Appendix C

Fluvial Audit Report

Ballater Flood Protection Scheme

Fluvial Audit Report

cbec eco-engineering UK Ltd

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1. INTRODUCTION

With the goal of providing a more detailed understanding of contemporary geomorphic processes in the River Dee, cbec was commissioned by RPS to undertake a repeat fluvial audit in the vicinity of Ballater. The field-based assessment reported here will subsequently be used to support the development of options to be included in the Ballater Flood Protection Scheme (FPS).

1.1 SUMMARY OF PREVIOUS GEOMORPHIC ASSESSMENT (2017)

To characterise catchment-scale fluvial processes operating in the River Dee and influencing flood risk at Ballater, cbec undertook a fluvial audit in the fall of 2017 which included:

- A ~12 km section of the main-stem River Dee, from OS NGR NO 32682 96518 (upstream) to NO 41064 98167, (approximately 3.8 km downstream of Ballater).
- Sections of four tributaries to their confluences with the Dee:
    - Girnock Burn from NO 32580 95745;
    - River Gairn from NO 34541 98325;
    - River Muick from NO 35525 94155; and
    - Tullich Burn from NO 38736 97494.

The extended fluvial audit (Figure 1.1) supported the development of a conceptual Geomorphic Process Model (GPM) model and a semi-quantitative analysis of the Dee system surrounding Ballater. As part of this assessment, indices of Geomorphic Process Intensity (GPI) or dynamic behaviour were calculated to provide an indication of the likely sensitivity of the system to change (e.g. during a large-scale flood event). Of particular relevance to the current stage of the project, the previous assessment concluded that:

- Storm Frank had likely temporarily lowered thresholds for geomorphic change in a number of key locations in the River Dee upstream of Ballater Bridge (Girnock Burn confluence, River Gairn confluence and vicinity of Ballater golf course);
- The section of River Dee bordering Ballater Golf Course scored the highest of all sections of river for GPI/ potential for future change.
- Lowering of thresholds for geomorphic change was likely to result in frequent adjustment of channel form in the vicinity of the River Muick confluence, even at relatively small flood events.

Since this completion of this assessment (in early 2018), several high flow events have occurred in the River Dee, prompting a reassessment of channel morphology to ensure that future flood protection measures are well aligned to the Dee's likely trajectory of morphological evolution.

A high-resolution fluvial audit was therefore commissioned for the areas in closer proximity to Ballater, along the main stem of the River Dee. Its methodology and results are reports in **Section 2**.

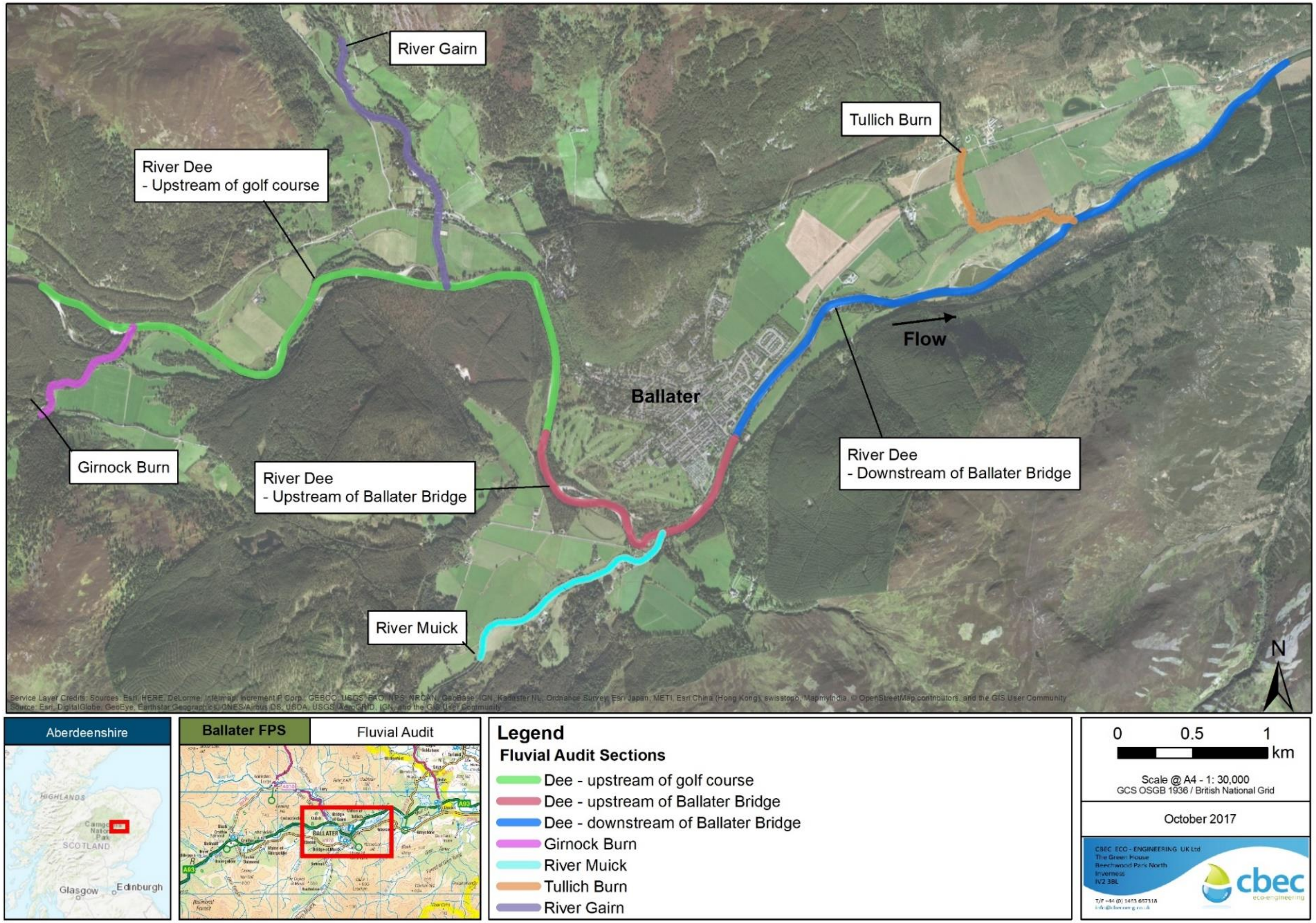

Figure 1.1 Overview of Sections surveyed under the 2017 fluvial audit

2. FLUVIAL AUDIT

2.1 METHODOLOGY

cbec has undertaken a repeat fluvial audit of ~2.5 km of the River Dee adjacent to the golf course in Ballater (Table 2.1) to assess the distribution of morphological, sedimentary and ecological factors in combination with human impacts along the length of the studied sections. The findings of the fluvial audit are to be compared with those of the previous audit undertaken in 2017. The fluvial audit procedure is a location-specific inventory of the physical form of the river (i.e. morphology and sedimentology) that creates a template for key habitats and all likely influencing factors, providing an understanding of both form and function. This enhances our understanding of the causes of river degradation and supports the implementation of sustainable measures to address such degradation.

We have collected information including, but not limited to, the following:

- Reach-scale channel morphology (e.g. step pool, plane bed, pool-riffle, wandering). We use a classification system that is a combination of recognised procedures (i.e. Montgomery and Buffington, 1997; Brierley and Fryirs, 2000).
- Morphological/ habitat units (i.e. pools, riffles, runs). These are specific 'mesoscale' features that, together, define reach-scale morphology. Such features can be regarded as the fundamental physical 'building blocks' of river channels and are closely related to habitat patterns. Therefore, such data can provide potentially valuable information to support assessments of ecological condition and habitats.
- Indicators of the sediment transport regime (e.g. the size, form, texture, dominant particle size and vegetation cover of bar features and bed forms). This information is essential for interpreting physical process within the river and has implications for ecological condition and habitats.
- Sediment sources (e.g. from upstream on the main river, tributaries, bank/ terrace erosion). These sources have been recorded in terms of severity and extent to allow an index of sediment supply to be calculated.
- In-channel sediment storage (including alluvial bar features and evidence of bed accumulation). This dataset also provides an indication of the rate and distribution of sediment supply to downstream areas from within-channel sources. This includes any indicators of sediment transport (e.g. the size, form, texture and vegetation cover of bar features and bed forms).
- Large wood. The incidence, location (e.g. mid-channel, bank-side) and extents of large wood within the active channel, including their physical and ecological influence, have been documented.
- Vegetation. Both in-channel vegetation (e.g. macrophytes) and riparian/bank-side cover have been recorded, as well as invasive/non-native species.
- River engineering pressures (e.g. weirs, lades, impeded side channels, bank protection, canalisation, embankments, bridge crossings). These features have been characterised in terms of their extents and the severity of their impacts on river process.
- Floodplain morphology, including drainage channels/ ditches, relict natural secondary channels, wetland areas and swales.
- Other indicators of the dynamic physical behaviour of the channel (e.g. abandoned channel courses, historic side channels, age structure of vegetation within the riparian corridor).

- Other land use pressures in the areas draining directly into the watercourses surveyed (e.g. urban drainage, livestock poaching, poor forestry drainage, field cultivation close to channel margins).

The collected data have been recorded using a mobile GIS platform, Qfield, with integral GPS capability. This allowed accurate determination of the position and extent of important features (e.g. length of bank erosion, area of sediment stored in active bar features). High-resolution georeferenced photos were also taken throughout the survey reach to capture significant features/ structures and illustrate the general character of specific reaches.

Table 2.1. Fluvial audit extents.

Reach	Upstream Extent	Downstream Extent	Description	Channel Length
1	NO 36019 96073	NO 35966 95696	Old Line Road car park downstream to Ballater Golf Course	~380 m
2	NO 35966 95696	NO 37041 95198	Ballater Golf Course to its boundary with Ballater Caravan Park	~1,760 m
3	NO 37041 95198	NO 37211 95588	Ballater Caravan Park downstream to the B976 (Bridge Street) road bridge	~480 m

2.2 ASSESSMENT OF PHYSICAL FORM AND PROCESS

The section of the River Dee assessed during the fluvial audit exhibits characteristics of a pool-riffle reach, comprising predominantly interspersed riffles, runs and glides, with extensive formation of alluvial bar forms (particularly in Reach 2, where considerable aggradation has occurred) and bank erosion. However, no well-developed pools were observed during the audit. The bedload here is mixed, with predominantly cobbles and boulders, although gravel is dominant locally and sandy deposits were widespread on the floodplain, particularly in Reach 2. The river can broadly be considered partially confined, although less so in Reach 2, where pronounced lateral migration of the channel has occurred. Bank protection is widespread throughout the reach and is primarily historical. An embankment is also present along the left bank for much of the audit section, and an extensive network of side/ secondary channels was observed, both on the river left floodplain and in areas of complex alluvial bar forms. The fluvial audit section has been split into three separate reaches based on the dominant boundary conditions and fluvial form and process; these reaches are described in turn in the following maps and tables.

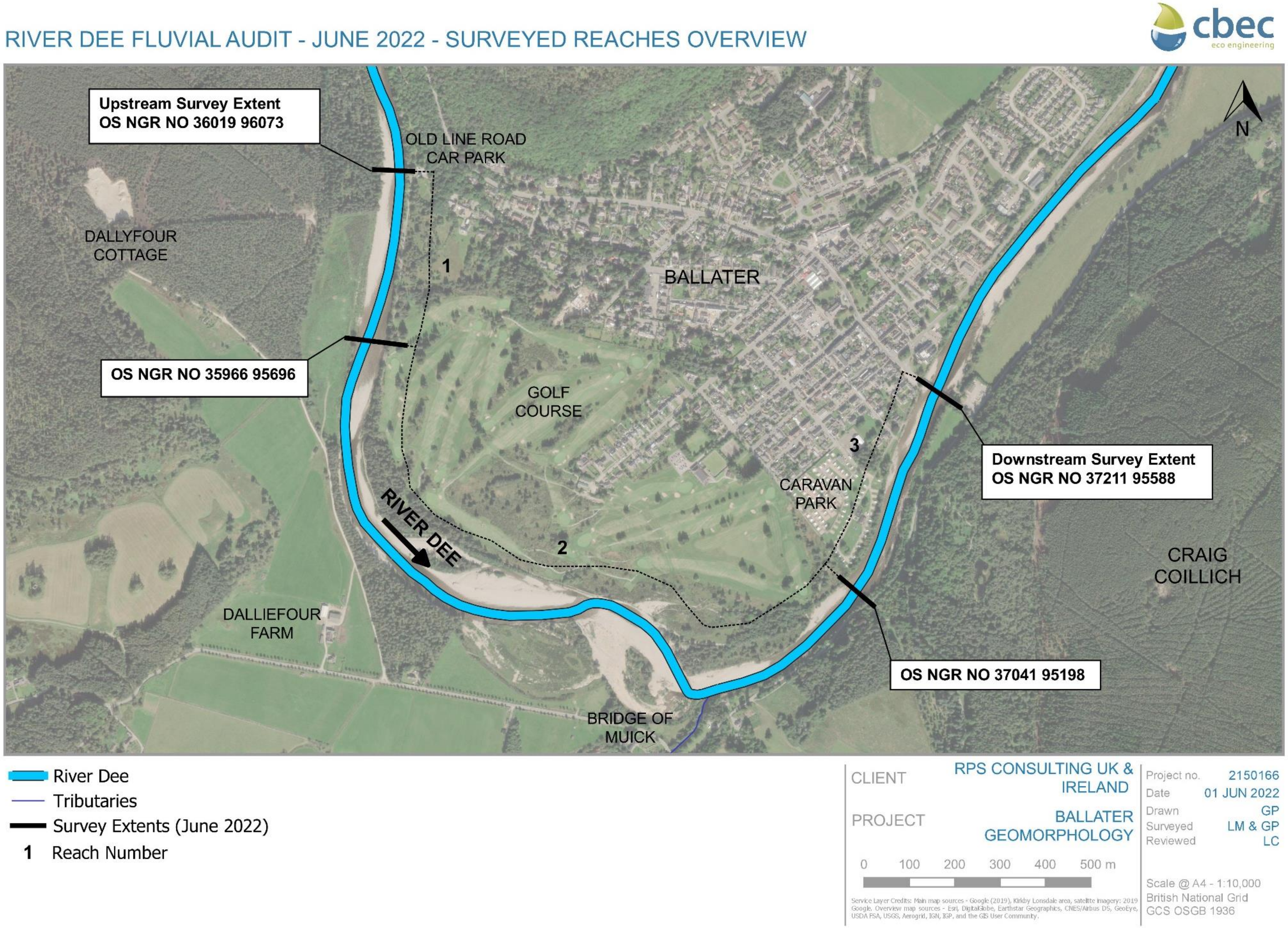

Figure 2.1 Overview of the geomorphic reaches surveyed during the June 2022 fluvial audit.

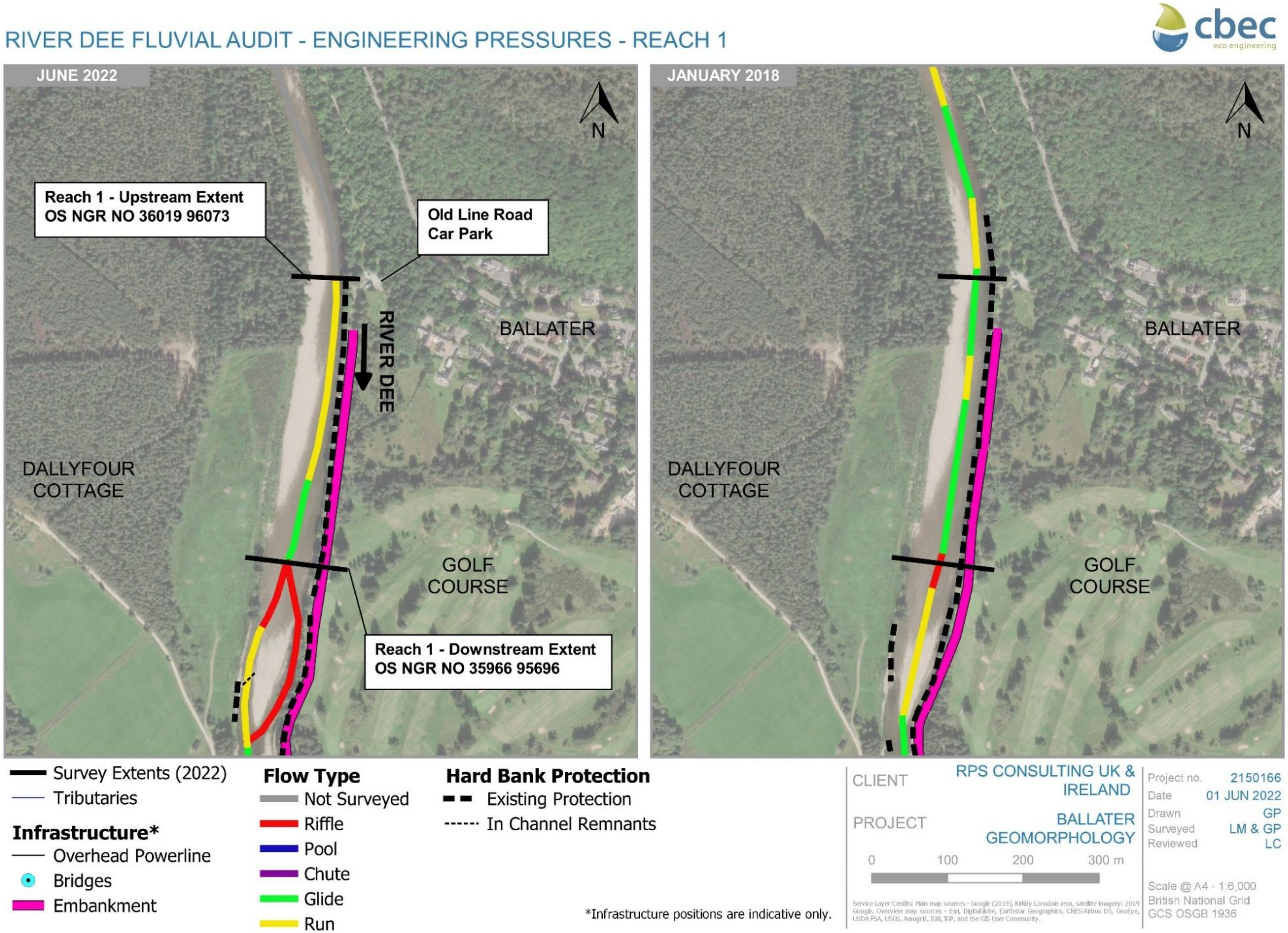

Figure 2.2 Morphological units and engineering pressures: Reach 1.

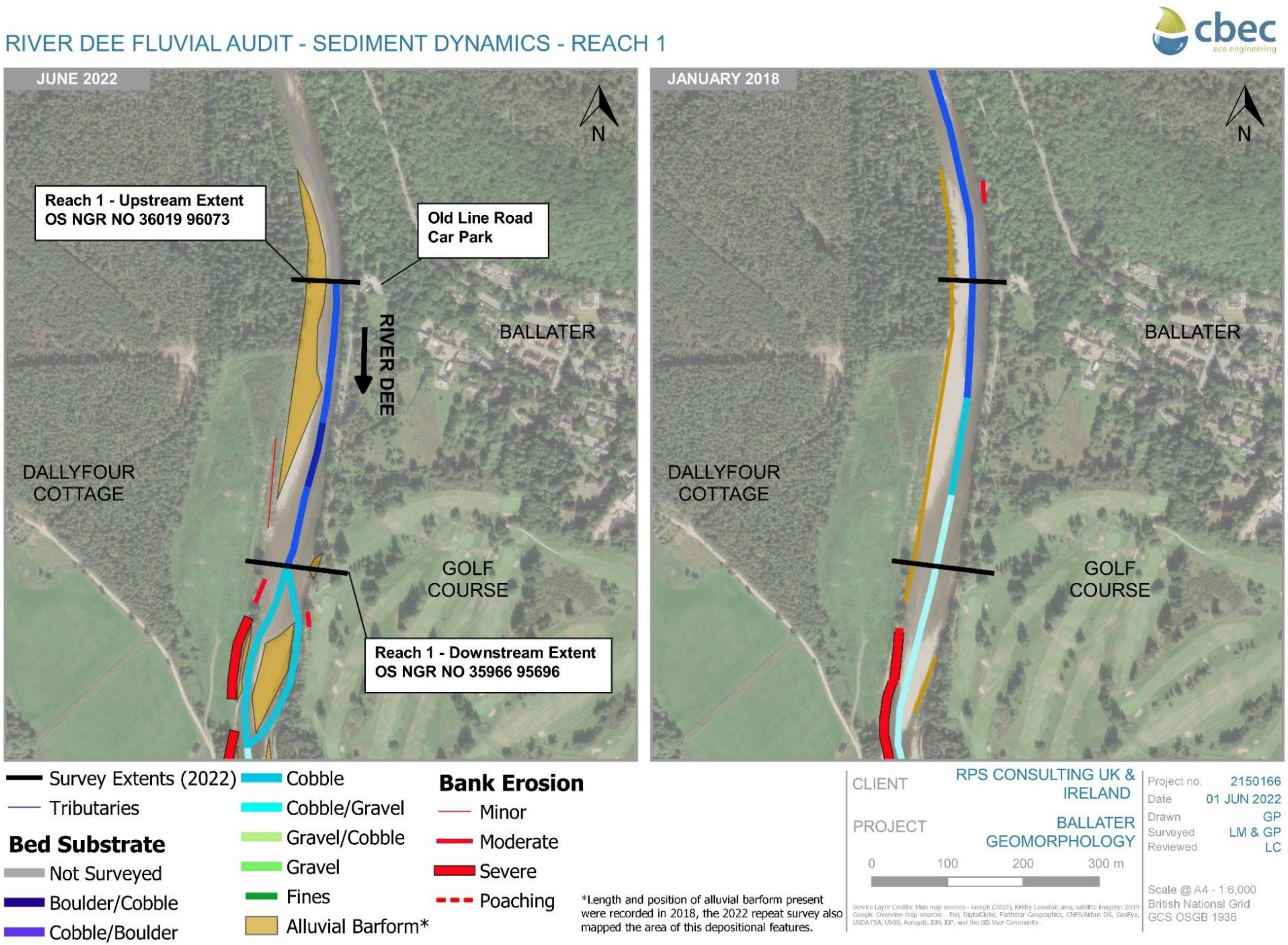

Figure 2.3 Sediment dynamics: Reach 1.

Table 2.2. Summary of fluvial form and process: Reach 1.

River Dee at Ballater, Reach 1	
Dominant features • Units dominated by glides and runs • Historical bank protection along left bank for entire reach • Embankment present along footpath to left bank (runs along floodplain side of footpath in upper section and river side further downstream) • No additional morphological pressures noted • Alluvial bar form present along much of right bank • Bed substrate dominated by boulder/cobble and cobble/boulder units • Bed substrate generally active and clean • Trees present along river left channel margin for much of reach • Floodplain more open and covered with gorse to river right • Golf course located on river left floodplain • Large wood otherwise absent • Banks generally stable, with minor erosion of right bank at downstream end of reach supplying sand/silt and cobbles	 Hard bank protection  Embankment on floodplain side  Embankment on river side  Lateral deposition along river right

River Dee at Ballater, Reach 1

Change since previous fluvial audit

- No notable change in planform
- Still dominated by run and glide morphology, although run section more extensive
- General coarsening of bed substrate with less gravel observed now
- No notable change in configuration of alluvial bar forms (lateral bar)


Minor bank erosion


Trees in channel margin


Typical reach character


River left bank top area

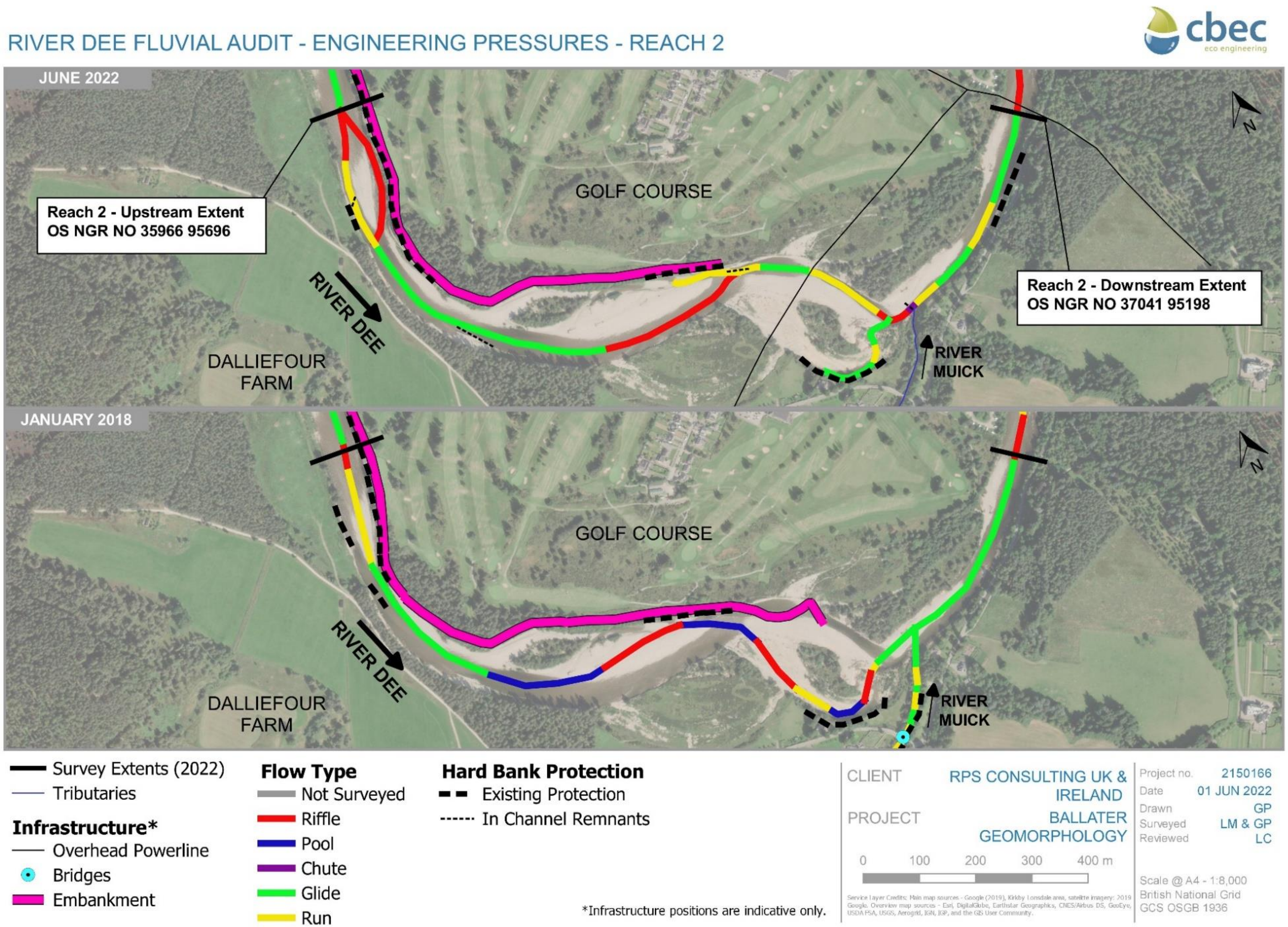

Figure 2.4 Morphological units and engineering pressures: Reach 2.

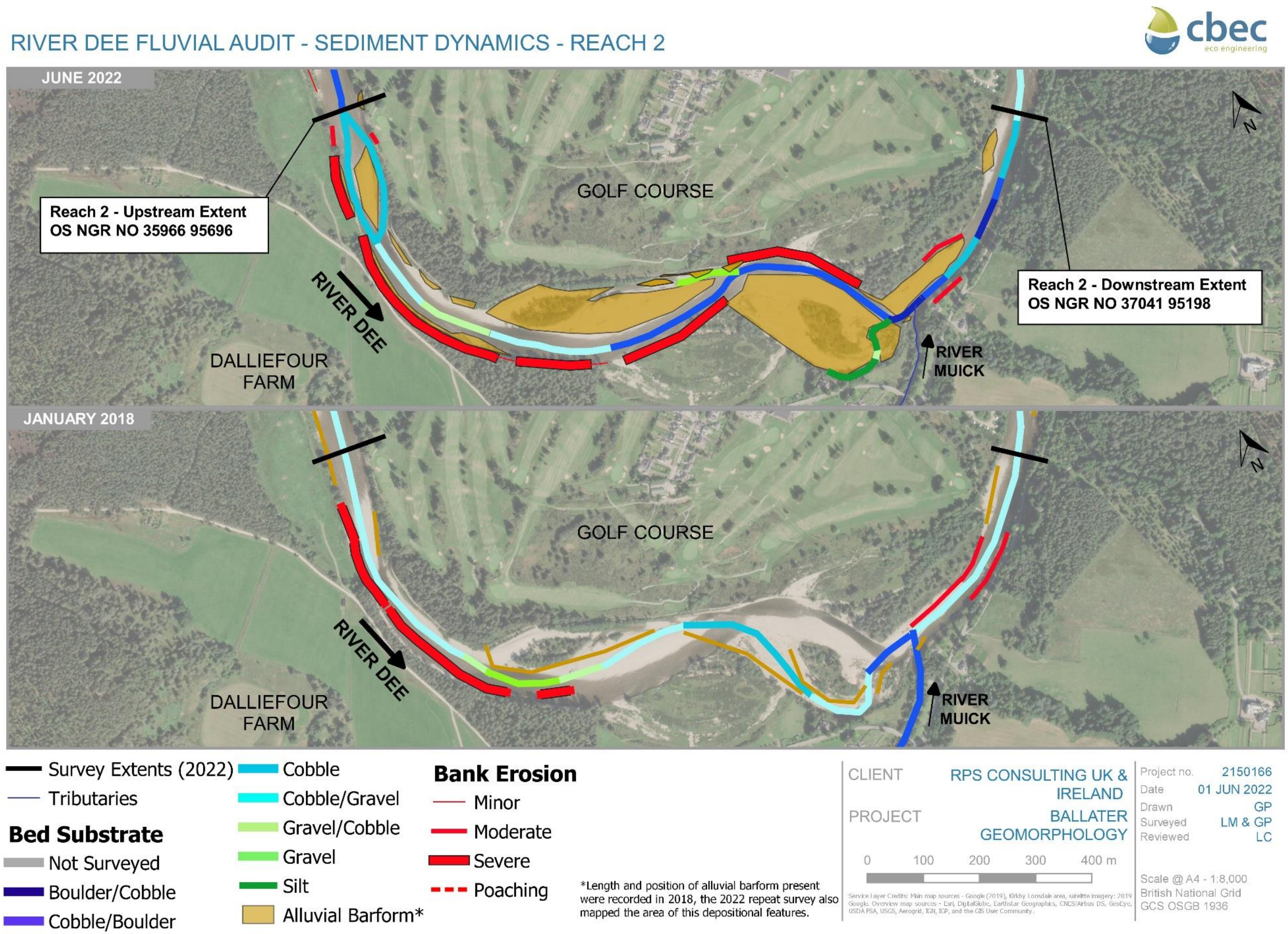

Figure 2.5 Sediment dynamics: Reach 2.

Table 2.3. Summary of fluvial form and process: Reach 2.

River Dee at Ballater, Reach 2

Dominant features

- Dominated by glides, riffles and runs, with short chute section near Muick confluence
- Historical bank protection present but discontinuous along both banks
- Embankment continues along much of upstream part of reach, with associated hard bank protection in place
- Some failing hard bank protection observed in channel
- River Muick enters mainstem Dee from river right
- Variable bed substrate ranging from gravel/cobble to boulder/cobble
- Bank erosion extensive and severe, particularly on outsides of bends, providing abundant supply of coarse sediment
- Bed substrate generally active and clean
- Alluvial bar forms both medial and lateral (point bars) in upstream part, gravel-dominated
- Extensive alluvial deposition in middle to lower sections, often with considerable aggradation
- Large complex bar form to river right upstream of Muick confluence, partly vegetated, abundant large wood present across full extent of deposition area


Eroding cliff, river right


Example secondary channel


Bank protection


Severe erosion, left bank

River Dee at Ballater, Reach 2	
• Large-scale avulsion of channel has caused severe bank erosion, affecting footpath; coarse material deposited across river left floodplain • Large backwater formed along previous course of River Dee, silty substrate • Extensive network of secondary channels on river left floodplain with sandy substrate and large wood common • Much of bank/ floodplain area wooded outwith golf course **Change since previous fluvial audit** • Extensive planform change, with main channel shifting >150 m northwards in places, causing extensive erosion of left bank and footpath • Complete lack of defined pools, suggesting all pools infilled • General coarsening of bed substrate, now dominated by cobbles and boulders, with gravel restricted more to bar forms • Previous course of mainstem Dee now forming backwater • Extensive change in distribution of complex bar forms	 Secondary channel with sand and large wood  Muick confluence  Extensive complex bar form, river right  Backwater (previous course of Dee)

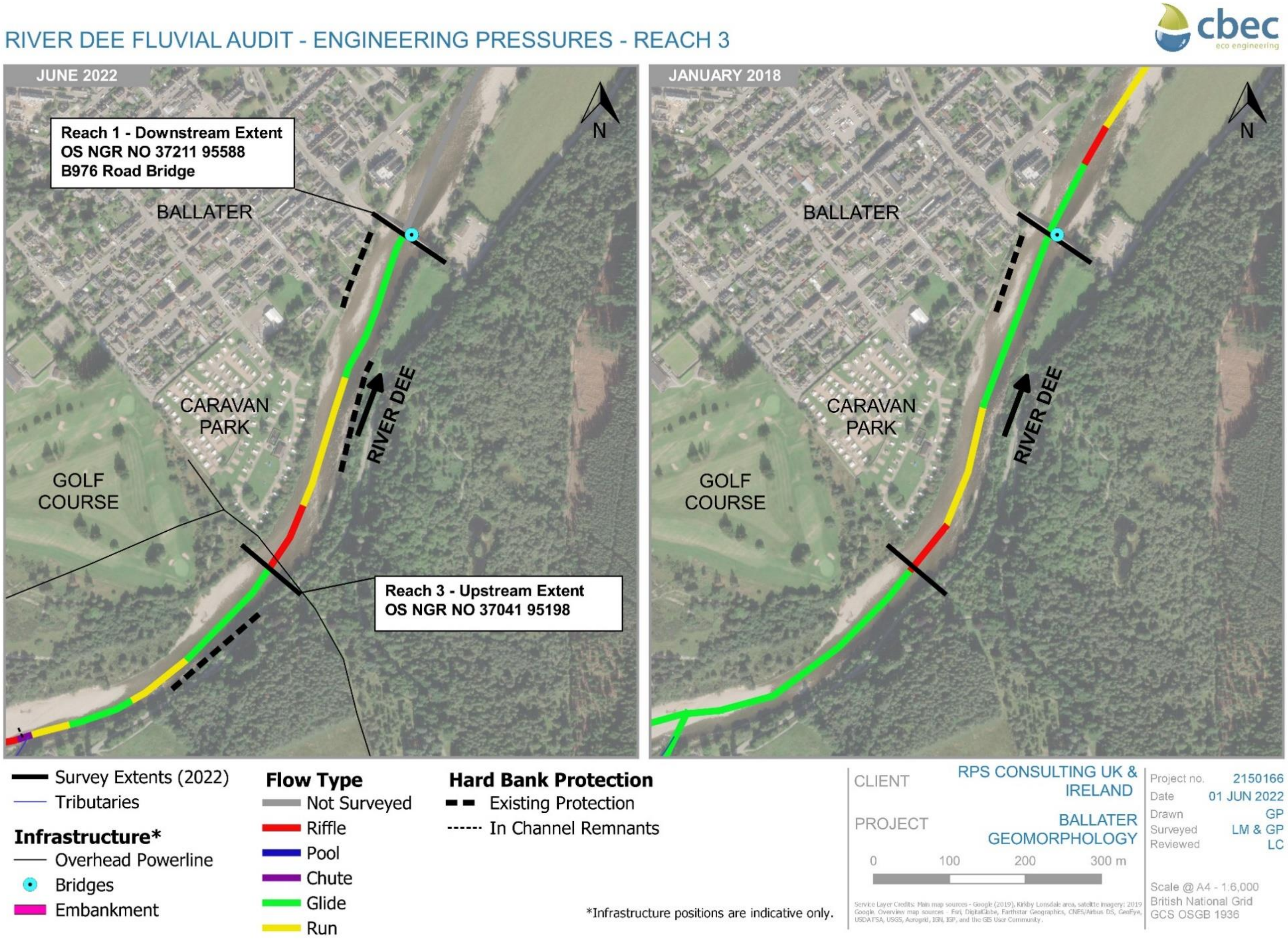

Figure 2.6 Morphological units and engineering pressures: Reach 3.

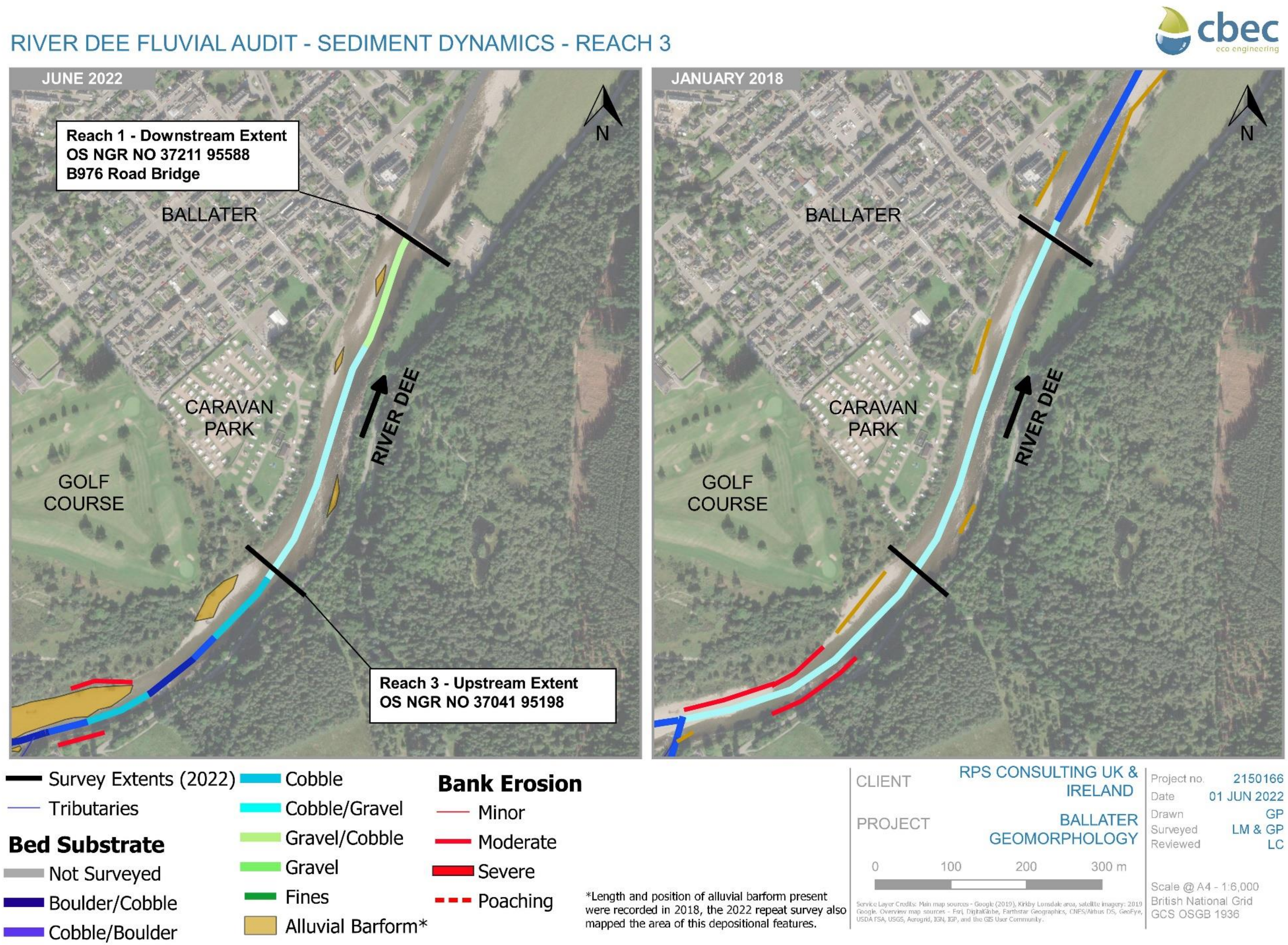

Figure 2.7 Sediment dynamics: Reach 3.

Table 2.4. Summary of fluvial form and process: Reach 3.

River Dee at Ballater, Reach 3

Dominant features

- Interspersed riffle, run and glide sections
- Banks generally stable and well vegetated with extensive tree cover, with little bank erosion
- Bank protection present locally
- Medial and lateral bar forms present, including vegetated island
- Bars and bed substrate dominated by cobbles and gravel in upper section and gravel downstream towards bridge
- Bed substrate generally active and clean
- Large wood generally absent except as trees in channel margin
- Channel more confined here, with steep wooded slope to river right providing constraint to lateral movement
- Caravan park and residential areas to river left
- No tributaries or drains here
- Bridge forms downstream boundary

River Dee at Ballater, Reach 3

Change since previous fluvial audit

- No notable change in planform
- No notable change in morphological units
- General fining of bed substrate with gravel dominant in section upstream of bridge
- No notable change in alluvial bar forms

Figure 2.8 Aerial Imagery between 2010 and 2021, showing channel planform adjustment and evolution of alluvial barforms throughout the last decade.

3. SUMMARY OF FINDINGS

The fluvial audit undertaken in June 2022 confirmed the trajectory and magnitude of geomorphic change previously predicted in 2018. As anticipated, the area in the vicinity of Ballater golf course has, since the previous fluvial audit, witnessed significant channel planform adjustment. Specifically:

- The sediment 'pulse' generated through Storm Frank has significantly altered the channel configuration in the vicinity of Ballater golf course, leading to a migration of the main stem of the River Dee;
- Where Storm Frank had locally increased cross-sectional area and lowered transport capacity (such as the area immediately upstream of the confluence with the River Muick), large alluvial deposits have developed in the period between fluvial audits.
- The development of these alluvial deposits has effectively cut-off the previous main flow route of the River Dee upstream of the Muick confluence, significantly altering the hydraulic patterns and shear stress observed at channel boundary along the left bank.
- This change in cross-sectional profile and channel hydraulics exacerbated erosional forces along the left bank of the Dee in the lower section of the embankment protecting the golf course and the town of Ballater.

In conclusion, while the trajectory of channel evolution observed in the present fluvial audit is consistent with the predictions of the previous geomorphological assessment, the dynamic character of the River Dee reach immediately upstream of the confluence with the Muick prompts recommendations for further, quantitative assessments of likely channel evolution. In particular, a morphodynamic modelling approach incorporating a mobile bed is recommended as the most accurate methodology available to assess the evolution of channel form and more accurately predict how this will likely influence the frequency and patterns of flooding at Ballater.

3.1 MINOR WORKS PROPOSALS

The above assessment of contemporary geomorphic processes and recent trajectory of channel evolution supported a preliminary qualitative assessment of the adequacy of minor works being proposed in the vicinity of Ballater.

4 options are being initially considered to provide a 1 in 10-year standard of flood protection to Ballater. Specifically:

1. Removal of dead trees to build up banks and decrease channel lateral migration
2. Re-excavate previous main-stem channel, diverting majority of flows from left bank/ golf course
3. Clear out channel on golf course outfall
4. Build up bund on gold course using Hesco barriers

At this stage, no options have been subject to a quantitative assessment through hydraulic modelling or been developed to a detailed design stage. Nonetheless, the additional understanding of likely channel adjustment trajectory brought about by this recent fluvial audit points towards:

- The suitability of Option 1 to decrease the rate of channel lateral migration in proximity to the golf course. This could contribute towards the natural reactivation of the previous primary flow route of the Dee as well as limiting the excessive recruitment of large wood that could further decrease conveyance during high flow events.

- The potential suitability of Option 2 to encourage the re-occupation of the previous main flow route. However, this intervention would require a robust detailed design process to provide evidence that newly dug main channel can be self-sustainable and will not perform as a sediment “sink” in the next high flow events.
- Some likely limitations to the long-term effectiveness of Option 3. Considering the grain diameter of sediment recently deposited in the area of woodland closer to the golf course it appears that, within the current channel configuration, relatively small events can deposit substantial volumes of fine material in these side channels. Therefore, the depositional character of this area can significantly limit the long-term effectiveness of this option.
- That Option 4 may provide a positive contribution to the desired 1 in 10 year standard of protection, with minimal impact to geomorphic processes. However, careful consideration will be necessary to ensure that final barrier configuration does produce the following negative impacts:
    1. Barriers deflecting hydraulic forces during a high flow event and increasing shear stress and erosive potential in the River Dee.
    2. Potential for changes in nearby flood levels in proximity to golf course and caravan park. In particular, it is recommended that barrier installation is not completed prior to undergoing hydraulic modelling updates.

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