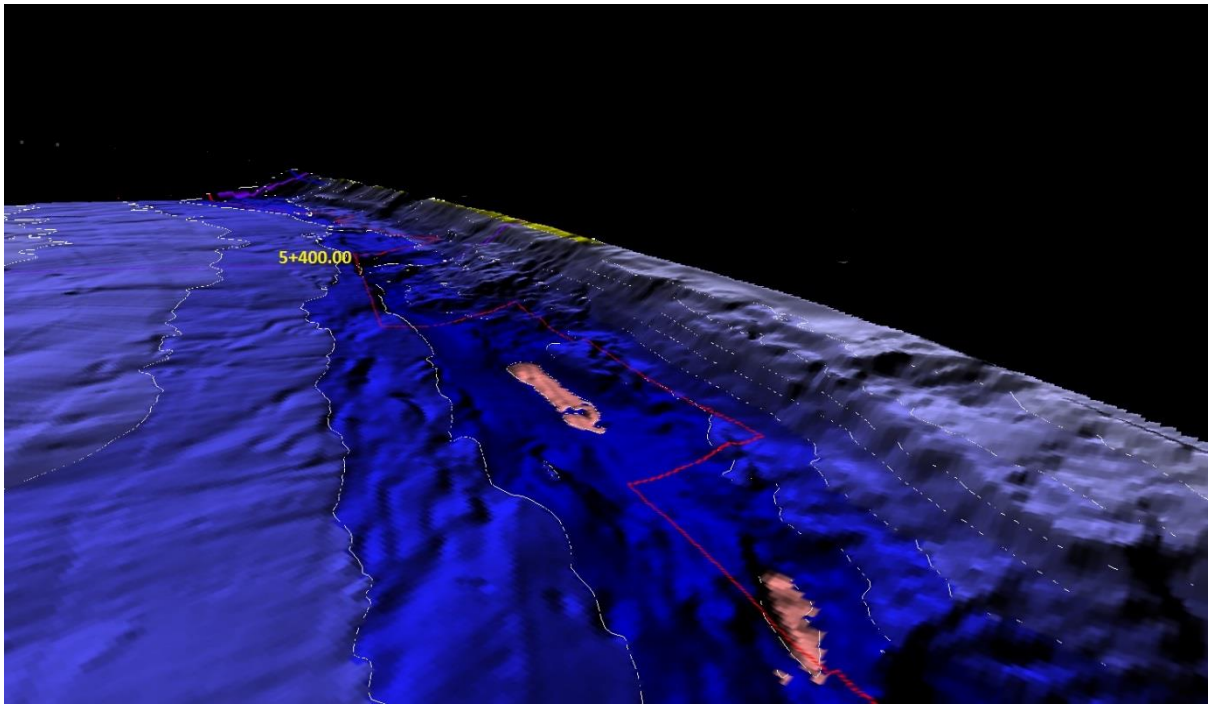


Figure 8-8 Underwater launched slope at 5+400.00

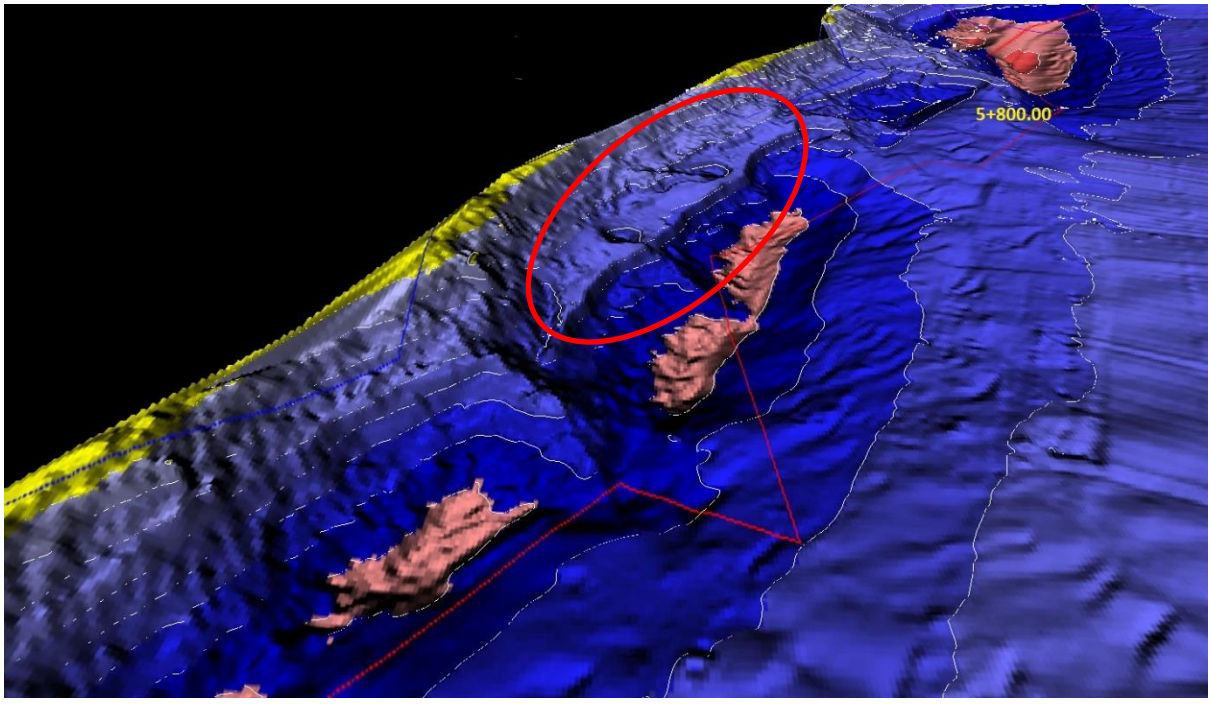
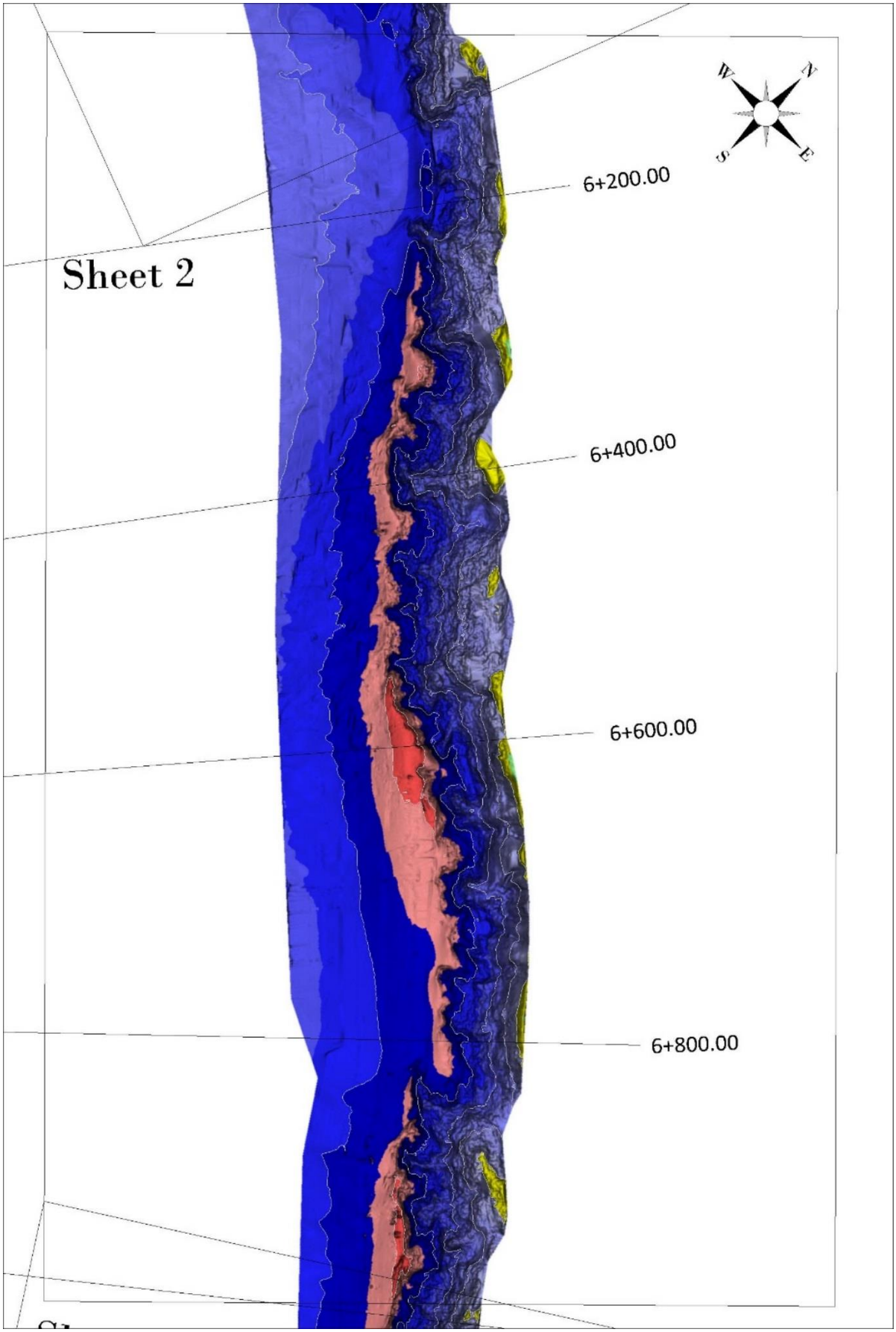


Figure 8-9 Underwater launched slope with sediment on top


Sheet 2
6+200.00
6+400.00
6+600.00
6+800.00
W
N
S
E

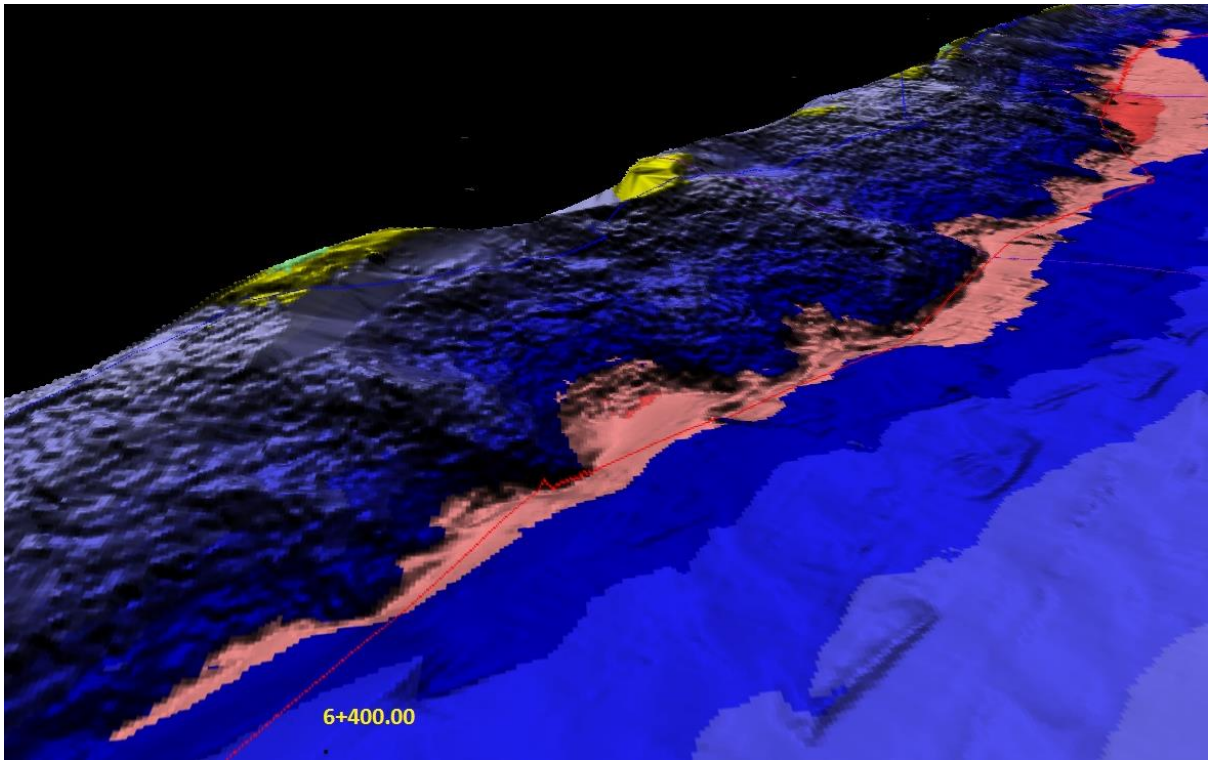


Figure 8-10 Improper launching at km 6+400

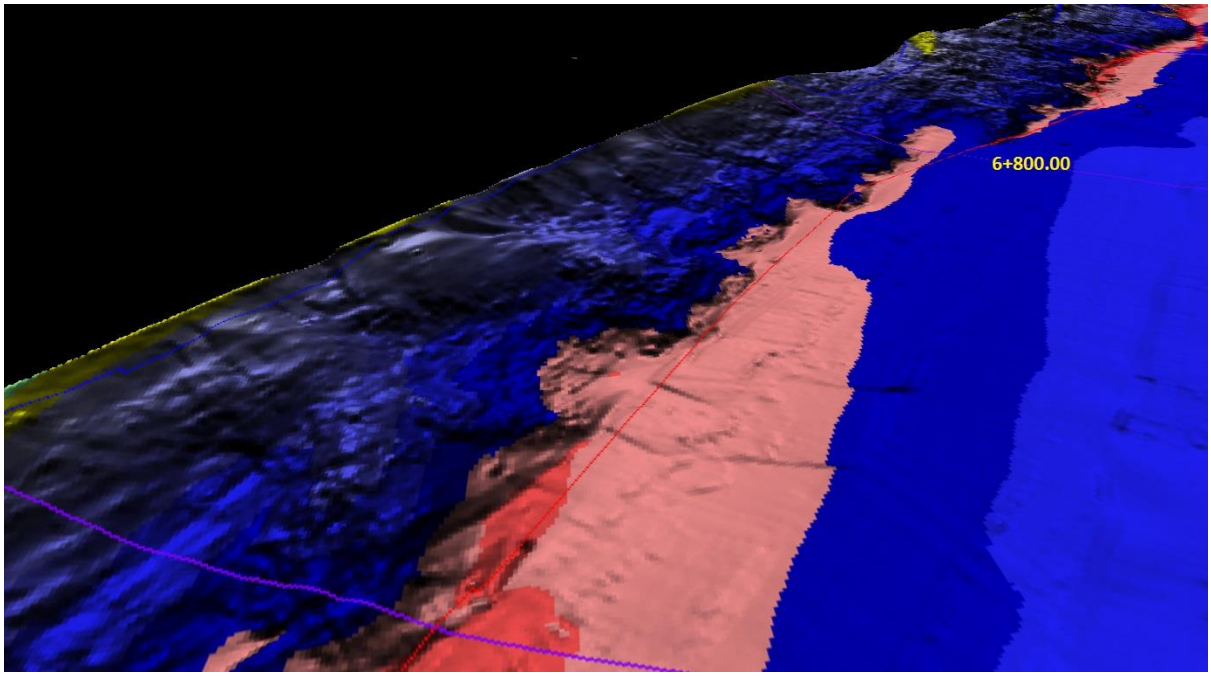
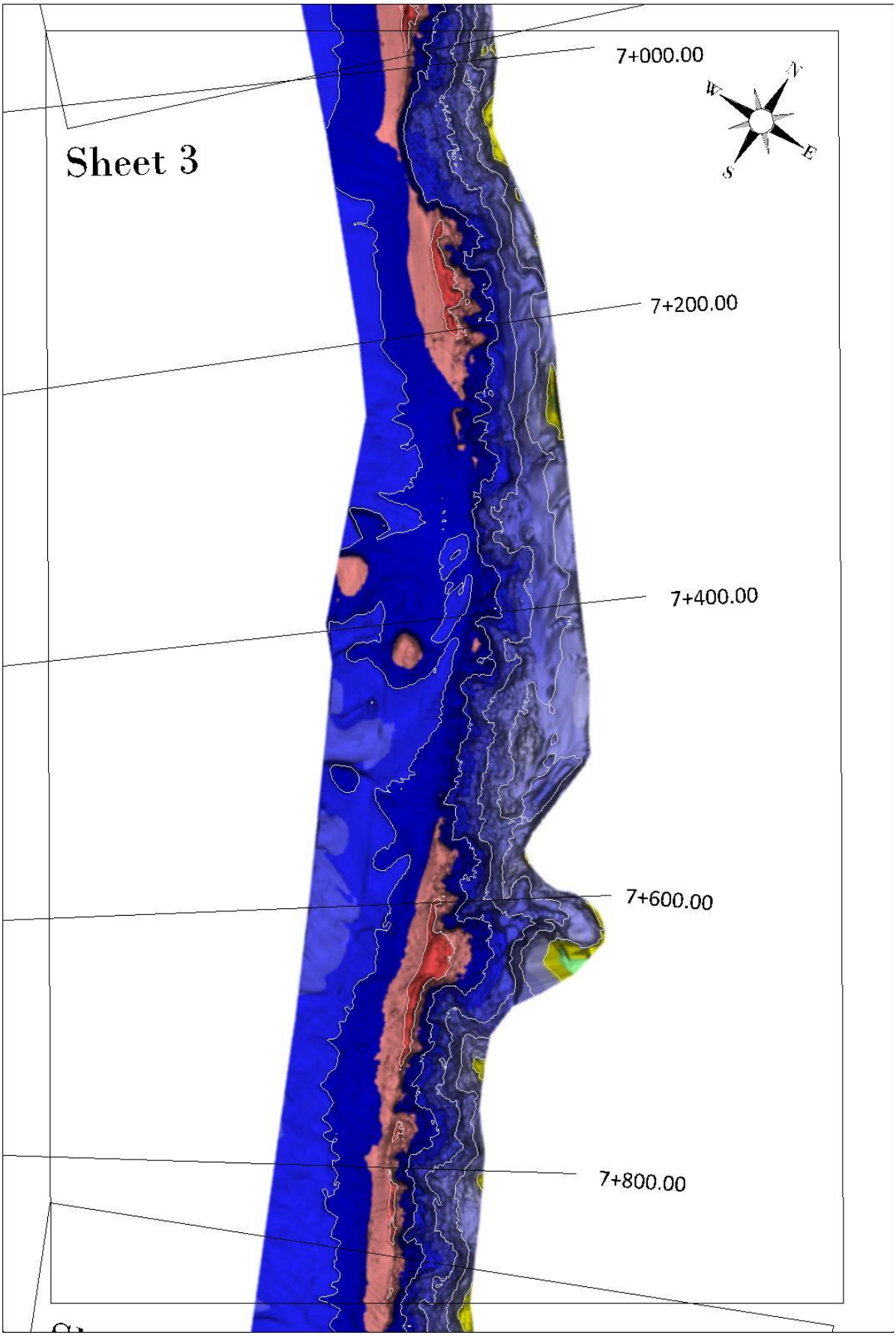


Figure 8-11 Improper launching at km 6+800


Sheet 3
7+000.00
7+200.00
7+400.00
7+600.00
7+800.00
N
W
E
S

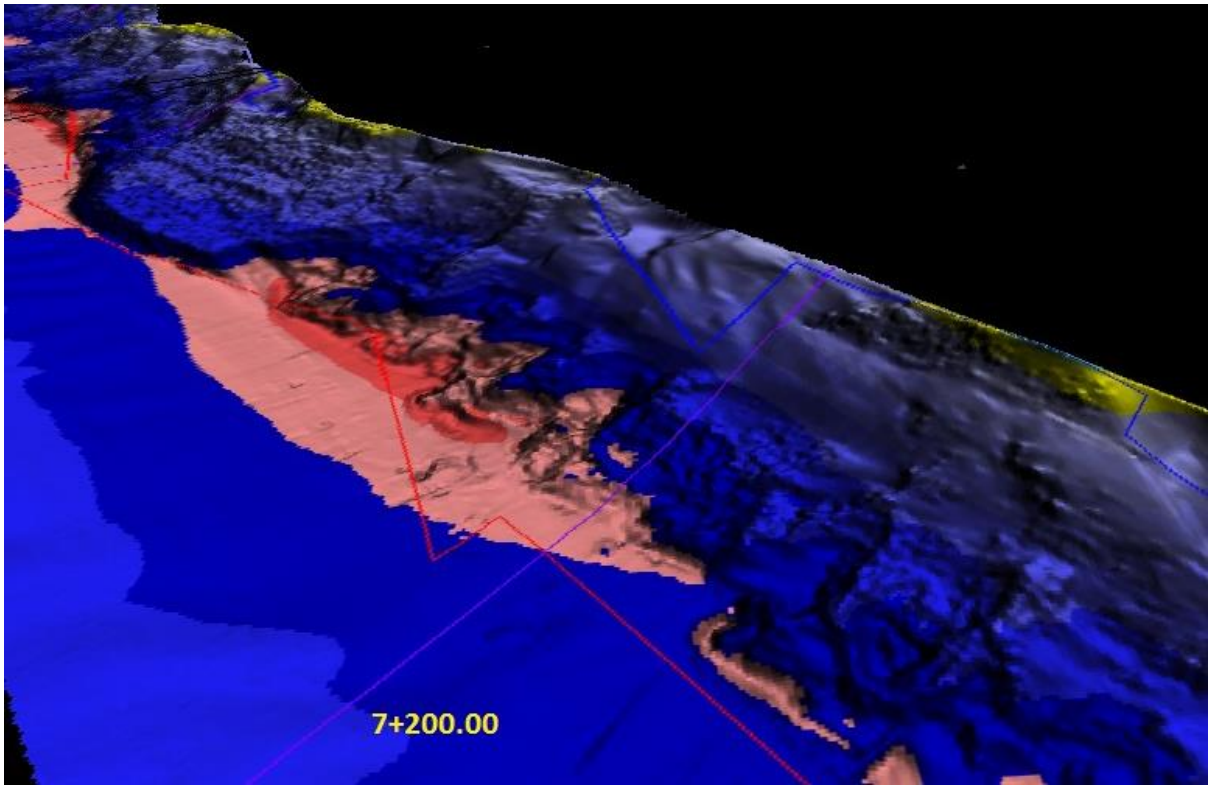
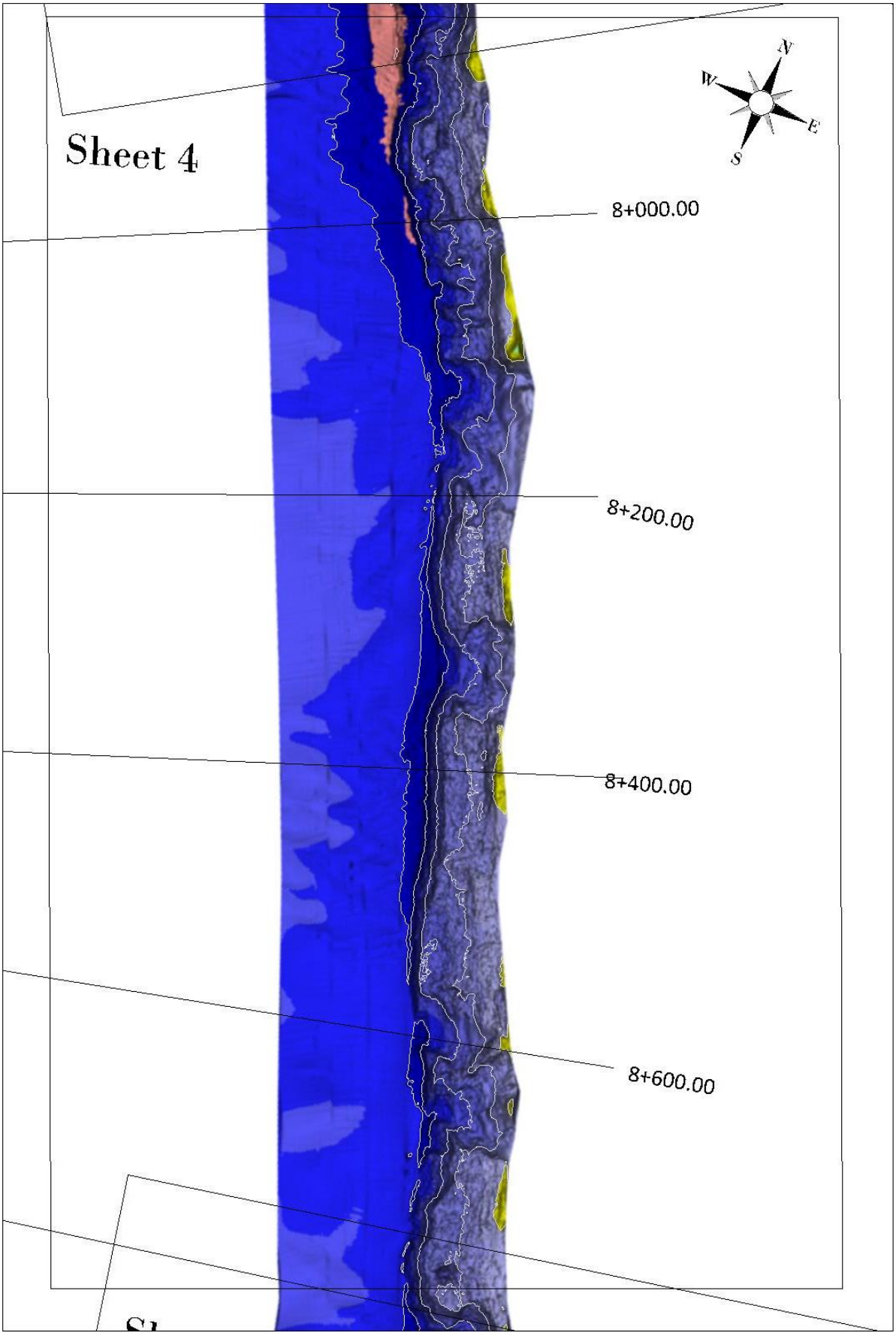


Figure 8-12 Improper launching at km 7+200


Sheet 4
N
W
E
S
8+000.00
8+200.00
8+400.00
8+600.00

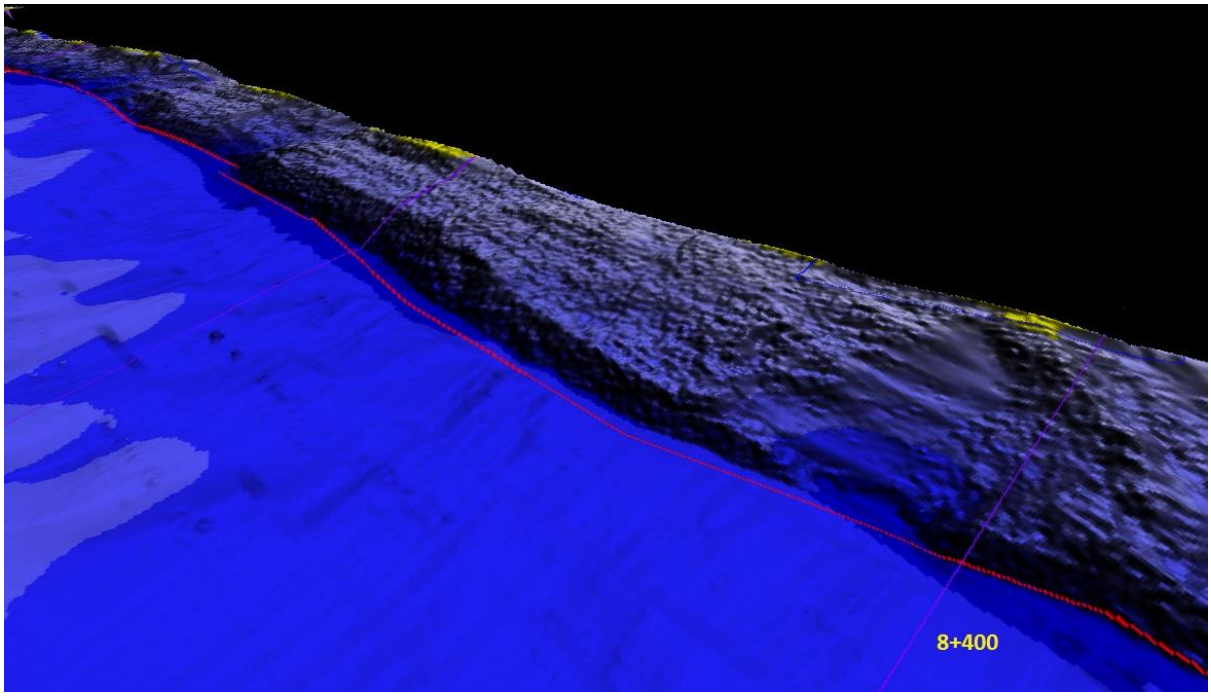


Figure 8-13 Launched slope at km 8+400

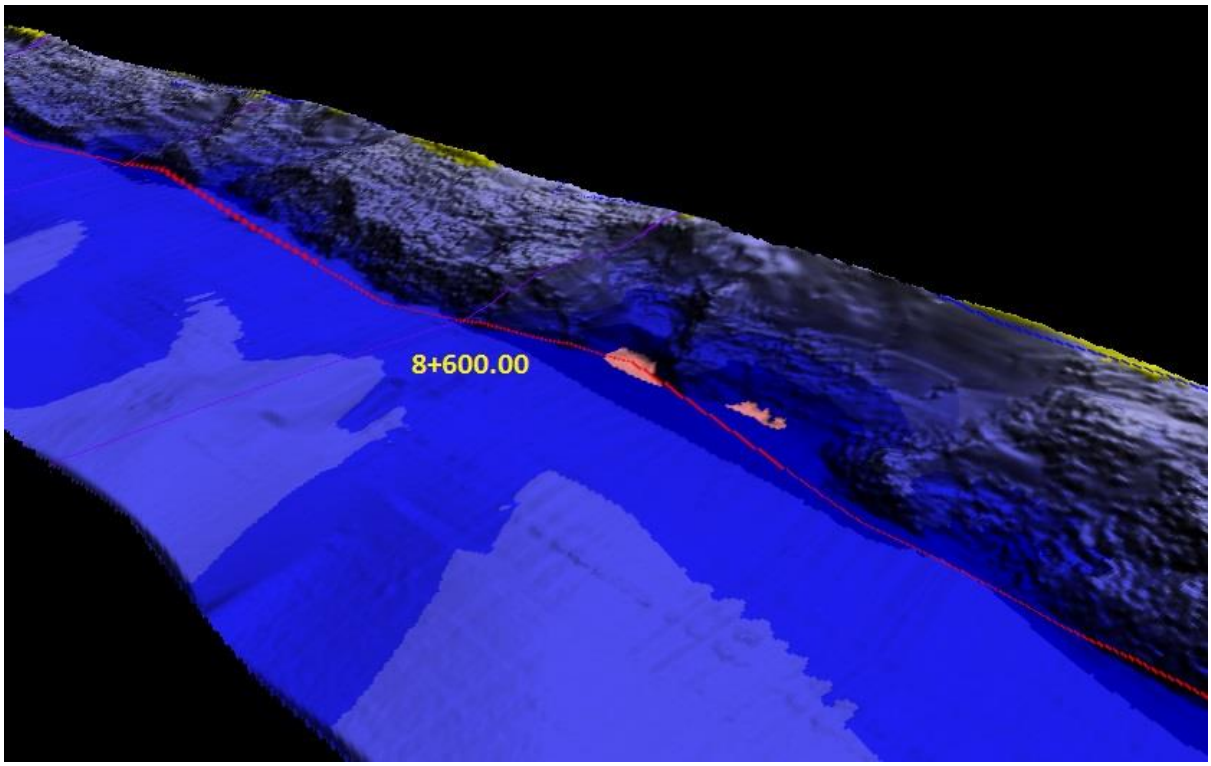
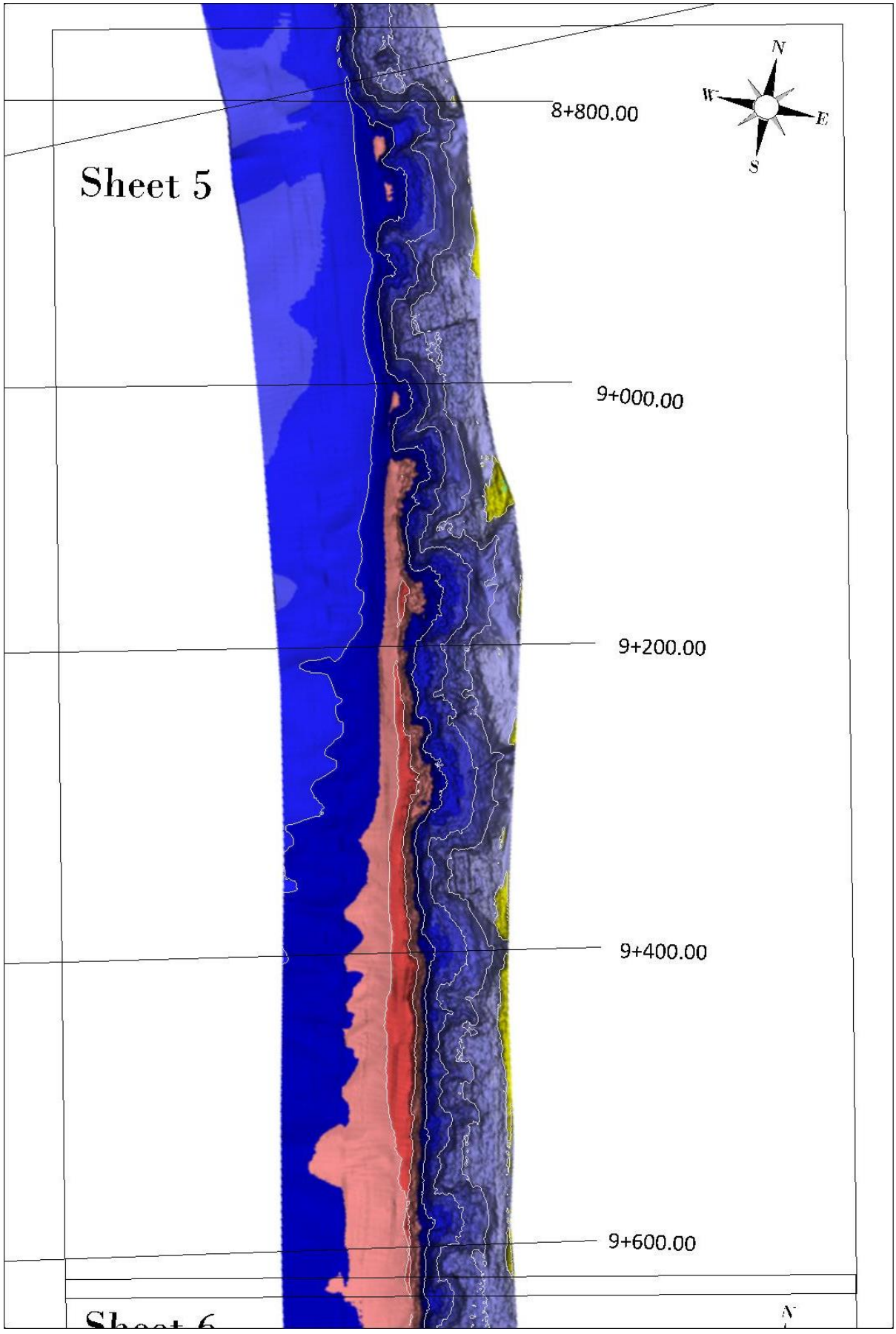


Figure 8-14 Slip circle at km 8+600


Sheet 5
8+800.00
9+000.00
9+200.00
9+400.00
9+600.00
N
W
E
S

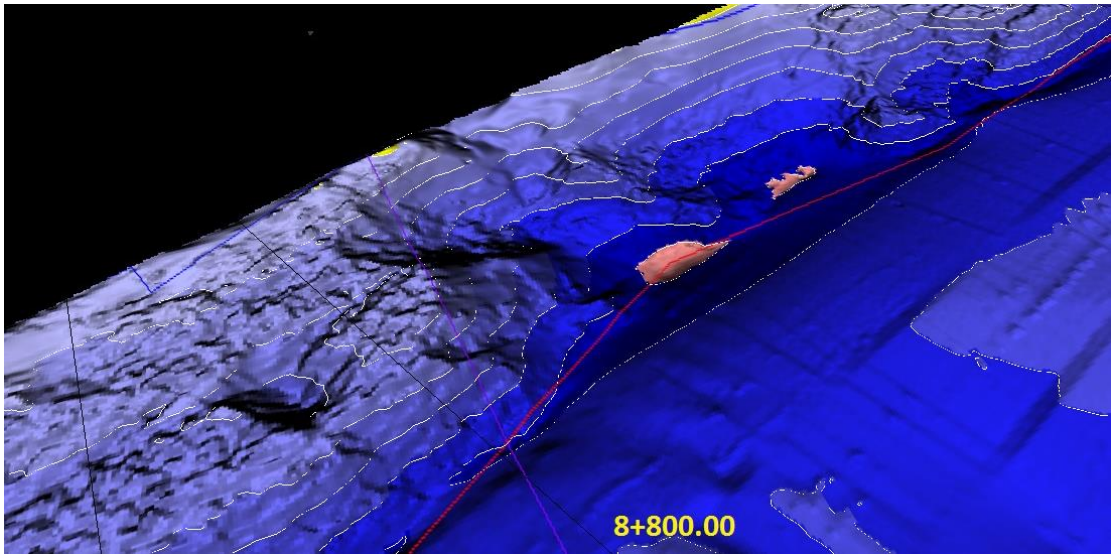


Figure 8-15 Underwater slip circle at km 8+800

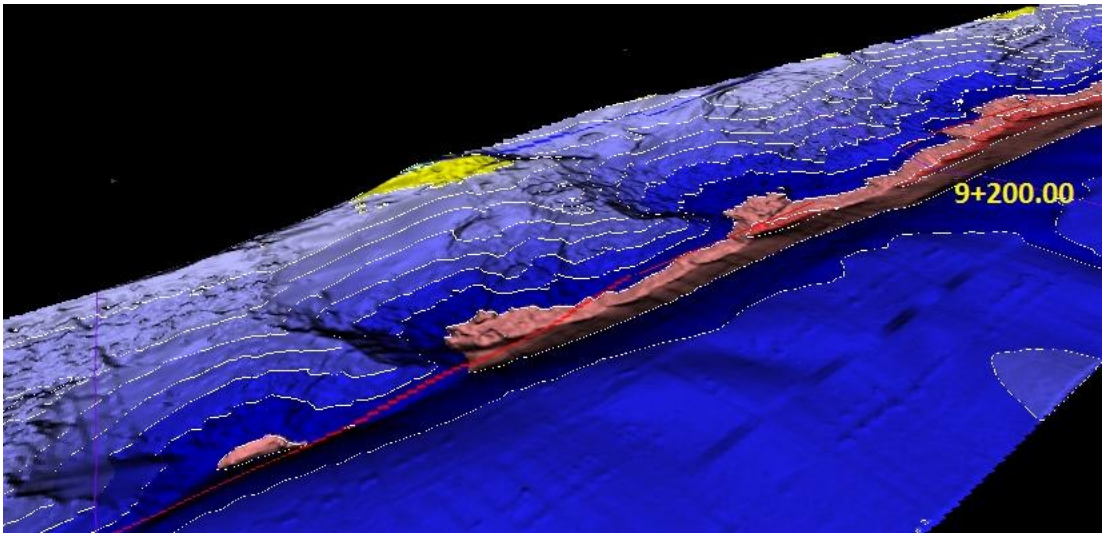


Figure 8-16 Underwater slip circle at km 9+200

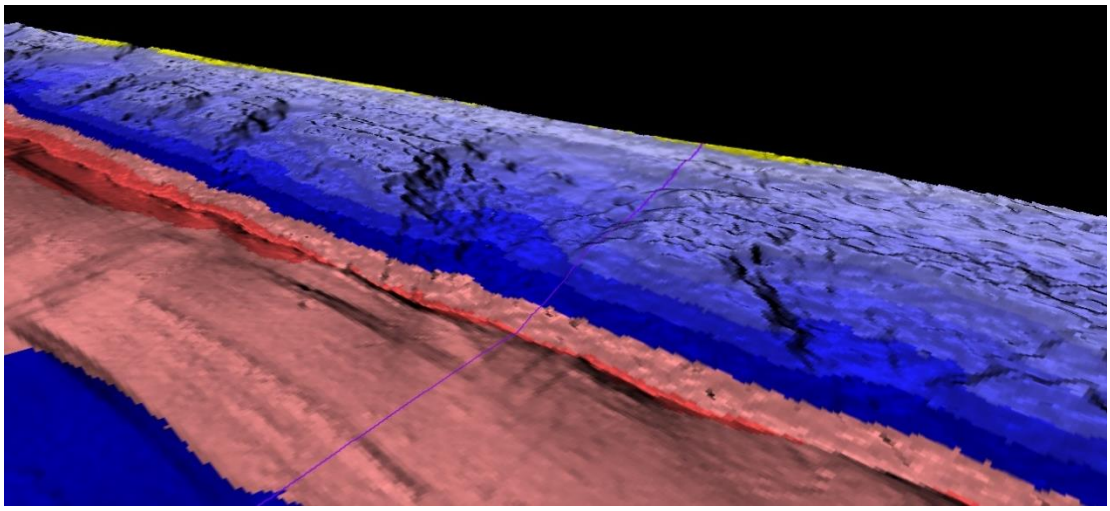
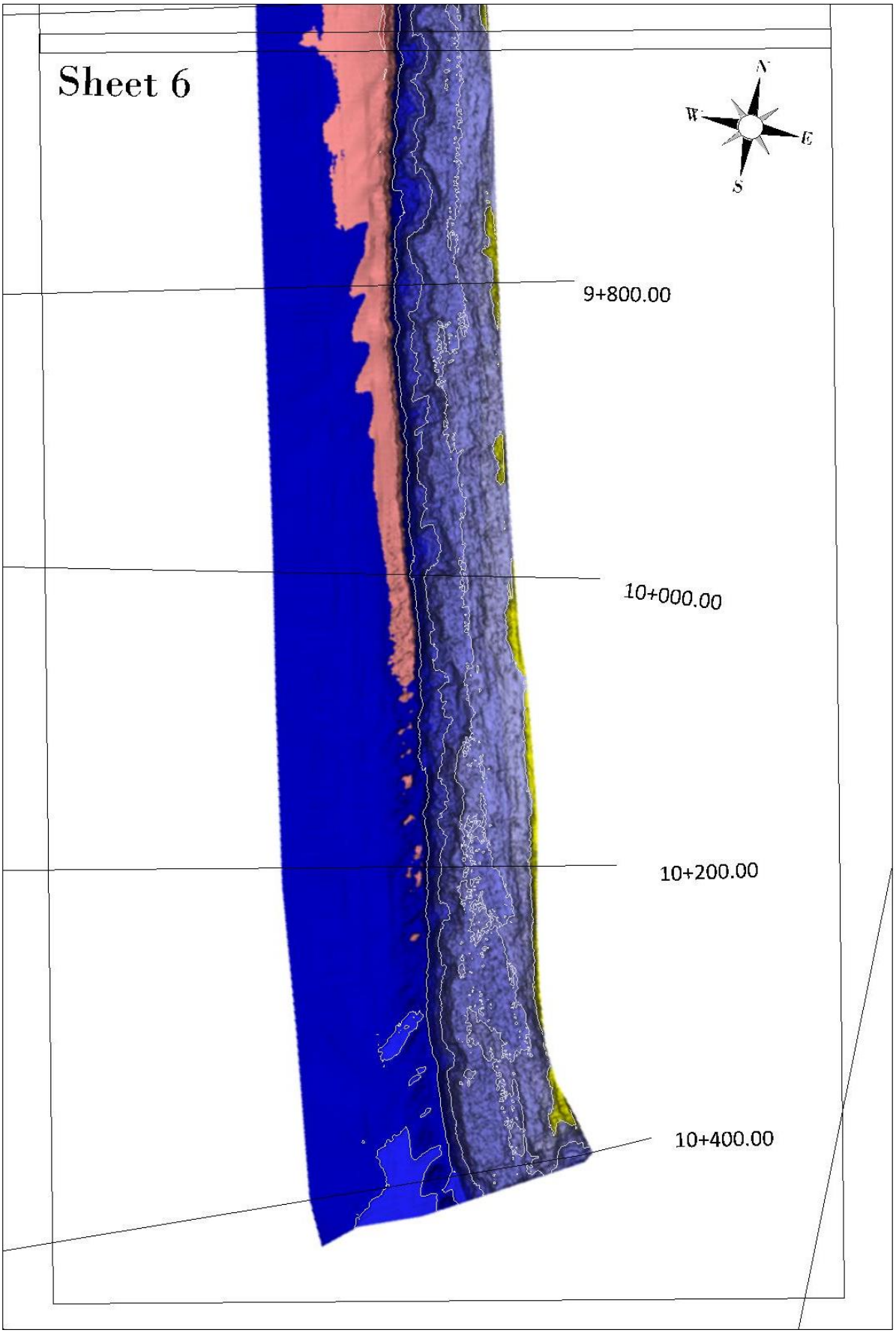


Figure 8-17 Underwater 1V:2H launched slope at km 9+400


Sheet 6
N
W
E
S
9+800.00
10+000.00
10+200.00
10+400.00

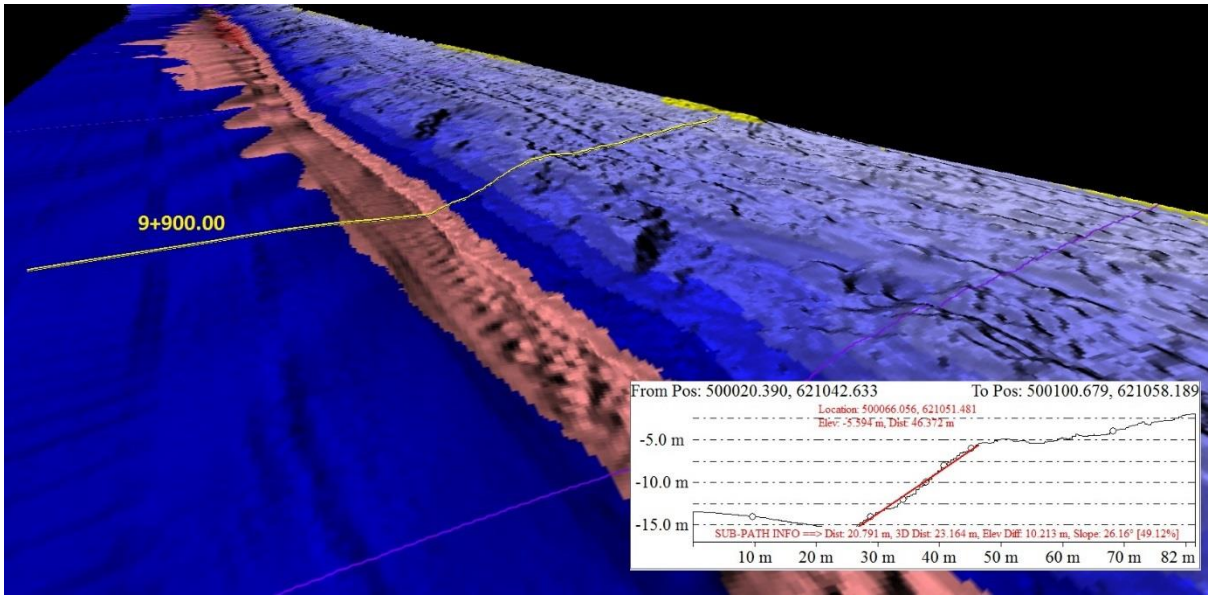


Figure 8-18 Underwater 1V:2H launched slope at km 9+900

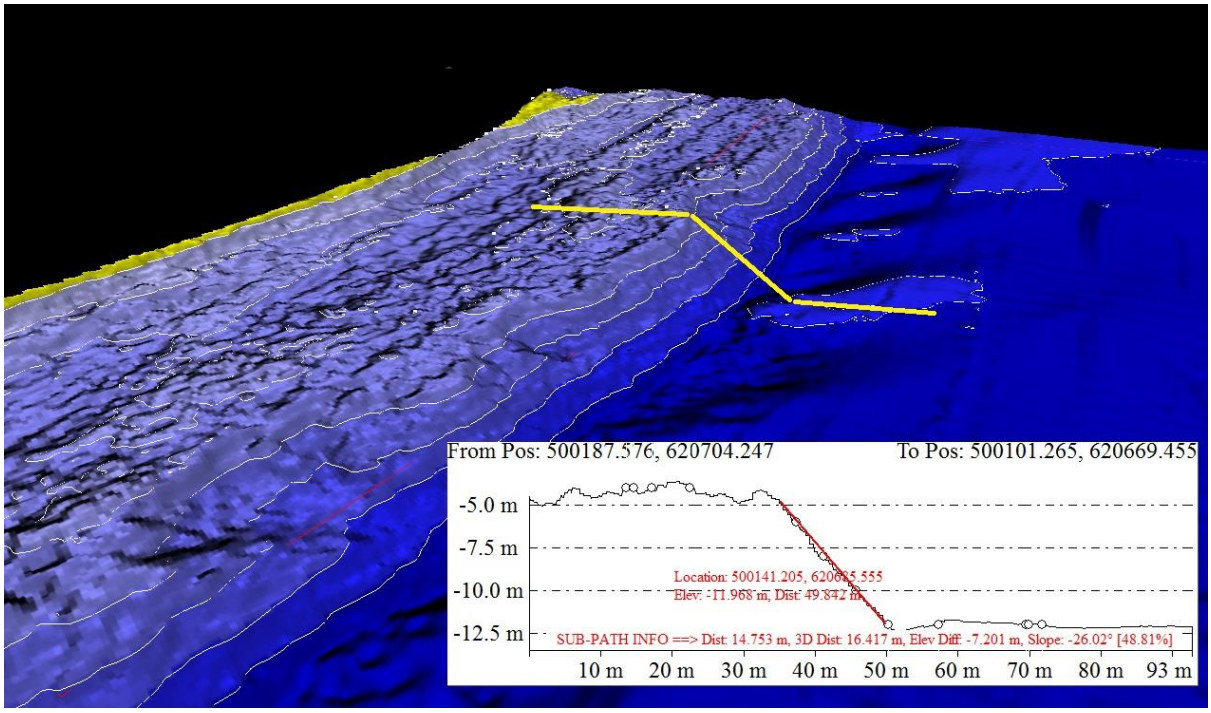
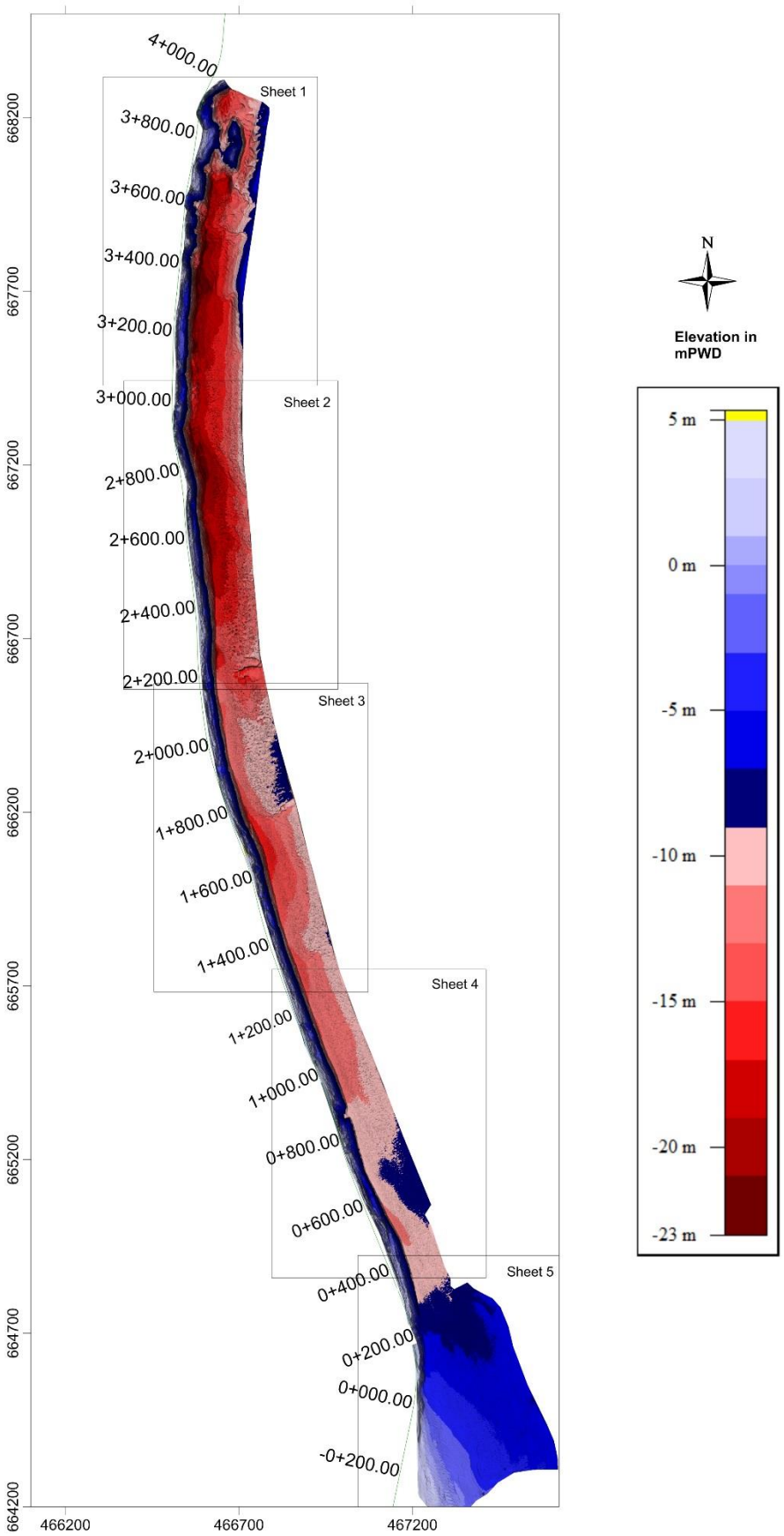
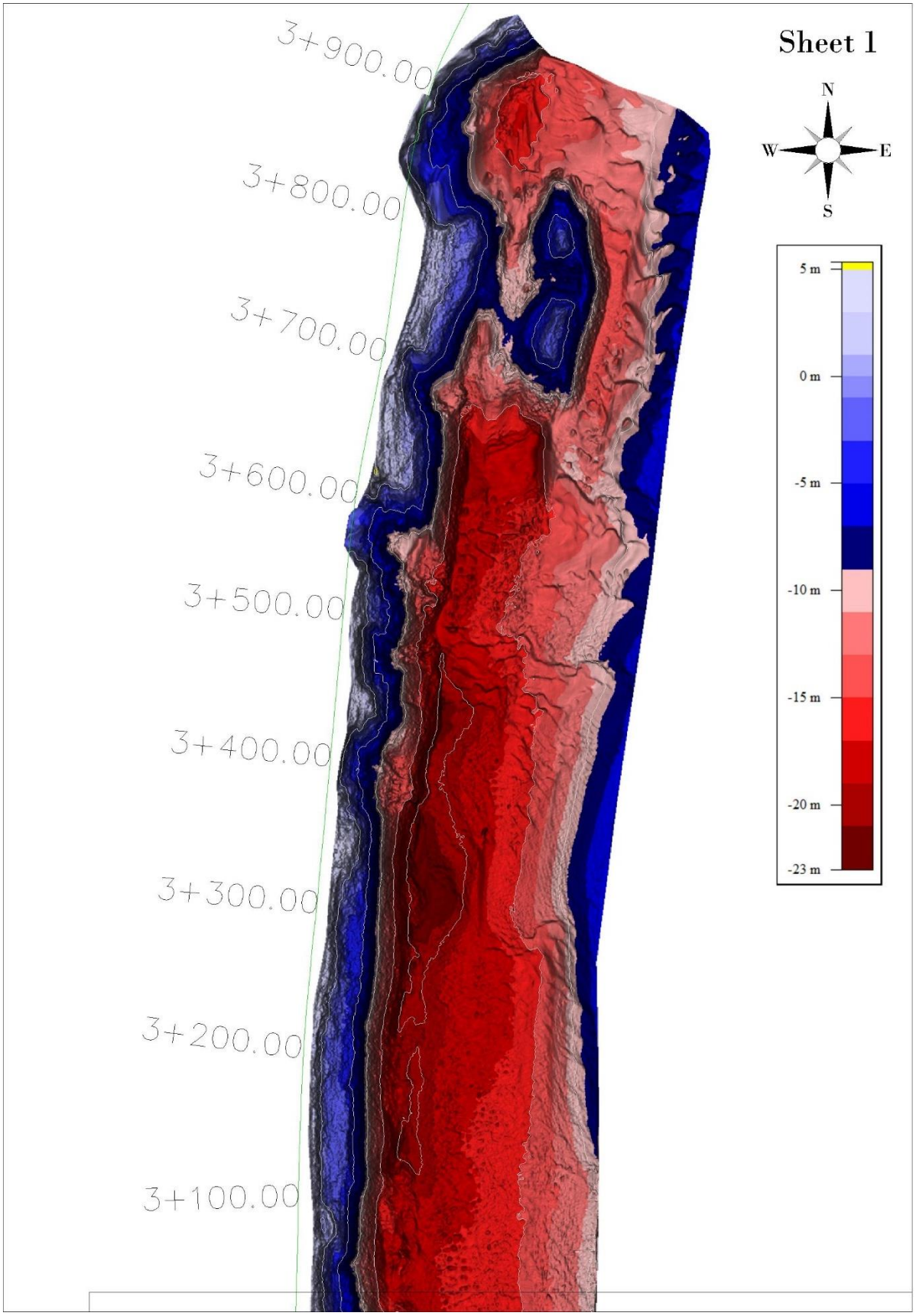


Figure 8-19 Underwater 1V:2H launched slope at km 13+000

8.4 Koijuri

Koijuri Multibeam Survey, 05-06 November 2019





At this location near km 3+800, 100m from the bankline one big hump observed. This natural earth formation could be clay which did not erroded .This hump could disturb the flow which might aggravate the underwater erosion located from 3+700 to 3+300.

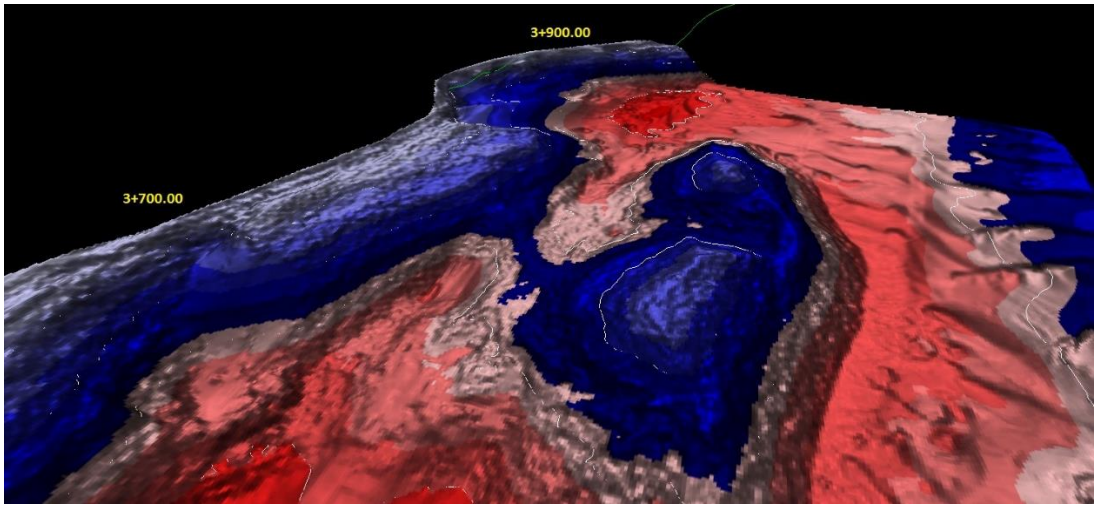


Figure 8-20 Under water erosion at km3+900.00 and launched slope

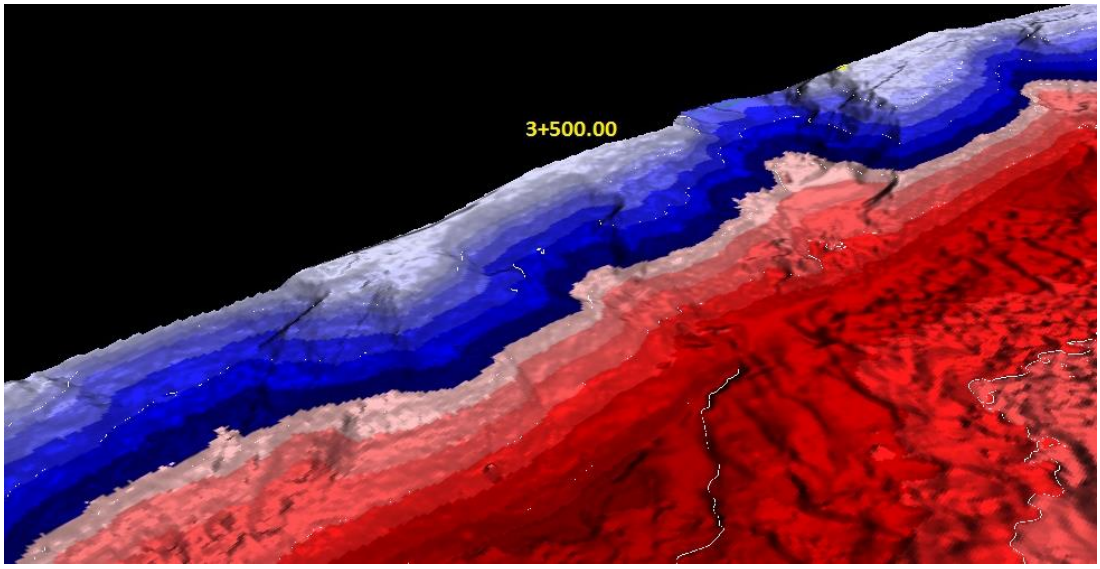


Figure 8-21 Underwater erosion

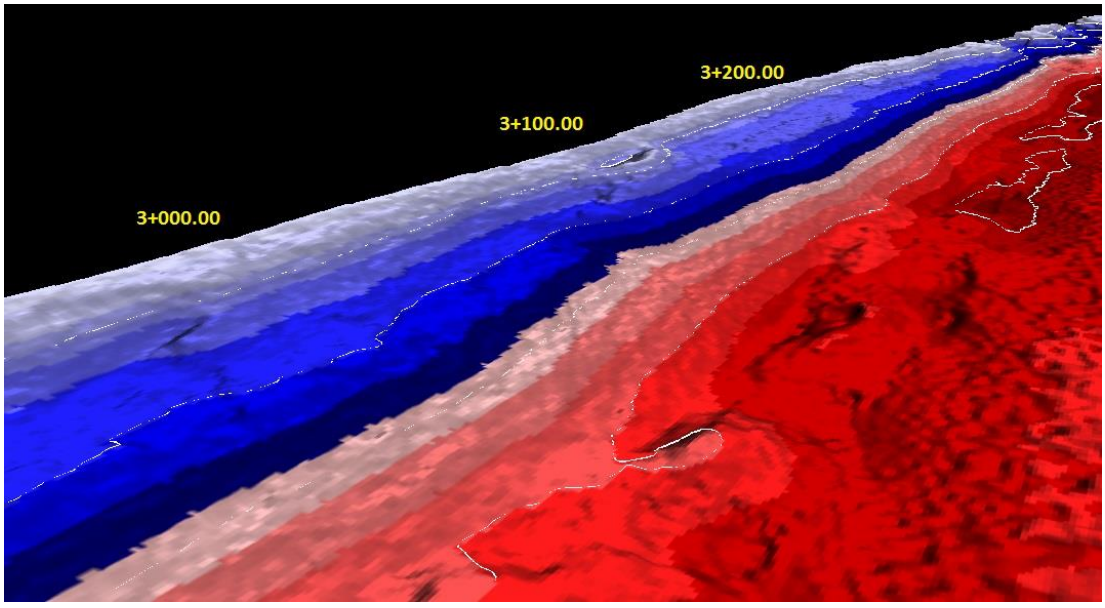
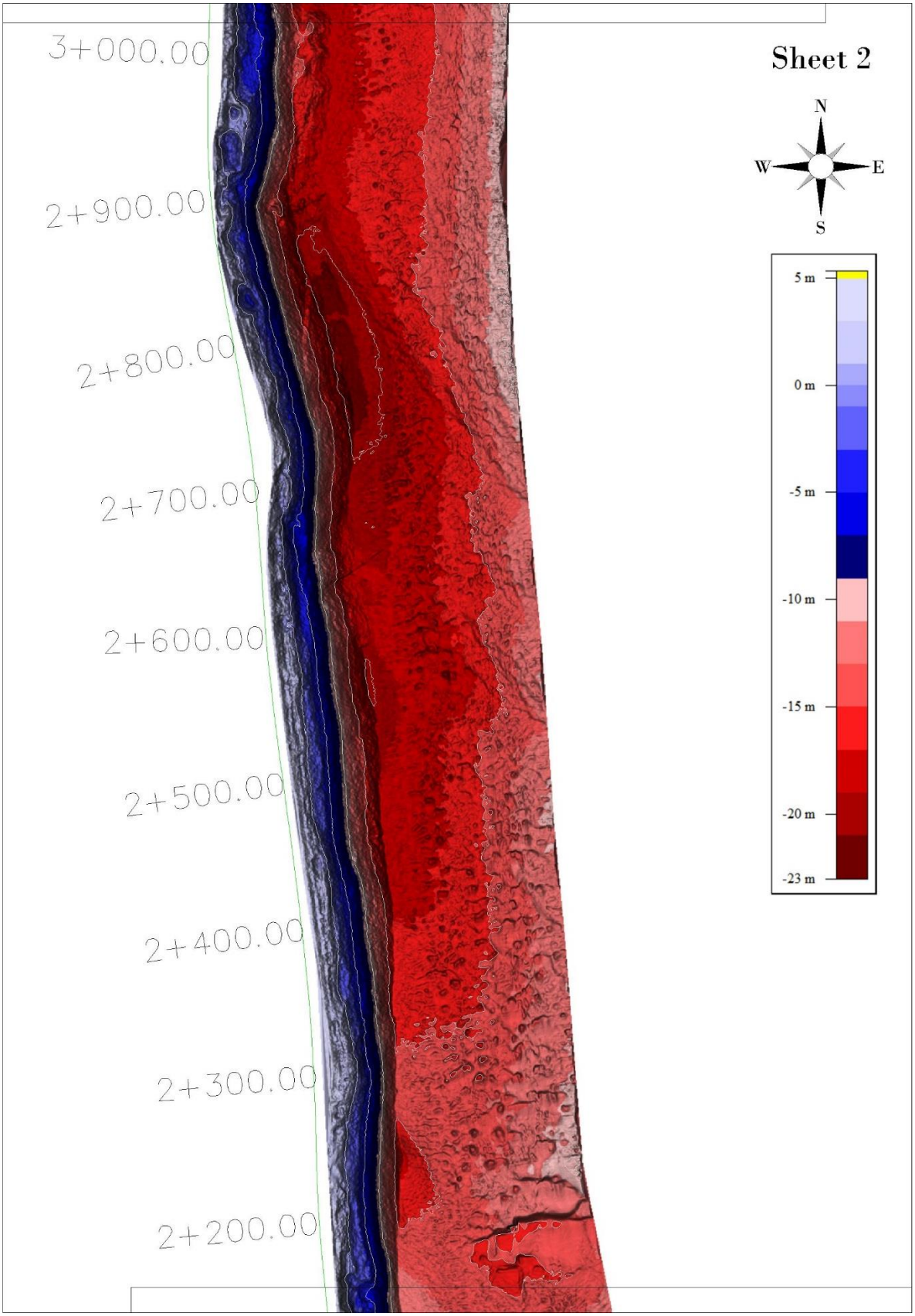


Figure 8-22 Under launched slope with geobag coverage



At this location two pockets in dumping observed at km 2+900 and 2+800. Other location shows nicely launched slope.

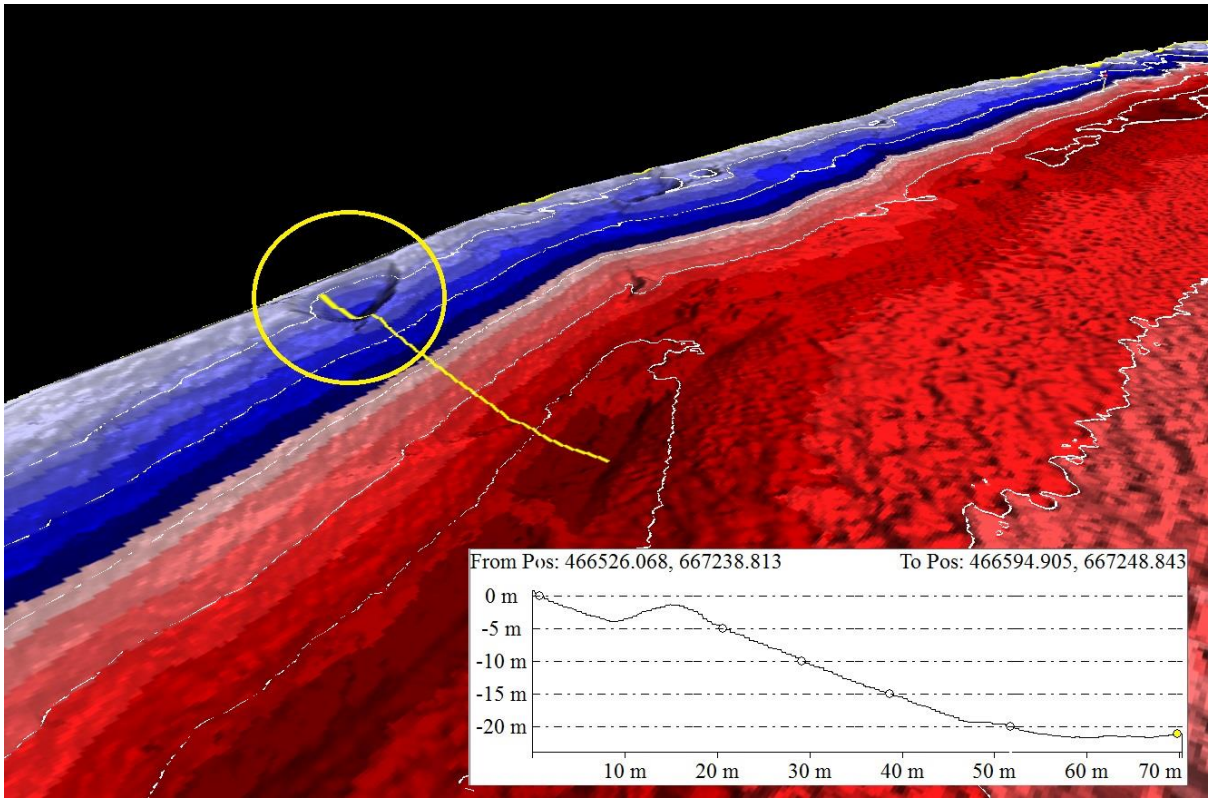


Figure 8-23 Pockets or holes at upperslope

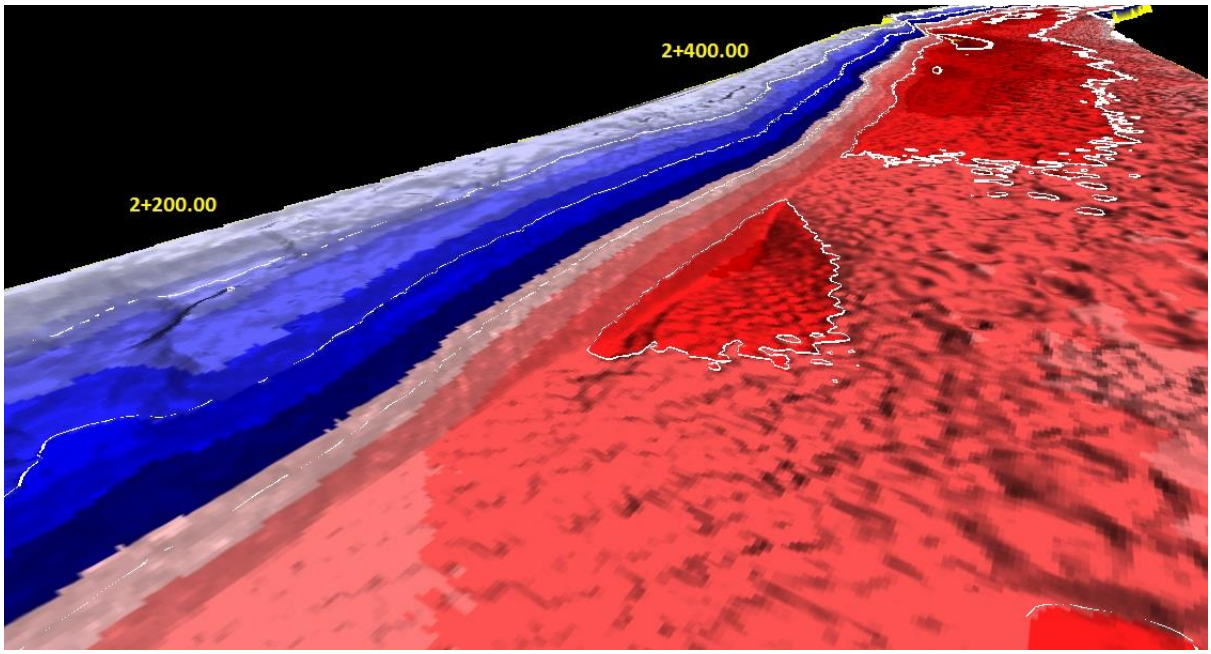
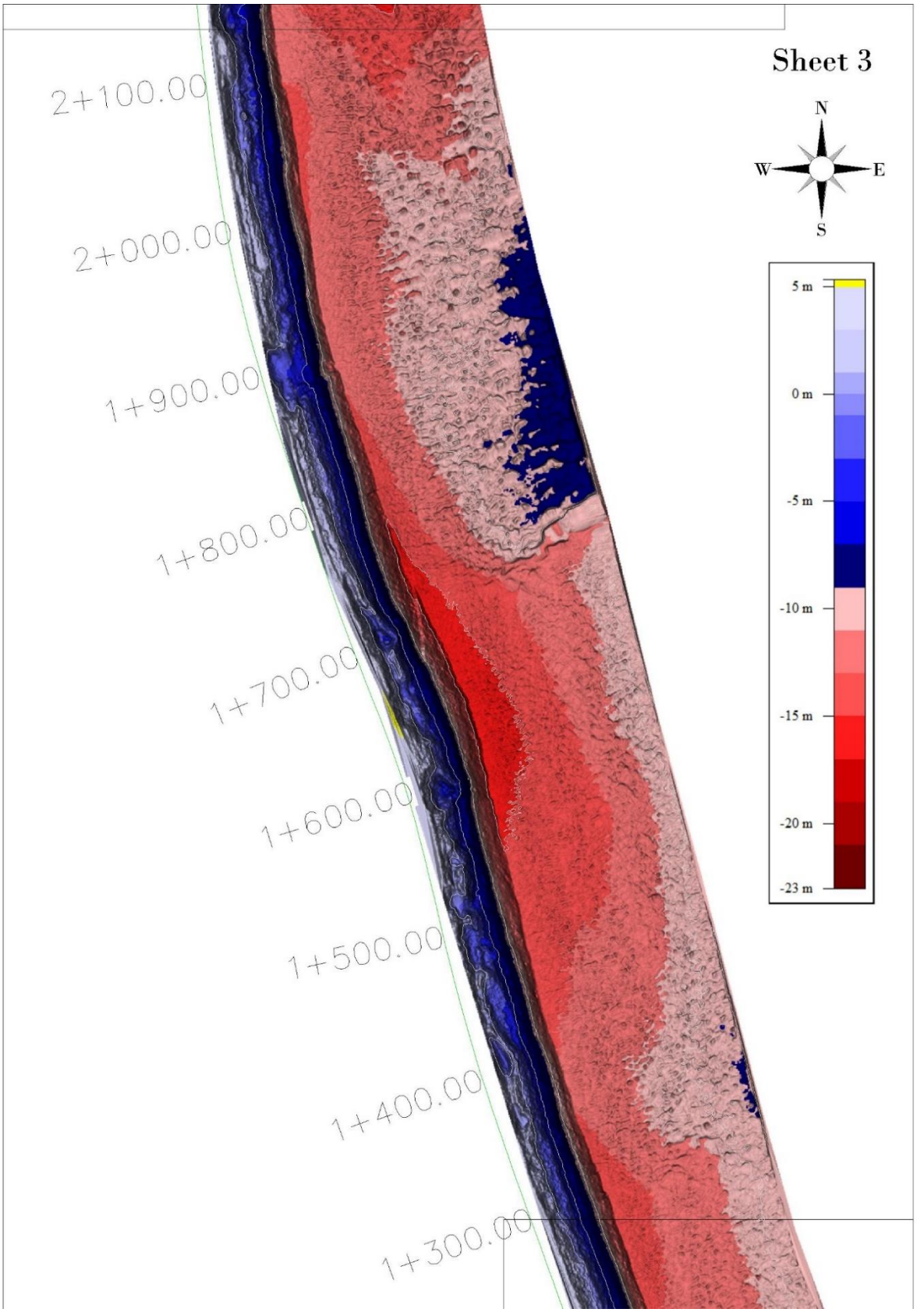


Figure 8-24 Underwater launched slope



At this location, pockets in dumping observed at three places, those are at km 1+700, km 1+600 and km 1+400. One slip circle observed at km 1+900 .

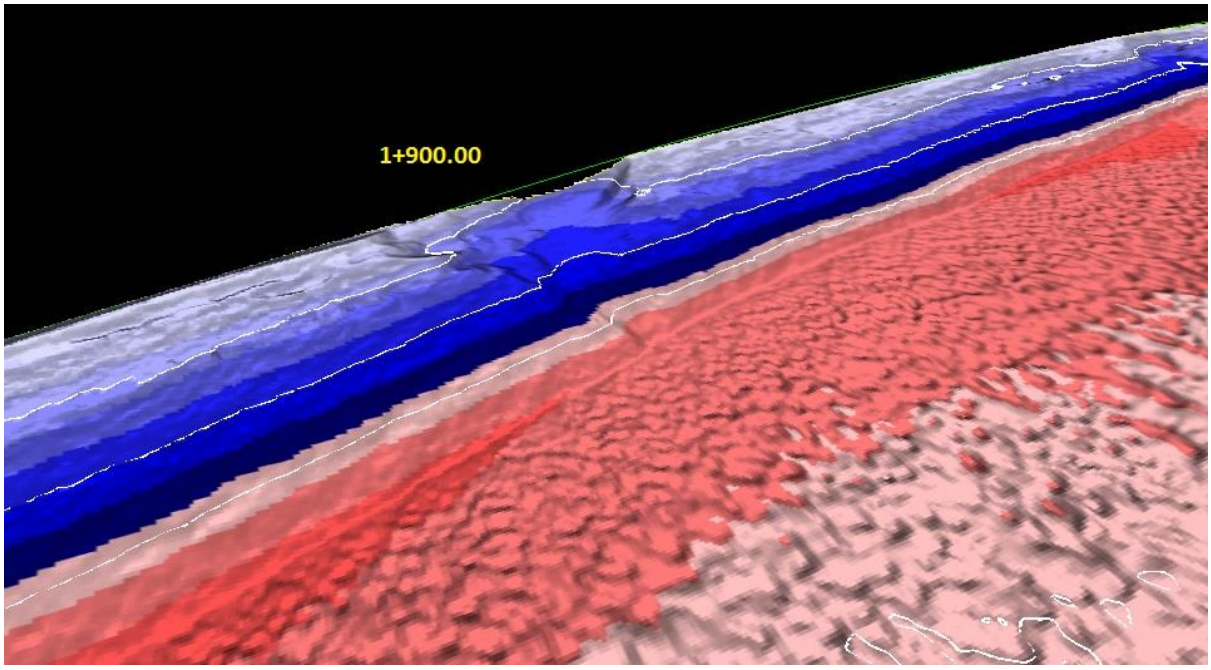


Figure 8-25 Under water slope failure at km 1+900

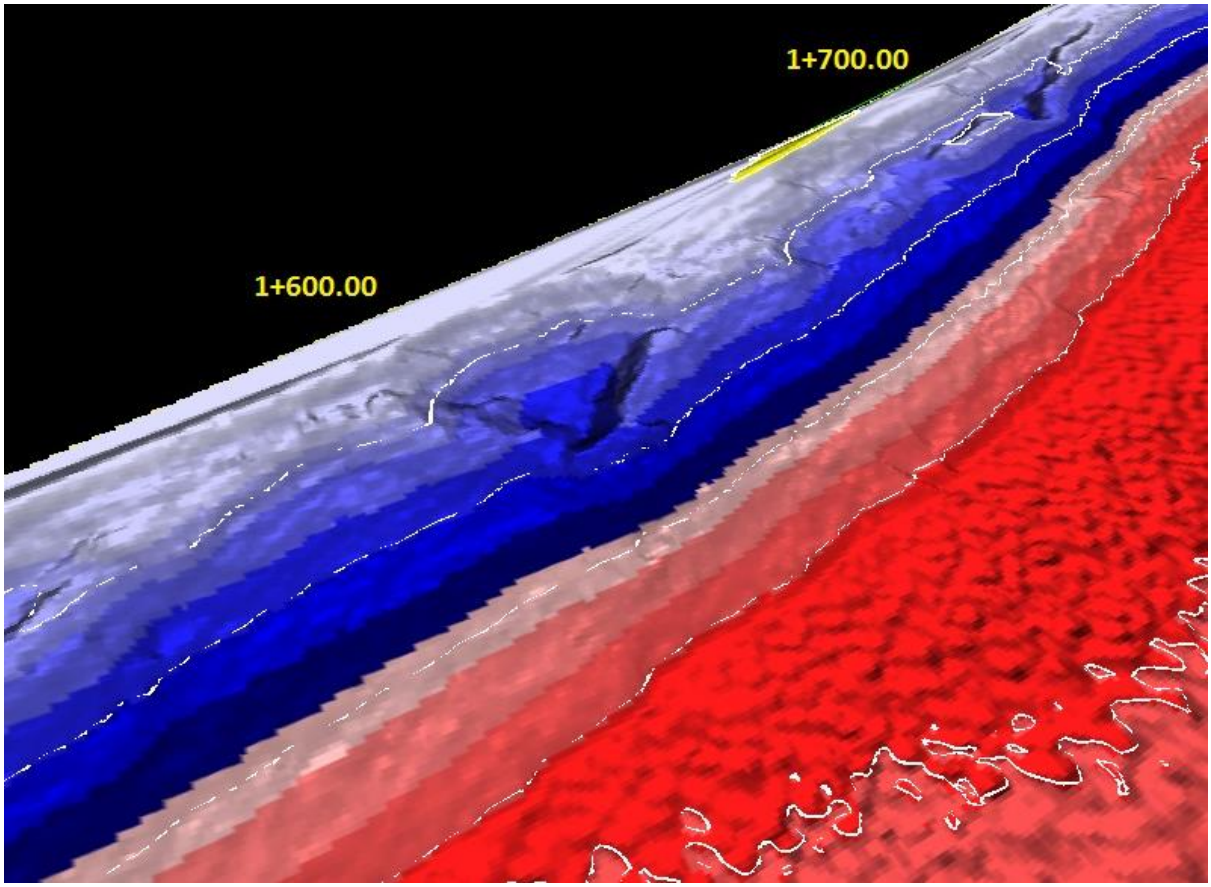
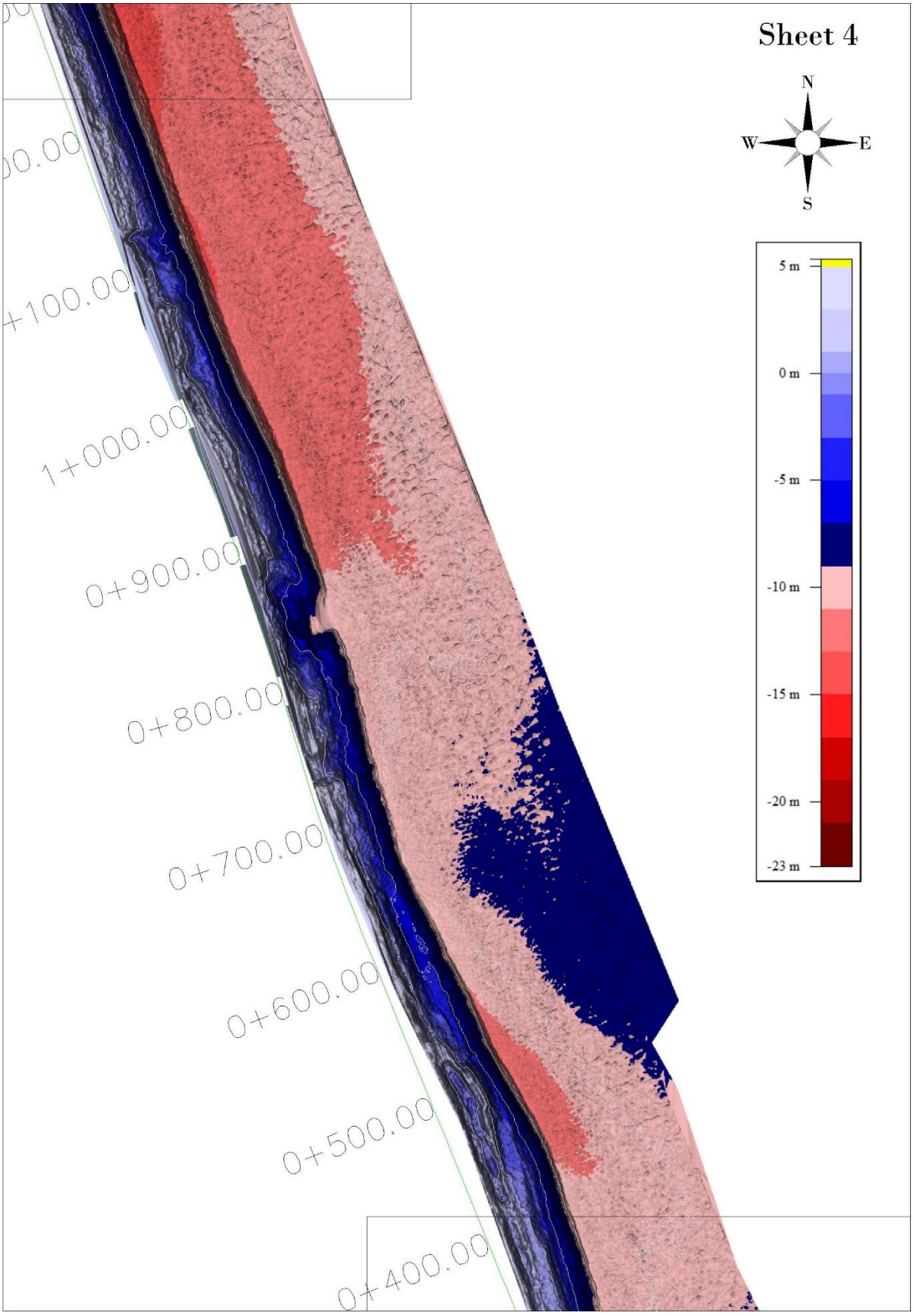


Figure 8-26 Under water slope failure at km 1+600 and pockets at upper slope at km1+700


Sheet 4
N
W
E
S
5 m
0 m
-5 m
-10 m
-15 m
-20 m
-23 m
+100.00
1+000.00
0+900.00
0+800.00
0+700.00
0+600.00
0+500.00
0+400.00

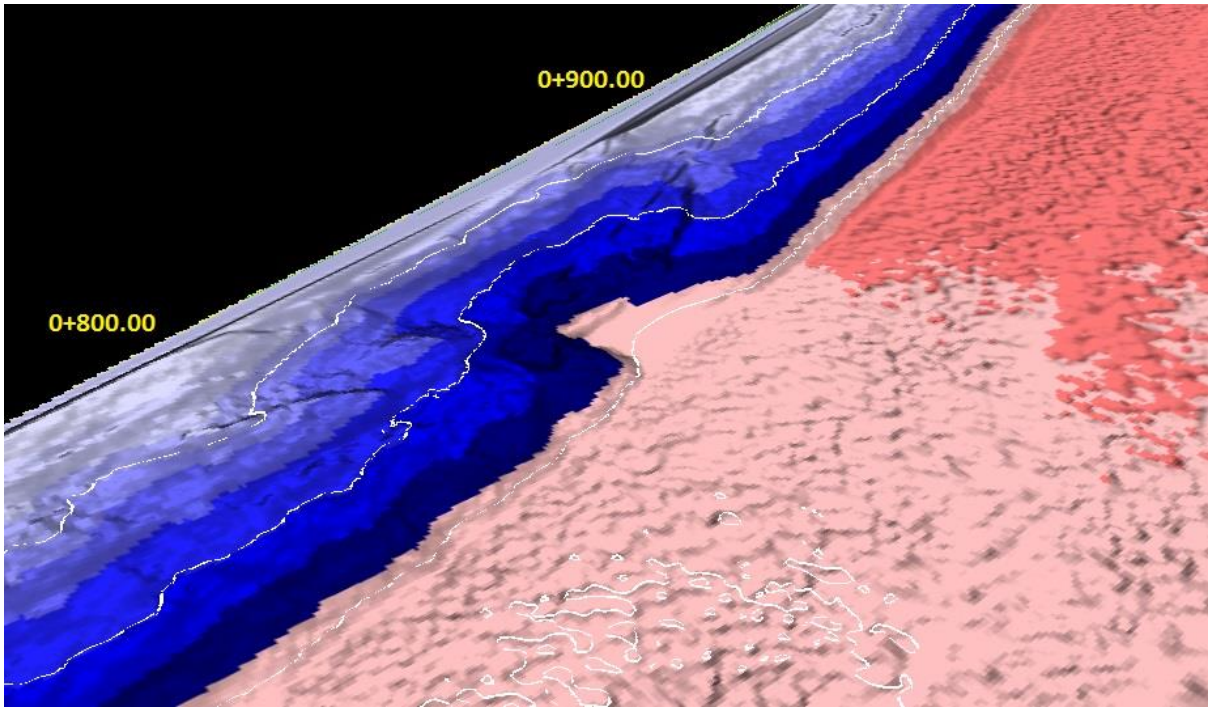


Figure 8-27 Slip circle failure at km 0+850

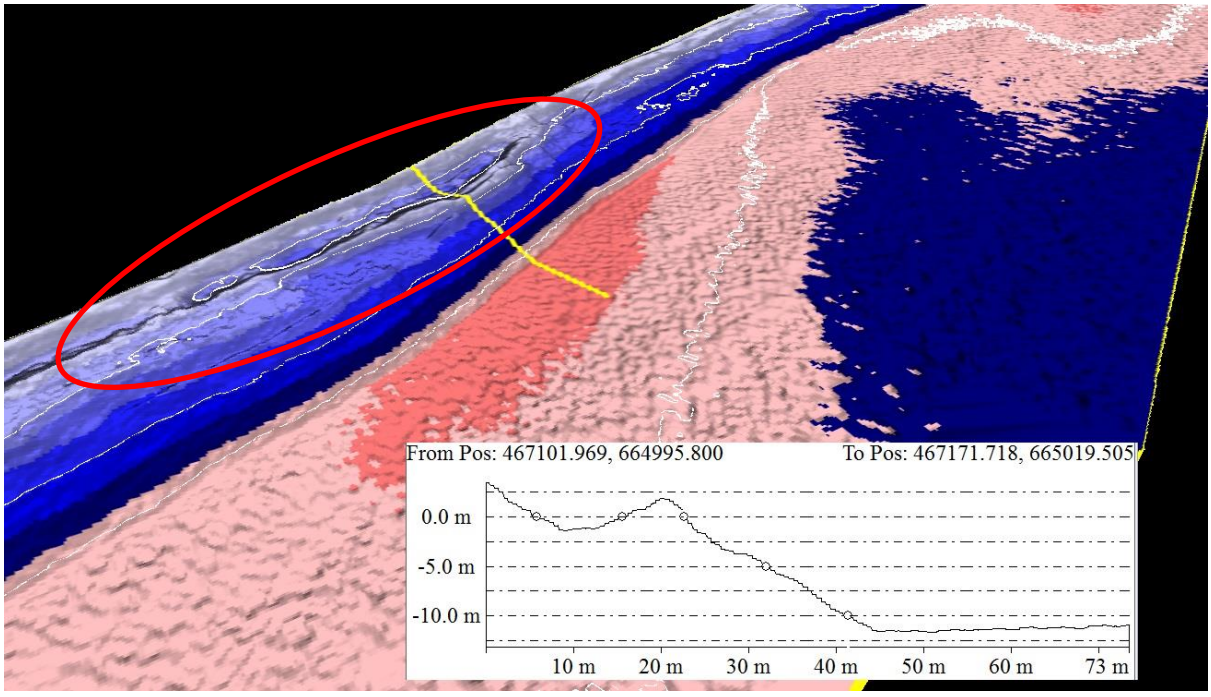
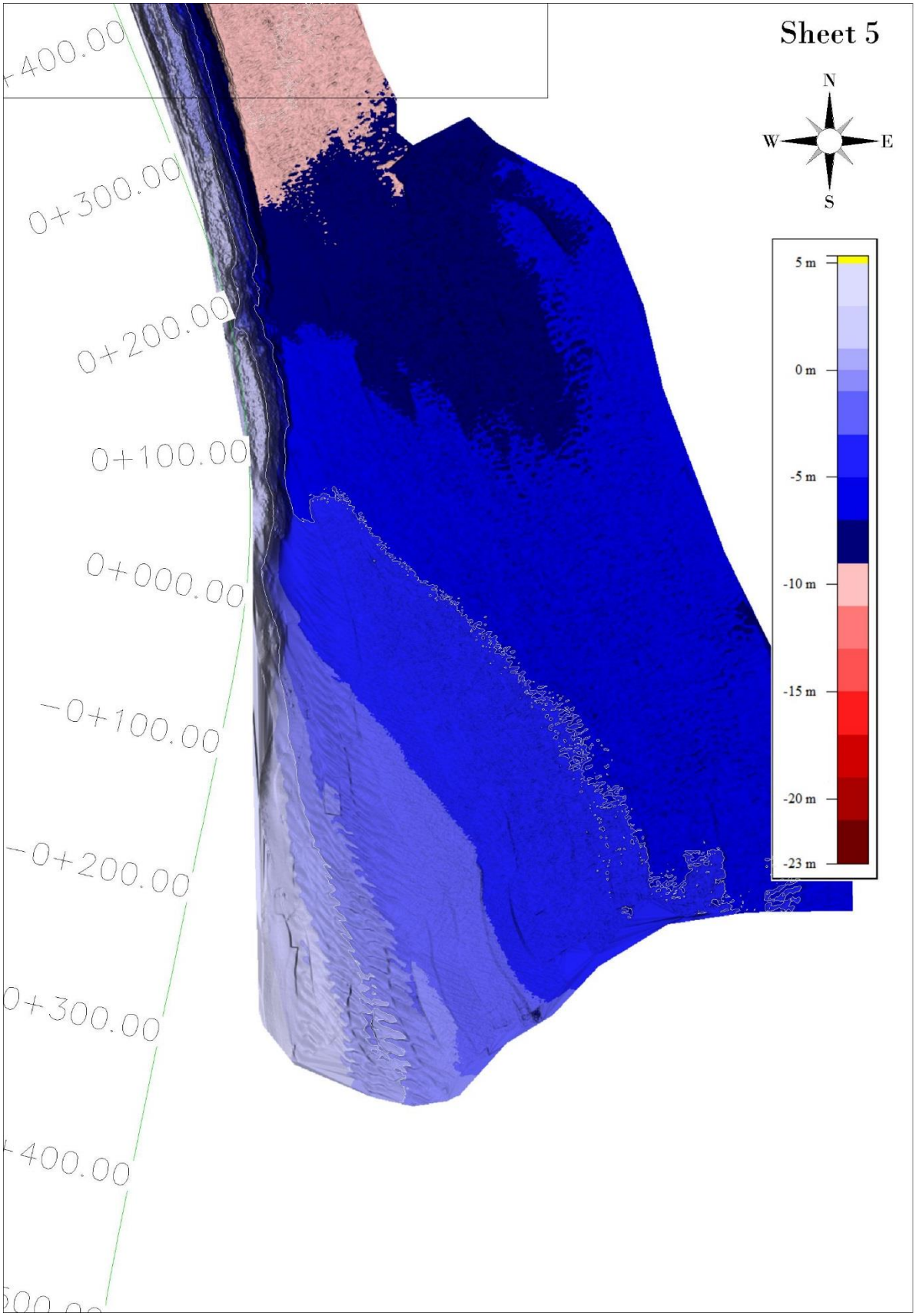
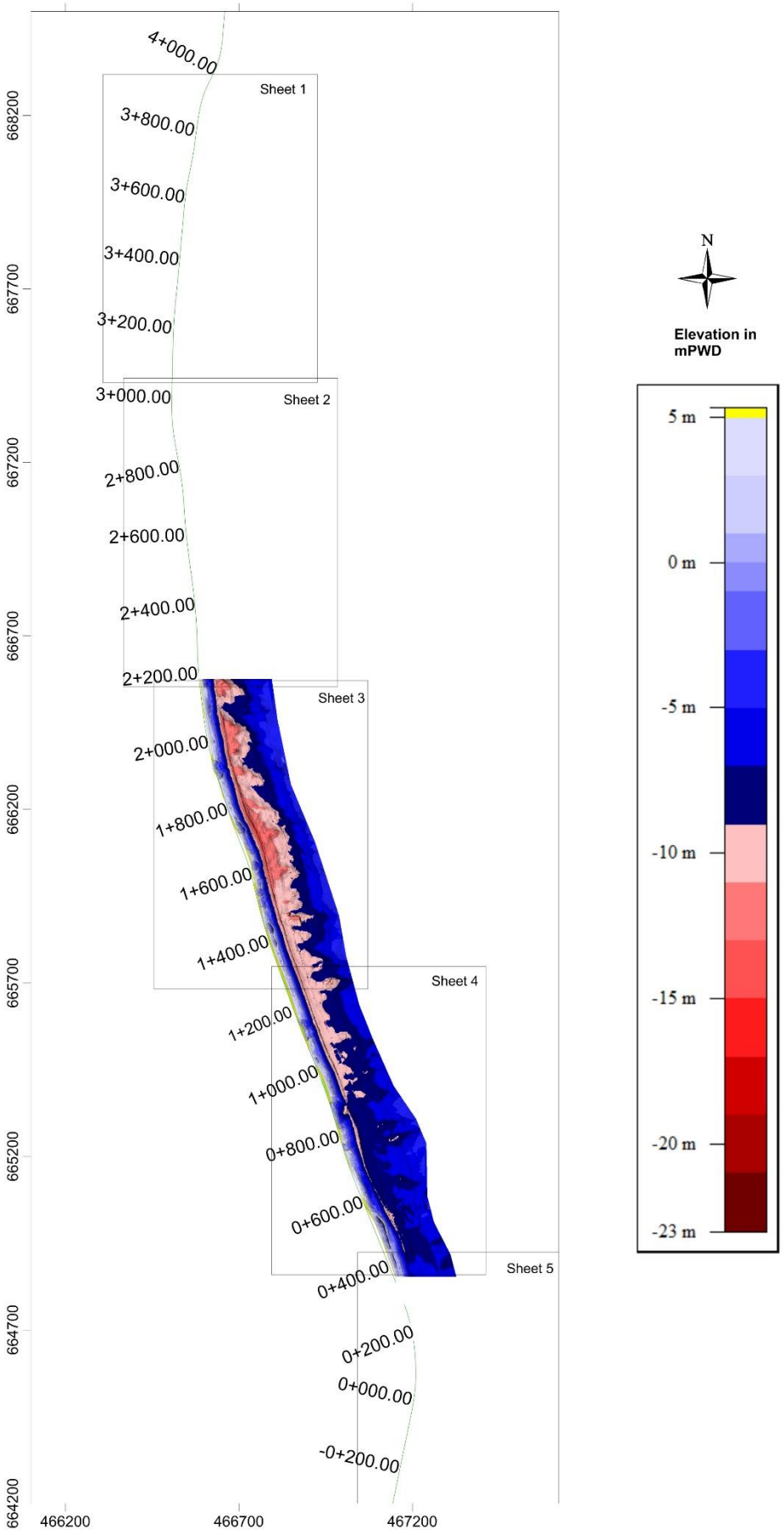
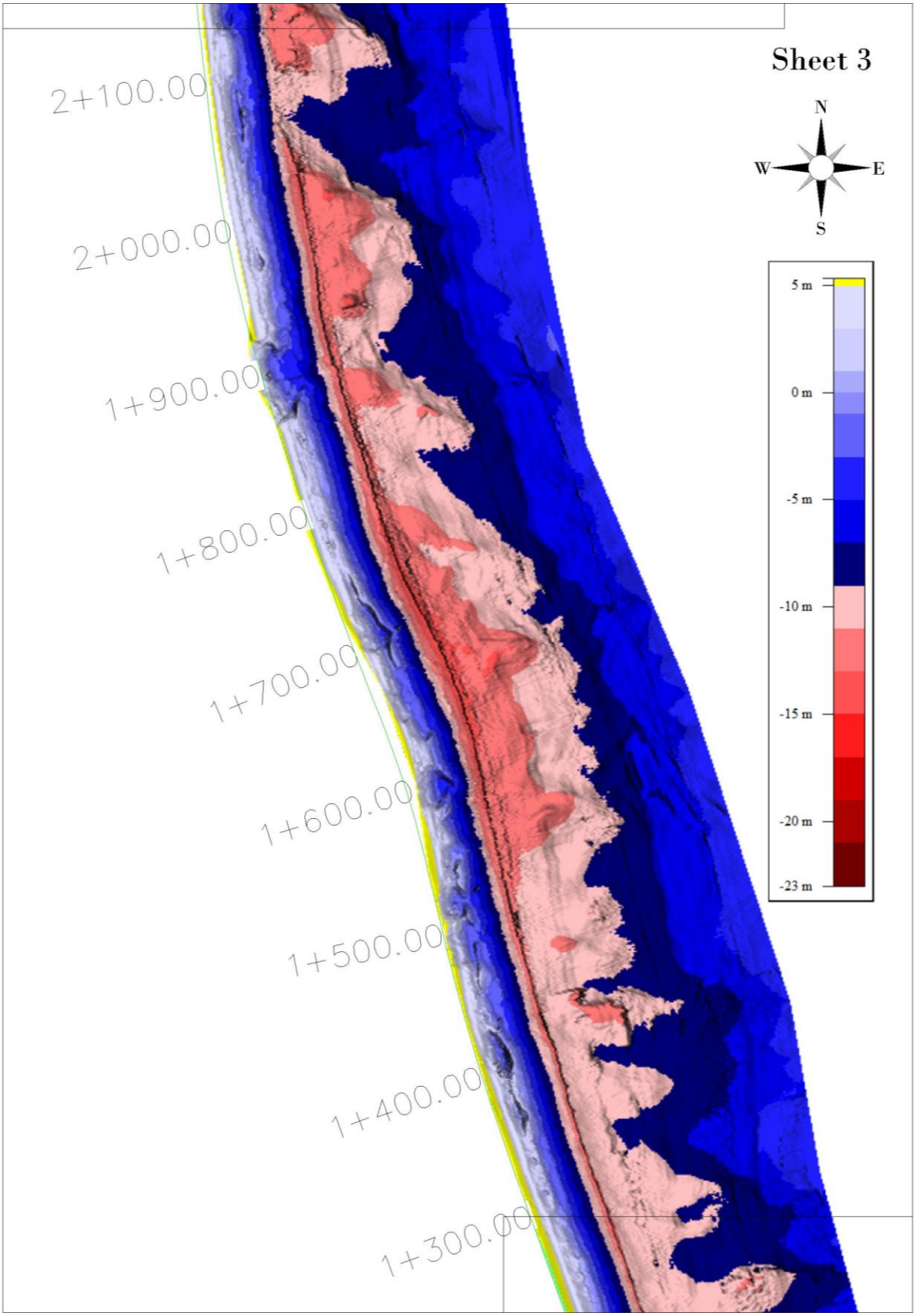


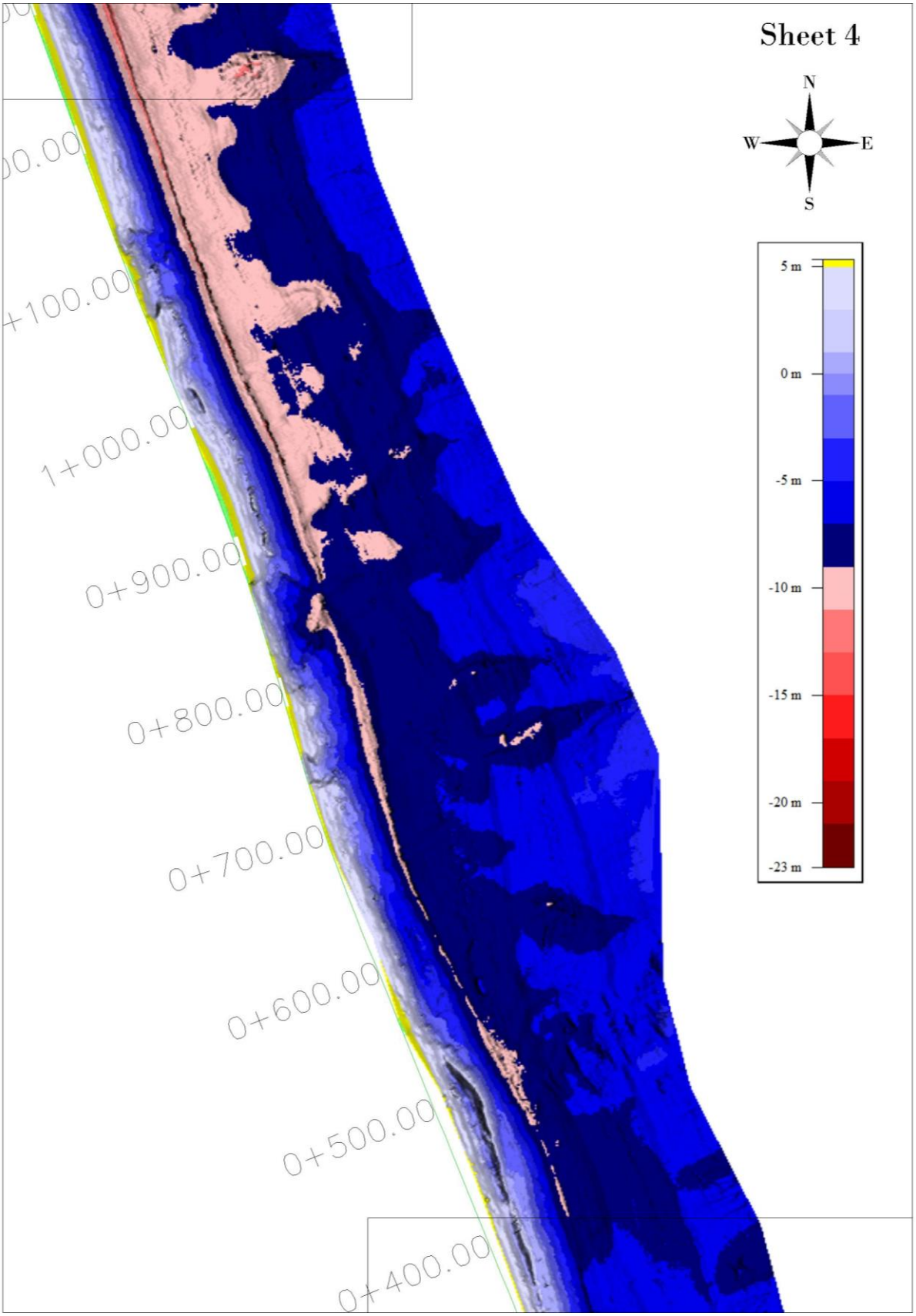
Figure 8-28 Pockets after the slope


Sheet 5
N
W
E
S
5 m
0 m
-5 m
-10 m
-15 m
-20 m
-23 m
0+400.00
0+300.00
0+200.00
0+100.00
0+000.00
-0+100.00
-0+200.00
-0+300.00
-0+400.00

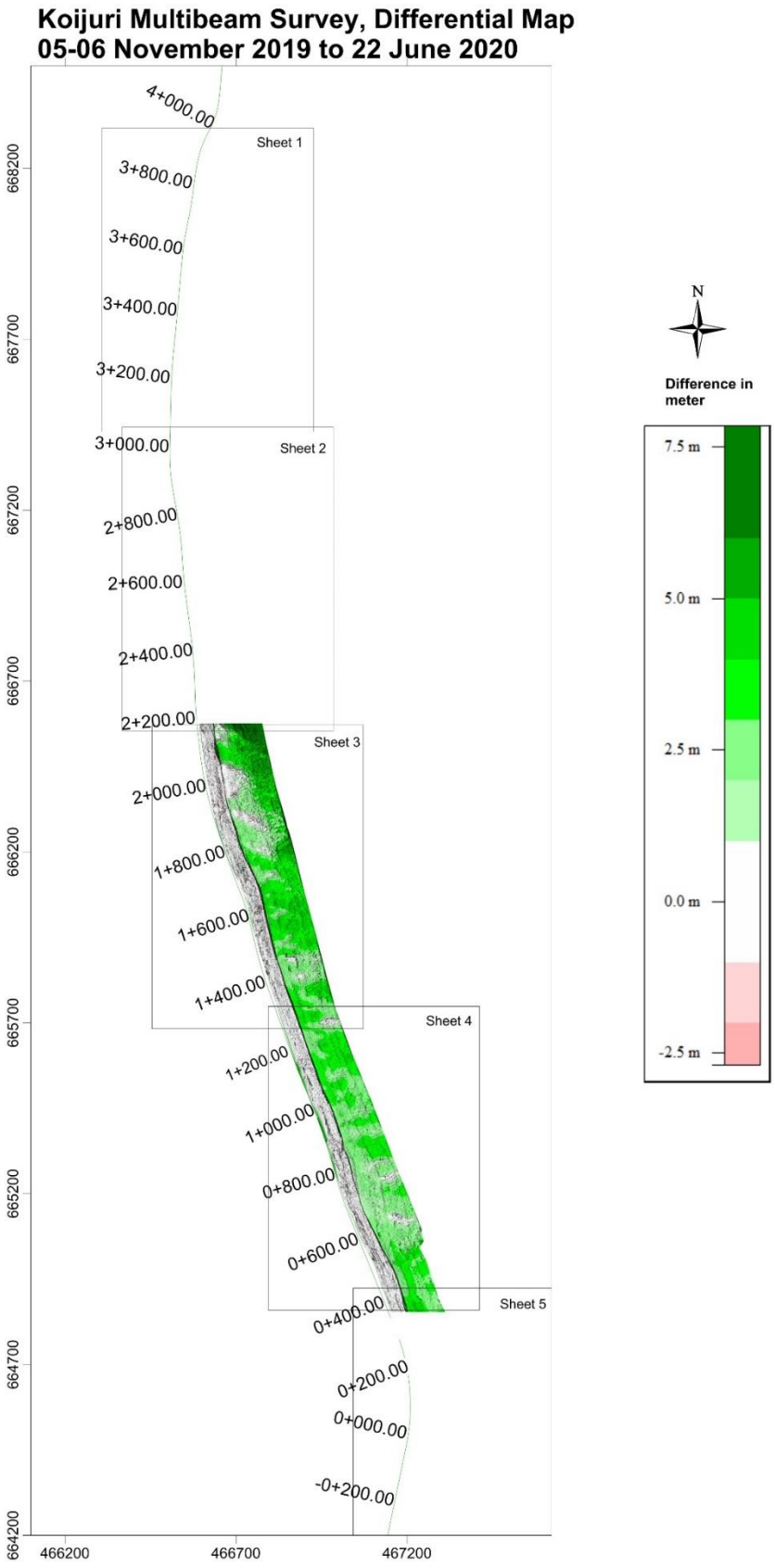
Koijuri Multibeam Survey, 22 June 2020

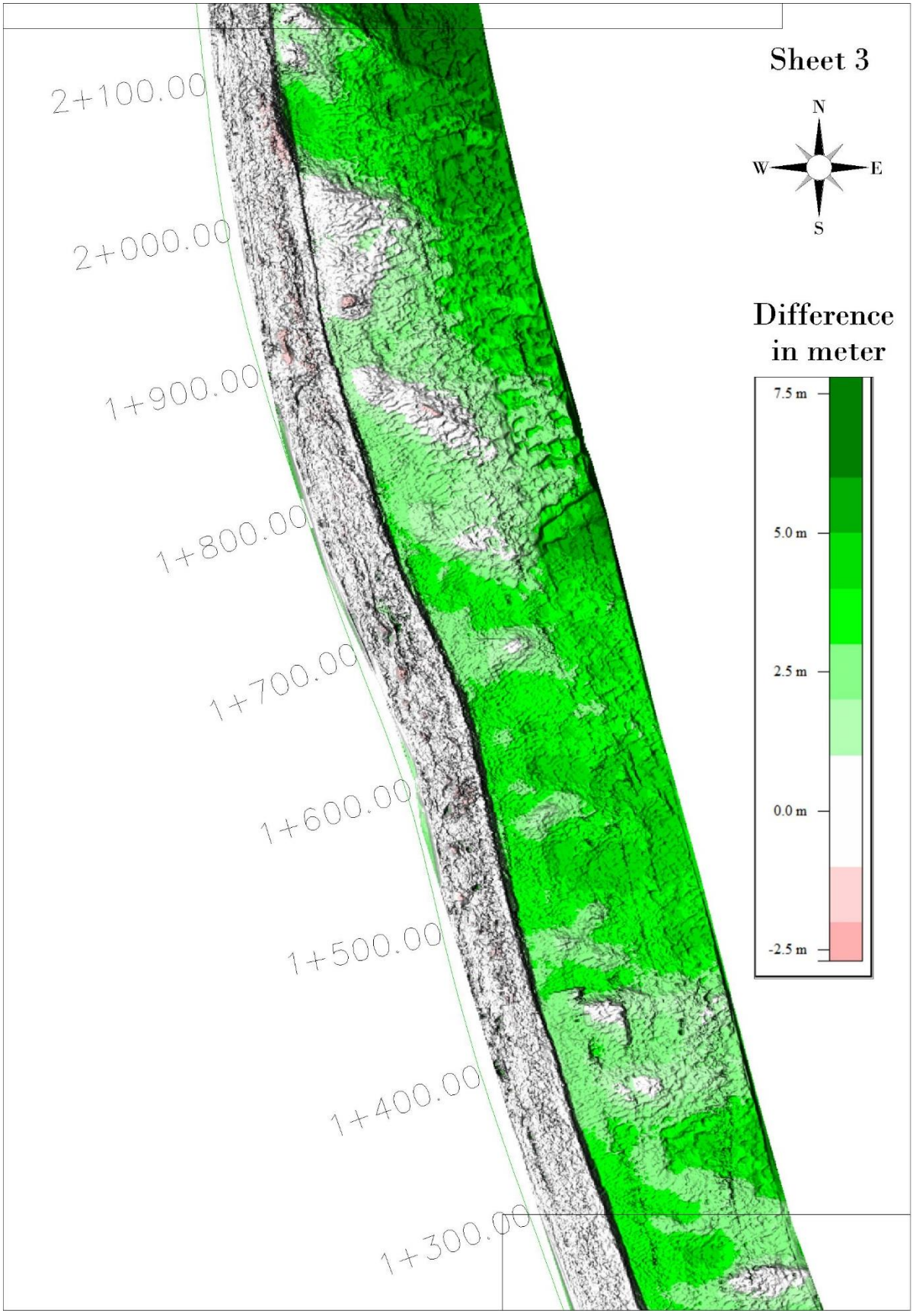


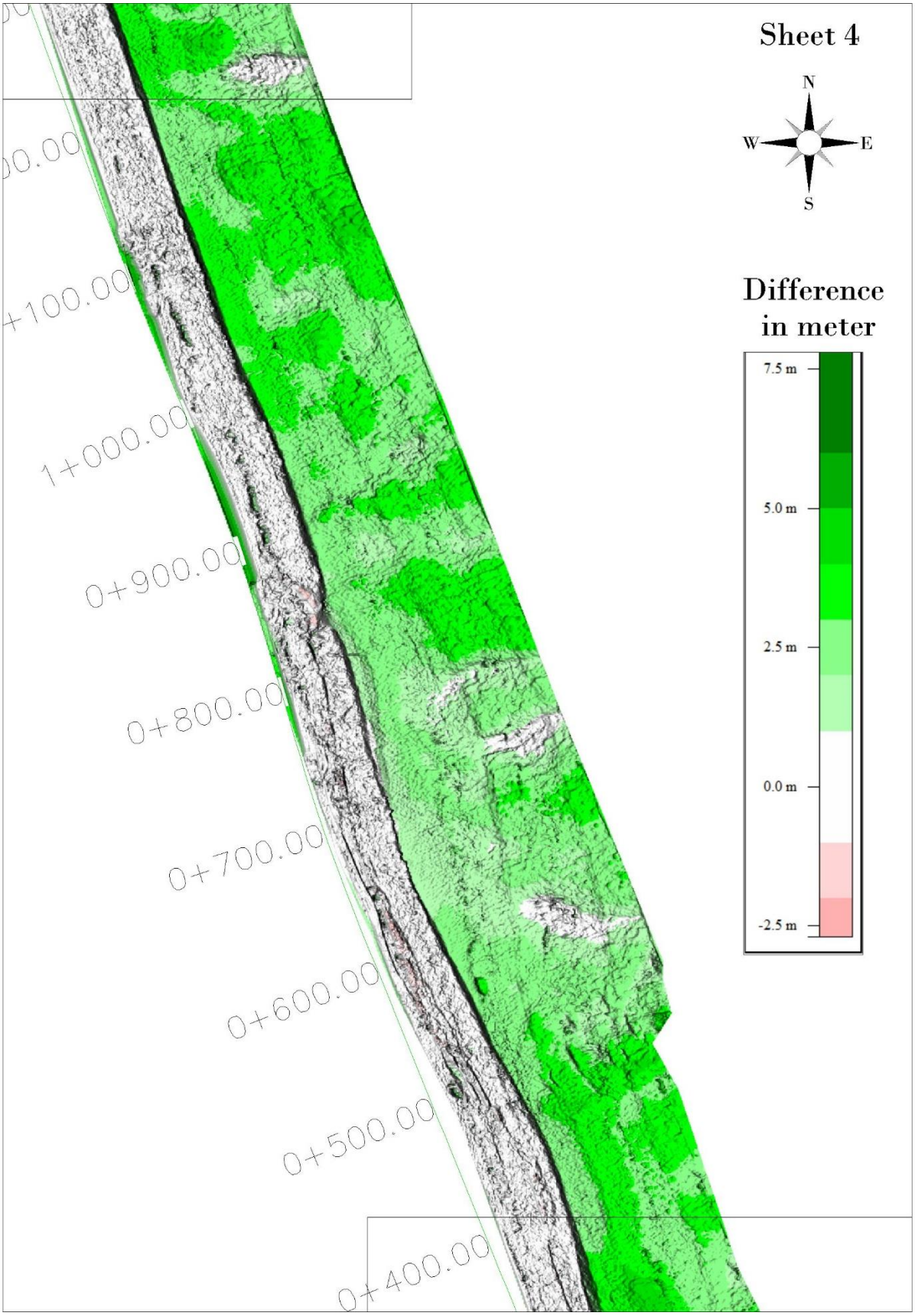

Sheet 3
N
W
E
S
5 m
0 m
-5 m
-10 m
-15 m
-20 m
-23 m
2+100.00
2+000.00
1+900.00
1+800.00
1+700.00
1+600.00
1+500.00
1+400.00
1+300.00


Sheet 4
N
W
E
S
5 m
0 m
-5 m
-10 m
-15 m
-20 m
-23 m
+100.00
1+000.00
0+900.00
0+800.00
0+700.00
0+600.00
0+500.00
0+400.00

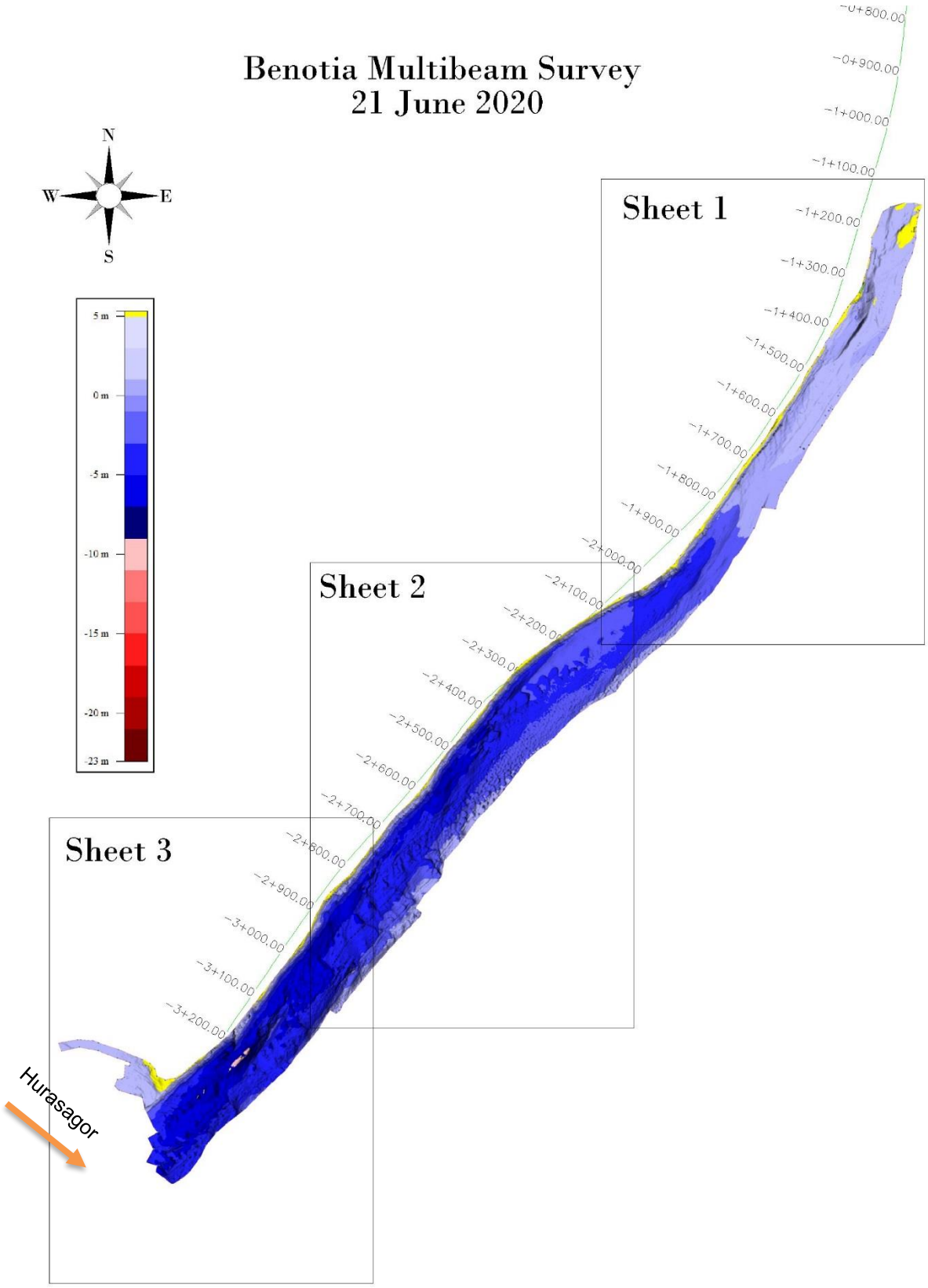
Koijuri Differential Survey: November 2019 to June 2020 differential does not show any changes in the launhched slope. After the slope, sedimentation observed. Sediment starts moving when the velocity increase during flood season. Normally it is better to compare flood season month's data to identify changes at the apron.



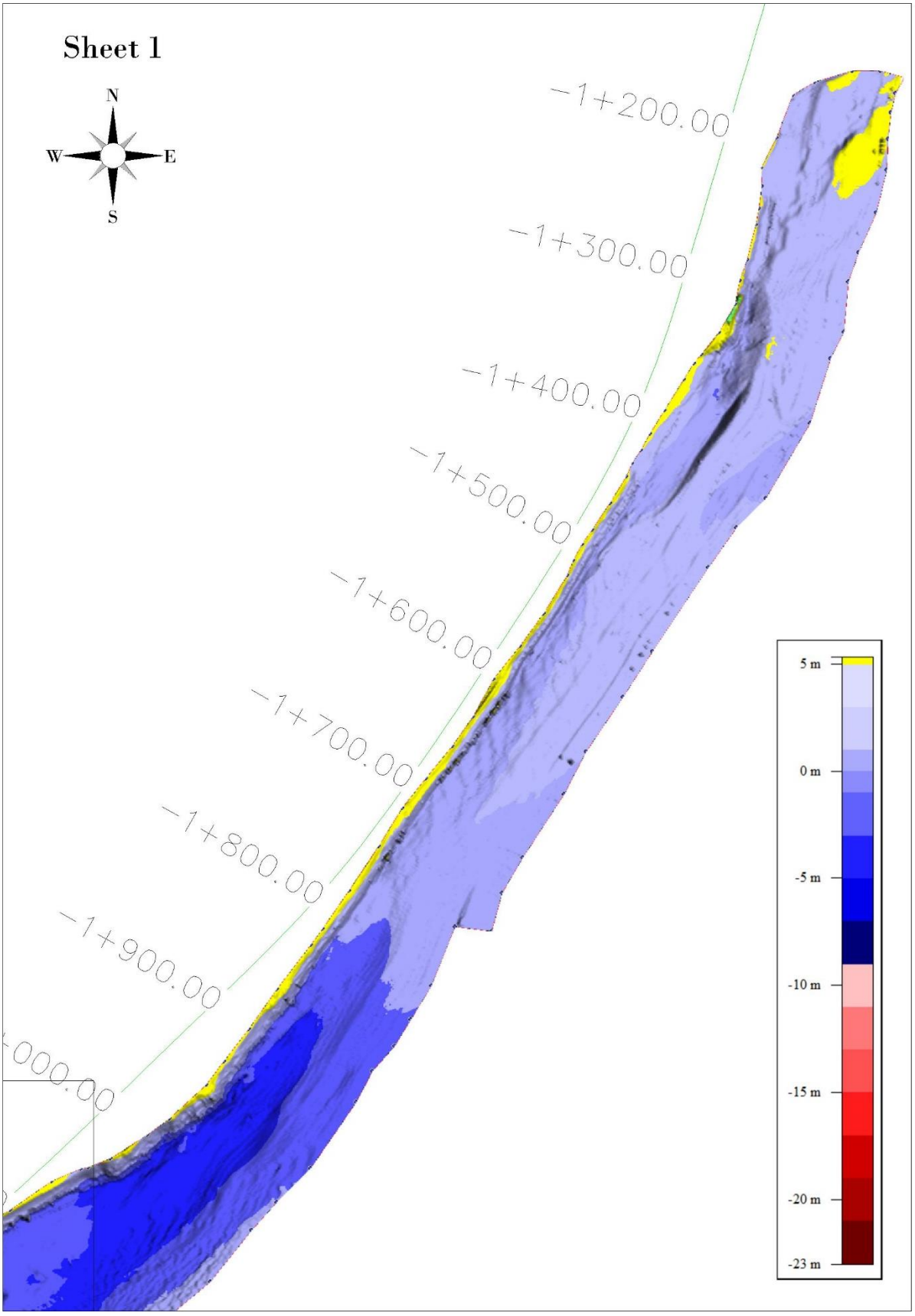

Sheet 3
N
W
E
S
Difference in meter
7.5 m
5.0 m
2.5 m
0.0 m
-2.5 m
2+100.00
2+000.00
1+900.00
1+800.00
1+700.00
1+600.00
1+500.00
1+400.00
1+300.00

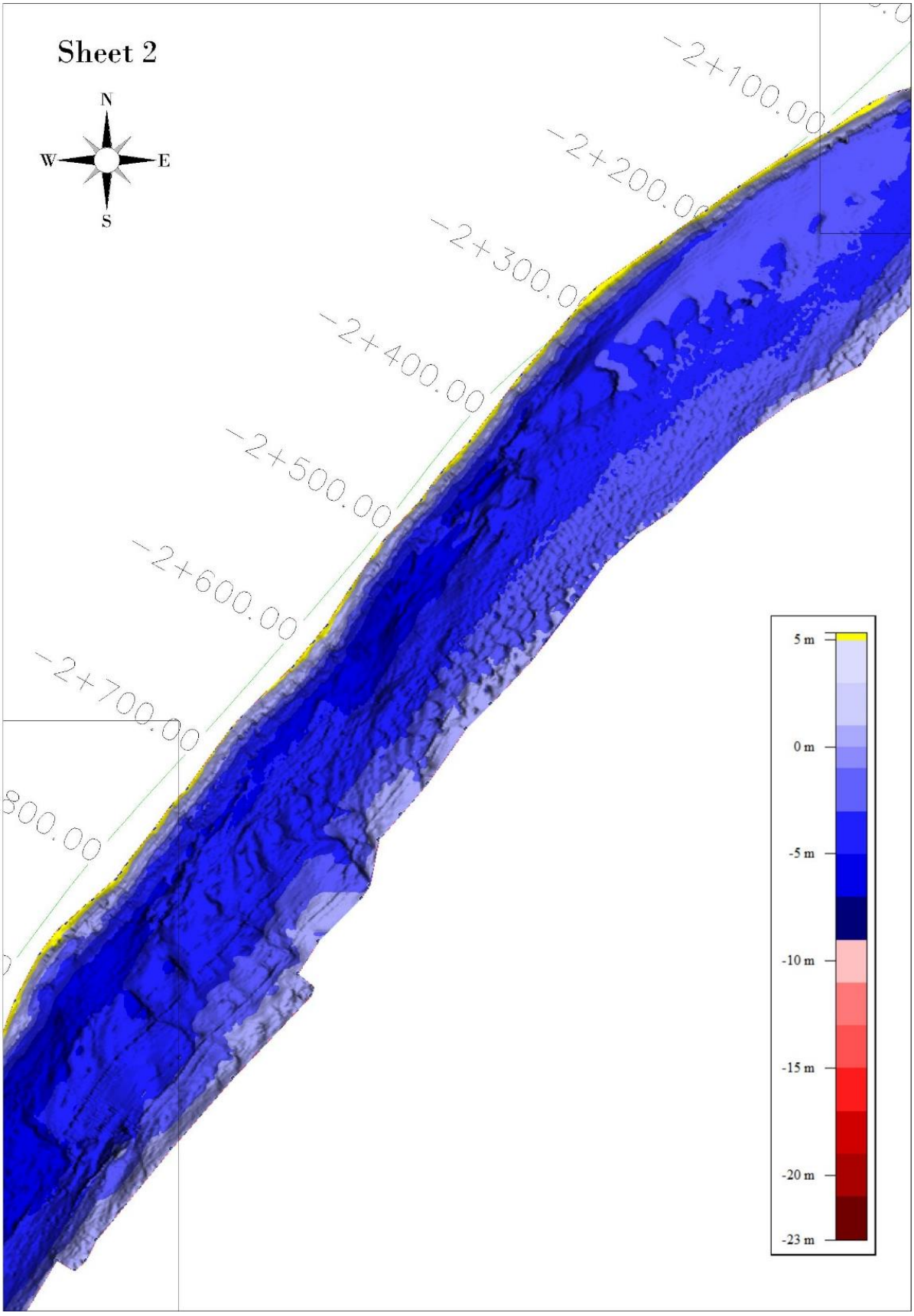

Sheet 4
N
W
E
S
Difference in meter
7.5 m
5.0 m
2.5 m
0.0 m
-2.5 m
1+100.00
1+000.00
0+900.00
0+800.00
0+700.00
0+600.00
0+500.00
0+400.00

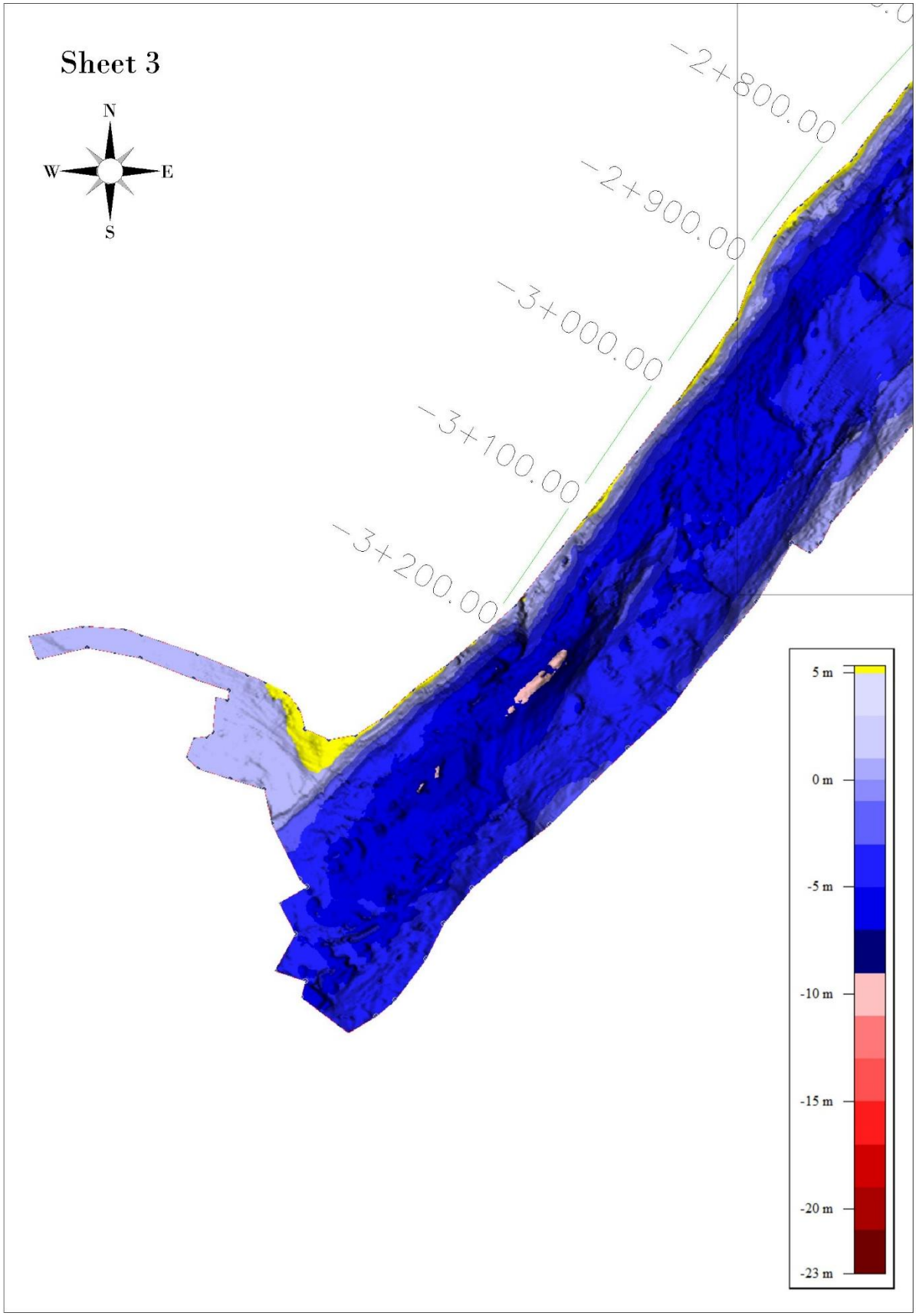
8.5 Benotia



Overall the channel is not very deep. From km -1+800 to above the average depth of this channel is 4mPWD. Downstream of km -1+800 to entrance of Hurasagor channel, average depth of the channel is -5mPWD. Only deep scour is observed at km -3+200.


Sheet 1
N
W
E
S
−1+200.00
−1+300.00
−1+400.00
−1+500.00
−1+600.00
−1+700.00
−1+800.00
−1+900.00
5 m
0 m
-5 m
-10 m
-15 m
-20 m
-23 m


Sheet 2
N
W
E
S
-2+100.00
-2+200.00
-2+300.00
-2+400.00
-2+500.00
-2+600.00
-2+700.00
800.00
5 m
0 m
-5 m
-10 m
-15 m
-20 m
-23 m


Sheet 3
N
W
E
S
-2+800.00
-2+900.00
-3+000.00
-3+100.00
-3+200.00
5 m
0 m
-5 m
-10 m
-15 m
-20 m
-23 m

8.6 PIRDP

8.6.1 Introduction

8.6.1.1 Underwater design

The underwater protection work consists of underwater slope protection and a falling apron following the JMREMP design standard (Figure 8-29). Figure 8-30 shows a standard design for riverbank and wave protection at the PIRDP. Table 8-1 shows the amount of protective work implemented under different work packages.

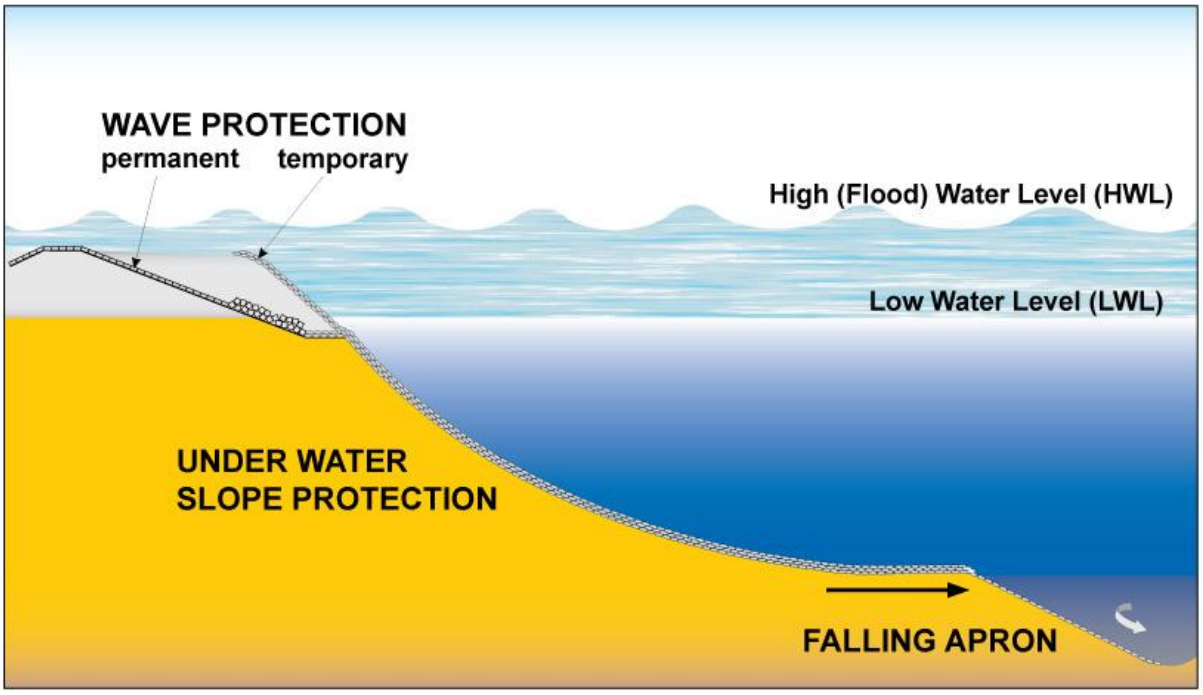


Figure 8-29 JRMEMP design standard

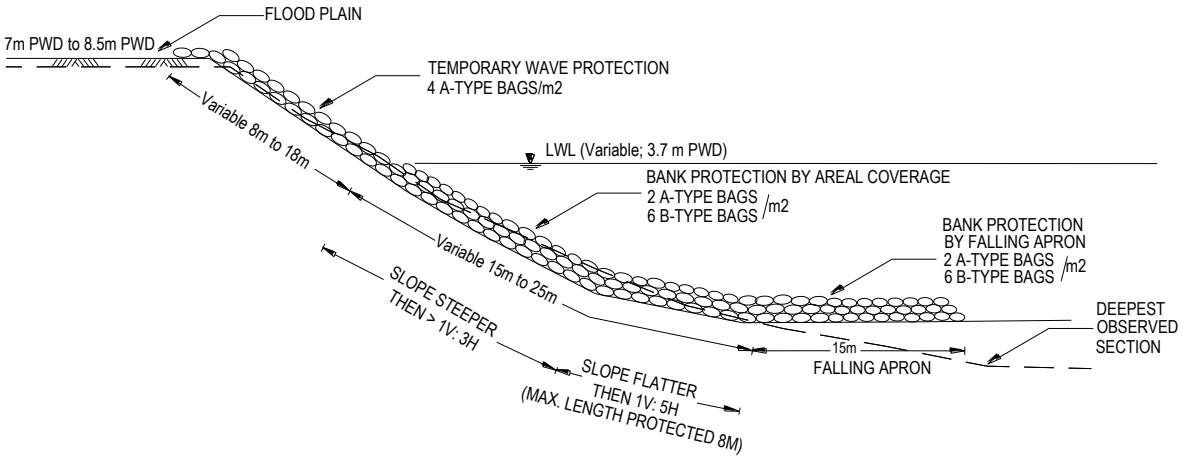


Figure 8-30: Standard design for Riverbank and Wave Protection at the PIRDP)

Table 8-1: Protection work under different contracts in PIRDP

Contract	Length of work along the bank line				
	Temporary Wave Protection	Permanent Wave Protection	Mass dumping	Area Coverage	Falling Apron
P1 (2003)	3250 m	345 m	500 m	2750 m	2750 m
P2 (2004)	378 m	-	2250 m	-	-
P3 (2005)	3850 m	-	-	3250 m	4250 m
P4 (2005)	-	1250 m	-	-	-
P5 (2005)	-	2280 m	-	-	-
P6 (2006)		1920 m			
P7 (2006)		2120 m			

The underwater slope protection and apron were built with a mix of 4 125 kg (Type A) bags and 6 78 kg (Type B) bags/m² resulting in a three layer coverage. The falling apron is built in the area where the slope starts to be flatter than 1V:5H (in many cases there is a sharp transition between the bank slope and the flat bottom of the river). During erosional attack expressed as deepening of the riverbed, the typically 15 m wide apron deploys (launches) down the eroding slope and thins from a 3-layer thick horizontal apron into to one-layer thick slope protection on a slope of about 1V:2H. The apron protects the riverbank temporarily as long as enough bags were stored in the horizontal apron. Table 8-1 also indicates the first kilometer of adaptation works built in 2005 (when comparing the last two columns). At that time an additional apron was placed along the deep downstream section, to provide additional safety for repeated river attacks. The “permanent wave protection” above low water level was completed by June 2008, coinciding with the original JMREMP completion date.

8.6.1.2 River developments alongside the PIRDP from 2001 to 2020

The river situation has undergone a number of changes over the last 20 years, because of morphological changes, but also as a result of the constructed protective works (Figure 8-32). First activities date back to 2001 and 2002 when emergency works was implemented along the lower 2 km of the site (from km 0 to 2,000). This work is reported in Geobag Revetments, 2003. From 2004 the main underwater works was built along 7 km of riverbanks in two main phases during the dry season 2004 and 2005 and completed by June 2006 (Figure 8-31). The works is reported in Special Report 21. Figure 8-32 demonstrates that the main works built in early 2004 was built at the deepest river conditions. This is likely the result of earlier river deepening in response to the emergency works in 2001 and 2002. The pattern of regular bankline surveys was discontinued from 2008 until 2018. This means that we have not much knowledge on any developments in terms of apron behavior. However, some coarser date (with 500 m or 1 km line spacing) from large scale surveys are available for 2011, and from 2016 until 2018. Importantly, recent river attack in the upper part of the protection has been documented in 2018 and 2019. In 2019 when the deepest launching, close to design scour level, had been reached, a high resolution multi-beam echosounder survey has been conducted documenting the performance of the works.

Table 8-2 provides an overview of all available river surveys.

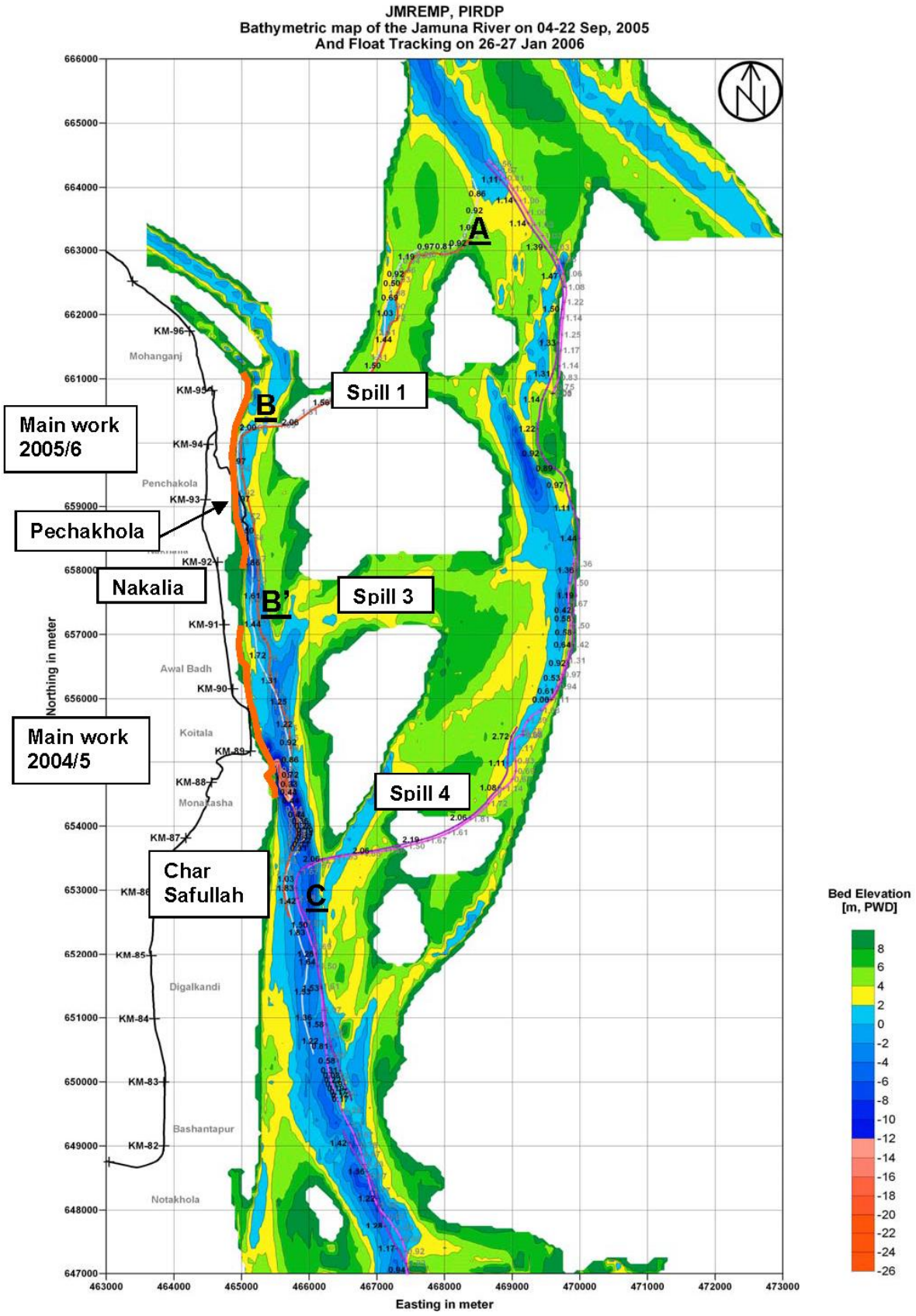


Figure 8-31 River changes and site situation January 2006 (flood season survey Sep. 2005)

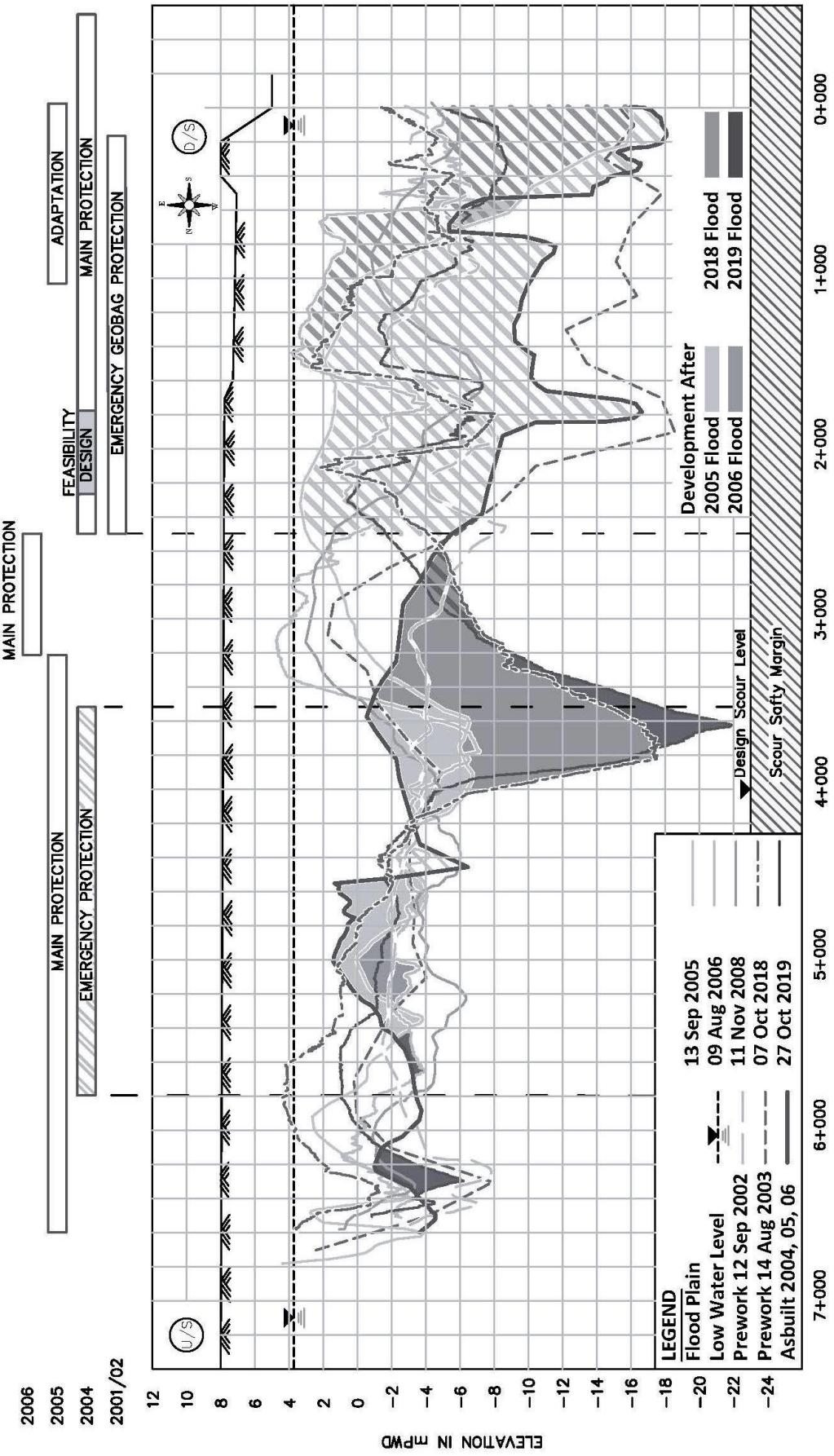


Figure 8-32 Long section along the apron at the PIRDP with major documented changes

Table 8-2 Available river surveys along the site

Year	Large-scale survey	Bankline survey	Remarks
1992		Apr 30	Precursor during the Flood Action Plan
2001		Sep 02	After 1st inconsistent emergency protection
2002	Dec 17	June 06, 16, 26; July 23, Sep 12, Dec 17	After 2nd emergency protection
2003	Aug 14,	Sep 02, 09, 17, 23, 30; Dec 13	After partial emergency protection
2004	June 17, Oct 13	Apr 23, 24, 25, 26; May 09, 12, 14 to 29, 31; July 04 to 08, 10, to 14, 18	After main protection from km 0+000 to km 2+500
2005	Sep 4 to 22	Jan 09, 17	After main protection from km … to km …
2006	Oct 02	Mar 07, Aug 09	
2007	Sep 18	Jan 26; Mar 19, 20; Apr 07, 08, 24; May 31; Aug 2, 3, 6, 17, 19, 20, 21; Sep 22, 23,24, 25, 26, 30; Oct 03	
2008		Jan 12, 17, 29, Feb 08, 19, Mar 10, 13	
2011	Flood season		
2016	Sep 16		ISPMC Monitoring survey
2017	Aug 15 to 29 and Dec 21, 2017 to Jan 09,2018		ISPMC Monitoring survey
2018	Aug 15 to Sep 10	07 Oct 2018	ISPMC Monitoring survey
2019	Sep 17-22	29 Oct 2019 Single beam and 7 to 10 Nov 2019 Multibeam survey	2019 Nov 1st multi-beam survey

8.6.1.3 Objective and Limitations of the Multi-beam Survey

- Identify underwater situation of the protected riverbank
- Identify performance of the launched apron
- Identify need for adaption works
- Due to the low water level during the survey, the transition to the upper slope could not surveyed
- The survey coverage is 10 to 15m to the waterline.

8.6.2 Multi-beam Echosounder Survey

Figure 8-33 shows the plan view of the two multi-beam survey locations, and Figure 8-34 shows the details of the two survey locations. Larger scale figure follow thereafter.

At location 1 sheet 1 (Figure 8-35), two representative cross-sections have been taken (Figure 8-36). In all cases the cross-sections show 1V:2H slopes, which agree with typical launched slopes. Close to the low water line, there are some pockets probably resulting from the excavation of the transitional berm. The 3D view clearly depict that the connection in these places might have been imperfect (Figure 8-37). Diving investigation would be required to verify connection of apron and upper slope. One underwater failure can be seen at km 4+000 (Figure 8-38). Given indications of rapid scour and

experience from Chauhali where similar shapes have been observed in 12 locations under much more severe attack, it can be assumed that this is related to flow slides. Flow slides are a result of rapid scouring and unloading of the toe of the protected works. They can only be controlled through wide aprons. As the approach channel turns sharply, resulting in pronounced bend scour, flow slides are likely. The lesson learned is that adaptation works has to be implemented immediately after the detection, in order to avoid progression of the flow slide and damage to the upper slope. The primary means to avoid the translation into the upper slope remains building wider aprons.

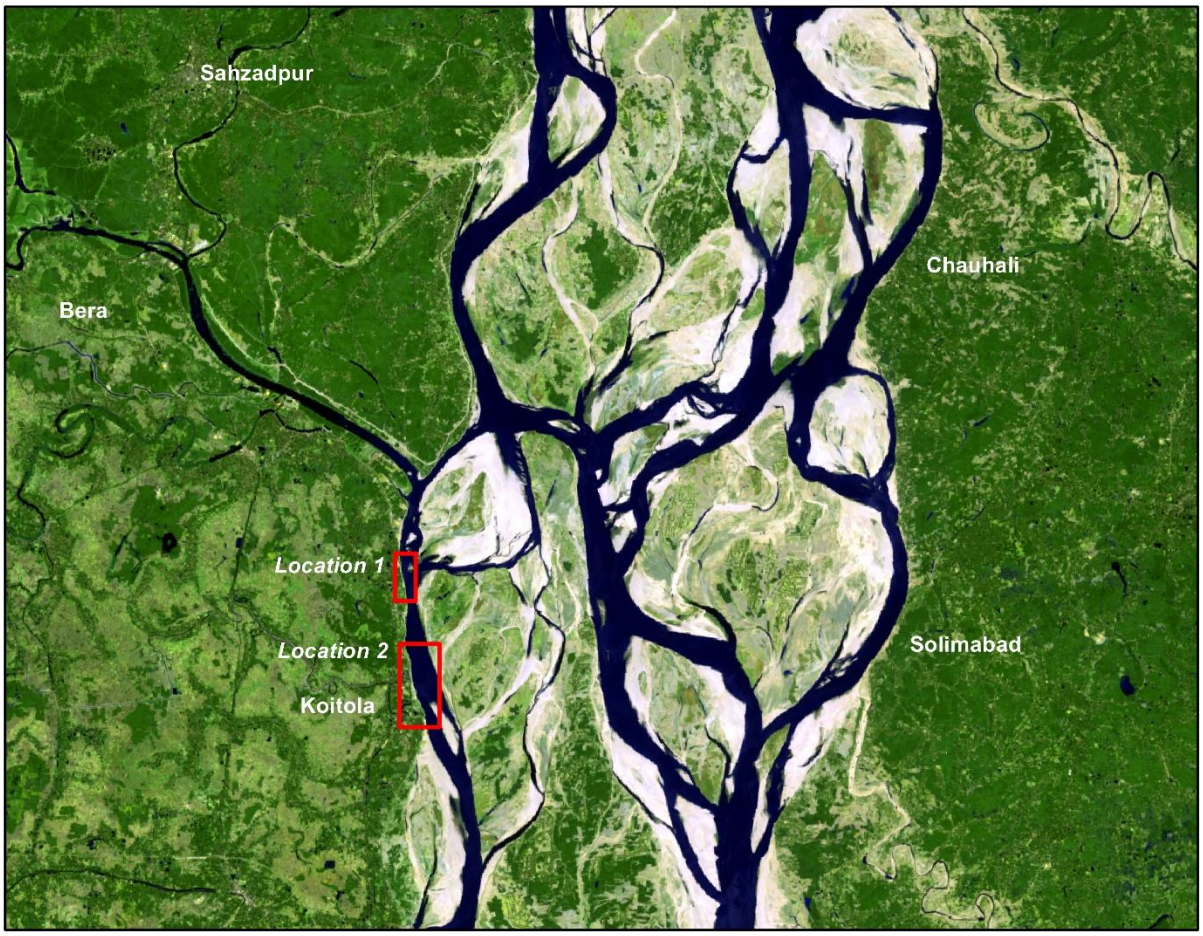


Figure 8-33 Planview of the multibeam surveyed location

Three cross-sections have provided for sheet 2 (Figure 8-39). The cross-section in Figure 8-40 show 1V:2H slope which represent typical launched slopes. The channel approaching between station 3,900 and 3,800 makes a sharp bend at station 3,750. In this area the deepest slope is observed apparently with the launching quantities exhausted (Figure 8-41). Upstream and downstream the apron is still visible. Also here adaptation works will be required.

Further downstream the situation is different; sheet 3 to 6 cover this area. Sheet 3 (Figure 8-43) shows a deeper channel from Station 1,900 to 1,700. The apron was placed here at a deep bed elevation, on average at --12m+PWD. The cross sections (Figure 8-44) in this area of sedimentation do not allow a clear assessment of the launching behavior. The 3D view in Figure 8-45 indicates again some pockets at the transition between upper slope and lower slope. These pockets could be a result of imperfect excavation during the construction of the upper slope in 2008.

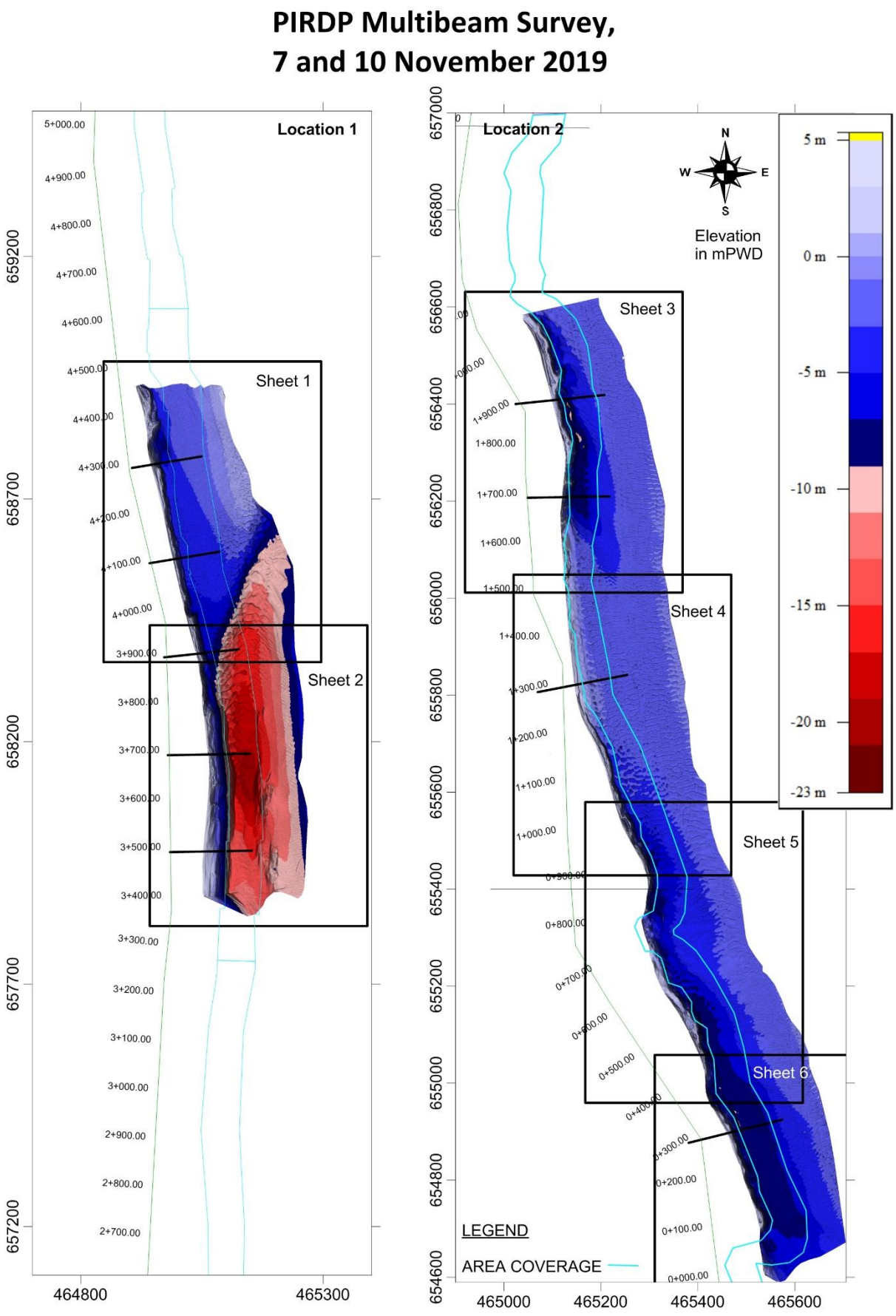


Figure 8-34 Overview of the multi-beam survey

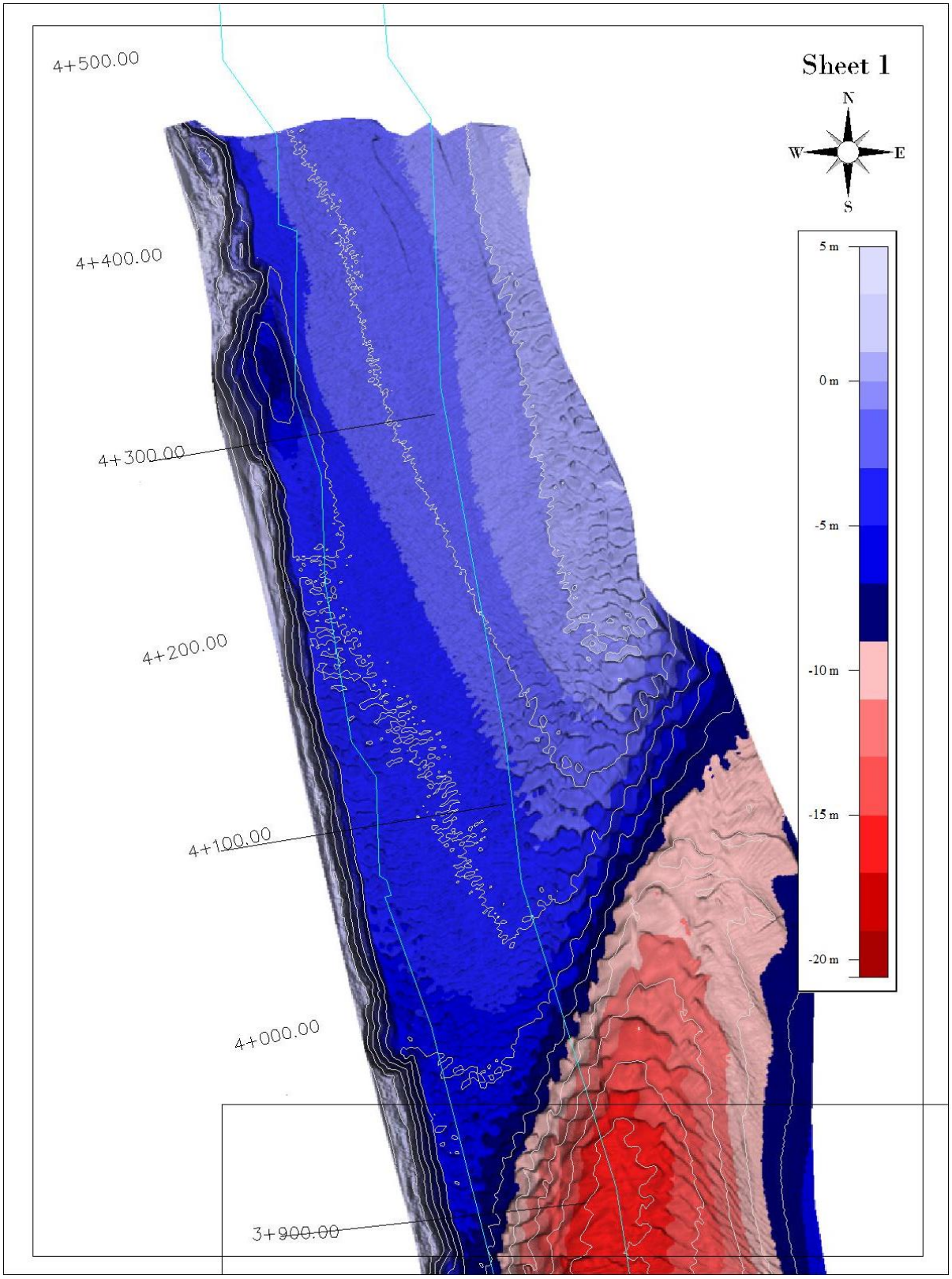


Figure 8-35 Sheet 1 of the multi-beam survey

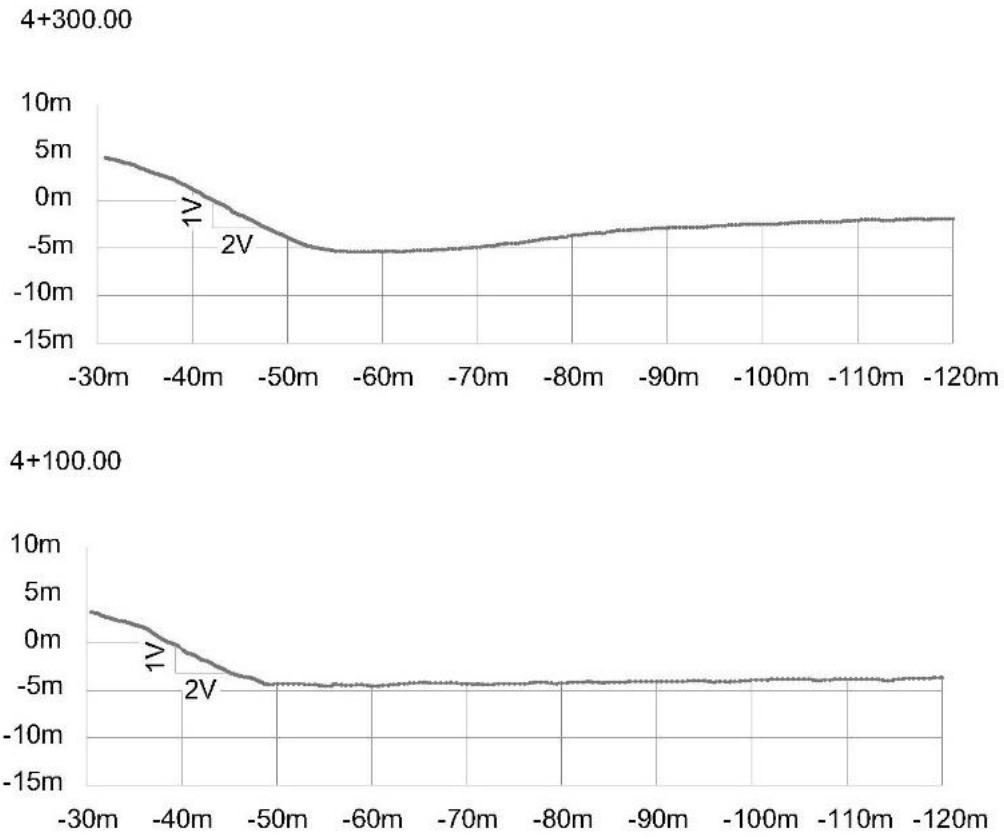


Figure 8-36 Cross sections at station 4,100 and 4,300

3D View

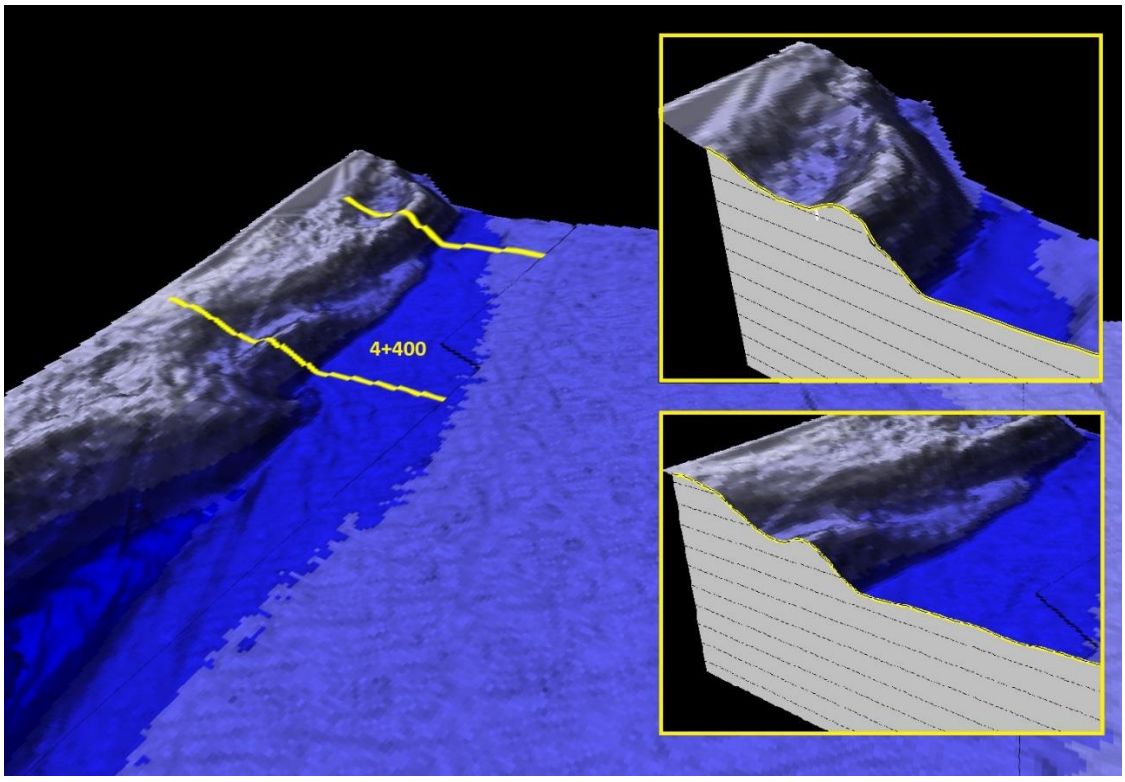


Figure 8-37 : Pockets between slope and underwater apron

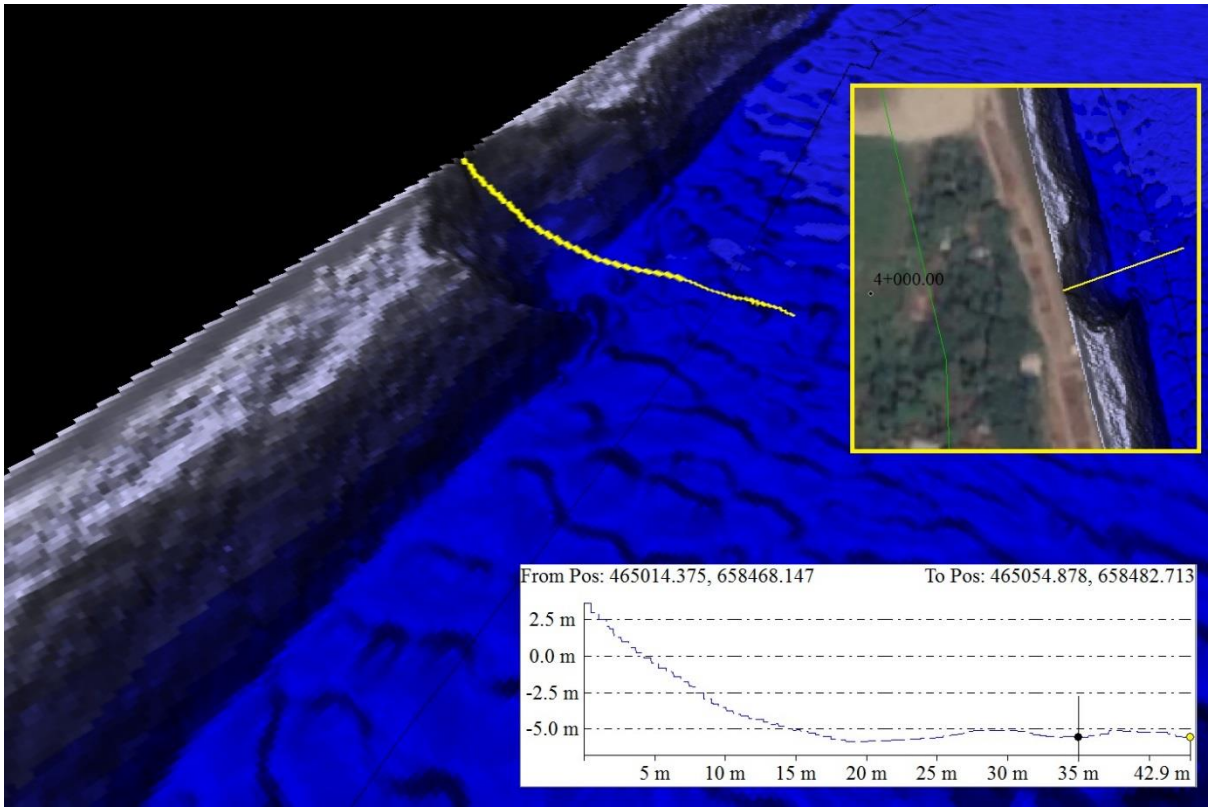


Figure 8-38 : Localized failure of the slope, potentially resulting from flow sildes triggered by rapid scouring

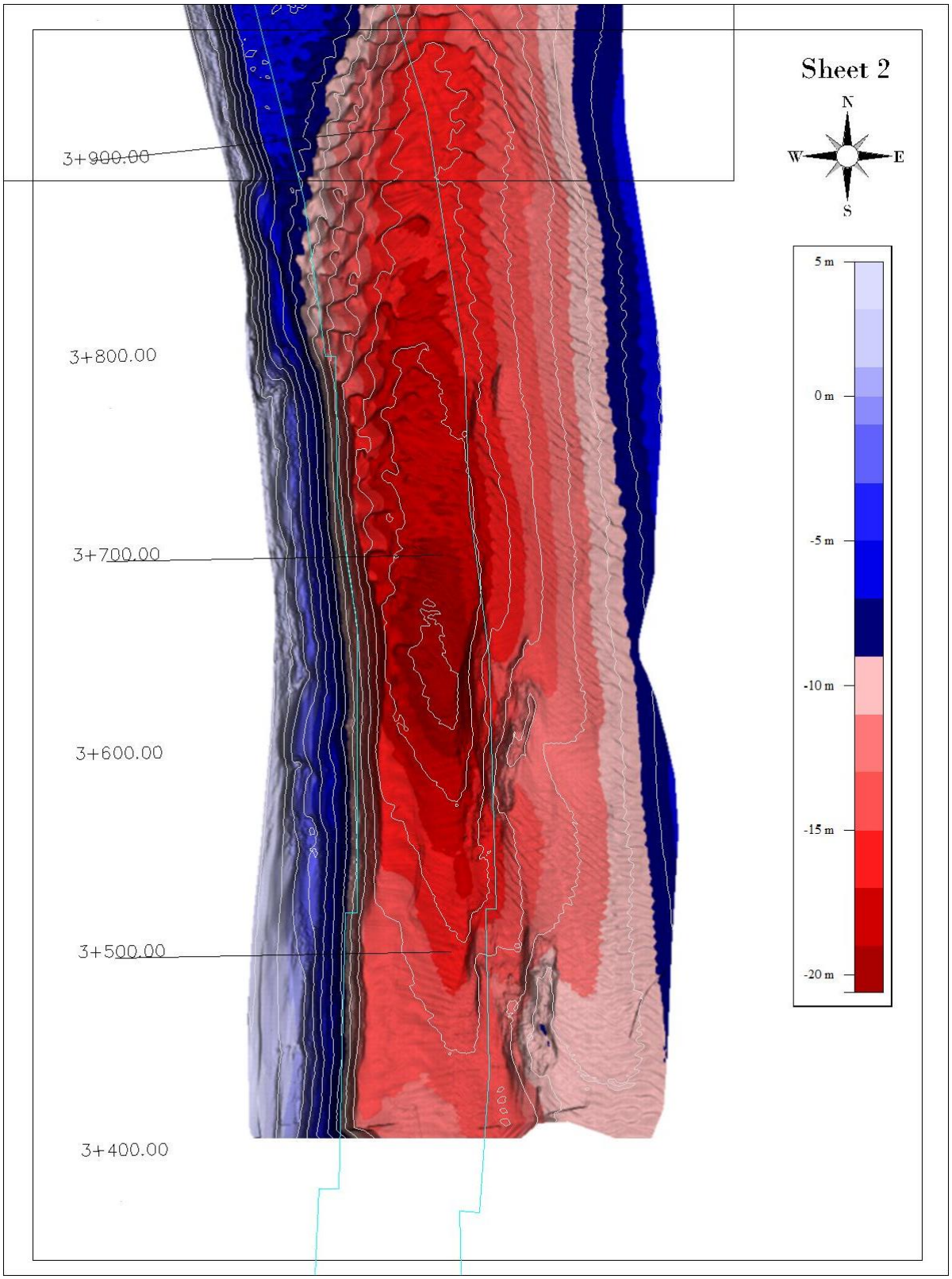


Figure 8-39 Sheet 2 of the multi-beam survey

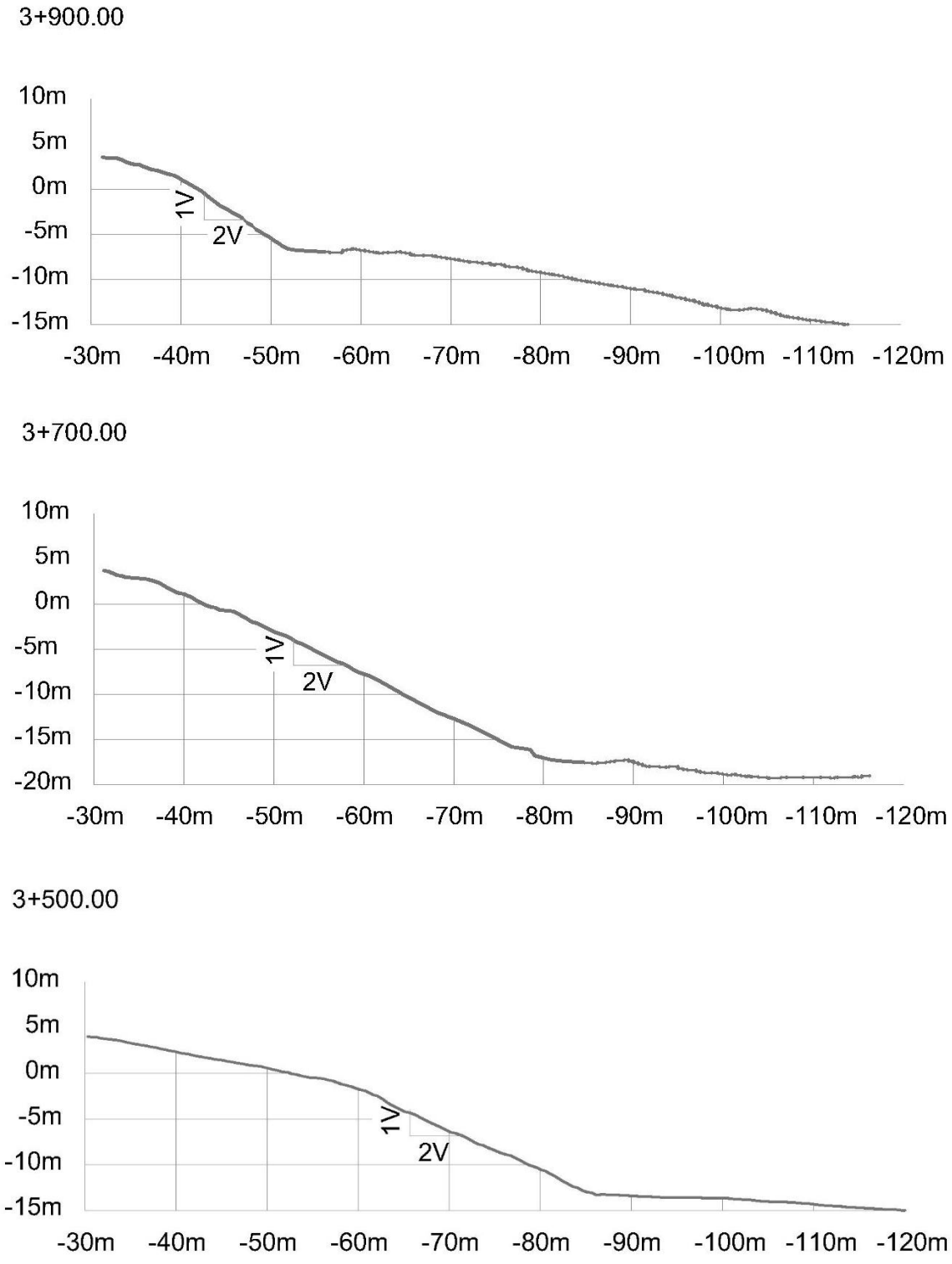


Figure 8-40 Cross sections at Stations 3,500, 3,700 and 3,900

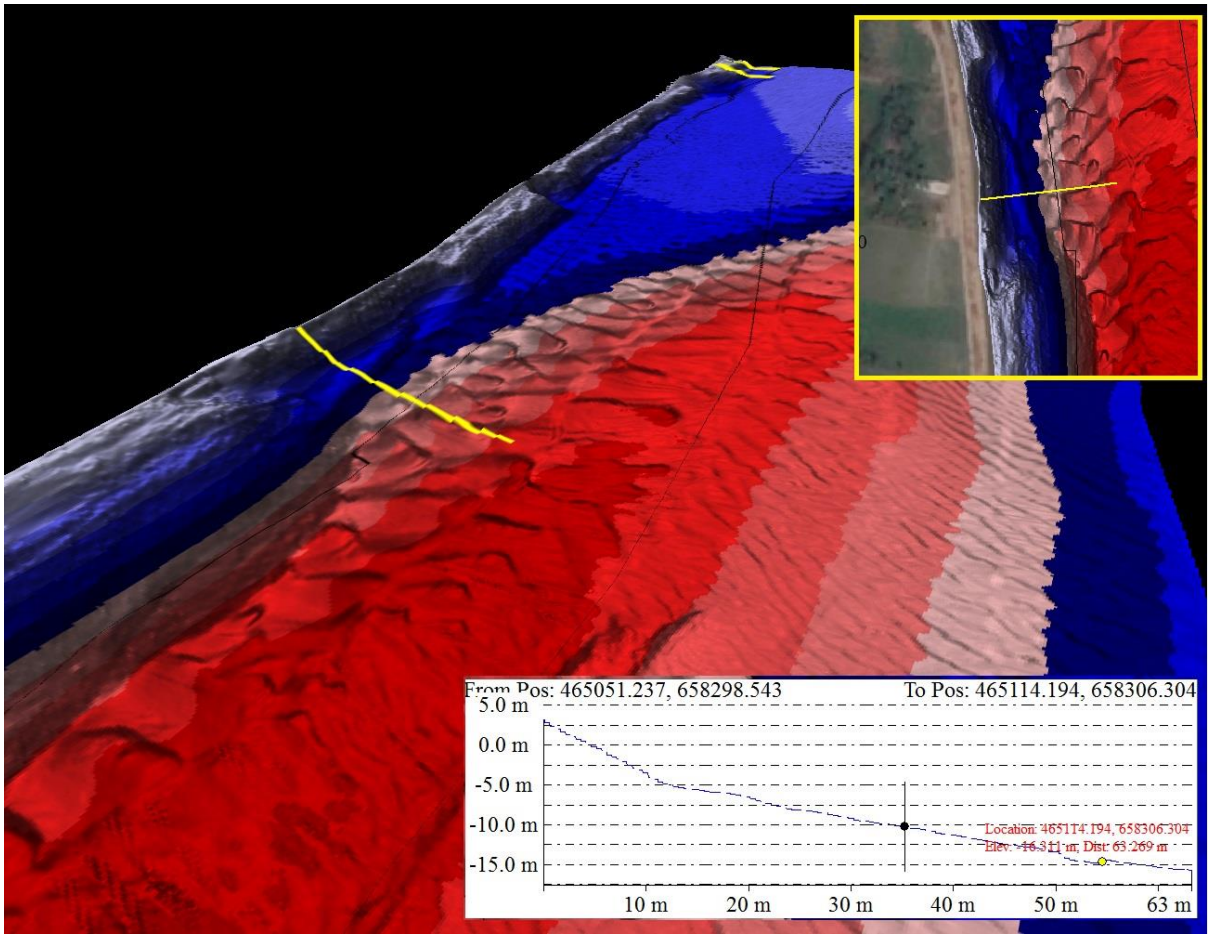


Figure 8-41 : Steepest slopes at *station* 3,*700*

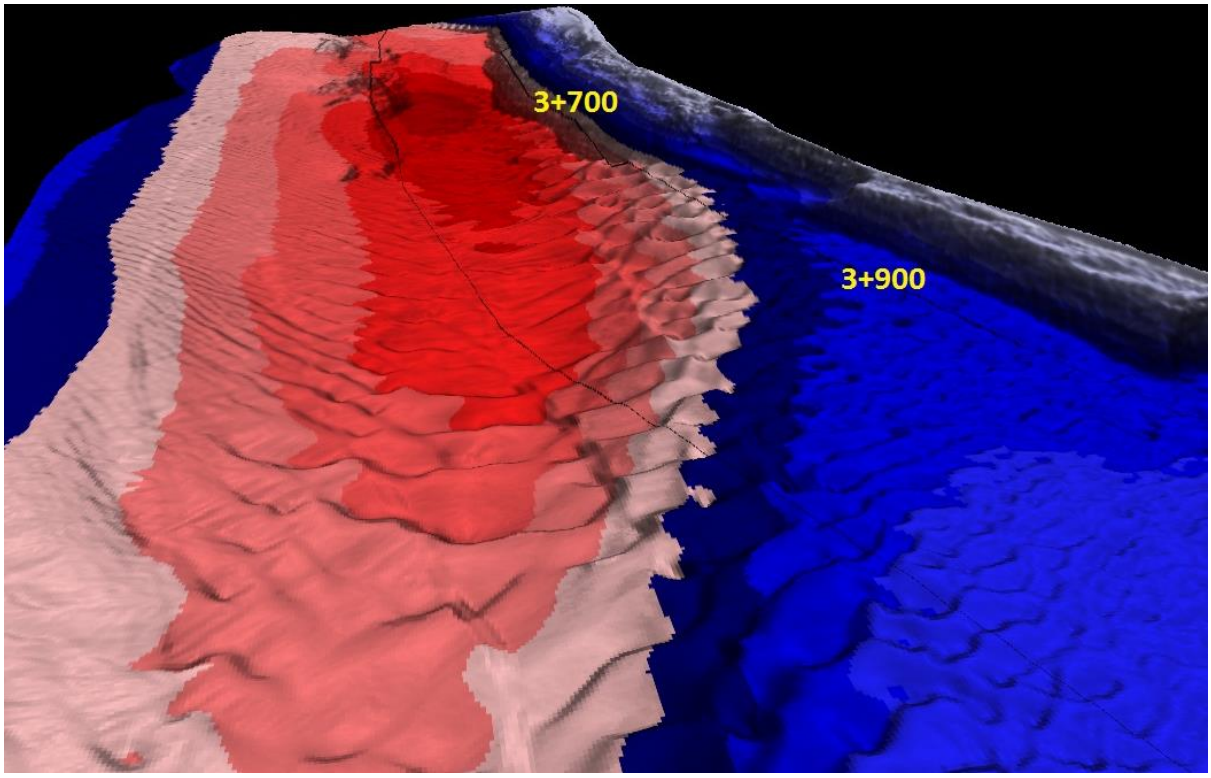


Figure 8-42: Deep channel after the bend

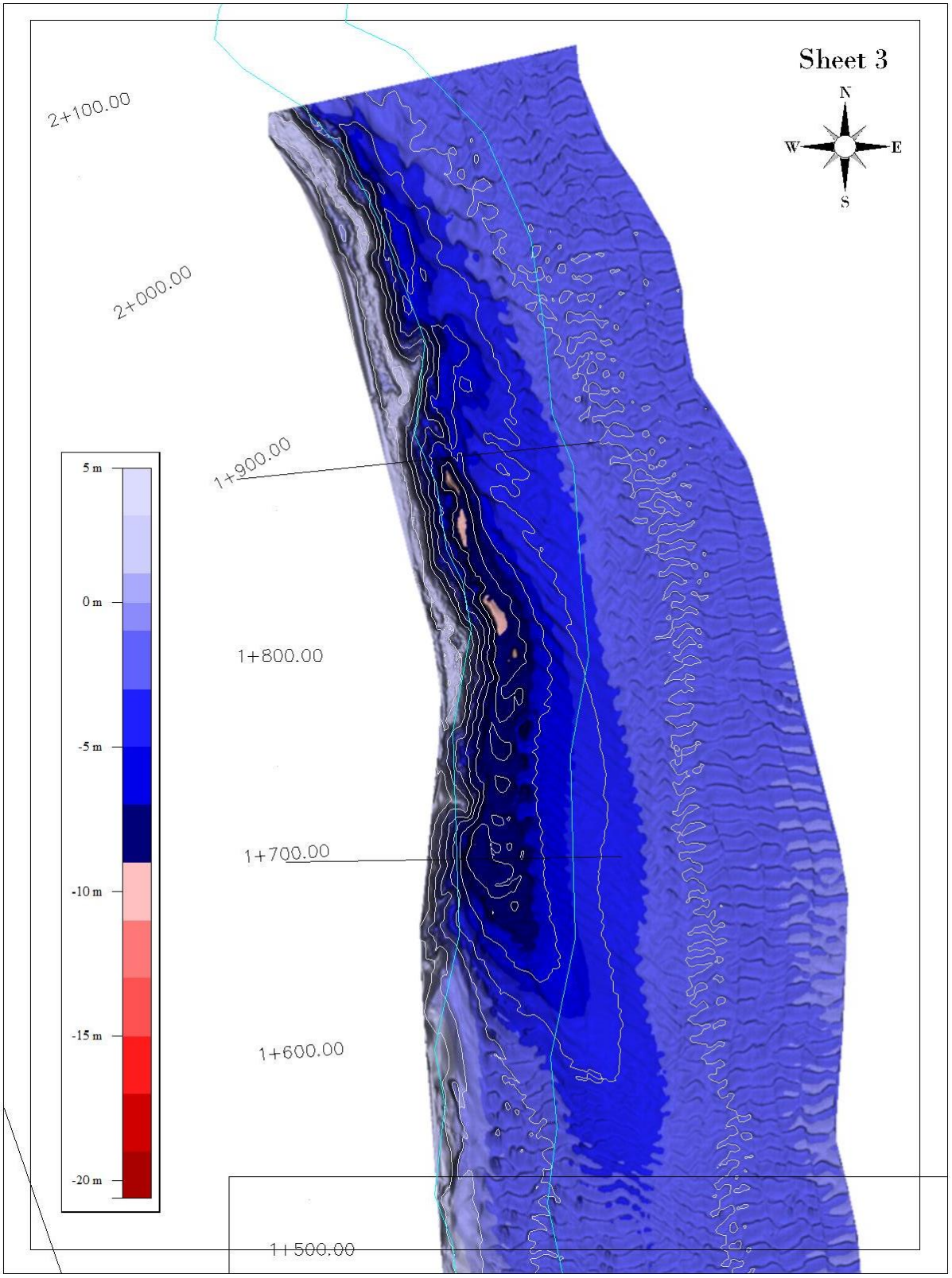


Figure 8-43 Sheet 3 of the multi-beam survey

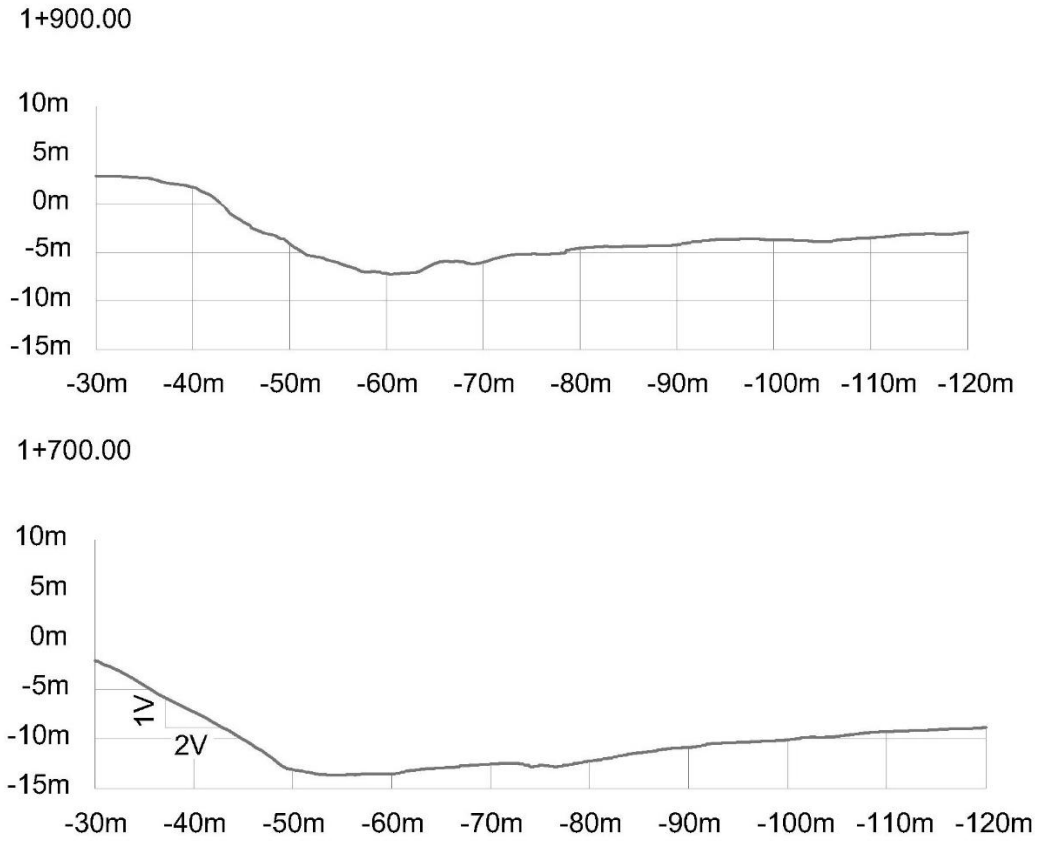


Figure 8-44 Cross sections at Station 1,700 and 1,900

3D view

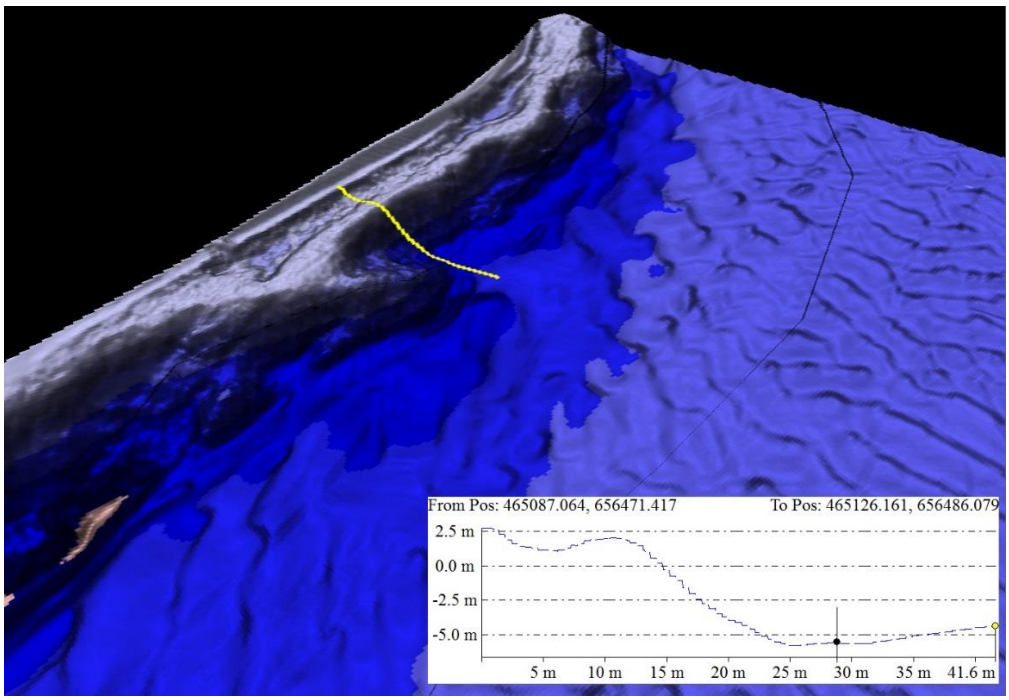


Figure 8-45: Location with apparently a pocket along the transition from upper to lower protection

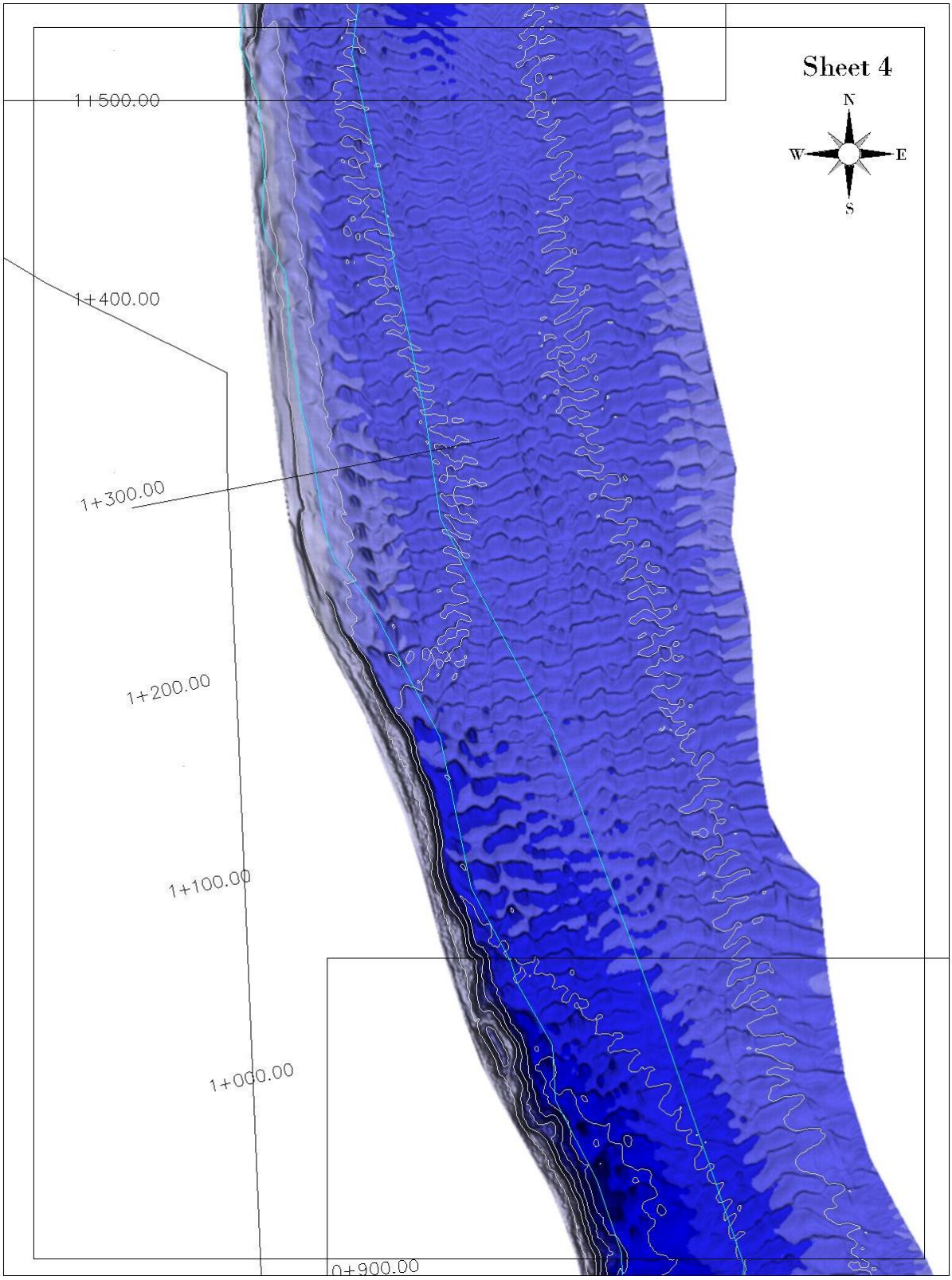


Figure 8-46 Sheet 4 of the multi-beam survey

The apron in sheet 4 (Figure 8-46) was placed during 2004 dry season at deepest bed levels. The average apron was placed at -10m+PWD. Now the underwater slope is covered with sediment. The sample section in Figure 8-48 demonstrates this. Again, at the transition from upper to lower slope the multi-beam survey identified a pocket at Station 1,000 (Figure 8-49).

In sheet 5 (Figure 8-47) the apron was placed during the 2004-05 dry season at the recorded lowest bed level between -14mPWD at Station 1,400 and -12mPWD at Station 400. Also here the launched slope is covered with sediment.

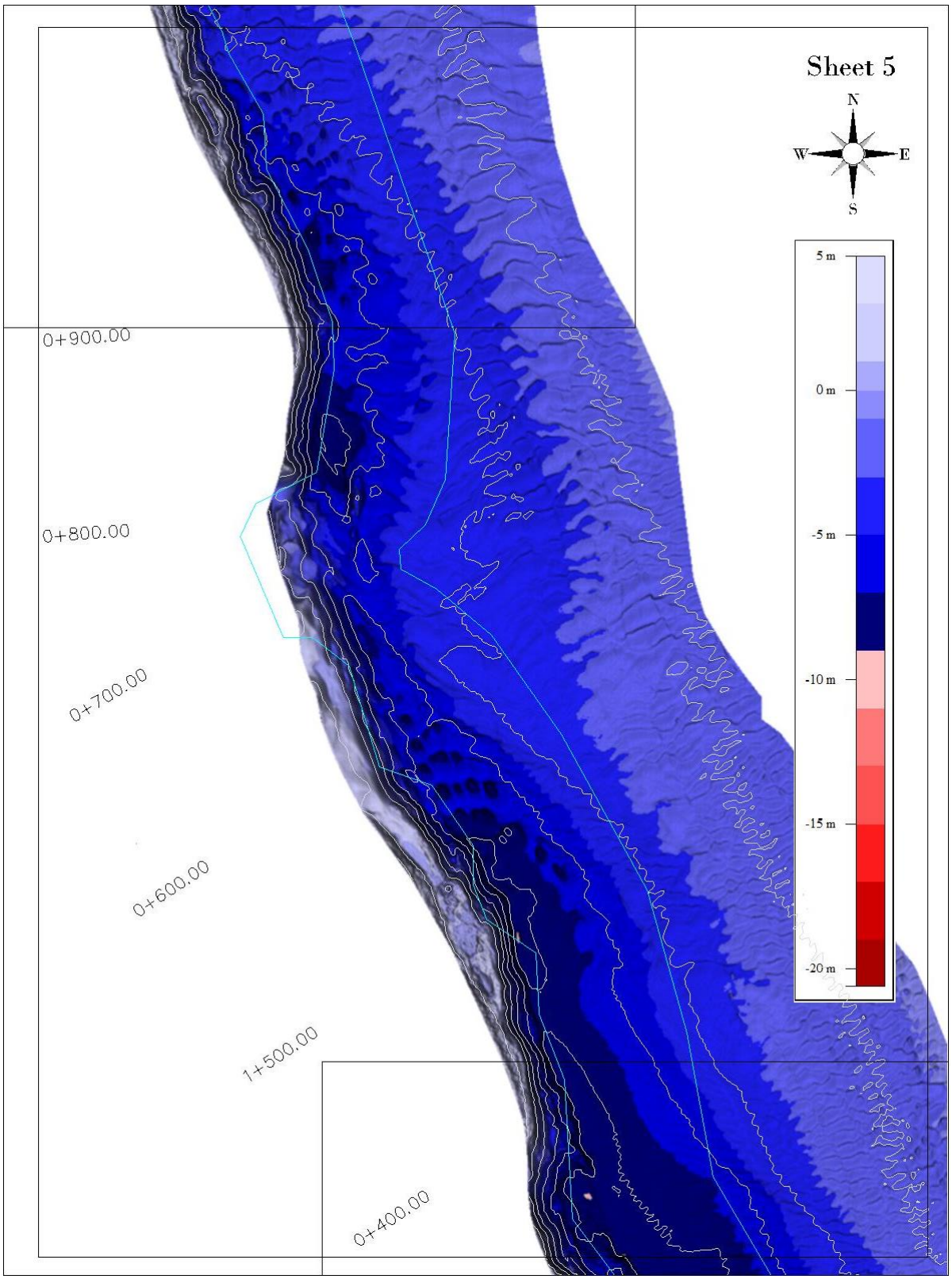


Figure 8-47 Sheet 5 of the multi-beam survey

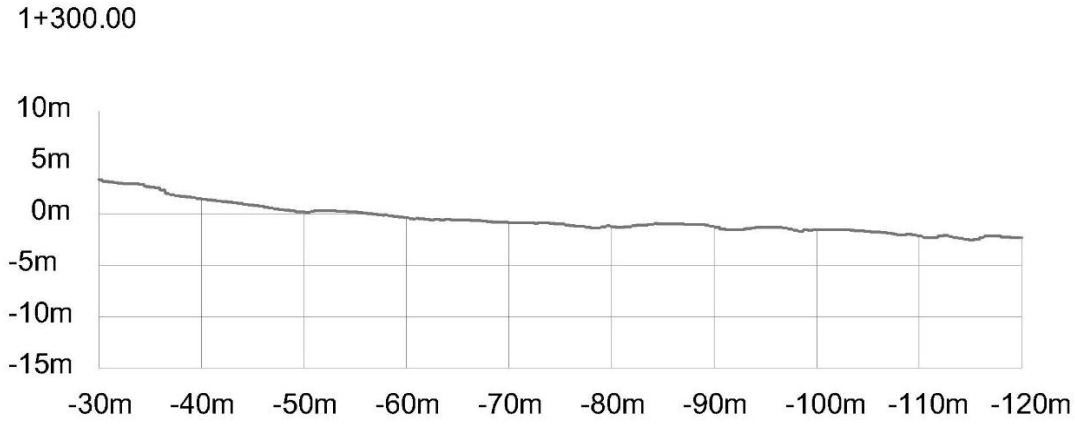


Figure 8-48 Cross section at Station 1,300

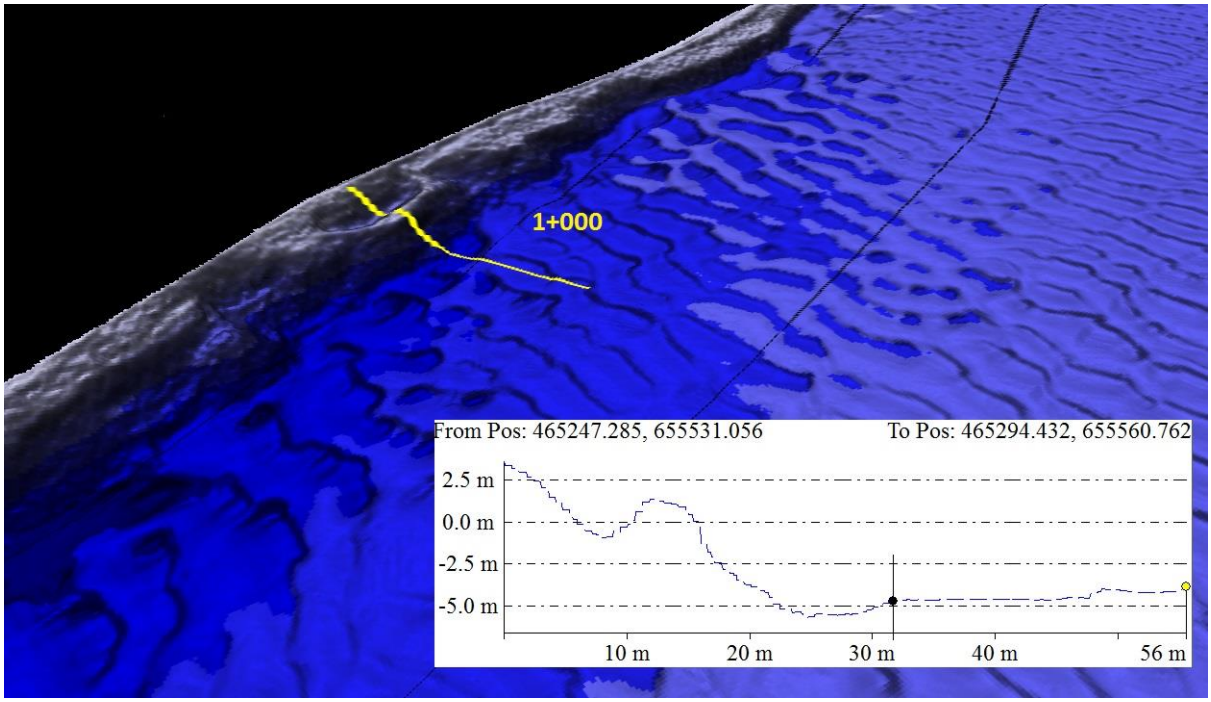


Figure 8-49: Pockets at transition from upper to lower slope

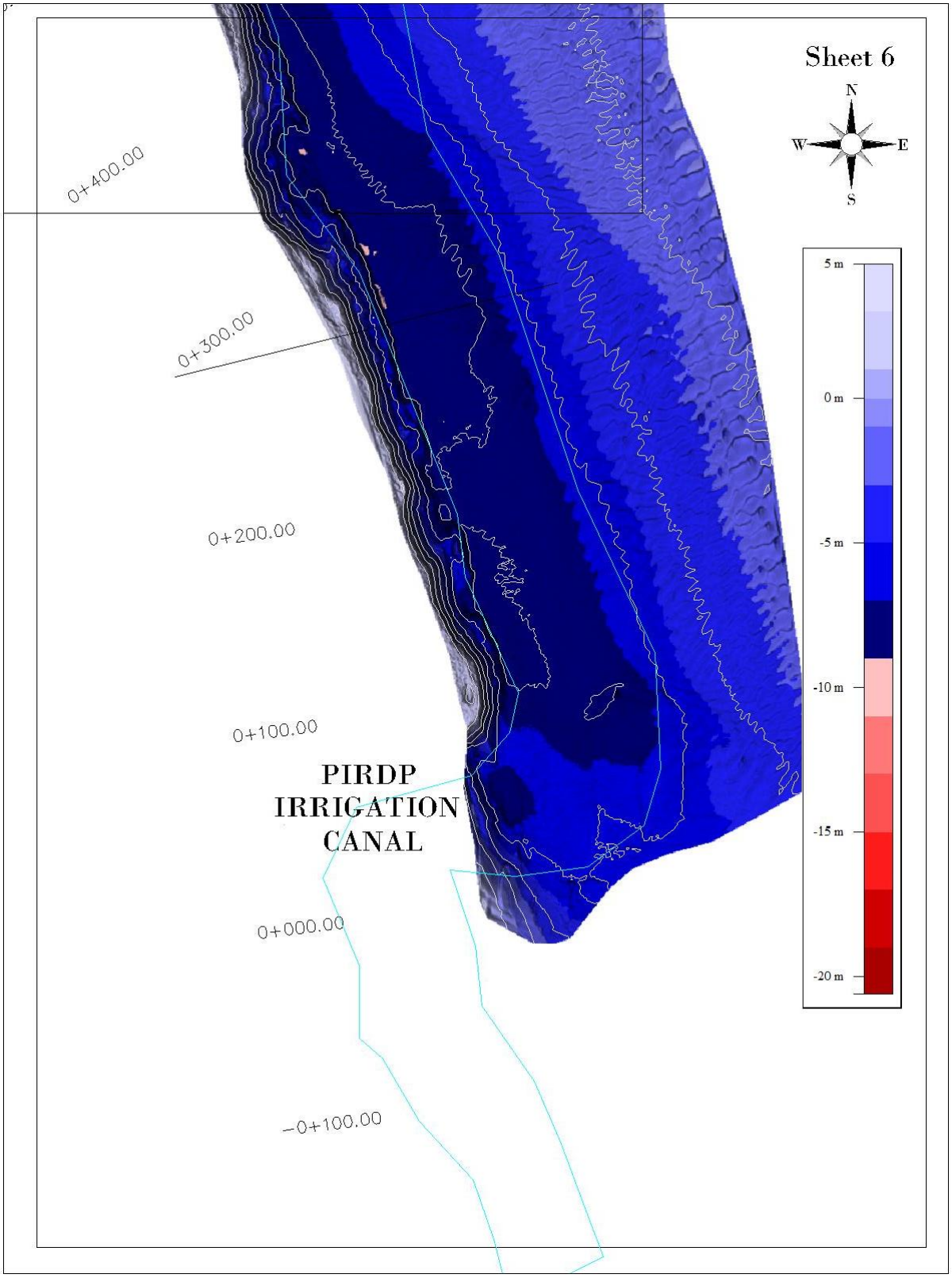


Figure 8-50 Sheet 6 of multi-beam survey

The most downstream part of the PIRDP protection (Figure 8-50) was constructed at deep bed levels in 2004. Cross section at Station 300 (Figure 8-51) indicates the upper protected slope however most of the cross section appears to be sedimented in. In 2005 the first ever “adaptation works” was built here (from Station 0 to 1,000. The cross section at Station 150 (Figure 8-52) indicates secondary launching, as clearly visible step. At Station 200 launching appears to have exhausted the provision

of the apron or rapid scouring has led to a flow slide through the second apron of the adaptation works (Figure 8-52).

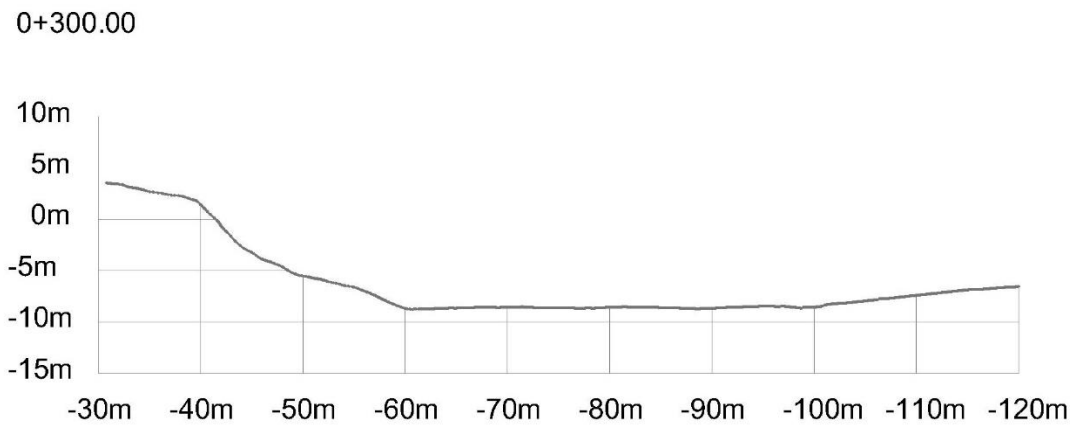


Figure 8-51 Cross section 300

3D view

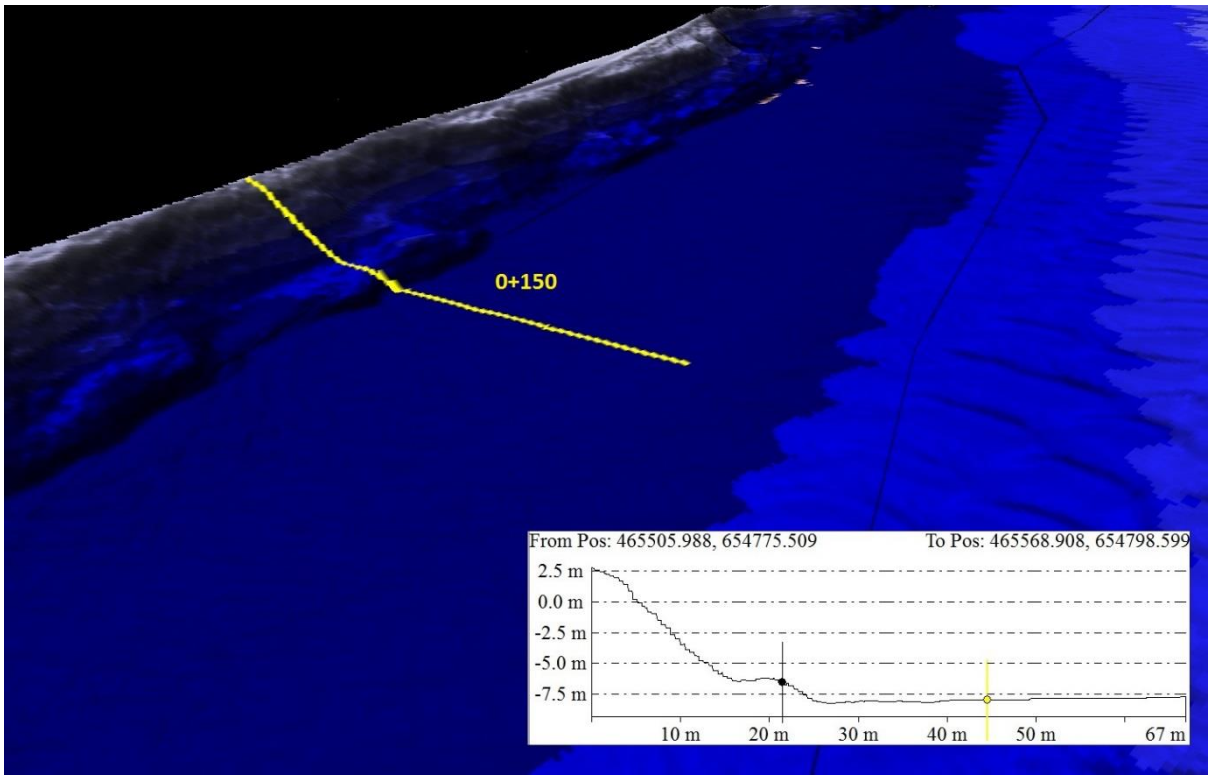


Figure 8-52: Step shape launching after the adaptation work

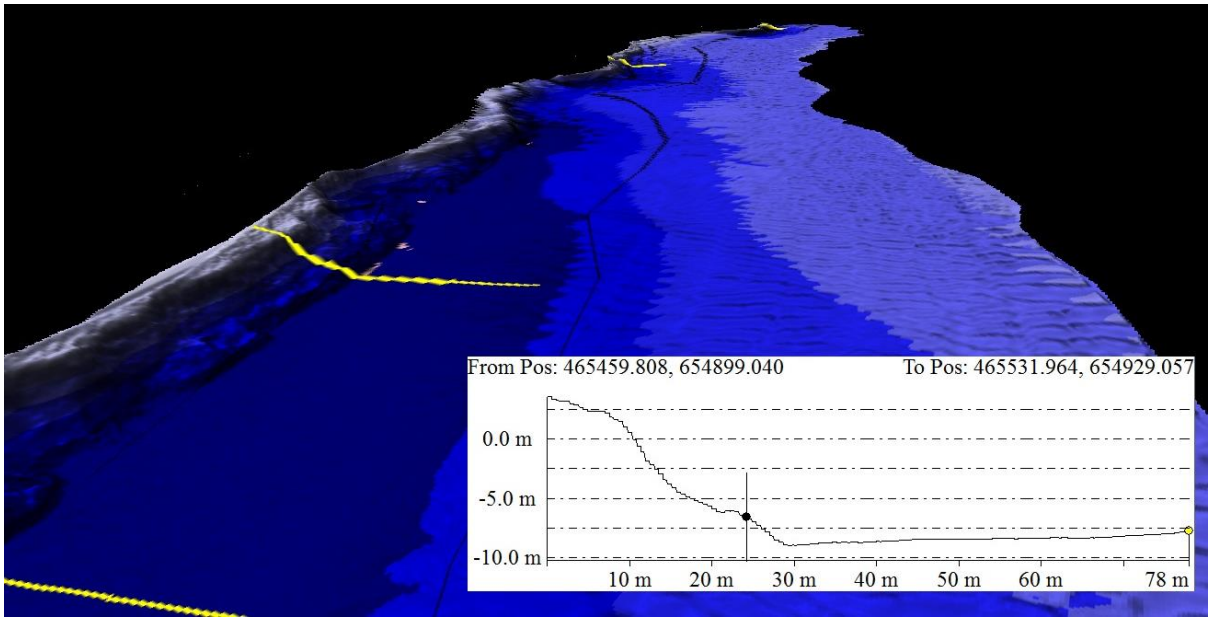


Figure 8-53: Step shape launching after the adaptation work

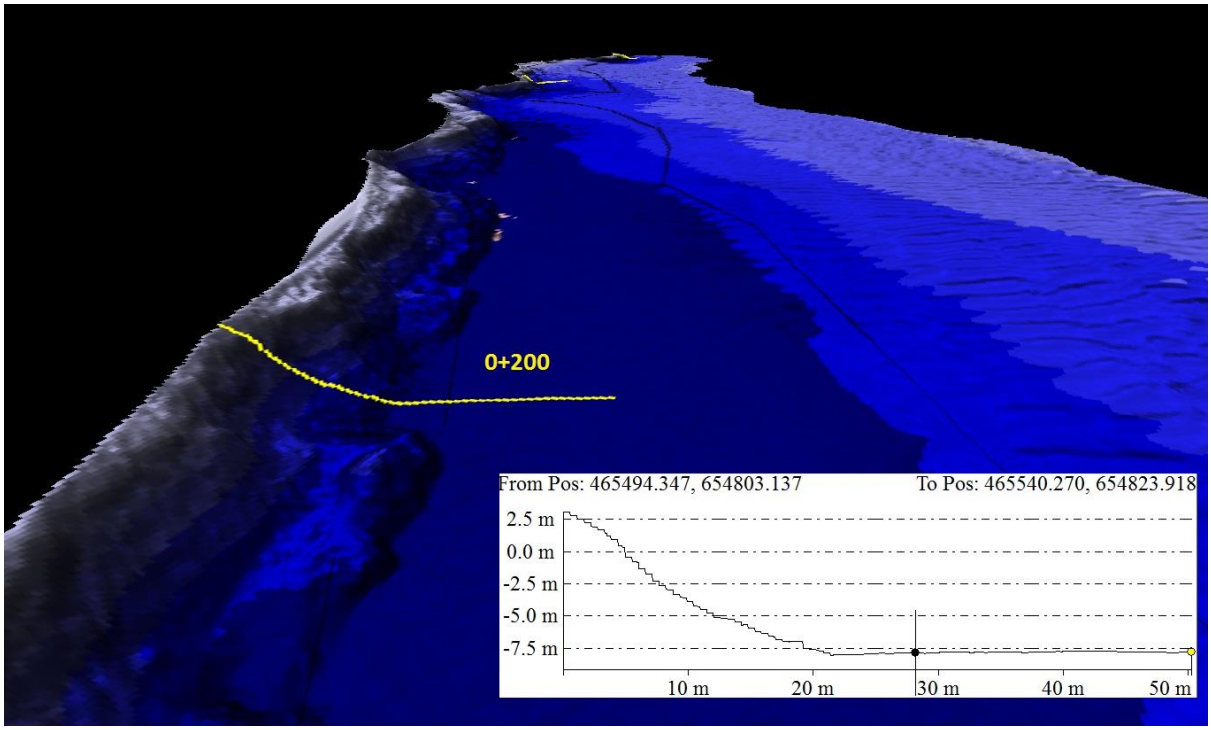


Figure 8-54: Potential flow slide from rapid scouring through the secondary apron.

In summary, the works appears to have performed quite well despite localized aggressive river attack triggering flow slides. The lack of ten years of data hampers the understanding. However, more regular multi-beam surveys could improve the sitation. Naturally, adaptation works would be required at a number of locations.

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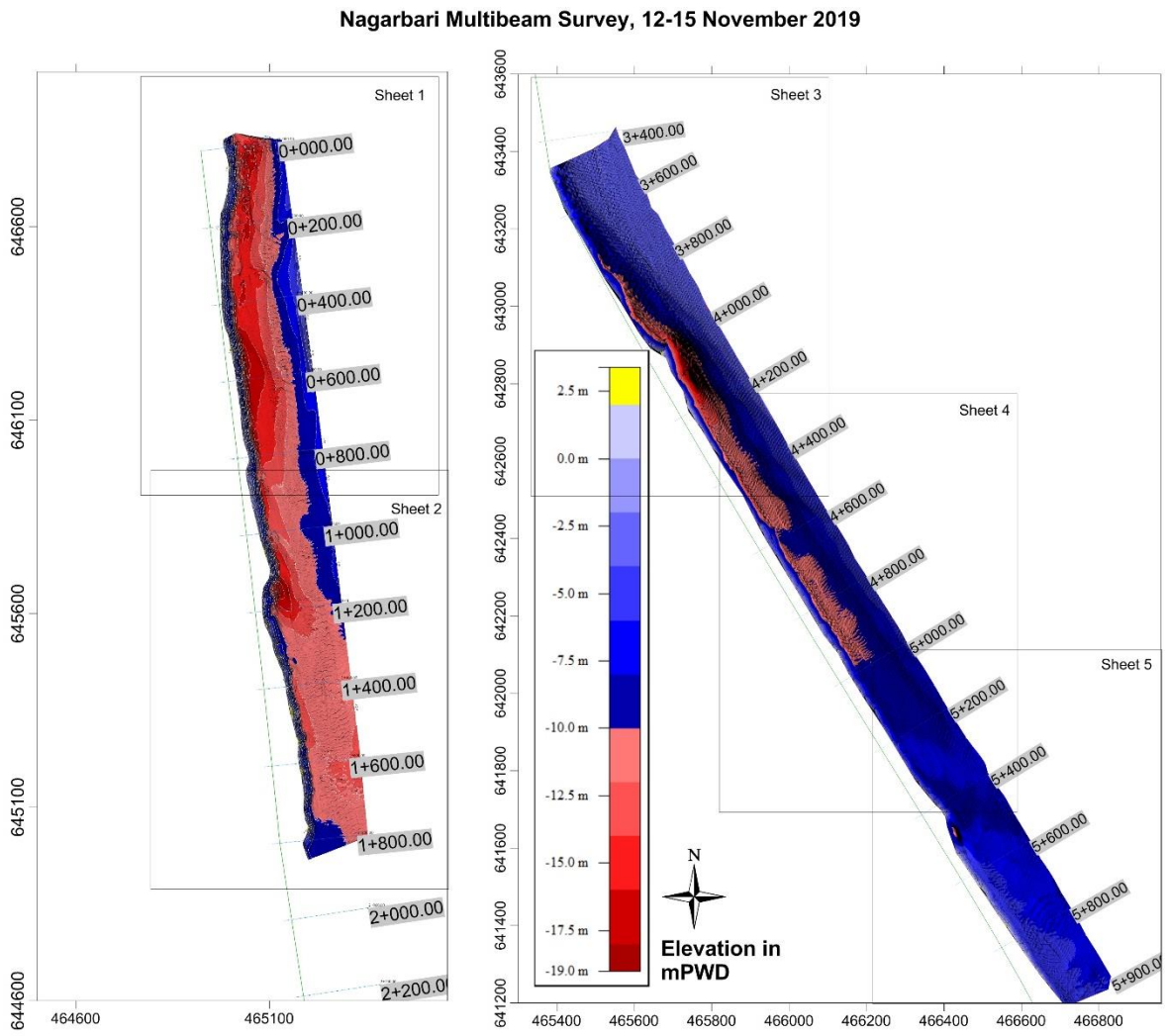
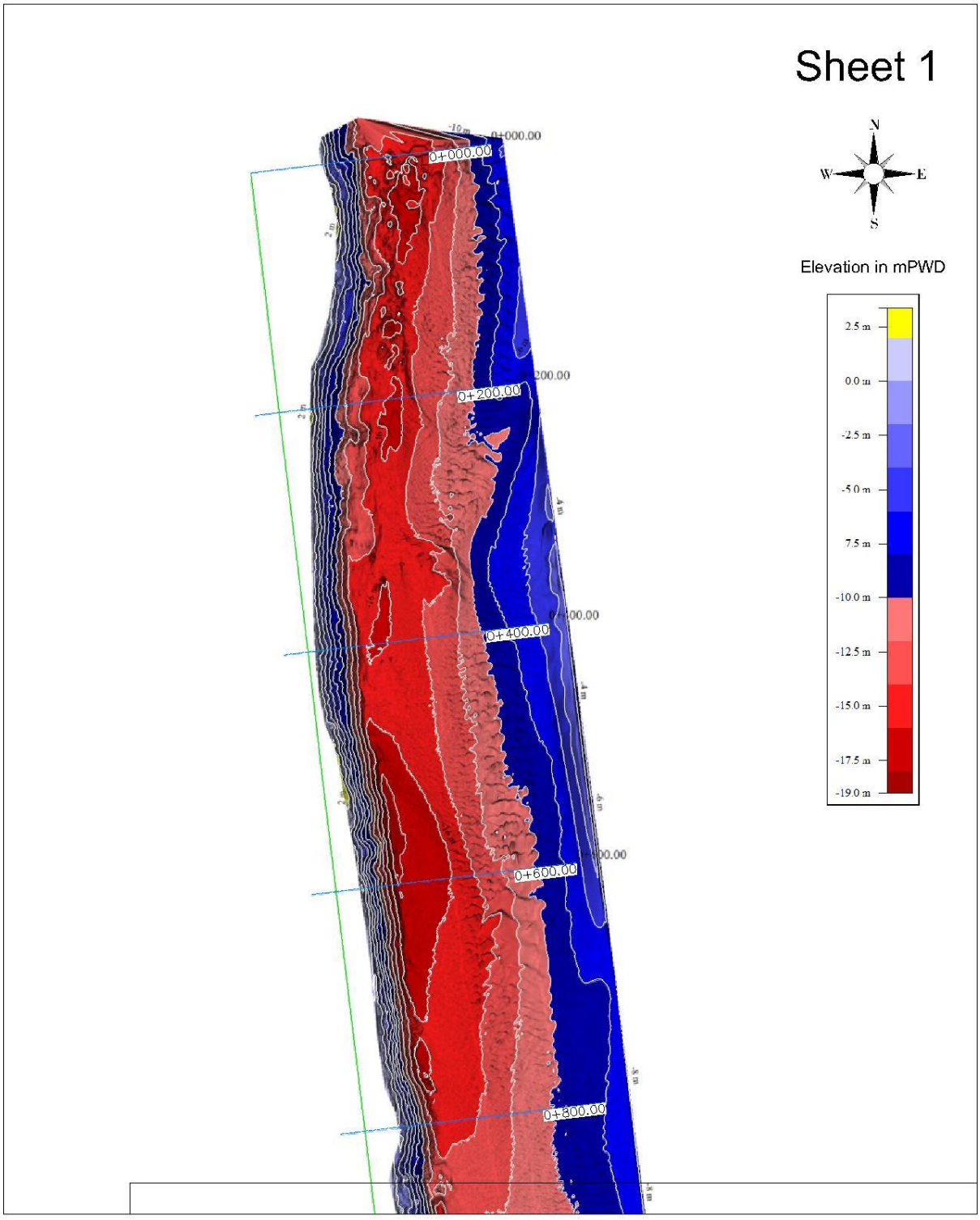
8.7 Nagarbari





At this location roughly 1V:2H launched geobag slope observed. No underwater erosion observed. Two 3D view shown below shows the launched slope.

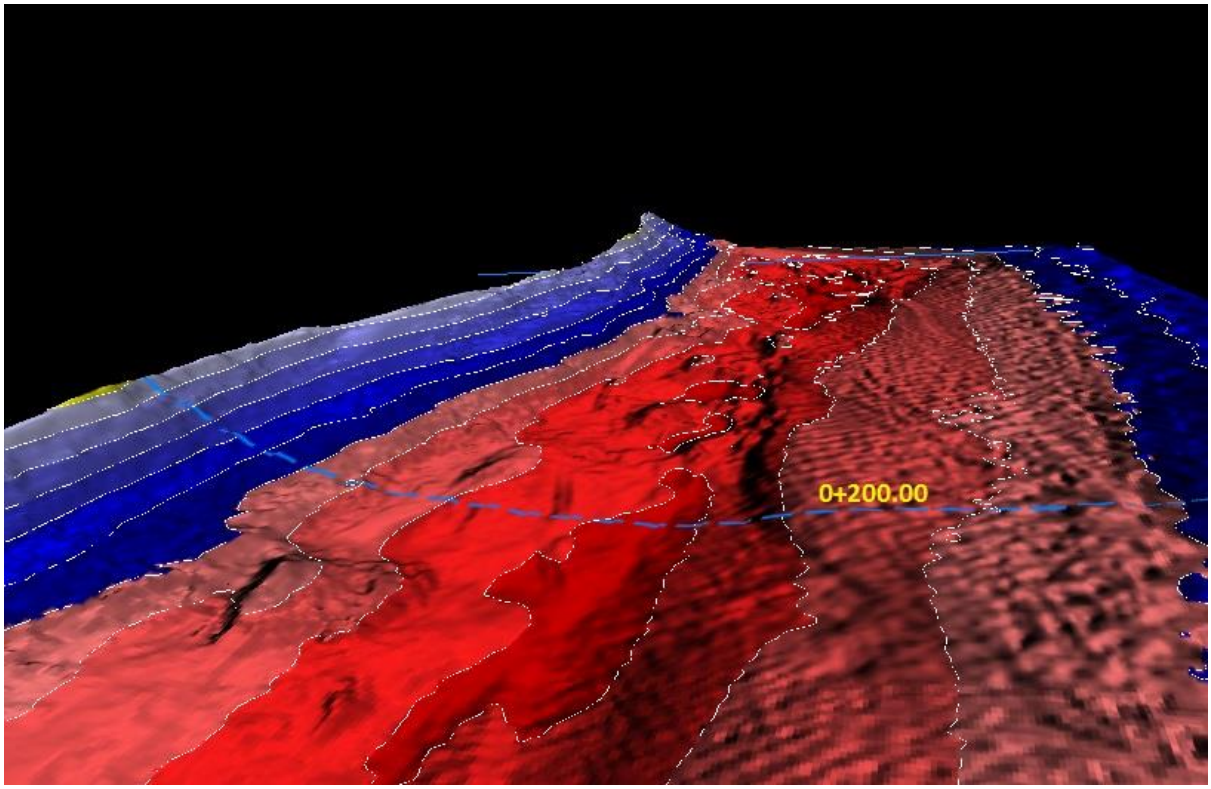


Figure 8-55 3D view of underwater launched geobag slope

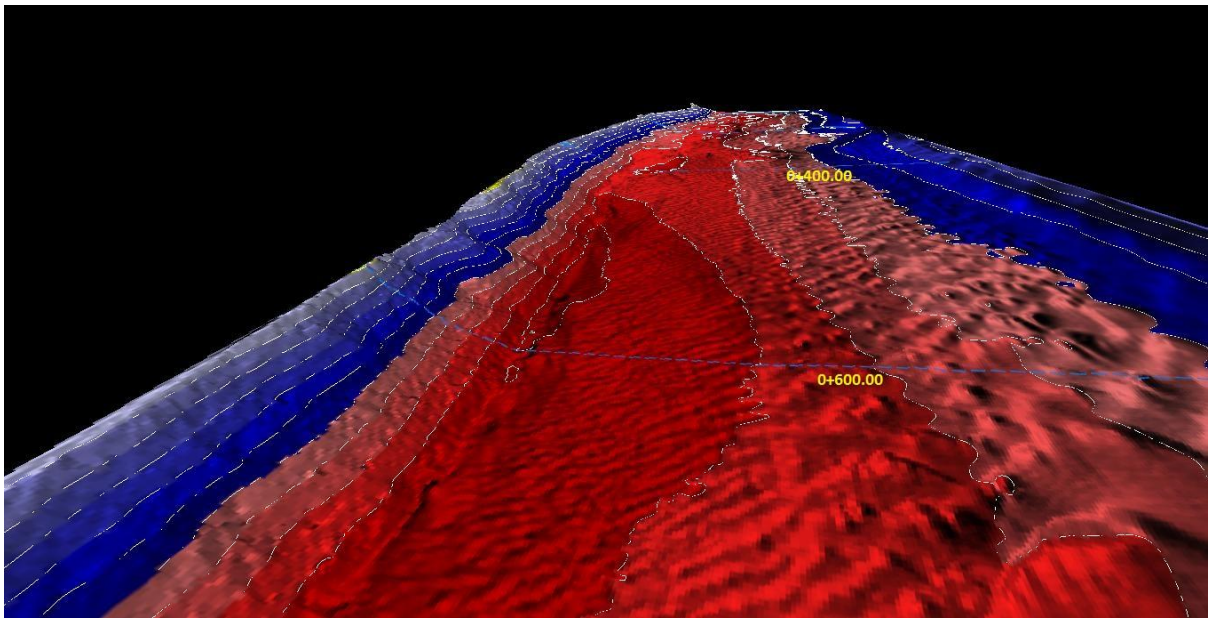
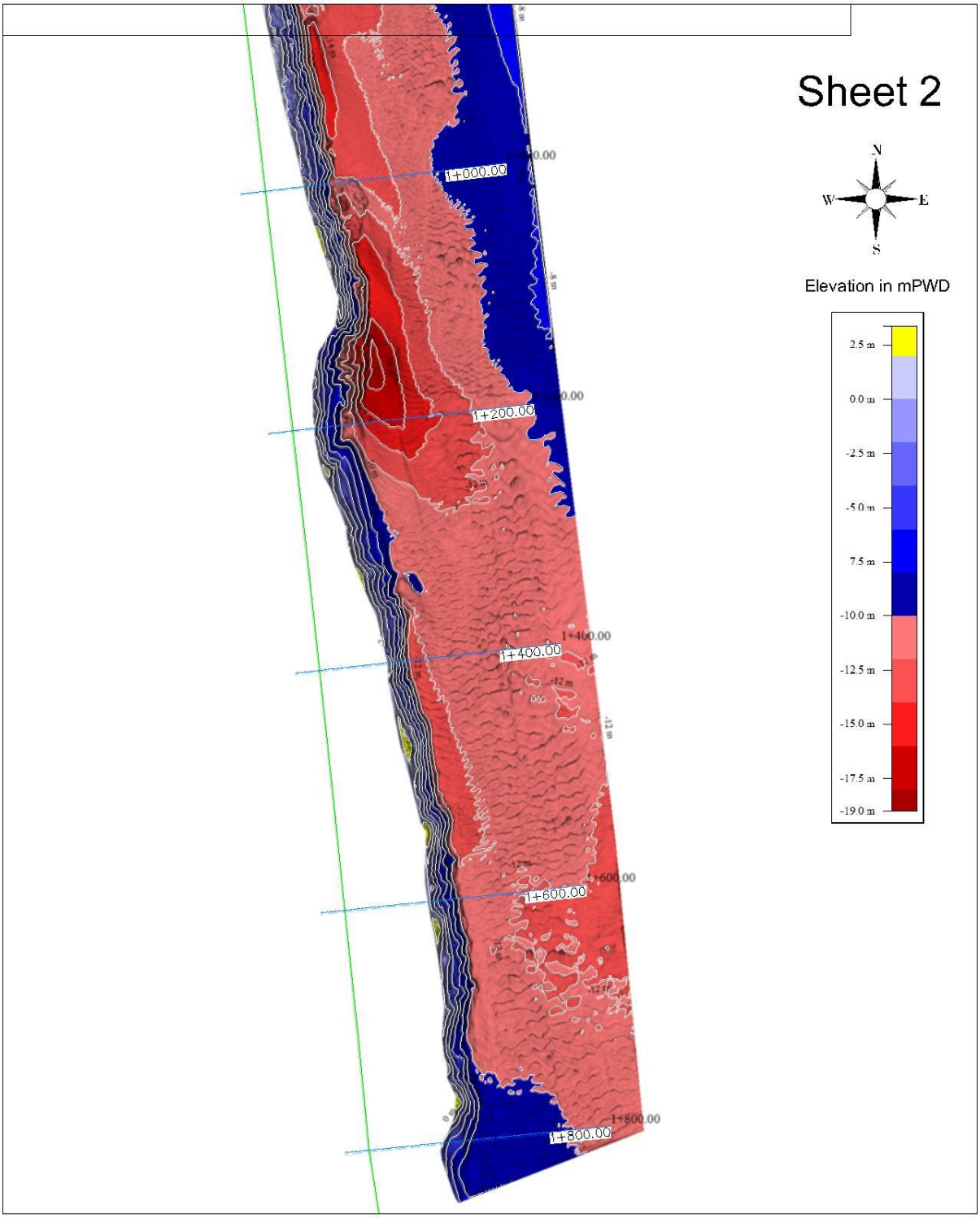


Figure 8-56 3D view of underwater launched geobag slope



At km 1+200, an inner bend formed. One slip circle observed there. Rest of the location has a 1V:2H launched slope.

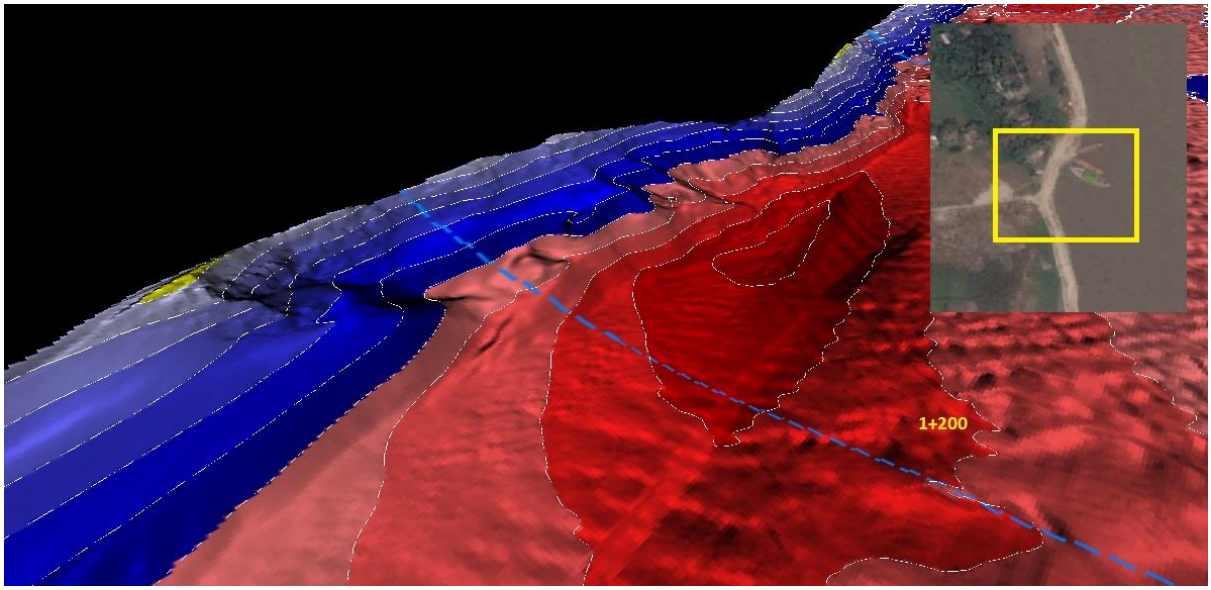
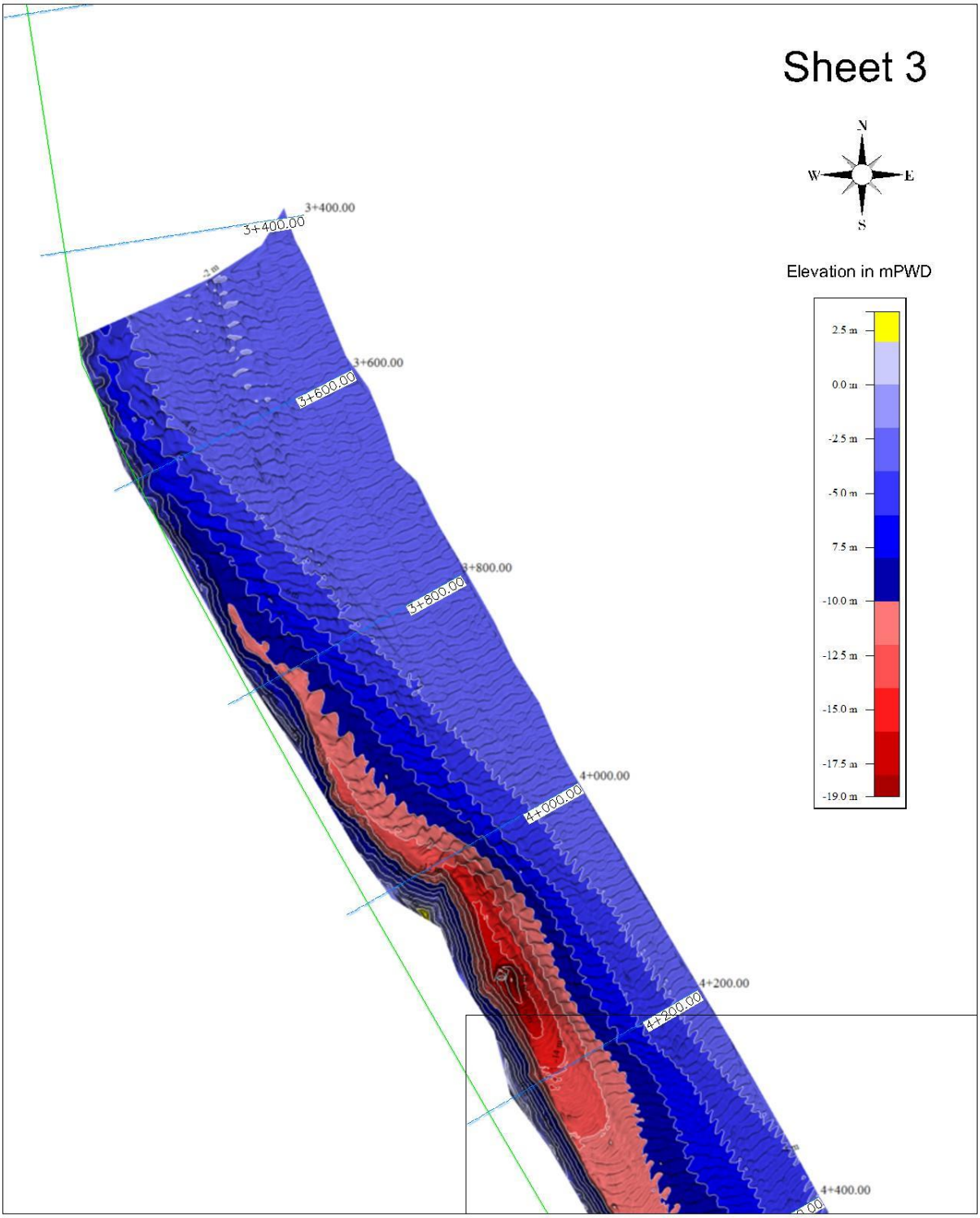


Figure 8-57 3D view of underwater launched geobag slope at bend area



Most of the location from km 3+400 to 4+000 is sedimented. Sand dunes can be seen. From km 4+000 to 4+400, 1V:2H launched slope observed. No underwater erosion observed here.

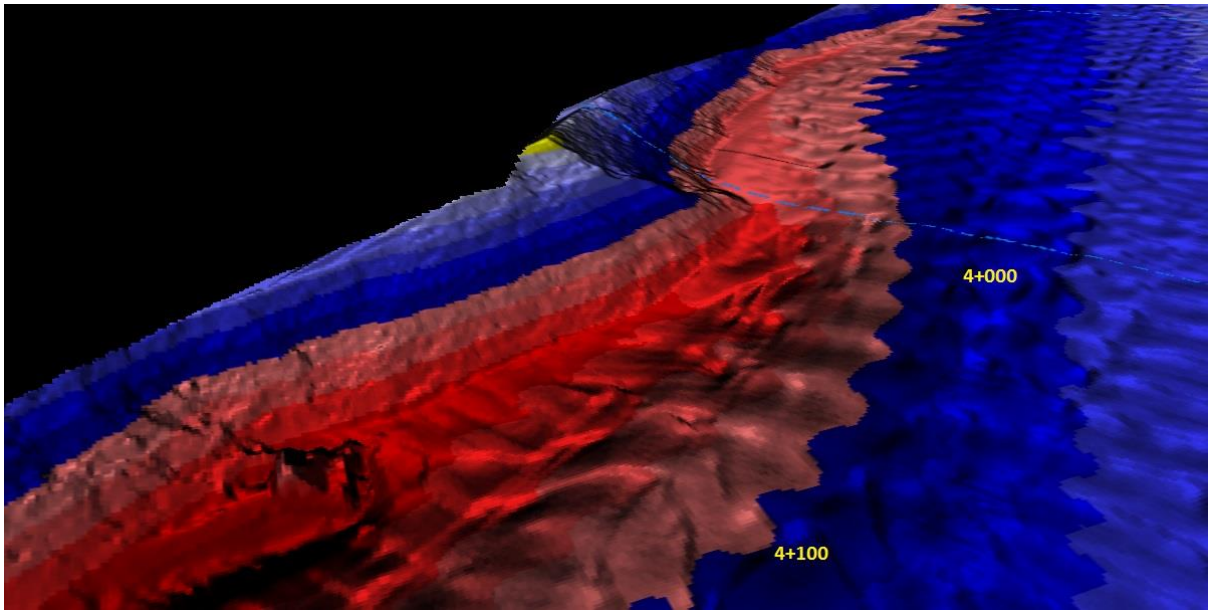


Figure 8-58 Underwater launched slope at km 4+100

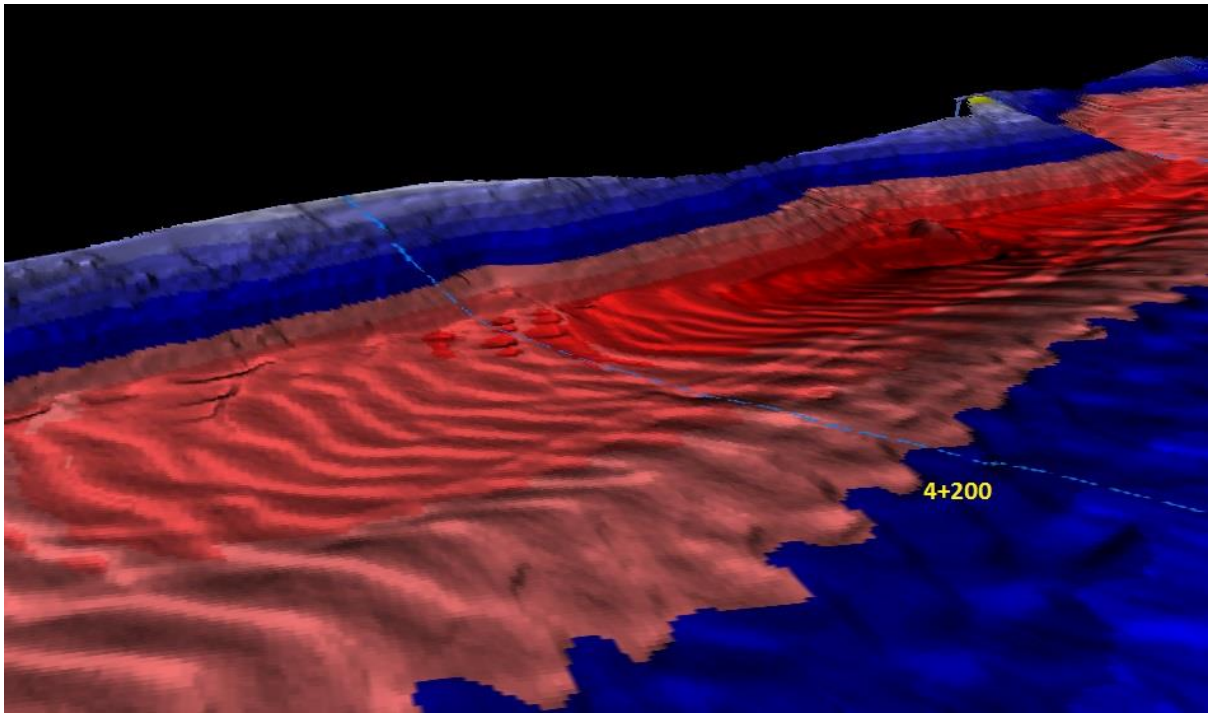
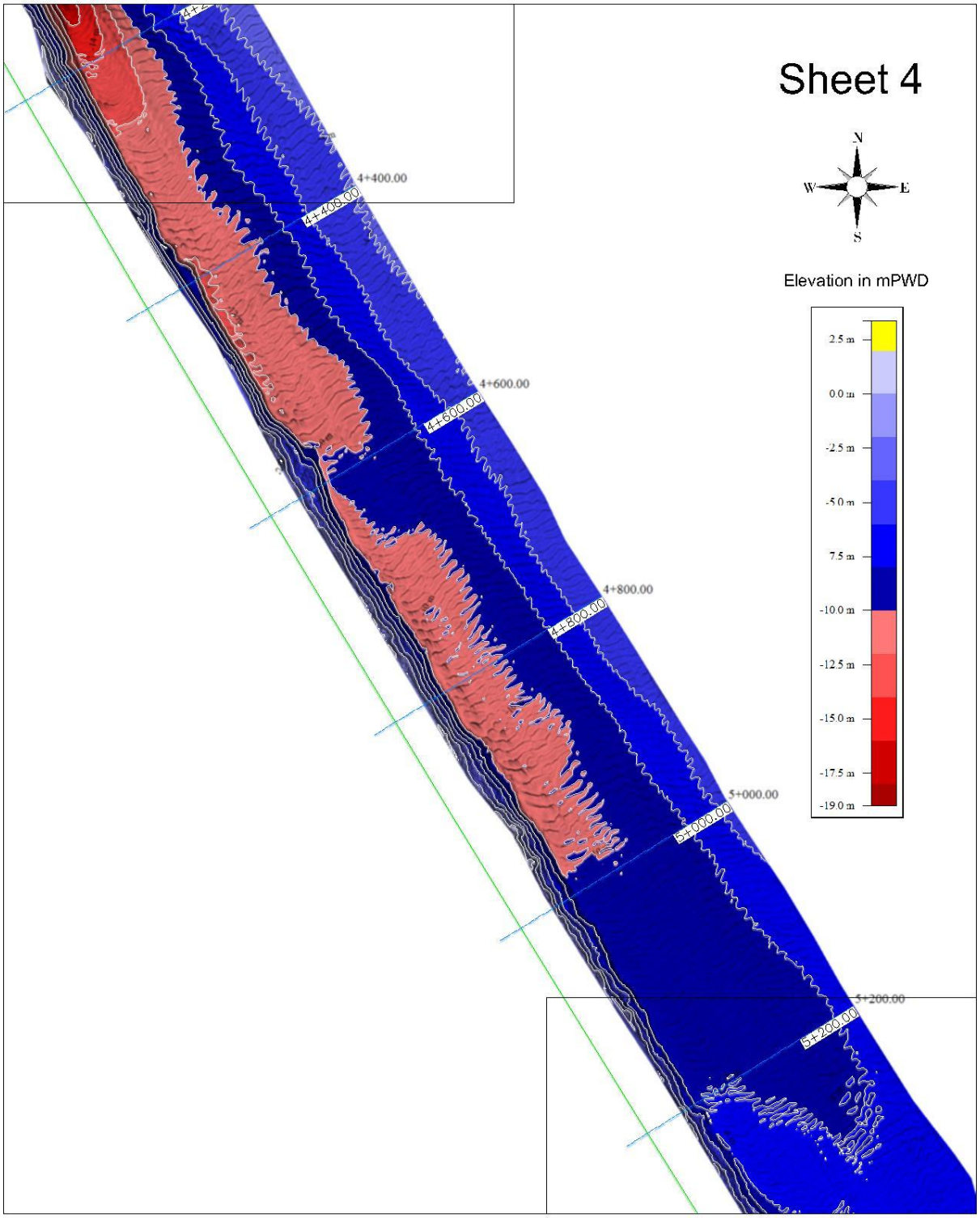


Figure 8-59 Underwater launched slope at km 4+200



At this location no underwater erosion observed. 1V:2H launched slope observed.

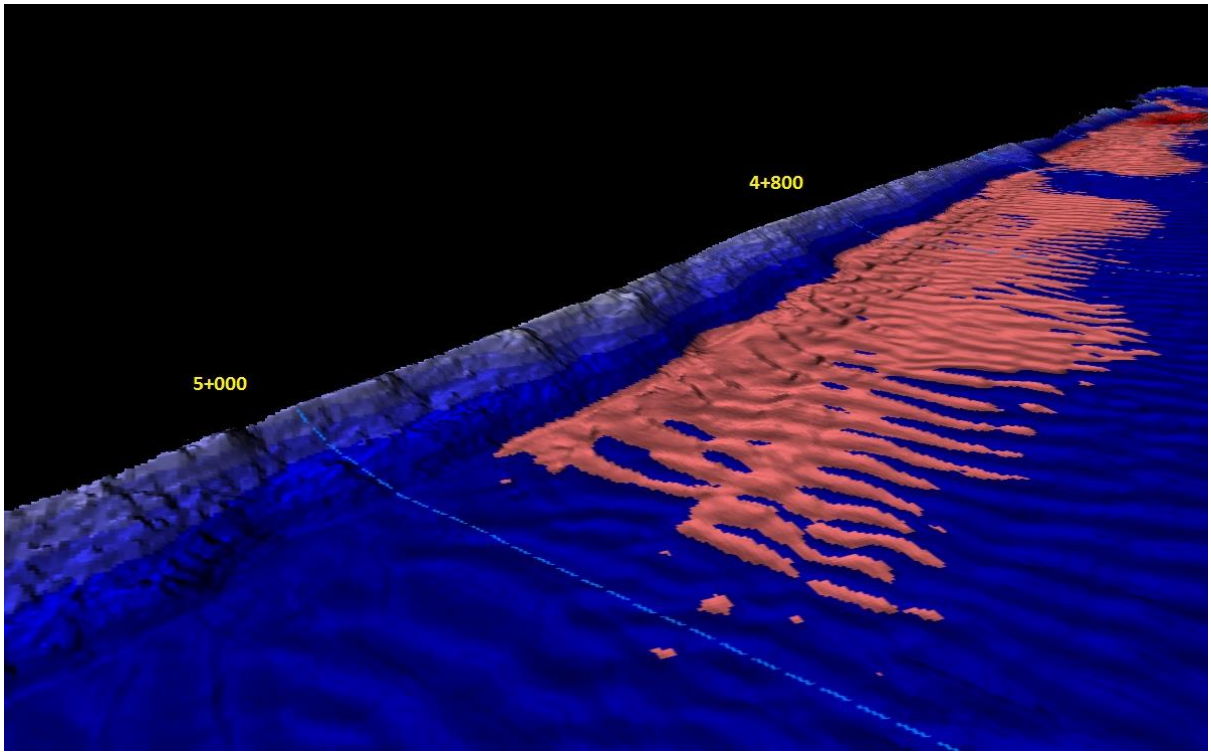
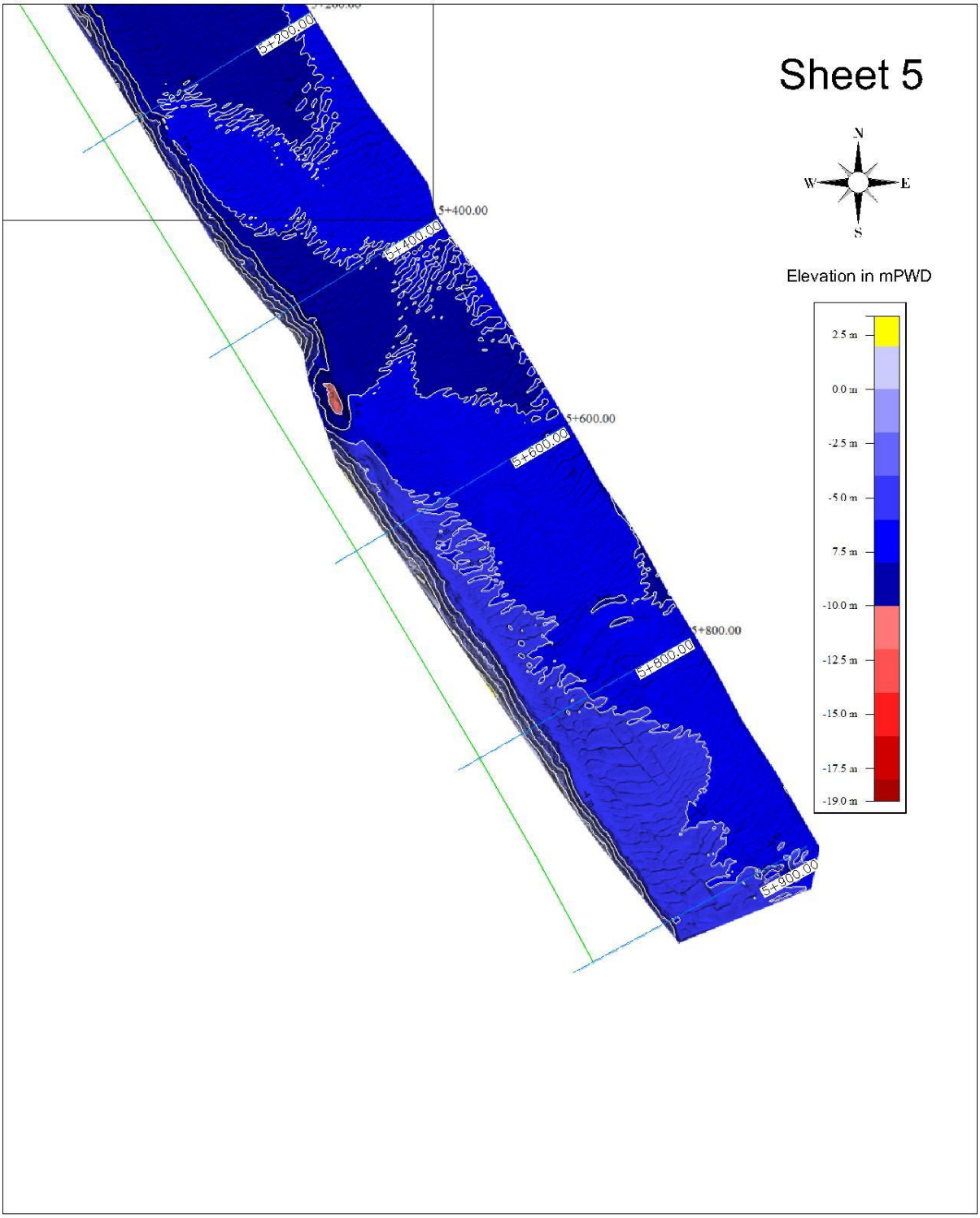


Figure 8-60 Underwater launched slope at km 5+000 to upstream



Overall launched slope obsereved at this location.

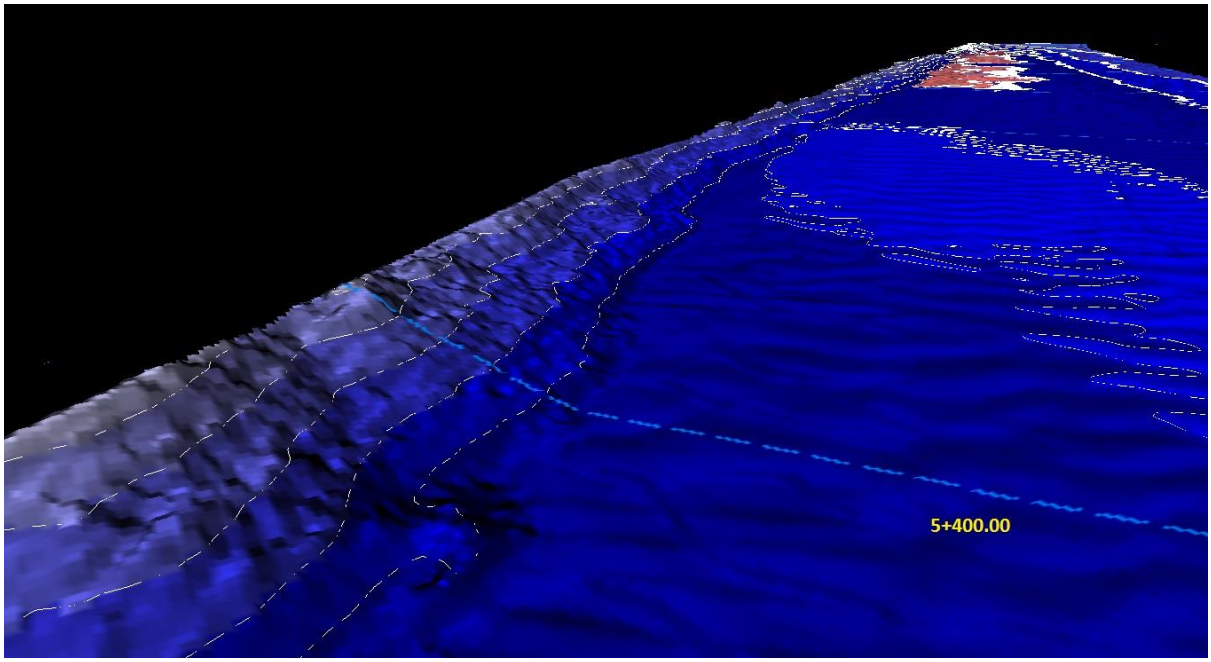
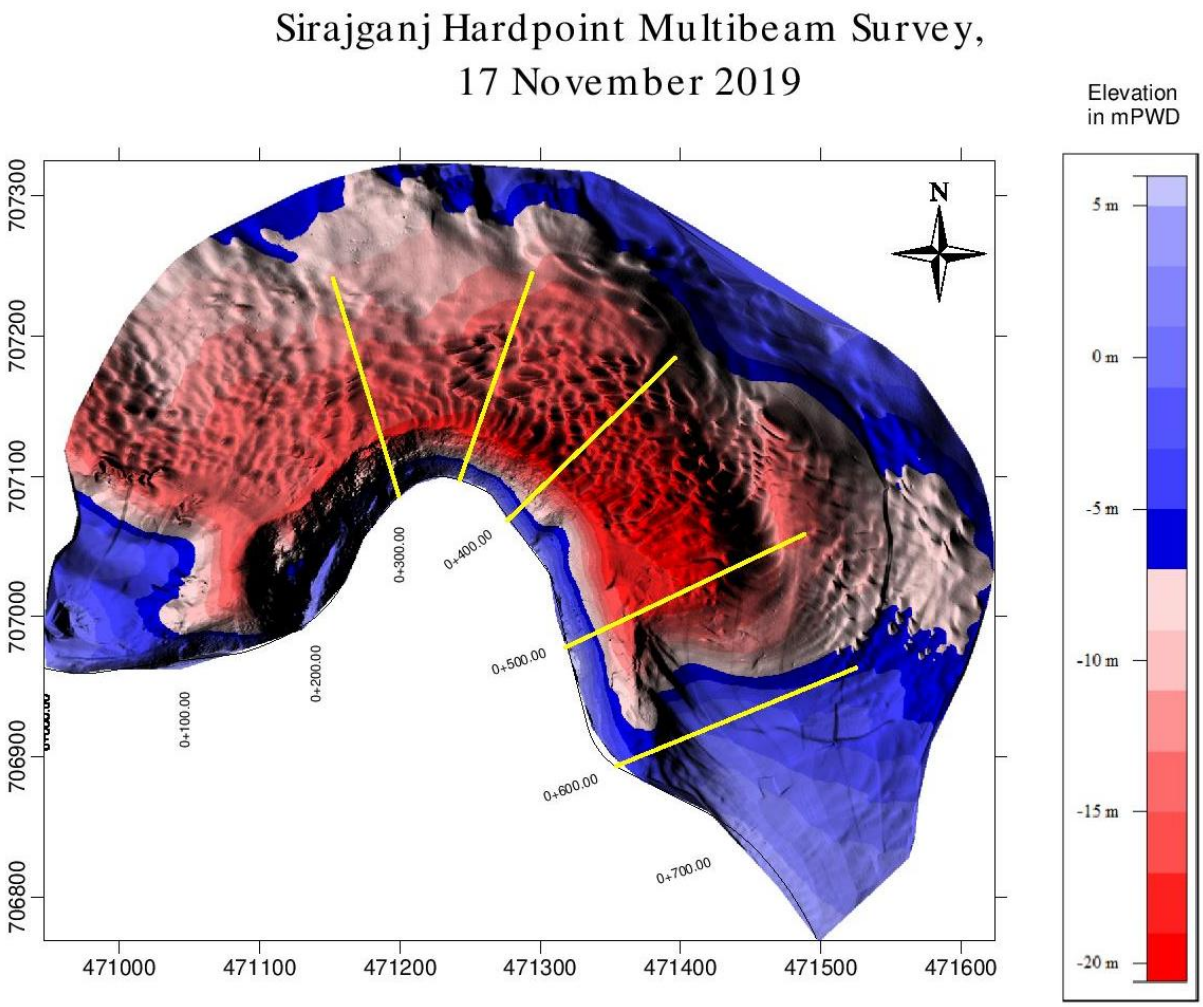


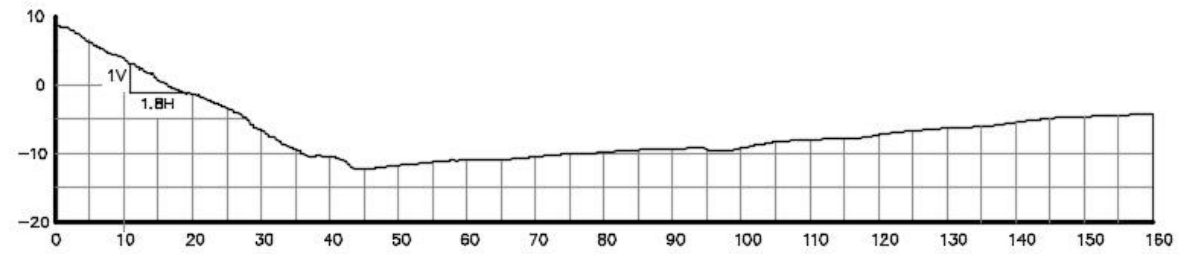
Figure 8-61 3D view of underwater slope protection

8.8 Sirajganj Hardpoint

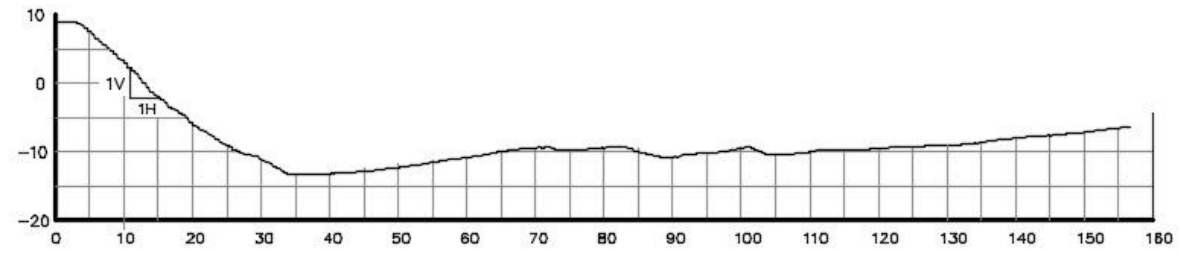


At Hardpoint site, there are variations in slopes in different places. Five representative cross-sections are shown below to show the different cross-section and different slope angle.

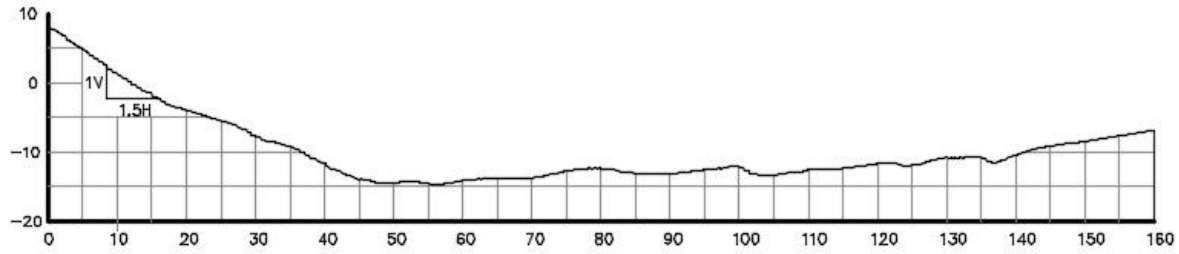
0+300.00



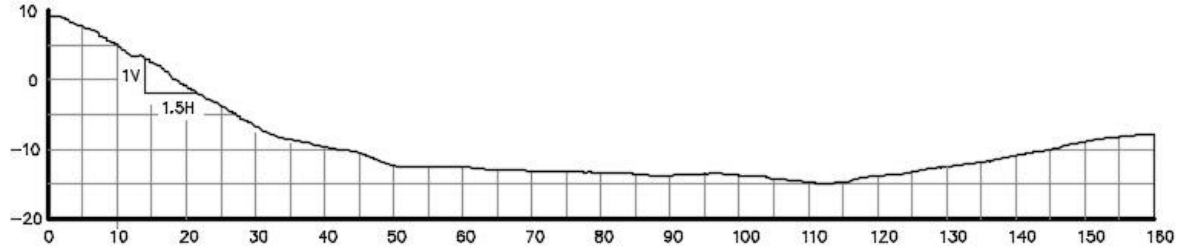
0+350.00



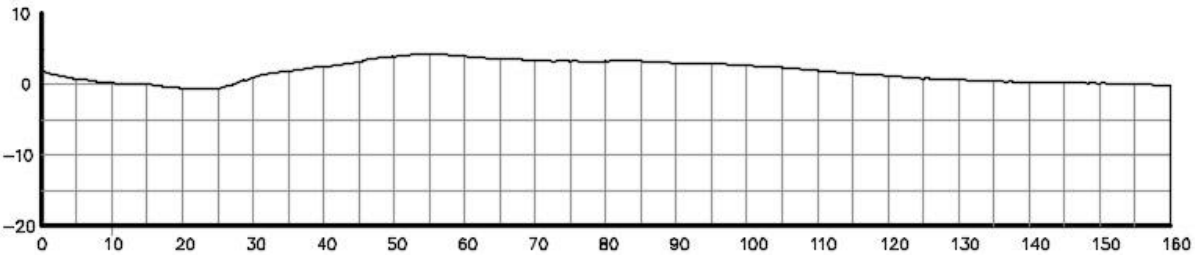
0+400.00



0+500.00



0+600.00



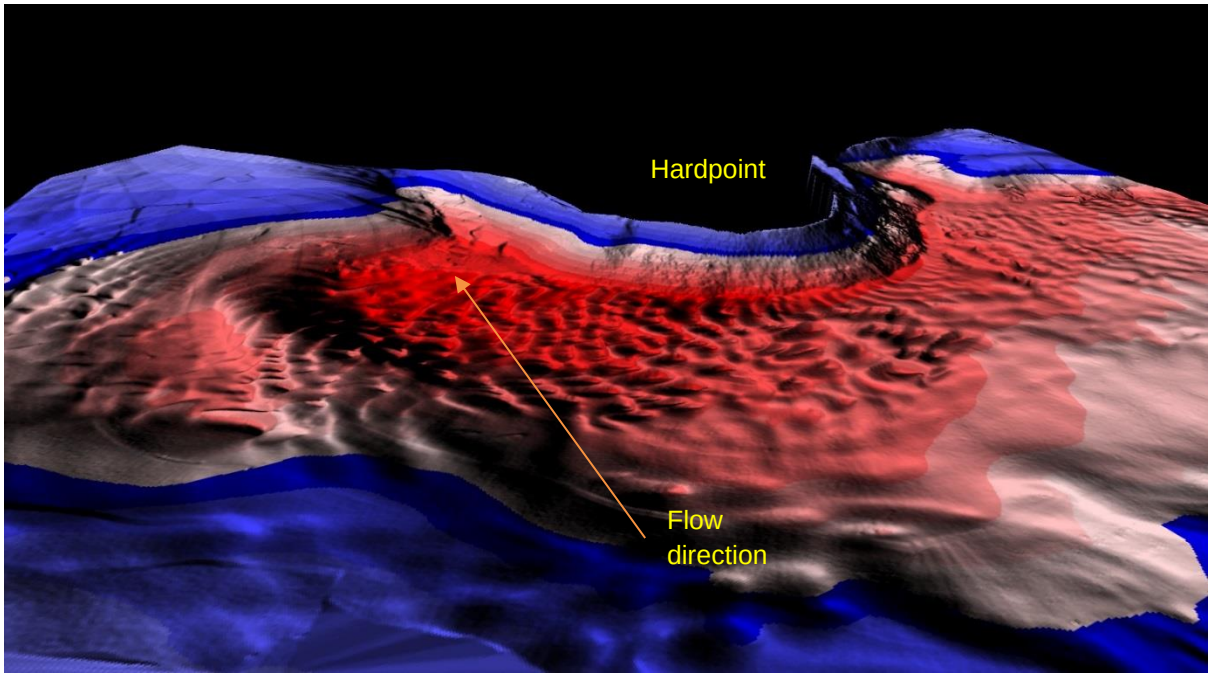
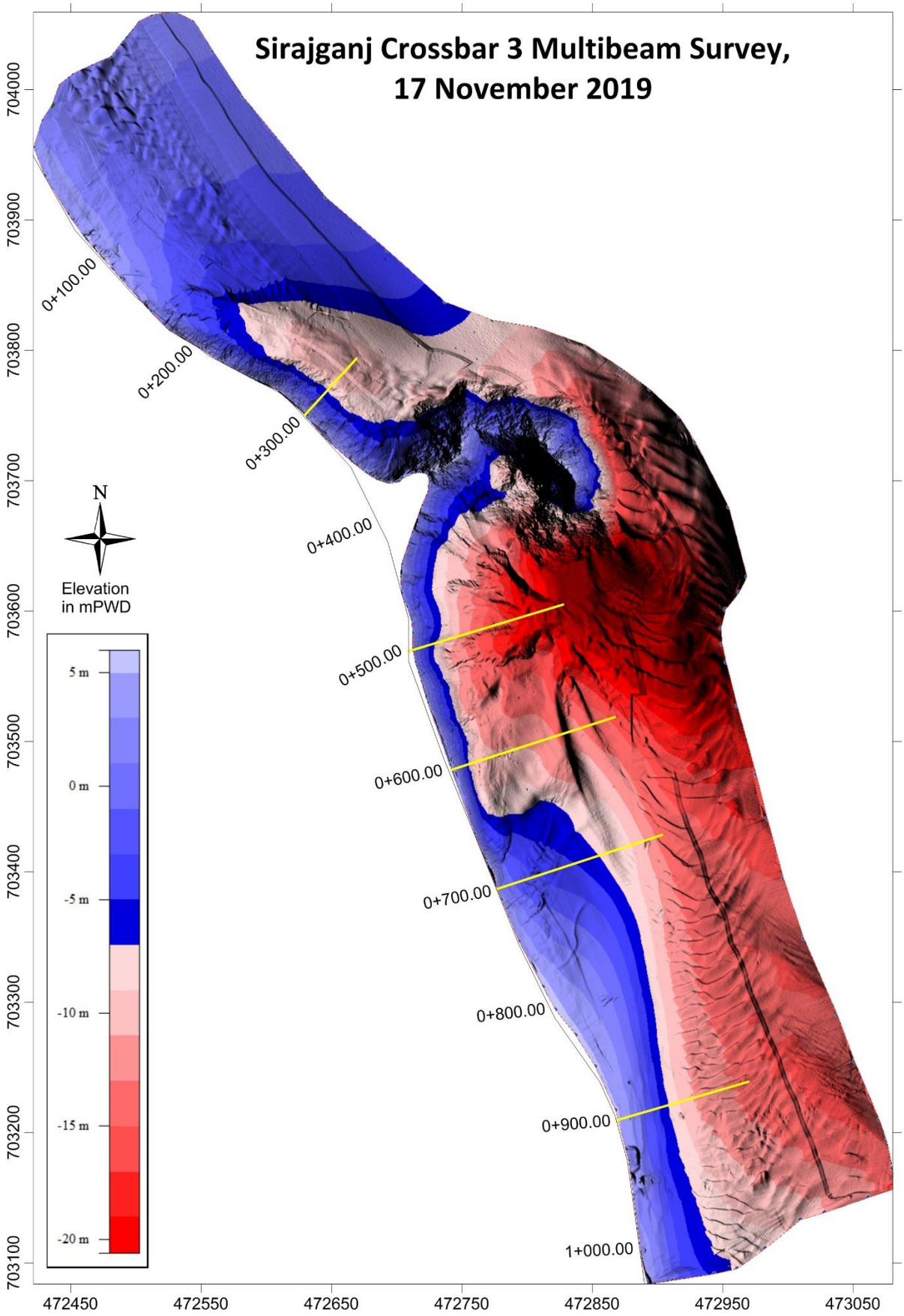


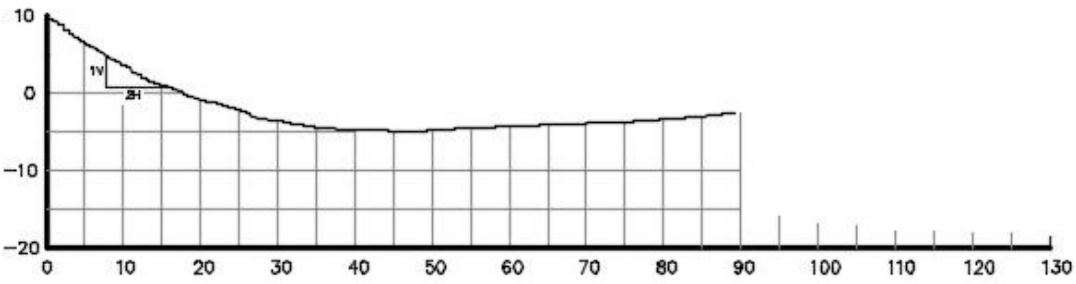
Figure 8-62 3D view of underwater hardpoint location

8.9 Sirajganj Crossbar

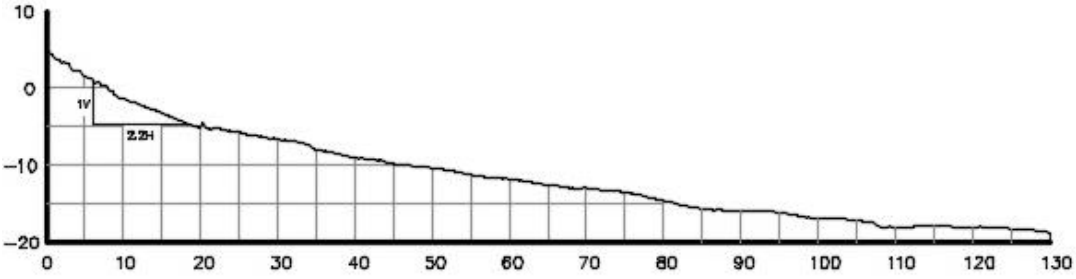


At Sirajganj cross bar 3 site upstream part is silted. At stn 0.4km there a heap of boulders that act like a spur and due to that downstream stn 0.5km was affected. Stn 0.6km shows launched stone covered slope. From stn 0.7km to downstream there sedimentation observed. Below some cross section was provided. The yellow line in the plan view represents the cross section line.

0+300.00



0+500.00



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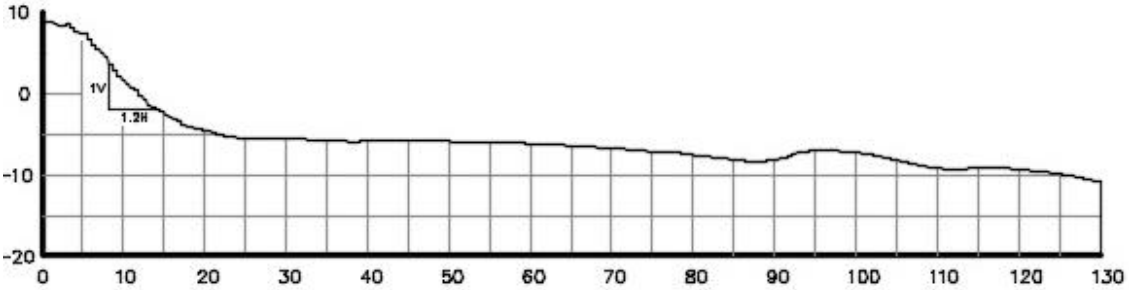

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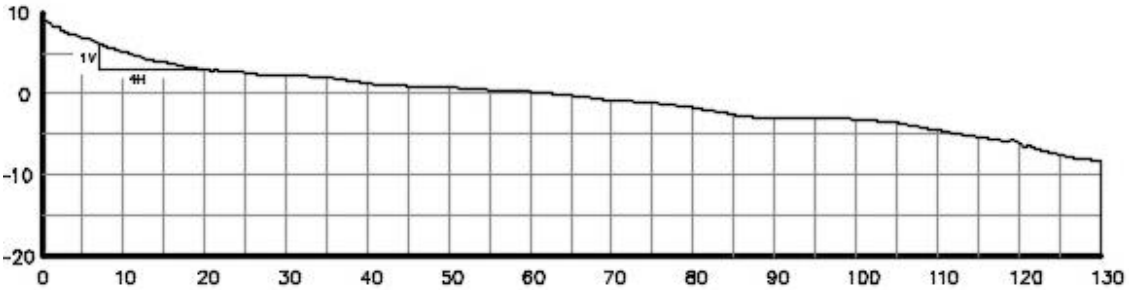


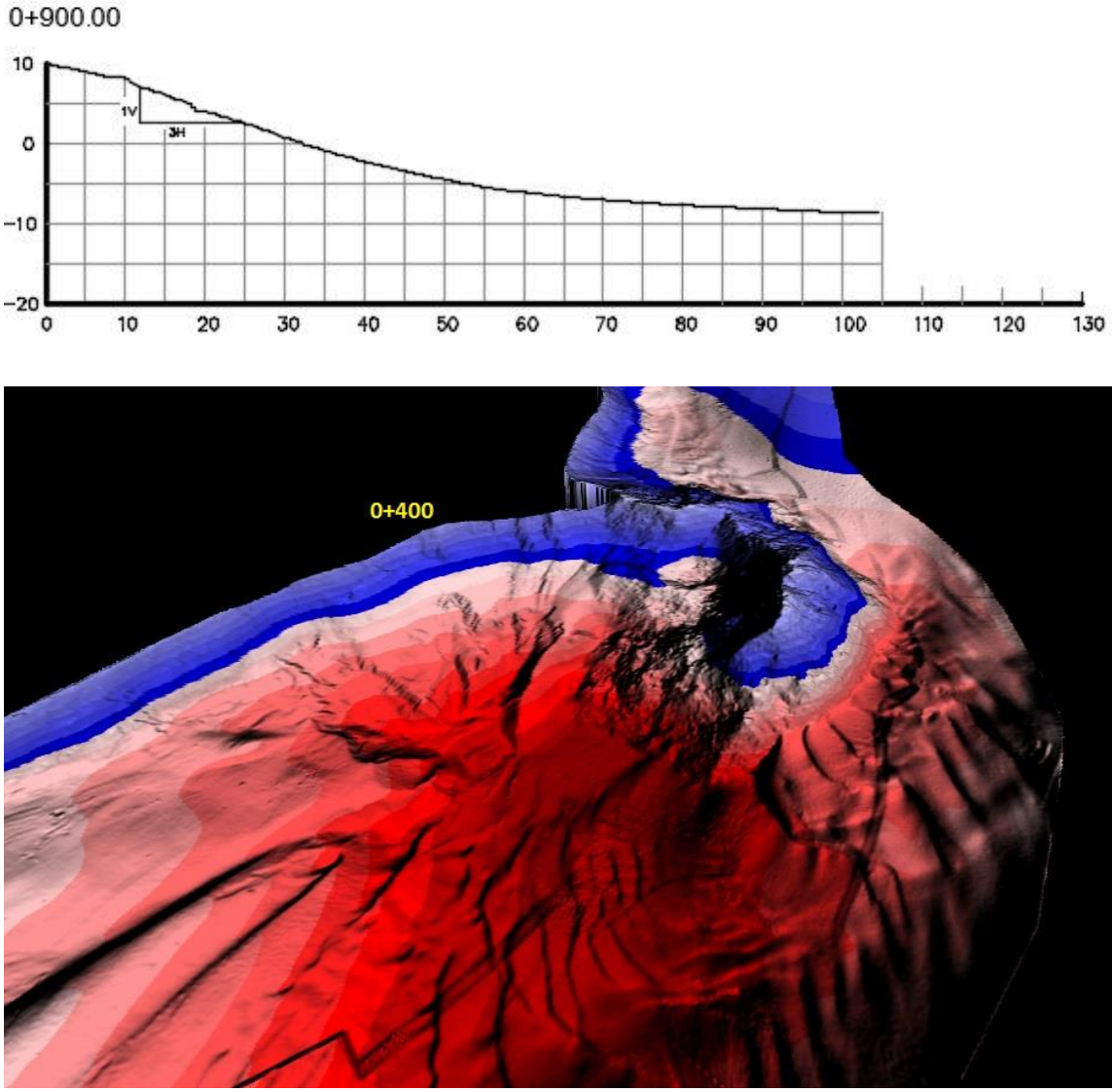
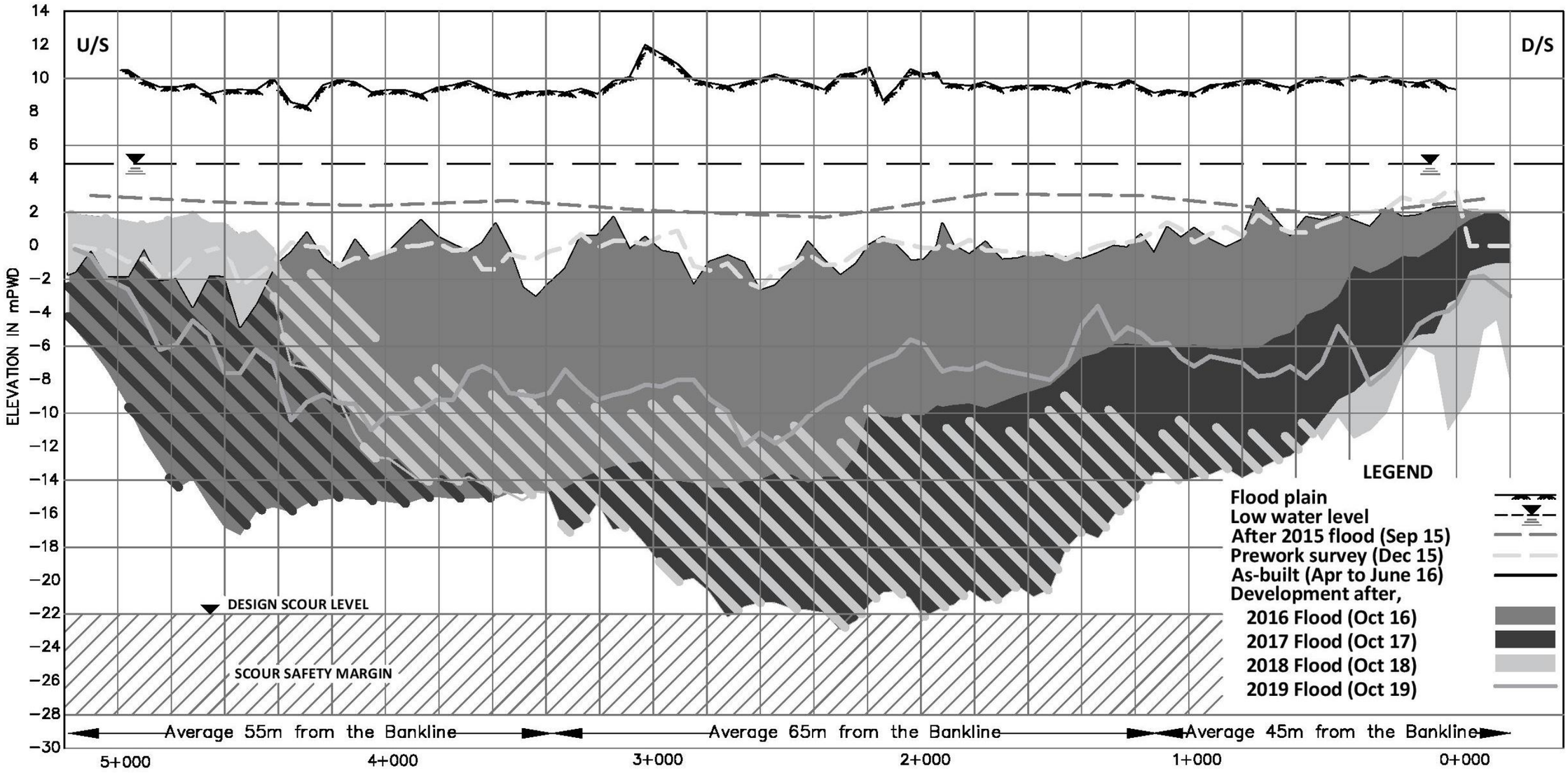


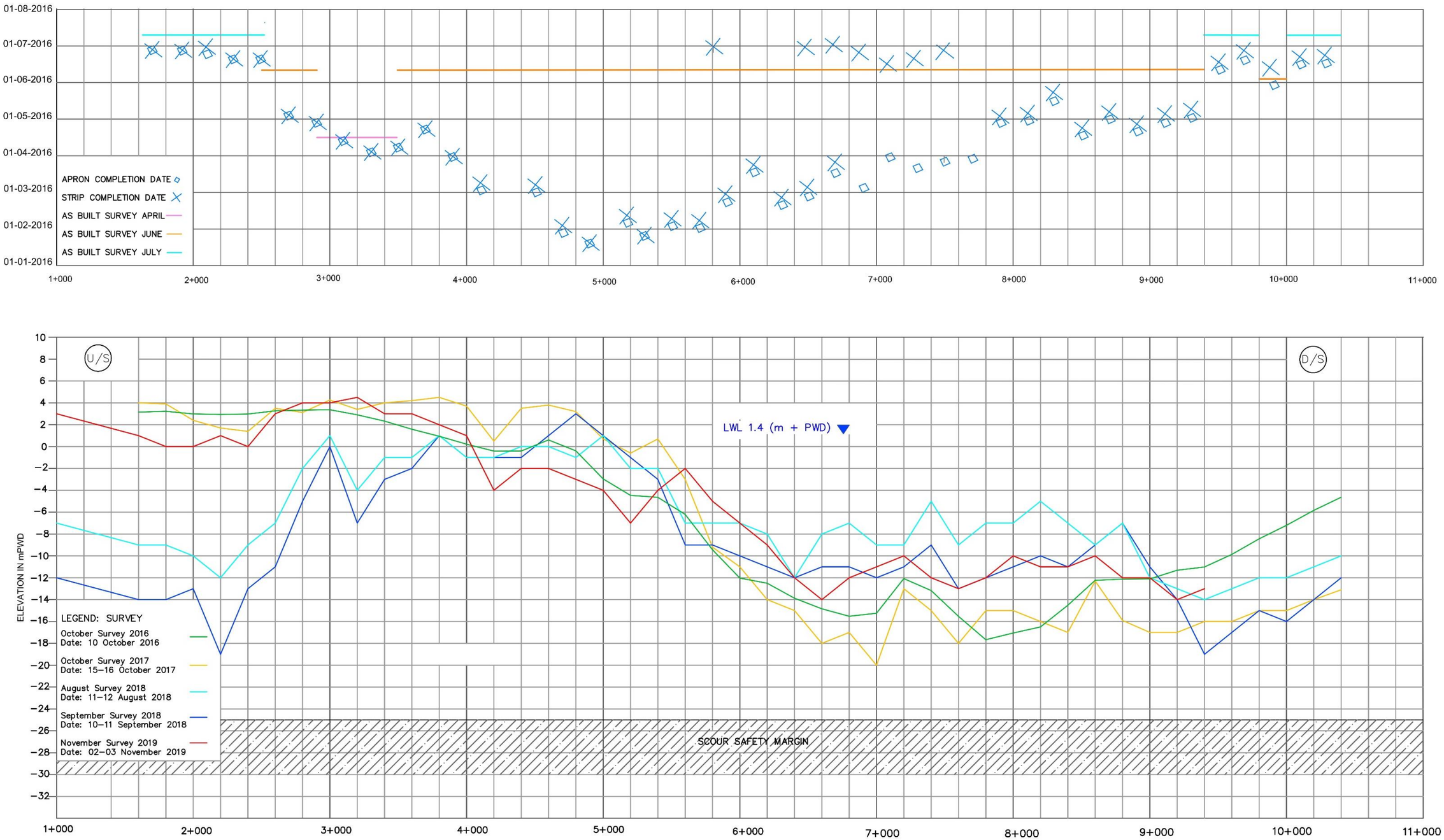
Figure 8-63 Underwater scour due to heap of boulders at km 0+400

9 Longitudinal Section – Launching of Apron

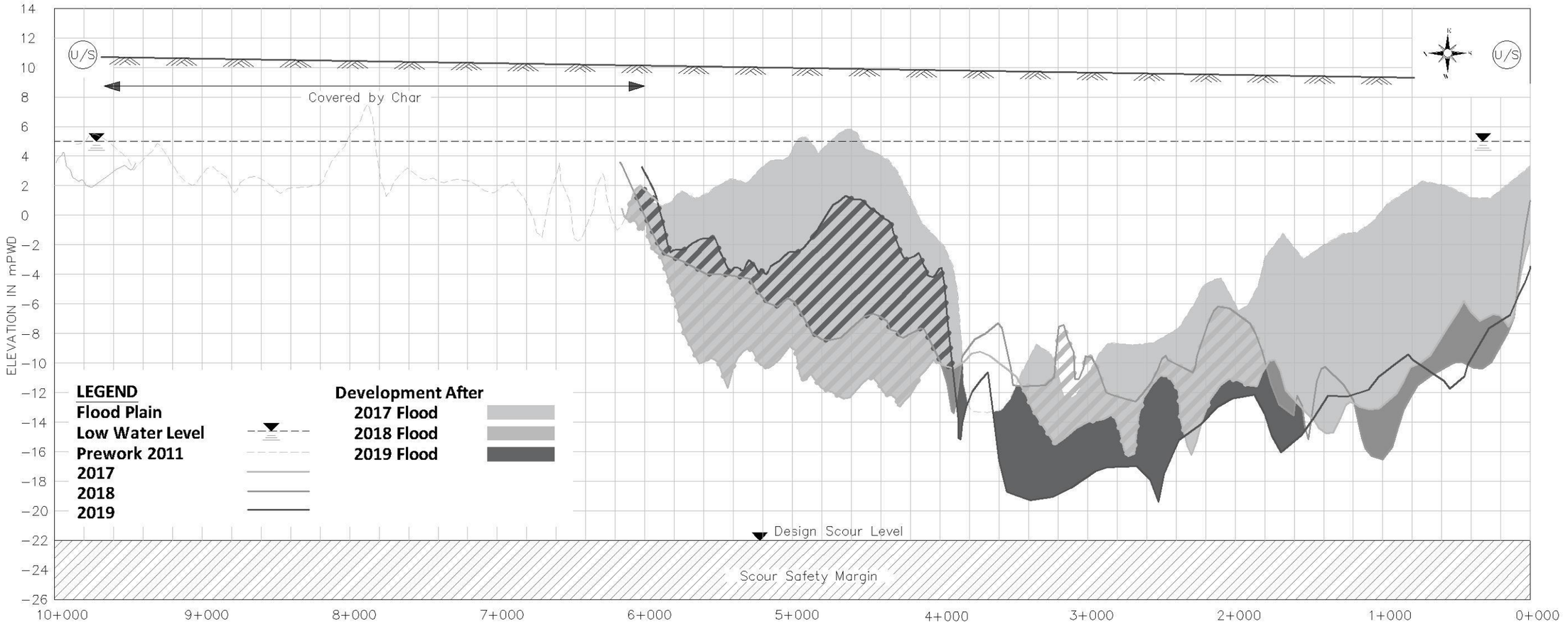
9.1 Longitudinal Section of Chauhali



9.2 Longitudinal Section of Harirampur



9.3 Longitudinal Section of Koijuri



9.4 Longitudinal Section of PIRDP