A1 in Northumberland: Morpeth to Ellingham

Scheme Number: TR010059

6.47 River Coquet Fluvial Geomorphology Assessment

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1 INTRODUCTION

1.1.1. The A1 in Northumberland: Morpeth to Ellingham, (Scheme), comprises two sections known as Part A: Morpeth to Felton (Part A) and Part B: Alnwick to Ellingham (Part B). The Scheme aims to increase capacity by widening the existing single carriageway to a dual carriageway along an approximately 12.6 km section of Part A (approximately 6.5 km of online widening and approximately 6.1 km of new offline highway) and along an approximately 8 km section of Part B.

1.1.2. An application for development consent for the Scheme was submitted by Highways England (Applicant) on 7 July 2020. The application was accepted for Examination on 4 August 2020. The Applicant submitted a change request to the Examining Authority (ExA) at Deadline 4 of the Examination (Change Request). On 9 April 2021, the ExA accepted the Change Request as part of the Application.

1.1.3. The Change Request incorporated three proposed changes:

a. The Earthworks Amendments;
b. The Stabilisation Works; and
c. The Southern Access Works.

1.1.4. Further details as to the nature of each of these changes is set out in 6.36 Environmental Statement Addendum: Earthworks Amendments for Change Request [REP4-061], 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] submitted at Deadline 4 of the Examination.

1.1.5. As stated at paragraphs 9.5.2 and 9.5.3 of the 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and paragraphs 8.5.2 to 8.5.3 of 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064], the assessments submitted at Deadline 4 of the Examination in respect of the Stabilisation Works and the Southern Access Works were prepared on the basis of Manning's calculations and associated geomorphological calculations and, in order to verify those assessments, 2-dimensional (2D) hydraulic modelling of the River Coquet was required, including in respect of the previous fluvial geomorphology assessment on which the 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] relied.

1.1.6. This report sets out the fluvial geomorphology assessment methodology and results for the assessment undertaken since Deadline 4 of the Examination in relation to the Stabilisation Works and the Southern Access Works. In doing so, this report takes into account the results of the 2-D hydraulic modelling and additional information from a further site visit on 25th March 2021 (undertaken to gather further sediment survey data), to confirm the robustness of the 6.38 Environmental Statement Addendum: Stabilisation Works for

Change Request [REP4-063]and 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] submitted at Deadline 4 of the Examination.

2 BACKGROUND

2.1.1. Paragraph 9.10.9 to Paragraph 9.10.14 of 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and Paragraph 8.10.7 to Paragraph 8.10.22 of 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] concluded that impacts from the Scheme Construction on the sediment regime and natural fluvial processes could occur across the full range of flow conditions, with impacts from fine sediment ingress likely to be higher during low flow conditions and impacts on coarse sediment transport and erosion greater during higher and out-of-bank flows.

2.1.2. Specifically, it was assessed that the constriction placed on channel width by the Temporary Works (as defined at paragraph 5.1 of this report) would increase water velocities, depths and sediment transport competence, i.e. the potential size of sediment that may be entrained at a given location during a given flood event. These effects were assessed to have the potential to result in bed scour and downstream eddying (beyond the channel constriction), which may locally alter fluvial processes and the distribution of erosional and depositional features. However, it was also assessed that the limited duration of the works (16 months for near-channel and in-channel Scheme Construction works) and the reinstatement of the baseline cross sectional profile outside the extent of any permanent works meant that these impacts could be considered localised, short term and reversible.

2.1.3. The assessment concluded that the loss of some bank features was unlikely to be reversible through natural processes and some sedimentary bed deposits which show indications of long-term stability may be unlikely to reform in the short term through natural deposition. In the case of the latter, the assessment concluded that, where such features were impacted, specific measures should be implemented to reinstate larger (>0.5m particles) in their original location. This would allow deposition of finer sediments through sheltering and, in turn, allow such features to reform.

2.1.4. Paragraph 9.10.18 to Paragraph 9.10.36 of 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and Paragraph 8.10.23 to Paragraph 8.10.42 of 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] concluded that the impacts of the Scheme in Operation were likely to be localised to the footprint of the erosion protection and reinstated made ground around the north bank and the south bank where permanent works were being undertaken. This assessment indicated that there would be a localised loss of bank features such as exposed roots, undercut banks and exposed bedrock within the footprint of the works. However, it also concluded that the overall channel cross sectional area would be maintained as far as practicable, and therefore the dynamics of water flow, and impacts on geomorphological processes, would only be locally affected, with effects being restricted to the channel margins adjacent to the scour protection and immediately downstream.

3 SUMMARY

3.1.1. This report details the methodology and results from the following investigations:

a. site reconnaissance and geomorphological mapping, including approximate delineation of bank and bed features, observed flow types and processes;
b. sediment sampling to inform the geomorphological baseline; and
c. a geomorphological dynamics assessment, based on 2D hydraulic modelling of the Scheme Construction and Scheme in Operation scenarios.[1]

3.1.2. The results of the above investigations are then considered in the context of the 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] submitted at Deadline 4 of the Examination, to confirm the findings presented in those addenda in relation to fluvial geomorphology and highlight any changes to the conclusions drawn in 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] submitted at Deadline 4 of the Examination.

[1] The Scheme Construction scenario represents the situation during the construction of the Scheme, and takes account of a reprofiling of the valley sides to accommodate piling platforms and associated changes in roughness, and the construction of training walls which will temporarily reduce the channel cross section to accommodate the piling platforms and a temporary crossing to access the south bank. The Scheme in Operation scenario represents the situation following the construction of the Scheme, and comprises bank protection 86 m (62 m of rock armour plus an additional 24 m of green-grey bank protection) along the north bank and 45 m (around 28 m of rock armour and 17 m of green-grey bank protection) along the south bank, as well as the proposed bridge piers themselves and a concrete pilecap around the south pier rising to 36 m OD.

4 SITE RECONNAISSANCE AND MAPPING

4.1.1. Site reconnaissance and mapping was undertaken to confirm the baseline against which to assess the works described in 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] and to provide further detail on the areas around the proposed works. The information gathered has also been used to inform and verify aspects of the Baseline scenario hydraulic model as described in 6.50 River Coquet Hydraulic Modelling Report (document reference 6.50), including the nature and extent of existing channel modifications, roughness values included in the model, and river behaviour at specific locations.

4.2 FIELD STUDY AREA

4.2.1. The field study area is shown in Figure 1. The study area comprises an approximate 1.2 km reach of the River Coquet, near Felton, with the existing A1 river crossing located approximately at the midpoint. The reach is in a gorge, incised into bedrock of variable strata and is delineated by a river-wide bedrock ledge at its upstream end, and a river-wide weir at its downstream end, both of which mark step-changes in bed level and combine two meander wavelengths. This reach is the same as the study reach used in 6.7 Environmental Statement Appendix 10.7 – Geomorphology Assessment – River Coquet Parameter 10 Part A [APP-260]. It was considered reasonable to maintain this reach for field study as the boundaries were morphologically justifiable (on the basis of the step changes in bed level and the at least partial interruptions to sediment continuity the features at the boundaries would provide), and to maintain consistency with earlier assessment. This study reach is a subsection of the reach as ‘defined by the confined gorge’ in paragraph 9.10.22 of 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and paragraph 8.10.29 in 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] which extends around a further 200m upstream.

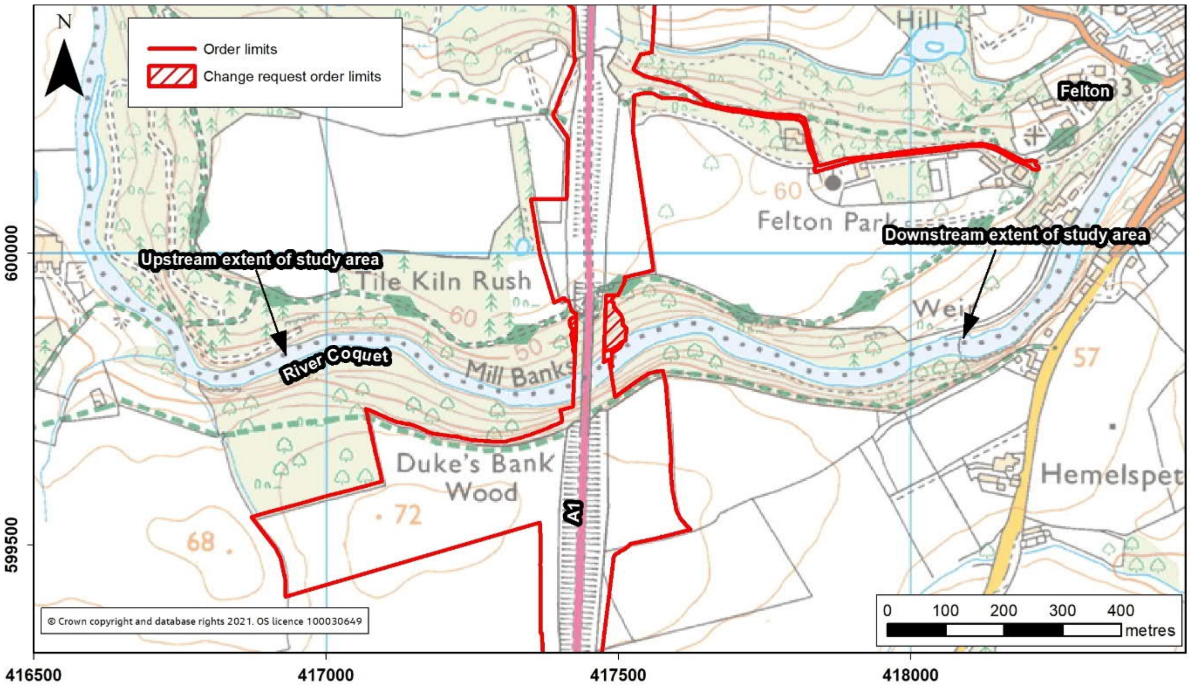


Figure 1 - Field Study Area Location Map

4.2.2. Further information on the wider River Coquet catchment and background information on the study reach, such as environmental designations and WFD status can be found in Section 3 of 6.7 Environmental Statement Appendix 10.7 – Geomorphology Assessment – River Coquet Parameter 10 Part A [APP 260] and Section 4.2 of 6.44 Water Framework Directive Addendum for Change Request [REP4-068].

4.3 APPROACH

4.3.1. Site reconnaissance and mapping was undertaken on 26th January 2021 and 26th February 2021. Weather on both days was generally dry, with some light rain on 26th January. River levels on both days had been falling for several days, with both the Rothbury and Morwick gauges at around 0.6m on 26th January and 0.7m on 26th February. Discharges at the Morwick gauges on these dates were 9.46m3/s on 26th January (approximately Q25, i.e. flows exceed or equal this discharge approximately 25% of the time), and 12.1 m3/s on 26th February (approximately Q18, i.e. flows equal or exceed this level approximately 18% of the time) (CEH, 2021).

4.3.2. Site reconnaissance and mapping on 26th January involved walking the whole of the study area north bank, mapping bank and bed features, processes and flow types, and capturing photos and video of both banks where possible. Site reconnaissance on 26th February focused on capturing detail about the banks and flow conditions within the footprint of the proposed works on the south bank, but reconnaissance of the study area from the south bank was also undertaken within the study reach.

4.3.3. Appendix A presents an overview map indicating the flow conditions and bank and bed features throughout the study reach, and Appendix B presents a larger scale presentation of the same map in the vicinity of the existing bridge, with both the footprint of the temporary and permanent works overlain.

4.3.4. A further site visit was undertaken on 25th March 2021, specifically to undertake a Wolman (1954) sediment count on a gravel-cobble-boulder bar within the longitudinal extent of the proposed north bank Scheme Construction and Scheme in Operation works, to allow an analysis of the impact of the works on this feature. Weather on the day of the survey was fine and dry with discharge on the Rothbury gauge recorded as 3.17 m3/s, slightly below Q50 (i.e. flows equal or exceed this discharge slightly more than 50% of the time). Discharge on the Morwick gauge was recorded at 4.52 m3/s, also slightly below Q50. On 26th January 2021 and 26th February 2021, river levels had been such that it had not been deemed safe to access this feature.

4.4 KEY OBSERVATIONS

GENERAL

4.4.1. The River Coquet within the study reach is characterised by a predominantly bedrock channel with boulder, cobble and limited gravel deposits. Overbank and marginal deposits are predominantly sandy and are found on both vegetated benches and floodplain fragments. Cobbles and boulders are frequently moss covered and mid-channel bars support vegetation indicating limited mobility and general stability of these features.

4.4.2. Valley side failures are spatially relatively common and comprise both rockfalls from sandstone bedrock in the upper cliffs and larger mass movements incorporating sandstone, mudstone and colluvium, all of which transport material from the valley sides to the fluvial zone.

BED

4.4.3. The riverbed is predominantly bedrock, with occasional riffles and mid-channel and marginal bars formed from sand, gravel, cobbles and boulders. In some locations, these features have formed where there has been an input of material from valley side failures.

BANKS

4.4.4. Banks are predominantly well vegetated, with mature trees and exposed soil or bedrock being confined to the bank toe. Where there has been rockfall activity from the upper cliff, the banks are formed of large rockfall blocks, mostly heavily mossed with trees rooted in the colluvial matrix or underlying soil as indicated in Figure 2.

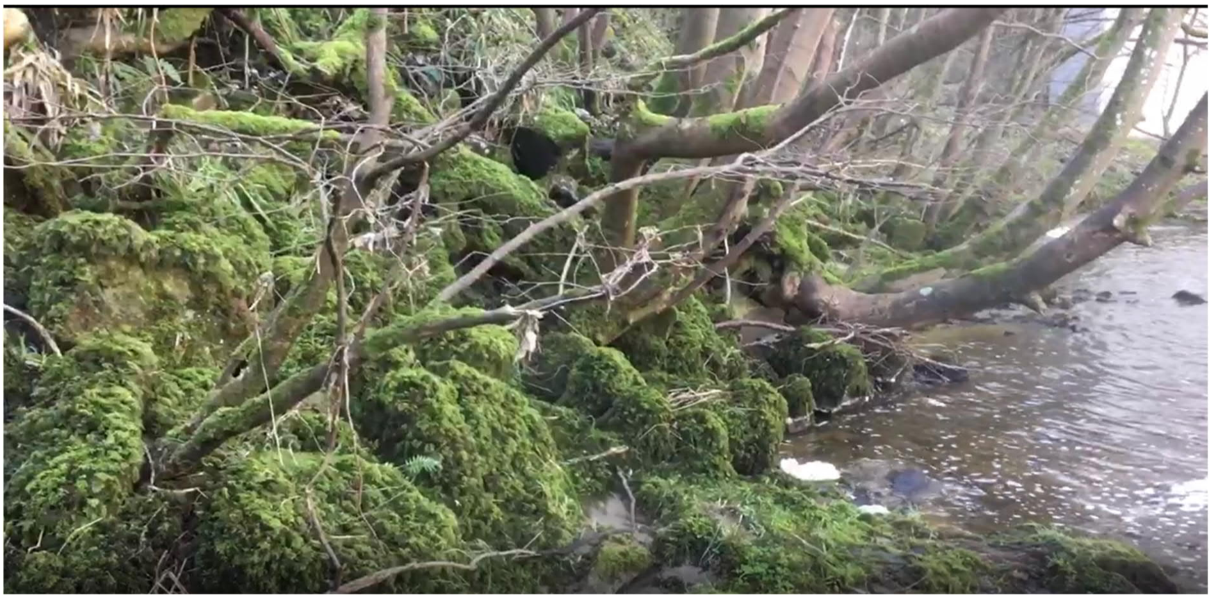


Figure 2 - Heavily Mossed Rockfall Blocks Forming Bank Downstream of Southern Pier

4.4.5. Localised evidence of bank undercutting exists, but there are also areas of more extensive erosion around 550m upstream and 250m downstream of the existing A1 crossing, where valley side failure deposits are present at riverbank level as shown in Figure 3. At these locations, rates of lateral erosion appear to be moderated by the presence of boulders which remain as lag deposits as finer material is eroded away.

Figure 3 - Erosion at Toe of Valley Side Failures, 550m Upstream (Left Image) and 250m Downstream (Right Image) of the Existing A1 Crossing

MID-CHANNEL BAR

4.4.6. A mid-channel bar has formed around 40m downstream of the existing A1 crossing of the River Coquet. This bar is primarily comprised of gravel, cobbles and boulders and, while predominantly unvegetated, has vegetated at its downstream end (including a tree which has taken root), indicating a level of short to medium term stability. The bar is separated from the left bank at low flows by an approximately 7m to 11m wide channel. The bar is approximately 6m wide and 30m long, subject to the degree of exposure at the observed water level. Sediment size was observed to get finer from upstream to downstream. Figure 3 shows a photograph of the bar on the day of the sediment count.

4.4.7. A Wolman (1954) count was undertaken on the bar on 25th March 2021. A total of 299 particles were measured using a Gravelometer and tape measure, with the survey taking place in a 'zigzag' across the bar from upstream to downstream. Table 4-1presents key statistics from the count, Figure 4 presents the sediment curve from the count, and Figure 5 presents the data as collected from upstream to downstream, which supports the observation of a fining of sediment downstream.

Figure 3 - Mid-channel bar from left bank looking downstream

Table 4-1 - Key Sediment Size Statistics from Mid-Channel Bar Sediment Count

Parameter	Value
D_{16}	16 mm
D_{50}	45 mm
D_{84}	205 mm
D_{16}/D_{50}	0.4
D_{50}/D_{84}	0.2

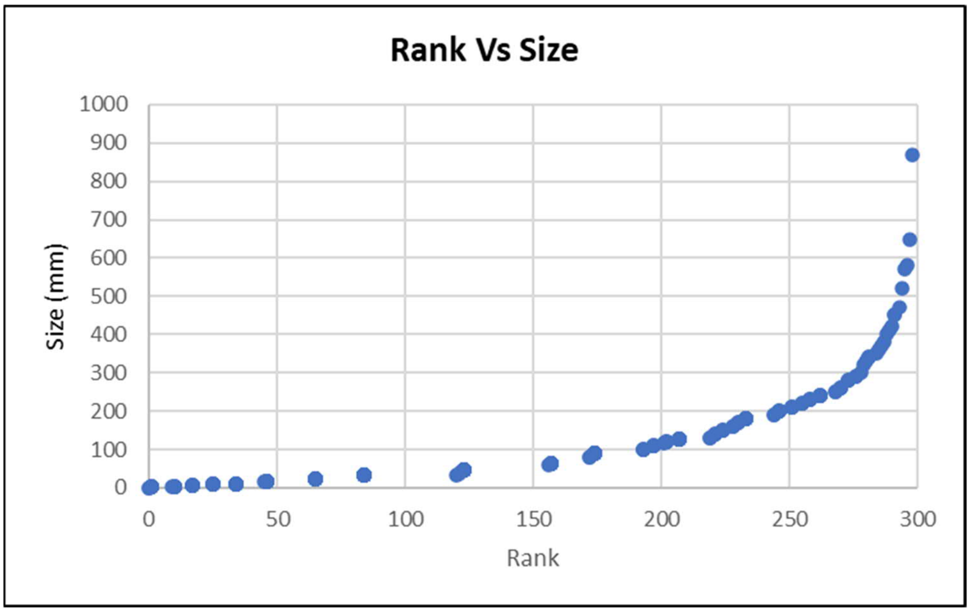


Figure 4 - Sediment Size Distribution (Cumulative)

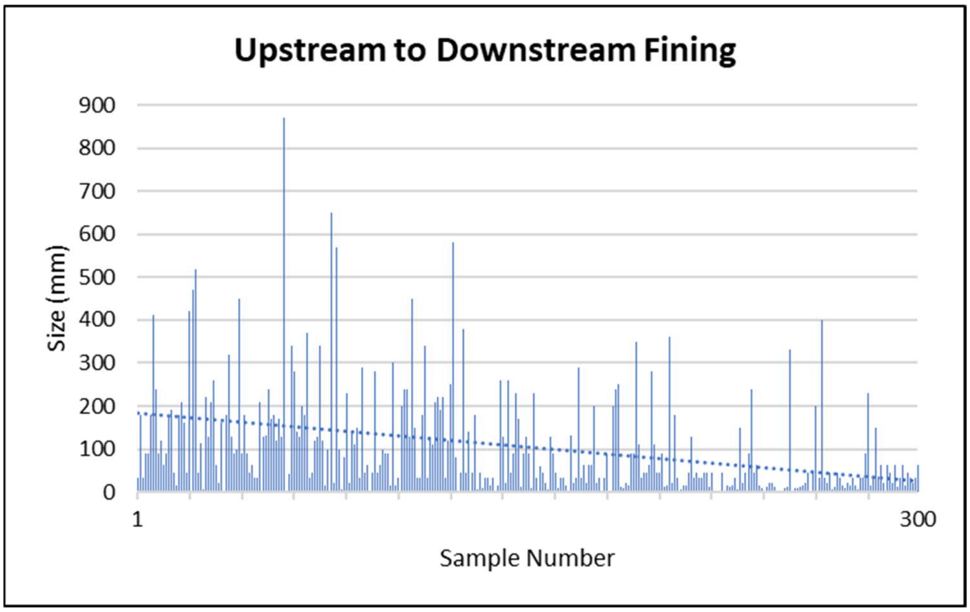


Figure 5 - Downstream Fining of Material on Bar (1 – Furthest Upstream Sample, 300 – Furthest Downstream Sample)

EXTENT OF NON-NATURAL BANK

4.4.8. Throughout the majority of the study area the banks are natural, other than the installation of and minor modification for individual fishing platforms and their accesses. However, in the immediate vicinity of the existing bridge there have been historical engineered modifications to the bank associated with the construction of the existing A1 bridge. These modifications include:

a. River training works (as shown in Figure 6) which extend around 12m upstream and 12m downstream of the existing pier on the south bank; and
b. A reprofiled section (relating to the construction access for the existing bridge) of at least 17m of the north bank which includes a drainage outfall and informal protective rock armour on its upstream side, as shown in Figure 7.

Figure 6 - River Training Works on South (Right) Bank

Figure 7 - Drainage Outfall and Associated Informal Rock Armour, North (Left) Bank

4.4.9. Around 650m downstream of the site, the river-wide weir at Felton old mill impounds flow for around 300-350m, and to within 300-350m of the site. The weir is shown Figure 8.

Figure 8 - Felton Old Mill Weir

FLOW CONDITIONS

4.4.10. Flow conditions vary throughout the study reach. Chute and freefall flow is restricted to the bedrock ledge at the upstream extent of the study reach and the weir at the downstream extent. Alternating riffle and run flow occurs immediately downstream of the bedrock ledge at the upstream end of the study area, until it has passed a constriction created by a valley side failure (the toe of which is eroding) at approximate NGR 416962 599840. Downstream of here, smooth flow occurs through a pool for around 70m before a glide-riffle-run sequence occurs roughly around the meander apex (approximately 400m upstream of the existing crossing, NGR 417085 599858), and where bedrock emerges at the channel margins. Downstream of this sequence, smooth flow through a pool returns for around 200m although some upwelling occurs around the bedrock margins, particularly immediately downstream of the glide-riffle-run sequence against the left bank.

4.4.11. Around 120 m upstream of the existing bridge crossing (approximate NGR 417331 599761), flow crosses a bedrock ledge, submerged at the time of survey. Vegetated bedrock emerges from the flow in the mid-channel downstream of this point, and there is an apparent steepening in gradient. The combined effect of the steepening gradient and emerging bedrock directs flow towards both the left and right bank as it approaches the existing bridge crossing. Here, unbroken standing waves and riffle flow occurs against the left bank but remains relatively smooth towards the right bank. Further downstream, where the river training works are present around the existing southern (right bank) bridge pier, flow is fast against this bank reinforcement and descends a bedrock ledge beneath the existing bridge. A change in alignment of the river training works occurs immediately downstream of the southern pier, and slower, smooth pool flows occur against the right bank in an eddy for around 28m downstream before a boulder deposit protrudes from the bank.

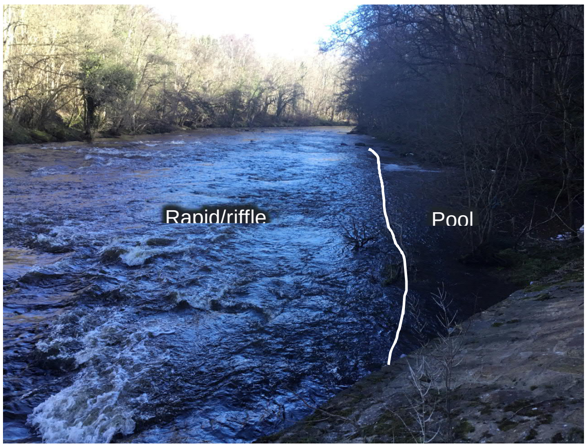


Figure 9 - Flow Conditions through the Proposed Site (Left Photo taken from Right Bank Looking Across Channel. Right Photo taken from Right Bank Looking Downstream.)

4.4.12. In the central channel and towards the left bank, riffle flow occurs as flow crosses bedrock and boulder features, before being split around a partly vegetated mid-channel bar around 50-70m downstream of the existing bridge crossing. Around 100-130m downstream of the existing crossing, flow transitions from this more turbulent and varied section of flow to smooth flow for around 100m around the apex of a meander (approximate NGR 417651 599879). Erosion of the left bank (comprised of colluvium from valley side failure); is evident at this meander apex; large rockfall blocks are present and the poorly sorted colluvial deposit including angular cobbles and boulders and a finer grained matrix is exposed in the bank. Downstream of this point, flow becomes more turbulent for around 100m through a glide-riffle-run sequence, in part created by a constriction where further valley side failure has occurred and large rockfall remnants are present towards the left bank. The channel returns to pool flow downstream of this sequence for around 300-350m, heavily influenced by the partial impoundment created by the weir at the downstream extent of the study reach.

5 GEOMORPHOLOGICAL DYNAMICS ASSESSMENT

5.1.1. The geomorphological dynamics assessment has been undertaken using the outputs of the 2-dimenionsonal hydraulic modelling described in 6.50 River Coquet Hydraulic Modelling Report (document reference 6.50). The model covers an area of 1.7 km2 and includes the River Coquet from east of Elyhaugh Farm Cottage (415960E 599785N), approximately 2.5km upstream of the existing A1 River Coquet crossing, to a point approximately 200 m downstream of Felton New Bridge (418695E 600434N), which is approximately 1.5km downstream of the existing A1 River Coquet crossing. Three scenarios were output from the model:

c. The Baseline scenario representing the current, preconstruction topography and roughness characteristics of the channel;
d. The Scheme Construction scenario representing the ‘Temporary Works’ for the construction of the Scheme (constituting the temporary works on both banks) as described in Section 2.4 of 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and Section 2.4 of 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064]. These comprise a reprofiling of the valley sides to accommodate piling platforms and associated changes in roughness, and the construction of training walls which will temporarily reduce the channel cross section to accommodate the piling platforms and a temporary crossing to access the south bank; and
e. The Scheme in Operation scenario representing the Scheme once completed (constituting the permanent works on both banks), as described in Section 2.4 of 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and Section 2.4 of 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064]. These comprise bank protection 86 m (62 m of rock armour plus an additional 24 m of green-grey bank protection) along the north bank and 45 m (around 28 m of rock armour and 17 m of green-grey bank protection) along the south bank, as well as the proposed bridge piers themselves and a concrete pilecap around the south pier rising to 36 m OD.

5.1.2. A full description of the modelling, including a detailing of topographic and roughness inputs, can be found in the in 6.50 River Coquet Hydraulic Modelling Report (document reference 6.50).

5.1.3. Multiple return period events were simulated in the hydraulic model for a variety of purposes, including flood risk assessment and scheme design, as well as geomorphological assessment. For the geomorphological assessment the return period events indicated in Table 5-1, listed with their associated peak flows, have been used. These events have been chosen to represent a range of flood events, from the low-magnitude, high-frequency 50% Annual Exceedance Probability (AEP) event, through to the high-magnitude, low-frequency event represented by the 0.5% AEP (200-year) event. The 2% AEP (50-year) event was selected as an intermediate event between the 50%AEP (2-year) and 0.5% AEP (200-year) event. As also indicated in Table 5-1, Q50 flows were considered, specifically for assessing the impact of the proposed scheme on physical biotopes at more frequently occurring flow levels (Entwistle et al., 2019).

Table 5-1 - Peak flows considered in geomorphological dynamics assessment

Flood Event/Flow Level	Modelled Peak Flow (m^3/s)
50% AEP (2-year) event	154.2
2% AEP (50-year) event	343.6
0.5% AEP (200-year) event	452.82
Q50	4.41

5.1.4. The output from the model provided the following parameters on which an assessment of change between the Baseline and the Scheme Construction and Scheme in Operation scenarios could be undertaken:

f. Depth
g. Velocity
h. Specific stream power

5.1.5. Additionally, the outputs from the model, specifically the maximum boundary shear stress (which represents the force exerted on the channel boundaries by flowing water) and Froude number (a dimensionless quantity used to indicate the influence of gravity on fluid motion), have allowed change in the following parameters between the Baseline and Scheme Construction and Scheme in Operation scenarios to be assessed:

i. Mobile particle size using Shields' (1936) equation
j. Shields (1936) parameter value based on the measured D50 and D84 particle size.
k. Physical biotope (an approximation of complex aquatic environments, which can be determined through the physical character of the water surface, or using the Froude number, Entwistle et al., 2019)

5.1.6. Equations and parameters used to calculate specific stream power, sediment entrainment and Froude number and physical biotope are described below.

SPECIFIC STREAM POWER

5.1.7. Geomorphological theory and Bagnold's sediment transport equation show that the ability of flow to do geomorphological work may be characterised by its stream power (Sear et al., 2003). As such, changes in stream power may result in increased erosion or deposition. Between the scenarios, changes in stream power per unit width occur either indirectly due to the alterations in water depth and velocity resulting from roughness changes on the banks through the addition of rock armour, or directly due to constriction of the channel by the training works and temporary bridge abutments. The equation used for this is:

$$\omega = \frac{\rho g Q S}{w}$$

Eq. 1

5.1.8. Where ω is the specific stream power (W/m^2), ρ is the specific density of water, g is gravitational acceleration, Q is the discharge, S is slope and w is channel width. However, for this report, specific stream power is a direct output of the hydraulic model and this output has been used for the assessment of changes in specific stream power in this assessment.

SEDIMENT ENTRAINMENT (SHIELDS PREDICTED MOBILE PARTICLE SIZE AND SHIELDS PARAMETER Θ FOR MEASURED D_{50} AND D_{84})

5.1.9. The threshold for entrainment of particles of a given size can be defined by critical shear stress, and directly associates the hydraulic conditions near the channel bed where flow and bed particles interact. Shields' (1936) method allows for the calculation of the Shields parameter θ using the following equation:

$$\theta = \frac{\tau_0}{\rho g (\rho_s - \rho / \rho) D}$$

Eq 2.

5.1.10. Where τ_0 is the mean boundary shear stress, ρ is the density of water, g is gravitational acceleration, ρs is the sediment density and D is the particle size.

5.1.11. Mean boundary shear stress is a direct computational output of the hydraulic model.

5.1.12. The equation has been used in this assessment in two ways:

l. First, a rearranged version of the equation has been used to predict the particle size that would be at the threshold for entrainment, assuming a value of 0.056 for the Shields parameter θ for each Baseline, Scheme Construction and Scheme in Operation scenario and under each flood event.

m. Secondly, for each scenario and flood event the Shields parameter (θ) has been calculated to assess whether the changes in hydraulics between scenarios results in the likely value of θ changing sufficiently for entrainment of the measured D50 and D84 particle sizes to occur. The range of values between which entrainment may occur has been assumed to be between 0.03 to 0.06 and the measured D50 and D84 values have been taken from the Wolman count on the mid-channel bar in the vicinity of the proposed scheme (see Paragraph 4.4.6 to 4.4.70).

FROUDE NUMBER AND CORRESPONDING BIOTOPE

5.1.13. Entwistle et al. (2019) state the most widely utilised flow variable for characterising physical biotopes is the Froude number that defines the ratio of inertial to gravity forces in the flow:

$$Fr = \frac{V}{\sqrt{gd'}}$$

Eq. 3

5.1.14. Where Fr is the Froude number, V is the local flow velocity, g is the gravitational acceleration and d is the local flow depth. Figure 10 shows the relationship between Froude number and physical biotope. Changes in the Froude number across the channel in each scenario under a Q50 flow have been assessed, to understand the change in biotope that may occur as a result of the proposed works.

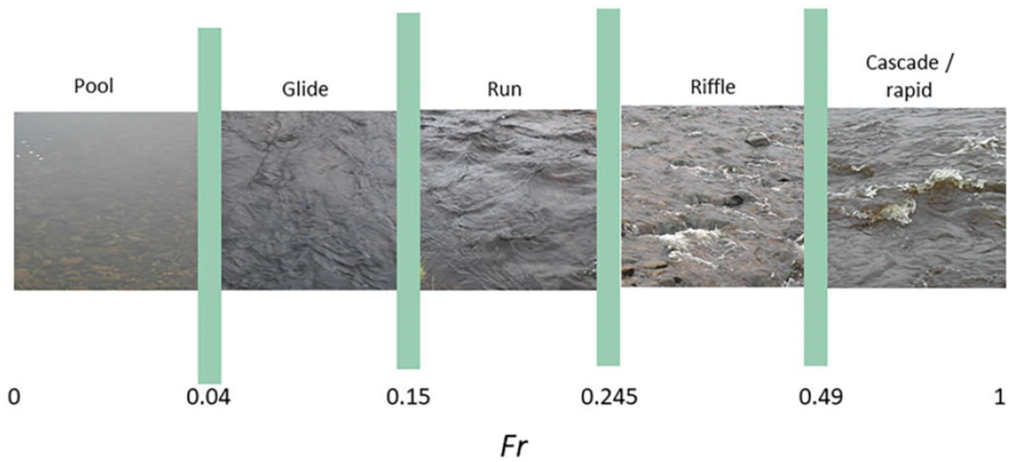


Figure 10 - Biotope type related to Froude number (Entwistle *et al.*, 2018)

6 RESULTS: SCHEME CONSTRUCTION SCENARIO

6.1.1. This section describes the changes between the Baseline scenario and Scheme Construction scenario for each modelled flow event. The alterations to the fluvial environment considered in the Scheme Construction scenario, as described in Section 2.4 of 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063 and Section 2.4 of 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064], comprise a reprofiling of the valley sides to accommodate piling platforms and associated changes in roughness, and the construction of training walls which will temporarily reduce the channel cross section to accommodate the piling platforms and a temporary crossing to access the south bank. Further information on the topographic and roughness changes incorporated in the construction scenario can be found in 6.50 River Coquet Hydraulic Modelling Report (document reference 6.50).

6.1.2. Throughout this section and the corresponding Scheme in Operation scenario section, a series of long profiles and maps are used to illustrate the extent and magnitude of change. Figure 11 shows the chainage in metres along the long profile.

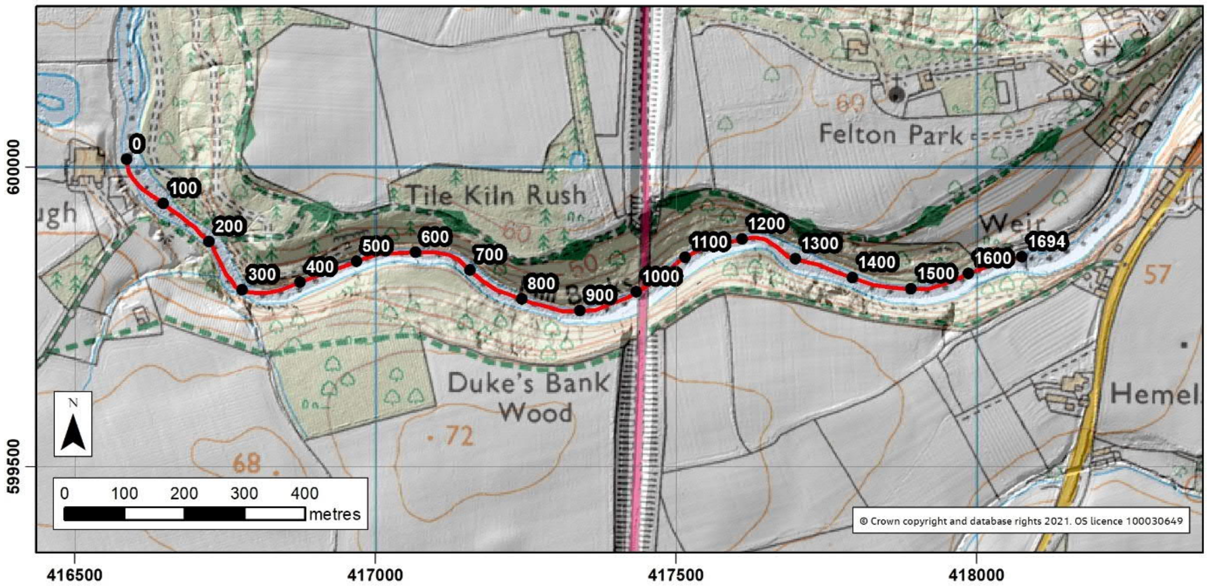


Figure 11 - Chainage (m) along long profiles used in Results Section

6.2 DEPTH

6.2.1. Figure 12 to Figure 15 show comparative long profiles of depth change and Appendix C Figures 1 – 3 show the change in depth spatially between the scenarios in the 50%AEP (2-year), 2%AEP (50-year) and 0.5% AEP (200-year) events.

6.2.2. For the Scheme Construction scenario, hydraulic modelling for the 50% AEP (2-year) event shows that there is an increase in depth due to Temporary Works which exceeds 10% of the existing water depth across the whole channel for around 50m upstream of Temporary Works. This impact extends for approximately 300m upstream at each channel margin, where water depth would be shallowest and an overall change in water surface elevation would have the greatest impact in percentage terms. Maximum increases in depth upstream of the works are indicated in the long profile to be around 0.34m, and maximum decreases through and downstream of the works around 0.1m.

6.2.3. At the 2% AEP (50-year) event, there is a change in depth exceeding 10% of the Baseline depth across the channel for around 100m upstream of the Temporary Works and the changes at the channel margin being continuous for around 700m upstream. Some increases in depth, predominantly limited to 10-30% of the existing water depth, are also seen on the floodplain upstream of Shothaugh. Through the Temporary Works and for around 50m downstream, change in water depth exceeds 10% (predominantly a decrease) only at the channel margins and discontinuously. Maximum increases in depth upstream of the works are indicated in the long profile to be around 0.7m, and maximum decreases through and downstream of the works around 0.1m.

6.2.4. At the 0.5% AEP (200-year) event, there are increases in depth which exceed 10% of the Baseline water depth across the channel extending to around 125m upstream of the Temporary Works. Increases in depth exceeding 10% further upstream at the channel margins and on floodplain fragments are more continuous than in the events with lower AEPs. The extent of change through the works and downstream is very similar to that indicated for the 2% AEP (50-year) event. Maximum increases in depth upstream of the works are indicated in the long profile to be around 0.9m, and maximum decreases through and downstream of the works around 0.15m.

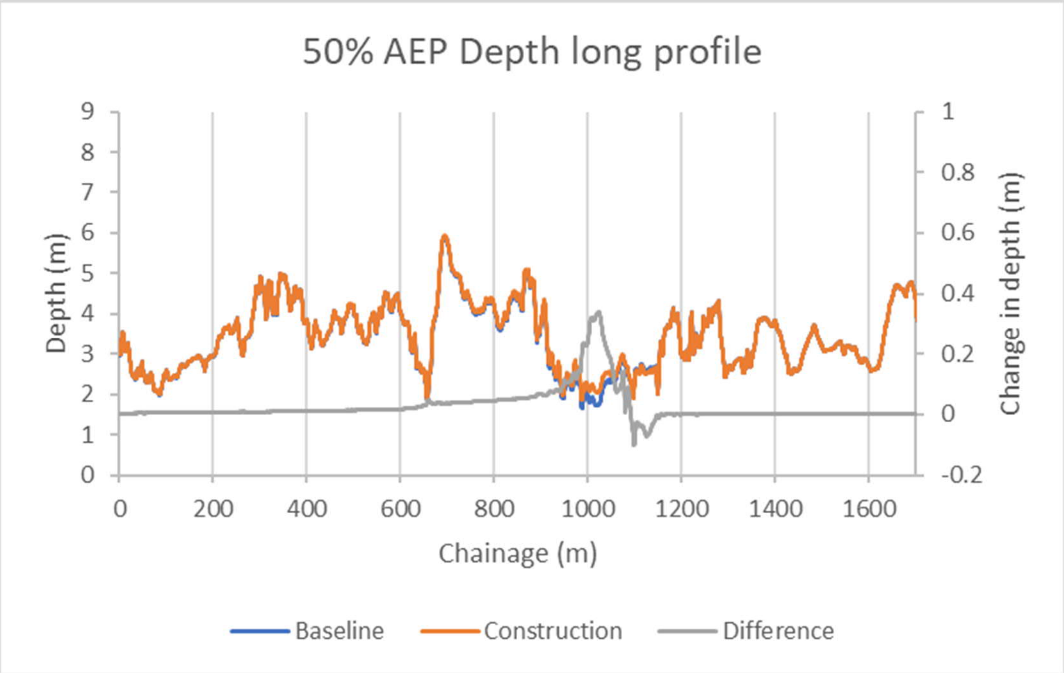


Figure 12 - Change in depth long profile, Scheme Construction scenario, 50% AEP (2-year) event

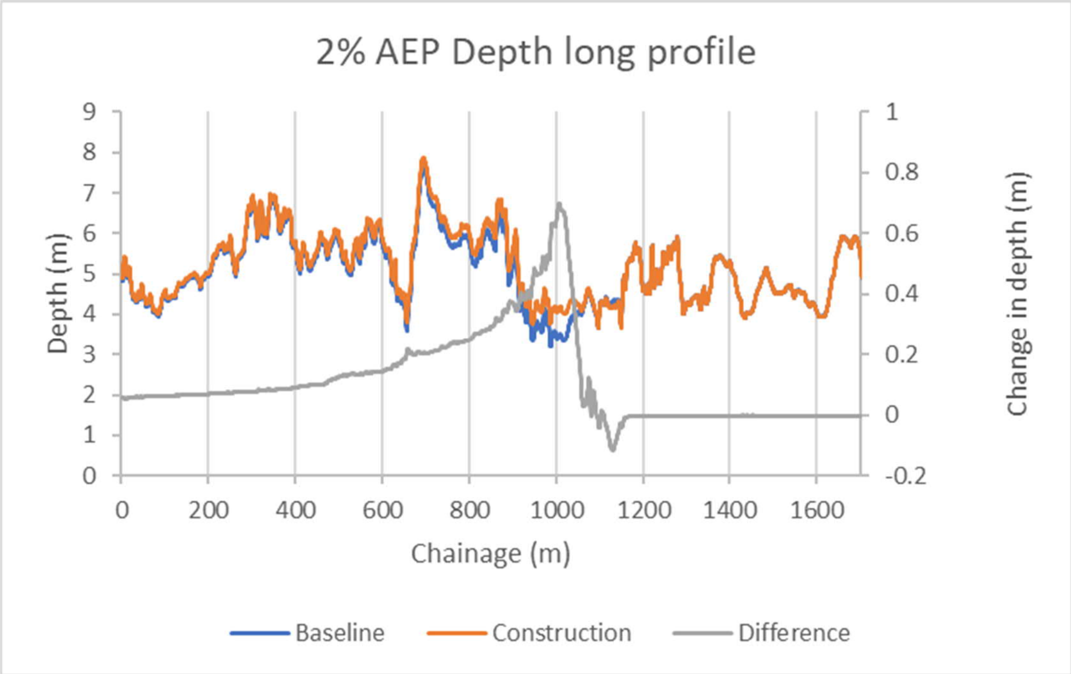


Figure 13 - Change in depth long profile, Scheme Construction scenario 2% AEP (50-year) event

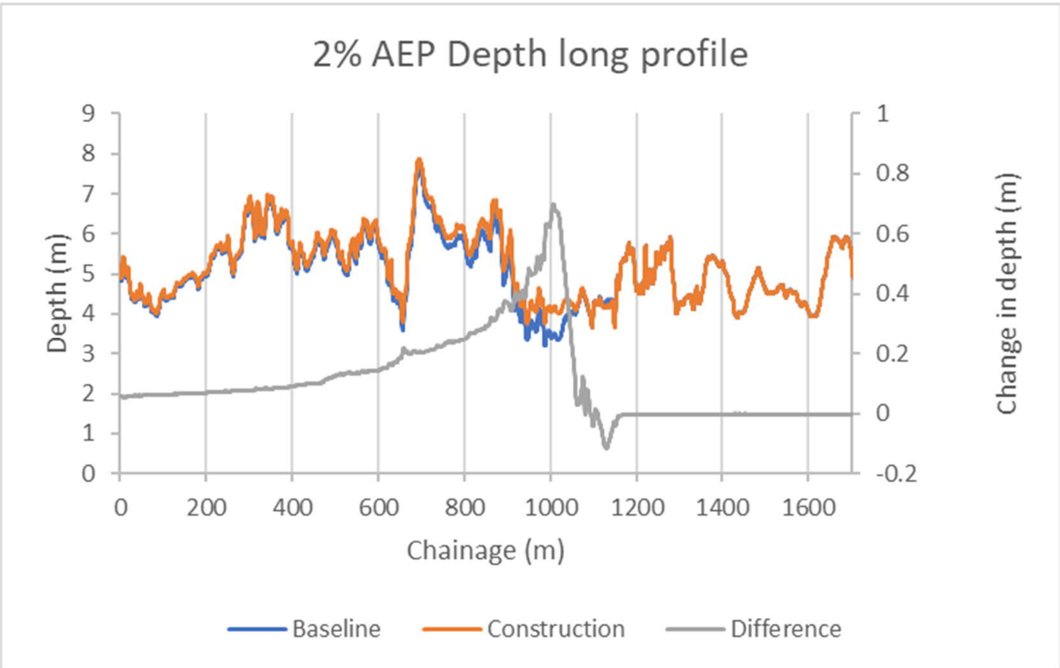


Figure 14 - Change in depth long profile, Scheme Construction scenario 2% AEP (50-year) event

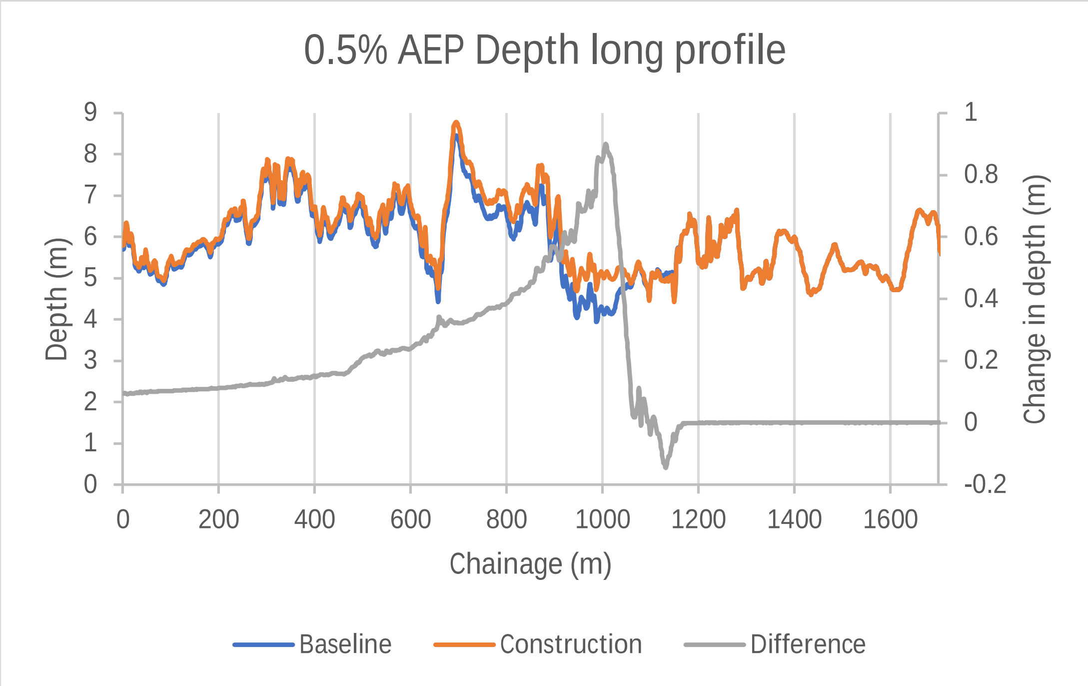


Figure 15 - Change in depth long profile, Scheme Construction scenario, 0.5% AEP (200-year) event

6.3 VELOCITY

6.3.1. Figure 16 to Figure 18 show a comparative long profile of velocity change and Appendix C Figures 4 – 5 show the change in velocity spatially between the scenarios in the 50%AEP (2-year), 2%AEP (50-year) and 0.5% AEP (200-year) events.

6.3.2. For the Scheme Construction scenario, hydraulic modelling for the 50% AEP (2-year) event indicates that there is a reduction in velocity of 10% to 30% for around 50m upstream of the Temporary Works, with the greatest reduction in velocity against the right bank immediately upstream of the proposed temporary training wall. Through the works, an increase in velocity, predominantly between 10% and 30%, occurs down the channel centre, extending to around 30m downstream of the works. However, at the channel margins, in the immediate lee of the training works, velocities are anticipated to reduce. Conversely, at around 35m downstream of the right bank works, channel velocities against the right bank increase by between 30% and 100%. Maximum decreases in velocity upstream of the works are indicated in the long profile to be around 0.5 m/s, and maximum increases through and downstream of the works around 0.6 m/s.

6.3.3. At the 2% AEP (50-year) event, a spatially-similar pattern of change occurs to that seen in 50% AEP (2-year) event, but with the 10% to 30% reduction in velocity upstream of the Temporary Works extending to around 80m upstream. The area within the longitudinal extent works where velocities increase by 30% to 100% of Baseline velocities increases within this area, although the overall area of increased exceeding 10% increase changes little. Beyond this immediate zone of influence, there are discontinuous changes exceeding 10% of the Baseline velocities, predominantly increases, at the channel margins and on floodplains where Baseline velocities were considerably lower than 1m/s in the Baseline scenario and remain so in the Scheme Construction scenario. Maximum decreases in velocity upstream of the works are indicated in the long profile to be around 0.65 m/s, and maximum increases through and downstream of the works around 1 m/s.

6.3.4. In the 0.5% AEP (200-year) event, the channel-wide 10% to 30% reduction in velocity upstream of the Temporary Works extends for around 175 m upstream from the works. There is little difference in the nature or extent of change downstream of the works, relative to the 2% AEP (50-year) event. Areas of increased velocity at the channel margins and on floodplains are more continuous, but with the greatest changes in percentage terms being areas where velocities were low in the Baseline scenario and remain under 1 m/s in the Scheme Construction scenario. Maximum decreases in velocity upstream of the works are indicated in the long profile to be around 0.7 m/s, and maximum increases through and downstream of the works around 1.3 m/s.

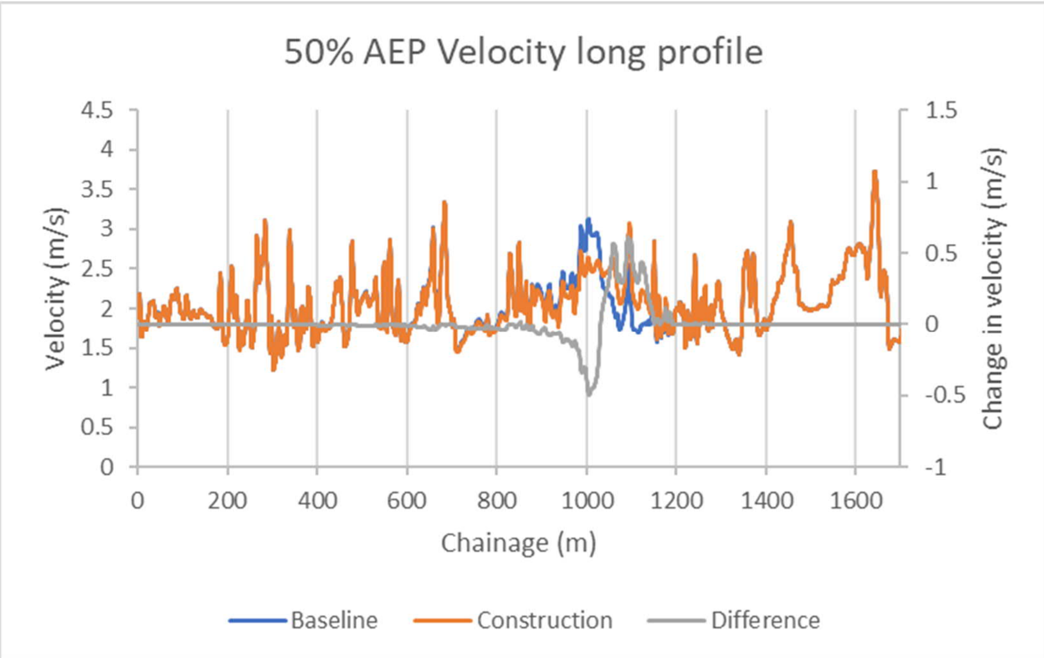


Figure 16 - Change in velocity long profile, Scheme Construction scenario, 50% AEP (2-year) event

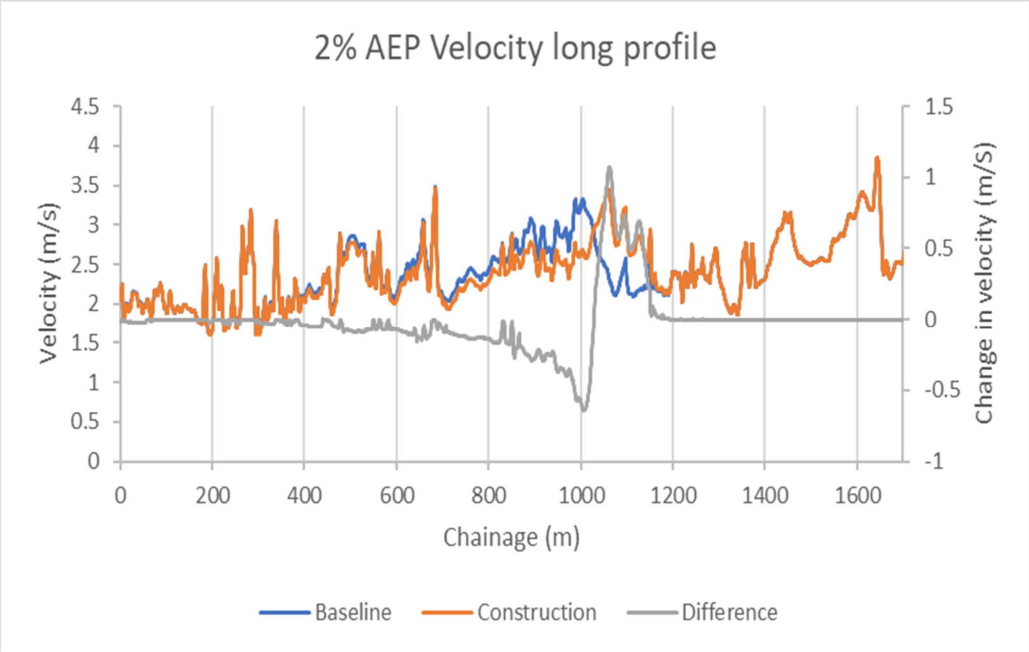


Figure 17 - Change in velocity long profile, Scheme Construction scenario , 2% AEP (50-year) event

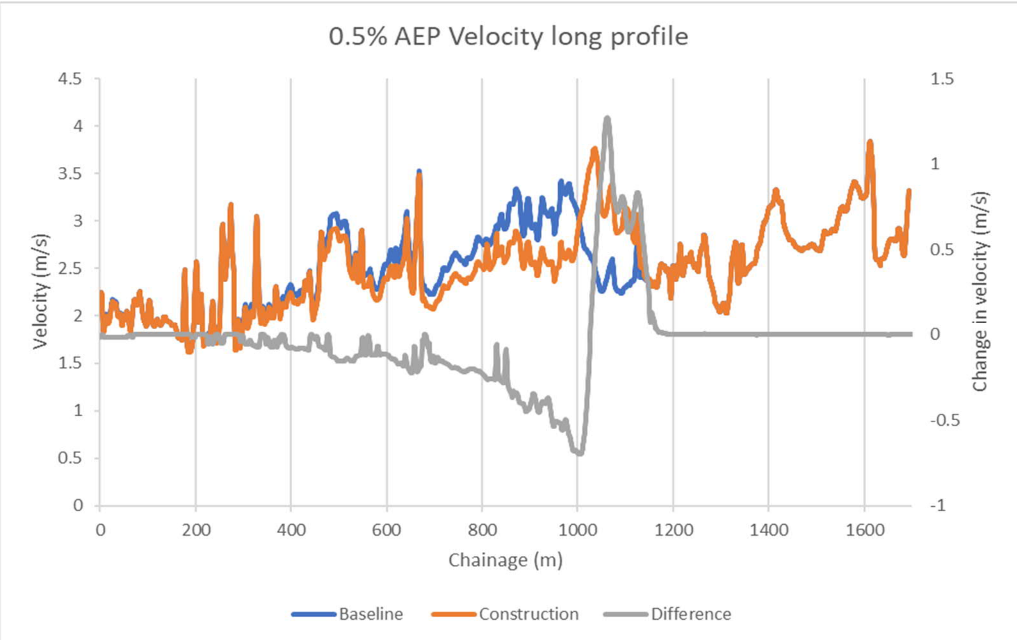


Figure 18 - Change in velocity long profile, Scheme Construction scenario, 0.5% AEP (200-year) event

6.4 STREAM POWER

6.4.1. Appendix C Figures 7 - 9 show the change in stream power spatially between the scenarios in the 50%AEP (2-year), 2%AEP (50-year) and 0.5% AEP (200-year) events.

6.4.2. For the Scheme Construction scenario, the hydraulic modelling indicates a >10% reduction in stream power for around 110m upstream of the Temporary Works, with an area of stream power decrease between 30% and 100% extending around 35m upstream of the Temporary Works. The modelling also indicates that stream power will predominantly increase through the Temporary Works by >10% in the 50% AEP (2-year) event, with relatively extensive parts of this area increasing stream power by 30%-100% and some areas exceeding a 100% increase. At the margins of the channel, against the proposed training walls and immediately downstream, there is a reduction in stream power of up to 100%, so additional deposition may be expected in these areas. Around 25m downstream of the works on the right bank, there is an area of increased stream power. Increases in stream power here fall into both the 30-100% change increase range, and the over 100% range. Here, there is increased potential for erosion. This effect lasts for around a further 40m before dissipating and stream power against this bank returning to similar levels to the Baseline. Changes in stream power elsewhere are limited to very small extents of floodplain fragments where stream powers remain below 35 W/m2 in both the Baseline and Scheme Construction scenario and are therefore unlikely to trigger erosion.

6.4.3. Qualitatively, the pattern of change between Baseline and Scheme Construction scenarios in the 2% AEP (50-year) event is very similar to the 50% AEP (2-year) event. However, the extent of the area of reduced stream power extends around 400m upstream of the works and the areas of increased stream power on the floodplains are greater but continue to occur only in areas where stream powers are low (<35W/m2). The increase in stream power against the right bank downstream of the works also intensifies in this event, with a greater proportion of the area exceeding a 100% increase in stream power.

6.4.4. In the 0.5% AEP (200-year) event, the pattern of change is again similar, with reductions in the stream power >10% relative to Baseline extending around 700m upstream from the Temporary Works, and greatest in the 170m upstream of the existing works. The magnitude of change also marginally increases in this event. Other than through the works and immediately downstream (as described above), areas of stream power increase >10% relative to Baseline are confined to the channel. The extent of the area against the right bank downstream of the works exceeding a 100% increase in stream power remains similar to the 2% AEP (50-year) event but increases in area elsewhere in the channel.

6.5 SEDIMENT ENTRAINMENT (SHIELDS)

6.5.1. Appendix C Figures 10 - 12 show the change in the modelled size of sediment entrained between the Baseline and Scheme Construction scenarios in the 50%AEP (2-year), 2%AEP (50-year) and 0.5% AEP (200-year) events.

6.5.2. The Baseline scenario shows that in the 50% AEP (2-year) event, flow is confined to the channel as might be expected for an event of this frequency. The modelled size of sediment entrained at this flow is predominantly gravel and cobbles, with some limited extents where boulders might be entrained. With the construction works in place, the Shields analysis indicates that the sediment size potentially entrained remains within ±10% of the Baseline scenario for the majority of the reach. A backwater effect from the construction works causes a reduction in the size of sediment entrained, predominantly of between 10% and 30% for around 80m upstream of the existing bridge, but with limited extents of greater decrease between 30% and 100% immediately upstream of the works. Decreases of similar magnitude also occur in the immediate lee of the proposed training walls and bridge abutment. A similar effect is seen in the Baseline in the lee of the existing southern pier training works and is also visible in the field where slower, less turbulent flow forms sand deposits against the south bank. Through the construction works there is increase in the modelled sediment size that could be entrained, predominantly between 30% and 100% relative to Baseline, but this effect dissipates at around 100m downstream of the proposed permanent crossing (30m downstream of the proposed training works). The partially vegetated gravel-cobble-boulder bar near the left bank at the downstream end of the works experiences <±10% change in the entrained sediment size.

6.5.3. At the 2% AEP (50-year) event Baseline scenario, upstream of the gorge, gravel and cobbles are predominantly transported within the channel with sand and gravels transported on the flood plain where inundated. Within the gorge, the modelled size of sediment entrained increases to be predominantly cobbles, with some limited areas of entrained gravels and boulders, the latter being particularly at the margins of the channel. With the construction works in place, the Shields analysis indicates a similar pattern of change in the potential size of sediment entrainment to that seen at the 50% AEP (2-year) event. The principle differences in the vicinity of the works are:

n. The backwater effect on sediment transport extends further upstream, with changes in the size of sediment entrained >±10% now extending around 350m upstream, and
o. In the area through the works there is an increase in the size of sediment transported between 30% and 100% extending across more of the channel. The gravel-cobble-boulder bar indicated is likely to be included within this area. However, in both the Baseline and Scheme Construction scenario, the sediment size entrained in the area of this bar remains within the cobble range.

6.5.4. There remain areas where there is a reduction in the size of sediment transported in the lee of the works. The downstream extent of the change >±10% does not extend significantly further than in the 50% AEP (2-year) scenario.

6.5.5. Beyond the immediate vicinity of the existing bridge, changes >±10% in the potential size of sediment entrained are indicated at the margins of some floodplains upstream. These are understood to be associated with minor changes in depth for a short time period at the flood peak and are therefore considered of Negligible impact magnitude and Neutral significance (not significant).

6.5.6. At the 0.5% AEP (200-year) event, with the construction works in place, the Shields analysis continues to indicate a similar pattern of change in the potential size of sediment entrainment between the Baseline and Scheme Construction scenarios to that seen in the 2%AEP (50-year) and 50% AEP (2-year) events. The principal differences in the vicinity of the bridge are:

p. The backwater effect increases, extending the limit of reductions in the modelled size of sediment entrained >10% to around 500m upstream of the existing crossing.
q. Through the works area, there continues to be an increase in the size of sediment entrained of between 30% and 100%, but this effect is limited to around 30m downstream of the proposed training works (as observed in smaller flood events). The size of sediment entrained at the location of the gravel-cobble-boulder bar increases by between 30% and 50% between the Baseline and Scheme Construction scenarios but remains within the cobble range.
r. There also continues to be a modelled reduction in the size of sediment entrained in the lee of the training works, but the scale of change remains similar to that seen in other events (reductions of between 30% and 100% between the Baseline and Scheme Construction scenarios).

6.5.7. One additional effect can be seen in the 0.5% AEP (200-year) scenario, which is that there is an increase in the size of sediment entrained at the margins of the channel around 160m upstream of the existing bridge on both sides of the channel and on the right (south) bank between around 260m and 340m upstream of the existing bridge. The increases in shear stress and size of sediment entrained may result in erosion at these locations in the event of a 0.5% AEP (200-year) event occurring within the 16-month construction period.

6.6 SHIELDS PARAMETER ASSESSMENT – MID-CHANNEL BAR

6.6.1. Appendix C Figures 13 and14 show the change in the value of the Shields parameter in the Baseline and Scheme Construction scenarios in the 50%AEP (2-year), 2%AEP (50-year) and 0.5% AEP (200-year) events spatially, for the D50 and D84 particle sizes respectively, as measured through the Wolman count on the mid-channel bar.

6.6.2. An analysis of the Shields parameter for the D50 sediment size (45mm) indicates that, in the Baseline scenario, entrainment would occur in all three assessed AEP events (50%, 2% and 0.5%). The introduction of the Temporary Works would potentially reduce the shields parameter below the threshold for entrainment in the 50% AEP (2-year) event for a marginal part of the bar adjacent to the temporary training walls, but for the remainder of the bar, and in all other events the threshold for entrainment continues to be exceeded.

6.6.3. An analysis of the Shields parameter for the D84 measured particle size on this bar (205mm) indicates that this size of sediment is unlikely to be entrained during the 50% AEP (2-year) event in the Baseline scenario, other than potentially near the upstream end of the feature. This pattern remains broadly the same in the Scheme Construction scenario for the same event. During the 2% AEP (50-year) event, there is a small increase in the extent of the bar falling within the range of Shields parameter values associated with entrainment (0.03 – 0.06) within the Scheme Construction scenario compared to the Baseline scenario, a pattern repeated at the 0.5% AEP (200-year) event. However, there are boulders substantially larger than the D84 particle size on the bar which are unlikely to move far and therefore likely to act to maintain the overall form of the feature even if the smaller material moves downstream, allowing the feature to reform once the Temporary Works are completed.

6.7 BIOTOPE

6.7.1. Appendix C Figure 15 shows the change in physical biotopes in the vicinity of the bridge between the Baseline, Scheme Construction and Scheme in Operation scenarios. The change in the Scheme Construction scenario is described below.

6.7.2. The Baseline shows an alternating pattern of extensive pool/glide sections, interspersed with sections of run/riffle/rapid sections. The area through the proposed construction works is categorised predominantly as glides and runs, separated by run/riffle/rapid and linear pool areas predominantly against the north bank.

6.7.3. In the Scheme Construction scenario, only very minor change in the vicinity of the works is predicted, including a small reduction in area of pool feature against the north bank and extremely localised change from riffle to cascade/rapid at the upstream end of the southern temporary bridge abutment.

7 RESULTS: SCHEME IN OPERATION SCENARIO

7.1.1. This section describes the modelled changes in the assessed parameters between the Baseline scenario and the Scheme in Operation scenario for each modelled flow event. The alterations to the fluvial environment considered in the Scheme in Operation scenario comprise rock armour on both banks extending approximately 86 m (62 m of rock armour plus an additional 24 m of green-grey bank protection) along the north bank and 45 m (around 28 m of rock armour and 17 m of green-grey bank protection) along the south bank, as well as the proposed bridge piers themselves and a concrete pilecap around the south pier rising to 36 m OD as described in Section 2.4 and Section 2.6 of 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and Section 2.4 and Section 2.5 of 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064]. Further information on the topographic and roughness changes incorporated in the Scheme in Operation scenario can be found in the River Coquet Hydraulic Modelling Report (document reference 6.50).

7.2 DEPTH

7.2.1. Figure 19 to Figure 21 show a comparative long profile of depth change and Appendix C Figures 16 – 18 show the change in depth spatially between the scenarios in 50%AEP (2-year), 2%AEP (50-year) and 0.5% AEP (200-year) events . This reduction in depth is attributed to the reduced hydraulic friction from the rock armour in comparison with the vegetated banks.

7.2.2. In the Scheme in Operation scenario, changes in depth exceeding 10% relative to Baseline in the 50% AEP (2-year) event are practically indiscernible, discontinuous, and limited to the margin of the right bank through the extent of the proposed works. Maximum increases in depth are indicated in the long profile to be around 0.002 m, and maximum decreases around 0.015 m.

7.2.3. In the 2% AEP (50-year) event, depth changes exceeding 10% of the existing channel depth are limited to the channel margins, albeit slightly more continuous on the right bank, and variable between increases and decreases. Maximum increases in depth are indicated in the long profile to be around 0.002 m, and maximum decreases of the works around 0.032 m.

7.2.4. In the 0.5% AEP (200-year) event, the pattern is again similar, albeit slightly more extensive on the right channel bank, but again limited to the extent of the works. Maximum increases in depth indicated in the long profile to be around 0.002 m, and maximum decreases around 0.033 m.

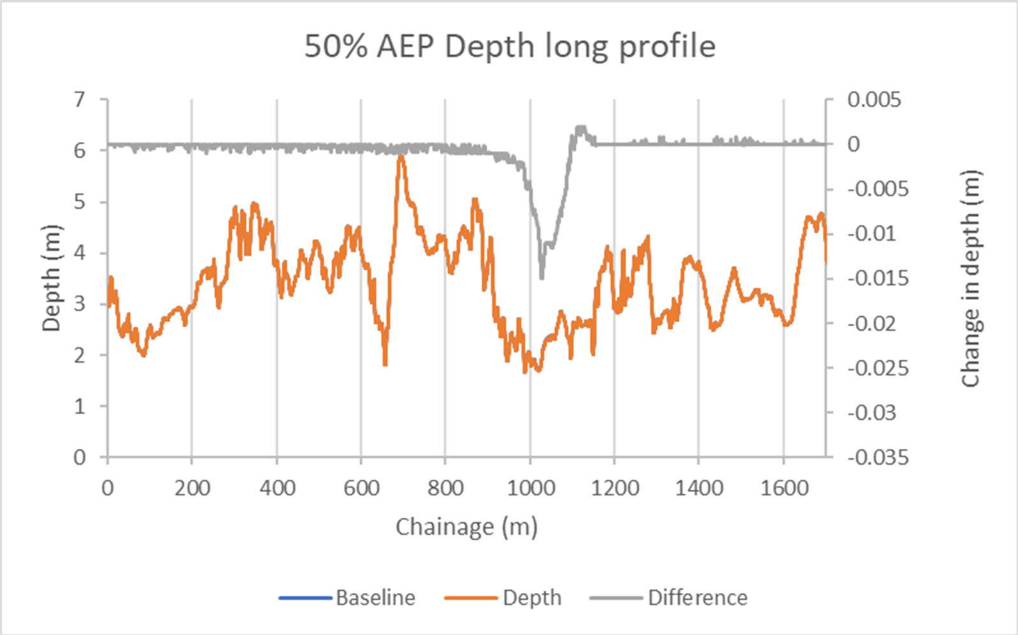


Figure 19 - Change in depth long profile, Scheme in Operation scenario, 50% AEP (2-year) event

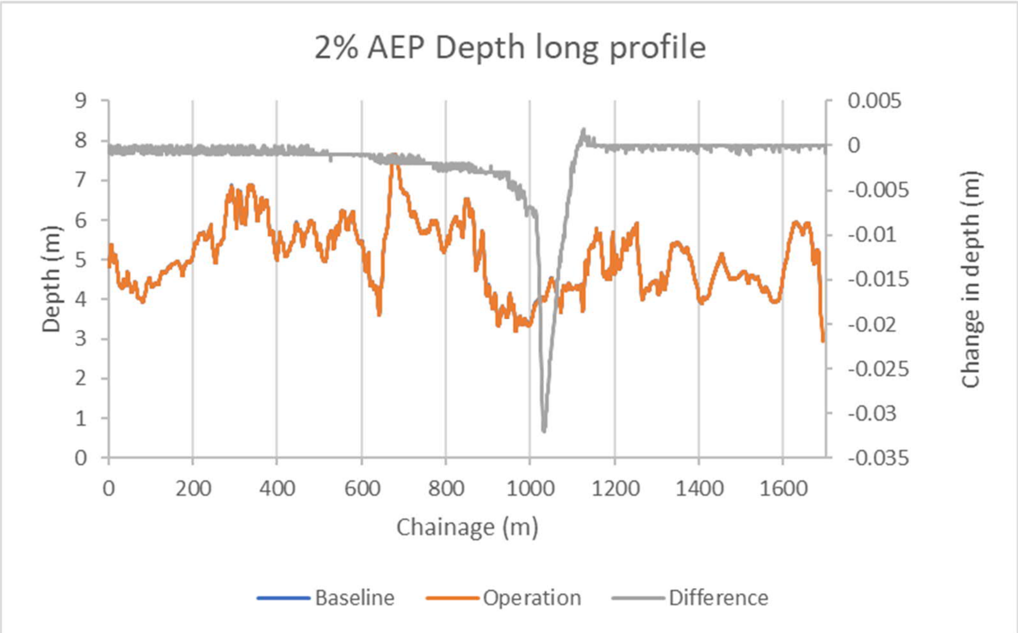


Figure 20 - Change in depth long profile, Scheme in Operation scenario, 2% AEP (50-year) event

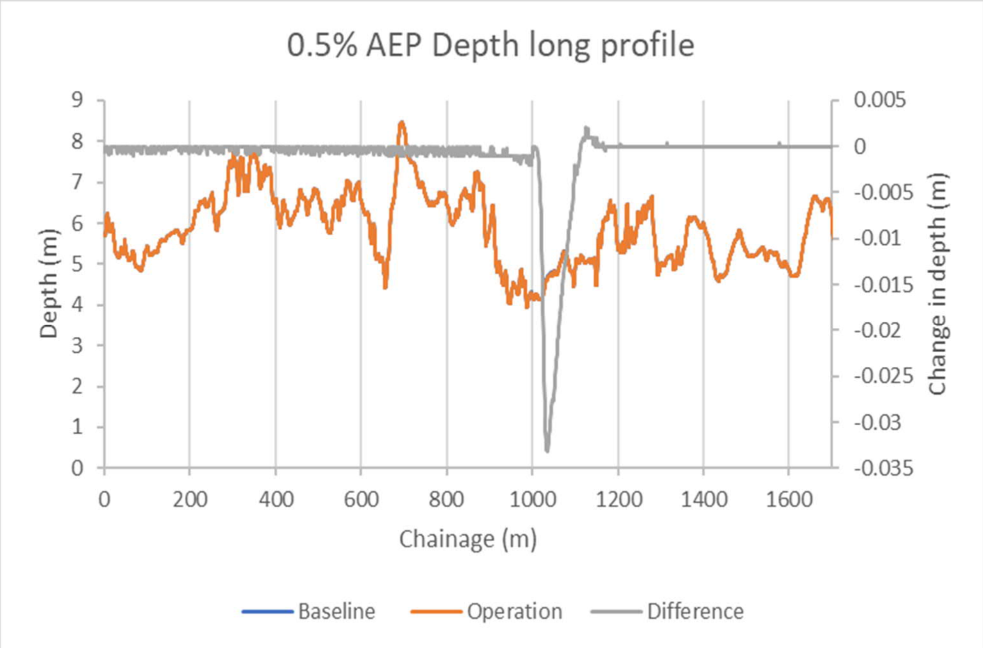


Figure 21 - Change in depth long profile, Scheme in Operation scenario, 0.5% AEP (200-year) event

7.3 VELOCITY

7.3.1. Figure 22 to Figure 24 show comparative long profiles of velocity change and Appendix C Figures 19 – 21 show the change in velocity spatially between the scenarios in the 50%AEP (2-year), 2%AEP (50-year) and 0.5% AEP (200-year) events .

7.3.2. In the Scheme in Operation scenario, change in velocity >±10% from the Baseline in the 50% AEP (2-year) scenario is almost entirely limited to the location of the proposed left bank rock armour, where increases in velocity of around 15% are anticipated. Changes in velocity exceeding 10% of the Baseline elsewhere occur very locally around the proposed south bank pier rock armour and are discontinuous and limited in extent. Maximum decreases in velocity upstream of the works are indicated in the long profile to be around 0.027 m/s, and maximum increases through and downstream of the works around 0.026 m/s.

7.3.3. In the 2% AEP (50-year) scenario, the extent of the changes exceeding ±10% of the Baseline is more limited than the 50% AEP (2-year) scenario, with the extent of the area on the left bank experiencing a >10% velocity change reducing. However, small but slightly more extensive areas of change >10% can be seen in the vicinity of the proposed works on the right bank and vary between localised increases and reductions in velocity. Maximum decreases in velocity are indicated in the long profile to be around 0.027 m/s, and maximum increases around 0.079m/s.

7.3.4. This pattern is repeated during the 0.5% AEP (200-year) scenario, but with the areas exceeding a ±10% change in velocity slightly increasing. The greatest increase in velocity is at the location of the pilecap for the southern pier, where flow will reduce in depth and roughness decrease relative to the Baseline. Maximum decreases in velocity upstream of the works are indicated in the long profile to be around 0.034 m/s, and maximum increases through and downstream of the works around 0.1 m/s.

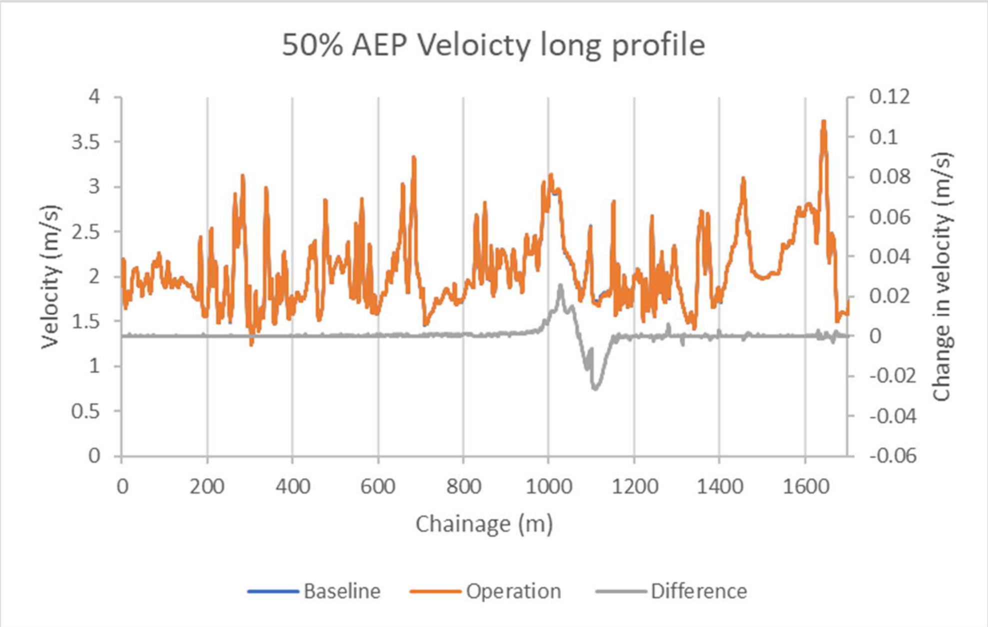


Figure 22 - Change in velocity long profile, Scheme in Operation scenario, 50% AEP (2-year) event

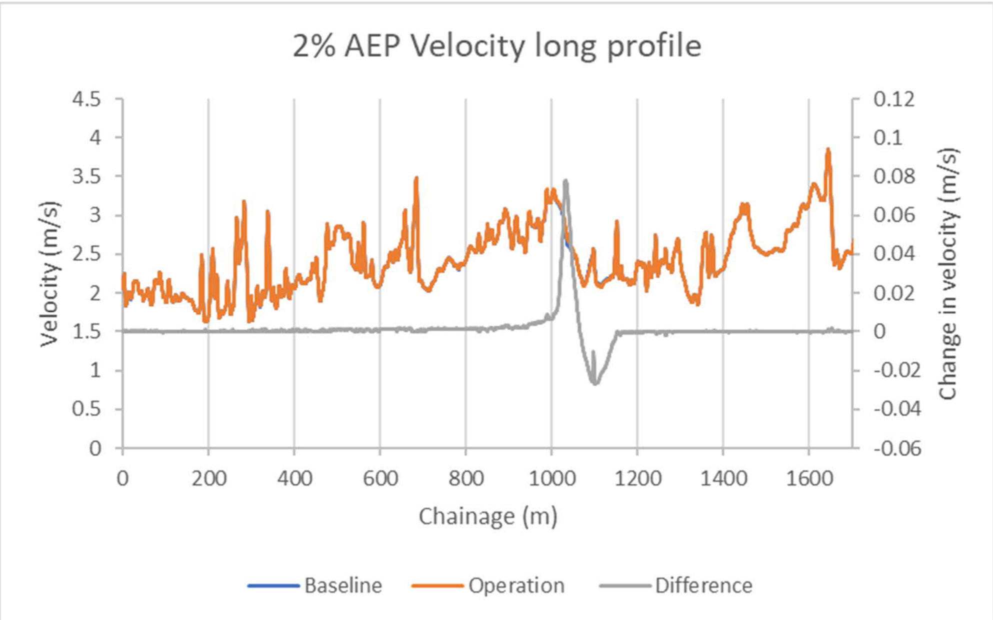


Figure 23 - Change in velocity long profile, Scheme in Operation scenario, 2% AEP (50-year) event

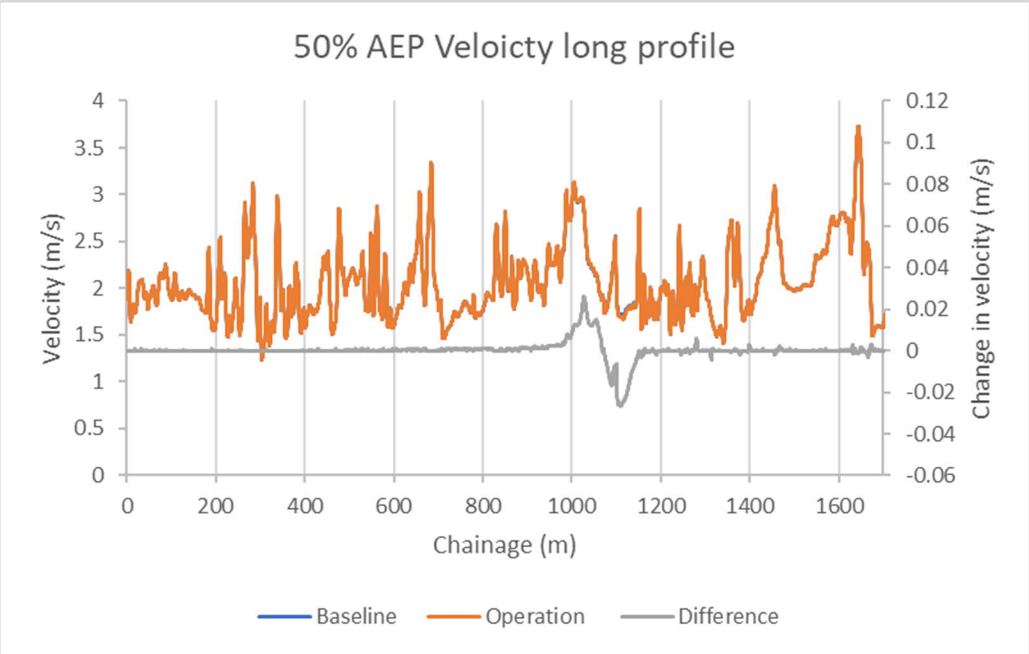


Figure 24 - Change in velocity long profile, Scheme in Operation scenario, 0.5% AEP (200-year) event

7.4 STREAM POWER

7.4.1. Appendix C Figures 22 - 24 show the change in stream power spatially between the scenarios in the 50%AEP (2-year), 2%AEP (50-year) and 0.5% AEP (200-year) events.

7.4.2. In the 50% AEP (2-year) event, change in stream power >10% of the Baseline is limited to the margins of the channel in locality of the proposed works. On the left bank, there is anticipated to be a reduction in stream power where the bank protection will be constructed, up to around 30% of Baseline stream power values and increase of up to around 30% immediately downstream. These areas of both increase and decrease predominantly occur in areas where stream power is very low (<35W/m2) in both the Baseline and operation scenarios. On the right bank, change in stream power increases to around 50% of the Baseline values, but is limited in extent, occurs very locally around the proposed south bank pier rock armour and is variable between increase and decrease in stream power over short distances. The pattern and extent of change is very similar in the 2% AEP (50-year) event, albeit with percentage changes in stream power being marginally higher in the same locations relative to the change modelled in the 50% AEP (2-year) event. The pattern and extent of change is, again, similar in the 0.5% AEP (200-year) event, albeit a zone where stream power increases by just over 10% extends across the channel at the upstream end of the proposed works. Bedrock is present in this area so unlikely to be affected by this level of change.

7.5 SEDIMENT ENTRAINMENT

7.5.1. Appendix C Figures 25 - 27 show the change in the modelled size of sediment entrained between the Baseline and Scheme Construction scenarios in the 50%AEP (2-year), 2%AEP (50-year) and 0.5% AEP (200-year) events spatially.

7.5.2. At the peak of the 50% AEP (2-year) event in the Scheme in Operation scenario, changes greater than ±10% in the modelled size of sediment entrained relative to the Baseline, are extremely localised to the extents of bank where the proposed bank protection is proposed. There is no change >±10% away from the banks. On the north bank, a reduction in the modelled size of sediment transported is indicated in the vicinity of the rock armour itself, with gravel rather than cobbles being mobilised against this bank during operation. Towards the downstream extent of the proposed bank protection along the north bank, there is an increase in the modelled size of sediment to be transported but limited to less than 30% of the modelled entrained sediment size in the Baseline scenario. On the south bank, there is a small extent where the modelled size of sediment would increase upstream of the proposed pier. However, this area is already bedrock and masonry/concrete associated with the existing pier. In the lee of the minor protrusion for the proposed southern pier pile cap, there is a reduction in the modelled size of sediment transported, likely a similar effect to that which we see in the lee of the existing south pier training works. Immediately downstream of this, there is an area of very limited extent where the size of sediment modelled to be entrained increases, but which is predominantly limited to 10%-30% of the size of sediment modelled to be entrained in the Baseline scenario and is in an area of bedrock and boulders. The area where the mid-channel gravel-cobble-boulder bar is located, experiences change of less than ± 10%.

7.5.3. At the peak of the 2% AEP (50-year) event in the Scheme in Operation scenario, the extent of the changes in entrained sediment size >±10% relative to the Baseline continue to be localised to the extent of the works and limited to the banks, with the majority of change being a reduction in the modelled size of sediment entrained reducing by 30-90%. There are minor changes in the extents of the changes, but the scale of change between the Baseline and Scheme in Operation scenario remains the same as during the 50% AEP (2-year) scenario. The area where the mid-channel gravel-cobble-boulder bar is located, experiences change of less than ± 10%.

7.5.4. At the peak of the 0.5% AEP (200-year) event in the Scheme in Operation scenario, the extent of the changes in entrained sediment size >±10% continue to be localised to the extent of the works and limited to the banks, with the majority of change being a reduction in the modelled size of sediment entrained reducing by 30-95%. There are minor changes in the extents of the changes, but the scale of change between the Baseline and Scheme in Operation scenario remains the same as during the 50% AEP (2-year) scenario. The area where the mid-channel gravel-cobble-boulder bar is located, experiences change of less than ± 10%.

7.6 SHIELDS PARAMETER ASSESSMENT – MID-CHANNEL BAR

7.6.1. Appendix C Figures 28 and 29 show the change in the value of the Shields parameter in the Baseline and Scheme in Operation scenarios in the 50%AEP (2-year), 2%AEP (50-year) and 0.5% AEP (200-year) events spatially, for the D50 and D84 particle sizes respectively, as measured through the Wolman count on the mid-channel bar.

7.6.2. In the Scheme in Operation scenario, the modelled threshold range for entrainment for the measured D50 in the vicinity of the bar is exceeded in the Baseline scenario in all events and continues to be so in the Scheme in Operation scenario in all events at this location. The Shields parameter value for the D84 particle size shows practically no change between the Baseline and Scheme in Operation scenarios across all three AEP events.

7.7 FROUDE

7.7.1. Appendix C Figure 15 shows the change in physical biotopes in the vicinity of the bridge between the Baseline, construction and operation scenarios.

7.7.2. There is no perceptible change to the biotopes, as indicated by the Froude number, at the Q50 level in the Scheme in Operation scenario relative to the Baseline.

8 CONCLUSIONS

8.1 BASELINE

8.1.1. Following geomorphology site visits to the River Coquet, observations have been made which allow the following conclusions to be reached in respect of the existing situation, in addition to those made in those made in 6.7 Environmental Statement Appendix 10.7 – Geomorphology Assessment – River Coquet Parameter 10 Part A [APP 260]:

s. Alterations to bed and banks are limited throughout most of the reach to informal fishing platforms and their accesses. However, in the vicinity of the existing bridge there are the following modifications:

   i. River training works finished with stone pitching extending for approximately 35m along the south bank around the existing south bridge pier.

   ii. A concrete outfall on the north bank, downstream of the existing pier.

   iii. Short sections of informal rock armour to mitigate erosion at a) the upstream extent of the south pier river training works and b) the north bank outfall.

   iv. Bank and valley side modification (either required or collateral) associated with the construction access for the original bridge extending downstream of the existing bridge.

t. The backwater effect of the existing Old Mill weir at Felton extends around 300-350m upstream of the weir, and to within around 300m of the proposed site (uncertainty due to anticipating variable extent of backwater effect).

u. Large rock is present on both the north and south bank derived either from:

   i. Rockfall directly from the upper cliff on the north bank.

   ii. Larger mass movements comprising a greater part of the valley side, and which remains once finer material is removed.

v. Erosion is present within the reach, particularly where colluvial deposits from mass movements have reached the river.

8.2 SCHEME IN CONSTRUCTION SCENARIO

8.2.1. The geomorphological dynamics assessment has indicated that the introduction of the Temporary Works and associated constriction of the river channel result in localised change during the 50% AEP (2-year) flood event, particularly away from the margins of the channel, where the reduced 'bank' roughness and channel constriction created by the Temporary Works results in localised changes in, depth, velocity, stream power and the size of sediment entrained. A limited backwater effect, with depth increases exceeding 10% of the Baseline for around 50m upstream of the Temporary Works occurs during this event, and velocities are indicated to increase through the works but with a limited downstream effect (exceeding 10% of the Baseline for only around 30m beyond the furthest downstream extent of the Temporary Works).

8.2.2. Change is more notable during the 2% AEP (50-year) and 0.5% AEP (200-year) flood events and there is a discernible (10% - >100%) increase indicated in most parameters (with the exception of depth) across most of the channel (between the training walls). However, these impacts would be limited to the duration of the works and extend only a limited distance downstream from the works. Specifically, notable changes are elevated stream power and consequent risk of erosion downstream of the proposed works on the right bank, and a slightly elevated likelihood of the D84 (205mm) sediment fraction becoming entrained during these higher flows on the mid-channel bar within the longitudinal extent of the works. However, the mobility of much larger boulders exceeding this size (up to around 900mm) are unlikely to be affected. In addition to the impacts between the training walls, the upstream backwater effect extends further upstream at the 2% AEP (50-year) and 0.5% AEP (200-year) events, than in the 50% AEP (50-year) scenario.

8.2.3. In the Scheme Construction scenario, the effect on biotopes is anticipated to be negligible in magnitude at normal levels of flow with any localised change occurring at the immediate boundary with the rock armour.

8.3 SCHEME IN OPERATION SCENARIO

8.3.1. In the Scheme in Operation scenario, for the 50%AEP (2-year) and 0.5% AEP (200-year) flood events, the inclusion of rock armour is likely to have a localised impact of limited magnitude on the geomorphological dynamics across most of the channel. There may be some minor limited changes in morphological dynamics at the channel margins resulting from the change in roughness that the construction of rock armour bank protection may introduce, most notably a slightly increased risk of erosion immediately downstream of the left bank rock armour.

8.3.2. In the Scheme in Operation scenario, the effect on biotopes is anticipated to be negligible in magnitude at normal levels of flow with any localised change occurring at the immediate boundary with the rock armour.

8.4 SUMMARY OF CONCLUSIONS RELATIVE TO DEADLINE 4 ASSESSMENT

8.4.1. In summary, the change likely to occur during the Scheme in Operation is primarily to the bank morphology with the impacts on geomorphological dynamics likely to be limited to very localised variations in stream power and sediment transport at the margins of the channel adjacent to the scour protection. However, the area in which the works will take place is already partly modified to accommodate the existing bridge, and large rock is also naturally present on the banks within the reach. Changes in stream power and potential sediment transport are likely to be more notable during the Scheme in Construction phase, principally due to the constriction created by the river training works. However, these effects are temporary, reversible and limited to the duration of the construction works.

8.4.2. This geomorphological dynamics assessment based on 2-D hydraulic modelling has allowed a detailed assessment of extent and magnitude of the change associated with the Scheme Construction and Scheme in Operation scenarios.

8.4.3. In the Scheme Construction scenario, the extent and magnitude of the anticipated changes from the Baseline are as reported 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064], with the following exceptions:

w. The extent of the 'backwater' effect created by the constriction through the Temporary Works has been quantified by the 2-D modelling. The results show that the impact extends from 50 to 700 hundred metres upstream, subject to the AEP of the event under consideration. An increase in coarse sediment deposition upstream of the works, commensurate with a reduction in velocity, stream power and sediment entrainment potential, was qualitatively described, but due to the cross-section basis of the previous hydraulic calculations (i.e. with no longitudinal dimension) the extent of this change was not quantified.

x. The magnitude of the increases in stream power and modelled sediment entrainment potential from the Baseline are greater than those anticipated through cross section-based calculations. Specifically, the maximum increases in stream power during construction were anticipated in Paragraph 8.10.13 of 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] to be around 59% in the 50% AEP (2-year) event and 48% in 0.5% AEP (200-year) event. The analysis based on 2-D hydraulic modelling indicates some areas through the longitudinal extent of the Temporary Works where increases in stream power may locally exceed 100% in the 50% AEP (2-year) event and more extensively (within the longitudinal extent of the Temporary Works) exceed 100% in the 0.5% AEP event. The increase in modelled sediment size entrained anticipated in Paragraph 8.10.13 of 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] was 6mm at the 50% AEP (2-year) event and 18mm at the 0.5% AEP (200-year) event. In the same area as the cross section was taken, the magnitude of change is similar in the 2-D model. Upstream and downstream of the cross section location but within the longitudinal extent of the Temporary Works higher magnitude increases in 2-D modelled sediment entrainment are anticipated (predominantly less than 100mm in the 50% AEP event and predominantly less than 200mm in the 2% AEP event). However, these increases are in areas where a) cobbles, boulders and bedrock are present in the channel, b) Baseline scenario already predicts large cobbles would be entrained and c) the relative change in sediment size is <100%.

8.4.4. However, the potential for these changes from the Baseline scenario were identified qualitatively in 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and Table 8-7 and Table 8-8 of 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] and, with the suggested mitigation, are not considered to significantly affect features of interest such as the mid-channel bar described in Paragraph 4.4.6 to 4.4.7 of this note. The overriding considerations in determining the Significance of Effect of the Scheme in Construction scenario stand, i.e. that the works are of relatively short duration and the effects on fluvial processes are reversible.

8.4.5. In the Scheme in Operation scenario, this has indicated the extent of anticipated changes are as reported in 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064], with notable change from the Baseline being confined to the margins of the channel within the extent of the Scheme in Operation works and immediately downstream. The magnitude of the change indicated in the 2-D modelling relative to that indicated using the cross section-based methodology at Deadline 4 of the Examination is broadly comparable, with areas of higher magnitude change being within the extent of those areas where bank protection is proposed. No other new information has been provided in this report and therefore it is considered that the assessment presented at Deadline 4 of the Examination in 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and Table 8-7 and Table 8-8 of 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] stands.

8.4.6. The Magnitude of Impact for both the Stabilisation Works and Southern Access Works therefore remains the same as that presented (Minor adverse) in Table 9-7 and Table 9-8 of 6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] and Table 8-7 and Table 8-8 of 6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064], and therefore the Significance of Effect for all geomorphological impacts remains Slight (not significant).

9 NEXT STEPS

9.1.1. Further, detailed topographic survey of the mid-channel bar and other prominent channel boulders should be undertaken to allow their reinstatement should they be required to be moved or be inadvertently moved during high flow events in which the pattern of flow is altered by the Temporary Works. Such a survey would be undertaken prior to construction when flow conditions permit (likely to be when the water level Morwick and Rothbury gauges are ≤0.4m), by a suitably qualified Topographic Surveyor, most likely using a Total Station due to limitations on GPS accuracy in the gorge, under the direction of a suitably qualified Geomorphologist. Alternative surveys could be considered including a terrestrial lidar scan or photogrammetric or lidar drone survey, ground-truthed with traditional survey methods, if suitable physical and licensing conditions can be met and accuracy can be assured. This action is included in the Updated Outline Construction Environmental Management Plan (item reference SW-W4 in 7.3 Updated Outline Construction Environmental Management Plan (Clean) - Rev 5 [REP-0625]).

10 REFERENCES

Examination Documents

6.7 Environmental Statement Appendix 10.7 – Geomorphology Assessment – River Coquet Parameter 10 Part A [APP-260]

6.32 Environmental Impact Assessment - River Coquet Geomorphology Modelling Assessment [REP-032]

6.38 Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063].

6.40 Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064].

6.44 Water Framework Directive Addendum for Change Request [REP4-068]

6.50 River Coquet Hydraulic Modelling Report

Centre for Ecology and Hydrology (CEH), 2021. https://nrfa.ceh.ac.uk/data/station/liveData/22001 . Accessed 19/03/2021 and 04/05/2021.

Entwistle N., Heritage G., Milan D., 2019. Ecohydraulic modelling of anabranching rivers. River Research and Applications, 2019, 1-12.

Sear D.A., Newson D.M., Thorne C.R., 2003. Guidebook of Applied Fluvial Geomorphology. R&D Technical Report FD1914. Defra, December 2003.

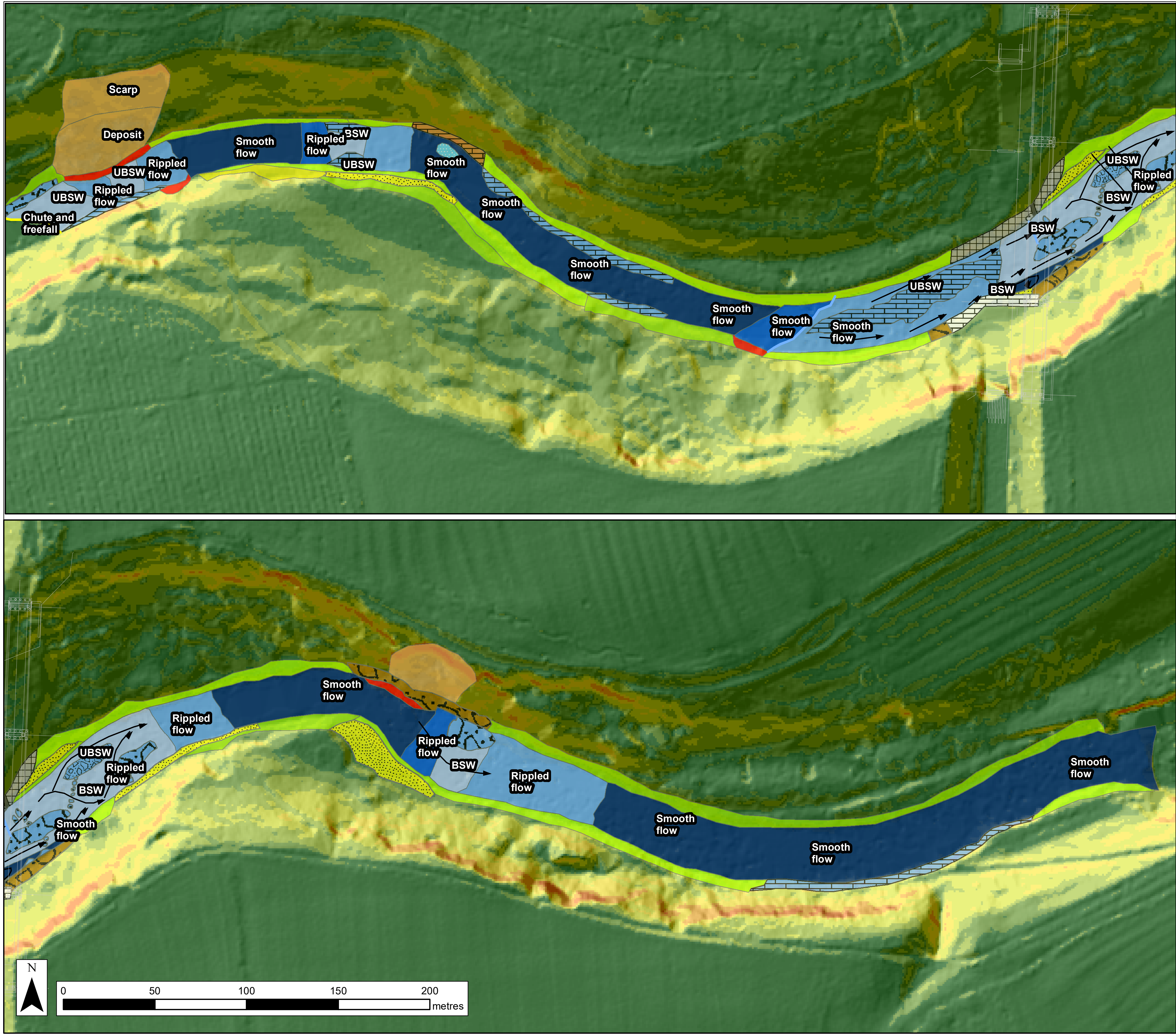
Shields A., 1936. Anwendung der Aehnlichkeitsmechanik under der Turbulenzfoschung auf di Geschiebebewegung. Preußichen Veruchsanstalt für Wasserbau und Schiffbau. Berlin.

Wolman, M.G., 1954. A method of sampling coarse bed material. American Geophysical Union, Transactions, 35: 951-956.

Appendix A

GEOMORPHOLOGICAL MAP – OVERVIEW

APPENDIX A



Legend

- Proposed bridge location (indicative)
- <all other values>
- Bedrock ledge (above observed water level)
- Bedrock ledge (below observed water level)
- Flow direction and type
- Bank erosion
- Bar
- Boulders
- Bedrock bank
- Emerging bedrock
- Floodplain fragment
- Gentle vegetated bank
- Non-natural bank (original construction works)
- Outfall
- Pool
- Glide
- Run
- Riffle
- Rock armour
- Rockfall
- Sandy deposit
- Scour protection (pitching/concrete)
- Steep vegetated bank
- Upwelling
- Valley side failure wth visibly eroding toe

Flow type abbreviations:
BSW - Breaking standing waves
UBSW - Unbroken standing waves

SKETCH MAP - NOT FOR DESIGN

Background mapping:

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	06/05/2021	Initial Issue	AB	SP	IG	XX

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Drawing Title
GEOMORPHOLOGY AND BIOTOPE MAPPING - REACH OVERVIEW

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S0 - INITIAL ISSUE

Scale @ A3	1:2,000	DO NOT SCALE
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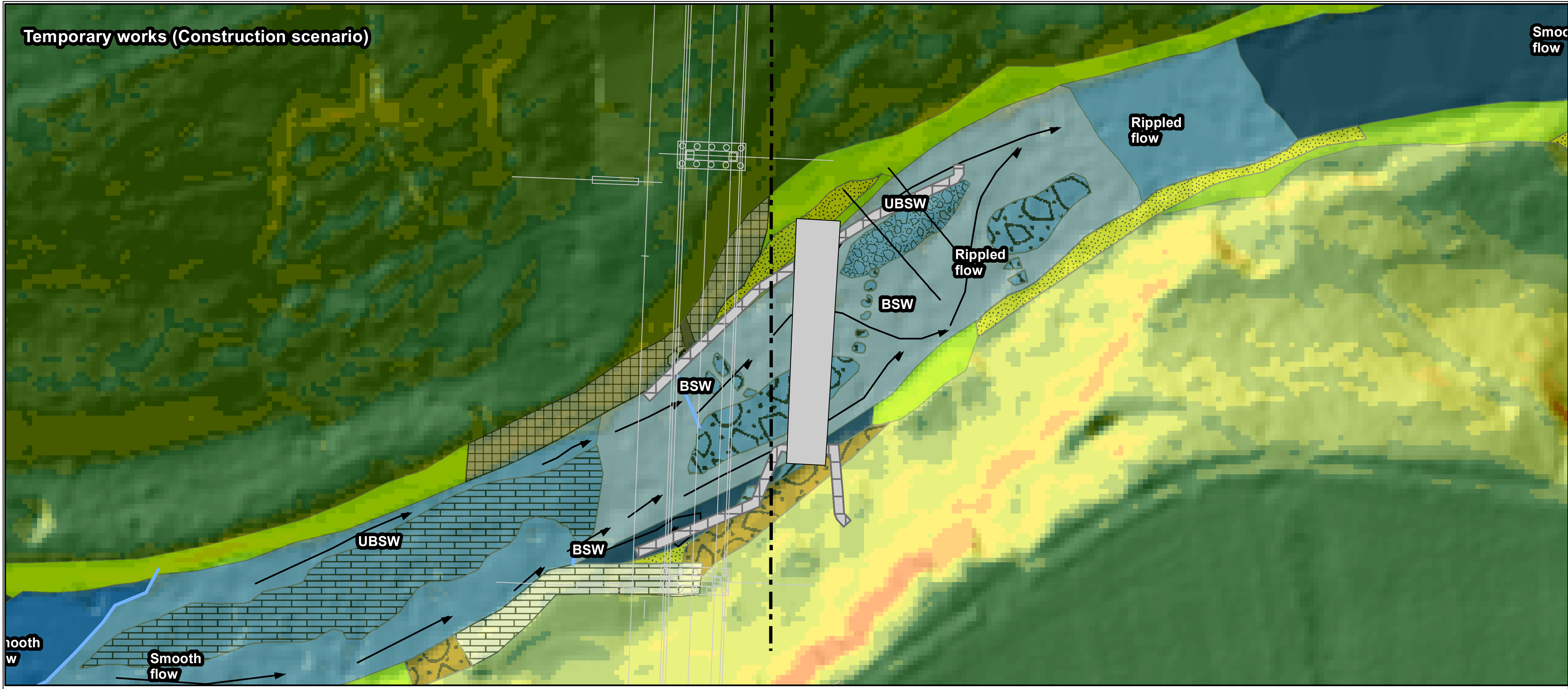
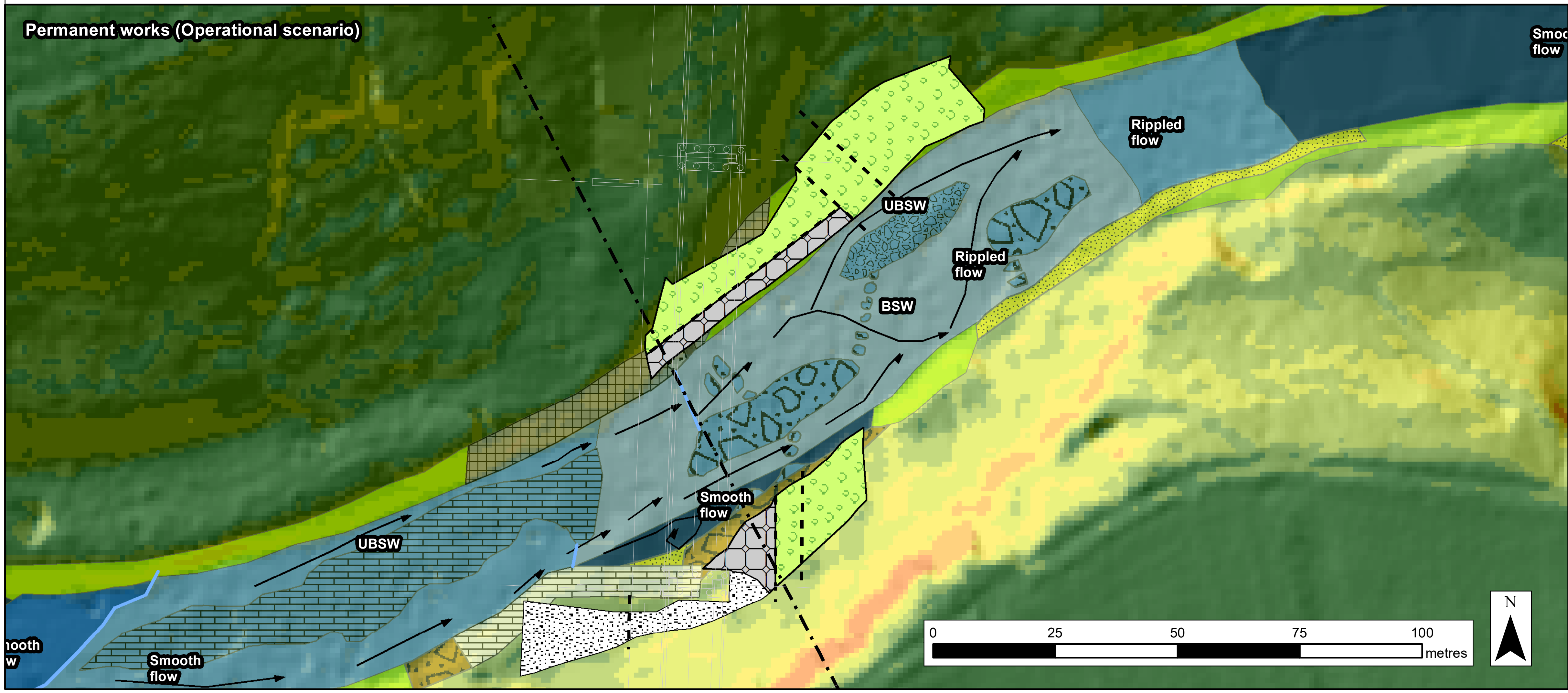
Appendix B

GEOMORPHOLOGICAL MAP - DETAIL





APPENDIX B

Operational scenario

- Proposed bridge location (indicative)
- Permanent works cross section alignment
- Extent of uncertainty in bank protection type
- Rock armour (dn50 800-1000mm)
- Reno mattress or rock armour
- Green-grey solution

Temporary works scenario

- Cross section used in analysis
- Retaining wall
- Temporary bridge

Geomorphological mapping (both scenarios)

- Bedrock ledge (above observed water level)
- Bedrock ledge (below observed water level)
- Flow direction and type
- Bank erosion
- Bar
- Boulders
- Bedrock bank
- Emerging bedrock
- Floodplain fragment
- Gentle vegetated bank
- Non-natural bank (original construction works)
- Outfall
- Pool
- Glide
- Run
- Riffle
- Rock armour
- Rockfall
- Sandy deposit
- Scour protection (pitching/concrete)
- Steep vegetated bank
- Upwelling
- Valley side failure with visibly eroding toe

Flow type abbreviations:
BSW - Breaking standing waves
UBSW - Unbroken standing waves

SKETCH MAP - NOT FOR DESIGN

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Drawing Title
GEOMORPHOLOGY AND BIOTOPE MAPPING - BRIDGE LOCATION DETAIL

Drawing Status
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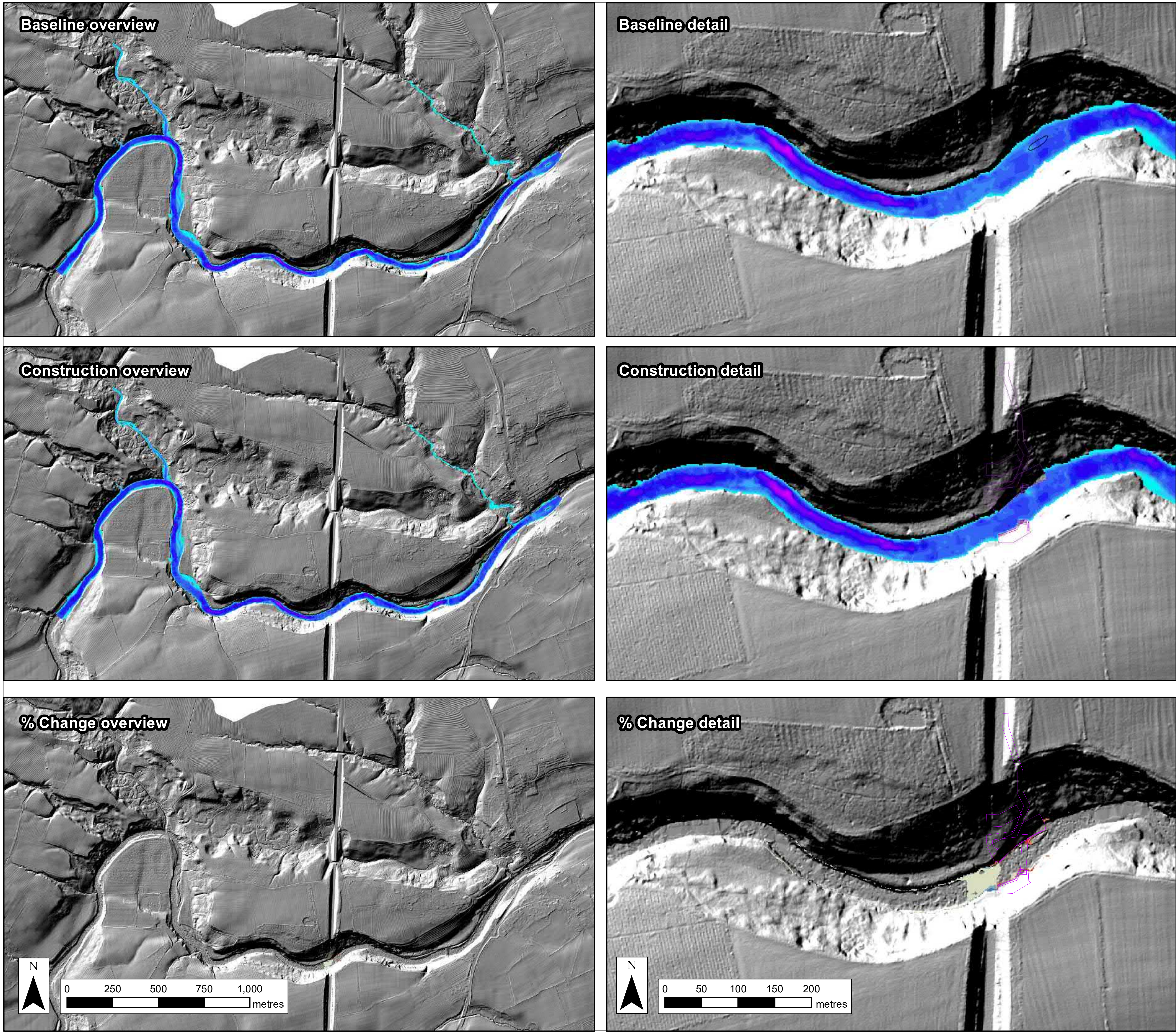
Appendix C

GEOMORPHOLOGICAL DYNAMICS ASSESSMENTS MAPS



APPENDIX C - FIGURE 1

Key

Water depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.5
- 5.5 - 6
- 6 - 6.5
- 6.5 - 7

% Change in water depth

- -100 - -30
- -30 - 10
- -10 - 10
- 10 - 30
- 30 -100
- >100
- Temporary works footprint (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
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Drawing Title: CHANGE IN MAXIMUM WATER DEPTH - BASELINE VS CONSTRUCTION 50% AEP EVENT

Drawing Status: S0 - INITIAL ISSUE

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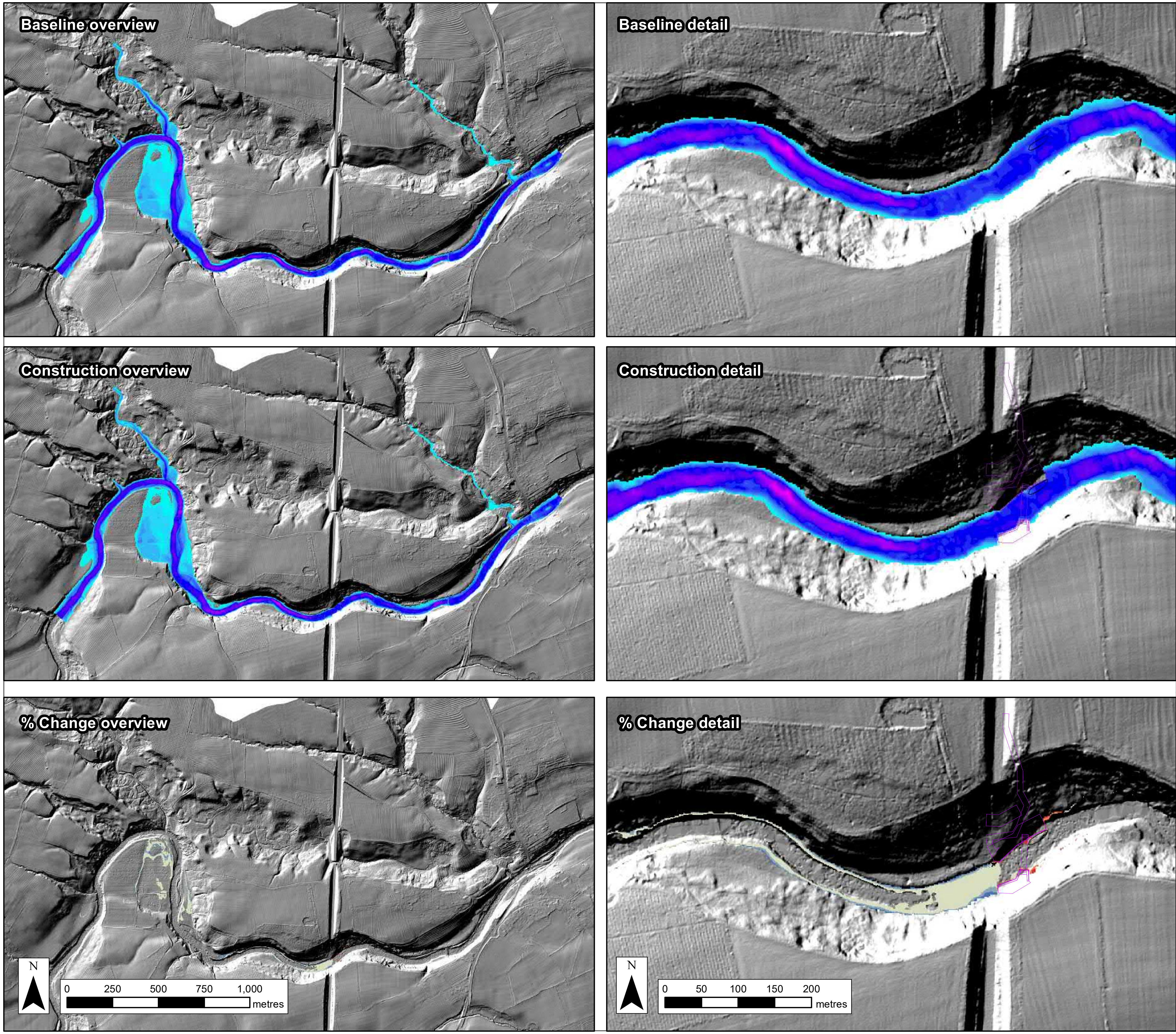
Drawing Number: As document

APPENDIX C - FIGURE 2



Key

Water depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.5
- 5.5 - 6
- 6 - 6.5
- 6.5 - 7
- 7 - 7.5
- 7.5 - 8
- 8 - 8.5

% Change in water depth

- -100 - -30
- - 30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100

- Temporary works footprint (indicative)
- Gravel-cobble-boulder bar

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Drawing Title
CHANGE IN MAXIMUM WATER DEPTH -
BASELINE VS CONSTRUCTION
2% AEP EVENT

Drawing Status
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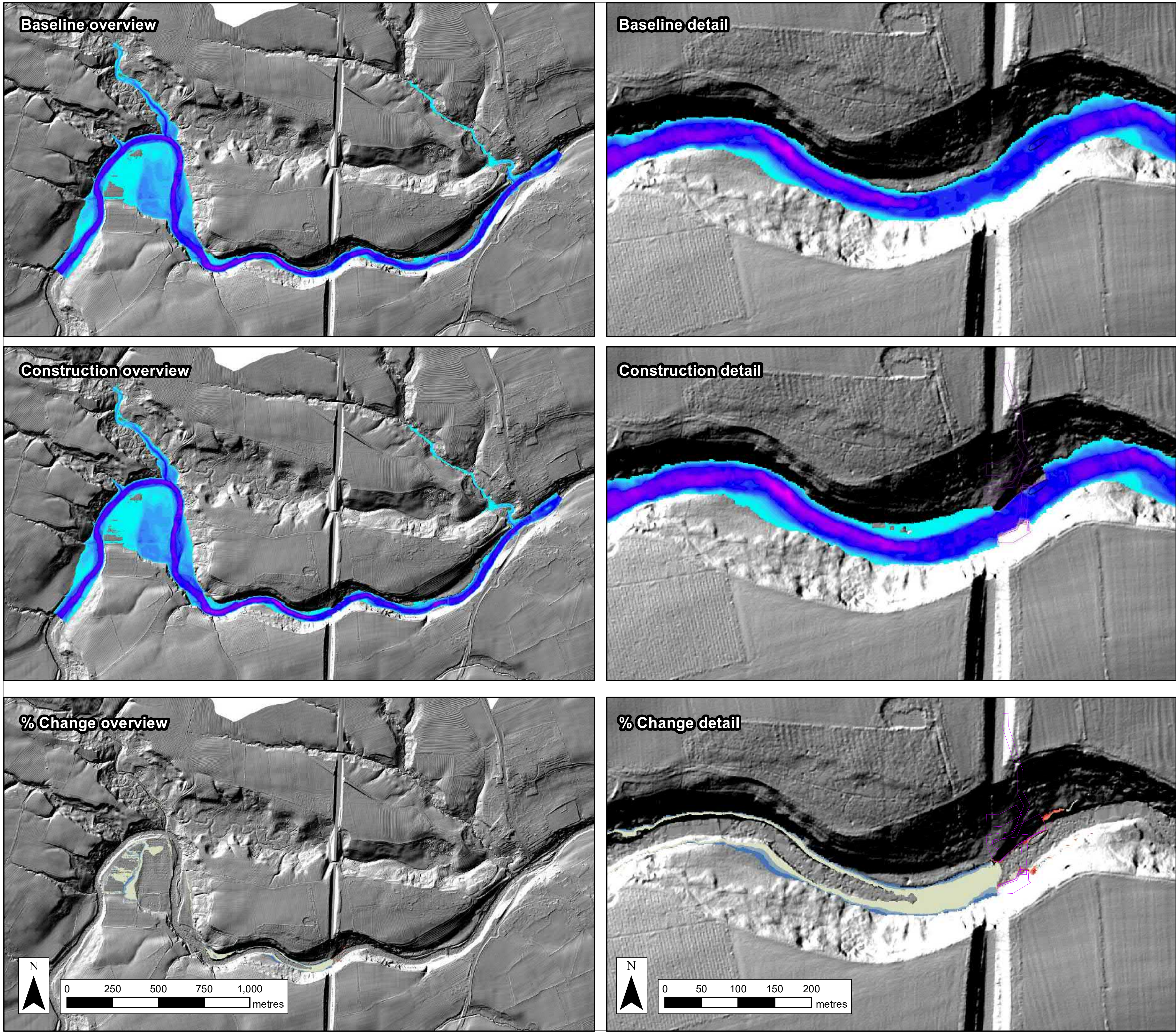
APPENDIX C - FIGURE 3



Key

Water depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 -4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.5
- 5.5 - 6
- 6 - 6.5
- 6.5 - 7
- 7 - 7.5
- 7.5 - 8
- 8 - 8.5
- 8.5 - 9
- 9 - 9.5

% Change in water depth

- -100 - -30
- -30 - 10
- -10 - 10
- 10 - 30
- 30 - 100
- >100

- Temporary works footprint (indicative)
- Gravel-cobble-boulder bar

Background mapping:

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Drawing Title
CHANGE IN MAXIMUM WATER DEPTH - BASELINE VS CONSTRUCTION
0.5% AEP EVENT

Drawing Status
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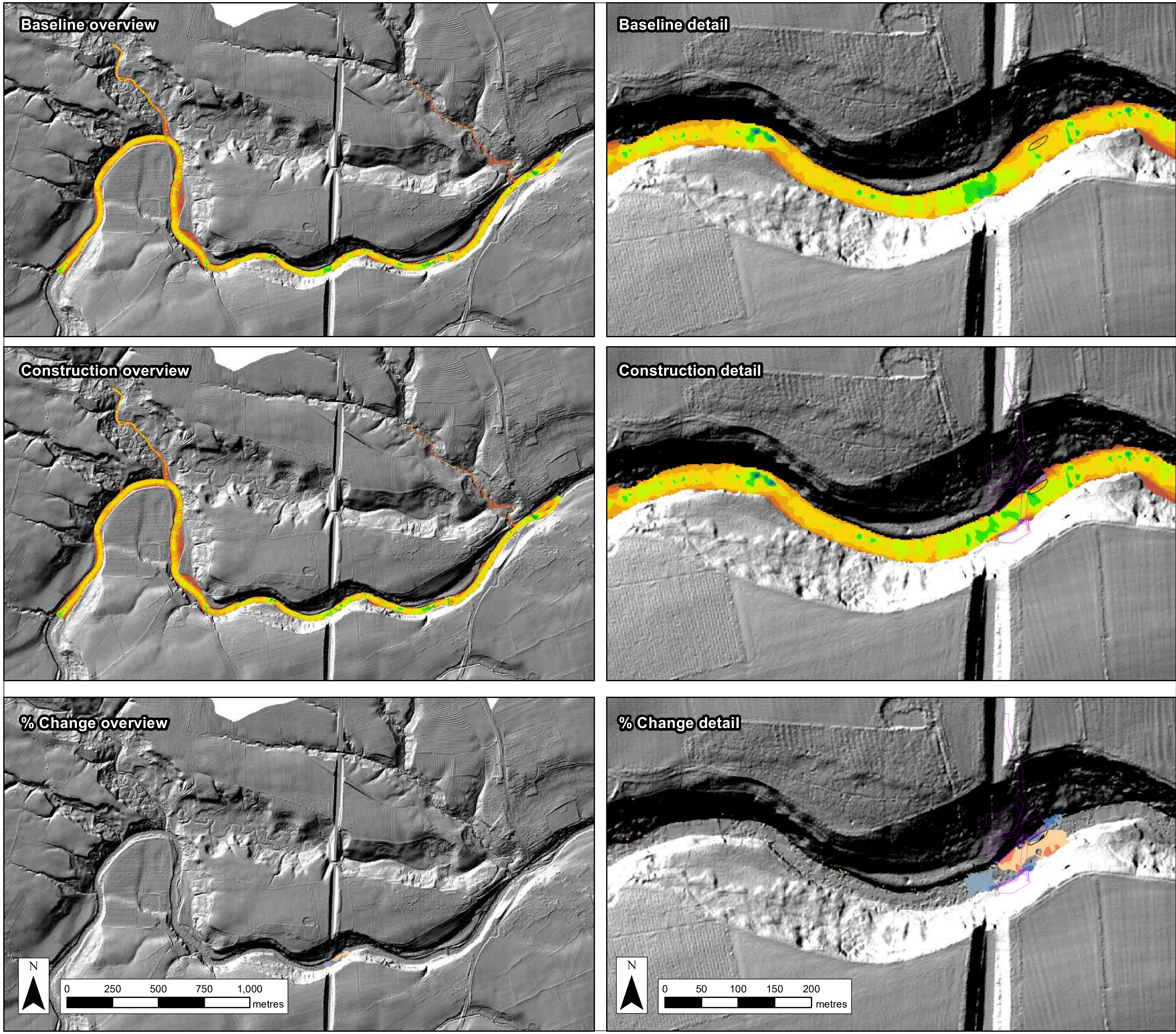

APPENDIX C - FIGURE 4

Key

Velocity (m/s)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5

% Change in velocity

- -100 - -30
- -30 - 10
- -10 - 10
- 10 - 30
- 30 - 100
- >100

- Temporary works footprint (indicative)
- Gravel-cobble-boulder bar

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Drawing Title
CHANGE IN MAXIMUM VELOCITY -
BASELINE VS CONSTRUCTION
50% AEP EVENT

Drawing Status
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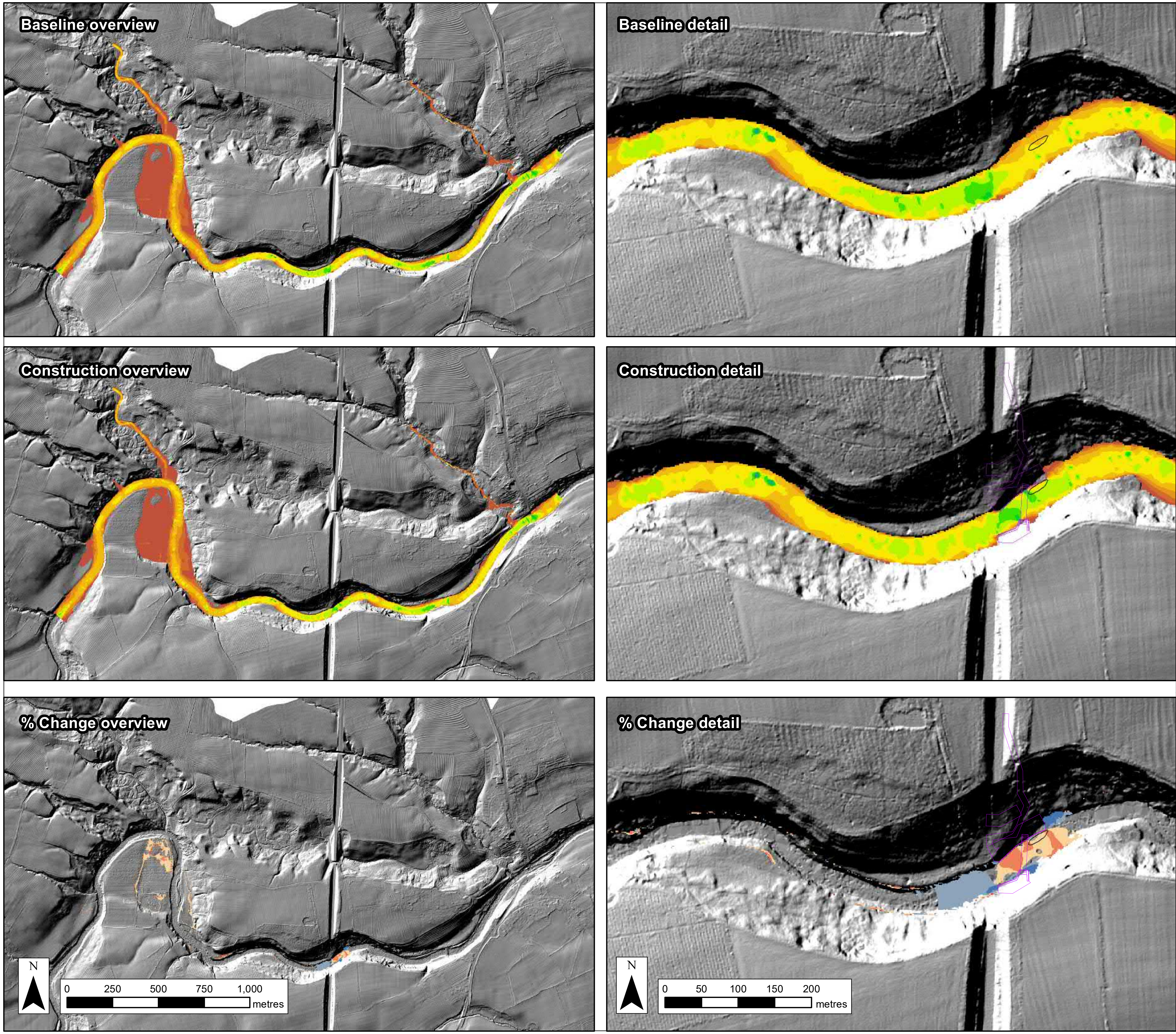

APPENDIX C - FIGURE 5

Key

Velocity (m/s)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.5
- 5.5 - 6

% Change in velocity

- -100 - -30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- 100 - 12,499.99902

- Temporary works footprint (indicative)
- Gravel-cobble-boulder bar

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Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd

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CHANGE IN MAXIMUM VELOCITY - BASELINE VS CONSTRUCTION 2% AEP EVENT

Drawing Status
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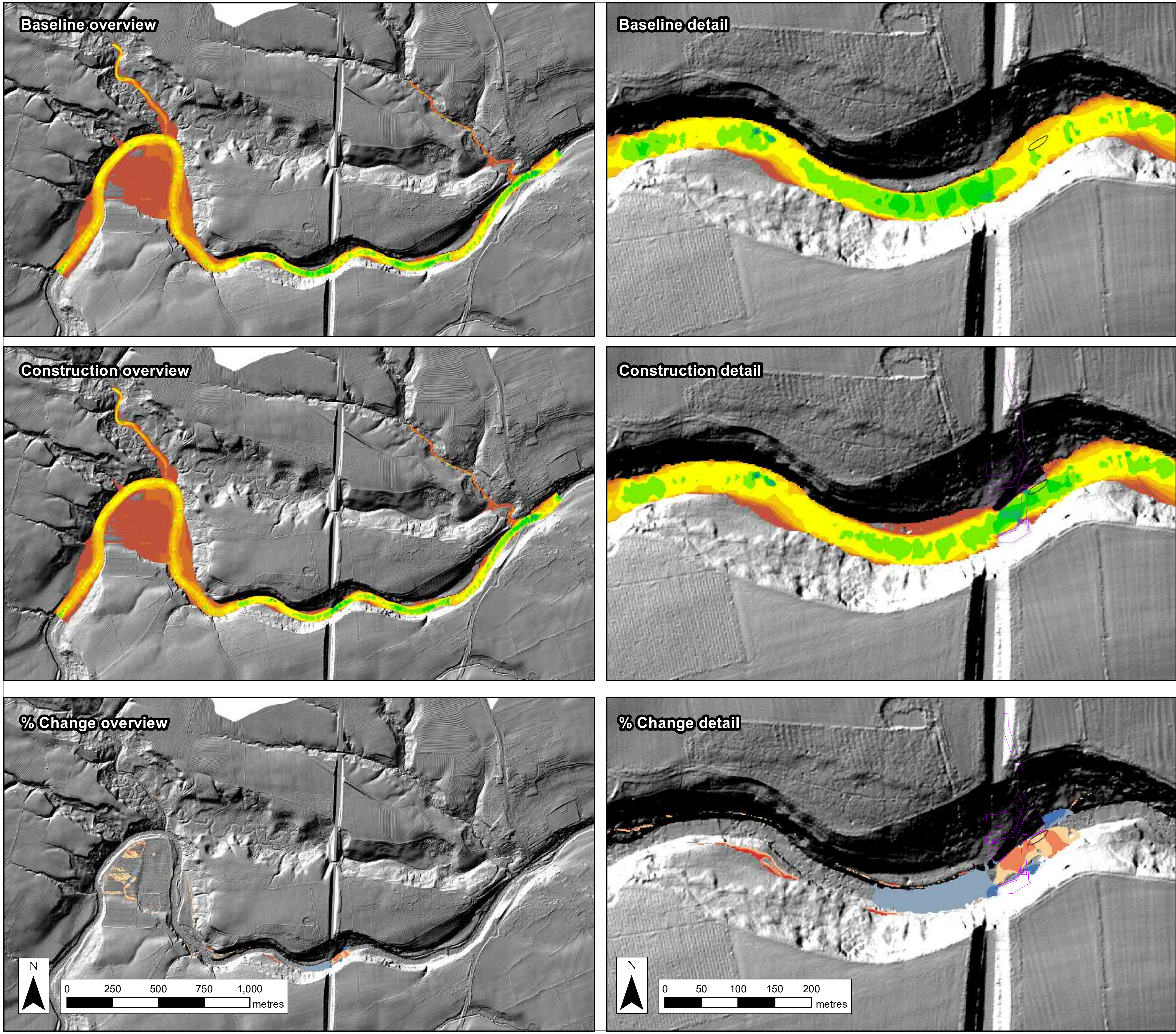
Client No.	As document	Rev P01

Drawing Number
As document



APPENDIX C - FIGURE 6

Key

Velocity (m/s)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.5

% Change in velocity

- -100 - -30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100

- Temporary works footprint (indicative)
- Gravel-cobble-boulder bar

Background mapping:

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

Contractor: COSTAIN

Designer: Jacobs
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www.jacobs.com

Client: highways england

Project
REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

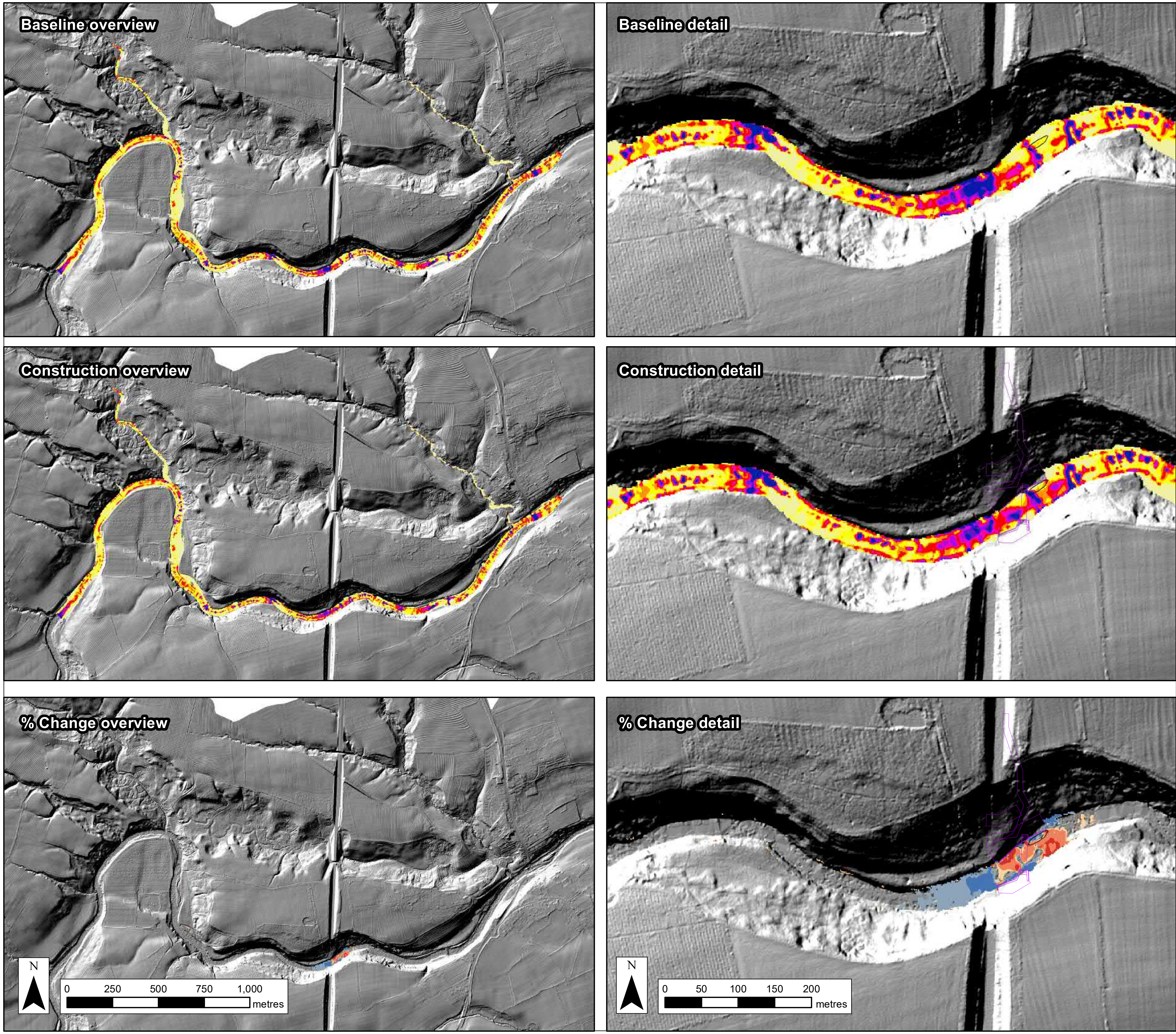
Drawing Title
CHANGE IN MAXIMUM VELOCITY -
BASELINE VS CONSTRUCTION
0.5% AEP EVENT

Drawing Status
S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:20,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
As document

APPENDIX C - FIGURE 7



Key

Stream power (W/m^2)

- 0 - 35
- 35- 50
- 50 - 75
- 75 - 100
- 100 - 150
- 150 - 200
- 200 - 250
- 250 - 300
- >300

% Change in stream power

- -100 - -30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100

- Temporary works footprint (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

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Client: highways england

Project
REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

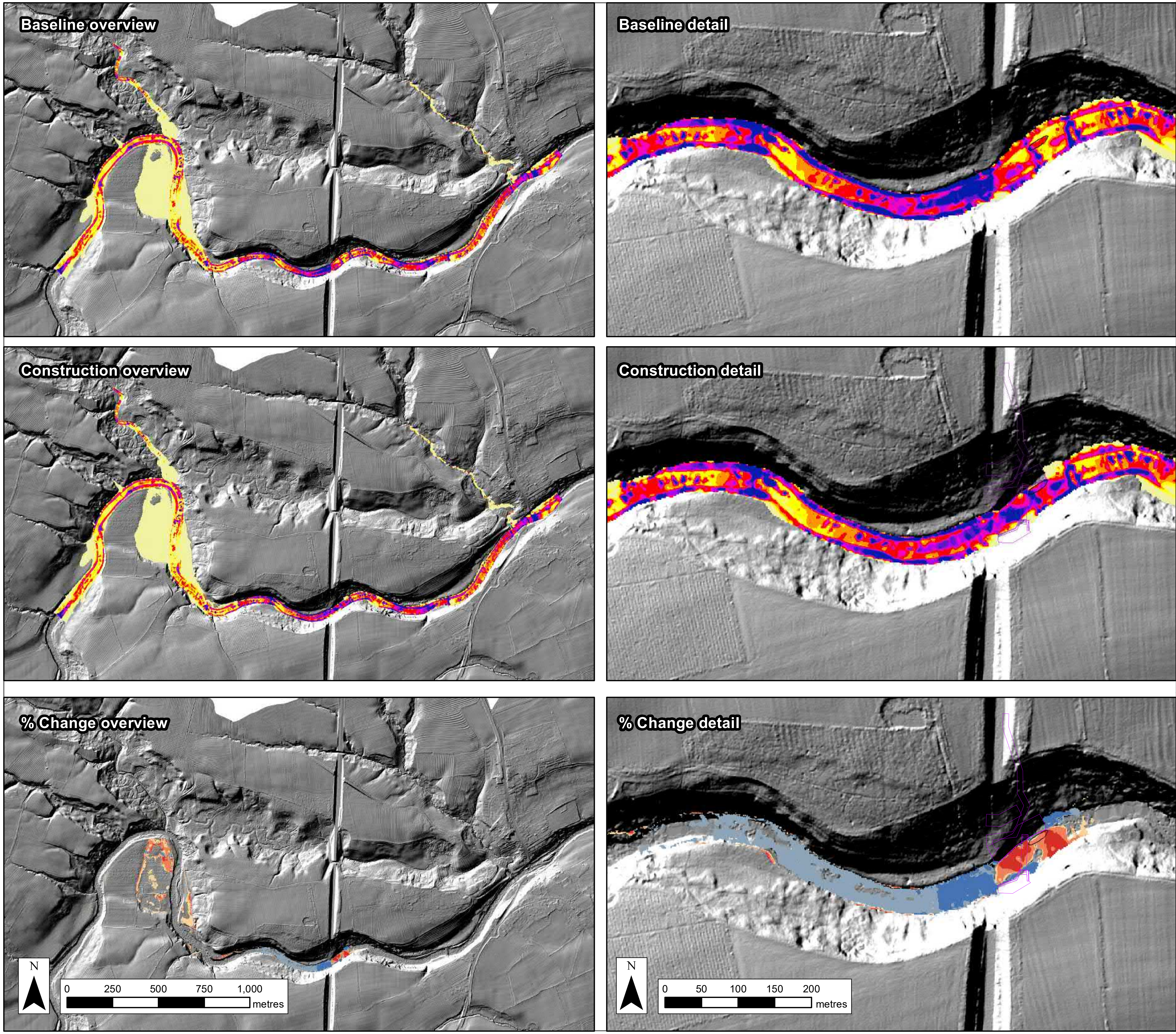
Drawing Title
CHANGE IN MAXIMUM STREAM POWER -
BASELINE VS CONSTRUCTION
50% AEP EVENT

Drawing Status
S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:20,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
As document

APPENDIX C - FIGURE 8



Key

Stream power (W/m^2)

- 0 - 35
- 35 - 50
- 50 - 75
- 75 - 100
- 100 - 150
- 150 - 200
- 200 - 250
- 250 - 300
- >300

% Change in stream power

- -100 - 30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100

- Temporary works footprint (indicative)
- Gravel-cobble-boulder bar

P01	29/04/2021	Initial Issue	AB	SP	IG	XX
Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd

Contractor: COSTAIN

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Client: highways england

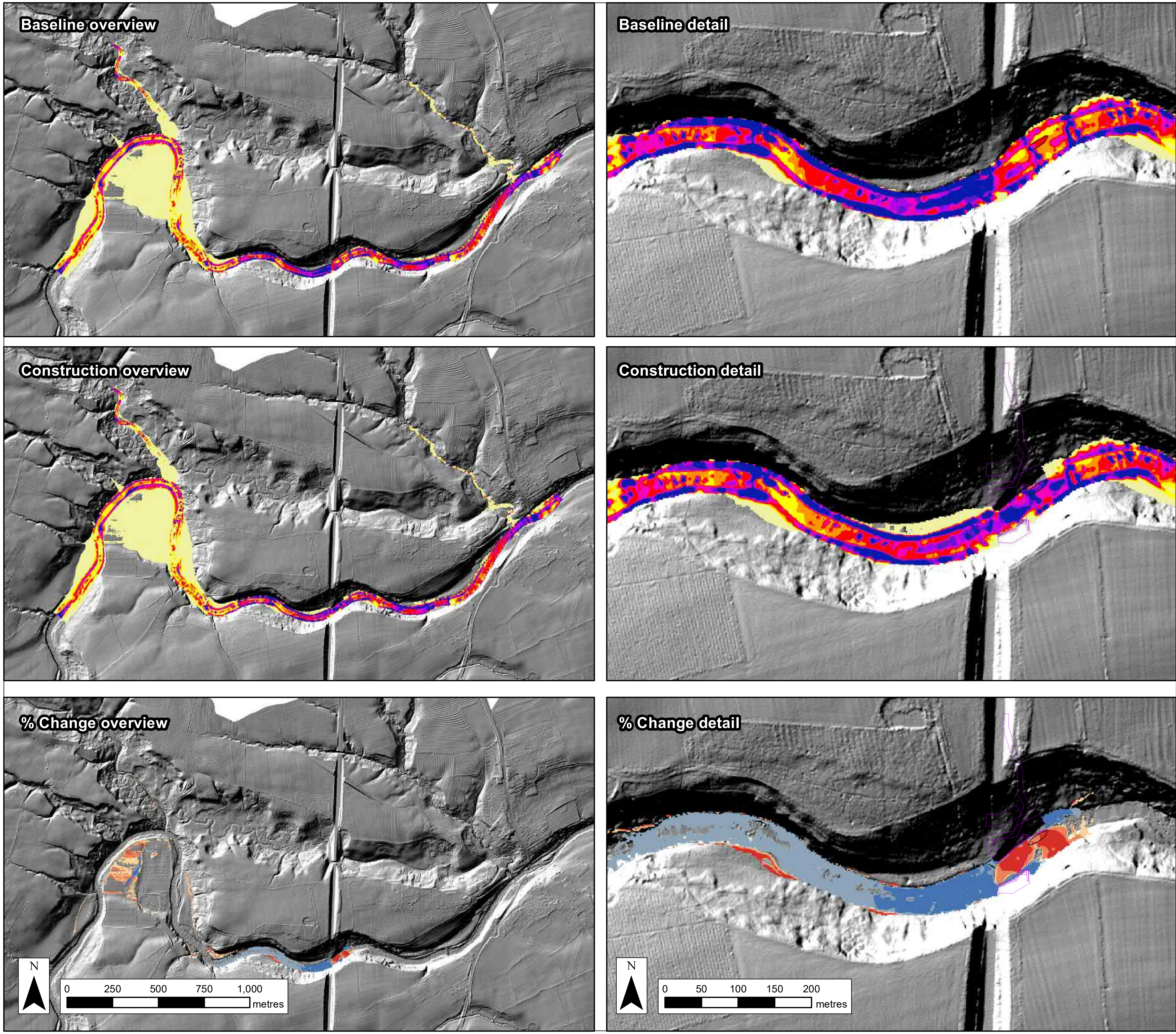
Project
REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

Drawing Title
CHANGE IN MAXIMUM STREAM POWER -
BASELINE VS CONSTRUCTION
2% AEP EVENT

Drawing Status: S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:20,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
As document



APPENDIX C - FIGURE 9

Key

Stream power (W/m^2)

- 0 - 35
- 35 - 50
- 50 - 75
- 75 - 100
- 100 - 150
- 150 - 200
- 200 - 250
- 250 - 300
- >300

% Change in stream power

- -100 - -30
- -30 - -30
- -10 - 10
- 10 - 30
- 30 - 10
- >100

- Temporary works footprint (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

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Client: highways england

Project
REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

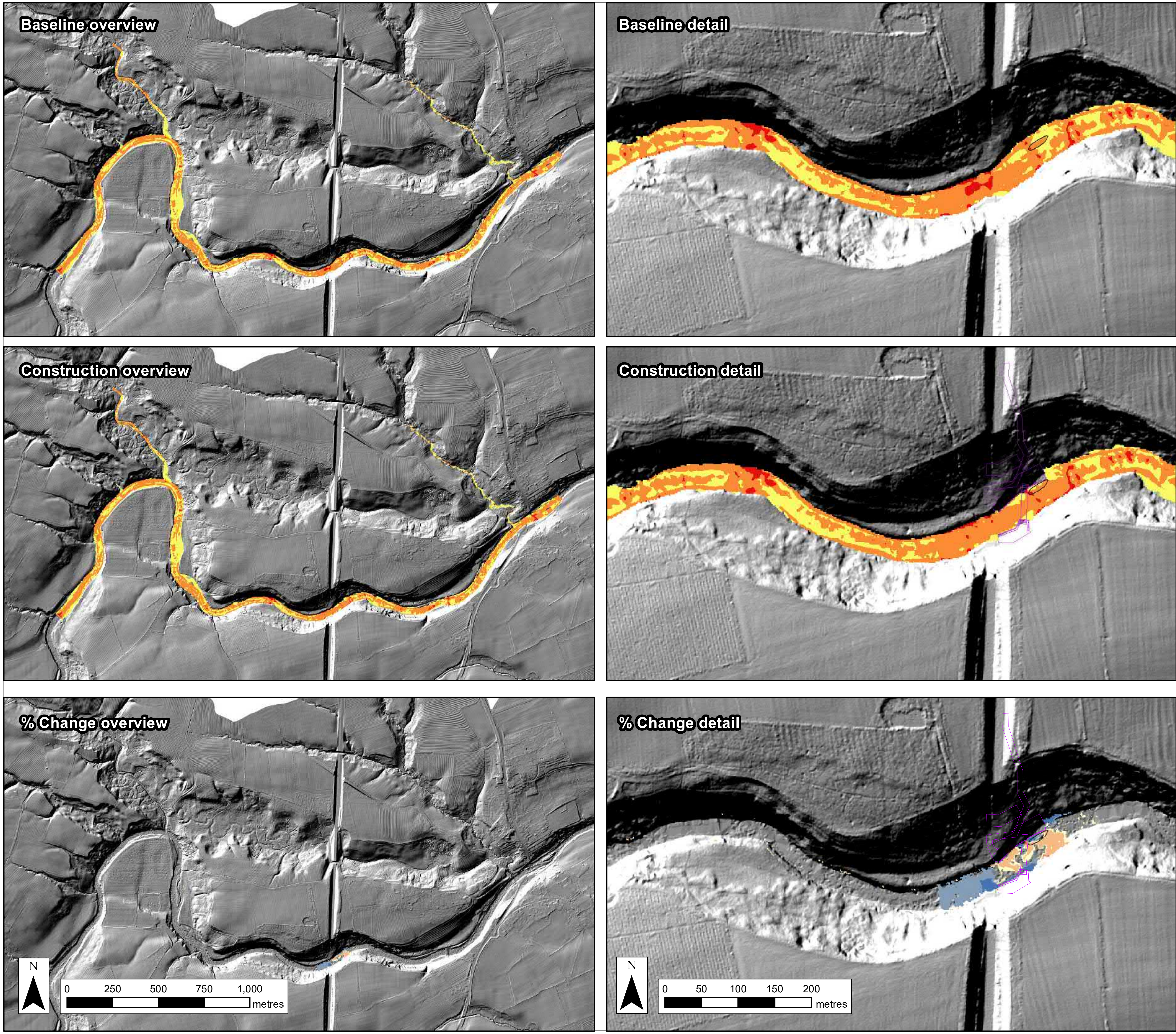
Drawing Title
CHANGE IN MAXIMUM STREAM POWER -
BASELINE VS CONSTRUCTION
0.5% AEP EVENT

Drawing Status
S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:20,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
As document

APPENDIX C - FIGURE 10



Key

Entrained sediment size (mm)

- <0.0625 (silt and clay)
- 0.0625 - 2 (sand)
- 2 - 64 (gravel)
- 64 - 256 (cobble)
- >256 (boulder)

% Change in entrained

- -100% - -30%
- -30% - -10%
- -10% - 10%
- 10% - 30%
- 30% - 100%
- 100% - 300%
- >300%
- Temporary works footprint (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

Contractor: COSTAIN

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Client: highways england

Project: REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

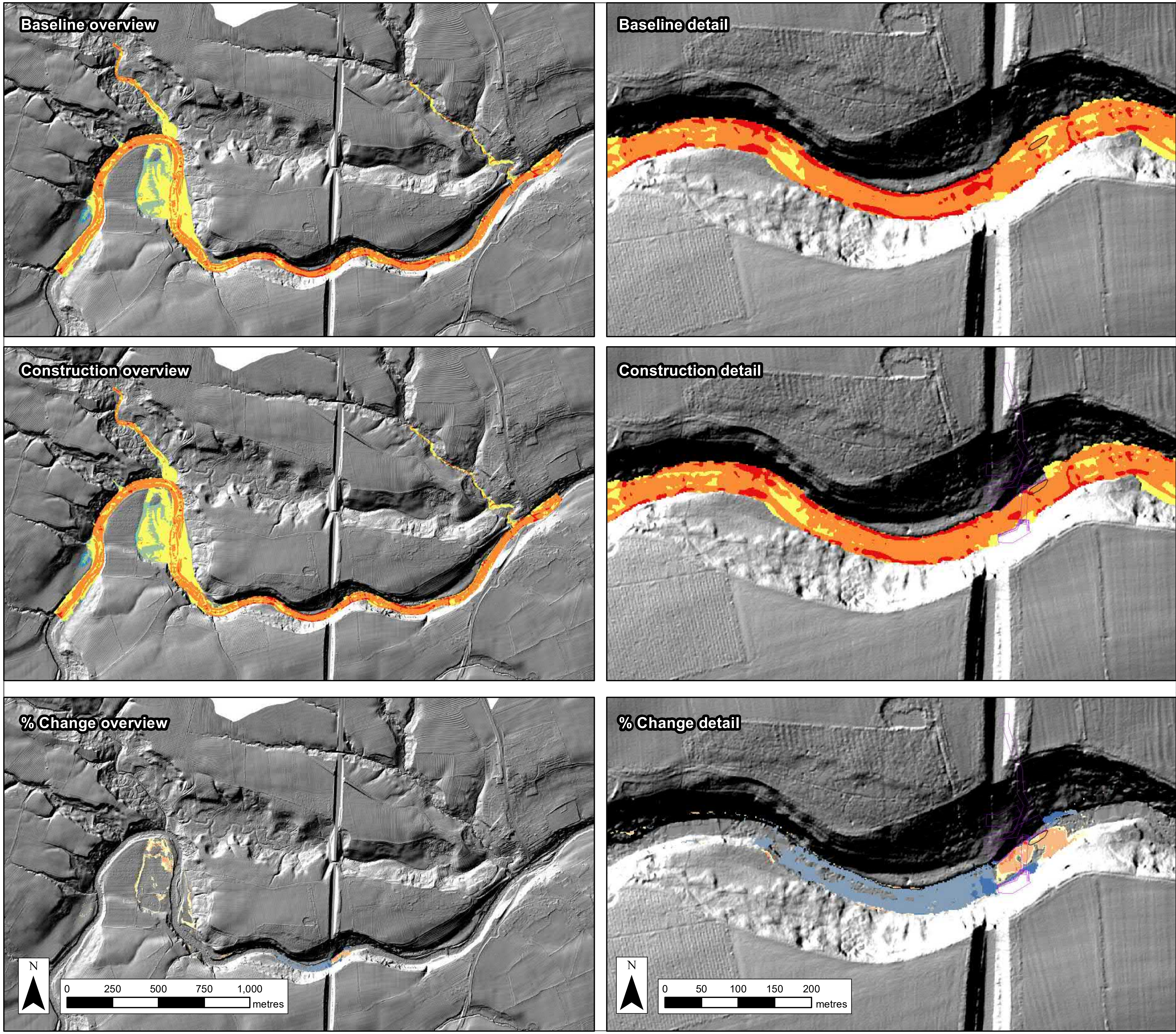
Drawing Title: ENTRAINED SEDIMENT SIZE -
BASELINE VS CONSTRUCTION
50% AEP EVENT

Drawing Status: S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:20,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number: As document

APPENDIX C - FIGURE 11



Key

Entrained sediment size (mm)

- <0.0625 (silt and clay)
- 0.0625 - 2 (sand)
- 2 -64 (gravel)
- 64 - 256 (cobble)
- >256 (boulder)

% Change in size entrained

- -100% - -30%
- -30% - -10%
- -10% - 10%
- 10% -30%
- 30% - 100%
- 100% - 300%
- >300%
- Gravel-cobble-boulder bar
- Temporary works footprint (indicative)

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

Contractor: COSTAIN

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Client: highways england

Project: REGIONAL DEVELOPMENT PROGRAMME A1 IN NORTHUMBERLAND

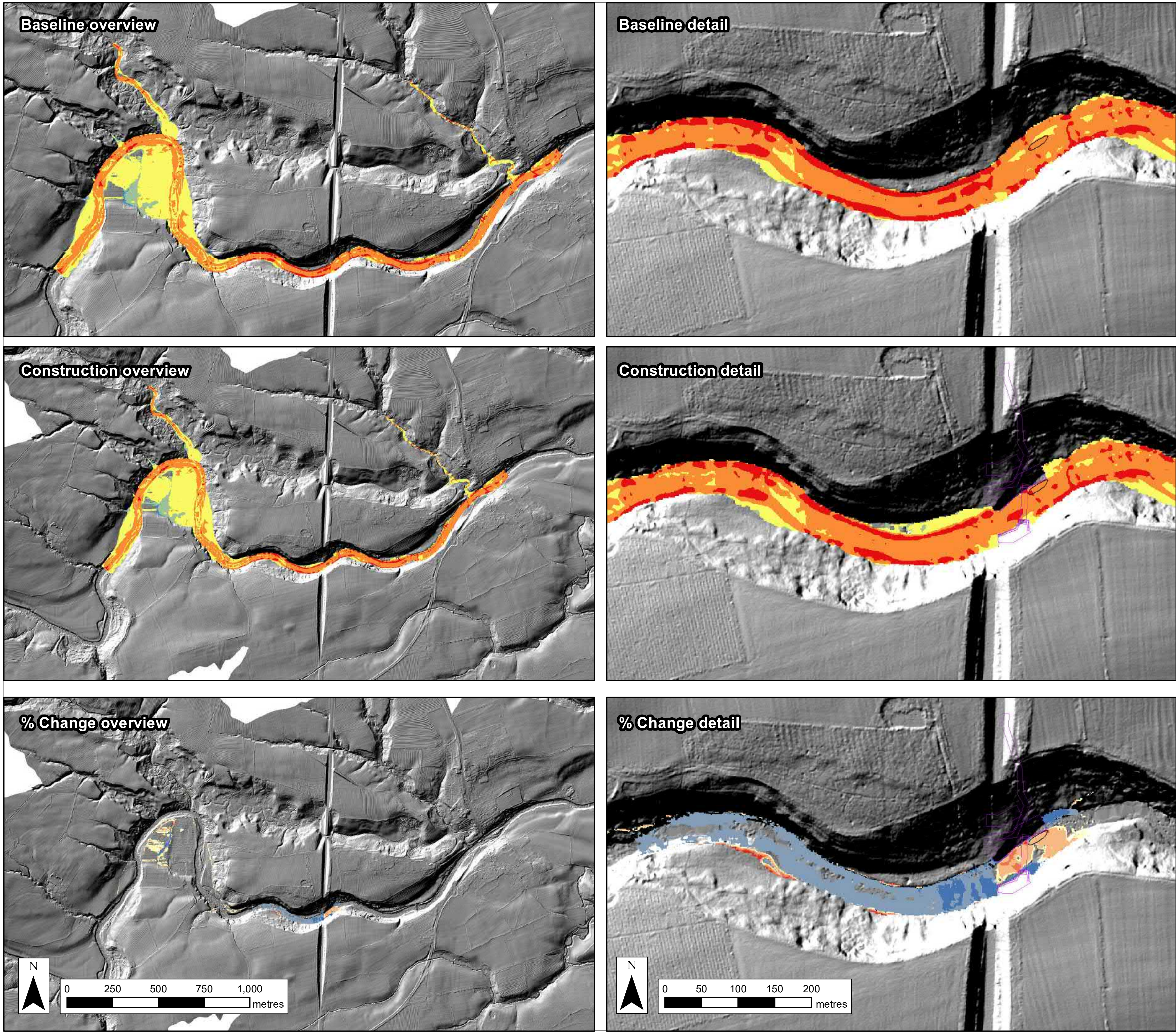
Drawing Title: ENTRAINED SEDIMENT SIZE - BASELINE VS CONSTRUCTION 2% AEP EVENT

Drawing Status: S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:20,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number: As document

APPENDIX C - FIGURE 12



Key

Entrained sediment size (mm)

- <0.0625mm (silt and clay)
- 0.0625mm - 2 mm (sand)
- 2mm - 64mm (gravel)
- 64mm - 256mm (cobble)
- >256mm (boulder)

% Change in sediment size entrained

- -100% - 30%
- -30%- -10%
- -10% - 10%
- 10% - 30%
- 30% - 100%
- 100% - 300%
- >300%
- Gravel-cobble-boulder bar
- Temporary works footprint (indicative)

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

Contractor: COSTAIN

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Client: highways england

Project: REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

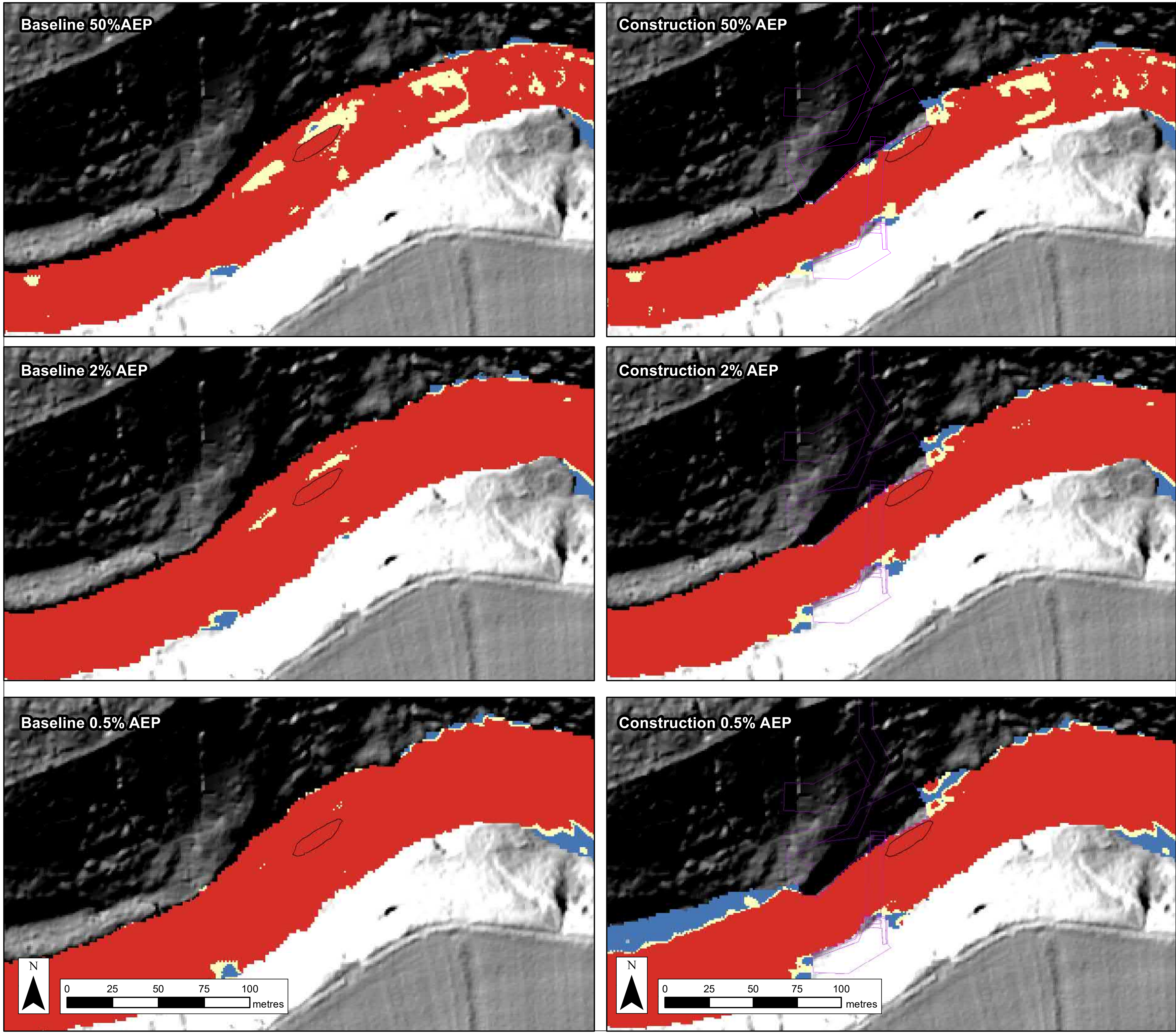
Drawing Title: ENTRAINED SEDIMENT SIZE -
BASELINE VS CONSTRUCTION
0.5% AEP EVENT

Drawing Status: S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:20,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	Rev P01
Client No.	As document	

Drawing Number: As document

APPENDIX C - FIGURE 13



Key

Shields Parameter for D50 @ 45mm

- < 0.03
- 0.03 - 0.06
- > 0.06
- Gravel-cobble-boulder bar
- Temporary works footprint (indicative)

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

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Project: REGIONAL DEVELOPMENT PROGRAMME A1 IN NORTHUMBERLAND

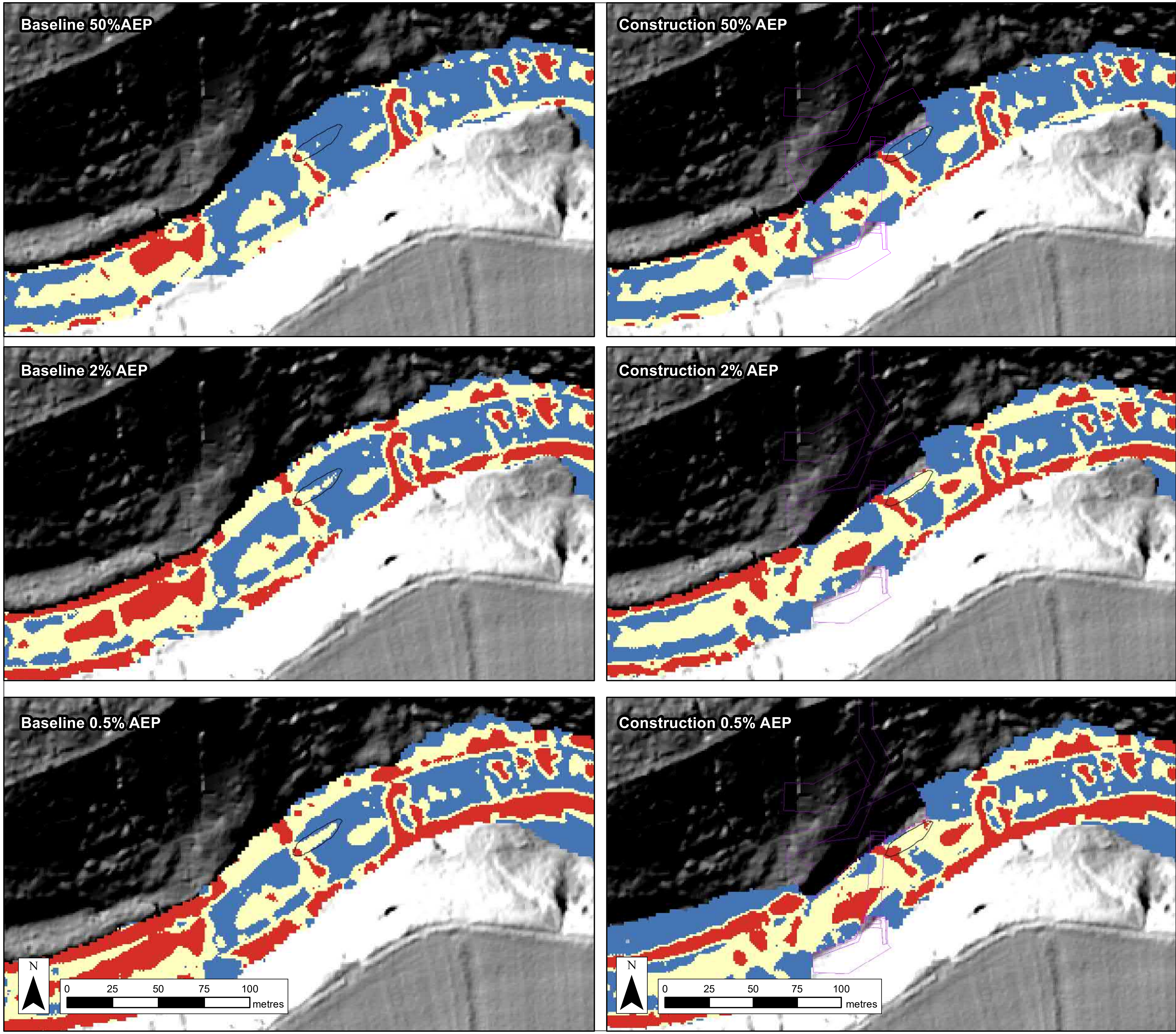
Drawing Title: SHIELDS PARAMETER D_{50} (45MM) - BASELINE VS CONSTRUCTION

Drawing Status: S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number: As document

APPENDIX C - FIGURE 14



Key

Shields Parameter for D84 @ 205mm

- < 0.03
- 0.03 - 0.06
- > 0.06
- Gravel-cobble-boulder bar
- Temporary works footprint (indicative)

P01	29/04/2021	Initial Issue	AB	SP	IG	XX
Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd

Contractor

COSTAIN

Designer

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Client

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Project

REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

Drawing Title

SHIELDS PARAMETER D_{84} (205MM) -
BASELINE VS CONSTRUCTION

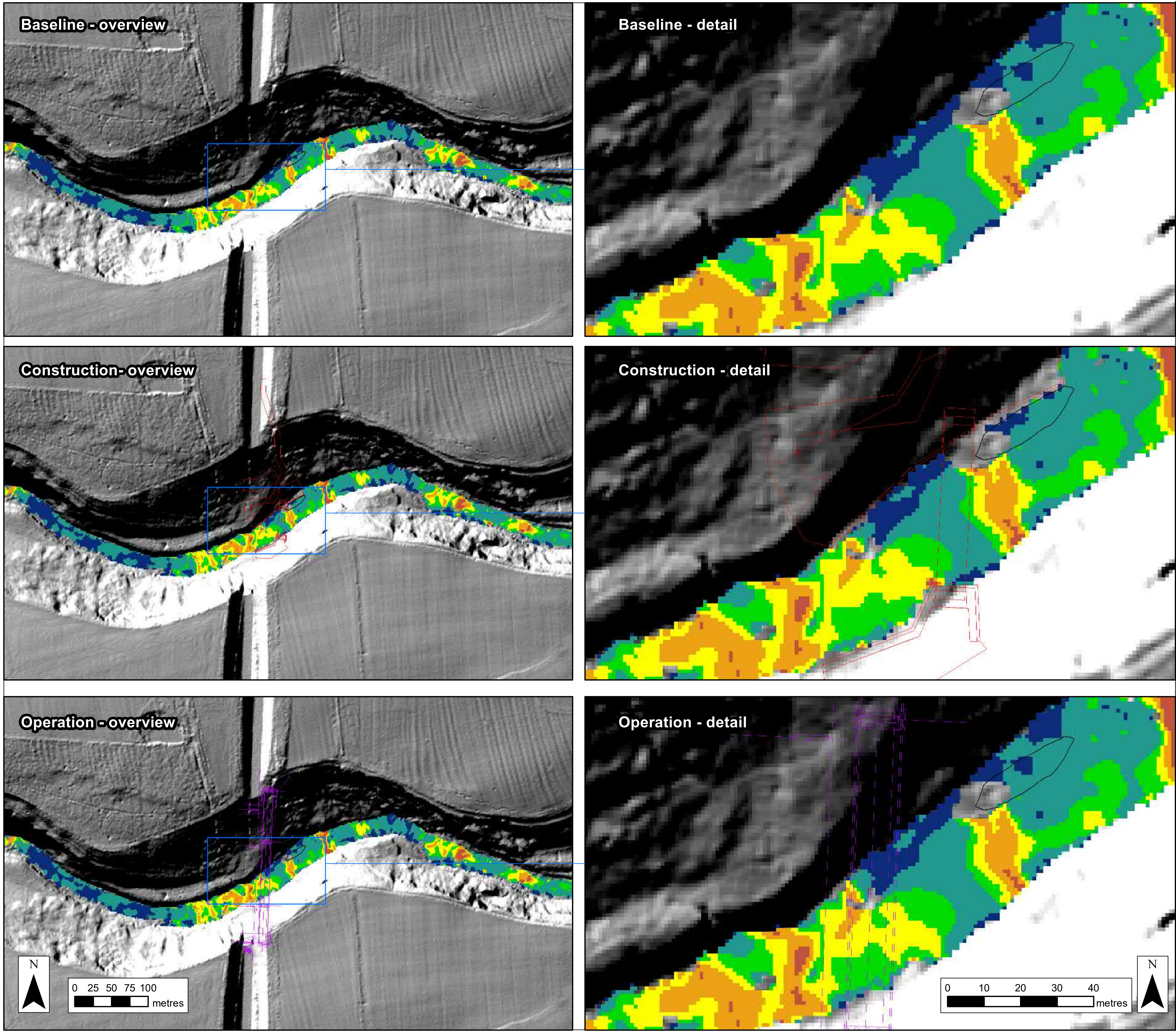
Drawing Status

S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
As document

APPENDIX C - FIGURE 15



Key

Froude Number (Biotope)

- 0 - 0.04 (Pool)
- 0.04 - 0.15 (Glide)
- 0.15 - 0.245 (Run)
- 0.245 - 0.49 (Riffle)
- 0.49 - 1 (Cascade/Rapid)
- > 1 (Supercritical)
- Temporary works footprint (indicative)
- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

Contractor: COSTAIN

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Project
REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

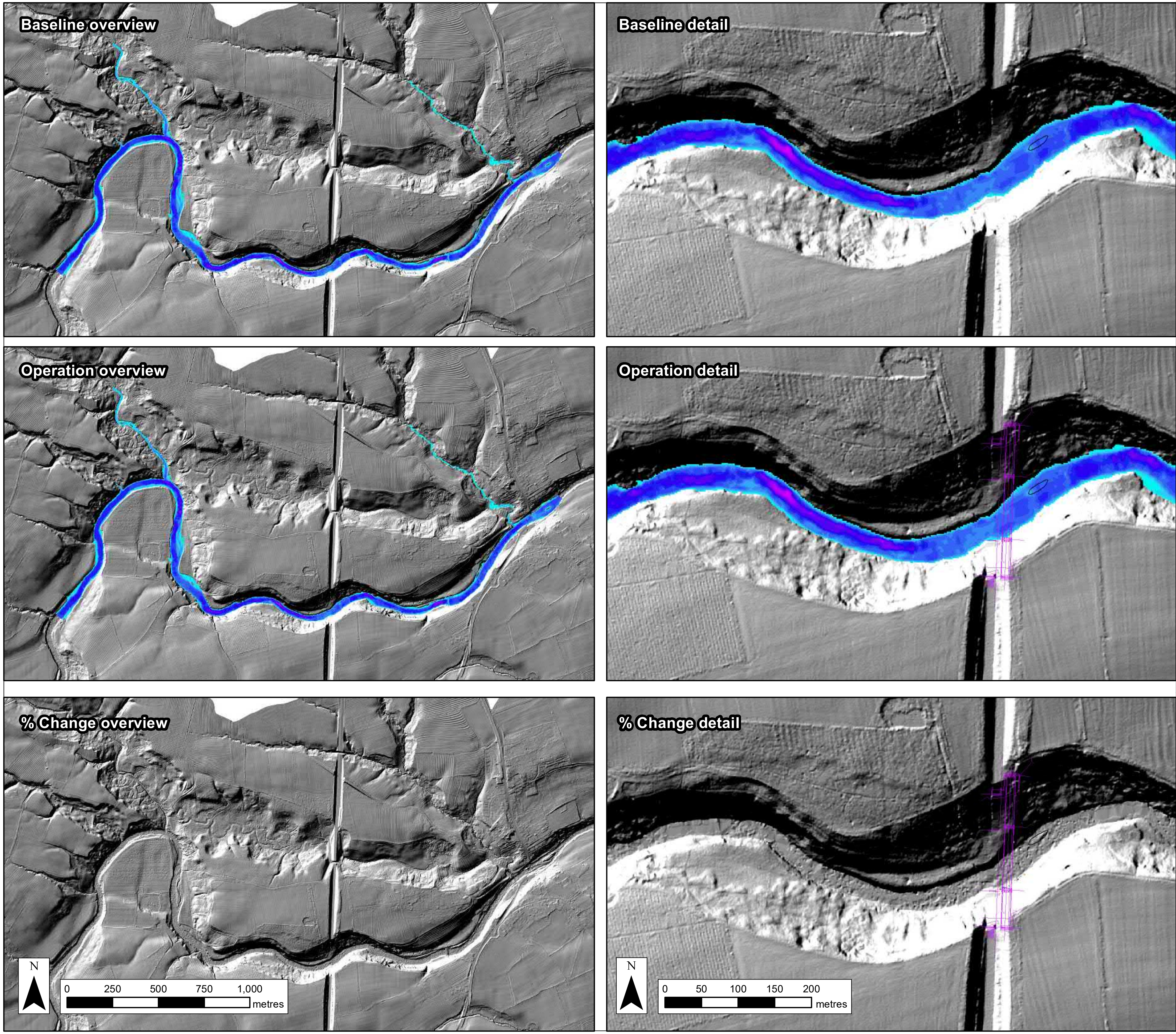
Drawing Title
BIOTOPE BY FROUDE NUMBER - Q50

Drawing Status
S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:500 - Detail maps 1:1,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
As document

APPENDIX C - FIGURE 16



Key

Water depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.5
- 5.5 - 6
- 6 - 6.5
- 6.5 - 7

% Change in depth

- -100 - -30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100
- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Background mapping:

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

Contractor: COSTAIN

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Client: highways england

Project
REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

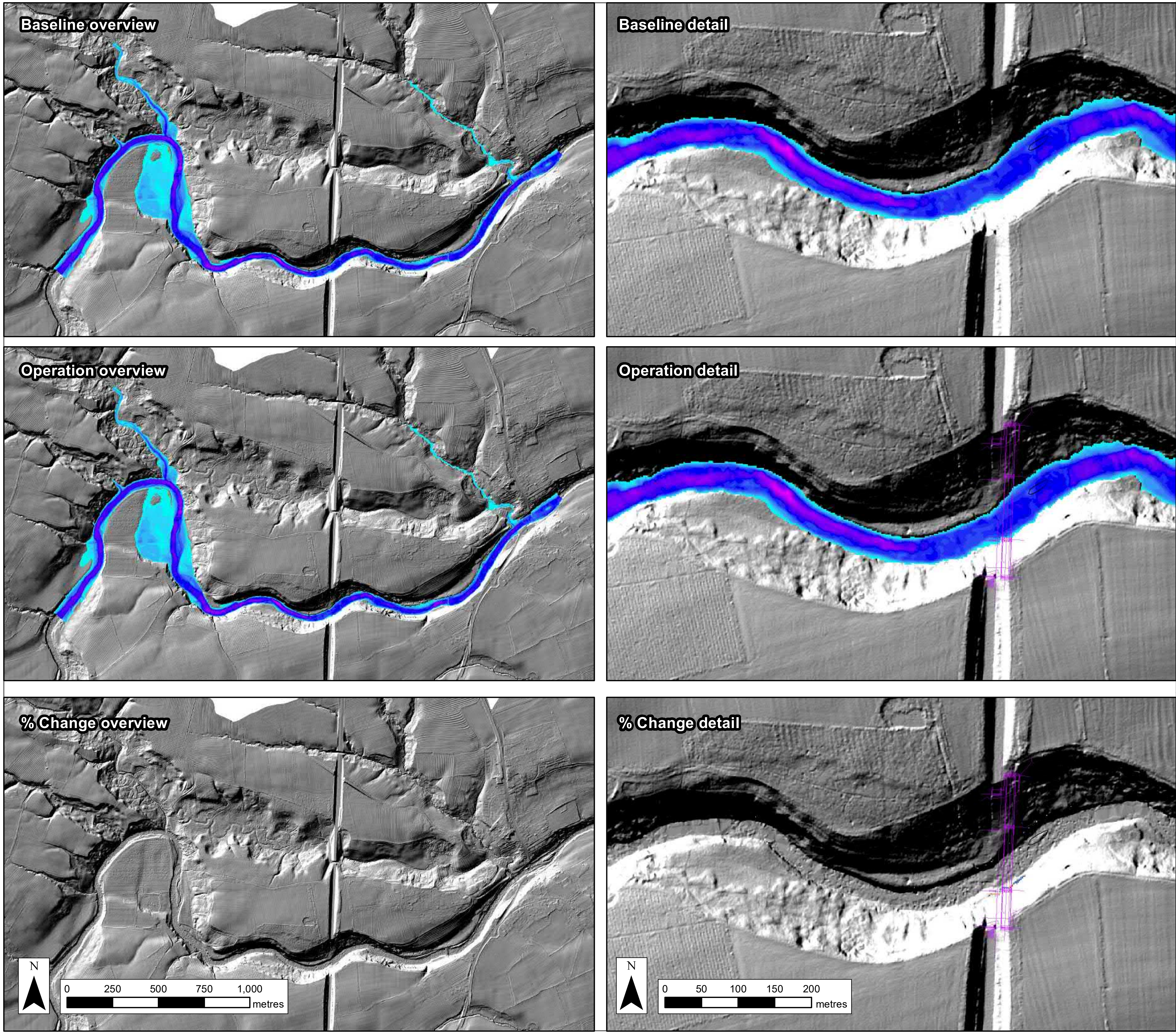
Drawing Title
CHANGE IN MAXIMUM DEPTH -
BASELINE VS OPERATION
50% AEP EVENT

Drawing Status
S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
As document

APPENDIX C - FIGURE 17



Key

Water depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 -2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.5
- 5.5 - 6
- 6 - 6.5
- 6.5 - 7
- 7 - 7.5
- 7.5 - 8
- 8 - 8.5

% Change in depth

- -100 - -30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100
- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

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Client: highways england

Project
REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

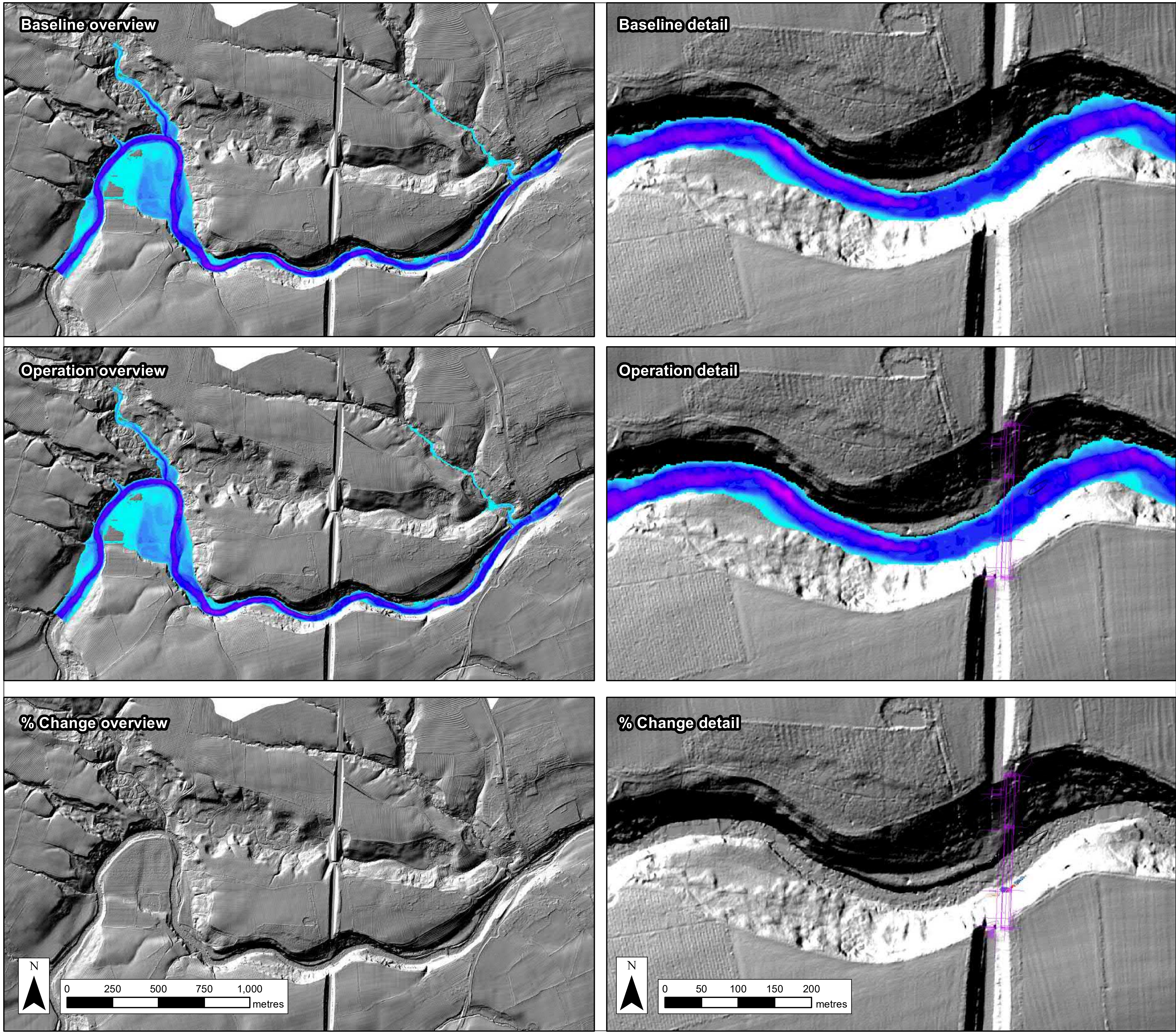
Drawing Title
CHANGE IN MAXIMUM DEPTH -
BASELINE VS OPERATION
2% AEP EVENT

Drawing Status
S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
As document

APPENDIX C - FIGURE 18



Key

Water depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 -4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.5
- 5.5 - 6
- 6 - 6.5
- 6.5 - 7
- 7 - 7.5
- 7.5 - 8
- 8 - 8.5
- 8.5 - 9
- 9 - 9.5

% Change in depth

- -100 - -30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100

- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Background mapping:

P01	29/04/2021	Initial Issue	AB	SP	IG	XX
Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd

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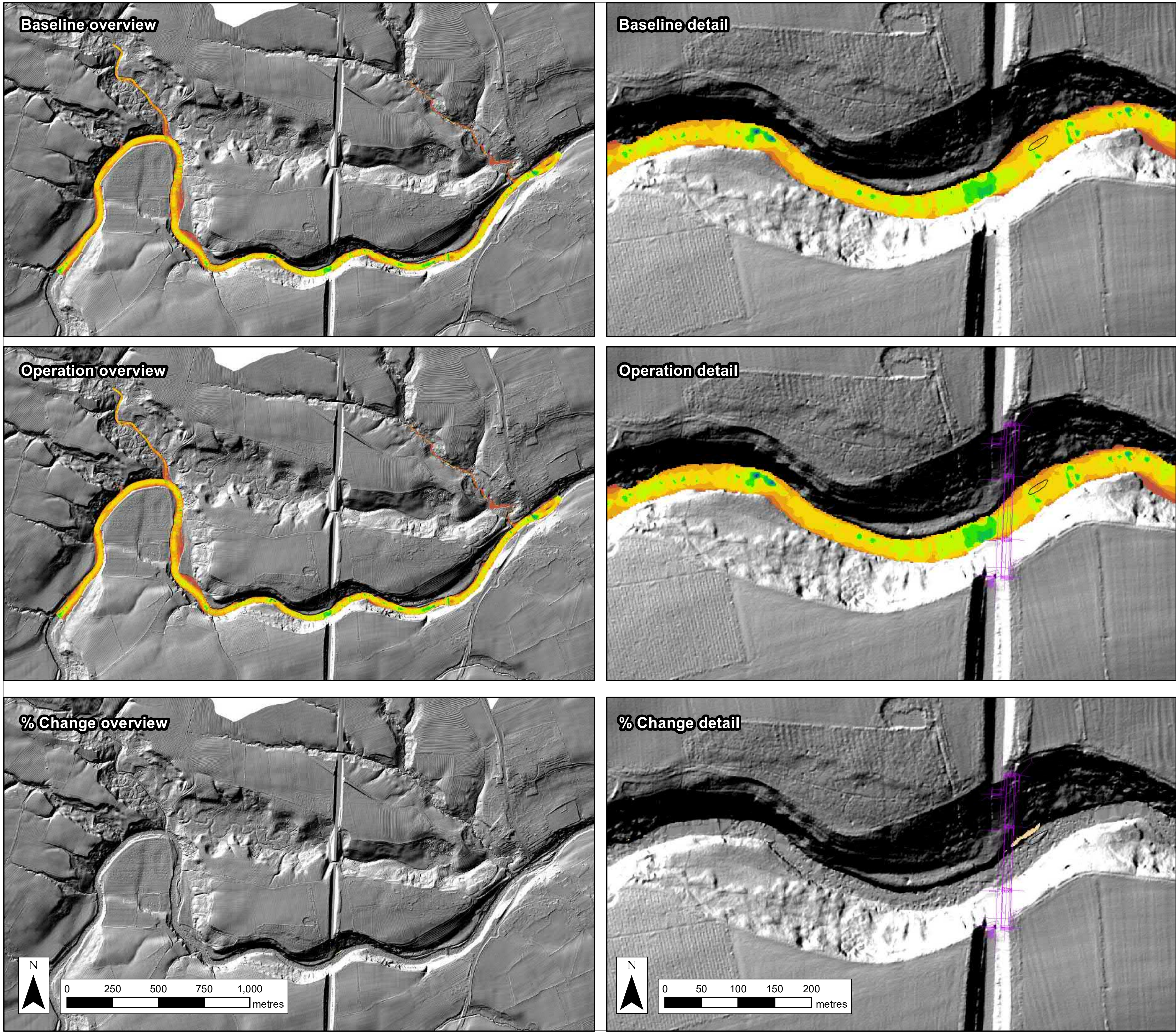
Project
REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

Drawing Title
CHANGE IN MAXIMUM DEPTH -
BASELINE VS OPERATION
0.5% AEP EVENT

Drawing Status
S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
As document



APPENDIX C - FIGURE 19

Key

Velocity (m/s)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5

% Change in velocity

- -100 - -30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100

- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

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Client: highways england

Project
REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

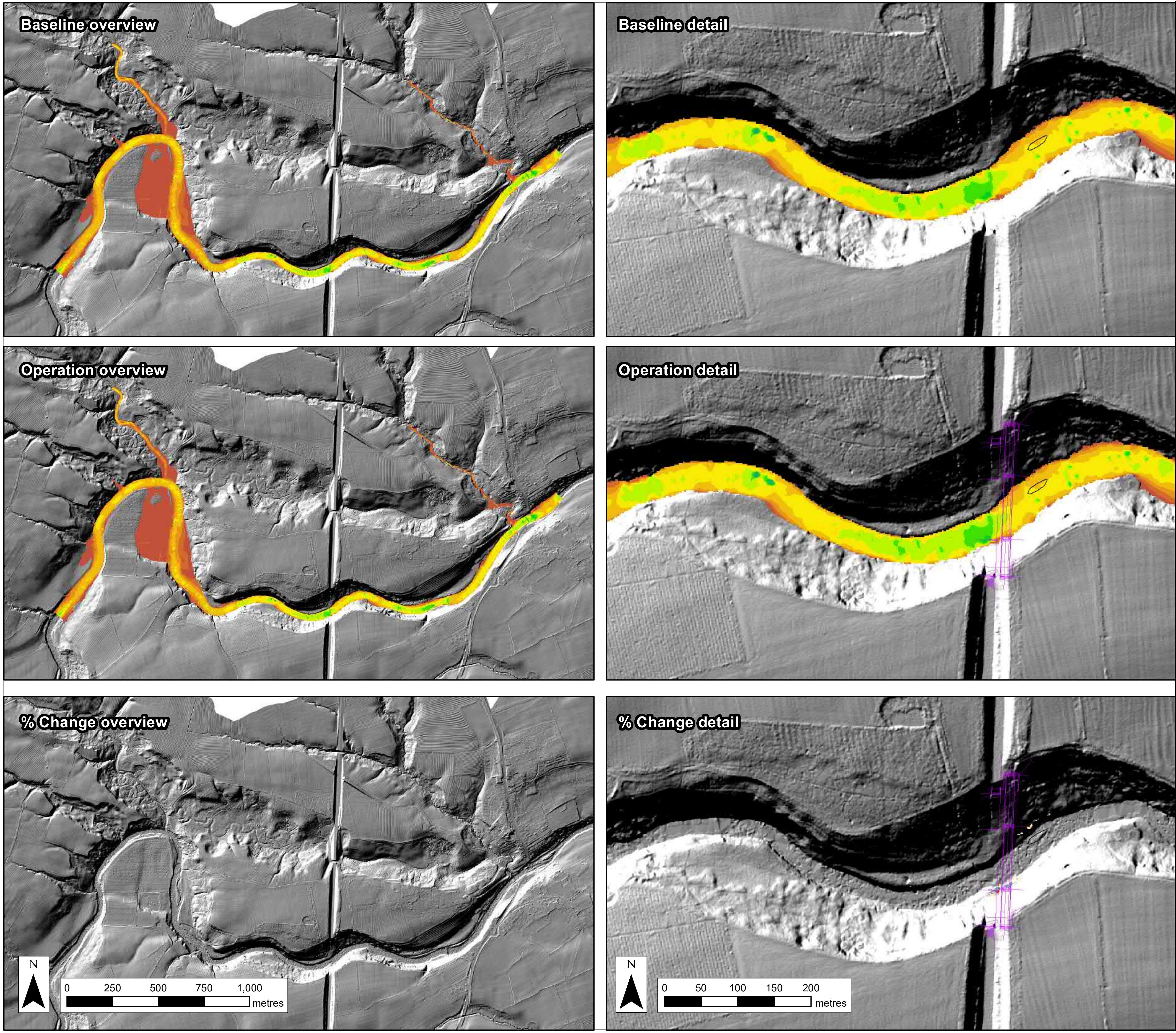
Drawing Title
CHANGE IN MAXIMUM VELOCITY -
BASELINE VS OPERATION
50% AEP EVENT

Drawing Status
S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
As document

APPENDIX C - FIGURE 20



Key

Velocity (m/s)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.5
- 5.5 - 6

% Change in velocity

- -100 - -30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100

- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

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Client: highways england

Project: REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

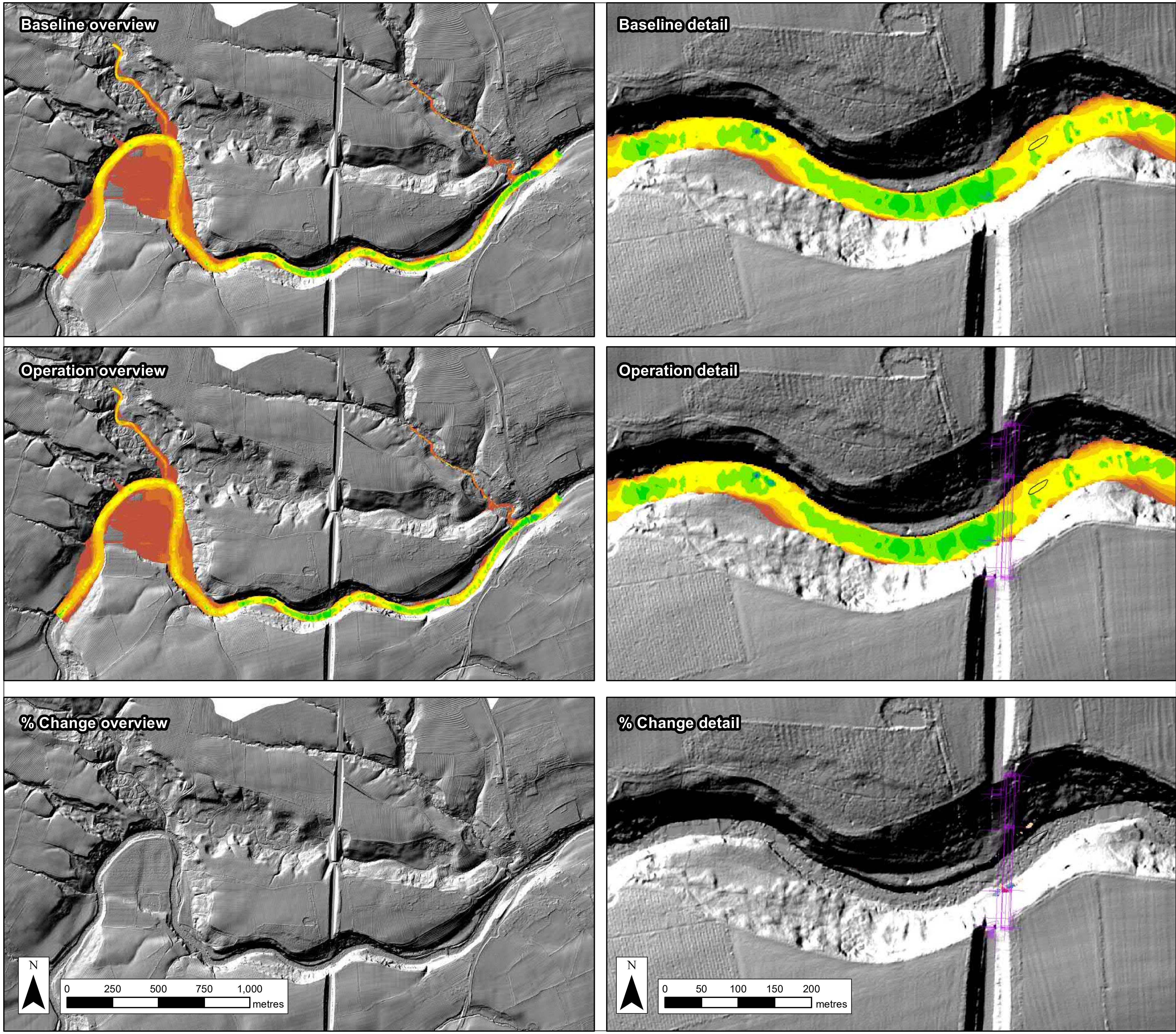
Drawing Title: CHANGE IN MAXIMUM VELOCITY - BASELINE VS OPERATION 2% AEP EVENT

Drawing Status: S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number: As document

APPENDIX C - FIGURE 21



Key

Velocity (m/s)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.5

% Change in velocity

- -100 - -30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100

Proposed bridge location (indicative)

Gravel-cobble-boulder bar

P01	29/04/2021	Initial Issue	AB	SP	IG	XX
Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd

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Client: highways england

Project
REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

Drawing Title
CHANGE IN MAXIMUM VELOCITY -
BASELINE VS OPERATION
0.5% AEP EVENT

Drawing Status
S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
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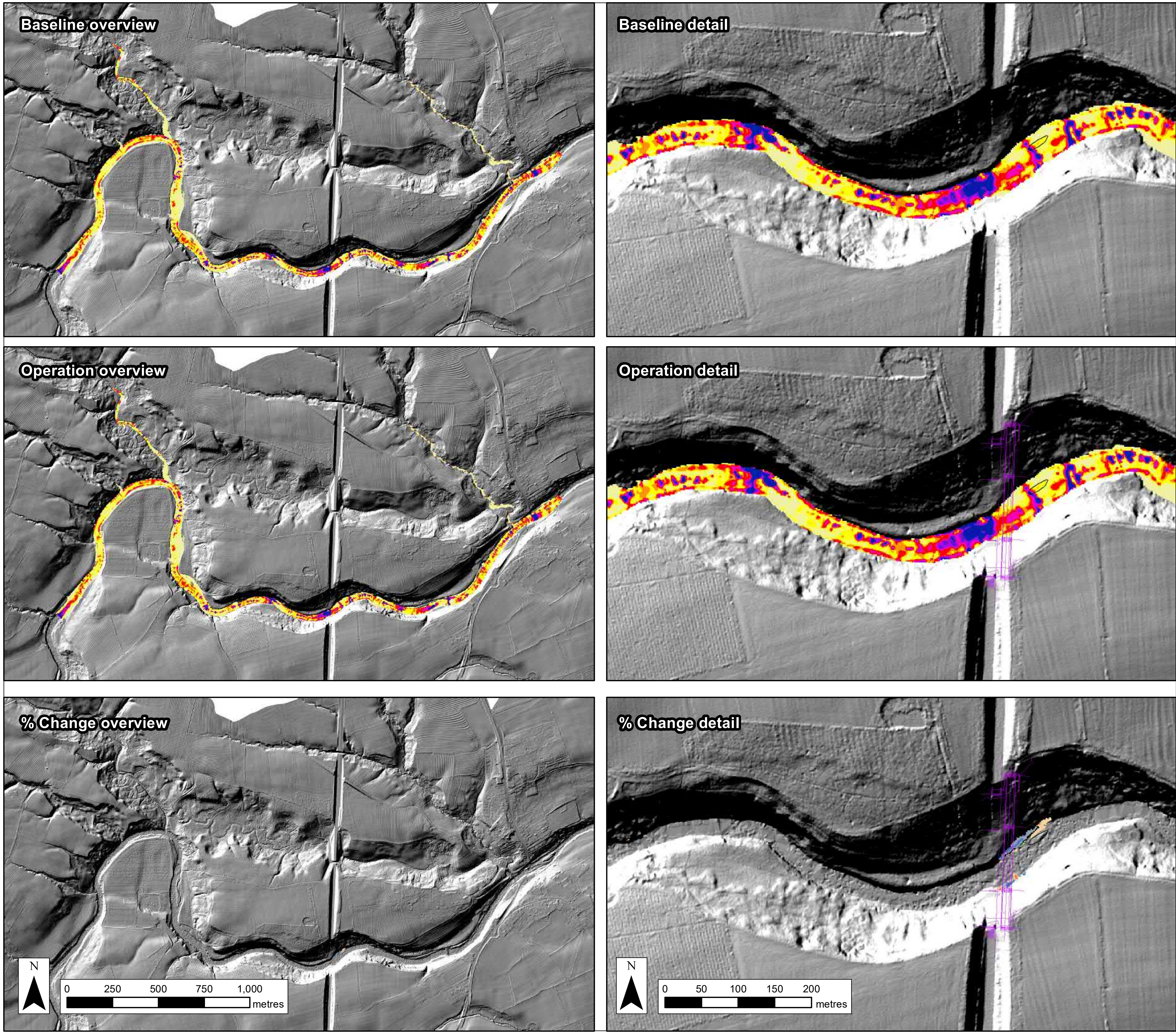
APPENDIX C - FIGURE 22



Key

Stream power (W/m^2)

- 0 - 35
- 35- 50
- 50 - 75
- 75 - 100
- 100 - 150
- 150 - 200
- 200 - 250
- 250 - 300
- >300

%Change in stream power

- -100 - -30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100

- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

Contractor: COSTAIN

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Client: highways england

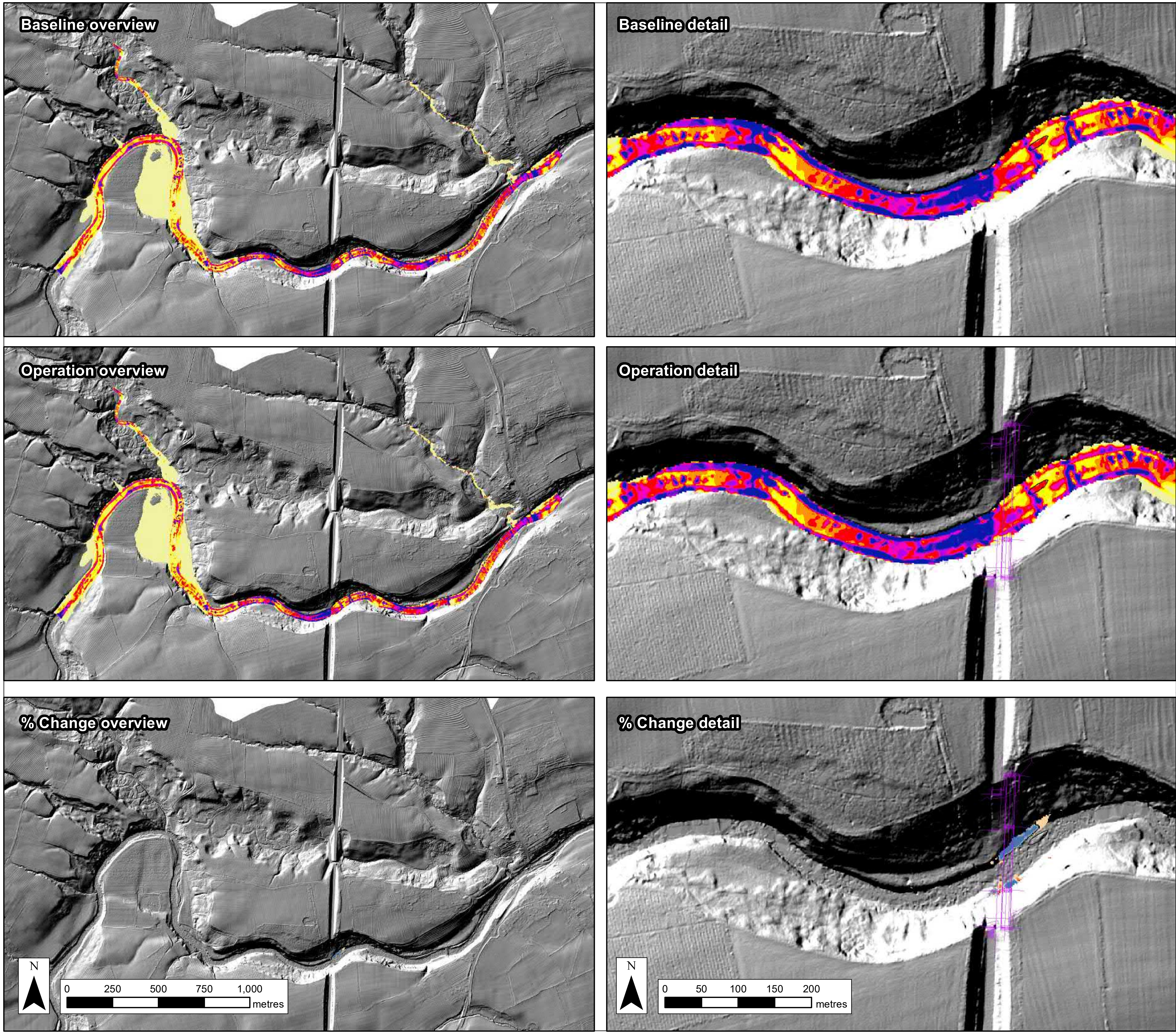
Project: REGIONAL DEVELOPMENT PROGRAMME A1 IN NORTHUMBERLAND

Drawing Title: CHANGE IN MAXIMUM STREAM POWER - BASELINE VS OPERATION 50% AEP EVENT

Drawing Status: S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number: As document



APPENDIX C - FIGURE 23

Key

Stream power (W/m^2)

- 0 - 35
- 35 - 50
- 50 - 75
- 75 - 100
- 100 - 150
- 150 - 200
- 200 - 250
- 250 - 300
- >300

% Change in stream power

- -100 - -30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100
- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

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Project
REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

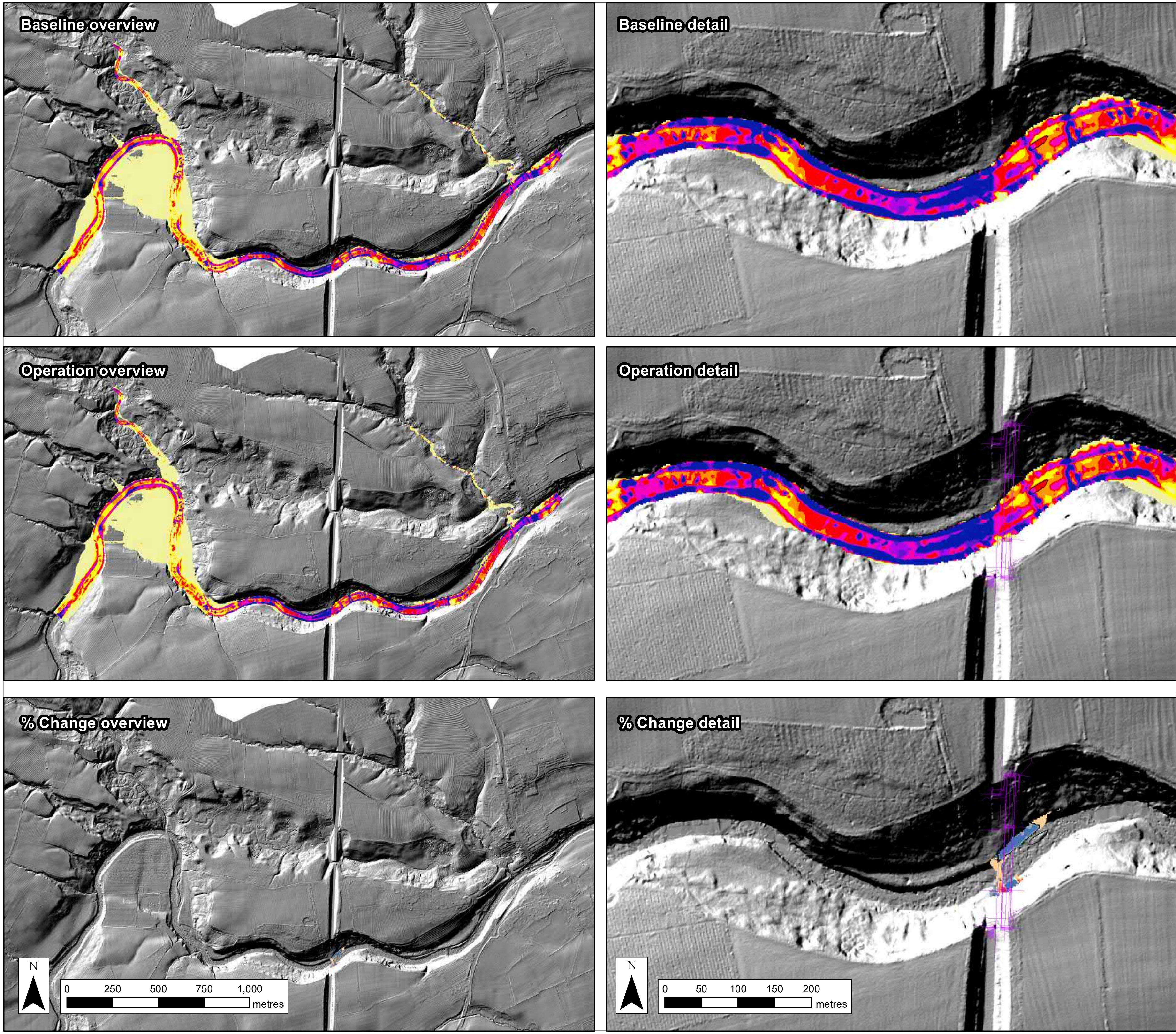
Drawing Title
CHANGE IN MAXIMUM STREAM POWER -
BASELINE VS OPERATION
2% AEP EVENT

Drawing Status: S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
As document

APPENDIX C - FIGURE 24



Key

Stream power (W/m^2)

- 0 - 35
- 35 - 50
- 50 - 75
- 75 - 100
- 100 - 150
- 150 - 200
- 200 - 250
- 250 - 300
- >300

% Change in stream power

- -100 - -30
- -30 - -10
- -10 - 10
- 10 - 30
- 30 - 100
- >100

- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

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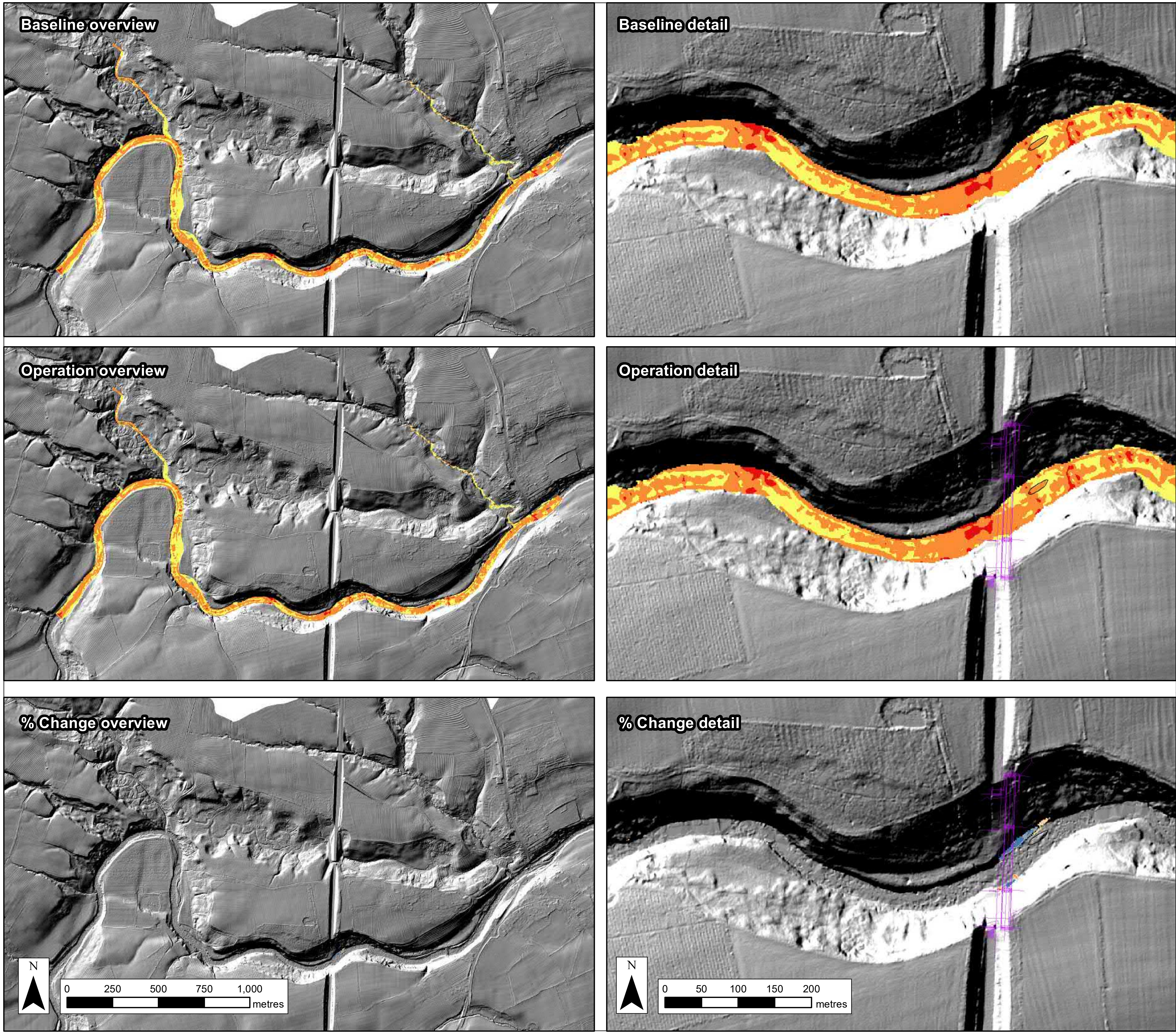
Project
REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

Drawing Title
CHANGE IN MAXIMUM STREAM POWER -
BASELINE VS OPERATION
0.5% AEP EVENT

Drawing Status
S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number
As document



APPENDIX C - FIGURE 25

Key

Entrained sediment size (mm)

- <0.0625 (silt and clay)
- 0.0625 - 2 (sand)
- 2 - 64 (gravel)
- 64 - 256 (cobble)
- >256 (boulder)

% Change in sediment size entrained

- -71% - -30%
- -30% - -10%
- -10% - 10%
- 10% - 30%
- 30% - 100%
- 100% - 357%
- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

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REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

Drawing Title

ENTRAINED SEDIMENT SIZE -
BASELINE VS OPERATION
50% AEP EVENT

Drawing Status

S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:20,000 - Detail maps 1:5,000	DO NOT SCALE
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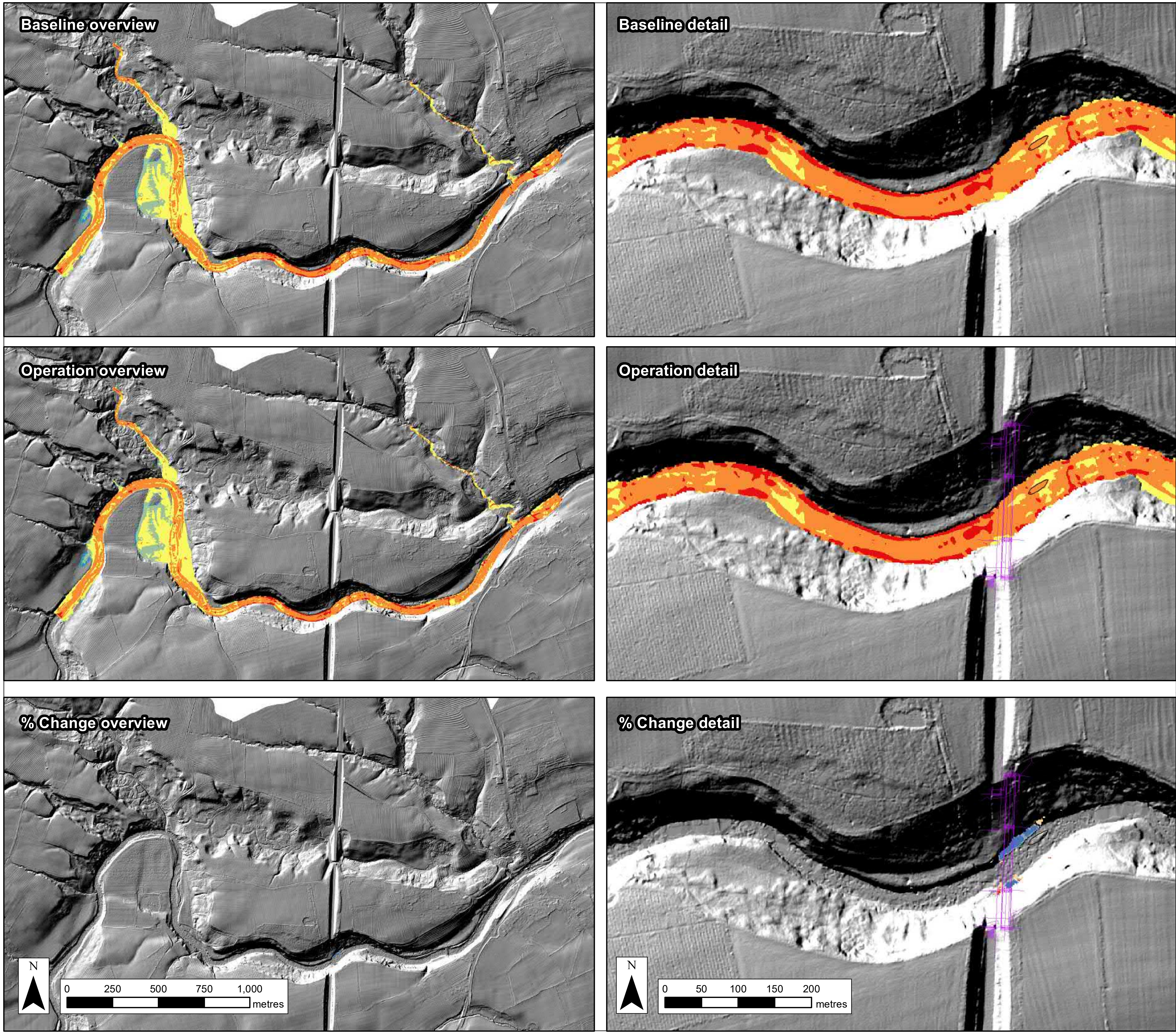

APPENDIX C - FIGURE 26

Key

Entrained sediment size (mm)

- <0.0625 (silt and clay)
- 0.0625 - 2 (sand)
- 2 -64 (gravel)
- 64 - 256 (cobble)
- >256 (boulder)

% Change in sediment size entrained

- -90% - -30%
- -30% - -10%
- -10% - 10%
- 10% - 30%
- 30% - 100%
- 100% - 249%
- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

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Client: highways england

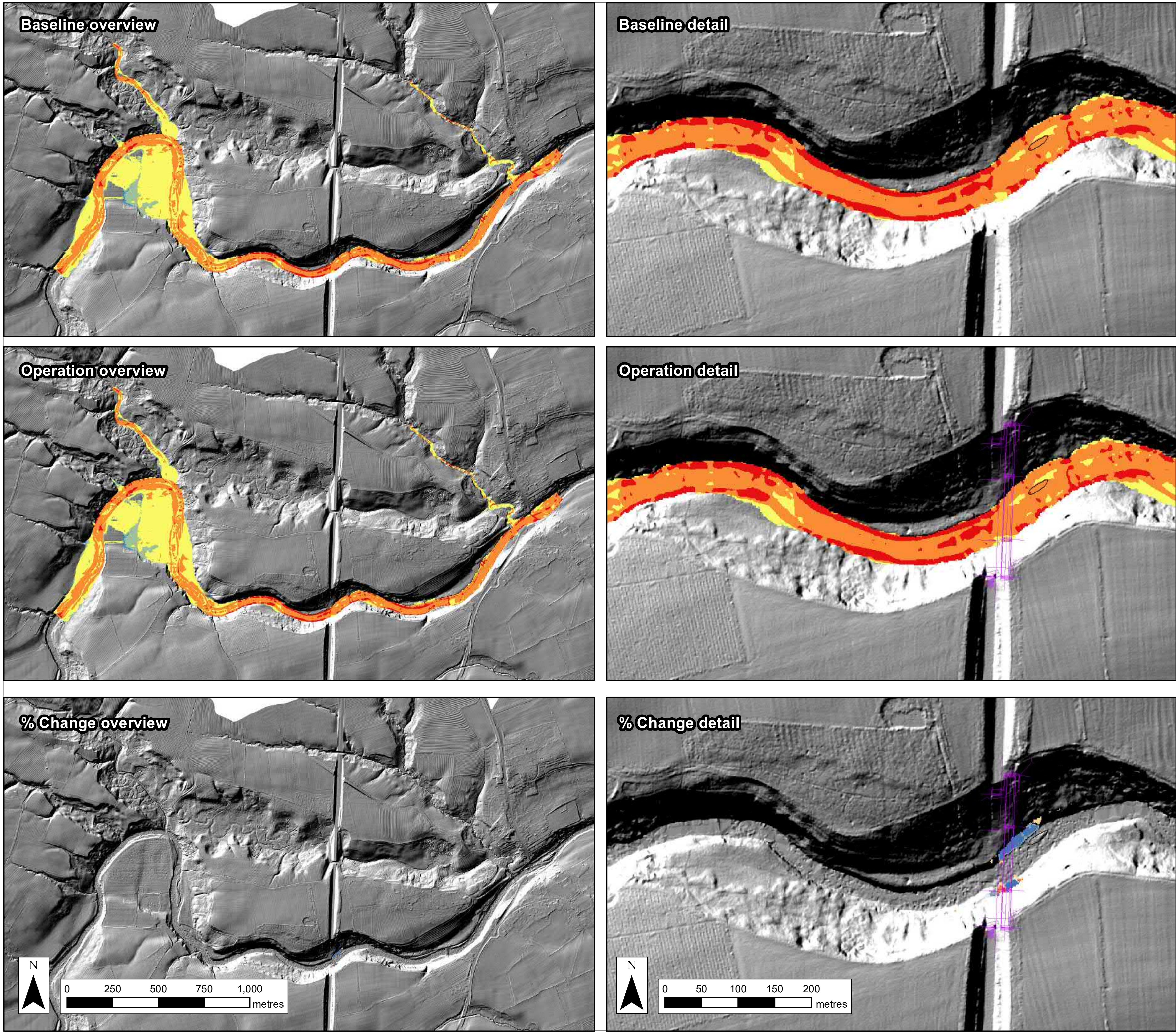
Project: REGIONAL DEVELOPMENT PROGRAMME A1 IN NORTHUMBERLAND

Drawing Title: ENTRAINED SEDIMENT SIZE - BASELINE VS OPERATION 2% AEP EVENT

Drawing Status: S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25=0,000 - Detail maps 1:5,000	DO NOT SCALE
Jacobs No.	As Document	
Client No.	As document	Rev P01

Drawing Number: As document



APPENDIX C - FIGURE 27

Key

Entrained sediment size (mm)

- <0.0625mm (silt and clay)
- 0.0625mm - 2 mm (sand)
- 2mm - 64mm (gravel)
- 64mm - 256mm (cobble)
- >256mm (boulder)

% Change in sediment size

- -95% - -30%
- -30% - -10%
- -10% - 10%
- 10% - 30%
- 30% - 100%
- 100% - 260%
- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P01	29/04/2021	Initial Issue	AB	SP	IG	XX

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Project

REGIONAL DEVELOPMENT PROGRAMME
A1 IN NORTHUMBERLAND

Drawing Title

ENTRAINED SEDIMENT SIZE - BASELINE VS OPERATION 0.5% AEP EVENT

Drawing Status

S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:20,000 - Detail maps 1:5,000	DO NOT SCALE
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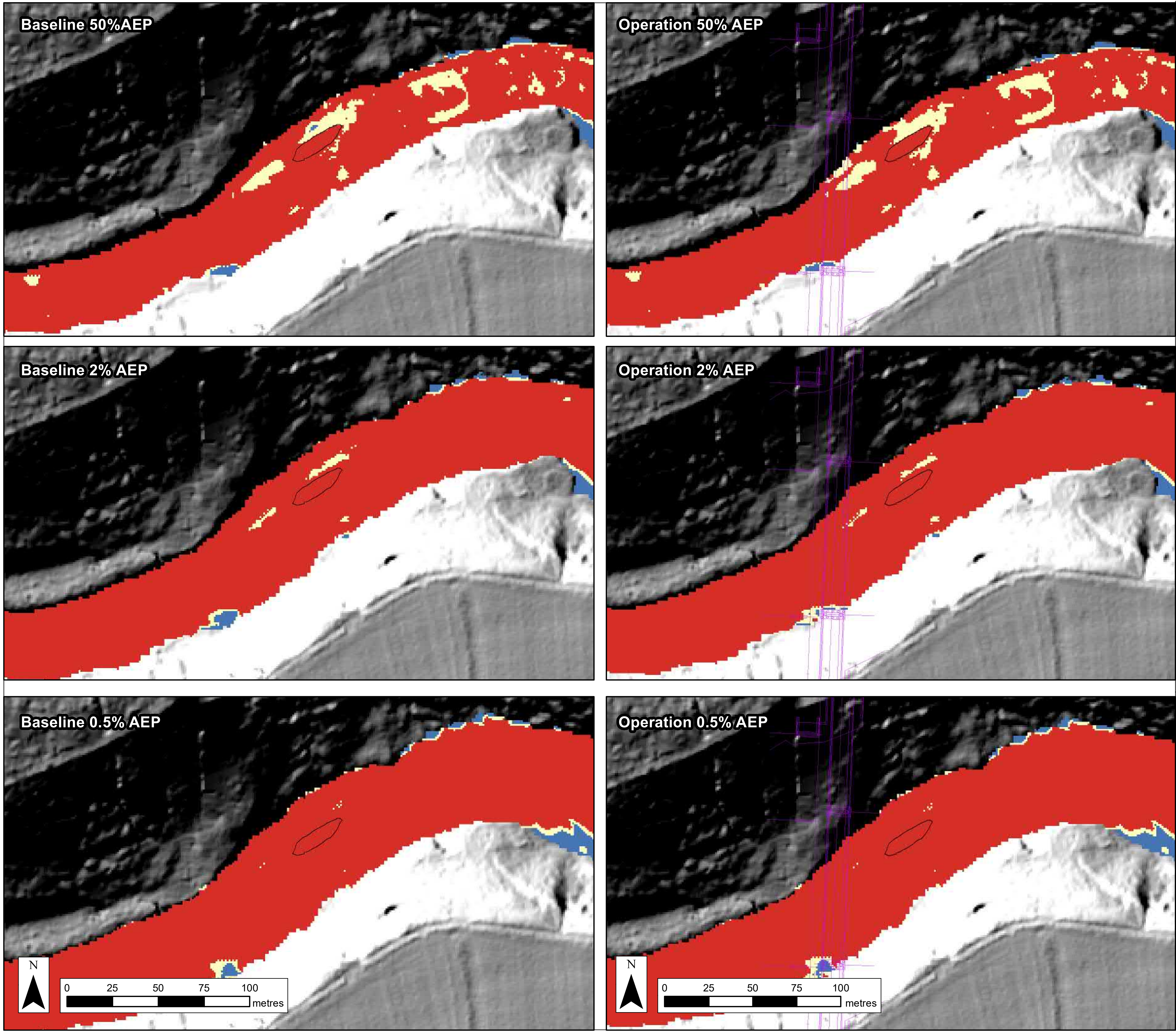
Client No.	As document	Rev P01

Drawing Number

As document

APPENDIX C - FIGURE 28



Key

Shields Parameter for D50 @ 45mm

- < 0.03
- 0.03 - 0.06
- > 0.06
- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

Rev.	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
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Drawing Title

SHIELDS PARAMETER D_{50} (45MM) -
BASELINE VS OPERATION

Drawing Status

S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
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Drawing Number

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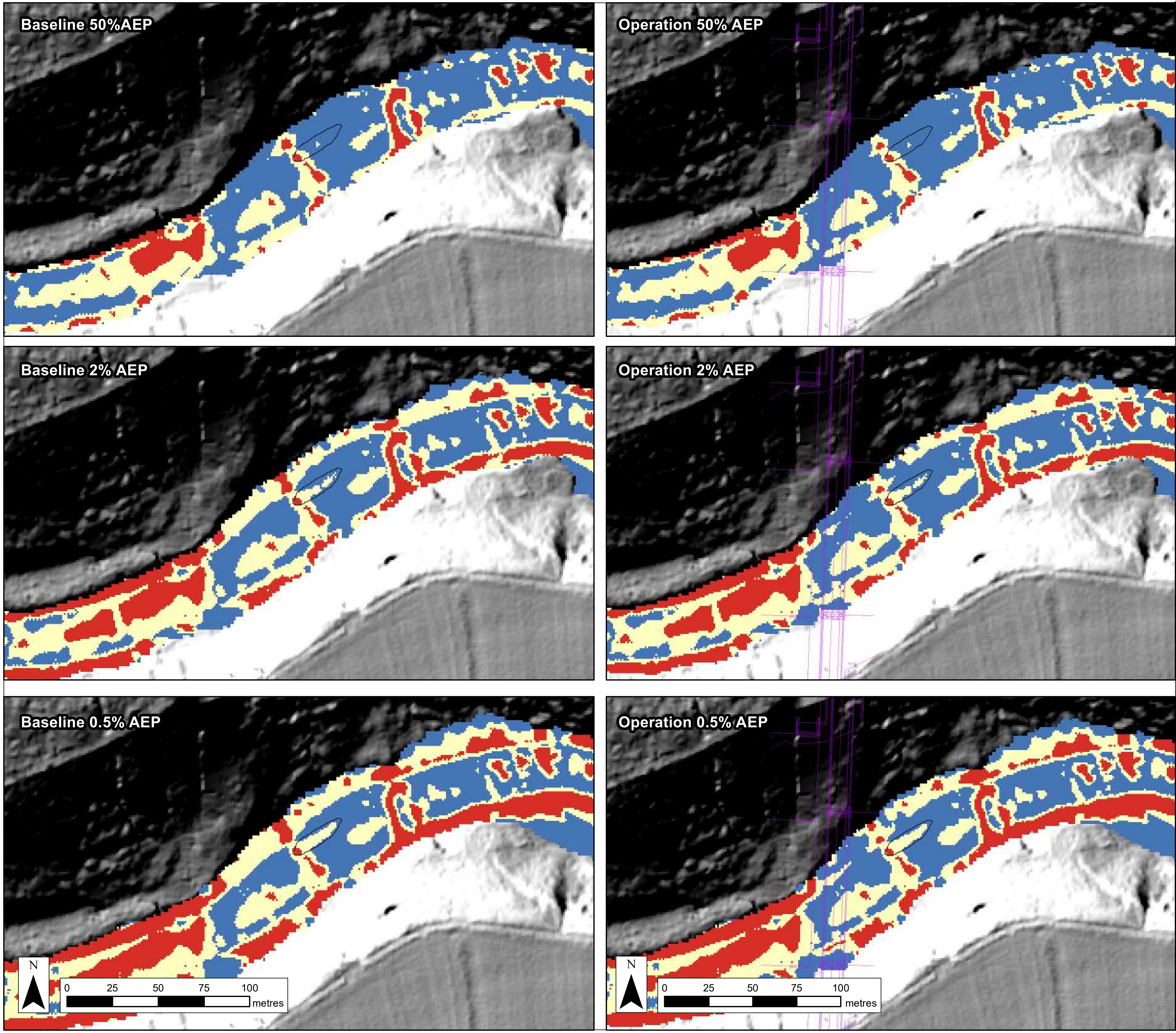
APPENDIX C - FIGURE 29



Key

Shields Parameter for D84 @ 205mm

- < 0.03
- 0.03 - 0.06
- > 0.06
- Proposed bridge location (indicative)
- Gravel-cobble-boulder bar

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Project
REGIONAL DEVELOPMENT PROGRAMME
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Drawing Title
SHIELDS PARAMETER D_{84} (205MM) -
BASELINE VS OPERATION

Drawing Status
S0 - INITIAL ISSUE

Scale @ A3	Overview Maps 1:25,000 - Detail maps 1:5,000	DO NOT SCALE
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