Environmental Impact Assessment Report

Appendix C10 Water Environment

Grangemouth Flood Protection Scheme 2024
Falkirk Council

GRANGEMOUTH
Flood Protection Scheme
Protecting the heart of our communities

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Appendix C10.1 Fluvial Geomorphology

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1. Introduction

This report forms an appendix to Chapter 10: Water Environment. The aim of Appendix C10.1 is to describe the baseline conditions of fluvial geomorphology receptors within the extent of the GFPS and to provide an assessment of the potential impacts to the geomorphology as a result of the Scheme. Where required, additional mitigation is provided to offset potentially significant effects. This assessment covers the fluvial sections of receptors within the study area; estuarine receptors are covered in Appendix C10.2 Estuarine Geomorphology.

2. Legislation

2.1.1 Water-Related Legislation

Chapter 10: Water Environment provides an outline of the policy and legislative framework relevant to the Scheme and this Appendix, including the following:

- Water Framework Directive (WFD) 2000/60/EC: Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy;
- Water Environment and Water Services Act (WEWS) (Scotland) 2003, which transposes the above directive into Scottish law (as amended by Environment (EU Exit) (Scotland) (Amendment etc.) Regulations 2019 and the European Union (Withdrawal) Act 2018); and
- Water Environment (Controlled Activities) (Scotland) Regulations 2011 (as amended by Water Environment (Controlled Activities) (Scotland) Amendment Regulations 2021) and the Water Environment (Miscellaneous) (Scotland) Regulations 2017).

2.1.2 Falkirk Council Local Development Plan 2: Adopted August 2020

The Falkirk Council Local Development Plan 2 (LDP2) outlines one policy which has informed the assessment of the fluvial geomorphology:

- PE22 The Water Environment: Aims to ensure integrity of water quality and habitat of the water environment, in line with the WFD, in addition to maintaining recreational amenity of water bodies. This is implemented through support of the development of measures to improve the ecological status of the water environment including naturalisation of watercourses and a general presumption against developments which have a detrimental effect on the ecological quality or recreational amenity of the water environment.

3. Methodology

3.1 Baseline Methodology

The Scheme has been divided into six Flood Cells in which construction works and operation of new structures will take place. The Flood Cells form the basis of the assessment. The study area for surface waters has been determined by the extent of the Marine Scotland and SEPA WFD baseline surface water body catchments overlapping the Flood Cells (Figure B10.1). A walkover of watercourse reaches directly impacted by the Scheme was undertaken in March 2016, and the results combined with a desk study to inform the baseline assessment.

The geomorphological baseline includes Flood Cells located on the River Carron and associated tributaries, the Grange Burn / Westquarter Burn, Polmont Burn, Grange Burn Flood Relief Channel, Millhall Burn and the River Avon. The walkover identified the morphological features, the scale of processes operating, and the areas deemed most vulnerable to change. Walkover data were supplemented by review of the available aerial photographs, photographic records, and previous geomorphology reports (CH2M, 2017). Millhall Burn, Polmont Burn, Westquarter Burn and the tributaries of the River Carron were not visited as part of the site walkover surveys. Baseline descriptions for these watercourses are provided from desk study information only.

Moreover, the status of the fluvial WFD waterbodies was obtained from SEPA's Water Classification Hub (SEPA, 2024ba). Other baseline information was supplied by SEPA following consultation, which included 'Less Than Good' survey data on morphological pressures, riparian vegetation, and channel typologies (SEPA, 2023).

3.2 Impact Assessment Methodology

The impact assessment methodology covers both the construction and operational phases of the Scheme and follows the methodology outlined in Section 10.3 in Chapter 10: Water Environment.

3.2.1 Sediment Dynamics Methodology

The Hjülstrom method has been used to estimate the basic parameters for erosion, deposition, and transport of sediment under baseline and 'with Scheme' scenarios. The Hjülstrom curve (Figure 1) describes the relationships between erosion, transportation, and deposition of sediments during different flow regimes. The relationship is plotted logarithmically, from which it is then possible to predict whether a river will erode, transport, or deposit sediment according to a particular particle size and water velocity.

A semi-quantitative assessment to enable comparison of variation to channel width and depth, water flows and levels, and potential for sediment entrainment, deposition, and erosion was also undertaken for baseline and with-scheme scenarios. This involved extracting velocity data from the numerical model, for various channel cross-sections along specific reaches of the receptors identified in Section 10.4 – Baseline. The data extracted from the numerical model includes the maximum velocities for the 50% Annual Exceedance Probability (AEP) (2-year), and 0.5% AEP (200-year) events for both a 'with-scheme' and 'without scheme' or 'baseline' scenarios and is presented in Annex A. These have then been plotted on the Hjulström curve to identify where there are likely changes in erosion, deposition and transport of bed sediment and the corresponding clast sizes as a result of the Scheme changing flow velocities within the receptors.

As a conservative approach, the maximum velocity under baseline and with Scheme conditions returned from the modelled cross sections has been used. A discussion of the baseline sediment transport analysis using this methodology is presented in Section 4.2.11. A discussion of the with Scheme results in comparison to the baseline is presented in Section 5.2.4.

Model data are not available for Chapel Burn and Mungal Burn. Therefore, the potential impacts on sediment dynamics are estimated qualitatively using professional judgement according to proposed structure type and the likely construction practices.

This method does have limitations, primarily due to the over-simplification of the fluvial processes (and pressures) occurring within the river channel. Due to these limitations, the results should be treated as a guide and used in conjunction with observations on site and professional judgement.

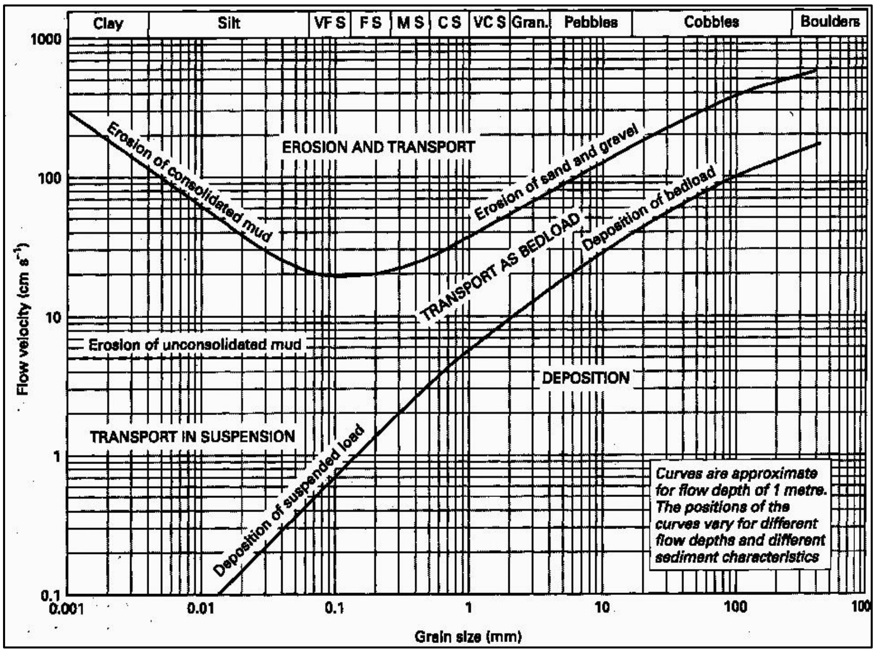


Figure 1: Hjülstrom curve depicting erosion, transport and depositional thresholds as a function of grainsize and velocity (Hjulstrom 1939)

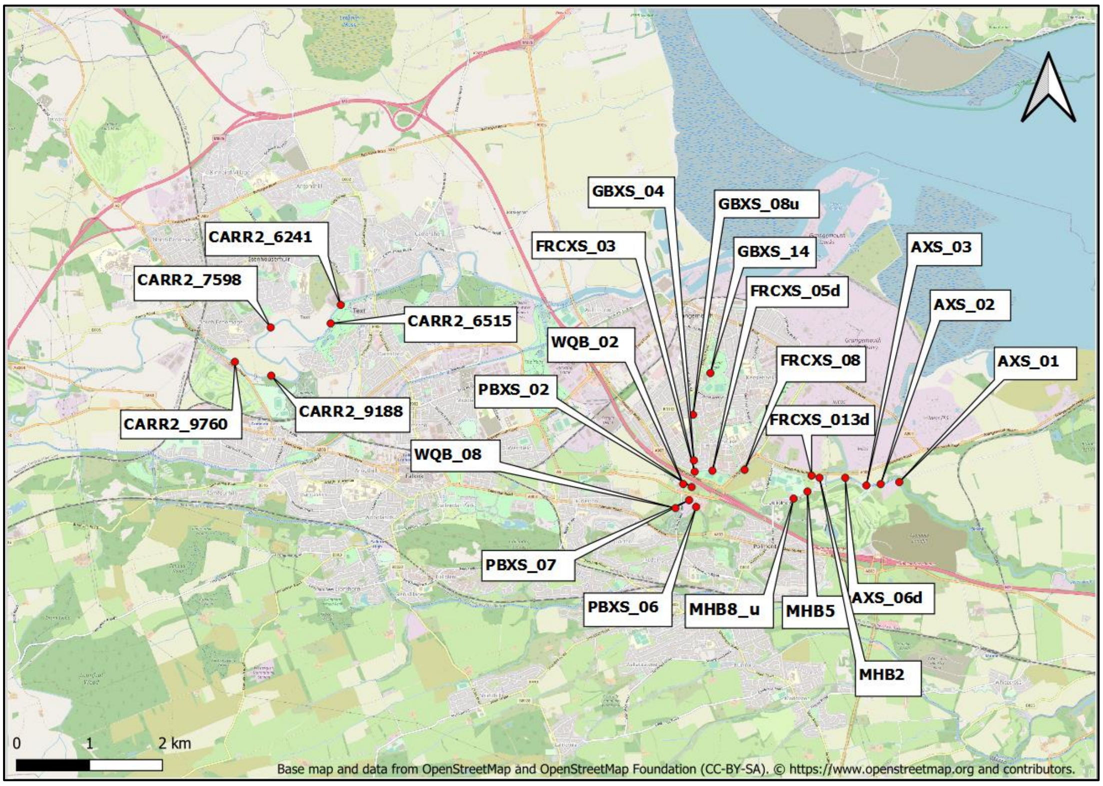


Figure 2: Modelled cross-section locations

4. Baseline

4.1 Receptors

WFD baseline waterbodies and their tributaries which interact within the Scheme as per the Flood Cell boundaries are shown in Figure B10.1. The latest WFD classification data and conditions of each water body are summarised in Table 1 (SEPA, 2024a; SEPA 2024b). The existing MImAS (Morphological Impact Assessment System) scores are provided by SEPA (SEPA, 2023).

Table 1: Waterbodies (receptors) and existing pressures (SEPA, 2024a; 2024b, 2023)

Waterbody	Overall current WFD Status	Hydromorphology	Water Flows and Levels	Existing Morphological Pressures	Overall target WFD status (2027)	MImAS baseline score and status
River Carron (Bonny Water confluence to Carron Estuary)	Poor	Moderate	High	Bank defences Bridges Channel realignment Embankments (including set-back) Flow deflectors Weirs (impoundments)	Good	37.80 % (MODERATE morphological status)
Grange Burn / Westquarter Burn	Moderate ecological potential	Bad	High	Bank defences Bed reinforcement Bridges Channel realignment Culverts Embankments (including set-back) Weirs (impoundments)	Good ecological potential	119.20 % (BAD morphological status)
River Avon (Logie Water confluence to estuary)	Moderate	High	High	Bank defences Bridges Embankments (including set-back) Weirs (impoundments)	Moderate	2.60 % (HIGH morphological status)

4.2 Channel Descriptions

The baseline channel descriptions are derived from site walkover data obtained in the period 10-13th March 2016 and complemented by desk study using data sources provided in Chapter 10 (Section 3.1).

Weather was dry and flows on the visited watercourses were within low to normal ranges. The survey covered reaches of the River Carron, Grange Burn and River Avon within the Flood Cells 1, 2, and 4.

4.2.1 River Carron (Bonny Water confluence to Carron Estuary)

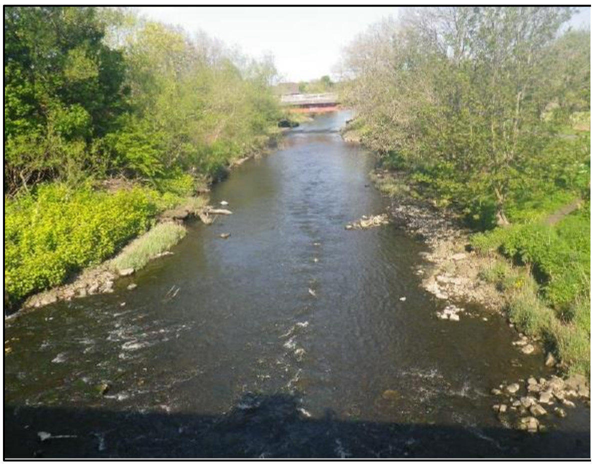
The fluvial WFD water body extent of the River Carron (Bonny Water confluence to Carron Estuary, herein referred to as the River Carron) is approximately 36 km long and lies within the upstream area of Flood Cell 1. The watercourse holds a Poor Overall status, and Moderate Hydromorphology status under the WFD. The watercourse has objectives to achieve Good for future WFD cycles.

The channel is disconnected from its floodplain in numerous reaches because of steep embankments on both sides of the channel. The left floodplain is urbanised and developed up to the bank top in numerous locations. The right bank floodplain is predominantly woodland and open parkland. Banks within upstream reaches of Flood Cell 1 are lower but increase in height and gradient downstream. Upstream of the New Carron Road and Stenhouse Road bridges on the left bank there is extensive wooden and cobble bank protection adjacent the channel. Mature deciduous vegetation along the banks exhibits various degrees of density. Between Dorrator Bridge and South Broomage, the channel is constrained on both sides by residential and industrial properties, and transport infrastructure.

Bed sediment size ranges from sands to boulders. The channel is approximately 30 m wide with a sinuous planform, meandering across a wide floodplain through agricultural and pastoral land. Morphological features include riffles, pools, glides, lateral and mid channel, vegetated and non-vegetated bars. Areas of actively eroding banks are present out with unprotected reaches and opposite mid and lateral gravel bars. Within the vicinity of Stenhouse Road and New Carron Bridges, the channel appears straightened, and exhibits uniform glide flow conditions with some riffles occurring immediately downstream of the bridge structures. There are a number of fallen bankside trees adding large wood to the channel throughout Flood Cell 1.

There are several major pressures on flows and levels throughout the catchment, including impoundment, abstraction, purification and distribution of water at Carron Valley Reservoir in the upper catchment and impoundment due to weirs in the lower catchment. Run-off and flow patterns are significantly affected by upstream reservoirs and run-off is increased by effluent returns (CEH, 2016). Historic weirs are located at National Grid Reference (NGR) NS 87914 82310 and NS 85598 81994.

Given the above, the River Carron is assigned an importance of **High**.



Plates 4.1 – 4.4: Lateral bars (top left), Actively eroding banks (top right). Failure of weir and bank (bottom left) and localised bank erosion and wood in channel (bottom right)

4.2.2 Chapel Burn

Chapel Burn is a relatively small watercourse and is not classified under the WFD. The watercourse has its source between King's Wood and Baxter Wood approximately 3 km north-west of Larbert although the precise source location is unclear. From its approximate source the channel is approximately 6.7 km long with a catchment area, as delineated on the Flood Estimation Handbook (FEH) web service, of 1.30 km^2. However, given the complex urban nature of the catchment, this only includes the area between the confluence with the River Carron (NGR NS 86214 81616) and the golf course at Stenhousemuir (NGR NS 85823 81210). A desk review of historical mapping suggests the true catchment area of the watercourse may be larger than reported on FEH.

The watercourse drains in a south-easterly direction through Larbert before discharging to the River Carron. The catchment area is characterised by agricultural land and woodland within the upper reaches. Downstream of the Forth Valley Royal Hospital, the catchment is almost entirely urban as the watercourse flows through the settlements of Larbert, Stenhousemuir, Carron and Carronshore. The riparian zone is fragmented for the length of the watercourse and absent in places where urban encroachment occurs.

Chapel Burn exhibits a predominantly straightened planform for most of its length. There is evidence of historic channel realignment around Forth Valley Royal Hospital and along Old Denny Road and culverting through North Broomage, Stenhousemuir Primary, Ochilview Park stadium and Larbert Cemetery.

Based on the above, Chapel Burn is assigned an importance of **Medium**.

4.2.3 Bainsford Burn – Tributary of the River Carron

Bainsford Burn is a small watercourse and is not classified under the WFD. Based on historic mapping, its source is anticipated to be in the Merchiston area of Falkirk. Mapping indicates the watercourse is culverted multiple times within the highly urbanised catchment. This makes delineating the precise source and catchment area of the watercourse difficult. The only open channel reach of the watercourse is downstream of Abbots Road Roundabout, where the watercourse flows for approximately 1 km prior to discharging into the River Carron. Upstream of this location the watercourse is entirely culverted. The catchment land use is predominantly urban, with woodland surrounding the open channel section upstream of the River Carron confluence. The riparian zone is continuous through the open channel section, through which the watercourse exhibits a predominantly sinuous planform. Aerial imagery indicates the presence of small reaches of bank erosion and potential early riffle development, indicating a degree of active fluvial process.

Given the above the Bainsford Burn is assigned an importance of **Medium**.

4.2.4 Mungal Burn – Tributary of the River Carron

Mungal Burn is a small watercourse with a catchment area of approximately 3 km^2 up to its confluence with the River Carron and a length of approximately 5km. The watercourse is not classified under the WFD. Based on historic mapping, its source is anticipated to be immediately south of the Bantaskin Estate (NGR NS 87243 80126), approximately 1 km west of Falkirk High train station. However, due to the extensive culverting and development of the area, including the Union Canal and Forth and Clyde Canal bisecting the catchment, the precise source and course of the watercourse is unclear. Between the reach upstream of the Union Canal and downstream of the Forth and Clyde Canal, the watercourse flows in a northerly direction through Summerford. Downstream of the Forth and Clyde Canal, it then continues in a northerly direction in a predominantly open channel from the south-west of Camelon (Falkirk) to Mungal (Falkirk) where it is culverted for approximately 800 m prior to discharging to the Burn.

For approximately 900 m from its source, the catchment land use is characterised by predominantly agricultural land and woodland; downstream of this, land use is almost entirely urban. The riparian zone is limited for the length of the watercourse. Where there is an open channel, Mungal Burn exhibits a predominantly straightened planform, with limited reaches of increased sinuosity.

Based on the Above, Mungal Burn is assigned an Importance of **Medium**.

4.2.5 Minor Tributary – Stirling Road - Tributary of the River Carron

A tributary of the River Carron crosses Stirling Road at approximate NGR NS 86207 81610 within Flood Cell 1. The watercourse displays a catchment area of approximately 4 km^2 up to its confluence with the River Carron and is not classified under the WFD. Historic mapping (National Library of Scotland, 2023) indicates the watercourse has its source at the confluences of a series of land drain features which converge north of Greenrig Strip. The watercourse drains northwards as a single thread channel through woodland prior to crossing the Union Canal in a culvert. North of the Union Canal, the watercourse flows through the urban areas of south-west Falkirk, to Falkirk Golf Course prior to flowing below Stirling Road and discharging to the River Carron. The riparian zone upstream of the A9 consists of dense mature deciduous vegetation along both banks, which thins along the right bank through the golf course where the channel appears to be confined by embankments.

The watercourse exhibits a predominantly straightened planform for most of its length. Localised increases in sinuosity are observed within the vicinity of the golf course indicating a degree of active fluvial processes and riverine recovery within the confines of the current channel.

Based on the above, the Minor Tributary – Stirling Road is assigned an importance of **Medium**.

4.2.6 The Grange Burn / Westquarter Burn

Grange Burn / Westquarter Burn holds a Bad classification for Hydromorphology and Morphology and is designated a heavily modified water body on account of physical alterations under the WFD (SEPA 2024b). The water body holds objectives to achieve Good ecological potential for future WFD cycles. The river is heavily modified with morphological alterations to the channel bed and banks (SEPA 2024a). The MiMAS assessment on the baseline situation shows approximately 119 % of the water body's total capacity is currently used.

The watercourse is crossed by the M9, upstream of which the waterbody is called Westquarter Burn and downstream is called Grange Burn.

Westquarter Burn is situated within Flood Cell 4 and has a catchment area of approximately 18 km^2 upstream of the M9. Its source is within a network of artificial drainage channels west of Gardrum Moss, approximately 2 km south-west of Shieldhill. It flows in a north-easterly direction beneath the Union Canal (where it is intersected by Glen Burn at NGR NS 90271 78359) and through Westquarter prior to being culverted beneath the M9. It meets Polmont Burn at the M9 crossing, however flow from Westquarter Burn continues along Grange Burn and flow from Polmont Burn continues along the Grange Burn Flood Relief Channel.

From Gardrum Moss to approximately 600 m west of the Pirleyhill Bridge at Shieldhill, the Westquarter Burn exhibits a largely straight planform. From this point to the confluence with Polmont Burn, Westquarter Burn is relatively sinuous and flows unconstrained across a wide floodplain. Channel width ranges from 6-8 m with a largely continuous mature deciduous riparian corridor. Aerial imagery indicates the presence of riffles and lateral bars with active bank erosion on outside of meander bends indicating a degree of active fluvial process.

The Grange Burn is approximately 14 km in length (including Westquarter Burn) and drains a lowland area of approximately 24 km^2 (including the Westquarter Burn catchment) into the Firth of Forth. Land use is a mixture of pastoral and urban development in the lower catchment. The Grange Burn commences at the outlet of the existing culvert below the M9. Downstream of the M9, the channel is up to 6 m wide and approximately 5 km in length prior to discharging to the Middle Forth Estuary. The channel has been straightened and embanked as part of previous flood defence works; there are, however, signs of adjustment and increased sinuosity, resulting from localised erosion within the existing channel form.

Downstream of the M9, the Grange Burn is constrained via grassed and tree lined embankments, flowing southwards through urban parkland. On the right side of the floodplain, urban areas open to a larger recreational parkland. The channel has been realigned and straightened but is showing adjustment with small reaches displaying increased sinuosity within the existing channel form. Bank slopes are steep, and uniform. There are localised areas of undercutting along the toe of the left- and right-hand embankments, and wooden bank protection lining the embankment toe in places. Bed sediment consists of sand, gravel, and occasional cobbles with fines infilling. Channel morphology is predominately plane bed with small reaches exhibiting loosely defined riffles. There are no active or static bars and river margins are vegetated. The offtake for the Grange Burn flood alleviation channel adjoins Grange Burn immediately downstream of the M9 culvert outlet reducing the discharge of the burn under higher flows. At this weir, Grange Burn spills over the structure into the Grange Burn Flood Relief Channel (FRC) and downstream into the River Avon (Logie Water confluence to estuary).

Based on the above, the Grange Burn / Westquarter Burn has been assigned an importance of **High**

Plates 4.5 – 4.9: Grange Burn: Grassy uniform embankments on floodplain (top left), culverts at upstream section where flood alleviation channel adjoins Grange Burn upstream (top right), Upstream the channel is narrower with wooden toe protection (bottom left). Bank protection is failing in places (bottom right).

4.2.7 Polmont Burn

Polmont Burn is not classified under the WFD. The watercourse has a length of approximately 8 km, displaying a catchment area of approximately 7 km^2. Aerial imagery and mapping indicate the watercourse flows in a northerly direction immediately upstream and below the M9. Under baseline conditions, flow from Polmont Burn is inhibited from entering Westquarter Burn upstream of the M9 culvert by a concrete weir which is affixed between the two watercourses, extending towards and through the M9 culvert. This acts to divert flow from Polmont Burn towards the downstream Grange Burn Flood Relief Channel. Upstream of the M9 culvert Polmont Burn displays a low sinuosity planform, approximately 4 – 6 m wide with small reaches of increased sinuosity. Downstream of Polmont Road the watercourse flows within a relatively unconstrained floodplain measuring approximately 200 m wide. As the watercourse approaches the M9 the channel is constrained by industrial developments along the left and right banks. Dense, deciduous riparian vegetation lines both banks along the full channel length and therefore further characterisation is difficult.

Based on the above Polmont Burn is assigned an importance of **Medium**.

4.2.8 Grange Burn Flood Relief Channel (FRC)

The Grange Burn FRC is an artificial trapezoidal channel with a concrete base which was constructed in the 1960s. The flow in the Grange Burn FRC is entirely controlled via inflows from Polmont Burn under normal flow conditions. The FRC moderates discharge downstream on Grange Burn at events greater than the 2-year event via a concrete overspill weir situated between Grange Burn and the FRC. The FRC is connected to the River Avon to which it discharges approximately 2 km downstream.

Grange Burn FRC is not classified under the WFD and shows no distinct morphological features or attempts to recover any sort of equilibrium. Site visits confirm the presence of formed embankments topped with managed short herbaceous grasses. Within the channel base, sporadic localised deposits of coarse sediment are present. These deposits are likely due to increased velocities during flood events carrying sediment downstream from Polmont Burn. As the hydrograph recedes the sediment is deposited in the channel base and re-entrained during the next event. Therefore, sediment transport erosion and deposition are considered intermittent within the FRC. The FRC lacks varied bed conditions, morphological features, and flow types. On the day of survey, flows were observed to be very low with some sections of the FRC largely dry highlighting the channels ephemeral nature.

Plates 4.10-4.11: High, uniform trapezoidal shaped embankments with low flow and ponding water under normal flow conditions (left) and localised areas of gravel deposition (right)

4.2.9 River Avon (Logie Water confluence to Estuary)

The River Avon (Logie Water confluence to Estuary - herein referred to as the River Avon) flows southwards through managed wooded and agricultural land within Flood Cell 4. The watercourse displays a sinuous channel upstream of the A905. Towards the A905 the valley opens out, and land use is a mixture of pastoral and arable agriculture on the floodplain. Riparian vegetation consists of dense mature deciduous trees, grasses and shrubs which line the left and right banks upstream of the A905.

Channel width varies but is on average approximately 20 m wide and confined by steep valley sides. The left bank appears steeper throughout the upstream reach and is densely vegetated with deciduous tree cover. Bedrock is exposed within the channel approximately 400 m upstream of the existing A905 bridge along the right bank. The channel bed is composed of sands, gravels, cobbles and boulders and channel morphology is predominantly pool-riffle with sporadic glides and pools on meanders. The coarse sediment morphology contributes to the creation of varied flow types and active morphological processes.

Modifications include infrastructure and development, notably the A905 road bridge crossing and nearby industrial buildings which encroach on the floodplain. Immediately upstream of the road bridge, the Grange Burn FRC discharges into the River Avon during high flow. The right bank of the River Avon, opposite the confluence with Grange Burn FRC is protected by rock gabions.

The water body is currently achieving High status for both Hydromorphology and Morphology quality elements under the WFD. The MiMAS assessment on the baseline situation shows approximately 2.6 % of the water body's total capacity is currently used and is therefore within 2.5 % of the morphological condition limit between High status and Good status for Hydromorphology. This means that any significant additional morphological pressures may result in a downgrade of the Hydromorphology status of the WFD water body.

Based on the above, the River Avon has been assigned an importance of **Very High**.

Plate 4.12 -4.15: Bedrock exposed on right bank and localised undercutting (top left). Bank undercutting on right bank side and riffle development (top right). Lateral gravel bars (bottom left) and boulders in-water boulders (bottom right)

4.2.10 Millhall Burn

Millhall Burn was not covered as part of the 2016 walkover surveys and is not classified under the WFD. The watercourse forms a tributary of the River Avon with a length of approximately 8.5 km and a catchment area of approximately 7 km^2 flowing south to north within Flood Cell 4. Millhall Burn has its source is close to the source of both Polmont Burn and Westquarter Burn, in a network of artificial drainage channels east of Gardrum Moss approximately 1 km south-west of California, Falkirk. It is called Gardrum Burn from its source to the crossing beneath the Union Canal, Gilston Burn to Millhall Reservoir and Millhall Burn downstream of Millhall Reservoir to the confluence with the Grange Burn Flood Relief Channel.

From its source to the crossing beneath Blackbraes Road (B8028), the planform of Gardrum Burn is predominantly straight through Gardrum Moss (historic peat works) and agricultural fields. Downstream of California, Falkirk, to the crossing beneath the Union Canal, Gardrum Burn exhibits a sinuous planform. The watercourse has a continuous riparian corridor aside from an approximate 700 m reach through Rumford, Falkirk where urban development within the floodplain is prevalent. Downstream of the Union Canal crossing (where the watercourse is named Gilston Burn), there is evidence of artificial straightening along field boundaries and the riparian corridor becomes more fragmentary. Downstream of the M9, flow from (the now) Millhall Burn is diverted into Millhall Reservoir, re-entering the straightened channel approximately 200 m downstream. Through Polmont Woods, Millhall Burn exhibits a predominantly sinuous planform to the crossing beneath Grange Road; downstream to the confluence with the River Avon, the planform is artificial.

Based on the above, and the criteria provided in Table 10 3, the Millhall Burn has been assigned an importance of **Medium**.

4.2.11 Summary of Baseline Sediment Dynamics

Table 2: Summary of sediment transport dynamics

Waterbody	Baseline flow event	Erosion and Transport (mm)	Transport as bed load (mm)	Deposition (mm)	Summary
River Carron (Bonny Water confluence to Carron Estuary)	50% AEP (2-year)	Up to 20.0	20.0 – 400.0	>400.0	Erosion and transport dominated with deposition of larger clasts
	0.5% AEP (200-year)	Up to 60.0	>60.0	N/A	
Grange Burn	50% AEP (2-year)	Up to 8.0	8.0 - 100.0	>100	Erosion and transport dominated with deposition of larger clasts
	0.5% AEP (200-year)	Up to 11.0	9.0-150.0	>150.0	
Westquarter Burn	50% AEP (2-year)	Up to 16.0	16.0-300.0	>300.0	Erosion and transport dominated with deposition of larger clasts
	0.5% AEP (200-year)	Up to 30.0	>30.0	N/A	
Polmont Burn	50% AEP (2-year)	Up to 25.0	>25.0	N/A	Erosion and transport dominated
	0.5% AEP (200-year)	Up to 35.0	>35.0	N/A	

Waterbody	Baseline flow event	Erosion and Transport (mm)	Transport as bed load (mm)	Deposition (mm)	Summary
River Avon (Logie Water confluence to estuary)	50% AEP (2-year)	Up to 20.0	>20.0	N/A	Erosion and transport dominated
	0.5% AEP (200-year)	Up to 40.0	>40.0	N/A	
Grange Burn FRC	50% AEP (2-year)	Up to 35.0	>35.0	N/A	Erosion and transport dominated
	0.5% AEP (200-year)	Up to 55.0	>55.0	N/A	
Millhall Burn	50% AEP (2-year)	Up to 42.0	>42.0	N/A	Erosion and transport dominated
	0.5% AEP (200-year)	Up to 40.0	>42.0	N/A	Erosion and transport dominated
Stirling Road Tributary	50% AEP (2-year)	Up to 10.0	10.0 – 200.0	>200.0	Erosion and transport dominated with transport of larger clasts as bedload
	0.5% AEP (200-year)	Up to 20.0	>20.0	N/A	Erosion and transport dominated

* Note that the 200-year modelled baseline velocities are heavily influenced by the discharge within the Carron. During such events the Carron creates a backwater effect which slows peak velocities within the Stirling Road Tributary. This effect is not present during 2-year flow and hence velocities are increased.

4.2.12 Summary of Baseline Importance

Following the assessment of the baseline condition for each water feature, an importance level has been assigned based on the methodology outlined in Chapter 10 – Water Environment, specifically Section 10.3.5 Table 10-3. Table 3 provides a summary of the fluvial geomorphology importance of the identified receptors.

Table 3: Overview of fluvial geomorphology importance of identified receptors.

Watercourse	Qualifying criteria for sensitivity of water features	Importance
River Carron and Grange Burn / Westquarter Burn	River Carron (Bonny Water confluence to Carron Estuary) and Grange Burn / Westquarter Burn are achieving less than 'Good' status for Hydromorphology. However, both are classified by SEPA under the WFD and have established objectives to achieve 'Good' status in 2021-2027 RBMP Cycles.	High
Tributaries of River Carron: Chapel Burn; Mungal Burn; Bainsford Burn; and Minor Tributary (Stirling Road)	Not designated under the WFD. Currently showing signs of existing and historical modifications with an attempt to recover to equilibrium.	Medium
River Avon	River Avon has 'High' status for Hydromorphology in the latest SEPA WFD classification.	Very High
Tributaries of River Avon: Millhall Burn; and	Not designated under the WFD.	Medium

Watercourse	Qualifying criteria for sensitivity of water features	Importance
Polmont Burn	Currently showing signs of existing and historical modifications with an attempt to recover to equilibrium withing artificial constraints.	
Grange Burn FRC	Grange Burn FRC is an artificial channel with no evidence of diverse fluvial processes and morphology.	Low

5. Impact Assessment

The potential impacts of the Scheme on fluvial geomorphology have been divided into construction and operational impacts. The construction impacts are those associated with activities undertaken during the construction phase. The operational impacts are longer-term impacts due to the presence of permanent infrastructure.

Although within the study area and included within the baseline, Bainsford Burn is scoped out of further assessment as there are no works within 1 km of the watercourse. This watercourse is therefore scoped out of further assessment.

5.1 Construction Phase

This section describes and considers the potential effects of the Scheme's construction activities to the fluvial receptors (described in Section 4). A description of the construction activities for each watercourse is provided in Table 4. Potential impacts for each of the identified receptors are outlined in Sections 5.1.1 – 5.1.4 and summarised in Table 4.

There would be no construction works or operational infrastructure on Bainsford Burn, therefore no changes to baseline conditions as a result of the Scheme are anticipated. Bainsford Burn is therefore scoped out of further assessment.

Table 4: Proposed construction phase activities

Baseline Waterbody	Flood Cell	Construction Phase activities	Waterbody Length (km)
River Carron	1	• Near channel working over an approximate length of 200m to construct sheet piled brick clad finished flood wall adjacent to Stirling Road. • In-channel working from an in-water platform at the confluence with Minor Tributary Stirling Road. • Near channel working to construct the proposed New Carron Bridge replacement. • Construction of setback earth embankment adjacent to Park Road residential complex.	36.0
Tributary of River Carron: Chapel Burn	1	• Formation of access track to access right and left channel bank for construction plant. • In-channel works from construction plant position on the channel banks, to construct approximately 360m of concrete formed sheet piled flood defence walls.	6.7
Tributary of River Carron: Mungal Burn	1	• Approximately 25 m of in-water working (construction plant positioned on a temporary working platform) to install extension to existing culvert and associated downstream headwall.	5.1
Tributary of River Carron:	1	• Near channel works to construct formed concrete flood defence walls.	4.1

Baseline Waterbody	Flood Cell	Construction Phase activities	Waterbody Length (km)
Minor Tributary Stirling Road		• Approximately 95 m of in-water works (construction plant positioned on a temporary working platform) to construct formed concrete flood defence walls.	
Grange Burn / Westquarter Burn	4	• Approximately 50 m of in-water works to extend the opening between the Grange Burn and FRC weir and construct new a flow control structure immediately downstream of the weir opening on Grange Burn. The construction plant would be positioned on a temporary working platform within this area of the watercourse. • Approximately 45 m of in-channel work which would take place from the bankside on Westquarter Burn immediately downstream of the A9 culvert. • 55m upstream of the Grandsable Road Bridge respectively. These works are required to construct formed concrete walls.	14.0 (inclusive of Westquarter Burn)
Polmont Burn	4	• Near channel works on Polmont Burn associated with the construction of formed concrete flood wall .	8.0
Millhall Burn	4	• Construction works to construct one new bridge / culvert structure at Reddoch Road. • Approximately 510 m of near channel working to construct new flood defence structures. Flood defence structures would consist of concrete formed sheet piled walls with various finishes including formed concrete and stone clad. • Approximately 140m of in-water works to construct stone clad flood defence walls between the Reddoch Road crossing and the A905 culvert. Works would take place from a temporary in-water working platform.	8.5
Grange Burn FRC	4	• Relining of the FRC would be undertaken to ensure structural integrity is maintained. Temporary working platforms would be formed over 200m sections of the FRC (Over its full length of approximately 2 km) to facilitate construction of the Scheme and re-lining of the channel. • Construction of a new raised bridge structure.	2.0
River Avon (Logie Water confluence to estuary)	5	• No in or near channel works would be required. All works would be set from the channel banks.	

5.1.1 Change to Structure and Substrate of the Bed

Temporary in-water and near channel working areas will be required for the activities listed in Table 4. These activities would require access along the channel bed and banks for plant and machinery. In-water working areas will require a temporary working platform (set to above the 1in2 year flow level) on top of which construction plant would operate. Working platforms would be built to allow for construction and transportation of materials / plant along part of the width the watercourse but would lead to a reduction in channel cross-sectional area.

Construction activities may potentially remove bed sediment and bank substrate which may permanently remove existing morphological features (where present) beneath the footprint of the works. Additionally works adjacent to the watercourse have the potential to increase fine sediment delivery to the channel which can alter the type and structure of the bed substrate.

The activities identified in Table 4 could lead to the impacts outlined in this section on the fluvial receptors in Section 5.1.1 – 5.1.4. Table 4 also identities the scale of impacts in relation to overall watercourse length which for all receptors minimal. Additionally, all impacts would be temporary over the construction period. Potential impacts may also occur for a period after the works as the channel adjusts and redistributes sediment in order to reach equilibrium.

5.1.1.1 River Carron

Given the scale of the works in relation to the overall water body length (Table 4), the need for working in-water in only one location, and the temporary and localised nature of the anticipated impacts, the magnitude of impact is reported as **Negligible.**

5.1.1.2 Chapel Burn, Mungal Burn and Minor Tributary – Stirling Road

Given the scale of the works in relation to the overall water body length (Table 4), impacts are considered localised. Therefore, the magnitude of impact is reported as **Minor Adverse**.

5.1.1.3 Grange Burn / Westquarter Burn

The need for working in-water in multiple locations on the West Quarter Burn and Grange Burn (Table 4) presents a risk to the structure and substrate of the channel bed over a longer length of watercourse and impacts would be at the reach scale. Therefore, the magnitude of impact is reported as **Moderate Adverse**.

5.1.1.4 Polmont Burn

There would be no requirement for in-water works on Polmont Burn. However temporary impacts and changes to the structure and substrate of the channel bed could still occur as a result of runoff from near channel works. Therefore, the impact is reported as **Minor Adverse.**

5.1.1.5 Grange Burn FRC

In-channel working would be required along the full length of the Grange Burn FRC. Impacts would be temporary (confined to 200 m sections as works progress) and taking place within a man-made channel which contains limited morphological receptors. The magnitude of impact is therefore reported as **Negligible**.

5.1.1.6 Millhall Burn

The need for working in (over a 140m reach) and adjacent to the channel (500 m reach) increases the potential to change bed sediment and its structure as a result of plant and machinery working in channel and construction runoff from the works area adjacent to the channel margins. Therefore, the magnitude of impact is reported as **Moderate Adverse**.

5.1.1.7 River Avon

Temporary in-water working would not be required the River Avon. The works are set back from the channel margins. Therefore, the magnitude of impact is reported as **Negligible**.

5.1.2 Change to Bank Form and Riparian Zone

The activities listed in Table 4 have the potential to destabilise and change the form of the banks from their current state. Construction activities such as piling result in ground vibration and loading of the bank top, which can loosen sub-surface material and destabilise the banks, resulting in modification and removal of material, and damage to the natural bank face. Vegetation clearance exposes the banks to subaerial weathering, as it reduces the surface cover, removes roots, and loosens sediment, increasing bank vulnerability to erosion. Working along the bank top to construct can also lead to deterioration of the natural bank due to plant and machinery tracking. The construction of new bridges also has the potential to remove or disturb bank material and remove / alter riparian structure due to the presence of bridge abutments. Such impacts would be temporary over the construction period and localised to the works area.

5.1.2.1 River Carron

Approximately 200 m of riparian vegetation and bank disturbance is anticipated over a total water body length of 36 km. The impacts would be temporary and are deemed to be highly localised at the waterbody scale. The magnitude of impact is reported as **Negligible**.

5.1.2.2 Chapel Burn, Mungal Burn and Minor Tributary – Stirling Road

Approximately 360 m, 50 m and 80 m of bank and riparian disturbance would occur on Chapel Burn, Mungal Burn and Minor Tributary – Stirling Road. Given the length of the listed watercourses (Table 4), all disturbance is considered localised. Therefore, the magnitude of impact is reported as **Minor Adverse**.

5.1.2.3 Grange Burn / Westquarter Burn

On Grange Burn there would be a need for approximately 50 m of in-water works (Table 4) from an in-water working platform. Additional in-water works on Westquarter Burn include 45 m downstream of the A9 where in-water works would be undertaken from the bankside, and 55 m of in-water works from a working platform upstream of the Grandsable Road. Given the requirement for in-water working platforms to be created, and additional in-water works from the bank, and the short distances between the works areas, the magnitude of impact is reported as **Moderate Adverse.**

5.1.2.4 Polmont Burn

On Polmont Burn, there is no requirement for in-water working. However, the requirement for near channel working to form the setback defences still presents a risk to the stability of the bank and for the removal of riparian vegetation over the works footprint. Given the scale of works in relation to the overall waterbody scale, the magnitude of impact is reported as **Minor Adverse**.

5.1.2.5 Grange Burn FRC

The bank profile and structure on Grange Burn FRC is formed from artificial embankments. Due to the need for in-water and bank top working over the full length of the channel there is potential for alteration to the existing bank and riparian structure. Impacts would be temporary and localised and given the artificial nature of the bank and riparian structure under baseline conditions, the magnitude of impact is reported as **Negligible**.

5.1.2.6 Millhall Burn

Given the scale of works and the need to undertake construction on approximately 500 m of bank, and the formation of in-water working platforms over approximately 140 m of channel, including the construction of a new bridge structure, the potential exists for impacts at the reach scale. Therefore, the magnitude of impact is reported as **Moderate Adverse**.

5.1.2.7 River Avon

On the River Avon, no change to bank form or riparian zone is anticipated as all flood walls and embankments would be set back from the watercourse in an area of land already dominated by managed agriculture. No new crossing structures are proposed along this section of the watercourse. Therefore, the magnitude of impact is reported as **Negligible**.

5.1.3 Change to Channel Width and Depth Variation, Water Flows, Levels and Sediment Transport

During the construction phase, dry in-water working areas will be required to facilitate the construction of flood walls, embankments. It is anticipated that these working areas will be created as described in Section 5.1.1 raised working platforms. This will have the effect of narrowing the channel, reducing cross-sectional area, leading to potential changes in flow velocities and the capacity of the channel to convey flow downstream. This has the potential to impact sediment dynamics locally and downstream of the in-water working areas.

At this stage only estimated widths of the in-water areas are currently known. The height of in-water working areas, the flow events at which they will remain dry (i.e., not be overtopped), and methods proposed to establish them are not currently confirmed. Therefore, modelling data of any temporary changes to flow velocity and channel capacity are not available. As a conservative approach, it is assumed the cofferdams and / or gravel filled bulk bags would span 50 % of the watercourse width on smaller watercourses (up to 10 m wide), and 25 % of the watercourse width on the larger channels (greater than 10 m wide). Works would be completed from one bank side and then the working platform removed and installed along the opposite bank to complete any works required. Table 5 presents the indicative channel width reductions for each in-water working area.

Table 5: Estimated channel width reduction due to in-water working areas during construction.

Water Feature (fluvial sections only)	Ref	In-water working type	Indicative Length (m)	Approx. River Width (m)	Indicative in water working width (m)	Indicative Width Reduction
River Carron	C1_IWWA 1	Construction plant positioned on a temporary work platform in the water environment.	6.0	20	N/A work from bankside	
Chapel Burn	C1_IWWA 6	Construction plant positioned on the bank, with its bucket/arm reaching into the water.	360	5.0	N/A work from bankside	
Mungal Burn	C1-IWWA 3	Construction plant positioned on a temporary work platform in the water environment.	25	4.0	2	50%

Water Feature (fluvial sections only)	Ref	In-water working type	Indicative Length (m)	Approx. River Width (m)	Indicative in water working width (m)	Indicative Width Reduction
Minor Tributary – Stirling Road	C1-IWWA 2	Construction plant positioned on the bank, with its bucket/arm reaching into the water.	95	4.0	N/A work from bankside	
Westquarter Burn	C4-IWWA 22	Construction plant positioned on the bank, with its bucket/arm reaching into the water.	55	5.0	N/A work from bankside	
	C4-IWWA 23	Construction plant positioned on a temporary work platform in the water environment.	45	7.0	3.5	50%
Polmont Burn	No in-water working required					
Grange Burn Flood Relief Channel	C4-IWW 24	Construction plant positioned on a temporary work platform in the water environment.	200m sections over full channel length (Approx 2 km)	6.0	3.0	50%
Grange Burn	C4-IWW 24	Construction plant positioned on a temporary work platform in the water environment.	50	6.0	3.0	50%
Millhall Burn	C4-IWWA 25	Construction plant positioned on a temporary work platform in the water environment.	140	4.0	2.0	50%
River Avon	No in-water working required within fluvial reaches.					
The required width for in-water working at this stage is unknown. As a conservative approach it is assumed the cofferdams and / or geotextile bulk bags would span 50 % of the watercourse width where the total watercourse width is <10 m, and 25 % of the watercourse width on channels >10 m.						

Where flood walls are to be constructed, the assumed in-channel working width remains as described above. This is based on experience from projects of a similar nature and is considered a conservative estimate. The above limitations will be explored further at the detailed design stage and through the production of the chosen contractor(s) construction method statements.

5.1.3.1 River Carron

There would be a requirement for one in-water working platform on the River Carron at the confluence with the Minor Tributary – Stirling Road resulting in a temporary and localised reduction in channel cross sectional area width over a length of approximately 8 m. Given that the works are split between the confluence of the Carron and Minor Tributary Stirling Road, they are not anticipated to extended over a large cross-sectional area of the Carron, with the majority of the works confined to the smaller Stirling Road tributary. Additionally, given the localised and temporary nature of the works in relation to the scale of the Carron, the magnitude of impact is reported as **Negligible**.

5.1.3.2 Chapel Burn

Works on Chapel Burn to construct the proposed flood defences would take place from the bankside/top, and no working platforms are required. Although no working platforms are required there is still potential for changes to channel width as a result of impacts to working from the channel bankside and bank top. Therefore, the magnitude of impact is reported as **Minor Adverse.**

5.1.3.3 Mungal Burn and Minor Tributary – Stirling Road

There would be a temporary and localised reduction in-water width of 50% for approximately 25 m, and 95 m on Mungal Burn and Minor Tributary – Stirling Road (Table 5). Given the temporary and localised nature of the potential impacts compared to the overall watercourse scales (Table 5), the magnitude of effect is reported as **Minor Adverse** for the listed watercourses.

5.1.3.4 Grange Burn / Westquarter Burn

There would be a temporary and localised reduction in-water width of 50% for approximately 50 m and, 100 m on Grange Burn, and Westquarter Burn (Table 5). Given the scale of the works in relation to the overall watercourse scales and the need for working over a significant length and within multiple sections of the watercourses, the magnitude of impact is reported as **Moderate Adverse** for the listed watercourses.

5.1.3.5 Polmont Burn

Works on Polmont Burn to construct the proposed flood defences would take place from the bankside/top, and no working platforms are required. Although no working platforms are required there is still potential for changes to channel width as a result of impacts to working from the channel bankside and bank top. Therefore, the magnitude of impact is reported as **Minor Adverse.**

5.1.3.6 Grange Burn FRC

The Grange Burn FRC will be temporarily diverted / dewatered in 200 m sections to create a dry working area to facilitate construction of the Scheme and re-lining of the channel. The channel has limited sediment transport capacity under baseline conditions and any impacts during construction would be temporary and localised to 200 m sections. Therefore, the magnitude of impact is reported as **Negligible**.

5.1.3.7 Millhall Burn

The indicative widths of Millhall Burn would be reduced by 50% over a length of approximately 140 m as a result of in-water works from a temporary working platform (Table 5). The impacts would be temporary and localised to working areas on Millhall Burn. Given the need for working over a significant length and within multiple sections of the watercourse, the magnitude of impact is reported as **Moderate Adverse**.

5.1.3.8 River Avon

No in-water works would be required within the River Avon. Additionally works would be set back from the channel Therefore the magnitude of impact is reported as **Negligible**.

5.1.4 Summary of Construction Impacts

A summary of the potential impacts and associated magnitudes for the fluvial sections of the identified receptors is provided in Table 6.

Table 6: Summary of pre-mitigation impacts to fluvial geomorphology during construction.

Receptor	Description	Importance	Magnitude	Significance of effect
River Carron	Change to structure and substrate of bed	High	Negligible	Slight
	Change to bank form and riparian zone			
	Change to continuity of sediment transport and channel width and depth variations			
Tributaries of River Carron: Chapel Burn Mungal Burn Minor Tributary – Stirling Road	Change to structure and substrate of bed	Medium	Minor Adverse	Slight
	Change to bank form and riparian zone			
	Change to continuity of sediment transport and channel width and depth variations			
River Avon	Change to structure and substrate of bed	Very High	Negligible	Slight
	Change to bank form and riparian zone			
	Change to continuity of sediment transport and channel width and depth variations			
Grange Burn / Westquarter Burn	Change to structure and substrate of bed	High	Moderate Adverse	Moderate
	Change to bank form and riparian zone:			
	Change to continuity of sediment transport and channel width and depth variations			
Polmont Burn	Change to structure and substrate of bed	Medium	Minor Adverse	Slight
	Change to bank form and riparian zone		Minor Adverse	Slight
	Change to continuity of sediment transport and channel width and depth variations		Minor Adverse	Slight

Grange Burn FRC	Change to structure and substrate of bed Change to bank form and riparian zone Change to continuity of sediment transport	Low	Minor Adverse	Slight
Millhall Burn	Change to structure and substrate of bed Change to bank form and riparian zone Change to continuity of sediment transport and channel width and depth variations	Medium	Moderate Adverse	Moderate

5.2 Operational Phase

This section considers the potential effects of permanent structures on fluvial receptors during operation of the Scheme and potential impacts which will occur following the completion of the Scheme. Operational activities are summarised in Table 7 with descriptions provided in Section 5.2.1 – 5.2.4.

Table 7: Proposed operational activities.

Baseline Waterbody	Flood Cell	Operational Phase	Waterbody Length (km)
River Carron	1	• Operation of approximately 200 m of concrete formed sheet piled wall adjacent to the River Carron alongside Stirling Road. • Setback earth embankment adjacent to Park Road.	36.0
Tributary of the River Carron: Chapel Burn	1	• 360 m (total) of new of concrete formed sheet pilled brick clad wall (Approx 180 m) along each of the right and left banks.	6.7
Tributary of the River Carron: Mungal Burn	1	• New extended 30 m culvert. • Set back embankment over extended culvert.	5.1
Tributary of the River Carron: Minor Tributary - Stirling	1	• 175 m of new sheet piled concrete formed walls on left and right banks.	4.1
Grange Burn / Westquarter Burn	4	• **On Grange Burn:** widened flow control structure between Grange Burn and the FRC immediately downstream of the M9 and Beancross Road culvert. • **On Grange Burn:** new flow control structure downstream of the widened weir between Grange Burn and the FRC. • **On Westquarter Burn**: A total of 150m of of concrete formed sheet piled wall encroaching on channel banks. 45m downstream of the A9 road and 115 m upstream of Grandsable Road.	14 (Inclusive of Westquarter Burn)
Polmont Burn	4	• **On Polmont Burn**: 280 m of set-back sheet piled, concrete formed flood wall.	8.0

Baseline Waterbody	Flood Cell	Operational Phase	Waterbody Length (km)
River Avon	5	• No impacts anticipated. All operational structures are set back from the channel	
Grange Burn FRC	4	• New flow control structure. • Re-lined channel. • New raised bridge structure.	2.0
Tributary of River Avon: Millhall Burn	4	• Approximately 650 (total) m of new of concrete formed sheet piled flood defence walls on a combination of the right and left banks. One new raised bridge structure;	8.5

5.2.1 Change to Structure and Substrate of Bed

The permanent loss of natural bed will occur below the footprint of flood walls and new culverts. This will lead to a reduction in the natural variability of the channel, with the potential to alter flow velocities related to new structures. Alteration of flow dynamics has the potential to effect sediment dynamics and thus bed structure and substrate. Potential impacts related to changes in flow velocities are discussed in Section 5.2.4. Additionally, loss and change to natural bed substrate would occur over extended culvert lengths and for a short distance downstream.

5.2.1.1 River Carron

Given the localised nature of the sheet piled flood defences (Table 7) relative to the overall watercourse length (36 km) the magnitude of impact is reported as **Negligible**.

5.2.1.2 Tributary of River Carron - Chapel Burn

The sheet piled defences in this location would be set back from the bank top adjacent to Stirling Road and would not extend out into the watercourse and are unlikely to directly interact with the watercourse bed during operation. Therefore the magnitude of impact is reported as **Negligible**.

5.2.1.3 Tributary of River Carron - Mungal Burn

There would be loss of natural bed material under the footprint of the extended culvert. This loss of material would be permanent and accompanied by potential changes to bed structure downstream of the culvert due to modified flow velocities discharged from the culvert outlet. This would occur (over approximately 25 m) relative to the overall watercourse length (5.2 km). Additionally, the existing culvert in this location is approximately 800m in length, therefore a significant proportion of this reach is already culverted under baseline conditions and, the magnitude of impact is reported as **Minor Adverse**.

5.2.1.4 Tributary of River Carron – Minor Tributary – Stirling Road

The proposed sheet piled defences are situated along an already laterally confined section of the watercourse. The defences would not extend out into the watercourse and are therefore unlikely to directly interact with the watercourse bed during operation. Given the limited interaction between the new defences and the channel bed the magnitude of impact is reported as **Negligible**.

5.2.1.5 Grange Burn / Westquarter Burn

The provision of in-channel structures including the modified and new flow control structures on Grange Burn would remove and / or modify the natural bed material below the footprint of the features. The exact dimensions of the flow control structures would be determined during detail design thus the exact area of bed material removal / modification required is unknown at this stage. However, the footprint of the weir is anticipated to be less than 1 m^2. To account for uncertainties in the bed modifications required around the structure, a conservative value of 35 m^2 has been assumed. This is considered localised in comparison to the watercourse length (14 km) additionally, the operational impacts relating to the flow control structure would occur on a section of watercourse that is already modified in relation to the existing flow control feature and M9 culvert.

Given the above, the magnitude of impact is reported as **Minor Adverse** for Grange Burn and Westquarter Burn.

5.2.1.6 Polmont Burn

The sheet piled defences are situated along an already laterally confined section watercourse. The defences would not extend out into the watercourse and are therefore unlikely to directly interact with the watercourse bed during operation. Therefore, the magnitude of impact is reported as **Negligible**.

5.2.1.7 Grange Burn FRC

The Grange Burn FRC bed would be re-lined in concrete and would interface with the channel as it does under baseline conditions. There is a lack of natural bed material within the channel under baseline conditions and this is not anticipated to change as a result of the Scheme. Therefore, the magnitude of impact is therefore reported as **Negligible**.

5.2.1.8 Millhall Burn

The sheet piled defences are situated along an already laterally confined section of the watercourse. The defences would not extend out into the watercourse and are therefore unlikely to directly interact with the watercourse bed during operation. Given the above, the magnitude of impact is reported as **Negligible**.

5.2.1.9 River Avon

All flood walls would be set back from the banks of the River Avon. Therefore, no change to watercourse bed relative to baseline conditions is anticipated. The magnitude of impact is therefore reported as **Negligible.**

5.2.2 Change to Bank Form and Riparian Zone

The permanent loss of natural bank form will occur below the footprint of flood walls which sit on the bank-tops. Riparian vegetation removed during construction to facilitate temporary access is currently expected to recover during the operational phase for all areas of the works.

The design of new and raised bridges is currently unknown. Given the relatively small width of the watercourses that the proposed new and raised bridges structures would operate on, it is assumed that the bridges would be clear span, with abutments set back within the floodplain. It is assumed bridges would be set above the design flood event to allow conveyance of flow below the structure in such events.

5.2.2.1 River Carron

The new sheet piled walls within Flood Cell 1 would operate on a section of the River Carron that is already laterally constrained along the right bank by Stirling Road and adjacent properties. Given the limited amount of loss of natural bank and riparian zone in relation to the water body length, the magnitude of impact is reported as **Negligible**.

5.2.2.2 Tributary of River Carron - Chapel Burn

New sheet piled walls would encroach on approximately 175 m of right and left bank riparian vegetation. Given limited amount of loss in relation to the water body length, impacts are deemed to be at a local scale. Therefore, the magnitude of impact is reported as **Minor Adverse**.

5.2.2.3 Tributary of River Carron - Mungal Burn

There would be permanent loss of natural bank material over the footprint of the 25 m extension to the existing culvert. Given the localised scale of the impact with respect to the overall watercourse length, impacts would be localised. Therefore, the magnitude of impact is reported as **Minor Adverse**.

5.2.2.4 Tributary of River Carron – Minor Tributary – Stirling Road

New sheet piled flood defences would operate on an already laterally constrained reach of the watercourse, upstream of the Stirling Road culvert. Defences would be set back from the channel margin. Impacts are anticipated to be at the local scale relative to the overall watercourse length on an already modified reach of watercourse. Therefore, the magnitude of impact is reported as **Negligible**.

5.2.2.5 Grange Burn / Westquarter Burn

New sheet piled walls would encroach on approximately 150 m of right bank that is already laterally constrained under baseline conditions. Given the scale of the potential loss in relation to the overall water body length, impacts at are anticipated to be localised. Therefore, the magnitude of impact is reported as **Minor Adverse**.

5.2.2.6 Polmont Burn

New sheet piled flood defences would be set back from the existing watercourse and would operate on an already laterally constrained right bank. The new defences would consist of approximately 300 m of formed concrete wall. This length is considered localised at the waterbody scale (the water body is 8 km in length) and the magnitude of impact is reported as **Minor Adverse**.

5.2.2.7 Millhall Burn

Approximately 650 m of formed concrete walls would operate on an already laterally constrained reach of the Millhall Burn. Additionally, there would be 1 clear span bridge. Loss of riparian vegetation would occur within the bridge and over the wall footprints. This loss is considered localised at the water body scale (the water body is >8 km long) and the magnitude of impact is reported as **Minor Adverse**.

5.2.2.8 River Avon

All flood walls would be set back from the banks of the River Avon therefore no change to baseline conditions of the watercourse bed and banks are anticipated. The magnitude of impact is therefore reported as **Negligible**.

5.2.3 Change to Channel Width and Depth Variation, Water Levels and Flows

During the operation phase, the presence of flood walls and embankments will contain flows up to the 200-year flood event. This would reduce the channel cross-section where new flood walls / embankments are proposed and lead to increased flow velocity and river discharges. Where watercourses are permitted to spill into their floodplain to a greater depth and extent, decreases in velocity and discharge volume are likely. This has the potential to impact channel form, including, channel width, depth and the water levels and flows within the channels. This could subsequently alter sediment transport, erosion, and deposition within the watercourses. Changes to velocity and discharge during a design event, in comparison to the baseline scenario, are presented in Table 8. However, while changes to watercourses will be long-term through the implementation of permanent structures, impacts will be short-term, limited to during more severe flood events.

The biggest impacts to velocity and flow will be on Grange Burn FRC, an artificial channel designed to convey additional flows from Grange Burn to the River Avon during flood events. The FRC will experience an average change to velocity of +95.20 % and increase in discharge of +99.5 %. Although the flows and discharge increase, these increases will still be temporary, and the channel is engineered such that it is fixed by embankments and therefore cannot easily vary its width and depths in response to increased velocities. The Scheme would not change this. Therefore, the magnitude of impact is reported as **Negligible**.

All other watercourses will experience up to a maximum average change to velocity of +0.94 % and discharge of -11.72 %. Therefore, given the temporary nature of the impact, the magnitude of impact for the River Carron, Chapel Burn, Mungal Burn, Grange Burn / Westquarter Burn, Polmont Burn, Millhall Burn, Stirling Road Tributary and the River Avon are reported as **Negligible**.

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Table 8: Change in velocity and discharge volume between the baseline and with Scheme scenarios.

Water Feature	Design Flood Event	Baseline velocity range (m/s)	Velocity range with-scheme (m/s)	Max. Decrease* (%)	Max. Increase* (%)	Average % change	Baseline discharge range (m^3/s)	Discharge with-scheme	Max Decrease (%)	Max Increase (%)	Average % change (%)
Westquarter Burn	0.5% AEP (200-year) Fluvial	1.40 – 4.90	1.40 – 4.90	-13.00	+44.20	+2.20	12.7 - 34.10	12.7 - 34.1	-37.5	+84.9	+23.4
Polmont Burn	0.5% AEP (200-year) Fluvial	1.4 - 2.90	1.30 - 2.90	-20.60	+6.60	-3.90	6.30 - 11.10	6.30 -13.60	-0.80	+30.30	+5.70
Grange Burn	0.5% AEP (200-year) Fluvial and Tidal	0.40 – 2.40	0.40 - 2.80	-40.10	+19.00	-1.90	1.80 – 89.80	1.60 – 89.10	-29.70	+47.10	+11.00
Grange Burn Flood Relief Channel	0.5% AEP (200-year) Fluvial	1.00 – 4.10	1.10 – 11.60	+4.70	+345.60	+95.20	8.80 - 15.70	11.10 – 38.70	+26.70	+150.40	+99.50
River Carron*	0.5% AEP (200-year) Fluvial and Tidal	0.80 – 3.40	0.80 - 3.50	-5.40	+1.60	0.20	132.70 - 377.70	132.60 – 361.90	-4.30	+3.00	+0.40
Minor Tributary – Stirling Road **	0.5% AEP (200-year) Fluvial	0.36 – 2.00	0.32 – 2.00	-48.40	+0.94	-2.48	3.90 – 23.00	2.62 – 6.32	-76.62	+38.14	-11.72
River Avon*	0.5% AEP (200-year) Fluvial and Tidal	0.90 – 3.20	0.70 – 3.10	-35.00	+42.6	-4.20	85.00 – 271.80	78.90 – 312.80	-44.70	+94.30	-1.70

*Max increase / decrease denotes the maximum increase or decrease in velocity or discharge volume at a single point as calculated by the hydraulic modelling performed to inform the Scheme design.

** Due to the dominant backwater effect of the Carron during the 200-year event, peak discharge at the confluence of Stirling Road Tributary is reduced compared to baseline conditions

5.2.4 Change to Continuity of Sediment Transport and Floodplain Connectivity.

As outlined in Section 5.2.3, proposed floodwalls and erosion protection will narrow the existing channels on which they occur. The degree of narrowing will dictate velocity changes within the channel, and where these occur there is a potential for changes to baseline sediment transport, erosion and deposition during flood events.

As outlined in Section 3.2.1 and where available, modelled velocities for various cross sections along the fluvial channels have been extracted from the hydraulic model and are presented in Annex A. Results from Hjülstrom analysis between baseline and with Scheme flow velocities is presented in Table 9.

Jacobs

Table 9: Baseline and with Scheme flow velocities and sediment transport

Waterbody	Baseline flow event	Erosion and Transport (mm)	Transport as bed load (mm)	Deposition (mm)	With Scheme flow event	Erosion and Transport (mm)	Transport as bed load (mm)	Deposition (mm)
River Carron (Bonny Water confluence to Carron Estuary)	50% AEP (2-year)	Up to 20.0	20.0 – 400.0	>400.0	50% AEP (2-year)	Up to 20.0	>20 – 400.0	>400
	0.5% AEP (200-year)	Up to 60.0	>60.0	N/A	0.5% AEP (200-year)	Up to 60.0	>60.0	N/A
Grange Burn	50% AEP (2-year)	Up to 8.0	8.0 - 100.0	>100	50% AEP (2-year)	Up to 6.0	6.0-80.0	>80.0
	0.5% AEP (200-year)	Up to 11.0	9.0-150.0	>150.0	0.5% AEP (200-year)	Up to 9.0	9.0 –150.0	>150.0
Westquarter Burn	50% AEP (2-year)	Up to 16.0	16.0-300.0	>300.0	50% AEP (2-year)	Up to 16.0	16.0 – 300.0	>300.0
	0.5% AEP (200-year)	Up to 30.0	>30.0	N/A	0.5% AEP (200-year)	Up to 25.0	>25.0	N/A
Polmont Burn	50% AEP (2-year)	Up to 25.0	>25.0	N/A	50% AEP (2-year)	Up to 20.0	>20.0	N/A
	0.5% AEP (200-year)	Up to 35.0	>35.0	N/A	0.5% AEP (200-year)	Up to 40.0	>40.0	N/A
River Avon (Logie Water confluence to estuary)	50% AEP (2-year)	Up to 20.0	>20.0	N/A	50% AEP (2-year)	Up to 20.0	>20.0	N/A
	0.5% AEP (200-year)	Up to 40.0	>40.0	N/A	0.5% AEP (200-year)	Up to 40.0	>40.0	N/A
Grange Burn FRC	50% AEP (2-year)	Up to 35.0	>35.0	N/A	50% AEP (2-year)	Up to 40.0	>40.0	N/A
	0.5% AEP (200-year)	Up to 55.0	>55.0	N/A	0.5% AEP (200-year)	Up to 800.0	>800.0	N/A
Millhall Burn	50% AEP (2-year)	Up to 42.0	>42.0	N/A	50% AEP (2-year)	Up to 30.0	>30.0	N/A
	0.5% AEP (200-year)	Up to 40.0	>42.0	N/A	0.5% AEP (200-year)	Up to 30.0	>30.0	N/A
Stirling Road Tributary	50% AEP (2-year)	Up to 10.0	10.0 – 200.0	>200.0	50% AEP (2-year)	Up to 10.0	10.0-150.0	>150.0
	0.5% AEP (200-year)	Up to 20.0	>20.0	N/A	0.5% AEP (200-year)	Up to 5.0	>5.0 - 70.0	> 70.0

5.2.4.1 River Carron

For the River Carron, comparison of the baseline and with Scheme velocities for 2-year flow indicate no change to velocities as a result of the Scheme. For the 200-year flows, there is an increase in maximum flow velocities of approximately 32 %. This does not lead to any changes in the size of sediment transported between baseline and with Scheme for the 2-year and 200-year events. Therefore, the impact is reported as **Negligible**.

5.2.4.2 Grange Burn

For Grange Burn at 2-year flow conditions there would be an decrease of approximately 13% in maximum flow velocities between baseline and with Scheme conditions. Hjülstrom analysis indicates that this change would be reflected in the size of sediment entrained, which would be a change from 8 mm under baseline flows to 6 mm under with Scheme flows.

At 200-year flow conditions, there would be a decrease of approximately 0.56% in maximum flow velocities between baseline and with Scheme conditions. The decrease in flow is attributed to the new flow control structure on Grange Burn which would limit the amount of a water flowing downstream, this will have a slight impact on the velocity of flow also.

Velocity decreases would not be significant enough to alter the overall erosion and transport. Additionally, the new flow control structure would allow flows up to the 2-year event to pass through Grange Burn unmodified. Therefore, no change to baseline conditions downstream of the flow control structure during the 2-year or 200-year events in relation to sediment dynamics is anticipated.

Although the new flow control structure would remove a substantial volume of flow within a 200-year event, there is still anticipated to be a marginal (0.56%) decrease in flow velocities on Grange Burn. Therefore, the impact is reported as **Negligible**.

5.2.4.3 Westquarter Burn

Westquarter Burn 2-year maximum flow conditions would decrease approximately 1.3% between baseline and with Scheme conditions. Hjülstrom analysis indicates that there would be no change in the size of material transported as a result of such a small decrease in velocity.

At 200-year flow conditions, there would be a decrease in velocity of 8% between 200-year baseline and 200-with Scheme conditions as the water upstream of the defence is allowed to spill on to floodplain upstream of Grandsable Road. This reduction in velocity is not reflected by a reduction or increase in the size of clasts transported during a 200-year event. Therefore, the magnitude of impact is reported as **Negligible**.

5.2.4.4 Polmont Burn

There would be very little change to 2-year flow velocities for Polmont Burn between baseline and with Scheme flows and therefore no change to sediment dynamics under such flows.

There would be a decrease in maximum flow velocity of 4% between 200-year baseline and 200-with Scheme conditions. This decrease in velocity is reflected by a decrease in the size of clasts transported (up to 5 mm smaller compared to baseline conditions). However, transport and erosion would remain the dominant processes. Therefore, the impact is reported as **Negligible**.

5.2.4.5 Grange Burn FRC

At 2-year flow conditions there would be a decrease increase of approximately 6% in maximum flow velocities between baseline and with Scheme conditions. At 200-year events max flow velocity would increase by 245%. This is to be expected given that the channel’s purpose is to convey flood flows during high magnitude events. Given the lack of coarse sediment supply under baseline conditions, changes to velocities would not impact sediment dynamics. Therefore, the magnitude of impact is reported as **Negligible**.

5.2.4.6 Millhall Burn

At 2-year and 200-year flow conditions there would be a no change in maximum flow velocities between baseline and with Scheme conditions (Table 10) and therefore the magnitude of impact is reported as **Negligible**.

5.2.4.7 River Avon

For the River Avon there is no change to velocities under the 2-year event. During the 200-year event maximum flow velocity would decrease by approximately 3.2% between 200-year baseline and with Scheme conditions. This is not significant enough to adversely impact sediment dynamics and therefore the magnitude of impact is reported as **Negligible**.

5.2.4.8 Tributary of River Carron – Minor Tributary – Stirling Road

Outputs from the hydraulic model indicate that at 2-year flows there is no change in peak flow velocity as a result of the Scheme. Therefore, no impacts on sediment transport are anticipated during such flows.

During larger flow events (i.e., 200-year events), peak velocities at and immediately upstream of the existing culvert below Stirling Road are influenced by the flows within the River Carron. Due to the volume of water contained within the River Carron at such events, peak velocities within the Stirling Road tributary are slower due to the backwater effect created, this would decrease by 48% as a result of the Scheme. As the water level of the Carron upstream of the confluence rises due water within the Stirling Road Tributary backs up and slows down.

The reduction in peak velocities is represented by a decrease in size of clasts transported during a 200-year event. Huljstrom analysis indicates that a reduction of 15 mm in the size of clasts eroded and transported. Additionally, there would be a 40 mm reduction in the size of clasts transported as bed load with clasts >70 mm being deposited. The changes outlined above would only occur during 200-year events but would likely occur to a lesser (proportional) degree during smaller events. Impacts would be temporary as the discharge within the Carron recedes. Therefore, the impact is reported as **Minor Adverse**.

5.2.4.9 Chapel Burn

As identified in Section 3.2.1 no modelled peak velocity data are available for Chapel Burn. However, given the presence of flood walls along the banks of the watercourse it is anticipated that velocities would increase due to a reduction in channel cross-section during higher flow events. As described for Stirling Road above, near the confluence with the River Carron, there may be a back water effect during higher flow regimes, which may slow peak velocities within Chapel Burn. This would be a localised temporary impact as the discharge within the Carron recedes.

The length of the channel banks where the proposed defences are situated already laterally constrained by existing infrastructure including residential properties and the local road network. Therefore, there is unlikely to be significant changes to with Scheme velocities and therefore sediment transport. The magnitude of impact is reported as **Minor Adverse**.

5.2.4.10 Mungal Burn

As identified in Section 3.2.1 no modelled peak velocity data are available for Mungal Burn. The existing culvert on Mungal Burn would be extended downstream to accommodate the proposed defence alignment. The watercourse is culverted for approximately 800 m under baseline conditions below residential areas of west Grangemouth. It is therefore unlikely that sediment transport is occurring over such a long, culverted length. Therefore, the addition of approximately 30 m of culvert at the downstream end is unlikely to have a significant impact on sediment transport and the magnitude of impact is reported as **Negligible**.

5.2.5 Summary of Operational Impacts

A summary of the potential operational impacts and associated magnitudes for the fluvial sections of the identified receptors is provided in Table 10.

Table 10: Summary of pre-mitigation impacts to fluvial geomorphology during operation

Receptor	Description	Importance	Magnitude	Significance of effect
River Carron	Change to structure and substrate of bed	High	Negligible	Slight
	Change to bank form and riparian zone			
	Change in width and depth variation and water flow and levels			
	Change to continuity of sediment transport			
Tributary of River Carron: Chapel Burn	Change to structure and substrate of bed	Medium	Negligible	Neutral
	Change to bank form and riparian zone		Minor Adverse	Slight
	Change in width and depth variation and water flow and levels		Negligible	Neutral
	Change to continuity of sediment transport		Minor Adverse	Slight
Tributary of River Carron: Mungal Burn	Change to structure and substrate of bed	Medium	Minor Adverse	Slight
	Change to bank form and riparian zone			
	Change in width and depth variation and water flow and levels			
	Change to continuity of sediment transport		Negligible	Neutral
Tributary of River Carron: Minor Tributary – Stirling Road	Change to structure and substrate of bed	Medium	Negligible	Neutral
	Change to bank form and riparian zone			
	Change in width and depth variation and water flow and levels			
	Change to continuity of sediment transport		Minor Adverse	Slight
Grange Burn / Westquarter Burn	Change to structure and substrate of bed	High	Minor Adverse	Moderate
	Change to bank form and riparian zone			
	Change in width and depth variation and water flow and levels		Negligible	Slight
	Change to continuity of sediment transport			
Polmont Burn	Change to structure and substrate of bed	Medium	Negligible	Neutral
	Change to bank form and riparian zone		Minor Adverse	Slight
	Change in width and depth variation and water flow and levels		Negligible	Neutral
	Change to continuity of sediment transport			
Grange Burn FRC	Change to structure and substrate of bed	Low	Negligible	Neutral
	Change to bank form and riparian zone			
	Change in width and depth variation and water flow and levels			
	Change to continuity of sediment transport			
Millhall Burn	Change to structure and substrate of bed	Medium	Negligible	Neutral
	Change to bank form and riparian zone		Minor Adverse	Slight
	Change in width and depth variation and water flow and levels		Negligible	Neutral
	Change to continuity of sediment transport			
	Change to structure and substrate of bed	Very High	Negligible	Slight

Receptor	Description	Importance	Magnitude	Significance of effect
River Avon (Logie Water confluence to estuary)	Change to bank form and riparian zone			
	Change in width and depth variation and water flow and levels			
	Change to continuity of sediment transport			

6. Mitigation

6.1 Construction Phase

6.1.1 Primary Mitigation

Primary mitigation measures are considered as modifications to the design of the Scheme intended to reduce the impacts without the requirement for additional mitigation measures. There are no primary mitigation measures to be implemented in relation to the Scheme construction methodology.

6.1.2 Secondary Mitigation

Secondary mitigation measures are elements of additional mitigation required to further reduce the impacts of the Scheme. The secondary mitigation items are presented Table 10-26, Section 10.6.1, Chapter 10 – Water Environment.

6.1.3 Tertiary Mitigation

Construction of the Scheme would include tertiary mitigation in the form of good practice undertaken by the Contractor(s) to reduce impacts to the water environment during construction. These should include:

- adherence to appropriate guidance outlined in Table 10-27 - Chapter 10 of the EIAR (**Mitigation Item W22**);
- compliance with the conditions of any Controlled Authority Regulation (CAR) Construction Site Licence authorisation (SEPA 2011) (**Mitigation Item W23**);
- consultation with SEPA on detailed construction method statements, Construction Environmental Management and Surface Water Management plans prior to commencement of works (**Mitigation Item W1**); and
- suitably qualified and experienced Environmental Clerk of Works and Geomorphological Clerk of Works shall be appointed by the Contractor(s) to oversee the implementation of mitigation and monitoring of the water environment (**Mitigation Item W2**).

6.2 Operational Phase

6.2.1 Primary Mitigation

The following primary mitigation measures are implemented in the Scheme design for operation:

- where possible, flood embankments have been chosen in preference to flood walls. Flood embankments allow for a more natural bank form and are therefore considered to have a lower impact on hydromorphology than flood walls; and
- defences have been set back as far from the banks as possible to reduce in-water working and allow maximum channel-floodplain connectivity and reduce the changes in velocity and resulting sediment transport.

6.2.2 Secondary Mitigation

Secondary mitigation measures are required to mitigate potential Moderate impacts on all fluvial waterbodies for geomorphology. Secondary mitigation items are shown in Figure B10.13 and presented Table 10-28, Section 10.6.2 in Chapter 10 – Water Environment.

Mitigation Item W26: Monitoring of the watercourses should be carried out to identify if there are any operational geomorphological issues associated with the Scheme, such as any impacts on watercourse stability (e.g., areas of excessive erosion or deposition) triggered by the Scheme. This will enable any such issues identified to be investigated and remediated as early in the operational phase as possible. It is recommended this would be carried out using fixed-point photography and comparison Repeat fixed point photography provides a means to qualitatively assess geomorphological change in-water and on the floodplain between successive surveys. Any areas where significant changes are observed may require additionally investigation, including topographical survey to further characterise change and develop potential remedial options. The monitoring plan should be agreed with SEPA in advance of construction works.

6.2.3 Tertiary Mitigation

Operation of the Scheme would include tertiary mitigation in the form of good practice with regular maintenance to reduce impacts to the water environment. These should include adherence to the following appropriate guidance **(Mitigation Items W38, W39, W40):**

- C786 Culvert, screen and outfall manual Culvert Design and Operation Guide (CIRIA, 2019);
- C720 Culvert design and operation guide supplementary technical note on understanding blockage risks (CIRIA, 2013);
- C763 River Weirs - Design, maintenance, modification, and removal (CIRA, 2016); and
- SEPA WAT-SG-44 - Riparian Vegetation Management (SEPA, 2009).

Detailed design of any permanent culverts and new bridge structures should ensure adherence to relevant design standards and good practice guidance, such as SEPA WAT-SG-25: Engineering in the Water Environment Good Practice Guide – River Crossings (SEPA, 2010), wherever practical. Designs will include, but may not be limited to:

- design will mitigate impacts on the water environment through appropriate design of culvert structures and watercourse modifications with respect to fluvial geomorphology, and both riparian and aquatic ecology;
- an experienced fluvial geomorphologist will input into the design of all watercourse crossings and associated engineering activities where appropriate;
- the design of culverts and associated watercourse modifications shall incorporate, wherever practical:
  - the channel cross section through culverts will be profiled to replicate the existing channel shape (and width) up to the predicted QMED water level where appropriate, thereby allowing for the appropriate conveyance of water and sediment for a range of flows (including during low flow conditions) and preserving existing morphological processes;
  - maintenance of the existing channel gradient through the structure to avoid erosion at the inlet and outlet of culverts;
  - avoidance of reduction of watercourse length through shortening of watercourse planform;
  - where practicable minimise culvert lengths. Align culverts as close as possible to the existing water feature;

- energy dissipation (e.g., stilling basins) and sediment retention measures where necessary;
- depressing the invert of culverts to allow for reinstatement of natural bed within the culvert; and
- roughening of culvert inverts to help reduce water velocities where required.

- bridge abutments should be set back within the floodplain as to reduce constriction of the channel through the structure;
- where possible in channel bridge elements should be avoided (i.e. in channel piers, cutwaters etc.);
- where possible the bridge deck should be set to above the design flow even such that water is not constricted causing a back water effect upstream of the bridge;
- re-planting of vegetation around culverts and bridges where required, tying in with natural vegetation, the re-planting of trees, where removed is of particular importance; and
- post-project appraisal to identify if there are issues that can be investigated and addressed as early in the operational phase as possible.

7. Residual Effects

Following effective implementation of the mitigation measures outlined in Section 6, the potential for significant impacts on surface waters would be avoided / prevented, reduced to Minor adverse significance (or below) or offset.

Potential impacts of 'Moderate adverse' significance have been identified during the construction phase for the pre-mitigation scenario on River Carron (Bonny Water confluence to Carron Estuary), Grange Burn / Westquarter Burn, Polmont Burn and Millhall Burn. These impacts are in relation to the need for temporary and localised in-water working with potential to impact the structure and substrate of the channel bed, natural bank profile and riparian zone, and temporary changes in channel width, depth, and sediment continuity. The proposed construction mitigation reduces the magnitude of impacts to 'Negligible' significance on the River Carron and 'Minor Adverse' Significance on the Grange Burn / Westquarter Burn, Polmont Burn and Millhall Burn resulting in a slight significance of impact.

Potential operational impacts of 'Moderate adverse' for the pre-mitigation scenario on the Grange Burn / Westquarter Burn. These impacts are due to changes to the structure and substrate of bed material and alterations to the bank and riparian zone as a result of permanent flood walls, with the potential for a reduction in morphological diversity of the channel. The proposed mitigation would offset upstream impacts by increasing morphological diversity through the creation of alternating berms which aid in promoting sinuosity within the confines of the existing channel. Reprofiling of the banks and removal or softening of existing bank protection within downstream sections of the watercourse will aid in reducing existing pressures on the watercourse. These would reduce the magnitude of impact to Negligible.

8. Potential enhancement opportunities

There are no specific areas identified for potential enhancement opportunities at this stage. Mitigation Item 26 (Chapter 10) will provide the opportunity for the implementation of enhancements as part of a separate programme of river restoration measures on Grange Burn / Westquarter Burn. This shall be committed to implement measures to improve the morphological diversity including measures to promote natural recovery and enhance riparian vegetation. However, Chapter 7: Biodiversity has identified areas for riparian planting to achieve positive effects for biodiversity which align with those areas identified in Mitigation Items W24, W25, W27 and W28 (Chapter 10).

The following areas along Grange Burn would be subject to riparian planting:

- Section of Grange Burn extending beyond Working Areas – NS 92685 80288 to NS 92706 80968;
- Working Area 4-5 and a section of Grange Burn extending beyond Working Areas – NS 92684 80946 to NS 92827 81371;
- Working Areas 4-5, 4-6 – NS 92827 81371 to NS 92993 81990; and
- Working Areas 4-7, 4-7, 4-9 – NS 92993 81990 to NS 94587 82541.

9. Summary

This report forms an appendix to the EIA Report for the Grangemouth FPS. The fluvial geomorphology of the catchments within the extent of the Grangemouth FPS are described along with the impacts and proposed mitigation to remove, reduce or offset potentially significant effects. The potential impact on the fluvial geomorphology is of minor adverse significance or below with the Scheme, assuming effective implementation of the mitigation items listed in Section 6.

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Annex A – Modelled 2-year and 200-year baseline and with Scheme velocities

For cross-section locations see Figure 2.

Table A- 1: Modelled baseline velocities for 2-year and 200-year flows

Water body Name	Cross Section ID	2-year max velocity (m/s)	Max velocity used in Huljstrom (cm/s)	200-year max velocity (m/s)	Velocity used in Huljstrom (cm/s)
River Carron	CARR2_9760	1.78	179.70	1.98	312.00
	CARR2_9188	1.36		1.47	
	CARR2_7598	1.77		2.98	
	CARR2_6515	1.07		3.12	
	CARR2_6241	1.54		2.76	
Grange Burn	GBXS_04	0.91	104.00	1.08	124.00
	GBXS_08u	1.04		1.24	
	GBXS_14	0.62		0.64	
Westquarter Burn	WQB_08	1.71	184.00	2.16	260.00
	WQB_02	1.84		2.00	
Polmont Burn	PBXS_10	1.42	201.00	2.32	260.00
	PBXS_08	1.50		2.60	
	PBXS_02	2.01		2.52	
Grange Burn FRC	FRCXS_03	2.51	251.00	2.98	298.00
	FRCXS_05d	2.07		2.30	
	FRCXS_08	1.71		1.79	
	FRCXS_13d	1.24		2.58	
River Avon	AXS_02	1.66	191.00	2.70	271.00
	AXS_05	1.88		2.52	
	AXS_06d	1.91		2.71	

Water body Name	Cross Section ID	2-year max velocity (m/s)	Max velocity used in Huljstrom (cm/s)	200-year max velocity (m/s)	Velocity used in Huljstrom (cm/s)
Millhall Burn	MHB8_u	0.92	256.00	0.92	256.00
	MHB5	2.56		2.56	
	MHB2	0.76		0.76	
Minor Tributary – Stirling Road	XS_43	1.13	113.00	1.91	191.00
	XS_47	0.79		0.75	

Table A- 2: Modelled with Scheme velocities for 2-year and 200-year flows.

Water body Name	Cross Section ID	2-year max velocity (m/s)	Max velocity used in Huljstrom (cm/s)	200-year max velocity (m/s)	Velocity used in Huljstrom (cm/s)
River Carron	CARR2_9760	1.79	179.00	1.97	318.00
	CARR2_9188	1.36		1.47	
	CARR2_7598	1.77		3.01	
	CARR2_6515	1.07		3.18	
	CARR2_6241	1.54		2.71	
Grange Burn	GBXS_04	0.82	90.00	1.06	124.00
	GBXS_08u	0.90		1.24	
	GBXS_14	0.60		0.62	
Westquarter Burn	WQB_08	1.69	182.00	2.00	200.00
	WQB_02	1.82		1.97	
Polmont Burn	PBXS_10	1.40	198.00	2.30	251.00
	PBXS_08	1.48		2.33	
	PBXS_02	1.98		2.51	
Grange Burn FRC	FRCXS_03	2.67	267.00	10.30	10300.00
	FRCXS_05d	2.15		8.04	
	FRCXS_08	1.73		2.52	

Water body Name	Cross Section ID	2-year max velocity (m/s)	Max velocity used in Huljstrom (cm/s)	200-year max velocity (m/s)	Velocity used in Huljstrom (cm/s)
	FRCXS_13d	0.94		2.80	
River Avon	AXS_02	1.67	191.00	2.31	280.00
	AXS_05	1.88		2.03	
	AXS_06d	1.91		2.80	
Millhall Burn	MHB8_u	2.01	201.00	2.01	201.00
	MHB5	1.50		1.50	
	MHB2	1.06		1.06	
Minor Tributary – Stirling Road	XS_43	1.13	113.00	0.98	98.00
	XS_47	0.79		0.75	

Environmental Impact Assessment Report

Appendix C10.2 Estuarine Geomorphology

Grangemouth Flood Protection Scheme 2024
Falkirk Council

GRANGEMOUTH
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Appendix C10.2 Estuarine Geomorphology

Contents

Figures

Tables

1. Introduction

This report forms an appendix to the Environmental Impact Assessment Report (EIAR) prepared to inform the Grangemouth Flood Protection Scheme (FPS) here in referred to as "the Scheme". The aim is to provide an assessment of the potential impacts and likely effects on estuarine processes as a result of the construction and operation of the FPS.

The potential for long-term changes in the estuarine geomorphology of the area was acknowledged at the scoping phase of the EIAR (Jacobs 2018) and these issues are consequently considered for estuarine environments for both the construction and operation phases in this appendix. In addition, impacts on the tidal sections of the rivers have been assessed, which include possible changes in water quality as well as loss or degradation to morphological receptors and processes.

The banks and estuarine frontage within the study area have existing defences of some form, which function as erosion control structures. Within the estuarine frontage, these defences are privately owned and are therefore considered informal defences. For this assessment, it has been assumed that, in the absence of the Scheme, the current defences will be maintained using a patch and repair approach. Assessment has been undertaken through comparison of two future scenarios:

- a baseline with the existing defences in place; and
- a with Scheme scenario.

A Water Framework Directive (WFD) compliance assessment has been undertaken and is included in Annex C10.5. It assesses the Scheme components against WFD quality elements within the relevant water bodies based on the potential estuarine impacts discussed within this Appendix and considers potential deterioration or betterment of each as a result.

Chapter 10 (Water Environment) and Chapter 2 (Legislation and Regulatory Context) provides an outline of the policy and legislative framework relevant to the Scheme and this Appendix.

2. Methodology

2.1 Baseline

The Scheme extent includes six Flood Cells (numbered 1 through 6) which form the Scheme boundary. The study area for the assessment of estuarine receptors includes the Middle Forth Estuary, which extends between Kincardine Bridge upstream and the town of Bo'ness, downstream on the southern bank of the Forth and includes the tidal reaches of the River Carron, Grange Burn and River Avon as shown in Figure 10-1, and listed below:

- the estuarine sections of River Carron, River Avon and Grange Burn, which extend between the Middle Forth Estuary to the Normal Tidal Limit (NTL);
- the estuarine frontage of the Scheme boundary within the Middle Forth Estuary; and
- the Middle Forth Estuary, which extends between Kincardine Bridge and the town of Bo'ness in the Firth of Forth. (Figure 1).

The effects on estuarine processes have been assessed for the following flood cells:

- Flood Cell 1 and 2: Transitional section of the River Carron up to the NTL (here in referred to as the Lower Carron Estuary);
- Flood Cell 3: Lower Carron Estuary and Middle Forth Estuary;
- Flood Cell 4: Transitional section of the Grange Burn from the NTL to the Middle Forth Estuary (herein referred to as Grange Burn Estuary);

- Flood Cell 5: Transitional section of the River Avon (herein referred to as the Lower Avon Estuary); and
- Flood Cell 6: Middle Forth Estuary

The baseline appraisal draws upon prior studies and modelling exercises for the estuary to inform baseline understanding of estuary dynamics. No new modelling has been undertaken for the Scheme.

Baseline surveys of the estuarine frontage were conducted between 10th and 13th May 2016 (CH2M, 2017) and supplemented by additional photographs taken between 10th and 11th April 2019. The site survey walkovers were supported with desk study analysis and have been used to establish the baseline for the study area and identify water environment receptors. An importance value was then assigned to each receptor, based on the criteria presented in Table 10-3 of Chapter 10: Water Environment.

Although waves and tides may be altered by the presence of a new structure, they largely represent 'pathways' as opposed to receptors. Alongside wind, waves and tides are the mechanisms that control local and regional patterns of sediment transport, erosion and deposition, and these, in turn, directly influence morphological change of the subtidal and intertidal areas. As such, it is typically the morphological features such as intertidal mudflats that form the key receptors. Designated estuary features are also included in the list of physical processes receptors. Importantly, the assessment of potential effects to nearby designated sites focuses upon the potential for significant modification of the naturally occurring physical processes and / or features that could indirectly impact the habitats they sustain.

2.2 Impact Assessment

2.2.1 General Assessment Methodology

Potential impacts resulting from the Scheme are identified along with the magnitude of the impact. The criteria for identifying the magnitude are presented in Table 10-4 of Chapter 10: Water Environment. The nature and characteristics of impacts have been described to enable their magnitude to be determined. The nature of the impacts has first been expressed as:

- Adverse – detrimental or negative impacts on an environmental resource or receptor;
- Beneficial – advantageous or positive impact on an environmental resource or receptor.

By considering the importance of the receptor and the magnitude of the impact, the significance of the effect on the receptors and receptor's attributes during construction and operation can be established using Table 10-6 of Chapter 10 (Water Environment).

The baseline material provides sufficient detail and understanding of estuary dynamics to inform the impact assessment. This is considered appropriate for the estuarine aspects of the EIAR for the following reasons:

- expert judgement at the start of the assessment identified that due to the small increase in defence footprint (see Section 0), changes in water levels / current speeds were likely to be negligible for the wider Firth of Forth and very small for the local area. This was confirmed when differences in tidal prisms with and without the Scheme locally and regionally were calculated; and
- previous hydrodynamic modelling undertaken for other developments within the Firth of Forth were reviewed in support of this assessment. Those were undertaken for the Forth Replacement Crossing (Jacobs and Arup, 2009a,) and Rosyth International Container Terminal (HR Wallingford, 2015; 2016).

Those effects described as 'Moderate Adverse' significance or above are significant for this assessment.

2.2.2 Habitat loss

The impact assessment for habitat loss is undertaken based on the comparison between the current estuarine baseline of the study area and potential changes due to the Scheme. Specifically, the calculations of potential habitat loss, both temporary and permanent, were established using buffers as defined by the design team (See Chapter 7 – Biodiversity for further details) and summarised in the follow points:

- temporary habitat loss during construction was calculated by subtracting the permanent works footprint from the site boundary footprint, which corresponds to the width of working areas for the Scheme. It is important to note, however, that this is likely to be less for in-channel working areas. It is assumed that temporary habitat loss within the working areas will be restored where possible; and
- permanent habitat loss due to defence footprint is calculated from the permanent works footprint.

The assessment methodology follows the source-pathway-receptor model. The receptor can only be exposed to a change if a pathway exists through which an impact can be transmitted between the source activity and the receptor.

3. Baseline

Sections 3.1 – 3.6 characterise the baseline environment of the receptors within the Flood Cells listed in Section 2.1.

3.1 Past and Current Estuarine Geomorphology

3.1.1 The Forth Estuary

3.1.1.1.1 Estuary form and evolution

The Forth Estuary is a transitional water body extending from the NTL in Stirling to immediately downstream of the Queensferry Crossing and covers an area of 8,400 ha of which around 4,800 ha is intertidal (ABPmer and HR Wallingford, 2007). As shown in Figure 1, the Forth Estuary is divided into the Upper, Middle and Lower Forth Estuary for the purposes of WFD designation. The estuarine section of the Scheme is located in the Middle Forth Estuary, which has an area of 3,824 ha and includes the transitional sections of the River Carron, River Avon and Grange Burn up to the NTL.

The Middle Forth Estuary, which extends between Kincardine Bridge to Bo'ness, is approximately 12 km long with a maximum width of 4.50 km between Torryburn and Bo'ness. Depths vary from around 17.50 m below Mean Lower Low Water Level (MLLW) in the middle of the channel opposite Dog Rock, to <0 m in its intertidal areas (Jacobs and Arup, 2009a; Forth Estuary Forum, 2019).

The Firth of Forth is a fjord type estuary. The morphology of these is typically of long narrow valleys with steep sides created by advancing glaciers (NOAA, 2021). The estuary was created predominantly by glacial scour excavating deep basins, whilst exploiting existing river valleys.

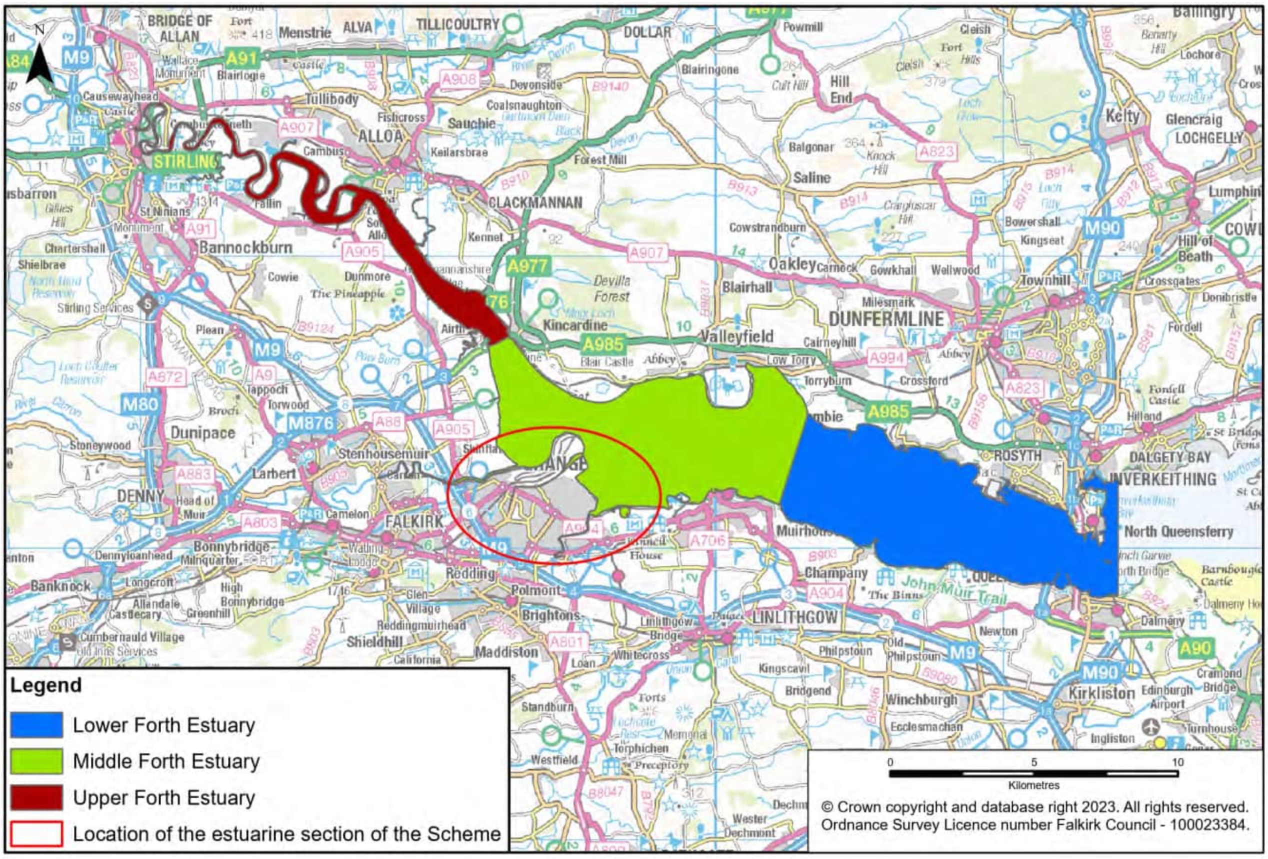

Figure 1: Forth Estuary: Upper, Middle, and Lower Forth Estuary

3.1.1.1.2 Present day geomorphology

In general, the Firth of Forth has mixed muddy bottom sediments, and a diverse morphological nature including saltmarshes, dune systems, maritime grasslands, heath and fen, cliff slopes, shingle and brackish lagoons (Jacobs and Arup, 2009a). Within the Middle Forth Estuary, mudflats are dominant, supporting a rich invertebrate fauna, and eelgrass. These features provide important food sources for the large numbers of migrating and wintering waterbirds that depend on the estuary (See Chapter 7 – Biodiversity for further details).

The Middle Forth Estuary represents a sediment sink, receiving material from the open coasts to both the north and south (Pontee et al., 2004). In the Middle and Upper Forth, intertidal areas (mudflats and saltmarshes) are mainly supplied with fine material on each tide from the relatively high suspended sediment concentrations (SSC) within the estuary, through the areas of channel restriction such as the Kincardine Bridge and Grangemouth (ABPmer, 2018). At these locations, the constriction leads to turbulent flows and sediment resuspension (ABPmer, 2014).

Rates of sea level rise are uncertain due to the combination of post-glacial isostatic uplift and the ongoing acceleration of eustatic sea level rise due to global climate change (Shennan et al., 2009; Rennie and Hansom 2011; Shennan 2013). It is clear that the rate of eustatic sea level rise has increased, whilst the rate of isostatic uplift in Scotland has decreased. Globally, over the last 100 years eustatic sea level has risen by between 0.30 and 3.00 mm/yr, with most estimates being in the range of 1-2 mm/yr (Gornitz, 1995 in Hill et al., 1998). It is possible that sea levels in the Forth are starting to rise as the climate change induced eustatic rise begins to exceed the rate of isostatic uplift and will continue to do so into the future (Horton et al., 2018; Palmer et al., 2018).

3.1.1.1.3 Human intervention

Recent changes in geomorphology in the Forth have been heavily dictated by anthropogenic pressures, such as land claim, construction of sea defences, bridges, piers, harbours, breakwaters and dredging within navigation channels. The morphology of the shoreline and channel of the Firth of Forth (offshore from the Scheme frontage) have been historically modified by engineering structures including the flood defence walls and associated infrastructure of the Port of Grangemouth (See Section 3.1.1.1.3 for further details).

Analysis of historic maps (CH2M, 2017) indicates that between 1750 and 1850, reclamation of land and the construction of breakwaters on both north and south banks of the River Carron occurred, together with the construction of the original Port of Grangemouth on the right bank of the river. Grange Burn was also realigned and straightened to bypass the port area to join the River Carron further downstream. The estimated intertidal habitat loss due to reclamation is between 33 % and 50 % of the pre-existing area over the last 160 years (RSPB, 2012).

Dredging of the River Carron was also ongoing between 1750 and 1850 in order to receive deeper draught vessels in the port. Between 1900 and 1921, the port was expanded to its current layout, removing saltmarsh habitats and pushing the entrance of the docks into the River Forth. The position of the port and breakwater built on the south bank of River Carron is likely to have acted as a shelter for the Skinflats, creating a favourable environment for the deposition of sediments. This has been to the extent that it has been suggested that the Skinflats Reserve, adjacent to Grangemouth, is the only naturally functioning section of intertidal habitat throughout the wider estuary (ABPmer, 2017a).

3.1.2 Lower Carron Estuary

The tidal section of the River Carron (herein referred to as the Lower Carron Estuary) is contained within Flood Cell 1, (NTL is immediately north of Carron Road – B902) extending downstream into Flood Cell 2 and partially into Flood Cell 3. The Mean High Water Springs (MHWS) line marks the boundary between the upstream (Fluvial) River Carron and the start of the tidal section (Lower Carron Estuary). The downstream boundary of the Lower Carron Estuary, which marks the transition to the Middle Forth Estuary, is taken as the upper tidal extents of the Skinflats Nature reserve (National Grid Reference (NGR) NS 93089 82835). Downstream of this location is considered to be within the Middle Forth Estuary.

The Lower Carron Estuary ranges in width between the NTL and its discharge into the Middle Forth Estuary from approximately 20 m in the upper reach to approximately 65 m at the A905 bridge. The upper reaches of this section are confined on the left bank, where there is urban development close to the bank top. Continuing downstream, the channel meanders across its floodplain through predominantly wooded parkland and appears confined on both banks by high embankments. Approaching the M9 and A905 bridges, the channel appears to have been straightened, and is intercepted by a canal extension built between 2012 and 2014.

Flow conditions within the reach appear relatively uniform. Morphological features include riffles related to deposition and associated scour at bridge piers, and erosion downstream of a partially-failed weir located close to the upper tidal limit. Within reaches downstream, fallen trees allow for a reduction in flow velocity contributing to the formation of bars. In reaches downstream of the NTL, where channel planform becomes more sinuous, morphologies are dominated and controlled by tidal influence, forming mud banks and bars. For further information on the River Carron upstream of its tidal limit, see Appendix B10.1: Fluvial Geomorphology.

3.1.3 Lower Avon Estuary

The tidal section of the River Avon (here in referred to as the Lower Avon Estuary) is contained within Flood Cell 5. The MHWS line marks the boundary between the upstream (Fluvial) River Avon and the start of the tidal section (Lower Avon Estuary). The downstream boundary of the Lower Avon Estuary marks the transition to the Middle Forth Estuary and is taken as the boundary between Flood Cell 5 and 6 (NGR NS 95605 81129) as this is the point at which the river becomes less confined, discharging into the wider Middle Forth. Downstream of this location is considered to be within the Middle Forth Estuary.

The Lower Avon Estuary appears unconstrained in the upstream section and meanders through a small, wooded valley. The maximum channel width is approximately 20 m. Downstream of the A905 bridge, the channel appears to have been historically managed and flows through a disused industrial development whereby the channel appears to have been straightened with the right and left banks consisting of anthropogenic embankments. The flood relief channel of the Grange Burn discharges into this section of the River Avon during high flows, and embankments on the opposite side of the channel are protected with rock gabions. Throughout the Lower Avon Estuary, bed morphology and flow conditions are variable. In the upper reaches, there is active erosion of the banks and failure of the cobble bank protection on the outside of meanders.

Further downstream, the channel is confined on either side by cobbled embankments and appears to have undergone planform straightening. Banks generally appear to be stable, but there is evidence of localised bank collapse associated with tree fall. Erosion and failure of wooden, cobble and brick defences is evident on the left bank throughout this reach. Where unmodified, banks are generally muddy, but there are several silt and gravel medial and lateral bars with riffles downstream. For further information on the River Avon upstream of its tidal limit, see Appendix B10.1: Fluvial Geomorphology.

3.1.4 Lower Grange Burn Estuary

The tidal section of the Grange Burn (here in referred to as the Lower Grange Burn Estuary) is contained within Flood Cell 4. The MHWS line marks the boundary between the upstream (Fluvial) Grange Burn and the start of the tidal section (Lower Grange Burn Estuary). The downstream boundary of the Lower Grange Burn Estuary, which marks the transition to the Middle Forth Estuary, is taken as the boundary between Flood Cell 4 and 6 (NGR NS 94571 82533) as this is the point at which the river becomes less confined, discharging into the wider Middle Forth. Downstream of this location is considered to be within the Middle Forth Estuary.

Downstream of the MHWS to the boundary between Flood Cell 4 and 6, the channel has been straightened, measuring approximately 8 m wide and is embanked as part of previous flood defence works. Where natural, the banks are steep, uniform and stable, consisting of clay, silt and fine sands with occasional gravel lenses with minor undercutting. Throughout this reach the channel displays limited morphological diversity. Bed sediment consists of silts and sands with occasional sporadic fine gravel deposits. Flow conditions within the tidal reach appear relatively uniform and are heavily influenced by tidal cycles within the Forth estuary. For further information on Grange Burn upstream of its tidal limit, see Appendix B10.1: Fluvial Geomorphology.

3.1.5 Navigation channels of Forth Estuary

The Grangemouth Port navigation channels are artificially formed, dredged channels to allow port access and egress to vessels berthing within the port of Grangemouth. The western channel is approximately 250 m in length, the eastern channel is approximately 255 m in length. Both channels are fronted by in channel flood gates, which periodically open and close to allow vessels to come and go from the port. The eastern channel contains a breakwater within the Middle Forth Estuary, sill depth at MHS is 11.7 m (Ports and Harbours of the UK, 2023).

Neither channel is designated under the WFD or contained within a designated site of international or national importance. The channels exhibit no morphological diversity and appear uniform and stable given their anthropogenic nature.

3.2 Protected areas

The intertidal areas of the Middle Forth Estuary are designated as part of the following protected areas:

- Firth of Forth Special Protection Area (SPA) under The Conservation of Habitats and Species Regulations 2017;
- a wetland of international importance under the RAMSAR Convention on Wetlands; and
- a Site of Special Scientific Interest (SSSI) under the Nature Conservation (Scotland) Act 2004. This includes the intertidal areas of the Firth of Forth up to Mean High Water Spring (MHWS), comprising Skinflats Nature Reserve, located upstream of Grangemouth Port. The saline lagoon and mudflats between Kinneil Nature Reserve and River Avon are also included in the Firth of Forth designations.

Further detail on designated areas is provided in Chapter 7: Biodiversity. The transitional sections of the Rivers Carron, River Avon and Grange Burn, beyond the MHWS are not included in any of the above designations.

3.3 Existing Defences within the estuarine study area

The condition of the existing defences within the estuarine sections along Cells 2, 3 and 6 (Figure 2 and Table 1) was assessed during the baseline surveys in May 2016 (CH2M, 2017) and April 2019.

In the Lower Carron Estuary, Lower Grange Burn Estuary and Lower Avon Estuary (Cells 1, 2 and 5), there was no published information available regarding the current defence footprints or alignments, and these could not be estimated from aerial imagery due to dense riparian vegetation. The position and alignment of the existing defences are estimated based upon a site walkover by the engineering team and are listed in Table 2. Figure 3 shows their location. It is important to note, however, that a low earth embankment is expected to exist along the river edge in Cells 1 and 5 to stabilise the river margins but has not been listed. In Cell 2, the existing defences appear to be formed of timber which are in a poor state of repair and are collapsing into the river.

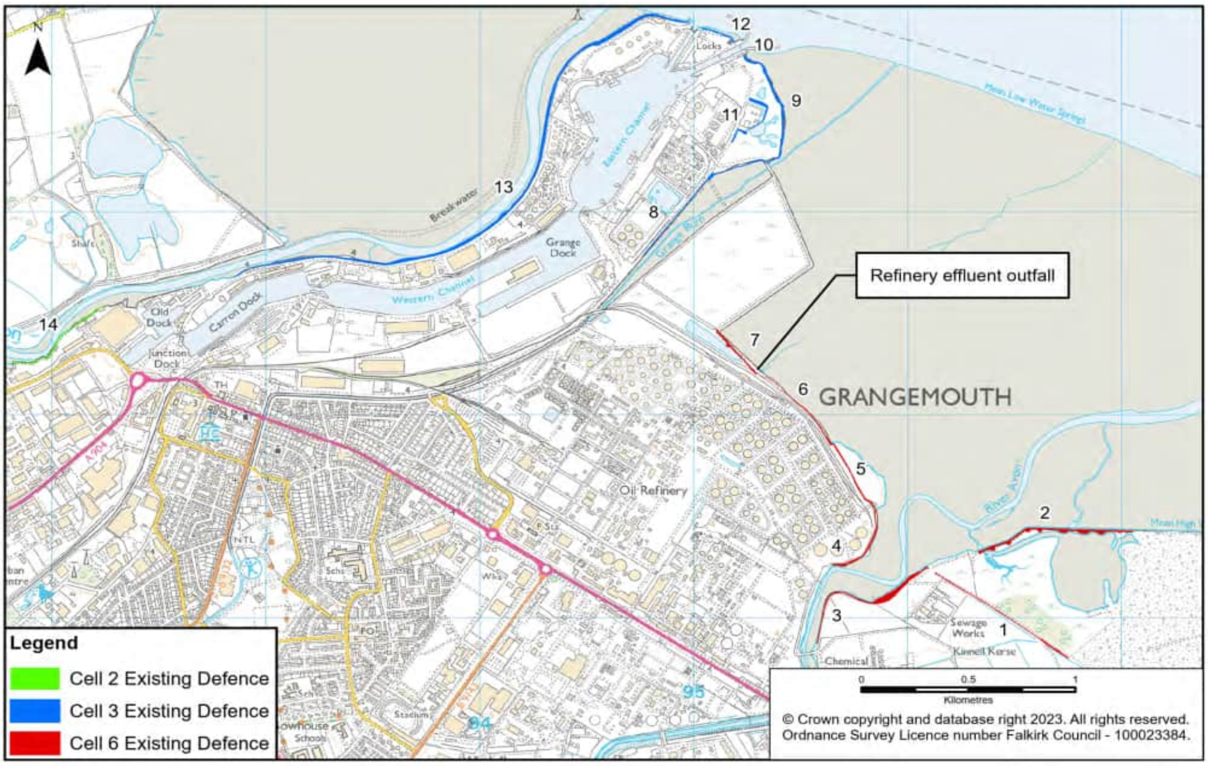

Figure 2: Location of the existing defences in Cells 2, 3 and 6. For defence number, see Table 1

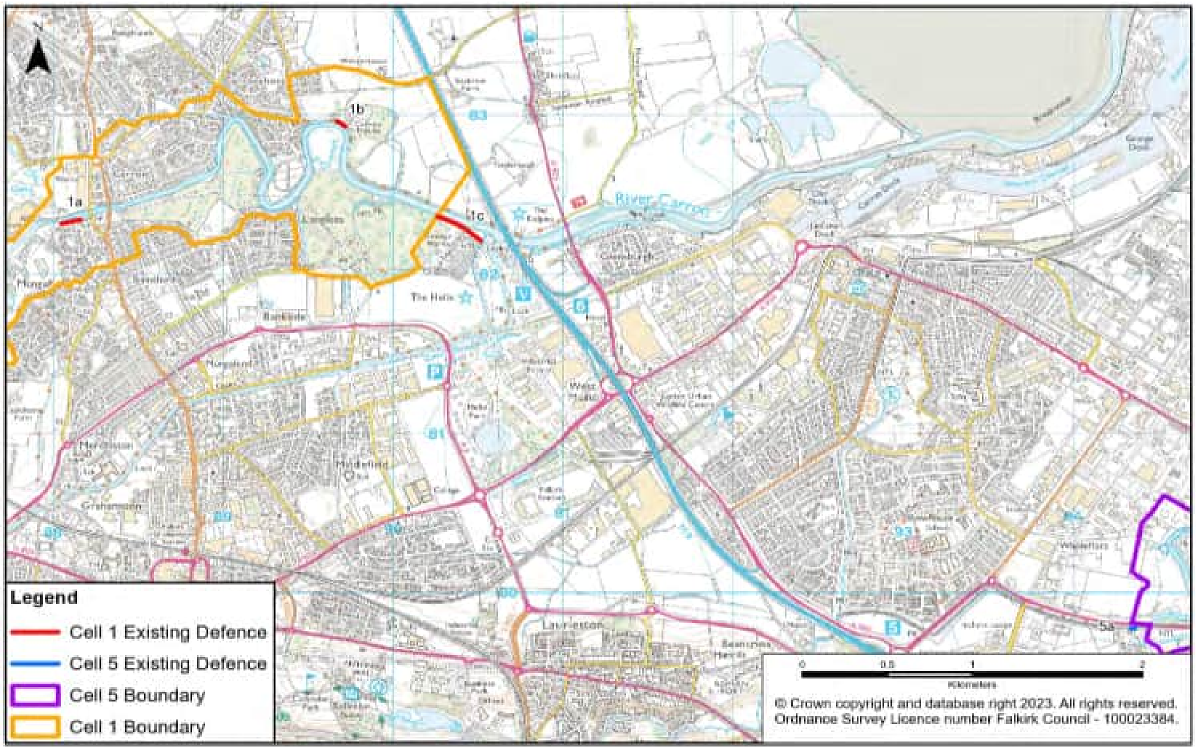

Figure 3: Location of the existing defences in Cells 1 and 5. For defence number, see Table 2

Table 1 shows the type, condition, and footprint of the existing defences for Cell 2, 3 and Cell 6. The existing defence footprint was estimated based on typical cross-section form using the data sources listed below. Expert engineering judgement was applied in areas where the alignment of defences was not entirely clear. The comparison between existing and proposed structures considered the following data sources:

- terrain elevation extracted and analysed using LiDAR;
- aerial photographs provided by Petroineos;
- oblique aerial photographs; and
- photographs taken during the two site visits in 2016 and 2019.

A comparison of current and proposed defence footprints and potential effects on the estuarine processes are further explained in Section 4.2.2.

Table 1: Location, type, condition, and footprint of existing defences for Cell 2, 3 and Cell 6 (CH2M, 2017)

Cell 2			
No. and location	**Type**	**Condition**	**Footprint (m^2)**
14 - Right bank of Lower Carron Estuary	Informal masonry stone wall	Poor	3,409
Total defence footprint in Cell 2 (m^2)			3,409
Cell 3			
No. and location	**Type**	**Condition**	**Footprint (m^2)**
8 – Left bank Grange Burn (Middle Forth Estuary)	Formal defence: embankment containing cut block stonework	Fair	3,070
9 – Between Grange Burn and c.100m of Port Entrance	Formal defence: concrete rubble on top of made ground	Poor	7,600
10 – Downstream of eastern breakwater at Port Entrance	Formal defence: gravel embankment	Good	1,110
11 – Northeast of Grangemouth – inland defence	Formal defence: construction unknown	Good	3,580
12 – Between Lock Gates	Formal defence: gravel embankment on made ground	-	1,253
13 – Port Entrance to Lower Carron Estuary	Formal defence: old breakwater constructed with rubble concrete and cut block stonework	Fair / Poor	35,060
Total defence footprint in Cell 3 (m^2)			51,673
Cell 6			
No. and location	**Type**	**Condition**	**Footprint (m^2)**
1 – Kinneil Kerse back defence	Formal defence: inner defence to Kinneil Kerse intertidal area	Fair	4,070
2 – Kinneil Kerse front defence	Formal defence: old breakwater embankment	Fair	8,890
3 – Between Kinneil Kerse and River Avon	Undefended made ground comprising of rubble	Poor	8,800
4 – Left bank of River Avon (Middle Forth Estuary)	Formal defence: stone work	Fair	2,794

5 – Promontory	Reclaimed area: promontory	Poor	2,855
6 – Between Promontory and refinery effluent outfall	Formal defence: gabion mattress, concrete wall and some sand and gravels and mudflat	Fair / Poor	1,684
7 – Effluent outfall to reclaimed peninsula	Formal defence: embankment	Fair	2,582
Total defence footprint in Cell 6 (m^2) (excludes the Promontory area as this is not considered to be a defence)			31,676

Table 2: Location, type and status of existing defences for Cell 1 and 5

Cell 1		
No. and location	**Type**	**Status**
1a	Embankment	Private
1b	Stone wall	Private
1c	Possible embankment	Private
Cell 5		
No. and location	**Type**	**Status**
5a	Wall	Private

*It is important to note that it is likely that a low earth embankment is located along the rivers, which have not been listed.

3.4 Hydrodynamic Regime

3.4.1 Tides

The Forth is a macrotidal estuary, with a mean spring tidal range of 5.20 m and a mean neap tidal range of 2.60 m in Grangemouth and an increasing tidal range further west into the estuary. Tidal levels for Rosyth, Grangemouth and Kincardine are shown in Table 3 below in both Chart Datum (CD) and Ordnance Datum Newlyn (ODN).

Table 3: Tide levels for Rosyth, Grangemouth and Kincardine, Firth of Forth. Source: UKHO (2018)

Tidal Levels	Rosyth[1]		Grangemouth[2]		Kincardine[3]	
	CD (m)	ODN (m)	CD (m)	ODN (m)	CD (m)	ODN (m)
Highest astronomical tide (HAT)	6.40	3.45	6.40	3.65	6.50	3.65
Mean High Water Springs (MHWS)	5.80	2.85	5.80	3.05	5.80	2.95
Mean High Water Neaps (MHWN)	4.70	1.75	4.60	1.85	4.50	1.65
Mean Water level (MWL)	3.30	0.35	3.10	0.35	3.10	0.25
Mean water level Neap (MLWN)	2.20	0.75	2.00	-0.75	1.70	-1.15
Mean Water Level Spring (MLWS)	0.80	-2.15	0.60	-2.15	0.50	-2.35
LAT	0.00	-2.95	-0.30	-3.05	-0.20	-3.05

Tidal Levels	Rosyth[1]		Grangemouth[2]		Kincardine[3]	
	CD (m)	ODN (m)	CD (m)	ODN (m)	CD (m)	ODN (m)
Spring range	5.00 m		5.20 m		5.30 m	
Neap range	2.50 m		2.60 m		2.80 m	

[1] ODN = -2.95 mCD at Rosyth

[2] ODN = -2.75 mCD at Grangemouth

[3] ODN = -2.85 mCD at Kincardine

Tide levels within the Firth of Forth experience double high and double low waters, known locally as the 'lackie tide', resulting in a prolonged period of weak tidal currents around the time of slack water (Elliot and Clarke, 1998). In general, flood currents are stronger on the north side of the estuary and ebb currents stronger on the south side, primarily due to the estuary bathymetry which deepens towards the northern shores.

Tidal flow speeds within the subtidal channel are available for a number of locations within the Firth of Forth and from different sources, including:

- diamond A (SN023F), located in the vicinity of Rosyth Terminal from Admiralty TotalTide; and
- subtidal channel in the vicinity of Grangemouth (ABPmer, 2018).

At Rosyth, measurements of depth-averaged mean flow speeds were found to have peak tidal velocities between 0.70 and 1.10 m/s during neap and spring ebb tides, and between 0.40 and 0.70 m/s during neap and spring flood (Jacobs and Arup, 2009b). At the subtidal channel at Grangemouth, measured flow speeds were approximately 0.80 m/s, with a maximum of 1.10 m/s during spring tides and reducing to 0.30 m/s during neaps (ABPmer, 2018).

Within the Forth, peak flows occur for longer (over 2 hours) on the ebb tide than the flood (around 1 hour). Additionally, low flow speeds dominate between 1.5 hours before and 0.5 hours after both high water and low water, providing a period of potential settling for suspended material (ABPmer, 2018).

Within the Lower Carron Estuary, tidal velocities vary according to the reach of the river. Tidal flow speeds were measured (RCFMG, 2012) and showed that close to the Western Docks, tidal flows are an average of 0.36 m/s, reaching up to 0.80 m/s during ebb tides. Further upstream, tidal flows drop considerably, reaching 0.10 m/s upstream of the M9. It is likely that up to the NTL, tidal flows drop further.

3.4.2 Waves and extreme water levels

Where the Scheme is located within the Middle Forth Estuary, it is relatively sheltered from offshore-generated swell waves It is likely that most of the wave activity within the Middle Forth Estuary are fetch derived wind waves generated within the estuary. Fetch wave heights rarely exceed 0.30 m (Firth et al., 1997), with a maximum height around 1 m.

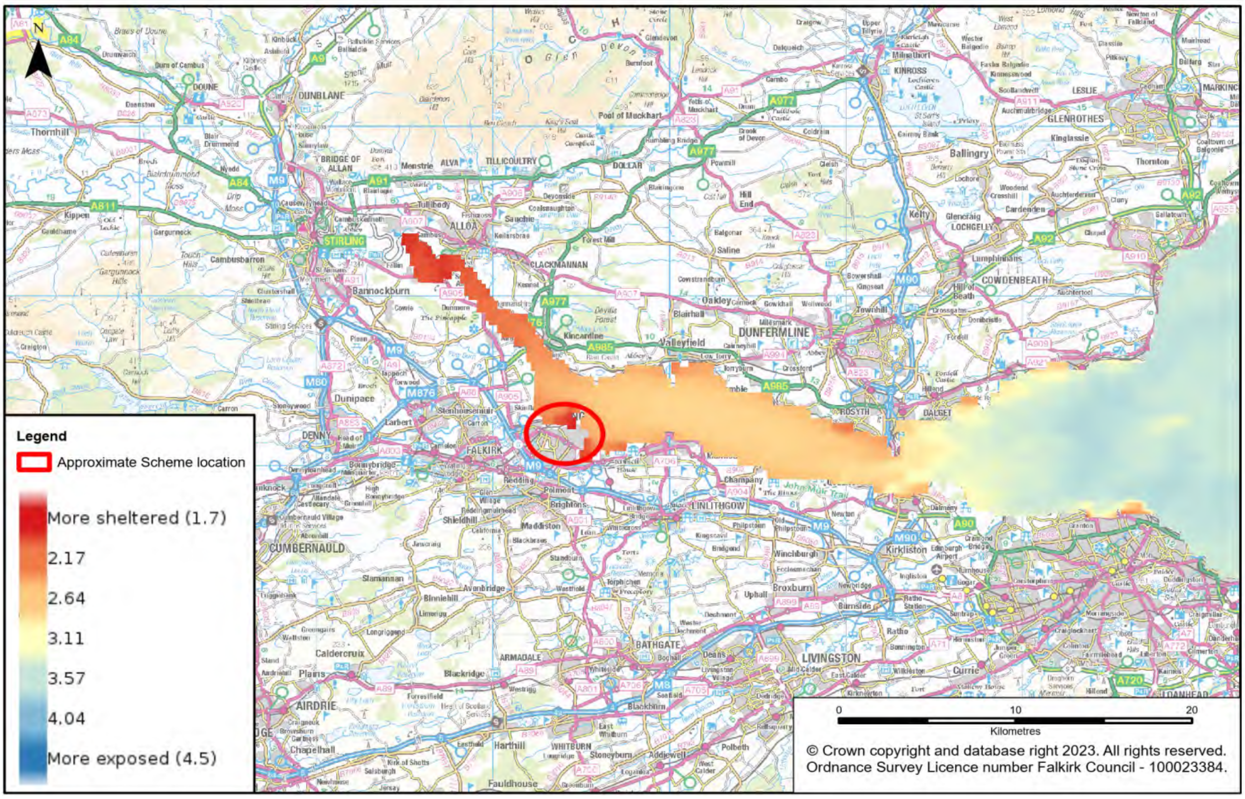

Figure 4: Distribution of wave energy (termed wave exposure index) for the Middle Forth Estuary, between Clackmannan and Limekilns (SAMS, 2023). Red circle denotes approximate Scheme location

The long fetch between Limekilns and Skinflats results in larger waves, which dissipate across the shallow intertidal areas. Grangemouth Port itself acts as a barrier against high wave energy to the Skinflats. Although wave energy is slightly greater between Bo'ness and Grangemouth frontage, a similar process occurs, with Bo'ness acting as a barrier for the Kinneil Nature Reserve. Shallow intertidal areas, including mudflats and saltmarshes are effective in dissipating storm waves, and therefore provide a valuable natural component of estuarine protection Schemes (Möller et al., 2014). Due to the relatively sheltered nature of the Middle and Inner sections of the Forth, the wave climate is dominated by locally generated wind waves.

Extreme water levels are available at Queensferry, approximately 20 km southeast of Grangemouth and Grangemouth Port using the Environment Agency (2011) coastal flood boundary dataset. Table 4 shows that extreme water levels for Queensferry is around 4.40 mODN (Ordnance Datum Newlyn) for the 0.5 % Annual Exceedance Probability (AEP) (200-year) event. For Grangemouth extreme water levels are around 4.90 mODN for the 0.5 % Annual Exceedance Probability (AEP) (200-year) event. This rise in extreme wave heights moving up the estuary confirms modelling results of tidal surges undertaken by ABPmer, 2017b, which indicates that for the 0.5 % AEP (200-year) event, surge heights increase with distance upstream in the estuary due to the funnelling effect of the narrowing estuary width from east to west.

Table 4: Extreme water levels at Queensferry for base year of 2017 (mODN)

EA Chainage	Return Periods (years)						
	100 % AEP (1-year)	10 % AEP (10-year)	5 % AEP (20-year)	2 % AEP (50-year)	1 % AEP (100-year)	0.5 % AEP (200-year)	0.1 % AEP (1000-year)
3416_8	3.58	3.85	3.93	4.05	4.13	4.22	4.43
3416_26	3.92	4.01	4.32	4.45	4.56	4.66	4.93

3.5 Sediment Dynamics

The Forth Estuary is characterised predominantly by fine sediments with coarser grained sands and gravels occurring around constrictions in the estuary, such as at Grangemouth Docks (ABPmer, 2018). In the Middle Forth Estuary around Grangemouth, Suspended Sediment Concentrations (SSC) vary between 150 mg/l during neap tides to 350 mg/l during springs tides (BTDB, 1966), although peak concentrations at the Grangemouth entrance can reach up to 2,000 mg/l.

The extensive intertidal mudflats present, particularly in the Middle Forth estuary, are indicative of the highly turbid nature of tidal waters (SEPA, 2015a). Indeed, the position of the turbidity maximum is important in relation to sediment deposition within the intertidal (ABPmer, 2018). Within the Forth, the position of the turbidity maximum varies depending on the ratio of tidal heights and freshwater inputs, migrating between the tidal limit at Stirling (under conditions of low freshwater flows and high tides) and the Kincardine Bridge (conditions of high freshwater flows and low tides). Between Alloa and Fallin, around 7 to 12 km upstream of Grangemouth, turbidity maximum SSC values can reach up to 10,000 mg/l, although more typical values are around 3,000 mg/l.

Wind-induced waves also contribute to the spatial and temporal distribution of suspended sediment, leading to wave resuspension of sediment over the extensive intertidal areas down-estuary of Kincardine (Lindsay et al., 1996). The high potential mobility of these intertidal mudflats means they represent important temporary sediment sinks for fine material which may be resupplied to the estuary during erosional events. Wide intertidal areas close to Grangemouth are therefore considered a large store of sediment that, under wind-wave conditions, can increase SSC within the adjacent areas of the estuary.

3.6 Future Estuarine Baseline

The future estuarine baseline utilises the latest climate change predictions for the UK (UKCP18, Met Office, 2018), and is based on the following:

- continuation of present-day management regime with no new developments within the study area; and
- implementation of the Scheme and the potential for habitat lost related to coastal squeeze.

It is important to note that changes to tidal range due to sea level rise (SLR) in estuaries are complex and would require hydrodynamic modelling to validate, therefore they are not considered within this assessment. It is assumed that the present-day tidal heights rise in line with the amount of SLR and the range remains the same. For the assessment of future baseline, the high emission scenario (RCP8.5[1]) in Edinburgh (closest published location) was used to predict increases in sea level, which forecasts a rise of between 0.30 m and 0.90 m by 2100 (relative to 1981 – 2000 baseline), with a mid-range projection around 0.55 m.

1 Representative Concentration Pathways (RCP) specify concentrations of greenhouse gases that will result in total radiative forcing increasing by a target amount by 2100, relative to pre-industrial levels. Each pathway results in a different range of global mean temperature increases over the 21st century. RCP8.5 represents a change in temperature of 4.3ºC on average (between 3.2 and 5.4ºC).

The majority of the intertidal areas within the Forth are currently constrained by existing flood defences (Section 3.3). Additional defences as part of the Scheme could result in coastal squeeze over the next 100 years and beyond. Coastal squeeze results due to loss of intertidal area where rising sea levels cause retreat of the Mean Low Water, but man-made structures (e.g. seawall / embankments) restrict the migration of Mean High Water onto backing low lying land. This results in a narrowing of the intertidal zone. Under present-day conditions most mudflats and saltmarshes in the study area appear to be building landward.

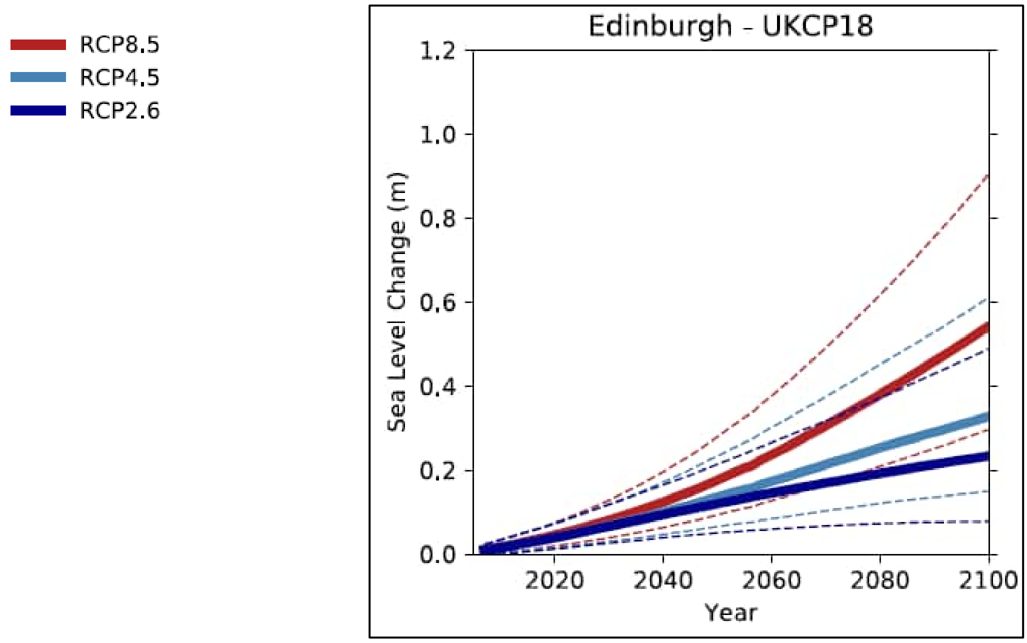

Plate 1: Time-mean sea level projections for Edinburgh provided under UKCP18 . UKCP18 results presented relative to a baseline of 1981-2000. UKCP09 results presented relative to a baseline of 1980-1999 (note that difference in baseline period equates to 1-2 mm). The solid lines indicate the central estimate and dashed lines indicate the range for each scenario as indicated in the legend. Modified from (Palmer et al., 2018)

Horton et al. (2018) suggests that the majority of saltmarshes in the UK would be expected to erode with a SLR of 7.10 mm/yr. For the study site, the UKCP18 SLR projections under RCP 8.5 suggest that this rate could be achieved between 2050 to beyond 2100, with the central estimate around 2070. Therefore, suggesting that until this time saltmarshes would remain stable, with the available sediment supply being sufficient for marshes to accrete vertically to keep pace with ongoing sea level rise. For this assessment, it has been assumed the same critical value of 7.10 mm/yr rate of SLR also applies to mudflats (i.e. mudflats would also be expected to be stable until around 2070).

There are three areas (A, B and C - Figure 5) where land levels landward of the current defences could allow the development of intertidal habitats (in the absence of defences). Future losses of intertidal habitats in front of these areas could therefore represent coastal squeeze.

Area A is the area behind the reclaimed peninsula and Area B is the area on the right bank of River Avon. These areas have an existing embankment over 5 m high and terrain elevations behind the defence ranging between MHWN (1.85 m) and MHWS (3.05 m). Saltmarsh habitat is currently located in front of Area A, whilst mudflat habitat currently fronts Area B. The existing defences in both locations are currently failing. Land elevation behind the existing structures within Area A would be suitable for the development of saltmarsh should the defences be removed or fail entirely. Revetment defences accompanied with sea level rise (after 2070) would reduce the intertidal area in-front of the defences and would constitute coastal squeeze.

Area B would require a 0.70 m rise in sea level in order to start developing mudflats, which is not likely to be achieved by 2100. Since this is reclaimed land any future losses of the existing habitats in front of proposed defences would potentially constitute coastal squeeze.

Area C comprises average terrain elevations above of 3.05 m (MHWS). The existing defences in this location are low enough to allow for inundation along the south-east frontage. Proposed defences would consist of a setback flood wall. Therefore, the area in between the existing and proposed defences could allow for salt marsh colonisation as sea levels rise. Based on the UKCP18 RCP 8.5 projections this could start around 2030 whereby a 0.10 m sea level rise is predicted. Since rising sea levels are not expected to result in the loss of present-day saltmarsh habitats until after 2070, the development of new marsh on the elevated platform from 2030 – 2070 would represent an increase in habitat extent at this site.

In summary the intertidal habitats in the Middle Forth have been showing accretion over the past 100 years. The rate of SLR that could lead to the erosion of saltmarshes and mudflats is not likely to be reached until 2070. Therefore, no coastal squeeze is currently occurring, nor is it likely to occur over the next 50 years. After this time there is some potential for losses of intertidal habitat (due to SLR) which would represent coastal squeeze in locations backed by anthropogenic structures or reclaimed land. Any losses against areas of naturally occurring high land would represent natural change rather than coastal squeeze.

Figure 5: Location of low-lying areas in Grangemouth frontage (between MHWN and HAT)

3.7 Receptor Identification

Based upon the baseline data presented, receptors which may potentially be affected by the Scheme are identified in Table 5. The importance of each receptor is determined in accordance with the criteria described in Table 10-3 of Chapter 10: Water Environment.

Table 5: List of identified physical processes receptors and their importance within the study area

Receptor	Indicators / features	Importance
Middle Forth Estuary	Overall WFD status of Moderate with objective to achieve Good by 2027. An estuarine waterbody which supports a range of species and habitats and includes sites of international importance and UK statutory nature conservation designations including a designated SSSI and Ramsar site, due to water-dependent ecosystems.	Very High
Lower Carron Estuary	Overall WFD status of Moderate with objective to achieve Good by 2027. An estuarine water body supporting a range of species and habitats sensitive to changes in erosion, sediment transport and deposition. Includes a range of estuarine morphologies, including some natural features with a higher likelihood of morphological adjustment related to excessive erosion and sediment deposition, as a direct result of modification.	High
Lower Grange Burn Estuary	Overall WFD status of Moderate with objective to achieve Good by 2027. An estuarine water body supporting some species and habitats sensitive to changes in erosion, sediment transport and deposition. Evidence of modification including embankment and channelisation with evidence of limited morphological features and process.	High
Lower Avon Estuary	Overall WFD status of Moderate with objective to achieve Good by 2027. An estuarine water body supporting a range of species and habitats sensitive to changes in erosion, sediment transport and deposition. Includes a range of estuarine morphologies, including some natural features with a higher likelihood of morphological adjustment, related to excessive erosion and sediment deposition, as a direct result of modification.	High
Navigation channel of Forth Estuary	Anthropogenic navigation channel which does not support any significant species sensitive to changes in erosion, sediment transport and deposition. Not a designated site of international or national importance. Exhibits no morphological diversity with extensive evidence of modification related to its manmade nature.	Low

4. Impact Assessment

Potential Impacts during construction operation of the Scheme are outlined below with the current working areas defined according to the Flood Cells shown in Figure 6 and Figure 7.

4.1 Potential impacts of construction

Construction of the Scheme (site boundary footprint) varies between approximately 5 m to 100 m seaward and landward of the proposed defence alignments.

It is assumed that most of the construction works located within the tidal rivers in Flood Cells 1, 2, 3, 4 and 5 will take place from the landward areas. However, it may be necessary to erect some temporary working areas within the intertidal and subtidal areas of the rivers (included within the construction areas). In Cell 6, some land reclamation may be required to construct a temporary access track to the frontage. Temporary working platforms will be required and would be situated above high tide level.

Temporary works within the intertidal areas of the Middle Forth Estuary and tidal river sections (Flood Cells 1, 2, 3, 4 and 5) have the potential to cause the following effects:

- changes in both erosion / accretion rates and locations in the intertidal and subtidal areas arising from changes in tidal flows (speed and direction). This has the potential for increased erosion around working platforms where the channel is constrained and accretion where channel is unconstrained;
- morphological changes due to the direct disturbance of intertidal areas by tracking of plant and heavy machinery, potentially causing erosion or compaction; and
- changes in the subtidal morphology due to erosion of the intertidal and release of sediments into the navigation channel.

4.1.1 Changes in flow speed and direction

Changes in the speed and direction of tidal flows could arise from temporary structures reducing channel cross-sectional area in the tidal sections of the rivers and at the estuarine frontage. This would have the potential to temporarily change erosion and accretion patterns in the intertidal and subtidal areas within the vicinity of the working area. Such changes, although noticeable, would be localised to the working areas and temporary during construction only, returning to pre-construction conditions once works are removed. Additionally, the changes would be small in relation to the overall scale of the water bodies. Therefore, given the temporary and highly localised nature of the potential impacts, the magnitude of impact is reported as a Negligible. This would result in a Slight significance of effect within the tidal sections of the rivers and the Middle Forth Estuary.

4.1.2 Changes to estuarine morphology

Morphological changes due to disturbance of intertidal areas could occur due to working platforms and any plant movements across the intertidal. This could potentially change the intertidal surface composition, allowing more sediment to be eroded or, where sediment is regularly driven over by heavy machinery compaction could reduce the erodibility of the material. A total of 6.82 ha of intertidal area (i.e. mudflats) would be temporarily affected due to construction, of which 0.34 ha from Cell 1, 0.10 ha from Cell 2, 0.65 ha from Cell 3, 1.02 ha from Cell 4, 3.47 ha from Cell 5 and 1.24 ha from Cell 6. This would be a temporary impact over the construction period which would be localised to the footprint of the works. Once the works are removed, the area will be reinstated after the construction and the waterbodies are anticipated to recover.

Such impacts have the potential to affect the intertidal areas of the Lower Carron Estuary, Lower Grange Burn Estuary, the Lower Avon Estuary and the intertidal areas of the Middle Forth Estuary. Given the temporary and localised nature of the potential impact relative to the overall water body scales, the magnitude of impact is reported as Minor Adverse for the Lower Carron Estuary, Lower Grange Burn Estuary, Lower Avon Estuary and Negligible for the Middle Forth Estuary. This results in a Slight significance of impact in the Lower Carron Estuary, Lower Grange Burn Estuary, Middle Forth Estuary and the Lower Avon Estuary.

Potential changes in subtidal areas could also occur due to the localised erosion of the foreshore during the transport of materials to the construction site. Erosion could release material to the subtidal channel, with the following potential effects:

- temporary local increase in suspended sediment concentrations which would lead to a reduction in water clarity, increased turbidity and a change to the type and size of material in suspension; and
- permanent shallowing of the subtidal slope due to deposition of material eroded from the intertidal, which could have implications for navigation.

Any increases in suspended sediment concentration would be temporary and localised to the working areas. Additionally, this is a macro tidal environment, with high suspended sediment concentrations under baseline conditions. As such the magnitude of impact is reported as Negligible given that changes are not likely to be discernible from background conditions. This results in a Slight significance of effect for the Middle Forth Estuary, Lower Carron Estuary, Lower Grange Burn Estuary and Lower Avon Estuary.

Permanent shallowing of the Middle Forth Estuary, Lower Carron Estuary, Lower Grange Burn Estuary and Lower Avon Estuary would be extremely localised given the likely volumes of sediment that would be produced in comparison to background conditions. Therefore, the magnitude of impact for the Middle Forth Estuary, Lower Carron Estuary, Lower Grange Burn Estuary and Lower Avon Estuary is reported as Negligible. This results in a Slight significance of effect for these waterbodies.

Permanent shallowing within the Navigation Channel of the Forth Estuary as a result of localised erosion is unlikely, given the artificial nature of the channel and its associated upstream components. Any impacts would be temporary and localised. The channel does not display any morphological characteristics that would be impacted through shallowing. Therefore, the magnitude of impacts is reported as Negligible. This results in a Neutral significance of effect.

Figure 6: Location of temporary construction working areas in Cells 1, 2 and 3

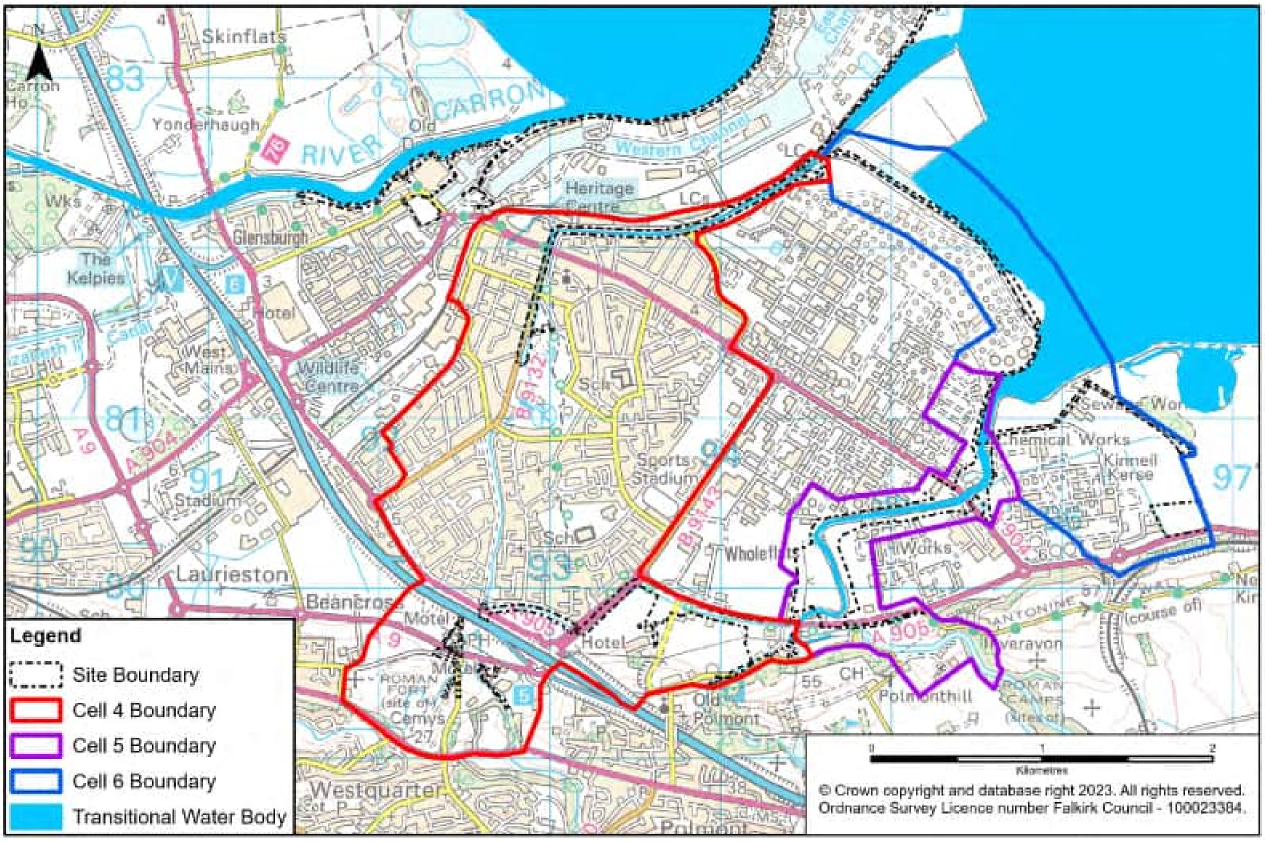

Figure 7: Location of temporary construction working areas in Cells 5 and 6

4.2 Operation

4.2.1 Introduction

The following section describes the general operational characteristics of the Scheme, provides a review of types of permanent impacts considered, and describes the impacts for each Flood Cell in which they could occur.

4.2.2 General description of the Scheme

The proposal for the new flood defences on the Lower Carron and Avon estuaries will mainly comprise new flood walls with the intention of minimising any encroachment and / or losses of intertidal areas. In certain sections, where the defence alignment is in close proximity to the waterbodies, bank protection will be added. This will vary depending on the section of the river on which the defences occur. The total footprint of the Scheme within the tidal sections of the rivers varies between approximately 0.5 m to 20 m seaward and landward of the proposed defence alignments.

The proposal for the new flood defences at the estuarine frontage of Grangemouth will comprise new flood walls and embankments with a fronting revetment.

Replacement bridges are required for the New Carron Road Bridge over the Lower Carron Estuary in Cell 1 and Dalratho Road Bridge over the Lower Grange Burn Estuary in Cell 4. Both bridges do not require in-water working and are expected have the same alignment and similar footprint as the existing bridges.

Table 7 shows the proposed and the existing defence footprints, areas of overlap, areas of potential encroachment and total potential loss of intertidal habitats. A description of each column is provided in the notes to Table 6.

Table 6: Proposed defences, existing defence, areas of overlap, areas of potential encroachment and area of potential loss of intertidal habitat due to increased defence footprint per cell (in m^2)

Cell	Proposed defence footprint (m^2)[1]	Existing defence footprint (m^2)[2]	Area overlap between proposed and existing defence (m^2)[3]	Area of potential encroachment (m^2)[4]	Total potential loss of intertidal habitat (m^2)[5]	Comments
1	4,091	NA	NA	19	0	A very small area of encroachment and loss of intertidal is predicted within this cell on the left bank of the River Carron.
2	5,450	3,409	90	0	0	All proposed defences will be built landward of the existing defences
3	13,587	51,673	7,653	865	2,916	The total potential loss of intertidal is located along the right bank of the River Carron and in small areas around the entrances to the Eastern Channel of the Grangemouth Ports.
4	7,792	NA	NA	26	0	A very small area of encroachment and loss of intertidal is predicted within this cell on the right bank of Grange Burn.
5	10,031	NA	NA	129	347	Existing defence footprint could not be estimated. A small area of encroachment and loss of intertidal is predicted within this cell on the left bank of the River Avon.
6	34,925	31,676	6,350	8,439	11,370	The potential loss of intertidal is due to reclamation at the estuarine frontage and on the left bank of River Avon.

Table 6 notes:

[1] The permanent works footprint varies approximately between 0.5 to 20 m seaward and landward of the proposed defence alignments.

[2] The existing defence footprint for Cells 2, 3 and 6 were estimated based on both vertical and oblique aerial photographs and Ordnance Survey maps. Existing defence footprint in Cells 1, 4 and 5 were not possible to estimate using the same method due to vegetation coverage of the riverbanks. In Cell 2,

there are limited formal defences in place, with most of this frontage being made ground with some rubble at the foreshore.

[3] The proposed and the existing defence footprints were overlapped to identify areas where the defences will be maintained in the current position.

[4] Areas of encroachment seaward (beyond the MHWS level) where a potential increase in defence footprint could occur were analysed on a cell-by-cell basis and are considered only when there was a potential increase of defence footprint seawards of the existing defences.

[5] Total potential loss of intertidal habitat was calculated by overlapping the Scottish Natural Heritage (SNH) Phase 1 habitat mapping layer with the permanent works footprint, according to Chapter 7 – Biodiversity. This is likely to be overestimated as it does not take into account existing defences. However, it is acknowledged that some areas of intertidal habitats may have been too small to map when the Phase 1 survey was conducted.

4.2.3 Description of potential operational impacts

The following Section provide an overview of the potential impacts as a result of the Scheme. Sections 4.2.4 to 4.2.9 consider the potential permanent (operational) impacts of the Scheme within each Flood Cell.

4.2.3.1 Loss of intertidal area

An increase in the footprint of flood defences could result in permanent loss of intertidal features, including designated features and those supporting important habitat, such as mudflats and saltmarshes.

4.2.3.2 Changes in water levels

Within the tidal sections of the rivers, encroachment and extension of the defences could reduce channel cross sectional area. A reduction in channel cross section has the potential to impact local water levels and velocities which could lead to some erosion of intertidal area particularly around meanders.

At the estuarine frontage, reclamation could potentially lead to imperceptible increases in water levels throughout the estuary, causing an indirect loss of intertidal area. This, however, is not likely to occur given the small size of reclamation in relation to the total area of the Forth Estuary. No changes to the tides within the Forth Estuary are expected due to the small-scale size of the proposed defences compared to the size of the estuary.

4.2.3.3 Changes in flow speeds and directions

Changes in flow speeds and direction might occur due to:

- defence alignment, with addition of corners or bends which could locally change flow patterns. This, however, is not proposed in any part of the Scheme and has not been considered further;
- increased defence footprint (seaward direction), which could cause a reduction in cross-sectional area, constraining flows through narrowing of channels; and
- opening of areas where there is currently an embankment, removing constrictions and modifying flow paths. This is not proposed in any part of the Scheme and has not been considered further.

For the Middle Forth Estuary, all proposed defences are shore-parallel, therefore, no change in oncoming wave dynamics are expected (refraction/diffraction would be expected around breakwaters). In addition, the proposed rock revetment sections will dissipate wave energy more than the existing structures. Where vertical walls are proposed, these are relatively low structures at the top or back of an embankment and in areas of lesser wave exposure. It is possible that some wave reflection could occur, but as the vertical walls are above normal tidal levels, this would only happen in extreme cases. Any wave action of note and wave heights would be expected to be very small and not have any impact on the estuary dynamics.

4.2.3.4 Changes in estuarine morphology

The appraisal of estuarine morphology, due to changes in tidal currents and accretion / erosion, is based on expert judgement, informed by the results of previous studies on the Forth Estuary and site visits by the project team. General changes in sediment dynamics could include:

- permanent loss of natural banks and bed where defences are constructed abutting or within the channel which could permanently reduce the sediment supply from adjacent banks;
- modifications to the sediment regime of the channel in areas where banks are currently able to erode and add sediment to the channel; and
- where channels are constrained by increased defence footprints, there is the potential for increased bed scour or intertidal erosion due to higher flow velocities within the narrower channel cross-section. This could also lead to increases in sediment supply as a result of increased bed and bank erosion.

4.2.3.5 Changes in estuarine geomorphology response under a scenario of climate change

It was noted in Section 3.6 that sea level rise may lead to the loss of intertidal area in the future. Assuming the overall present-day form of the estuary in this vicinity is maintained into the future then saltmarsh habitat losses would be expected to occur by around 2070 assuming the high emission scenario at Edinburgh occurs. Therefore, changes in the future under a scenario of climate change have been assessed taking into account the details in “Future Estuarine Baseline” (Section 3.6) and the potential for the proposed defences in each cell to cause changes.

Effects on wave climate have been scoped out of this assessment as there is considered to be no potential for the Scheme to modify the propagation of waves locally or in the wider estuary. Potential effects due to wave scour will be minimised by the incorporation of bank protection at the seaward side of the proposed defences in Cells 3 and 6 (those on the open estuary).

These impacts have been described per cell in the following sub-sections.

4.2.4 Cell 1

4.2.4.1 Scheme Overview

In Cell 1, flood walls will have a bank protection comprising of a softer option, such as geotextile. This was chosen due to the relatively low flow speeds in this section of the Lower Carron Estuary. There is one area of potential encroachment of intertidal area along the Lower Carron Estuary of 19 m^2 as shown in Figure 8.

The total proposed defence footprint in the tidal sections in Cell 1 is 4,091 m^2.

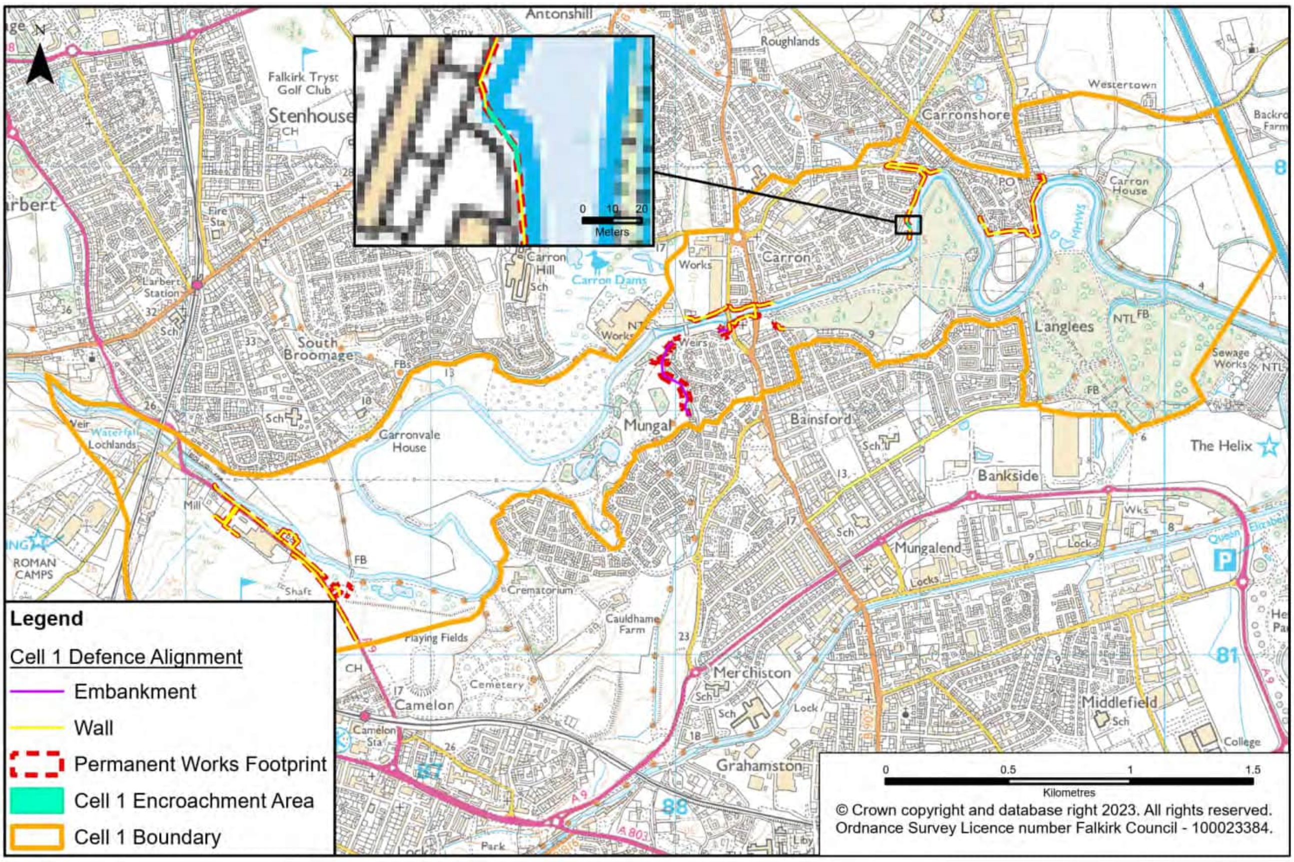

Figure 8. Proposed defence footprint in the Lower Carron Estuary - Cell 1

4.2.4.2 Potential losses of intertidal features

The Scheme within tidal section of Cell 1 has a total footprint of 4,091 m^2. There is one very small potential area of encroachment, and resulting loss of intertidal area, into the Lower Carron Estuary of 19 m^2 (Figure 8). Given the size of the potential encroachment are with regards to the overall waterbody scale, the magnitude of impact is reported as Negligible. This results in a Slight significance of impact on the Lower Carron Estuary.

4.2.4.3 Changes in water levels

Such a small area of encroachment (19 m^2) is unlikely to result in discernible changes in water levels at the water body scale, with any changes being small and extremely localised to the encroachment area. Therefore, the magnitude of impact is reported as Negligible. This results in a Slight significance of effect for the Lower Carron Estuary.

4.2.4.4 Changes in flow speeds and directions

The proposed defences within Cell 1, when adjacent to the river margins will be constructed following the current channel alignment. At their set back position, the proposed defences will be above MHW, therefore, changes in flow speeds and directions are considered of Negligible Impact. This results in a Slight significance of impact for the Lower Carron Estuary.

4.2.4.5 Changes in estuarine morphology

Permanent loss of natural bank would possibly occur over a length of 26 m, where the potential encroachment will be located on the left bank on the River Carron (NGR NS 88950 82777) (Figure 8). As already mentioned previously, an increased defence footprint in this area would be very small and above Mean Low Water (MLW). Given that the rest of the proposed defences will be built landwards above the MHW, and no further encroachment into Lower Carron Estuary is predicted, no further losses of natural bank are anticipated. The proposed defences are not likely to modify the sediment regime due to their landward position. Likewise, effects in terms of potential scour increase at the defence toe are not likely to occur. Therefore, the effect of the proposed defences on estuarine morphology is considered to be Negligible. This results in a Slight significance of effect for the Lower Carron Estuary.

Given that tidal flows are only likely to marginally increase locally, bed scour or intertidal erosion due to higher flow velocities is not likely to increase above background conditions. Therefore, the magnitude of impact is reported as Negligible. This results in a Slight significance of effect for the Lower Carron Estuary.

The proposed defences along Cell 1 will constrain around 27 % of the north bank and 5 % of the south bank of the Lower Carron Estuary. All the areas to receive new defences, however, are already constrained by residential properties and associated road infrastructure. In terms of modifications to the sedimentary regime, the proposed defences are not likely to change patterns of erosion of the riverbanks. Therefore, the magnitude of impact is reported as Negligible. This results in a Slight significance of effect for the Lower Carron Estuary.

4.2.4.6 Changes in estuarine geomorphology response under a scenario of climate change

The proposed defences along Cell 1 will be located within reaches already constrained by properties and infrastructure. In the absence of the Scheme, these areas would not develop intertidal areas in the future, albeit there would be a potential increase in tidal inundation under a scenario of sea-level rise. Therefore, the magnitude of impact is reported as Negligible.

With sea-level rise, the Scheme would restrict the locations where high water levels during storms could travel. An increase in inundation could potentially occur to areas not constrained by defences, such as at the vegetated areas on the south bank of the Lower Carron Estuary. This, however, would be difficult to quantify in scenarios both with or without the Scheme. This, therefore, has been considered to be of Negligible magnitude. This results in a Slight significance of effect for the Lower Carron Estuary.

4.2.5 Cell 2

4.2.5.1 Scheme Overview

In Cell 2, the existing defence footprint area totals 3,409 m^2. Part of the current defences along this section of frontage are made of wood and are in a poor condition. The new flood wall defence and embankment will be set back from the existing defence or within the existing footprint. The total defence footprint for the Scheme in Cell 2 is 5,450 m^2 with no areas of potential encroachment as shown in as shown in Figure 9.

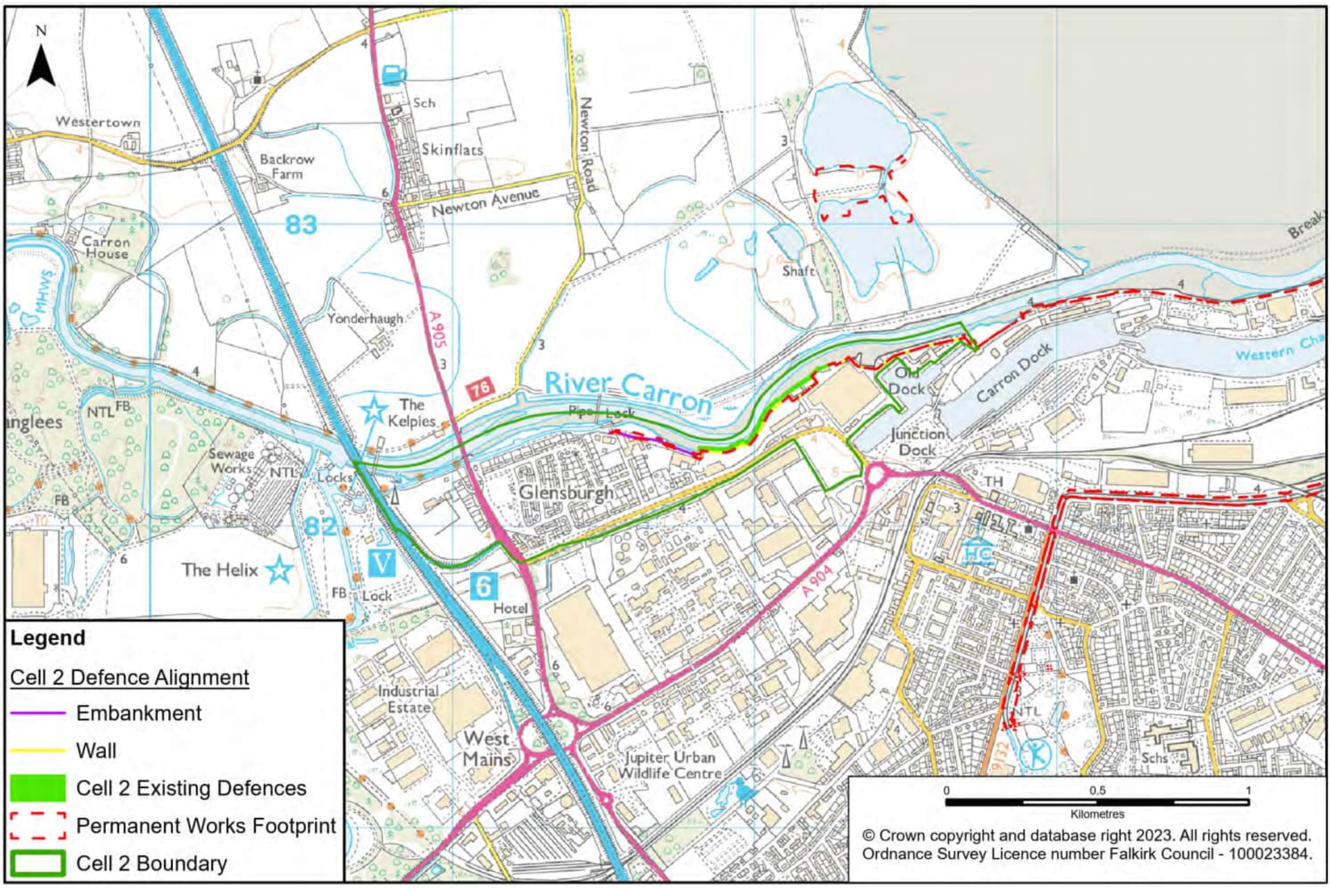

Figure 9: Proposed defence footprint in the Lower Carron Estuary - Cell 2

4.2.5.2 Potential losses of intertidal features

Negligible. This results in a Slight significance of effect for the Lower Carron Estuary.

4.2.5.3 Changes in water levels

Given that the proposed defences will be built landwards above MHW, and no encroachment into Lower Carron Estuary is predicted, the effect of the proposed defences on water levels are Negligible. This results in a Slight significance of effect for the Lower Carron Estuary.

4.2.5.4 Changes in flow speeds and directions

Given that the proposed defences will be built landwards above MHW, and no encroachment into Lower Carron Estuary is predicted, the effect of the proposed defences on flow speeds and directions are considered to be Negligible. This results in a Slight significance of effect for the Lower Carron Estuary.

4.2.5.5 Changes in estuarine morphology

Given that the proposed defences will be built landwards above the MHW, and no encroachment into Lower Carron Estuary is predicted, no losses of natural banks are likely.

The proposed defences are not likely to modify the sediment regime due to their landward position away from flow within the waterbody. Therefore, the effect of the proposed defences on estuarine morphology is Negligible. This results in a Slight significance of effect for the Lower Carron Estuary.

Given that tidal flows are only likely to marginally increase at a localised location, bed scour or intertidal erosion due to higher flow velocities is not likely to increase above background conditions. Therefore, the magnitude of impact is reported as Negligible. This results in a Slight significance of effect for the Lower Carron Estuary.

The proposed defences along Cell 2 will constrain approximately 64 % of the south bank of the Lower Carron Estuary. All the areas to receive new defences, however, are already constrained by residential and industrial properties including Grange Dock. In terms of modifications to the sedimentary regime, the proposed defences are not likely to change patterns of erosion of the riverbanks given the level of containment under baseline conditions. Therefore, the magnitude of impact is reported as Negligible. This results in a Slight significance of effect for the Lower Carron Estuary.

4.2.5.6 Changes in estuarine geomorphology response under a scenario of climate change

The proposed defences along Cell 2 will be located in areas constrained by industry and infrastructure. In the absence of the Scheme, these areas would not develop intertidal areas in the future due to the modified nature of the backing land, albeit there would be a potential increase in tidal inundation under a scenario of sea-level rise. Therefore, the magnitude of impact is reported as Negligible. This results in a Slight significance of effect for the Lower Carron Estuary.

Under a scenario of sea-level rise, the Scheme would restrict the propagation of high water levels during storms. An increase in sea levels in the future could result in faster tidal flows within Cell 2, which could increase the erosion of intertidal features within the Lower Carron Estuary. However, given that this section of the Carron is already constrained, the potential geomorphological changes under a scenario of climate change are anticipated to be Negligible, resulting in a Slight significance of effect.

4.2.6 Cell 3

4.2.6.1 Scheme Overview

In Cell 3, the existing defence footprint area totals 51,673 m^2. The proposed defence footprint is 13,587 m^2. The majority of the proposed defences will be built within the same footprint of the existing defences, and / or set back from MHW, as shown in Figure 10. The exception to this is on the right bank of the Lower Carron Estuary (Area 1 in Figure 10), across both locks to the Navigation Channels of Forth Estuary and at the bay north-east of Grangemouth Docks (Area 2 and 3). In these locations the proposed defences will be built slightly seawards of the existing defence footprint. This accounts for a total of 865 m^2 of encroachment, of which 361 m^2 would be located within the Lower Carron Estuary and 504 m^2 at the estuarine frontage of the Middle Forth Estuary.

The seaward facing side of the proposed defence will include rock revetment adjacent to the harbour entrance and scour protection revetment along the North Shore Road defences.

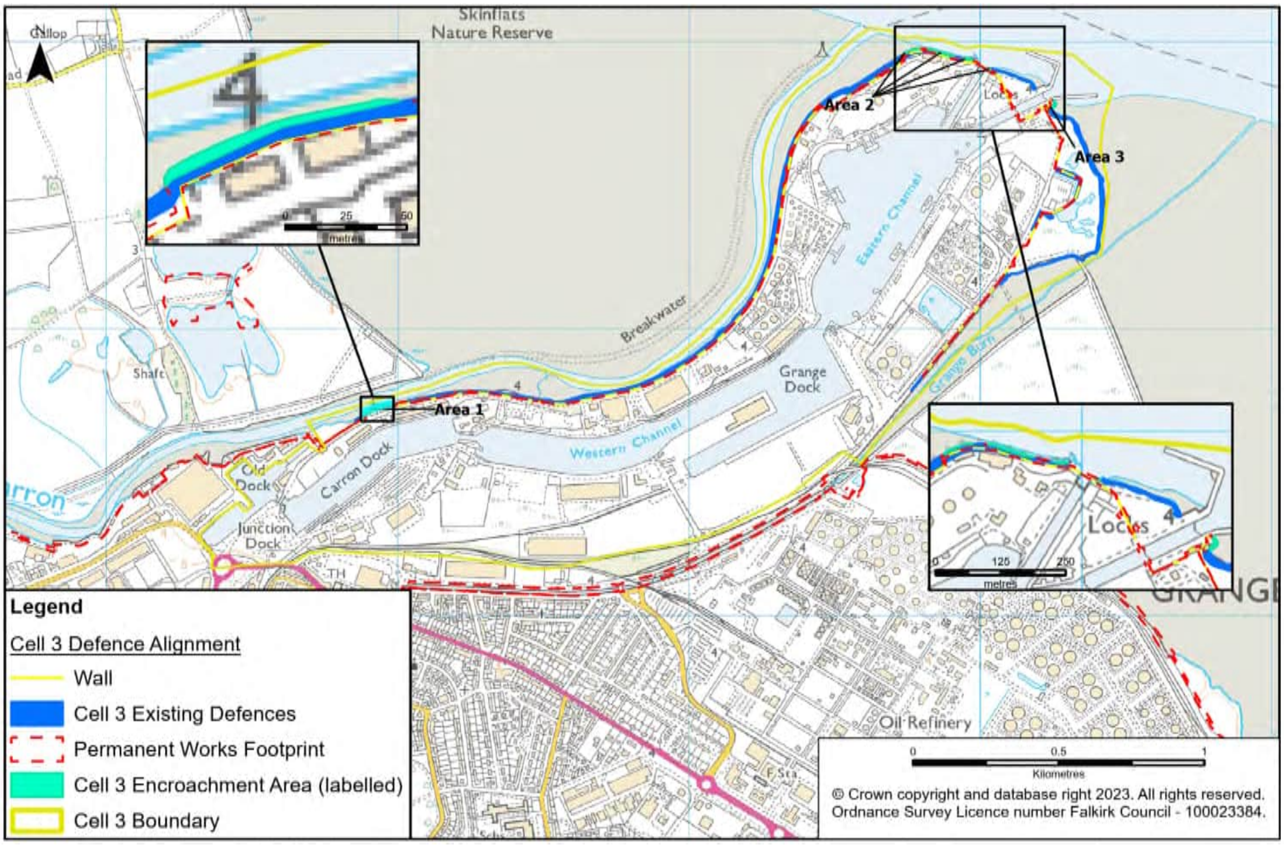

Figure 10: Existing and proposed defence footprint, location, and alignment in Cell 3

4.2.6.2 Potential losses of intertidal features

Within the Lower Carron Estuary (Area 1), encroachment areas would result in a loss of non-designated intertidal habitat (mud) of 361 m^2. Considering this is a small area and the habitat is not designated, the magnitude of impact is reported as Negligible. This results in a Slight significance of effect for the Lower Carron Estuary.

Along the estuarine frontage of the Middle Forth Estuary (Areas 2 and 3) this intertidal habitat loss is equal to 504 m^2 which is within the designated Firth of Forth RAMSAR and SSSI. Considering that this total loss of designated mudflats accounts for approximately 0.0007 % of the total area of the Firth of Forth SSSI and Ramsar, the magnitude of impact is reported as Negligible. This results in a Slight significance of effect for the Middle Forth Estuary.

4.2.6.3 Changes in water levels

The encroachment area provided in Section 4.2.6.1 represents 0.001 % of the plan area of the Middle Forth Estuary. This level of encroachment is very unlikely to impact on water levels and, therefore, the magnitude of impacts is reported as Negligible. This results in a Slight significance of effect for the Middle Forth Estuary.

Considering the small area of encroachment relative to the waterbody scale for the Lower Carron Estuary and the estuarine frontage of the Middle Forth Estuary, the magnitude of impacts on these receptors is reported as Negligible. This results in a Slight significance of effect for the Lower Carron Estuary and Neutral significance of effect for the Middle Forth Estuary.

4.2.6.4 Changes in flow speeds and direction

The majority of the proposed Cell 3 defences will have no impact on flows since the new defences will be mostly contained within the footprint of the old defences or moved landwards.

The exceptions to this are on the right bank to the Lower Carron Estuary (Area 1) and at the bay located north-east of Grangemouth Port (Area 3), where the proposed defences will protrude slightly into the estuary. Tidal flows are relatively slow at this section of the Lower Carron Estuary (less than 0.10 m/s as shown in Section 3.5.1). The area of encroachment would be localised relative to the water body scale, the magnitude of impact of changing tidal flow speeds is reported as Negligible for the Lower Carron Estuary and Middle Forth Estuary. This results in a Slight significance of effect for the Lower Carron Estuary and Middle Forth Estuary.

As discussed in Section 3.4.1, flow speeds at the subtidal channel close to Grangemouth vary between 0.30 m/s and 0.80 m/s, and the speed decreases over shallow intertidal areas. It is therefore, likely that flow speeds adjacent to Area 2 are slower than those observed within the subtidal channel. It is also important to note that this area currently has a gravel embankment in place (see Section 3.3).

Given the likely low flow speeds and that an existing defence is in place in Area 2, any potential changes in flow speeds and direction due to the proposed defence are likely to be small and localised. This results in a Neutral significance of impact.

4.2.6.5 Changes in estuarine morphology

For most areas in Cell 3 there will be no impact on estuarine morphology given the majority of the proposed defences will be contained within the footprint of the old defences or moved landwards. The areas of potential encroachment (Lower Carron Estuary and estuarine frontage of the Middle Forth Estuary) will represent a loss of intertidal habitat of 361 m^2 within Lower Carron Estuary and 504 m^2 within Middle Forth Estuary. This has the potential to marginally reduce sediment supply locally to the adjacent intertidal areas. The total area of intertidal encroached upon is small in relation to overall intertidal habitat within the Middle Forth and Lower Carron Estuaries. It is unlikely that such a small area of encroachment will promote a discernible change to the current sediment supply. Therefore, the magnitude of impact is reported as Negligible, resulting in a Slight significance of effect for the Middle Forth Estuary and Lower Carron Estuary.

Changes in flow speeds and direction are likely to be small and localised and therefore the potential increase in bed scour and indirect intertidal erosion are likely to be indiscernible. Therefore, the magnitude of impact is reported as Negligible. Resulting in a Slight significance of effect for the Middle Forth Estuary.

Areas where defences will be built in a setback position (such as at the northeast of Grangemouth Port) are not likely to cause changes in estuarine morphology given their scale in relation to the overall scale of the Middle Forth and Carron Estuaries. Therefore, the magnitude of impact is reported as Negligible for the Lower Carron Estuary and Middle Forth Estuary. The long-term impacts of these are considered under a climate change scenario in Section 4.2.6.6.

4.2.6.6 Changes in estuarine geomorphology response under a scenario of climate change

The entire Flood Cell 3 frontage is composed of made ground as a result of historic land reclamation (Section 3.3). Ground elevations range between 3.10 m and 6.50 m and given the present-day MHWS is at 3.05 m (Section 3.5.1). The estuarine area within Cell 3 under current sea level conditions is too high to develop saltmarsh. However, this could change as a result of future sea level rise (Section 3.7). Sea level rise would reduce the MHWS elevation, allowing the development of saltmarsh by 2030 (with a 0.10 m SLR at predicted rates) on the northeast section of Grangemouth Port (Area 3 in Figure 10), in the area between the estuarine frontage and the existing set back defence. Given that the Scheme is proposing a set-back defence at the same location as the existing embankment (Figure 10), the proposed structures will not change the development of saltmarsh in this area in the future. Any changes in estuarine geomorphology response under a scenario of climate change at the estuarine frontage is therefore considered to be of negligible magnitude.

The natural development of intertidal habitats along the left bank of the Lower Grange Burn Estuary (Figure 10) under rising sea levels could potentially change water levels or flow speeds within Grange Burn, with a marginal increase in water levels during high tides and increase in peak flow speeds during mid to high tides. Those changes would, however, be characterised as natural, given that there are no proposals to actively change defences in this location.

The frontages along the Lower Carron Estuary and Middle Forth Estuary are already constrained by defences and / or high made ground and, even in a future baseline scenario (i.e. without the proposed defences) would not develop intertidal habitats in the future. In addition, intertidal habitats are not likely to suffer coastal squeeze at least up to 2070 (Section 3.7). The proposed defences along both frontages are not likely to cause changes in estuarine geomorphology response under a climate change scenario. Therefore, the magnitude of impact is reported as Negligible for both receptors. This results in a Slight significance of effect for the Lower Carron Estuary and Middle Forth Estuary.

4.2.7 Cell 4

4.2.7.1 Scheme Overview

In Cell 4, most of the proposed defences will be built adjacent to the Lower Grange Burn Estuary and will comprise of flood walls. There is one area of potential encroachment of intertidal area along the Lower Grange Burn Estuary of 26 m^2 as shown in

Figure 11.

The total proposed defence footprint in the tidal sections in Cell 2 is 7,792 m^2.

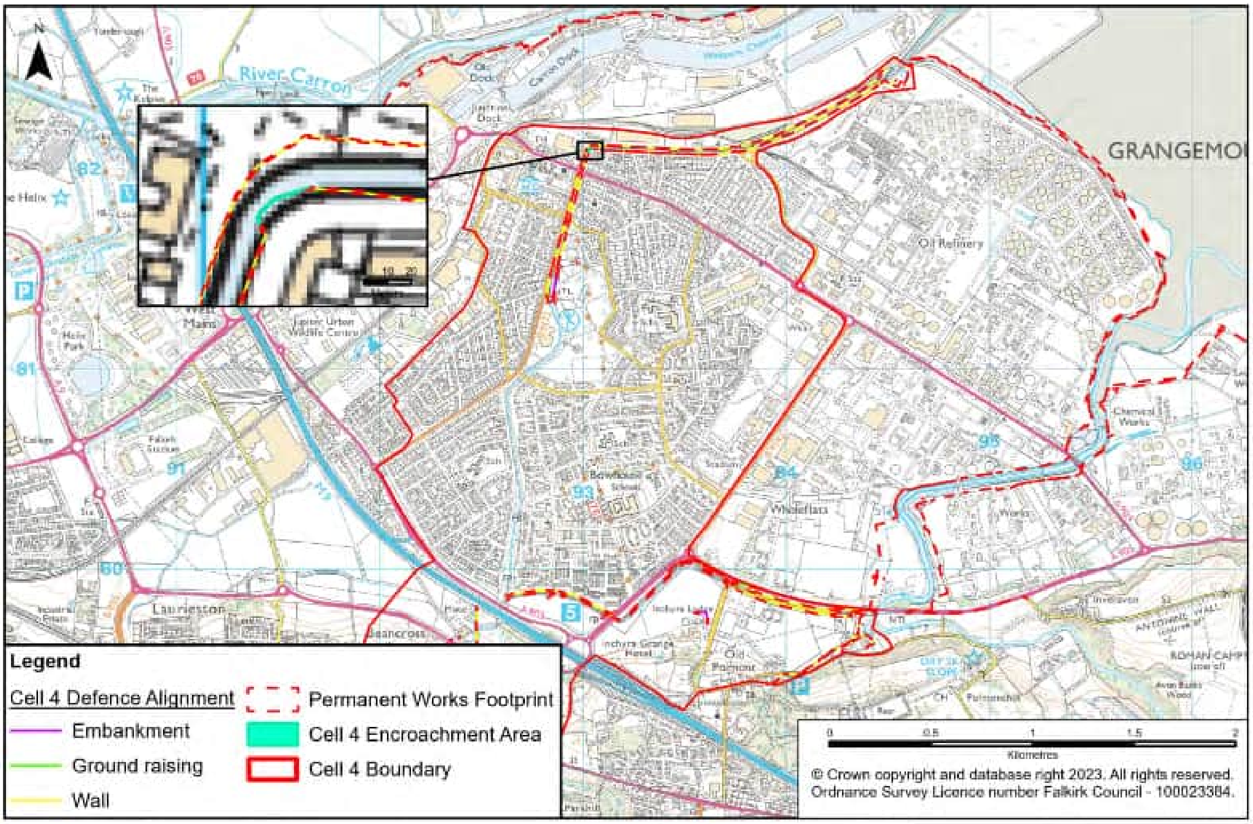

Figure 11. Proposed approximate defence footprint in Cell 4

4.2.7.2 Potential losses of intertidal feature

The Scheme within tidal section of Cell 4 has a total footprint of 7,792 m^2. There is one very small potential area of encroachment, and resulting loss of intertidal area, into the Lower Grange Burn Estuary of 26 m^2 (

Figure 11). Given the size of the potential encroachment are with regards to the overall waterbody scale, the magnitude of impact is reported as Negligible. This results in a Slight significance of impact on the Lower Grange Burn Estuary.

4.2.7.3 Changes in water levels

Such a small area of encroachment (26 m^2) is unlikely to result in discernible changes in water levels at the water body scale, with any changes being small and extremely localised to the encroachment area. Therefore, the magnitude of impact is reported as Negligible. This results in a Slight significance of effect for the Lower Grange Burn Estuary.

4.2.7.4 Changes in flow speeds and direction

The proposed defences within Cell 4, when adjacent to the river margins will be constructed following the current channel alignment. At their set back position, the proposed defences will be above MHW, therefore, changes in flow speeds and directions are considered of Negligible Impact. This results in a Slight significance of impact for the Lower Grange Burn Estuary.

4.2.7.5 Changes in estuarine morphology

The proposed defences are not likely to modify the sediment regime or natural bank profile due to the landward position in which they will be built. Likewise, effects in terms of potential scour increase at the defence toe are not likely to occur. Therefore, the effect of the proposed defences on estuarine morphology is considered to be Negligible. This results in a Slight significance of effect for the Lower Grange Burn Estuary.

Given that tidal flows are only likely to marginally increase within the vicinity of the encroachment, bed scour or intertidal erosion due to higher flow velocities is not likely to increase above background conditions. Therefore, the magnitude of impact is reported as Negligible, resulting in a Slight significance of impact for Lower Grange Burn Estuary.

The proposed defences along Cell 4 will constrain 100 % of both the north and south banks of the Lower Grange Burn Estuary. This will reduce the cross-sectional area of the channel during higher flows. However, the areas along the north and south banks where new defences are proposed are already constrained by properties and roads. In terms of modifications to the sedimentary regime, the proposed defences are not likely to significantly change patterns of erosion. Therefore, the magnitude of impact is reported as Minor Adverse. This results in a Slight significance of impact on the Lower Grange Burn Estuary.

4.2.7.6 Changes in estuarine geomorphology under a scenario of climate change

The proposed defences along Cell 4 will be located at areas already constrained by properties and infrastructure. In the absence of the Scheme, these areas would not develop intertidal areas in the future. Therefore, the magnitude of impact is reported as Negligible, resulting in a Slight significance of impact for Lower Grange Burn Estuary.

4.2.8 Cell 5

4.2.8.1 Scheme Overview

In Cell 5, most of the proposed defences will comprise flood walls constructed on ground adjacent to the Lower Avon Estuary intertidal areas. Bank protection along some of the walls will comprise of a softer option, such as geotextile. There are two areas of potential encroachment of intertidal area along the Lower Avon Estuary of 5 m^2 (Area 1) and 124 m^2 (Area 2) as shown in Figure 12. The total defence footprint for the Scheme in Cell 5 is approximately 10,031 m^2. The remaining area of proposed defences will be built above MHW, and no other areas of encroachment are predicted within Cell 5. The design of the structures will be adjusted as appropriate and constructed based on the space available without impinging in the Avon channel.

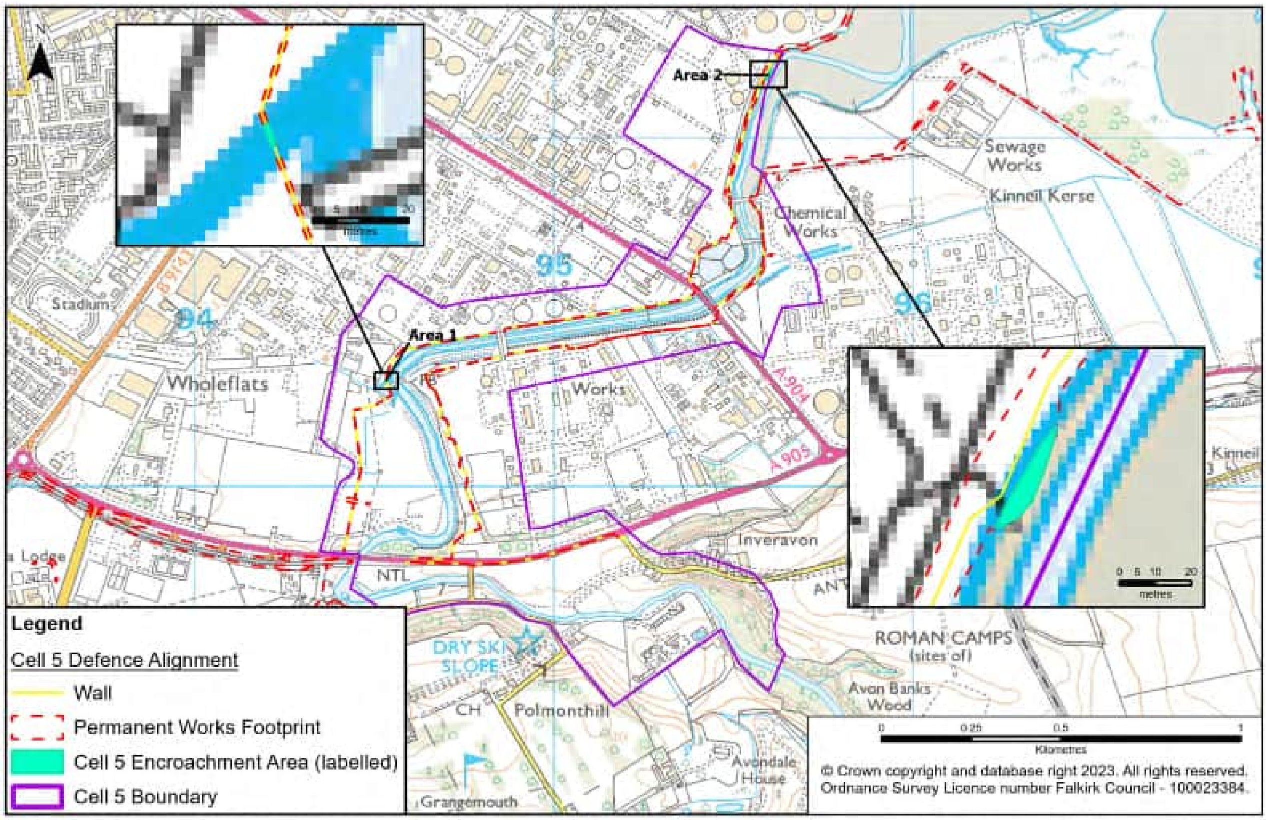

Figure 12. Proposed approximate defence footprint in Cell 5

4.2.8.2 Potential losses of intertidal feature

The Scheme within Cell 5 has a total footprint along of 10,031 m^2. There is one very small potential area of encroachment of 5 m^2 (Area 1) and another small potential area of encroachment of 124 m^2 (Area 2) into the Lower Avon Estuary, resulting loss of intertidal area (Figure 12). Considering this is a small area and the habitat is not designated, the magnitude of impact is reported as Negligible. This results in a Slight significance of impact on the Lower Avon Estuary.

4.2.8.3 Changes in water levels

The small areas of encroachment (5 m^2 and 124 m^2) are unlikely to result in discernible changes in water levels at the water body scale, with any changes being small and extremely localised to the encroachment area. Therefore, the magnitude of impact is reported as Negligible. This results in a Slight significance of effect for the Lower Avon Estuary.

4.2.8.4 Changes in flow speeds and direction

The proposed defences within Cell 5, when adjacent to the river margins will be constructed following the current channel alignment. At their set back position, the proposed defences will be above MHW, therefore, changes in flow speeds and directions are considered of Negligible Impact. This results in a Slight significance of impact for the Lower Avon Estuary.

4.2.8.5 Changes in estuarine morphology

In Cell 5, the very small area of encroachment of 5 m^2 is on a minor tributary / creek (NGR NS 94545 80314) (Area 1 in Figure 12), and therefore not within the active channel. This area of encroachment is unlikely to change the estuarine geomorphology of the Lower Avon Estuary.

Where the potential encroachment will be located on the left bank on the River Avon (NGR NS 95595 81172) (Area 2 in Figure 12), permanent loss of natural bank would possibly occur over a length of 35 m. As already mentioned previously, an increased defence footprint in this area would be very small and above Mean Low Water (MLW). Given that the rest of the proposed defences will be built landwards above the MHW, and no further encroachment into Lower Avon Estuary is predicted, no further losses of natural bank are anticipated. The proposed defences are not likely to modify the sediment regime due to their landward position. Likewise, effects in terms of potential scour increase at the defence toe are not likely to occur. Therefore, the effect of the proposed defences on estuarine morphology is considered to be Negligible. This results in a Slight significance of effect for the Lower Avon Estuary.

Given that tidal flows are only likely to marginally increase locally, bed scour or intertidal erosion due to higher flow velocities is not likely to increase above background conditions. Therefore, the magnitude of impact is reported as Negligible. This results in a Slight significance of effect for the Lower Avon Estuary.

The proposed defences along Cell 5 will constrain around 62 % of the north bank and 75 % of the south bank of the Lower Avon Estuary. All the areas to receive new defences, however, are already constrained by industrial infrastructure associated with the oil refinery. In terms of modifications to the sedimentary regime, the proposed defences are not likely to change patterns of erosion of the riverbanks. Therefore, the magnitude of impact is reported as Negligible. This results in a Slight significance of effect for the Lower Avon Estuary.

4.2.8.6 Changes in estuarine geomorphology under a scenario of climate change

The proposed defences along Cell 5 will be located at areas already constrained by earth embankments, industry and infrastructure. Under a scenario of sea level rise, either with or without the Scheme in place, these areas would not be likely to develop as intertidal areas in the future, albeit there would be a potential increase in tidal inundation under a scenario of sea-level rise. Therefore, the magnitude of impact is reported as Negligible. This results in a Slight significance of impact for the Lower Avon Estuary.

4.2.9 Cell 6

4.2.9.1 Scheme Overview

In Cell 6, the proposed defence footprint (Figure 13) accounts for a total of 34,925 m^2. The seaward facing side of the proposed defence will be a sloped rock revetment, with two layer of rock armour overlying riprap.

Between the right bank of the Avon and Kinneil Kerse within the Middle Forth Estuary, the proposed defences will be built in a set-back position, around 60 - 750 m further inland from the existing defences. As these are not predicted to be breached or changed by the proposals, no effects on water levels or the tidal prism are predicted in this section.

Area 1 (left bank of the Avon in the Middle Forth Estuary) and Area 2 (between the promontory and the reclaimed peninsula) mark the locations where reclamation will be required in order to build the proposed defences. At these two locations, encroachment of 8,439 m^2 is predicted between the MHW and MLW, of which 1,893 m^2 is in Area 1 and 6,546 m^2 is in Area 2.

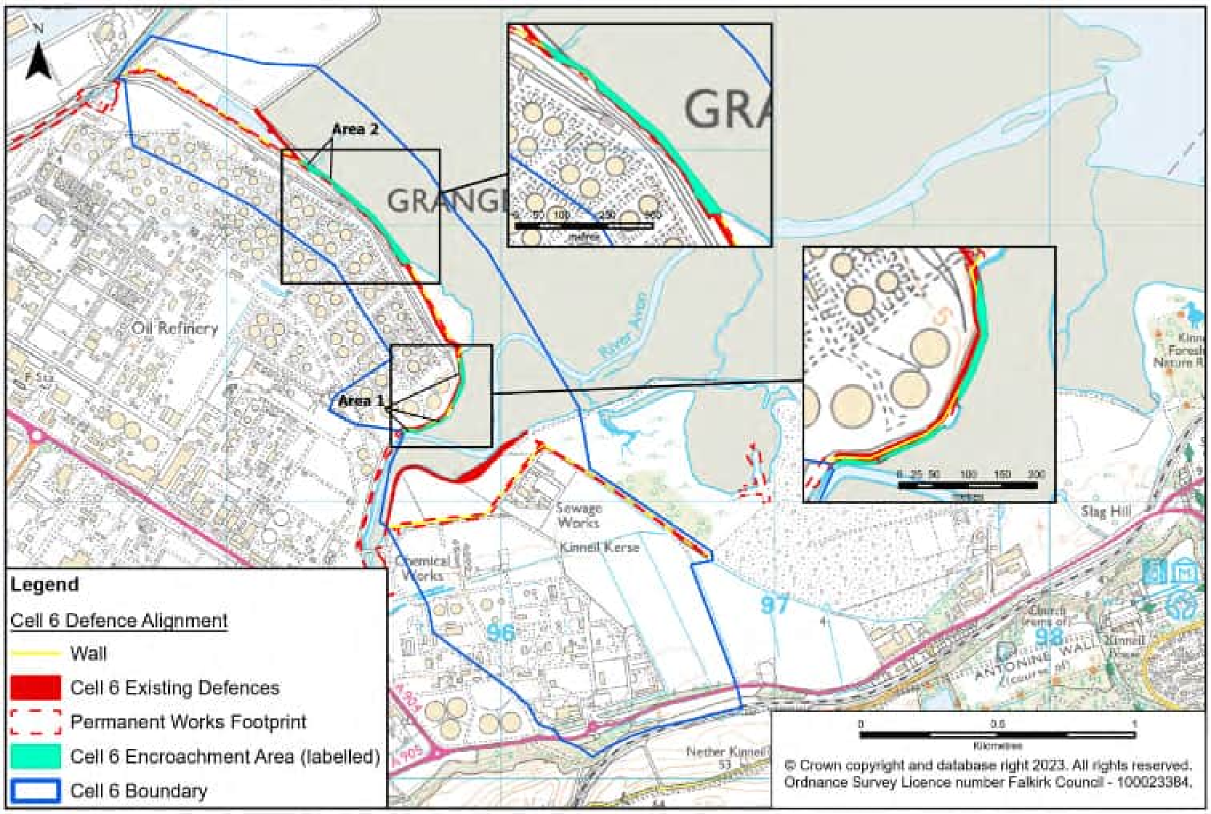

Figure 13: Existing and proposed defence footprint, location and alignment in Cell 6

4.2.9.2 Potential losses of intertidal area

A loss of 8,439 m^2 of designated intertidal area (i.e. mudflats) will be due to an increase in defence footprint in Cell 6. This accounts for a loss of 0.01 % of the total area of the Firth of Forth Ramsar and SSSI. The impacts are therefore considered to be extremely localised and likely indiscernible at the waterbody scale. The magnitude of impact is reported as Negligible, resulting Slight significance of effect for the Middle Forth Estuary and Skin Flats Nature Reserve.

4.2.9.3 Changes in water levels

The encroachment due to increases in defence footprint in both Areas 1 and 2 is unlikely to cause discernible changes to water levels to the Middle Forth Estuary given the scale of the changes in relation to the waterbody scale. In addition, the mouth of the Avon has been in a fixed position for at least 50 years due to land reclamation, with very little change in the extent of the mudflats at this location. Therefore, changes to water levels within the Middle Forth Estuary considered to be Negligible. This results in a Slight significance of impact.

4.2.9.4 Changes in flow speeds and direction

In Areas 1 and 2, the proposed increase in defence footprint will follow the current shoreline alignment, with the toe of the proposed defences placed below the MHW. In addition, the intertidal slope as measured from LIDAR (Scottish Government, 2009) below MHWN to the MLWN within these two areas is shallow, ranging between 1:50 and 1:80. As stated in Section 3.4.1, flow speeds at the subtidal area of Grangemouth vary between 0.30 m/s and 0.80 m/s depending on the stage of tides. As the intertidal mudflats at the Grangemouth frontage are wide, with a shallow slope, flow speeds at the top of the intertidal are likely to be much reduced than the subtidal values. It is therefore unlikely that the increase in defence footprint would cause a discernible change in flow speeds and direction in the Middle Forth Estuary. Therefore, the magnitude of impact is reported as Negligible. This results in a Slight significance of impact.

4.2.9.5 Changes in estuarine morphology

The increase in defence footprint in both Areas 1 and 2 will encroach into the mudflats. Although this area is designated as an important qualifying feature, its loss is considered Negligible (Section 4.2.9.2). In addition, the loss of mudflats at these two locations would unlikely cause a reduction in sediment supply, given that the fine sediments within the mudflats are related to the high concentrations of sediment in suspension within the Middle Forth Estuary (see Section 3.5).

Within both Areas 1 and 2, the slope of the intertidal is shallow. In Area 1, the leading edge of the mudflat is located around 100 m seawards of the proposed defences, whilst in Area 2, the leading edge of the mudflat is at some 2 km seawards. Predictions of sea level rise, mudflats and saltmarshes along this frontage are likely to keep pace with climate change predictions at least for the next 50 years as described in Section 3.6. The proposed defences will be built on the higher sections of the intertidal, with the defence footprint at or above MHWN. Therefore, it is unlikely that changes in estuarine morphology as a result of the Scheme would occur. The magnitude of impact is reported as Negligible. This results in a Slight significance of impact.

At Kinneil Kerse, the proposed defence alignment will be built approximately 180 - 680 m landwards of the estuarine frontage, part of the Scheme will be built at the back of the saline lagoon, with some loss of current habitat. This area, however, is not designated and the habitats to be lost are not intertidal. Changes in estuarine geomorphology in this area are unlikely.

4.2.9.6 Changes in estuarine geomorphology response under a scenario of climate change

The entire frontage within Flood Cell 6 is composed of made ground following historic land reclamation. As such elevations are higher than the Highest Astronomical Tide (HAT). As described in Section 3.6, there are two areas shown in Figure 5 (Areas A and B) which could potentially develop intertidal habitat if defences were to fail. In addition, the proposed defences will be built behind the Areas A and B.

According to the definition provided in Section 3.6, coastal squeeze is characterised by a loss of intertidal habitat due to both an existing defence in place and sea level rise. The intertidal habitats in the Middle Forth Estuary have shown to accrete over the past 100 years. The rate of SLR of which could erode saltmarshes and mudflats is not likely to be reached until 2070. Therefore, no coastal squeeze is currently occurring, nor is likely to occur for the next 50 years. By then, and if the current existing defences fronting Areas A and B fail, intertidal habitats could develop in the area between the existing and the proposed defences.

If the defences fail and intertidal habitat is developed along the right bank of the Avon within Area B, then water levels and flow speeds could potentially change along the mouth of the Avon and within the Middle Forth Estuary, increasing speeds during peak flows and increasing levels during high tides. Those changes would, however, be characterised as natural, given that there are no proposals to actively breach defences in this location.

Therefore, the proposed defences are not likely to cause coastal squeeze or changes in water levels / flow speeds along the Flood Cell 6 frontage. Therefore, the magnitude of impact is reported as Negligible for the Middle Forth Estuary. This results in a Slight significance of impact.

5. Mitigation

The Scheme is unlikely to cause significant effects to estuarine geomorphological receptors. However, mitigation items to further reduce the impacts of the Scheme on the Lower Grange Burn Estuary are presented in Table 7.

Table 7: Summary of secondary mitigation for operational phase

Item No.	Mitigation Description
W27	Soften banks on the Grange Burn (Grange Burn / Westquarter Burn) during reinstatement from Bo'ness Rd to the estuary, between NGR NS 92993 81990 and NS 94587 82541. Soft bank protection includes pre-planted coir matting or rolls which supports riparian vegetation to quickly re-establish.
W28	Reprofile the banks on the Grange Burn / Westquarter Burn along Grange Burn Road between NGR NS 93036 82090 and NGR NS 94587 82541 to restore morphological diversity to the channel. Slope reprofiling extent will limit the impact on tree and shrub cover on the north bank.

6. Residual effects

6.1 Construction phase

Residual impacts of **Slight adverse significance** or below are expected during the construction phase.

6.2 Operational phase

Residual impacts of **Slight adverse significance** or below are expected during the operational phase.

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Environmental Impact Assessment Report

Appendix C10.3 Flood Risk

Grangemouth Flood Protection Scheme 2024
Falkirk Council

GRANGEMOUTH
Flood Protection Scheme
Protecting the heart of our communities

Jacobs

Contents

1 Introduction

This appendix provides details on the impacts of flood risk from the proposed Scheme.

- This appendix is supported by the following Scheme documents:
- Grangemouth Flood Protection Scheme: Option Appraisal Summary Report (Jacobs, 2021) – see EIA Report Appendix C4.1.
- Grangemouth Flood Protection Scheme: Hydraulic Modelling Report (Jacobs, 2024a - available on request).
- Grangemouth Flood Protection Scheme: Secondary Flood Risk Assessment (Jacobs, 2024b - available on request).
- EIA Report Chapter 4: The Proposed Scheme.

2 Baseline Context

Grangemouth has a history of flooding, with records going back to 1926. Major flooding occurred in the 1950's; significant flood events occurred in 2002 and 2006 with a number of properties flooded; and several near misses have been recorded over the last 10 years, primarily due to high tide levels (Jacobs, 2018). The anecdotal and recorded evidence of flooding does not fully reflect the significance of the current flood risk to Grangemouth and the surrounding areas.

Due to the large number of residential properties, and nationally important infrastructure, being at risk of flooding, Falkirk Council instructed Halcrow (which became CH2M and is now Jacobs) in late 2011 to undertake a detailed flood risk mapping study. These investigations showed extensive inundation during a 0.5% Annual Exceedance Probability (AEP) (200-year) flood event, for both tidal and fluvial sources. This included extensive flooding to the port and petrochemical plant, predominantly caused by high tide levels and wave overtopping.

The Flood Risk Management Strategy for the Forth Estuary Local District Plan (LDP) was published in 2015 (SEPA, 2015) and identified that for the Falkirk, Grangemouth, Laurieston, Denny, Redding, Dunipace, Carron and Stenhousemuir (10/11) Potentially Vulnerable Area (PVA) there are approximately 2,000 residential and 330 non-residential properties at risk of flooding. The majority of flood risk originates from rivers (51%) with 21% originating from surface water (i.e., when the drainage capacity in the network is exceeded) and 28% from coastal sources. In December 2021 the Flood Risk Management Plan Forth Estuary Local Plan District (SEPA, 2021) was published after a period of consultation. In this document the Falkirk and Grangemouth (02/10/10) PVA was divided into eight areas for further assessment (target areas), and the Bo'ness (02/10/11) PVA into two target areas. Further details of these target areas are provided in Table 10-11 in Chapter 10: Water Environment. Concurrent with the preparation of the Flood Risk Management Strategy, CH2M were appointed by Falkirk Council to undertake an options appraisal and preferred scheme outline design for the Grangemouth Flood Protection Scheme (hereafter referred to as the Scheme).

To determine the existing flood risk in the Scheme study area, an updated linked 1D/2D hydraulic model run was undertaken using Flood Modeller software. Separate tidal and fluvial hydrological inputs were calculated for a range of flood events, as well as two combined fluvial and tidal scenarios to account for joint probability. The latest modelling results for the proposed Scheme identified that 2750 residential properties and 1200 non-residential properties are currently at risk of flooding during the 0.5% AEP (200-year) flood event (Jacobs, 2024a - available on request).

The highest risk of river flooding is from the River Carron in the Carron/Carronshore area; the Grange Burn in Grangemouth; the Westquarter Burn in Falkirk Westquarter; and the River Carron. The highest risk of coastal flooding is from the Firth of Forth in Grangemouth, and Carron/Carronshore areas.

The purpose of the Scheme is to mitigate flood risk to existing sensitive receptors and, due to the number of receptors currently at risk of flooding, these individual receptors/receptor types are not listed in detail.

A map showing the baseline modelled combined coastal and fluvial baseline 0.5% AEP (200-year) flood extents is presented in Figure B10.9 in Appendix B10.

3 Impact Assessment

3.1 Introduction

The purpose of the Scheme is to mitigate flood risk to existing sensitive receptors, however, in reducing flood risk to those receptors, adverse changes in flood depths may also be experienced elsewhere. The impact assessment for flood risk comprises a review of the hydraulic modelling undertaken to identify the beneficial and adverse impacts associated with the Scheme's construction and operation with a focus on changes to predicted flood depths with and without the Scheme during a 0.5% AEP (200-year) flood event.

3.2 Construction

At this stage the nature of in-water working areas, the flow events at which they will remain dry, and methods proposed to construct them are not currently known; therefore, modelling data of any temporary changes to flood risk during construction are not available at this stage.

3.3 Operation

3.3.1 Pluvial Flood Risk

Preliminary pluvial modelling predicted that surface water ponding during a 0.5% AEP (200-year) 1-hour storm event would be limited in extent with relatively shallow areas of inundation. However, there may be more substantial increases in depth (up to 1.4 m depth) and extent in some areas during the 6-hour storm event (Figure B10.12). Following a 6-hour storm event, there are several properties where the risk of flooding above the threshold level (i.e., bottom of front/rear doors) is increased when the defences are in place. While most properties would experience an increase of up to 0.2 m, at some locations small areas would experience increases >0.2 m. In Cell 1 locations include:

- Small areas near residential buildings and the bus depot on the right bank of the River Carron at Stirling Road (approx. NGR NS 86138 81560).
- Properties around Mungal Burn on Park Road (approx. NGR NS 88191 82278).
- Properties on Farm Street and Carronside Street on the right bank of the River Carron (approximately NGR NS 88408 82324).
- Areas near properties on Duncan Avenue on the left bank of Chapel Burn (approx. NGR NS 89018 83012).
- Properties on Dock Street and The Avenue on the left bank of the River Carron (approx. NGR NS 89445 82748 and NGR NS 89502 82944).

In Cell 2, locations include small areas of industrial properties on Dalgrain Road on the right bank of the River Carron (approx. NGR NS 92092 82421).

In Cell 3, locations include small areas of industrial properties on South Shore Road near the entrance to the Eastern Channel (approx. NGR NS 95132 83727).

In Cell 4, locations include:

- Properties on Grandsable Road on the right bank of Westquarter Burn (approx. NGR NS 92431 79410).
- A hotel on the right bank of Polmont Burn (approx. NGR NS 92642 79444).
- Inchyra Lodge (approx. NGR NS 93595 79768).
- Properties at Millhall Gardens on the left bank of Millhall Burn (approx. NGR NS 93945 79441).
- Properties around Milnholm Farm on the right bank of Millhall Burn (approx. NGR NS 94339 79638).
- Properties on Reddoch Road on the left bank of Millhall Burn and right bank of the Grange Burn Flood Relief Channel (approx. NGR NS 94333 79739).

No properties within Cell 5 and Cell 6 are affected by increases >0.2 m.

Based on these modelling outcomes, and following the approach outlined in Chapter 10: Water Environment, impacts from surface water flooding during operation are anticipated to be of Major magnitude, resulting in an effect of **Very Large Adverse** significance.

3.3.2 Fluvial and Coastal Flood Risk

A desk review was undertaken to compare the changes to flood extents and peak flood depths with the Scheme in place during the 'design flood event', defined as the 0.5% Annual Exceedance Probability (AEP) (200-year) flood event. The with-scheme modelling results are shown in Figure B10.10. Comparison was made against the baseline modelling of the design flood event without the Scheme. Individual or specific receptors/receptor types are only considered within the impact assessment where a change (increase or decrease) in flood depth and/or flood extent is predicted as a result of the Scheme.

The assessment follows the approach outlined in Chapter 10: Water Environment, however, further detail on the assigning of Receptor Importance is detailed below in Table 1-1, together with magnitude (Table 1-2) for reference.

Table 1-1: Guidance for Assigning Receptor Importance

Importance	Description	Examples
Very High	Most Vulnerable Land Uses, including critical/essential infrastructure as defined in SEPA LUPS-GU24 (SEPA, 2018) at risk from flooding during the 0.5% AEP (200-year) or 0.5% AEP (200-year) plus CC event.	Essential transport infrastructure (including mass evacuation routes), essential utility infrastructure (electricity generating power stations and grid and primary sub-stations, sewage treatment plants and water treatment works, wind turbines and other energy generating technologies), police stations, ambulance stations, fire stations, command centres and telecommunications installations required to be operational during flooding, emergency dispersal points, hospitals, schools, care homes, nurseries, residential institutions, e.g. prisons, children's homes, basement dwellings, isolated dwelling(s) in sparsely populated areas, dwelling houses situated behind informal embankments, caravans, mobile homes, chalets and park homes intended for permanent residential use, holiday caravan, chalet, and camping sites, installations requiring hazardous substance consent (e.g. Ineos)
High	Highly Vulnerable Land Uses as defined in SEPA LUPS-GU24 (SEPA, 2018) at risk from flooding during the 0.5% AEP (200-	Buildings used for dwelling houses, social services homes (ambulant/adult), hostels and hotels, student halls of residence, non-residential uses for health service, landfill and sites used for waste management facilities for hazardous waste

Importance	Description	Examples
	year) or 0.5% AEP (200-year) plus CC event.	
Medium	Least Vulnerable Land Uses as defined in SEPA LUPS-GU24 (SEPA, 2018) at risk from flooding during the 0.5% AEP (200-year) or 0.5% AEP (200-year) plus CC event.	Shops, financial, professional, and other services, restaurants and cafés, hot-food takeaways, drinking establishments, nightclubs, offices, general industry, storage and distribution, non-residential institutions not included in Most Vulnerable or Highly Vulnerable Uses, assembly and leisure, land and buildings used for agriculture and forestry that are subject to planning control, waste treatment (except landfill and hazardous waste facilities), minerals working and processing (except for sand and gravel).
Low	Water Compatible Land Uses as defined in SEPA LUPS-GU24 (SEPA, 2018) at risk from flooding during the 0.5% AEP (200-year) or 0.5% AEP (200-year) plus CC event.	Flood control infrastructure, environmental monitoring stations, water transmission infrastructure and pumping stations, sewage transmission infrastructure and pumping stations, sand and gravel workings, docks, marinas and wharves, navigation facilities, MOD installations, ship building, repairing, and dismantling, dockside fish processing and refrigeration and compatible activities requiring a waterside location, water-based recreation (excluding sleeping accommodation), lifeguard and coastguard stations, amenity open space, nature conservation and biodiversity, outdoor sports and recreation and essential facilities such as changing rooms, essential ancillary sleeping or residential accommodation for staff required by uses in this category, subject to a specific operational warning and evacuation plan.

Table 1-2 Guidance for Assigning Magnitude

Magnitude	Definition
Major Adverse	A loss of flood storage and/or significant increase in flood risk (i.e., an increase in the 0.5% AEP peak flood level >100 mm).
Moderate Adverse	An increase in flood risk (i.e., an increase in the 0.5% AEP peak flood level >50 mm and <100mm).
Minor Adverse	A slight increase in flood risk (i.e., an increase in the 0.5% AEP peak flood level >10 mm and <50mm).
Negligible	An insignificant increase in flood risk (i.e., an increase in the 0.5% AEP peak flood level <±10 mm);

While the Scheme will significantly reduce flood depths at receptors within the areas protected by the defences, some receptors within the vicinity of the Scheme will experience increased flood depths compared to the fluvial and coastal flood risk baseline. Some areas within the vicinity of the Scheme will also experience increased flood levels as they are being used intentionally as additional flood storage as part of the Scheme.

Figures B10.11a and B10.11b show the areas where increases and decreases in flood depths are predicted, respectively. Each area has been assigned a reference, I1 to I10 and D1-D13, with 'I' and 'D' indicating 'increased' and 'decreased' flood depths.

The corresponding impacts are detailed in Table 1-3 below. Where impacts to multiple receptors have been identified within a single area, the highest importance receptor has been used to inform the impact magnitude and significance.

Table 1-3: Changes in flood depth compared to the baseline scenario.

Location ID	Watercourse (bank)	Flood Cell	Description	Receptor	Receptor Importance	Magnitude	Significance
Beneficial Impacts (decreased flood depths)							
D1	River Carron (right bank)	1	**A9 Stirling Road, 0.37 km north west of Camelon Roundabout (NS 86755 80952), to 0.28 km south east of Lochlands Avenue junction with A9 Stirling Road (NS 86203 81617):** Flood risk removed during the 0.5% AEP (200-year) flood event to properties (bus depot, industrial properties and residential properties) on the southern side of Stirling Road, and to the road itself. Smaller decreases in flood depths of -0.1 m to -0.01 m to properties (industrial and residential) are present north of Stirling Road over an area of approximately 0.06 ha. Further isolated decreases in flood depths to the River Carron floodplain, north of Stirling road, of -0.01 m to -0.5 m totalling approx.0.9 ha and substantial decreases in flood depths to the golf course south of Stirling Road of -2 m to -0.5 m (approx. 5.8 ha).	River Carron floodplain, Bus depot, Industrial estate, Residential properties, Stirling Road (A9), Falkirk Golf Club.	High	Major Beneficial	Very Large Beneficial
	River Carron (left bank)	1	**River Carron flood plain north west of Dorrator Bridge (NS 86541 81428):** Decrease in peak flood depths of <-0.01 m during the 0.5% AEP (200 year) flood event over an area of approximately 1.7 ha in the River Carron floodplain on the left bank.	River Carron floodplain, Agricultural land.	Medium	Negligible	Slight Beneficial
D2	River Carron (right bank)	1	**Park Road and Sainford Crescent by Carron Road (NS 88232 82292):** Flood risk removed during the 0.5% AEP (200-year) flood event.	River Carron floodplain, Residential properties in Sainford Crescent and Park Road, Stenhouse Road, Church (Dawson Community Church), Parkland.	High	Major Beneficial	Very Large Beneficial
	River Carron (left bank)	1	**West of New Carron Road (B902), south of Carron Roundabout (NS 88167 82566):** Flood risk removed during the 0.5% AEP (200-year) flood event.	River Carron floodplain, Residential properties at Burder Park,	High	Major Beneficial	Very Large Beneficial

Location ID	Watercourse (bank)	Flood Cell	Description	Receptor	Receptor Importance	Magnitude	Significance
			South of Carronshore Road from the Chambers Drive to The Meadows and properties at Duncan Avenue: Flood risk removed during the 0.5% AEP (200-year) flood event.	Residential properties at Bryce Avenue, Chambers Drive, Anderson Drive, Mylne Place, Cameron Place and Duncan Avenue.			
D3	River Carron (left bank)	1	**Dock Street to Riverside Stables (NS 89457 82748):** Flood risk removed during the 0.5% AEP (200-year) flood event. **Carron House and Carronhouse Cottage:** Small decreases in peak flood depths of <-0.01m during the 0.5% AEP (200-year) flood event. **Carron House to M9 crossing:** Decreases in peak flood depths in relict meander bends of the River Carron of -0.1 m to -0.01 m during the 0.5% AEP (200-year) flood event.	Residential properties around Dock Street, River Carron floodplain, Riverside Stables, Carron House, Carronhouse Cottage.	High	Major Beneficial	Very Large Beneficial
	River Carron (right bank)	1	**Abbotshaugh Community Woodland:** Small decreases in peak flood depths typically <-0.01m in the River Carron floodplain within the woodland and along the channel of Bainsford Burn.	Abbotshaugh Community Woodland, River Carron floodplain.	Low	Negligible	Neutral
D4	Forth Estuary River Carron (left bank)	2	**Coastline around Skinflats, Skinflats Nature Reserve, (NS 91141 83055):** Localised increases can be seen along the coastline although these do not reflect a wider scale change in the flood risk and are likely related to the influence of the nearby boundary conditions.	Residential properties at Skinflats, Agricultural land.	High	Negligible	Slight Beneficial
D5	River Carron	2	**Queen Elizabeth Canal (right bank) from M9 crossing (NS 90768 82106) to Glensburgh Road (A905) (NS 91044 82207):** Flood risk removed during the 0.5% AEP (200-year) flood event. **Queen Elizabeth Canal (right bank) A905 crossing (NS 91057 82213) to industrial land on north of Dalgrain Road (NS 91982 82231):** Flood risk removed during the 0.5% AEP (200-year) flood event. **Industrial land north of Dalgrain Road (NS 91982 82231) to Junction Dock and Old Dock to North Shore Road at NS 92809 82607:** Flood risk removed during the 0.5% AEP (200-year) flood event.	River Carron floodplain, Rugby Pitches (Grangemouth Stags Rugby Club), Dalgrain Park, Residential properties within Glensburgh housing estate,	Very High	Major Beneficial	Very Large Beneficial

Location ID	Watercourse (bank)	Flood Cell	Description	Receptor	Receptor Importance	Magnitude	Significance
				Industrial land including goods warehouse, Electricity substations and pumping stations, Junction Dock and Old Dock.			
D6	Carron Dock, Grange Dock, Forth Estuary	3	**Carron Dock and Grange Dock, Western and Eastern Channels (NS 92508 82372 to NS 95201 83820):** Flood risk removed during the 0.5% AEP (200-year) flood event.	Old Dock, Carron Dock, Grange Dock, West and East Jetty, Rail lines, Oil distribution depot, Industrial land, Electricity substations.	Very High	Major Beneficial	Very Large Beneficial
D7 & D8	Forth Estuary, River Avon	4/5/6	**Oil refinery centred on approx. NGR NS 94864 81565:** Flood risk removed during the 0.5% AEP (200-year) flood event.	Forth Estuary, River Avon floodplain, Oil Refinery (INEOS), Industrial land.	Very High	Major Beneficial	Very Large Beneficial
D9	River Avon, Forth Estuary	5/6	**Oil Refinery on River Avon right bank north of Wholeflats Road (A905) (NS 94704 79791), along the right bank to Kinneil Kerse Sewage Works (NS 96138 81161) to Grangemouth Road (A904) at NS 97553 80486:** Flood risk removed during the 0.5% AEP (200-year) flood event.	River Avon floodplain, Forth Estuary, Oil Refinery (INEOS), Industrial land, Agricultural land, Kinneil Kerse WWTP.	Very High	Major Beneficial	Very Large Beneficial
D10	Westquarter Burn	4	**Westquarter Burn A9 (NS 92468 79602) crossing to M9 (NS 92480 79811), along south edge of M9 to NS 92176 80003:** Flood risk removed during the 0.5% AEP (200-year) flood event.	Westquarter Burn floodplain, Retail parks with hotels, Nursery,	Very High	Major Beneficial	Very Large Beneficial

Location ID	Watercourse (bank)	Flood Cell	Description	Receptor	Receptor Importance	Magnitude	Significance
			Areas of agricultural land north of the A9, north of Laurieston and Beancross (NS 90968 80028 to NS 91924 79946): Flood risk removed during the 0.5% AEP (200-year) flood event. There are smaller decreases in flood risk of -0.5 m to -1.0 m in the fields south of the M9, centred at NGR NS 91652 80276 and NS 91883 80195, with some isolated areas decreasing by -1.0m to -1.5m. **Thornbridge Industrial Estate and rail dept south of M9 (NS 91487 80797):** Flood risk removed during the 0.5% AEP (200-year) flood event. Small areas of flood risk remain along Laurieston Road and within woodland between the rail depot and M9 with decrease in peak flood depths of -1.0 m to -0.5 m during the 0.5% AEP (200-year) flood event. **West of Grandsable Cemetery, 0.25 km north west of the Grandsable Road junction with Polmont Road (A803) (NS 92173 79150) on the right and left bank of the meander, and at the north of the cemetery (NS 92438 79422):** Decrease in peak flood depths of <-0.01 m to -1.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 0.7 ha in the Westquarter Burn floodplain, spread across the right and left banks over woodland and grassland. A further area of approximately 0.5 ha to the north of the cemetery and on Grandsable Road in the vicinity of the Westquarter Burn crossing, has decreases of -2.0 m to -0.01 m.	Agricultural land, Thornbridge Industrial Estate, Rail distribution depot, Newlands Cottage (residential), Grandsable Cottage (residential), Grandsable Cemetery, Electrical substation.			
	Polmont Burn		**Upstream of Polmont Burn A9 crossing, from approx. NS 92593 79550 to approx. NS 92744 79375:** Flood risk removed during the 0.5% AEP (200-year) flood event.	Polmont Burn floodplain, Retail parks with hotels and garden centre, Agricultural land., Electrical substation.	Very High	Major Beneficial	Very Large Beneficial
D11	Grange Burn (right bank)	4	**Dalratho Road crossing (NS 92919 81749), north east of Carronflats Road, to Queen Street junction with Albert Avenue (NS 93774 82057) and around**	Grange Burn floodplain, Residential properties and places of worship on right	High	Major Beneficial	Very Large Beneficial

Location ID	Watercourse (bank)	Flood Cell	Description	Receptor	Receptor Importance	Magnitude	Significance
			the Oxgang Road junction with Bo'ness Road (A904): Flood risk removed during the 0.5% AEP (200-year) flood event.	bank north of Dalratho Road/Carronflats Road, Residential properties north of Bo'ness Road (A904), Zetland Park.			
	Grange Burn (left bank), Westquarter Burn, Polmont Burn	4	**Beancross Road (A905) to Bo'ness Road (A904):** Flood risk removed during the 0.5% AEP (200-year) flood event. **Industrial land between approx. NGR NS 92325 81567 and NS 91989 82025, north-west of rail line and south-east of Forth-Clyde Way:** Flood risk removed during the 0.5% AEP (200-year) flood event.	Grange Burn floodplain, Police Station, Zetland Nurseries (pre-school), Housing east of railway to left bank, Industrial land east and west of railway and west of Earls Road (A904) Retail, office, leisure and administrative uses within Grangemouth Town Centre, bounded by Bo'ness Road, Union Road, Kerse Road and Abbots Road, Juniper Urban Wildlife Centre, Electrical substation.	Very High	Major Beneficial	Very Large Beneficial
D12	Westquarter Burn, Polmont Burn,	NA	**South-east of Falkirk Road (A904) to rail line by Falkirk Stadium (NS 90969 80380) up to M9 rail crossing (NS 91533 80864):** Flood risk removed during the 0.5% AEP (200-year) flood event.	River Carron floodplain, West Mains Industrial Estate,	Very High	Major Beneficial	Very Large Beneficial

Location ID	Watercourse (bank)	Flood Cell	Description	Receptor	Receptor Importance	Magnitude	Significance
	unnamed watercourses		**West Mains Industrial Estate, north-west of Falkirk Road (A904) (NS 91094 81286):** Flood risk removed during the 0.5% AEP (200-year) flood event.	Nursery (within Falkirk Stadium), Helix Park, Rail Depot, Fuel Station (Earlsgate Service Station).			
D13	River Avon (left bank), Grange Burn Flood Relief Channel (right bank)	4	**Grange Road junction with Wholeflats Road (A905) (NS 93738 79909), along south side of Grange Burn Flood Relief Channel to Reddoch Road (NS 94358 79751), along left bank of Millhall Burn, to Smiddy Brae (NS 93982 79472):** Flood risk removed during the 0.5% AEP (200-year) flood event.	River Avon and Grange Burn Flood Relief Channel floodplain, Little Kerse Sports facility (Galaxy Little Kerse), Residential properties on Reddoch Road, Agricultural land.	High	Major Beneficial	Very Large Beneficial
Adverse Impacts (increased flood depth)							
I1	River Carron (right bank)	1	**North of Stirling Road, opposite bus depot (NS 86376 81506):** Increase in peak flood depths of 0.01 m to 0.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 0.33 ha to properties (industrial and residential) and in the River Carron floodplain on the right bank. Small increases spread over an area of approximately 5 ha south east of these properties in the River Carron floodplain. **River Carron floodplain adjacent to housing estate at Cotland Drive, downstream to housing estate at Park Road:** Increase in peak flood depths of 0.01 m to 0.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 41 ha in the River Carron floodplain on the right bank.	Industrial, residential (two properties) and commercial (Dance Studios) properties, Agricultural land, Parkland (Camelon Riverside Nature Site (as identified in the Falkirk Council LDP), River Carron floodplain, Core Paths.	High	Major Adverse	**Very Large Adverse**
	River Carron (left bank)	1	**Stirling Road (A9) crossing (NS 85984 81819) and over caravan park and (plant) nurseries:** Increase in peak flood depths of 0.01 m to 0.5 m during the	Caravan park and plant nursery,	Very High	Major Adverse	**Very Large Adverse**

Location ID	Watercourse (bank)	Flood Cell	Description	Receptor	Receptor Importance	Magnitude	Significance
			0.5% AEP (200-year) flood event over an area of approximately 0.46 ha over the caravan park and nurseries in the River Carron floodplain on the left bank. **River Carron floodplain from access track at Dorrator Bridge (NS 86667 81345) to Mill Lade, along to the unnamed waterbody confluence with River Carron (NS 87057 82094):** Increase in peak flood depths of 0.01 m to 0.1 m during the 0.5% AEP (200-year) flood event over an area of approximately 12.2 ha over the River Carron floodplain on the left bank.	River Carron floodplain, Core Paths.			
I2	River Carron (right bank)		**New Carron Road crossing to Lomond Drive at NS 89151 82428 over Abbotshaugh Community Woodland:** Increase in peak flood depths of 0.001 m to 0.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 22.3 ha over Abbotshaugh Community Woodland within the River Carron floodplain on the right bank. **Lomond Drive, east of residential properties over Langlees Community Woodland:** Isolated areas with increases in peak flood depth of <0.01 m during the 0.5% AEP (200-year) flood event.	River Carron floodplain, Cobblebrae Community Woodland, Abbotshaugh Community Woodland, Langlees Community Woodland, Core Paths.	Low	Major Adverse	**Moderate Adverse**
I3	River Carron (right bank)	2	**Queen Elizabeth II Canal on right bank of River Carron from approx. NGR NS 91528 82341 to NS 90768 82112:** Increase in peak flood depths of 0.01 m to 0.5 m during the 0.5% AEP (200-year) flood event following the route of the Queen Elizabeth II Canal.	Queen Elizabeth II Canal within River Carron floodplain.	Low	Major Adverse	Slight Adverse
I3/I4	Forth Estuary	NA	**Coastline for Skinflats Nature Reserve (including Island Farm lagoons/Bothkennar Pools), and around Skinflats (NS 91141 83055):** Localised increases can be seen along the coastline although these do not reflect a wider scale change in the flood risk and are likely related to the influence of the nearby boundary conditions.	Agricultural land.	Medium	Negligible	Neutral
I5	Forth Estuary	3	**Lock to West Jetty and East Jetty (NS 95176 83787):** Increase in peak flood depths of 0.01 m to 0.05 m during the 0.5% AEP (200-year) flood event, across the middle and outer lock gates to the East and West Jetties and the woodland north of the middle and outer lock gates over an area of approximately 1.79 ha.	Lock gates, woodland and wetland areas at Grangemouth Docks.	Low	Moderate Adverse	Slight Adverse

Location ID	Watercourse (bank)	Flood Cell	Description	Receptor	Receptor Importance	Magnitude	Significance
			West of North Shore Road at approx. NGR NS 94492 83775: Increase in peak flood depths of 0.001 m to 0.01 m over an area of approximately 0.11 ha. **Woodland and wetland area between approx. NGR NS 94625 82553 and NS 94854 82538 (also extends into area I10):** Increase in peak flood depths of 0.01 m to 0.1 m over an area of approximately 1.83 ha (additional area in I10).				
	Grange Burn	3	**Pond and wooded area adjacent to South Shore Road (NS 94567 82469):** Increase in peak flood depths of 0.01 m to 0.5 m during the 0.5% AEP (200-year) flood event, across the wooded area and pond over an area of approximately 0.39 ha.	Grange Burn floodplain.	Low	Major Adverse	**Moderate Adverse**
I6	Grange Burn	4	**No notable increases in peak flood depth outwith the Grange Burn channel.**	Grange Burn floodplain.	Low	Negligible	Neutral
I7	Westquarter Burn (left bank)	4	**North of Grandsable Cemetery (NS 92342 79453) between A803 and A9:** Increase in peak flood depths of between 0.1 to 2.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 3.9 ha within the Westquarter Burn floodplain on the left bank, up to the A9. **Left bank floodplain, north of A9 to M9 crossing (NS 92517 79747):** Increase in peak flood depths of 0.5 m to 1.5 m during the 0.5% AEP (200-year) over an area of 0.76 ha on the left bank within the Westquarter Burn floodplain immediately upstream of the M9 crossing.	Westquarter Burn floodplain, Agricultural land, Murmills Road (cycle path), Core Paths.	Medium	Major Adverse	**Large Adverse**
	Westquarter Burn (right bank)	4	**North and west of Grandsable Cemetery (NS 92328 79195):** Increase in flood depths of 0.01 m to 0.5 m over an area of approximately 0.18 of the Westquarter Burn floodplain in an area adjacent to the Grandsable Cemetery.	Outbuilding associated with Grandsable Cemetery. Westquarter Burn floodplain.	Low	Major Adverse	**Moderate Adverse**
	Westquarter Burn (right bank) Polmont Burn	4	**East of Grandsable Road, south of A9 crossings (NS 92472 79581 and NS 92596 79554):** Increase in peak flood depths of 0.01 m to 1.0 m during the 0.5% AEP (200-year) flood event over an area of approximately 0.78 ha within the Westquarter Burn and Polmont Burn floodplains. Falkirk Distillery car park not at risk based on topographical survey data (May 2020).	Westquarter Burn/Polmont Burn floodplain.	Low	Major Adverse	**Moderate Adverse**

Location ID	Watercourse (bank)	Flood Cell	Description	Receptor	Receptor Importance	Magnitude	Significance
	(left bank)		**North of A9 crossings (NS 92472 79581 and NS 92596 79554) to M9 Crossing (NS 92606 79788):** Increase in peak flood depths of 0.01 m to 1.0 m immediately upstream of the M9 crossing, over an area of approximately 0.87ha immediately north of the A9 crossings within the Westquarter Burn and Polmont Burn floodplains during the 0.5% AEP (200-year) flood event.				
	Polmont Burn (right bank)	4	**North of A9 crossing (NS 92596 79554) to M9 Crossing (NS 92606 79788):):** Increase in peak flood depths of <0.01 m between the A9 and M9 crossings, over an area of approximately 2.32 ha within the Polmont Burn floodplain during the 0.5% AEP (200-year) flood event.	Polmont Burn floodplain.	Low	Negligible	Neutral
	Grange Burn Flood Relief Channel (right bank)	4	**Rannoch Park, north of A905 (Beancross Road) crossing (NS 92642 79822) to A905 (Inchyra Road) crossing (NS 93140 79760):** Increase in peak flood depths of 0.01 m to 0.1 m during the 0.5% AEP (200-year) flood event over small, isolated areas within the park, notably to the east of the recreation ground near to the footbridge crossing. **North of Inchyra Lodge, East of the A905 (Inchyra Road) crossing (NS 93140 79760), west of Grange Road/Smiddy Brae (south of its crossing of the channel at NS 93709 79927):** Increase in peak flood depths of 1.0 m to 1.0 m during the 0.5% AEP (200-year) flood event over an area of approximately 4.85 ha near the A905, Inchyra Lodge and the right bank floodplain.	Rannoch Park. Grange Burn Flood Relief Channel floodplain, Core Paths.	Low	Major Adverse	**Moderate Adverse**
	Grange Burn Flood Relief Channel (left bank)	4	**West of A905 (Inchyra Road) crossing (NS 93140 79760):** Localised increases can be seen along the Grange Burn Flood Relief Channel left bank although these do not reflect a wider scale change in the flood risk.	Grange Burn Flood Relief Channel floodplain.	Low	Negligible	Neutral
I8	River Avon (right bank)	5	**A905 (Wholeflats Road) crossing (NS 94454 79796) to tidal limit of flood model downstream of Pipe Bridge crossing at NS 94575 80345:** Increase in peak flood depths of 0.01 m to 2.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 3.0 ha in the River Avon floodplain on	River Avon floodplain.	Low	Major Adverse	**Moderate Adverse**

Location ID	Watercourse (bank)	Flood Cell	Description	Receptor	Receptor Importance	Magnitude	Significance
			the right bank, covering woodland and grassland, on the perimeter of the refinery site. **Tidal limit of flood model downstream of Pipe Bridge crossing at NS 94575 80345 to Road 33 crossing (NS 94846 80424) to A904 (Bo'ness/Grangemouth Road) crossing (NS 95424 80535):** Increase in peak flood depths of 0.01 m to 0.1 m during the 0.5% AEP (200-year) flood event over an area of approximately 2.12 ha in the River Avon floodplain on the right bank, covering grassland, along the perimeter of the refinery site.				
	River Avon (left bank)	5	**A905 (Wholeflats Road) crossing (NS 94454 79796) to tidal limit of flood model downstream of Pipe Bridge crossing (NS 94575 80345):** Increase in peak flood depths of 0.1 m to 0.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 8.46 ha in the River Avon floodplain on the left bank, covering woodland, grassland, and industrial land. **Tidal limit of flood model to Road 33 crossing (NS 94846 80424) to A904 (Bo'ness/Grangemouth Road) crossing (NS 95424 80535):** Increase in peak flood depths of 0.01 m to 0.1 m during the 0.5% AEP (200-year) flood event over an area of approximately 0.50 ha at the edge of the River Avon channel on the left bank, along the perimeter of the refinery site. **A904 (Grangemouth Road) (NS 95424 80535) crossing to Buchan Road pipeline crossing (NS 95518 80820):** Increase in peak flood depths of 0.01 m to 0.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 1.68 ha within the River Avon floodplain on the left bank, covering refinery reservoirs and industrial land.	River Avon floodplain, Settlement ponds.	Low	Major Adverse	Slight Adverse
I9	River Avon (left bank)	5	**Pumping station (NS 95444 79636) east of Polmonthill Cottage to corner of Avondale Road 0.06 km north of Polmonthill ski slope (NS 94977 79615):** Increase in peak flood depths of 0.01 m to 0.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 1.55 ha in the River Avon floodplain on the left bank, on the inside of the meander covering the track to the pumping station, with areas toward to west on Avondale Road experiencing a higher increase of 0.5 m to 1.0 m.	River Avon floodplain, Sewage Pumping station and associated access, Agricultural land, Access road, Core Path.	Medium	Major Adverse	**Large Adverse**

Location ID	Watercourse (bank)	Flood Cell	Description	Receptor	Receptor Importance	Magnitude	Significance
			Avondale Road crossing to A905 (Wholeflats Road) (NS 94779 79733): Increase in peak flood depths of 0.01 m to 2.0 m during the 0.5% AEP (200-year) flood event over an area of approximately 0.90 ha in the River Avon floodplain on the left bank, west and east of the crossing, with a total length of approximately 0.34 km.				
	River Avon (right bank)	5	**South of Inveravon Cottages (NS 95494 79607) to Avondale Road crossing to A905 (Wholeflats Road) (NS 94779 79733), east side:** Increase in peak flood depths of 0.01 m to 1.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 5.26 ha in the River Avon floodplain on the right bank, east of the Avondale Road crossing to the A905. **Avondale Road crossing to A905 (Wholeflats Road) (NS 94779 79733), west side, to A905 crossing (NS 94454 79796):** Increase in peak flood depths of 0.1 m to 1.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 1.78 ha in the River Avon floodplain on the right bank, up to the A905.	River Avon floodplain, Inveravon woodland, Agricultural land.	Medium	Major Adverse	**Large Adverse**
	River Avon (left bank) Grange Burn Flood Relief Channel (right bank) Millhall Burn (left and right banks)	4	**East of Reddoch Road (NS 94358 79681), along River Avon left bank (NS 94438 79770) and along Millhall Burn to crossing at NS 93989 79464:** Increase in peak flood depths of 0.1 m to 1.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 0.97 ha in the River Avon floodplain on the left bank, the right bank of the Grange Burn Flood Relief Channel and the left and right bank of Millhall Burn, covering industrial land, Reddoch Road the travelling people's site.	River Avon/Grange Burn Flood Relief Channel/Millhall Burn floodplain, Pumping station, Agricultural land, Milnholm Farm / Travelling people's site.	Very High	Major Adverse	**Very Large Adverse**
I10	River Avon, Forth Estuary	6	**Woodland and wetland area between approx. NGR NS 94854 82538 to NS 95261 82239 (also extends into area I5):** Increase in peak flood depths of 0.01 m to 0.1 m over an area of approximately 2.92 ha (additional area in I5). **Northern extent of refinery on right bank of River Avon (NS 95591 80897) to Kinneil Kerse sewage works (NS 96135 81154):** Increase in peak flood	River Avon floodplain, Forth estuary coastline, Agricultural land.	Medium	Major Adverse	**Large Adverse**

Location ID	Watercourse (bank)	Flood Cell	Description	Receptor	Receptor Importance	Magnitude	Significance
			depths of 0.01 m to 0.5 m during the 0.5% AEP (200-year) flood event over an area of approximately 8.02 ha in the River Avon floodplain on the right bank, covering the grassland north of the refinery. **Kinneil Kerse grassland and woodland:** Increases in peak flood depth during the 0.5% AEP (200-year) flood event of 0.01 m to 0.1 m over an area of approximately 38.1 ha can be seen, however these do not reflect a wider scale change in the flood risk and are likely related to the influence of the nearby boundary conditions.				

4 Mitigation and Residual Impacts

4.1 Construction

It is anticipated that the contractor will be required to implement the following mitigation measures **(W11)** during construction to enable adverse impacts to be reduced (where feasible):

- In-water working areas will be agreed with SEPA and Marine Scotland through the production of method statements, with the design, timing and location of works aiming to reduce the impact on water flows and levels as far as practicable.
- In-water working areas, working platforms and other associated infrastructure will be designed to withstand flood events as far as is practicable.
- Develop a flood response plan for all activities to be located within the functional floodplain (defined here as the 0.5% AEP (200-year) flood extent).
- Any temporary works within the functional floodplain will be made resistant or resilient to flood impacts.
- If reasonably practicable, plant and material will be stored outside the 10% AEP (10-year) flood extent.
- In advance of extreme flood events (e.g., 0.5% AEP (200-year), in-water working areas will be evacuated and allowed to flood to prevent any increases in flood levels from constriction of flows.

4.2 Operation

4.2.1.1 Fluvial and Coastal Flood Risk

Where localised areas of increased tidal and fluvial peak flood depths or extent during the 0.5% AEP (200-year) event result in significant adverse effects, consultation with affected parties will be required to identify potential mitigation that is practical and appropriate to the level of flood risk at that receptor.

Discussions have taken place with affected stakeholders throughout the development of the Scheme and will continue after publication of the Scheme and through further detailed design to assess appropriate mitigation. Pluvial Flood Risk

Further pluvial modelling will be undertaken at the detailed design stage to inform the impact of surface water flooding on receptors. Where necessary, additional surface water drainage should be implemented; for example, additional storage, higher capacity drainage and/or pumping stations. The assessment will also consider the interaction of proposed flood defences with existing surface water drainage and the Scottish Water drainage and sewerage network.

5 Residual Effects

5.1 Construction

Residual effects of **Minor adverse** significance or below are expected during the construction phase, provided all proposed mitigation measures are effectively implemented. It is noted that detailed construction flood modelling should be carried out, as outlined in the mitigation section above, to confirm the potential impacts to changes in flood risk.

5.2 Operation

Overall, the residual effects associated with reduced flood risk across the Scheme area will be of **Very Large Beneficial** significance during the operation phase. However, there are localised areas within the Scheme where isolated effects of up to **Very Large Adverse** significance have been identified. Practical and appropriate mitigation will be identified at later project stages to mitigate this risk.

With regard to pluvial flood risk during operation, as outlined in the mitigation section above, modelling shall be carried out to confirm whether potentially significant impacts may arise and establish whether feasible mitigation may be required.

6 References

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Environmental Impact Assessment Report

Appendix C10.4 Groundwater

Grangemouth Flood Protection Scheme 2024
Falkirk Council

GRANGEMOUTH
Flood Protection Scheme
Protecting the heart of our communities

Appendix C10.4 Groundwater

Contents

Figures

Tables

1 Introduction

This appendix presents supporting information for Chapter 10 (Water Environment) to inform the baseline and impact assessment for groundwater receptors for the Scheme. This includes a desk study of available information, including published data from Scottish Environment Protection Agency (SEPA) and British Geological Society (BGS).

A review of available ground investigation (GI) information is presented, including historical BGS logs and previous GIs undertaken within the study area. GIs are currently ongoing for the Scheme and Phases 1-8, for which final factual reports are available, are assessed here.

This topic has close alignment with the following chapters:

- Chapter 7 – Biodiversity
- Chapter 11 – Soils, Geology and Land Contamination

This appendix is supported by Annex 10.4.1: Groundwater Dependent Terrestrial Ecosystem (GWDTE) Scoping Assessment.

2 Study Area

The general study area for groundwater bodies is defined as a 1km buffer from the alignment of the defences, which was selected to allow for the identification of groundwater resources that could reasonably be impacted by construction works or the operation of the Scheme. A more refined (<1 km) buffer was identified for particular receptors that may be supported by groundwater resources such as abstractions, Groundwater Dependent Terrestrial Ecosystems (GWDTEs) or buildings. The study area applicable to the various receptors that may be impacted by the Scheme is set out in Table 2-1.

Table 2-1: Study area for groundwater receptors

Receptor	Study Area
Groundwater Resource	1 km buffer from proposed permanent defences
GWDTEs	250 m from excavations in accordance with SEPA LUPS-GU31 (SEPA, 2017).
Groundwater abstractions	850 m from excavations as recommended by The Water Environment (Controlled Activities) (Scotland) Regulations (Scottish Government, 2011).
Watercourses	850 m from excavations as recommended by The Water Environment (Controlled Activities) (Scotland) Regulations (Scottish Government, 2011).
Buildings	Potential impacts relate to groundwater drawdown leading to subsidence of buildings. The study area for buildings is 100 m from proposed permanent defences due to the low permeability geological conditions across much of the Scheme and the maximum drawdown in excavations likely to be in the order of 5 m.

3 Aims and Objectives

The objective of this appendix is to provide a detailed baseline of the groundwater environment and present the assessment of the potential impacts of the Scheme to groundwater receptors.

The specific aims include the following:

- Provide an understanding of existing baseline groundwater conditions within the study area.
- Identify groundwater receptors and relative importance.
- Present an assessment of potential impacts to identified groundwater receptors.

- Inform the relevant EIA Chapters.

4 Baseline

4.1 Introduction

The baseline assessment presents available data for the following:

- Groundwater resource: identifies groundwater bodies and associated hydrogeology including ground conditions and groundwater levels and flow mechanisms. This section also identifies whether there are any Drinking Water Protection Areas, groundwater abstractions and surface watercourses.
- Groundwater quality: identifies likely groundwater quality within the study area based on available GI and SEPA monitoring information. This section also considers results from any available groundwater monitoring carried out during ongoing GIs and is aligned with the findings descripted in Chapter 11 (Soils, Geology and Land Contamination).
- GWDTEs: identifies potential GWDTEs within the study area and defines the likelihood of groundwater dependence.
- Buildings: identifies buildings which may be considered at risk of subsidence due to groundwater dewatering, including residential and commercial properties as well as scheduled monuments.

The following subsections provide the data used to inform the baseline assessment presented in Chapter 10: Water Environment of the EIA Report.

4.2 Aquifers

The Hydrogeological Map of Scotland (1:625,000) (BGS, 1988) shows that the study area overlies superficial aquifers from the Quaternary Period. The predominant aquifers are of limited or local potential. These are stated to comprise fine grained sands, silts and clays with localised deposits of sand, gravel and cobbles. Borehole yields are described as typically 1 l/s to 2 l/s, although yields may be larger in coarser deposits.

To the southern-most extent of the study area (Flood Cells 4 and 5), aquifers in which intergranular flow is significant are present and are described as being locally important (BGS, 1988). These aquifers comprise sand and gravel of glaciofluvial origin from terraced and gently sloping moundy ground and are of sand and silt grade through to cobble grade. The groundwater resource potential of these deposits varies according to the thickness of the saturated material, and borehole yields up to 10 l/s and exceptionally 15 l/s have been obtained.

The updated BGS hydrogeology (1:625,000) data (BGS, 2019) show the presence of the following Carboniferous sedimentary bedrock aquifers within the study area.

- Scottish Coal Measures Group: Moderately productive aquifer. Flow is virtually all through fractures and other discontinuities. This is a regional cyclic, multi-layered aquifer with low yields from the sandstone horizons. There are higher yields where mining has taken place however is poor quality water, including high iron and fluoride concentrations. This aquifer underlies Flood Cells 1 and 4.
- Clackmannan Group: Moderately productive aquifer. Flow is virtually all through fractures and other discontinuities. This is a multi-layered aquifer with low yields except where disturbed by mining. The Passage group has moderate yields up to 10 l/s. This aquifer underlies all Flood Cells except Flood Cell 1.

The hydrogeology of the Carboniferous sedimentary aquifers in the Midland Valley is complex due to the cyclical sedimentary sequence of alternating fine- and coarse-grained rocks which form multi-layered aquifers. In this scenario, sandstone units effectively act as separate aquifers, interspersed with lower-permeability siltstones and mudstones (BGS, 2011).

Recent research carried out by BGS has identified the study area is underlain by a buried valley. Buried valleys are valleys created by ancient rivers or subglacial drainage networks that have been either partly or completely buried by more recent sediment. The structure of buried valleys is typically complex due to repeated erosion and deposition (Sandersen and Jørgensen, 2003) and likely date from the last ice age. The buried valley beneath Grangemouth has been found to be over 162 m deep and is predominately infilled by clay (Kearsey et al., 2018).

BGS 1:50,000 geological data (BGS, 2019) is reproduced in Figures B11.2a-g which shows that superficial deposits within the majority of the study area are Intertidal Deposits (silt and clay) and Raised Tidal Flat Deposits of Flandrian Age (silt and clay). However, the upper catchments of the River Carron and Westquarter Burn transition from the raised tidal flat deposits to alluvium in the eastern part of the study area. Raised marine deposits are also present in large outcrops within the study area to the west.

Bedrock within the study area is dominated by Passage Formation and Upper Limestone Formation (belonging to the Clackmannan Group) as well as Scottish Lower Coal Measures Formation, which belongs to the Scottish Coal Measures Group (Figure B11.1). A small area of Scottish Middle Coal Measures is also present.

The BGS aquifer productivity map (1:50,000) (BGS, 2019) shows that Intertidal Deposits and Raised Tidal Flat Deposits of Flandrian Age are not considered to be significant aquifers, with typical yields of less than 0.1 l/s. The alluvium present upstream at the River Carron and Westquarter Burn is considered to have a moderate to high productivity, with typical yields of 1 to >10 l/s. The raised marine deposits to the west are shown as low to moderate with a typical yield of 0.1 to 10 l/s. The distribution of superficial aquifer productivity is illustrated in Figure B10.3.

Bedrock aquifer productivity within the study area is shown as moderate to high with intergranular and fracture flow or significant fracture flow. Table 4-1 provides a description of the superficial and bedrock deposits within the study area and their relative productivity based on BGS mapping. The distribution of bedrock aquifer productivity is illustrated in Figure B10.4.

Historic coal mining has the potential to alter groundwater flow and quality within aquifers. Records of shallow coal mining and mine entries (Coal Authority, 2023) indicate the presence of Past and Probable Shallow Coal Mine Workings in parts of Flood Cell 1, in the southern end of Flood Cell 4 and in the southeast corner of Flood Cell 6, and the presence of Mine Entries (predominantly Shafts) in Flood Cell 1 and in the vicinity of Flood Cell 2.

Table 4-1: Superficial and bedrock aquifers within the study area and associated productivity (BGS, 2019)

Geological Receptor	Description	Aquifer Productivity
Superficial Deposits		
Raised Tidal Flat Deposits of Flandrian Age	Comprises silt, clay and fine-grained sand with lenses of gravel. Groundwater in these deposits is likely to be hydraulically connected to coastal waters.	Not a significant aquifer
Intertidal Deposits	Variable lithology, with deposits from gravel through to clay and may be rich in organic matter due to connection to intertidal zone. Groundwater in these deposits is likely to be hydraulically connected to coastal waters.	Not a significant aquifer

Geological Receptor	Description	Aquifer Productivity
Till	Comprises clay, sand and gravel with boulders in variable size. Limited spatial extent within the study area.	Not a significant aquifer
Peat	Partially decomposed vegetation, typically grows under waterlogged anaerobic conditions	Not a significant aquifer
Raised Marine Deposits	Variable lithology, typically comprising gravel, sand, silt and clay and commonly includes organic debris. Limited spatial extent within the study area.	Low to moderate productivity with intergranular flow.
Alluvium	Comprises clay, silt and gravel. Groundwater within alluvial deposits would also be expected to be hydraulically connected to surface waters. Limited spatial extent within the study area.	Moderate to high productivity with intergranular flow
Glaciofluvial Ice Contact Deposits	Comprises gravel sand and silt. Limited spatial extent within the study area.	High productivity with intergranular flow
Bedrock		
Passage Formation	Belonging to the Clackmannan Group, predominantly comprises coarse sandstones and seatearths.	High productivity with significant intergranular flow.
Upper Limestone Formation	Belonging to the Clackmannan Group, predominantly comprises marine limestones.	Moderate productivity with intergranular and fracture flow.
Scottish Lower Coal Measures Formation	Predominantly comprises sandstone, siltstone and mudstone and coal seams are common.	Variable productivity within the study area, ranging from Moderate to High, with both intergranular and fracture flow.
Scottish Middle Coal Measures Formation	Predominantly comprises sandstone, siltstone and mudstone and coal seams are common. Limited spatial extent within the study area.	Moderate productivity with intergranular and fracture flow.

4.3 WFD Groundwater Bodies

There are eight WFD groundwater bodies identified by SEPA within the study area (Figures B10.5a and B10.5b). The WFD status information for the baseline classified groundwater bodies within the study area are listed in Table 4-2 below (SEPA, 2023).

Jacobs

Table 4-2: Summary of WFD groundwater bodies within the study area (SEPA, 2023)

WFD Groundwater Body	SEPA ID	Total Catchment Size (km^2)	Aquifer Type	Aquifer Productivity	Overall Status	Quantitative Status	Chemical Status	Specific Chemical Parameters with Poor Status	Approximate percentage of catchment within Study Area
Avon Sand and Gravel	150759	18.1	Superficial	Moderate to high productivity with intergranular flow	Good	Good	Good		Less than 10%
Carron Sand and Gravel	150774	27.5	Superficial	Moderate to high productivity with intergranular flow	Good	Good	Good		Less than 10%
Pow Burn and Stenhousemuir Sand and Gravel	150764	19.6	Superficial	Moderate to high productivity with intergranular flow	Good	Good	Good		Less than 10%
Falkirk	150511	49.4	Carboniferous – extensively mined for coal	Moderate productivity with fracture (minor intergranular) flow and flow through mined voids	Poor	Good	Poor	Other substances and Electrical conductivity	Less than 10%
Kinneil	150444	13.1	Carboniferous – extensively mined for coal	Moderate productivity with fracture (minor intergranular) flow and flow through mined voids	Poor	Good	Poor	Other substances and Electrical conductivity	Less than 10%
Grangemouth	150503	44.3	Carboniferous – not extensively mined for coal	Moderate productivity with fracture (minor intergranular) flow and flow through mined voids	Poor	Good	Poor	Manganese	Approximately 30%

Castle Cary	150560	79.7	Carboniferous – not extensively mined for coal	High productivity with intergranular flow	Good	Good	Good		Less than 10%
Stenhousemuir	150452	16.7	Carboniferous – extensively mined for coal	High productivity with intergranular flow	Poor	Good	Poor	Other substances and Electrical conductivity	Less than 10%

4.4 Groundwater Quailty

All aquifers within the study area are located within a Drinking Water Protection Area (SEPA, 2015). Table 4-2 presents a summary of the SEPA groundwater quality WFD status for the groundwater bodies as of 2020 (SEPA, 2020). All superficial aquifers have been assigned a groundwater quality status of Good.

The Falkirk, Kinneil, and Stenhousemuir Carboniferous groundwater bodies are classed as Poor for electrical conductivity for general testing. The elevated electrical conductivity can be partly attributable to seawater spray, but it is also likely associated with Lower Carboniferous calcareous sandstones and limestones and industrial pollution (BGS, 2011). SEPA has reported existing pressures on these groundwater bodies due to the legacy left by mining and quarrying (SEPA, 2023). No actions are possible to address the pressure and recovery will be natural, albeit not possible within WFD timescales.

The Grangemouth groundwater body was classed as Poor due to manganese concentrations. The highest concentrations of manganese within Carboniferous aquifers are typically found in the Coal Measures Group and Clackmannan groups. Dissolved manganese is most likely to be derived from the reductive dissolution of its respective oxide mineral phase, particularly in carbonaceous horizons (BGS, 2011).

4.5 Groundwater Levels and Flow

4.5.1 Groundwater Levels

Ground Investigations for the Scheme have been undertaken in 12 separate phases, commencing in 2014 and continuing until 2022. The individual phases of GI have tended to be focussed on specific geographical areas, e.g. the River Avon, River Carron, Forth Ports, etc. Final Factual Reports for Phase 1-8 of the GI, which cover all locations where direct defences are proposed, were available at the time of writing, and have been considered during this assessment.

Table 4-3 provides a summary of groundwater monitoring data gathered during the project-specific ground investigations, differentiating groundwater levels in superficial deposits from bedrock, where encountered. Locations where groundwater level monitoring information is available are shown on Figure B10.6.

Artesian conditions were encountered in places, either during drilling or later during the monitoring period. Artesian conditions, when encountered, are recorded in Table 4-3. This confirms the presence of confining conditions across the study area.

Groundwater flood risk mapping (GeoSmart, 2019, Figure B10.7) indicates groundwater flood risk is mostly classified as moderate, with some areas of lower risks (i.e. low and negligible). Table 4-3 provides a summary of groundwater flood risk in relation to each flood cell. Where groundwater risk is considered to be moderate, this provides an indication of areas where groundwater levels are shallower.

Table 4-3: Groundwater Levels and Flood Risk in relation to Flood Cells

Flood Cell	Groundwater Levels (m bgl)	Groundwater Flood Risk
1 (Upper Carron)	Monitored levels range from 0.46 to 15.10m bgl (5 locations, with one of these having a dual installation) in superficial deposits. No groundwater monitoring available in bedrock. 1 dual installation indicates a downward vertical gradient with groundwater perched in made ground. Artesian conditions encountered during drilling in 3 locations (2 in superficial deposits at depths ranging from 15m to 23m bgl and 1 in bedrock at depth circa 50m bgl), and artesian conditions developed post drilling but pre-backfilling in 1 location terminated at 28m bgl in superficial deposits.	Moderate risk Evidence of 2 issues in the transitioning zone between upper & Lower Carron
1 (Lower Carron)	Monitored levels range from -0.38 (1 location recorded intermittent artesian conditions) to 5.83m bgl (18 locations in total) mostly in superficial deposits except three in made ground. One vibrating wire piezometer was installed at 32m bgl in bedrock and recorded deeper groundwater levels at 17 – 18m bgl. One dual installation indicates an upward vertical gradient with groundwater perched in made ground. Artesian conditions during drilling in 9 locations (4 in superficial deposits at depths ranging from 11 to 35m bgl and 5 in bedrock at depths ranging from 43 to 80m bgl). Some of these locations were monitored and two of them recorded sub-artesian to artesian conditions.	Predominately moderate risk with localised areas which are low or negligible. Evidence of 1 issue in the northern end of Cell 1

Flood Cell	Groundwater Levels (m bgl)	Groundwater Flood Risk
2	Monitoring levels range from 0.22 to 10.82m bgl (9 locations). However, one location has been discounted on the basis that the monitoring results from the datalogger appear erroneous. All monitoring has taken place within the superficial deposits. Investigations reached bedrock at 88mbgl at one location. No information on groundwater in bedrock is available. One dual installation indicates a downwards vertical gradient with groundwater perched in made ground. However, there is evidence in one location of confined groundwater conditions (based on a strike at 63mbgl then rising to 1.35m bgl after 2 hours, which is indicative at this location of an upward vertical gradient). No artesian conditions were encountered.	Predominately moderate risk with localised areas which are low or negligible. Evidence of 1 issue in the western part of Cell 2
3	Monitoring levels range from 0.30 to 4.40mbgl (16 locations, with four of these containing a dual installation) mainly within the superficial deposits, except four in made ground. Two of the locations monitor groundwater levels across both the made ground and superficial deposits. Investigations reached bedrock at 56-62mbgl at three locations. Other deeper boreholes did not reach bedrock. No information on bedrock groundwater levels is available. No artesian conditions were encountered.	Predominately moderate risk with some areas of low risk. Localised areas of negligible risk. No evidence of spring
4 (Grange Burn North)	Monitoring levels range from 0.29 to 8.40m bgl (9 locations, with one containing a dual installation) within the superficial deposits. One of the locations is screened across both made ground and superficial deposits. Bedrock was not encountered, with the deepest borehole at 80m bgl. Therefore, no information regarding bedrock groundwater levels is available for this part of Cell 4. One dual installation indicates groundwater levels in made ground and shallow superficial deposits versus deep superficial deposits are a similar piezometric level. No artesian conditions were encountered.	Predominately moderate risk along Grange Burn, with areas of negligible or low risk to the edges of the cell.

Flood Cell	Groundwater Levels (m bgl)	Groundwater Flood Risk
4 (Grange Burn Flood Relief Channel, Grange Burn South and Polmont Burn)	Monitoring levels range from -0.31 (artesian) to 11m bgl (24 locations), mainly in superficial deposits, with the exception of locations containing VWP which have been installed in bedrock. Bedrock was reached at depths ranging from 6 to 17m bgl. As part of the groundwater monitoring two VWPs were installed in one location, while single VWPS were installed in two other locations. All VWP were installed in sandstone. Artesian conditions encountered during drilling in four locations, all in bedrock at depths of between 10 to 33m bgl. An additional location recorded artesian conditions between the completion of drilling and backfilling the borehole, within the superficial deposits. Subsequent monitoring recorded artesian levels in seven locations, two of which are screened in bedrock.	Predominately moderate risk, including along the course of Westquarter burn and Polmont Burn, however low or negligible risk either side of the Grange Burn Flood Relief Channel. Evidence of 2 issues in the southern part of Cell 4
5	Monitoring levels range from: artesian (in three locations with VWPs) to 14m bgl (however, the 14m bgl is considered to be erroneous) at 13 locations, mainly in superficial deposits, except three locations which are in bedrock. Bedrock was encountered at depths ranging from 4 to 40m bgl. 1 dual installation containing two VWP indicates an upwards vertical gradient with groundwater showing to be artesian at both depths. Artesian conditions were encountered in three locations during drilling, all within superficial deposits between depths of 11.50 to 17m bgl. One additional borehole became artesian overnight during drilling, also in superficial deposits at approximately 15m bgl. Throughout the monitoring period, two of the boreholes which encountered artesian conditions during drilling, continued to present artesian conditions. An additional location screened in the superficial deposits also presented artesian conditions throughout the monitoring period.	Predominately moderate risk in the southern part of the cell surrounding the River Avon with minimal localised areas of low or negligible risk. The northern part of the cell is predominantly negligible risk, with localised areas of moderate and low risk surrounding the River Avon. No evidence of springs within the Cell.

Flood Cell	Groundwater Levels (m bgl)	Groundwater Flood Risk
6	Monitoring ranges from -0.17 (artesian) to 3.89m bgl (13 locations, 4 with a dual installation. The majority of monitoring has taken place within the superficial deposits, except three locations in made ground (part of dual installations). No groundwater monitoring is available in bedrock. No artesian conditions were encountered during drilling, however one location encountered artesian conditions during the monitoring period within the superficial deposits.	In the south the risk from groundwater flooding is predominately moderate with some areas of low and negligible risk. In the northern part of the cell which does not lie in the estuary of the River Forth, groundwater flood risk is predominantly negligible with small, localised areas of low and moderate risk. In the Forth/ River Avon estuary groundwater flood risk is moderate. Evidence of 3 issues within Cell 5 and 3 more issues at the boundary of the Cell, south of the River Avon.

The presence of springs provides an indication that groundwater is at or near the surface. Springs and water "issues" were identified through a desk study review of 1:3000 OS mapping. The desk-study found springs to be predominately located within the southern and eastern-most extents of the study area, in cells 1 and 2 and in the southern part of cells 4, 5 and 6 (Figure B10.2). No additional springs were identified during ecological walkover surveys, and the presence of Spr-06 was not confirmed when the location was surveyed. The location of identified springs are predominately within areas of moderate groundwater flood risk, with the exception of Spr-09, Spr-12, Spr-15, Spr-17 and Spr-19, which are within areas of negligible risk and Spr-26, Spr-27 and Spr-30 within areas of low groundwater flood risk.

It should be notes that Springs 21 to 23 are marked as issues on OS mapping. They supply a drainage channel which falls within the Firth of Forth Site of Special Scientific Interest (SSSI), Special Protection Area (SPA) and Ramsar site. Spring 21 is located within the Firth of Forth SSSI, SPA and Ramsar site. These springs are further associated with a potential GWDTE (GW24), which lies partially within the Firth of Forth SSSI, SPA and Ramsar site.

4.5.2 Groundwater Flow

Due to the complex nature of layered groundwater horizons within the superficial deposits present in the study area, many discontinuous perched groundwater horizons seem to be present, with also evidence of numerous confining conditions which give rise in places to sub-artesian to artesian conditions. Within the buried valley predominately infilled with clay, groundwater bodies are expected to be constrained, as clayey valley walls restrict the aquifers' lateral extent and groundwater flow is restricted, resulting in limited water exchange between aquifers (Sandersen and Jørgensen, 2003). Therefore, groundwater flow directions are difficult to distinguish locally and likely change between different isolated aquifer units within the multi-layered aquifers depending on the conditions in each.

At regional level, groundwater flow is likely to be dominantly towards the Forth Estuary. However, locally, groundwater flow direction within the study area will be variable with the local rivers influencing flow direction in areas where groundwater is hydraulically connected to the rivers. This is more likely in areas where groundwater levels have been found to be shallow through the GI, especially when adjacent to the rivers. Groundwater flows directly adjacent to the Forth are likely to be influenced by the tides, particularly in the east of the site, as evidenced by the GI in places where loggers have been installed.

Groundwater flow within the Midland Valley Carboniferous aquifers is predominately expected to be through fracture flow. However, an exception to this is the Passage Formation, which underlies much of the study area and is dominated by loosely-cemented sandstone resulting in higher permeability and an increased proportion of intergranular flow (Robins, 1990, MacDonald et al., 2005). The average yield of known abstraction boreholes in the Passage Formation is 4l/s to 10l/s and for the Limestone and Coal Measures formations is 1l/s to 2l/s (Ball, 1999).

4.6 Rainfall

Over fifty years of rainfall data from 1961 to 2017 are available for the study from the SEPA gauging station within Flood Cell 5 ('Avon at Polmont' National Grid Reference (NGR): NS 951 796). The average rainfall at this location is 1,044 millimetres per annum (mm/a), with a range of 729 mm/a in 1973 to 1330.4 mm/a in 2008, and a general increasing trend (Figure 4-1).

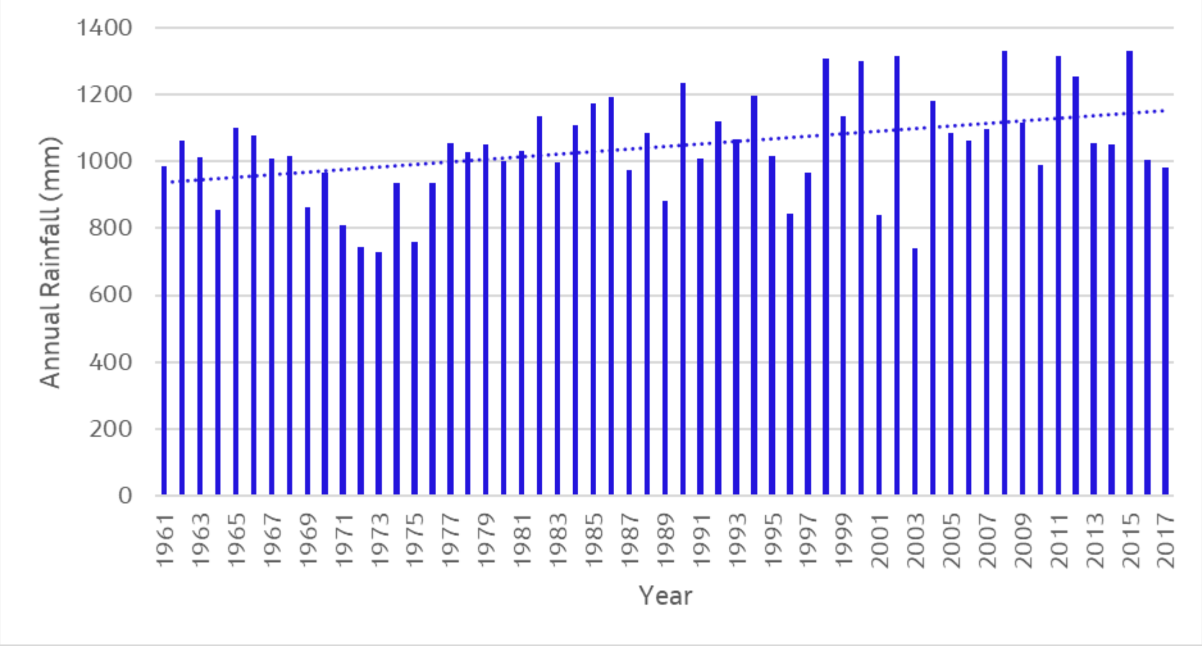

Figure 4-1: Annual rainfall data for Avon at Polmont between 1961 and 2017 (National River Flow Archive, 2022)

Groundwater recharge refers to the flux of water that moves from the ground surface or a surface water body into an underlying aquifer. From a groundwater perspective rainfall is often the most significant source of recharge, although only a proportion of total annual rainfall (effective rainfall) enters the groundwater system.

Bedrock aquifers within the Midland Valley have been found to contain a high proportion of relatively old water, which was recharged more than 35 years ago, with a significant proportion of water having been recharged more than 60 years ago. However, there is no evidence of the existence of palaeowater (older than 10,000 years) within Midland Valley Carboniferous aquifers (BGS, 2011).

Many of the groundwaters within other buried valleys show evidence of having been impacted by ion-exchange reactions (sodium for calcium exchange), suggesting shallow groundwater has mixed with older, more mineralised water. Therefore, possible limited groundwater recharge takes place within the area of the valley and a significant proportion of groundwater recharge occurs at a relatively large distance from the valley within areas where the geology has a greater permeability (Sandersen and JØrgensen, 2003). In addition to this the high proportion of low permeability deposits across the study area will limit the amount of rainfall infiltration into the underlying aquifers.

4.7 Abstractions

One abstraction recorded under Controlled Activity Regulation (CAR) as a registration by SEPA (i.e abstraction volumes between 10 and 50 m3/day) is reported to be abstracted from groundwater. This abstraction is detailed in Table 4-4. It should be noted however that the coordinates recorded by SEPA may not reflect the location of the point of abstraction, but refers to the land holding where the abstraction is taken from.

Table 4-4: Authorised groundwater abstraction in the vicinity of the Scheme

Reference	Authorisation No.	Authorisation Activity	NGR	General Location
Abs-01	CAR/R/1014879	Industrial or Commercial: Process Water – source of abstraction unspecified by SEPA. Enquiries were made to Forth Ports; the current occupiers of the land advised that no boreholes or abstractions are currently active at this location, and that the authorisation likely relates to historic land use. This abstraction is therefore considered to be inactive.	NS 93937 82510	Forth Ports

A consultation with Falkirk Council did not identify any further groundwater abstractions within the study area. A complementary desk review of "wells" on 1:3,000 OS mapping was undertaken. It should be noted that where wells are marked on OS maps, these may be no longer in use, and no field verification has been undertaken.

Potential abstractions are shown on Figure B10.2.

4.8 GWDTEs

Potential GWDTEs were identified by a desk review of existing Phase 1 habitat surveys and complementary Phase 1 surveys carried out in June 2019, followed by site visits to 16 locations (GW01-GW16) in 2020, the results of which are presented in Chapter 7: Biodiversity. A subsequent UK Habitats survey was undertaken in 2022/2023, following which a desk review has identified ten additional potential GWDTEs (GW17-GW26). Table A1 in Annex 10.4.1 provides a review of the likelihood of groundwater dependency for areas identified as potential GWDTEs which may be affected by the Scheme, and determine which wetlands are expected to be GWDTEs. Where uncertainties remain, a conservative approach was adopted. The scoping assessment for potential GWDTEs considered the following:

- Distance to surface water features: locations close to surface water features or below MHWS were assumed to be more reliant on surface water than groundwater, without ruling out the contribution of groundwater;
- Extent of fluvial and tidal flood extents: it was assumed that greater extents may indicate a lower dependency on groundwater, without ruling out the contribution of groundwater;
- Shallowness of groundwater (based on nearest GI information (where available) and groundwater flooding risk maps): shallower groundwater may indicate a greater groundwater contribution; and

- Underlying geology: indicating areas that are more likely to be a significant aquifer.

The potential GWDTE GW03 is associated with spring Spr-25 and lies within the Carron Dams SSSI and Local Nature Reserve (LNR), a wetland featuring rich fen and deciduous woodland within the partially drained reservoirs of the former Carron Iron Works; while GW-24 is associated with springs Spr-21, Spr-22 and Spr-23 and lies partially within the Firth of Forth SSSI, SPA and Ramsar site, specifically within the vicinity of Kinneil Kerse, on reclaimed land which features noted intertidal bays and transition grassland. These associated features have been treated as compound receptors during the assessment.

Potential GWDTEs are shown on Figure B10.15. Figure B10.15 also indicates the location of other wetlands.

4.9 Watercourses

Information on watercourses within the study area for the proposed Scheme is presented in Chapter 10: Water Environment and associated appendices (Appendix C10.1: Fluvial Geomorphology, Appendix C10.2: Estuarine Geomorphology and Appendix C10.3: Flood Risk).

4.10 Importance

The importance of receptors has been assigned in accordance with Table 10-2 in Chapter 10, Water Environment. Table 4-5 provides an overview of the importance of each receptor in relation to the groundwater environment as well as the justification for the assignment of importance. The importance of surface watercourses is as described in Section 10.4.5 of Chapter 10: Water Environment.

Table 4-5: Importance of groundwater environment receptors and justification

Receptor	Justification for Importance	Importance
Groundwater Resources		
Raised Tidal Flat Deposits of Flandrian Age	Not a significant aquifer, based on BGS mapping (BGS, 2019)	Low
Intertidal Deposits	Not a significant aquifer, based on BGS mapping (BGS, 2019)	Low
Till	Not a significant aquifer, based on BGS mapping (BGS, 2019)	Low
Peat	Not a significant aquifer, based on BGS mapping (BGS, 2019)	Low
Raised Marine Deposits	Low to moderate productivity with intergranular flow, based on BGS mapping (BGS, 2019)	High
Alluvium	Moderate to high productivity with intergranular flow, based on BGS mapping (BGS, 2019)	High
Glaciofluvial Ice Contact Deposits	High productivity with intergranular flow, based on BGS mapping (BGS, 2019)	High
Upper Limestone Formation	Moderate productivity with intergranular and fracture flow, based on BGS mapping (BGS, 2019)	High
Passage Formation	High productivity with significant intergranular flow, based on BGS mapping (BGS, 2019)	High
Scottish Lower Coal Measures Formation	Variable productivity, ranging from Moderate to High, with both intergranular and fracture flow, based on BGS mapping (BGS, 2019)	High
Scottish Middle Coal Measures Formation	Moderate productivity with intergranular and fracture flow. Limited spatial extent within the study area, based on BGS mapping (BGS, 2019)	High

Receptor	Justification for Importance	Importance
Buildings and Infrastructure		
Residential	Buildings are considered to be of local value.	Medium
Retail/ Commercial and Community Facilities	Buildings are considered to be of regional value.	High
Industrial Buildings, Critical Infrastructure, Scheduled Monuments and listed buildings	Buildings are considered to be of national value.	Very High
Abstractions and Private Water Supplies		
Well 1 to Well 5 (from 1:3,000 OS map)	Usage unknown and presence unconfirmed. The locations do not correspond to any known licensed abstractions.	High
Abs-01	Historic groundwater abstraction. Not currently active and unlikely to become active again.	None
GWDTEs		
GW03, GW24	Likely high to moderate groundwater dependence. Located within a SSSI and LNR.	Very High
GW05, GW06, GW10, GW11, GW12, GW13, GW16, GW17, GW18, GW19, GW21, GW22, GW23, GW25 & GW26	Likely moderate groundwater dependence. Not located within a designated area.	Medium
GW20	Likely low groundwater dependence. Not located within a designated area.	Low
Springs		
Springs 1-20, 24 and 26-30	Marked as issues on OS mapping. Supplies small drainage channels which are of low hydrological value.	Low
Spring 25	Marked as a spring on OS mapping. Supplies drainage channel within Carron Dams.	Medium
Springs 21-23	Marked as issues on OS mapping. Supplies drainage channel which is hydrologically linked to a water feature within the Firth of Forth SSSI, SPA and Ramsar.	Very High

5 Impact Assessment

5.1 Introduction

The following section presents potential impacts during construction and operation, prior to the implementation of mitigation. Residual impacts, considering mitigation, are presented in Chapter 10: Water Environment and Appendix C10.6: Impact Assessment Tables.

Details of importance criteria, impact magnitude descriptions and the significance of effects matrix are provided in Table 10-3, Table 10-4 and Table 10-5 within Chapter 10: Water Environment respectively.

Based on the proposed design, the following assumptions have been made:

- Excavations for direct defences (flood walls and embankments) would be no greater than 1.0 m in depth.

- Excavations for replacement of bridge abutments would be no greater than 5.0m in depth.
- It is assumed the haul roads will require only soil stripping, but no excavations.
- Construction of new lock gates will take place within the concrete-lined lock at the entrance to Forth Ports and any necessary dewatering would not extend beyond the lock structure.
- Ground improvement by the introduction of an additive to ground along the estuary frontage in Flood Cell 6 would extend no greater than 4.0 m bgl. The additive would likely be a mixture of lime, cement and pulverised fuel ash (PFA), which would not be a free-draining liquid. This additive would act like a grout and harden in-situ once emplaced, hence its potential to impact on groundwater quality would be negligible.
- Piling would be required beneath all flood walls and some embankments. Most piling would be sheet piling and would vary in depth, reaching a maximum of 18.50 m bgl dependent on the thickness of superficial deposits and geotechnical requirements. Piling through improved ground along the estuary frontage in Flood Cell 6 would be bored piling up to a maximum depth of 4.0 m bgl. The variability in the depth of piling between Flood Cell Working Areas is illustrated in Table 5 1.

Table 5-1: Maximum Depth of Piling within Cell Working Areas

Cell Working Area	Maximum Depth of Piling (m bgl)
1-1 Stirling Road	9.0
1-2 Carron Bridges	15.0
1-3 Chapel burn	10.0
1-4 Dock Street	11.0
2-1 Forth & Clyde Canal Lock	7.5
2-2 Jarvie Plant	9.5
3-1 Mouth of the River Carron	5.0
3-2 West Coast of the Port	8.0
3-3 West Gate to Port	10.0
3-4 East Gate to Port	7.0
3-5 Mouth of the Grange Burn	5.0
4-1 Upstream of M9	3.7
4-2 Rannoch Park	4.2
4-3 Inchyra Road	5.0
4-4 Wholeflats Road	5.0
4-5 Zetland Park	3.5
4-6 Dalgrain to Bo'Ness Road	3.5
4-7 Grangeburn Road	3.2
4-8 Petroineos	4.6
4-9 Mouth of the Grange Burn	4.6
5-1 Smiddy Brae & Avondale Road	18.5
5-2 Flare Road & Road 33	18.5
5-3 Grangemouth Road	7.3
5-4 Mouth of the River Avon	4.5

Cell Working Area	Maximum Depth of Piling (m bgl)
6-1 Beach Road	4.0
6-2 Petroineos Mouth of River Avon	6.5
6-3 Chemical Works at River Avon	13.5
6-4 Water Treatment Works	13.5

5.2 Construction

5.2.1 Introduction

The types of potential impacts to groundwater during construction of the Scheme include the following:

- Direct impact from construction activities, including construction compounds.
- Dewatering of excavations for bridge abutments may alter groundwater levels and flow paths.
- Subsidence in buildings and buried services due to changes in groundwater levels leading to consolidation of compressible soils such as peat and soft silt and clay. In general, damage to buildings is more likely to arise from differential rather than uniform settlement.
- Excavation or perforation of overlying confining layers may lead to release of artesian water.
- Spillage or leakage of fuels or oils from storage tanks or construction plant which, without suitable mitigation measures, can enter aquifers and subsequently migrate to receptors such as abstractions or GWDTEs. Piling may create pathways for these contaminants to enter groundwater.
- Use of potentially polluting materials, particularly cementitious materials, in construction of flood defences may result in changes to groundwater quality (cementitious materials have the potential to alter pH), while disturbance of soil during excavations may lead to groundwater with elevated suspended solids and high turbidity. This groundwater can then discharge to receptors such as GWDTEs or abstractions. This is most likely to occur where groundwater flow is in fractures or other discontinuities such as mine workings where there is less opportunity for attenuation between the source of contamination and the receptor.
- Piling may permit mixing of groundwater between different WFD groundwater bodies if multiple aquifer units are intercepted.
- Construction of haul roads.

Potential impacts in relation to the mobilisation of any pre-existing contaminants through changes to the groundwater regime are considered in Chapter 11: Soils, Geology and Land Contamination.

5.2.2 Excavation Works

As described in Section 5.1, all excavations for flood walls and embankments are assumed to be no greater than 1m in depth. To facilitate construction of these defences, no to very minimal localised dewatering will be required, and therefore no to negligible dewatering impacts are anticipated.

Excavations for the replacement of bridge abutments (Figure B10.2) are assumed to be no greater than 5 m in depth and laterally no greater than 20 m in breadth. Therefore, localised dewatering may be required in locations where groundwater levels are less than 5 m bgl.

To assess the distance within which potential impacts may be observed from any dewatering activities, calculations have been undertaken. Sichardt's equation (CIRIA, 2016) was used to calculate the potential radius of influence assuming dewatering from a rectangular excavation. The parameters used for the assessment are shown in Table 5-2, where the radius of influence from the excavation (R_O) is calculated as R_O=C.s.$K^{0.5}$.

Table 5-2: Parameters for Sichardt's equation

Parameter	Unit	Assumed value	Explanation
Constant, C	-	3000	A value of 3000 is taken for rectangular excavations
Maximum drawdown, s	m	5	The maximum depth of excavation for the Scheme is 5m, and a near-surface groundwater level is assumed, as has been recorded in some GI monitoring locations
Permeability, K	m/s	0.00002	Based on the maximum value for silt calculated by Domenico & Schwartz. (1990)

Based on the parameters in Table 5-2, a radius of approximately 70m has been estimated. Therefore, all receptors outwith this region are unlikely to be affected by drawdown from dewatering of excavations. If lower permeability deposits are encountered than those assumed in Table 5-2, as may be anticipated from the findings of the GI, then the radius of influence will be lower than calculated. At the scale of the aquifers, these changes to groundwater flows and levels are assessed as negligible, resulting in a **significance of neutral**.

No potential impacts from temporary changes to groundwater levels and resulting from dewatering of excavations for bridge abutments during construction are anticipated for groundwater abstractions or groundwater dependent receptors (such as GWDTEs and springs) due to the distance of these receptors from proposed excavations (as shown in Figure B10.2), the extent of the proposed excavations, and the low permeability of the superficial aquifers within the study area.

Groundwater baseflow to watercourses may be impacted by temporary changes to groundwater levels because of dewatering. Without mitigation, the potential for temporary dewatering of excavations for bridge abutments to impact adjacent watercourses has been assessed as having a minor adverse magnitude, due to the minor extent of the dewatering in relation to the scale of the aquifers, resulting in potential impacts of **moderate significance**.

Dewatering of excavations during construction has the potential to impact buildings and infrastructure within the study area due to subsidence. As the maximum depth of excavation is 5 m, the effect is expected to be localised. Therefore, potential impacts to buildings located within 50 m to 70 m from the proposed excavations have been assessed as having a minor magnitude, resulting in potential impacts of **slight** to **moderate significance** on existing buildings.

Further details for individual receptors are presented within Appendix C10.6: Impact Assessment Tables.

5.2.3 Sheet Piles

Construction of below ground structures, such as sheet piles, has the potential to intercept bedrock in Flood Cell 4-South and Flood Cell 5 where bedrock was intercepted during the GI at depths ranging from 2.55 m bgl (Flood Cell 5) to 24.25 m bgl (Flood Cell 4-South), as outlined in Table 5 3. The low permeability of the overlying superficial deposits will provide some degree of protection to underlying bedrock aquifers from construction activities at the surface, however there is potential for contamination of bedrock aquifers in Flood Cell 4-South and Flood Cell 5, if sheet piles create pathways for contaminants through the overlying superficial material. At the aquifer scale, the risk of sheet piles impacting the water quality of bedrock aquifers has been assessed to have a minor adverse magnitude, resulting in effects of **slight significance.**

As shown in Table 5-3, superficial deposits in Flood Cells 1, 2, 3 and 6 have been observed to be thicker than the maximum proposed depth of piling, with the depth to bedrock in these cells ranging from 22.7 m bgl (Flood Cell 1) to 88.5 m bgl (Flood Cell 2). While no direct observations of bedrock depth were made in Flood Cell 4-North during the GI, the trend of observations is for increasing depth to bedrock from south to north within the study area. This in combination with the shallow depth of proposed piles indicates there will be no potential for piles to intercept bedrock in this Flood Cell. It is therefore unlikely that below ground structures will intercept bedrock in Flood Cells 1, 2, 3, 4-North and 6, and no potential impacts on the groundwater quality of bedrock aquifers are anticipated in these cells.

The superficial Raised Tidal Flat Deposits, Raised Marine Deposits, Intertidal Deposits, Till, and Alluvium have been observed to contain material of varying permeability, ranging from low permeability clays to high permeability gravels. Sheet piles may intercept layers of material of varying permeability, and potentially create pathways from the surface to superficial aquifers which would otherwise be protected by overlying low-permeability material. At the aquifer scale, the risk of sheet piles impacting the water quality of superficial aquifers has been assessed to have a minor adverse magnitude, resulting in effects of **slight significance**.

Construction activities will not take place in Glaciofluvial Ice Contact Deposits (only present in Flood Cell 4-South and Flood Cell 5) or Peat (only present in Flood Cell 1), therefore no potential impacts to these aquifers would occur.

Table 5-3 summarises for each cell the proposed sheet pile designs in the context of the geological and groundwater settings that have been used for the purposes of this assessment, and Figure B10.14 shows the location of the proposed sheet piles in relation to cells and their subdivisions (i.e cells 1-1, 1-2, 2-1, etc.). The depth of the proposed piles will be confirmed at detailed design. .

Table 5-3: Potential for Piling to Intercept Bedrock and Groundwater by Flood Cell

Flood Cell	Max. Depth of Proposed Piles within Cell (m bgl)	Min. Observed Depth to Bedrock (m bgl)	Max. Observed Depth to Bedrock (m bgl)	Potential for Piles to Intercept Bedrock	Range of Depths at which Artesian Groundwater was Encountered (m bgl)	Potential for Piles to Intercept Artesian Groundwater	Min. Depth to Water (m bgl)
1	15.0	22.7	55.65	No	11.0 – 67.5	Yes	-0.38
2	9.5	88.5	88.5	No	N/A	N/A	0.22
3	10.0	56.4	62	No	N/A	N/A	0.30
4-North	4.6	No Data	No Data	No	N/A	N/A	0.29
4-South	5.0	5.0	24.25	Yes	10.0 – 33.0	No	-0.31
5	18.5	2.55	40.6	Yes	11.2 – 17.0	Yes	0.00
A – Artesian groundwater in Flood Cell 6 observed during monitoring period only. Borehole screened from 7.0 - 20.0m bgl.							

As described in Section 4.2, Past and Probable Shallow Coal Mine Workings are indicated in Flood Cell 1 and Flood Cell 4-South. Sheet piles are not likely to intercept bedrock in Flood cell 1, and an analysis of the proposed depth of sheet piles against depth to bedrock indicates that piles will not intercept bedrock in areas of shallow coal mining in Flood Cell 4-South.

As described in Section 4.5.1, artesian groundwater conditions were observed in Flood Cells 1, 4-South, 5 and 6 during the GI. A comparison of the depths of proposed piles and depths at which artesian groundwater was encountered is presented in Table 5-3. Artesian conditions have not been encountered at depths shallower than 7m bgl across the study area, hence the potential for piles to intercept artesian groundwater in Flood Cell 4-South is low. However, in Flood Cell Working Area 1-2, artesian groundwater was intercepted at 11m bgl within Alluvium, adjacent to the proposed location of sheet piles which are planned to extend 10.5m bgl. There is therefore a moderate risk of intercepting artesian groundwater at this location within Flood Cell 1. All remaining artesian groundwater interceptions in Flood Cell 1 were below the depth of proposed piles. In Flood Cell Working Area 5-1, artesian groundwater was encountered in four boreholes within Raised Tidal Flat Deposits at depths between11.2m bgl and 17.0m bgl, all adjacent to the proposed location of sheet piles which are planned to extend to 18.5m bgl. There is therefore a high risk of intercepting artesian groundwater in this location. In Flood Cell Working Area 6-4, artesian groundwater was observed during monitoring in one borehole screened in Raised Tidal Flat Deposits between 7m bgl and 20m bgl where sheet piles are proposed to a depth of 13.5m bgl. As the depth of the artesian horizon is uncertain, there is a moderate risk that sheet piles will intersect artesian groundwater at this location At the scale of the Alluvium and Raised Tidal Flat Deposits aquifers, releasing localised artesian conditions are expected to have a minor to negligible impact on the aquifer, which would result in a potential **significance** of **slight**.

One spring (Spr-30) is located approximately 175 m northwest of the location of artesian water strikes in flood cell Working Area 5-1, however this spring is upgradient of the proposed defences and therefore no potential impacts to this spring are foreseen. No springs are located within the vicinity of the GI locations where artesian groundwater was observed in Flood Cell Working Areas 1-2 and 6-4, and no potential impacts on springs from intersection of artesian horizons are foreseen in these areas.

A potential GWDTE (GW24) covers an area approximately 150 m deep and at least 700 m wide, north of proposed sheet piles in Flood Cell Working Area 6-4, where artesian groundwater conditions have been observed in one location and are suspected to be localised. While the proposed sheet piles in this area are upgradient of the potential GWDTE, they do not extend across the full breadth of the zone of contribution, and therefore the potential impacts of sheet piles intersecting artesian horizons on the flow of groundwater to this potential GWDTE has been assessed to have a negligible magnitude resulting in an effect of **slight significance**.

A further potential GWDTE (GW03) is located approximately 160 m north of proposed sheet piles in Flood Cell Working Area 1-2, where artesian groundwater conditions have been observed in several locations. Analysis of ground investigation data collected locally indicates that the proposed sheet piles will penetrate cohesive marine deposits, while the artesian groundwater has been intercepted in underlying granular glacial deposits. As such, it has been assessed that the potential for sheet piles to intercept artesian groundwater in this location is unlikely, and the potential effect on the flow of groundwater to the GWDTE is negligible, resulting in an effect of **slight significance.** No potential GWDTEs have been identified in the vicinity of Flood Cell Working Area 5-1, and no potential impacts from sheet piles intersecting artesian horizons are anticipated in this area.

Where the installation of sheet piles has the potential to intercept artesian groundwater, the unmitigated release of groundwater at surface may lead to flooding. The release of artesian groundwater could have a minor impact on built environment receptors, which would result in effects of **slight** to **moderate significance**, depending on the importance of the receptor.

Further details for individual receptors are presented within Appendix C10.6: Impact Assessment Tables.

5.2.4 Direct Impacts on Groundwater Features

An assessment of the locations of identified potential GWDTEs, abstractions, wells and springs has identified one potential GWDTEs (GW22) and one spring (Spr-06), which are located within the footprint of permanent works, and may potentially be impacted as a result of the works. As detailed in Section 4.5.1, Spr-06 was not observed during ecology surveys in the area, and the spring has accordingly been discounted as a receptor. Potential GWDTE GW22 would be partially impacted by proposed sheet piles, which have been assessed to have moderate adverse magnitude resulting in effects of **moderate significance**.

Two additional springs (Spr-13 and Spr-16) and one potential GWDTE (GW12) are located within the footprint of temporary works (site compounds) and may be impacted as the result of the works. It should be noted that the presence of the springs has not been confirmed on site, but in any case, these springs are not supporting GWDTEs or pre-existing water supplies. Therefore, despite the loss of these features being a major adverse magnitude, this would result in potential impacts of slight significance. Potential GWDTE GW12 would be partially impacted by a proposed site compound, which has been assessed to have moderate adverse magnitude resulting in an effect of **moderate significance**.

5.2.5 Spillages or Leakage

Groundwater vulnerability to pollution typically varies according to the thickness and permeability of superficial deposits in an area. While most of the study area is underlain by relatively thick, low permeability deposits, localised areas to the west and south of the Scheme, specifically the west of Flood Cell 1, and the south of Flood Cell 4 and Flood Cell 5, where thinner, high permeability deposits have been observed during the GI, could be vulnerable to potentially contaminating substances released during construction.

The potential impacts to groundwater resources due to leaks and spills of fuels or oils, chemicals, cementitious materials or increases in suspended solids due to excavations may result in a Moderate change to groundwater quality of superficial aquifers, and a Minor change to bedrock aquifers, with the exception of the bedrock Passage Formation, where the planned depth of sheet piles in Flood Cell 4-South and Flood Cell 5 may extend through the full thickness of the overlying superficial deposits and create a pathway for contaminants to reach bedrock without attenuation. These impacts have been assessed as Moderate magnitude for superficial aquifers and the Passage Formation, and as Minor magnitude for all remaining bedrock aquifers, resulting in a **slight to large significance**, depending on the sensitivity of the receptor. Construction activities will not take place in Glaciofluvial Ice Contact Deposits or Peat, therefore no impacts to these aquifers would occur. Full details of impacts to individual receptors are presented in Appendix C10.6: Impact Assessment Tables.

Any changes to groundwater quality also have the potential to impact upon GWDTEs, groundwater abstractions, wells and springs. The extents of potential impacts are dependent on intervening topography and distance from the incident. The magnitude of potential impacts to receptors such as GWTDEs, springs and abstractions, has been assessed as negligible (**significance of neutral to slight**) for the majority of receptors. However, potential impacts on groundwater quality have been assessed as moderate adverse for springs Spr-2, Spr-13, Spr-14 and Spr-16, and GWDTEs GW13, GW16, GW17, GW20 and GW24,and as major adverse magnitude for GWDTEs GW10, GW12, GW22 and GW23 predominately due to their proximity to temporary works areas. Given the low sensitivity of Springs Spr-2, Spr-13, Spr-14 and Spr-16, the potential **significance** of impact is assessed as **slight**. The assessed significance of the potential impacts to GWDTEs GW10, GW12, GW13, GW16, GW17, GW20, GW22, GW23 and GW24 varies from **slight** to **large**, depending on importance of the receptor.

The risk to groundwater receptors from the mobilisation of historical contaminated land is assessed in Chapter 11: Soils, Geology and Contamination.

5.3 Operation

5.3.1 Introduction

The Scheme may result in potential impacts to the groundwater environment during operation, including the following:

- Changes to groundwater levels and flow paths because of permanent below-ground structures creating barriers to groundwater flow.
- Increased risk of groundwater flooding resulting from increased groundwater levels upgradient of permanent below-ground structures which create barriers to groundwater flow.
- Changes to contaminant flow pathways due to changes to hydrogeological regime.

Following construction of the flood defences there are potential impacts to groundwater during operation because of permanent changes to groundwater flow paths due to below ground structures such as piles for embankments and flood walls. Potential impacts include changes to groundwater levels or flows within aquifers and indirect impacts to groundwater receptors such as abstractions, springs and GWDTEs, as well as base flow to watercourses due to a reduction in groundwater supply.

No permanent below-ground structures are proposed which will intersect Till, Peat or Glaciofluvial Ice Contact Deposits, therefore no potential impacts are foreseen for these aquifers during operation of the Scheme.

Permanent below-ground structures such as sheet piles have the potential to exacerbate the risk of groundwater flooding in specific locations by permanently increasing static groundwater levels upgradient of the structures.

Potential impacts to groundwater quality from changes to the hydrological regime may lead to mobilisation of existing contaminant plumes, and any potential alteration to contaminant pathways has been considered via a conceptual site model (CSM), presented in Chapter 11: Soils, Geology and Land Contamination.

5.3.2 Groundwater Levels and Flow

As described in Section 4.5.2, groundwater flows within the study area are highly variable and predominantly confined, due to the complex nature of the layered aquifers. Nonetheless, general trends of regional groundwater flow towards the Forth Estuary and localised flow towards surface watercourses can be discerned. The proposed below-ground structures have the potential to impede and disrupt groundwater flow patterns. Whilst it is likely that groundwater would find alternative flow pathways around the sheet piles, the creation of an impediment to flow is likely to result in an increase in groundwater levels upgradient of the piles, with a decrease in groundwater levels expected on the downgradient side. Following completion of the works the piles would remain in-situ, and therefore any impacts would be long term in nature. Risks associated with a potential rise in groundwater levels in relation to potential groundwater flooding are discussed in Section 5.3.3. Aside from risks to groundwater flooding, the potential impacts of disruptions to groundwater levels and flows at the scale of the aquifers is assessed to have a negligible to minor adverse magnitude, depending on the depth and length of piles and as a result, potential impacts on aquifers have been assessed to have **neutral** to **slight significance**. Further details are presented within Appendix C10.6: Impact Assessment Tables.

Most springs are located sufficiently far from permanent below-ground structures that no potential impacts are foreseen. Six springs are situated in locations where proposed sheet piling may have potential impacts of minor adverse magnitude, of which three springs are associated with a potential GWDTE which falls within the Firth of Forth SSSI, SPA and Ramsar site and have been assessed as a compound receptor with the GWDTE. The potential effects to the three isolated springs have been assessed to have **neutral significance.** Further details are presented within Appendix C10.6: Impact Assessment Tables.

The potential impacts of permanent below ground structures to base flow of the River Carron has been assessed as having a moderate magnitude resulting in potential impacts of large significance. Potential impacts to base flow to all other surface water features have been assessed as having negligible impact, resulting in potential impacts of **neutral** to **slight significance** depending on the importance of the receptor.

The potential impacts of permanent below ground structures to the groundwater supply contributing to GWDTEs within the study area has been assessed as having impacts of no to moderate magnitude. For those GWDTEs where an impact is foreseen, the resulting effects have been determined to have a **significance** of **neutral to large**, depending on the importance of the receptor, including effects of moderate significance to GW16 and GW22, and effects of large significance to the compound receptor comprising GW24, Spr-21, Spr-22 and Spr-23. Further details are presented in Appendix C10.6: Impact Assessment Tables.

5.3.3 Groundwater Flooding

As discussed in Section 5.3.2, sheet piles emplaced through saturated permeable material would be likely to create an impediment to groundwater flow, especially where piles are constructed perpendicular to the existing groundwater flow direction. The proposed sheet piles vary in length across the Scheme, from a 75m long section in the south of the Wholeflats Road Working, to an approximately 4km long section starting on the Grange Burn in Working Area 4-6 and extending along the Forth estuary waterfront to Working Area 6-2. A summary of the longest continuous length of piles within each Working Area and how the piles are oriented in relation to the expected groundwater flow direction is presented in Table 5-4.

The current groundwater flooding risk class in all Flood Cell Working Areas is predominantly Moderate, with localised areas of Low risk. As detailed in Table 5-4, proposed sheet piles in Flood Cell 1, Flood Cell 4 and Flood Cell 6 could have a high potential to cause a local change in groundwater levels upgradient of the piles, thereby leading to an increased risk of groundwater flooding to receptors in these areas. This would potentially result in localised negative groundwater flooding impacts upgradient of the piles and localised positive groundwater flooding impacts downgradient of the piles. In Flood Cell 1, Flood cell 4-North and Flood Cell 6, built environment receptors are located upgradient of piles, while in Flood Cell 4-South, built environment receptors are predominantly located downgradient of piles. The potential impact is assessed to have a moderate adverse magnitude with resulting **significance** of **moderate to very large** depending on the importance of the receptor.

Further details are presented within Appendix C10.6: Impact Assessment Tables.

Table 5-4: Summary of proposed sheet piles and groundwater levels within each Flood Cell Working Area

Cell Working Area	Min. Observed Depth to Water (m bgl)	Maximum Depth of Piling (m bgl)	Length of Longest Continuous Pile within Working Area (m)	Orientation of Groundwater Flow in Relation to Piles	Potential for Groundwater to Reach Surface
1-1 Stirling Road	0.45	9.0	650	Perpendicular	High
1-2 Carron Bridges	-0.38	15.0	410	Oblique	High
1-3 Chapel Burn	1.67	10.0	690	Perpendicular	Medium
1-4 Dock Street	0.53	11.0	530	Oblique	High
2-1 Forth & Clyde Canal Lock	0.54	7.5	640	Parallel	Low
2-2 Jarvie Plant	0.22	9.5	830	Parallel	Low

Cell Working Area	Min. Observed Depth to Water (m bgl)	Maximum Depth of Piling (m bgl)	Length of Longest Continuous Pile within Working Area (m)	Orientation of Groundwater Flow in Relation to Piles	Potential for Groundwater to Reach Surface
3-1 Mouth of the River Carron	0.50	5.0	920	Parallel	Low
3-2 West Coast of the Port	1.08	8.0	970	Parallel	Low
3-3 West Gate to Port	0.30	10.0	1,100	Parallel	Low
3-4 East Gate to Port	0.92	7.0	790	Parallel	Low
3-5 Mouth of the Grange Burn	1.73	5.0	670	Parallel	Low
4-1 Upstream of M9	0.00	3.7	380	Oblique	Medium
4-2 Rannoch Park	-0.31	4.2	560	Perpendicular	High
4-3 Inchyra Road	0.00	5.0	680	Perpendicular	High
4-4 Wholeflats Road	0.00	5.0	870	Perpendicular	High
4-5 Zetland Park	0.49	3.5	390	Oblique	Medium
4-6 Dalgrain to Bo'Ness Road	0.29	3.5	230	Oblique	High
4-7 Grangeburn Road	0.87	3.2	630	Perpendicular	High
4-8 Petroineos	0.30	4.6	520	Perpendicular	High
4-9 Mouth of the Grange Burn	0.86	4.6	660	Oblique	Medium
5-1 Smiddy Brae & Avondale Road	0.45	18.5	620	Oblique	High
5-2 Flare Road & Road 33	0.00	18.5	450	Parallel	Medium
5-3 Grangemouth Road	No observations	7.3	450	Oblique	Medium
5-4 Mouth of the River Avon	No observations	4.5	430	Parallel	Low
6-1 Beach Road	0.33	4.0	1,410	Perpendicular	High
6-2 Petroineos Mouth of River Avon	1.32	6.5	720	Perpendicular	Medium

Cell Working Area	Min. Observed Depth to Water (m bgl)	Maximum Depth of Piling (m bgl)	Length of Longest Continuous Pile within Working Area (m)	Orientation of Groundwater Flow in Relation to Piles	Potential for Groundwater to Reach Surface
6-3 Chemical Works at River Avon	0.77	13.5	690	Oblique	High
6-4 Water Treatment Works	-0.17	13.5	730	Perpendicular	High

5.3.4 Groundwater Quality

No direct impact to groundwater quality from operation of the Scheme has been identified, as there would be no ongoing use of substances likely to cause contamination or contaminated discharges to the ground. As such, the impact from operation on groundwater in all aquifers and associated receptors during operation is considered to be of **neutral significance**.

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Annex 10.4.1: Groundwater Dependent Terrestrial Ecosystems (GWDTE) Scoping Assessment

Table A-1: Potential GWDTE Scoping Assessment

Site	Ecological Assessment	Potential GWDTE	Hydrogeological assessment	Initial Assessment of Groundwater Dependency	Designation	Importance
GW01	Vegetation composition indicated a mesotrophic grassland rather than a wetland. Not a GWDTE	No	Not applicable			
GW02	To the western part of the site is a small, ponded area with fringes of vegetation which are not classed as GWDTE. Limited vegetation surrounding main waterbody which are not a GWDTE. This area is not a GWDTE, however it would count as a wetland.	No	Not applicable			
GW03	The woodland areas within the survey area were not mapped due to the high-water levels and difficult access, but woodland akin to the W4 Betula pubescens-Molinia caerulea woodland was present. Possible for some transitioning to something akin to W2 Salix cinerea-Betula pubescens-Phragmites australis woodland. The former is highly groundwater dependent whereas the latter is moderately dependent.	Yes	Situated in the former reservoirs of the Carron Iron Works, which were drained to form wetland habitat. Adjacent to pond No available GI information within 100m Not within a floodplain Area at moderate risk of groundwater flooding Underlain by raised tidal flat deposits	High to moderate	SSSI & LNR	Very High

Site	Ecological Assessment	Potential GWDTE	Hydrogeological assessment	Initial Assessment of Groundwater Dependency	Designation	Importance
GW04	Carron Meander SINC. Two areas of vegetation within the site largely comprise S4 Phragmites australis swamp and reed-beds and S28 Phalaris arundinacea tall-herb fen. Neither are GWDTEs. Not a GWDTE but could be classed as a wetland.	No	Not applicable			
GW05	Likely that higher, drier areas have been agriculturally improved and are MG6 Lolium perenne-Cynosurus cristatus grassland with small rather indistinct patches of MG10 (Holcus lanatus-Juncus effusus rush pasture) a moderately water dependent GWDTE.	Yes	Near to River Carron Within 1-in-2-year modelled tidal flood area Area at low risk of groundwater flooding Located within intertidal deposits and raised tidal flat deposits Nearest groundwater monitoring records groundwater levels between 1.45 and 2.07m bgl	Moderate	None	Medium
GW06	The main area of GW06 is the same species composition as GW05. Therefore contains GWDTE habitats.	Yes	Adjacent to drainage channel No available GI information within 100m Within 1-in-2-year modelled tidal flood extents Area at moderate risk of groundwater flooding Underlain by intertidal deposits	Moderate	None	Medium

Site	Ecological Assessment	Potential GWDTE	Hydrogeological assessment	Initial Assessment of Groundwater Dependency	Designation	Importance
GW07	Revised habitat mapping changed swamp to being predominantly mudflats and a saltmarsh. This is not expected to be a GWDTE, but classifies as a wetland	No	Not applicable			
GW08	No vegetation classed as moderately or highly dependent on groundwater was present within the survey area. This area features a large area of wetland but is not a GWDTE.	No	Not applicable			
GW09	Initially identified as swamp, subsequent UK habitat mapping identified f2e reedbeds, both common reed. This habitat type is not a GWTDE but classifies as wetland.	No	Not applicable			
GW10	Complex site comprised of a series of zones around the open water area. The majority of the vegetation types appeared to be non-groundwater dependant. However, the presence of M23 Juncus effusus/acutiflorus-Galium palustre rush-pasture suggests some groundwater input. Subsequent UK Habitats mapping classed this area as f2a – Lowland fens.	Yes	Adjacent to Westquarter Burn Within 1-in-2-year modelled flood event as well as area upstream Area at moderate risk of groundwater flooding Area adjacent to watercourses likely to have surface water component Predominately underlain by alluvium Groundwater monitoring records groundwater between 1.17 and 2.94m bgl	Moderate	None	Medium

Site	Ecological Assessment	Potential GWDTE	Hydrogeological assessment	Initial Assessment of Groundwater Dependency	Designation	Importance
GW11	Includes a rushy area identified as M23 Juncus effusus/acutiflorus-Galium palustre rush-pasture which is highly dependent on groundwater. Within the rushy area M27 Filipendula ulmaria-Angelica sylvestris mire is present. This is classed as moderately dependent on groundwater.	Yes	Adjacent to Westquarter Burn No available GI information within 100m Within 1-in-2-year modelled fluvial flood extents Area at moderate risk of groundwater flooding Underlain by alluvium	High to moderate	None	Medium

Site	Ecological Assessment	Potential GWDTE	Hydrogeological assessment	Initial Assessment of Groundwater Dependency	Designation	Importance
GW12	Adjacent to the Grange Burn Flood Relief Channel the vegetation is non-GWDTE common reed, however this transitions into zones of GWDTE habitats 30-40m from the channel. The vegetation appeared to be M23 Juncus effusus/acutiflorus-Galium palustre rush-pasture, a highly groundwater dependent community. M23 can form a fringe around common reed communities which has happened here. Where the rush element is less extensive, the vegetation is more akin to MG10 Holcus lanatus-Juncus effusus rush-pasture - a moderate GWDTE. Additionally, where tufted hair-grass increased in cover and soft-rush declined the vegetation would be more like MG9 Holcus lanatus-Deschampsia cespitosa grassland, also a moderate GWDTE.	Yes	Surface water channels in vicinity may indicate partially surface water fed Not within floodplain Area at moderate risk of groundwater flooding Groundwater monitoring records groundwater levels between 0 and 0.57m bgl Within raised tidal flat deposits	High to moderate	None	Medium

Site	Ecological Assessment	Potential GWDTE	Hydrogeological assessment	Initial Assessment of Groundwater Dependency	Designation	Importance
GW13	The main rush area appeared to be M23 Juncus subnodulosus-Cirsium palustre fen-meadow, a high GWDTE. However, the community did not seem to be as species-rich as others – this could be a result of previous grazing regimes. Patches of OV28 Agrostis stolonifera-Ranunculus repens community appeared to be associated with this, and MG9/MG10 may have been present in even smaller patches (both are classified as moderately groundwater dependent).	Yes	Adjacent to drainage channel No available GI information within 100m Not within a floodplain Area at moderate risk of groundwater flooding Underlain by raised tidal flat deposits	High to moderate	None	Medium
GW14	Much of the area was grassland of various types. These areas could be very variable and in mosaics, and whilst they clearly contained species typical of damp soils, the vegetation was not a GWDTE.	No	Not applicable			
GW15	Much of this old lagoon area comprised common nettle, with cleavers. The swamp area appeared to comprise mainly common reed with patches of reed canary-grass. Patches of rosebay willowherb were also present. None of these vegetation types are GWDTEs.	No	Not applicable			

Site	Ecological Assessment	Potential GWDTE	Hydrogeological assessment	Initial Assessment of Groundwater Dependency	Designation	Importance
GW16	The south of the site includes areas of Atlantic salt meadows, dense common reed habitats, and sea club-rush swamp, none of which are GWDTEs. However, the north of the site is a complex area of grassland types including three mesotrophic grassland types with moderate groundwater dependency.	Yes	Situated on reclaimed land built on the mudflats of the Forth Estuary. Areas below MHWS likely predominately surface water fed Within 1-in-5-year modelled tidal flood extents Area at moderate risk of groundwater flooding Located on intertidal deposits Groundwater monitoring records groundwater levels between 0.93 and 3.89m bgl	Moderate	None	Medium
GW17	Survey notes indicated wet marshy areas at two locations within a modified grassland (golf course).	Yes	Upslope of River Carron Within 5yr modelled fluvial flood extent Moderate groundwater flooding risk Underlain by Alluvium and Raised Tidal Flat Deposits No groundwater monitoring data within 50m	High to moderate	None	Medium
GW18	Mapped as wetland in the north and is possibly reedbed. Mapped as grassland in the south but appears to be similar to northern area.	Yes	Adjacent to River Carron Moderate groundwater flooding risk Underlain by Intertidal Deposits Groundwater monitoring only available on opposite bank of the Carron	Moderate	None	Medium

Site	Ecological Assessment	Potential GWDTE	Hydrogeological assessment	Initial Assessment of Groundwater Dependency	Designation	Importance
GW19	Mapped as swamp at Phase 1, but not visited and actual habitat is unclear.	Yes	Adjacent to River Carron Within 10yr modelled fluvial flood extent Moderate groundwater flooding risk Underlain by Intertidal Deposits Groundwater monitoring only available on opposite bank of the Carron	High to moderate	None	Medium
GW20	An area of pond and probably reedbed.	Yes	Lies on reclaimed land between forth Ports and the outlet of the Grange Burn Within 5yr modelled tidal flood extent Moderate groundwater flooding risk Assume underlain by made ground No groundwater monitoring within 100m	Low	None	Low
GW21	Possibly ornamental pond and wetland area in cemetery.	Yes	Upslope of the Westquarter Burn Outside 200yr modelled fluvial flood extent Moderate groundwater flooding risk Underlain by Raised Marine Deposits No groundwater monitoring within 100m	High to moderate	None	Medium

Site	Ecological Assessment	Potential GWDTE	Hydrogeological assessment	Initial Assessment of Groundwater Dependency	Designation	Importance
GW22	Mapped as UKHabs f2f - Other swamps. Comprises bulrush and soft-rush. Whilst soft-rush vegetation can be a GWDTE, bulrush vegetation isn't. There is a possibility that there could be some groundwater influence, but this is not possible to determine from the vegetation alone.	Yes	150m inland of River Avon Within 2yr modelled tidal flood extent Low groundwater flooding risk Underlain by Intertidal Deposits Monitored groundwater levels between 1.01 and 3.22m bgl	Moderate	None	Medium
GW23	Likely wet grassland but not confirmed.	Yes	75m inland of River Avon Within 5yr modelled tidal flood extent Low groundwater flooding risk Underlain by Intertidal Deposits No groundwater monitoring within 100m	High to moderate	None	Medium
GW24	Kinneil Lagoons. Most of the area would be wetland although some areas would be wet (and some dry). Some small areas of potential moderate GWDTE.	Yes	Situated on reclaimed land built on the mudflats of the Forth Estuary. Adjacent to Kinneil Lagoons Within 2yr modelled tidal flood extent Moderate groundwater flooding risk Underlain by Intertidal Deposits No groundwater monitoring within 100m	Moderate	SSSI	Very High

Site	Ecological Assessment	Potential GWDTE	Hydrogeological assessment	Initial Assessment of Groundwater Dependency	Designation	Importance
GW25	Likely wet grassland but not confirmed.	Yes	240m from Firth of Forth Within 20yr modelled tidal flood extent Low groundwater flooding risk Underlain by Intertidal Deposits Monitored groundwater levels between 1.95 and 2.10m bgl	High to moderate	None	Medium
GW26	Likely wetland type habitat, but actual vegetation not confirmed.	Yes	Lies on reclaimed land adjacent to Grange Burn. Two sub-sites in the west and centre subsequently identified as a pond and topsoil mound respectively. Sub-site in the east potentially groundwater dependent. Partially within 20yr modelled tidal flood extent Low to moderate groundwater flooding risk Assume underlain by made ground Monitored groundwater levels between 0.86 and 1.50m bgl	Moderate	None	Medium

Environmental Impact Assessment Report

Appendix C10.5 WFD Compliance Assessment

Grangemouth Flood Protection Scheme 2024
Falkirk Council

Jacobs

Grangemouth Flood Protection Scheme

Environmental Impact Assessment Report

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Contents

Foreword

This Water Framework Directive compliance assessment appendix has been prepared for the Grangemouth Flood Protection Scheme. The report provides supporting information to Chapter 10: Water Environment of the associated Environmental Impact Assessment Report. The Water Framework Directive assessment is presented as three Annexes:

- Annex C10.5.1 (Fluvial Water Framework Directive Assessment) comprises an assessment of the fluvial water bodies associated with the Scheme to inform a detailed compliance assessment.
- Annex C10.5.2 (Coastal and Estuarine Water Framework Directive Assessment): comprises a 'Clearing the Waters for all' assessment, which applies to transitional and coastal water bodies, to inform a detailed compliance assessment.
- Annex C10.5.3 (Groundwater Water Framework Directive Compliance Assessment) comprises an assessment of the groundwater bodies associated with the Scheme to inform a detailed compliance assessment.

Annex C10.5.1: Fluvial WFD Assessment

1. Introduction

1.1 Background

This Water Framework Directive (WFD) compliance assessment report has been prepared for the Grangemouth Flood Protection Scheme (FPS), 'herein referred to as 'the Scheme'. The report will be submitted as part of a planning application on behalf of Falkirk Council. This assessment comprises an assessment of the fluvial water bodies associated with the Scheme to inform a detailed compliance assessment.

The Water Framework Directive establishes the European Commission (2000) Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy. The WFD is transposed into Scottish Law by way of the Water Environment and Water Services Act 2003 (WEWS) (as amended by Environment (EU Exit) (Scotland) (Amendment etc.) Regulations 2019. The WEWS Act gave Scottish Ministers powers to introduce regulatory controls over water activities, in order to protect, improve and promote sustainable use of Scotland's water environment. This includes wetlands, rivers, lochs, transitional waters (estuaries), coastal waters and groundwater. The WEWS Act requires any activity that is liable to cause water pollution to be authorised, which was implemented through Section 20 of the Act as the Water Environment (Controlled Activities) Regulations 2011 (as amended by Water Environment (Controlled Activities) (Scotland) Amendment Regulations 2021) and the Water Environment (Miscellaneous) (Scotland) Regulations 2017).

1.1.1 Background to the Legislative Requirements

The Water Framework Directive (WFD)[1] requires all water bodies to achieve both good chemical and ecological status (GES). For each River Basin District, a River Basin Management Plan (RBMP) outlines the actions required to enable natural water bodies to achieve this. Water bodies that are designated as Heavily Modified Water Bodies (HMWB) or Artificial Water Bodies (AWB) within the RBMP may be prevented from reaching good ecological status by the physical modifications for which they are designated or the purpose for which they were constructed (e.g. navigation, flood defence, urbanisation). Instead, they are required to achieve good ecological potential through the implementation of a series of mitigation measures outlined in the applicable RBMP (and in some cases updated since the publication of the RBMP) and as provided on the SEPA Environment Hub[2].

Overall ecological status (or potential) is made up of a number of biological, hydromorphological and chemical quality characteristics called elements. The overall status is determined by the lowest element status. Any activity which has the potential to impact on ecology needs consideration in terms of whether it could cause deterioration to the ecological status or potential of a water body. It is, therefore, necessary to consider the possible changes associated with the Scheme.

The assessment needs to consider the objectives set out within the legislation:

- no changes affecting high status sites;
- no changes that will cause failure to meet surface water good ecological status or potential or result in a deterioration of surface water ecological status or potential;

[1] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

[2] SEPA 2023: https://www.sepa.org.uk/data-visualisation/water-environment-hub/

- no changes which will permanently prevent or compromise the environmental objectives being met in other water bodies; and
- no changes that will cause failure to meet good groundwater status or result in a deterioration groundwater status.

Where there are sites protected under the Habitats Regulations 2019, the WFD aims for compliance with any relevant standards or objectives for these sites. For the Scheme, this relates to the following designated sites:

- Firth of Forth Special Protection Area (SPA); and
- Firth of Forth Ramsar (wetland) site.

1.2 Scheme Outline

In total, the Scheme comprises an approximate total length of 8km of flood defences along fluvial waterbodies. Defence types consist of flood walls, earth embankments, relining of existing flood relief channels and new flow control structures. Additional structures to accommodate flood defences include extended culverts and raised bridges. To accommodate access, the Scheme also includes pedestrian and vehicular flood gates, ramps and access tracks or footpaths. It is anticipated construction will take up to ten years to complete with discrete sections being completed in phases within that time.

The Scheme has been divided into six Flood Cells (Figure B10-1), and each Flood Cell is sub-divided into working areas (Table 1.1). The Scheme has a total of four flood cells within a fluvial environment, which are broken down in to eight working areas. Defence lengths are provided as measured upstream of the Normal Tide Limit (NTL).

1.2.1 Scheme layout

The Scheme design includes a combination of the following flood protection measures:

- fluvial flood walls and embankments: concrete or sheet pile walls and earth embankments;
- a flow control structure (weir) on the Grange Burn near the confluence of the flood relief channel and Grange Burn; and
- relining of the flood relief channel to improve flows and repair damage.

Table 1.1. Cell numbers and working area components within fluvial waterbodies

Cell no.	Working Areas	Location	Waterbody	Forms of Construction	Approximate Overall Length of Flood Defences (m)*
1	1-1	Stirling Road	Carron, Stirling Road Tributary	Piled Wall (Brick Clad),	1525
4	4-1	Upstream of M9 Road	Grange Burn/Westquarter Burn	Piled wall (Formed concrete and stone clad)	720
	4-2	Rannoch Road	Grange Burn Flood Relief Channel	Piled Wall (Formed concrete finish)	550
			Grange Burn Flood Relief Channel (FRC)	Relining of the FRC	560
			Grange Burn	Flow Control Structure	35 (m^3)
	4-3	Inchyra Road	Grange Burn Flood Relief Channel	Piled Wall (Formed concrete finish)	380
			Grange Burn Flood Relief Channel (FRC)	Relining of the FRC	711
	4-4	Wholeflats Road	Millhall Burn	Piled walls with various finishes	912
			Grange Burn FRC	Piled walls with various finishes	1230
5	5-1	Smiddy Brae and Avondale Road	Avon (Setback)	Piled Wall (formed concrete finish)	544

* Defence lengths measured upstream from the NTL and do not include defences within transitional reaches

1.3 WFD screening

This WFD assessment covers only those components of the Scheme that could affect the fluvial water body features, i.e., the works in Cells 1, 4 and 5, and the respective working areas within each of these Cells (specifically 1-1, 1-2, 1-3 (along Chapel Burn), 4-1 to 4-4 and 5-1) as shown in Table 1.1. The assessment looks at the effect of new modifications to the water bodies and any changes to existing modifications. The impacts on the transitional and coastal water bodies are assessed in Annex C10.5.2 Estuarine WFD Assessment. Groundwater impacts are assessed and presented in Annex 10.5.3.

2. Methodology

Water body data have been extracted from SEPA's water classification hub[3] to assess water bodies present within the Scheme's study area (Table 1.1).

[3] SEPA 2023: Water Classification Hub

There are several stages to this assessment:

- presentation of baseline data and scoping (Section 3)
- an assessment against water body quality elements (Section 4);
- an assessment of the receptors scoped in against the Scheme elements (Section 5); and
- an assessment of the Scheme against mitigation measures (Section 6).

3. Baseline scoping

3.1 Water body scoping and screening

The following fluvial WFD designated surface water bodies are located within the study area are:

- River Carron (Bonny Water Confluence to Carron Estuary) (4200).
- Grange Burn/Westquarter Burn (3300).
- River Avon (Logie Water Confluence to Estuary) (3100).

The SEPA water classification hub shows Grange Burn to extend beyond the tidal limit, to the Middle Forth Estuary. However, the water body is tidally influenced until the entrance of the Zetland Park in Orchard Street (National Grid Reference (NGR) NS 92842 81336), as shown by the Marine Scotland online mapping tool. Therefore, it is considered that downstream of this point all waters are transitional and hence will be assessed in Annex C10.5.2.

The listed surface water bodies are scoped into further assessment due to the location of the Scheme's works within or adjacent to them. A summary of the status of the quality elements for the in-scope water bodies is provided in Table 3.1

Table 3.1. WFD surface water bodies baseline information

Water body Name in RBMP	SEPA ID	Flood Cell ID	Artificial Water Body (AWB) or Heavily Modified Water Body (HMWB) (Yes/No)	Overall Status/Potential	Overall Ecology	Overall Chemistry	Priority Substances	Physico-chemical	Biological Elements	Specific Pollutants	Hydromorphology
River Carron (Bonny Water Confluence to Carron Estuary)	4200	1	No	Poor Status	Poor	Pass	Pass	Moderate	Poor	Fail	Moderate
Grange Burn/Westquarter Burn	3300	4	Yes	Moderate Ecological Potential	Bad	-	-	Good	Good	Pass	Bad
River Avon (Logie Water Confluence to Estuary)	3100	5	No	Moderate Status	Moderate	Pass	Pass	Good	Moderate	Pass	High

4. Assessment against quality elements

This section details a site-specific assessment of the Scheme against biological, physico-chemical and hydromorphological quality and supporting elements for the fluvial water bodies (Table 4.1).

Table 4.1. Scoping of quality and supporting elements for fluvial water bodies

Element considered	Scoping		
Fluvial Water bodies	**River Carron (Bonny Water confluence to Carron Estuary)**	**Grange Burn/Westquarter Burn**	**River Avon (Logie Water confluence to Estuary)**
Biological quality elements			
Macrophytes and phytobenthos	Scope in	Scope in	Scope in
Benthic invertebrate fauna			
Fish fauna			
Hydromorphological quality elements			
Hydrological regime			
Quantity and dynamics of water flow	Scope in	Scope in	Scope in
Connection to groundwater bodies			
Morphological conditions			
River continuity	Scope in	Scope in	Scope in
River depth and width variation			
Structure and substrate of the riverbed			
Structure of the riparian zone			
Physico-chemical elements			
Thermal conditions	Scope in	Scope in	Scope in
Oxygenation conditions	Scope out due to no considered impact.	Scope out due to no considered impact.	Scope out due to no considered impact.
Salinity	Scope out: No interaction with salt water due to fluvial elements of the Scheme being above tidal limit. Therefore, mixing of saline water and fresh water would be negligible (if at all) and therefore scoped out of further assessment.		
Acidification status	Scope out: No likely pathway or control that would induce changes in acidification.		
Nutrient conditions	Scope out: No likely pathway or control that would induce changes in nutrient conditions (agriculture and sewage treatment).		
Specific pollutants			
Pollution by all priority substances identified as being discharged in significant quantities into the body of water	Scope out: No pathways for priority substances to enter receptor.		
Pollution by other substances identified as being discharged in	Scope in during construction: Accidental spillages and discharges of potentially polluting substances.		

Element considered	Scoping		
Fluvial Water bodies	**River Carron (Bonny Water confluence to Carron Estuary)**	**Grange Burn/Westquarter Burn**	**River Avon (Logie Water confluence to Estuary)**
significant quantities into the body of water			

5. Assessment of receptors against individual Scheme elements

This section provides further detail on how each Scheme component activity within the Flood Cells could impact on the quality elements of the receptors assessed in Section 4 (Table 4.1). Only the receptors scoped in (Section 3) in are taken forward into assessment.

Table 5.1. Impact Assessment

Key to Impact							
Negative	×	Negligible	•	Positive	✓	No change	~

Cell ID	WFD element likely to be impacted (and description of impact)	Options for environmental mitigation
Cell 1 (River Carron): 1-1, Cell 4 (Grange Burn): 4-1 and 4-3	Sheet Pile Wall	
Macrophytes, phytobenthos and benthic invertebrate fauna	• During construction, there will be disturbance to the substrate, and therefore loss and/or disturbance of species in these areas depending on whether these are mobile or sessile. There will also be removal of species in preparation for the works, and also secondary effects of suspended sediment as a result of works within and adjacent to the channel. Vegetation is likely to be removed as part of works which could lead to local loss/displacement of species. Sediment could be remobilised during works. a) Sediment disturbance will be likely in channel margins. b) Potential smothering is likely to downstream channel bed features or spawning grounds. c) Species disturbance within the channel margins and floodplain. Overall, risks would be localised to and immediately downstream of the works. Any potential impact would be temporary to the construction period and localised to the construction footprint and unlikely to cause deterioration at the water body scale. Post-completion of works, there will be an absence of marginal habitat unless reinstated. Changes will be localised. Overall, there is unlikely to be disturbance sufficient to cause water body scale deterioration.	Compile and adhere to a Construction Environmental Management Plan (CEMP) and ensure materials do not pollute substrate or water body. All pollution to be controlled under current legislation and best practice. Ensure riparian vegetation removal is kept to an absolute minimum and any removal is reinstated post construction.
Fish fauna	× As with other biological elements. Working within or adjacent to the channel could increase the suspended sediment concentrations presenting a temporary and localised risk to fish, particularly by temporarily affecting migration due to noise.	Implementation of a CEMP.

	This could also affect downstream to the transitional reaches. However, this impact is not anticipated to cause a deterioration at the water body scale. • Post works, potential for localised change in species numbers and quality but not enough to cause water body status deterioration.	Timing of works should not coincide with migration / spawning periods.
Quantity and dynamics of water flow	• Overall, no significant change although potential effects of: Reduction in channel cross-sectional area due to in-water working, increased flow velocities through the reduced channel area. This would be a temporary effect over the construction period and localised to and immediately downstream of the works footprint. Destabilisation of downstream bed and banks where unprotected in the absence of the wall lining the channel; and Variability in upstream and downstream siltation due to changing flow velocities and in-water working. • Post works, possible reduction in connectivity of the floodplain due to the new flood walls. Reduced uncontrolled flood flows onto the surrounding floodplain in undefended areas downstream of new defences. Constraints to flow could lead to increased flow homogeneity in areas already modified and at risk of canalisation.	Improvement in dynamics of water flow could be achieved by increasing channel heterogeneity. Consider varying sediment size in channel to increase heterogeneity in other hydromorphic characteristics as a well as dynamics. This can be trapped in the margins to encourage marginal habitat.
River depth and width variation, structure and substrate of riverbed and structure of the riparian zone	• Works can potentially reduce channel cross-sectional area, increase suspended sediment concentrations, and influence the structure of the bed. Potential indirect impacts from construction of the Scheme include the aggregation of fines (potential for) in slacker areas of water. Impacts would be temporary over the construction period and localised to the works footprint. These can be managed during construction through construction best practice. Riparian vegetation would be reinstated at the end of construction works. Overall, no significant change. • Post works, possible constraints to flow could lead to increased homogeneity in areas already modified and at risk of canalisation. Therefore, morphological diversity will potentially be limited due to constraints of the flood walls. However, due to existing conditions imposed by current structures, little change in the channel form is anticipated. Additionally, the walls would not interface with the channel during normal flow conditions, so any changes to the width and depth of	Compile and adhere to a CEMP. Potential to improve depth and width variation with planting of marginal habitat and introduction of sediment of varying sizes through natural riverine sediment transport and deposition (caution here as too much marginal habitat could cause flood risk). Potential to improve river margins through planting and incorporation of green niches.

	the channel would be considered temporary, during a flood event and as the hydrograph recedes.	
Water Quality (Physico-chemical elements)	• During works, potential localised and temporary increases in suspended sediment due to excavation and construction works and run-off and spillages from vehicles and machinery, affecting water quality. These would be temporary over the construction period. The implementation of measures within the CEMP to manage potentially polluting substances and activities would be followed. Therefore, deterioration at the water body scale is not anticipated.	Compile and adhere to a CEMP.
	~Post works, no change from current conditions likely given there would be no additional discharges	
INNS – Invasive species	× Risk of spread of invasive species if present. Risk of Himalayan Balsam and Japanese Knotweed spreading if not controlled as a result of construction.	INNS are reportable and should be reported if found. Compile and adhere to an CEMP and Invasive Species Management Plan (ISMP).
Cell 4 (Grange Burn): 4-2	Sheet Pile Wall and construction of new flow control structure.	
Macrophytes and phytobenthos and benthic invertebrate fauna	• Potential deterioration from impacts outlined for Cell 1-1, 4-1 and 4-3. Impacts to species would be the same under the footprint of the works to install the new flow control structures. Mobile species would be displaced, any impacts would be temporary and localised. Thus, deterioration at the waterbody scale is not anticipated. • Post works, potential for localised change in species numbers and quality due to presence of new flood walls and below the footprint of the flow control structure but not enough to cause water body status deterioration.	Compile and adhere to a CEMP. Production of detailed method statement to construct the flow control structure. In-water works should take place during periods of low flow where possible, and outwith fish spawning seasons. Ensure flows up to QMED are allowed to pass through the flow control structure unaltered to facilitate fish passage/migration.
Fish fauna	× Impacts would be the same as outlined for cells 1-1, 4-1 and 4-3 from noise and mobilised sediment. Impacts would be temporary and localised. No deterioration at the water body scale is anticipated.	
	~ The flow control structure will be an orifice with an overflow weir; hence it is not anticipated to impact the fish passage during normal flow conditions. Any impact during flood conditions would be temporary and localised during and for a short period after the flood event as the hydrograph recedes. Fish are unlikely to be migrating upstream during flood conditions due to the flow velocities. Therefore, it	

	is unlikely that the flow control structure would have an impact at a water body scale.	
Quantity and dynamics of water flow River continuity, River depth and width variation, Structure and substrate of riverbed and Structure of the riparian zone	• Same impacts as outlined for Cells 1-1, 4-1 and 4-3 above. Reduction in channel cross section due to in-water works. Potential changes to flow velocities, and sediment continuity. Temporary over the construction period and localised to the working area. No deterioration at the water body scale anticipated. Post works, possible reduction in connectivity to the adjacent floodplain ad described for Cell 4-2. As the wall would not interface with the channel during normal flow regimes, this impact is considered temporary during flood events of a higher magnitude until the hydrograph recedes. Given the temporary nature, and the scale of the defences compared to the overall water body scale, no deterioration at the water body scale is anticipated.	Potential to improve depth and width variation with planting of marginal habitat and introduction of sediment of varying sizes through natural riverine sediment transport and deposition (caution here as too much marginal habitat could cause flood risk).
Water Quality (Physico-chemical elements)	• Impacts during works as outlined for Cell 1-1, 4-1 and 4-3. Localised to the working area and temporary over the construction period. No deterioration anticipated. ~ Post works, no change from current conditions likely.	Compile and adhere to a CEMP.
INNS – Invasive species	× As outlined for impacts in Cells 1-1, 4-1 and 4-3.	INNS are reportable and should be reported if found. Compile and adhere to ISMP.
Cell 4 (Grange Burn): 4-4	Sheet pile wall, bridge raising and regrading existing embankment.	
Macrophytes and phytobenthos, benthic invertebrate fauna	• Impacts as described for cells 1-1, 4-1 and 4-3. Overall, there is unlikely to be any deterioration to the macrophytes and phytobenthos element of the water body during construction, considering that potential impact is deemed to be temporary and localised. ~ Post construction, no change from current conditions likely assuming riparian vegetation is reinstated.	Compile and adhere to a CEMP. Ensure riparian vegetation removal is kept to an absolute minimum and any removal is reinstated post construction.
Fish fauna	× Impacts as described for Cells 1-1, 4-1 and 4-3. Temporary and localised over the construction period and footprint, although this would be a negative effect, no impacts are anticipated at the water body scale.	Compile and adhere to a CEMP.

	~ Post works, no change from current conditions likely.	Timing of works should not coincide with migration / spawning periods.
Quantity and dynamics of water flow River continuity, River depth and width variation, Structure and substrate of riverbed and Structure of the riparian zone	• Impacts are as described for Cells 1-1, 4-1 and 4-3. Such impacts would be temporary and localised to the construction period and over the works footprint. Therefore, no deterioration at the waterbody scale is anticipated. Post works, impacts are as outlined for Cell 4-2. As the wall would not interface with the channel during normal flow regimes, impacts are considered temporary during flood events of a higher magnitude until the hydrograph recedes therefore no deterioration at the water body scale is anticipated.	Where possible minimise the footprint of in-water working and undertake such works during periods of low flow.
Water quality (Physico-Chemical)	• During works, impacts are as described for Cells 1-1, 4-1 and 4-3. Post works, no change as a result of post-construction.	Compile and adhere to a CEMP.
INNS – Invasive species	**Construction:** Impacts as described for Cells 1-1, 4-1 and 4-3.	INNS are reportable and should be reported if found. Compile CEMP and ISMP
Cell 1 (River Carron): 1-2, Cell 5 (River Avon): 5-1	Sheet pile wall and embankment and culvert extension	
Macrophytes, phytobenthos and benthic invertebrate fauna	• Impacts in relation to the flood walls would be the same as those described for Cells 1-1, 4-1 and 4-3. The formation of the earth embankment would be set back from the River Carron, and the flood walls on the River Avon would also be set back from the water body. Any potential impact is deemed to be temporary and localised. Post construction, riverbanks and riparian vegetation would be reinstated. Overall unlikely to cause deterioration at the water body scale.	Compile and adhere to a CEMP.
Fish fauna	• Impacts would be as described for Cells 1-1, 4-1 and 4-3. Such impacts would be temporary over the construction period and can be controlled through implementation of a CEMP and environmental best practice and are therefore unlikely to result in deterioration at the water body scale. ~ Post works, potential for localised change in species numbers and quality but not enough to cause water body status deterioration.	Compile and adhere to a CEMP. Timing of works should not coincide with migration /spawning periods and where possible should take place during periods of low flow.
Quantity and dynamics of water flow River continuity,	• The formation of the earth embankment would be set back from the River Carron, and the flood walls on the River Avon would also be set back from the water body	Compile and adhere to a CEMP.

River depth and width variation, Structure and substrate of riverbed and Structure of the riparian zone	therefore no impacts anticipated for the listed quality elements. Where flood defences are closer to the channel. Potential impacts are as described for flood cells 1-1, 4-1 and 4-3. These would be temporary and localised with no deterioration at the waterbody scale anticipated.	
Water quality (physico-chemical)	• Impacts during the works would be as described for Cells 1-1, 4-1 and 4-3. Such impacts would be lessened given the distance between the works and the waterbodies within these flood cells on the Avon and Carron. Post works there would be no change.	Compile and adhere to a CEMP. Monitoring may be required if there is a risk of exposure of contaminated sediments in the ground during works due to the high industry presence in the area.
INNS – Invasive species	As described for Cells 1-1, 4-1 and 4-3.	INNS are reportable and should be reported if found. Compile and adhere to a ISMP.

5.1 Consequences for transitional and coastal water bodies downstream of works

Potential impacts on transitional and coastal (TraC) water bodies could occur because of works within the upstream fluvial waterbodies. Impacts from the works in the fluvial water bodies may propagate downstream to the estuarine frontage of Grangemouth as a result of the nature of the stream flow towards the river mouth.

Examples of potential impacts include:

- working in water could mobilise sediment to be readily entrained downstream. However, this is negligible given the distance transported, and the opportunity further upstream for sediment to be more easily deposited in margins or deeper areas of the channels;
- increased runoff downstream due to the flashy nature of the channels, and due to potential narrowing of rivers upstream because in-water works; and
- working in the channel could mobilise pollutants upstream to be readily entrained downstream. This will be negligible because of the distance transported, and the opportunity further upstream for pollutants to drop out or be diluted.

In summary, the upstream works will not cause long-term deterioration to the transitional water bodies associated with the Scheme due to the distance upstream in which they would occur. There is no obvious conflict with WFD objectives due to the scale of the water body (Middle Forth) and the nature of the resultant effects versus background conditions. Therefore, changes to the overall status are not likely.

6. Assessment of the Scheme against mitigation measures

Within each RBMP, there is a list of mitigation measures, or environmental improvements, which have been identified by the RBMP, which need to be implemented to improve the ecology of water bodies by a specified date. A requisite of the WFD is to consider these measures and assess whether the Scheme can either contribute to them or might obstruct any of them from being delivered.

Table 6.1 provides a list of all mitigation measures applicable to Scottish water bodies, and an explanation of why the Scheme might/ might not be able to achieve or contribute to mitigation measures.

Table 6.1. Mitigation measures and assessment of whether the Scheme will help to contribute to these (management plan)

Mitigation Measure	Will the Scheme help to achieve or contribute to mitigation measure?
Improving the physical condition of these water bodies	
Contributions to flood risk management	Yes. This is the purpose of the Scheme.
Improved bank side vegetation to reduce the risk of diffuse pollution	No. There are no plans to improve bankside vegetation along the fluvial waterbodies. There are no plans to incorporate any restoration/ rehabilitation to improve.
Improving fish migration	
Restoring salmon runs to inaccessible sections of the river	Yes. Fish passage is being facilitated by integration of measures in the upstream sections of the Grange

Mitigation Measure	Will the Scheme help to achieve or contribute to mitigation measure?
	Burn to make the water bodies more attractive to fish migration and spawning.
Improving the quality and resilience of fisheries by restoring fish access to natural spawning and nursery habitats	Yes. Fish passage is being facilitated by integration of measures in the upstream sections Grange Burn to make the water bodies more attractive to fish migration and spawning.
Helping conserve populations of pearl mussel	No. There are no plans put forward to address this issue as part of the Scheme.
Improving water flows and levels	
Improving the quality of landscapes	Yes. Incorporation of landscaping adjacent to Grange Burn.
Restoring and supporting migratory fish runs	No. No plans to improve runs in-water levels and flows.
Improving health and range of populations of wild plants and animals	No. There are no plans put forward to address this issue as part of the Scheme.
Expanding opportunities for water based recreation	No. There are no plans put forward to address this issue as part of the Scheme.
Preventing spread of Invasive Non-native Species	
Protecting native wildlife	No. This is not explicit in the Scheme plans put forward to address this issue as part of the Scheme.
Preventing impacts on economically important activities	No. not explicitly, although reducing flood risk is an economical gain.

The above is further supported by information contained on the SEPA Water Environment Hub which outlines the pressures for individual water bodies and the reasons why WFD status for certain quality elements is not being achieved. The SEPA hub outlines not just the quality elements but also the pressures faced for the water bodies appropriate to this Scheme. Commentary is also provided on whether there are water body specific mitigation measures. A summary of this is provided below:

- River Carron (Bonny Water Confluence to Carron Estuary): This water body is under pressure from physical condition and water quality. Its physical condition is affected by pressures on the bed, banks and shoreline modifications from farming activities. Water quality pressures relate to land contamination and point source sewage/wastewater discharges. These are being addressed by SEPA, other public bodies, voluntary organizations, site/land managers and Scottish Water;
- Grange Burn/Westquarter Burn: This water body is heavily modified on account of physical alterations that cannot be addressed without a significant impact from an increased risk of subsidence or flooding. Its physical condition is the impact affected by modifications to bed, banks and shores from urban development and is being addressed by SEPA through the Water Environment Fund, other public bodies, voluntary organisations and land managers between 2021 and 2027; and
- River Avon (Logie Water confluence to estuary): This water body is under pressure from ecological condition caused by unknown pressures on water, animals and plants. The ecological pressure is to be determined.

In summary, it is unlikely that the nature of the works would impede any mitigation measures put forward as part of the RBMP or water body specific measures. Further, the nature of the works is unlikely to impede achievement of GEP in any of the relevant water bodies.

7. Compliance Conclusions

Taking into consideration the anticipated impacts of the Scheme on the biological, physico-chemical and hydromorphological quality elements, it is unlikely to compromise progress towards achieving good ecological potential or cause a deterioration of the overall ecological potential of any of the water bodies that are in scope. This is dependent on the implementation of the design and construction mitigation measures that are identified in this assessment.

Table 7.1. Compliance of the Scheme with the environmental objectives of the WFD

Environmental Objective	Scheme	Compliance with the WFD Directive
No changes affecting high status sites	There are no water bodies within the study area at high status	Yes
No changes that will cause failure to meet surface water good ecological status or potential or result in a deterioration of surface water ecological status or potential	The Scheme options will not cause deterioration in the status of the water bodies if mitigation is put in place.	Yes
No changes which will permanently prevent or compromise the Environmental Objectives being met in other water bodies	The Scheme options will not cause a permanent exclusion or compromise achieving the legislation's objectives in any other bodies of water within the River Basin District. The works within the Flood Cells associated with the fluvial water bodies (1, 4 and 5) are unlikely to cause deterioration to the downstream water bodies (i.e., the transitional Sections of the rivers and the Middle Forth Estuary). This is due to the comparatively large distances from works to these water bodies. Therefore, the current Scheme complies with Article 4.8.	Yes
No changes that will cause failure to meet good groundwater status or result in a deterioration groundwater status.	The Scheme options will not cause deterioration in the status of the of the groundwater bodies.	Yes

Annex C10.5.2 Estuarine WFD Assessment

1. Introduction

1.1 Background

The background to the legislation and the requirement for this WFD compliance assessment are explain in Section 1 of Annex C10.5.1. This annex covers the transitional (estuarine) and coastal waterbodies.

1.2 Outline of the Scheme

1.2.1 Overview of the Preferred Option and Scope of this Assessment

The Scheme has been divided into six Flood Cells (see Figure B10-1), and each Flood Cell is then sub-divided into distinct Working Areas provided in Table 1.1.

Table 1.1. Cell numbers and working area components

Cell no.	Working Areas	Location	Approximate Overall Length of flood defences (m)	Form of Construction
1	1-2	Carron Bridges	295	Piled walls with various finishes, and Replacement Bridge structure over the River Carron
	1-3	River Carron – Carrondale Nursing home to Rae Court	320	Piled walls with brick cladding finish
	1-4	Dock Street	535	Piled walls with formed concrete finish
2	2-1	Forth and Clyde Canal Lock	638	Bare sheet piled walls and earth embankment
	2-2	Jarvie Plant	800	Bare sheet piled walls
3	3-1	Mouth of the River Carron	915	Bare sheet piled walls
	3-2	West Coast of the Port	965	Bare sheet piled walls
	3-3	West Gate to the Port	1,170	Bare sheet piled walls
	3-4	East Gate to the Port	1,020	Piled walls with various finishes
	3-5	Mouth of the Grange Burn	580	Bare sheet piled walls
4	4-5	Grange Burn – Zetland Park	741	Piled stone clad wall and earth embankment
	4-6	Middle Forth Estuary – Dalgrain to Bo'Ness Road	730	Piled stone clad wall
	4-7	Middle Forth Estuary – Grangeburn Road	1,245	Piled wall with various finishes

Cell no.	Working Areas	Location	Approximate Overall Length of flood defences (m)	Form of Construction
	4-8	Middle Forth Estuary – Petroineos	1,065	Piled wall with various finishes
	4-9	Middle Forth Estuary – Mouth of GGrange Burn	1,005	Bare sheet
5	5-1	Smiddy Brae and Avondale Road	1,746	Piled wall with various finishes
	5-2	Flare Road and Road 33	877	Bare sheet piled wall
	5-3	Grangemouth Road	1,650	Bare sheet piled wall
	5-4	Mouth of the River Avon	428	Bare sheet piled wall
6	6-1 and 6-2	West of River Avon (Beach Road and Mouth of River Avon)	2,134	Bare sheet piled wall
	6-3 and 6-4	East of River Avon (Chemical Works at River Avon and Chemical Works)	1,419	Bare sheet piled wall

1.3 WFD Screening

This compliance assessment covers only those components of the Scheme that could affect the transitional water body features, i.e. within the working areas in shown in Table 1.1.

Table 1.1. The remaining working areas in Cells 1 and 4 are only assessed in terms of upstream works that may have the potential to impact downstream water bodies and downstream cells.

2. Methodology

The methodology follows that outlined in guidance provided by DEFRA 'Clearing the Waters for all[4] which applies to transitional and coastal (TraC) water bodies.

3. Baseline Scoping

3.1 Water Body Scoping

The following WFD classified water bodies are in scope within this compliance assessment:

- Middle Forth Estuary (200436);
- Island Farm Lagoon – Skinflats. Firth of Forth (200324);

In SEPA's water classification Hub Grange Burn extends beyond the tidal limit, to the Middle Forth Estuary. However, it is noted there is a discrepancy between SEPA and Marine Scotland Mapping. Marine Scotland mapping shows the tidal extents of Grange Burn extend to approximate NGR NS 92842 81336[5]. SEPA mapping indicates a much smaller tidal section of river on the Grange Burn. This

[4] DEFRA, 2017: Water Framework Directive assessment: estuarine and coastal waters

[5] Marine Scotland, 2023: https://marinescotland.atkinsgeospatial.com/nmpi/default.aspx?layers=1921

assessment uses the Marine Scotland tidal limits. Therefore, beyond the coordinates above, all waters are a part of Middle Forth Estuary and hence will be assessed as this water body herein.

Although hydrologically connected to waterbodies that could potentially be impacted by the Scheme, the Lower Forth Estuary is >5km from the Scheme. Given the distance between the Scheme and the receptor, any impacts are unlikely to be realised in this water body. It is therefore scoped out of further assessment.

A summary of the quality element status of scoped in water bodies is included in

Table 3.1.

Table 3.1. WFD surface water bodies baseline information

Water body ID	Name of water body in RBMP	Hydro-morphology	Overall Ecology	Overall Chemistry	Current Overall Status / Potential
Middle Forth Estuary	200436	Moderate	Moderate	Not assessed	Moderate ecological potential
Island Farm Lagoon - Skinflats. Firth of Forth	200324	High	Good	Not assessed	Good

3.2 Clearing the Waters Assessment Scoping

3.2.1 Protected Areas

The WFD requires that activities are also in compliance with other relevant legislation related to protected areas, as considered below.

3.2.2 Nature Conservation Designations

These are areas previously designated for the protection of habitats or species where maintaining or improving the status of water is important for their protection. They comprise the aquatic part of Natura2000 sites (Habitats Regulations 2019) Special Protection Areas (SPAs) and Special Areas of Conservation (SACs), and RAMSAR sites.

The Department for Energy food and Rural affairs (DEFRA) online mapping tool[6] was used to find out the nature conservation designations within 2km of the site. These include the following sites:

- Firth of Forth SPA (UK9004411) - Designated for the protection of an internationally important population of waders and wildfowl which visit the area during winter, and for Sandwich tern migration; and
- Firth of Forth Ramsar site (UK13017) - Designated for protection of waterfowl assemblages and certain bird species populations of international importance.

[6] Department for Environment, Food and Rural Affairs (DEFRA), 2023: https://magic.defra.gov.uk/magicmap.aspx

3.2.3 Bathing Waters

The Bathing Water (Scotland) Regulations 2008 requires that there are not impacts to bathing waters as a result of proposed works in or adjacent to designated areas. As per the clearing the water for all guidance, bathing water are including in the scoping.

A review of SEPA's[7] online mapping tool indicates there are no bathing waters within 2km of the Scheme.

3.2.4 Nutrient Sensitive Areas

Nutrient sensitive areas comprise nitrate vulnerable zones designated under the Nitrate Vulnerable Zones (Scotland) Regulations 2015. This legislation aims to protect the environment from the adverse effect of the collection, treatment, and discharge of urban wastewater. Sensitive areas are those affected by eutrophication associated with elevated nitrate concentration and as an indicator for required action to prevent further deterioration.

There are no nutrient sensitive sites within 2km of the Scheme. The closest is a Nitrate Vulnerable Zone (Edinburgh, East Lothian and Borders) that is more than 30km from the Scheme[8].

3.2.5 Shellfish Waters

A review of the SEPA Shellfish Water locations online tool[9] indicates there are no shellfish waters within 2km of the Scheme.

4. Assessment

This section details a site-specific assessment of the Scheme against quality elements.

4.1 Hydromorphology

This section provides a summary of the known existing hydromorphology risk issues for the transitional water bodies (Table 4.1).

Table 4.1. Hydromorphology scoping summary

Hydromorphology Considerations	Middle Forth Estuary	Island Farm Lagoon - Skin flats
Consider if your activity could impact on the hydromorphology (for example morphology or tidal patterns) of a water body at high status?	No. This water body not at high status.	No. Although this water body is at High status, in-flows are already controlled from a sluice on the transitional section of the River Carron which allows water ingress during the flood tide. The Scheme would not change this. Additionally, the closest construction would be approximately 300m away on the opposite bank of the River Carron. No operational infrastructure would interface with this location. Therefore, no impacts are anticipated to the hydromorphological status of this water body.

[7] SEPA 2023: https://www2.sepa.org.uk/bathingwaters/locations.aspx
[8] SEPA 2023: https://www.sepa.org.uk/environment/water/monitoring/protected-areas/
[9] SEPA 2023: https://www2.sepa.org.uk/bathingwaters/Locations.aspx

Consider if your activity could significantly impact the hydromorphology of any water body?	No. This water body is heavily defended and modified along much of its extent under baseline conditions. The Scheme is proposing to modify, realign, and construct new defences where appropriate. Overall, the scale of the proposed change is assessed as not being sufficient to significantly impact the water body at the water body scale.	No. As above, no construction or operational impacts anticipated on the hydromorphology of this water body.
Consider if your activity is in a water body that is heavily modified for the same use as your activity?	Yes. Middle Forth is a heavily modified water body on account of existing flood protection works.	No. This water body is not heavily modified.

Given that the Middle Forth is already defended with a suite of coastal structures already in place, little change to the water body hydromorphology status is predicted. Impacts are likely to be limited, localised and temporary. Predominantly, these are likely to be at the base / toe of the flood defence due to changes in the footprint and encroachment onto the shore fronting the defence-line, hence this is scoped into assessment.

4.2 Biology

4.2.1 Habitats

Table 4.2 presents a summary of biology (habitat) considerations and associated risk issues for the works for the transitional water bodies.

Table 4.2. Biology scoping summary

Biology Considerations	Middle Forth Estuary	Island Farm lagoon - Skinflats
Is the footprint of the activity 0.5 km^2 or larger?	Yes, inclusive of working areas: 1-2 – 1-4, 2-1 – 2-2, 3-1 – 3-5, 4-5 – 4-9, 5-1 – 5-4 and 6-1 – 6-4.	No. No construction works or operational infrastructure anticipated.
Is the footprint of the activity 1% or more of the water body's area?	No.	No.
Is the footprint of the activity within 500 m of any higher sensitivity habitat?	No.	No.
Is the footprint of the activity 1% or more of any lower sensitivity habitat?	No. This lower sensitivity habitat is subtidal soft sediments, sands and muds, which are extensive across the Firth of Forth Middle Estuary water body.	

Risks to the receptor during construction include tracking of plant along the intertidal, and/or damage to habitat from tracking of plant, machinery and riparian vegetation removal which could lead to the loss of, or disturbance to invertebrates. There is anticipated to be some loss/disturbance to species during construction, however impacts would be controlled through the implementation of a

Construction Environmental Management Plan (CEMP) and working to best practices. Given the overall scale of the construction works relative to the water body scale, and the implementation of construction controls there is not anticipated to be a deterioration in the biological quality elements during construction of the Scheme.

During the operation of the Scheme new flood walls and embankments could permanently remove habitat below their footprint. Additionally, there is also a risk of potential coastal squeeze where defences encroach beyond existing defences. There may be some localised displacement and disturbance of species, however the potential for these impacts to impact at the water body scale is very low. Thus, the biological quality elements of the Middle Forth Estuary are scoped out of further assessment.

4.2.2 Fish

Activities occurring within an estuary or inshore environment could impact on normal fish behaviour such as movement, migration, or spawning. Table 4.3 presents a summary of biology (fish) considerations and associated risk issues for the works.

Table 4.3. Biology (fish) scoping summary

Biology (fish) Considerations	Middle Forth Estuary	Island Farm Lagoon - Skinflats
Consider if your activity is in an estuary and could affect fish in the estuary, outside the estuary but could delay or prevent fish entering it or could affect fish migrating through the estuary?	Yes (see below).	No, it is a lagoon.
Consider if your activity could impact on normal fish behaviour like movement, migration or spawning (for example creating a physical barrier, noise, chemical change or a change in depth or flow)?	Construction could cause noise which could impact on fish behaviour. Also, construction could cause a temporary increase in suspended sediment concentrations within the water column as a result of transportation to the shore, siting of the materials onshore for storage and construction of the revetments. Impact assessment required.	
Consider if your activity could cause entrainment or impingement of fish?	No.	

The risks to the Middle Forth receptor during construction are due to noise from construction of the proposed defences, and also the potential release of suspended sediment concentrations and the creation of plumes as a result of working along the foreshore and within the inter-tidal. These impacts would be temporary to the construction period and localised to and within the vicinity of the works footprint. Suspended sediment concentrations released as a result of works, and due to disturbance of the seabed are likely to be very temporary and very localised, and not significantly greater than background conditions in this macro tidal environment. Any plumes that do form will be dispersed by hydrodynamic processes including by waves and the incoming and outgoing tides. Should there be any settlement, this is unlikely to cause disturbance to fish. In-water and near water works within the more confined sections of the Middle Forth (along the transitional sections of the Carron, Avon and Grange Burn) could create temporary barriers to fish movement. Due to the importance of fish on the water environment, this receptor has been scoped into the impact assessment for the Middle Forth Estuary water body.

4.3 Water Quality

Consideration should be made regarding whether phytoplankton status and harmful algae could be affected by the works, as well as identifying the potential risks of using, releasing or disturbing chemicals. Table 4.4 presents a summary of water quality considerations and associated risk issues of the works for the transitional water body.

Table 4.4. Water quality scoping summary

Water Quality Considerations	Middle Forth Estuary	Island Farm Lagoon - Skinflats
Consider if your activity could affect water clarity, temperature, salinity, oxygen levels, nutrients, or microbial patterns continuously for longer than a spring neap tidal cycle (about 14 days)?	Yes, activities extend beyond a 14-day period; effects on water quality anticipated during construction. Requires impact assessment.	
Consider if your activity is in a water body with a phytoplankton status of moderate, poor or bad?	The phytoplankton status has not been assessed for these water bodies.	
Consider if your activity is in a water body with a history of harmful algae?	No records for this.	
If your activity uses or releases chemicals (for example through sediment disturbance or building works) consider if the chemicals are on the Environmental Quality Standards Directive (EQSD) list?	No. There is the potential for release of contaminated sediments due to replacement of the middle lock gate within the western navigational channel of Grangemouth Port. However, the base of this navigation channel is formed from concrete, and under baseline conditions the channel is regularly flushed by the tide which aids in maintaining the channel depth for vessels entering the port. Therefore, under baseline conditions, potentially contaminated sediment within the navigational channel is regularly flushed out in to the Middle Forth and diluted by wave and tidal processes. The Scheme would not change this as the new lock gate would operate the same as the existing. Therefore, no change to baseline conditions in relation to chemicals on the Cefas and EQSD lists are anticipated. There may be some additional disturbance during construction of the new lock gate, however controls would be in place downstream of the gate to ensure any additional sediment entrained is captured	Although there is a pathway to the receptor, there is no identified sustainable source of pollution.
If your activity uses or releases chemicals (for example through sediment disturbance or building works) consider if it disturbs sediment with contaminants above Cefas Action Level 1?		
If your activity has a mixing zone (like a discharge pipeline or outfall) consider if the chemicals released are on the Environmental Quality Standards Directive (EQSD) list?		

	and allowed to settle prior to release in to the wider Middle Forth Estuary.	

As at least one water quality consideration indicates that a risk to the Middle Forth Estuary could be associated with the works, this receptor has been scoped into the impact assessment.

4.4 Protected Areas

Consideration should be made regarding whether protected areas are at risk from a proposed activity. Table 4.5 presents a summary of protected area considerations and associated risk issues of the works. As the protected areas considerations indicate that a risk could be associated with the works, this receptor has been scoped into the impact assessment.

Table 4.5. Protected Areas

Protected Area Considerations	Middle Forth Estuary	Island Farm lagoon
Consider if your activity is within 2 km of any WFD protected area?	Yes. It is within Firth of Forth SPA and Ramsar site.	

4.5 Invasive Non-Native Species (INNS)

Consideration should be made regarding whether there is a risk the activity could introduce or spread INNS. Risks of introducing or spreading INNS include materials or equipment that have come from, had use in or travelled through other water bodies, as well as activities that help spread existing INNS, either within the immediate water body or other water bodies. Table 4.6 presents a summary of INNS considerations and associated risk issues of the works. As no indication of marine invasive species is made, this receptor has been scoped out the impact assessment.

Table 4.6. INNS considerations

INNS Considerations	Middle Forth Estuary	Island Farm lagoon
Introduction or spread of INNS	No. There are no marine invasive species.	No. There are no marine invasives.

4.6 Assessment summary

The site-specific impacts of the Scheme on the biological, physico-chemical and hydromorphological quality elements of the water bodies are shown in the assessment above and summarised in Table 4.7.

Table 4.7. Scoping summary

Receptor	Potential risk to receptor?	Note the risk issue(s) for impact assessment
Hydromorphology	Yes	Impacts are likely to be at the base/toe of the flood defence due to changing in the footprint and

		encroachment onto the shore fronting the defence-line.
Biology: habitats	No	Potential for impacts to the water body is low due to existing footprint of shoreline/flood defences.
Biology: fish	Yes	Potential disturbance from noise and suspended solids.
Water quality	Yes	Activities extend over a 14-day period.
Protected areas	Yes	Site within Firth of Forth SPA and Ramsar.
Invasive non-native species	No	No risk to marine areas as no marine species.

5. Assessment of Receptors against Individual Scheme Elements

The following section provides further detail on how each Scheme component per working area could impact on the quality elements outlined in Section 4, for the receptors outlined in Section 3. Only the receptors scoped in are taken forward into this assessment (Table 4.7).

Jacobs

Table 5.1. Screening of Scheme activities against status objectives and quality elements for transitional water bodies

Key to Impact							
Negative	×	Negligible	•	Positive	✓	No change	~~

Middle Forth Estuary	WFD element likely to be impacted (and description of impact)	Environmental mitigation
Cell 1: 1-3 Cell 2: 2-1 Cell 4: 4-5 and 4-9 Cell 5: 5-2, 5-3 and 5-4	Piled walls and earth embankments	
Hydromorphology	• Although the majority of construction will take place adjacent to and from the landward side of the waterbodies, there will be a requirement for in-water to construct on some sections of the sheet piled walls within working area 1-3. Near and in-water working has the potential to increase fine sediment discharge to the water body. Additionally, in-water working will remove/disturb natural bed material along the footprint of the toe. Any changes in suspended sediment are unlikely to be greater than the background levels experienced within the estuary. The impacts would be temporary over the construction period and localised to and within the vicinity of the works footprint. Controls would be in place to manage sediment generated from the works. Therefore, there is not anticipated to be a deterioration at the water body scale. Post works, the normal channel would not interface with the new defences. Any impacts to hydromorphology would be related to a reduction in channel cross-sectional area during flood events. This would alter the hydrodynamics and flow velocities with a potential to change deposition, erosion and transport of material over the impacted reach. This would be localised with regards to the water body scale, and temporary during a flood event. The extension of the culvert on the connected tributary of Mungal Burn would not impact the Middle forth at the water body scale.	Compile and adhere to a Construction Environmental Management Plan (CEMP) and ensure materials do not pollute substrate or water body. All pollution to be controlled under current legislation and best practice.
Biology - Fish	× Below the tidal limit, works could affect fish in the estuary and in the transitional sections of the rivers due to noise, remobilisation of sediment and increase in suspended sediment concentrations. Disturbance to	Compile and adhere to a CEMP and ensure materials do not pollute

Middle Forth Estuary	WFD element likely to be impacted (and description of impact)	Environmental mitigation
	species could include temporary interruption to any migration (if occurring) towards the River Carron, Avon and Grange Burn. Working within or close to the channel/frontage could disturb fish presenting a temporary but localised risk to species.	substrate or water body. All pollution to be controlled under current legislation and best practice. Monitoring could be put in place to monitor fish numbers and migration. Timing of works should not coincide with migration/spawning periods.
	• Post works, potential for localised change in species numbers and quality but not enough to cause water body status deterioration.	
Water quality	• During works, potential increases in suspended sediment concentrations within the water body as a result of excavations and the construction of the embankments and sheet piling. Piling is likely to be the activity that creates most issues to water quality due to the invasive nature of the works into the substrate. Moreover, run-off and spillages from vehicles and machinery could affect the water quality should it be allowed to enter the receptor. However, any changes in suspended sediment, salinity and chemistry are likely to be diluted with the tides and are unlikely to likely to be greater than the background levels in the Forth experienced on a daily basis. Thus, there is unlikely to be any deterioration to water quality elements within the water body.	Compile and adhere to a Construction Environmental Management Plan (CEMP) and ensure materials do not pollute substrate or water body. All pollution to be controlled under current legislation and best practice. Monitoring may be required if there is a risk of exposure of contaminated sediments in the ground during works.
	~~ Post works, there will be no change to status. There could be an improvement in Cell 3 as the rock revetment could act as a green niche whereby invertebrates use it as a reef system and colonise it.	N/A
Protected areas	~~ No change as a result of works or post-construction. The scale of the works and magnitude of likely impacts through suspension of sediment and/or changes to water quality and/or changes to the shoreline are negligible at the waterbody scale, and therefore not likely to impede the objectives of the Habitats regulations. Therefore, the integrity of the protected areas is not affected.	N/A
Cell 1: 1-4 Cell 2: 2-2 Cell 3: 3-2, 3-4 and 3-5 Cell 4: 4-7 and 4-8	Piled walls	

Middle Forth Estuary	WFD element likely to be impacted (and description of impact)	Environmental mitigation
Hydromorphology	✖ Impacts on hydromorphology related to the construction of sheet piled walls would be the same as those described for Cell 1-3 in relation to increased sediment inputs and in-water working. Such impacts would be temporary over the construction period and localised to the working area. Additionally, controls for managing sediment would be in place as outlined in the CEMP. Therefore deterioration at the water body scale is not anticipated. ● Post works impacts would be as described for Cell 1-3. Such impacts would be localised with regards to the water body scale, and temporary during a flood event given that the flood walls would not interact with the water body during normal flows tides. Therefore, deterioration at the waterbody scale is not anticipated.	Compile and adhere to a CEMP.
Biology - fish	✖ Below the tidal limit, works could affect fish in the estuary and in the upstream section of the Middle Forth Estuary due to noise, remobilisation of sediment and increase in suspended sediment concentrations. Disturbance to species could include temporary interruption to any migration (if occurring) towards the River Carron, Avon and Grange Burn. Working within or close to the channel could disturb fish presenting a temporary but localised risk to species within the channel during works and therefore the shoreline. ~~Post works, there will be no change to status.	Compile and adhere to a CEMP. Timing of works should not coincide with migration/spawning periods.
Water quality	●As above, potential increases in suspended sediment concentrations within the water body as a result of excavations and sheet piling. Moreover, run-off and spillages from vehicles and machinery could affect the water quality should they enter the water body. However, any changes in suspended sediment, salinity and chemistry are likely to be diluted with the tides and are unlikely to likely to be greater than the background levels in the Forth experienced on a daily basis. Thus, there is unlikely to be any deterioration to water quality elements within the water body. ~~It is unlikely to have any change as a result of works or post-construction.	Compile and adhere to a CEMP. Monitoring may be required if there is a risk of exposure of contaminated sediments in the ground during works.
Protected areas	~~ No change as a result of works or post-construction. The scale of the works and magnitude of likely impacts through suspension of sediment and/or changes to water quality and/or changes to the shoreline are negligible at the waterbody scale, and therefore not likely to impede the objectives of the Habitats regulations. Therefore, the integrity of the protected areas is not affected.	N/A

Middle Forth Estuary	WFD element likely to be impacted (and description of impact)	Environmental mitigation
Cell 1: 1-2 Cell 4: 4-6	Piled wall, earth embankment and replacement bridges	
Hydromorphology	✖ During works impacts would be as outlined for Cell 1-3 as a result of near and in-water working. Any changes in suspended sediment are likely to be diluted with the tides and are unlikely to likely to be greater than the background levels experienced on a daily basis. No change to tides or currents anticipated. The impacts would be temporary over the construction period and localised to and within the vicinity of the works footprint. Controls would be in place to manage sediment generated from the works. Therefore, there is not anticipated to be a deterioration at the water body scale.	Compile and adhere to a CEMP.
	• Post works, the normal flow within the channels would not interface with the new defences. Any impacts to hydromorphology within the transitional reaches would be related to a reduction in channel cross-sectional area during flood events. This would alter the hydrodynamics and flow velocities with a potential to change deposition, erosion, and transport of material over the impacted reach. This would be localised with regards to the water body scale, and temporary during a flood event..	
Biology - fish	✖ Below the tidal limit, works could affect fish in the estuary and in the transitional sections of the rivers due to noise, remobilisation of sediment and increase in suspended sediment concentrations. Disturbance to species could include temporary interruption to any migration (if occurring) towards the River Carron, and Grange Burn. Working within or close to the channel / frontage could disturb fish presenting a temporary but localised risk to species.	Compile and adhere to a CEMP and ensure materials do not pollute substrate or water body. All pollution to be controlled under current legislation and best practice. Monitoring could be put in place to monitor fish numbers and migration. Timing of works should not coincide with migration / spawning periods.
	~~: Post works, no change from current conditions. Raised bridge abutments would remain in the same position and therefore limited change to baseline conditions. There may be minor beneficial impacts during flood event if the raised bridges are above the design event. Overall, no significant change.	
Water quality	• During works, impacts are as described for Cell 1-3 relating to temporary and localised sediment input to the waterbody as a result of adjacent and in-water works. Given the temporary and localised nature, deterioration at the waterbody scale is not anticipated.	Compile and adhere to a CEMP
	~~ Post construction, there will be no change.	N/A
Protected areas	~~ The works could impact both the Middle Forth and Island Farm Lagoon due to disturbance of species, including invertebrates, macrophytes and fish, and small loss of footprint of potential feeding habitat	N/A

Middle Forth Estuary	WFD element likely to be impacted (and description of impact)	Environmental mitigation
	fronting the defences, for the birds within the SPA and the Ramsar site. However, the area disturbed would be minimal at the waterbody scale.	
Cell 3 and 6: 3-1, 3-3, 6-1, 6-2, 6-3 and 6-4	Piled wall and embankment with revetment	
Hydromorphology	✖ During works impacts would be as outlined for Cell 1-3 as a result of near and in-water working. Any changes in suspended sediment are likely to be diluted with the tides and are unlikely to likely to be greater than the background levels experienced on a daily basis. No change to tides or currents anticipated. The impacts would be temporary over the construction period and localised to and within the vicinity of the works footprint. Controls would be in place to manage sediment generated from the works. Therefore, there is not anticipated to be a deterioration at the water body scale.	Compile and adhere to a CEMP.
	• Sheet pile walls and associated revetments may reflect wave energies and tidal currents during adverse weather and during extremes. During normal conditions, this is unlikely to happen due to the relatively low energy along the foreshore and therefore would be a temporary impact during inclement weather and storms. The frontage could be prone to scour of the foreshore in some cases, which could lead to localised beach lowering, sediment movement offshore and subsequent loss of intertidal habitat, invertebrates, flora and fauna and macrophytes. Additionally, sediment movement offshore could lead to increased suspended sediment / turbidity over localised areas. Overall, there may be negligible change, but it is difficult to ascertain if this change would be greater than that experienced without the defences. Given the macrotidal nature of the tides, these changes may occur anyway.	
Biology - fish	✖ Impacts would be the same as those outlined for working area 1-2 above. Disturbance to species within the Middle Forth could include temporary interruption to any migration (if occurring) towards the River Carron, Grange Burn River Avon. Working within or close to the channel could disturb fish presenting a temporary but localised risk to species during works.	Compile and adhere to a CEMP. Timing of works should not coincide with migration / spawning periods.
	~~ Post works, there will be no change to status.	
Water quality	• Potential impacts related to near and in-water working as a result of increased sediment as described for Cell 1-3. Any changes in suspended sediment, salinity and chemistry are likely to be diluted with the tides	Compile and adhere to a CEMP.

Middle Forth Estuary	WFD element likely to be impacted (and description of impact)	Environmental mitigation
	and are unlikely to likely to be greater than the background levels in the Middle Forth experienced on a daily basis. Thus, there is unlikely to be any deterioration to water quality elements within the water body.	Monitoring may be required if there is a risk of exposure of contaminated sediments in the ground during works due to the high concentration of boat yards and industry around the shoreline.
	~~ Post construction, there will be no change.	
Protected areas	~~ The works could impact both the Middle Forth and Island Farm Lagoon due to disturbance of invertebrates, macrophytes and fish, and small loss of footprint of potential feeding habitat on the foreshore fronting the defences, for the birds within the SPA and the Ramsar. However, the impacts are unlikely to be realised at the waterbody scale.	N/A
	✓ Post works, there could be an improvement as the rock revetment could act as a green niche whereby invertebrates use it as a reef system and colonise it. This could improve species numbers for the birds in the Ramsar and SPA.	

5.1 Consequences for TraC Water Bodies of Upstream Works

In addition to the changes occurring within Cells 2, 3, 5 and 6, directly as a result of the works in each individual Cell, there will also be impacts occurring in each, potentially as a result of works occurring within the river water bodies of the Scheme. These include the River Avon, Grange Burn/Westquarter Burn and the River Carron. Impacts from the works in each of these water bodies may propagate downstream to the estuarine frontage of Grangemouth as a result of the nature of stream flow, which is towards the river mouth.

Examples of potential impacts include:

- working in the channel could mobilise sediment to be readily entrained downstream. This will be negligible because of the likely distance transported, and the opportunity further upstream for sediment to be more easily deposited in channel margins or deeper areas of a river;
- increased runoff downstream due to the flashy nature of the channels, and due to potential narrowing of rivers upstream either because of works or in-channel works; and
- working in the channel could mobilise pollutants upstream to be readily entrained downstream. This will be negligible because of the likely distance transported, and the opportunity further upstream for pollutants to drop out.

In summary, the upstream works will not cause deterioration to the transitional water bodies associated with the Scheme, with no obvious conflict with WFD objectives. This is due to the comparatively large distances from the Scheme, and no identifiable pathway by which the Scheme could affect them. Overall, the potential effects of these works are localised and temporary and unlikely to cause significant effects, or changes to quality elements.

6. Assessment of the Scheme against mitigation measures

Within each RBMP, there is a list of mitigation measures, or environmental improvements, which have been identified by the RBMP, which need to be implemented in order to improve the ecology of water bodies by a specified date in order for the UK to meet the target date set by the Water Framework Directive. Part of the WFD compliance assessment is to consider mitigation measures and assess whether a proposed Scheme can contribute to them or might obstruct any of them from being delivered.

Table 6.1 provides a list of all mitigation measures applicable to Scottish water bodies, and an explanation of why the Scheme might or might not be able to achieve or contribute to mitigation measures.

Table 6.1. Mitigation measures and assessment of whether the Scheme will help to contribute to these (management plan)

Mitigation Measure	Will the Scheme help to achieve or contribute to mitigation measure?
Improving the physical condition of these water bodies	
Contributions to flood risk management	Yes. This is the purpose of the Scheme.
Improved bank side vegetation to reduce the risk of diffuse pollution	No. There are no plans to improve bankside vegetation along the estuary. Seaward of the defences is saltmarsh. There are no plans to incorporate any restoration/rehabilitation to improve.
Improving fish migration	
Restoring salmon runs to inaccessible sections of the river	No. There are no plans put forward to address this issue as part of the Scheme.
Improving the quality and resilience of fisheries by restoring fish access to natural spawning and nursery habitats	No. There are no plans put forward to address this issue as part of the Scheme.
Helping conserve populations of pearl mussel	No. There are no plans put forward to address this issue as part of the Scheme.
Improving water flows and levels	
Improving the quality of landscapes	Yes. Incorporation of landscaping and softening of grey areas further upstream.
Restoring and supporting migratory fish runs	No. No plans to improve runs in-water levels and flows.
Improving health and range of populations of wild plants and animals	No. There are no plans put forward to address this issue as part of the Scheme.
Expanding opportunities for water based recreation	No. There are no plans put forward to address this issue as part of the Scheme.
Preventing spread of non-native invasive species	
Protecting native wildlife	No. This is not explicit in the Scheme plans put forward to address this issue as part of the Scheme.
Preventing impacts on economically important activities	No, not explicitly, although reducing flood risk is an economical gain.

Table 6.1 further supported by the SEPA hub information outlining the pressures for individual water bodies and the reasons why WFD status for certain quality elements is not being achieved. The SEPA hub outlines not just the quality elements but also the pressures faced for the water bodies appropriate to this Scheme. Commentary is also provided on whether there are water body specific mitigation measures. A summary of this is provided below:

Middle Forth (ID 200436): physical condition is the pressure influencing this water body due to modifications to bed, banks and shores. The activities responsible for this are land use and navigation. The water body has been designated as a heavily modified water body on account of physical alterations that cannot be addressed without a significant impact on navigation and from an increased risk of subsidence or flooding. There are no mitigation measures identified. However, the Scheme, although it cannot interfere with navigation, it has been designed to improve flooding.

Island Farm Lagoon - Skinflats (ID 200324): is a transitional water body at High. There are no pressures or mitigation measures identified.

In summary, it is unlikely that the nature of the works would impede any mitigation measures put forward as part of the RBMP or water body specific measures. Further, the nature of the works is unlikely to impede achievement of GEP in any of the relevant water bodies, notable the Middle Forth and Island Farm Lagoon.

7. Compliance Conclusions

Taking into consideration the anticipated impacts of the Scheme on the biological, physico-chemical and hydromorphological quality elements, it is unlikely to compromise progress towards achieving good ecological potential or cause a deterioration of the overall ecological potential of any of the water bodies that are in scope. This is dependent on the implementation of the design and construction mitigation measures that are identified in this assessment.

Table 7.1. Compliance of the Scheme with the environmental objectives of the WFD

Environmental Objective	Scheme	Compliance with the WFD Directive
No changes affecting high status sites	After consideration as part of the detailed compliance assessment, none of the options considered will cause a change to the high-status sites in the study are if mitigation is put in place.	Yes
No changes that will cause failure to meet surface water good ecological status or potential or result in a deterioration of surface water ecological status or potential.	After consideration as part of the detailed compliance assessment, the Scheme options will not cause deterioration in the status of the water bodies if mitigation is put in place.	Yes
No changes which will permanently prevent or compromise the Environmental Objectives being met in other water bodies	The Scheme options will not cause a permanent exclusion or compromise achieving the WFD objectives in any other bodies of water within the River Basin District.	Yes

No changes that will cause failure to meet good groundwater status or result in a deterioration groundwater status.	The Scheme options will not cause deterioration in the status of the of the groundwater bodies.	Yes

Annex C10.5.3: Groundwater WFD Assessment

1. Introduction

1.1 Background

The background to the legislation and the requirement for this WFD compliance assessment are explain in Section 1 of Annex C10.5.1. The WFD requires that environmental objectives are set for all groundwater bodies in order to:

- progressively reduce pollution from priority substances and cease or phase out emissions, discharges and losses of priority hazardous substances; and
- prevent deterioration in status and prevent or limit input of pollutants to groundwater.

Any activity which has the potential to impact on groundwater needs consideration in terms of whether it could cause deterioration in the status of a groundwater body. It is, therefore, necessary to consider the possible changes associated with the preferred design option for the Scheme.

Where there are sites protected under the Habitats Regulations 2019, the WFD aims for compliance with any relevant standards or objectives for these sites. For the Scheme, this relates to the following designated sites:

- Firth of Forth Special Protection Area (SPA); and
- Firth of Forth Ramsar (wetland) site.

1.2 Outline of the Scheme

The Scheme will provide a minimum of 1 in 200-year standard of protection[10] to over 3,000 residential and non-residential properties, plus the refinery, petrochemical plant, port and associated nationally important infrastructure. It has been identified as the highest priority Scheme in the national flood risk management strategy published by the Scottish Environment Protection Agency (SEPA)[11].

The Scheme will provide protection from fluvial flood risk primarily from the River Carron, River Avon and Grange Burn (including the Westquarter and Polmont Burns) and coastal flood risk from the Firth of Forth. Some secondary measures shall also be integrated into the Scheme to protect against pluvial flood risk.

In total, the Scheme comprises an approximate total length of 27 km of flood defences, consisting of flood walls, embankments, coastal revetment, the relining of an existing flood relief channel and a new flow control structure on the Grange Burn. To accommodate access, the Scheme also includes pedestrian and vehicular flood gates, ramps and access tracks or footpaths. It is anticipated that construction will take up to ten years to complete, with discrete sections being completed in phases within that time.

[10] The Scheme provides a 1 in 200-year standard protection from both tidal and fluvial sources. This is a measure of the annual probability of flooding in any year. This is also referred to as 0.5% annual exceedance probability.
[11] SEPA 2015 "Flood Risk Management Strategy Forth Estuary". Available at: Forth Estuary Local Plan District | Flood Risk Management Strategies (sepa.org.uk)

1.2.1 Overview of the Preferred Option and Scope of this Assessment

The Scheme has been divided into six Flood Cells (see Figure B10.1 in Appendix B), and each Flood Cell is then sub-divided into distinct working areas (Table 1.1). The Working Areas are based on form of construction, geographic divisions, source of flooding and sensible breaks within the Flood Cell. The Scheme has a total of three flood cells within a fluvial environment, which are broken down in eight number of working areas.

1.2.2 Scheme Layout

The outline Scheme design includes a combination of the following flood protection measures:

- fluvial and coastal flood walls: concrete or sheet pile walls with seepage control rock armour revetment to attenuate wave energy (coastal flood walls only);
- earth embankments: granular filled embankment with impermeable core (possibly clay, concrete or bentonite core);
- bridge replacement: including construction of new abutments and decks;
- works to the lock gates at the port of Grangemouth;
- a flow control structure (weir) on the Grange Burn near the confluence of the flood relief channel and Grange Burn; and
- relining of the flood relief channel to improve flows and repair damage.

Table 1.1. Cell numbers and working area components

Cell no.	Working Areas	Location	Overall Length of flood defences (m)	Form of Construction
1	1-1	Stirling Road	1,525	Sheet Pile Wall
	1-2	Carron Bridges	880	Sheet Pile Wall, Embankment and Replacement Bridge
	1-3	Chapel Burn	580	Sheet Pile Wall, Embankment, Culvert Extension and Headwall
	1-4	Dock Street	540	Sheet Pile Wall
2	2-1	Forth and Clyde Canal Lock	660	Sheet Pile Wall and Embankment
	2-2	Jarvie Plant / Rossco Properties	805	Sheet Pile Wall
3	3-1	Mouth of the River Carron	915	Sheet Pile Wall with Revetment
	3-2	West Coast of the Port	960	Sheet Pile Wall
	3-3	West Gate to the Port	1,170	Sheet Pile Wall with Revetment
	3-4	East Gate to the Port	1,020	Sheet Pile Wall
	3-5	Mouth of the Grange Burn	580	Sheet Pile Wall
4	4-1	Upstream of M9	1,030	Sheet Pile Wall

Cell no.	Working Areas	Location	Overall Length of flood defences (m)	Form of Construction
	4-2	Rannoch Park	580	Sheet Pile Wall
	4-3	Inchyra Road	1,090	Sheet Pile Wall
	4-4	Whole-flats Road	2,315	Sheet Pile Wall, Raising Footway and Regrading Existing Embankment
	4-5	Zetland Park	741	Sheet Pile Wall and Embankment
	4-6	Dalgrain to Bo'Ness Road	730	Sheet Pile Wall and Replacement Bridge
	4-7	Grangeburn Road	1,245	Sheet Pile Wall
	4-8	Petroineos	1,065	Sheet Pile Wall
	4-9	Mouth of GB	1,005	Sheet Pile Wall and Embankment
5	5-1	Smiddy Brae and Avondale Road	1,746	Sheet Pile Wall and Embankment
	5-2	Flare Road and Road 33	877	Sheet Pile Wall and Embankment
	5-3	Grangemouth Road	1,651	Sheet Pile Wall and Embankment
	5-4	Mouth of the River Avon	440	Sheet Pile Wall and Embankment
6	6-1 and 6-2	West of River Avon (Beach Road and Mouth of River Avon)	2,135	Sheet Pile Wall and Embankment with Revetment and associated ground improvements
	6-3 and 6-4	East of River Avon (Chemical Works at River Avon and Chemical Works)	1,425	Sheet Pile Wall and Embankment with Revetment

2. Methodology

The WFD data have been extracted from SEPA's water classification hub to assess groundwater bodies present within the Scheme's study are, and includes their ID numbers, designation, and classification details. The WFD compliance mapping for groundwater risk and status assessment was also reviewed along with any other supporting data.

There follows a baseline assessment of the main groundwater bodies, and a scoping assessment of the principal receptors potentially affected by the works. This is followed by the impact assessment, which considers the potential impacts of an activity, identifies ways to avoid or minimise impacts, and indicates if an activity may cause deterioration or jeopardise the water body achieving Good status.

There are several stages to this assessment:

- screening of proposed activities (Section 3);
- scoping of the main receptors (Section 4.1);
- scoping of the screened activities against quantitative and chemical quality elements (Section 4.2);

- an assessment of the scoped-in receptors against the quality elements (Section 5.1);
- an assessment of the Scheme against mitigation measures (Section 5.2); and
- a cumulative assessment against other proposed Schemes (Section 5.3).

3. Screening

3.1 Screening of Activities

The main activities of the Scheme are presented in Table 3.1, alongside a screening assessment as to whether further assessment would be required of the activity.

Table 3.1. Screening of the proposed activities

Project stage	Activity	Screened in or out?	Justification
Enabling works and construction	Site Compounds	In	Potential impact from excavation/soil compaction or accidental leaks/spills of polluting substances and resultant effects on groundwater quality.
	Sheet piled flood walls	In	Potential impact from piles and resultant groundwater flow disturbance.
	Earth Embankments	In	Potential impact from soil compaction, and resultant groundwater flow disturbance.
	Bridge Replacements	In	Potential impact from excavation for abutments, and resultant groundwater flow disturbance.
	Works to the lock gates at the Port of Grangemouth	Out	No interaction with groundwater
	Flow control structure	Out	No interaction with groundwater
	Relining of the flood relief channel	Out	No interaction with groundwater
Operation	Sheet piled flood walls	In	Potential impact from groundwater flow disturbance.

4. Scoping

4.1 Identification of WFD Water Bodies

The following groundwater WFD water bodies may be impacted by the works:

- Avon Sand and Gravel groundwater body (150759)
- Carron Sand and Gravel groundwater body (150774)
- Castle Cary groundwater body (150560)
- Falkirk groundwater body (150511)

- Grangemouth groundwater body (150503) and
- Kinneil groundwater body (150444).

A summary of the status of the above water bodies is included in Table 4.1.

Table 4.1. WFD groundwater bodies baseline information (Cycle 2 (2020), SEPA12)

Water body ID	Water body name	Overall Status	Quantitative Status	Chemical Status	Reasons for not achieving Good Status
150759	Avon Sand and Gravel	Good	Good	Good	N/A
150774	Carron Sand and Gravel	Good	Good	Good	N/A
150560	Castle Cary	Good	Good	Good	N/A
150511	Falkirk	Poor	Good	Poor	Poor Chemical – General Test - Electrical Conductivity
150503	Grangemouth	Poor	Good	Poor	Poor Chemical - Surface Water Interaction - Manganese
150444	Kinneil	Poor	Good	Poor	Poor Chemical – General Test - Electrical Conductivity

4.2 Scoping of WFD Quality Elements

Table 4.1 outlines the potential generic impacts of each of the proposed activities outlined in Section 3 on the scoped in WFD groundwater bodies. Where an impact would not be anticipated, the quality element has been scoped out.

Section 5 provides a more comprehensive assessment of those quality elements scoped in.

[12] SEPA, 2023 https://www.sepa.org.uk/data-visualisation/water-classification-hub/

Table 4.2: Scoping of proposed activities and WFD quality elements for scoped in WFD groundwater bodies

Quality elements		Potential impacts per activity			
		Site compounds	Sheet piled flood walls	Embankments	Bridge Replacements
Avon Sand and Gravel					
Quantitative	Saline intrusion	**Scoped Out** No site compounds proposed within the groundwater body.	**Scoped Out** Groundwater body is distant from coastal sources and other saline waters.	**Scoped Out** No embankments proposed within the groundwater body.	**Scoped Out** No Bridge replacements proposed within the groundwater body.
	Water balance		**Scoped In** Potential reduction of, or disturbance to, groundwater levels and flows from installation of sheet piles.		
	GWDTEs		**Scoped Out** No designated GWDTEs within the groundwater body		
	Dependent surface water body		**Scoped In** Potential reduction of, or disturbance to, surface water baseflow from installation of sheet piles.		
Chemical	Saline intrusion	**Scoped Out** No site compounds proposed within the groundwater body.	**Scoped Out** Groundwater body is distant from coastal sources and other saline waters.	**Scoped Out** No embankments proposed within the groundwater body.	**Scoped Out** No Bridge replacements proposed within the groundwater body.
	Drinking Water Protected Area		**Scoped Out** No DWPA in the vicinity of the Scheme.		

Quality elements		Potential impacts per activity			
		Site compounds	Sheet piled flood walls	Embankments	Bridge Replacements
	GWDTEs		**Scoped Out** No designated GWDTEs within the groundwater body		
	Dependent surface water body		**Scoped In** Potential reduction of, or disturbance to, surface water baseflow quality from installation of sheet piles.		
	Chemical test		**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.		
Carron Sand and Gravel					
Quantitative	Saline intrusion	**Scoped Out** Groundwater body is distant from coastal sources and other saline waters.	**Scoped Out** Groundwater body is distant from coastal sources and other saline waters.	**Scoped Out** Groundwater body is distant from coastal sources and other saline waters.	**Scoped Out** No Bridge replacements proposed within the groundwater body.
	Water balance	**Scoped Out** No significant excavation required, therefore dewatering would not affect water balance.	**Scoped In** Potential reduction of, or disturbance to, groundwater	**Scoped Out** Proposed embankments are limited in scale therefore	

Quality elements		Potential impacts per activity			
		Site compounds	Sheet piled flood walls	Embankments	Bridge Replacements
			levels and flows from installation of sheet piles.	limited potential for change to water balance.	
	GWDTEs	**Scoped Out** No designated GWDTEs within the groundwater body	**Scoped Out** No designated GWDTEs within the groundwater body	**Scoped Out** No designated GWDTEs within the groundwater body	
	Dependent surface water body	**Scoped Out** No significant excavation required, therefore dewatering would not affect surface waters.	**Scoped In** Potential reduction of, or disturbance to, surface water baseflow from installation of sheet piles.	**Scoped Out** Proposed embankments are limited in scale therefore limited potential for change to surface water baseflow.	
Chemical	Saline intrusion	**Scoped Out** Groundwater body is distant from coastal sources and other saline waters.	**Scoped Out** Groundwater body is distant from coastal sources and other saline waters.	**Scoped Out** Groundwater body is distant from coastal sources and other saline waters	**Scoped Out** No Bridge replacements proposed within the groundwater body.
	Drinking Water Protected Area	**Scoped Out** No DWPA in the vicinity of the Scheme.	**Scoped Out** No DWPA in the vicinity of the Scheme.	**Scoped Out** No DWPA in the vicinity of the Scheme.	
	GWDTEs	**Scoped Out** No designated GWDTEs within the groundwater body	**Scoped Out** No designated GWDTEs within the groundwater body	**Scoped Out** No designated GWDTEs within the groundwater body	

Quality elements		Potential impacts per activity			
		Site compounds	Sheet piled flood walls	Embankments	Bridge Replacements
	Dependent surface water body	**Scoped Out** No significant excavation required, therefore dewatering would not affect surface waters.	**Scoped In** Potential reduction of, or disturbance to, surface water baseflow quality from installation of sheet piles.	**Scoped Out** Proposed embankments are limited in scale therefore limited potential for change to surface water baseflow quality.	
	Chemical test	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	
Castle Cary					
Quantitative	Saline intrusion	**Scoped Out** Proposed site compound is distant from coastal and other saline waters and is not considered to be likely to lead to saline intrusion.	**Scoped Out** Proposed sheet piles are distant from coastal and other saline waters and are not considered to be likely to lead to saline intrusion.	**Scoped Out** Proposed embankments are not considered to be likely to lead to saline intrusion.	**Scoped Out** Dewatering for bridge abutments will not take place near coastal or other saline waters therefore potential for saline intrusion is limited.
	Water balance	**Scoped Out** Proposed site compound is limited in scale therefore limited potential for change to water balance.	**Scoped In** Potential temporary reduction of, or disturbance to groundwater	**Scoped Out** Proposed embankments are limited in scale therefore	**Scoped Out** Dewatering for bridge abutments is unlikely to impact the

Quality elements		Potential impacts per activity			
		Site compounds	Sheet piled flood walls	Embankments	Bridge Replacements
			levels and flows due to construction of sheet piles.	limited potential for change to water balance.	groundwater body water balance at the aquifer scale.
	GWDTEs	**Scoped Out** Proposed site compound is downstream of Carron Dams SSSI and LNR, therefore impact to potential GWDTE is unlikely.	**Scoped Out** Proposed sheet piles are downstream of Carron Dams SSSI and LNR, therefore impact to potential GWDTE is unlikely.	**Scoped Out** Proposed earth embankment is distant from Carron Dams SSSI and LNR, therefore impact to potential GWDTE is unlikely.	**Scoped Out** Proposed bridge replacement is distant from Carron Dams SSSI and LNR, therefore impact to potential GWDTE is unlikely.
	Dependent surface water body	**Scoped Out** No significant excavation required, therefore dewatering would not affect surface waters.	**Scoped In** Potential reduction of, or disturbance to, surface water baseflow from installation of sheet piles.	**Scoped Out** Proposed embankments are limited in scale therefore limited potential for change to surface water baseflow.	**Scoped Out** Dewatering for the bridge abutments is unlikely to lead to significant impacts on surface water baseflows given the low rates.
Chemical	Saline intrusion	**Scoped Out** Proposed site compound is distant from coastal and other saline waters and is not considered to be likely to lead to saline intrusion.	**Scoped Out** Proposed sheet piles are distant from coastal and other saline waters and are not considered to be likely to lead to saline intrusion.	**Scoped Out** Proposed embankments are not considered to be likely to lead to saline intrusion.	**Scoped Out** ▪ Dewatering for bridge abutments will not take place near coastal or other saline waters therefore potential for saline intrusion is limited.
	Drinking Water Protected Area	**Scoped Out** No DWPA in the vicinity of the Scheme	**Scoped Out** No DWPA in the vicinity of the Scheme.	**Scoped Out** No DWPA in the vicinity of the Scheme.	**Scoped Out** ▪ No DWPA in the vicinity of the Scheme.

Quality elements		Potential impacts per activity			
		Site compounds	Sheet piled flood walls	Embankments	Bridge Replacements
	GWDTEs	**Scoped Out** Proposed site compound is downstream of Carron Dams SSSI and LNR, therefore impact to potential GWDTE is unlikely.	**Scoped Out** Proposed sheet piles are downstream of Carron Dams SSSI and LNR, therefore impact to potential GWDTE is unlikely.	**Scoped Out** Proposed earth embankment is distant from Carron Dams SSSI and LNR, therefore impact to potential GWDTE is unlikely.	**Scoped Out** Proposed bridge replacement is distant from Carron Dams SSSI and LNR, therefore impact to potential GWDTE is unlikely.
	Dependent surface water body	**Scoped Out** No significant excavation required, therefore dewatering would not affect surface waters.	**Scoped In** Potential reduction of, or disturbance to, surface water baseflow quality from installation of sheet piles	**Scoped Out** ▪ Proposed embankments are limited in scale therefore limited potential for change to surface water baseflow quality.	**Scoped Out** Dewatering for the bridge abutments is unlikely to lead to significant impacts on surface water baseflow quality given the low rates.
	Chemical test	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.
Falkirk					
Quantitative	Saline intrusion	**Scoped Out**	**Scoped Out**	**Scoped Out**	**Scoped Out** No Bridge replacements proposed within the groundwater body

Quality elements		Potential impacts per activity			
		Site compounds	Sheet piled flood walls	Embankments	Bridge Replacements
		Groundwater body is distant from coastal sources and other saline waters	Groundwater body is distant from coastal sources and other saline waters	Proposed embankments are not considered to be likely to lead to saline intrusion.	
	Water balance	**Scoped Out** Proposed site compounds are limited in scale therefore limited potential for change to water balance.	**Scoped In** Potential temporary reduction of, or disturbance to groundwater levels and flows due to construction of sheet piles.	**Scoped Out** Proposed embankments are limited in scale therefore limited potential for change to water balance.	
	GWDTEs	**Scoped Out** No designated GWDTEs within the groundwater body	**Scoped Out** No designated GWDTEs within the groundwater body	**Scoped Out** No designated GWDTEs within the groundwater body	
	Dependent surface water body	**Scoped Out** No significant excavation required, therefore dewatering would not affect surface waters.	**Scoped In** Potential reduction of, or disturbance to, surface water baseflow from installation of sheet piles.	**Scoped Out** Proposed embankments are limited in scale therefore limited potential for change to surface water baseflow.	
Chemical	Saline intrusion	**Scoped Out** Groundwater body is distant from coastal sources and other saline waters	**Scoped Out** Groundwater body is distant from coastal sources and other saline waters	**Scoped Out** Proposed embankments are not considered to be likely to lead to saline intrusion.	**Scoped Out** No Bridge replacements proposed within the groundwater body
	Drinking Water Protected Area	**Scoped Out** No DWPA in the vicinity of the Scheme	**Scoped Out** No DWPA in the vicinity of the Scheme	**Scoped Out** No DWPA in the vicinity of the Scheme	

Quality elements		Potential impacts per activity			
		Site compounds	Sheet piled flood walls	Embankments	Bridge Replacements
	GWDTEs	**Scoped Out** No designated GWDTEs within the groundwater body	**Scoped Out** No designated GWDTEs within the groundwater body	**Scoped Out** No designated GWDTEs within the groundwater body	
	Dependent surface water body	**Scoped Out** No significant excavation required, therefore dewatering would not affect surface waters.	**Scoped In** Potential reduction of, or disturbance to, surface water baseflow quality from installation of sheet piles.	**Scoped Out** Proposed embankments are limited in scale therefore limited potential for change to surface water baseflow quality.	
	Chemical test	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	
Grangemouth					
Quantitative	Saline intrusion	**Scoped Out** Proposed site compounds are not considered to be likely to lead to saline intrusion.	**Scoped Out** Proposed sheet piles are not considered to be likely to lead to saline intrusion.	**Scoped Out** Proposed embankments are not considered to be likely to lead to saline intrusion.	**Scoped Out** Dewatering for bridge abutments will not take place near coastal or other saline waters therefore potential for saline intrusion is limited.

Quality elements		Potential impacts per activity			
		Site compounds	Sheet piled flood walls	Embankments	Bridge Replacements
	Water balance	**Scoped Out** Proposed site compounds are limited in scale therefore limited potential for change to water balance.	**Scoped In** Potential temporary reduction of, or disturbance to groundwater levels and flows due to construction of sheet piles.	**Scoped Out** Proposed embankments are limited in scale therefore limited potential for change to water balance.	**Scoped In** Potential temporary reduction of, or disturbance to groundwater levels and flows due to dewatering required for construction of abutments.
	GWDTEs	**Scoped Out** Proposed site compounds are downstream of Avon Gorge SSSI, therefore impact to potential GWDTE is unlikely.	**Scoped Out** ▪ Proposed sheet piles are downstream of Avon Gorge SSSI, therefore impact to potential GWDTE is unlikely.	**Scoped Out** Proposed earth embankments are distant from Avon Gorge SSSI, therefore impact to potential GWDTE is unlikely.	**Scoped Out** Proposed bridge replacements are distant from Avon Gorge SSSI, therefore impact to potential GWDTE is unlikely.
	Dependent surface water body	**Scoped Out** No significant excavation required, therefore dewatering would not affect surface waters.	**Scoped In** Potential temporary reduction of, or disturbance to surface water baseflow due to construction of sheet piles.	**Scoped Out** Proposed embankments are limited in scale therefore limited potential for change to surface water baseflow.	**Scoped Out** Dewatering for the bridge abutments is unlikely to lead to significant impacts on surface water baseflows given the low rates.
Chemical	Saline intrusion	**Scoped Out** Proposed site compounds are not considered to be likely to lead to saline intrusion.	**Scoped Out** Proposed sheet piles are not considered to be likely to lead to saline intrusion.	**Scoped Out** Proposed embankments are not considered to be likely to lead to saline intrusion.	**Scoped Out** Dewatering for bridge abutments will not take place near coastal or other saline waters therefore potential for saline intrusion is limited.
	Drinking Water Protected Area	**Scoped Out** No DWPA in the vicinity of the Scheme	**Scoped Out** No DWPA in the vicinity of the Scheme	**Scoped Out** No DWPA in the vicinity of the Scheme	**Scoped Out** No DWPA in the vicinity of the Scheme

Quality elements		Potential impacts per activity			
		Site compounds	Sheet piled flood walls	Embankments	Bridge Replacements
	GWDTEs	**Scoped Out** Proposed site compounds are downstream of Avon Gorge SSSI, therefore impact to potential GWDTE is unlikely.	**Scoped Out** Proposed sheet piles are downstream of Avon Gorge SSSI, therefore impact to potential GWDTE is unlikely.	**Scoped Out** Proposed earth embankments are distant from Avon Gorge SSSI, therefore impact to potential GWDTE is unlikely.	**Scoped Out** Proposed bridge replacements are distant from Avon Gorge SSSI, therefore impact to potential GWDTE is unlikely.
	Dependent surface water body	**Scoped Out** No significant excavation required, therefore dewatering would not affect surface waters.	**Scoped In** Potential temporary reduction of, or disturbance to surface water baseflow quality due to construction of sheet piles.	**Scoped Out** Proposed embankments are limited in scale therefore limited potential for change to surface water baseflow quality.	**Scoped Out** Dewatering for the bridge abutments is unlikely to lead to significant impacts on surface water baseflows given the low rates.
	Chemical test	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.
Kinneil					
Quantitative	Saline intrusion	**Scoped Out** Proposed site compound is distant from coastal and other saline	**Scoped Out** Proposed sheet piles are not considered to be likely to lead to saline intrusion.	**Scoped Out** No embankments proposed within the groundwater body	**Scoped Out** No Bridge replacements proposed within the groundwater body

Quality elements		Potential impacts per activity			
		Site compounds	Sheet piled flood walls	Embankments	Bridge Replacements
		waters and is not considered to be likely to lead to saline intrusion.			
	Water balance	**Scoped Out** Proposed site compounds are limited in scale therefore limited potential for change to water balance.	**Scoped Out** Installation of sheet piles unlikely to lead to reduction of, or disturbance to, groundwater levels at the scale of the groundwater body.		
	GWDTEs	**Scoped Out** Proposed site compounds are distant from Kinneil Lagoons therefore limited potential for change to potential GWDTE.	**Scoped In** Potential reduction of, or disturbance to groundwater contribution to potential GWDTE due to construction of sheet piles.		
	Dependent surface water body	**Scoped Out** No significant excavation required, therefore dewatering would not affect surface waters.	**Scoped In** Potential temporary reduction of, or disturbance to surface water baseflow due to construction of sheet piles.		
Chemical	Saline intrusion	**Scoped Out** Proposed site compound is distant from coastal and other saline waters and is not considered to be likely to lead to saline intrusion.	**Scoped Out** Proposed sheet piles are not considered to be likely to lead to saline intrusion.	**Scoped Out** No embankments proposed within the groundwater body	**Scoped Out** No Bridge replacements proposed within the groundwater body

Quality elements		Potential impacts per activity			
		Site compounds	Sheet piled flood walls	Embankments	Bridge Replacements
	Drinking Water Protected Area	**Scoped Out** No DWPA in the vicinity of the Scheme	**Scoped Out** No DWPA in the vicinity of the Scheme		
	GWDTEs	**Scoped Out** Proposed site compounds are distant from Kinneil Lagoons therefore limited potential for change to potential GWDTE.	**Scoped In** Potential reduction of, or disturbance of groundwater contribution to potential GWDTE due to construction of sheet piles may affect quality.		
	Dependent surface water body	**Scoped Out** No significant excavation required, therefore dewatering would not affect surface waters.	**Scoped In** ▪ Potential temporary reduction of, or disturbance to surface water baseflow quality due to construction of sheet piles.		
	Chemical test	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.	**Scoped Out** Any impacts would not be widespread enough to compromise the use of the groundwater resource either currently or in the future for the groundwater body as a whole.		

5. Assessment

5.1 Site-specific Assessment against WFD Quality Elements

This section provides a comprehensive site-specific assessment of the scoped in Proposed Docker Section activities on the WFD quality elements at WFD water body scale (Table 5.1).

Impacts are assessed in terms of risk of deterioration to WFD elements using the following:

- White – Negligible risk of deterioration of status.
- Green - Low risk of deterioration of status with localised impacts anticipated (impacts managed by best practice measures).
- Orange - Medium risk of deterioration of status (additional mitigation required).
- Red - High risk of deterioration of status (potential for non-compliance in combination with other impacts).

Table 5.1. Assessment of the WFD groundwater bodies for the Scheme

Scheme element	WFD quality element		Potential impacts	Relevant WFD groundwater body	Additional mitigation required
Sheet piled flood walls	Quantitative	Water balance	Sheet piles have the potential to locally alter groundwater flow paths and levels but are not expected to have significant impacts on water balances at the aquifer scale, or on flow between groundwater bodies. In flood cells 1, 5 and 6, sheet piles may intercept artesian groundwater which has the potential to discharge at surface.	Avon Sand and Gravels Carron Sand and Gravels Caste Cary Falkirk Grangemouth	To mitigate against a potential increase in groundwater level reaching the ground surface, filter drains will be placed on the upgradient side of the defences to intercept rising groundwater, should it occur, with gravity outfalls to the nearest watercourse. The filter drains will be regularly maintained to ensure they are operational at all times. The filter drains will be sized to ensure they evacuate groundwater volumes sufficiently so that no new groundwater flooding events occur as a result of the proposed Scheme. The detailed design stage will therefore need to be supported by a more detailed groundwater flow and level risk assessment. Detailed design should be cognisant of the presence of artesian groundwater in flood cells 1, 5 and 6 and should make provisions to ensure that artesian groundwater is prevented from reaching the surface
	Quantitative	GWDTEs	Sheet Piles have the potential to alter groundwater flow paths and reduce the quantity of groundwater contributing to the potential GWDTE at Kinneil Lagoons, part of the Firth of Forth SSSI, SPA and Ramsar site.	Kinneil	A detailed hydrological – hydrogeological assessment of the terrestrial portion of the Firth of Forth SSSI, SPA and Ramsar would be carried out. In particular, the detailed assessment would investigate the proportion of groundwater and run-off that contributes to sustaining this protected environment, with a view to adjust the detailed design of the proposed direct defence (with below ground structure) east of the existing water treatment works. If required, a Water

Scheme element	WFD quality element		Potential impacts	Relevant WFD groundwater body	Additional mitigation required
					Compensation Strategy would be put in place to redirect lost water towards the impacted area.
	Quantitative	Dependent surface water bodies	Sheet piles have the potential to reduce baseflow contributions to surface water bodies along some reaches of the River Carron, River Avon, Grange Burn and their tributaries. Potential impacts to the River Carron are anticipated to be limited, due to the discontinuous nature of the proposed sheet piles in the upper reaches of the river, and their presence on only the south bank of the river in the lower reaches. However, proposed sheet piles in Flood Cell 1 may intersect high permeability Alluvium, where the proportion of baseflow to the river may be significant. While continuous sheet piles are proposed on both banks of the River Avon and Grange Burn in their lower reaches, the rivers pass through low-permeability tidal flat and intertidal deposits here, where baseflow contributions to the water bodies are anticipated to be small, and hence potential impacts to these water bodies would be minor.	Avon Sand and Gravels Carron Sand and Gravels Caste Cary Falkirk Grangemouth Kinneil	A detailed hydrogeological assessment of baseflow groundwater contributions to the River Carron in Flood Cell 1 would be undertaken to support the re-direction of abstracted groundwater to the River Carron and compensate baseflow losses. To mitigate against a potential increase in groundwater level reaching the ground surface, filter drains will be placed on the upgradient side of the defences to intercept rising groundwater, should it occur, with gravity outfalls to the nearest watercourse. The filter drains will be regularly maintained to ensure they are operational at all times. The filter drains will be sized to ensure they evacuate groundwater volumes sufficiently so that no new groundwater flooding events occur as a result of the proposed Scheme. The detailed design stage will therefore need to be supported by a more detailed groundwater flow and level risk assessment.
	Chemical	GWDTEs	Sheet Piles have the potential to alter groundwater flow paths and reduce the quantity of groundwater contributing to the potential GWDTE at Kinneil Lagoons, part of the Firth of Forth SSSI, SPA and Ramsar site. Changes in the proportion of groundwater contributing to the Lagoons may impact on the GWDTE's water quality.	Kinneil	A detailed hydrological – hydrogeological assessment of the terrestrial portion of the Firth of Forth SSSI, SPA and Ramsar would be carried out. In particular, the detailed assessment would investigate the proportion of groundwater and run-off that contributes to sustaining this protected environment, with a view to adjust the

Scheme element	WFD quality element		Potential impacts	Relevant WFD groundwater body	Additional mitigation required
					detailed design of the proposed direct defence (with below ground structure) east of the existing water treatment works. If required, a Water Compensation Strategy would be put in place to redirect lost water towards the impacted area.
	Chemical	Dependent surface water bodies	As discussed above, sheet piles have the potential to disturb groundwater flows. In addition, to prevent build up of groundwater upgradient of the sheet piles, filter drains will be placed on the upgradient side of the defences to intercept rising groundwater, should it occur, with gravity outfalls to the nearest watercourse. These measures have the potential to therefore affect the water quality of the River Carron, River Avon, Grange Burn and their tributaries.	Avon Sand and Gravels Carron Sand and Gravels Caste Cary Falkirk Grangemouth Kinneil	A detailed hydrogeological assessment of baseflow groundwater contributions to the River Carron in Flood Cell 1 would be undertaken to support the re-direction of abstracted groundwater to the River Carron and compensate baseflow losses. The filter drains will be sized to ensure they evacuate groundwater volumes sufficiently so that no new groundwater flooding events occur as a result of the proposed Scheme. The detailed design stage will therefore need to be supported by a more detailed groundwater flow and level risk assessment. Based on the outcome of the detailed dewatering and groundwater flow assessments as well as findings associated with contamination outlined in the Chapter 11: Soils, Geology and Land Contamination chapter, additional mitigation measures may be required to treat groundwater.

5.2 Review of WFD Specific Mitigation Measures

Within each River Basin Management Plan (RBMP), there is a list of mitigation measures, or environmental improvements, which have been identified for implementation by a specified date for the UK to meet the target date set by the WFD. Part of the WFD compliance assessment is to consider these WFD specific mitigation measures and assess whether the Proposed Scheme can contribute to them or could obstruct any of them from being delivered.

SEPA's RBMP[13] outlines the pressures for individual water bodies and the reasons why WFD status for certain quality elements is not being achieved. As detailed in section 4.2, three groundwater bodies which have been scoped into this assessment were assigned Poor overall status during the most recent available classification in 2020. All three groundwater bodies, namely Falkirk, Grangemouth and Kinneil were determined to face pressure on water quality due to legacy pollution from mining and quarrying. While the Grangemouth groundwater body is expected to achieve Good overall status by 2027, the Falkirk and Kinneil groundwater bodies are expected to achieve Good overall status after 2027, as while action has been completed to address the pressure on these bodies, ecological recovery is expected to take longer to achieve.

As such, the nature of the works is unlikely to impede achievement of Good overall status in any of the relevant groundwater bodies.

5.3 Compliance with WFD Objectives

Table 5.2 provides a summary of the compliance of the Scheme against the WFD objectives outlined in Section 1.1. In summary, it is considered that at a WFD water body scale the Scheme would be compliant for all WFD water bodies assessed. This is dependent on the implementation of the mitigation measures that are identified in this assessment.

Table 5.2. Compliance of the Scheme with the environmental objectives of the WFD

Environmental Objective	Scheme	Compliance with the WFD Directive
No changes affecting high status sites	Not applicable – no high-status water bodies present.	Yes
No changes that will cause failure to meet surface water good ecological status or potential or result in a deterioration of surface water ecological status or potential	The Scheme as outlined would not cause deterioration in the status of any identified WFD surface water body if mitigation is put in place.	Yes
No changes which will permanently prevent or compromise the Environmental Objectives being met in other water bodies	The Scheme would not cause a permanent exclusion or compromise achieving the WFD objectives in other bodies of water within the River Basin District.	Yes
No changes that will cause failure to meet good groundwater status or result in a deterioration groundwater status.	The Scheme would not cause deterioration in the status of any groundwater body.	Yes

[13] SEPA 2021: https://informatics.sepa.org.uk/RBMP3/

Environmental Impact Assessment Report

Appendix C10.6 Impact Assessment Tables

Grangemouth Flood Protection Scheme 2024
Falkirk Council

Appendix C10.6 Impact Assessment Tables

Contents

Note: No impact assessment table is included for Surface Water Quality during operation as no impacts are anticipated during this phase. Impacts on Flood Risk during construction and operation are detailed in Appendix C10.3: Flood Risk.

Table C10.6.1: Impact Assessment – Surface Water Quality – Construction

Impact	Receptor	Existing WFD status Target Status Relevant WFD Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation ID	Post-mitigation (residual effect)	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
Sediment delivery from runoff (haul routes, material stockpiles and working areas).	**River Carron** (WFD Waterbody: 4200-Bonny Water confluence to Carron Estuary)	Overall status: Poor Target Status (2027): Good Biological Elements: Poor Physico-chemical: Moderate	High	The establishment and operation of site compounds and haul routes may generate sediment-laden run-off, which could be transported into watercourses. Any areas of exposed ground, and stockpiles of construction materials, could result in the generation of sediment-laden (and any contaminants bound to them, if present) runoff, which could be transported to watercourses during periods of heavy rain should these areas not be properly maintained and contained. During flood conditions, working areas may be inundated with floodwater, which can mobilise sediment and other potential contaminants located within the working areas and wider floodplain. Should uncontrolled fine sediment release occur at low flows, then this may result in 'blinding' of the river bed with fine sediment where low flow speeds allow it to settle. Demolition of existing crossing structures (where required) and construction of new watercourse crossing structures may generate sediment-laden (and any contaminants bound to them, if present) runoff, which could be transported to watercourses. This may occur where a new bridge is required at Millhall Gardens on Millhall Burn and construction of new culverts are required on Millhall Burn at Reddoch Road and on Mungal Burn (30m culvert). The increased input of sediment-laden runoff during construction of linear flood defences may impact on Physico-chemical quality elements and Biological Elements quality elements for: • up to 4.25km of the River Carron WFD water body extent / 6.65km of River Carron including tidal reaches, 0.1km of minor watercourse at Stirling Road, <0.1km of Mungal Burn and 0.17km of Chapel Burn as shown on OS mapping. • up to 1.6km of the Grange Burn WFD water body extent / 3.5km of Grange Burn including tidal reaches, 0.5km of Westquarter Burn as shown on OS mapping. • up to 0.4km of the River Avon WFD water body extent / 3.0km of River Avon including tidal reaches, 0.5km of Polmont Burn and 0.6km of Millhall Burn (if they were classified). • for up to 2.1km of the Grange Burn Flood Relief Channel as shown on Ordnance Survey (OS) mapping (if it were classified). This could result in a measurable deterioration in water quality; however, the magnitude of this impact is dependent on the length of water body potentially affected and dispersal time. This impact would therefore likely be short-term. The length of water body affected would be dependent on the location and spatial extent of the incident.	Moderate Adverse	Large	W1 W2 W12 W13 W22 W23	Negligible	Slight
	Grange Burn *Westquarter Burn (tributary)* (WFD Waterbody: 3300-Grange Burn/ Westquarter Burn)	Overall: Moderate ecological potential Target Status (2027): Good ecological potential Biological elements: Good Physico-chemical: Good	High		Major Adverse	Very Large		Negligible	Slight
	River Avon (WFD Waterbody: 3100-Logie Water confluence to estuary)	Overall: Moderate Target Status (2027): Moderate Biological Elements: Moderate Physico-chemical: Good	Very High		Minor Adverse	Slight		Negligible	Slight
	Tributaries of River Carron: Chapel Burn Mungal Burn Minor watercourse at Stirling Road	N/A	Medium		Major Adverse	Large		Negligible	Neutral
	Polmont Burn *(River Avon tributary)*				Moderate Adverse	Moderate		Negligible	Neutral
	Millhall Burn *(River Avon tributary)*				Major Adverse	Large		Negligible	Neutral
	Grange Burn Flood Relief Channel				Major Adverse	Large		Negligible	Neutral

Impact	Receptor	Existing WFD status Target Status Relevant WFD Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation ID	Post-mitigation (residual effect)	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
	Middle Forth Estuary (WFD Waterbody: 200436- Middle Forth Estuary)	Overall: Moderate ecological potential Target Status (2027): Good Ecological Potential Biological Elements: Good Physico-chemical: Good	Very High	Increased input of sediment-laden runoff during construction of linear defences and associated works including: Cumulative inputs from works on areas of and tributaries of the Middle Forth Estuary WFD water body, impacting on its Physico-chemical status and Biological Elements status. Areas which may contribute to cumulative inputs, include: • up to 10.9km of River Carron (including tidal reaches). • up to 0.1km of minor watercourse at Stirling Road. • up to 0.1km of Mungal Burn. • up to 0.17km of Chapel Burn. • up to 5.1km of Grange Burn (including tidal reaches). • up to 0.5km of Westquarter Burn. • up to 3.4km of River Avon (including tidal reaches). • up to 0.5km of Polmont Burn. • up to 0.6km of Millhall Burn. • up to 2.1km of the Grange Burn Flood Relief Channel. Demolition of existing crossing structures (where required) and construction of new watercourse crossing structures. This may occur in areas included in the Middle Forth Estuary WFD water body extent where new bridges are required at New Carron Road on the River Carron and Kerse Road/ Dalratho Road on Grange Burn, and construction of a new culvert is required on an unnamed creek formed by historic drainage channels (12m culvert) discharging to the Middle Forth Estuary (approx. NGR NS 95304 82201). The above impacts could result in a measurable deterioration in water quality, however dependent on dispersal time in estuarine waters, this impact would likely be short-term.	Moderate Adverse	Very Large		Negligible	Slight
	Bainsford Burn *(River Carron tributary)*	N/A	Medium	No change					
	Island Farm Lagoon (WFD Waterbody: 200324- Island Farm Lagoon)	Overall: Good Target Status (2027): High Biological Elements: High Physico-chemical: Good	Very High	No change					
River bed disturbance (from in-channel works).	**River Carron** (WFD Waterbody: 4200- Bonny Water confluence to Carron Estuary)	Overall status: Poor Target Status (2027): Good Biological Elements: Poor Physico-chemical: Moderate	High	Disturbance of existing river bed sediment caused by in-channel working, primarily through vehicles tracking within the watercourses, may cause increases in suspended sediment concentrations. The placement of imported material to create the 'working platforms' or river crossings would likely introduce a source of sediment to the watercourse channels and may affect their physical condition. In the event of a flood during the works, any imported material may also be mobilised. Demolition of existing crossing structures (where required) and construction of new watercourse crossing structures may disturb existing sediment and introduce imported materials into watercourses. This may	Minor Adverse	Slight	W1 W2 W12 W13 W22 W23	Negligible	Slight

Impact	Receptor	Existing WFD status Target Status Relevant WFD Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation ID	Post-mitigation (residual effect)	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
	Grange Burn *Westquarter Burn (tributary)* (WFD Waterbody: 3300- Grange Burn/ Westquarter Burn)	Overall: Moderate ecological potential Target Status (2027): Good ecological potential Biological elements: Good Physico-chemical: Good	High	occur where the new bridge is required at Millhall Gardens on Millhall Burn and new culverts required on Millhall Burn at Reddoch Road and on Mungal Burn (30m culvert). Disturbance of the river bed during the establishment of in-channel working areas to facilitate the construction of direct defences, including: • Minor watercourse at Stirling Road – 0.12km (discontinuous). • Mungal Burn – 0.05km. • Chapel Burn – 0.17km. • Westquarter Burn – 0.13km (discontinuous). • Grange Burn – 0.04km. • Millhall Burn – 0.24km (discontinuous). The above impacts could result in a measurable deterioration in water quality; however, the magnitude of this impact is dependent on the length of water body potentially affected and the duration of the impact is likely to be short term.	Major Adverse	Very Large		Minor Adverse	Slight
	River Avon (WFD Waterbody: 3100- Logie Water confluence to estuary)	Overall: Moderate Target Status (2027): Moderate Biological Elements: Moderate Physico-chemical: Good	Very High		Minor Adverse	Slight		Negligible	Slight
	Tributaries of River Carron: Chapel Burn Mungal Burn Minor watercourse at Stirling Road	N/A	Medium		Major Adverse	Large		Minor Adverse	Slight
	Polmont Burn *(River Avon tributary)*		Medium		Minor Adverse	Slight		Negligible	Neutral
	Millhall Burn *(River Avon tributary)*		Medium		Major Adverse	Large		Minor Adverse	Slight
	Grange Burn Flood Relief Channel		Medium	Disturbance of approximately 2.1km of the channel bed during the establishment of in-channel working areas to facilitate the construction of direct defences and relining of the Grange Burn Flood Relief Channel. This could involve demolishing and rebuilding the channel or relining the channel with engineered pre-cast concrete sections or shotcrete. This would likely be undertaken in stages. The duration of this impact would likely be short-term.	Major Adverse	Large		Negligible	Neutral

Impact	Receptor	Existing WFD status Target Status Relevant WFD Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation ID	Post-mitigation (residual effect)	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
	Middle Forth Estuary (WFD Waterbody: 200436-Middle Forth Estuary)	Overall: Moderate ecological potential Target Status (2027): Good Ecological Potential Biological Elements: Good Physico-chemical: Good	Very High	Disturbance of up to approximately 6.82ha of intertidal area with associated disturbance of sediment to facilitate the construction of direct defences. This includes: • 1.3km of the tidal of River Carron (discontinuous). • 0.03km of the tidal of Chapel Burn. • 0.16km of the tidal of Grange Burn(discontinuous). • 0.35km of the tidal of River Avon. • 0.03km of the tidal of minor tributary to River Avon. • 1.31km along the coastal front of Middle Forth Estuary (discontinuous). Demolition of existing crossing structures (where required) and construction of new watercourse crossing structures may disturb existing sediment and introduce imported materials into watercourses. This may occur in the Middle Forth Estuary where new bridges are required at New Carron Road on River Carron and Kerse Road/ Dalratho Road on Grange Burn, and construction of a new culvert is required on an unnamed creek formed by historic drainage channels (12m culvert) discharging to the Middle Forth Estuary (approx. NGR NS 95304 82201). The duration of these impacts would likely be short-term.	Major Adverse	Very Large		Negligible	Slight
	Bainsford Burn *(River Carron tributary)*	N/A	Medium	No change					
	Island Farm Lagoon (WFD Waterbody: 200324-Island Farm Lagoon)	Overall: Good Target Status (2027): High Biological Elements: High Physico-chemical: Good	Very High	No change					
Accidental spillage of fuels, oils, chemicals, cementitious materials etc.	**River Carron** (WFD Waterbody: 4200-Bonny Water confluence to Carron Estuary)	Overall status: Poor Target Status (2027): Good Biological Elements: Poor Physico-chemical: Moderate	High	The use of potentially polluting substances, including organic compounds, metals, concrete, greases, vehicular oils, hydraulic fluids, fuels and other chemicals/ compounds, on site for the works has the potential to pollute watercourses. This is particularly likely during in-river working, vehicle movements, material storage and movement and concrete pouring, via leakage or accidental spillage. Release or mobilisation of these potentially polluting substances during the construction of the scheme may result in the deterioration of the water quality of these surface waters, as well those further downstream. Fuels, oils and other chemicals can bind to sediments and become persistent in aquatic ecosystems. Uptake by aquatic organisms can also take place. Cementitious materials can significantly increase the pH of receiving watercourse, chemicals can increase Biological and Chemical Oxygen Demand, reducing dissolved oxygen concentrations. The above impacts have the potential to result in a measurable deterioration in water quality, for the same watercourse reaches as described under "Sediment delivery from runoff (haul routes, material stockpiles and working areas)". Length affected and duration dependent on scale of incident. Duration of impacts could be long-term as substances can bind to sediments.	Moderate Adverse	Large	W1 W2 W12 W13 W22 W23	Minor Adverse	Slight
	Grange Burn *Westquarter Burn (tributary)* (WFD Waterbody: 3300-Grange Burn/ Westquarter Burn)	Overall: Moderate ecological potential Target Status (2027): Good ecological potential Biological elements: Good Physico-chemical: Good	High		Major Adverse	Very Large		Minor Adverse	Slight

Impact	Receptor	Existing WFD status Target Status Relevant WFD Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation ID	Post-mitigation (residual effect)	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
	River Avon (WFD Waterbody: 3100-Logie Water confluence to estuary)	Overall: Moderate Target Status (2027): Moderate Biological Elements: Moderate Physico-chemical: Good	Very High		Minor Adverse	Large		Negligible	Slight
	Tributaries of River Carron: Chapel Burn Mungal Burn Minor watercourse at Stirling Road	N/A	Medium		Major Adverse	Large		Minor Adverse	Slight
	Polmont Burn *(River Avon tributary)*	N/A	Medium		Moderate Adverse	Moderate		Negligible	Neutral
	Millhall Burn *(River Avon tributary)*	N/A	Medium		Major Adverse	Large		Minor Adverse	Slight
	Grange Burn Flood Relief Channel	N/A	Medium		Major Adverse	Large		Minor Adverse	Slight
	Middle Forth Estuary (WFD Waterbody: 200436-Middle Forth Estuary)	Overall: Moderate ecological potential Target Status (2027): Good Ecological Potential Biological Elements: Good Physico-chemical: Good	Very High		Moderate Adverse	Very Large		Negligible	Slight
	Bainsford Burn *(River Carron tributary)*	N/A	Medium	No change					
	Island Farm Lagoon (WFD Waterbody: 200324-Island Farm Lagoon)	Overall: Good Target Status (2027): High Biological Elements: High Physico-chemical: Good	Very High	No change					

Impact	Receptor	Existing WFD status Target Status Relevant WFD Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation ID	Post-mitigation (residual effect)	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
Disturbance of potentially contaminated bed-sediment from lock gate replacement.	**Middle Forth Estuary** (WFD Waterbody: 200436-Middle Forth Estuary)	Overall: Moderate ecological potential Target Status (2027): Good Ecological Potential Biological Elements: Good Physico-chemical: Good	Very High	Disturbance of potentially contaminated bed sediment from lock gate replacement works may result in contaminants re-entering the dissolved phase, resulting in the deterioration of the water quality of connected surface waters.	Moderate Adverse	Very Large	W1 W2 W14 W15 W22 W23	Negligible	Slight

Table C10.6.2: Impact Assessment – Fluvial Geomorphology – Construction

Impact	Receptor	Existing WFD status Target Status Relevant WFD Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
Change to structure and substrate of bed.	**River Carron**	Overall: Poor Target Status (2027): Moderate Hydromorphology: Moderate	High	Temporary in-water and near channel working areas will be required during construction. These activities would require access along the channel bed and banks for plant and machinery. In-water working areas will require a temporary working platform (set to above the 50% AEP (1 in 2 year) flow level) on top of which construction plant would operate. Working platforms would be formed to allow for construction and transportation of materials / plant along part of the width the watercourse and would lead to a reduction in channel cross-sectional area. Construction activities may potentially remove bed sediment and bank substrate which may permanently remove existing morphological features (where present) beneath the footprint of the works. Additionally works adjacent to the watercourse have the potential to increase fine sediment delivery to the channel which can alter the type and structure of the bed substrate.	Negligible	Slight	W1 W2 W3 W4 W5 W6 W7 W8 W9 W10 W11	Negligible	Slight
	Tributaries of River Carron: Chapel Burn Mungal Burn Minor watercourse at Stirling Road	Not classified	Medium		Minor Adverse	Slight		Negligible	Neutral
	Grange Burn *Westquarter Burn (tributary)*	Overall: Moderate ecological potential Target Status (2027): Good ecological potential Hydromorphology: Bad	High		Moderate Adverse	Moderate		Minor Adverse	Slight
	Polmont Burn	Not classified	Medium		Minor Adverse	Slight		Minor Adverse	Slight
	River Avon	Overall: Moderate Target Status (2027): Good Hydromorphology: High	Very High		Negligible	Slight		Negligible	Slight
	Grange Burn Flood Relief Channel	Not classified	Low		Negligible	Neutral		Negligible	Neutral
	Millhall Burn *(River Avon tributary)*	Not classified	Medium		Moderate Adverse	Moderate		Minor Adverse	Slight

Impact	Receptor	Existing WFD status Target Status Relevant WFD Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
Change to bank form and riparian zone.	**River Carron**	Overall: Poor Target Status (2027): Moderate Hydromorphology: Moderate	High	Temporary near water and in-water working have the potential to change channel bank form and alter the structure of the riparian zone. Construction activities such as piling result in ground vibration and loading of the bank top, which can loosen sub-surface material and destabilise the banks, whilst excavation works result in modification and removal of material, and damage to the natural bank face. Vegetation clearance exposes the banks to subaerial weathering, as it reduces the surface cover, removes roots, and loosens sediment, increasing bank vulnerability to erosion. Working along the bank top to construct can also lead to deterioration of the natural bank due to plant and machinery tracking. The construction of new bridges also has the potential to remove or disturb bank material and remove / alter riparian structure due to the presence of bridge abutments within the floodplain. Such impacts would be temporary over the construction period and localised to the works area (although riparian loss because of the bridge abutment footprints would be permanent). It is anticipated all riparian vegetation would be restored to or provide betterment on baseline conditions.	Negligible	Slight	W1 W2 W3 W4 W5 W6 W7 W8 W9 W10 W11	Negligible	Slight
	Tributaries of River Carron: Chapel Burn Mungal Burn Minor watercourse at Stirling Road	Not classified	Medium		Minor Adverse	Slight		Negligible	Neutral
	Grange Burn *Westquarter Burn (tributary)*	Overall: Moderate ecological potential Target Status (2027): Good ecological potential Hydromorphology: Bad	High		Moderate Adverse	Moderate		Minor Adverse	Slight
	Polmont Burn	Not classified	Medium		Minor Adverse	Slight		Negligible	Neutral
	River Avon	Overall: Moderate Target Status (2027): Good Hydromorphology: High	Very High		Negligible	Slight		Negligible	Slight
	Grange Burn Flood Relief Channel	Not classified	Low		Negligible	Neutral		Negligible	Neutral
	Millhall Burn	Not classified	Medium		Moderate Adverse	Moderate		Minor Adverse	Slight
Change to Channel Width and Depth Variation, Water Flows, Levels and Sediment Transport.	**River Carron**	Overall: Poor Target Status (2027): Moderate Hydromorphology: Moderate	High	During the construction phase, in-water working areas formed from working platforms from will be required to facilitate the construction of flood walls and embankments,. It. This will have the effect of narrowing the channel, reducing cross-sectional area, leading to potential changes in flow velocities and the capacity of the channel to convey flow downstream. This has the potential to impact sediment dynamics locally and downstream of the in-water working areas. At this stage only estimated widths of the in-water areas are currently known. The height of in-water working areas, the flow events at which they will remain dry (i.e., not be over topped), and methods proposed to establish them are not currently confirmed. Therefore, modelling data of any temporary changes to flow velocity and channel capacity are not available. As a conservative approach, it is assumed the working platforms would span 50 % of the watercourse width on smaller watercourses (up to 10 m wide), and 25 % of the watercourse width on the larger channels (greater than 10 m wide). Working platforms would be situated from one side and then the platform removed and installed along the opposite side to complete any works required.	Negligible	Slight	W1 W2 W3 W4 W5 W6 W7 W8 W9 W10 W11	Negligible	Slight
	Tributaries of River Carron: Chapel Burn Mungal Burn Minor watercourse at Stirling Road	Not classified	Medium		Minor Adverse	Slight		Negligible	Neutral
	Grange Burn *Westquarter Burn (tributary)*	Overall: Moderate ecological potential Target Status (2027): Good ecological potential Hydromorphology: Bad	High		Moderate Adverse	Moderate		Minor Adverse	Slight
	Polmont Burn	Not classified	Medium		Minor Adverse	Slight		Negligible	Neutral
	River Avon	Overall: Moderate Target Status (2027): Good Hydromorphology: High	Very High		Negligible	Slight		Negligible	Slight

Impact	Receptor	Existing WFD status Target Status Relevant WFD Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
	Grange Burn Flood Relief Channel	Not classified	Low		Negligible	Neutral		Negligible	Neutral
	Millhall Burn	Not classified	Medium		Moderate Adverse	Moderate		Minor Adverse	Slight

Table C10.6.3: Impact Assessment – Estuarine Geomorphology – Construction (note only residual impact magnitude and significance are given as specific mitigation for Estuarine Geomorphology is not required during construction).

Impact	Receptor	Value of Receptor	Receptor-specific Description of Impact	Residual	
				Magnitude of Impact	Significance
Morphological changes due to changes in flow speed and direction.	**Middle Forth Estuary**	Very High	Changes in both erosion / accretion rates and locations in the intertidal and subtidal areas arising from changes in tidal flows (speed and direction). This has the potential for increased erosion around working platforms where the channel is constrained and accretion where channel is unconstrained. Changes would be localised to the working areas and temporary during construction only, returning to pre-construction conditions once works are removed.	Negligible	Slight
	Lower Carron Estuary	High		Negligible	Slight
	Lower Grange Burn Estuary	High		Negligible	Slight
	Lower Avon Estuary	High		Negligible	Slight
	Navigation channel of Forth Estuary	Low		Negligible	Neutral
Direct changes in estuarine morphology due to heavy machinery.	**Middle Forth Estuary**	Very High	Morphological changes due to the direct disturbance of intertidal areas by tracking of plant and heavy machinery, potentially causing erosion or compaction. This would be a temporary impact over the construction period which would be localised to the footprint of the works. Once the works are removed, the area will be reinstated after the construction and the waterbodies are anticipated to recover.	Negligible	Slight
	Lower Carron Estuary	High		Minor Adverse	Slight
	Lower Grange Burn Estuary	High		Minor Adverse	Slight
	Lower Avon Estuary	High		Minor Adverse	Slight
Potential changes to the subtidal areas.	**Middle Forth Estuary**	Very High	Potential changes in subtidal areas could also occur due to the localised erosion of the foreshore during the transport of materials to the construction site. Erosion could release material to the subtidal channel, with the following potential effects: temporary local increase in suspended sediment concentrations which would lead to a reduction in water clarity, increased turbidity and a change to the type and size of material in suspension; and permanent shallowing of the subtidal slope due to deposition of material eroded from the intertidal, which could have implications for navigation.	Negligible	Slight
	Lower Carron Estuary	High		Negligible	Slight
	Lower Grange Burn Estuary	High		Negligible	Slight
	Lower Avon Estuary	High		Negligible	Slight
	Navigation channel of Forth Estuary	Low		Negligible	Neutral

Table C10.6.4: Impact Assessment – Groundwater – Construction

Impact	Receptor	Importance	Receptor-specific Description of Impact Prior to Mitigation	Duration of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
Changes to groundwater levels and flows due to dewatering of excavations for bridge abutments (up to 5m depth).	Raised Tidal Flat Deposits of Flandrian Age	Low	Dewatering of excavations in Flood Cells 1 and 4 could result in a temporary, localised reduction of groundwater levels and changes to groundwater flow direction within Raised tidal Flat Deposits.	Short-term	Negligible	Neutral	N/A	Negligible	Neutral
	Intertidal Deposits	Low	Dewatering of excavations in Flood Cell 1 could result in a temporary, localised reduction of groundwater levels and changes to groundwater flow direction within Intertidal Deposits.	Short-term	Negligible	Neutral	N/A	Negligible	Neutral
	Raised Marine Deposits	High	No dewatering expected.	N/A	N/A	N/A	N/A	N/A	N/A
	Alluvium	High		N/A	N/A	N/A		N/A	N/A
	Wells 1 to 5	High		N/A	N/A	N/A		N/A	N/A
	Springs 1 to 20, 24 and 26 to 30	Low		N/A	N/A	N/A		N/A	N/A
	River Carron	Very High	Dewatering of excavations for bridge abutments adjacent to the River Carron, Grange Burn and Millhall Burn have the potential to impact on baseflow to these watercourses.	Short-term	Minor Adverse	Moderate	W21	Negligible	Slight
	Grange Burn	Very High		Short-term	Minor Adverse	Moderate		Negligible	Slight
	Millhall Burn	Very High		Short-term	Minor Adverse	Moderate		Negligible	Slight
	Chapel Burn	Very High	No dewatering expected.	N/A	N/A	N/A	N/A	N/A	N/A
	Westquarter Burn Polmont Burn	Very High		N/A	N/A	N/A		N/A	N/A
	River Avon	Very High		N/A	N/A	N/A		N/A	N/A
	Grange Burn Flood Relief Channel	Low		N/A	N/A	N/A		N/A	N/A
	Island Farm Lagoon	Very High		N/A	N/A	N/A		N/A	N/A
	GW20	Low	No dewatering expected.	N/A	N/A	N/A	N/A	N/A	N/A
	GW05, GW06, GW10-13, GW16-19, GW21-23, GW25, GW26	Medium		N/A	N/A	N/A		N/A	N/A
	GW03 & Spr-25	Very High		N/A	N/A	N/A		N/A	N/A
	GW24, Spr-21, Spr-22 & Spr-23	Very High		N/A	N/A	N/A		N/A	N/A
	Residential buildings	Medium	Dewatering of excavations for bridge replacements in Flood Cells 1 and 4 has the potential to create minor differential settlement, due to the limited depth of excavations and localised extent of associated groundwater drawdown.	Long-term	Minor Adverse	Slight	W18	Negligible	Neutral
	Retail/ Commercial and Community Facilities	High		Long-term	Minor Adverse	Moderate		Negligible	Slight
	Industrial Buildings, Critical Infrastructure and Scheduled Monuments	Very High		Long-term	Minor Adverse	Moderate		Negligible	Slight
Changes to groundwater	Passage Formation	High	Proposed sheet piles have the potential to intersect bedrock in Flood Cell 4-South and Flood Cell 5, creating pathways through superficial deposits and enabling transport of contamination from surface to bedrock aquifers.	Long-term	Minor Adverse	Slight	N/A	Minor Adverse	Slight

Impact	Receptor	Importance	Receptor-specific Description of Impact Prior to Mitigation	Duration of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
quality due to creation of pathways from surface by sheet piles.	**Scottish Lower Coal Measures Formation**	High		Long-term	Minor Adverse	Slight		Minor Adverse	Slight
	Raised Tidal Flat Deposits of Flandrian Age	Low	Proposed sheet piles have the potential to intersect layers of varying permeability within superficial deposits, creating pathways through low-permeability material to high-permeability material and enabling transport of contamination from surface to superficial aquifers.	Long-term	Minor Adverse	Slight		Minor Adverse	Slight
	Intertidal Deposits	Low		Long-term	Minor Adverse	Slight		Minor Adverse	Slight
	Till	Low		Long-term	Minor Adverse	Slight		Minor Adverse	Slight
	Raised Marine Deposits	High		Long-term	Minor Adverse	Slight		Minor Adverse	Slight
	Alluvium	High		Long-term	Minor Adverse	Slight		Minor Adverse	Slight
Changes to groundwater levels and flow paths due to interception of artesian groundwater by sheet piles.	**Raised Tidal Flat Deposits of Flandrian Age**	Low	Proposed sheet piles in Flood Cell Working Areas 5-1 (Smiddy Brae & Avondale Road) and 6-4 (Water Treatment Works) have the potential to intercept artesian groundwater recorded by the GI data locally.	Short-term	Minor Adverse	Slight	N/A	Minor Adverse	Slight
	Alluvium	High	Proposed sheet piles in Flood Cell Working Area 1-2 (Carron Bridges) have the potential to intercept artesian groundwater recorded by the GI data locally.	Short-term	Minor to Negligible Adverse	Slight		Minor to Negligible Adverse	Slight
	GW03	Very High	Proposed sheet piles in Flood Cell Working Area 1-2 (Carron Bridges) have the potential to intercept artesian groundwater recorded by the GI data locally, which may affect potential groundwater contributions to the GWDTE.	Short-term	Negligible	Slight	W17	Negligible	Slight
	GW24	Very High	Proposed sheet piles in Flood Cell Working Area 6-4 (Water Treatment Works) have the potential to intercept artesian groundwater recorded by the GI data locally, which may affect potential groundwater contributions to the GWDTE.	Short-term	Negligible	Slight		Negligible	Slight
Risk of flooding due to intersection of artesian groundwater by sheet piles.	**Residential buildings**	Medium	Proposed sheet piles may intersect artesian groundwater in flood cell working areas 1-2, 5-1 and 6-4, which has the potential to create pathways for groundwater to release at surface and may lead to flooding.	Short-term	Minor Adverse	Slight	W1 W17	Negligible	Neutral
	Retail/ Commercial and Community Facilities	High		Short-term	Minor Adverse	Moderate		Negligible	Slight
	Industrial Buildings, Critical Infrastructure and Scheduled Monuments	Very High		Short-term	Minor Adverse	Moderate		Negligible	Slight
Loss of feature due to direct impact of construction.	**GW22**	Medium	Located partially within the permanent works footprint and therefore part of the GWDTE is likely to be removed as a result of the works.	Long-term	Moderate Adverse	Moderate	W19	Minor Adverse	Slight
	Spr-13 and Spr-16	Low	Located within the temporary works footprint (site compound and haul road) and therefore spring and surrounding area may be removed as a result of the works.	Long-term	Major Adverse	Slight	N/A	Major Adverse	Slight
	GW12	Medium	Located partially within the temporary works footprint (site compound) and therefore part of the GWDTE is likely to be removed as a result of the works.	Long-term	Moderate Adverse	Moderate	W19	Minor Adverse	Slight
Accidental spillage of fuels, oils, chemicals, cementitious materials, mobilisation of	**Raised Tidal Flat Deposits of Flandrian Age**	Low	The use of potentially polluting substances (through vehicle movements, material storage and movements and concrete pouring) may result in contamination of groundwater, particularly during excavation or via accidental spillage of vehicular oils, hydraulic fluids and fuels in highly permeable areas. Release of potentially contaminating materials (cementitious materials, greases, oils and other chemicals/compounds) during the construction of the scheme may result in the deterioration of the groundwater quality. In particular, cementitious materials may cause alterations of pH or increase turbidity.	Long-term	Moderate Adverse	Slight	W1 W2 W20	Minor Adverse	Slight
	Intertidal Deposits	Low		Long-term	Moderate Adverse	Slight		Minor Adverse	Slight
	Till	Low		Long-term	Moderate Adverse	Slight		Minor Adverse	Slight

Impact	Receptor	Importance	Receptor-specific Description of Impact Prior to Mitigation	Duration of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
suspended solids etc.	**Raised Marine Deposits**	High	Excavations below the water table have the potential to increase suspended solids in the groundwater. However, due to the filtering effect of the low permeability aquifers, migration of suspended solids would be minimal. Attenuation of contaminants in low permeability superficial deposits will reduce the impact of contamination incidents in the bedrock strata located at depth. Sheet piles in Flood Cell 4-South and Flood Cell 5 have the potential to intersect bedrock of the Passage Formation and create pathways for contaminants to bypass superficial deposits. The magnitude of potential impacts in this formation are thus elevated to the same magnitude as for the superficial deposits.	Long-term	Moderate Adverse	Large		Minor Adverse	Slight
	Alluvium	High		Long-term	Moderate Adverse	Large		Minor Adverse	Slight
	Passage Formation	High		Long-term	Moderate Adverse	Large		Minor Adverse	Slight
	Upper Limestone Formation	High		Long-term	Minor Adverse	Slight		Minor Adverse	Slight
	Scottish Lower Coal Measures Formation	High		Long-term	Minor Adverse	Moderate		Minor Adverse	Slight
	Scottish Middle Coal Measures Formation	High		Long-term	Minor Adverse	Moderate		Minor Adverse	Slight
	Wells 1 to 5	High	Located approximately 240m to 720m from construction activities. Superficial aquifers within the vicinity of the wells are of low permeability and dominantly intergranular flow, so attenuation of contaminated groundwater is likely. Therefore, the wells are considered unlikely to be indirectly impacted by changes to groundwater quality.	Long-term	Negligible	Slight	W1 W2	Negligible	Slight
	Springs 2, 13, 14 and 16	Low	Spring 2 is located approximately 40m from a proposed haul road and may be indirectly impacted by changes to groundwater quality resulting from accidental spillage of pollutants while in transit. Springs 13, 14 and 16 are located approximately 5m to 15m outside a proposed site compound and may be indirectly impacted by changes to groundwater quality resulting from accidental spillage of pollutants in transit, during handling or in storage.	Long-term	Moderate Adverse	Slight		Minor Adverse	Neutral-Slight
	Springs 1, 3-5, 7-12, 15, 17-20, 24 and 26-30	Low	Located approximately 100m to 1.3km from construction activities. Therefore, they are considered unlikely to be indirectly impacted by changes to groundwater quality.	Long-term	Negligible	Neutral		Negligible	Neutral
	GW03 and Spr-25	Very High	Located 110m upgradient from construction activities and therefore unlikely to be impacted by any changes to groundwater quality.	Long-term	Negligible	Slight	W1 W2 W19	Negligible	Slight
	GW05	Medium	Located approximately 325m from construction activities and therefore unlikely to be impacted by any changes to groundwater quality.	Long-term	Negligible	Neutral		Negligible	Neutral
	GW06	Medium	Located approximately 410m from construction activities and therefore unlikely to be impacted by any changes to groundwater quality.	Long-term	Negligible	Neutral		Negligible	Neutral
	GW10	Medium	Located adjacent and upgradient to construction activities. Due to the high permeability of the underlying aquifer, the likelihood of unmitigated release of pollutants affecting the quality of groundwater contributing to the GWDTE is potentially significant.	Long-term	Moderate Adverse	Moderate		Minor Adverse	Slight
	GW11	Medium	Located 110m upgradient from construction activities and therefore unlikely to be impacted by any changes to groundwater quality.	Long-term	Negligible	Neutral		Negligible	Neutral
	GW12	Medium	Located within the extent of construction activities, while the underlying aquifer is of low permeability the likelihood of unmitigated release of pollutants affecting the quality of groundwater contributing to the GWDTE is potentially significant.	Long-term	Major Adverse	Large		Minor Adverse	Slight
	GW13	Medium	Located 75m from construction activities, with underlying aquifer of low permeability, the likelihood of unmitigated release of pollutants affecting the quality of groundwater contributing to the GWDTE is potentially significant.	Long-term	Moderate Adverse	Moderate		Minor Adverse	Slight
	GW16	Medium	Located 70m from construction activities, with underlying aquifer of low permeability, the likelihood of unmitigated release of pollutants affecting the quality of groundwater contributing to the GWDTE is potentially significant.	Long-term	Moderate Adverse	Moderate		Minor Adverse	Slight
	GW17	Medium	Located 40m upgradient from construction activities, while the underlying aquifer is of high permeability, the likelihood of unmitigated release of pollutants affecting the quality of groundwater contributing to the GWDTE is potentially significant.	Long-term	Moderate Adverse	Moderate		Minor Adverse	Slight

Impact	Receptor	Importance	Receptor-specific Description of Impact Prior to Mitigation	Duration of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
	GW18	Medium	Located 25m from construction activities, on opposite bank of River Carron and therefore unlikely to be impacted by any changes to groundwater quality.	Long-term	Negligible	Neutral		Negligible	Neutral
	GW19	Medium	Located 45m from construction activities, on opposite bank of River Carron and therefore unlikely to be impacted by any changes to groundwater quality.	Long-term	Negligible	Neutral		Negligible	Neutral
	GW20	Low	Located 30m from construction activities, with underlying aquifer of low permeability, the likelihood of unmitigated release of pollutants affecting the quality of groundwater contributing to the GWDTE is potentially significant.	Long-term	Moderate Adverse	Slight		Minor Adverse	Slight
	GW21	Medium	Located 120m upgradient from construction activities and therefore unlikely to be impacted by any changes to groundwater quality.	Long-term	Negligible	Neutral		Negligible	Neutral
	GW22	Medium	Located within the extent of construction activities, while the underlying aquifer is of low permeability the likelihood of unmitigated release of pollutants affecting the quality of groundwater contributing to the GWDTE is potentially significant.	Long-term	Major Adverse	Large		Minor Adverse	Slight
	GW23	Medium	Located adjacent to construction activities, while the underlying aquifer is of low permeability the likelihood of unmitigated release of pollutants affecting the quality of groundwater contributing to the GWDTE is potentially significant.	Long-term	Major Adverse	Large		Minor Adverse	Slight
	GW24, Spr-21, Spr-22 and Spr-23	Very High	Located 75m from construction activities, with underlying aquifer of low permeability, the likelihood of unmitigated release of pollutants affecting the quality of groundwater contributing to the GWDTE is potentially significant.	Long-term	Moderate Adverse	Large		Negligible	Slight
	GW25	Medium	Located 95m upgradient from construction activities and underlain by low permeability aquifer, therefore unlikely to be impacted by any changes to groundwater quality.	Long-term	Negligible	Neutral		Negligible	Neutral
	GW26	Medium	Located 75m upgradient from construction activities and underlain by low permeability aquifer, therefore unlikely to be impacted by any changes to groundwater quality.	Long-term	Negligible	Neutral		Negligible	Neutral

Table C10.6.5: Impact Assessment – Fluvial Geomorphology – Operation

Impact	Receptor	Existing WFD status Target Status Relevant Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
Change to structure and substrate of bed.	**River Carron**	Overall: Poor Target Status (2027): Moderate Hydromorphology: Moderate	High	The permanent loss of natural bed will occur below the footprint of flood walls and new culverts. This will lead to a reduction in the natural variability of the channel, with the potential to alter flow velocities related to new structures. Alteration of flow dynamics has the potential to affect sediment dynamics and thus bed structure and substrate. Potential impacts related to changes in flow velocities are discussed in Section 5.2.4 of the Appendix C10.1. Additionally, loss and change to natural bed substrate would occur over extended culvert lengths and for a short distance downstream.	Negligible	Slight	N/A	Negligible	Slight
	Tributaries of River Carron: Chapel Burn	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral
	Tributaries of River Carron: Mungal Burn	Not classified	Medium		Minor Adverse	Slight	W26 W38 W39 W40	Negligible	Neutral

Impact	Receptor	Existing WFD status Target Status Relevant Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation Magnitude of Impact	Pre-mitigation Significance	Mitigation ID	Residual Magnitude of Impact	Residual Significance
	Tributaries of River Carron: Minor Tributary at Stirling Road	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral
	Grange Burn *Westquarter Burn (tributary)*	Overall: Moderate ecological potential Target Status (2027): Good ecological potential Hydromorphology: Bad	High		Minor Adverse	Moderate	W24 W25	Negligible	Neutral
	Polmont Burn	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral
	River Avon	Overall: Moderate Target Status (2027): Good Hydromorphology: High	Very High		Negligible	Slight	N/A	Negligible	Slight
	Grange Burn Flood Relief Channel	Not classified	Low		Negligible	Neutral	N/A	Negligible	Neutral
	Millhall Burn	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral
Change to bank form and riparian zone.	**River Carron**	Overall: Poor Target Status (2027): Moderate Hydromorphology: Moderate	High	The permanent loss of natural bank form will occur below the footprint of flood walls which sit on the bank-tops or below embankments where the banks are currently un-engineered. Riparian vegetation removed during construction to facilitate temporary access is currently expected to recover during the operational phase for all areas of the works. The design of new and raised bridges is currently unknown. Given the relatively small width of the watercourses that the proposed new and raised bridges structures would operate on, it is assumed that the bridges would be clear span, with abutments set back within the floodplain. It is assumed bridges would be set above the design flood event to allow conveyance of flow below the structure in such events.	Negligible	Slight	N/A	Negligible	Slight
	Tributaries of River Carron: Chapel Burn	Not classified	Medium		Minor Adverse	Slight	N/A	Minor Adverse	Slight
	Tributaries of River Carron: Mungal Burn	Not classified	Medium		Minor Adverse	Slight	W26 W38 W39 W40	Negligible	Neutral

Impact	Receptor	Existing WFD status Target Status Relevant Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation	Residual	
					Magnitude of Impact	Significance	ID	Magnitude of Impact	Significance
	Tributaries of River Carron: Minor watercourse at Stirling Road	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral
	Grange Burn *Westquarter Burn (tributary)*	Overall: Moderate ecological potential Target Status (2027): Good ecological potential Hydromorphology: Bad	High		Minor Adverse	Moderate	W24 W25 W27* W28*	Negligible	Slight
	Polmont Burn	Not classified	Medium		Minor Adverse	Slight	W26 W38 W39 W40	Negligible	Neutral
	River Avon	Overall: Moderate Target Status (2027): Good Hydromorphology: High	Very High		Negligible	Slight	N/A	Negligible	Slight
	Grange Burn Flood Relief Channel	Not classified	Low		Negligible	Neutral	N/A	Negligible	Neutral
	Millhall Burn	Not classified	Medium		Minor Adverse	Slight	W26 W38 W39 W40	Negligible	Neutral
Change to Channel Width and Depth Variation, Water Levels and Flows.	**River Carron**	Overall: Poor Target Status (2027): Moderate Hydromorphology: Moderate	High	During the operation phase, the presence of flood walls and embankments will contain flows up to the 200-year flood event. This would reduce the channel cross-section where new flood walls / embankments are proposed and lead to increased flow velocity and river discharges. Where watercourses are permitted to spill into their floodplain to a greater depth and extent, decreases in velocity and discharge volume are likely. This has the potential to impact channel form, including, channel width, depth and the water levels and flows within the channels. This could subsequently to alter sediment transport, erosion, and deposition within the watercourses. Changes to velocity and discharge during a design event, in comparison to the baseline scenario, are presented in Table 8 of Appendix C.10. While changes to watercourses will be long-term through the implementation of permanent structures, impacts will be short-term, limited to during more severe flood events.	Negligible	Slight	N/A	Negligible	Slight
	Tributaries of River Carron: Chapel Burn	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral
	Tributaries of River Carron: Mungal Burn	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral

Impact	Receptor	Existing WFD status Target Status Relevant Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
	Tributaries of River Carron: Minor watercourse at Stirling Road	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral
	Grange Burn *Westquarter Burn (tributary)*	Overall: Moderate ecological potential Target Status (2027): Good ecological potential Hydromorphology: Bad	High		Negligible	Slight	N/A	Negligible	Neutral
	Polmont Burn	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral
	River Avon	Overall: Moderate Target Status (2027): Good Hydromorphology: High	Very High		Negligible	Slight	N/A	Negligible	Slight
	Grange Burn Flood Relief Channel	Not classified	Low		Negligible	Neutral	N/A	Negligible	Neutral
	Millhall Burn	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral
Change to continuity of sediment transport and floodplain connectivity.	**River Carron**	Overall: Poor Target Status (2027): Moderate Hydromorphology: Moderate	High	As outlined in Section 5.2.3 of Appendix C10.1, proposed floodwalls and erosion protection will narrow the existing channels on which they occur. The degree of narrowing will dictate velocity changes within the channel and where these occur, there is a potential for changes to baseline sediment transport, erosion and deposition during flood events. Modelled velocities for various cross sections along the fluvial channel have been extracted from the hydraulic model and are presented in Annex A of Appendix C10.1. Results from Hjülstrom analysis between baseline and with Scheme flow velocities is presented in Table 9 in Appendix C10.1.	Negligible	Slight	N/A	Negligible	Slight
	Tributaries of River Carron: Chapel Burn	Not classified	Medium		Minor Adverse	Slight	N/A	Minor Adverse	Slight
	Tributaries of River Carron: Mungal Burn	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral
	Tributaries of River Carron: Minor Tributary – Stirling Road	Not classified	Medium		Minor Adverse	Slight	N/A	Minor Adverse	Slight

Impact	Receptor	Existing WFD status Target Status Relevant Parameters	Importance	Receptor-specific Description of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
	Grange Burn *Westquarter Burn (tributary)*	Overall: Moderate ecological potential Target Status (2027): Good ecological potential Hydromorphology: Bad	High		Negligible	Slight	N/A	Negligible	Slight
	Polmont Burn	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral
	River Avon	Overall: Moderate Target Status (2027): Good Hydromorphology: High	Very High		Negligible	Slight	N/A	Negligible	Slight
	Grange Burn Flood Relief Channel	Not classified	Low		Negligible	Neutral	N/A	Negligible	Neutral
	Millhall Burn	Not classified	Medium		Negligible	Neutral	N/A	Negligible	Neutral

*Note Mitigation Items W29 and W30 are within the tidal reach of the Grange Burn, however they are included in this table as they should be considered collectively with the fluvial geomorphology mitigation.

Table C10.6.6: Impact Assessment – Estuarine Geomorphology – Operation (note only residual impact magnitude and significance are given as specific mitigation for Estuarine Geomorphology is not required during operation).

Impact	Receptor	Value of Receptor	Receptor-specific Description of Impact	Residual	
				Magnitude of Impact	Significance
Loss of intertidal area.	**Middle Forth Estuary**	Very High	An increase in the footprint of flood defences could result in permanent loss of intertidal features, including designated features and those supporting important habitat, such as mudflats and saltmarshes.	Negligible	Slight
	Lower Carron Estuary	High		Negligible	Slight
	Lower Grange Burn Estuary	High		Negligible	Slight
	Lower Avon Estuary	High		Negligible	Slight
	Navigation channel of Forth Estuary	Low			
Water levels.	**Middle Forth Estuary**	Very High	Modified defence alignment may restrict or enhance water passage through the estuary which in turn could affect water levels. A reduction in channel cross section has the potential to impact local water levels and velocities which could lead to some erosion of intertidal area particularly around meanders. Reclamation could potentially lead to imperceptible increases in water levels throughout the estuary, however, is not likely to occur given the small size of reclamation in relation to the total area of the Forth Estuary.	Negligible	Slight
	Lower Carron Estuary	High		Negligible	Slight
	Lower Grange Burn Estuary	High		Negligible	Slight
	Lower Avon Estuary	High		Negligible	Slight

Impact	Receptor	Value of Receptor	Receptor-specific Description of Impact	Residual	
				Magnitude of Impact	Significance
	Navigation channel of Forth Estuary	Low			
Flow speeds and Directions.	Middle Forth Estuary	Very High	Modified defence alignment may restrict or enhance water passage through the estuary which in turn could affect flow speeds and direction. For the Middle Forth Estuary, all proposed defences are shore-parallel, therefore, no change in oncoming wave dynamics are expected.	Negligible	Slight
	Lower Carron Estuary	High		Negligible	Slight
	Lower Grange Burn Estuary	High		Negligible	Slight
	Lower Avon Estuary	High		Negligible	Slight
	Navigation channel of Forth Estuary	Low		Negligible	Neutral
Changes in estuarine morphology.	Middle Forth Estuary	Very High	General changes in sediment dynamics include: Permanent loss of natural banks and bed where defences are constructed abutting or within the channel which could permanently reduce the sediment supply from adjacent banks. Modifications to the sediment regime of the channel in areas where banks are currently able to erode and add sediment to the channel. Where channels are constrained by wider defence footprints, there is the potential for increased bed scour or intertidal erosion due to higher flow velocities. This could lead to increases in sediment supply from eroded areas.	Negligible	Slight
	Lower Carron Estuary	High		Negligible	Slight
	Lower Grange Burn Estuary	High		Minor Adverse	Slight
	Lower Avon Estuary	High		Negligible	Slight
Changes in estuarine geomorphology response under a scenario of climate change.	Middle Forth Estuary	Very High	Sea level rise may lead to the loss of intertidal area in the future and saltmarsh habitat losses would be expected to occur by around 2070 assuming the high emission scenario at Edinburgh occurs. Changes in the future under a scenario of climate change have been assessed considering the details in “Future Estuarine Baseline” (Section 3.6 in Appendix C10.2) and the potential for the proposed defences in each cell to cause changes.	Negligible	Slight
	Lower Carron Estuary	High		Negligible	Slight
	Lower Grange Burn Estuary	High		Negligible	Slight
	Lower Avon Estuary	High		Negligible	Slight

Table C10.6.7: Impact Assessment – Groundwater – Operation

Impact	Receptor	Importance	Receptor-specific Description of Impact	Duration of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
Changes to groundwater levels and groundwater	Raised Tidal Flat Deposits of Flandrian Age	Low	Potential alteration to direction of groundwater flow and changes to groundwater levels. Due to the low permeability of these aquifers, current flows are expected to be limited. Therefore, resultant changes to groundwater levels and flows are expected to be minor.	Long-term	Minor Adverse	Neutral	N/A	Minor Adverse	Neutral
	Intertidal Deposits	Low		Long-term	Minor Adverse	Neutral		Minor Adverse	Neutral

Impact	Receptor	Importance	Receptor-specific Description of Impact	Duration of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
flow direction due to piling	**Raised Marine Deposits**	High	Potential alteration to direction of groundwater flow and changes to groundwater levels. As permanent below-ground structures would only be constructed downgradient of this aquifer resultant changes to groundwater levels and flows are expected to be minor.	Long-term	Minor Adverse	Slight		Minor Adverse	Slight
	Alluvium	High	Potential alteration to direction of groundwater flow and changes to groundwater levels due to the orientation of proposed sheet piles within Flood Cell 1 and Flood Cell 4-South.	Long-term	Minor Adverse	Slight		Minor Adverse	Slight
	Wells 1 to 5	High	Located approximately 240m to 720m from the nearest permanent structures. Therefore, no impacts to these receptors are anticipated.	Long-term	N/A	N/A	N/A	N/A	N/A
	Springs 9 and 20	Low	Located 170m to 190m upgradient from the nearest permanent structures, therefore potential impacts on groundwater supply to this receptor would be minor.	Long-term	Minor Adverse	Neutral	N/A	Minor adverse	Neutral
	Spring 30	Low	Spring 30 is located 160m from the nearest permanent structures in Flood cell 5 and 600m downgradient of further permanent structures in Flood Cell 4-South, however the spring is located within low-permeability Raised Tidal Flat Deposits and therefore the potential impacts on this spring would be minor.	Long-term	Minor Adverse	Neutral		Minor adverse	Neutral
	Springs 1-5, 7, 8, 10-19, 24 and 26-29	Low	Located approximately 200m to 1.3km from the nearest permanent structures. Therefore, no impacts to this receptor are anticipated.	Long-term	N/A	N/A	N/A	N/A	N/A
	River Carron	Very High	Potential change to groundwater base flow to the River Carron in Flood Cell 1 would be moderate, due to alteration to direction of groundwater flow and changes to groundwater levels, particularly those areas underlain by Alluvium. Potential change to base flow to the River Carron in Flood Cells 2 and 3 would be negligible, as proposed below ground structures in these areas lie on a spit of land between the mouth of the River Carron and Forth Ports.	Long-term	Moderate Adverse	Large	W32	Negligible	Slight
	Chapel Burn	High	Potential change to base flow to the Chapel Burn would be negligible, as proposed below ground structures are only planned at the confluence of this watercourse with the River Carron.	Long-term	Negligible	Slight	N/A	Negligible	Slight
	Grange Burn	Very High	Potential change to groundwater base flow to the Grange Burn in Flood Cell 3 and Flood Cell 4-North would be negligible, due to the low permeability of the Intertidal and Raised Tidal Flat Deposit aquifers in these areas, as a result of which - current groundwater discharges to the watercourse are likely to be small.	Long-term	Negligible	Slight		Negligible	Slight
	Westquarter Burn **Polmont Burn**	Very High	Potential changes to base flow to the Westquarter and Polmont Burns would be negligible, as proposed below ground structures are only planned at the confluence of these watercourses with the Grange Burn in Flood Cell 4-South.	Long-term	Negligible	Slight		Negligible	Slight
	River Avon	Very High	Potential change to groundwater base flow to the River Avon in Flood Cell 5 would be negligible, due to the low permeability of the Intertidal and Raised Tidal Flat Deposit aquifers in this area, as a result of which - current groundwater discharges to the watercourse are likely to be small.	Long-term	Negligible	Slight		Negligible	Slight
	Millhall Burn	Very High	Potential changes to base flow to the Millhall Burn would be negligible, as proposed below ground structures are only planned at the confluence of this watercourse with the River Avon in Flood Cell 4-South.	Long-term	Negligible	Slight		Negligible	Slight
	Grange Burn Flood Relief Channel	Low	Potential changes to groundwater base flow to the Grange Burn Flood Relief Channel in Flood Cell 4-South would be negligible, due to the low permeability of the Raised Tidal Flat Deposit aquifer in this area, as a result of which - current groundwater discharges to the watercourse are likely to be small.	Long-term	Negligible	Neutral		Negligible	Neutral
	Island Farm Lagoon	Very High	Located approximately 600m from the nearest flood wall. Therefore, no impacts to this receptor are anticipated.	Long-term	N/A	N/A	N/A	N/A	N/A
	GW03 and Spr-25	Very High	Located approximately 200m north of the nearest permanent structures in Flood Cell 1. Groundwater flow is likely to flow from the north, towards the River Carron and therefore no impacts to this receptor are anticipated.	Long-term	N/A	N/A	N/A	N/A	N/A

Impact	Receptor	Importance	Receptor-specific Description of Impact	Duration of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
	GW05	Medium	Located approximately 330m east of the nearest permanent structures in Flood Cell 1. Groundwater flow is assumed to be towards the River Carron, located to the west and south of GW05. Therefore, no impacts to this receptor are anticipated	Long-term	N/A	N/A		N/A	N/A
	GW06	Medium	Located approximately 420m from the nearest permanent structures in Flood Cell 1, therefore no impacts to this receptor are anticipated.	Long-term	N/A	N/A		N/A	N/A
	GW10	Medium	Located approximately 10m south of the nearest permanent structures in Flood Cell 4. Groundwater supply is likely to flow from the south and west (towards the coast and the Westquarter Burn) following local topography. Therefore, minor impacts to this receptor are anticipated.	Long-term	Minor Adverse	Slight		Minor	Slight
	GW11	Medium	Located approximately 120m southwest of the nearest permanent structures in Flood Cell 4. Groundwater supply is likely to flow from the south and west (towards the coast and Westquarter Burn) following local topography. Therefore, no impacts to this receptor are anticipated.	Long-term	N/A	N/A		N/A	N/A
	GW12	Medium	Located approximately 10m west of the nearest permanent structures in Flood Cell 4. Groundwater flow is likely to flow from the south following local topography. Therefore, minor impacts to this receptor are anticipated.	Long-term	Minor Adverse	Slight		Minor	Slight
	GW13	Medium	Located approximately 85m northwest of the nearest permanent structures in Flood Cell 4. Groundwater supply is likely to flow from the south and east (towards the coast and parallel to the River Avon) following local topography. Therefore, negligible impacts to this receptor are anticipated.	Long-term	Negligible	Slight		Negligible	Slight
	GW16	Medium	Located approximately 80m north of the nearest permanent structures in Flood Cell 6. Proposed sheet piles cut are 4.5m deep and obliquely across the likely local groundwater flow path and could intercept a significant portion of the groundwater flowing towards this receptor. Groundwater supporting the habitat is likely to have a significant tidal element, however the proportion of freshwater and saline water is unknown. Due to the proposed ground improvement, changes to groundwater flows to the habitat to the south may result in a substantial change to groundwater supply to this area.	Long-term	Moderate Adverse	Moderate	W34 W37	Minor	Slight
	GW17	Medium	Located approximately 50m southwest of the nearest permanent structures in Flood Cell 1. Groundwater is likely to flow from the south and west (towards the River Carron) following local topography. Therefore, only minor impacts to this receptor are anticipated.	Long-term	Minor Adverse	Slight	N/A	Minor	Slight
	GW18	Medium	Located approximately 25m southeast of the nearest permanent structures in Flood Cell 1, on the opposite bank of the River Avon. Groundwater flow is likely to flow from the south (towards the River Carron). Therefore, no impacts to this receptor are anticipated.	Long-term	N/A	N/A		N/A	N/A
	GW19	Medium	Located approximately 50m southwest of the nearest permanent structures in Flood Cell 1, on the opposite bank of the River Avon. Groundwater flow is likely to flow from the south (towards the River Carron). Therefore, no impacts to this receptor are anticipated.	Long-term	N/A	N/A		N/A	N/A
	GW20	Low	Located approximately 40m northwest of the nearest permanent structures in Flood Cell 3. The site is located between Forth Ports and the mouth of the Grange Burn, and groundwater supply is likely to flow from the southeast towards the Firth of forth. Groundwater supply is further likely to have a tidal element due to the proximity to the coast. Therefore, only minor impacts to this receptor are anticipated.	Long-term	Minor Adverse	Neutral		Minor	Neutral
	GW21	Medium	Located approximately 125m south of the nearest permanent structures in Flood Cell 4. Groundwater supply is likely to flow from the south (towards the coast and Westquarter Burn) following local topography. Therefore, no impacts to this receptor are anticipated.	Long-term	N/A	N/A		N/A	N/A
	GW22	Medium	Located adjacent to and north of the nearest permanent structures in Flood Cell 6. Groundwater supply is likely to flow from the south (towards the Firth of Forth) following local topography. Proposed sheet piles cut are 13.5m deep and obliquely across the likely local groundwater flow path and could intercept a significant portion of the groundwater flowing towards this receptor. The sheet piles would be partially located within GW22. As a result, changes to groundwater flows to the habitat is expected to result in a substantial change to groundwater supply to this area. Therefore, moderate impacts to this receptor are anticipated.	Long-term	Major Adverse	Moderate	W34 W37	Minor	Slight

Impact	Receptor	Importance	Receptor-specific Description of Impact	Duration of Impact	Pre-mitigation		Mitigation ID	Residual	
					Magnitude of Impact	Significance		Magnitude of Impact	Significance
	GW23	Medium	Located approximately 15m to the south of the nearest permanent structures in Flood Cell 6. Groundwater supply is likely to flow from the south (towards the Firth of Forth) following local topography. Therefore, minor impacts to this receptor are anticipated.	Long-term	Minor Adverse	Slight	N/A	Minor	Slight
	GW24, Spr-21, Spr-22 and Spr-23	Very High	Located approximately 100m to the northeast of the nearest permanent structures in Flood Cell 6. Groundwater supply is likely to flow from the south (towards the Firth of Forth) following local topography. However, proposed sheet piles are 13.5m deep and obliquely cut across the likely regional groundwater flow path and could intercept a significant portion of the groundwater flowing towards this compound receptor. Surface water run-off would also be expected to be intercepted, which could result in 30 to 50% of freshwater flow being reduced. Groundwater supply is further likely to have a tidal element due to the proximity to the coast and the underlying aquifer is low-permeability Intertidal Deposits, however the presence of transitional habitat and freshwater habitat indicates the contribution of freshwater is expected to be key.	Long-term	Moderate Adverse	Large	W34 W35 W36 W37	Minor	Moderate
	GW25	Medium	Located approximately 100m to the southeast of the nearest permanent structures in Flood Cell 6. Groundwater supply is likely to flow from the south (towards the Firth of Forth) following local topography. Therefore, minor impacts to this receptor are anticipated.	Long-term	Minor Adverse	Slight	N/A	Minor	Slight
	GW26	Medium	Located approximately 90m southeast of the nearest permanent structures in Flood Cell 6. Groundwater supply is likely to generally flow from the south (towards the Firth of Forth) following local topography. Therefore, no impacts to this receptor are anticipated.	Long-term	N/A	N/A		N/A	N/A
Changes to groundwater flood risk due to piling.	**Residential buildings**	Medium	Sheet piles have the potential to increase groundwater flood risk in Flood Cell 1, Flood Cell 4-North and Flood Cell 6, where sheet piles are proposed downgradient of receptors in relation to local and regional groundwater flow paths.	Long-term	Moderate Adverse	Moderate	W33	Negligible	Slight
	Retail/ Commercial and Community Facilities	High		Long-term	Moderate Adverse	Large		Negligible	Slight
	Industrial Buildings, Critical Infrastructure and Scheduled Monuments	Very High		Long-term	Moderate Adverse	Very Large		Negligible	Slight