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To:	Peter Evoy, South Cumbria Rivers Trust		
From:	Hamish Moir, cbec eco-engineering UK Ltd		
Project:	Bowston Weir		
Subject:	Technical Summary for Bowston Weir Scheme Design Adaptation		

1. INTRODUCTION

cbec eco-engineering UK Ltd was commissioned by South Cumbria Rivers Trust (SCRT) to adapt designs for the Bowston Weir site on the River Kent, Cumbria, in view of community concerns. This latest work follows from a previous design phase completed in March 2018. Following community consultation undertaken by SCRT, it was determined that the previous weir removal design required revision in order to address concerns relating to ecological impacts in the weir pond as a consequence of the proposed works.

The adapted design has been developed in close consultation between cbec, SCRT, George Heritage (AquaUoS) and the Environment Agency (EA) and includes the replacement of the weir with a lower elevation rock ramp structure slightly downstream. The rock ramp is designed to reinstate sediment transport continuity, permit fish passage and improve navigation on the River Kent. The weir structure (and associated fish passes) will be removed with the bed upstream of the rock ramp (i.e. mainly through the extents of the current weir pond) being regraded.

Further details of the design are provided in Section 2 below, alongside a series of mobile bed sediment transport and hydraulic model results (Section 0). Technical engineering drawings will be provided separate to this document, alongside an updated design method statement, sediment management document, risk assessment and bill of quantities.

Summary of benefits associated with adapted design:

- → Provides a more naturally functioning channel in terms of morphology and habitat
- → Reduces flood risk to property on the right bank immediately downstream of the weir
- → Reduces risk of large sediment flux downstream during flood events through construction of ‘proto-channel’ and through removal of weir (avoiding potential future failure of the structure)
- → Improves fish passage
- → Provides an ephemeral wetland environment (with associated succession of vegetation and animal communities) upstream of the weir on river right, an area seen as important by the local community
- → Provides potential for recreational navigation of the water course (e.g. canoeing)

2. FINAL DESIGN DETAILS

The adapted design for the Bowston site involves three main components:

- the removal of the weir structure and associated fish passes
- the construction of a rock ramp and
- the excavation of a 'proto-channel' from the rock ramp crest extending ~140 m upstream.

A plan-view of the design is provided in Figure 2.1.

The weir and two associated fish passes will be removed in their entirety[1], with ~2,000 m^3 of accumulated sediment upstream of the weir[2] being regraded (in the formation of the 'proto-channel' through the sediment accumulated in the weir pond), with approximately 75% of the 'cut' material being used to fill the section of channel between the weir and the rock ramp crest (i.e. providing an initial even bed gradient upstream from the rock ramp crest (i.e. with no sudden elevation changes which would increase the risk of progressive head-cut/ incision processes).

The excavated 'proto-channel' will extend a total length of ~140 m upstream from the rock ramp location and will grade from the current left bank to the riverside edge of the 'wetland' habitat on river right (see Figure 2.2). For simple construction throughout this section, the proto-channel has been designed with a simple geometry; however, sediment transport modelling (Section 3) has predicted that the channel will quickly evolve to a dynamically stable riffle-pool morphology, reflective of the river upstream of the study site and given the imposed physical conditions (i.e. slope, hydrology and sediment size/ supply rates). To ensure a stable design, sediment sizes through this section of the restoration reach require to be coarse gravel and cobble (with a D_{50} of 60-70 mm).

A rock ramp will be constructed, with the crest of the structure positioned ~20 m downstream from the current weir crest location. The structure will span the full width of the channel between chainages 465 m and 520 m, a total length of 55 m. The lateral structures set within the rock ramp (see Figure 2.1) are informal boulder 'spurs' or steps (with a D_{50} of ~400 mm) to alternately obstruct the flow through the centre of the structure (i.e. providing improved opportunity for fish passage). In front of the spurs, 'pool' type features provide resting locations for fish passing up though the structure. This design form reflects the channel morphology (boulder cascade/ step-pool) that would develop given the imposed bed slope, hydrology and substrate size. It shall be constructed to provide a degree of variability in form to better reproduce natural conditions while conforming to the general geometrical design requirements. Figure 2.3 provides a view upstream through the section of channel the rock ramp is to be located.

The stability and performance of the final design has been assessed in detail through a series of hydraulic and sediment transport models, the output from which are summarised in Section 0 (i.e. confirming that the design functions as intended). Further details of the final design and approach for construction will be included within a design method statement provided separate to this document.

Additionally, future opportunity exists to reroute a field drain on river right upstream of the weir, through the field to the north west of Bowston village, to allow the ephemeral wetland environment to be wetted on a more regular basis. Following discussion with SCRT and the project group, it was agreed that this would be undertaken at a later stage and is therefore not included within the design.

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[1] This is expected to be confirmed by a structural engineer following submission of completed technical design drawings.

[2] Volumes based on survey data collected in January 2021.

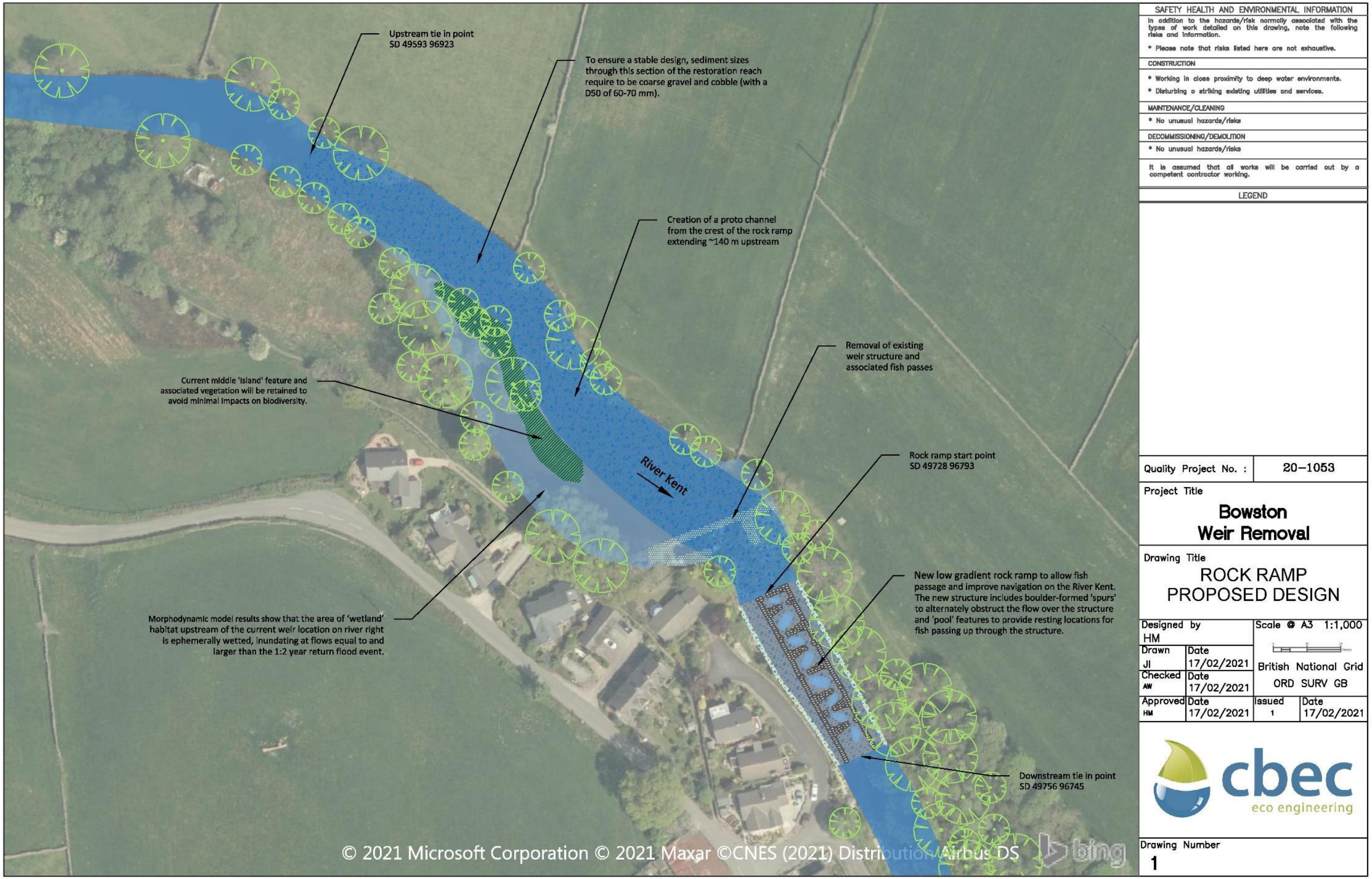

Figure 2.1. Plan view showing final design details

Figure 2.2. View looking upstream into current weir pond, showing location of proposed 'proto-channel' (to the right of the photo) and ephemeral wetland environment (to the left)

Figure 2.3. View from right bank looking upstream towards Bowston Weir, showing section rock ramp is to be located.

Summary of benefits associated with adapted design:

→ The final design has been developed in collaboration with a number of expert technical specialists and stakeholders and has considered feedback from community consultation. Therefore, we believe that the design presented offers the best possible balance in terms of improvements to fish passage, sediment continuity, flood risk and wider biodiversity, whilst also offering secondary benefits such as potential for water course navigation.

→ Importantly, the management of sediment through this design will limit potential impacts to Burneside Mill downstream.

3. MODELLING OF ADAPTED DESIGN

A series of sediment transport, mobile bed, low flow and high flow hydraulic models were run to assess the evolution of the proto-channel and hydraulic performance of the rock ramp design at the Bowston study site. Specifically, the following scenarios were modelled:

- QMED (i.e. 1 in 2-yr) peak flow run for 12, 24, 48 hours for sediment transport and mobile bed simulation
- Fish passage flows – daily Q_{95}, Q_{50}, Q_{10} for the evolved channel bed (i.e. the form of the proto-channel subsequent to the mobile bed/ morphodynamic model runs)
- Flood flow – 1 in 100-yr plus 35% climate uplift

The results of the above models are discussed in the following sections with key figures presented and supporting information included in Appendix A, for reference.

3.1.1. Mobile bed sediment transport model

A mobile bed, sediment transport model was used to make a prediction of how the morphology of the site will adjust in relation to high flows and the imposed change to channel slope as a result of weir removal. The model has provided crucial insights as to likely channel response both within the specific design site and ex-situ (i.e. the predicted formation of pools and riffles upstream of the immediate design site and limited bed elevation changes downstream).

Outputs from the model (Figure 3.1 and Appendix A) show the evolution of a dynamically stable pool-riffle sequence at the 1 in 2-yr return period flood event. The spacing of these features (~5 – 7 times channel width) is reflective of those found in a natural system (i.e. unimpacted by anthropogenic pressures).

The model also shows the deposition of a small thickness (~100 mm) of sediment downstream of the rock ramp, which is expected to be naturally redistributed downstream through the system, over time.

Key benefits of design:

→ Mobile bed model results show evolution of a stable bed with pool-riffle morphology, reflective of physical conditions of the site under 'un-impacted' conditions.

→ The outputs show that the area of 'wetland' habitat upstream of the current weir location on river right is ephemerally wetted, inundating at flows equal to and larger than the 1 in2-yr return flood event.

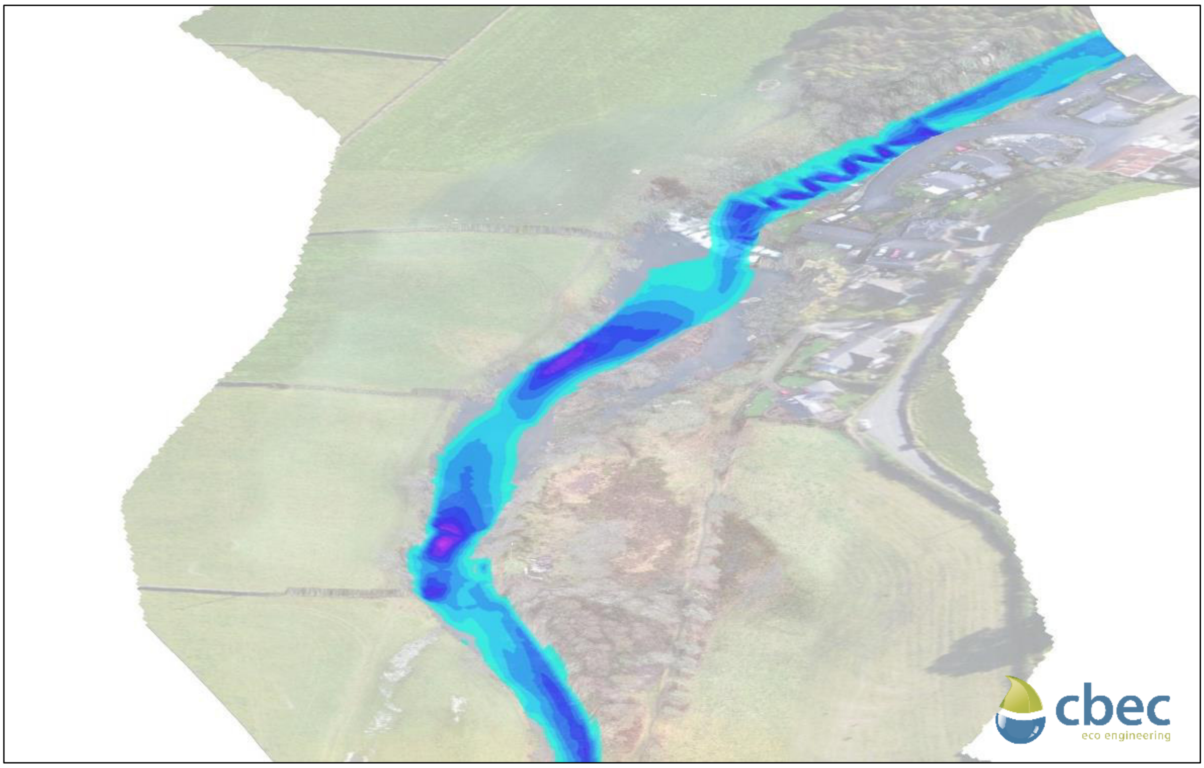

Figure 3.1. Hydraulic model output showing an oblique view of the Q_{50} flow once a pool-riffle morphology has developed.

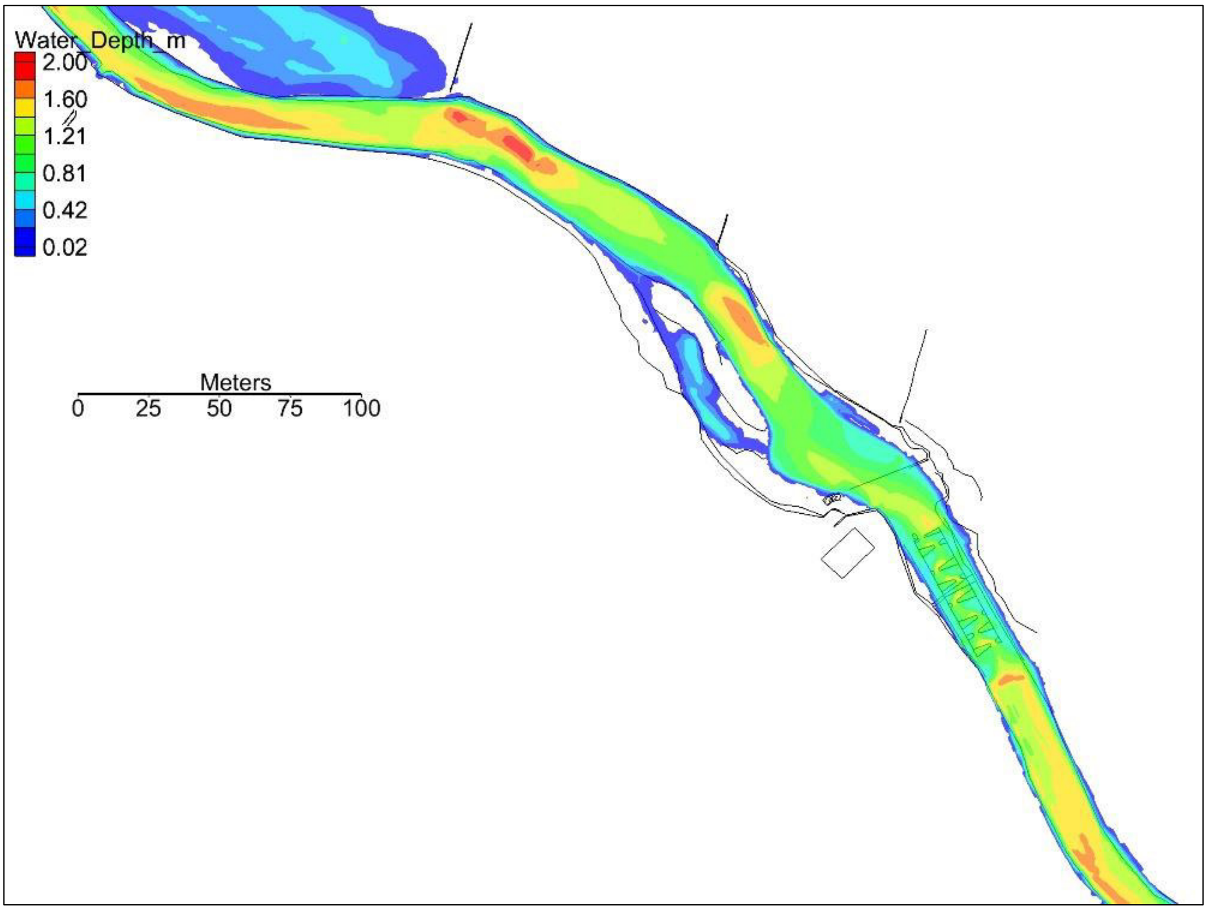

Figure 3.2. 2-yr event depths for the Bowston weir adapted design including ramp design (clearly showing the spatial pattern of deeper pools and shallower riffles).

3.1.2. Low Flows Assessment

An important criteria for the final design at Bowston is to ensure fish passage across a range of flows, including low summer flows. To assess the function of the design in relation to this requirement, the design was modelled for the Q_{10}, Q_{50} and Q_{95} daily flows. The resulting variation in depth and velocity at each of these discharges is shown in Figures 3.2 – 3.4.

The model output demonstrates that there is appreciable longitudinal and lateral variability in depth and velocity throughout the reach at each of the flows assessed. This variation is largely driven by the localised fluctuations in bed slope throughout the reach, reflecting the evolved pool-riffle morphology.

Such variability will be reflected in habitat diversity (further amplified with the spatial sorting of sediments as a result of differential hydraulic conditions).

There are areas of high velocities within the rock ramp (most significant for the Q10 model run) but these are sufficiently localised (i.e. just a few metres in longitudinal extent) to permit fish (particularly salmonids) to easily negotiate them through 'burst' swimming. In addition, the lower velocity pools between the faster flow zones provide sufficient resting conditions for fish. Furthermore, even at Q95, the alternate 'boulder spur' structures within the centre region of the rick ramp maintain sufficient flow depth for fish passage.

Key benefit of design:

→ Low flow modelling suggests that the design remains passable to fish (i.e. Salmonid species) across a range of flows assessed, including low summer flows, with areas of faster flow interspersed with sections of calmer flow providing resting pools for migrating fish.

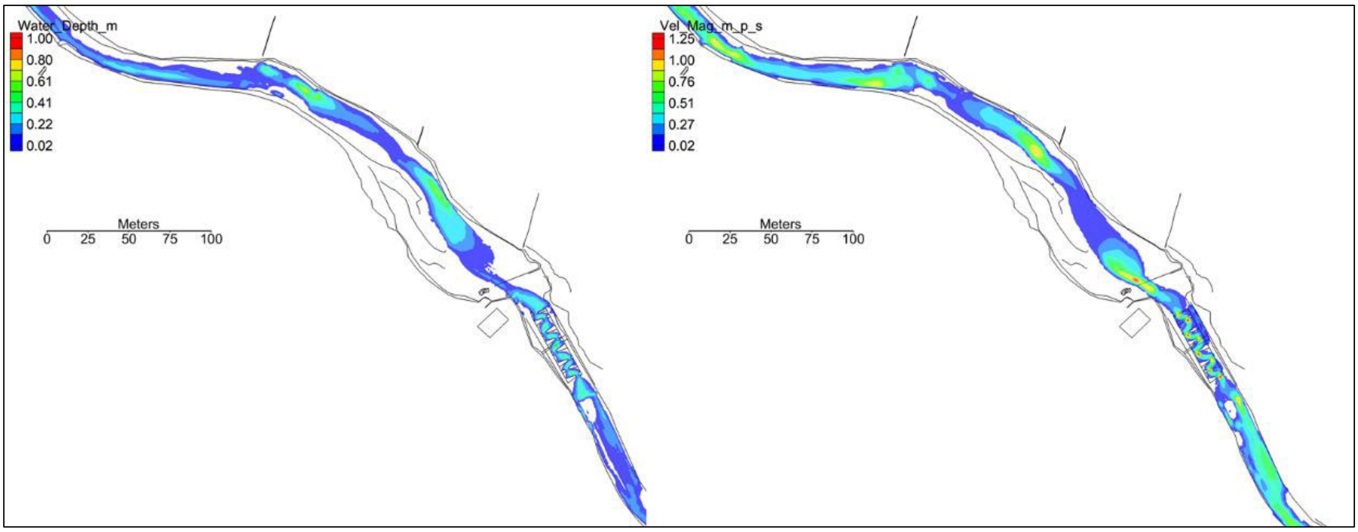

Figure 3.3. Q95 depth and velocity (post bed evolution).

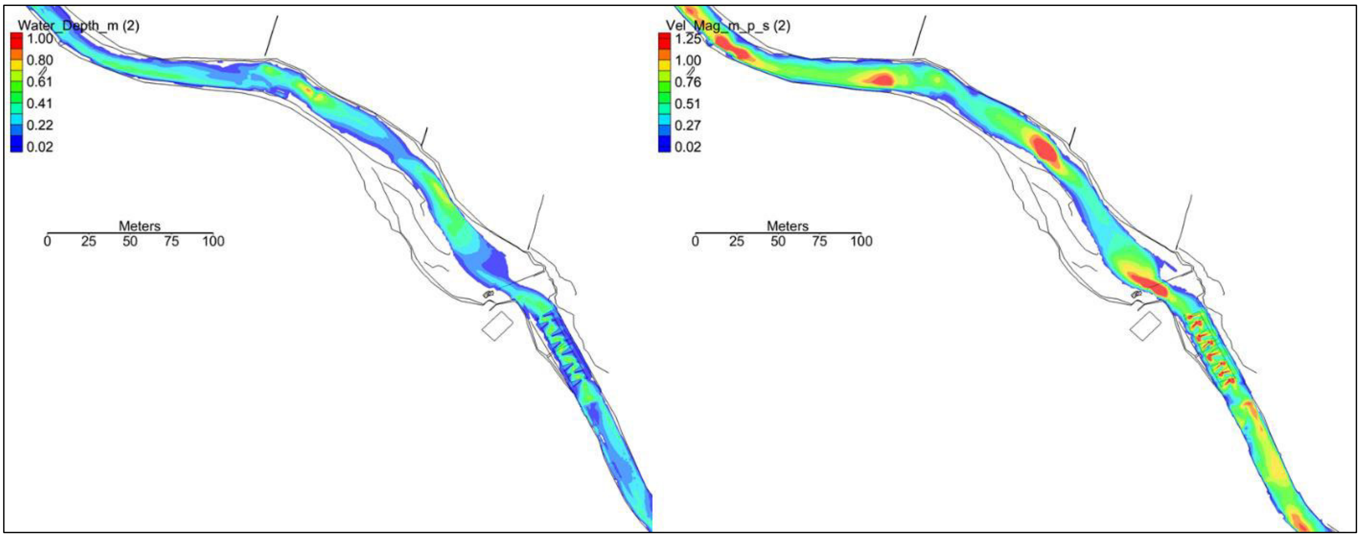

Figure 3.4. Q50 depth and velocity (post bed evolution). Riffle obvious ~100 m upstream of ramp crest and ~100 m to next upstream riffle. Pool-riffle morphology evolves and is stable for 2 year events.

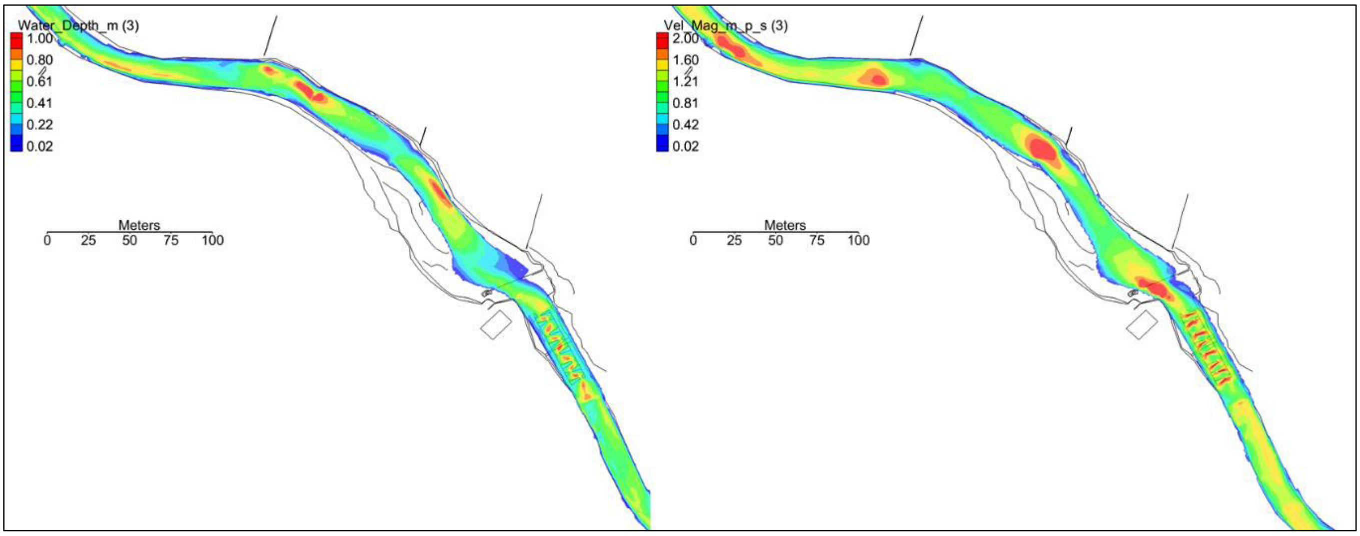

Figure 3.5. Q10 depth and velocity (post bed evolution). Riffle obvious ~100 m upstream of ramp crest and ~100 m to next upstream riffle. Pool-riffle morphology evolves and is stable for 2-year events

3.1.3. Hydraulic Flood Model Runs

A further criterion for the final design was to ensure no increase in flood risk (compared to existing conditions) as a result of the design. To assess this, a 2D hydraulic model was run, using the evolved bed from the morphodynamic model for a 1 in 100-yr return period flow + 35% climate change uplift.

Outputs from the model (Figure 3.6) show a decrease in flood risk on the right bank, specifically in relation to the house adjacent to the fish pass on Kent Close and also the next property further downstream.

A small area of left bank immediately downstream of the current weir location shows a greater level of inundation at this flood return event but this does not pose risk to nearby infrastructure or property.

Overall, the design is shown to have a positive impact to flood risk.

Key benefit of design:

→ Hydraulic modelling shows a decrease in flood risk, particularly to properties on Kent Close, at the 1 in 100-yr event, as a result of the design.

Figure 3.6. 100-year plus 35% climate uplift. Grey area is existing conditions, blue area is design conditions.

APPENDIX A

SUPPORTING MODEL OUTPUTS

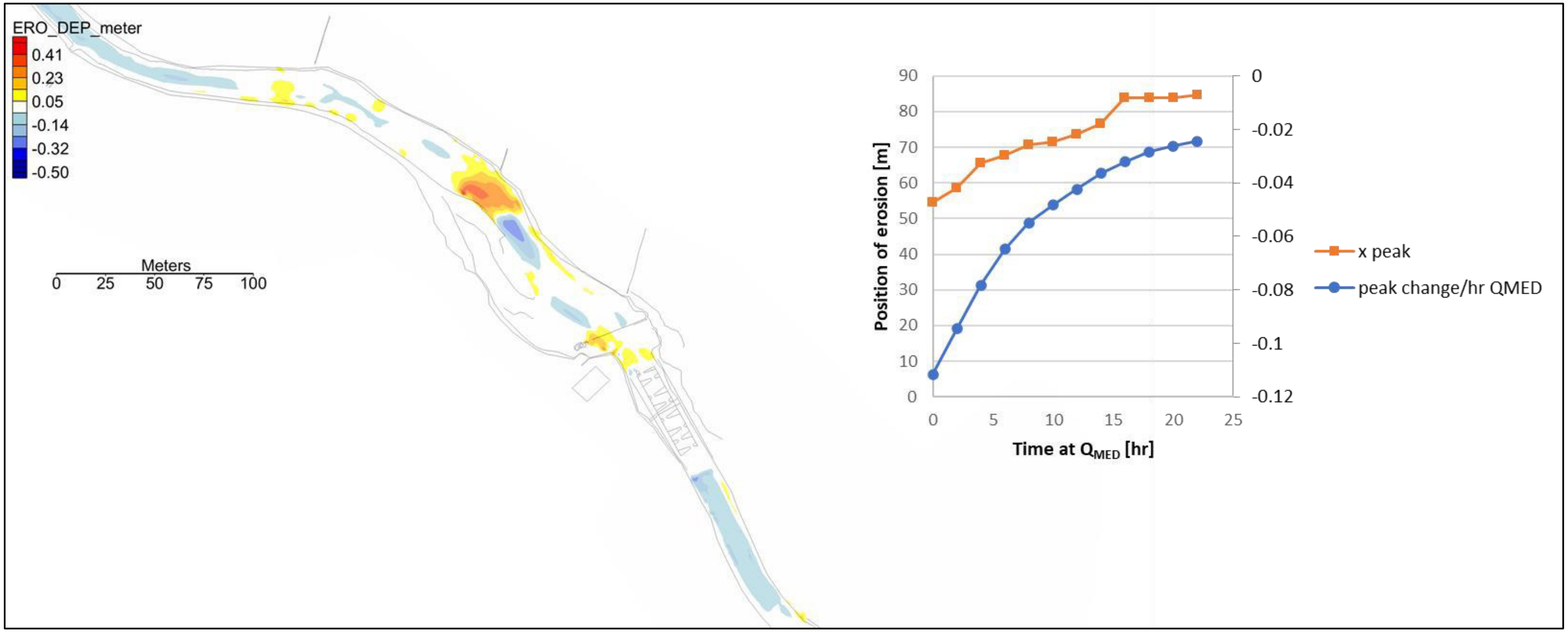

Figure A1. Erosion/deposition pattern during 2-year events is that pools form, riffle migrates upstream to ≈ 125 – 100 m spacing (5-6 channel widths). The inset graph demonstrates that erosion reduces over time (tending to zero after a sufficient duration of flood event) and the riffle position stabilises.

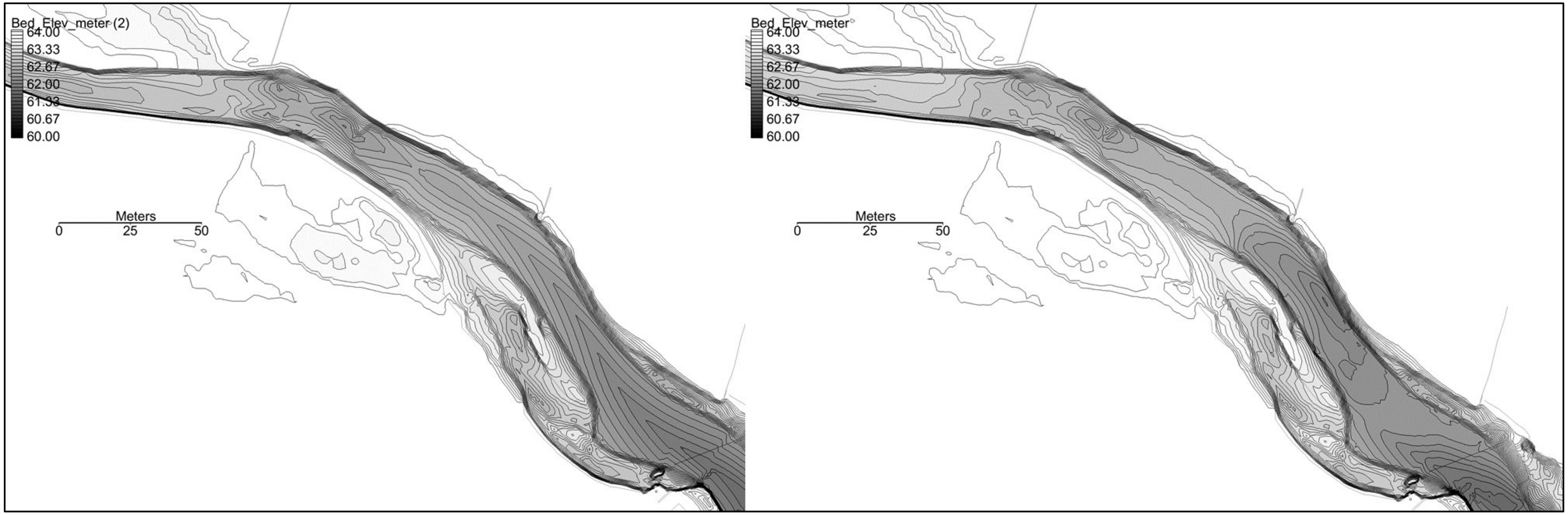

Figure A2. Evolved bed-form complexity: initial (i.e. 'proto-channel') left, evolved right, showing development of pools and riffles.

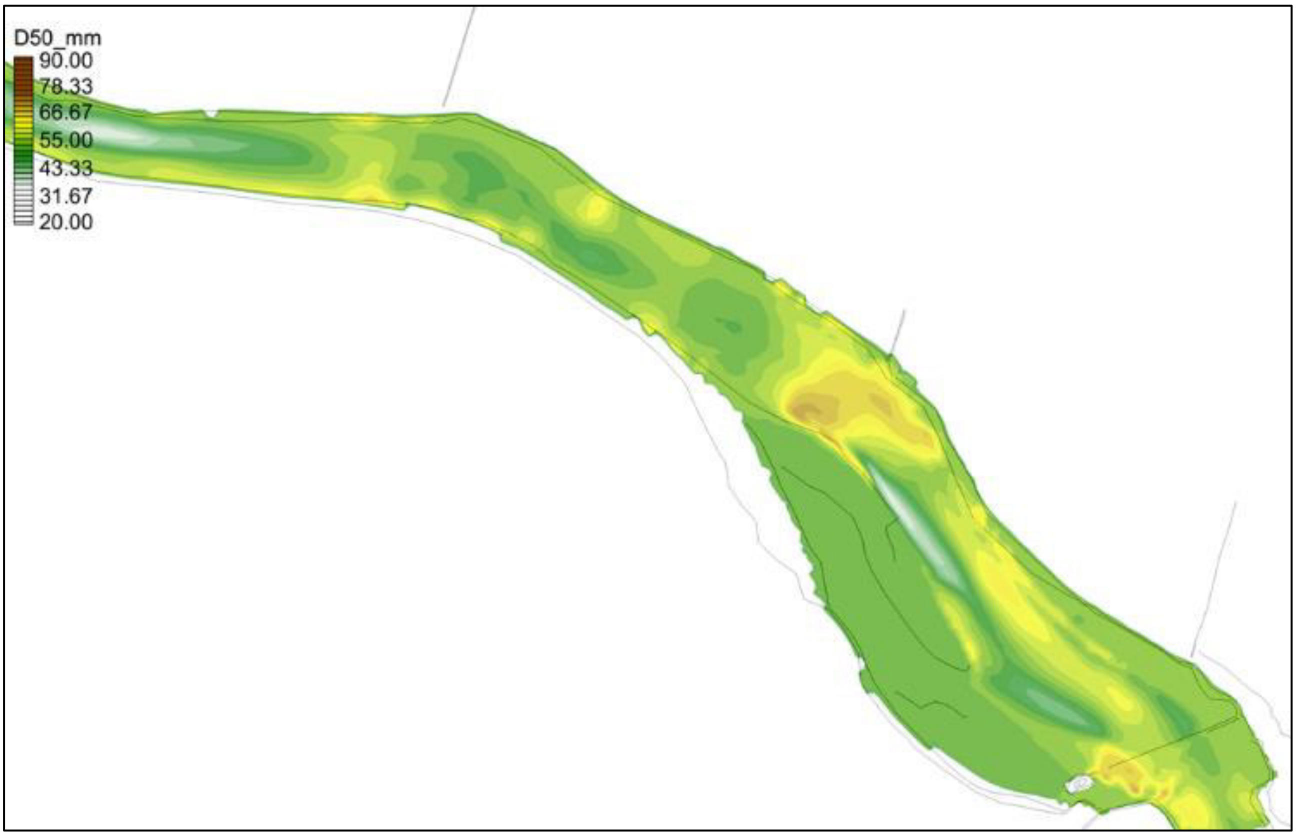

Figure A3. Sediment size sorting in the evolved channel (from a starting position of the 'proto-channel' having a homogenous substrate texture).

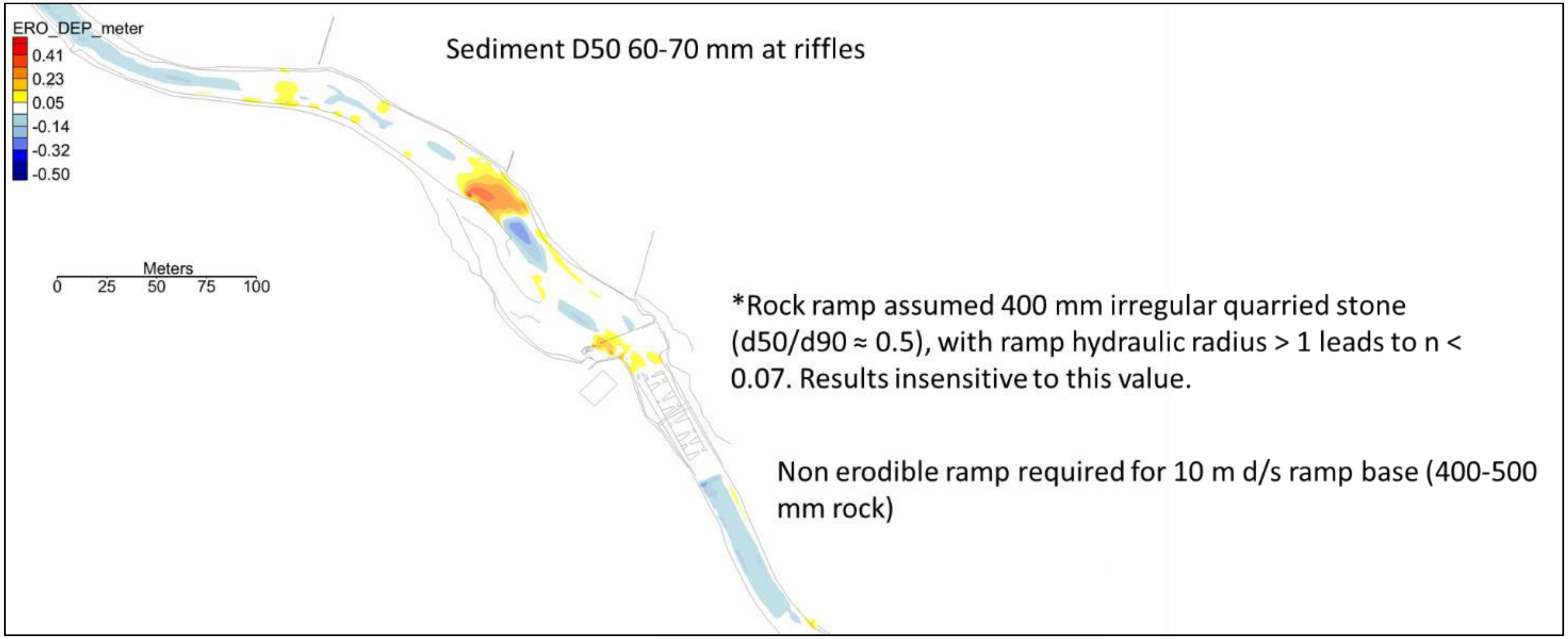

Figure A4. Further information on model assumptions for the design.

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