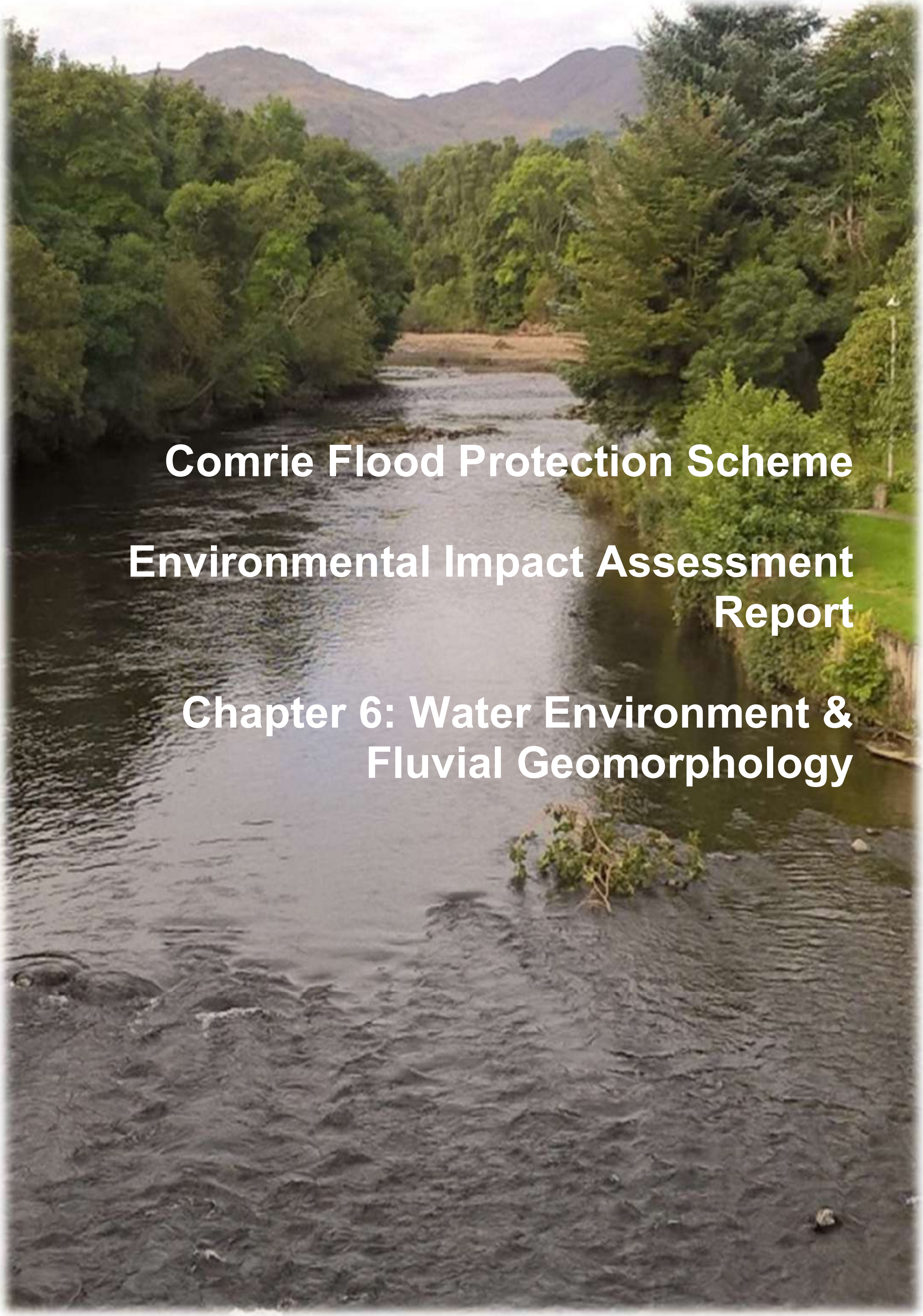

Comrie Flood Protection Scheme

Environmental Impact Assessment Report

Chapter 6: Water Environment & Fluvial Geomorphology

Document Control

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CONTENTS

FIGURES

APPENDICES

6 Water Environment & Fluvial Geomorphology

6.1 Introduction

6.1.1 This chapter provides an assessment of the effects of the Scheme on various 'attributes' of the surface water environment; namely hydrology and flood risk, fluvial geomorphology and water quality, during both construction and permanent/operational phases.

6.1.2 These attributes of the surface water environment are also closely linked to groundwater and contaminated land (**Chapter 7: Hydrogeology and Contamination**) and aquatic ecological receptors (**Chapter 8: Ecology and Nature Conservation**). The environmental teams undertaking each of these assessments worked closely to cover interactions between these topics and cross-discipline information has been referenced throughout this chapter where relevant.

6.1.3 This chapter is supported by the following documents;

- **Figure 6.1** Water Environment
- **Figure 6.2a** Modelled 1:200 Year Baseline Flood Extent
- **Figure 6.2b** Modelled 1:200 Year Defended Flood Extent
- **Appendix 6.1**: Sweco (2018) Comrie Flood Protection Scheme – Fluvial Geomorphology and Erosion Protection Technical Note
- **Appendix 6.2**: Sweco (2019) Water of Ruchill Fluvial Audit

6.1.4 There is also a glossary provided at the end of the chapter (**Section 6.10**) that explains the various technical terms used within the text.

6.2 Policy and Guidance

6.2.1 The assessment reported in this chapter was carried out in accordance with the following legislation, policy, published guidance and other relevant sources. More information on legislation and policy relevant to the Scheme can be found in **Chapter 2: Flood Act Remit & Policy Background**.

Flood Risk Management (Scotland) Act 2009 (FRMS Act)

6.2.2 The FRMS Act sets in place a statutory framework and a risk-based approach to managing flooding in Scotland. It places a duty on Scottish Ministers, SEPA, local authorities, Scottish Water and other responsible authorities to manage and reduce flood risk and to promote sustainable flood risk management. Schedule 2 of the Act outlines the procedure for obtaining consent for a flood protection scheme.

Water Framework Directive (WFD) 2000/60/EC and the Water Environment and Water Services (Scotland) Act 2003 (WEWS Act)

6.2.3 The Water Framework Directive (WFD), transposed into Scottish law by the WEWS Act, sets targets for restoring and improving the ecological, hydromorphological and chemical status of water bodies and preventing deterioration. This is managed in Scotland by SEPA through River Basin Management Plans (RBMPs). To achieve the objectives of the WFD (i.e. for all waterbodies to achieve or maintain an overall status of 'Good' by agreed timescales), SEPA introduced a risk-based classification system in 2009. This included five quality classes for natural water bodies (High, Good, Moderate, Poor and Bad). Heavily modified and artificial water bodies have other targets to meet and need to achieve a status of at least 'Good Ecological Potential' over similar timescales. SEPA has identified a number of improvement measures in order for failing water bodies to meet WFD objectives over time.

6.2.4 Consideration has been given to the requirements of the WFD during assessment of the baseline sensitivity of watercourses, design of the flood and erosion protection measures of the Scheme, and selection of mitigation measures.

The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (as amended) (CAR)

6.2.5 The Controlled Activities Regulations (CAR) is a primary tool in achieving the WFD objectives in Scotland. This legislation controls engineering works within inland water bodies, as well as point source discharges, abstractions and impoundments. There are three different levels of authorisation under CAR: General Binding Rules (GBR), Registration and Licence (either Simple or Complex); the level of regulation increasing with higher risk activities.

6.2.6 Specific activities for the Scheme may require authorisation, such as licences for river engineering works and a construction site licence to manage water runoff from the site during construction. CAR authorisation is required from SEPA prior to the start of construction to protect the water environment from construction activities.

Scottish Planning Policy (SPP)

6.2.7 SPP requires planning authorities to consider all sources of flooding; coastal, rivers (fluvial), surface water (pluvial), groundwater, reservoirs and drainage systems, and their associated risks when preparing development plans and reviewing planning applications. The predicted effects of climate change must also be taken into consideration.

Perth & Kinross Local Development Plan (LDP2)

6.2.8 The following local policies in the recently adopted Perth & Kinross Council (the Councils) LDP2 (2019) are relevant to this chapter:

- Policy 52: New Development and Flooding – provides guidance on the type(s) of development that are permissible, adopting the flood risk framework in SPP (i.e. areas identified as medium to high flood risk, low to medium flood risk and little to no flood risk), as well incorporating a suitable climate change allowance and freeboard allowance. There is a general presumption against new development where there is a significant probability of flooding from any source or where it would increase the risk of flooding elsewhere. Infrastructure should be designed to be free from surface water (pluvial) flooding (exceeding 0.5% Annual Exceedance Probability (AEP) (1:200 year return period) rainfall events) and a Drainage Impact Assessment (DIA) is required to consider pluvial flooding for any development greater than 1,000m2.
- Policy 53: Water Environment and Drainage – development should protect, and where possible improve, the water environment in line with the WFD. Proposals for development which do not accord with the Scotland RBMP and any associated Area Management Plans will be refused planning permission unless the development is judged by the Council to be of overriding benefit to society (public interest) and/or the wider environment. All new developments require Sustainable Drainage Systems (SuDS), including temporary drainage systems during construction, where relevant.

Published Guidance and Other Relevant Sources

6.2.9 The following guidance and previous studies provided key information for this chapter:

- Technical Flood Risk Guidance for Stakeholders, v12 (SEPA, 2019)[1];
- Flood Modelling Guidance for Responsible Authorities, v1.1 (SEPA, undated)[2];
- CAR Practical Guide v8.4 (SEPA, 2019)[3];
- DMRB Volume 11, Section 3, Part 10 (HD45/09): Road Drainage and the Water Environment (Highways Agency et al., 2009)[4];
- The Guidebook of Applied Fluvial Geomorphology (Sear et al., 2003)[5];
- Review of Impact Assessment Tools and Post Project Monitoring Guidance (Skinner and Thorne, 2005)[6];

[1] SEPA (2019) Technical Flood Risk Guidance for Stakeholders – SEPA requirements for undertaking a Flood Risk Assessment. Version 12, May 2019, SS-NFR-P-002. Accessed 01/10/2019 [https://www.sepa.org.uk/media/162602/ss-nfr-p-002-technical-flood-risk-guidance-for-stakeholders.pdf]

[2] SEPA Flood Modelling Guidance for Responsible Authorities, Version 1.1. Accessed 01/03/2019 [https://www.sepa.org.uk/media/219653/flood_model_guidance_v2.pdf]

[3] SEPA (2019) The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (as amended) - A Practical Guide. Version 8.4 October 2019. Accessed 01/10/2019 [https://www.sepa.org.uk/media/34761/car_a_practical_guide.pdf]

[4] Highways Agency et al. (2009) HD 45/09: Design Manual for Roads and Bridges (DMRB), Volume 11, Section 3, Part 10, Road Drainage and the Water Environment, 2009. The Highways Agency, Scottish Executive Development Department, The National Assembly for Wales and The Department of Regional Development Northern Ireland. Accessed 21/02/2019 [http://www.standardsforhighways.co.uk/ha/standards/dmrb/vol11/section3/hd4509.pdf]. This guidance has now superceded (2019) but the changes don't alter the assessment methodology or the conclusions in anyway.

[5] Sear, D.A. Newson, M.D. and Thorne, C.R. (2003) Guidebook of Applied Fluvial Geomorphology. R&D Technical Report FD1914. DEFRA/ Environment Agency. Flood and Coastal Defence R&D Programme.

[6] Skinner, K. and Thorne, C.R. (2005) Review of Impact Assessment Tools and Post Project Monitoring Guidance. Report prepared for SEPA. Accessed 01/03/2019 [https://www.sepa.org.uk/media/152207/wat_sg_30.pdf]

- The Fluvial Design Guide (Environment Agency, 2010)[7];
- Water of Ruchill, Comrie: Sustainable River Management (Hey, 1999)[8];
- Comrie and Dalginross Flood Study: Flood Option Assessment (Mouchel, 2010)[9];
- Comrie and Dalginross Flood Alleviation Scheme: Fluvial Geomorphological Reconnaissance Survey (cbec, 2011)[10];
- Comrie Flood Protection Scheme – Geomorphological Assessment Report, Final Report (cbec, 2018)[11]; and
- SEPA's Hydromorphology File Notes (2012[12], 2014[13], 2016[14]).

6.3 Methodology

Introduction

6.3.1 Key details of the assessment methodologies are provided in the following section, including information on assessment study area, approaches and sensitivity/impact criteria, and any assumptions or limitations to the assessment.

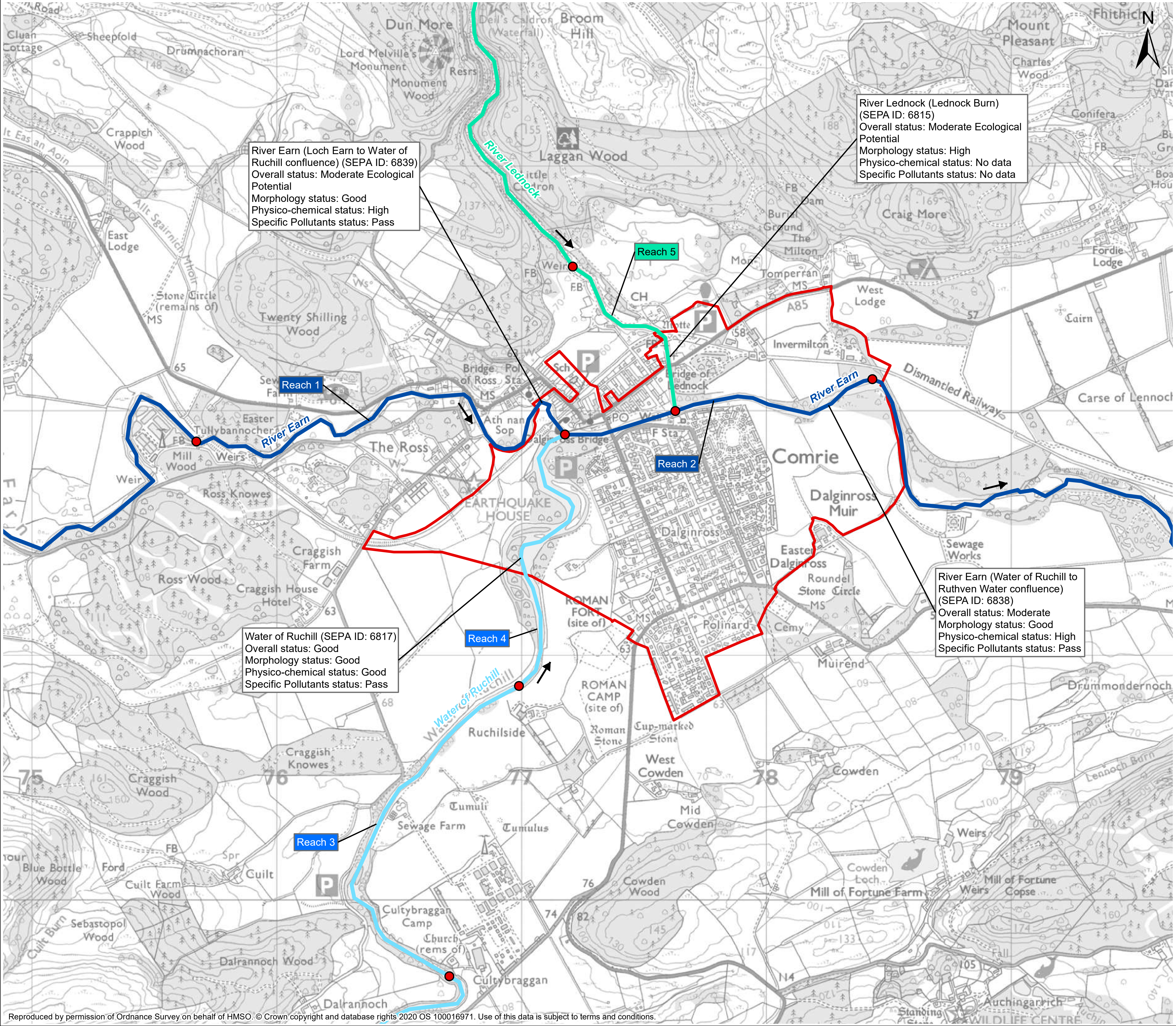
Study Area

6.3.2 The study area for the fluvial geomorphology and water quality assessments was up to 1km from the edge of the Scheme and generally within the EIA study area shown on **Figure 6.1**. Due to the importance of fluvial geomorphology for the Scheme, additional upstream stretches of the watercourses were included to provide a more comprehensive study area for the assessment.

6.3.3 For hydrology and flood risk, the study area was determined by the river catchments and upstream/downstream flood modelling boundaries.

6.3.4 Information on the watercourses in the study area and their characteristics is provided in **Section 6.5 (Baseline Assessment)**.

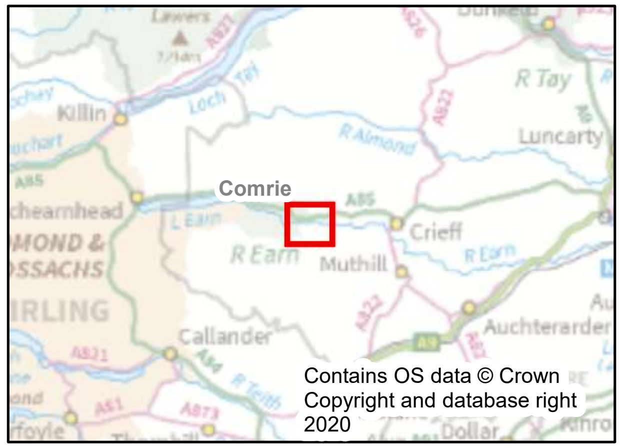
[7] Environment Agency (2010) The Fluvial Design Guide. Accessed 01/03/2019 [http://evidence.environment-agency.gov.uk/FCERM/en/FluvialDesignGuide/Fluvial_Design_Guide_Overview.aspx]
[8] Hey, R.D. (1999) Water of Ruchill, Comrie: Sustainable River Management. ENVMAN Ltd. Report prepared for Perth & Kinross Council.
[9] Mouchel (2010) Comrie and Dalginross Flood Study: Flood Option Assessment. Report Prepared for Perth & Kinross Council.
[10] cbec eco-engineering UK Ltd. (2011) Comrie and Dalginross Flood Alleviation Scheme: Fluvial Geomorphological Reconnaissance Survey. Report Prepared for Mouchel Ltd. and Perth & Kinross Council.
[11] cbec eco-engineering UK Ltd. (2018). Comrie Flood Protection Scheme – Geomorphological Assessment Report. Report Prepared for Sweco and Perth & Kinross Council.
[12] SEPA (2012) SEPA Hydromorphology File Note. 120905 hydromorphology report after flooding.
[13] SEPA (2014) SEPA Hydromorphology File Note. 140909 Hydromorphology Report – Water of Ruchill.
[14] SEPA (2016) SEPA Hydromorphology File Note. 160526 Site visit to Ruchill at Comrie.



Legend

- EIA Study Area
- Watercourse
- River Earn
- River Lednock (Lednock Burn)
- Water of Ruchill
- Geomorphic Study Reach Boundary
- Flow Direction
- WFD — Water Framework Directive (WFD) Status (2017)

0 0.5 1 Km



Rev.	Rev. Date	Drawing Suitability	Drawn	Appr'd
P01.1	04/02/2020	For Information	JB	RMcL

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PERTH & KINROSS COUNCIL

Project

Comrie Flood Protection Scheme 2020

Drawing Title

Figure 6.1 - Water Environment

Scale @ A3	1:15,000
Project No.	119702

Approach to Assessment

Assessment Methodologies

6.3.5 Baseline information was collected from a range of sources including desk studies, site visit walkovers and surveys, and information obtained through data requests and consultation feedback. More information on relevant consultations undertaken for the assessment is provided in **Section 6.4 (Consultation)**.

Hydrology and Flood Risk

6.3.6 The SEPA Flood Risk Management Maps[15] provide indicative mapping of flood risk from a range of sources (including river, surface water and coastal flooding) and at a range of likelihoods (low, medium and high), and was used to review the existing flood risk in the area.

6.3.7 Hydraulic modelling was undertaken to refine the flood risk information available, in line with SEPA's guidance '*Flood Modelling Guidance for Responsible Authorities*'. The model extents covered all of Comrie and Dalginross, with upstream extents of both the River Earn and Water of Ruchill extending 2km upstream of their confluence and the downstream extents situated approximately 6km downstream of the town to ensure that the full impact of the Scheme could be assessed. The model incorporated existing and recently-commissioned survey in addition to LiDAR data, which formed an accurate representation of ground elevations in the area. All significant structures such as The Ross, Dalginross and A85 bridges were also incorporated.

6.3.8 The impacts on flood risk have been assessed quantitively through the construction and simulation of a 1D-2D linked hydraulic model in Infoworks ICM software. This model, which was used to help develop and assess the Scheme design, contains geometry representative of the baseline (pre-development) and post-development scenarios.

6.3.9 Model geometry was obtained through detailed topographic surveys and also using data from the *LiDAR for Scotland* dataset[16]. Additionally, a doorstep threshold survey was used to provide data on the finished floor levels of all receptors expected to be at risk of flooding in the baseline scenario.

[15] SEPA Flood Risk Management Maps. Accessed 01/03/2019 [http://map.sepa.org.uk/floodmap/map.htm]

[16] Scottish Remote Sensing Portal. Accessed 01/03/2019 [https://remotesensingdata.gov.scot/products?collections=scotland-gov/lidar/phase-1/dsm]

6.3.10 Simulation of the full suite of hydrological events up to the 0.5% AEP (1:200 year return period) flood event for both the baseline and post-development scenarios provided information on:

- in-channel flows;
- flow velocities;
- flood inundation extents; and
- receptor inundation depths.

6.3.11 The modelling examined both fluvial and pluvial-dominant flood risk sources such that flood risk from the rivers and secondary flood risk from surface water could be assessed. The hydrological inputs to the model were reviewed and approved by SEPA and Scottish Water during consultations in 2018.

6.3.12 An uplift to account for future climate change, predicted in line with UKCP09 projections, was also estimated at the same range of return periods up to the 0.1% AEP event as specified by the Council and SEPA for the Scheme.

6.3.13 The impact assessment of flood risk used relevant guidance within DMRB HD45/09, where the sensitivity of land was based on the number of sensitive receptors which may be impacted; and the magnitude of impact based upon an increase or decrease in flood depth or frequency of flooding at receptors.

6.3.14 Manning's roughness within the model was calibrated using three past storm events. A validation exercise, using a further past storm event, was carried out to compare the model predictions to measured water levels in a major storm event. This exercise showed the model to be capable of predicting levels within a maximum tolerance of ±150mm and therefore indicated the model outputs had a high level of accuracy.

Fluvial Geomorphology

6.3.15 Due to the history of flooding and previous flood scheme interventions in Comrie, as well as the dynamic nature of the watercourses within the study area, several previous studies have been undertaken which document the geomorphological characteristics of the watercourses referred to in **Section 6.2** above. The Comrie Geomorphology Report (**Appendix 6.1**) includes the results of a geomorphological walkover undertaken by cbec eco-engineering UK Ltd in 2017 and a WFD/RBMP appraisal of the watercourses in the study area against the likely effects of further development on existing WFD status. This report informed the Scheme flood defence and bank erosion structure design and provides a recent description of the geomorphic characteristics of the watercourses.

6.3.16 These reports were reviewed along with other relevant information including photographs from previous site visits; historical Ordnance Survey (OS) mapping[17] and WFD hydromorphic classification data from SEPA's online database[18].

6.3.17 Following the RBMP assessment, and early consultation with SEPA (refer to **Section 6.4: Consultation**), a fluvial audit was undertaken on the Water of Ruchill catchment in January 2019. The Fluvial Audit Report is provided in **Appendix 6.2** and provides a more detailed assessment of the Water of Ruchill catchment.

6.3.18 Since the DMRB does not provide a methodology for assessing impacts on fluvial geomorphology, impact assessment criteria have been developed using industry-accepted methods including Sear et al. (2003), Skinner and Thorne (2005) and Environment Agency (2010).

6.3.19 SEPA's Morphological Impact Assessment System (MImAS) data was also used to inform the baseline and impact assessment of the three watercourses.

6.3.20 Morphological pressures are quantified by SEPA using their MImAS tool, which calculates the 'capacity used' or 'capacity remaining' by artificial modifications to the watercourse on a percentage basis (**Table 6.1**Table). This score is used to determine the morphological quality of a watercourse, one of the criteria used to determine the WFD status of a waterbody. SEPA can also use MImAS to predict whether proposed activities will result in deterioration of the morphological quality of a waterbody, which in most cases would be unacceptable and require a 'derogation' to the CAR licensing process[19] (SEPA, 2012[20]).

Table 6.1: Morphological Condition (Capacity Used) Thresholds for Waterbody Assessments

Water Body	WFD Status (morphology)				
	High	Good	Moderate	Poor	Bad
Channel, banks and riparian zone	<5%	5%-25%	25%-50%	50%-75%	>75%

Water Quality

6.3.21 The water quality baseline assessment was informed by WFD data obtained from SEPA's Water Environment Hub Interactive Map[18], data and consultation responses received from SEPA (refer to **Section 6.4: Consultation**) and watercourse chemistry sampling data collected during the ground investigation (GI) works undertaken by Sweco in 2018.

6.3.22 Surface water sampling data was collected on two occasions from upstream and downstream locations on the three watercourses. The concentrations were compared against Environmental Quality Standards (EQS) for freshwaters

[17] National Library of Scotland, Georeferenced map viewer. Accessed 08/08/2018 [https://maps.nls.uk/geo/explore]
[18] SEPA water classification hub. Accessed 01/03/2019 [https://www.sepa.org.uk/data-visualisation/water-classification-hub/]
[19] SEPA would consider authorising an activity if the benefits to human health, safety or sustainable development outweighed the benefits of protecting the water environment
[20] SEPA (2012) Supporting Guidance (WAT-SG-21) Environmental Standards for River Morphology. Version v2.1. Accessed 01/03/2019 [https://www.sepa.org.uk/media/152194/wat_sg_21.pdf]

which provided in-situ chemistry data to augment the WFD information on SEPA's online database.

6.3.23 Potential impacts of the Scheme on water quality during both construction and permanent/operational phases were assessed qualitatively.

Impact Assessment Methodology

6.3.24 Impact significance is a function of the sensitivity (value/importance) of an attribute and the magnitude of impact (assessed before and after mitigation).

6.3.25 The sensitivity of each watercourse and the magnitude of each potential impact was based on professional judgement, guided by the criteria outlined in **Tables 6.2 to 6.4**. These criteria have been defined for each attribute (hydrology and flood risk, fluvial geomorphology and water quality). Where two values for significance are given in **Table 6.4** (e.g. Slight/Moderate), one significance rating has been chosen based on professional judgement.

6.3.26 Mitigation measures have been identified based on SEPA and other good practice guidance during both construction and operational phases.

Impact Assessment Criteria

Table 6.2: Criteria for assessing Baseline Sensitivity

Topic	Importance (value/sensitivity)			
	Very High	High	Medium	Low
Hydrology and Flood Risk	Floodplain containing, or flood defence protecting, more than 100 residential or non-residential properties. Floodplain containing critical civil infrastructure (such as hospitals, schools, care homes, emergency service stations) or ecosystems that would be very sensitive to permanent changes in flow characteristics.	Floodplain containing, or flood defence protecting, 11-100 residential or non-residential properties. Floodplain containing locally important civil infrastructure (such as electrical sub-stations, major roads and railway lines) or ecosystems that would be sensitive to permanent changes in flow characteristics.	Floodplain containing 10 or fewer residential or non-residential properties. Floodplain containing civil infrastructure (such as minor roads) or ecosystems of limited importance.	Floodplain without residential and non-residential properties. Floodplain containing no civil infrastructure or ecosystems.
Fluvial Geomorphology	Channel Morphology: Watercourse is in a natural state with no artificial modifications or morphological pressures. Watercourse exhibits a wide range of features that would be expected of the typology of the watercourse in question (e.g. riffles, pools, bar forms and a wide variety of natural bank profiles). Rare stream types (e.g. active braided rivers). Fluvial Processes and Sediment Regime: Watercourse is in a state of equilibrium with the sediment regime reflecting the nature of the natural catchment and fluvial system. Predominantly natural watercourse which displays a wide range of fluvial processes (e.g. erosion, deposition, varied flow types). WFD morphology status of 'High'.	Channel Morphology: Watercourse appears to be in a generally natural state with limited artificial modifications or morphological pressures. Watercourse exhibits a range of geomorphological features (e.g. riffles, pools, bar forms and a variety of natural bank profiles). Where modifications have occurred, there is significant evidence of the watercourse returning to its natural form. Fluvial Processes and Sediment Regime: Watercourse has a sediment regime reflecting the nature of the natural catchment and fluvial system. Watercourse displays several fluvial processes. WFD morphology status of at least 'Good'.	Channel Morphology: Watercourse displays some geomorphic features (e.g. riffles, pools, bar forms). The channel cross-section has been modified in places with obvious signs of changes to the channel morphology. Some natural recovery to the channel form may be evident (e.g. depositional features, bank erosion). Fluvial Processes and Sediment Regime: Watercourse with significant modifications, causing notable alterations to the sediment transport pathways, sources and deposition areas. Watercourse has some natural fluvial processes and flow types; however human modifications have an obvious impact on natural flow regime. WFD morphology status	Channel Morphology: Watercourse has been modified to an extent where a uniform, featureless channel has been created. Channel displays very limited morphological diversity, with uniform banks and absence of bars. Fluvial Processes and Sediment Regime: Highly modified sediment regime with little to no capacity for natural recovery. Watercourse has a uniform flow type with minimal secondary currents and/or displays an unnatural flow regime. Limited evidence of active fluvial processes. WFD morphology status of 'Poor' or

Topic	Importance (value/sensitivity)			
	Very High	High	Medium	Low
			of at least 'Moderate' or not classified by SEPA.	'Bad' or not classified by SEPA.
Water Quality	WFD physico-chemical status of 'High'. Specific pollutants status of 'Pass'. No identified pollutant pressures. Habitats and/or species protected under EU legislation (Special Area of Conservation (SAC), Special Protection Area (SPA), Ramsar site). Designated salmonid waters under WFD. Natural watercourses only (i.e. not heavily modified or artificial).	WFD physico-chemical status of at least 'Good'. Specific pollutants status of 'Pass'. None or very limited pressures identified. Habitats and/or species protected under EU or UK legislation, including Sites of Special Scientific Interest (SSSI). Designated salmonid/cyprinid waters under WFD.	WFD physico-chemical status of at least 'Moderate'. Specific pollutants status of 'Pass' or not classified by SEPA. Water quality likely to be affected by pollutant inputs or other pressures. Could support a limited number of protected habitats or species.	WFD physico-chemical status of at least 'Poor' or 'Bad'. Specific pollutants status of 'Fail' or not classified by SEPA. Water quality highly likely to be affected by pollutant pressures. Generally, supports no protected habitats or species. Likely to be heavily modified or an artificial waterbody. Likely to be ephemeral in nature and not used for water supply, including short road and field drains.

Table 6.3: Criteria for assessing Impact Magnitude

Topic	Impact Magnitude			
	Major Adverse/Beneficial	**Moderate Adverse/Beneficial**	**Minor Adverse/Beneficial**	**Negligible**
Hydrology and Flood Risk	Increase or decrease in the number of residential properties or business-related buildings flooded in comparison with the baseline (existing) scenario. Increase or decrease in the frequency of any receptor flooded in comparison with the baseline scenario.	Increase or decrease in the frequency of flooding on any parcel of land, without any residential properties or business-related buildings impacted, in comparison with the baseline scenario. Increase or decrease in the depth to which any receptor is flooded in comparison with that same return period event in the baseline scenario; where that depth is greater than the calculated value of model tolerance (±150mm).	Increase or decrease in the depth to which any residential property or business-related building is flooded in comparison with that same return period event in the baseline scenario; where that depth is less than the calculated value of model tolerance (±150mm).	No measurable change from baseline conditions, from the hydraulic model outputs.
Fluvial Geomorphology	Channel Morphology: Significant and extensive changes to the planform and/or cross-section of the channel, including modification of bank profiles and replacement of the natural bed. Fluvial Processes and Sediment Regime: Significant shift from baseline conditions with potential to alter fluvial and sediment processes at the catchment scale. Significant impacts to the watercourse bed, banks and vegetated riparian corridor resulting in significant changes to sediment characteristics, transport processes, sediment load and turbidity. Changes are likely to be irreversible and impacts are at the waterbody scale. Or significant improvement to a watercourse as a result of substantial restoration or mitigation.	Channel Morphology: Moderate changes to channel planform and/or cross section of multiple reaches (e.g. modification to bed and bank profiles, new embankments). Fluvial Processes and Sediment Regime: A shift from baseline conditions with the potential to alter fluvial and sediment processes over multiple reaches. Moderate changes and impacts to watercourse bed, banks and vegetated riparian corridor resulting in some changes to sediment characteristics, transport processes, sediment load and turbidity.	Channel Morphology: Localised modifications to channel planform and/cross section (e.g. upgrades to bank protection). Fluvial Processes and Sediment Regime: Minimal shift from baseline conditions with impacts localised to the reach scale. Limited changes and impacts to watercourse bed, banks and vegetated riparian corridor resulting in limited (but notable) changes to sediment characteristics, transport processes, sediment load and turbidity. Slight improvement of the river channel from baseline conditions as a consequence of the works (generally on existing heavily modified/artificial watercourses).	Minimal or no measurable change from baseline conditions which is barely distinguishable. Any changes are highly localised and have no effect on a reach scale.

Topic	Impact Magnitude			
	Major Adverse/Beneficial	Moderate Adverse/Beneficial	Minor Adverse/Beneficial	Negligible
		Improvement to a watercourse (e.g. through means of some restoration or mitigation).		
Water Quality	Serious pollution risks from multiple in-channel works resulting in substantial/irreversible deterioration of the quality of existing water, such that aquatic ecology is greatly changed from the baseline situation and viable populations may be lost. Major shift away from baseline conditions. Or removal of existing polluting discharge or removing the likelihood of polluting discharges occurring to a watercourse.	Pollution risks from in-channel works or works in close proximity to bank resulting in partial deterioration in the quality of existing water such that aquatic ecology may be adversely affected. Moderate shift away from baseline conditions. Or moderate reduction of existing polluting discharge resulting in partial improvement in quality of existing water.	Minor shift away from baseline conditions. Measurable deterioration in the quality of the water resulting from in-channel or bankside works but of limited duration and extent with only slight effects on aquatic ecology. Or minor reduction of existing polluting discharge resulting in slight/perceptible improvement in quality of existing water.	Imperceptible change to water quality or aquatic ecology.

Table 6.4: Criteria for assessing Impact Significance

Sensitivity	Magnitude of Impact			
	Major	**Moderate**	**Minor**	**Negligible**
Very High	Very Large	Large / Very Large	Slight / Moderate / Large	Neutral
High	Large / Very Large	Moderate / Large	Slight / Moderate	Neutral
Medium	Large	Moderate	Slight	Neutral
Low	Slight / Moderate	Slight	Neutral	Neutral

Assumptions and Limitations

6.3.27 The assessment relies on assumptions about the type and nature of construction activities required for in-channel and bankside works for the Scheme. More specific details on in-channel works and construction methods, construction compounds and lay-down areas will be provided in the Contractor's Construction Environmental Management Plan (CEMP) and Construction Method Statements (CMS), subject to discussion with statutory and key environmental consultees, which is out with the scope of the EIA.

6.3.28 As chemistry sampling data was only collected from the watercourses on two occasions during the GI works, this only provided a snapshot of water quality conditions rather than a longer-term trend. This sampling data was used to augment the longer-term classification data available on SEPA's online database and therefore is not considered a limitation to the assessment.

6.4 Consultation

6.4.1 Consultation was undertaken with statutory and other key stakeholders during the EIA Scoping phase, and subsequently during the assessment phase, to inform the scope, approach and key issues to be addressed in this chapter. Information and data were also requested to augment the baseline information and to input to the flood modelling work. A summary of relevant consultations (and actions taken) is provided in **Table 6.5**.

6.4.2 Further consultation will be undertaken with SEPA on CAR licence requirements during the detailed design stage. The Contractor will need to ensure that any licences required for works have been approved by SEPA prior to start of construction.

Table 6.5: Summary of Consultations and Actions Taken

Consultee (Date)	Summary of Consultation	Comment/Action Taken
SEPA (hydrology team) (16 October 2017)	Meeting with SEPA to discuss proposed hydrology and hydraulic modelling approaches.	SEPA recommended that some new areas of topographic survey were obtained; and provided additional data to improve the model build. Agreement on the model boundary locations.
SEPA (hydrology team) (7 March 2018)	SEPA hydrology team expressed concerns that the predicted flows at Dalginross were significantly greater than those expected at a downstream gauge located at Kinkell Bridge.	A large floodplain exists between the gauges at Dalginross and Kinkell Bridge. Hydraulic modelling and analysis of floodplain storage was carried out to justify the proposed hydrological estimates.
Tay District Salmon Fisheries Board (3 April 2018)	Consultation feedback indicated that salmon fry had been recorded in the downstream reaches of the Water of Ruchill indicating the presence of spawning salmon. In-channel works should be avoided between November and May whilst salmon eggs and alevins are in the gravel.	Any in-channel construction works will be planned outwith November – May and this has been included as a mitigation requirement in this chapter.
SEPA (geomorphology team) (26 July 2018)	A teleconference to discuss the WFD status of the Water of Ruchill. The RBMP assessment identified that the Water of Ruchill only has 4% 'capacity remaining' in MImAS before it would be downgraded from 'good' to 'moderate' status. As a result, any works in or near the channel would likely result in the watercourse failing to meet WFD objectives. This may require a 'derogation' in any subsequent CAR licence application (post EIA stage).	A RBMP/WFD assessment on the Water of Ruchill (**Appendix 6.1**) and a Fluvial Audit report (**Appendix 6.2**) were prepared, which informed the design of the Scheme to minimise further impact on the watercourse. An on-site walkover with the Council and SEPA was arranged in October 2018 (see below). The works on the Ruchill and assessment of predicted effects took the existing MImAS score into consideration.
Scottish Water (28 September and 3 December 2018)	Meeting with Scottish Water to discuss model build and verification (MBV) report. Second meeting (03.12.18) to discuss the proposed secondary flooding interventions.	Consideration of secondary flooding and the impact which this could have on the Scottish Water network. The concept of property-level protection at impacted properties was considered, which reduced the need to carry out potentially disruptive works on the Scottish Water network.

Consultee (Date)	Summary of Consultation	Comment/Action Taken
SEPA (geomorphology team) (9 October 2018)	A walkover of the Water of Ruchill with the Council and SEPA was undertaken to discuss Scheme design options, as well as upstream options, to minimise further impact on the watercourse. SEPA suggested that the erosion issues on the Ruchill may be related to sediment supply and identifying the source of the sediment deposited around the confluence with the River Earn would be useful. Managing the sediment supply may provide a more sustainable solution to the bank erosion problems on the Ruchill. The Council highlighted that modification on the upstream reaches of the Ruchill would be out with the scope of this project. However, it was concluded that identifying the source of the issue was key to determining how it could be managed.	SEPA recommended a fluvial audit be carried out on the Ruchill catchment to identify upstream sediment sources and show commitment to remediation. A Fluvial Audit report was prepared and is included in **Appendix 6.2.**
Comrie Angling Club	Provided information on angling and recreational activities of the watercourses.	This information was included in the baseline assessment of this chapter.

6.5 Baseline Assessment

6.5.1 There are three main watercourses within the Scheme study area, comprising the River Earn and two of its tributaries, Water of Ruchill and the River Lednock. The Water of Ruchill flows in a north-easterly direction and joins the River Earn on the west side of Comrie. The River Lednock flows in a southerly direction and joins the River Earn on the east side of Comrie.

6.5.2 The River Earn flows from Loch Earn west of Comrie and flows for approximately 74km before discharging into the River Tay south-east of Perth (the catchment area at Comrie is approximately 183km^2). There are two monitored reaches of the River Earn within the study area:

- Loch Earn to Water of Ruchill confluence (SEPA ID: 6839) – approximately 10.9km in length. This reach is designated as a heavily modified waterbody due to physical alterations relating to water storage (hydroelectricity generation).
- Water of Ruchill to Ruthven Water confluence (SEPA ID: 6838) – this is a natural reach of the watercourse and is approximately 28.7km in length.

6.5.3 The Water of Ruchill (SEPA ID: 6817) drains the hills surrounding Glen Artney to the south of Comrie, with a total catchment area of approximately 103km^2 and is approximately 10.7km in length to its confluence with the River Earn. This watercourse is characterised by steep gradients with a rapid rainfall response.

6.5.4 The River Lednock (also recorded by SEPA as Lednock Burn) (SEPA ID: 6815) is the smallest of the three watercourses and has a total length of 17.3km (approximate total catchment area of 62km^2). It is designated as a heavily modified waterbody due to physical alterations relating to water storage (hydroelectricity generation). The upstream catchment is controlled by the Glen Lednock Dam which forms part of the Breadalbane Hydroelectric Power Scheme.

6.5.5 The watercourses are used for recreational activities including fishing by Comrie and Crieff Angling Clubs (species include Atlantic salmon and sea trout) and there is anecdotal evidence of canoeing activities.

Hydrology and Flood Risk

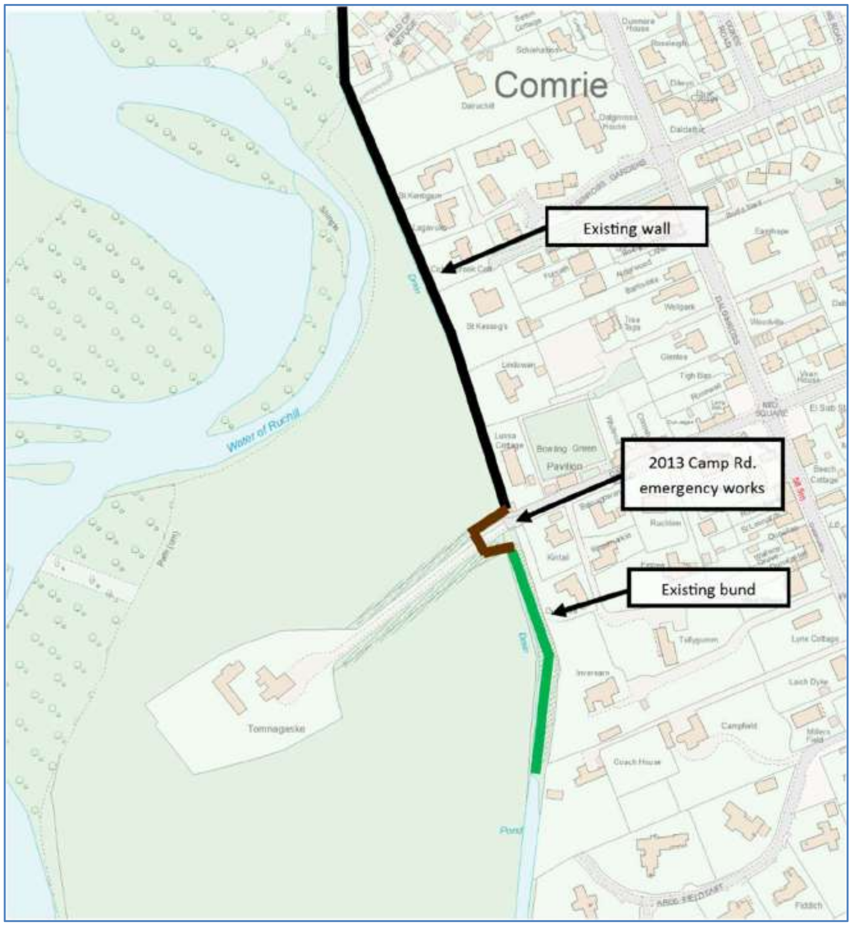
6.5.6 Comrie is particularly susceptible to flooding because of its location on the confluence of three watercourses. At this point the watercourse gradients begin to reduce, and the topography starts to open to wider flatter ground, which also contributes to flooding. During extreme flood events, flood waters flow overland through Comrie and Dalginross and re-enter the River Earn just downstream (east) of the town.

6.5.7 SEPA's Flood Risk Management Maps indicate there is a high likelihood of fluvial flooding (10% AEP, 1:10 year event) in areas of the town near to the River Earn downstream of the Dalginross Bridge. The mapping also suggests a medium likelihood of fluvial flooding (0.5% AEP, 1:200 year event) would result in significant inundation of Dalginross.

6.5.8 The town has been subject to repeated flooding in the past. The most recent flood events occurred in January 1993, February 1997, December 2006, August 2012 and November 2012. The latter of the 2012 events was significant and impacted approximately 150 properties within Dalginross. **Photograph 6-1** shows the severity of the flooding during the August 2012 event at Barrack Road in Dalginross.

Photograph 6-1: Flooding at Barrack Road (Dalginross), August 2012

6.5.9 Following the two major events in 2012, a flood defence in the form of a raised hump situated between Camp Road and the Tomnagaske Estate driveway was constructed in 2013. This is shown in **Schematic 6-1**, with the existing flood defence features. This was intended to be a temporary solution until a full flood protection scheme could be constructed. Recent assessment of this defence has found that, assuming a modest freeboard allowance, it provides a 1% AEP (1:100 year event) standard of protection to land in the west of Dalginross.



Schematic 6-1: Existing flood defence features in west Dalginross with the Camp Road/ Tomnagaske Estate emergency works constructed following the floods in 2012

6.5.10 Results from the baseline modelling show parts of the town near Tay Avenue to be at risk of flooding from the 10% AEP event. Moving through the return periods of decreasing statistical frequency, inundation extents increase through Dalginross from Tay Avenue; and out-of-bank flow occurs to the north of the River Earn near Ancaster Lane and also at the Comrie Holiday Park. At the 0.5% AEP event, the 2013 flood defence is bypassed but this does not begin to inundate any receptors until the 0.5% AEP (plus 20% climate change) event. The modelled baseline flood extent at the 0.5% AEP (1:200 year) event is shown on **Figure 6.2a**.

6.5.11 Due to the large number of properties (i.e. more than 100) within the study area subject to flood risk due to the interaction of the three watercourses, the area is assigned 'Very High' sensitivity to flood risk. These areas are situated within Comrie and Dalginross bounded to the north by the A85 and to the south by South Crieff Road.

6.5.12 Outside the study area, land is characterised by pastoral agricultural fields with few, sparsely distributed residential/non-residential receptors (i.e. 10 or less) as well as large areas with no properties. Therefore, these areas are considered to have a 'Medium' or 'Low' sensitivity to flood risk.

Fluvial Geomorphology

River Earn

6.5.13 The River Earn is split into two morphologically-distinct reaches (**Figure 6.1**):

- Reach 1, extending from the upstream boundary at Tullybannocher (approximate NGR NN 7567 2187) to the confluence with the Water of Ruchill; and
- Reach 2, extending for the Water of Ruchill confluence to the downstream boundary at A & B Gairns Contractors (approximate NGR NN 7847 2211).

6.5.14 Reach 1 (**Photograph 6-2**), the upper reach of the River Earn is a moderate to low gradient channel which flows through a moderately confined valley with a limited floodplain. The typology of the channel alternates between pool-riffle and plane bed. Glides and runs were identified within the channel with a small number of pools and poorly defined riffles.

6.5.15 This reach of the River Earn is monitored by SEPA. The most recently determined 2017 WFD morphology status of the reach was classified as 'Good'. Despite the 'good' status, there are several morphological pressures on the channel, including a stone weir in the upstream section of the reach. There are also several sections of piled stones, embankments and flood walls along the banks, particularly in the downstream section of the reach. These confine the watercourse within its current alignment and are causing incision, as evidenced by intermittent bedrock outcrops in the base of the channel.

Photograph 6-2: Upstream reach of the River Earn (Reach 1)

6.5.16 Reach 2 (**Photograph 6-3**), the lower reach of the River Earn, is a low gradient channel set within a wide valley and alluvial floodplain. The reach is predominantly slow glide, with reduced complexity of bedforms throughout this section of the channel. The WFD morphology status of the reach was classified as ‘Good’ in 2017.

6.5.17 Historic OS maps of the River Earn show large alluvial bar features in a wider channel in the upper part of the reach, near the confluence with the Water of Ruchill. However, currently there is very limited sediment storage in this part of the reach. This may be a result of recent and historic works on the Water of Ruchill, which have resulted in significant deposition and reduced capacity to transport material out of the tributary. Bar formations are more common in the downstream section of the reach where the channel is slightly more sinuous.

6.5.18 The banks are mainly stable throughout the reach with continuous coverage of mature trees and shrubs. There are only two instances of moderate bank erosion on the left bank; one at Comrie Holiday Park and the other downstream of Comrie, close to Invermilton Farm.

6.5.19 The River Earn displays some geomorphic features but has some modifications which are confining the channel and altering the natural processes. Overall, the River Earn has been assigned a ‘High’ sensitivity to modification from a geomorphology perspective.

Photograph 6-3: Downstream reach of the River Earn (Reach 2)

Water of Ruchill

6.5.20 The Water of Ruchill is a dynamic gravel-bed river, with a steep upland catchment. Evidence of high rates of geomorphic activity are visible on the downstream reach of the Water of Ruchill, close to the confluence with the River Earn. Extensive gravel bars display high rates of deposition and stretches of severe erosion were observed. Although these geomorphic processes are natural, the rate at which they are occurring has greatly increased in recent years.

6.5.21 These high rates of geomorphic activity are likely a result of the long history of land and watercourse management activities which have put pressure on the channel and altered the sediment transport and regime characteristics of the channel to be out of equilibrium. These are detailed in the Fluvial Audit Report (**Appendix 6.2**), but the main factors potentially contributing to this are:

- peat drainage in the upper catchment;
- channel straightening prior to 1862;
- channel dredging in 1997; and
- subsequent installation of bank protection.

6.5.22 The Water of Ruchill can be split into two morphologically-distinct reaches (**Figure 6.1**):

- Reach 3 extends from Cultybraggan Camp (approximate NGR NN 7674 1966), to Ruchilside (approximate NGR NN 7697 2086); and
- Reach 4 extends from Ruchilside to the confluence with the River Earn.

6.5.23 Reach 3 (**Photograph 6-4**), the upper reach of the Water of Ruchill comprises a moderate gradient channel, which appears to have maintained its unnaturally straight form. The watercourse has tree-lined banks and sits within a wide alluvial valley.

6.5.24 The channel typology is mainly cascade or bedrock in the upstream section of the reach, whereas downstream the channel transitions to a plane bed typology. Closer to Ruchilside the morphology is less diverse and alternating glide and run units dominate this section.

6.5.25 The upper reach exhibits localised areas of both erosion and deposition, except for an area of significant erosion on the left bank. In the downstream section of the reach towards Ruchilside, where there is a lack of tree cover on the left bank, there has been some bank protection installed in this area, but it does not cover the extent of the erosion. For the most part, continuous tree cover of the banks has provided stability to the channel and prevented it from returning to its naturally wandering state.

Photograph 6-4: Upstream reach of the Water of Ruchill (Reach 3)

6.5.26 Reach 4 (**Photograph 6-5**), the lower reach of the Water of Ruchill, exhibits a moderate to low gradient channel situated in a wide alluvial valley and floodplain. This reach displays evidence of returning to its naturally wandering state potentially due to the lack of mature trees stabilising the banks[21]. The watercourse has a multi-thread channel throughout the reach, with some old channels significantly aggraded with coarse gravel and cobble deposits, and other channels which are wetted.

6.5.27 The channel has a pool-riffle typology throughout the extent of the reach. The reach displays evidence of active sediment recruitment, transfer and storage processes which contribute to channel evolution and lateral migration. The lower reach of the Water of Ruchill is a significant zone of sediment storage with extensive alternating bar forms and flood deposits. There are also multiple cases of severe bank erosion along the reach, as well as erosion of previously dredged gravel heaps. Recruitment of large woody debris is evident throughout the dynamic section of the reach.

6.5.28 Gravel extraction and the heaping of gravel material along the banks are putting significant morphological pressure on the channel. Other morphological pressures include extensive lengths of hard (rip-rap) bank protection, which have been installed on the right bank in the upper section of the reach, as well as a series of J-vanes which extend into the channel, aimed at deflecting flow towards the centre of the channel to decrease the potential for future erosion of the right bank.

6.5.29 There is an additional area of rip-rap on the right bank at the outer meander bend further downstream. The channel has become over-widened in the downstream section of the reach, encouraging further sediment build-up and shallowing of the channel. In addition, a flood wall is located on the floodplain set-back from the right bank, protecting local housing.

6.5.30 The Water of Ruchill is monitored by SEPA; the WFD morphology status of the reach was classified as ‘Good’ in 2017. However, the RBMP assessment identified that the Water of Ruchill has the potential to be downgraded to ‘moderate’ status, because it only has 4% ‘capacity remaining’ due to existing modifications.

6.5.31 The Water of Ruchill is a very dynamic watercourse which displays a range of fluvial processes and exhibits a range of geomorphological features. Although it has been historically straightened, it is returning to its naturally wandering state, indicated by significant bank erosion. Overall, the Water of Ruchill has been assigned a ‘High’ sensitivity to modification from a geomorphology perspective.

[21] Hey (1999) Water of Ruchill, Comrie: Sustainable River Management

Photograph 6-5: Downstream reach of the Water of Ruchill (Fluvial audit undertaken in January 2019) (Reach 4)

River Lednock

6.5.32 The River Lednock (**Photograph 6-6**) has a moderate to steep gradient channel, sitting within a narrow valley. The upper part of the channel is straight and steep, and is bedrock dominated. Downstream the valley width increases, with river terrace deposits around its confluence with the River Earn.

6.5.33 The typology of the River Lednock alternates between step-pool and cascade in the steep upper part of the channel, and transitions to plane bed and pool-riffle further downstream.

6.5.34 The reach is dominated by sediment transport processes. Along the lower part of the channel, the banks are protected by continuous mature vegetation, which acts to stabilise the banks. As a result, only minor bank erosion was observed along the reach.

6.5.35 The River Lednock channel appears to have undergone historic narrowing and straightening towards the downstream extent of the reach at the confluence with the River Earn. Other morphological pressures observed on the lower part of the channel were two bridges with abutments (footbridge and road bridge). In addition to this, a concrete weir from a former mill was situated on a bedrock outcrop at the upstream extent of the reach, and multiple cases of bank protection (piled stone and intact stone wall) were observed throughout the reach.

6.5.36 The River Lednock is monitored by SEPA with the most recently determined WFD morphology status of 'High' in 2017. However, the RBMP assessment identified that the River Lednock has the potential to be downgraded from High to Good status with only 1% ‘capacity remaining’.

6.5.37 The River Lednock displays good diversity of channel morphology, however due to modifications adding morphological pressures to the channel, it has been assigned a ‘High’ sensitivity to modifications from a geomorphology perspective.

Photograph 6-6: River Lednock in vicinity of the cycle path crossing (approximate NGR NN 776 223)

Water Quality

River Earn

6.5.38 As stated above, the upstream reach of the River Earn (Loch Earn to Water of Ruchill confluence) is classified as heavily modified on account of flow regulation, abstraction and impoundment (in upstream Loch Earn) for the purposes of hydroelectricity generation. SEPA classified the overall status of this reach as ‘Moderate Ecological Potential’ in 2017. The ‘physico-chemical’ status of this reach was classified as ‘High’ and ‘specific pollutants’ status of ‘Pass’ in 2017.

6.5.39 SEPA classified the downstream reach of the River Earn (Water of Ruchill to Ruthven Water confluences) with an overall status of ‘Moderate’ in 2017. The ‘physico-chemical’ status of this reach was classified as ‘High’ and ‘specific pollutants’ recorded as ‘Pass’ in 2017. In accordance with this, chemistry sampling data collected from the River Earn showed that concentrations of detected metals and polycyclic aromatic hydrocarbon (PAHs) generally all fell within Environmental Quality Standard (EQS) thresholds for freshwaters, with the exception of dissolved copper which was slightly elevated. This dissolved metal may have originated from a number of upstream sources as it is commonly used in industry and present in routine runoff from road surfaces.

6.5.40 In both reaches existing pressures include the presence of alien species (North American signal crayfish), which contribute to the ‘Moderate’ status. The River Earn is designated salmonid waters under the WFD.

6.5.41 A number of protected species are known to be present in the Earn including Atlantic salmon, brown/sea trout, European eel and lamprey species (refer to **Chapter 8: Ecology and Nature Conservation** for more information).

6.5.42 There are several licensed discharges to the River Earn including from the Comrie Holiday Park within the study area. The River Earn is a medium sized watercourse, with a low flow value (Q95) of approximately 1.3m^3/s (upstream of the Scheme), and therefore is considered to have a relatively good capacity to dilute pollutants.

6.5.43 The main risk of known contamination in the study area is the former gas works, which is located immediately upstream of the Earn-Lednock confluence (approximate NGR NN 776 220). Elevated concentrations of metals and other hazardous chemicals may be present within the soil and through construction a pathway could be created to the river. Further information on contaminated land and how this potential impact/risk is going to be managed is provided in **Chapter 7: Hydrogeology and Contamination**.

6.5.44 Overall, the River Earn has been assigned ‘High’ sensitivity for water quality on account of its High physico-chemical status and chemistry sampling data, salmonid waters designation and it supports European protected species.

Water of Ruchill

6.5.45 SEPA classified the Water of Ruchill as overall ‘Good’ status in 2017 and no existing pressures are recorded on the watercourse. The Water of Ruchill is designated salmonid waters under the WFD. The ‘physico-chemical’ status is ‘Good’ with a status of ‘Pass’ recorded for ‘specific pollutants. Chemistry sampling data in the Ruchill collected upstream and downstream of the study area showed that for a range of metals and PAHs, concentrations all fell within published EQS for freshwaters.

6.5.46 A number of protected species are known to be present in the Water of Ruchill including Atlantic salmon, brown trout and European eel populations (refer to **Chapter 8: Ecology and Nature Conservation** for more information).

6.5.47 The Ruchill is a medium sized watercourse, with a low flow value (Q95) of approximately 0.4m^3/s (upstream of the Scheme), and therefore may have a moderate capacity to dilute pollutants.

6.5.48 Overall, the Water of Ruchill has been assigned 'High' sensitivity for water quality on account of its High physico-chemical status and no recorded pressures, chemistry sampling data, its salmonid waters designation and it supports a number of European protected species.

River Lednock

6.5.49 SEPA classified the River Lednock in 2017 as being a heavily modified waterbody with an overall status of 'Moderate Ecological Potential' due to the Glen Lednock Dam on the Loch Lednock Reservoir. The pressure of this upstream abstraction and flow regulation for the purposes of renewable electricity generation contributes to this WFD status. The River Lednock is designated salmonid waters under the WFD.

6.5.50 There was no other WFD information on water quality available from SEPA online sources. Chemistry sampling data collected from the River Lednock showed that for a range of metals and PAHs, concentrations generally all fell within published EQS for freshwaters with the exception of dissolved copper which was slightly elevated. Again, this dissolved metal may have originated from a number of upstream sources including routine runoff.

6.5.51 The River Lednock is a small watercourse and may have limited capacity to dilute pollutants.

6.5.52 Despite the heavily modified waterbody status, the River Lednock has been assigned 'High' sensitivity for water quality due to being a tributary of the River Earn, high quality chemistry sampling data and its designated salmonid waters status.

6.6 Potential Effects

Construction Effects

6.6.1 The construction phase is generally when there is most activity on site and therefore poses the greatest risk of adverse impacts to the water environment and associated groundwaters and aquatic ecology.

Hydrology and Flood Risk

6.6.2 There is potential for construction activity, or a partially constructed scheme, to impact on the level of flood risk to sensitive receptors. The potential risks associated with construction sequencing is presented below.

6.6.3 Firstly, to the south of the River Earn no additional flood risk occurs if the defences were to be constructed in a clockwise direction starting in the south-west of Dalginross at Aros Field road. However, if the defence construction sequence occurred in an anti-clockwise direction (starting in the north-east of Dalginross near Tay Avenue), this would exacerbate the flood inundation extents of a flood occurring before the Scheme is completed, potentially as frequently as the 50% AEP (1:2 year return period) flood event. This would happen because the construction process would cut off the east-flowing flood recession route, creating a physical barrier resulting in pooling throughout a wide area of Dalginross.

6.6.4 Similarly, at locations where flood walls/embankments are proposed along both sides of the River Earn, construction sequencing could also have an impact. This is because a completed defence on one bank can deflect water during flood conditions onto the opposite (incomplete) side of the river which would in turn exacerbate the inundation extents compared to the baseline.

6.6.5 The potential locations of satellite construction compounds are situated in flood risk areas and therefore could be at risk of flooding. Unsecured materials and plant could exacerbate flood risk by causing flow restrictions if washed into the channel or if situated on the floodplain.

6.6.6 Within the Scheme extents, the potential impact should appropriate sequencing not be adopted is predicted to be of major adverse magnitude in areas of very high sensitivity and therefore a Very Large significance of impact on flood risk overall during construction. This is, however, dependent on construction sequencing and that will form part of the mitigation and a requirement upon the future contractor.

6.6.7 There is predicted to be no change in flood risk during the construction phase in areas out with the Scheme extents. This results in an impact magnitude of negligible and a Neutral significance on flood risk in these areas.

Fluvial Geomorphology

6.6.8 Potential effects related to the geomorphology of watercourses during the construction phase of the Scheme include:

- disturbance/damage to existing watercourse banks and bed;
- disruption/change to natural flow patterns and velocities; and
- increase in sediment supply to watercourses.

6.6.9 Each of these potential effects is considered below.

Disturbance and damage to existing river banks

6.6.10 There is potential for adverse effects to occur in areas where flood defences are constructed close to the banks and where installation of bank protection is proposed.

6.6.11 Scour protection is proposed to be installed on the right bank of the River Earn at Strowan Road, and on the right bank of the Water of Ruchill at the Field of Refuge.

6.6.12 On the River Earn, hard bank protection in the form of a block stone wall will be installed on the right bank at Strowan Road. In addition, construction of the proposed flood wall will occur close to the top of bank in this location. This will result in high potential for disturbance of the existing bank profile, along an approximately 120m stretch of bank. The bank is very steep in this location so there is potential for bank collapse/slope failure when construction is undertaken. This would result in both disturbance of the existing bank profiles and release of fine sediment into the watercourse. Disturbance of the existing river banks is predicted to have an impact of moderate adverse magnitude on the River Earn, resulting in an impact of Moderate significance.

6.6.13 On the Water of Ruchill, removal of the existing rip-rap and installation of the new root wad revetment on the outer meander bend (right bank) at the Field of Refuge has high potential to result in positive changes to the existing bank profiles over an approximately 250m stretch of the right bank. The existing rip-rap is a morphological pressure on the channel, extending into the channel and resulting in increased rates of bank erosion immediately downstream. Therefore, the impact associated with its removal is predicted to be beneficial as it will remove this existing pressure. On the River Lednock, construction of the proposed flood defences will occur close to the top of bank on both sides of the watercourse, upstream of the A85 Drummond Street (A85) road bridge. Disturbance of the existing river banks on the River Lednock is predicted to have an impact of minor adverse magnitude resulting in an impact of Slight significance.

Disturbance or damage to existing river bed/Change to natural flow patterns and velocities

6.6.14 There is potential for adverse effects to occur to the river bed in areas where in-channel construction is required. At this stage, in-channel construction is anticipated to be required on the River Earn to install bank protection on the right side of the channel between Dalginross Bridge and Lochay Drive, and on the Water of Ruchill to install bank protection on the meander bend at the Field of Refuge. There is no in-channel construction anticipated on the River Lednock at this stage.

6.6.15 In-channel construction has the potential to result in increased basal scour in the channel due to disturbance or removal of the armour layer. Disturbance of the existing river bed is predicted to have an impact of moderate adverse magnitude, resulting in an impact of moderate significance on the River Earn and the Water of Ruchill.

6.6.16 In-channel construction is likely to require one or a mixture of temporary sheet piles, in-channel platforms and/or a temporary frame dam, which will be required to create a ‘dry’ working area for construction. These options would result in temporary narrowing of the channel, which could result in changes to existing flow patterns and velocities, leading to changes in the existing sediment transport patterns in the River Earn and Water of Ruchill.

6.6.17 However, in-channel construction will be temporary and will occur in stages during months when high flow conditions are less likely to occur. Therefore, it is predicted that the impact of changes in flow patterns and velocities due to in-channel construction are likely to be of minor magnitude and Slight significance on the River Earn and the Water of Ruchill.

Increase in sediment supply to watercourses

6.6.18 Construction activities occurring close to the river banks and removal of bankside vegetation are likely to result in increased volumes of sediment entering the watercourses. Settling of fine-grained sediment in the channel can result in a loss of morphological diversity on the river bed, as features such as pools can be filled in by the accumulating sediment.

6.6.19 The effects of increased sediment supply are likely to be temporary due to the fast-flowing nature of the watercourses within the study area. This is predicted to result in an impact of moderate magnitude and Moderate significance on the watercourses.

Water Quality

6.6.20 Construction activities have the potential to cause pollution and have adverse effects on watercourses, groundwater and aquatic ecology. These could include:

- site clearance and ground preparation works, including soil stripping, tree removal and stockpiling of soils and materials, which could also result in disturbance/mobilisation of contaminated soils;
- bankside works in the vicinity of watercourses including construction of flood defence walls and earthwork embankments, as well as preparation of haul roads and site compounds;
- potentially polluting activities including vehicle washing, cement mixing, re-fuelling and oil/fuels storage, and operation of staff welfare facilities;
- the movement of construction vehicles and transport of potentially polluting materials around the site; and
- in-channel works associated with construction of bank erosion protection measures.

6.6.21 Site clearance, soil stripping and tree removal activities near the bank edge could result in increased silt-laden runoff to watercourses and increased volumes of suspended sediment in the channel, affecting the chemical and ecological quality of the watercourses. Preparation of site compounds and any haul roads during the construction phase would also increase the risk of uncontrolled silt-laden runoff entering nearby watercourses. This sediment could settle on the bed smothering aquatic habitats.

6.6.22 These works could also result in disturbance/mobilisation of contaminated soils (particularly at the former gas works), which could temporarily affect the quality of watercourses and groundwaters. Further information on risks of contamination is provided in **Chapter 7**: **Hydrogeology and Contamination**.

6.6.23 An increased risk of silt-laden and contaminated runoff is predicted to result in an impact of moderate magnitude and Moderate significance on the water quality of all three watercourses.

6.6.24 Runoff from site compounds may also contain pollutants and spillages of hydrocarbons, chemicals, fuel, oils and unset cement which can be toxic to aquatic species and affect the quality of watercourses and groundwaters. Accidental leaks/spillages from mobile/stationary plant and storage tanks, as well as spillages during transportation of hazardous substances around site, could potentially enter watercourses and cause acute pollution incidents. The risk of pollution incidents in the River Earn will be highest during in-channel construction works required for installation of erosion protection measures. Potential effects of construction works on aquatic species is detailed in **Chapter 8**: **Ecology and Nature Conservation**.

6.6.25 Uncontrolled release or plant/vehicle washings and concrete spills are highly alkaline and if they enter watercourses or groundwater, could have a localised adverse effect on aquatic species by raising the water pH. Accidental/ uncontrolled release of sewage from on-site welfare facilities could also pollute watercourses and groundwater.

6.6.26 An increased risk of pollutants and accidental spillages is predicted to result in an impact of moderate magnitude and Moderate significance on water quality of the Water of Ruchill and River Lednock. Due to the heightened risk of pollution events associated with in-channel works in the River Earn, an impact of moderate magnitude and Large significance on the water quality of the Earn is predicted.

Operational Effects

Hydrology and Flood Risk

6.6.27 Hydraulic modelling of the Scheme has shown a positive impact on flood risk throughout the study area. This is demonstrated through the predicted widespread reduction of receptors subject to flooding at all return period events (from the 50% AEP to the 0.1% AEP event), as shown in **Table 6.6**. Refer to **Figure 6.2a and b** for a comparison of the modelled flood extents in the baseline (pre-development) and post-development scenarios. In terms of this assessment, the impact is therefore predicted to be of Very Large Beneficial significance on residential/non-residential receptors within the study area. For the 1% AEP (and less frequent) flood events, some individual properties are still subject to flood risk out with the Scheme study area (no worse than the existing scenario) and these properties are subject to ongoing discussions with the Council.

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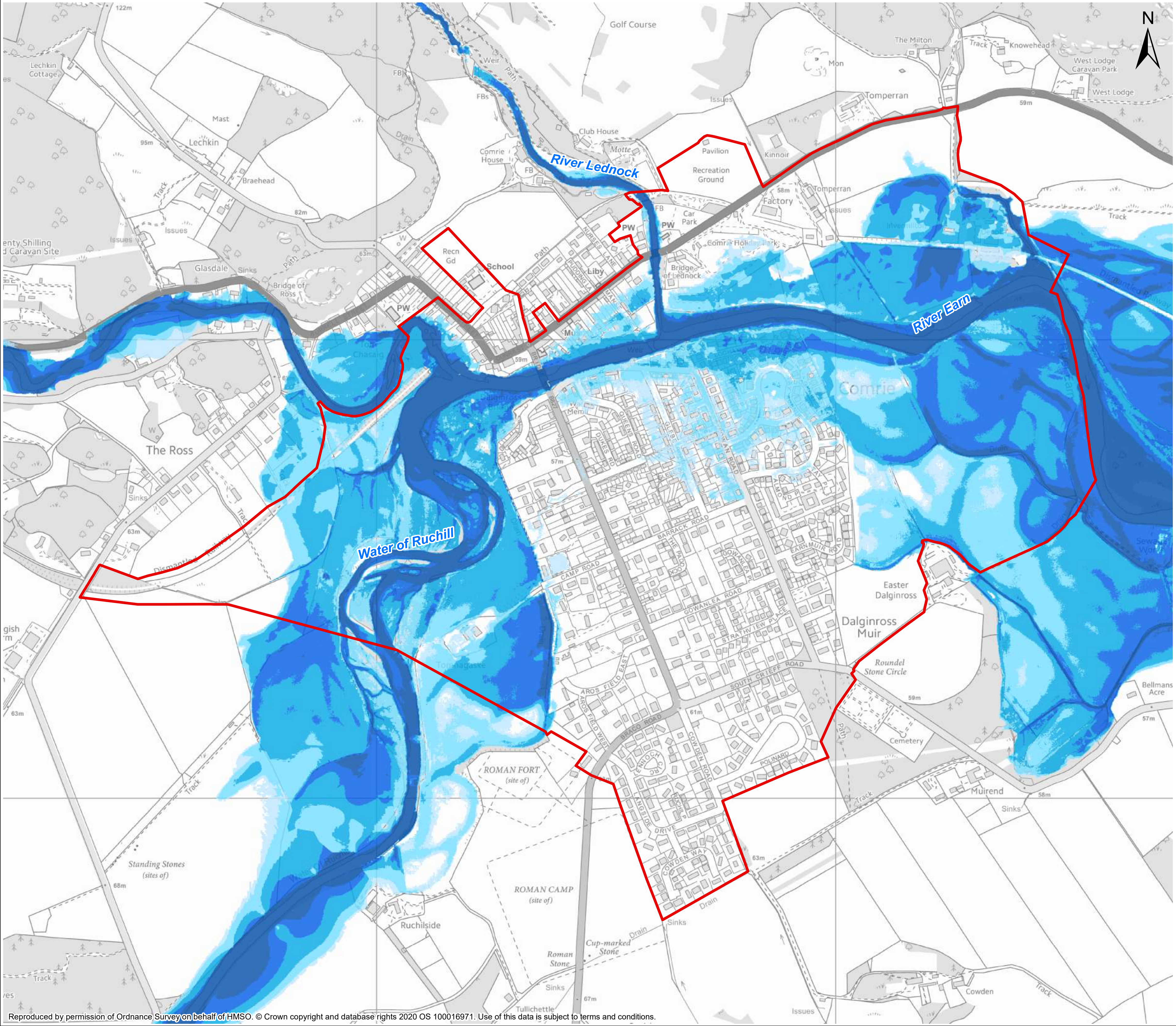

Legend

EIA Study Area

Run 1-2 (1:200 Year)

Depth (m)

- 0 - 0.15
- 0.15 - 0.5
- 0.5 - 1
- 1 - 1.5
- >1.5

0 200 400 Metres

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Rev.	Rev. Date	Drawing Suitability	Drawn	Appr'd

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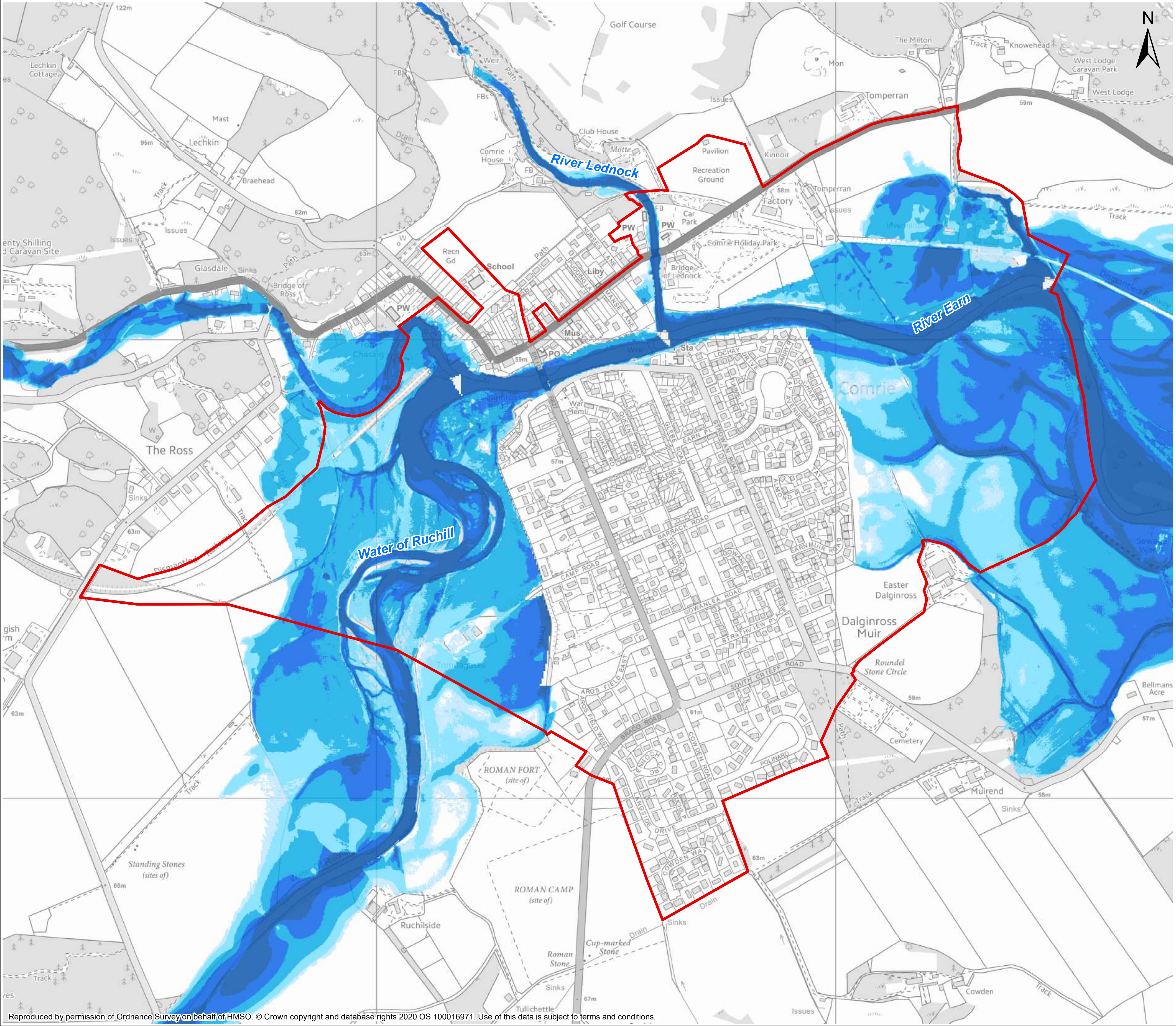
Project

Comrie Flood Protection Scheme 2020

Drawing Title

Figure 6.2a - Modelled 1:200 Year Baseline Flood Extent

Scale @ A3	1:8,000
Project No.	119702



Legend

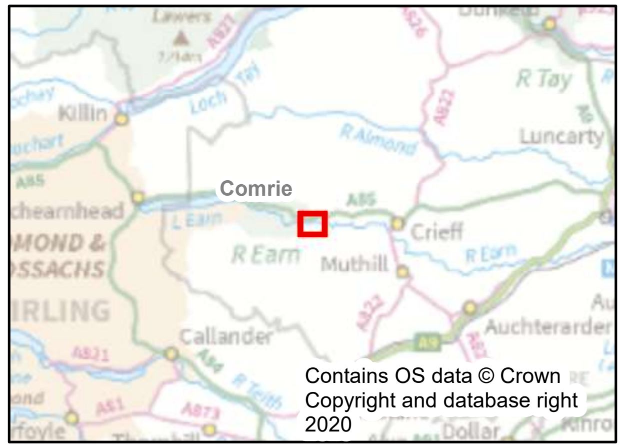
- EIA Study Area

Run 2-2 (1:200 Year)

Depth (m)

- 0 - 0.15
- 0.15 - 0.5
- 0.5 - 1
- 1 - 1.5
- >1.5

0 200 400 Metres



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Project

Comrie Flood Protection Scheme 2020

Drawing Title

Figure 6.2b - Modelled 1:200 Year Defended Flood Extent

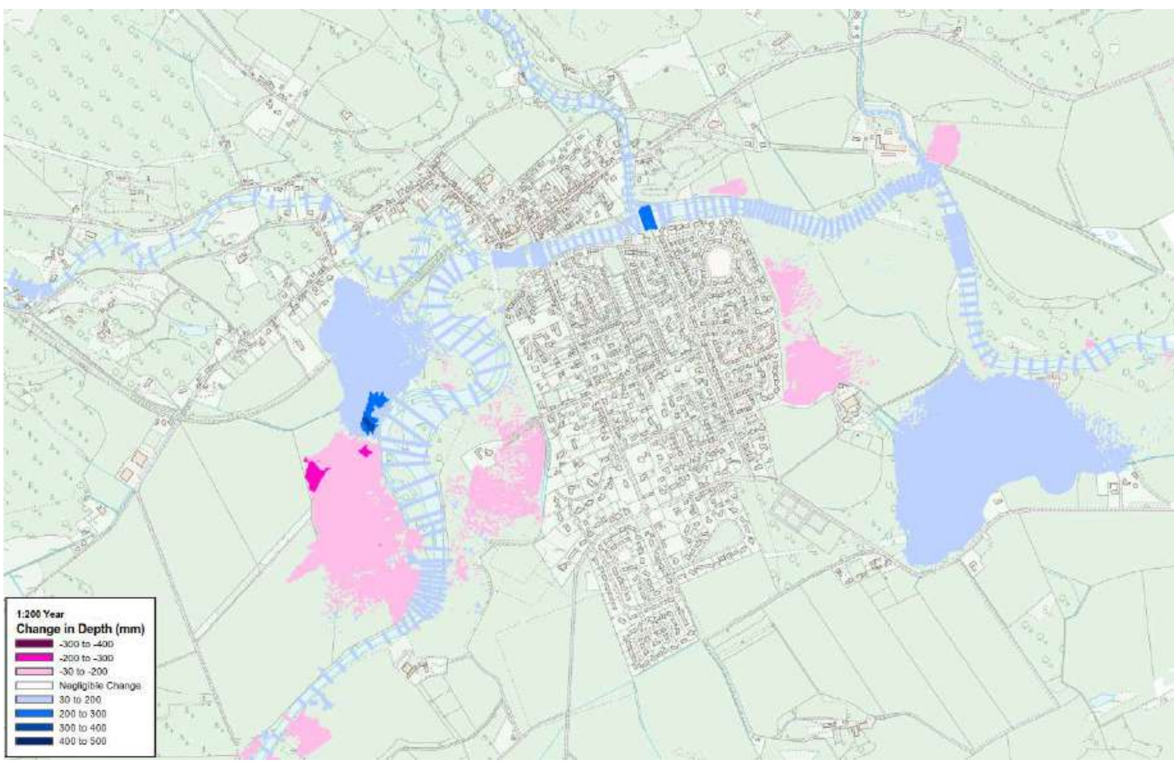
Scale @ A3	1:8,000
Project No.	119702

Table 6.6: Predicted changes in flooded receptors with completed Scheme compared to baseline

Return Period (%AEP, 1:X)	Number of receptors flooded (baseline)	Number of receptors flooded (with Scheme)
50% AEP (1:2 year)	1	0
20% AEP (1:5 year)	5	0
3.3% AEP (1:30 year)	56	0
1% AEP (1:100 year)	117	1
0.5% AEP (1:200 year)	193	4
0.1% AEP (1:1000 year)	421	50

6.6.28 The Scheme removes the existing overland flow route through the town, and instead, the same volume of water reaches the downstream reach of the River Earn via the river channel. Timings on when the flow reaches certain downstream locations may change as a result of this.

6.6.29 Analysis of the hydraulic modelling outputs has shown an impact at locations resulting from the change in flow regime post-development. Increase in flood depth of up to 200mm is predicted on parcels of land out with the study area which do not contain any residential or non-residential receptors (i.e. low sensitivity), as shown on **Schematic 6-2**. This results in an impact of moderate magnitude and therefore Slight significance due to flood risk.



Schematic 6-2: Predicted change in water depth at 0.5% AEP (1:200 year return period) flood event with Scheme (red indicates decrease and blue indicates increase in flood depth)

6.6.30 Secondary (surface water) flooding impacts have been predicted by the hydraulic model at three properties. These properties were at risk of river (fluvial) flooding in the baseline scenario and will be protected from this type of flooding by the Scheme. However, the presence of flood defences makes it more difficult for surface water to drain from the area and therefore the three properties identified are subject to increased risk of surface water (pluvial) flooding during Scheme operation. Increases in flood depth of up to 102mm is predicted at these receptors in comparison with the baseline scenario. Secondary flooding represents an impact of minor magnitude (in a medium sensitivity floodplain) therefore resulting in an impact of Slight significance.

Fluvial Geomorphology

6.6.31 During operation, there could be disruption/change to natural flow patterns and velocities. Along the River Earn and River Lednock where the new flood walls are located close to the top of both banks, flow will be confined during extreme flood events resulting in higher velocities. These high velocities may result in increased rates of erosion and bedload transport in the watercourses through Comrie. There is not predicted to be a disruption/change to natural flow patterns and velocities on the Water of Ruchill since the proposed flood defences are set further back from the banks and are only located on one side of the channel.

6.6.32 The magnitude of potential impact of changes to flow and velocity on the River Earn and River Lednock (classified as high sensitivity) is predicted to be minor adverse, resulting in an impact of Moderate significance.

6.6.33 The construction of the flood defences on the floodplain, and the scour protection measures on the river banks, will add additional morphological pressure to the river channels. As discussed above, the RBMP assessment identified that the Water of Ruchill has the potential to be downgraded to ‘moderate’ from ‘good’ status, with only 4% ‘capacity remaining’ due to existing modifications. The Water of Ruchill Fluvial Audit report (**Appendix 6.2**) provides further information on the morphological pressures and sediment supply in the Water of Ruchill catchment. It also makes short-term and longer-term recommendations for managing sediment supply issues on the Water of Ruchill.

6.6.34 As the Water of Ruchill is so close to the threshold of being downgraded, the addition of morphological pressures (classified as high sensitivity) is predicted to result in an impact of moderate magnitude and Moderate significance (this also takes into consideration the positive effect of replacing the existing rip-rap with the new root wad revetment on the outer meander bend at the Field of Refuge).

Water Quality

6.6.35 There may be a risk of scour of the erosion protection measures and flood walls near the bank edge introducing sediment to the watercourses. However, this risk is considered to be very localised and therefore the impact on the watercourses (classified as high sensitivity) is predicted to be of negligible magnitude and Neutral significance.

6.6.36 The risk of pollutants entering the watercourses from maintenance vehicles undertaking routine inspections of the flood defence measures is also considered to be very low. The impact is therefore predicted to be of negligible magnitude and Neutral significance.

6.6.37 Potential risk of contamination of groundwaters from imported fill materials and longer-term mobilisation of existing contamination (such as through deep excavations or dewatering of excavations) is considered in **Chapter 7: Hydrogeology and Contamination**.

6.7 Mitigation Measures

6.7.1 The following mitigation measures are required to avoid, reduce or offset any significant predicted effects identified in **Section 6.6**. These are split into embedded mitigation (i.e. included in the Scheme design), and mitigation during construction and operational phases of the Scheme. Mitigation to protect the water quality of surface waters will also protect aquatic ecology and underlying groundwaters.

Embedded Mitigation

6.7.2 The Scheme comprises flood walls, earthwork embankments and erosion protection measures along the three watercourses. The walls and embankments have been set-back from the watercourses where possible and scour protection is installed in areas where the flood defences are located close to the banks and/or where higher rates of erosion are predicted to occur as a result of the new flood defences. A detailed description of these flood protection measures is provided in **Chapter 3**: **Scheme Description and Alternatives**.

Construction Mitigation

6.7.3 In order to avoid exacerbating flood risk throughout Dalginross during the construction phase, the Contractor will be required to carefully consider the construction sequence in the construction programme, including any seasonal ecological constraints. There will be least effect on temporary flooding if the flood defences are constructed in a clockwise direction starting in the south-west of Dalginross at Aros Field road.

6.7.4 Where flood walls/embankments are to be constructed on both sides of the River Earn, construction on both banks in tandem would mitigate the risk of any flows deflecting onto the opposite bank. If this is not possible, the northern defences should be constructed first (as properties on the southern bank of the River Earn are at a slightly higher elevation and therefore are at less risk of flooding).

6.7.5 Property-level protection (PLP) for properties identified to be at risk from secondary flooding will be constructed in advance of the Scheme defence works to ensure site-specific flooding impacts are avoided. The design and form of the PLP is yet to be determined and will be agreed with the property owners and the Council.

6.7.6 SEPA flood warnings in the local area will be reviewed on a daily basis by the Environmental Manager (or equivalent). Appropriate action will be taken in the event of predicted heavy rainfall to protect unsecured materials/plant and items located in site compounds to prevent their movement or release. Plant and materials will be stored in safe areas out with the floodplain where practicable.

6.7.7 Prior to construction, the Contractor will be required to prepare a Construction Environmental Management Plan (CEMP), building on the information laid out in the EIAR and Outline CEMP, describing methods and techniques that will be employed during construction to ensure compliance with legislation, good practice and legally-binding mitigation measures identified in the EIA. The Contractor's CEMP will need to be approved by SEPA prior to construction. The CEMP will include a Pollution Incident Plan (or equivalent) to describe the measures to minimise the risk of a serious pollution incident and actions to take in the event of a spillage during construction, taking cognisance of SEPA's Guidance for Pollution Prevention (GPP) 21: Pollution incident response planning and GPP22: Dealing with spills. Emergency spill kits will be available on site to deal with accidental spillages and leaks.

6.7.8 The Contractor will also prepare a Construction Method Statement(s) to plan and manage in-channel works and works on the bank, to be approved by SEPA prior to construction. An outline CMS has been prepared as part of the EIA and is provided in **Appendix 3.2.** This will include specific details of construction methods and measures to reduce potential risks of bank collapse/slope failure, sediment-release and pollution during installation of erosion protection measures in the watercourses. The Contractor will aim to limit the extent of river bed disturbance in the River Earn and Water of Ruchill by employing the most appropriate construction methods and techniques.

6.7.9 During site clearance works, bankside vegetation will be retained wherever possible to help bind the soil, and root wads will be kept within the bank to aid bank stability. The extent and duration of bare/exposed surfaces will be limited as much as possible, and restoration works as soon as possible following construction, to minimise risk of silt-laden runoff entering watercourses.

6.7.10 An Environmental/Ecological Clerk of Works (ECoW) will monitor construction works to ensure working methods and temporary mitigation measures are effectively protecting watercourses and aquatic species/habitats from sediment and pollutants, particularly in-channel works.

6.7.11 In-channel works will be avoided during November and May to avoid the sensitive spawning period for salmon. Refer to **Chapter 8: Ecology and Nature Conservation** for further information.

6.7.12 The Contractor will adhere to SEPA and CIRIA best practice guidance to manage and reduce the risk of water pollution and sediment release including SEPA's Pollution Prevention Guidelines (PPG)/Guidance for Pollution Prevention (GPP) series[22], SEPA's Engineering in the Water Environment Good Practice Guides[23] and CIRIA guidance[24].

6.7.13 The Contractor will implement sediment/pollution control measures to minimise the risk of silt-laden and polluted runoff entering watercourses. This may include silt/sediment traps and fences, temporary drainage provision and cut-off ditches around construction works, site compounds and soil/material stockpiles. The Contractor will also maintain robust surfacing of the site compounds to minimise the pooling of surface water.

6.7.14 The Contractor will need to apply to SEPA for a Construction Site Licence (with an accompanying Pollution Prevention Plan) under CAR to be authorised by SEPA prior to construction.

6.7.15 Potentially polluting activities such as refuelling, vehicle washing and stockpiling of soils/materials will be undertaken within site compounds, or controlled areas a safe distance from watercourses, and will be appropriately bunded/contained to prevent any uncontrolled runoff to watercourses. Where possible, plant and machinery will be stationed on hardstanding surfaces with spillage/drip trays used where required. Construction plant will be regularly checked for leakages and will undergo regular maintenance.

6.7.16 Pre-fabricated concrete units will be brought to site during construction rather than concrete being cast on site to reduce the risk of unset cement washing into watercourses, wherever possible.

6.7.17 Best practice measures associated with storage of oils and fuels will be followed in compliance with CAR and SEPA's GPP2: Above ground oil storage tanks. Oils will be stored within a leak-proof container and be contained within a secondary containment system with a capacity of 110% or more of the containers storage capacity, in line with CAR General Binding Rule (GBR) 28.

6.7.18 Sewage from site welfare facilities will be disposed of appropriately either to the foul sewer with the permission of Scottish Water, or in accordance with GPP4: Treatment and disposal of wastewater where there is no connection to the public foul sewer.

[22] PPGs are in the process of being replaced by the new GPP series. Relevant guidance includes: GPP2 (Above ground oil storage tanks); GPP4 (Treatment and disposal of wastewater); GPP5 (Works and maintenance in or near water); PPG6 (Working at construction and demolition sites); GPP8: Safe storage and disposal of used oils; GPP13 (Vehicle washing and cleaning); GPP21: Pollution incident response planning) and GPP22 (Dealing with spills).

[23] SEPA (2008) WAT-SG-23 Bank Protection Rivers and Lochs, 1st edition, April 2008. Accessed 04/03/2019 [https://www.sepa.org.uk/media/150971/wat_sg_23.pdf]; SEPA (2009) WAT-SG-29 Temporary Construction Methods, 1st edition, March 2009. Accessed 04/03/2019 [https://www.sepa.org.uk/media/150997/wat_sg_29.pdf].

[24] CIRIA (2001) Control of water pollution from construction sites – guidance for consultants and contractors (C532); CIRIA (2006a) Control of water pollution from linear construction projects: technical guidance (C648); CIRIA (2006b) Control of water pollution from linear construction projects: site guide (C649); CIRIA (2016) Environmental good practice on site pocket book, 4th edition (C762)

6.7.19 Remediation/removal of contaminated soils/land, such as at the former gas works, is considered in **Chapter 7: Hydrogeology and Contamination**.

Operational Mitigation

6.7.20 Due to the highly active nature of the watercourses within the study area, it is recommended that monitoring of the watercourses and bank protection measures should be undertaken annually and following flood events, by the Council to ensure that the bank erosion protection and vegetation is establishing effectively. This monitoring should be undertaken by a trained geomorphologist.

6.7.21 Any periodic maintenance works will be subject to the same level of mitigation and good practice as during the construction phase to ensure risks of pollution to watercourses is minimised.

6.7.22 In addition, it is recommended that measures to alleviate the severe erosion and deposition currently occurring on the downstream reach of the Water of Ruchill are undertaken by the Council, as detailed in the Water of Ruchill Fluvial Audit (**Appendix 6.2**). It is also recommended small-scale gravel extraction on the Water of Ruchill should be continued, following SEPA's best practice guidance for sediment management[25].

6.8 Residual Effects

Construction Effects

Hydrology and Flood Risk

6.8.1 Satellite construction compounds will remain in areas close to the construction works known to be at risk of flooding for return period events up to the 50% AEP (1:2 year) event. Therefore, there remains a temporary residual effect of minor magnitude and Slight significance.

6.8.2 Following the implementation of mitigation, particularly careful programming/ sequencing of the flood defence works, all other residual effects on hydrology and flood risk are predicted to be of negligible magnitude and Neutral significance during the construction phase.

Fluvial Geomorphology

6.8.3 With the implementation of mitigation, the following residual effects related to fluvial geomorphology are predicted during construction:

- Bank disturbance on the River Earn and Water of Ruchill is predicted to be of minor magnitude and Slight significance.

[25] SEPA (2010) Engineering in the water environment: good practice guide – Sediment management, 1st edition, June 2010. Accessed 04/03/2019 [https://www.sepa.org.uk/media/151049/wat-sg-26.pdf]

- Bank disturbance on the River Lednock is predicted to be of negligible magnitude and Neutral significance.
- Disturbance of the existing river bed of the River Earn and the Water of Ruchill is predicted to be of minor magnitude and Slight significance.
- Changes in flow patterns and velocities due to in-channel construction are predicted to be of negligible magnitude and Neutral significance on the River Earn and the Water of Ruchill.
- The risk of increased sediment supply to all three of the watercourses is predicted to be of minor magnitude and Slight significance.

Water Quality

6.8.4 Following the implementation of mitigation during the construction phase, residual effects on water quality as a result of increased suspended sediment and polluted runoff to watercourses is predicted to be of minor magnitude and Slight significance overall.

Operational Effects

Hydrology and Flood Risk

6.8.5 The residual effect of taking hundreds of residential/non-residential properties out of existing flood risk with the completed Scheme is predicted to be of Very Large Beneficial significance (refer to **Table 6.6**).

6.8.6 An increased risk of flooding on land parcels out with the Scheme study area (containing no residential/non-residential properties) was predicted to have an impact of Slight significance during operation before mitigation (refer to **Schematic 6-2**). These land parcels are not at increased risk of flooding as a result of the constructed Scheme and therefore the residual effect of moderate magnitude and Slight significance is predicted to remain.

Fluvial Geomorphology

6.8.7 With the implementation of mitigation measures, changes to natural flow patterns and velocities on all watercourses is predicted to result in a residual effect of minor magnitude and therefore Slight significance.

6.8.8 With mitigation in place the addition of morphological pressures on the Water of Ruchill (classified as high sensitivity) will potentially result in an impact of minor adverse magnitude resulting in an impact of Slight significance.

Water Quality

6.8.9 The residual effects on water quality during the operational phase are predicted to be of negligible magnitude and therefore Neutral significance on all watercourses. There will likely be a benefit to water quality during Scheme operation as the potential for surcharging sewers and pollution events during flood events will be removed.

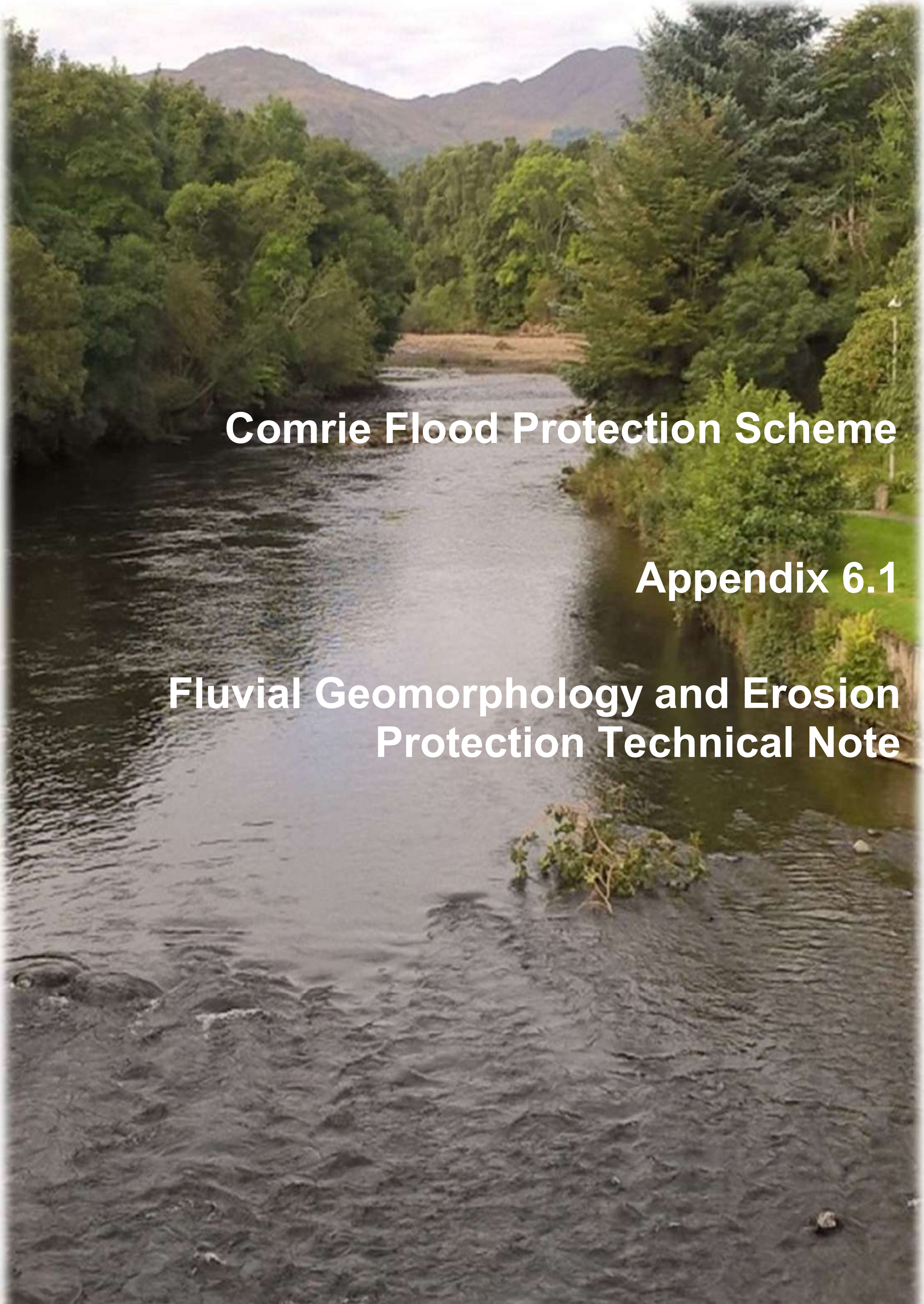
6.9 Glossary

- Annual Exceedance Probability (AEP) – the chance that a flood event equal to or greater than a specific magnitude will occur in any given year.
- Bar Forms – an accumulation of alluvium (usually gravel or sand) caused by a decrease in sediment transport capacity on the inside of meander bends or in the centre of an overwide channel.
- Cascade – a short, steep drop in streambed elevation often marked by boulders and agitated white water.
- Catchment – the area upstream of a point from which water drains towards that point.
- Equilibrium – a river is said to be in a state of equilibrium when rates of erosion and deposition are roughly equal.
- Fluvial Audit – a catchment scale survey, involving both a desktop study and a walkover survey of the watercourse. A Fluvial Audit is generally completed to gain a qualitative understanding of the sediment budget and sediment transport through the catchment by identifying sources, transfer pathways and storage areas for sediment.
- Fluvial Flooding – flooding from a river (rainfall to a catchment, draining into a river which then exceeds its channel capacity).
- Glide – a section of stream that has little or no turbulence.
- J-vanes – piers, composed of cobbles and boulders, which extend into the channel in a J-shape. They are generally used to control flow and deposition patterns in the channel.
- LiDAR – a type of 3D ground model. Points on the ground are obtained through remotely sensed data. The time of return for a pulse of light fired at the ground from height (e.g. a receiver in a plane or drone) can be used to quantify that height which can then, in turn, be used to ascertain the ground level above mAOD. This data is subject to post-processing with algorithms to remove potentially erroneous points.
- MImAS – Morphological Impact Assessment System. An ‘environmental standards’ test which calculates the ‘capacity used’ by artificial modifications to a watercourse on a percentage basis.
- Pluvial Flooding – flooding from surface water (direct rainfall).
- Pool – a section of stream that is characterised by deep, low-velocity water and a smooth surface.
- Q95 – low flow value; a flow that is expected to be exceeded at least 95% of the time
- Riffle – a section of stream characterised by shallow, fast-moving water.
- Run – a section of stream characterised by fast-flowing, low turbulence water.
- Salmonid Waters – freshwaters capable of supporting fish species including salmon and trout.

- Secondary Flooding – Flood risk which may occur when the route for surface water to drain from urban areas is cut-off; for example by the construction of a flood protection scheme preventing overland flow into a river.
- Turbidity – a measure of the content of suspended material that interferes with the passage of light through the water or in which visual depth is restricted. Suspended sediments are only one components of turbidity.
- UKCP09 – a set of climate change projections, the outcome of research by the UK Met Office published in 2009 and considered an industry-standard reference.
- Weir – a structural barrier built across a stream to raise upstream water levels.

Channel Typology

- Active-meander – shallow gradient, with a wide floodplain. Extensive depositional and erosional features, and well-developed meanders leading to a sinuous planform.
- Bedrock/Cascade – typically, steep gradient, bed and channel banks show significant areas of obvious bedrock. Cobbles and gravels may exist on the bed also. Boulders are common in the channel along with sections of agitated white water. No floodplain development.
- Plane-bed – a transitionary typology between step-pool and pool-riffle. Typically, moderate gradient, with some floodplain development, but channel often incised below floodplain. Featureless bed often armoured with cobbles. Irregular steps, and irregular bars might be present, as well as a relatively straight planform.
- Pool-riffle – generally shallow gradient, and a relatively wide floodplain. Planform becomes sinuous, with more obvious depositional features such as bars, and more signs of erosion on banks.
- Step-pool – gradient still generally steep, with little floodplain development. Channel has regular or semi-regular well-developed steps, separated typically by pools. Substrate typically composed of large cobbles and boulders, with some gravels.



Comrie Flood Protection Scheme

Appendix 6.1

Fluvial Geomorphology and Erosion Protection Technical Note

Report

Fluvial Geomorphology and Erosion Protection

Technical Note

Comrie Flood Protection Scheme

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Appendices

1 Introduction

Sweco have been commissioned by Perth and Kinross Council (PKC) to design a flood protection scheme for the town of Comrie. A fluvial geomorphology and erosion protection assessment is required to inform the design of the scheme. This report provides a technical summary of work carried out under Work Area 4 – Fluvial Geomorphology and Erosion Protection, and includes the following:

- A description of the baseline geomorphology conditions of rivers in the study area, comprising a summary of the geomorphic assessment and geomorphological walkover survey carried out by cbec;
- A River Basin Management Plan (RBMP) assessment to determine whether the proposed scheme will affect the Water Framework Directive (WFD) status of rivers within the study area;
- A scour and erosion assessment to determine what affect the proposed scheme will have on rates of bank erosion and scour on the rivers within the study area;
- Proposed solutions and mitigations for areas of increased bank erosion; and
- A summary of consultation with the Scottish Environmental Protection Agency (SEPA);

1.1 Study Area

There are three watercourses which intersect the town of Comrie, which are in close proximity to the proposed flood defences: the River Earn, the River Lednock and the Water of Ruchill. The sections of these three rivers that pass through Comrie were included in the assessment and are shown in Figure 2-1.

2 Geomorphology Baseline Conditions

2.1 Methods

2.1.1 Review of Existing Information

Due to the history of the flood scheme and the dynamic nature of the rivers within the project area, several previous studies have been undertaken which document the geomorphological characteristics of the rivers in the Comrie area. The following reports were reviewed, and used to provide baseline information for this report:

- Water of Ruchill, Comrie: Sustainable River Management (Hey, 1999);
- Comrie and Dalginross Flood Study: Flood Option Assessment (Mouchel, 2010);
- Comrie and Dalginross Flood Alleviation Scheme: Fluvial Geomorphological Reconnaissance Survey (cbec, 2011);
- SEPA's Hydromorphology File Notes (2012, 2014, 2016);
- Comrie Field of Refuge, River Bank Management – Rock Armour Remediation and Bank Scour Management Report (Mouchel, 2017); and
- Comrie Flood Protection Scheme – Geomorphological Assessment Report, Final Report (cbec, 2018).

2.1.2 Geomorphological Field Assessment

A geomorphological walk over (modified 'fluvial audit') survey was undertaken by cbec on 13th – 14th November 2017[1]. Sections of the three rivers running through Comrie, the River Earn, River Lednock, and the Water of Ruchill, were included in the survey. Survey extents are provided in Table 2-1 and displayed on Figure 2-1.

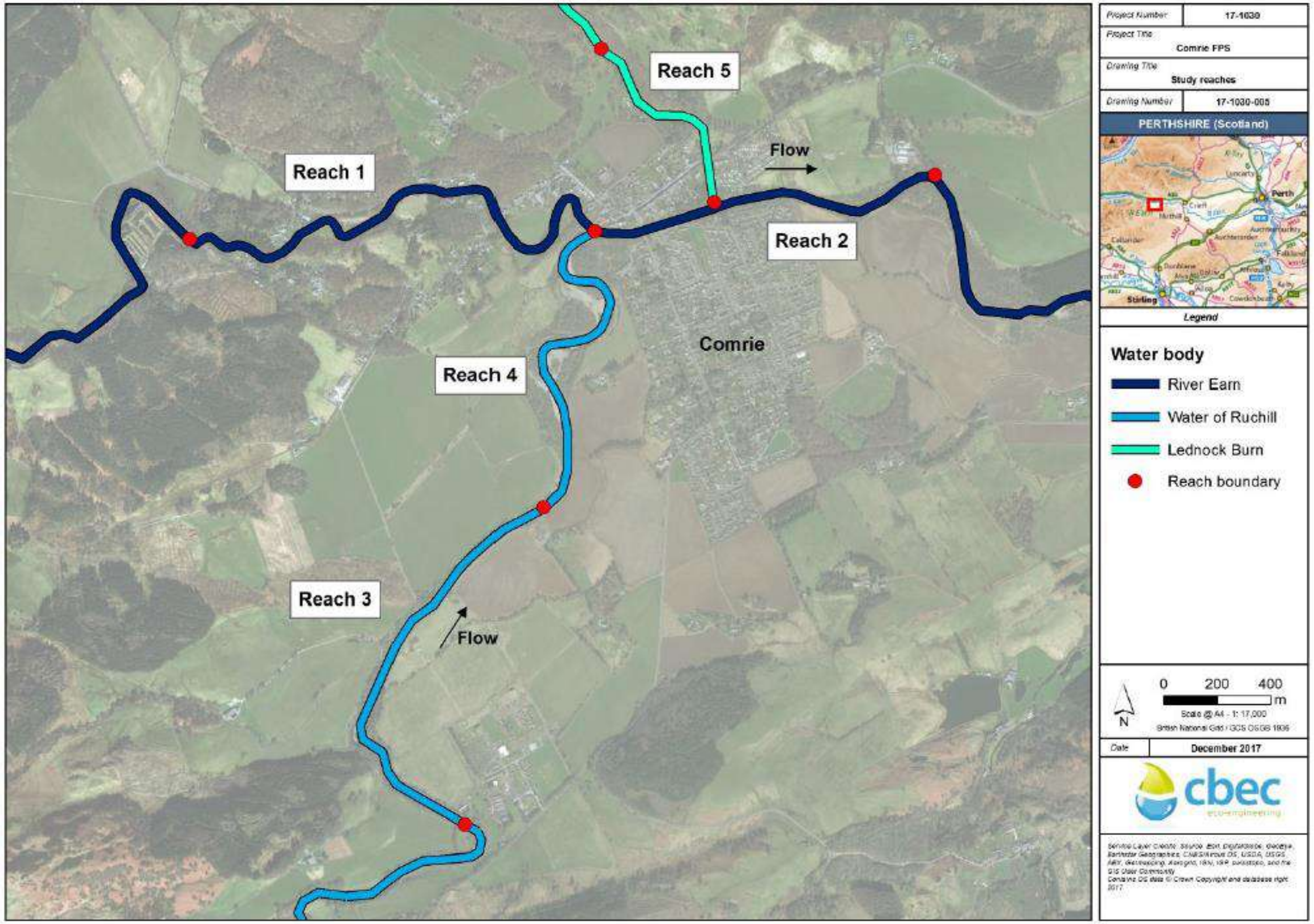
Table 2-1: Survey extents for geomorphological walk overs

River	Survey Extent	
	Upstream Grid Reference	Downstream Grid Reference
River Earn	NN 75669 21867	NN 78466 22111
Water of Ruchill	NN 76741 19664	NN 77171 21893
River Lednock	NN 77248 22568	NN 77623 22012

Further information on the methods of the field assessment are provided in cbec's Geomorphological Assessment report (Appendix A).

[1] cbec (2018). Comrie Flood Protection Scheme – Geomorphological Assessment Report, Final Report.

Figure 2-1: Map showing the survey extents for geomorphological walkover surveys undertaken in the Comrie area (From cbec, 2018[1])



2.2 Results

Baseline geomorphology conditions are summarised in Table 2-2. More detailed information is provided in cbec's Geomorphological Assessment Report (Appendix A).

2.2.1 River Earn

The River Earn can be split into two morphologically distinct reaches: Reach 1 extends from the upstream boundary at Tullybannocher to the confluence with the Water of Ruchill; and Reach 2 extends from the Water of Ruchill confluence to the downstream boundary at A & B Gairns Contractors.

Reach 1 - the upper reach of the River Earn is a moderate to low gradient channel which flows through a moderately confined valley with a limited floodplain (Figure 2-2). The typology of the channel alternates between pool-riffle and plane bed, with alternating glides and runs, and a small number of pools and poorly defined riffles.

There are several sections of piled stones, embankments, and walls along the banks, particularly in the downstream section of the reach, which are confining the river within its current alignment and causing incision, as evidenced by intermittent bedrock outcrops in the base of the channel.

Figure 2-2:Photo taken during the site visit of the upstream reach of the River Earn (Reach 1)

Reach 2 - the lower reach of the River Earn is a low gradient channel set within a wide valley and alluvial floodplain (Figure 2-3). The channel typology is predominantly slow glide, indicating reduced complexity of bedforms throughout this section of the channel.

Historic Ordnance Survey (OS) maps of the River Earn show large alluvial bar features in a wider channel in the upper part of the reach, near the confluence with the Water of Ruchill. However, currently there is very limited sediment storage in this part of the reach. This may be a result of recent and historic works on the Water of Ruchill which have resulted in significant deposition within the tributary and reduced capacity to transport material out of the tributary. Bar formations are more common in the downstream section of the reach where the channel is slightly more sinuous.

Figure 2-3:Photo taken during the site visit of the downstream reach of the River Earn (Reach 2)

2.2.2 Water of Ruchill

The Water of Ruchill is a dynamic gravel-bed river which has undergone significant changes over the past 150-200 years. Historic OS maps indicate that, prior to 1862, the Water of Ruchill was a naturally dynamic river which historically migrated (wandered) across its entire floodplain[2].

[2] Hey, R.D. (1999) Water of Ruchill, Comrie: Sustainable River Management. ENVMAN Ltd. Report Prepared for Perth and Kinross Council

However, at some point prior to 1862, this river appears to have been artificially straightened causing the sediment supply and regime characteristics of the channel to be out of equilibrium.

The Water of Ruchill can be split into two morphologically distinct reaches; Reach 3 extends from Cultybraggan Camp to Ruchilside; and Reach 4 extends from Ruchilside to the confluence with the River Earn.

Reach 3 - the upper reach of the Water of Ruchill comprises a moderate gradient channel, which appears to have maintained its unnaturally straight form (Figure 2-4). The river has tree lined banks and sits within a wide alluvial valley. The channel typology is mainly cascade in the upstream section of the reach, whereas, downstream it transitions to plane bed.

The upper reach comprises localised areas of both erosion and deposition, which are fairly minor, except for an area of significant erosion on the left bank, in the downstream section of the reach towards Ruchilside, where there is a lack of tree cover on the left bank. There has been some bank protection installed in this area, but it does not cover the extent of the erosion (Figure 2-4A). For the most part, continuous tree cover of the banks has provided stability to the channel and prevented it from returning to its naturally wandering state.

Figure 2-4: Photos of the upstream reach of the Water of Ruchill (A) Shows rip-rap bank protection on the left bank which has been out flanked at the downstream end. (B)Shows a typical stretch of the Reach 3

Reach 4 - the lower reach of the Water of Ruchill comprises a moderate to low gradient channel, situated in a wide alluvial valley and floodplain (Figure 2-5). This reach displays evidence of returning to its naturally wandering state, potentially due to the lack of mature trees stabilising the banks[2].The river has a multi-thread channel throughout the reach, with some old channels which are significantly aggraded with coarse gravel and cobble deposits, and other channels which are wetted. The channel displays alternating pool-riffle typology throughout the extent of the reach.

The reach displays evidence of active sediment recruitment, transfer and storage processes which contribute to channel evolution and lateral migration. The lower reach of the Ruchill is a significant zone of sediment storage with extensive alternating bar forms and flood deposits. There are also multiple cases of severe bank erosion along the reach, as well as erosion of previously dredged gravel heaps. Recruitment of large woody debris is evident throughout the dynamic section of the reach.

The Water of Ruchill is a very dynamic watercourse which displays a range of fluvial processes and exhibits a range of geomorphological features. Although it has been historically straightened, it is attempting to return to its naturally wandering state, as evidenced by the significant bank erosion.

Figure 2-5: Photo taken during the site visit of the downstream reach of the Water of Ruchill (Reach 4)

2.2.3 River Lednock

Reach 5 - the River Lednock has a moderate to steep gradient channel, which sits within a narrow valley. The upper part of the channel is straight and steep, and is bedrock dominated (Figure 2-6). Downstream, the channel widens into an alluvial valley with river terrace deposits around its confluence with the River Earn. The channel alternates between step-pool and cascade typologies in the steeper upper part of the channel, which transitions to plane bed and pool-riffle further downstream.

The reach is dominated by sediment transport processes. Along the lower part of the channel, the banks are protected by continuous mature vegetation, which acts to stabilise the banks. As a result, only minor bank erosion was observed along the reach.

Figure 2-6: Photo taken during the site visit of the River Lednock

Table 2-2 Summary of Baseline Geomorphology Conditions

RIVER	RIVER EARN	RIVER LEDNOCK	WATER OF RUCHILL
STREAM TYPE	• Alternating between riffle-pool and plane bed	• Cascade and step-pool transitioning to plane bed/ riffle-pool downstream	• Cascade transitioning to riffle-pool downstream
BANK CONDITIONS	• Banks mainly stable with continuous mature trees and shrub coverage • Two instances of moderate bank erosion on the left bank; one near the caravan park and one further downstream.	• Mostly stable vegetated banks • One significant area of erosion on left bank upstream of foot bridge	• Multiple cases of severe bank erosion in lower reach • Upper reach has vegetated banks, so less erosion
ANTHROPOGENIC PRESSURES	• Two stone weirs • Piled stone and stone walls along banks • Stone arch bridge (Bridge of Ross) • 7m high set back embankment • Embankments along field boundaries and Comrie Holiday Park • Realigned sections • Bank protection • Invasive Species – Japanese Knotweed and Rhododendron	• Concrete weir (not intact) • Two bridges with abutments • Bank protection – piled and intact stone wall • Realignment – narrowing and straightening of channel	• Realignment - Straightening of channel • Significant and extensive hard bank protection • Significant embankments and dredged material along banks • Gravel extraction • Over-widening • Invasive Species – Japanese Knotweed
PHOTO			

3 River Basin Management Plan (RBMP) Assessment

An assessment of the likelihood that the proposed flood protection scheme will impact the WFD status of waterbodies within the study area was undertaken by cbec[3]. The WFD requires that all European Union (EU) countries achieve 'good status' for all groundwater and surface waterbodies. To achieve 'good status' overall, a waterbody must achieve good status in all the RBMP assessment criteria (biological, hydro-morphological, physio-chemical and chemical quality), therefore, a deterioration in one of these criteria may result in the waterbody failing to meet the WFD objectives.

3.1 Methods

Assessment of the morphological quality of the rivers and the potential for the flood protection scheme to downgrade the morphological quality was based on SEPA's Morphological Impact Assessment System (MImAS), which was used to perform an environmental standards test which determines whether an activity will result in deterioration of the morphological quality of a waterbody.

SEPA provided current MImAS scores for waterbodies within the study area. The current MImAS scores are given as a 'capacity used' percentage based on the type and length of existing engineering pressures along the channel. These are provided in the table below.

3.2 Results

The results of the RBMP assessment are summarised in Table 3-1, and are described in more detail in the RBMP assessment report, provided in Appendix B.

The Lednock Burn (River Lednock) is designated a heavily modified waterbody (HMWB) due to the hydroelectric dam on the upper reaches of the Lednock.

In terms of potential impacts of the flood scheme on RBMP criteria, hydro-morphological quality of the rivers is predicted to be the most sensitive. The potential impacts on chemical and physio-chemical quality of the rivers is predicted to be negligible, since there will be minimal change to rural diffuse pollution, as the flood walls will not be placed on agricultural land. Potential impacts on biological quality of the rivers can be minimised by utilising good working practices regarding the spread of invasive species. However, the flood defences are predicted to add additional morphological pressures to the rivers which could result in downgrading their WFD status. Specifically, there is potential for downgrades in hydro-morphology status of the following rivers:

- The River Lednock may be downgraded from 'high' to 'good' status. This will not impact the WFD status of the water body both because it will still meet the WFD objective, and because the Lednock is a HMWB.

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[3] Cbec. (2018) Comrie Flood Protection Scheme RBMP Assessment.

- The Water of Ruchill may be downgraded from ‘good’ to ‘moderate’ status. This would result in a downgrade in the overall status of the waterbody from ‘good’ to ‘moderate’, meaning the Water of Ruchill would fail to meet the WFD objective.

Table 3-1 MImAS Scores for Waterbodies Impacted by the Comrie Flood Protection Scheme

Waterbody	WFD Status	MiMAS Score	Potential Impacts	Recommendations
River Earn (Loch Earn to Ruchill confluence)	MODERATE	8% GOOD	• Flood walls will reduce floodplain connectivity and increase channel confinement • Bank protection will add morphological pressure. • Potential for increased deposition around the Ruchill confluence due to channel confinement caused by flood walls creating a backwater effect which will slow water upstream and increase deposition.	• Use good work practices to limit spread of invasive plants. • Use 'green' bank protection as opposed to hard bank protection.
River Earn (Ruchill confluence to Ruthven confluence)	GOOD	14% GOOD	• Flood barriers and bank protection will add morphological pressure • Flood walls will reduce flood plain connectivity, particularly when placed along top of bank. • During high magnitude flood events, higher rates of bedload transport will occur due to channel confinement by the flood walls along this reach. Further downstream, where floodwalls do not confine the channel, there will be higher rates of deposition.	• Use good work practices to limit spread of invasive plants. • Use 'green' bank protection as opposed to hard bank protection.
Water of Ruchill	GOOD	21% GOOD	• River is very sensitive to morphological pressure. • Capacity used is close to threshold (4% remaining) for a reduction in morphological status from 'good' to 'moderate'.	• Since flood barriers and bank protection will add morphological pressure it is recommended that flood walls are set back from the top of bank to allow the river to naturally migrate, and that 'green' bank protection is used as opposed to hard bank protection.
Lednock Burn (River Lednock)	HIGHLY MODIFIED MODERATE	4% HIGH	• Capacity used is close to threshold (1% remaining) for a reduction in morphological status from 'high' to 'good'. • Flood walls will reduce flood plain connectivity and increase channel confinement	• Use good work practices to limit spread of invasive plants.

4 Bank Erosion

4.1 Scour and Erosion Assessment

A scour and erosion assessment was undertaken by cbec for the three rivers within the project area, with the aim of determining if the proposed flood defences would result in increased rates of bank erosion. Cross sectional data and flow velocities from the post design 1D model outputs for the 1 in 2-year, and 1 in 100-year flood events were used to calculate shear stress[4]. Based on an estimated grain size of 64 mm (from field observations), the critical shear stress at which particles will mobilise was estimated to be 0.06, from the Shields Curve[5]. Cross sections with shear stress greater than to equal to the critical shear stress of 0.06 were determined to have higher erosion risk, due to the higher shear stress being able to mobilise particles more easily. Cross sections with shear stresses lower than 0.06 were determined to have lower erosion risk, due to shear stress not being high enough to mobilise particles.

The erosion risk map for the 1 in 100-year flood event is provided below (Figure 4-1), and both the 1 in 2-year (A) and the 1:100-year flood event (B) erosion risk maps are provided in Appendix C. The results of the erosion model show that there was negligible difference between the impacts on bank erosion between the 1 in 2-year, and the 1 in 100-year flood events. Nine areas were identified to experience increased bank erosion as a result of the proposed flood defences:

1. The upper section of the River Lednock;
2. The Water of Ruchill Upstream;
3. The bend in the Water of Ruchill at Ruchillside;
4. The left bank of the Water of Ruchill at Tomnagaske;
5. The right bank of the Water of Ruchill at Field of Refuge;
6. The left bank of the River Earn at Tullybannocher;
7. The River Earn at The Ross;
8. The River Earn at the Lednock confluence; and
9. The River Earn at the caravan site.

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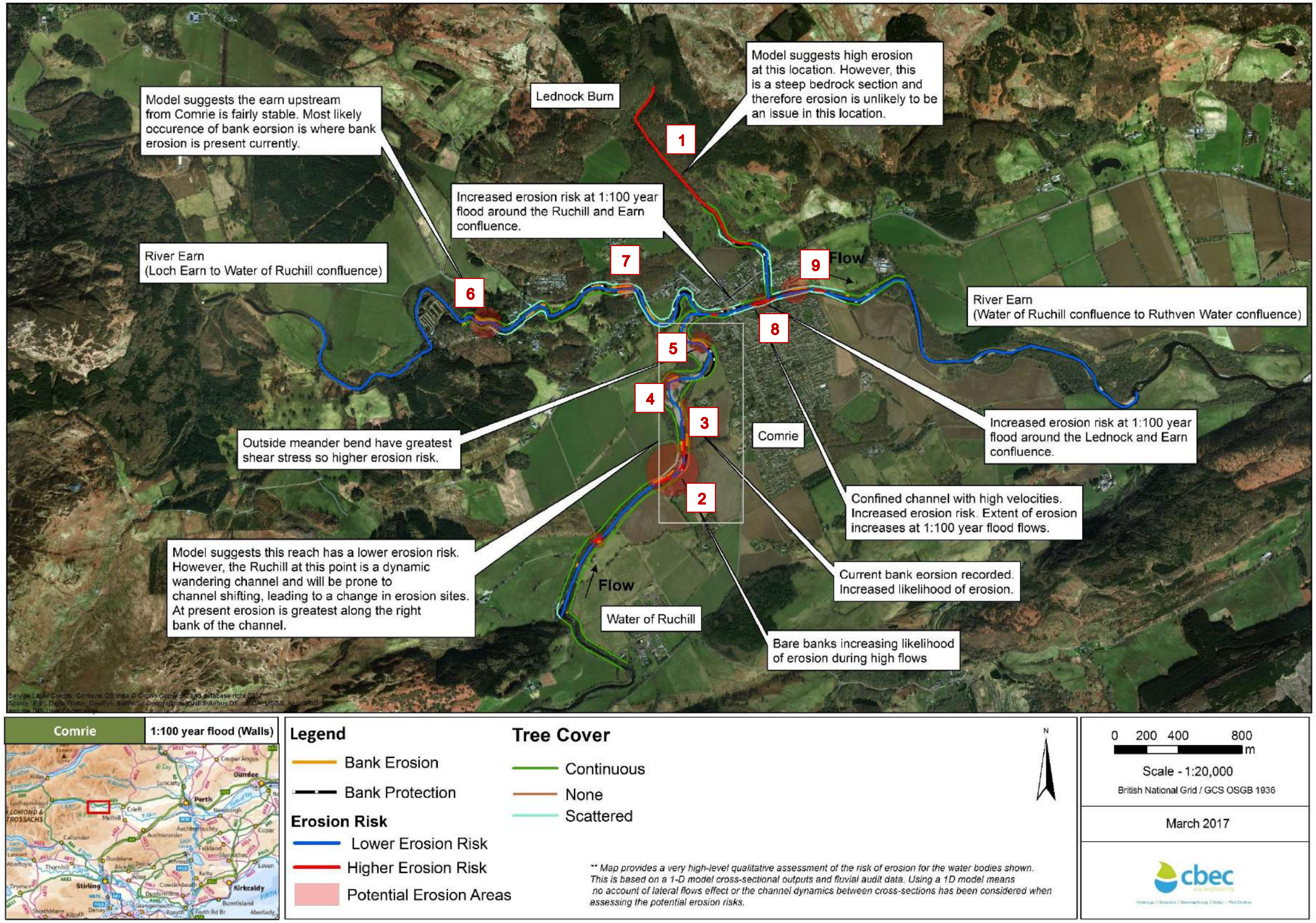
[4] The 1 in 2-year event was chosen as this is known to result in the highest rates of geomorphic change in the channel, the so-called ‘channel forming’ flood. The 1 in 100-year event was then used for comparison, and very little change was observed in the results between the two flood events.

[5] Shields, A. (1936). Application of similarity mechanics and turbulence research on shear flow. Mitteilungen der Preußischen Versuchsanstalt für Wasserbau. 26. Berlin: Preußische Versuchsanstalt für Wasserbau.

Figure 4-1: Erosion risk map for the 1 in 100-year design flood event



4.2 Bank Protection Assessment

A bank protection assessment was carried out in accordance with SEPA's Good Practice Guide on Bank Protection[6]. The scour and erosion assessment identified nine areas where bank erosion is expected to increase as a result of the proposed flood defences. However, bank protection is not required at all of these locations. Bank protection is only deemed necessary in areas where infrastructure will be at risk from increased or existing bank erosion.

Bank protection is required at four of the nine areas identified as having increased risk of bank erosion. These are the Water of Ruchill at the Field of Refuge, the River Earn at The Ross, the River Earn at the Lednock confluence, and the River Earn at the caravan site. These sites were identified as requiring bank protection as at these sites the proposed flood defences may be at risk from bank erosion. Although the scour and erosion model identified the upper reach of the River Lednock as an area which is likely to experience increased bank erosion, it is known from the site visit that the Upper River Lednock is dominated by steep bedrock, so erosion is unlikely to be an issue. There are also no proposed flood defences located along this section of the Lednock which would require bank erosion protection.

In addition to the areas identified through the scour and erosion assessment, two additional areas have been identified as requiring bank protection, due to the steepness and height of the bank in these locations; (1) the right bank of the River Earn along Strowan Road, where the proposed flood wall is located along the top of a steep, tall river bank; and (2) the right bank of the Water of Ruchill on the outer meander bend at the Field of Refuge. Although the Field of Refuge meander already has bank protection, an assessment of this protection found it to be inadequate and in need of repair[7] (Figure 4-2).

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[6] SEPA (2008) Engineering in the Water Environment Good Practice Guide. Bank Protection: Rivers and Lochs.
[7] Mouchel (2017) Rock Armour Remediation and Bank Scour Management Report. Comrie Field of Refuge, Riverbank Management. Perth and Kinross Council.

Figure 4-2: Photo showing the rip-rap bank protection on the right bank at the meander bend of the Water of Ruchill

4.3 Bank Protection Optioneering

After identifying areas requiring bank protection, it was necessary to select an appropriate type of bank protection for each area. Several different types or methods of bank protection are available. SEPA divide these into two categories: grey and green. Grey bank protection involves major engineering of the banks with hard materials, such as concrete or rock armour. Whereas, green options involve the use of biodegradable materials, with hard materials restricted to the toe of the bank[5].

Many factors were considered when selecting which bank protection option was appropriate for each site.

- **Cause of erosion** – It is important to select a solution which provides mitigation to the problem.
- **Maintenance** – Need to consider the cost of maintaining the bank protection solution.
- **Life span of the bank protection** – When will the bank protection need to be replaced?
- **Robustness** – Need to ensure the solution will withstand the predicted flow velocities
- **River type** – The solution should be designed to work with the channel dimensions and flow type.

- **Space available** – Need to ensure there is enough room for installation and maintenance of the bank protection option.
- **Construction** – Need to ensure construction of the proposed options would be feasible given the site constraints such as access, water depths and vegetation
- **Aesthetics** – It is important to select bank protection which fits in with the aesthetic of the town.

From a sustainability perspective, green bank protection is preferred, as these options minimise environmental harm. However, we also need to ensure that the solution is robust enough to solve the erosion problem. Where possible, options which minimise environmental harm and maximise environmental benefit were selected. In many cases, combinations of different options have been selected, for example, re-profiling combined with a geotextile. A table outlining all the bank protection options considered, and the factors involved in the selection process is provided in Appendix D.

4.4 Solutions

The plan of proposed bank protection options is presented in Appendix E.

The right bank of the Water of Ruchill, at the Field of Refuge, is arguably the most critical site requiring bank protection, since the current bank protection is failing, and rapid bank erosion is occurring downstream of the bank protection. The bank is eroding due to rapid flow velocities, particularly at the bank toe which undermines the bank and results in bank collapse. A robust bank protection is required to withstand the rapid flow velocities, so a root wad revetment with rock roll toe was selected to protect the bank in this area. The revetment will match the current bank height (approximately 3 m) and will be approximately 260 m in length. Tree trunks with the root wads attached will be pushed into the bank (trunk first) with the roots exposed. These will act to increase bank roughness and slow down the flow, providing a means of working with the river to prevent exacerbating erosion problems downstream. The root wads will also provide in stream habitat, and the rip rap will provide otter habitat. Since erosion at the toe of the bank is the cause of bank collapse, the toe will be reinforced with rock rolls.

At Strowan Road, where the flood wall is proposed to be located along the top of the right bank of the River Earn, space to install bank protection or reprofile the bank is limited. It is also essential to provide robust protection in this area, since the wall will be in such close proximity to the river, the walls foundations are at potential risk from erosion. For these reasons, a block stone wall has been selected to provide erosion protection. This will extend approximately 115 m long and have a height of approximately 3 m. It will tie-in with the proposed flood wall with a reprofiled, geotextile reinforced slope.

On the left bank of the River Earn adjacent to the caravan site, the bank will be repaired with stacked coir roll. These will provide biodegradable protection to the bank in the short term until vegetation establishes. The roots of the vegetation will self-stabilise the bank, as well as being aesthetically pleasing. This is a green solution which will enhance the biodiversity of the area.

5 Consultation

A consultation meeting was held with SEPA on 26th July 2018 to discuss the flood scheme and the effects on the WFD status of the rivers. Although SEPA were generally positive about the bank protection proposals and the emphasis on green bank protection measures, they raised concerns regarding the likelihood of future channel movement on the right bank of the Water of Ruchill, where bank protection has been proposed to protect the flood wall (located 15 m behind the bank). Fixed banks on the Water of Ruchill, whilst protecting the scheme, would not address wider issues on the watercourse and a wider scale approach may be more appropriate.

SEPA suggested that a more sustainable long-term solution for the Water of Ruchill should be investigated, that would remediate some of the wider issues on the river, alongside the location specific bank protection. SEPA also informed us that the MiMAS scoring system can be used to 'predict' improvements in status, e.g. through river restoration. Upstream improvements to address sediment storage (e.g. re-meandering) would likely be beneficial and may offset some of the impact of the scheme.

Sweco recommends that a feasibility study is undertaken to provide an assessment of options for restoration techniques that deliver wider improvements to the morphological condition of the river. Sweco notes that PKC would prefer the most 'maintenance free' solution possible, which will guide our thinking.

6 Summary and Conclusions

Three waterbodies intersect the town of Comrie: the River Earn, the River Lednock and the Water of Ruchill. These are gravel bed rivers which have already undergone several anthropogenic modifications, such as straightening and bank reinforcement. This has added morphological pressures to their channels, particularly on the Water of Ruchill (a wandering gravel river) which has been historically straightened. It is now actively trying to return to its natural course and is extensively eroding its banks as a result.

There is potential for these rivers to be impacted by the proposed flood protection scheme. Particularly, the WFD morphology status of the rivers, which may be downgraded as a result of the flood defences constricting the flow and adding morphological pressure to the channels. A RBMP assessment was carried out to assess the potential for the proposed flood defence scheme to impact the WFD status of the rivers. Two key potential impacts of the scheme on the WFD status of the rivers were identified:

- The River Lednock may be downgraded from 'high' to 'good' status. This will not impact the WFD status of the waterbody.
- The Water of Ruchill may be downgraded from 'good' to 'moderate' status. This would result in a downgrade in the overall status of the waterbody from 'good' to 'moderate', meaning the Water of Ruchill would fail to meet the WFD objective.

There is also potential for these rivers to have impacts on the flood protection infrastructure. The added pressure of the flood defences may increase bank erosion, which may result in undermining of the flood defence foundations. A scour and erosion assessment was carried out to determine areas which would experience increased bank erosion following the installation of the flood defences. Bank protection options were assessed for these areas if they were adjacent to the proposed flood defences. Both hard engineered 'grey' bank protection methods and softer 'green' bank protection methods were considered. Different methods have been selected for each site that will be robust enough to protect the banks from the predicted flow velocities, but also minimise environmental detriment whilst maximising environmental benefit.

Appendix A – Geomorphological Assessment Report

cbec eco engineering

COMRIE FLOOD PROTECTION SCHEME

GEOMORPHOLOGICAL ASSESSMENT REPORT

FINAL REPORT

Prepared for

Sweco

and

Perth and Kinross Council

Prepared by

cbec eco-engineering UK Ltd

February 2018

cbec Project #: U17-1027

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1. INTRODUCTION

Comrie is a village in Perthshire, central Scotland, located in the catchment of the River Earn and built on the floodplain of the Earn and two tributaries (the Water of Ruchill and Lednock Burn). The village is prone to flooding as a result of its location at the confluence of both tributaries with the main stem. Flood events in 1993 and 1997 resulted in Perth and Kinross Council undertaking emergency works on the lower Water of Ruchill system in an attempt to reduce the risk of further flooding to the Dalginross area of the village. Since the initial works, another two high flow events (August and November 2012) resulted in widespread flooding affecting a large number of properties within the town.

A previous study undertaken by Mouchel as part of the Comrie Flood Protection Scheme has appraised and identified flood protection measures throughout the village. Perth and Kinross Council have now commissioned this next phase of the Scheme, with the ultimate aim of developing outline designs and implementing flood protection measures identified previously. Proposed measures include an extensive flood wall along a significant length of the village, as well as three earth embankments, to the south of Tomnagaske farmhouse, along the south east boundary of Comrie Holiday Park, and the south east side of the village.

cbec was approached to undertake a river reconnaissance survey of the water bodies within the study area, with the aim of assessing channel morphology and current physical processes within the system, linking these to potential flood risk. Following this interim report, a further assessment will be undertaken to consider the impact to, and from, the rivers, in relation to the proposed flood protection measures[1].

1.1 CATCHMENT AND SITE OVERVIEW

The main stem Earn flows east from Loch Earn at St Fillans, for approximately 8 km, before entering Comrie. Here, it meets with the highly dynamic Water of Ruchill (OS NGR NN 77169 21898). As the river flows further east through the village, it passes under the Bridge of Dalginross, before being joined by the Lednock Burn on its left bank. From here the river flows towards Creiff and Perth, through a valley consisting largely of alluvial and river terrace deposits[2], before entering the River Tay close to Abernethy. The floodplain is dominated throughout by woodland, pastoral and, increasingly, arable agricultural land.

The headwaters of the Water of Ruchill flow from the hills of Glen Artney, where multiple high-gradient streams meet to form the main water course. The area is dominated by glacial till, contributing coarse, unsorted sediment into the Ruchill system. Approximately 3 – 4 km upstream from its confluence with the River Earn, the river enters a wide, low lying area of the valley dominated by alluvial/ river terrace deposits (comprising gravels, sands, silts and clays), becoming increasingly dynamic and wandering in nature as it approaches the mainstem Earn.

The Lednock Burn originates from Loch Lednock Reservoir, and flows in a south easterly direction towards the River Earn. Glen Lednock, through which the burn flows, is dominated by glacial till and alluvium. Here, it is joined by multiple high gradient feeder tributaries, which are likely to be a significant source of sediment.

[1] These assessments will be undertaken following receipt of modelling results.

[2] All geological data sourced from the British Geological Survey, available online at: http://mapapps.bgs.ac.uk/geologyofbritain/home.html?, accessed December 2017).

Sections of each river surveyed as part of this project are shown in **Figure 1.1**. Analysis of historical OS maps[3] suggests that there has been little change in planform of the study area of the River Earn, Lednock Burn, and upper section of the surveyed Water of Ruchill (upstream of Ruchilside), since the mid-1800s. However, the lower ~2 km of the latter has seen significant change during this time. Since 1999, works undertaken along the reach have resulted in significant changes to the system as the river now attempts to revert back to a more natural 'wandering' state. This has included significant areas of sediment aggradation, severe bank erosion along extensive sections of the bank, a notable increase in recruitment of large wood material from the banks, and the continuing headward erosion of the channel bed. Key changes to the channel over this period as a result of the works are detailed in reports by Hey (1999) and cbec (2011). The following sections of this report focus on the current observed setting and characteristics of the site.

1.2 FIELD-BASED GEOMORPHOLOGICAL ASSESSMENT METHODOLOGY

A geomorphological walkover ('fluvial audit') was undertaken on 13th – 14th November 2017, under normal flow conditions, with only minor rainfall during the course of the two days.

The survey covered approximately 8 km of river, including sections of main stem River Earn, Water of Ruchill and Lednock Burn, centred around Comrie (**Figure 1.1**). Grid references for the surveyed extents are given in **Table 1.1**.

Table 1.1 Grid references of the survey limits

Location	National Grid Reference	
	Upstream extent	Downstream extent
River Earn	NN 75669 21867	NN 78466 22111
Water of Ruchill	NN 76741 19664	NN 77171 21893
Lednock Burn	NN 77248 22568	NN 77623 22012

Any feature providing an indication of, or influence on, fluvial form/ process was recorded using an Android-based field data collection app (Qfield), which allowed field data to be automatically processed within a GIS environment. High resolution photographs were also taken throughout the site and can be provided separate to this report.

The types of features and characteristics recorded during the walkover included:

- Reach scale channel morphology (using a classification scheme that draws on aspects of other recognised procedures - Montgomery and Buffington 1997, Brierley and Fryirs, 2000).
- Morphological units (i.e. pools, riffles, runs). These are the specific 'meso-scale' features that, together, define reach scale morphology.
- Indicators of the sediment transport regime (e.g. the form, texture and vegetation cover of bed forms and bar features).
- Sediment sources/ storage (e.g. tributaries, bank erosion, within-channel storage in alluvial barforms), noting dominant sediment sizes.

[3] Available from http://maps.nls.uk/geo/explore/#zoom=5&lat=56.0000&lon=-4.0000&layers=1&b=1 (accessed November 2017).

- River engineering pressures (e.g. bank protection, canalisation/ realignment, embankments, hydraulic structures, bridge crossings, culverts etc.).
- Floodplain morphology and land use.
- Vegetation - both in-channel vegetation (e.g. 'large woody material') and riparian/bankside cover, as well as invasive non-native species.

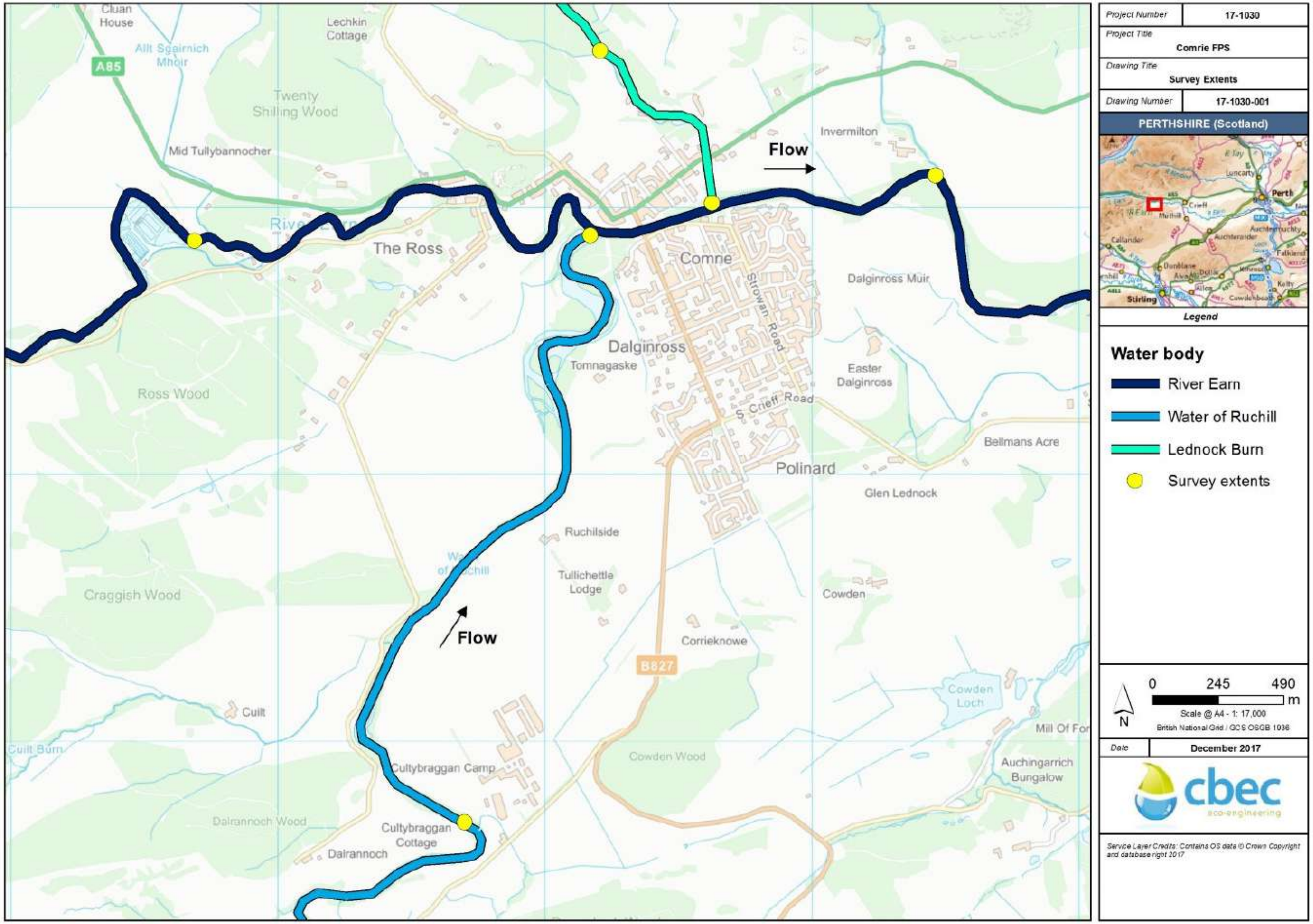

Figure 1.1 Surveyed extents of main water bodies associated with the Comrie Flood Protection Scheme.

2. SYSTEM CHARACTERISATION

To facilitate analysis of the desk and field-based data, the study area was divided into five separate reaches (**Figure 2.1**) each with differing morphological character.

- **Reach 1** - extends from the upstream boundary of the River Earn survey, to the Water of Ruchill confluence. The main engineering pressures and geomorphological features of this unit are detailed in **Section 2.1.1**.
- **Reach 2 -** extends downstream from the Water of Ruchill confluence, to the downstream limit of the surveyed main stem River Earn, adjacent to A & B Gairns Contractors, Invermilton. This reach is detailed in **Section 2.1.2**.
- **Reach 3 -** extends from the section of Water of Ruchill adjacent to Cultybraggan Farm, to Ruchilside. This is detailed in **Section 2.1.3.**
- **Reach 4 –** extends from Ruchilside, to the confluence with the River Earn, and includes the highly dynamic section of the Water of Ruchill. **Section 2.1.4** of this report details the main pressures, as well as the geomorphological and sedimentary characteristics of this reach.
- **Reach 5** - extends the full length of the surveyed section of the Lednock Burn, from the weir at NN 77248 22568 to the confluence with the main stem River Earn. This is detailed in **Section 2.1.5.**

To further assist with analysis, maps have been produced to illustrate the current physical form and character of the reaches surveyed. Data relating to classified reach type and engineering pressures are provided in **Figure 2.2**. Information on sediment within each system (in terms of input sources, transport process, and depositional features) is shown in **Figure 2.3**, and the morphological units along each water body are presented in **Figure 2.4**.

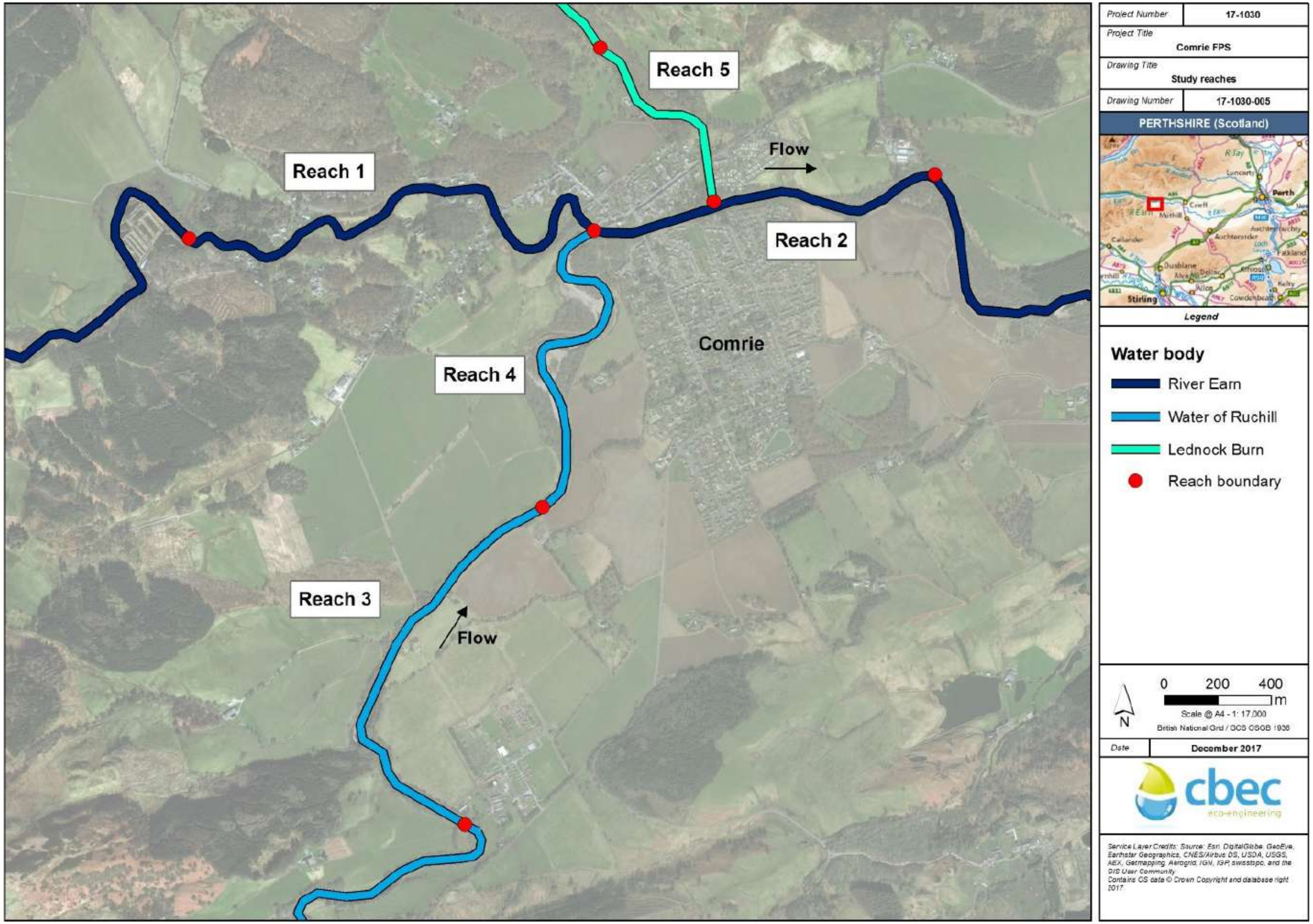

Figure 2.1 Fluvial audit reaches for analysis

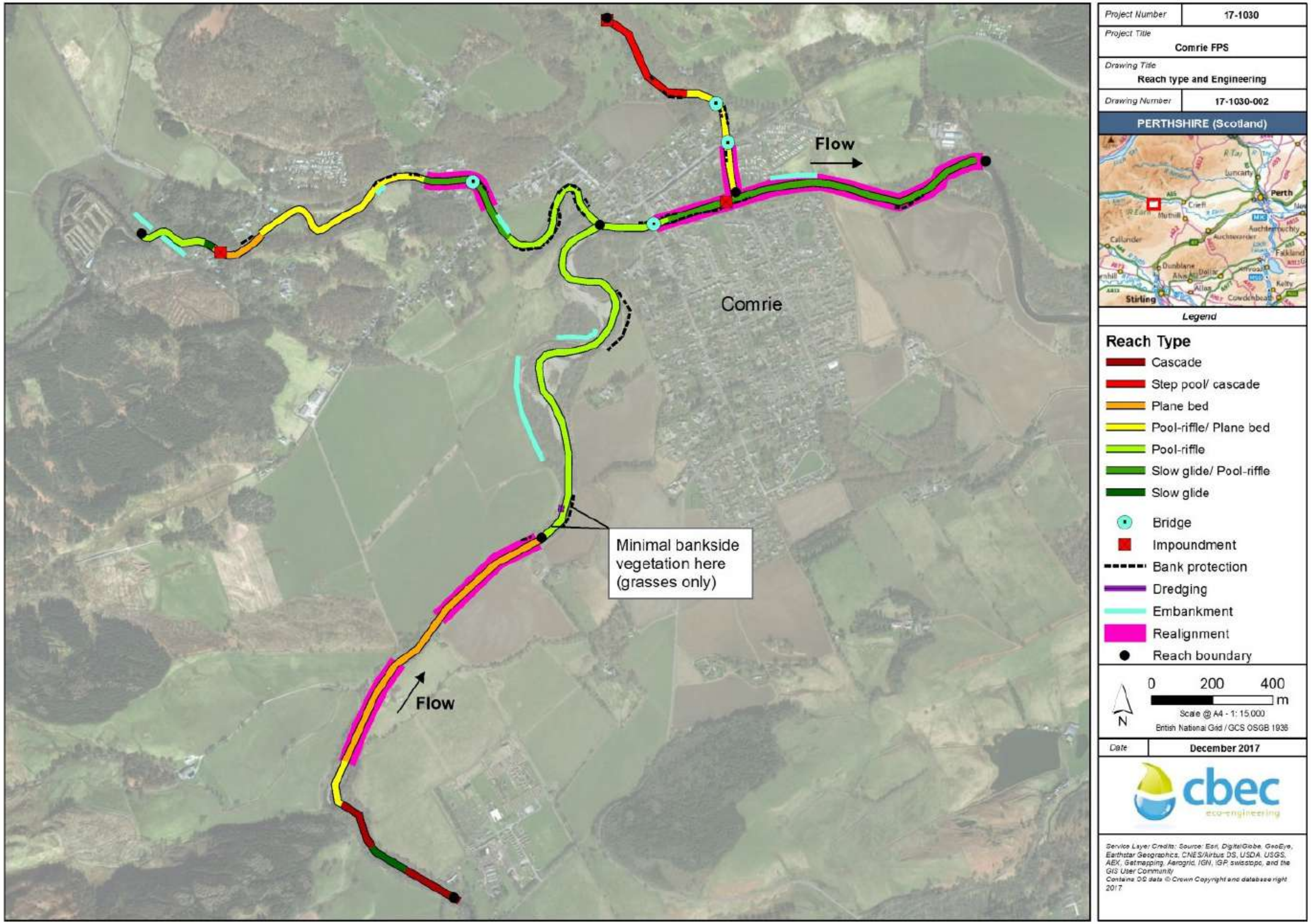

Figure 2.2 Reach Type and Engineering Pressures

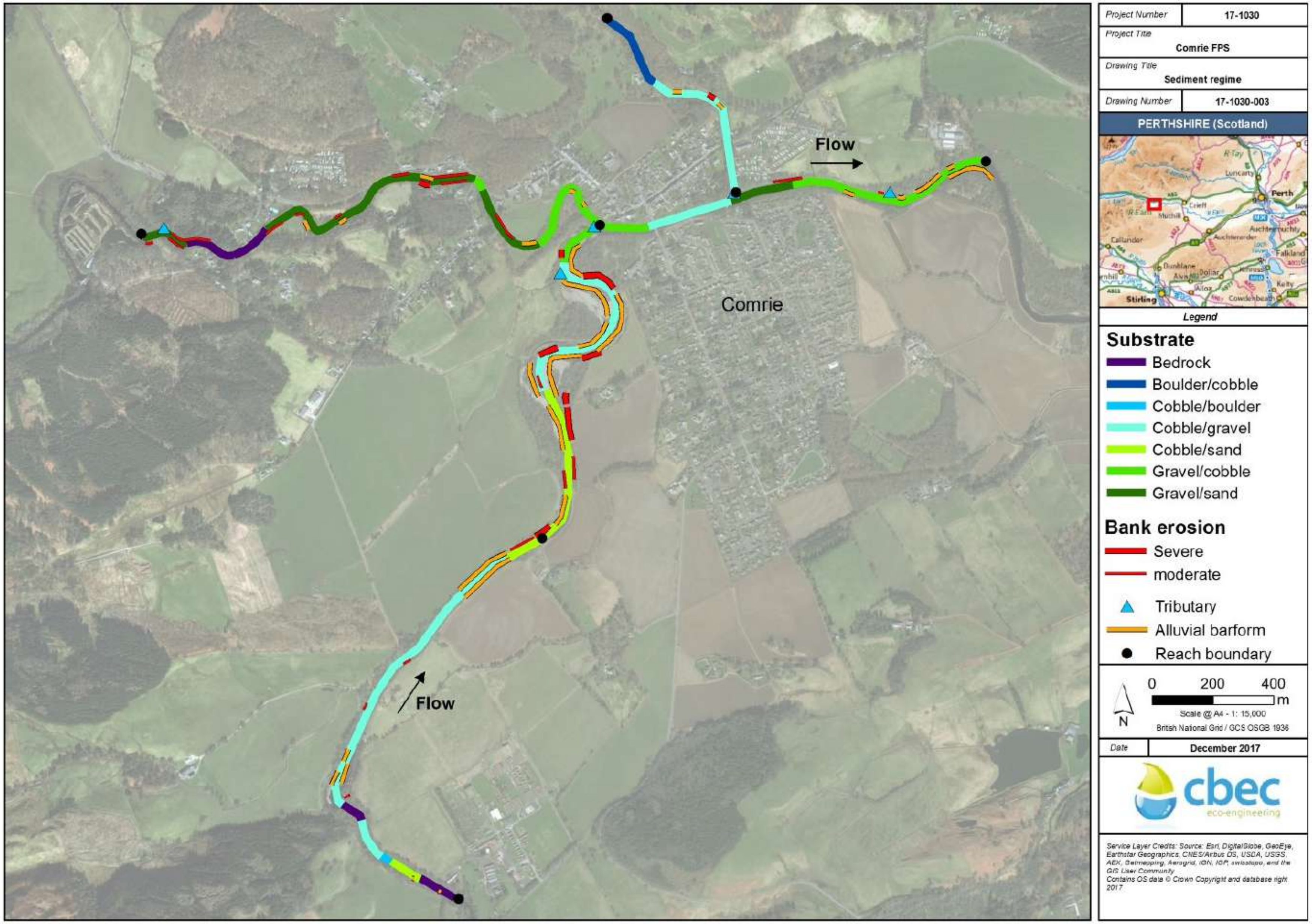

Figure 2.3 Sediment dynamics

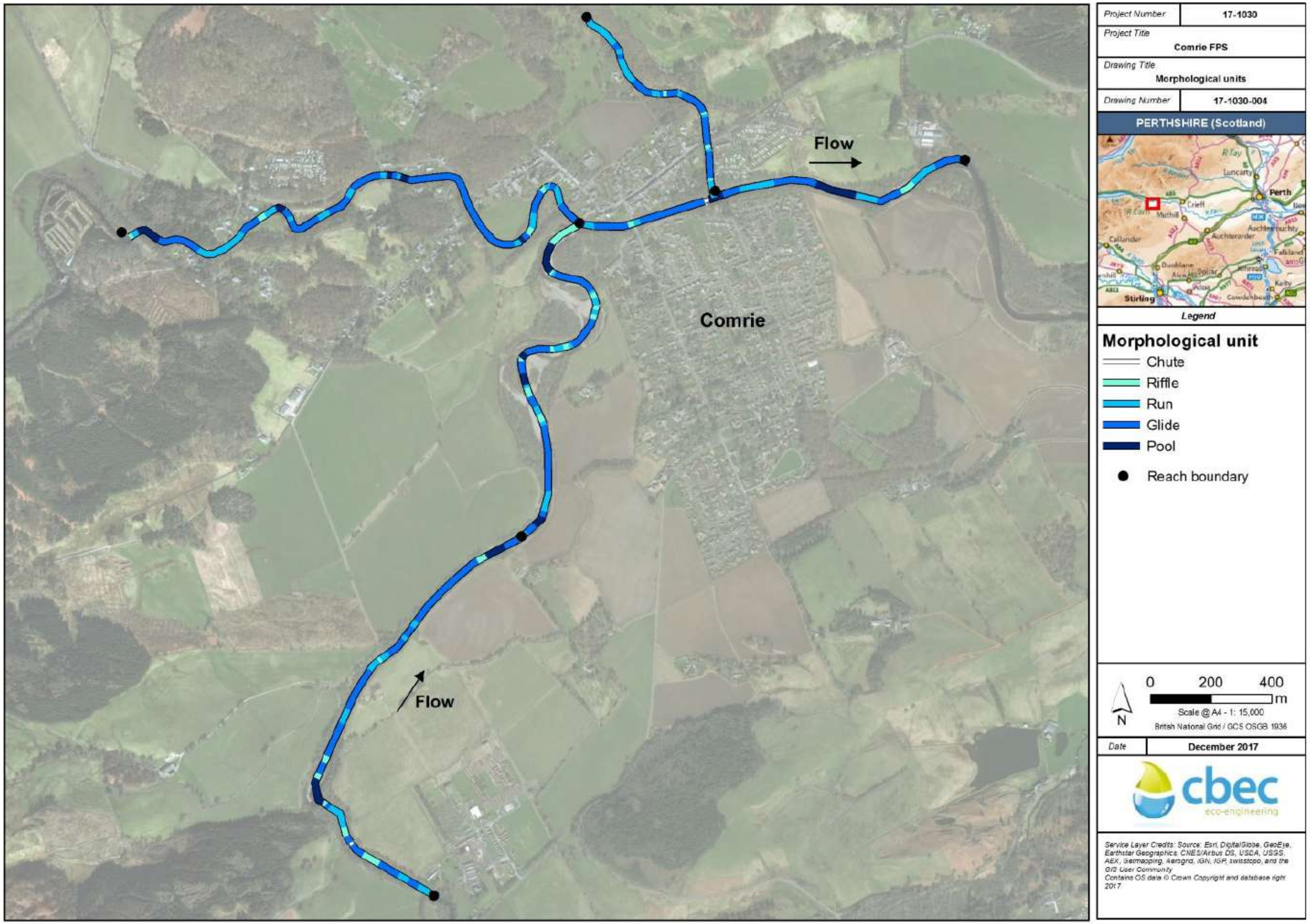

Figure 2.4 Morphological units

2.1.1. Reach 1 (River Earn – upstream)

Table 2.1: Reach 1 engineering pressures and physical characteristics.

Reach	**1**
Length (m)	1975
Setting	Moderately confined valley and floodplain. Land use dominated by woodland upstream, and infrastructure relating to Comrie town towards downstream extent.
Morphological pressures	• One stone weir towards the upstream extent of the reach, with an irregular face, resulting in ~50 m of upstream impounded flow. • Several sections of piled stone and stone/ flood wall along the banks, particularly in the downstream section of the reach, protecting the A85 main road and residential/ commercial properties but confining the river within its current alignment. • One stone arch bridge (Bridge of Ross). • Section of river immediately upstream and downstream of the bridge appears to have been realigned historically. • Large (~7 m tall) setback embankment at upstream end of the reach, associated with an old, disused railway. • Two minor embankments (~0.5 m high) along field boundaries. • Small sections of Invasive Non-Native Species (INNS) rhododendron recorded within middle section of reach.
Physical behaviour and characteristics	• A moderately confined valley and limited floodplain (increasing towards downstream end of reach). • Reach alternates between pool-riffle, plane bed, and pool-riffle / plane bed transitional typologies, indicating moderate topographic diversity in bed and repeating bedforms. • One small section of slow glide attributable to impounded flow from the weir structure. • Intermittent sections of bedrock-dominated bed occur throughout the reach, with overlying gravels/ sand and cobbles. • Bedrock outcrops observed within the lower section of the reach are a result of incision of the bed, caused by confinement of the channel within its current course. • Boulders were present in the bed in places. • Morphological units within the reach alternate mainly between glides and runs, with a small number of pools and poorly defined riffles.
Additional comments	Photos for this reach are provided in **Figure 2.5**.

Figure 2.5 Survey photos from mainstem River Earn (upstream). Top left: significant gravel/ cobble deposition, bottom left: stone wall bank protection aligning road on left bank, top right: low embankment on left bank bordering pastoral land, bottom right: section of bedrock outcrop on approach to Water of Ruchill confluence, with some coarse cobble deposition, and large rip rap bank protection on right bank (view upstream)

2.1.2. Reach 2 (River Earn – downstream)

Table 2.2: Reach 2 engineering pressures and physical characteristics.

Reach	2
Length (m)	1390
Setting	Wide alluvial floodplain within an urban and agricultural setting.
Morphological pressures	• A major weir structure with irregular rock face spans the width of the channel upstream of the Lednock Burn confluence. This is causing an extended section of impounded flow, with associated impact on channel bed structure/ morphology and interruption to downstream sediment transfer. Not a barrier to fish passage. • Bank protection (piled stone) is extensive between Dalginross Bridge and the Lednock confluence (particularly on the left bank). • ~1 m embankment on the right bank downstream of Comrie Holiday Park. • Evidence of Japanese knotweed along left bank downstream of the Lednock confluence (recent signs of treatment).
Physical behaviour and characteristics	• Low gradient channel set within a wide valley and alluvial floodplain. • Reach type was predominantly slow glide, indicating reduced complexity of bedforms throughout this section of river. • The substrate largely comprised cobbles, gravels and sand (the latter particularly evident within channel margins downstream in the reach). • Very limited sediment storage was evident in the upper half of the reach. Old maps indicate large alluvial bar features within a wider channel (the Water of Ruchill being a main source of input). Lack of accumulated material could be a result of the historic and recent works on the Water of Ruchill, which have resulted in significant deposition within the tributary, and a reduced capacity for sediment transport out of the tributary. • Bar formations become more frequent towards the downstream extent of the reach as sinuosity increases slightly. • Two instances of moderate bank erosion on the left bank. Banks mainly stable with continuous mature trees and shrub coverage.
Additional comments	Photos for this reach are provided in **Figure 2.6**.

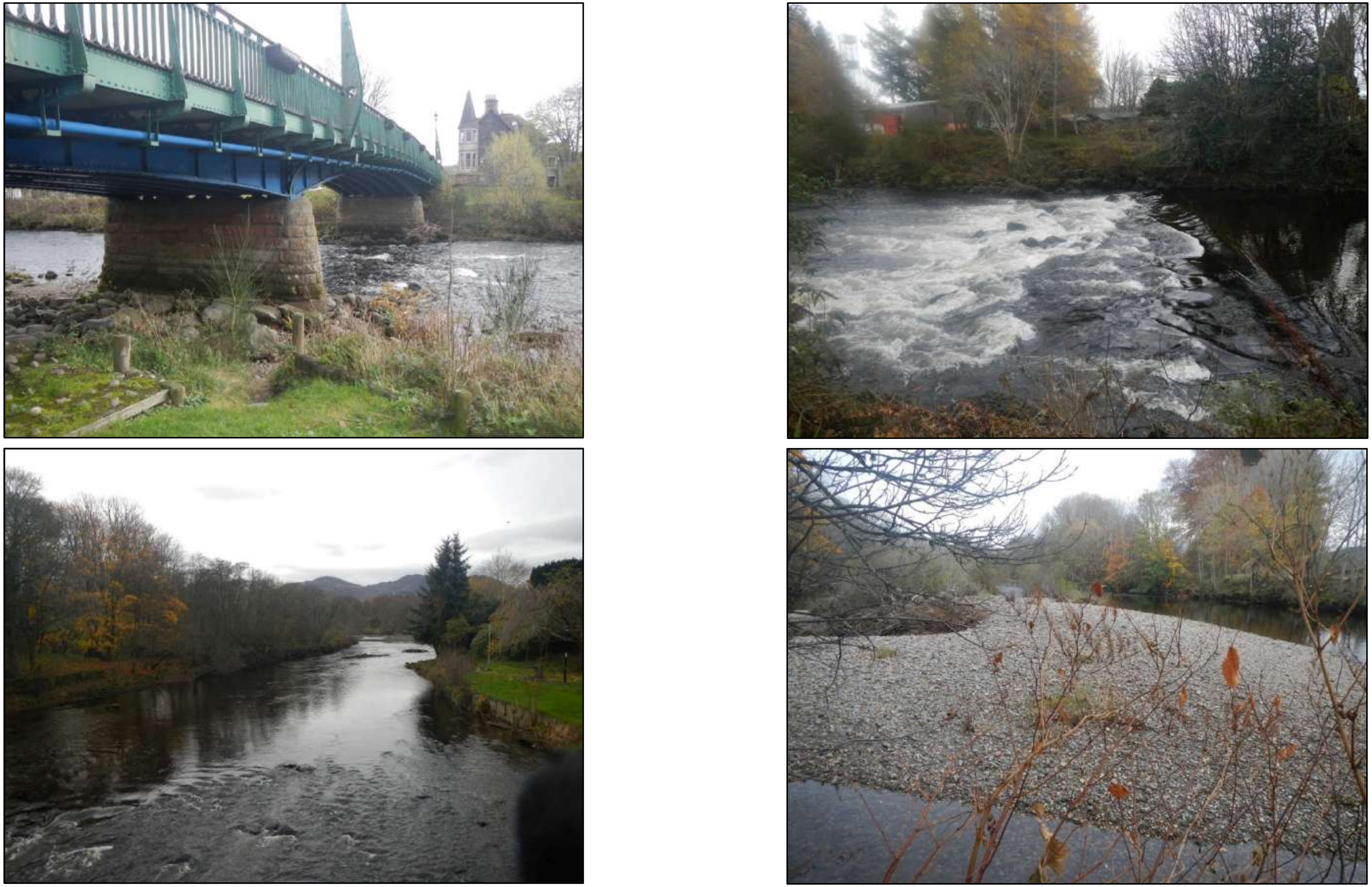

Figure 2.6 Survey photos from mainstem River Earn (downstream). Top left: Two pier Bridge of Dalginross, bottom left: view upstream from bridge, towards Water of Ruchill confluence, top right: large rock weir spanning width of channel, bottom right: large, localised unstabilised deposition at downstream end of reach).

2.1.3. Reach 3 (Water of Ruchill – Cultybraggan to Ruchilside)

Table 2.3: Reach 3 engineering pressures and physical characteristics.

Reach	3
Length (m)	1700
Setting	Alluvial valley with grazing and arable land on floodplain.
Morphological pressures	• Likely to have been historically straightened/ realigned[4] for agricultural purposes within the middle and lower sections of the reach. The channel is lined with mature trees, with associated root systems providing stability to the banks. • Area of bank protection at downstream extent of the reach in a location which has suffered significant erosion (erosion evident immediately downstream of bank protection). • Lack of tree cover along left bank at downstream end of reach, which has led to destabilisation of the bank and a subsequent increase in erosion here.
Physical behaviour and characteristics	• Moderate gradient channel within a wide alluvial valley. • Moderate valley confinement on the left bank towards the upstream extent of the reach. • Reach type was predominantly cascade within the upper half of the reach, which co-incides with a bed consisting largely bedrock and coarse cobble. • Two localised areas of deposition, one upstream at a location where the channel splits into two threads around a stabilised island feature, and one downstream where sediment has been deposited as lateral barforms on both banks. • Further downstream, reach type transitions to plane bed, with substrate a combination of cobble (dominant) with gravels and sand. • Some localised instances of bank erosion and deposition observed within this reach. Towards downstream extent of the reach, significant erosion is occurring on the left bank, contributing cobbles/ gravels and sand to the channel in this area. • Continuous tree cover was noted on both banks throughout the reach, with coverage denser in some localised areas than others. • Less diverse morphology within the lower two thirds of the reach, reflected in the alternating glide and run units which dominate this section.
Additional comments	Photos for this reach are provided in **Figure 2.7**.

[4] Realignment pre-dates oldest available maps.

Figure 2.7 Survey photos from Water of Ruchill (Cultybraggan to Ruchilside). Top left: bedrock dominated reach, bottom left: tree-lined, stable banks, top right: low gradient arable land in right bank floodplain, bottom right: severe bank erosion on left bank at downstream end of the reach (view upstream).

2.1.4. Reach 4 (Water of Ruchill – Ruchilside to River Earn confluence)

Table 2.4: Reach 4 engineering pressures and physical characteristics.

Reach	4
Length (m)	1450
Setting	Wide, low gradient alluvial valley, with Comrie village located on right bank at downstream extent of reach.
Morphological pressures	• Significant embankments and previously dredged material located along banks in downstream half of reach. • Extensive length of rip rap bank protection on the right bank in the upper section of the reach, with associated j-vanes in channel aimed at deflecting flow towards the centre of the channel, decreasing potential for future erosion of the right bank. • Complete lack of mature/ established vegetation in this section of right bank at the upstream extent of the reach, with top of bank dominated by grasses only. • Hard bank protection placed in right bank in two places with the aim of minimising risk from lateral channel migration, protecting local infrastructure. • Gravel extraction (licenced) ongoing within the lower extents of the reach. • Evidence of previously felled trees from river banks, exacerbating erosion of banks particularly on the left bank. • Over-widened channel in downstream section of reach encouraging further sediment build up and shallowing of channel. • Flood wall on right bank set-back from river channel, protecting local housing. • A small patch of Japanese knotweed was noted within the middle section of the reach.
Physical behaviour and characteristics	• Moderate/ low gradient channel within a wide alluvial valley and floodplain. • This section of the Water of Ruchill is generally set within relatively erodible superficial geology (dominated by wide alluvial deposits and laterally constricted by river terraces and glacio-fluvial deposits), resulting in a relatively low threshold for geomorphic change. • Multi-thread channel throughout the downstream extent of the reach, with some old channels significantly aggraded with coarse cobble/ gravel material, and others wetted. • Reach type was pool-riffle throughout, indicating topographic diversity in the bed and repeating bedforms. • This reach is a significant zone of sediment storage, with extensive, alternating alluvial bar features and flood deposits. • Multiple cases of severe bank erosion were observed throughout the reach. Additionally, evidence of erosion of previously dredged gravel heaps evident. • The substrate was cobble dominated, with gravels and sands, fining on approach to the confluence. The bed generally appeared mobile.

Reach	4
	• Bank cover is predominantly woodland vegetation, with localised areas of less dense tree cover. • Large wood recruitment in-channel evident throughout dynamic section of reach. • The reach displays evidence of active sediment recruitment, transfer and storage processes that contribute to channel evolution and lateral migration.
Additional comments	Photos for this reach are provided in **Figure 2.8** and **Figure 2.9**.

Figure 2.8 Survey photos from Water of Ruchill (Ruchilside to River Earn confluence). Top left: extensive rip rap bank protection and in-channel j-vanes, bottom left: large lateral bar feature on left bank, top right: significant volumes of accreted cobble/ gravel alluvial material, bottom right: existing flood wall on right bank.

Figure 2.9 Survey photos from Water of Ruchill (Ruchilside to River Earn confluence) continued. Top left: extensive rip rap bank protection in right bank, bottom left: Major breach of vegetated, stabilised bank, with new channel formed to the right of the breach and large wood recruitment (view upstream), top right: significant bank erosion on left bank, bottom right: wide and overly shallow/ aggraded channel on approach to confluence.

2.1.5. Reach 5 (Lednock Burn)

Table 2.5: Reach 5 engineering pressures and physical characteristics.

Reach	5
Length (m)	810
Setting	Narrow valley and floodplain. Land use dominated by woodland upstream, and infrastructure relating to Comrie village downstream.
Morphological pressures	• One concrete weir (not intact) for a former mill, situated on a bedrock outcrop at the upstream extent of the reach. • Two bridges (one footbridge, one road bridge), both with abutments. • Multiple cases of bank protection (piled stone and intact stone wall) throughout the reach. • Historic narrowing/ straightening of the channel towards the downstream extent of the reach on approach to the River Earn. The burn is now incised, and banks are now stabilised with mature vegetation.
Physical behaviour and characteristics	• Moderate gradient channel within a narrow valley of glacial till, widening into an alluvial valley with river terrace deposits on approach to the River Earn. • Reach type was step-pool/ cascade within the higher gradient upstream extents of the reach, transitioning to plane bed/ pool riffle further downstream. • The substrate was coarse boulder and cobble, reducing in coarseness to cobble/ gravel further downstream and towards the confluence. • One significant section of bank erosion on the left bank upstream of the footbridge, posing potential risk to single building adjacent to the bank. • Minor evidence of any further bank erosion within the Lednock was attributed to the continuous mature vegetation along the lower extents of the burn, acting to stabilise both banks. • Two areas of cobble/ gravel deposition were noted within the middle section of the reach. This, in addition to the channel gradient, suggests that sediment transport processes dominate this reach. • Morphological units were predominantly glides and runs, with minor insipient riffle features forming further downstream within the reach.
Additional comments	Photos for this reach are provided in **Figure 2.10**.

Figure 2.10 Survey photos from Lednock Burn. Top left: weir structure at upstream extent of reach, bottom left: coarse deposition and view of wooded riparian zone, top right: significant bank erosion on left bank upstream of footbridge, bottom right: view downstream from footbridge showing medial bar feature comprised cobble.

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Appendix B – RBMP Assessment Report

Date:	18.04.18
To:	Stephen Hughes, Sweco
From:	Fiona Thompson, cbec eco-engineering UK Ltd
Project:	Comrie Flood Protection Scheme
Subject:	RBMP Assessment (Task 80 of Scope Document)

1. ASSESSMENT OF RBMP STATUS AND LIKELY IMPACTS

This brief report/ technical note provides an assessment of the potential impacts of the proposed flood defence measures at Comrie (Perthshire) on the four intersecting water bodies at the town on achieving of RBMP objectives set out by the Water Framework Directive (WFD). WFD requires that all European Union (EU) members achieve 'good status' for all ground and surface water bodies. The criteria used to assess surface water bodies are biological, hydromorphological, physio-chemical and chemical quality. Water bodies need to achieve good status in all categories to achieve 'good status' overall. If the proposed works lead to a downgrade in hydromorphology, there is the potential to downgrade the overall water body status, ultimately contributing to Scotland failing to achieve its WFD objectives in the affected water bodies.

The four water bodies which will be influenced by the proposed Flood Protection Scheme (FPS) at Comrie are the Water of Ruchill (ID 6817), River Earn from Loch Earn to Water of Ruchill confluences (ID 6839), and the River Earn from the Water of Ruchill confluence to Ruthven Water confluence (ID 6838) and Lednock Burn (ID 6816). To determine whether each of the water bodies will be downgraded, SEPA will use their Morphological Impact Assessment Tool (MImAS). The tool currently allows for the calculation of a 'capacity used' score for each water body, based on the type and length of different engineering pressures present along the length of each.

Current RBMP classifications for the four water bodies influenced directly by the proposed FPS are provided in Table 1.1. A subsequent qualitative assessment of the proposed Comrie flood protection scheme on these aspects of the RBMP objectives was undertaken for each water body, the findings of which are summarised in Tables 1.2 - 1.5. For the purposes of this report, the assumption is that the proposed flood scheme is to build a flood wall and embankments around the town of Comrie as shown in Appendix 1 Mouchel, 2016).

Table 1.1 Current Water Body RBMP Classification (latest classification 2014)

Water body:	Water of Ruchill	R.Earn (u/s – 6839)	R.Earn (d/s - 6838)	Lednock Burn
Overall Status:	Good	Moderate	Good	Moderate
Access for Fish Migration:	High	High	High	High
Water Flows and Levels:	High	Good	Good	Moderate
Physical Condition:	Good	Good	Good	High
Freedom from Invasive Species:	High	Moderate	High	High
Water Quality:	Good	High	Good	High

Table 1.2 Water of Ruchill: Assessment of potential influence of Comrie FPS on RBMP Objectives

Water body/ ID:	**Water of Ruchill (6817)**
Potential Impact on Reference Conditions[1]:	• The Water of Ruchill at the town of Comrie has a wandering channel morphology, meaning that it actively migrates across its floodplain reworking alluvial material which is deposited from upstream and eroding banks. Given that the proposed flood scheme will not confine the channel along the left bank and channel confinement will be minimised along the right bank (i.e. by setting back the floodwall and embankments from the bank top) the probability of the reference condition of the Ruchill being altered by the proposed flood scheme measures is low. • Upstream the channel appears more stable, with intermittent bedrock providing some bed stability and base level control. The channel flows through a steep confined valley with a plane-bed/ step-pool morphology and is unlikely to be impacted by the proposed works.
Potential impact on current WFD classification/ water body status:	• The Water of Ruchill has a MImAS 'capacity used' score of 21 %, meaning there is only an additional 4 % of capacity available before the water body will be downgraded for morphology. The overall status of the Water of Ruchill is 'good', meaning that a downgrade in morphology would result in the WFD status of the water body being reduced from 'good' to 'moderate'.
Potential Impacts on WFD Classification Elements:	• The implementation of a flood wall is likely to have a very limited impact on fish passage. • Minimal change to rural diffuse pollution as the floodwall will not be placed on agricultural land. • Invasive species have been noted within the catchment (i.e. on the Upper River Earn). Good working practices should ensure no spread of invasive species along the water body. • Floodplain connectivity will be reduced along the right bank, leading to a potential reduction in floodplain biodiversity.
Additional Considerations	• The river is actively eroding into the right-hand floodplain and bank protection has been put in place to prevent further erosion. It is essential to ensure that this bank protection is well maintained. To achieve this, one method would be to taper out the severity of the bank protection (e.g. reducing the size of the material comprising the protection works), ensuring there are no abrupt changes in bank texture and strength. Many potential undermining of the bank

[1] Reference condition here refers to the channel current post works reach type.

	protection means bank erosion could continue to toward the base of the flood wall. If the right bank was to migrate towards the flood wall further, lateral adjustment would be restricted, encouraging vertical adjustment and the formation of a pool. Vertical erosion would increase the potential for the floodwall to become undermined during a higher magnitude (> 1:10 year) flood event. If the floodwall did become unstable its integrity could be compromised, increasing flood risk to the town. It would be recommend that 2D hydraulic/ sediment transport modelling is undertaken to assess hydraulic forces acting on the channel boundary throughout this dynamic reach. Over much longer time scales (> 20 years) as the river adjusts and reworks sediment delivered from upstream the main channel may revert to its former alignment running primarily along the left bank reducing erosion pressure along the right bank. • Flood walls being set-back from the channel will limit the impact on morphological processes and give the channel more space to naturally migrate across its floodplain. • To reduce the likelihood of the water body being downgraded it is recommended that the floodwall is set back from the bank top as much as possible and hard bank protection measures avoided in preference of 'soft-engineering'/ 'green' alternatives such as large wood structures.

Table 1.3 River Earn (Loch Earn to Water of Ruchill Confluence): Assessment of potential influence of Comrie FPS on RBMP Objectives

Water body/ ID:	River Earn (Loch Earn to Water of Ruchill Confluence) (6839)
Potential Impact on Reference Conditions:	• There is limited potential for the reference condition (active meandering) of the water body to be modified as a result of the proposed works. The channel throughout this reach is relatively stable in parts, and in others is already confined by a mixture of commercial and residual infrastructure. • Locations where the proposed flood wall is to be placed along the bank top, lateral adjustment will be restricted, reducing rates of input of alluvial material from the river banks and impacting meander evolution.
Potential impact on current WFD classification/ water body status:	• The River Earn from Loch Earn to the Water Ruchill currently has a MImAS capacity used score of 8%, representing 'good' status for hydromorphology. Whilst the proposed floodwall embankment is unlikely to downgrade the status of the water body, it will increase this 'capacity used' figure. • A high presence of invasive species on the River Earn means the overall water body status is 'moderate'. Care needs to be taken to limit further spread of invasive species along the River Earn during construction, as this poses risk of further reducing the water body status.
Potential Impacts on WFD Classification Elements:	• The implementation of a flood wall is likely to have a very limited impact on fish passage under normal flow conditions. • The potential for change to levels of rural diffuse pollution is minimal. • Good working practices should ensure no spread of invasive species. • In areas where the flood wall is located along the bank top, floodplain connectivity will be restricted, reducing heterogeneity, productivity and biodiversity in such areas. In doing so, this will diminish the ecological integrity of the riparian margins.
Additional Considerations	• The proposed floodwall will reduce floodplain connectivity and increase channel confinement downstream of the Earn/ Ruchill confluence, particularly during higher magnitude flood events (> 1:50 year). The increase in channel confinement may result in a backwater effect upstream from near the Earn/ Ruchill confluence Earn during higher magnitude flow events when the channel would have historically flooded its floodplain. A backwater effect would reduce flow velocity and increase sediment deposition in this area.

	• Morphodynamic modelling is recommended to assess the sediment dynamics throughout the study reach under a range of flows.

Table 1.4 River Earn (Water of Ruchill to Ruthven Water Confluence): Assessment of potential influence of Comrie FPS on RBMP Objectives

Water body/ ID:	River Earn (Water of Ruchill to Ruthven Water Confluences) (6838)
Potential Impact on Reference Conditions:	• The reference condition for the River Earn is active meandering. If the flood wall will be less than one channel width back from the channel in most locations along this reach there is likely to be some degree of impact to lateral physical process and a reduction in floodplain connectivity (albeit this not likely to be significant). • Setting back the flood wall from the bank top means the effect on the long-term 'channel forming' flow (often estimated as being the 1:2-year return interval flood) is limited, resulting in the current channel morphology being maintained.
Potential impact on current WFD classification/ water body status:	• The River Earn from the Ruchill to Ruthven confluences currently sits at 'good' status for hydromorphology, with a MImAS capacity used score of 14%. The significant length (approximately 650 m) of floodwall along both banks of the channel means the potential for this water body to be downgraded for morphology is moderate. • A downgrade in morphology would result in the downgrade of the entire water body.
Potential Impacts on WFD Classification Elements:	• The implementation of a flood wall is likely to have a very limited impact on fish passage under normal flow conditions. • The proposed scheme will also have minimal impact to levels of rural diffuse pollution. • Good working practices should ensure no spread of invasive species. • In areas where the flood wall is located along the bank top, floodplain connectivity will be restricted reducing heterogeneity, productivity and biodiversity and in doing so diminish the ecological integrity riparian margins.
Additional Considerations	• During high magnitude flood events, the channel through this section will be highly confined, likely leading to higher velocities and increased rates of bedload transport through the town of Comrie compared to unprotected (i.e. existing) conditions). Downstream of the floodwall where channel confinement decreases and floodplain connectivity is maintained, there will be increased potential for sediment deposition as energy reduces here. This would likely be associated with enhanced lateral channel migration in this reach. • During large flood events, there is also the potential for increased erosion along the river banks within the area immediately

	downstream of the flood wall (i.e. due to likely higher velocities as a result of the flood protection works). • Morphodynamic modelling is recommended to assess the sediment dynamics throughout the study reach. • The geomorphic walkover highlighted the presence of Japanese Knotweed along the left bank close the proposed floodwall locations. Extreme care would need to be taken to ensure the implementation of the floodwall did not increase the spread of INNS along this bank.

Table 1.5 Lednock Burn: Assessment of potential influence of Comrie FPS on RBMP Objectives

Water body/ ID:	Lednock Burn (6815)
Potential Impact on Reference Conditions:	• The upper reach of the Lednock Burn has a steep cascade/ step-pool morphology and is very stable. It is therefore unlikely to undergo any morphological adjustment due to the proposed flood scheme. • Although the lower reach of the Lednock Burn will be more constrained by the presence of the flood walls along the bank top, the reach morphology is expected to remain as plane bed/ pool-riffle.
Potential impact on current WFD classification/ water body status:	• The Lednock Burn currently has a MImAS capacity used score of 2% meaning the water body sits at 'high' status for morphology. The proposed floodwalls along the Lednock Burn would be likely to downgrade the water body to 'good' status for morphology. Although a downgrade in morphology is not encouraged, a relegation from 'very good' to 'good' would not result in the Lednock Burn failing WFD for morphology. • The current overall water body status of the Lednock Burn is moderate for water levels, so no downgrade in overall WFD status is predicted.
Potential Impacts on WFD Classification Elements:	• The implementation of a flood wall is likely to have a very limited impact of fish passage during normal flows. • Minimal change to rural diffuse pollution as the floodplain will not be placed along agricultural land. • Good working practices should ensure no spread of invasive species. • Floodplain connectivity reduced along the left and right bank, which will potentially reduce floodplain biodiversity.
Additional Considerations	• The proposed floodwalls at the downstream extent of the Lednock Burn will increase channel confinement through this area. In this location, where the channel meets the River Earn, there is the potential during over bank flows (i.e. flows where water will be between the bank and the flood wall) for water levels to increase due to the reduction in the width of the river corridor. This would need to be confirmed through 2D hydraulic modelling.

2. SUMMARY OF CUMULATIVE IMPACTS OF MULTIPLE FLOOD MITIGATION MEASURES

The implementation of the proposed floodwall and embankments around the town of Comrie to protect it from future flooding, has the potential to downgrade at least two of the four waterbodies which intersect at Comrie. Specifically:

- The Lednock Burn is very likely to be downgraded from 'high' status to good, and
- The Water of Ruchill has the potential to be downgraded from 'good' status to 'moderate' status.

A downgrade from 'high' to 'good' morphological status on the Lednock Burn would not negatively impact the ability to achieve an overall 'good' status (i.e. in line with WFD objectives) as it currently has an overall water body classification of 'moderate'. A morphological downgrade from 'good' to 'moderate' status on the Water of Ruchill would result in an overall water body downgrade from 'good' to 'moderate' and this water body failing to achieve its WFD objective. The River Earn from Loch Earn to the Water of Ruchill confluence and from Water Ruchill confluence to Ruthven confluence is unlikely to be downgraded from the proposed works. However, the additional MImAS 'capacity used' to implement the flood scheme along both these water bodies would limit the potential for any future work to be undertaken without a significant risk of water body downgrade. To ensure morphological impacts across all water bodies are kept to the minimum, it would be recommended to set-bank embankments and flood walls as much as possible and use greener/ soft-engineering bank protection measures (that may be more physically appropriate in some locations).

During higher magnitude flow events where the out of bank flow is restricted due to the flood walls or embankments, in-channel fluvial processes have the potential to be enhanced. The presence of flood walls through the town of Comrie will result in increased channel confinement and a significant reduction in floodplain connectivity. The loss of floodplain connectivity means that, during high magnitude events, water cannot spill onto the floodplain and increased water depths and velocities within the channel are likely through this reach. At higher magnitude flows this could potentially create a backwater effect further upstream near the confluence of the River Earn and Water of Ruchill, potentially reducing channel velocity and increased sediment deposition. A similar backwater effect may also occur upstream of the floodwalls on the Lednock Burn during very high magnitude flood events (1:100 year) where the channel is constrained by the protection works. This is less likely to happen at lower flood magnitudes (i.e. 1:2 year return interval and smaller) where floods water will remain in the channel or can still flood the floodplain in front of the flood wall. To accurately determine the nature of these processes, and estimate the response of the river to physical changes as a result of the FPS, 2D hydraulic modelling would be recommended (potentially also sediment transport/ morphodynamic modelling).

Due to the presence of invasive non-native species (INNS) located in some areas along the banks, care would need to be taken to ensure that these species are not spread further within the catchment through the implementation of the flood scheme. The spread of these species would also increase the MImAS capacity used score and thus increase the likelihood of a water body downgrade for morphology. An increase in the extent and density of INNS could lead to a water body downgrade for INNS by the Alien Species Advisory Group (ASG). At present the only the Water Ruchill fails to achieve 'high' status for INNS.

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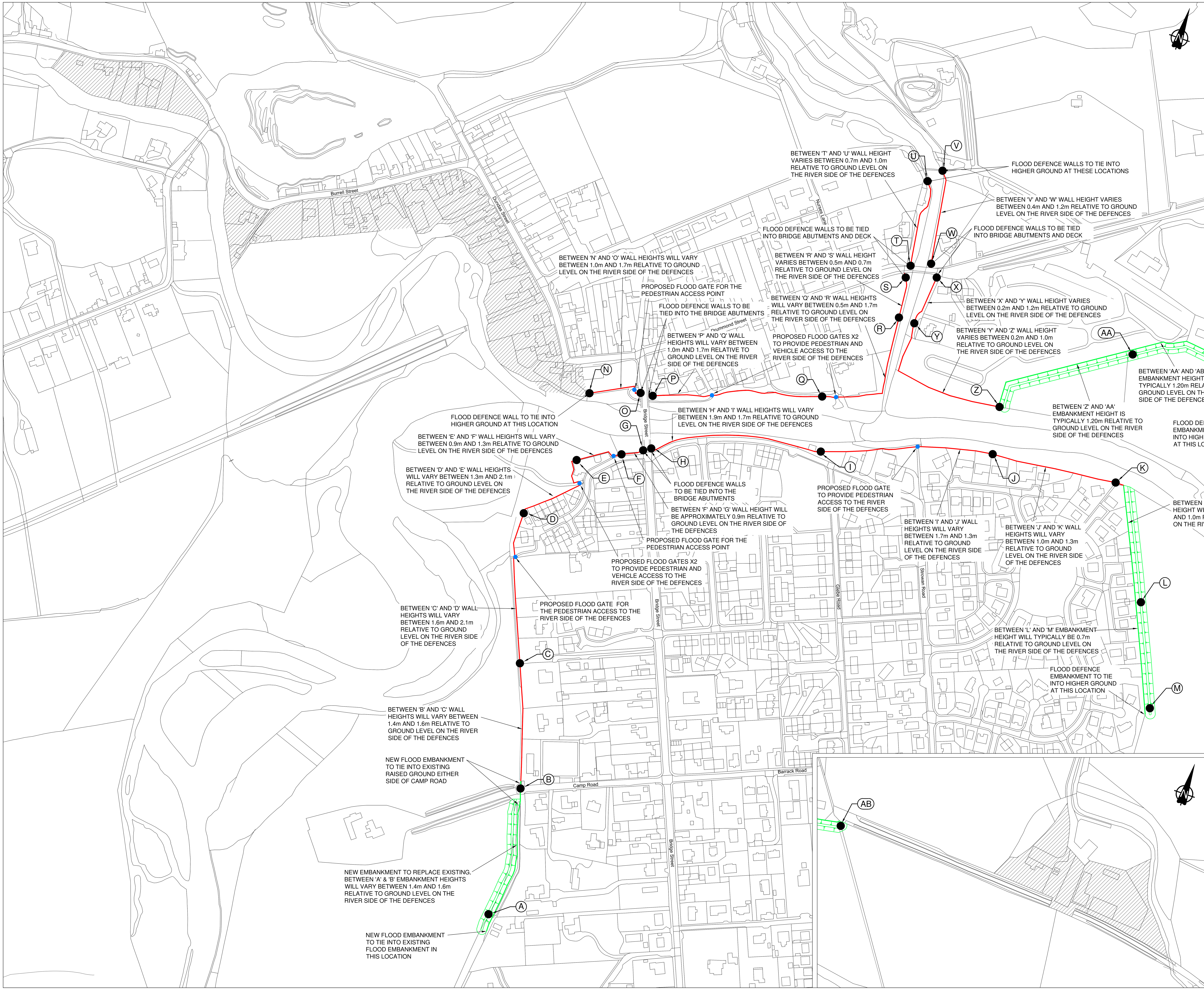
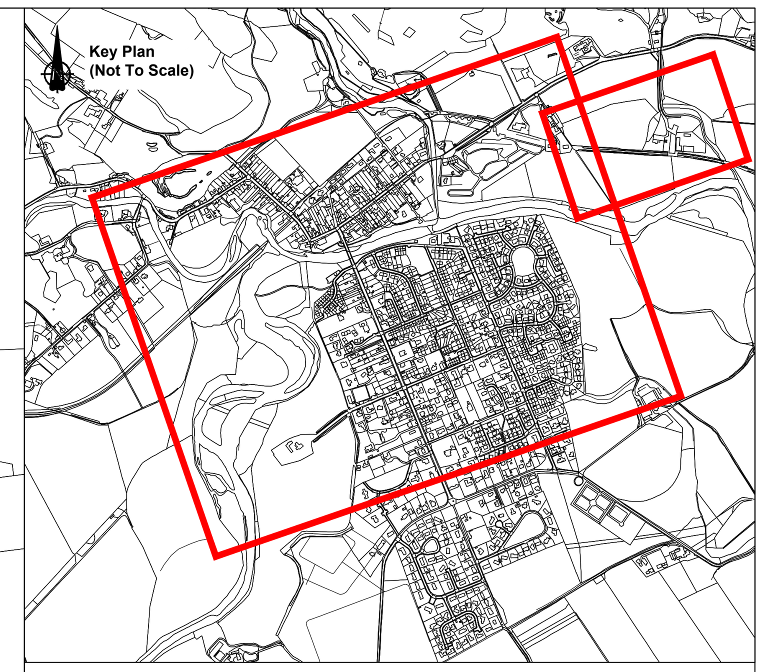
APPENDIX 1

Comrie and Dalginross Flood Defence Scheme - Traditional Wall and Embankment Proposal

Undertaken from: Comrie Flood Protection Scheme, Feasibility Study Report (DRAFT), produced for Perth and Kinross Council by Mouchel Ltd, December 2016





KEY

- Earth Embankment
- Flood Wall
- Local defences will be required within the property boundary or property level protection will be implemented. This will be confirmed in the next phase of the study.
- Flood Gates
- Cross Section Location

Rev	Date	Description	By	Ch'd

Client

PERTH & KINROSS COUNCIL

mouchel
building great relationships

Status

DRAFT

Project

Comrie & Dalginross
Flood Defence Scheme

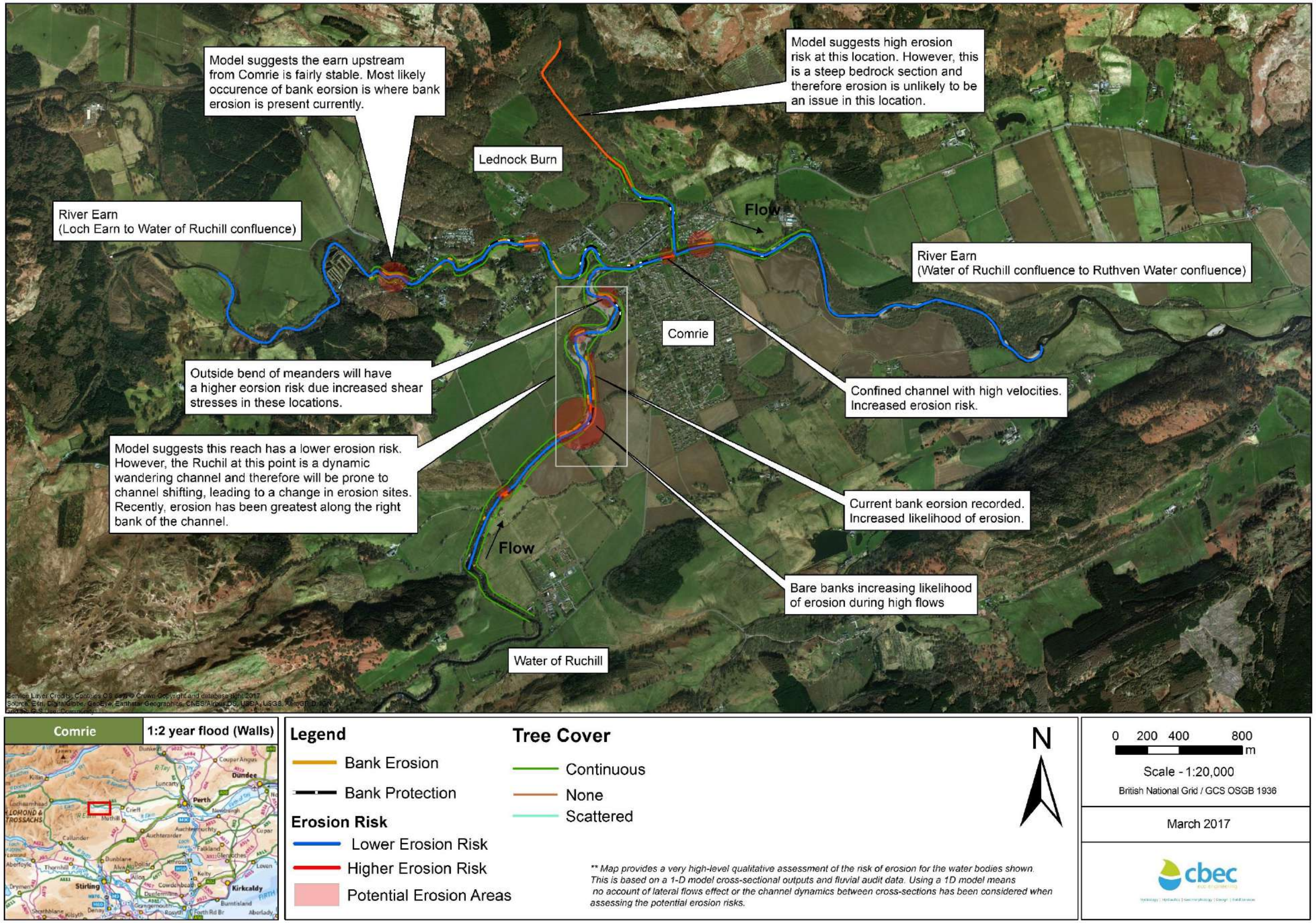
Title

Traditional Wall and Embankment
Sheet 1 of 1 - Plan

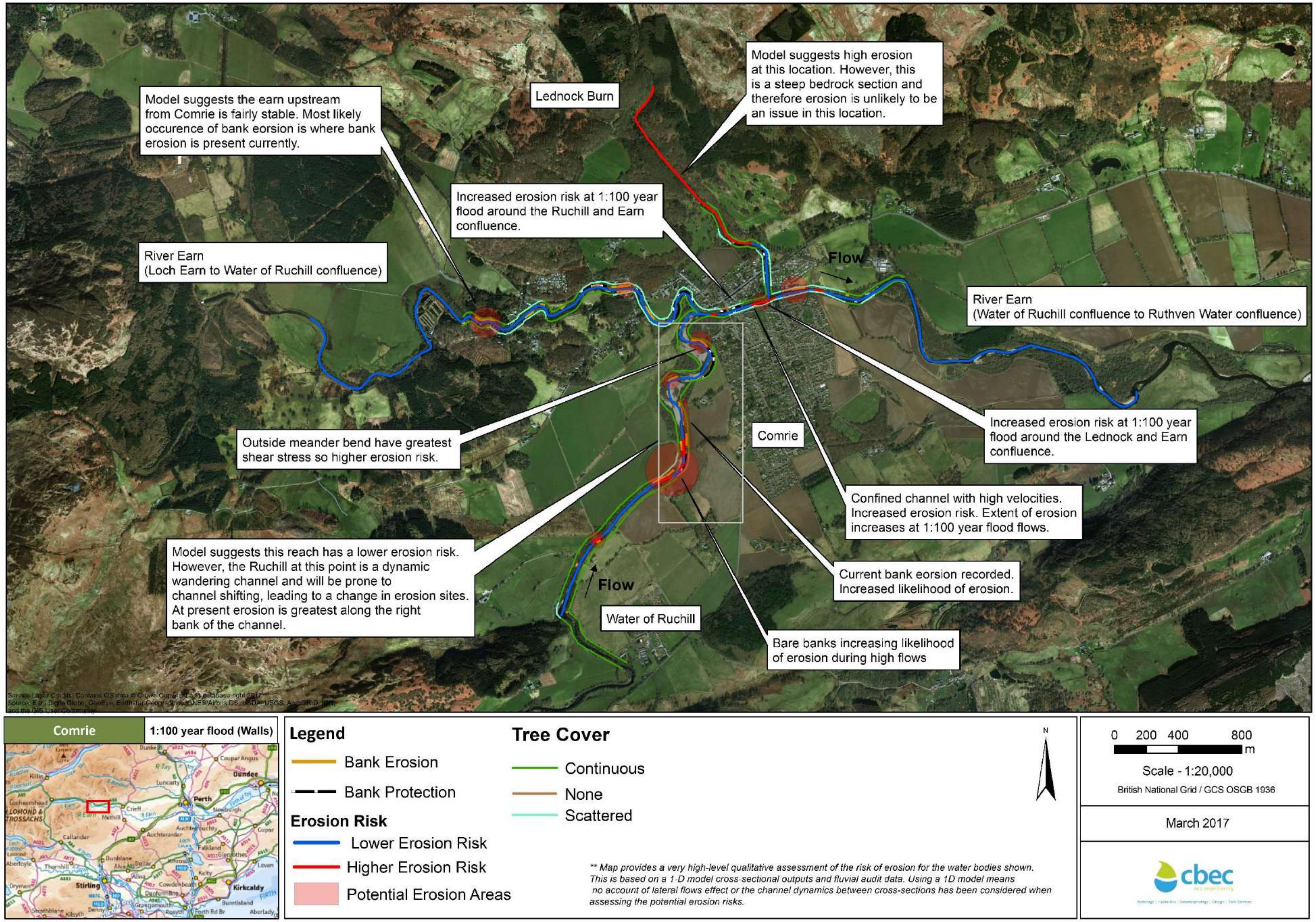
Drawn	SP	Date	15/10/2015
Checked	AW	Scale	Plan 1:2000
Approved	PS	Sheet No.	1 of 1
Drawing No.	1069622-009-003	Rev	A

Original Drawing Size: A1 Do not scale this drawing

Appendix C – (A) Scour Mapping for the 1 in 2 Year Flood Event



(B) Scour Mapping for the 1 in 100 Year Flood Event

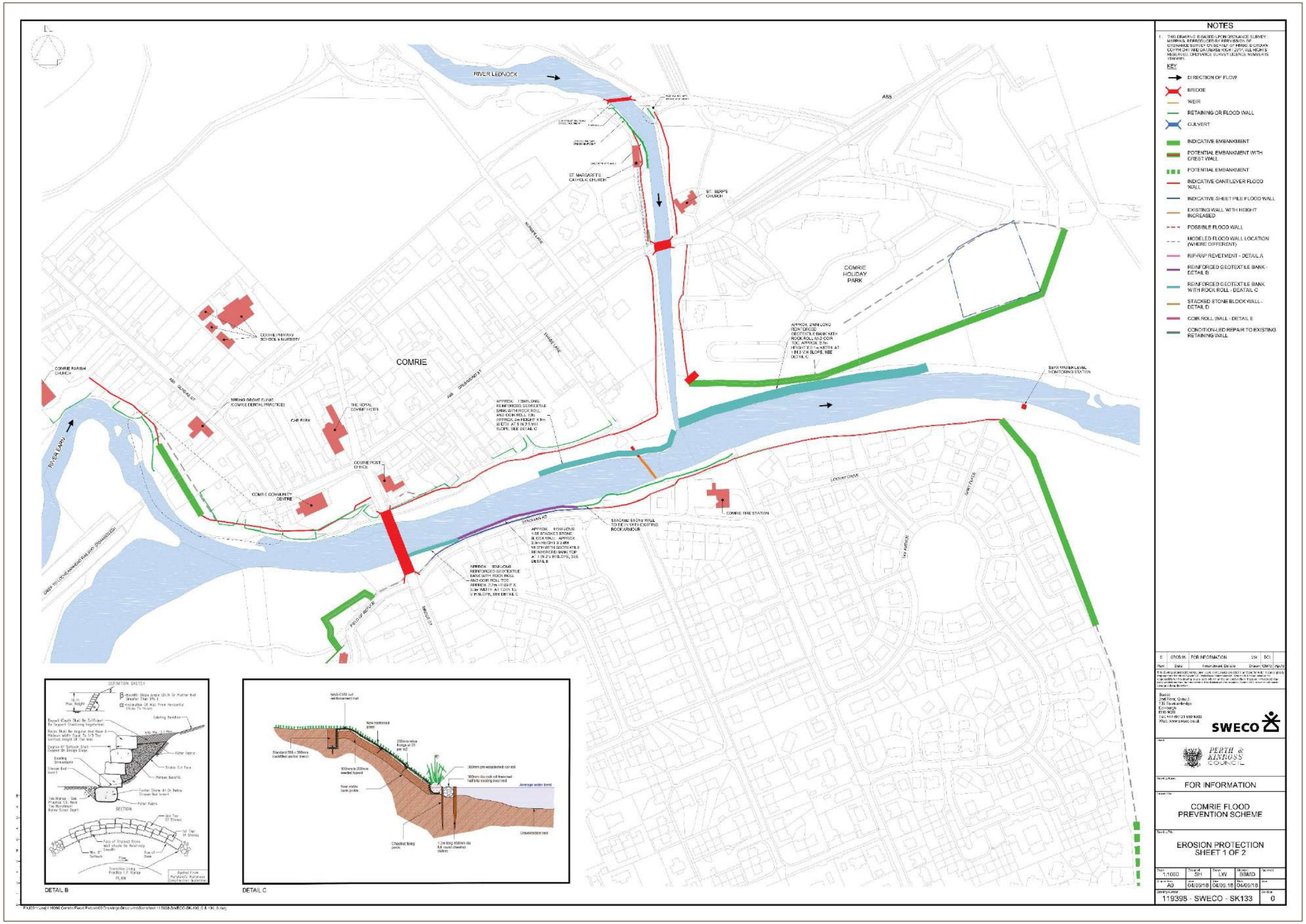


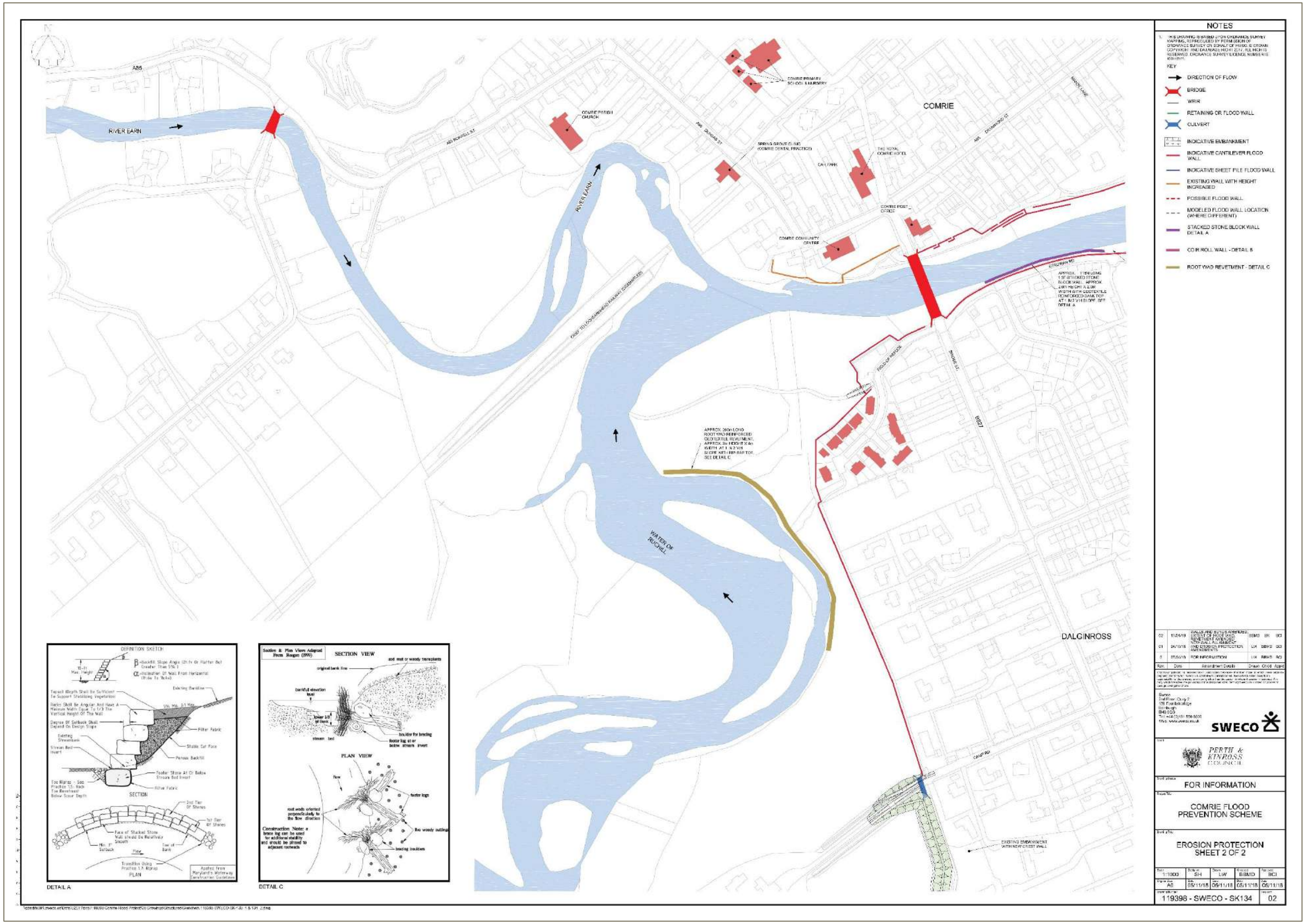
Appendix D – Bank Protection Options Considered for Comrie

BANK PROTECTION OPTION	DESCRIPTION	TYPE	SUITABILITY	ADVANTAGES	DISADVANTAGES
Root Wads	Tree trunks with the roots attached pushed into the bank (trunk first), with the roots exposed. The roots increase bank roughness and therefore dissipate the water energy, sheltering the bare banks.	Green	High velocity	• Useful on meandering or high velocity streams • Habitat creation • less maintenance than simple tree revetment	• Limited life depending on tree species • heavily dependent on correct placement/installation • Disturbed banks can be more prone to erosion • Not suitable for sandy banks (<15% silt/clay)
Tree Revetment	Trees are anchored along the bank to increase roughness and offer resistance to flow.	Green	Medium velocity	• Makes use of available material • Traps sediment, resulting in the bank re-building • Habitat creation • Can provide toe protection	• Risk of downstream blockage • Limited life • Maintenance of cables/ties • Dependent on bank soil strength.
Willow Spilling	Woven, living willow to form flexible, live, growing structures which resist and deflect water flows, enabling the bank and vegetation to naturally re-generate and stabilise to prevent further erosion.	Green	Medium velocity	• Useful on outside of bends • Can be used to form a low wall at slope bottom, • Habitat creation • Useful on small fast flowing streams	• Complex construction • Expensive installation and maintenance • Maximum height approx. 2.4m
Coir Roll Walls	Coir is the stiff fibre from the outside of coconuts. It can be woven and pressed into many shapes including rolls (which are usually compressed into a relatively solid matrix) and matting of various thicknesses.	Green	Medium to low velocity	• Habitat creation • Aesthetically pleasing • Self-stabilising as plant roots will bind soil in bank	• Maximum height approx. 2.5m • Not suitable for fast flowing rivers • Takes time to establish
Biodegradable Geotextiles	Meshes or rolls of natural fibre that protect and stabilise the riverbank while allowing vegetation to grow through.	Green	Low to medium velocity	• Habitat creation • Aesthetically pleasing • Self-stabilising as plant roots will bind soil in bank	• Root zone requires protection • Not suitable for fast flowing rivers • Bank needs to be reprofiled so larger space required (>2m) • Takes time to establish
Re-profiling	Involves excavating and / or filling the raw eroded stream bank to a low gradient slope without either increasing the bank height or the channel width. Use of natural materials (locally sourced earth / vegetation / surface protection as above) only.	Green	Low to medium velocity	• Stabilises bank to prevent collapse	• Larger space required (>2m) • Needs to be combined with another method or there will be increased soil erosion.
Live stakes	Living, woody plant cuttings capable of quickly rooting in moist soils.	Green	Low velocity	• Low Cost • Ease of installation • Self-stabilising as plant roots will bind soil in bank	• Takes time to establish • Requires robust toe protection
Brushwood Mattress	A thick layer of branch cuttings is installed to cover and physically protect stream banks. The mattresses are effective at trapping fine sediment during flooding, and work well on a wide range of steep banks and fast flowing streams.	Green	Medium to high velocity	• Low Cost • Widely applicable	• Can be used below water line if dead material used. • No toe protection provided. • Max 2:1 slope. • May need watering in dry periods. • May need drainage or geotextile
Concrete Retaining Walls	Concrete walls are usually massed structures reinforced with steel. Their durability depends on the composition (cement content and aggregate size/shape/grading) and design.	Grey	High velocity	• Highly durable • Suitable for steep banks with limited space	• Can cause erosion problems downstream
Timer Retaining Walls	Full face placement of timber pilings, stakes or boards placed along the bank.	Grey	Low to medium velocity	• Suitable for steep banks with limited space • Aesthetically pleasing	• Can cause erosion problems downstream • Short design life
Gabion Baskets	Stone-filled mesh structures used to reduce water velocity through friction, which leads to the dissipation of erosive energy. Gabions, are square or rectangular	Grey	Low to medium velocity	• Suitable for steep banks with limited space	• Can cause erosion problems downstream • Often become undermined and spill material

	wire cages filled with stone, which can be stacked vertically				
Stacked Stone Wall	A wall composed of tightly-packed stones.	Grey	High velocity	• Highly durable • Suitable for steep banks with limited space	• Low vegetative establishment • Can be high cost • Can cause erosion problems downstream
Boulder Revetment	Large fragments of quarried rock placed at the toe of banks to protect from erosion.	Grey	High velocity	• Robust toe protection • Easy to install	• Usually needs to be combined with re-profiling • High cost
Rock Armour	Large fragments of quarried rock placed across banks to protect from erosion.	Grey	High velocity	• Highly durable • Flexible • Ease of Placement • Low maintenance	• Can cause erosion problems downstream • High cost • Requires underlayer and/filter layer
Non-biodegradable Geotextiles	Meshes, fabrics and mats made from synthetic material that are designed to stabilise soils. They come in various forms. Those with larger voids are designed to allow vegetation to colonise the exposed surface.	Grey	High velocity	• Highly durable • Easy installation • Can be seeded to provide habitat	• Can be high cost • Specialists required for installation
Rock Vane Deflectors	A low wall built into the channel for the purposes of deflecting flow away from the bank.	Grey	High velocity	• Can be used on meanders and gravel rivers to deflect flow	• Can cause erosion problems downstream • High Cost of Material • Heavy equipment required

Appendix E – Proposed Bank Protection Plan for Comrie




NOTES
1. THIS DRAWING IS BASED UPON ORDNANCE SURVEY MAPPING, REPRODUCED BY PERMISSION OF ORDNANCE SURVEY ON BEHALF OF HMSO. © CROWN COPYRIGHT AND DATABASE RIGHT 2017. ALL RIGHTS RESERVED. ORDNANCE SURVEY LICENCE NUMBER IS
KEY
DIRECTION OF FLOW
BRIDGE
WEIR
RETAINING OR FLOOD WALL
CULVERT
INDICATIVE EMBANKMENT
INDICATIVE CANTILEVER FLOOD WALL
INDICATIVE SHEET PILE FLOOD WALL
EXISTING WALL WITH HEIGHT INCREASED
POSSIBLE FLOOD WALL
MODELED FLOOD WALL LOCATION (WHERE DIFFERENT)
STACKED STONE BLOCK WALL DETAIL A
COIR ROLL WALL - DETAIL B
ROOT WAD REVETMENT - DETAIL C
RIVER EARN
A85
COMRIE
COMRIE PARISH CHURCH
COMRIE PRIMARY SCHOOL & NURSERY
COMRIE COMMUNITY CENTRE
COMRIE POST OFFICE
CAR PARK
WATER OF RUCHILL
DALGINROSS
B827
APPROX. 260m LONG ROOT WAD REINFORCED GEOTEXTILE REVETMENT. SEE DETAIL C
EXISTING EMBANKMENT
DEFINITION SKETCH
SECTION
PLAN
DETAIL A
SECTION VIEW
PLAN VIEW
DETAIL C
02 | 17/04/18 | WALLS AND BUNDS AMENDED, EXTENT OF ROOT WAD REVETMENT AMENDED | BBMD | ER | BCI
01 | 24/10/18 | NEW WALL ALLIGNMENT AND EROSION PROTECTION AMENDMENTS | LW | BBMD | BCI
0 | 07/05/18 | FOR INFORMATION | LW | BBMD | BCI
Rev. | Date | Amendment Details | Drawn | Chcd | Appd
Sweco
Edinburgh
Web: www.sweco.co.uk
SWECO
PERTH & KINROSS COUNCIL
FOR INFORMATION
COMRIE FLOOD PREVENTION SCHEME
EROSION PROTECTION SHEET 2 OF 2
1:1000 | SH | LW | BBMD | BCI
A0 | 05/11/18 | 05/11/18 | 05/11/18 | 06/11/18
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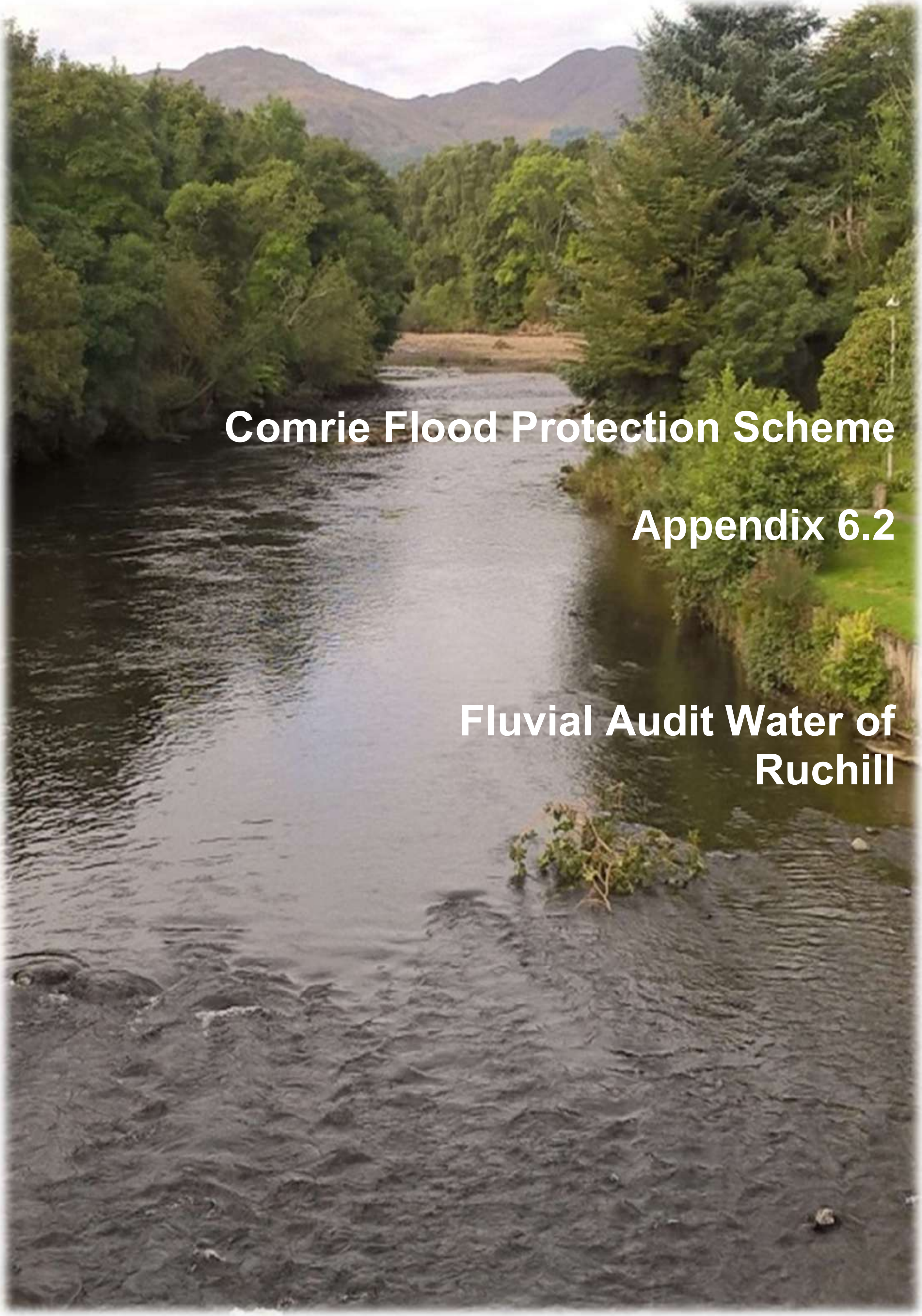

Comrie Flood Protection Scheme

Appendix 6.2

Fluvial Audit Water of Ruchill

Report

Fluvial Audit

Water of Ruchill

Comrie Flood Protection Scheme

Report prepared for Perth and Kinross Council

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[2]	27.02.19	FINAL	ER	27.02.19	JP	28.02.19	JB	28.02.19
[3]	[00.00.00]	[Text]	[XX]	[00.00.00]	[XX]	[00.00.00]	[XX]	[00.00.00]

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Appendices

1 Introduction

Sweco were commissioned by Perth and Kinross Council (PKC) to undertake a fluvial audit for the Water of Ruchill catchment as part of the Comrie Flood Protection Scheme (FPS) project. A fluvial audit is a catchment scale survey technique used to gain a qualitative understanding of the sediment budget and sediment transport through the catchment by identifying sources, transfer pathways and storage areas for sediment. This report describes the methods and results of the Water of Ruchill fluvial audit and makes recommendations of sustainable solutions intended to return the river to a more natural state.

1.1 Background

The Water of Ruchill (Figure 1-1) is a dynamic gravel-bed river which has undergone extensive changes over the past 200 years. Significant modifications have been made to the river, in particular to the downstream reach between Cultybraggan Camp and the River Earn confluence. This has added significant morphological pressure to the river.

The Water Framework Directive (WFD) requires that all European Union countries achieve ‘good status’ for all ground and surface waterbodies. To achieve ‘good status’ overall, a waterbody must achieve good status in all assessment criteria (biological, hydro-morphological, physio-chemical and chemical quality). Therefore, a deterioration in one of these criteria may result in the waterbody failing to meet the WFD objectives.

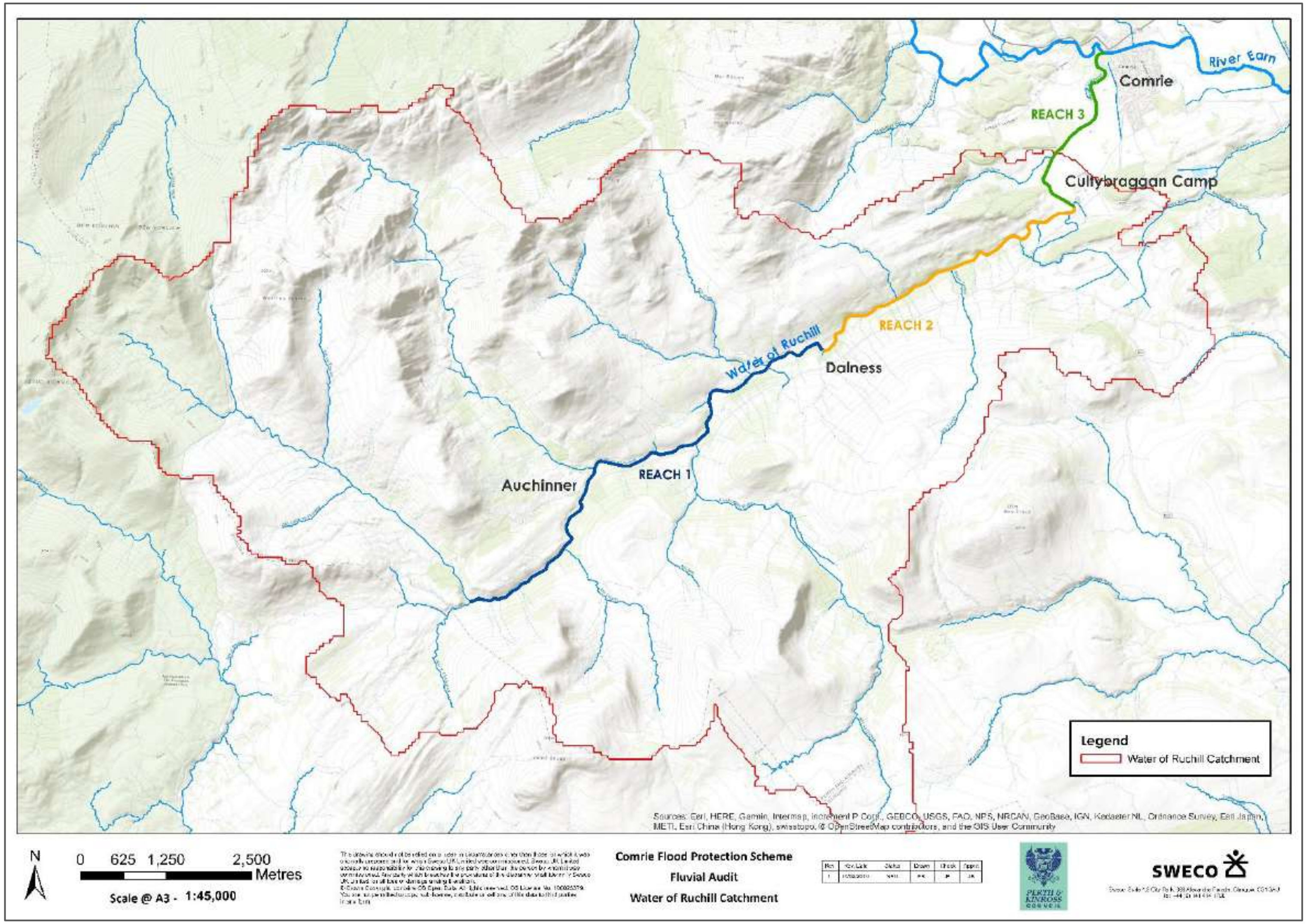
Morphological pressures are quantified by SEPA using the Morphological Impact Assessment System (MiMAS); an environmental standards test which calculates the ‘capacity used’ by artificial modifications to the river on a percentage basis. The ‘capacity used’ score is used to determine the morphological quality of the river, which is one of four criteria used to determine the WFD status of a waterbody.

Currently, the Water of Ruchill has a capacity used of 21%, meaning that there is only 4% remaining before the morphology status is downgraded from ‘good’ to ‘moderate’. This downgrade would result in a downgrade to the overall WFD status from ‘good’ to ‘moderate’, and consequently, the Water of Ruchill would fail to meet the WFD objective. Therefore, any work carried out on the Water of Ruchill or its flood plain as part of the Comrie FPS is highly likely to result in deterioration of the Water of Ruchill’s WFD status and will require a derogation from the CAR licensing process.

Early consultation was undertaken with SEPA. A teleconference meeting (26th July 2018) and a site visit (9th October 2018) were undertaken to discuss the potential deterioration of the Water of Ruchill’s WFD status and the CAR licence derogation. SEPA indicated that they would like to investigate a more sustainable long-term solution for the Water of Ruchill that would remediate some of the wider issues on the river. Upstream improvements to address sediment supply would likely be beneficial and may offset some of the impact of the scheme on the ‘capacity’ used score.

High rates of geomorphic activity were observed during the site visit in the form of extensive gravel bars and severe bank erosion. SEPA recommended that a fluvial audit was carried out to determine the sources of the significant volumes of sediment present in the Water of Ruchill close to the confluence with the River Earn.

Figure 1-1: Overview map of the Water of Ruchill catchment



2 Methods

A fluvial audit was carried out for the Water of Ruchill catchment. This involved both a desktop assessment and a walkover survey. The methods of both are summarised below.

2.1 Desktop Review

A desktop review of background and historical information related to the Water of Ruchill and the surrounding catchment area was undertaken to characterise the geological setting of the catchment, and to produce a timeline of changes to the catchment over time. This helped to identify any Potentially Destabilising Phenomena (PDP) occurring within the catchments which may have resulted in changes to sediment supply. A list of common PDP is provided in Table 2-1.

Table 2-1: Commonly encountered PDP [1]

	Increased sediment supply	**Decreased sediment supply**
Catchment Factors	Climate change (> rainfall)	Climate change (< rainfall)
	Upland drainage	Dams/river regulation
	Afforestation	Reduced cropping/grazing
	Mining spoil inputs	Cessation of Mining
	Urban development	Vegetation of slopes/scars
	Agricultural drainage	Sediment management
Channel Factors	Upstream erosion	Upstream deposition
	Agricultural run-off	Sediment traps
	Tributary input	Bank protection
	Bank retreat	Vegetation on banks
	Tidal input	Dredging (shoals and berms)
	Straightening	Channel widening upstream
	Upstream embanking	Upstream weirs/bed controls

The following information sources were reviewed as part of the desktop assessment:

- Superficial and bedrock geology maps of the catchment area from the British Geological Survey;
- Historical Ordnance Survey (OS) maps from the National Library of Scotland;
- Historical air photos and satellite imagery;
- WFD monitoring data for the catchment;
- Documents related to land use and channel adjustments (e.g. Estate Papers, River Board and Water Authority records); and
- Reports documenting any previous research undertaken on the rivers.

[1] From Sear, D.A., Newson, M. D. and Thorne C.R. Guidebook of Applied Fluvial Geomorphology. R&D Technical Report FD1914. (Table 4.4)

2.2 Geomorphic Walkover Survey

The walkover survey was undertaken to ground truth evidence of the channels response to any PDP identified in the desktop review, and to identify the dominant geomorphic processes occurring on each river reach.

The walkover survey was conducted between November 2018 and January 2019. A ruggedized tablet computer loaded with ArcGIS Collector was used to record key geomorphic features, processes and anthropogenic pressures whilst walking the length of the river. This enabled the production of more accurate mapping of the extent and location of features using the tablet's GPS receiver, and subsequently recorded features were automatically uploaded to a GIS system.

The following information was recorded during the walkover surveys:

- Typology of the river and whether this differed from what the predicted natural typology would be (See Appendix A);
- The stability status of the channel, which characterises the dominant processes occurring within the reach (See Appendix B);
- Substrate of the channel;
- Significant areas of bank erosion or basal scour;
- Significant areas of deposition;
- Sources and type of sediment input to the channel (e.g. landslides, rock fall, bank erosion, tributary streams, poaching, etc.);
- Anthropogenic pressures on the channel (e.g. bridges, bank protection, weirs, realignments, invasive species, etc.)

3 Results

Results of both the desktop assessment and walkover survey for the Water of Ruchill fluvial audit are provided below. For this assessment, the Water of Ruchill has been divided into three distinct reaches (Figure 1-1) based on typology and dominant processes occurring on the reach.

3.1 Desktop assessment

3.1.1 Channel Mapping

To assess the rate of geomorphic activity, aerial imagery (Google Earth Pro) of the downstream section of the Water of Ruchill, from Ruchilside to the River Earn confluence were analysed, and recent channel changes were recorded, presented in Figure 3-1 below. Imagery from 2005, 2015, and 2018 were available. The bank lines from the 2005 image were traced and overlain on the 2015 and 2018 images to identify areas of channel change (erosion and deposition).

Significant change is observed between the 2005 and 2018 imagery. The area of the gravel bars has increased by over 50%, from approximately 27,000 m^2 in 2005 to 50,900 m^2 in 2018.

Five areas of significant erosion were identified between 2005 and 2015; these are labelled (A-E) on Figure 3-1B. Between 2015 and 2018, areas A and C decreased in area, suggesting that deposition has occurred in these areas during this time period. Area E did not change, due to the construction of bank protection in this area. However, areas B and D increased in size significantly, indicating high rates of erosion in these areas.

Both the 2015 and 2018 image show the formation of a new lateral bar on the inside of the meander bend, opposite the bank protection at Ruchilside. This has likely formed due to the J-vanes (stone piers extending into the channel) which extend from the right bank, and slow down the flow, resulting in deposition on the left bank.

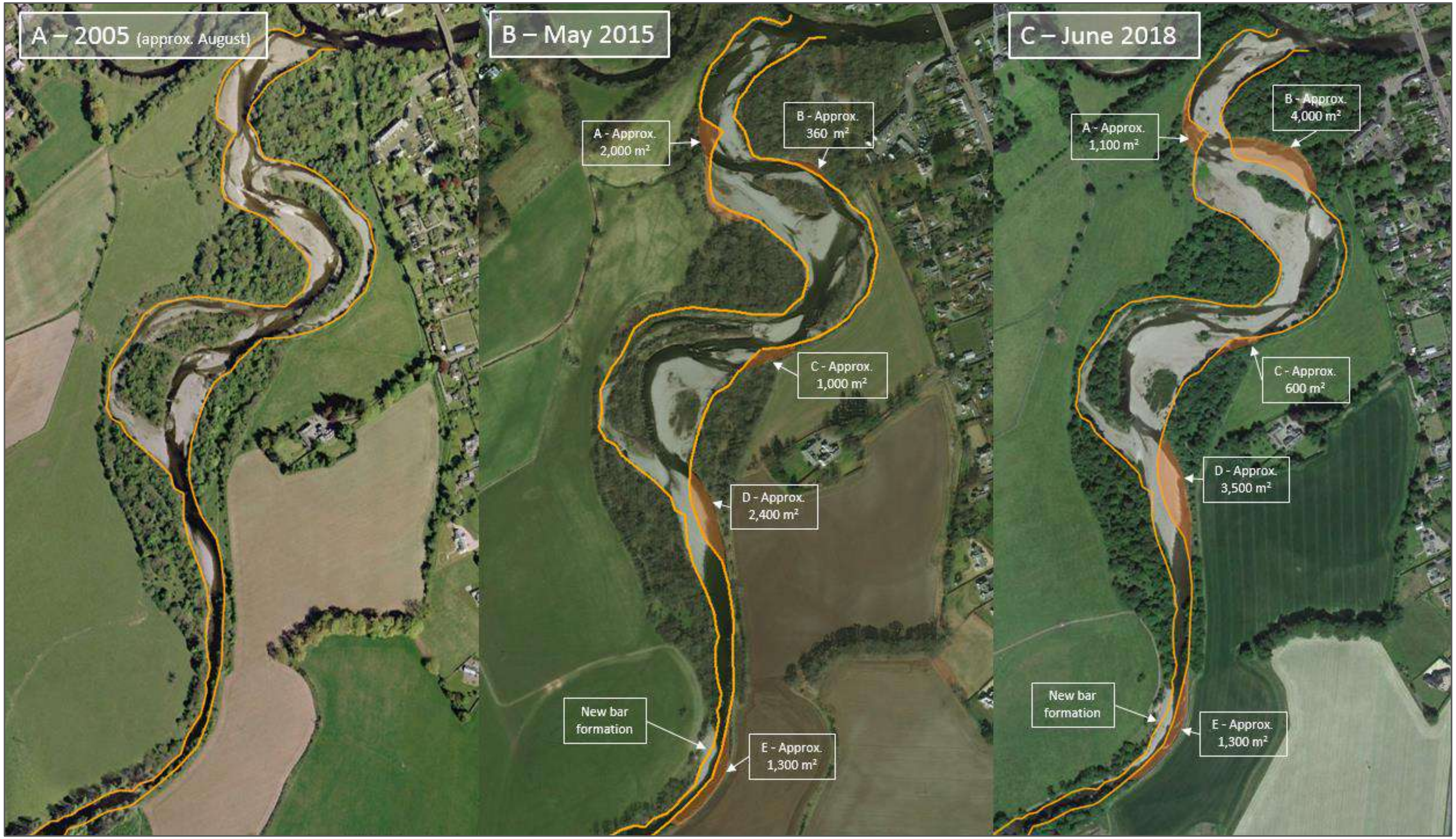


Figure 3-1: Satellite images from Google Earth showing channel change between 2005 and 2018. The 2005 bank lines are shown in orange on all images.

3.1.2 Geological Setting

The bedrock geology underlying the catchment is displayed on Figure 3-2. The lower reach of the Water of Ruchill (reach 3), between Cultybraggan Camp and the confluence with the River Earn, is mainly underlain by metamorphic rocks from the Ben Ledi Grit Formation, comprising metamudstone and metasandstone, interbedded with pelite. Upstream of Cultybraggan Camp, the catchment has a more complex geology. The eastern side of the catchment is predominantly underlain by conglomerate (Arbuthnott-Garvock Group) and sandstone (Craig of Monievreckie Conglomerate Formation). The east side of the catchment is underlain by sandstone and mudstone (Ruchill Flagstone Formation) and some conglomerate (Arbuthnott-gravock Group and Strathmore Group). There are also some intrusions of basalt from the Central Scotland Late Carboniferous Tholeiitic Dyke Swarm crossing the catchment[2].

The superficial deposits underlying the catchment are displayed on Figure 3-3. The lower reaches of the Water of Ruchill, downstream of Cultybraggan Camp cross a wide fluvial plain, with terraced river deposits located to the east of the river. Upstream of Cultybraggan Camp the river sits in a V-shape valley, which narrows upstream. The valley sides are mantled by till, and sporadic, discontinuous fluvial deposits have been deposited on the valley floor. Small areas of glaciofluvial (sand and gravel deposited by glacial meltwater) deposition are located on the upper reaches of the Water of Ruchill, and hummocky till lines the valley sides of the upper tributary streams in the catchment. Peat has accumulated in depressions and flatter areas surrounding the hummocky till[3].

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[2] British Geological Society: Geology of Britain – Bedrock Geology Map (http://mapapps.bgs.ac.uk/geologyofbritain3d/index.html - accessed 14/11/2018)

[3] British Geological Society: Geology of Britain – Superficial Geology Map (http://mapapps.bgs.ac.uk/geologyofbritain3d/index.html - accessed 14/11/2018)

Figure 3-2: Bedrock geology underlying the Water of Ruchill catchment

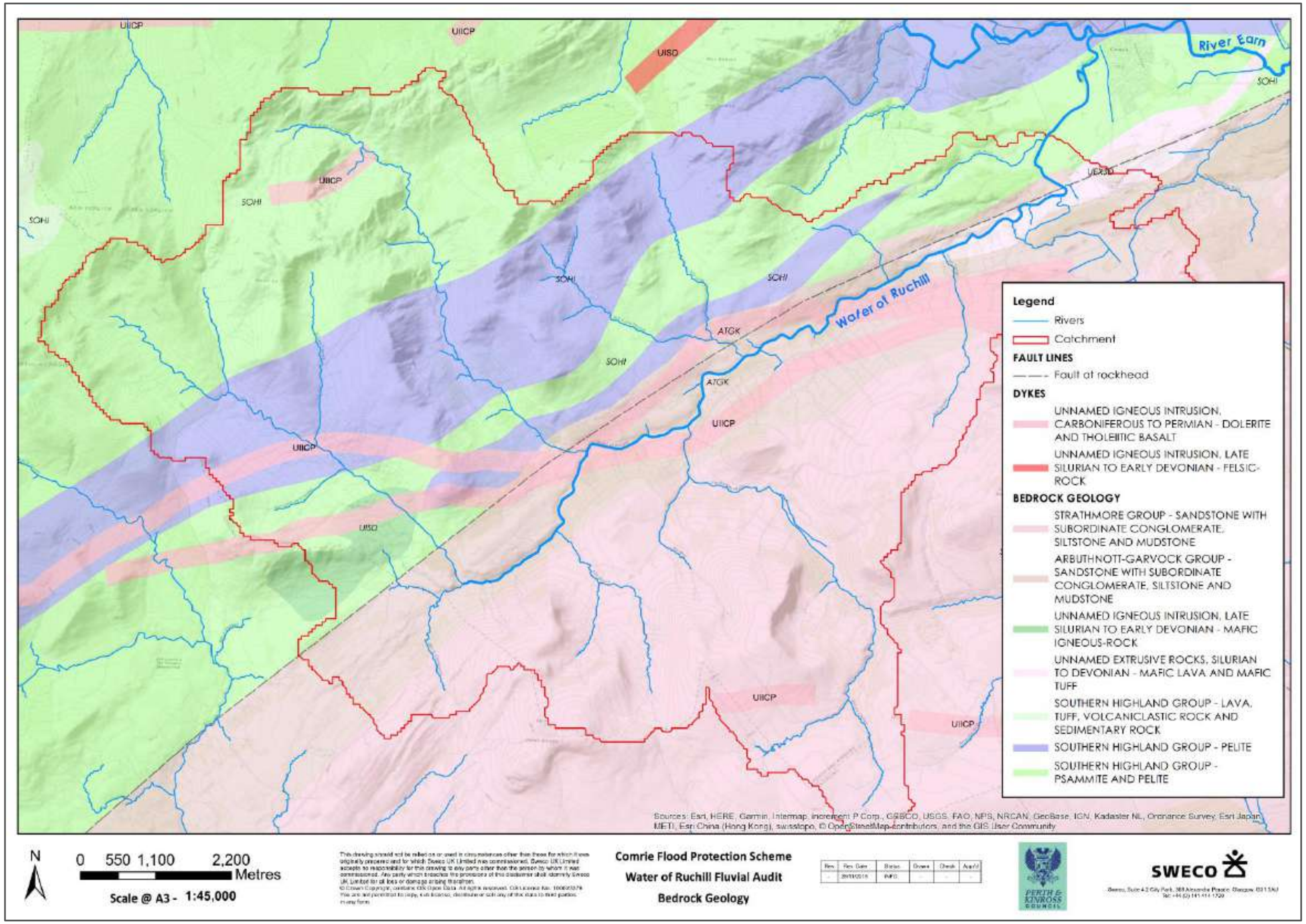
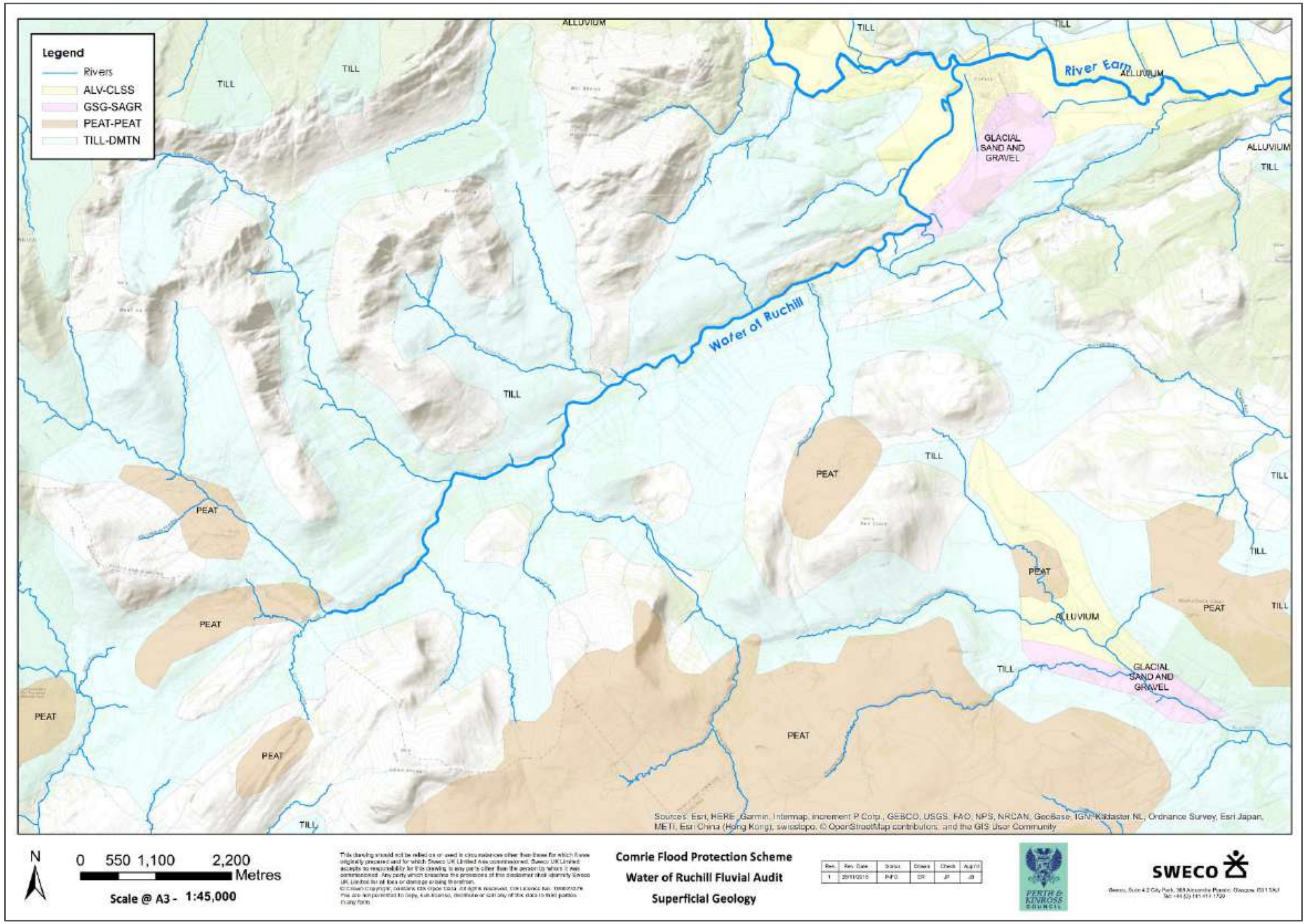


Figure 3-3: Superficial geology underlying the Water of Ruchill catchment



3.1.3 Timeline of Potentially Destabilising Phenomena

Table 3-1: PDP in the Water of Ruchill catchment identified through the desktop assessment

PDP	Approximate Timing	Effect on River
Land drainage in Glen Artney (Peat drainage)	Ongoing	Drainage of upland peat deposits has resulted in an increased rate of gully erosion and increased the volume of sediment input to the river.
Sheep grazing	Ongoing	Livestock grazing is damaging upland peat bogs, which can result in increased run-off, increasing rates of gully erosion leading to higher sediment input to the river.
Maintenance works at the Field of Refuge involving dredging of a new channel along the alignment of a former course and widening of the main channel to provide a flood relief channel. Dredged gravel was placed in high embankments immediately adjacent to both channels.	Nov.1997	Formation of a knick point in the channel which resulted in increased basal scour and bank erosion.
Gravel Extraction – Removal of a riffle at the downstream end close to the River Earn confluence, to obtain gravel for an access road.	March 1999	Increase in erosion of the right bank. This was partially restored by the contractor.
Installation of bank protection at Field of Refuge	1999 - 2012	Reduction in erosion where rip-rap protected the bank, but an increase in bank erosion downstream.
Installation of bank protection at Ruchilside	March 2013	Reduction in erosion where rip-rap protected the bank, but an increase in deposition on the opposite bank.

3.1.3.1 Land drainage

Extensive land drainage modifications have occurred in the upper reaches of the Water of Ruchill catchment. This is apparent from series of parallel drainage trenches cut into the upper slopes of the valley, visible on aerial imagery of the catchment. These trenches or channels are typically dug to drain peat deposits to make land more suitable for livestock grazing. However, they can result in drying out and degradation of the peat, which in turn results in an increase in surface water run-off on the valley side slopes. Livestock grazing can result in further degradation of the peat, and consequently large areas of peat bog appear to have been lost in the Water of Ruchill catchment over time. The increased volume of water entering the channel may have an impact on downstream flood risk.

The imagery of the catchment also reveals that the altered slope drainage patterns have resulted in extensive gully erosion close to the river. The canalized surface run-off has formed a series of gullies on the river escarpments, resulting in gully formation and erosion. The gullies start as small drainage channels on the side slopes but enlarge due to headward erosion and slumping of the side walls, adding sediment to the channel. Figure 3-4 provides an example of areas where gully erosion appears to have resulted from upslope changes to slope drainage. Overall, peat drainage could be playing a role in increasing volumes of both water and sediment entering the river.

Figure 3-4: Google Earth image showing areas of gully erosion which appear to have resulted from changes to drainage patterns from upslope peat drainage.

3.1.3.2 Channel straightening

Analyses of historic OS maps suggests that the Water of Ruchill was straightened between Cultybraggan Camp and the confluence (reach 3) prior to 1862. Following this, the upper part of the reach from Cultybraggan to Ruchilside has remained relatively straight, likely due to trees lining the banks arresting channel migration. However, the lower reach, downstream of Ruchilside, has returned to a wandering state.

3.1.3.3 Channel dredging

In November 1997 maintenance works were carried out on the Water of Ruchill, aimed at decreasing the flood frequency in Dalginross. These works involved dredging a new channel along the alignment of a former course and widening the main channel to provide a flood relief channel. The dredged gravel was placed on the banks in high embankments immediately adjacent to both channels. This caused significant disturbance to the river; disrupting the natural sediment transport processes.

Dredging of the channel resulted in the formation of a step or elevation drop on the bed, known as a knick point, which produced higher flow velocities at the channel bed. Over time, the knick point has ‘migrated’ upstream from the Field of Refuge to upstream of the Cultybraggan Camp, through headward erosion. This has led to a decrease in bed elevation in this reach, undermining of the banks and overloading the river downstream with sediment. The long-term consequences of this has been extensive bank erosion and collapse, particularly on the outer (right) meander bend at the Field of Refuge, and deposition of large volumes of gravel downstream.

3.1.3.4 Installation of Bank protection

Following the channel dredging, rip-rap bank protection was put in place on the right bank at the Field of Refuge, to prevent further erosion and to protect the flood wall from collapse.

As the knick point retreated upstream, enhanced bank erosion resulted on the outer meander bend at Ruchilside. Large flood events in August and November of 2012 resulted in the erosion of a 200m length of riverbank at Ruchilside, which is estimated to have released approximately 3000m^3 of sediment downstream.

Figure 3-5: Photo showing bank protection and J-vanes at Ruchilside

This erosion also resulted in bank retreat which opened a low point on the right bank where flood waters where able to flow out of bank and cause flooding in Dalginross. As a result, a rip-rap embankment was installed on the right bank at Ruchilside in March 2013 (Figure 3-5). The embankment was designed to raise the height of the right bank, so that is prevents further erosion and keeps higher flows in channel. Four J-vanes extend from the bank to divert flows away from the toe of the right bank.

3.2 Geomorphic Walkover Assessment

A summary of the geomorphic walkover results is provided in Table 3-2, and the extent of the survey is shown on Figure 3-6. In addition, maps showing the key geomorphic features and processes on each reach are provided in Appendix C. A glossary of geomorphic classification terms used is provided in Appendix A and Appendix B.

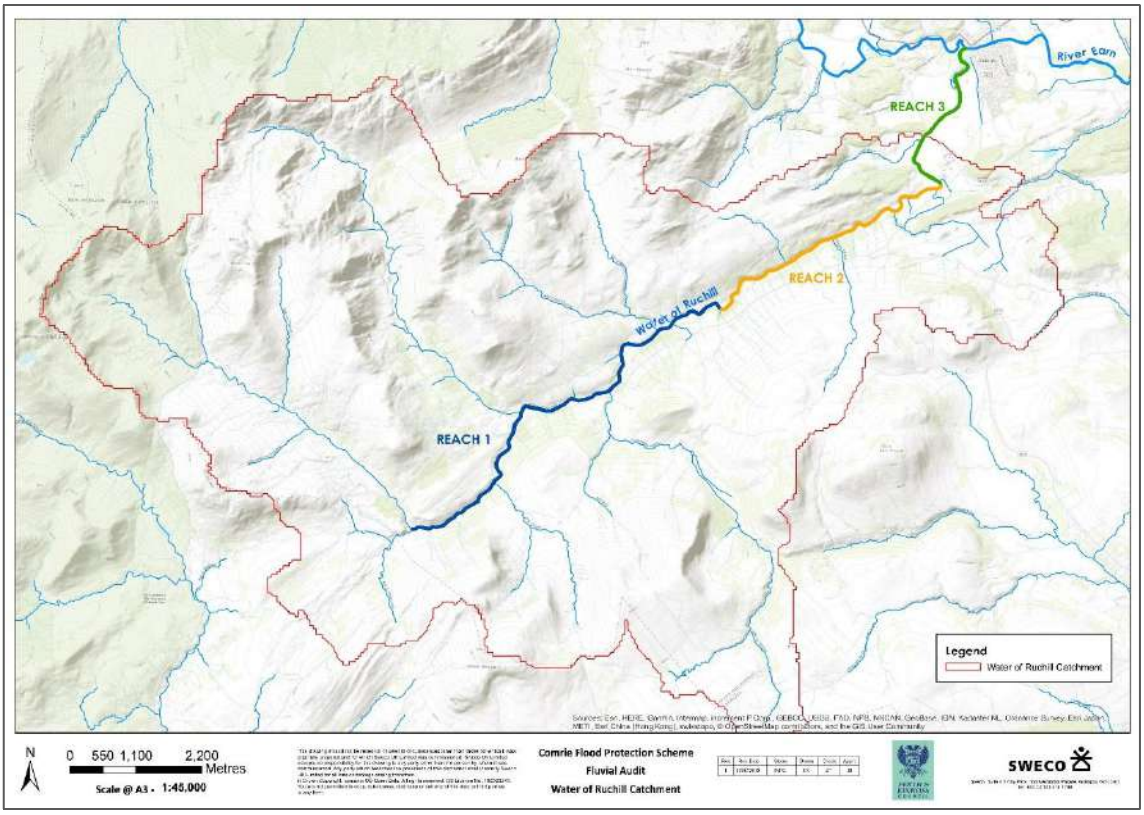


Figure 3-6 - Map showing Water of Ruchill catchment and the reach divisions which were included in the walkover survey

Table 3-2: Summary of results of the geomorphic walkover of the Water of Ruchill catchment

REACH	**1 – Auchinner to Dalness**	**2 – Dalness to Cultybraggan**	**3 – Cultybraggan to Earn confluence**
DOMINANT TYPOLOGY	step-pool/ plane bed	step-pool/ bedrock transitioning to plane bed/ bedrock	plane bed transitioning to pool-riffle
DOMINANT CHANNEL STABILITY SATUS	balance transport	Mainly balance transport. Minor depositional exchange	depositional exchange upstream transitioning to balance exchange downstream
SUBSTRATE	mainly boulders and cobbles	boulders cobbles and coarse gravel	small cobbles and well-graded gravel
MAIN SEDIMENT INPUT AND TYPE	• input of cobbles, boulders and gravel from tributaries. • coarse and fine material from landslides	• coarse and fine material from landslides • blocky material from rockfall	• transport of gravel and cobbles from upstream • gravel from erosion of the flood plain.
ANTHROPOGENIC PRESSURES	• Peat drainage on the upper slopes • Forestry on valley side slopes • 3 bridges • 1 incidence of poaching	• Peat drainage on the upper slopes	• 3 significant extents of rip-rap bank protection • agricultural realignment • gravel abstraction • set back flood wall on right bank • Japanese Knotweed • channel diversion for flood relief

3.2.1.1 Reach 1: Auchinner to Dalness

Between Auchinner and Dalness the Water of Ruchill flows through a U-shaped valley, which is relatively wide at Auchinner but widens with distance downstream towards Dalchruin. The valley sides are mantled by till and alluvium and terraced river deposits have accumulated on the valley floor, forming a discontinuous flood plain, which narrows downstream towards Dalness.

There is limited tree cover on the valley side slopes between Auchinner and Dalness.

The typology of the channel alternates between step-pool and plane bed along the reach, with topography as the main driver of this transition (Figure 3-7). The river is confined along some sections of the channel. In these sections, the channel has a relatively straight planform with a steep stream gradient, and a step-pool typology has developed. In wider sections of the valley, the river is less confined with a slightly sinuous planform. As a result, the stream gradient is reduced and the typology transitions to plane bed. The valley floor has a relatively steep gradient and consequently the river has a relatively straight to slightly sinuous planform.

Figure 3-7: Photos of Reach 1. (A) Shows a typical wide section of the valley with plane bed stream typology. (B) Shows a confined section of the reach with step-pool typology.

There are some small lateral bars along the reach, mainly composed of boulders and larger cobbles. However, smaller grain sizes of sediment appear to be transported further downstream. The stability status of the reach is mainly balance transport.

The main sediment input to the reach appears to be from gully erosion. In the confined sections of the reach, the till, which mantles the steep valley sides, has developed a series of parallel gullies which are related to surface water drainage from channels dug into the peat deposits upslope. Slumping of the side walls and headward erosion was observed in these gullies, adding sediment to the river (Figure 3-8).

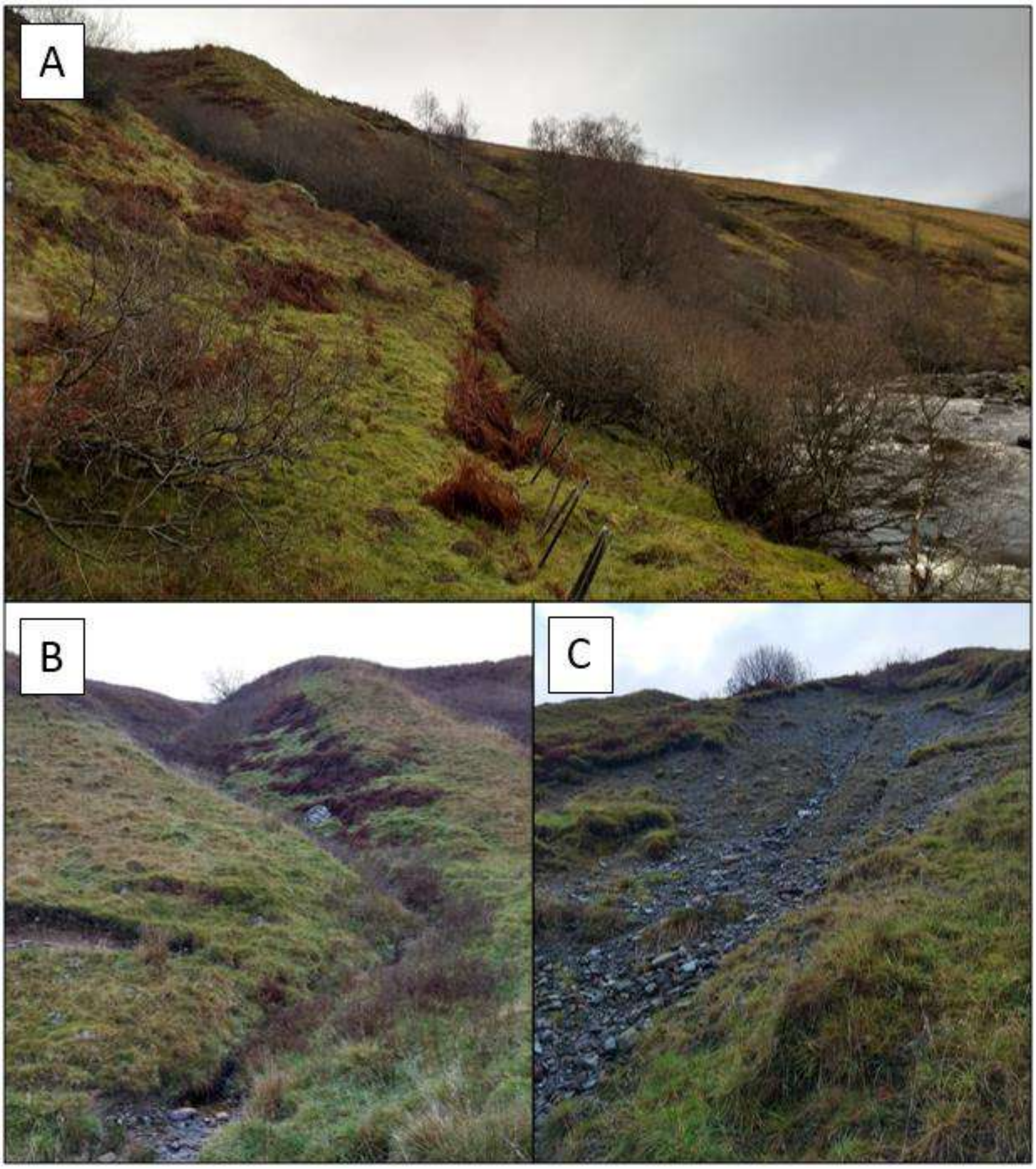


Figure 3-8: Photos showing sediment delivery to the channel through gully erosion. (A) Shows an overview of the gullied till side slope. (B) Shows gully development due to surface water drainage. (C) Shows a fresh slump on the gully side wall.

Additional input of sediment is provided through several major tributaries. The Allt Srath a Ghlinne, Findhuglen Water, Allt Coire Choire and Allt Glas all join the Water of Ruchill on this reach (see

Appendix C). These tributaries originate in corries located at the top of the valleys and receive sediment from debris torrents from the steep upper slopes of these corries.

With the exception of two bridges crossing the river, there are no anthropogenic pressures on the Water of Ruchill channel on this reach. However, there is commercial forestry on the righthand valley slope around Auchinner, and extensive peat drainage on both valley slopes which are potentially having indirect effects on the channel.

3.2.1.2 Reach 2: Dalness to Cultybraggan

Between Dalness and Cultybraggan the Water of Ruchill flows through a confined valley, with steep sides and frequent outcrops of bedrock both in the channel and on the valley sides. The channel has a straight planform with very little flood plain development along this reach until the valley widens just upstream of Cultybraggan.

There is extensive tree cover on the lower valley side slopes, adjacent to the river between Dalness and Cultybraggan. However, the upper slopes are relatively clear of trees.

The channel has a steep gradient with frequent stretches of exposed bedrock; the typology alternates between bedrock and step-pool. Small lateral bars were observed throughout the reach, which were mainly composed of boulders and large cobbles with finer material seemingly transported through the reach. Most of the reach has a stability status of balance transport, however as the valley widens upstream of Cultybraggan the stream gradient reduces and there is an extensive area of deposition which is classified as depositional exchange. The typology transitions to pool-riffle at this point.

The main sediment inputs to the channel along this reach appears to be from landslides and rockfall. Rockfall is common close to the channel, where it has down-cut into well-jointed bedrock, forming scarps composed of fragmentary bedrock. This is adding angular, blocky sediment to the channel (Figure 3-9).

Figure 3-9: Photos of rockfall on escarpments adjacent to the channel. (A) Well-jointed fragmentary bedrock exposed in on the river scarp. (B) Angular rockfall debris adjacent to the channel.

Slumping is frequent on the steep escarpments adjacent to the river throughout the reach, on both river banks. Slumping occurs when the river erodes the toe of the slope, leaving the slope unsupported, and results in rotational slumping of the surface deposits. Slumping is particularly prevalent where shallow deposits overlie bedrock; when the river erodes away the toe of the slope, the bedrock acts as a slip plane for the shallow surface deposits to slide off (Figure 3-10). Slumping adds both fine- and coarse-grained sediment to the channel. In addition to slumping, sediment is added to the river through shallow translational slides, occurring on gully side walls.

Figure 3-10: Photos of slumping adjacent to the river. (A) Shows an old slump scar on the valley side wall. (B) Shows slumping of the superficial material over shallow bedrock.

There were no anthropogenic modifications to the channel along this reach, however artificial drainage channels were observed on the valley sides. This increases the volume of surface water drainage, resulting in a higher potential for landslide initiation, and has the potential to deliver more sediment to the channel.

3.2.1.3 Cultybraggan to River Earn confluence

To the south west of Cultybraggan Camp the valley opens out, and the river meanders across the flood plain. The stream gradient reduces and the typology transitions to pool-riffle. This decrease in gradient of the stream results in a loss of energy in the river, which leads to the formation of multiple gravel bars along this reach. The river is classified as depositional exchange at this section.

At the camp, the course of the river turns sharply, approximately 150° to the north west, due to the topographic barrier of the higher ground at the camp. The channel has a bedrock typology in this section of the reach. Between the camp and Linn Hulloch there is a decrease in the river bed elevation; the river has incised into the bedrock between the camp and has formed a series of cascades (Figure 3-11). At Linn Hulloch the river channel takes another sharp turn, approximately 90°, to the north east. Increased rates of basal scour are present in this reach, with a large scour pool present in the channel downstream of the bedrock cascades.

Figure 3-11: Photo showing the Water of Ruchill as it passes Cultybraggan Camp. The channel has a bedrock typology and has formed a series of cascades.

Between Cultybraggan Camp and the confluence with the River Earn, the Water of Ruchill crosses a wide floodplain. The floodplain is composed mainly of gravel deposits.

The planform of the river, which was straightened prior to 1962, has remained relatively straight in the upper section of the reach between the camp and Ruchillside. The channel has a plane bed typology in this section and there is little evidence of erosion or deposition. Trees lining both banks and an over-deepened channel in this reach, incising into the bedrock, may contribute to this planform stability.

Approximately 200 m upstream of Ruchilside, a hydraulic jump was observed in the channel, caused by a sudden drop in bed elevation. No further bank erosion was observed upstream of this point, and bedrock is present in the channel. Based on these observations, it seems likely that the knick point has stabilised in this location against the more resistant bedrock (Figure 3-12).

Figure 3-12: Map showing the potential location of the knick point where it appears to have stabilised against bedrock. A drop in bed elevation was observed.

Several extents of bank erosion and bank protection were observed downstream of the knick point. These sections of bank erosion appear to have occurred progressively as the knick point has migrated upstream. Approximately 50 m downstream of the knick point location rip-rap bank protection was observed on the left bank which does not quite cover the extent of bank erosion.

The bank protection at Ruchilside was observed to be in good condition. A gravel bar has formed on the inside of the meander bend opposite the rip-rap embankment. This is likely formed due to the J-vanes decreasing the velocity at the meander bend. Some gravel extraction appears to have been undertaken on this bar, with gravel piled adjacent to the channel (Figure 3-13). During a high flow event, this now unconsolidated gravel could be mobilised and transported downstream.

Figure 3-13: Photo of rip-rap bank protection and J-vanes at Ruchilside. A gravel bar has formed on the inside meander bend. Evidence of gravel extraction is visible on this bar.

Downstream of Ruchillside the river appears to be attempting to return to its natural wandering state. There are extensive sections of severe bank erosion as well as large gravel bar deposits.

Erosion is particularly severe on the right bank downstream of the rip-rap bank protection at the Field of Refuge. The bank protection was observed to be failing, with erosion of the bank behind the protection causing the protection to extend into the channel itself. This is increasing the rate of downstream bank erosion. Rapid bank retreat is occurring in this location and several collapsed trees were observed in the channel (Figure 3-14).

Figure 3-14: Photo of severe bank erosion downstream of the failing rip-rap bank protection at the outer meander bend at the Field of Refuge.

4 Discussion of Results

The Water of Ruchill is a dynamic gravel bed river, with a steep upland catchment, which is composed of thick till deposits mantling the valley slopes, and blanket bogs on the gentle upland slopes. The upper tributaries flow through wider U-shaped valleys and corries before converging and being channeled into Glen Artney, a V-shaped valley in which the river is more confined, with a steep stream gradient. The planform of the river is relatively straight and confined until it reaches the River Earn flood plain south west of Comrie where it begins to meander before its confluence with the River Earn.

Evidence of high rates of geomorphic activity are visible on the downstream reach of the Water of Ruchill, close to the confluence with the River Earn. Extensive gravel bars display high rates of deposition and stretches of severe erosion were observed. Although these geomorphic processes are natural, the rate at which they are occurring has greatly increased in recent years.

The fluvial audit provided an assessment of the catchment to determine the cause of the high rates of geomorphic activity. An assessment of background data related to the catchment revealed that extensive peat drainage is occurring on the upper slopes of Glen Artney to drain the upland blanket bogs. Large areas of man-made parallel drainage channels were observed on the upper slopes, potentially causing the peat to dry out and degrade and resulting in increased run-off on the slope.

Slope run-off from the peat drainage channels appeared to be linked to the formation of gullies downslope. The parallel drainage channels tend to channel run-off through these and down the slopes, increasing gully erosion on the till mantled slopes close to the river. The gullies, which start as small drainage channels on the side slopes, enlarge due to headward erosion and slumping of the side walls, adding sediment to the channel.

Throughout the upland section of the catchment (upstream of Cultybraggan) the channel has a stability classification of both balance exchange and balance transport. This is mainly controlled by topography; the river becomes confined in a V-shaped valley with a steep stream gradient. As a result, the large volumes of run-off and sediment delivered to the channel in the upper-catchment are transported quickly through Glen Artney. Downstream of Cultybraggan the topography flattens and the Water of Ruchill crosses a wide flood plain before draining into the River Earn.

The downstream reach of the Water of Ruchill has been historically straightened. The section between Ruchilside and the River Earn confluence has begun to re-meander, however the upper section between Cultybraggan Camp and Ruchilside has remained relatively straight since it has incised below the floodplain and has lost the ability to naturally migrate. This means that the effects of the increased volume of sediment input to the river from upstream are only visible in the small section between Ruchillside and the Earn confluence, where increased deposition was observed.

The river loses energy in the area downstream of Ruchillside, due to the decrease in stream gradient, and large extents of gravel deposition were observed in this area. The increased volume of gravel deposition has the potential to decrease the conveyance capacity of the channel, which could increase flood risk without continued extraction and/or stabilisation efforts.

The remediation works completed in 1997, which involved dredging of a new channel along the alignment of an abandoned channel of the Water of Ruchill and widening of the main channel to provide a flood relief channel, had the unintended consequence of the creation of a knick point, created by artificially lowering a small section of channel bed. As water flows over the knick point, the increase in velocity causes basal scour and ultimately increased rates of bed and bank erosion. The effects of the knick point development have been observed over the last 20 years, as the knick point has migrated up-channel by headward erosion causing severe bank erosion which has progressively extended upstream. The knick point seems to have migrated far enough up-stream now that it has stabilised against the bedrock.

Rip-rap bank protection has been installed in two locations to prevent further bank erosion: the outer meander bed at the Field of Refuge and at Ruchilside. At the outer meander bed at the Field of Refuge the bank protection is failing and has been out flanked, so that it extends into the channel. This is increasing the rate of erosion on the bank downstream.

5 Recommendations

Even in its 'natural' state, the Water of Ruchill is a dynamic wandering river, prone to naturally migrating across the floodplain and may behave in an unpredictable manner. No single solution will arrest the high rates of geomorphic activity seen close to the River Earn confluence. Because of the complex nature of the river and land ownership in the catchment, both long-term and short-term recommendations are provided.

5.1 Long-term recommendations

There are two key 'long-term' recommendations for the Water of Ruchill: (1) restoring the upland blanket bogs, and (2) Re-meandering the river between Cultybraggan Camp and Ruchilside. It is understood that these recommendations may be outside of the jurisdiction to PKC and will likely require collaboration of several stakeholders. However, these are included as indicators of future work that may be undertaken as part of a full catchment restoration.

5.1.1 Restoration of Upland Blanket Bogs

Restoring blanket bogs in the upland areas of the catchment would help to retain water in the upland areas of the catchment, leading to a decrease in surface run-off. This would require widespread changes in land management practice. It is understood that much of the upland area is under private ownership and that the pattern of land tenure and management is often complex.

Although this change in land management practice to preserve and restore peat bogs may not be feasible as a short-term solution, and further work must be undertaken to understand the hydrological connection between upland run-off and downstream flood risk and sediment dynamics, this could be considered as a long-term goal for the Water of Ruchill catchment.

Restoration of upland blanket bogs can have many economic and environmental benefits, including reduction in flood risk and increased carbon storage. For the Water of Ruchill restoring the peat bogs would involve blocking the drainage channels to encourage rewetting of the peat and the re-establishment of blanket bog vegetation to promote the accumulation of organic material on the slopes. This is particularly relevant to areas of bog which are closely associated with areas of gully erosion downstream. Efforts would also need to be made to restore the downstream gullies following blanket bog restoration.

5.1.2 Re-meandering the river between Cultybraggan Camp and Ruchilside

Re-instating the natural channel on the section between Cultybraggan Camp and Ruchilside would benefit the river by returning the river to its natural state and improving habitat diversity, as well as naturally attenuating flow. Detailed hydrological and geomorphological studies would need to be taken to ensure the new channel dimensions are appropriately designed so that the river was in an equilibrium state, i.e. excessive rates of erosion and deposition do not occur. This option would require agreement of adjacent landowners.

5.2 Short-term recommendations

This section outlines feasible 'short-term' solutions for PKC to mitigate current problems on the reach of the Water of Ruchill currently undergoing severe erosion and deposition.

5.2.1 Monitor knick point migration

The location of the knick-point, which appears to have stabilised, should be monitored to ensure that this is the case and that there is no progressive bank erosion occurring. This would take the form of an annual survey by a trained geomorphologist. If any up-stream migration of the knick-point is observed, it may be advisable to review options to artificially stabilise the knick-point.

5.2.2 Small-scale sediment removal

Small-scale gravel extraction could be undertaken in the downstream reach of the Water of Ruchill close to the River Earn confluence. It is understood that two landowners currently hold a license for gravel extraction in this area. It should be ensured that this extraction is taking place periodically and that they are following SEPA's best practice guide for sediment management. Only dry deposits should be extracted from un-vegetated gravel bars, and sediment should be skimmed from the top of the bars without leaving any pits or holes. This process may help allow the excess sediment from gully erosion to be kept under control so that flood risk is not further increased.

6 Conclusion

From the results of the fluvial audit, we can conclude that there are multiple factors which have progressively led to the significant rates of geomorphic activity on the Water of Ruchill. Interventions and modifications in recent years have failed to resolve these issues, and many have resulted in exacerbating the rates of geomorphic activity. We have provided two-long term solutions linked to upland management and re-meandering the Water of Ruchill downstream, and two short-term solutions related to monitoring knick-point migration and sediment extraction from the river (under controlled circumstances).

Appendix A – Classification of River Typology

Table A-6-1: Description of typologies used.

TYPOLOGY	CHARACTERISTICS
Bedrock	Typically, steep gradient, bed and channel banks show significant areas of obvious bedrock. Cobbles and gravels may exist on the bed also. No floodplain development
Step-pool	Gradient still generally steep, with little floodplain development. Channel has regular or semi-regular well-developed steps, separated typically by pools. Substrate typically composed of large cobbles and boulders, with some gravels.
Plane-bed	A transitionary typology between step-pool and pool-riffle. Typically, moderate gradient, with some floodplain development, but channel often incised below floodplain. Featureless bed often armoured with cobbles. Irregular steps, and irregular bars might be present, as well as a relatively straight planform.
Pool-riffle	Generally shallow gradient, and a relatively wide floodplain. Planform becomes sinuous, with more obvious depositional features such as bars, and more signs of erosion on banks.
Active-meander	Shallow gradient, with a wide floodplain. Extensive depositional and erosional features, and well-developed meanders leading to a sinuous planform.

N.B. In practice, sometimes rivers go through a transitionary reach between typologies, or can be 'more' one typology than another. In these cases, it falls to the expert judgment of the surveyors to understand which typology is more dominant.

Appendix B – Channel stability status classification

A visual assessment of the dominant processes occurring on each reach were classified based on the criteria outlined in Table B-1. This involved recording observations of erosional or depositional processes occurring within the channel (

Table B-2). The assessment is derived from field assessments conducted as part of the ST:REAM (Sediment Transport: Reach Equilibrium Assessment Method)[4].

Table B-1: Criteria for classification of dominant processes[5]

STABILITY STATUS	CHARACTERISTICS
Erosional source	No evidence of deposition, only erosion.
Erosional exchange	Erosion dominant, but some small-scale depositional features present.
Balance exchange	Evidence of both deposition and erosion are both present on the reach.
Balance transport	Limited evidence of either deposition or erosion observed (generally bedrock channels or heavily modified channels have this classification)
Depositional exchange	Depositional features dominant, but some evidence of erosion observed.
Depositional sink	Only depositional features present (typically approaching lakes or confluences)

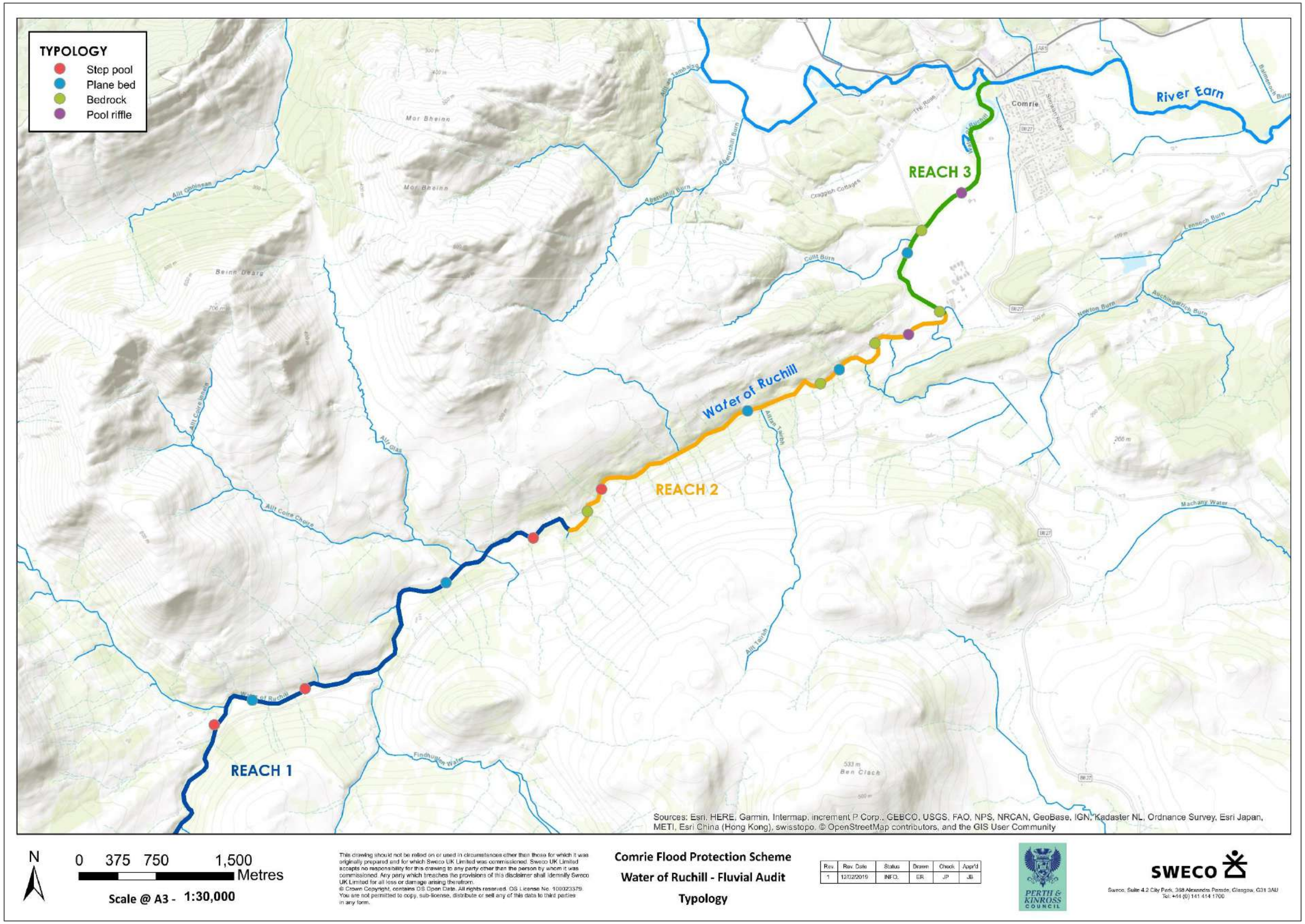
Table B-2: Field observations indicating erosion or depositional dominant channels (From Parker et al., 2015)

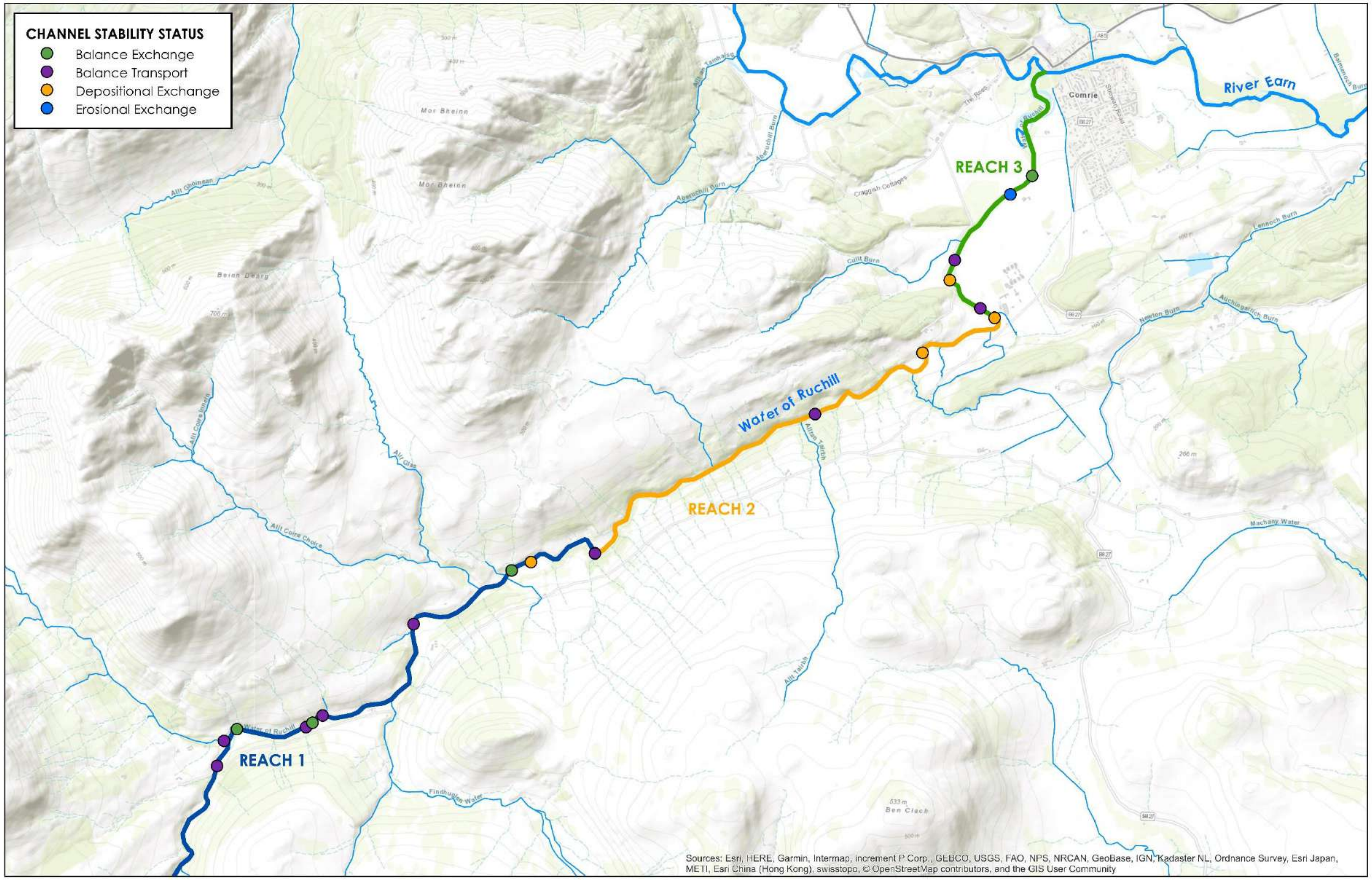
DOMINANT PROCESS	INDICATORS
Erosion	Terraces
	Old channels in floodplain
	Undermined structures
	Exposed tree roots
	Tree collapse (both banks)
	Trees leaning towards channel (both banks)
	Drowned trees in channel
	Narrow/deep channel
	Bank failures (both banks)
	Thick gravel exposure in the banks overlain by fines
	Armoured compacted bed
Deposition	Buried structures
	Buried soil horizons
	Many uncompacted 'overloose' bars
	Eroding banks at shallows
	Contracting bridge openings
	Deep, fine sediment overlying coarse particles in bed/banks
	Many unvegetated bars

[4] Parker, C. Thorne, C. R., and Clifford, N. J. (2015) Development of ST:REAM: a reach-based stream power balance approach for predicting alluvial river channel adjustment. Earth Surface Processes and Landforms 40, 403-413

[5] Modified from SEPA (2013) Heightened Hydro-morphological Activity Reaches. Explanatory Note V.2

Appendix C – Water of Ruchill Catchment Maps





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Scale @ A3 - 1:30,000

Comrie Flood Protection Scheme

Water of Ruchill - Fluvial Audit

Channel Stability Status Classification

Rev.	Rev. Date	Status	Drawn	Check	Appr'd
1	12/02/2019	INFO.	ER	JP	JB

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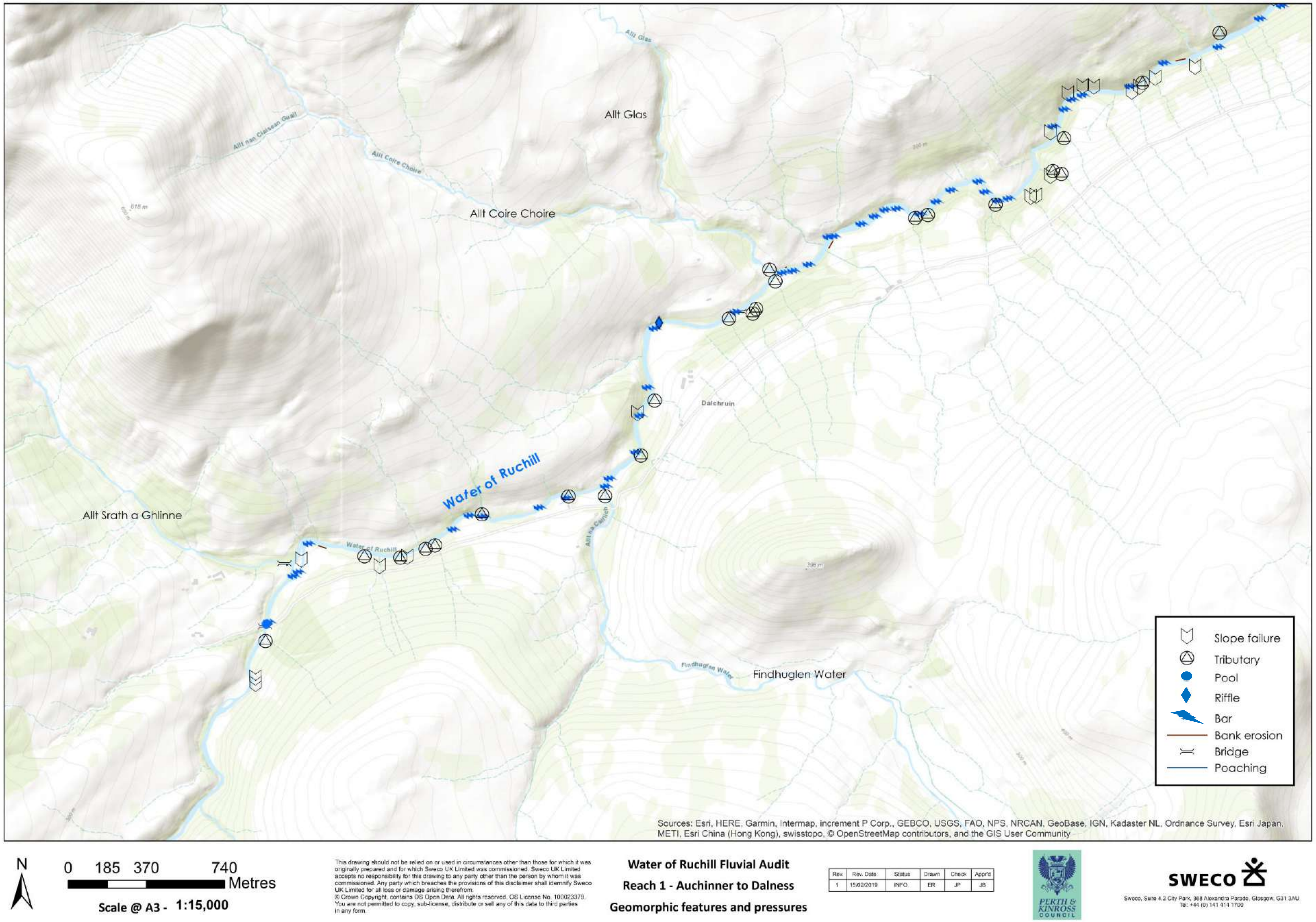

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Water of Ruchill Fluvial Audit

Reach 1 - Auchinner to Dalness

Geomorphic features and pressures

Rev	Rev. Date	Status	Drawn	Check	App'd
1	15/02/2019	INFO	ER	JP	JB

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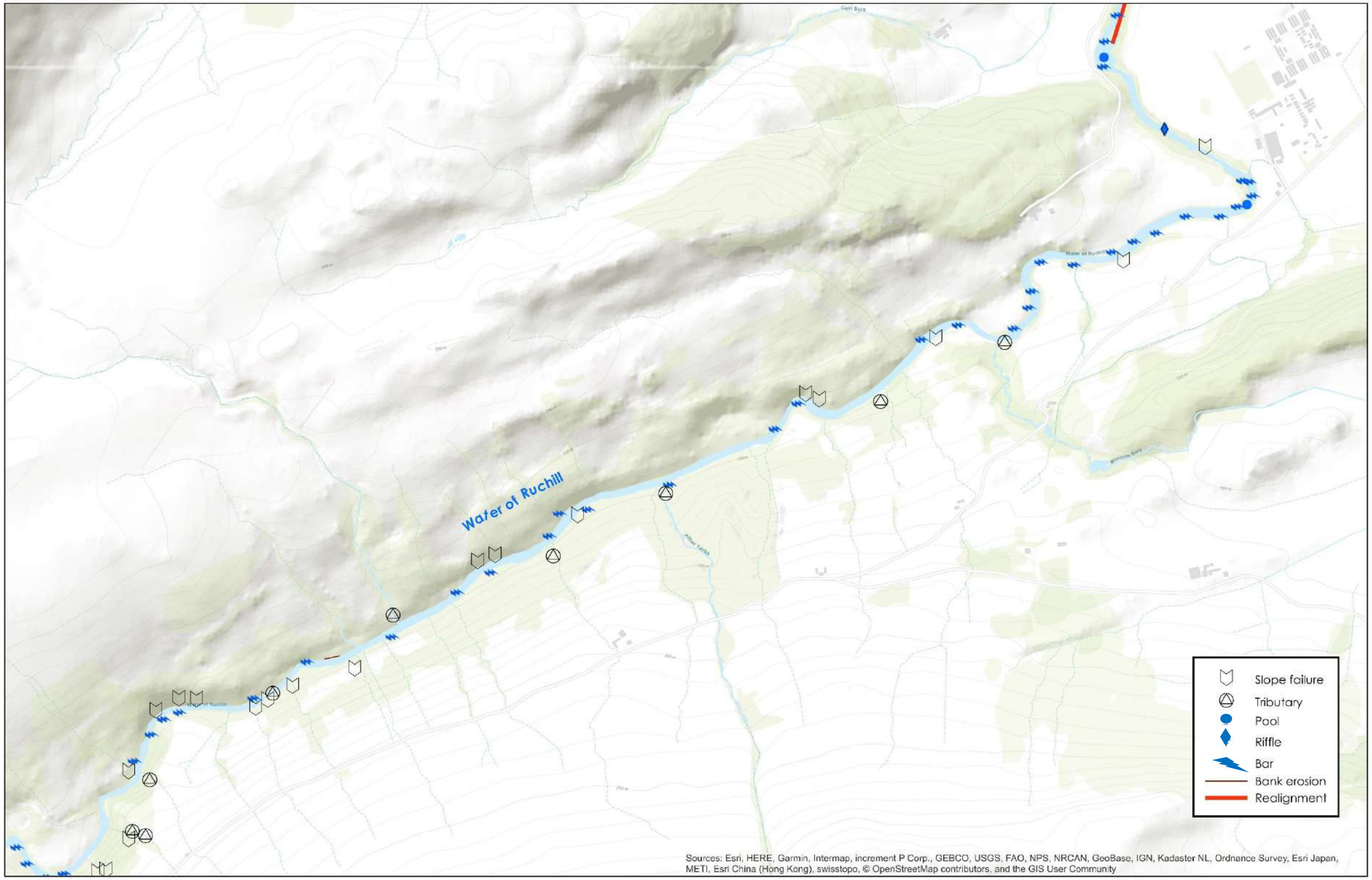

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Scale @ A3 - 1:10,000

Comrie Flood Protection Scheme

Reach 2 - Dalness to Cultybraggan Camp

Geomorphic features and pressures

Rev.	Rev. Date	Status	Drawn	Check	Appr'd
1	12/02/2019	INFO.	ER	JP	JB

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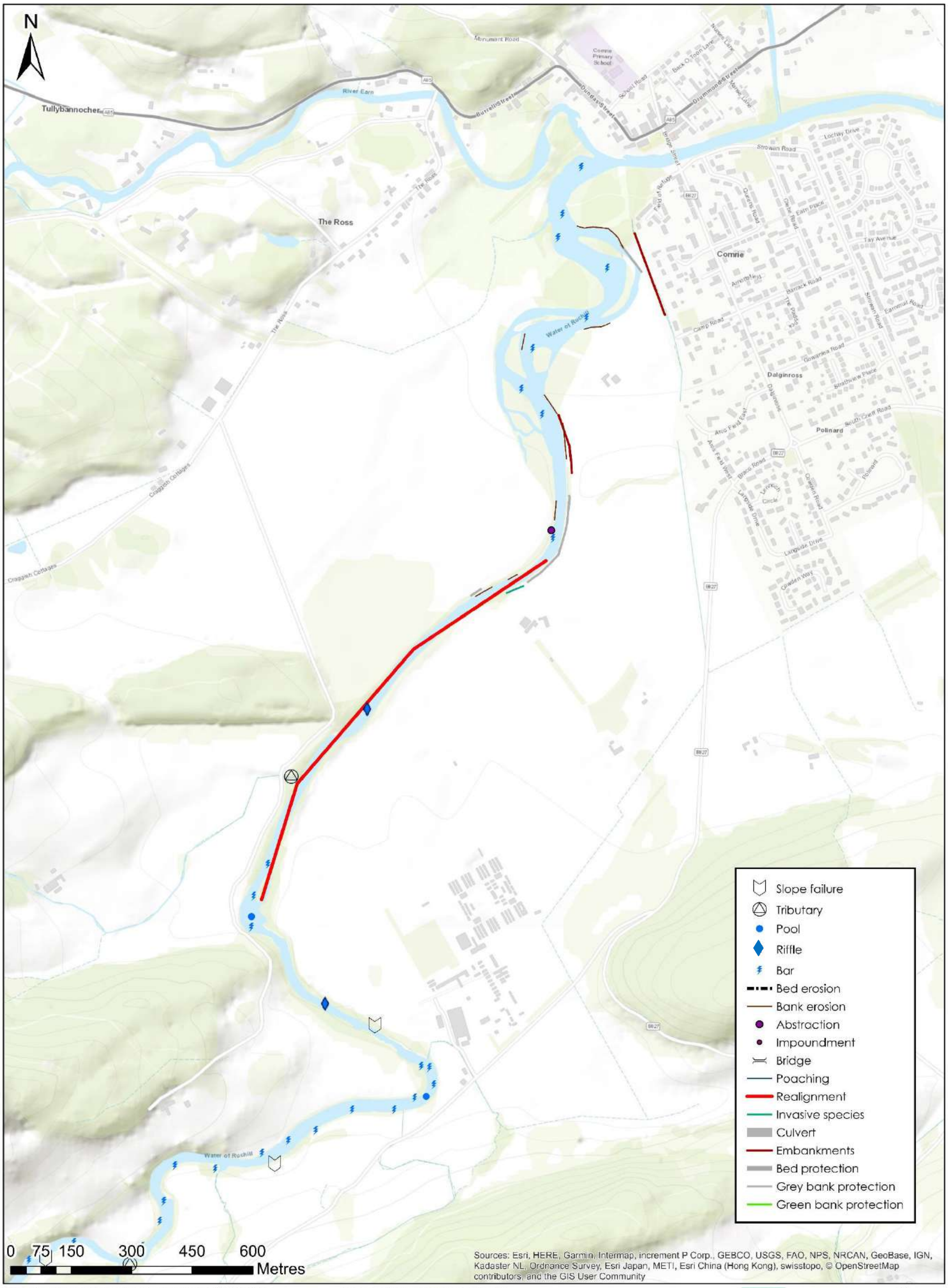

Water of Ruchill Fluvial Audit

Reach 3 - Cultybraggan Camp to Earn Confluence

Geomorphic features and pressures

-	12/02/2019	INFO.	JP	JB	JB
Rev.	Rev. Date	Status	Drawn	Check	Appr'd

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