Groundwater Technical Note

Lowestoft Flood Walls

Document Version: Final

Document Number: CRM72114-JAC-00-ZZZ-TN-GT-0002

Jan 2019

Document history

This document has been issued and amended as follows:

Version	Date	Description	Created by	Verified by	Approved by
0	11th January 2019	Groundwater Technical Note – Lowestoft Flood Walls	Sam Wood	Toby Gill	Laurent Cadieu

Contents

Introduction

1.1. Background

As part of the proposed Lowestoft Flood Wall Scheme, impermeable barriers, generally sheet piled walls, will be provided to limit the flow of flood water beneath the proposed flood walls. The hydraulic conductivity of these barriers will be low enough that groundwater flow which is normally discharging to the sea will be impeded. Therefore, this groundwater technical note has been undertaken to establish the risk of groundwater flooding post construction and to satisfy the requirement of a site-specific Flood Risk Assessment as detailed on page 48 of the 2008 Suffolk Coastal and Waveney District Strategic Flood Risk Assessment (SFRA).

1.2. Limitations of Groundwater Technical Note

This groundwater technical note assessment assumes that the strata has been suitably characterised by CH2M to assess groundwater flood risks and that there are no sensitive structures located in the immediate proximity of the proposed Flood Wall Scheme such as sewers or basements that would require more detailed field investigation and assessment with respect to groundwater flooding. It also assumes that the study area does not rely on infiltration drainage that may be affected by high groundwater levels.

2. Proposed Design of Flood Defences

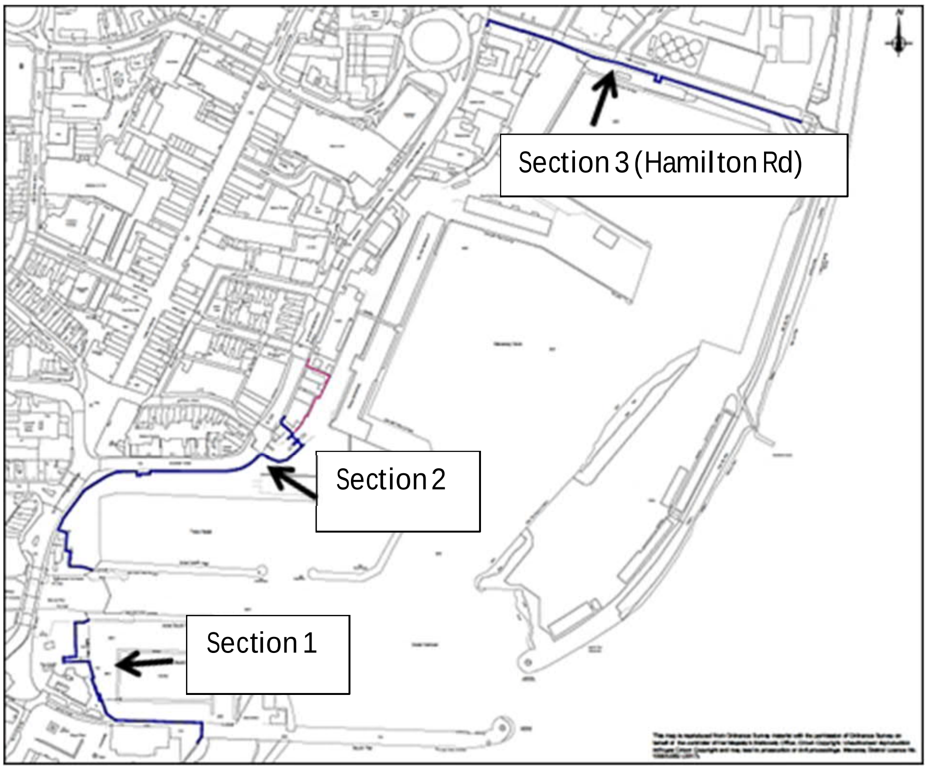
2.1. Locations and Length

The flood walls are required to link the tidal barrier structure to high grounds and existing coastal defences. The tie-in flood walls will comprise the provision of a combination of flood walls, demountable barriers and flood gates that will be up to 1.6m high subject to existing ground levels. The proposed flood walls can be split in 3 sections and are summarised in Table 2.1 and shown in in Figure 2.1.

Table 2.1: Flood Wall Descriptions and Lengths

Section	Name	Description	Proposed Length (m)
1	Southern Flood Walls	Includes Royal Norfolk and Suffolk Yacht Club to South Beach peninsula	242
2	Northern Flood walls	Located between the dock basins and the Bridge Control including flood walls (Waveney Road)	320
3	Hamilton Rd	Located to the north of Hamilton Dock along Hamilton Road	340

Figure 2.1: Flood Wall Locations



3. Existing Ground and Groundwater Conditions

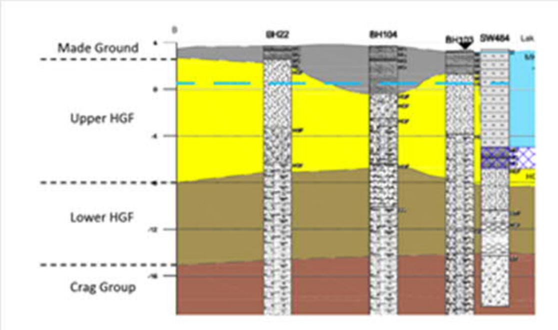
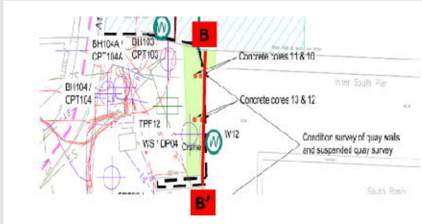
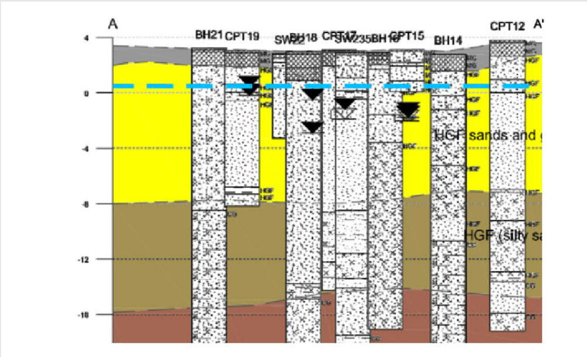
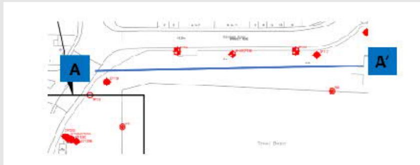
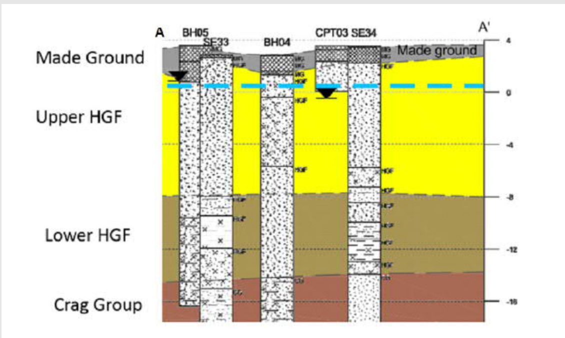
3.1. Site Geology

Made Ground across the site is of limited thickness, consisting typically of hard surfacing and subbase materials. The Made Ground is underlain by the Happisburgh Glacigenic Formation (HGF), which comprises an upper and lower layer. The upper layers consist of sands and gravels whereas the lower layer is defined by silty sands. The border between these deposits is located at approximately -8m AOD. Deposits of alluvium and Tidal River Deposits also surround the proposed flood defences. At approximately -14m AOD, the HGF deposits are underlain by the Crag Group sediments consisting of medium dense to dense sand.

Typical geological cross sections with water levels are shown in Figure 3.1.

Figure 3.1: Site Geology

Section	Name	Generalised Geological Profile	Location of Cross Section

1	Southern Flood Walls		
2	Northern Flood walls		
3	Hamilton Rd		

Note: Refer to Flow Rate Calculation Reports for further detail (see References).

3.2. Hydrogeology

The Happisburgh Glacigenic Formation is classified by the EA as a Secondary A Aquifer. These have permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifers. The Upper HGF, having a higher proportion of sands and gravels, will comprise the more permeable unit. The Crag Group is classified as a Principal Aquifer. These are layers of rock or drift deposits that have high intergranular and/or fracture permeability - meaning they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale. In most cases, principal aquifers are aquifers previously designated as major aquifer. The flow system is controlled by the alternating layers of clays, silts and sands and their contrasting permeabilities. In the vicinity of the proposed Flood Wall Scheme, the existing harbours, tidal defences, surface watercourses and variable geology creates complex set of boundary conditions. The sea is considered to be the ultimate discharge point for groundwaters in the area.

3.3. Permeability

The permeabilities of the geological units have been assessed from a mixture of grain size analysis and slug tests. Assessed permeabilities that have been used by CH2M for the design of the flood defences are summarised in Table 3.1. The HGF has a wide range in permeability values and is heterogeneous.

Table 3.2: CHM2 Assessed Permeabilities

Stratum	Aquifer Designation	Permeability m/d	
		Range	Characteristic Value
Made Ground (Sandy gravels – above 1m aod)		1 to 86	9
Upper HGF (1 to -8m aod)	Secondary A Aquifer	0.01 to 86	1
Lower HGF (-8 to -14m aod)		0.1 to 9E-06	As range
Crag Group (below -14m aod)	Principal Aquifer	0.001 to 1	0.01

3.4. Groundwater Monitoring

The 2016 ground investigation and post fieldwork monitoring by White Young Green generally recorded groundwater strikes and monitoring levels between 0.5maod and 1.0maod through the winter flood season from October 2016 to April 2017, typically occurring in the upper HGF sand layer along the northern floodwall and in the Made Ground along the southern floodwall (between October 2016 to April 2017, groundwater levels were generally 2 to 3.6m bgl). The groundwater levels recorded did not vary significantly across the monitoring period, generally within 0.5m. There was no evidence of large widespread groundwater fluctuations that could cause clearwater flooding i.e. water rising above the land surface in a response to extreme rainfall.

There is only a minor lag difference of up to 1 hour between peak tide level (hydraulic conductivity with the North Sea) and peak groundwater level which indicates that the strata is relatively high permeability, and there is a quick but not instantaneous response in groundwater levels particularly during flood events (which is constituent with a water table as opposed to a confined aquifer).

Groundwater flow except where influence by shallow structures and drainage, would be expected to be broadly parallel to the coast. Therefore, Sections 1 and 2 are likely to broadly parallel, and Section 3 perpendicular to the direction of regional groundwater flow (refer to Figure 2.1).

3.5. Regional Hydraulic Gradient

The regional hydraulic gradient at the coast, the ultimate discharge point for shallow groundwaters would be expected to be very flat (typically <<0.5%).

3.6. Groundwater Flooding

Groundwater flooding is assumed a secondary risk in the catchment (Broadlands Rivers Catchment Flood Management Plan, 2009). The predominant risk to flooding in Lowestoft is tidal. We understand that there is no anecdotal evidence for groundwater flooding.

3.7. Topographic Considerations

The topographic profile of Section 2 (northern area) from high ground falling seaward will promote groundwater flows in an easterly direction. Sheet piling in this area may have the greatest potential to affect the natural flow of groundwater and land drainage. However, in Section 1 (southern area), the topography profile is reversed with the land reducing in elevation from the coast to the Kirkley river valley and there is the potential for groundwater flow/saline intrusion from the coast inland.

4. Impermeable Barrier Design

4.1. Types of Impermeable Barrier

Steel sheet piles (SSP) will be used to limit the flow of flood water beneath the above-ground floodwall structures. Alternative seepage barrier techniques might be used near sensitive structures / services. This might take the form of continuous flight auger (CFA) piling with grout curtain or intersecting secant piling. Therefore, it is possible that some flow may leak through the barrier in such locations.

4.2. Proposed Depth

The toe level of the impermeable barriers has been assessed by using Plaxis 2D and Seep/W models. This has been modelled under steady state conditions to suit stability in accordance Eurocode 7 and limit seepage rates underneath the flood walls for the design high tide conditions (I in 200 years including climate change for the design life of 100years). A toe level of -5.2mAOD or typically 8.5m below ground level has been recommended

4.3. Seepage Rates through Steel Sheet Piles

The steel sheet piles themselves are completely impermeable and therefore the only potential pathway for groundwater to pass through the SSP is via the interlocks. The interlocks are used to connect the individual sheet pile to form a continuous wall. During installation, each sheet pile is guided laterally by the interlock (clutch) of the previously driven sheet pile. A small amount of leakage through the clutches can be expected.

4.4. Steel Sheet Pile Design

The SSP are required to avoid hydraulic failure behind the walls and to minimize localised flooding from seepage during a tidal surge event. However, as a full seepage cut-off will not be provided, groundwater flows will continue across the proposed structure albeit delayed in time. Selected design elements of the floodwall relevant to groundwater flooding are summarised in Table 4.1 (as taken from the Technical Notes in the References). It is proposed that the new SSP will be located adjacent to 70% of the Upper HGF (it is not proposed to install sheet piles to the base of the less permeable Upper HGF.). The existing SSP in the Southern section are located adjacent to only 47% of the Upper HGF.

Table 1.1 Key Steel Sheet Pile Design Parameters

Design Element (dry side of the floodwall where applicable)	Elevation/Thickness (m aod)				
	Section 1 – Southern Flood Walls		Section 2 – Northern Flood Walls	Section 3 - Hamilton Road	
	CH0 to CH30	CH70 to CH130	CH0 to CH260	CH 0 to 120m	CH 120 – 300m
Elevation of Existing Ground Level at dry side of the floodwall	+3.00m aod		+2.80m aod	+3.60m aod	3.10m aod
Elevation of groundwater level on the dry	+0.5	N/A (assumed +3.00m aod)	+0.5m aod	+0.5m aod	+0.5m aod

side of the floodwall					
Unsaturated zone thickness (dry side)	2.5m	0	2.3m	3.1m	2.6m
Base of Made Ground	+1.35m aod	1.35m aod	+0.9m aod	+0.8m aod	+1.30m aod
Floodwall toe elevation (% of Upper HGF piled)	-5.20m (70%)	-3.0m aod (47% - Existing structure)	-5.20m (69%)	-5.20m (68%)	-5.20m (70%)
Base of Upper HGF	-8m aod				-7.9m aod

5. Potential Up-gradient Impact of Steel Sheet Piles on Groundwater Flow and Groundwater Flooding

5.1. Potential Upgradient Impact of Steel Sheet Piles

Underground obstacles to groundwater flow, such as SSP, modify the groundwater flow because the structure partially reduces the aquifer section. Thus, effective transmissivity is reduced, leading to a rise in the water table upgradient and a lowering downgradient. These modifications of the water table can have negative consequences and potentially, it could have two impacts on groundwater flows:

- Impede the flow of groundwater with head increases close to the structure; and/or
- Impact the groundwater budget of the flow system with head increases over long distances

The risks of impeding groundwater flow and causing rising water levels upgradient include damage to buildings by flooding of lower levels. Other impacts associated with the rise in heads include reduction of the bearing capacity of shallow foundations, expansion of heavily compacted fills under foundation structures, settlement of poorly compacted fills on wetting, corrosion of foundations, increase in the need for drainage in temporary excavations, slope stability issues, damage to services and propagation of contaminants contained in the partially saturated zone.

5.2. Qualitative Assessment of Steel Sheet Piles on Groundwater Flooding

The concern is that the hydrostatic barrier effect of the SSP will cause an increase in head upgradient of the barrier due to the loss of transmissivity induced by the underground construction and may cause groundwater flooding. Any increase in head upgradient of the SSP post construction is however considered to be small given that:

- Groundwater levels are typically greater than 2 to 3.6m bgl, therefore small changes in groundwater level because of the SSP would not immediately result in increased groundwater flooding risk.
- Extensive barriers, including the harbour wall and associated structures (refer to Figure 2.1 and References), already exists along the study area. Therefore, conceptually, it is unlikely that the complex hydrogeological regime at the coast will be significantly changed - the SSP will simply form yet another barrier with limited cumulative impact on groundwater levels (the SSP does not fully penetrate the Upper HGF).
- The SSP does not form a very long linear structure (e.g. cuttings for roads railways and tunnels for example) and sit within with low permeability strata where significant effects of barrier systems on groundwater levels have typically been proven.
- The SSP do not form watershed-scale barriers to groundwater flow. The HGF in which they are installed, outcrop in a much wider area. Groundwater flows will naturally find alternative path of least resistance through the ground at tie-in points, interlocks connecting the sheet piles or behind the proposed flood defences along Lake Lothing. Therefore, the SSP, are unlikely to significantly disturb the mass balance of the groundwater flow system.
- The impact/flow across the sheet piling is partially dependent upon the difference in hydraulic head across the sheet pile (in combination with the total height of the sheet piling and characteristics of the soils in which the sheet pile is driven). Given that the regional gradient at the coast will be very low combined with relatively permeable Upper HGF, any impact on upgradient heads is also likely to be low (and groundwater flows will naturally find alternative path of least resistance).
- The HGF are relatively permeable and from the monitoring undertaken, there is a lack of significant groundwater level fluctuations in response to rainfall. This implies that there is reasonable available storage and that any local impact of the structure is likely to result in nominal head changes under steady state conditions.

Furthermore:

- Section 3 is likely to be perpendicular to the coast/regional groundwater flow direction and have a limited impact on the existing groundwater regime.
- The sheet piles will increase the tidal lag, i.e. delay the rise in groundwater levels inland caused by the tide and hence help further reduce the potential for increased groundwater levels particularly during tidal flood events.
- In Section 1 (Southern Area) the topography profile is reversed with the land reducing in elevation from the coast to the Kirkley river valley and there is the potential for groundwater flow from the coast inland. Therefore, increases in groundwater levels in this setting would seem unlikely.

5.3. Requirement for Analytical and Numerical Analysis

Analytical solutions are not readily available since the barrier effect problem has not been adequately formalised. Whilst it is possible to use the existing SEEP/W models to undertake transient analysis, there is some uncertainty whether the model assumptions are applicable to the site. Flow around barriers however could be modelled with numerical models, but to achieve reasonable accuracy requires fine grid near the barrier and extremely fine spacing where flow curls around the end of a barrier. However, given the complex boundary conditions and low sensitivity of the site to groundwater flooding, numerical modelling is not deemed necessary to substantiate the level of risks associated with the proposed seepage barrier on groundwater flow. If further confidence is required/sensitive structures identified and further assessment required, it would be more practical to undertake groundwater monitoring and if appropriate undertake corrective actions to allow groundwater to pass through or bypass the SSP.

6 Conclusions

Post construction of the SSP, whilst impacts localised to the SSP in the short term may occur before steady state conditions are established, it is likely that the risk of widespread groundwater flooding will remain low and be unaffected by the proposed works. If further confidence or assessment of sensitive structures is identified, groundwater monitoring and if appropriate, mitigation measures, should be considered as part of the SSP design.

7 References

- E-mail from Cadieu, Laurent/UKP dated 6th December 2018
- Jacobs. November 2018. Flood Risk Assessment. Lowestoft Flood Walls and Barrier
- Jacobs. November 2018. Technical Note: Flow Rate Calculations. Hamilton Road. CH0 to CH320.
- Jacobs. November 2018. Technical Note: Flow Rate Calculations. Tie-In with Barrier Works. CH0 to CH30
- Jacobs. November 2018. Technical Note: Flow Rate Calculations. Yacht Club CH70 to CH130
- Jacobs. November 2018. Technical Note: Flow Rate Calculations. Waveney Road CH0 to CH260
- WYG. January 2017. Ground Investigation Factual Report.