Ehen Compensatory Measures

United Utilities

Crummock Water Abstraction Infrastructure Removal - Full Technical Report

04 | Final

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Research Measure 6

Ehen Compensatory Measures

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04	29/06/2020	Final report	AF/SC	IG	AF

Contents

Executive Summary

United Utilities (UU) have commissioned Jacobs to undertake an investigation in the engineering feasibility of removing abstraction infrastructure at Crummock Water, together with a hydro-geomorphological and ecology impact assessment of infrastructure removal. This specific study forms part of Research Measure 6 of an overall package of Compensatory Measures aimed at improving habitat for Atlantic salmon. These Measures are required to compensate for adverse impact that abstraction for public water supply and a potential future drought order at Ennerdale Water has on designated features of in the River Ehen Special Area of Conservation (SAC). This includes freshwater mussels and Atlantic salmon, which are protected under the Habitats Directive.

At key stages throughout the study Jacobs have involved UU and the Project Steering Group (PSG), consisting of the Environment Agency (EA) and Natural England (NE) and periodically, the National Trust and West Cumbria River Trust.

The study has been split into three stages:

- **Scoping Stage** involving a high-level baseline study and gap analysis by each discipline covered (engineering, geomorphology, hydraulics and ecology), definition of scope in terms of infrastructure to be included in the study and determination of an approach to the Main Stages of the project. This was agreed with the PSG before proceeding to the Main Stages of the project.
- **Main Stage A** involving completion of baseline assessments for each discipline, an options appraisal and identification of a shortlist of potential options agreed with the PSG. At the PSG's request, a lead option (full weir removal of abstraction infrastructure with two variants for restoration at Park Beck) was chosen for detailed assessment and carried forward into Main Stage B.
- **Main Stage B** involved detailed assessment of the lead option and design iterations to identify a preferred option.

Following presentation of results from Main Stage A to the PSG, the lead option of full removal of all abstraction related infrastructure was taken forward into Main Stage B. This involves Crummock Water weir, wave wall, water intake pipes and two variants for the restoration of Park Beck; full re-meandering and assisted natural recovery. Outline designs were drawn up for these components and following this a more detailed investigation into the impacts of the design was undertaken by all disciplines involved (civils, flood risk, geomorphology and ecology).

The preliminary design and impacts were presented to the PSG in December 2018 when it was decided to proceed with the option but only to investigate the 'assisted natural recovery' component on Park Beck. A series of minor design iterations took place following a further teleconference with the PSG and those results are presented within this report.

Overall the results of the study show that full removal of all abstraction infrastructure and the assisted natural recovery component of Park Beck are technically feasible, provided there is input from a Reservoirs Inspection Engineer, and that the benefits to flood risk, ecology and geomorphology are unanimously beneficial.

The designs referred to in this report are outline design only and "not for construction" as they will require further study to refine the design. Recommendations are provided at the end of this report for next steps.

1. Introduction

1.1 Background

The River Ehen in West Cumbria is designated as a Special Area of Conservation (SAC) and Site of Special Scientific Interest (SSSI). It is also within the Lake District National Park, which gained UNESCO World Heritage Status in 2017. Freshwater mussels (*Margaritifera margaritifera*) and Atlantic salmon (*Salmo salar*) are both of high conservation importance and are the primary and qualifying reasons, respectively, for the designation of the upper River Ehen as a SAC. The river supports the largest population of freshwater mussels in England. The SAC is divided into two management units and both are currently assessed as being in ‘unfavourable declining’ condition due to insufficient freshwater mussel recruitment, making the current population unsustainable.

Ennerdale Water, upstream of the River Ehen SAC, and part of Ennerdale SSSI, is currently a key source of public water supply for West Cumbria and United Utilities is licensed to abstract water under the Water Resources Act 1991. The Ennerdale Water abstraction licence has recently undergone a series of reviews by the Environment Agency (EA) through the Habitats Directive ‘Review of Consents’ process. The current abstraction and a potential future drought order at Ennerdale Water have been determined to have potentially significant negative impacts on both interest features of the River Ehen SAC. In December 2013, the EA confirmed the decision ‘to revoke the Ennerdale Water abstraction licence as soon as is reasonably practicable and to investigate options regarding the timing of weir removal and withdrawal of the compensation flow’. Evidence from the severe stress event affecting mussels in the spring and early summer of 2012 contributed to the decision.

United Utilities (UU) will continue to significantly decrease public water supply abstraction from Ennerdale Water until the complete removal of abstraction is possible in 2022, when the West Cumbria water resource zone will be connected to the UU Integrated resource zone via the Thirlmere Transfer pipeline. There is over-riding public interest to continue to provide public water supply until the replacement source is fully connected. In accordance with Article 6(4) of the Habitats Directive, compensatory measures need to be secured because it cannot be concluded that continued abstraction would not lead to an adverse effect on site integrity.

It should be noted that the Habitats Directive has been transposed into UK law by the Habitats and Species Regulations 2017, which is currently being updated in line with the UK leaving the EU on the 31st January 2020.

UU, in conjunction with Natural England (NE) and the EA, has developed a package of compensatory measures that would reduce, or offset, adverse impacts on the River Ehen SAC as a result of continued abstraction from Ennerdale Water, and a potential drought order, whilst the alternative public supply is put in place. This package includes both physical ecological measures and research measures and was submitted to DEFRA in February 2014. A legal agreement exists, signed in July 2015 between UU, NE and the EA describing each physical and research measure, programme and governance of the package. The aim of the agreed package of measures is to restore habitat which enables the sustainable recruitment of freshwater mussels and salmon, primarily in the River Ehen SAC, and to undertake research and monitoring to understand how this outcome could best be achieved. There are also studies which form part of the Ehen Compensatory Measures package involving habitat improvement elsewhere in West Cumbria out with the Ehen catchment which is where this study comes in.

This study has been undertaken as part of Research Measure 6 and covers investigation of the feasibility and environmental impacts of removing the abstraction infrastructure at Crummock Water.

1.2 Aims and Objectives of this Study

This study considers the potential removal of abstraction related infrastructure at Crummock Water, to re-naturalise flow regimes and improve salmon migration along the River Cocker.

A key objective of this study is to determine a preferred option and outline design for the abstraction infrastructure with appropriate assessment to justify this.

This study fulfils parts of Research Measure 6 ‘Environmental Engineering Assessment of infrastructure removal’.

A preliminary scope was initially agreed with the Project Steering Group (PSG) (comprising representatives from UU, Natural England and the Environment Agency) in October 2015 and received final agreement at the PSG meeting held in May 2016. Following this meeting the scoping report (Jacobs, 2016a) was signed off by the PSG in June 2016.

To determine the preferred option for abstraction infrastructure removal at Crummock Water, the study includes the following objectives:

- **engineering feasibility assessment** of a range of options concerning the removal of abstraction infrastructure, as well as ‘Do nothing’ and ‘Do minimum options’
- **geomorphic, hydrology and hydraulic assessment** of a range of options at Crummock Water, Park Beck and the River Cocker. The scope of the hydrology and hydraulics assessment has been to provide data for the ecology and geomorphic assessments, but also to provide an analysis of flood risk
- **ecology assessment** for a whole range of options at the Crummock Water, Park Beck and the River Cocker

Other aspects that could comprise a multi-disciplinary assessment of the preferred option include landscape, archaeology and social impacts which during the scoping phase were agreed did not form part of this scope but could be considered later during the Environmental Impact Assessment stage.

This report provides details of each of the stages of the study to show how and why decisions were made throughout the assessment process to ultimately arrive at a preferred option agreed from a multi-disciplinary, multi-stakeholder perspective. This assessment provides the evidence required for the PSG to sign off the Crummock Water aspects of Research Measure R6.

2. Approach

The study has used a multi-disciplinary approach involving various external stakeholders at key points throughout the option development process (outlined in Figure 2-1). The Jacobs only elements of the investigation have been coordinated by a technical lead with contributions and guidance from subject matter experts in engineering, hydrology, hydraulic modelling, geomorphology and ecology through discipline specific investigations and multi-disciplinary workshops. This has led to the development of a preferred option with consideration of all relevant technical aspects.

UU have participated throughout the assessment as part of the technical team and this has been beneficial in providing a wider contextual perspective during the options development process.

The study was delivered in three stages:

- **Scoping Stage** involved a high-level baseline study and gap analysis by each discipline (engineering, geomorphology, hydrology, hydraulics and ecology). It also defined the scope in terms of the components to be included in the study, the technical disciplines to be considered (landscape, social and archaeology were scoped out for this assessment) and the approach to the Main Stages of the project. The scoping document was approved by the PSG before proceeding to the Main Stages of the project.
- **Main Stage A** involved completion of baseline assessments for each discipline, an options appraisal and identification of a shortlist of potential options which were agreed with the PSG and carried forward into Main Stage B.
- **Main Stage B** looked into more detail at the full removal of all abstraction related infrastructure and two options at Park Beck: natural recovery and full channel re-meandering.

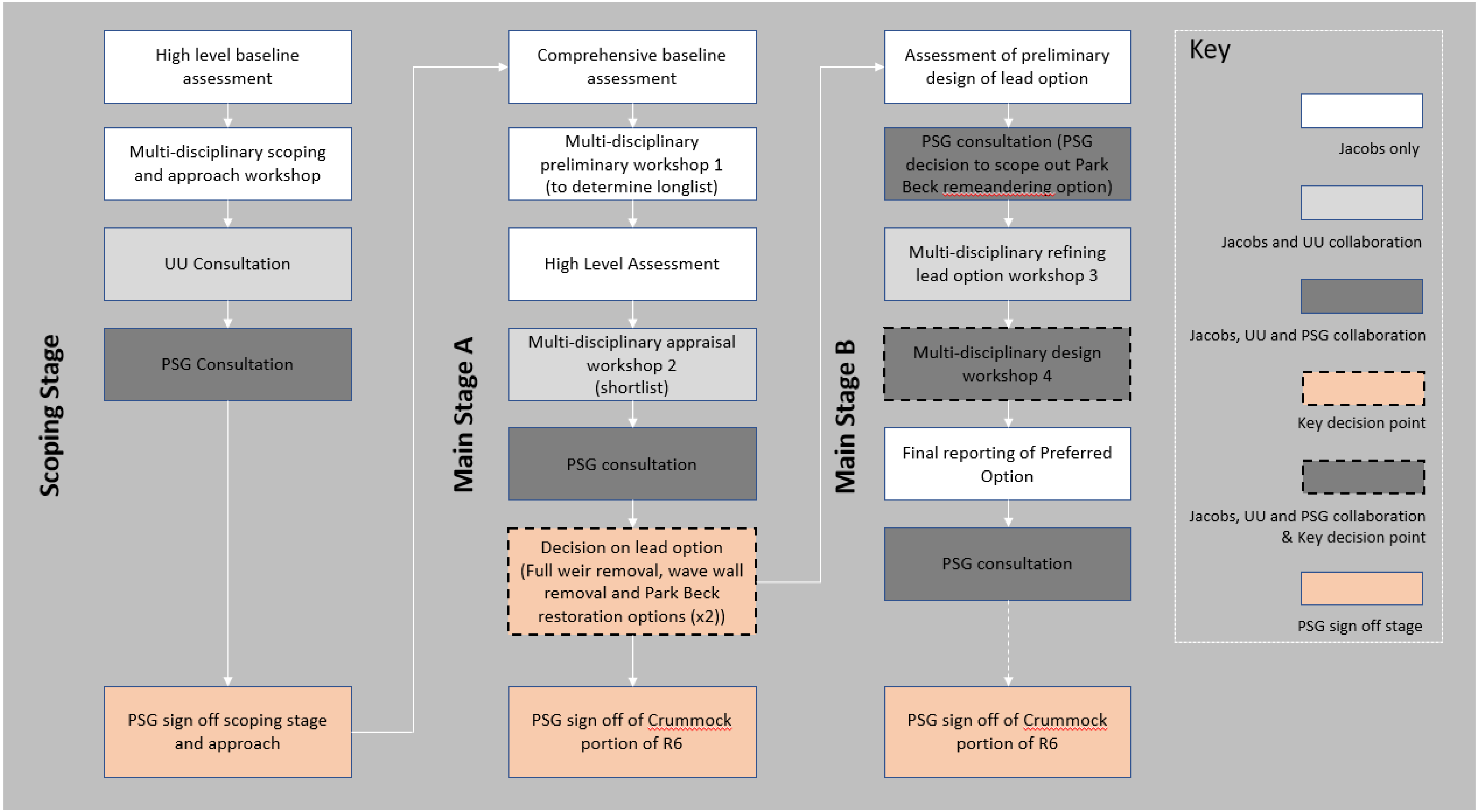

Figure 2-1: Key stages of approach during the options development for the Crummock Water, (UU= United Utilities and PSG = Project Steering Group)

3. Study Area

3.1 Overview of the study area

The study area in West Cumbria, to the south of Cockermouth (Figure 3-1).

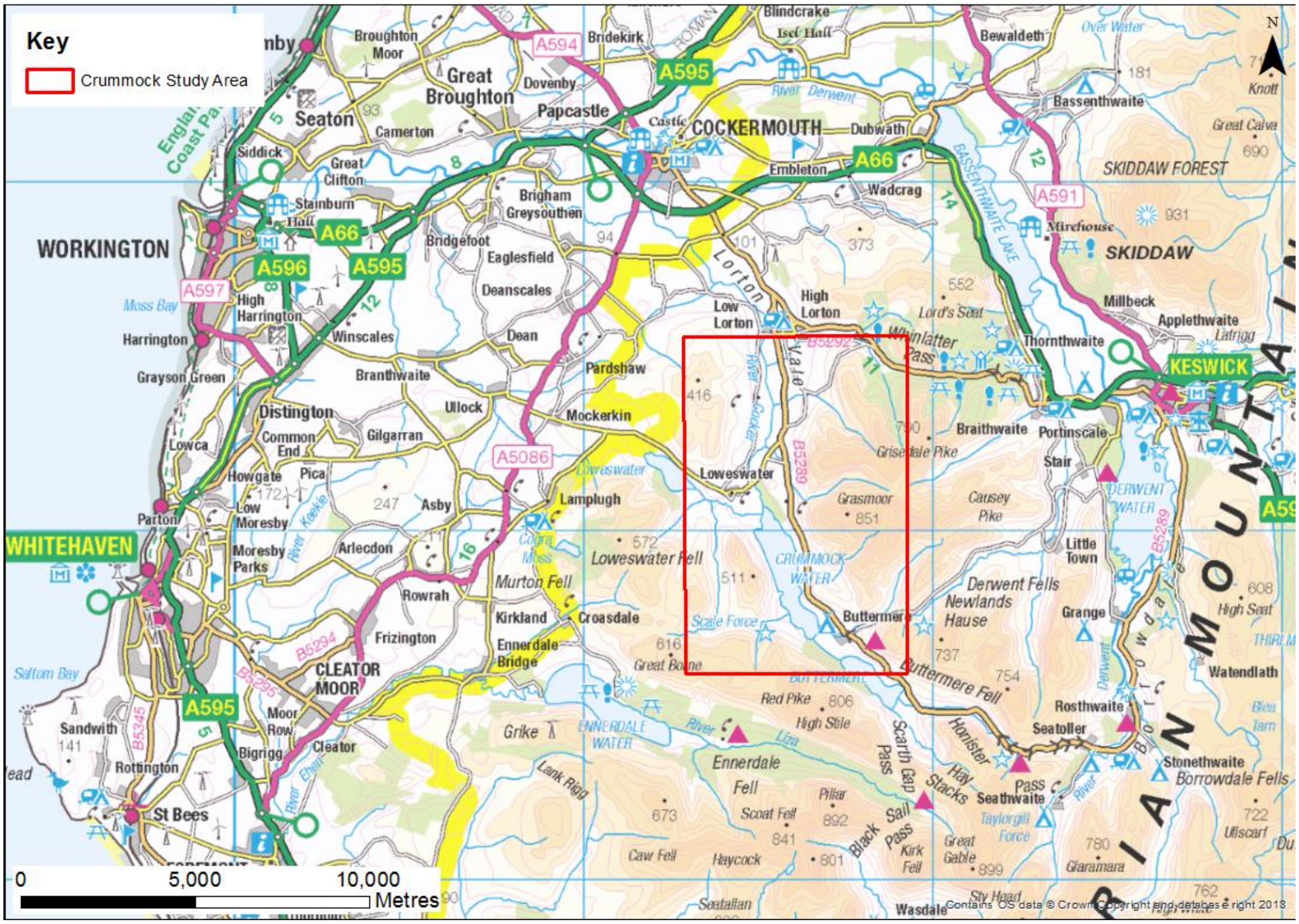

Figure 3-1: Location of Study Area in West Cumbria

The Study Area has been defined as Crummock Water, its tributaries (including Park Beck) and the River Cocker and tributaries. Figure 3-2 shows the extents of the hydrology, hydraulics, geomorphology and ecology assessments.

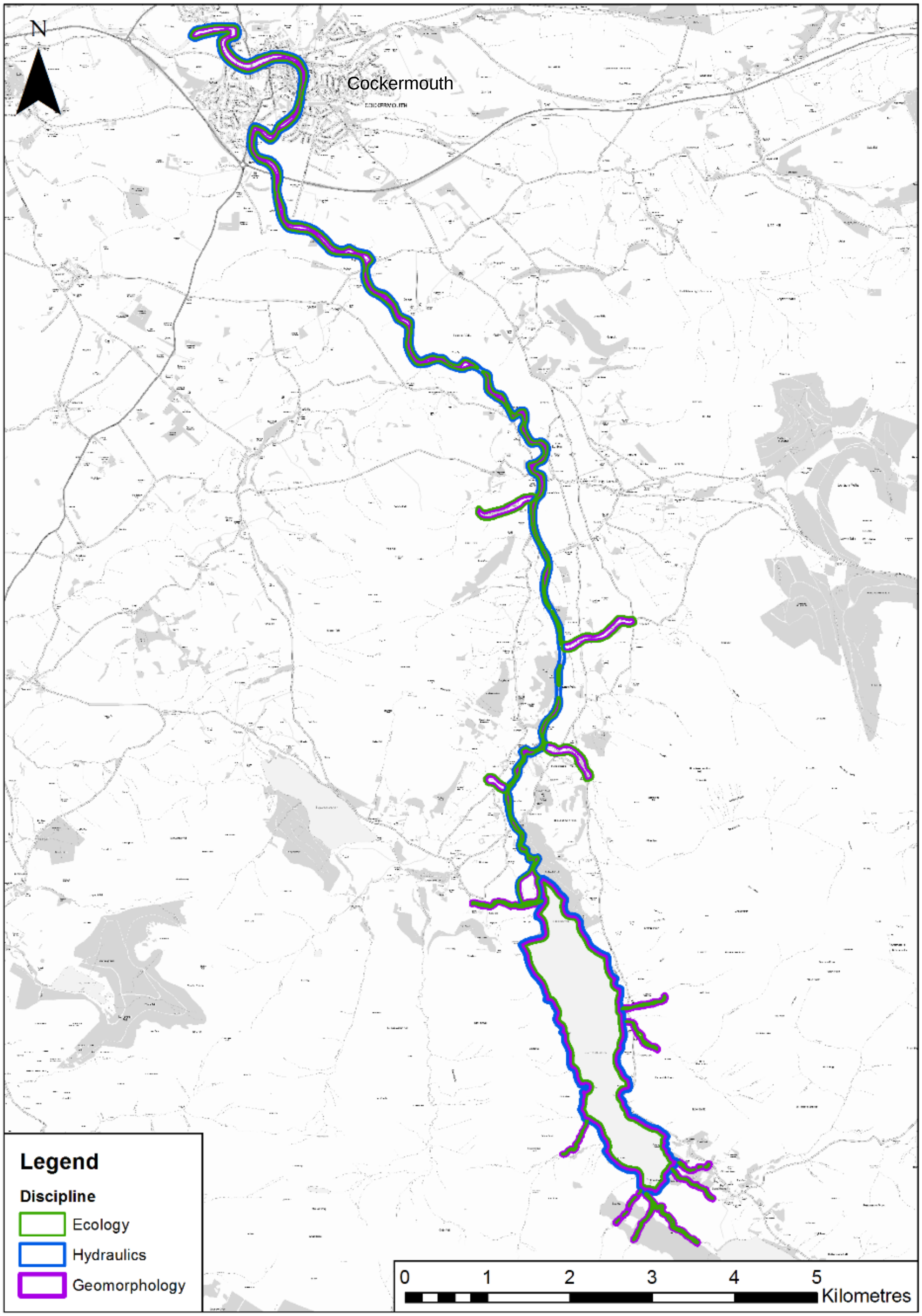

Figure 3-2: Study area of Crummock Water for geomorphology, hydrology and ecology

3.2 Crummock Water abstraction infrastructure

Figure 3-3 illustrates the abstraction infrastructure being considered for removal in this study and the extent of the hydraulics, geomorphology and ecology impact assessments.

The abstraction infrastructure included within the scope of this assessment and shown in Figure 3-3 comprises:

- Crummock Water weir and fish pass;
- water intake pipes in the lake and screens;
- the surrounding wave wall located on the north west shore between Park Beck outlet and the Crummock Water weir; and
- Park Beck (a main river that historically has been artificially straightened).

The raw water pipe running from the pumping station to Cornhow Water Treatment Works was scoped out of the assessment at the end of the Scoping Stage in conjunction with the PSG. This is because it was decided that work to remove the entire pipe was unnecessary. Consideration of this pipe would only need to be given for the Park Beck proposals where natural recovery of the channel through re-meandering could potentially expose the pipe.

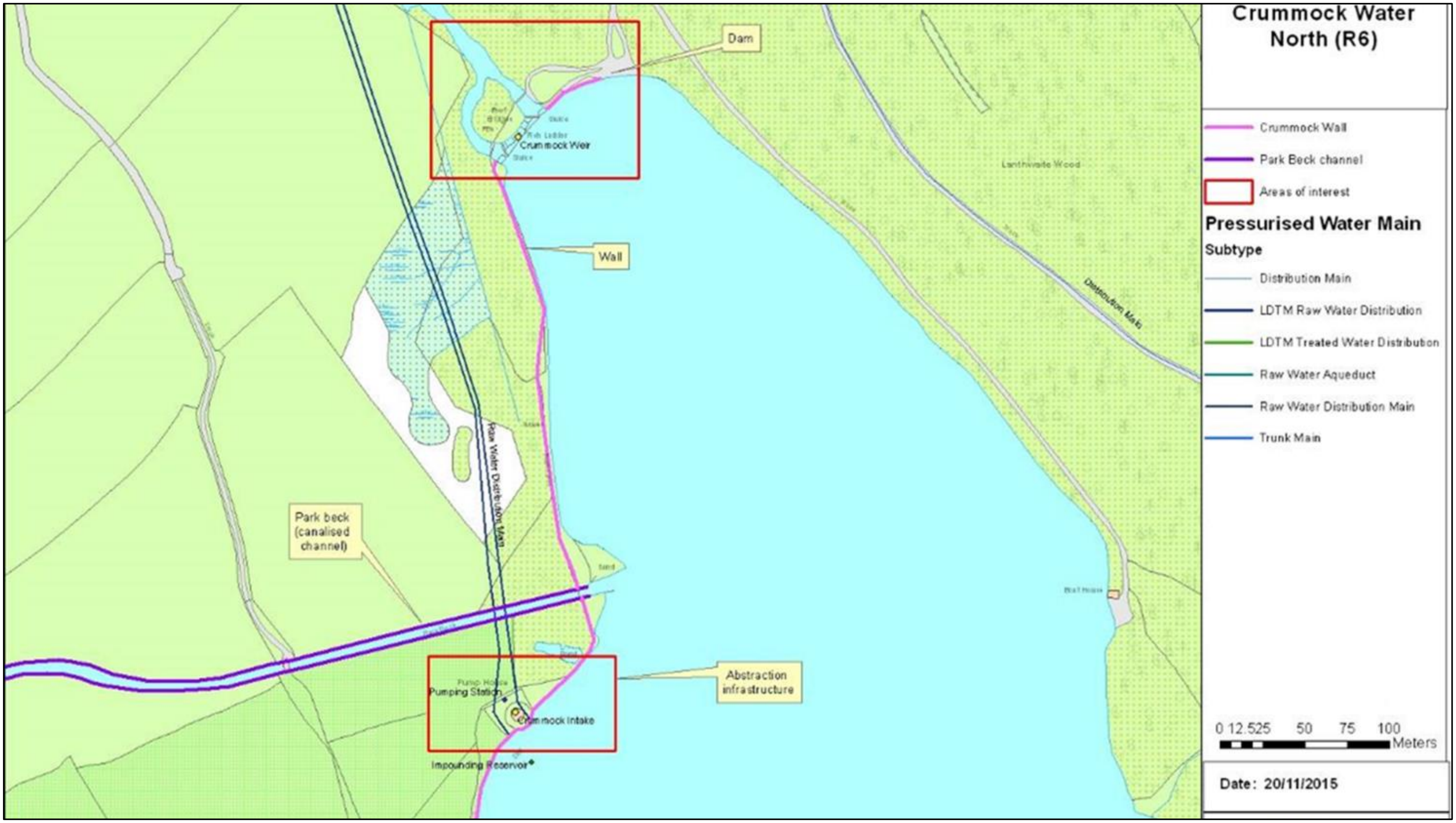

Figure 3-3: Study area of Crummock Water for Engineering, including abstraction infrastructure included within scope

3.3 Overview of the Crummock Water/ River Cocker catchment

Crummock Water was originally a natural lake in a glacial valley which is currently impounded by a low artificial weir. The lake is situated 12km south of Cockermouth and 14km west of Keswick in the Allerdale District of Cumbria (OS grid reference NY 157 191). The lake has a capacity of 3,400,000m^3 (Cranfield University, 2016) and a surface area of 2,510,000m^2 (UU, 2005)[2] when full to its top water level of 98.530mAOD (Cranfield University, 2016).

Crummock Water is fed by overflows from Buttermere and Sail Beck to the south, and Loweswater and Park Beck to the west. There is no control on the inflow entering the lake. At the northern end of the lake, compensation flows pass over a spillway, feeding directly into the River Cocker. The catchment has an area of 64.75km^2 and is upland in character, with mountains, farmland and moorland in the lower areas. The standard average annual rainfall is 2520mm.

The River Cocker flows from the outlet at Crummock Water and is contained in a relatively artificially straightened channel through Lorton Vale for approximately 20km prior to the confluence with the River Derwent at Cockermouth.

Land use within the study area consists primarily of improved pasture with woodlands clustered throughout. Being set within the Lake District National Park, much of the land is unmanaged on moorlands, peat bogs and steep-sided mountains not used for agricultural purposes. There are small settlements within the study area, such as Low Lorton and Buttermere, with the only major urban area, Cockermouth, sited at the downstream limit of the River Cocker catchment, where it joins the Derwent.

Soils throughout most of the study area are freely draining and acidic with a loamy texture underlain by rock. The soils support steep acidic upland pastures and dry heath and moor habitats with some bracken, gorse and oak woodland habitats. The soil drains to the local groundwater and to the local river channel network. For this soil type there is a risk of erosion, particularly during re-seeding of fields (due to farm vehicle movement), and un-metalled roads providing an additional sediment source (Cranfield University, 2016).

In the upland areas, soils are shallow, very acidic and peaty underlain by a layer of rock. This provides habitats in the form of rugged wet heather and grass moor with bare rock and large areas of vegetation habitats also provided in hollows. Overgrazing at this location is known to lead to erosion of the peaty surface, with fine sediment particles delivered to adjacent channels through overland flow. In the downstream reaches, soils are described as freely draining floodplain, acidic with a loamy and clayey texture (BGS, 2019).

Most of the study area is underlain by Ordovician rocks composed of mudstone, siltstone and sandstone with small extents of conglomerate rock. The headwaters of the River Cocker catchment within the study area are composed of igneous intrusions with extents of Ordovician and Silurian felsic rock. Superficial deposits within the river corridor comprise alluvium and alluvial fan deposits made up of clay, silt, sand and gravel. Elsewhere in the study area superficial deposits consist of Devensian till, head deposits and Devensian hummocky glacial deposits (BGS, 2019).

3.4 Historical changes in the Crummock Water and River Cocker catchment

3.4.1 Crummock Water

Crummock Water is a ribbon lake formed during and after the last glaciation. It is suggested that immediately after the last glaciation Buttermere and Crummock Water were joined as one lake. It is said that two lakes subsequently formed due to land erosion and input of sediment from adjoining becks (National Trust, 2019).

According to records now held by UU, the first impoundment of the lake was carried out in 1878 where a timber weir was constructed to aid the abstraction of drinking water, this is demonstrated on the drawing titled “Plan and Weirs of Sluice Board and Fish Pass at Crummock Lake” by Pickering and Crompton dated 1881. It is believed that as part of the first scheme, the lake level was not raised but the flows from the lake were regulated by the formation of the weir to the equivalent natural ground level, the excavation of the outlet channel and the introduction of a sluice. It is understood that the reason for not raising the water level was that the landowners did not want land flooded, this included woodrush islands to the south not being inundated during this stage.

Sometime between 1899 and 1903 a larger masonry impounding weir was constructed which raised lake levels by around 0.6m (2 feet). This weir had two sluice gates and a central stepped fish pass. It is believed that this weir was constructed several meters further into the lake and the subsequent rise in water levels resulted in the need for the construction of the wave wall along the left flank of the lake to prevent flooding of the adjacent fields. The woodrush islands previously noted as not inundated in the 1878 scheme were recorded as inundated at this stage.

In 1968 extensive repairs were made to the weir, however is believed that the height and extent of the weir did not change during these works. This is based upon comparison between drawings showing details of the weir by James P Williamson dated 1965 and details of the repairs on a suite of drawings by Herbert Lapworth Partners dated 1967.

The above stages of modifications to the weir structure have led to a significant volume of water (estimated to be in the region of approximately 1,900,000m^3) being stored above the natural ground level, according to bathymetric data held by UU. The Timeline of events and modifications to lake levels are summarised in Table 3.1.

Table 3.1 Timeline of weir modifications at Crummock Water

Scheme	Date	Weir Elevation	Measured Water Level	Notes
First Scheme Timber weir to keep winter lake level.	1879	97.91m AOD (estimated from drawing of present day weir)	97.96m AOD (June 1895)	Weir is said not to have raised natural winter water level as landowners did not want land flooded, outlet channel excavated and woodrush islands to south not flooded
Second Scheme Masonry Impounding Weir	1899-1903	Assumed 98.52m AOD, as this is the current height of weir and documentation suggests no changes to height have been made since the second scheme)		Larger impounding masonry weir raised lake levels by approximately 2 feet (0.6m). The weir was moved by 2m into the lake and subsequently flooded surrounding land. Woodrush islands to south became flooded.
Herbert Lapworth and Partners Design of Repairs	1967	98.52m AOD		Apparently, these works provided no change to water levels or weir height from the works in 1903.
Third Scheme Repairs to Weir	1969	98.52m AOD		

3.4.2 Park Beck

The earliest historical maps from 1867 depict Park Beck entering the lake approximately 50m to the south of the current location. At this time, Park Beck had already been significantly modified at the downstream length immediately upstream of Crummock Water. It then appears to have been realigned again sometime between 1947 and 1951. Except for this change, there have been no significant changes to the position of the channel.

Upstream of the heavily modified length of Park Beck, the channel appears to have been active but mostly stable.

3.4.3 River Cocker

Apart from some minor lateral adjustments and a meander cut-off occurring approximately 3.5km downstream of Crummock Water, the River Cocker appears to have undergone little change since the first detailed mapping of 1867. Modification to Crummock Water, including installation of a sluice, resulted in a slight modification to the channel immediately downstream of Crummock Water. However, it is apparent from the earliest maps that a significant proportion of the River Cocker has been artificially straightened. During site walkovers, many of the straightened lengths appeared to have embankments (possibly composed of spoil from the channel) and were over deep. These modifications have limited the level of lateral adjustment of the river channel. Site walkovers also revealed several knickpoints alongside the straightened lengths, suggesting that despite the lack of lateral channel adjustment, the channel has not been stable throughout the period and it is evident that there has been downcutting of the bed in some locations. Historical channel change has been observed along one short length of the River Cocker for approximately 220m at the confluence with Hope Beck. Here the secondary channel that Hope Beck currently feeds into was previously the main River Cocker channel. This appears to be an artificial modification that occurred between 1900 and 1970.

3.4.4 Other Tributaries

Approximately 4.5km downstream of Crummock Water, Whit Beck, a tributary of the River Cocker, was channelised and straightened for a length of approximately 500m between 1867 and 1900 immediately upstream of its confluence with the Cocker. Apart from this modification, the Whit Beck is confined within a narrow valley and had not measurably changed its planform since map records first began. More recently a restoration project led by the Environment Agency has caused change. This project involved restoring the lower 350m of straightened channel of the Whit Beck to a more sinuous planform with construction of morphological features including a two-stage channel and side deposits.

More information and a timeline of historical activities from a UU Geotechnical and Geoenvironmental Desk Study Report (United Utilities, 2018) can be viewed in Appendix A.

3.5 Legislation and Policies within the River Cocker Catchment

The Crummock Water / River Cocker Catchment sits within the Lake District National Park, which gained UNESCO World Heritage Status in 2017. Whilst a heritage assessment is not part of the scope of this study, it will need to be considered at EIA stage.

However, there are several other designations within the Crummock Water/ River Cocker Catchment that have been considered throughout this assessment:

3.5.1 Natural Environment and Rural Communities (NERC) Act 2006 (England)

The NERC Act (England) 2006 provides a legal framework to promote biodiversity in England and protect natural areas and wildlife. Section 41 of this act identifies Species and Habitats of Principal Importance in England. These species are those that are considered the rarest and most threatened species in England. For a subset of these species, Priority Actions have been identified to assist in their recovery.

3.5.2 Habitats Directive and Regulations

The whole of Crummock Water and the River Cocker form part of the River Derwent and Bassenthwaite Lake Special Area of Conservation (SAC). This SAC is designated for the following species and habitats (*primary reason for selection of site):

- marsh fritillary butterfly (*Euphydryas* (*Eurodryas, Hypodryas*) *aurinia*) (1065)*;
- sea lamprey (*Petromyzon marinus*) (1095)*;
- brook lamprey (*Lampetra planeri*) (1096)*;
- river lamprey (*Lampetra fluviatilis*) (1099)*;
- Atlantic salmon (*Salmo salar*) (1106)*;
- otter (*Lutra lutra*) (1355)*;
- floating water-plantain (*Luronium natans*) (1831)*;
- oligotrophic to mesotrophic standing waters with vegetation of the *Litorelletea uniflorae* and/or the *Isoëto-Nanojuncetea* (3130)*; and

- watercourses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation (3260); rivers with floating vegetation often dominated by water-crowfoot).

The Lake District High Fells SAC also forms part of the study area to the east of Crummock Water. This SAC is designated for oligotrophic to mesotrophic standing waters with vegetation of the *Litorelletea uniflorae* and/or the *Isoëto-Nanojuncetea* (3130) as well as a range of heaths, grasslands and bogs.

3.5.3 Wildlife and Countryside Act (1981), Section 28

Crummock Water and the River Cocker are both designated as a Site of Special Scientific Interest (SSSI). The 'River Derwent and Tributaries' has 29 live units of which 55% are classed as 'unfavourable – no change', 21% are 'unfavourable – recovering', 24% are 'favourable' and less than 1% are classed as 'unfavourable – declining'. The SSSI is notified for the following species and habitats:

- Atlantic salmon (*Salmo salar*);
- brook lamprey (*Lampetra planeri*);
- river lamprey (*Lampetra fluviatilis*);
- sea lamprey (*Petromyzon marinus*);
- otter (*Lutra lutra*);
- breeding population of nationally rare fish species – Vendace (*Coregonus albula*);
- ecotypic or genetically distinctive fish populations – Arctic charr (*Salvelinus alpinus*);
- Invertebrate assemblage;
- M23 – *Juncus effusus/acutiflorus – Gallium palustre* rush pasture;
- M27 – *Filipendula ulmaria – Angelica sylvestris* mire;
- M6 – *Carex echinata – Sphagnum recurves (fallax)/ auriculatum (denticulatum)* mire;
- Population of Schedule 8 plant – *Luronium natans*, floating water-plantain;
- W1 – *Salix cinerea – Gallium palustre* woodland;
- W7 – *Alnus glutinosa – Fraxinus excelsior – Lysimachia nemorum* woodland; and
- Floating waters – Type VIII: rivers common throughout western Britain over hard rocks.

3.5.4 Natura 2000 Site Improvement Plan

There is a Natura 2000 Site Improvement Plan (SIP) in place for the 'River Derwent and Bassenthwaite Lake' and the 'Lake District High Fells' which tackles several issues identified within the catchment which could impact on the notable features of the SACs. These include water pollution, siltation, invasive species, change in woodland management and hydrological changes.

3.5.5 Water Framework Directive (WFD)

The study area encompasses five WFD water bodies: two fluvial water bodies upstream of Crummock Water and two fluvial water bodies downstream (Table 3.2) and one lake water body (Table 3.3).

Table 3.2 : WFD river water body information for the Crummock Water study area based on 2016 Cycle 2 data (Environment Agency, 2019)

Category	Description			
Water Body Name	Dub (Park) Beck	Cocker - Crummock Water and Buttermere	Cocker – Crummock Water to conf Whit Beck	Cocker – conf Whit Beck to conf Derwent
Type	River	River	River	River
Water Body ID	GB112075070360	GB112075070350	GB112075070370	GB112075070400
Hydromorphological Designation	Not A/HMWB	HMWB	HMWB	HMWB
Water Body Length	13.03km	24.01km	4.96km	17.91km
Catchment Area	21.84km^2	40.75km^2	15.76km^2	41.96km^2
Overall Water Body Status/Potential	Good	Moderate	Moderate	Moderate
Biological Quality Elements				
Fish	High	High	Moderate	Good
Invertebrates	Good	Good	High	High
Macrophytes and Phytobenthos Combined	Good	High	Good	Good
Hydromorphological Supporting Elements				
Hydrological Regime	High	No data	No data	Supports Good
Morphology	Supports Good	No data	No data	No data
Physico-chemical Quality Elements				
Ammonia	High	High	High	High
Dissolved Oxygen	High	High	High	High
pH	High	High	High	High
Phosphate	High	High	High	High
Temperature	High	High	High	High
Supporting Elements				
Mitigation Measures Assessment	Not assessed	Moderate or less	Moderate or less	Moderate or less

Table 3.3: WFD lake water body information for the Crummock Water study area (Environment Agency, 2019)

Category	Description
Water Body Name	Crummock Water
Type	Lake
Water Body ID	GB31229000
Hydromorphological Designation	HMWB
Water Body Length	N/A
Catchment Area	2.5km^2
Overall Water Body Status	Moderate
Biological Quality Elements	
Chironomids	High
Littoral Invertebrates	High
Macrophytes and Phytobenthos Combined	Good
Phytoplankton	High
Hydromorphological Supporting Elements	
Hydrological Regime	No data
Physico-chemical Quality Elements	
Acid Neutralising Capacity	High
Ammonia	High
Dissolved Oxygen	High
Salinity	High
Total Phosphate	Good
Supporting Elements	
Mitigation Measures Assessment	Moderate or less

4. Baseline Assessments

Comprehensive baseline assessments have been undertaken by engineering, hydrology, hydraulics, geomorphology and ecology disciplines focusing on discipline specific observations from site visits and desk studies. These were undertaken between 2015 and 2017 and identified initial risks and opportunities. Each baseline assessment also identified which assessment criteria would be used in the options appraisal assessment, the next step in the assessment.

The Multi Criteria Assessment (MCA) (see Section 5 of this report) includes a description of potential positive and negative impacts removing abstraction infrastructure could have within the study area. To understand these impacts, it is necessary to compare them with baseline conditions. For the purposes of this study, baseline has been identified as the current day environment, except for the hydraulics baseline, which assumes a future scenario without abstraction of water from Crummock Water, as defined in this section of the report.

4.1 Engineering Baseline

This section of the report provides an overview of the main findings from the preliminary engineering investigations at the Crummock Water abstraction infrastructure (Figure 3-3). The engineering baseline study was carried out using site specific information provided by United Utilities, site visits and desk studies by civil engineers with an extensive background of engineering in fluvial systems.

4.1.1 Criteria forming the engineering baseline assessment

For each element of existing infrastructure noted in Section 3.2, the engineering baseline assessment includes a commentary on seven criteria used in the multi-criteria assessment (Table 4.1). These have been identified in the scoping study.

Table 4.1: Multi-criteria assessment performance criteria

Multi-criteria assessment performance criteria	Assessment methodology for high level assessment
Legislative requirements (Reservoirs Act, licensing)	Determine whether the option is governed by legislative requirements that would influence the cost and ease of implementation.
Health and Safety (preparation, demolition, construction)	Determine relative health and safety risk of option assuming industry standard methods of working. Review of principal construction hazards and ease of mitigation.
Buildability (access, temporary works)	Review OS plans, topographic survey and site visit to assess physical access constraints. Use option descriptions and as-built drawings (where available) to assess complexity of option implementation (scale, construction features, and hazards).
Technical merit (engineering performance)	Decide on short and long-term effectiveness of option in achieving desired engineering outcome. Assess complexity of engineering design (if required).
Impact on adjacent infrastructure	Determine short and long-term impact on neighbouring infrastructure (walls, structures, footpaths, fence lines etc.). Review OS plans, topographic survey and site visit to identify impacted features required.
Cost	Engineering judgement to assess the relative capital and design costs of each high-level option.
Maintenance and operation (short, medium, long-term)	Engineering judgement of short, medium and long-term operation and maintenance implications.

4.1.2 Description of infrastructure

4.1.2.1 Crummock Water weir and fish pass

The weir runs east-west, facing north and is approximately 59.3m long, with a maximum height of 1.14m. At the centre of the weir, an island on the downstream side splits the river channel into two. A concrete fish pass has been constructed at the centre of the weir.

There is access to the eastern end of the weir by an unsurfaced hard track from an unclassified road to Loweswater Village from the B5298. Access to the western end of the weir is possible via a farm track and across adjacent farmland. Vehicular access to the centre of the weir is possible only by fording the river channels. Pedestrian access to the weir over the River Cocker can be achieved via timber footbridges. The lake and surrounding land are owned by the National Trust with provision of public access.

Crummock Water is classified as a 'Category A' reservoir under the ICE Floods and Reservoir Safety Guidance. This classification is given to dams where a breach would endanger lives in a downstream community.

The main features of the weir and lake and summarised in Table 4.2 below.

Table 4.2 : Main Features of Crummock Water

Grid Reference	NY 157 191
Type of dam	Concrete/masonry weir
Capacity	3,400,000 m^3
Maximum height	1.14 m
Crest length	59.3 m
Crest level	Weir level 98.50mAOD, fish notch 98.30mAOD
Overflow	Broad-crested weir
Freeboard	N/A
Drawdown	Two timber penstocks, built into weir structure

The weir is made of concrete with a crest level of approximately 98.50m AOD (approx. height of 0.5m above ground/silt on upstream side) and a crest length of 59.3m. There is no embankment other than the weir. The most recent inspection report and construction drawings dated 1967 for repair work to the weir, suggest that the weir was first constructed in concrete in 1878 and raised to its present level using concrete and masonry in 1900. The original level of the weir is not known.

At the centre of the weir is a shallow 'V' notch with a minimum invert level of 98.30m AOD. This forms the inlet to a fish pass and controls water levels (Figure 4-1). A small stilling pond is located downstream of the 'V' notch from which water flows towards the western and eastern channels of the River Cocker around the island at this point. Eel tiles and passes (not pictured) have since been added to the structure to improve migratory passage for European eels.

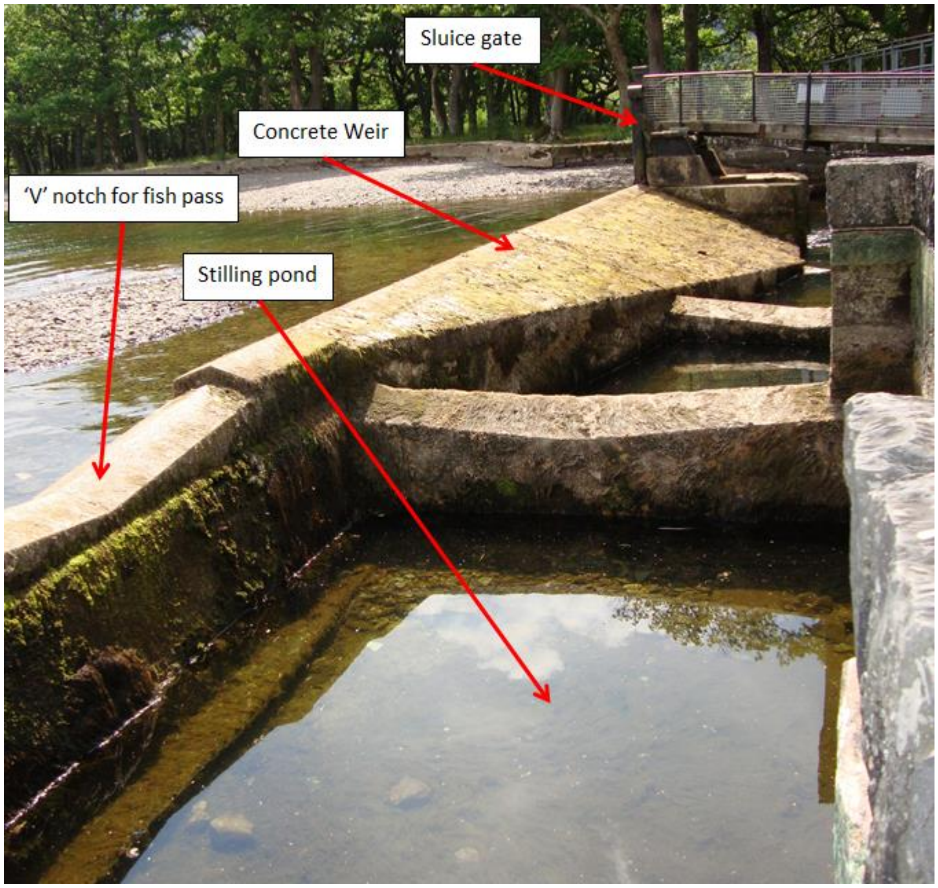

Figure 4-1: Weir and fish pass

The existing drawdown facility for the lake consists of two manually controlled sluice gates, located either side of the fish pass feeding into two identical drawdown channels. Both channels are 2.5m long and taper from 1m wide at the upstream end to 2m wide at the downstream end. The sluice gates (Figure 4-2) can be raised manually to give an opening height of approximately 1m (no telemetry was evident on site) and access to each sluice gate is via metal footbridges with locked gates. Condition of the bridges suggests that these have been recently replaced.

Figure 4-2: Sluice Gate

Either side of the sluice gates, the downstream apron of the weir is formed from irregular, hand placed pitching stone protecting the channel from potential scour and assisting with dissipation of energy in the flow before it enters the River Cocker (**Error! Reference source not found.**).

To the left of the weir, the top of the wall is 550mm above the weir crest (United Utilities, 2016). The wall to the right-hand side of the weir is 470mm above the weir crest, with a length of approximately 15m. The wall on the right sits at a lower level than the left-hand side and therefore acts as an auxiliary overflow (

Figure 4-3). When this wall is overtopped, water enters a concrete overflow channel directing flow to the eastern arm of the River Cocker via a small stepped masonry channel.

Overall, the weir and ancillary structures appeared to be well-maintained and in good condition and visited by the appointed supervising Engineer and at the defined Inspections period defined under the Reservoirs Act 1975.

All elevations and distances quoted have been referenced from the available reports and the topographic surveys.

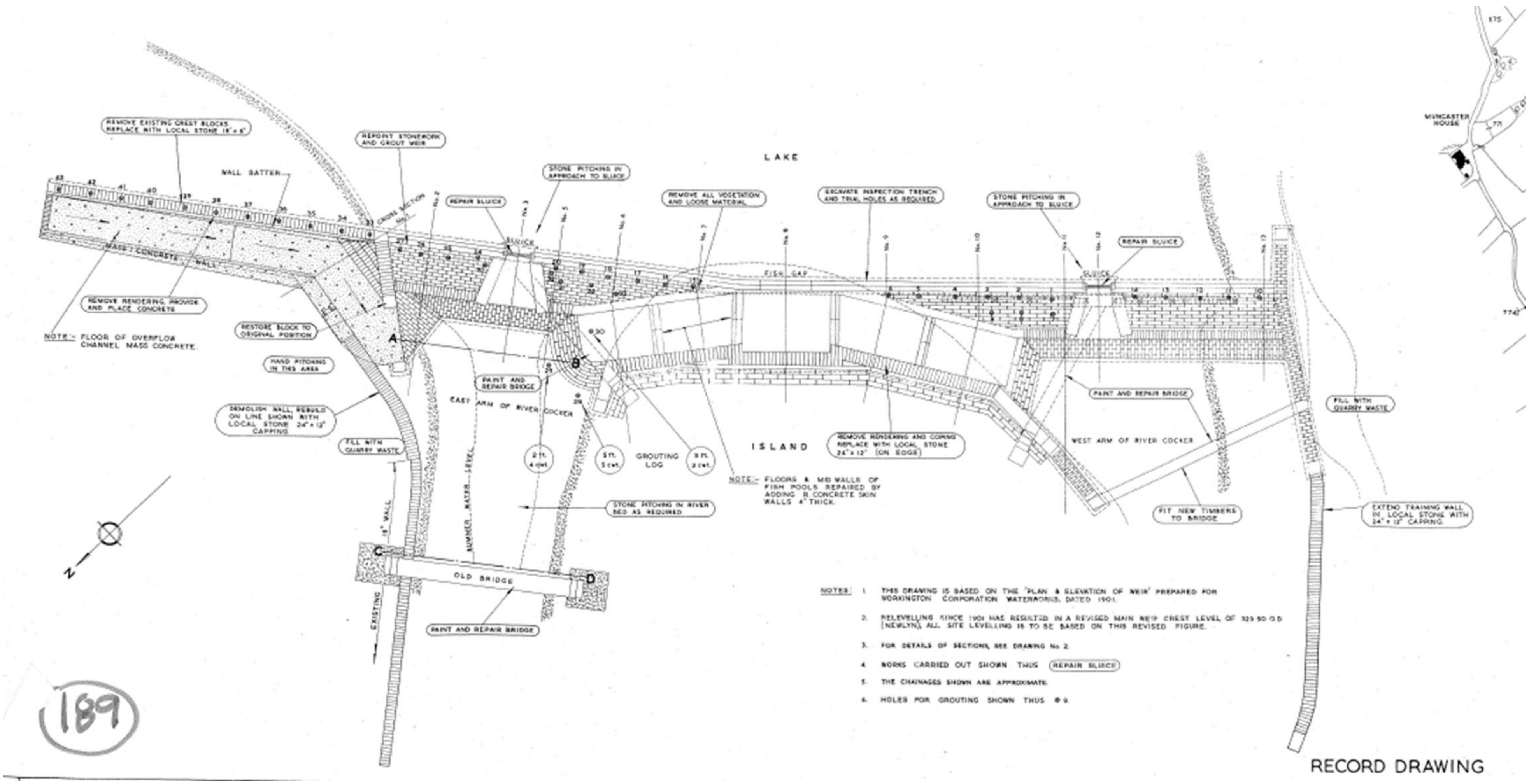

Figure 4-3 Weir general plan drawing: (provided by United Utilities from West Cumberland Water Board, October 1967, Repairs to Crummock Water Weir, Herbert Lapworth Partners)

Figure 4-3: Overflow channel

A masonry wall is located either side of the central island, downstream of the sluice gates, the purpose of which is unknown (Figure 4-4). Both walls have four pairs of stop log grooves allowing for flow control for operational or maintenance purposes.

Approximately 25m downstream of the weir, the western channel bends by roughly 45 degrees (towards the right bank) joins the eastern channel of the River Cocker.

Figure 4-4: Masonry Walls

A public footpath runs along the bank of Crummock Water and is carried by two timber footbridges, allowing pedestrian access across the two channels around the island on the River Cocker.

4.1.2.2 Water intake pipes in the lake and screens

Water is abstracted from Crummock Water via two 30m long abstraction intakes (610mm and 760mm diameter). The intakes are situated on the lake bed and protected by a fish screen. Abstracted water passes through to an octagonal stone abstraction house located 350m south of the spillway on the west shore of the lake. From here water flows to Cornhow Water Treatment Works, approximately 1.6km to the north. The route of the raw water mains can be seen crossing Park Beck in Figure 3-3. The edge of the lake upstream of the abstraction house is formed from a gently sloping masonry revetment.

When Crummock Water weir was constructed in 1878, an intake was located on the east bank of the lake. It is unknown whether the first intake was decommissioned or infilled.

4.1.2.3 Adjacent wall between Park Beck outlet and the Crummock Water weir

A 300m long concrete wave wall running along the west shore of the lake between the weir and the pump house is in good condition, with minor signs of weathering and spalling concrete evident (Figure 4-6). The wall is approximately 0.45m wide, 0.5m high above the natural ground level and ties into the retaining wall on the left-hand side of the weir. The level of the wall at this point is approximately 0.55m above the weir crest. The depth of the wall below the ground level is unknown.

Historical drawings suggest that this wave wall could have been constructed in the late 1900s following a period of bank erosion.

Figure 4-6: Length of adjacent wall

4.1.2.4 Park Beck

Park Beck joins Crummock Water from the west, approximately 270m south of the weir (Figure 3-3). Hard engineering of the channel is apparent along approximately 350m of the channel immediately upstream of Crummock Water (

Figure **4-**7). Along this length the channel has been straightened, with a concrete lining along the full length of the left bank and a concrete and masonry lining along the right bank as illustrated in Figure 4-8. The upstream channel appears to be in a good condition, whilst the downstream end of the channel is overgrown and poorly maintained.

Two single span bridges cross Park Beck, one providing vehicular access to farms approximately 200m upstream of Crummock Water and the other providing pedestrian access across Park Beck approximately 10m upstream of Crummock Water.

Figure 4-7: Park Beck facing downstream to Crummock Water

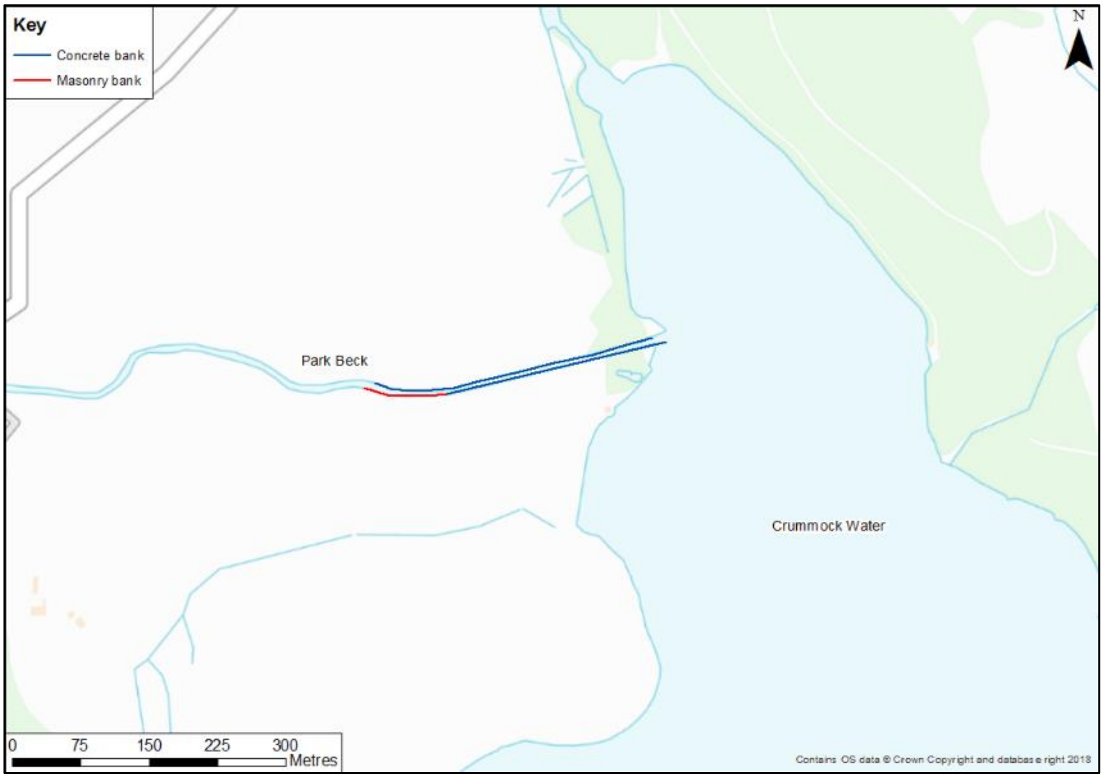

Figure 4-8: Park Beck bank engineering (bank lining marked in blue (concrete) and red (masonry))

4.1.3 Findings of Structural and Geotechnical Studies

A summary of findings of the structure and geotechnical studies relating to the engineering baseline assessment are shown below in Table 4.3.

Table 4.3: Findings of Structural and geotechnical studies

Area	Findings
Crummock Water weir and fish pass	The weir and associated ancillary structures are well-maintained and generally in good condition. A small amount of debris was identified behind the two sluice gates. As Crummock Water is a statutory reservoir, a Supervising Engineers Report (Dixon, 2016) covers structures related to the reservoir, i.e. dam structure, training (wave) wall, draw-off works. There were no recommended actions in the interests of safety to be undertaken. Minor defects related to holes to stonework in the dam walls, were still to be completed, when conditions allow. The Ground investigation (Geotechnics, 2018) carried out in September has shown a cohesive clay substrate is located close to the weir and fish pass structures. This cohesive clay material would assist with formation of the new re-naturalised outlet channels of the River Cocker.
Water intake pipes and lake screens	Through discussions with United Utilities the approximate depth of the pipework below ground level is believed to be in the region of 5.5m.
Adjacent wall between Park Beck outlet and Crummock Water weir	It is understood that no as-built drawings or structural condition reports of the existing wall at Crummock Water and the walls along Park Beck channel exist. Therefore, no comment on the structural integrity can be made. The walls on the northwestern shore of Crummock and the walls of Park Beck, however, were noted to locally be in a poor state of repair with minor defects. There has been a lot of surface weathering of the concrete joints and top stone work but overall the walls appear straight with no sign of deflection along their length.
Park Beck	No information about the presence of contaminants in the study area is currently available. Further information on soil composition is discussed in 4.3.2.2.

4.1.4 Engineering opportunities and constraints for abstraction infrastructure

Opportunities and constraints of the baseline environment are noted against Multi-Criteria Assessment parameters in Table 4.4 for each piece of abstraction infrastructure.

Of the services information received, no other buried infrastructure or overhead services other than that described in 4.1.2.2 could be seen.

Table 4.4 Baseline assessment of Multi-Criteria Assessment (MCA) criteria for each piece of abstraction infrastructure

MCA criteria	Crummock Water weir and fish pass	Water intake pipes and lake screens	Surrounding wave wall	Park Beck
Legislative requirements (Reservoirs Act, licensing)	Crummock Water is classed as a large raised reservoir under the Reservoirs Act. As a result, the Environment Agency must be notified of any modifications or discontinuance of large raised reservoirs under the Act. The Act requires the undertaker to employ a Construction Engineer to design and supervise the alteration. As mentioned in Section 4.1.4, under the Act the reservoir has a stringent maintenance regime.	The abstraction license from Crummock Water is being revoked in 2021 and is a main driver for this study.	Works to the wall are not considered to compromise reservoir safety and so will not need to be considered under the Act, subject to agreement with the Reservoir Inspecting Engineer.	Park Beck is not part of the reservoir therefore works to Park Beck will not need to be considered under the Act. Any works to a Main River would require an Environmental Permit.
Health and Safety (preparation, demolition, construction)	The dam and fish pass form an impounding structure and associated spillway and thus any works would need to make sure that as a minimum the baseflow from the Crummock Water into the River Cocker is maintained during the works. Given the large catchment that feeds the reservoir and that the inflows into the reservoir are not controlled, provision will need to be in place for flood events. The lake is owned by the National Trust and is a popular walking destination for the public. A public footpath crosses the footbridges immediately downstream of the weir outlet. Temporary footpath diversions and safety fencing could be needed to prevent conflict with site activities and make sure the safety of the public during the works.	The upstream end of the pipework is within the reservoir, so drawdown would be required to seal the upstream end. If not possible then the pipework could be sealed by mechanical means in the abstraction house. However, the upstream end in the reservoir could be needed to be sealed by divers.	The wall currently acts as a wave wall. The reservoir would need to be drawn down prior to its removal.	The condition of the channel walls could not be determined due to the overgrown vegetation. Any works to the channel would require working near or in water; the flood risk would also need to be considered.

MCA criteria	Crummock Water weir and fish pass	Water intake pipes and lake screens	Surrounding wave wall	Park Beck
Buildability (access, temporary works)	Access to the east end of the weir can be obtained from the B5289 via an unsurfaced hard track which leads to the reservoir, approximately 45m east of the weir structure. The track is a popular walking route used by the public. Whilst the track is wide enough to provide one-way vehicular access, other constraints exist. The western edge of the track is bounded by a steep slope which falls to the river, whilst the opposite edge steeply rises to the north east. Both boundaries are covered in mature trees and vegetation. This means that weight and height restrictions could apply to any plant movement along this track. No formal access is available to western end of the weir, with access only possible via a farm track and across farmland. Vehicular access to the island is possible only by fording the river channels or traversing the upstream shoreline following drawdown of the reservoir. Pedestrian access across the River Cocker is currently provided by two footbridges. Access for plant during construction would therefore be difficult to achieve without disruption to pedestrians and landowners or without the removal of trees and vegetation. No overhead services were identified during the site visit.	Following drawing down of the reservoir, if exposed the upstream end of the pipe work would need to be sealed. If not possible sealing by mechanical means within the abstraction house could be required...	Works to the wall would not compromise reservoir safety and so would not need to be considered under the Reservoirs Act 1975, subject to agreement with the Reservoir Inspecting Engineer.	Park Beck can be accessed via a farm track and adjacent farmland. A single span concrete bridge allows access to both the right and left banks. It is unlikely that this single span bridge is suitable for use by construction traffic.
Technical merit (engineering performance)	The weir currently acts as a retaining structure, maintaining the water levels within the reservoir. As has been noted previously, the reservoir is classed as a large raised reservoir under the Reservoirs Act 1975 and any works to modify the structure must be permitted by the Reservoir Inspecting Engineer.	The pipework currently supplies the nearby works. As this would no longer be required then the pipes would be redundant. There would be no benefit in removing the full length of this pipework due to the costs involved.	The wall currently acts as a wave wall. The reservoir would need to be drawn down prior to its removal and its removal permitted by the Reservoir Inspecting Engineer.	Park Beck is a main river flowing into Crummock Water.
Impact on adjacent infrastructure	There is no immediate infrastructure near the weir. A public footpath around Crummock Water is a popular walking route passing close to the weir. This would need to be temporarily diverted during any works.	There is no adjacent infrastructure that could be affected by abandonment of these pipes.	Access to the wall is along a farm track and the adjacent fields or alternatively by the shoreline following drawdown.	There is no anticipated impact on the adjacent infrastructure as the current abstraction pipework is of believed to

MCA criteria	Crummock Water weir and fish pass	Water intake pipes and lake screens	Surrounding wave wall	Park Beck
			The wall forms the interface between the reservoir and the public footpath that runs around the perimeter of the reservoir.	be of sufficient depth not to be affected by the works.
Cost	An assessment of high-level costs for this option has been undertaken and can be found in Appendix J. Costs are initially estimated to be between £1,138k and £1,213k.			
Maintenance and operation (short, medium, long-term)	The reservoir volume exceeds 25,000m^3 hence the Reservoirs Act 1975 applies. This requires the reservoir to be inspected annually by a Supervising Engineer and a minimum of once every ten years by an Inspecting Engineer. Any recommendations made by the Inspecting Engineer place legal obligations on United Utilities (the undertaker) to make sure that they are carried out within the required timescale. The reservoir therefore has a stringent maintenance regime. It is understood that the sluice gates operate satisfactorily and are opened regularly to control discharge downstream. The reservoir drawdown facility consists of two sluice gates with an invert level of 97.15mAOD, which can be raised by 1m. If there is no inflow to the reservoir, the sluice gates could draw the reservoir down to a level of 97.15mAOD in around seven days. When the base inflow into the reservoir is considered, the reservoir can only be drawn down 0.6m to a level of 97.79mAOD. At this level the baseflow equals the drawdown flow. It would take 10 to 11 days to reach this depth[1].	The pipework would be abandoned as part of the works so this removes the Maintenance and Operation requirements.	No current operational or maintenance procedures in place.	There is no known operational and maintenance regime other than adhoc repairs along the stone masonry length and sediment management to reshape the deposit at the confluence with Crummock Water.

[1] United Utilities, September 2016, Asset Management Report

4.2 Hydrological and hydraulic baseline

Hydrological and hydraulics assessments have been undertaken to determine the baseline (and later the design) situations for the normal flow range, including low flows (see hydrological assessment in Appendix B) and flood risk (see hydraulics assessment in Appendix C).

4.2.1 Criteria forming the hydrological and hydraulics assessment

The following assessment criteria have been used in the multi-criteria assessment (Table 4.5). These have been identified in the scoping study.

Table 4.5: Multi-criteria assessment performance criteria

Multi-criteria assessment performance criteria	Definition
Impact on peak flood levels (See 4.2.3 and Appendix C)	Assessment into the risk/likelihood of current and future peak flood levels changes for a range of event magnitudes.
Impact on flood frequency (See 4.2.3 and Appendix C)	Assessment into the risk/likelihood of current and future flood frequency changes for a range of event magnitudes.
Impact on low flow regime (See 4.2.2 and Appendix B)	Assessment into the risk/likelihood of a change occurring from the baseline normal flow regime which includes low flows.

4.2.2 Hydrological baseline

A hydrological analysis into the baseline (and potential) outflow regime has been undertaken for this study, the detail of which is presented in Appendix B.

The baseline study concluded that the natural flow regime of the River Cocker at the outflow from Crummock Water has to some extent been altered by the artificial management of the lake. The impact, to varying degrees, will have been caused by:

i) water abstracted from the lake,

ii) the artificial outflow arrangement (the weir which has effectively raised the lake artificially as a result of the impoundment); and

iii) the provision of a compensation flow to maintain downstream low flows during dry periods.

In the baseline situation, compensation flow arrangements make sure that there is always some flow in the River Cocker and they therefore provide a buffer in dry conditions. It should be noted that following removal of infrastructure, the River Cocker would be subject to a natural hydrological regime and there would be no requirement or ability to release compensation flow or manage flows in the river. This could leave the potential for periods of very low flow or dry periods. Despite this, the PSG issued a statement in January 2018, signed by the Environment Agency and Natural England which stated that they fully support the removal of Crummock Water weir and that the benefits of restoring natural processes outweighed any potential negative impacts (See PSG Statement in Appendix F).

Appendix B summarises the hydrological analysis incorporating factors listed above in the long-term time-series simulation of the behaviour of the lake-outflow system and includes simulations of future scenarios with and without abstraction, compensation flow and the presence of the weir. Results of this study suggested that full infrastructure removal would be a suitable option to take forward to further investigation.

4.2.3 Hydraulic baseline

To define the existing and design flood risk for the study area, a hydrodynamic model of Park Beck, Crummock Water and the River Cocker has been constructed with the extent shown in Figure 4-9

Figure 4-9. Information on the development of the hydraulic model (which has also been used later in the in the assessment to determine changes to flood risk in the design scenario) can be found in Appendix C.

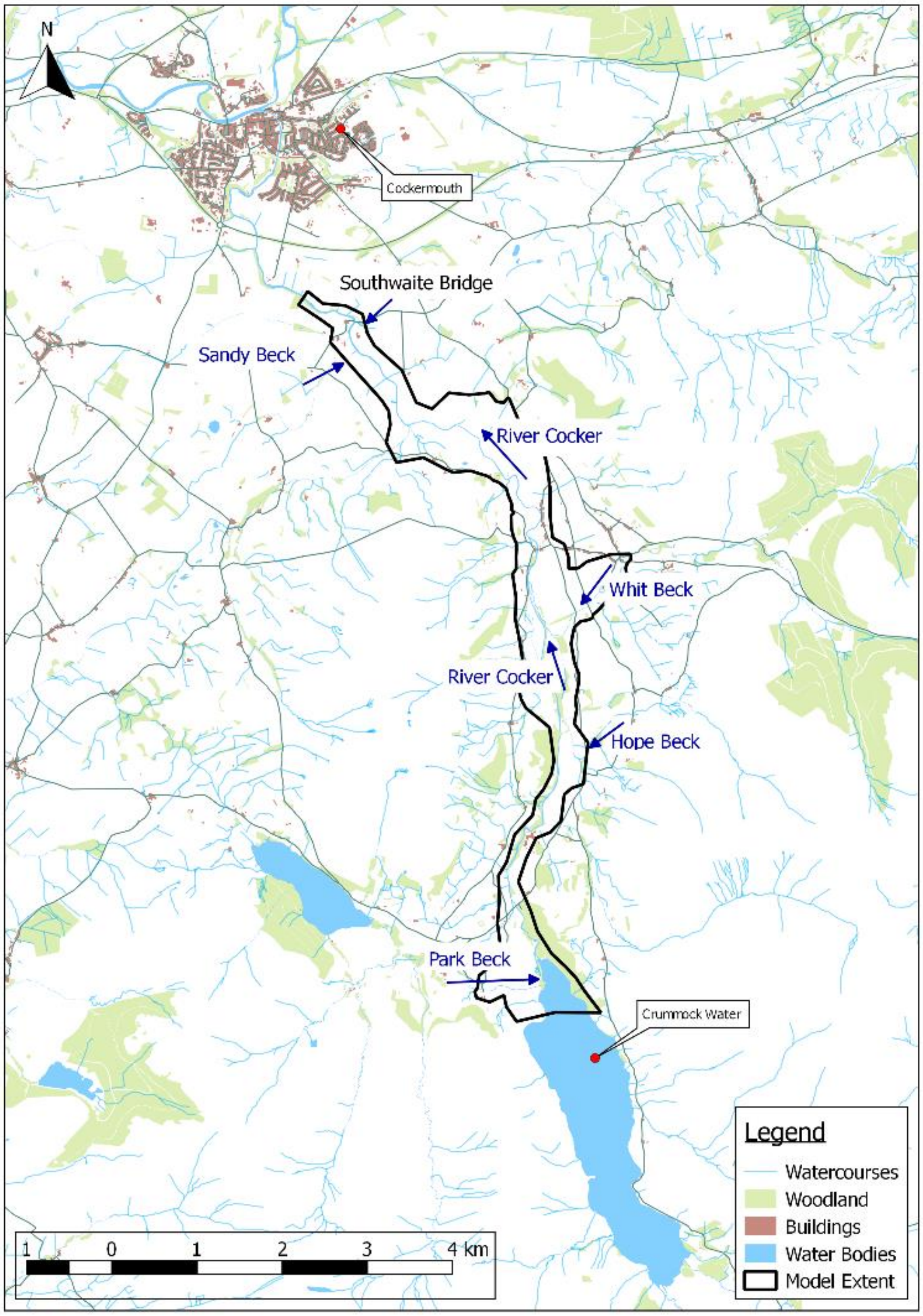

Figure 4-9: Hydraulic Model extent

The hydraulic model has been run for 50%, 20%, 10%, 3.33%, 2%, 1.33%, 1% and 0.5% AEP (Annual Exceedance Probability) flood events as well as the 1% AEP plus Climate Change[2] event. The maximum flood extents for the baseline 50%, 10% and 1% AEP flood events are shown in Figure 4-10.

[2] 25% uplift was used to account for Climate Change for the 1% AEP Event

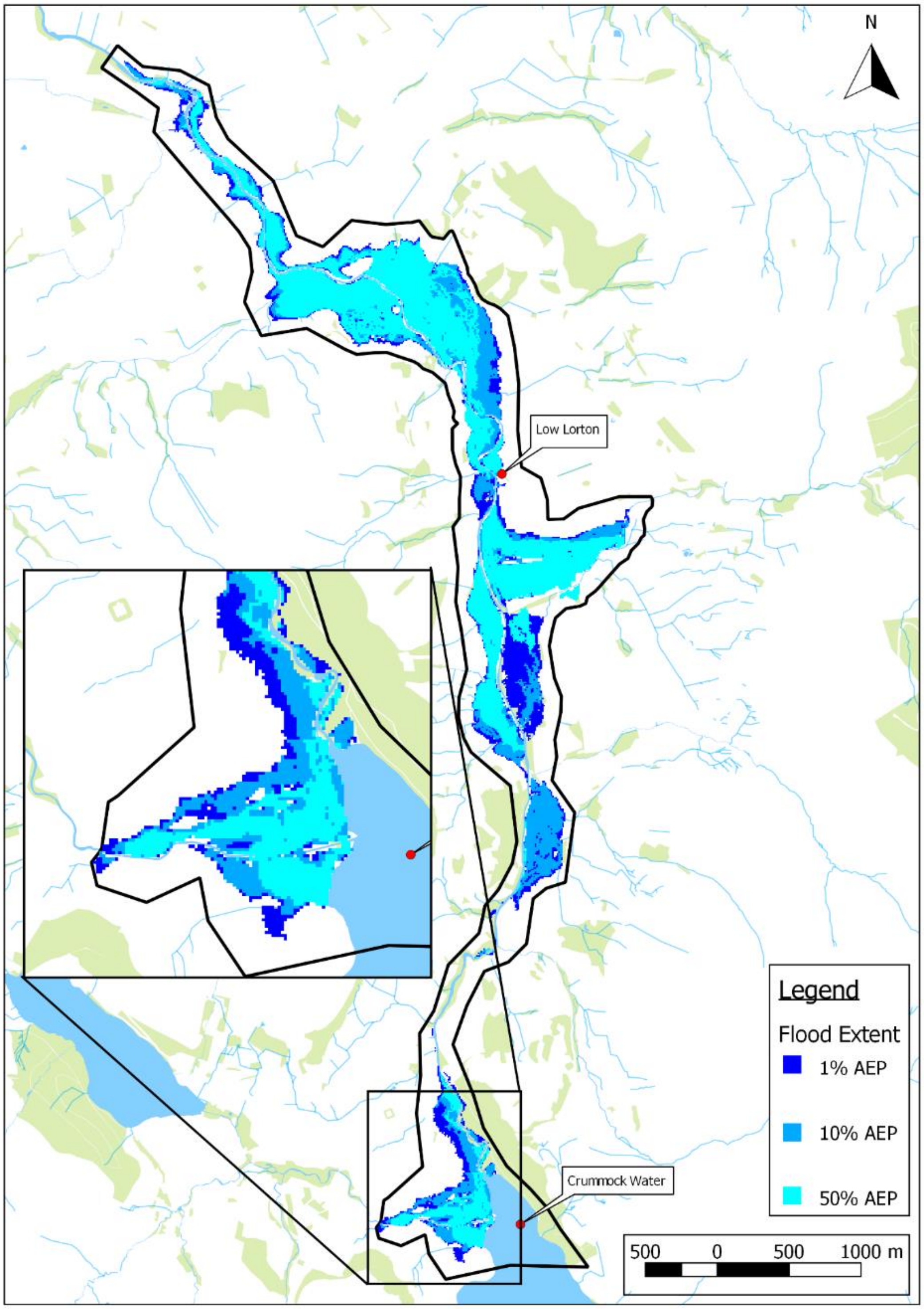

Figure 4-10: Baseline hydraulic flood model results

The model results show significant flooding within the functional floodplain. Flow overtops the banks along Park Beck, Whit Beck and parts of the River Cocker in the 50% AEP event and in many areas flood extents are similar between events. The key receptors are mostly located at Low Lorton where the onset of flooding occurs between a 1.33% AEP and 1% AEP event.

Figure 4-11 shows the flood mechanism for Park Beck. The onset of flooding from Park Beck happens at a flow of approximately 14 m^3/s and is greater along the left bank. Flood water from the left bank flows downhill towards Crummock Water but is then re-directed downstream when it reaches the wave wall running adjacent to the north west bank of Crummock Water.

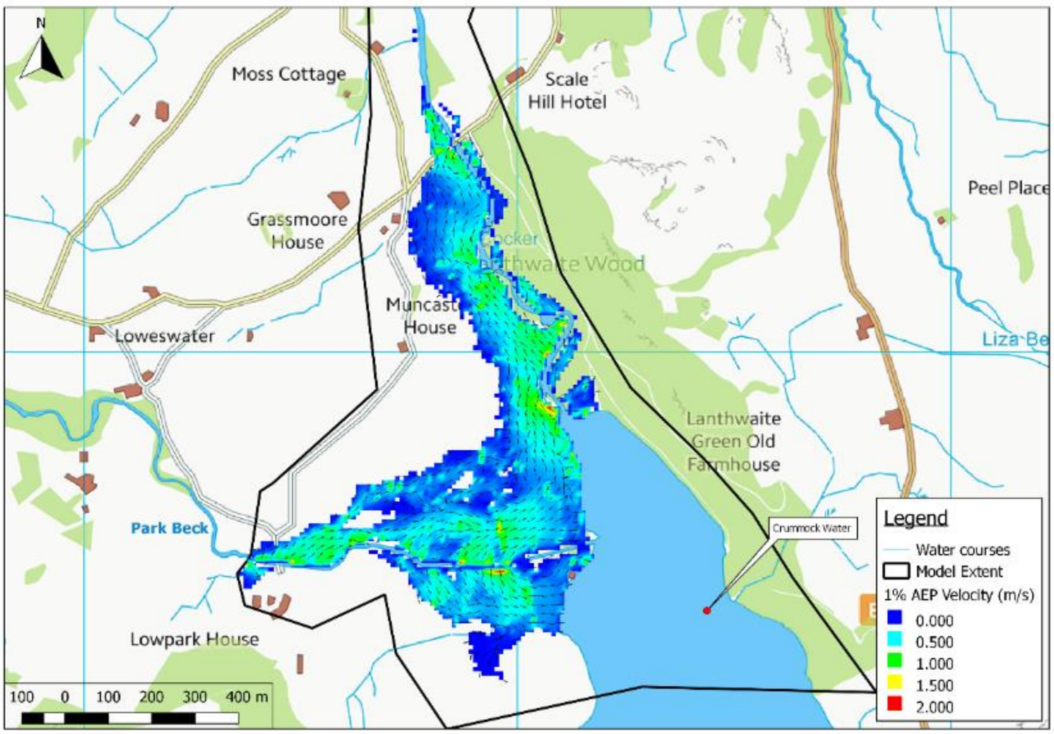

Figure 4-11: Baseline Flood Mechanism from Park Beck

4.3 Geomorphology Baseline

The geomorphology assessment investigated the following water bodies:

- Crummock Water;
- Tributaries of Crummock Water (including Buttermere Dubs, Sail Beck, Scale Beck);
- Park Beck (a tributary of Crummock Water which connects Crummock Water with Loweswater);
- River Cocker; and
- Tributaries of the River Cocker (including Whit Beck).

Several water bodies are not covered by the baseline due to their isolation from Crummock Water, notably Buttermere which would be unlikely to have a significant direct effect on the morphology of Crummock Water. However, any fine sediment supply from Buttermere would be routed through Buttermere Dubs and this is included in this baseline assessment. This assessment has been undertaken using information gained on two geomorphological reconnaissance surveys (June 2015 and May 2017), as well as a range of contemporary and historical maps and aerial photographs.

4.3.1 Criteria forming the geomorphology baseline assessment

The following criteria have been used in the multi-criteria assessment (MCA) and form the basis of the geomorphology baseline assessment (Table 4.6). These have been identified in the scoping study.

Table 4.6 : Multi-criteria assessment performance criteria

Multi-criteria assessment performance criteria	Definition
River/lake reactivity (See baseline observations in 4.3.2, 4.3.4 and 4.3.5)	Assessment of risk/likelihood of Crummock Water, the River Cocker and tributaries undergoing significant channel change (i.e. changes to morphology and fluvial processes) both upstream and downstream.
Impacts on sediment regime (See baseline observations in 4.3.3, 4.3.4 and 4.3.5)	Assessment of risk/likelihood of Crummock Water, the River Cocker and tributaries of undergoing a change of sediment regime (i.e. changes in erosion, rates of sediment transport and deposition).
Impacts on longitudinal and latitudinal connectivity (See baseline observations in 4.3.4 and 4.3.5)	Assessment of risk/likelihood of Crummock Water, the River Cocker and tributaries of undergoing a change that could result in an increase or reduction in connectivity upstream/ downstream or with the floodplain.

4.3.2 Description of geomorphological features

4.3.2.1 Crummock Water

In its present state, the EA have designated Crummock Water as a heavily modified waterbody (HMWB) with Moderate Potential. It is possible that following the cessation of abstraction in 2021 that this water body could be reclassified as pressures would be removed and the lake would no longer be required for drinking water purposes.

Crummock Water, a relic ribbon lake, is constrained by its geographical positioning and appears to have undergone very little morphological change since the last glaciation. Fluvial, wave and hillslope processes appear to dominate geomorphological features.

The lake is fed by direct hillslope runoff and several tributaries, including Buttermere Dubs and Mill Beck from the south and Park Beck in the west. Buttermere Dubs is a short watercourse that links Buttermere and Crummock Water.

Crummock Water exhibits a range of geomorphological features along its shores as illustrated in Figure 4-11. Gravel beaches are found all around the lake, particularly on the eastern shoreline, with sediment also accumulating at the mouths of numerous tributaries, including Park Beck and Sail Beck. Several sediment sources have been observed whilst on site including:

- Scale Beck and Far Ruddy Beck - likely sources of large boulders;
- Grasmoor and Mellbreak – likely sources of scree material;
- Park Beck and Sail Beck catchments – sources of gravels and cobbles; and
- Crummock Water shoreline - likely sources of finer material, eroded by wind-wave processes.

At the weir, bathymetry data reveals that the bed of Crummock Water gently slopes from the weir towards the centre of the lake at a gradient of approximately 1 in 8m whilst the slope of the lake bed at the western edge of the lake is much steeper with a gradient of approximately 1 in 4.5m. This suggests that the bed of the lake behind the weir is approximately 0.9-1m higher than the bed of the River Cocker below the weir. Grab samples from the lake bed (<0.2 m) at the weir consisted of sandy clay with some gravel and woody debris. Gravel was found to be sub angular to sub rounded with a low cobble content.

A geophysical survey has also been undertaken on Crummock Water in 2018 along a cross section behind Crummock Water weir (TerraDat, 2018). This revealed that surface sediments consist of clay-rich sediments with sand and gravel-rich alluvial and lacustrine deposits below. The base of the sand and gravel layer is marked by a thick layer of clay corresponding to the glacial till unit. The composition and thickness of the till layer varies across the lake particularly where the weir is located. This survey also located a strong bedrock layer (likely to be the Kirk Stile Formation mudstone and siltstone). This layer is bowl-shaped, indicating a broad but now infilled paleochannel.

Borehole surveys have been also undertaken along the north western shore of the lake behind the wave wall. These showed that the shallow subsurface (>0.4 m) is generally characterised by a layer of sandy, coarse gravel underlain by cobbles or boulders below (Geotechnics, 2018).

Crummock Water generally appears to have a stable morphological regime unlikely to significantly change following weir removal.

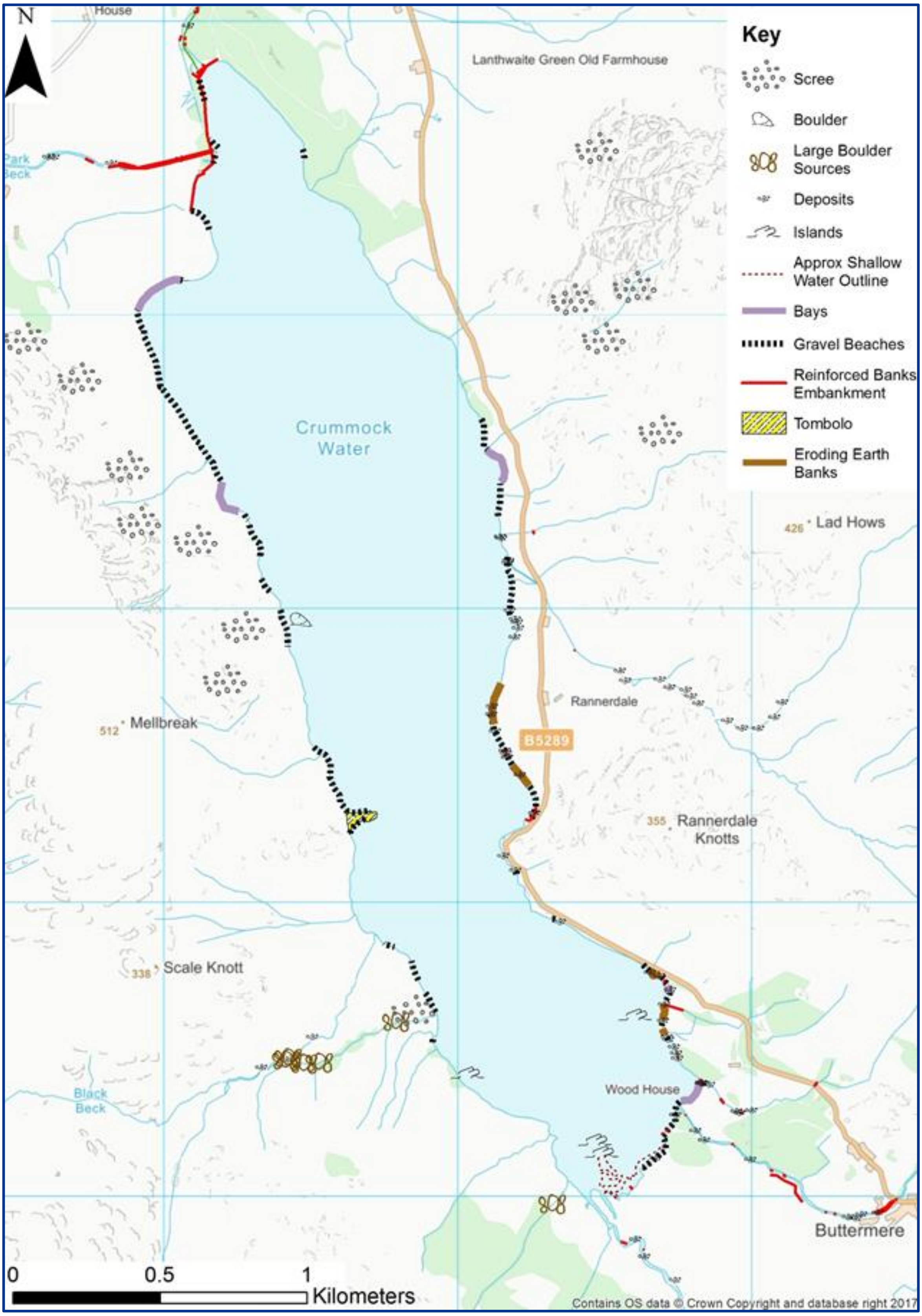

Figure 4-11: Geomorphological features observed at Crummock Water

4.3.2.2 Park Beck

In its present state the EA have classified the river as a natural water body of ‘Good’ status under the Water Framework Directive.

Park Beck is an active gravel bed river draining from Floutern Tarn and Loweswater Fell via Mosedale, Whiteoak and Highnook Becks as well as Loweswater via Dub Beck, becoming a named watercourse downstream of High Nook Farm. As it flows into Kirkgill Wood the channel exhibits a naturally sinuous planform, depositing a mix of coarse gravels, pebbles and small boulders as natural point, side and mid-channel bars. The channel is multi-threaded, with several side channels and secondary channels. Riparian vegetation is dense and takes the form of large trees and other woody vegetation (Figure 4-12a).

Evidence of erosion by livestock entering the channel (poaching) was observed along the right bank where the fields are unfenced. Fluvial erosion was also observed along the outside of meander bends with slumped earth material along bank toes and bank undercutting (Figure 4-12b). Despite the active nature of the channel, the planform of Park Beck appears to be relatively stable with little evidence of historical channel change.

Immediately upstream from the confluence with Crummock Water, the channel has been extensively modified by channel straightening and bed and bank reinforcement. It is possible that the channel was originally modified to minimise channel movement and to control the inflow point into the lake to protect the pumping station from erosion. The modifications are also likely to cause a reduction of lateral connectivity with the adjacent floodplain, serving to reduce flooding and increase the water volume delivered to the lake. Sediments within the modified channel are typically larger clasts (i.e. cobbles, with isolated deposition of fine sediment). This suggests that sediment is efficiently transported along this length of the river at most flows. Borehole surveys undertaken in 2018 (Geotechnics, 2018), revealed that the topsoil (< 0.2m) in the mid to lower lengths of the Park Beck contains a layer of silts and sands with some fine to coarse gravels. The layer beneath generally contains fine to coarse sands and gravels changing to a predominantly clay layer with increased depth. This is followed by cobbles, boulders or clays at around 2.6 m.

At the confluence with Crummock Water, there is a large gravel deposit which was subject to gravel management in 2015.

A small drain is located to the east of Park Beck on OS maps and linking to the River Cocker. The course of this artificial drain is demarked by a line of trees.

Park Beck has an active but relatively stable morphology but works could destabilise this length. As cohesive soils (silts, sands and clays) are present either side of Park Beck, this would minimise lateral movement compared with non-cohesive banks. It is also possible that there could be bed adjustment following a decrease of lake level after dam removal.

a) Wooded riparian zone offers continuous shade through Kirkhead

b) Eroded bankside sediments

c) Channel banks reinforced for a significant length of the lower reaches of Park Beck with stone and concrete material.

Figure 4-12: A selection of photographs along Park Beck

4.3.2.3 Buttermere Dubs

Buttermere Dubs is 1.1km in length and links Buttermere Lake to Crummock Water. The channel has a sinuous planform and active gravel bed, with a range of depositional and erosional features present along its length. Gravel and cobble side bars were observed alongside both banks and the channel appears to have moved laterally, as evidenced by a series of historical channel courses flowing into the lake. However, the planform has changed little when compared to historical maps. Currently the channel flows into Crummock Water, depositing a delta of fine sediment below the water level alongside both banks.

In terms of river reactivity, it is possible that following the proposed infrastructure removal works there would be some adjustment in Buttermere Dubs to adjust to the new water level in Crummock Water, but this is unlikely to be significant.

4.3.2.4 River Cocker

In its present state the EA have classified the River Cocker as a HMWB of Moderate Potential under the Water Framework Directive. A reach by reach detailed description of the River Cocker baseline with photos can be found in Appendix D and geomorphological maps of the walkover survey are in Appendix E.

Although map evidence suggests that the River Cocker has been highly reactive to flood events and land management in the past (Jacobs, 2010a), human intervention has meant that the course of the river and tributaries (with the exception of Whit Beck which has undergone restoration) has remained in-situ since 1867, with the exception of some minor lateral adjustments and a meander cut-off approximately 3.5km downstream of Crummock Water.

From the site walkover (undertaken in May 2017), many modifications were evident. These included channel straightening, dredging, deepening, over-widening and embankments. Many of these modifications could have contributed to the lack of lateral channel adjustment over the years. As land use is predominantly rural, these modifications are likely to have been made to increase field size and reduce flooding in the upstream reaches of the Cocker. Weirs were also evident and could have facilitated old mills or crossing points and, in some cases, could have acted as bed check weirs.

In several locations there was evidence of bed incision along lengths of the River Cocker where excess stream energy had been expended vertically due to being constrained laterally by bank protection and embankments.

Generally, the channel appeared to have a well-established riparian zone along its length. However much of the River Cocker is embanked to prevent flooding of adjacent land.

During the site visits, there appeared to be a good sediment supply to the River Cocker channel and a varied mix of bed substrates (cobbles, boulders, gravels). Sediment supply came mainly from tributaries such as the River Liza. Within the channel immediately downstream of the weir the channel appeared to be starved of finer sediments. The lack of finer sediments was apparent as far as the confluence with the River Liza. Flow types varied throughout the River Cocker with uniform where the channel had been artificially straightened.

Borehole surveys undertaken in 2018 showed that along the right bank of the River Cocker immediately downstream of the weir the topsoil (< 0.1m) generally consists of silts, sands and fine to medium gravel. Below this is a layer of coarse silts and sands with some fine to coarse gravel is present. This transitions about 0.3m below the surface to a layer of clay with fine to coarse gravel. The left bank at this location consists of fine to coarse gravel of sandstone, mudstone and limestone with some sand.

In terms of river reactivity, the River Cocker does show some signs of adjustment in response to artificial modification. However, the removal of the weir at Crummock Water would be unlikely to have a significant effect on the River Cocker, except for restoration of sediment conveyance.

4.3.2.5 Hope Beck, Liza Beck and Other Tributaries

The tributaries of the River Cocker have been surveyed by both a geomorphologist and an ecologist. From a geomorphological point of view, the tributaries of the River Cocker were largely of interest because they supply sediment to the main stem.

Generally, the tributaries throughout the study area were found to be active and to provide significant sediment sources to the River Cocker. There is evidence of extensive modification in terms of channel straightening, embankments and channel dredging. It is presumed that these modifications were originally carried out on the tributaries to reduce flood risk to adjacent fields and to form straight field boundaries between parcels of land. Sediments tend to be carried directly through these modified reaches, rather than being stored, and delivered to the River Cocker channel downstream. Bed substrate within the tributaries is varied with gravels, cobbles and boulders, giving rise to varied flow characteristics with riffle-pool sequences and runs present. Bank tops are generally well vegetated, although lack of fencing leaves them vulnerable to cattle poaching.

4.3.3 Baseline Sediment Regime for the Crummock Water/ River Cocker catchment

Site evidence suggests that Crummock Water is receiving sediment (from boulders to gravels) from a number of sources including hillslope scree, tributaries and eroding shorelines.

Using EA approved methods, the sediment yield for Park Beck and Crummock Water catchments has been estimated. The results are shown in Table 4.7. Sediment is sourced primarily from scree slopes and hillslope failure, although bank erosion has also been observed throughout both catchments. Large sediment clasts such as gravels dominate the bed loads in both catchments, with some finer sediments being transported into Crummock Water primarily from Buttermere.

Average yields given for UK upland areas range from 30-50 tonnes per km^2 per year (Natural England, 2008), distinctly lower than other values from other parts of the world. The bedload yields calculated for the Park Beck are much higher than the UK average and although the calculation has been based on numerous assumptions, it suggests this channel is likely to continue to transport and deliver sediment to Crummock Water for the foreseeable future. A calculation of the entire catchment sediment yield for Crummock Water was also undertaken to provide an understanding of the proportion of sediment the Park Beck is likely to contribute.

Table 4.7: Estimated sediment yields for Crummock Water and Park Beck catchments

Site	Catchment type	Catchment area (km^2)	Notes	Annual bedload yield per area (tonnes/km^2/year)	Annual bedload yield (tonnes/year)	Annual suspended load yield (tonnes/km^2/year)	Annual suspended load yield (tonnes/year)
Park Beck	Small	21.8	Park Beck and all tributaries	163.5	3571	416.3	9092
Crummock Water	Small	62.7	Includes Park Beck	416	26083	510	31977

The above suggests that there is a considerable sediment yield within the Crummock Water catchment, much of which is currently settling within the lake. The continued transport of this sediment downstream into the Cocker will be hindered to a degree by the presence of the weir. However, the lake will also act as a natural sediment sink. From the site walkover it was apparent that some small volumes of sediment must be transported over the weir, particularly as suspended sediment. However, it is the downstream tributaries such as the River Liza that visibly contribute sediment such as cobbles and gravels to the main stem of the River Cocker.

The River Cocker is impacted on by several artificial impoundments along its length including culverts, weirs and bank reinforcement, preventing or limiting longitudinal connectivity. Man-made embankments along the Cocker also impact lateral connectivity along a number of lengths.

4.3.4 Conceptual Models for Baseline

Conceptual models of geomorphological processes (flow and sediment) of the focused study area have been developed to indicate key processes operating in the baseline situation. This is provided in Figure 4-13.

The conceptual model for flow depicts all the tributaries feeding into Crummock Water, with larger arrows representing larger tributaries and small arrows representing relatively small tributaries or ditches.

The conceptual model for sediment shows the dominant substrate type within each tributary. The arrows depict whether the sediment appeared to be reaching the lake or not as evidenced during the walkover survey. The arrow directions within the lake show the interpreted sediment movement within the body of water.

The conceptual model shows that although there are several tributaries feeding into Crummock Water system, the lake acts as a natural sediment trap and only smaller fractions (such as suspended sediment) passes through the lake.

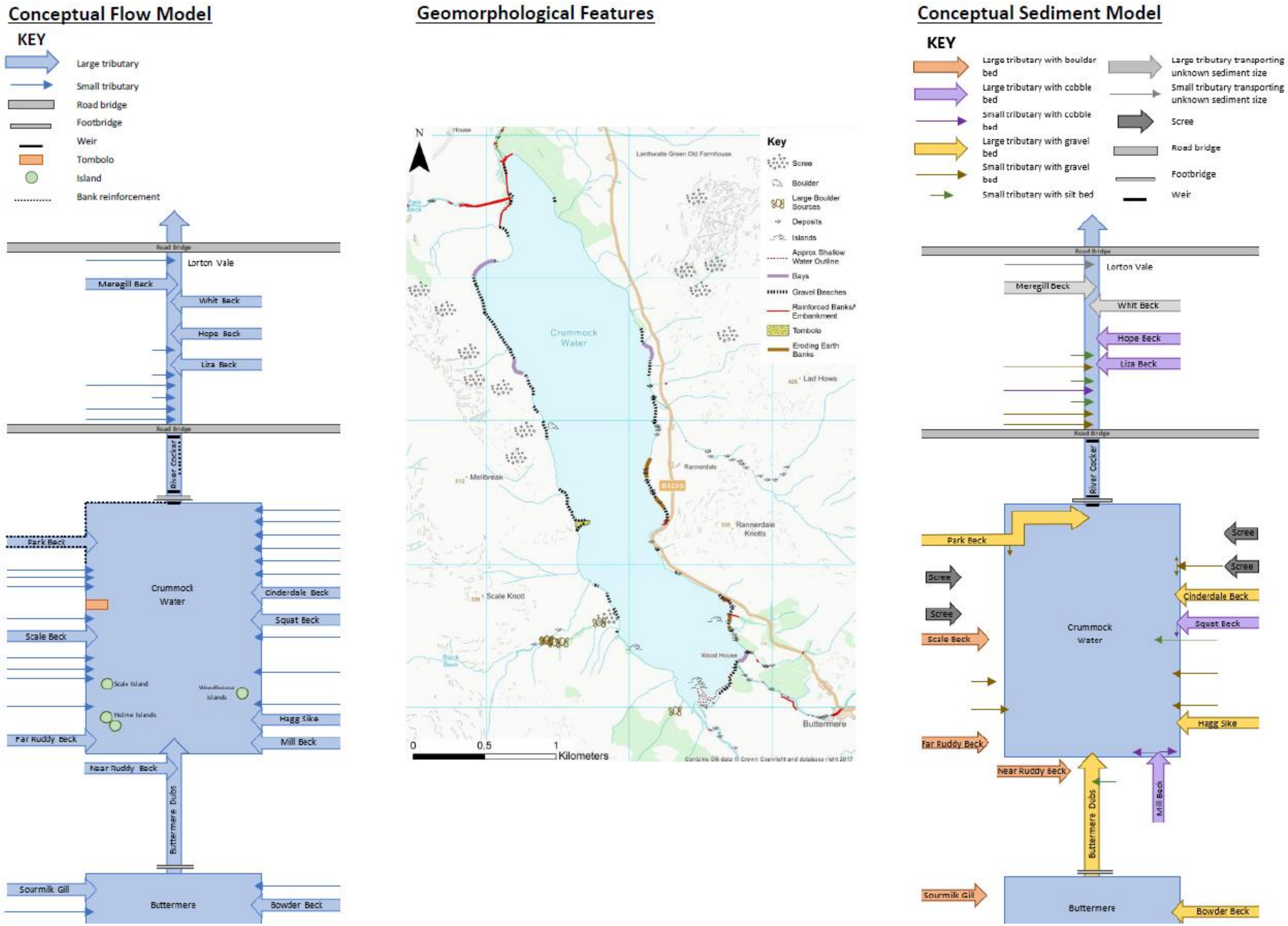

Figure 4-13: Flow and sediment conceptual models for Crummock Water focused study area

4.3.5 Opportunities and constraints

Table 4.8 identifies some of the key opportunities and constraints arising for Crummock Water, the River Cocker and Park Beck and judged against performance criteria used in the subsequent multi-criteria analysis.

Table 4.8: Baseline assessment results.

Performance criteria	Crummock Water	River Cocker	Park Beck
River reactivity	The morphology of Crummock Water has not changed significantly since historical maps began. It appears to have a stable geomorphological regime.	The River Cocker appears to be relatively static, but not stable. The static nature appears to have been caused by a large number of modifications along its length restricting channel change. Knickpoints are evident along certain lengths of the channel suggesting that is adjusting vertically. However, it is not envisaged that this rate of change would accelerate if the weir is removed.	Since the earliest historical maps, Park Beck does not appear to have adjusted its planform and appears to be in a relatively static condition. Between 1947 and 1955 it appears the outlet was artificially moved several metres to the north. The lack of channel movement is likely due to the reinforcement of bed and banks with concrete and masonry in the lower length. There is a risk that upon removal of the reinforcement, the river could begin adjusting...
Sediment regime	Sediment is sourced from hillslope processes, tributaries and wind-wave action along the lake shore.	Crummock Water weir is a significant barrier to sediment movement and the main source of sediment to the downstream River Cocker is from its tributaries such as Liza Beck, Hope Beck and Whit Beck. Weir removal would provide an opportunity to improve sediment transport in the upper reaches of the Cocker.	Sediment is efficiently transported along Park Beck and into the lake, to the point where a sediment management regime has been required at the confluence. Re-naturalisation of Park Beck could eventually result in a more sinuous course which could delay the delivery of sediment.
Longitudinal and latitudinal connectivity	All tributaries entering Crummock Water have good connectivity with the lake in terms of sediment transport. The only length along the lake where lateral connectivity is restricted is where the wave wall is located along the north western shore. Removal of the wall along the north western shore would reconnect the lake with the adjacent land and this has the potential to increase the storage area of the lake at certain flows. Grab samples from behind Crummock Water weir indicate that sediment is predominantly clay with sands and gravel. Loose sediments should be removed prior to any weir removal. This material could potentially be used to create features such as berms or a low flow channel within the Park Beck. Due to the fine nature of the sediment it is not recommended that it is re-introduced downstream in the River Cocker.	Lengths of the River Cocker are embanked, over deep and show evidence of dredging. These types of modification limit the lateral connectivity of the river channel with its floodplain. Several weirs have been historically installed along the River Cocker (see maps in Appendix E) and these act as barriers to longitudinal connectivity. Crummock Water weir appears to act as a significant barrier to sediment movement. Weir removal would provide an opportunity to naturalise the sediment regime and improve the longitudinal connectivity of the river and sediment transport downstream.	The walls along the Park Beck constrain lateral connectivity with the floodplain. Concrete bed and bank removal would provide the opportunity to reconnect Park Beck with its floodplain which would provide an overall benefit from a geomorphological perspective, but could also risk losing some of the adjacent land to erosion and occasional flooding. .

4.4 Ecological Baseline

Restoring habitat for Atlantic salmon is the primary focus of this study, although impacts on the following key species are also considered in this assessment:

- brown/ sea trout (*Salmo trutta*),
- Arctic charr (*Salvelinus alpinus*),
- brook lamprey (*Lampetra planeri*),
- river lamprey (*Lampetra fluviatilis*),
- sea lamprey *(Petromyzon marinus*),
- European eel (*Anguilla anguilla*) and
- European otter (*Lutra lutra*).

Macrophyte communities are also considered because aquatic habitats characterised by the macrophytes *Littorelletea uniflorae* and/ or *Isoeto-Nanojuncetea* are a primary designating feature for the River Derwent and Bassenthwaite Lake SAC and watercourses with water crowfoot (*Ranunculion fluitinatis*) and *Callitricho-Batrachion* vegetation are also a qualifying feature of the SAC.

Improving habitat for the key species would also improve habitat for the aquatic macrophytes and macroinvertebrates which, in addition to fish, are biological quality elements for rivers listed under the WFD. Changes to the flow regime and hydromorphological elements of Crummock Water and the River Cocker could influence availability and quality of aquatic macrophyte habitat.

The following sections of the report provide a summary of a detailed assessment of baseline conditions within the study area for the aquatic species and taxa groups identified above. The assessment has been based on a desk study and field survey of habitat conditions and covered the River Cocker and several targeted tributaries, Crummock Water and several targeted tributaries and Park Beck. The full detailed baseline assessment is provided in Appendix G.

The ecology assessment is closely linked to the geomorphological assessment as river forms and processes shape and modify habitats for Atlantic salmon within the Crummock Water and River Cocker catchment. As a result, the geomorphology and ecology walkover surveys have been undertaken together and habitat mapping produced (See Appendix G).

4.4.1 Criteria forming the ecological baseline

The ecology baseline assessment includes baseline information for the subsequent multi-criteria assessment (MCA) criteria (Table 4.9). These have been identified in the scoping study.

Table 4.9: Multi-criteria assessment performance criteria

Multi-criteria assessment performance criteria	Definition
Maintained/ enhanced key species habitat (See whole section 4.4.2 and Appendix G)	Assessment of risk/likelihood that the provision of suitable habitats for a functioning and sustainable aquatic community would be changed
Maintained/ enhanced key lake species habitat and populations (spawning habitat for Arctic charr, wetland habitat, designated	Assessment of risk/likelihood that lake habitats could be changed (flow, substrate and connectivity between important life stages)

macrophytes assemblage) (See Section 4.4.2.9 and Appendix G)	
Maintained/ enhanced passage of migratory fish	Assessment of risk/likelihood that the connectivity/passability of the Crummock Water system could be impacted and have consequent effects on spawning success in associated headwaters/ tributaries?
Maintain/ enhance habitat for designated terrestrial receptors – otter (See section 4.4.2.8 and Appendix G)	Assessment of risk/ likelihood that terrestrial species and riparian land would be impacted along with conservation objectives of qualifying species.

4.4.2 Key species habitat baseline

Restoring habitat for Atlantic salmon is the primary focus of this study and in this section of the report, details of salmon preferred habitat have been defined along with the current status of habitat. It is important that this is clearly stated. The options considered in this study are based upon trying to achieve optimum conditions. Habitat requirements and current status are also defined for other key species and in more detail for Atlantic salmon in the detailed ecology baseline assessment found in Appendix G. The study is based upon a site visit, desk study and a literature review.

4.4.2.1 Atlantic salmon habitat requirements

A literature review has been undertaken to complement the results of walkover surveys in 2017 and establish baseline conditions within the study area. The core habitat requirements for Atlantic salmon are shown below in Table 4.10.

Table 4.10 Habitat Requirements of Juvenile and Adult Atlantic Salmon (Hendry and Cragg-Hine, 2003)

Juvenile fish <1yr old (fry)	
Water depth	≤20cm
Water velocity	50-65cm/s
Substrate type *winter *summer	Gravel and cobble (16-64mm) Cobble up to boulder (64-256mm)
Juvenile fish >1yr old (parr)	
Water depth	20-40cm
Water velocity	50-75cm/s
Substrate	Cobble up to boulder (64-256mm)
Adult spawning	
Water depth	0.17-0.76cm (in main stems often much deeper)
Water velocity	25-90cm/s
Substrate	Mix of fine materials (<2mm), pebbles and cobbles

Consideration has been taken of the above ecological constraints during the assessment of infrastructure removal (outlined in Section 5), in relation to potential changes in habitat suitability, tributary connectivity and migratory pathways which should remain in place or be improved.

4.4.2.2 Atlantic Salmon – current status in the study area

The River Derwent (of which the River Cocker is a tributary) is a principal Atlantic salmon river in England (Centre for Environment, Fisheries and Aquaculture Science, 2018). The river has been assessed as ‘Probably at Risk’ of not meeting stock conservation limits in 2018, and for projected values up to 2023. Habitat availability on the River Cocker was mapped in 2009 from the Crummock Water weir to the confluence with the Derwent and each of the main tributaries (Whit and Sandy Becks) entering the Cocker along this reach (Jacobs, 2010a). Thirty-four percent of the River Cocker below Crummock Water weir was recorded as suitable habitat for salmonid spawning; this habitat was principally located in the mid-section of the catchment in an area of coarse gravel and a run/ glide flow sequence. Salmonid fry habitat was poorly represented along the River Cocker. As this study took place prior to Storm Desmond (which occurred in 2015), it is possible that habitat abundance and distribution may have changed since then.

The 2017 walkover surveys found that numerous watercourses in the study area, particularly the River Cocker between Low Lorton and Liza Beck have been artificially straightened creating reduced riparian zones, limited macrophyte cover and a highly embedded channel. As a result, these areas offered limited habitat for juvenile Atlantic salmon or spawning adults. They are primarily suitable as migratory corridors for Atlantic salmon, particularly adults moving upstream to spawning habitats and as such much of the river is restricted to functioning just as a migratory corridor. Data from the EA confirmed that adults have been observed upstream of the Crummock Water weir which would suggest that the River Cocker is a migratory corridor. The weir is expected to hinder or delay migration, but not completely prevent it, and under some flow conditions may present a barrier to migration.

Despite the artificial impacts to watercourses in the study area, supporting habitat for Atlantic salmon was found downstream of Crummock Water weir (see Figure 4-8); particularly in the upper reaches of Liza Beck and the lower reaches of Hope Beck. Suitable spawning substrates and juvenile habitat were also observed along several tributaries to Crummock Water.

The results of a desk study and detailed walkover surveys conducted in 2017 show that there is a range of habitat for Atlantic salmon present in the study area, but that alterations to watercourses downstream of Crummock Water weir have limited the quantity of habitat available. Atlantic salmon can in some conditions migrate upstream and downstream past Crummock Water weir in its current condition. However, there is limited data available on actual numbers of Atlantic salmon in the study area and it is likely that the weir may present a barrier in some conditions that could hinder or delay some fish movements under low flow conditions. Rod catch data from the River Derwent indicates that numbers of Atlantic salmon are declining, in keeping with a general pattern of decline over time for the whole of England.

For further detail, see the detailed baseline assessment in Appendix G.

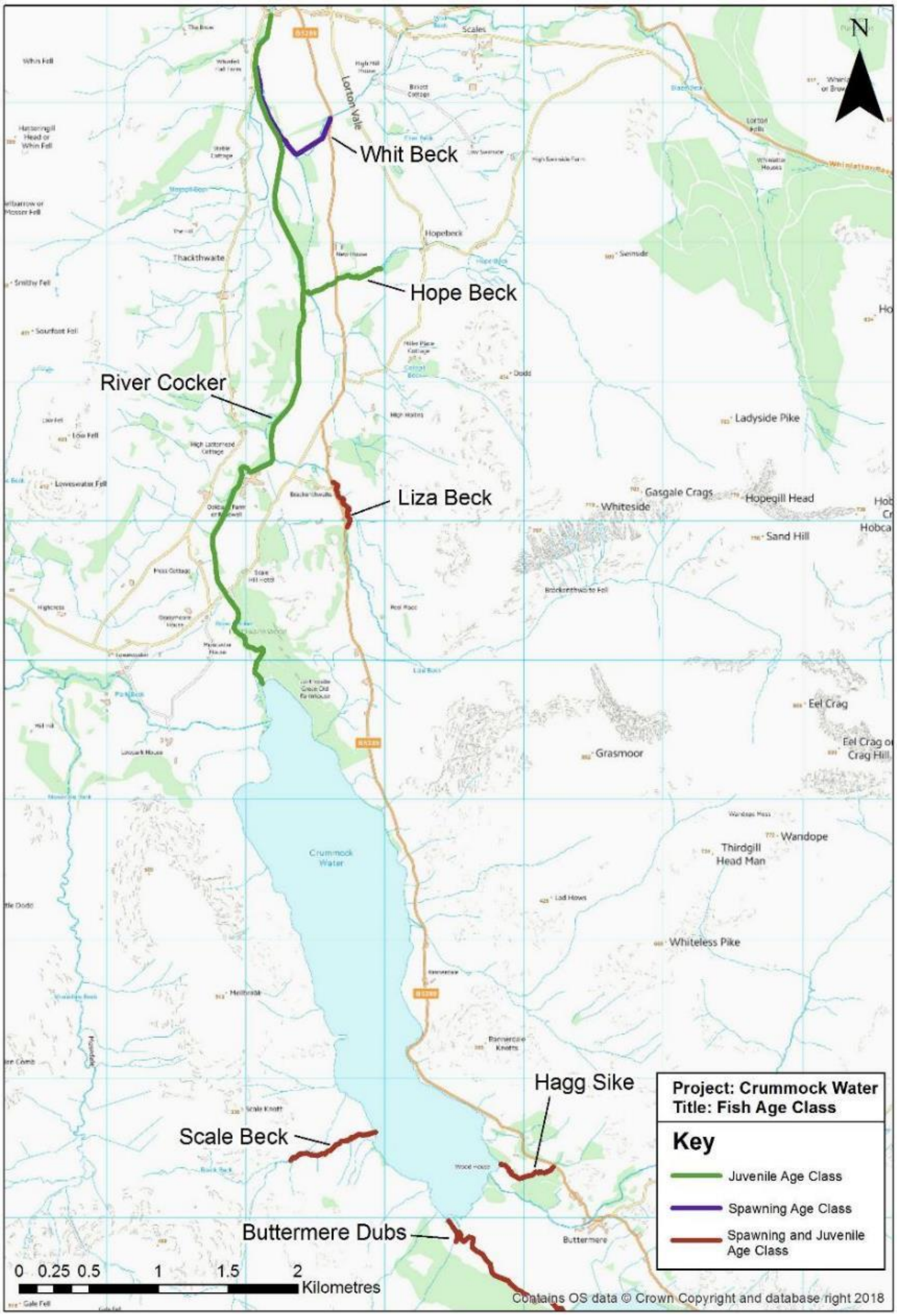

Figure 4-8: Suitable habitat locations for various salmonid age classes.

4.4.2.3 Sea Lamprey and River Lamprey – current status in the study area

Electrofishing surveys of the River Cocker from 2003 to 2017 confirmed the presence of lamprey (unidentified species) along the River Cocker between Yewdale (NY157249) and Cockermouth (NY122304) (EA, 2018a, West Cumbria Fisheries Trust, 2017). One confirmed river lamprey catch was reported downstream of Low Lorton (NY147266) in 2003, but no other specific records of sea or river lamprey have been obtained for the catchment. No lampreys were observed during the walkover survey.

Suitable ammocoete (juvenile) habitat was found in several lower tributaries of the River Cocker, such as at the confluence of Hope Beck and the River Cocker and in the re-meandered lengths of Whit Beck. Ammocoete habitat was also observed in Park Beck. Potential spawning habitat was observed in the re-meandered length of Whit Beck and in the River Cocker between Crummock Water and Scale Bridge. Habitat for all life stages of lamprey was recorded in the River Cocker at Langthwaite Wood. Between Redhow Wood and Longlandsgill Wood, the gradient in the river was steep. Much of the substrate in this reach was bedrock and flows were cascade and fast run, with some vertical drops. The cascade and bedrock lengths between Redhow Wood and Longlandsgill Wood potentially act as a natural barrier to river and sea lamprey upstream migration, and no lampreys were recorded in the River Cocker upstream of this reach. However, it is unclear whether the absence of records of lamprey upstream of this reach is due to the absence of lampreys, or a lack of targeted surveys for these species.

For more information on sea and river lamprey habitat requirements and current status, see Appendix G.

4.4.2.4 Brook Lamprey – current status in the study area

Brook lamprey were identified through electrofishing surveys of the River Cocker from 2003 to 2013 between Yewdale (NY157249) and Cockermouth (NY122304). The species has been reported in the River Cocker between Southwaite and Littlethwaite, but not in the upper reaches of the River Cocker towards Crummock Water (UK Species Inventory, 2018a). Brook lamprey have similar habitat requirements to river and sea lamprey, and thus the habitats reported in Section 4.4.2.3 are suitable for brook lamprey.

For more information on brook lamprey habitat requirements and current status, see Appendix G.

4.4.2.5 Arctic Charr – current status in the study area

Arctic charr is considered a lacustrine (lake) species and as such Crummock Water was the focus of the habitat assessment. Little is known about the habitat preferences of juvenile Arctic charr, although recently-hatched fry are known to feed and seek shelter in mixed composition substrates close to spawning gravels, such as that observed in the shallow margins of Crummock Water. The sheltered inlets of the eastern banks and the area immediately south of the Park Beck inlet contained several suitable stretches of fry habitat. Adult Arctic charr are thought to reside in the deeper reaches of Crummock Water and whilst it was not possible to survey these habitats, the report by Winfield and James (2017[22]) into the Arctic charr population of Crummock Water confirmed that suitable habitat is available.

High quality spawning habitat was observed around the eastern and western margins of Crummock Water, particularly in the north-facing inlets and beaches where large stretches of loose and clean gravel substrates were prevalent. Water depth at these locations ranged from 0.5-1.0m before the substrates dropped abruptly away and could not be observed from the shore. Suitable spawning habitat was recorded by Winfield and James (2017[22]) at depths more than 1.7m in many areas and up to 10.0m in one area.

Winfield and James (2017) recorded active recruitment in the resident Arctic charr population in Crummock Water, although there is an indication of medium-term population decline since 2010. Despite this, abundance estimates are considered high relative to the other Cumbrian lakes.

For more information on Arctic charr habitat requirements and current status, see Appendix G.

4.4.2.6 European eel – current status in the study area

Environment Agency surveys of the River Cocker from 2001 to 2017 recorded both elvers (juveniles) and adult eels spanning the length of the River Cocker, from Crummock Water to the River Derwent. Adults and elvers were also present upstream of Crummock Water and Buttermere, suggesting there are no barriers to upstream migration and that suitable habitat is present. The current structure is however not optimally designed to allow eel passage and therefore is expected to hinder and delay upstream migration, but not completely prevent it. Suitable habitat was observed throughout the study area during the walkover.

For more information on European eel habitat requirements and current status, see Appendix G.

4.4.2.7 Brown/ sea trout – current status in the study area

Brown/ sea trout are present along the full length of the River Cocker and its tributaries (including Park Beck), and in both Crummock Water and its upland tributaries. Reported rod catches for sea trout in the River Derwent show fluctuating catch records between 2005-2017 (EA, 2018b). It should be noted that this information is reliant upon accurate catch reports from recreational anglers and gives no measure of catch effort (i.e. number of active fisherman), so is not directly representative of current stock conditions.

Brown/ sea trout have similar habitat requirements to juvenile and adult Atlantic salmon, therefore the habitat conditions reported previously are also applicable to this species (see Section 4.4.3). Schools of adult brown trout were seen from the shoreline along the south-east margins of Crummock Water during the walkover survey. The habitat within the lake is thought to support a large population of resident brown trout, which spawn in the accessible spawning grounds of Rannerdale Beck, Scale Beck, Buttermere Dubs and Hagg Sike.

For more information on brown/ sea trout habitat requirements and current status, see Appendix G.

4.4.2.8 European otter – current status in the study area

Limited information is available on the presence of otter within the River Cocker catchment and Crummock Water. Surveys carried out in 2005 in the West Cumbria area by the EA showed a substantial increase in the number of active otter sites observed since 1998, although with a reduction in the number of active otter sites between 2002 and 2005 (EA, 2005). No conclusive evidence of otter activity was found during walkovers. One observation of a potential print was reported on Park Beck however the quality was insufficient for identification purposes.

The habitat along the River Cocker and its tributaries appeared of mixed quality for otters. Embankment stabilisation measures across large lengths of river channel reduced habitat potential, preventing the formation of natural holts and couches in the river bank. Dredging deposits along the embankment of several tributaries also restrict access to the river and covered over potential holt and couch habitat. The upper reaches of the River Cocker closer to the Crummock Water weir provided more natural embankments, but there was a high level of disturbance from dog walking and recreational activities. The more natural un-straightened upstream length of Park Beck and the re-meandered length of Whit Beck are likely to provide the most suitable otter habitat within the surveyed area, with high potential for lying up sites (holts and couches) within these reaches

For more information on European otter habitat requirements and current status, see Appendix G.

4.4.2.9 Aquatic Macrophytes – current status in the study area

Macrophytes can modify the adjacent habitat by trapping sediments and altering nutrient flows in the surrounding area and providing important supporting habitat for other ecological receptors. Macrophyte communities vary in their tolerance to periods of drought but will generally adapt to gradual changes in water level, provided key areas of macrophyte growth remain regularly irrigated. Key habitat requirements are summarised in Appendix G.

A lake margin assessment was undertaken at Crummock Water and focused on available fish and macrophyte habitat. A desk-based assessment showed that SSSI units 126 (Buttermere Dubs Wetland, Buttermere Outflow), 127 (Buttermere Dubs Wetland, West), 128 (Buttermere Dubs Wetland, East), and 129 (Crummock Water

Wetland) are in Favourable status with no identified condition threat to these fen, marsh and swamp lowland habitats.

A 2013 study (Marshall Ecology, 2013) which investigated the potential effect of drawdown on the wetland communities of Crummock Water highlighted key wetland areas in the southern length of Crummock Water around Buttermere Dubs, on the eastern margins south of High Wood, and along the western fringes immediately south of Park Beck extending to the upper reaches of the River Cocker. The wetlands along the southern and north-west margins were considered at highest risk of habitat modification as a result of lake draw-down. A drop in the overall water level of Crummock Water is likely to reduce available wetland habitat, leading to a change in wetland community composition around Buttermere Dubs (Marshall Ecology, 2013). However, the study found that a temporary drawdown of up to 1.1m was expected to have minor impacts to the predominant species of *Littorelletea* habitat.

A targeted macrophyte study conducted in 2013 and 2014 (Amec, 2014) noted a lack of aquatic vegetation in the River Cocker between Lorton and Crummock Water. The macrophyte community was dominated by *Fontinalis squamosa*, *Fontinalis antipyreteca*, *Platyhypnidium ripariodes*, *Myriophyllum alterniflorum* and *Callitriche brutia var. hamulata*, all thriving in locations where they are predominantly submerged. Water crowfoot (*Ranunculus aquatilis*) was noted further downstream between Lorton and Cockermouth, and is a species known to tolerate prolonged periods of exposure resulting from a decrease in water level. The rare moss *Schistidium agassizii* was reported in the cascade length above Cornhow and is well adapted to locations where it is regularly exposed to periods of drought.

During 2017 walkovers, aquatic macrophyte communities were observed in several locations within the River Cocker. Large assemblages were observed in the re-meandered lengths of Whit Beck close to the confluence with the River Cocker (NY 15092 25111) and in the lower reaches of Hope Beck (NY 15448 23644). Wetlands were recorded in the southern length of Crummock Water, on both sides of the mouth of Buttermere Dubs and extending east towards Mill Beck (close to NY 16532 16979). No mats of floating vegetation were observed within Crummock Water.

4.4.3 Passability of Crummock Water system to migratory fish

The River Cocker is a migratory corridor for Atlantic salmon and sea trout and facilitates the movement of adults of these species to upstream spawning grounds and the movement of smolts downstream to the sea. Records of Atlantic salmon upstream of the Crummock Water weir confirm the River Cocker to be a migratory corridor for anadromous salmonids and that the fish pass on Crummock weir is passable in both upstream and downstream directions, at least under some flow conditions. However, it is likely that the weir may present a significant barrier in some conditions that could hinder or delay some fish movements under low flow conditions.

In December 2017, Natural England and the Environment Agency provided the following statement on the passability of the weir and the benefits of removing it (See also Appendix F for the rest of the statement):

"The weir at Crummock Water is fitted with a fish pass which does not meet current fish pass standards. It enables some adult fish to pass upstream in some flow conditions, but we consider the weir and fish pass together to constitute a partial barrier to both upstream migration of salmon adults and downstream migration of smolts.

This is based on studies, e.g. Newton et al. (2018), showing that even small barriers and those fitted with fish passes are likely to delay upstream migrating fish as they search for the easiest upstream route. Delays can result in loss of fitness from stress and unnecessary energy expenditure, sub-optimal arrival at spawning grounds, or mortality from predation and disease. A proportion of migrating fish are also likely to turn back and spawn downstream of any barrier, potentially restricting the range of the species over time.

There is also a body of evidence (e.g. Aarestrup and Koed, 2003; Gauld et al., 2013; Nyqvist et al., 2016) that the downstream migration of salmon smolts can be significantly delayed by artificial barriers with and without bypass *facilities and especially in low flow conditions. Smolts are susceptible to damage and disease, and are vulnerable to predation, so delays at barriers can result in significant mortality.*

It is highly likely that adult salmon are delayed or turned back by Crummock Water weir, and that salmon smolts are also delayed, especially in low lake level conditions. We have no doubt that weir removal at Crummock Water will benefit the catchment salmon population by preventing these impacts."

River, sea and brook lamprey are poorer swimmers than Atlantic salmon and sea trout, and thus some features (natural and anthropogenic) that salmon can pass (including fish passes) are still migration barriers to these species. (such as the cascade and bedrock lengths of the River Cocker at the northern tip of Redhow Wood (See Appendix G, Figure G-4). Crummock Water weir acts as a barrier to the migration of brook lamprey.

The Arctic charr in Crummock Water do not migrate up the tributaries and instead spawn within the lake and so are not dependent on access to tributaries.

European eels, both elvers and adults have been recorded upstream of Crummock Water weir and all the way down the River Cocker, suggesting that with the current eel passes, there are no total barriers to migration for a range of age classes. Crummock Water weir is not optimally designed to allow eel passage and therefore is expected to hinder and delay upstream migration, but not completely prevent it.

4.4.4 Opportunities and constraints

Table 4.11 identifies some of the main opportunities and constraints identified for each MCA criteria in different parts of the study area.

Table 4.11: Baseline assessment of the study area

Multi-criteria assessment performance criteria	Crummock Water	River Cocker	Park Beck
Maintained/ enhanced key river species habitat	Crummock Water weir currently holds back sediment, depriving the reach downstream of the weir of finer sediments. Removal of the weir would restore longitudinal connectivity, sediment regime and in turn improve habitats in the upper reaches of the River Cocker.	The River Cocker provides a migratory corridor for Atlantic salmon, brown/ sea trout, eel, and river and sea lamprey (the latter two naturally only recorded as high as Redhow Wood and Longlandsgill Wood. Spawning habitat for fish species was observed in the River Cocker, although more prevalent to the reaches below the Crummock weir. Suitable spawning habitat for Atlantic salmon, brown/ sea trout, and brook, river and sea lamprey was present in the re-meandered length of Whit Beck. Since the re-meandering works have been completed in Whit Beck, salmonid spawning has been noted in this area. Juvenile habitat for each of these species, along with adult brown trout habitat, was also found in the same area. Salmonid spawning gravels, juvenile habitat and brown trout adult habitat were observed in Liza Beck. Removal of Crummock Water weir would enable improved sediment transport downstream into the River Cocker and could improve habitats	Park Beck offered particularly good otter habitat, but no conclusive evidence of otters was found at this time. The lower length of Park Beck has relatively poor habitat but acts as a migratory route to salmonids. Restoration of the Park Beck would increase overall habitat availability for all age classes of Atlantic salmon, brown/ sea trout and lamprey species and will create more refuge areas for fish migrating to suitable habitat in the upper reaches of Park Beck.
Maintained/ enhanced key lake species habitat and populations (spawning habitat for Arctic charr, wetland habitat, designated	Crummock Water is one of eight Lake District lakes that contain resident Arctic charr. The Arctic charr population of Crummock Water is considered stable, with active juvenile recruitment. A condition assessment of the Crummock Water SSSI, based on the standing open water and canals habitat, reported a stable macrophyte community of favourable condition, with no evidence of alien	N/A	N/A

Multi-criteria assessment performance criteria	Crummock Water	River Cocker	Park Beck
Macrophytes assemblage) species)	species within Crummock Water. Crummock Water has also been assigned a good WFD designation for macrophytes and phytobenthos. High quality spawning habitat was observed around the eastern and western margins of Crummock Water, particularly in the north-facing inlets and beaches. Large lengths of loose and clean gravel substrates were found at depths ranging from 0-1 m. Suitable substrates for spawning were found at depths in excess of 1.7 m and up to 10 m. Macrophyte species predominant in Littorelletea /Isoetid habitats were recorded as being present at depths that would exceed a drawdown level of 2 m. Key wetland areas were recorded in the southern length of Crummock Water around Buttermere Dubs, on the eastern margins south of High Wood, and along the north western shore from just south of Park Beck to Crummock weir. A reduction in water level due to weir removal could reduce some of the available spawning habitat for Arctic charr, however the re-naturalisation of the lake would provide better lateral connectivity with the northern lake shore during high flow events. Natural England has confirmed that the SAC boundary will not move with a reduction in lake level, and therefore new marginal lake habitat will be created within the SAC. Appropriate planting or other habitat improvement measures will be undertaken to ensure that suitable species colonise the newly exposed areas.		
Maintained/ enhanced passage of migratory fish	Spawning substrates and juvenile nursery habitat were observed in several tributaries to Crummock Water. Migration into two of these tributaries, Buttermere Dubs and Scale Beck, could be temporarily hindered if lake levels drop, due to shallow waters at their inflows.	The River Cocker provides a migratory corridor for anadromous Atlantic salmon and sea/brown trout and migrating European eels. The upper length of the River Cocker may not be accessible to sea, river and brook lamprey due to the bedrock and cascade lengths present in Redhow Wood. Fish survey data from the EA confirms the presence of lamprey within the River Cocker between Yewdale and	Park Beck does not have any significant barriers to fish movement. However, the lower modified length does not provide much refuge for migratory fish in its current condition and may inhibit upstream or downstream fish migration in low flows. Re-naturalisation of Park Beck would create in-channel

Multi-criteria assessment performance criteria	Crummock Water	River Cocker	Park Beck
		Cockermouth. River lampreys have been reported as far upstream as Lower Lorton, although no published records exist for the upper reaches of the River Cocker. Records of Atlantic salmon, brown/ sea trout and European eels in the tributaries of Crummock Water confirm that the fish pass on Crummock Dam allows the upstream migration of these species under certain flow conditions. Removal of Crummock Water weir would reinstate free passage for salmonids and would potentially open up the catchment to brook lamprey.	features and flow and substrate variation enabling more refuge areas for migrating fish. Removal of the Crummock Water weir could result in more migratory fish reaching Park Beck.
Maintain/ enhance habitat for designated terrestrial receptors (e.g. otter)		Embankment modifications in several channels throughout the catchment have limited habitat quality, although suitable otter habitat was noted along Park Beck, Liza Beck and the unmodified lengths of the River Cocker. Reports have shown an overall increase in the local otter population between 1998-2010, although more recent figures are not available. A potential otter print was observed on Park Beck close to Kirkstile Bridge, although the quality of the print was not sufficient to confirm the presence of otter in this area. The abstraction infrastructure removal would need to at least maintain current habitat availability.	

5. Multi-Criteria Analysis and High-Level Results

5.1 Determining the Long List of Options

Following the baseline assessments for all disciplines, a multi-disciplinary internal workshop (Workshop 1) was held to determine a long list of options. The instructions for the workshop were to put forward all options, regardless of any initial views on technical feasibility, stakeholder acceptability or economic factors. This was to ensure that no options were overlooked.

All the options relate to one of three structures/modifications; Crummock Weir, Crummock Water wall and Park Beck, with a number of sub-options investigated for each area. Table 5.1 lists the options considered as the long list. The options for Park Beck could require the footbridge over Park Beck to be relocated, as lateral adjustment of the re-naturalised channel could undermine bank abutments.

Table 5.1: Summary of options considered in the MCA

Area	ID	Option type	Description
Crummock Weir/ River Cocker	A1	Do nothing	Allow natural decay
	A2	Do minimum	Maintain current weir condition
	A3	Assisted natural recovery (strategically remove parts of structure)	Remove parts of weir to allow option A1 to occur quicker
	A4	Partial removal of one side of weir	Partial removal of the left-hand side of the weir at Crummock
	A5	Lower weir	Lower weir height to increase flow diversity downstream
	A6	Full weir removal	Full removal of weir, return towards historic conditions
Crummock Water wall	B1	Do Nothing	Allow natural decay
	B2	Do minimum	Maintain current weir condition
	B3	Assisted natural recovery (strategically remove parts of structure)	Remove parts of weir to allow option B1 to occur quicker
	B4	Lower wall	Lower wall height to allow flooding of area behind wall
	B5	Full wall removal	Return bank to natural state
Park Beck	C1	Do Nothing	Allow natural decay
	C2	Do minimum	Maintain current wall condition
	C3	Installation of woody debris/ other geomorphological features	Install natural features to reduce in-channel uniformity
	C4	Partial removal of concrete bed and banks	Remove parts of concrete bed/banks, allow channel to naturally adjust
	C5	Full removal of concrete bed and banks	Remove concrete channel and banks, allow channel to naturally adjust
	C6	Re-meander Park Beck with full removal of concrete	Return channel and banks to natural state and attempt to replicate historical planform
	C7	Re-align Park Beck into the River Cocker	Provide connectivity between two channels to improve fish passage

5.2 Multi-Criteria Analysis

The Multi Criteria Analysis (MCA) approach was agreed with the PSG in 2016. The government guidance on MCA has been broadly followed, developing a performance matrix for options judged against selected criteria. It should be noted that the methodology has evolved through an iterative approach and is slightly different to that which was discussed in the original Scoping Report, but follows a published approach developed for assessing acid waters in Wales (Brookes *et al.*, 2001)[3]. The MCA approach attempts to avoid pitfalls such as double counting of criteria. The approach adopted can be used to undertake a statistical analysis of the performance matrix if required as an additional method of trying to discern between options.

A summary of the scoring criteria, simplified results and key findings of the MCA are detailed in Section 5.2.2 with a breakdown of MCA results contained in Appendix H.

5.2.1 High level assessment key findings

The key findings at this stage of the assessment that were used in the MCA were reported to the PSG at a meeting held in November 2017 and the subsequent issue of the Main Stage A Technical summary report.

5.2.1.1 Flood modelling

The key findings from the high level options flood modelling concluded:

- The combined full removal of both Crummock Water weir and Crummock Water wall provides the greatest flood risk benefits to downstream receptors;
- The removal of the Crummock Water Weir on its own results in significant flood risk benefits to the downstream receptors. The hydraulic modelling results demonstrated that removing the weir reduces the head at the top of the system which slows the flow of water and allows the lake to attenuate flood event inflows more effectively.
- Removal of the Crummock Water Wall on its own increases flood risk at downstream receptors, as water is able to spill over the side of the lake at lower events, bypassing the weirs and increasing flow downstream.
- When both the weir and the wall are removed in combination, flood risk benefits for downstream receptors are maximised because: (1) the lake can attenuate inflows more effectively due to reduced lake level and head height of the system, (2) there is further reduction in spills from the lake (compared to weir removal only) due to increased storage and 3) the proportion of Park Beck floodplain flows that bypass the lake and directly enter the downstream river system is reduced.

5.2.1.2 Hydrological modelling

The results from the hydrological modelling exercise helped show that weir removal and cessation of the abstraction and compensation flow (i.e. returning the area to near natural conditions) could have negligible implications or possibly slightly beneficial impacts for salmon during low and normal regimes. For more detail see Appendix B.

5.2.1.3 Geomorphology assessment

From a geomorphological perspective, weir removal would improve longitudinal connectivity for sediment movement and help to return the natural sediment regime. This would be significant for the reach between the Crummock water outlet and the first tributary on the River Cocker (Liza Beck).

[3] Brookes, A., Eales, R., Fisher, J., Foan, C and Twigger Ross (2001). An Approach to integrated appraisal: Progress by the Environment Agency in England and Wales., J. Env. Assesment. Policy Management., 3 (2001)

5.2.1.4 Ecology assessment

It has been assessed that there would be a favourable effect from weir removal, as any artificial impediments to fish migration would be removed. As hydrological modelling results suggested that removing the weir and ceasing the abstraction and compensation flow would lead to slightly higher flows across most of the flow range; though for the lowest of flows (Q99 and smaller) the flows would be slightly less than baseline. It has also been determined that good baseline habitat already exists in the study area.

5.2.2 Scoring Criteria

The scoring criteria are shown below in Table 5.2. It should be noted that the appraisal period for this study is approximately 40 years from implementation of a preferred option. This means options could score differently than if they were being assessed over a shorter or longer time period.

Table 5.2: Scoring criteria used for MCA

Major Beneficial	+++	Significant benefits/opportunities for those criteria that **substantially improve the situation** over the base-case. Would be seen as a major positive effect of the option in the overall context of the study.
Moderate Beneficial	++	Clearly positive with **moderate benefits/opportunities,** that would be seen as favourable effect of the scheme/option
Low Beneficial	+	Probably/likely positive but **minor benefits/opportunities.** Would not be seen as a significant benefit of the scheme.
Negligible	=	No discernible effect, either positive or negative
Minor Negative	-	Some **minor negative effects** that would be acceptable in the wider context of the scheme. i.e. wider benefits judged against other criteria or with additional mitigation.
Moderate Negative	- -	Clearly negative with **moderate effects,** that would be seen as a risk to the viability of the scheme/option, but not necessarily a "showstopper". Risks could be mitigated for.
Major Negative	- - -	**Serious adverse effect** likely to be extremely difficult to overcome in the context of the scheme. A clear and high risk to the aims and objectives of the scheme/study without chance of mitigation.
Unknown	?	Not enough information to make an initial assessment.

5.2.3 MCA summary of results

A summary of the option scores based on full MCA is contained in Table 5.3. The scores are based upon a comparison against the present-day baseline situation.

For a breakdown of how these summary scores were reached, see Appendix H.

Table 5.3: Simplified MCA results

		Option Name	Engineering	Flood Risk and Hydraulics	Geomorphology	Ecology[44]	Shortlisted	Justification
Crummock Water Weir	A1	Do nothing	- - - Little cost, however would likely be in breach of Reservoirs Act 1975.	- Deterioration of weir could cause localised blockages of channel, increasing flood risk. Not modelled.	- Allowing uncontrolled decay of weir could have negative impacts on river reactivity.	= Likely to be no or negligible change from the present day.	No	Unlikely to comply with legislation, notably Reservoirs Act 1975.
	A2	Do minimum	= Likely to be no or negligible change from the present day.	= Likely to be no or negligible change from the present day.	= Likely to be no or negligible change from the present day.	= Likely to be no or negligible change from the present day.	Yes	This would form a baseline against which other options would be measured.
	A3	Assisted natural recovery	- - Potential to undermine existing structures, also H&S risk at working in/near water. Would be unlikely to comply with Reservoirs Act 1975.	+ + + Weir removal reduces head at the top of the system. This slows passage of water and allows lake to attenuate water more effectively. Improves onset events and reduces flood levels.	+ + + Removal of barrier to flow and sediment control.	+ Could allow easier passage of fish to Crummock Water.	No	Unlikely to comply with legislation, notably Reservoirs Act 1975 and other options more beneficial.
	A4	Partial weir removal (one side)	- Potential to undermine existing structures and H&S risk of working near water.	++ Reduction in flood levels and onset downstream.	+ + As A3, however some restriction still in place so less beneficial.	++ Could allow easier passage of fish to Crummock Water, possible creating habitat downstream.	Yes	Reasonable benefits, although a weaker option than full weir removal. Can be considered as a stand-alone option.
	A5	Lower weir	- - Greater H&S risks involved than A4 as working in water likely required	+ Reduced flood levels and onset downstream, but not to the extent of A4.	+ Improvement to longitudinal connectivity, however presence of structure still creating a barrier to movement of sediment and flow	+ Could allow easier passage of fish to Crummock Water.	No	Offers less benefit than partial weir removal (one side). If full weir removal is found to be not feasible during detailed assessment, then this could be scoped back in.
	A6	Full weir removal	- - Achievable but would require significant planning of works. Temporary working areas and installations likely. Increased cost compared to other options.	+ + + Weir removal reduces head at the top of the system. This slows passage of water and allows lake to attenuate water more effectively. Improves onset events and reduces flood levels.	+ + + Would allow naturalised sediment and flow regime to establish.	+ + Allows free fish passage and improves downstream sediment availability. Reduced lake level could negatively impact Arctic charr and lake macrophyte community. However Arctic charr habitat is abundant and a slow reduction in water level would allow macrophytes to habituate. Provided the gradient and flows of tributaries upstream of Crummock Water maintain accessibility, a drop in lake level would be unlikely to impact fish migration in the long term.	Yes	Improves geomorphology of River Cocker and passage of migratory fish whilst reducing flood risk. Can be considered as a stand-alone option.
Crummock Water Wall	B1	Do nothing	= Generally, no change to the system. Over time could negatively impact adjacent infrastructure, but there are no maintenance costs.	- Generally, no change until wall collapses after which flood risk is increased at lower onset events from current baseline at downstream receptors.	= Likely to be no or negligible change from the present day.	= Likely to be no or negligible change from the present day.	No	Offers no benefits but increase flood risk in time.
	B2	Do minimum	= Likely to be no or negligible change from the present day.	= Likely to be no or negligible change from the present day.	= Likely to be no or negligible change from the present day.	= Likely to be no or negligible change from the present day.	Yes	This would form a baseline against which other options would be measured.
	B3	Assisted natural recovery (strategically remove parts of wall)	- Minor costs incurred, reduction in wall functionality.	- - Wall would eventually degrade. Increase in flood risk at lower onset events from current baseline at downstream receptors.	+ Improved interaction between lake and riparian zone.	+ Compacted sediment could become looser and more useable for charr.	No	Increases flood risk downstream with only minor positive impact to habitat.

[44] All ecology results are pending low flow modelling results for Q90 and Q10 which will be presented at the Project Steering Group meeting on the 17/11/17.

		Option Name	Engineering	Flood Risk and Hydraulics	Geomorphology	Ecology[4]	Shortlisted	Justification
	B4	Lower wall	- Minor costs incurred, reduction in wall functionality.	- - Increased flood risk at lower onset events from current baseline at downstream receptors.	= Negligible improvement in interaction between lake and riparian zone.	= Likely to be no or negligible change from the present day.	No	Increases flood risk downstream with only minor positive impact to habitat.
	B5	Full wall removal	- - Could be costly to remove as significant enabling works envisaged.	- - - As B4, but with increased flood risk.	+ + Potentially allows establishment of aquatic plant and animal communities in the shore zone, as well as sediment input from riparian land/floodplain.	+ + Improved sediment pathway, therefore likely to improve downstream habitats.	No	Not a viable stand-alone option, however would be considered in conjunction with partial or full weir removal as flood risk is mitigated by weir removal.
Park Beck	C1	Do nothing	= Minimal impacts expected, although re-naturalisation of channel could cause undermining of existing assets.	- - Increased deposition/vegetation over time likely to increase risk of flooding.	= Likely to be no or negligible change from the present day.	= Likely to be no or negligible change from the present day.	No	Option does not provide strong enough benefits to be included.
Park Beck	C2	Do minimum	= Likely to be no or negligible change from the present day.	= Likely to be no or negligible change from the present day.	= Likely to be no or negligible change from the present day.	= Likely to be no or negligible change from the present day.	Yes	This would form a baseline against which other options would be measured.
Park Beck	C3	Install woody debris/natural features	- Minor costs, but 'soft' structures tend to have a shorter life than 'hard' solutions.	- Increased deposition/vegetation over time likely to increase risk of flooding.	+ Diversified channel processes.	+ Marginal improvement to instream habitats	No	Option could be considered as an enhancement of another option but is not a suitable standalone option.
Park Beck	C4	Partial removal of concrete bed/banks	- H&S implications of working in channel. Existing structures could end up being undermined as channel re-naturalised.	= No foreseeable impact on flood risk. Not modelled.	+ Potential for naturalisation of channel form and functions over time however these would probably not be significant in the context of the wider catchment.	+ Potential for habitat improvements, however these could not be significant in the context of the wider catchment.	No	Not as strong as full removal of concrete bed and banks or re-meandering, however could be a compromise on cost.
Park Beck	C5	Full removal of concrete bed/banks	- - H&S implications of working in channel. Existing structures could end up being undermined as channel re-naturalises. Maintenance required would be less than options where concrete is left in. Possible risk of erosion to pumping station and pipes underground.	= No foreseeable impact on flood risk. Modelled.	+ + Potential for naturalisation of channel form and functions over time. Delivers WFD objectives.	+ Increased sediment inputs to Crummock Water, also improved local habitat for migratory fish.	Yes	Allows for river to adjust naturally over time, potentially improving in-stream and marginal habitats. Could be issues if lake levels are lowered (Options A4 and A6). Can be considered as a stand-alone option.
Park Beck	C6	Re-meander Park Beck and remove concrete	- - H&S implications of working in channel. Existing structures could end up being undermined as channel re-naturalised. Maintenance required would be less than options where concrete is retained. Possible risk of erosion to pumping station and pipes underground.	= No foreseeable impact on flood risk. Not modelled.	+ + + As C5, plus creates additional habitats by modifying form and function of channel.	+ + Increased sediment inputs to Crummock Water, also improved local habitat for migratory fish.	Yes	Allows for river to adjust naturally over time, potentially improving in-stream and marginal habitats. Could be issues if lake levels are lowered. Can be considered as a stand-alone option. It is unclear if reach was historically meandering or not so may not be restoring 'natural' form.
Park Beck	C7	Re-align Park Beck into River Cocker	- Risk can be minimised if re-alignment can be achieved offline.	- Assumes all flows from Park Beck enter River Cocker downstream of current weir. Likely to improve low flows, however some increase in water levels and flood frequency downstream.	- No evidence found that Park Beck has historically directly connected to River Cocker. Would diminish sediment input to Crummock Water.	= A natural channel could create additional habitat, plus open up an additional migratory route. However, if the channel is not natural, this could also result in adverse impacts to habitats.	No	There is no evidence showing that Park Beck once lowed directly to the River Cocker. Following the PSG meeting in November 2017 it was decided to screen this option out as there is no evidence to suggest this.

		Option Name	Engineering	Flood Risk and Hydraulics	Geomorphology	Ecology[4]	Shortlisted	Justification
Option combinations	D1	**Full weir removal + Full Wall removal**	- - Feasible but with significant planning required.	+ + + This option provides the greatest flood risk benefits up to the 100 year flood event.	+ + + Would re-naturalise flow and sediment regime within the Cocker, whist also improving lateral connectivity between the lake and its margin.	+ + Positive as would result in reducing barrier to all fish passage, naturalised flow and sediment regime which would help improve downstream habitats. Modelling results show slightly higher flows across the majority of the flow range. Reduced lake level could negatively impact Arctic charr and lake macrophyte community. However Arctic charr habitat is abundant and a slow reduction in water level would allow macrophytes to habituate. Provided the gradient and flows of tributaries upstream of Crummock Water maintain accessibility, a drop in lake level would be unlikely to impact fish migration in the long term.	Yes	Greatest overall benefit according to the MCA.
	D2	**Removal of one side of weir + full wall removal**	- - Feasible but with significant planning required.	+ + + This option provides the second greatest flood risk benefits (after option D1) up to the 100 year flood event.	+ + + Would to a slightly lesser degree than D1 re-naturalise flow and sediment regime within the Cocker. A structure would remain constraining flow at the lake outlet. Lateral connectivity between the lake and its margin would be reinstated.	+ + Positive as would result in reducing barrier to all fish passage, naturalised flow and sediment regime helping to improve downstream habitats. Modelling results show slightly higher flows across the majority of the flow range. Reduced lake level could negatively impact Arctic charr and lake macrophyte community. However Arctic charr habitat is abundant and a slow reduction in water level would allow macrophytes to habituate. Provided the gradient and flows of tributaries upstream of Crummock Water maintain accessibility, a drop in lake level would be unlikely to impact fish migration in the long term.	Yes	Second greatest overall benefit according to the MCA.

6. Design Iterations

6.1 Overview of design iterations

During the Project Steering Group (PSG) meeting on the 16th November 2017, the findings of Main Stage A assessment (baseline and high-level multi-criteria assessment) were presented by Jacobs. This was also followed up with an interim Summary Report. The PSG confirmed that whilst they agreed with the shortlisted options put forward for detailed assessment in Main Stage B, they wanted 'full removal of all abstraction infrastructure' to be investigated as the lead option with two variants on Park Beck – assisted natural recovery and full re-meandering. These have been defined as:

- **Lead option 1:** Full removal of the weir at the outlet, full removal of the wave wall, removal of the water intake pipes within the lake restored back to the original lake margin and full removal of the concrete bed and banks on Park Beck ("natural recovery"); and
- **Lead option 2:** Full removal of the weir at the outlet, full removal of the wave wall, removal of the water intake pipes within the lake restored back to the original lake margin and full removal of the concrete bed and banks on Park Beck ("re-meandering").

If issues arise following the more detailed assessment, then other options in the shortlist could be resurrected and considered in more detail. This decision marked the end of Main Stage A and the beginning of Main Stage B; the detailed assessment stage.

The subsequent approach undertaken for the development of the outline design was to produce a series of "design fixes" and hold check point discussions with UU and the PSG to reach a preferred outline design agreed upon by all stakeholders. Table 6.1 summarises this process which is assessed in more detailed in sections 6.2 - 6.3. The final outline design drawings are shown in section 6.4.

Table 6.1: Summary of design fixes

	Description	PSG comments
Design Fix 1	Preliminary design of weir and wave wall removal at Crummock Water. Also included a preliminary design for both the assisted natural recovery and full re-meandering options at Park Beck.	Presented to the PSG in November 2018. PSG agreed largely with the design but asked that the re-meandering option on Park Beck be scoped out and for Lead option 1 to be taken forward (full weir and wall removal and removal of concrete bed and banks at Park Beck with assisted natural recovery).
Design Fix 2	Further refined design for weir and wave wall removal and only the assisted natural recovery option for Park Beck.	Presented to the PSG in December 2018 at Workshop 4. Minor amendments from comments received from PSG to finalise the design.
Final Design Fix	All comments from PSG taken on board and issued in this assessment as the final design	

6.2 Detailed assessment of Design Fix 1

For Design Fix 1, outline designs for the assisted natural recovery and re-meander options for Park Beck (detailed in Section 5) have been produced by an engineer specialising in reservoirs with inputs from a geomorphologist. A detailed assessment has been completed on the initial designs by each of the disciplines (engineering, hydraulics, geomorphology and ecology) and opportunities and constraints of these designs were discussed in a multi-disciplinary workshop (Workshop 3) with UU present.

Table 6.2 shows the key findings of the detailed assessment of Design Fix 1 from each of the disciplines discussed during workshop 3. During this workshop, both options for Park Beck were discussed.

Table 6.2: Detailed assessment of Design Fix 1 (DF1)

DF1	Crummock Water Weir removal	Removal of wave wall	Re-naturalisation of Park Beck	Additional comments
Engineering	**Buildability/ viability of design**			**Health and Safety and Access**
	The existing weir across the River Cocker and the several ancillary structures facilitating access for pedestrians and operations staff are generally in good condition. The final method of demolition would need consultation and agreement with the Contractor, other stakeholders and an All Reservoirs Panel Engineer but the general sequencing is likely to be as follows: i. The water level of the Crummock Water would be required to be lowered and controlled in advance of the works, this would initially be through the use of the two sluice gates on the weir structure. This would reduce the water level to the base of the weir. Further lowering would be required to allow access to the works and to provide a buffer to protect the working area and afford the Contractor to evacuate the working area should an increase in water level occur. The control of the water level could have to be achieved by mechanical means, such as pumps, over pumping water from the reservoir to an area downstream of the works. Timing of the works would also be a contributing factor as working in drier months could reduce the requirement for over pumping. ii. The weir has several ancillary structures, bridges penstocks and screens. It is likely that these would be removed prior to the demolition of the weir structure. It is anticipated that this would be achieved in a sequential fashion by manual dismantling and removal in lengths by small lifting plant for disposal off site. iii. It is anticipated that the existing weir and associated wall structures would be likely to be demolished by a combination of hand breakers and machinery due to the original masonry and concrete construction. The size	The concrete/masonry wall that runs along the entire left flank of Crummock Water is to be removed, including the length of wall to the south of Park Beck. The walls are seen to be in fair condition. In addition to the removal of wall an area of stone pitching fronting the lower length of wall would be removed as part of the works. The Contractor would need to provide adequate segregation between the members of the public using the footpath and the Contractor's plant operating in the area. This should include segregation zones and temporary diversions of the public right of way. Several mature trees are growing immediately behind the wall especially in the area to the north of Park Beck, which would have to be considered by the Contractor in the staging of the demolition works. It is anticipated that most of the wall would be saw cut by hand and broken up using a mechanical breaker. However, the lengths that have trees behind the wall could need removing by hand to minimise any damage to the trees. The demolished lengths of wall would be removed off site via the Park Beck access route as this would allow the Contractor to use larger plant to minimise the number of journeys. Ground works following removal of the wall and pitching would be carried out by a small to medium sized excavator.	**Assisted natural recovery or full re-meandering** The re-naturalisation of the Park Beck channel would have some challenges, but it is considered viable and required as part of the works. A list of potential issues are provided below: The Park Beck channel is concrete sided with an assumed concrete base. It is assumed that demolition of this element would be carried out using a combination of mechanical breakers and medium sized plant to remove the broken lengths which would be too heavy for manual handling. To allow the Contractor to carry out these works in the dry some form of flow control/diversion measures would have to be established. Following the demolition of the concrete element of Park Beck, the bank would be required to be re-profiled, the exact methodology for this would have to be agreed with the Contractor and the Regulators but the options to carry out the works could include: i. Using small excavators and dumpers within the watercourse to carry out the re-profiling, it is likely that this would be unavoidable as the removal of the concrete invert could only be achieved from the channel. Access would be either from the shoreline of the Crummock Water or via temporary ramped access. The risk of pollution from plant operating in the watercourse would remain. However, with careful planning and mitigation measures the risks could be minimised. ii. Using a medium reach excavator (i.e. 20 tonnes) it could be possible to carry out the re-profiling from either bank following demolition of the existing concrete structure. This has the	From an engineering perspective, the main impacts associated with this option would be health and safety risks associated with the demolition of the weir, adjacent wave walls and the lined length of Park Beck. Specific risks include the need for Contractors' staff and equipment to operate directly within the lake bed/watercourse including dealing with and controlling flows, lifting operations, bank instability and access to the various areas of the site. Access to the River Cocker and the existing weir structure at the north end of the lake is via the gated forestry track adjacent to the small public car park off the C2030. The C2030 forms part of the coast to coast cycle route and the gated forestry track is a public right of way, so interaction with users of these routes would need to be managed for the duration of the works. To allow removal of the weir and re-naturalisation of the river Cocker the water level of Crummock Water would need to be lowered to allow the works to be carried out in the dry. During this element of the works the Contractor would need to consider the removal of silt that has accumulated on the upstream side of the weir. It is possible that this material could be re-used to provide aquatic/geomorphological benefit or elsewhere on the site for landscaping. Access to the works for the re-naturalisation of Park Beck and the southern lengths of the adjacent wave wall could be achieved by a private track off an unclassified road. The track is initially treelined, which the Contractor would need to consider when programming the work. It is understood that this

DF1	Crummock Water Weir removal	Removal of wave wall	Re-naturalisation of Park Beck	Additional comments
	and weight of the masonry elements would be likely to restrict the Contractor removing the waste material by hand, however the loading could be facilitated by small excavator. iv. Temporary access to the exposed shoreline of Crummock Water directly upstream of the weir would be required for the demolition of the weir and removal of the accumulated silt. The removal of the silt could be undertaken following initial drawdown with the weir in place. This would introduce the potential for an environmental incident should there be a diesel spill etc. However, this risk could be minimised by the Contractor having a spill kit etc on site.		benefit of minimising plant movement in the bed of the channel. iii. For full re-meandering of the channel, more extensive excavation, bank reprofiling and flow diversions would be required, all subject to detailed design and agreement with the contractor.	track is also designated as a public right of way, similarly the track to the rear of the adjacent wave wall is designated as a public right of way. This would need to be considered by the Contractor as temporary diversions could be required. A Hazard Elimination and Risk Reduction (HERR) assessment has been carried out identifying the hazards not be obvious to a competent Contractor and has been included in Appendix I for reference.
Hydraulics	DF1 was not modelled as results from the high-level assessment already indicated a significant reduction in flood risk when both weir and wave wall removal were combined and options on Park Beck were not thought to significantly impact downstream flood risk. Later design fixes were modelled. See Table 6.3.			
Geomorphology	From a geomorphology perspective, following the removal of the Crummock Water weir and a period of natural adjustment there would be an overall positive impact. It would allow re-naturalisation of the natural lake outlet and downstream channel over the medium term to a state that existed some 140 years ago, pre-dam closure. There could be localised and temporary adjustments following dam removal. This would be pre-empted as far as possible as part of the detailed design. However, the dam weir is likely to have caused downstream adjustment through some scour. If a scoured area exists, then a rock ramp or similar feature could be built to accommodate differences of bed level (albeit these are likely to be minor). The Ground Investigation has shown a cohesive clay substrate close to the outlet and it is likely that such geology would have inhibited downcutting and would also minimise future adjustment through knickpoint migration upstream. A new equilibrium would most likely be attained relatively quickly. There is also the potential for either the right or left channel (i.e. either side of the existing island) to develop as a predominant low flow channel over time. It is	Removal of the wall along the edge of the lake upstream of the existing weir would potentially improve connectivity of Crummock Water with a previous floodplain. Its removal would allow more sediment interaction to/ from the lake	**Full Re-meandering of Park Beck** Intervention to re-establish or create meanders in the lower reaches of Park Beck would provide an opportunity to relatively quickly return the natural sediment and flow regime within the channel. However, careful design of the channel would be required and historical maps do not go back far enough to show what the channel would have looked like prior to its artificial straightening. However, an adjacent reach of Park Beck further upstream with similar gradient and geology does provide an analogue for a meandering channel with alternating gravel bars. However, works for this option would be extensive, including carving a new meandering channel planform and actively placing gravels in the channel to pre-empt the formation of deposits. Similar benefits could be realised over a longer period through assisted natural recovery and therefore full re-meandering was scoped out and assisted natural recovery put forward.	

DF1	Crummock Water Weir removal	Removal of wave wall	Re-naturalisation of Park Beck	Additional comments
	considered that this should be regarded as natural adjustment, potentially beneficial to fish movement/migration. There could also be other potential effects of dam/weir removal. In the immediate short term any accumulated fine silt could become washed out, although if this is non-cohesive it is likely to be re-suspended rapidly and that it would be only very localised in the reach below the dam/ weir. Based on a review of the literature, it is unlikely that effects would be more than ephemeral. It is not anticipated that there are accumulations of coarser material behind the dam/ weir sufficient to cause downstream channel change after removal.		**Assisted Natural Recovery of Park Beck** Assisted recovery of the lower reaches of Park Beck would involve removing the existing hard bank reinforcement and embankments and re-establishing some connectivity with the floodplain. Gravels and natural flow deflectors (such as woody material and boulders) would be placed strategically to encourage development of secondary currents and meander bends within the existing channel planform. This option would be self-limiting as meanders would only develop in response to sufficiently powerful currents, eventually reaching an equilibrium. Removal of artificial embankments and creation of a two-stage cross-section would allow connectivity with parts of the floodplain compared to the current over-deep channel that exists. The reduction in water level in Crummock Water following weir removal would have the potential for knickpoint formation in the Park Beck, commencing at the current delta and moving slowly upstream, particularly during flood flows. Design/construction methods would seek to counter any sudden changes in long profile that could lead to knickpoint formation.	
Ecology	Removal of the Crummock Water weir would give migrating fish free access from the River Cocker into Crummock Water and its tributaries. Although the presence of Atlantic salmon and European eel upstream of the weir indicates that it is currently passable by these species, it is considered that at low flows this weir would delay migration of fish. Thus, the removal of this weir and restoration of the outflow of Crummock Water into the River Cocker would permit upstream and downstream fish migration even at low flows. Although the removal of the weir would result in a drop-down in the Crummock Water lake level, which would expose some substrates suitable for Arctic charr spawning, Winfield and James (2017[11]) reported ample spawning habitat for Arctic charr at depths in excess of 1.7m and up to 10.0m and concluded that a 1.5m drop in lake level would have no	Removal of the wall would reconnect Crummock Water with the adjacent floodplain. This has the potential to loosen the compacted substrates along the wall which could free up more spawning habitat in the lake for Arctic charr and possibly provide more habitat for macrophytes, depending on the amount of wave action in the naturalised lake. The reconnection of Crummock Water with adjacent floodplain would also help to improve existing and create new wetland habitat.	The wall and concrete bedding along Park Beck together with its straightened course created a channel with little to no habitat complexity for fish species and thus is useful only for fish migration. Additionally, no suitable habitat for otter resting places (i.e. couches and holts) has been observed in the straightened length of Park Beck and no macrophytes have been observed. It is predicted that both options (assisted natural recovery and full re-meandering) would eventually result in a sinuous channel with varying flow and substrate conditions and natural substrate transport. This would increase habitat complexity in the watercourse and benefit all aquatic species that use Park Beck including otter. Of the two options, full re-meandering would be preferred from an ecological perspective as it would improve habitat conditions more quickly. Both options involve the potential removal of two	Overall, the removal of Crummock Water weir and the wall would result in a moderate improvement in access to Crummock Water to fish moving both upstream and downstream and the removal of the infrastructure at Park Beck would improve habitat conditions for all aquatic species including otter. Although the weir is expected to hinder or delay migration it is not a complete barrier to migration in all flow conditions. Full re-meandering of Park Beck would improve habitat conditions more rapidly than natural recovery. Habitat for Arctic charr spawning and juveniles has been observed in the vicinity of the proposed works, and it is important to protect these

DF1	Crummock Water Weir removal	Removal of wave wall	Re-naturalisation of Park Beck	Additional comments
	significant impact to Arctic charr in Crummock Water. The removal of the weir, and subsequent natural adjustment, would result in a more naturalised channel in the River Cocker with varying flow and substrate conditions. This would benefit fish species, as some lengths of the River Cocker have been identified as migratory corridors only with no habitat variety. Wetland habitats have been recorded in several locations in Crummock Water, particularly in the southern area around Buttermere Dubs, and a drop-down in lake level following weir removal would be expected to reduce overall wetland habitat in Crummock Water. The Marshall Ecology (2013) study on macrophyte distribution around Crummock Water concluded that, based on species composition at different depths in the near-shore area of the lake, a temporary drop-down in Crummock Water of up to 1.1m would be expected to have only minor effects on the predominant macrophyte species in *Littorelletea* habitats.		footbridges over Park Beck, and the replacement bridges must be constructed in a way that does not inhibit fish migration into Park Beck.	habitats during construction (e.g. through timing works to avoid sensitive periods) and retain or improve them after the works are complete. These areas include Arctic charr spawning habitat around Crummock Water weir, close to the proposed site compound east of the weir and alongside the wall to Park Beck. It also includes juvenile Arctic charr habitat south from Park Beck; and juvenile and spawning habitats for salmonids and lamprey species in the River Cocker from Crummock Weir to Scale Bridge. Further, since soft substrates have been identified around the infrastructure these should be removed to prevent fine sediments from moving downstream into the River Cocker and smothering substrates used for spawning and by juvenile fish. All potential impacts associated with construction works would need to be mitigated through the implementation of best practice measures.

6.3 Design Fix 2

Following Design Fix 1 and the PSG meeting in December 2018 the lead option was further refined to display more sinuous outlet channels following removal of the weir, a suggested new location for a river crossing point and inclusion of only the assisted natural recovery option in more detail along Park Beck.

The key findings/impacts of each discipline for Design Fix 2 are presented in Table 6.3.

Table 6.3 Detailed assessment of Design Fix 2 (DF2)

DF2	Crummock Water Weir removal	Removal of wave wall	Re-naturalisation of Park Beck
Engineering	The refinement of the design looks at the original concepts defined in Design Fix 1 of the works and develops these and includes the additional elements to take them forward to a 90% design, identifying key elements for each of the specified work areas. An overview of the refinements is offered below:		
	From investigation of the available historical drawing and a review of the bathymetric survey the levels at the base of the control sluices on the weir has been identified. This has then been used as the defining factor to set the level of the outlet channels from Crummock Water. Setting the invert of the re-naturalised channel as 97.15m AOD achieves a fall tying into the level of 97.06m AOD at the convergence of the two channels. Following removal of the weir structure, the void left by the fish pass length would need to be infilled, graded and landscaped to suit the re-naturalised channels on either side. The works to remove the existing weir structure would remove all the existing bridge structures and replace them with a single access bridge located at the downstream end of the re-naturalisation works. Due to the size of the channel at this location this could be a single span timber kit bridge supported by a steel sub-frame suitable for satisfying the required load capacity. Should it not be possible to construct a bridge without intermediate supports at this location then it would be necessary to move the Public Right of Way to allow a single span bridge to cross the River Cocker downstream of the current location. These works would require to be discussed with the National Trust and the Lake District National Park. The bridge should be ramped for easy access.	The northern length of wall at the left flank of the reservoir has been identified for removal over a length of approximately 250m. From the 2017 topographical survey it suggests that the profile of the existing ground is similar on either side of the wall, so it is anticipated that minimal re-profiling works would be required. However, the “Public Right of Way” runs directly behind the wall and on completion of the works would have to be reinstated in a “like for like” fashion. The southern length of wall below Park Beck has been identified over a length of approximately 50m, including an area of masonry pitched slope, of some 500m². The “Public Right of Way” runs behind this length of wall for some 15m before turning in a western direction and this would require reinstatement in a like for like fashion over this length. Re-profiling of the pitched area following removal of the pitching would be required, the finished profile should match the line and level of the adjacent shoreline and be constructed from similar materials to the natural shoreline.	The design of the works to Park Beck has been refined to demonstrate an approximation of what the channel would look like following the re-naturalisation works. During this process it was decided that the most suitable location to begin the re-naturalisation works would tie into the existing large gravel bank at the western bank of the lake. From this point the channel follows a meandering profile set within a 40m river corridor within which the channel could adjust naturally. Consideration would need to be given to the removal of vegetation by the works. It was discussed with the PSG that the bridge across the western end of Park Beck could be replaced with a bridge that was of similar in construction and have a similar weight capacity. This is because UU do not own some of the land in this area and access could have to maintained.
Hydraulics	The Main Stage B hydraulic modelling involved simulation of the outline design for the full infrastructure removal of the Crummock Water overflow weir, along with the re-naturalisation of Park Beck and the removal of the western wave wall.		
	Re-naturalising the overflow from Crummock Water would reduce the efficiency of the overflow arrangement, less flow would be passed for any given water level. This increase in driving head would cause an increase in storage, and therefore more flow attenuation within the lake. This would result in reduced flood extents downstream and reduced pass forward flows. Removal of the weir infrastructure would reduce the lake top water level by 0.73m from 99.55 mAOD to 98.82 mAOD. As a result, the peak storm water levels in the lake would be reduced relative to the baseline, existing situation case (See Figure 6-1).	Removal of the wave wall on the west of the lake would also contribute to flow attenuation on the River Cocker, allowing flood waters from Park Beck to enter the lake instead of being re-directed towards the River Cocker (See Figures 6-1 and 6-2).	Naturalisation of the downstream end of Park Beck would have minimal effect on the modelled flood extent. There would be some reduced capacity noted on Park Beck where raised bank tops were removed along with increased roughness. However, the effect would be minimal and occur within and area of wet woodland land type owned by United Utilities. Some increased flooding could occur upstream of the access bridge and it is understood that this land is owned by a private landowner, not United Utilities (See Figure 6-1 and 6-2).
Geomorphology	As for DF1.	As for DF1	Assisted natural recovery impacts are discussed in DF1.

DF2	Crummock Water Weir removal	Removal of wave wall	Re-naturalisation of Park Beck
			All parties agreed that addition of gravel bars to promote natural adjustment as a suitable way to 'assist' the recovery of these artificially straightened lengths of channel.
Ecology	As for DF1. The design of the outflow of Crummock Water into the River Cocker should be graded to allow for fish movement into and out of the lake during all flow conditions through at least one of the two outflow channels.	As for DF1	As for DF1. The outflow of Park Beck would be regraded such that the watercourse was connected to Crummock Water in all flow conditions. If the infrastructure at Park Beck was removed and the outflow regraded, it is recommended that some restoration activities should be undertaken to assist in this recovery, such as strategic placement of boulders or large woody debris to create variable flow conditions. These assisted natural recovery activities would improve habitat by providing refuge for fish, altering flows and substrate deposition, and creating habitats for aquatic plants. When Park Beck became reconnected with its adjacent floodplain, it could also create wetland habitats.

6.4 Final Outline Design of Preferred Option

Following Workshop 4 held on the 21st December 2018, where Design Fix 2 was presented via telecom to the PSG, very minor changes were made to the outline design to agree on terminology and to make clearer some of the geomorphological features.

Key results of the final detailed assessment are shown below and the series of final outline design drawings are shown at the end of this section.

6.4.1 Engineering

It is anticipated that within the 40 years following infrastructure removal, the lake and associated watercourses would return to a naturalised state and evidence of any historical hard engineering would no longer be present in the landscape. The outline design drawings have been updated to include comments made by the PSG and are displayed as Figures 6-4 through to 6-12.

A high-level assessment on costings for this option has been undertaken and can be found in Appendix J. UU cost engineers/ quantity surveyors will need to determine final costs following the detailed design.

Following the development of the final outline design, new information came to light on the historical construction activities at the weir through Darryl Hughes' currently unpublished PhD research. A review of this information was carried out to assess the possibility of returning the outlet level of Crummock Water to the original outlet level as recorded in 1879 prior to the timber weir being installed. From this it was determined that whilst this would re-naturalise flow regimes and improve salmon migration along the River Cocker, this scenario would not remove the lake from the Reservoirs Act or remove United Utilities responsibilities as Undertaker for the lake as it would still be classed as being able to hold a body of water, greater than 25,000m^3, above the natural ground. In order to remove this obligation under the act, the new natural lake outlet is required to be set at the level of the lower sluice gate (97.15m AOD), which is what the final outline design is based upon. More detail on this decision is provided in Appendix K.

6.4.2 Hydraulics

With all abstraction infrastructure removed, flood modelling results show that the naturalised outfall from Crummock Water makes it less efficient, resulting in greater flood rise in Crummock Water, and increased attenuation, thereby reducing the flows in the River Cocker (Figure 6-1). At Park Beck, removal of the walls would allow surcharged flows to discharge into Crummock Water, rather than by-passing the lake. This would further reduce the maximum flow within the River Cocker as shown in Figure 6-2.

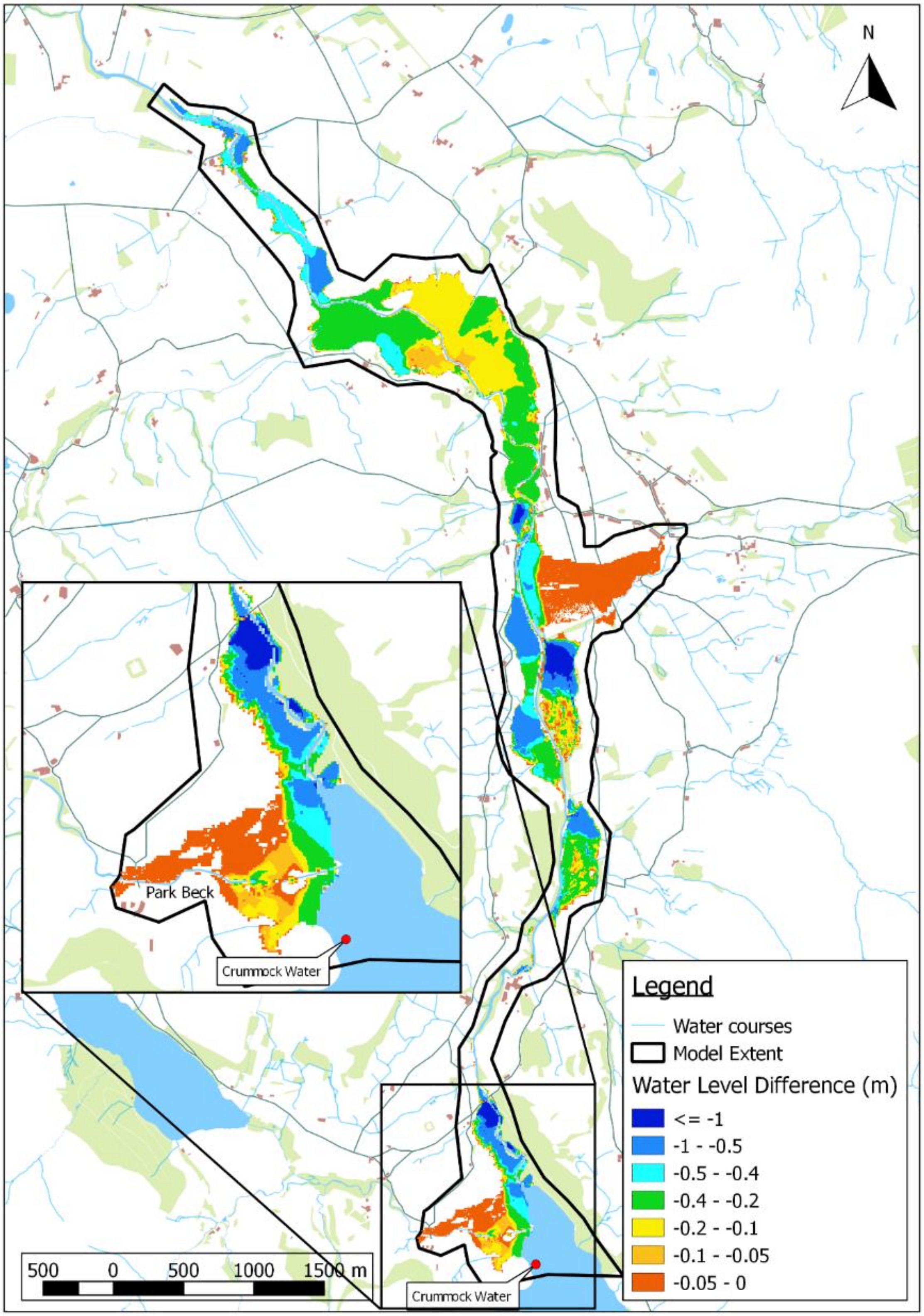

Figure 6-1: Water Level Difference 1% AEP Design vs Baseline

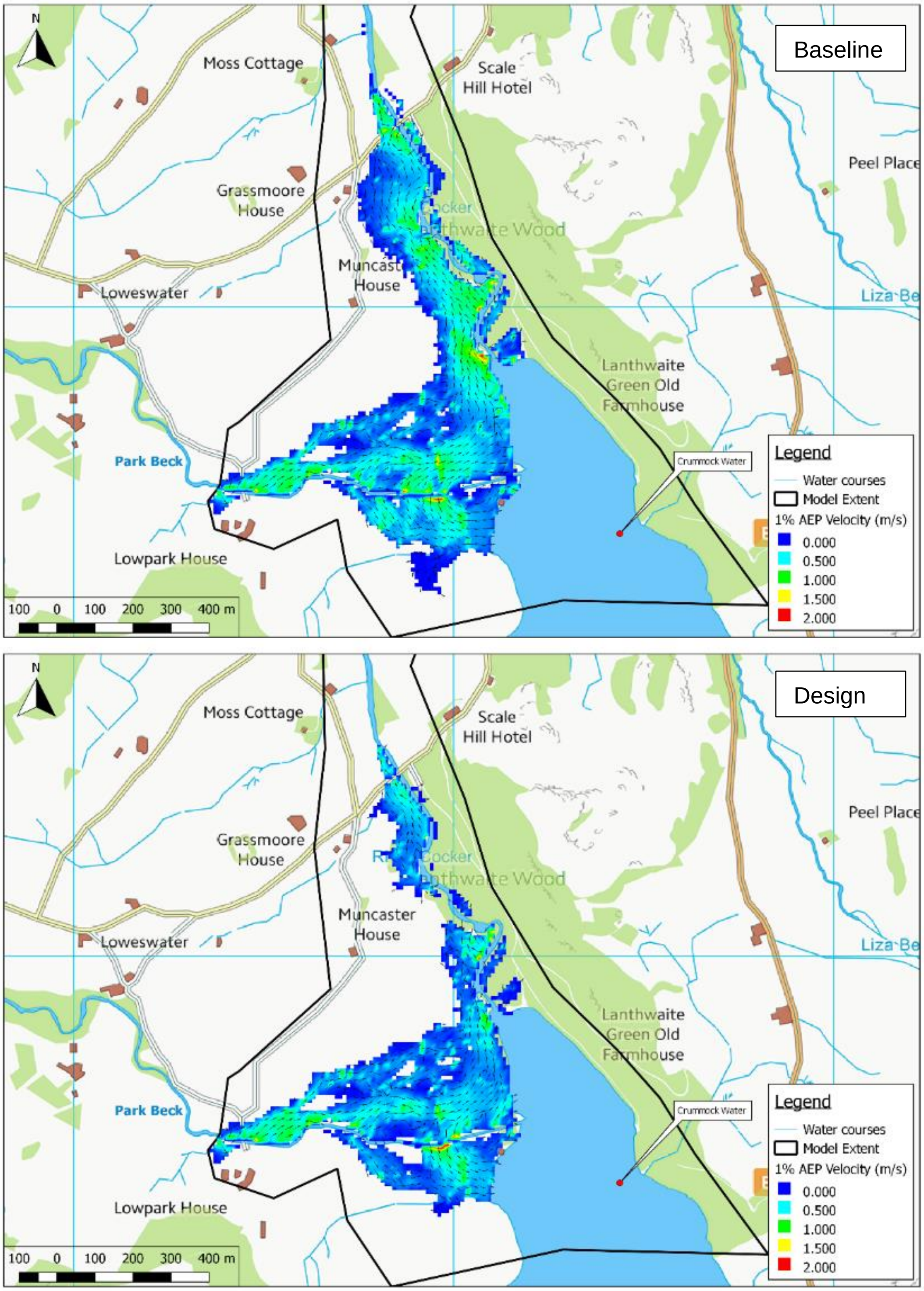

Figure 6-2: Park Beck Flood Mechanism with Design compared to the Baseline

6.4.3 Geomorphology and ecology

Full removal of the Crummock Water weir, Crummock Water wall and hard infrastructure in Park Beck would allow free movement of fish in the short term. In the short to long term, the natural transport of substrates would be re-established. Both flow regime and supporting habitat for aquatic species would be improved, likely increasing spawning gravels extent and quality for Atlantic salmon.

Although some spawning gravels in Crummock Water for Arctic charr would be lost, this could be ameliorated through loosening up of compacted substrates and an increase in sediment transport from Park Beck. Flooding of the woodlands to either side of Park Beck could result in the creation of wetland habitat.

Natural recovery at Park Beck would be expected to take several decades, possibly up to 100 years, as this is not a highly active channel. However, it is anticipated that this channel, the lake and other associated channels would likely establish an equilibrium (i.e a naturalised state) substantially within the next 40 years. It is expected that some habitat complexity in Park Beck would have been achieved more quickly through the addition of boulders and large woody debris and that the habitat for aquatic species would be improved in Park Beck.

A conceptual model for the final outline design is shown in Figure 6-3.

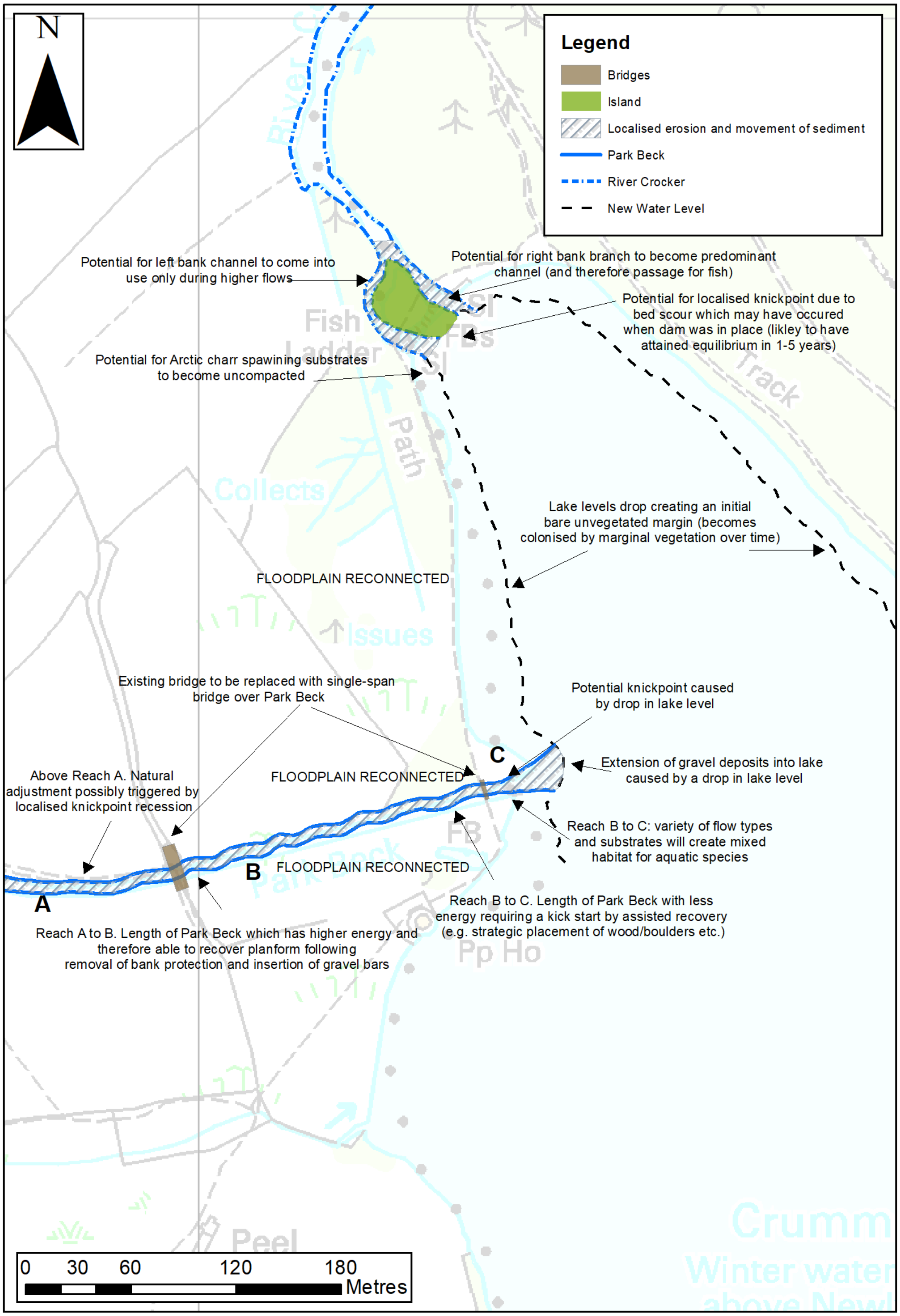

Figure 6-3: Conceptual model showing Crummock Water, Park Beck and the River Cocker following the removal of abstraction infrastructure

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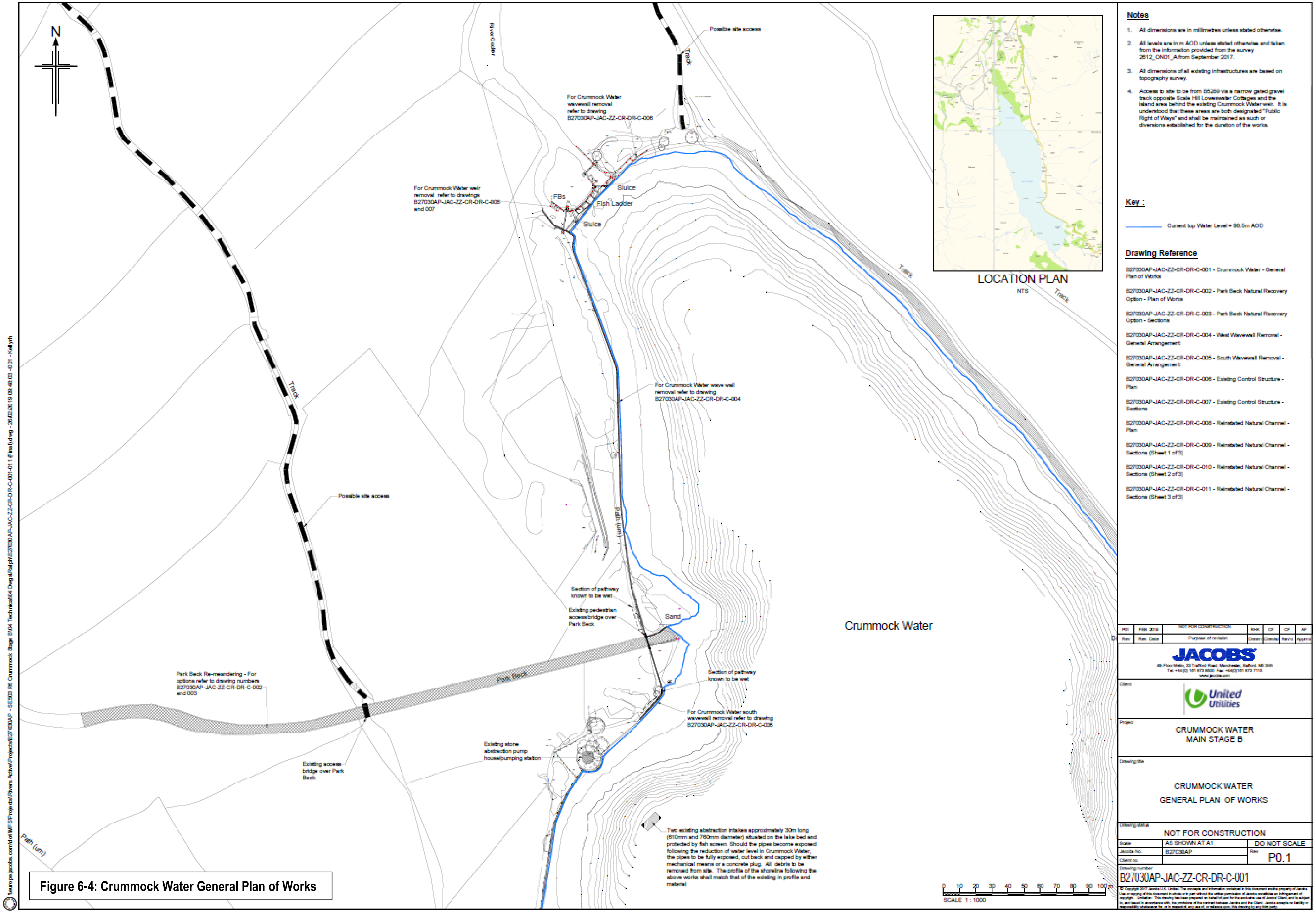

Figure 6-4: Crummock Water General Plan of Works

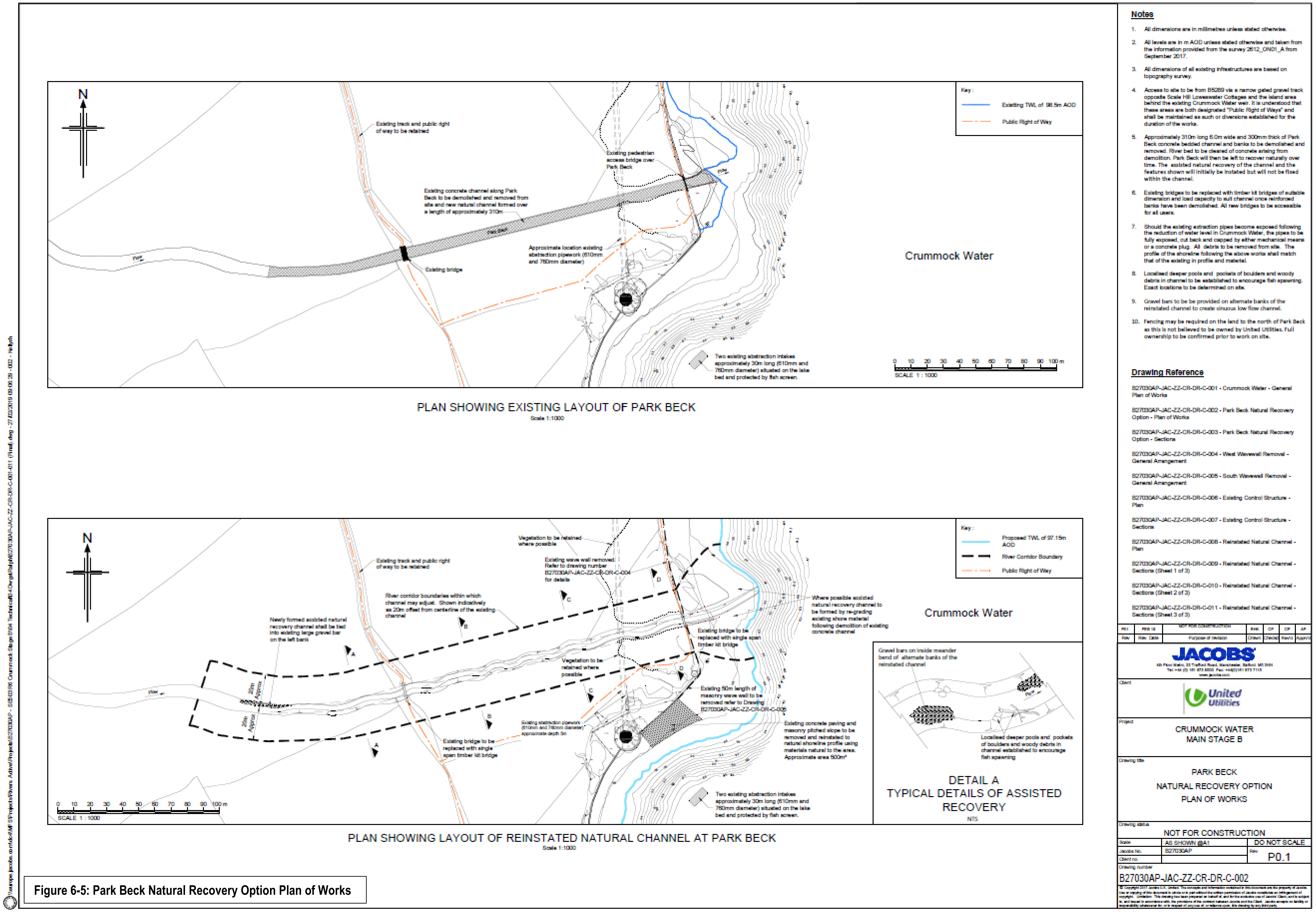

Figure 6-5: Park Beck Natural Recovery Option Plan of Works

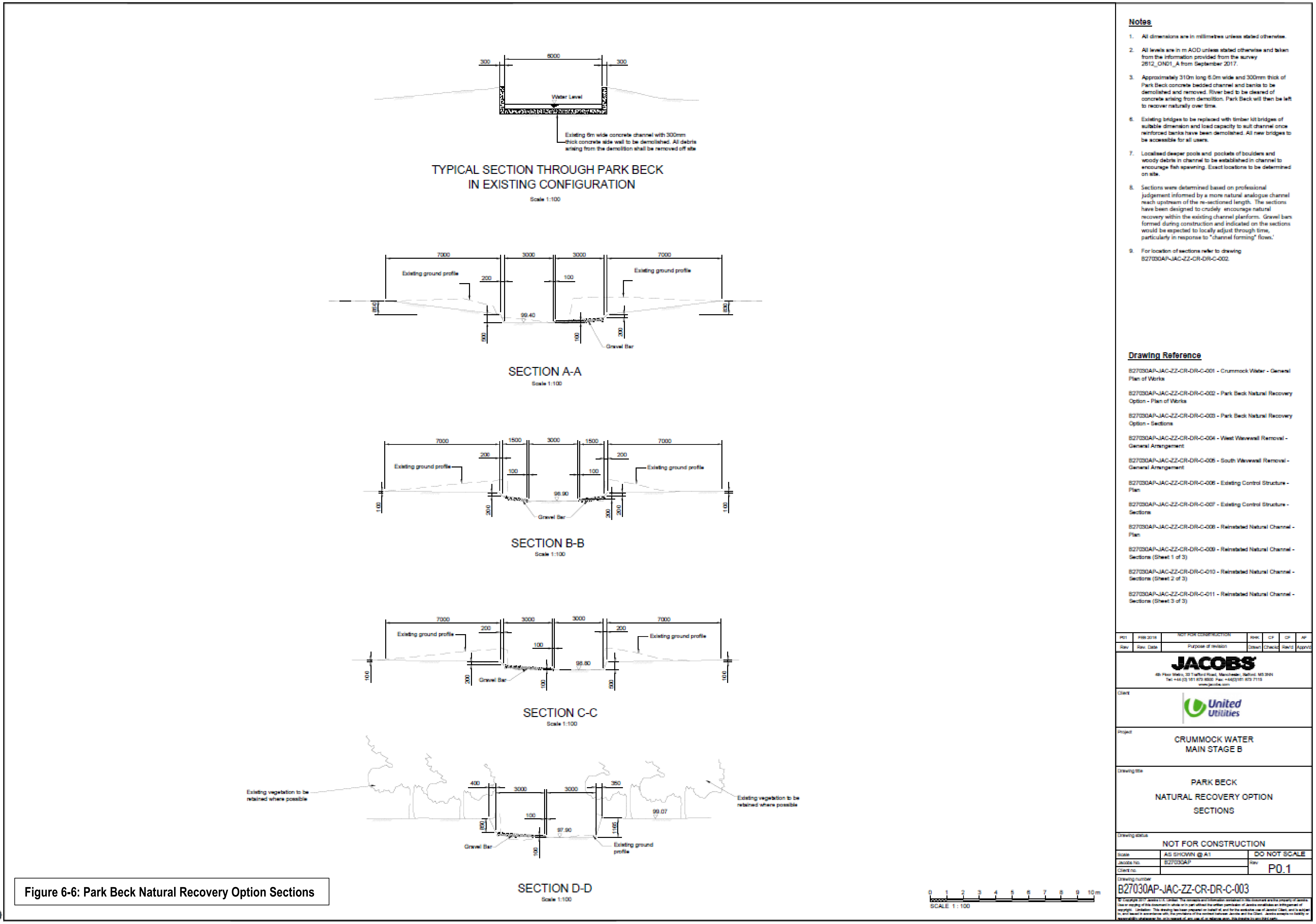

Figure 6-6: Park Beck Natural Recovery Option Sections

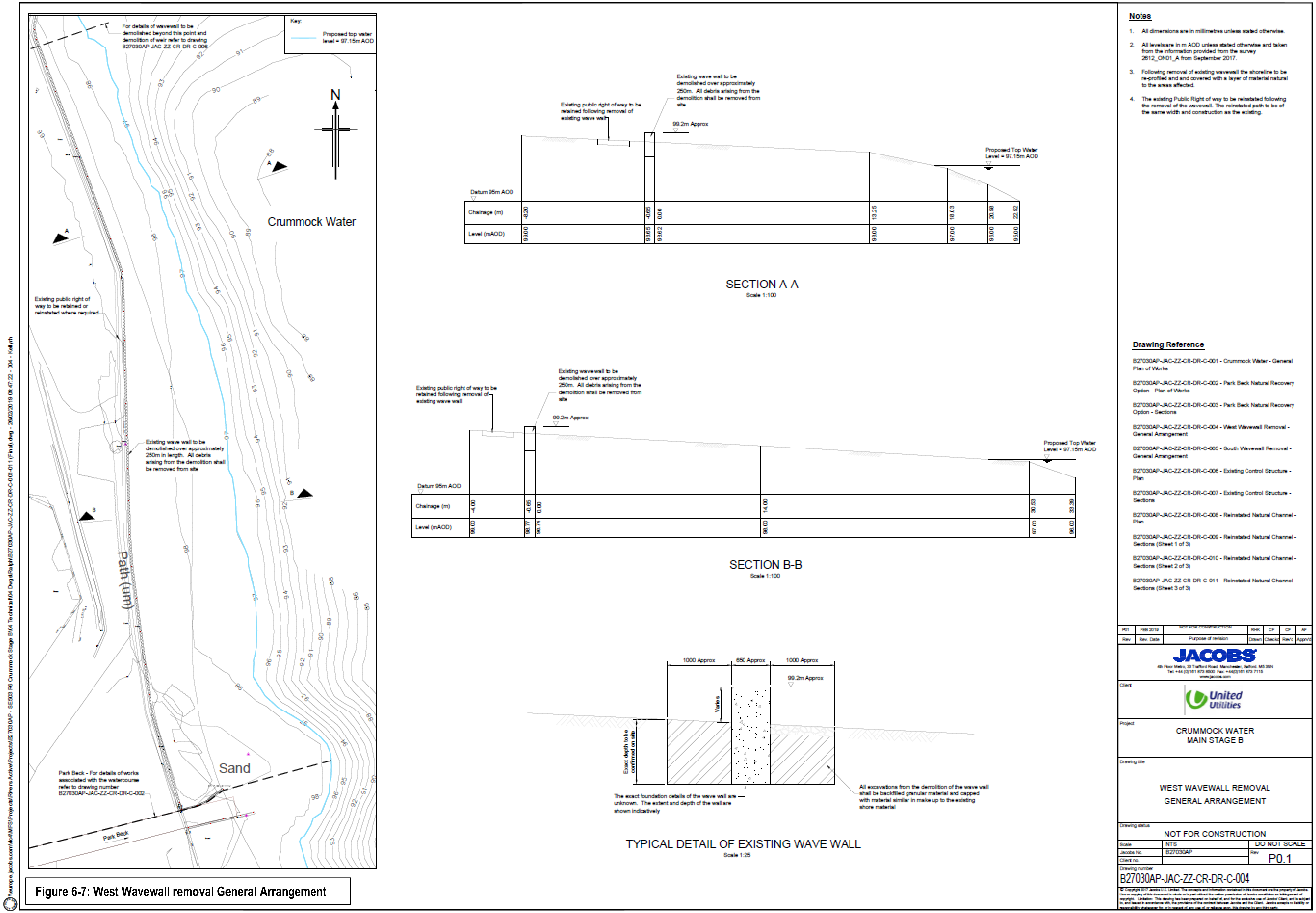

Figure 6-7: West Wavewall removal General Arrangement

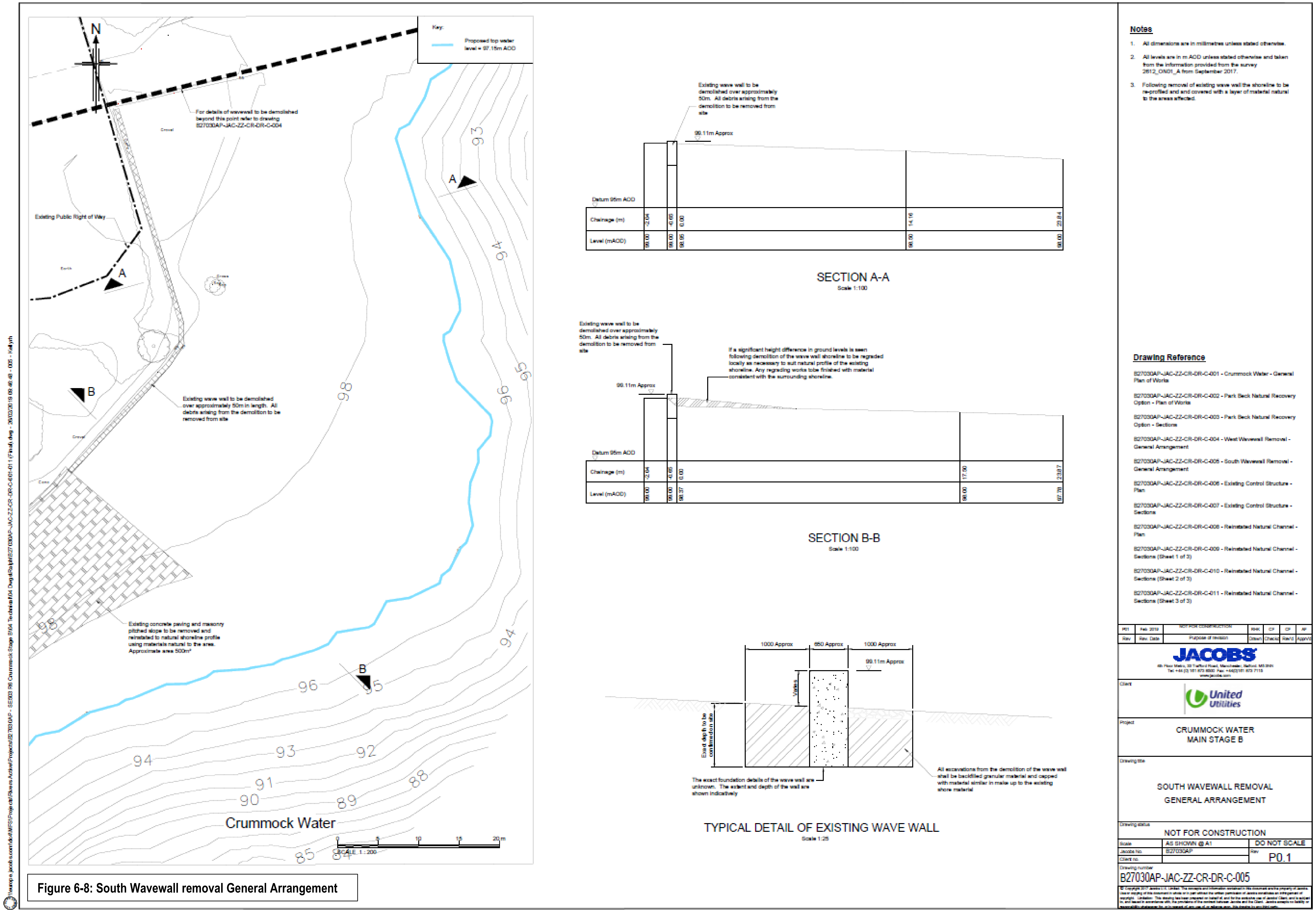

Figure 6-8: South Wavewall removal General Arrangement

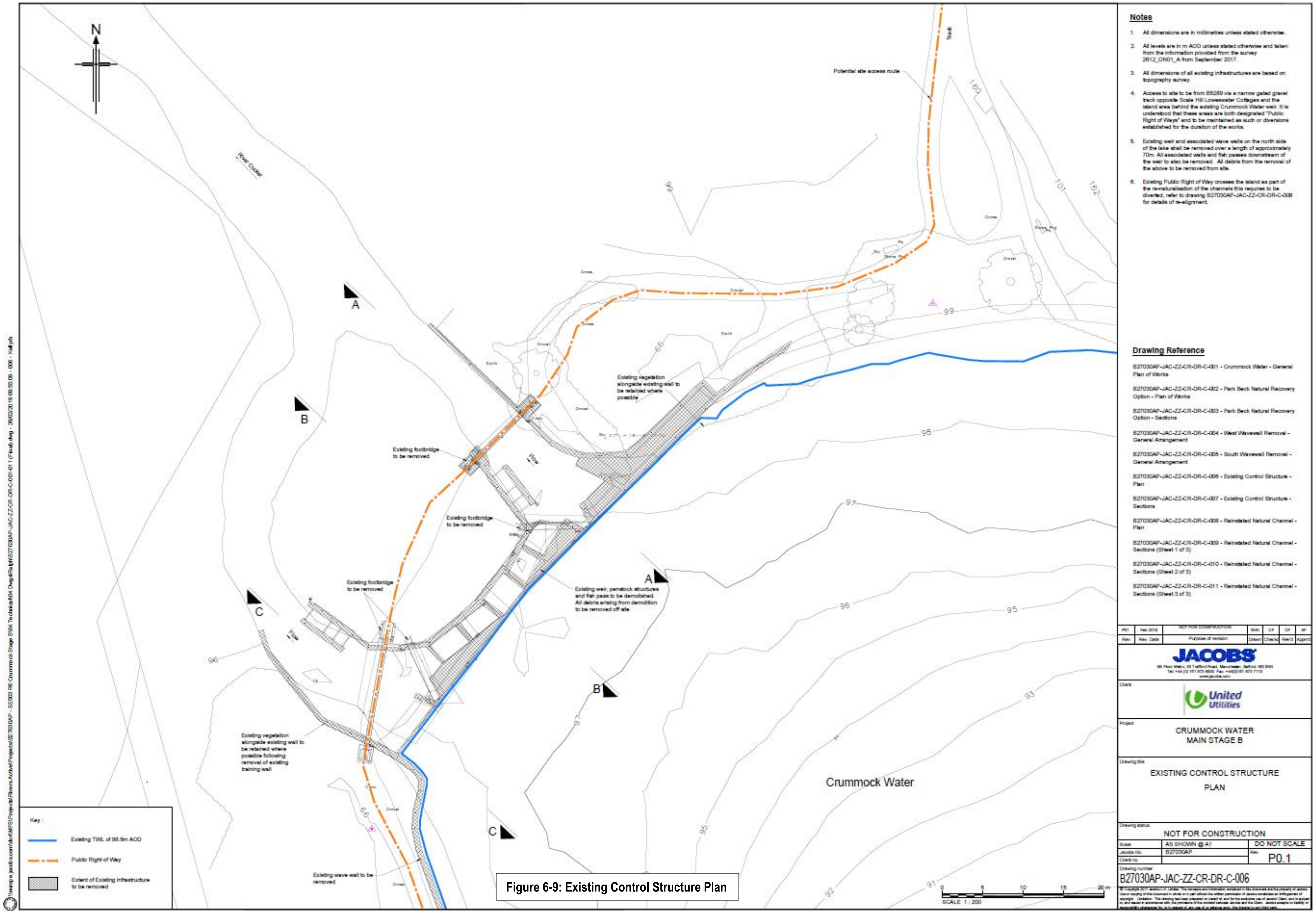

Figure 6-9: Existing Control Structure Plan

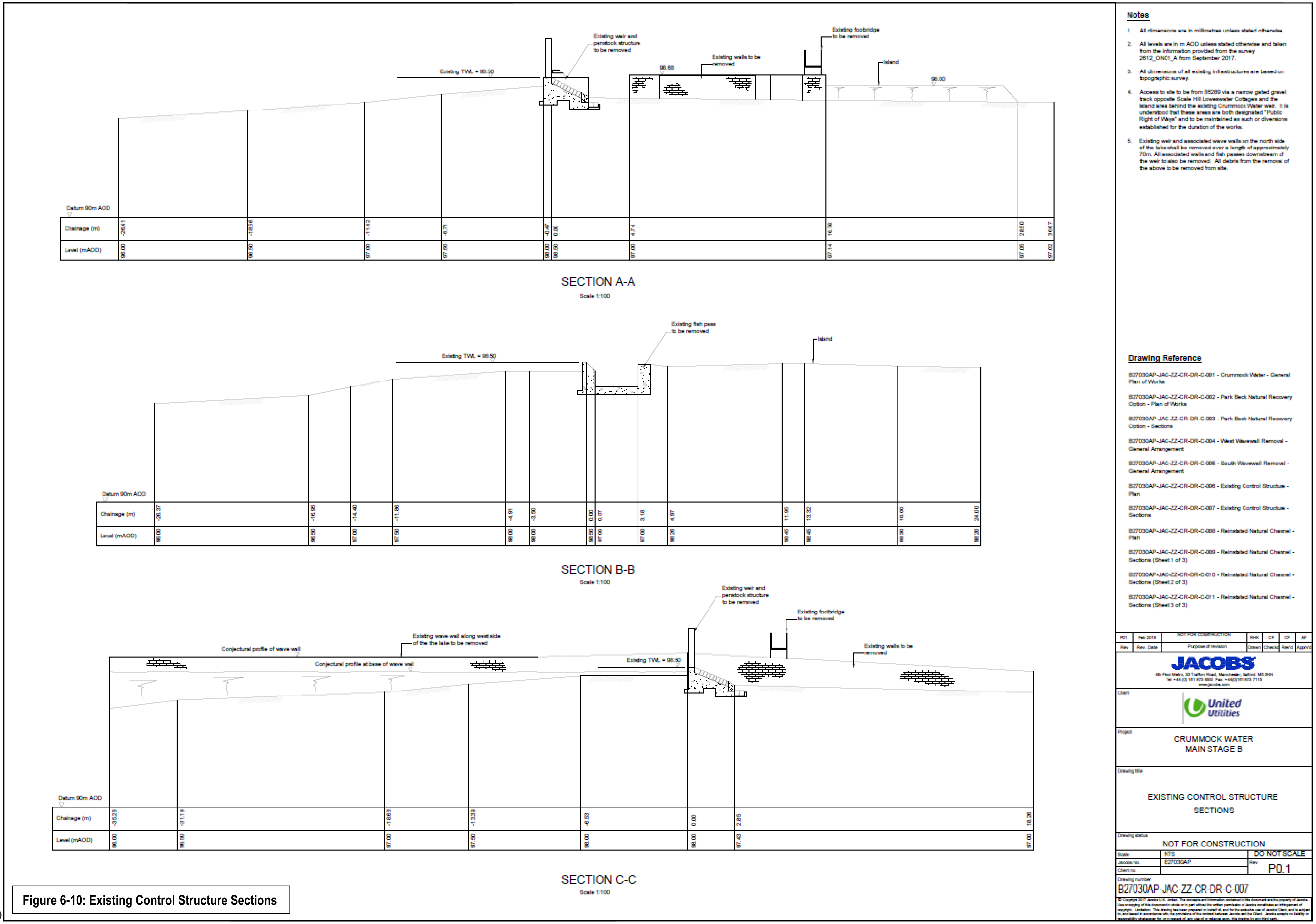

Figure 6-10: Existing Control Structure Sections

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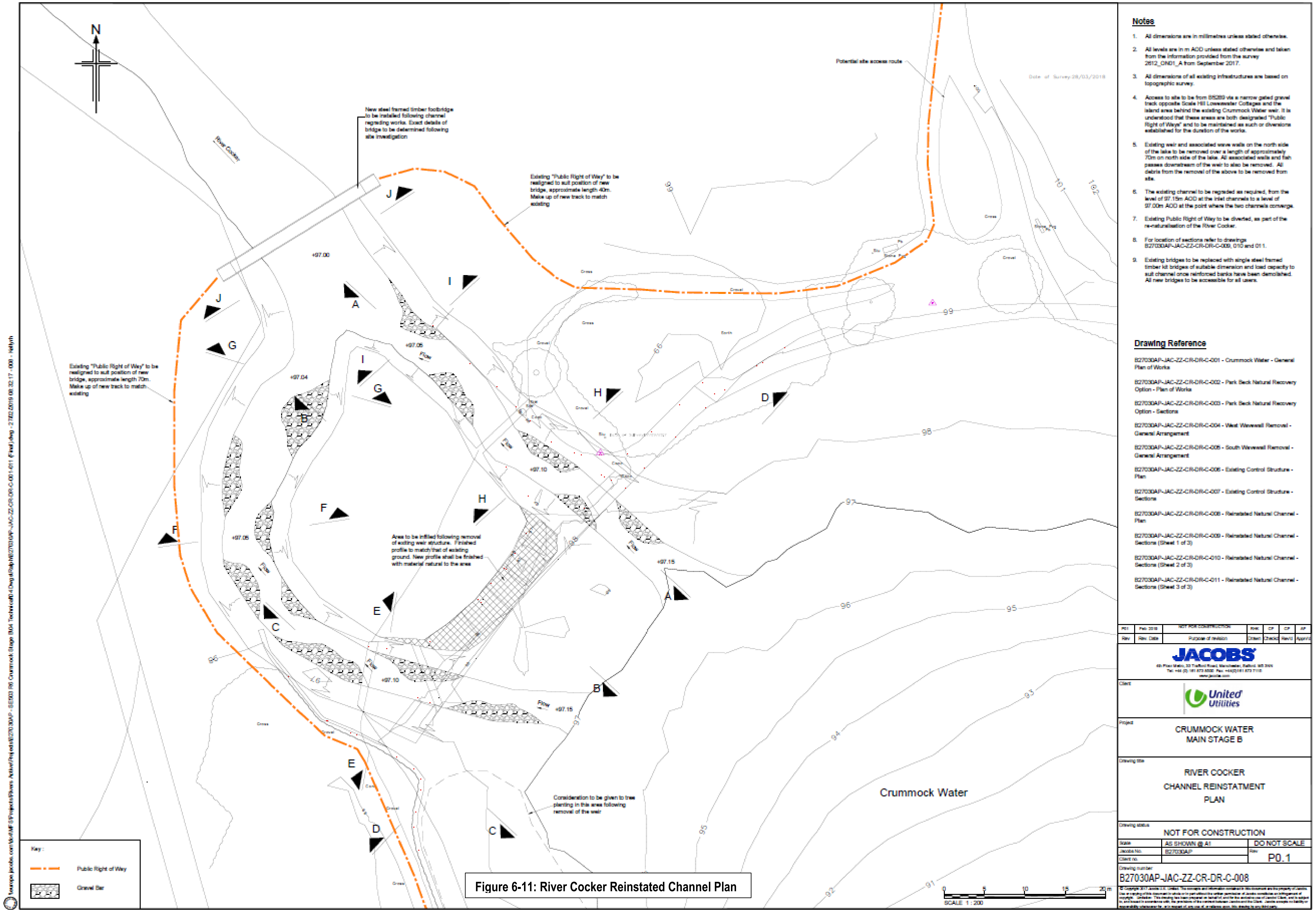

Figure 6-11: River Cocker Reinstated Channel Plan

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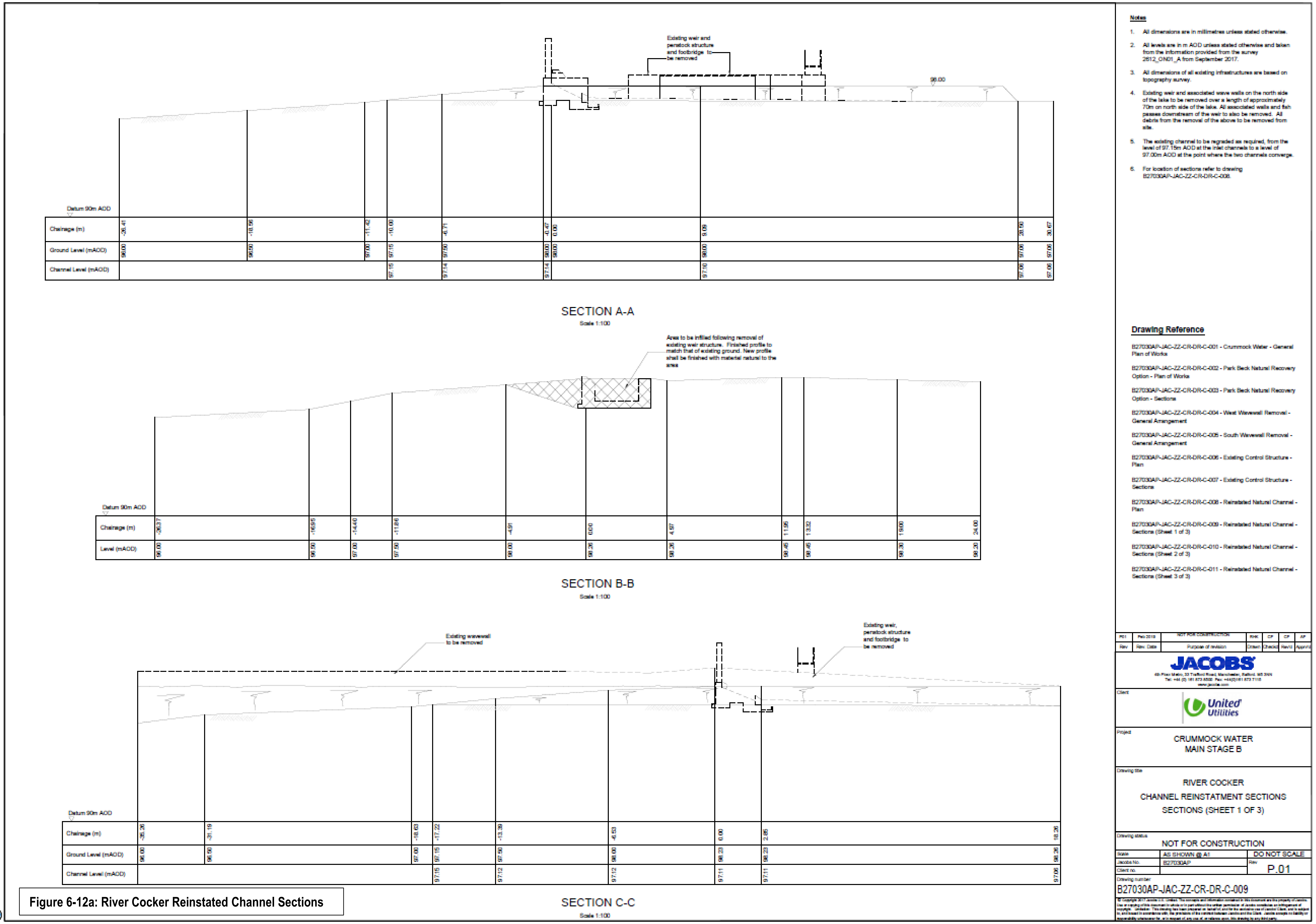

Figure 6-12a: River Cocker Reinstated Channel Sections

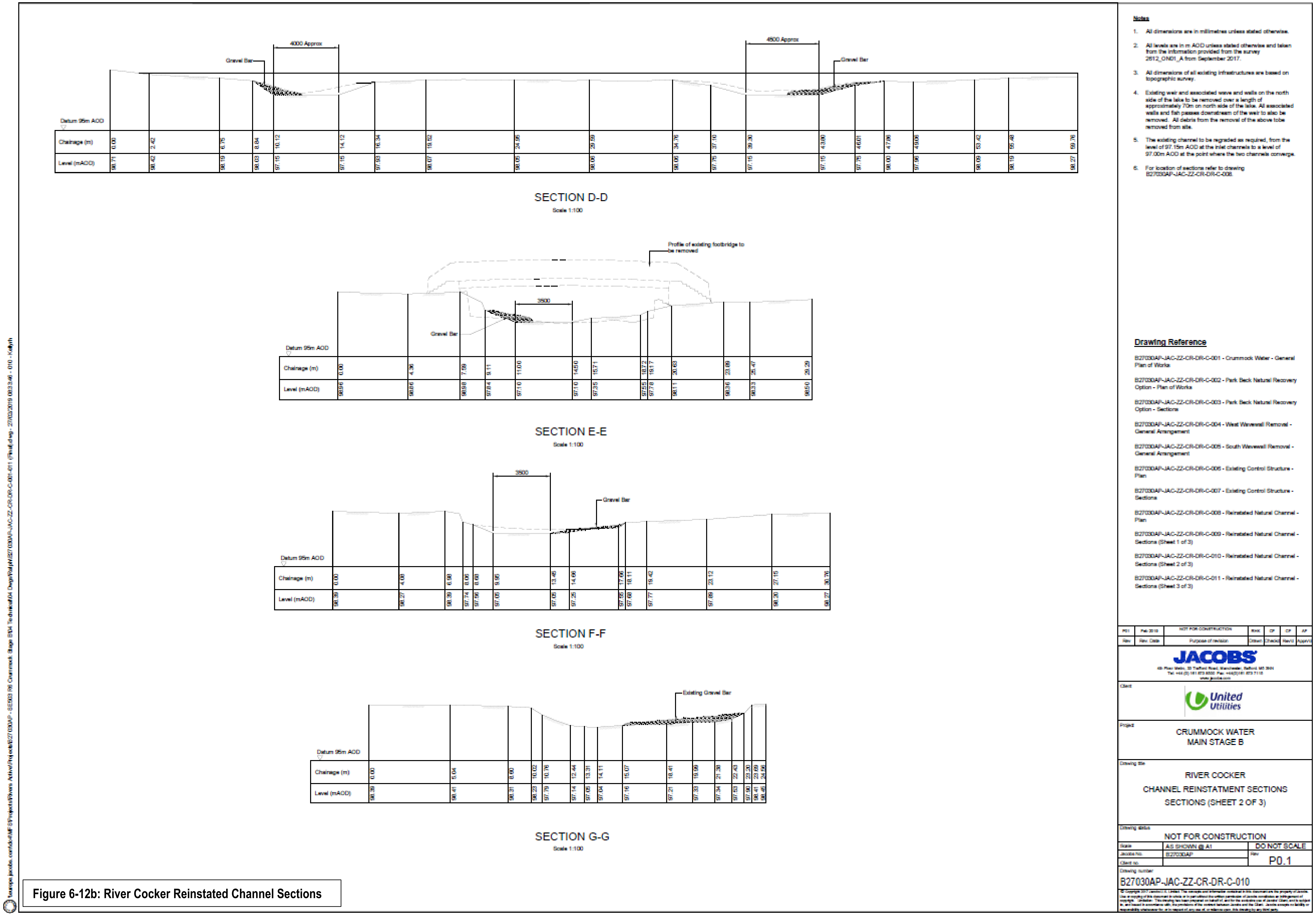

Figure 6-12b: River Cocker Reinstated Channel Sections

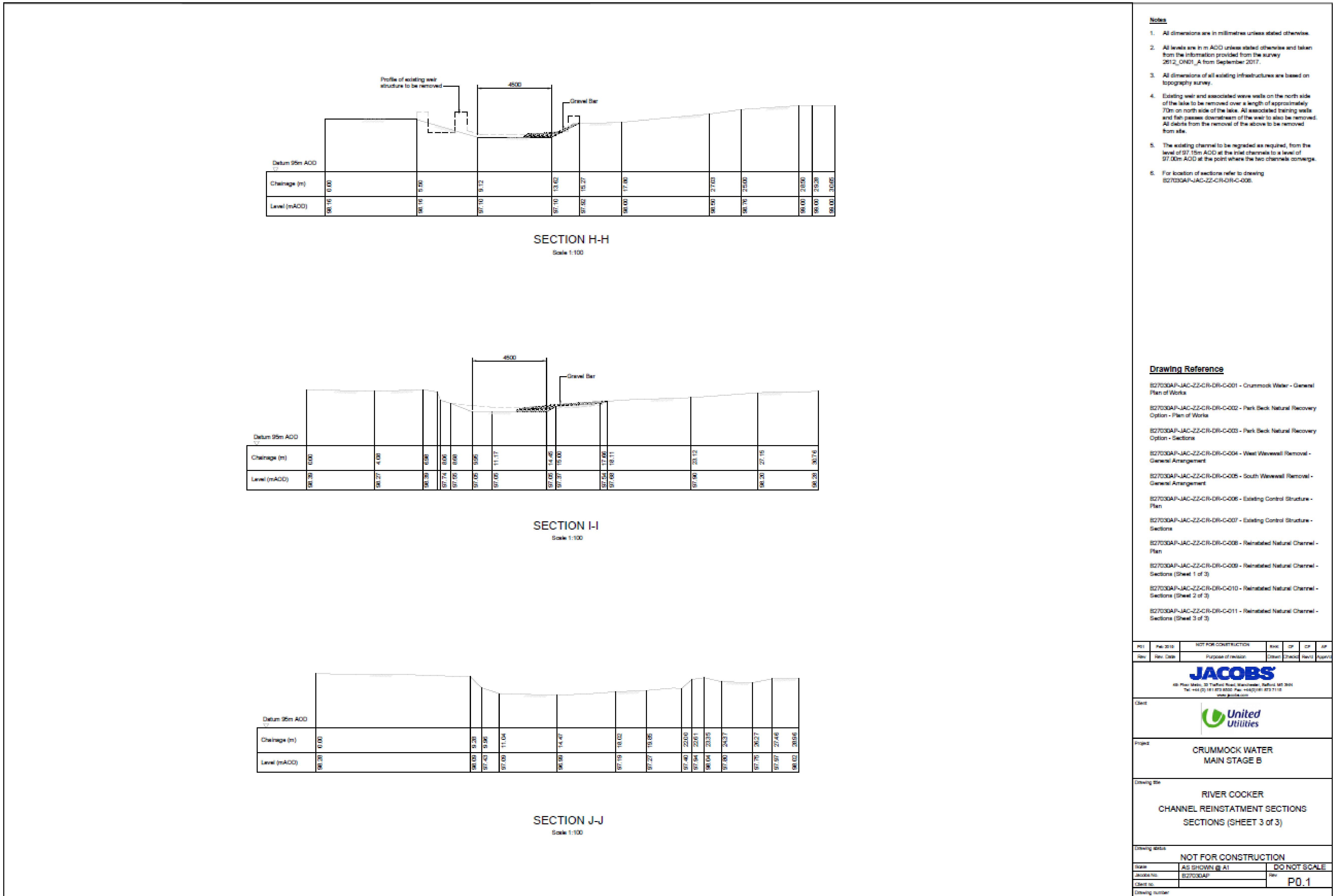

Figure 6-12c: River Cocker Reinstated Channel Sections

7. Recommendations

To proceed from outline design to a more detailed design, the following recommendations are given for implementation during the next stage of the development:

- Consideration should be given to the final design of the bridges, such that they single span with no intermediate supports within the watercourses and are in keeping with the adjacent areas. In addition to this, loadings and ground conditions should be confirmed prior to the final design.
- The ownership and maintenance regime for any new infrastructure, mainly the bridges, should be considered to make sure that the bridges meet health and safety legislation and remain in a functional state over their design life.
- Sediment transport equations should be applied to determine an appropriate sizing of bed material for placed bars in Park Beck and Crummock Water.
- Consideration should be given to the re-use of existing sediment where possible (e.g. re-use of accumulated delta material at confluence of Park Beck with Crummock Water). Further discussion would be required at the detailed design stage.
- Additional information for other tributaries of Crummock Water should be collected to make sure that they do not become disconnected from the lake due to the general drawdown of water levels following the weir removal. Mitigation for such an effect (if proven) could be to excavate tributary channels of suitable size across the newly exposed lake margin to contain flow. Any abrupt changes in channel slope or substrate should be avoided at each of these locations to obviate adverse knickpoint formation/recession upstream.
- It is extremely likely that a full Environmental Impact Assessment would be required to take works forward to detailed design. Such an assessment should cover environmental issues not covered to date, such as landscape, heritage, archaeological, social and the appearance of a lowered lake in the short term. Flood risk modelling would need to go into more detail to assess a potential for flood peaks of the River Cocker coinciding with flood peaks on River Derwent downstream.
- A detailed Water Framework Directive Assessment should be completed at the next stage to avoid deterioration in the four WFD water bodies potentially affected by the works. It is possible that Crummock Water could be required to be reclassified to a non-HMWB following the cessation of water abstraction and removal of infrastructure. This would be a positive outcome.
- A Habitat Regulations Assessment will be required.
- A comprehensive land quality study should be undertaken of the area adjacent to Park Beck to make sure that there are no contaminants that could pollute the water environment when a wider channel cross-length is dug into the existing floodplain.
- A Construction Environmental Management Plan (CEMP) should be implemented and include mitigation measures to reduce the likelihood of fine sediment delivery downstream as a consequence of weir removal on Crummock and hard bank reinforcement removal along Park Beck.
- A stakeholder engagement strategy should be developed to take on board all viewpoints and to get maximum engagement from local communities.

8. References

Aarestrup, K. and Koed, A. (2003) Survival of migrating sea trout (Salmo trutta) and Atlantic salmon (Salmo salar) smolts negotiating weirs in small Danish rivers. Ecology of Freshwater Fish 12: 169–176. https://doi:10.1034/j.1600-0633.2003.00027.x

Amec Foster Wheeler (2014). Technical note: River Cocker Macrophyte Survey.

APEM (2012). NEP Fish Screen/Pass Project Crummock Water near Brackenthwaite, Cumbria.

Armstrong, J. D., Kemp, P. S., Kennedy, G. J. A., Ladle, M., & Milner, N. J. (2003). Habitat requirements of Atlantic salmon and brown trout in rivers and streams. Fisheries Research, 62(2), 143–170.

Atlantic Geomatics (UK) Ltd (2017). Topographical Survey Report: Crummock Water to IR to Cornhow WTW

Biological Records Centre (2018). Crayfish Occurrence Record 283092441. Available at: https://records.nbnatlas.org/occurrences/fb57ff33-72f6-4726-9c4f-5ebbbcb1cf8a (Accessed October 2018).

British Geological Survey (BGS) (2019). Geology of Britain Viewer. Available online at: http://mapapps.bgs.ac.uk/geologyofbritain/home.html. [Accessed 14/02/2019].

British Library. (2017). Ordnance Survey mapping. Reading Rooms, London.

Brookes, A., Eales, R., Fisher, J., Foan, C and Twigger Ross (2001). An Approach to integrated appraisal: Progress by the Environment Agency in England and Wales., J. Env. Assesment. Policy Management., 3 (2001)

Cascade (2014). United Utilities Crummock Water Drought Order Environmental Scoping Report. Final Report to United Utilities

Capital Symonds and AECOM (2018) Kendall Appraisal Package, Appendix A, May 2018

Channin, P. (2003). Ecology of the European otter. Conserving Natura 2000 River Ecology Series No. 10. English Nature, Peterborough.

Centre for Environment, Fisheries and Aquaculture Science (2019). Assessment of Salmon Stocks and Fisheries in England and Wales, 2018. Available at: https://www.gov.uk/government/publications/assessment-of-salmon-stocks-and-fisheries-in-england-and-wales-in-2018 (accessed February 2020).

CH2M (2016). Cockermouth Model Handover Note

Chow, Ven Te (1959). Open-Channel Hydraulics. McGraw-Hill

Cranfield Soil and Agrifood Institute (2016). Available at: http://www.landis.org.uk/soilscapes/about.cfm [Accessed14/09/2017].

Dawson, H., Quintella, B.R., Almeida, P.R., Treble, A.J. and Jolley, J.C. (2015). Chapter 3 The ecology of larval and metamorphosing lampreys. In: Docker, M. (ed.) The Biology of Lampreys, Springer.

Dixon M. (2016) Dixon M. (2016) Supervising Engineer's Statement, Crummock, United Utilities

Environment Agency (2005) The West Cumbria Otter Survey, Technical Memorandum 827 (02/06).

Environment Agency (2015) North West River Basin Management Plan (RBMP). Available online at: https://www.gov.uk/government/publications/north-west-river-basin-district-river-basin-management-plan. [Accessed 14/09/2017].

Environment Agency (2017a) Catchment Data Explorer. Available online at: http://environment.data.gov.uk/catchment-planning/. [Accessed 14/09/2017].

Environment Agency (2017b) 2009 1m resolution LiDAR DTM data obtained from Survey Open Data. [online] Available at http://environment.data.gov.uk/ds/survey/index.jsp#/survey [Accessed September 2017].

Environment Agency (2017c) Salmonid and fisheries statistics for England and Wales 2015. Available from: https://www.gov.uk/government/publications/salmonid-and-freshwater-fisheries-statistics [Accessed February 2020].

Environment Agency (2018a) Salmonid and fisheries statistics for England and Wales 2017. Available from: https://www.gov.uk/government/publications/salmonid-and-freshwater-fisheries-statistics [Accessed February 2020].

EA (Environment Agency) (2019) What's in your backyard? Catchment Data Explorer, Available from: https://environment.data.gov.uk/catchment-planning/OperationalCatchment/3095 [Accessed on 19/2/19]

Environment Agency (2020). Freshwater Fish Counts for all Species, all Areas and all Years. Available at: https://data.gov.uk/dataset/f49b8e4b-8673-498e-bead-98e6847831c6/freshwater-fish-counts-for-all-species-all-areas-and-all-years (Accessed February 2020).

Environment Agency (2018c) Crummock Water WFD Water body information http://environment.data.gov.uk/catchment-planning/WaterBody/GB31229000 (Accessed October 2018).

Environment Agency (2018d). River Cocker Catchment Summary. Available at: http://environment.data.gov.uk/catchment-planning/OperationalCatchment/3095/Summary (Accessed October 2018).

Environment Agency (2018e). Cocker – conf Whit Beck to conf Derwent. Available at: http://environment.data.gov.uk/catchment-planning/WaterBody/GB112075070400 (Accessed October 2018).

Environment Agency (2018f). Whit Beck. http://environment.data.gov.uk/catchment-planning/WaterBody/GB112075070380 (Accessed October 2018).

Environment Agency (2018g). Cocker – Crummock Water to conf Whit Beck. Available at: http://environment.data.gov.uk/catchment-planning/WaterBody/GB112075070370 (Accessed October 2018).

Environment Agency (2018h). Crummock Water. Available at: http://environment.data.gov.uk/catchment-planning/WaterBody/GB31229000 (Accessed October 2018).

Environment Agency (2018i). Dub (Park) Beck. Available at: http://environment.data.gov.uk/catchment-planning/WaterBody/GB112075070360 (Accessed October 2018).

Environment Agency (2018j). Fifth otter survey of England 2009-2010. Technical Report. Available at; http://www.thepredationactiongroup.co.uk/images/EA_otter_survey_oct10.pdf (Accessed October 2018).

Environment Agency (2019) Assessment of Salmon Stocks and Fisheries in England and Wales in 2018. Available at; https://www.gov.uk/government/publications/assessment-of-salmon-stocks-and-fisheries-in-england-and-wales-in-2018 (Accessed February 2020).

Gauld, N., Campbell, R. and Lucas, M. (2013) Reduced Flow Impacts Salmonid Smolt Migration in a River with Low-Head Weirs. Science of the Total Environment 458: 435–443.

Geotechnics (2018) Ground Investigation - Crummock Water GI Factual Report for United Utilities Limited. Project Number PN183877. United Utilities

Grey, J., Thackeray, S.J., Jones, R.I. and Shine, A. (2002). Ferox trout (Salmo trutta) as 'Russian dolls': complementary gut content and stable isotope analyses of the Loch Ness foodweb. Freshwater Biology 47:1235-1243.

Hendry, K. & Craggs-Hine, D. (2003) Ecology of the Atlantic salmon. Conserving Natura 2000 Rivers Ecology Series No.7. English Nature, Peterborough.

International Union for Conservation of Nature (IUCN) (2018). Anguilla anguilla. Available at: http://www.iucnredlist.org/details/60344/0 (Accessed October 2018).

Jacobs (2010a) PSA3 Riverine SSSI Restoration Visions. November 2009 Flood Impact Survey. Report for the Environment Agency and Natural England

Jacobs (2010b). Development of a loch routing model approach for estimating the impact of lochs on flow statistics. Report for SEPA

Jacobs (2016a) Ehen Compensatory Measures-Scoping report for R6 and R3 Bleaching weirs removal. Report for United Utilities

Jacobs (2016b). NEP AMP6 Sediment Management Plan Crummock Water. Final report for United Utilities

Jacobs, (2018). Ehen Compensation Measures: Crummock Water – Summary Report for Main Stage A. Report for United Utilities (Research Measure 6)

JBA Consulting (2013), River Cocker at Low Lorton and Whit Beck at High Lorton – Modelling Report

Joint Nature Conservation Committee (2018). River Derwent and Bassenthwaite Lake. Available at: http://jncc.defra.gov.uk/protectedsites/sacselection/sac.asp?EUCode=UK0030032 (Accessed October 2018).

Joint Nature Conservation Committee (2015) http://jncc.defra.gov.uk/protectedsites/sacselection/n2kforms/UK0030057.pdf.

Jones, I. D., Winfield, I. J., & Carse, F. (2008). Assessment of long-term changes in habitat availability for Arctic charr (Salvelinus alpinus) in a temperate lake using oxygen profiles and hydroacoustic surveys. Freshwater Biology, 53(2), 393–402.

Kelly, F.L. and King, J.J. (2001). A review of the ecology and distribution of three lamprey species, Lampetra fluviatilis (L.), Lampetra planeri (Bloch) and Petromyzon marinus (L.): a context for conservation and biodiversity considerations in Ireland. Biology and Environment: Proceedings of the Royal Irish Academy, vol. 101B, no. 3, pp. 165-185.

Klemetsen, A., Amundsen, P.-A., Dempson, J., Jonsson, B., Jonsson, N., O'Connell, M., & Mortensen, E. (2003). Atlantic salmon Salmo salar L., brown trout Salmo trutta L. and Arctic charr Salvelinus alpinus (L.): a review of aspects of their life histories. Ecology of Freshwater Fish, 12, 1–59.

Knights, B. & White, E.M. (1998) Enhancing immigration and recruitment of eels: the use of passes and associated trapping systems. Fisheries Management and Ecology, 5: 459-471.

LEAP West Cumbria Action Plan (1999). Available at: http://www.environmentdata.org/fedora/repository/ealit:1617/OBJ/20000940.pdf. (Accessed October 2018)

Maberly, S. C., De Ville, M. M., Thackeray, S. J., Feuchtmayr, H., Fletcher, J. M., James, J. B., Kelly, J. L., Vincent, C. D. & Winfield, I. J. (2011). A survey of the lakes of the English Lake District: The Lakes Tour 2010. NERC/Centre for Ecology & Hydrology, C04357, 137pp.

Marshall Ecology (2013). Crummock Water Wetland Survey. Report no. 130502/02.2.

Maitland, P. S. (2003). Ecology of the River, Brook and Sea Lamprey. Conserving Natura 2000 Rivers Ecology Series No. 5, English Nature, Peterborough.

Maitland, P.S. (2007) Scotland's Freshwater Fish. Ecology, Conservation & Folklore, Trafford Publishing (UK) Ltd.

Maitland, P. S., Winfield, I. J., McCarthy, I. D., & Igoe, F. (2007). The status of Arctic charr Salvelinus alpinus in Britain and Ireland. Ecology of Freshwater Fish, 16(1), 6–19.

Miller, H., Winfield, I. J., Fletcher, J. M., Ben James, J., van Rijn, J., Bull, J. M., & Cotterill, C. J. (2015). Distribution, characteristics and condition of Arctic charr (Salvelinus alpinus) spawning grounds in a differentially eutrophicated twin-basin lake. Ecology of Freshwater Fish, 24(1), 32–43.

Natural England (2008). Investigations into the use of sediment critical sediment yields for assessing and managing fine sediment inputs into freshwater ecosystems, University of Exeter, ISSN 1754-1956

Natural England (2010a). River Derwent and Tributaries SSSI – Crummock Water (120): https://designatedsites.naturalengland.org.uk/UnitDetail.aspx?UnitId=1028816 (Accessed October 2018).

Natural England (2010b). Buttermere Dubs Wetland, East (128): https://designatedsites.naturalengland.org.uk/UnitDetail.aspx?UnitId=1029200 (Accessed October 2018).

Natural England (2010c). Buttermere Dubs Wetland, West (127): https://designatedsites.naturalengland.org.uk/UnitDetail.aspx?UnitId=1029199 (Accessed October 2018).

Natural England (2010d). River Derwent and Tributaries SSSI – River Cocker (123): https://designatedsites.naturalengland.org.uk/UnitDetail.aspx?UnitId=1028819 (Accessed October 2018).

Natural England (2012). River Derwent and Tributaries SSSI – Crummock Water wetland (120): https://designatedsites.naturalengland.org.uk/UnitDetail.aspx?UnitId=1029201 (Accessed October 2018).

Natural England (2014). Site Improvement Plan: River Derwent and Bassenthwaite Lake: http://publications.naturalengland.org.uk/publication/5735697705074688 (Accessed October 2018).

Natural England (2017). River Derwent and Bassenthwaite Lake SAC publication.

Natural England (2018a). Designated Sites View; River Derwent and Tributaries SSSI. Available at: https://designatedsites.naturalengland.org.uk/SiteDetail.aspx?SiteCode=S2000214&SiteName=&countyCode=9&responsiblePerson= (Accessed October 2018).

Natural England (2018b). Section 41 species – Priority Actions Needed (B2020-008). Available at: http://publications.naturalengland.org.uk/publication/4958719460769792 (Accessed October 2018).

National Trust (2019). Buttermere and Crummock Water. Available online at: https://www.nationaltrust.org.uk/buttermere-valley/features/buttermere-and-crummock-water. (Accessed 14/02/2019).

Newton, M, Dodd, J.A., Barry, J., Boylan, P., and Adams, C. E. (2018) The impact of a small-scale riverine obstacle on the upstream migration of Atlantic Salmon. Hydrobiologia 806: 251-264. https://doi.org/10.1007/s10750-017-3364-3

NFRA (2018) 75016 – Cocker at Scalehill, http://nrfa.ceh.ac.uk/data/station/info/75016 (Accessed January 2018)

Nyqvist, D., McCormick, S. D., Greenberg, L., Ardren, W. R., Bergman, E., Calles, O. and Castro-Santos, T. (2017) Downstream Migration and Multiple Dam Passage by Atlantic Salmon Smolts. North American Journal of Fisheries Management 37(4): 816-828.

Price D.J., (2012). Scottish loch hydrology: improved understanding and recent methodological advancements. British Hydrological Society's 11th National Symposium, Dundee

Solomon, D.J. and Beach, M.H. (2004). Fish pass design for eel and elver (Anguilla Anguilla). EA R&D Technical Report W2-070/TR1.

TerraDat (2018) Geophysical Survey Report - P-wave, S-wave, resistivity and GPR survey to characterise geology across Crummock Water. Geophysical Survey Report Reference 6048.

UK Species Inventory (2018a). River Lamprey Occurrence Records. Available at: https://species.nbnatlas.org/species/NBNSYS0000188584. (Accessed 6 July 2017)

UK Species Inventory (2018b). Atlantic salmon Occurrence Records Available at: https://species.nbnatlas.org/species/NBNSYS0000188606. (Accessed October 2018).

UK Species Inventory (2018c). Brook Lamprey Occurrence Records. Available at: https://species.nbnatlas.org/species/NHMSYS0000544685. (Accessed October 2018).

UK Species Inventory (2018d). European Eel Occurrence Records. Available at: https://species.nbnatlas.org/species/NBNSYS0000188599#tab_mapView. (Accessed October 2018).

UK Species Inventory (2018e). Brown Trout Occurrence Records. Available at: https://species.nbnatlas.org/species/NBNSYS0000188607. (Accessed October 2018).

UK Species Inventory (2018f). Eurasian Otter Occurrence Records. Available at: https://species.nbnatlas.org/species/NBNSYS0000005133 (Accessed October 2018).

UU (United Utilities) (2005), Impounding Reservoirs Drawdown Capacity Studies 2005, MWH

UU (United Utilities) (2014) Ennerdale Longshore Processes – Desktop Analysis. Project Name: Ben Gill AMP5 Q (Hab).

United Utilities, (2016) Asset Management Report

UU (United Utilities) (2018) Geotechnical and Geoenvironmental Desk Study Report, Crummock Water Infrastructure Removal, Project no: 770000002256, January 2018, Version 1.0

West Cumbria Rivers Trust (2020). River Derwent Catchment Fish and Habitat Surveys: Fish Survey Results: 2018. Available from: https://westcumbriariverstrust.org/projects/fish-surveys/results-2018 [Accessed February 2020].

West Cumbrian River Trust (2018). Whitbeck Diversion. Available at: http://westcumbriariverstrust.org/projects/river-restoration-strategy/whit-beck. (Accessed October 2018).

Winfield, I. J., Fletcher, J. M., & James, J. Ben. (2008). The Arctic charr (Salvelinus alpinus) populations of Windermere, UK: Population trends associated with eutrophication, climate change and increased abundance of roach (Rutilus rutilus). Environmental Biology of Fishes, 83(1), 25–35.

Winfield, I. J. and James, J. B. (2017). Crummock Water: Arctic Charr Monitoring and Assessment of the Potential Impacts of Drought Permit Implementation. Final Report.

Appendix A. Historical Map analysis of activity at Crummock Water

The table below is an extract taken from a United Utilities Geotechnical and Geoenvironmental Desk Study Report and has been used in this report as an appendix with written permission from United Utilities (United Utilities, 2018). The below is based solely on available historical maps. Further information came to light on the historical activities at the weir, which are not shown on the maps, and these are documented in Appendix K.

Historical Maps – extract taken from UU (2018)

Map Year (Scale)	Onsite Historical Features	Offsite Historical Features
1865 (1:2,500) 1863 (1:10,560)	A wooded island is shown dividing two channels at the source point of the R.Cocker at Crummock Water Woodland is shown covering a narrow corridor to the western shore of the lake between Park Beck and R. Cocker Park Beck is shown flowing west to east with a slight meander entering the lake in a straight channel section, slightly offset to south.	Lanthwaite Wood is shown on the right bank of the R. Cocker and covering the land to the north and east of the lake. The land past the western shore of the lake is indicated as agricultural land.
1899 (1:2,500) 1900 (1:10,560)	No significant change	No significant change
1947 (1:10,560)	No significant change	No significant change
1951 (1:10,560)	Park Beck is shown flowing in a straightened channel section realigned, approximately 30m to the north of former channel.	No significant change

Map Year (Scale)	Onsite Historical Features	Offsite Historical Features
1970 (1:2,500)	Sluice and fish ladder shown at source point of R. Cocker at lake edge. Marshy vegetation shown on land to west of narrow corridor of woodland between Park Beck and R. Cocker. Northeast flowing drains are indicated, marked ‘collects’ connecting to a straight NNW – SSE orientated channel coincident with western boundary of narrow woodland corridor (with source point marked ‘issues’ 100m north of Park Beck. which flows to its confluence with the R. Cocker approximately 90m downstream from the source point at the lake. Evidence of potential washout material in the lake is shown approximately 40-50m to the south of the source point of the R. Cocker. The material is crescent shaped and wooded situated downstream of a cluster of the aforementioned drains. See Figure 3.3 below. Deposition is shown built up at the mouth of Park Beck at the lake edge. A pond is shown a short distance from the lake edge on the former alignment of Park Beck. A pump house is shown approximately 30m to the south of the pond.	No significant change
1976 (1:10,560)	Lake is labelled ‘Winter water level 99m above Newlyn Datum, 1972.	Two disused quarries are marked in the high ground above Lanthwaite Wood approximately 400m to the northeast of the source point of R. Cocker
1994 (1:2,500)	No significant change	No significant changes
2002 (1:10,560) 2010 (1:10,560) 2014 (1:10,560)	No significant change	No significant change

Appendix B. Crummock Water baseline and potential future outflow regimes

The aim of this assessment is to provide indications of the likely change to the flow regime leaving Crummock Water as a result of returning the lake to varying degrees of near natural conditions.

The following scenarios are assessed:

Scenario A – Past flow regimes with both abstraction and artificial control (by means of the existing weir structure and the existing release regime of prescribed compensation flows) included. This represents the current arrangement and management of the flow regime.

Scenario B – As for Scenario A but without the abstraction and with compensation flow.

Scenario C – With the weir remaining, but no abstraction and no provision of compensation flow.

Scenario D – Near-natural scenario with the weir removed and no abstraction nor compensation flow provision.

The impact upon the river flow regime immediately downstream of the weir is provided in the form of flow duration curves with particular emphasis on the lower to medium flows that could be of particular significance to salmon.

B.1 Introduction

The natural flow regime of the River Cocker at the outflow from Crummock Water has to some extent been altered by the artificial management of the lake. The impact would have been, to varying degrees, a result of:

iv) water abstracted from the lake,

v) the artificial outflow arrangement (a low impoundment with a relatively long spilling weir forming what is effectively a raised lake), and

vi) the provision of a compensation flow to maintain downstream low flows during dry periods.

These factors combine to alter what was once a natural outflow regime and the directly related natural lake level regime.

This appendix summarises the hydrological analysis that incorporates all these factors in the long-term time-series simulation of the behaviour of the lake-outflow system for each of the scenarios. The methodology used is that reported in Jacobs (2010b) and Price (2012). The technical approach was originally developed by Jacobs to help Scottish Water better understand loch hydrology within water supply schemes. Jacobs (2010b) reports the subsequent research work undertaken by Jacobs for the Scottish Environment Protection Agency (SEPA) where the methodology was further developed and tested in detail.

B.2 Approach

The method is based upon the routing of several decades of daily inflows through the lake, taking into account changes in storage and the outflow channel characteristics for the calculation of outflow to the downstream river. In the simulation, the water balance of the lake system is preserved and the lake level is allowed to build up and diminish depending on the wetness of the period enabling the antecedent lake level to be allowed for. The methodology, its development and validation is described in Jacobs (2010a). Rules regarding abstraction and release of compensation flow can be readily introduced into the daily water balance component of the model.

The information and data required by the method together with their sources are given below.

B.2.1 Daily inflow

The inflow series (1961 – 2015) to Crummock Water (1961 – 2015) was supplied by United Utilities from their water resources model of the system. This is understood to have been calculated by the Environment Agency using a mass-balance approach, where the inflow equals the change in storage plus outflow plus abstraction. The storage is calculated from level data and the depth storage relationship of the lake. The storage is mainly calculated using daily level data, however a recent update means that from 2011 onwards the storage is calculated using 15min level data. The change in storage is then calculated from this data using a daily time step. The level data uses the EA Crummock Water gauge with data from 1973 onwards. The flow data uses the EA gauge at Scale Hill from 1974 onwards. By using the change in lake level, this accounts for all rainfall and evaporation in the calculation. It is not known how the 1961-1973 inflow series that predates the installation of the gauges was estimated.

B.2.2 Lake area

The surface area of the lake was taken to be 2.58km^2 (Cascade, 2014). This was modelled as invariant. In a more detailed study this can be modelled as a function of water level. This refinement is likely to have only a limited effect upon the results unless the bathymetry or the water body suggest that the level-area relationship is particularly sensitive.

B.2.3 Outflow level-flow relationships

The outflow level-flow relationships were derived by the following means:

Scenarios A, B and C

For the current weir configuration (Scenarios A, B, & C) this was obtained from the hydraulic representation used in Jacobs (2018).

Scenario D

For the near natural situation where the weir has been removed (Scenario D), the generalised approximation by Price (2012) was used in the absence of site-specific data. This is based on an average low to medium flow hydraulic control cross section (developed from a survey of Scottish loch outflow channels), and its representation by multiple broad-crested weir equations. The Crummock Water outflow is formed from two adjacent channels (verified from old OS maps as having been present over the last 100 years) and these have been combined in the simulation as a single channel. The width of the combined channel (approximately 12m) was estimated from aerial imagery has been used in the near natural representation of the hydraulic control. The sensitivity analysis suggests limited impact to the simulated flow regime of +/-4m to this channel width.

B.2.4 Abstraction rules

Abstraction rules regarding permitted maximum abstraction rates as a function of lake level were taken from the abstraction licence (27/75/012/028) These are given in Table B.0.1 with respect to the level of the weir.

Table B.0.1 Crummock Water Abstraction rules

Water level above weir (m)	Compensation flow (Ml/d)	Compensation flow (m^3/s)
Greater than 0m	31.8	0.368
Between 0m and -1.1m	27.3	0.316
Less than -1.1m	0	0

The above rules provide the maximum allowable abstraction rates. No record of the actual abstractions was readily available, and it is possible that rates of abstraction have varied over time below the maximum prescribed by the rules. Within the routing model, a facility to linearly scale down the abstraction rate uniformly across the whole period of simulation was included. This enabled the sensitivity of the system to the abstraction rate to be considered.

B.2.5 Compensation flow

The required compensation flow is 27.3 Ml/d (0.316 m^3/s) according to licence (27/75/012/028). No compensation flow records were available, and it has been assumed that releases via the penstocks have always been made at times of low flow to make sure the required flow has been in the river.

The Crummock Water catchment has an Environment Agency river flow gauge (Station number 75016, Cocker at Scalehill) approximately 700m downstream of the outflow from the lake. In the National River Flow Archive its catchment area is given as 64 km^2, whilst the Crummock Water catchment is given as 62.6 km^2 by the FEH catchment descriptors (a difference of only 2%). If accurate, these records offer a means of checking the output of the routing method for Scenario A, assuming the abstraction rates and compensation flow were fully achieved. Recorded daily flows (1976 to 2015) were downloaded from the NFRA (2018) web site. The record is 99% complete.

The routing model was first run for the period 1974 to 2015 for Scenario A (i.e. the simulation of the past with the weir in place, abstraction occurring and the provision of compensation flow). The simulated outflow flow duration curve could then be compared to the Scalehill monitored flow duration curve. This acts as a check, and if necessary to form the basis of any calibration. Assuming reasonable performance, then each of the scenarios are modelled and their flow duration curves compared to assess the influence of the possible changes to the management of the system (this was undertaken using the full period of available inflow record [1961-2015]).

B.3 Results

B.3.1 Comparison of routed outflows to the Scalehill gauged record

Figure B.0.1 compares the modelled flow duration curve for the outflow from Crummock Water to that of the actual monitored flow at the Scalehill gauge. The Scalehill flows have been marginally reduced (factor 0.98) to account for the slight difference in catchment area.

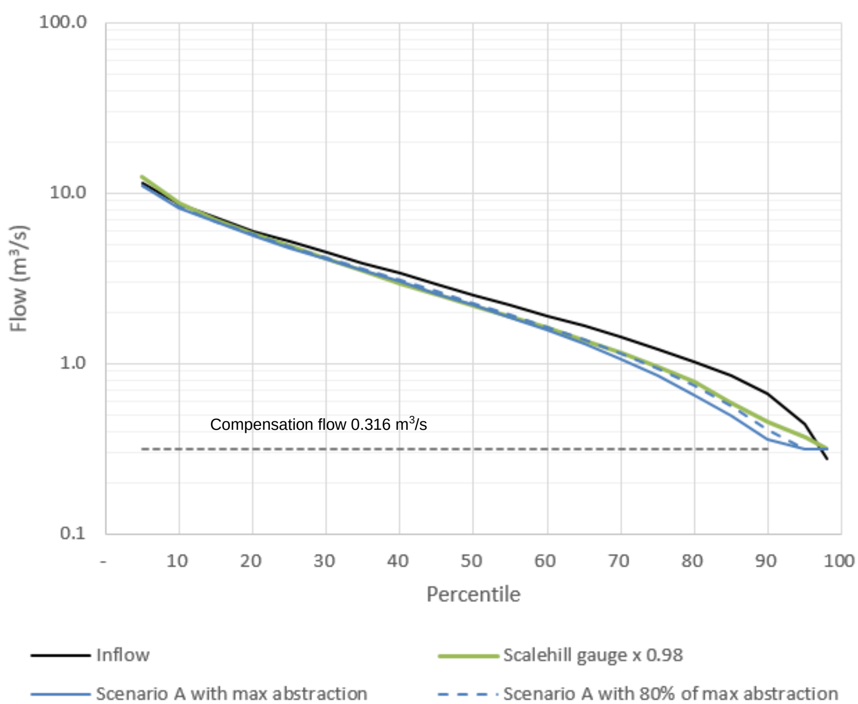

Figure B.1 Comparison of the modelled outflow to that monitored by the Scalehill flow gauge for the period 1974 to 2015

When it is assumed that the maximum abstraction was always achieved (subject to the operation rules), the simulated and observed results are in reasonably close agreement. Undertaking sensitivity analysis on whether the full maximum permitted abstraction was achieved or not resulted in an improved match when an abstraction rate scaling factor of 0.8 was used (see the dotted line in Figure B.1). In Section B.5.2, the 0.8 factor version of Scenario A is used for other scenario comparisons.

B.3.2 Comparison of the scenario flows

Figures B.2 a and b compare the flow duration curves associated with each of the four scenarios based on the simulation of flows for the period 1961-2015.

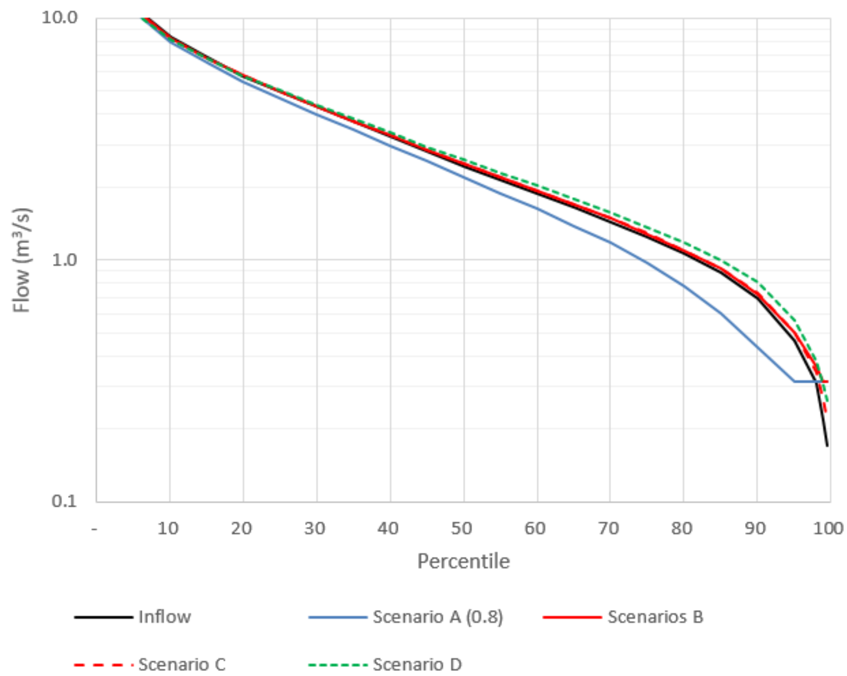

Figure B.2 a) Simulated outflow flow duration curves for each of the Crummock Water scenarios

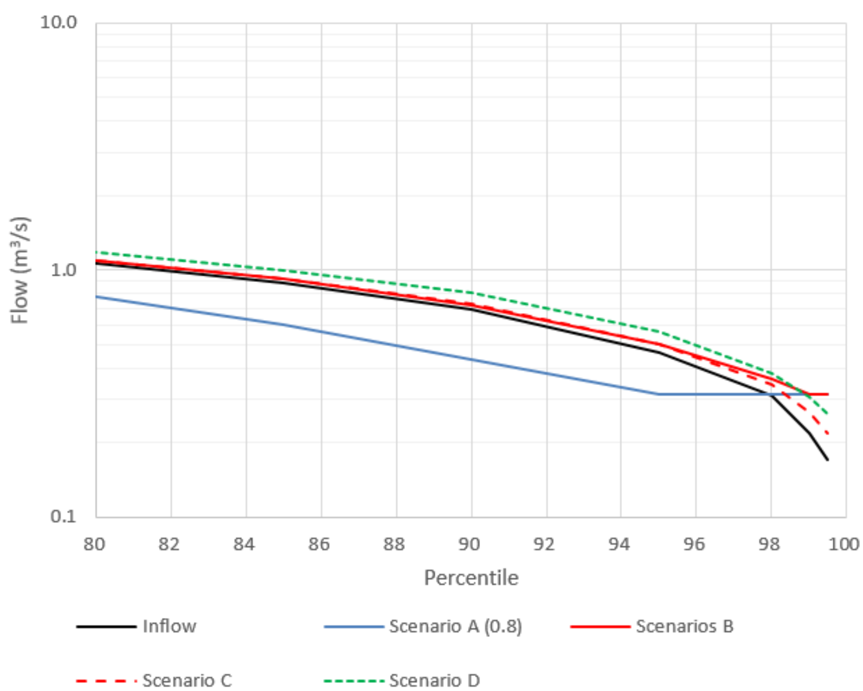

Figure B.2 b) As for a) but expanded at low flows

The peak numerical values for each of the flow duration curves are given in Tables B.2a and B.2b (ML/d).

These initial results suggest that removing the weir and ceasing the abstraction and compensation flow (i.e. returning the area to near natural conditions) would lead to slightly higher flows across the majority of the flow range; though for the lowest of flows (Q99 and smaller) the flows would be slightly less. This is equivalent to 1% of the time that the forward flow would be less than is presently the case (i.e. less than the current compensation flow of 27.3 Ml/d).

Table B.2a: Simulated outflow to River Cocker flow duration curves for each Crummock Water scenario

Percentile	Inflow (m^3/s)	Scenario A (0.8) (m^3/s)	Scenario B (m^3/s)	Scenario C (m^3/s)	Scenario D (m^3/s)
5	11.18	10.70	11.00	11.00	10.64
10	8.37	8.00	8.30	8.30	8.19
15	6.85	6.53	6.84	6.84	6.78
20	5.77	5.49	5.79	5.79	5.78
25	4.98	4.68	4.98	4.98	5.02
30	4.30	4.02	4.32	4.32	4.40
35	3.72	3.46	3.76	3.76	3.84
40	3.25	2.97	3.27	3.27	3.36
45	2.81	2.56	2.86	2.86	2.95
50	2.45	2.20	2.50	2.50	2.60
55	2.14	1.89	2.20	2.20	2.29
60	1.89	1.63	1.93	1.94	2.04
65	1.65	1.39	1.70	1.70	1.79
70	1.44	1.17	1.48	1.49	1.57
75	1.24	0.97	1.28	1.28	1.36
80	1.06	0.78	1.09	1.09	1.17
85	0.89	0.60	0.92	0.93	1.00
90	0.70	0.43	0.72	0.73	0.81
95	0.47	0.32	0.50	0.50	0.56
98	0.31	0.32	0.36	0.34	0.38

Table B.2b: Simulated outflow to River Cocker flow duration curves for each Crummock Water scenario (in ML/d)

Percentile	Inflow (ML/d)	Scenario A (0.8) (ML/d)	Scenario B (ML/d)	Scenario C (ML/d)	Scenario D (ML/d)
5	965.8	924.5	950.4	950.4	919.2
10	723.4	691.0	717.0	717.0	707.5
15	592.2	564.5	590.5	590.6	586.1
20	498.4	474.1	500.6	500.6	499.6
25	429.9	404.3	430.4	430.4	433.6
30	371.4	347.5	373.6	373.6	380.3
35	321.8	298.7	324.8	324.8	331.8
40	280.4	256.6	282.8	282.9	290.1
45	242.8	221.0	247.0	247.1	254.6
50	211.6	189.7	215.9	216.1	224.8
55	185.3	163.3	189.7	189.9	198.3
60	163.0	140.6	167.1	167.3	176.1
65	143.0	119.9	146.9	147.0	154.8
70	124.0	101.4	128.2	128.4	135.8
75	107.0	83.5	110.7	111.0	117.9
80	91.5	67.0	94.2	94.5	101.3
85	76.7	51.8	79.7	80.0	86.5
90	60.2	37.6	62.3	62.8	70.0
95	40.2	27.3	43.5	43.5	48.5
98	27.0	27.3	31.5	29.7	32.8
99	19.0	27.3	27.3	23.0	26.4

B.4 Caveats

The results presented in Figure B.1 and Table B.2 provide an indicative estimate of the likely flows entering the River Cocker from Crummock Water under each of the scenarios. A more refined understanding could be obtained if the following issues are considered in greater detail.

- Obtain and use the Environment Agency Crummock Water level record to further check / calibrate the routing model.
- The inclusion of a fuller understanding of the actual time sequence of abstraction would be beneficial.
- Inclusion of an improved level-volume relationship of the lake across the level range of the lake (i.e. inclusion of the shoreline bathymetry which was obtained after this study took place).
- Obtain a better understanding of the near natural outflow channel characteristics to enable a more accurate representation of the outflow hydraulic control.

- There appears to be a slight imbalance in the water balance of the system over the Scalehill period of record. It would be prudent to investigate this further to understand why this could be the case.

- Understand better how the penstocks supplying the compensation flow have been operated.

These refinements would help supply a more robust simulation of the scenarios, nevertheless the general patterns of difference between the flow duration curves are not considered likely to change because of the refined understanding. It is understood that United Utilities could engage a university student to take these refinements forward.

Appendix C. Hydraulic Modelling Detailed Assessment

This appendix includes information on how the hydraulic model has been constructed, the baseline and impact assessment of the preferred option.

C.1 Methodology

The hydraulic model developed for this study is a linked one-dimensional/two-dimensional (1D/2D) hydraulic model, with the river channel represented as a 1D component using Flood Modeller Pro and the floodplain represented in 2D using TUFLOW. The linked 1D/2D approach means that the model dynamically transfers the water between the river channel and the floodplain as a flood event unfolds.

The study area is shown in Figure C.1. It starts at Crummock Water and ends at Southwaite Bridge, 3.6 km upstream of the town of Cockermouth. The model extent was determined based on the requirements of the study and using the EA's online flood maps.

The model has been used to assess the baseline and design in order to assess the effect on flood risk resulting from the proposed design. The data used to inform the model is summarised in Table C.1.

Table C.1: Key data used for the model

Data	Description	Source
LiDAR DTM	1m horizontal resolution Digital Terrain Model (DTM) derived from bathymetric LiDAR.	United Utilities March 2018
Combined DTM	Combined DTM for areas not covered by new 2018 LiDAR.	EA previous model of River Cocker
Elevation Data Points	LiDAR Digital Terrain Model data for areas not covered by new 2018 LiDAR and Combined DTM.	EA previous model of River Cocker
Survey Data	Bathymetric data for Lake and River lengths Topographic survey of the Crummock Water overflow weir and western wall	United Utilities September 2017
Hydrology	Inflows for all Rivers and Tributaries	Jacobs July 2017

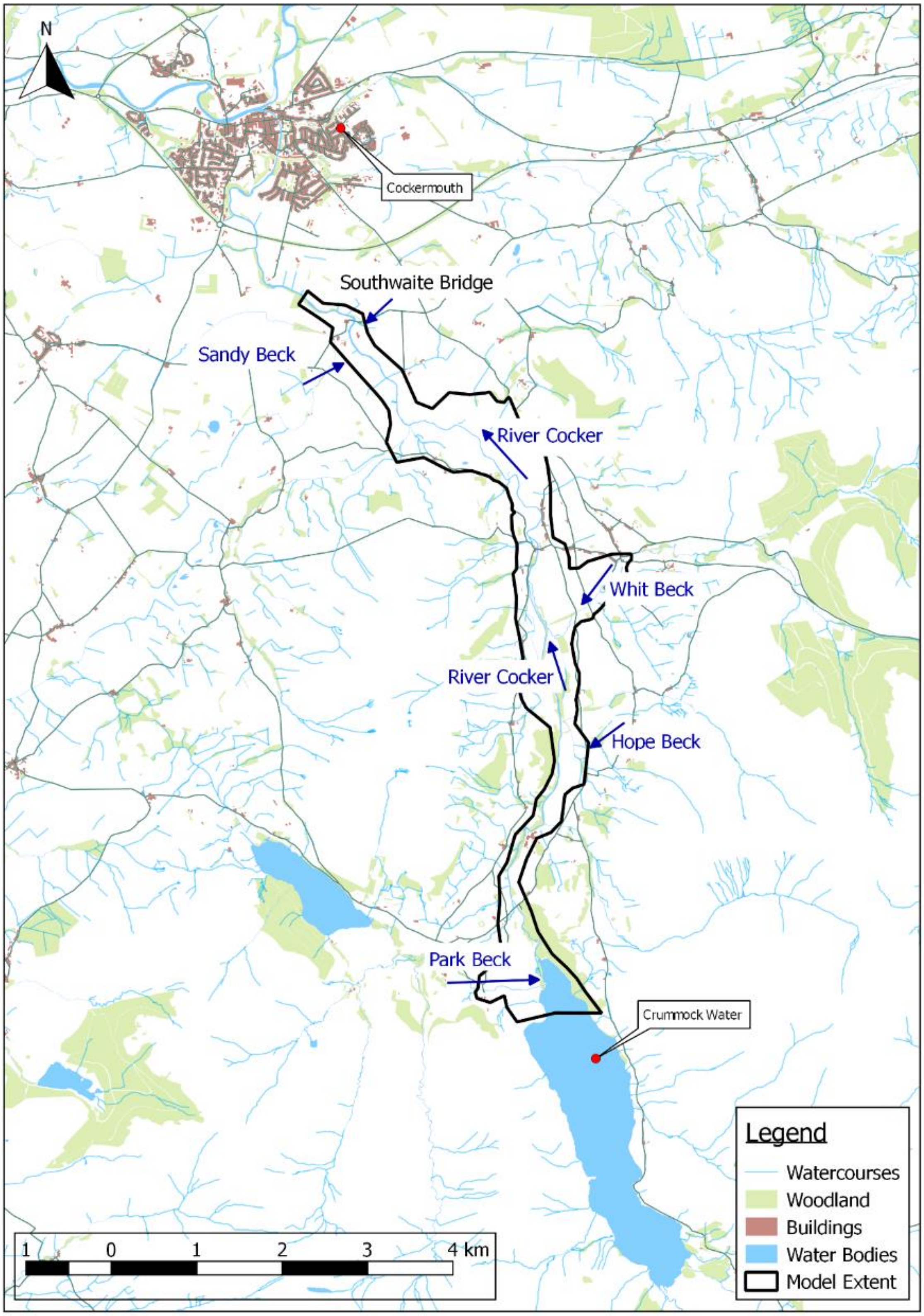

Figure C-1: Crummock Hydraulic Model Extent

C.2 Hydrology

Hydrological inflows to the hydraulic model have been calculated for ten discrete sub-catchments draining into Park Beck, Crummock Water, Whit Beck, Liza Beck, Hope Beck, Sandy Beck, and along the modelled length of the River Cocker, using FEH (Flood Estimation Handbook) methodologies. The routed flows through the hydraulic model have been reconciled against the hydrological estimates at the Southwaite Bridge Gauging Station for a range of Annual Exceedance Probability (AEP) events, as shown in Table C.2.

Table C.2: Hydrological Estimates at Southwaite Bridge Gauging Station

	50% AEP	20% AEP	10% AEP	3.33% AEP	2% AEP	1.33% AEP	1% AEP	0.5% AEP
Gauge Estimated Flow at Southwaite Bridge Gauging Station (m^3/s)	52.7	76.7	94.5	118.6	140.3	153.1	162.6	187
Hydrological Scaling Factor	1.33	1.27	1.24	1.14	1.2	1.15	1.13	1.05
Predicted Peak flow at gauge location (m^3/s)	53.6	77.1	93.8	117.6	147.6	156.0	165.1	180.6
% difference	1.8%	0.5%	-0.7%	-0.8%	5.2%	1.9%	1.5%	-3.4%

C.3 Model Schematisation

Crummock Water and the River Cocker are schematised in 1D using Flood Modeller Pro version 4.4.1. The 2D domain is modelled with TUFLOW version 2018-03-AB-iDP-w64 and is linked to the 1D domain via a hxi (dynamic head transfer) boundary. The combined model extends about 9km downstream of Crummock Water. It includes the Park Beck and Whit Beck tributaries as well as the Liza Beck, Hope Beck and Sandy Beck as direct inflows to the River Cocker.

C.3.1 Watercourse Schematisation – 1D Domain

C.3.1.1 Topography

The river lengths for Park Beck and 3.6km of River Cocker immediately downstream of Crummock Water are based on survey data obtained from United Utilities (Atlantic Geomatics, 2017). The 1D model was built by combining the river cross-section data from survey and cross-section data from two existing Environment Agency (EA) models of the River Cocker (Low Lorton (JBA Consulting, 2013) and Cockermouth (CH2M, 2016). LiDAR DTM data (EA, 2017b) was also used to extract cross-section data for a 1.2km reach of the River Cocker between Low Lorton and Southwaite Bridge (model nodes CKER2_1489u to CKER2_0171). For these model nodes, the full depth of the channel could therefore be underestimated.

Crummock Water lake has been represented using an elevation-area curve in Flood Modeller Pro with dimensions taken from the bathymetric survey data. The initial water level in the lake is assumed to be at the spill level of the lake (98.53mAOD) at the start of all the simulations.

The wave wall along the western edge of the lake and the overflow has been modelled using the topographic survey as spills in the 1D model, with associated linkage to the 2D domain.

C.3.1.2 Hydraulic Friction

A uniform bed roughness of Manning's *n* of 0.035 has been applied across most of the model following standard guidance (Chow, 1959) for a relatively clean, winding river. The exception is the downstream end of Park Beck, where the channel is concrete. At these locations, a Manning's *n* of 0.03 is used. Also, the downstream reach of the River Cocker has an in-channel Manning's *n* of 0.045. Out of bank areas within the 1D domain have been given a Manning's *n* roughness of 0.06 to 0.1 to account for general rural land cover and wooded land cover respectively.

C.3.1.3 Hydraulic Structures

Several hydraulic structures were schematised in 1D and they have been summarised in Table C.3.

Table C.3: Hydraulic Structures in the Model

Structure	Schematisation
Crummock Water Overflow	The overflow from Crummock Water consists of an overflow weir with a fish pass and sluice gate embedded in the structure. The effective spill profile of these elements is represented with Flood Modeller spill units based on the topographic survey. Following the weir there are two man-made channels separated by an island, which then combine at the head of the River Cocker. This arrangement is schematised with river units and lateral spills as shown in Figure C-2.
Footbridge at the overflow	Not included in the model as it is small and has insignificant impact on the flow for Baseline.
Existing Wall around Crummock Water	This is schematised as spills informed with elevation data obtained from topographic survey.
3 footbridges on Park Beck	Upstream bridge is modelled as an arch bridge with a spill at the deck level. The other 2 bridges are schematised as flat bridges with spills at their deck levels.
Gauging weir at Scale Hill bridge	A compound crump weir, schematised with three parallel crump weir units based on survey data.
Scale Hill bridge	This is schematised as a double arch bridge.
Southwaite and Low Lorton Bridges	These are schematised as multiple arch bridges as in the existing EA models.
5 Whit Beck bridges	These are schematised as arch or flat bridges as in the existing EA model.

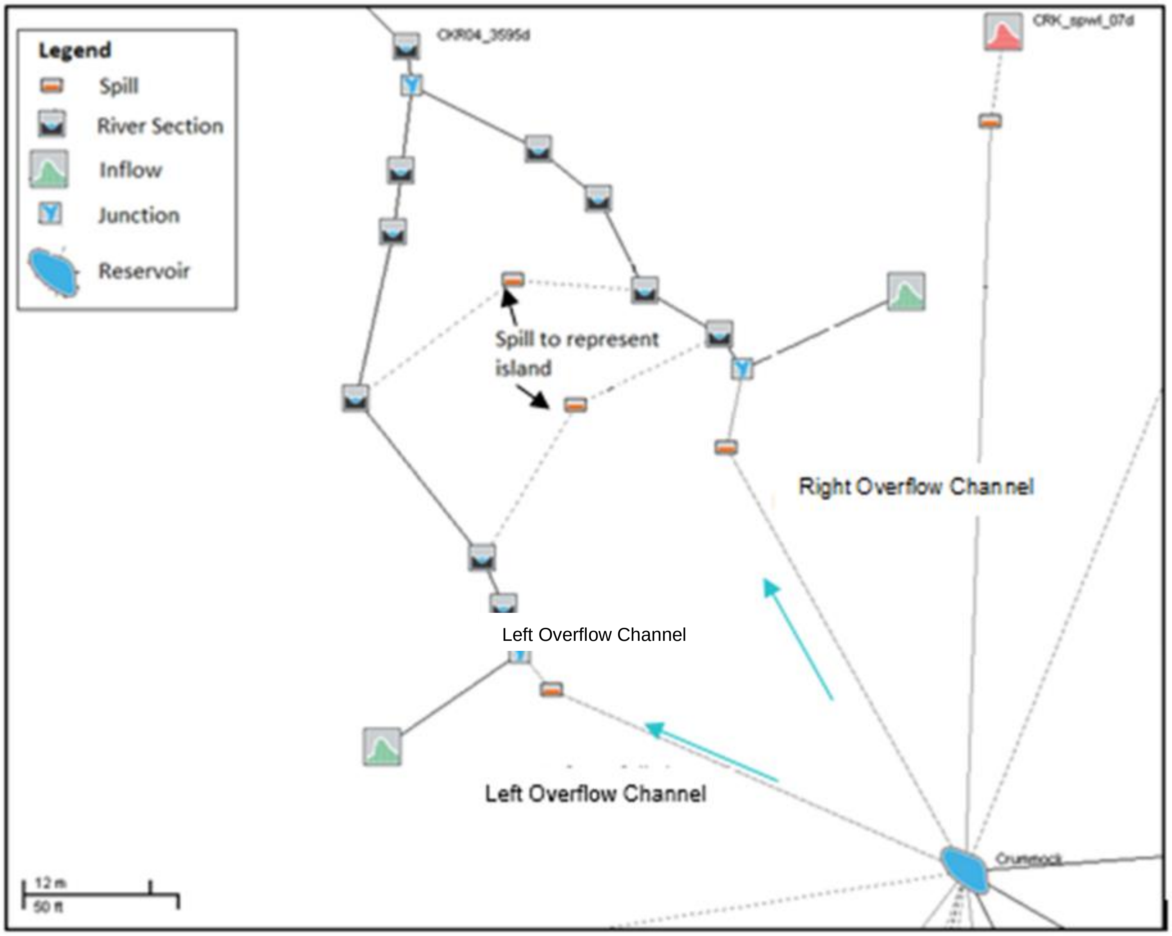

Figure C-2: Schematisation of the Overflow from Crummock Water

C.3.1.4 Boundary Conditions

The model inflow boundaries are based on the hydrology analysis carried out and are implemented as Flow-Time (Q-T) boundaries. At the downstream model extent, which is 500m downstream of Southwaite Bridge, a prescribed Flow-Head (Q-H) boundary is specified, based on the 0.1% AEP results from the EA Cockermouth model. Table C-4 describes all the boundaries in the model.

Table C-4: Boundaries in the Model

Type of Boundary	Flood Modeller Node	Description
Flow-Time Boundary	Buttermere	Hydrological inflow applied directly to Crummock Water from Buttermere Lake
Flow-Time Boundary	Crummock	Hydrological inflow applied directly to Crummock Water representing direct rainfall
Flow-Time Boundary	Crummock_res	Hydrological inflow applied directly to Crummock Water from residual flows into the lake.
Flow-Time Boundary	HopeBeck	Hydrological inflow applied to the River Cocker representing Hope Beck tributary.
Flow-Time Boundary	LizaBeck	Hydrological inflow applied to the River Cocker representing Liza Beck tributary.
Flow-Time Boundary	PB_0841	Hydrological inflow applied to upstream end of Park Beck tributary.
Flow-Time Boundary	WHIB02_0140	Hydrological inflow applied to upstream end of Whit Beck tributary.
Flow-Time Boundary	SandyBeck	Hydrological inflow applied to the River Cocker representing Sandy Beck tributary.
Flow-Time Boundary	Cocker_up	Hydrological inflow applied as a lateral on the upstream part of River Cocker (nodes CKR04_2807 to CKER03_1118).
Flow-Time Boundary	Cocker_Lo	Hydrological inflow applied as a lateral on the downstream part of River Cocker (nodes CKER03_0014 to CKER01_3563).
Downstream	CKER01_3448	Flow-Head Boundary applied to the downstream end of the River Cocker.

C.3.2 Flood Plain Schematisation – 2D Domain

C.3.2.1 Topography

The 2D domain covers an area of 5.7km^2 and is represented with a grid of 10m cell size.

The topography for the 2D model is based on 1m resolution LiDAR. Where there were gaps in the LiDAR, this was filled in, firstly, by using the Combined DTM and secondly, using the elevation data points (See Table C-1 for sources). The transition between the different sources did not require any smoothing.

C.3.2.2 Hydraulic Friction

The 2D model grid has also been informed with hydraulic roughness information based on the landuse in the floodplain taken from OS Mastermap data as shown in Table C-5.

Table C-5: Landuse and Corresponding Roughness Coefficients

Landuse	Manning's N
Grass pasture -turf with undulations	0.06
Woodland - heavy stand, some downed, depth below branches	0.10
Heavy scrub - medium brush and trees, summer	0.10
Main roads	0.05
Rural Developments and obstructions such as homes with parking	0.05
Stability patch	1.0
Building	1.0

C.3.2.3 Boundary Conditions

No inflows were implemented directly into the 2D domain. Any flow across the 2D domain is as a result of the 1D channel being overtopped, simulating out of bank conditions. The 2D domain extents were set far enough from the predicted flooded areas to make sure no occurrence of glass walling.

C.3.3 Outline Design - Model Schematisation

For the proposed design the following three changes were made to the Baseline:

- Overflow of Crummock Water naturalised,
- Wave Wall on the western edge of Crummock Water removed,
- Park Beck downstream channel naturalised (approximately 270m).

C.3.3.1 Crummock Overflow Schematisation Changes

The proposed Crummock overflow was schematised by modifying the spills and the two channels according to the drawings[5] provided. Connecting spills and cross-sections were changed to match the new profile of the channels and the weir coefficients of the spill units were reduced to represent the natural overflow form.

C.3.3.2 Wall Removal Schematisation Changes

The west wave wall removal was schematised by interrogating the LiDAR ground levels along the relevant alignments and updating the spill levels in the 1D model. It is noted that the western footpath runs along a ridge of high ground, forming a new crest for flow into, and spill out of Crummock Water. The wall removal allows surcharged flow from Park Beck to flow into the lake, instead of being re-directed to the River Cocker.

C.3.3.3 Park Beck Schematisation Changes

Figure C-3 shows a typical change made to the downstream lengths of Park Beck. The channel is naturalised by lowering the bed level by 300mm to represent the removal of the concrete base of the present channel. The new bed form is a 6m wide low flow slot and the new bank sides are tied into the natural ground levels over a width of 6m on each side. This form broadly matches that of the natural upper channel.

NOTE: Additional details are provided in the design drawings[5] detailing gravel bar features and alternate channel geometry for left and right bends on meanders. These features are not significant for the hydraulic modelling of the overall channel capacity and have not been considered.

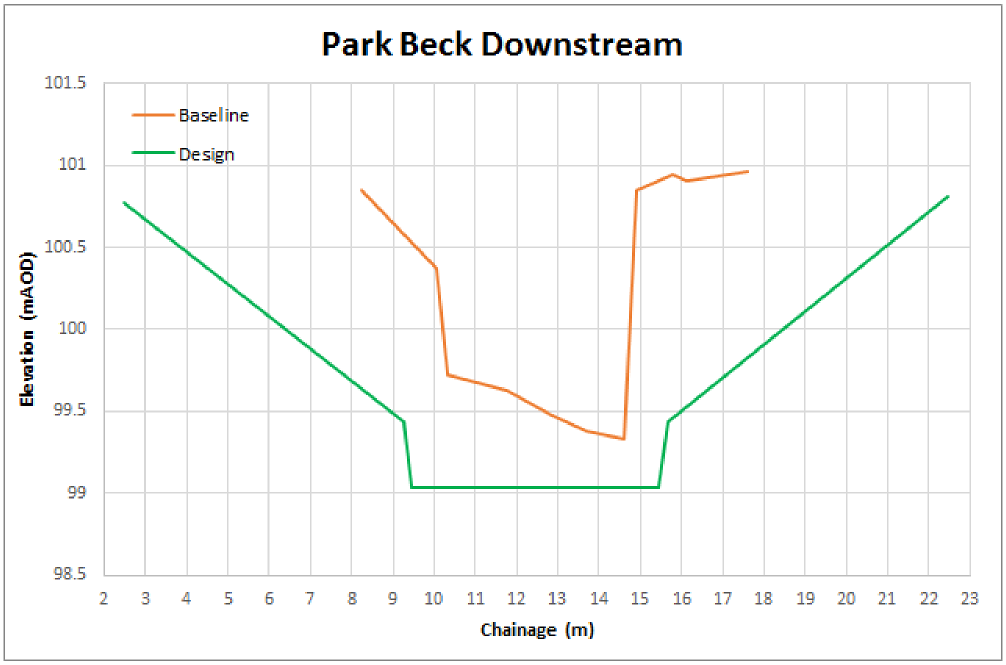

Figure C-3: Typical Change to Park Beck for Design

C.4 Model Proving

The following sections discuss the model performance and the verification process. In addition, details relating to the additional runs carried out to test the sensitivity of the model to key variables are also discussed.

C.4.1 Model Performance

Run performance was monitored throughout the model build process and then during each simulation carried out, to make sure a suitable model convergence was achieved.

The cumulative mass error reports output from the TUFLOW 2D model have been checked. Figure C-4 shows the mass balance plot for a simulation. The recommended tolerance range is +/- 1% Mass Balance error. The change in volume through the model simulation can also be seen. It shows that the cumulative mass error is within tolerance for the entire simulation. In addition, the change in volume is generally smooth, which is an indicator of good model stability.

Figure C-5 shows the 1D model mass balance error as a percentage of the peak system volume as output by Flood Modeller. The overall mass error is less than 1% in all events and scenarios. However, the 1D model diagnostics do indicate some non-convergence occurrences at approximately 6 and 10 hours in the baseline

[5] Figures 6-4 to 6-11 in section 6 of this report.

scenario. This had been tracked to 4 model nodes on Park Beck. Adding cross-section interpolates improved the model convergence and reduced the instabilities, but still showed some peak flows and stages being affected on Park Beck. However, it was found that this improvement did not change the model outputs in the overall modelled area and especially along the River Cocker. It is therefore estimated that the residual instability on Park Beck is not significant for the flood risk assessment of Crummock Water, and no further improvements to the model were deemed necessary. If detailed analysis of flows around Park Beck (under the existing situation arrangement) are required in a future project, then further improvement to the model is recommended.

In the design scenario, the Park Beck lengths are modified, and no model instability is noted, as shown in Figure C-6.

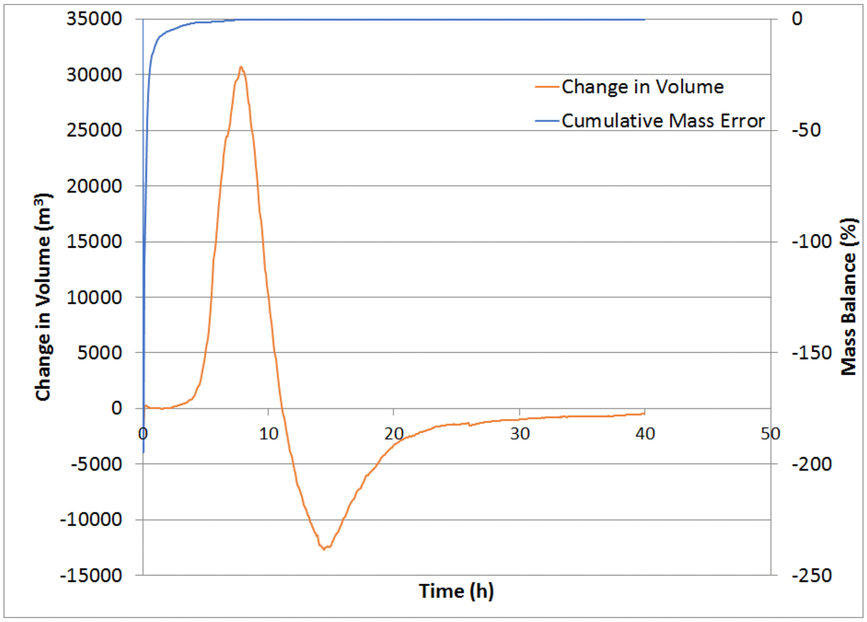

Figure C-4: Mass Balance for a Typical Simulation

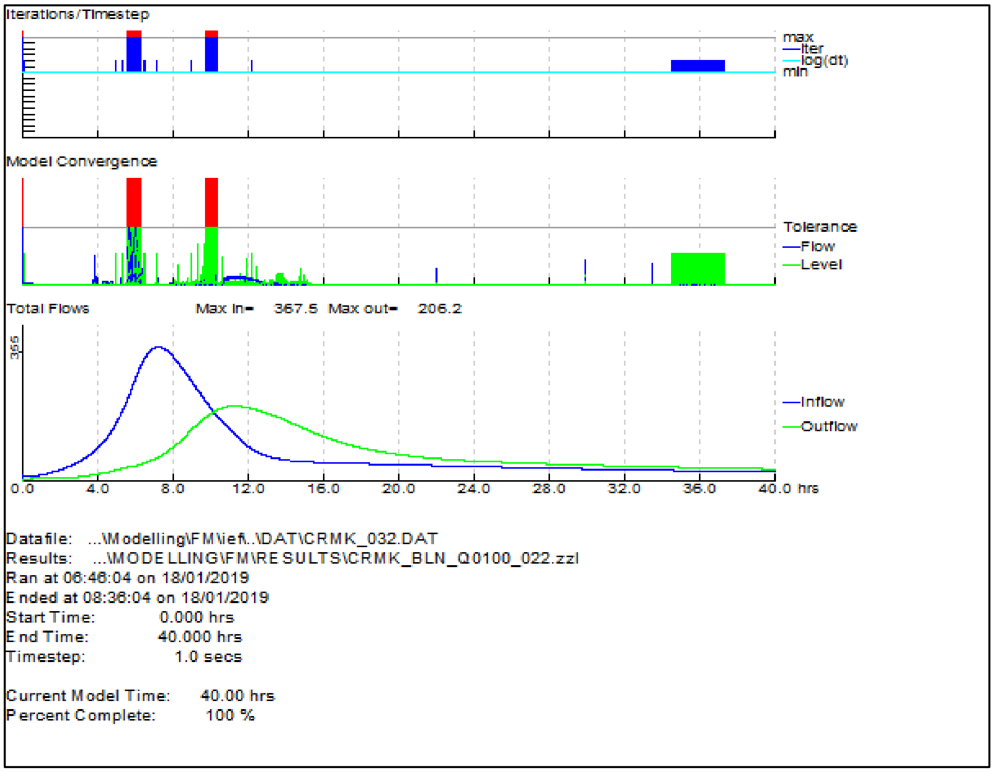

Figure C-5: Model Convergence in 1D for Baseline Scenario – 1% AEP event

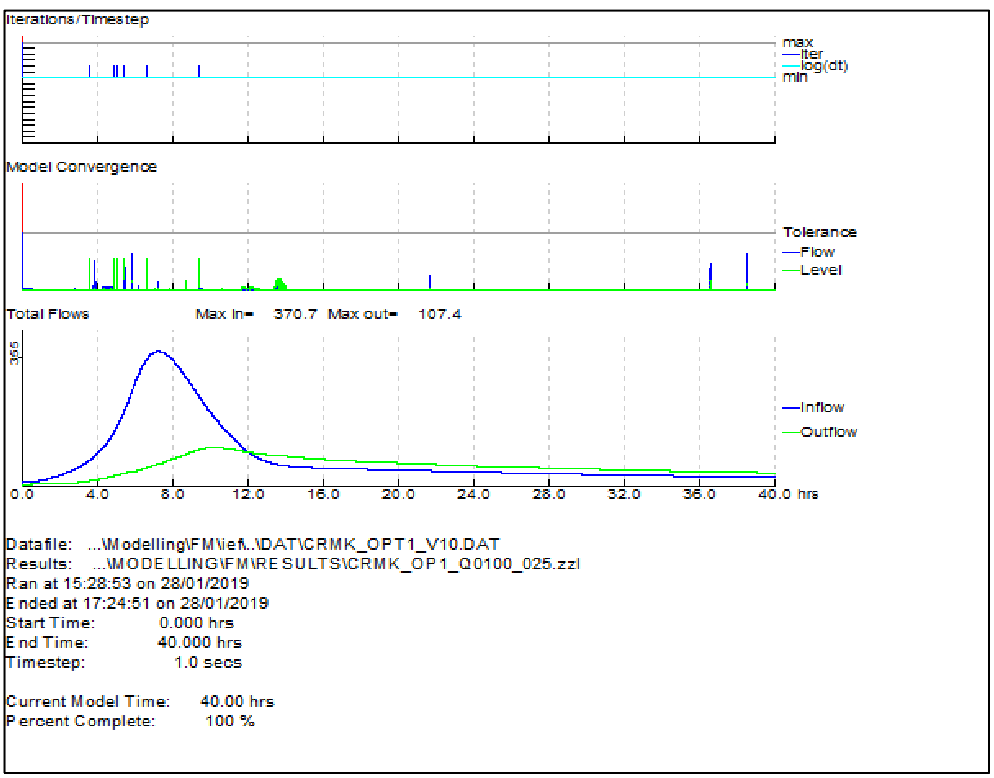

Figure C-6: Model Convergence in 1D for Design Scenario – 1% AEP event

C.4.2 Calibration & Verification

It was agreed with United Utilities that the hydraulic model would not be calibrated to historical flood events. However, a high-level verification has been carried out through comparison of model outputs associated with the 1% AEP flood event with EA Flood Zone 2 maps and the existing Low Lorton model. The results were generally found to be in good agreement.

Checks have been completed on the design peak flows used for the present study, against work undertaken on the catchment by Capita Symonds in May 2018. It was found that design peak flows at Southwaite Bridge are consistent with the values obtained by Capita Symonds.

C.4.3 Sensitivity Analysis

A sensitivity analysis was carried out to see how the model responded to changes in roughness and flow.

C.4.3.1 Roughness Sensitivity

The roughness of the river bed over the 1D model was increased and decreased by 20%. The results for peak water level are shown in Table C-6. An increase in roughness results in an increase in peak water levels in the channel as velocity is reduced. Hence there is more spill into the 2D resulting in larger flood extents. This can be seen on the flood map in Figure C-7. Decreasing roughness allows more flow to stay in channel which reduces flooding. The results show that the modelled water levels are relatively sensitive to changes in roughness. However, the modelled flood extends do not respond significantly. Although, there are some high localised differences in water level, on average, the typical maximum change in water level is about 200mm.

Table C-6: Roughness Sensitivity Results Relative to Baseline Water Levels

Sensitivity	Water Level Difference (m) with 1% AEP Event		
	Max	Min	Average
+ 20% Roughness	0.344	0.168	0.196
- 20% Roughness	-0.289	-0.270	-0.264

C.4.3.2 Flow Sensitivity

Flow sensitivity was tested by increasing and decreasing the model inflows by 20%. This was done by modifying the hydrological scaling factors. The results are shown in Table C-7. The flow adjustment causes a difference in water level, which is expected. The flood maps are also affected in some locations, notably around Park Beck as shown in Figure C-8.

Table C-7: Flow Sensitivity Results Relative to Baseline Water Levels

Sensitivity	Water Level Difference (m) with 1% AEP Event		
	Max	Min	Average
+ 20% Flow	0.395	0.210	0.175
- 20% Flow	-0.497	-0.078	-0.224

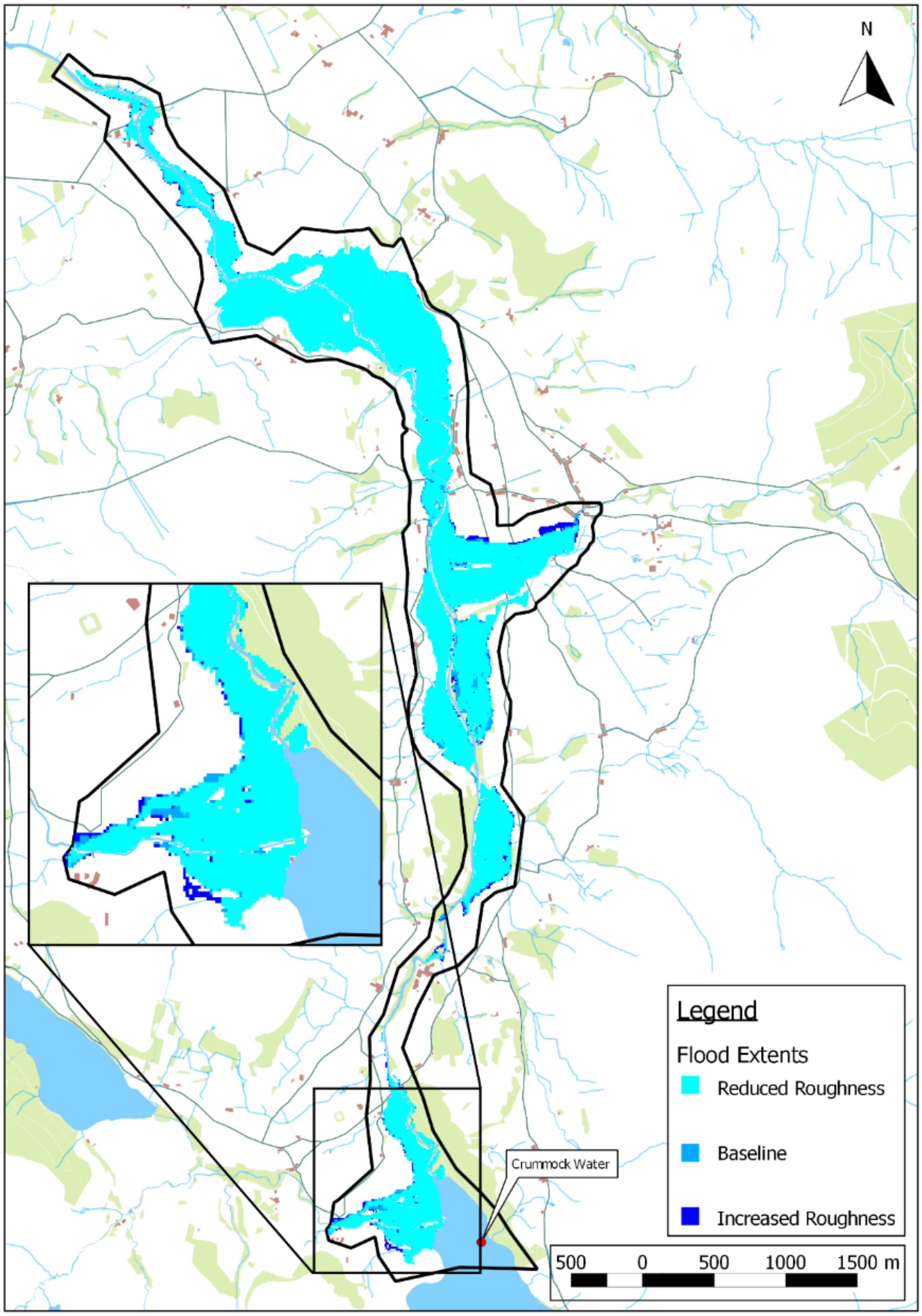

Figure C-7: Flood Extent for Roughness Sensitivity

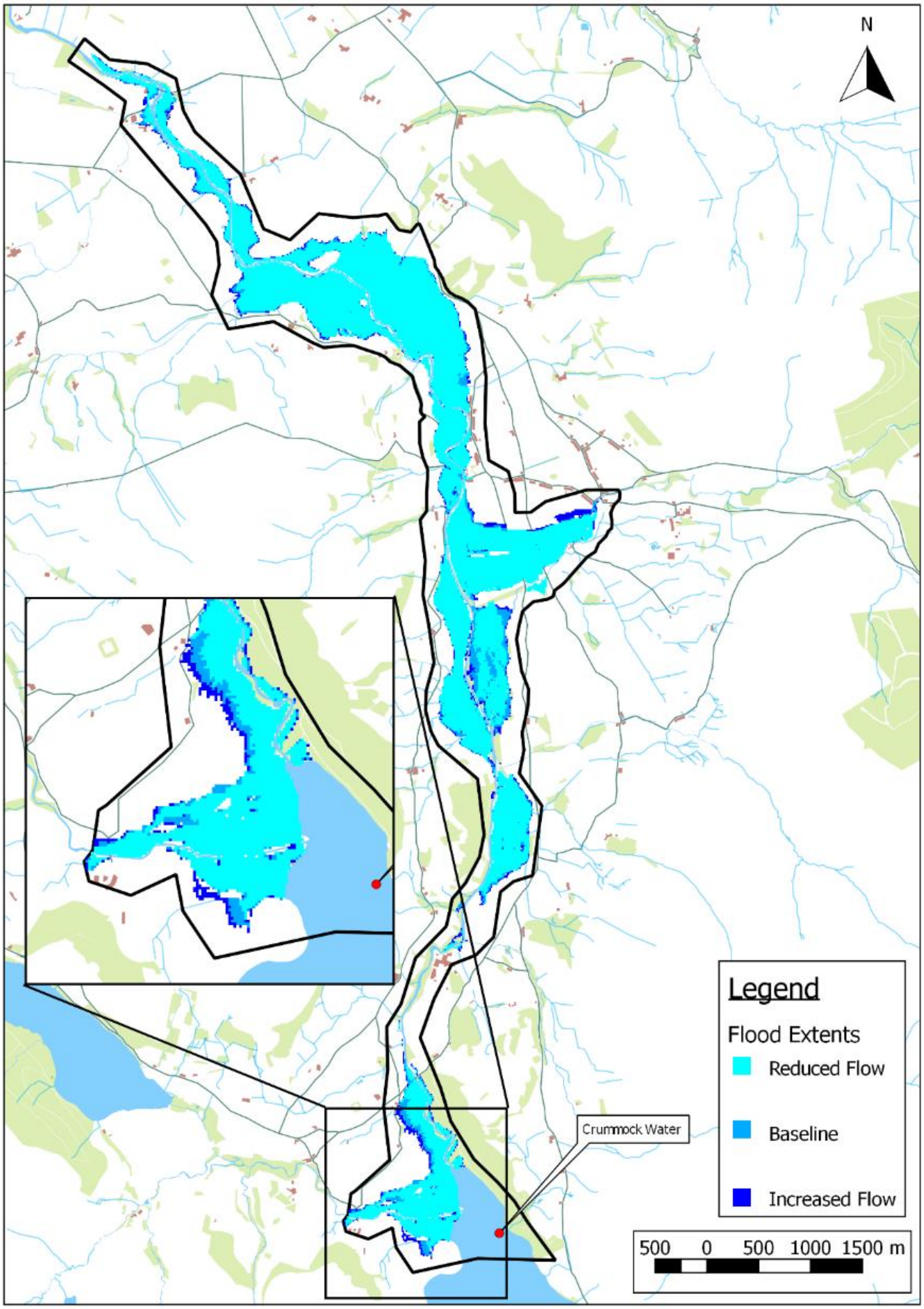

Figure C-8: Flood Extent for Flow Sensitivity

C.5 Model Results

Table C-8 shows the series of flood events that have been simulated with the hydraulic model for the scenarios considered in this study.

Table C-8: Modelled Events

Scenario	50% AEP	20% AEP	10% AEP	3.3% AEP	2% AEP	1.3% AEP	1% AEP	0.5% AEP	1% +CC
Baseline	✓	✓	✓	✓	✓	✓	✓	✓	✓
Design	✓	✓	✓	✓	✓	✓	✓	✓	✓
Roughness Sensitivity							✓		
Flow Sensitivity							✓		

C.5.1 Baseline Results

The hydraulic model has been run for 50%, 20%, 10%, 3.33%, 2%, 1.33%, 1%, 0.5% and 1% AEP plus climate change flood events. The maximum flood extents for the 50%, 10% and 1% AEP flood events are shown in Figure C-10.

The model results show a significant amount of flooding within the river floodplain. Flow is seen to overtop the banks along Park Beck, Whit Beck and parts of the River Cocker in the 50% AEP event and in many areas flood extents are similar between events.

Figure C-11 shows the flood mechanism for Park Beck. The onset of flooding from Park Beck happens at approximately 14 m^3/s and is greater on the left bank. Flood water from the left bank travels downhill towards Crummock Water but is then re-directed downstream when it reaches the wave wall which runs along the north west bank of Crummock Water.

C.5.2 Design Scenario Results

With the scheme in place, the naturalised outfall from Crummock Water makes it less efficient, resulting in greater flood rise in Crummock Water, and increased attenuation, thereby reducing the flows in the River Cocker. At Park Beck, since the wall is removed, surcharged flows go into the Crummock Water, rather than by-passing the lake. This further reduces the maximum flow within the River Cocker as shown in Figure C-12.

C.5.3 Comparison of Baseline and Design

The proposed design reduces the water level throughout the model. For the 1% AEP event, a reduction of between 0.5m and 0.7m is noted for most of the in-channel river reach. Figure C-13 shows a map of the difference in water level between the baseline and design case. The reduction in peak pass forward flow at the downstream extent of the model is from 165.9m^3/s to 107.4 m^3/s, which is a 35% reduction. Figure C-9 shows the flow at the downstream end of the model for both the baseline and design case. However, the trailing limb exhibits attenuation in the design case, and a flow increase of approximately 4 m^3/s is evident from around 25 hours onwards. The significance of this effect on flood risk to Cockermouth might be determined by considering relative timing of storm flows on the River Derwent.

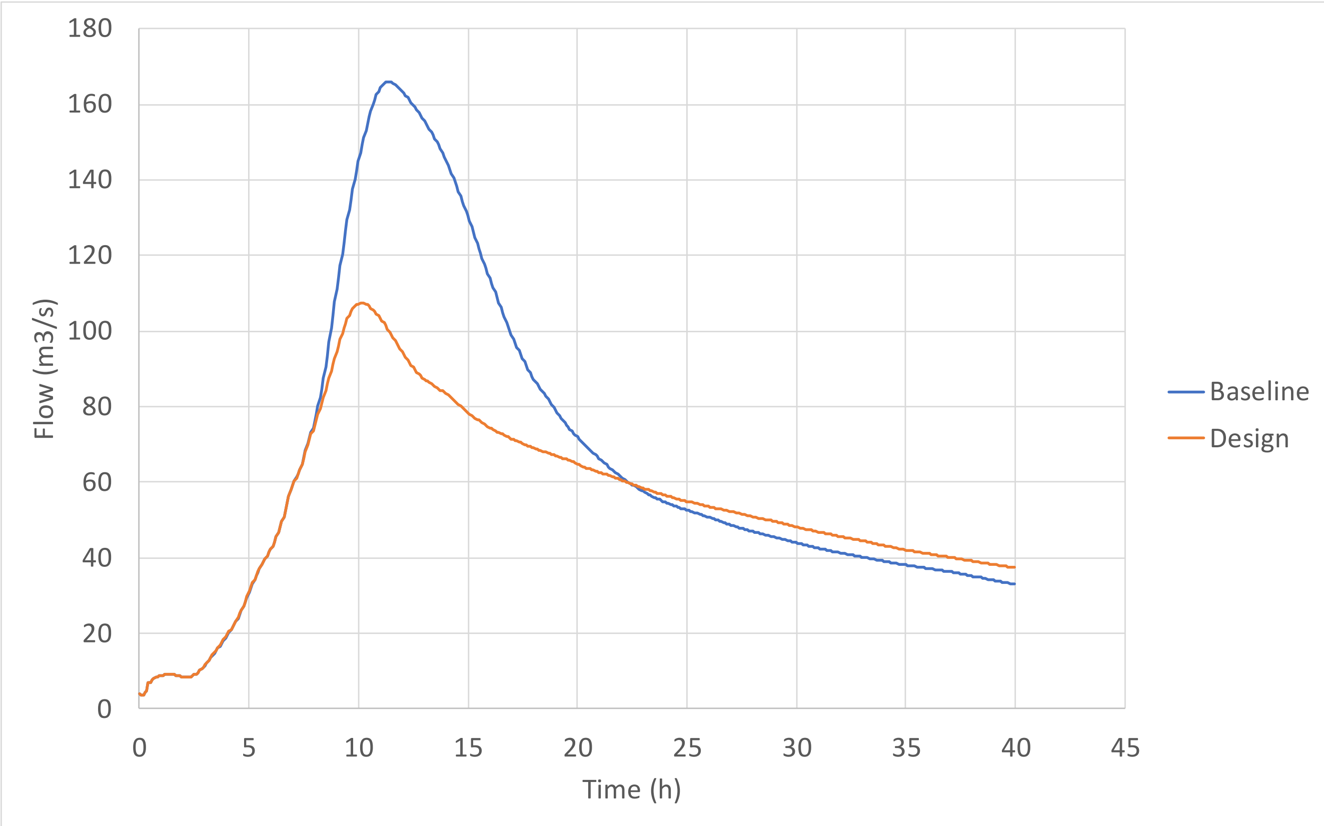

Figure C-9: Flow at the Downstream End of the Model

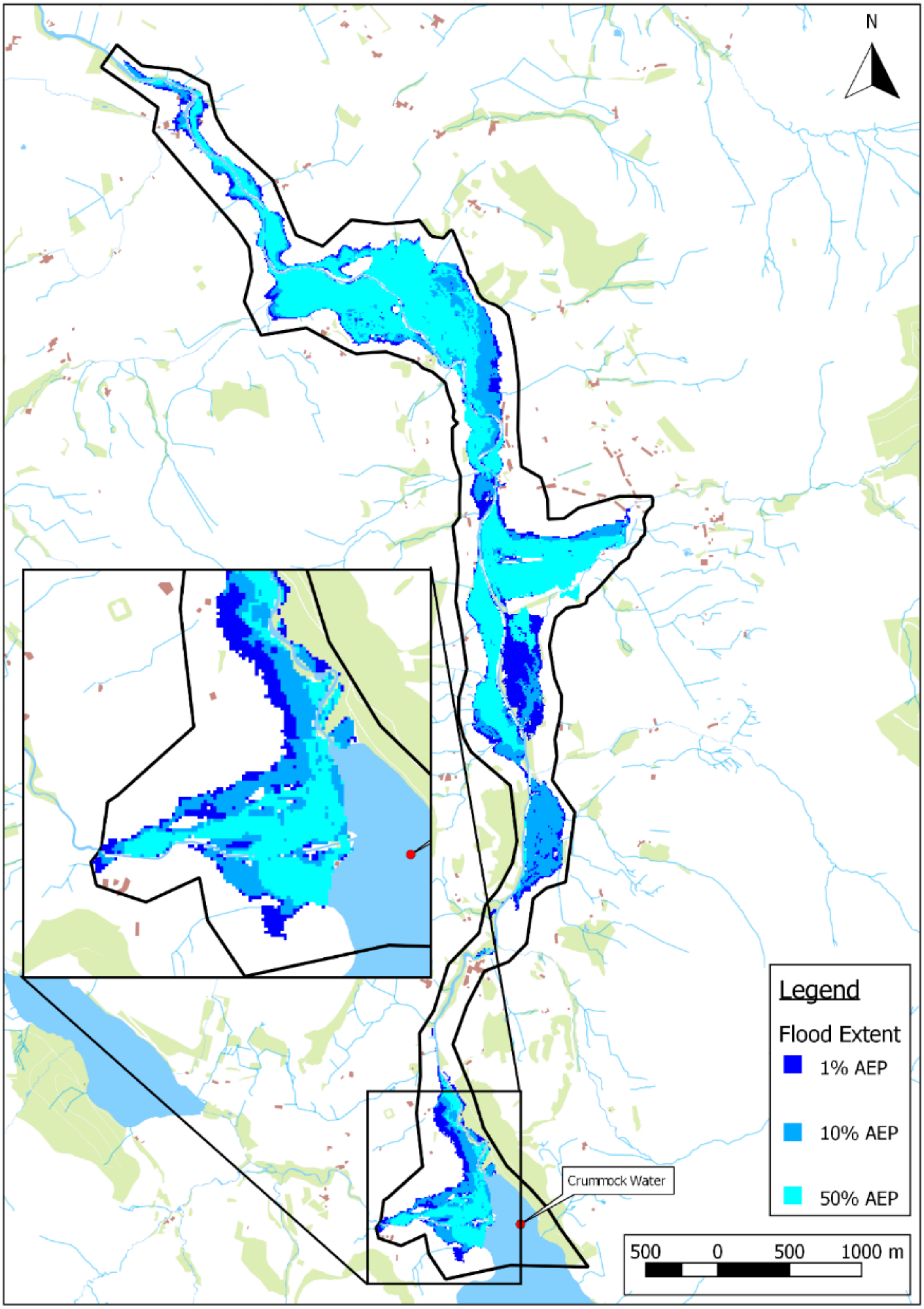

Figure C-10: Baseline Flood Extent for the 50%, 10% and 1% AEP events

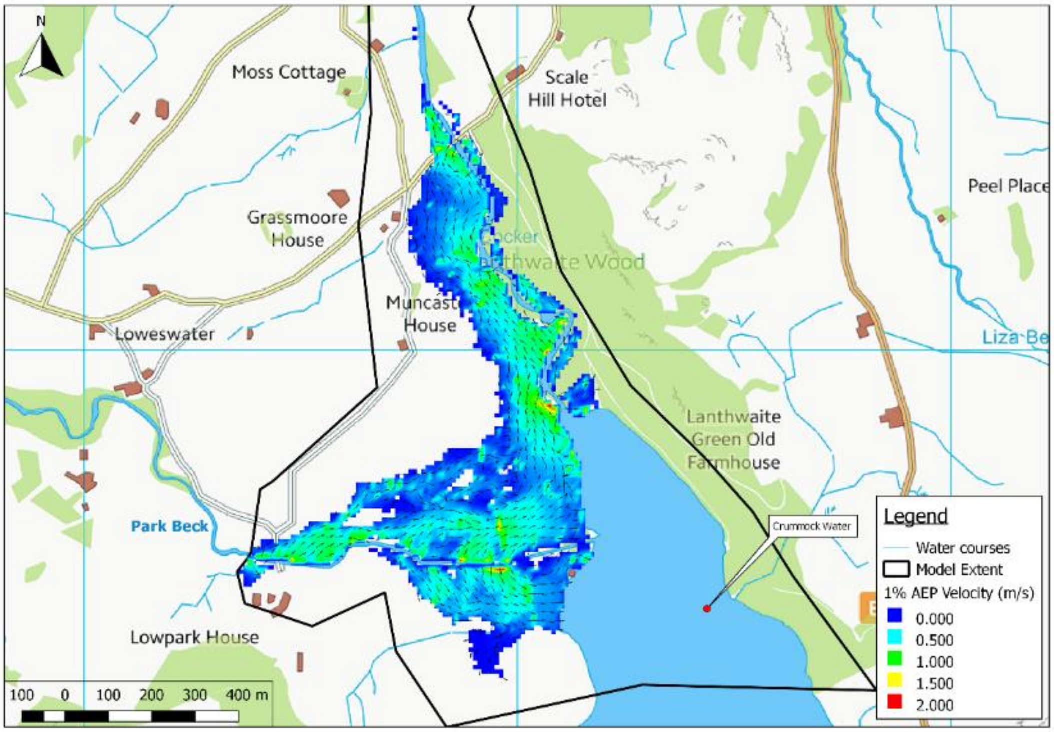

Figure C-11: Baseline Flood Mechanism from Park Beck

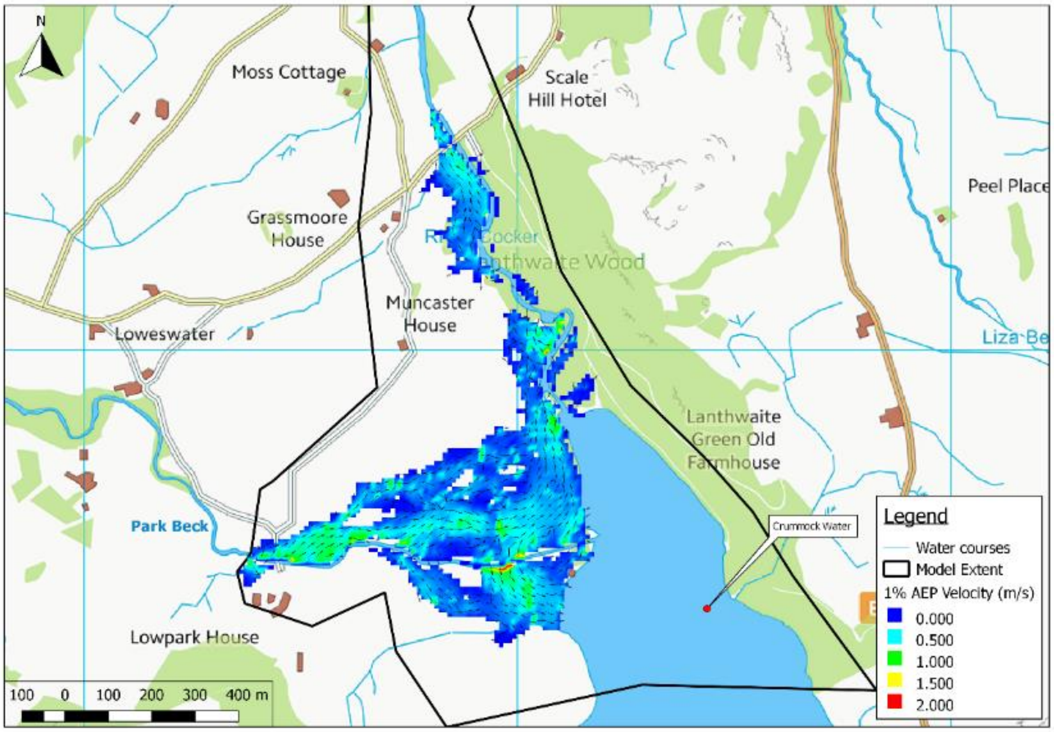

Figure C-12: Park Beck Flood Mechanism with Design

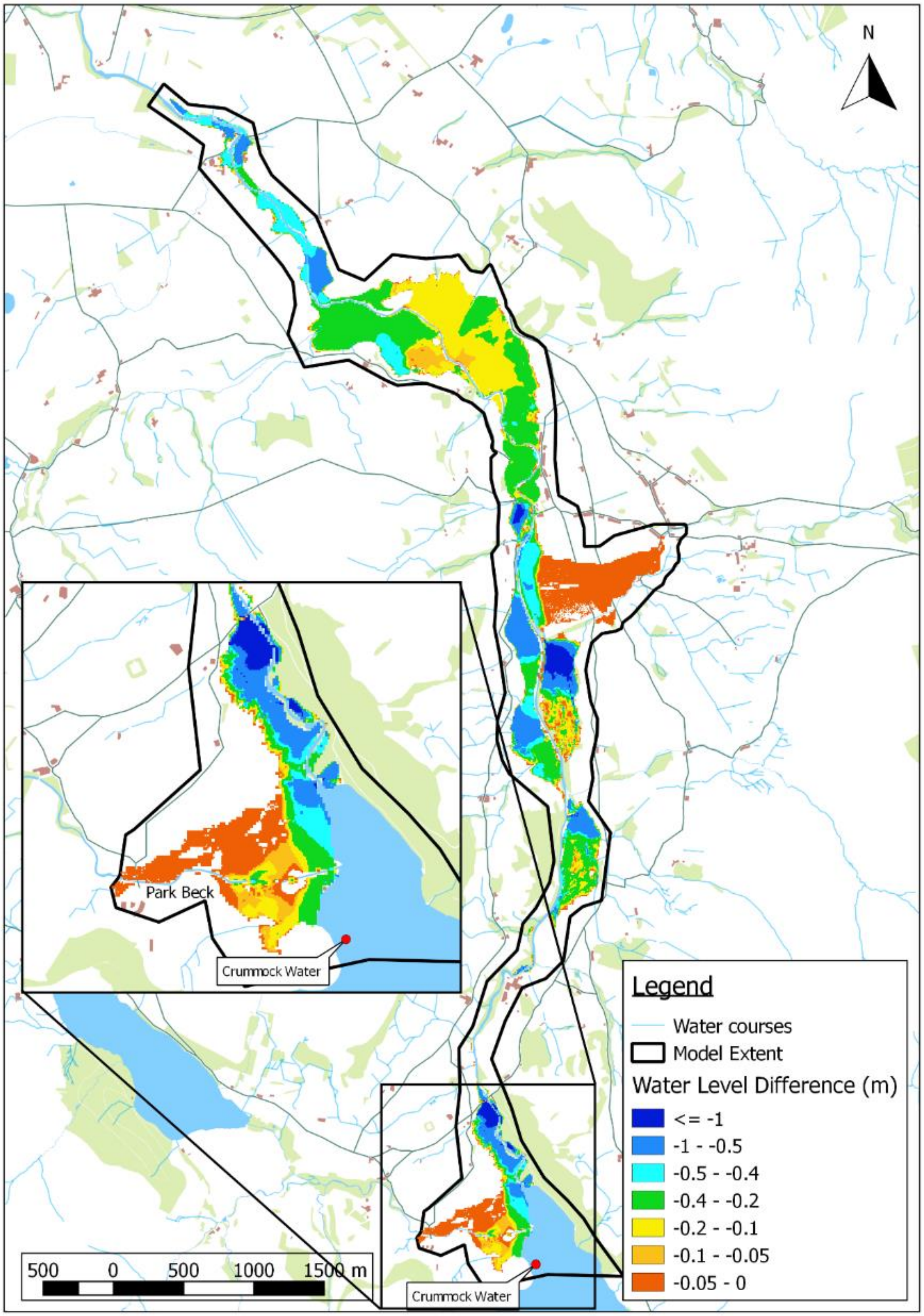

Figure C-13: Water Level Difference 1% AEP Design vs Baseline

C.6 Modelling Assumptions and Limitations

Whilst the most appropriate available information has been used to construct the model, there are uncertainties and limitations associated with it. Efforts have been made to assess and reduce levels of uncertainty in each aspect of the modelling process. Additionally, the sensitivity analysis carried out allows for the understanding of potential uncertainty associated with key model parameters.

The key sources of uncertainty in the model and its limitations are summarised below:

- A constant channel roughness has been applied across the model extents based on the best available information and standard guidance. In reality, channel roughness varies across the channel and with the time of the year. Sensitivity tests have been carried out to quantify the impact of changes in roughness.
- The accuracy and validity of the hydraulic model results is heavily dependent on the accuracy of the topographic data included in the model. The most up to date topographic data was used wherever possible. However, beyond the extent of the 2018 1m LiDAR DTM, levels were obtained from a mixture of survey data and the older (2009) LiDAR DTM.
- The 2D model cell size is 10m, which has been chosen to provide a comprehensive understanding of the flood mechanisms and risk over a large study area under the baseline and design scenarios. However, this does not allow for the accurate modelling of local flood mechanisms.
- No specific model calibration to observed data has been carried out. However, verification has been done by comparison of model outputs from the 1% AEP flood event with the published EA Flood Zone 2 maps and the existing Low Lorton model. The results were generally found to be in good agreement.
- The Park Beck component of the model has some computational instabilities that affect the flow hydrograph peaks in certain lengths. The model was therefore improved, but the instabilities were not fully removed. However, the improvement did not change flows and flood extents along the River Cocker. Hence, no further improvement was made as it was determined that the effect was localised and not significant to the overall accuracy of the study.

C.7 Conclusion

The results of the modelling analysis of the Crummock Water area and the proposed design are:

1. In the baseline scenario, there is significant active floodplain along the River Cocker. It is also shown that surcharged flows from Park Beck are re-directed at the western wave wall of Crummock Water towards the River Cocker, bypassing the lake.

2. Re-naturalisation of the Crummock Water overflow reduces its efficiency and significantly reduces the flood risk downstream on the River Cocker, due to increased attenuation in Crummock Water.

3. Removing the western wave wall further reduces flood risk downstream by allowing flood water from Park Beck to enter Crummock Water.

4. Re-naturalisation of Park Beck causes some localised increase in flood risk to adjacent land; however, this is designated wet woodland, and is owned by United Utilities. Otherwise, there is either no change evident, or there is a flood risk benefit.

Appendix D. Geomorphological site walkovers

In May 2017, a site walkover survey was undertaken by a geomorphologist and an ecologist along most of the River Cocker between the outlet at Crummock Water downstream to Low Lorton, at locations where access was permitted. Information from spot checks undertaken the previous year for a different study between Low Lorton and Cockermouth was utilised to define the lower reaches. The below is an account on a reach by reach basis of the geomorphological features and modifications found.

Figure D-1 shows how the site walkover was divided up into ten reaches.

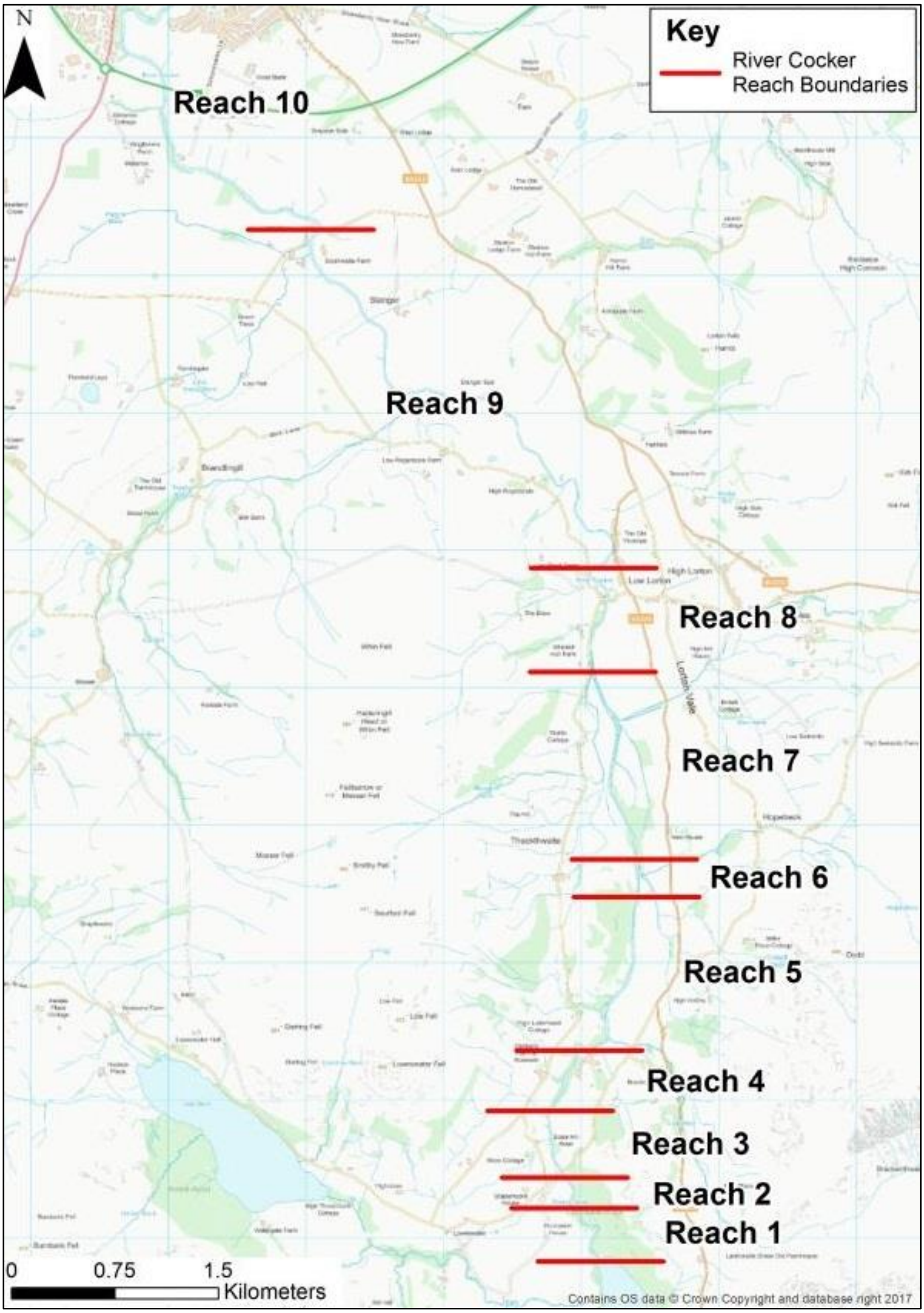

Figure D-1: Geomorphological reaches for the Cocker defined through site walkover observations

Reach 1	**Key features**
  	This reach runs from the Crummock Water outlet to the small weirs approximately 400m downstream of Crummock Water weir. The channel had a sinuous meandering planform and varied cross section. Immediately downstream of the Crummock Water weir the channel substrate appeared to be consolidated and not mobile. Any sediment passing over the weir does not appear to be deposited and is likely to be carried downstream. This reach appeared to be starved of finer sediment. The bed structure consists of large pebbles and cobbles with some small gravel filling the interstitial spaces. Further downstream substrate changes, with smaller mobile sediment particles with patches of gravel. Gravel sized material was noted to be the more dominant bed material with larger size sediments throughout. Whilst large cobbles and boulders were observed within the channel banks, they were generally formed of earth material. Riparian vegetation for the reach was woodland. Large trees bind bank material together, as is evident by lengths of exposed bank face that have suffered erosion or undercutting followed by bank failure. Erosion was prevalent throughout this reach with numerous areas of scour and bank undercutting, with fallen trees indicating undercutting and bank failure. Furthermore, the channel appeared to have incised through passage of a knickpoint. Deposits were observed along both banks throughout the reach. These varied in size and shape. Larger particles were found in the upper reach and smaller pebbles in the downstream reach. Mid-channel bars and vegetated islands were also noted. The abundance of erosive and depositional features suggests that the channel is adjusting and that it could be reactive to changes. Two small weirs were found to be located at or close to the first meander downstream of the weir in Lanthwaithe Wood. Both were noted to be approximately 0.3m in height. These could act as a barrier to coarse sediment movement downstream.
Reach 2	**Key Features**

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Reach 2 extends from the small weirs to the road bridge. The channel did not appear to be embanked and was well connected, exhibiting a meandering planform across the floodplain. Channel width varied significantly from 10m-20m along this reach.

Bed and bank material comprised finer materials and gravel and cobble substrates.

Flows in the reach were noted as varied with presence of riffles, runs, glides and backwaters.

Trees appeared to have fallen into the river channel evidenced by remnants of large woody debris (tree trunks and large branches). The woody material offered further localised flow variation suitable for varying species.

Deposition appeared to be the prevalent process, evidenced by side bars composed of pebbles and silt on the inside of bends and in the backwaters behind fallen trees. Erosion was observed at one location only along the right bank (middle photograph). This involved the scour with consequent bank failure.

Artificial bed and bank reinforcement and in-channel structures were found just upstream of the road bridge close to the gauging station weir. This EA gauging weir (bottom photograph) reduces the longitudinal connectivity of the channel evidenced by the sediments stored upstream.

Macrophytes were present in the channel upstream of the weir and in strands downstream.
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<td>Reach 3</td>
<td>Key features</td>
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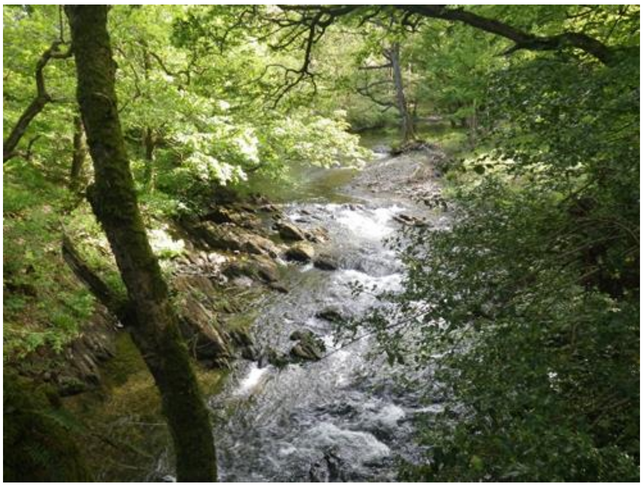
 	Reach 3 (approx. 380m) runs from the road bridge to the first meander bend downstream and is slightly wider than Reach 2 upstream of the road bridge. The channel had previously been modified and straightened at this location. The left bank within Reach 3 was unfenced whilst the right was fenced with marshy ground indicating good lateral connectivity. The channel also appeared to have become incised at the downstream end of the reach, developing a knickpoint (top photograph). This suggests that the channel here is unstable, but that the engineering structures in the channel have prevented lateral migration. However, areas of exposed bank from scour were noted and a large bank failure associated with the knickpoint (bottom photograph).

Reach 4	Key features
 	The channel entered a gorge (approximately 350m in length) with mixed areas of bedrock or coarse sediment composition of the bed and banks. The gorge feature naturally restricts lateral connectivity of the channel, instead promoting longitudinal connectivity of flows and sediment throughout the reach. Substrate between bedrock lengths comprised pebbles and cobbles. These are likely to have been deposited above solid bedrock. Where the bedrock was exposed, cascading flow was evident (top photograph). The predominant flow type was a mix of run-riffle lengths. Tree coverage was continuous in the gorge, primarily along the right bank. At the downstream limit of this gorge feature a large pool was observed leading into a meander bend. The diverse morphology of the reach has resulted in a heterogeneous channel cross length with varied depths and widths. A weir demarks the downstream extent of the reach, prior to the meander pool which is likely to affect the longitudinal connectivity of the channel in some flows (bottom photograph).

Reach 5	Key features
	Reach five runs for approximately 1.2km from the weir at the downstream extent of reach 4. Throughout this reach, the channel was much wider and straighter than the naturally constrained gorge upstream, suggesting that the channel has been artificially modified. Ranging between 11m and 15m width the channel is much shallower with a gravelly cobble substrate. The channel appeared to have been embanked alongside the right bank and there was some deposition along both the left and right bank toe, possibly sourced from the bank. Downstream of the collapsed bank a side bar of deposited gravels and pebbles were found. Over bank deposits were found in fields adjacent to the channel, likely to have been deposited on the floodplain by very large floods (such as the 2009 flood and the 2015 flood (Storm Desmond) (photograph to left). This suggests some lateral connectivity with the floodplain during extreme high flows, but the embankments along the channel sides would limit connectivity during lower magnitude events. Jacobs (2010a) suggests that the river at this location is eroding and causing local aggradation which in the past has caused high flows to be routed across the floodplain. The mounding of some of these sediments is evidence of intervention by the farmer who undertook works to reinstate the river back into its pre-flood channel. This involved dredging and piling of sediment along the right bank (Jacobs, 2010a).

<table>
<tr><th>Reaches 6 and 7</th><th>Key features</th></tr>
<tr><td></td><td>Reach 6 runs for approximately 300m with a channel that is uniform, embanked, wide and shallow with a depth of 1m and 6-8m wide. There are local lengths of artificial channel straightening. At the upstream end of the reach, there is a natural bedrock step, with a cascade flow, resulting in a drop of channel profile of approximately 1.5m.

In reach 7, channel width is approximately 10m. There were relatively shallow lengths, interspaced between deeper areas of water.

Scour, bank undercutting and poaching (due to unfenced fields) were observed. Locally there had been bank failure revealing coarse material, consisting of cobbles and gravels (photograph to the left). The predominant flow type was riffles and pools. However, area of runs, and bedrock/boulder cascades were also recorded. These flow types offer flow variation, and associated habitat. Numerous manmade structures were found within the channel such as weirs, pipe-works and bridges.

Large volumes of gravel were found in the reach which had become deposited overbank (predominantly the left bank), suggesting connectivity to the floodplain during high magnitude events. There was also evidence of dredging and artificial over widening of the channel.</td></tr>
</table>

Reach 8	**Key features**
 	Reach 8, immediately upstream of Low Lorton was noted to be wide (8.5m to 14m) and artificially straightened. Riparian vegetation was relatively uniform throughout the reach. Above Low Lorton the right bank of the channel was found bordered by agricultural land use. The substrate was found to be pebbles and large cobbles with a large side bar deposit located at the meander bend immediately upstream of Low Lorton with run flow type. Much of the channel was found to be embanked on one or both sides with either cobble brick walls at the rear of domestic properties (mostly within Low Lorton) (top photo) or naturally by large cobble and boulder embankments (bottom photo) restricting lateral connectivity. Longitudinal connectivity was found to be unrestricted by artificial or natural features upstream of Low Lorton. The bridge crossing over the River Cocker could locally create a bottleneck to flow in high flow events and result in the collection of woody material, trash or debris.

Reaches 9 and 10	Key features
 	The channel downstream of Low Lorton appeared uniform and approximately 8m in width. Mid-channel, side and point bars were found throughout this part of the River Cocker. Many of the mid-channel bars appear to have become vegetated indicating that they have not been mobile for some time. A weir was observed at the spot check at Mill House (top photo indicated by red arrow) partially restricting the longitudinal movement of sediments from upstream to downstream. However, evidence of recent deposits downstream of the weir indicate that it is passable for some sizes of sediment. Below the bridge there is also evidence of mid-channel bar deposits in an over-wide channel. This bar had become vegetated by grasses, large shrubs and several small trees. A spot check at Fern Bank road between Cockermouth and the A66 revealed an over-wide channel with several additional shallow channels passing over an area of considerable deposition. These deposits had varied sediment sizes ranging from small gravels to large boulders. At the upstream extent of this deposition a small weir was present, retaining a large backwater upstream. Downstream of this a small bedrock waterfall appears to have formed. By Reach 10, the character of the river was noted to have changed as the channel enters Cockermouth, at Lorton Street-Victoria Road (bottom photograph). Here it was found to be artificially embanked along the left bank by a brick wall approximately 2m in height. The channel was found to be also constrained by a high right bank. Passing under Castlegate the channel was fully reinforced, protecting the adjacent residential properties from floods and preventing any lateral connectivity.

Appendix E. Geomorphological feature maps of River Cocker

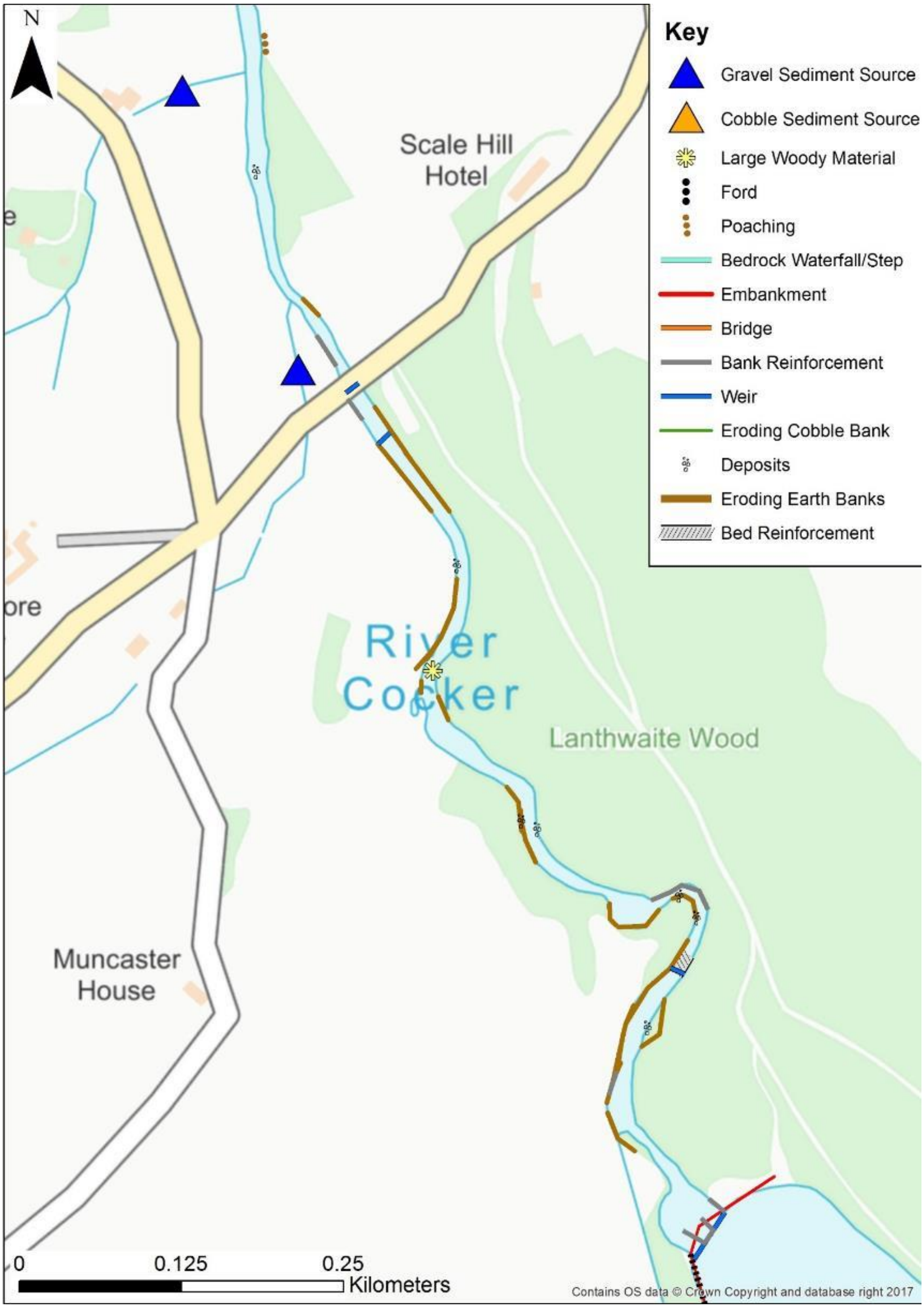


Figure E-1: Geomorphological features observed on the River Cocker

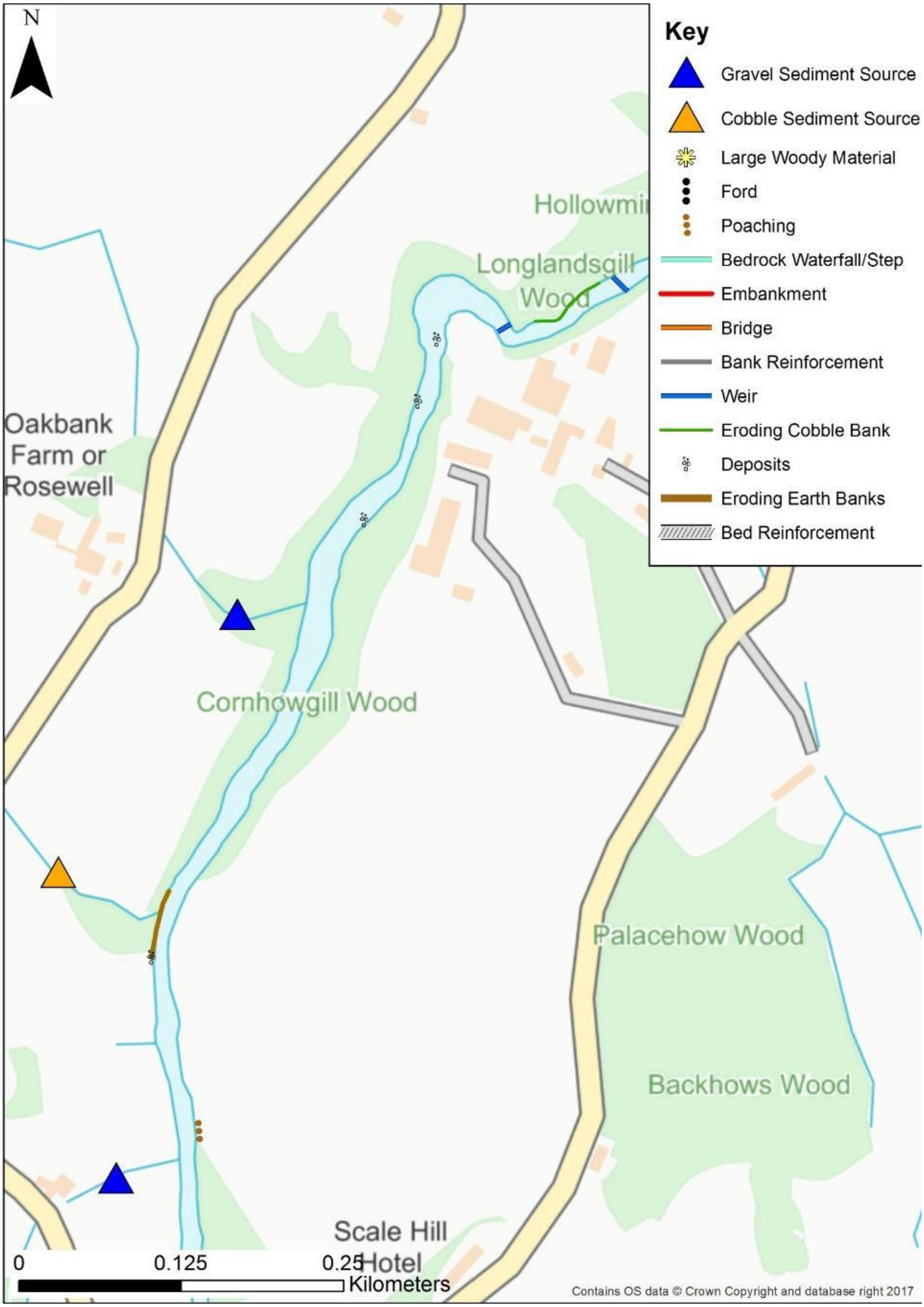


Figure E-2 : Geomorphological features observed on the River Cocker

Figure E-3 : Geomorphological features observed on the River Cocker

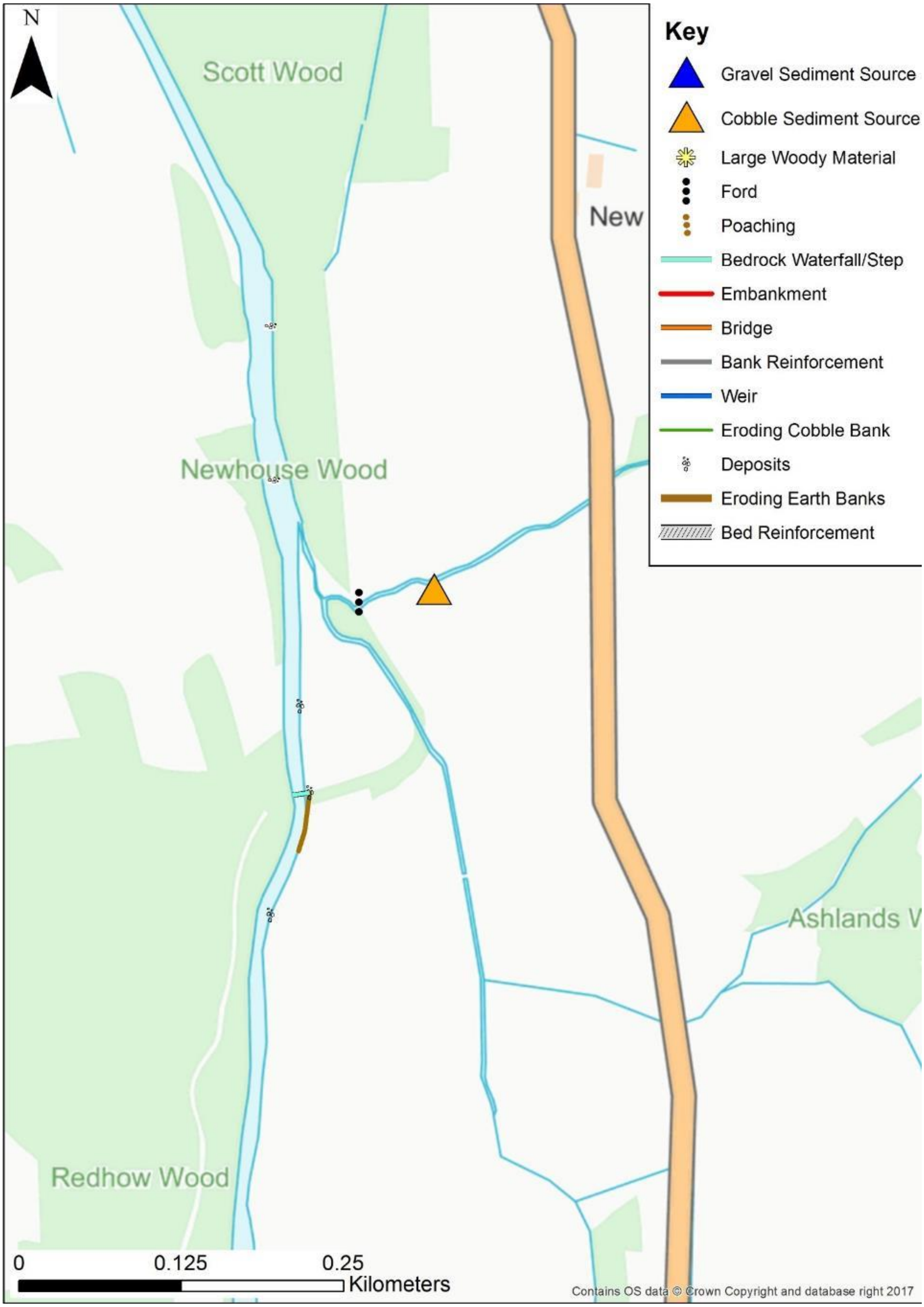


Figure E-4: Geomorphological features observed on the River Cocker

Appendix F. PSG statement

River Ehen SAC Compensatory Measures – R6 Infrastructure Removal

Expected benefits of Infrastructure Removal at Crummock Water

Compensatory measure R6 comprises research into the technical, environmental and economic feasibility of removing abstraction-related infrastructure at a number of sites including Crummock Water.

The Measure Scope (2015) sets out the environmental issues with existing infrastructure, namely disruption of connectivity for migratory species and of natural hydrology and geomorphology.

As part of Jacobs' work on the Main Stage A report for Crummock Water, they have raised concerns that they believe the weir does not affect connectivity for salmon and that the River Cocker in its current modified state provides suitable salmon habitat.

This note is to confirm that Natural England (NE) and the Environment Agency (EA) expect direct and indirect benefits to salmon from infrastructure removal at Crummock Water. In this respect, it would be appropriate for this work to be part of Compensatory Measures to address the impact of continuing abstraction from Ennerdale Water.

Crummock Water dam and fish pass

The weir at Crummock Water is fitted with a fish pass which does not meet current fish pass standards. It enables some adult fish to pass upstream in some flow conditions but we consider the weir and fish pass together to constitute a partial barrier to both upstream migration of salmon adults and downstream migration of smolts.

This is based on studies, e.g. Newton *et al.* (2018), showing that even small barriers and those fitted with fish passes are likely to delay upstream migrating fish as they search for the easiest upstream route. Delays can result in loss of fitness from stress and unnecessary energy expenditure, sub-optimal arrival at spawning grounds, or mortality from predation and disease. A proportion of migrating fish are also likely to turn back and spawn downstream of any barrier, potentially restricting the range of the species over time.

There is also a body of evidence (e.g. Aarestrup and Koed, 2003; Gauld *et al.*, 2013; Nyqvist *et al.*, 2016) that the downstream migration of salmon smolts can be significantly delayed by artificial barriers with and without bypass facilities and especially in low flow conditions. Smolts are susceptible to damage and disease, and are vulnerable to predation, so delays at barriers can result in significant mortality.

It is highly likely that adult salmon are delayed or turned back by Crummock Water weir, and that salmon smolts are also delayed, especially in low lake level conditions.

We have no doubt that weir removal at Crummock Water will benefit the catchment salmon population by preventing these impacts.

Benefits to salmon of natural hydrological and geomorphological function

Restoration of these processes is a key aim for this compensatory measure, as set out in the measure scope. Implicit within that is the benefit to the ecosystem as a whole and to native species including salmon.

Some gravel does get moved over the weir through wave action and longshore drift but the weir does interrupt sediment flow and modify river flow to an extent. The restoration of an uninterrupted sediment transport and a fully natural flow regime will, over time, improve salmon spawning and juvenile habitat in the upper river.

Concern was expressed at the R6 Measure meeting on Nov 16th 2017 that ceasing abstraction, and therefore compensation flow provision, may have a negative impact on salmon as the river will subsequently experience lower flows than at present.

Whilst periods of low flows below the current compensation flow (currently thought to be around the Q98 level) may indeed impact juvenile salmon in the short term, restoration of the full range of natural flows is an essential component of ecosystem restoration. Both Water Framework Directive (WFD) and the Site of Special Scientific Interest (SSSI) Favourable Condition Tables have a target of natural flow regimes, with the underlying principle that natural flows will support a river's characteristic species, such as salmon, over the long term.

Restoration of salmon habitat in the River Cocker

The River Cocker has been significantly modified along much of its length in the past, as set out in the River Derwent Restoration Plans (2010) produced by Jacobs for NE and the EA.

This has resulted in long degraded stretches without the full range of habitats required for all salmonid life stages. There is no doubt that the salmon population of the Cocker system is artificially low with the partial barrier of the lake weir, the modified channel and the modified flow and sediment regimes all contributing factors.

The Defra bodies are progressing a number of habitat improvement and restoration plans on the river, all of which will be underpinned in the long term by re-naturalised flow and sediment regimes.

Chris Addy, Biodiversity Technical Specialist, Environment Agency

Andy Gowans, Fisheries Technical Specialist, Environment Agency

Simon Webb, Lead Conservation Adviser, Natural England

Melanie Fletcher, Lead Freshwater Adviser, Natural England

JACOBS

References

Aarestrup, K. and Koed, A. (2003) Survival of migrating sea trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*) smolts negotiating weirs in small Danish rivers. *Ecology of Freshwater Fish* 12: 169–176. https://doi:10.1034/j.1600-0633.2003.00027.x

Gauld, N., Campbell, R. and Lucas, M. (2013) Reduced Flow Impacts Salmonid Smolt Migration in a River with Low-Head Weirs. *Science of the Total Environment* 458: 435–443.

Jacobs (2010) *PSA3 Riverine SSSI Restoration Visions River Derwent Catchment – Technical Report B1284600/D01*. Jacobs Engineering U.K. Limited, London.

Newton, M, Dodd, J.A., Barry, J., Boylan, P., and Adams, C. E. (2018) The impact of a small-scale riverine obstacle on the upstream migration of Atlantic Salmon. *Hydrobiologia* 806: 251-264. https://doi.org/10.1007/s10750-017-3364-3

Nyqvist, D., McCormick, S. D., Greenberg, L., Ardren, W. R., Bergman, E., Calles, O. and Castro-Santos, T. (2017) Downstream Migration and Multiple Dam Passage by Atlantic Salmon Smolts. *North American Journal of Fisheries Management* 37(4): 816-828.

United Utilities (2015) *Research Measure 6: Environmental & engineering assessment of infrastructure removal.* United Utilities, Warrington.

Appendix G. Detailed Ecology Baseline Assessment

The River Cocker starts at the Crummock Water outlet and flows through Lorton Vale to Cockermouth, where it meets the River Derwent. Both Crummock Water and the River Cocker are within the River Derwent and Bassenthwaite Lake Special Area of Conservation (SAC) (Joint Nature Conservation Committee (JNCC, 2018) and the River Derwent and Tributaries Site of Special Scientific Interest (SSSI) (Natural England, 2018a). The SAC qualifying features include the following habitats and species (-primary reason for selection of the site):

- Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/ or *Isoeto-Nanojuncetea*. (Clear-water lakes or lochs with aquatic vegetation and poor to moderate nutrient levels) (3130)*;
- Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho batrachion* vegetation. (Rivers with floating vegetation often dominated by watercrowfoot);
- Floating water-plantain (*Luronium natans*) (1831)*;
- Atlantic salmon (*Salmo salar*) (1106)*;
- Brook lamprey (*Lampetra planeri*) (1096)*;
- River lamprey (*Lampetra fluviatilis*) (1099)*;
- Sea lamprey (*Petromyzon marinus*) (1095)*;
- Otter (*Lutra lutra*) (1355*); and
- Marsh fritillary butterfly (*Euphydryas (Eurodryas, Hypodryas) aurinia*) (1065)*.

A Site Improvement Plan (SIP) was developed in 2014 for the River Derwent and Bassenthwaite Lake SAC which identifies pressures and threats to the SAC and its qualifying features and outlines measures required to improve conditions (NE, 2014). This plan (SIP140) identified a number of issues affecting the qualifying species in the SAC including water pollution, siltation, invasive species, physical modification, water abstraction, changes in species distribution, changes in land management, forestry and woodland management, fish stocking and atmospheric nitrogen deposition. Changes in hydrology was identified as a pressure to the qualifying habitat features, but not the species and management measures identified to improve habitat for marsh fritillary. The SIP was intended to be a high-level review covering the entire SAC, so not all pressures applied to all qualifying features in all areas of the SAC.

A 2010 condition assessment of the Crummock Water SSSI, based on the standing open water and canals habitat, reported a stable macrophyte community of favourable conditions, with no evidence of alien species (NE, 2010a). Favourable conditions were also noted in the condition assessment of the Crummock Water and Buttermere Dubs Wetlands, based on fen, marsh and swamp (lowland) habitat (NE, 2012), (NE,2010b and c). A condition assessment of the River Cocker component of the River Derwent and Tributaries SSSI classified the River Cocker as unfavourable in 2010, due to the presence of intensive agriculture and overgrazing along the embankments (NE, 2010d).

Of the species designated in the River Derwent and Bassenthwaite Lake SAC, Atlantic salmon, brook lamprey, otter, river lamprey and sea lamprey are within the scope of this study, with salmon being the primary focus. Aquatic macrophytes and wetland habitats are also within the scope of this study, as ‘habitats supporting macrophyte communities’ are a qualifying feature of the SAC. Habitat modifications that improve water quality and habitat availability for these qualifying species would also improve habitat for the designated macrophyte communities within the River Derwent and Bassenthwaite Lake SAC.

Arctic charr are cited in the River Derwent and Tributaries SSSI, known to reside in Crummock Water and are nationally scarce in England. Given their presence in Crummock Water and their national importance, Arctic charr is also a focal species in this study.

The River Cocker and tributaries of Crummock Water are known to support Atlantic salmon, brown/ sea trout , European eel, sea lamprey and river lamprey (Environment Agency, 2018a). A gill-netting survey conducted in July of 2013 and 2016 found populations of Arctic charr, brown trout, perch (*Perca fluviatilis*) and minnow (*Phoxinus phoxinus*) within Crummock Water (Winfield and James, 2017). The EA lists native white-clawed crayfish (*Austropotambius pallipes*) as a key species within the River Derwent catchment (EA, 2018d), but the closest confirmed record that could be found was on the River Ive near Stockdalewath (Biological Records Centre, 2018).

A geophysical survey was undertaken in August 2018 to identify the substrates present in the northern end of Crummock Water, including behind the weir (TerraDat, 2018). This survey found that behind the weir, bedrock ranged between 8 to18 m below ground level and the overlying substrate was sand and gravel, typical of alluvial and lacustrine deposits.

An environmental assessment was undertaken to assess the potential impact of lowering water levels in Crummock Water when implementing a drought permit in support of UU’s drought plan (Cascade, 2014). A reduction in lake levels of up to 1.5 m below the weir crest was expected to limit habitat availability and impede the movement of fish into tributaries for spawning in some areas of Crummock Water. The assessment used bathymetry data to identify areas of the lake with a gentle slope which would be at risk of exposure if lake levels were lowered. These areas were mainly in the southern area of the lake, particularly near the inflows for Buttermere Dubs, Scale Beck and Low Ling Crag, and in the southeast area of the lake opposite Woodhouse Islands (north of Hagg Sike). Connectivity with Park Beck and Buttermere Dubs were assessed as poor not considering the drought permit due to the presence of weirs at Crummock Dam and Buttermere outfall, respectively. The assessment did, however, predict that otters could benefit because their prey species would be more accessible.

Current Water Framework Directive (WFD) classifications for Crummock Water, Park Beck and the River Cocker are given in Table G.1. It should be noted that Crummock Water is protected under the Drinking Water Protected Area directive (EA, 2018c). Crummock Water and the River Cocker are classified as heavily modified reaches, due to the physical alterations in place to support flood defences and water storage throughout the catchment. The overall biological quality of each length is classified as Good, with the exception of the area immediately downstream of Crummock Water, which is designated Moderate.

Table G.1 WFD Classifications for 2016 (EA, 2018e,f,,g,,h,,i)

Parameter	Cocker - conf Whit Beck to conf Derwent	Whit Beck	Cocker - Crummock Water to conf Whit Beck	Crummock Water	Dub (Park) Beck
ID	GB11207 5 070400	GB112075 070380	GB11207 5070370	GB112075 070350	GB112075 070360
Hydromorphological designation	Heavily modified	n/a	Heavily modified	Heavily modified	n/a
Overall status	Moderate	Good	Moderate	Moderate	Good
Chemical status	Good	Good	Good	Good	Good
Fish	Good	High	Moderate	n/a	High
Macroinvertebrates	High	High	High	n/a	Good
Chironomids (CPET) and Littoral Invertebrates	n/a	n/a	n/a	High	n/a
Macrophytes & Phytobenthos	Good	Good	Good	Good	Good
Physico-chemical elements	High	High	Good	Good	High
Hydromorphological elements	Supports good	Supports good	n/a	n/a	Supports good

G.1 Atlantic Salmon

G.1.1 Overview

Atlantic salmon is listed in accordance with the requirements of Section 41 of the Natural Environment and Rural Communities (NERC) Act 2006 (England) (NE, 2018b). Atlantic salmon is an Annex II contributing species for the River Derwent and Tributaries SSSI, and a qualifying species for the River Derwent and Bassenthwaite Lake SAC. Maintaining suitable habitat for all life stages of Atlantic salmon is therefore a legal requirement for this river.

G.1.2 Desk Based Literature Review

The River Derwent is considered a principal salmon river in England (Centre for Environment, Fisheries and Aquaculture Science (CEFAS) *et al*., 2019). This river has bene assessed as Probably at Risk of not meeting is compliance targets for salmon fishing conservation limits in 2018, and project values up to 2023.

Reported rod catches for the River Derwent (of which the River Cocker is a tributary), gave an annual catch of 335 individuals in 2017 (EA, 20208a). Catchment data compiled over a 13-year period (2005-2017) showed an overall pattern of decline in rod catch, from a maximum of 1,458 in 2007 to a minimum 132 in 2015 (Figure G-1, EA, 2017c, EA, 2018a). It should be noted that this information is reliant upon accurate catch reports from recreational anglers and gives no measure of catch effort (i.e. number of active fisherman), so is not directly representative of current stock conditions. Further, the decline in salmon numbers are in keeping with a general pattern of decline over time for the whole of England.

Records available from the National Biodiversity Network (NBN) Atlas and EA show the presence of Atlantic salmon along the full extent of the River Cocker and some of its tributaries (including Park Beck), and in both Crummock Water and some of its upland tributaries (UK Species Inventory, 2018b; EA, 2020). The presence of Atlantic salmon upstream of Crummock Dam indicates that the fish pass is not preventing migration to upstream spawning habitats.

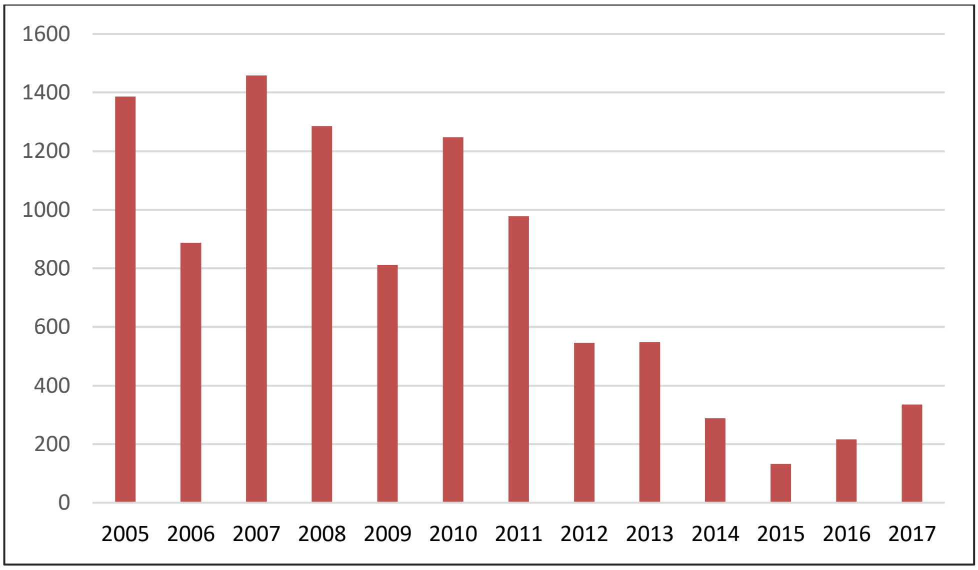


Figure G-1: EA Rod Catch Data for Atlantic Salmon 2005 to 2017

Macro-habitat availability on the River Cocker was mapped in 2009 from the Crummock Dam to the confluence with the Derwent and each of the main tributaries (Whit and Sandy becks) entering the Cocker on this reach (Jacobs, 2010a). Thirty-four percent of the Cocker below the Crummock Dam was recorded as suitable habitat for salmonid spawning; this habitat was principally located in the mid-length of the catchment in an area of coarse gravel and a run glide flow sequence. Salmonid fry habitat was poorly represented along the Cocker.

The re-meandering at Whit Beck has provided a more naturalised area with riffle/ glide sections, pools and spawning gravel deposits, and 20 redds (mixed Atlantic salmon and brown/ sea trout) were reported in the autumn of 2014 following the completion of re-meandering works earlier in the year (West Cumbria Rivers Trust, 2018). Prior to this the Whit Beck demonstrated restricted suitable habitat for salmonids due to historical modification in its mid-catchment. In the 2009 habitat study of the Derwent catchment, the top of the Sandy Beck runs through steep sided woody valley dominated by shallow high energy flow types, suitable for salmonid spawning. As the floodplain opens there are a mix of substrates, supporting potential salmon spawning at above the confluence with the Cocker.

Atlantic salmon are anadromous, hatching and spending their juvenile life stages (fry and parr) in freshwater, migrating out to sea as smolts where they undergo rapid growth and, after a few years, return to their natal rivers as adults to spawn. During their freshwater phases, habitat requirements of salmon are relatively specific with clean cobble/ pebble mixes being the preferred habitat. An absence of excessive fine sediments in spawning grounds is essential (Miller *et al*., 2015). Favourable locations for spawning are likely to occur where there is a river gradient of ≤3% and sites are typically in transitional areas between pool and riffle where suitable course gravels and cobbles are present. Relatively shallow depths (20-40 cm) and fast flows (50-75 cm/s) are optimal for juveniles (Table G.2) although migrating adults generally require higher flows especially if there are obstructions to pass. Slow flowing systems with a high proportion of silt are not suitable for Atlantic salmon (Hendry and Cragg-Hine, 2003). In general, juvenile fish are more sensitive than adults as they are less mobile, being more dependent on specific habitats during development stages. However, much of the available data quantifying impacts relate to adults. Very good water quality is required at all stages of the salmon life cycle.

Table G.2 Habitat Requirements of Juvenile and Adult Atlantic Salmon (Hendry and Cragg-Hine, 2003)

Juvenile fish <1yr old (fry)	
Water depth	≤20 cm
Water velocity	50-65 cm/s
Substrate type *winter *summer	Gravel and cobble (16-64 mm) Cobble up to boulder (64-256 mm)
Juvenile fish >1yr old (parr)	
Water depth	20-40 cm
Water velocity	50-75 cm/s
Substrate	Cobble up to boulder (64-256 mm)
Adult spawning	
Water depth	0.17-0.76 cm (in main stems often much deeper)
Water velocity	0.25-0.90 m/s
Substrate	Mix of fine materials (<2 mm), pebbles and cobbles

G.1.3 Site Visit Findings

Long lengths of the River Cocker between Lower Lorton and Liza Beck are artificially straightened, creating reduced riparian zones, limited vegetative cover, and highly embedded channel substrates that offer little habitat for juvenile salmonids (Atlantic salmon and brown/ sea trout). Dredging has also been undertaken in numerous areas, removing optimal spawning gravels from the main channel and depositing them along artificially built-up embankments. The resultant loss of spawning and juvenile nursery habitat restricts the main stem of the River Cocker and the lower reaches of several of its tributaries to use as migratory corridors for Atlantic salmon only. The River Cocker is an migratory corridor for Atlantic salmon and sea trout; and facilitates the movement of adults of these species to upstream spawning grounds.

Suitable salmonid spawning habitat was found in the upper reaches of Liza Beck (Figure G-4), where gravel deposits were found in riffle/ run lengths of moderately flowing water. Hope Beck also contained potential spawning gravels, which were located in the lower reaches of the tributary close to pools (Figure G-4). The upper reaches of Hope Beck provided more vegetative cover and longer riffle lengths, although dredging activities have removed large portions of pebbles and spawning gravels from the channel, reducing habitat quality for spawning.

Suitable spawning substrates and juvenile nursery conditions are abundant in several tributaries of Crummock Water (Figures G-4 to G-7). Salmonid fry were observed in the lower reaches of Scale Beck, Buttermere Dubs, and Hagg Sike. Each tributary contained suitable spawning gravels in moderately flowing water and provided mixed cobble/ pebble substrates downstream for fry and parr life stages. Rannerdale Beck also contained pockets of suitable spawning gravels and larger cobbles downstream to provide habitat for fry and parr (Figure G-6).

G.1.4 Baseline Summary for Atlantic salmon

A summary of the desk based and site visit findings is given in the sections below for the different age classes of Atlantic salmon.

Table G.3 Summary of habitat conditions for different age classes of Atlantic salmon

Spawning	Juvenile	Adult
Spawning habitat is present through the Cocker where suitable flow and substrate conditions are suitable. The un-modified reaches of Liza Beck (upstream of the B5269, Figure G-5), and lower reaches of Hope Beck and Whit Beck were all identified as areas containing suitable spawning habitat. Salmonid spawning has already been noted in the re-meandered length of Whit Beck, indicating the high quality of habitat available in this area. Spawning gravels were also present in Park Beck, close to Kirkstile Bridge, Rannerdale Beck and the lower reaches of Scale Beck, Buttermere Dubs and Hagg Sike (Figures G-6 and G-7).	The high level of substrate embeddedness observed in the straightened channel sections of the River Cocker limits its capacity to support juvenile salmonids. Juvenile habitat is available in the meandered lengths, where mixed composition substrates provide the crevices and cover necessary to support these life stages (Figures G-5 and G-6). Suitable habitat was also noted in the upper reaches of Liza Beck and in the lower reaches of Hope Beck. Salmonid juveniles (both fry and parr life stages) were observed in several tributaries of Crummock Water. Scale Beck, Buttermere Dubs and Hagg Sike all offered the necessary riffle/ run lengths and mixed substrates required to support juvenile life stages (Figure G-7).	Records of Atlantic salmon upstream of the Crummock Water Dam confirm the River Cocker to be a migratory corridor for anadromous salmonids, at least under moderate flow conditions. The fish pass currently in place at Crummock Dam is passable by salmon, given their presence in Crummock Water upstream of the dam. The weir is however expected to hinder or delay upstream or downstream migration, but not completely prevent it, and under some low flow conditions may present a barrier to migration.

G.1.5 Main Opportunities and Constraints

Limited information on supporting habitat for spawning and juvenile fish is available from literature review. The site visit confirmed the presence of suitable spawning habitat on the main River Cocker and in several tributaries of Crummock Water, some of which contained juvenile salmonids. The areas of Crummock Water near the inflows for Buttermere Dubs and Scale Beck were identified by bathymetry data as being at risk from exposure if lake levels were reduced, and this might hinder the ability of Atlantic salmon to reach the spawning habitat observed in the lower reaches of these two tributaries, particularly at Buttermere Dubs where connectivity was assessed as poor prior to drawdown from a drought order. This would however be a short-term effect.

Spawning habitat was available upstream of the straightened length of Park Beck (Figure G-6). Gravel deposits were observed on the sand bank at the mouth of Park Beck and are thought to have originated from this tributary. The straightened length of Park Beck contains compacted sediments and limited habitat for fish and aquatic invertebrates. Re-meandering the straightened length would naturalise the channel and improve fish habitat, by trapping finer sediments and forming gravel beds suitable for salmonid spawning. Removal of the wall to the north of Park Beck, in conjunction with re-meandering the tributary would open up a larger area of spawning habitat, similar to naturalised length of Whit Beck.

Access to the spawning habitat in Hope Beck, Rannderdale Beck, Scale Beck and Buttermere Dubs is contingent upon the River Cocker providing a migratory corridor for adult Atlantic salmon returning to spawn. Flow conditions around the cascade and bedrock lengths at the northern tip of Redhow Wood (Figure G-4) and Longlandsgill Wood (Figure G-4) must maintain sufficient water depth and moderate flows to allow migrating adults to overcome the natural barriers in these lengths. Flows that are too high would also render this length of river impassable.

Although the weir is expected to hinder or delay migration it does not present a complete barrier to upstream or downstream under all flows. However, under low flows fish may be prevented from migrating and thus the weir would present a barrier. Therefore, the removal of the weir would reinstate free passage for Atlantic salmon of all age classes.

G.1.6 Risks and Uncertainties

It is not known whether the salmonid juveniles observed in Scale Beck, Buttermere Dubs and Hagg Sike were Atlantic salmon, brown trout or sea trout, so the species spawning in these locations could not be confirmed Information from the field survey of the River Cocker is limited as access to all areas of the river was not possible due to deep water. In addition, it was not possible to survey both banks along the entire survey stretch and key areas of supporting habitat could have been missed.

G.2 Sea Lamprey and River Lamprey

G.2.1 Introduction

River and sea lamprey are listed in accordance with the requirements of Section 41 of the Natural Environment and Rural Communities (NERC) Act 2006 (England) (NE, 2018b). As noted previously, both species are also Annex II primary species for the River Derwent and Bassenthwaite Lake SAC and contributing species for the River Derwent and Tributaries SSSI.

G.2.2 Desk Based Literature Review

There is very little available information for any species of lamprey in the catchment.

The Environment Agency and West Cumbria Rivers Trust (WCRT) (EA, 2020, WCRT, 2020) conducted electrofishing surveys of the River Cocker from 2003 to 2018 and confirmed the presence of lamprey (unidentified species) along the River Cocker between Yewdale (NY157249) and Cockermouth (NY122304). One confirmed river lamprey catch was reported downstream of Lower Lorton (NY147266) in 2003, but no other specific records of sea or river lampreys have been obtained for the catchment. An NBN Atlas search returned five records for river lamprey in the River Cocker (no records for sea lamprey in the river), and none of these were from further upstream than the EA record at Yewdale (UK Species Inventory, 2018a).

Macro-habitat availability on the River Cocker was mapped in 2009 from the Crummock Dam to the confluence with the Derwent and each of the main tributaries (Whit and Sandy Becks) entering the Cocker on this reach. This study supports the records of EA data, with lamprey ammocoete habitat predominantly restricted to the River Cocker catchment below the confluence with Sandy Beck. Lamprey spawning habitat, similar to the spawning habitat requirements of salmonids, is present in the upper reaches of the Cocker below the Crummock Dam. There is relatively good interconnectivity between different life cycle habitats,

River and sea lamprey require the same habitat for spawning and the development of ammocoetes (juveniles) (Table G.4). Spawning times for the two species differ and are dependent on temperature, and clean gravels in flowing water are essential for spawning (Maitland, 2003).

Hatching larvae migrate downstream to nursery areas in slow flowing reaches. Examples of potentially suitable habitat include large deposits of silt and sand on river or stream margins, detritus covering coarser substrates, and patches of silt and sand found among tree roots, emergent vegetation, submerged woody debris or larger substrates. Ammocoetes burrow down into the silt/ sand substrate and spend several years developing in tunnels within the sediment. Older ammocoetes could prefer coarser sand and gravel during this time (Maitland, 2003;

Dawson *et al*., 2015). Because of their habitat preferences, ammocoetes exhibit a patchy distribution at small and large spatial scales as they seek out suitable habitat. When ideal habitat is not found, ammocoetes would occupy less suitable habitat at lower densities, such as areas with mobile coarse sand and gravel (Dawson *et al.,* 2015). The interconnectivity between spawning and juvenile habitats is important in determining sustainable populations.

Adult lampreys require suitable vegetative or rocky cover to provide hiding places where they could rest while waiting for suitable water temperatures for spawning. After metamorphosis, young adults migrate downstream to estuaries (river lamprey) or open seas (sea lamprey), where they feed and develop into adults. Adults of both species then migrate upstream to suitable freshwater spawning habitat and die shortly after spawning is complete.

River and sea lamprey are poorer swimmers than Atlantic salmon, and thus some features (natural and anthropogenic) that salmon can pass (including fish passes) are still migration barriers to these species.

Table G.4 Summary of Habitat Requirements for River and Sea Lamprey

Species	General	Adults	Spawning	Ammocoetes
River lamprey & sea lamprey	No barriers to migration Average gradient up to 5.7 m/km, rare >7.6 m/km Pollution sensitive	Stones and vegetation for hiding Migrate to spawning areas: October-December (river) April-May (sea)	Gravel and sand substrate with water flow through substrates Water temperature: 10-11°C (river) 15°C (sea) Eggs incubate 15-30 days	Fine substrates Low flows Metamorphosis July to September, immediate migration to sea at night

G.2.3 Site Visit Findings

The cascade and bedrock lengths of the River Cocker at the northern tip of Redhow Wood (Figure G-4) and at Longlandsgill Wood (Figure G-4) are potentially impassable natural barriers to river and sea lamprey migration. This is in part due to the physical barrier caused by the abrupt raising of some bedrock lengths, with was noted to reach up to 1.5 m in places, and the high flows present in these areas. The presence of barriers would explain the lack of lamprey records in the upper reaches of the River Cocker.

Potential spawning substrates are present in the length of river between Crummock Water and Scale Bridge, particularly in Lanthwaite Wood (Figure G-5). Suitable adult holding areas with ample vegetative cover, and silt/ sand beds in the immediate downstream vicinity, are also present in this area. Between Redhow Wood and Longlandsgill Wood, the gradient in the river was steep. Much of the substrate in this reach was bedrock and flows were cascade and fast run, with some vertical drops. These cascade and bedrock lengths potentially act as a natural barrier to river and sea lamprey upstream migration, and no lampreys were recorded in the River Cocker upstream of this reach. However, it is unclear whether the absence of records of lamprey upstream of this reach is due to the absence of lampreys, or a lack of targeted surveys for these species.

Ammocoete (juvenile) habitat was also noted in Park Beck, between Kirkstile Bridge and the artificially straightened length of the river (Figure G-6). Small patches of silt/ sand beds were found in slow flowing lengths along the margins of the river, downstream of clean gravels that were present in shallow riffle/ run lengths. If river and sea lamprey were able to reach these upstream regions, suitable habitats are available for all life stages.

Under present conditions, suitable spawning and ammocoete habitat was found in several lower tributaries of the River Cocker, such as at the confluence of Hope Beck and the River Cocker, and the re-meandered lengths of Whit Beck (Figure G-4).

G.2.4 Baseline Summary

A summary of the desk based and site visit findings is given in the lengths below for the different age classes of river and sea lamprey.

Table G.5: Summary of habitat conditions for different age classes of River and Sea Lamprey

Spawning	Juvenile	Adult
Potential spawning habitat was available in the lower reaches of the re-meandered length of Whit Beck (Figure G-4).	Silt beds for ammocoetes were recorded in the lower length of Whit Beck and near the confluence of Hope Beck and the River Cocker, and in Park Beck (Figures G-4 and G-6). There is limited ammocoete habitat in the upper reaches of the River Cocker.	The cascade and bedrock lengths of the River Cocker at the northern tip of Redhow Wood (Figure G-4) and at Longlandsgill Wood (Figure G-4) are thought to be an impassable barrier to river and sea lamprey migration. As such there may not be limited benefit in enhancement of lamprey habitat up to and above the Crummock Dam.

G.2.5 Main Opportunities and Constraints

The bedrock and cascade length of the River Cocker at the northern tip of Redhow Wood (Figure G-4) is likely to restrict access to upper reaches of the River Cocker, particularly in low or extremely high flow conditions. The EA data did not record lamprey at survey sites located upstream of this length of the River Cocker. Removal of Crummock Water Dam could alter the flow conditions within the river and prevent migratory lamprey accessing the upper regions of the River Cocker. Removal or modification of natural barriers is outside the scope of this study but maintaining suitable flow conditions should be considered.

G.2.6 Risks and Uncertainties

Little information on sea and river lamprey distribution was available from literature review. The results of previous studies do not report lamprey in the upper reaches of the River Cocker, although it is unclear whether this is due to a lack of access or habitat, or limited studies in the area.

Access to the bedrock and cascade lengths of the river in Redhow Wood was limited, due to the elevated embankment in this area. Obtaining accurate measurements of water depth and the dimensions of the barriers present was therefore not possible.

G.3 Brook Lamprey

G.3.1 Introduction

As noted previously, brook lamprey is listed on the River Derwent and Tributaries SSSI citation.

G.3.2 Desk Based Literature Review

The Environment Agency has conducted electrofishing surveys of the River Cocker from 2003 to 2018 and reported the presence of lamprey (species unidentified) along the River Cocker between Yewdale (NY157249) and Cockermouth (NY122304) (EA, 2020, WCRT, 2020). Brook lamprey have been reported in the River Cocker between Southwaite and Littlethwaite, but not in the upper reaches of the River Cocker towards Crummock Water (UK Species Inventory, 2018c).

Brook lamprey are resident in freshwaters throughout their entire life cycle but require the same habitat for spawning and the development of ammocoetes as river and sea lamprey (see Table G.6 for a description). Interconnectivity between spawning and juvenile habitats is important. Whilst not undertaking catchment wide migrations brook lamprey would move between different habitat types at different points of their life cycle.

Brook lamprey do not feed as adults, and therefore only require vegetative or rocky cover to provide hiding places where they could rest while waiting for suitable water temperatures for spawning and a migration route free from barriers. If suitable spawning and ammocoete habitat are located close to each other, brook lamprey do not need to migrate large distances, although are capable of considerable migrations if required. Nests are often constructed immediately downstream of a large boulder or other obstruction mid-reach in the main stem or the bottom of a large tributary (Kelly and King, 2001).

General habitat requirements and important times of year are summarised in Table G.6.

Brook lamprey are poorer swimmers than Atlantic salmon, river lamprey and seas lamprey, and thus some features (natural and anthropogenic) that salmon can pass (including fish passes) are still migration barriers to brook lamprey.

To attain Favourable Condition, an SAC assessment unit (stretch of river where more than thirty 100 m long sites are surveyed) must have a mean density of *Lampetra* ammocoetes > 5 m^{-2}, must have evidence of recent recruitment and *Lampetra* ammocoetes must be present in at least 50% of sites surveyed (Joint Nature Conservation Committee, 2015).

Table G.6 Summary of Habitat Requirements for Brook Lamprey

Species	General	Adults	Spawning	Ammocoetes
Brook lamprey (*Lampetra planeri*)	No barriers to migration Average gradient 0.2 – 0.6 m/km Pollution sensitive	Stones and vegetation for hiding Migrate to spawning areas in spring at night	Gravel and sand substrate behind larger object Water temperature 10-11°C Spawn April-June Eggs hatch June-July	Fine substrates Low flows Metamorphosis July to September

G.3.3 Site Visit Findings

The cascade and bedrock lengths of the River Cocker at the northern tip of Redhow Wood (Figure G-4) and at Longlandsgill Wood (Figure G-4) are potentially impassable barriers to brook lamprey movements. This is in part due to the physical barrier caused by the abrupt raising of some bedrock lengths, with was noted to reach up to 1.5 m in places, and the high flows present in these areas.

Suitable ammocoete habitat was found within Park Beck, between Kirkstile Bridge and the artificially straightened length of the river (Figure G-6). Small patches of silt/ sand beds were found in slow flowing lengths along the margins of the river, downstream of clean gravels that were present in shallow riffle/ run lengths.

Similar to river and sea lamprey, potential spawning substrates are also present in the length of river between Crummock Water and Scale Bridge, particularly in Lanthwaite Wood (Figure G-5). Suitable adult holding areas with ample vegetative cover, and silt/ sand beds in the immediate downstream vicinity, are present in this area. The length upstream of the confluence between Hope Beck and the River Cocker also provided suitable habitat for all age classes of brook lamprey (Figure G-4).

G.3.4 Baseline Summary

A summary of the desk based and site visit findings is given in the lengths below for the different age classes of brook lamprey.

Table G.7 Summary of habitat conditions for different age classes of Brook Lamprey

Spawning	Juvenile	Adult
Potential spawning substrates are present in the length of river channel between Crummock Water and Scale Bridge, particularly in Lanthwaite Wood (Figure G-5).	Silt beds for ammocoetes were recorded in the lower length of Whit Beck and near the confluence of Hope Beck and the River Cocker (Figure G-4). Further upstream, suitable substrates present in the length of river between Crummock Water and Scale Bridge, particularly in Lanthwaite Wood (Figure G-5). The length upstream of the confluence between Hope Beck and the River Cocker also provided suitable habitat for all age classes.	Suitable adult habitat was found in Lanthwaite Wood (Figure G-5). The length upstream of the confluence between Hope Beck and the River Cocker also provided suitable habitat for all age classes

G.3.5 Main Opportunities and Constraints

It is not known whether brook lampreys are present within Park Beck or any of the tributaries of Crummock Water. The desk-based review did not find any records of brook lamprey in these waterbodies. Re-meandering the straightened length of Park Beck, would naturalise the channel and improve fish habitat by trapping finer sediments and forming sand/ silt beds that would offer potential habitat for developing ammocoetes. Suitable spawning substrates were noted further upstream of this length so the naturalisation of the straightened length of Park Beck would provide a continuous stretch of river that could support multiple brook lamprey life stages.

The complete removal of the Crummock Water Dam would allow brook lamprey to access the suitable spawning and ammocoetes habitat of Park Beck, which is not currently accessible downstream of this structure. If brook lampreys are present in the Cocker catchment above Redhow and Longlandsgill Wood, the improvement of passability or enhancement of habitat could allow greater integration of isolated populations. To support the upstream migration of brook lamprey, the upper length of the River Cocker immediately downstream of the Crummock Water Dam would need to fulfil the gradient requirements discussed in Table 4.3. The removal of infrastructure has the potential to remobilise sediments from the sediment sink at Crummock Water. The redistribution of fine sediment has the potential to create or enhance depositional habitats for juveniles. Re-mobilisation of coarse substrates from Crummock Water or changes to the lake tributaries has the potential to create spawning habitat in the main stem river, however under high flow conditions remobilisation could result in scour or smothering of existing habitat.

G.3.6 Risks and Uncertainties

Little information on local distribution and supporting habitat for brook lamprey is available from literature review. Information from field survey is limited as access to all areas of the river was not possible due to deep water. In addition, it was not possible to survey both banks along the entire survey stretch and key areas of supporting habitat could have been missed.

G.4 Arctic Charr

G.4.1 Introduction

Arctic charr is listed in accordance with the requirements of Section 41 of the Natural Environment and Rural Communities (NERC) Act 2006 (England), and priority actions have been identified for this species (NE, 2018b). The native distribution of Arctic charr in England is restricted to eight lakes within the Lake District, including Crummock Water (Winfield and James, 2017).

8.1.1 Desk Based Literature Review

Historical records of the English population outside of Lake Windermere are sparse. A recent assessment by Winfield and James (2017) within Crummock Water recorded active recruitment within the Arctic charr populations, although there was an indication of medium-term population declined since 2010. However, abundance estimates were reported as 116.7 fish ha^{-1} in 2012 and 18.7 fish ha^{-1} in 2016, which are considered high relative to the other Cumbrian lakes (Winfield and James, 2017).

Eutrophication, temperature increase and competition were recognised as the most significant threats to Arctic charr in nearby Lake Windermere (Winfield *et al*., 2008). Other documented threats within the UK include habitat modifications caused by acidification, afforestation, engineering and exploitation (Maitland *et al*., 2007). Access to deep water is of high importance for Arctic charr survival, and reduced oxygen availability at depth as a result of eutrophication has been identified as an inhibiting factor in Windermere (Jones *et al*., 2008; Winfield *et al*., 2008). A water quality assessment of Crummock Water conducted between 1995 and 2015 showed that stable abiotic conditions had generally been maintained for the duration of the study (Maberly *et al*., 2011). In addition, Winfield and James (2017) did not consider eutrophication an area of concern for this region at present.

Maintaining access to suitable habitat is fundamental to Arctic charr survival, and the cool, oligotrophic conditions in Crummock Water provide optimum water quality parameters. Arctic charr is considered a habitat generalist, usually residing in the profundal zone of lakes when they are found living in competition with other salmonid species (Klemetsen *et al.,* 2003). Hydroacoustic surveys in nearby Lake Windermere have shown that adults regularly avoid the upper 10 m of lakes, spending the majority of their time in deeper reaches, relative to oxygen availability (Jones *et al*., 2008). The population in Crummock Water exhibit both spring (February) and autumn (November) spawning, and spawning habitat requirements vary for each season. Deep offshore regions are utilised in spring, and winter spawning occurs in shallow lake margins (<3 m depth). Winfield and James (2017) reported that spawning habitat was widespread in the immediate nearshore areas of Crummock Water at a depth of approximately 0.5 m. Furthermore, Winfield and James (2017) found that this suitable habitat extended down to depths in excess of 1.7 m in many areas, and up to 10 m at one location. Spawning substrates are hard and range from sand through to small boulders (0.25 m diameter) (Miller *et al*., 2015). Documented spawning habitat in nearby Lake Windermere ranged from lake margins (for autumn spawning) to 57 m depth (spring spawning) (Miller *et al.,* 2015). Little is known of juvenile habitat preferences since these small fish are rarely observed in field studies, however recently-hatched Arctic charr fry (juveniles) are thought to feed in stones and gravel within the littoral zone, where coarse substrates also provide shelter from predatory birds and piscivorous fishes (Klemetson *et al*., 2003).

A recent investigation into the potential impacts of reducing the water level in Crummock Water for drought management concluded that a temporary drop in water level by 1.5 m would have no significant impact on the population of Arctic charr in Crummock Water (Winfield and James, 2017). It should be noted, however, that the model used in this study assumed the reduction in lake levels was temporary, and therefore did not investigate the ecological implications of a permanent drop in lake water levels.

G.4.2 Site Visit Findings

As local Arctic charr are considered a lacustrine (lake) species, Crummock Water was the sole focus of the Arctic charr habitat assessment.

Large areas of spawning habitat were present around the western margins of Crummock Water (Figure G-3). Substrates were mostly loose and of mixed gravel/ pebble composition, extending to depths of at least 0.5 m. The north-facing beaches of the numerous small inlets of the western lake margins provided particularly favourable conditions, with loose pebble/ gravel deposits visible as far as 5 m from the shoreline and up to 20 m along the shoreline in some areas. Depths in these locations ranged from 0.5-1 m, before the substrates abruptly dropped away to deeper reaches of the lake. Ample spawning gravels were also present on the eastern margins of Crummock Water, particularly in the regions around the boat house in the north-east length, and between the boat house and the dam in the north. A mix of coarse gravels and small pebbles extended from the lake shoreline to depths of 0.5-1 m. Substrates became coarser with increasing depth, with more cobbles visible in the deeper reaches greater than 1 m. The steep drop-off from the lake margins prevented further observations of the availability and composition of substrates at greater depths. The north-facing beaches and sheltered inlets around the eastern and western margins of Crummock Water appear to offer ample Arctic charr spawning substrate under present conditions.

Little is known about the habitat preferences of juvenile Arctic charr, although recently-hatched fry are known to feed and seek shelter in mixed composition substrates close to spawning gravels. Suitable areas of fry habitat were distributed all round Crummock Water, particularly along the eastern margins (Figure G-3). Large stretches of shallow mixed cobble/pebble substrates suitable for fry were also found immediately south of Park Beck and at the southern extent of Crummock Water.

The infrastructure in place at Crummock Water weir appeared to trap a layer of silts and fine sediments, which was found covering the substrates immediately behind the weir. The substrate here was also firmly compacted and covered in a blanket layer of macrophytes. For this reason, the region immediately upstream of the Crummock Dam is considered to be low quality spawning habitat (Figure G-3).

The walled length immediately to the north-west of Crummock Water weir contained mixed gravel and pebble deposits that were moderately compacted. The fine silt layer visible immediately behind the dam extended along the north-west margin for 140 m, producing a short length of low quality spawning habitat. The remainder of the walled length and associated lake margins contained a pebble/ cobble mix (and one sand bank length) that was more loosely formed, and therefore offered better quality spawning habitat.

The southern extent of Crummock Water generally did not provide suitable habitat for Arctic charr. This area was characterised by fine sediments and emergent vegetation, and these conditions are not ideal for Arctic charr spawning, juveniles or adults.

G.4.3 Baseline Summary

A summary of the desk based and site visit findings is given in the lengths below for different age classes.

Table G.8 Summary of habitat conditions for different age classes of Arctic charr

Spawning	Juvenile	Adult
High quality spawning habitat was observed around the eastern and western margins of Crummock Water, particularly in the north-facing inlets and beaches. Large stretches of loose and clean gravel substrates were found at depths ranging from 0-1 m. Mixed composition pebble/ gravel substrates were found at greater	Little is known about the habitat preferences of juvenile Arctic charr, although recently-hatched fry are known to feed and seek shelter in mixed composition substrates close to spawning gravels. Several stretches of mixed composition gravel, pebble and cobble beds were observed around the shallow margins of Crummock Water. The sheltered inlets of the eastern	Adult Arctic charr are thought to reside in the deeper reaches of Crummock Water. It was not possible to survey these habitats, but a recent study into the Artic Charr population of Crummock Water described the population as stable (Winfield and James, 2017). This study found that Arctic charr rarely inhabited the shallow nearshore area of Crummock

depths and could also offer suitable spawning substrate.	banks and the area immediately south of the Park Beck inlet contained several suitable stretches of fry habitat. The presence of these regions adjacent to identified spawning habitat, coupled with the stable population densities reported for Crummock Water Arctic charr, suggest that suitable juvenile habitat is present in the lake under current conditions.	Water outside of the spawning season, and instead resided almost exclusively in the deeper areas of the lake.

G.4.4 Main Opportunities and Constraints

Removal of the infrastructure at Crummock Dam would cause a drop in water level that would render the winter spawning gravels visible at 0.5 m depth potentially inaccessible, particularly near Low Ling Crag and opposite Woodhouse islands, which were identified as being at risk of exposure (Cascade, 2014).

Ample spawning habitat is present around the lake margins of Crummock Water. Much of this habitat was not in areas identified as being at high risk of exposure from a reduction in lake level, and in fact, the areas identified as at risk were not identified as suitable habitat for Arctic charr during both the 2017 surveys and in the desk-based review (Cascade, 2014; Winfield and James, 2017). Spawning substrates were found to extend to depths greater than 1.7 m in many areas of the lake, and a recent study concluded that much of the suitable spawning habitat for Arctic charr would not be exposed if the lake was drawn down to 1.5 m below weir crest level (Winfield and James, 2017). Substrates of a suitable size and composition were present behind the Crummock Water Dam and in the stretch of water that borders the wall on the north-west of the lake. This gravel/ pebble mix was heavily impacted and covered in a fine layer of silt. Removal of the Crummock Water wall could create more space for sediment movement and deposition, resulting in substrates that were less compacted and enhancing the overall quality of the habitat for spawning (Jacobs, 2016b). Removal of the Crummock Water Dam could also release the layer of silt covering the substrates in this area, resulting in cleaner spawning gravels of a higher quality. Dam removal could also result in the loss of coarse substrates under high flows, potentially influencing charr spawning in the suboptimal southern end of Crummock Water.

Suitable juvenile habitat is present in the region immediately south of Park Beck, although the substrates in this area are fairly compacted. Removal of the wall to the north and south of this length could lessen the force applied to the lake bed, resulting in less compacted substrates and improved overall juvenile habitat quality. Given the presence of suitable Arctic charr fry habitat in this region, improving the quality of spawning habitat to the north of Park Beck could provide an uninterrupted stretch of suitable habitat for multiple Arctic charr life stages.

G.4.5 Risks and Uncertainties

Winter spawning habitat only was the focus of the fieldwork undertaken. Spring spawning occurs in the deep offshore lengths of Crummock Water and it was not possible to view the quality and quantity of substrates available in these stretches during the site visit. This information would be a useful addition to the baseline assessment, in order to confirm the area of habitat available for spring spawning. However, changes to the water level of Crummock Water associated with the removal of Crummock Dam would not affect habitat availability, due to the depths associated with spring spawning habitat. As spawning in spring has been confirmed in the Arctic charr population of Crummock water, suitable offshore spawning habitat must be currently available. The exclusion of this information is therefore not considered to be a limitation of this habitat assessment.

G.5 European Eel

G.5.1 Introduction

The European eel is listed in accordance with the requirements of Section 41 of the Natural Environment and Rural Communities (NERC) Act 2006 (England), and priority actions have been identified for this species (NE, 2018b). The Eel (England and Wales) Regulations (2010) provide protection to the passage of European eel through riverine catchments and prevention of unsustainable exploitation. The species is classified as Critically Endangered by the International Union for Conservation of Nature (IUCN) and has experienced substantial declines (up to 90%) in its range (IUCN, 2018).

G.5.2 Desk Based Literature Review

Within the River Cocker, records available from NBN Atlas show the presence of European eel along the full extent of the River Cocker and its tributaries (including Park Beck), and in the upland tributaries that drain into Crummock Water (UK Species Inventory, 2018d). The Environment Agency (EA, 2020) has conducted electrofishing surveys of the River Cocker from 1991 to 2017 and reported both elvers (eel larvae) and adult eels spanning the length of the River Cocker, from Crummock weir to the River Derwent. Adults and elvers were also present in Honnister Pass (NY210148), upstream of Crummock Water and Buttermere. This suggests habitat availability and access to the catchment for a number of different age classes of European eel. The current infrastructure and habitat modification in place along the River Cocker and at Crummock Dam therefore do not pose a significant barrier to European eel.

Movement throughout the catchment is facilitated by the presence of an eel pass along an impassable length of river at Low Liza Bridge on Liza Beck (NY 15312 22414). A previous study found that Crummock Water weir was not passable by eels migrating upstream (although they could migrate downstream) (APEM, 2012), and in 2018 improvements were made to the weir to improve passability. Although the fish pass at the Crummock Water weir is not optimally designed for eel passage due to its substrate, gradient and height, records of adults and elvers in upstream sub catchments (UK Species Inventory, 2018d) demonstrate that this structure does facilitate the movement of eels from the tributaries of Crummock Water to the sea.

Eels are catadromous and live their adult lives in freshwater before returning to sea to spawn. Elvers enter freshwaters in late winter to spring where they mature into adults and remain in freshwaters for as long as 40 years (Maitland, 2007). Eel habitat is particularly hard to define, as the species is capable of thriving in all freshwater habitats, providing there is access to the sea. During the daytime eels remain buried under weeds or stones or in mud but can be found on a variety of other substrate types (Maitland, 2007).

Eels are incapable of swimming through strong laminar flows or jumping in excess of half their body length, so vertical falls represent a barrier to upstream migration (Knights and White, 1998). As such traditional fish passes may not assist upstream migration of European eel, although utilisation of some fish pass types has been observed in larger (>30 cm) individuals. Eels can use boundary layers and rough substrates to facilitate migration and the design of eel passes over barriers often incorporates brushes or bristles to encourage climbing as opposed to swimming (Solomon and Beach, 2004). As eels increase in size so does their swimming ability and elvers over 10 cm in length can negotiate flows of 1.5-2 m/s^{-1}. Up to 12 cm elvers can climb surfaces (particularly if covered in moss or algae) although ability decreases with increasing size without the presence of a vegetated or uneven surface.

G.5.3 Site Visit Findings

Eel habitat was found in large portions of the catchment, wherever cover was provided by vegetation, woody debris and rocky crevices. A large eel (approximately 60 cm) was observed immediately downstream of Scale Bridge (NY148214, Figure G-5) at the time walkovers were conducted.

G.5.4 Baseline Summary

A summary of the desk based and site visit findings is given in the lengths below for the different age classes of eel.

Table G.9 Summary of habitat conditions for different age classes of European eel

Juvenile	Adult
Elvers have been recorded upstream of Crummock Water and Buttermere, which suggests that no barriers to upstream migration are present in the catchment downstream of Crummock Water, and that the improvements to the dam facilitates upstream migration. Eel habitat was found throughout the catchment (Figures G-4 to G-7).	Habitat for adult eels was widespread throughout the catchment, and an eel was observed in the River Cocker downstream of Scale Bridge (Figure G-4). The presence of an eel pass at Low Liza Bridge has improved access to the upper reaches of this tributary (Figure G-4).

G.5.5 Main Opportunities and Constraints

The complete removal of Crummock Water weir would improve the upstream and downstream migration of European eel. The presence of elvers in tributaries upstream of this structure suggests that eels must be able to overcome this barrier, however the current structure is not optimally designed to allow eel passage and therefore is expected to hinder and delay upstream migration, but not completely prevent it. Eels are capable of utilising a range of substrates as habitat, and a drop in water level caused by the removal of Crummock Water weir is unlikely to affect the quality of quantity of habitat available for this species.

G.5.6 Risks and Uncertainties

Given the presence of all age classes of eels throughout the catchment, no sources of uncertainty or key risks were identified.

G.6 Brown/ Sea Trout

G.6.1 Introduction

Brown/ sea trout is listed in accordance with the requirements of Section 41 of the Natural Environment and Rural Communities (NERC) Act 2006 (England) (NE, 2018b). Within the River Cocker, records available from NBN Atlas show the presence of brown/ sea trout along the full extent of the River Cocker and its tributaries (including Park Beck), and in both Crummock Water and its upland tributaries (UK Species Inventory, 2018e).

G.6.2 Desk Based Literature Review

Reported rod catches for sea trout in the River Derwent (of which the River Cocker is a tributary), gave an annual catch of 176 individuals in 2017 (EA, 2018a). Catchment data compiled over a 13-year period (2005-2017) showed fluctuations in rod catch, from a maximum of 482 in 2014 to a minimum of 159 in 2008, although values obtained in 2014 were approximately double those given for 2015-2017 (Figure G.2). It should be noted that this information is reliant upon accurate catch reports from recreational anglers and gives no measure of catch effort (i.e. number of active fisherman), so is not directly representative of current stock conditions.

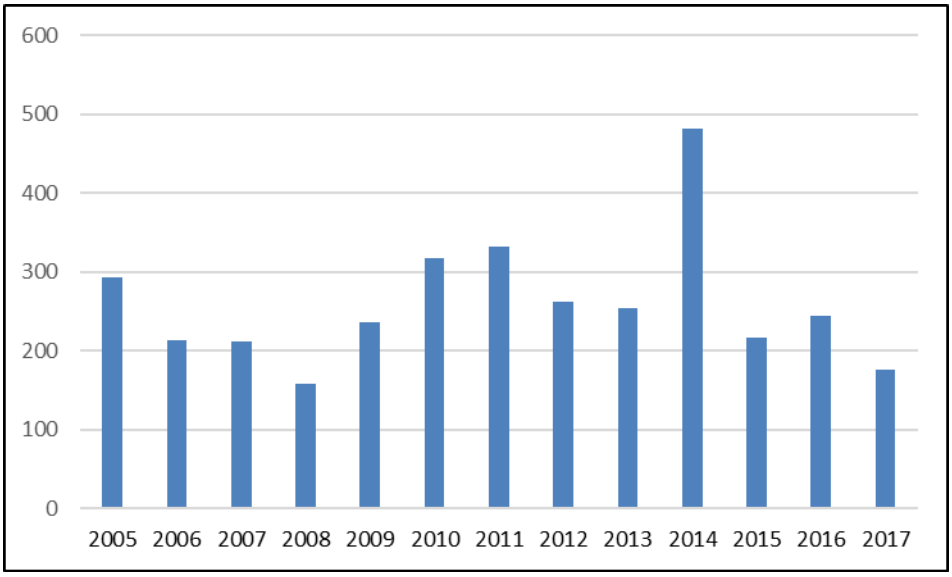


Figure G-2: EA Rod Catch Data for Sea Trout 2005 to 2017

Environment Agency surveys were conducted from 2010 to 2018 and demonstrated the presence of brown/ sea trout throughout the length of the River Cocker, including some of its tributaries, and in Crummock Water, Park Beck and Buttermere Dubs (EA, 2020).

Brown trout and sea trout represent different morphs of the same species. Sea trout are anadromous, hatching and spending their juvenile life stages (fry and parr) in freshwater, and migrating out to sea as smolts. Sea trout adults return to natal rivers to spawn, after spending several months to a year in rich coastal feeding grounds. Brown trout complete their entire life cycle in the freshwater environment and could undertake localised migrations between different functional habitats at different life stages. Interbreeding occurs between sea and brown trout, and habitat requirements for spawning and successful juvenile development are therefore the same. Trout share similar spawning preferences with Atlantic salmon, although trout would reproduce earlier in the season and use smaller headwaters (Armstrong *et al.,* 2003). Relatively shallow depths (20-30 cm) and moderate flows (20-50 cm/s) are optimal for juveniles (Table G.10) although migrating adults generally require higher flows especially if there are obstructions to pass. In general, juvenile fish are more sensitive than adults as they are less mobile, being more dependent on specific habitats during development stages. However, much of the available data quantifying impacts relate to adults. Very good water quality is required at all stage of the trout life cycle.

Table G.10 Habitat Requirements of Juvenile and Adult Brown Trout (adapted from Armstrong *et al*., 2003)

Juvenile fish <1 year old (fry)	
Water depth	<20-30 cm
Water velocity	0-20 cm/s
Substrate type	Gravel and cobble (10-90 mm)
Juvenile fish >1 year old (parr)	
Water depth	<20-30 cm
Water velocity	20-50 cm/s
Substrate	Gravel and cobble (10-90 mm)
Adult spawning	
Water depth	6-82 cm
Water velocity	10.8-80.2 cm/s
Substrate	Mix of fine materials (8-128 mm), gravels

G.6.3 Site Visit Findings

Juvenile brown/ sea trout and adult sea trout have similar habitat requirements to juvenile and adult Atlantic salmon. The site visit findings described in Section G.1.3 are consequently also applicable to brown/ sea trout.

Schools of adult brown trout were seen from the shoreline along the south-east margins of Crummock Water. The habitat provided by the lake is thought to support a large population of resident brown trout, which spawn in the accessible spawning grounds of Rannerdale Beck, Scale Beck, Buttermere Dubs and Hagg Sike (Figures G-6 and G-7). Brown trout have separate feeding and habitat niches to Arctic charr, so relatively little competition is evident between the two species (Klemetsen *et al*., 2003). However, brown trout are known predators of Arctic charr (Grey *et al*., 2002).

G.6.4 Baseline Summary

A summary of the desk based and site visit findings is given in the lengths below for the different age classes of brown/ sea trout.

Table G.11 Summary of habitat conditions for different age classes of brown trout

Spawning	Juvenile	Adult
The un-modified upper reached of Liza Beck, and lower reaches of Hope Beck and Whit Beck were all identified as areas containing suitable spawning habitat (Figure G-4). Salmonid spawning has already been noted in the re-meandered length of Whit Beck, indicating the high quality of habitat available in this area. Spawning gravels were also present in the upper reaches of Hope Beck close to Kirkstile Bridge, Rannerdale Beck and the lower reaches of Scale Beck, Buttermere Dubs and Hagg Sike (Figures G-4, G-5 and G-6).	Requirements for juvenile Atlantic salmon and brown/ sea trout are very similar. The high level of substrate embeddedness observed in the straightened channel sections of the River Cocker limits its capacity to support juvenile salmonids. Juvenile habitat is available in the meandered lengths, where mixed composition substrates provide the crevices and cover necessary to support these life stages (Figures G-4 and G-5). Suitable habitat was also noted in the upper reaches of Liza Beck and in the lower reaches of Hope Beck. Salmonid juveniles (both fry and parr life stages) were observed in several tributaries of Crummock Water. Scale beck, Buttermere Dubs and Hagg Sike all offered the necessary mix of riffle/ run lengths and mixed substrates required to support juvenile life stages (Figures G-6 and G-7).	Resident adult brown trout were observed from the shoreline at Crummock Water. The River Cocker is thought to be a migratory corridor for anadromous salmonids, at least under high flow conditions. Access to the high quality spawning grounds in the tributaries of Crummock Water is therefore thought to be possible for brown and sea trout, although it is not known whether records of trout in the area refer to adult brown trout or sea trout.

G.6.5 Main Opportunities and Constraints

Habitat requirements for spawning and juveniles of both brown and sea trout, and migratory requirements for adult sea trout, are similar to those of Atlantic salmon. The opportunities and constraints discussed in section G.1.5 therefore apply to both Atlantic salmon and brown/ sea trout.

G.6.6 Risks and Uncertainties

It is not known whether the salmonid juveniles observed in Scale Beck, Buttermere Dubs and Hagg Sike were Atlantic salmon, brown trout or sea trout. It was also not possible to determine whether records of adult trout in Crummock Water and its tributaries refer to brown trout or sea trout individuals.

Information from field survey is limited as access to all areas of the river was not possible due to deep water. In addition, it was not possible to survey both banks along the entire survey stretch and key areas of supporting habitat could have been missed.

G.7 European Otter

G.7.1 Introduction

European otter is an Annex II contributing species for the River Derwent and Tributaries Site of SSSI, and a qualifying species for the River Derwent and Bassenthwaite Lake SAC. Otters are listed in accordance with the requirements of Section 41 of the Natural Environment and Rural Communities (NERC) Act 2006 (England), and priority actions have been identified for this species (NE, 2018b).

G.7.2 Desk Based Literature Review

Limited information is available on the presence of otters within the River Cocker catchment and Crummock Water. The Otter and Rivers Project 1991-1994 reported that the best rivers in Cumbria had only low/ transient otter populations with a complete absence of otter in some areas (LEAP, 1999). The NBN Atlas provides records of otters across the catchment, from Crummock Water to Southwaite and in several tributaries of the River Cocker (UK Species Inventory, 2018f).

Surveys carried out in West Cumbria in 2005 (EA, 2005) (report provided by Diane O'Leary, West Cumbria Rivers Trust) by the Environment Agency showed a substantial increase in the number of active otter sites observed since 1998, but a reduction across the Cocker sub-catchment between 2002-2005 (Table G.12).

Table G.12 Results Reported in Environment Agency 2005 Technical Memorandum 827 (EA, 2005)

Survey Date	Number of Sites	Number of Positive Sites	Percentage of Positive Sites
May 1998	19	3	15.8
May 2002	19	14	73.7
May 2005	21	11	52.4

The EA reported a substantial increase in otter signs in West Cumbria during surveys in 2009 and 2010 with seven positive sites out of 18 in comparison to zero out of 13 sites when surveys were first conducted between 1977 and 1979 (EA, 2018j).

Otters utilise a wide range of aquatic habitat types, and in freshwater habitat have been recorded on both still waters (e.g. canals, ponds, lakes, reservoirs) and streams and rivers (Channin, 2003). Otters require suitable areas for resting which could consist of a hole in the ground (a holt) or a depression under the roots of a bankside tree or other vegetation (a couch). They breed throughout the year, and rear their young in holts, so suitable habitat to dig out a holt is a requirement for a breeding population of otters.

G.7.3 Site Visit Findings

No conclusive evidence of otter activity was found during 2017 fieldwork. Attempts were made to identify field signs but only one observation of a potential print was reported on Park Beck (Figure G-6), and the quality of the print was insufficient for identification purposes.

The habitat along the River Cocker and its tributaries appeared of mixed quality for otters. Embankment stabilisation measures across large stretches of river reduced habitat potential, preventing the formation of natural holts and couches in the river bank. The presence of dredging deposits along the embankment of several tributaries also restrict access to the river and covered over potential holt and couch habitat. The upper reaches of the River Cocker closer to the Crummock Water Dam provided more natural embankments, but there was a high level of disturbance from dog walking and recreational activities. The un-straightened upstream length of Park Beck and the re-meandered length of Whit Beck are likely to provide the most suitable otter habitat within the surveyed reach, with high potential for lying up sites (holts and couches) with these stretches.

G.7.4 Baseline Summary

Previous studies have shown that a small population of otters is present in the catchment, although no evidence of otters was found during the 2017 site visits. Embankment stabilisation works in several areas of the River Cocker have reduced the availability of otter habitat, although suitable habitat was found at Park Beck, the length of the River Cocker close to Crummock Water and the re-meandered length of Whit Beck.

G.7.5 Main Opportunities and Constraints

Otter habitat could be improved throughout the catchment if the practice of placing dredged channel deposits along the embankment was reduced. Processes that naturalise straightened embankments, such as the re-meandering of Whit Beck, would also improve habitat quality for riparian land users. Re-meandering the straightened length of Park Beck would therefore provide improved otter habitat.

The removal of Crummock Water weir is unlikely to directly influence otter habitat, although improvements to fish passage would consequently increase otter prey availability in Crummock Water and its tributaries.

G.7.6 Risks and Uncertainties

There is a lack of baseline data describing the otter population of Crummock Water and the River Cocker catchment. The otter population in the area is thought to be relatively low but has increased in size since surveys were conducted in 1998. No recent data on otter numbers or distribution within the area are available. The most recent data on otters in the Study Area is from 2005, so otter distribution and population status in the Study Area is currently unknown.

G.8 Aquatic Macrophytes and Wetland Habitats

G.8.1 Introduction

Aquatic habitats characterised by the macrophytes *Littorelletea uniflorae* and/ or *Isoeto-Nanojuncetea* are the primary reason for the River Derwent and Bassenthwaite Lake SAC. Watercourses with water crowfoot (*Ranunculion* fluitantis) and *Callitricho-Batrachion* vegetation are a qualifying feature of this SAC (NE, 2017). Macrophytes act as either a sink or source of nutrients in the water column and provide habitat for other ecological receptors. Wetland habitats form a transitionary zone between terrestrial and aquatic ecosystems, support a unique biological community and often act as silt traps.

G.8.2 Desk Based Literature Review

A desk-based assessment showed that SSSI units 126 (Buttermere Dubs Wetland, Buttermere Outflow), 127 (Buttermere Dubs Wetland, West), 128 (Buttermere Dubs Wetland, East), and 129 (Crummock Water Wetland) are in Favourable status with no identified condition threat to these fen, marsh and swamp lowland habitats. Crummock Water and the River Cocker achieved Good status for macrophytes in the latest round of WFD classifications (EA, 2018c). The results of a study conducted in 2012 found that the macrophyte community was representative of what would be expected in an oligotrophic lake and that the characteristic species in a *Littorelleta* community (Marshall Ecology, 2013).

Four macrophyte species that are predominant in *Littorelleta/Isoetid* habitats were recorded as present at depths that were beyond a drawdown level of 2 m, however a substantial proportion of each species' existing population was predicted to be exposed at that level of draw down (Marshall Ecology, 2013). Their presence at these depths indicates that a population would remain in Crummock Water if the lake level is lowered, although it would be reduced in extent.

A 2012 study (Marshall Ecology, 2013) looking at the potential effect of temporary draw-down on the wetland communities of Crummock Water highlighted key wetland areas in the southern length of Crummock Water around Buttermere Dubs, on the eastern margins south of High Wood, along the north western shore immediately south of Park Beck extending to the upper reaches of the River Cocker. The wetlands along the southern and north-west margins were considered at highest risk of habitat modification as a result of temporary lake draw-down. A drop in the overall water level of Crummock Water is likely to reduce available wetland habitat, leading to a change in wetland community composition around Buttermere Dubs (Marshall Ecology, 2013).

A targeted macrophyte study conducted in 2013 and 2014 (Amec, 2014) noted a lack of aquatic vegetation in the River Cocker between Lorton and Crummock Water. The macrophyte community was dominated by *Fontinalis squamosa*, *Fontinalis antipyreteca*, *Platyhypnidium ripariodes*, *Myriophyllum alterniflorum* and *Callitriche brutia var. hamulata*, which all thrive in locations where they are predominantly submerged. Water Crowfoot (*Ranunculus aquatilis*) was noted further downstream between Lorton and Cockermouth and is a species known to tolerate prolonged periods of exposure resulting from a decrease in water level. The rare moss *Schistidium agassizii* was reported in the cascade length above Cornhow and is well adapted to locations where it is regularly exposed to periods of drought.

G.8.3 Site Visit Findings

During 2017 walkovers, aquatic macrophyte communities were observed in several locations within the River Cocker and its tributaries. Large assemblages were observed in the re-meandered lengths of Whit Beck close to the confluence with the River Cocker (NY 15092 25111) and in the lower reaches of Hope Beck (NY 15448 23644).

Wetlands were recorded in the southern length of Crummock water, on both sides of the mouth of Buttermere Dubs and extending east towards Mill Beck (close to NY 16532 16979). A matt of silt-covered macrophytes were observed covering substrates immediately upstream of Crummock Water weir. Additional macrophytes were observed towards the deeper central regions of Crummock Water in waters that were too deep to access during the site visit, but the overall density appeared to be low. Oligotrophic conditions and the steep shelving off of lake substrates within Crummock Water are thought to offer suboptimal conditions for macrophyte growth.

G.8.4 Baseline Summary

Supporting habitat for aquatic macrophytes is present in tributaries of the River Cocker, particularly Whit Beck and Hope Beck. Lake topography and the oligotrophic conditions of Crummock Water do not support a substantial macrophyte community, although some matts were observed. Wetlands are present on the lake margins to the south and north-west and are regularly irrigated under normal flows.

G.8.5 Main Opportunities and Constraints

Re-naturalisation of Park Beck would produce complex and variable flow types and increase habitat diversity throughout the restored area. This could create new habitat for macrophyte species in slow flowing areas of the beck.

G.8.6 Risks and Uncertainties

The results of the drought permit environmental assessment indicated that four primary species in the *Littorelleta/Isoetid* community are all present at drawdown levels up to 2 m. However, a substantial proportion of their populations would be exposed at this level of drawdown, and it is currently unclear how well these species would recover from permanent drawdown and populate new areas that were previously too deep to support macrophytes. In addition, several other species were noted as only populating the shallows, and would be almost entirely or entirely exposed under drawdown scenarios of 1.1 m, 1.5 m and 2.0 m. It is unclear if these populations would be able to compete with the species already populating the newly created shallow areas.

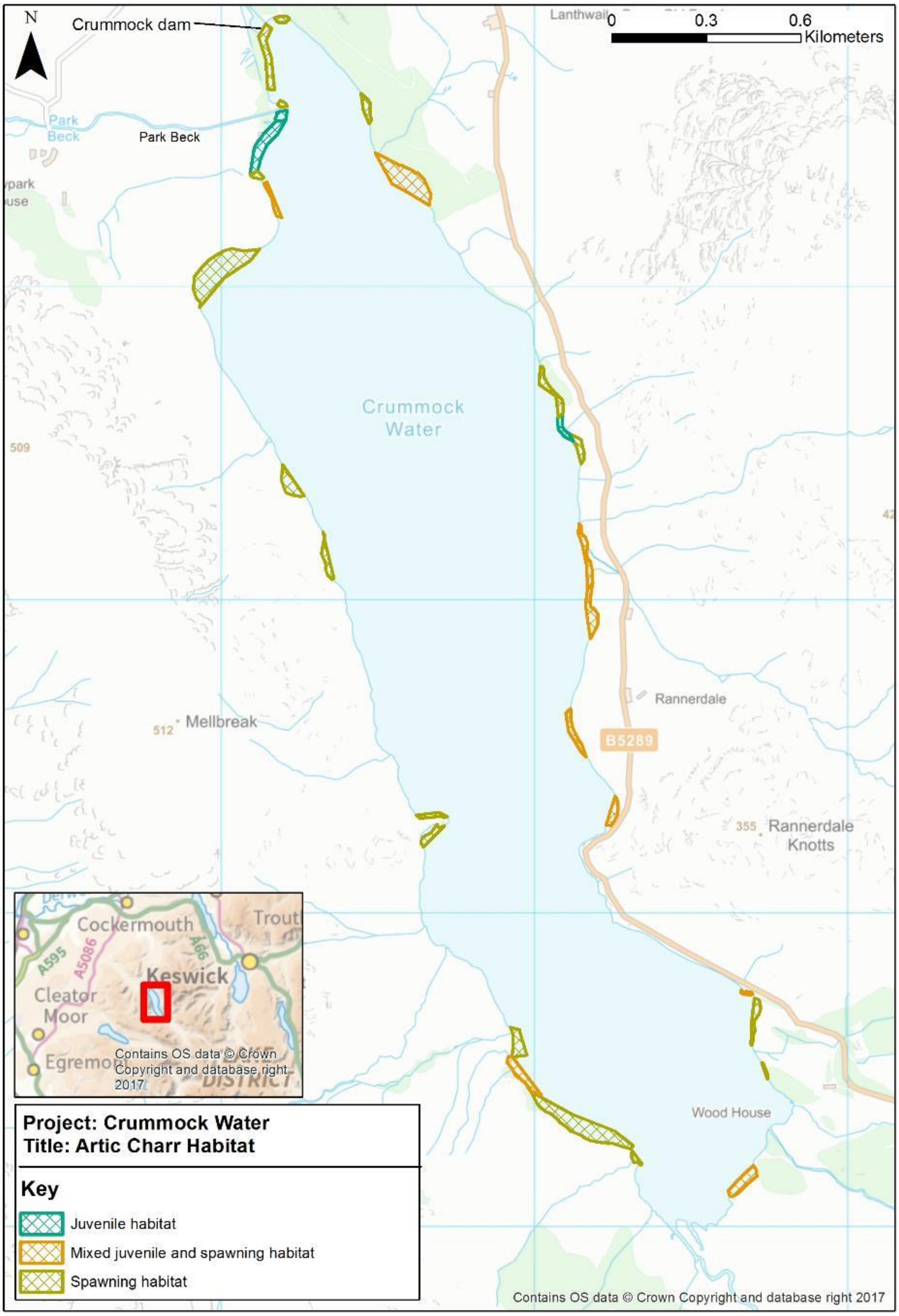


Figure G-3: Arctic Charr Habitat in Crummock Water

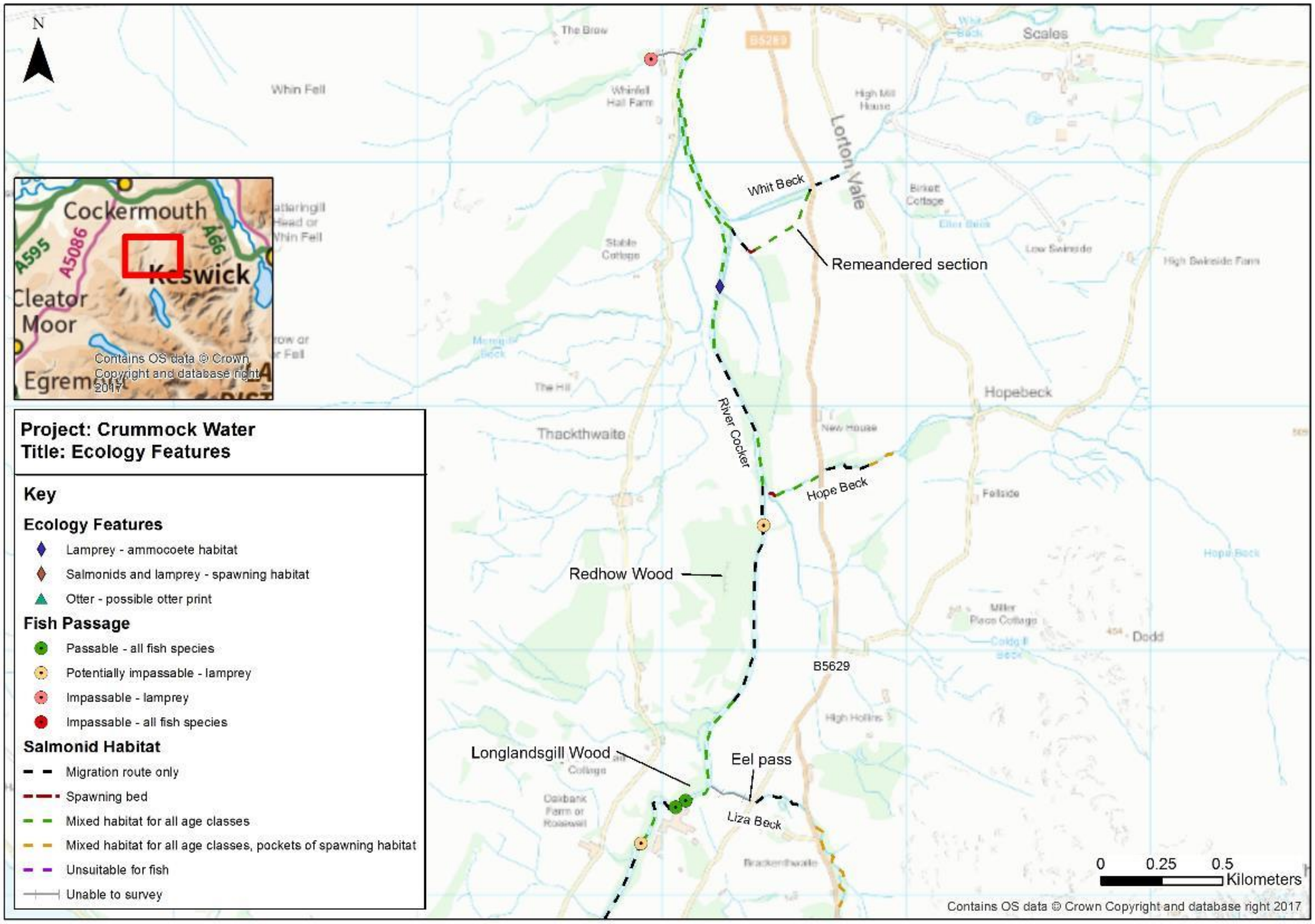


Figure G-4: Ecology Features in the River Cocker and its Tributaries

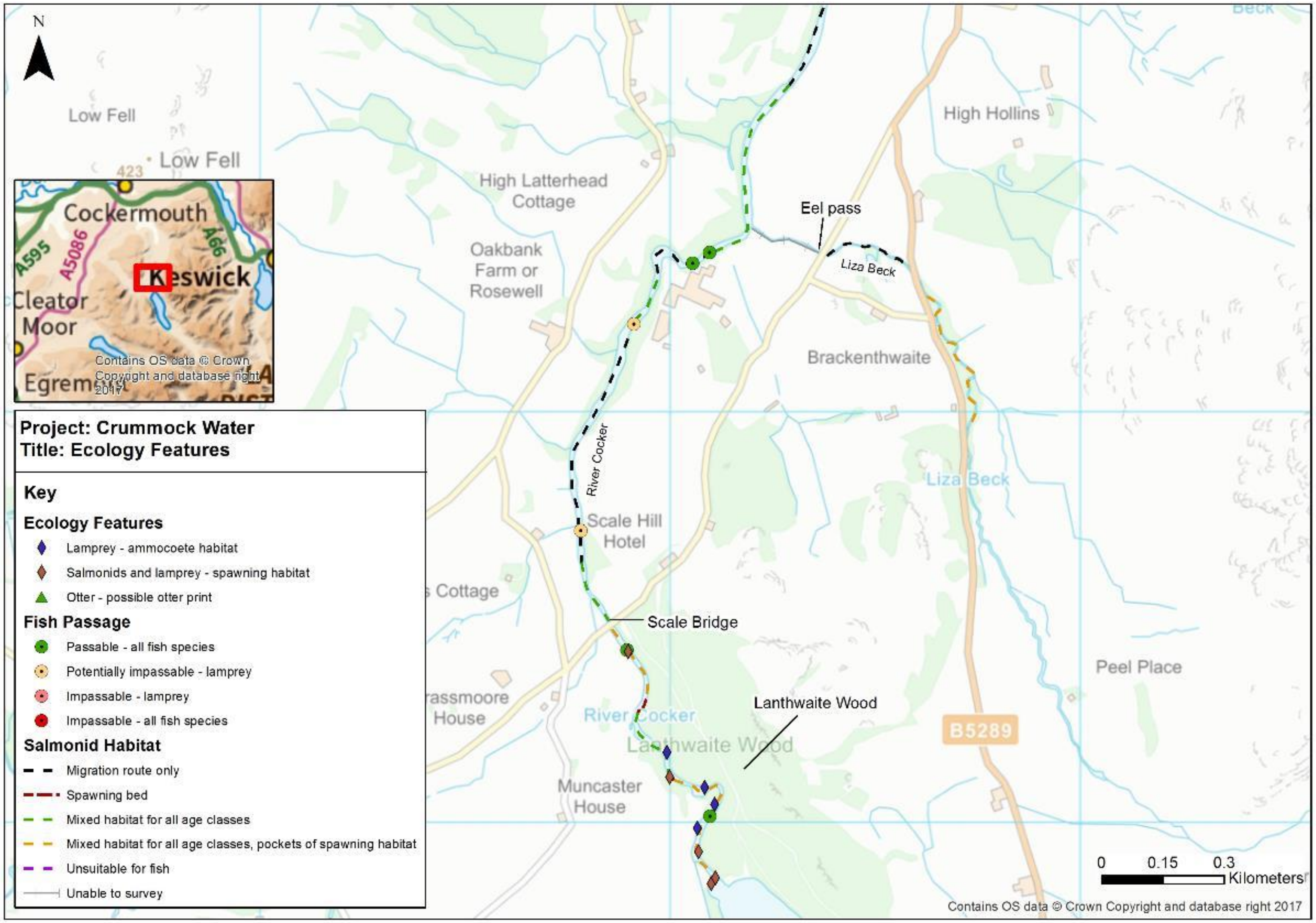


Figure G-5: Ecology Features in the River Cocker and its Tributaries

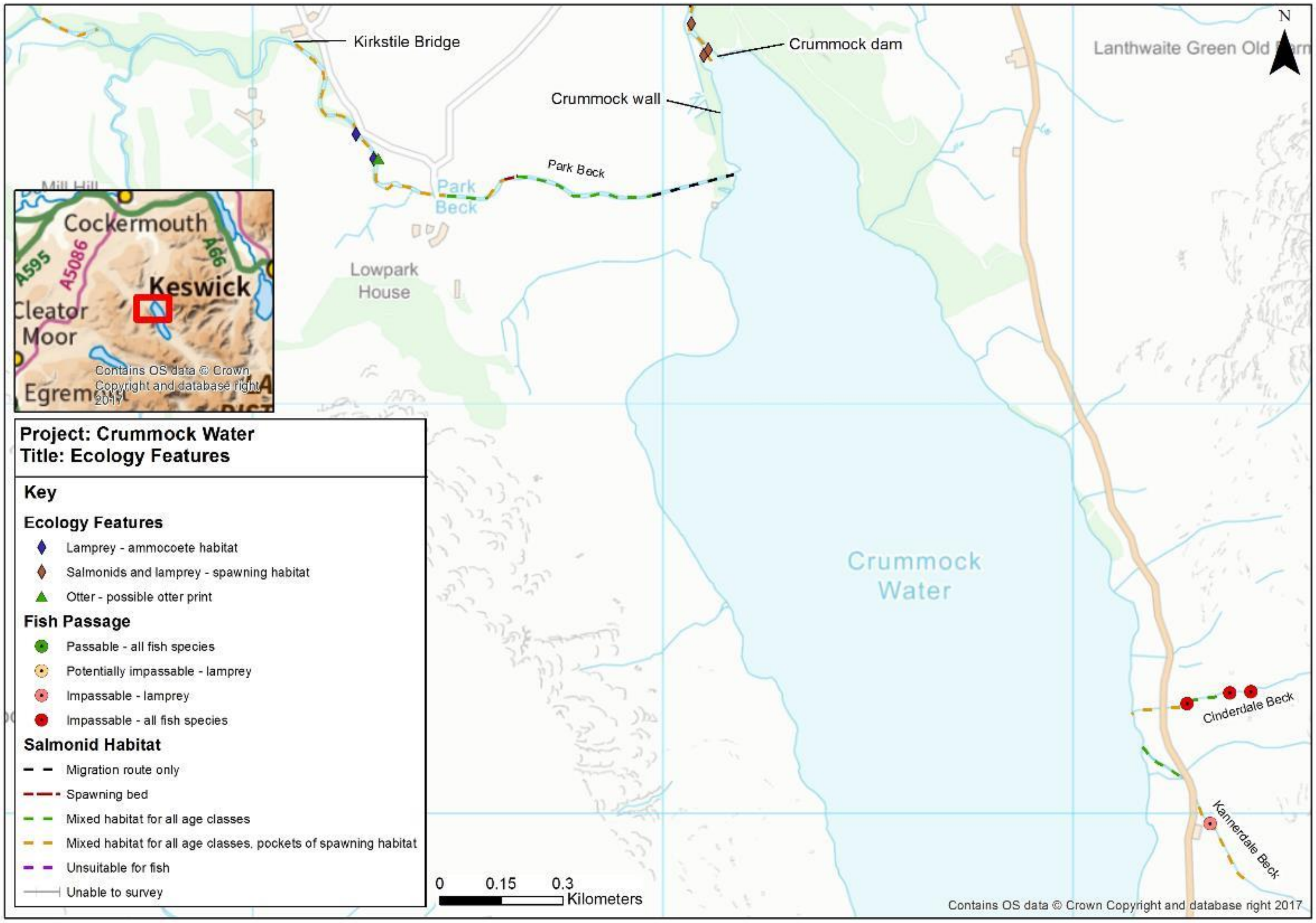


Figure G-6: Ecology Features in the River Cocker and Tributaries to Crummock Water

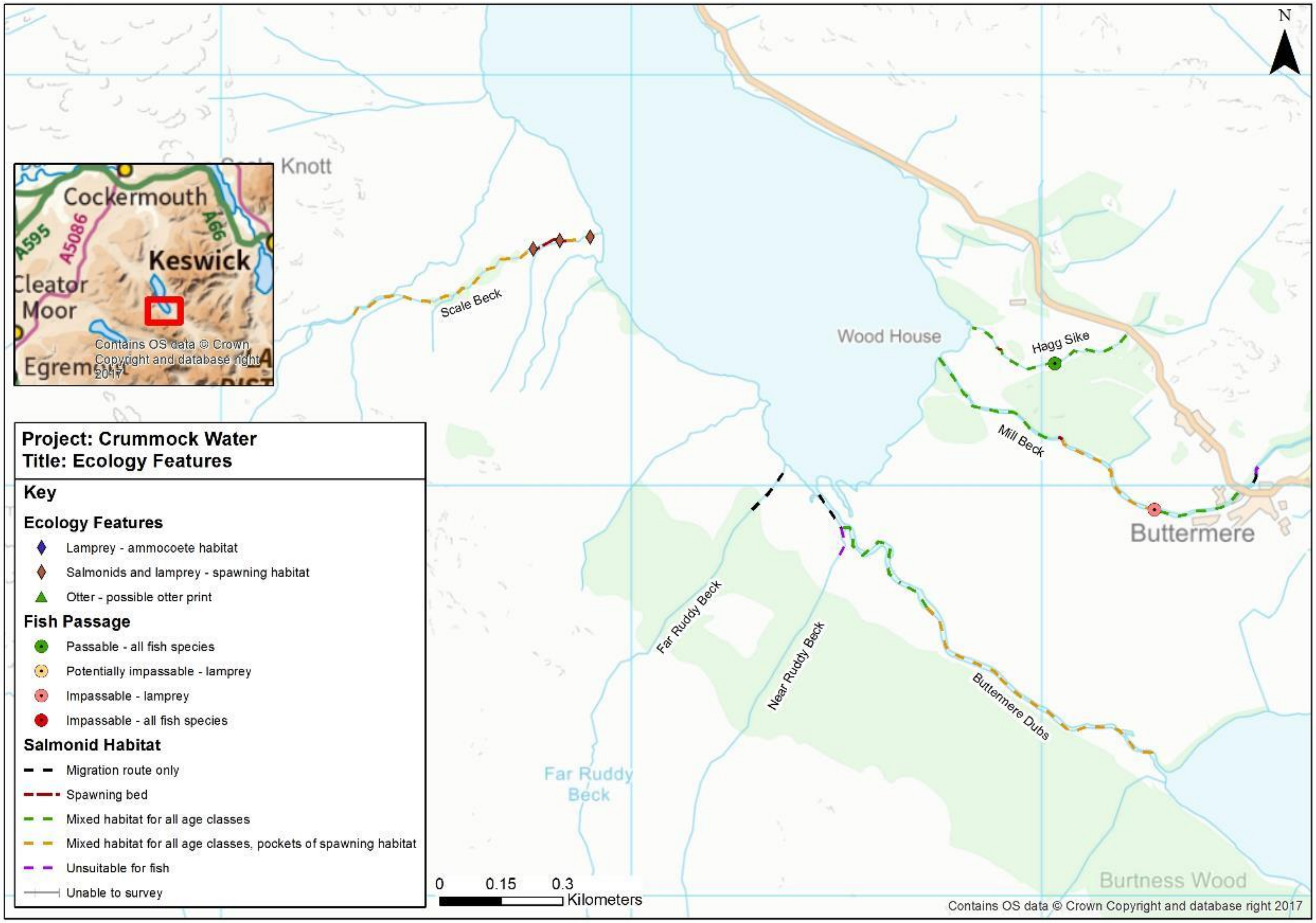


Figure G-7: Ecology Features in Tributaries to Crummock Water

Appendix H. Preliminary Long-List of Options

Area	ID	Option type	Engineering: Health and Safety (Construction, demolition, preparation)	Engineering: Technical merit (engineering performance)	Engineering: Impact on adjacent infrastructure	Engineering: Buildability (Access, temp works)	Engineering: Capital Costs	Engineering: Maintenance and operation (short, med, long term)	Engineering: Legislative Requirements	Hydraulics: Impact on peak flood levels	Hydraulics: Impact on flood frequency	Hydraulics: Impact on low flow regime	Hydraulics: Legislative Requirements
Crummock Weir/ River Cocker	A1	Do Nothing - Allow natural decay	+	- -	- - -	=	=	+	- - -	-	=	-	-
	A2	Do minimum - monitor and maintain	=	=	=	=	=	=	=	=	=	=	=
	A3	Assisted natural recovery (strategically remove parts of structure)	-	-	-	-	-	=	- -	++	+++	-	++
	A4	Partial removal of one side of weir	-	-	-	-	-	=	- -	++	+++	-	++
	A5	Lower weir	- -	-	-	- -	- -	=	- -	+	+	=	++
	A6	Full weir removal	- -	- -	-	- -	- -	+	+++	++	+++	-	++
Crummock Water wall	B1	Do Nothing - Allow natural decay	+	-	-	=	=	+	=	- -	- - -	=	-
	B2	Do minimum - monitor and maintain	=	=	=	=	=	=	=	=	=	=	=
	B3	Assisted natural recovery (strategically remove parts of structure)	-	-	=	-	-	=	=	- -	- - -	=	- -
	B4	Lower wall	-	-	-	-	-	=	=	- -	- -	=	- -
	B5	Full wall removal	- -	-	-	- -	- -	+	=	- -	- - -	=	- - -
	B6	Set back lake footpath	=	=	=	-	-	=	=	=	=	=	=
	B7	Wetland restoration/ natural flood management along north western periphery	=	=	-	-	-	-	=	+	=	=	+
Park Beck	C1	Do nothing - Allow natural decay	+	-	-	=	=	+	=	- -	- -	=	- -
	C2	Do minimum - monitor and maintain	=	=	=	=	=	=	=	=	=	=	=
	C3	Installation of woody debris/ other geomorphological features	-	-	=	-	-	-	=	-	-	=	-
	C3	Partial removal of concrete bed and banks	- -	-	-	- -	- -	-	=	=	=	=	+
	C4	Full removal of concrete bed and banks	- -	-	- -	- -	- -	+	=	=	=	=	+
	C5	Remeander Park Beck with full removal of concrete	- -	=	- -	- -	- -	+	=	=	=	=	+
	C6	Realign Park Beck into the River Cocker	-	=	- -	- -	- -	+	=	-	-	+	-

Area	ID	Option type	Geomorphology: River reactivity (width and depth)	Geomorphology: Impacts on sediment regime	Geomorphology: Impacts on longitudinal and lateral connectivity	Geomorphology: Legislative Requirements	Ecology: Maintained/ enhanced key species habitat	Ecology: Maintained/ enhanced populations of important lake species (spawning Arctic charr, wetland habitat, designated macrophytes assemblage)	Ecology: Maintained/ enhanced passage of migratory fish	Ecology: Maintain/ enhance habitat for designated terrestrial receptors (e.g. otter)	Ecology: Legislative Requirements
Crummock Weir/ River Cocker	A1	Do Nothing - Allow natural decay	-	- -	- -	- - -	=	+	=	=	=
	A2	Do minimum - monitor and maintain	-	-	- - -	- - -	=	+	=	=	=
	A3	Assisted natural recovery (strategically remove parts of structure)	++	+++	++	++	+	-	+	=	=
	A4	Partial removal of one side of weir	+	+	+	+	++	-	+	=	-
	A5	Lower weir	+	+	+	+	+	-	+	=	-
	A6	Full weir removal	+++	+++	+++	+++	+++	- - -	++	=	=
Crummock Water wall	B1	Do Nothing - Allow natural decay	=	-	- -	-	=	-	=	=	=
	B2	Do minimum - monitor and maintain	=	-	- -	-	=	-	=	=	=
	B3	Assisted natural recovery (strategically remove parts of structure)	=	+	++	+	+	+	NA	=	-
	B4	Lower wall	=	=	+	-	=	=	NA	=	-
	B5	Full wall removal	=	++	+++	++	++	++	NA	=	-
	B6	Set back lake footpath	=	=	=	=	=	=	=	=	=
	B7	Wetland restoration/ natural flood management along north western periphery	+	+	+	+	NA	+	NA	=	=
Park Beck	C1	Do nothing - Allow natural decay	-	-	-	-	=	=	=	=	=
	C2	Do minimum - monitor and maintain	- -	- -	- -	- -	=	=	=	=	=
	C3	Installation of woody debris/ other geomorphological features	+	+	+	+	+	=	=	=	++
	C3	Partial removal of concrete bed and banks	+	+	+	+	+	=	=	+	+
	C4	Full removal of concrete bed and banks	++	++	++	++	++	+	+	+	+
	C5	Remeander Park Beck with full removal of concrete	+++	+++	+++	+++	++	+	++	++	++
	C6	Realign Park Beck into the River Cocker	-	-	-	-	++	-	+	++	++

High Beneficial	Moderate Beneficial	Low Beneficial	Negligible	Minor Negative	Moderate Negative	Major Negative	Unknown
+++	++	+	=	-	- -	- - -	?
Significant benefits/opportunities for that criteria that **substantially improve situation** over the base-case. Would be seen as a major postive of the option in the overall context of the project.	Clearly positive with **moderate benefits/opportunities**, that should be seen as favourable impact of the scheme/option	Probably/likely positive but **minor benefits/opportunities.** Should not be seen as a significant benefit of the scheme.	No discernible impact, either postive or negative	Some **minor negative** impacts/risks that could be acceptable in the wider context of the scheme. i.e. wider benefits against other criteria or with additional mitigation.	Clearly negative with **moderate impacts**, that should be seen as risk to the viability of the scheme/option, but not necessarily a "showstopper". Risks could be mitigated for.	**Serious adverse impact** that is likely to be extremely difficult to overcome in the context of the scheme. A clear and high risk to the aims of the scheme/project without chance of mitigation.	Not enough information to make an initial assessment.

Figure H-1: Long list of options assessed against all MCA criteria

Appendix I. Hazard Elimination and Risk Reduction Form

DESIGN HAZARD ELIMINATION AND RISK REDUCTION (HE & RR) FORM

Project name:	**Crummock Water Infrastructure Removal**	**Design stage:**		**Engineering Discipline:**	**Civil**	**Structure:**	**Crummuck Water Re-Naturalisation**
Project No: B27030AP	**Doc. Ref.:**	**Revision: Working Copy**	**Prepared by: R H Kelly**	**Date: 15/01/2019**	**Checked by: C D Fisher**	**Date: 29/01/2019**	

Ref.	Phase C/M/D /UaW	Topic	Potential Specific Hazards	Person(s) at Risk	Risk Rating (H/M/L)	Options and Practicability to Eliminate Hazards	Options and Practicability to Reduce Risk	Significant or Unusual Residual Risk remains?	Summary of Information to be provided? Drawing No(s). or other doc. (give ref.)	Con-firmed
Access Risks										
1	C	Access to both elements of the site, Park Beck and the Weir at the River Cocker is via rough single-track roads. This could limit the size of plant that can access the working areas.	Traffic incidents with construction traffic and general public.	Contractors Staff and Members of the Public	L	There is no practical method of eliminating the hazard as there are no other access routes to get to access the site.	Contractor shall develop a traffic management plan prior to start on site.	No	B27030AP-JAC-ZZ-CR-DR-C-001	
Demolition Risks										
2	C	Removal of existing access bridges over Park Beck and River Cocker.	Collapse of existing structure during demolition and removal.	Contractor	M	The removal of the bridges is an essential element of the works.	Bridges and associated structures to be assessed by the Contractor and dismantled in a sequential fashion.	No	B27030AP-JAC-ZZ-CR-DR-C-002,007, 010 and 006	

3	C	Potential to damage existing draw-off pipework from Crummock Water	Damage to the pipework could cause inundation of the works if the control valves at Crummock lake are inoperable and/or have not been plugged.	Existing Infrastructure	L	Checks have been undertaken with the Client and it is understood that the existing pipework is approximately 5m below the ground level.	Contractor shall identify and mark the approximate location of the pipework on site. Care shall be exercised whilst working in the vicinity of the pipes so as not to strike them during excavations. Valves at Crummock Water to be closed and locked off.	Yes	B27030AP-JAC-ZZ-CR-DR-C-002	
Construction Risks										
4	C	Discovery of contaminated material during the re-naturalisation of both Park Beck and the River Cocker		Contractors Staff	L	Initial GI for various locations suggests that no contaminated materials exist	Contractor to adopt precautionary material management protocols.	No	B27030AP-JAC-ZZ-CR-DR-C-002 and 006	
	C	Working within a live watercourse	Risk of inundation of the working area	Contractors Staff	M	Working within the watercourse is unavoidable.	Contractor to identify suitable working methods to allow works to be carried out in the dry and a suitable evacuation procedure.	No	B27030AP-JAC-ZZ-CR-DR-C-002	
5	C	Public right of way runs through the site and is affected directly by the works and works area.	Members of the public could come into direct contact with the works.	Public	H	There is no practical method of eliminating the hazard as the right of way runs directly behind the wave wall and across the bridges to be removed.	The Contractor shall provide diversions, including where necessary temporary bridges and adequate segregation from the working areas for the public.	No	B27030AP-JAC-ZZ-CR-DR-C-002 and 006	
6	C	Unstable excavations when forming the re-naturalised channel.	During the re-naturalisation the ground could become unstable.	Contractors Staff	M	The Design of the new channel is such that the slopes have been battered back reducing the potential for collapse of slopes.	Contractor to make sure slopes of excavations are battered back no steeper than the gradients shown on the drawings and that all works shall be carried back a suitable distance from the edge.	No	B27030AP-JAC-ZZ-CR-DR-C-002 and 008	
Risks to the Environment										

7	C	Contamination of downstream channel/reservoir due to plant movements in channel or lake bed.	The use of plant in the river channels and bed of the reservoir could lead to diesel spills etc.	Environment	H		The Contractor shall prepare a detailed method statement outlining mitigation and control measures to prevent the release of contaminants to the watercourse. These measures are likely to include the use of spill kits, positioning of generators etc.	No	B27030AP-JAC-ZZ-CR-DR-C-002 and 008	
8	C	Contamination of downstream channel/reservoir	Possible migration of silts and materials during weir removal and channel re-naturalisation works.	Environment	H	The purpose of the works is to re-naturalise Park Beck and the River Cocker. So direct working in the channel is unavoidable.	The Contractor shall prepare a method statement outlining the measures to minimise the effect of or eliminate an environmental incident. Contractor to install settlement pool to trap material and dispose off-site.	No	B27030AP-JAC-ZZ-CR-DR-C-002 and 008	

Phase
C= Construct
M= Maintain / Clean
D= Demolish and/or Adapt
UaW = Use as Workplace

Severity of Injury	
H:	Major, Fatal or long term disabling injury or illness.
M:	Moderate injury or illness
L:	Minor injury/ illness

Probability (Prob.)	
H:	Highly likely
M:	Likely event
L:	Possible

Hierarchy of Mitigation	
1	Eliminate hazard (design out)
2	Reduce risk at source (amend design)
3	Provide risk information (add to design)

Appendix J. High-level Costings

The estimated high-level costings based on the rates provided by UU and the rates from the SPON'S civil engineering pricing handbook. Table J.1 includes 10% inflation within the total value and Table J.2 is without inflation.

Table J.1: Cost estimate of Crummock Water infrastructure removal with 10% inflation

Area	Item No	Item	Unit	Quantity	Rate	10% x rate	Cost
Park Beck	1	Demolition of Existing Park Beck Channel - Concrete Section	m³	579.6	150.76	165.84	96118.55
	2	Demolition of Existing Park Beck Channel - Masonry Section	m³	96	82.91	91.20	8755.30
	3	Disposal of Park beck channel - Concrete Section	m³	579.6	39.5	43.45	25183.62
	4	Disposal of Existing Park Beck Channel - Masonry Section	m³	96	39.5	43.45	4171.20
	5	Excavation for new channel works - normal materials	m³	2080	4.08	4.49	9335.04
	6	Excavation for new channel works - assumed volume of rock	m³	5	39.46	43.41	217.03
	7	Park Beck Bridge Removal including for disposal (2no)	Sum				5000.00
	8	Park Beck Replacement bridges including for the supply and erection on site (2no)	Sum				40000.00
	9	Park Beck Vegetation Clearance	Sum				2500.00
River Cocker	10	River Cocker footbridge removal and disposal (4no)	Sum				10000.00
	11	River Cocker Footbridge replacement (1no)	Sum				50000.00
	12	Removal of penstock and associated metalwork (2no)	Sum				5000.00
	13	New footpath for public right of way diversion	m	100	42.62	46.88	4688.20
	14	Demolition of Existing Weir - Concrete Section	m³	355	150.76	165.84	58871.78
	15	Demolition of Existing Weir - Masonry Section	m³	238	82.91	91.20	21705.84
	16	Disposal of Existing Weir - Concrete Section	m³	355	39.5	43.45	15424.75
	17	Disposal of Existing Weir - Masonry Section	m³	238	39.5	43.45	10341.10
	18	Area to be infilled following fish pass removal (imported material)	m³	10	50	55.00	550.00
	19	Area to be infilled following fish pass removal (existing material)	m³	2	50	55.00	110.00
	20	Excavation to create renaturalised channel at River Cocker	m³	251.25	8.7	9.57	2404.46
	21	Infilling required to create renaturalised channel at River Cocker	m³	25	50	55.00	1375.00
	22	Assumed quantities of sediment to excavated from front of weir	m³	300	8.7	9.57	2871.00
Wave Wall Removal	23	Removal of concrete wave wall at River Cocker Weir	m³	40	150	165.00	6600.00
	24	Removal of concrete wave wall along left flank of reservoir	m³	300	150	165.00	49500.00
	25	Disposal of concrete wave wall at River Cocker Weir	m³	40	39.5	43.45	1738.00
	26	Disposal of concrete wave wall along left flank of reservoir	m³	300	39.5	43.45	13035.00
	27	Excavation for wall removal	m³	680	8.7	9.57	6507.60
	28	Reuse of material following removal of wall to reprofile shoreline	m³	680		0.00	0.00
	29	Imported material for reprofiling shoreline	m³	221	50	55.00	12155.00
	30	Stone Pitching removal at Park Beck Pump House	m³	150	82.91	91.20	13680.15
	31	Assumed volume of stones/gravels to be imported following pitching removal	m³	150	50	55.00	8250.00
Misc	32	Tree Removal behind wall on left flank	Sum				2500.00
	33	Concrete Plug to existing pipe work (assume a length of 10m for each pipe)	m³	30	174.4	191.84	5755.20
	34	Plating of existing pipework	Sum				2000.00
	35	Removal of fish screen by diver assume 2.5 days at £2000/day	Sum				5000.00

Area	Item No	Item	Unit	Quantity	Rate	10% x rate	Cost
Access	36	Provide stone to resurface existing access on north side of reservoir (3m wide x 0.25 deep 750 length)	m³	562.5	47.7	52.47	29514.38
	37	Provide stone to resurface existing access on to Park Beck (3m wide x 0.25 deep 750 length)	m³	1000	47.7	52.47	52470.00
General items	38	*Including: Contractual Requirements (bonds and insurances), Accommodation, equipment and attendance for the Engineer's staff, Testing of materials and the Works, Temporary Works, Contractor's site accommodation, Contractor's general plant and Contractor's supervision (Allow 30%)*	Sum	583328.19			174998.46
	39	*Optimism Bias (TBC)*	Sum				TBC
					Total		758,327

Appendix K. Investigations into Original Lake level

K.1 Background

In April 2019 Daryll Hughes, a PHD student working with United Utilities, discovered information on the history of Crummock Water, in particular the creation and evolution of the weir structure. This information raised questions regarding the original natural level of the lake outlet and what the impact of this is based on the final outline design presented in this report. The PhD report is, as yet, unpublished.

K.2 Timeline of Works to Crummock Water

Darryl Hughes' study (not yet published) into the modifications to the natural water level at Crummock water showed that the first damming of the lake was carried out in 1878, whereby a timber weir was constructed to aid the abstraction of drinking water, this is demonstrated on the drawing titled "Plan and Weirs of Sluice Board and Fish Pass at Crummock Lake" by Pickering and Crompton dated 1881. It is believed that as part of the first scheme, the lake level was not raised but the flows from the lake were regulated by the formation of the weir to the equivalent natural ground level, the excavation of the outlet channel and the introduction of a sluice. It is understood that the reason for not raising the water level was that the landowners did not want land flooded. This included the woodrush islands to the south not being inundated during this stage.

In 1899, a larger masonry impounding weir was constructed which raised lake levels by around 2 feet. This weir had two sluice gates and a central stepped fish pass. It is believed that this weir was constructed several meters further into the lake and the subsequent rise in water levels resulted in the need for the construction of the wave wall along the left flank of the lake to prevent flooding of the adjacent fields. The woodrush islands, previously noted as not inundated in the 1878 scheme, were inundated at this stage.

In 1968 extensive repairs were made to the weir, however is believed that the height and extent of the weir did not change during these works. This is based upon comparison between drawings showing details of the weir by James P Williamson dated 1965 and details of the repairs on a suite of drawings by Herbert Lapworth Partners dated 1967.

The above stages of modifications to the weir structure have led to a significant volume of water (estimated to be in the region of approximately 1,900,000m^3) being stored above the natural ground level. The timeline of events and modifications to lake levels are summarised below in Table K.1. However, the measurements recorded in this table are given as a guide only as the historical evidence used to compile them is unconfirmed and the method of measurement is unknown.

Table K.1 Historical activities at Crummock Water weir

Scheme	Date	Weir Elevation	Measured Water Level	Notes
First Scheme Timber weir to keep winter lake level.	1879	97.91m AOD (estimated from drawing of present day weir)	97.96m AOD (June 1895)	Weir is said not to have raised natural winter water level as landowners did not want land flooded, outlet channel excavated and woodrush islands in the south of Crummock Water were not flooded
Second Scheme Masonry Impounding Weir	1899-1903	Assumed 98.52m AOD, as this is the current height of weir and documentation suggests no changes to height have been made since the second scheme)		Larger impounding masonry weir raised lake levels by approximately 2 feet (0.6m). The weir was moved by 2m into lake and subsequently flooding surrounding land. Woodrush islands to south became flooded.
Herbert Lapworth and Partners Design of Repairs	1967	98.52m AOD		Apparently, these works provided no change to water levels or weir height from the works in 1903.
Third Scheme Repairs to Weir	1969	98.52m AOD		

K.3 Discussions with All Reservoir Panel Engineer (ARPE)

The findings of the research paper were reviewed by the Design Team including a fluvial geomorphologist where consideration was given to raising the bed level to previous natural levels after the weir and sluice gates had been removed. Initially it was not clear whether restoring to this level would remove the lake from the Reservoirs Act.

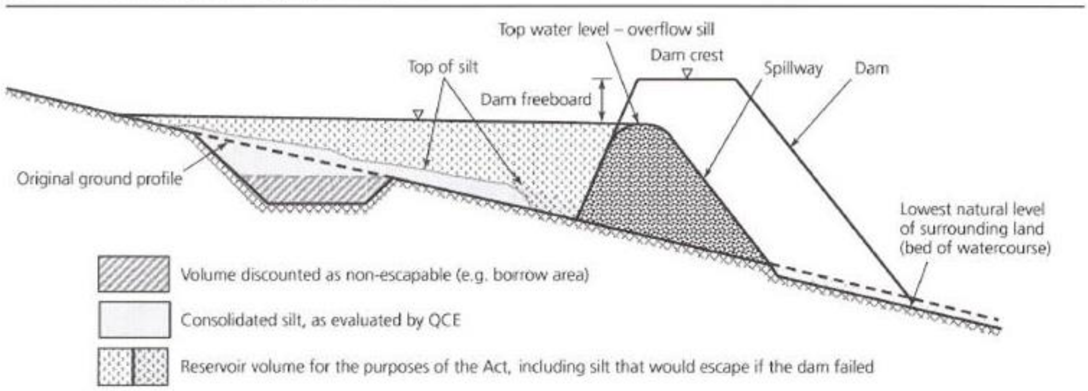
Through consultation with an All Reservoirs Panel Engineer (ARPE), it was discussed whether the original stream bed or base of the outlet pipe/sluices should be the governing level for discontinuance. The Reservoir Act states that the following are relevant

Statutory Instrument 2013 No 1677 (Prescribed Form of Record)	Height	From lowest natural ground level at the toe (including stream bed)
	Lowest natural level	Section 2 interpretation “Includes the lowest bed level of the watercourse
	Natural level	Section 2 interpretation “bed level of the natural land remaining after the construction or alteration”

It was advised by the ARPE that information is slightly ambiguous and is open to interpretation on whether the trench was in erodible ground i.e. could lead to a large breach (“escape of water”), or in rock so the escape of water would be controlled.

However, A Guide to The Reservoirs Act 1975 Second Edition covers this on page 27, paragraph 2 as screen shot below shows.

Figure B.1 Definition of statutory reservoir volume



which is not the impounded watercourse. In this instance, the toe of the embankment would normally relate to the point where the embankment meets the undisturbed foundation. However, where the safety of the reservoir could be impaired by erosion of the bank by river flows then it should be considered part of the reservoir and managed as such.

If a trench is cut through natural ground to form a low-level outlet, which is subsequently backfilled, then the lowest level would be the bottom of that trench. However, if a trench is excavated in the vicinity of a dam wall but does not extend through the entire structure then it is considered that natural ground still exists under the dam. It is recognised that interpretation may impact the legal status of partially buried service reservoirs that feature conduits in a trench below the reservoir.

From this it can be concluded that the level for discontinuance is the base of the trench for the outlet, which in the case of Crummock Water is the base of the sluice gate.

From the information and discussions, whilst it would be possible to reinstate the original outlet level as recorded in 1879 prior to the timber weir being installed, this would not remove the Lake from the Reservoirs Act or remove United Utilities Duties as Undertaker for the lake as it would still be classed as being able to hold a body of water above the natural ground. In order to remove this obligation under the act the new natural lake outlet is required to be set at the level of the lower sluice gate (97.15m AOD) approximately 740mm lower than outlet level in 1879.