Skoenmakers River Maintenance

River rehabilitation

DRAFT REPORT Rev 1

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1 INTRODUCTION

ASP Technology (Pty) Ltd was appointed by BVi Consulting Engineers Eastern Cape (Pty) Ltd on 7 May 2014 to evaluate the river hydraulics and fluvial morphology of the Skoenmakers River. This river is used by the Department of Water and Sanitation to transfer up to 25 m^3/s from the Orange-Great Fish River system to the Sundays River. Low level causeways were constructed on farms along the Skoenmakers River, but due to the increased base flows, especially during floods these bridges have experienced problems such as blockage by debris, frequent spillage over the causeways and bypassing of the causeways as approach roads are washed away. In addition, the increased base flow in the river has caused river bed and bank erosion.

The objectives of the study were to evaluate the river hydraulics and rehabilitate the causeways where necessary, but also to evaluate the fluvial morphology and river planform stability in general due to the increased base flow in the river.

This report discusses the river bank erosion, identifies critical zones, and proposes mitigation measures in the form of riprap (dumped rock) to prevent further bank erosion.

2 METHODOLOGY

The LiDAR survey of the river was used with the hydrology to set up a hydrodynamic model of the river with its tributaries. The hydrodynamics and sediment dynamics were investigated with the model. Zones of river bank erosion as simulated and as identified from the aerial photographs from the survey, were used to prioritize and design riprap erosion protection.

3 FLOOD HYDROLOGY

The annual recurrence interval flood peaks for the 10 and 10 year floods, including a maximum base flow (transferred water) of 25 m^3/s, were determined by BVi as shown in Table 3.1. There is no long term flow record for the river which could be used to simulate the hydrodynamics of the river. It was decided that for river bank stability at least a main channel bankfull flood should be used in modelling the fluvial morphology. Both the 2 year and 10 year floods were evaluated. The 2 and 10 year Annual Recurrence Interval (ARI) flood peaks were therefore used along the river as indicated in Table 3.1 in the hydrodynamic modelling to identify critical erosion zones. For the actual design of stable rock in the riprap bank protection, the 100 year flood peaks were used as indicated below. This design approach was adopted due to the high cost of riprap and therefore the rocks should not be washed away in frequent flood events.

The 2 and 10 year ARI floods were used in prioritization of the erosion protection zones.

Table 3.1 Annual recurrence interval flood peaks including 25 m^3/s base flow at the causeways/bridges (BVi)

Bridge/causeway No.	2 year flood peak flow (m^3/s) including 25 m^3/s base flow	10 year flood peak flow (m^3/s) including 25 m^3/s base flow	100 year flood peak flow (m^3/s) including 25 m^3/s base flow
1*	39	72	143
2	2	77	158
3	5	94	198
4	10	126	279
5	8	143	324
6	1	144	327
7	2	147	331
8	5	162	369
9	13	201	468
10	3	206	476
11	27	300	715
12	4	316	759

Note: * Bridge 1 is upstream

4 HYDRODYNAMIC MODELLING

4.1 MODELLING METHODOLOGY

The two dimensional hydrodynamic model Mike 21C of the DHI Group, Denmark, was used to simulate the 2, 10 and 100 year ARI floods in the Skoenmakers River. The model uses a curvilinear mesh specifically developed for alluvial river hydrodynamics with typical outputs: water depths and velocities. These outputs are necessary for the riprap size design. The sediment transport module in the model simulates the erosion and deposition of the different fractions of sediment, coupled with the hydrodynamics in each time step. Secondary flow patterns and scour at river bends are also simulated. The typical output is bed level change and elevations, required to evaluate zones needing bank erosion protection.

To successfully describe the study area in the model the following tasks were completed: bathymetry setup and boundary creation. These are discussed further.

4.2 MODEL SETUP

The study area has a downstream boundary at Darlington Reservoir, with upstream boundary located at the outlet of Skoenmakers canal. Eight main tributaries were identified in between the twelve bridges to be rehabilitated. Having drawn the general outline of the river, a suitable grid mesh for the model area was set up using the MIKE 21C grid generator and later surveyed elevations were imported into the orthogonalised curvilinear grid. A mesh size of about 2 x 6 m (width x length), was found to accurately simulate the main channel and floodplain flow. All vegetation and buildings were removed from the survey and elevations imported. At the bridges, the new proposed bridge dimensions were used mimicking a partial blocked scenario. The resulting bathymetry is illustrated in Figure 4.2.

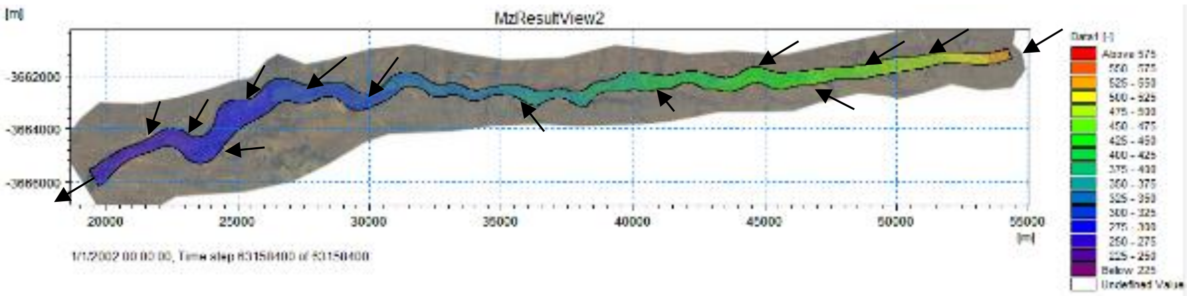


Figure 4.2-1 Model bathymetry

Hydraulic roughness was specified based on vegetation height obtained from the LiDAR survey, and Table 4.1 illustrates the values used. For the main channel the Manning value of 0.035 was used.

Table 4.1 Hydraulic roughness based on vegetation height

Vegetation height	Manning's value n
>3 m	0.070
1-3 m	0.055
0-1 m	0.050

Constant inflows were used for the identified nine inflows (main channel upstream and 8 tributaries), and the values used are shown in Table 4.2. Constant water levels were used for the downstream boundary: 255.7 masl for the 2 year ARI flood, 256.4 masl for the 10 year ARI flood and 258.0 masl for the 100 year flood.

Table 4.2 Model boundary inflows (including 25 m^3/s base flow)

Bridge No	Annual recurrence interval flood peaks (m^3/s)		
	2 year	10 year	100 year
1*	40	72	143
2	2	5	15
3	5	16	41
4	10	32	81
5,6,7	8	22	52
8	5	15	38
9,10	13	44	107
11	27	94	239
12	4	16	44

Note: *Includes base flow due to DWS transfer in main channel

Visually from aerial photographs, bedrock zones were identified along the river and erosion limited to zero. The observed average bed and bank sediment grading is as shown in Figure 4.2-1. Six fraction sizes best described the grading after normalizing; the fractions are represented in Table 4:3.

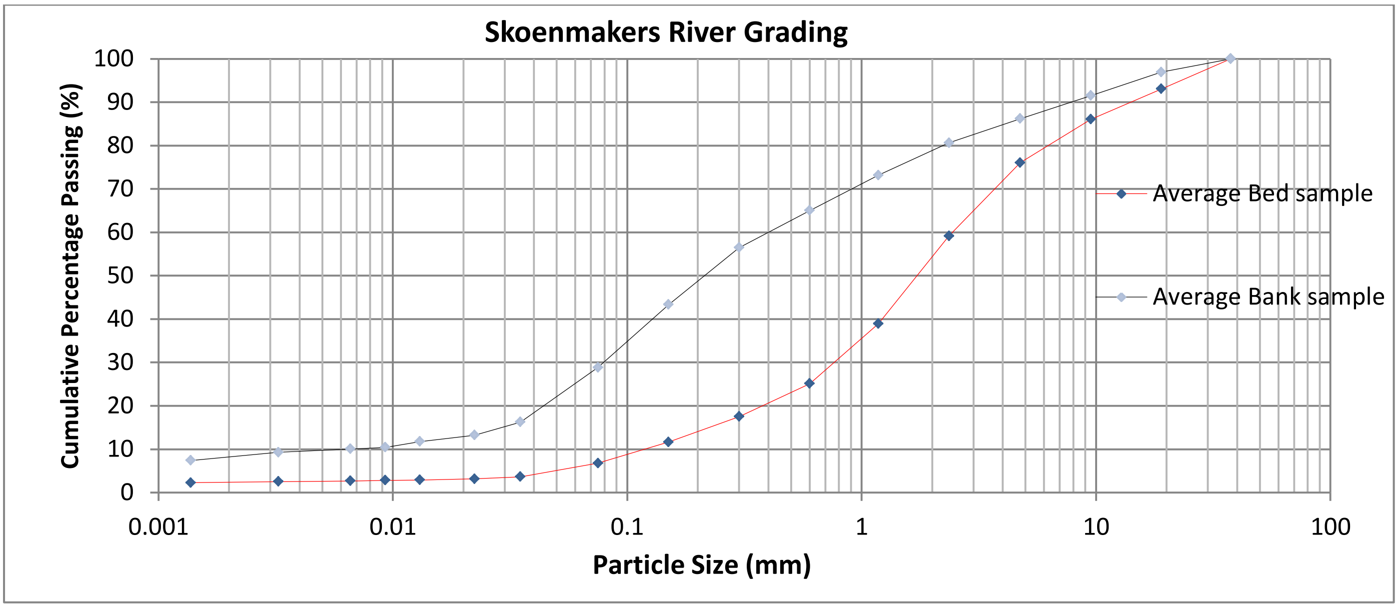


Figure 4.2-1 Skoenmakers river average bed and bank sample grain size distribution

Table 4:3 Grain fraction sizes

Fraction No	1	2	3	4	5	6
Grain size (mm)	0.052	0.370	2.680	14.160	25.000	37.500

The fraction percentages specified spatially in the bed of the model was based on the field work sediment sampling and grading analysis.

4.3 MODEL SIMULATION SCENARIOS

The 2, 10 and 100 year ARI peak flow simulations were carried out. The inflows were kept steady at the flood peak. The simulation duration was 2 years and 1 year for the 2 and 10 year floods respectively, at the peak flow, with general time step of 30 seconds. A scaled dynamic simulation was used and thus the hydrodynamics time step was 0.1 seconds.

Note that the 2 and 10 year flood scour patterns were used to identify the problem erosion zones (not the 100 year flood, because one expects bank erosion in such an extreme resetting flood). The 100 year flood simulation results were however used to design the proposed river bank protection.

The Engelund & Hansen formula was used to calculate the sediment transport with the model calculating the sediment loads at the inflow boundaries based on the sediment transport capacities. The general outputs were: water surface elevation, bed levels, bed level change, water depth and velocities.

It was found in general that not much lateral erosion is experienced for the 2 year flood, because the current river channel has experienced degradation (bed scour) due to the transfer base flow, which increases the discharge capacity at bankfull flow. The 10 year flood is therefore more representative of the bankful flow and should be used to evaluate the lateral migration of the channel. The 2 year flood was however simulated with and without the baseflow, to evaluate the effect of increased local scour due to the transfer flow.

5 EROSION PROTECTION DESIGN

5.1 EROSION ZONE IDENTIFICATION

The following criteria were used to identify areas needing erosion protection:

- Areas crossing the river servitude
- Areas encroaching farmland but within river servitude
- Zones with bank instability as identified from aerial photographs

Making use of the 10 ARI peak flood, 72 critical zones were identified. These sections are shown in Appendix 1 to Appendix 70. The servitude is shown in the Appendix drawings with the identified erosion zones.

5.2 RIPRAP DESIGN

Riprap (dumped rock) is proposed for erosion protection on the Skoenmakers River. Riprap has minimal maintenance compared to other mitigation measures such as Reno mattresses, gabion boxes or concrete blocks.

The riprap size was designed in accordance with SANRAL (2015) guidelines. A sample of the guidelines is as illustrated in Figure 5.2-1. The riprap angle of repose was taken as 40 degrees and the angle of the sides slope of the channel as 1:2.5 (V: H). A steeper slope will increase the riprap diameter, and contractors found 1:2.5 to 1:3 more practical slopes to work with in the past. The 100 year ARI flood was used to design the riprap sizes.

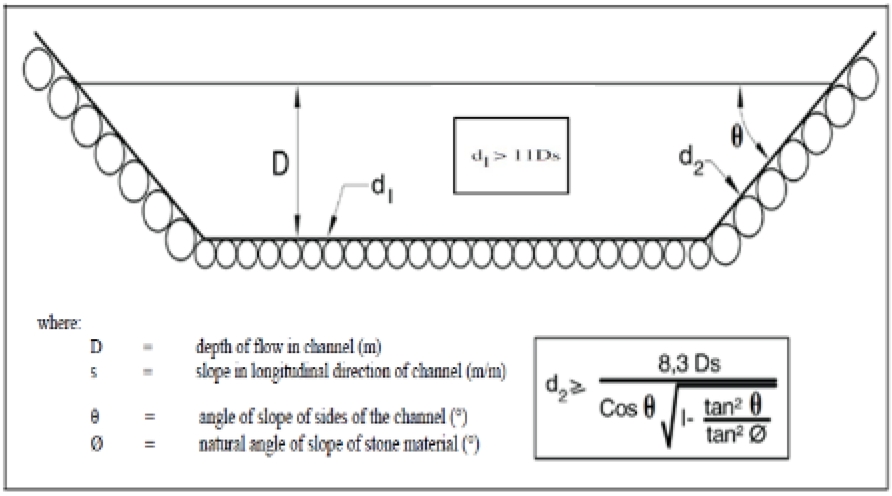


Figure 5.2-1 Required sizes of rock for erosion protection of loose bed channels (SANRAL, 2015)

Based on the identified critical erosion zones, corresponding 100 year ARI flood water depths, velocities, water level elevations and scour depth values were extracted from the simulated MIKE 21C results. At the selected zone, the simulated maximum scour depth was taken as the required toe elevation of the riprap (refer to Appendices).

From the energy slope and the simulated water depth, the median riprap diameter d_{50} was calculated. A factor of safety of 1.3 was used on the riprap diameter and riprap sizes were rounded up to the nearest 50 mm. The top elevation of the riprap was calculated based on the maximum water level at the selected location and 0.5 m freeboard allowance. In scenarios where the 100 year ARI water level was above the natural ground elevations, the ground elevation (top of bank) was used to determine the top of the riprap. These riprap solutions are shown through Appendix 1 to Appendix 70 and discussed further in the subsequent section. A typical cross section and grading to be used is shown in Figure 5.2-2.

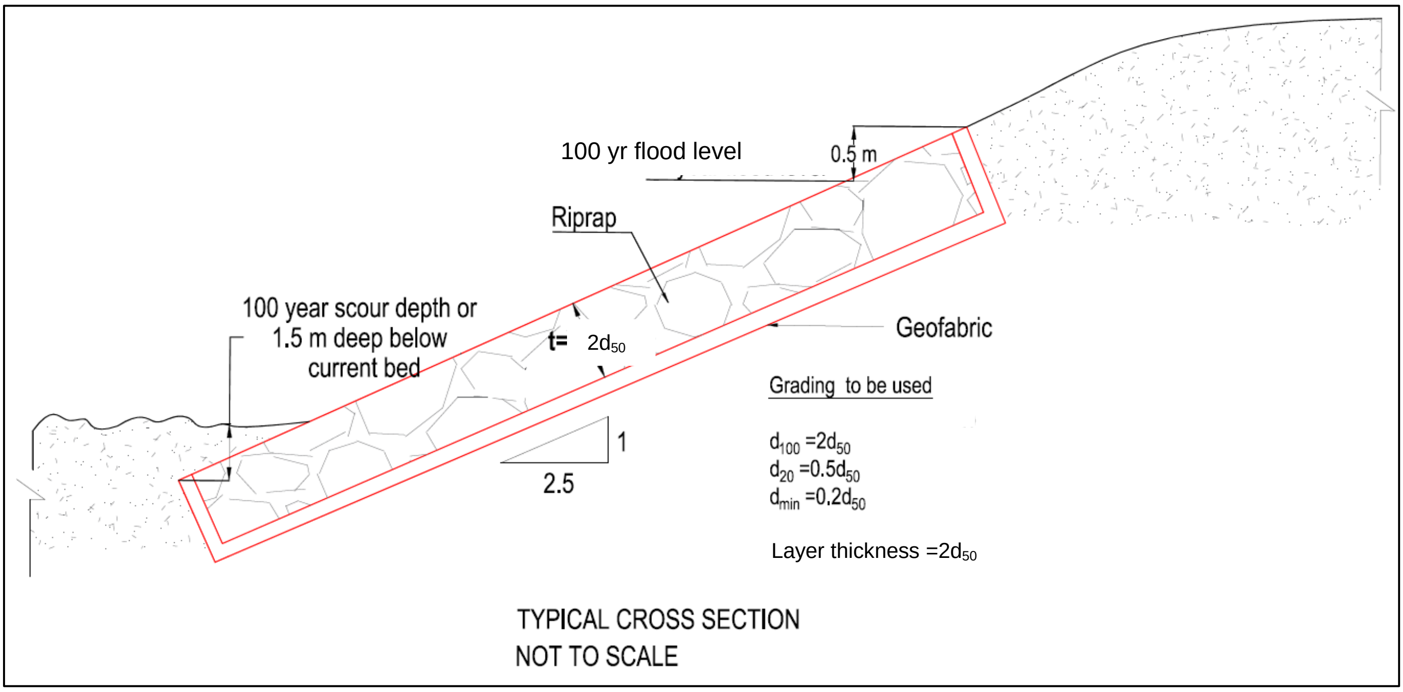


Figure 5.2-2 Typical riprap cross section

The grading of the riprap and the thickness is as indicated in the figure above. The slope should be 1:2.5 (V: H). The toe of the riprap should be at least 1.5 m deep below the current river bed level at the bank in alluvial material, or to rock. The riprap should therefore be extended into the main channel as required to achieve this toe depth. The riprap rock should be slightly angular or angular in shape, and should be durable.

Note that the filter as shown in Figure 5.2-2 is as important as the riprap median diameter and the grading as indicated in the figure. The filter should consist of a geofabric, with subsequent layers above it designed as a natural filter. The filter layers median diameters should not vary from layer to layer by more than a factor 5. The first layer on top of the geofabric could be gravel. The natural filter layers are required to protect the geofabric during dumping of the riprap rocks, as well as during turbulent flood flows. The proposed minimum thickness of each filter layer is 2xd_{50} of the layer, but not less than 0.1 m. It is also proposed that the grading of each natural filter layer should be based on the riprap grading as indicated in Figure 5.2-2.

5.3 BANK EROSION ZONES IDENTIFIED

The identified erosion zones are indicated below, with more details provided in the Appendices. Note that proposed construction priorities are discussed in Section 6.

Zone 1_1

This area is within the servitude and has unstable banks encroaching farmland. Riprap d_{50} = 0.45 m was found to be appropriate. A typical layout and elevations are shown in Appendix 2.

Zone 1_2

This area is within the servitude and has unstable banks. Due to the bedrock at the location, the banks do not need protection and the servitude seems incorrect. This zone is shown in Appendix 3.

Zone 1_3 and 1_4

This area is within the servitude and protection does not seem necessary. A typical layout is shown in Appendix 4.

Zone 1_5

This area is within the servitude and has unstable banks encroaching a road. d_{50} = 0.5 to d50 = 0.6 m was found to be appropriate. A typical layout and elevations are shown in Appendix 5.

Zone 1_6

This area has unstable banks crossing the servitude. d_{50} = 0.8 m was found to be appropriate. A typical layout and elevations are shown in Appendix 6.

Zone 1_7

This area are within the servitude but encroaching the servitude. d_{50} = 0.55 m was found to be appropriate. A typical layout and elevations are shown in Appendix 7.

Zone 1_8

This area has banks partially crossing the servitude. d_{50} = 0.25 m was found to be appropriate. A typical layout and elevations are shown in Appendix 7.

Zone 2_1

The banks are encroaching the servitude but protection does not seem necessary. This area is shown in Appendix 9.

Zone 2_2

This area has unstable banks crossing the servitude. d_{50} = 0.45 m and d_{50} = 0.6 m was found to be appropriate. A typical layout and elevations are shown in Appendix 10.

Zone 2_3

This area has unstable banks are encroaching on the servitude. d_{50} = 0.9 m was found to be appropriate. A typical layout and elevations are shown in Appendix 11.

Zone 2_4

This area crosses the servitude but due the wide flood plain flow, protection is not viable. This is shown in Appendix 12

Zone 2_5

This area is within the servitude but encroaches farmland that is within the servitude. d_{50} = 0.4 m was found to be appropriate. A typical layout and elevations are shown in Appendix 13.

Zone 2_6

This area is within the servitude but has unstable banks that encroach a road. d_{50} = 0.2 m was found to be appropriate. A typical layout and elevations are shown in Appendix 13.

Zone 2_7

This area is within the servitude but encroaches farmland that is within the servitude. Protection does not seem necessary. A typical layout and elevations are shown in Appendix 14.

Zone 2_8 and 2_9

The banks are encroaching the servitude and farmland. d_{50} =0.3 m and d_{50} =0.4 m were found appropriate. This area is shown in Appendix 15.

Zone 2_10

The banks are encroaching the road but within the servitude. d_{50} = 0.3 m and d_{50} = 0.6 m were found appropriate. This area is shown in Appendix 16.

Zone 2_11

The unstable banks are crossing the servitude and encroaching onto farmland. d_{50} = 0.25 m was found appropriate. This area is shown in Appendix 16.

Zone 2_12 and 2_14

This area is within the servitude but encroaches farmland. An old weir diverts water inducing erosion. Protection does not seem necessary. A typical layout is shown in Appendix 17.

Zone 2_13

The unstable banks are encroaching the servitude and farmland. d_{50} = 0.5 m was found appropriate. This area is shown in Appendix 17.

Zone 2_15

The unstable banks are encroaching the servitude and farmland. Protection was deemed not necessary. This area is shown in Appendix 18.

Zone 3_1

The zone has unstable banks crossing the servitude. d_{50} = 0.45 m was found appropriate. This area is shown in Appendix 20.

Zone 3_2

Flow in this area is in a wide floodplain crossing the servitude and protection in not viable. Appendix 21 shows this.

Zone 3_3

The zone has unstable banks crossing the servitude. d_{50} = 0.4 m and d_{50} = 0.45 m were found appropriate. This area is shown in Appendix 22.

Zone 3_4

Flow in this area is in a wide floodplain and protection is not necessary. Appendix 22 shows this.

Zone 3_5

The zone has unstable banks crossing the servitude. d_{50} = 0.4 m was found appropriate. This area is shown in Appendix 23.

Zone 3_6

The zone has unstable banks but within the servitude. Protection was found not necessary. This area is shown in Appendix 23.

Zone 3_7

The zone has unstable banks encroaching the servitude and road. d_{50} = 0.1 m was found appropriate. This area is shown in Appendix 24.

Zone 3_8

The zone has unstable banks within the servitude. Protection was found not necessary. This area is shown in Appendix 25.

Zone 3_9

The zone has unstable banks encroaching the servitude and farmland d_{50} = 0.15 m was found appropriate. This area is shown in Appendix 26.

Zone 3_10

The zone has unstable banks within the servitude. Protection was found not necessary. This area is shown in Appendix 26.

Zone 4_1

The zone has unstable banks crossing the servitude and encroaching the road. d_{50} = 0.55 m was found appropriate. This area is shown in

Appendix 28.

Zone 4_2

The zone has unstable banks crossing the servitude and encroaching the road. d_{50} = 0.3 m and d_{50} = 0.45 m was found appropriate. This area is shown in

Appendix 29.

Zone 4_3

The zone has unstable banks crossing the servitude. d_{50} =0.3 m, d_{50} =0.45 m and d_{50} =0.6 m was found appropriate. This area is shown in Appendix 30.

Zone 4_4

The zone has unstable banks crossing the servitude and encroaching the road. d_{50} =0.3 m and d_{50} =0.6 m was found appropriate. This area is shown in Appendix 31.

Zone 4_5 and 4_6

Flow in this area is on a wide floodplain and erosion induced by a tributary thus protection is deemed not necessary. Appendix 32 shows this.

Zone 5_1

The zone has banks encroaching the servitude. d_{50} = 0.85 m was found appropriate. This area is shown in

Appendix 34.

Zone 5_2

The zone has unstable banks encroaching servitude and farmland. Protection in this zone does not seem necessary. This area is shown in Appendix 35.

Zone 5_3

The zone has banks crossing the servitude and encroaching farmland. d_{50} = 0.5 m was found appropriate. This area is shown in Appendix 36.

Zone 5_4

The zone has banks crossing the servitude. d_{50} = 0.5 m and d_{50} = 0.85 m was found appropriate. This area is shown in Appendix 37.

Zone 5_5

The zone has banks within the servitude. Flows are wide oin the floodplain and protection not necessary. Appendix 38 shows this.

Zone 5_6

The zone has banks within the servitude. Flows are wide on the floodplain and protection not necessary. Appendix 39 shows this.

Zone 5_7 and 5_8

Unstable banks within the servitude. The servitude seems to be incorrect and protection is deemed not necessary. Appendix 40 shows this.

Zone 6_1

The zone has banks crossing the servitude and encroaching farmland. d_{50} = 0.45 m, d_{50} = 0.7m and d_{50} = 0.85 m were found appropriate. This area is shown in Appendix 42.

Zone 6_2

The zone has banks within the servitude. Upstream tributary flow induces the erosion and protection will constrict the flow thus not necessary. This area is shown in Appendix 43.

Zone 6_3

The zone has banks crossing the servitude and encroaching farmland. d_{50} = 0.9 m was found appropriate. This area is shown in Appendix 44.

Zone 6_4

The zone has banks crossing the servitude but with bedrock outcropping. d_{50} = 0.65 m was found appropriate. This area is shown in Appendix 45.

Zone 6_5

The zone has unstable banks within the servitude and protection is not necessary. Appendix 46 shows this.

Zone 6_6

The zone has banks crossing the servitude and encroaching farmland. d_{50} = 0.35 m, d_{50} = 0.45 m, d_{50} = 0.55 m, d_{50} = 0.6 m and d_{50} = 0.75 m were found appropriate. This area is shown in Appendix 47.

Zone 7_1

The zone has unstable banks within the servitude and protection is not necessary.

Appendix **49** shows this.

Zone 7_2

The zone has banks crossing the servitude. d_{50} = 0.4 m and d_{50} = 0.45 m was found appropriate. This area is shown in Appendix 50.

Zone 7_3

The zone has unstable banks within the servitude. d_{50} = 0.55 m was found appropriate. This area is shown in Appendix 51.

Zone 7_4

This area's river servitude seems inaccurate. This is shown in Appendix 52.

Zone 8_1

The zone has unstable banks within the servitude thus protection is not necessary. This area is shown in Appendix 54.

Zone 8_2

The zone has unstable banks crossing the servitude and encroaching onto farm land. d_{50} = 0.65 m was found appropriate. This area is shown in Appendix 55.

Zone 8_3

Flow in this region is on a wide floodplain and protection will constrict the flow further, thus not necessary. This area is shown in Appendix 56.

Zone 9_1

The zone has unstable banks crossing the servitude and encroaching onto farm land. d_{50} = 0.3 m, d_{50} = 0.35 m and d_{50} = 0.45 m were found appropriate. This area is shown in Appendix 57.

Zone 9_2

The zone has unstable banks within the servitude thus protection is not necessary. This area is shown in

Appendix 59.

Zone 9_3

The zone has unstable banks crossing the servitude which seemed to be inaccurate. d_{50} = 0.6 m and d_{50} =0.85 m was found appropriate. This area is shown in

Appendix 60.

Zone 10_1

The area's river servitude seems to be inaccurate. This is shown in Appendix 62.

Zone 10_2

The zone has unstable banks within the servitude. Protection in this area is not necessary. This area is shown in Appendix 63.

Zone 10_3

The zone has banks crossing the servitude. d_{50} = 0.35 m was found appropriate. This area is shown in Appendix 63.

Zone 10_4

The zone has banks within the servitude. Upstream tributary flow induces the erosion and protection will constrict the flow thus not necessary. This area is shown in Appendix 64.

Zone 11_1

The zone has unstable banks crossing the servitude and flow is on a wide floodplain. d_{50} =0.4 m, was found appropriate. This area is shown in Appendix 66.

Zone 11_2

The area river servitude is inaccurate. This is shown in Appendix 67.

Zone 11_3

The area’s river servitude seems inaccurate. This is shown in Appendix 68.

Zone 11_4

The zone has unstable banks within the servitude. Protection in this area is not necessary. This area is shown in Appendix 68.

Zone 12_1

The zone has unstable banks crossing the servitude. d_{50} =0.35 m was found appropriate. This area is shown in Appendix 70.

6 PROPOSED RIVER BANK PROTECTION CONSTRUCTION PRIORITIES

Long term simulations were carried out to evaluate the rate of lateral channel migration and impacts of the 25 m^3/s water transfer base flow. Four main simulations were carried out as summarized in Table 6.1.

Table 6.1 Prioritization simulation scenarios

Scenario	ARI (year)	Simulation duration (years)
1a	Q_2 including 25 m^3/s base flow	2
1b	Q_2 no base flow	2
2a	Q_{10} including 25 m^3/s base flow	1
2b	Q_{10} no base flow	1

The two year floods were found not to affect the bank erosion significantly, because of the general river bed degradation caused by the transfer flow, and therefore the 10 year flood results were used to evaluate the bank migration. The 2 year flood scenarios without base flow and with base flow (transfer flow) were however used to evaluate the bed scour at the critical bank erosion zones. Details are provided in Table 6.2.

The erosion protection zones were prioritized into five categories summarized in Table 6.1. Aided with the long term simulation results they were further prioritized using the rate of lateral migration (including effects of transfer base flow). Twenty three zones were identified as having crossed the servitude, nine having priority 2, ten having priority 3, twenty nine not needing protection and one of the zone where the servitude is probably incorrect. This is summarized in Table 6 with corresponding riprap median size(s) proposed.

Table 6.2 Prioritization selection table

Category No.	Criterion
1a	River banks crossing current servitude impacting on crops or roads
1b	River banks crossing current servitude in riparian zone without crops or roads near the bank
2	Unstable banks encroaching servitude and farmland
3	Banks within servitude encroaching farmland and erosion protection not deemed necessary
4	• Previously identified zones • Flow on wide floodplain (floodplain flow causes scour) • Erosion caused by immediate upstream tributary
5	Possible inaccurate servitude location

Table 6.3 Proposed river bank erosion protection zones based on the category numbers of Table 6.2 and ranked in each category based on the rate of lateral bank erosion

Count	Zone	Table 6.2 Category No.	Median riprap rock size d_{50} (m) based on 100 yr ARI design flood	Rate of lateral bank migration (m/month) 10 yr ARI flood with transfer flow***	Transfer flow effect on relative scour depth at river bank for 2 year ARI food (m)*
1	6_3	1a	0.9	0.25	-1.20
2	6_1	1a	0.45, 0.7, 0.85	0.23	-2.00
3	5_4	1a	0.5, 0.85	0.22	-1.50
4	2_11	1a	0.25	0.10	-1.80
5	5_3	1a	0.5	0.10	0.50
6	2_6	1a	0.2	0.02	-0.18
1	11_1	1b	0.4	0.67	-3.00
2	4_2	1b	0.3, 0.45	0.42	-2.00
3	2_2	1b	0.45, 0.6	0.33	0.50
4	4_3**	1b	0.3, 0.45, 0.6	0.27	-2.00
5	4_4**	1b	0.3, 0.6	0.27	-2.20
6	8_2	1b	0.65	0.27	-3.00
7	3_5	1b	0.4	0.26	-0.50

8	4_1	1b	0.55	0.25	-2.50
9	1_6	1b	0.8	0.19	-0.50
10	1_7	1b	0.55	0.18	-0.50
11	12_1	1b	0.35	0.13	-3.00
12	10_3	1b	0.35	0.09	2.50
13	3_1	1b	0.45	0.08	0.50
14	3_3	1b	0.4, 0.45	0.08	0.50
15	9_3	1b	0.6, 0.85	0.07	1.00
16	7_2	1b	0.4 ,0.45	0.03	-2.00
17	9_1	1b	0.3, 0.35, 0.45	0.03	-3.00
1	1_8	2	0.25	0.28	1.00
2	2_10	2	0.3, 0.6	0.21	-2.00
3	5_1	2	0.85	0.21	-2.00
4	2_13	2	0.5	0.08	-2.00
5	2_3**	2	0.9	0.29	-2.00
6	2_5	2	0.4	0.22	-0.60
7	2_9	2	0.3, 0.4	0.16	-0.50
8	3_7	2	0.1	0.09	-2.00
9	1_5	2	0.5	0.06	-1.00
1	1_4	3		0.09	-2.50
2	5_2	3			
3	10_2	3		0	
4	8_3	3			
5	9_2	3			
6	6_6	3	0.35, 0.45, 0.55, 0.6 ,0.75	0.24	-3.00
7	1_1	3	0.45	0.23	0.50
8	3_9	3	0.15	0.08	3.00
9	6_4	3	0.65	0.09	-1.80
10	7_3	3	0.55	0.09	-2.50
1	1_2	4			
2	1_3	4			
3	10_4	4			
4	11_4	4			
5	2_1	4		0.13	
6	2_12	4			
7	2_14	4			
8	2_15	4			
9	2_4	4			
10	2_7	4			
11	2_8	4			

12	3_10	4			
13	3_2	4			
14	3_4	4			
15	3_6	4			
16	3_8	4			
17	4_5	4			
18	4_6	4			
19	5_5	4			
20	5_6	4			
21	5_7	4			
22	5_8	4			
23	6_2	4			
24	6_5	4			
25	7_1	4			
26	8_1	4			
27	10_1	4			
28	11_2	4			
29	11_3	4			
1	7_4	5			

Notes: * Negative means scour depth with base flow is deeper than without baseflow. These relative scour depths were not used in the prioritization, but give an indication of the relative impact of the transfer flow in terms of scour depth.

** Could be 1:2 (V:H) riprap slopes to fit in between the river and the servitude, but the riprap size will be larger. Currently riprap designed for 1:2.5 slope.

** Used to rank the proposed erosion protection sites in each category.

7 CONCLUSION AND RECOMMENDATIONS

The hydrodynamic model MIKE 21C was successful set up and the 2, 10 and 100 year ARI river floods were simulated including the base transfer flow of 25 m^3/s in the Skoenmakers River. By using the simulated 2 and 10 year ARI flood peak scour patterns, 72 erosion zones were identified. Riprap (dumped rock) was designed as bank erosion mitigation measure in accordance with the SANRAL (2015) methodology with the 100 year ARI flood as the design flood

Long term 2 and 10 year ARI floods were simulated with and without the transfer base flow giving rates of lateral migration and long term effects of base transfer flow. This aided in prioritizing the designed zones into five categories in terms of construction priorities. 23 zones were found to having breached the servitude, 9 were within the servitude but encroaching onto farm land, 29 were not necessitating protection and 1 zone requires the servitude to be redrawn. The number of sites in the highest category 1 could be reduced by 2 to 21, if the riprap bank protection slope is made steeper at 1:2. Furthermore, 6 higher priority category 1 zones (category 1a in Table 6.2), were identified where the eroded river bank is crossing the servitude and scouring into crops or roads.

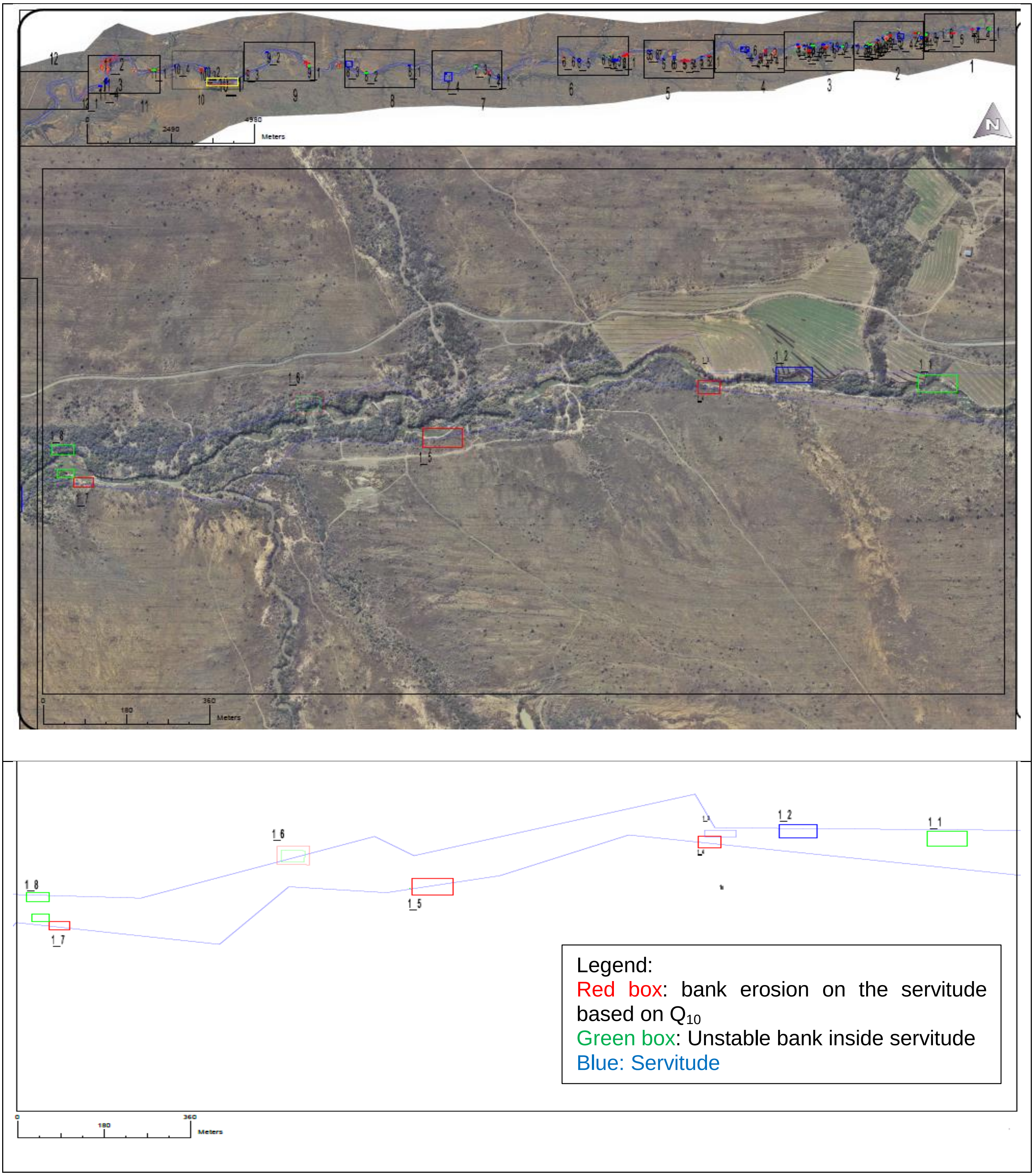
Note that at some erosion zones the farmland is closer than 32 m from the edge of the river, and in many cases the riparian vegetation has also been removed due to the farming activity. As part of the river maintenance exercise, crops should not be allowed closer than 32 m from the river banks, and riparian vegetation should be re-established near locations where bank erosion problems have been identified in this report.

For categories 1a, then 1b, erosion protection as proposed here in the form of riprap protection should be considered as highest priority. Category 2 is still a high priority, but a monitoring programme could be established to resurvey the bank location over time relative to the current location and the servitude. The same applies to category 3.

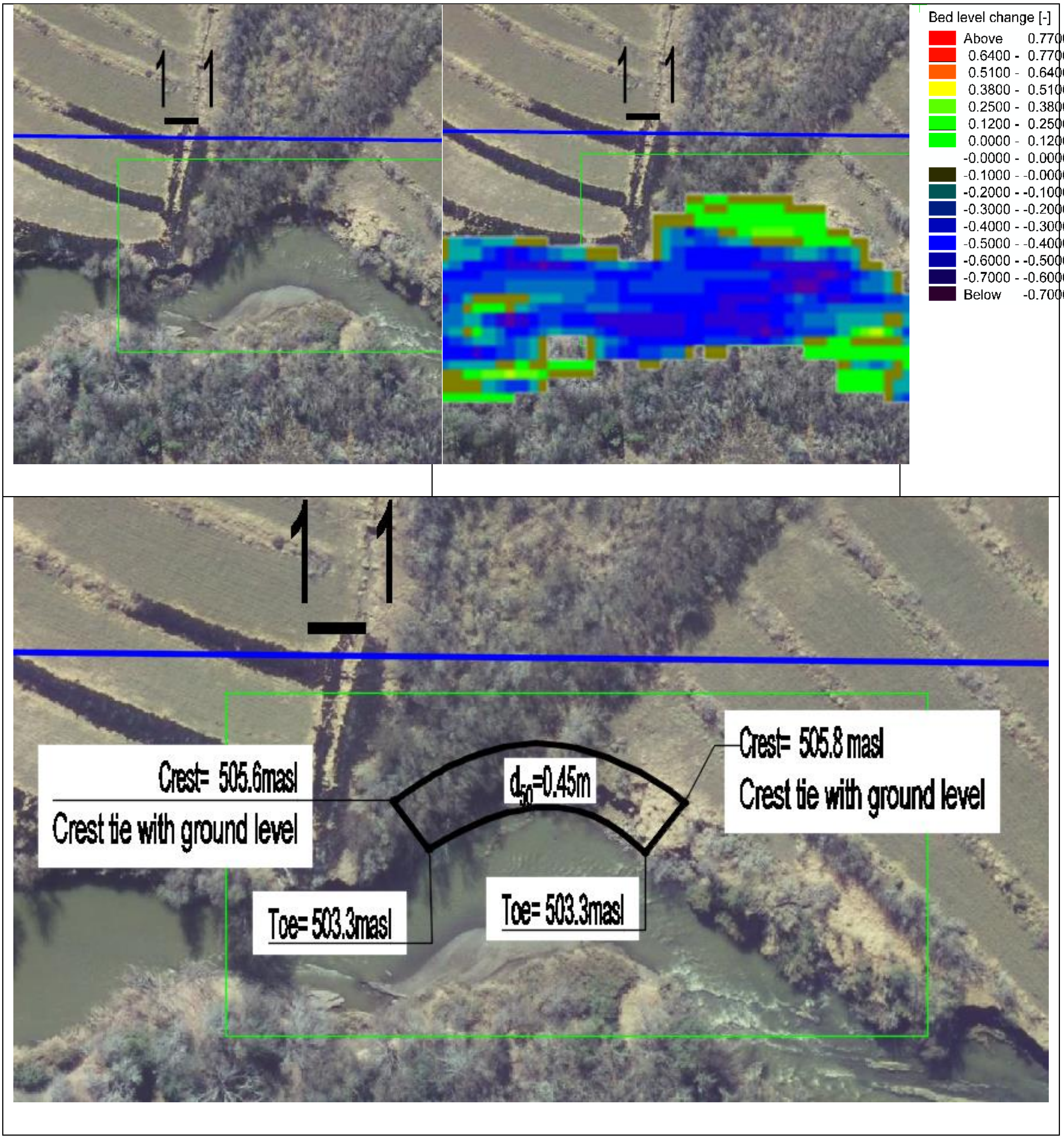
8 APPENDICES

SIMULATED BED LEVEL CHANGE ON THE SKOENMAKERS RIVER, CRITICAL BANK EROSION ZONES AND PROPOSED RIPRAP PROTECTION

Appendix 1: Zone 1

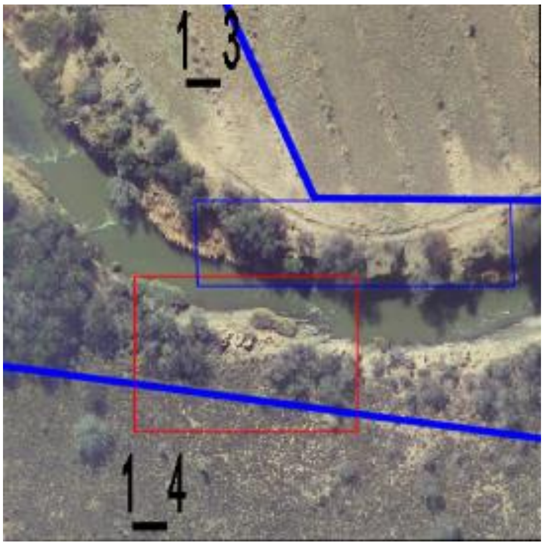


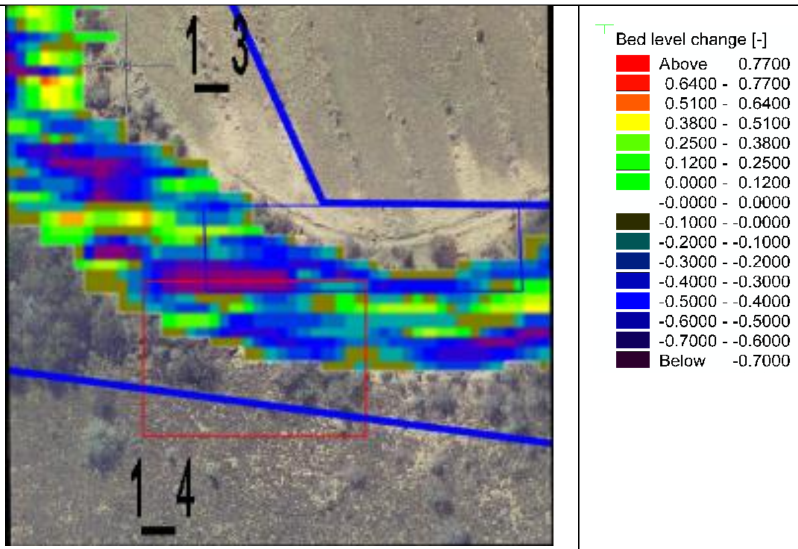
Appendix 2: Zone 1_1 Q10 flood peak scour pattern and proposed scour protection

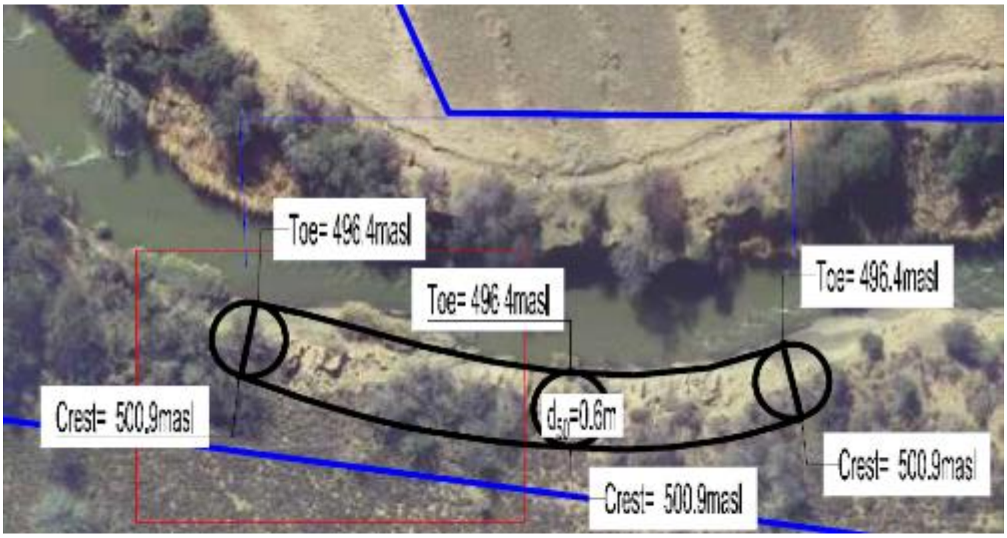


Appendix 3: Zone 1_2 Q10 flood peak scour pattern

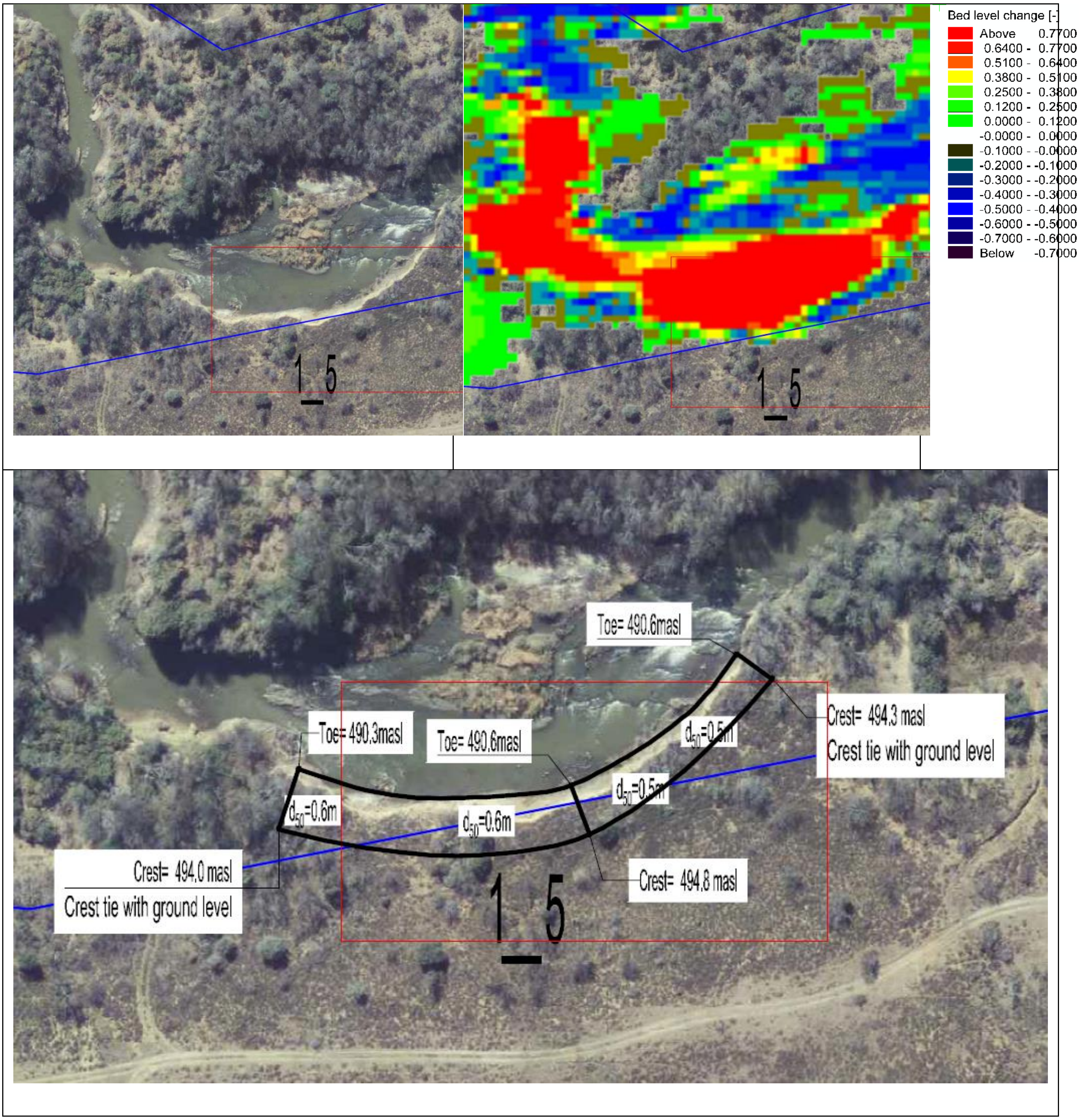
Appendix 4: Zone 1_3 and 1_4 Q10 flood peak scour pattern and proposed scour protection



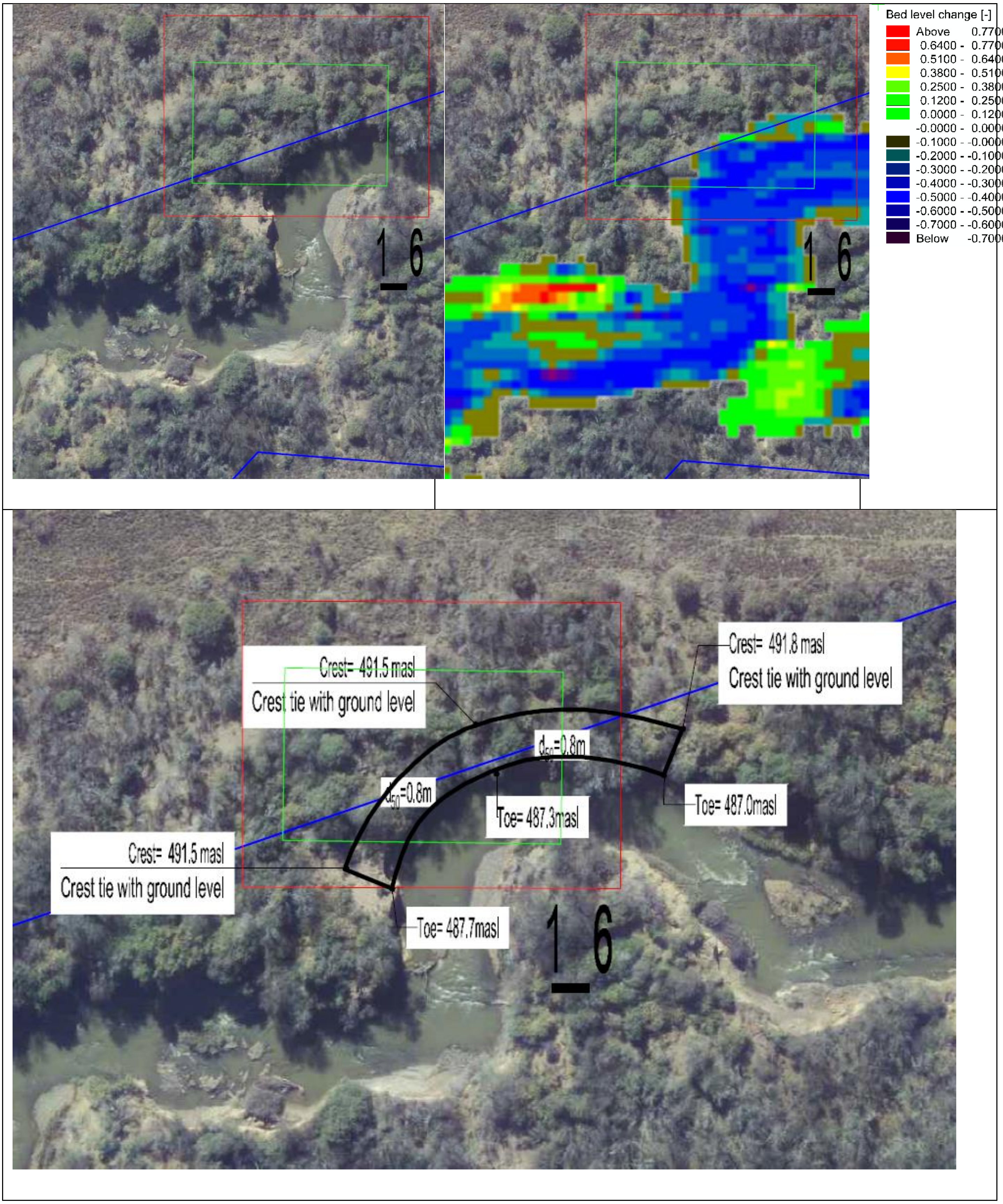




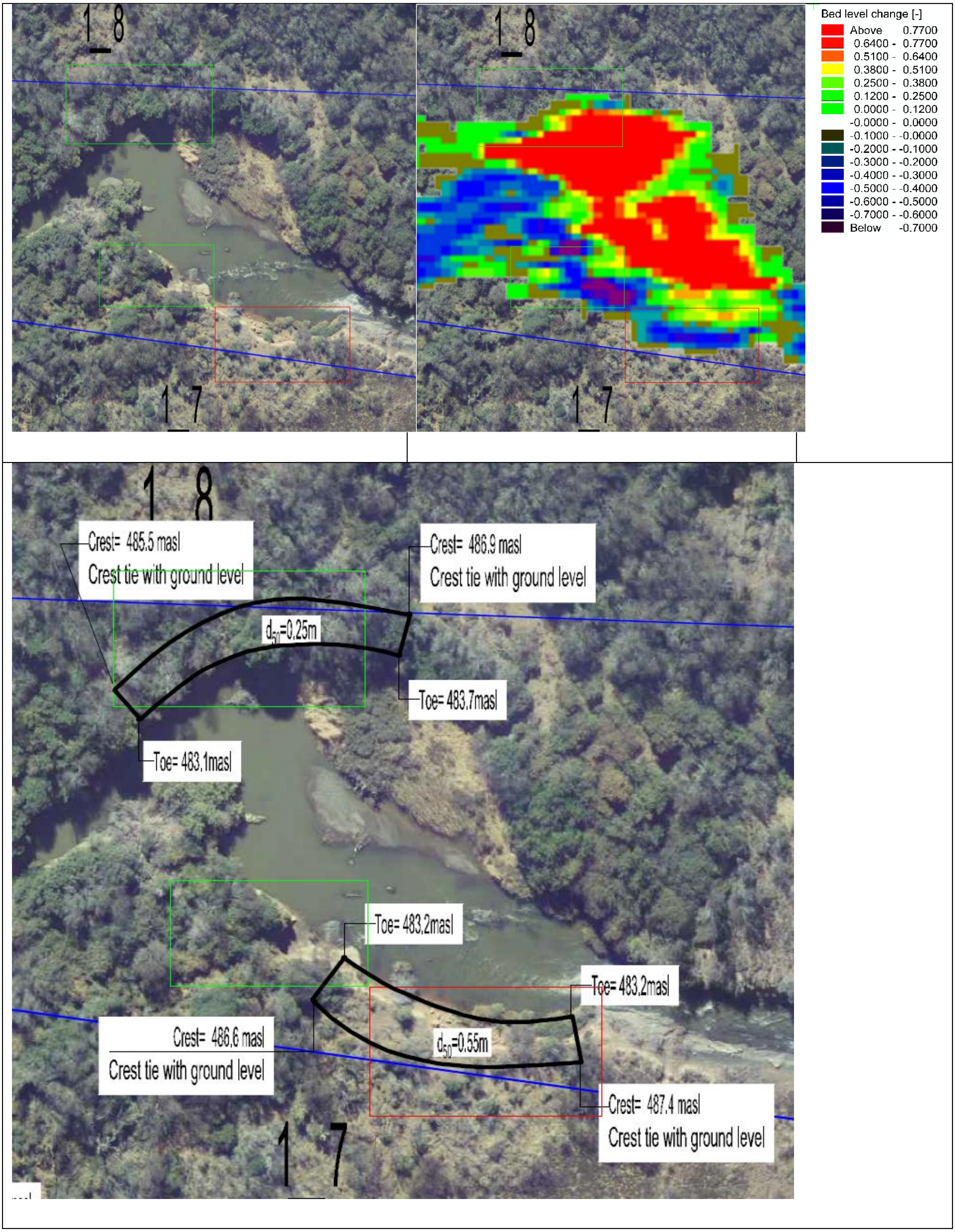
Appendix 5: Zone 1_5 Q10 flood peak scour pattern and proposed scour protection



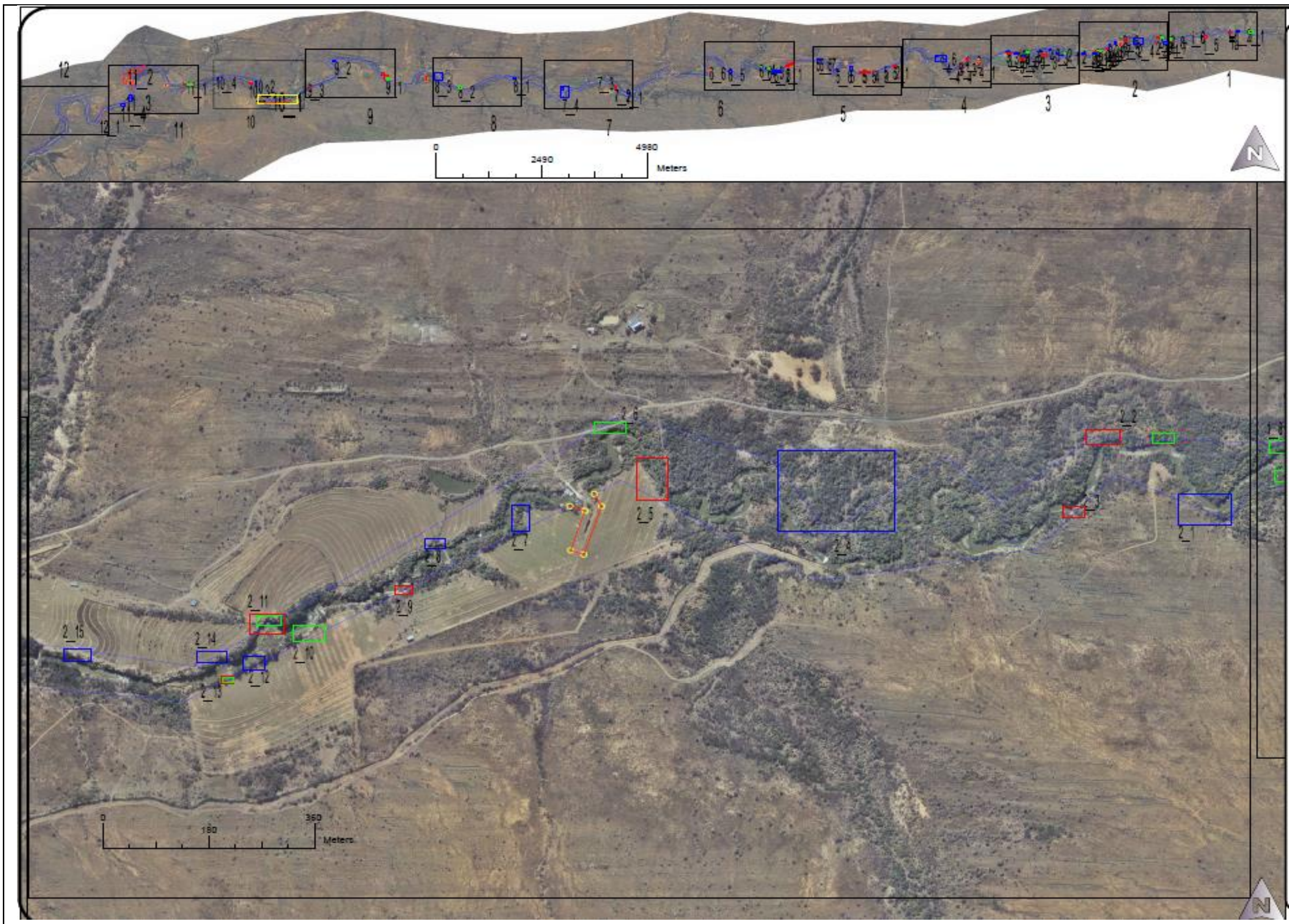
Appendix 6: Zone 1_6 Q10 flood peak scour pattern and proposed scour protection

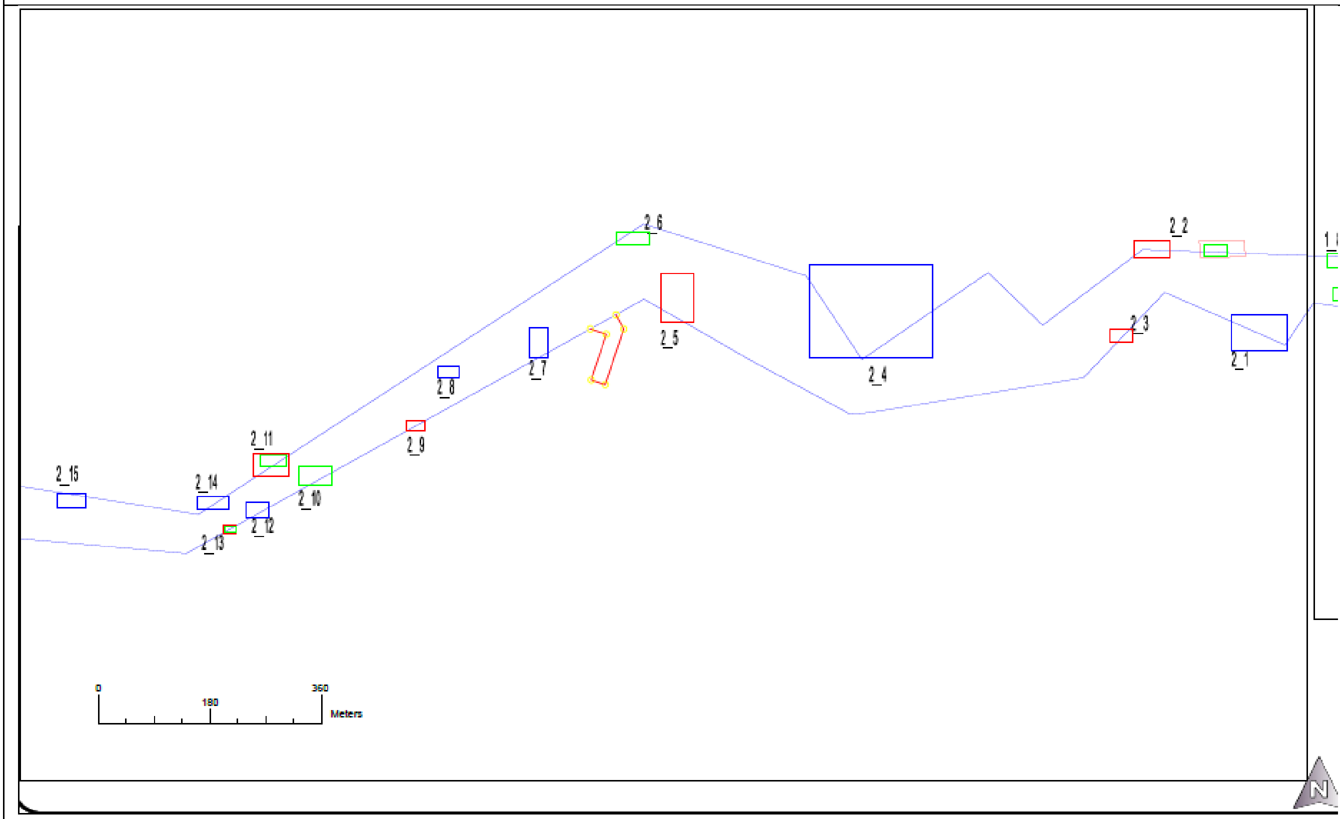


Appendix 7: Zone 1_7 and 1_8 Q10 flood peak scour pattern and proposed scour protection

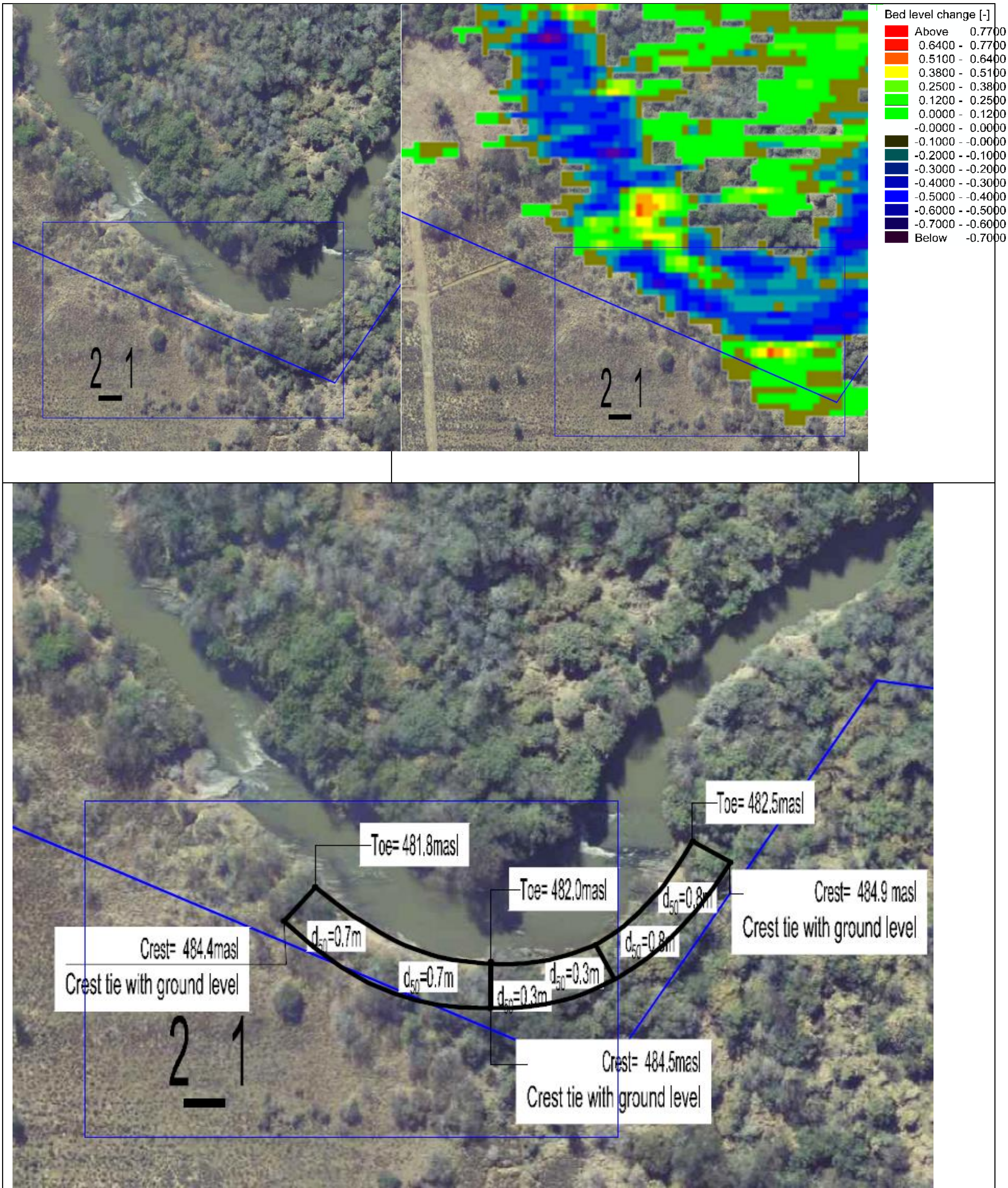


Appendix 8: Zone 2

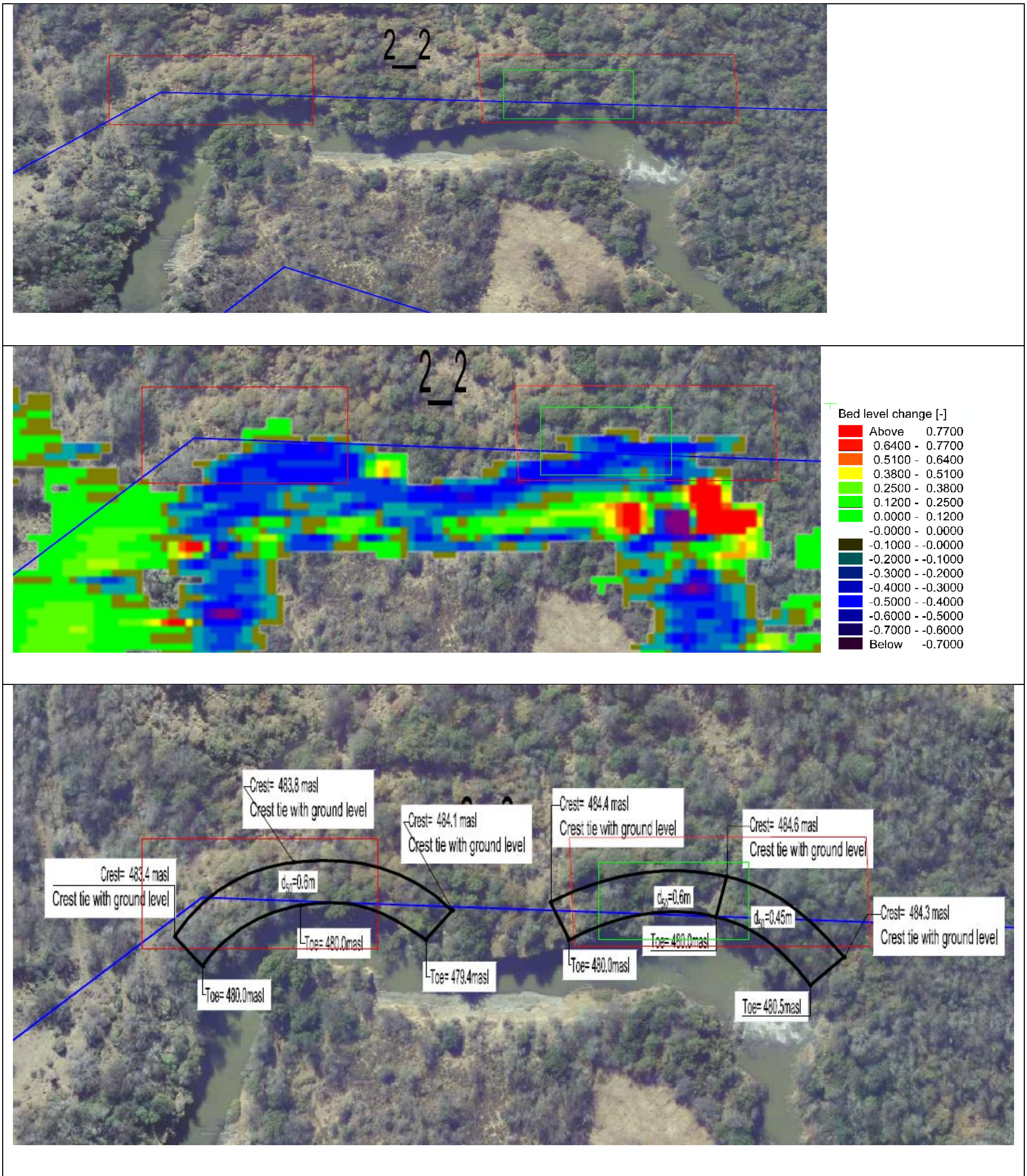




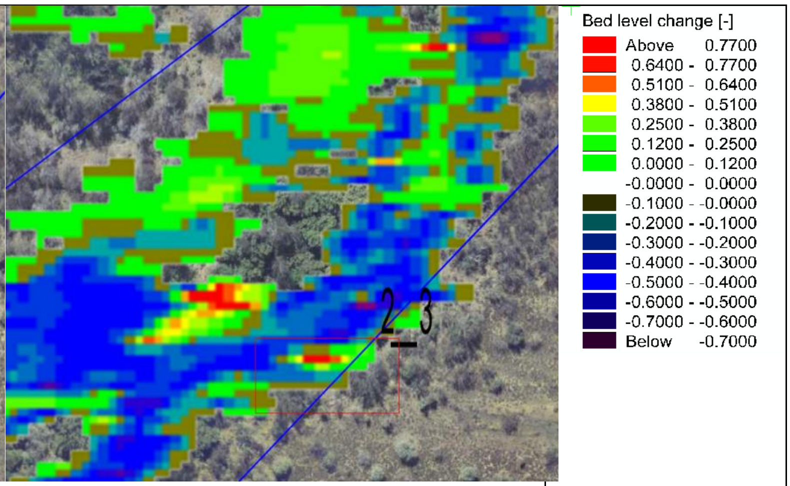
Appendix 9: Zone 2_1 Q10 flood peak scour pattern and proposed scour protection

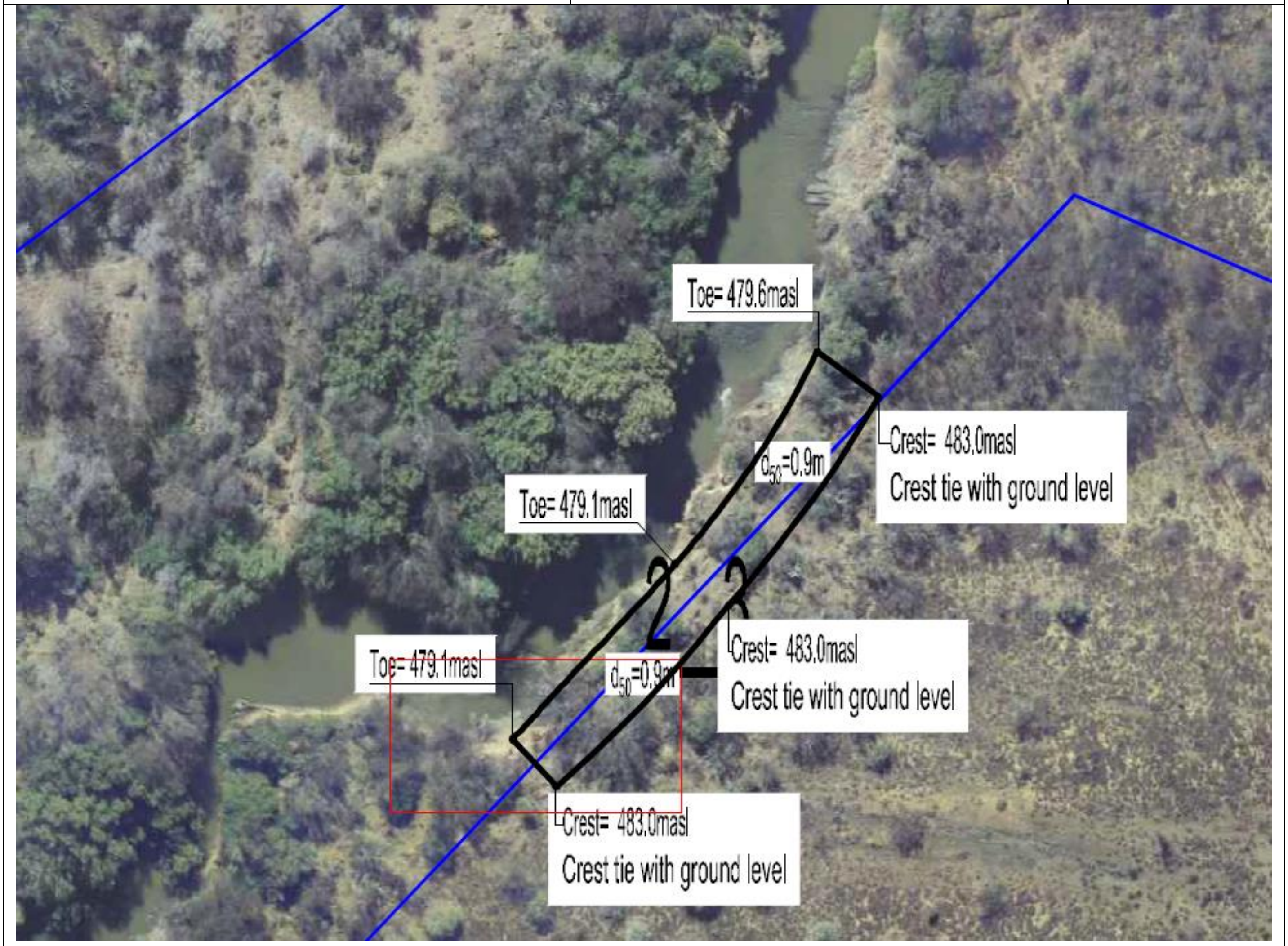


Appendix 10: Zone 2_2 Q10 flood peak scour pattern and proposed scour protection

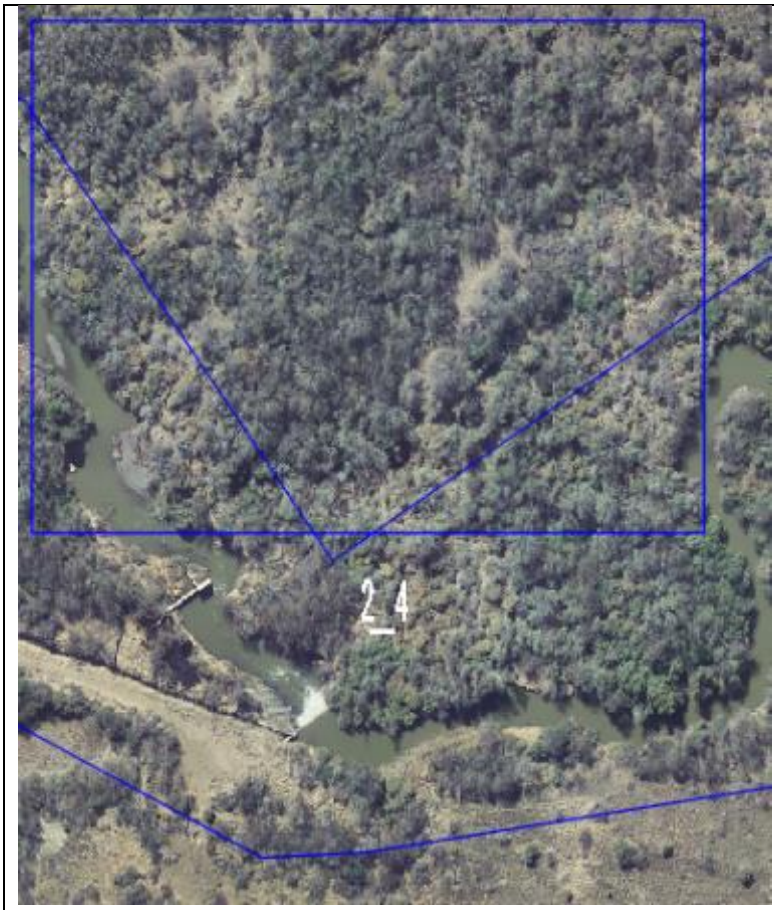


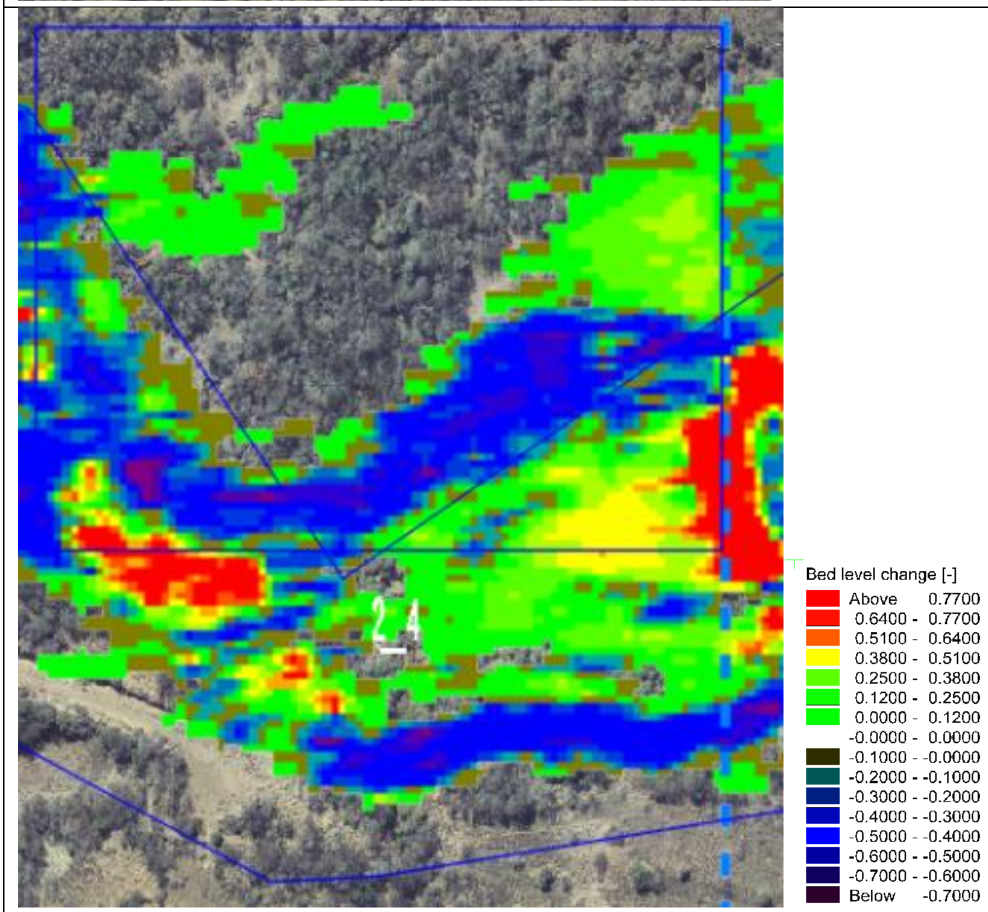
Appendix 11: Zone 2_3 Q10 flood peak scour pattern and proposed scour protection



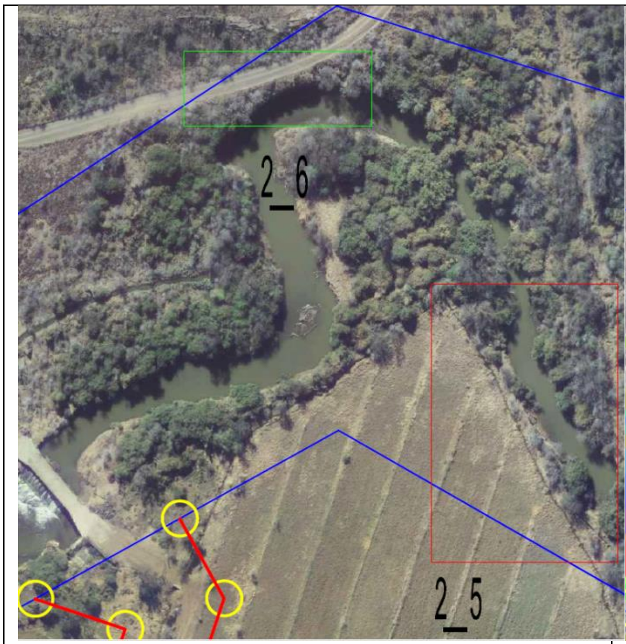


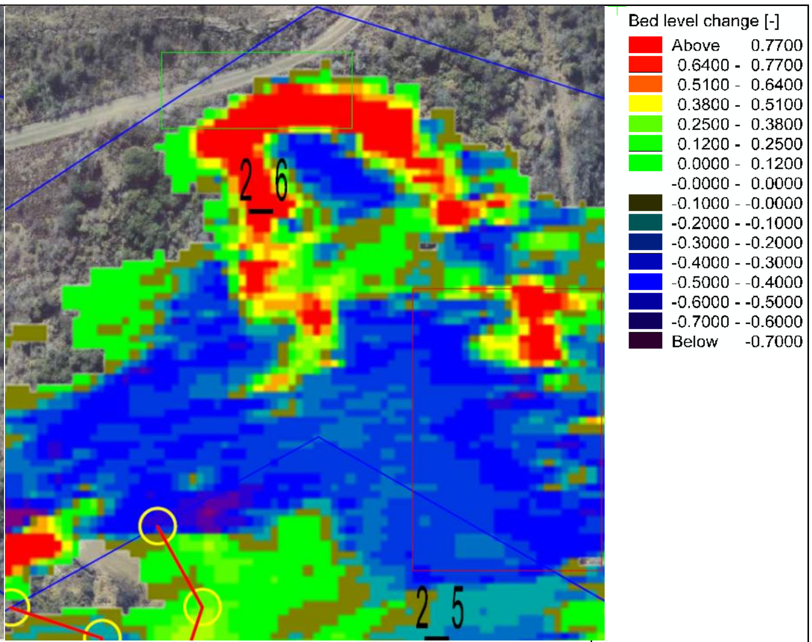
Appendix 12: Zone 2_4 Q10 flood peak scour pattern

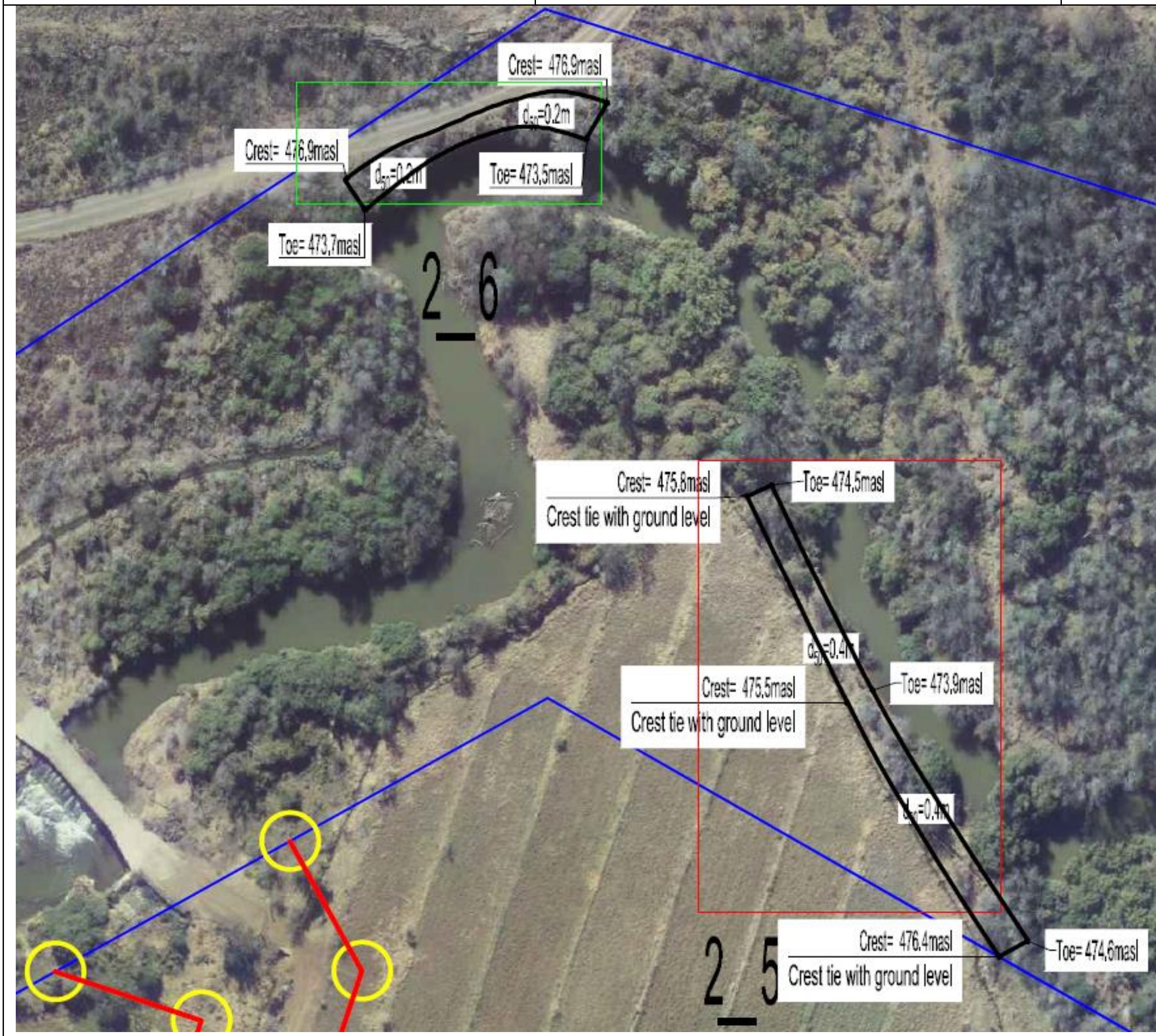




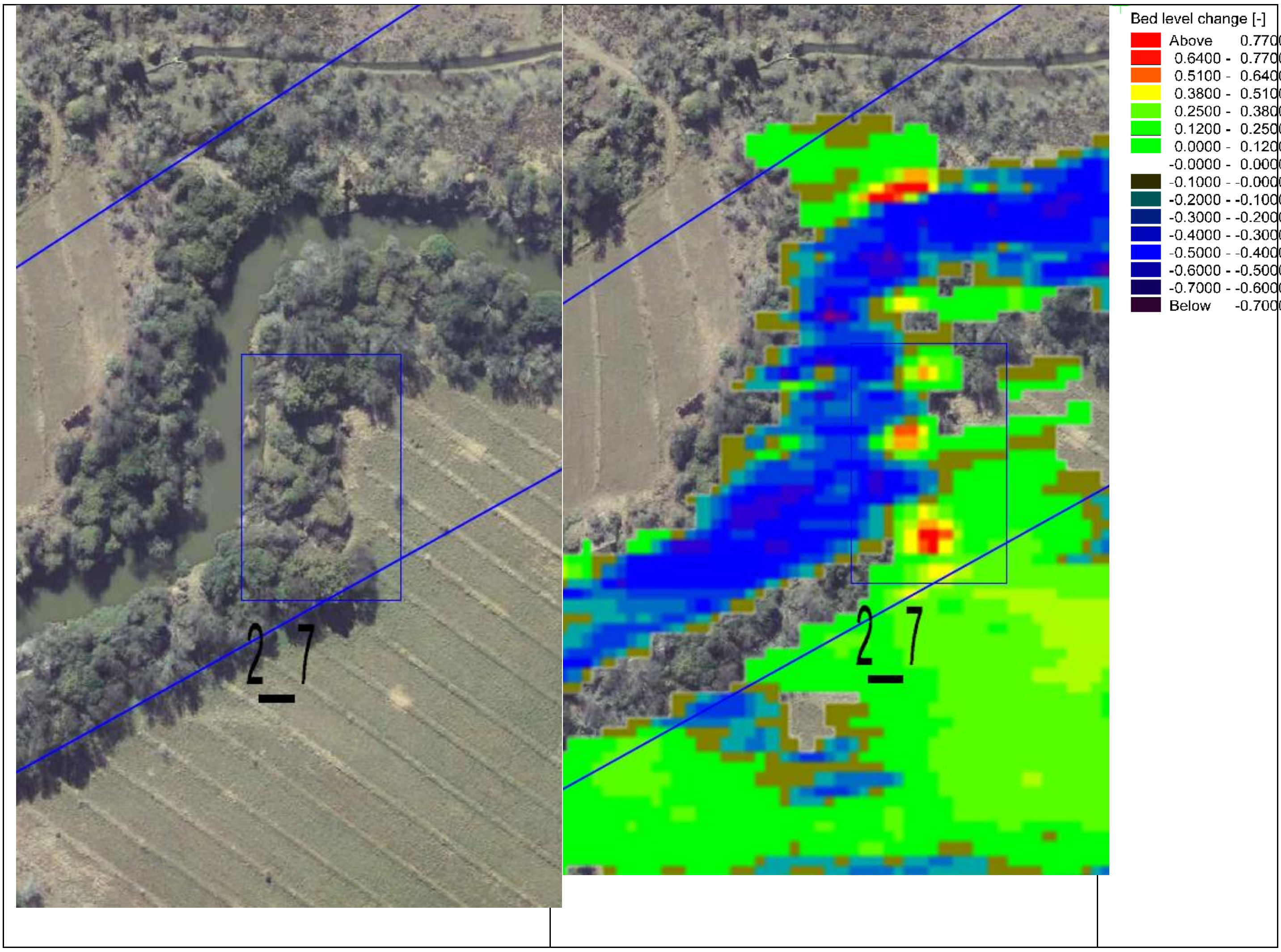
Appendix 13: Zone 2_5 and 2_6 Q10 flood peak scour pattern and proposed scour protection



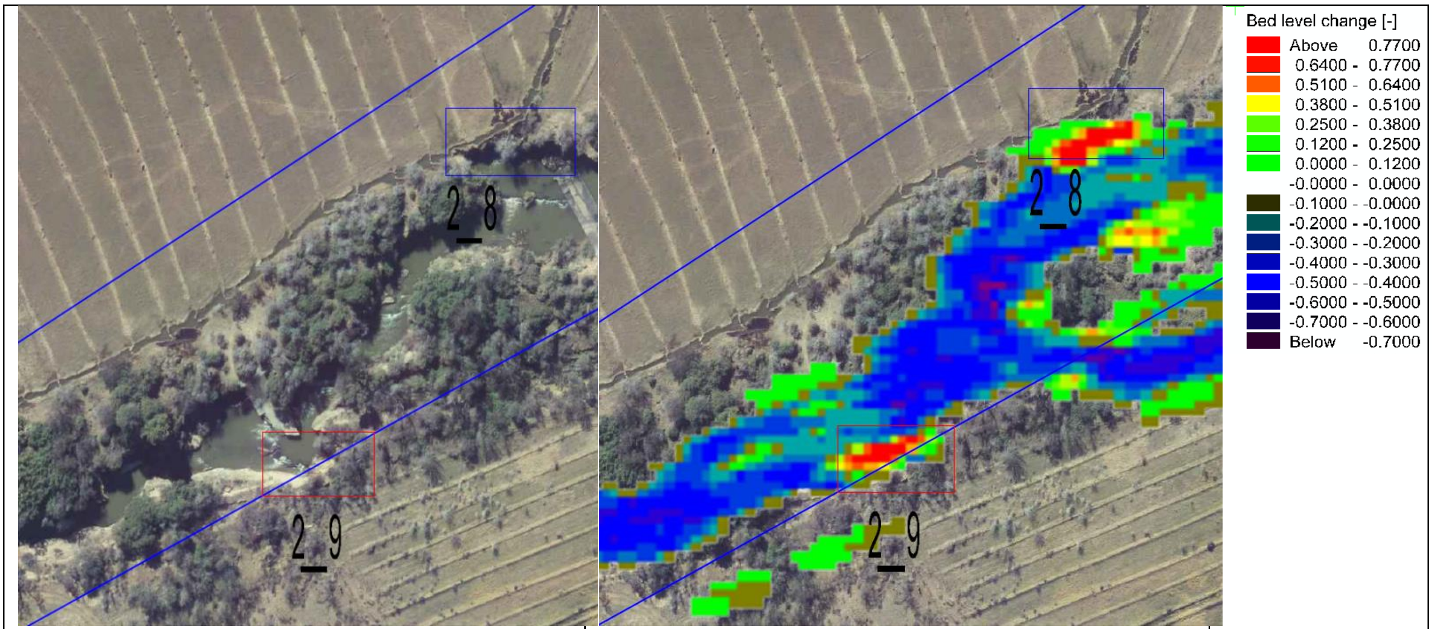


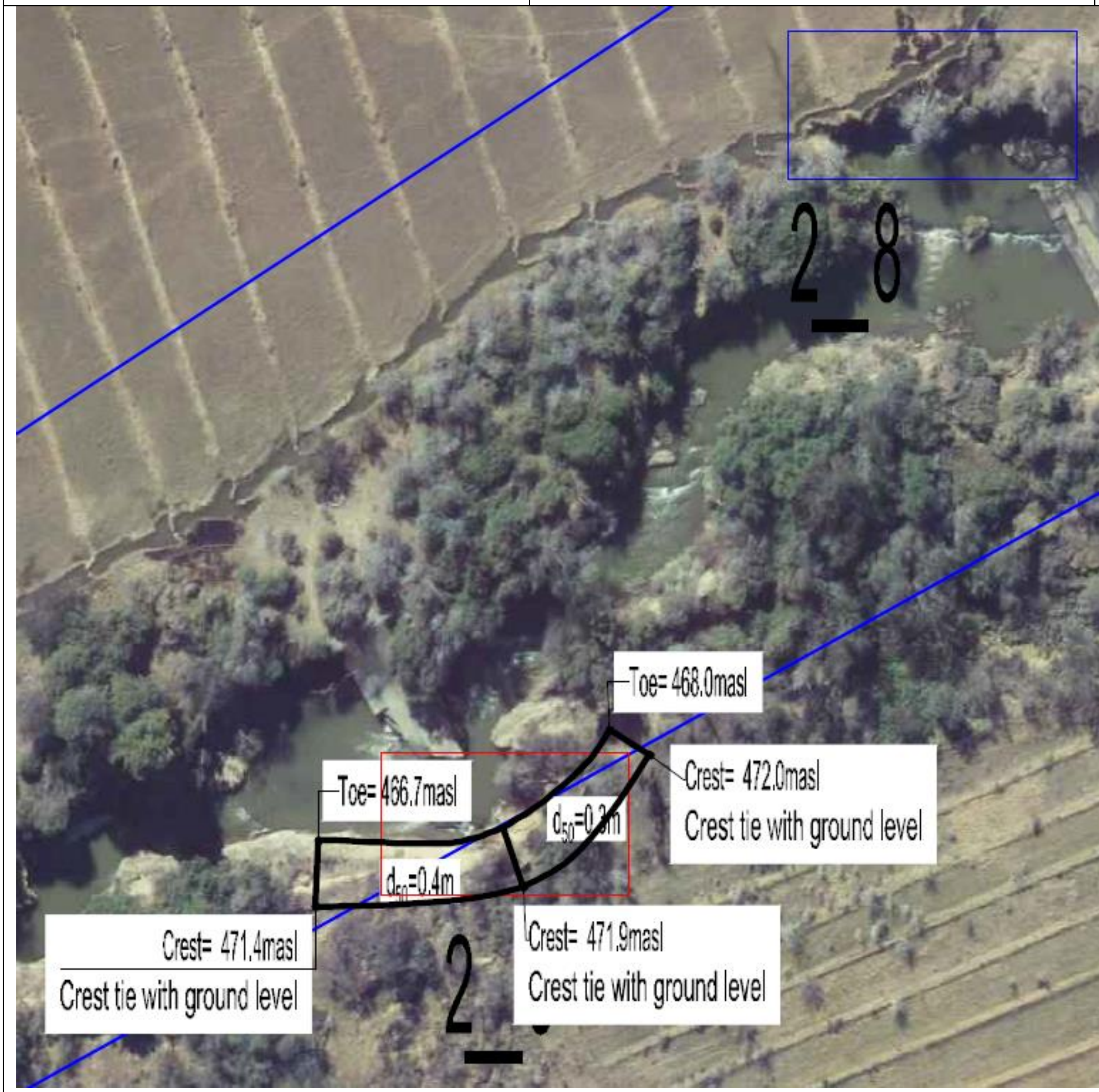


Appendix 14: Zone 2_7 Q10 flood peak scour pattern

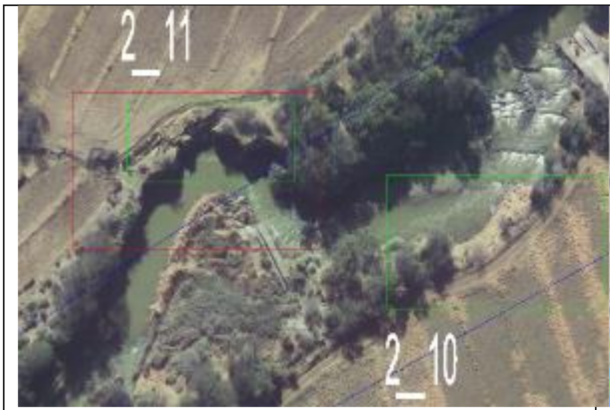


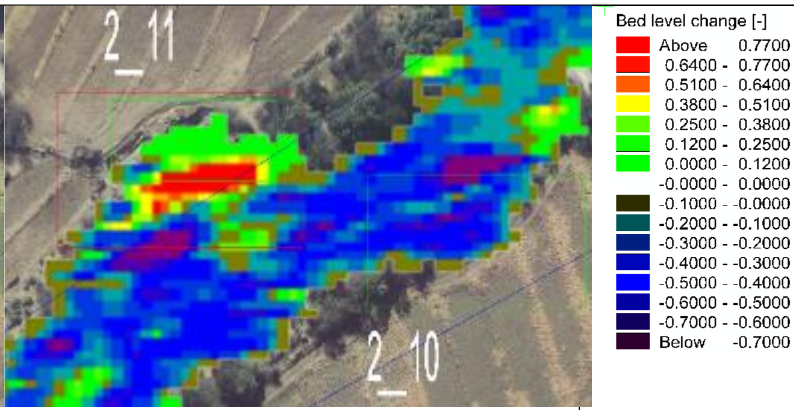
Appendix 15: Zone 2_8 and 2_9 Q10 flood peak scour pattern and proposed scour protection

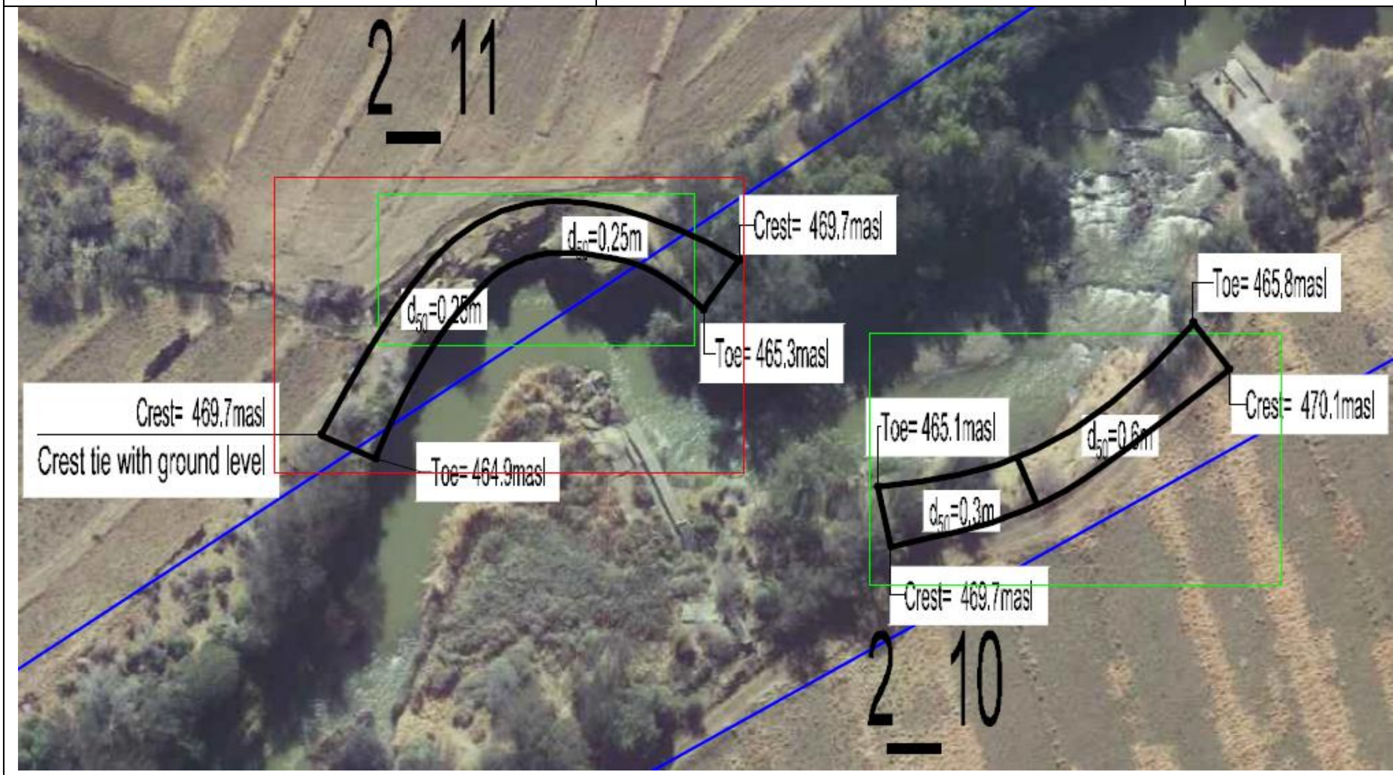




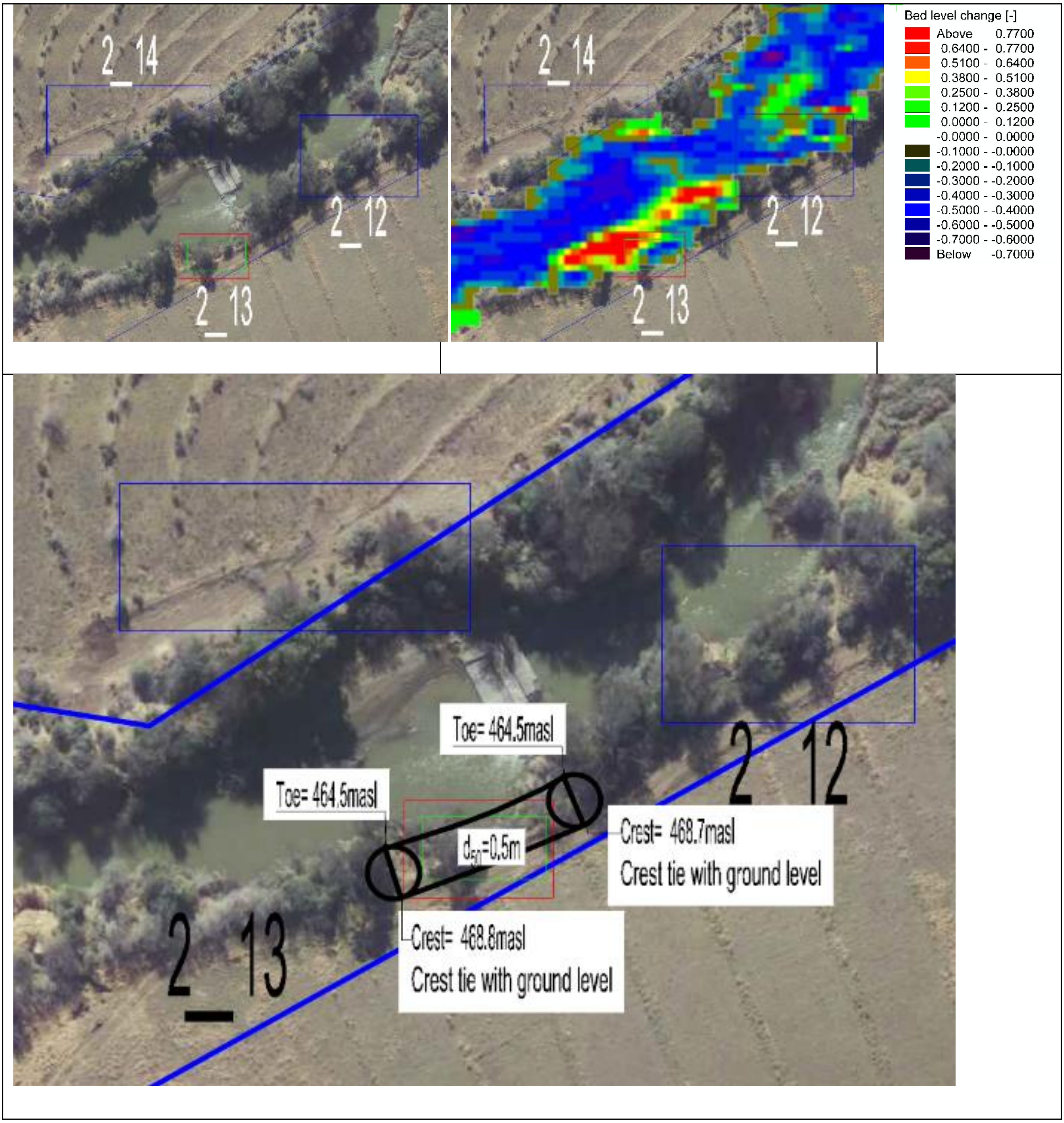
Appendix 16: Zone 2_10 and 2_11 Q10 flood peak scour pattern and proposed scour protection



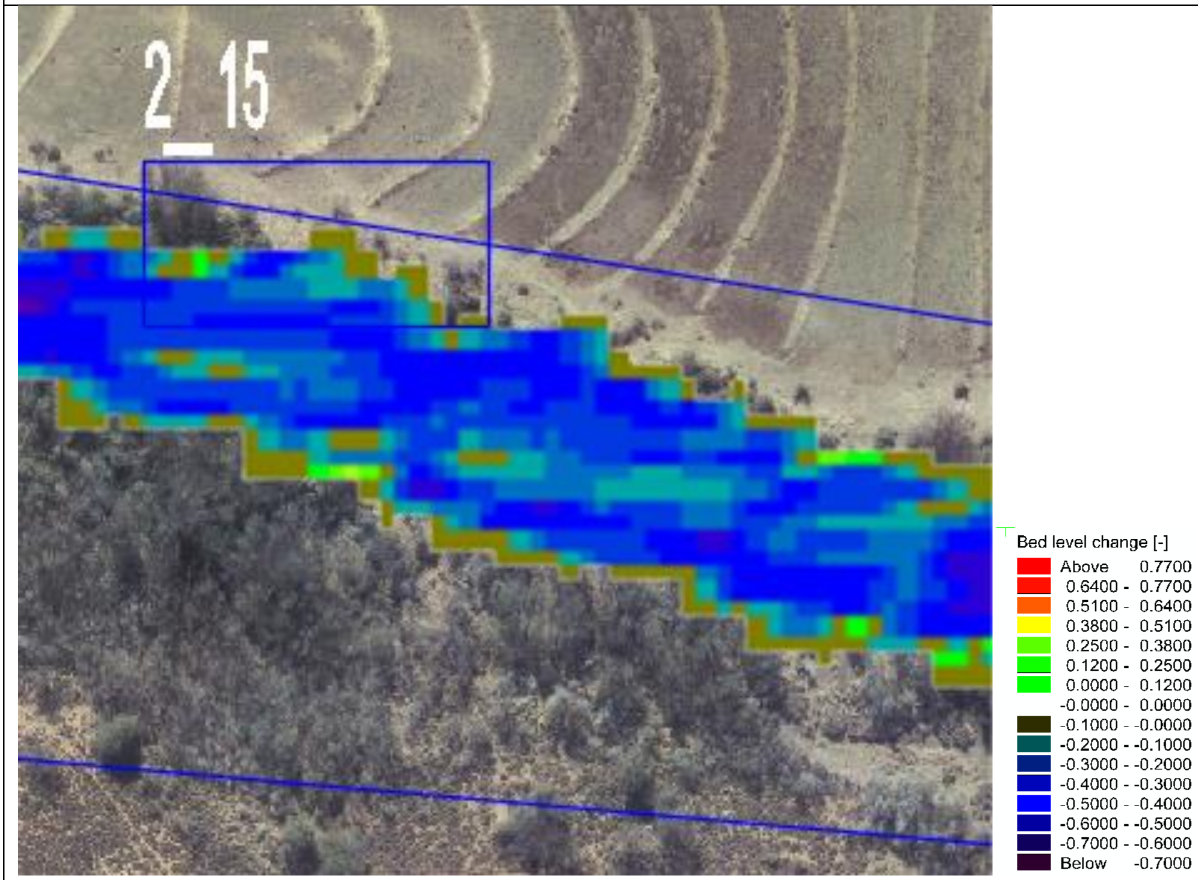




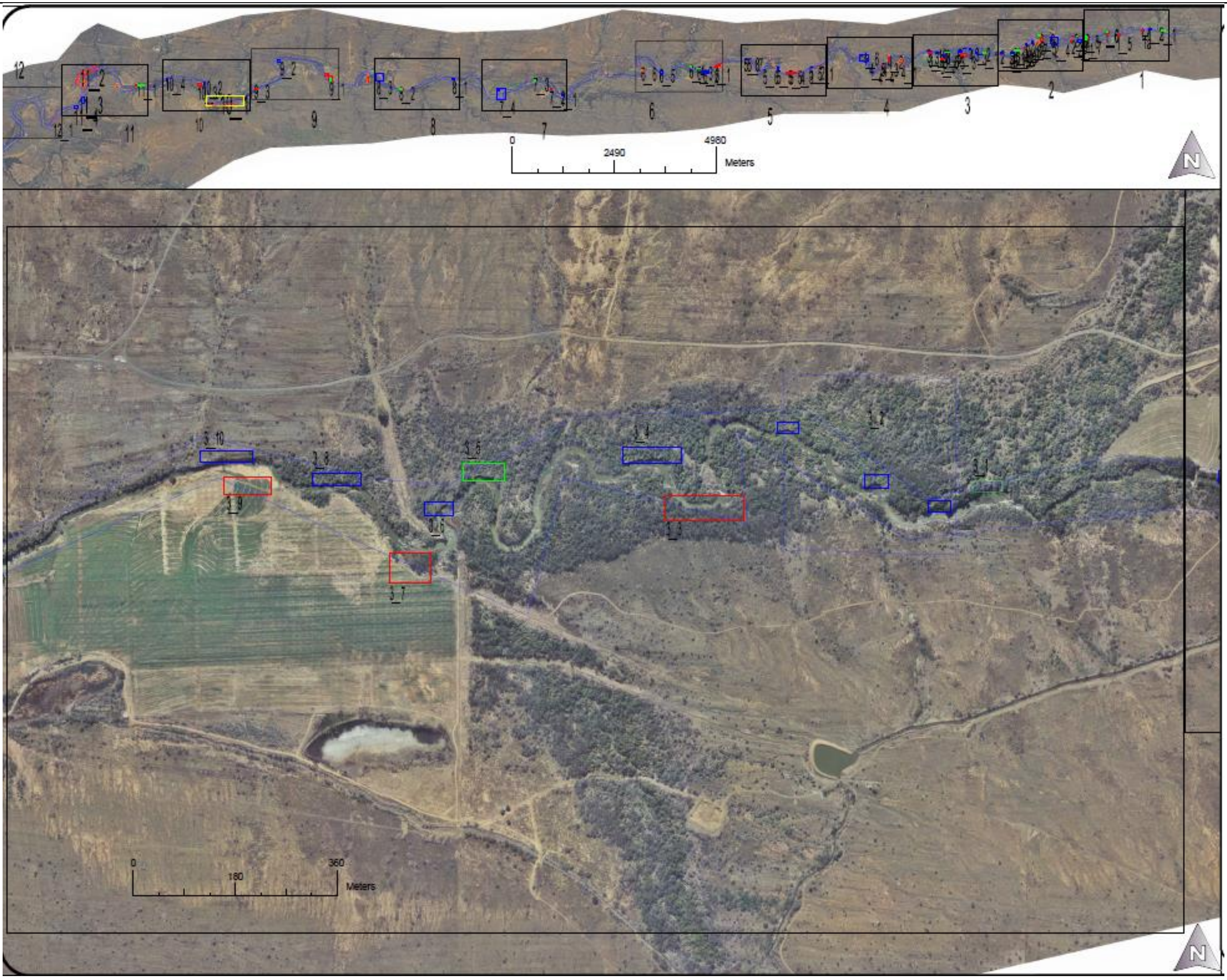
Appendix 17: Zone 2_12, 2_13 and 2_14 Q10 flood peak scour pattern and proposed scour protection

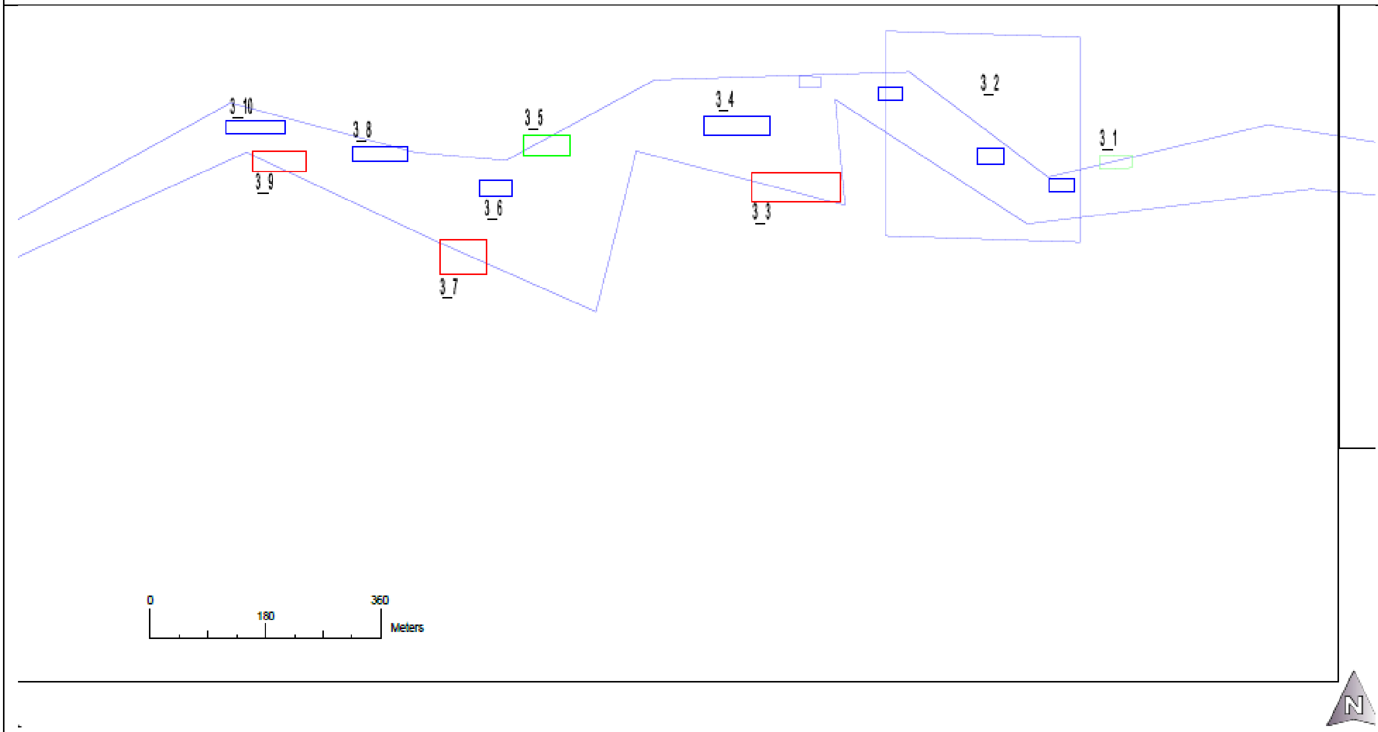


Appendix 18: Zone 2_15 Q10 flood peak scour pattern

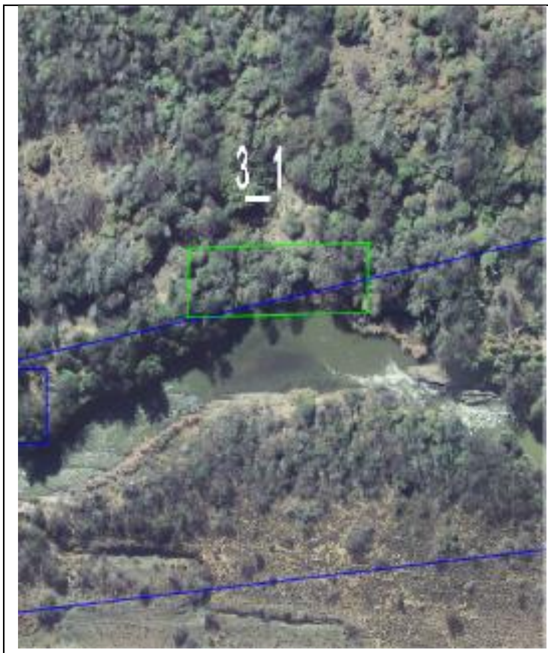


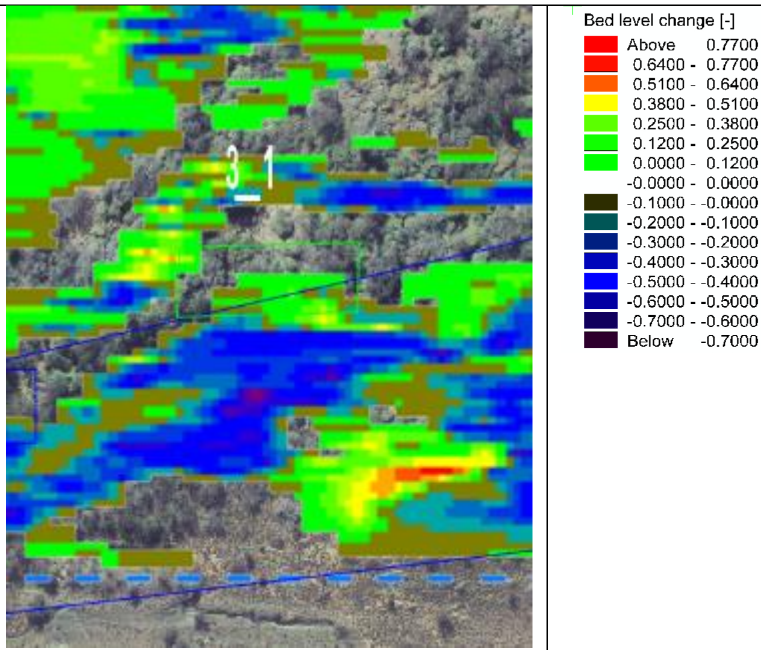
Appendix 19: Zone 3

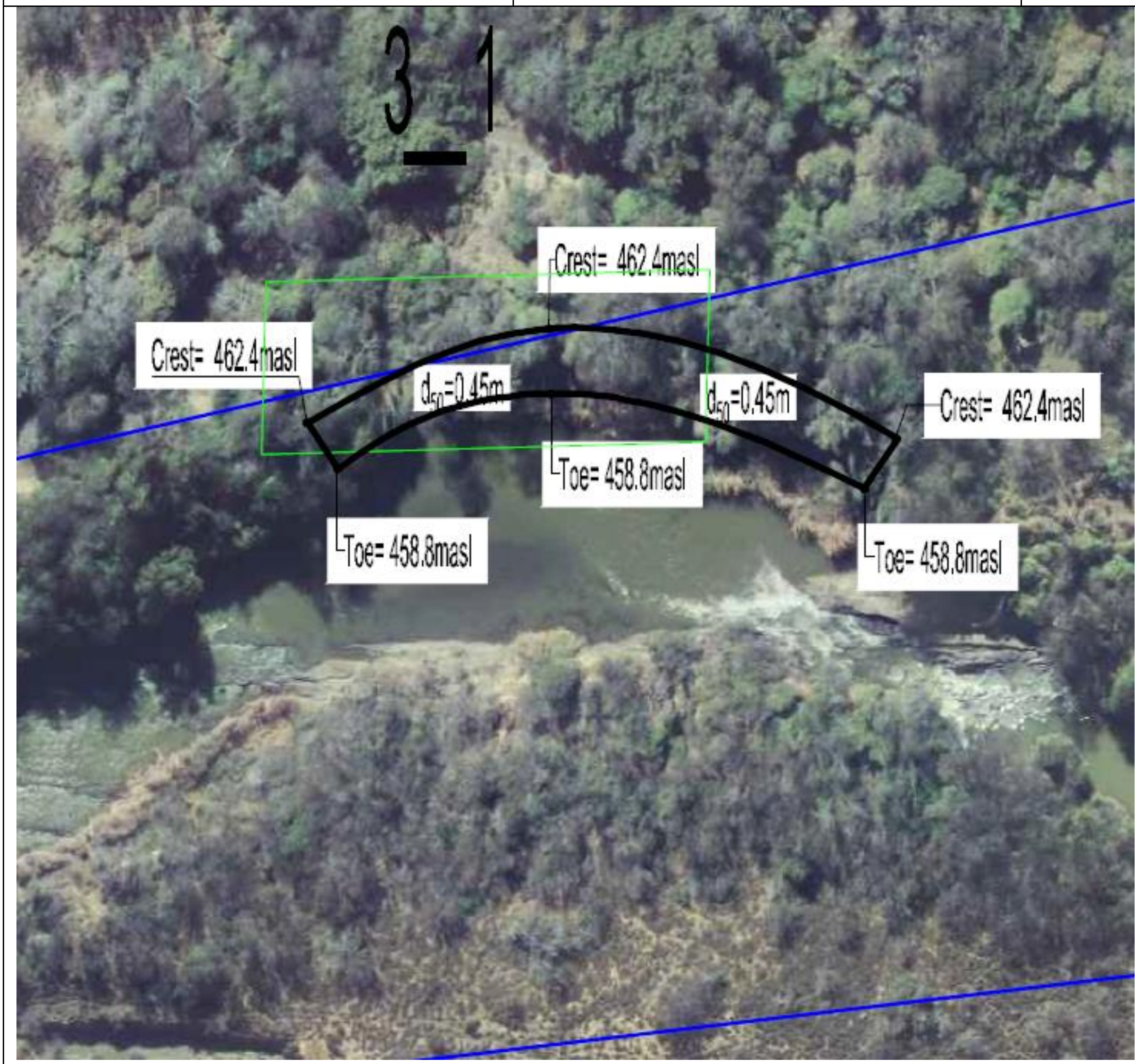




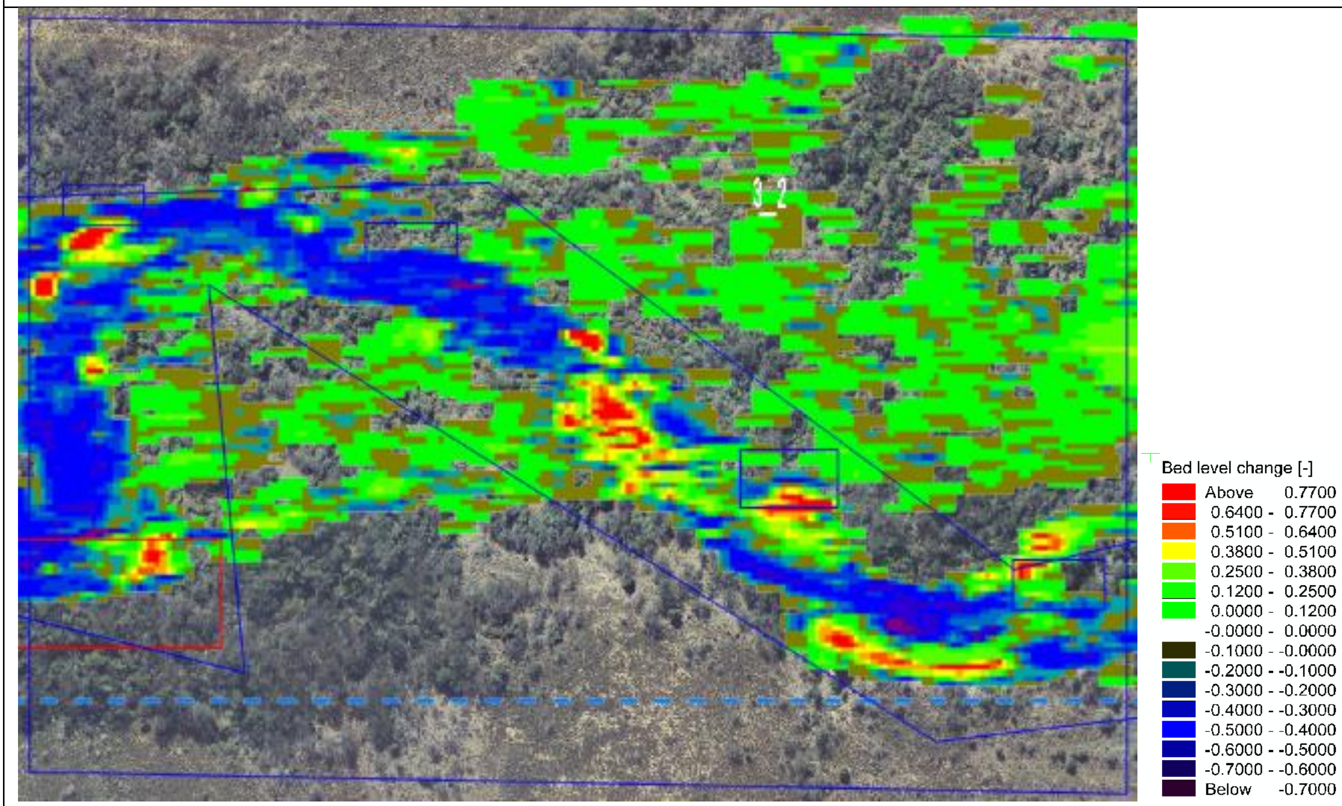
Appendix 20: Zone 3_1 Q10 flood peak scour pattern and proposed scour protection



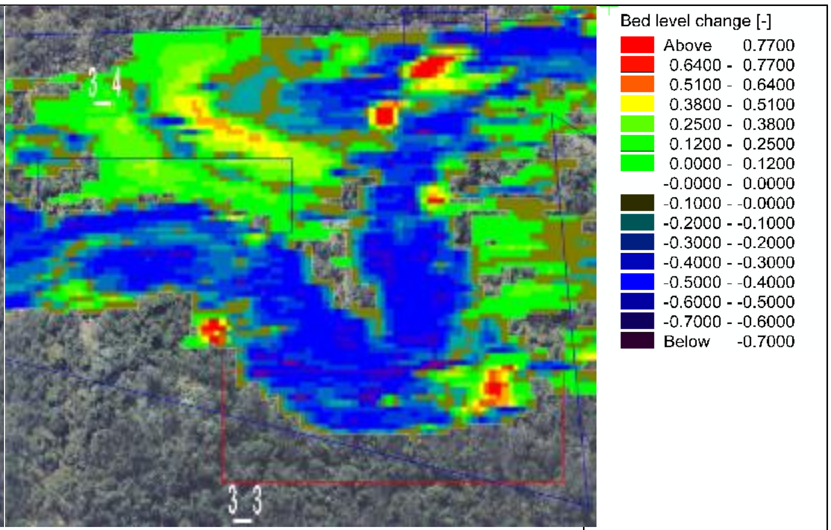


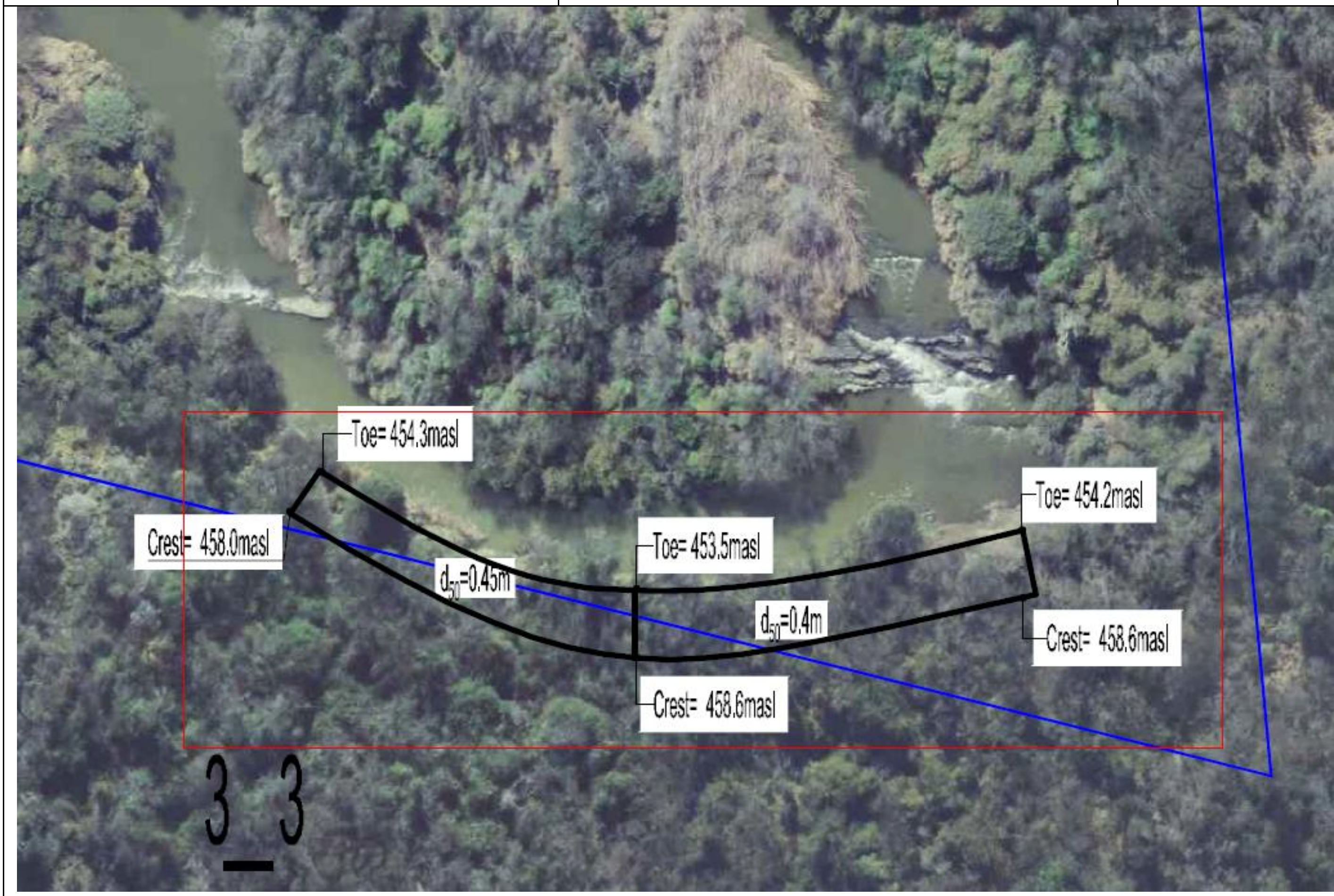


Appendix 21: Zone 3_2 Q10 flood peak scour pattern

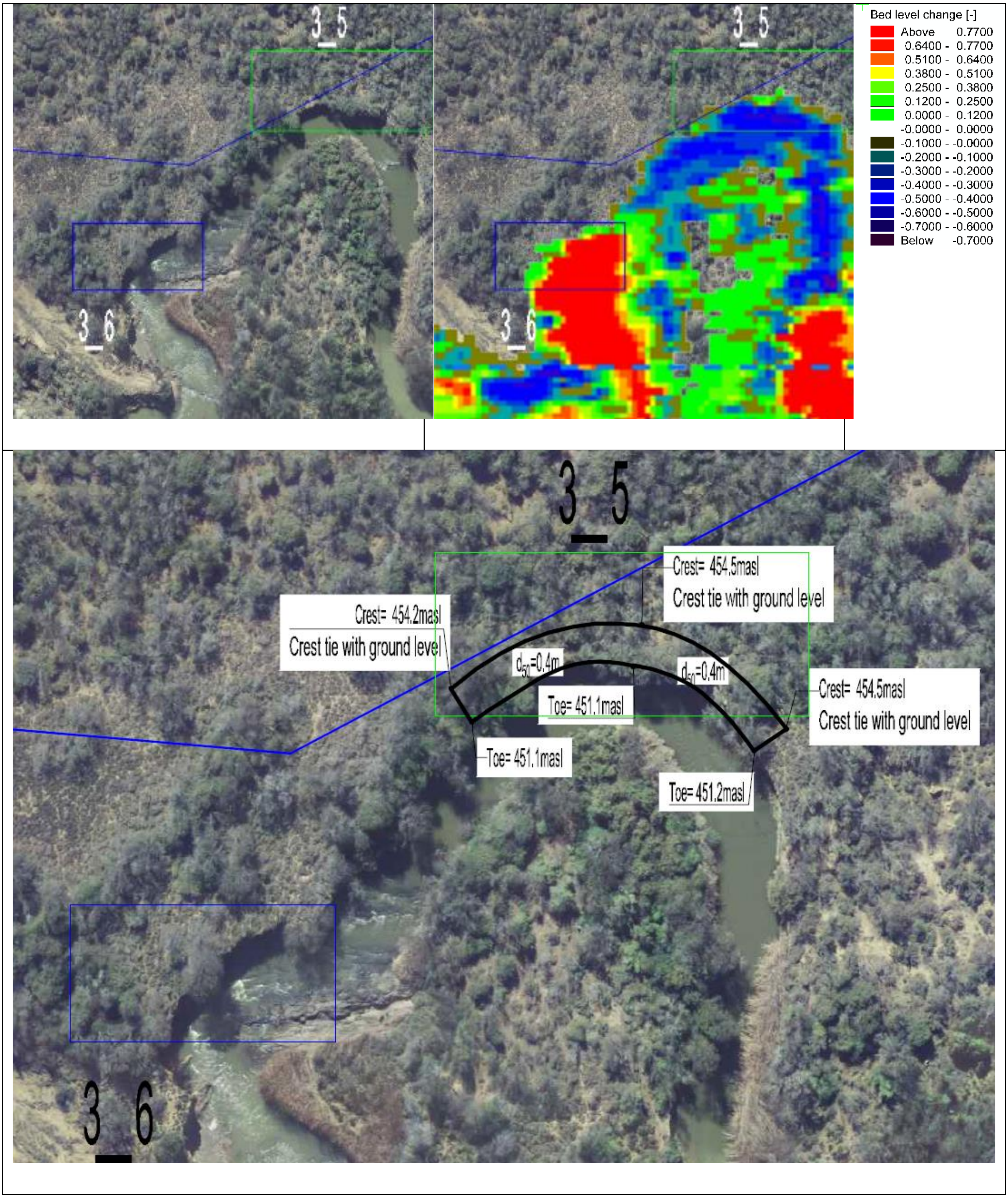


Appendix 22: Zone 3_3 and 3_4 Q10 flood peak scour pattern and proposed scour protection

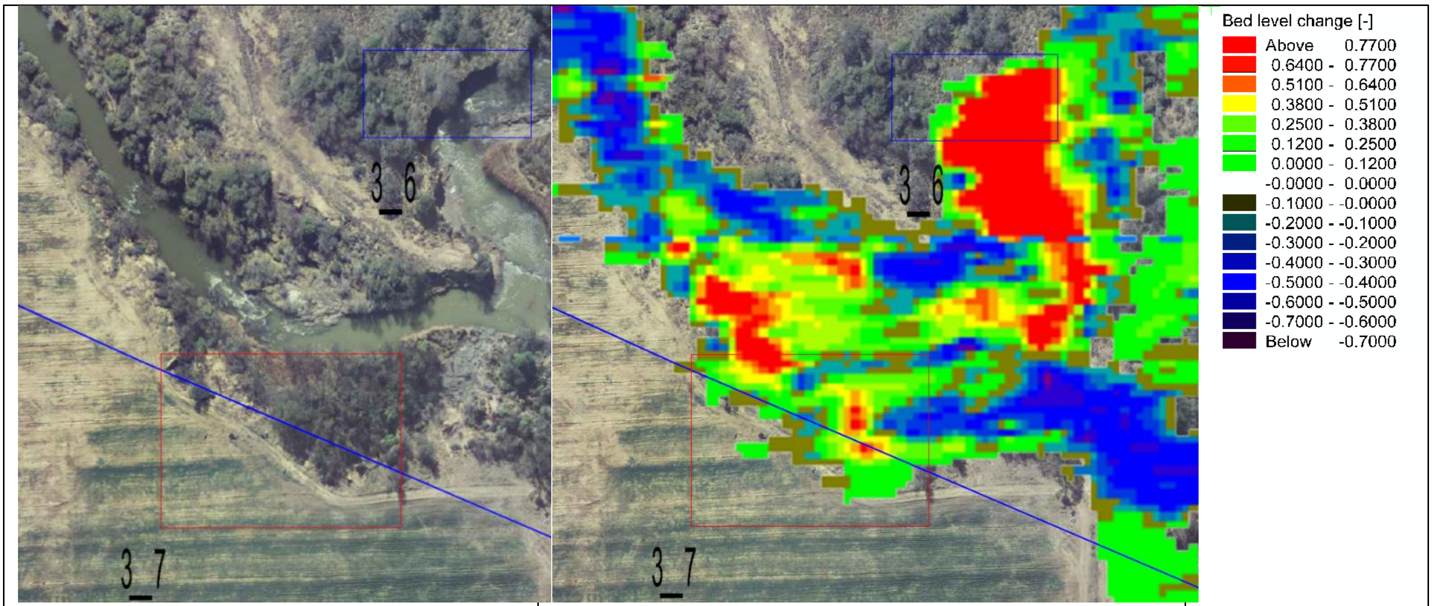


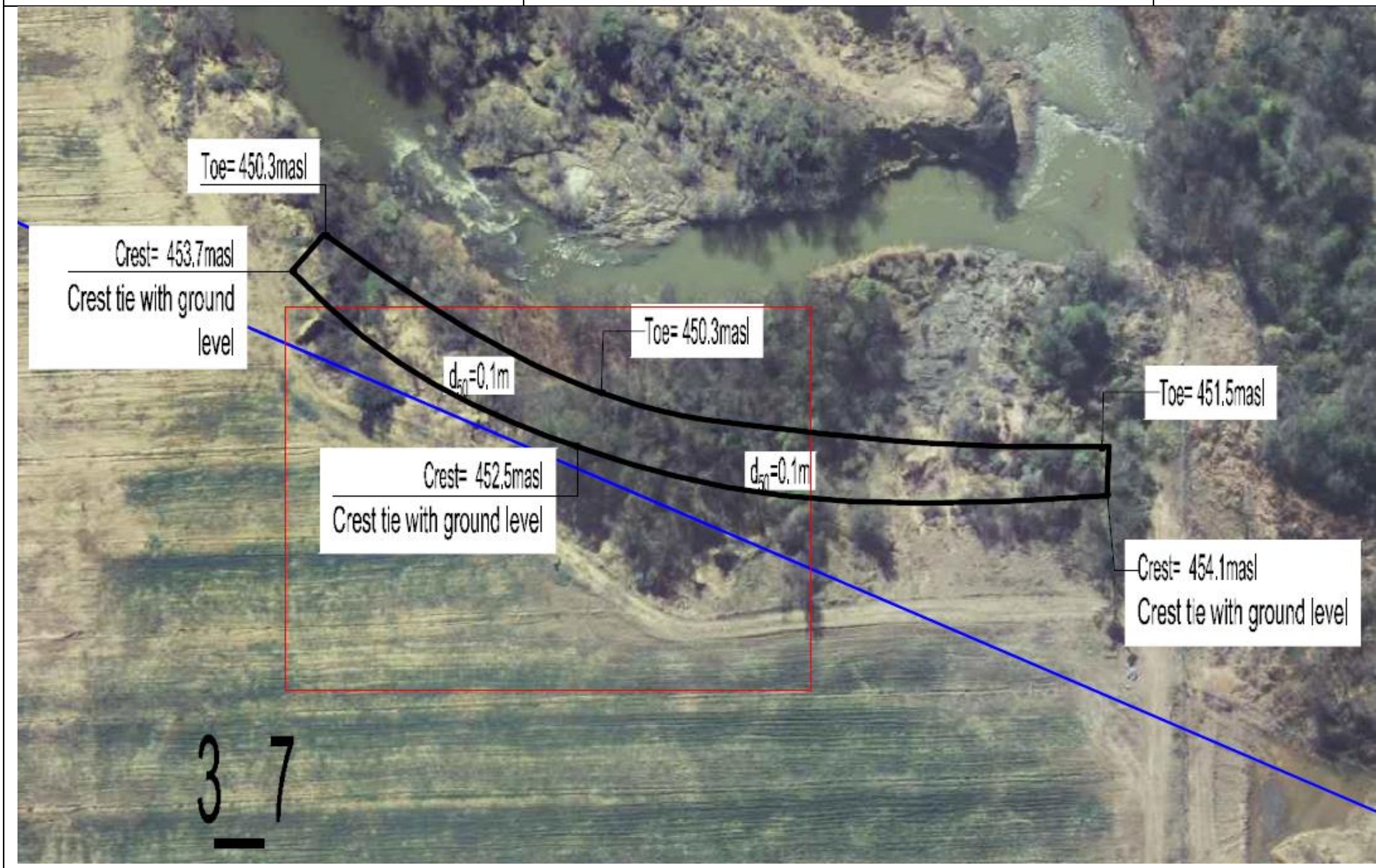


Appendix 23: Zone 3_5 and 3_6 Q10 flood peak scour pattern and proposed scour protection

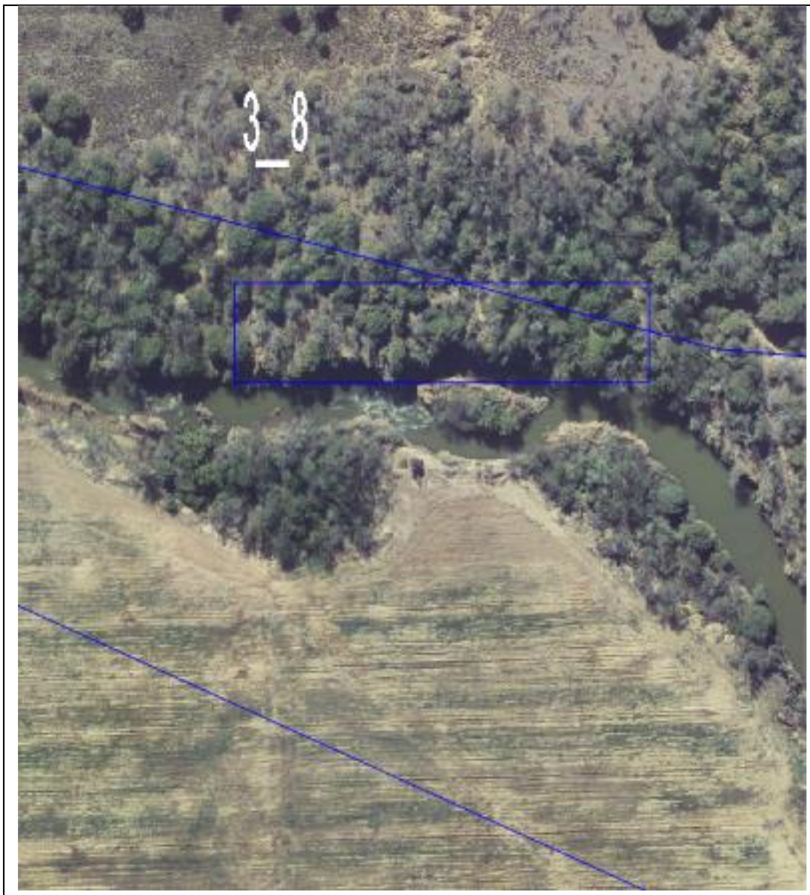


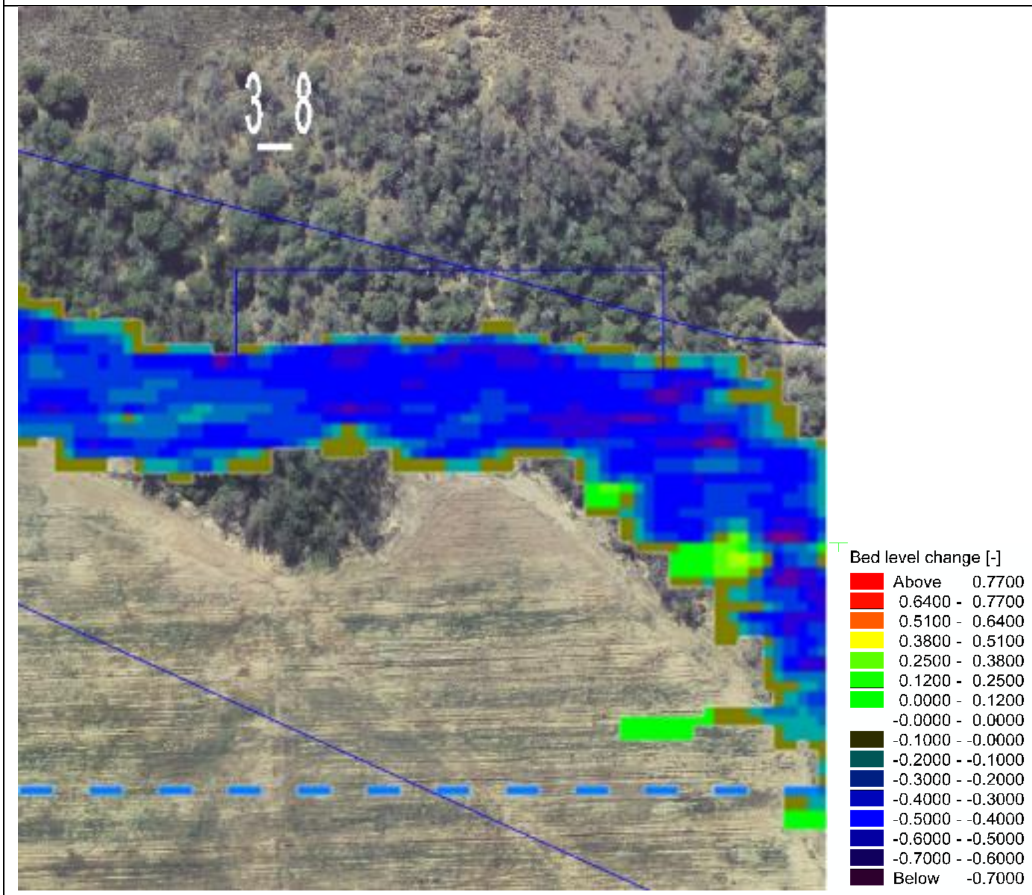
Appendix 24: Zone 3_6 and 3_7 Q10 flood peak scour pattern and proposed scour protection



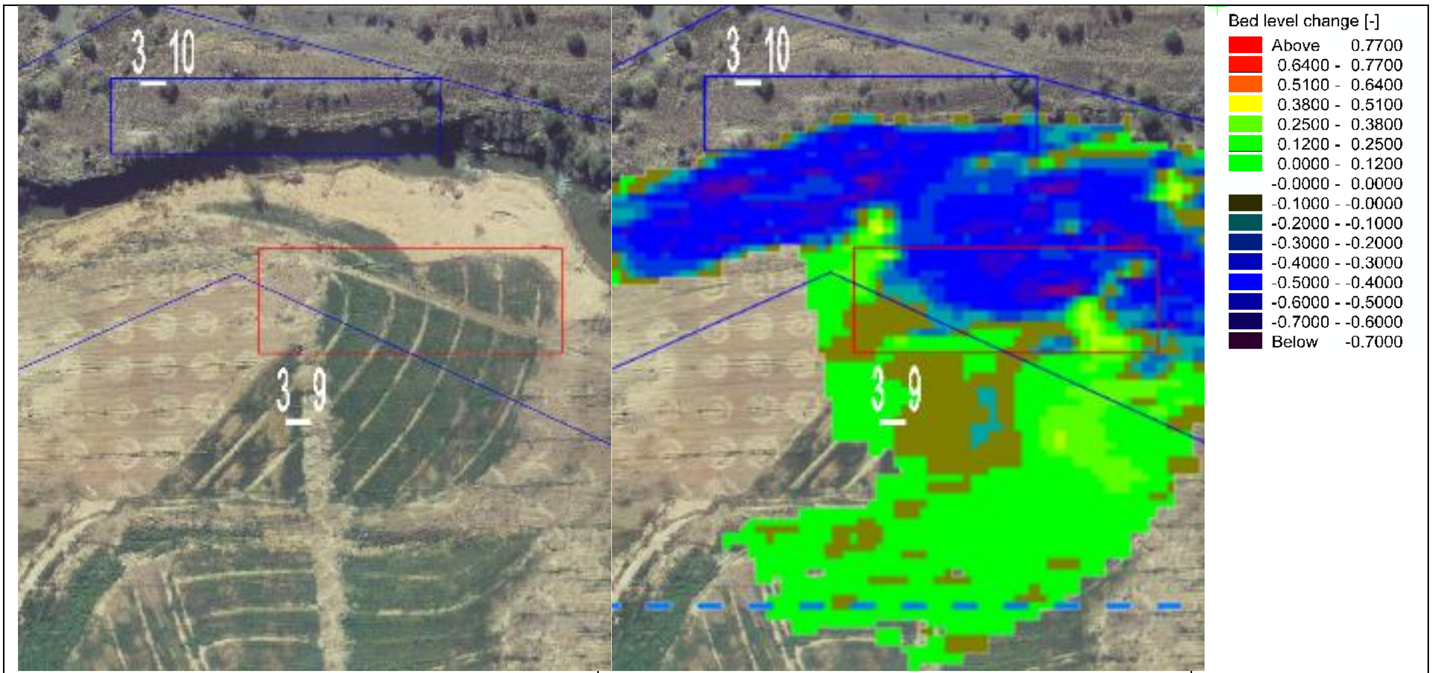


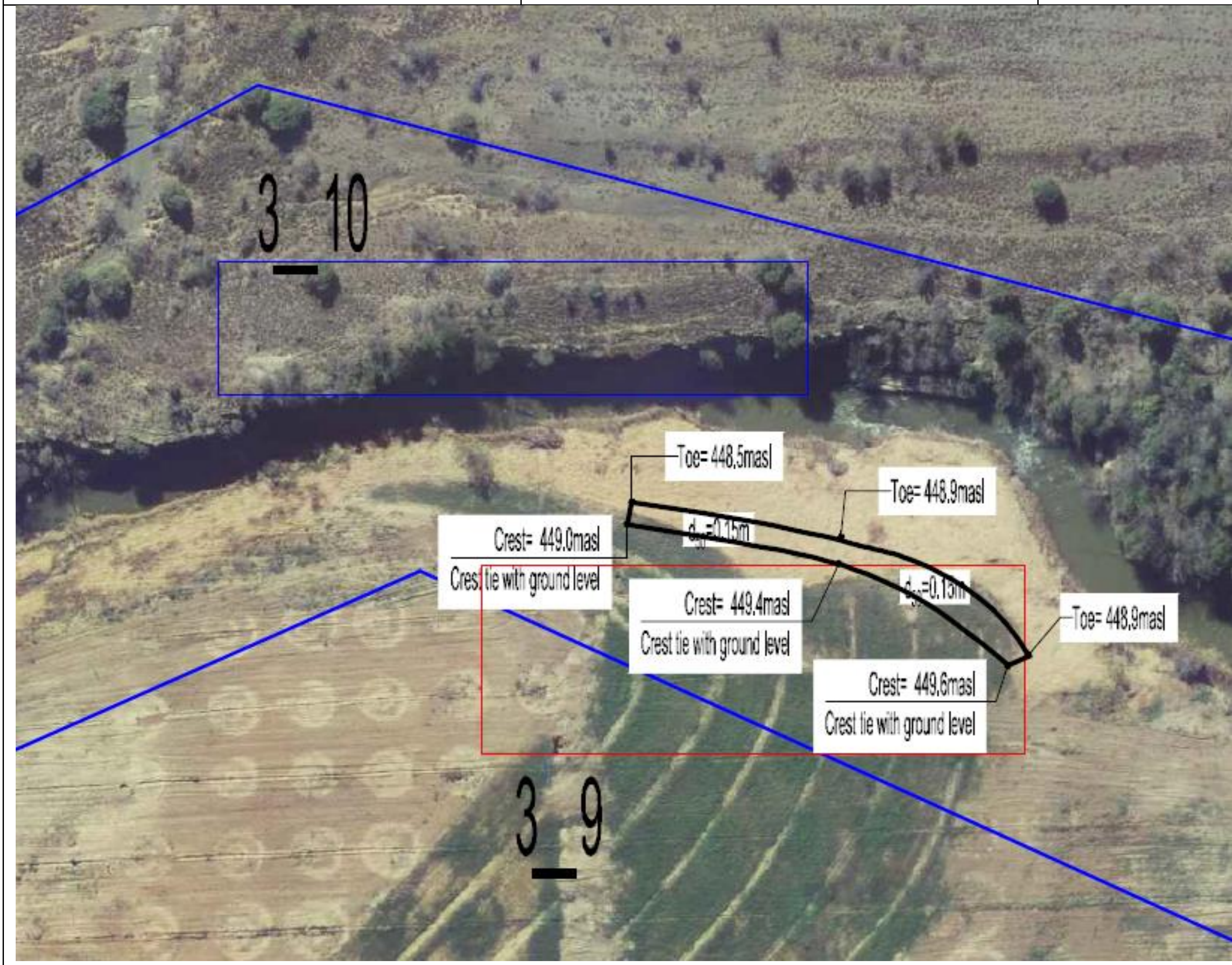
Appendix 25: Zone 3_8 Q10 flood peak scour pattern and proposed scour protection



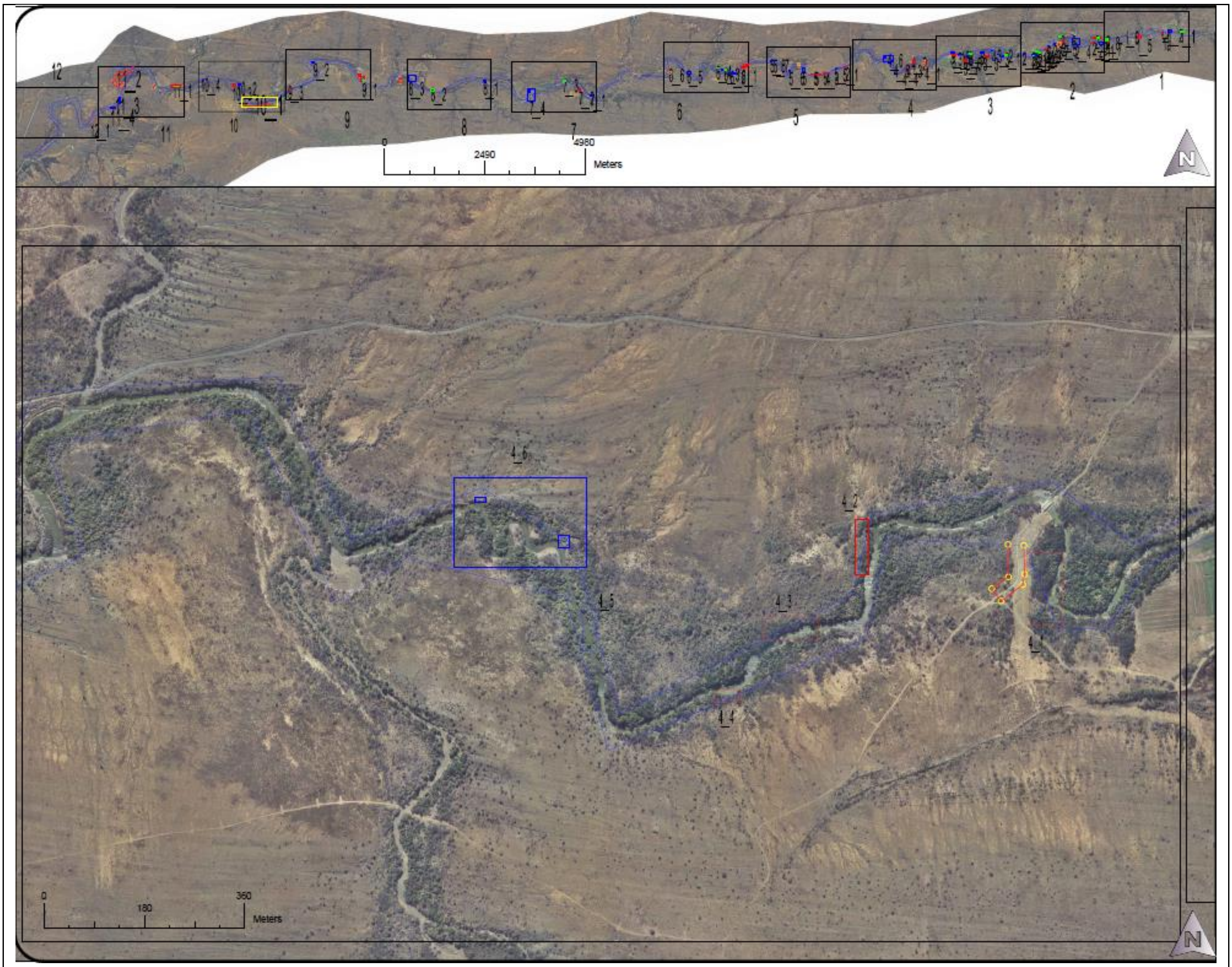


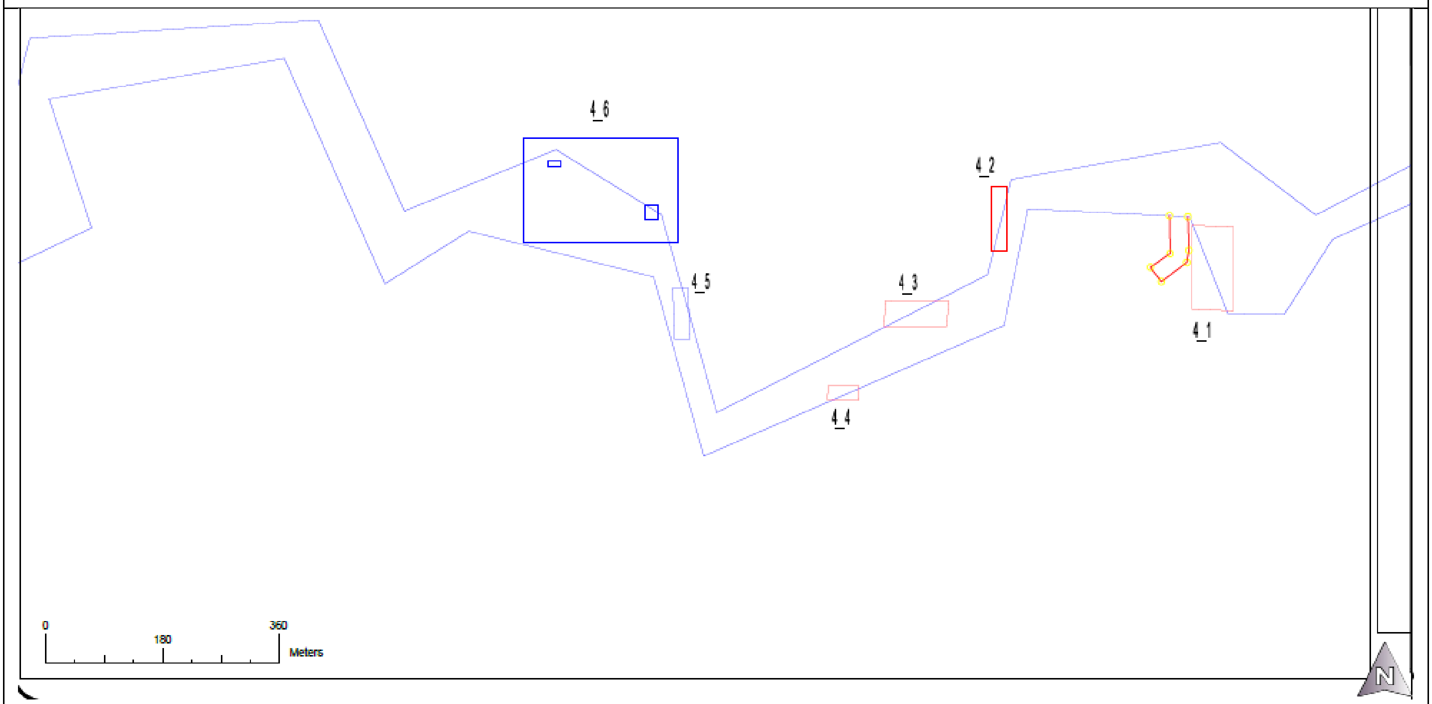
Appendix 26: Zone 3_9 and 3_10 Q10 flood peak scour pattern and proposed scour protection



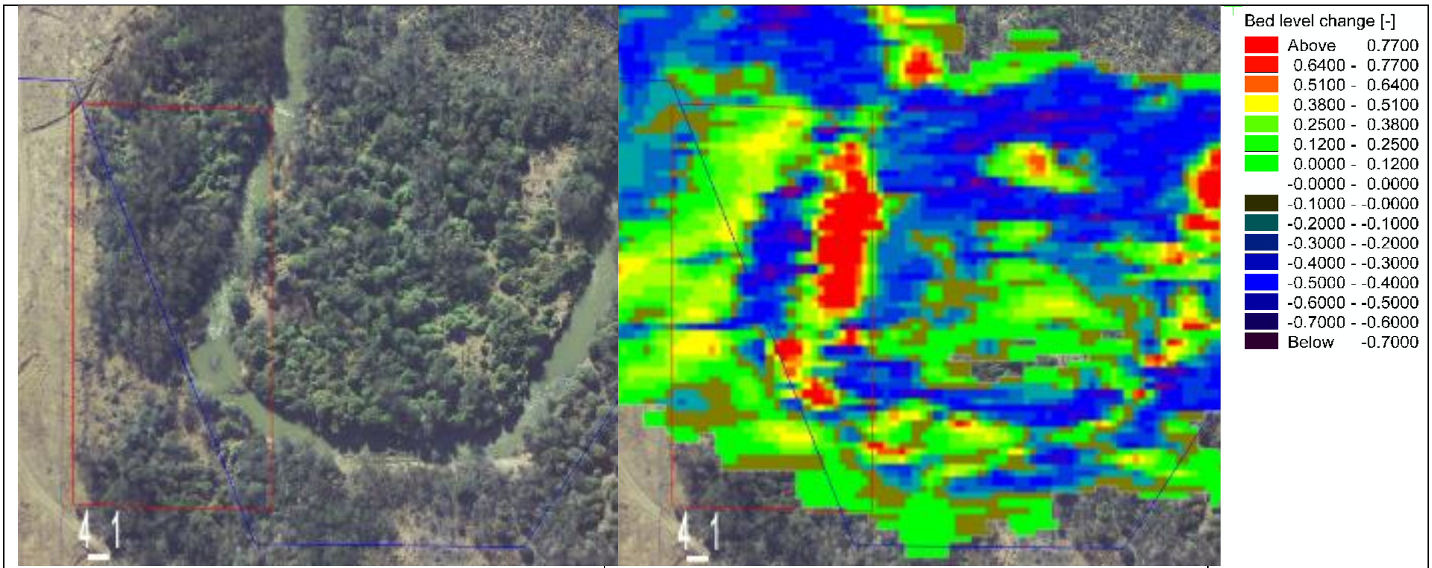


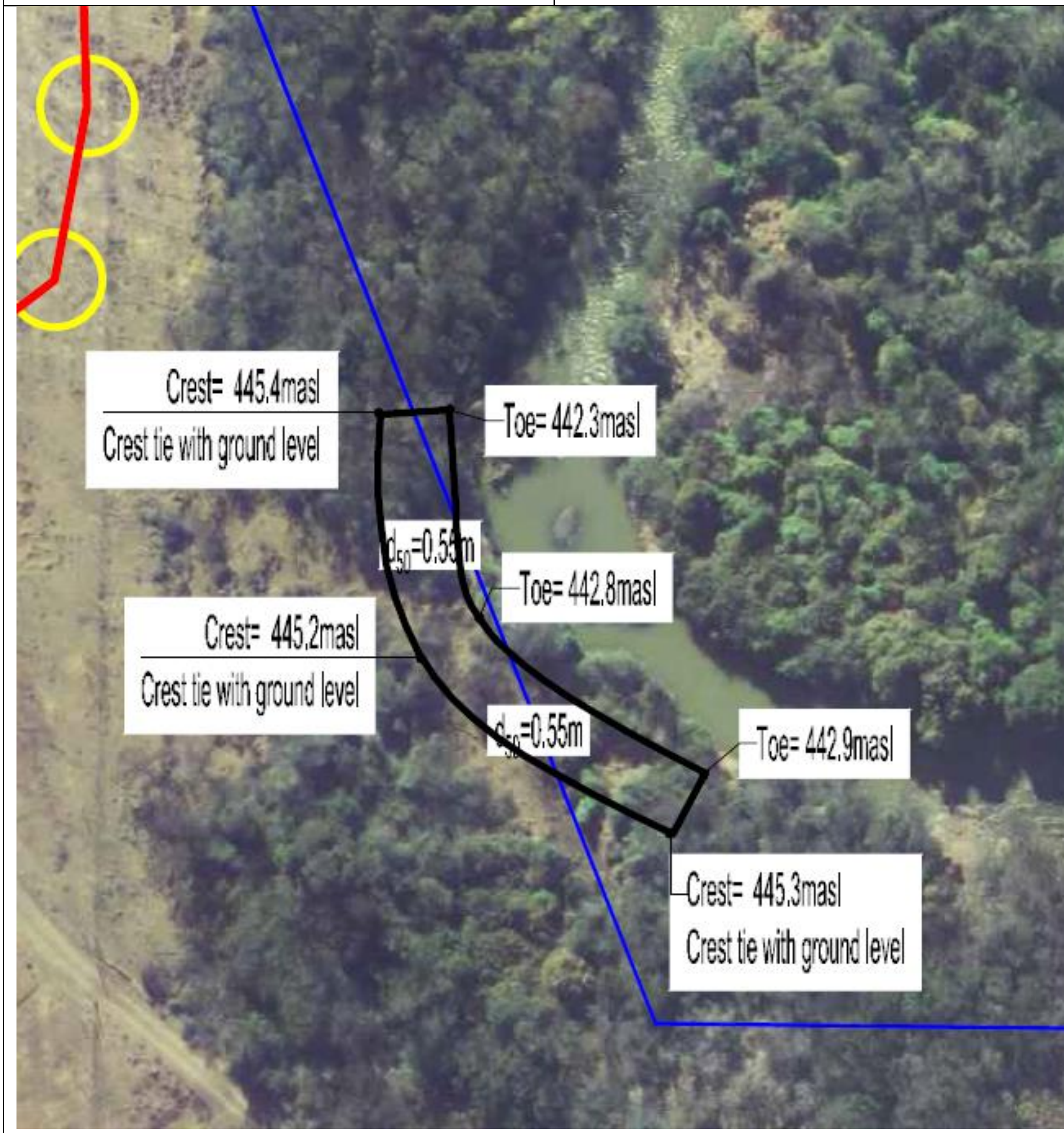
Appendix 27: Zone 4



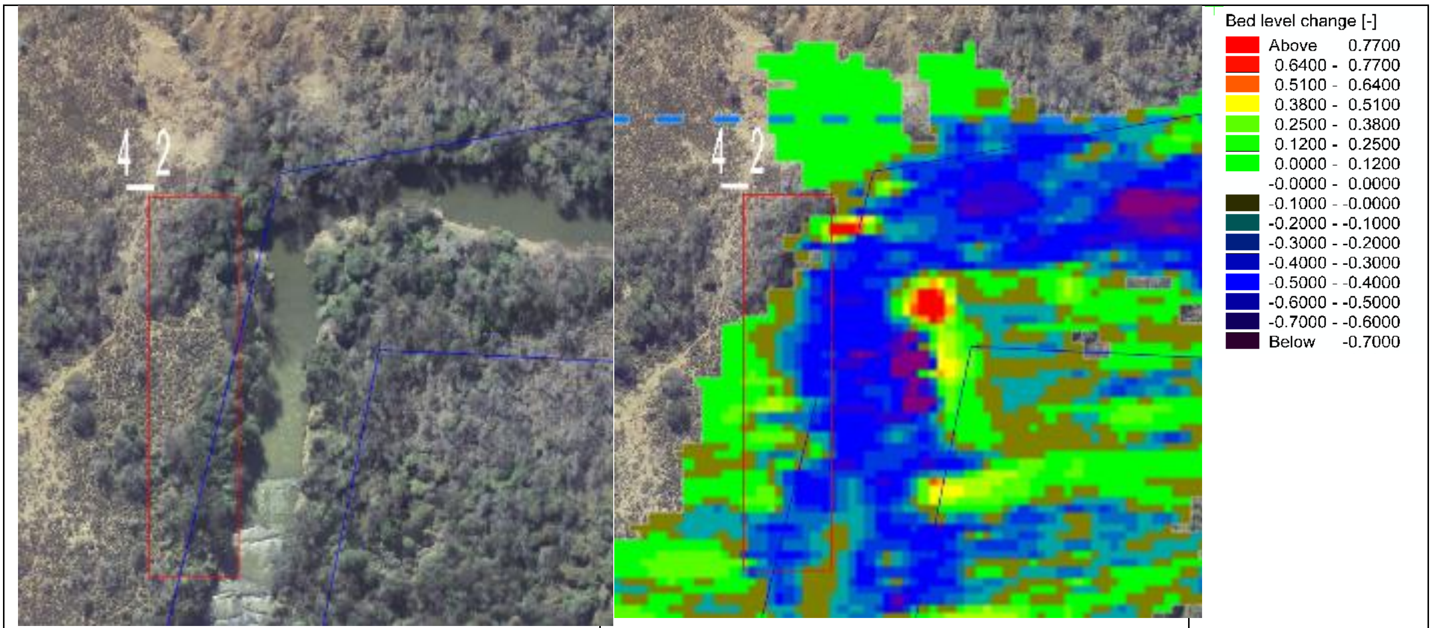


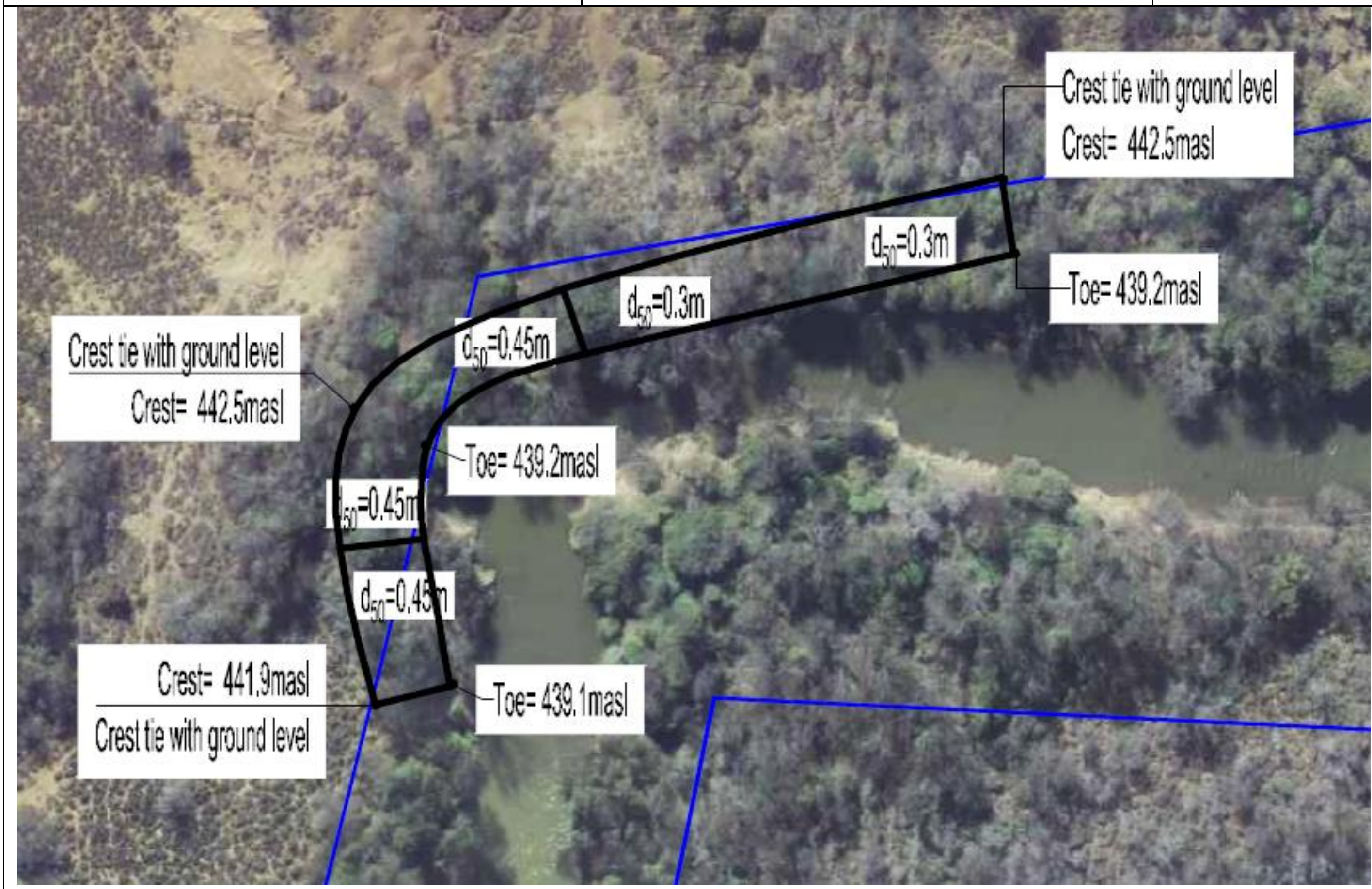
Appendix 28: Zone 4_1 Q10 flood peak scour pattern and proposed scour protection



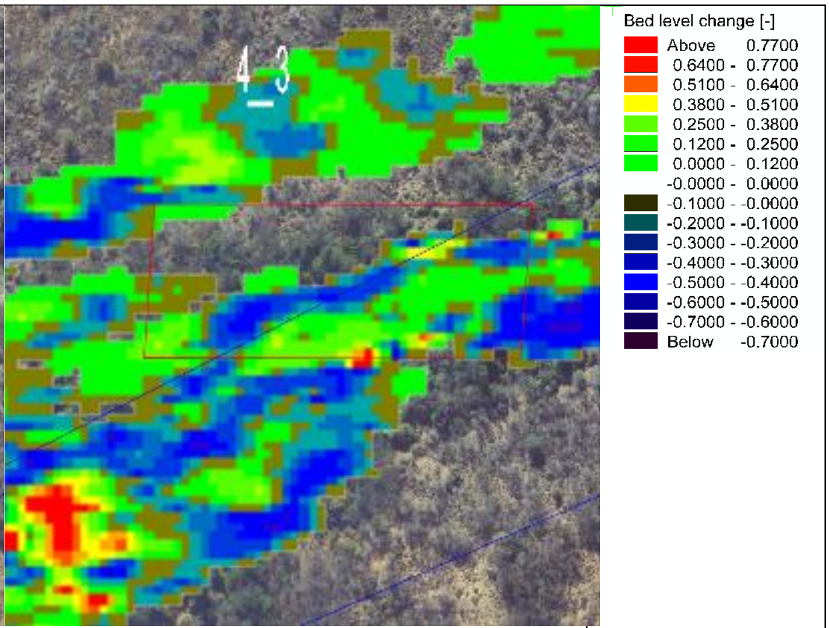


Appendix 29: Zone 4_2 Q10 flood peak scour pattern and proposed scour protection

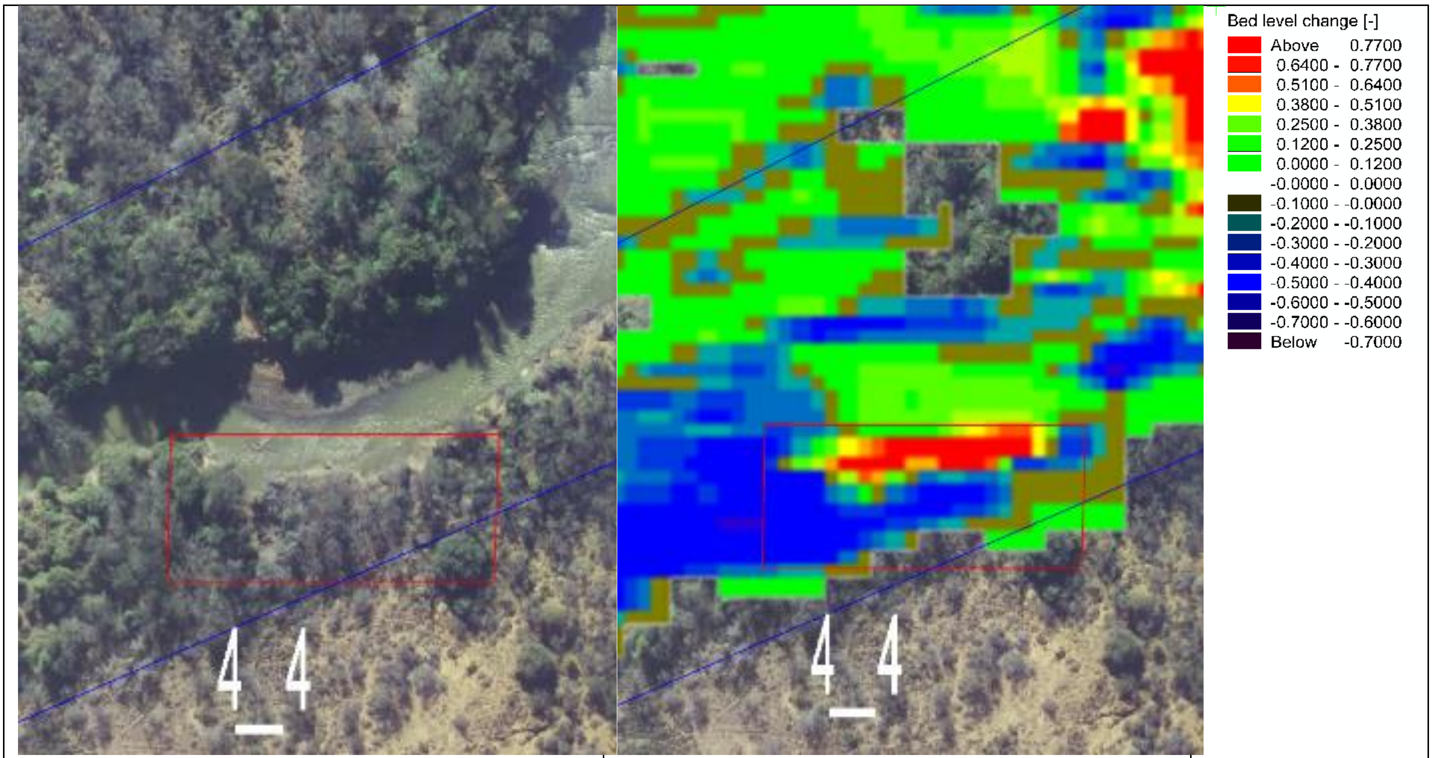




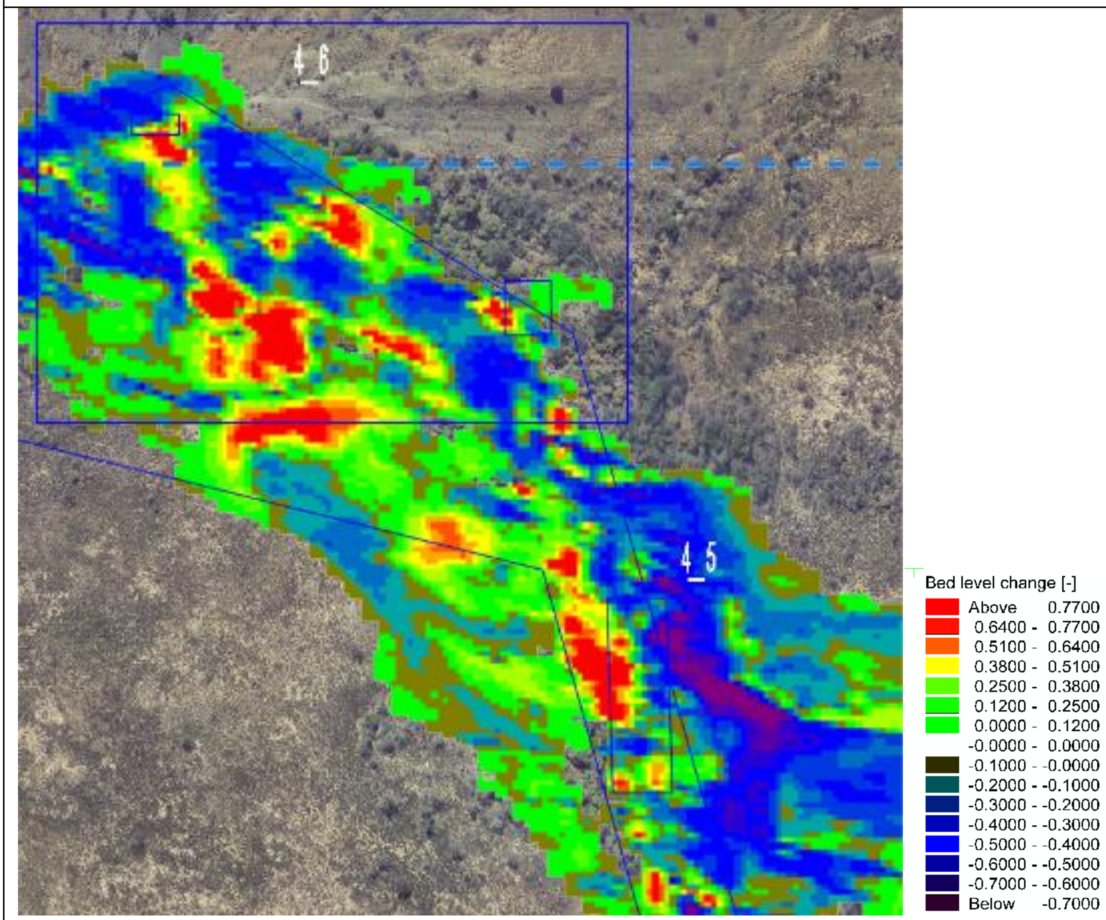
Appendix 30: Zone 4_3 Q10 flood peak scour pattern and proposed scour protection



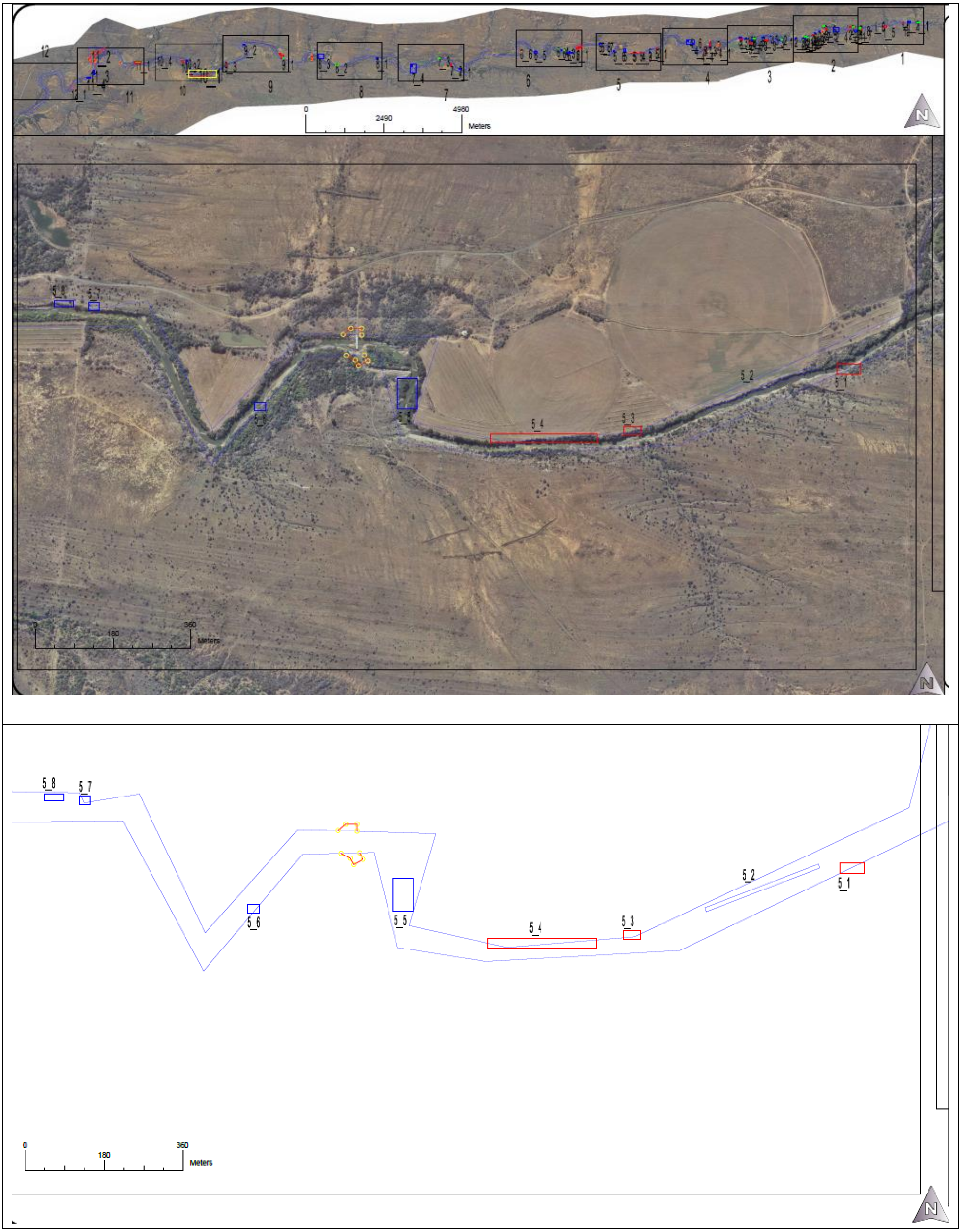
Appendix 31: Zone 4_4 Q10 flood peak scour pattern and proposed scour protection



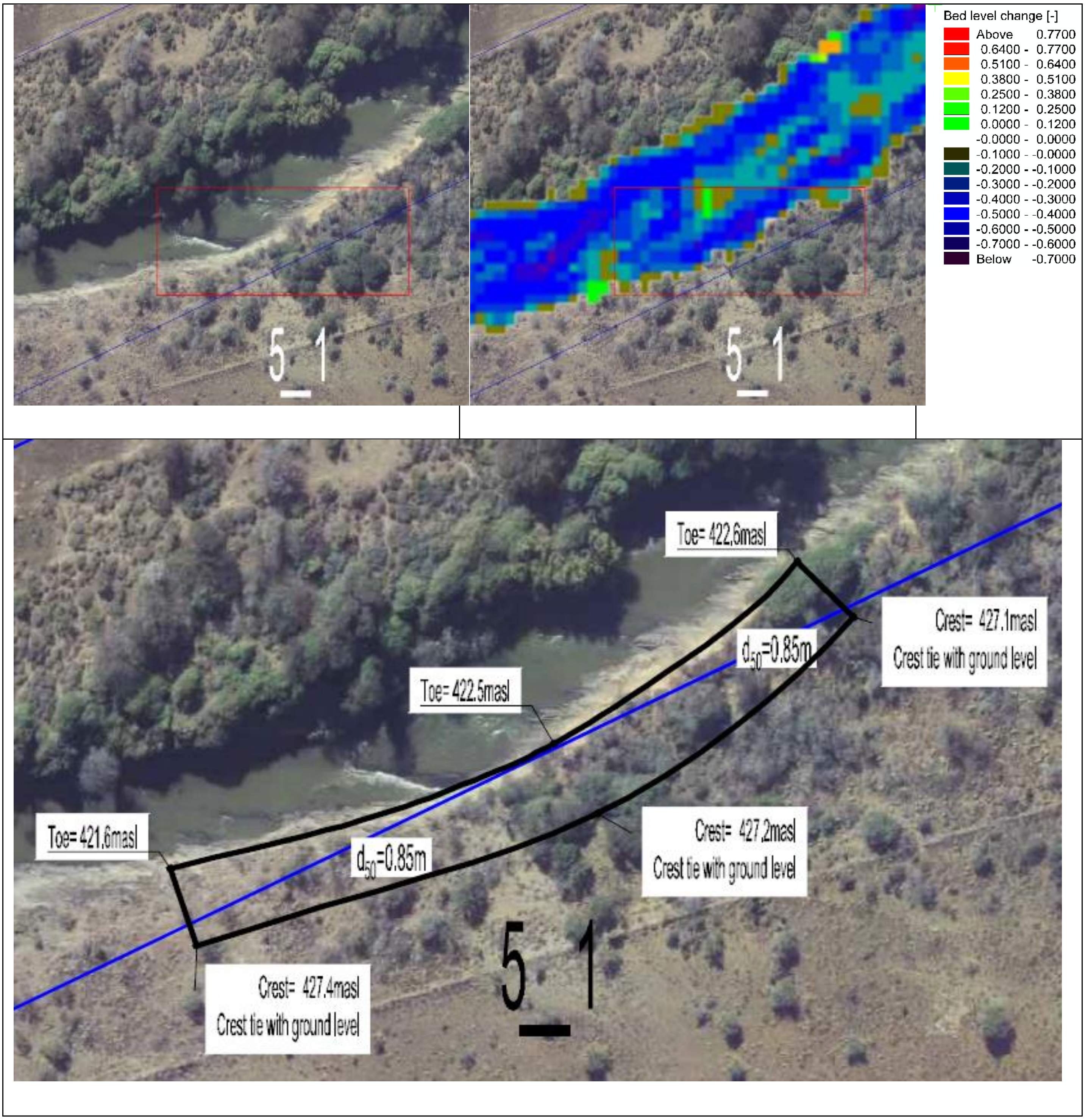
Appendix 32: Zone 4_5 and 4_6 Q10 flood peak scour pattern and proposed scour protection



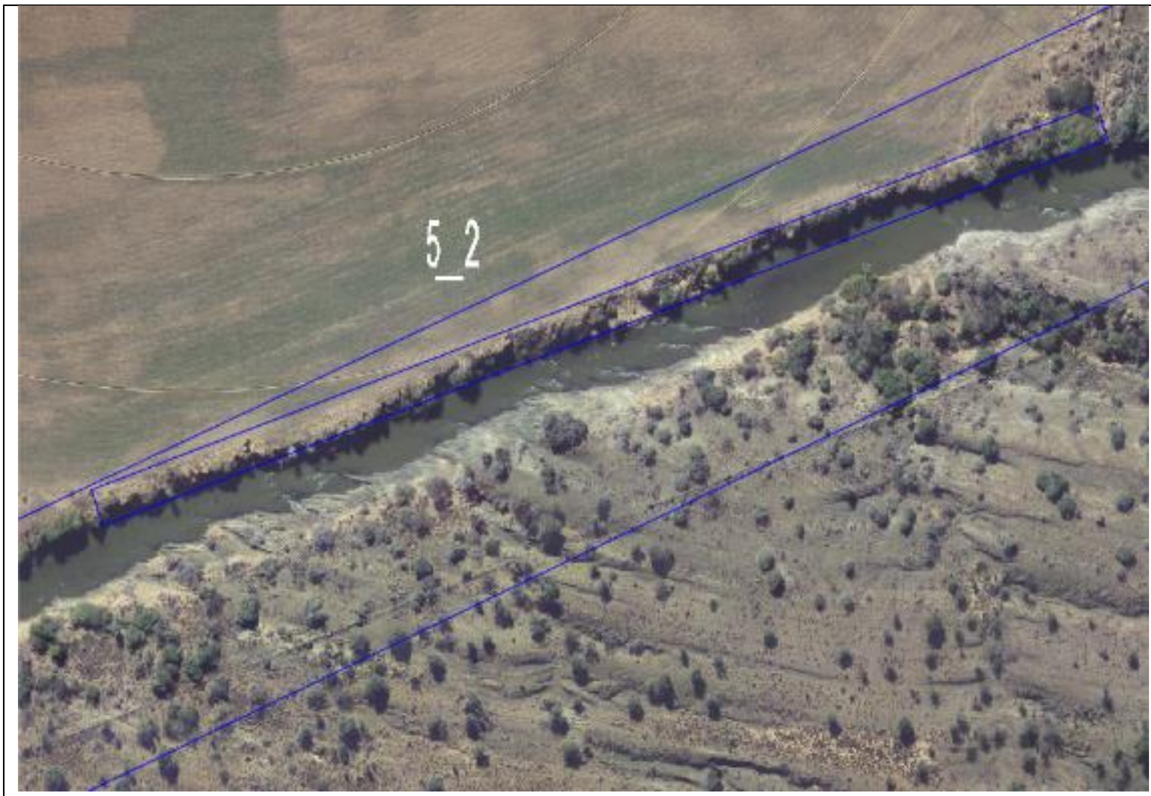
Appendix 33: Zone 5

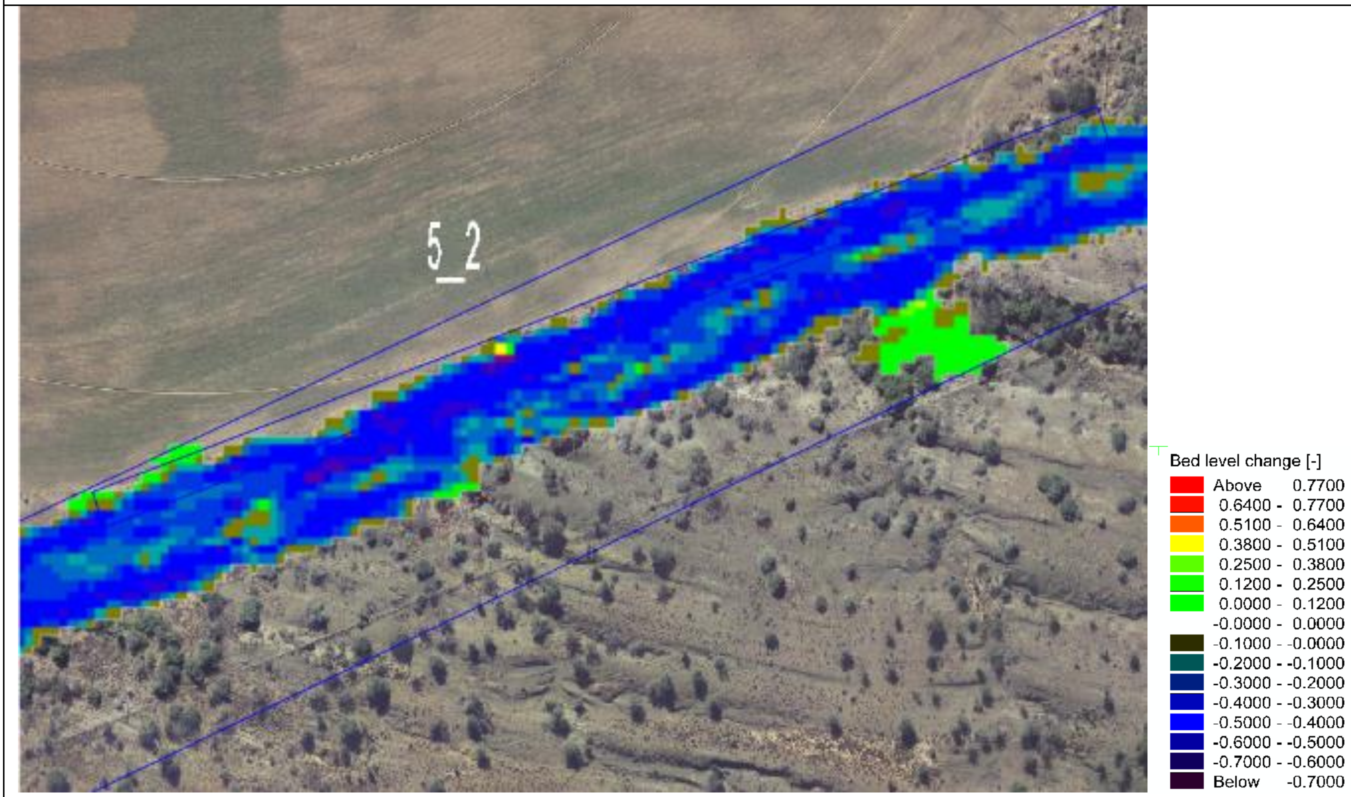


Appendix 34: Zone 5_1 Q10 flood peak scour pattern and proposed scour protection

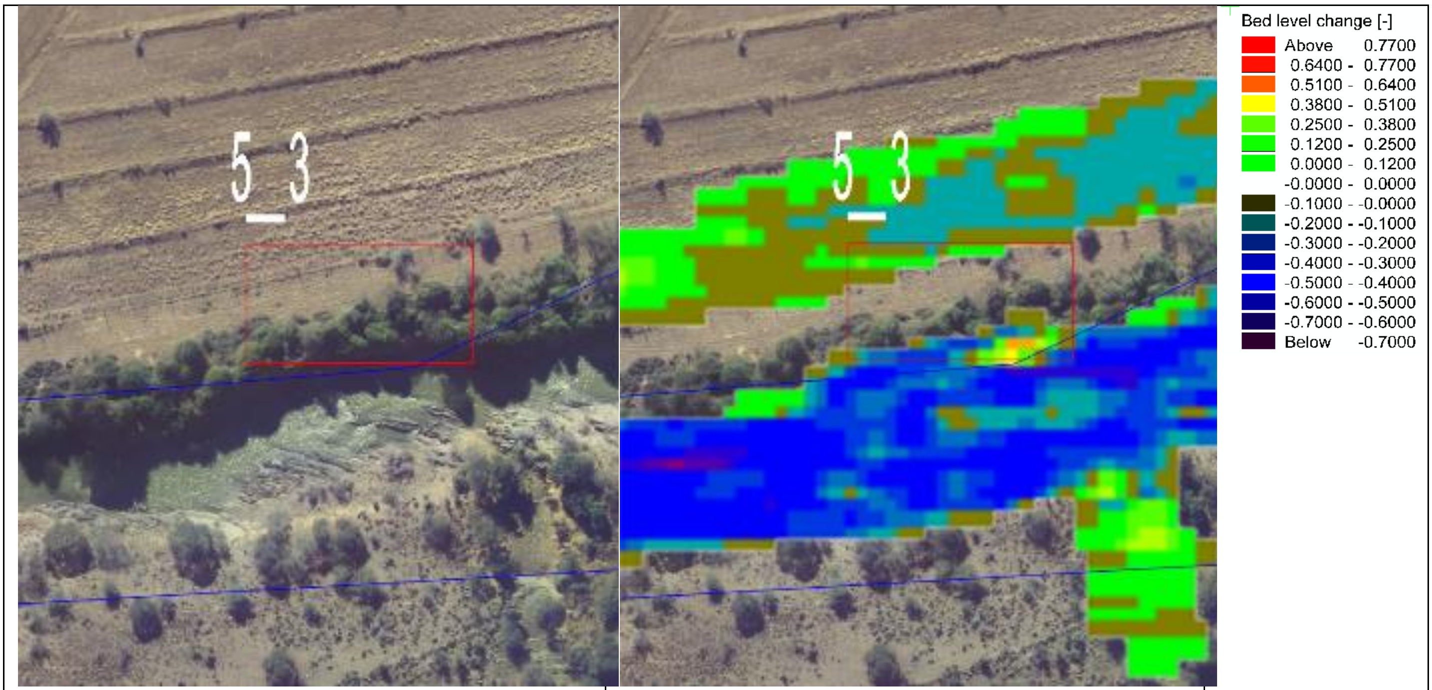


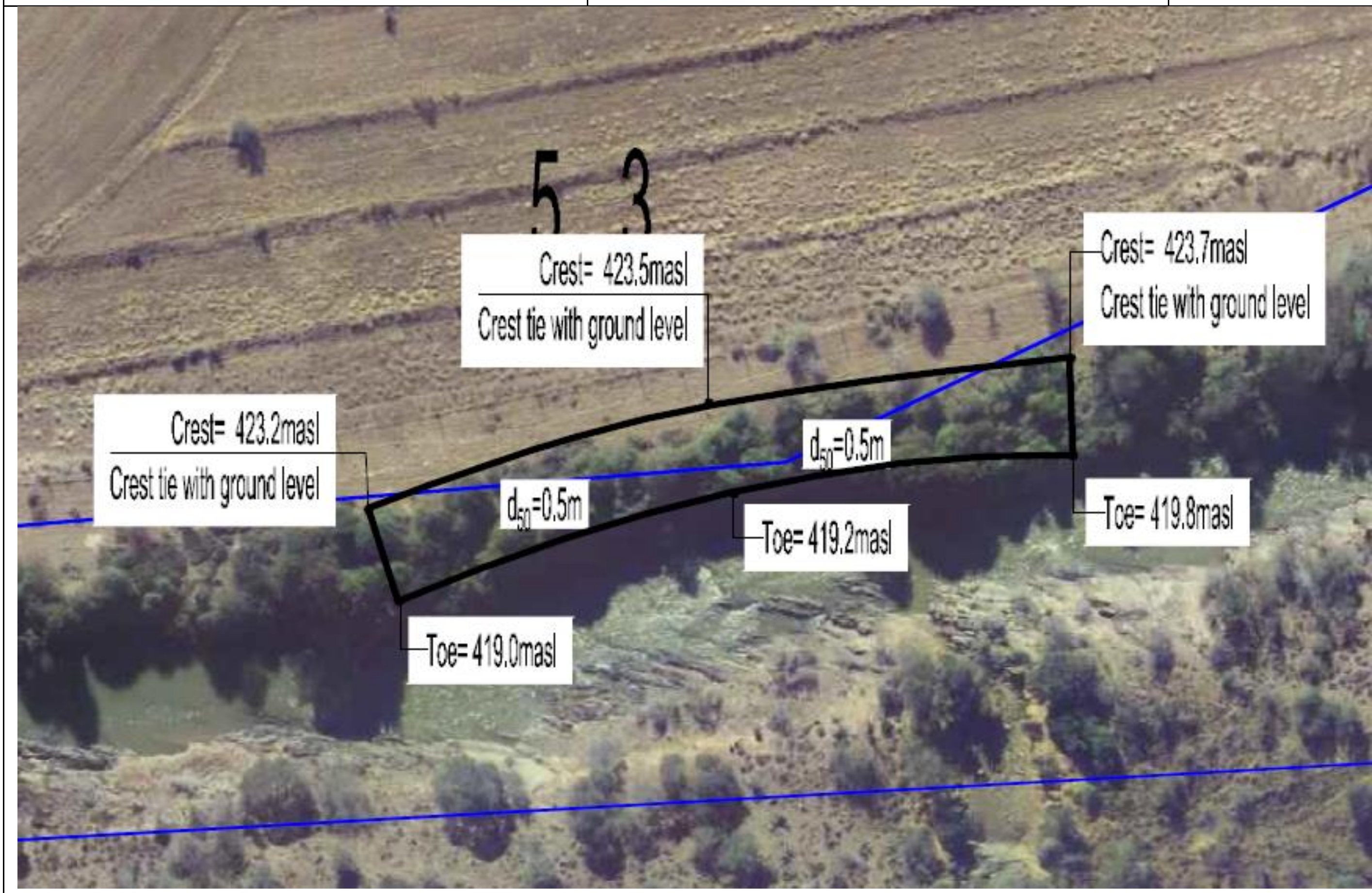
Appendix 35: Zone 5_2 Q10 flood peak scour pattern and proposed scour protection



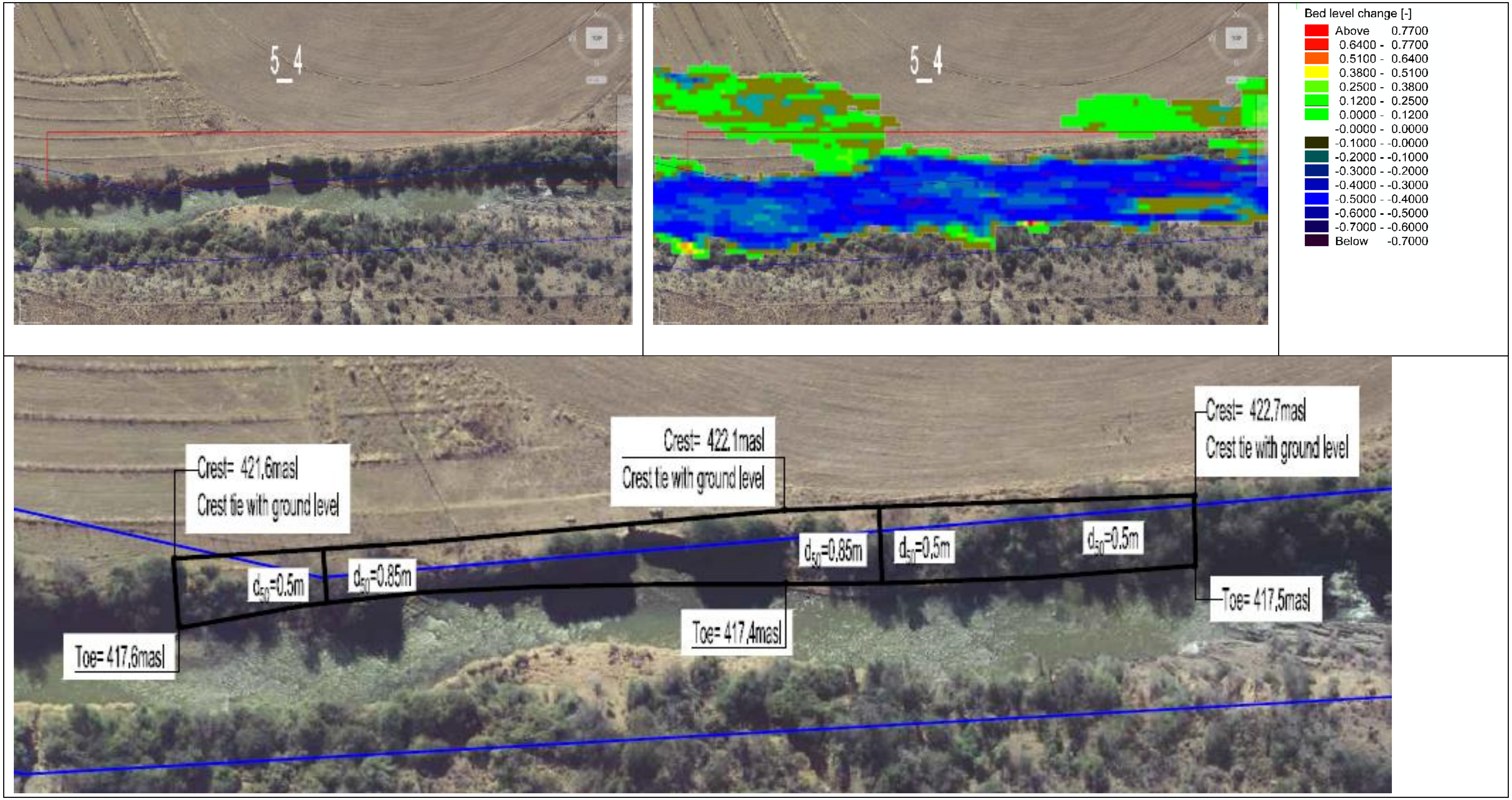


Appendix 36: Zone 5_3 Q10 flood peak scour pattern and proposed scour protection

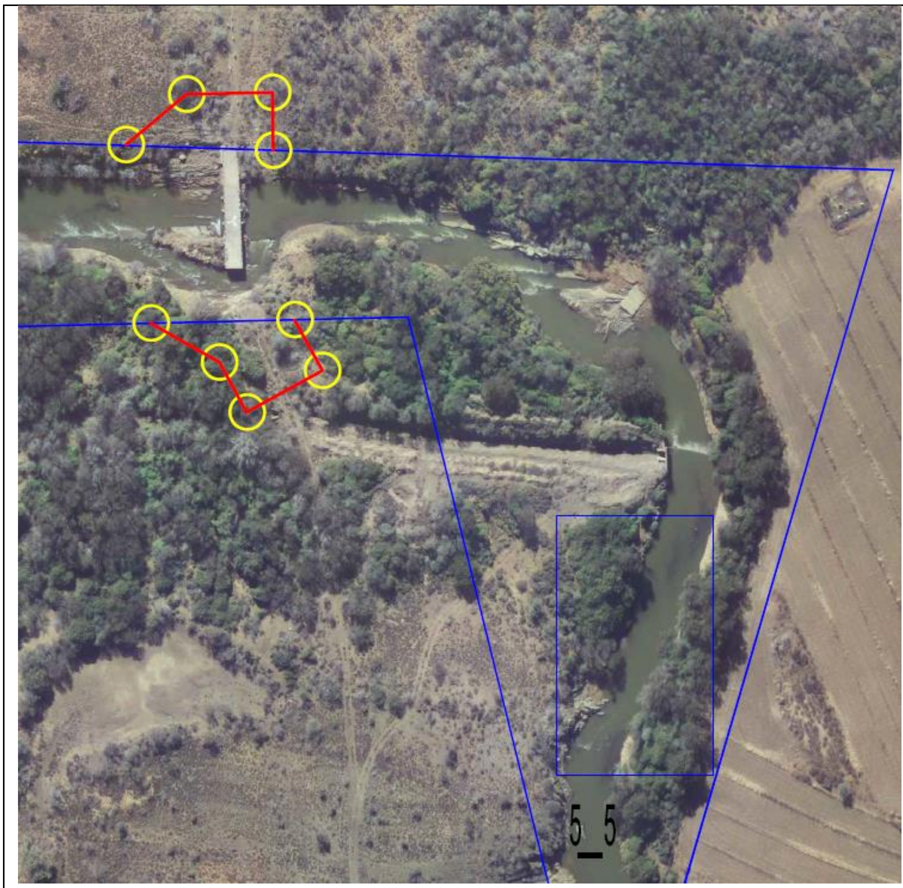


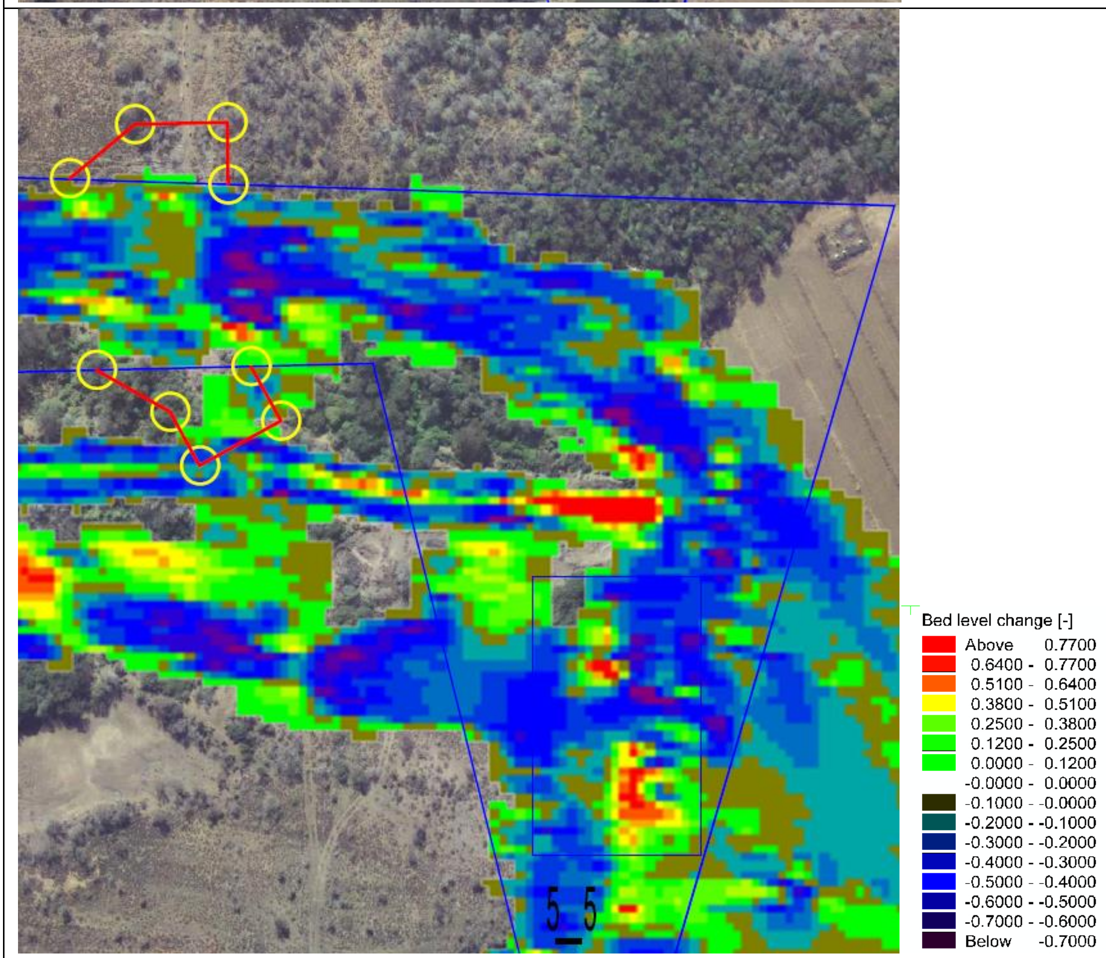


Appendix 37: Zone 5_4 Q10 flood peak scour pattern and proposed scour protection

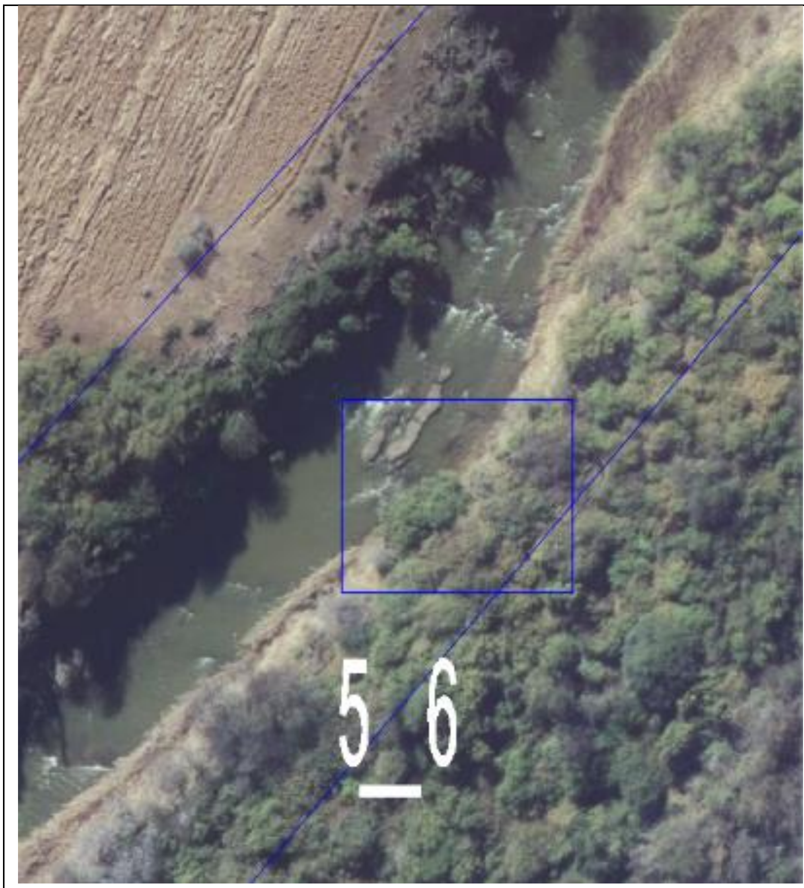


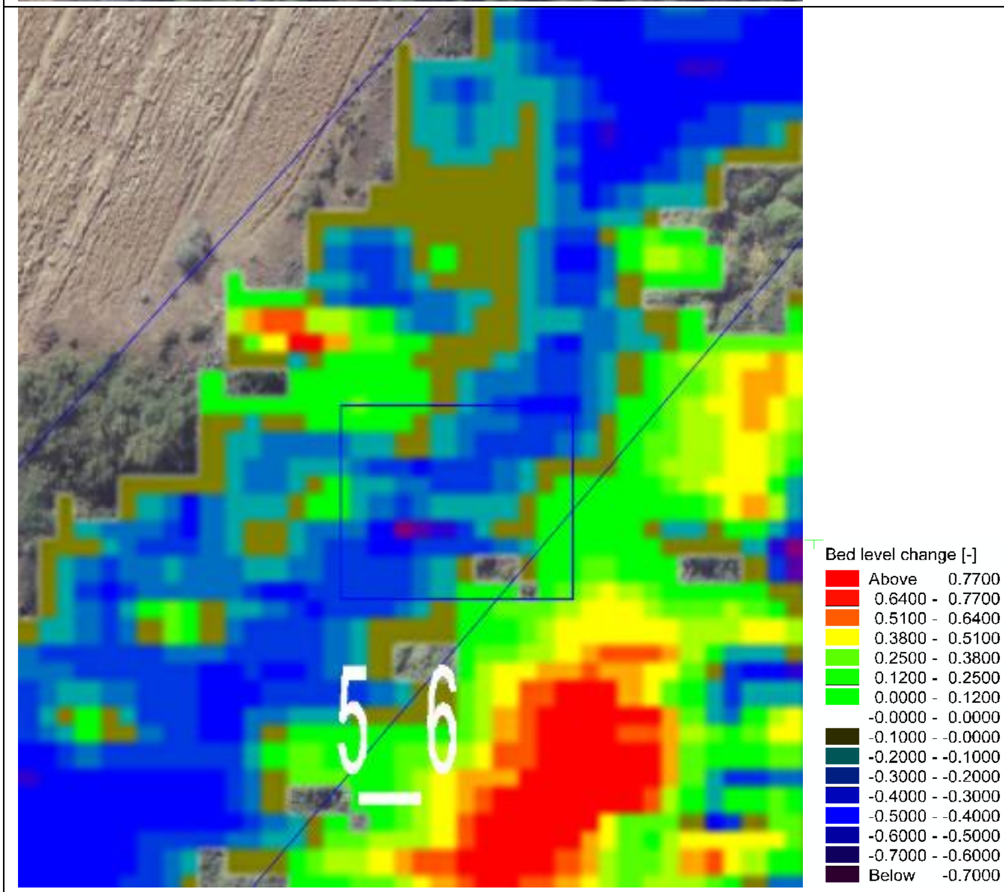
Appendix 38: Zone 5_5 Q10 flood peak scour pattern



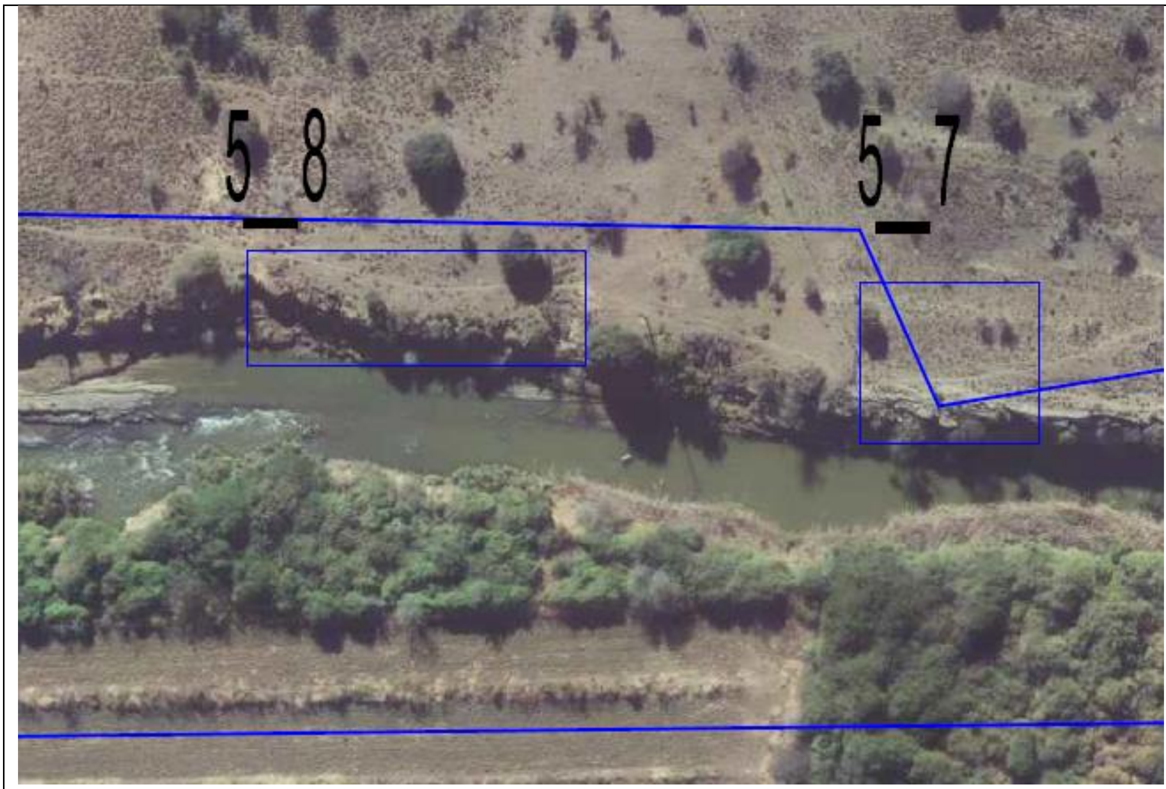


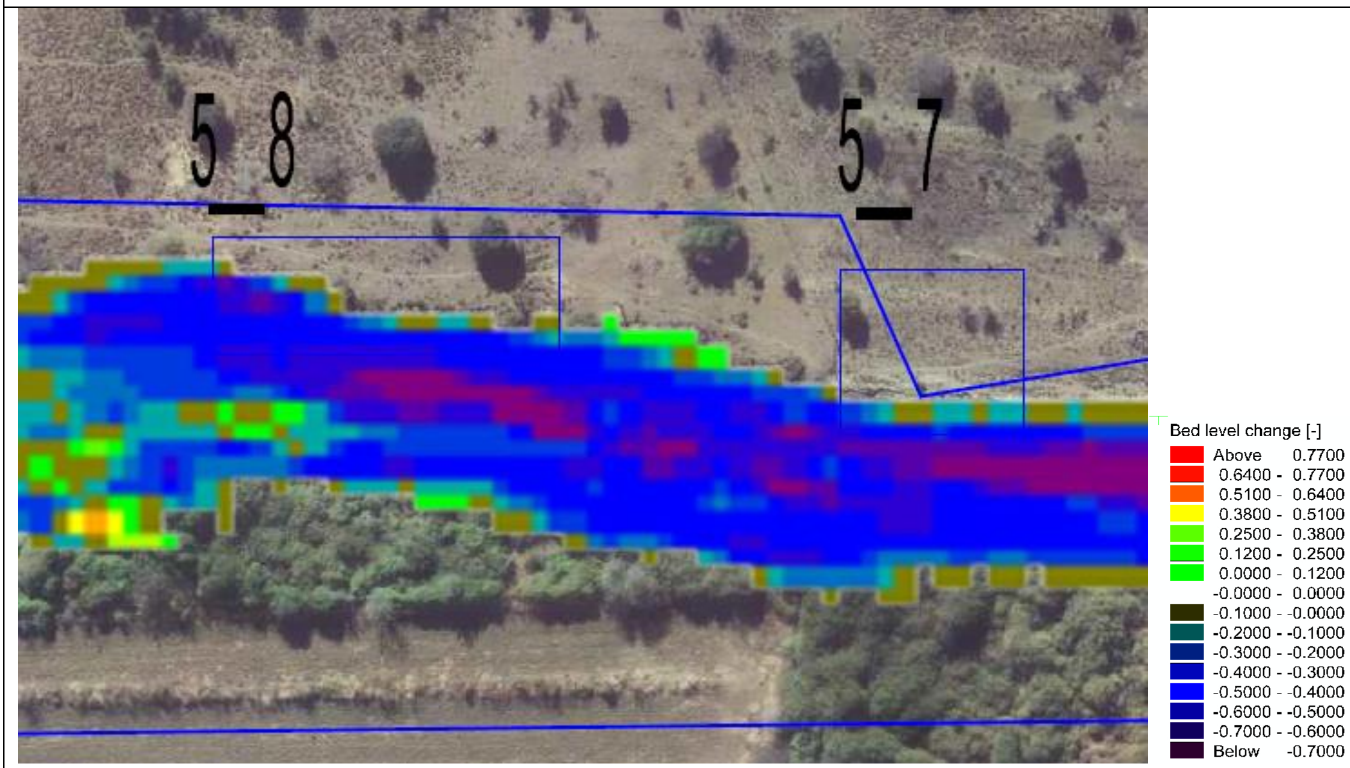
Appendix 39: Zone 5_6 Q10 flood peak scour pattern



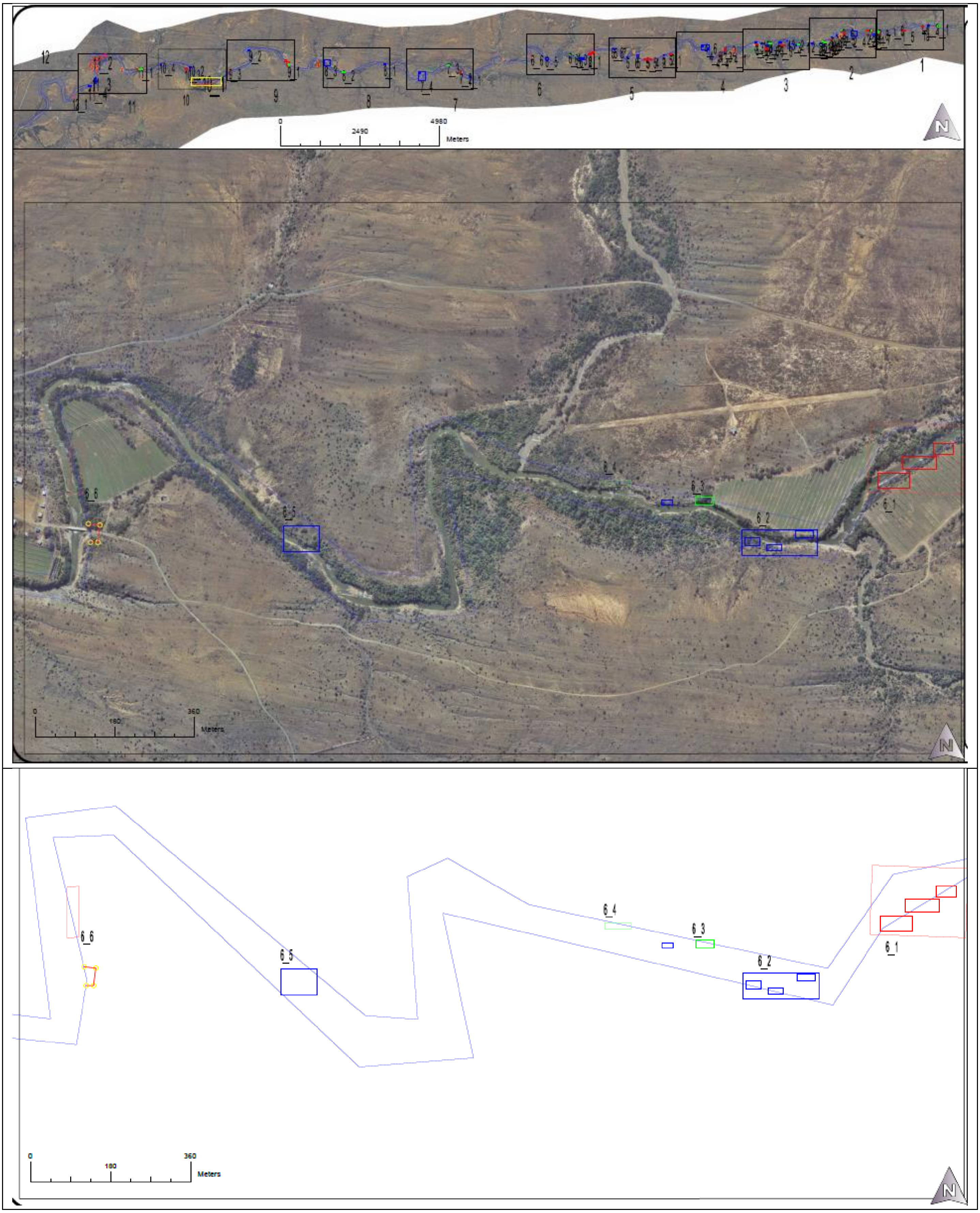


Appendix 40: Zone 5_7and 5_8 Q10 flood peak scour pattern

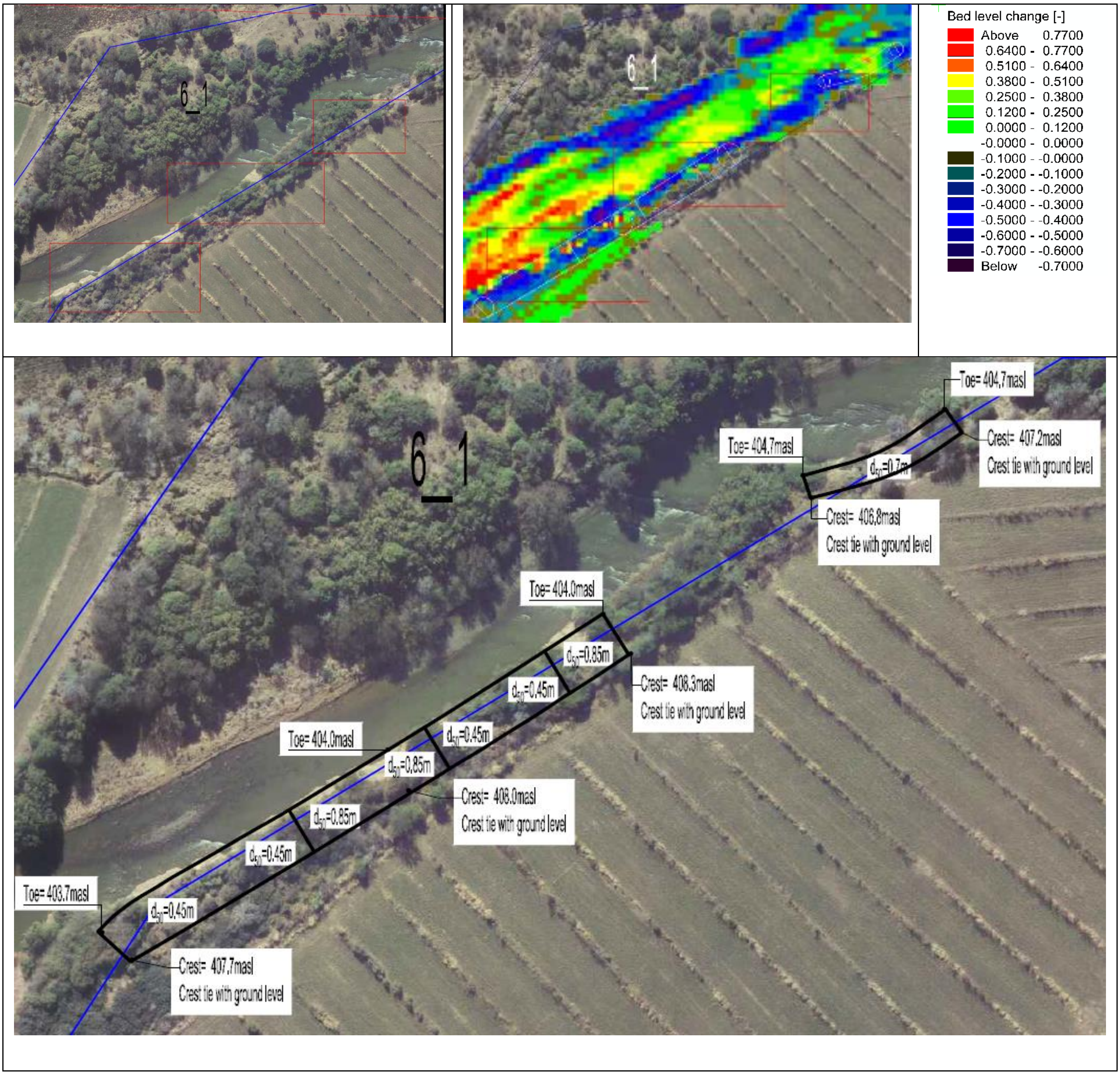




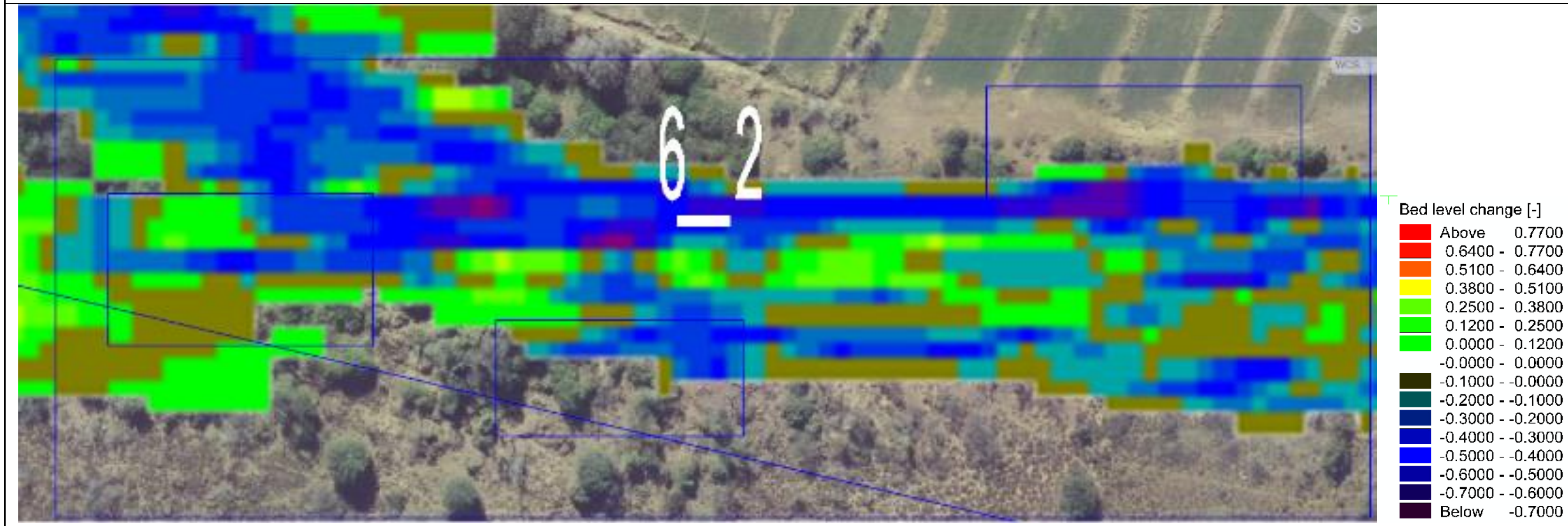
Appendix 41: Zone 6



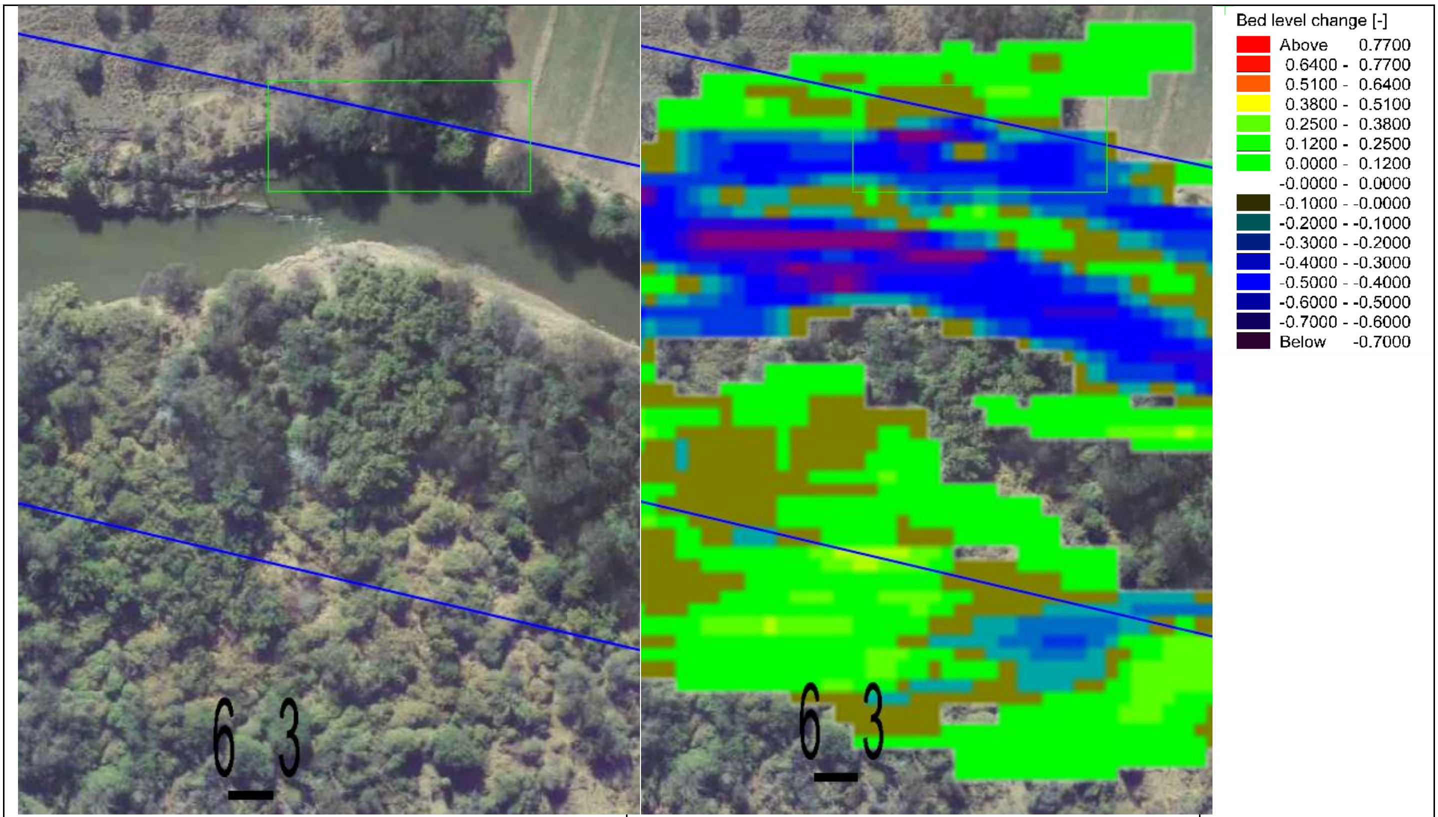
Appendix 42: Zone 6_1 Q10 flood peak scour pattern and proposed scour protection

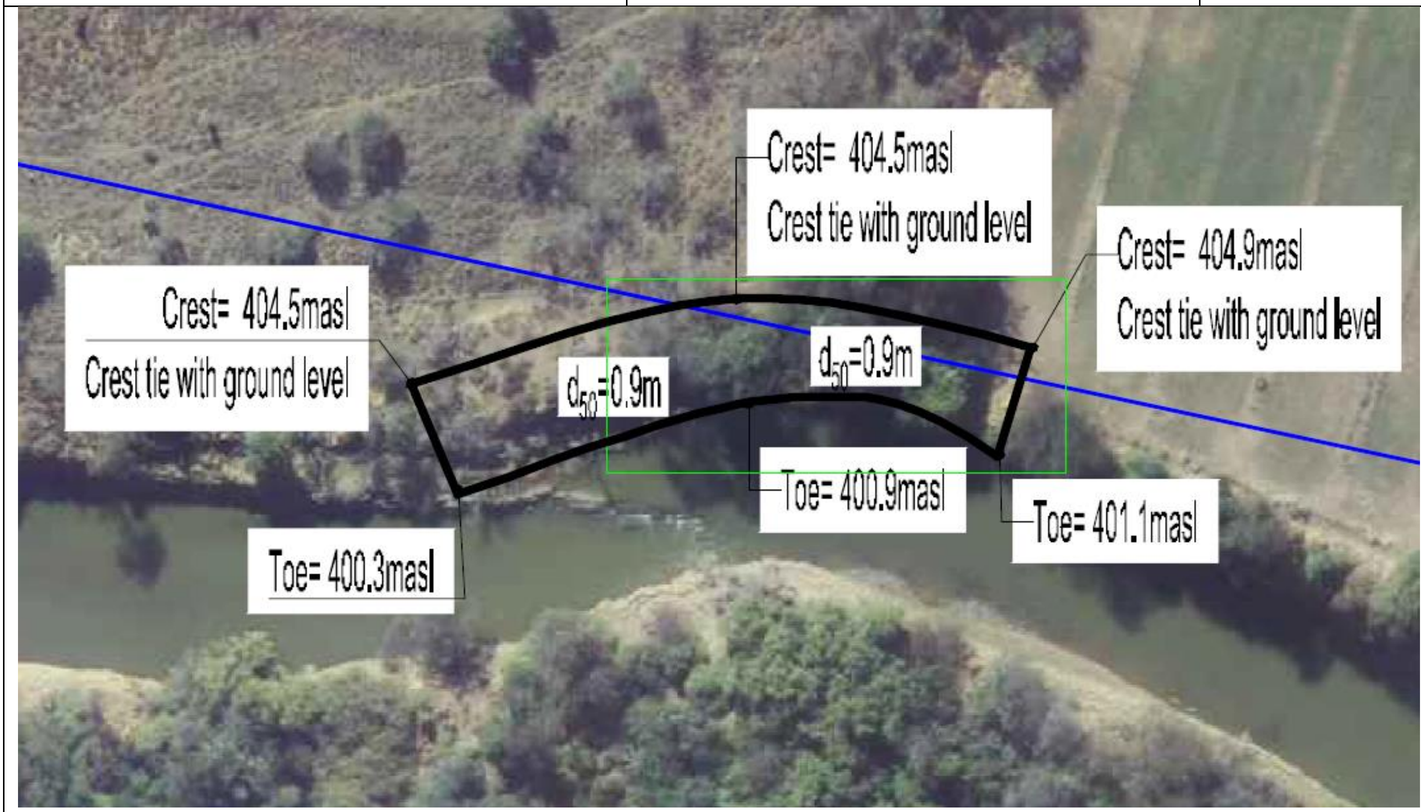


Appendix 43: Zone 6_2 Q10 flood peak scour pattern

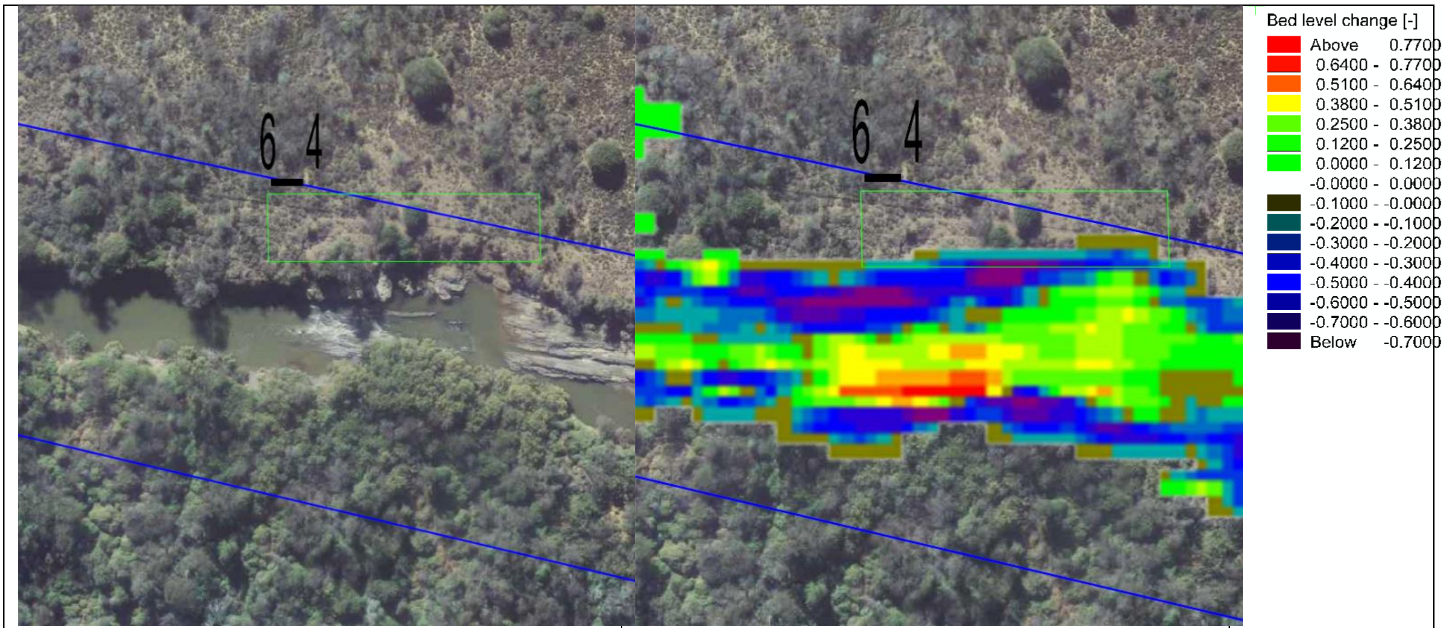


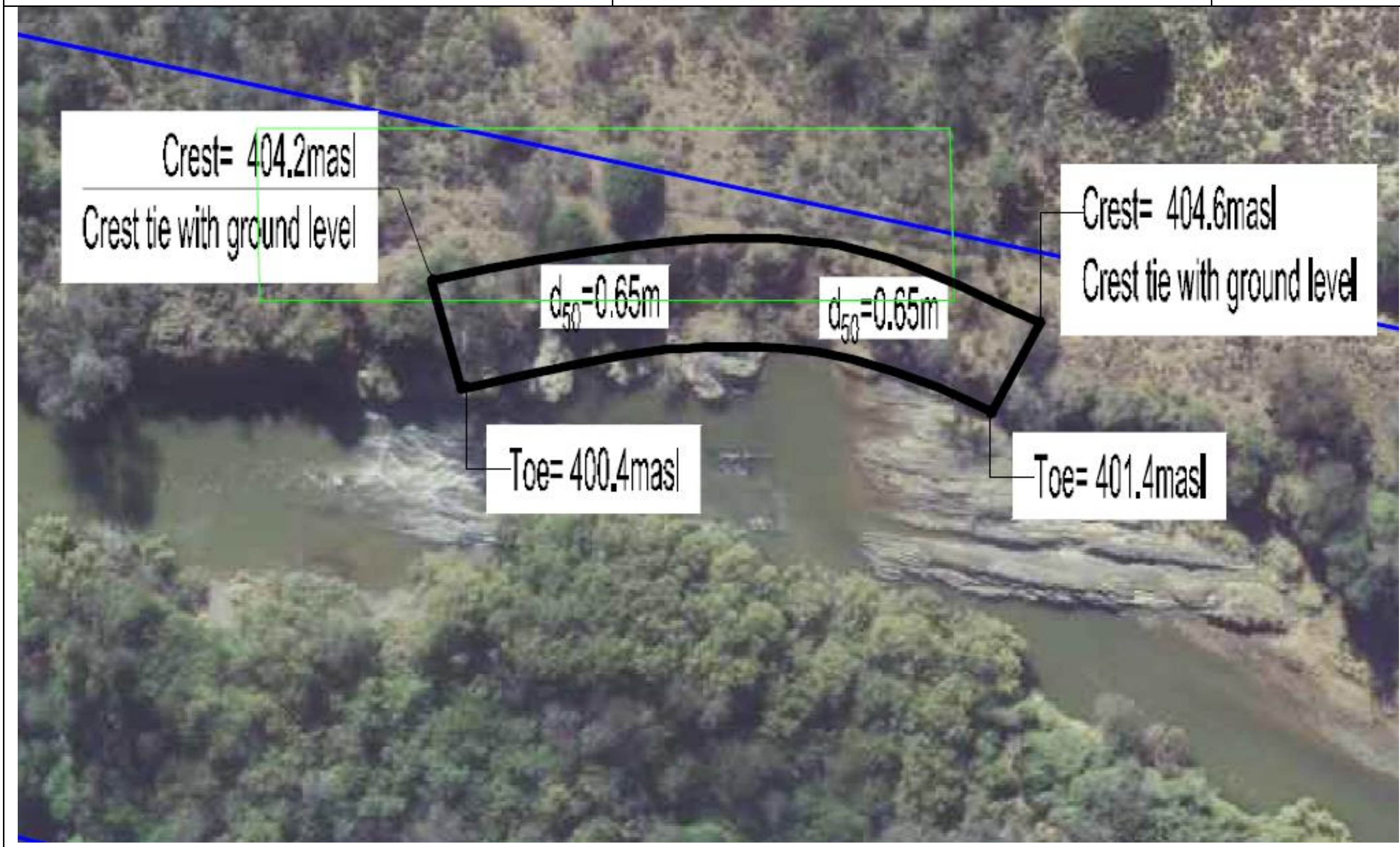
Appendix 44: Zone 6_3 Q10 flood peak scour pattern and proposed scour protection



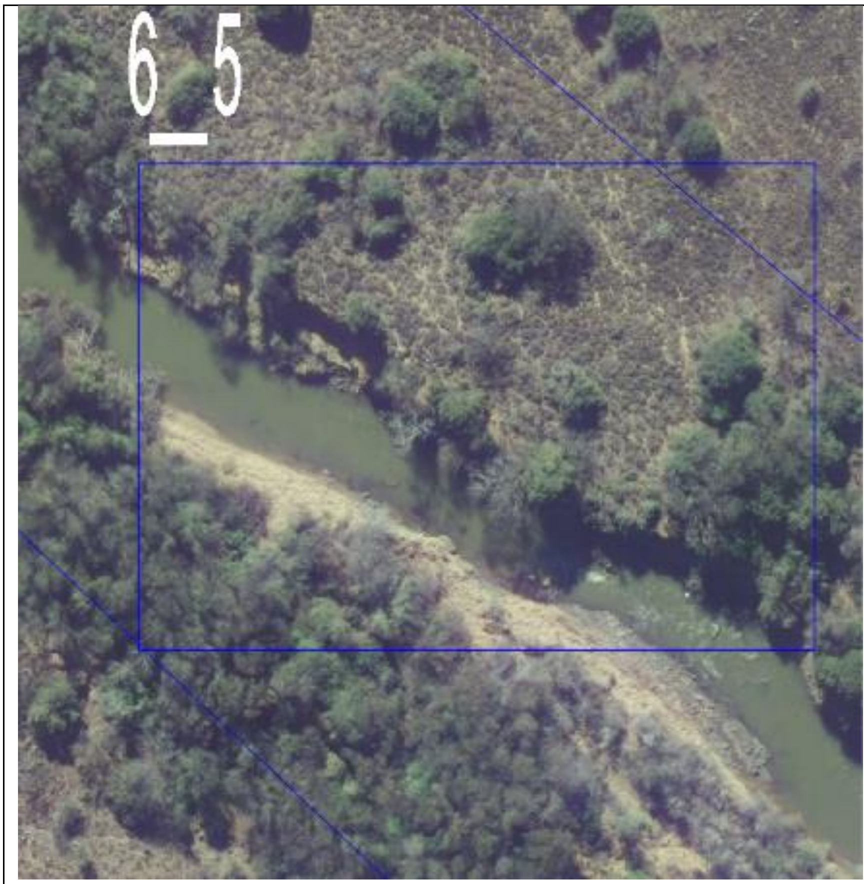


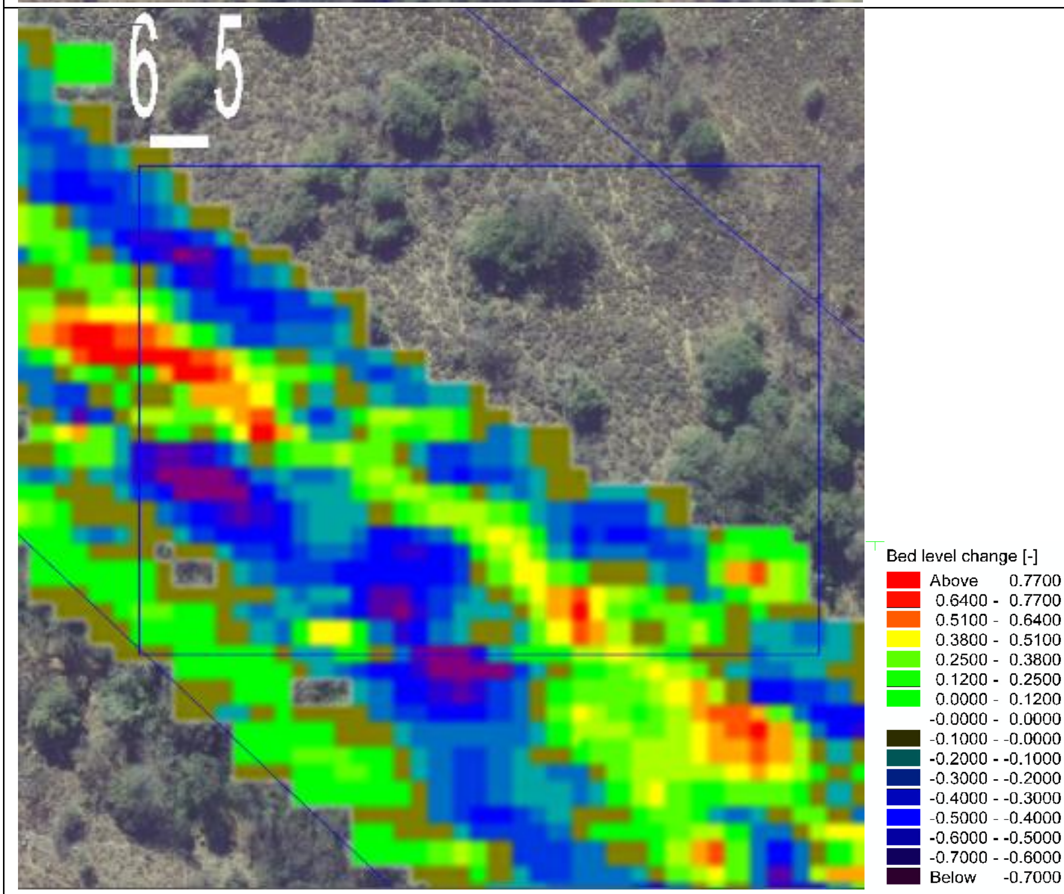
Appendix 45: Zone 6_4 Q10 flood peak scour pattern and proposed scour protection



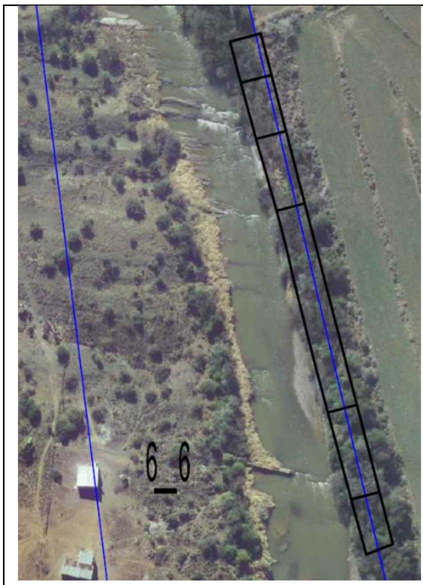


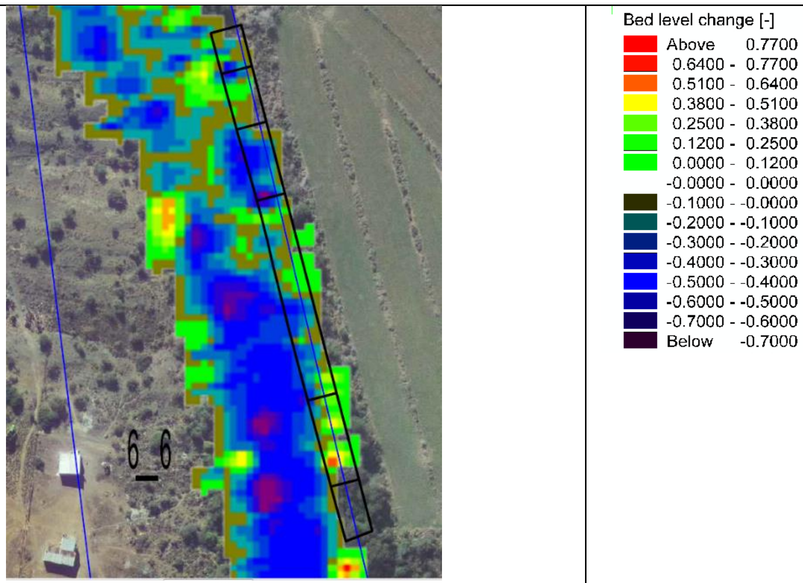
Appendix 46: Zone 6_5 Q10 flood peak scour pattern and proposed scour protection

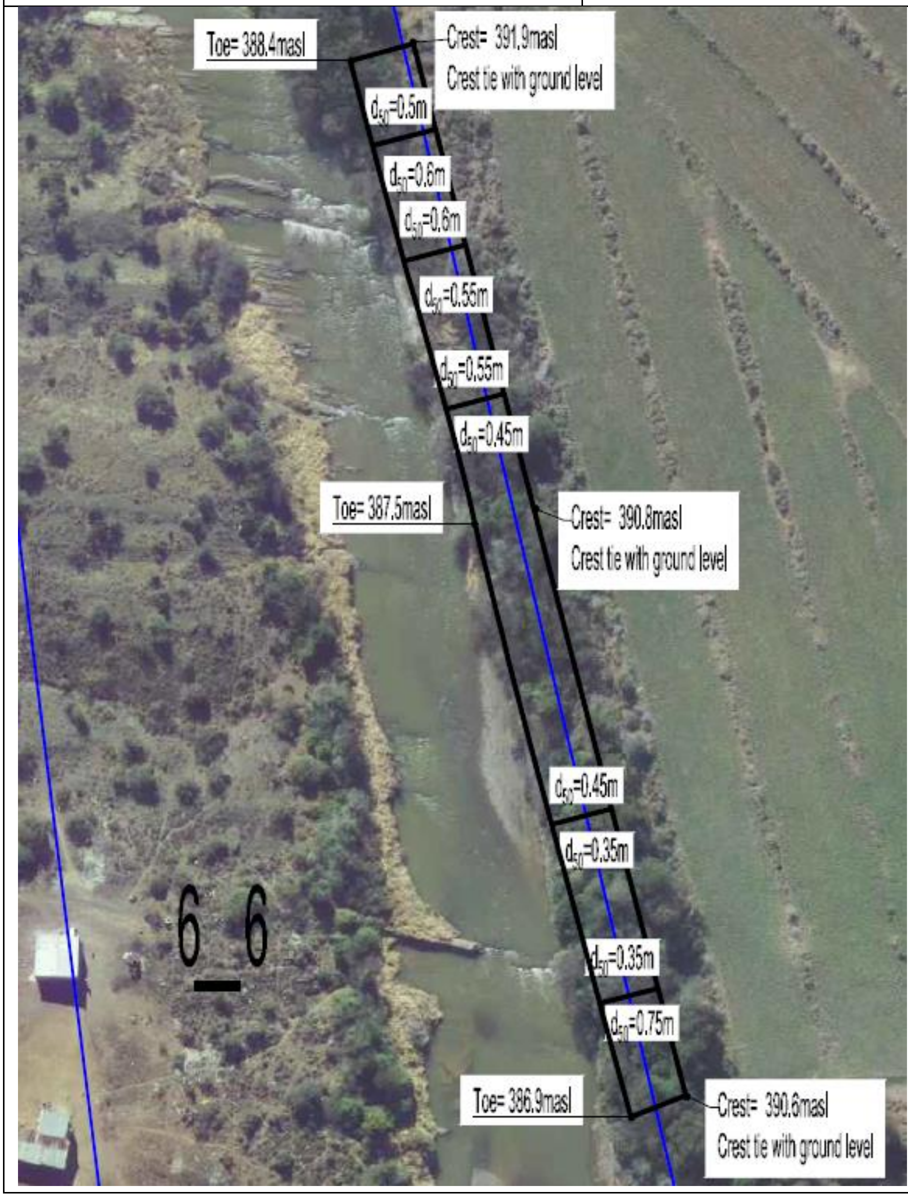




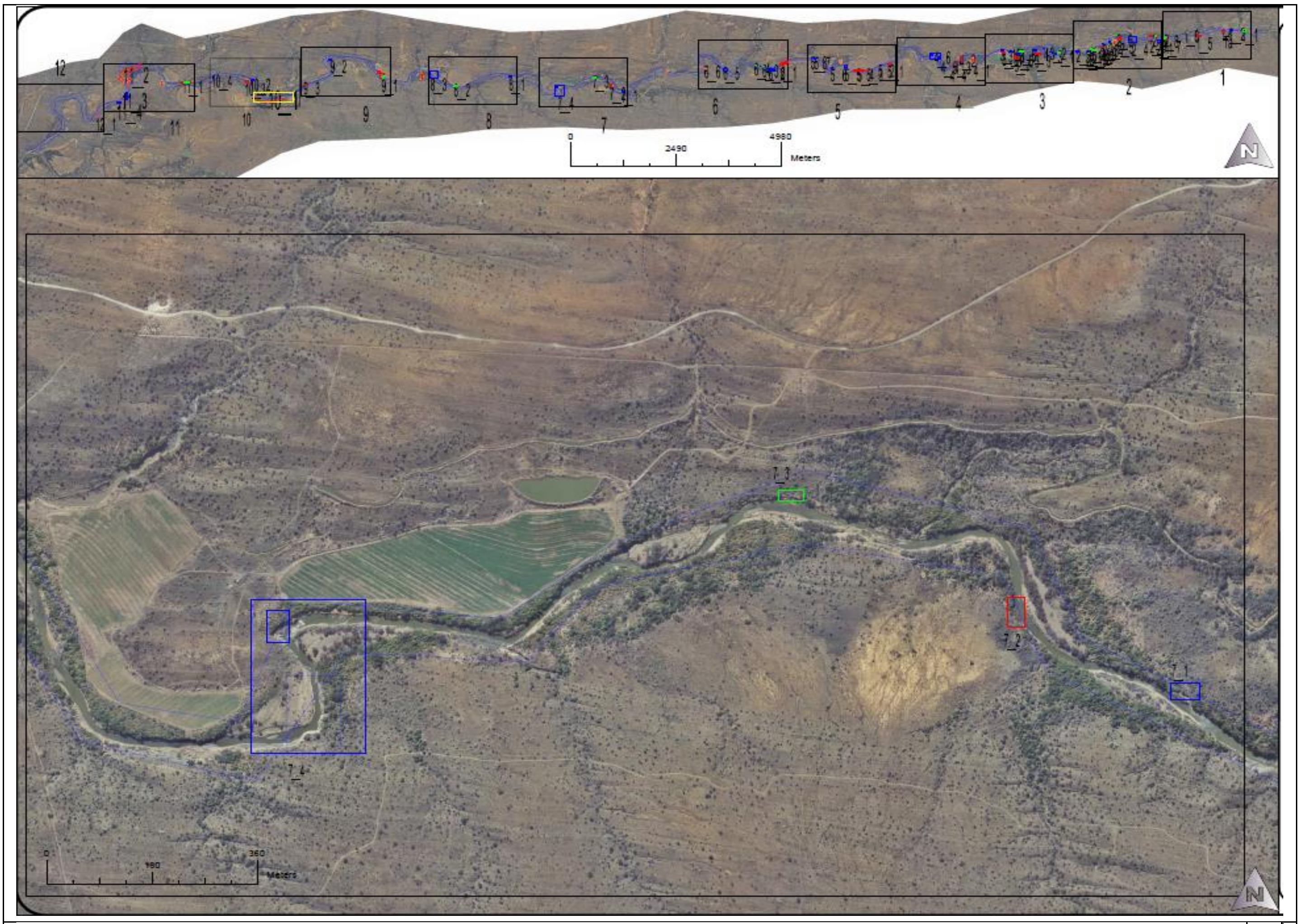
Appendix 47: Zone 6_6 Q10 flood peak scour pattern and proposed scour protection

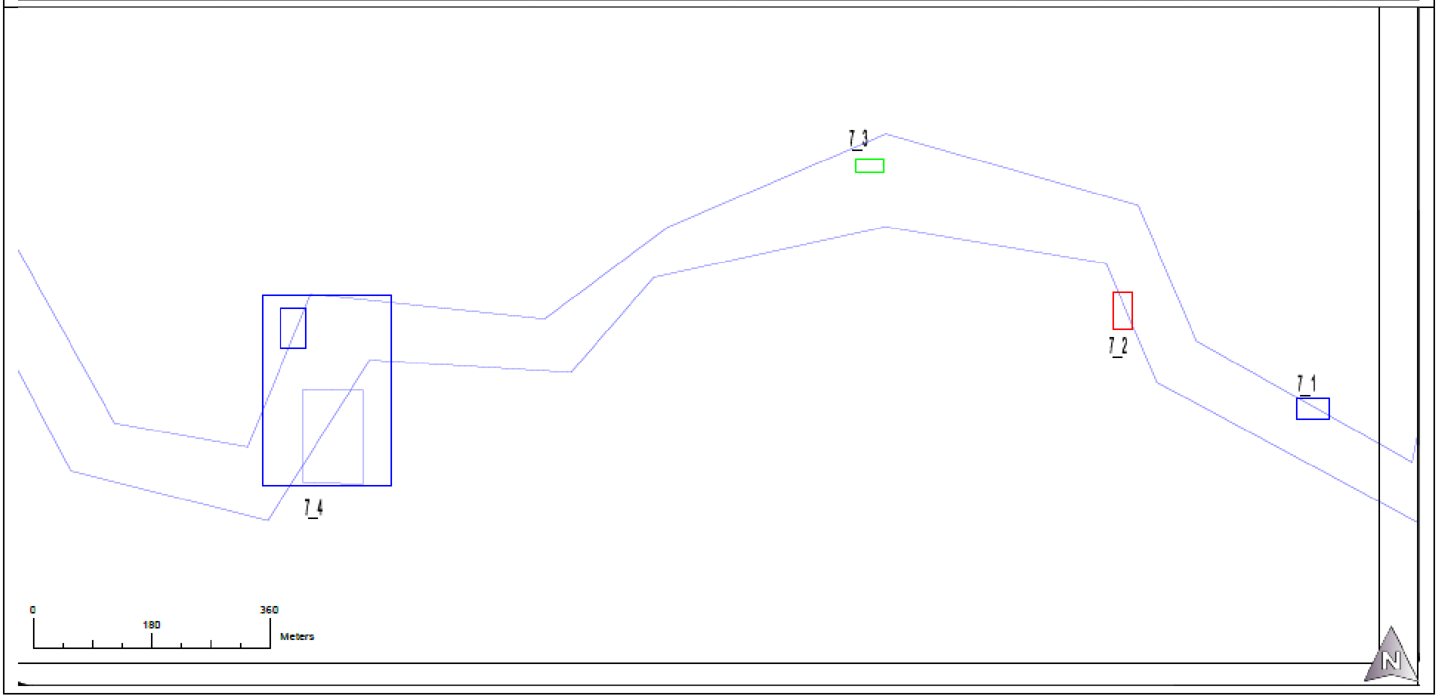




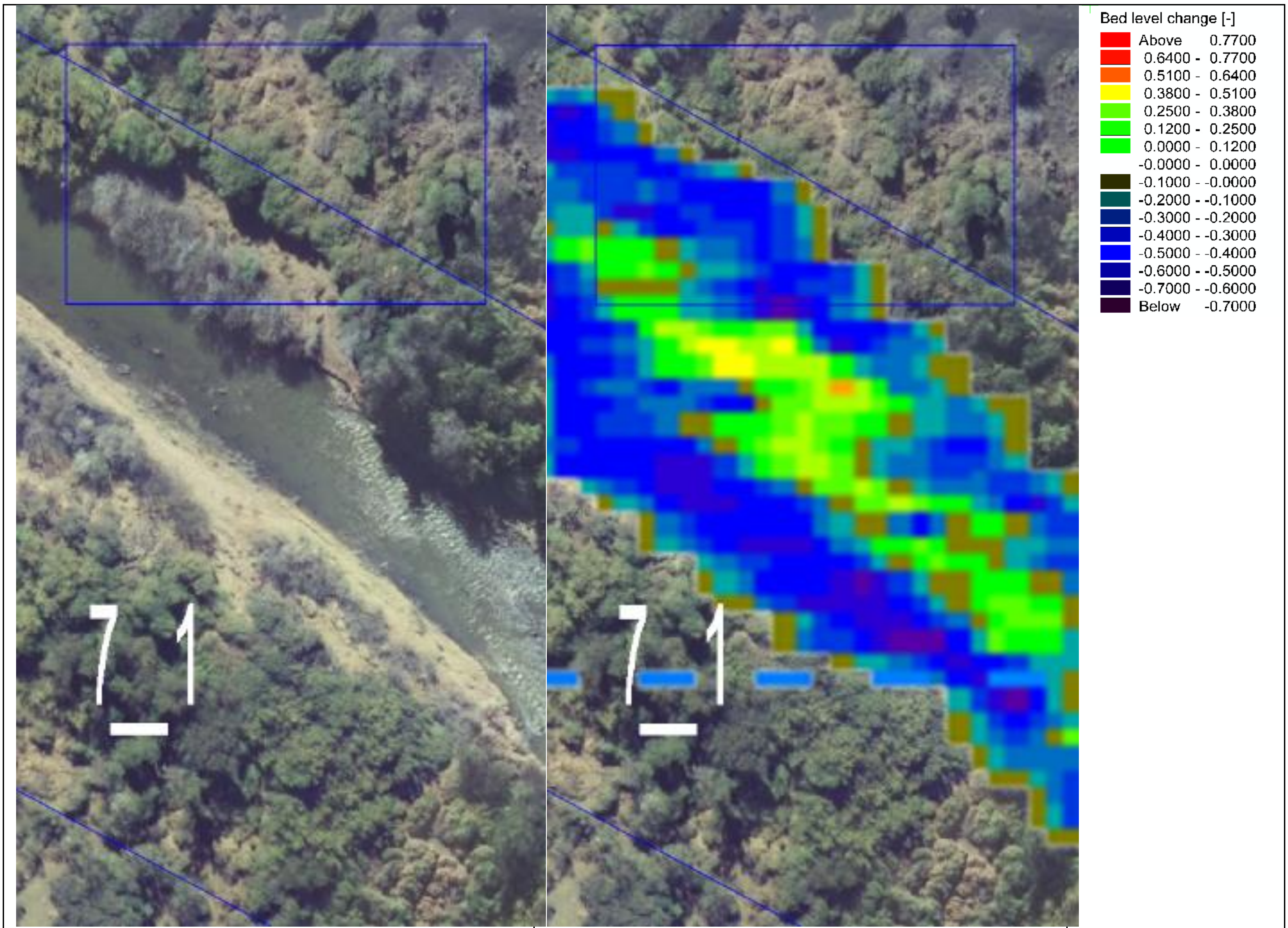


Appendix 48: Zone 7

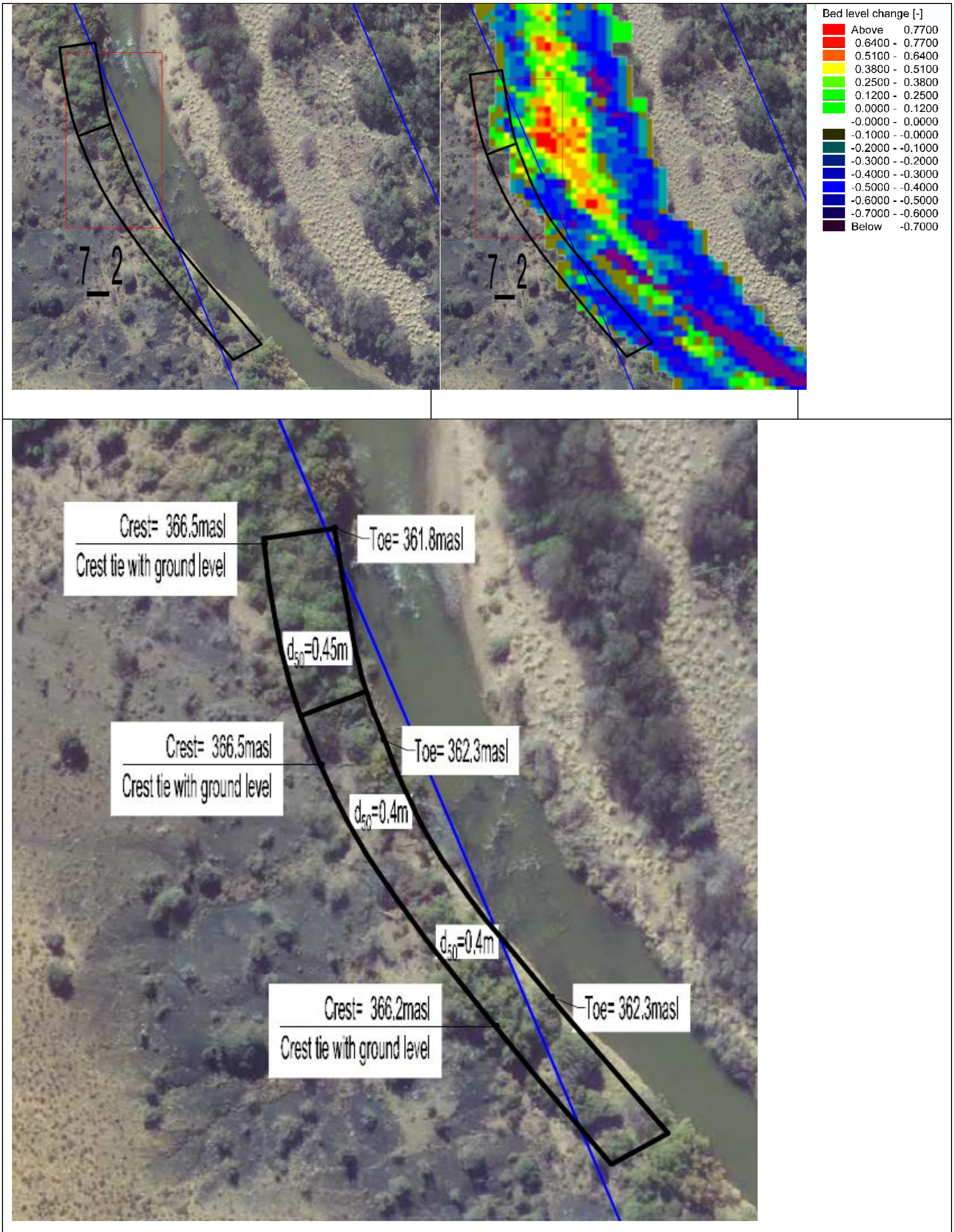




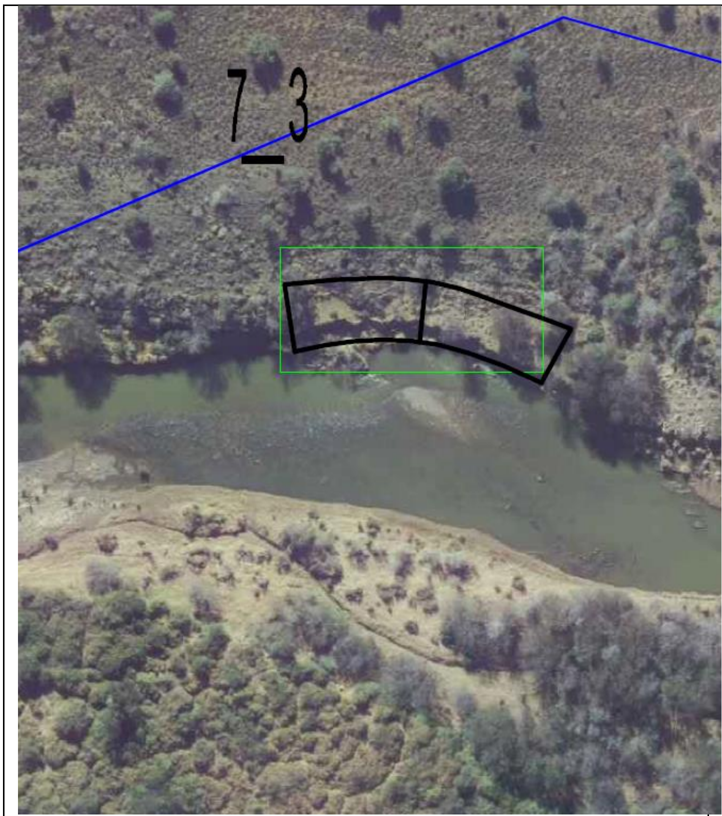
Appendix 49: Zone 7_1 Q10 flood peak scour pattern

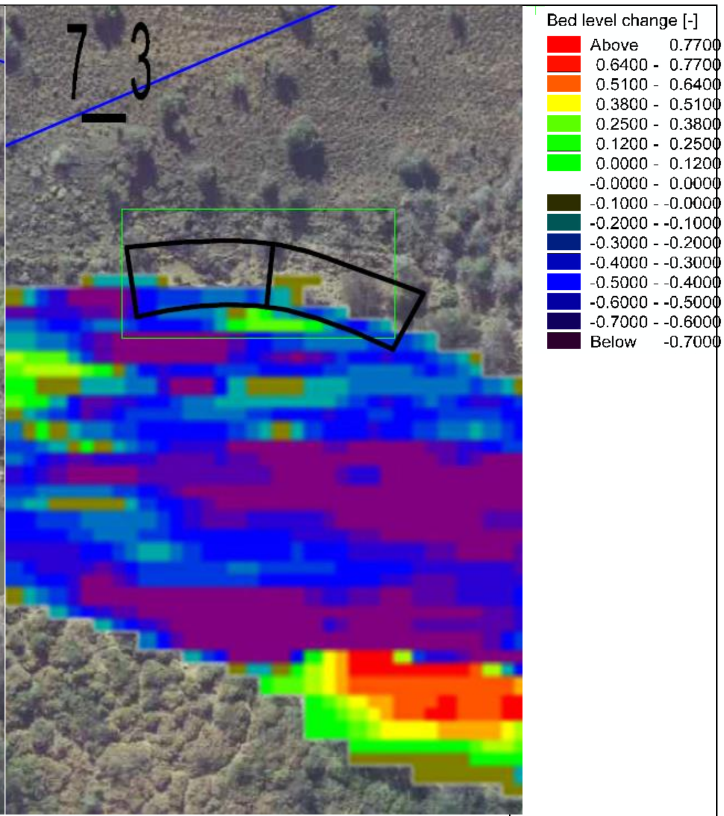


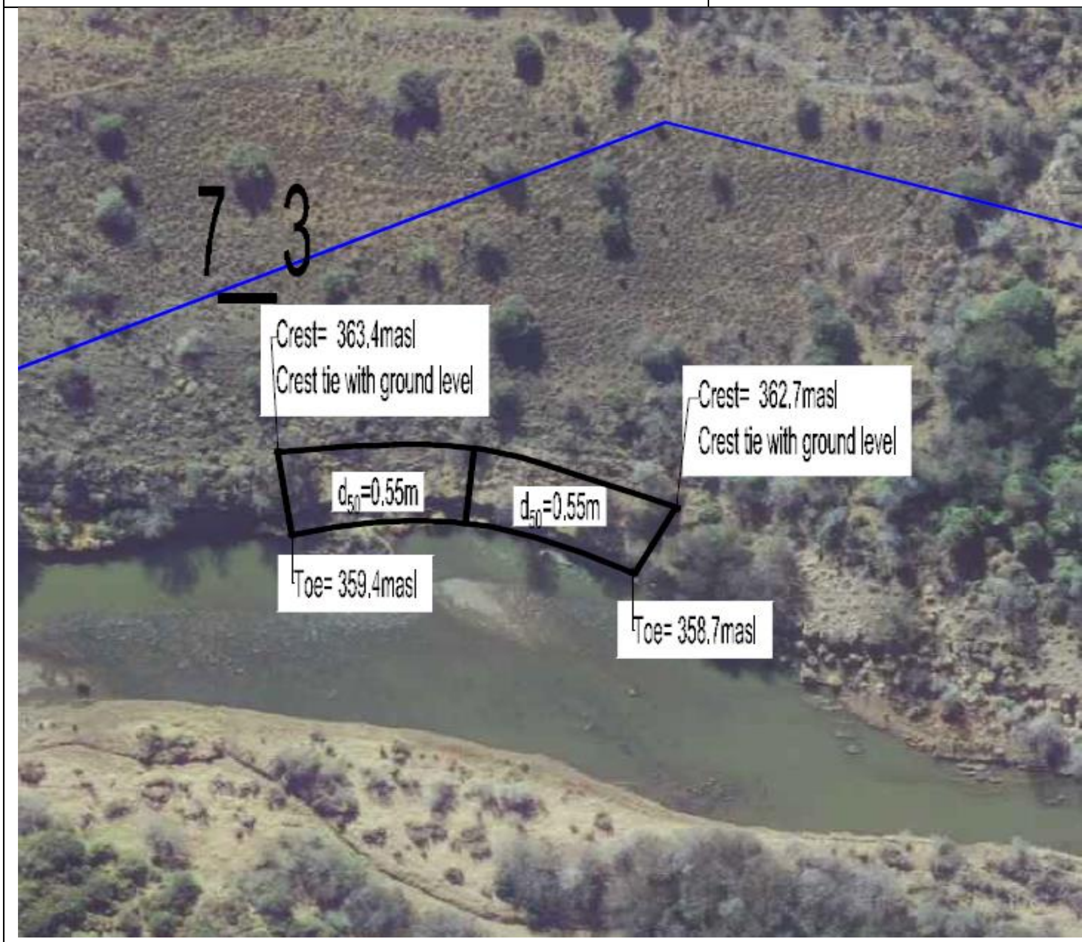
Appendix 50: Zone 7_2 Q10 flood peak scour pattern and proposed scour protection



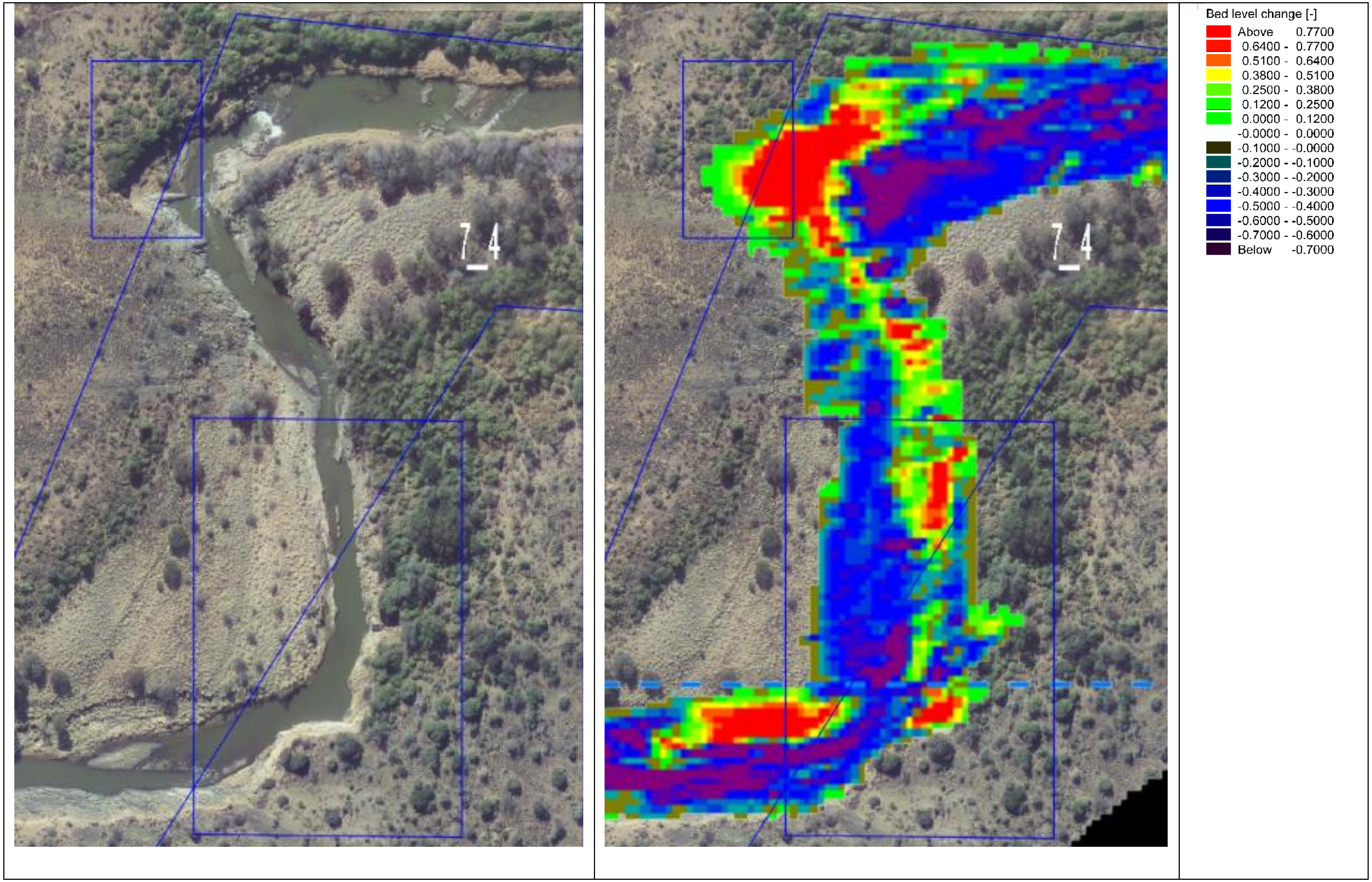
Appendix 51: Zone 7_3 Q10 flood peak scour pattern and proposed scour protection



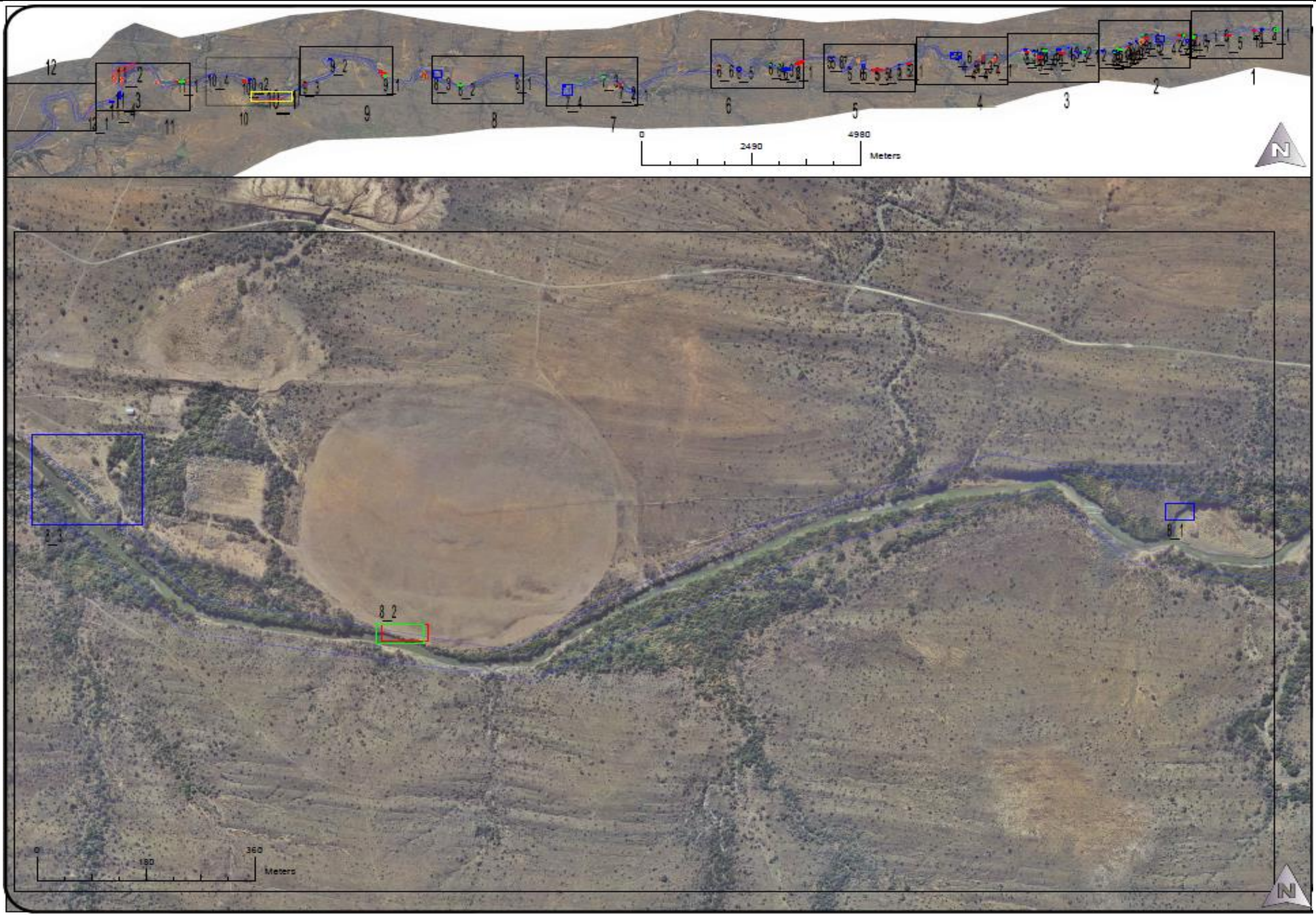


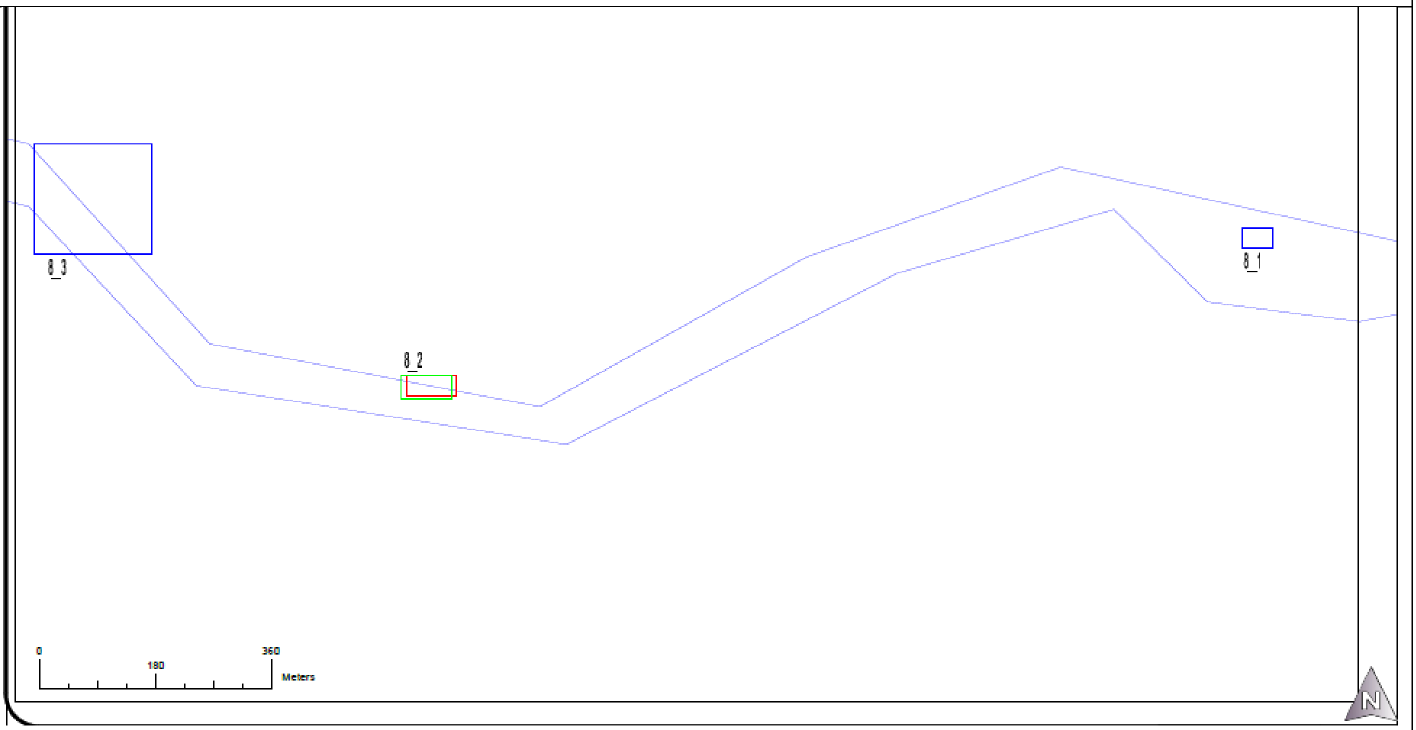


Appendix 52: Zone 7_4 Q10 flood peak scour pattern

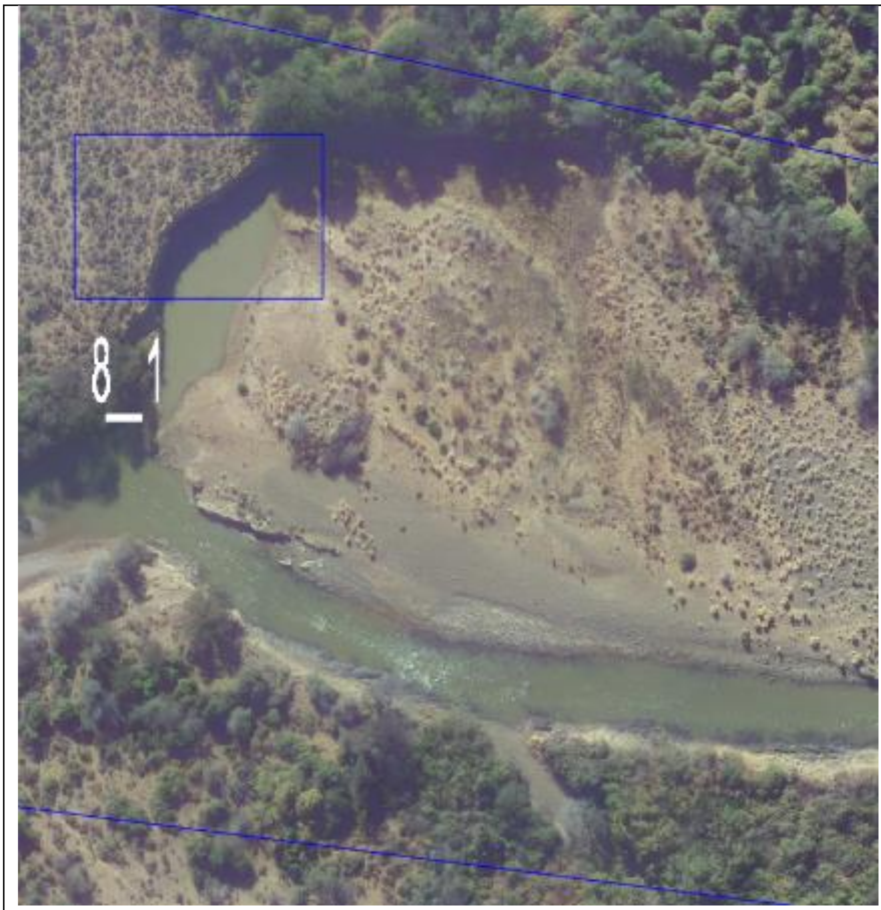


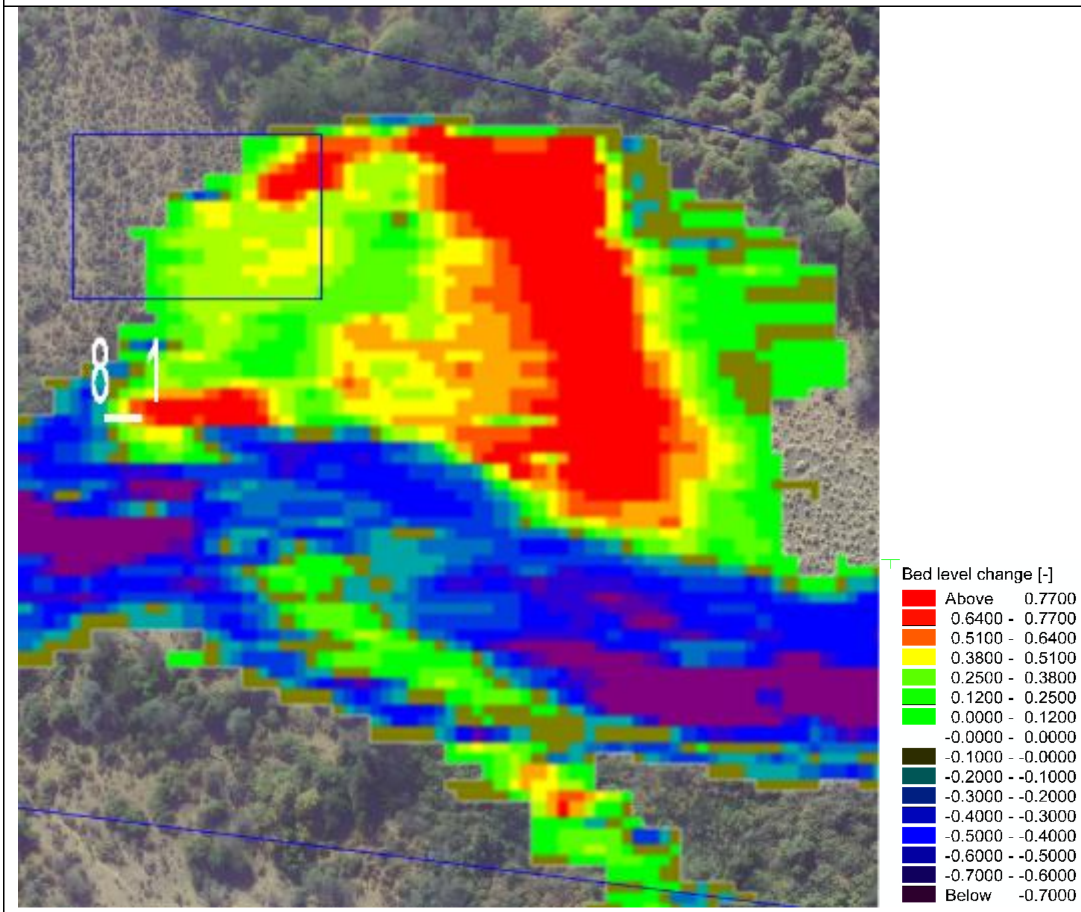
Appendix 53: Zone 8



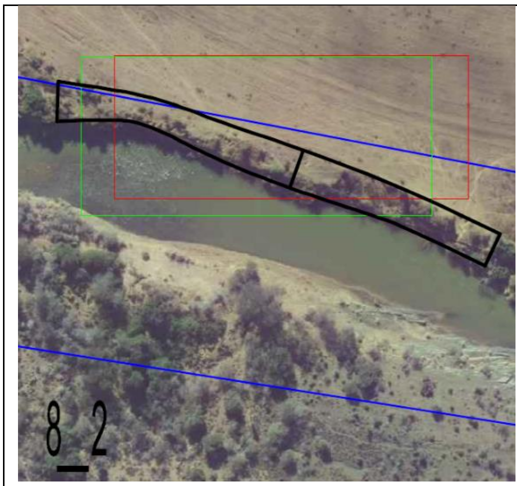


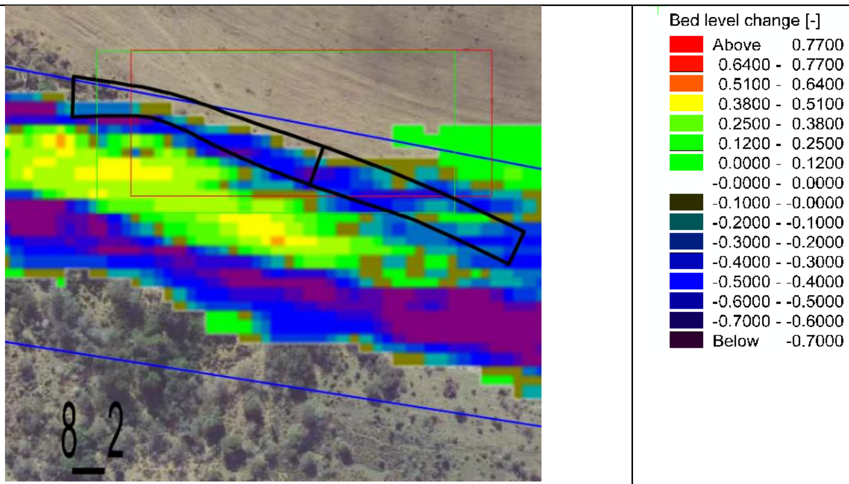
Appendix 54: Zone 8_1 Q10 flood peak scour pattern

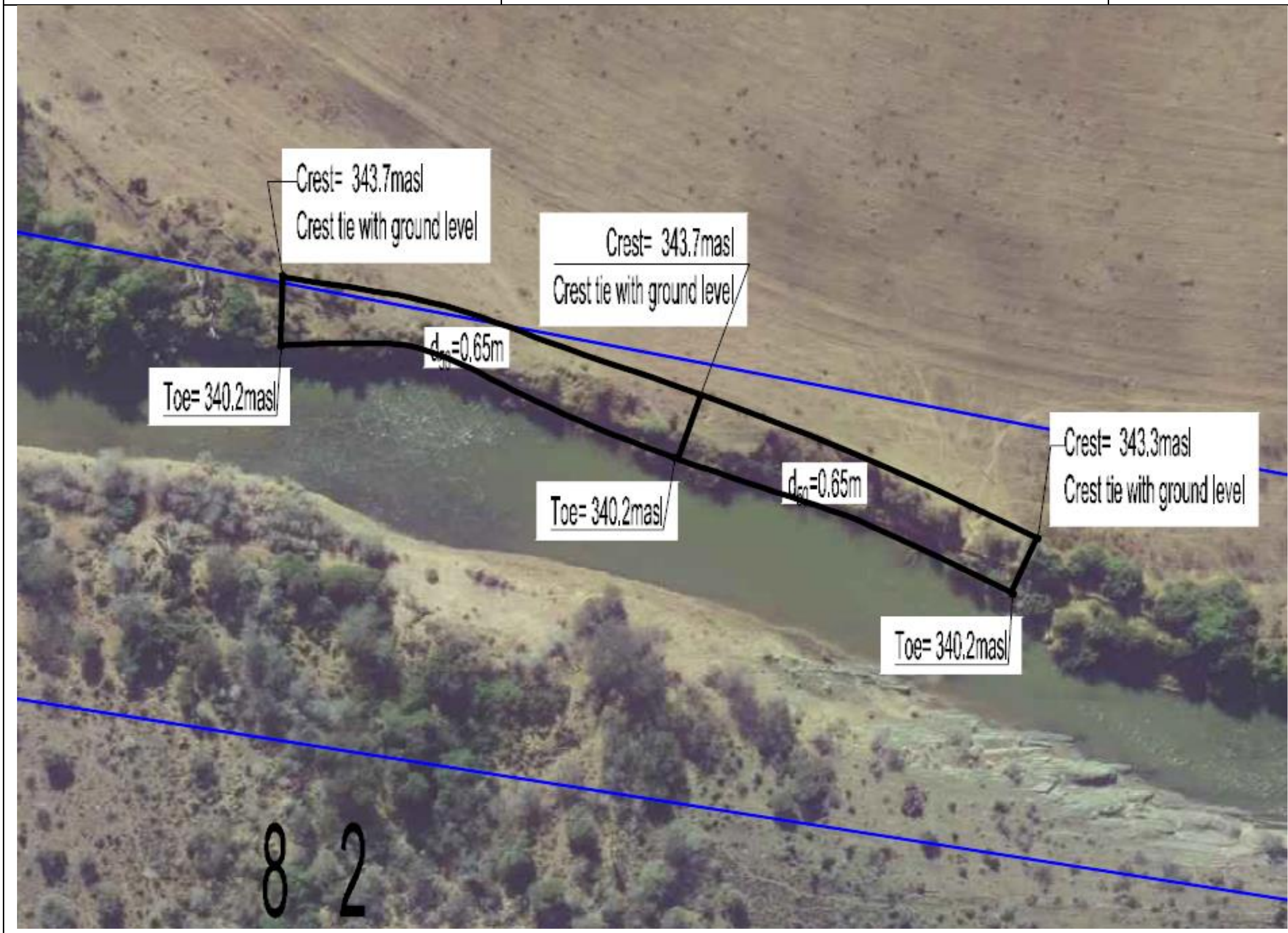




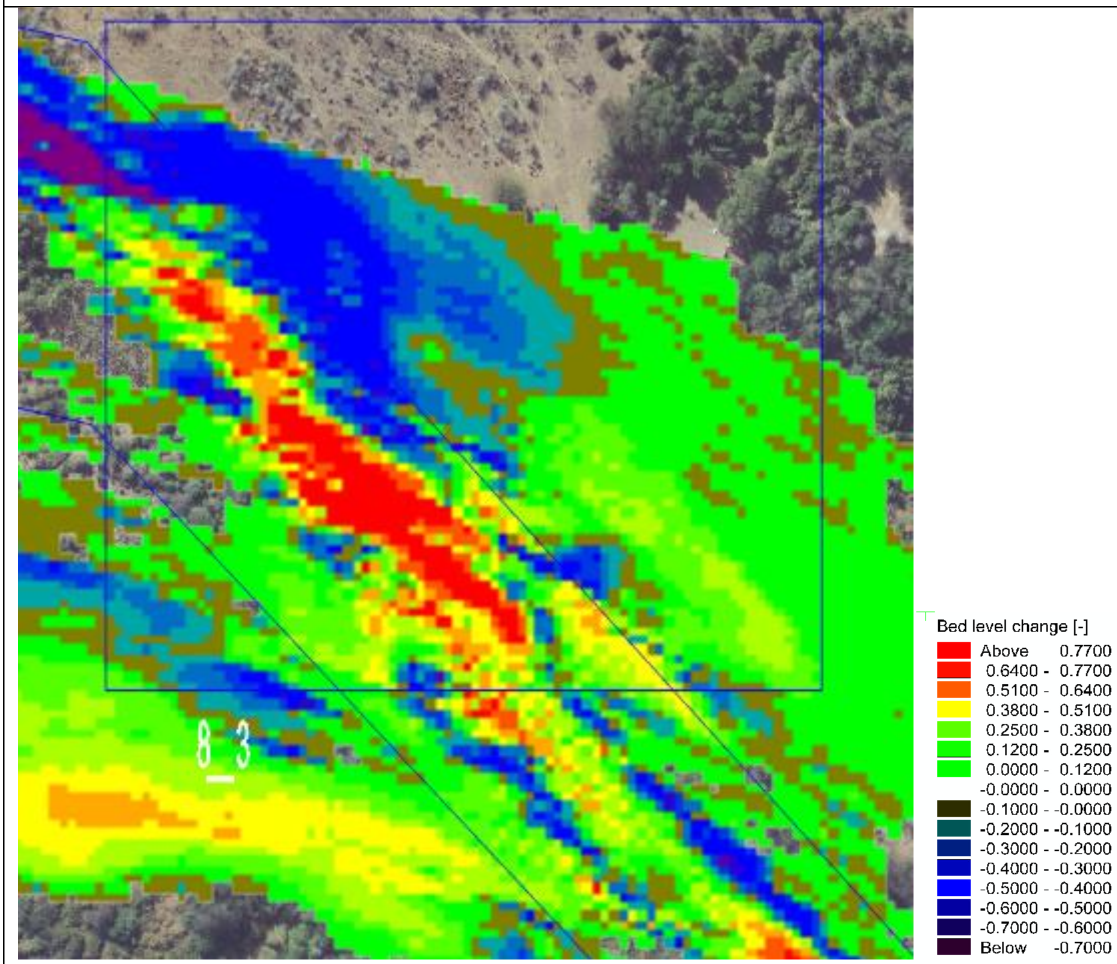
Appendix 55: Zone 8_2 Q10 flood peak scour pattern and proposed scour protection



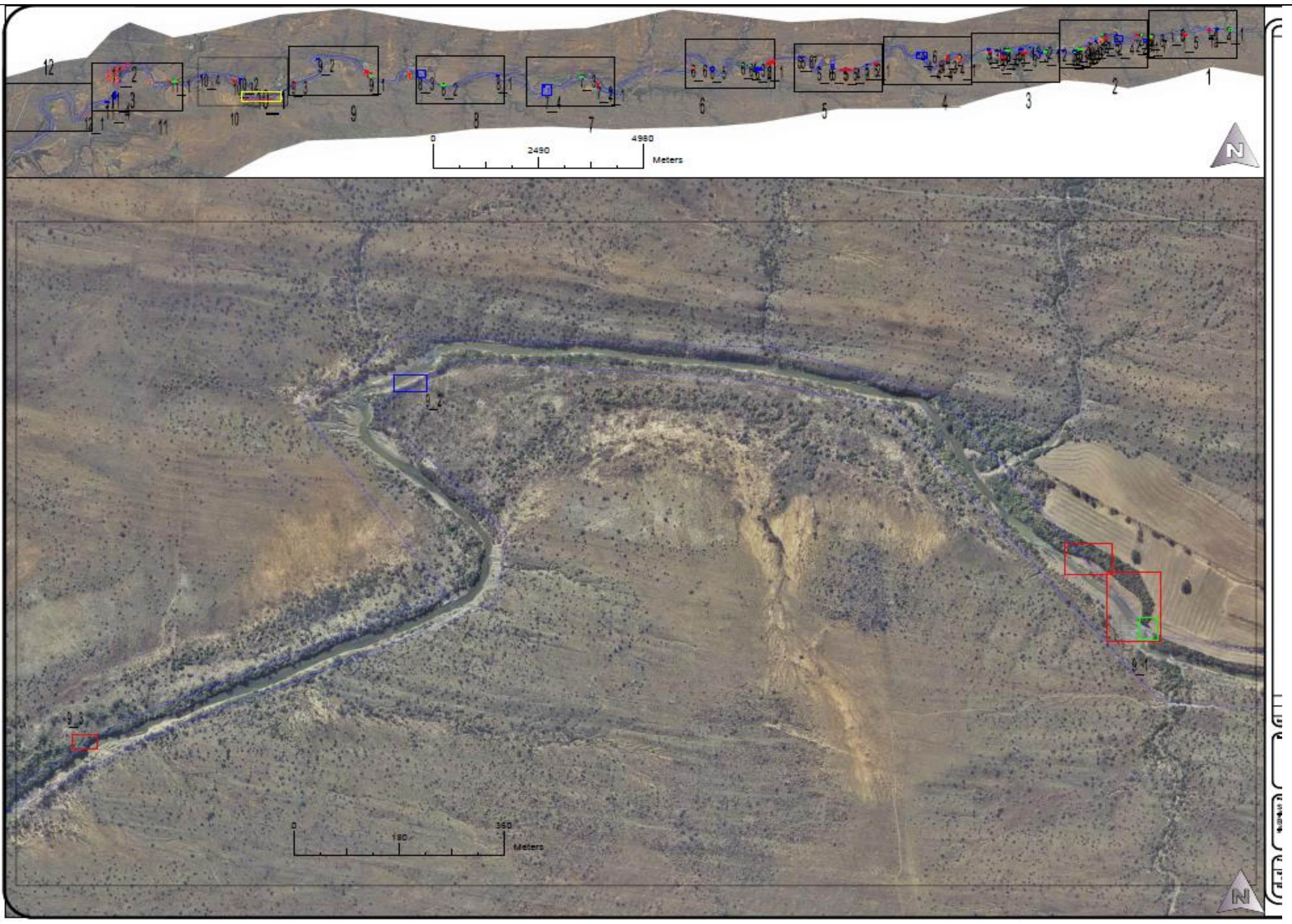


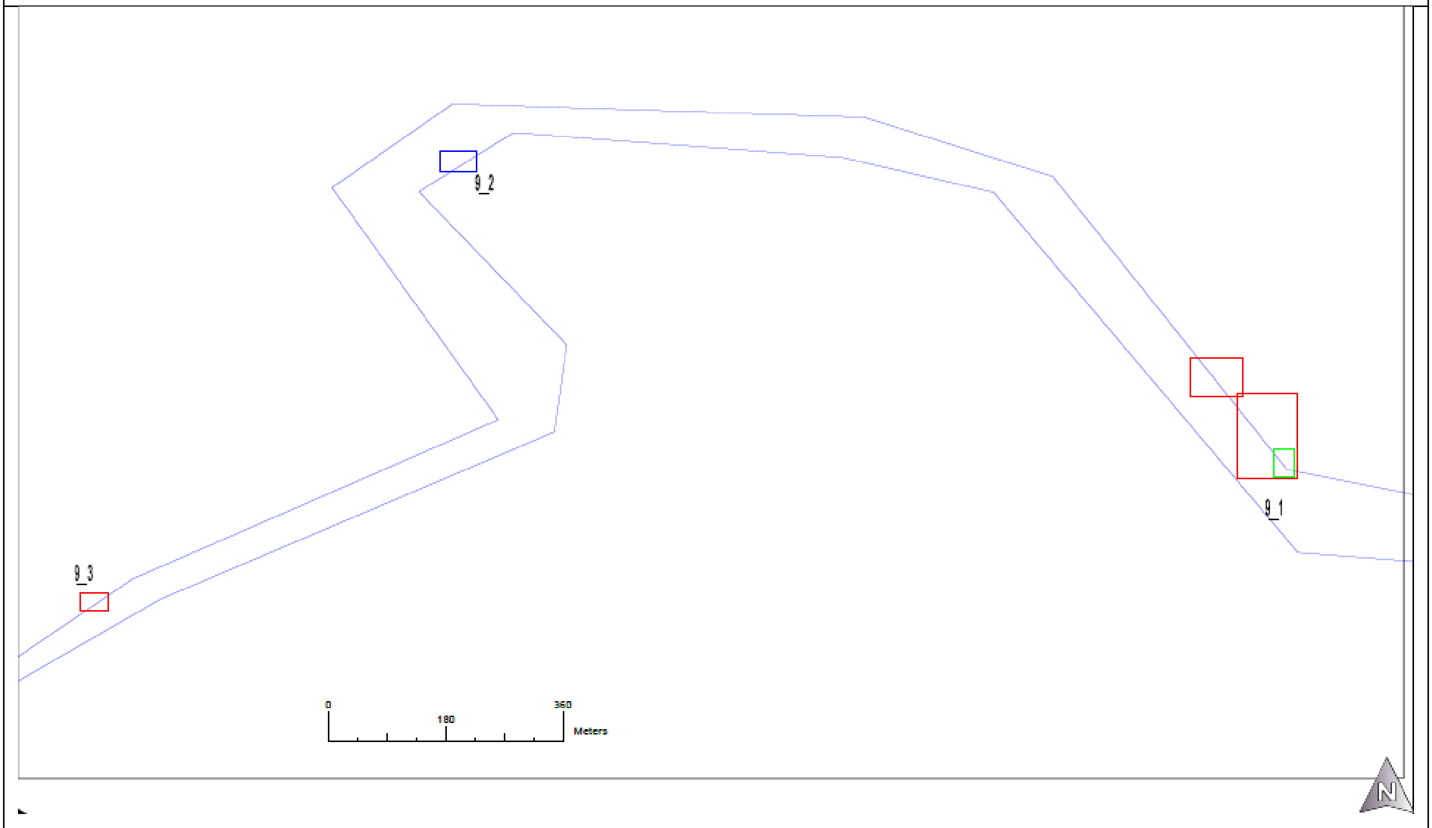


Appendix 56: Zone 8_3 Q10 flood peak scour pattern

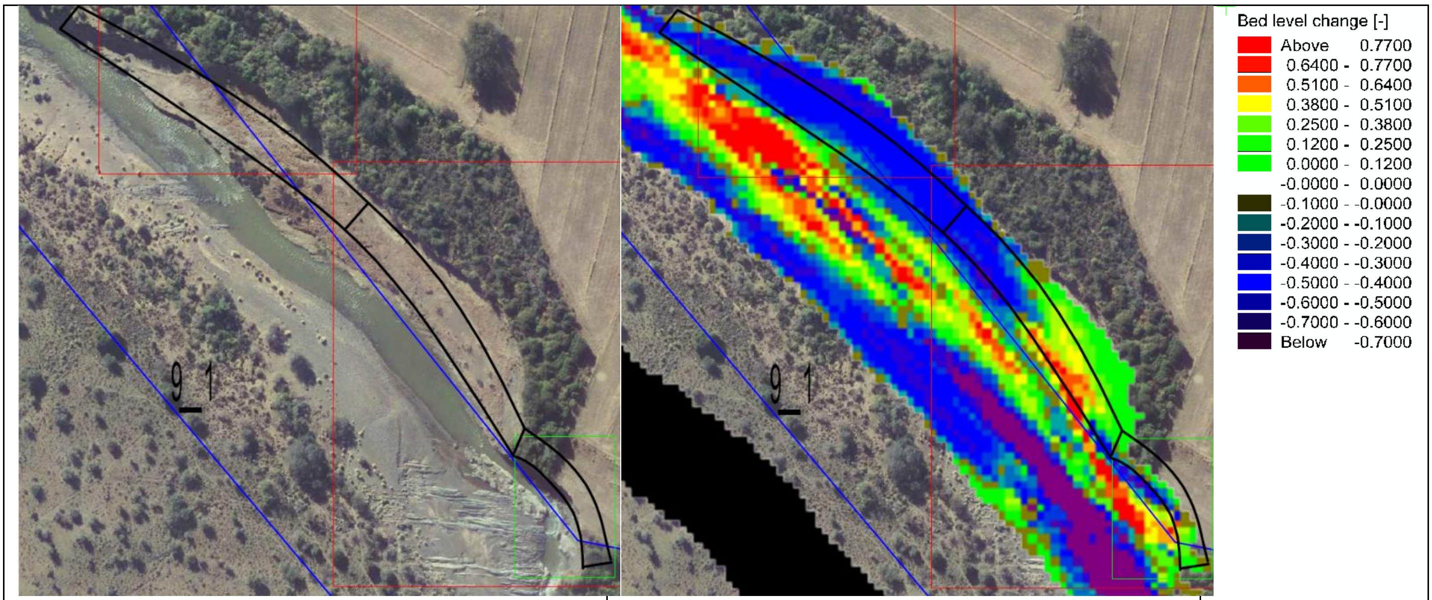


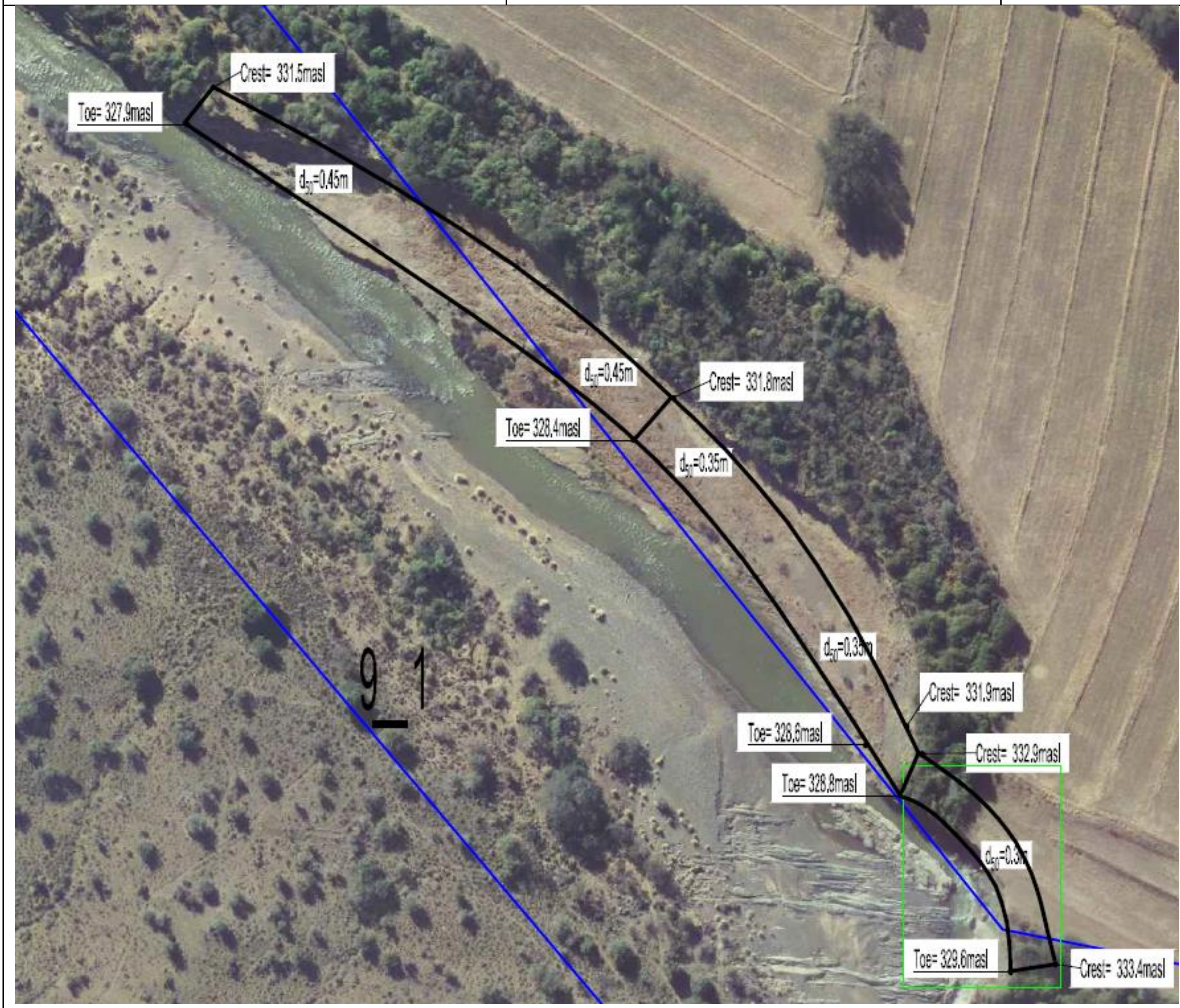
Appendix 57: Zone 9



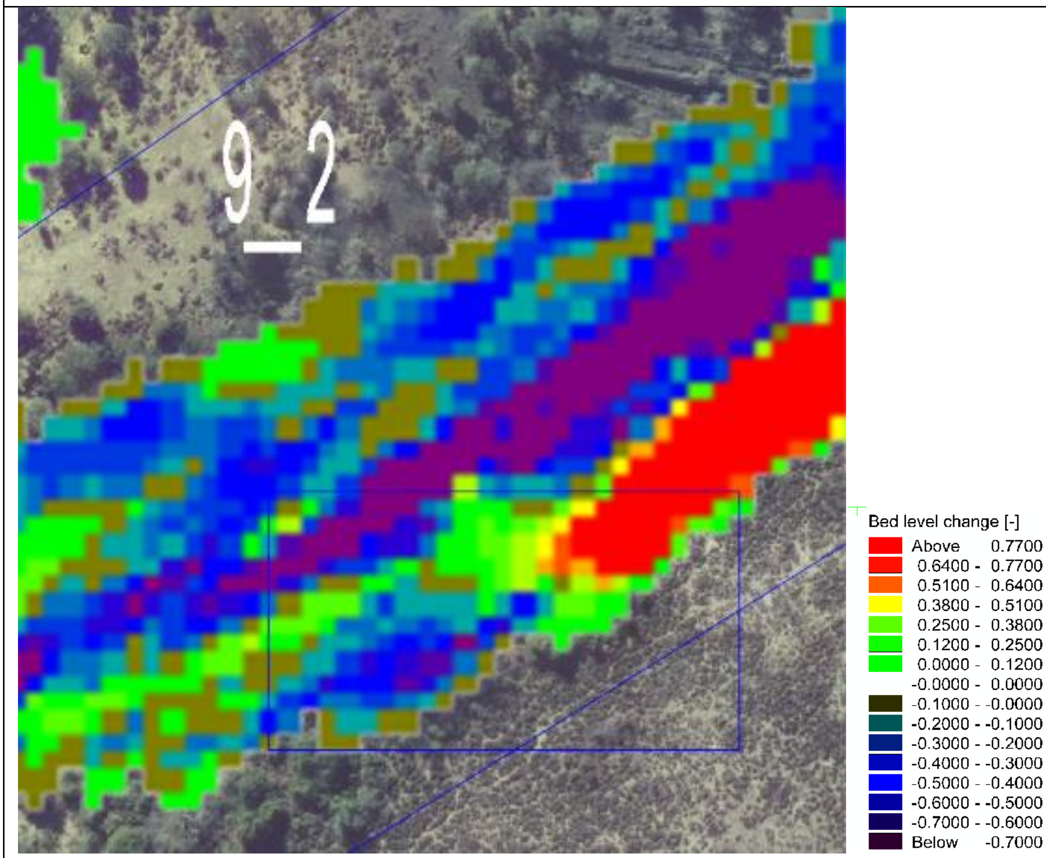


Appendix 58: Zone 9_1 Q10 flood peak scour pattern and proposed scour protection

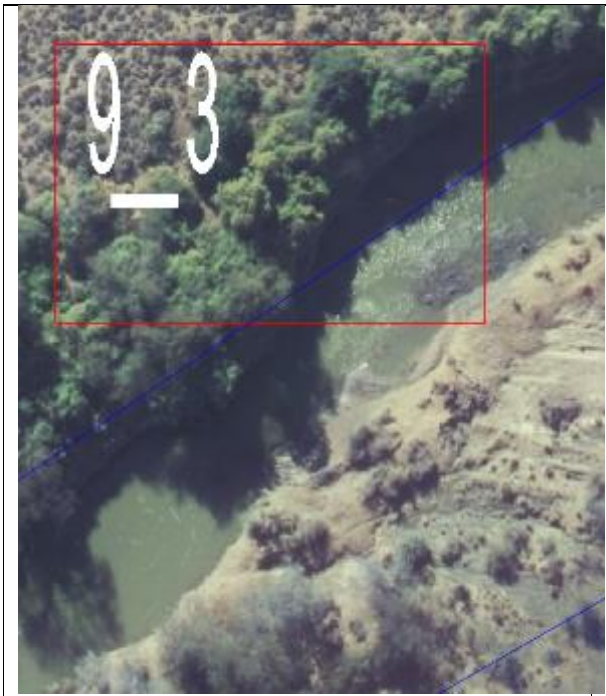


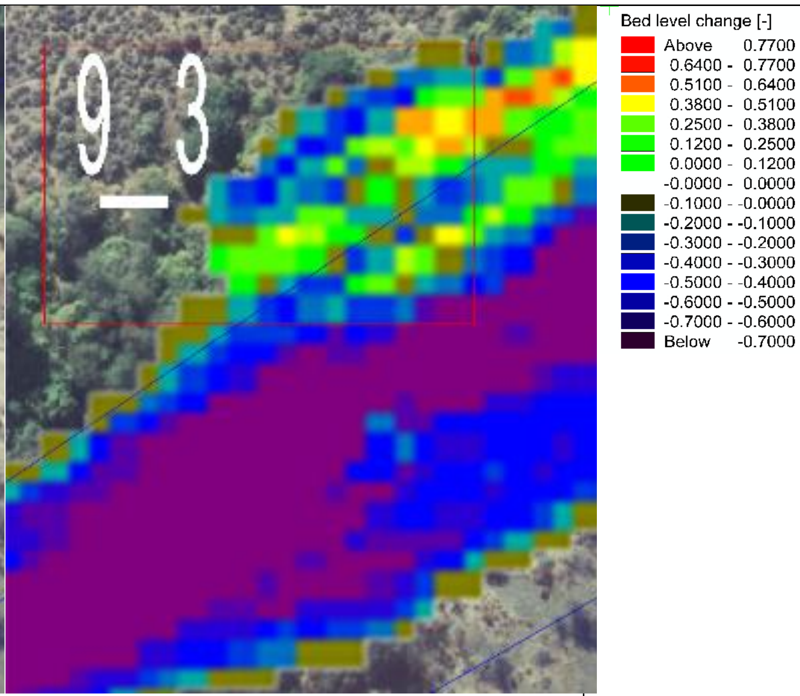


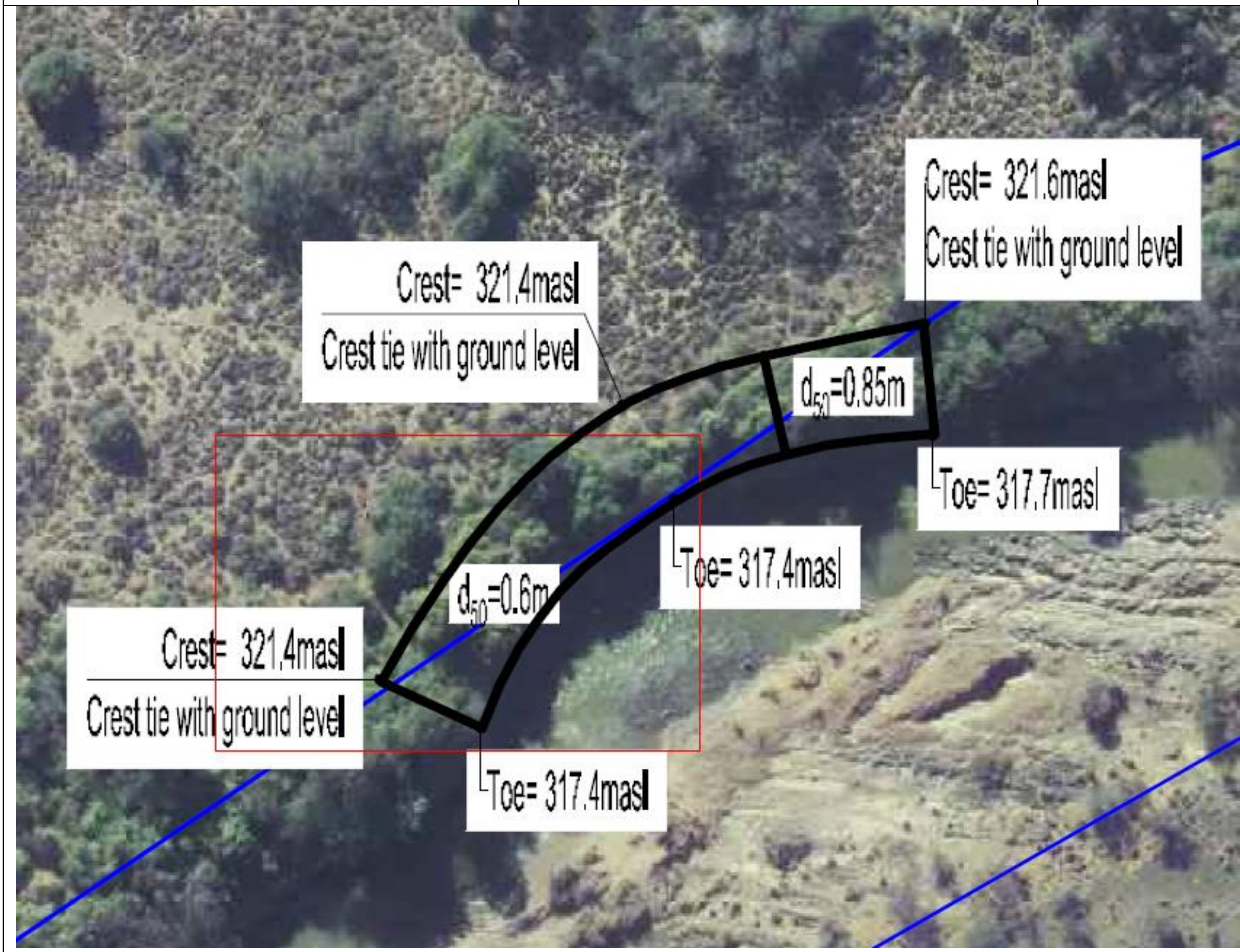
Appendix 59: Zone 9_2 Q10 flood peak scour pattern



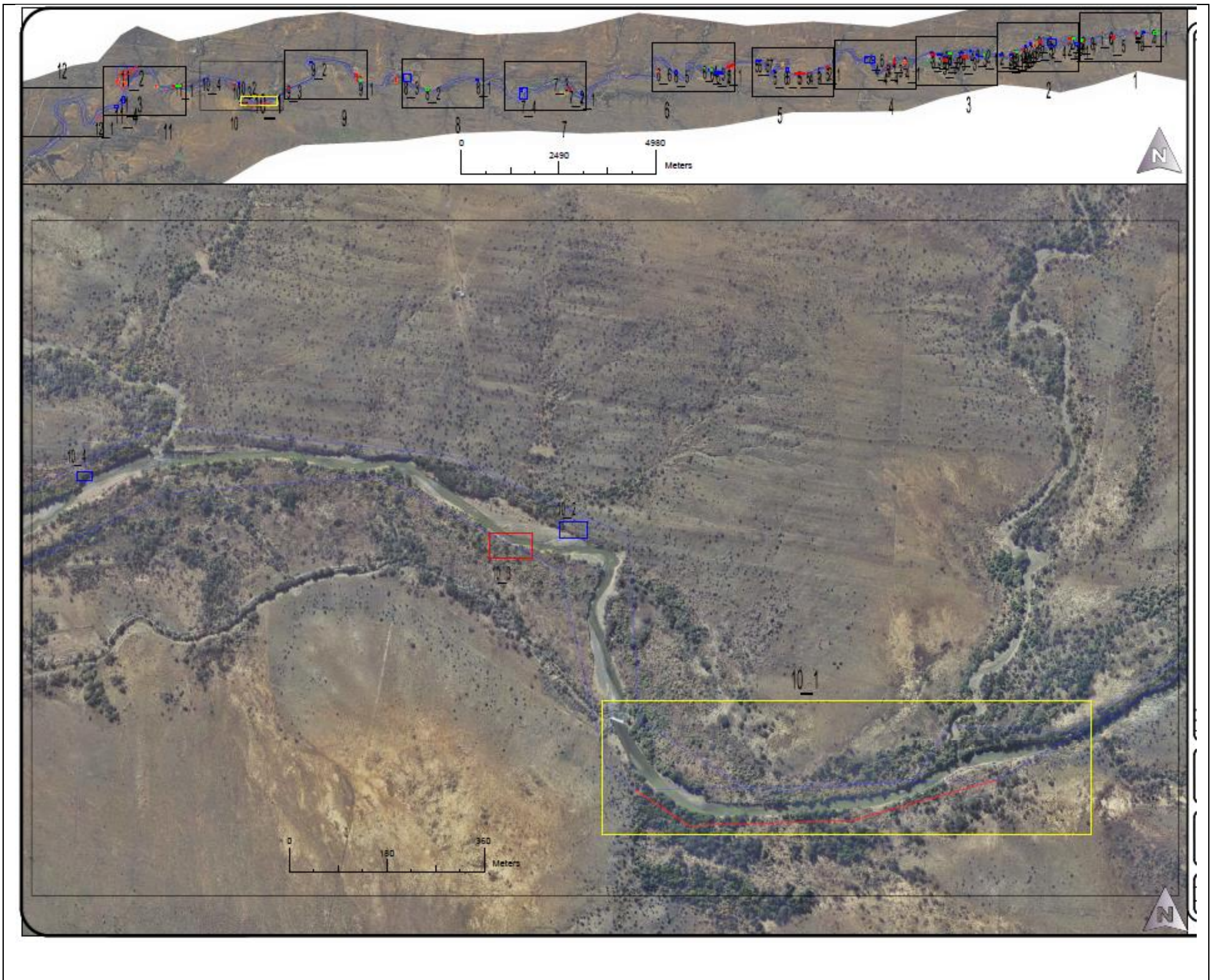
Appendix 60: Zone 9_3 Q10 flood peak scour pattern and proposed scour protection

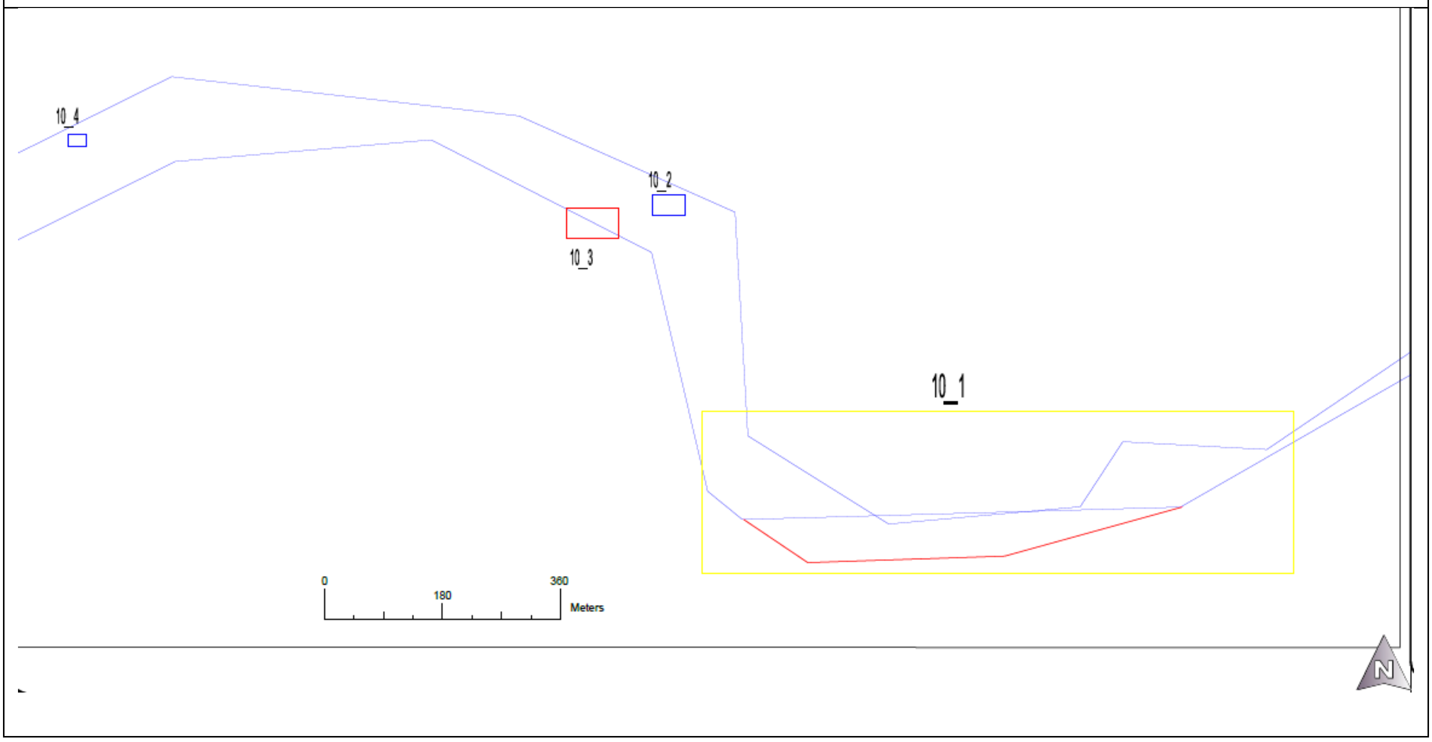




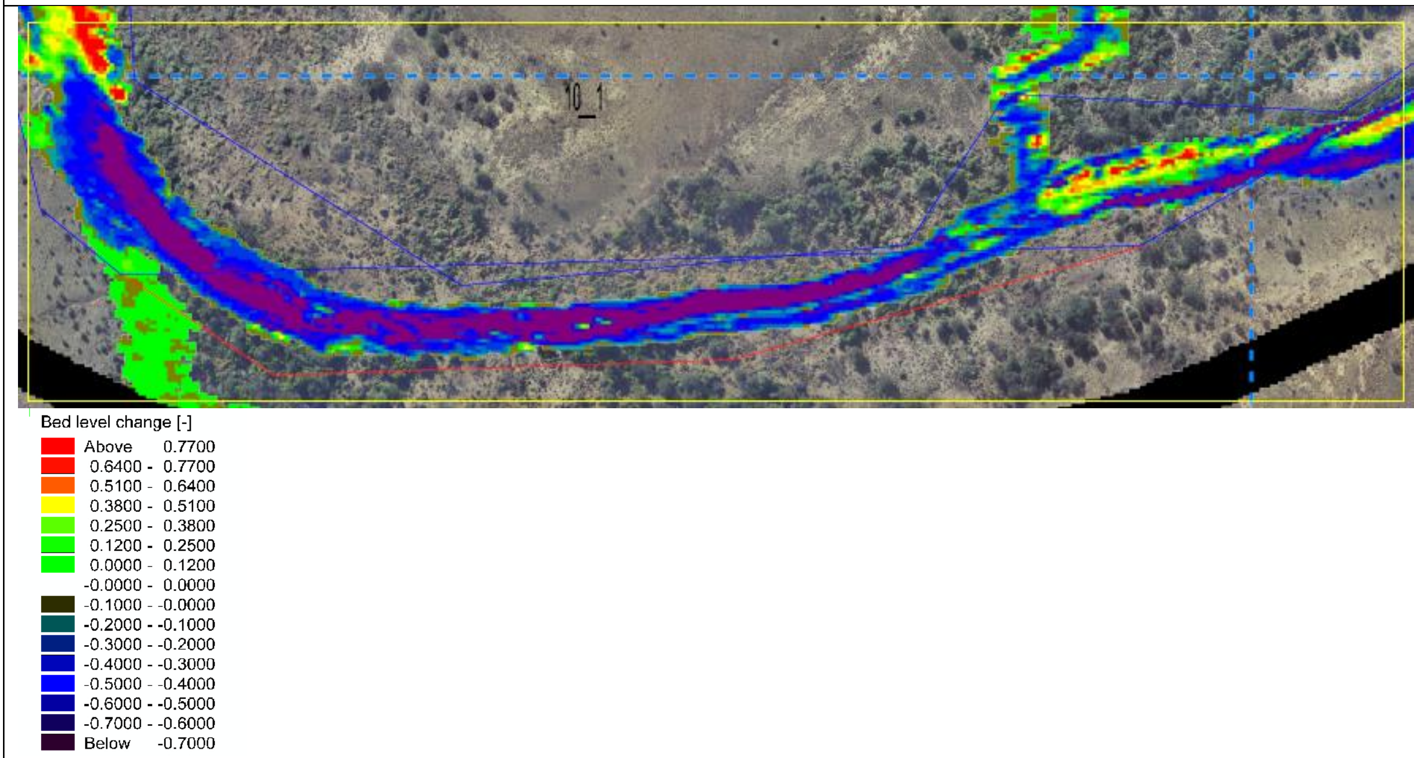


Appendix 61: Zone 10

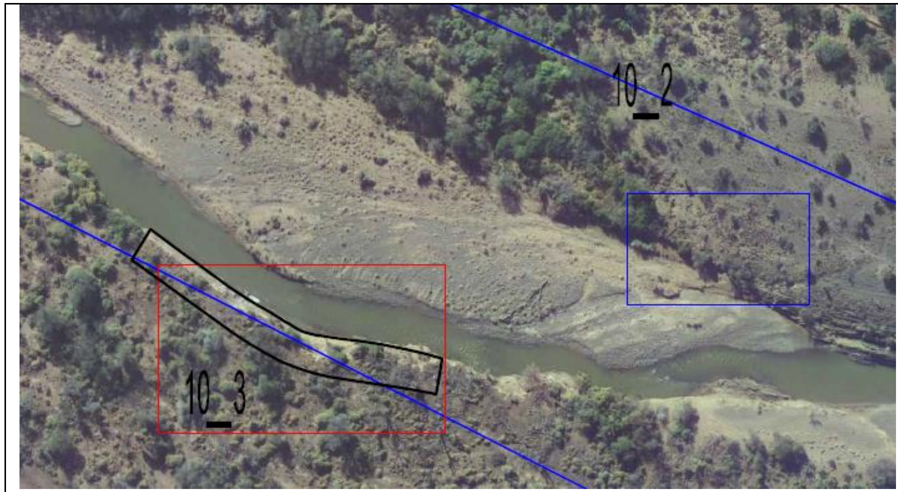


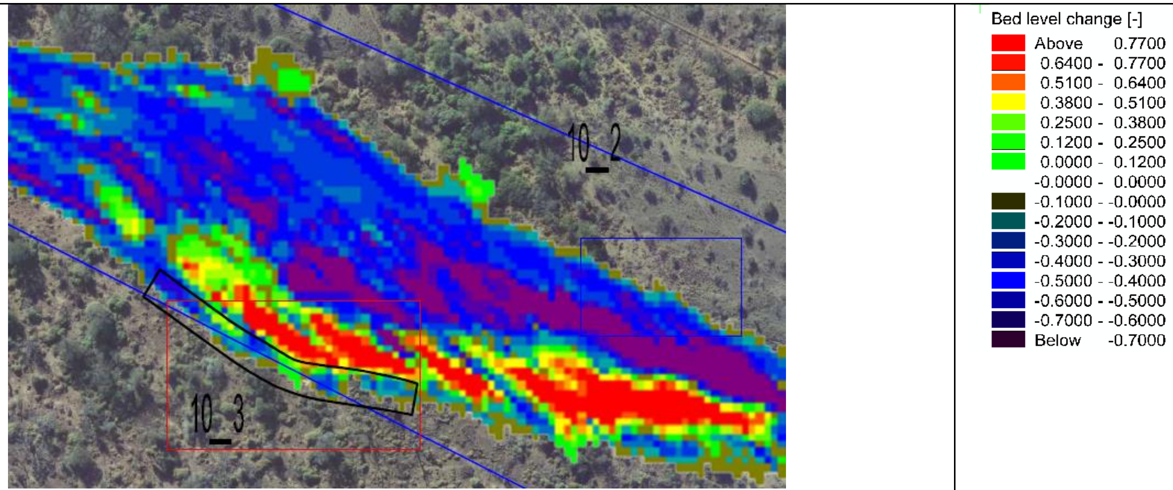


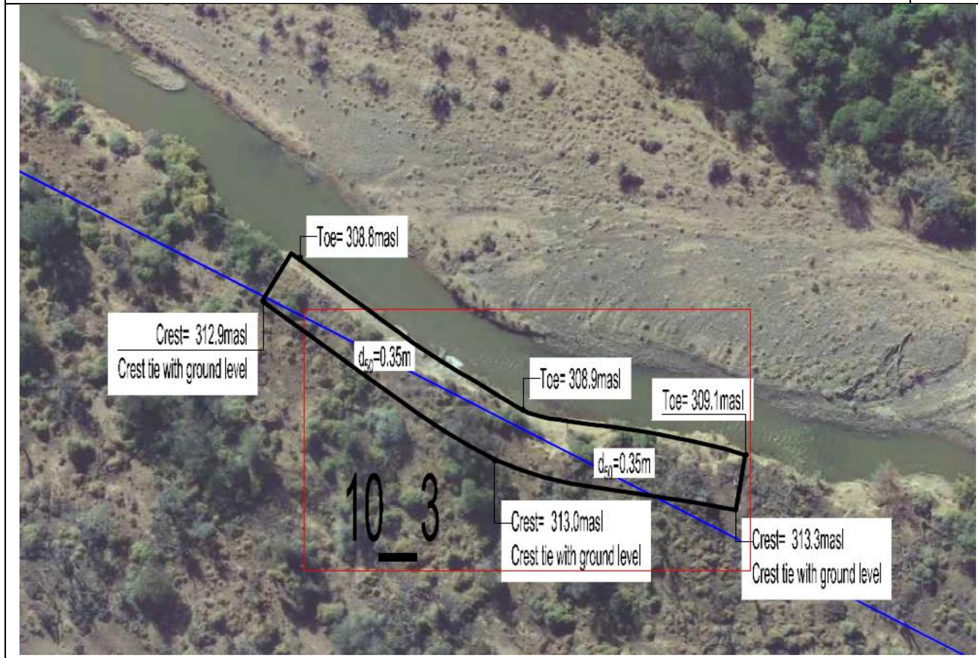
Appendix 62: Zone 10_1 Q10 flood peak scour pattern



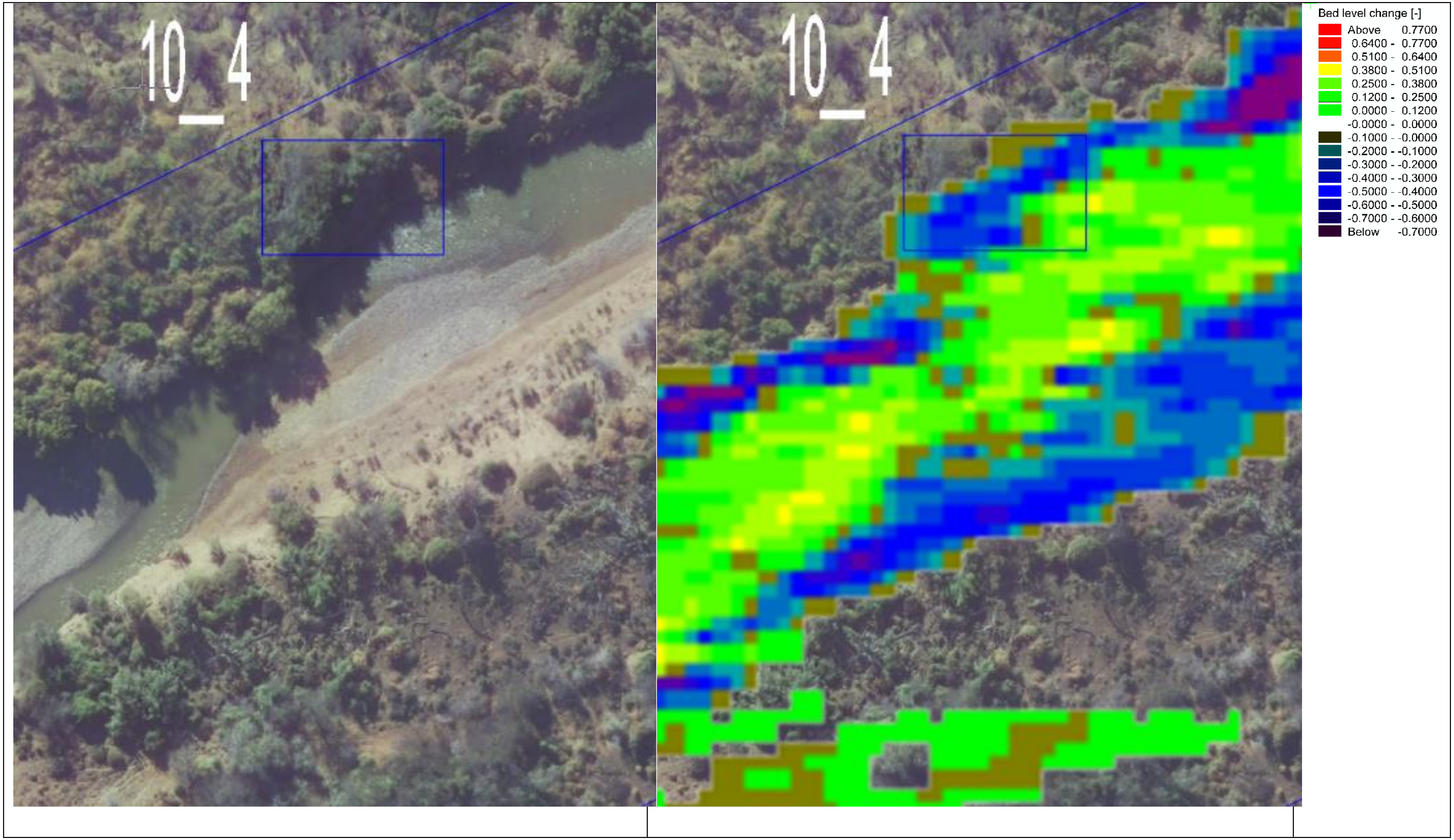
Appendix 63: Zone 10_2 and 10_3 Q10 flood peak scour pattern and proposed scour protection



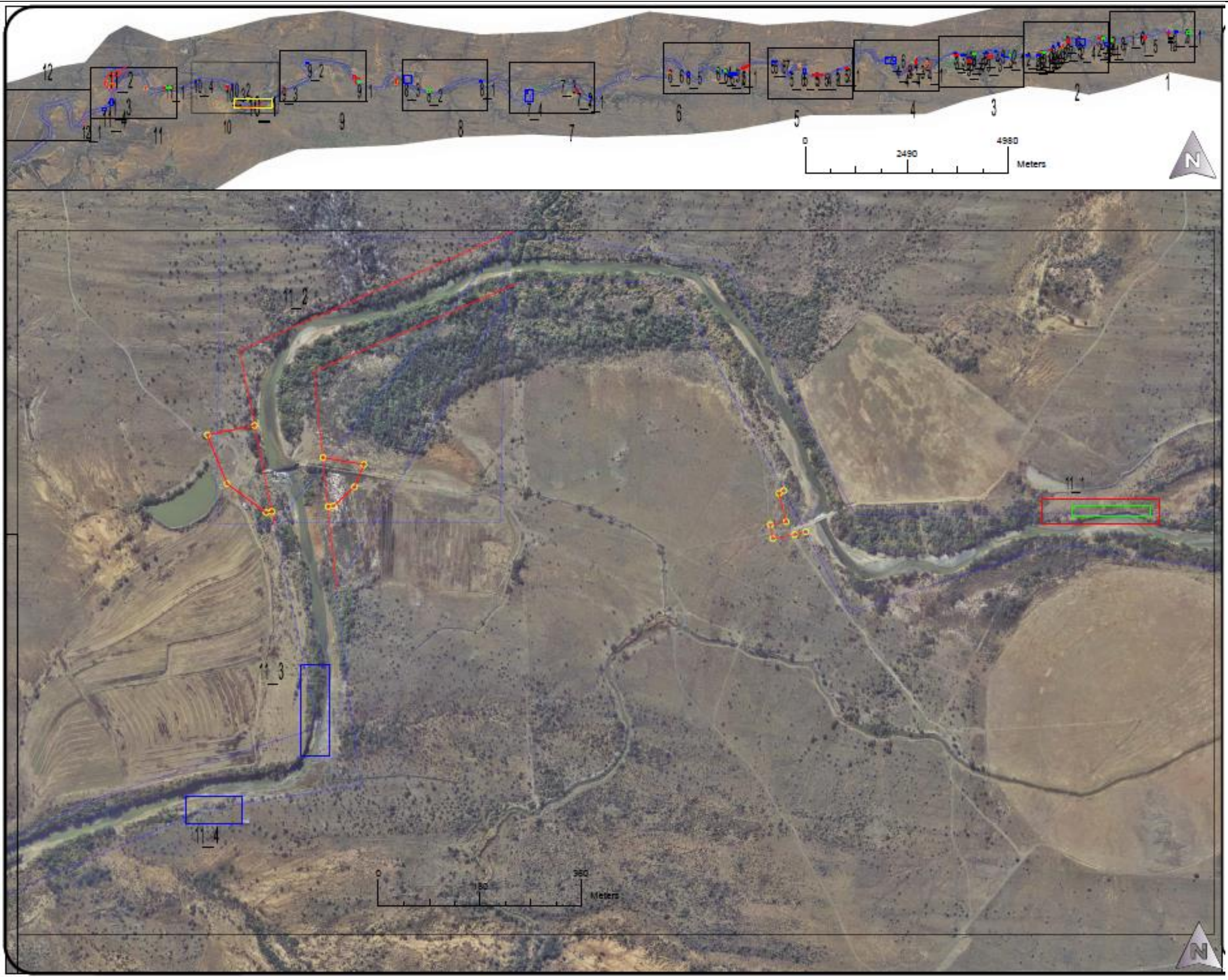


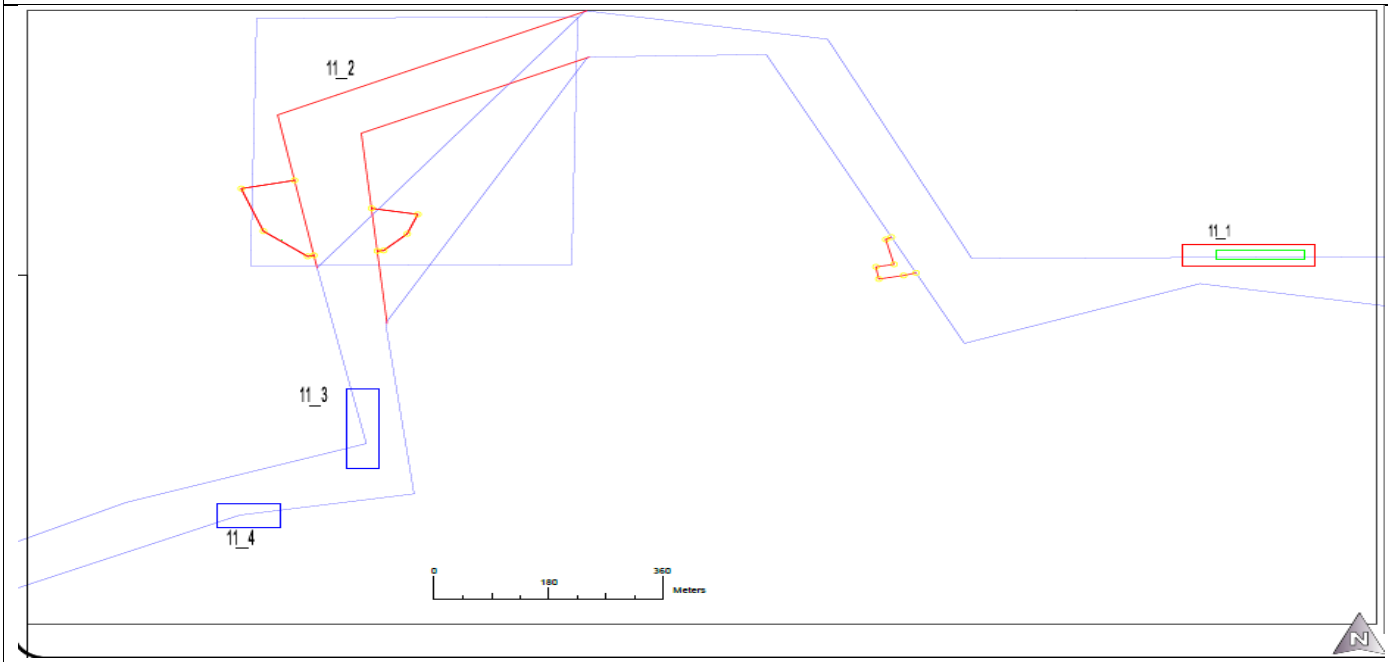


Appendix 64: Zone 10_4 Q10 flood peak scour pattern

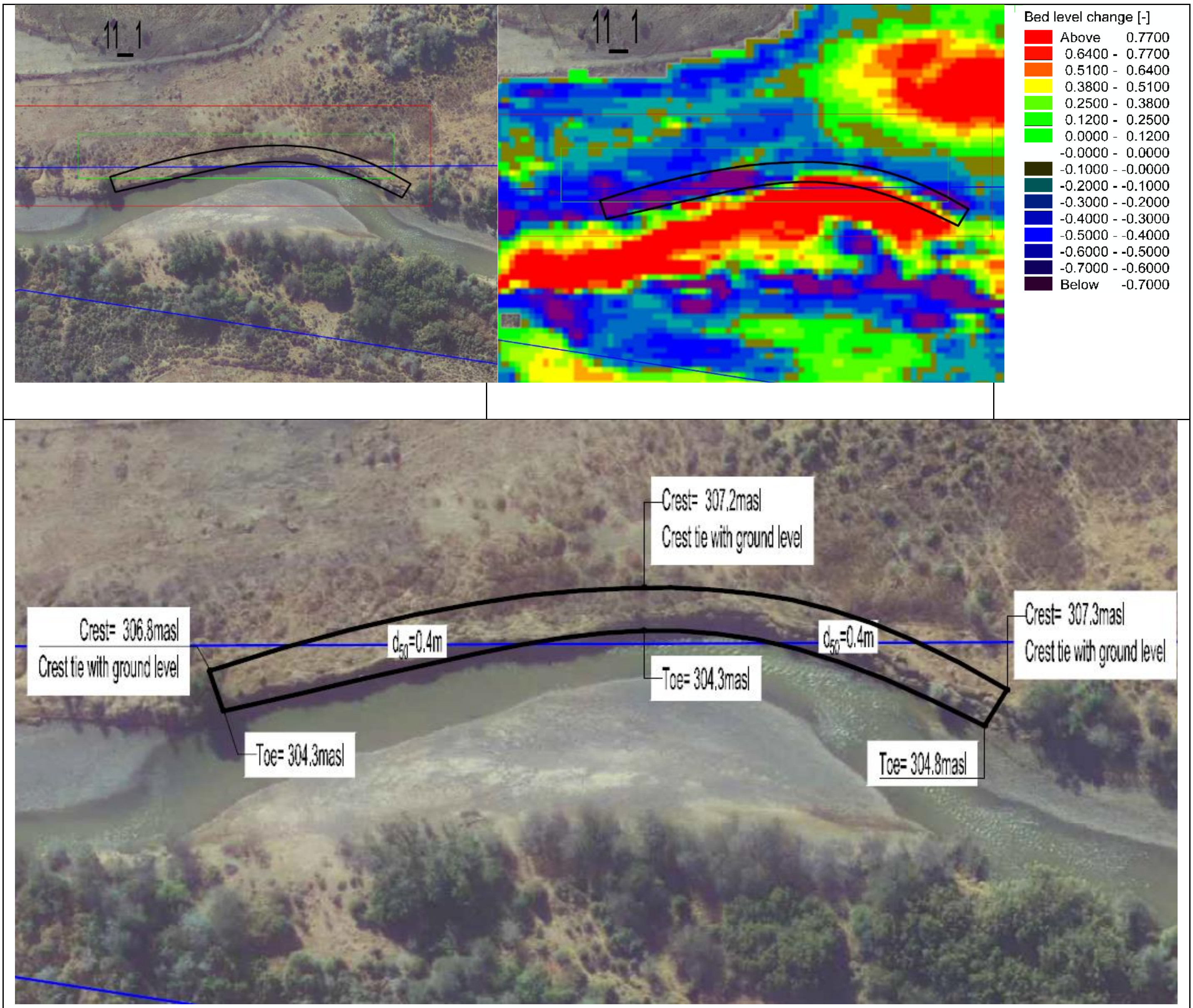


Appendix 65: Zone 11

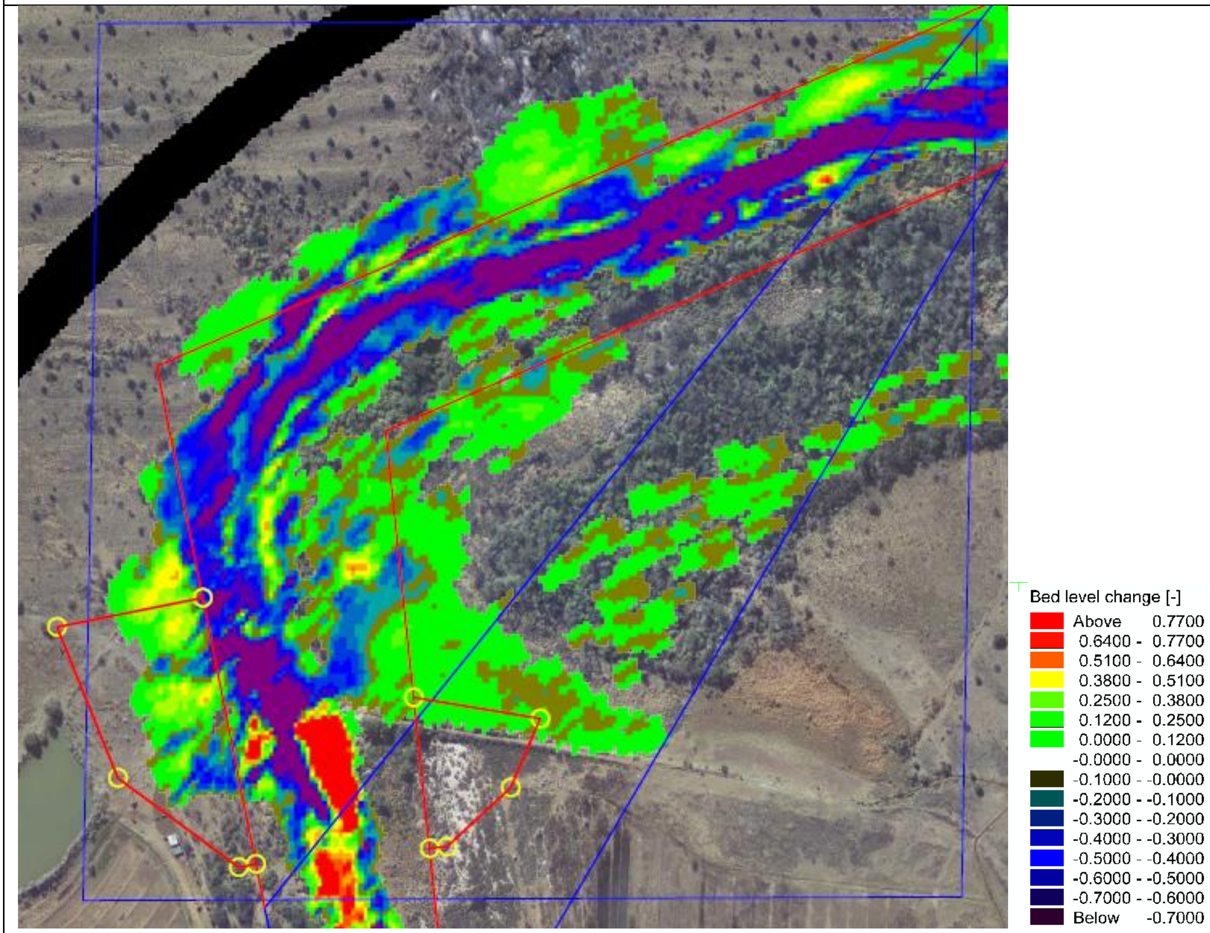




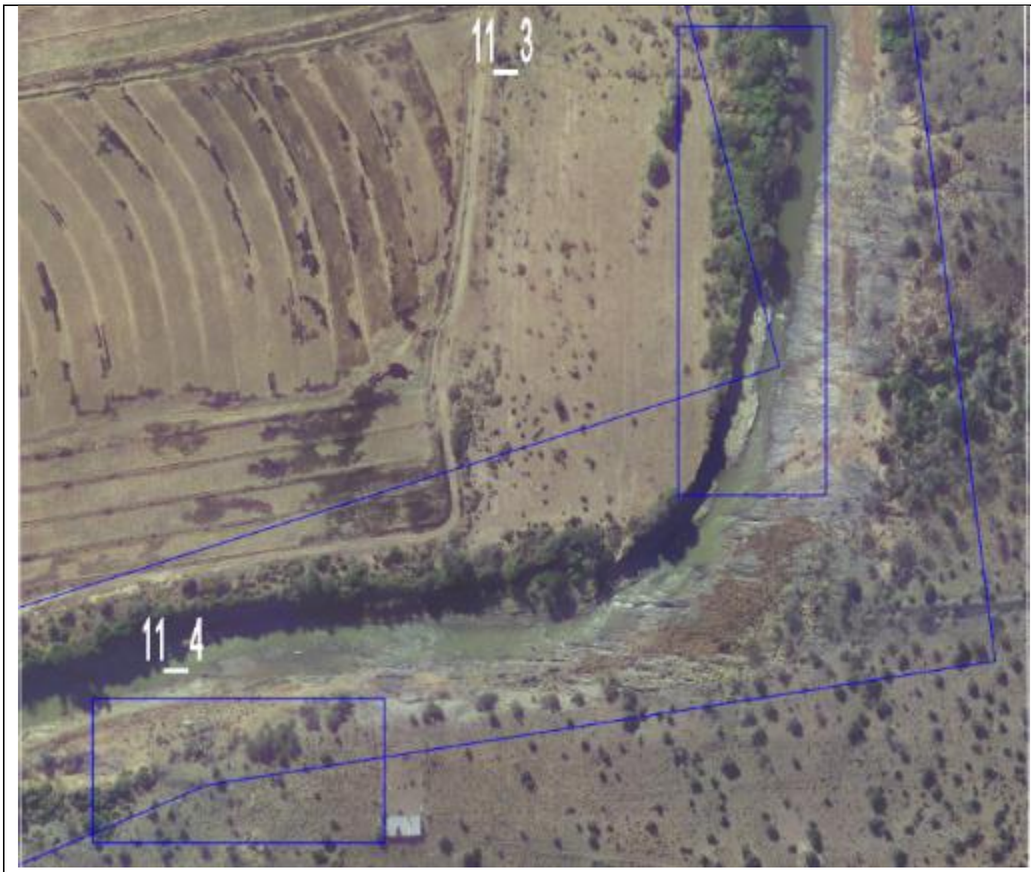
Appendix 66: Zone 11_1 Q10 flood peak scour pattern and proposed scour protection

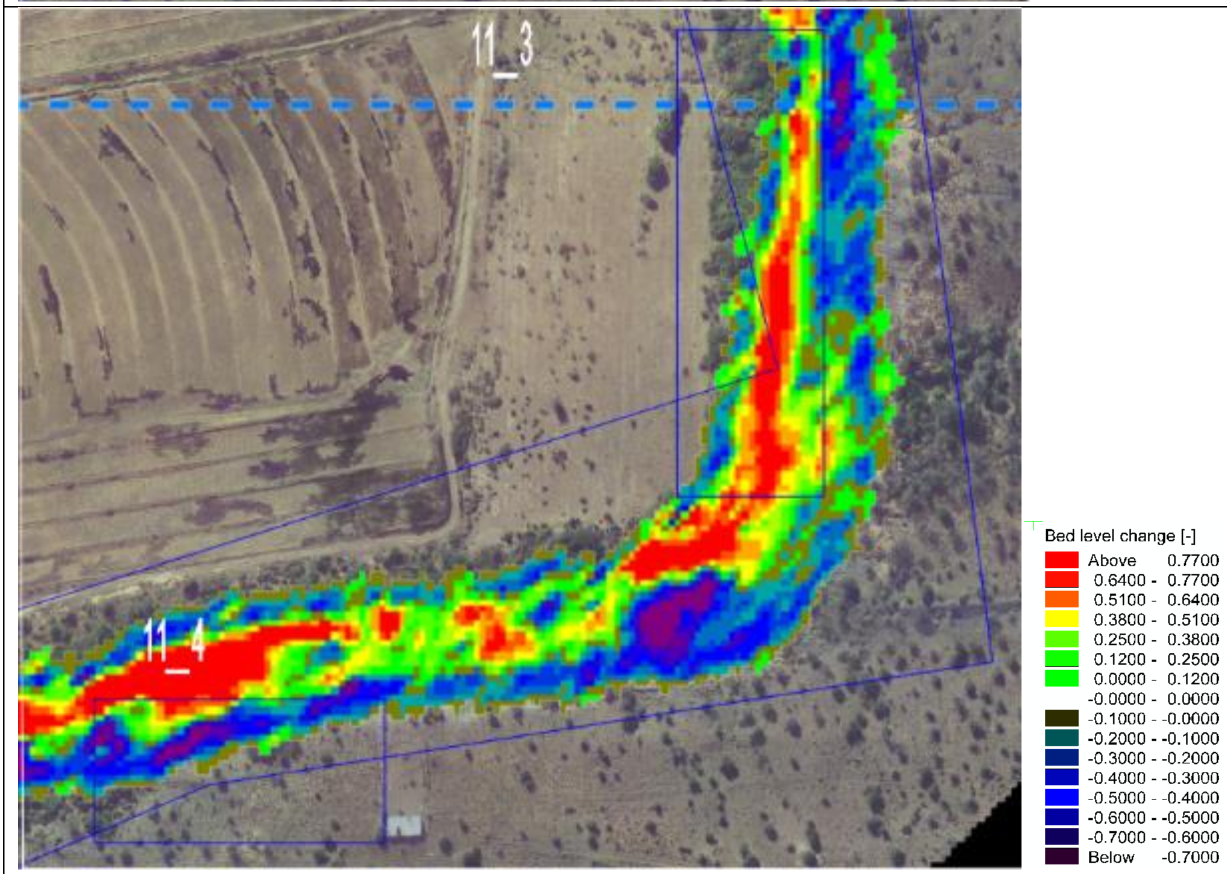


Appendix 67: Zone 11_2 Q10 flood peak scour pattern

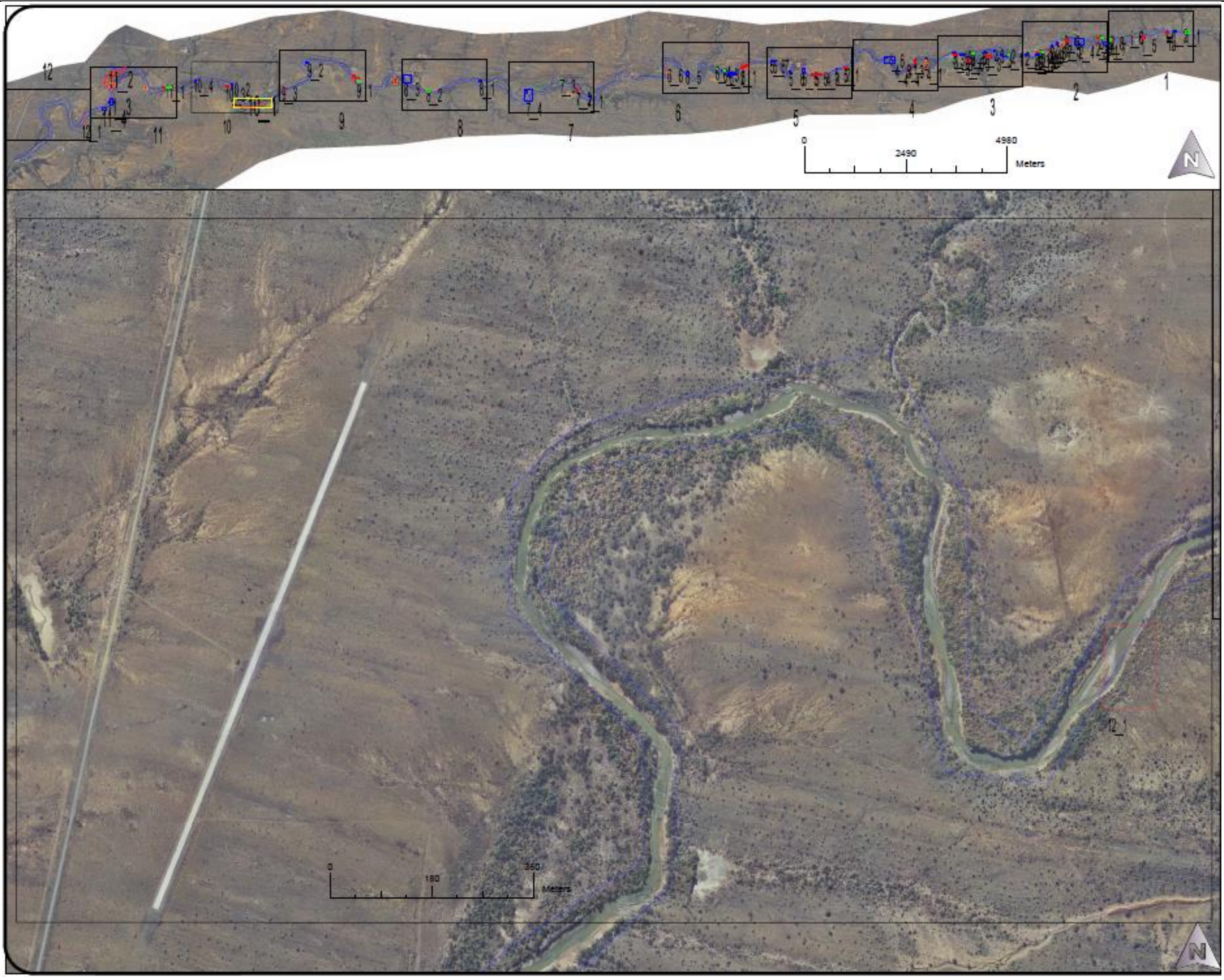


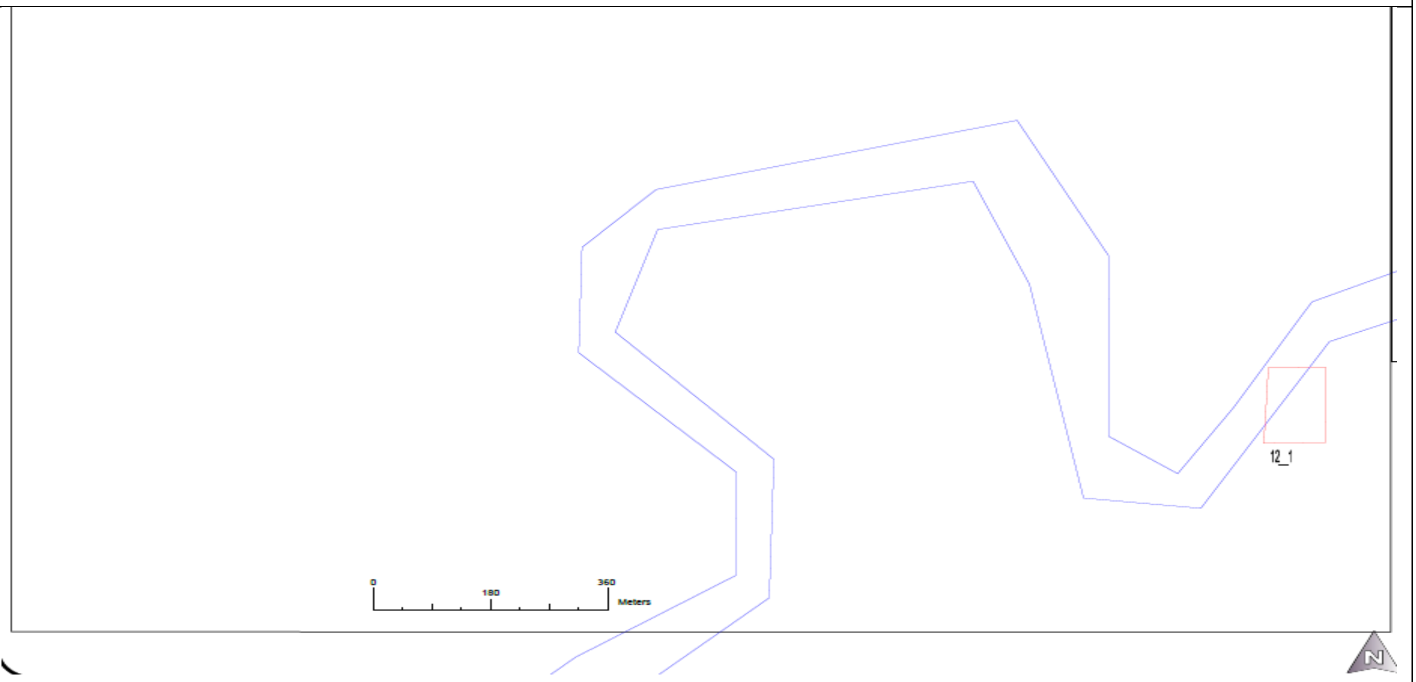
Appendix 68: Zone 11_3 and 11_4 Q10 flood peak scour pattern





Appendix 69: Zone 12





Appendix 70: Zone 12_1 Q10 flood peak scour pattern and proposed scour protection