Grangemouth Flood Protection Scheme

Technical Note - Flood Defence Alignment Options for Port of Grangemouth

B2386100-JEC-S4-C03-ZZZ-TN-C-0002 | P04

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Falkirk Council

B2386100

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Grangemouth Flood Protection Scheme

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Contents

1. Guidance to readers

This Technical Note (TN) has been produced to assist and support the decision-making process during the Outline design of the Grangemouth Flood Protection Scheme (the Scheme). There are multiple TN's for the Scheme and each TN focuses on identifying a recommended design solution for one specific location or area.

TN's are produced where there may be multiple design options for a flood defence solution, each within their own positive and negative impacts in relation to parameters such as Time, Cost, Social or Environmental disturbance, and are a means, within the design process, to help assess and refine those options.

The TN's should not be considered as full option appraisals, or should they have to meet the formal requirements of that process as outlined in "Options appraisal for flood risk management: Guidance to support SEPA and the responsible authorities", published by the Scottish Government in 2016. The TN's have been developed by members of the Technical Workstream and drafted in an open and transparent manner, with the principal focus of the TN being technical aspects. The TN's have been drafted using experience and professional judgement gained from working on other flood protections schemes in Scotland. Within the TN's any comparative assessment in relation to parameters such as 'time' or 'cost' , i.e. Low, Medium or High impacts, for any option, are relative comparisons measured only, unless specifically noted otherwise, against the alternative options contained within that specific TN.

The variation between a 'Low', 'Medium' or 'High' value is typically where the measure being compared is considered to have a difference in quantum which is judged to be significant enough to influence the decision-making process for the options being assessed within each individual TN. There are no overarching threshold trigger levels between these categories which extend to all TN's, and a high-level comparison of these categories between other TN's shouldn't be carried out, what is a high cost option in one TN could very well be a low cost compared to options being considered in another TN.

A Equality Poverty Impact Assessment (EPIA) has not been carried for this TN, as it was not deemed to be applicable by the project team. Each TN will review the options being considered against the twenty Design Principles which have been developed to record and justify how the flood defence alignment has been determined by the project team. Not all the design principles will be applicable to all the options considered in the TN's, professional judgement will be used to determine which principles should be scoped out.

The recommended option identified for each TN, should be seen as an interim recommendation that will be subject to change once the 'next steps' are completed. Additional checks and reviews will also be undertaken as the outline design process is concluded prior to developing the scheme documents. It should also be noted that once any 'next steps' identified are carried out the TN will be subject to a further review to confirm the continued suitability of the recommended option or otherwise.

2. Introduction

The purpose of this technical note is to outline the construction method and flood defence alignment options within the Port of Grangemouth to protect against 1 in 200-year flood event.

It should be noted that a 'do nothing' option would leave the port and surrounding areas at risk of flooding. The indirect impact of flooding in the port would have a knock-on effect to the petrochemical plant and could result in shutdown of the whole plant.

This technical note will consider proposed flood defences at the following areas within the Port of Grangemouth (refer Figure 2): The provision of flood defences in these areas have been identified as being required to provide the desired levels of protection to the critical infrastructure within the port which is essential for its operation and also to prevent flooding of surrounding areas.

1. Boat Yard
2. North Shore Road
3. INEOS FPS RLPG Site
4. Port Entrance
5. Upper South Shore Road
6. Lower South Shore Road

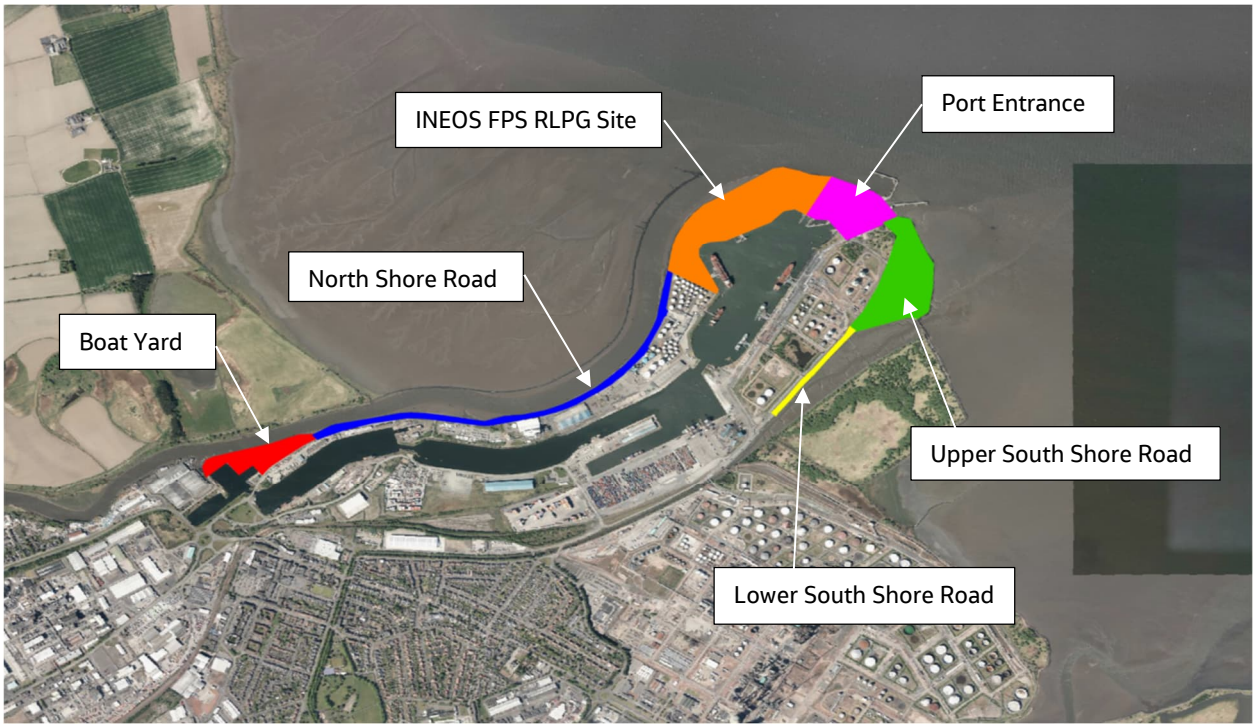

Figure 1 – Working Areas within Port of Grangemouth

The flood defence alignment is based on 'the general design principles' that have been devised in conjunction with Falkirk Council and incorporate:

- SEPA requirements,

- Marine Scotland requirements,
- Construction Design Management Regulations (CDM 2015) and,
- Environmental considerations.

The 'general design principals' for the scheme are set-out in the following Technical Note 'General Alignment Principles for Flood Defences' (Doc. No. B2386100-JEC-S4-XXX-XXX-TN-C-0001) and have been applied where practicable across the Grangemouth Flood Protection scheme (GFPS).

The objectives of this document are to:

- Outline the method of construction
- Outline the alignment options
- Compare alignment options with the 'General Principles for Flood Defence Alignment'
- Provide recommendations for flood defence alignment

2.1 Site Description

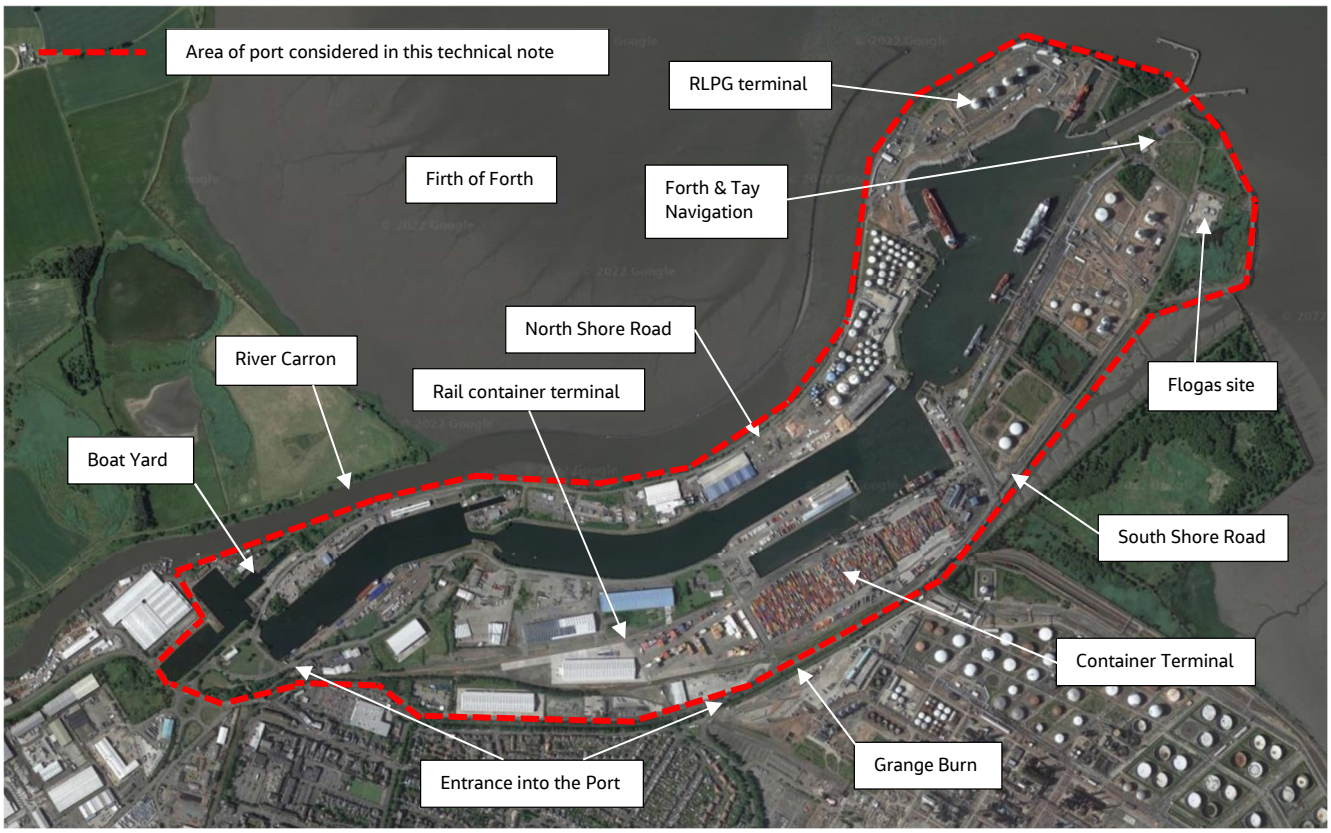

Figure 2 – Location Plan, Port of Grangemouth

The Port of Grangemouth lies to the north-east of the town of Grangemouth and is bound by the River Carron to the north, the Firth of Forth to the east and the Grange Burn to the south. The port has been built on reclaimed land that extends out into the Firth of Forth.

There are two main vehicular routes within the port, North Shore Road providing access to the RLPG terminal and various commercial/industrial premises along the north side of the port. South Shore Road provides access to the container terminal, Flogas site and the Forth & Tay navigation offices. The port of Grangemouth is the largest container port in Scotland and has a dedicated rail container terminal. North Shore and South Shore Roads are the only entrances into the port and serve as key transport arteries around the port.

2.2 Construction Method

It is proposed to install an exposed sheet pile floodwall, refer to Figure 3, through-out the Port of Grangemouth this is the preferred method for industrial areas within the scheme (refer Technical Note for 'Type of Flood Defences for Industrial Areas' doc. No. B2386100-JEC-S4-ZZZ-XXX-TN-C-0001).

Sheet piling is a common form of construction, that is generally quicker to install when compared with alternative 'flood defence' construction methods, such as reinforced concrete flood walls which require multiple construction stages. There may however be areas where pre-auguring is required, with made ground reaching up to ~7m depth, which can increase sheet pile installation durations. Sheet piling also minimises the required construction footprint and is suited to areas where spatial constraints are encountered.

Temporary traffic management measures will be in operation along North Shore Road, South Shore Road and along the access road within the RLPG site during the construction phase. Traffic management measures and access arrangements will be subject to agreement with Forth Ports and INEOS FPS. Access within the Port will be maintained at all times, with no full road closures proposed.

Figure 3 – Coated exposed sheet pile floodwall (Perth Flood Prevention Scheme)

3. Flood Defence Alignment

3.1 Boat Yard Alignment Options

The following section outlines the alignment options for a section of floodwall within the Boat Yard and highlights which of the flood defence alignment principles are met for each option. Options are discussed and considered before a recommendation is made.

3.1.1 Alignment Option A

This option locates flood defences inland away from the riverbank, along the back of the existing dockside retaining wall.

All buildings and boats within the boat yard would remain at risk of flooding with exception of the building owned by Forth Ports, which would be protected, floodgates would be installed at access points. Ramped access would be provided over the floodwall where it crosses the site access track near North Shore Road.

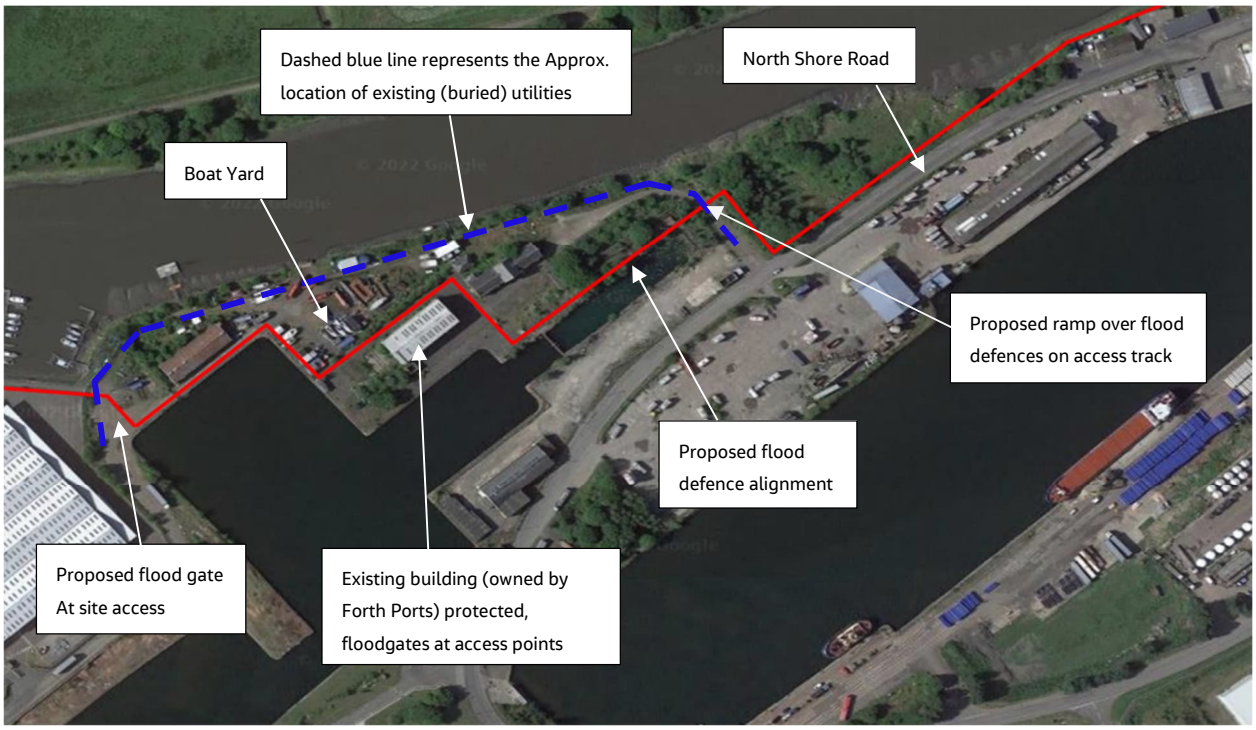

Figure 4 – Alignment Option A, Boat Yard

3.1.2 Alignment Option B

This option locates flood defences along the top of the riverbank, protecting all property within the boat yard and protecting an area of un-developed land to the east of the Boat Yard. The floodwall would be designed to fully retain the bank, allowing for vehicle surcharge loading. The sheet pile lengths would be considerably longer than option A.

There is no requirement for additional floodgates/ramps with this option. A raised platform area may need to be constructed on the dry side of the floodwall to allow for the safe craning of boats over the flood defence.

Information provided by utility companies identifies multiple buried services within the access track and in proximity to the riverbank. Diversion of services, inclusive of Scottish Power LV/HV cables and Scottish Gas (intermediate pressure) pipelines would likely be required.

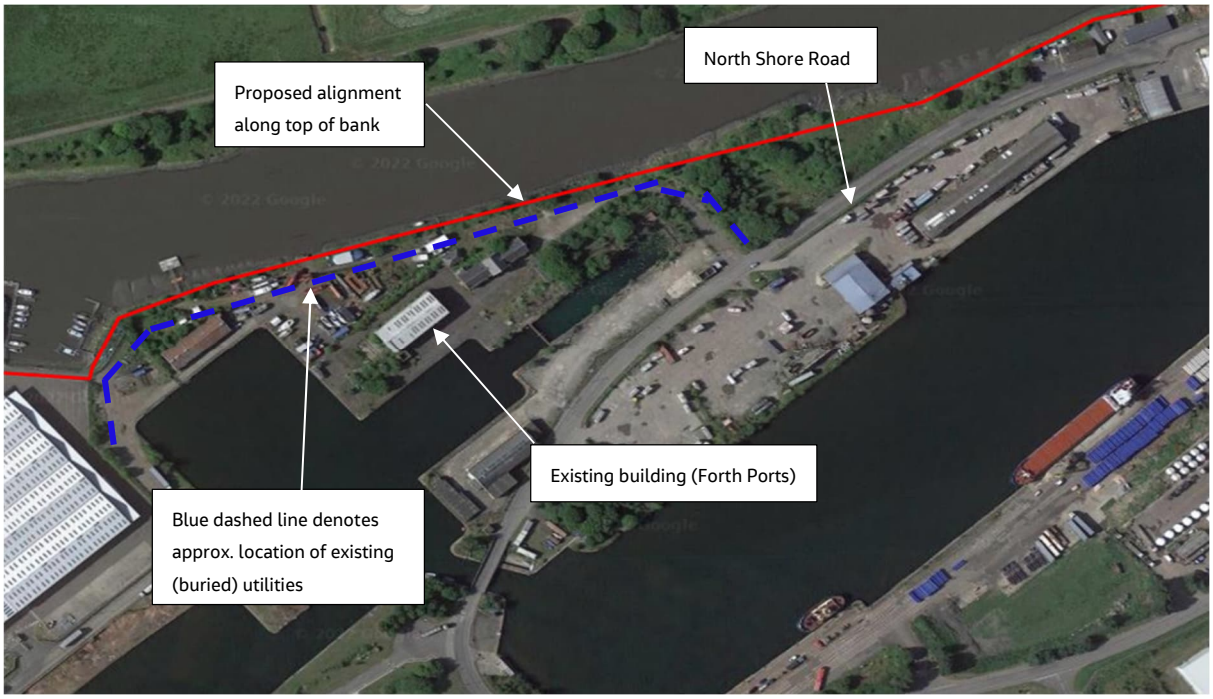

Figure 5 – Alignment Option B, Boat Yard

3.1.3 Alignment Option C

This alignment sets-back flood defences from the riverbank. Diversion work to multiple buried services which are located in the riverbank would be avoided, although further investigation into the location of buried services is required.

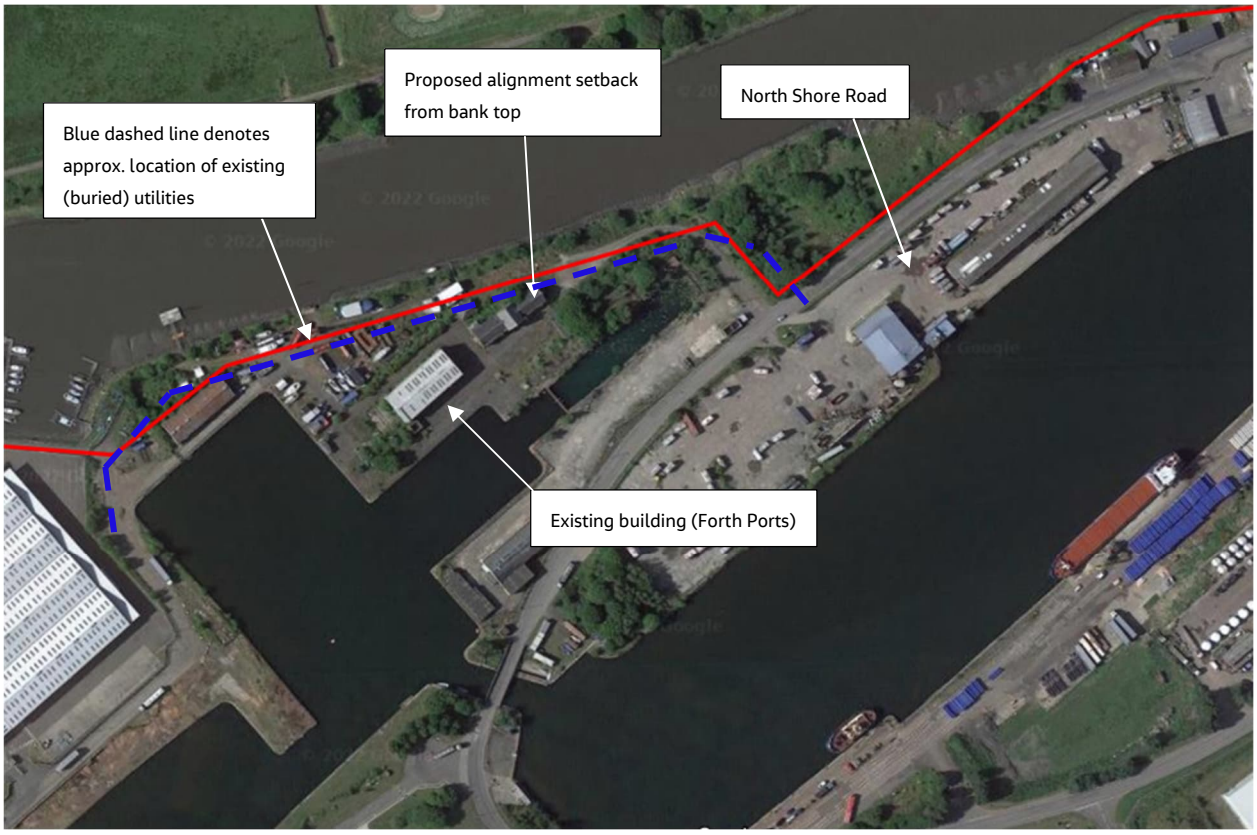

Figure 6 – Alignment Option C, Boat Yard

3.1.4 Comparison of Options and 'Alignment Principles'

Alignment Principles		Option A	Option B	Option C
1	Protect existing buildings and infrastructure	✗	✓	✓
2	Avoid encroachment into sensitive environmental sites	✓	✗	✓
3	Minimise disturbance of existing riverbanks and coastline	✓	✗	✓
4	Retain existing undeveloped land/ flood plains	✓	✗	✓
5	Avoid in water working	✓	✗	✓
6	Avoid utility diversions	✓	✗	✓
7	Locating flood defence adjacent to residential properties and outside the residential property boundary to reduce the loss of private garden	-	-	-
8	Locating flood defences out-with the operation areas of the petrochemical site	-	-	-
9	Retain passive resistance to embedded walls to reduce pile lengths	✓	✗	✓
10	Consider Loading, Form of Defence and Land Take	✓	✓	✓
11	Adopt solutions that minimise disturbance of contaminated soils	✓	✓	✓
12	Maintain a straight alignment where possible e.g., avoid frequent changes in direction	✗	✓	✓
13	Minimise the use of floodgates and demountable defences	✗	✓	✗
14	Maintain a consistent standard of protection	✓	✓	✓
15	Avoid tree felling and vegetation clearance	✓	✗	✓
16	Consideration of future maintenance and access requirements	✓	✓	✓
17	Ensure the residual pluvial flood risk is appropriately mitigated	✓	✓	✓
18	Ensure key transport arteries are resilient to a 200yr event	✓	✓	✓
19	Minimise impact on the road network	-	-	-
20	Minimise impact on cultural heritage sites	-	-	-

Table 1 – Alignment principles, Boat Yard

3.1.5 Discussion of Alignment Options

Option A – Locating the flood defences along the dockside (set-back ~2m from back of dockside retaining wall) maximises open space within the boat yard, mitigates costs associated with service diversions and limits

construction risk. The building owned by Forth Ports would be protected and additional floodgates are required at access points. Other buildings within the Boat Yard would not be protected. This alignment involves multiple changes in direction and moves away from the straight alignment principle.

Option B - Locating the flood defences along top of bank protects all property within the boat yard. An area of un-developed land to the east of the Boat Yard is protected which is against the 'general alignment principles' for the scheme. Protecting areas of natural flood plain has a negative cumulative effect on the overall scheme and should be avoided where possible.

Flood defences would be designed to retain full height riverbank to avoid stabilisation/protection work to the existing bank, increasing sheet pile lengths. This option is likely to impact on the SPA, through disturbance to the riverbank and would involve significantly higher construction risk and costs than Options A and C. Existing buried utilities on the riverbank are likely to be diverted, increasing overall capital cost.

Option C – Flood defences would be set-back ~10m from top of bank, most buildings would be protected. The useable space within the Boat Yard would be slightly reduced but still functional as a boat yard, additional floodgate(s) may be required to provide direct access through the defences to the riverbank. Access to the dry-side of the flood defences would be maintained via Grange Lane and South Shore Road.

3.1.6 Recommendation

Option C should be taken forward it would significantly reduce capital cost of the scheme and reduce construction risks for site personnel.

3.2 North Shore Road Alignment Options

The following section outlines the alignment options for a section of floodwall along North Shore Road and highlights which of the flood defence alignment principles are met for each option. Options are discussed and considered before a recommendation is made.

Figure 7 – Extent of Flood Defences along North Shore Road

3.2.1 Alignment Option A

This option sets-back the flood defences from top of bank, offset at ~1m distance from the back of kerb, along North Shore Road.

Existing lighting columns on the north side of the road would be taken down during construction and temporarily erected on the south side and then re-instated on completion of the works. Diversion of a Scottish Power (HV) cable over a short section on North Shore Road may also be required.

An existing concrete wall is located on the north side of North Shore Road adjacent to Nustar, refer Figure 9, over a length of ~380m and appears to be offset from the road by around 0.6m with the top of the wall being ~0.5m above the road surface.

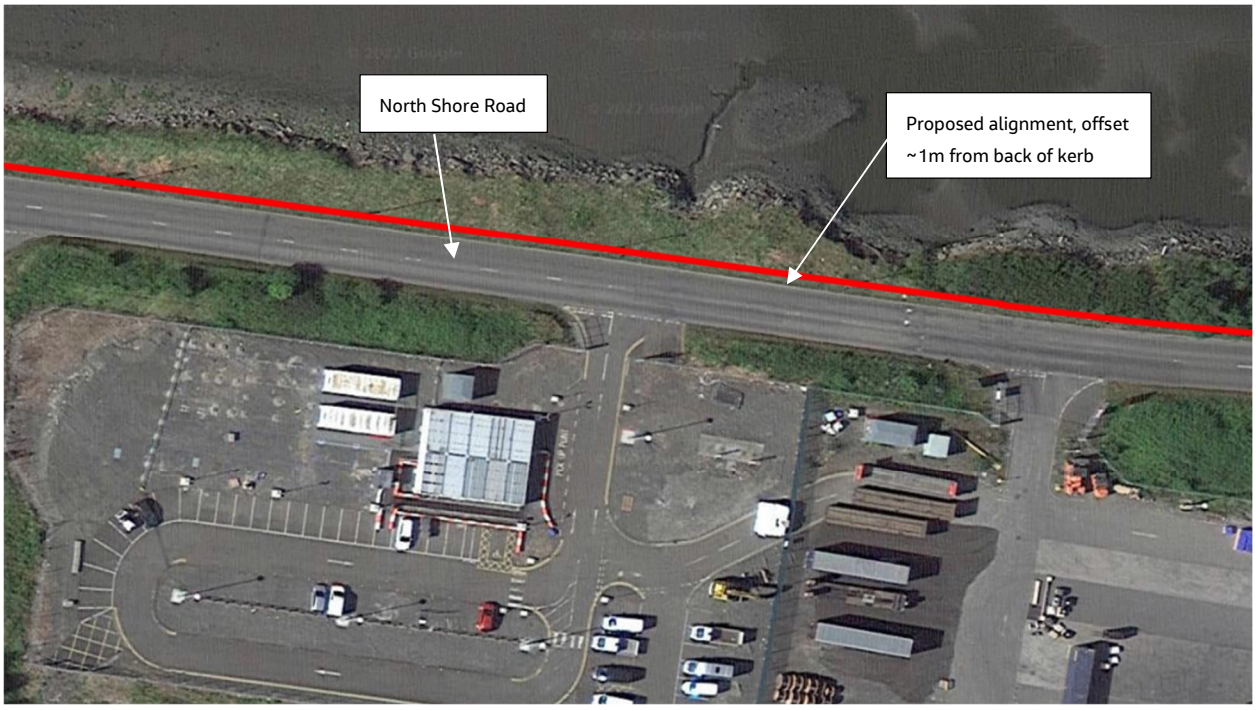

Figure 8 – Alignment Option A (Typical), North Shore Road

Figure 9 – Concrete wall adjacent to Nustar, view looking east along North Shore Road

3.2.2 Alignment Option B

Flood defences located along top of bank are designed to retain the full height of the riverbank, allowing for vehicle surcharge loading. Sheet pile lengths are longer than Option A and may require additional strengthening or reinforcement.

For some sections the flood defence would require a revetment structure in front of the flood defences to absorb wave energy and reduce wave height and wave overtopping. Existing lighting columns on the north side of the road would be taken down and temporarily erected on the south side during construction and re-instated on completion of the works to their original position.

Figure 10 – Alignment Option B (Typical), North Shore Road

3.2.3 Comparison of Options and 'Alignment Principles'

Alignment Principles		Option A (setback from top of bank)	Option B (along top of bank)
1	Protect existing buildings and infrastructure	✓	✓
2	Avoid encroachment into sensitive environmental sites	✓	✗
3	Minimise disturbance of existing riverbanks and coastline	✓	✗
4	Retain existing undeveloped land/ flood plains	✓	✗
5	Avoid in water working	✓	✓
6	Avoid utility diversions	?	?
7	Locating flood defence adjacent to residential properties and outside the residential property boundary to reduce the loss of private garden	-	-
8	Locating flood defences out-with the operation areas of the petrochemical site	-	-
9	Retain passive resistance to embedded walls to reduce pile lengths	✓	✗
10	Consider Loading, Form of Defence and Land Take	✓	✓
11	Adopt solutions that minimise disturbance of contaminated soils	✓	✓

12	Maintain a straight alignment where possible e.g., avoid frequent changes in direction	✓	✗
13	Minimise the use of floodgates and demountable defences	✓	✓
14	Maintain the same standard of protection	✓	✓
15	Avoid tree felling and vegetation clearance	✗	✗
16	Consideration of future maintenance and access requirements	✓	✓
17	Ensure the residual pluvial flood risk is appropriately mitigated	✓	✓
18	Ensure key transport arteries are resilient to a 200yr event	✓	✓
19	Minimise impact on the road network	-	-
20	Minimise impact on cultural heritage sites	-	-

Table 2 – Alignment Principles, North Shore Road

3.2.4 Discussion on Alignment Options

Option A – Setting back flood defences from the top of bank, ~1m to the back of kerb along North Shore Road provides sufficient ground in front of the flood defences to contribute to the global stability of the structure and maximises the opportunity for straight alignment.

The concrete wall adjacent to the Nustar site dictates the clear opening for manoeuvring heavy loads along North Shore Road, measuring ~10m clear width from inside face of wall to the fence line on the south side of the road carriageway the wall is ~0.5m high from carriageway level. The proposed flood defence is to be set-back to ~1m from back of kerb, increasing the clear width along the carriageway to ~10.5m. The top of the proposed defences would be constructed to the same level as the existing wall (or an alternative height as agreed with Forth Ports), the remainder of the wall height (up to ~0.5m) made up with a demountable top to flood defence level (FDL +5.2m), which would only be installed in the event of a flood warning. Demountable defences could be left in-situ (erected) but this could reduce the life span of the demountable structures.

The north verge of North Shore Road is vegetated, some clearance work would be required; however, it is likely any clearance work would be limited to within ~2m metre zone of the carriageway, leaving most of the vegetation and the bank in its natural state, contributing to overall bank stability. Bank protection work may be required at some sections where scour of the riverbank is evident and would take the form of armour stone placed on the existing bank. Very little would be required in the channel.

Option B - Locating flood defences along top of bank would maximise available land space and clearance from the carriageway. Flood defences would be designed to fully retain the riverbank and include for vehicle surcharge, pile lengths would double in length compared to option A. This option significantly increases construction costs, increases risk to construction personnel, limits the opportunity for straight alignment, encroaches into the SPA and significantly disturbs the riverbank and increases overall time to construct.

Existing utilities information shows multiple buried utilities within North Shore Road, it's not evident how close to the north verge utilities are located, so there is the possibility that diversion/protection work may be required for both alignment options.

3.2.5 Recommendation

Option A should be progressed. Construction costs are lower compared to Option B. It reduces the encroachment into the SPA and avoids disturbing the existing riverbank, which can remain in-situ. This recommendation has been made with the assumption that any service diversion costs for Option A will not be greater than the savings made in overall construction cost between the two options, and should be re-visited to confirm once a full understanding of the service locations is obtained.

3.3 INEOS FPS RLPG Site Alignment Options

The following section outlines the alignment options for a section of floodwall through the INEOS FPS RLPG site and highlights which of the flood defence alignment principles are met for each option. Options are discussed and considered before a recommendation is made.

3.3.1 Alignment Option A

The proposed alignment is located along the top of bank at the back of the blast proof walkway/escape structure and the RLPG facility office buildings. Spatial constraints dictate in channel working is likely along parts of this section. The flood defences would be designed to fully retain the bank. A ~2m wide pedestrian access track is proposed on the dry side of the flood wall.

The alignment returns inland along the existing perimeter fence line (not protecting an area of undeveloped land) and continues along high ground (limiting the height of defences), parallel with the existing site access road, offset ~1m distance from the back of road carriageway. Existing lighting columns on the north side of the site access road would need to be taken down temporarily during the construction phase and re-instated on completion of the works.

This section of flood defences is exposed to the Forth Estuary and a revetment structure may be constructed in front of the defences to absorb wave energy, reducing wave height.

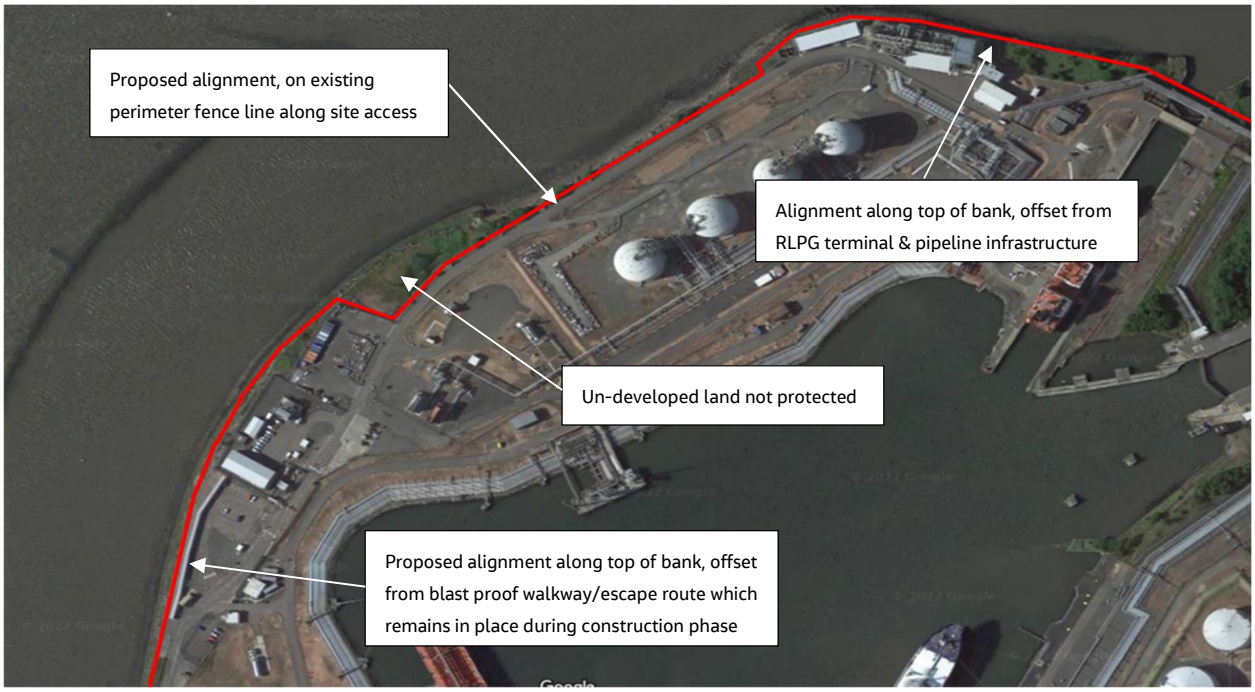

Figure 11 – Alignment Option A, INEOS FPS RLPG Facility

3.3.2 Alignment Option B

The proposed alignment is as per Option A (Section 2.3.1), but flood defences would continue along top of bank protecting an area of un-developed land to the north of the RLPG facility buildings.

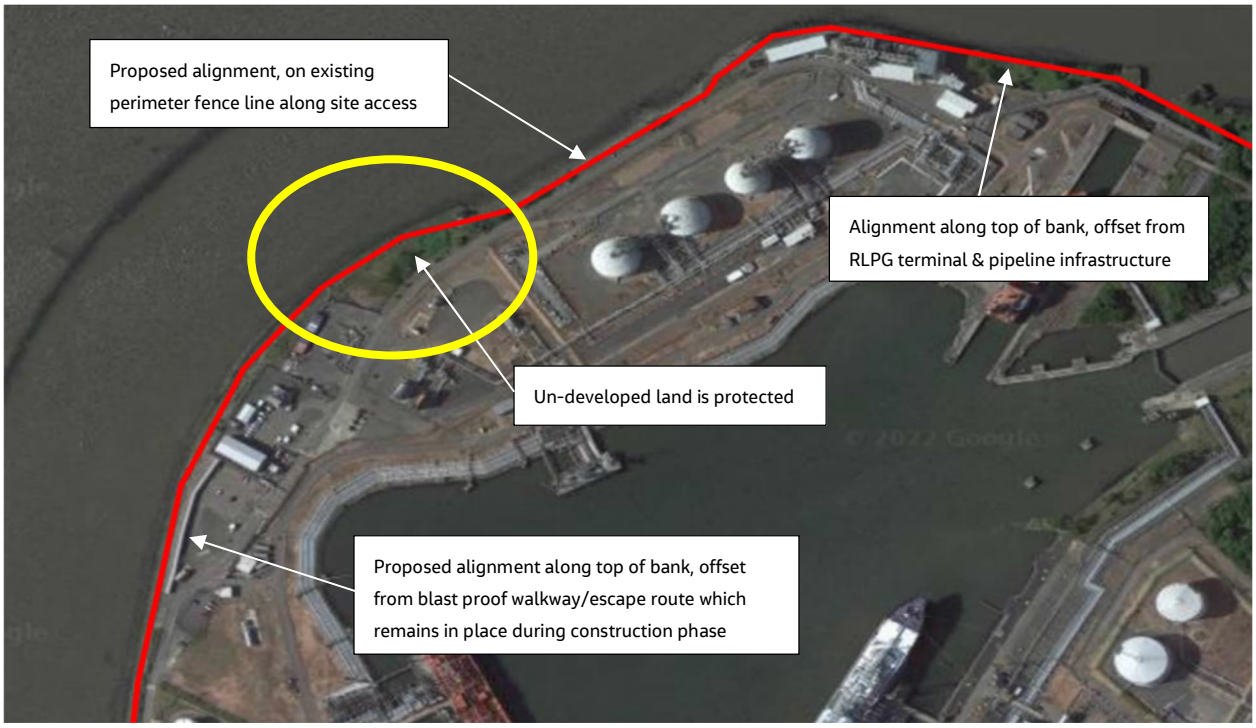

Figure 12 – Alignment Option B, INEOS FPS RLPG Facility

3.3.3 Comparison of Options and 'Alignment Principles'

	Alignment Principles	Option A	Option B
1	Protect existing buildings and infrastructure	✓	✓
2	Avoid encroachment into sensitive environmental sites	✗	✗
3	Minimise disturbance of existing riverbanks and coastline	✗	✗
4	Retain existing undeveloped land/ flood plains	✓	✗
5	Avoid in water working	✗	✗
6	Avoid utility diversions	✓	✓
7	Locating flood defence adjacent to residential properties and outside the residential property boundary to reduce the loss of private garden	-	-
8	Locating flood defences out-with the operation areas of the petrochemical site	-	-
9	Retain passive resistance to embedded walls to reduce pile lengths	✗	✗
10	Consider Loading, Form of Defence and Land Take	✓	✓
11	Adopt solutions that minimise disturbance of contaminated soils	✓	✓
12	Maintain a straight alignment where possible e.g., avoid frequent changes in direction	✓	✓

13	Minimise the use of floodgates and demountable defences	✓	✓
14	Maintain the same standard of protection	✓	✓
15	Avoid tree felling and vegetation clearance	✗	✗
16	Consideration of future maintenance and access requirements	✓	✓
17	Ensure the residual pluvial flood risk is appropriately mitigated	✓	✓
18	Ensure key transport arteries are resilient to a 200yr event	✓	✓
19	Minimise impact on the road network	-	-
20	Minimise impact on cultural heritage sites	-	-

Table 3 – Alignment Principles, INEOS FPS RLPG facility

3.3.4 Discussion of Alignment Options

Option A – There is no scope to move flood defences away from the top of bank behind the RLPG facility buildings. Space is constrained between the perimeter security fence and the top of bank; its likely temporary platforms would need to be constructed out into the Forth Estuary if utilising traditional piling methods. Alternatively, a silent pressing method (Giken) of installing sheet piles could be used at these locations to avoid working in the river channel. Constructing flood defences on the existing perimeter fence line along the site access road, is essentially the top of bank and there is no scope to push defences out towards the estuary without encroaching further into the SPA, increasing sheet pile lengths and construction costs.

Option B – Similar to Option A but would involve protecting an area of undeveloped land. Protecting areas of natural flood plain have a negative cumulative effect on the overall scheme and should be avoided where possible.

3.3.5 Recommendation

There is little scope in this area for an alternative flood defence alignment other than along top of bank due to the spatial constraints of the INEOS FPS RLPG site,

Option A should be progressed as it avoids protecting an area of natural flood plain and would have less impact on the SPA.

3.4 Port Entrance

The following section outlines the alignment options for a section of floodwall at the Port entrance and highlights which of the flood defence alignment principles are met for each option. Options are discussed and considered before a recommendation is made. The proposed flood defence alignment crossing the old port entrance, current port entrance and around dockside infrastructure is to be detailed in a separate study. This technical note will only consider the flood defence alignment on the land between the locks.

3.4.1 Alignment Option A

The proposed alignment will continue along top of bank from the INEOS FPS RLPG Terminal and maintain a sufficient distance from existing pipeline infrastructure refer Section 2.3.1. The alignment returns inland (not protecting undeveloped land). A ramp structure is proposed over the flood defence and will interface with the existing road bridge/culvert that cross multiple pipelines to the east of the old/berthing lock.

Flood defences on the east side of the port entrance continue inland along South Shore Road (not protecting undeveloped land) at a ~1m offset from back of road kerb.

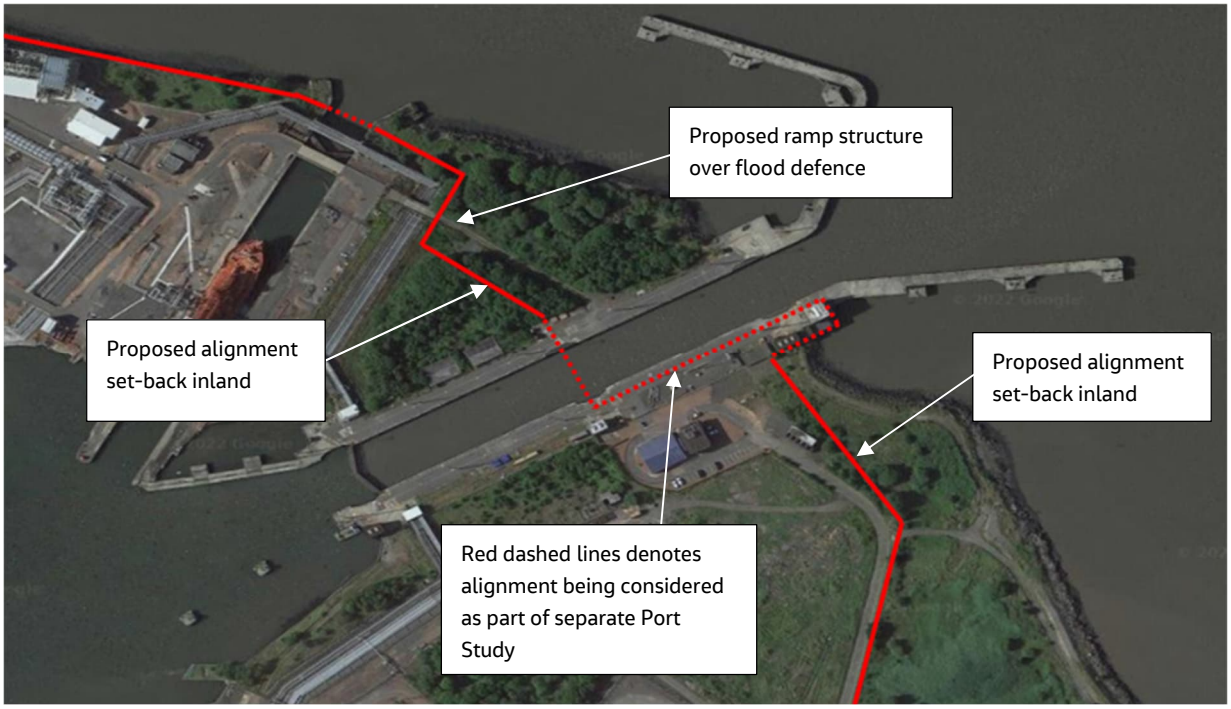

Figure 13 – Alignment Option A, Port Entrance

3.4.2 Alignment Option B

The proposed alignment is as per Option 1 (Section 3.4.1) with flood defences continuing along the top of bank, protecting areas of un-developed land to the west and east of the main port entrance. The sheet piles would be longer than Option A and may require additional strengthening.

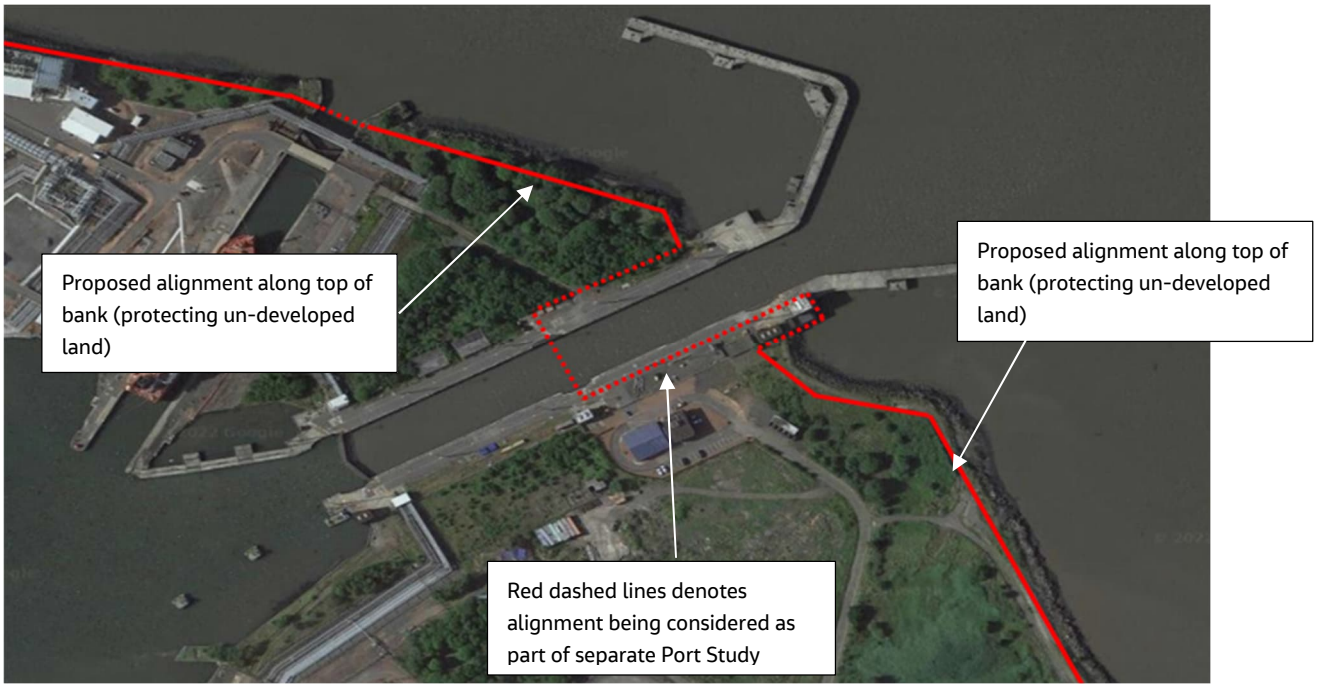

Figure 14 – Alignment Option B, Port Entrance

3.4.3 Comparison of Options and 'Alignment Principles'

	Alignment Principles	Option A	Option B
1	Protect existing buildings and infrastructure	✓	✓
2	Avoid encroachment into sensitive environmental sites	✓	✗
3	Minimise disturbance of existing riverbanks and coastline	✓	✗
4	Retain existing undeveloped land/ flood plains	✓	✗
5	Avoid in water working	✓	✓
6	Avoid utility diversions	-	-
7	Locating flood defence adjacent to residential properties and outside the residential property boundary to reduce the loss of private garden	-	-
8	Locating flood defences out-with the operation areas of the petrochemical site	-	-
9	Retain passive resistance to embedded walls to reduce pile lengths	✓	✗
10	Consider Loading, Form of Defence and Land Take	✓	✓
11	Adopt solutions that minimise disturbance of contaminated soils	✓	✓
12	Maintain a straight alignment where possible e.g., avoid frequent changes in direction	✓	✓

13	Minimise the use of floodgates and demountable defences	✓	✓
14	Maintain the same standard of protection	✓	✓
15	Avoid tree felling and vegetation clearance	✗	✗
16	Consideration of future maintenance and access requirements	✓	✓
17	Ensure the residual pluvial flood risk is appropriately mitigated	✓	✓
18	Ensure key transport arteries are resilient to a 200yr event	✓	✓
19	Minimise impact on the road network	-	-
20	Minimise impact on cultural heritage sites	-	-

Table 4 – Alignment Principles, Port Entrance

3.4.4 Discussion of Alignment Options

Option A – The flood defences are moved away from the top of bank so as not to impact upon areas of un-developed land to the west and east of the port entrance. Some de-vegetation/ clearance work would be required but this would not extend out to the top of bank, limiting disturbance to the riverbank and contributing to bank stability. Pile lengths are also reduced, to compared to option B.

Option B – Locating defences along the top of bank results in disturbance to the riverbank, potential for further impact on the SPA, increases sheet pile length, increases construction risk and overall capital cost.

3.4.5 Recommendation

- Option A should be progressed – it would be the most cost-effective solution and the existing riverbanks remain undisturbed.

3.5 Upper South Shore Road - Alignment Options

The following section outlines the alignment options for a section of floodwall on land to the east of lock and identifies which of the flood defence alignment principles are met for each option. Options are discussed and considered before a recommendation is made.

3.5.1 Alignment Option A

This alignment sets-back the flood defences along South Shore Road at a ~1m offset from back of road kerb and along the existing perimeter fence line around the 'Flogas' site. Construction access may be gained from South Shore Road with appropriate traffic management implemented. The un-developed floodplain to the east of the flood defence would not be protected as part of the scheme.

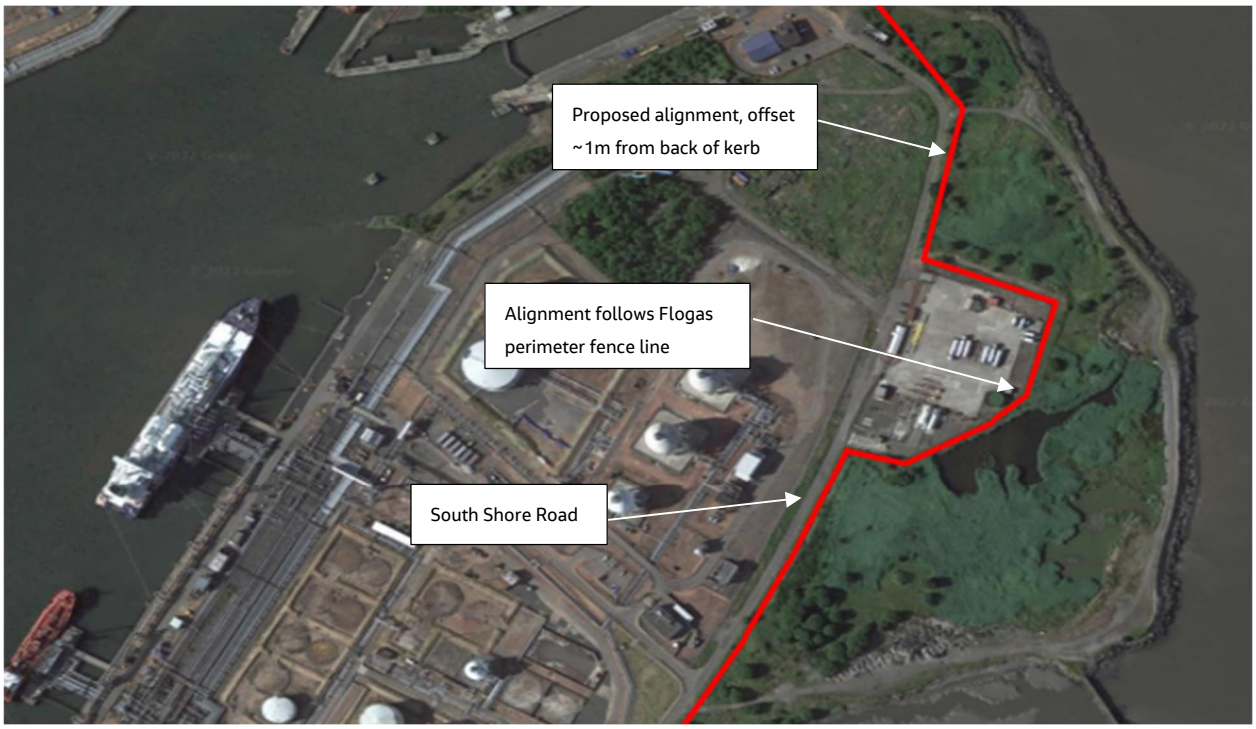

Figure 15 – Alignment Option A, Upper South Shore Road

3.5.2 Alignment Option B

Locating the flood defences along the top of bank would require the flood defences to be designed to retain full height riverbank, with pile lengths longer than option A. A revetment structure would likely be required in front of the flood defences, where there is exposure to the Forth Estuary.

There appears to be an existing granular bund around the perimeter of the site (along top of bank). It is likely that the bund is not a formal flood defence and may contain contaminated materials, further investigation is required to determine the nature of the bund material. The flood defence could be constructed parallel to the back toe of the bund.

Existing ground conditions in this area may dictate that the construction of purpose-built haul roads for construction traffic would be required to access the site perimeter, although an existing gravel track is evident, it is not known if it could accommodate the necessary construction plant.

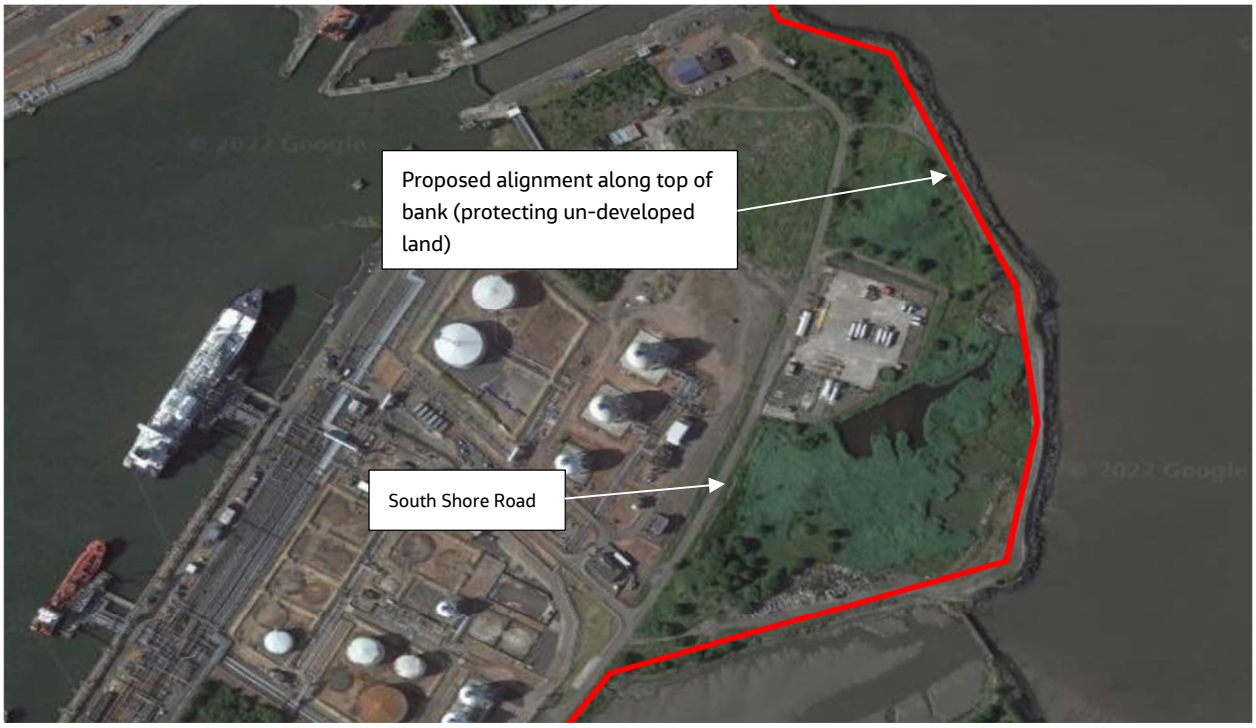

Figure 16 – Alignment Option B, Upper South Shore Road

3.5.1 Comparison of Options and 'Alignment Principles'

Alignment Principles		Option A	Option B
1	Protect existing buildings and infrastructure	✓	✓
2	Avoid encroachment into sensitive environmental sites	✓	✗
3	Minimise disturbance of existing riverbanks and coastline	✓	✗
4	Retain existing undeveloped land/ flood plains	✓	✗
5	Avoid in water working	✓	✓
6	Avoid utility diversions	✓	✓
7	Locating flood defence adjacent to residential properties and outside the residential property boundary to reduce the loss of private garden	-	-
8	Locating flood defences out-with the operation areas of the petrochemical site	-	-
9	Retain passive resistance to embedded walls to reduce pile lengths	✓	✗
10	Consider Loading, Form of Defence and Land Take	✓	✓
11	Adopt solutions that minimise disturbance of contaminated soils	✓	?
12	Maintain a straight alignment where possible e.g., avoid frequent changes in direction	✓	✗

13	Minimise the use of floodgates and demountable defences	✓	✓
14	Maintain the same standard of protection	✓	✓
15	Avoid tree felling and vegetation clearance	✓	✗
16	Consideration of future maintenance and access requirements	✓	✓
17	Ensure the residual pluvial flood risk is appropriately mitigated	✓	✓
18	Ensure key transport arteries are resilient to a 200yr event	✓	✓
19	Minimise impact on the road network	-	-
20	Minimise impact on cultural heritage sites	-	-

Table 5 – Alignment Principles, Upper South Shore Road

3.5.1 Discussion of Alignment Options

Option A – Locating flood defences away from the top of bank maintains a large area of undeveloped floodplain, access for construction work is close to South Shore Road, pile length is reduced compared to Option B. Construction work is further away from the SPA.

Option B - Locating the flood defences along the top of bank would maximise available land space but results in protecting undeveloped floodplain. Constructing defences along the top of bank would increase sheet pile lengths, resulting in higher construction costs, greater construction risk and may involve removing potentially contaminated material from site, adding significantly to overall capital costs. Potential for greater impact on the SPA.

3.5.2 Recommendation

Option A should be progressed - achieves all of the 'general alignment principles' and would be the most cost-effective solution. There are advantages environmentally, where encroachment into the SPA is limited and the riverbank remains un-disturbed.

3.6 Lower South Shore Road – Alignment Options

The following section outlines the alignment options for a section of floodwall along South Shore Road and highlights which of the flood defence alignment principles are met for each option. Options are discussed and considered before a recommendation is made.

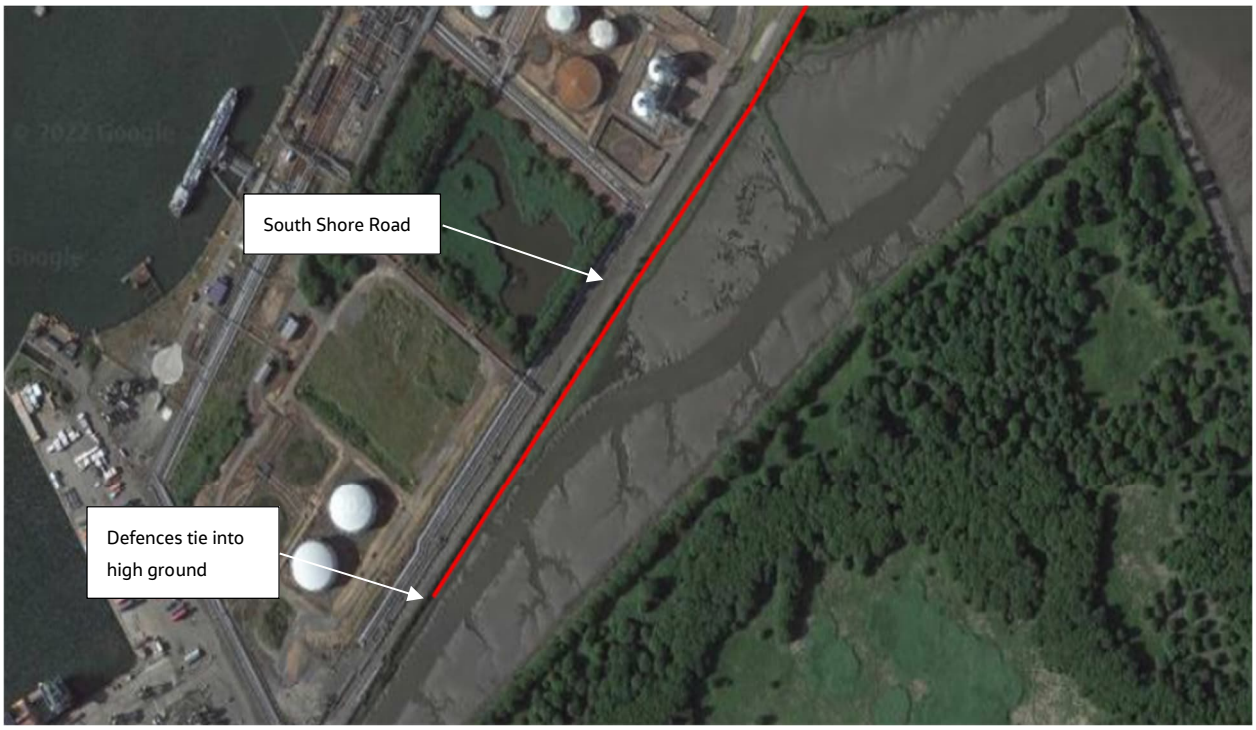

Figure 17 – Extent of Alignment along Lower South Shore Road

Figure 18 – Alignment Option A (Typical), Lower South Shore Road

3.6.1 Alignment Option A

This alignment sets-back the flood defences from the top of bank, offset at ~1m distance from the back of kerb, along South Shore Road. There is little scope to move flood defences further towards the Grange Burn due to the steep topography of the existing riverbank, where the proposed ~1m offset is generally at top of bank. Similar to Option A for flood defences along North Shore Road (refer Section 3.2.1) the top of the permanent sheet pile wall could be limited to a set height above road level (~0.5m as per North Shore Road) as agreed with Forth Ports , with the remainder to flood defence level (FDL +5.2m) made up with demountable barrier sections which would be installed in the event of a flood warning, allowing for wide load vehicles to manoeuvre unimpeded along the length of South Shore Road.

3.6.1 Comparison of Options and 'Alignment Principles'

Alignment Principles		Option A
1	Protect existing buildings and infrastructure	✓
2	Avoid encroachment into sensitive environmental sites	✗
3	Minimise disturbance of existing riverbanks and coastline	✗
4	Retain existing undeveloped land/ flood plains	-
5	Avoid in water working	✓
6	Avoid utility diversions	✗
7	Locating flood defence adjacent to residential properties and outside the residential property boundary to reduce the loss of private garden	-
8	Locating flood defences out-with the operation areas of the petrochemical site	-
9	Retain passive resistance to embedded walls to reduce pile lengths	✗
10	Consider Loading, Form of Defence and Land Take	✓
11	Adopt solutions that minimise disturbance of contaminated soils	✓
12	Maintain a straight alignment where possible e.g., avoid frequent changes in direction	✓
13	Minimise the use of floodgates and demountable defences	✓
14	Maintain the same standard of protection	✓
15	Avoid tree felling and vegetation clearance	✗
16	Consideration of future maintenance and access requirements	✓
17	Ensure the residual pluvial flood risk is appropriately mitigated	✓

18	Ensure key transport arteries are resilient to a 200yr event	✓
19	Minimise impact on the road network	-
20	Minimise impact on cultural heritage sites	-

Table 6 – Alignment Principles, Lower South Shore Road

3.6.1 Discussion of Alignment Options

Option A – Locating the alignment ~1m from back of road kerb ensures that the proposed flood defences don't encroach beyond the top of bank along South Shore Road. There is a need to maintain carriageway width and keep the carriageway open in the event of a flood event due to its importance for operation of the Port. Therefore, there is no alternative option at this location to move the defences further out towards the Grange Burn, without encroaching onto the embankment slope or into the carriageway and reducing road width.

3.6.2 Recommendation

Option A should be progressed as no alternative option is practicable.

4. Summary

The table 7 shows the proposed flood defence alignment options that are being progressed as part of the flood defences for the Grangemouth Flood Protection Scheme.

Location	Preferred Option	Option Description
Boat Yard	Option C	Setback ~10m from top of bank
North Shore Road	Option A	Offset ~1m from back of road kerb
RLPG Site	Option A	Along top of bank
Port Entrance	Option A	Set-back from top of bank
Upper South Shore Road	Option A	Offset ~1m from back of road kerb & around perimeter of Flogas site
Lower South Shore Road	Option A	Offset ~1m from back of road kerb

Table 7 – Summary of preferred alignment options

5. Next Steps

Continue to engage with Forth Ports on the proposed alignment of flood defences within the Port of Grangemouth. We understand from previous correspondence with Forth Ports that their preference is for flood defences to be aligned close to the bank top as far as practical, however, the design team have outlined within this technical note the reasoning for aligning the flood defences away from the top bank where possible.

Appendix A

Technical Note on the General Alignment Principles for Flood Defences' (Ref. B2386100-JEC-S4-XXX-XXX-TN-C-0001)

Grangemouth Flood Protection Scheme

Technical Note - General Principles for Flood Defence Alignment

B2386100-JEC-S4-XXX-XXX-TN-C-0001/P04

February 2022

Falkirk Council

B2386100

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Grangemouth Flood Protection Scheme

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Contents

1. Introduction

This technical note outlines the 'general principles' that have been applied when determining the flood defence alignment as part of the Grangemouth Flood Protection Scheme (Grangemouth FPS).

Multiple factors can influence the alignment of flood defences such as, but not limited to, ground conditions, location of existing utilities, physical constraints, environmental considerations, economics, and buildability. Therefore, the level at which these principles have been incorporated or met will vary across the scheme, the 'general principles' for the alignment of proposed flood defences have been used as a guide to the design in an effort to apply consistency across the entire scheme whilst recognising that elements of the design won't satisfy all of these principles.

The 'general guidance / principles' to be followed for determining flood defence alignment are identified below and discussed further in later sections:

- Protect existing buildings and infrastructure and land identified in local development plan for development
- Avoid encroachment into sensitive environmental sites
- Minimise disturbance of existing riverbanks and coastline
- Retain existing undeveloped flood plains
- Avoid in water working
- Avoid utility diversions
- Locating flood defence adjacent to residential properties but outside the residential property boundary to reduce the loss of private garden
- Locating flood defences out-with the operational areas of the petrochemical site
- Retain passive resistance to embedded walls to reduce pile lengths
- Consider Loading, Form of Defence and Land Take
- Adopt solutions that minimise disturbance of contaminated soils
- Maintain a straight alignment e.g., avoid frequent changes in direction
- Minimise the use of floodgates and demountable defences
- Maintain consistent standard of protection
- Minimum tree felling and vegetation clearance
- Consideration of future maintenance and access requirements
- Ensure the residual pluvial flood risk is appropriately mitigated and no increase in pluvial risk as a result of the construction of fluvial/coastal flood defences, and provide betterment
- Ensure key transport arteries are resilient to flood events
- Minimise impact on the road network
- Minimise impact on cultural heritage sites
- Use topography to reduce visible height of flood defences

2. General Alignment Principles

2.1 Protect existing buildings and infrastructure and land identified in local development plan for development

Flood protection schemes are for the "management of flood risk" in an area, typically with a principal aim to protect people, property, important historic or environmental sites and infrastructure from flooding. Flood defences should be constructed to protect residential properties and commercial/industrial premises at risk of flooding; however buildability, economic viability and technical construction aspects will be considered when determining flood defence alignment. In some situations, it may be impractical to protect existing properties and alternatives such as property flood resilience measures or purchasing/relocating the building/land may be required.

However, it may also be appropriate to consider including land identified within the local development plan and other similar plans and strategies within the area protected. These sites when developed will however have to consider flood risk in line with current planning guidance.

2.2 Avoid or reduce encroachment into sensitive environmental sites such as SPA's, SAC's and SSSI's

The impact of a flood protection scheme on the surrounding environment must be assessed through an Environmental Impact Assessment (EIA) and where necessary a Habitats Regulations Assessment (HRA). The EIA provides information to determine the potential impact of the project on the environment though an assessment that covers a range of topics. Any potential adverse impacts should be mitigated, through the scheme design or additional mitigation measures.

Special Protection Areas (SPA), Special Areas of Conservation (SACs) and Sites of Special Scientific Interest (SSSIs) are designated sites that should be avoided or safeguarded. Mitigation measures may need to be incorporated to offset any potential impact. Early discussions with NatureScot will provide clarity as to wider mitigation and compensatory measures which may be available together with the extent to which these measures can be incorporated either into the Scheme design or committed to by the Council at a later stage in Scheme construction or operation.

2.3 Minimise disturbance on riverbanks and coastline

Engineering activities within the water environment are regulated by SEPA through the Controlled Activities Regulations 2011 (CAR) or Marine Scotland through a Marine Licence. Construction work must demonstrate that best practice has been adopted. Minimising disturbance of existing riverbanks limits ecological harm, provides natural erosion protection, and maintains natural sediment processes.

2.4 Retain floodplain

It is best practice to avoid the loss of flood plain storage by setting back flood defences where practical or possible. The benefits of this approach are to maximise water storage and slow the flow of water in the river channel. This has the effect of reducing flood risk further downstream and reducing the height of flood defences. Additional benefits from retaining the natural flood plain include the reduction in levels of bank erosion/sediment loss, improving habitat diversity, increasing biodiversity both in channel and on land and improving the aesthetics of the landscape.

2.5 Avoid or reduce in water working

As stated in Section 2.3, SEPA regulations (CAR) stipulate that adoption of best practice is to be demonstrated when considering engineering activity within or close to a watercourse. Avoiding or reducing in water working significantly reduces the risk of a pollution incident and avoids the potential for geomorphological impacts

caused by the in water temporary works. Other benefits include the reduction in risk associated with high river/ water levels causing delays and disruption during the construction phase.

Furthermore, under the Construction Design and Management Regulations 2015 (CDM 2015) it is the responsibility of the 'designer' to identify any hazards arising from proposed construction works and to reduce or mitigate the associated risks to avoid injury/death to construction personnel. The best way to mitigate risk is to avoid the hazard in the first instance, so working within the watercourse should be avoided or reduced.

2.6 Avoid or reduce required utility diversions

Diversion of existing buried or above ground utilities or pipelines can have significant capital costs and have a longer-term negative impact on road users, pedestrians and local residents, especially if the diversion of multiple utilities is required. Flood defence type and position should be selected to avoid the need to divert utilities and any crossing of utilities required being perpendicular to the utility.

2.7 Locate flood defences outwith residential property boundaries

Flood defences should be positioned outwith the boundary of residential properties to avoid the reinstatement of private gardens and reduce the potential need for liability agreements with landowners.

2.8 Locate flood defences outwith the operational areas of the petrochemical site

Flood defences should be positioned outside the boundary fence of the petrochemical plant to avoid construction work taking place within the operational site, this would bring complex interactions with infrastructure and operations at the petrochemical plant along with health & safety considerations, both in terms of the construction and operation. It is likely that construction work out-with the boundary fence will also need to be authorised by the petrochemical plant operators, if it is proposed on land they own or near their apparatus.

2.9 Retain passive resistance to embedded walls to reduce pile length

The soil in front of an embedded wall can contribute to the passive resistance, aiding the global stability of the structure. Where there is limited soil in front of an embedded wall, it is not considered in the stability analysis and the wall must be designed for full height retention and any additional forces behind the wall. This is likely to result in a much more expensive solution where significantly longer pile lengths are required, and construction duration is increased. The benefits of retaining sufficient soil in front of the wall will also support the principle of setting the flood defences back from the riverbank.

2.10 Adopt solutions that minimise disturbance of contaminated soils

As stated in Section 2.5, under CDM 2015, there is a responsibility on 'designers' to identify hazards and reduce/mitigate risks associated with engineering proposals. Where work is to take place on contaminated or potentially contaminated land, risks to construction personnel can be reduced or mitigated by the adoption of design solutions that limit the need for excavation and removal of contaminated soils from site. Additional benefits include the avoidance of soil remediation or the disposal of soil which can add significant costs to the project.

2.11 Consider loading, form of defence and land take

The position of the flood defence can have an impact on the design loading e.g. a wall placed adjacent to a road may require the loading from vehicle impacts to be considered. This in turn can have an impact on the form of flood defence e.g. gravity wall, embedded wall with or without tie rods/ ground anchors. The form of defence can then impact on the required land take, potentially dictating the minimum separation between the flood defence and adjacent structures to accommodate foundations and other critical components that contribute to the stability and strength of the flood defence.

2.12 Maintain a straight alignment

Cost savings can be found in the simplification of the flood defence alignment. Constructing a flood defence with minimal changes in direction reduces material, and construction time costs allowing for standardisation and repetition. Additionally, consistence with wall finishes, reduces the number of bespoke wall finishes for individual properties.

2.13 Minimise use of floodgates or demountable barriers

Floodgates require a long-term maintenance regime and usually personnel to operate, the additional costs associated to both, need to be considered. It is good practice to design out floodgates with the adoption of passive structures e.g. stairs and ramps to cross over flood defences.

The above generally applies to flood gates that are normally open and closed when a flood is forecast. Flood gates or demountable barriers may be used to provide access for maintenance and would be normally closed/ erected and only opened/removed when access is required. Reducing floodgates/demountable barriers would lower the risk of the barriers not being fully closed or failure to deploy correctly and the risk of vandalism.

2.14 Maintain consistent level of protection

The same level of protection is to be applied (e.g. a 1 in 200 year standard). This should be with consistent reference to the 'general principles' and with a consistent 'protect / not protect' approach applied.

2.15 Avoid the felling of trees/vegetation

Design the flood defences to ensure existing trees and vegetation is retained. Where trees and vegetation will need to be cleared for the scheme, appropriate replanting/reinstatement will be necessary.

2.16 Consideration of future maintenance and access requirements

The flood defence alignment should allow for future access for both planned and unplanned maintenance. Positioning flood defences close to existing roads and access tracks is the simplest way of achieving this although as noted in Section 2.9 this can impact on the loads considered in the design of the defence.

2.17 Ensure the residual pluvial flood risk from the proposed flood defences is appropriately mitigated

Allow sufficient space on the dry side of the proposed flood defences for a secondary drainage system to be installed to mitigate any pluvial flood water that may pond here.

2.18 Ensure key transport arteries within the scheme area are resilient to tidal/fluvial flooding and operational up to a 1 in 200yr event

Ensure key road and rail routes are resilient to tidal/fluvial flooding, this may require new bridge structures to be built to ensure the structure remains operational during a flood event. This also potentially reduces the number of gate/ramp structures.

2.19 Minimise impact on the road network

Minimise the use of local roads by building dedicated haul roads within the construction boundary. The introduction of traffic management measures will be necessary at some locations and will be carefully planned in consultation with the local authority to reduce impact upon road users and the local community.

2.20 Minimise impact on cultural heritage sites

Avoid construction where within known sites of historical interest or cultural heritage sites. Early dialogue with Historic Environment Scotland (HES) is recommended to identify historic sites across the proposed scheme and ensure proposed construction activity does not adversely impact on these sites and that protection measures are adopted. The proposed works should also be sensitively designed to ensure no impacts on the setting of the site.

2.21 Use topography to reduce visible height of flood defences

The flood defence alignment should make use of existing topography to minimise the height of flood defences above existing ground level. This could be achieved by positioning the flood defences at the top of riverbanks on higher ground rather than positioning at the bottom of, or on slopes.

3. Summary

The 'general principles' set out in this technical note provide a basis for determining the flood defence alignment. These principles, guide the design, to ensure a level of consistency across the scheme. As highlighted in this document, the level at which these principles have been incorporated or met will vary across the scheme. The 'general principles' for the alignment of proposed flood defences act as a guide to the design but it must be recognised that elements of the design won't satisfy all these principles.

Appendix B

Technical Note on the Type of Flood Defences for Industrial Areas (Ref. B2386100-JEC-S4-ZZZ-XXX-TN-C-0001).

Grangemouth Flood Protection Scheme

Technical Note - Flood Defence Options for Industrial Areas

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August 2021

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B2386100

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Grangemouth Flood Protection Scheme

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Contents

1. Introduction

The purpose of this technical note is to outline the construction options for the provision of formal flood defences for Flood Cells 3, 5 and 6 of the Grangemouth Flood Protection Scheme (GFPS) which will protect against a 1 in 200-year flood event.

Flood Cells 3, 5 and 6 are predominantly located within heavily industrialised areas, therefore several issues need to be considered when selecting the most appropriate method of constructing flood defences. Items for consideration include:

- potential contaminated ground:
    - exposure to construction worker and others when in use
    - cost of dealing with contaminated ground (disposal or remediating it)
    - degradation of flood defences
- cost of constructing flood defences
- complexity of temporary works and access
- time taken to construct flood defences
- maintenance of flood defences
- ability to adapt flood defence to account for climate change
- risks that could impact on cost, quality or time should they materialise e.g. adverse weather

The following methods of constructing flood defences will be considered:

- Earth embankment, with seepage cut off
- Sheet pile wall – exposed steel
- Sheet pile wall with reinforced concrete cap/ stem
- Secant pile wall
- Reinforced concrete cantilever wall with seepage cut off

For each construction method the following will be considered:

- outline of construction methods and associated advantages/ disadvantages
- estimate of construction costs and indication of future maintenance requirements
- comment on environmental impacts
- estimate of whole-life carbon costs
- ability to adapt flood defences to account for climate change
- potential of dealing contaminated ground

1.1 Site Description

A brief description of each Flood Cell is outlined below.

<u>Cell 3:</u>

Flood defences are proposed around the Port of Grangemouth (operated by Forth ports) which is Scotland's largest sea container port. The site has a long history of industrial activity, including rope works, gas works,

docklands, shipyard, hydrocarbon storage, smithy and timber yards. Currently the Port of Grangemouth supports multiple industries such as, chemicals, agricultural, recycling and oil & gas, see Figure 1 for outline of Flood Cell 3. It has been classified as a Yellow Category site in conjunction with the British Drilling Association (BDA) guidance for safe intrusive activities on contaminated land or potentially contaminated land, where sites are classified into green, yellow, amber or red sites. BDA guidance classifies red sites as the most hazardous, however based on historical and current land uses the site has been classified as a Yellow Category site.

The port area is built on reclaimed land with made ground of variable composition (clay to gravel and topsoil, rubble, cinders, brick slag and clinker). From completed ground investigation works the anticipated depth of made ground is up to ~7m below existing ground levels, although this is likely to vary across the site. The superficial geology is shown to be mainly soft cohesive soils, largely comprising intertidal marine deposits (clayey sand to glacial till deposits). The thickness of these deposits varies across the site, from ~40m-60m.

Figure 1, Flood Cell 3

Cell 5:

Flood defences are proposed on both banks of the River Avon and north and south of the A905. The land to the north of the A905 is currently occupied by the Grangemouth petrochemical plant. The site has a history of industrial activity, including a knackery, sewage works and various chemical and petrochemical works, see Figure 2 for outline of – Flood Cell 5. it has been classified as a Yellow Category site in conjunction with BDA guidance as the presence/extent of contaminants is unknown.

The site is underlain by made ground such as colliery waste (spoil heaps). The superficial geology is shown to be mainly soft cohesive intertidal and river tidal deposits comprising of silt, clay and fine-grained sand (marine deposits) to a thickness of ~10m-40m with thicknesses increasing in depth towards the Forth Estuary.

Figure 2, Flood Cell 5

Cell 6:

The flood defences located along the Forth Estuary on land currently occupied by the Grangemouth Refinery and Kinneil Kerse wastewater treatment works. The site has a history of industrial activity, including an oil refinery, rifle range, sewage works, electrical sub-station and railway land, see Figure 3 for outline of Cell 6.

The site is underlain by made ground such as colliery waste (spoil heaps). The superficial geology is shown to be mainly soft cohesive intertidal and river tidal deposits comprising of silt, clay, and fine-grained sand to a thickness of between ~40m-60m with the thickest band between the River Avon and Grange Burn.

Figure 3, Flood Cell 6

2. Flood Defence Options

The following section outlines possible options for the provision of flood defences within Flood Cells 3, 5 and 6.

2.1 Option 1 - Earth Embankment

The construction of an earth embankment is generally dependent on available land space and has a much larger footprint than a flood wall. Embankments tend to be seen as more visually appealing than wall structures.

A flood embankment structure is formed from engineering fill which is compacted in layers, grass covered and may have a crest footpath if appropriate. An impermeable core is required to reduce seepage through the embankment and may extend many metres below ground to reduce seepage underneath the embankment. As an alternative to an impermeable core the entire embankment may be constructed from low permeability fill e.g., cohesive fill/ glacial till but this still may require a cut off below the base of the embankment to reduce seepage. An earth embankment will require some degree of excavation to key the structure into the existing ground and construction activities are highly weather dependant.

Figure 4, Earth embankment cut-off trench (Selkirk FPS)

2.2 Option 2 - Exposed Sheet Pile Wall

This option is a fast form of construction and generally lower in cost when compared to other wall options. Dependent upon ground conditions the ground can be pre-augured where necessary and various driving methods (percussive, vibratory, or possibly silent pressing) used to install the piles to the required depth. This form of construction is least affected by weather.

An exposed sheet pile wall may be more practical and visually acceptable than other methods. Leaving the pile exposed above ground level would avoid the additional time and cost casting a reinforced concrete stem or encasing the pile with concrete. There may be slightly higher maintenance requirements than compared to a concrete encased wall, but this will be dependent on the method of corrosion protection used. Protective paint systems offer long lasting protection against atmospheric corrosion and cathodic protection techniques could be considered. The piles could also be left uncoated providing sufficient sacrificial thickness of steel is allowed. see Figure 5. The plie clutches would need to be sealed or welded, particularly the above ground sections and possible for a section below ground if seepage is a concern.

A double row of sheet piles could be adopted where more difficult ground conditions are encountered closer to the Forth Estuary. Two rows of sheet piles could be installed roughly 1-1.5m apart and tied together to act as a

uniform structure. This method helps to enhance global stability, increase bending capacity and can significantly reduce lateral deflections and sheet pile embedment length.

Figure 5 , Coated exposed sheet pile (Perth FPS)

2.3 Option 3 - Sheet Pile Wall with Reinforced Concrete Stem

The construction of a sheet pile wall with a reinforced concrete pile-cap and stem allows for a more visually appealing finish. A trench is created along the wall centreline and the sheet piles are driven to the required toe depth with the pile top at or just below ground level. The top of the sheet piles are encased in a reinforced pile cap to just below finished ground level. A reinforced concrete stem is then cast on the pile-cap up to flood defence level. The wall stem can be masonry clad or have an in-situ cast pattern profile finish. Some excavation is required for this option with concrete works being slightly weather dependant.

Figure 6, Sheet pile with reinforced concrete stem (White Cart Water FPS)

2.4 Option 4 – Secant Pile Wall

Secant pile walls are formed by constructing reinforced concrete piles that interlock and tend to be constructed using Continuous Flight Auger Piles (CFA). This is a cast in-situ method of piling that comprises a hollow stem auger being screwed into the ground to the required design depth, concrete is pumped through the hollow stem of the auger whilst being slowly retracted. The advantage of secant pile walls is that there is minimal vibration, low noise levels during installation and increased wall stiffness in comparison to sheet piles. The piles can be installed through soft and hard ground including rock. Some excavation is required through hollowing out the pile and to construct the; this construction method is less weather dependant than other options. Depending on ground conditions a temporary casing may also be used to control the diameter of the pile.

A reinforced concrete capping beam would be cast to tie the top of the piles together and provide a base to cast a reinforced concrete wall stem to top of wall level, providing a reinforced concrete stem that can be clad in masonry or have an in-situ cast pattern profile finish.

Figure 7, Bromford Flood Risk Management Scheme – Secant pile wall ready for reinforced concrete stem to be constructed.

2.5 Option 5 – Reinforced Concrete Cantilever Wall

The option of a reinforced concrete cantilever wall is generally more expensive in comparison to an exposed sheet pile form of construction. In some cases, it may not be possible to drive sheet piles to a depth which will permit global stability because of dense granular type soils or high rock-head levels. Therefore, a reinforced concrete cantilever wall is an alternative form of construction when this situation occurs, see Figure 7. This form of construction is perhaps the most likely wall construction to be impacted by weather and flooding particularly the initial stages of forming the base. It is also more likely to disturb any contamination due to the large excavations required.

Figure 8, ***Reinforced concrete cantilever wall*** *(White Cart Water FPS)*

3. Carbon Footprint

Figure 9 indicates the least and most Carbon heavy forms of Flood defences. This is based on a high-level estimate of comparative whole-life carbon impacts for each flood defence type. The calculations are based on the embodied carbon dioxide (CO2e) of materials plus the CO2e associated with their transportation. It also considers personnel travel, site energy use and waste management and has been calculated using the Environment Agency's Carbon Planning Tool – version 5.5.

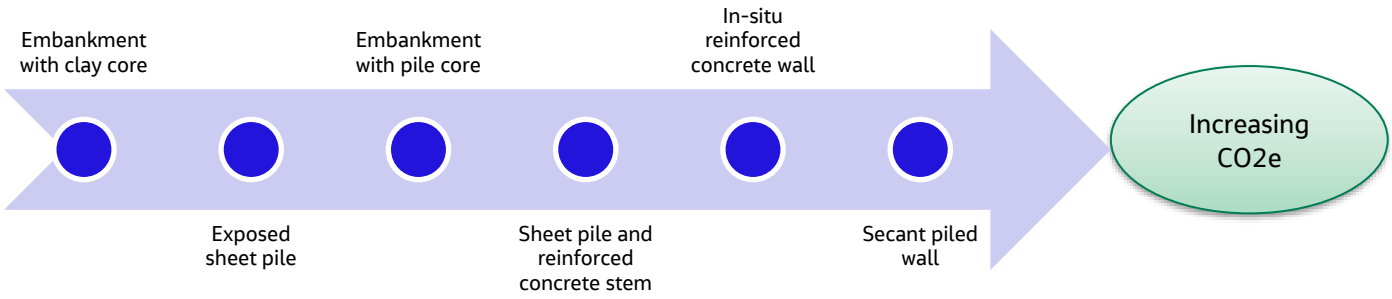

Figure 9 outlines the embodied carbon of different flood defence structures

4. Adaptability to account for climate change

4.1 Earth Embankment

Increasing the height of the embankment, would increase the spatial footprint of the embankment structure. Any change to the footprint of the embankment would need to consider local surroundings to ensure there is sufficient space to increase the embankment footprint. For some areas within the petrochemical plant site there is limited space to increase the footprint of the flood defences. An alternative method of raising would be to construct a wall (either reinforced concrete or sheet pile) on the crest of the embankment, maintaining the original footprint.

4.2 Exposed Sheet Pile Wall

The length of the pile is usually determined by ground conditions and up-stand height. Any increase in the up-stand height is likely to require the overall pile length to increase. Piles could be designed (sized) on a more extreme design scenario (which accounts for climate change) with the piles driven to the required toe level based on a future flood defence level. Increasing the height would be difficult and very expensive as individual pile extensions would need to be welded on. An alternative would be to cast a reinforced concrete pile cap and stem if this type of wall was to be raised in the future.

4.3 Sheet Pile Wall with Reinforced Concrete Stem

Like the exposed sheet piled wall, the sheet pile could be designed (sized) on a more extreme design scenario and driven initially to the required future toe level. However, the reinforcement in the stem of the wall would also need to be sized accordingly to account for any increase in height. Any future increase in height could be done by extending the reinforced concrete stem or fixing some form of steel or glass panel to the top of the original stem.

4.4 Secant Pile Wall

Like a sheet pile solution, the secant piles could be designed based on the future flood defence level with the toes of the piles bored to the depth required for the future flood defence level. The pile diameters and reinforcement would also need to be designed for the future flood defence level. Increasing the height of the reinforced stem would be like that for the sheet pile wall with reinforced concrete stem.

4.5 Reinforced Concrete Cantilever Wall

Increasing the height of a reinforced concrete cantilever wall would require the base of the wall to be sized and constructed to suit the future flood defence level. This might require a much wider base to be built which may not be possible due to space constraints.

5. Contaminated Ground

5.1 Earth Embankment

Potential for exposing and dealing with contaminated ground. Cost, time and health and safety implications. Depending on ground conditions the quantity of excavation may be small unless there are significant thicknesses of made ground present.

5.2 Exposed Sheet Pile Wall

Low risk of encountering and disturbing contaminated ground as very little excavation is required.

5.3 Sheet Pile Wall with Reinforced Concrete Stem

Reduced risk of encountering contaminated ground, but some excavation is required for the pile cap/ wall stem.

5.4 Secant Pile Wall

Reduced risk of encountering contaminated ground as some excavation required to form the concrete guide trench.

5.5 Reinforced Concrete Cantilever Stem

Potential for exposing and dealing with significant contaminated ground due to the large excavation required. Cost, time and health and safety implications.

6. Option Appraisal

The following table highlights the main advantages and disadvantages for each proposed construction method. The total cost shown is an estimate of the construction costs for building the flood defences and does not factor in the cost of preliminaries, traffic management, temporary works or utility / pipeline diversions. The cost for each construction method is based on a 1m length of flood defence at a nominal 1m high for a comparative cost estimate.

Option	Description of construction method	Key Advantages	Key Disadvantages	Estimated Total Cost (per metre)	Verdict
1	Earth Embankment	• Simple maintenance • Relatively easy to incorporate seepage cut-off if required • Low cost compared to other flood defence options unless deep seepage cut off is required • Aesthetically attractive • Low carbon option, particularly if material can be won locally and a clay core is used.	• Large construction footprint • Potential for long-term settlement depending on ground conditions • Very dependent on weather conditions for installation • Cost can increase significantly if deep seepage cut off is required • Susceptible to damage by animals • Excavation required • Regular grass cutting (maintenance) is required	• £1,714 **Other costs not included** - seepage cut-off, maintenance, flood gate / ramps, demolishing and rebuilding structures	CONSIDER – take forward to scheme design stage
2	Exposed Sheet Pile Wall	• Speed of construction • Provision of seepage cut-off incorporate in flood wall • No excavation or very small amount of excavation required, depending if the piles are above ground level • Lower cost compared to Option 3 • Lower carbon option compared to Options 1, 3, 4 & 5 • Not dependent on weather	• Risk of hitting obstructions during installation, although can be mitigated by pre-augering • Potentially higher maintenance compared to Option 3 • Requires tight tolerance on pile alignment • Requires pile clutches to be sealed/ welded • Anti-corrosion treatment required or alternatively adopt larger section	• £2,656 **Other costs not included** – maintenance, flood gate, demolishing and rebuilding structures	CONSIDER – take forward to scheme design stage

Option	Description of construction method	Key Advantages	Key Disadvantages	Estimated Total Cost (per metre)	Verdict
			size to cater for anticipated corrosion rates. • Small construction footprint		
3	Sheet pile wall with reinforced concrete stem	• Speed of construction • Provision of seepage cut-off • Low maintenance • Minimal excavation • More aesthetically pleasing than exposed piles with opportunity to clad wall stem • Can accommodate misalignment of pile installation	• Risk of hitting obstructions during installation, although can be mitigated by pre-augering • Longer construction time than Option 2 • Higher capital cost • Some parts of construction weather dependant • Small construction footprint	• £5,121 **Other costs not included** - flood gate, maintenance, demolishing and rebuilding structures, wall cladding	REJECT- Higher total cost than Options 1 & 2
4	Secant pile wall	• Durable construction • Low maintenance • Provision of seepage cut-off • Minimal vibration & noise during installation • Avoids deep excavation • Suitable for most ground conditions	• Longer construction time than Option 2 and probably Option 3 • Higher capital cost • Some parts of construction weather dependant • Small construction footprint	• £6,825 **Other costs not included** - flood gate, demolishing and rebuilding structures, wall cladding	REJECT- Higher total cost than Option 1 & 2
5	Reinforced concrete cantilever wall	• Durable construction • Low maintenance • Suitable for most ground conditions • Relatively straight forward to incorporate seepage cut off • More aesthetically pleasing than exposed piles with opportunity to clad wall stem	• Largest excavation and therefore more likely to disturb contamination and/ or existing utilities • Longer construction time than Option 2,3 and 4 and weather dependant construction	• £4,897 **Other costs not included** – seepage cut-off, maintenance, flood gate, demolishing and rebuilding structures, wall cladding	REJECT- Higher total cost than Option 1 & 2

Table 1- flood defence type options

7. Discussion

This technical note has outlined five methods of constructing flood defences within Flood Cell's 3, 5 and 6 which are all industrial areas within the scheme.

The proposed flood defence options considered are as follows:

- Earth embankment
- Steel sheet pile wall – exposed
- Steel sheet pile wall – with reinforced concrete stem
- Secant pile wall – bored piles
- Reinforced concrete cantilever wall

The construction of flood defences on land within the Port of Grangemouth and the Petrochemical Plant is challenging and there is a high degree of risk associated with constructing on land that has a long history of industrial activity. Through ground investigation work carried out to date we understand the nature and extent of ground contaminants across all three flood cells, however, there is the chance that unknown ground contaminants could be exposed. Therefore, all three cells have been classified as Yellow Category sites indicating at least some contamination if envisaged.

The option of constructing an earth embankment and or an exposed sheet pile wall solution helps mitigate the potential risks to construction personnel as both construction methods substantially reduce the amount of excavation required in comparison to a reinforced concrete cantilever wall. The exposed sheet pile wall solution will require the least excavation of all the methods.

Earth embankments need to be keyed into the existing ground, but excavation is not normally to be to any significant depth (depending on ground conditions), although this does not fully avoid the potential of encountering buried contaminants and will depend on the nature of the soil at each specific location.

Sheet pile construction requires minimal excavation and would be the preferred method of construction on ground that is potentially contaminated. The installation of a sheet piled wall would limit ground disturbance and thus reduce the potential for exposure to ground contaminants for construction personnel. The preferred form of sheet pile construction would be Option 2 – an exposed sheet pile wall in areas where the piles are not generally visible to the public. The flood defence is to be constructed within an industrialised area and an exposed sheet pile wall will not look out of place within the surrounding environment and will significantly reduce construction time and capital cost in comparison to Option 3 – A sheet pile wall with a reinforced concrete stem.

Exposed sheet pile wall construction has the lowest carbon footprint of all proposed options primarily due to the removal of all concrete. This is as expected with a singular 100% recyclable material used to construct the flood defences, speedy installation mitigating energy use of construction equipment and low maintenance requirements over its design life. The earth embankment option was shown to be the second lowest in terms of carbon output with similar advantageous to a sheet pile construction method in that materials are almost 100% recyclable; construction material can be sourced from local suppliers although due to the quantities of material required transportation demand is far greater than sheet pile wall requirements. There are potential energy requirements from maintenance of the embankment i.e. grass cutting but this can be mitigated by the use of wild seed mixes that provide natural habitat for many birds and insects and do not require regular cutting.

With space being limited within the petrochemical plant, options that require increased footprints to deal with future increases in flood level are not favoured. Therefore, the exposed sheet pile wall or the sheet pile wall with reinforced concrete stem are more appropriate in these locations. The exposed sheet pile wall will be more straight forward to adapt and involve less disruptive work than compared to the other options.

8. Recommendations

The preferred form of flood defence to be adopted in the industrial areas is the exposed sheet pile wall. This solution has many advantages over the other options, including:

1) minimal excavation and therefore minimises the risk of disturbing contaminated ground and/ or INNS;
2) can be carried out in all weather conditions avoiding the risk of downtime due to adverse weather;
3) quick form of construction and provision of flood protection as soon as piling is complete;
4) minimises the construction footprint;
5) no separate seepage cut off required;
6) aesthetics is not a significant concern given the proposed location;
7) minimal future maintenance;

One of the main disadvantages of this option is the ability to raise the flood defence height in the future. It would be difficult and time consuming to weld extensions to the piles. The only practical way of increasing the height would be to cast a concrete pile cap/ stem providing the depth of embedment was sufficient for the increased height.