Comrie Flood Protection Scheme 2020

Technical Report

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APPENDIX: FLOOD MAPPING

1 INTRODUCTION

Sweco were commissioned by Perth & Kinross Council (hereafter referred to as the Council) to develop a flood protection scheme in Comrie. The Comrie Flood Protection Scheme 2020 has been, hereafter, referred to as ‘the Scheme’. The purpose of this Technical Report is to provide a summary of key information and decisions that have ultimately led to the outline design presented within the Flood Order.

1.1 Document Structure

The report summarises the work undertaken by each technical discipline to inform the design process. Each key project area has been outlined in the following chapters:

- **Chapter 1** has introduced the Technical Report structure, and context;
- **Chapter 2** has summarised the hydrological estimates;
- **Chapter 3** has presented a summary of the hydraulic modelling;
- **Chapter 4** has outlined the freeboard design process;
- **Chapter 5** has presented the secondary flooding assessment;
- **Chapter 6** has summarised the geomorphological investigation;
- **Chapter 7** has presented a summary of the ground investigations;
- **Chapter 8** has outlined the potential ground contamination and remediation;
- **Chapter 9** has detailed the structural design;
- **Chapter 10** has summarised the public utility diversions and enabling works;
- **Chapter 11** has presented a summary of the Environmental Impact Assessment;
- **Chapter 12** has presented the economic appraisal;
- **Chapter 13** has summarised the statutory consultation;
- **Chapter 14** has presented a summary of the public consultation; and
- **Chapter 15** has summarised the content of the Technical Report.

Signposting to the relevant accompanying reports have been provided throughout each chapter, should the reader be interested in further information.

1.2 Location

Comrie is located towards the western edge of the Perth & Kinross Council area. It is situated approximately 40 kilometres west of Perth along the A85 trunk road and is approximately 7 kilometres from the eastern boundary of the Loch Lomond and Trossachs National Park. The relative position of Comrie within the Perth and Kinross Council area is shown below in **Figure 1.1**.

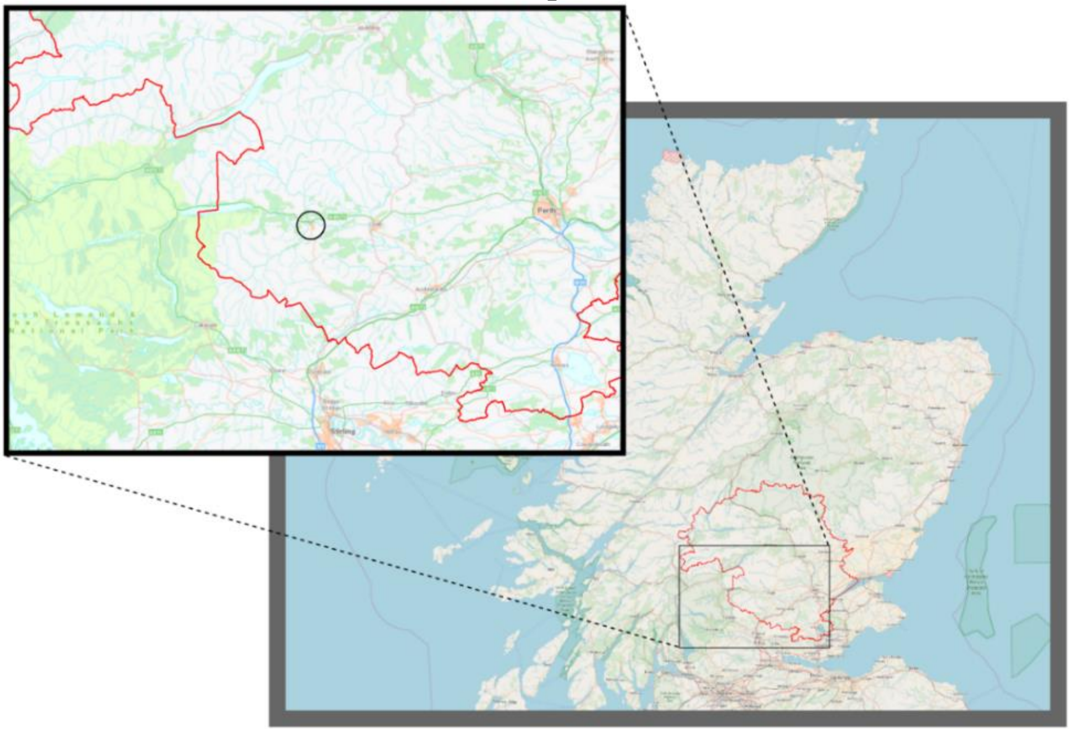

Figure 1.1 Site Location

1.3 Community

Comrie hosts many local events throughout the year and has a tradition of laying on a range of festivities for all ages during the Comrie Fortnight each July and August. The village is also a regular contender for the annual national Village in Bloom competition. Comrie has a primary school, shops and other facilities and services attractive to tourists such as the golf course and holiday park. The Comrie Holiday Park is identified in the Local Development Plan as making significant contribution to the provision of visitor accommodation within the Comrie area. Comrie also has a Scottish Fire and Rescue Service station, located on Strowan Road.

1.4 Character

Much of Comrie is designated as a Conservation Area in recognition of its special architectural and historic character. The main street is lined with listed buildings in a variety of styles. There are 2 category A listed buildings in Comrie – the Old Parish Church and No. 1 Dunira Street, and a further eighty properties designated as Category B and C listed buildings. The iconic Dalginross Bridge is also a

Category C listed building. The remains of a scheduled monument - Dalginross Roman Fort is located to the south west of Comrie. There are two Sites of Special Scientific Interest (SSSIs) (Biological and Geological) and a Special Area of Conservation (SAC) within 1km of the scheme extent study area. These areas comprise a complex network of woodland sites. **Image 1.1** highlights particular features that shapes the character of Comrie.

Public access routes in Comrie include core paths and Public rights of ways which are commonly found along the riverbanks. 'Comrie Walks' form part of a larger network of routes in the area and have been set up with support of local landowners and farmers. The three rivers are also popular with recreational users including anglers and canoeists.

Image 1.1: Photographs taken in and around Comrie

1.5 Rivers

The River Lednock and the Water of Ruchill meet the River Earn at Comrie. The River Lednock drains a catchment of approximately 62km^2, comprising the upland slopes of Glen Lednock. The upland head of the catchment is controlled by the Glen Lednock Reservoir which forms part of the Breadalbane Hydroelectric Power Scheme.

The River Earn flows eastwards, from its source 8km west of Comrie and Dalginross, draining a number of glens including Glen Ogle. The catchment size of the River Earn, measured at Comrie, is 183km^2. The runoff characteristics are partially controlled by St.Fillans offtake weir, which forms part of the Breadalbane Hydroelectric Power Scheme.

The Water of Ruchill drains the hills surrounding Glen Artney to the south of Comrie and Dalginross, and the catchment covers an area of 103km^2. The catchment features steep gradients with a very rapid rainfall response. The river is morphologically active, frequently changing the position of the low flow channel into Comrie.

There are three river gauges in the area that have provided useful information regarding the predicted peak flows. The gauges are located at two positions on the River Earn, upstream and downstream of Comrie; and upstream of Comrie on the Water of Ruchill. Although the Breadalbane Hydroelectric Power Scheme complicates the catchment, the effects of the scheme have been captured in the gauge records.

1.6 History of Flooding

Records of flooding in Comrie extend back as far as 1920. The town has been subject to regular inundation from the Water of Ruchill, River Earn and River Lednock. Most recently, there have been 6 major events (recorded since January 1993). Two major flood events occurred in 2012 on the Water of Ruchill during the feasibility stage of the study. Due to the severity of the damage that these events caused, the Council implemented emergency flood protection works at Camp Road to reduce the immediate local risk. Despite this interim intervention having been constructed, approximately 189 properties are predicted to remain at risk of flooding for a 1:200 year event. Hence, the requirement to provide a flood protection scheme for the town.

Image 1.2: Previous Flooding Events in Comrie

1.7 Design principles

Climate change is predicted to result in more frequent and severe flooding in the future. The scheme has been designed to a minimum 1 in 200 year standard of protection. An allowance to take full account of likely future climate change would have raised flood defence heights by a further 600mm at some locations. When balanced against visual impact, this was considered too imposing.

The scheme has been designed to be passive in operation. No flood gates need to be shut in the event of a flood, reducing the risk of the defence failure. In addition, the scheme does not require any pumps reducing operation costs, point of failure and embodied carbon. Carbon emissions associated with the operation and maintenance of the scheme are likely to be minimal, with most carbon associated with the scheme's construction and the embodied carbon of materials. Some existing materials are to be recycled, including existing rock armour on the water of Ruchill; and numerous trees will be reused as part of the proposed erosion protection.

1.8 The Outline Design

The preferred option, developed by Mouchel, was approved by the Council's Environment, Enterprise and Infrastructure Committee on 6 September 2017. Sweco were subsequently commissioned to develop the earlier feasibility study to a standard suitable for flood scheme publication. The outline design developed is predicted to provide a minimum 1:200 year standard of protection to 189 properties previously at risk of flooding.

1.9 Flood Order Process

A Flood Order is a statutory instrument that can be enacted, under Part 4 of the Flood Risk Management (Scotland) Act 2009, to enable local authorities to seek permission from the government to implement a flood risk 'scheme' in areas of high flood risk.

This Scheme will be published in accordance with the statutory process under the Flood Risk Management (Scotland) Act 2009 and the Flood Risk Management (Flood Protection Schemes, Potentially Vulnerable Areas and Local Plan Districts) (Scotland) Amendment Regulations 2017.

Statutory Process

- Flood Risk Management Act (2009);
- Publish flood scheme and notify community;
- Flood scheme confirmed;
- Planning consent from Scottish Ministers.

The community and statutory consultees will be informed when the Scheme has been published under the Flood Order. The consultees will have an opportunity to provide a response to the Scheme which will be taken into consideration by Scottish Ministers prior to planning consent (Statutory Process).

Once the Scheme is confirmed, the design will be finalised, and appropriate licenses secured (Detailed Design). The project will then be issued for tender and a contract awarded for the construction of the Scheme (Procurement). The contractor will inform the works programme and together with the Council, continue to engage with the community and landowners (Construction).

2 Hydrology

This chapter summarises the technical work and consultation undertaken to arrive at the hydrological estimates inputted to the hydraulic model. These estimates were agreed with SEPA as being suitable for this stage of the Flood Protection Scheme.

2.1 Previous stage of work

The feasibility phase of the project, undertaken by Mouchel, was concerned with identifying a preferred option after investigation a wide range of potential options. The hydrological estimates identified were conservative but appropriate for the level of investigation. It was judged that the existing estimates of peak flow needed to be updated for the investigation of the preferred option, undertaken to support Flood Order submission.

2.2 Consultation with SEPA

The following milestones occurred during consultation with SEPA:

- First contact with SEPA was made (03/10/2017) to establish their position. SEPA communicated that they were not satisfied with previous efforts to account for joint probability and explained the numerous factors that could affect hydrological estimates. These included (but were not limited to) accuracy of gauge data, reservoir operation, post-flood survey estimates, geomorphological activity and the reactiveness of the various catchments.
- A second meeting took place on (16/10/2017) so that hydrometric information could be discussed with expert contextual information from SEPA. This included discussion of rating curves from SEPA and Mouchel.
- Two reports were shared with SEPA that assessed the existing model and hydrological estimates and supplied Sweco's recommendations (12/12/2017).
- Sweco's initial position regarding hydrological peak flow estimates was shared with SEPA for an opinion (20/02/18). This was followed up with a face to face meeting (07/03/2018).
- SEPA had doubt regarding the peak 1:200 year flow estimate at the Dalginross gauge as it was significantly higher than the Kinkell Bridge gauge estimates. Sweco responded to these concerns with a briefing note (23/03/2018).
- Agreement was reached (12/04/2018) regarding peak flow estimates and the approach to joint probability.

2.3 Peak Flow Estimate

Sweco's hydrological estimates were based on a statistical analysis of gauged data within the catchment. This section has outlined the relevant catchment data and the development of the hydrological estimates. Further details may be found in the accompanying calculation sheet "*Comrie FPS - Hydrological Boundaries*".

Hydrological Catchment

The peak flow estimates for Comrie were complex due to the location of interest being close to the confluence of three rivers: River Lednock; River Earn; and the Water of Ruchill. Each river catchment can be seen in **Figure 2.1**

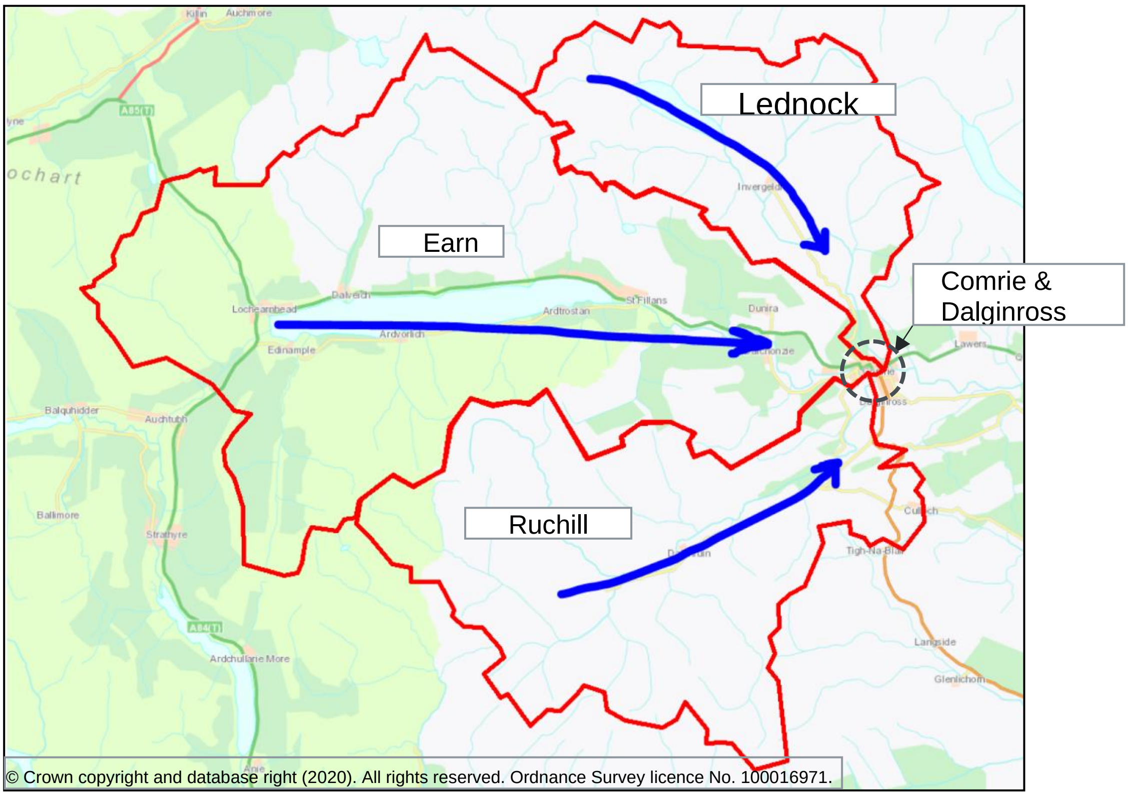

Figure 2.1: Catchment area of River Earn at Dalginross gauge

Available Data

Three river gauges are present within the overall catchment area as shown in **Figure 2.2**. Although the data had some limitations, the gauges provided the best source of information regarding peak flows on the River Earn (at Aberuchill and Dalginross) and the Water of Ruchill (at Cultybraggan). A long-term gauge record was not available on the River Lednock and hence the NRFA Peak Flow Dataset (Version 6) was used in conjunction with catchment descriptors from the UK Centre for Ecology and Hydrology and flood observations from SEPA. Gauge data at Kinkell bridge, located approximately 20km downstream, was used to sense check the flow estimates at Dalginross.

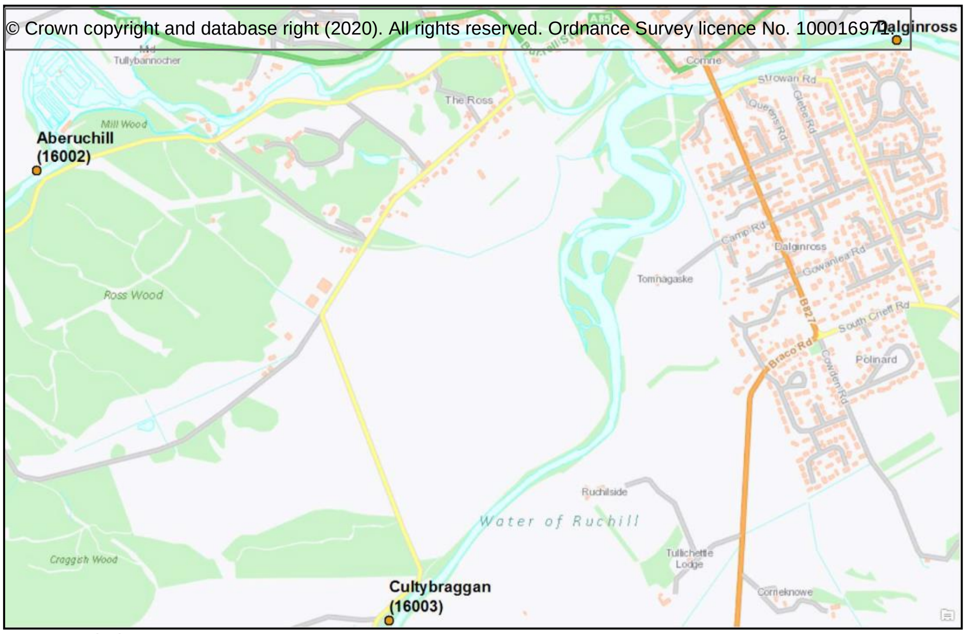

Figure 2.2: River gauge locations

Approach to Flow Estimation

The Dalginross gauge is located downstream of all three contributing catchments (Earn, Ruchill and Lednock). Hence, the approach to flow estimation was to identify a combination of events across these contributing catchments which resulted in the target (known) flows at Dalginross.

Analysis of Gauge Data

The stage data from each of the gauging stations was converted to flows using SEPA's rating curve at Cultybraggan and using rating derived curve from the hydraulic model for the remainder.

An instrument error was identified at Aberuchill, which was corroborated by SEPA. A correction factor was developed using estimates for baseflow (from catchment descriptors: C_{ini}, SAAR and AREA) at each station to sense check the data quality. The Aberuchill gauge exhibited a significant error that was found to be growing over time. Less significant errors were also found at the Dalginross and Cultybraggan gauges, these were found to be constant with time. To maintain consistency, a correction was applied to data at all three gauges to account for their stage discrepancy.

River Earn at Dalginross

The Statistical FEH approach was taken to predict the peak flows at Dalginross. QMED was estimated from 25 years of AMAX data to be 202m^3/s. An enhanced pooling group, judged to be acceptably homogenous, was established of statistically similar catchment (12+1) to provide a 527 year record of Data. A good fit to the pooling group data was found with the Generalised Logistic distribution. The 1:200 year peak flow was estimated to be 488m^3/s.

River Earn at Aberuchill

The Statistical FEH approach was taken to predict the peak flows at Aberuchill. QMED was estimated from a donor site (16003) to be 70m^3/s, this dropped to 47m^3/s with stage correction applied. An enhanced pooling group, judged to be acceptably homogenous, was established of statistically similar catchment (12+1) to provide a 503 year record of Data. A good fit to the pooling group data was found with the Generalised Logistic distribution. The 1:200 year peak flow was estimated to be 162m^3/s.

Water of Ruchill at Cultybraggan

The Statistical FEH approach was taken to predict the peak flows at Cultybraggan. QMED was taken to be 161m^3/s on SEPA's advice and was consistent with other estimates. An enhanced pooling group, judged to be acceptably homogenous, was established of statistically similar catchment (13+1) to provide a 519 year record of Data. A good fit to the pooling group data was found with the Generalised Logistic distribution. The 1:200 year peak flow was estimated to be 318m^3/s.

River Lednock

The Statistical FEH approach was taken to predict the peak flows from the Lednock. QMED was taken to be 35m^3/s from catchment descriptors. A pooling group, judged to be acceptably homogenous, was established of statistically similar catchment (15) to provide a 516 year record of Data. A good fit to the pooling group data was found with the Generalised Logistic distribution. The 1:200 year peak flow was initially estimated to be 88m^3/s. The flood frequency curve was adjusted to match a SEPA observation that suggested the 1:10-20 year event should have flows between 75-90m^3/s. This raised the 1:200 year event to 133m^3/s.

Peak Inflows

The peak inflows at each location are shown in **Table 2.1**. These flows were used to establish a 'worst case' hydrological event on each river, where the target river would experience a 1:200 year event whilst the other rivers experience a 1:2 year event.

Table 2.1: Peak flow estimates from statistical FEH method

Return Period 1 in …	Peak flow estimates from stat. FEH (m^3/s)			
	Dalginross	Lednock	Ruchill	Upper Earn
2	202	52	161	70
5	257	67	193	86
10	295	77	214	98
25	347	92	243	114
50	389	104	266	128
100	436	118	291	144
200	488	133	318	162
500	564	155	358	191

Historical Distribution of Flow

Having established a 'worsts case' hydrological scenario on each river, a fourth scenario, representing the most likely distribution of flow from historical records, was created. Six large events from gauge records were used to compare the distribution of flow between the three watercourses. An average distribution was identified after outliers were excluded. Assuming all flow passed through the Dalginross gauge, for a given event, the average distribution of flows were: 13% from Aberuchill, 63% from Cultybraggan and 36% from the River Lednock. Note that these contributions don't sum to 100%, this is due to averaging across 4 historical events and a correction factor applied to the River Lednock.

2.4 Hydrological Scenarios

Having established 4 scenarios that represented the worst-case water levels at all locations, some rationalisation was needed to reduce the computational overhead of having 4 scenarios to run in the hydraulic model. It can be seen from **Table 2.2** that Scenario 4 is very close to having a 1:200 year event both the Ruchill (+8m^3/s) and Lednock (-5m^3/s). Consequently, a small adjustment was made to scenario 4 rendering scenarios 1 and 2 unnecessary. Scenario 3 was retained.

Table 2.2: The 4 worst case hydrological scenarios

Return period by river (Stat FEH flows m^3/s)			Hydrological Scenario
Upper Earn	Ruchill	Lednock	
1:2 (70)	1:2 (161)	1:200 (133)	1 - worst case Lednock
1:2 (70)	200 (318)	1:2 (52)	2 - worst case Ruchill
1:200 (162)	1:2 (161)	1:2 (52)	3 - worst case Upper Earn
1:2 (70)	1:158 (310)	1:231 (138)	4 - worst case Dalginross – most probable flow distribution

The final scenario, agreed with SEPA, can be seen in **Table 2.3**. These two events produced the worst-case hydrology for all watercourses ensuring that the design of the defence was robust throughout Comrie and Dalginross.

Table 2.3: Hydrological scenarios

Return Period by River (Stat. FEH Flows m^3/s)			Hydrological Scenario
Upper Earn	Ruchill	Lednock	
1:200 (162)	1:2 (161)	1:2 (52)	Worst case Upper Earn
1:2 (70)	1:200 (318)	1:200 (133)	Most probable combination

2.5 Hydrograph Shape

Normalised hydrograph shapes, from observed events, were averaged to obtain a typical hydrograph for each river. The normalised and averaged hydrographs were scaled to match the peak flows agreed with SEPA. The hydrographs were then applied to the model at the gauge locations. On the River Lednock, the hydrograph was applied downstream of the Deil's Cauldron area, where no upstream influence was possible.

3 Hydraulic Model Build

This chapter summarises the technical work and consultation that were undertaken in the production of a hydraulic model suitable for the outline design phase of the Flood Protection Scheme.

3.1 Previous work

The feasibility phase of the project, undertaken by Mouchel, was concerned with identify a preferred option after investigation all feasible options. A hydraulic model was built for this investigation. Following review of this model, it was determined that building a more detailed model to progress the design was appropriate. Further details regarding this review can be found in the accompanying report "Existing Hydraulic Model Review Report".

3.2 Topographic & Bathymetric Data

The model consists of two linked computational domains, a 1D domain that represent rivers, and a 2D domain (mesh) that represents the landscape. The two domains were built using the best available data, this included topographic and bathymetric information from a variety of sources. The origin of this data, and its subsequent use, has been summarised in this section. Greater detail on this survey data has been provided in: "Fluvial Hydraulic Model Build and Verification Report" Chapter 2.

Existing Survey Information

Survey information was available from the previous project stage, and the following has been utilised within the updated model build:

- **2006 Survey:** This work captured 82 river cross-sections on all three watercourses (Water of Ruchill, River Earn and River Lednock), coarsely spaced spot levels on ground to at Ruchilside, and road levels through Dalginross.
- **2009 Survey:** This work captured 27 river sections across all three watercourses, coarsely spaced spot levels across the urbanised areas of Comrie, road levels to the north of the River Earn and 379 doorstep threshold levels.
- **2012 Survey:** A further 4 river sections were captured on the Water of Ruchill following observations of high morphological activity in the preceding years.
- **2014 Survey:** An additional 81 river sections were captured further upstream of Comrie along all three watercourses. Not all of these were implemented in the updated model as their extents were considered far outwith the scope of the study area.
- **2015 Survey:** A survey of the Dalginross Bridge was carried out, along with finely spaced spot levels at the caravan park. 22 further doorstep threshold levels were also obtained along with spot levels along the A85 road.
- **2016 Survey:** SEPA commissioned a topographic survey, with 254 river cross sections mostly downstream of Comrie and throughout Crieff. Not all of these were implemented in the updated model as the downstream extent was considered far outwith the scope of the study area.

Figure 3.1 provides a summary of the existing survey data within the central Comrie area.

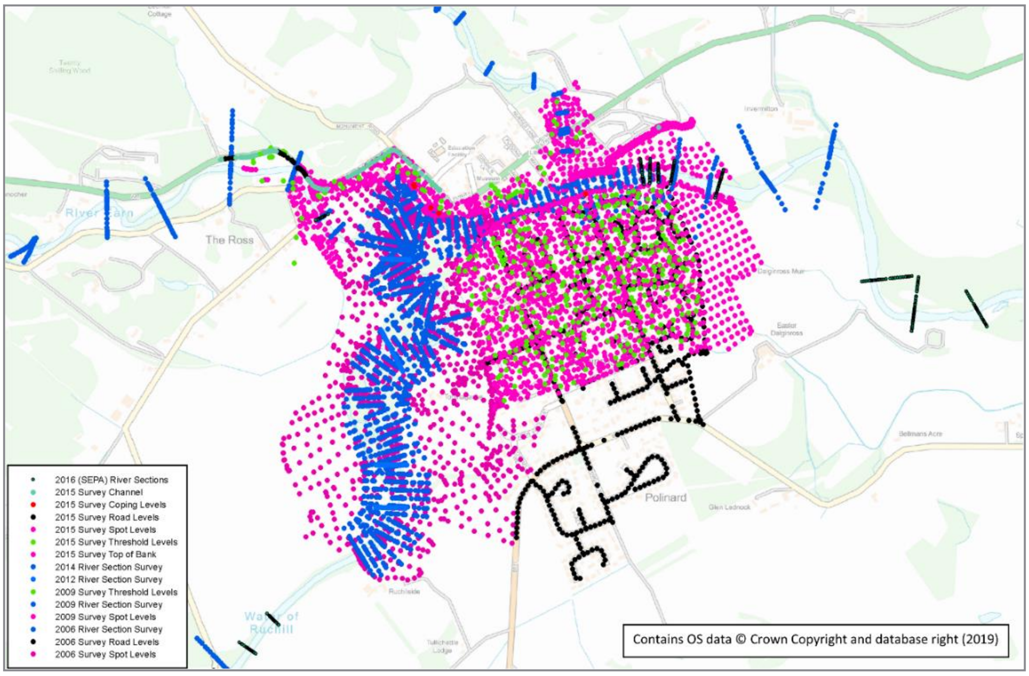

Figure 3.1: Summary of survey information existing at start of outline design stage.

Contemporary Survey Data

Prior to the model update, additional survey requirements were identified and agreed with the Council. Additional river sections were obtained on the Water of Ruchill, due to the high morphological activity which has been observed in recent years. Further river sections were also taken on the River Earn, in particular around the fish farm to better define how water flows through the area. A further set of river sections were also taken on an unnamed tributary situated approximately 500 m downstream of Comrie. Details on 3 weir structures were also obtained.

Finely spaced (vary 1 – 5m spacing) spot levels were taken at various locations across Comrie, providing detail where it was judged most important. A small number of doorstep threshold levels were also taken, filling in gaps from past datasets. These levels were mostly on the north side of the River Earn and the area around The Ross. Further survey data were later obtained, following initial modelling, to address the following from the initial survey:

- Clarification on the height of the Fey Burn wall;
- Additional detail beneath dense vegetation at the Camp Road emergency works; and
- Additional, finer spot levels along a key section of the flood bund situated on the western edge of Dalginross.

Figure 3.2 provides a summary of contemporary (2018) survey data within the central Comrie area.

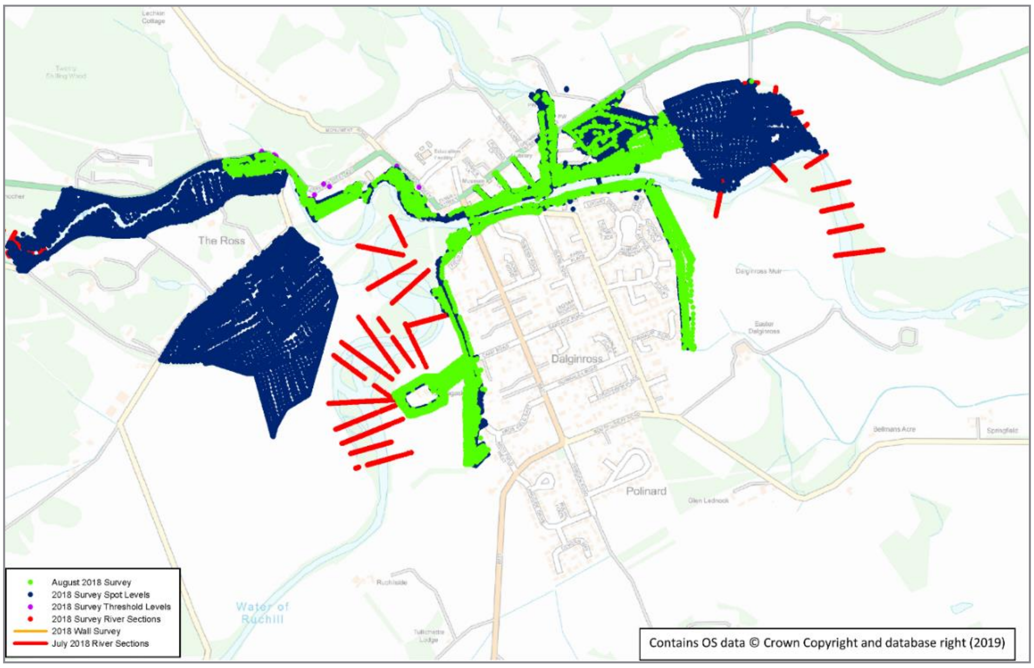

Figure 3.2: Summary of contemporary survey information, scoped at the start of the outline design stage.

LiDAR Data

LiDAR data was available from the LiDAR for Scotland Phase I dataset. This data was collected between 2011 and 2012 and no major topographic changes (outwith the rivers) have occurred in the area since this time.

An assessment of the available data found that the use of LiDAR within some areas of Comrie provided better topographic detail than the topographic survey data. Spot levels gathered on a coarse grid were found to omit important features, which were present in the LiDAR. The topographic survey data were used to ground-truth the LiDAR at these locations. The LiDAR was found to be within 5 cm of the surveyed ground elevations within the areas where LiDAR was used.

Model Boundaries

Model boundaries were chosen to cover the study area and locations downstream to ensure that any downstream impacts could be identified. Consideration was also given to a nearby ongoing development – the Comrie to Crieff footpath – which may be impacted by the proposed works. Upstream boundary locations were placed at the following locations, also shown on **Figure 3.3**

- River Earn: At the Aberuchill gauging station;
- Water of Ruchill: At the Cultybraggan gauging station;
- River Lednock: Upstream of Comrie Golf Club, just downstream of Deil's Cauldron waterfall; and
- Unnamed Tributary: Near to A.B. Gairns' contractors' downstream of the watercourse crossing of the A85.

The downstream 1D boundary was situated just downstream of Strowan Woodland. This was selected as at this point there were no out-of-bank flows recorded at any of the return period events tested. Furthermore, the river slope upstream of this location was found generally to be consistent, permitting the valid application of a normal depth condition on the furthest downstream 1D river section. This condition meant that there was no 'backing-up' effect from the downstream boundary.

The geographical locations of these boundaries are shown on **Figure 3.3** Note the upstream boundary of the River Lednock is outwith the 2D zone, and this watercourse has been modelled purely 1D to the point at which it enters the 2D zone. No 'glass-wall' effects were observed across the 1D sections.

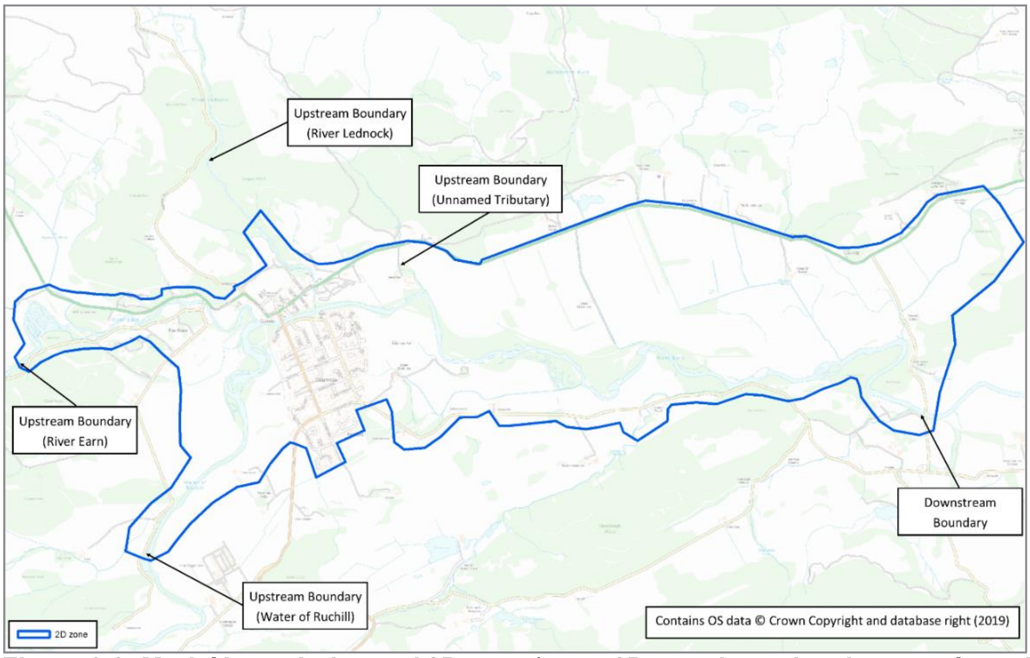

Figure 3.3: Model boundaries and 2D zone (note: 2D zone boundary is normal condition)

1D River Sections

The 1D river section data originated from a combination of the 2006, 2009, 2012, 2014, 2015, 2016 and 2018 surveys. Each of the river sections was checked and clipped to their highest points on each bank. This meant that water would only flow into the 2D zone within the model once it had exceeded bank-full stage.

Particular attention was paid to the sections along the Water of Ruchill, where part of the reach was known to be highly morphologically active. Major changes were observed and, thus, it was difficult to determine an appropriate past date which could take a 'worst-case' reach alignment into account. On this basis, the 2018 survey data were used along the whole Water of Ruchill on the understanding that any future use of the model may require further survey work. Bank protection work from 2013 on the Water of Ruchill was integrated within the model using as-built drawings. A full analysis of this can be found in Section 4.1 of the "*Fluvial Hydraulic Model Build and Verification Report*".

2D Zone

The 1D river sections interfaced with the 2D zone via the use of bank lines, permitting smooth exchange of flows between 1D and 2D as the model simulation progresses. The 2D zone itself comprised a flexible triangular mesh, with minimum and maximum mesh element areas set to 5m2 and 200m2 respectively. A feature of the model known as terrain sensitive meshing has been used to automatically increase mesh resolution in areas where the ground model has large variations in height.

Roads have been represented within the mesh using mesh zones to drop the mesh level by 100mm along road lines, which were defined using OS Mastermap data. Walls, identified through and with elevations defined by the survey data, have been represented within the mesh using 2D base linear structure features. The Fey Burn wall, Camp Road emergency works and flood embankment to the south of Camp Road have all been represented within the model in this way.

Roughness within the 2D zone has been defined as a standard Manning's n value of 0.045. Departures from this value have been implemented in certain areas through the use of roughness zone elements as follows:

- Buildings, n = 1.000
- Gardens / green open space, n = 0.030; and
- Roads, n = 0.020.

The above features were identified using OS Mastermap data, which was provided by the Council. More detailed information on the 2D zone can be found in the "*Fluvial Hydraulic Model Build and Verification Report*", Chapter 5.

Buildings

In addition to the increase in roughness defined for buildings which were identified through the use of OS Mastermap data, additional attributes were assigned to these features within the model to enhance their representation. Each building was assigned a unique receptor identifier. This identifier relates back to National Receptor Dataset (NRD) data, provided by the Council. The NRD are GIS data which provided a nationally-consistent definition of flood receptors (i.e. homes and businesses) for the estimation of flood damages. Buildings were also assigned a platform elevation. This elevation was representative of the ground finished floor level of the building. These elevations have been assigned using one of the following two methods;

1. Data from the doorstep threshold survey, if this exists; or
2. Estimate from surrounding ground levels using an Environment Agency (EA) equation.

The buildings were raised to the platform elevation within the 2D mesh. This has allowed the estimation of flood depths both within and outside receptors for use in the economic appraisal.

3.3 Model Calibration & Validation

The model was calibrated to 3 historical events using roughness as the free parameter. The Manning's n values (within the 1D river cross-sections) were modified, with multipliers ranging 0.5 – 1.15 in intervals of 0.05, to optimise the model prediction against historical records. The event taken from gauge records occurred on the following dates:

- 16th January 1993;
- 19th February 1997; and
- 30th December 2015.

The calibration exercise resulted in the Manning's n values being reduced by 4%. Not all available past events were used in model calibration and these three events were selected because they were all distinct from each other and provided a wide range of flows over which the model could be satisfactorily calibrated. Full details on the model calibration can be found in Section 7.1 of the "*Fluvial Hydraulic Model Build and Verification Report*".

Model Validation

To validate the calibrated model, it must be tested against another past flood event, to which it has not been calibrated. The 23 February 2014 event was used to validate the model. The models prediction of the observed hydrograph, at the Dalginross gauge, was good. The calibrated model also predicted a peak water depth within 100mm of the observed value. This was within the agreed tolerance of 150mm that had been agreed with the Council and is recommended by SEPA's *Flood Modelling Guidance for Responsible Authorities*. This outcome can be seen in **Figure 3.4**. Full details on the model calibration can be found in Section 7.2 of the "*Fluvial Hydraulic Model Build and Verification Report*".

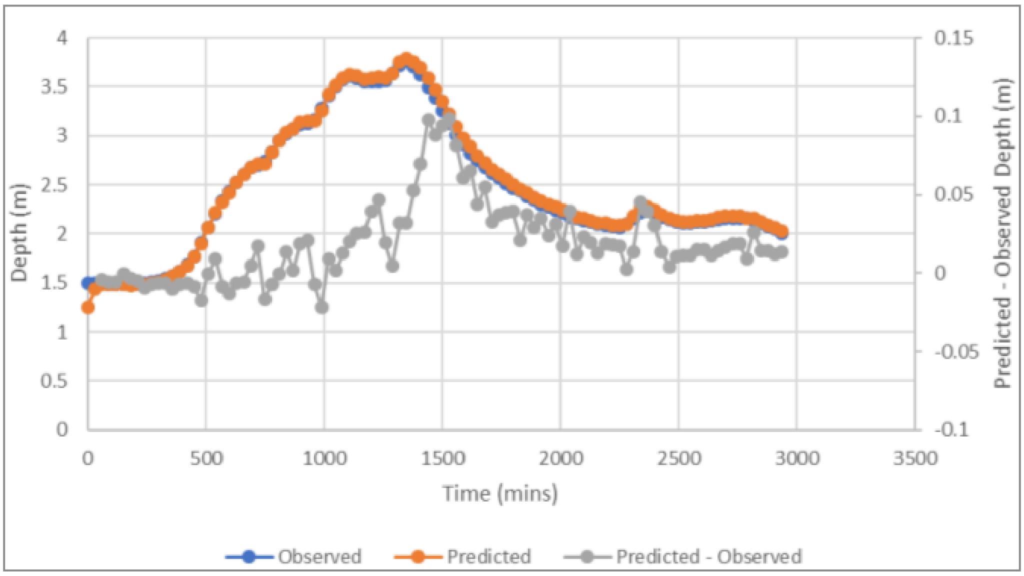

Figure 3.4 - Model validation chart

Model Sensitivity

To understand how the model would behave to small changes to its inputs, a series of sensitivity simulations were carried out. Sensitivity to the input values of Manning's n were found to display a moderate sensitivity with increases of 20% and 40% yielding respective peak water depth increases of 12% and 22%. A similarly moderate sensitivity to flow inputs were found, with a respective increase in peak water depths of 6-11% and 9-18% (depending on location) resulting from flow increases of 20% and 35%.

First order uncertainty analysis was undertaken for a 95% confidence interval, which placed model uncertainty at 0.191m. Given the high quality of the calibration/validation, and the moderate sensitivity of the model to small changes in input, the predicted uncertainty was judged to be conservative.

3.4 Model Use

The hydraulic model has been used to simulate the baseline (i.e. present-day) condition at the following range of return period events: 1:2, 1:5, 1:10, 1:30, 1:50, 1:75, 1:100, 1:200 and 1:1000 year. Each of these return period events have also been simulated with the mid-epoch climate change (+20%) and end-epoch climate change (+35%) uplifts.

The baseline model was used as a design tool for testing of various potential defence alignment scenarios. In order to correctly define the defence elevations, the proposed defence alignment was implemented within the model as a 2D base linear structure with infinite height. The elevation to which the water reached during the design event was taken as the defence design height less freeboard.

A final defence alignment and height, less freeboard, was simulated in the model for the same return period events and climate change uplifts as the baseline simulations. These have been used to produce flood mapping and to aid future planning for design exceedance events. Further details on the defence alignment, its modelling and residual risk post-development can be found in the accompanying report *"Flood Defence and Residual Risk Report"*.

Outputs from the model have also been used to inform the economic appraisal, network results polygon and network results line elements provided estimated depths within and outside the building (respectively) at each simulation run.

4 Freeboard

This section has outlined the technical work that was undertaken to establish the design freeboard. The final freeboard recommendations have also been discussed. The application of the freeboard to the flood defences has been detailed in the accompanying report "*Flood Defence and Residual Risk Report*".

4.1 Definition of Freeboard

The hydraulic model was used to estimate the worst-case water levels at all locations during times of flooding. Freeboard was added to these elevations to account for (1) model uncertainty and (2) physical processes that were not included in the simulation.

4.2 Model Uncertainty

Model uncertainty arises from three main areas:

- **Geometry** – rivers can realign themselves suddenly, or progressively, which can improve or reduce conveyance of the channel.
- **Hydrology** – hydrology is inherently uncertain and usually presents the largest source of uncertainty. Factors that may affect the run-off characteristics of a catchment include: land use; climate; and the operation of Breadalbane Hydroelectric Power Scheme.
- **Roughness** – model roughness is used to represent varying resistance to water flow from plants, fields, and other surface types. It is applied to the model using engineering judgement and experience. Factors that affect roughness include: land use; climate; and seasonality.

As the predictions made by the hydraulic model, are based on a snapshot in time, account was taken of the afore mentioned uncertainties to ensure that the recommended design wall heights were robust. First order uncertainty analysis was undertaken for a 95% confidence interval, which placed model uncertainty at 0.191m.

4.3 Physical Processes

Physical processes that the model does not account for were also estimated.

Hydraulic Controls

Hydraulic structures that may control flow were well represented in the model. The model cross-sections were created from survey and the 'backing up' from 'throttle points' was present in the model. However, to account for re-circulations, and other dynamics that are not captured, a factor-of-safety has been applied at appropriate locations:

- +15% of the uncertainty allowance for walls; and
- +30% of the uncertainty allowance for embankments.

This safety factor was also been applied at the confluence between the River Earn and Water of Ruchill because deposition at this location suggested reduced momentum, raising the static head.

Superelevation at Bends

Superelevation has the potential to raise water elevation as a result of increased centipedal force at river bends. Estimates of superelevation were made considering the channel velocity, channel width, gravitational acceleration and radius of curvature. A 1.15 factor of safety was also applied to this calculation to account for uncertainty. Two areas influenced by superelevation were identified:

- Water of Ruchill, upstream of its confluence with the River Earn; and
- River Earn, upstream of its confluence with the Water of Ruchill.

Wave Prone Areas

The ‘fetch’, or the distance over water that the wind can act to make waves, in front of the line of defence extends up to ~520 m. The expected waves highs were not insignificant and hence wave height, run-up, and overtopping volume were estimated using standard engineering formulae, in-line with the guidance given in Flood and Reservoir Safety Fourth Edition (Institute of Civil Engineers 2015).

4.4 Overall Freeboard Calculation

The overall freeboard calculation for any given location was summed from the following:

1. Model uncertainty at 191mm;
2. Minimum wave action (+35mm for wall, +80mm for bund);
3. Wave prone area calculation (superseding 2);
4. Potential future asset degradation (+40mm for wall, + 150mm for bund);
5. Minimum superelevation (+20mm in all cases);
6. Calculated superelevation (superseding 5); and
7. Hydraulic control.

The estimated freeboard was added to the maximum water levels predicted by the hydraulic model. This resulted in a robust design water level to inform the design of flood defence structures.

5 Secondary Flooding

The proposed flood protection scheme has potential to trap surface water, behind the walls and embankments, that would have ordinarily flowed overland to a River. This problem is referred to as ‘secondary flooding’. Properties that may benefit from the proposed fluvial flood protection scheme could experience increased surface water flooding as a result of secondary flooding. To understand this risk, a hydraulic model of the sewer network was developed for the baseline (present day arrangement) and the post-development (the baseline with the addition of proposed flood defences) scenarios. Potential areas of detriment were identified through comparison of these two scenarios. Mitigation measures were then developed in the post-development scenario to mitigate the identified detriment from the proposed scheme.

For clarity, secondary flooding mitigation only addresses the additional surface water risk brought about by the proposed scheme; and does not seek to make improvements to existing (i.e. present-day) surface water flooding.

5.1 Background

Comrie and Dalginross is served by public sewerage. The area is relatively flat and sewer flows are driven by several pumping stations to a treatment works approximately 1km east of Dalginross. This treatment works is owned and operated by Scottish Water. Scottish Water previously commissioned Atkins and RPS Consultancy, operating under the ARC consortium, in September 2016 to undertake a Flood Risk Management Section 16 (S16) Assessment Study for the Comrie Drainage Operational Area DOA000672. This included the production of a hydraulic model. The model had not passed audit to Scottish Water standards at the time it was passed to Sweco. The deficiencies were set out in a Scottish Water audit sheet, and have been addressed as part of this study to enable the model to be used for the assessment of secondary flooding.

Sweco also integrated several datasets that had not previously been used. These datasets were held by the Council and Sweco and included: LiDAR, manhole surveys, drop tests, impermeable area survey and CCTV. The depth duration frequency (DDF) rainfall events utilised in the model runs were also updated to the flood estimation handbook (FEH) 2013 DDF model.

The updated network model was built in Infoworks ICM to allow the pre-development and post-development pluvial flood risk to be estimated. By comparing these two scenarios Sweco have been able to identify areas that may be detrimentally affected by the proposed Flood Protection Scheme. More information regarding the model build can be found in the following reports:

- ***Comrie FPS Model Build Report: Pluvial*** – this report outlines the updates to the section 16 model supplied by Scottish Water.
- FRM Section 16 Model Build Report: DOA000672 (Comrie) Version 1 02/08/2017 – this report details the construction of the original S16 model.
- ***Secondary Flooding Mitigation Options Briefing Note*** – this report presents the initial mitigation option presented to Scottish Water and SEPA.

- ***Secondary Flooding 14/01/2020*** – this report summarised the optioneering and preferred mitigation options.

5.2 Consultation

Extensive consultation took place with Scottish Water and SEPA to ensure that measures proposed to mitigate the detriment were acceptable to all parties. Initially 8 mitigation scenarios were shared with consultees, detailed further in '*Secondary Flooding Mitigation Options Briefing Note*'. A further 7 variants of option 3 were offered at subsequent meeting.

Measures aimed to reduce overall volume in the landscape, which was mainly achieved through changes to Scottish Waters sewer network. The focus was moved away from total volume in the landscape, towards receptors, by consultees. A significance threshold of 30mm was also advised by Scottish Water.

Additionally, consultees requested more sustainable means of achieving mitigation, such as surface water separation. In response to this challenge several options to separate surface water, from the combined sewer, were explored. These options were judged to have a low likelihood of success due to the flat topography in the area.

Localised measures were explored when larger scale measures were judged to be unacceptable to the consultees. A strategy to pursue localised measures was agreed, with the residual risk documented and communicated, as shown in **Table 5.1**.

Table 5.1: Agreed strategy with stakeholders

<table>
<tr><th>Scenario</th><th>Target / receptor</th><th>Measure</th><th>Residual detriment - not addressed through scheme</th></tr>
<tr><td rowspan="3">Option 1</td><td>R674</td><td>local intervention, flap valve bypass or similar</td><td rowspan="3">84 MHs will see detriment to water levels>5mm

marginal increase to volume at the works for a JP event =1:200y

an extra 386m3 flooding in the urban area affecting roads and curtilage

reduced development potential</td></tr>
<tr><td>R136</td><td>improve drainage, small pump to bypass defence</td></tr>
<tr><td>R727</td><td>local intervention, flap valve bypass or similar</td></tr>
</table>

5.3 Preferred options

Back of wall drainage has been specified in some areas to collect and convey surface water, that would otherwise pool behind the proposed defences, to outfalls. This surface water does not necessarily cause detriment, but the proposed drainage prevents water pooling for long durations. This was viewed to be advantageous for structure longevity and public health. All drainage will be gravity driven; no pumping stations will be required. Passive operation will reduce the lifetime cost of drainage and improve the sustainability of the scheme. The back of wall drainage requires 3 outfalls to the River Lednock, 4 outfalls to the River Earn and 1 outfall at Fey Burn. All outfalls will feature a non-return mechanism and will be situated at the highest possible elevation to minimise fluvial locking. A more detailed description of the interventions can be found in report: **Secondary Flooding 14/01/2020.**

The mitigation offered at Receptor R674 and R727 was integrated into the back of wall drainage by upsizing the slotted pipe to the maximum possible diameter (525mm). This improved the collection potential whilst also providing in-line storage, in the event that the outfall becomes locked. A typical back of wall cross-section can be seen in **Figure 5.1**. Note that the slotted pipe is bedded in gravel and isolated with a geotextile surround.

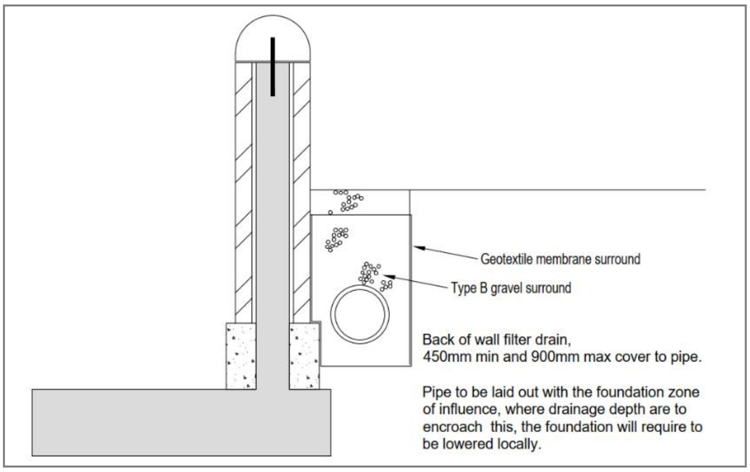

Figure 5.1: typical back of wall drainage cross-section

Mitigation at R136 consisted of surface water separation. This will reduce the load to the combined sewer locally, reducing the probability of the sewer backing up. Surface water will discharge freely to the drainage ditch to the west via a non-return mechanism, reducing surface water pooling on the road locally, as shown in **Figure 5.2**

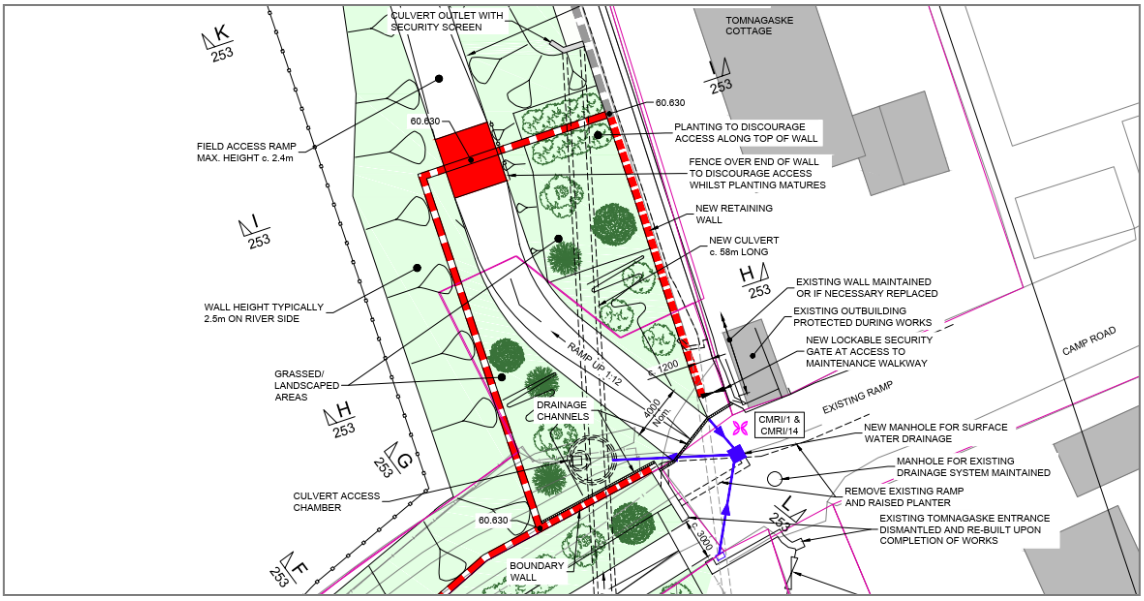

Figure 5.2: Camp Road arrangement, proposed drainage in blue

5.4 Summary

A surface water flooding model was developed from an existing Scottish Water model. The model provided had not passed an internal audit and significant work was undertaken to improve the model. Additional survey data was utilised to update the model, and an IAS survey was undertaken to better estimate sub-catchment runoff parameters.

The proposed fluvial defences were added to the baseline model to enable the secondary flooding impact to be investigated. Several approaches to control secondary flooding were discussed with Scottish Water and SEPA, with local interventions becoming the leading option at three sites identified as having secondary flooding detriment above threshold level.

In addition to localised measures, several areas of the proposed defence have been specified with back of wall drainage to prevent pooling behind the proposed defences. This drainage requires 3 outfalls to the River Lednock, 4 outfalls to the River Earn and 2 outfalls to the Fey Burn. All outfalls will feature a non-return mechanism and will be situated at the highest possible elevation to minimise fluvial locking. All drainage will be gravity driven; no pumping stations will be required. Passive operation will reduce the lifetime cost of drainage and improve the sustainability of the scheme.

6 Fluvial Geomorphology and Erosion Protection

The following chapter has summarised the geomorphological investigations and consultation undertaken as part of the Comrie Flood Protection Scheme. 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. Details of these studies were used to inform the development of erosion protection options, of which the full list can be found in Chapter 2.1 of the Document CFPS_GM01.

6.1 Background

A geomorphological walk over (a modified 'fluvial audit') survey was undertaken by consulting geomorphologists, cbec on 13 – 14 November 2017. Sections of the three rivers running through Comrie - the River Earn, River Lednock, and the Water of Ruchill - were included in this survey. Details of survey extents and results are found in Document CFPS_GM04 and have been summarised below for each watercourse.

River Earn

Image 6.1: River Earn

A photograph typifying the River Earns character can be seen **Image 6.1**. The fluvial audit considered the following:

Stream Type:

- Alternating between riffle-pool and plane bed.

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.

Anthropogenic Pressures:

- Two stone weirs;
- Piled stone and stone walls along banks;
- Stone arch bridge (Bridge of Ross);
- Embankments along field boundaries and Comrie Holiday Park;
- Realigned sections;
- Bank protection; and
- Invasive Species – Japanese Knotweed and Rhododendron.

River Lednock

A photograph typifying the character of the River Lednock is shown in **Image 6.2**. The fluvial audit considered the following:

Stream Type:

- Cascade and step-pool transitioning to plane bed/riffle-pool downstream.

Bank Conditions:

- Mostly stable vegetated banks;
- One significant area of erosion on left bank upstream of foot bridge.

Anthropogenic Pressures:

- Concrete weir (not intact);
- Two bridges with abutments
- Bank protection – piled and intact stone wall;
- Realignment – narrowing and straightening of channel.

Image 6.2: - River Lednock

Water of Ruchill

A photograph typifying the character of the Water of Ruchill is shown in **Image 6.3.** The fluvial audit considered the following:

Stream Type:

- Cascade transitioning to riffle-pool downstream.

Bank Conditions:

- Multiple cases of severe bank erosion in lower reach;
- Upper reach has vegetated banks, so less erosion.

Anthropogenic Pressures:

- Realignment - Straightening of channel;
- Significant and extensive hard bank protection;
- Significant embankments and dredged material along banks;
- Gravel extraction;
- Over-widening; and
- Invasive Species – Japanese Knotweed.

Image 6.3: Water of Ruchill

An assessment of the likelihood that the proposed flood protection scheme will impact the Water Framework Directive (WFD) status of waterbodies within the study area was also undertaken by cbec, after the fluvial audits were completed. 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) and a deterioration in one of these criteria may result in the waterbody failing to meet the WFD objectives.

Full results of the RBMP survey can be found in the accompanying report "*RBMP Assessment*" and are also summarised here, in **Table 6.1.**

Table 6.1 - Summary of WFD Status

Waterbody	WFD Status	Potential Impacts	Recommendations
River Earn (Loch Earn to Ruchill confluence)	MODERATE	Flood walls will reduce floodplain connectivity and increase channel confinement Bank protection will add morphological pressure.	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	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 where possible.
Water of Ruchill	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 where possible.
Lednock Burn (River Lednock)	HIGHLY MODIFIED MODERATE	Capacity used is close to threshold (1% remaining) for a reduction in	Use good work practices to limit spread of invasive plants.

Waterbody	WFD Status	Potential Impacts	Recommendations
		morphological status from 'high' to 'good'. Flood walls will reduce flood plain connectivity and increase channel confinement	

These assessments laid the groundwork to undertake scour, erosion and bank protection assessments in order to understand the existing sediment regimes. A scour and erosion assessment was undertaken by cbec for the three rivers within the project area, with the aim of identifying at-risk banks. Nine areas were identified:

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.

6.2 Bank Protection Optioneering

The at-risk areas were filter to those that either impacted the function of the scheme or were detrimentally affected by the scheme. Several different types of bank protection were considered. SEPA divide these into two broad 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.

The following 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.

Consultation with both SEPA and the Council was undertaken with regards to the Water of Ruchill. A walkover survey with representatives of both was carried out on the 9 October 2018. Full details of the outcomes of this consultation can be found in accompanying technical note "*Water of Ruchill Geomorphic Walkover memo*". SEPA raised concerns that the Water of Ruchill may be downgraded from 'good' to 'moderate' status should grey bank protection be installed. 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. A further fluvial audit was undertaken on the Water of Ruchill to attempt to identify sources of sediment and potential controls on this sediment. Full details of the fluvial audit can be found in the accompanying report "*Fluvial Audit – Water of Ruchill*".

Following the fluvial audit report, SEPA responded by stating that they had no specific concerns regarding the scheme. They would prefer to see bank protection being composed of natural elements rather than hard structures.

SEPA also raised concern that the River Lednock may be downgraded from 'high' to 'good' status, however this will not impact the WFD status of the waterbody.

Thus, from a sustainability perspective, and to satisfy SEPA's requirements, green bank protection is preferred, as these options minimise environmental harm. However, it was also required to ensure that the solution is robust enough to resolve erosion issues. 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.

6.3 Solutions

The plans and details of proposed bank protection options are presented more fully in the accompanying technical note "*Fluvial Geomorphology and Erosion Protection*"; but the key outcomes have been summarised here.

The right bank of the Water of Ruchill, at the Field of Refuge, is arguably the most critical site requiring bank protection. The current bank protection is failing, and rapid bank erosion was found to be occurring downstream of this bank protection. The bank was seen to be eroding due to rapid flow velocities, particularly at the bank toe which undermines the bank resulting in collapse. Robust bank protection was required to withstand the rapid flow velocities, and a root wad revetment with rock roll toe was selected in this area. The proposed revetment will match the current bank height (approximately 3m) and will be approximately 260m 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, the flood wall has been located along the top of the right bank of the River Earn, and space to install bank protection or reprofile the bank is limited. However, it was essential to provide robust protection in this area because the proposed flood wall will be in close proximity to the river. To mitigate this risk, a rock roll toe and reinforced bank was selected to provide erosion protection. This will extend approximately 115m and have a height of approximately 3m. 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.

6.4 Summary

The process for developing the detailed bank protection options for the Comrie Flood Protection Scheme began with fluvial audits and WFD impact surveys to identify areas most at risk from erosion, as well as areas that may suffer WFD derogation due to the impact of the Scheme. Bank protection options were developed, after further consultation with SEPA, according to certain criteria to maximise the sustainability of said bank protection, which also ensuring that the Scheme meets its objectives.

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7 Ground Investigations

The following chapter details the ground investigations undertaken to support the outline design, and the subsequent detailed design and construction of the Comrie Flood Protection Scheme.

Previous feasibility reporting, carried out by others (notably Mouchel), has been produced for the Scheme. This reporting, which includes desktop, environmental baseline reporting and optioneering studies (including preliminary GI), led to the development of a preferred design option for the flood defences. These included extension of existing / construction of new flood defence walls, and formation of earthwork embankments to provide 1 in 200 year flood defences along the River Lednock, Water of Ruchill and the River Earn.

The works undertaken by Sweco include desktop reporting, detailed intrusive ground investigation and subsequent factual and interpretative reporting (including seepage analysis). In this instance, two phases of intrusive investigations were undertaken by Sweco; an initial main investigation, and a subsequent additional ground investigation targeting secondary flooding risks.

The ground investigations undertaken by Sweco were designed and executed in line with UK best practice, notably BS5930:2015 Code of Practice for Site Investigations and BS10175:2011+A2:2017 Investigation of Contaminated Sites - Code of Practice, together with BS EN 1997-1 (2004), BS EN 1997-2 (2007) and BS EN ISO 22475-1 (2006).

At the request of the client, the ground investigations and associated reporting were checked and certified within the framework of the DMRB Volume 4, Section 1, Part 2, HD 22/08 Managing Geotechnical Risk.

7.1 Key Reports

The following main reports were produced by Sweco as part of the works undertaken:

- Geotechnical Statement of Intent, Comrie Flood Protection Scheme, 119398-SWECO-FPS-SOI, Version 2, Sweco, October 2018;
- Preliminary Sources Study Report, Comrie Flood Protection Scheme, 119398-DOC-200-201, Version 3, Sweco, January 2019 ('the PSSR');
- Ground Investigation Report, Comrie Flood Protection Scheme, 119398-300-007, Version 3, February 2019 ('the GIR'); and
- Technical Note: Seepage Analysis, Comrie Flood Prevention Scheme, 119398-300-008, Version 01, Sweco, September 2019.

In addition to the above, a number of factual reports on Ground Investigations were produced, as detailed below:

Main Ground Investigation:

- Comrie Flood Protection Scheme: Holequest Factual Report (dated 17 September 2018, Document Reference: S/CFPS/0418/Fact, Rev. 1 Final).

Additional Ground Investigation:

- Comrie Flood Protection Scheme Additional Works Holequest Factual Report (dated 18 February 2019, Document Reference: S/CFPS/0119/Fact, Rev 1 Final).

A full list of the pertinent historical reporting and historical ground investigations reviewed are provided within the **PSSR** and **GIR** documents, with the most pertinent being as follows:

- Mouchel: Comrie & Dalginross Flood Study – Preliminary Ground Investigation Report. Version B, May 2016. Document reference: 1033064/R/60.

7.2 Consultation

As part of the GI works, a number of statutory bodies were consulted during 2017 and 2018. Details are provided in **Table 7.1** below. In addition, as a curtesy, all landowners where GI works were completed were contacted via letter or face to face prior to GI works commencing.

Table 7.1: Consultation relating to Ground Investigations

Consultee	Summary of consultation	Comment/ Action taken
Perth & Kinross Conservation Officer	Walkover and submission of a Tree Works Application for limited tree removal within Comrie Conservation Area (notably the gas works site).	Provision of Licence to fell trees provided by email response on 20/12/2017.
SEPA and Scottish Water meeting on 31/08/2018	Review of proposed Ground Investigation associated with SEPA and SW assets	Review of GI locations to take into account SEPA and SW comments, and liaison with SW to gain access to SW owned land during the GI works in 2018.
Perth and Kinross Heritage Trust/ PKC	Review of Ground investigation to inform on impact on Archaeology from GI works	Requirement for watching brief on a number of GI locations which were in proximity to Archaeological Assets. Watching brief completed and report provided by Headland Archaeology in February 2018

7.3 Desk Based Assessment (PSSR)

A desk based review of all pertinent historical data (including historical ground investigation reported in the Mouchel Preliminary GIR) relating to the Scheme was undertaken. The objective of the review was to summarise the available geotechnical and geoenvironmental data and provide a geotechnical and geoenvironmental assessment of the ground conditions within the Scheme area, and to identify any notable geotechnical or geoenvironmental constraints to design. Geotechnical risks to design and construction emerging from the assessment were presented as a risk register, in line with the requirements of HD22/08, and recommendations for mitigation presented.

A number of main geotechnical constraints identified are summarised as follows:

- Insufficient historical ground investigation information to establish appropriate geotechnical parameters for detailed design;
- Potential presence of soft compressible soils (particularly Alluvium and River Terrace deposits) throughout the Scheme area;
- Potentially difficult ground conditions for construction (i.e. driving sheet piles);
- Limited information available on the groundwater regime;
- Potential for shallow groundwater across the Scheme area;
- Complex superficial geology with varying engineering properties; and
- Uncertain bedrock profile, with potential for bedrock depths to vary significantly across the scheme.

In addition, a number of geoenvironmental constraints were identified:

- the potential for contamination associated with historical site uses, in particular railway land, Gasworks and made ground associated with former land uses; and
- Uncertain extent, thickness and nature of made ground across the Scheme, most pertinently at a historical Gas Works site, and within wider Scheme.

Further commentary on geoenvironmental aspects is provided in the subsequent chapter of this report.

Based on the assessment, the need for detailed ground investigations was identified in order to assess and mitigate the identified risks and address the main constraints, develop the ground model for the scheme, and allow characterisation of the geotechnical and geoenvironmental properties of the ground underlying the scheme area. The resultant factual data would be utilised to inform the design of the flood defences of the Scheme.

7.4 Ground Investigation Works

A ground investigation scope was developed based on the findings of the PSSR to investigate the identified ground risks. The works were completed in two phases; a main investigation, completed between January and April 2018, and an additional phase carried out in October and November of 2018.

The main ground investigations were targeted on the location of the proposed flood defences for the Scheme. The additional investigation works were predominantly targeted to potential locations identified at potential risk from secondary flooding mitigation/infrastructure, largely distant from the proposed flood defences. Plans and logs of the intrusive investigations, together with testing data are provided within the Factual Reports for each phase (referenced above).

The scope of the investigations are summarised below:

Main ground Investigation

37 boreholes, of which:

- 5 were completed by cable percussive drilling only, within superficial soils;
- 9 were completed by cable percussive drilling, with rotary coring follow on in bedrock;
- 23 rotary boreholes, of which 9 were progressed by rotary openhole within superficials soils only, and the remaining 14 penetrated rock through rotary coring;
- 42 machine excavated trial pits, within superficial soils;
- 45 shallow hand pits within superficial soils;
- Installation of 21 ground water and ground gas monitoring wells;
- In situ testing, including SPTs and in situ permeability testing;
- Laboratory testing of selected soils sample for geotechnical and geoenvironmental analysis; and
- Groundwater and ground gas monitoring of selected borehole installations.

Additional Ground Investigation

- 4 cable percussive boreholes within superficial soils;
- 16 window sampler boreholes within superficial soils;
- 17 machine excavated trial pits, within superficial soils; and
- 45 shallow hand pits within superficial soils.

7.5 Investigation Findings

Full assessment of the findings of the ground investigation data are presented in the Ground Investigation Report (the GIR) prepared by Sweco. It is noted that for the purposes of the GIR, the additional investigation data was excluded as it was generally distant from the location of the Scheme flood defences.

In summary, the investigations largely confirmed the findings of the historical ground investigations and were generally as anticipated in the **PSSR** reporting. **Table 7.2**, below, details the ground conditions identified, together with depth of occurrence and proven thickness throughout the Scheme area.

Table 7.2: Summary of Ground Investigation Data (Main Investigation and Historical Data)

Strata	Description	Occurrence	Depth to top of strata (mbgl)	Depth to base of strata (mbgl)	Proven Thickness (m)
Made Ground	Reworked silty sands, sandy gravel or sandy gravelly clays with extraneous/ man made materials. Where GI positioned on the road, made ground comprised granular fill associated with road makeup.	Proven locally, particularly at the old gas Works site and in	GL	0.1 – 3.9	0.1 – 3.9
Topsoil	Clayey gravelly sandy topsoils with rootlets; locally sandy gravely clay	Across Scheme area	GL – 1.1	0.05 – 1.5	0.05 – 1.2
Cohesive Alluvium (Clay)	Soft to firm mottled sandy clay, occasionally with rootlets	Shallow occurrence, typically as localised lenses	GL – 1.1	0.4 – 1.5	0.3 – 1.1
Granular Alluvium	Extensive sequence of alluvial sands and gravels, described a s medium dense to very dense sandy gravels and medium dense sands. Locally, drilling found “running” or “blowing” conditions, inhibiting sampling and testing,	Across Scheme area	GL – 3.9	3.2 – 36.4	2.3 – 33.75
Cohesive Alluvium (Silt)	Very soft to soft sandy slightly gravelly clayey silt; typically discreet lenses within alluvial sequence. Encountered as a more significant unit within several boreholes, and noted to become stiffer with depth, recorded as “hard silt” locally.	Locally across scheme area, typically as lenses within granular alluvial sequence, and rarely as more extensive units	0.75 – 14.8	1.6 – 28.55	0.85 – 15.2

Strata	Description	Occurrence	Depth to top of strata (mbgl)	Depth to base of strata (mbgl)	Proven Thickness (m)
Glacial Till	Very stiff slightly sandy slightly silty gravelly clay with low cobble and boulder content passing onto gravel at depth	Only within two boreholes, encountered at depth below alluvium	6.2 – 34.6	7.0 – 35.6	1.0 – 5.05 (base not proven)
Bedrock	Typically Metamorphic strata of the Ben Ledi Grit Formation, comprising weak to strong meta siltstones and meta sandstones (pelitic and psammitic rock). Locally, igneous strata (dolerite and granodiorite) recorded, interpreted as localised intrusions (dykes or sills)	Proven across scheme	3.2 – 35.6	Proven to 38.0	15 proven

Groundwater

Groundwater strikes were recorded within historical and recent exploratory holes across the Scheme area between ground level and a maximum recorded depth of 8.55mbgl.

The groundwater strikes recorded during the recent investigations were recorded within the granular alluvial deposits, or at the boundary between the made ground /cohesive alluvial deposits and the granular alluvial deposits. During historical ground investigations, groundwater was encountered predominantly within granular alluvial deposits, with the exception of a number of boreholes which encountered groundwater within granular made ground deposits.

In general, it can be seen that the groundwater observations of the recent and historical investigations are broadly in agreement, with groundwater strikes typically shallow (<5mbgl) and typically coincident with granular alluvial strata.

Geotechnical Characteristics and Summary of Risks

Based on the findings of the ground investigation, and in line with Eurocode and HD22/08 guidance, characteristic design parameters were derived for each encountered stratum. These values, presented in the Sweco GIR referenced above, were utilised as part of the outline design of the flood prevention structures forming the Scheme.

In addition, the geotechnical risk register identified within the PSSR report was updated and presented within the report, in order to be utilised as a basis for ongoing geotechnical risk management throughout the Scheme design and construction. The most pertinent residual risks identified (classified as substantial or above) are briefly listed below.

- Local variability of superficial deposits- unexpected ground conditions such as running Sands;
- Made ground on uncertain depth and extent;
- Soil Contamination;
- Deep excavations in superficial deposits;
- Variable rock levels (shallow or at depth)- impact on construction (drivability of sheet piles);
- Presence of Shallow Groundwater;
- Steep unstable existing slopes;
- Presence of protected species; and
- Insufficient GI should scheme design change significantly or additional proposals be included.

The development and implementation of mitigation measures for the identified risks will be continued through detailed design and construction of the Scheme.

7.6 Seepage Analysis

As part of the scope of works for the Scheme, seepage analysis was undertaken for the proposed flood defence structures. The aim of the analysis was to establish the suitability of the structures in preventing seepage flow rising above ground level on the protected (or dry) side of the structures. The applicable reporting is referenced previously in this document.

Through use of the ground investigation data, a model of the soil permeability below each structure was developed, and subject to transient analysis in SEEP/W. The following key criteria were adopted:

- Key ground parameters (including soil permeability, existing groundwater levels) were derived from available ground investigation data.
- Flood hydrographs modelling peak flood levels at a 1 in 200 year return period were used for each structure.
- Serviceability criteria: to prevent the water table rising above ground level on the defended side of the structure.

Through the transient analysis, and through appropriate sensitivity analysis of the results, the seepage analysis indicated that a number of structures would fail the serviceability criterion. As a consequence, impermeable seepage cut offs were recommended for impacted structures, ranging in depth from 0.5m to 3m below the structural formation. Locally, where conditions were favourable, no seepage cut off was required.

The nature of any seepage cut off employed will depend on the ground conditions and nature of the structure but would most likely comprise an impermeable barrier to seepage flow, either through placement of a sheet pile cut off wall, or a shallow trench infilled with impermeable material (clay or cement).

It is noted that the seepage analysis undertaken represents an initial assessment, with structural positions and the nature of the flood defences modelled correct at the time of writing, but subject to change as part of the outline and detailed design. As a consequence, some degree of risk remains regarding the seepage analysis, which should be addressed by further analysis at detailed design.

To address these risks, the report recommends further targeted to ground investigation at a number of locations to provide greater confidence on the ground parameters derived, which should be undertaken as part of detailed design when structural details are finalised. In addition, depending on risk acceptance, relaxation of the key serviceability criterion may allow reduction in the required cut off depths locally.

8 Contamination Assessment

8.1 Introduction

This chapter summarises works undertaken to assess potential ground contamination in terms of risks to humans and the wider environment, based on the current use, and which may result during construction of the Scheme, or as part of the final design. These works include a desk study and intrusive investigation undertaken across the Scheme Area, the objective of which was to assess potential contamination and associated constraints to the Scheme, especially associated with the former Comrie Gas Works, and to outline the measures that may be required in the form of a Remediation Strategy.

8.2 Relevant Reports

The following reports were completed as part of this assessment, and are referenced within this chapter:

- Preliminary Sources Study Report, Comrie Flood Protection Scheme, 119398-DOC-200-201, Version 3, Sweco, January 2019 (‘***PSSR***’).
- Former Gas Works Area, Contamination Assessment, Comrie Flood Protection Scheme, Version 2, Sweco, January 2019 (‘***Gas Works Contamination Assessment Report***’).
- Former Gas Works Area, Remediation Strategy, Comrie Flood Protection Scheme, 119398/RS/DEP/2019, Revision 2, Sweco, January 2019 (‘***Gas Works Remediation Strategy***’).
- Contamination Assessment Report, Comrie Flood Protection Scheme, 119398/CFP/CAR/2019, Issue 1, Sweco, March 2019 (‘***FPS Contamination Assessment Report***’).

8.3 Consultation

Consultation has been undertaken with statutory organisations regarding potential contamination associated with the Scheme to inform the scope of assessment, and on the subsequent assessment reports. The consultation responses received are summarised in **Table 8.1.**

Table 8.1: Consultation Relating to Contamination

Consultee & date of consultation	Summary of consultation	Comment/ Action taken
PKC via email on 18/12/2017	Request for information regarding areas of potentially contaminated land.	PKC's reply by email on 15/1/2018 supplied a map locating areas of potentially infilled ground and previous land uses within the Scheme layout and beyond the boundary. PKC referred to the former gas works and indicated that some work had been carried out that identified hydrocarbon and heavy metal contamination. PKC referred to a former decommissioned filling station on Drummond Street and that more information could be given if requested.
SEPA via email on 18/12/2017	Request for information regarding licensed activities within the Scheme layout.	SEPA's reply by email on 18/1/2018 indicated several licenced activities relating to private sewage works. No groundwater abstractions were noted.
PKC meeting on 29/08/2018	Meeting to discuss gas works contamination issues.	Meeting included discussion on the findings of the Contamination Assessment Report, on the status of the flood protection design, and on the likely remediation solutions.
PKC meeting on 10/01/2019	Meeting to discuss gas works contamination issues.	PKC confirmed there were no major comments from the Contaminated Land Officer on the Remediation Strategy and advised that final versions of the Contamination Assessment Report and Remediation Strategy should be issued, subject to some minor changes.
SEPA via PKC email 23/01/2019	Request for clarification from SEPA if a CAR license is required for gas works remediation works.	SEPA noted in their response email of 01/02/19 that as the proposed earthworks at the gas works site are unlikely to extend below the water table it is unlikely that any dewatering would be required or that the earthworks are likely to significantly impact on the local groundwater. Consequently, they did not consider that a CAR authorisation or groundwater monitoring would be required for the works.

8.4 Desk Study Information and Historical Report Review

Desk-based information was compiled through site reconnaissance, environmental data review and mapping research (historical, geological and hydrogeological). Additionally, the available historical ground investigation reports for the Scheme, which included intrusive site investigation data for the Comrie Gas Works, were reviewed and summarised. The information reviewed was assessed against the current and proposed use to enable potential contamination issues to be identified through the development of a Conceptual

Site Model (CSM). This allowed an appropriate ground investigation to be designed to further investigate potential risks to human health and the wider environment.

The desk study review for the overall Scheme is presented in the PSSR. This identified the potential for ground contamination associated with various historical uses, in particular railway land, a former gas works, and made ground associated with former and current surrounding land uses. The potential sources and receptors identified (based on current and proposed uses) were used to develop an initial contamination CSM which in turn was used to inform the design of the scheme-wide intrusive site investigation.

An additional detailed desk study for the Gas Works is presented in the Gas Works Contamination Assessment Report, which used historical maps and gas works plans from the Scottish Gas Board to identify the location of former gas works buildings and structures that may result in contamination. A review of the available historical site investigation data in the context of the CSM identified gaps in the data that required further investigation and assessment.

8.5 Ground Investigation

An intrusive ground investigation was undertaken in accordance with UK best practice, notably BS10175:2011+A2:2017 Investigation of Contaminated Sites - Code of Practice and BS5930:2015 Code of Practice for Site Investigations. The investigation resulted in environmental data sets in the form of factual Ground Investigation data, gas and groundwater monitoring data, and associated laboratory chemical analysis results.

A detailed intrusive site investigation designed by Sweco was carried out in two phases by Holequest Limited in 2018, which included boreholes by light cable percussion, competitor, rotary open and core drilling techniques, machine excavated trial pits, hand excavated trial pits, and the installation of combined gas and groundwater monitoring wells in selected boreholes. Laboratory chemical analysis of soils, surface water and groundwater was completed on samples from a selection of investigation positions chosen to address the identified investigation requirements, and three rounds of gas and groundwater monitoring were completed on the borehole installations. The investigation covered the requirements for data on both the wider scheme and the former gas works, and the factual reports (Document References: S/CFPS/0418/Fact, Rev. 1 Final, Holequest, September 2018 and S/CFPS/0119/Fact, Issue 1 Final, Holequest, February 2019) are presented in the appendices of the FPS Contamination Assessment Report and the Gas Works Contamination Assessment Report.

8.6 Assessment Conclusions

Gas Works Contamination Assessment

The Gas Works Contamination Assessment Report included a review of data from both historical and recent investigations, and a contamination risk assessment to identify potentially significant pollutant linkages at the site of the former gas works through revision of the CSM, under both current and proposed uses. In summary, it presented the following key conclusions:

- The investigation identified potential risks to human health (current and future site users, and construction workers) from the site soils, due to concentrations of various contaminants including cyanide, metals, asbestos, PAH, and TPH compounds, which require remediation.
- On this basis it is considered possible that the site of the former gas works in its current state would be classed as Contaminated Land (as defined in Part IIa of the 1990 Environmental Protection Act). The assessment also concluded that the site of the former gas works is considered suitable for development as part of the flood protection scheme, although remediation of potential pollutant linkages (of risk to human health) would be required to facilitate development.
- Although potentially leachable contaminants were identified within the soils (cyanide, ammoniacal nitrogen and PAH compounds), chemical analysis of the underlying groundwater and adjacent surface water did not indicate any impact from the site of the former gas works on the water environment. Additionally, as the proposed remediation would remove the main source of potentially leachable contaminants, no specific remedial measures are considered necessary in relation to the water environment.

Gas Works Remediation Strategy

Following the assessment, a remediation strategy was developed for the gas works, which included the following main requirements to ensure the site of the former gas works is suitable for use as public open space alongside the flood protection works:

- Excavation and offsite disposal of contaminated made ground soils, along with removal of any encountered historical gas works infrastructure (e.g. gas holder base, foundations, tanks, pipework).
- Placement of clean fill material to cover any residual contaminated soils, to a depth of between 0.4m and 1.0mbgl (thickest in the area of the historical gas holder, retort buildings and coal storage where the highest concentrations of contaminants were encountered), with a geotextile membrane at a depth of 0.4m to act as a demarcation layer.
- A landscaping requirement to retain trees along this bank, both as a visual amenity and to protect the river bank from erosion. The report consequently recommended measures to protect the trees following British Standard 5837:2012 (*Trees in relation to design, demolition and construction: Recommendations*). It is also noted that the planting of

trees as part of the landscaping works for the final flood protection scheme would require localised puncturing of the geotextile membrane to provide a suitable depth of growing medium, so it is recommended that the Validation Report be included within the Health and Safety file, to ensure that the membrane is cut, opened and replaced around the planting areas, and that the underlying soils are not left at the surface.

Contamination Assessment – Remainder of Scheme

The FPS Contamination Assessment Report concluded the following:

- Considering the current and proposed use of the remainder of Scheme Area, it is not considered that the concentrations of contaminants identified would constitute a significant risk to any receptors and that the land within the Scheme Area (excluding the former Gas Works) in its current state would not be classed as Contaminated Land (as defined in Part IIa of the 1990 Environmental Protection Act). Additionally, the Scheme Area is considered suitable for development with the proposed flood defence structures.
- The soils across the Scheme are considered to represent a low risk to human health under the current and proposed uses. Exceedances of the public open space (POSResi) screening values for PAH compounds were recorded in a single location (BHD07 in the Dalginross area) associated with made ground soils with a hydrocarbon odour, and although the risk is generally also considered to be low, it is recommended that appropriate health and safety precautions are implemented during construction works and that material excavated from this location is not reused at shallow depths within the Scheme.
- Given the proximity of the surface water bodies (River Earn, Lednock and Water of Ruchill) they are considered major discharge zones, therefore shallow groundwater is not considered to be a receptor in accordance with SEPA Position Statement WAT-PS-10-01 (Aug 2014). Chemical analysis of the surface waters indicates that the soils within the Scheme Area also present a low risk to surface water.

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9 Flood Protection Proposals

9.1 Introduction

This chapter has presented the design principles and activities that drove the outline design process. The preferred option has been presented alongside the key considerations that led to it being identified as the preferred option.

9.2 Background

In 2016/17 Consultants WSP (formerly Mouchel) assessed a range of potential flood alleviation options on behalf of Council. The resulting feasibility study[1] concluded the preferred scheme should consist of a combination of traditional walls and embankments to provide a 1 in 200 year return period standard of protection. Approximately 2.0km of walls, 0.75km of embankments and 1.0km of defences in the upper reaches of the River Earn were recommended.

9.3 Design Principles

Several design principles were established by Sweco and the Council to guide the development of the outline design, as shown in **Table 9.1**. Several opportunities were identified to address the agreed design principles and have also been discussed.

Table 9.1: Key design principles of flood defences for scheme stage

Scheme Stage	Design Principle
Construction	• Minimise tree loss • Minimise disruption to residents • Minimise cost to construct • Minimise service diversions • Minimise in-channel working • Minimise environmental impacts • Minimise complexity
In Service	• Minimise visual impact • Maximise floodplain storage and river conveyance • Ensure ease of public access is maintained • Effectively manage secondary flooding • Safeguard future bank erosion • Minimise human intervention during a flood event • Minimise impact on existing key assets (e.g. bridges) • Utilise existing walls and defences (where possible)
Maintenance	• Ensure safe access for maintenance • Minimise whole life costs to maintain

[1] Comrie Flood Protection Scheme Feasibility Report Rev. 4 issued 5th September 2017

Minimise tree loss and minimise visual impact

The landscape and character of Comrie and Dalginross is enriched by leafy tree-lined stretches of the three rivers that run through the towns, with many mature trees visible from the public domain. Lessons learnt from previously implemented flood schemes informed the engineering teams of the importance of avoiding a large-scale loss of trees.

Careful selection of the structural form of flood wall, efficient sizing of footings, in order to ensure excavations are minimised, a review of expected construction corridors and the micro-positioning of flood embankments became key considerations throughout.

Close working between the Landscape and Environment team and the structural engineering team was established at an early stage. Collaborative sessions to optimise the plan alignment of flood defences was made possible with the commissioning of tree surveys by a specialist arboriculturalist. These surveys informed the prominence and health of individual trees, trunk girths and their plan positions. Importantly, the plan extent of tree root-zones was postulated in the output from the tree surveys.

Maximise river conveyance

The Scheme has sought to position flood defences away from the top of riverbanks to provide the greatest opportunity for flood storage, this will also:

- minimise the contractor’s exposure to the health and safety risks associated with construction activities in close proximity to moving water;
- avoid impacting normal fluvial processes;
- allow a secondary use of the floodplain e.g. for agricultural, social and recreation activities; and
- maintain normal flow within the defined channel.

Minimise human intervention during a flood event

Flood gates are a common feature of flood protection schemes and are installed where access through a new flood wall must be maintained. However, they represent an on-going operations and maintenance burden for Council, health and safety risks, and introduce the potential risk of a defence failing.

Considerations for access for traffic and pedestrians at new defences and the alternative use of ‘passive’ access interventions, such as ramps and walkover steps in lieu of flood gates, became a key opportunity to explore. .Examples of alternatives to flood gates, implemented in recently constructed flood schemes, have been provided in **Image 9.1**

Pedestrian access 'steps over'

Vehicle access ramp

Image 9.1: Examples of 'passive' alternatives to flood gates

9.4 Design Process

The assessment and in-service performance of the Comrie Flood Protection Scheme in flooded conditions was approached by the structural engineering team from the following perspectives:

- Review and assess existing structures and flood defences - Determine the condition and performance of existing formal and informal flood protection structures within the scheme extents. This approach was necessary to give confidence in the functionality and safety of any incorporated structure and whether a strengthening or adaptation design was to become a recommendation of the outline stage design.
- Develop new flood defence structures - The statutory and non-statutory processes of scoping opinions, consulting with regulatory bodies, the general public, affected residents, local interest groups, the community council and the collection of survey data, guided the project team to a robust flood protection solution. This included initial structural design and testing proposals for a range of flood events up to the design level of protection.

Design Layout Process

To determine the optimum layout for flood defences, an iterative based approach was adopted. Mutual working between the flooding and structural engineering teams became the norm.

In the first stage of this process an initial 'best estimate' line for flood defences was evaluated in the fluvial flood model, for a range of flooding scenarios up to the design event. This early line for flood defences was informed by the feasibility stage study. Localised design iterations were then tested in the hydraulic model. The model predictions update the design water levels, which were fed back to the design team.

9.5 Existing Structures

In November 2017, river and floodplain reconnaissance surveys were undertaken by the structural engineering team. In total 28 structures were identified within the early extents of the Scheme, with the potential to:

- be adversely affected by modified (raised) surface water levels in a major flood event - a usual consequence of laterally restricting fluvial flow by the introduction of flooding defences;
- impede the installation of future flood defences; or
- be safely incorporated into the future flood defence scheme.

These structures were reported in the report "*Existing Structures Scoping Report*" Doc. Ref. 119398-400-05 Rev. 01 and comprised of a wide variety of existing structures, being riverbank rock armour, free-standing flood or property boundary walls, weirs and historic bridges.

Detailed condition inspections, of those elements of existing structures accessible by foot, were subsequently carried out in the early part of 2018, with each structure assigned an overall condition grading in accordance with the guidance outlined in the Environment Agency's "Condition Assessment Manual". Riverbank walls concealed by vegetation, moss and lichen were cleared in advance of inspections. These condition inspections were reported in "*Existing Structures Condition Appraisal Report*" Doc. Ref. **119398-400-06 Rev. 01**. **Table 9.2** below highlights significant existing structures within the extents of the Scheme, which includes four bridge crossings.

Table 9.2: Significant Existing Structures

Dalginross Bridge	
	This bridge is an historic Category C listed three span wrought iron girder bridge over the River Earn and built in 1901. It provides the main link for north-south vehicle and pedestrian movements on the B827 (Bridge Street) and links the settlements of Comrie and Dalginross. The bridge was strengthened in 1997/8 and consequently relatively contemporary records of the bridge were available to the structural engineer; including material testing results. The Dalginross Bridge is a Council asset.
Bridge of Ross	
	The Bridge of Ross is a Category B listed structure giving it regional importance. It is a two span masonry arch 'humpback' bridge connecting 'The Ross' and Comrie districts and is situated in the upper reaches of the River Earn. The Bridge of Ross is Council asset.
A85 Lednock Bridge	
	The Lednock Bridge is a single span half-through steel bowstring arch bridge over the River Lednock supported on vertical full height stone masonry abutments. The bridge carries the A85 trunk road and is a Transport Scotland asset with Bear Scotland currently responsible for Operation and Maintenance of the bridge.
Laggan Footbridge	
	The Laggan Footbridge is a single span steel bridge crossing the River Lednock. The main steelwork has a hot dipped galvanised finish and a timber deck. The bridge superstructure is supported on stone masonry abutments which were previously part of the Dundas railway bridge. The Laggan Footbridge is Council asset.

<table>
<tr><th colspan="2">Fey Burn Flood Wall</th></tr>
<tr><td></td><td>The Fey Burn flood wall is a gravity wall with a stem constructed in sections of either natural stone masonry or mass concrete. The wall includes an inclined concrete apron along the full length.

The Fey Burn flood wall is a Council asset.</td></tr>
</table>

Developed Scenario: Bridges

The potential for existing bridges within the limits of the Scheme, to experience an increase in hydrodynamic thrust during a major flood event, was a significant risk reviewed by the structural engineering team at an early stage. In particular, the two historic bridges over the River Earn. The Dalginross Bridge and The Bridge of Ross were thought to be sensitive to any meaningful increase in lateral loading, due to their age and structural forms.

The following actions were taken to better understand and manage this risk:

- A topographic survey was commissioned in January 2018 to establish detailed bridge soffit level profiles for upstream and downstream elevations;
- Predicted flood levels and corresponding flow velocities at the four existing bridges, as reported by the feasibility stage model, were reviewed for a range of flood events up to the Schemes design flood event. This study indicated to the project team flooding 'behaviours' at existing bridges and informed decision making for further inspection and assessment work. Refer to Technical Note "*Review of Mouchel Flood Levels at Structures*" Doc. Ref. **119398-400-09 Rev 01**.
- A future structural assessment strategy for the Dalginross and The Bridge of Ross Bridge's was developed and discussed with Council's Structures Team; refer to Technical Notes "*Dalginross Bridge (E08) Assessment Method*" Doc. Ref. **119398-400-07 Rev 00** and "*Bridge of Ross (E11) Assessment Method*" Doc. Ref. **119398-400-08 Rev 00**.
- A Special Inspection of the Dalginross Bridge superstructure and The Bridge of Ross (including the adjacent A85 River Earn left bank wall) was commissioned with assistance of a specialist rope access inspection squad working under the instruction of the project teams structural engineer. The Dalginross Bridge inspection was undertaken in February 2018 and reported in the "*Dalginross Bridge – Inspection for Assessment Report*" Doc. Ref. **119398-400-07 Rev. 02**. The Bridge of Ross and A85 wall inspections were carried out in March 2018 and reported in "The Bridge of Ross – Inspection for Assessment Report" Doc. Ref. **GTS4126 Rev 1** (by Others) and "A85 Retaining Wall –

Inspection for Assessment Report" Doc. Ref. **GTS4126 Rev 1** (by Others);

- An initial assessment of the Dalginross Bridge for a speculated range of fluvial flood levels was commenced by the structural engineering team.
- Predicted flood levels and flow velocities reported by the detailed hydraulic models' final fluvial flood levels were again reviewed against bridge elevations to compare the baseline and defended scenarios; results reported in Technical Note "*Review of Sweco flood levels at structures*" **119398-400-12 Rev 03**.

The predictions of the final fluvial model proved favourable. No discernible increase in flood levels at bridges was observed, when town flood defences (as modelled) are operational. The relative differences in flood levels and flow velocities at bridges is reported in **Table 9.3**.

Table 9.3: Difference in flood levels and velocities at existing bridges

Existing Bridge	Watercourse	Maximum Difference (Developed minus Baseline)	
		Level (mm)	Velocity (m/s)
The Ross Bridge	River Earn	+1.0	0.0
Dalginross Bridge	River Earn	+13.0	0.0
Laggan Footbridge	River Lednock	+5.0	0.0
A85 Lednock Bridge	River Lednock	+20.0	0.2

The overarching conclusion of Sweco became that the proposed scheme will have no adverse impact on the existing bridges. This enabled on-going structural assessments to cease and the potential need for strengthening or bridge raising, with all interfacing works, to be eliminated from the conceived scope of the Operations.

Developed Scenario: Fey Burn Wall

The Fey Burn flood wall is an existing flood defence along the 'right' bank of the Water of Ruchill. It is situated along the Western periphery of the Dalginross settlement and is approximately 267m long; see **Image 9.2**.

Image 9.2: Location of existing Fey Burn flood wall

The wall was assigned a 'fair' condition rating following inspection and, while repairs to surveyed cracks and mortar loss was deemed a possibility, the structural engineer concluded it was not economically viable to incorporate the wall into the Scheme and an alternative (replacement) flood defence was required at this location.

To support the Scheme's damages calculations and business case assessment an equilibrium analysis to predict the level of flood water that may coincide with a structural collapse of the Fey Burn flood wall, was undertaken. The results of this assessment were reported in the Technical Note "*Assessment of Fey Burn Flood Wall (E02)*" Doc. Ref. **119398-400-16 Rev 02**.

9.6 Scheme Layout

The flood defences have been aligned to be broadly parallel with the riverbanks of the River Earn, River Lednock and Water of Ruchill as depicted in **Figure 9.1**. The defences have been set back from the normal water level such that everyday fluvial processes are not affected by the proposed defence, this has also maximised floodplain conveyance.

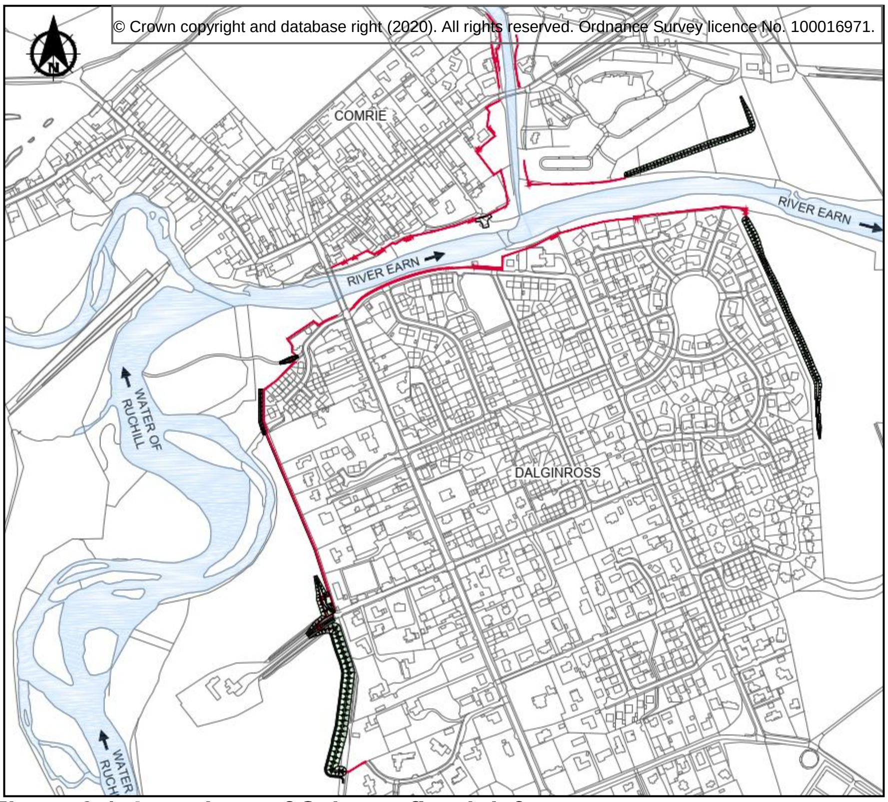


Figure 9.1: Locations of Scheme flood defences

The cumulative length of proposed flood embankments and walls is approximately 2.8km, with above ground heights varying from approximately 0.3m to 3.3m. A breakdown of these new defences by watercourse is provided in **Table 9.4**, noting river bank orientations 'left" and "right", are determined by the observer when facing in the direction of flow (being downstream).

Table 9.4: Summary of flood defence lengths by watercourse

Watercourse	Defence length (m)		Total by river (m)
	Left Bank	Right Bank	
River Earn	675	1,077	1,752 (61%)
Water of Ruchill	0	701	701 (24%)
River Lednock	107	328	435 (15%)
Total			2,888

When constructed, the recommended flood defences are predicted to protect approximately 189 residential and commercial properties across the settlements of Comrie and Dalginross from the effects of flooding up to and including the 1 in 200 year flood event; before the impacts of future climate changes are considered.

9.7 Upper Earn Defences

Through the processes of developing a more detailed hydraulic model, improving hydrological estimates and the collection of further topographic, bathymetric and threshold surveys to inform this model, Sweco had the certainty to remove all flood defences in the upper reaches of the River Earn. This outcome was broadly supported by the residents in this area and avoided significant disruption and environmental impact associate with construction in this area.

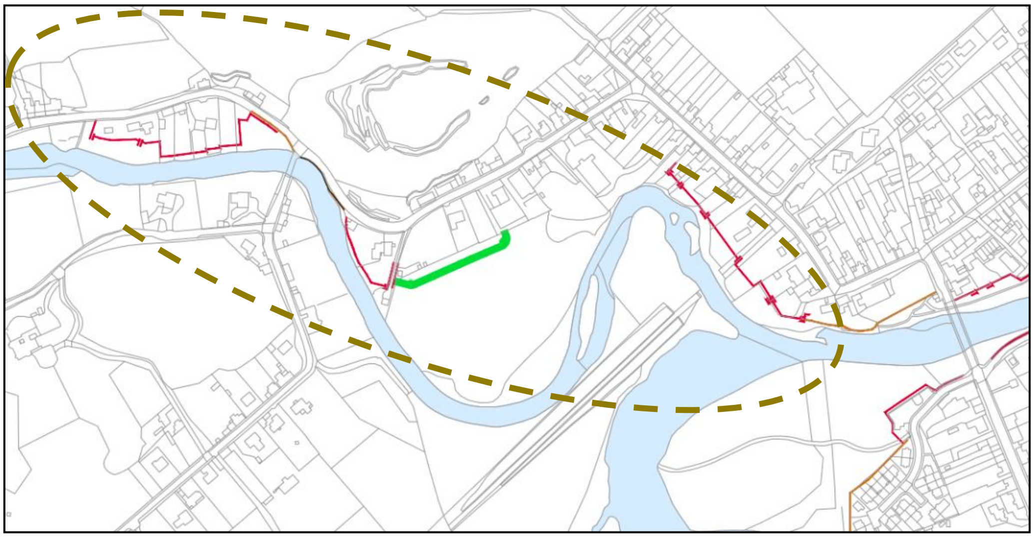


Figure 9.2: Extent of the Upper River Earn flood defences removed from the Scheme

9.8 Flood Defence Selection

Formal flooding interventions can be generally categorised as either ‘hard’ or ‘soft’ flood defences and are described below.

Soft Defences

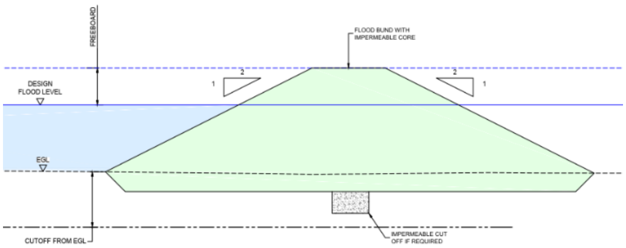
Constructed of materials more sympathetic to the landscape, flood embankments with grassed side slopes are designed to blend into the environment. This form of defence is not overly complex to construct and is often reserved for use in wide open spaces at considerable distance from the riverbank edge.

Hard Defences

Engineered flood defences are constructed from manmade materials, such as: reinforced concrete, brick masonry, steel (or plastic) sheet piles, or a combination of these. Natural stones may also be used. Hard defences can give the appearance of a boundary walling and as such are typically used along property boundaries, in towns and other areas where working space restrictions control.

Table 9.5 illustrates those conventional forms of flood defences that were considered by the structural engineering team in the outline design process. The unique advantages and disadvantages of each structural form is discussed.

Table 9.5: Comparison of conventional flood defence forms

Type 1A: Flood Embankment	
Typical Cross Section  Description Earthen embankment of varying height (1 to 3m is typical) incorporating gentle side slopes and a flat, wide crest. Depending on soil permeability, flood embankments are commonly constructed with an impervious core are grassed and include scour protection.	Advantages • Inobtrusive and visually appealing • A natural solution to flood protection • Typically, most economic to construct • May be formed by site won material • Not complex to design and construct Disadvantages • Occupies a wide footprint with varying width and thus a high land take • Large volumes of imported fill required to construct • At risk of damage by roots (if unkept) • Through access may be difficult (if required) • Frequent maintenance required for grass cutting; operation can be difficult • Erosion protection may be necessary • Higher freeboard in comparison with flood walls

Type 1B: Combined Flood Embankment

Typical Image

Description

Traditional flood embankment incorporating a low height crest wall formed by either a reinforced concrete wall or driven steel sheet piles.

Advantages

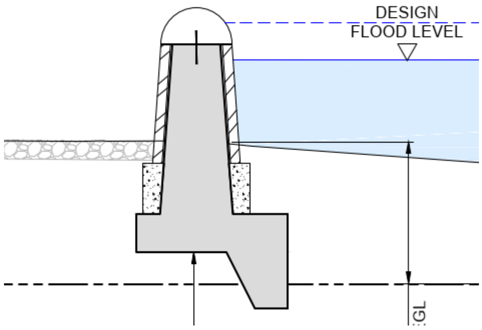
- Hybrid solution that can be less obtrusive and more visually appealing than a plain flood wall
- Incorporates natural finishes
- Reduced footprint in comparison with traditional flood embankment; for same height
- May be formed by site won material
- Reduced erosion potential; introduction of crest wall may allow overall height reduction
- Crest wall can provide dual flood and person access protection

Disadvantages

- Will occupy a wide footprint with varying width and thus a high land take
- Relatively large volumes of imported fill required to construct
- At risk of damage by roots (if unkept)
- Through access may be difficult (if required)
- Frequent maintenance required for grass cutting; operation can be difficult
- Higher construction cost than traditional flood embankment

Type 2: Mass Concrete (or Masonry) Gravity Flood Wall

Typical Cross Section



Description

Mass concrete flood wall cast in situ typically in 10-12m lengths and on a prepared formation. Pattern profiled concrete finishes or decorative masonry can be incorporated.

Advantages

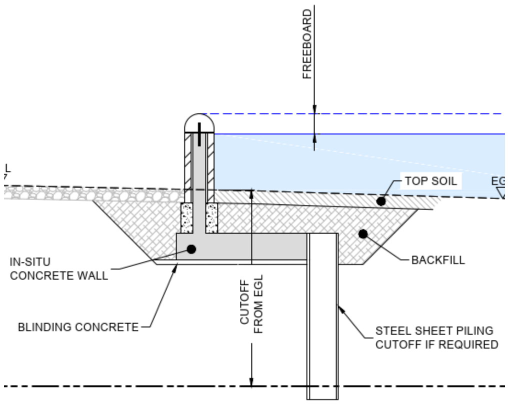
- Simple form of flood wall to design and construct
- Heavy piling and lifting equipment not required for construction
- Design can incorporate high quality finishes

Disadvantages

- Large volume of ready-mix concrete to be delivered to site
- Inefficient use of materials
- Typically requires a wide and tapering section giving the appearance of a heavy bulky wall

Type 3A: In *situ* Reinforced Concrete ‘L’ (or Inverted ‘T’) Shaped Flood Wall

Typical Cross Section



Description

Reinforced concrete wall with asymmetric slab foundation cast in situ. Typically completed with natural masonry cladding and coping stones for aesthetic appeal.

Advantages

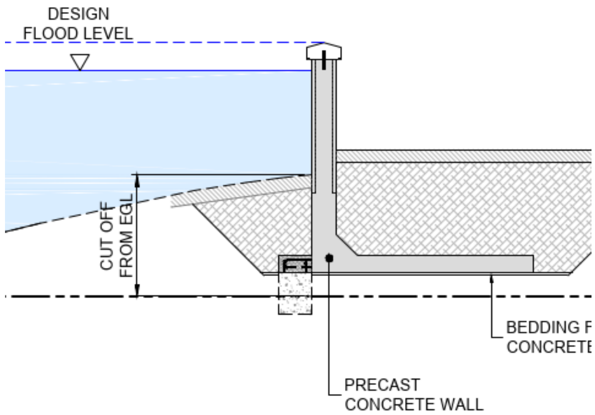
- Traditional construction method utilising normal plant
- Occupies a narrower footprint than an embankment equivalent
- Moderately economic form of construction
- Geometry is highly adaptable in design and on site and can be readily designed to accommodate service diversions in Operations
- Ground obstructions can be removed in excavation

Disadvantages

- Ready-mix concrete to be delivered to site
- Wider footprint than a non-displacement structural form of wall e.g. SSP wall
- Slower construction speed than precast or SSP alternatives

Type 3B: Precast Reinforced ‘L’ Shaped Flood Wall

Typical Cross Section



Description

Factory cast reinforced concrete wall and base slab delivered to the works as complete units. An as-cast pattern profiled finish or in situ cladding can be provided.

Advantages

- High quality factory cast product
- Occupies a narrower footprint than an embankment equivalent
- Moderately economic form of construction
- Offers speedy construction on site
- Low volume of heavy construction plant movements

Disadvantages

- Many joints along length to be made watertight
- Wider footprint than non-displacement form of wall e.g. SSP wall
- More susceptible to uplift water pressures
- Limited potential for site adjustments e.g. to suit service diversions

Type 4A: Bare Steel Sheet Pile (SSP) Flood Wall

Typical Finished Elevation

Description

SSP flood wall with piles driven to a depth to suit local ground conditions and required seepage protection; 5 to 15m is common.

Advantages

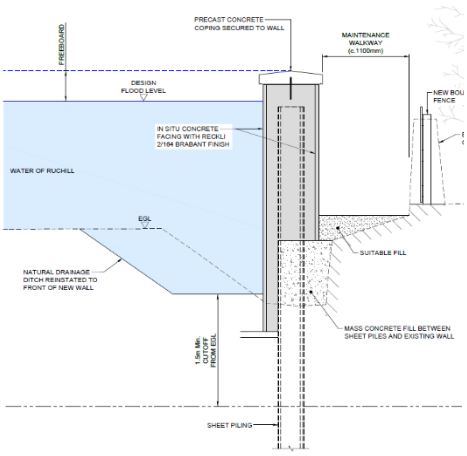
- Fast on-site construction technique
- Non-displacement (no arisings) form of construction
- Economic form of construction

Disadvantages

- Bare steel will rust giving flood wall an 'industrial' appearance that may be undesirable
- A painted finish will attract significant whole life maintenance costs
- Will require large working space for piling rig including overhead clearances

Type 4B: Steel Sheet Pile (SSP) Flood Wall with Facing

Typical Cross Section



Description

SSP flood wall with non-structural reinforced in situ concrete or masonry facing to visible and above ground portion. SSP's are driven to a depth to suit local ground conditions and required seepage protection; 5 to 15m is common.

Advantages

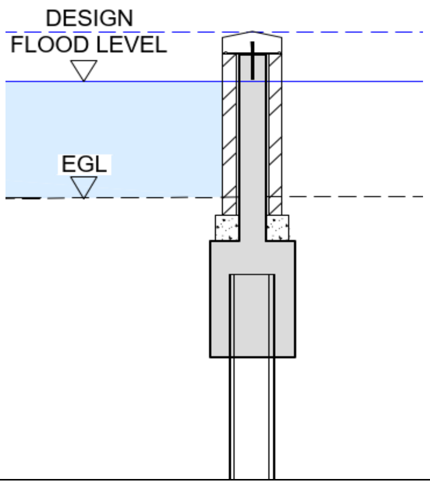
- As-per bare SSP
- Can incorporate high quality finishes such as pattern profiled concrete, masonry cladding & coping stones

Disadvantages

- Upper reinforced concrete section will slow construction rate
- Multiple construction methods used; expensive
- Will require large working space for piling rig including overhead clearances

Type 4C: Steel Sheet Pile (SSP) 'I' Shaped Flood Wall

Typical Cross Section



Description

Flood wall incorporating a structural in situ or precast reinforced wall where above ground. SSP's are driven to a depth (below ground) to suit local ground conditions and required seepage protection; 5 to 15m is common. High quality pattern profile or masonry cladding can be incorporated to suit.

Advantages

- SSP installation is a fast construction technique
- Arisings are limited; only small excavations at head of SSP is required
- Narrow above ground wall; potentially in-keeping with existing boundary walls
- Upper wall can be either in situ or precast panels

Disadvantages

- Upper reinforced concrete section will slow construction rate
- Multiple construction methods used; considered expensive
- Will require large working space for piling rig including overhead clearances

Selection Criteria

The choice of 'hard' versus 'soft' flood defence options is heavily dependent on the land available and surrounding land use(s). For example, defences constructed within a town environment as opposed to open spaces such as farm fields or parklands. Where existing walls or embankments will not be retained within the Scheme's formal defences, a conscious effort to develop a similar appearing replacement flood defence has been taken by the structural engineer. The 'like-for-like' strategy in the replacement of existing town defences and walls further fulfils the design principle to minimise visual impact of the Scheme. Other considerations such as groundwater seepage protection requirements, presence of mature trees, location of public utilities, access for construction and ground conditions among others, were taken into consideration when developing the outline design.

The traditional flood wall types presented in
Table were initially costed on a per metre run basis as, whilst strictly not the most imperative driver in a flood scheme, the capital cost of the scheme overall is important to the Business Case Ratio (BCR) and future success of the Scheme. Construction costs ranged from £850 /m run to £2,520 /m run.

Type 2 flood defences, a mass concrete (gravity type) flood wall, was rejected on grounds of sheer size and the volume of concrete required. Its construction would be impractical within the confines of the Comrie and Dalginross villages. Where local constraints allowed, the more cost-efficient Type 3A in situ cantilever flood wall form has been adopted. The precast equivalent has been proposed for locations where construction widths are not challenged, however speed of construction is believed to be a highly desirable design principle to be met. The relatively modest groundwater seepage cut off depths, established in the initial geotechnical analyses (see section 9.10 below), strengthens the case for traditional walling over driven steel sheet piles; that would otherwise offer combined flooding and seepage protection.

The following defence structural forms for flood defences have been proposed for use in the final Scheme:

- Soft defences:
    - Type 1A: Flood embankment
- Hard defences:
    - Type 3A: In *situ* reinforced concrete ‘L’ shaped flood wall
    - Type 3B: Precast ‘L’ shaped reinforced concrete flood wall
    - Type 4B: Steel sheet pile (SSP) flood wall with facing

9.9 Flood Defence Basis of Design

Outline Design Process

The outline design for flood walls was undertaken in accordance with the relevant parts of the Eurocodes and British Standards and has considered geotechnical and equilibrium limit states.

Horizontal thrust imparted on a flood wall from flood waters 'held back' is the dominant destabilising load in flood wall design and was considered as follows:

- Hydrostatic
- A head of water taken from the ground level adjacent to a walls' wet face to an elevation +100mm above the top of wall. This represents an overtopping condition.
- Hydrodynamic

Results from the fluvial model for the developed condition indicated that proposed flood walls are sufficiently remote from the chanellised flow such that they will not be subject to high flood velocities. The exception to this was found to be flood defence ER03 on the right bank of the River Earn. Here a relatively short length of new defences, where opposite the River Lednock's confulence with the River Earn, is approached by flood waters travelling at a predicted mean velocity of 1.75m/s. The angle of hydrodynamic attack at ER03 was taken to be normal to the wall. This represented a worst case loading condition.

Other destabilising actions considered in the outline design for defences were: earth pressures, vehicle and pedestrian surcharge loads and effects of buoyancy.

As Scheme constraints became better understood the importance of accurately defining the extents of wall foundations (width and buried depth) became clear. Primarily for tree and public utility avoidance in the route selection process. A parametric study to determine optimum wall geometry was completed by the structural engineer with convenient lookup tables prepared for key dimensions to streamline the optioneering. This study also yielded improved accuracy of quantities take off's, the capital cost and embodied carbon estimates.

Cantilever steel sheet pile walls were modelled using the package WALLAP by Geosolve using a range of soil parameters considered to conservatively represent local ground conditions.

Design life

Main structural elements of flood wall type defences will be designed for a minimum working life of 100 years. All replaceable structural parts, such as handrails, will be designed for an intended 50 year life.

Aesthetic Considerations

In elevation the above ground height of new flood defences will vary to suit the protection required by the fluvial model. Typically, the top of walls will be horizontal with step changes in height positioned to coincide with precast panel or in situ construction joints; or other requirement as directed by the projects Landscape Architect. The visual appearance of new walls will be to suit the local vernacular. Either precast concrete 'flag' type copings or natural stone will be used to provide a finished appearance to wall tops and to discourage 'wall walking'. The exposed face of walls will be one of three types; plain concrete with a proprietary pattern profile finish, random whinstone rubble, or, regular courses of ashlar sandstone.

Interface with Existing Structures

There are several locations where the proposed flood walls will interface with existing structures, all of which are masonry. At these locations new walls will abut existing stonework with no load being imparted on the existing structure. This was a key requirement of consultees Council and Transport Scotland who own and operate the interfacing assets.

Interface or 'tie-in' locations in the outline design are:

- North abutment and east side tie-in with the Dalginross Bridge;
- Glenbuckie residential property flood wall tie-in with A85 wall;
- Tie-in with existing St. Margarets Church walls; and
- St. Serf's Church tie-in with A85 Lednock Bridge north east wing wall.

The detailed design will consider the requirement for further investigations at existing structures such that robust construction details can be developed.

Drainage Considerations

Surface water runoff from rainfall events may cause ponding behind the proposed flood defence. This unintended consequence of installing town defences is called 'secondary flooding'. To alleviate this flooding water will be transferred through by means of either a piped weep hole in the wall located at ground level with a non-return valve or conveyed to an outfall via a piped system. The collection methods would be either a filter trench or gulley to the pipe generally located behind the wall, with chambers located at each change of direction and or level, this will lead to an outfall located on the river side that in normal conditions allow the water to freely flow into said river, in flood conditions the outfall will be blocked via the installed non-return or flap valve.

Health and Safety

Sweco, as Designer, have complied with designer duties as required by the CDM Regulations 2015 for the outline design.

Future Design

The future detailed design for flood defences will be undertaken in accordance with the details contained in the "*Comrie Flood Protection Scheme Flood Defences Approval in Principle*" Doc. Ref. **119398-400-15 Rev 01**.

9.10 Geotechnical Considerations

Ground Conditions

Generally speaking, the ground conditions anticipated within the Scheme's boundary comprise topsoil or pockets of made ground overlying alluvial deposits predominantly granular with occasional layers of cohesive material along all river banks with localised cohesive glacial deposits present east (left bank) of the River Lednock. Bedrock underlies the scheme with depths proven in recent ground investigation works to range from 3.20m to 21.0m below ground existing level (begl).

Conceptual design work indicated bearing pressures under foundations of new flood walls to be modest; 20-30 kPa characteristic (or unfactored). As such spread footings with direct bearing can be founded safely within the dominant granular deposits. Any localised 'soft' spots in formations will require dig out and replace with an engineered fill as can normally be expected.

Seepage Protection Considerations

Seepage is a natural process where water, acting under a hydrostatic head in a flooded condition, migrates below or through a flood defence from the wet to dry (or defended) side. The outline design has considered a zero seepage boundary condition on the dry side in order to prevent secondary flooding and damage to pavements or those properties in close proximity to defences.

Analysis by the geotechnical engineer in the outline design phase has indicated the minimum seepage cut-off depths will be of the order 1.0 to 3.0m begl. These depths are modest and further support the selection of a cantilever type of flood wall.

Where required, protection against groundwater seepage at cantilever 'L' walls will be provided by driven steel (or plastic) sheet piles, or a trench backfilled with a suitably impermeable material; seepage protection will be located on the wet side of walls.

Hydrodynamic Uplift

For full or partially saturated ground conditions, hydraulic uplift forces will occur on the underside of a wall foundation. The magnitude of this uplift pressure is proportional to the static head of flood water and is influenced by the flood hydrograph and permeability of surrounding soils.

Geotechnical modelling to-date, to determine seepage cut-off depths at new defences, informs that uplift forces can be simplified as a triangular pressure distribution. Pressure varying from 50% of the hydrostatic head to a reduced 35% of the pressure head from wet to defended wall sides respectively. This approximation will be reviewed at detailed design stage, potentially with the benefit of further soil permeability test results and by reviewing additional cross sections.

9.11 Operational Considerations

Flood gates

1 No. sealed flood gate has been incorporated into the Scheme. This gate will be located in Comrie at the end of Manse Road to provide periodic access for Scottish Water maintenance vehicles servicing the combined sewer chamber.

This flood gate shall remain closed at all times when vehicle access is not required. Control of access will be the responsibility of Council with suitable arrangements to be developed at the detailed design stage.

Image 9.3 Example vehicle access flood gate

A review of the provisions for access to the planned location of the flood gate highlighted that the footprint of historic buildings on Commercial and Ancaster Lane were pinch points. As such in consultations with Scottish Water the original vehicle to be accommodated was down rated to an 18t vactor unit; a vehicle similar in size to a refuse lorry. Consultation with Scottish Water also confirmed:

- The vactor to access and exit the ramp in a forward gear with a turning area provided close to the CSO chamber; and
- Access to the south chamber will be on foot with an overland hose used for jetting.

There are no other flood gates to be provided in the Scheme.

Future Inspection and Maintenance Regimes

Future inspection and maintenance regimes will be in accordance with the Design Manual for Roads and Bridges requirements.

Existing Bridges

Sweco has predicted that a negligible increase in water level and channel flow velocities at existing bridge sites can be expected. As such normal river flows and velocities at bridge supports can be expected, and Council's current inspection regimes are assumed to be satisfactory.

Proposed Flood Defences

Inspection and maintenance of formal flood defences will be the responsibility of Council. General Inspections will be undertaken at 24 month intervals for determining the in-service physical condition of defences. Every third general inspection will be offset by a more comprehensive Principal Inspection - within touching distance of all inspectable elements.

The majority of flood defences can be safely inspected by foot with some stretches of walling requiring access to be gained through private land. A dedicated maintenance passage is proposed on the dry side of WR03 (west of Dalginross) with security gates at each end to restrict access by the public. A similar maintenance strip is provided on the dry side of ER03.

Safe access to the higher flood walls (being those greater than 2.0m in height i.e. ER03, ER04, WR01 and WR03), for undertaking a Principal Inspection or maintenance repairs, should be assessed based on the actual activity intended. Ladders, and mobile work platforms are considered likely means of access at these walls.

For flood wall ER02, its proximity close to the right bank of the River Earn and the proposed stone revetment, will mean it is unsafe to walk on the wet side when unrestrained. Inspection of the wet side could however be undertaken with an IRATA trained rope access squad tethered to a temporary secure point on Strowan Road. The future design will also consider a permanent horizontal lifeline system at this location.

Any maintenance and repair work can be scheduled and prioritised.

Special Inspections

It is anticipated that riverbanks, flood defences and existing bridges will also be inspected following any major flood event. These inspections would typically include:

- The probing of foundations to determine occurrence of any scouring or undercutting of foundations;
- To look for signs of deposition of debris or blockages in the waterway; and
- An examination of defences for signs of collision damage, subsidence or other ground movement.

9.12 Outline Design

Table 9.6 below summaries the key features of the recommended flood defences, alternatives considered, and future investigation work required to inform the detailed design stage.

For further details refer to the flood order drawings 119838-400-300 and 400 series and the description of the Operations.

Table 9.6: Outline Design Details

Ref. Section	Location	Outline specification for Flood defence (all dimensions approximate)	Key local constraints and other considerations	Key features of the outline design & design principles achieved	Alternative design(s) and interventions considered	Future investigation work & key detailed design stage considerations
EL02	River Earn left bank from Dalginross Bridge to Ancaster Lane	Selected Type: 3A Defence Length: 140m Height: 1.1 to 1.6m Seepage cut-off: 3.0m	• Maintained access to 'boulevard' for recreational activities • River access for residents • Maintained access for SW vehicles • Retention of mature trees where practicable • Commercial/ Ancaster/ Manse Lane public utilities	• Flood wall set-back from riverbank to maximise 'boulevard' open spaces and flood storage • 5No. residential access stairs & 1No. public access stairs (avoidance of flood gate) • Flood gate for SW maintenance access – locked and in a closed position when not in use • Vehicle parking bays	• Vehicle access ramp discounted due to large footprint & land owner preferences. Upgrade of Legion Park included in Operations to ensure a viable alternative venue is available for the Comrie Fortnight • Commercial lane pedestrian access ramp discounted in lieu of access improvements upstream of Dalginross Bridge (ref. EL01)	• Trenching to determine actual SW asset line and depth at end of Manse Lane. Flood wall to accommodate pipe without diversion • Trial pits to determine location/ depth of existing wall footings
EL03	River Earn left bank from Ancaster Lane to River Earn and River Lednock confluence	Selected Type: 3A Defence Length: 138m Height: 0.8 to 1.2m Seepage cut-off: 1.5m	• Former gas works • Overhead power lines to Earnbank • Existing trees	• Flood wall positioned to maximise flood storage	• A free-standing reinforced concrete gravity flood wall was considered the most economically advantageous type due to relatively low (depth) seepage protection requirements	• Review chemical class of soil to derive any concrete protection measures • Effective detailing for secondary drainage to manage potential for transporting ground water contaminants

Ref. Section	Location	Outline specification for Flood defence (all dimensions approximate)	Key local constraints and other considerations	Key features of the outline design & design principles achieved	Alternative design(s) and interventions considered	Future investigation work & key detailed design stage considerations
EL04	River Earn left bank from River Lednock confluence along Comrie Holiday Park boundary	Selected Type:3A Defence Length:142m Height: 0.7 to 0.9m Seepage cut-off: 0.5m	• Comrie Holiday Park static homes • Public utilities: gas, LV overhead power, HV underground power • Mature trees left bank of River Earn	• Flood wall set-back from riverbank to maximise flood storage and to maintain tree line.	• Flood embankment discounted due to higher land take	• Trenching to accurately position existing gas main
EL05	River Earn left bank from Comrie Holiday Park boundary to field boundary	Selected Type:1A Defence Length:239m Height:1.6 to 2.0m Seepage cut-off: 0.5m	• Maintained access to riverside where severed by flood defence	• Optimum position of flood embankment achieved to suit topography and flood storage requirements • Pedestrian access stairs incorporated into flood embankment (avoidance of flood gates)	• The selected flood embankment was deemed the most appropriate form of flood defence at this location. Open space, limited local constraints and natural appearance of this form of defence were key considerations	• None

Ref. Section	Location	Outline specification for Flood defence (all dimensions approximate)	Key local constraints and other considerations	Key features of the outline design & design principles achieved	Alternative design(s) and interventions considered	Future investigation work & key detailed design stage considerations
ER01	River Earn right at Field of Refuge from car park to Dalginross Bridge	Selected Type: 3A Defence Length:122m Height:0.5 to 0.7m Seepage cut-off: 1.5m	• Scottish Water (SW) pumping station located at Field of Refuge car park • Existing private access • Interface with Dalginross Bridge • Access for pedestrians and equestrian users • Public utilities: surface water, LV street lighting and water main	• Flood wall positioned back of Field of Refuge verge and car park to maximise flood storage and minimise tree loss • Vehicle and pedestrian access ramp (at 1:8 gradient) to be provided with lockable gate. • Bridle access gate agreed by consultation with British Horse Society (BHS) • Pedestrian access immediately west of Dalginross Bridge achieved by terminating the flood wall short of the bridge parapet walls, made possible by detailed review of design flood levels	• A free-standing reinforced concrete gravity flood wall was considered the most economically advantageous type due to relatively low (depth) seepage protection requirements	• None
ER02	River Earn right bank from Dalginross bridge to Legion Park	Selected Type: 3A Defence Length:179m Height: 0.4 to 1.4m	• Adjacent Strowan Road and access for fire station • Existing public utilities: Buried HV & LV power lines, Telecommunication	• 3No. traffic calming blisters incorporating plantings to protect the flood wall and improve the streetscape • River Earn right bank erosion protection	• A steel sheet piled (Type 4C) flood defence was initially considered. Supplementary soil sampling and testing ultimately led to less conservative assumptions in	• A successful design at this location will fully consider the flood wall interface with erosion protection proposals, the sequencing of construction and

Ref. Section	Location	Outline specification for Flood defence (all dimensions approximate)	Key local constraints and other considerations	Key features of the outline design & design principles achieved	Alternative design(s) and interventions considered	Future investigation work & key detailed design stage considerations
		Seepage cut-off: 1.5m	cables, gas main, street lighting and overhead power lines • Existing trees lining right bank of the River Earn • Narrow verge/ informal footpath on riverside of Strowan Road • Turning geometry for fire engines for movements to/ from Bridge Street	incorporated into defence solution	early seepage calculations and a more modest seepage protection requirement was determined. As such a traditional 'L' wall became the preferred defence type at this location • Positioning of the flood defence on the riverside of Strowan Road, as opposed to the residential side with use of ramps, became the only viable alignment	environmental controls to the satisfaction of SEPA
ER03	River Earn right bank from Legion Park to Garry Place	Selected Type: 3B Defence Length: 248m Height:1.3 to 2.1m Seepage cut-off: 1.5m	• Proximity of residential properties • Existing mature trees • Public utilities: HV overhead power lines, surface water, overhead and underground street lighting	• 1No. pedestrian access ramp and 3No. access steps to maintain connectivity with informal river path (avoidance of flood gates) • Provision of maintenance access strip for Council inspection of flood wall • Precast wall type chosen to improve construction speed and disturbance to residents	• Various configurations for access stairs opposite 3 & 4 Lochay Drive were considered with adopted layout incorporating natural and hard screening measures (tree plantings and new fencing)	• Detailed design shall carefully consider foundation widths to ensure construction corridor and tree loss is minimised • Consultation with SEPA to determine exact requirements for temporary and relocated river monitoring gauge

Ref. Section	Location	Outline specification for Flood defence (all dimensions approximate)	Key local constraints and other considerations	Key features of the outline design & design principles achieved	Alternative design(s) and interventions considered	Future investigation work & key detailed design stage considerations
ER04	River Earn right bank from Garry Place to Tay Place	Selected Type: 3B Defence Length: 325m Height: 1.1 to 2.1m Seepage cut-off: 0.5m	• Public utilities: Surface water, overhead power line and waste water	• Toe of new flood embankment positioned east of existing surface water pipe • Spare duct to be installed beneath embankment to permit future safe replacement of existing waste water pipe	• The selected flood embankment was deemed the most appropriate form of flood defence at this location. Open space (agricultural field), limited local constraints and natural appearance of this form of defence were key considerations	• Establish safe protection for waste water pipe where beneath new flood embankment
WR01	Water of Ruchill right bank adjacent to Aros Field East	Selected Type: 3A Defence Length: 37m Height: 0.8 to 3.4m Seepage cut-off: 1.5m	• Aros Field East and existing out building at No. 4 • Existing mature trees	• New flood wall to be extended to existing gate at end of Aros Field East	• Steel sheet piling considered a viable alternative here but was discounted for this short isolated length	• Commission topographic survey of existing out buildings to establish exact positions
WR02	Water of Ruchill right bank from Aros Field East to Camp Road	Selected Type: 1A Defence Length: 245m Height: 3.0 to 3.3m	• Existing Fey Burn ditch and culvert • Views west for those properties adjacent to proposed line of defence • Existing mature trees	• Alignment of new flood embankment (south of Camp Road) devised to avoid loss of mature trees • Existing Tomnagaske driveway ramp raised and re-graded	• Defences round Tomnagaske discounted on grounds of cost and appearance • Option for shared driveway to access Tomnagaske and agricultural field discounted due to reasons of land ownership	• Develop service diversion designs and explore the option for a shared service corridor

Ref. Section	Location	Outline specification for Flood defence (all dimensions approximate)	Key local constraints and other considerations	Key features of the outline design & design principles achieved	Alternative design(s) and interventions considered	Future investigation work & key detailed design stage considerations
		Seepage cut-off: 1.5m	• Farm vehicle access to field north of Camp Road • Secondary flooding • Public utilities: overhead and underground telecommunication lines, gas main, waste water pipe, overhead power lines • Tomnagaske access	• Steel sheet pile core introduced at ramp to reduce erosion potential and freeboard provisions; new ramp lowered c.600mm as a result with benefit of a reduced footprint and number of mature trees (lining Tomnagaske drive) to be felled • New precast box culvert to maintain Fey Burn flow beneath Tomnagaske drive • New ramp for farm vehicle and pedestrian access to field north of Camp Road.	• Option for self-raising flood gate into Tomnagaske discounted due to risk of failure and operation and maintenance burden	
WR03	Water of Ruchill right bank from Camp Road to Field of Refuge	Selected Type: 4B Defence Length: 271m Height: 1.4 to 2.4m Seepage cut-off: 1.5m	• Existing Fey Burn flood wall • Fey Burn drainage ditch • Existing and mature trees • Existing pedestrian access at Field of Refuge	• Sheet piled wall solution with concrete facing proposed • Access stairs provided to maintain pedestrian connection with Field of Refuge • Maintenance access strip created between proposed and existing Fey Burn flood wall	• Reinforced concrete 'L' wall discounted due to risk of excavations undermining existing Fey Burn flood wall • Flood embankment discounted due to land take • Options to demolish existing Fey Burn flood wall discounted due to felling of mature trees	• None

Ref. Section	Location	Outline specification for Flood defence (all dimensions approximate)	Key local constraints and other considerations	Key features of the outline design & design principles achieved	Alternative design(s) and interventions considered	Future investigation work & key detailed design stage considerations
WR04	Water of Ruchill right bank at Field of Refuge from Hillcrest dwellings to car park	Selected Type: 4B Defence Length: 115m Height: 0.8 to 1.3m Seepage cut-off: 1.5m	• Condition of existing Hill Crest Housing estate concrete retaining wall • Existing Fey Burn ditch • Existing trees	• Steel sheet piled flood wall with concrete facing to be constructed in front of existing concrete wall • Berm constructed on wet side of wall for safe access • Fey burn ditch realigned	• Option to drill and fix resin anchors to heighten existing wall was discounted due to poor condition of wall	• None
LL01	River Lednock left bank from St. Serf's Church meadow to A85	Selected Type: 3A Defence Length: 74m Height: 0.4 to 1.6m Seepage cut-off: 1.5m	• Relatively close proximity of St. Serf's Church • Clearance between church and new defence for grass cutting • Access to A85 bridge for future inspection and maintenance operations • Mature trees • Septic tank • Edge of riverbank working • Public utilities: gas main, surface water and LV overhead power lines	• Reinforced concrete 'L' wall with suitable cladding • 1No. access steps for access to wet side of wall and A85 bridge • Optimum flood wall alignment chosen to follow topography, avoid septic tank and minimise tree loss	• Wall alignments that wrapped around St.Margaret's Church to minimise impact to existing glade discounted due to length and interference with foul sewer line • Wall alignment along riverbank full extents discounted due to tree loss, length and increased exposure to working adjacent to watercourse	• Trench adjacent to near corner of church to determine depth and of foundations • Review secondary drainage falls to low point and determine best position for outfall

Ref. Section	Location	Outline specification for Flood defence (all dimensions approximate)	Key local constraints and other considerations	Key features of the outline design & design principles achieved	Alternative design(s) and interventions considered	Future investigation work & key detailed design stage considerations
LL02	River Lednock left bank at River Earn and River Lednock confluence	Selected Type: 3A Defence Length:32m Height: 0.3 to 0.9m Seepage cut-off: 1.5m	• Existing trees • Public utilities: gas main and overhead power lines • Edge of riverbank working • Comrie Holiday park static homes	• Reinforced concrete 'L' wall with suitable cladding	• None	• Trenching to determine actual line and depth of existing gas main
LR01	River Lednock right bank from dismantled railway bridge abutment to A85	Selected Type: 3A Defence Length: 117m Height: 0.7 to 1.3m Seepage cut-off: 3.0m	• A85 Lednock Bridge and masonry walls • Existing trees along right bank of River Lednock • Works in close proximity to residential properties • St. Margaret's Church foundations and existing walls • Existing mass concrete wall • Secondary flooding on defended side • Accessibility to A85 Lednock Bridge for future inspection and maintenance	• Operations will incorporate a vehicle access hump on the St. Margaret's Church drive • The preferred option has positioned the new flood wall to the property side of the St. Margaret's Church access drive thereby increasing out of channel flood storage and has maintained a green link to the River and safe access to the A85 River Lednock South Bridge abutment	• New flood wall initially aligned at top of Lednock riverbank for tie-in with Lednock Bridge	• Trenching to determine depth of St. Margaret's Church foundations

Ref. Section	Location	Outline specification for Flood defence (all dimensions approximate)	Key local constraints and other considerations	Key features of the outline design & design principles achieved	Alternative design(s) and interventions considered	Future investigation work & key detailed design stage considerations
LR02	River Lednock right bank from A85 to River Earn and River Lednock confluence	Selected Type: 3A Defence Length: 121m Height: 0.4 to 1.6m Seepage cut-off: 1.0m	• Former gas works • Overhead power lines to Earnbank • Existing trees • Secondary flooding • Maintained access to garden for Glenbuckie residential property	• New flood wall has been aligned to be in front of existing Glenbuckie terrace on south and east elevations of house, thereby reducing loss of existing garden and mature trees, and provides increased flood storage • 1No. access steps and 1No. access ramp to be incorporated into wall for Glenbuckie owner's access to rear garden	• New flood wall initially aligned on west side of River Lednock trees	• Commission further tree surveys along west boundary of Glenbuckie and the adjacent properties

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10 Public Utilities Diversions

10.1 General

The planned work areas of the proposed scheme contain a number of existing and buried services (electricity, gas, telecommunications, water, surface and waste water), as well as overhead services (telecommunications, electricity and lighting). Many of these services present an obstacle for construction of the recommended flood defences.

A desk top study was carried out by Sweco to identify all known services within the proposed scheme. Services which are either clashing with, or in close proximity to, an element of the proposed flood defences will require to be protected or diverted as part of the Operations.

The process of diverting services is regulated under the New Roads and Streetworks Act (NRSWA) 1991; however, this includes no provision for enforcing diversions to be completed within a specific time period. This could lead to programme delay and significant compensation events if included within the scope for the main works contract. It is anticipated that service diversions will take place in advance of the main works contract to mitigate the risk of any delay and cost increase from service diversions.

10.2 NRSWA C3 Budget Estimates

C3 budget cost estimates were gathered for each proposed service diversion. Diversion of services is known to be a complex and lengthy process and therefore the project team adhered strictly to the NRSWA Code of Practice (CoP) recommendations, used exemplar proforma in communications and tracked responses issued-received throughout.

C3 enquiries were issued to the following utility companies with known apparatus within the Scheme extents:

- BT (Openreach) – Underground and overhead telecommunication lines
- SW (Scottish Water)
- SGN (Scottish Gas networks)
- SSE (Scottish and Southern Energy)
- PKC (Perth & Kinross Council)

Perth & Kinross Council have extensive experience with projects involving significant diversion works, this experience has been used to justify a high-risk factor applied to the C3 diversion costs as part of the overall scheme costing.

10.3 Services to be Diverted

All utility companies contacted will have apparatus to be diverted as part of the Operations. These diversions have been included within the flood order documentation.

The total C3 utility diversion cost was estimated to be approximately £576k and includes an allowance for risk.

10.4 Future work

The live status of a number of BT services was found to be unknown when discussing C3 quotations. In addition, conservative assumptions on actual buried service alignments with potential to clash with a new defence was taken to inform diversion cost estimates. As such it will be necessary in the detailed design phase to undertake strategic CAT scanning, alignment surveys and trial pits to accurately locate (plan and depth) and the nature of buried services. This work shall consider the individual requirements of utility companies.

It should also be noted that the waste water sewer pipe which flows under the River Earn crosses the line of proposed defences on both sides of the river bank. However, this will not be diverted as part of the works and the detailed design will be developed to allow this service to remain unaltered.

Finally, robust C4 cost estimates will be requested.

11 Environment

11.1 Introduction

The proposed flood risk management solution and outline design (hereafter referred to as the Scheme) presented in the Flood Order has been achieved by the design team working together and ensuring that all disciplines including environment have been accounted for with embedded solutions incorporated in the design as required.

The environmental team comprising EIA lead consultants, landscape architects, ecologists, heritage consultants, geo-environmental engineers and hydrologists, have been involved throughout the design process and have actively informed the outline design wherever possible. This inclusive design approach has ensured that identified constraints and environmental matters such as public access, visual impact and Comrie conservation status, have been accounted for early in the process.

The key considerations for any scheme in Comrie is preserving the landscape character and rich cultural heritage of the town. The landscape character and the cultural heritage assessments undertaken as part of the EIA have been instrumental in preparing the outline design, particularly with regards to the visual aesthetics of the wall features. Compensatory tree planting, wildflower planting and other environmental enhancements for public amenity and ecological benefit have been added to the scheme by the Environment team. All are detailed within the Environmental Impact Assessment (EIA) Report (EIAR) which accompanies the Flood Order.

A full summary of the EIA process undertaken by the environment team is provided below and how the development of the EIA has been used to inform the outline design.

11.2 Environmental Impact Assessment (EIA)

Introduction

Environmental Impact Assessment (EIA) is the process of gathering together and assessing the environmental information associated with a proposed development. EIA aims to ensure that likely environmental impacts are properly understood, and likely significant impacts of a proposal are assessed to ensure that the decision maker has all the required information prior to any development consent is granted or approved.

The EIA has been prepared by Sweco (and Headland Archaeology) for the Council in support of the Flood Order for the Comrie Flood Protection Scheme. The EIA undertaken for the Scheme is considered an adequate assessment of the baseline conditions and all potential construction and operational impacts which may result and adequately assesses the effects these may have on the environment.

Legislation

The EIA has been prepared in accordance with good practice and the regulatory requirements of the following legislation:

- The Flood Risk Management (Scotland) Act 2009
- The Flood Risk Management (Flood Protection Schemes, Potentially Vulnerable Areas and Local Plan Districts) (Scotland) Amendment Regulations 2017

EIA - Process

EIA Screening

A screening request to determine whether the Scheme required EIA was submitted to the Councils Planning Service in November 2016. The Screening Opinion returned (dated 21 November 2016) confirmed the need for an EIA to accompany the application for deemed planning consent.

EIA Scoping

A Scoping Opinion was provided by the Council Planning Service in June 2017 following the submission of a baseline environmental report in December 2016 by the Council's Team.

The baseline environmental report outlined topic areas for inclusion in an EIA but did provide detail on the proposed scope or methodology required for EIA. An updated EIA Scoping Report was prepared by Sweco on behalf of the Council and submitted directly to the Council Planning Service and to statutory consultees in November 2017. The scope and methodology was agreed by all parties.

The updated 2017 Flood Regulations[2] identify additional topics (human health, natural disasters, climate and material assets) which also require assessment. These additional topics were not covered within the original Scoping or Updated Scoping Report but have been incorporated into the assessments presented within the EIAR.

EIA Approach

Baseline

The EIA study area was defined to provide a consistent approach to the assessment for each technical specialism and covers all geographical areas which could potentially be impacted by the Scheme proposals. The EIA study area also encompasses an allowance for the anticipated construction footprint, construction compound / laydown areas and construction access routes.

[2] The Flood Risk Management (Flood Protection Schemes, Potentially Vulnerable Areas and Local Plan Districts) (Scotland) Amendment Regulations 2017

Baseline information was gathered from a variety of sources including but not limited to site visits / surveys and statutory and non-statutory consultation, all of which are detailed within the EIAR.

The baseline information gathered by each EIA topic was collated to produce an environmental constraints plan that was shared across the design team. This is shown on EIAR Figure 4.1.

Policy

Each technical chapter within the EIAR contains topic specific information on the policy and guidance adopted in each assessment and relevant legislation followed including demonstrating compliance.

Methodology

Predicted impacts and the significance arising from the Scheme is assessed in the EIAR based on the outline design proposals presented in the Flood Order. The sensitivity or value of the receptor is determined at the baseline stage and the scale of magnitude of the environmental impact is defined in order to assess the impact significance.

Mitigation measures are recommended where required to reduce any predicted impacts with a resultant residual impact identified for the Scheme. Where possible, mitigation measures have been embedded into the design (**Table 11.1**). The mitigation measures proposed which are not included in the outline design should be taken forward and implemented as part of the detailed design phase.

The impact assessment adopts a matrix-based approach consistently across the EIA. Impact significance is a function of the sensitivity (value/importance) of an attribute and the magnitude of impact (assessed before and after mitigation).

Environmental Impact Assessment Report (EIAR)

An Environmental Impact Assessment Report (EIAR) has been produced in support of the Flood Order. **Table 11.1** below summarises the agreed EIAR topics as per the Scoping Opinion and updated 2017 Flood Regulations[3] and how these topics have informed the outline design.

During the production of the EIAR, Sweco and the Council have actively engaged with SEPA, SNH and other statutory and non-statutory bodies as appropriate. This is summarised within each technical chapter of the EIAR and chapter 13 of this technical report.

[3] The Flood Risk Management (Flood Protection Schemes, Potentially Vulnerable Areas and Local Plan Districts) (Scotland) Amendment Regulations 2017

Table 11.1: EIA Topics and how they have informed the outline design

Topic	EIAR Chapter Overview	Informed Outline Design Process
EIAR Chapter 5: Landscape and Visual Impact Assessment	Comprises the Landscape Character Assessment and provides the results of the tree survey undertaken across the EIA study area. The impacts from the Scheme have been minimised as far as possible through sympathetic design but with the required tree loss to construct the various flood walls and embankments, and the introduction of new hard structures, there will be residual moderate landscape and visual effects within the town, which will decrease with time. There will however also be beneficial effects for some viewpoints as the changes in tree cover will open up longer range views of the conservation area.	The landscape and townscape character has been established and the extent of the conservation status of the town confirmed. The outline design seeks to maintain the visual aspect of the town through style of wall and type of cladding to be used. The results of the tree survey were provided early in the design process so that tree loss could be minimised, and defences re-aligned so that trees could be retained wherever possible. Collaborative working between the structural team and landscape architects was a key design focus. Landscape planting is proposed across the Scheme including compensatory tree planting and enhancement ornamental planting in amenity and greenspace areas.
EIAR Chapter 6: Water Environment (including Flooding) and Fluvial Geomorphology	Provides an assessment on various 'attributes' of the surface water environment; namely hydrology and flood risk, fluvial geomorphology and water quality, during both construction and operational phases. Once completed, the Scheme will take an estimated 189 properties in Comrie and Dalginross out of existing flood risk at the 0.5% AEP (1:200 year) event, a significant positive benefit of the scheme. With careful design, appropriate construction phasing and suitable mitigation measures, the negative effects on water environment are predicted to be not significant. The scheme will in fact have a positive effect by reducing the number of flood events and the potential impacts that these events have on the Rivers and their water quality.	Scour protection has been included in the design where higher rates of erosion are predicted to occur as a result of the new flood defences. Erosion protection measures have been included on the Water of Ruchill and River Earn Mitigation and standard work practice methods to prevent water pollution of the watercourses during construction activities are provided in the outline CEMP.
EIAR Chapter 7: Hydrogeology and Contamination	Provides an assessment of the effects on hydrogeology as well as any significant environmental issues associated with potential contamination.	The scheme accounts for the identified contamination at the former area of the gas works and the remediation

Topic	EIAR Chapter Overview	Informed Outline Design Process
	With the implementation of suitable mitigation measures during construction the effects on geology, soils and hydrogeological environment (including contamination) is predicted to be not significant.	strategy proposals are included as part of the Flood Order. Contamination and remediation is discussed further within **Chapter 8 of this Technical Report.**
EIAR Chapter 8: Ecology and Nature Conservation	Evaluates the current nature conservation interest of the study area and assesses the potential impacts of the scheme on nature conservation interests during construction and operation. The chapter provides the results of the Phase 1 Habitat Survey; Protected Species Surveys; and invasive non-native species (INNS) surveys undertaken across the EIA study area. With the implementation of mitigation measures, the effects on all important ecological receptors is predicted to be not significant.	Protected species surveys have been undertaken and assessed against the proposed scheme design and construction footprint. Mitigation has been proposed in the form of bat boxes and an otter holt to offset any potential disturbance which may develop during construction. Management of INNS species known to be present within the construction/works area has also been included as part of the advance works for the scheme. Measures which should be implemented during construction will be detailed in the Construction Environmental Management Plan (CEMP).
EIAR Chapter 9: Cultural Heritage	Comprises the Cultural Heritage Assessment and presents an assessment of the scheme on the historic environment. With the implementation of the suggested mitigation measures the effects on all important cultural heritage receptors is predicted to be not significant.	Avoidance is the primary mitigation for direct impacts on historic environment assets and the scheme design has followed this principle. The constraints map identified key assets to be avoided. Sympathetic design solutions for the proposed wall finishes in sensitive parts of the townscape and accounting for the conservation status.
EIAR Chapter 10: Socio-economics, Public Access and Amenity (including impacts to human health)	Assesses the potential socio-economic effects (local economics, health safety and wellbeing and agricultural land take) as well as the disruption to public access and amenity resources	EIAR Figure 10.4 and 10.5 identifies the existing public access key routes used by NMUs; key land, facilities and venues used by the local community and annotates the type of agricultural land within the study area.

Topic	EIAR Chapter Overview	Informed Outline Design Process
	With the implementation of suitable design and mitigation the negative effects on Socio-economics, Access and Amenity (including health) are predicted to be not significant and the Scheme will benefit the local community by removing 189 properties from being currently at risk.	This information has been used in the design development to ensure appropriate access arrangements are provided during construction and operation of the Scheme. Consideration of community facilities and events have been included in the design and the upgrade of the entrance into Legion Park has been included as an alternative venue for public events such as Comrie Fortnight.

11.3 Summary

The EIA provides an assessment of all potential construction and operational impacts which may result due to the proposed Scheme and adequately assesses the effects these may have on the environment.

Appropriate mitigation measures and environmental enhancement and community benefits have been embedded into the design solution so that negative effects are reduced, managed or minimised as far as possible. Where impact remain, additional mitigation has been recommended.

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12 Economic Appraisal

The following chapter has summarised the estimation of 'whole life' present value flood damages, and costs, avoided. It goes on to summarise the comparisons made to establish value-for-money. The parameter used to characterise value-for-money of the 'do something' option was the Benefit-Cost-Ratio (BCR), where a BCR>1 has a net economic benefit.

12.1 Previous work

The feasibility phase of the project, undertaken by Mouchel, was concerned with identifying a preferred option after investigation of all feasible options. Initial, high-level economic assessments were undertaken for the preferred option and this provided an estimated BCR of 2.0, thus representing an economic benefit. The previous economic appraisal was updated, to reflect the updated hydrological estimates; hydraulic modelling; and design, made in this subsequent phase of the project.

12.2 Updated Economics

The outline design for the preferred option was subject to an economic appraisal, to determine whether it represented value-for-money. Greater detail on damage estimation techniques can be found in the "*Economic Appraisal Report*", Chapter 3. The appraisal of the outline design involved four key stages:

- establishing the 'do nothing' 'do minimum' and 'do something' scenarios;
- estimating the economic damages, and damages avoided, arising from flooding across the design life of the scheme, for the scenarios identified;
- estimating the whole-life costs (construction, maintenance, design etc.) of the identified scenarios; and
- appraisal of the various scenarios against one another using the BCR.

12.3 Damage Estimation

Economic damages due to flooding were estimated using industry standard guidance from the Multi-Coloured Handbook (MCH). The MCH provides a set of damage tables that associates receptor (e.g. residential or non-residential property) damages with a flooded depth. These tables are periodically reviewed and updated; the 2017 version of these tables were used in this assessment. By comparing the damages associated with each of the economic scenarios identified, the damages avoid were established.

Residential Damages

Residential damages were calculated using property type/age and the social grade, as outlined in the MCH. Property type data was obtained from the NRD, and age-of-property data was estimated by examining historical mapping. The social grade of an area was estimated using the Scottish Index of Multiple Deprivation (2016). In accordance with FCERM guidance, all property damages were capped.

Residential receptor dominated the economic assessment, providing the bulk of damages in the baseline ‘do nothing’ and ‘do minimum’ scenarios. It follows that the bulk of the damages avoided in the ‘do something’ scenarios were also from residential receptors.

Non-Residential Damages

Non-residential damages were estimated using floor area, receptor type, and the depth to which a receptor was predicted to flood. An estimate of the likely value of each non-residential property was obtaining using the ‘rateable value’ from the Scottish Assessors Association (SAA) and applying a multiplier of 10. The total value estimates were used to cap the non-residential damages.

Road Closure

The cost of diverting vehicles, for the duration of flood-related road closures, was calculated following the MCM methodology. The calculation was based on monitising the additional carbon emitted from transport, as a result of a given flood. Annual average daily flows (AADF), provided by the Department for Transport (DfT), were used to estimate the number and type of vehicles. Diversion routes and speeds were manually established, and the duration of closure was estimated using the hydraulic model.

The Do Nothing & Minimum scenarios were predicted to effect two roads, Dalginross Road and the A85 (between Comrie and St. Fillans). In both cases, the diversion routes were long, 20.5km and 7km respectively, and thus these closures were considered significant enough to be included within the economic appraisal.

Other Damages

Other damages that were estimated using the MCH methodology included: vehicle damage; evacuation costs; and intangible health benefits (e.g. the reduction in physical and mental health problems arising because people have been flooded).

Some damages were considered too minor to include in the assessment, such as the failure of utilities. However, not including them leaves the calculation conservative. Potential recreational gains from improvements the design brings to the environment have also been omitted from the appraisal. These environmental improvements may change at detailed design stage and, again, their omission leaves the calculation conservative. More detailed information on the assessment of flood damages can be found in the “*Economic Appraisal Report*”.

Economic Scenarios and Epochs

Three economic scenarios were assessed when considering flood damages.

- The 'Do-Nothing' scenario assumes no interventions are made to the existing defences, and that maintenance of assets ceases.
- The 'Do-Minimum' scenario assumes no interventions are made to the existing defences, but maintenance of assets continues.

  The 'Do-Nothing' and 'Do-Minimum' scenarios were considered very similar because of a critical asset, situated along the western boundary of Dalginross, that is expected to degrade whether maintenance continues or not.
- The 'Do-Something' scenario assumes implementation of the flood scheme comprising the direct defences stated in the outline design.

The potential future impact of climate change has been considered through the economic appraisal. Damages for all simulations were assessed at three climate epochs: Present-day; mid-epoch, +20% on peak flows (years 2050 – 2080); and an end-epoch, +35% on peak flows (year 2080 onwards). It has been assumed that the flood bund along the western edge of Dalginross is fully functional in the present-day and has degraded to the point of no protection by the mid-epoch (2050).

To estimate the present-value (PV) direct damage (i.e. the monetary value of damages' today'), the annual average damages (AAD) were first calculated for each climate epoch. Interpolate values of AAD were calculated between the epoch dates (i.e. present-day, 2050 and 2080). For each year across the 100-year appraisal period the relevant AAD was discounted to present-value; and the summation of these has provided the total PV direct damages.

Full details of the damage estimation can be found in the "*Economic Appraisal Report*". A summary of the damages are shown in **Table 12.1** with the figure shown in bold being the direct damages avoided through scheme implementation. These figures are all to 2017 prices, in line with the MCH damage tables used.

Table 12.1 - Summary of estimated direct damages

Scenario	Do-Minimum	Do-Something	Difference
Present-Day (AAD)	£264,139	£2,752	£261,387
Mid-Epoch (AAD)	£1,514,147	£95,931	£1,418,216
End-Epoch (AAD)	£2,271,021	£345,993	£1,925,028
TOTAL (PV)	£35,568,053	£3,187,338	£32,380,715

12.4 Whole Life Cost Estimation

Costs were split into three categories:

- Capital expenditure (CAPEX): the direct costs associated with implementation of the scheme;
- General items: indirect costs associated with the scheme generally assumed to be an uplift on the CAPEX; and
- Other costs: such as ongoing maintenance, design costs and scheme-specific expenses.

Full details on the estimated scheme costs can be found in the "*Economic Appraisal Report*". Following their estimation, figures were discounted to 2017 prices. This was to facilitate later comparison with the estimated damages avoided.

Capital Expenditure

The capital cost estimate for the Comrie FPS was derived using rates given in the *Spon's Civil Engineering and Highway Works Price Book 2017*. The method adopted for preparing a Bill of Quantities for the Operations was the 'Civil Engineering Standard Method of Measurement' by the Institution of Civil Engineers. In some cases, a design choice remained to be made on the construction method and in these cases the most onerous costing scenario was chosen to remain conservative. The CAPEX associated with the scheme implementation can be seen in **Table 12.2**.

These figures were calculated using 2020 prices, **when discounted to 2017 prices, the total CAPEX was £10,046,673.**

Table 12.2: Summary of estimated direct damages

Cost Element	Estimated Cost (2020 Price base)
Flood Walls	£7,410,619
Flood Embankments	£1,842,995
Landscaping	£868,041
Scour Protection	£513,698
Contaminated Land	£474,704
Habitat Protection	£8,580
Invasive Species Removal	£3,780
GI at Detailed Design	£55,789
Engineering Administration	£275,000
Total CAPEX	£11,453,207

General Items

The general items have been presented, in **Table 12.3**, as a percentage uplift on the overall CAPEX. This uplift was based on the outcomes of previous similarly-sized projects. In some cases, the general items have a fixed cost based on the advice and experience of the Council.

These figures were calculated using 2020 prices, **when discounted to 2017 prices, the general items were £2,027,855**.

Table 12.3: Estimated costs (general items)

Cost Element	Percentage on CAPEX	Estimated Cost (2020 Price Base)
Contractors' Fee	6.50%	£744,458
SI and Survey	-	£483,000
Consultants' Contingency	-	£400,000
Project Management	-	£284,000
Site Supervision	-	£400,296
Total General Items	-	£2,311,754

Operation and Maintenance (OPEX) Cost Estimate

A Whole Life Cost (WLC) model for the recommended flood defences was compiled using published guidance by the Environment Agency and their Flood & Coastal Risk Management (FCRM) project. WLC profiles were evaluated by the project team assuming a median rate of deterioration and a target replacement age for defences of 100 years. The results of the WLC assessment modelling were presented in Technical Note **119398-400-21 Rev. 00**.

Operation and maintenance of the scheme has been based on an assumed regular annual maintenance and inspection regime, alongside two major repair operations for the defences. These costs (discounted to 2017 prices) were estimated to be £862,647.

Other Costs

Other costs unique to the scheme were estimated as follows:

- Land acquisition and compensation; sunk costs accounting for feasibility & outline design: £2,931,741
- Detailed design costs: £197,340

These figures were calculated using 2020 prices, but when discounted to 2017 prices, the total of the other costs were £2,744,808.

Cost Summary

A summary of the whole-life costs (in 2017 prices) have been provided in **Table 12.4** These costs are before any consideration of optimism bias.

Table 12.4: Total estimated scheme cost

Cost Element	Estimated Cost (at 2017 price base)
CAPEX	£10,046,673
General Items	£2,027,855
Other Costs	£2,744,808
Secondary Flooding Capital Costs	£111,668
OPEX	£862,647
Total Estimated Scheme Costs	£15,793,650

12.5 Benefit-Cost Ratio

The BCR for the proposed scheme was based on a comparison of the whole life present value damages avoided and costs related to the 'do-something' scenario in comparison with 'Do-Minimum/Nothing' scenario.

Risk and Optimism Bias

A large risk sum for public utility diversions represented by a percentage uplift of 350% was justified on experience gained from previous schemes. This value was thought to also capture unmapped services and private utility diversions. A further 14% uplift on the public utility component cost was added to account for traffic management costs.

The optimism bias represents the known tendency for large scale infrastructure projects to be overly optimistic in their initial cost/timescale estimates. This factor, which has been based on guidance from *"Flood Prevention Schemes: Guidance for Local Authorities*", was set at 43%. This means that an additional 43% has been added to the CAPEX plus General Items plus Secondary Flooding Capital Costs. The 43% of the total of these figures (£12,186,195 at 2017 prices) was £5,240,064 at 2017 prices.

Addition of the calculated £5,240,064 optimism bias to the total estimated scheme cost of £15,793,650 yields a total of £21,033,714 at 2017 prices.

One final consideration is that of utility diversion, which has its own risk factor of 350% based on lessons-learned from previous work of a similar scale. The cost of utility diversions plus its risk factor and accounting for traffic diversions was estimated to be £2,360,526 at 2017 prices. Addition of this figure to the £21,033,714 gives the proposed scheme costs – and yielded a total estimated scheme cost to £23,394,240 at 2017 prices.

Capital Cost

Submission of the Flood Order required an estimate of the overall capital cost of proposed scheme construction. This cost was the total estimated scheme cost (£23,394,240) minus operation and maintenance costs (£862,647). Hence, the total estimated capital cost of the scheme construction was calculated to be £22,531,593 at 2017 prices. **Discounting this to 2020 prices gives an estimated cost to construct of £25,686,016**.

Benefit-Cost Ratio

The total scheme whole life present value damages, across the 100-year appraisal period, have been estimated across three climate and condition epochs to a 2017 cost basis. The following comparison has been made between the 'Do-Minimum' and 'Do-Something' scenarios:

- Total flood damages estimated in the 'Do-Nothing' and 'Do-Minimum' scenarios, over the appraisal period, were £35,568,053.
- Total flood damages estimated in the 'Do-Something' scenario, over the appraisal period, were £3,187,338.
- Hence, the predicted total flood damages avoided, over the appraisal period by implementation of the flood scheme, were £32,380,715.
- The cost of scheme construction was estimated to be £23,394,240.
- Therefore, the benefit-cost ratio for the comparison of 'Do-Nothing/Minimum' with 'Do-Something' is **1.38**.

12.6 Summary

A previous economic appraisal, carried out at feasibility stage, was updated to reflect change is design and improvements in hydraulic modelling. Direct damages due to flooding have been estimated in-line with guidance set out in the Multi-Coloured Handbook (MCH). Costs have been estimated, accounting for capital expenditure, operation & maintenance as well as other associated costs such as land acquisition and service diversions. An optimism bias of 43% has been applied to the scheme costs, which total £21,308,236. When compared with the £32,380,715 of direct damages avoided this yields a positive BCR of 1.38.

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13 Statutory Consultation

13.1 Introduction

Throughout the Comrie Flood Protection Scheme study, the Council have sought stakeholder opinion and have valued all feedback provided to date.

Prior to Sweco being commissioned in 2017, the Council and earlier appointed consultants had undertaken previous statutory consultation. Feedback from these consultations was constructive in the evolving development of the Scheme and continues to be represented in the published Flood Order.

This chapter refers to statutory consultation undertaken during Sweco's commission in the flood protection study which has comprised the following:

- Design led statutory consultation;
- EIA led statutory and non-statutory consultation;
- Value Management (VM) consultation

13.2 Design led Consultation

Consultation has been undertaken with key statutory consultees including SEPA, Scottish Water and Perth & Kinross Council. The design led requirements for these consultations are discussed within each of the preceding chapters of this technical report with a summary provided below for reference.

Early consultation provided the opportunity for any issues affecting the design or layout of the scheme to be discussed at an early stage and provided an early opportunity for representations to be considered and addressed as necessary.

Consultation has primarily comprised written correspondence by email with follow on meetings and telephone conversations as required.

13.3 EIA led Consultation

Consultation with statutory and non-statutory bodies has been undertaken as part of the EIA by Sweco. Early consultation provided the opportunity for any issues affecting the design or layout of the scheme to be discussed at an early stage and provided an early opportunity for representations to be considered and addressed as necessary.

Consultation has primarily comprised written correspondence by email with follow on meetings and telephone conversations as required. A summary of all the statutory and non-statutory consultations undertaken during the EIA is provided in EIAR Appendix 4.3 and discussed specifically within each EIAR chapter.

The following statutory and non-statutory consultees have provided information for use in the baseline assessments which then informed the scheme design.

- Perth & Kinross Council;
- SEPA;
- British Horse Society;
- Comrie Angling Club;
- Crieff Angling Club;
- Forestry Commission Scotland;
- Perth & Kinross Heritage Trust;
- Scotways; and
- Tay District Salmon Fisheries Board.

13.4 Value Management (VM) Consultation

Stakeholder consultation has been undertaken in the form of value management (VM) meetings. Three VM meetings have been held by the Council to present the project to key stakeholders. Two of these meetings have comprised a workshop format in order to obtain opinions and feedback from the invited attendees as a presentation followed by a group led session.

The first VM workshop was held in the Council's Civic Office in Perth on 16th April 2018. The workshop was hosted by the Council and Sweco and presented the initial outline design and constraints identified to date. The VM1 meeting proved useful in terms of providing local knowledge of the area which was incorporated into the subsequent design stage as required.

VM2 was held on 25th June 2018 and comprised a client design review session between the Council and Sweco.

VM3 workshop was held on 25th April 2019 to invited stakeholders at the North Inch Community Campus hosted by the Council and Sweco. The session presented the revised design highlighting changes proposed since VM1.

14 Public Consultation

14.1 Introduction

To develop the initial proposals for the Scheme, the Council engaged consulting engineers, Mouchel. A wide range of potential options for managing the risk of flooding were considered and a preferred option was recommended to the Council. This preferred option included new flood walls and embankments along the Water of Ruchill, River Earn and River Lednock river corridors. During this process the community were engaged through community drop-in sessions (September 2016). The Council also prepared a feed-back ‘Question and Answers’ document.

The preferred flood protection option was approved by the Council's Environment, Enterprise and Infrastructure Committee on 6 September 2017. Sweco were subsequently commissioned to review and develop the earlier feasibility study to a standard suitable for flood scheme publication. The Council have continued to seek feedback from the community during this period. Details have been made available on the Councils website [4] and community newsletters have been delivered intermittently.

This chapter has summarised the public consultation undertaken since the preferred option was approved by the Council's Environment, Enterprise and Infrastructure Committee. This has included:

- community liaison;
- community newsletters;
- a Scheme webpage; and
- two public exhibition events.

14.2 Community Liaison – Public and Community Groups

The Council have consulted with the local community, individual landowners and local community groups throughout the scheme development and welcomed feedback and comments provided to them by these groups.

Individual meetings with affected landowners was undertaken where possible to ensure that the individuals were fully appraised of the flood risk and interventions proposed on their land. The Council, with support from Sweco, have met with the majority of affected landowners to date and welcome the opportunity to continue to do so. At each of these meetings a drawing was provided showing the specific proposals in the vicinity of the property with an opportunity presented to discuss any concerns the owner may have with regards to both the design and construction of the scheme on (or near to) their land.

The Council have met with local community groups including Comrie Community Council, Comrie in Colour, Comrie Fortnight and Comrie Fire Station to discuss the

[4] https://www.pkc.gov.uk/comriefloodscheme

scheme proposals and to understand the needs and expectations of the community.

14.3 Community Newsletters and Webpage

Newsletters were distributed to the local community by the Council. The newsletters provided an update on the development of the scheme and provide contact details for key project team representatives; encouraging contact with the Council at all times.

The community newsletters are available to view on the Councils scheme webpage: https://www.pkc.gov.uk/article/15455/Comrie-flood-protection-scheme

A dedicated Comrie flood protection scheme webpage has been set up on the Perth & Kinross Council website: https://www.pkc.gov.uk/article/15455/Comrie-flood protection-scheme

The webpage provides links to the feasibility study and the outline design for the scheme.

14.4 Public Exhibitions – April and May 2019

Two public exhibitions, displaying the proposed outline design, were held in Comrie Community Centre (known locally as the 'White Church') on 30th April & 8th May 2019 between 2pm – 8pm.

The local community were invited to attend the exhibition through the distribution of newsletters, personal letters/emails to interested parties and also through advertising posters displayed at local locations. The Council prepared a press release with details of the event appearing in 'The Courier' and on the Council's Twitter and Facebook pages.

The exhibition itself comprised the following:

- A central display comprising 11 poster boards explaining the proposed outline design in detail and the legal (Flood Order) process;
- A full set of the proposed scheme outline design drawings;
- Proposed scheme computer-generated visualizations at key locations;
- Flood maps showing the river modelling results for the current (baseline) situation and with the proposed scheme in place; and
- A looped power point presentation by the Council providing background information on other action to raise awareness of flood risk and improve flood resilience in Comrie.

Tables were set up to allow those attending to sit and view the available information and to discuss the proposals with the officers' present. Members of staff from the Council's flooding team were available to discuss the proposals; as were members of staff from Sweco. On the 8th May event, SEPA and the Scottish Flood Forum were also in attendance and participated in advisory discussions with the community.

Both exhibitions were well attended, with approximately 80 attendees each day. At the close of the consultation event, the posters and flood maps comprising the central display were left at the White Church for a short period of time giving community further opportunity to view them.

The information presented at the exhibition event is available to view on the Councils website: www.pkc.gov.uk/comriefloodscheme and on the Councils Consultation Hub: https://consult.pkc.gov.uk/

Following the exhibitions, all feedback received was collated and reviewed by the Council and the design team. Sweco, in collaboration with the Council, provided individual written responses to local residents who raised complex or detailed concerns. Minor alterations were made to the outline design based on the community comments received, all which are reflected within the Public Consultation Report.

The Public Consultation Report was prepared by the Council and Sweco which addressed each response/comment received following the exhibitions. Where concerns were specific to an individual property, the owner received a tailored response to ensure comments in the Public Consultation Report remained anonymous.

14.5 Summary

The Council are committed to ongoing engagement with the local community and affected landowners. A key objective of engagement is to provide a mechanism for discussion which ensures that the proposed design will meet expectation and reflects the needs of the local community.

Comments provided by the community have been reviewed by the Council and the design team and incorporated into the outline design where relevant as presented in the Flood Order. The comments received from the community following the Public Exhibition event and the Council's response has been outlined in the Public Consultation Report.

Any comments outwith the Public Exhibition events (such as landowner meetings) have been addressed and discussed respectively between the individual and the Council.

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15 Conclusion

Records of flooding in Comrie extend back as far as 1920. Flood protection works were carried out in the 1960's and are still present in the town. The town has been subject to regular inundation from the Water of Ruchill, River Earn and River Lednock. Recently two major flood events in 2012, on the Water of Ruchill, required emergency flood protection works at Camp Road to reduce the immediate risk. Despite this interim intervention, approximately 189 properties remain at risk of flooding.

In response to the flood risk the Council have promoted a Flood Protection Scheme in Comrie and Dalginross. This document has summarised the technical work undertaken to develop the preferred option to an outline design standard suitable for submission. The preferred option has emerged from a rigorous design process that has identified an appropriate engineering solution, judged to be technically robust, sustainable, and provide value-for-money.

The outline design has been developed in close consultation with stakeholders including statutory and non-statutory consultees, community groups and affected landowners. The mechanism of engagement has enabled a collective discussion on issues which have informed the Scheme at critical stages in the design.

The scheme consists of flood embankments and walls that are sympathetic to the character of the town and its conservation area status. The Standard of Protection was selected after weighing the benefits of higher defences, against the visual impact of the defences on the character of the town. The 1 in 200 year fluvial event was targeted for the Standard of Protection, this does not feature an allowance for climate change.

An assessment to determine any increased risk of damage to existing and historical river bridges, as a consequence of constructing new town defences, was undertaken. This assessment concluded existing bridges can be safely incorporated into the Scheme without modification.

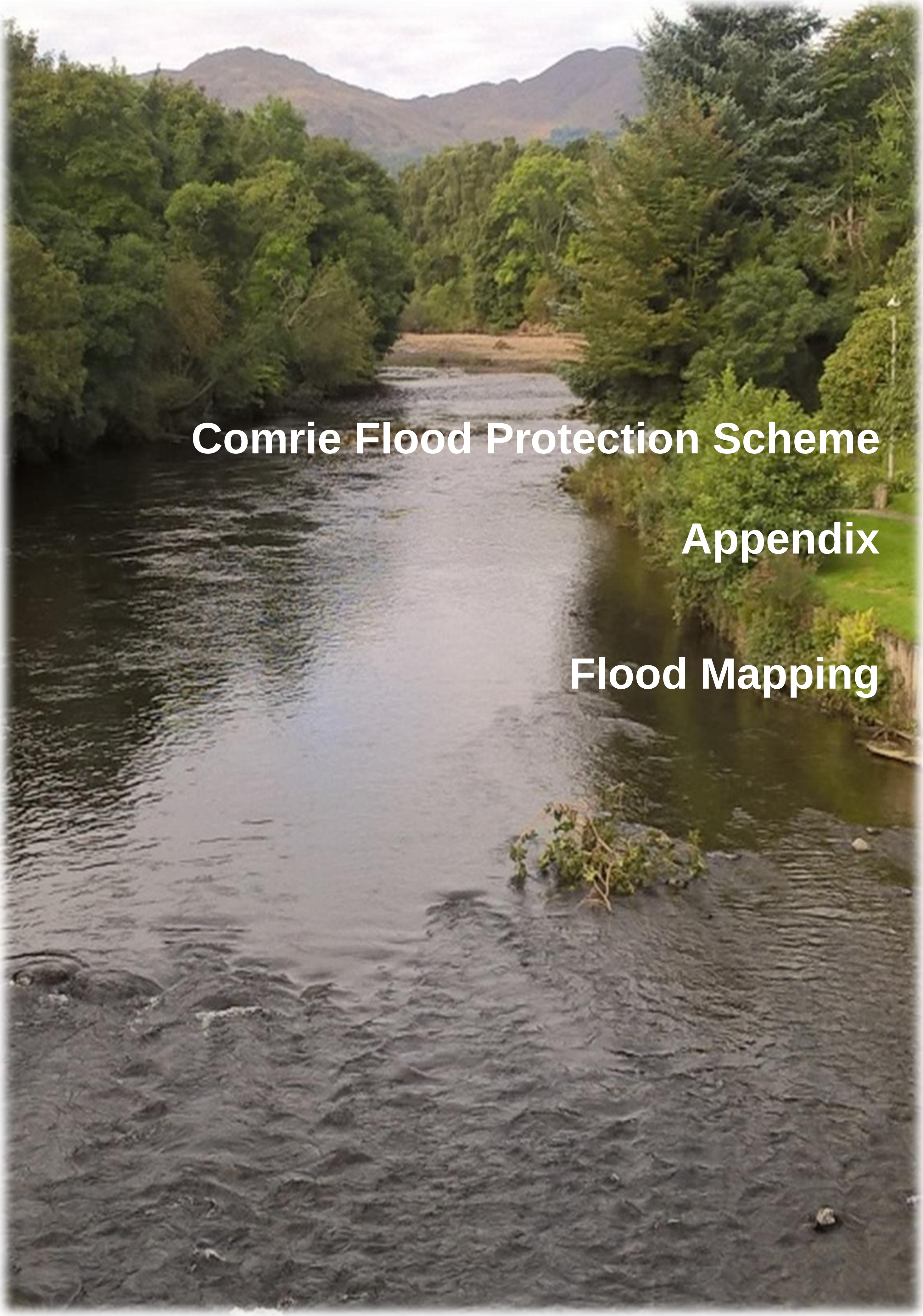
The Scheme objectives seek to manage flood risk in a sustainable environmental, social and economic manner. Embedding solutions in the design to ensure that it is compliant in terms of flood risk protection, engineering requirements and environmental constraints has been a key focus.

The scheme has been designed to be passive in operation. No flood gates need to be shut in the event of a flood, reducing the risk of the defence failing. In addition, the scheme does not require any pumps reducing operation costs, points of failure and embodied carbon. Carbon emissions associated with the operation and maintenance of the scheme are likely to be minimal, with most carbon associated with the scheme's construction and the embodied carbon of materials. Some existing material are to be recycled, including existing rock armour on the water of Ruchill; and numerous trees will be reused in the proposed erosion protection works. All material required for the embankments will be sourced from earthworks on site (where deemed suitable for re-use) or imported to site from local sources wherever possible.

Although the scheme does not account for climate change, it does not preclude future intervention in the upper catchment to mitigate the effects of climate change on the performance of the preferred option.

The design of the defences has been carefully selected to ensure that in terms of visual impact and public access, impact to the community is minimal. Tree retention has been a focus of the design process. Tree loss is compensated wherever possible with appropriate landscaping and planting schedules, allowing for more than three trees to be planted for every tree felled. Ecological mitigation including provision of an artificial otter holt bat and bat roosting habitat are included to ameliorate ecological effects of the Scheme. Management of invasive plant species has already commenced. The use of green bank protection is also included where possible to limit any impact on the physical habitat condition for the waterbodies across the Scheme.

The estimated whole life (construction, maintenance and operation) present value cost of the scheme has been estimated to be approximately £23.4M. This compared favourably to the estimated present value flood damages avoided of approximately £32.4M across the 100-year design life of the scheme. From these, the benefit-cost-ratio was calculated as 1.38, suggesting a net economic betterment from the proposed scheme.



Comrie Flood Protection Scheme

Appendix

Flood Mapping