A1 in Northumberland: Morpeth to Ellingham

Scheme Number: TR010059

River Coquet Geomorphology Modelling Assessment

Rule 8(1)(c)

Planning Act 2008

Infrastructure Planning (Examination Procedure) Rules 2010

February 2021

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The Infrastructure Planning (Examination Procedure) Rules 2010

The A1 in Northumberland: Morpeth to Ellingham

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1 INTRODUCTION

1.1 BACKGROUND

1.1.1. The purpose of this report is to provide robust evidence to address the queries raised in the Relevant Representations from the Environment Agency [RR-004] as detailed in in paragraphs A56, A57, A59, A60, A62, A63, A64, A65, A66, A67, A68, A69, A70, A71 and A72 of **7.9.1 Appendix A Response to RR-04 Environment Agency** [**REP1-065**]. To achieve this purpose, quantitative analysis has been undertaken using 2D hydraulic modelling to analyse the potential impacts of the Scheme upon the fluvial geomorphological processes operating within the River Coquet study area (including Parameter 10 detailed in **Chapter 2: The Scheme** of the Environmental Statement [**APP-037**]).

1.1.2. This report is supplementary to two fluvial geomorphological assessments previously undertaken in support of the Environmental Statement prepared for the A1 in Northumberland: Morpeth to Ellingham road scheme[1]. This report draws upon the baseline data presented within those two geomorphological assessments. This data are not presented within this report to avoid repetition of previous assessments.

1.2 AIMS AND OBJECTIVES

1.2.1. The primary aim of this report is to test the hypothesis that there is no notable change in the fluvial geomorphological processes operating within the study area as a result of the Scheme. To that, the following key objectives are set:

a. To quantify potential impacts upon the geomorphological processes of erosion, deposition and sediment transport between baseline, construction and operation[2] of the Scheme for a range of flood return periods;
b. To quantify changes in velocity, stream power and shear stress between baseline, construction and operation of the Scheme for a range of flood return periods;
c. To quantify changes to in-channel habitat features between baseline, construction and operation of the Scheme for a range of flood return periods; and
d. To determine whether the potential impacts of the Scheme would disturb the dynamic equilibrium that maintains the current depositional feature in the vicinity of the existing

[1] A1 in Northumberland: Morpeth to Ellingham – **Appendix 10.4 Geomorphological Assessment – River Coquet** [**APP-257**] (this assesses the Scheme with the proposed piers in alignment; and A1 in Northumberland: Morpeth to Ellingham – **Appendix 10.7 Geomorphological Assessment – River Coquet Parameter 10** [**APP-260**].
[2] The construction arrangements will consist of a sheet-piled coffer dam working area around the footprint of the proposed piers – whether they are in alignment and out of alignment. For the operation phase, the sheet-piled coffer dam would be reduced to the design event level.

and proposed viaduct between baseline, construction and operation for a range of flood return periods.

1.2.2. The outcomes of the aims and objectives provide quantitative evidence which is then used in **Appendix A** to provide answers to the series of questions asked in the Relevant Representations raised by Environment Agency [RR-004] (see **Appendix A**). This report assesses the potential impacts of the following proposed design options for both construction and operation compared to baseline conditions:

a. Baseline conditions;
b. Baseline model with the addition of the proposed viaduct piers in alignment;
c. Baseline model with the addition of the working area for the construction phase for the proposed viaduct piers in alignment;
d. Baseline model with the addition of the proposed viaduct piers out of alignment[3]; and
e. Baseline model with the addition of the working area for the construction phase for the proposed viaduct piers out of alignment.

[3] The options with piers out of alignments represent the Parameter 10 option as reported in **Appendix 10.7 Geomorphological Assessment – River Coquet Parameter 10** [**APP-260**] of the Environmental Statement.

2 LIMITATIONS AND ASSUMPTIONS

2.1.1. The hydraulic models utilised in this assessment have been developed using open-source aerial LiDAR data. No bathymetric or in-channel topographic survey has been incorporated into the models; therefore, channel bed levels are not accurately represented in regions of deeper water, or where over-hanging trees and the existing viaduct structure obscured the LiDAR signal during data acquisition. However, while it is widely accepted that LiDAR is a relatively unreliable method of acquiring submerged topography, particularly in deep water, the purpose of this study is to confirm the relative change to the geomorphic functioning of the reach between baseline, construction and proposed for each modelled variable.

2.1.2. The methodological approach was presented to and agreed upon in consultation with the Environment Agency on 10 December 2020. A copy of the meeting minutes is provided in **Appendix D**. In addition, the Environment Agency determined the flood return periods to be assessed in the analysis and confirmed the Manning's n values to be applied.

3 METHODOLOGY

3.1 INTRODUCTION

3.1.1. This assessment has utilised a fully two-dimensional hydrodynamic model to elucidate geomorphic processes operating within the study reach under a range of flow events. A baseline model has been developed to provide a basis against which results from both construction and operation are compared. The software used for this approach, TUFLOW, is capable of simulating a wide range of variables, many of which are useful for informing fluvial geomorphological process within a modelled reach. For the purposes of this assessment, velocity, stream power and shear stress have been selected for analysis, because these are the fundamental driving forces of geomorphic change, including erosion, deposition, and sediment transport processes. Thus, changes to these variables as a result of activities relating to the Scheme would signify a potential impact, depending on the severity of change and frequency at which it occurs. A detailed description of each of these variables is provided in **Appendix 10.4 Geomorphological Assessment – River Coquet** [**APP-257**] and **Appendix 10.7 Geomorphological Assessment – River Coquet Parameter 10** of the Environmental Statement [**APP-260**]; therefore, only a brief summary of these variables is provided in subsequent sections of this report.

3.1.2. In addition to assessing the forces responsible for driving geomorphic adjustment, this assessment considers the eco-hydraulics of the reach and demonstrates, quantifiably, the variety and variability of flow types (also referred to as 'hydraulic habitat' and 'biotopes') that exist across the flow regime. In order to meet this objective, Froude number (Fr) was selected as an output variable from the hydraulic models and has been employed here as a surrogate for representing flow types.

3.1.3. The rationale for using the Froude number is that, by using modelled data, ambiguity and surveyor bias associated with traditional habitat mapping techniques (e.g. Hendry and Cragg-Hine, 1997) is removed. In addition, hydraulic modelling permits assessment of physical habitat across a broad range of flood return periods (which would normally require multiple site visits); furthermore, potential changes to habitat brought about by the Scheme may be simulated and assessed. More detail on this variable is presented below.

3.2 HYDRAULIC MODELLING AND HYDROLOGY

3.2.1. A fully two-dimensional hydraulic model was built using open source aerial LiDAR data in lieu of bathymetric/topographic data. The model outputs demonstrate relative change in the geomorphic variables assessed for a range of flood return periods. Resulting systematic error from LiDAR data was discussed and accepted during the consultation meeting held with the Environment Agency on 10 December 2020.

3.2.2. Hydrology was developed using a standard methodology, and is based on data retrieved from two gauging stations – 22009 - Coquet at Rothbury and 22001 - Coquet at Morwick – situated upstream and downstream of the viaduct crossing respectively. The modelled flood return periods discussed and agreed at the meeting with the Environment Agency officer on 10 December 2020 are provided in **Table 1**. An overview of the hydraulic modelling and hydrology development methodology is provided in **Appendix B**.

Table 1 - Modelled flood return periods and associated peak flows. Values have been rounded to one decimal place

Return Period (year)	Peak Flow (m^3/s)
2	148.7
10	253.8
50	355.8
100	401.9
100+cc*	602.9
200	462.6

* 50% increase for climate change allowance

3.3 VELOCITY ANALYSIS

3.3.1. An initial sediment transport assessment was undertaken by comparing modelled velocity results with empirical sediment transport data derived from Hjulström (1935), illustrated in **Figure 1**. Using this chart, the likelihood of erosion, sediment transport and deposition within the channel may be implied. Previously, the median (D50) particle size was assessed using this approach; however, in order to provide a more comprehensive understanding of thresholds of entrainment, the lower (D16) size fraction of the sediment sample has been analysed. Modelled velocity results of each design option and flood return period have been sampled along three cross sections in the vicinity of the proposed works and an average has been taken. The average velocity has been compared against the D16, thereby informing, albeit indicatively, the sediment transport capacity of the study reach in the vicinity of the Scheme. Cross section locations are provided in **Figure 2**.

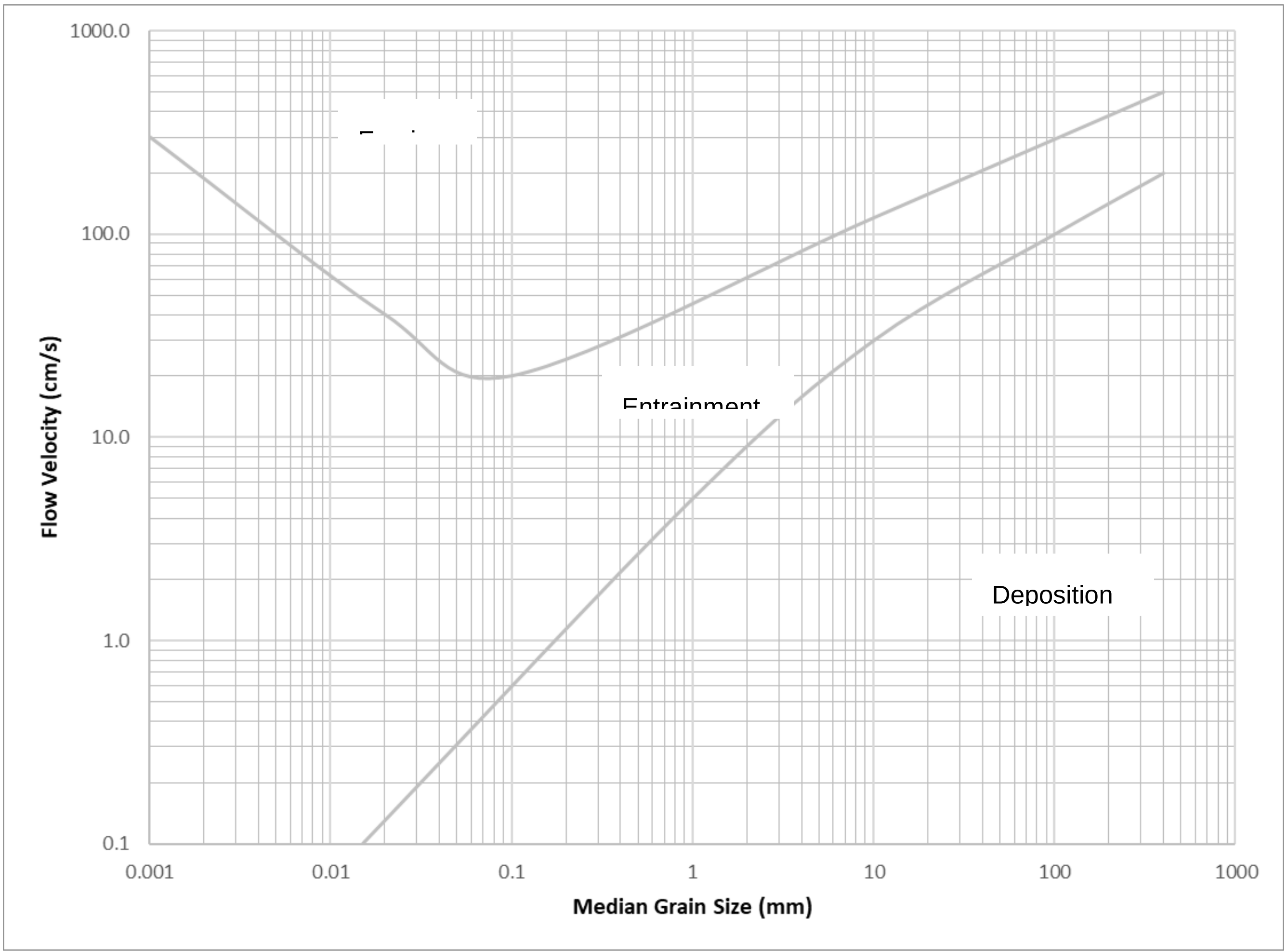

Figure 1 - Plot showing the empirical relationship between flow velocity with erosion, sediment transport and deposition (Hjulström,1935). The two lines delineate zones of deposition, entrainment and erosion

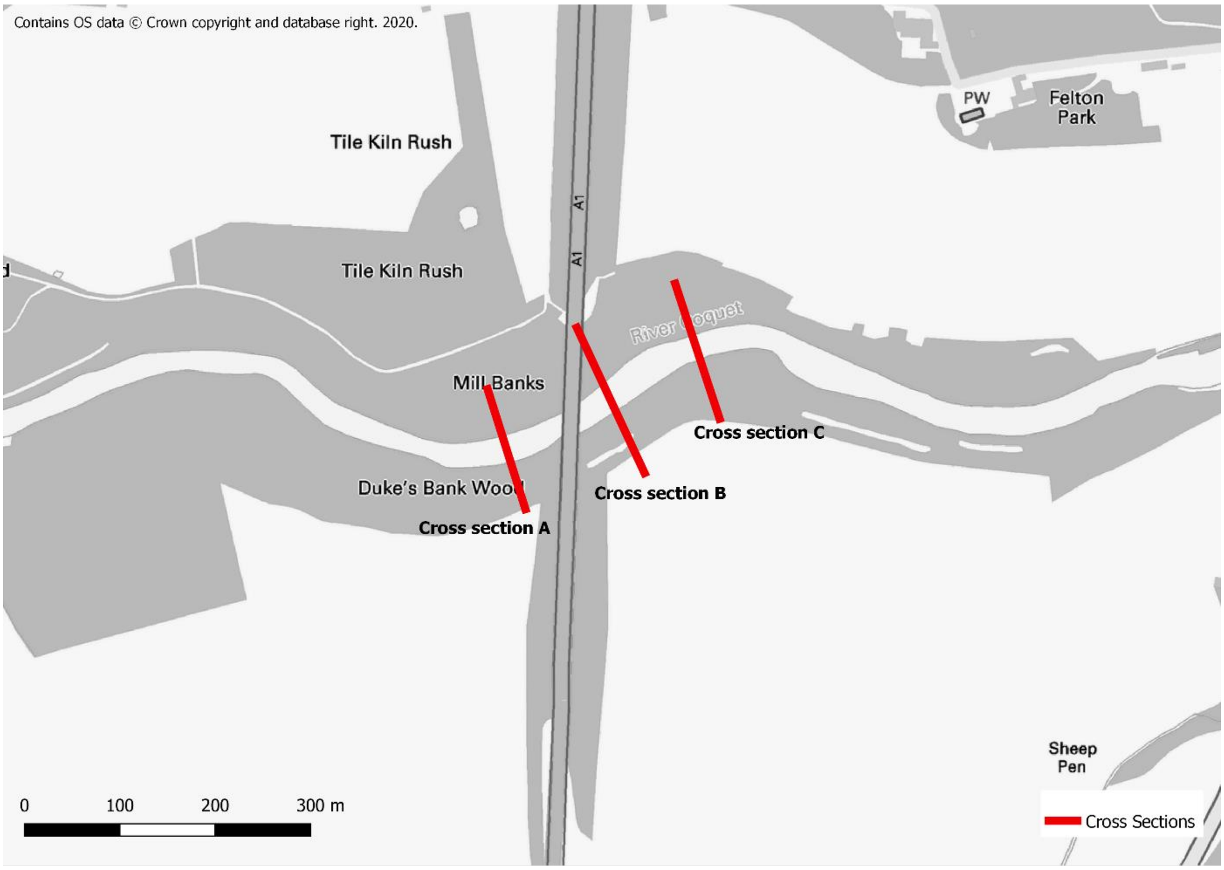

Figure 2 - Cross section locations used in velocity analysis. These were drawn in a GIS to sample underlying modelled raster grids and extract results for each cross section

3.4 STREAM POWER ANALYSIS

3.4.1. Stream power is fundamental concept in fluvial geomorphology. It is a measure of the principle driving forces within river channels and determines their capacity to transport sediment and erode their boundary (bed and banks): it is literally a measure of a river's ability to perform geomorphic work. Stream power is therefore employed in this study to understand any changes in the river's ability to undergo geomorphic adjustment both during and following construction of the Scheme. The stream power threshold for channel instability is reported as being between 30 and 35 W/m (Brookes, 1990); thus, flows that generate stream power above this threshold have the potential to initiate erosion-dominated processes.

3.4.2. Total stream power was selected as an output in the hydraulic model and generated as a raster grid of the entire reach for both baseline and proposed designs assessed. Specific stream power was generated for the entire survey reach using a novel methodology developed for the purposes of this assessment. Vector-based line shapefiles of cross sections, spaced at 10m intervals, were generated automatically in a GIS platform and assigned a unique identifier number for each feature. The cross section lines were clipped to the bank-full flood extent and their length geometry was calculated. The bank-full extent was used as a delineator because specific stream power is measured as a function of bank-full width.

3.4.3. The cross sections were then used to sample the underlying raster grid of total stream power for baseline and proposed (construction and operation) for each flood return period, providing a set of sampled results at 2m increments (concurrent with the model resolution) along the cross section lines. Each set of results was then summed and divided by the corresponding cross section line width to provide specific stream power for baseline and proposed for each flood return period. For visualisation purposes, the sampled cross section line shapefile, which contained within its attributes the specific stream power results for baseline and each design option, was assigned a 5-metre buffer to create channel segments to which the specific stream power attribute was assigned. These were again clipped to the bankfull flood extent and rendered to create a 'heat map' of specific stream power through the study area. Stream power results are summarised in the Results Section for each of the cross section locations shown in **Figure 2**.

3.5 SHEAR STRESS ANALYSIS

3.5.1. Boundary shear stress is a measure of the tractive forces required to move loose gravels relative to the gravitational forces that resist movement. Accordingly, analysis of boundary shear stress in this study is employed as a measure of thresholds of motion. There is an approximately linear relationship between boundary shear stress (Nm2) and the D84 mobility threshold of loose gravels, such that a shear stress of 64mm would suggest particles of 64mm would be mobile. This approximation does not take into account hiding, imbrication, particle shape and cohesion of sediments, nor can the model identify instantaneous spikes of shear stress that occur in nature, which can be responsible for initiating entrainment. However, simulated boundary shear stress, modelled in a 2D domain, provides an indication of the distribution of forces responsible for transporting sediment over an extensive area. Accordingly, these results allow an assessment of impact to be made with a greater degree of confidence than would be provided by cross sectional analysis.

3.5.2. In order to provide context to modelled boundary shear stress results, the output raster grids were rendered with an identifying colour for sediment size fractions taken from the Wentworth (1922) sediment scale. These results may be compared against sediment data gathered on site.

3.6 FROUDE ANALYSIS

3.6.1. Froude number is essentially a dimensionless indicator of flow turbulence and defines the ratio of internal to gravitational forces in flow:

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

Where *Fr* is Froude number, *V* is velocity, *g* is gradational acceleration, and *d* is flow depth.

3.6.2. The interplay of flow depth, velocity and bed roughness is widely reported as being the determinant process of physical habitat; therefore, Froude is the most commonly utilised variable for characterising flow. At Froude values below 1, flow is dominated by gravitational forces and is subcritical; whereas Froude values greater than one flow is dominated by internal forces and is supercritical (Entwistle et al., 2019). In essence, the greater the Fr value, the more turbulent the flow. Froude number may be analysed in greater detail if Fr values between 0 and 1 are divided into sub-units that each represents a characteristic flow type (see Entwistle et al. 2019) and is demonstrated in **Figure 3**.

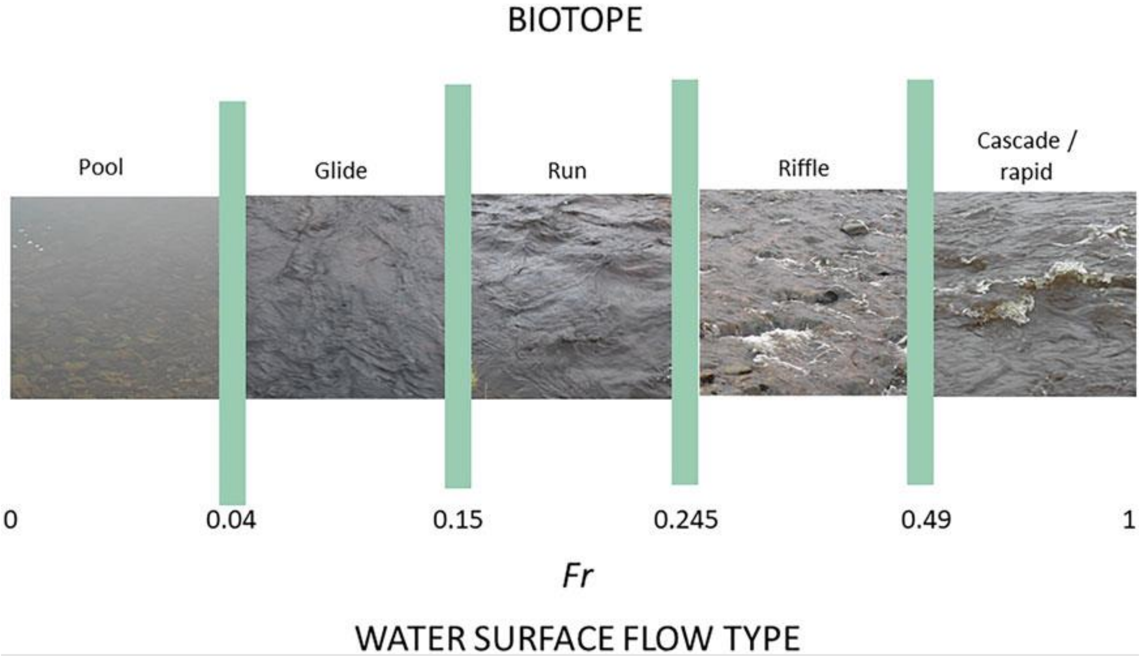

Figure 3 - Biotope characterisation determined by Froude number boundaries (from Entwistle et al., 2019)

3.6.3. Modelled Froude results for each of the return periods presented in **Table 1** were saved as an .asc format raster surface and imported into a GIS (QGIS 3.8). The raster grids were then rendered by the flow type Froude thresholds presented in **Figure 3** and assigned an identifying colour for visual outputs. For numerical analysis, the raster surfaces were classified based on their Froude ranges and a simple analysis of absolute proportions of flow types were extracted for each flood return period for baseline, construction and operation design options. These results were then directly compared to reveal any changes to physical habitat that would occur as a result of the Scheme.

4 RESULTS

4.1.1. For ease of reading, the hydraulic modelling results presented as figures in this section represent a sample of modelled return periods and design options only, unless otherwise stated. For the full suite of results, refer to **Appendix C**. Each figure presented below shows a comparison of the baseline and proposed construction option with piers out of alignment (as per Parameter 10 of the ES) for the 100-year plus climate change flow, because this is considered the most potentially impactful design option. The full suite of results are also presented numerically where practicable.

4.1.2. The full range of results (as presented in **Appendix C**) are considered when addressing the both the hypothesis being tested and the objectives of this report. The variables assessed, velocity, stream power and shear stress, need to be considered in combination to determine whether there would be alteration to the baseline regime for the geomorphological processes of erosion, deposition and sediment transport.

4.2 VELOCITY

4.2.1. A comparison of velocity results for baseline and the proposed piers in alignment option during construction is presented in **Figure 4**. The model results reveal negligible change between baseline and proposed for each simulated return period (see **Appendix C**), with the extreme 100-year plus climate change simulations generating a <3cm/s increase flow velocity between baseline and proposed.

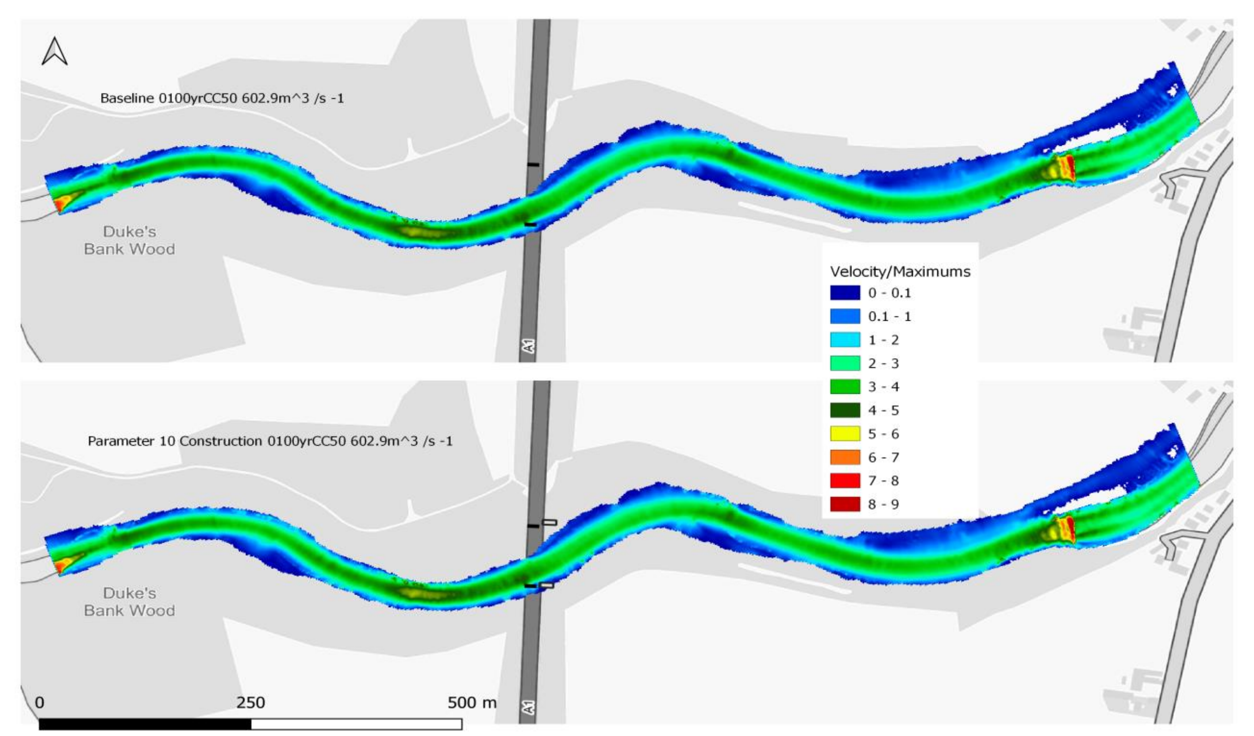

Figure 4 - Modelled 100yr +CC flow velocity for baseline and proposed piers in alignment design option – Construction phase

4.2.2. The entire suite of width-averaged velocity results is summarised below in **Tables 2** to **4** and are presented as Hjulström plots shown in **Figures 5** to **7**.

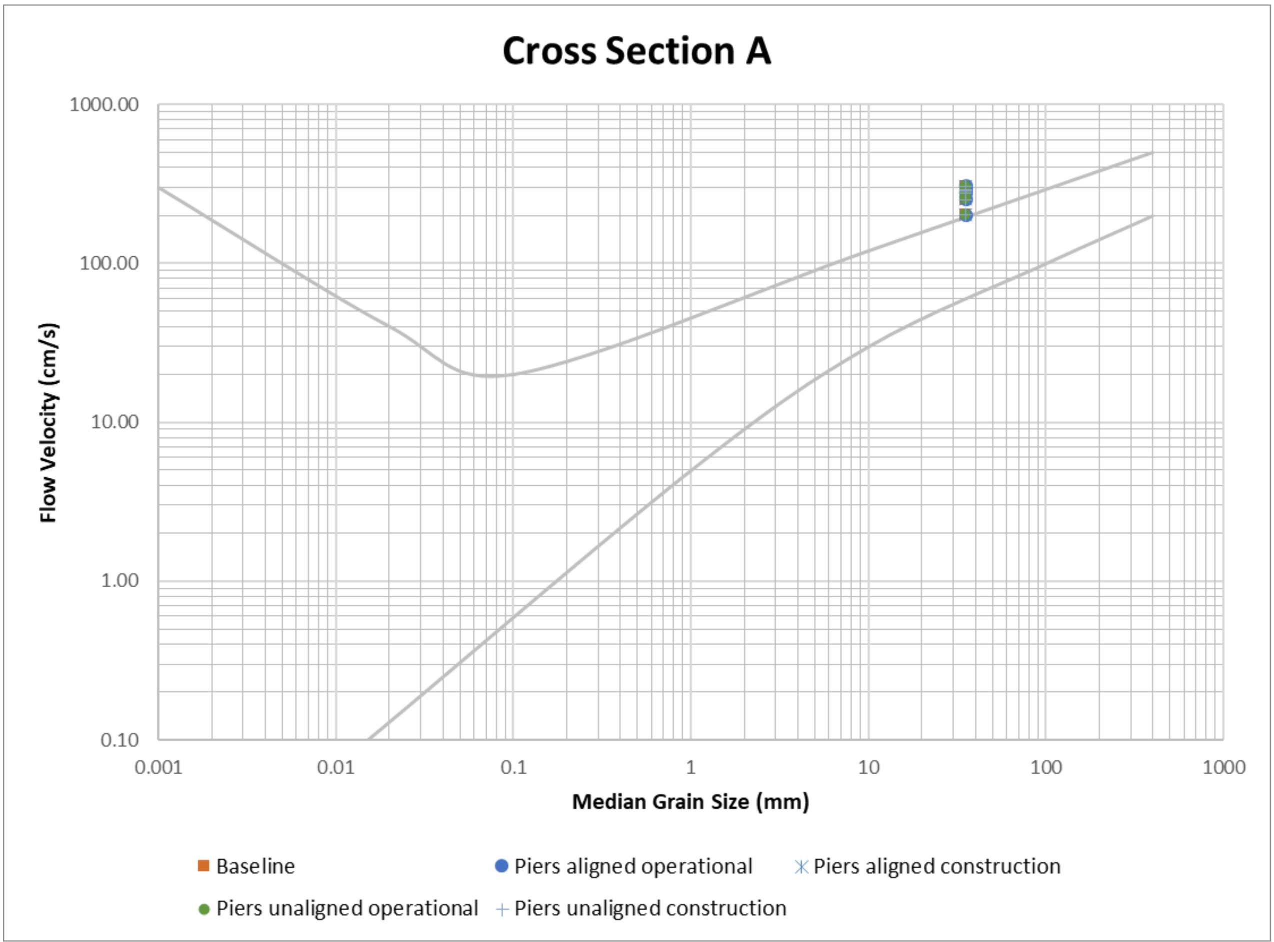

Figure 5 - Velocity results for all design options and all flows plotted against the D_{16} grain size: cross section A. Some points are obscured to negligible changes in velocity

Table 2 - Width-averaged velocity results for cross section A

Return Interval (year)	Grain Size	Baseline Velocity (cm/s)	Piers aligned Operational Velocity (cm/s)	Piers aligned Construction Velocity (m³/s)	Piers unaligned Operational	Piers unaligned Construction
2	35.4	201.27	200.23	200.20	200.23	200.31
10	35.4	251.42	252.82	252.06	252.76	249.11

Return Interval (year)	Grain Size	Baseline Velocity (cm/s)	Piers aligned Operational Velocity (cm/s)	Piers aligned Construction Velocity (m^3/s)	Piers unaligned Operational	Piers unaligned Construction
50	35.4	275.26	277.12	277.26	277.49	277.09
100	35.4	288.47	290.53	290.39	290.10	290.79
100cc	35.4	303.75	306.30	305.76	305.57	305.71
200	35.4	282.28	283.62	283.94	284.12	283.87

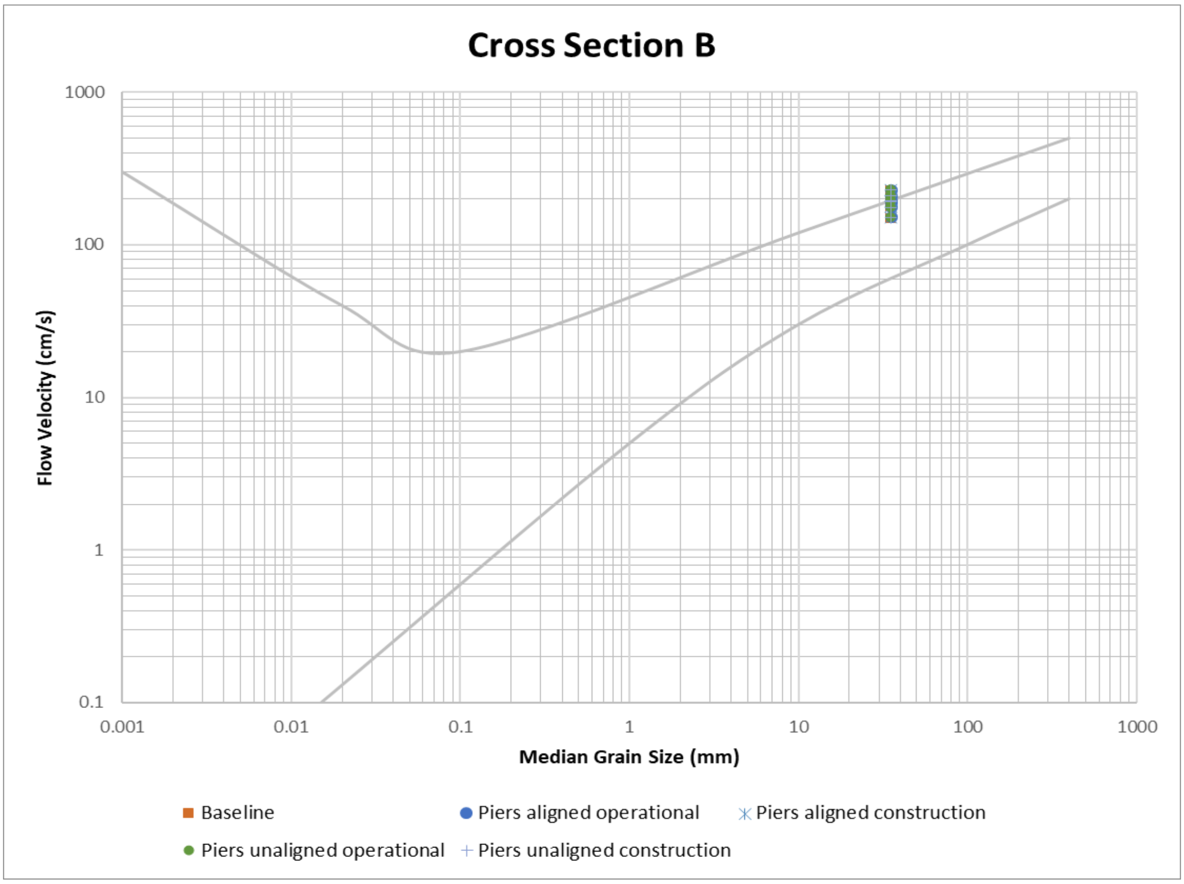

Figure 6 - Velocity results for all design options and all flows plotted against the D[16] grain size: cross section B. Some points are obscured to negligible changes in velocity

Table 3 - Width-averaged velocity results for cross section B

Return Interval (year)	Grain Size	Baseline Velocity (cm/s)	Piers aligned Operational Velocity (cm/s)	Piers aligned Construction Velocity (m^3/s)	Piers unaligned Operational Velocity (cm/s)	Piers unaligned Construction Velocity (cm/s)
2	35.4	148.29	151.68	151.66	151.63	151.13
10	35.4	176.71	176.21	178.41	176.33	175.81
50	35.4	190.06	191.28	191.23	191.43	190.86
100	35.4	192.52	194.58	194.44	194.36	194.64
100cc	35.4	226.83	229.46	229.46	229.55	229.71
200	35.4	205.84	208.55	208.48	208.53	208.97

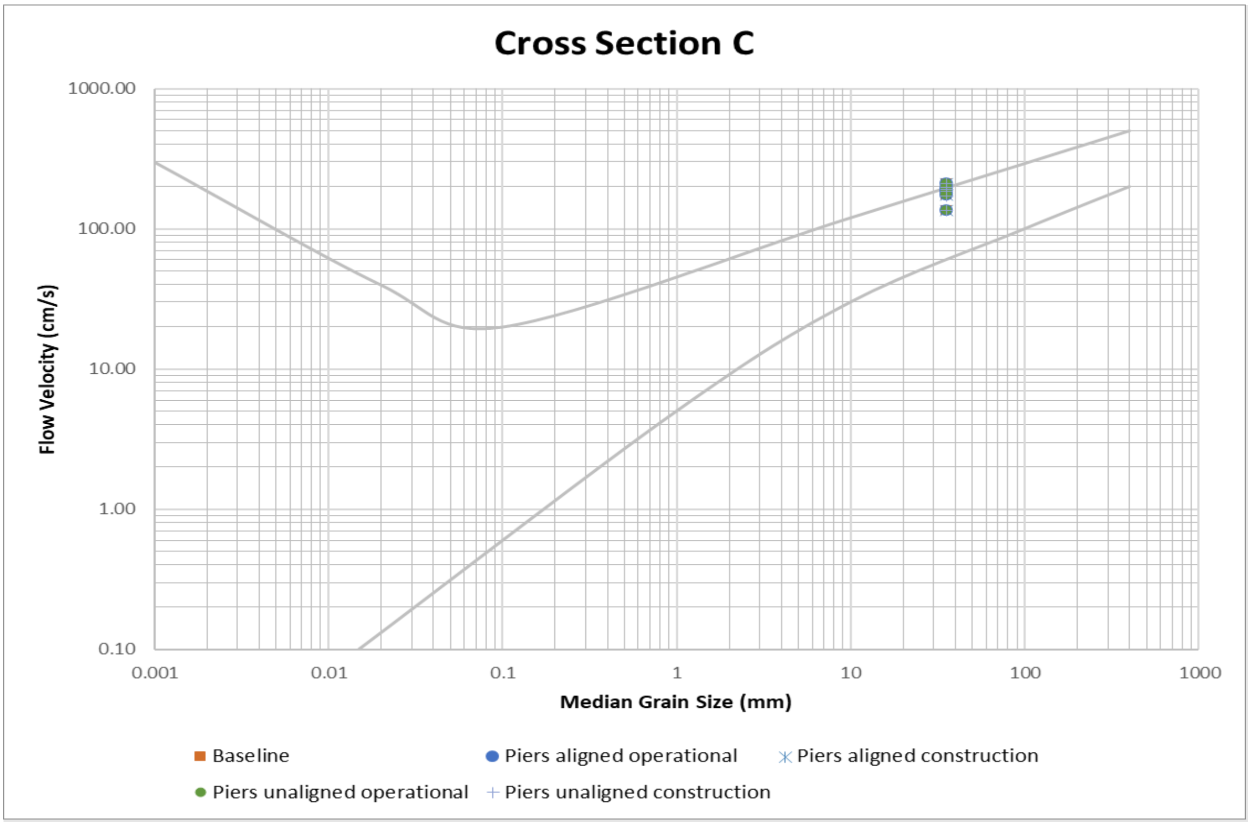

Figure 7 - Velocity results for all design options and all flows plotted against the D_{16} grain size: cross section C

Table 4 - Width-averaged velocity results for cross section C

Return Interval (year)	Grain Size	Baseline Velocity (cm/s)	Piers aligned Operational Velocity (cm/s)	Piers aligned Construction Velocity (m^3/s)	Piers unaligned Operational Velocity (cm/s)	Piers unaligned Construction Velocity (cm/s)
2	35.4	135.31	135.49	135.50	135.51	135.39
10	35.4	173.82	174.81	174.03	175.15	171.33

Return Interval (year)	Grain Size	Baseline Velocity (cm/s)	Piers aligned Operational Velocity (cm/s)	Piers aligned Construction Velocity (m^3/s)	Piers unaligned Operational Velocity (cm/s)	Piers unaligned Construction Velocity (cm/s)
50	35.4	185.95	186.23	186.15	186.15	186.42
100	35.4	190.09	190.22	190.16	190.18	190.14
100cc	35.4	210.23	210.49	210.39	210.42	210.39
200	35.4	195.98	195.91	195.90	195.89	195.88

4.3 STREAM POWER

4.3.1. Hydraulic modelling results reveal negligible change in specific stream power between baseline and proposed for all simulated return periods. There is slight disparity under flows greater than the 100-year flood, with a maximum increase of around 30 watts at the 200-year flood at cross section B (**Figure 8**). However, this increase would not initiate any sudden, potentially destabilising processes over and above baseline conditions because the river is, in places (including at the viaduct crossing location), far in excess of the 35-watt threshold for erosion. Stream power results for the three cross sections presented in **Figure 2** are summarised in **Tables 5** to **7**.

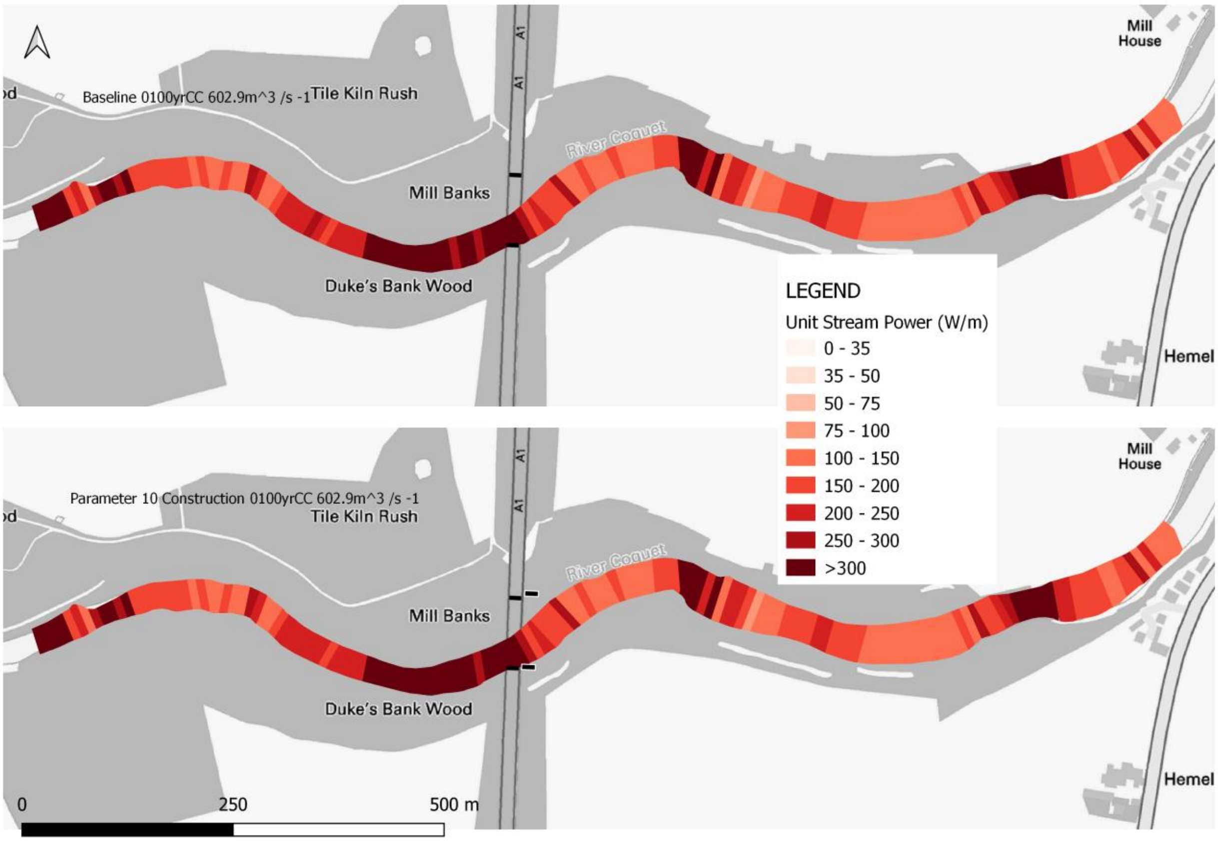

Figure 8 - Modelled 100yr +CC specific stream power for baseline and proposed piers out of alignment design option – construction phase

Table 5 - Specific stream power results for cross section A

Return Interval (year)	Baseline Stream Power (W)	Piers aligned Operational Stream Power (W)	Piers aligned Construction Stream Power (W)	Piers unaligned Operational Stream Power (W)	Piers unaligned Construction Stream Power (W)
2	54.51	52.80	52.77	52.78	52.83
10	119.45	121.17	120.25	121.25	114.57
50	153.54	156.25	156.23	156.27	156.23
100	176.74	179.74	179.87	179.76	179.71

Return Interval (year)	Baseline Stream Power (W)	Piers aligned Operational Stream Power (W)	Piers aligned Construction Stream Power (W)	Piers unaligned Operational Stream Power (W)	Piers unaligned Construction Stream Power (W)
100cc	295.89	301.68	301.53	301.34	300.83
200	214.08	235.71	217.11	216.85	217.08

Table 6 - Specific stream power results for cross section B. Note the reduction in stream power during both construction and operation within this zone of deposition, thus indicating the deposits would not be at risk of being washed out as a result of the scheme

Return Interval (year)	Baseline Stream Power (W)	Piers aligned Operational Stream Power (W)	Piers aligned Construction Stream Power (W)	Piers unaligned Operational Stream Power (W)	Piers unaligned Construction Stream Power (W)
2	41.28	39.38	39.37	39.37	39.25
10	73.59	69.36	68.07	69.19	65.54
50	95.15	87.20	87.00	86.96	86.55
100	107.15	99.62	99.61	99.57	99.06
100cc	174.51	164.68	164.69	165.26	165.58
200	129.58	158.60	121.08	121.21	120.71

Table 7 - Specific stream power results for cross section C

Return Interval (year)	Baseline Stream Power (W)	Piers aligned Operational Stream Power (W)	Piers aligned Construction Stream Power (W)	Piers unaligned Operational Stream Power (W)	Piers unaligned Construction Stream Power (W)
2	22.59	22.65	22.64	22.64	22.61
10	48.86	50.01	49.74	50.49	47.75
50	66.22	66.40	66.41	66.41	66.41
100	76.73	76.60	76.57	76.50	76.64
100cc	130.52	130.72	130.59	130.60	130.57
200	91.27	104.55	91.06	91.04	91.02

4.4 SHEAR STRESS

4.4.1. Boundary shear stress results generated from hydraulic modelling similarly reveal very little change between baseline and proposed for all simulated return periods (see **Appendix C**). There is minor disparity between baseline and proposed at the proposed southern (right bank) pier location; however, this is very localised and confined to a few wetted cells, beyond which the influence of the pier is rapidly diminished. The results for the 100yr +CC flow boundary shear stress for baseline and proposed piers in alignment design option during construction is presented in **Figure 9**.

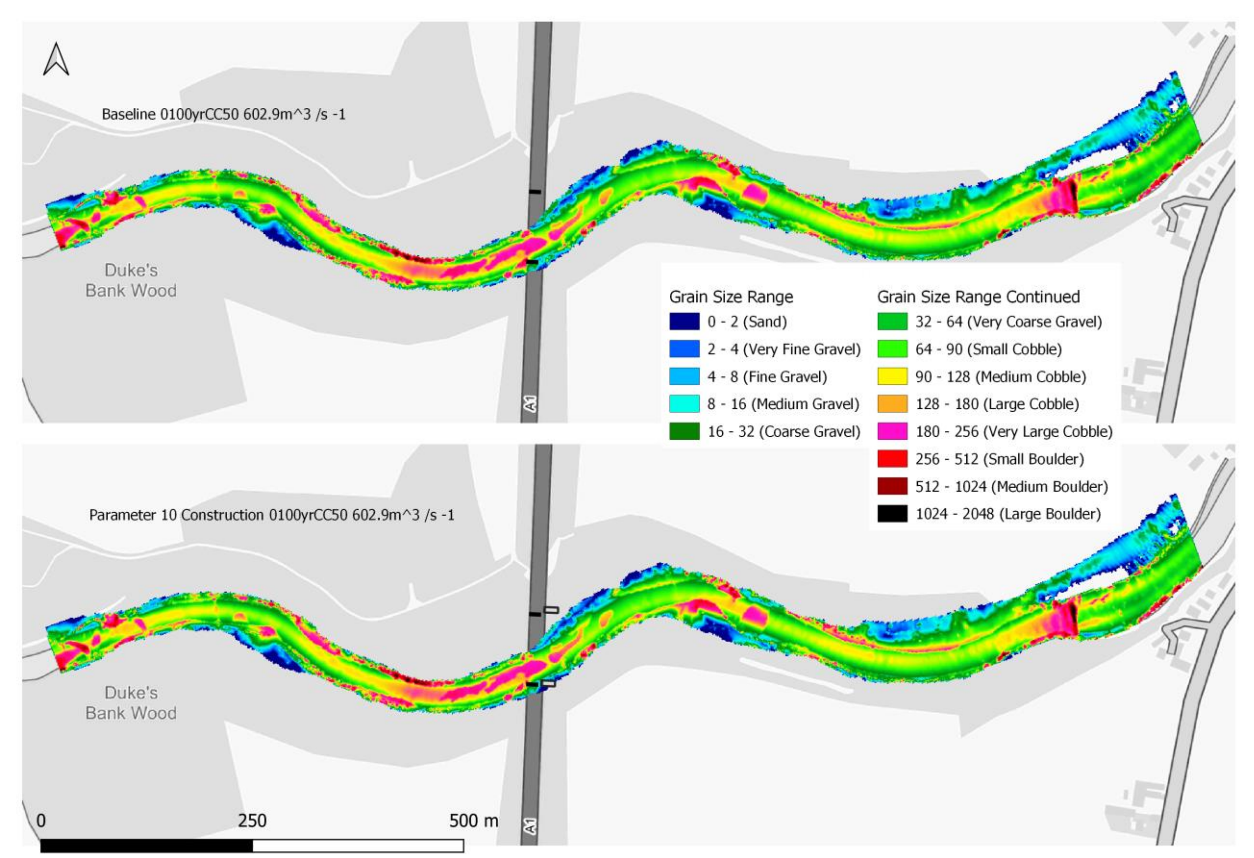

Figure 9 - Modelled 100yr +CC flow boundary shear stress for baseline and proposed piers in alignment design option – Construction phase

4.5 FROUDE

4.5.1. Finally, simulated Froude results once again demonstrate negligible change in the distribution and proportions of hydraulic biotopes between baseline and proposed for all simulated return periods. This is shown in **Figure 10** for the 100-year plus climate change (construction phase) design option and summarised in **Figures 11** to **14**. There is no more than 1% proportional difference in hydraulic biotopes between baseline and proposed, and this only occurs at high magnitude, low frequency flood return periods.

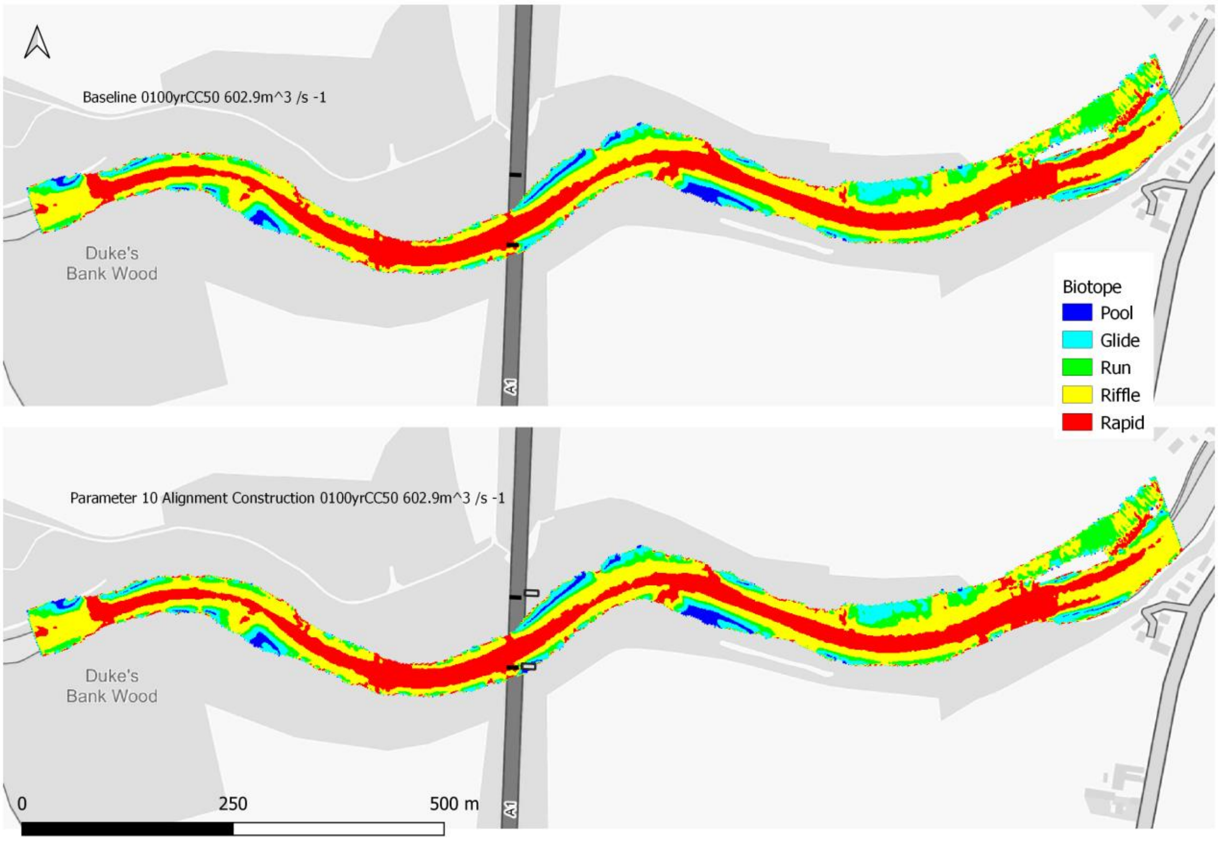

Figure 10 - Modelled 100yr +CC flow Froude for baseline and proposed piers in alignment design option – Construction phase

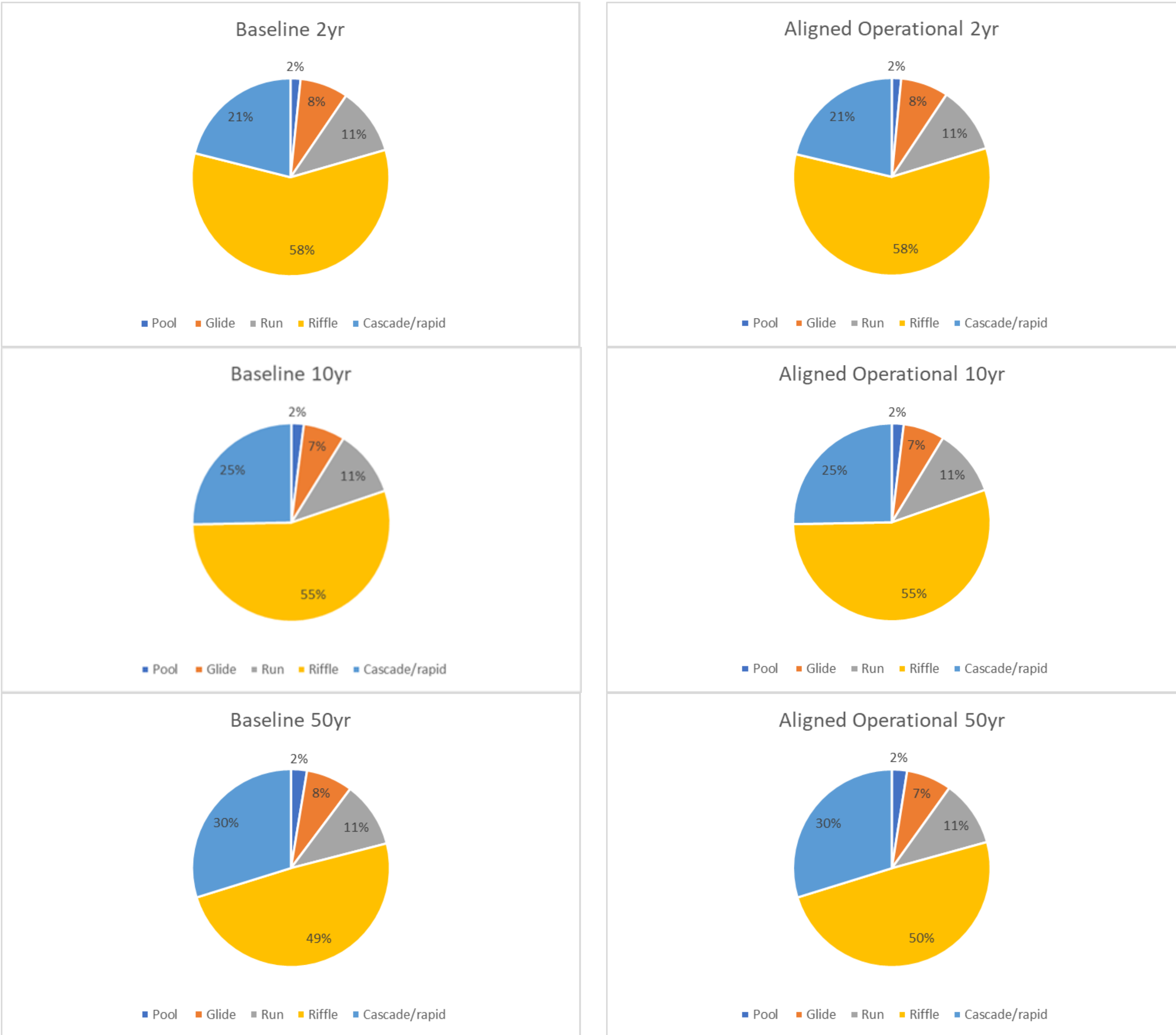

Figure 11a - Proportions of biotopes within the modelled reach under each simulated flow – Baseline vs Piers Aligned Operational

Figure 12b - Proportions of biotopes within the modelled reach under each simulated flow – Baseline vs Piers Aligned Operational

Figure 13a - Proportions of biotopes within the modelled reach under each simulated flow – Baseline vs Piers Aligned Construction

Figure 14b - Proportions of biotopes within the modelled reach under each simulated flow – Baseline vs Piers Aligned Construction

Figure 15a - Proportions of biotopes within the modelled reach under each simulated flow – Baseline vs Piers Unaligned Operational

Figure 16b - Proportions of biotopes within the modelled reach under each simulated flow – Baseline vs Piers Unaligned Operational

Figure 17a - Proportions of biotopes within the modelled reach under each simulated flow – Baseline vs Piers Unaligned Construction

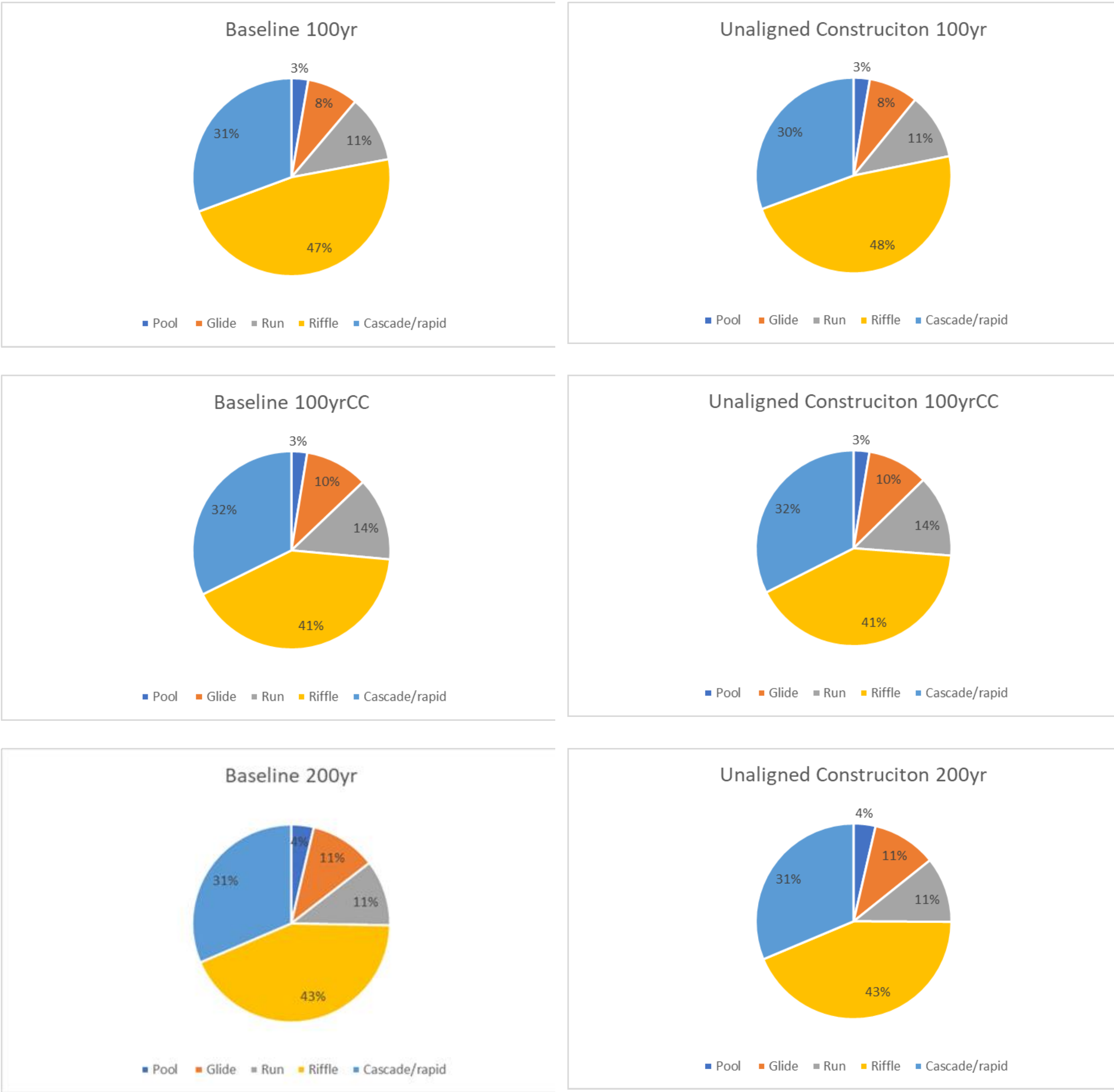

Figure 18b - Proportions of biotopes within the modelled reach under each simulated flow – Baseline vs Piers Unaligned Construction

5 DISCUSSION AND CONCLUSION

5.1 MODELLING RESULTS

5.1.1. The suite of analyses employed in this study has revealed minor, almost imperceptible impacts on reach-scale hydraulics resulting from the Scheme and its variations for both construction and operational phases. These indiscernible differences are clearly observed in the mapped outputs provided in **Appendix C**. This is the case for the design options tested with the piers in alignment, out of alignment and incorporating the working area for the construction of the piers.

5.1.2. Velocity results suggest that the maximum increase between baseline and proposed is around 3cm per second for the extreme 100-year plus climate change flow event. This is so inconsequential and would occur so infrequently, that it would have no significant impact on the wider geomorphic functioning of the river local to the proposed site of works over and above existing conditions; particularly as baseline velocity during extreme flow events far exceeds the threshold for coarse sediment transport. In addition, the 'flashy' nature of the river's hydrological regime means that this very small increase would not be sustained for more than a few hours per century. As such, this slight increase would not be sufficient to destabilise and remove bedforms if they were to otherwise survive under baseline conditions.

5.1.3. Stream power is minimally affected by the Scheme and its variations. As with velocity, the specific stream power threshold for erosion is significantly exceeded under the simulated baseline extreme flood events. Whilst the distribution of stream power is altered slightly due to the influence of the proposed piers, no overall increases are observed, therefore the influence of the Scheme would not result in the exceedance of erosion thresholds that are not already surpassed under baseline conditions. Furthermore, at cross section B, the stream power results indicate a slight reduction thus indicating a reduced risk of the depositional feature being mobilised as a result of the Scheme.

5.1.4. Similarly, no significant changes to boundary shear stresses were revealed through hydraulic modelling. There are localised regions of change due to the inclusion of additional piers, particularly the unaligned 'Parameter 10' arrangement; however, this is confined to just a few wetted cells and is not propagated beyond the immediate vicinity of the proposed piers.

5.1.5. The results indicate that the thresholds for entrainment of sediment would not be altered as a result of the Scheme (both construction and operation) in comparison to baseline. The results in **Appendix C** reveal that even under the extreme 100 year plus CC event, the threshold for transporting boulders would not be exceeded. It is important to note that these boulders provide the hiding effect for the other substrate fractions, thus raising the threshold required for the entrainment and mobilisation of the smaller particle sizes present. The sediment is also imbricated, which provides additional resistance to the frictional forces operating on sediment, which need to be overcome to enable entrainment then mobilisation.

5.1.6. Thus, the results conclude that the Scheme would not result in the entrainment and mobilisation of the depositional feature observed in the vicinity of the existing and proposed viaduct location over and above what occurs under baseline conditions.

5.1.7. Finally, the proportion and composition of hydraulic biotopes, represented as Froude, appears to be largely unaffected by the Scheme and its variations. Only minor (approx. 1%) changes between baseline and proposed was revealed through hydraulic modelling, and this appears to be initiated during high magnitude, low frequency flood return periods.

5.1.8. Therefore, there is no notable effect on the proportion of biotopes for a range of flood return periods within the reach assessed between baseline, construction and operation for either pier arrangement.

5.2 IMPACTS ON REACH MORPHOLOGY

5.2.1. The primary aim of this report is to test the hypothesis that there is no notable change in the fluvial geomorphological processes operating within the study area as a result of the Scheme. This aim is underpinned by the objectives presented at the beginning of this report, which are addressed in turn below.

5.2.2. In order to quantify potential impacts, the results of the 2D modelling demonstrate that there is no notable change in the processes of erosion, deposition and sediment transport between baseline, construction and operation for the two pier arrangements assessed for a range of flood return periods.

5.2.3. In order to quantify changes in velocity, stream power and shear stress between baseline, construction and operation of the Scheme, the results in **Appendix C** reveal no notable difference in velocity, stream power or shear stress for each design option tested for a range of flood return periods compared to baseline conditions. Thus it is concluded that the Scheme would not cause alteration to the geomorphological processes of erosion, deposition and sediment transport.

5.2.4. To quantify changes to in-channel habitat features between baseline, construction and operation of the Scheme for a range of flood return periods, the mapped and plotted outputs for Froude reveal that the spatial distribution and proportion of each habitat type within the reach under different flood return periods is predominantly unaffected as a result of the Scheme for each design option tested. Only negligible differences of just 1% were observed for extreme events. Thus it is concluded there would be negligible impact to in-channel habitat under extreme events only and no impact under lower magnitude, high frequency flood return periods.

5.2.5. To determine whether the potential impacts of the Scheme would disturb the dynamic equilibrium that maintains the current depositional feature in the vicinity of the existing and proposed viaduct between baseline, construction and operation for a range of flood return periods. The following explanation is provided based upon the results of the 2D modelling. Potential impacts on an existing depositional sediment bar in the immediate vicinity of the viaduct crossing is a key concern expressed by the Environment Agency, and thus forms one of the key objectives of this assessment.

5.2.6. The bar is comprised of poorly sorted material that represents a broad range of grain sizes and has been colonised by terrestrial vegetation. The emergence and subsequent survival of this sediment bar was dependent upon a number of factors and a complex interplay of processes. However, a local source of coarse boulder-sized clasts that are able to resist entrainment and transport during flood events was probably central to its formation (Knighton, 1998). This material, which likely originates from the local valley sides – as evidenced by its blocky, angular form – provided localised anchor points among which much smaller particles, that would otherwise be transported through the system, could deposit. This 'hiding' effect and subsequent deposition of smaller clasts and fines provided a growing medium for pioneer plant species whose root systems, once established, further stabilised the feature and promoted additional deposition.

5.2.7. It must be noted that the smaller calibre material within the depositional bar is not permanent. Bar forms represent transient sediment storage features that are periodically re-worked and replenished with material delivered from upstream – thus, they may be described as quasi-permanent. However, the largest clasts within the deposits observed on site are afforded a much greater degree of permanence due to their size, angular shape and mass, and thus permit the initiation and continuation of the feedback mechanisms described above. Indeed, their permanency is signified by an extensive covering of moss and lichen whose growth has been permitted by their host stone remaining immobile during flood events. The Scheme and its variations would not impact upon the delivery of more readily transported sediment from upstream, which appears to be relatively unimpeded[4]; nor does it appear to change the hydraulic conditions that drive these processes. Consequently, the influence of proposed piers on local hydraulics is so minimal and infrequent that no significant adverse geomorphological impacts could arise. The results of the 2D modelling indicate that the Scheme would not disturb the dynamic equilibrium that maintains the current depositional feature in the vicinity of the existing and proposed viaduct given that no notable change has been identified for the geomorphological processes assessed.

5.2.8. Immediately downstream of the existing and proposed viaduct, the channel is slightly wider. This is due to the channel narrowing that occurred as a result of the river training works during the construction of the existing pier and the associated bank protection. The wider channel downstream represents the more natural channel width and boundary conditions. The 2D modelling results reveal low velocities and low shear stress indicating that scour is

[4] The reach is naturally sediment supply limited. That is, transport rates are limited by the supply of sediment rather than the ability of flow to transport it.

not occurring. Furthermore, no evidence of scour was observed immediately downstream of the river training works during field investigations.

5.2.9. In conclusion, this analysis suggests that the Scheme does not significantly change the driving forces responsible for performing geomorphic work; therefore, there is minimal to no risk of the existing bar local to the proposed site of work being destabilised and washed out. Furthermore, wider, reach-scale geomorphic processes would be neither accelerated nor curtailed as a result of the Scheme. Therefore, this assessment concludes no notable change in the fluvial geomorphological processes operating within the study area as a result of the Scheme.

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Appendix A

ENVIRONMENT AGENCY QUERIES

DATE

An updated response to the Environment Agency's Relevant Representations and informal consultation is provided below based upon the results of the 2D modelling presented in this report. **Table A1** relates to the initial comments received during informal consultation from the Environment Agency on 14 May 2020 based on draft documents which were superseded by **Appendix 10.4 Geomorphological Assessment – River Coquet** [**APP-257**]. **Table A2** relates to the Relevant Representations raised within the letter dated 29 October 2020 against **Appendix 10.7 Geomorphological Assessment – River Coquet Parameter 10** of the Environmental Statement [**APP-260**].

Table A1 - Responses to the Environment Agency comments raised in the letter dated 14 May 2020

EA Comment	WSP Response
The basic geomorphology of the study reach is described. However, there is no indication what the levels where on the day on the survey and how visible the bed was.	The water level on the day of survey was 31.87m AOD with bed levels typically greater than 31m AOD.
The report needs to include an accurate map highlighting in-stream features, significant bed rock outcrops and boulders, flow types etc.	This has been provided in **Appendix C** of this report where Froude is used to determine habitat biotopes. This method was discussed and agreed with the Environment Agency at a meeting on 10 December 2020.
The location of the two piers, the extant of temporary river training works, the footprint of the working platform the extent of vegetation clearance and the location of the measurement transects should also be included.	The engineering design drawing of the viaduct available at the time of submission is included within the report. The location of the piers and construction footprint is provided in the results in **Appendix C**. The transect used in the original assessment has been supplied to the Environment Agency with the meeting minutes recorded on 10 December 2020. This is provided in **Appendix D** of this report. Vegetation clearance plans are provided in the DCO submission – see A1 in Northumberland: Morpeth to Felton. Scheme no. TR010041. 6.2 Env Statement – Figures – 7.9 Vegetation Clearance Plans.
In order to assess the geomorphology impacts, we would welcome further clarity regarding the following matters: **Question 1**: Why are the discharge numbers for Scenarios A and B apparently low and what is the return period for all 3 Scenarios?	In order to verify the results of the geomorphological assessment submitted in support of the Environmental Statement, 2D modelling has been undertaken with the results presented within this report. The analysis used newly derived hydrology data and modelled flood return periods, as agreed with the Environment Agency at a meeting on 10 December 2020.
Question 2: Table 4-3 indicates that the discharge varies quite considerably between the baseline and the construction scenarios. How were these numbers calculated, and what is the reason for the variations?	In the original assessment, the peak flow recorded for the reach was used to calculate the hydrological data, which was used to inform the Flood Risk Assessment. New hydrology information has now been derived and used to model flow for a range of flood return periods. The results of this 2D modelling has been used to provide a more robust and quantitative assessment of potential effects.
Question 3: Can it be confirmed whether sheet piling will be used to establish safe working area, the location and height of this on a detailed plan, and there will be no additional river training/bunding of the working area?	Sheet piling for the proposed pier will provide the coffer dam for the safe working area. No additional river training is proposed. The information available is presented on the design drawing submitted with the DCO application. The footprint and dimensions of this sheet piling has also been incorporated into the 2D modelling for the construction phase. No further design information is available at present.

EA Comment	WSP Response
Furthermore, can it be confirmed that there will be no additional scour protection added to the southern pier? If both these elements are added, then the geomorphological assessment will need to consider the impact of these.	No additional scour protection is proposed for the designs assessed. Any introduction of scour protection would be assessed by CJP.
The report implies that the working area will be inundated under a flood event of between 38.8m3/s and 54.38m3/s (see table 4-3, scenario B). This would suggest that there is a strong probability that the working area will be inundation during the period of construction, and if it does it is likely to cause damage and erosion leading to a sediment release. Given the depth of the excavation is considerable and it is below river bed level, the difference in elevation could cause severe erosion (during peak flows) where the flow drops into the excavation (e.g. head-cut erosion), scour within and around the excavation could also occur.	The 2D model results reveal that the working area would only be inundated during high magnitude, low frequency events, thus the risk to the working area is low. The working area would also be protected by a sheet pile coffer dam where the level of the sheet piling would be higher than projected flood levels. In the previous assessments, a more risk averse approach was taken due to the absence of modelled flood levels.
The very steep (re-profiled) valley side may (depending on materials) be vulnerable to collapse.	Slope stability will be of paramount importance for the construction zone and covered under CDM regulations. The slope would be made stable prior to construction of the pier thus would not be prone to collapse.
Question 4a): What are the return periods associated with the discharges for scenario 2?	No hydraulic modelling was undertaken, as stated in paragraph 2.4.4 of **Appendix 10.4 Geomorphological Assessment – River Coquet** [**APP-257**]. The scoping out of hydraulic modelling was agreed with the Environment Agency. Therefore, return periods were not available to inform the original geomorphology assessment. Flood return periods, as agreed with the Environment Agency at a meeting on 10 December 2020, have been used in the 2D model and presented within this report. A full suite of mapped outputs for each return period are provided in **Appendix C**.
b) What is the assessed risk of the working area being inundated and significant scour developing around the excavations, during both construction and operation?	The mapped outputs from the 2D modelling show that the working area becomes at risk of inundation during low frequency events, such as the 50-year return period plus. Therefore, the risk of inundation is low. Furthermore, the construction zone will be protected by a sheet pile coffer dam to protect the excavation from inundation. During operation, the 2D modelling results indicate that the risk of scour around the pier is limited to extreme flood events only with minor changes at the 100-year return period and localised increases in shear stress values at the 200-year event and the 100-year plus CC event.
c) What mitigation measures are in place to minimise the impact of the working area being flooded?	Standard mitigation measures would be provided and detailed in the CEMP. Further information would be provided during the development of detailed design and prepared by the Contractor. The sheet piling will also serve as a coffer dam during construction.
d) The second pier will interrupt overland flow routes. If this is a high frequency event what are the likely risks, and how will the mitigated for? Priority must be to avoid a hard engineered solution?	Overland flows will alter following the regrading of the valley side for slope stabilisation and the haul routes. Information on the regrading is not yet available and will be developed during detailed design.

EA Comment	WSP Response
e) Can the piles and pile cap be set below the level of the riverbed designing out the need for any scour protection measures?	To set the piles and cap below the level of the river bed would require people to work below river level, which has safety in design implications under CDM regulations. Such safety issues are typically designed out to eliminate safety risks as far as practicable.
Question 5a: the river appears to widen directly downstream of the existing pier, is this a natural feature or has it been caused by the existing pier?	New information has been provided since undertaking the original assessment. Design drawings from the construction of the existing bridge reveal the inclusion of river training works which extended out into the channel and form the current bank protection works around the existing pier. Thus the channel has been narrowed in the vicinity of the existing crossing. The wider channel downstream indicates the natural channel width. Given that the channel is bound by the bedrock, no notable scour of the bank has occurred due to the channel narrowing and the river has adjusted to the modifications introduced. This new information does not alter the outcomes of the assessment in relation to impacts of the Scheme on the fluvial processes operating. The 2D modelling results also reveal no notable effects of the Scheme upon the fluvial geomorphology.
b) What is the combined footprint of the two piers, and will the new pier and any associated infrastructure encroach into and narrow the channel?	Each pier is approximately 8m x 2m. The proposed piers would not encroach into or narrow the channel.
We recommend that a detail plan of the bridge is included within the geomorphology assessment.	The plan of the viaduct drawing was submitted as part of the DCO application.
The channel downstream of the existing bridge pier appears to be wider than the reach upstream of the bridge. This is also the reach with the greatest distribution and volume of sediment.	As stated above, the channel was narrowed during the construction of the existing viaduct by the river training works introduced around the existing pier. The channel width downstream represents the natural channel width and is bound by the bedrock substrate of the channel and banks.
Question 6a: Is the width of the channel downstream of the bridge why there more sediment stored within the channel here?	There appears to be a word or words missing from this question so it is not clear what you are asking. The doming of the bedrock in the vicinity of the viaduct, which is a natural feature, will reduce the ability of the river to transport sediment due to increased frictional forces. The 2D modelling results reveal a reduction in stream power, shear stress and velocity, which reduces the river's ability to transport sediment, resulting in deposition.
b) Is there a drop of steam power downstream of the existing pier?	The results for stream power in **Appendix C** of this report demonstrate a marked reduction in stream power immediately downstream of the existing viaduct. This is the case under baseline, construction and operation. Shear stress, which is a measure of the ability of the river to overcome the frictional forces required to entrain and then transport sediment, reduces downstream of the existing viaduct under baseline, construction and operation, with imperceptible changes between baseline, construction and operation (see **Appendix C)**. The exception is for the 100-year plus CC event, where the shear stress remains high for baseline, construction and operation with imperceptible difference between baseline and proposed. Thus the river has reduced ability for sediment entrainment and transport immediately downstream of the existing viaduct.

EA Comment	WSP Response
c) Will the new pier change this in any way?	The 2D modelling results presented in **Appendix C** of this report reveal a similar pattern in both stream power and shear stress for each return period modelled for baseline, construction and operation. A slight reduction in stream power within the zone of the existing deposit as a result of the Scheme is observed. Therefore, this suggests that the depositional feature would not be at risk of being washed out as a result of the Scheme. No adverse impacts upon fluvial processes have been identified as a result of the Scheme.
Most bedrock channels are sediment transfer zones. Small pockets or accumulations of sediment are uncommon, and in terms of habitat and species diversity these areas are disproportionately more valuable for biodiversity then would be elsewhere. They tend to develop around natural depressions bedrock or in the protective shadow of a large boulder. The report refers to channel bar downstream of the existing bridge footing. However, without it shown on a plan that includes the existing and new piers, then the location value and vulnerability of this feature cannot be accurately understood.	The feature is indicated by the riffle habitat, transforming to rapid under higher flows, in the habitat maps provided in **Appendix C** of this report. The 2D modelling results indicate no adverse effects on sediment entrainment and sediment transport processes, therefore this feature is no more vulnerable to being washed out as a result of the Scheme compared to baseline conditions. Indeed, the stream power results indicate a slight reduction in stream power in the vicinity of this feature as a result of the Scheme, therefore suggesting a slight reduced risk to the vulnerability of this feature. In-channel habitat biotopes are mapped and presented in **Appendix C**.
Question 7a: Can a detailed field map/plan be produced that shows in-channel features, the location of the different flow types, any depositional areas, along with the accurate location for the two piers along with the footprint of any temporary works.	See **Appendix C** of this report. It was agreed at a meeting with the Environment Agency on 10 December 2020 that maps would be generated of habitat biotopes using the Froude number.
b) We would also welcome a description/interpretation about how the mid-channel bar may have originally formed; if there any keystone boulders; how does the presence of the bar relate to the described doming of the bedrock; and the widening of the channel.	Further explanation is provided within the report to which this forms an Appendix.
c) Given the lifetime of the bridge, how vulnerable is such a feature and are the flows used in Scenario C reflective of a likely flood event during the lifetime of the bridge?	The results of the 2D modelling, as presented in **Appendix C** of this report, reveal imperceptible difference in the geomorphological processes that drive sediment entrainment and transport. Slight reductions were observed in stream power at the location of this depositional feature as a result of the Scheme. Thus it may be concluded that during the lifetime of the viaduct, the feature is no more vulnerable compared to baseline. The high shear stress values that could have the potential to mobilise the larger substrate that provides the anchor around which the deposit forms, are only achieved during high magnitude, low frequency events, with the most extreme event modelled (the 100-year plus CC) being the event most capable of mobilising sediment both under baseline and proposed.
The geomorphological assessment uses a number of methods to understand the sediment dynamics of the study area. These include calculating stream power, shear stress and flow velocity (utilising of the Hjulstrom curve). To populate and derive any of the outputs a series of physical measurements need to be used, including average water depth, bankfull width, the width of the wetted perimeter, gradient etc. This information is generally collected through a series of channel transects, either through field surveys or remotely via lidar etc. The more transects there are, the more accurate your outputs will be.	The questions raised here have been addressed through the development of a 2D hydraulic model using LiDAR data to assess the potential impacts of the Scheme on the fluvial processes between baseline, construction and proposed for a range of flood return periods. These results are presented in this report. The methodology for the 2D modelling was presented to and agreed by the Environment Agency at a meeting on 10 December 2020. It was also confirmed that the results of the 2D modelling would provide the evidence needed to address the concerns raised by the Environment Agency.

EA Comment	WSP Response
Question 8a): With respect to the assessment of the sediment dynamics within the study area, how were these physical parameters measured?	Hydrology data has now been derived and fed into the 2D hydraulic model to assess variance in stream power, shear stress, velocity, and Froude throughout the reach and for each design option tested for a range of flood return periods.
b) How many transects were used to populate the outputs in table 4-3, and where are they located within the study reach?	LiDAR data for approximately a 1km long river reach has now been used to assess the geomorphological processes. The methodology is presented in the report, to which this forms an Appendix.
The extent and location of the areas earmarked for vegetation stripping should be shown on a plan.	Vegetation clearance plans are provided in the DCO submission – see A1 in Northumberland: Morpeth to Felton. Scheme no. TR010041. 6.2 Env Statement – Figures – 7.9 Vegetation Clearance Plans.
It would be valuable to add context to the outputs in Table 4-3 by doing a similar piece of analysis on an indicative section of the upper and lower reaches of the study area.	The 2D modelling covers approximately a 1km reach of the River Coquet and results are provided for this full length of the river reach (see **Appendix C** of this report).
Question 9a): Is the upstream weir playing a role in restricting the supply of sediment to the study reach, and how would this change if the weir collapsed, or was it breached/removed?	This study is related to the construction of the proposed A1 river crossing. It is not within the scope of work to assess what if scenarios relating to weir failure or weir removal. The weir is an informal structure and may allow the transport of sediment downstream.
b) How does the impounding effect of the downstream weir influence the lower end of the study area?	There is some deeper water on the approach to the downstream weir. This impounding impact does not extend far enough upstream to be interacting with the bridge location.
c) What would the consequences be if this weir failed or was breached/removed?	Consequences of weir failure or removal was not within the scope of this assessment. This assessment is focused on the proposed A1 river crossing. It is unlikely that such scenario would impact upon the operation of the viaduct. The viaduct is not going to cause any increase in hydraulic loading on the downstream weir, so weir removal or failure is not pertinent to this assessment.
Given the expected lifespan of the bridge, the age and condition of the weirs, and the long term WFD aspiration to see them removed, it is reasonable for the assessment to consider what the impact would be if one or both were removed.	This is not within the scope of the geomorphological assessment, where the aim is to assess the potential construction and operational impacts of the Scheme on fluvial geomorphological processes. It is not related to weir removal or aspirations for the removal of these weirs. This matter was neither discussed nor agreed as additional scope at consultation meetings with the EA.
The report does not take into account the consequences of climate change, the expectation that low to moderate floods will become much more frequent and that the scale of the largest floods is likely to get worse. The assessment implies that the existing and the new pier are already within the 50% AEP zone. Climate change will only increase the level and intensity of inundation. The final design, ground levels and reinstated land will need to factor in these future risks. These issues should be reflected within the assessment.	The 2D hydraulic modelling included a 100-year plus climate change event. There was predominantly no perceptible difference in the stream power, shear stress, velocity or Froude between baseline, construction and proposed. A minor increase in values was observed around the proposed pier locations on the southern bank with impacts highly localised to a few wetted cells only.

EA Comment	WSP Response
Overall, the geomorphology assessment methodology is appropriate and assesses all of the areas that we would expect to see in a report of this nature. However, we would welcome clarity regarding the above matters and that the document is updated to reflect the current design proposal. Until this information is provided, and the report is updated, we are unable to verify the assessment, the impacts and the conclusions outlined in the assessment.	2D hydraulic modelling has been undertaken to address the concerns raised by the Environment Agency. The methodology for the 2D modelling was presented to and agreed by the Environment Agency at a meeting on 10 December 2020. The Environment Agency also provided the flood return period requirements for the modelling runs. The results of the 2D modelling reveal no notable effects between baseline, construction and proposed.

Table A2 - Responses to the Environment Agency comments raised in the letter dated 29 October 2020

EA Comment	WSP Response
The 7 flow regimes tested are baseline (existing), 10 year, 5 year, 485 year, 525 year, 100 year, 30% climate change and 100 year , 50% climate. 1. Scenario A – Existing (baseline) conditions with no new structures; 2. Scenario B – Design prepared for the DCO application; 3. Scenario C – A design option which relates to a channel width constrained to the width of the Southern pier with no bypass flow behind the Southern pier 4. Scenario D – A design option which relates to a channel width constrained to the width of the Southern pier with bypass flow behind the Southern pier.	The fully two-dimensional model which extends approximately 1km upstream and downstream of the viaduct crossing has been developed. A suite of flood return periods was built into the model, with the returns periods to be assessed provided by the Environment Agency at a meeting on 10 December 2020. Accordingly, hydrology was developed for each of these flood events using a standard FEH statistical methodology. Model simulations were run for baseline, construction and operation for each design option.
In the absence of any modelling the methodology outlined in the report is suitable, provided the data used is accurate and robust. It is noted that modelling was scoped out on flood risk grounds and not hydrogeomorphological grounds.	2D modelling has now been undertaken and the results confirm no notable effects between baseline, construction and operation on the fluvial processes operating. As stated in the Meeting Minutes of 19 December 2018 (item 4.9 of the Meeting minutes dates 19 December 2018), the EA also agreed to the de-scoping of hydraulic modelling on geomorphology grounds following presentation of baseline findings following a site investigation. Item 4.9 of the Meeting Minutes states, '*EA geomorphologist agreed with WSP geomorphologist that following initial results no hydraulic modelling is required for the geomorphological assessment – prompted by findings – amount of bedrock present on river bed, size of sediment. The cable stay option would further support this decision, however; should the temporary pier option be taken forward, the hydraulic modelling required for that would provide extra re-assurance*'.
The report describes the study reach as a predominantly bed rock channel with localised pockets of sediment, ranging in size from boulder to coarse sand. In general, the dominance of bedrock in the channel and on the banks means the channel is very resilient. This dominance of bedrock makes the reach a sediment transport reach, meaning that pockets of mobile sediment disproportionately valuable (at the reach scale) as they add diversity to the flow regime and instream habitat.	The 2D modelling results reveal no notable effects between baseline, construction and operation, therefore the evidence concludes that there would be no impact upon the flow or sediment regime as a result of the scheme. This is demonstrated in the results presented in **Appendix C**.
The report rightly argues that the boulders are hiding or protecting the smaller sized sediment, and that the presence of moss suggests long term stability. However, as	The 2D modelling results provide mapped visual representation of shear stress throughout the modelled study reach. The results reveal predominantly imperceptible difference within the channel between baseline,

EA Comment	WSP Response
these boulders are sitting directly on bedrock, the forces necessary to initiate movement would generally be less as they are not embedded into the bed. Movement to or the loss off any boulder will have a disproportionately high impact on the surrounding sediment given the "hiding effect". Understanding how these boulders will respond to the new flow regimes, resulting from the new bridge pier are crucial for assessing the risks to the current sediment regime.	construction and proposed. Therefore, the results suggest the sediment regime, and the mobility of the sediments, would not be altered as a result of the scheme. The modelled stream power results suggest a slight reduction in stream power within the zone of deposition, thus suggesting that the depositional feature may have a potentially lower likelihood of being washed out as a result of the Scheme.
The methodology used in the report relies on accurate field data to develop the findings. There are a number of areas where the robustness of the data used is weak or not clearly explained. We therefore believe that the report as it stands does not clearly demonstrate that the construction and operation of the proposed new River Coquet bridge do not cause significant alteration to the fluvial processes operating within the study reach and have no adverse impact on either the sediment entrainment and transport capability of the watercourse or the erosion and depositional processes.	The 2D modelling has been undertaken to provide more confidence in the assessment results. The results presented within this report and **Appendix C** demonstrate no perceptible change in fluvial processes between baseline, construction and operation for a range of flood return periods including extreme events. Therefore, the Scheme would have no adverse impact upon sediment entrainment, transport capacity or erosion and depositional processes.
Given our concerns around an adverse change to the form and processes of the reach, we have significant concerns regarding the proposed development and require further information and clarity on the following:	2D modelling results presented within this report and **Appendix C** reveal no adverse change to the form and processes of the reach. The results of the 2D modelling are used to provide further response and clarity to the concerns raised below regarding the Scheme.
Question 1: Clarity of the cross section used to produce the physical parameters such as channel width, area, wetted perimeter, hydraulic radius. The cross section needs to be accurate, to scale, and must show the 4 scenarios and the levels of the 7 flow regimes.	Cross-section-based analysis has been replaced with fully two-dimensional modelling and analysis utilising LiDAR data. The modelling has been undertaken for a wide range of flood return periods for baseline, construction and operation of the two design options assessed. Data constraints were discussed with the Environment Agency on 10 December 2020
Question 2: Relying on the 1 cross section to generate the conclusions feels weak. Further cross sections up stream of and downstream of the new pier will create a much better picture, and more confidence in the findings.	The fully two-dimensional model extends approximately 1km with the existing viaduct located approximately at midpoint. Notwithstanding the data constraints (which were deemed acceptable by the EA), the 2D model reveals the impacts (or lack of impacts) of the Scheme over a significantly greater area than a single cross section.
Question 3: Clarity on the flow data used. How were the numbers for velocity and discharge derived? What is the reasoning behind using a 485 and 525 yr flow, why no 100yr flow? The description of mean flow, Q10 and Q5 in the executive summary appears to be different to the flows used in Table 4.3	A range of flood return periods, as requested by the EA officer on 10 December 2020, were simulated within the 2D modelling. Accordingly, hydrology was developed for each of these flood return periods using a standard FEH statistical methodology.
Question 4: Rational for using a single manning's number for all scenarios. The number feels high for a bedrock channel, especially mid channel where the majority of the sedimentary deposits are located;	The 2D model allows for inclusion of multiple Manning's values. These were discussed and agreed at the meeting with the EA on 10 December 2020 and were subsequent built into the model.
Question 5: The data collected during the sediment analysis does not truly reflect the composition and makeup of the mobile sediment within the reach. The inclusion of bedrock in the sediment analysis massively skews the results. The sediment analysis needs to focus on mobile sediment rather than the makeup of the bed.	The 2D model does not require sediment size data to simulate flows. However, the sampled D16 was used in the recent analysis, which demonstrates that there is no increase in transport capacity between baseline, construction and operation for all modelled flood return periods and associated flows.

EA Comment	WSP Response
Question 6: The footprint of the sheet piling and the foundations of the pier will be greater than the pier itself. The impact will be greatest during construction, has this been taken into account?	This has been incorporated into the 2D model and assessed for all flood return periods modelled.
Question 7: Appendix 10.4 implied that the working area was vulnerable to low magnitude, high frequency flood events, meaning that the risk to the working area is high. Appendix 10.7 does not highlight this, therefore will this risk be adequately assessed and mitigated for within the CEMP; and	The 2D model results reveal that the working area would not be vulnerable to low magnitude, high frequency flood events and would only be inundated during high magnitude, low frequency events, thus the risk to the working area is low. The working area would also be protected by a sheet pile coffer dam where the level of the sheet piling would be higher than projected flood levels. In the previous assessments, a more risk averse approach was taken due to the absence of modelled flood levels.
Question 8: It's also worth noting that the cross sections shown in the two geomorphological reports is different. Why is this, and does it influence the outputs from question 1?	The cross section used to inform the two geomorphology assessments was the same and that cross-section was acquired specifically for the geomorphology assessment. It is assumed that the comment is referring to differences in the engineering drawings. These were produced by the design team and are standard drawings for the DCO application and not specifically created for any technical report, thus any sections used in the engineering drawings do not relate to the one used in the geomorphology analysis. The cross section used in the geomorphology assessment has been provided to the Environment Agency and is provided in **Appendix D**.
Question 9: A detailed field map/plan should be produced that shows in-channel features, the location of the different flow types, any depositional areas, along with the accurate location for the two piers and the footprint of any temporary works.	Froude maps have been produced to inform the distribution of flow types within the study reach, which relate to habitat biotopes. The pier locations have been included on all output maps, in addition to the construction footprint for each pier alignment option.
Question 10: Given that we now know that the existing pier was built within the active channel, does this change the interpretation of channel form downstream of this point? The previous summary suggests that the widening of the channel, the formation of the bar etc. and natural processed. Is it possible that this change was driven by the work associated with the first bridge?	As stated in Table A1 above, new evidence reveals that the channel was narrowed during the construction of the existing viaduct by the river training works introduced around the existing pier. The channel width downstream represents the natural channel width and is bound by the bedrock substrate of the channel and banks. This does affect the description of the channel form in this location, which is described in the report. However, the river has since adjusted to the presence of this river training and, given the confined valley setting and predominance of bedrock, this new information does not to affect the outcomes of the assessment.
In conclusion, overall, the geomorphology assessment methodology is appropriate and assesses all of the areas that we would expect to see in a report of this nature. However, we would welcome clarity regarding the above matters. Until this information is provided, and the report is updated, we are unable to verify the assessment, the impacts and the conclusions outlined in the assessment.	The 2D modelling results reveal no notable effects upon the fluvial geomorphology of the River Coquet between baseline, construction and operation for each flood return period, which includes extreme events.

Appendix B

HYDRAULIC MODEL BUILD AND HYDROLOGY

INTRODUCTION

A fully 2D hydraulic modelling exercise has been undertaken to demonstrate the relative changes between the baseline and a range of four alternative layouts. The four layouts are as follows; the piers in alignment, the piers out of alignment (Parameter 10) and construction layouts for the two pier layouts.

DATA FOR LAYOUTS

Existing pier locations have been informed by:

- Topographical survey for the River Coquet undertaken in March 2019.
- Piers alignment and associated coffer dam areas.
- General arrangement for the River Coquet bridge as shown in Parameter 10 Extent of Pier Movements to the North within **Appendix 2.2 Technical Drawings** [**APP-188**].
- **Vegetation Clearance Plans** [**APP-013**]

SUMMARY OF MODEL BUILD

A hydraulic model extent map is provided in **Figure B1** the model extent was presented to and agreed upon by the Environment Agency (EA) at a meeting on the on the 10 December 2020. The 2D hydraulic modelling software TUFLOW Single Precision version 2020-10-AA has been utilised for the exercise.

The hydraulic model base Digital Elevation Model (DEM) has been constructed utilising 1m horizontal resolution EA Light Detecting and Ranging (LiDAR) digital terrain model (DTM) downloaded in December 2020. The use of LiDAR data to represent channel bed levels was discussed and agreed with the EA at a meeting on the 10 December 2020, acknowledging that the absolute elevation values may contain error but the assessment of relative change resulting from the pier layouts remains valid in the absence of bathymetric survey data.

The existing piers have been represented within the 2D hydraulic model utilising TUFLOW z-shape lines, the lines raise pier levels to 60m AOD which is above any anticipated water level. The THICK shape option has been specified so the lines raise cell centres and ensure that the pier width is not underestimated. Pier widths vary between 1.5-1.6m within the supplied drawings, as such using the THICK command marginally overestimates the width by raising a whole model cell and the result is conservative. The same approach has been adopted to represent the piers in alignment and Parameter 10 proposed pier layouts. To represent construction areas for the two proposed pier layouts, TUFLOW z-shape polygons have been utilised. The construction areas use a similar approach to the piers themselves but raise more cells to represent the footprint of the coffer damming and associated barrier to flow.

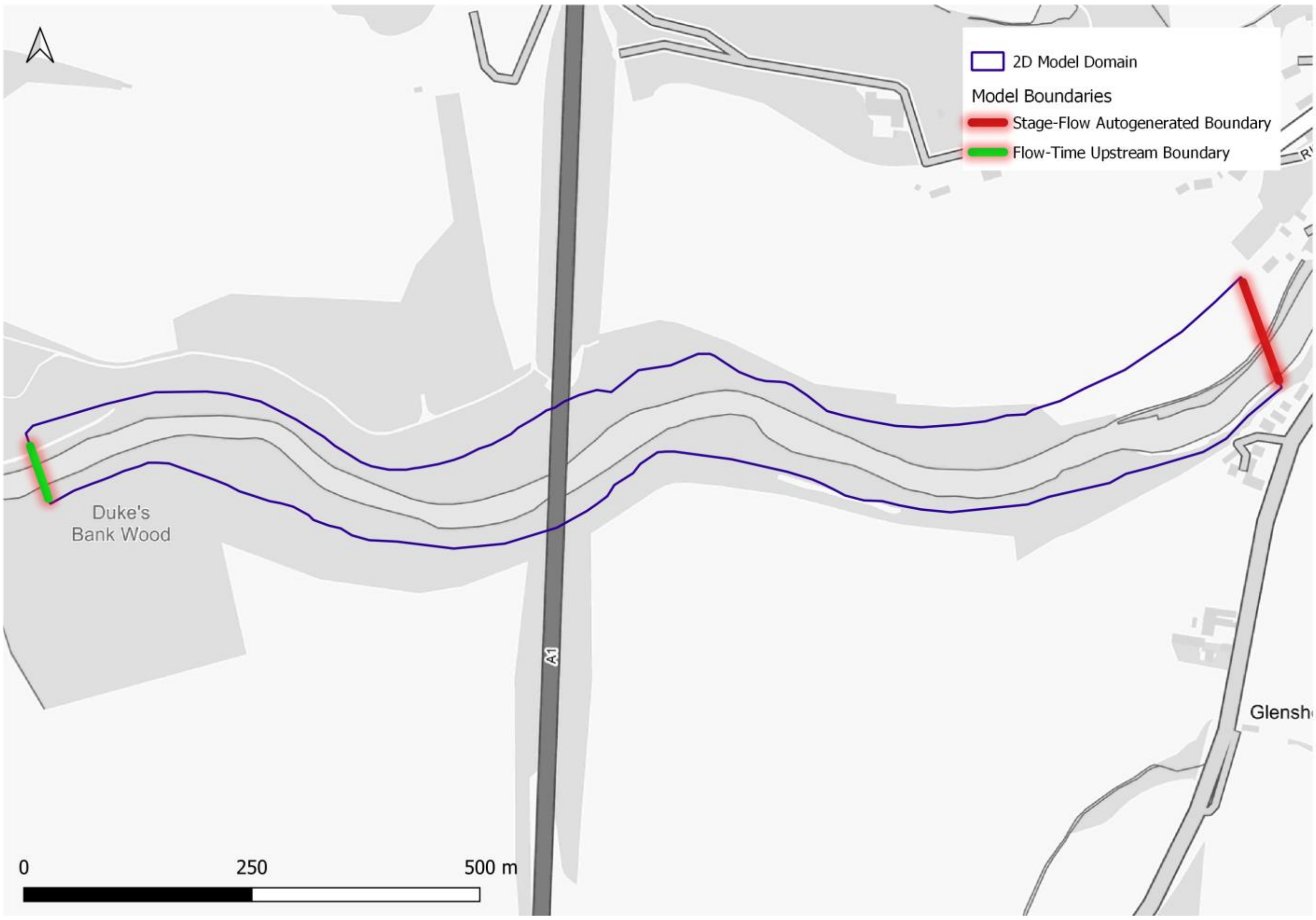


Figure B1 - The hydraulic modelling extent and model boundaries

The 2D hydraulic model cell size has been set at 2m which provides a detailed resolution whilst retaining reasonable model simulation times and stability. A 1m cell size was initially tested however significant runtimes with additional model instability were encountered which were not manageable within the timeframe required to complete the assessment. The 2m grid size is considered a high resolution considering the River Coquet width, typically between 20-30m at the location.

The hydraulic model roughness has been represented utilising Manning's n values applied to the 2D domain with polygon shapefiles. The Manning's n values utilised were discussed with the EA and agreed at a meeting on the 10 December 2020. The values have been based on the values within Chow 1959, some degree of judgement has been applied as the values in Chow 1959 are based on cross-sectional Manning's n values and as a key part of the assessment the modeller has represented specific features within a 2D domain. A key consideration is the representation of the channel as relatively smooth considering the bedrock morphology, this approach has been considered through discussion with the EA who agree that the skin-friction of the bedrock is smoother and specific rougher features would be best represented through individual rougher Manning's 'n' values. The Manning's n values used are provided in **Table B1** below.

Table B1 – Selected Manning's n values utilised in the hydraulic modelling

Manning's 'n' value	Description
0.035	Normal watercourse assuming smooth flow over bedrock channel
0.035	Smooth valley sides underneath the existing and proposed A1 carriageway and where vegetation is removed as part of the scheme
0.050	Rough channel features, such as large gravel/cobbles in channel, vegetated mid-channel bars etc
0.070	Dense tree coverage on the valley sides and banks
0.070	Boulder weir at upstream extent of modelled River Coquet

The hydraulic model has a single upstream inflow comprising a flow-time (QT) inflow boundary. The model is set up to simulate peak flows only rather than a full flood hydrograph, however to ensure the model can achieve a stable steady state flow for each return period an initial flow of 1.1m^3 s^{-1} (approximate Q95 low-flow for the River Coquet at site) is specified and then ramped up for two hours to the peak for the specific return period. To determine the peak flows for each return period a hydrology assessment was undertaken on the River Coquet using FEH-statistical and ReFH2.3 methods. A Summary of the peak flows for each return period simulated is provided in **Table B2**.

Table B2 - Modelled return periods and corresponding discharge

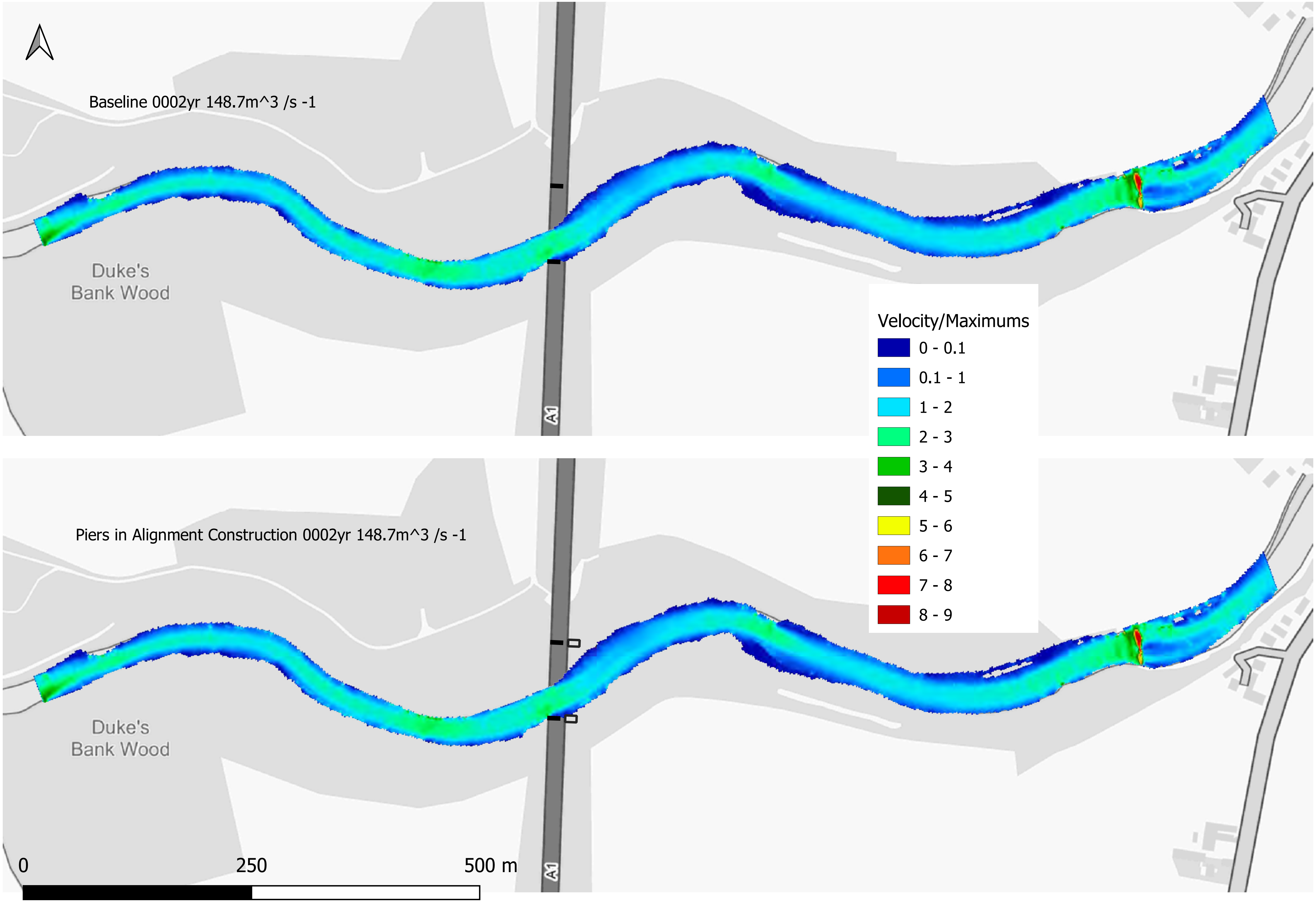
Return Period	Flow (m^3/s)
2-year	148.7
10-year	253.8
50-year	355.8
100-year	401.9
100CC50	602.9
200	462.6

The hydraulic model has one downstream boundary location comprising three adjacent Stage-Flow (HQ) downstream boundary conditions. The HQ relationships have been automatically generated by TUFLOW utilising the normal depth equation, underlying DTM ground levels and a specified slope value of 0.001. The general gradient for the modelled reach is around a 2% gradient (0.02 slope), however the downstream extent of the hydraulic model around Felton Weir is significantly flatter than the overarching study reach. The shallower slope value (0.001) has been adopted to best represent conditions local to the downstream boundary. Initially the downstream boundary was specified slightly upstream from Felton Weir, initial test simulations showed that the boundary location may have been artificially influencing water levels at the site, thus the boundary was moved further downstream.

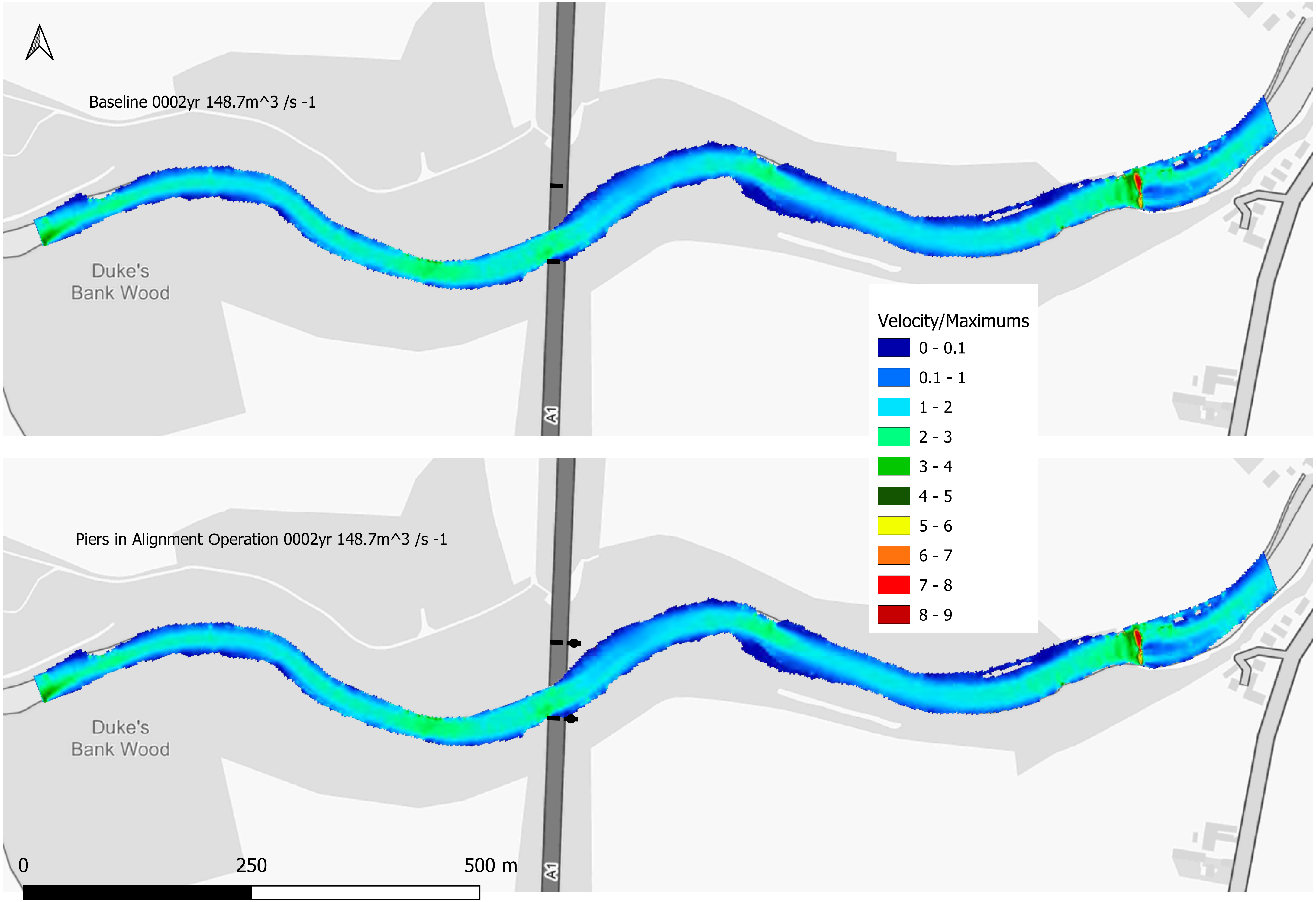
Appendix C

HYDRAULIC MODELLING RESULTS

Velocity Results



Baseline 0002yr 148.7m^3 /s -1
Piers in Alignment Construction 0002yr 148.7m^3 /s -1
Duke's Bank Wood
Duke's Bank Wood
A1
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
0
250
500 m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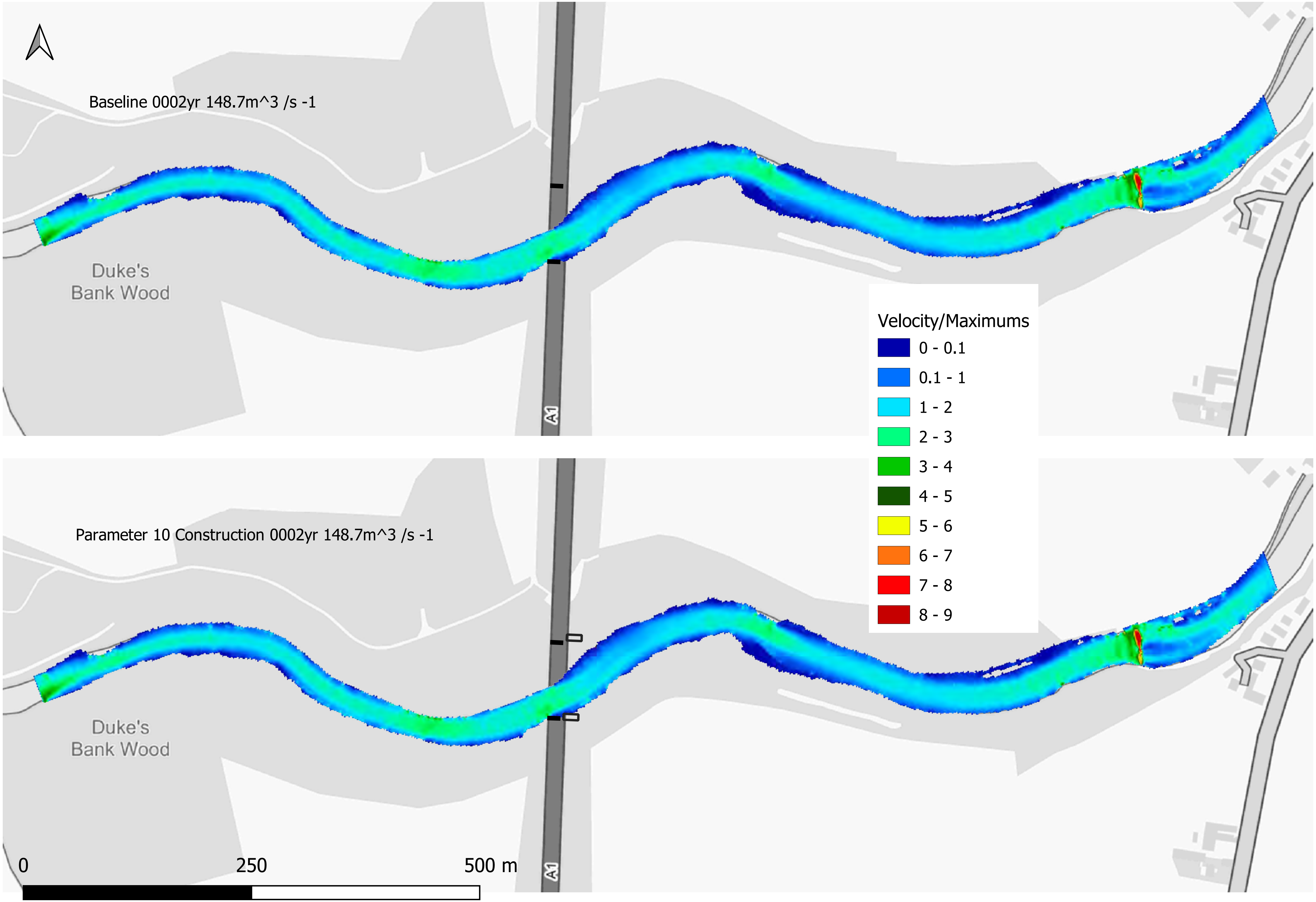
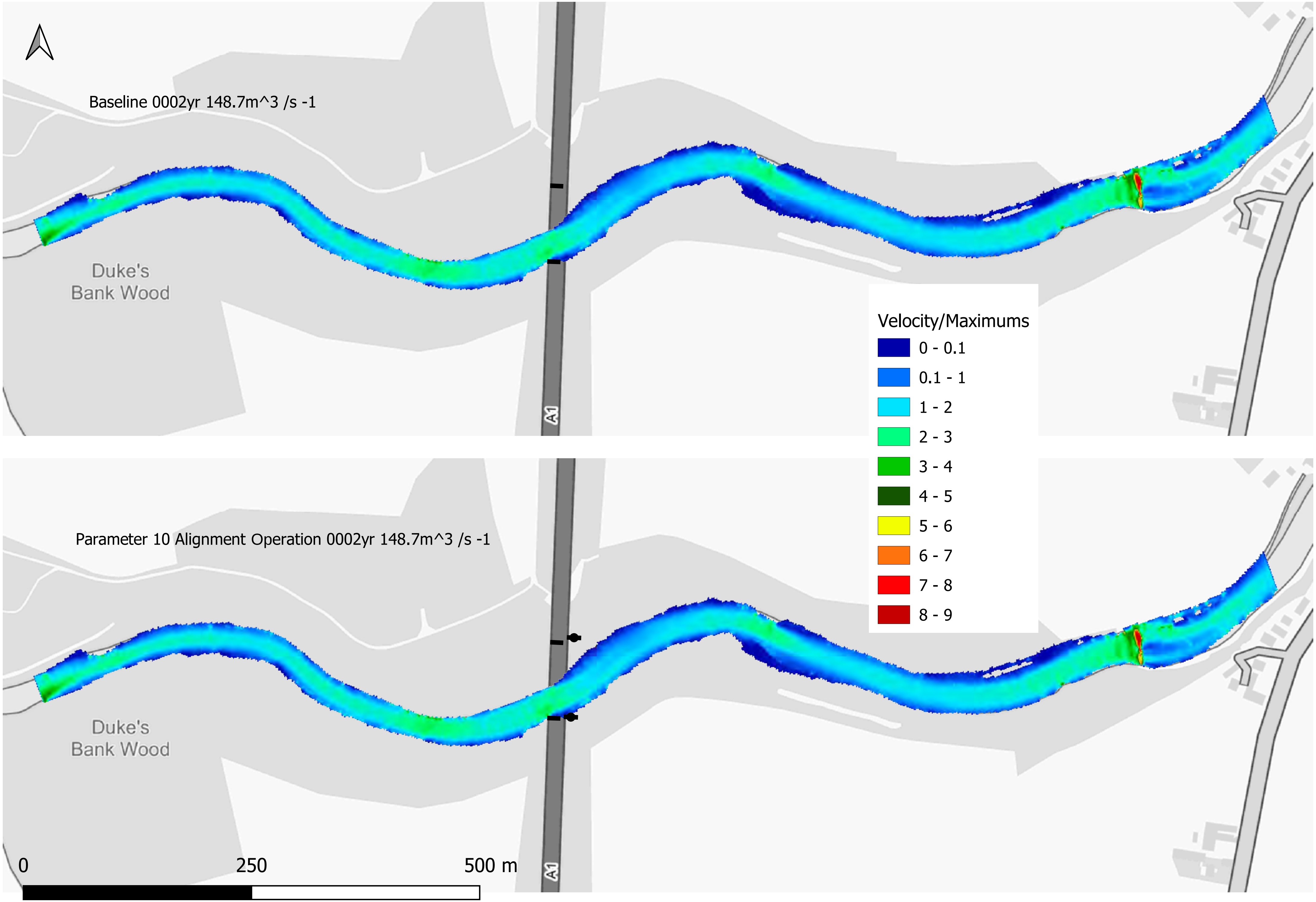
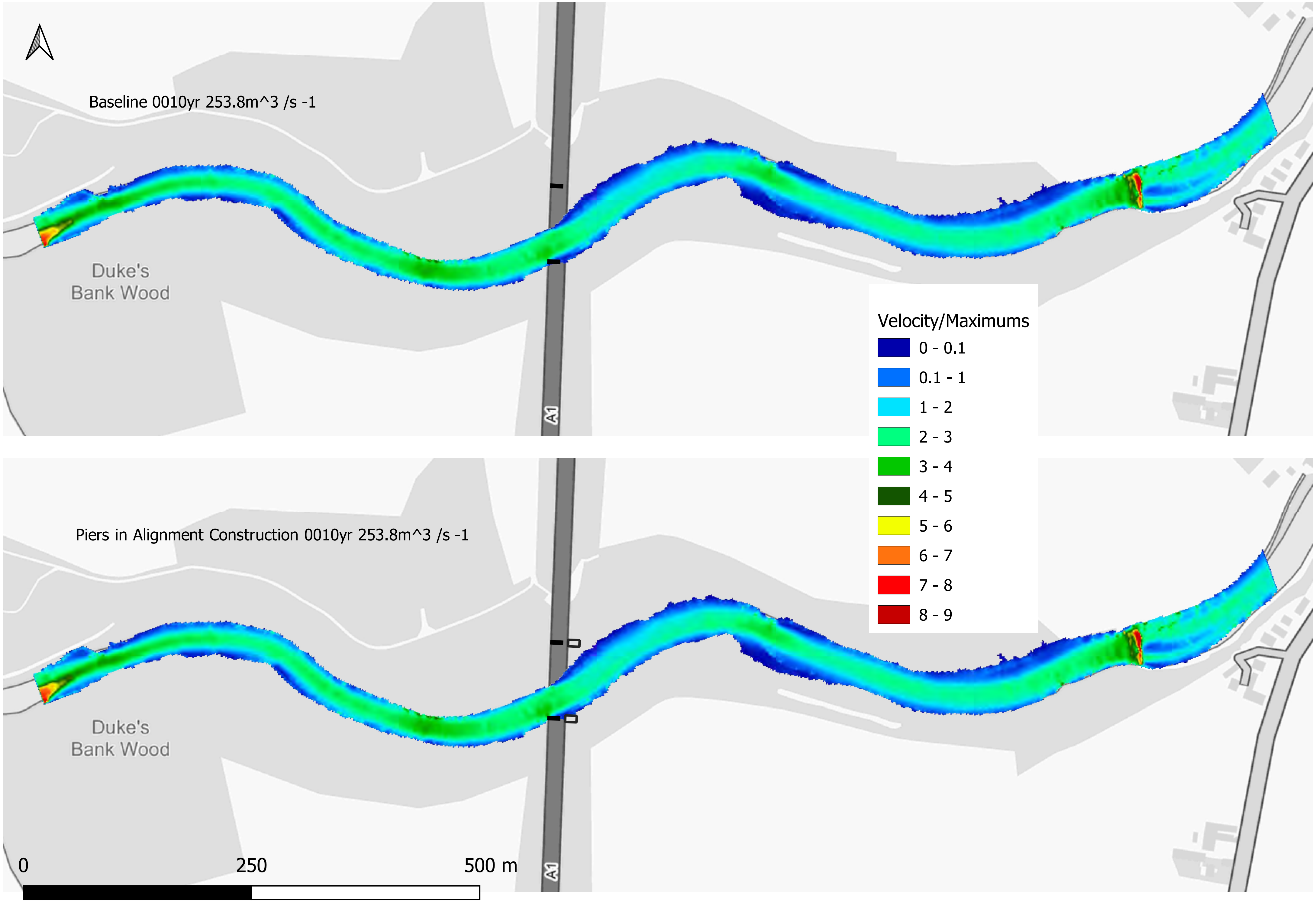
Duke's Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
Piers in Alignment Operation 0002yr 148.7m^3 /s -1
Duke's Bank Wood
0
250
500 m
A1


Baseline 0002yr 148.7m^3 /s -1
Duke's
Bank Wood
A1
Parameter 10 Construction 0002yr 148.7m^3 /s -1
Duke's
Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
0
250
500 m



Baseline 0002yr 148.7m^3 /s -1
Duke's Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
Parameter 10 Alignment Operation 0002yr 148.7m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m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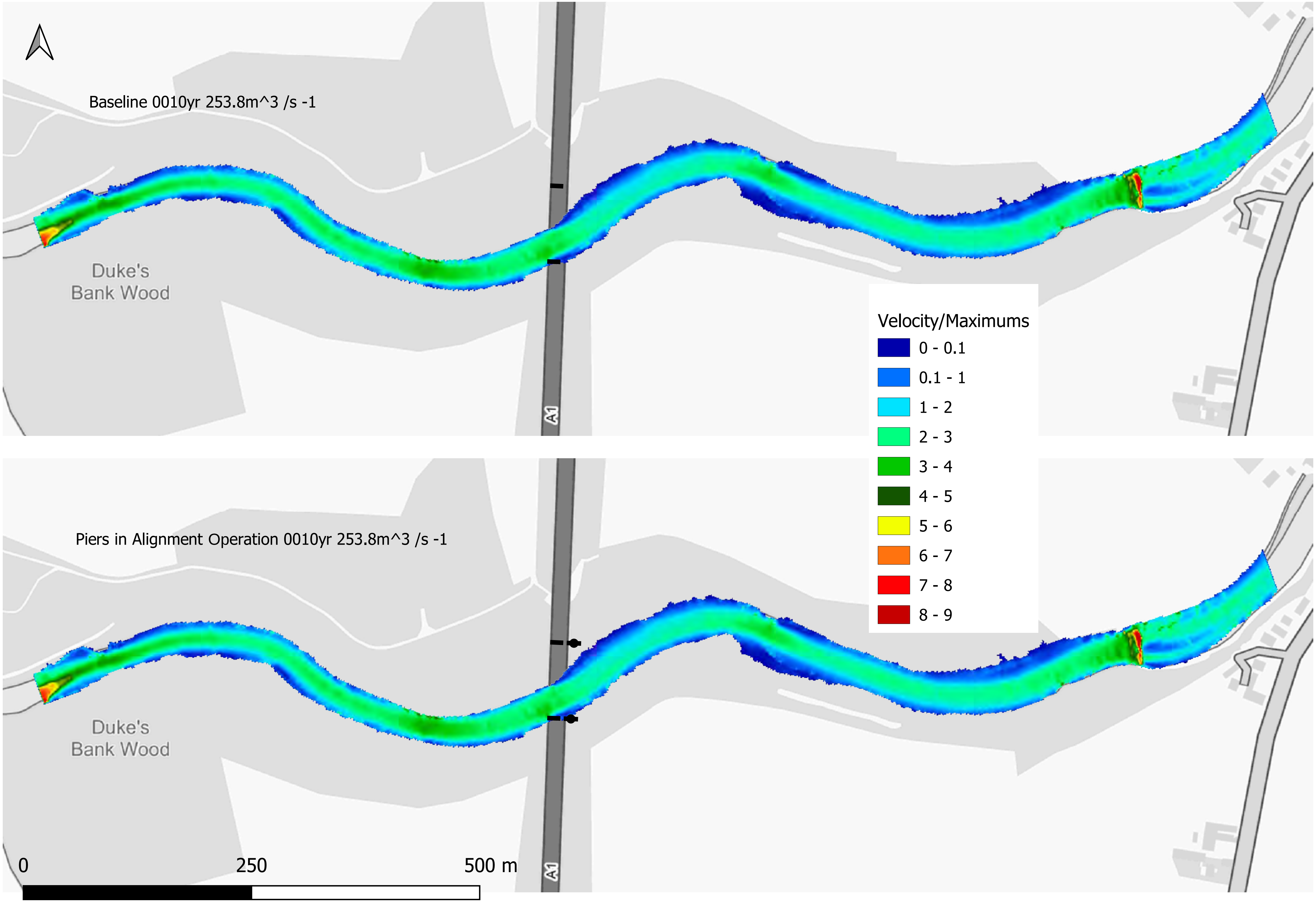
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
Piers in Alignment Construction 0010yr 253.8m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m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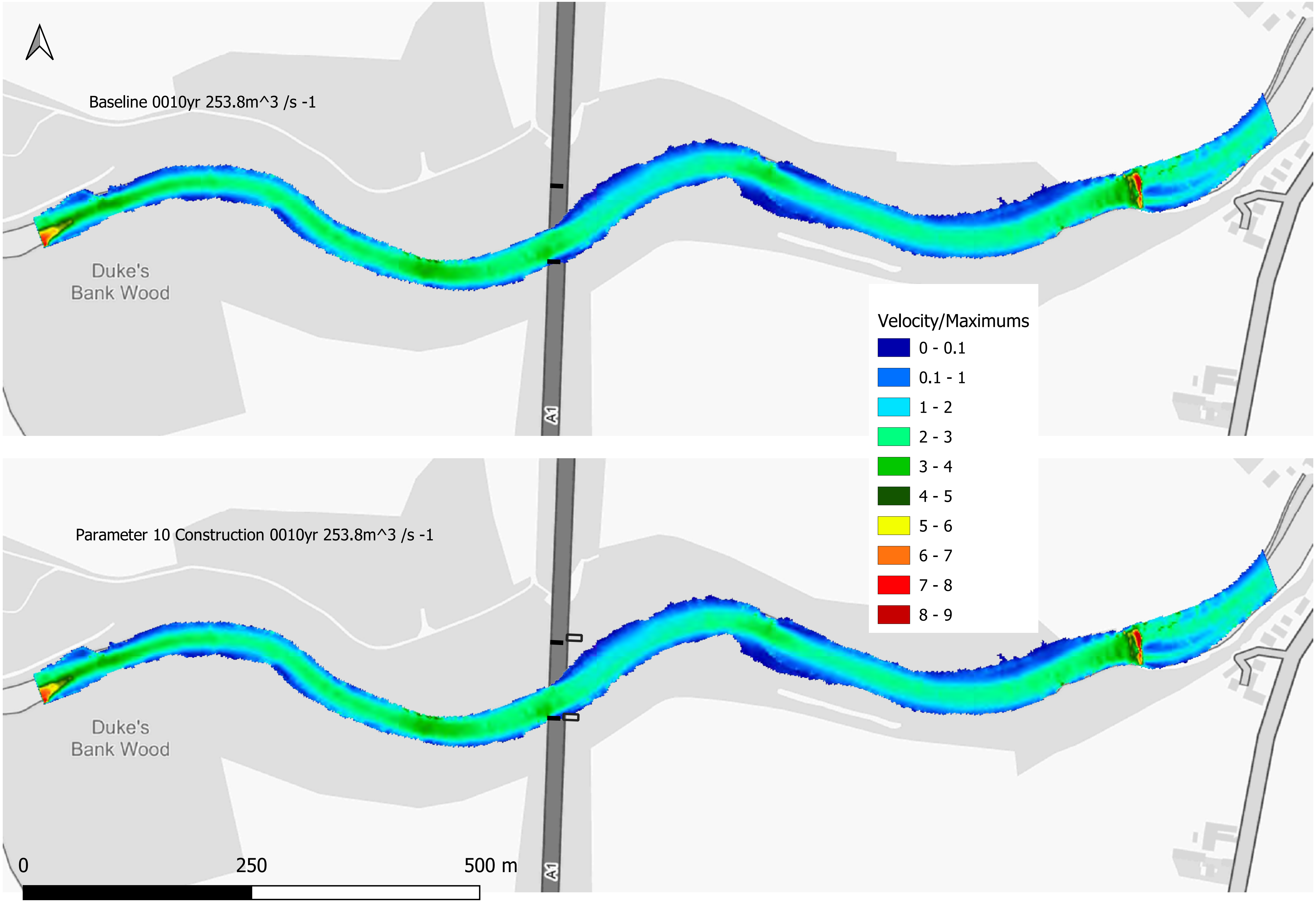
Piers in Alignment Operation 0010yr 253.8m^3 /s -1
Duke's Bank Wood
Duke's Bank Wood
A1
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
0
250
500 m


Baseline 0010yr 253.8m^3 /s -1
Duke's
Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
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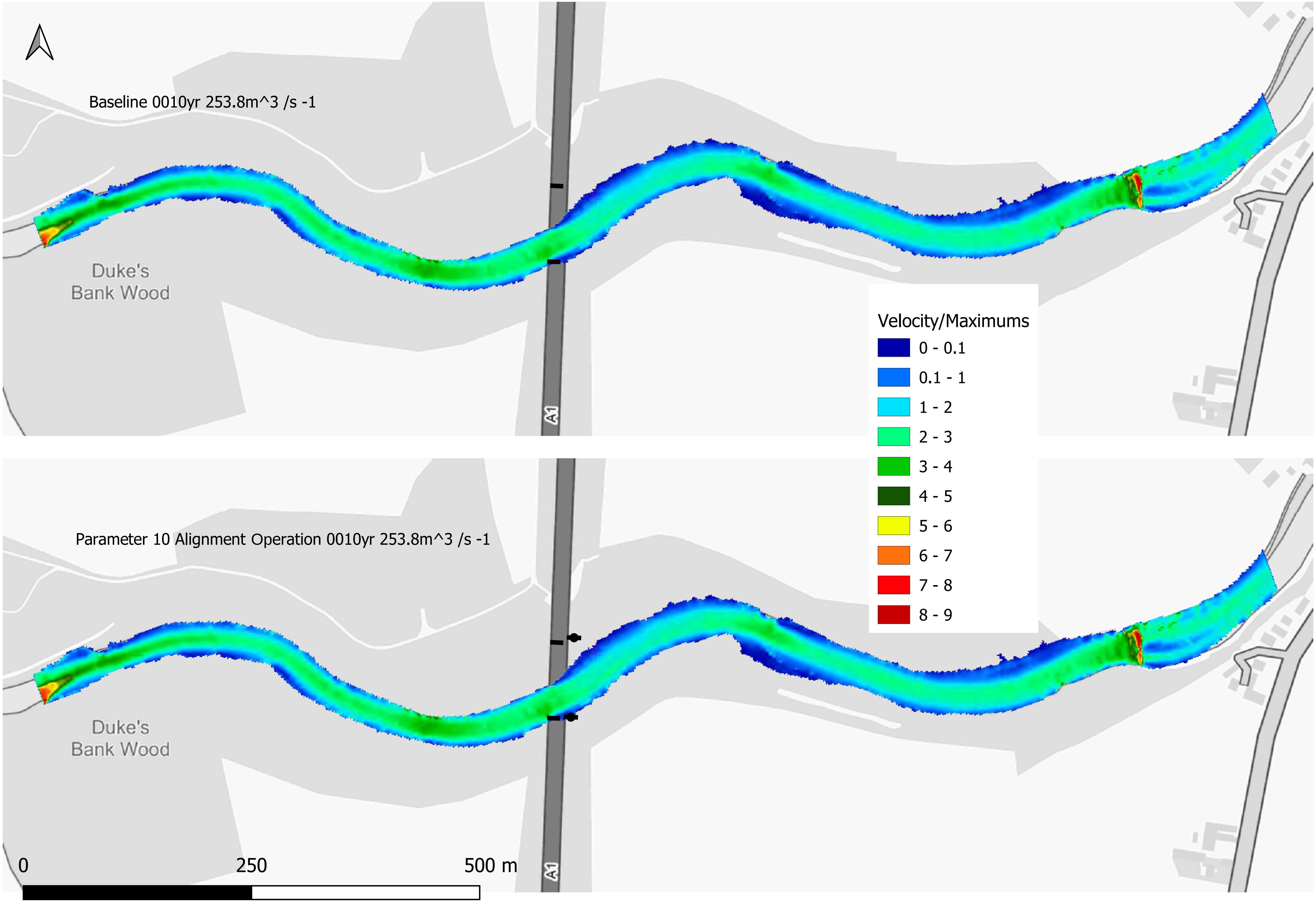
8 - 9
Parameter 10 Construction 0010yr 253.8m^3 /s -1
Duke's
Bank Wood
A1
0
250
500 m



Baseline 0010yr 253.8m^3 /s -1
Duke's
Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
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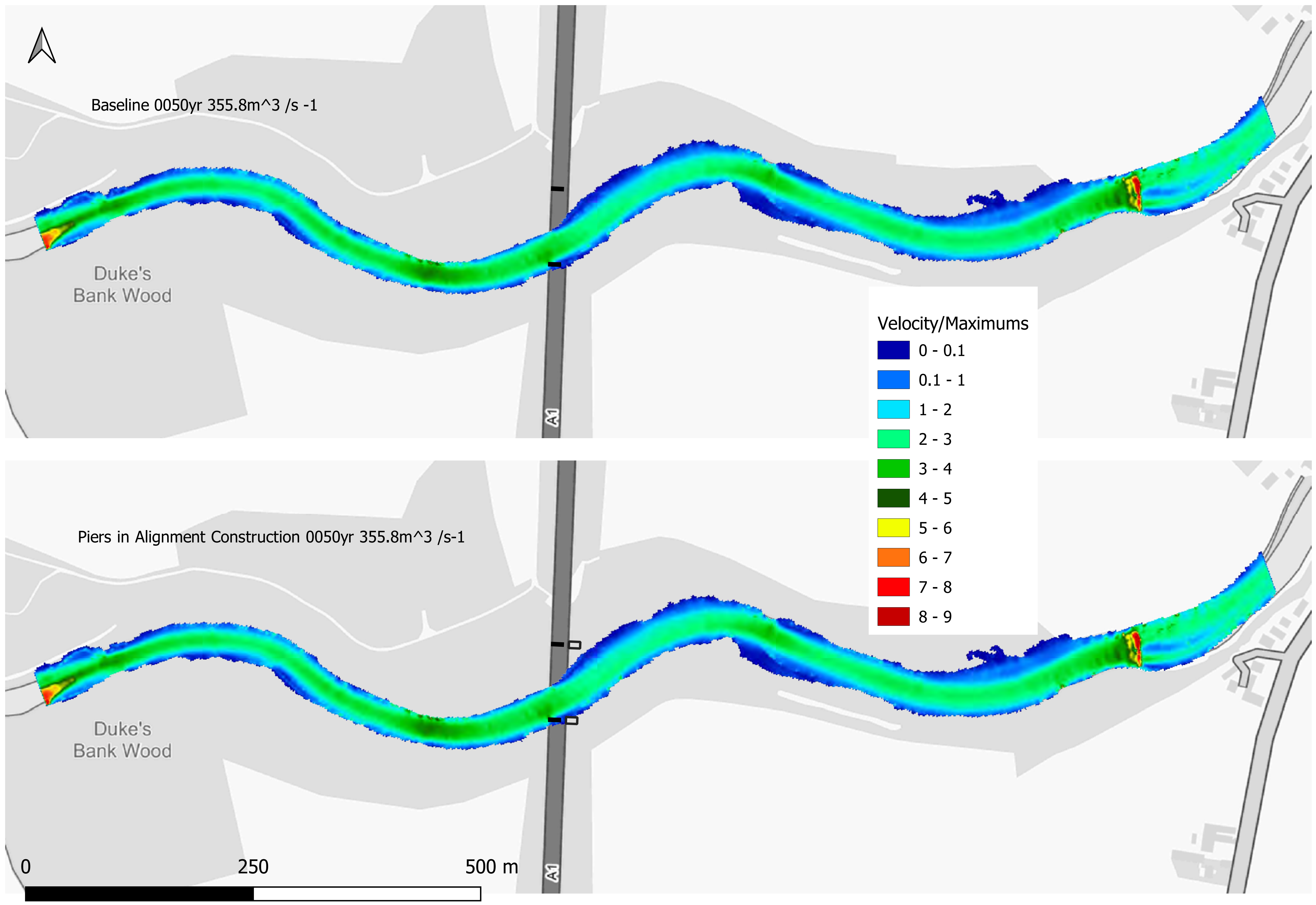
6 - 7
7 - 8
8 - 9
Parameter 10 Alignment Operation 0010yr 253.8m^3 /s -1
Duke's
Bank Wood
A1
0
250
500 m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Duke's Bank Wood
A1
Velocity/Maximums
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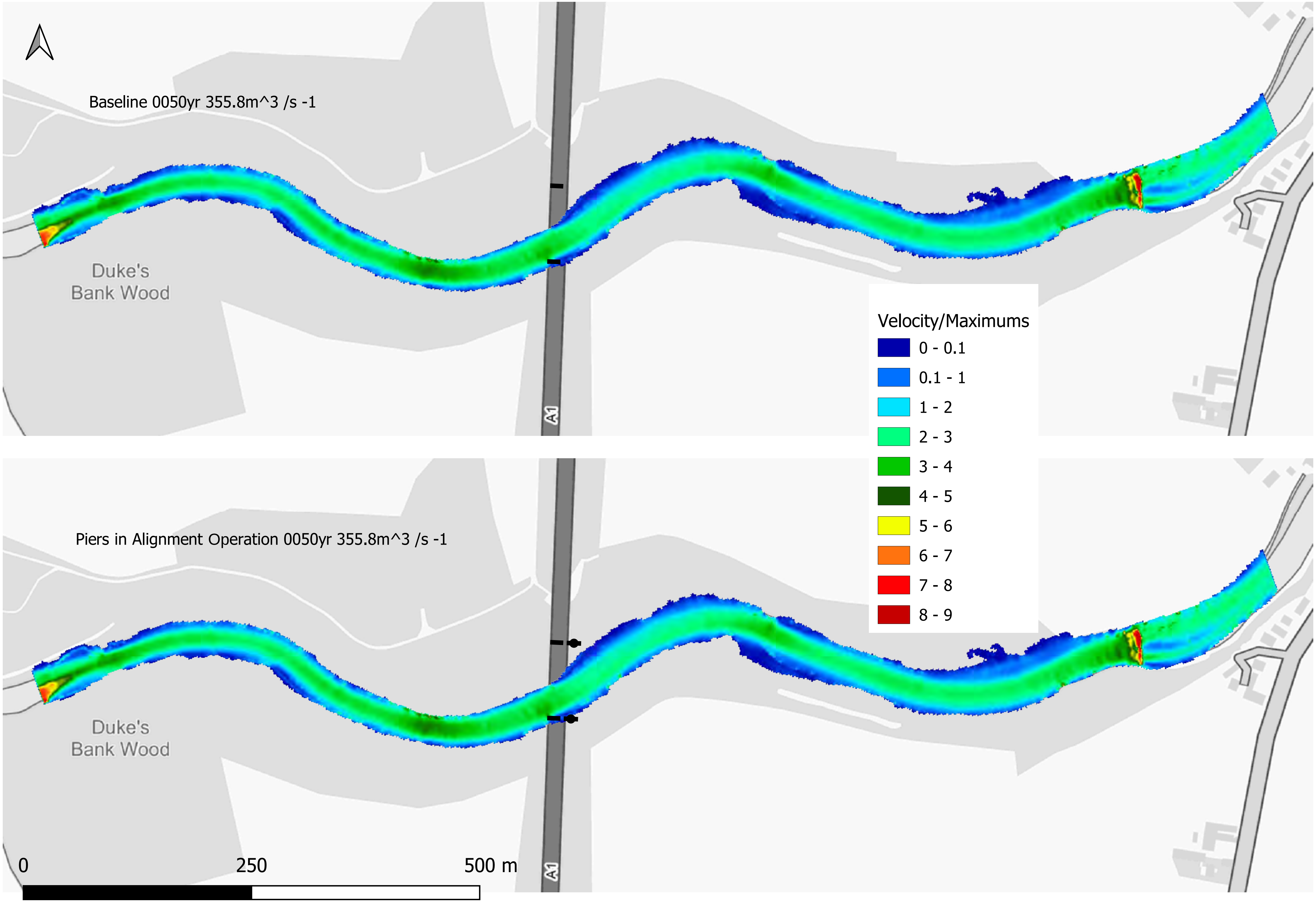
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
Piers in Alignment Construction 0050yr 355.8m^3 /s-1
Duke's Bank Wood
A1
0
250
500 m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Duke's
Bank Wood
A1
Velocity/Maximums
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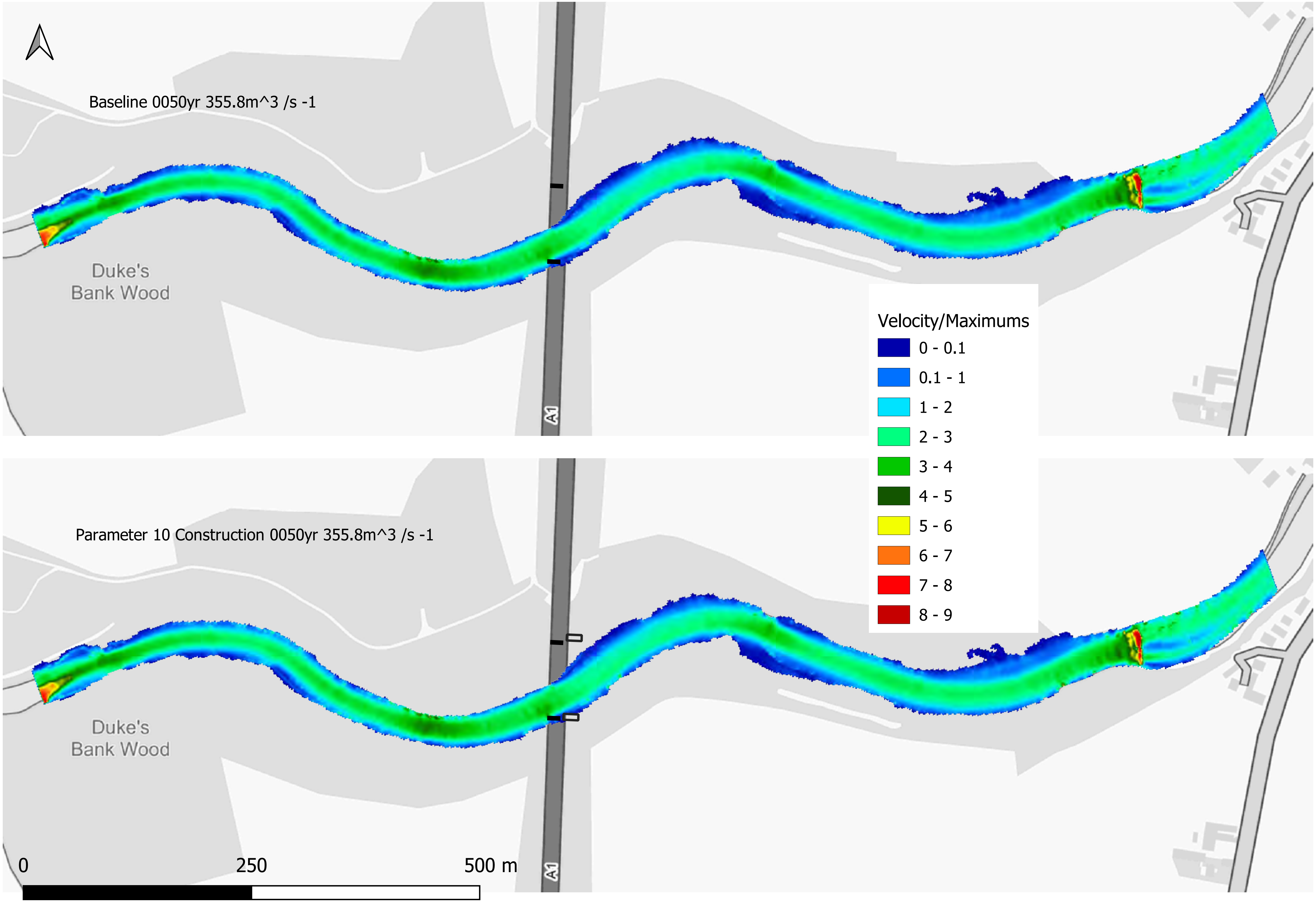
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
Piers in Alignment Operation 0050yr 355.8m^3 /s -1
Duke's
Bank Wood
0
250
500 m
A1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Duke's Bank Wood
A1
Velocity/Maximums
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0.1 - 1
1 - 2
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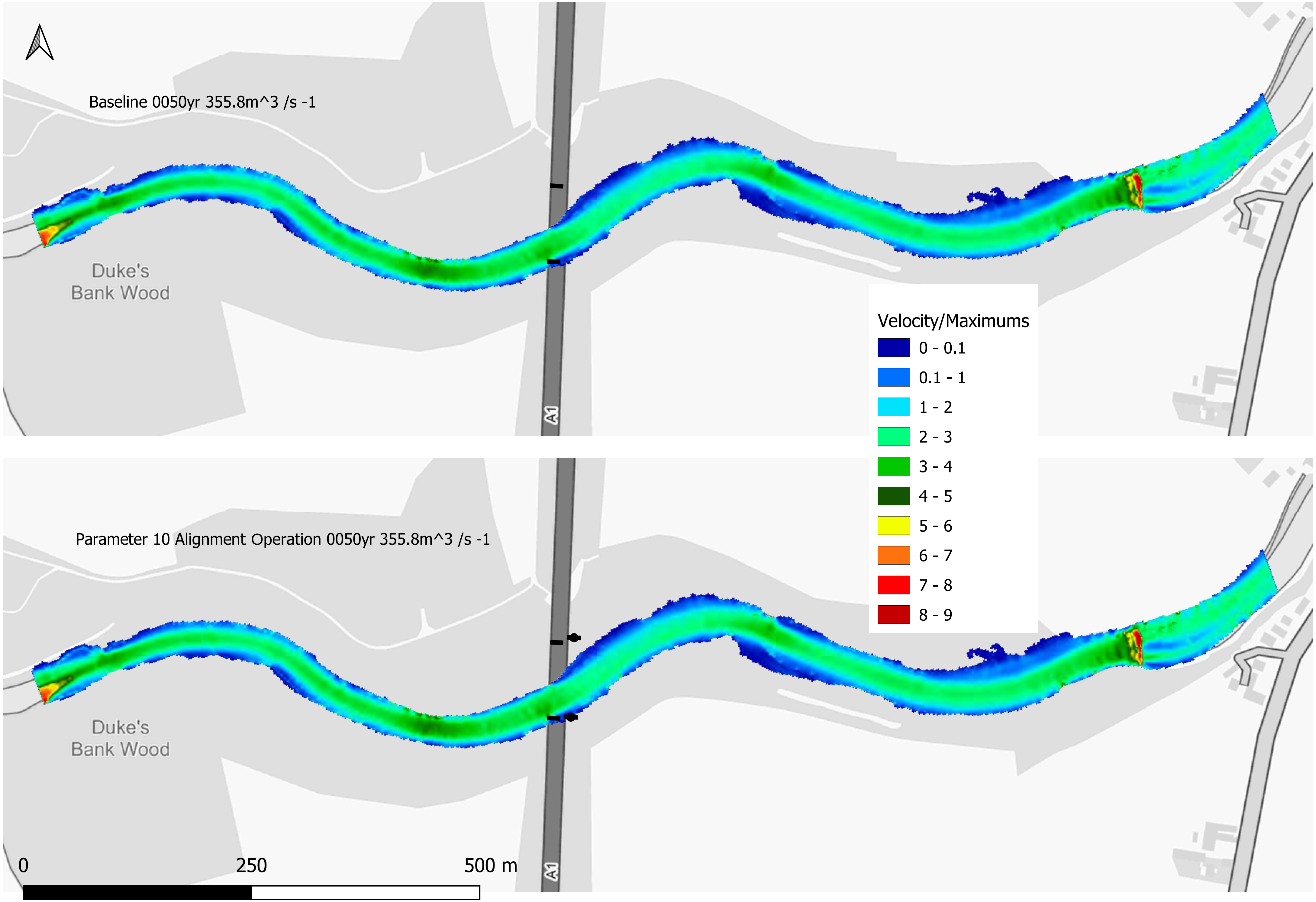
Parameter 10 Construction 0050yr 355.8m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m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Duke's
Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
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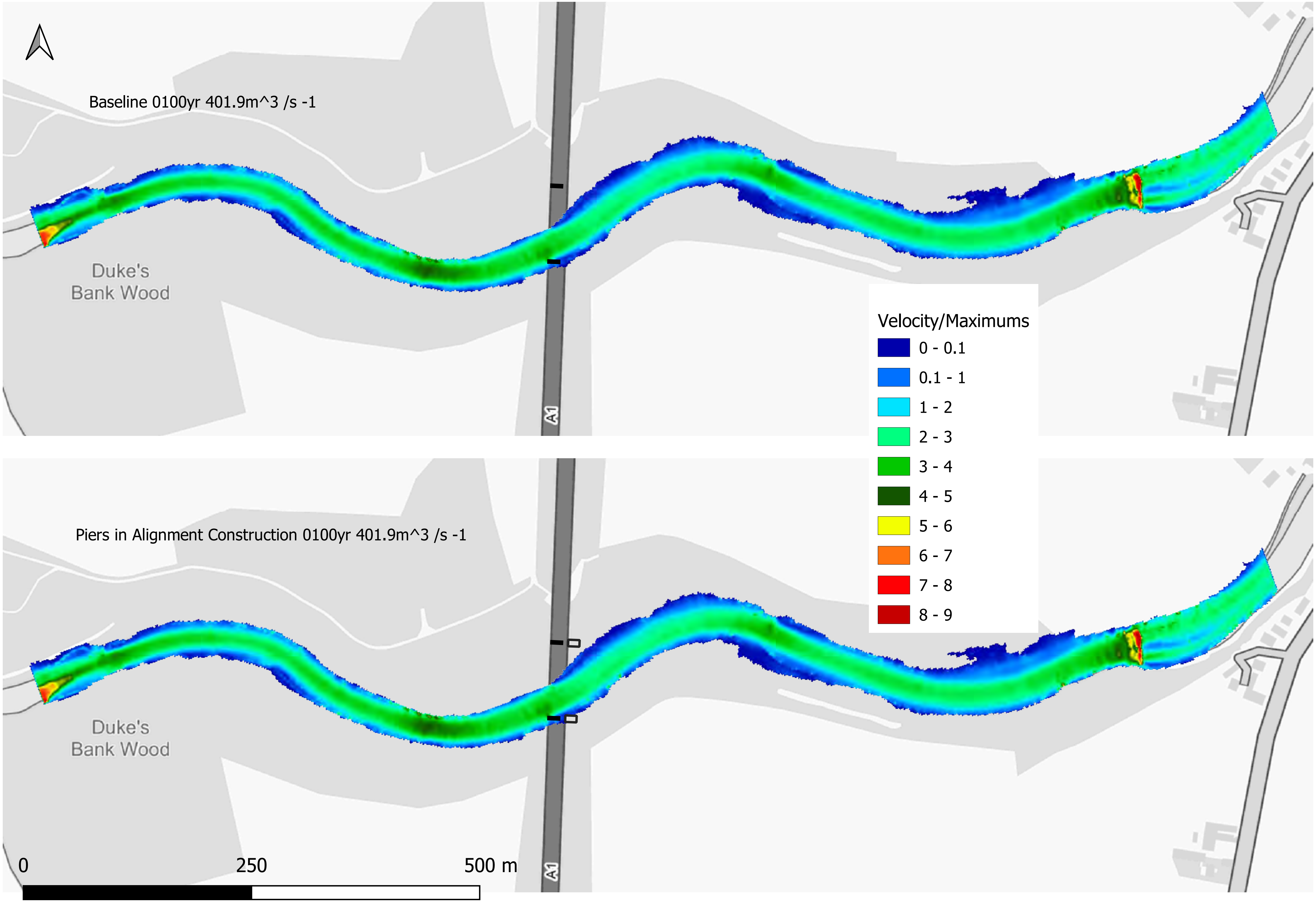
8 - 9
Parameter 10 Alignment Operation 0050yr 355.8m^3 /s -1
Duke's
Bank Wood
A1
0
250
500 m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Duke's Bank Wood
A1
Velocity/Maximums
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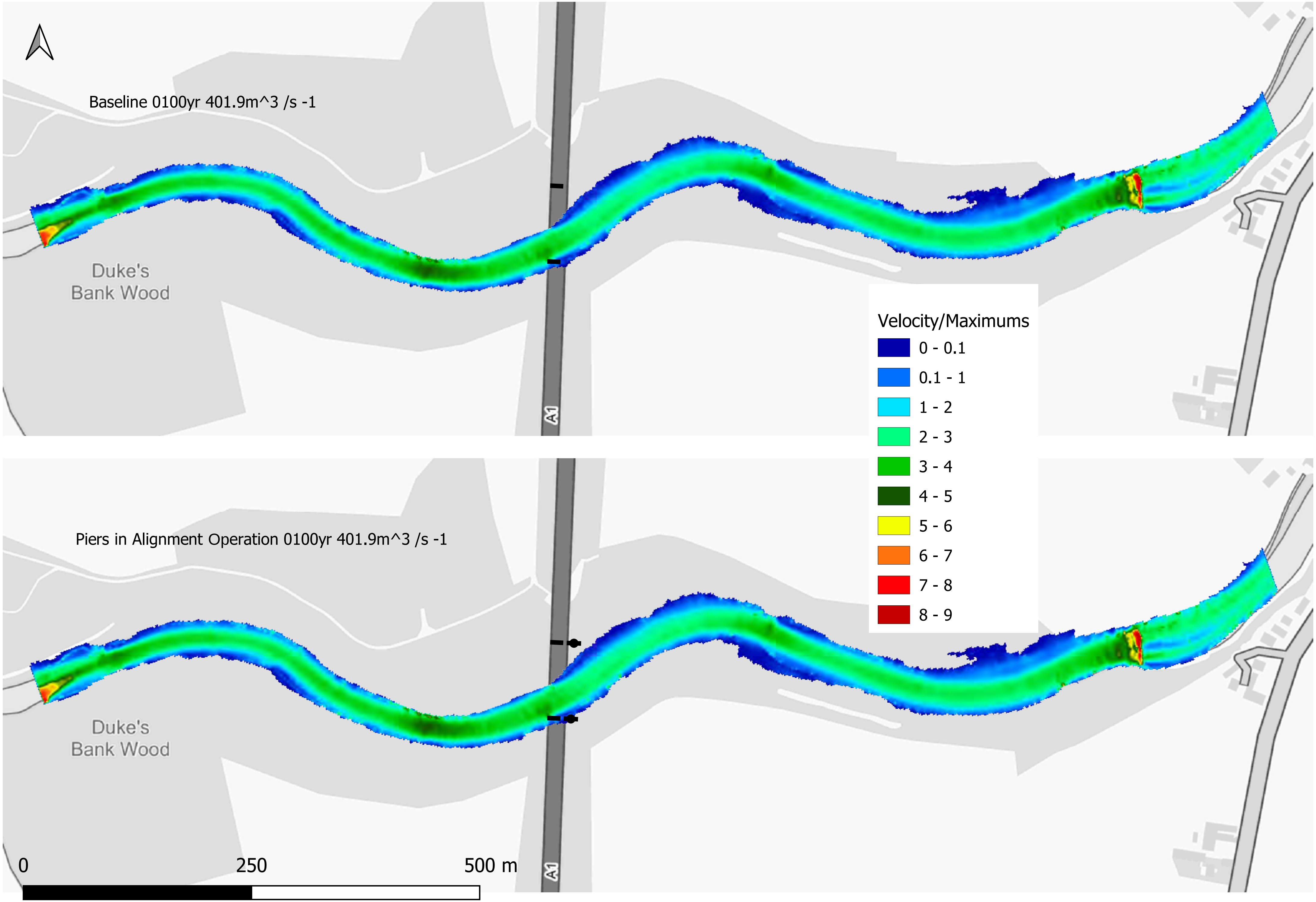
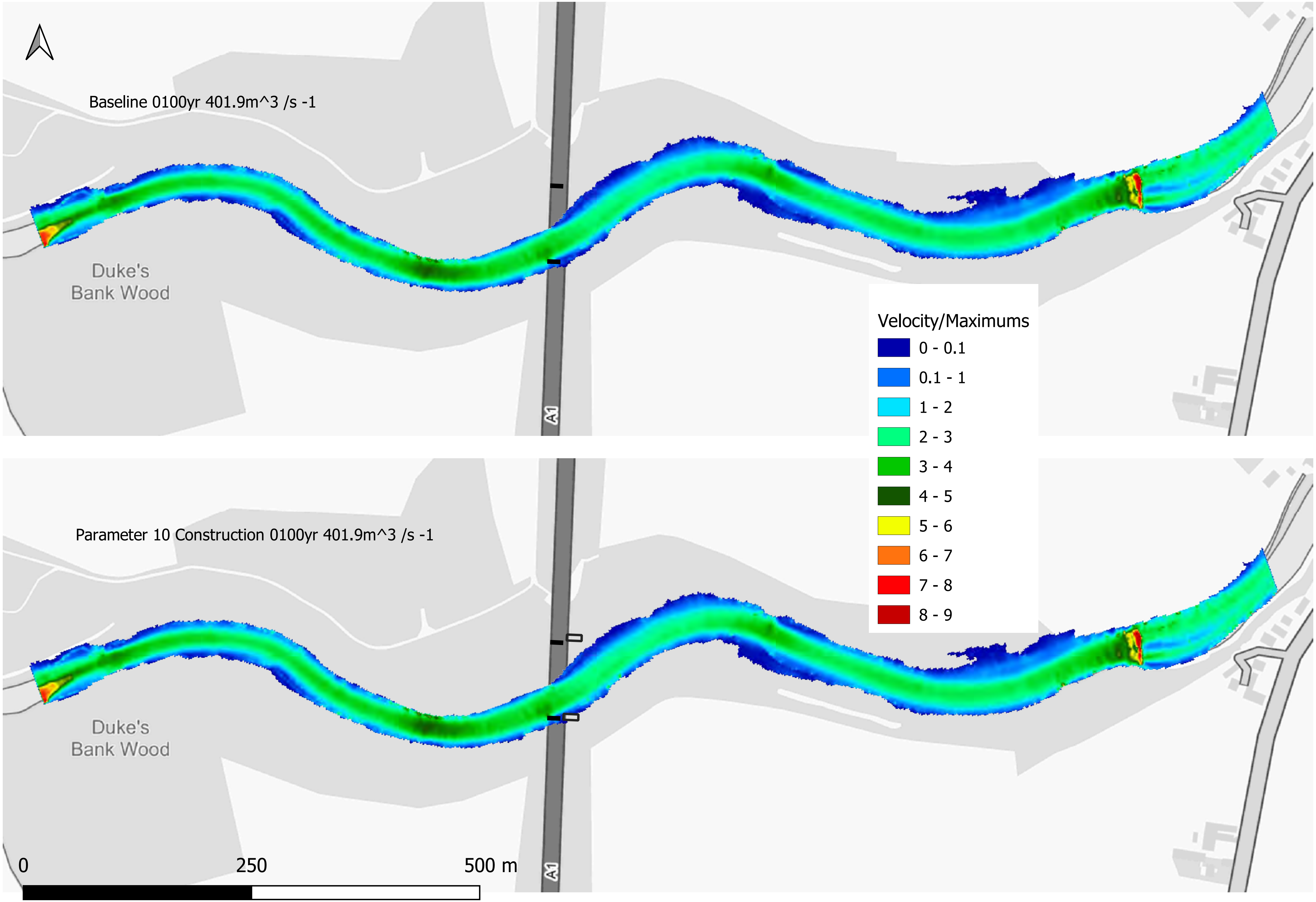
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
Piers in Alignment Construction 0100yr 401.9m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m


Baseline 0100yr 401.9m^3 /s -1
Duke's Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
Piers in Alignment Operation 0100yr 401.9m^3 /s -1
Duke's Bank Wood
0
250
500 m
A1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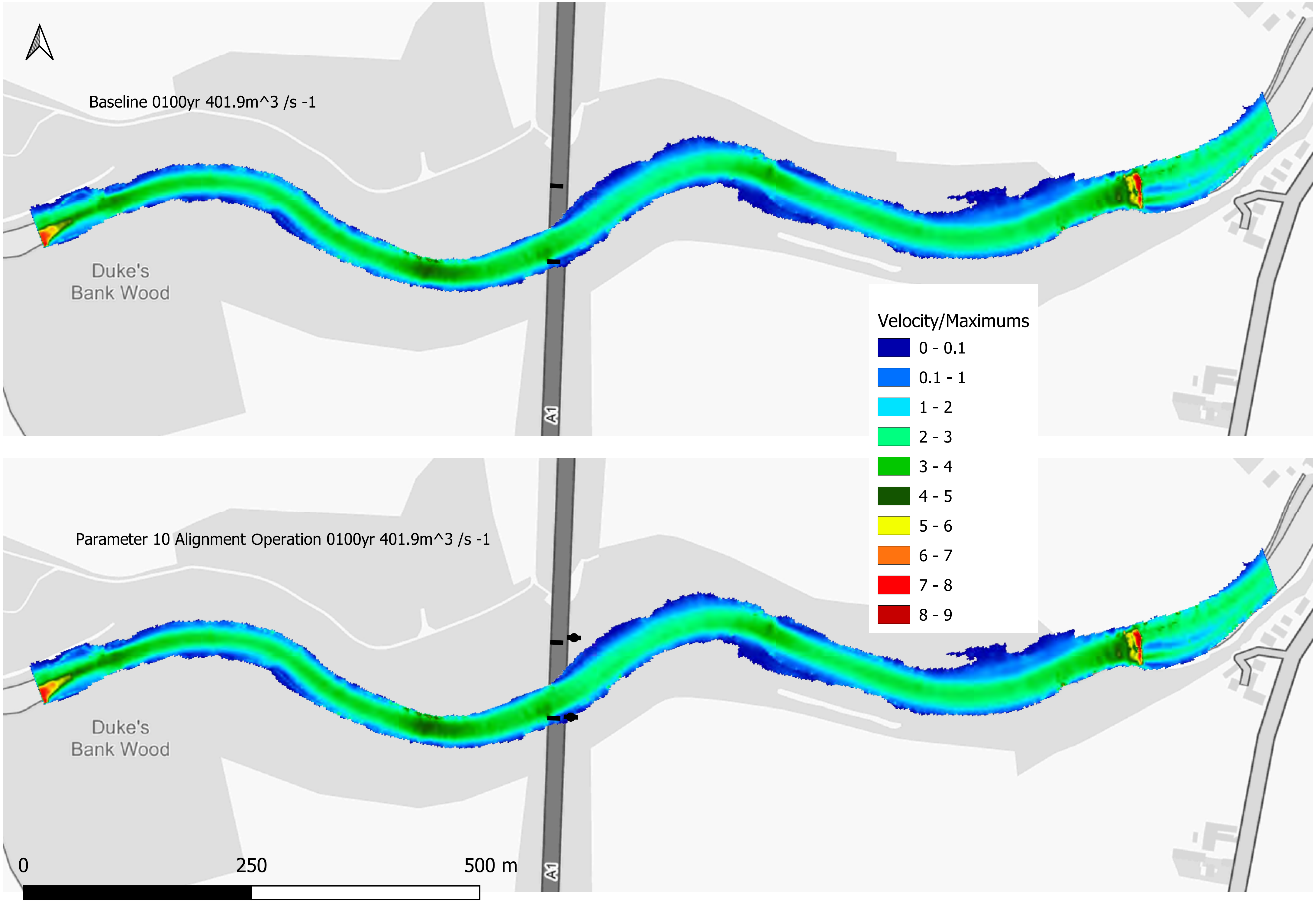
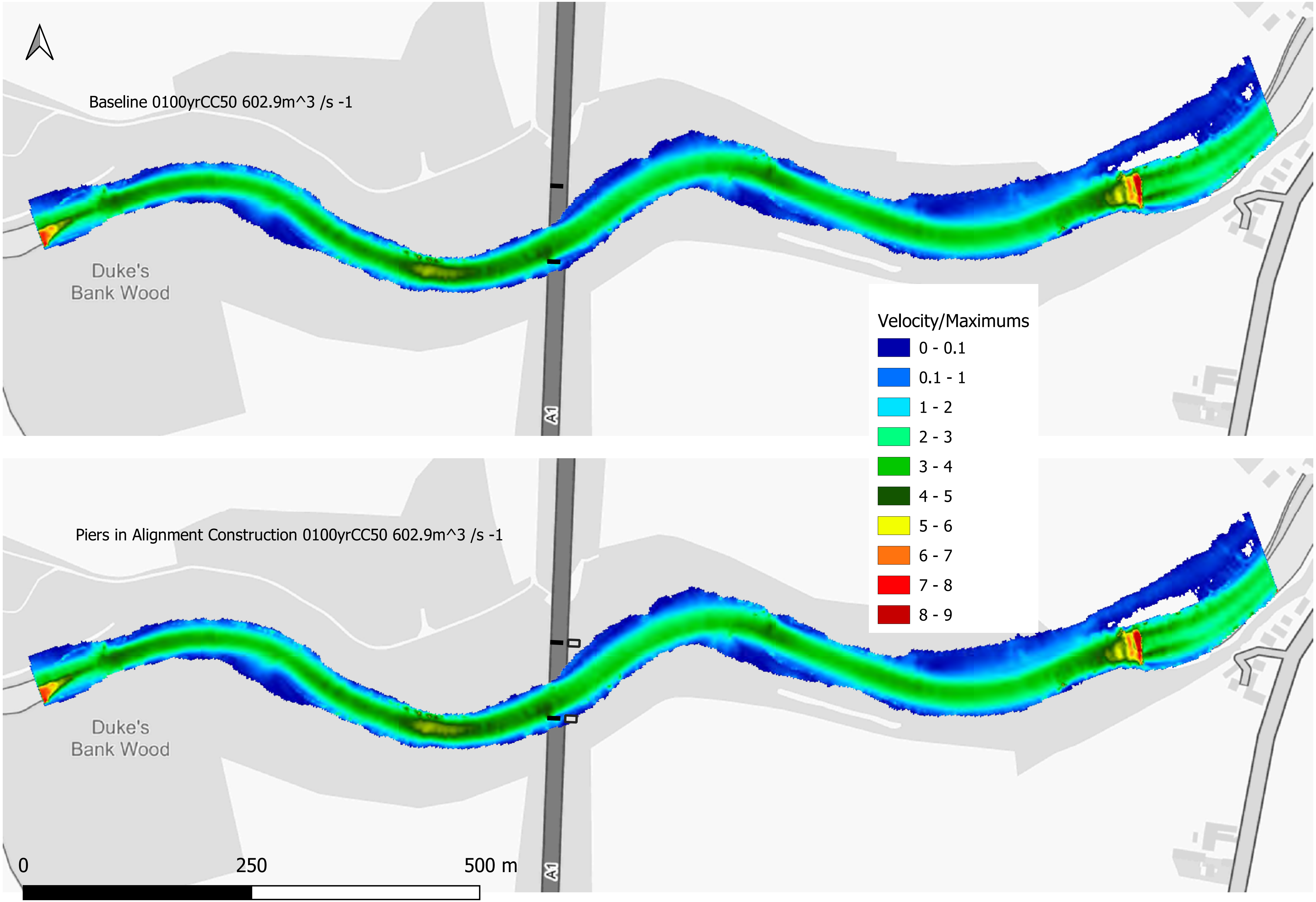
Duke's
Bank Wood
A1
Parameter 10 Construction 0100yr 401.9m^3 /s -1
Duke's
Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
0
250
500 m


Baseline 0100yr 401.9m^3 /s -1
Duke's Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
Parameter 10 Alignment Operation 0100yr 401.9m^3 /s -1
Duke's Bank Wood
0
250
500 m
A1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Duke's
Bank Wood
A1
Velocity/Maximums
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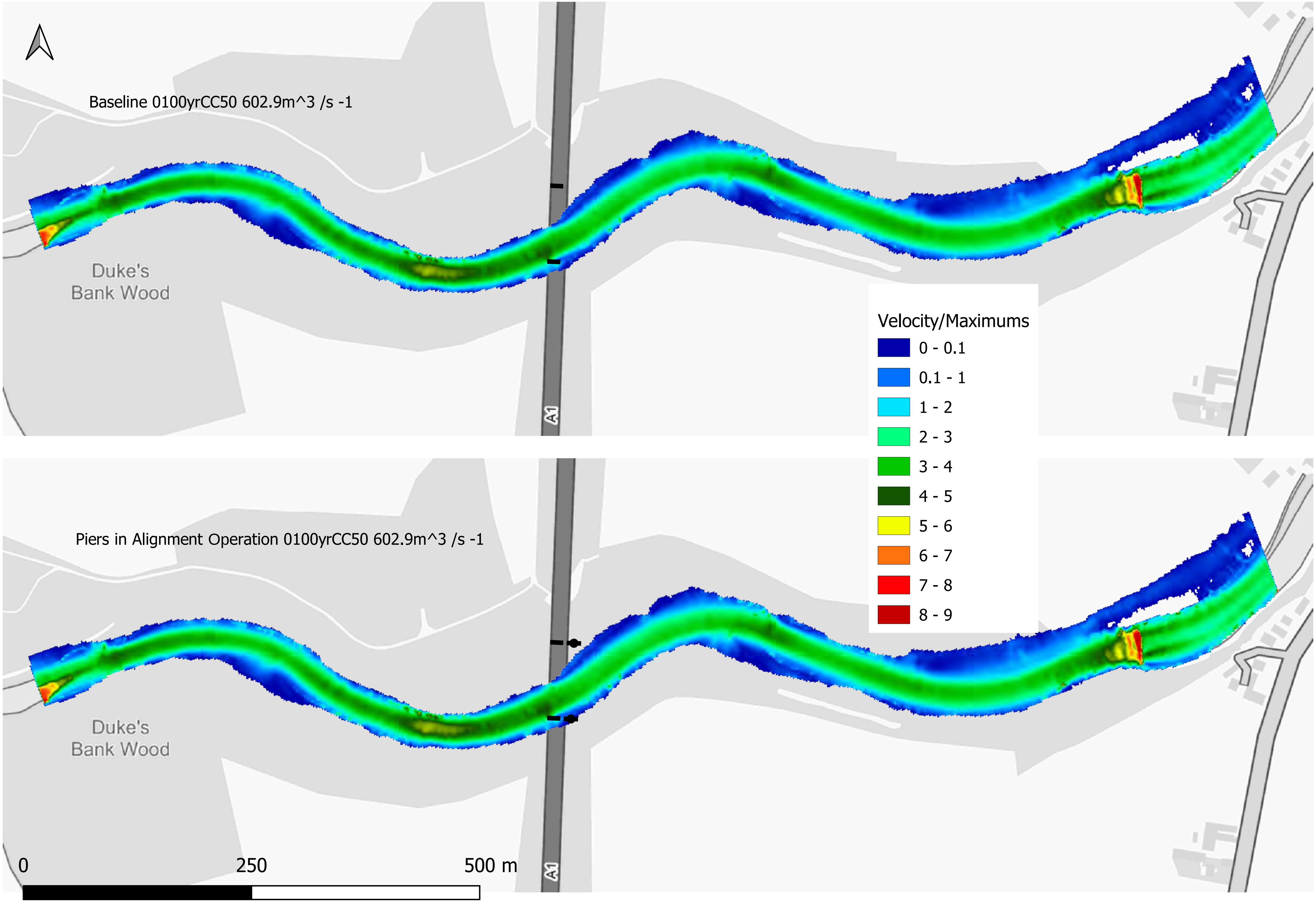
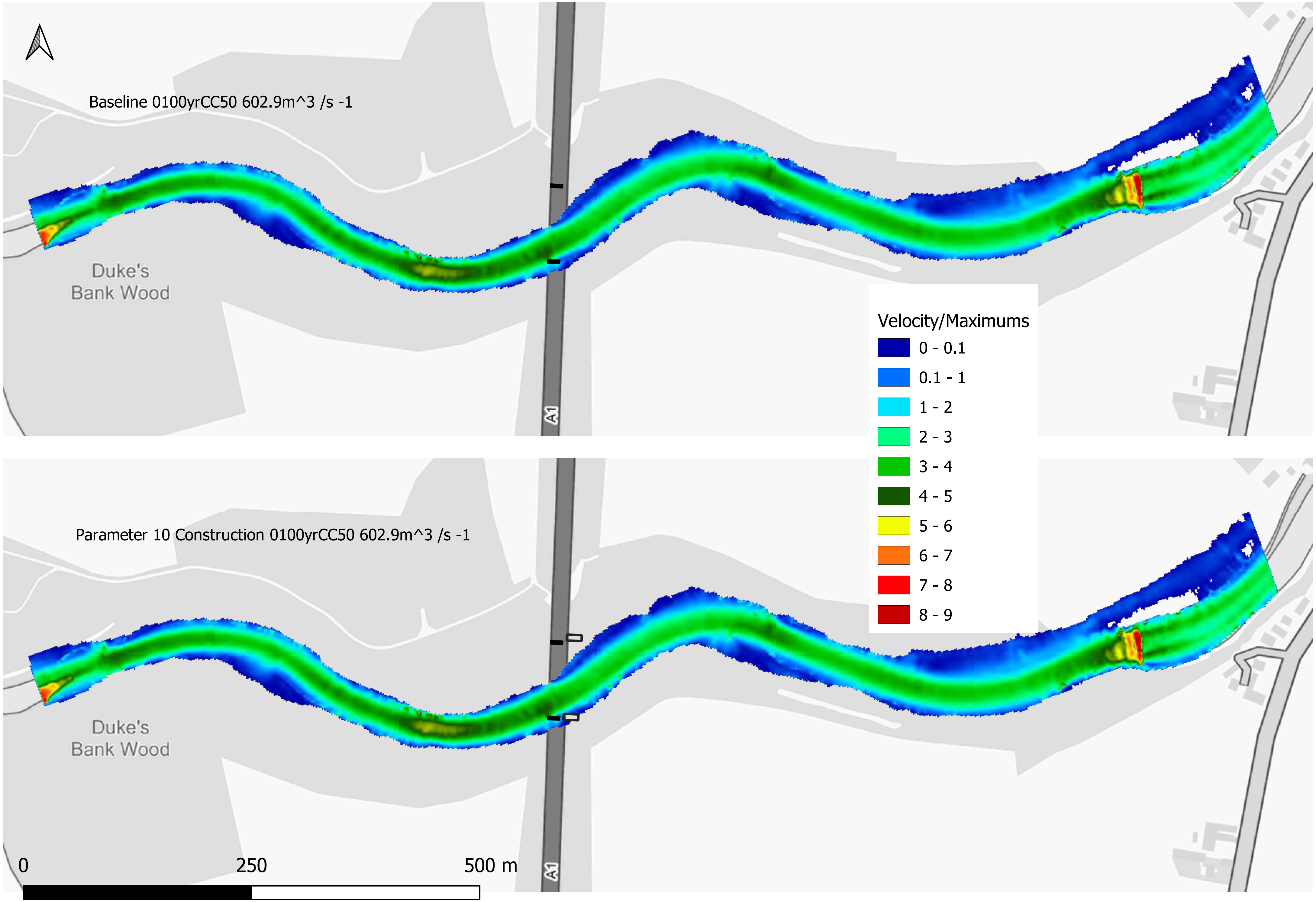
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
Piers in Alignment Construction 0100yrCC50 602.9m^3 /s -1
Duke's
Bank Wood
A1
0
250
500 m



Baseline 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
Piers in Alignment Operation 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
0
250
500 m
A1



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Parameter 10 Construction 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
Duke's Bank Wood
A1
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
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4 - 5
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8 - 9
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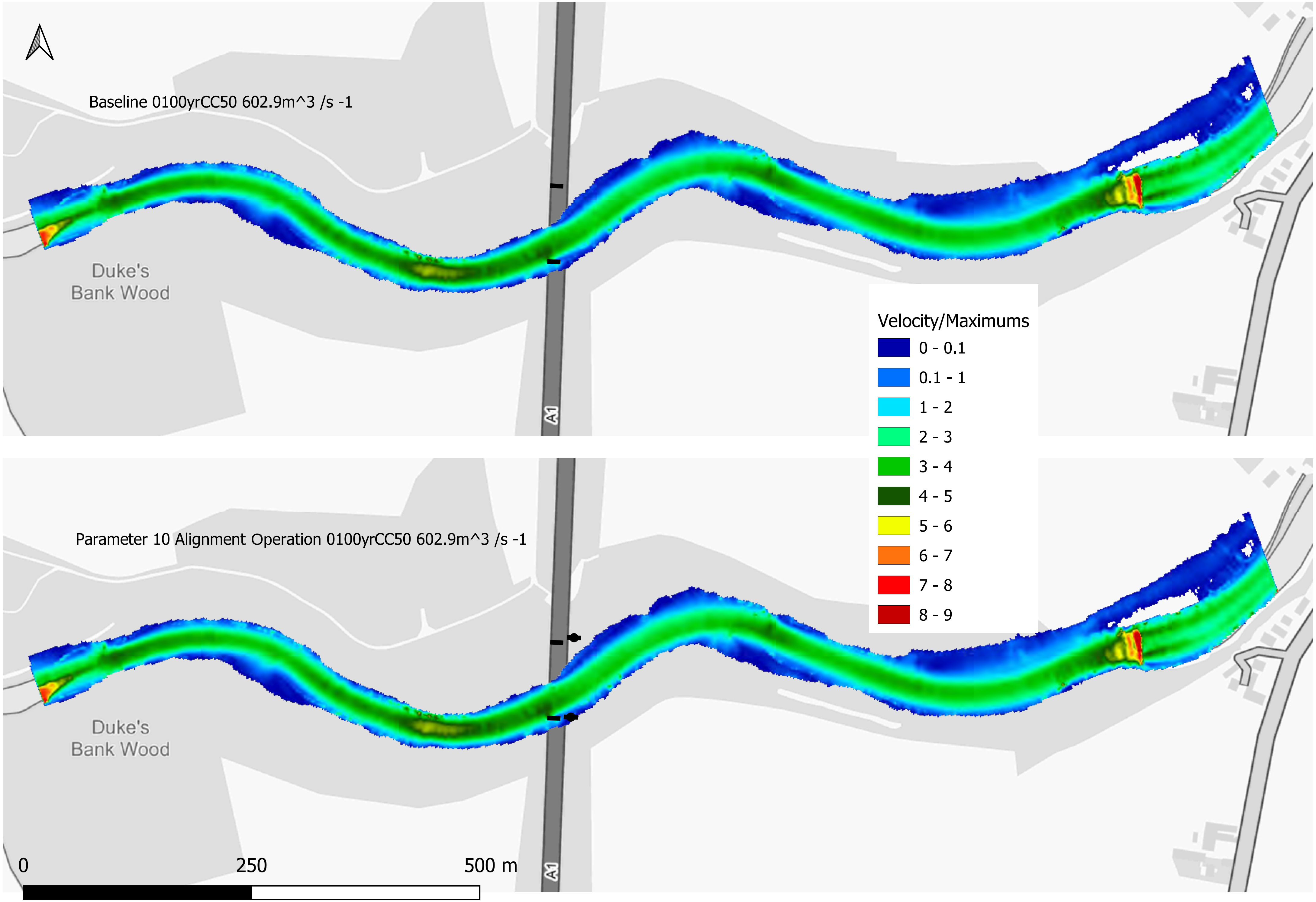
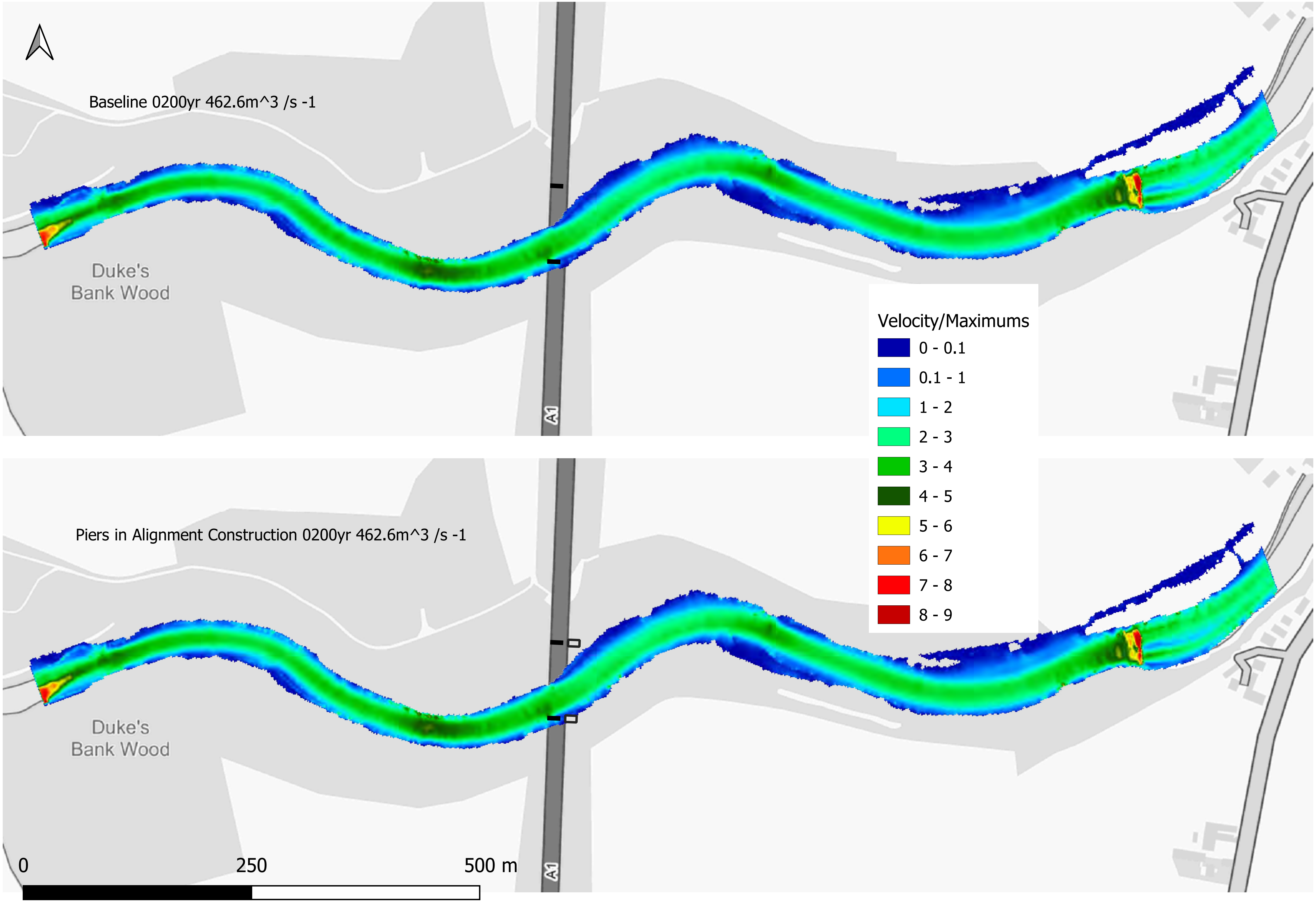
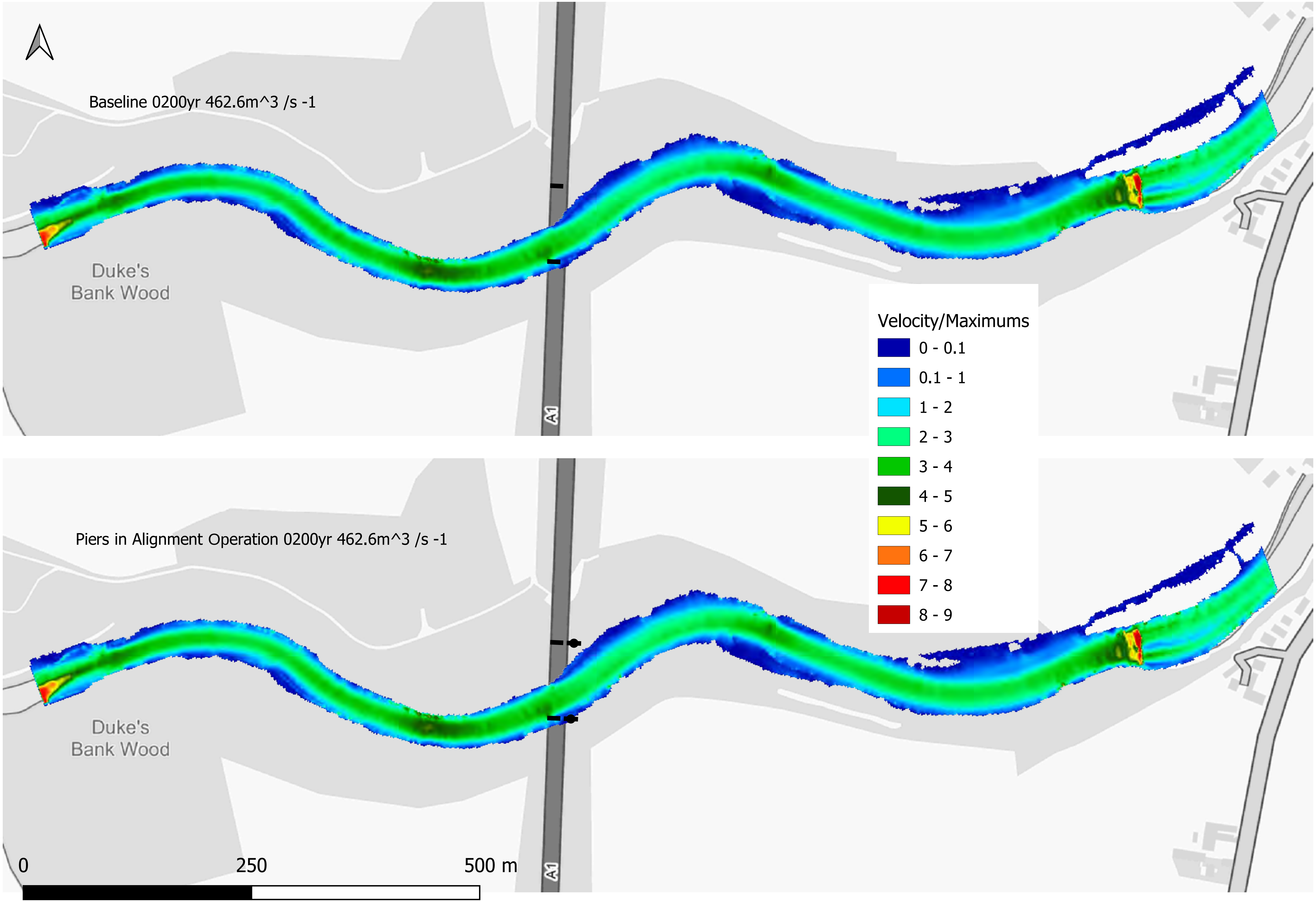
250
500 m

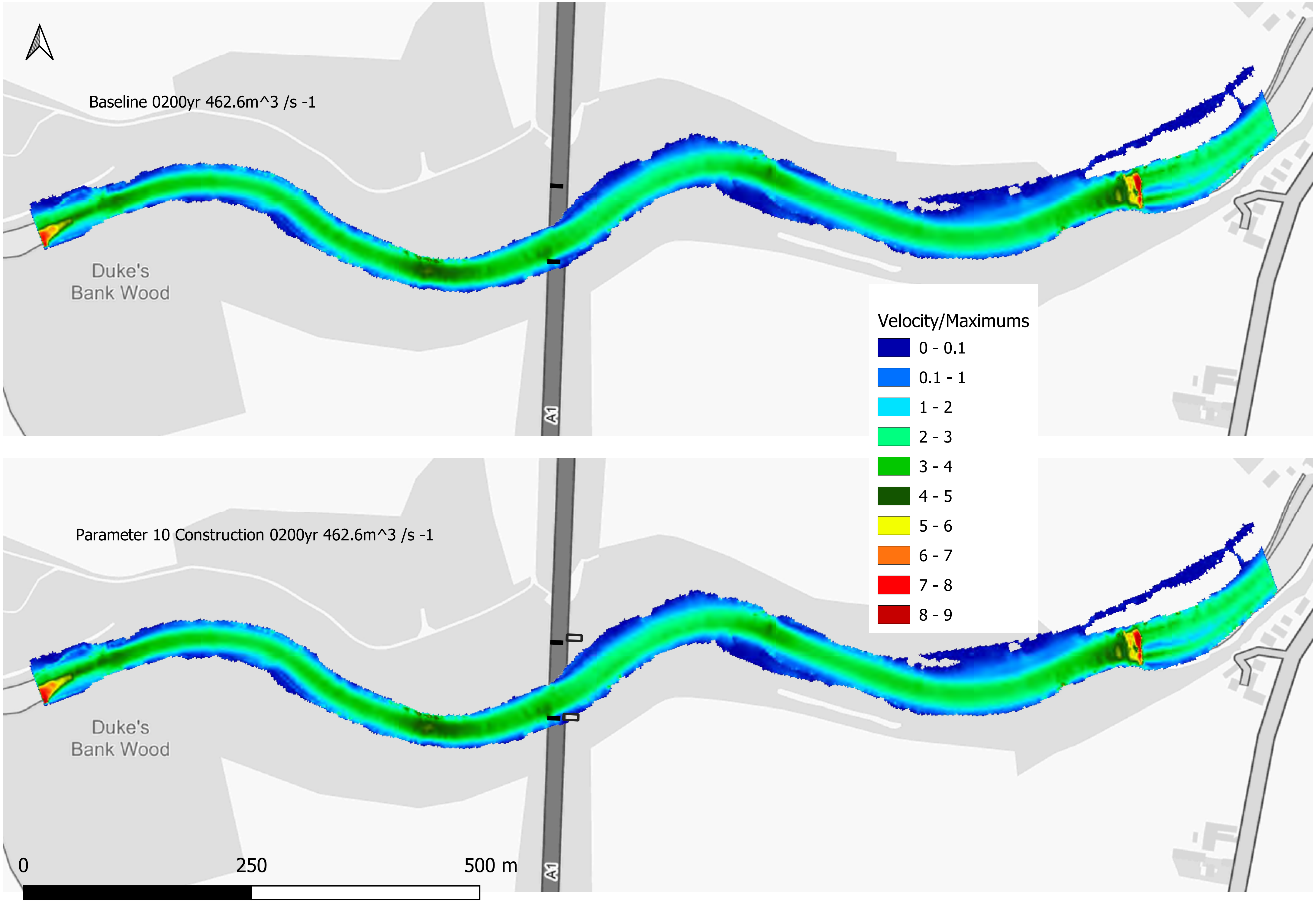


Baseline 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
A1
Parameter 10 Alignment Operation 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
0
250
500 m

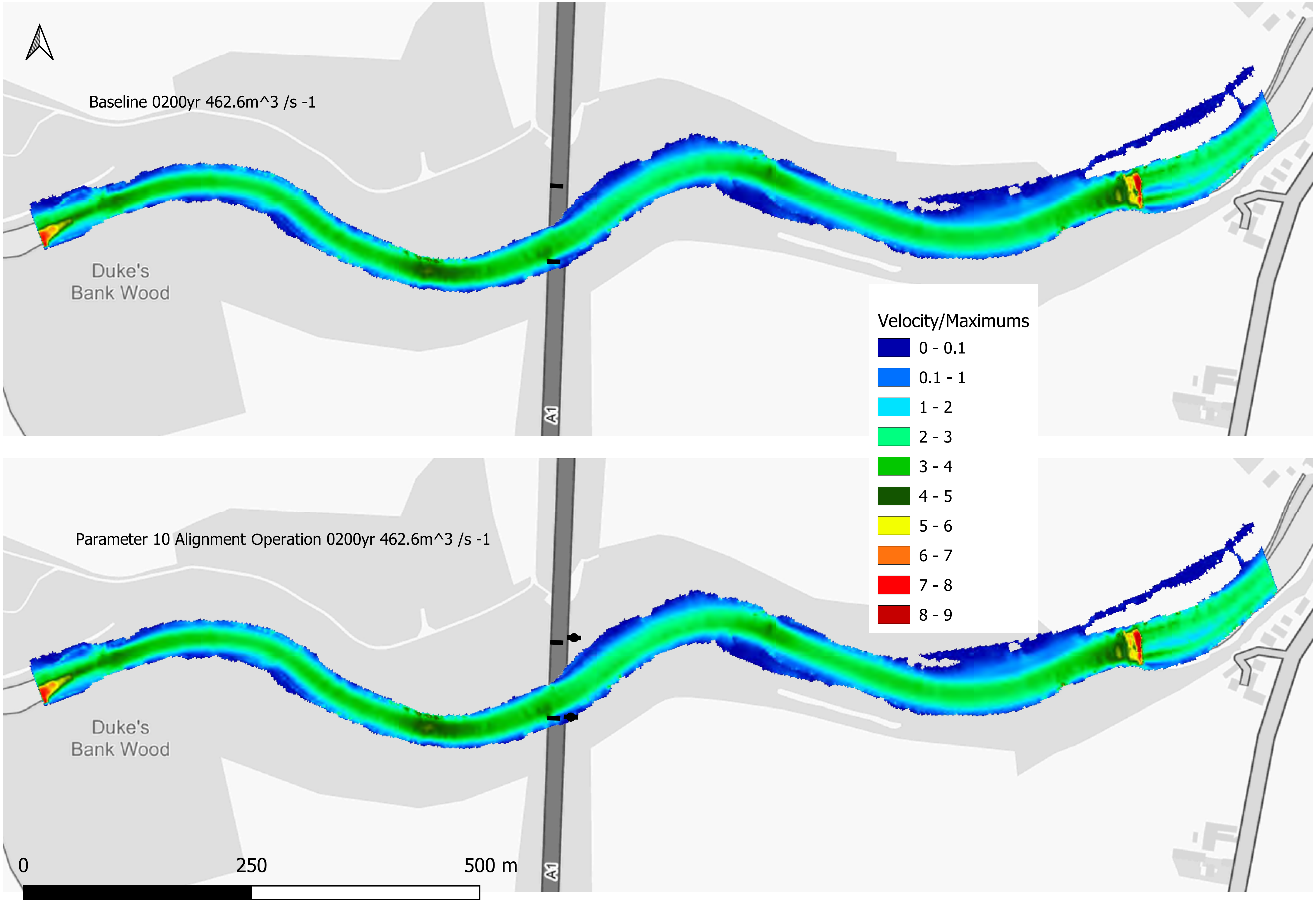

Baseline 0200yr 462.6m^3 /s -1
Duke's Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
Piers in Alignment Construction 0200yr 462.6m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m



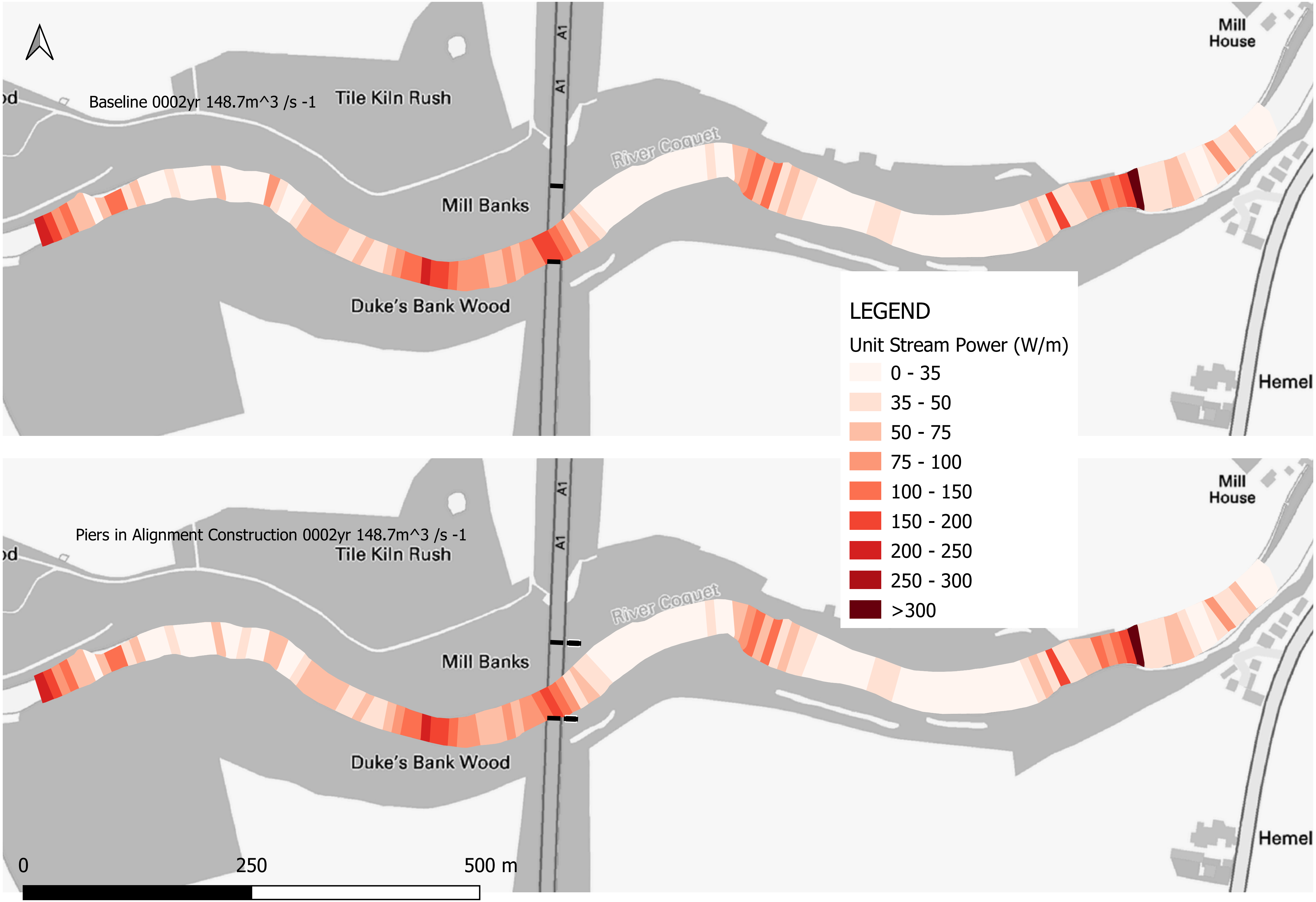
Baseline 0200yr 462.6m^3 /s -1
Duke's Bank Wood
A1
Piers in Alignment Operation 0200yr 462.6m^3 /s -1
Duke's Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
0
250
500 m

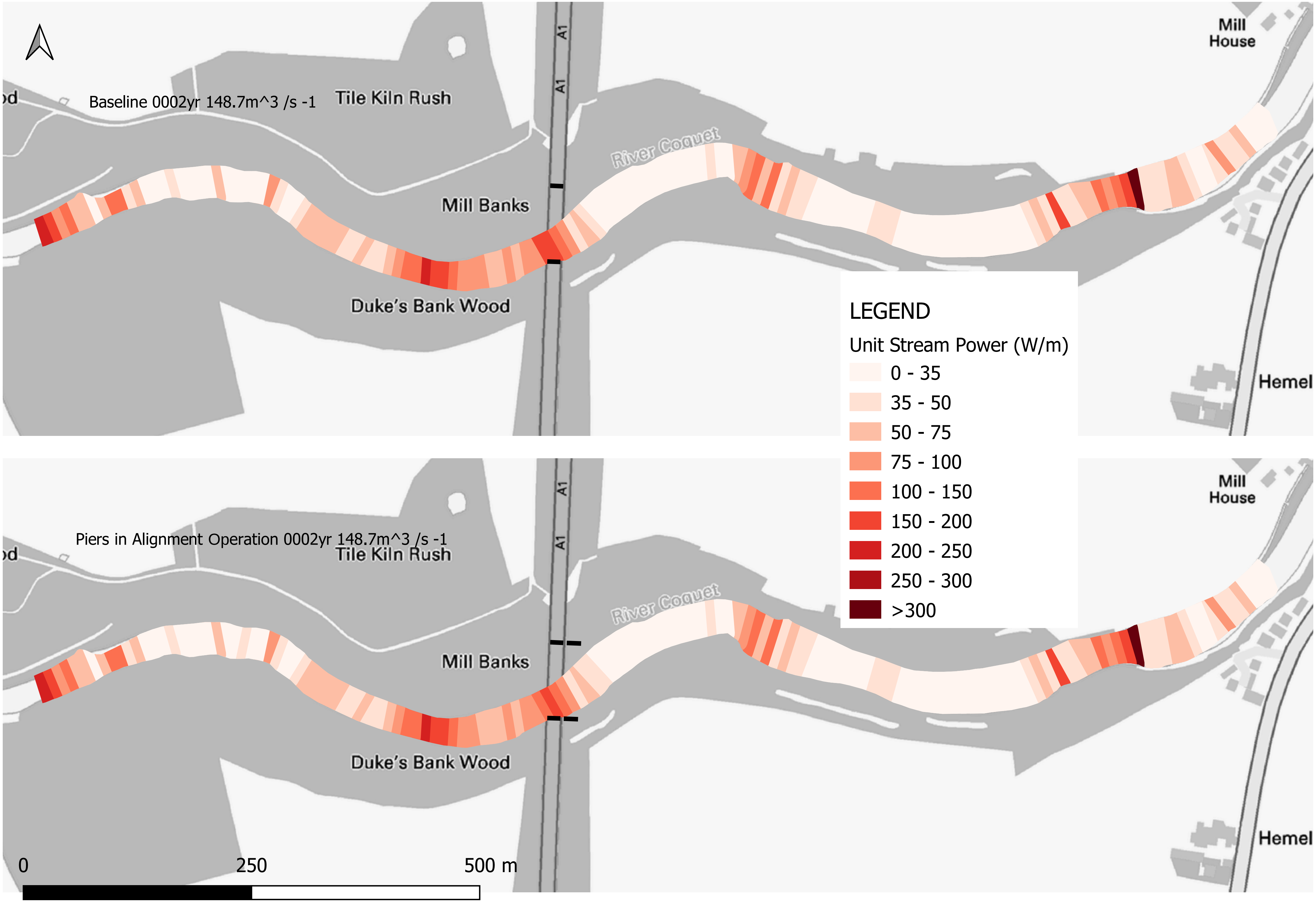


Baseline 0200yr 462.6m^3 /s -1
Duke's
Bank Wood
A1
Parameter 10 Construction 0200yr 462.6m^3 /s -1
Duke's
Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
0
250
500 m

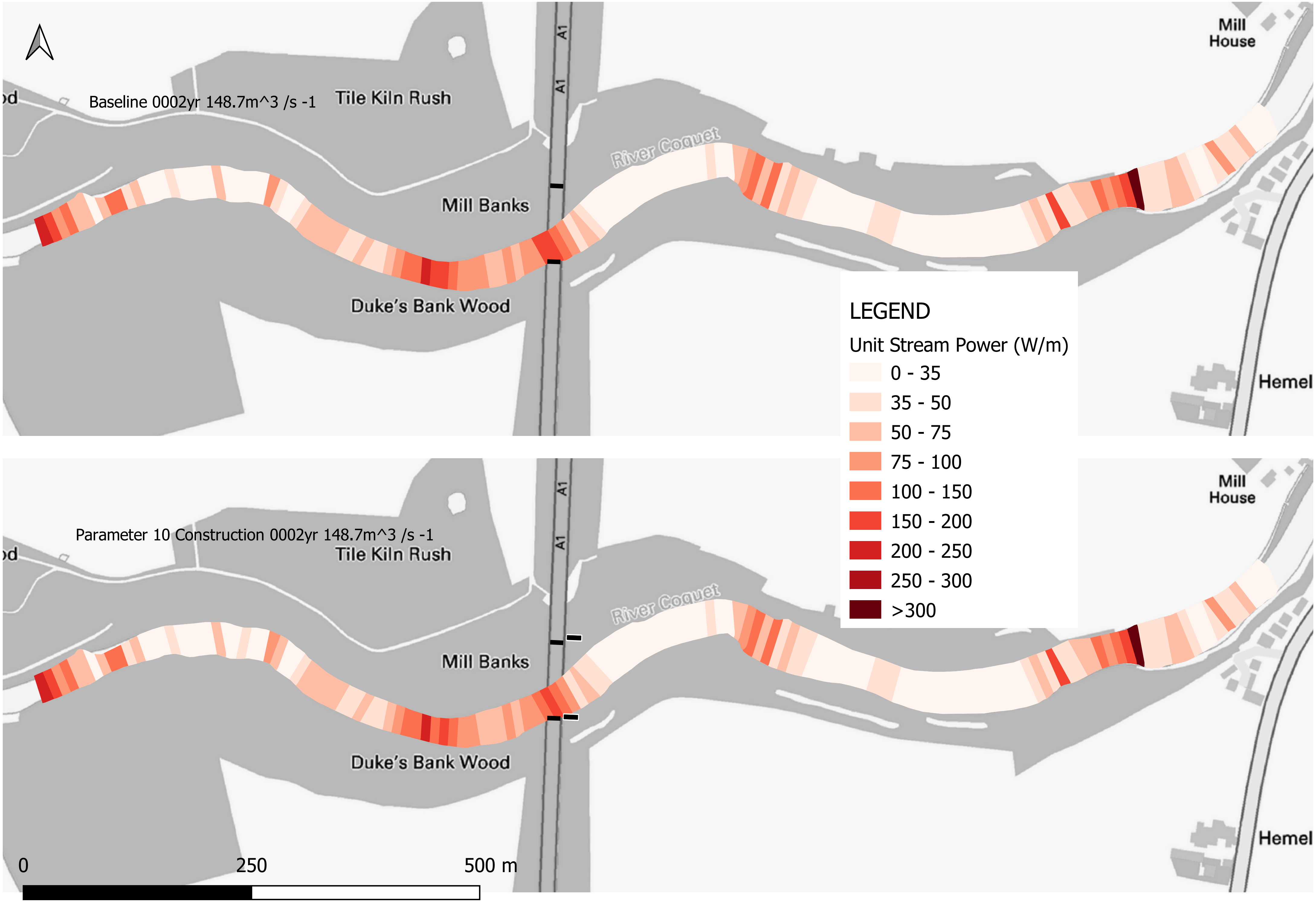

Baseline 0200yr 462.6m^3 /s -1
Duke's Bank Wood
A1
Velocity/Maximums
0 - 0.1
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
Parameter 10 Alignment Operation 0200yr 462.6m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m

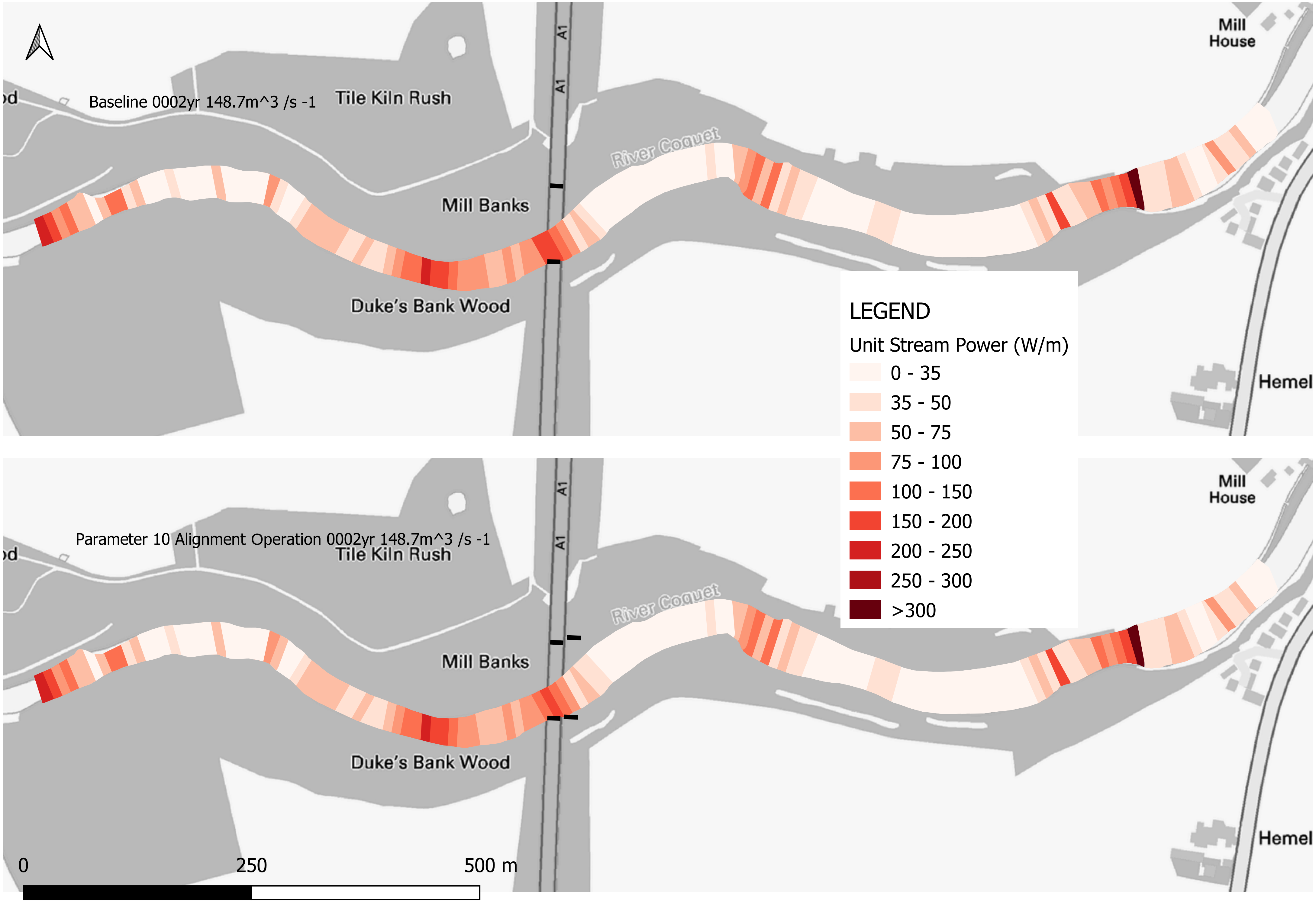
Specific Stream Power Results


Baseline 0002yr 148.7m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
Piers in Alignment Construction 0002yr 148.7m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m

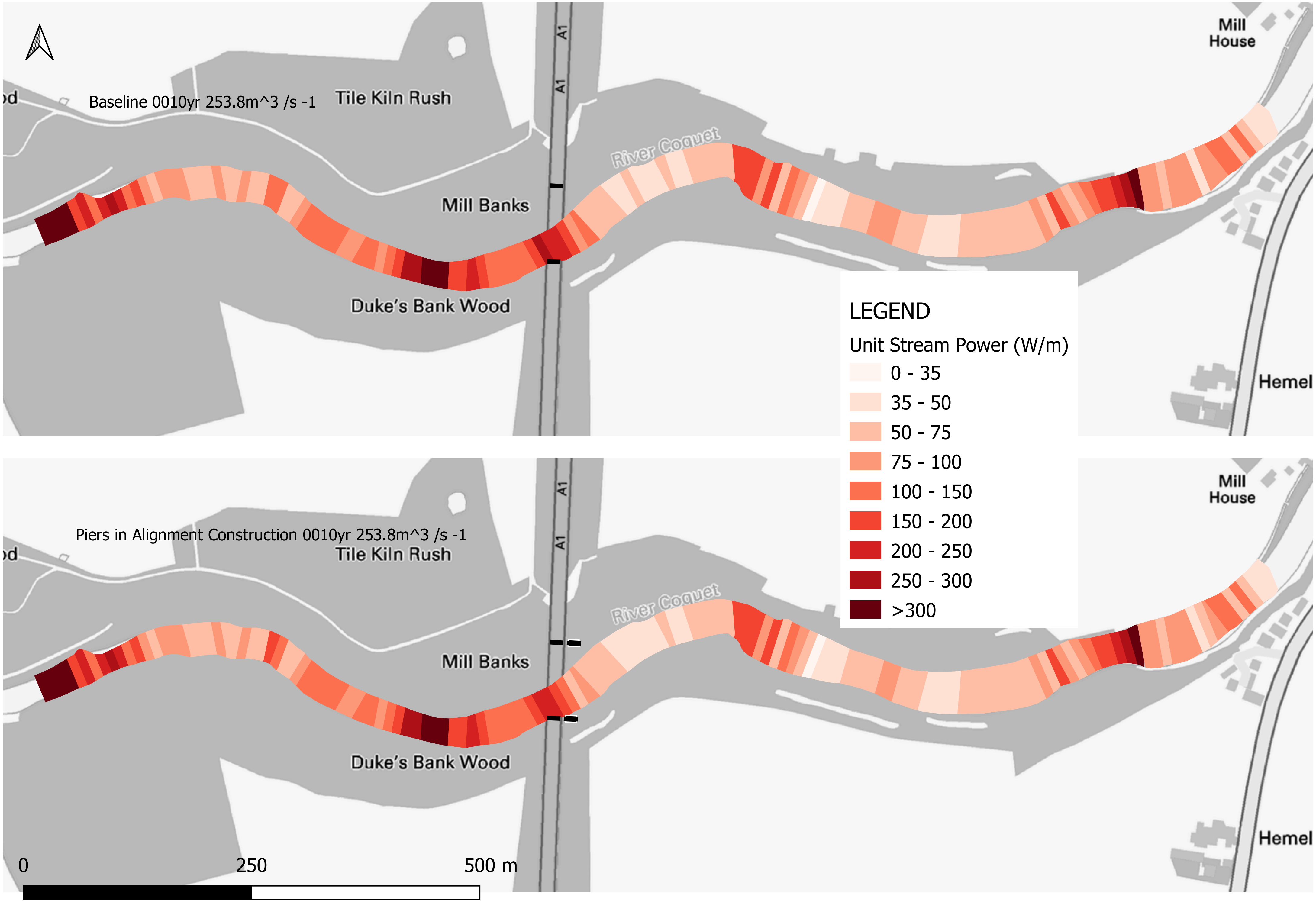


Baseline 0002yr 148.7m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
Piers in Alignment Operation 0002yr 148.7m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m

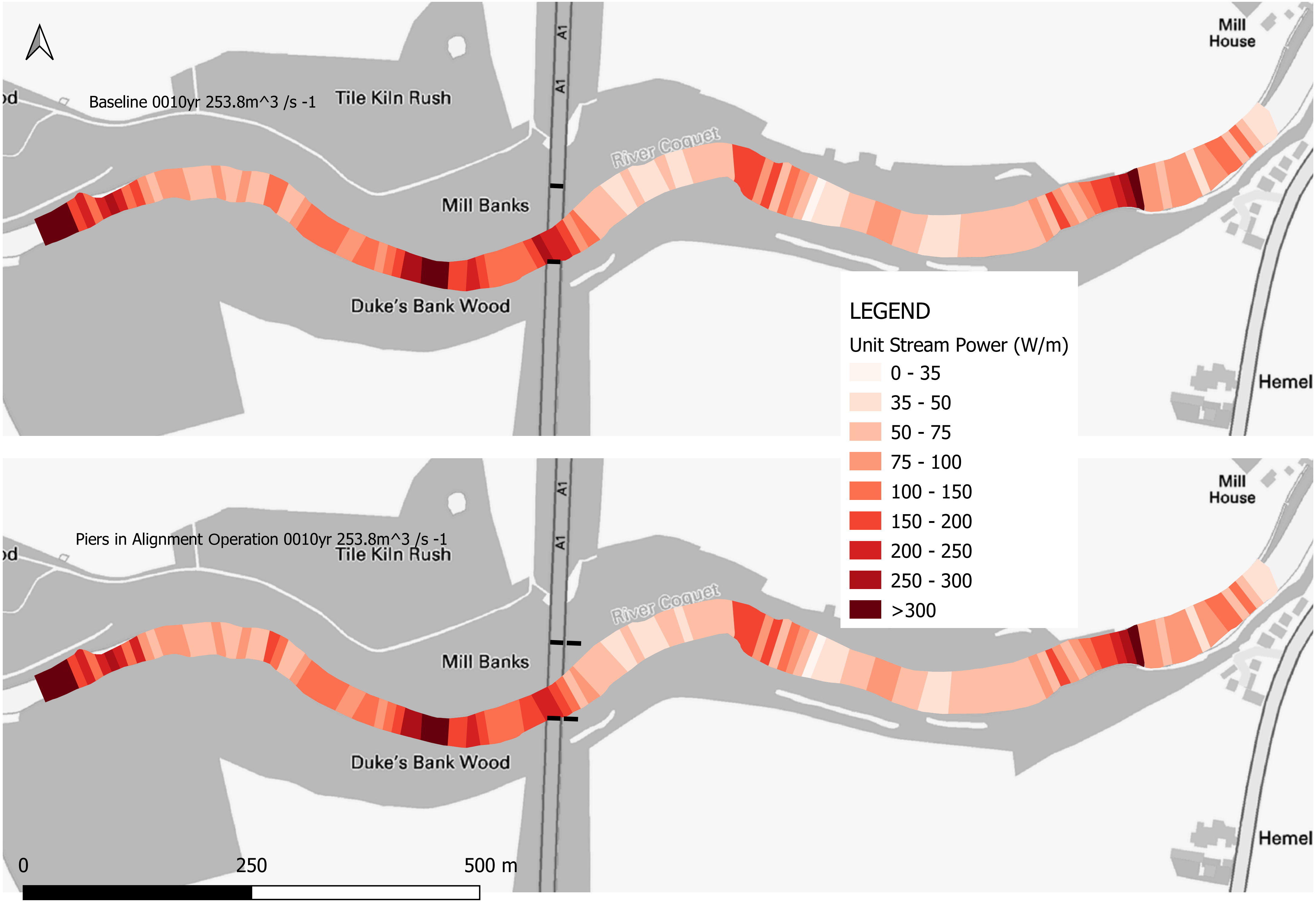

Baseline 0002yr 148.7m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
Parameter 10 Construction 0002yr 148.7m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m



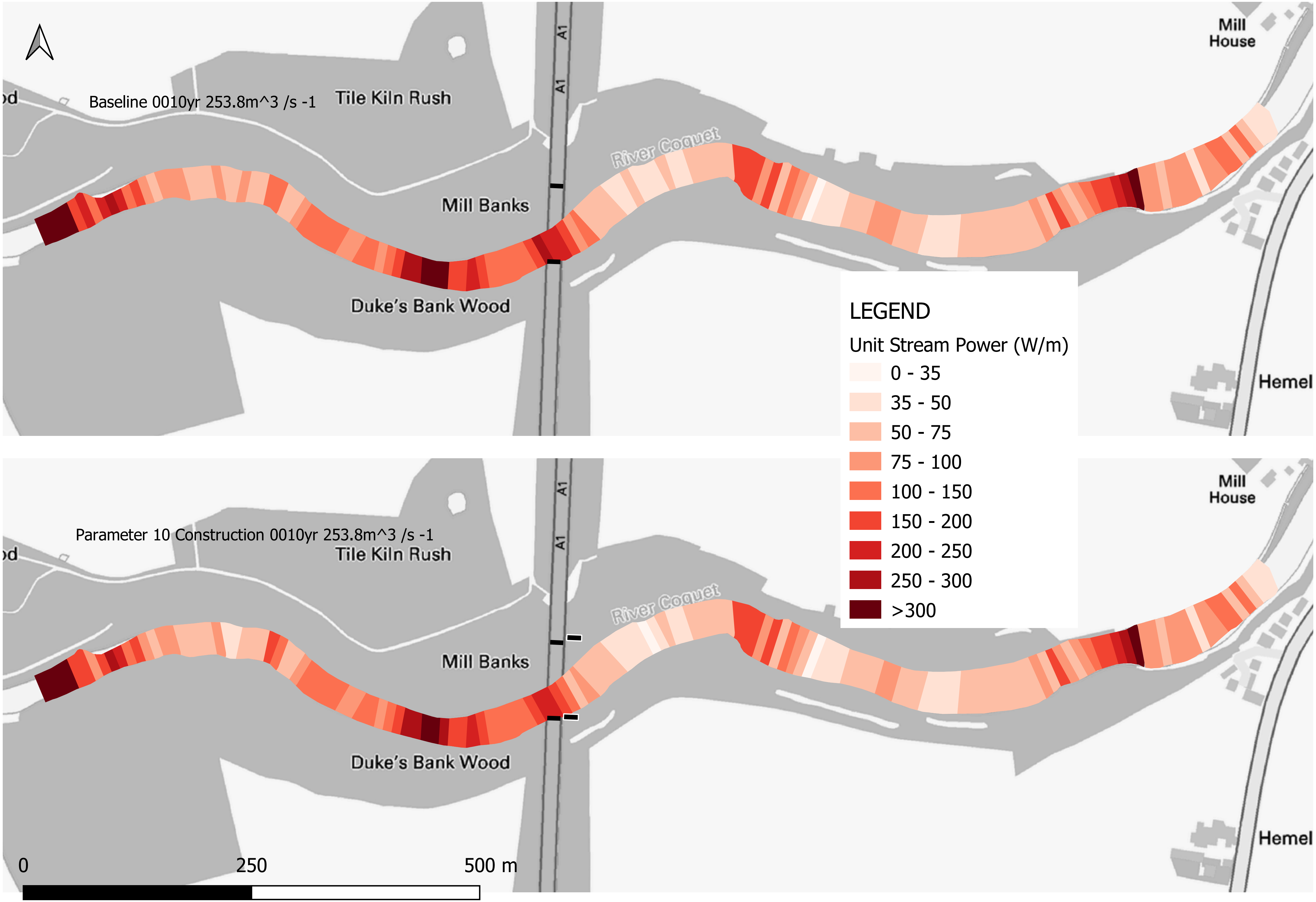
Baseline 0002yr 148.7m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
Parameter 10 Alignment Operation 0002yr 148.7m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
0
250
500 m



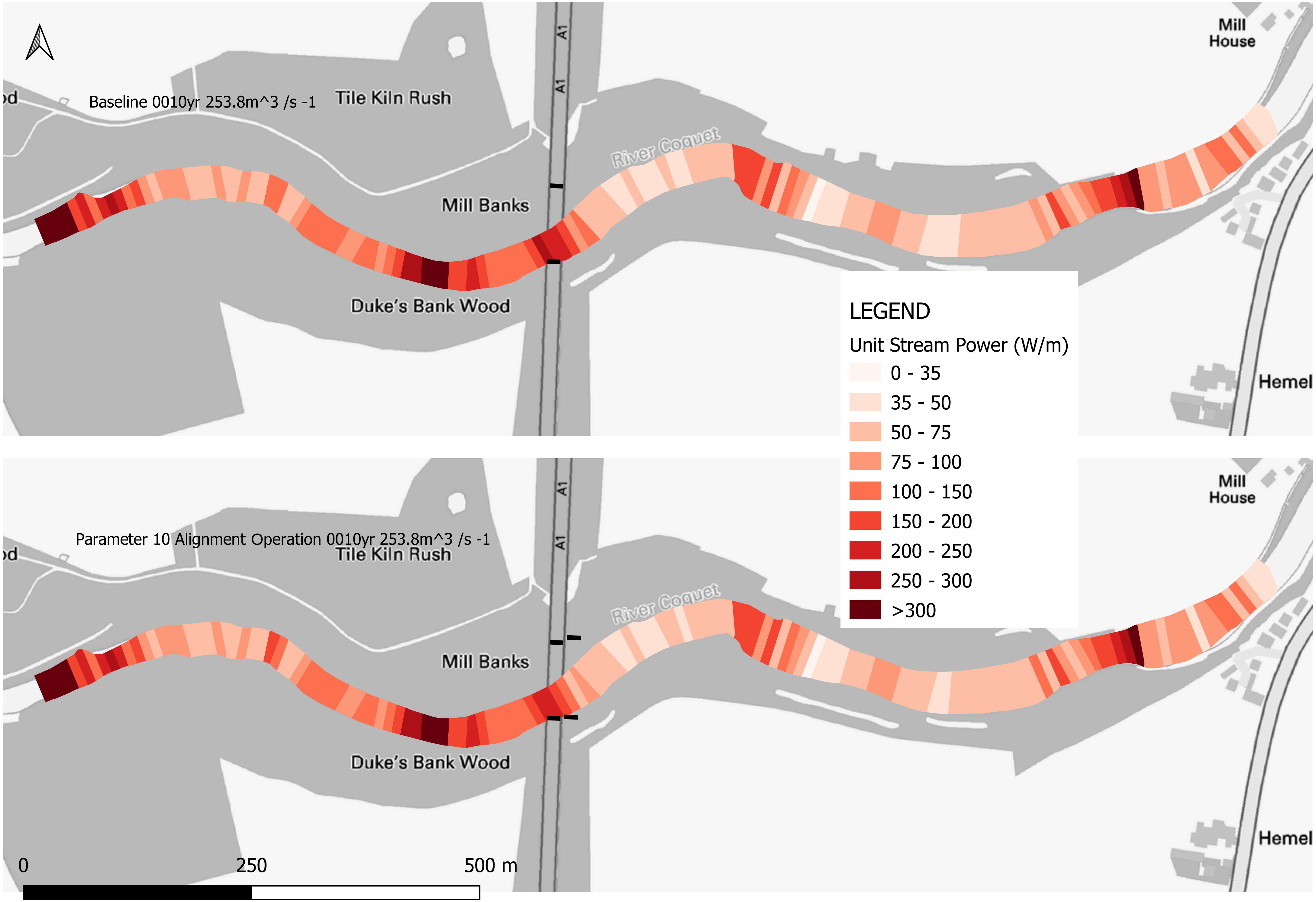
Baseline 0010yr 253.8m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
Piers in Alignment Construction 0010yr 253.8m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m



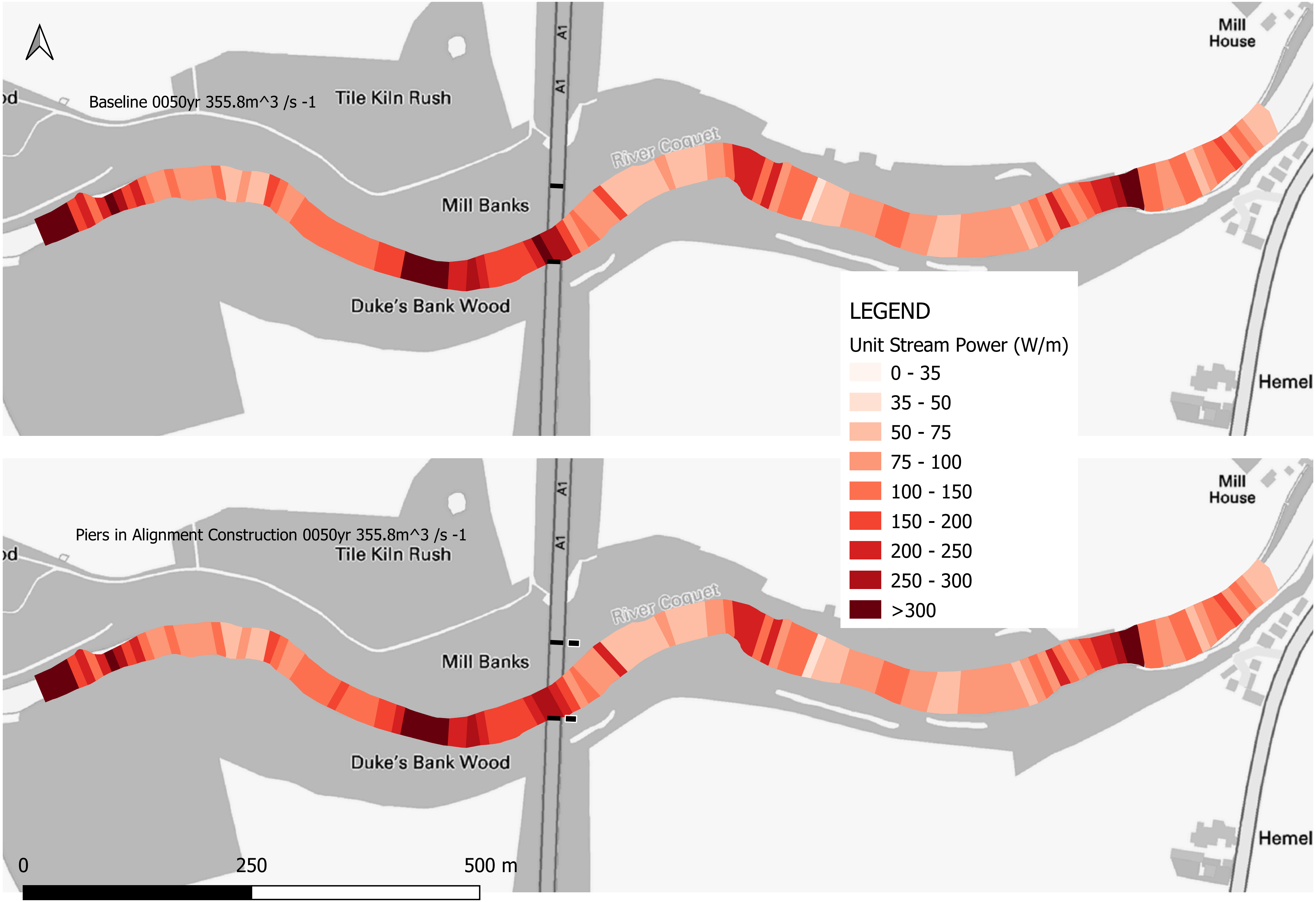
Baseline 0010yr 253.8m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
Piers in Alignment Operation 0010yr 253.8m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
0
250
500 m



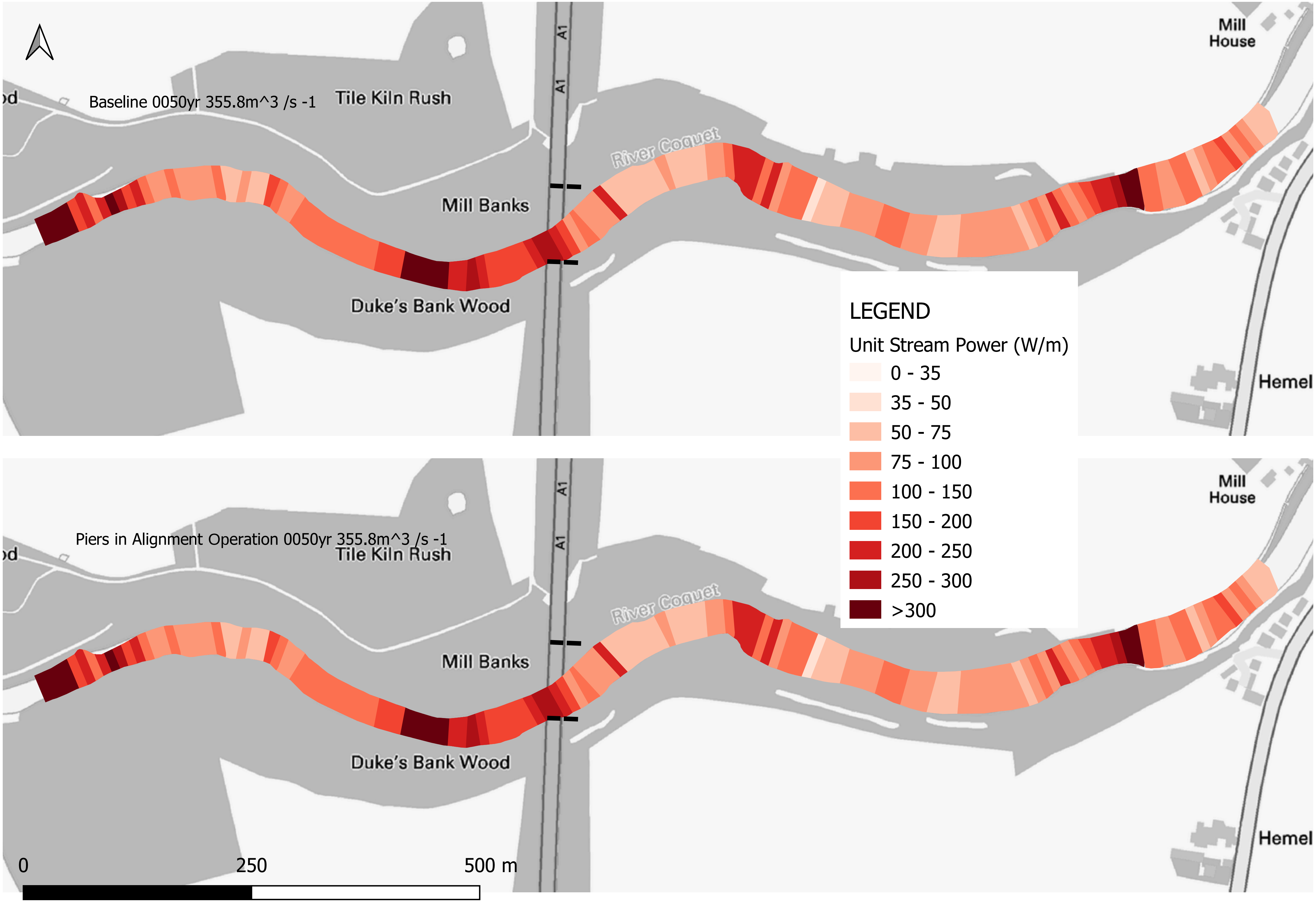
Baseline 0010yr 253.8m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
Parameter 10 Construction 0010yr 253.8m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m



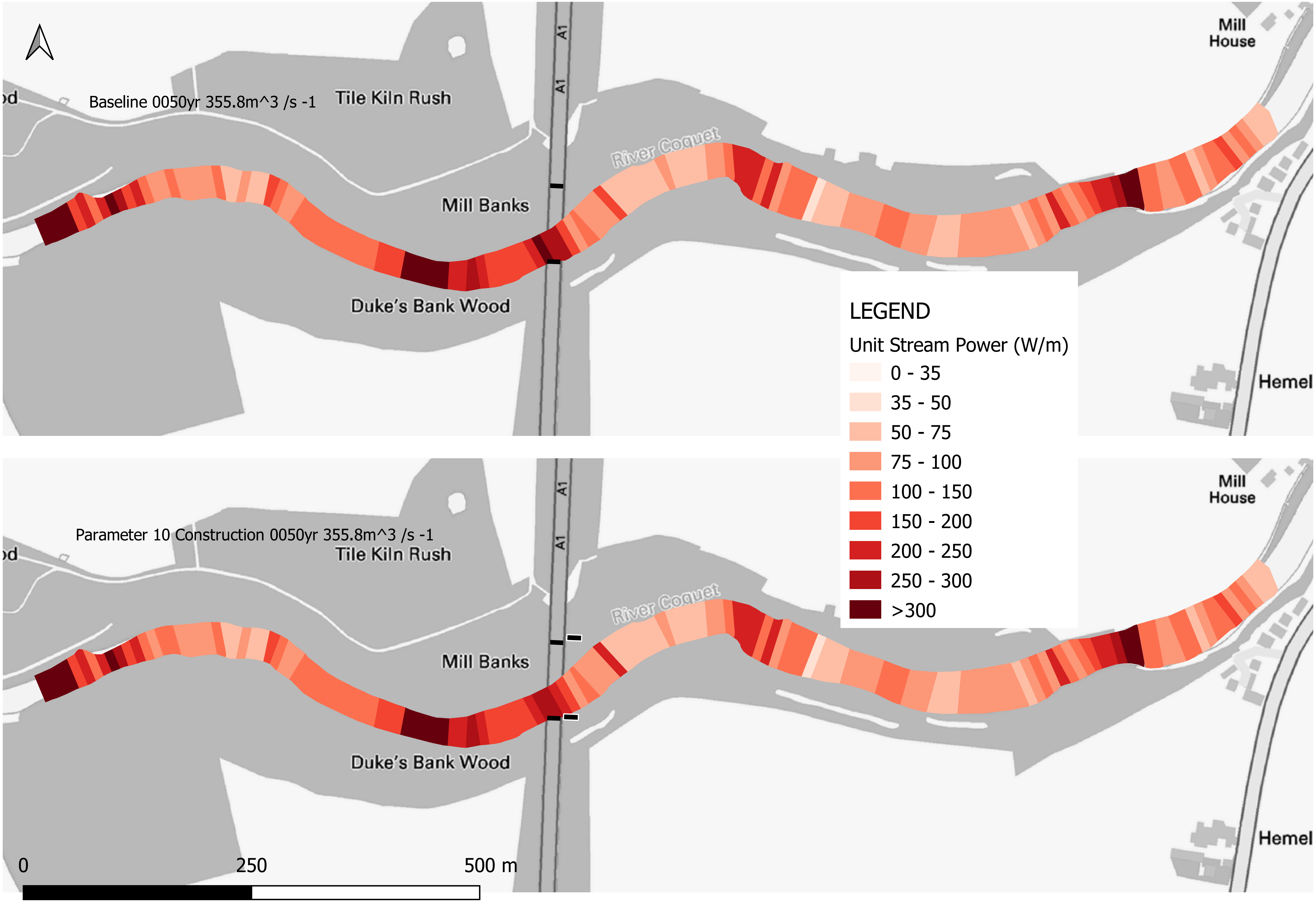
Baseline 0010yr 253.8m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
Parameter 10 Alignment Operation 0010yr 253.8m^3 /s -1
0
250
500 m

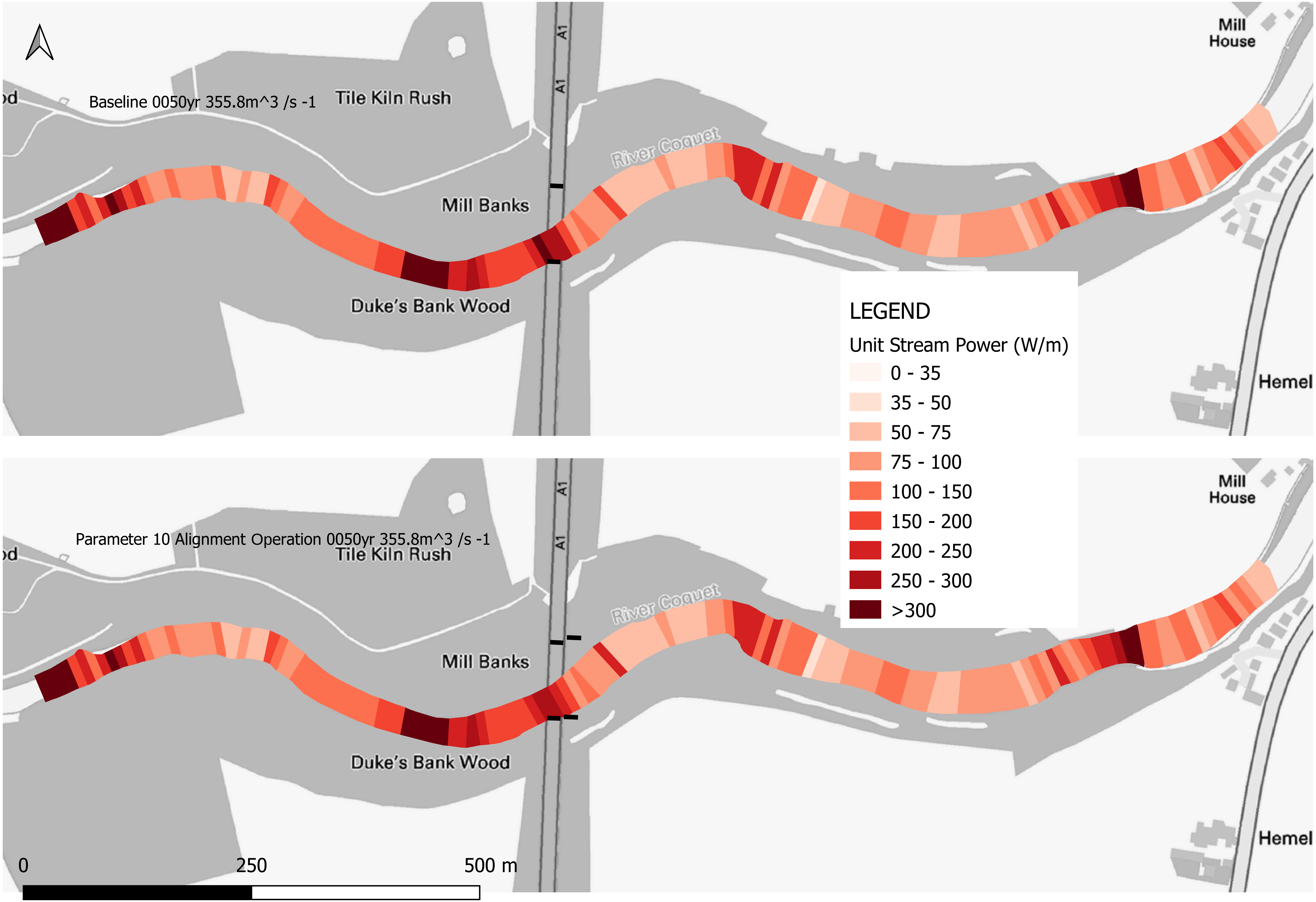


Baseline 0050yr 355.8m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
Piers in Alignment Construction 0050yr 355.8m^3 /s -1
0
250
500 m

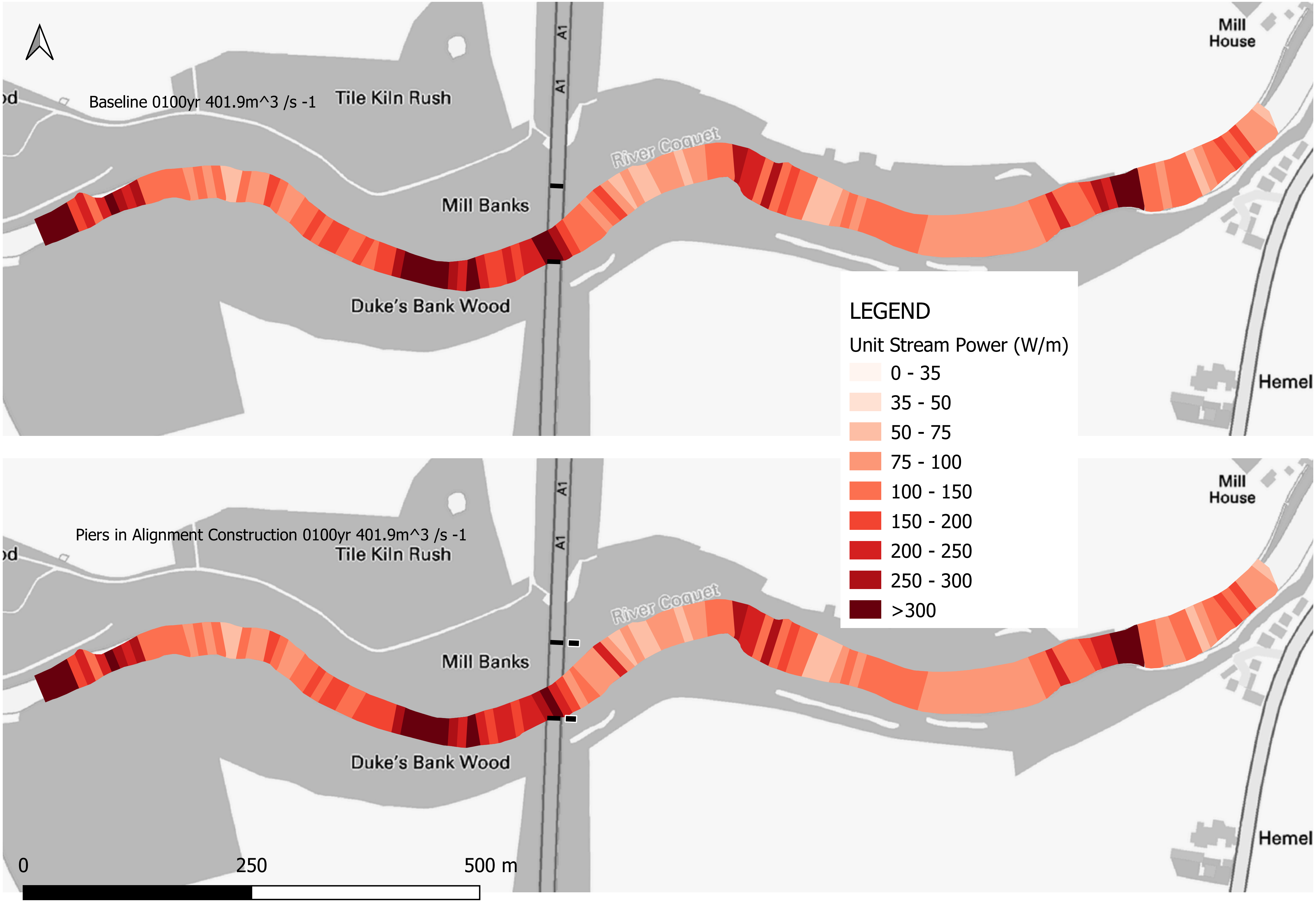


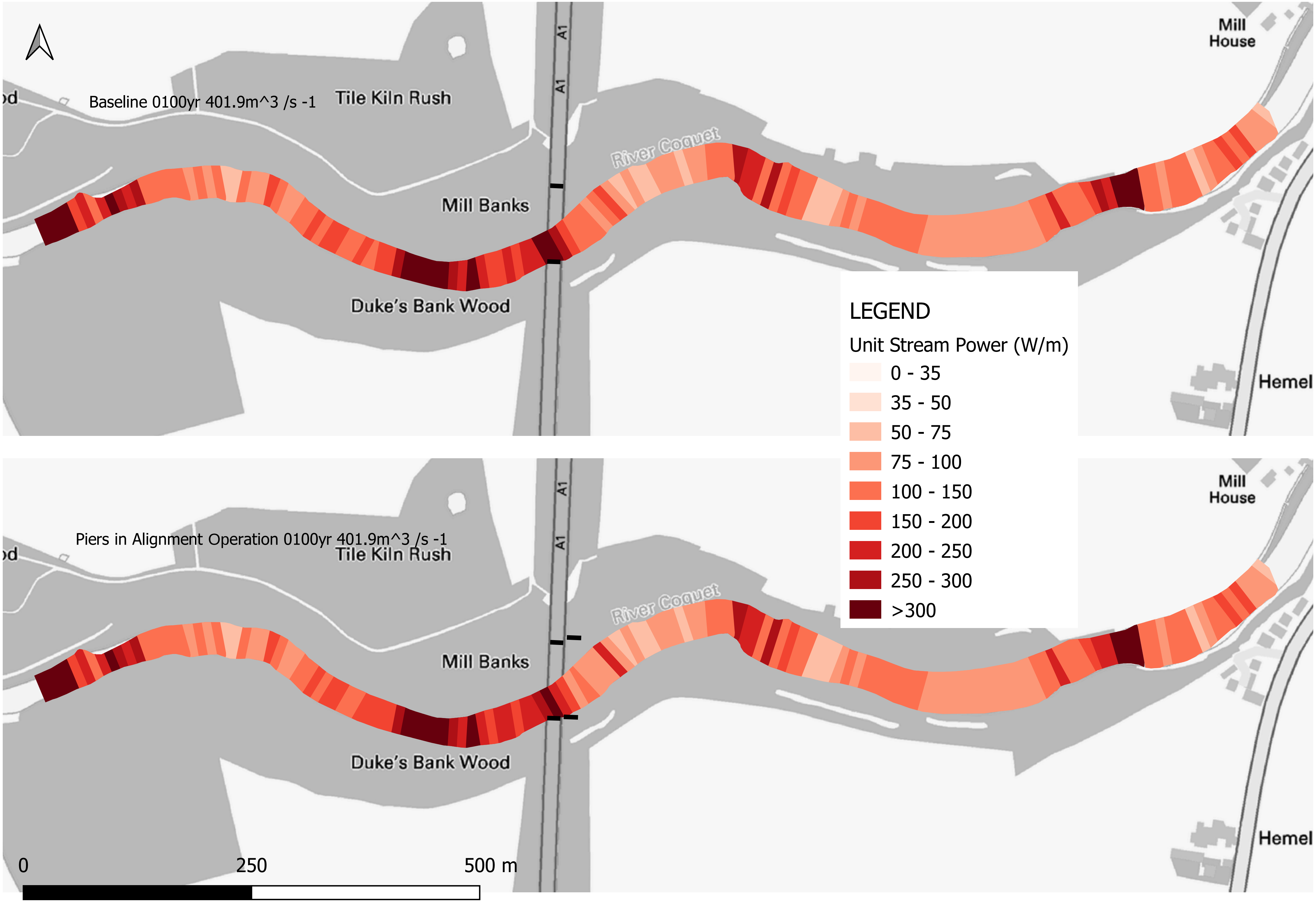
Baseline 0050yr 355.8m^3 /s -1
Piers in Alignment Operation 0050yr 355.8m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
Mill House
Hemel
A1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m

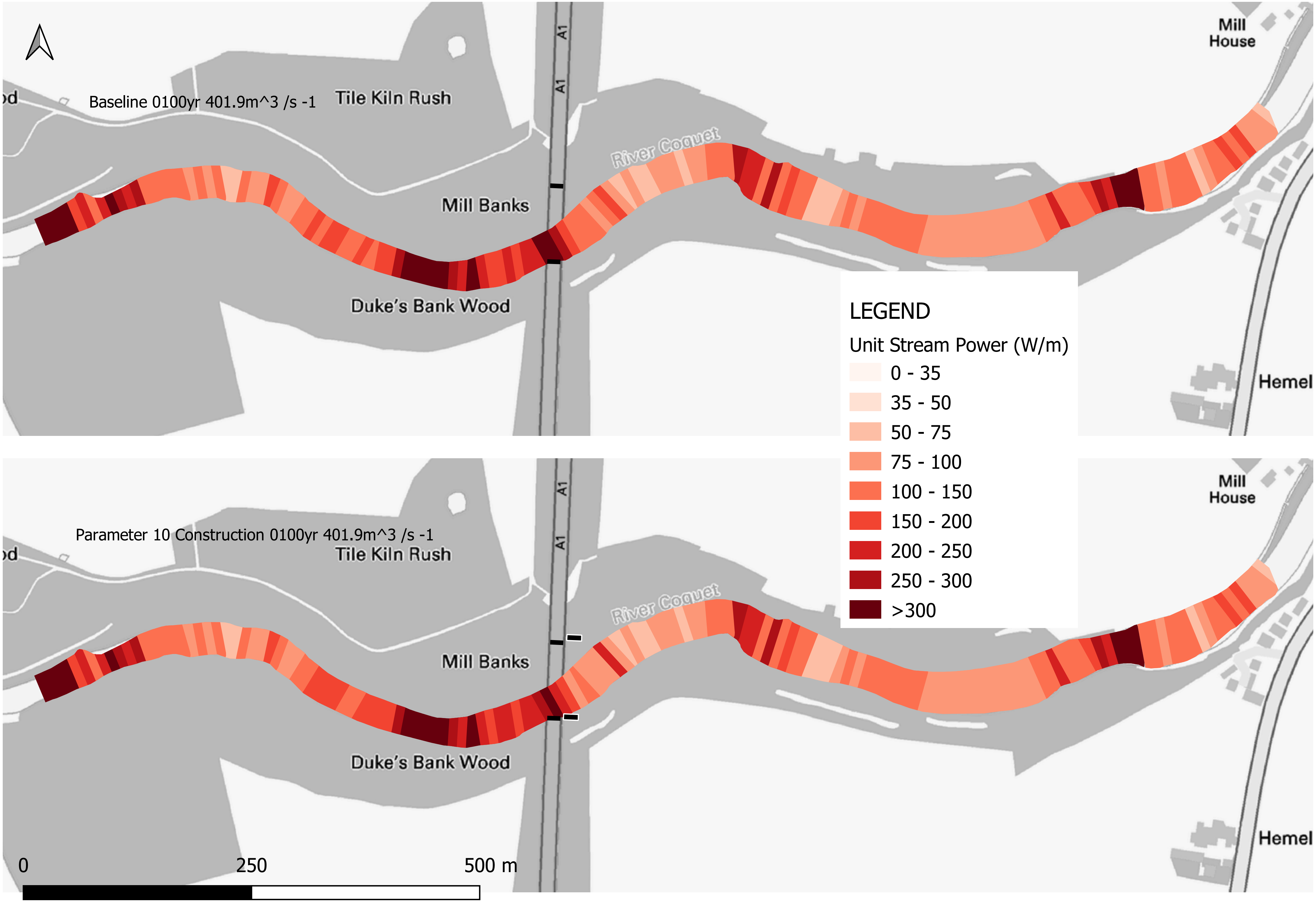

Baseline 0050yr 355.8m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
Parameter 10 Construction 0050yr 355.8m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m

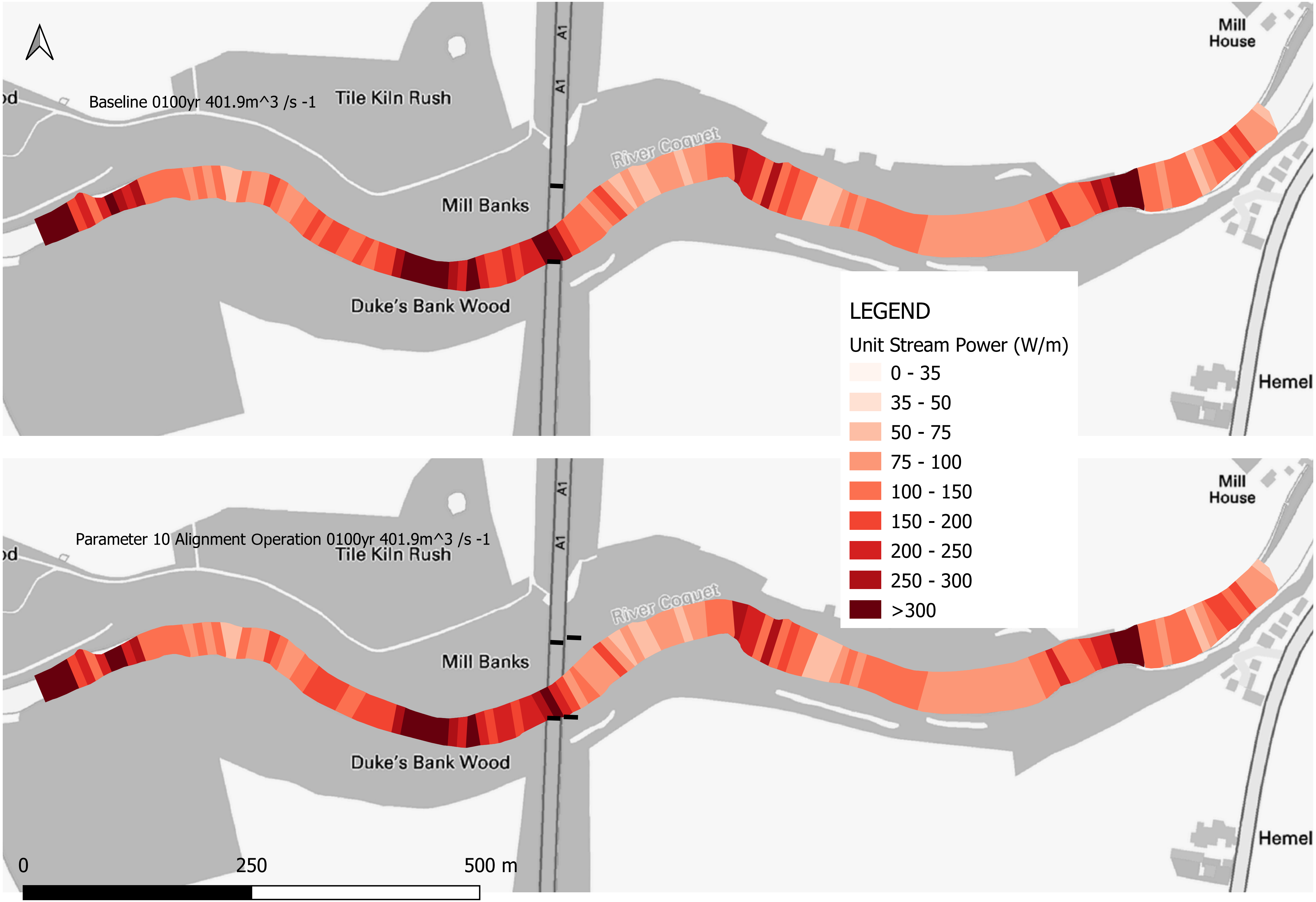


Baseline 0050yr 355.8m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
Parameter 10 Alignment Operation 0050yr 355.8m^3 /s -1
0
250
500 m

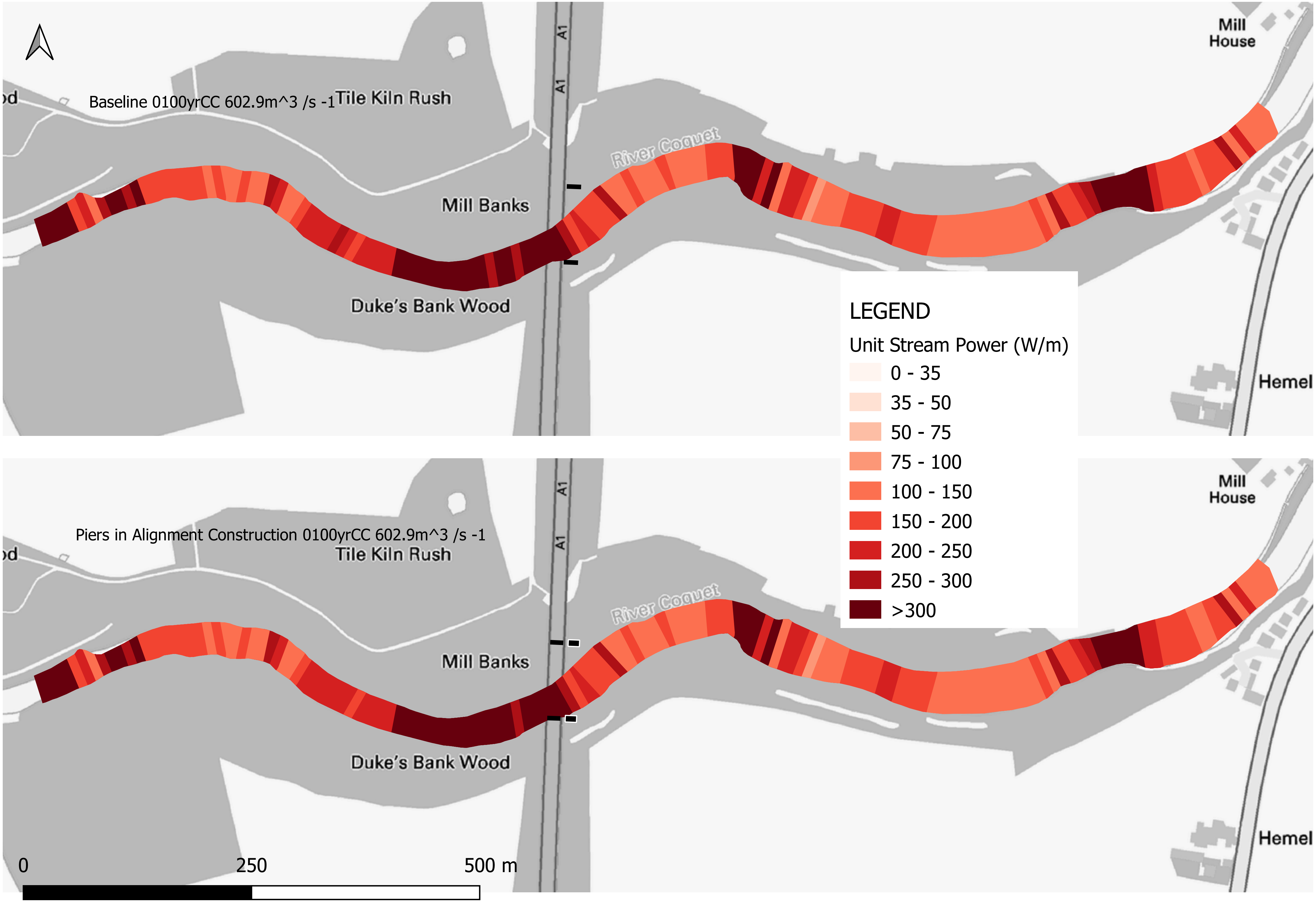

Baseline 0100yr 401.9m^3 /s -1
Tile Kiln Rush
A1
A1
River Coquet
Mill Banks
Duke's Bank Wood
Mill House
Hemel
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
Piers in Alignment Construction 0100yr 401.9m^3 /s -1
Tile Kiln Rush
A1
A1
River Coquet
Mill Banks
Duke's Bank Wood
Mill House
Hemel
0
250
500 m

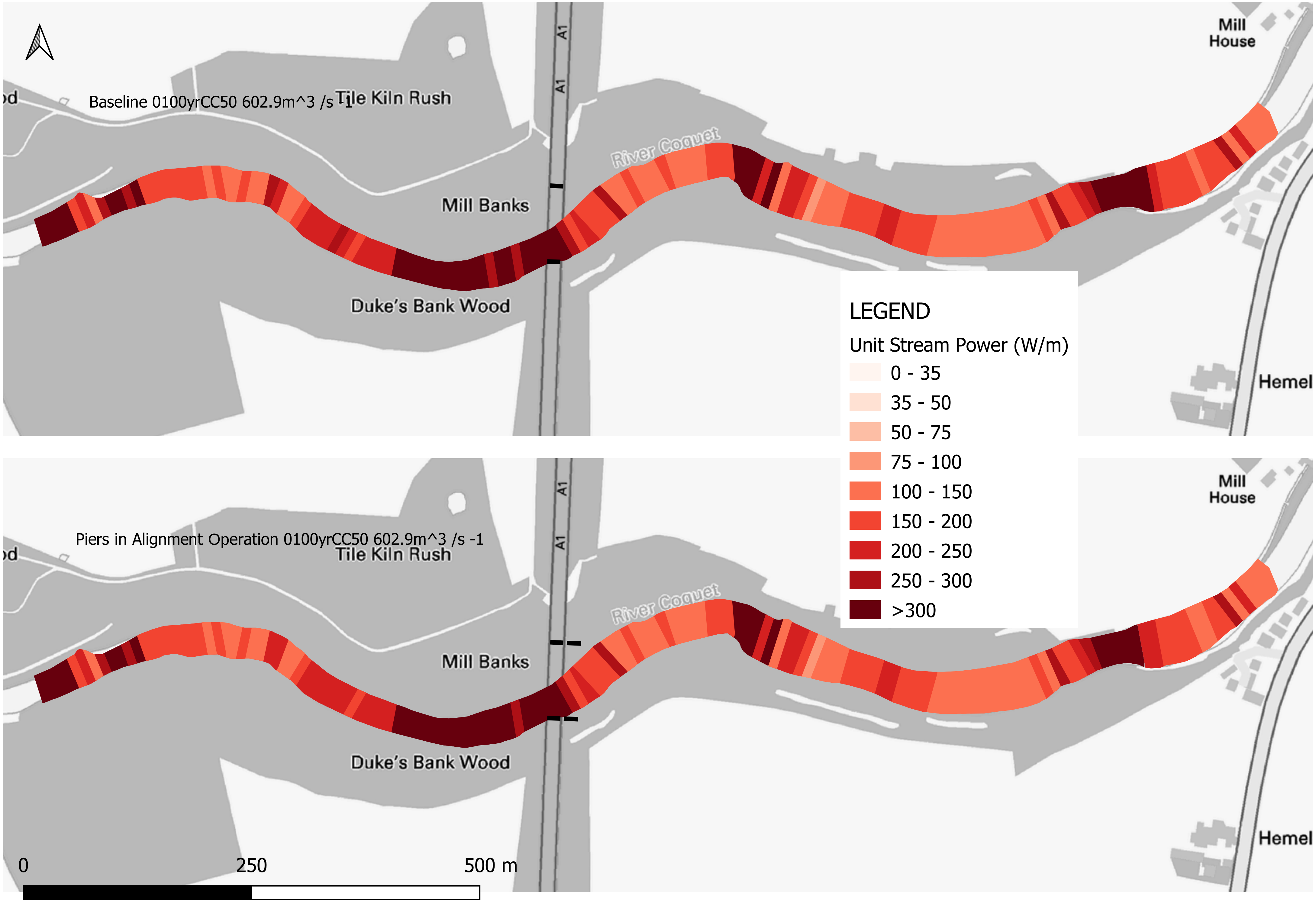

Baseline 0100yr 401.9m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
Piers in Alignment Operation 0100yr 401.9m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m


Baseline 0100yr 401.9m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
Parameter 10 Construction 0100yr 401.9m^3 /s -1
0
250
500 m

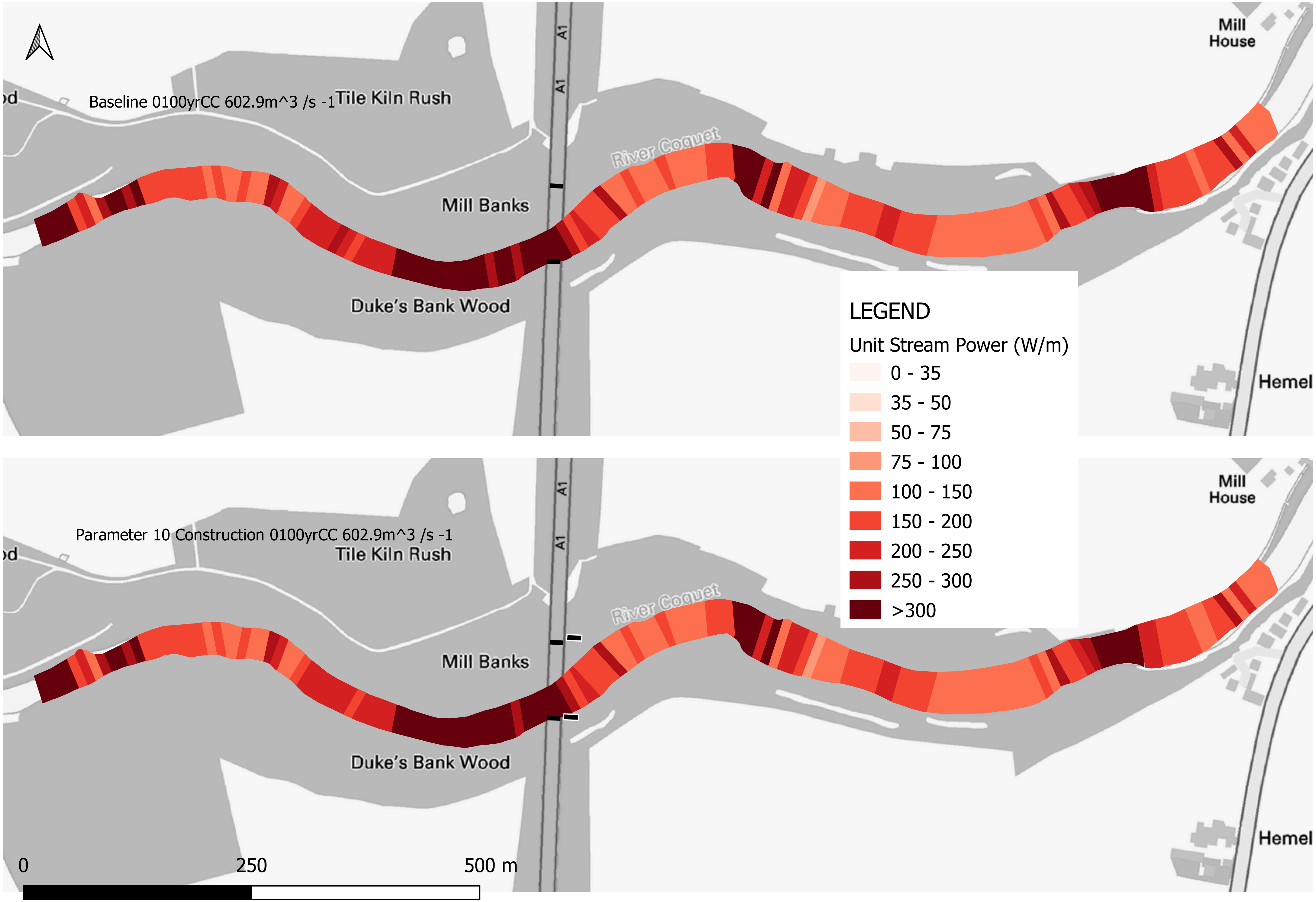


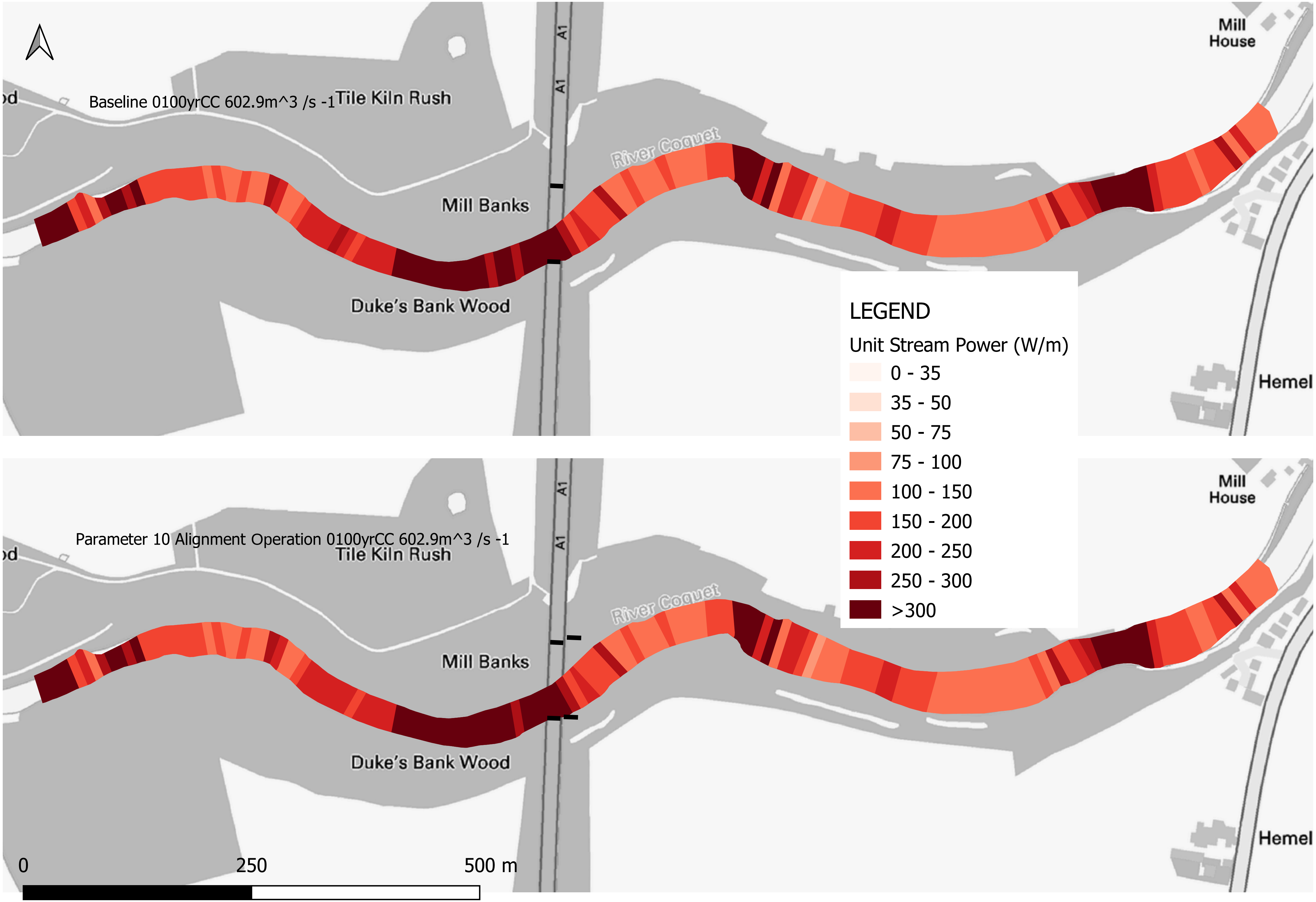
Baseline 0100yr 401.9m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
Parameter 10 Alignment Operation 0100yr 401.9m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m


Baseline 0100yrCC 602.9m^3 /s -1
Tile Kiln Rush
River Coquet
Mill Banks
Duke's Bank Wood
A1
Mill House
Hemel
Piers in Alignment Construction 0100yrCC 602.9m^3 /s -1
Tile Kiln Rush
River Coquet
Mill Banks
Duke's Bank Wood
A1
Mill House
Hemel
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m

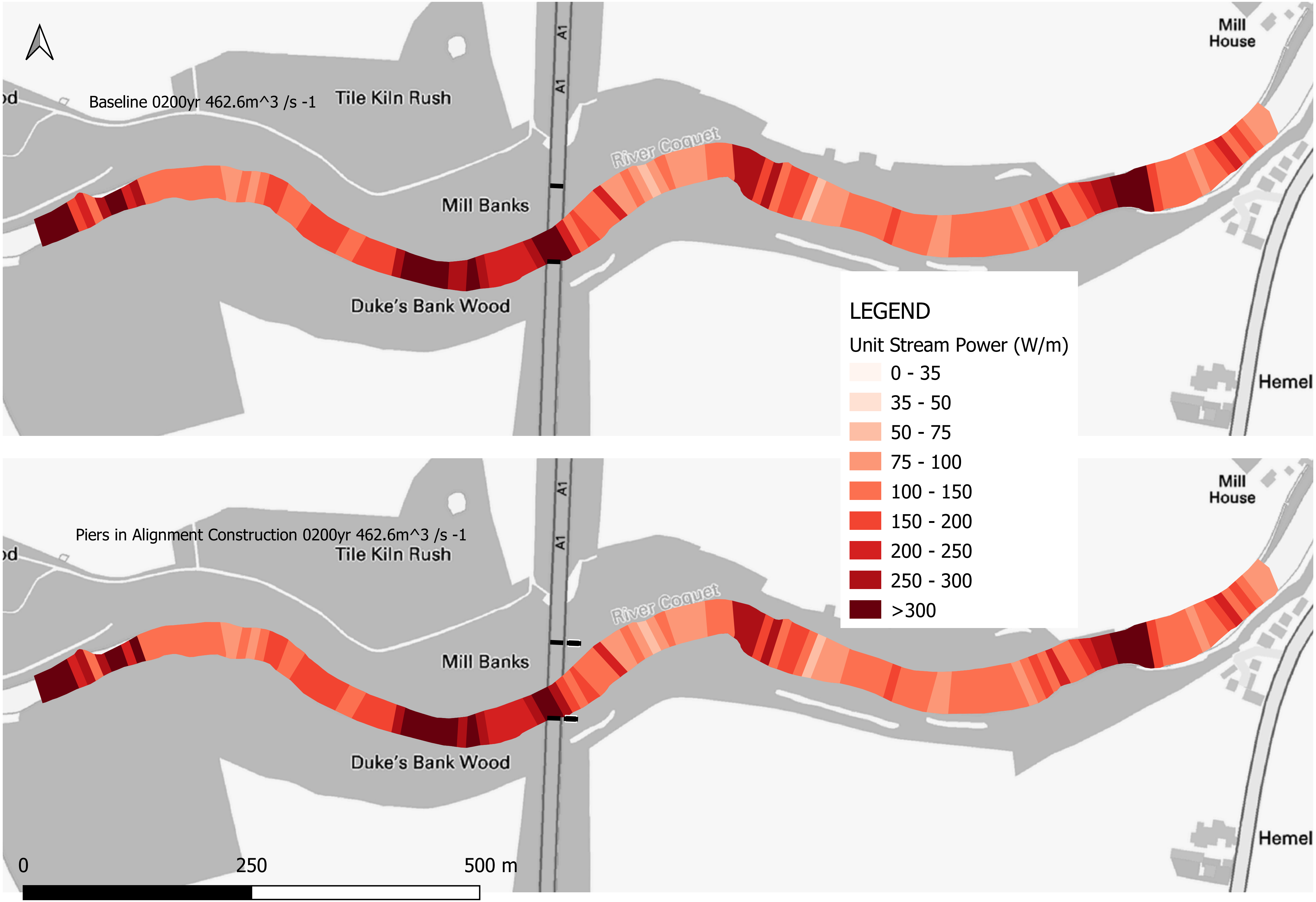


Baseline 0100yrCC50 602.9m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
Piers in Alignment Operation 0100yrCC50 602.9m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m

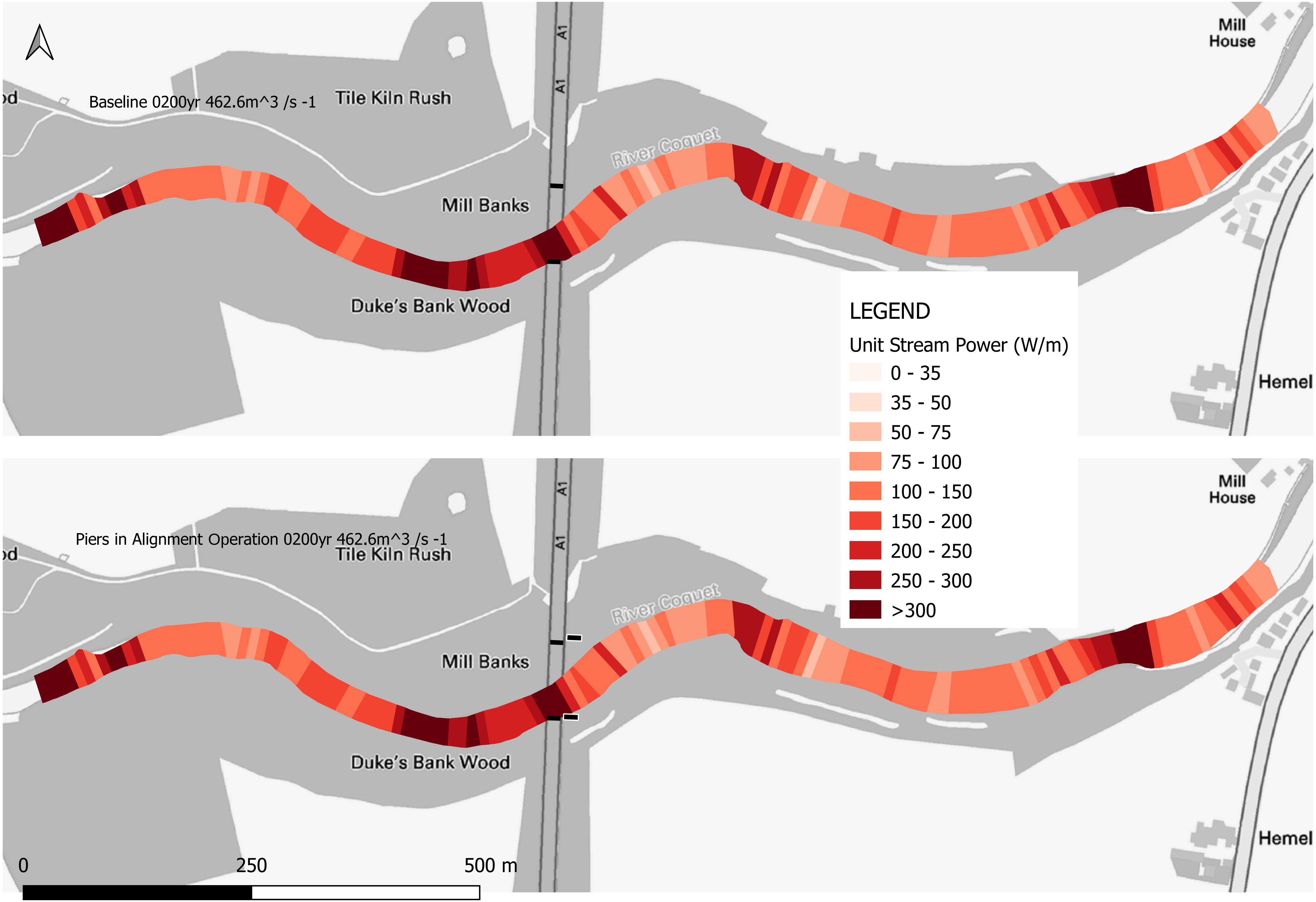

Baseline 0100yrCC 602.9m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
A1
Mill House
Hemel
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
Parameter 10 Construction 0100yrCC 602.9m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
A1
Mill House
Hemel
0
250
500 m

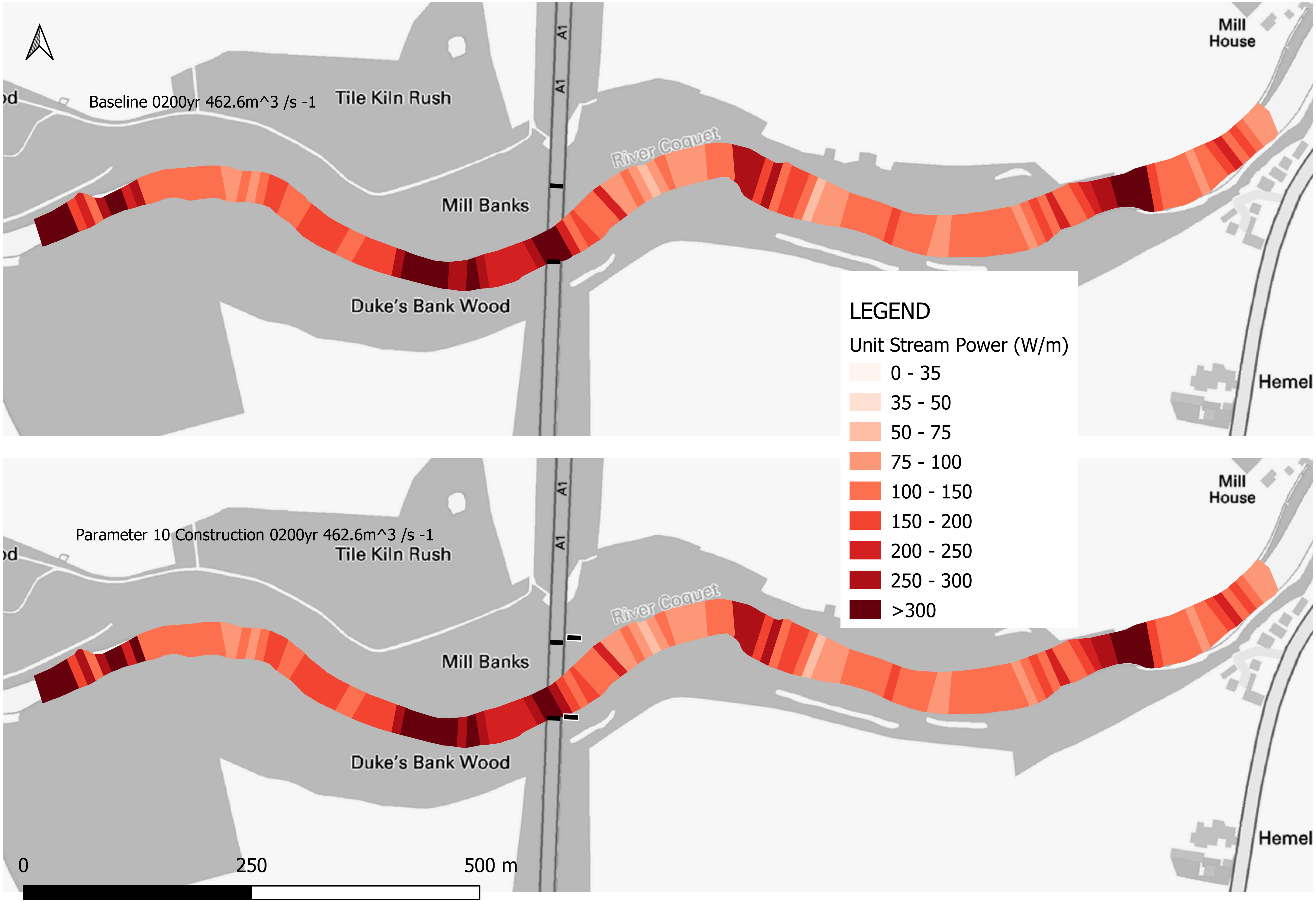


Baseline 0100yrCC 602.9m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
Parameter 10 Alignment Operation 0100yrCC 602.9m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
0
250
500 m

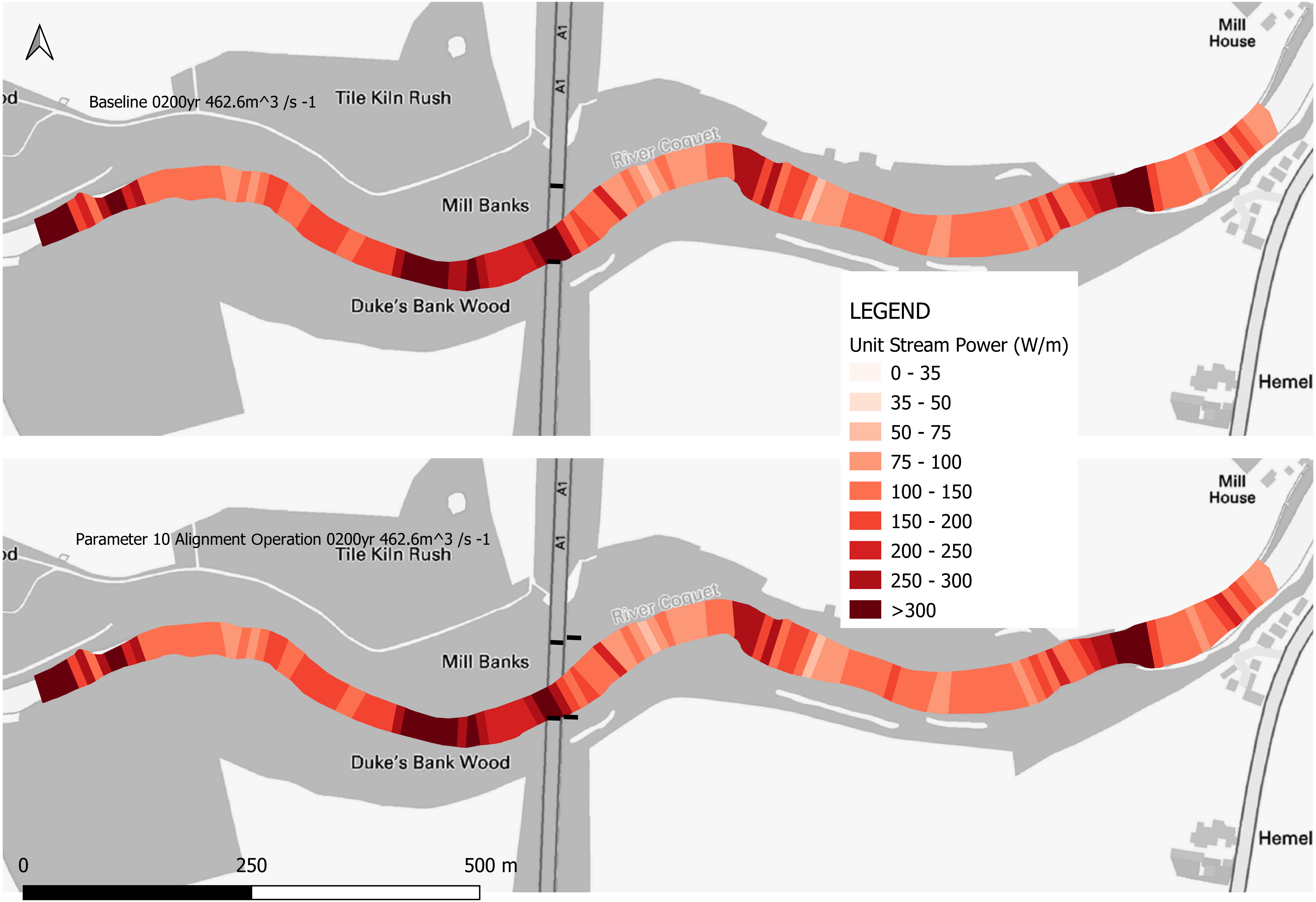


Baseline 0200yr 462.6m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
Piers in Alignment Construction 0200yr 462.6m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m


Baseline 0200yr 462.6m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
Piers in Alignment Operation 0200yr 462.6m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m



Baseline 0200yr 462.6m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
A1
Mill House
Hemel
Parameter 10 Construction 0200yr 462.6m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m

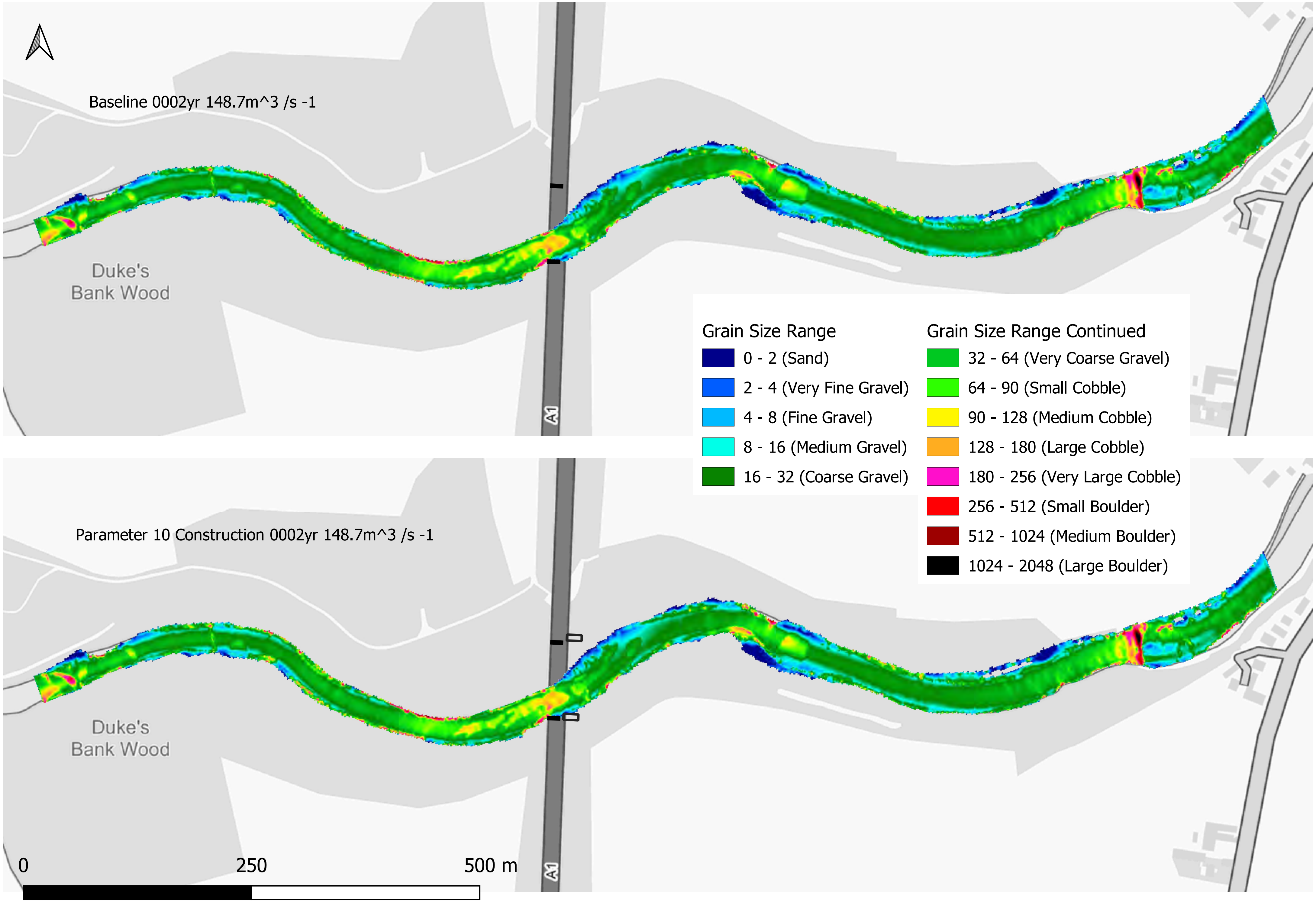


Baseline 0200yr 462.6m^3 /s -1
Tile Kiln Rush
Mill Banks
Duke's Bank Wood
River Coquet
Mill House
Hemel
A1
Parameter 10 Alignment Operation 0200yr 462.6m^3 /s -1
LEGEND
Unit Stream Power (W/m)
0 - 35
35 - 50
50 - 75
75 - 100
100 - 150
150 - 200
200 - 250
250 - 300
>300
0
250
500 m

Boundary Shear Stress Results

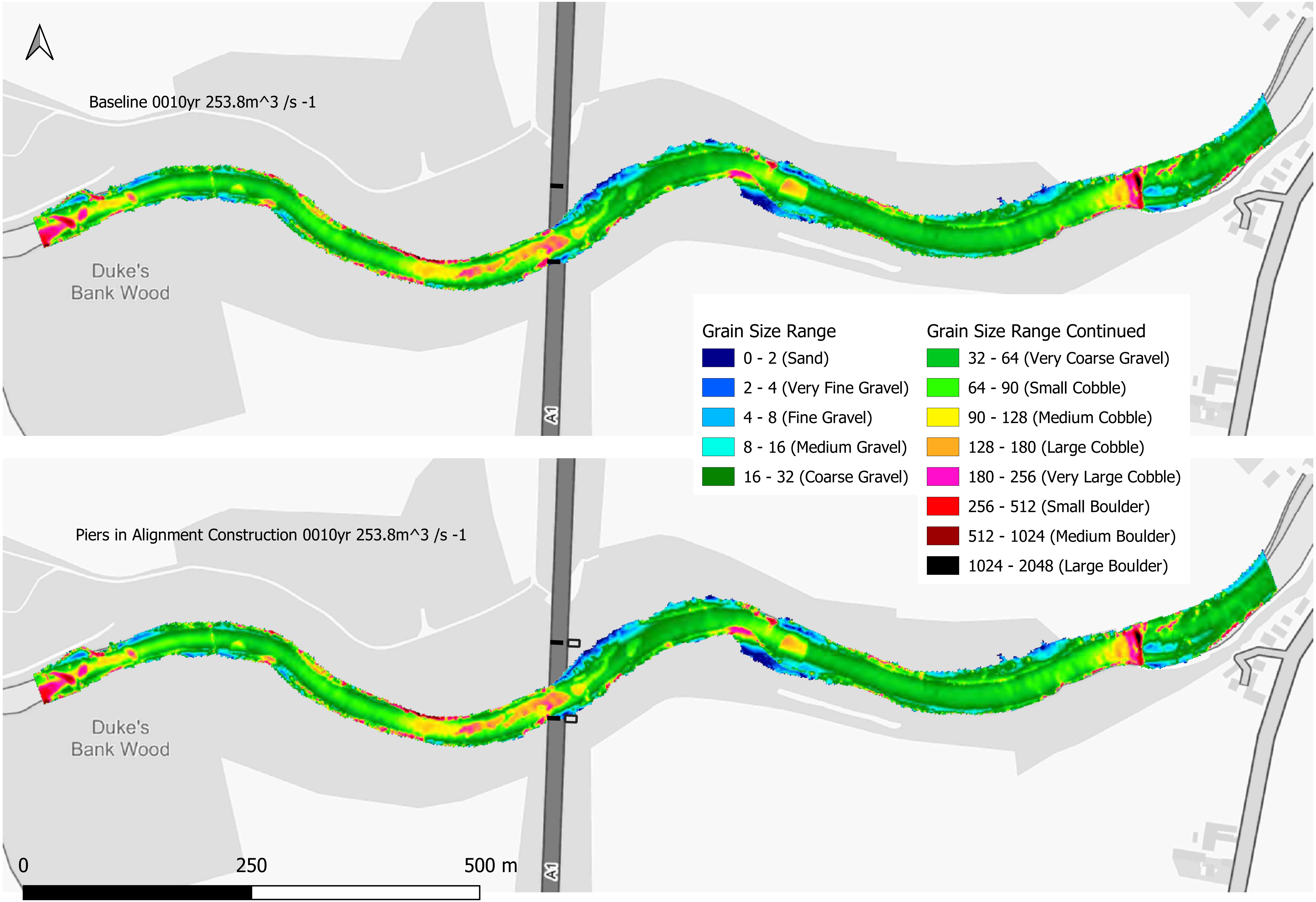
Baseline 0002yr 148.7m^3 /s -1
Duke's Bank Wood
A1
Piers in Alignment Construction 0002yr 148.7m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)

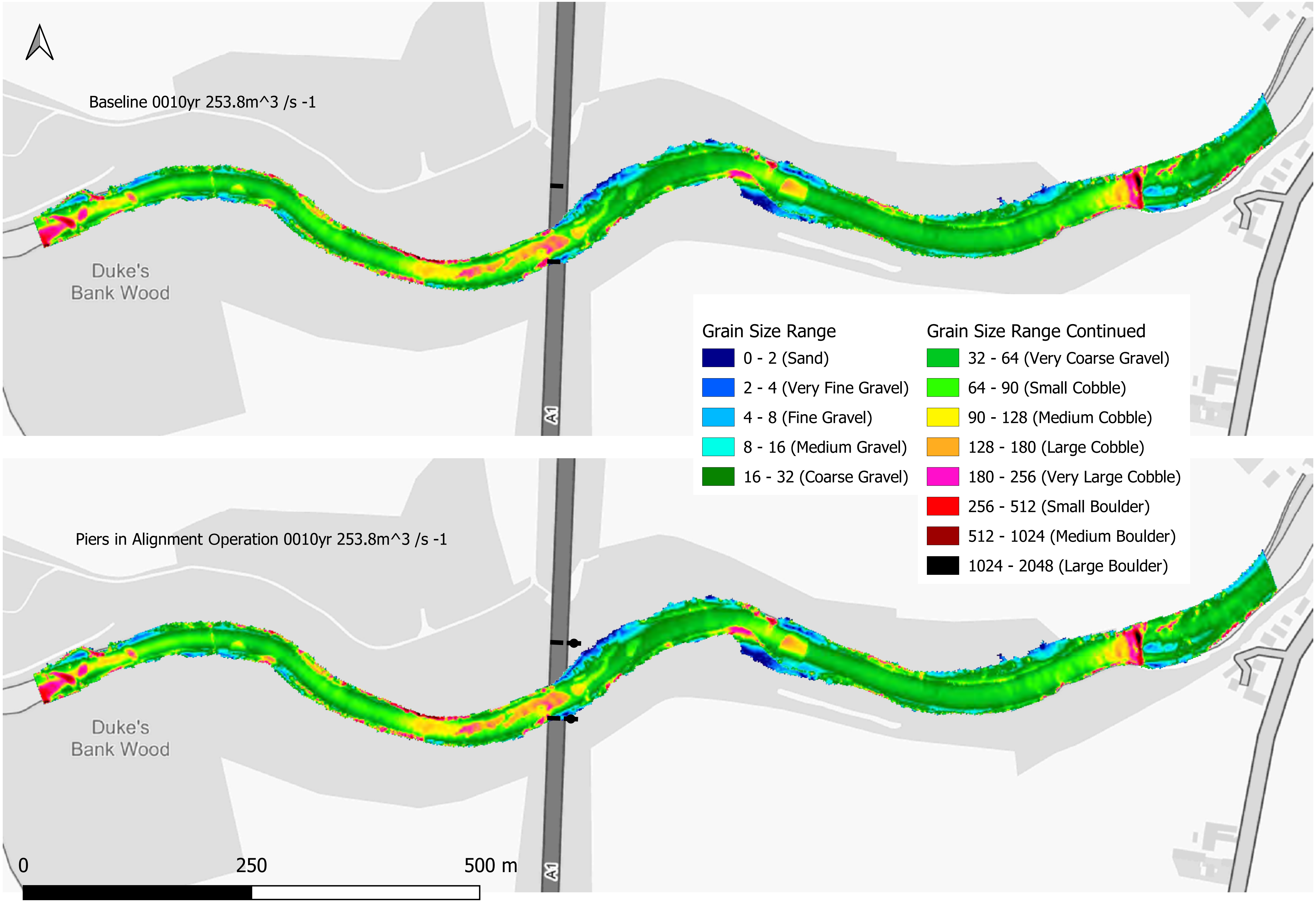

Baseline 0002yr 148.7m^3 /s -1
Duke's Bank Wood
A1
Piers in Alignment 0002yr Operation 148.7m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
0
250
500 m

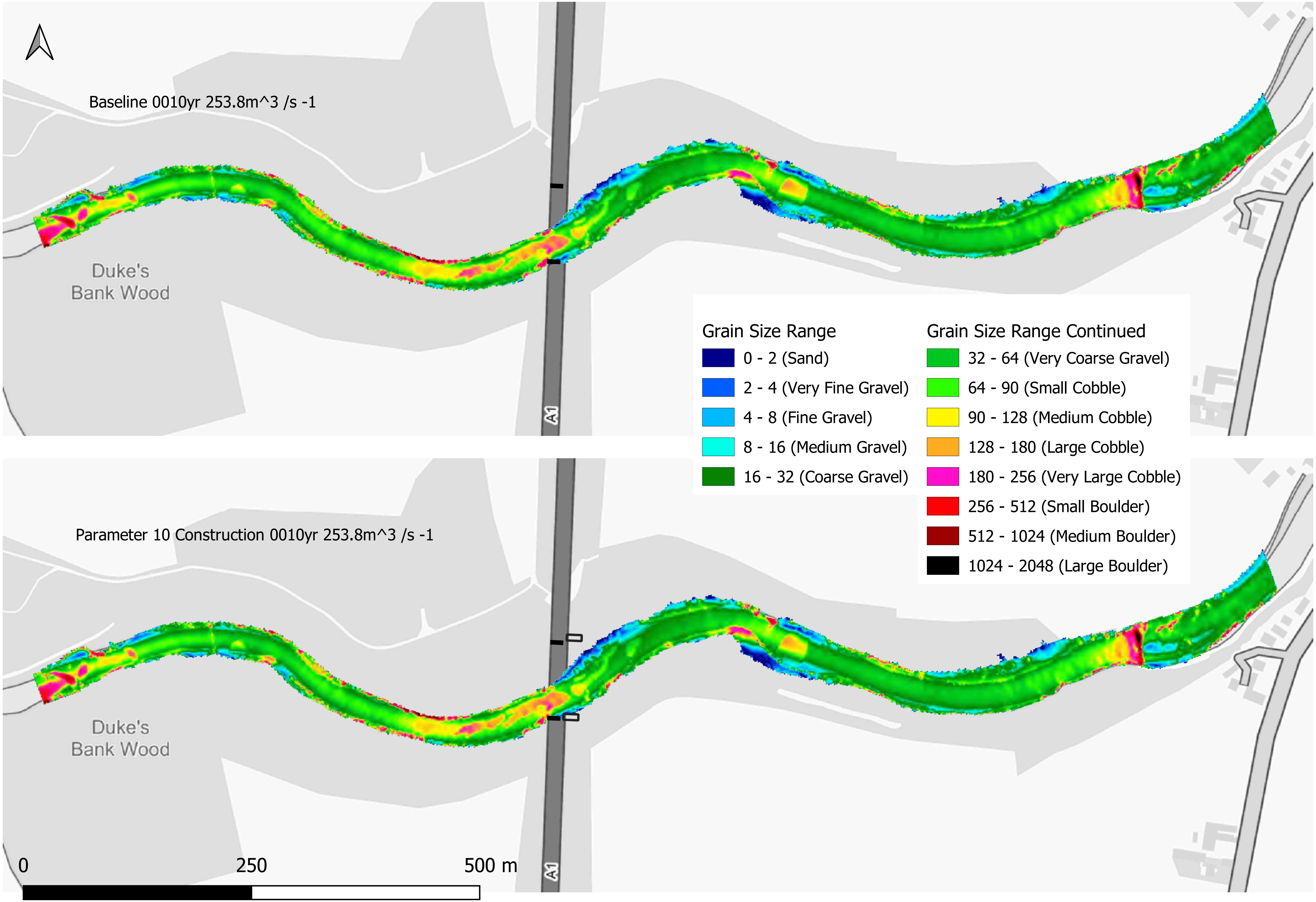


Baseline 0002yr 148.7m^3 /s -1
Duke's Bank Wood
A1
Parameter 10 Construction 0002yr 148.7m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
0
250
500 m

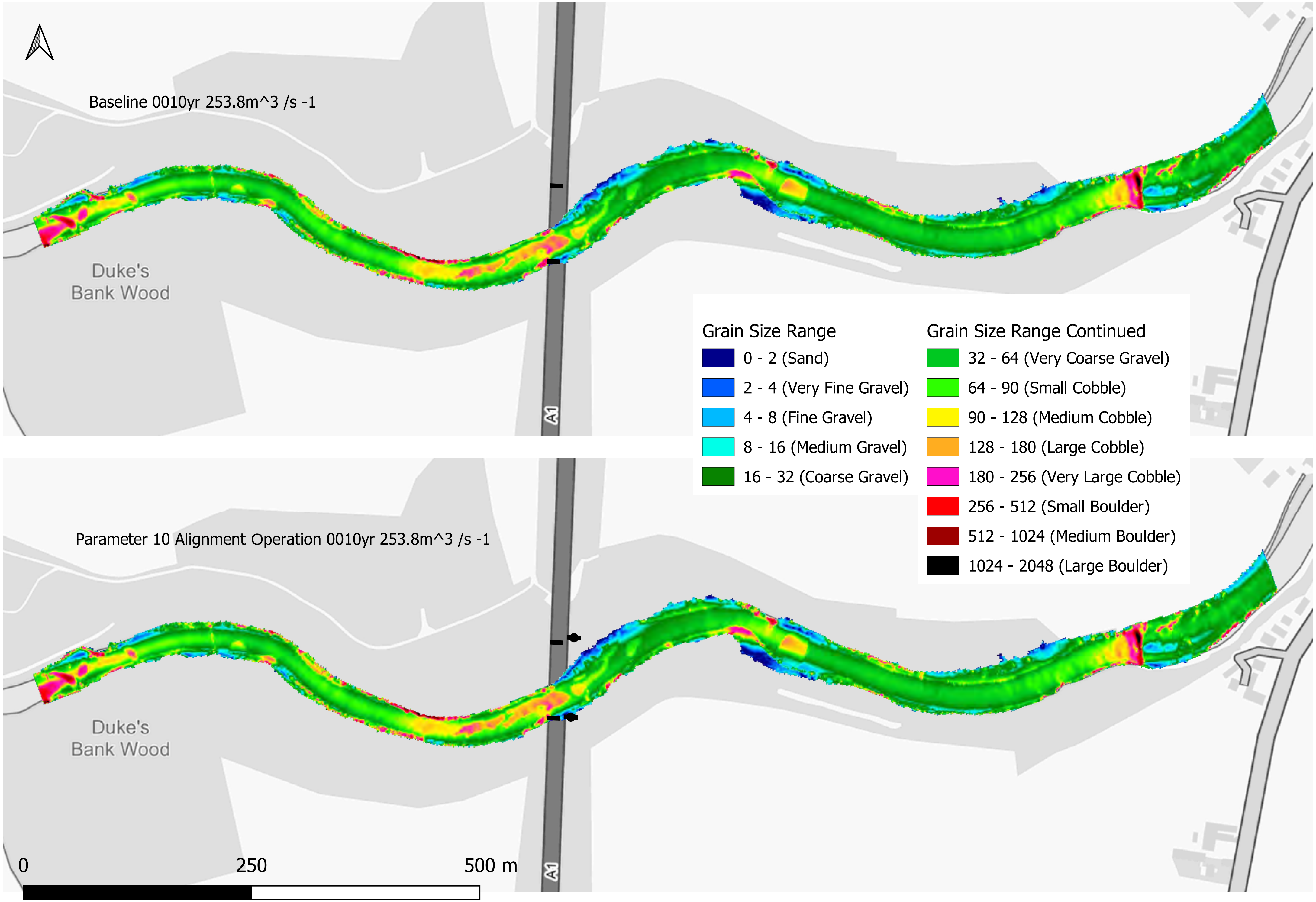

Baseline 0002yr 148.7m^3 /s -1
Duke's Bank Wood
A1
Parameter 10 Alignment Operation 0002yr 148.7m^3 /s -1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
0
250
500 m

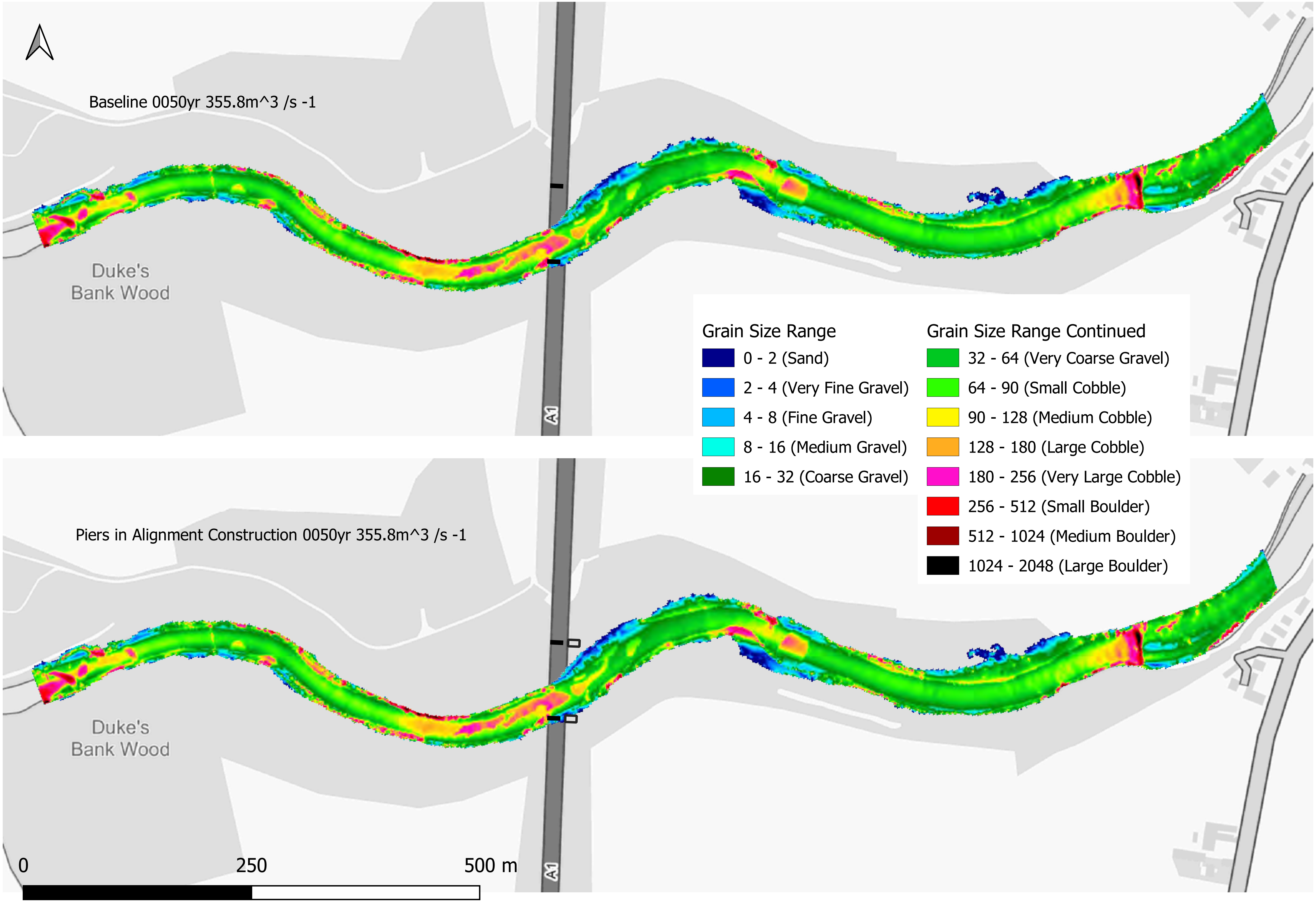

Baseline 0010yr 253.8m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Piers in Alignment Construction 0010yr 253.8m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m


Baseline 0010yr 253.8m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Piers in Alignment Operation 0010yr 253.8m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m

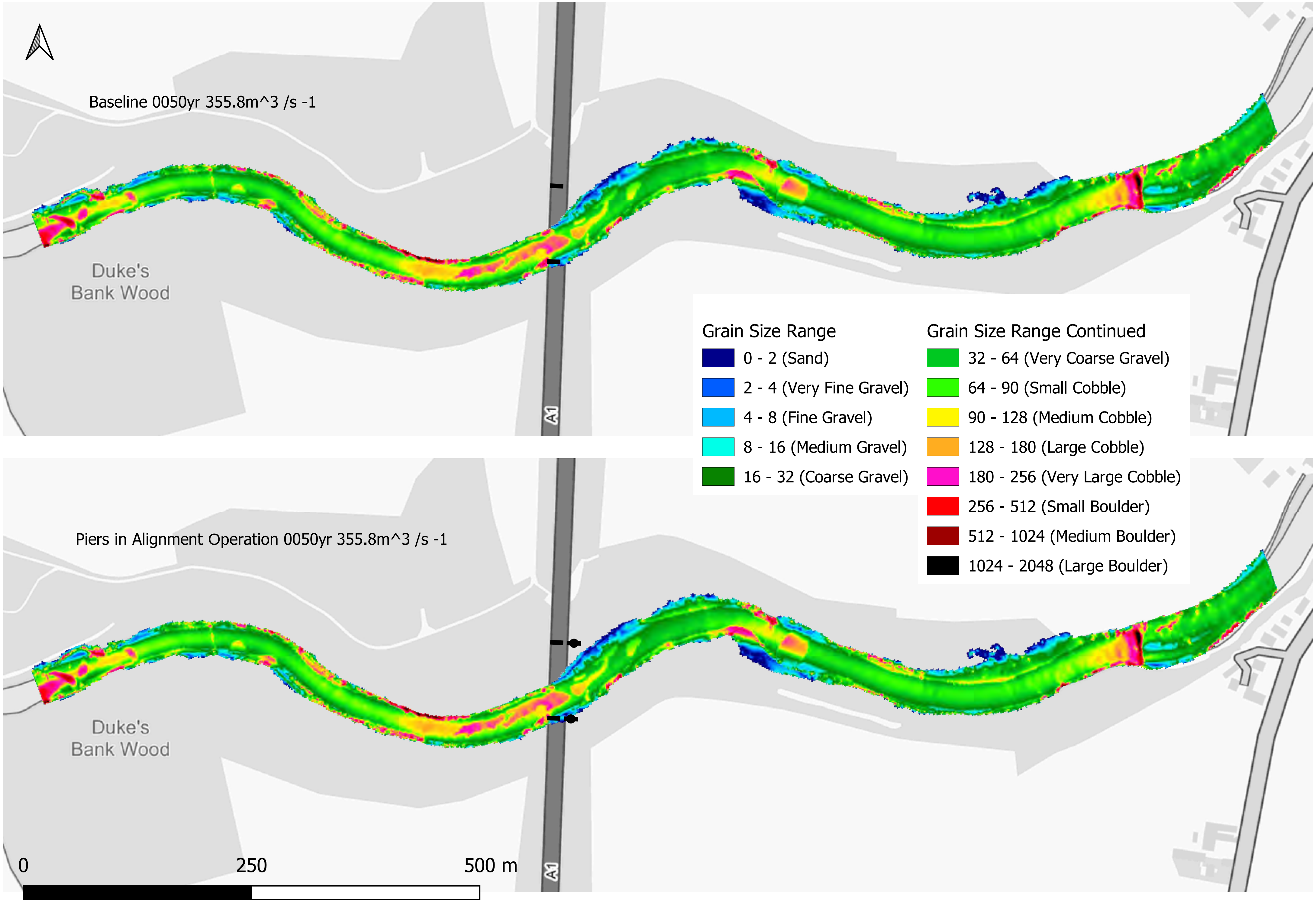


Baseline 0010yr 253.8m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Parameter 10 Construction 0010yr 253.8m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m

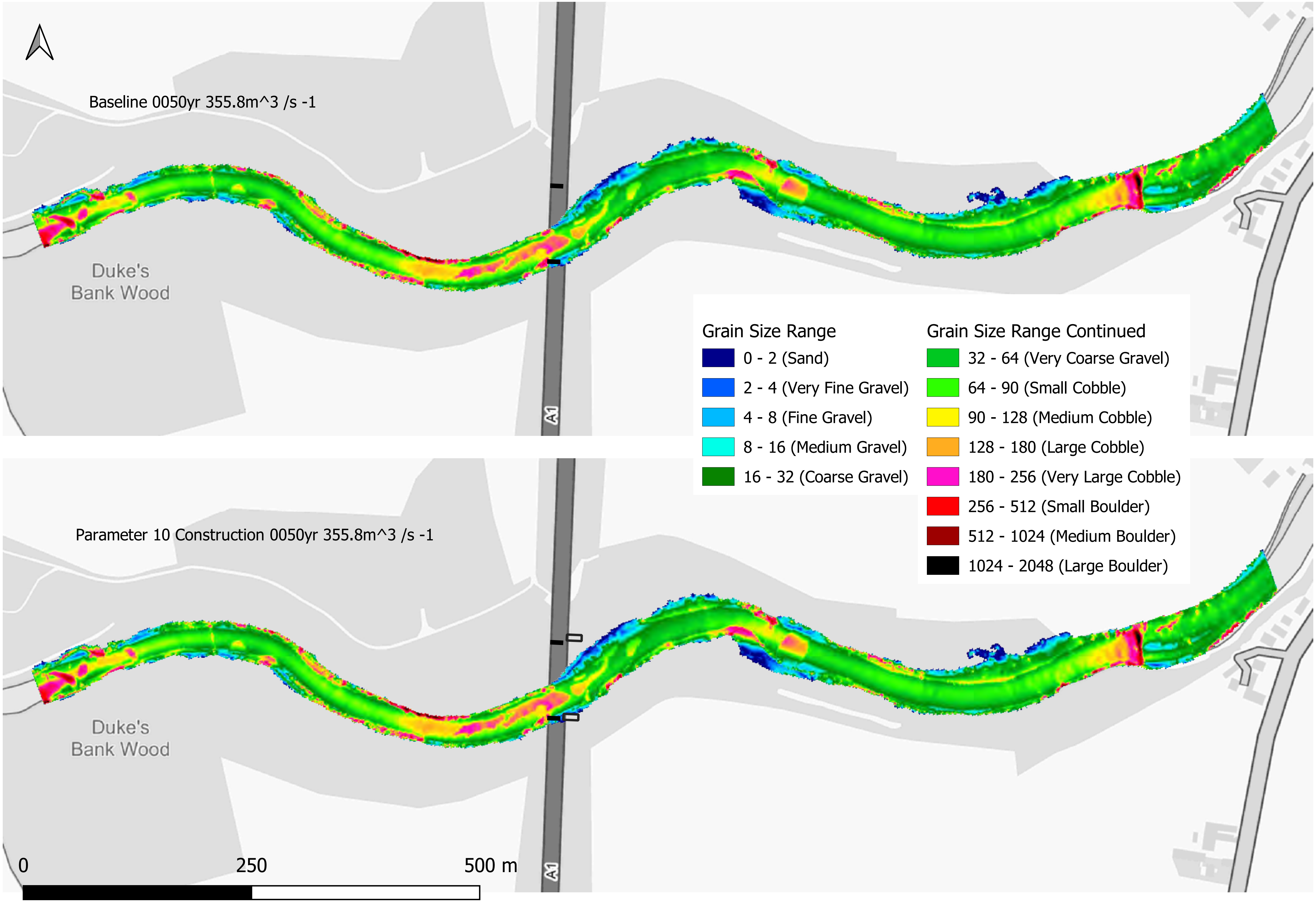

Baseline 0010yr 253.8m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Parameter 10 Alignment Operation 0010yr 253.8m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m

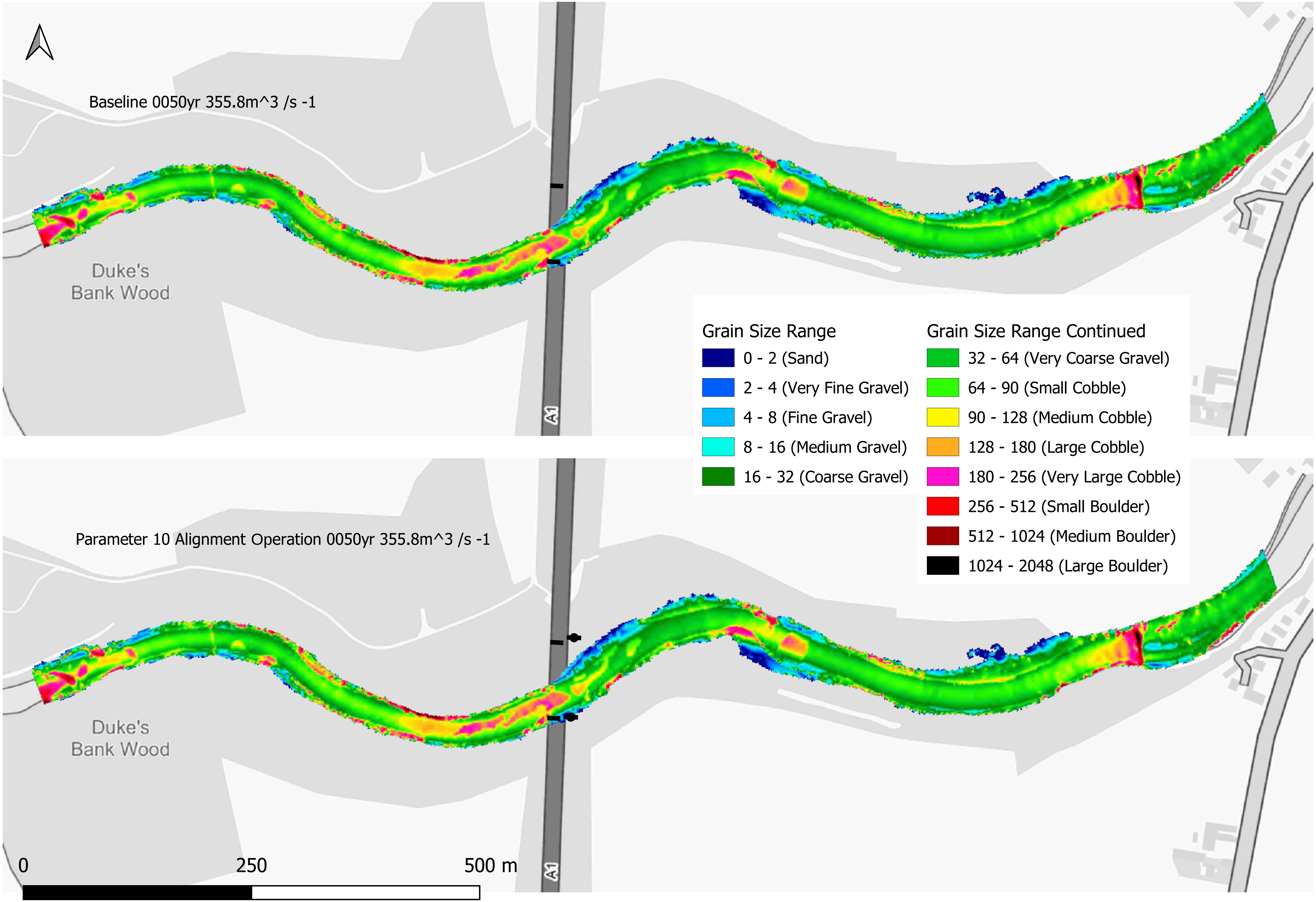


Baseline 0050yr 355.8m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Piers in Alignment Construction 0050yr 355.8m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m

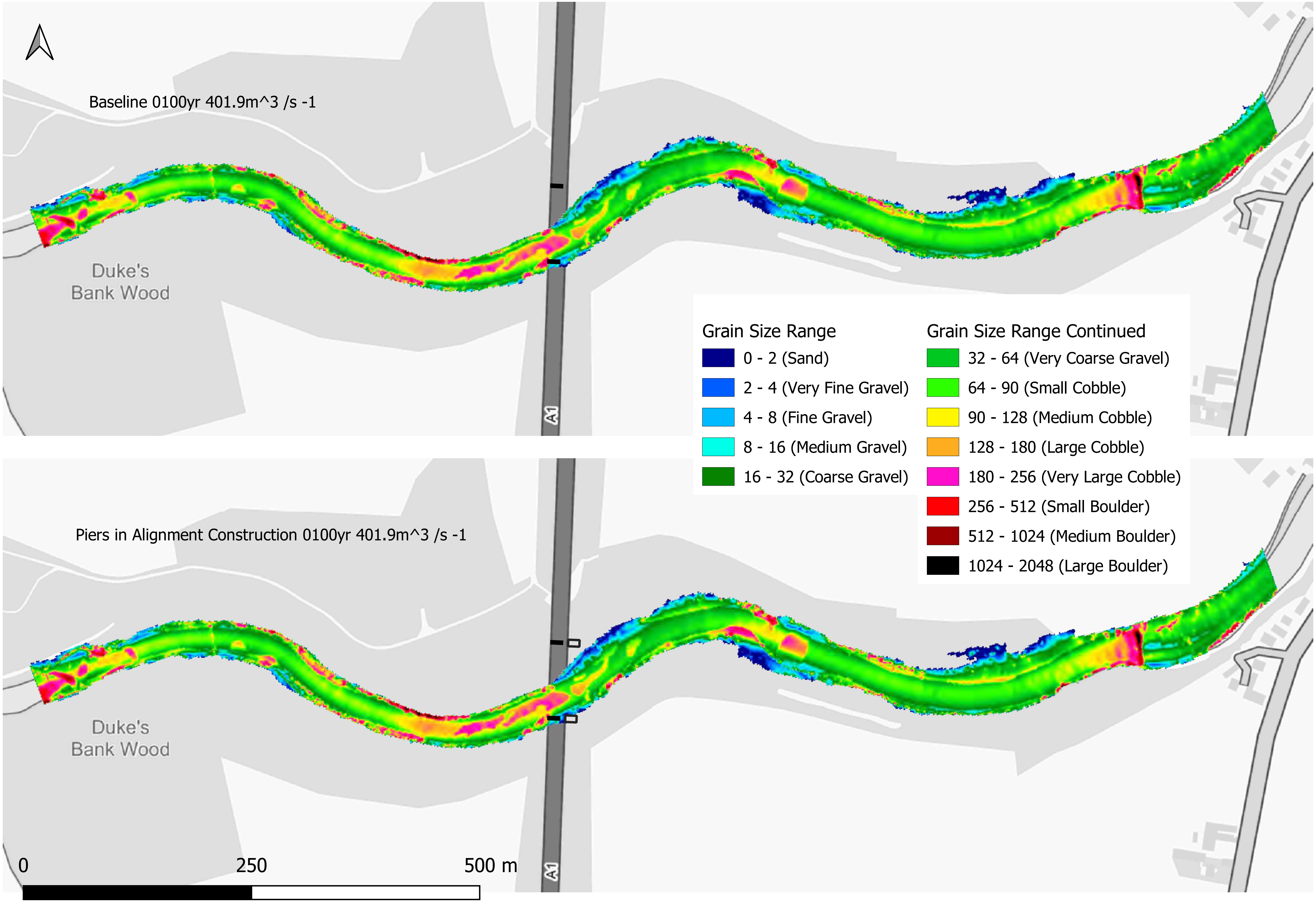


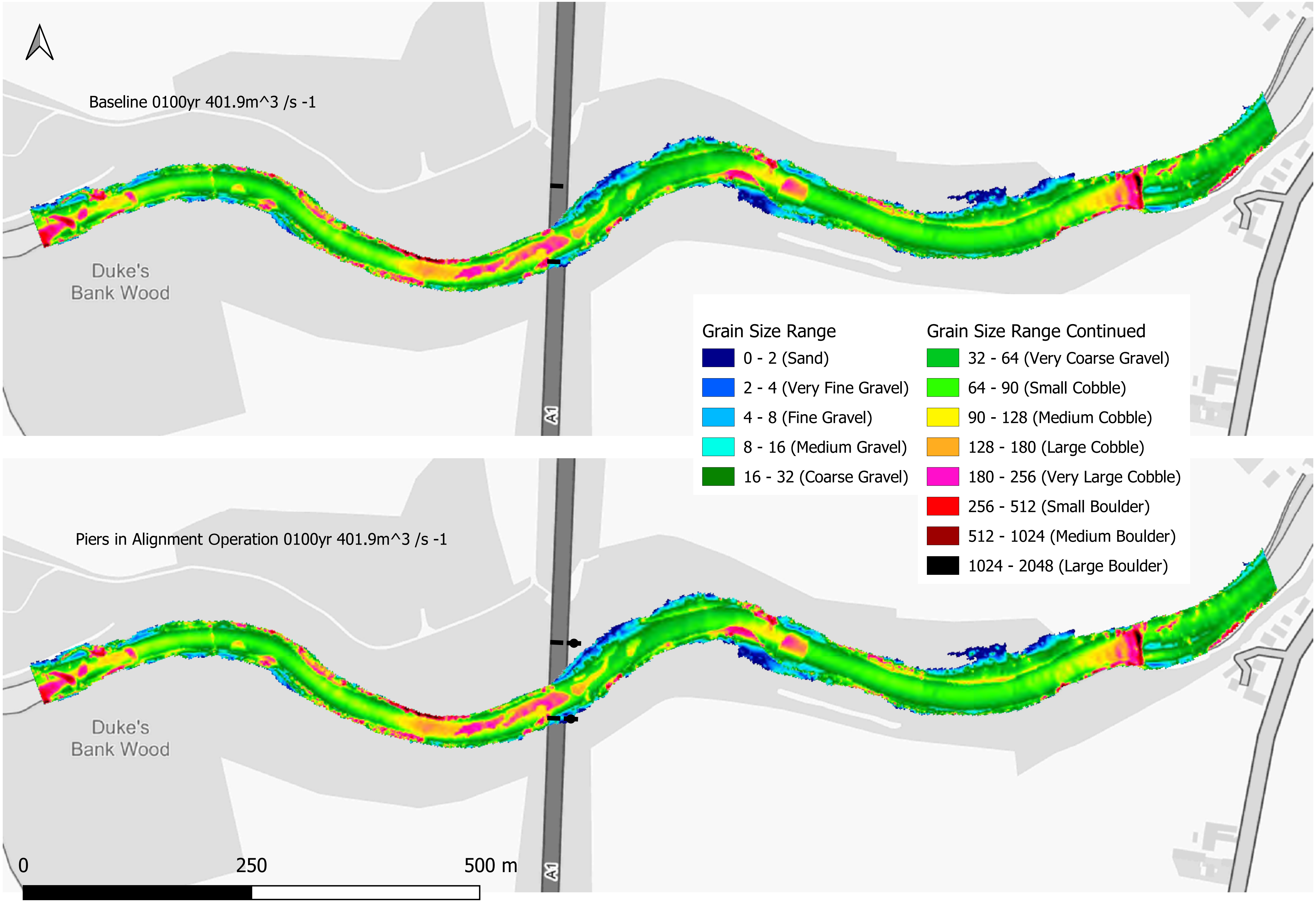
Baseline 0050yr 355.8m^3 /s -1
Duke's Bank Wood
A1
Piers in Alignment Operation 0050yr 355.8m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
0
250
500 m

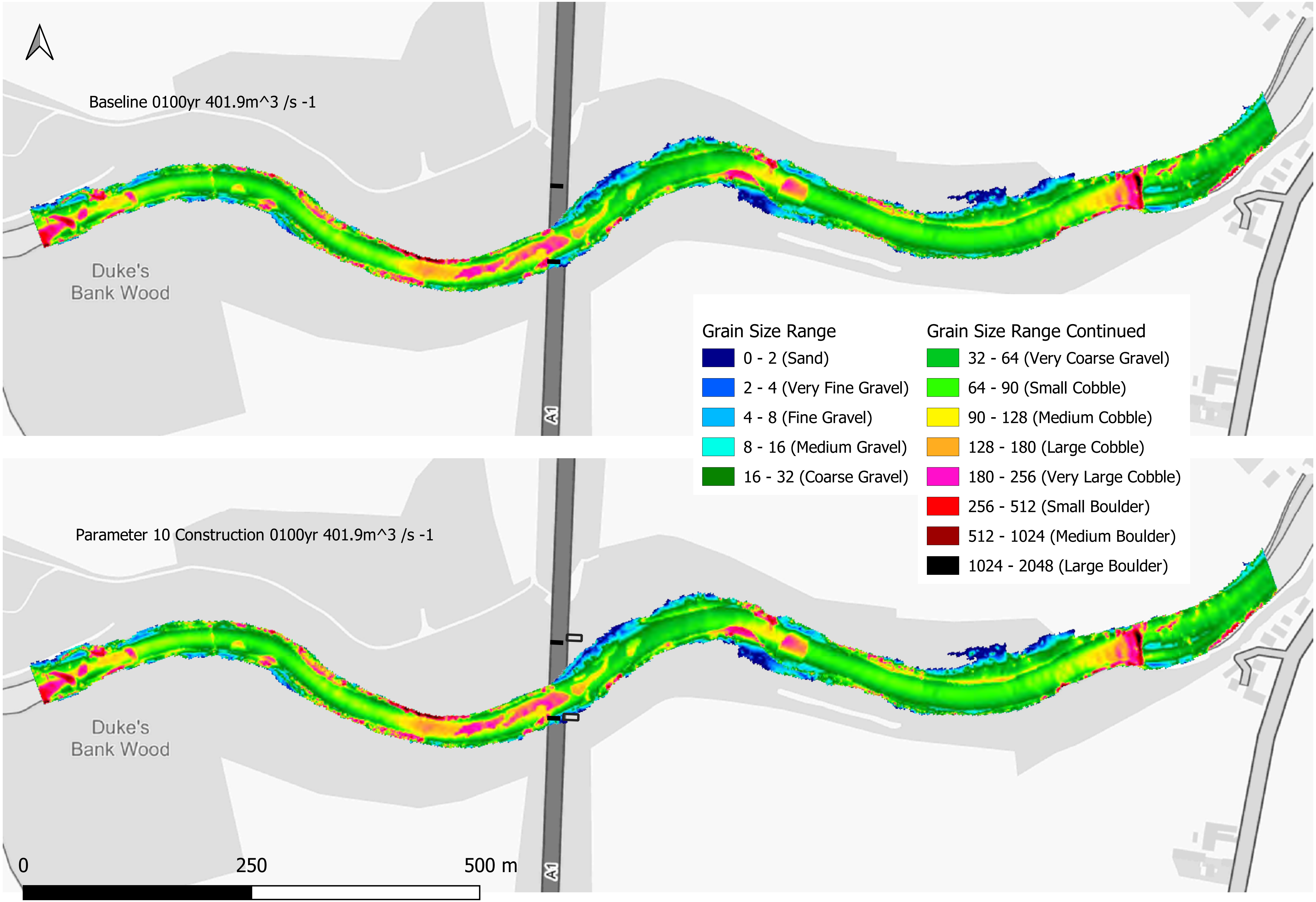

Baseline 0050yr 355.8m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Parameter 10 Construction 0050yr 355.8m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m

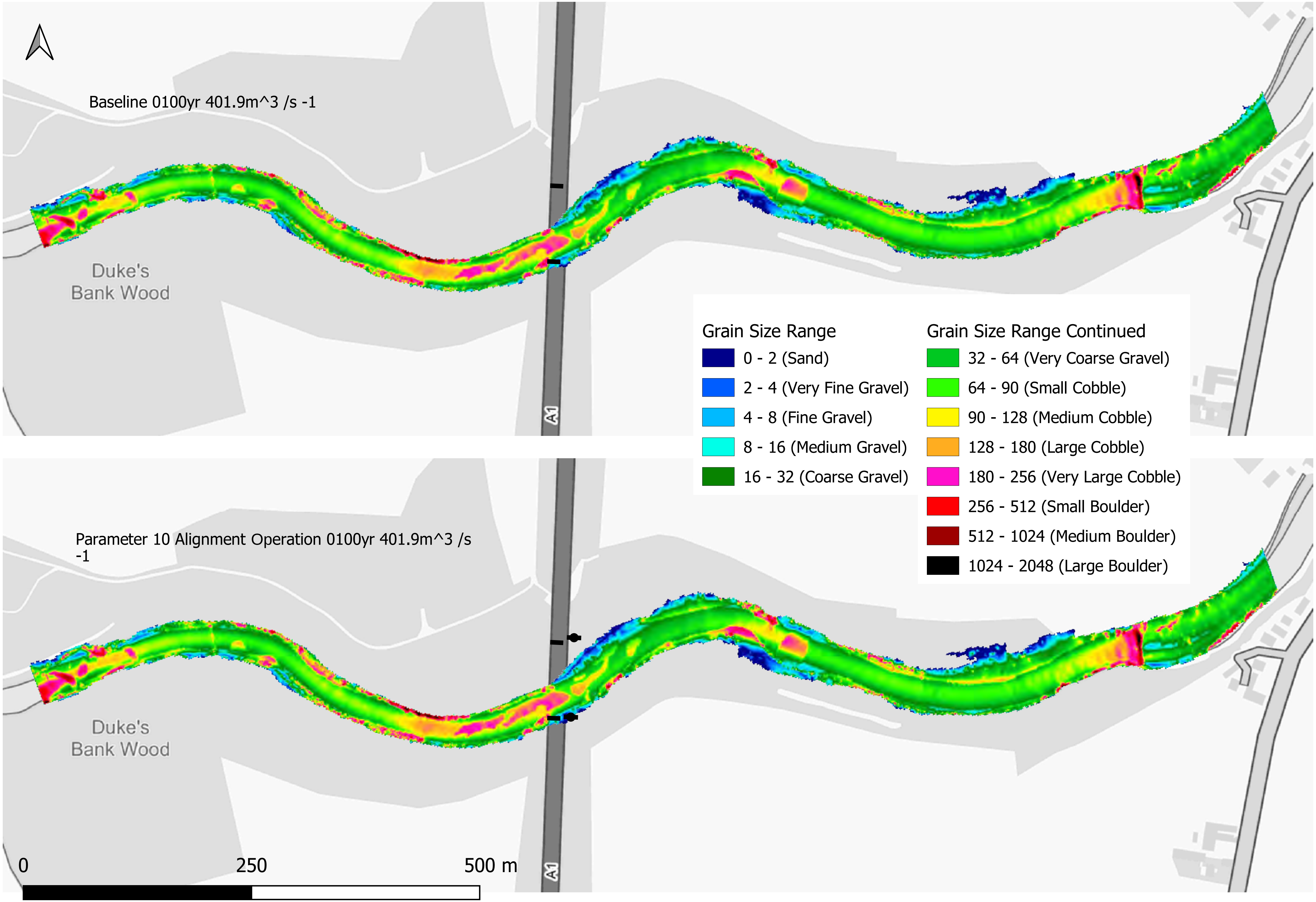


Baseline 0050yr 355.8m^3 /s -1
Duke's
Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Parameter 10 Alignment Operation 0050yr 355.8m^3 /s -1
Duke's
Bank Wood
0
250
500 m
A1

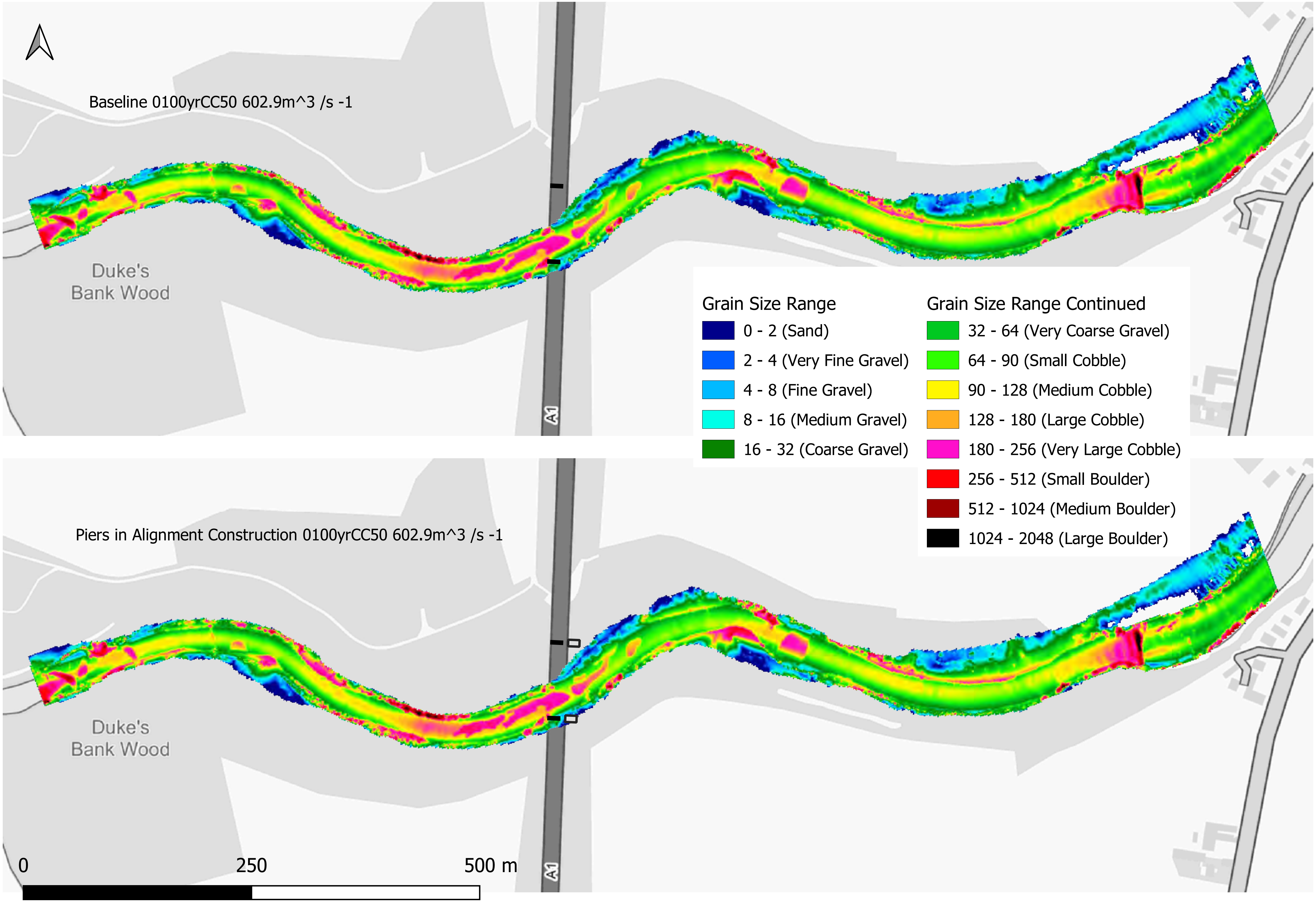

Baseline 0100yr 401.9m^3 /s -1
Duke's Bank Wood
A1
Piers in Alignment Construction 0100yr 401.9m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
0
250
500 m

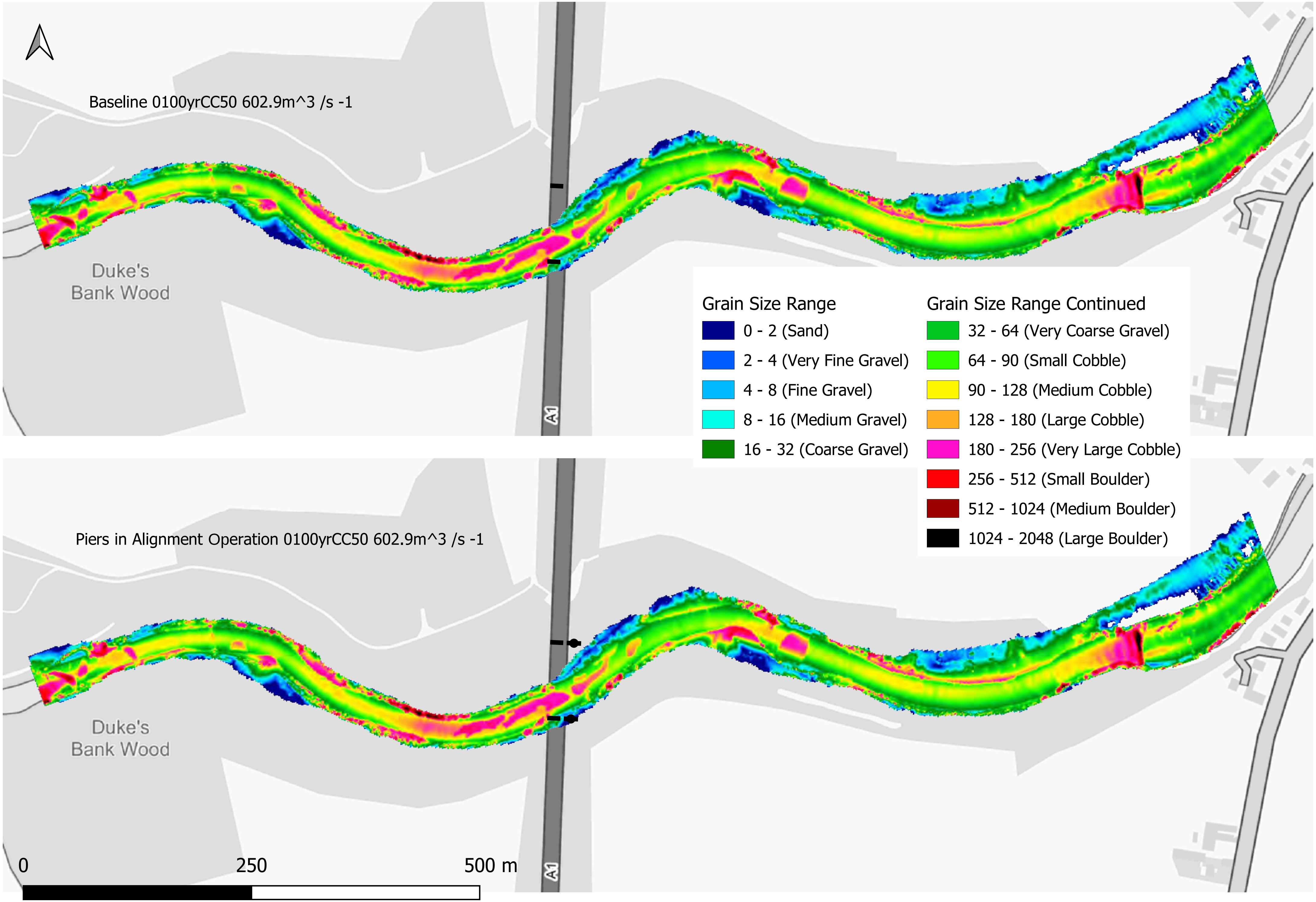

Baseline 0100yr 401.9m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Piers in Alignment Operation 0100yr 401.9m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m


Baseline 0100yr 401.9m^3 /s -1
Duke's Bank Wood
A1
Parameter 10 Construction 0100yr 401.9m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
0
250
500 m

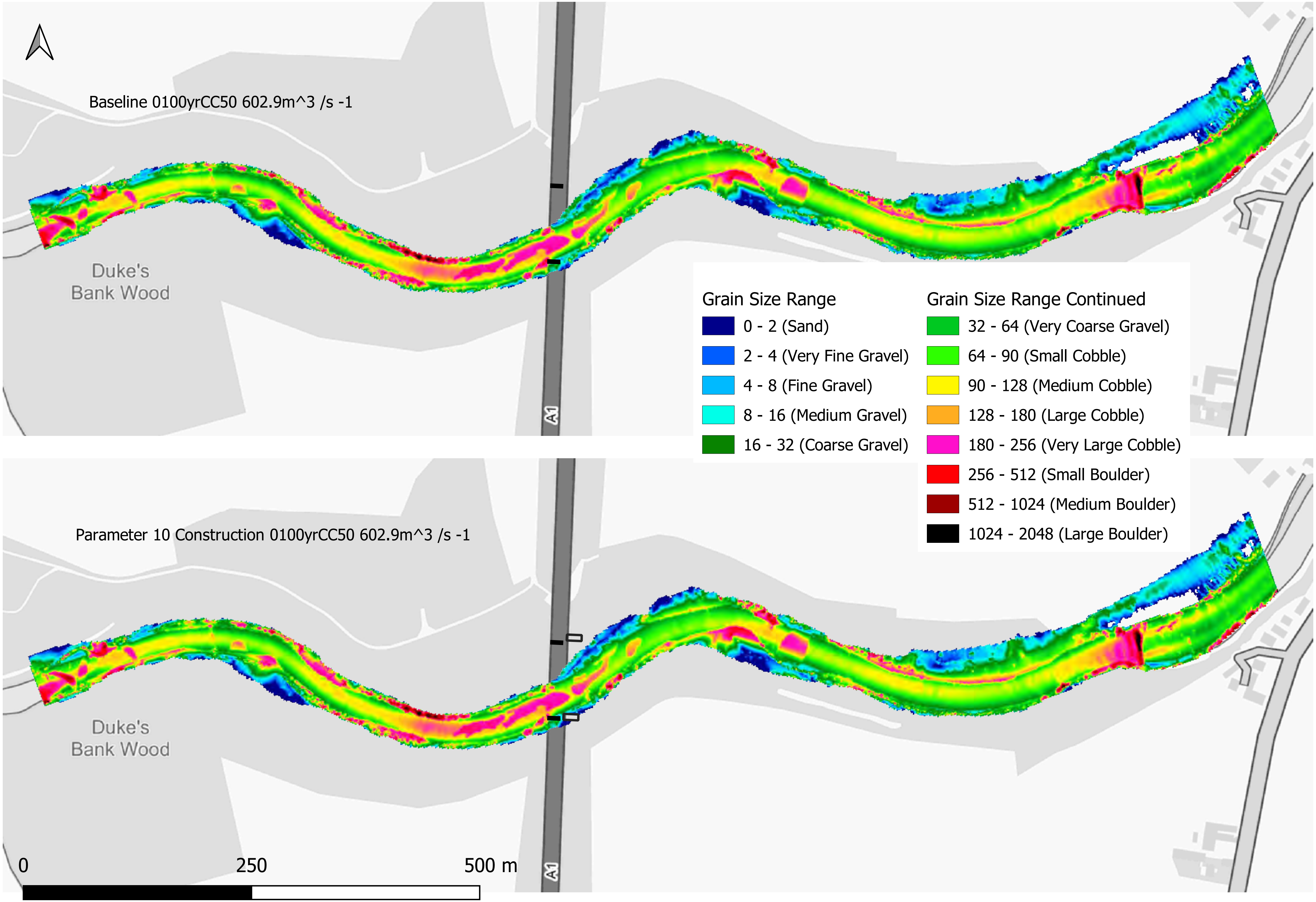


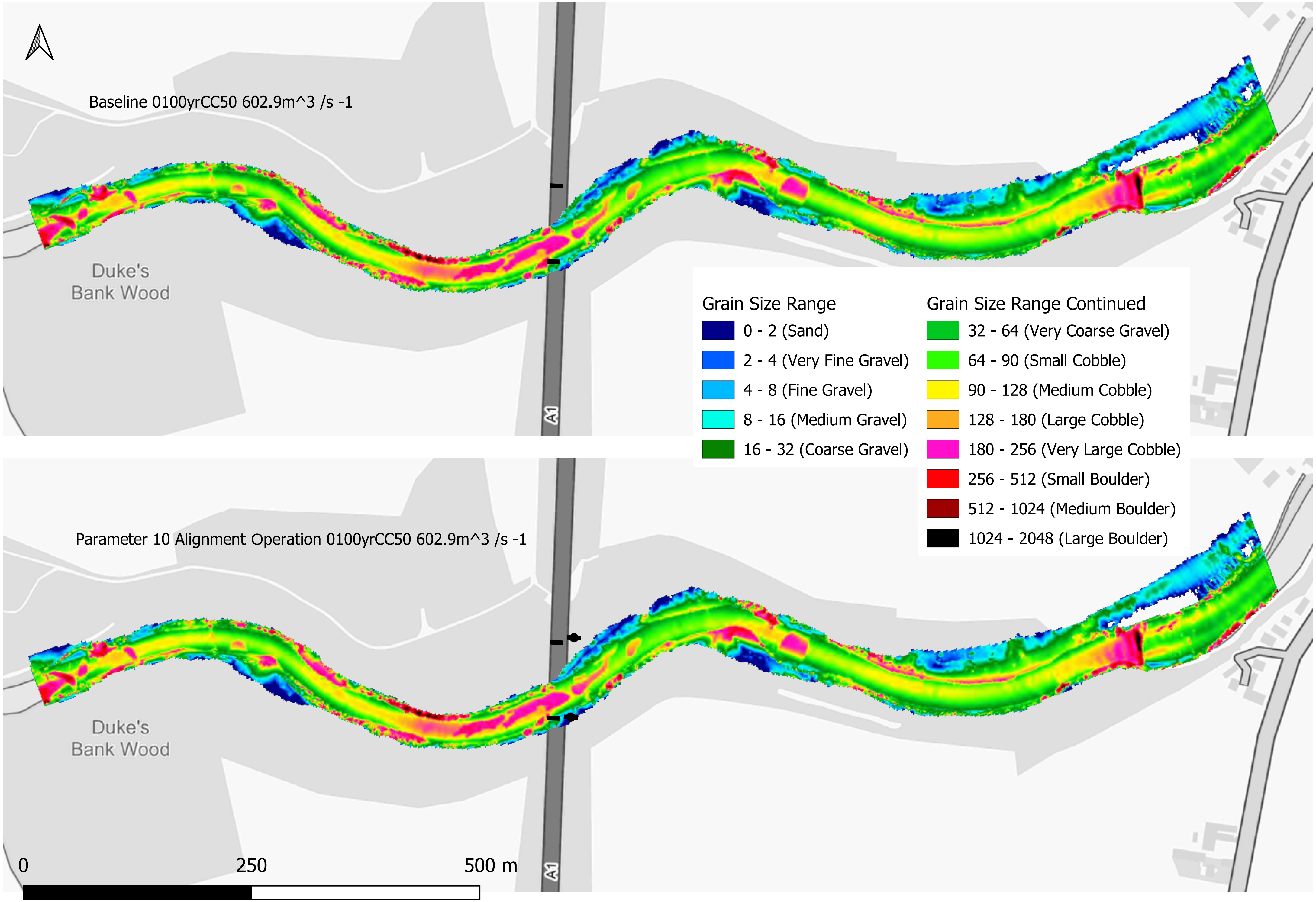
Baseline 0100yr 401.9m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Parameter 10 Alignment Operation 0100yr 401.9m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m


Baseline 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Piers in Alignment Construction 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m

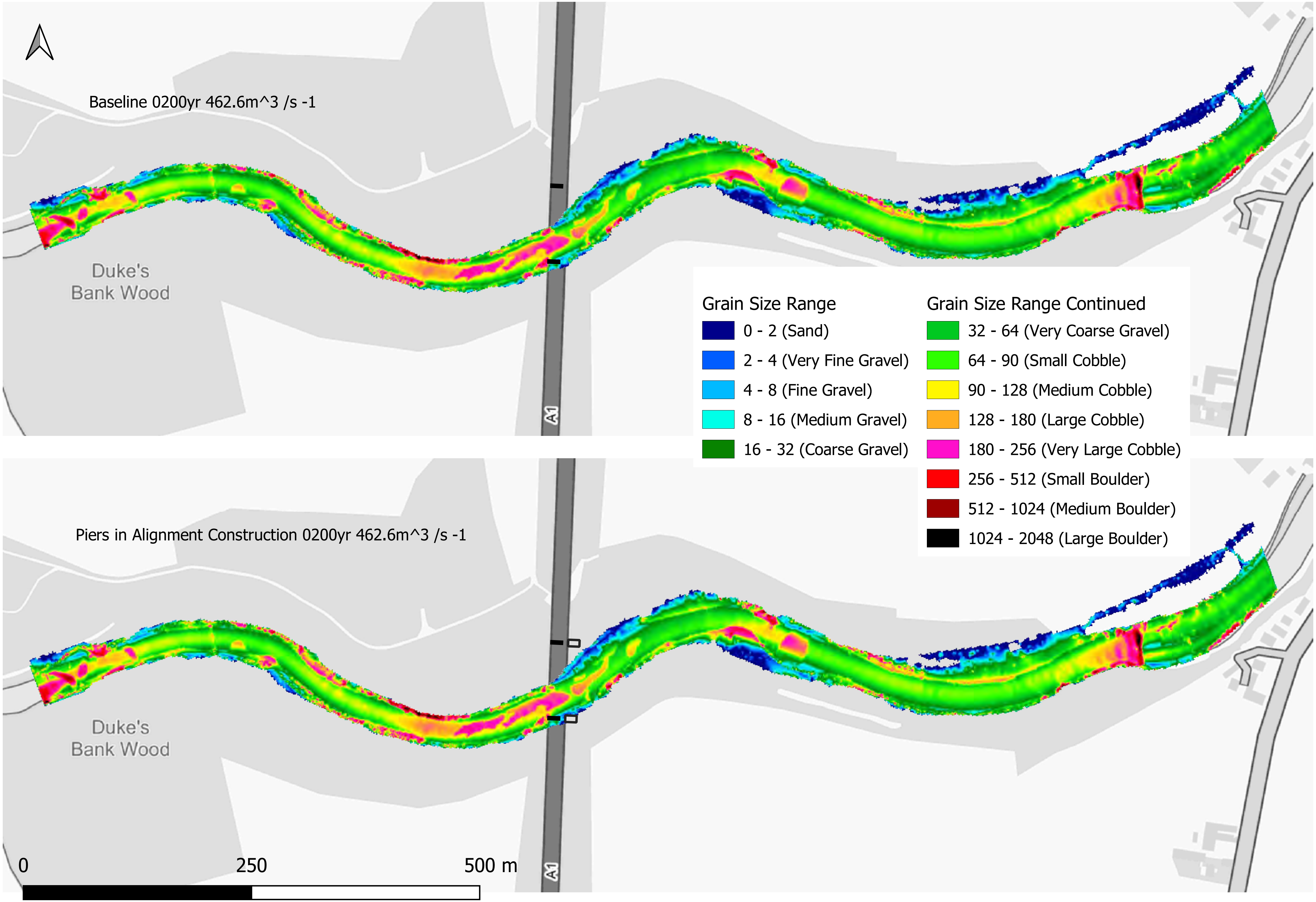


Baseline 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Piers in Alignment Operation 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m

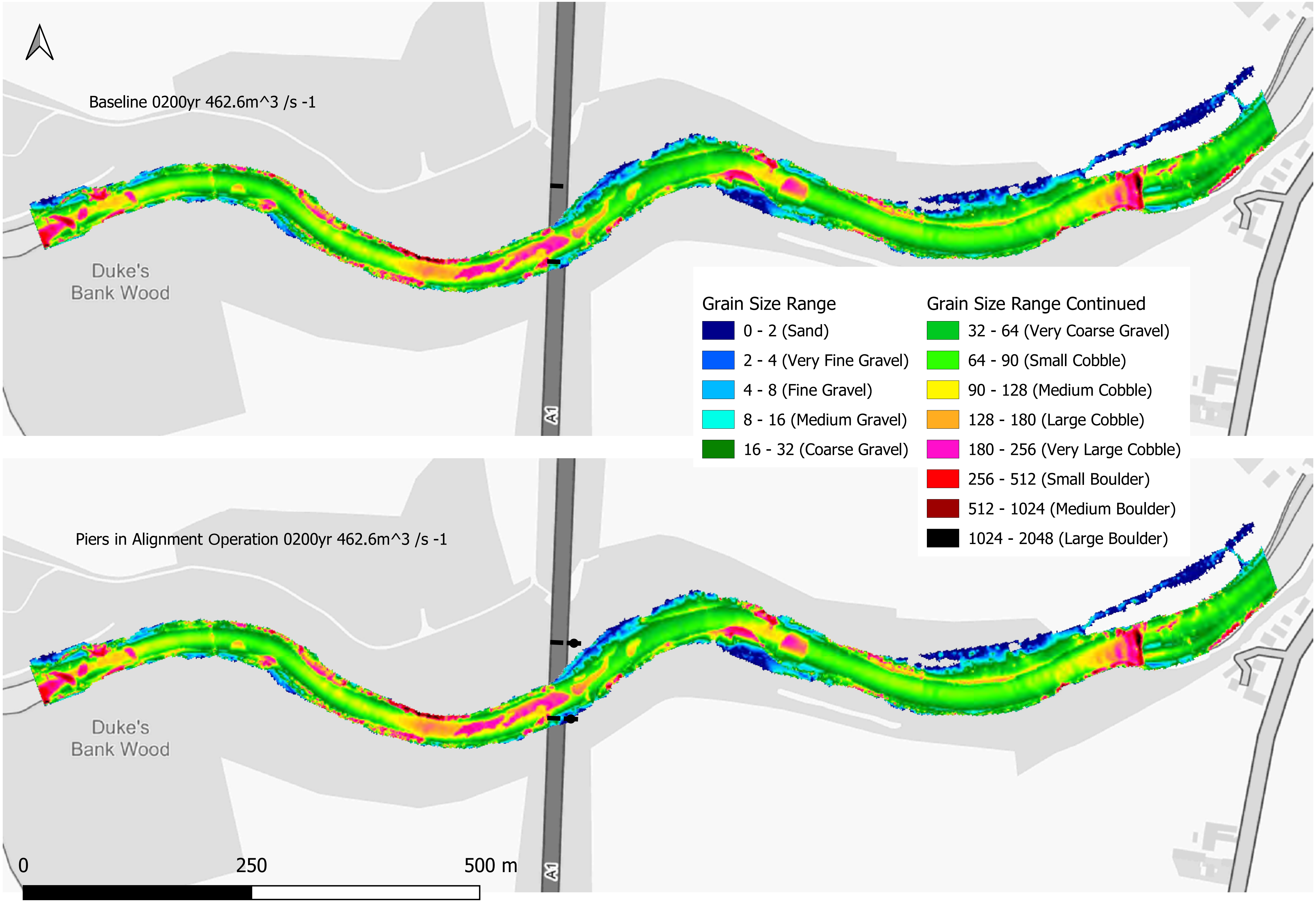

Baseline 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Parameter 10 Construction 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m

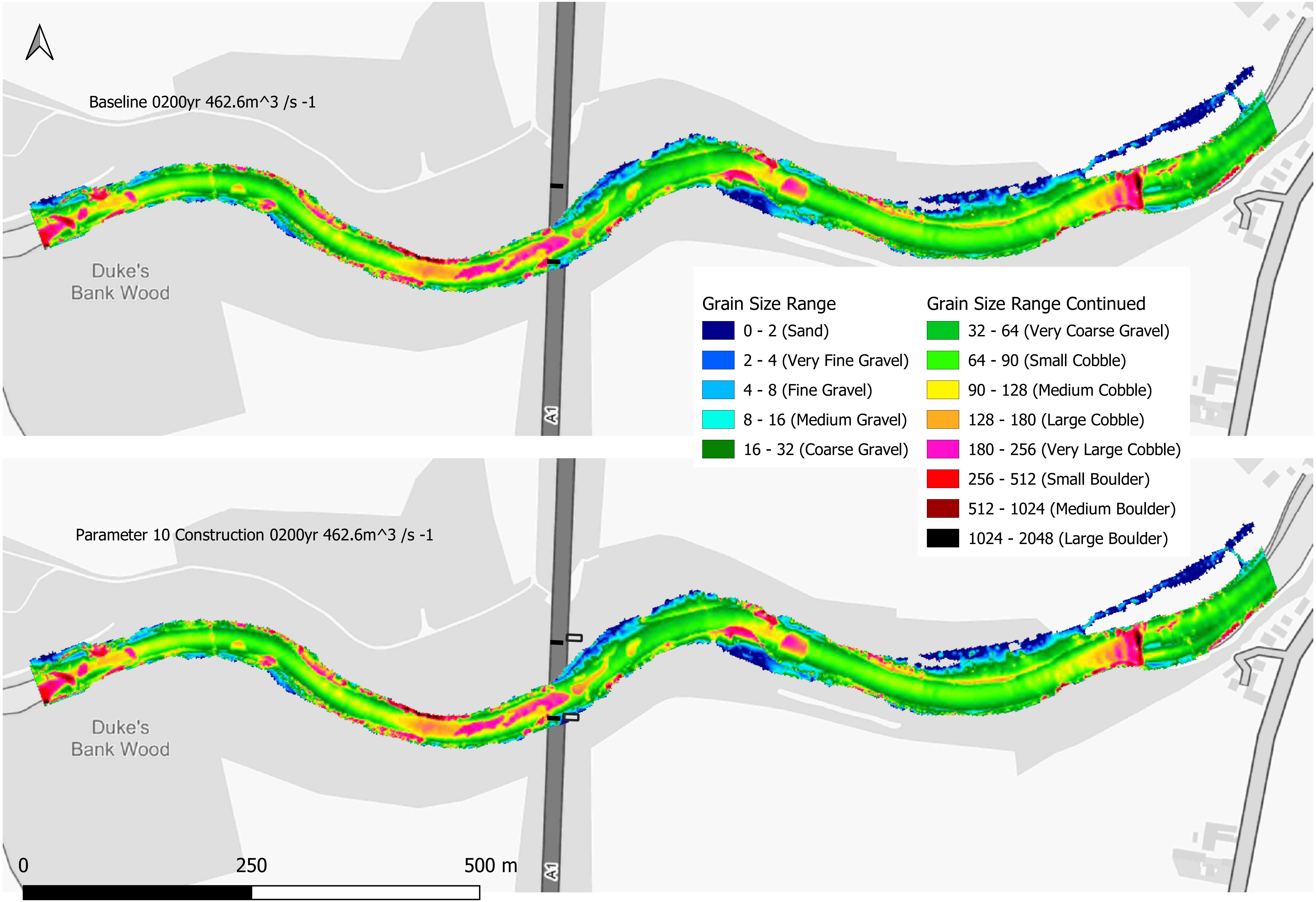


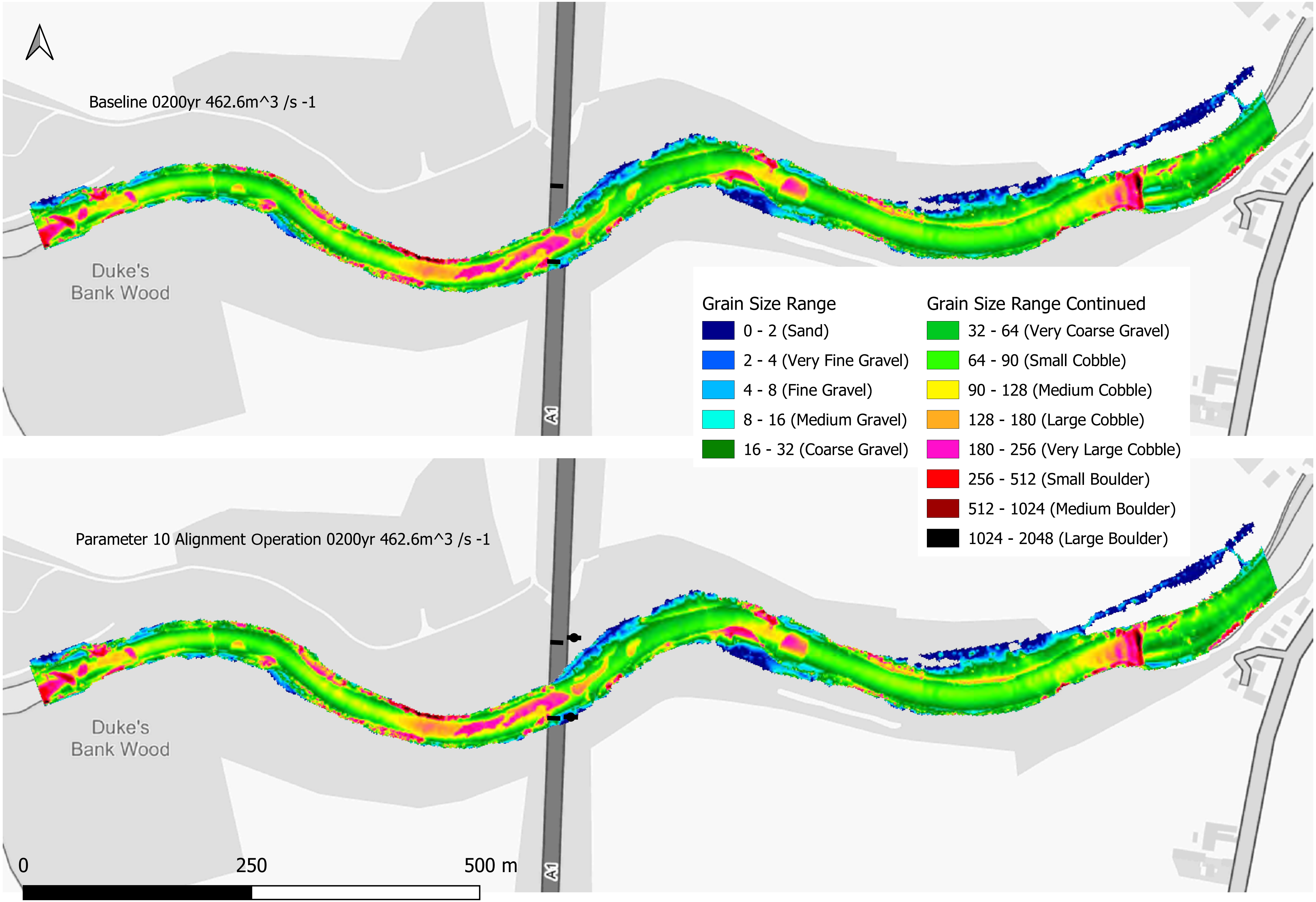
Baseline 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
A1
Parameter 10 Alignment Operation 0100yrCC50 602.9m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
0
250
500 m



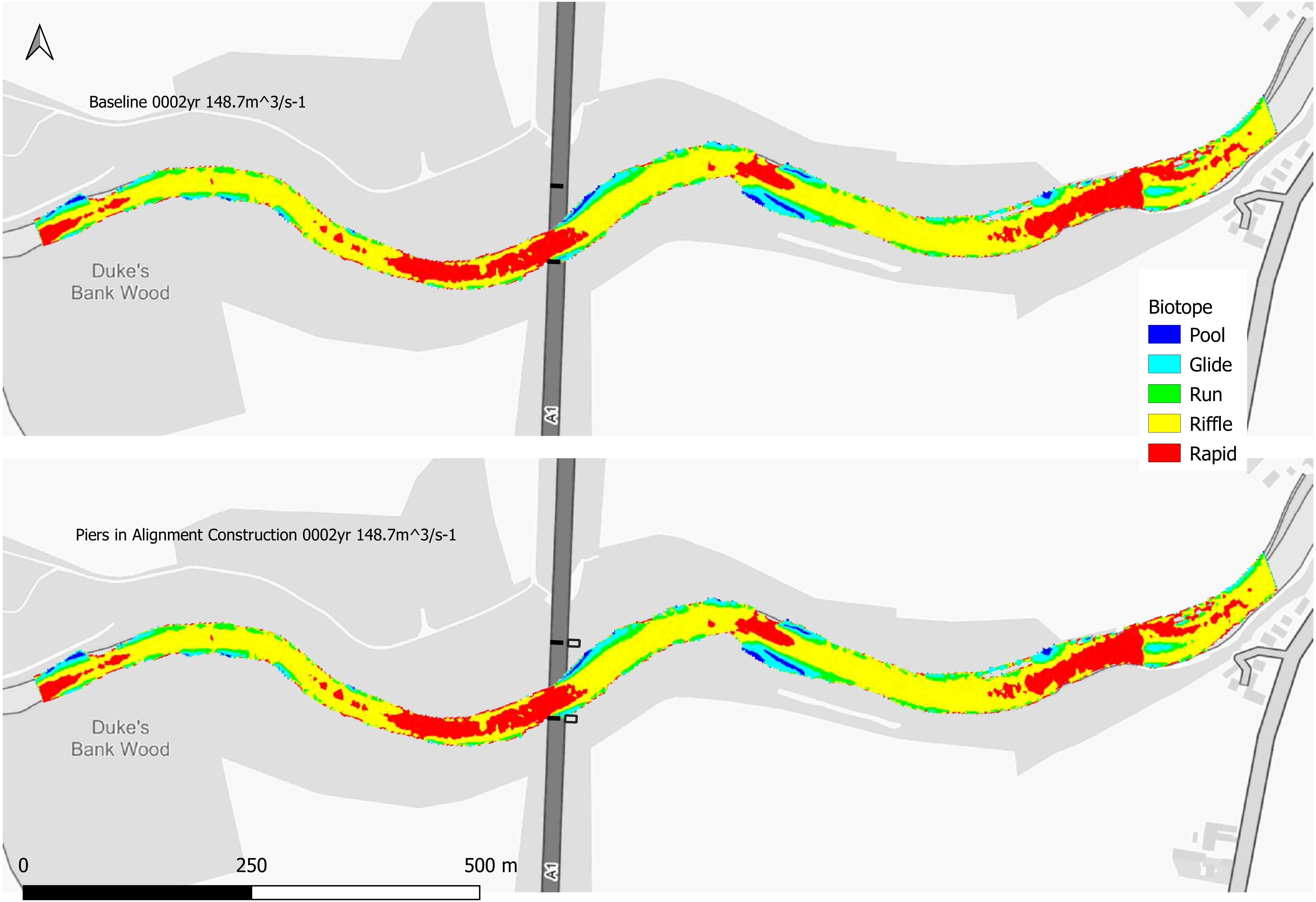
Baseline 0200yr 462.6m^3 /s -1
Duke's
Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Piers in Alignment Construction 0200yr 462.6m^3 /s -1
Duke's
Bank Wood
A1
0
250
500 m


Baseline 0200yr 462.6m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Piers in Alignment Operation 0200yr 462.6m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m

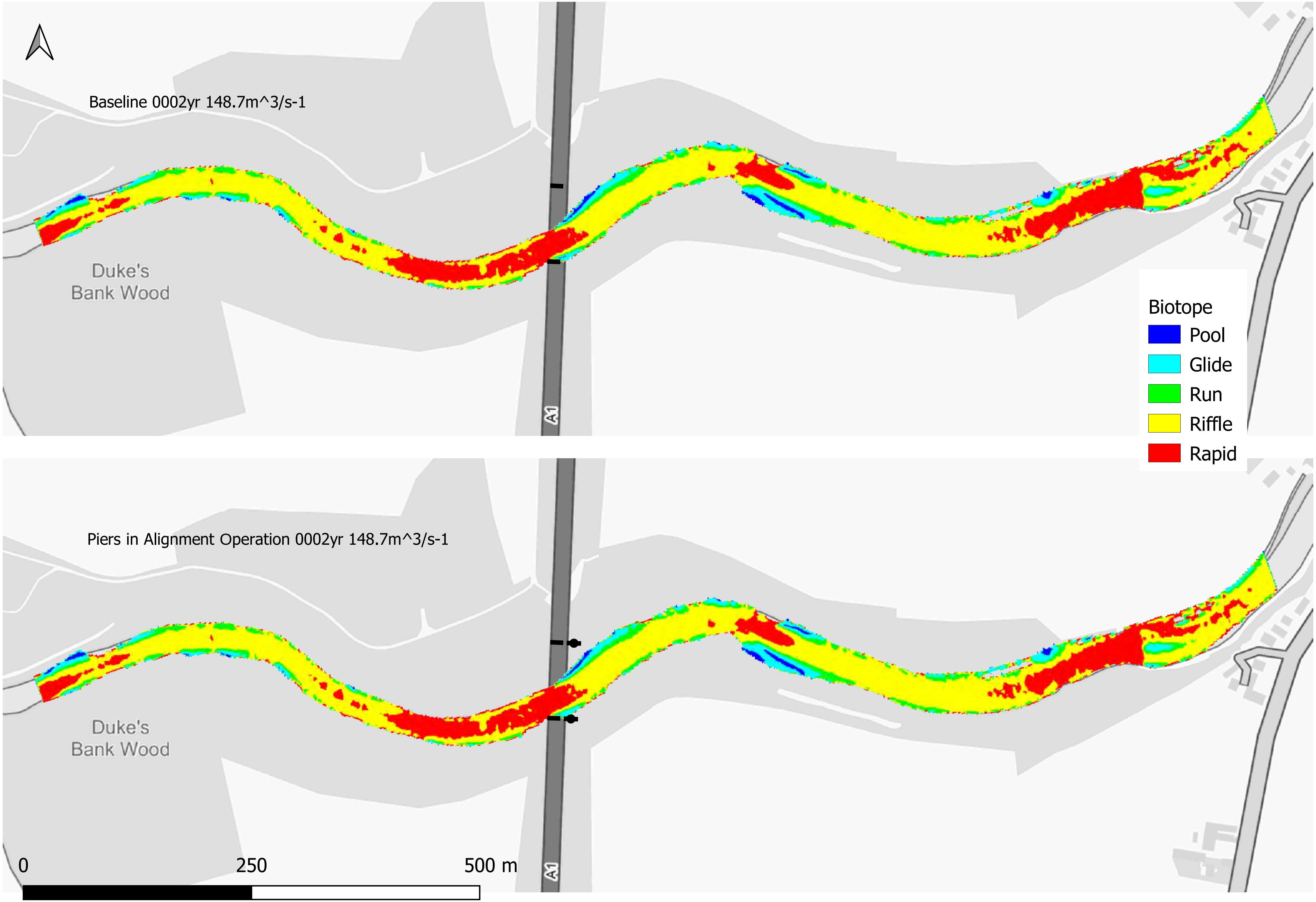

Baseline 0200yr 462.6m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Parameter 10 Construction 0200yr 462.6m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m


Baseline 0200yr 462.6m^3 /s -1
Duke's Bank Wood
A1
Grain Size Range
0 - 2 (Sand)
2 - 4 (Very Fine Gravel)
4 - 8 (Fine Gravel)
8 - 16 (Medium Gravel)
16 - 32 (Coarse Gravel)
Grain Size Range Continued
32 - 64 (Very Coarse Gravel)
64 - 90 (Small Cobble)
90 - 128 (Medium Cobble)
128 - 180 (Large Cobble)
180 - 256 (Very Large Cobble)
256 - 512 (Small Boulder)
512 - 1024 (Medium Boulder)
1024 - 2048 (Large Boulder)
Parameter 10 Alignment Operation 0200yr 462.6m^3 /s -1
Duke's Bank Wood
A1
0
250
500 m

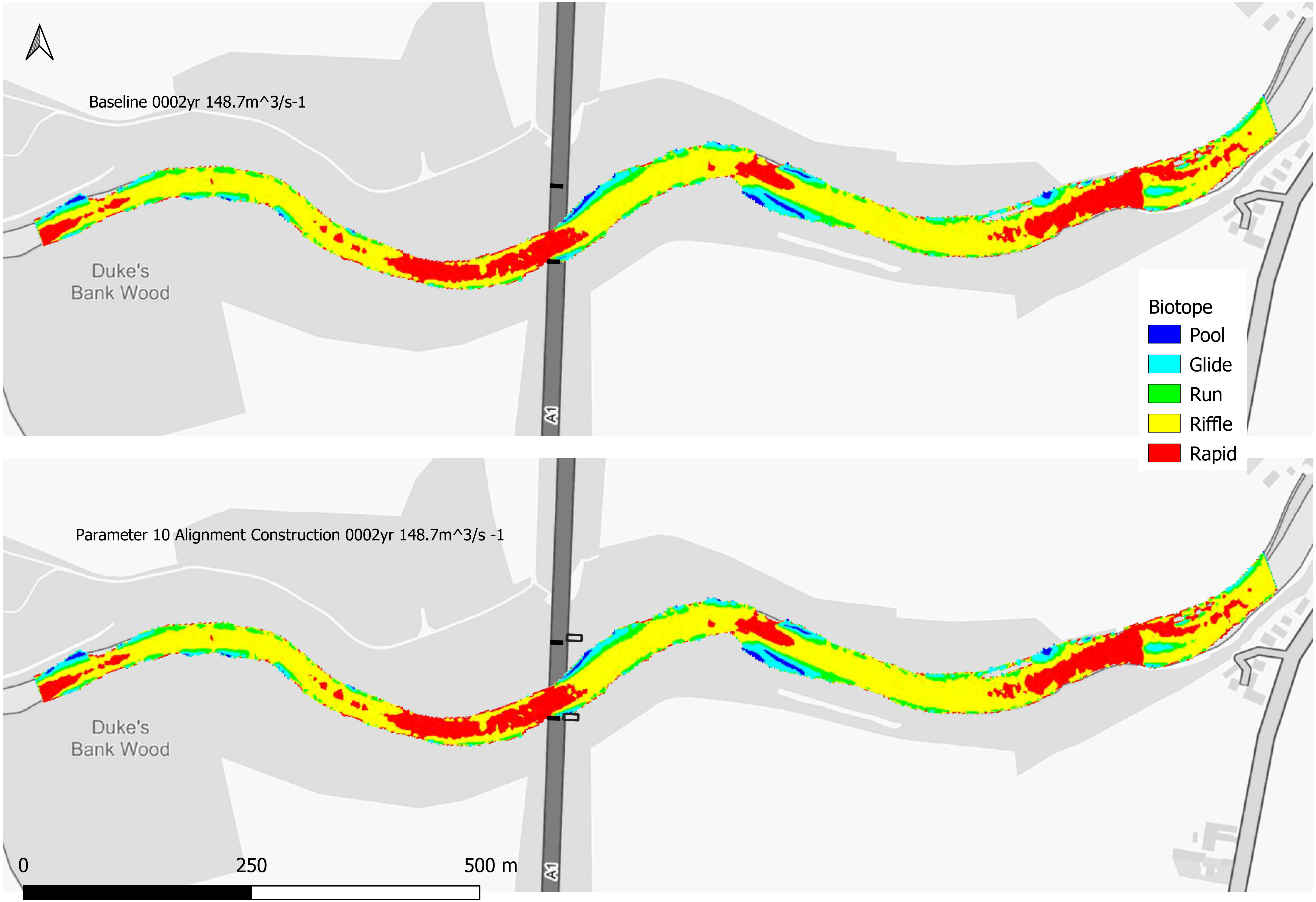
Froude Results



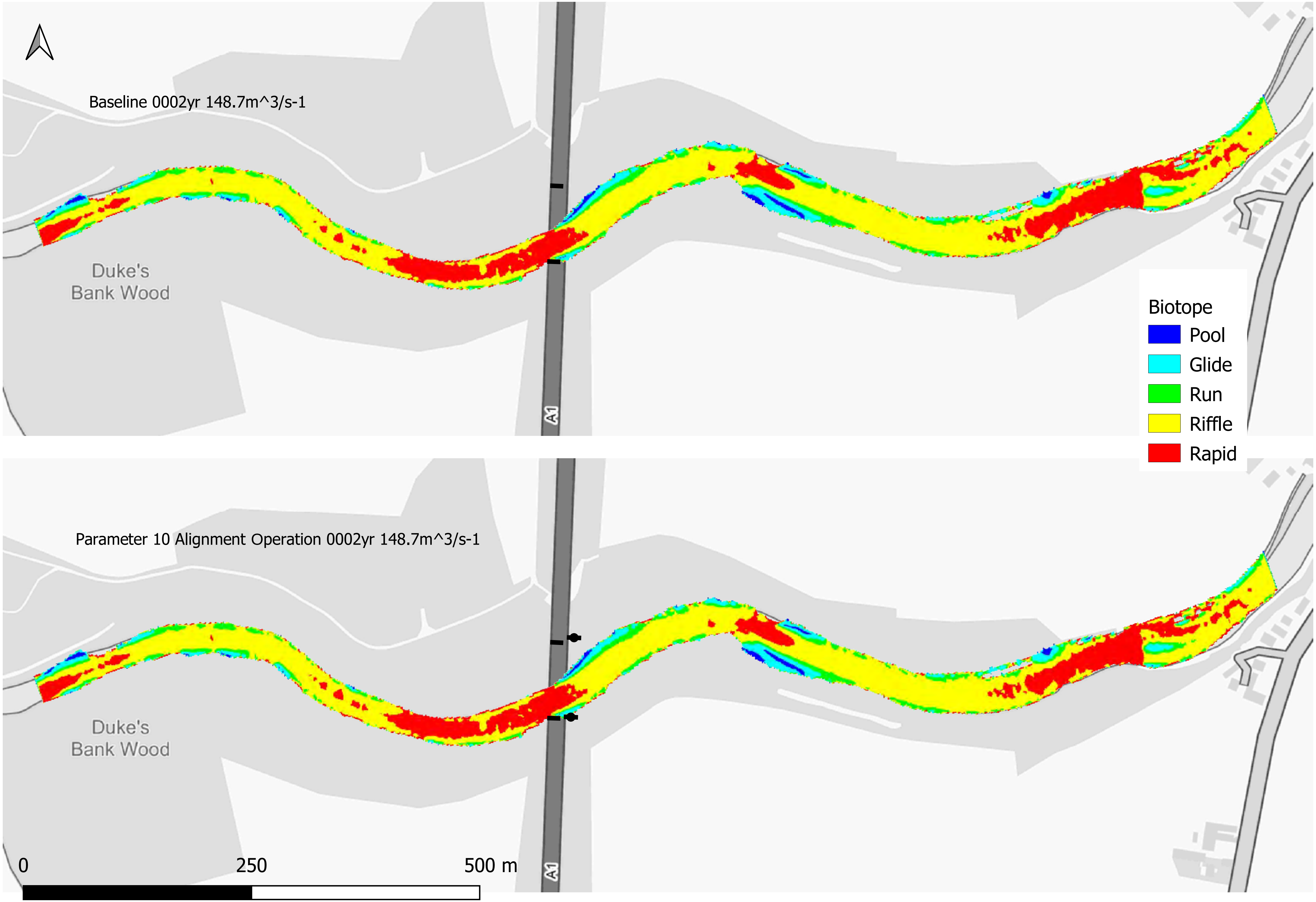
Baseline 0002yr 148.7m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Piers in Alignment Construction 0002yr 148.7m^3/s-1
Duke's Bank Wood
A1
0
250
500 m



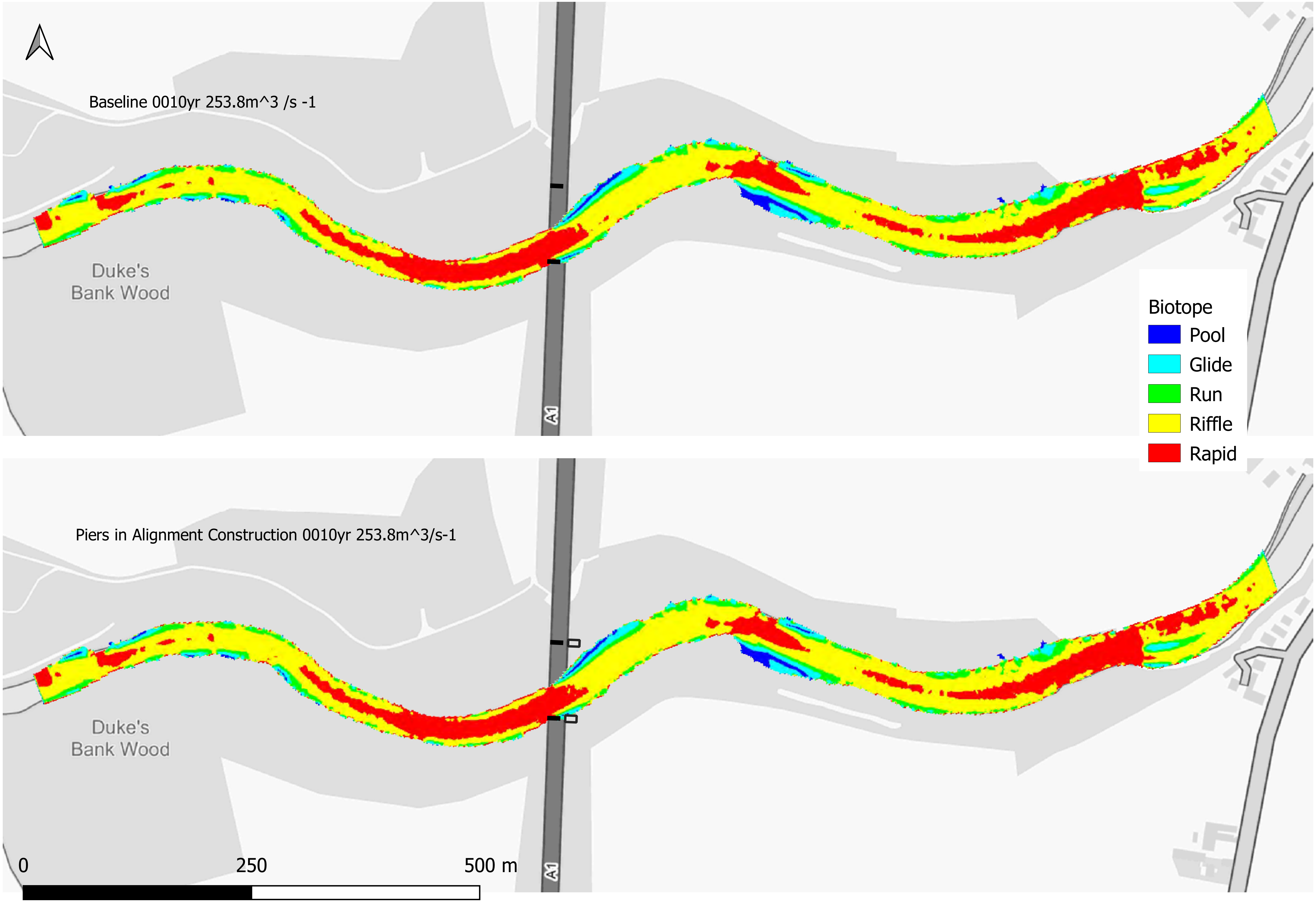
Baseline 0002yr 148.7m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Piers in Alignment Operation 0002yr 148.7m^3/s-1
Duke's Bank Wood
A1
0
250
500 m



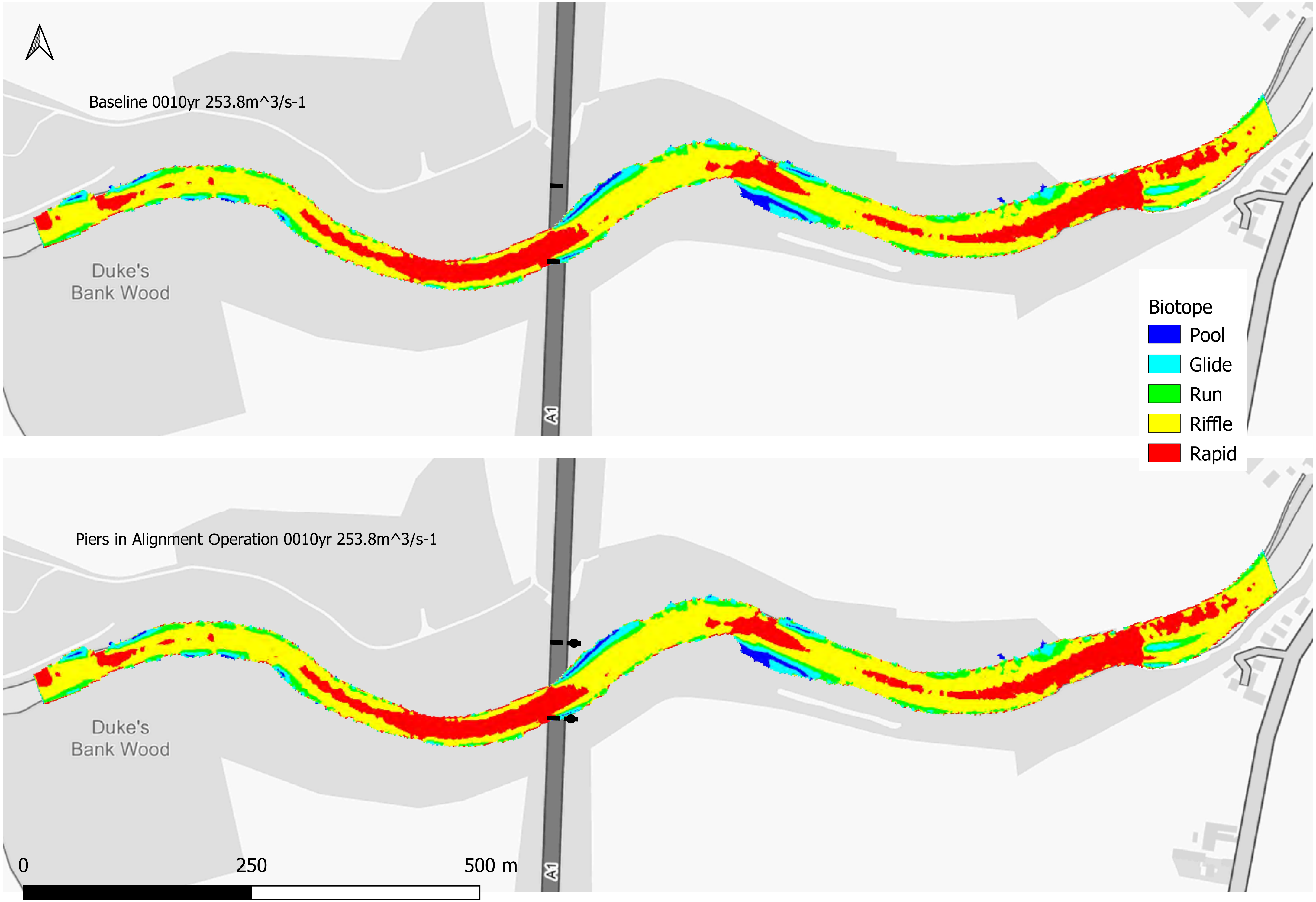
Baseline 0002yr 148.7m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Parameter 10 Alignment Construction 0002yr 148.7m^3/s -1
Duke's Bank Wood
A1
0
250
500 m



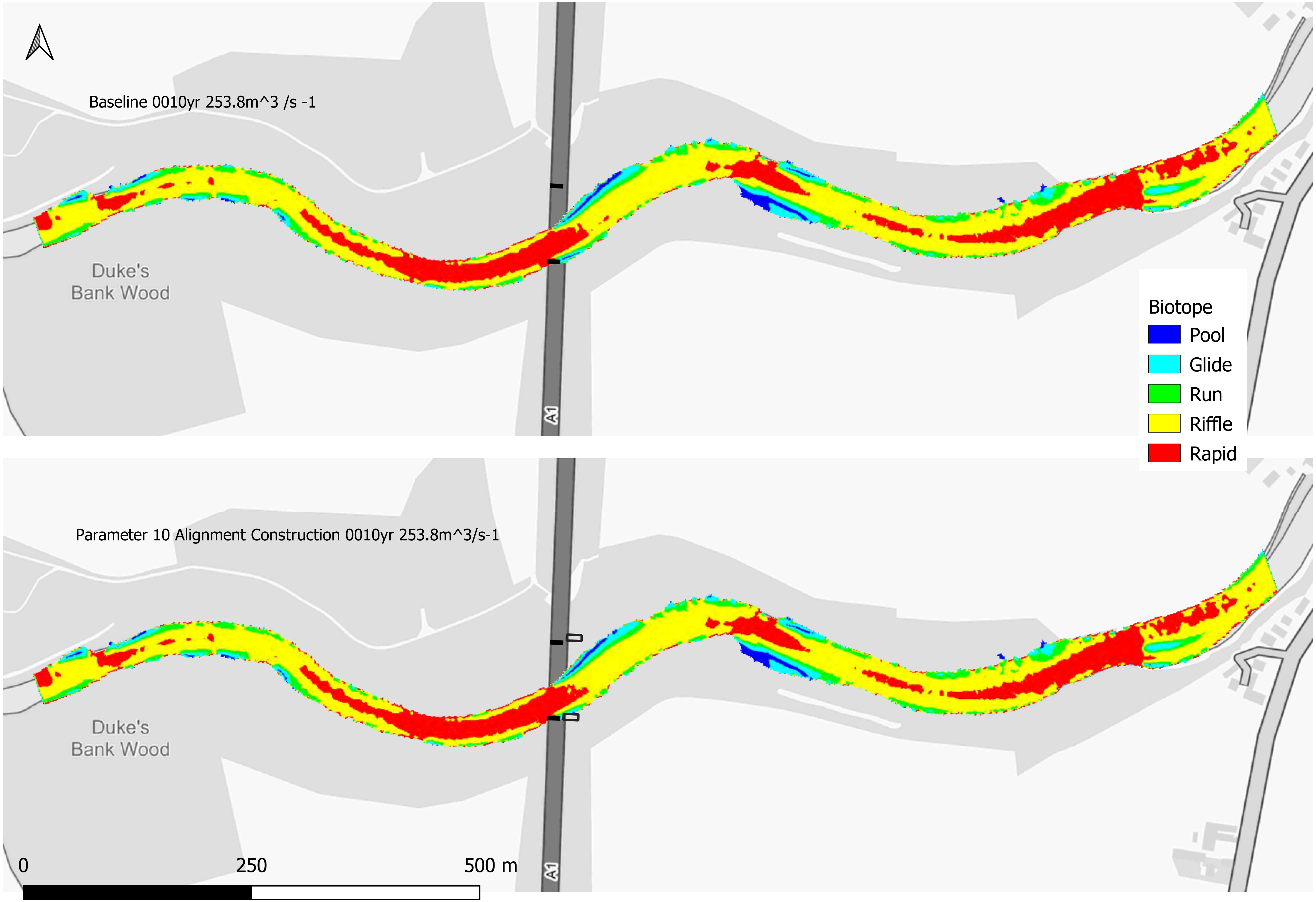
Baseline 0002yr 148.7m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Parameter 10 Alignment Operation 0002yr 148.7m^3/s-1
Duke's Bank Wood
A1
0
250
500 m

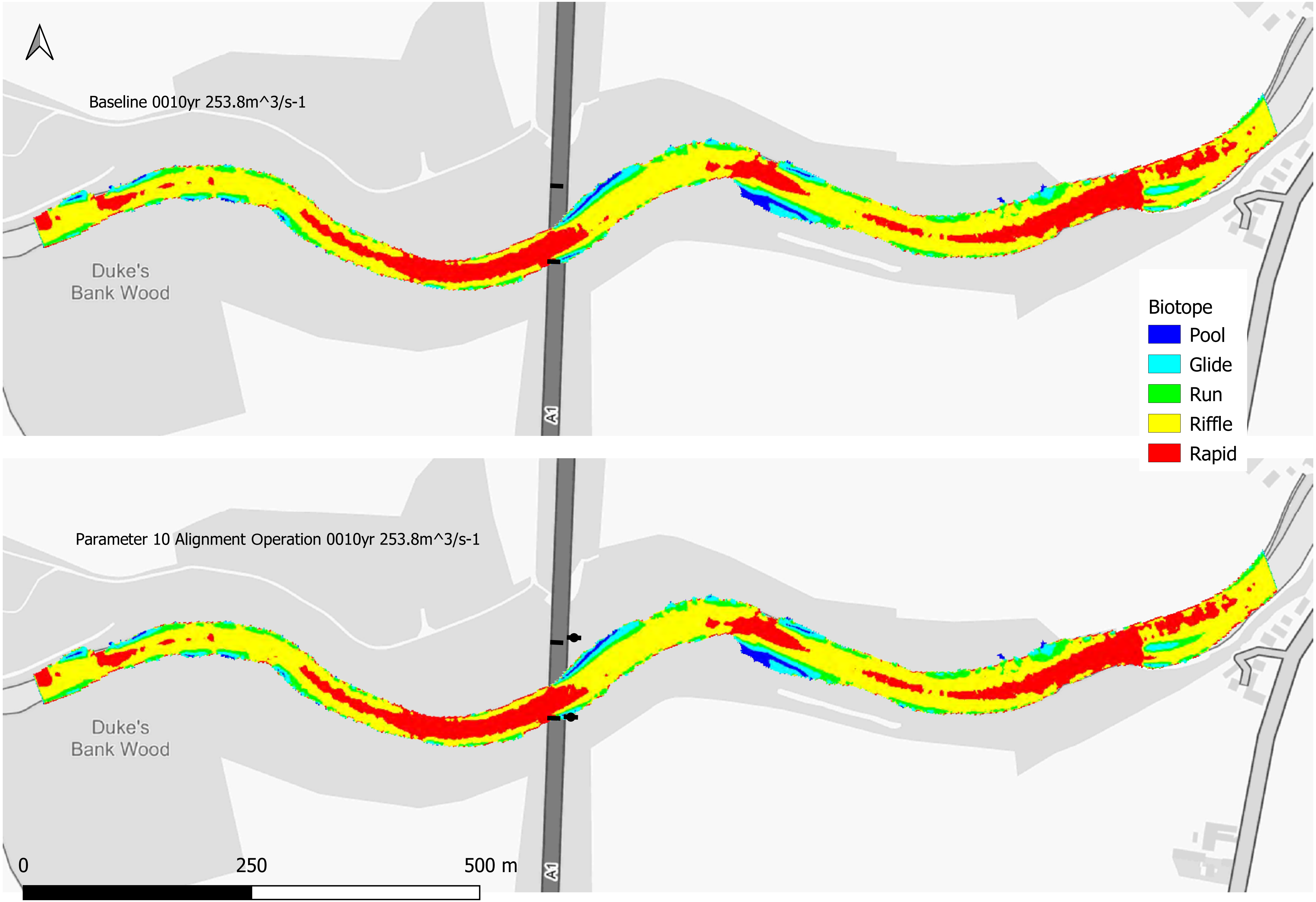


Baseline 0010yr 253.8m^3 /s -1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Piers in Alignment Construction 0010yr 253.8m^3/s-1
Duke's Bank Wood
A1
0
250
500 m

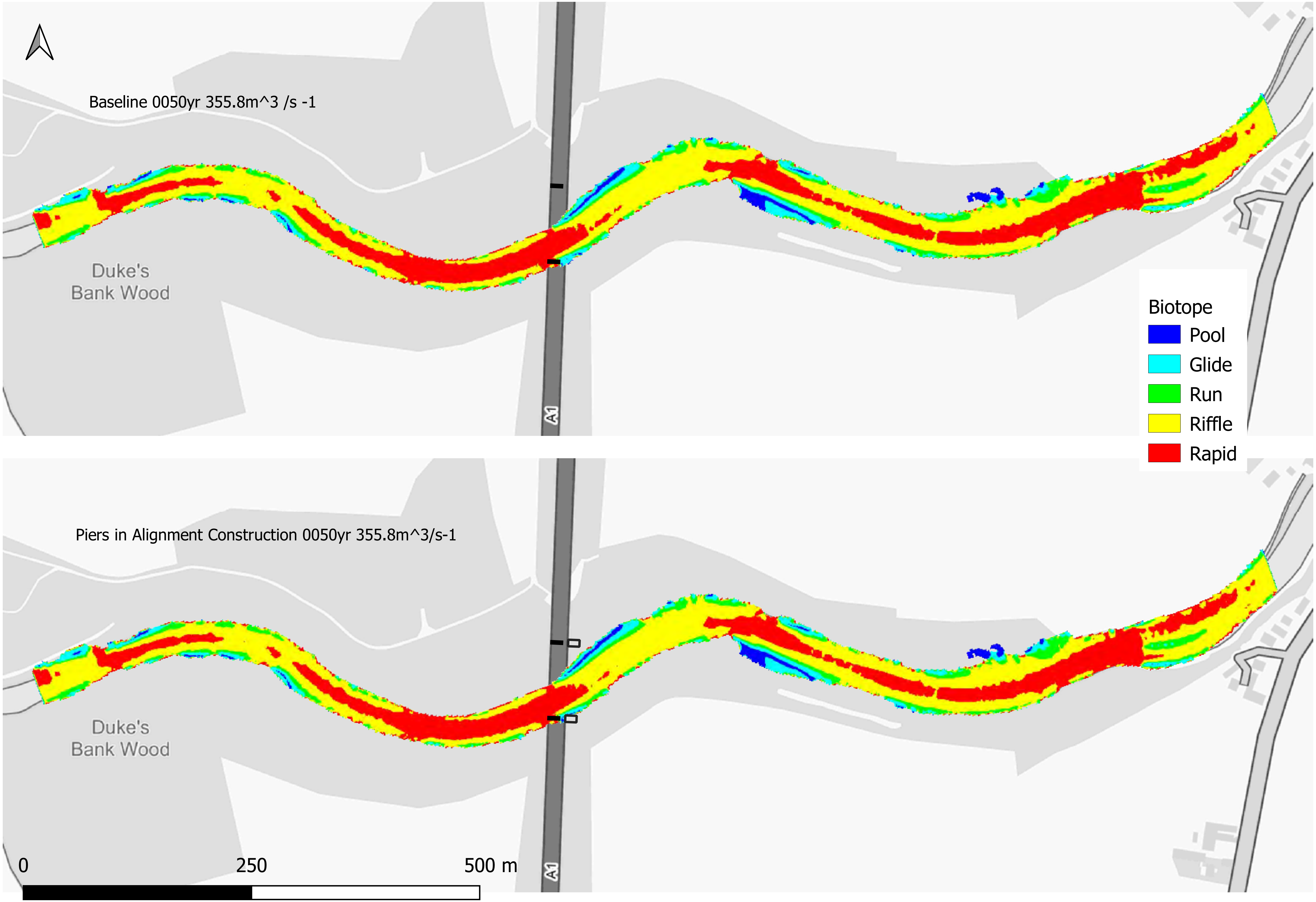


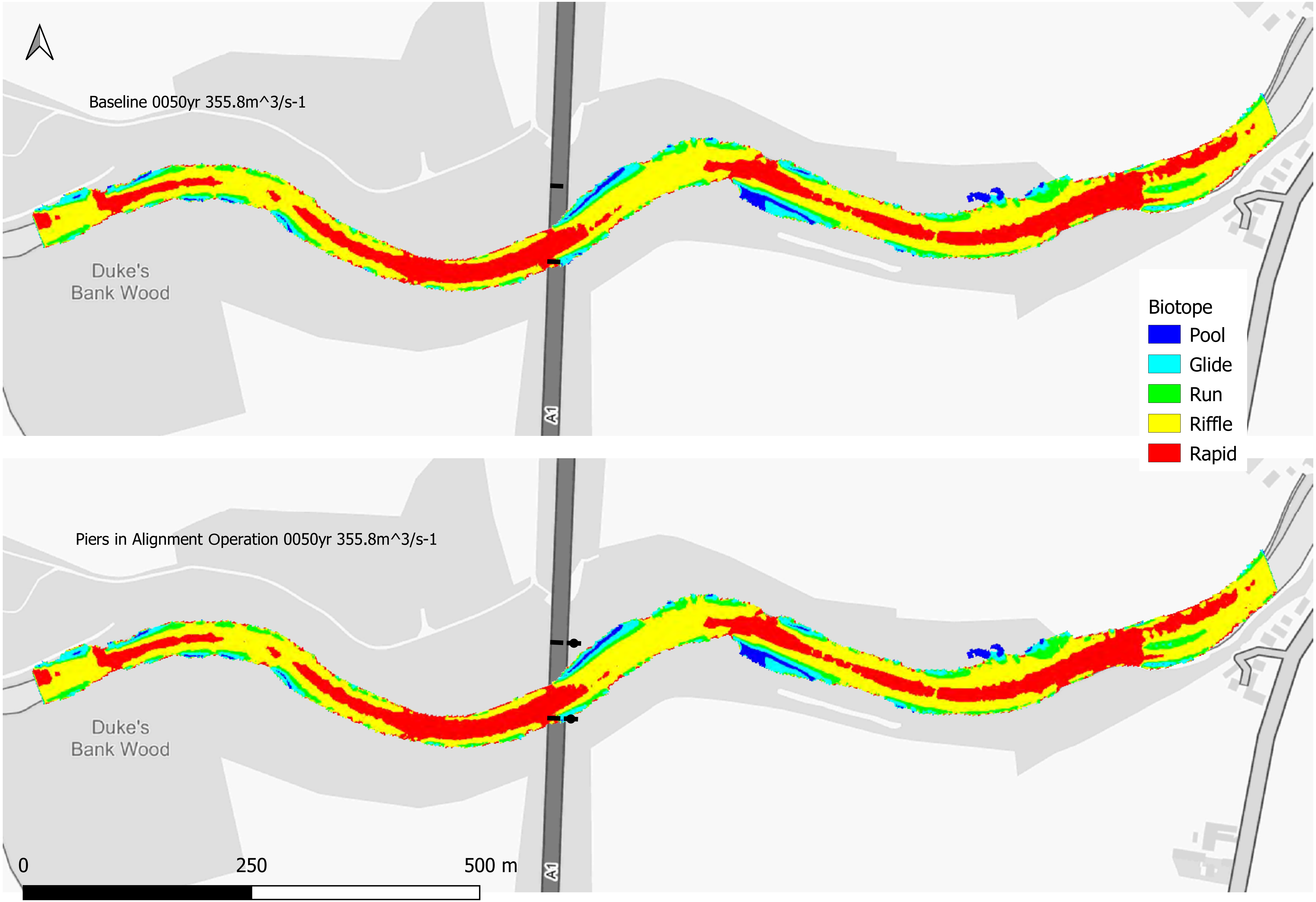
Baseline 0010yr 253.8m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Piers in Alignment Operation 0010yr 253.8m^3/s-1
Duke's Bank Wood
A1
0
250
500 m


Baseline 0010yr 253.8m^3 /s -1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Parameter 10 Alignment Construction 0010yr 253.8m^3/s-1
Duke's Bank Wood
A1
0
250
500 m

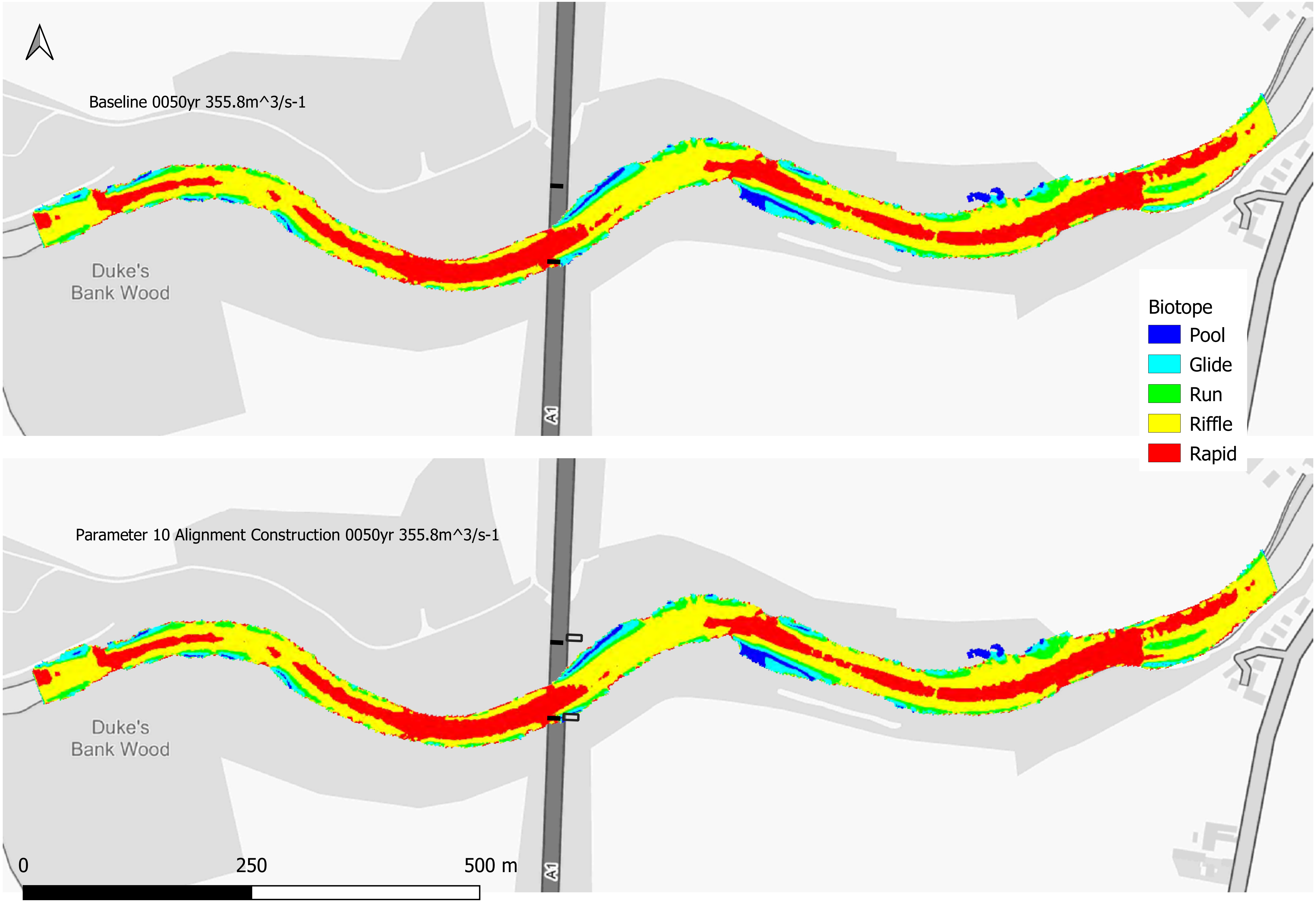


Baseline 0010yr 253.8m^3/s-1
Duke's
Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Parameter 10 Alignment Operation 0010yr 253.8m^3/s-1
Duke's
Bank Wood
0
250
500 m
A1

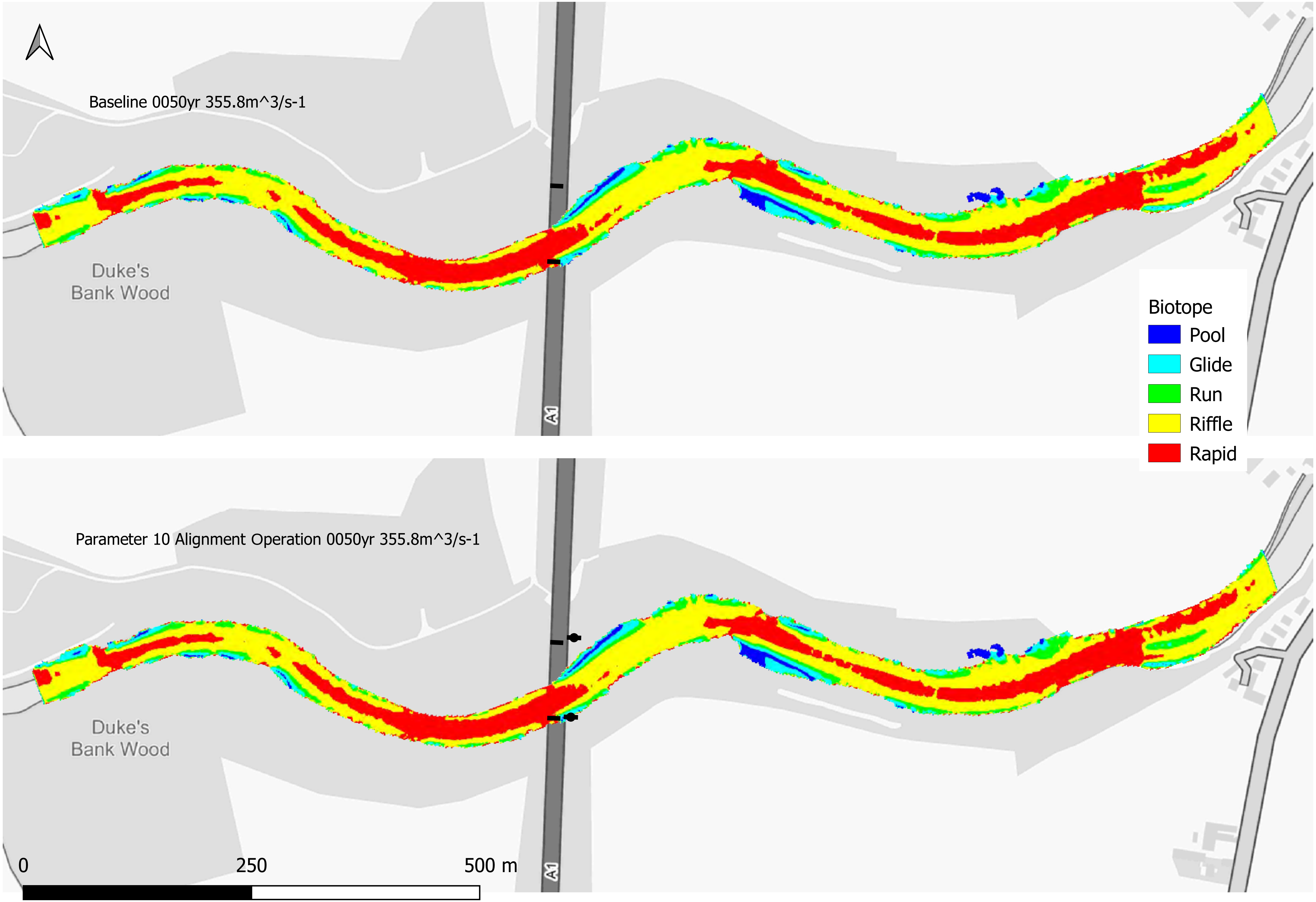

Baseline 0050yr 355.8m^3 /s -1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Piers in Alignment Construction 0050yr 355.8m^3/s-1
Duke's Bank Wood
A1
0
250
500 m



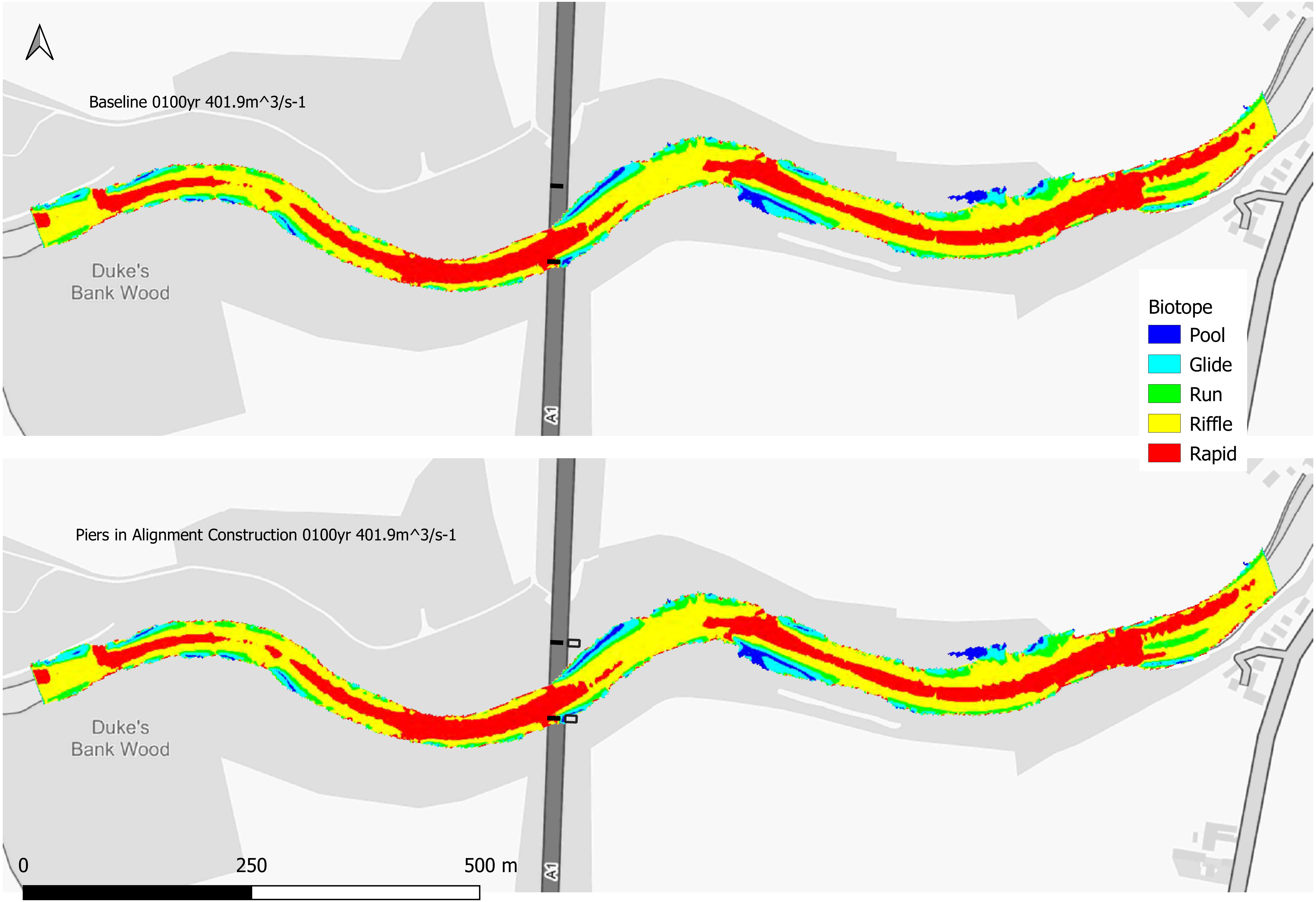
Baseline 0050yr 355.8m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Piers in Alignment Operation 0050yr 355.8m^3/s-1
Duke's Bank Wood
A1
0
250
500 m

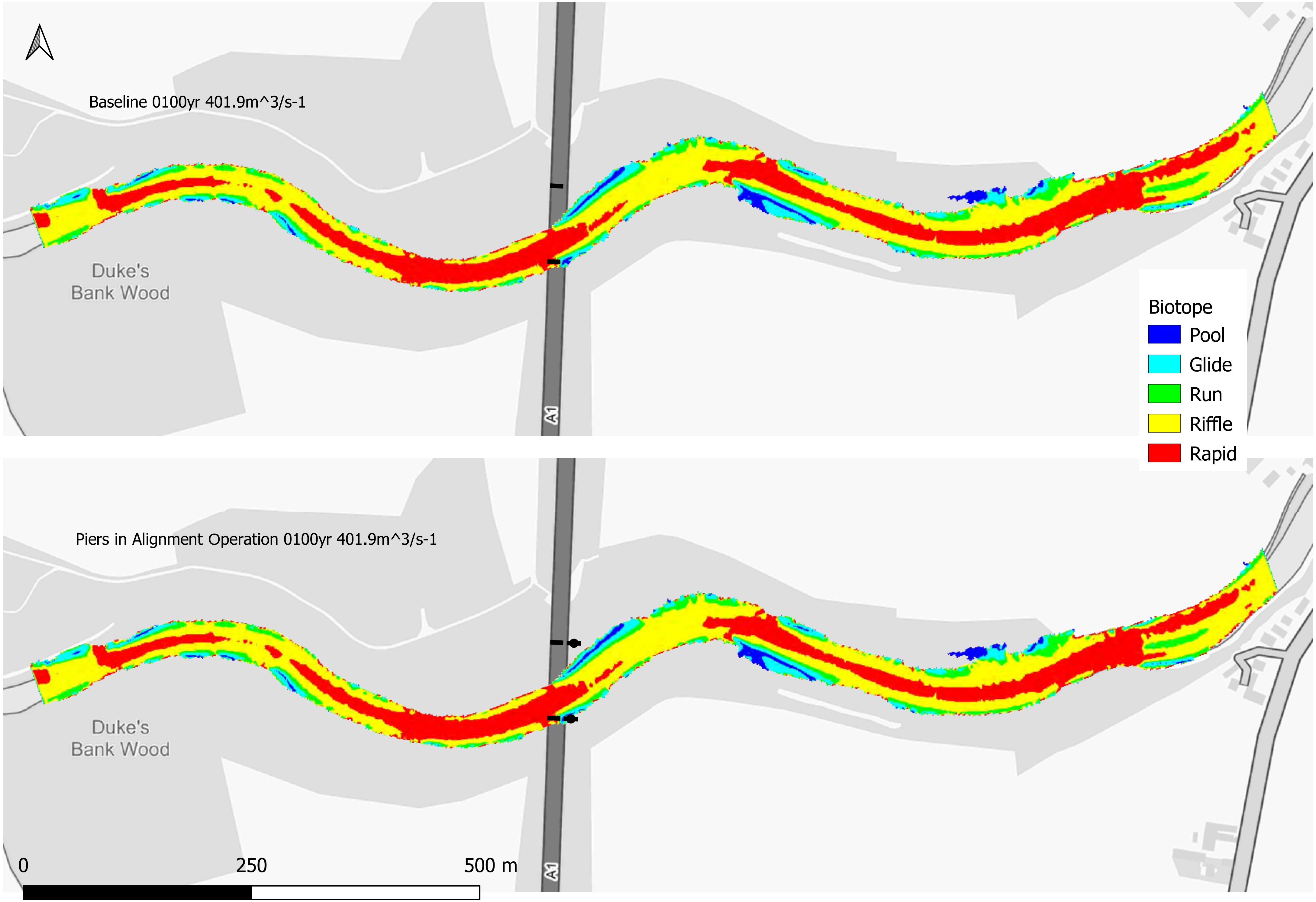


Baseline 0050yr 355.8m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Parameter 10 Alignment Construction 0050yr 355.8m^3/s-1
Duke's Bank Wood
A1
0
250
500 m

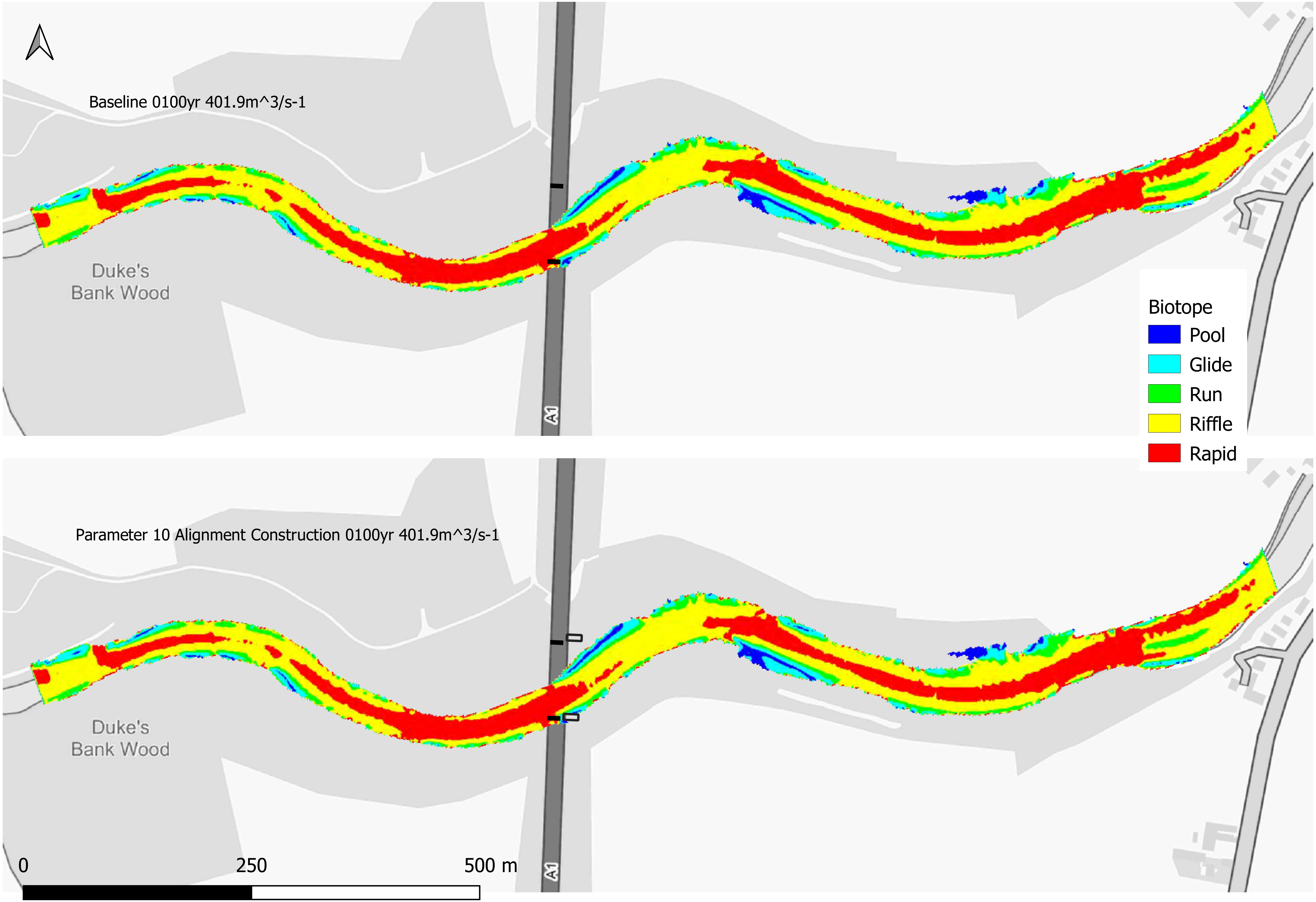


Baseline 0050yr 355.8m^3/s-1
Duke's
Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Parameter 10 Alignment Operation 0050yr 355.8m^3/s-1
Duke's
Bank Wood
A1
0
250
500 m

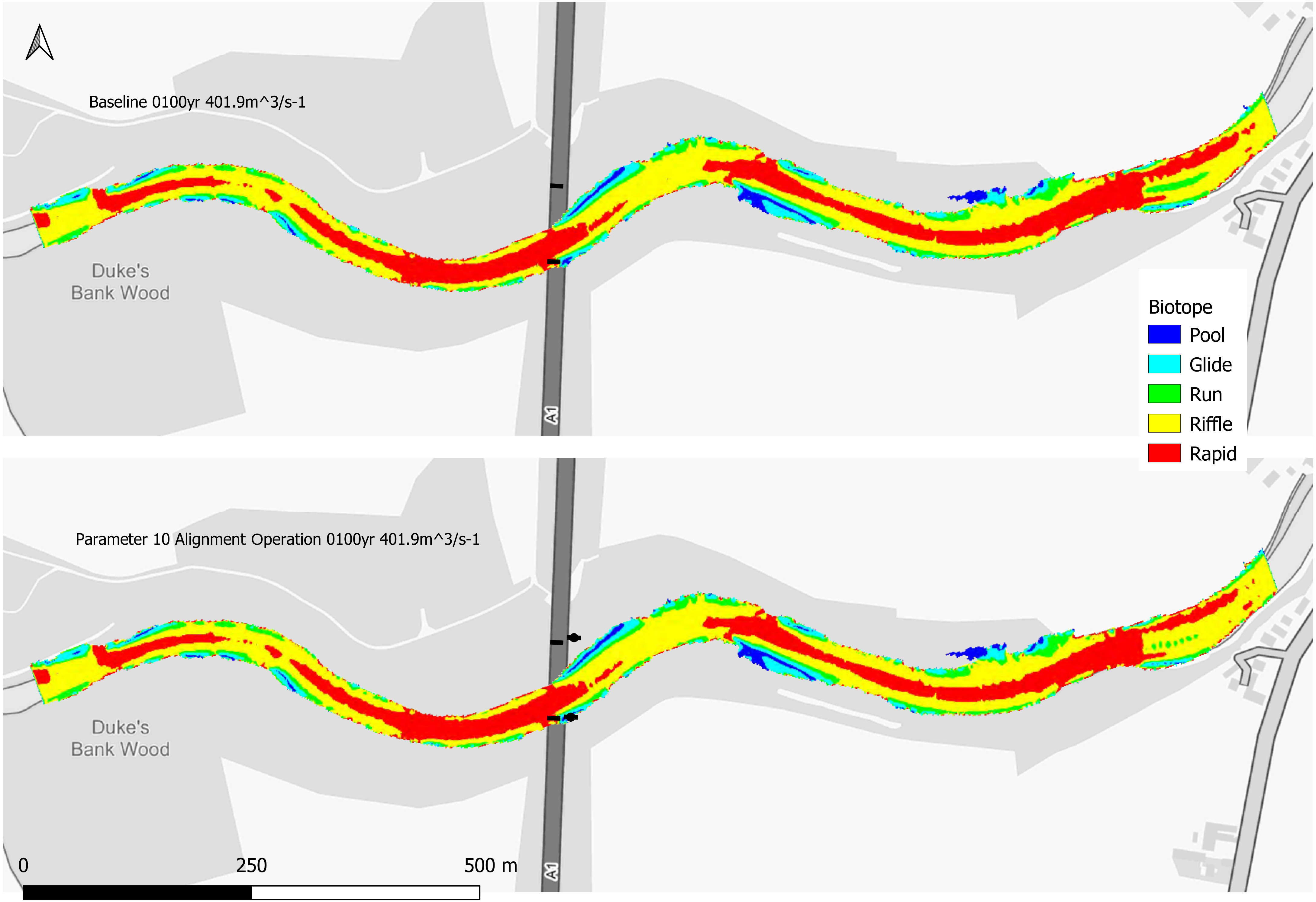

Baseline 0100yr 401.9m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Piers in Alignment Construction 0100yr 401.9m^3/s-1
Duke's Bank Wood
A1
0
250
500 m



Baseline 0100yr 401.9m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Piers in Alignment Operation 0100yr 401.9m^3/s-1
Duke's Bank Wood
A1
0
250
500 m



Baseline 0100yr 401.9m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Parameter 10 Alignment Construction 0100yr 401.9m^3/s-1
Duke's Bank Wood
A1
0
250
500 m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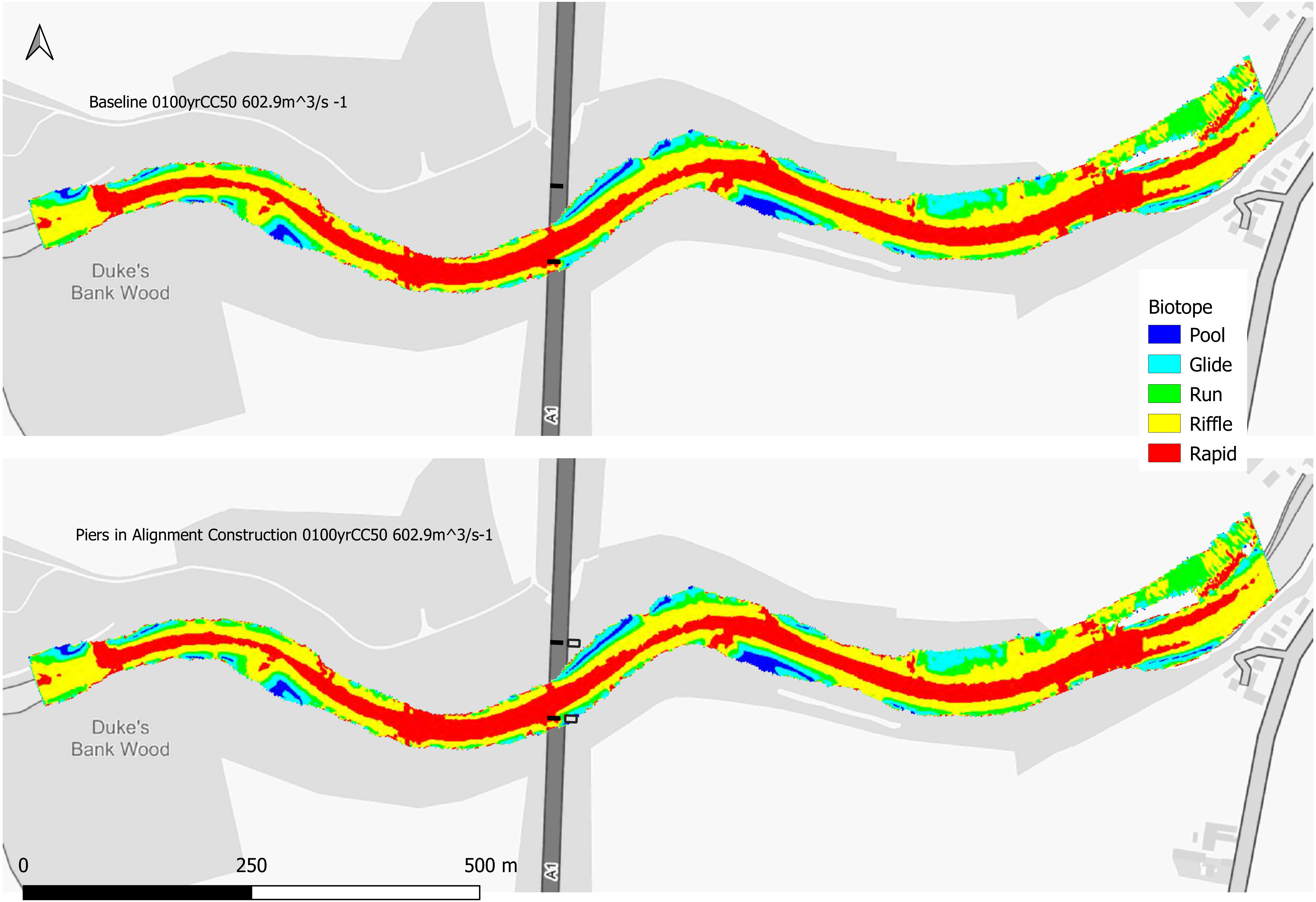
Duke's
Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Parameter 10 Alignment Operation 0100yr 401.9m^3/s-1
Duke's
Bank Wood
0
250
500 m
A1



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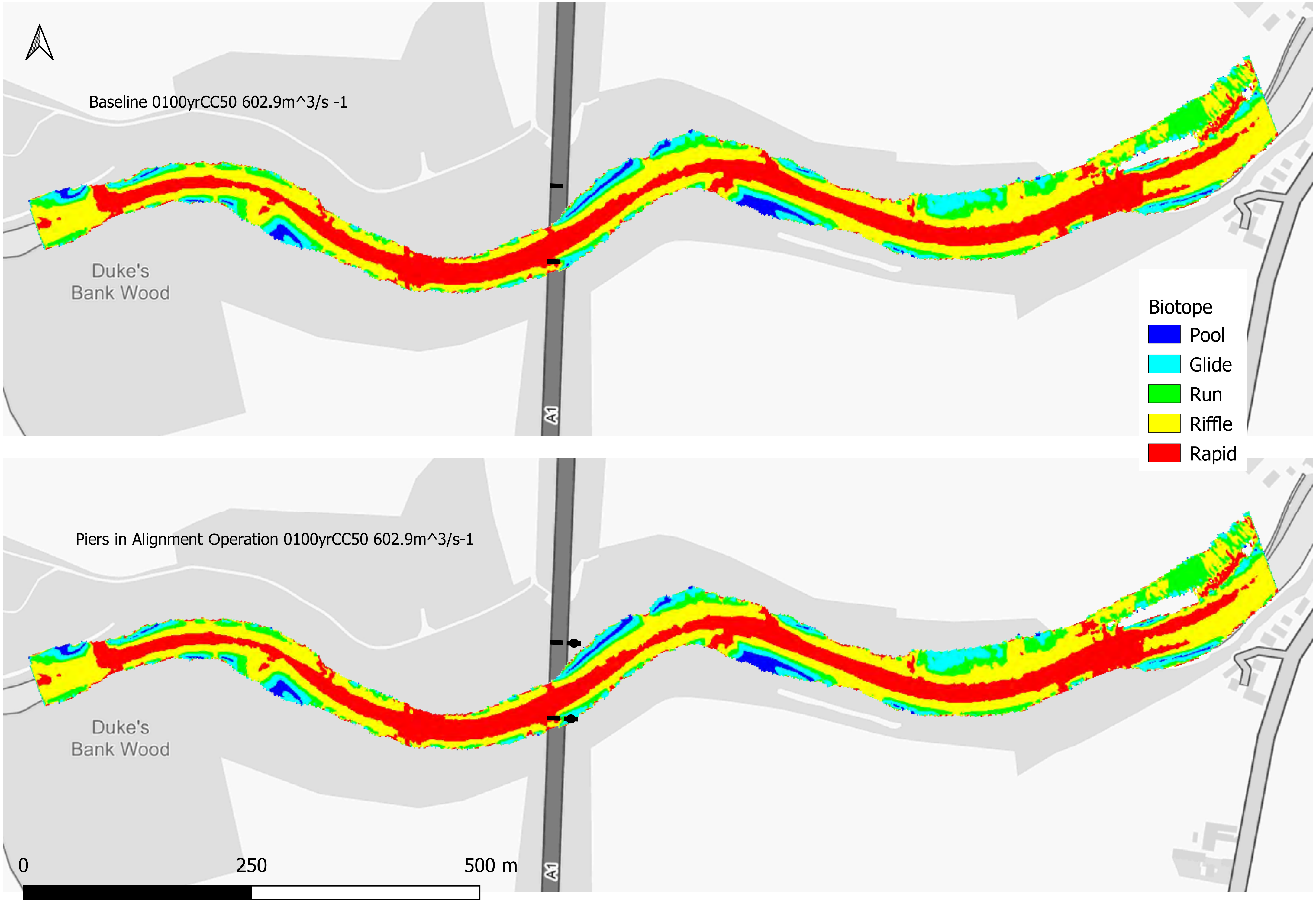
Duke's
Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Piers in Alignment Construction 0100yrCC50 602.9m^3/s-1
Duke's
Bank Wood
A1
0
250
500 m



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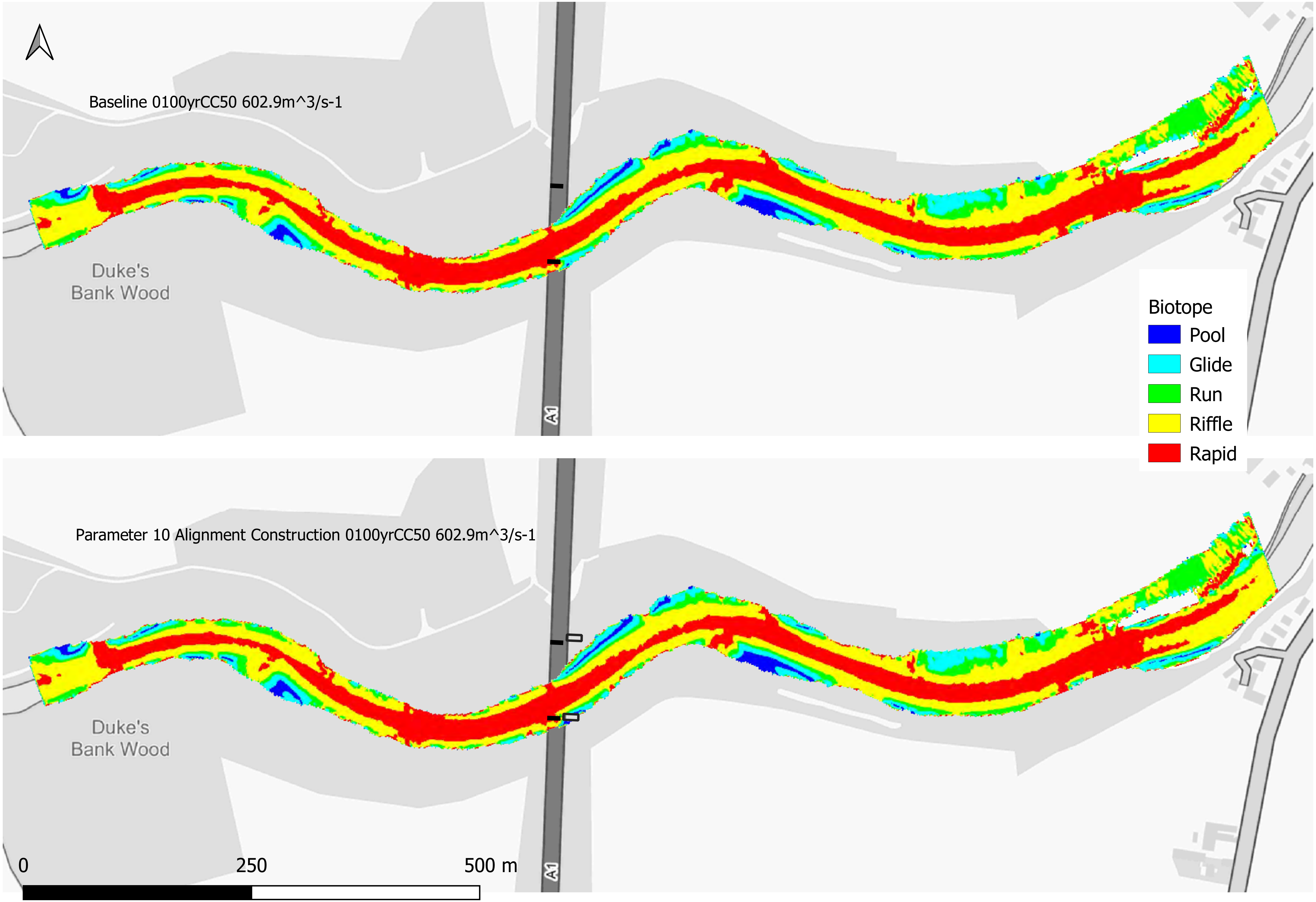
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Piers in Alignment Operation 0100yrCC50 602.9m^3/s-1
Duke's Bank Wood
A1
0
250
500 m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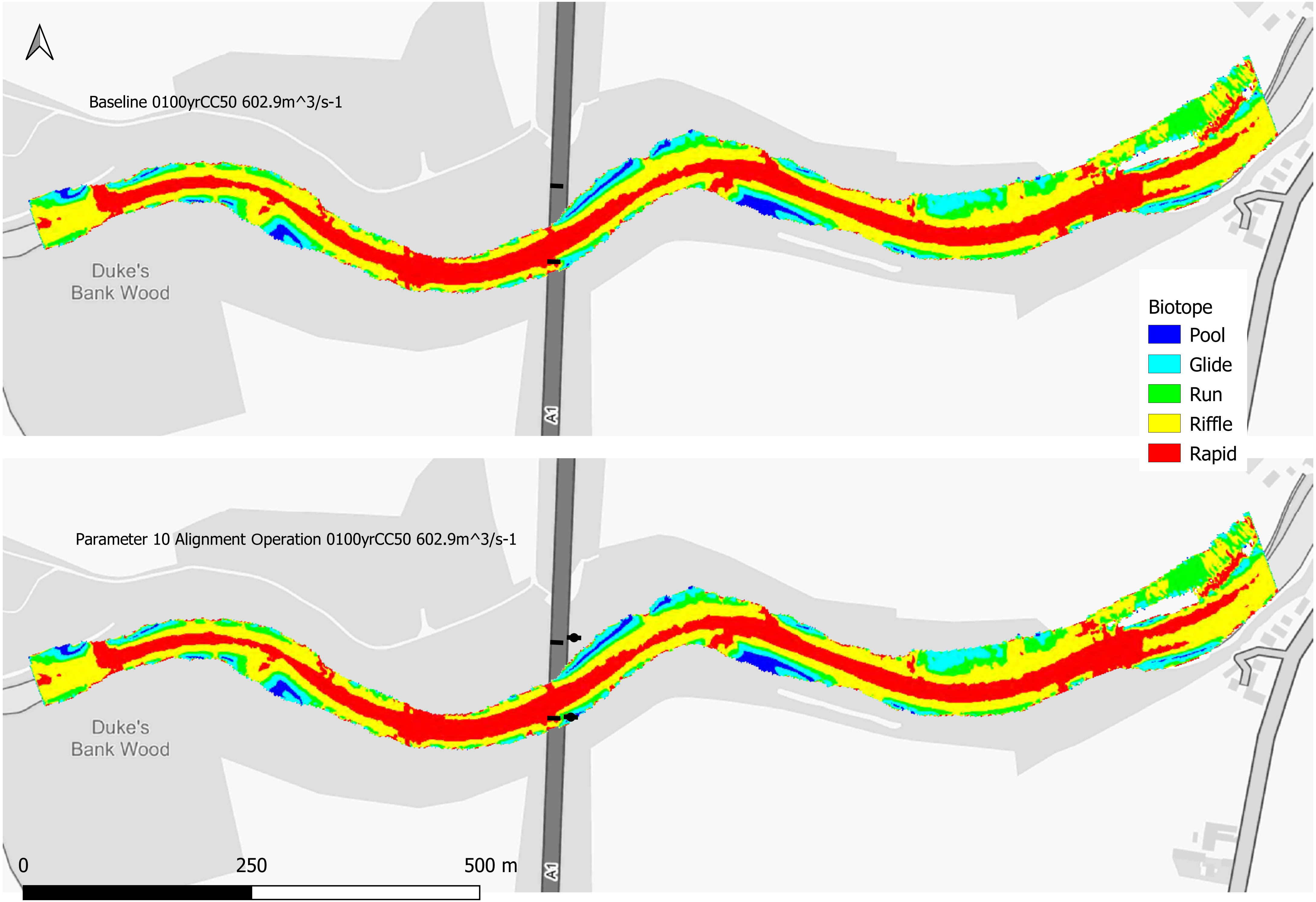
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Parameter 10 Alignment Construction 0100yrCC50 602.9m^3/s-1
Duke's Bank Wood
A1
0
250
500 m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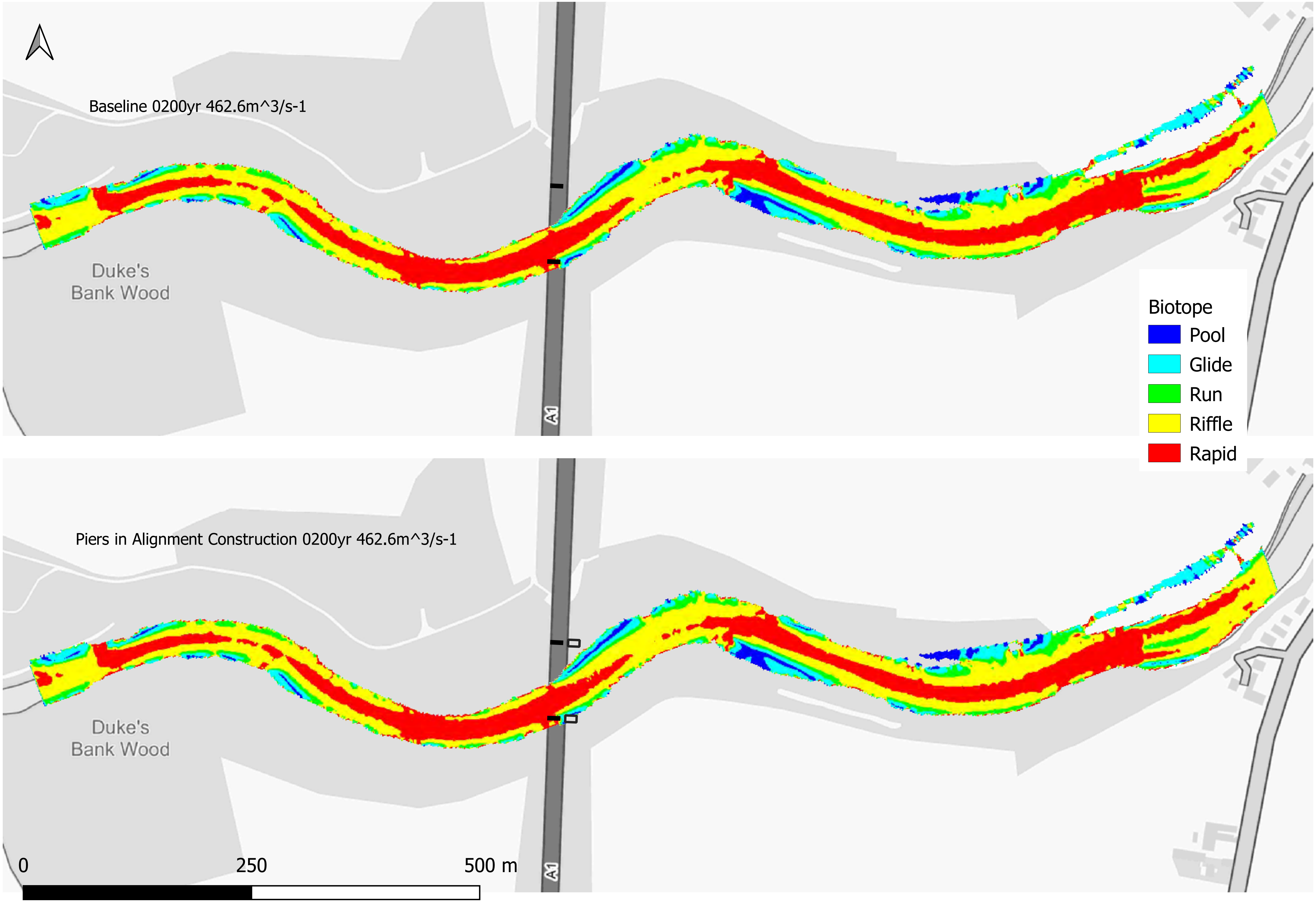
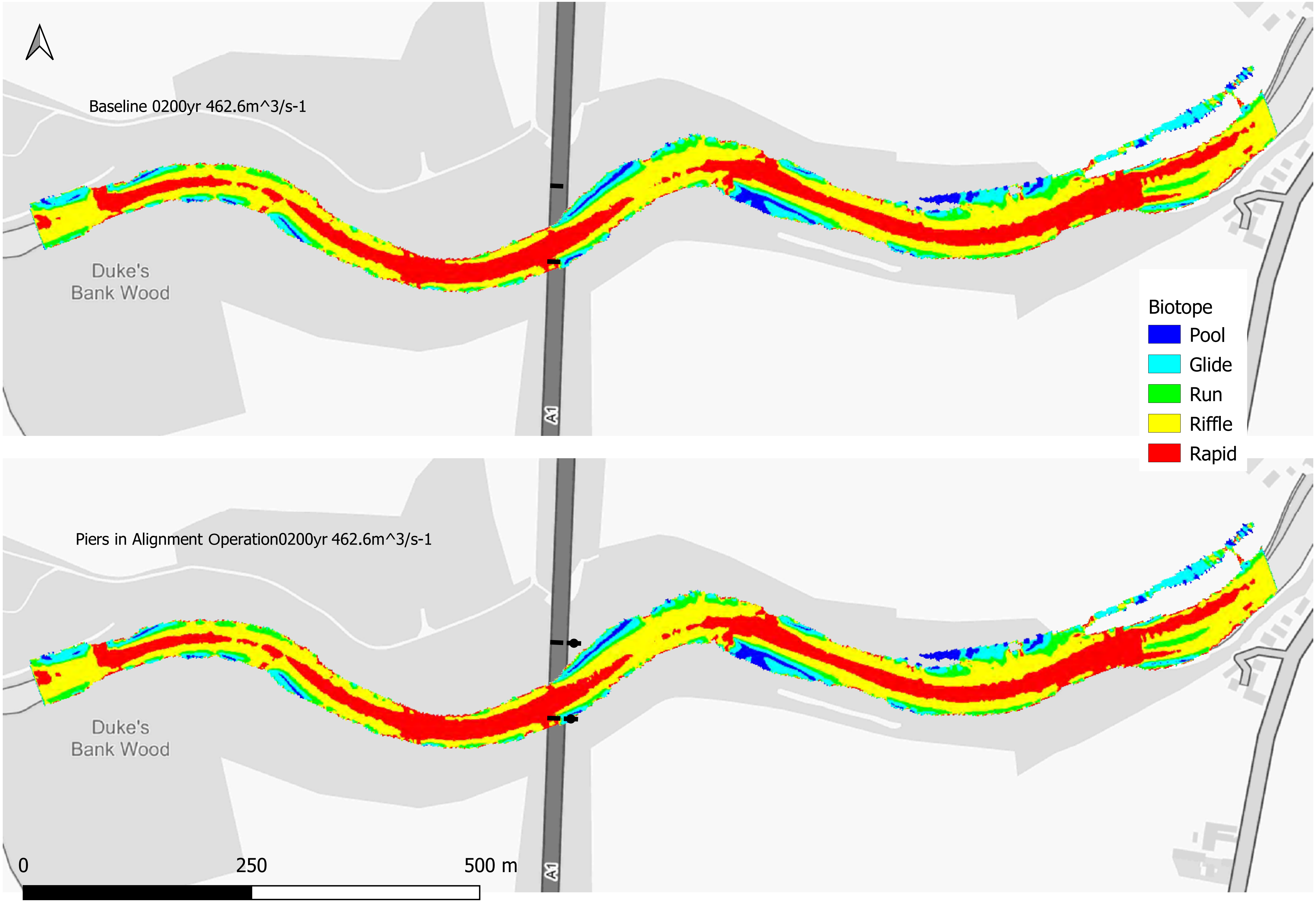
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Parameter 10 Alignment Operation 0100yrCC50 602.9m^3/s-1
0
250
500 m


Baseline 0200yr 462.6m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Piers in Alignment Construction 0200yr 462.6m^3/s-1
Duke's Bank Wood
A1
0
250
500 m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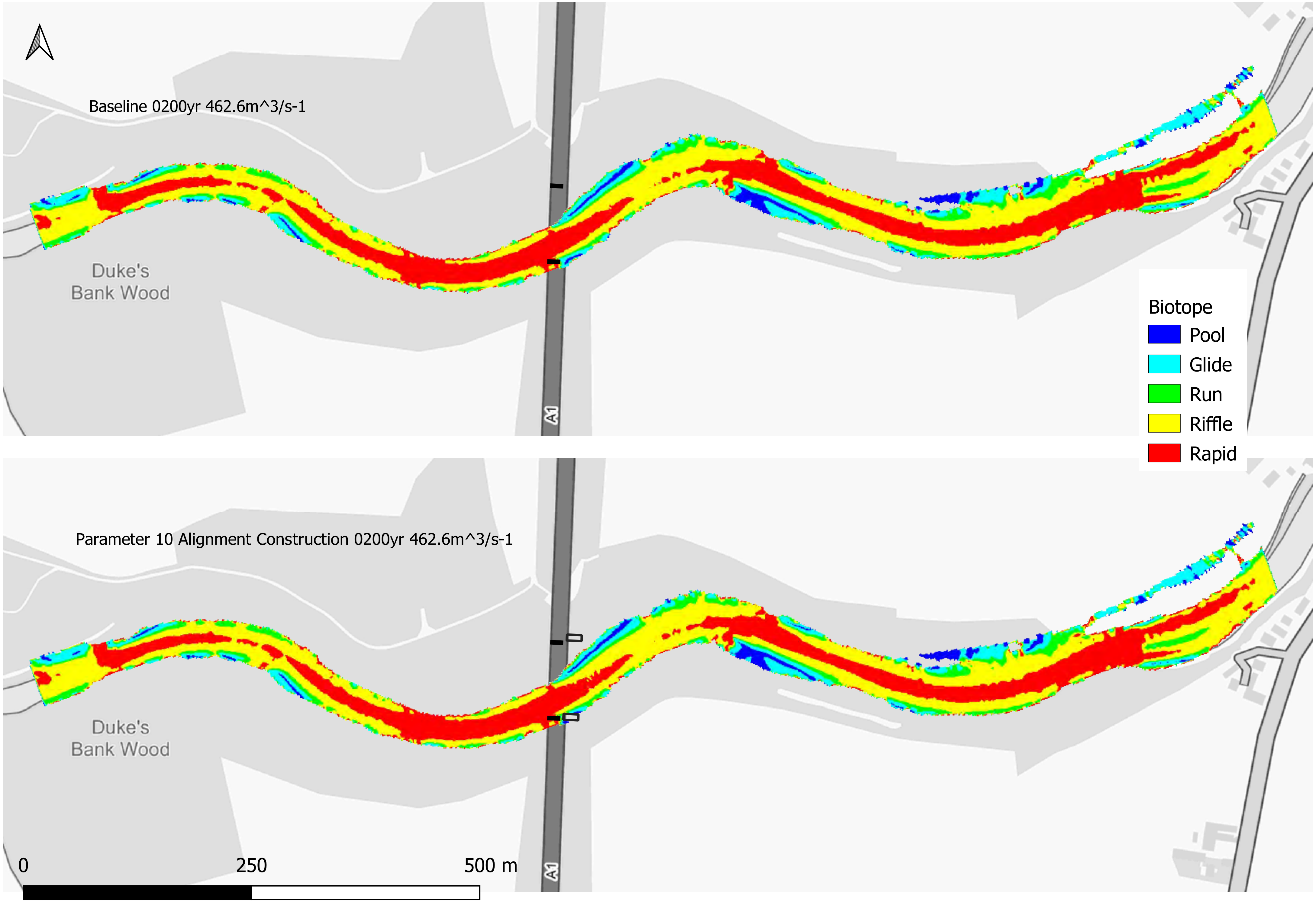
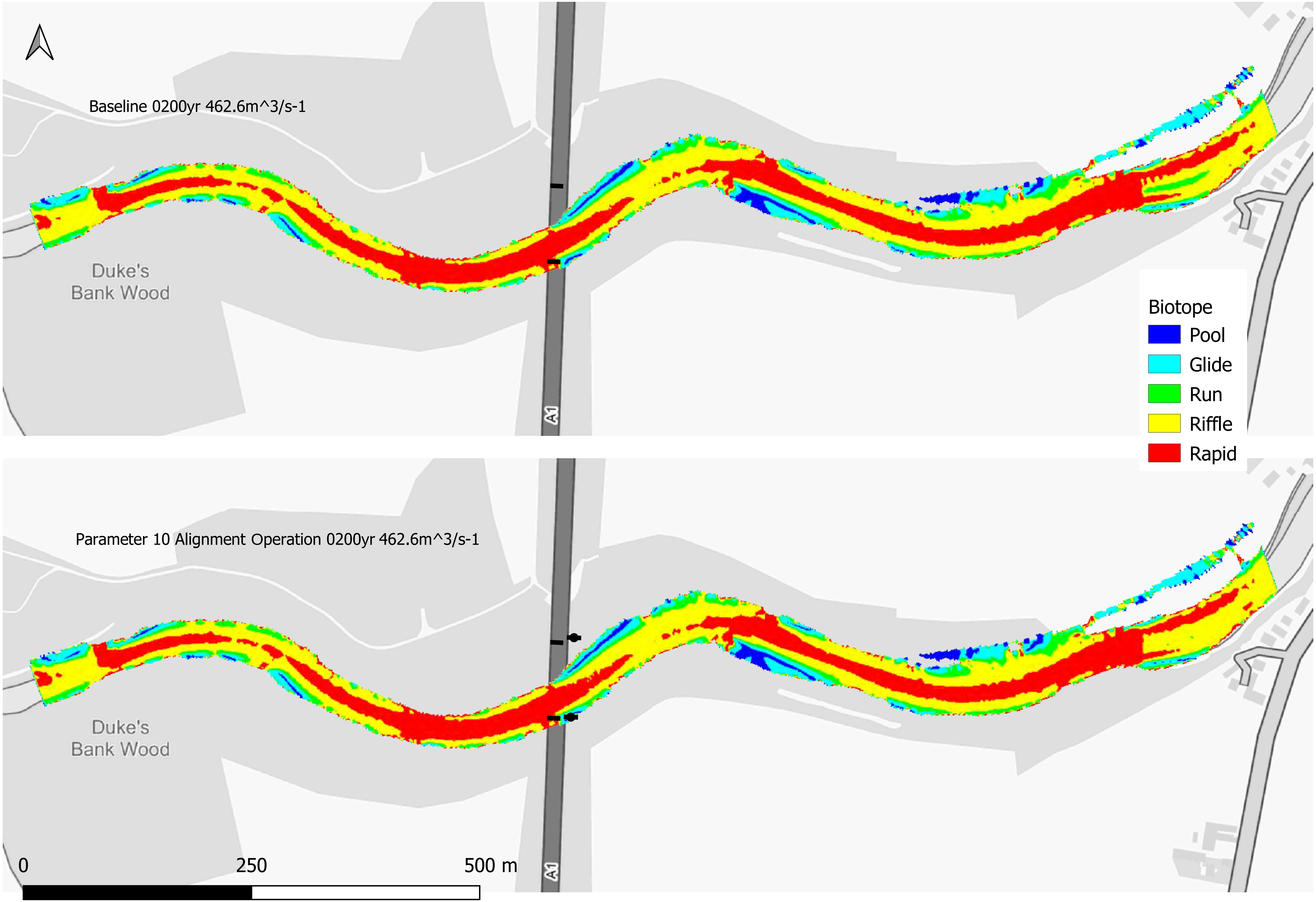
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Piers in Alignment Operation0200yr 462.6m^3/s-1
Duke's Bank Wood
A1
0
250
500 m



Baseline 0200yr 462.6m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Parameter 10 Alignment Construction 0200yr 462.6m^3/s-1
Duke's Bank Wood
A1
0
250
500 m



Baseline 0200yr 462.6m^3/s-1
Duke's Bank Wood
A1
Biotope
Pool
Glide
Run
Riffle
Rapid
Parameter 10 Alignment Operation 0200yr 462.6m^3/s-1
Duke's Bank Wood
0
250
500 m
A1

Appendix D

ENVIRONMENT AGENCY AGENDA & MEETING NOTES

DATE

APPENDIX D - AGENDA & MEETING NOTES

PROJECT NUMBER	70044136	**MEETING DATE**	10 December 2020
PROJECT NAME	A1 IN NORTHUMBERLAND: MORPETH TO ELLINGHAM	**VENUE**	MS Teams
CLIENT	Highways England	**RECORDED BY**	NB
MEETING SUBJECT	Discussion of 2D modelling approach to answer Relevant Representation queries (geomorphology)		

PRESENT	[redacted] – WSP; [redacted] – WSP; [redacted] – WSP; and [redacted] – the Environment Agency
APOLOGIES	Click here to enter text.
DISTRIBUTION	As above plus: Click to type
CONFIDENTIALITY	**Confidential**

Overview

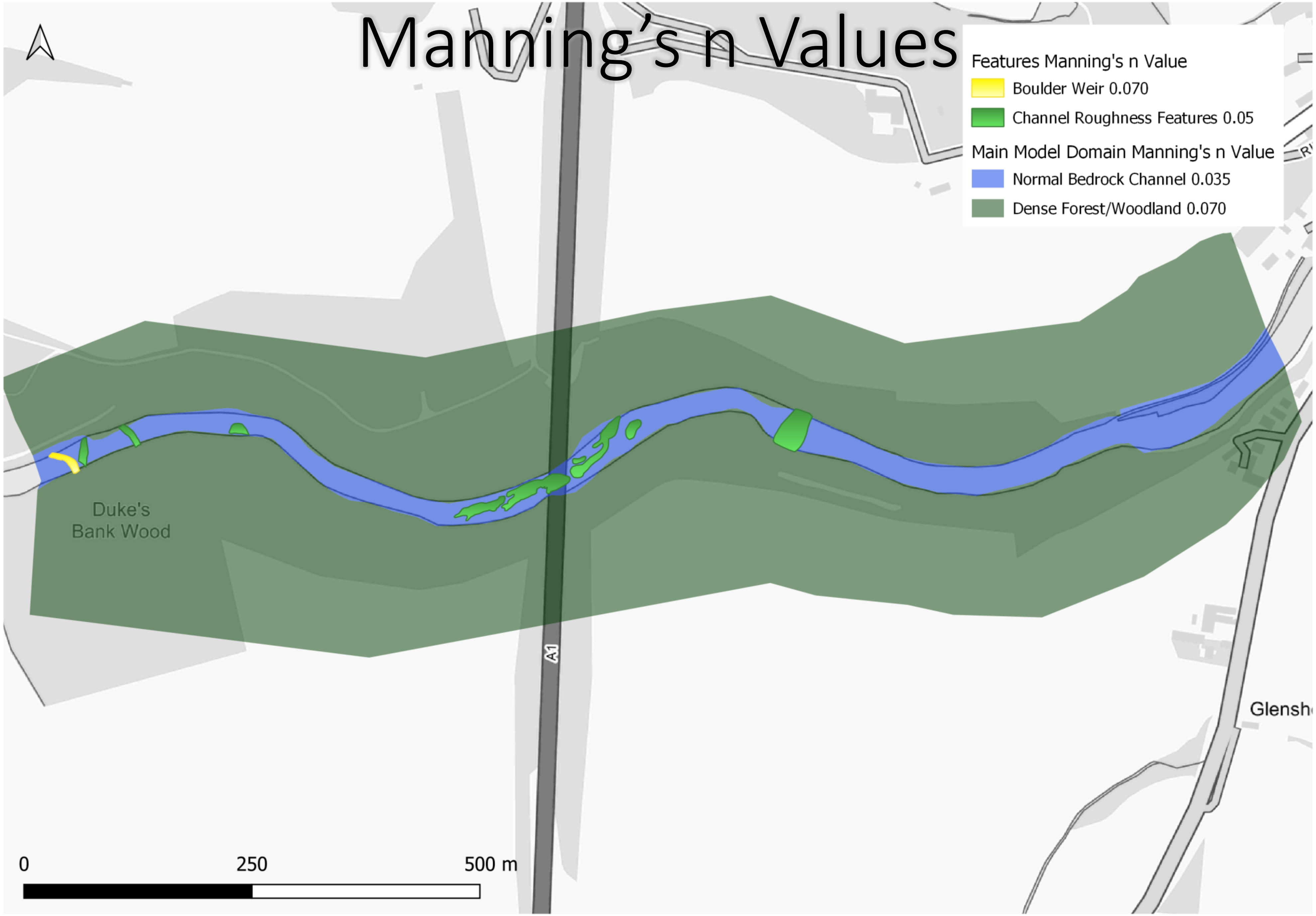
The purpose of this meeting was to discuss the EA's Relevant Representations relating to the Geomorphology Assessment reports submitted as part of the DCO application for the Proposed Scheme. A 2D modelling approach, proposed by WSP, was discussed. This additional analysis is intended to provide reassurance that conclusions of geomorphology studies previously undertaken to assess the Proposed Scheme are robust. Various limitations and benefits of using this approach were also discussed in addition to the outputs WSP intend to analyse and present. [redacted] was broadly happy with the approach WSP has proposed and acknowledged the limitations therein. [redacted] confirmed that, upon completion of the modelling and successful meeting of its objectives (i.e., to demonstrate no impact) the questions posed in the Relevant Representation queries would be satisfactorily answered and provide confidence in the results presented within the reports. The WSP presented preliminary model results and described its compilation, including rationale of Manning's values used to represent channel features.

ITEM	SUBJECT	DISCUSSION
1	Clarity of the cross section used to produce the physical parameters such as channel width, area, wetted perimeter, hydraulic radius. The cross section needs to be accurate, to scale, and must show the 4 scenarios and the levels of the 7 flow regimes;	[redacted] explained that 2D modelling is now being proposed to assess impacts of the scheme and to provide robustness to previous analyses, rather than continuing with the cross-section approach. The cross-section will also be provided to [redacted] as part of the slide pack prepared for this meeting along with its location transposed onto a plan.

2	Relying on the 1 cross section to generate the conclusions feels weak. Further cross sections up stream of and downstream of the new pier will create a much better picture, and more confidence in the findings	WSP team in agreement, hence development of 2D model. Limitations of using LiDAR were discussed but [redacted] agrees that this approach is preferable to using single cross section for analysis.
3	Clarity on the flow data used. How were the numbers for velocity and discharge derived? What is the reasoning behind using a 485 and 525 yr flow, why no 100yr flow. The description of mean flow, Q10 and Q5 in the executive summary appears to be different to the flows used in Table 4.3;4.	[redacted] explained that flow data was generated for purposes of flood risk assessment. [redacted] explained that hydrology has been developed for the 2D modelling. [redacted] confirmed that flows to be assessed are: 2, 10, 50, 100+cc and 200-year events.
4	Rational for using a single manning's number for all scenarios. The number feels high for a bedrock channel, especially mid channel where the majority of the sedimentary deposits are located;	[redacted] and [redacted] explained the inclusion of multiple Manning's values in the 2D model to better represent roughness. [redacted] happy with values. [redacted] confirmed that a sense check on highest flow would be carried out. [redacted] also provided further explanation of why a mix of Manning's values were used in the initial assessment report and a single value in the Parameter 10 report. The first report the Manning's values were set by the WSP geomorphology team with different values used to reflect out-of-bank flows for baseline, proposed and the construction phase. For the Parameter 10 report, the hydrological data was provided by CJP, who had used a single value. Due to time constraints for completing the Parameter 10 assessment, it was not feasible to have the calculations re-run and meet the submission deadline.
5	The data collected during the sediment analysis does not truly reflect the composition and makeup of the mobile sediment within the reach. The inclusion of bedrock in the sediment analysis massively skews the results. The sediment analysis needs to focus on mobile sediment rather than the makeup of the bed;	Sediment data were explained and justified with photos of bar features. [redacted] discussed use of D16, D50 and D84 across the full suite of flows for robustness/completeness. [redacted] happy with this approach.

6	The footprint of the sheet piling and the foundations of the pier will be greater than the pier itself. The impact will be greatest during construction, has this been taken into account;	[redacted] explained that sheet piling and working area will be modelled for full suite of flows. [redacted] explained that sheet piling will not exceed bed level once complete. [redacted] happy with this approach. [redacted] will seek information on the construction period and the land take. [redacted] explained that some of this information may be high-level at this stage as it is often deferred to the Contractor.
7	Appendix 10.4 implied that the working area was vulnerable to low magnitude, high frequency flood events, meaning that the risk to the working area is high. Appendix 10.7 does not highlight this, therefore will this risk be adequately assessed and mitigated for within the CEMP; and	WSP team explained that this will be modelled. [redacted] confirmed this would be dealt with in the CEMP.
8	It's also worth noting that the cross sections shown in the two geomorphological reports is different. Why is this, and does it influence the outputs from question 1?	[redacted] explained the difference and that it doesn't influence outputs for Q1.
9	A detailed field map/plan should be produced that shows in-channel features, the location of the different flow types, any depositional areas, along with the accurate location for the two piers and the footprint of any temporary works.	WSP team presented an preliminary Froude map as an indicator of flow types in reach. [redacted] happy with this approach.
10	Given that we now know that the existing pier was built within the active channel, does this change the interpretation of channel form downstream of this point? The previous summary suggests that the widening of the channel, the formation of the bar etc. and natural processed. Is it possible that this change was driven by the work associated with the first bridge?	This was discussed based upon new information relating to the construction of the existing bridge. A revised description will be provided in the technical note being produced. No evidence of scour was observed due to the river training works for the existing bridge pier.

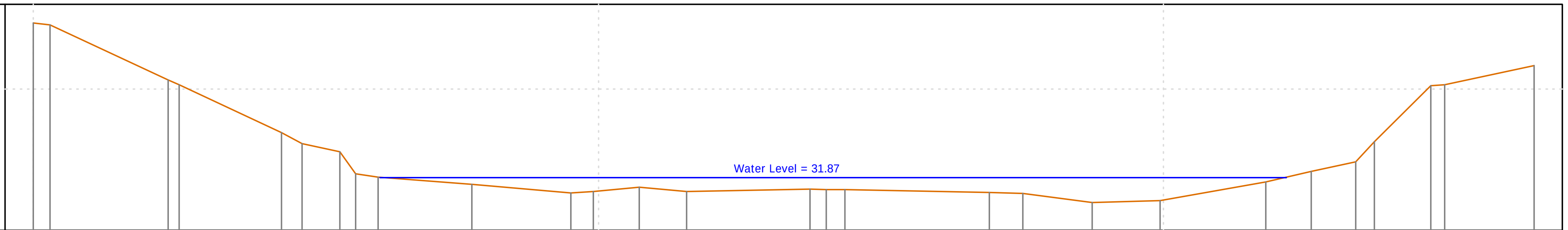
Manning's n Values



River Coquet Cross Section

Section Line

Vt Scale 1:200
Hz Scale 1:200
Datum 30.00m



Chainage	Level : m.A.O.D	Easting	Northing	Code
0.000	37.334	417444.91	599829.35	SPOT LEVEL
0.597	37.265	417445.18	599828.82	BANK TOP
4.777	35.321	417447.11	599825.11	SPOT LEVEL
5.163	35.145	417447.29	599824.77	SPOT LEVEL
8.790	33.461	417448.96	599821.55	SPOT LEVEL
9.517	33.057	417449.29	599820.91	BANK BOTTOM
10.840	32.775	417449.90	599819.73	BANK TOP
11.402	32.005	417450.16	599819.23	BANK BOTTOM
12.206	31.875	417450.54	599818.52	BED LEVEL
15.518	31.619	417452.06	599815.58	BED LEVEL
19.030	31.326	417453.68	599812.46	BED LEVEL
19.813	31.375	417454.04	599811.77	BED LEVEL
21.437	31.520	417454.79	599810.33	BED LEVEL
23.113	31.366	417455.56	599808.84	BED LEVEL
27.481	31.456	417457.58	599804.96	BED LEVEL
28.060	31.444	417457.85	599804.45	BED LEVEL
28.726	31.431	417458.15	599803.86	BED LEVEL
33.832	31.338	417460.51	599799.33	BED LEVEL
35.026	31.303	417461.06	599798.27	BED LEVEL
37.479	30.990	417462.19	599796.09	BED LEVEL
39.884	31.042	417463.30	599793.96	BED LEVEL
43.627	31.702	417465.02	599790.64	BED LEVEL
45.227	32.074	417465.76	599789.22	BED LEVEL
46.804	32.427	417466.49	599787.82	BANK BOTTOM
47.472	33.139	417466.80	599787.23	BANK TOP
49.459	35.109	417467.71	599785.46	BANK TOP
49.951	35.139	417467.94	599785.03	SPOT LEVEL
53.124	35.822	417469.40	599782.21	SPOT LEVEL

NOTES

Datum: Ordnance Survey Datum (OSGM15)

SURVEY LEGEND

REV.	DETAILS	DRN	CHKD	DATE

STATIONS

Lanark Court, Ellismuir Way, Tannochside Park, Glasgow, G71 5PW, UK
T+ 44 (0) 1698 802 850
wsp.com

Project / Drawing Title

A1 Morpeth to Felton
River Coquet
Cross Section

Scale	Size	Date
1:200	A3	07/03/2019
Drawn By	Checked By	Approved By
R Lorimer	A Moffat	S Smith

Drawing Name / Number

River Coquet
Cross Section

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If you have any enquiries about this document A1inNorthumberland@highwaysengland.co.uk

or call **0300 470 4580***.