Stonehaven Flood Protection Scheme - Seepage and Piping Analysis

Final Report

November 2014

Aberdeenshire Council
Carlton House
Arduthie Road
Stonehaven AB39 2DP

JBA Project Manager

René Dobson
1 Longcraig Road
Port Neuk
South Queensferry
Edinburgh
EH30 9TD

Revision History

Revision Ref / Date Issued	Amendments	Issued to
Initial Draft 3/4/2014	Modification following technical review by Ulisse Pizzi	Rene Dobson
Draft Report	Alex Jones addressed comments from Mark McMillan and Stephen Farrar	Stephen Farrar

Contract

This report describes work commissioned by Willie Murdoch, on behalf of Aberdeenshire Council. By a letter dated 14 March 2013. Aberdeenshire Council's representative for the contract was Rachel Kennedy. Alex Jones, Ulisse Pizzi of JBA Consulting carried out this work.

Prepared by ....Alex Jones BSc MSc

Analyst (Hydrogeologist)

Reviewed by ....Michael McDonald PhD, MSc, BSc

Principal Hydrogeologist

Mark McMillan MEng

Engineer

Approved by..Rene Dobson BEng CEng MICE

Principal Engineer

Purpose

This document has been prepared as a Final Report for Aberdeenshire Council. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

JBA Consulting has no liability regarding the use of this report except to JBA Consulting.

Copyright

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of if 100% post-consumer recycled paper is used and if primary-source paper is used. These figures assume the report is printed in black and white on A4 paper and in duplex.

JBA is aiming to reduce its per capita carbon emissions.

Contents

List of Figures

List of Tables

1 Introduction

1.1 Introduction

The proposed Flood Protection Scheme (FPS) in Stonehaven is designed to mitigate flooding from the River Carron and Glaslaw Burn through the use of direct defences (flood walls and embankments) to increase flow capacity within the river channel. This will increase peak water levels within the river channel by confining flows behind flood walls and create a hydraulic gradient between the wet side and dry side of the proposed defences. In this situation it may be possible for ground water to be forced under the flood defences and surface on the dry side, creating an additional flood risk.

The purpose of this report is to detail the methodology and the results of seepage and piping analysis carried out at 14 cross sections along the length of the proposed defences based on the proposed flood wall designs. . For this seepage analysis, the SEEP/W v8 (Geostudio, 2012) software package has been utilised.

The locations of the cross sections modelled are shown in Appendix D.

1.2 Sources of Information

The table below outlines the sources of information used within the assessment.

Table 1-1: Sources of Information

Topic	Sources of Information
Geology	BGS Digital 1:50,000 Mapping BGS Online Borehole Archive Costain Environmental Services, January 2014. Stonehaven River Carron & Burn of Glaslaw Flood Alleviation Scheme - Ground Investigation; Factual Report on Ground Investigation
Topography	Ordnance Survey 1:50,000 and 1:10,000 maps, digital editions.
Surface Waters	Ordnance Survey 1:50,000 and 1:10,000 maps, digital editions. http://www.sepa.org.uk/data/classification/index.htm SEPA Flood Map available at http://map.sepa.org.uk/floodmap/map.htm Stonehaven River Carron Flood Alleviation Study, JBA Consulting, September 2011 Stonehaven River Carron and Glaslaw Burn Preferred Flood Protection Scheme, November 2013, JBA Consulting
Groundwater	Brassington, R., 2007. Field Hydrogeology. Third Edition, The Geological Field Guide Series, Wiley, 264pp Costain Environmental Services, January 2014. Stonehaven River Carron & Burn of Glaslaw Flood Alleviation Scheme - Ground Investigation; Factual Report on Ground Investigation Macdonald, A. M., Ball, D. F., Dochartaigh, B. E., 2004. A GIS of aquifer productivity in Scotland: explanatory notes. British Geological Survey Commissioned Report. CR/04/047N. 21pp.
Piping Analysis	Robin Fell, Patrick MacGregor, David Stapledon, Graeme Bell (2005), Geotechnical Engineering of Dams, CRC Press

2 Baseline Description

2.1 Hydrology

There are two watercourses within the study area. The River Carron forms the main river through the centre Stonehaven, with the Glaslaw Burn as a tributary from the south with its confluence at approximately NGR 387091, 785654.

2.2 Topography

The flood plain of the River Carron is relatively flat and varies from approximately 50m wide in the west to 300m wide near the White Bridge. Downstream of White Bridge the valley joins a narrow coastal plain which extends north of The River Carron. The floodplain of the Glaslaw Burn is approximately a uniform width of 100m. At the edge of the floodplains the ground rises steeply.

2.3 Geology

The following table is a summary of the general geology in the location. The main sources of information used to inform the descriptions and thicknesses are also indicated.

Table 2-1: Summary of Geology

Age	Unit	Descriptions	Thickness	Location
Quaternary	Made Ground	Variable - ranging from Tarmac to sandy gravelly deposits(2)	Up to 3.2m	Widely present in the east and west of the study area
	Alluvium	Highly variable - a mixture of sands and gravels, sand and silt, and silt and clay deposits.(2)	Over 10m in places. Thinnest in west	50m wide strip along Carron Water and Burn of Glaslaw
	River Terrace Deposits	Likely to be similar to the alluvium(1)	Over 10m in places.	On the floodplain outside the belt of alluvium
	Raised Marine Deposits	Sands and gravels(1)	Unknown	Occurs in a 200m wide band from the coastline (where alluvium not present)
	Glacio-Fluvial Sands and Gravels	Sands and gravels(1)		On the edge of the valley sides in the west of stone haven
	Till (Mill of Forest Till Formation)	Sandy diamicton, red-brown with clasts(1)		On the slopes surrounding the floodplain
Wenlock Epoch — Ludlow Epoch	Carron Sandstone Formation	Course to Medium Grained Sandstone(2)	Unknown	Beneath the site - regularly encountered within boreholes
Sources: BGS 1 to 50k digital mapping (1), Costain (2014)(2)				

2.3.1 Superficial Geology

BGS online 1:50:000 mapping indicates that the proposed flood defences are located within a belt of alluvium. River Terrace Deposits are mapped across the remainder of the flood plain, as indicated by SEPA's Indicative Fluvial Flood Map. LIDAR data for the area indicates that there is no topographical difference, or step between the alluvium and River Terrace Deposits suggesting that they may potentially be one unit.

Where the floodplain widens out to the coast, the river terrace deposits are replaced by Raised Marine deposits which are described as being sand and gravel in nature (BGS online). Within the study area, these appear to extend from the coast up to the Bridgefield Bridge.

Till and Glacio-fluvial deposits line the valley sides on the edge of the floodplain. The BGS online borehole archive has no available borehole logs to confirm the local nature of these deposits.

2.3.2 Bedrock Geology

The study area is underlain by the Carron Sandstone Formation. Borehole Logs (Costain 2014) describe it as a course to medium grained Sandstone. Within the site investigation (Costain 2014) it is regularly encountered along Carron Water between 3.5mbgl (BH11a) and 9mbgl (BH9). Downstream of the White Bridge bedrock was not encountered in the site investigation, suggesting that the rock head lies deeper beneath the surface towards the coast.

2.4 Hydrogeology

The hydrogeological units on the site and in the surrounding area are summarised in Table 2-2.

An aquifer is a layer of permeable sediment or rock (such as sand or sandstone) that can store and transmit a significant quantity of water (e.g. to a well or spring). In contrast, an aquitard is a low permeability layer (such as silt or clay) that allows only very slow seepage of water.

The bedrock has been classified as a moderately productive aquifer and the groundwater flow within it is dominated by intergranular and fracture flow (BGS 2004).

The superficial deposits within the floodplain and coastal plain along the line of the proposed flood defences, (which include the Alluvium, River Terrace Deposits and Raised Marine Deposits) are in general highly variable in nature comprising more permeable sands and gravel layers and lower permeability silts and clay units. The results of the ground investigation[1] suggest that there is very limited lateral continuity to the units. This means that the groundwater flow patterns within the superficial deposits in the floodplain is likely to be complex. For example groundwater flow could be concentrated in continuous high permeability units which are dissected by the river channels.

Table 2-2: Summary of Hydrogeology

Unit	Descriptions	Thickness	Location	Hydrogeology
Made Ground	Variable - ranging from Tarmac to sandy gravelly deposits[(4)]	Up to 3.2m	Widely present in the east and west of the study area	Aquifer/Aquitard Permeability is be highly variable due to the highly variable nature of this unit
Alluvium	Highly variable - a mixture of sands and gravels, sand and silt, and silt and clay deposits.[(4)]	Over 10m in places. Thinnest in the west	50m wide strip along Carron Water and Burn of Glaslaw	Aquifer/Aquitard Permeability variable due to the highly variable nature of this deposit.
River Terrace Deposits	Likely to be similar to the alluvium	Likely to be similar to the alluvium	On the floodplain outside the belt of alluvium	Aquifer/Aquitard Permeability variable due to the highly variable nature of this deposit.
Raised Marine Deposits	Sands and gravels[(1)]	Unknown	Occurs in a 200m wide band from the coastline (where alluvium not present)	Aquifer/Aquitard Permeability is likely to be relatively high
Glacio-Fluvial Sands	Sands and gravels[(1)]	Unknown	On the edge	Aquifer/Aquitard

[1] Factual report on Ground Investigation: Stonehaven River Carron & Burn of Glaslaw Flood Alleviation Scheme - Ground Investigation, Costain Environmental Services, January 2014

Unit	Descriptions	Thickness	Location	Hydrogeology
and Gravels			of the valley sides in the west of stone haven	Permeability is likely to be relatively high
Till (Mill of Forest Till Formation)	Sandy diamicton, red-brown with clasts	Unknown	On the slopes surrounding the floodplain	Aquifer/Aquitard Permeability is likely to be low to moderate.
Carron Sandstone Formation	Course to Medium Grained Sandstone[4]	Unknown	Beneath the site - regularly encountered within boreholes along	Aquifer/Aquitard Moderate Productivity - Fracture/ intergranular flow dominated (BGS 2004)
Sources: BGS 1 to 50k digital mapping[1] , Costain (2014)[4]				

Limited in-situ permeability testing was carried out during the, Costain (2014), investigation comprising 6 falling head tests in individual boreholes. However, where this was done the monitoring installations comprised slotted sections which extended across a range of soil types and therefore these tests provide only "bulk" permeability estimates rather than formation specific information.

3 Seepage Analysis

Modelling has been undertaken in order to provide indicative estimates of groundwater flow and seepage rates through the proposed FPS based on current outline designs

Numerical seepage modelling was carried out using GEO-SLOPE SEEP/W which uses a finite element approach to solving the differential equations describing water flow through porous media. The analysis is undertaken by defining regions through typical cross-sections that define the strata in each location. Borehole log data from the Costain 2014 site investigation has been used to develop likely geological profiles along sections of the flood defence scheme to support the numerical modelling.

3.1 Model Geometry and Layering

A model section was developed at a number of locations throughout the proposed FPS. The location of these sections was determined to include different elements of the proposed scheme in close proximity to boreholes recorded as part of the ground investigations. The modelled sections are shown in Appendix D and their location described in Table 3-1. Appendix A shows the geometry of each section.

Table 3-1: Seepage Section Locations

Section	Location
Section 1	Carron Terrace Upstream of Green Bride (LHB)
Section 2	Upstream of White Bridge (RHB)
Section 3	Cameron Street Upstream of White Bridge (LHB)
Section 4	Between White Bridge and Bridgefield Bridge (LHB)
Section 5	Between White Bridge and Bridgefield Bridge (RHB)
Section 6	Salmon Lane Downstream of Bridgefield Bridge (LHB)
Section 7	Downstream of Woodview Court (LHB)
Section 8	Upstream of Woodview Court (LHB)
Section 9	Upstream of Woodview Court (RHB)
Section 10	Upstream of Green Bridge (RHB)

Section	Location
Section 11	Carron Terrance Between Green Bridge and White Bridge
Section 12	Carron Gardens Upstream of Section 8 (LHB)
Section 13	Carron Gardens Upstream of Section 12 (RHB)
Section 14	Between Red Bridge and Green Bridge (RHB)

The geometry of the cross sectional models is based on a series of cross-sections which are typical representation the proposed flood defences (Appendix A). The design of the flood defences varies along their length with some defences formed from bunds and other walls. The distance to the river channel also varies with some defences set on the river bank and other set further back.

The model vertical layering of the stratigraphy shown in the model geometries in Appendix A are based on the ground investigation records[2].

It should be noted that the ground investigation data indicates a relatively complex and variable sequence of superficial deposits along the length of the proposed defences and therefore simplifying assumptions have been made as follows:

- The site stratigraphy has been divided into five basic layer types with differing material properties: made ground; sand & gravel; sand and silts; silts and clays; and, bedrock;
- An average groundwater level has been selected based on monitoring data. In reality, it is likely that a number of perched aquifers and variable water table conditions exist within the superficial deposits based upon the contrasting permeability of the various materials present; and,
- Depending upon the location and depth of intrusive locations surrounding the cross sections, the stratigraphy developed may be based upon aggregation of a number of surrounding borehole locations, rather than use of data from a single borehole. The source of the information used to derive the stratigraphy is detailed within in Appendix B.

3.2 Model Hydrogeological Properties

SEEP/W requires certain hydrogeological properties of the strata to be defined. These are the horizontal hydraulic conductivities (K), the total porosity (n), the Specific Yield (Sy) and the residual water content, calculated based on porosity and specific yield. Where a layer will remain saturated through modelling scenarios the residual water content and specific yield do not need to be defined. The majority of hydrogeological properties used within the models have been estimated from the descriptions of the materials given in the borehole logs (Appendix A) and published literature[3]. These have been cross checked where possible within in-situ testing presented within the factual ground investigation report also taking into account the limitations of these tests as highlighted above[4]. The hydrogeological properties assigned to the models for each stratigraphic layer are presented in the tables in Appendix B.

3.3 Model Simulated Scenarios

For each cross section, the following scenarios were simulated:

- Steady state: modelling a typical steady state (baseline) situation, and,
- Transient state: modelling groundwater levels through a flood event with a return period of 200 years

The 200 year hydrograph for each section were derived from the hydraulic model of the proposed FPS. This was modelled in InfoWorks RS as a 1D unsteady state model (JBA

[2] Factual report on Ground Investigation: Stonehaven River Carron & Burn of Glaslaw Flood Alleviation Scheme - Ground Investigation, Costain Environmental Services, January 2014

[3] Brassington, R., 2007. Field Hydrogeology. Third Edition, The Geological Field Guide Series, Wiley, 264pp

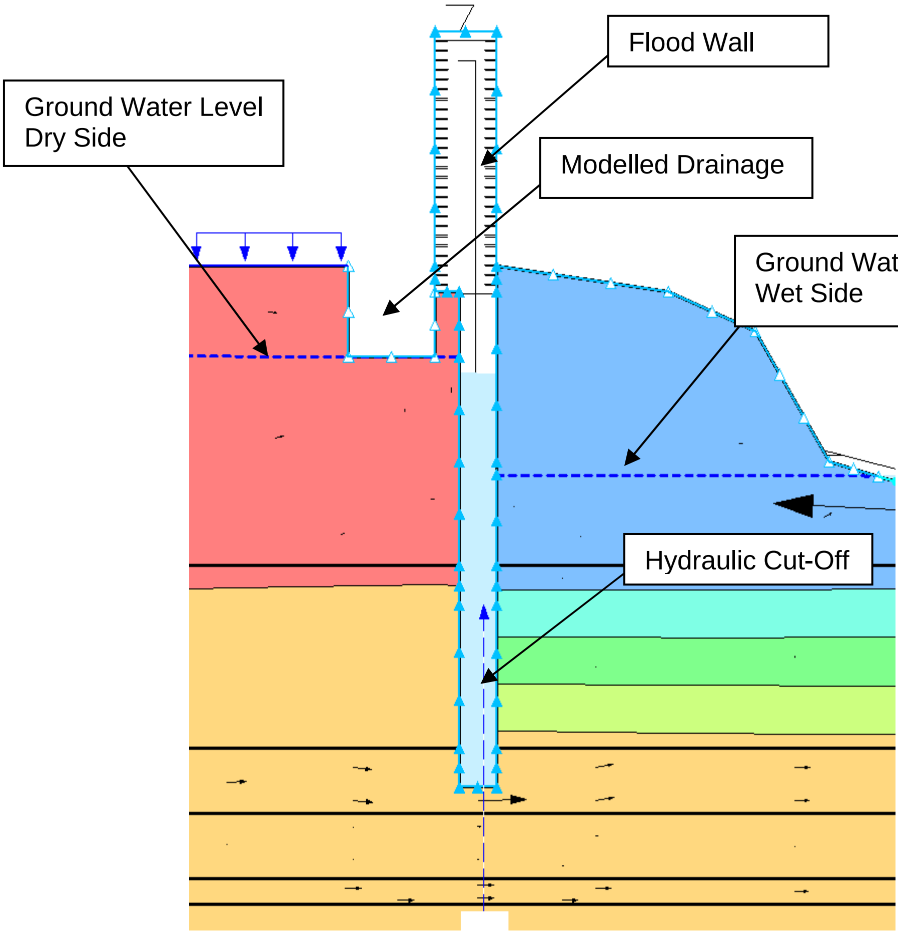
[4] Costain Environmental Services, January 2014. Stonehaven River Carron & Burn of Glaslaw Flood Alleviation Scheme - Ground Investigation; Factual Report on Ground Investigation.

Consulting 2011[5] and 2013[6]). In addition, the models were run with a range of hydraulic cut-off depths to identify optimal flood defence geometries that would result in:

- No piping conditions occurring within both the steady state and transient model; and,
- No groundwater flooding under the flood defences occurred during the period over which the transient model was run.

In a number of steady state models scenarios, deepening the hydraulic cut-off raised groundwater levels such that the water table breached the surface on the landward (dry) side of the proposed defences. In these situations a drainage system was added to the model. This took the form of a drain set 0.7m below the ground surface immediately behind the flood defences (see Figure 3-1). The drains were operational for the steady state models but were assumed not to be operational during flood events as a traditional gravity sewer would be unable to discharge during a flood event.

Figure 3-1: Example of a drainage system added to a flood defence.



Additional scenarios were also simulated for Sections 3, 4, 5, and 6. These sections have been identified as being susceptible to erosion. Therefore, to replicate these two scenarios the following were considered:

- Scour - in these models the bed of the river was lowered by 2.4m.
- Rock Armour - in this scenario the bed was maintained at the current elevation as the bed was protected from scour. The rock armour has not been added to these models as a hydrogeological unit because it has been assumed that it would have negligible impact upon flows and hydraulic gradients. The rock armour model thus also represents a pre-scour erosion scenario.

[5] Stonehaven River Carron Flood Alleviation Study, JBA Consulting, September 2011

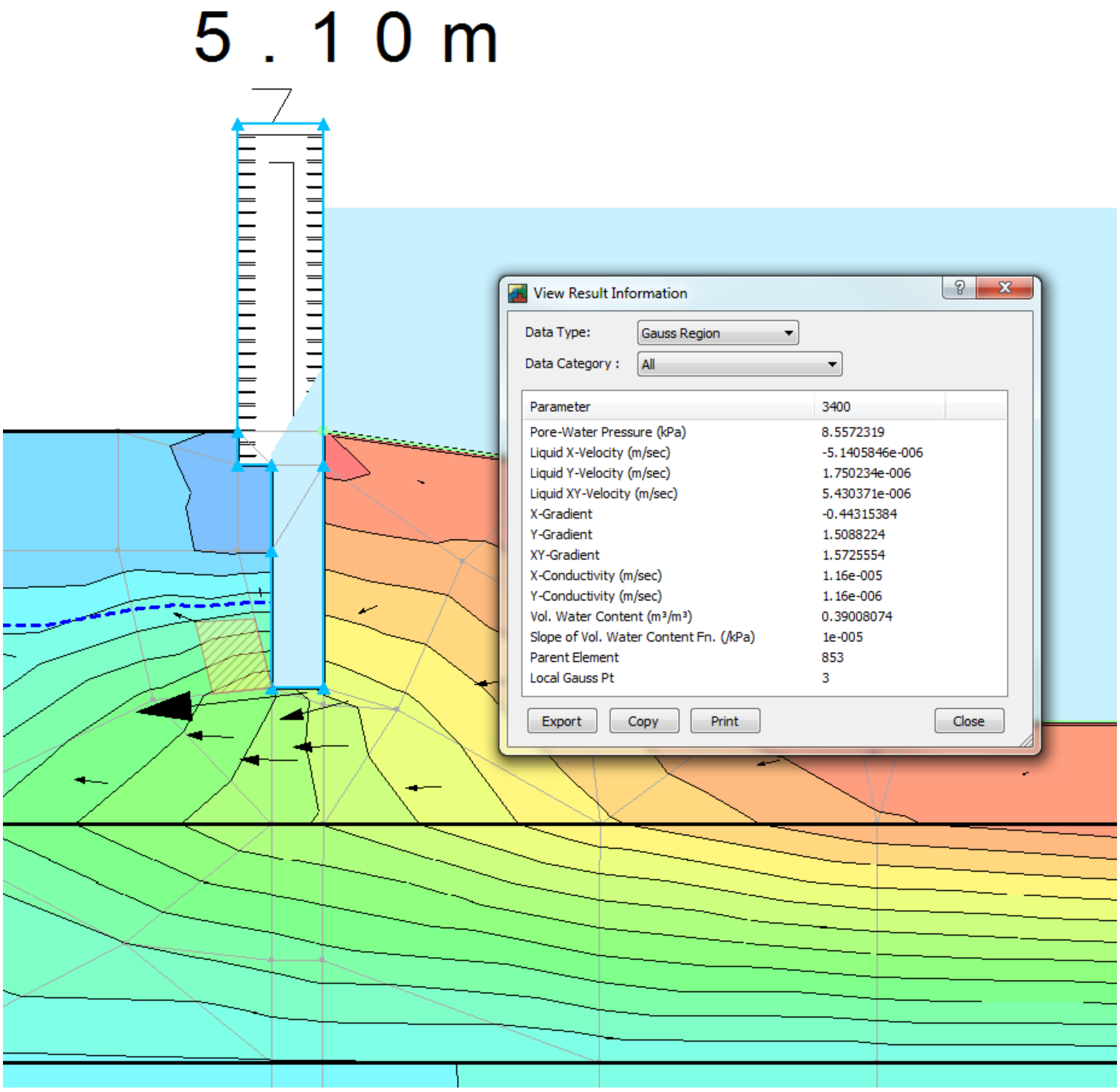
[6] Stonehaven River Carron and Glaslaw Burn Preferred Flood Protection Scheme, November 2013, JBA Consulting

Both scenarios were modelled as a deeper channel created by scouring, created a deeper bank through which greater flows of groundwater within flood events can propagate. The scour scenarios are thus more likely to require hydraulic cut-off or deeper hydraulic cut-offs

3.3.1 Piping Analysis

Piping can occur where the vertical hydraulic gradient underneath the flood defence is equal to or greater than 1. The SEEP/W models can be interrogated to ascertain the vertical hydraulic gradient in each element of the model.

Figure 3-2: Example of Model Element Interrogation to identify vertical (y) hydraulic gradient



An additional analytical analysis has been conducted for the steady state conditions. In this analysis, the vertical hydraulic gradient is calculated using the following equation:

$$i_e = \frac{H}{2D}$$

Where

i_e = exit gradient

H = head loss between the area up gradient and down gradient of the flood defence

D = depth of the hydraulic cut-off

A factor of safety of 4 was applied (based on Fell et al. 2005), and the piping conditions were checked verifying the following condition:

$$\frac{2D}{H} > 4$$

In some situations where the river channel was some distance from the line of the hydraulic cut-off, the equations used in the analysis are not appropriate as the point of groundwater exit was too distant from the piling (Section 9 and 13). In these situations the SEEP/w model was only used to assess the potential for piping. The results are presented in Appendix E.

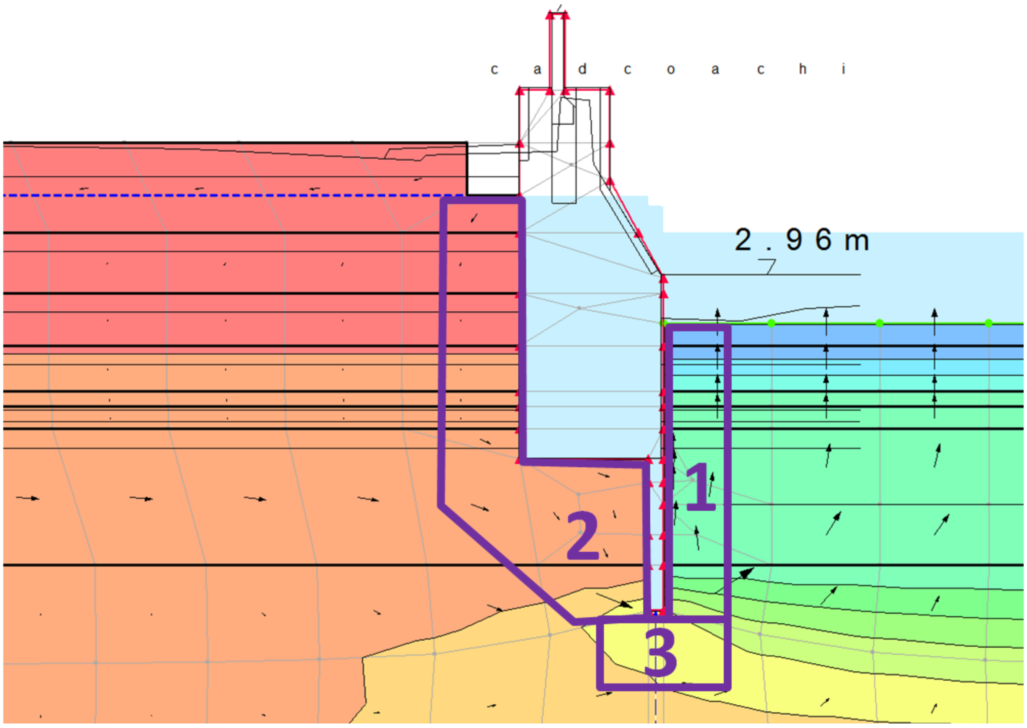
This analysis has not been conducted for the transient scenarios as hydraulic equilibrium, either side of the piles, does not form in the period of the flood event. This means that the analytical equations are not valid.

3.3.2 Model Results

The results of the modelled scenarios are presented in tabular form in Appendix C. It presents results for the steady state and transient analysis under the following headings:

- Piping Conditions,
- Does the SEEP/W analysis show a y-gradient greater than 1 (or close to 1 for an extended period) within the model - Yes or No.
- Groundwater flooding,
- Does the model suggest that in a flood event there would be groundwater flooding - Yes or No (i.e. does the transient model show the groundwater levels rise above ground level on the landward side during a flood event?)
- Calculated flow rate under the sheet pile (or structure without piling) (m^3/s).
- Gradient on river side face of piling,
- SEEP/W model is interrogated along the river side face of the flood defence to identify the highest y-gradient value (see Zone 1 in Figure 3-2)
- Where the y-gradient is negative, this is noted but a value not presented.
- Gradient on bank side of piling,
- SEEP/W model is interrogated along the bank side face of the flood defence to identify the highest y-gradient value (see Zone 2 in Figure 3-2)
- Where the y-gradient is negative, this is noted but a value not presented.
- Toe of piling hydraulic gradient,
- SEEP/W model is interrogated across the base of the flood defence to identify the highest y-gradient value (see Zone 3 in Figure 3-2)
- Where the y-gradient is negative, this is recorded.
- Length of sheet piling/defence from the ground surface (m),
- Total length of the flood defence from the ground surface (measured from the bank side) used within the model scenario
- Base of the piling (mAOD),
- The base of the piling/ flood defence in metres Above Ordinance Datum (mAOD) in the modelled scenario.
- Drainage required,
- Notes if drainage is required on the bank side as a result of the flood defence raising groundwater levels above ground surface, through blocking groundwater flows.
- Drainage is modelled in scenarios requiring it, by creating a drain on the bank side of the flood defence which intercepts groundwater from 0 to 0.7mbgl

Figure 3-2: Diagram showing Y-Gradient Measurement Zone



In most model runs, not all elements of the tables in Appendix C are completed. This is because at different stages in the analysis process, a flood defence geometry can be proven to be unsuitable. At that stage the analysis was stopped.

3.4 Limitations

The main limitations of the SEEP/W models surround the uncertainty in the model geometry and variation in the stratigraphy of the floodplain, the key impacts of which are:

- The narrow valley floor at some cross section locations means that the model is unlikely to be an accurate representation of the stratigraphy of the cross section, especially where the distance from the flood defence increases.
- The stratigraphic units identified in borehole locations may not extend horizontally beneath the flood defence and as such the piles may not in reality key into the units modelled.
- The strata described within the boreholes may not represent the material lining the channel of the river.
- The nature of the river bed material might retard or increase groundwater flows out of the river during a flood event.

It addition to these limitations, the analysis represents a 2D situation at various positions along the length of the proposed defences. The stratigraphy in the area is known to be laterally variable and therefore close to the line of the modelled cross section the geology may produce different seepage fluxes and piping conditions.

Another significant limitation is that only very limited site specific hydrogeological testing data were available. As such, the majority of hydrogeological properties used within the model have been derived from published values[7] rather than site specific data, which in general was not appropriate for assessment of actual permeability values in the soils present along the river channel.

[7] Brassington, R., 2007. Field Hydrogeology. Third Edition, The Geological Field Guide Series, Wiley, 264pp

4 Results

Table 4-1 gives a summary of the results showing the recommended depth of the hydraulic cut-off (piling) and whether drainage will be required. Appendix C outlines the results of each model run.

Table 4-1: Summary of Results

SECTION ID	Length of sheet pile/defence from ground surface (m)	Base of piling (mAOD)	Drainage Required	Scenarios
Section 1	4	4.6	Yes	
Section 2	2.9	2.2	No	
Section 3	6.2	-1.5	Yes	Rock Armour
Section 3	7.2	-2.5	Yes	Scour
Section 4	6.3	-2.5	Yes	Scour
Section 4	4.6	-0.8	Yes	Rock Armour
Section 5	3.5	-0.8	Yes	Rock Armour
Section 5	4.5	-1.8	Yes	Scour
Section 6	5.5	-2.2	Yes	Scour
Section 6	3.6	-0.7	Yes	Rock Armour
Section 7	1.2	7.4	No	
Section 8	5.5	3.3	Yes	
Section 9	1.1	7.9	No	
Section 10	3.1	5.2	No	
Section 11	4.1	0.8	No	
Section 12	2.6	6.8	Yes	
Section 13	0.8	9.5	No	Pile through bund
Section 14	4	4.5	No	

4.1 Section Commentary

The results for certain sections require some additional commentary and discussion.

4.1.1 Section 8

The analysis for Section 8 showed an unusual situation. The flood defence in this section is set approximately 2m from the edge of the channel. During the transient model on the rising limb of the hydrograph (i.e. development of flood conditions), the model shows water flowing out of the river and groundwater table rising against the river side face of the piling (see Figure 4-1). This causes a vertical hydraulic gradient of more than 1 to form against the river side face of the piling. Given the location of this high vertical hydraulic gradient, increasing piling length is not an effective mitigation measure.

However, further analysis of the SEEP model has shown that the high vertical hydraulic gradients that develop on the river side are associated with a relatively low permeability sandy gravel clay layer, which serve to restrict flow. Excavating this material from the front of the piles and replacing it with a higher permeability fill in the form of a drainage blanket or sheet would reduce the hydraulic gradient as shown in

Figure 4-2.

Figure 4-1: Transient Model Run of Section 8

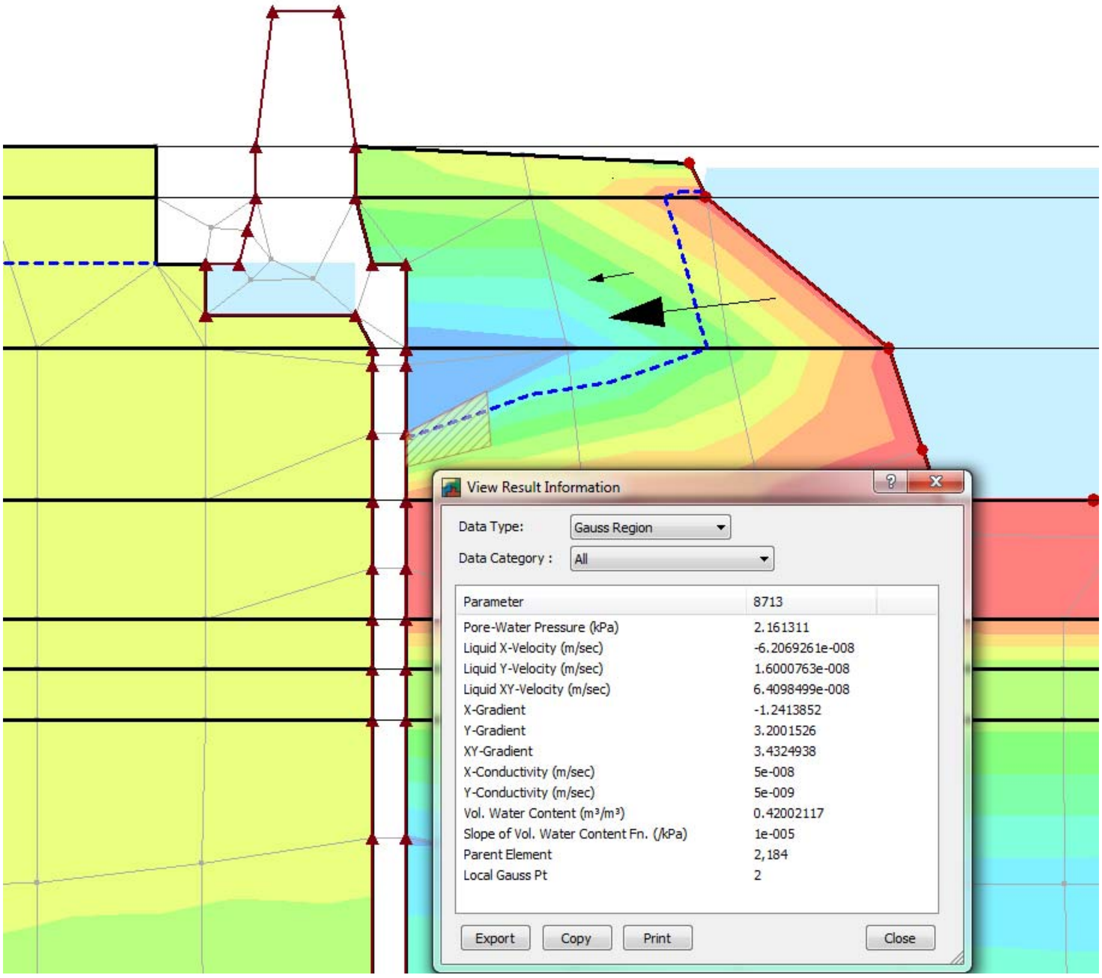
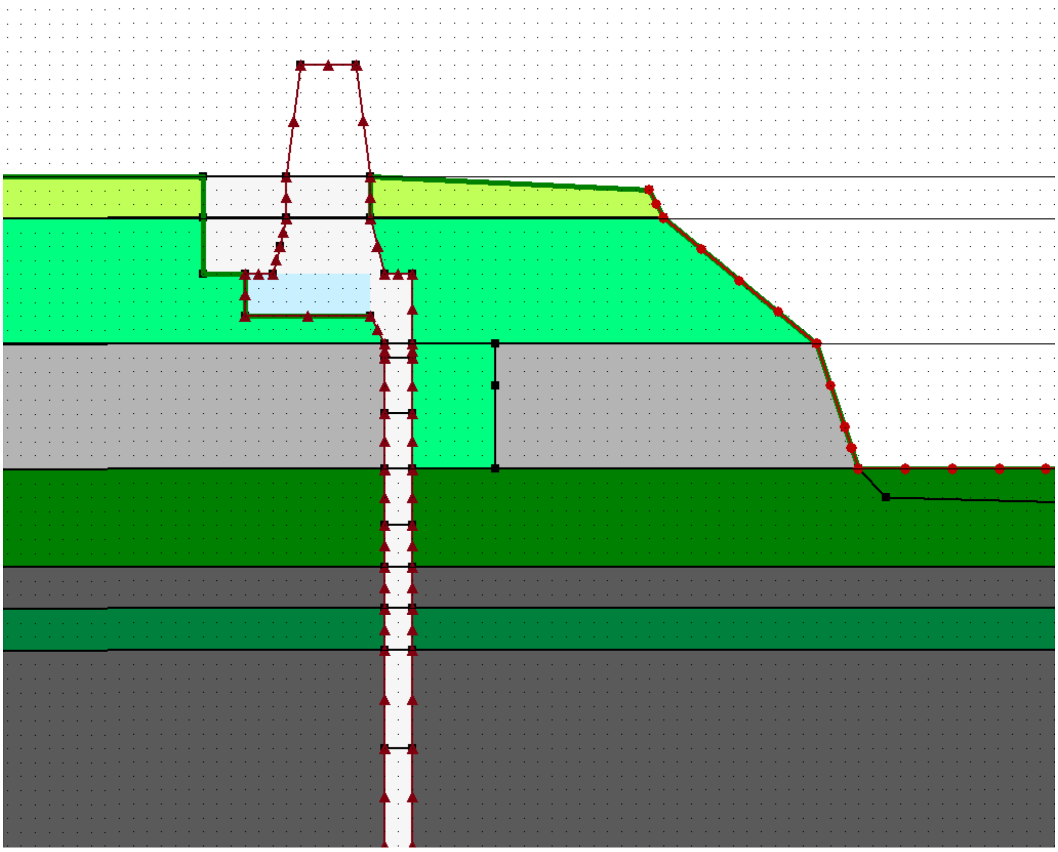


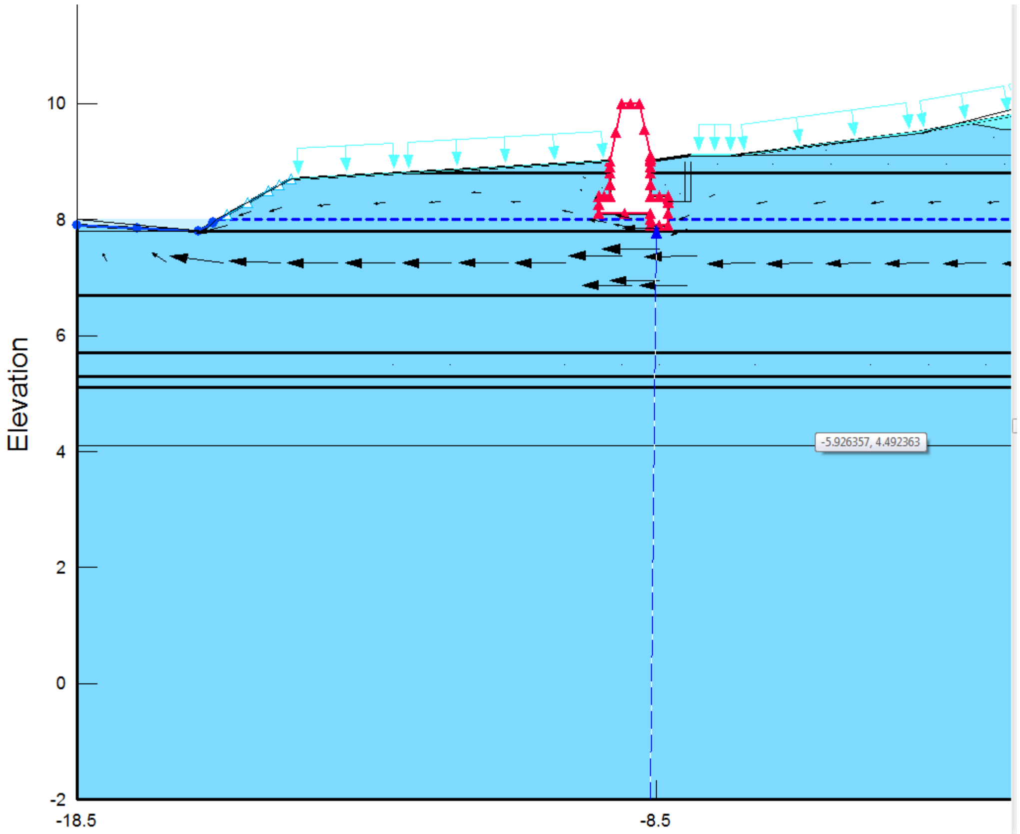
Figure 4-2: Geometry of High Permeability Fill Model



4.1.2 Sections 9 and 13

In Section 9 and 13, the river is relatively distant from the flood defences. In these two sections only relatively shallow flood defences are required. As such the base of the flood defences are above the bed of the river. In this situation the equation used analytical analysis, presented in Section 3.3.1, are not appropriate as the discharge point is some distance from the flood defence. For both sections, as the flood defences are not deep, the difference in hydraulic head either side is negligible (see Figure 4-3).

Figure 4-3: Section 9 Steady State Model



4.1.3 Section 11

At Section 11, a buried relic flood defence wall runs parallel with the proposed line of the hydraulic cut-off of the flood defence. There are two current unknowns related to this buried wall:

- The hydrogeological properties of the wall and its impact on groundwater movement,
- The geometry of the wall in relation to the piling (e.g. will the piles go through the wall, will there be a gap between the piles and the wall, and if there is a gap, how large will it be?).

Conservative assumptions have been made in relation to assessing piping conditions for this section. The conditions most conducive for creating piping would be where in a flood groundwater flows were focused into a narrow gap between the wall and piles. As a result, it has been assumed that the wall is effectively impermeable and a gap of 20cm has been modelled. With these model parameters, scenarios show that piling would lead to piping conditions in this gap for the 3.1m long piling scenario (see Figure 4-4 and Appendix C).

Further analysis has shown that removing the toe of the wall such that there is 0.5m gap between the piling and the wall appear to be sufficient to reduce the vertical hydraulic gradient within the gap (see Figure 4-5). An alternative solution would be to offset the line of the flood wall by a similar distance such that there is a wider zone to allow for flow of groundwater between the buried wall and the pile faces.

Figure 4-4: Section 11 Transient Model showing flows funnelled through the gap between the relic wall and piling

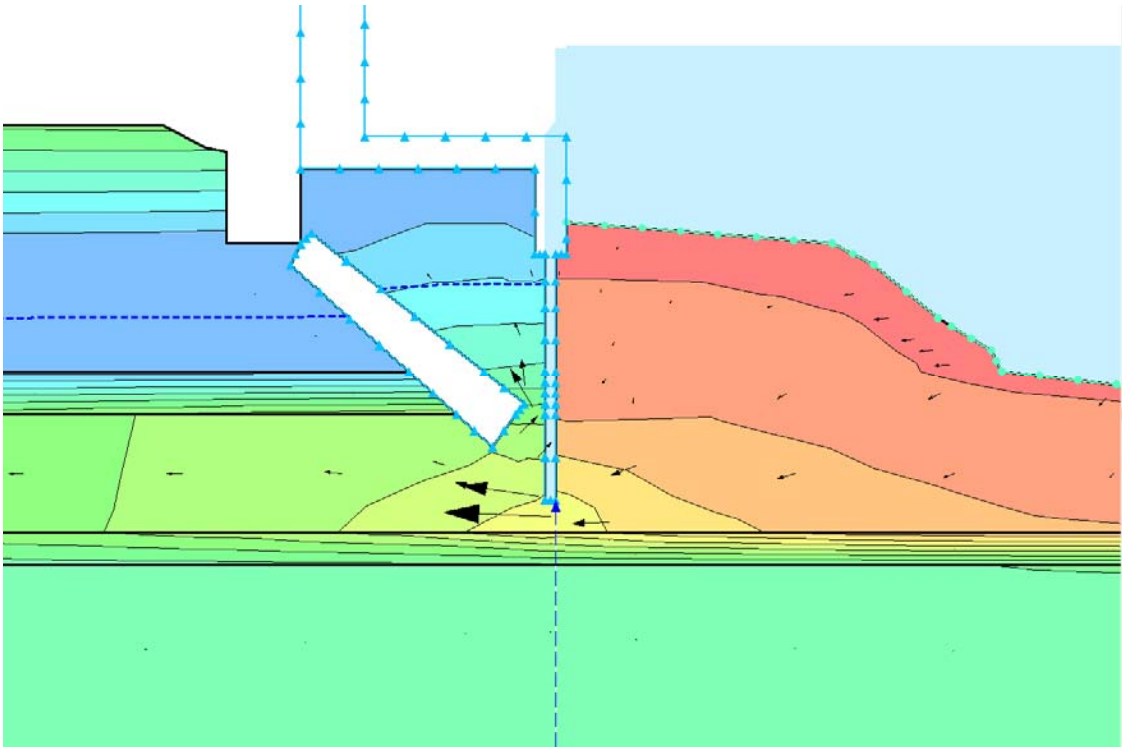
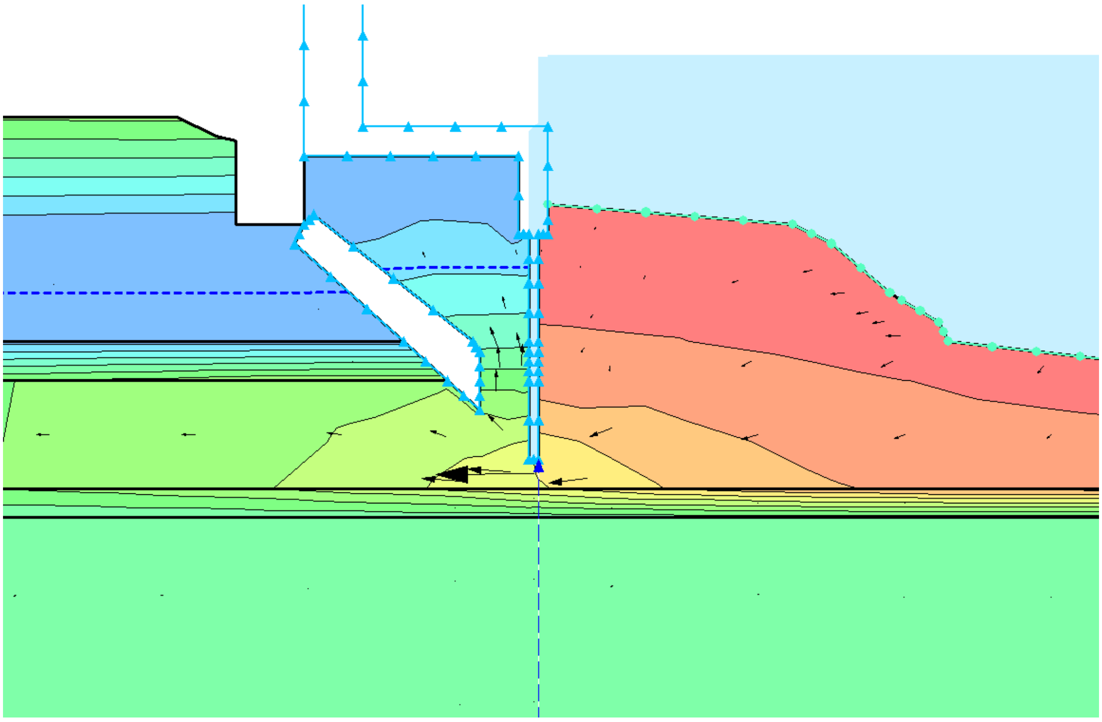


Figure 4-5: Section 11 Transient Model showing flows funnelled through a 0.5m wide gap between the relic wall and piling



Since the running of the model the geometry of the above ground elements of the flood defence have been reconfigured. The location of the piling will however be approximately the same. It is therefore assumed that the results of the current model hold true for the new arrangement.

5 Conclusions and Recommendations

The following section presents the overall conclusions of the seepage and piping analysis and highlights where further work is required.

5.1 Summary of Findings by Reach

Table 5-1summarises the results of the modelling by reach and bank. The variable nature of the geology (evidenced through review of ground investigation data) means that few general patterns emerge and modelled conditions are generally specific to the locations selected. However, the following is noted:

- The Glaslaw Burn reach in general has relatively short hydraulic cut-offs, however Section 8 has a modelled cut-off of 5.5m. This is due to the ground investigation in the vicinity of this section indicating a high proportion of more permeable materials which allows for greater flow of groundwater.
- The three sections upstream of the Green Bridge all have a similar length of cut-offs. Despite the bedrock being shallowest in this area, no modelled cut-offs extend into rock head.
- Where rock armour is used, the depth of the cut-offs required reduces compared to the scour scenario.
- Downstream of the Green Bridge, there is a significant range of piling requirements between 2.9mbgl and 7.3 mbgl (or 6.3mbgl if the scour scenarios are excluded).
- In the majority of locations, the recommended depth of piling is controlled by the requirement to limit piping (i.e. groundwater flooding is limited with less piling than it takes to control piping).

Table 5-1: Conclusions

Reach	Bank	Section ID	Length of Cutoff Required (m)	Base of piling (mAOD)	Drainage Required	Scenarios
Upstream of Green Bridge	Right	Section 14	4	4.5	No	
		Section 10	3.1	5.2	No	
	Left	Section 1	4	4.6	Yes	
Glaslaw Burn	Right	Section 7	1.2	7.4	No	
		Section 9	1.1	7.9	No	
	Left	Section 13	0.8	9.5	No	Pile through bund
		Section 12	2.6	6.8	Yes	
		Section 8	5.5	3.3	Yes	
		Section 7	1.2	7.4	No	
Green Bridge to White Bridge	Right	Section 2	2.9	2.2	No	
	Left	Section 11	4.1	0.8	No	
		Section 3	6.2	-1.5	Yes	Rock Armour
		Section 3	7.2	-2.5	Yes	Scour
White Bridge to Bridgefield Bridge	Right	Section 5	3.5	-0.8	Yes	Rock Armour
		Section 5	4.5	-1.8	Yes	Scour

	Left	Section 4	4.6	-0.8	Yes	Rock Armour
		Section 4	6.3	-2.5	Yes	Scour
Downstream of Bridgefield Bridge	Right	Section 6	5.5	-2.2	Yes	Scour

5.2 Findings in Relation to Flood Defence Geometry

The geometry of the flood defences vary along the scheme, with two main variables:

- The presence of either walls or bunds (or a combination of both); and,
- Distance from the channel, either:
    - On the channel bank (e.g. Section 3),
    - Slightly set back (e.g. Section 1),
    - Set back a significant distance (e.g. Section 2).

In broad terms the flood defences which comprise walls located on the banks of the channel require deeper piles for two reasons:

- Under steady state conditions, the exit groundwater gradients from the base of the piling to the channel bed are highest; and,
- In transient flooding conditions, there the less material for the flood water to propagate through to reach the base of the cut-offs.

However, there are three exceptions to this general pattern:

- Section 8 is located slightly away from the channel but requires relatively deep piling because of the deeper inferred higher permeability deposits in this area, which allows groundwater to quickly propagate through in flood conditions (see Section 4.1.1). This means that the recommended piling depth is relatively deep (5.5mbgl) for this section even though it is located slightly away from the channel banks.
- Section 11 has particular piping conditions created by the presence of a buried wall (see Section 4.1.3). This means that the recommended piling depth at this section is relatively deep (4.2mbgl) given its position relative to the channel banks.
- The model at Section 12 has a relatively thick low permeability unit close to the surface. The piles key into this layer and therefore the recommended piling (2.6mbgl) is significantly less than other "wall" sections on the banks of the channel.

5.3 Drainage Requirement Calculations

During normal conditions, where the hydraulic gradient is from the land towards the river, the construction of hydraulic cut-offs through the use of sheet piles which intersect the water table will reduce the transmissivity (defined as the thickness of saturated aquifer multiplied by the permeability of the aquifer) beneath the structure, such that it will lead to a rising of groundwater levels on the landward side (i.e. the hydraulic cut-off can act to reduce base flow input into the river which could lead to groundwater flooding if not addressed through additional drainage measures).

The SEEP/W models created give an indication where the cut-offs could limit groundwater base flow into the river and therefore where drainage mitigation is likely to be required. Given the variable nature of the superficial deposits and the variation in the depth of the required cut-offs, there is no clear spatial pattern showing where base flow mitigation drainage will and will not be required. It is therefore recommended that base flow migration drainage capacity be extended along the whole of the proposed length of the flood defences to account for the natural variability and set at such a height that it will maintain similar groundwater levels within the floodplain to the pre-defence conditions.

It should be noted that the model used is not appropriate for specifying the rate of groundwater flow to the drains for a flood situation. Therefore, additional assessment to quantify the potential base flow contribution along the flood defence reaches is required. This could involve a water budget analysis to determine the likely base flow inputs along the flood defence reach.

5.4 Recommendations

Modelling has indicated that a number of sections of the proposed flood defence structure are more susceptible to potential piping of soils, which would lead to a loss of overall ground stability. These conditions typically occur in locations which are adjacent to river channels. A key variable in determining whether or not piping is likely to occur is the permeability of the soils towards the base of the sheet pile.

Given the inherent variability of the soils demonstrated through site investigation and the assumptions that have been made in the modelling it is recommended that additional, targeted hydrogeological investigations are undertaken in those areas which may be more susceptible to piping in order to confirm local ground conditions. The investigations should involve a combination of:

- Detailed logging of soil types through the full depth of the proposed piles including geotechnical testing to obtain information on the physical properties of soils;
- Monitoring of local groundwater conditions and levels; and,
- Determination of the hydraulic characteristics of the soils towards the planned base of the piles through a combination of in-situ and laboratory permeability tests.

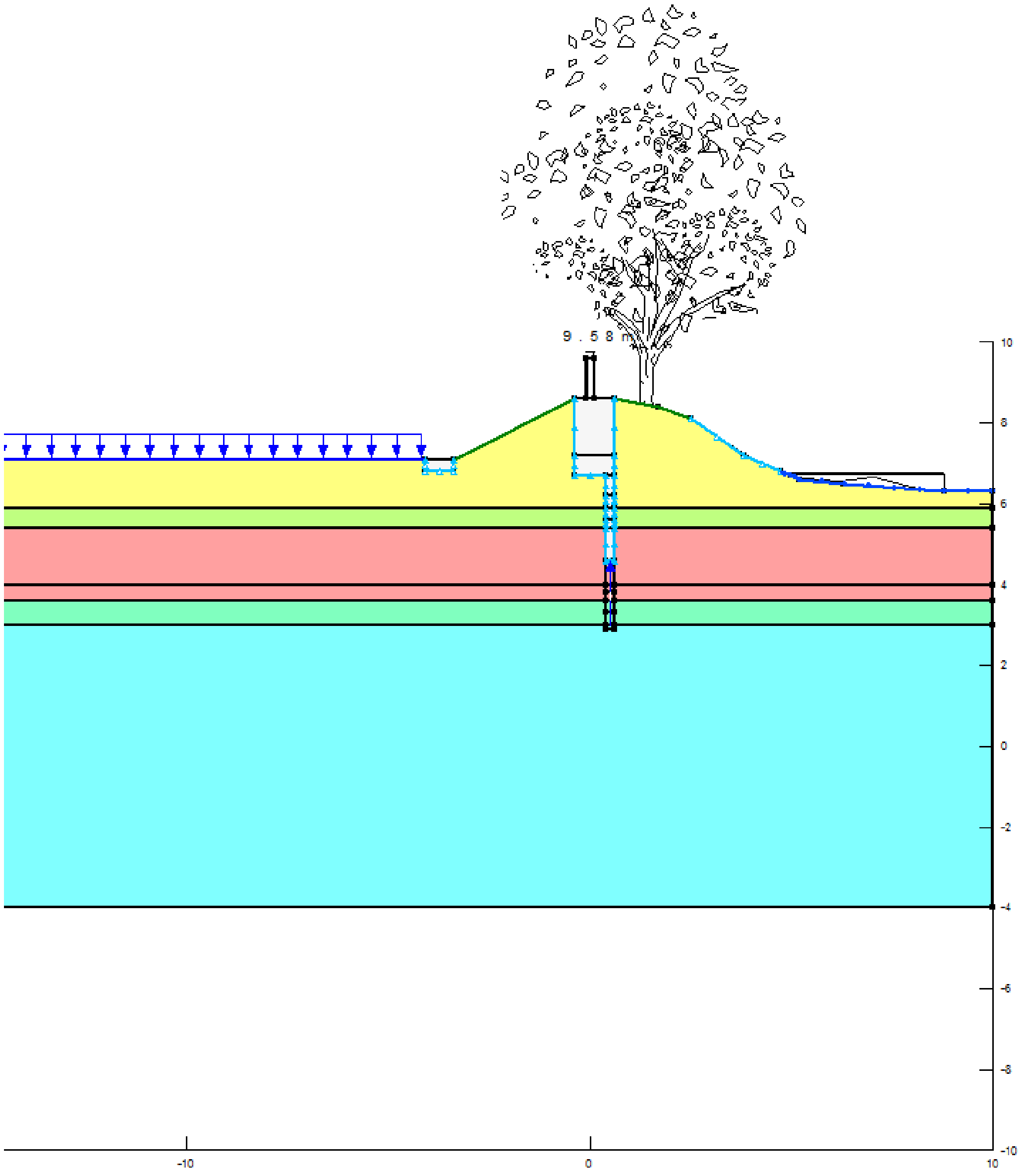
An alternative to further investigation would be to make conservative assumptions regarding the piling requirements in these areas and provide a "worse case" pile design to deal with potential piping of soils.

In addition, it is also recommended that further assessment of the base flow contribution to flow into the river channel is undertaken to determine the sizing and placement of drains which would need to be installed to prevent groundwater flooding caused by installation of the sheet piles.

Appendices

A Model Geometry

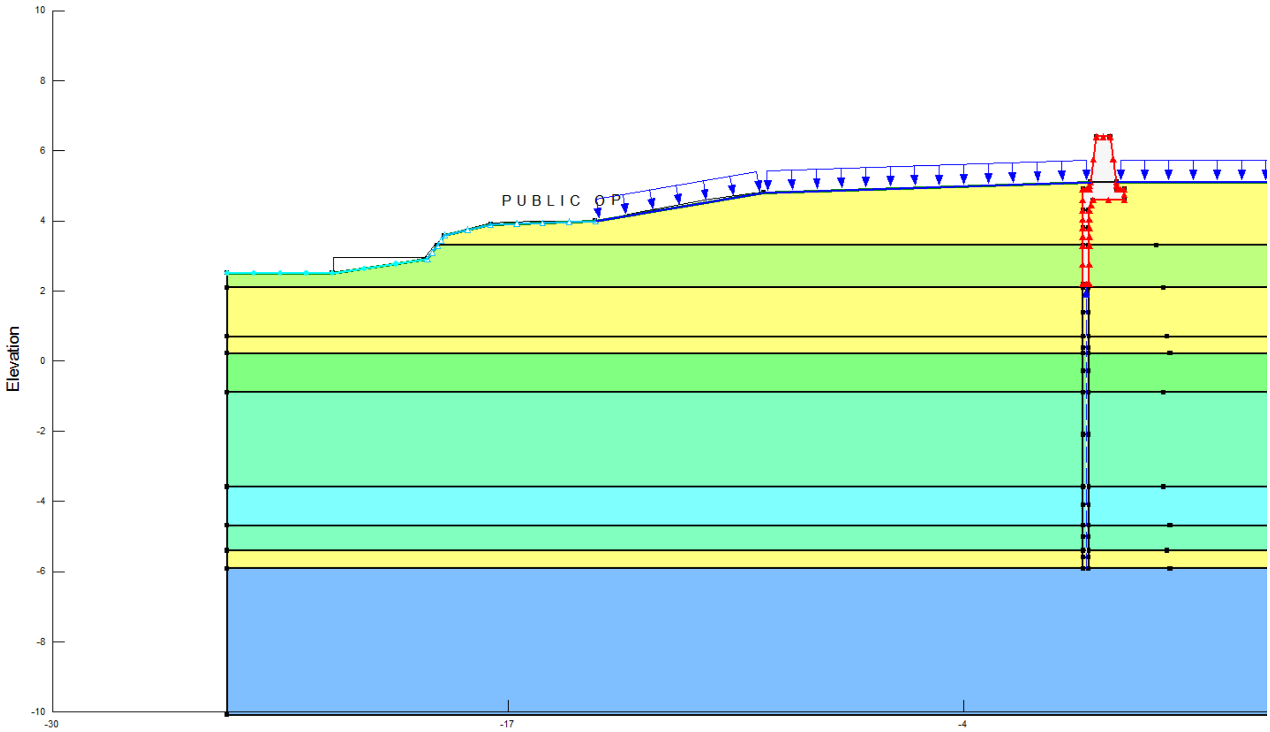
Figure A 1: Geometry of Section 1



Materials

Name	Color
1-mg gravelly sand	
2-snady silt	
3-gravelly sand	
4-clayey sandy gravel	
5-sandstone	

Figure A 2: Geometry of Section 2



Materials

Name	Color
1, 3 and 8- gravelly sand	
2- sandy silt	
4- sandy gravel	
5 and 7- sandy, gravelly clay	
6- clay gravelly sand	
9 sandstone	

Figure A 3: Geometry of Section 3 - Rock Armour Scenario

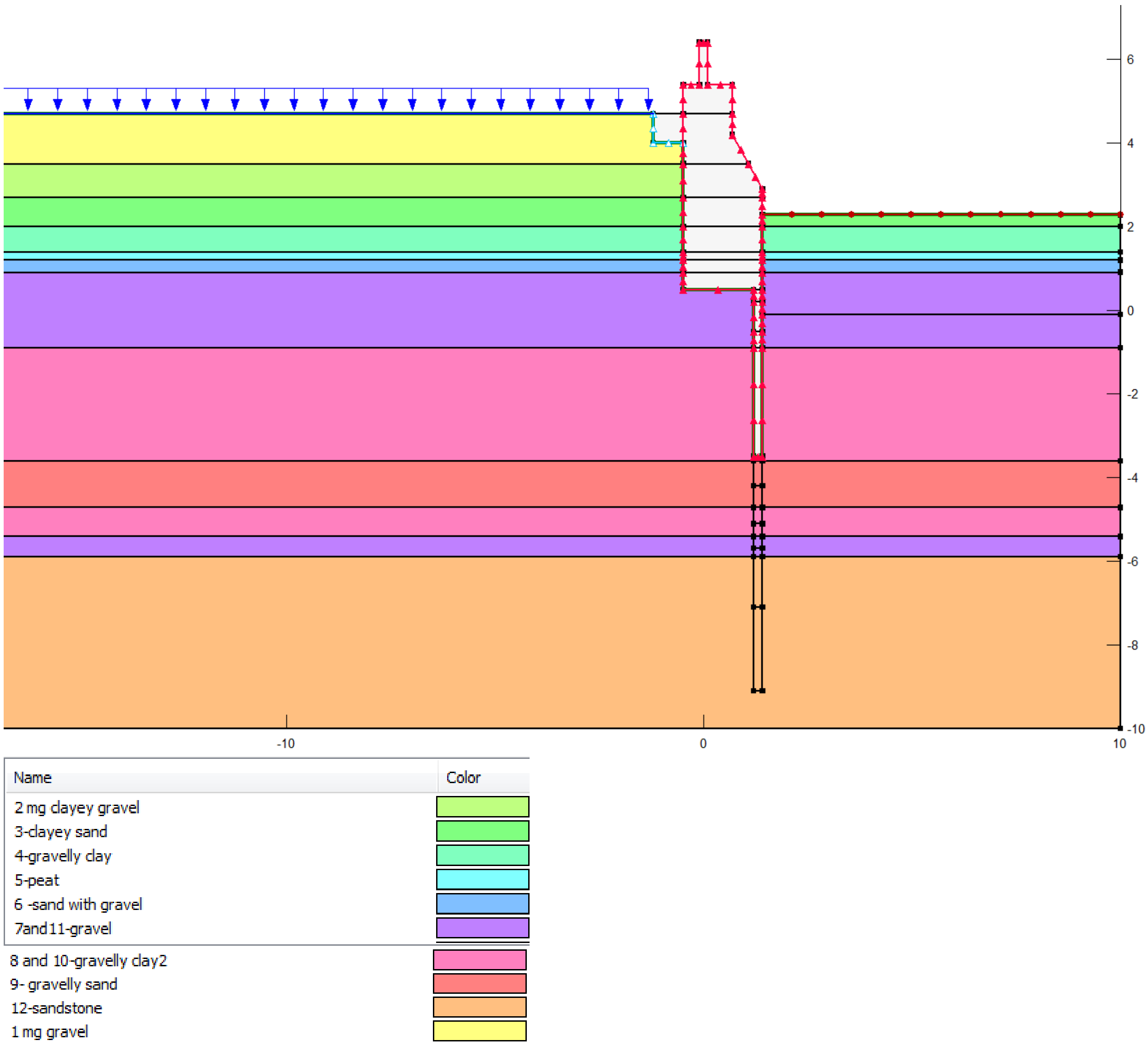


Figure A 4: Geometry of Section 3 - Scour Scenario

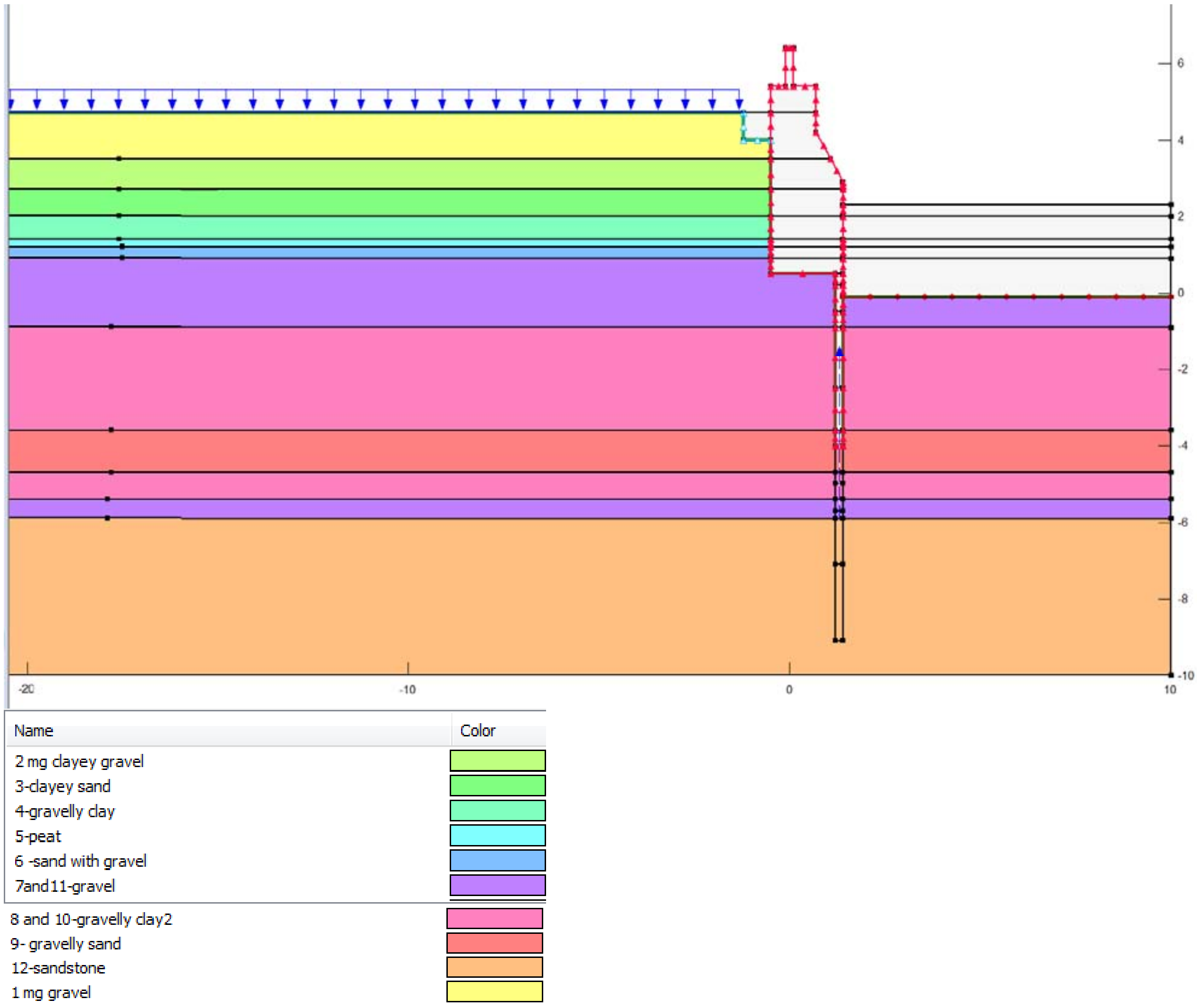


Figure A 5: Geometry of Section 4 - Rock Armour Scenario

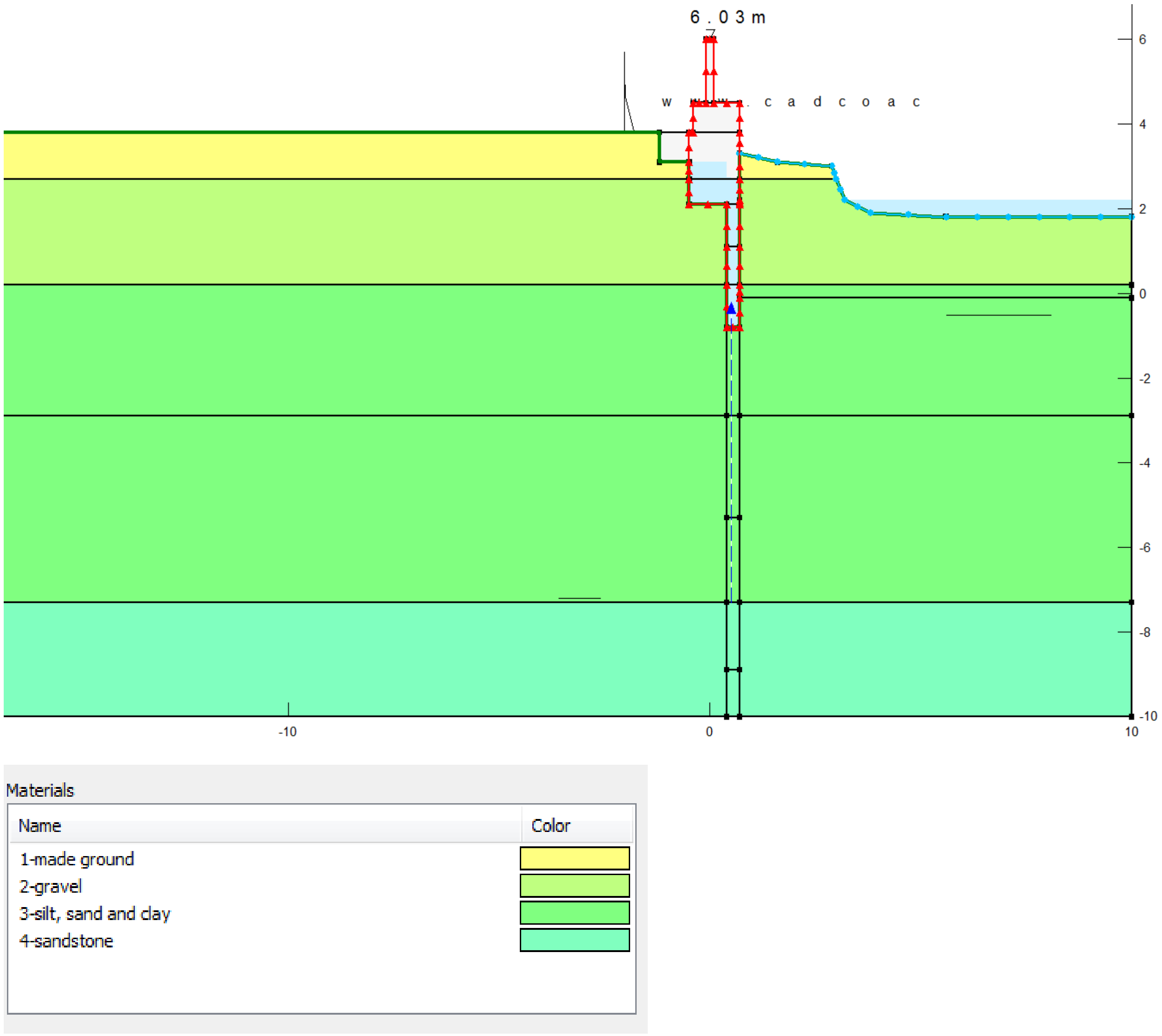
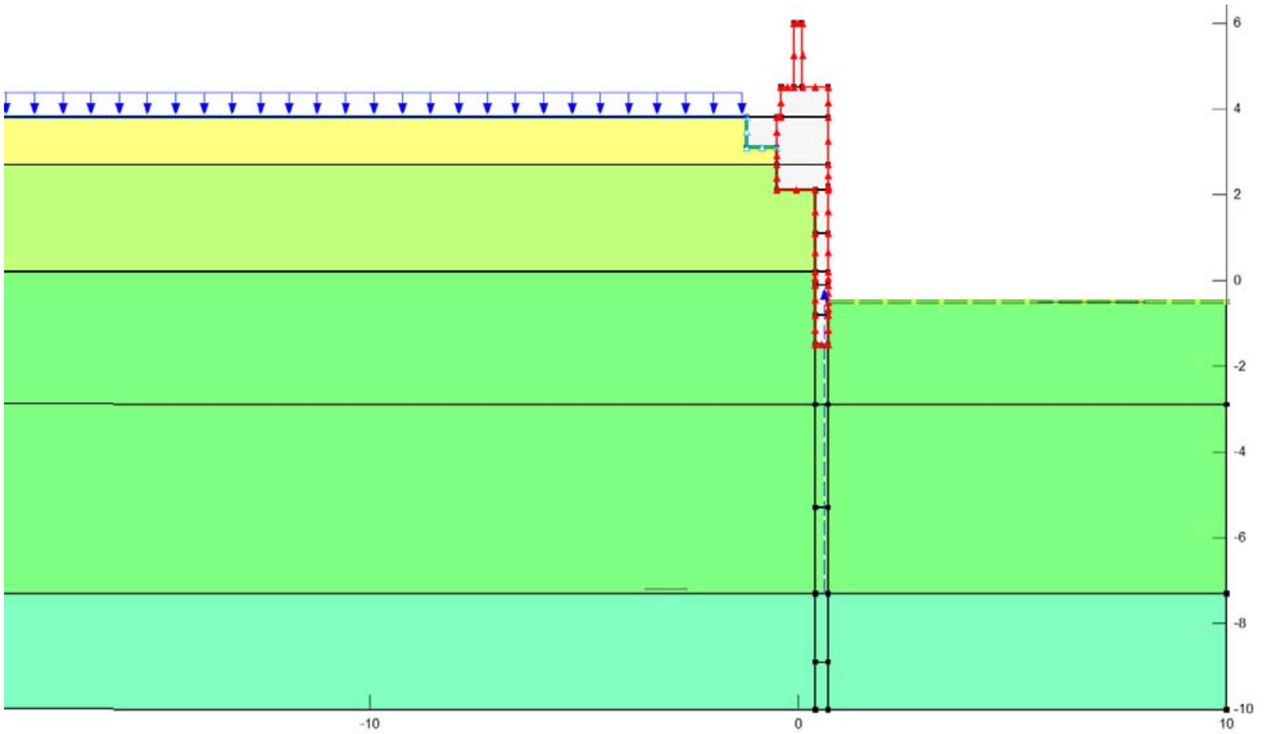


Figure A 6: Geometry of Section 4 - Scour Scenario



Materials

Name	Color
1-made ground	
2-gravel	
3-silt, sand and clay	
4-sandstone	

Figure A 7: Geometry of Section 5 - Rock Armour Scenario

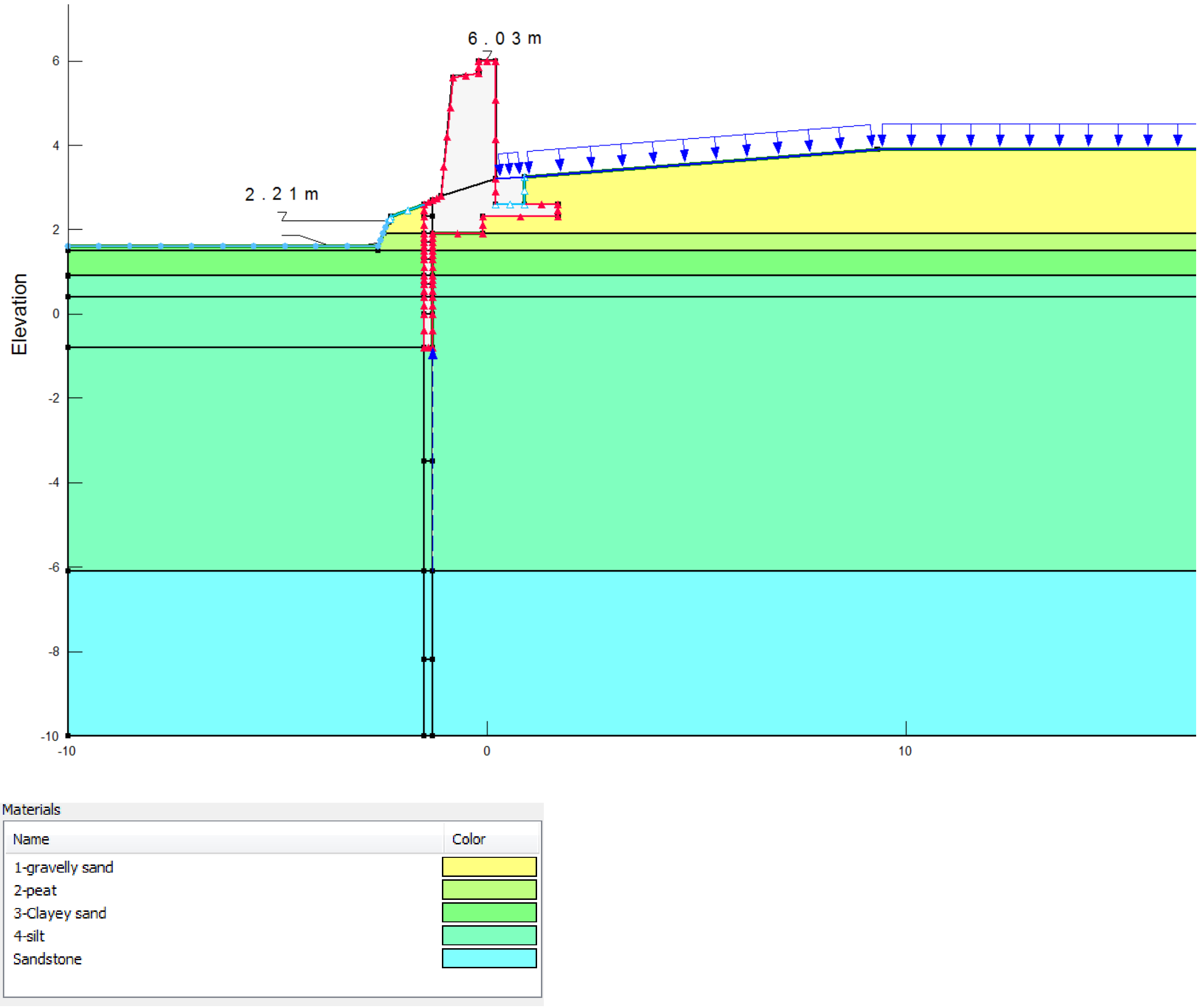


Figure A 8: Geometry of Section 5 - Scour Scenario

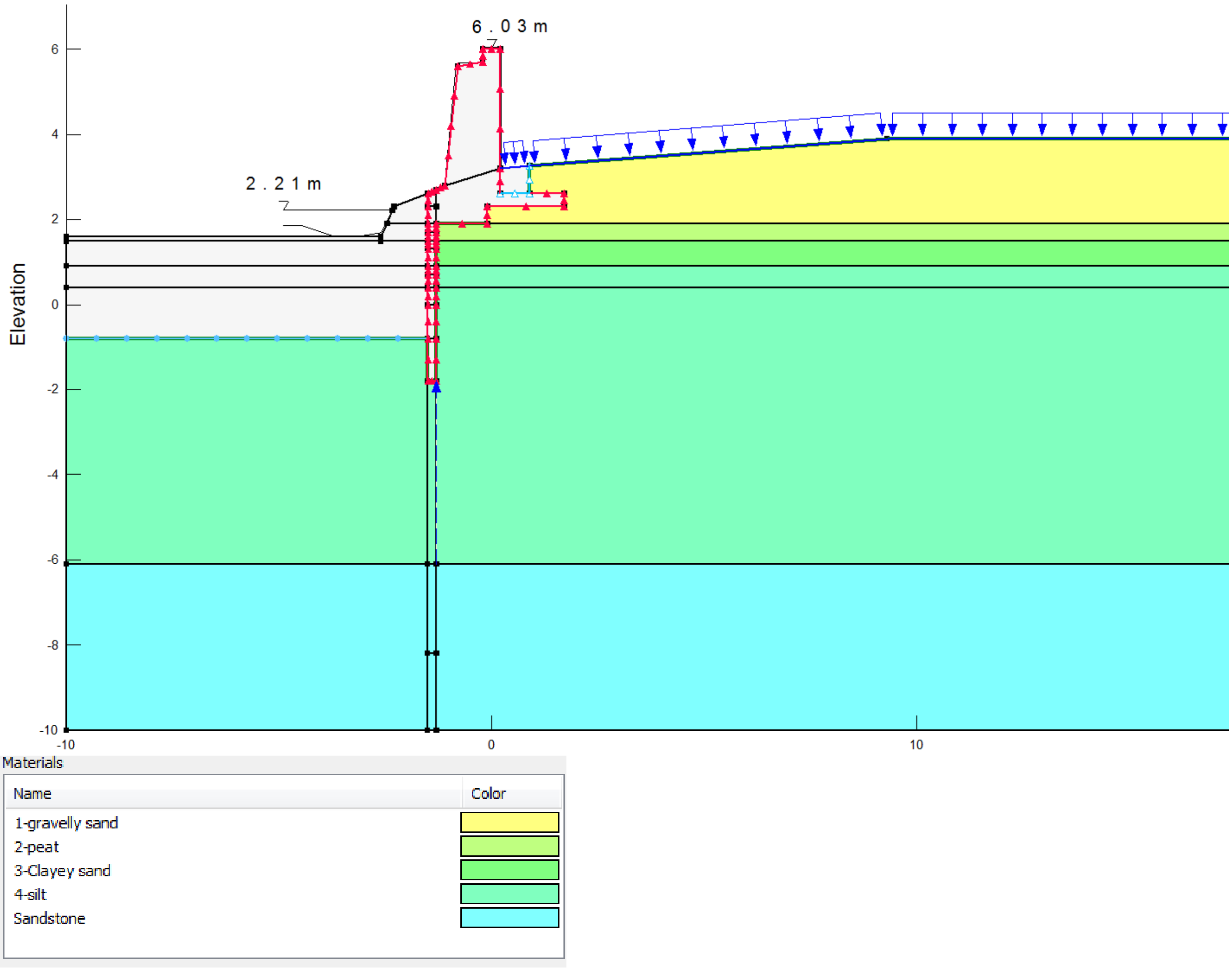
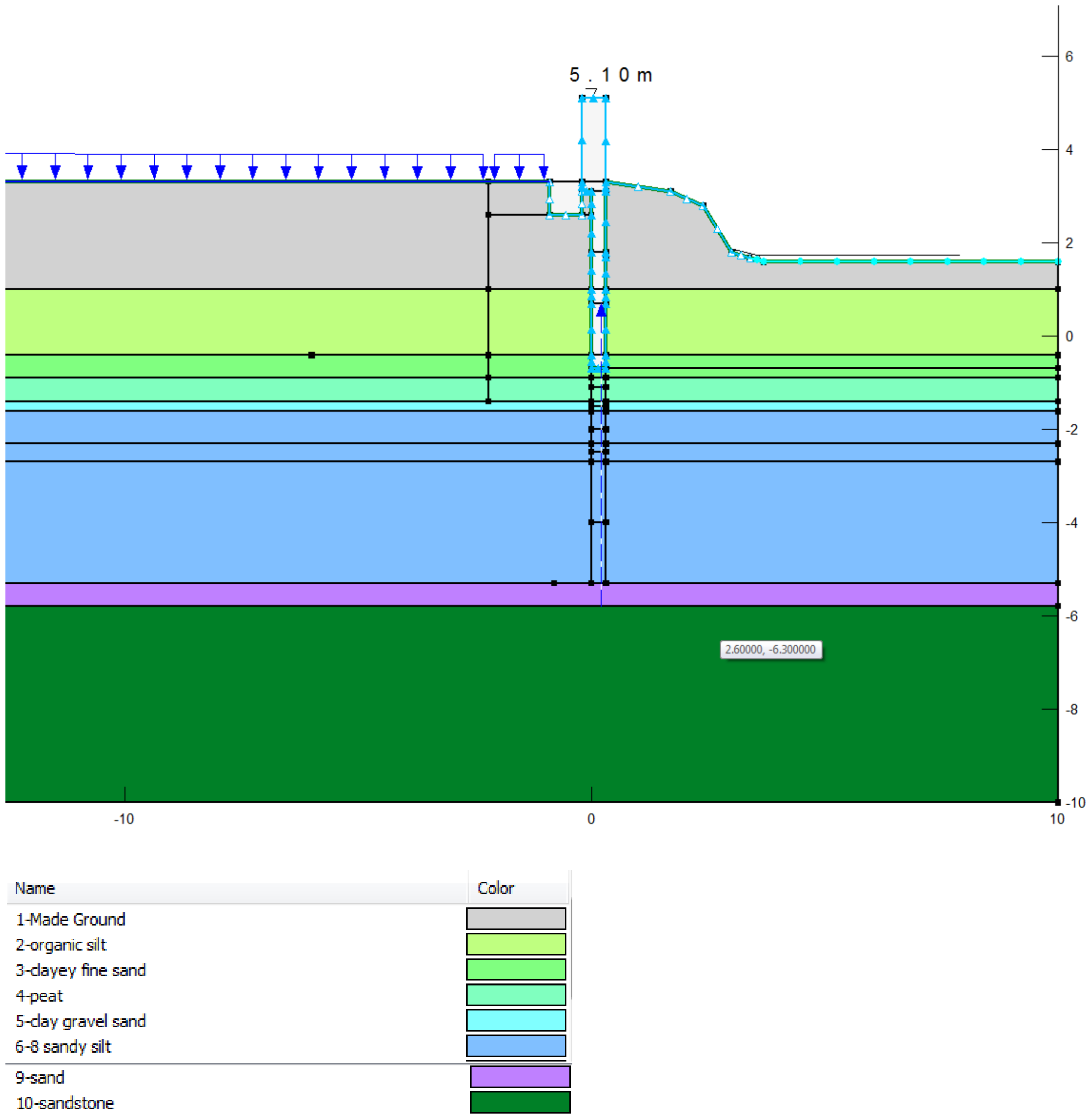


Figure A 9: Geometry of Section 6 - Rock Armour Scenario



JBA consulting

Figure A 10: Geometry of Section 7

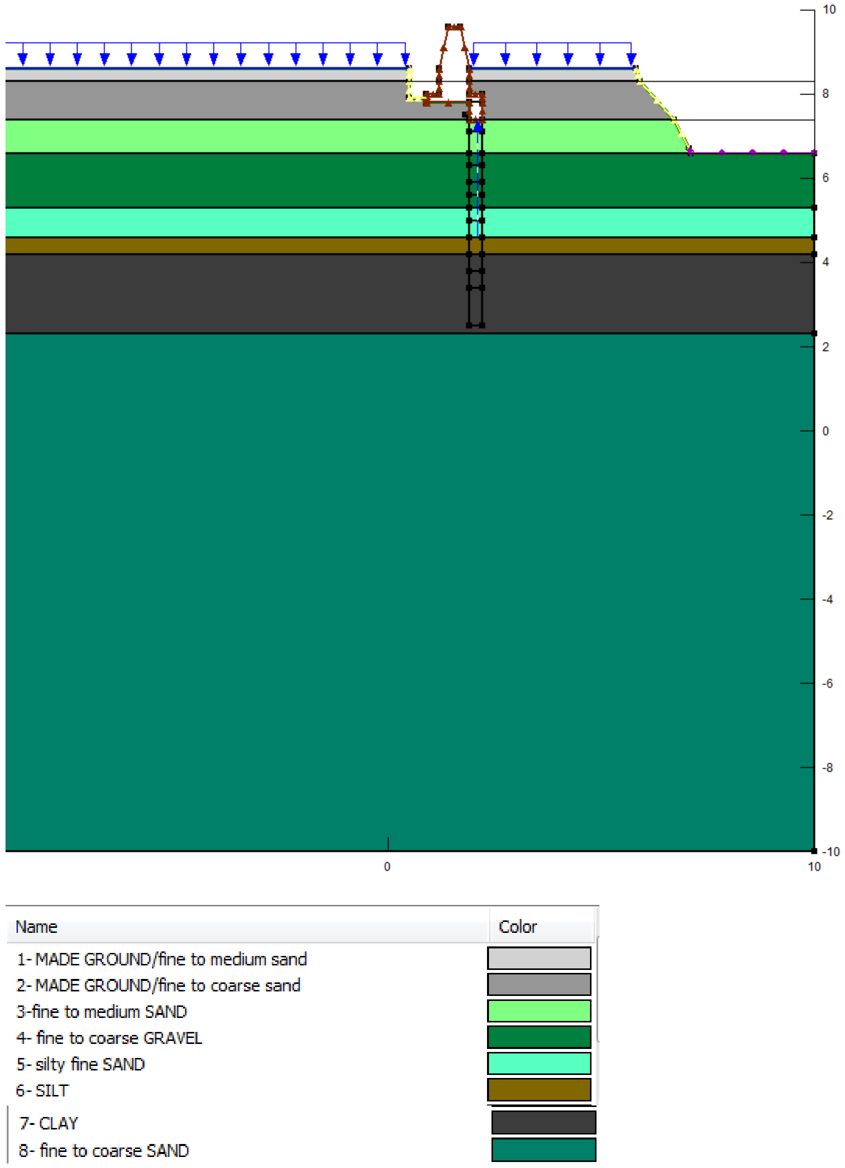
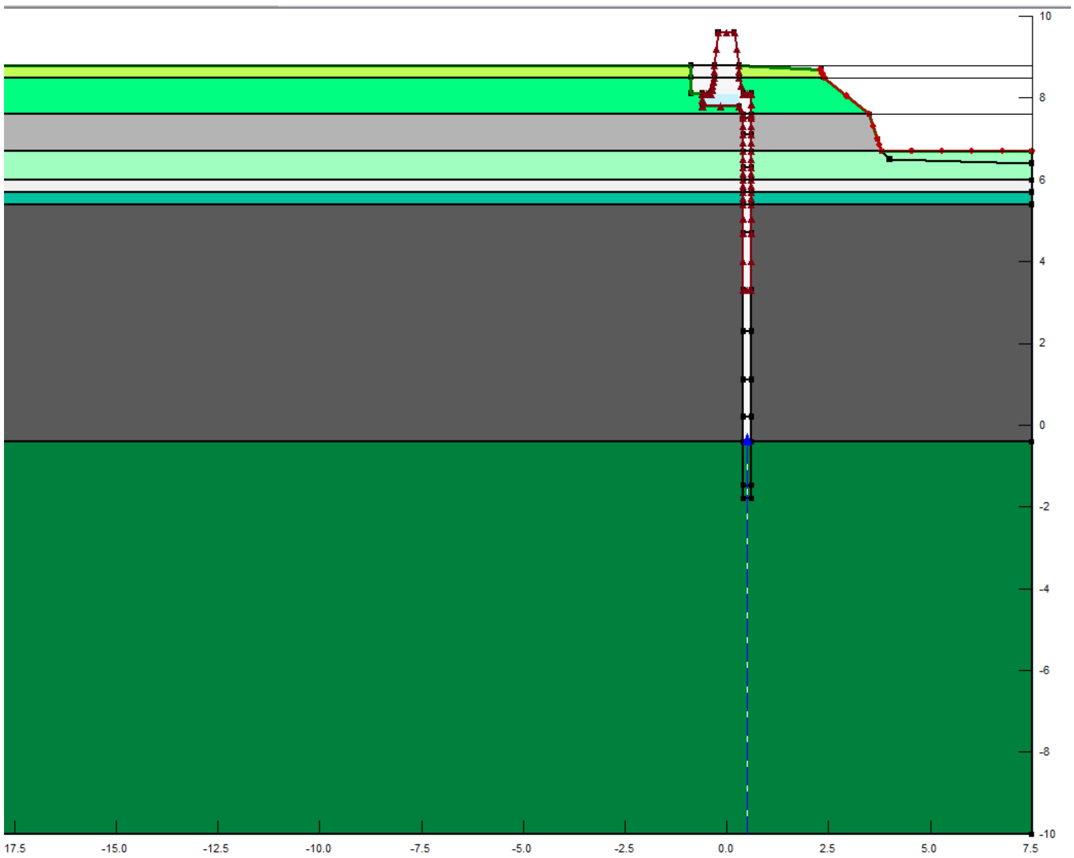


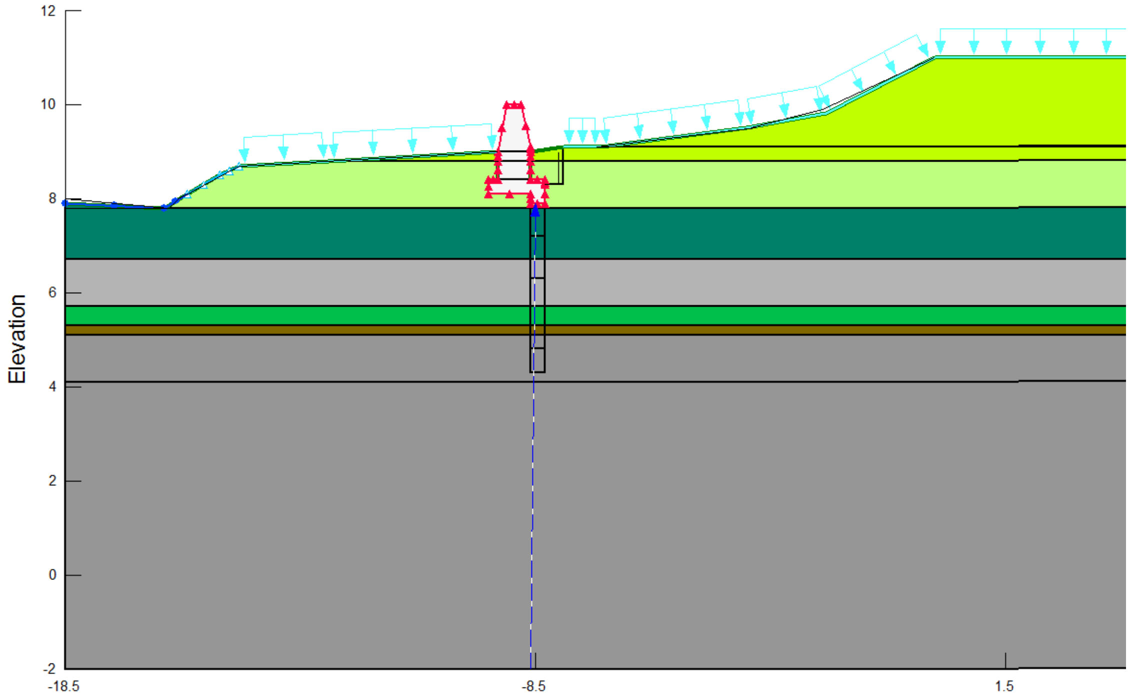
Figure A 11: Geometry of Section 8



Materials

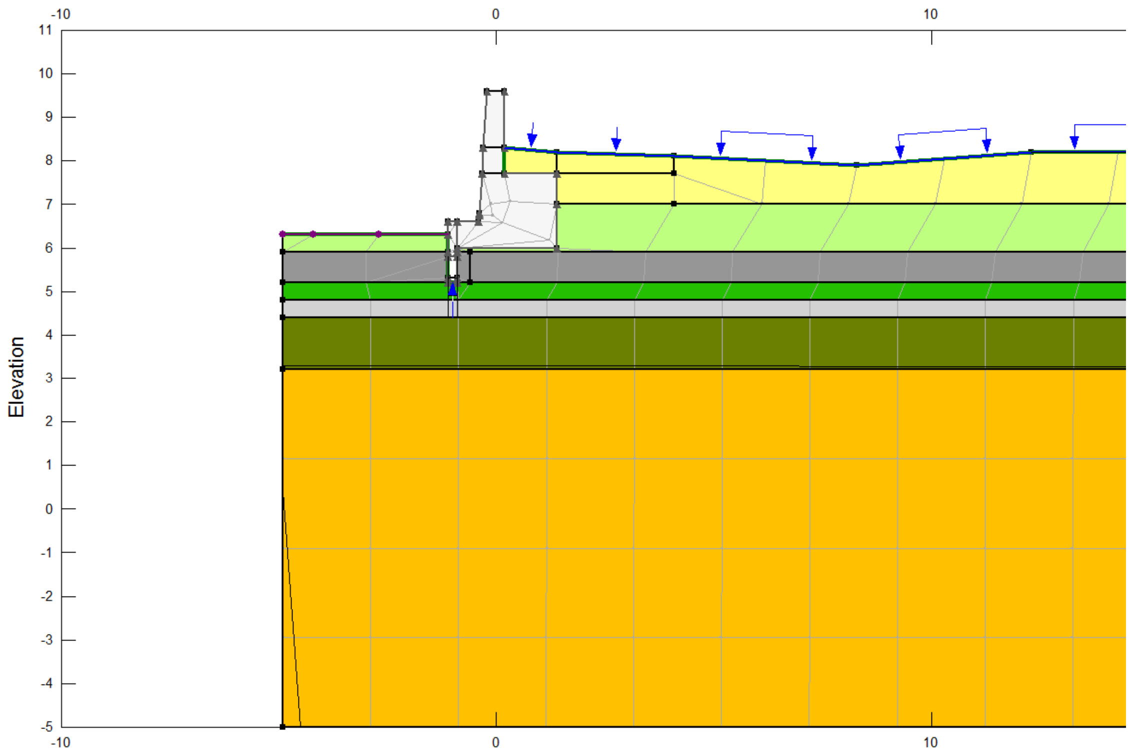
Name	Color
1 -fine to coarse SAND, slightly clayey gravelly	
2- fine to coarse SAND, sligthly clayey gravelly	
3- sandy gravelly CLAY	
4 -fine to coarse GRAVEL, sligthly clayey very sandy	
5- sandy gravelly CLAY	
6- fine to coarse GRAVEL, sligthly clayey very sandy	
7- firm CLAY, slightly sandy sligthly gravelly	
8 -fine to coarse GRAVEL	

Figure A 12: Geometry of Section 9



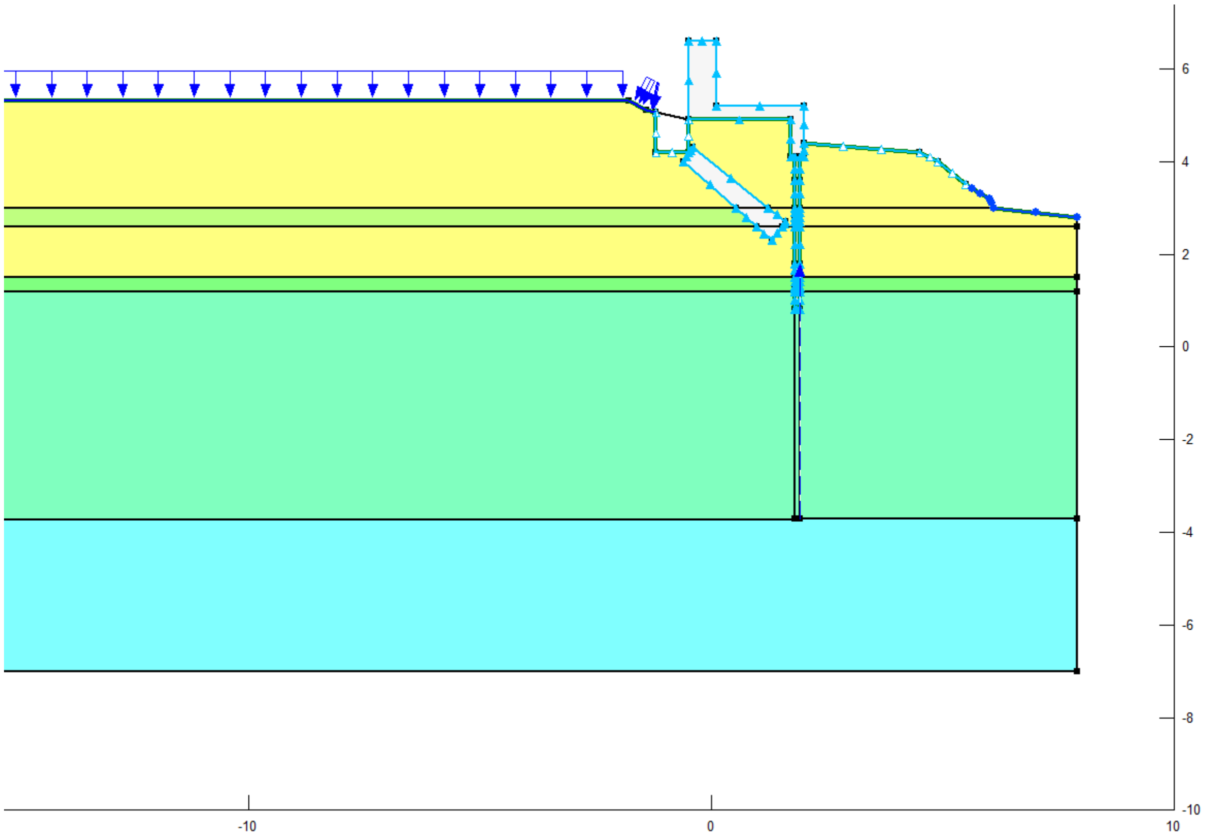
Name	Color
1-sligthly gravelly clayey fine to medium SAND, topsoil	
2-sligthly gravelly silty fine to medium SAND	
3-sligthly silty sandy GRAVEL	
4-sligthly sandy slightly gravelly CLAY	
5-clayey gravelly fine to coarse SAND	
6-sligthly gravelly sandy SILT	
7-slightly sandy slightly gravelly CLAY	

Figure A 13: Geometry of Section 10



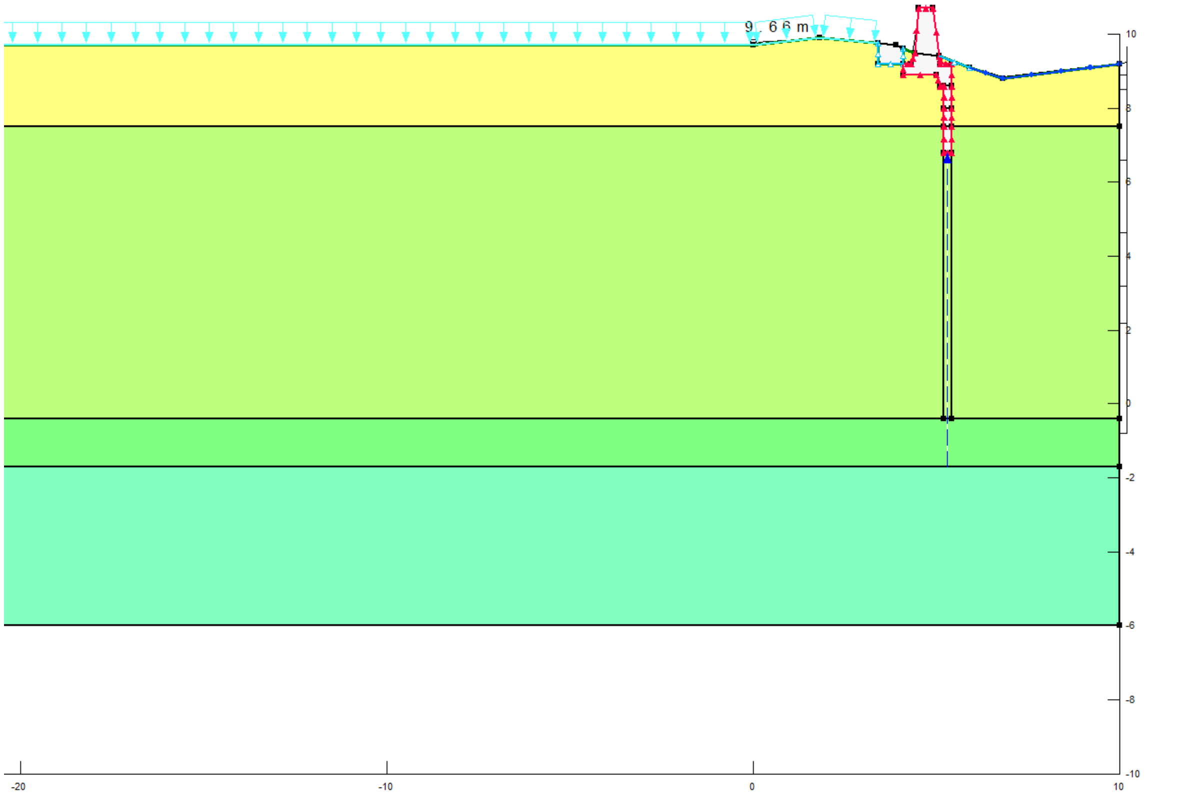
Name	Color
1-Gravelly SAND	
2-Silty gravelly SAND	
3-Sandy gravelly CLAY	
4-Gravelly clayey SAND	
5-Sandy gravelly CLAY (2)	
6-Clayely SAND	
7-SANDSTONE	

Figure A 14: Geometry of Section 11



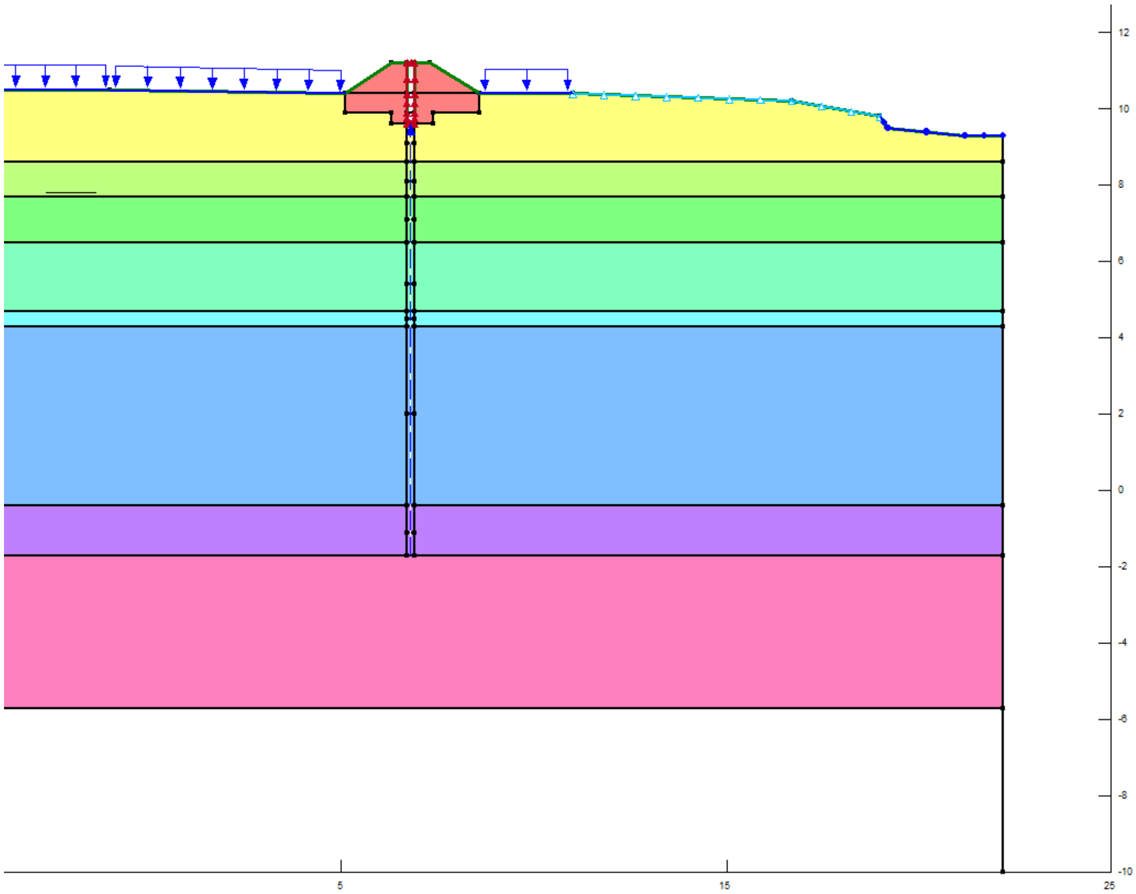
Name	Color
1 and 3-gravelly sand	
2- sandy clay	
4- slightly gravelly clay	
5- gravelly clayey sand	
6- sandstone	

Figure A 15: Geometry of Section 12



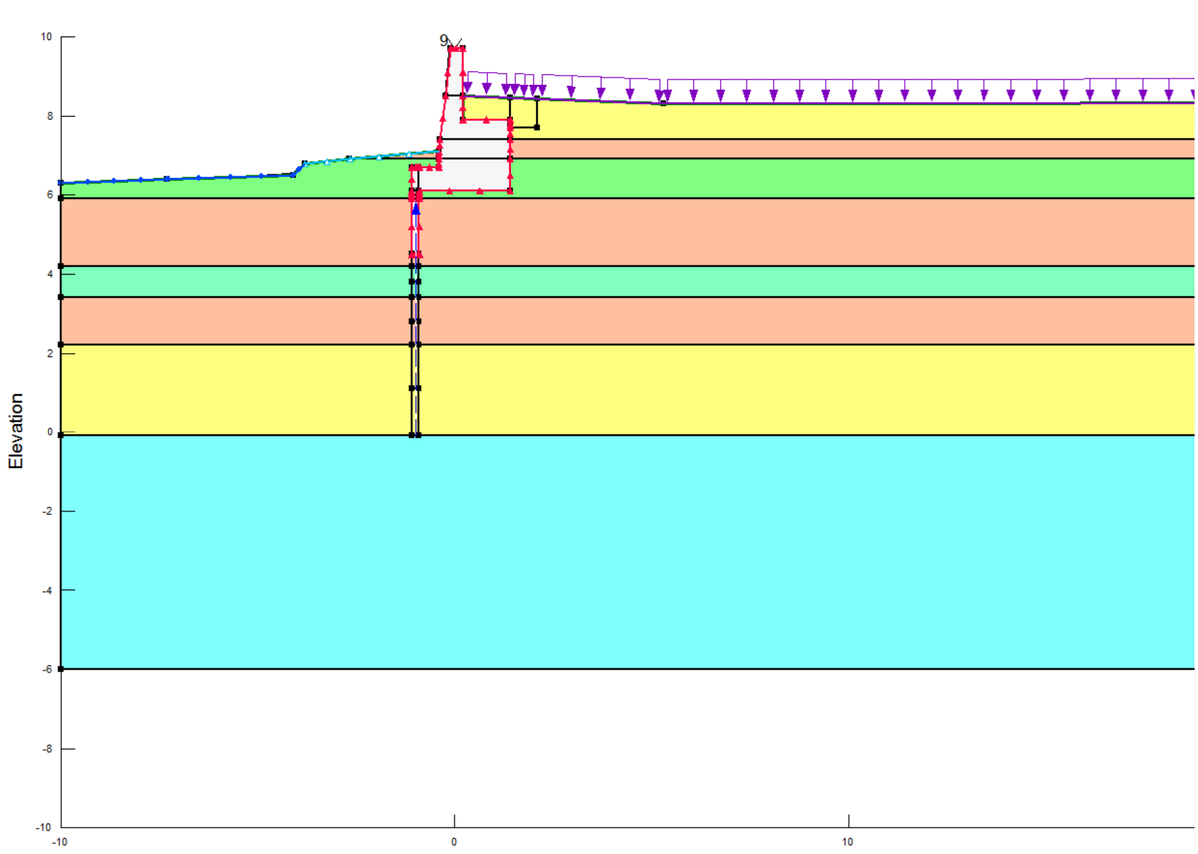
Name	Color
1-mg- silty gravelly sand	
2-sandy silt	
3- sandy gravel	
4- Sandstone	

Figure A 16: Geometry of Section 13



Name	Color
1- gravelly clayey sand	
2-clay and sand	
3- clayey sand	
4- gravelly clay	
5- clayey gravelly sand	
6- sandy clay	
7- sandy gravel	
8- sandstone	
Fill	

Figure A 17: Geometry of Section 14



Name	Color
1 and 7-mg gravelly sand	
2, 4 and 6- clayey gravelly sand	
3-silty sand	
5-gravellly sandy clay	
8- Sandstone	

B Hydrogeological Properties

Table B1: Section 1 Model Layer Properties

Model Layer	Depth (mbgl)	Layer base (mAOD)	Thickness (m)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
1	0 - 1.4	5.86	1.4	Made ground: gravelly fine-med sand with medium cobble content	0.001157	0.28	0.39	0.11	TP6
2	1.4 - 1.8	5.46	0.4	Very sandy silt	1.16E-07	0.12	0.45	0.33	BH10
3	2.5 - 4.3	3.66	1.8	Slightly silty gravelly fine-coarse sand	0.000116	0.28	0.39	0.11	BH10
4	4.3 - 5	2.96	0.7	Slightly clayey sandy fine to coarse gravel of sandstone	0.001157	0.24	0.32	0.08	BH10
5	5+			Sandstone	5.80E-05		0.33		BH14 & BH9

Table B2: Section 2 Model Layer Properties

Model Layer	Depth (mbgl)	Layer base (mAOD)	Thickness (m)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
1	0 - 2	3.25	2	Slightly silty/clayey gravelly fine-med sand	0.000115741	0.23	0.39	0.16	BH18
2	2 - 3.3	2.05	1.3	Slightly sandy organic silt	1.15741E-07	0.08	0.46	0.38	BH18
3	3.3 - 4.5	0.75	1.2	Clayey very gravelly fine-coarse sand	0.000115741	0.28	0.39	0.11	BH18
	4.5 - 5	0.25	0.5	Clayey very sandy gravel with low-med cobble content	0.000115741	0.25	0.35	0.1	BH18
4		-0.85	1.1	Very sandy fine-coarse gravel	0.001157407	0.25	0.34	0.09	BH5
5		-3.6	2.75	Slightly sandy slightly gravelly clay with low cobble content	1.15741E-07	0.05	0.41	0.36	BH5
6		-4.65	1.05	Slightly clayey, gravelly fine-coarse sand with low cobble content	1.16E-04	0.28	0.39	0.11	BH5
7		-5.35	0.7	Gravelly very sandy clay with low cobble content	1.15741E-07	0.1	0.42	0.32	BH5
8		-5.85	0.5	Gravelly fine-med sand	0.000115741	0.28	0.39	0.11	BH5
9				Sandstone	5.80E-05		0.33		BH5

Table B3: Section 3 Model Layer Properties

Model Layer	Depth (mbgl)	Layer base (mAOD)	Thickness (m)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
	0 - 0.20	4.46	0.2	Asphalt					BH5
1	0.20 - 1.20	3.46	1	Made Ground: sandy fine-coarse gravel of sandstone	0.001157407	0.24	0.32	0.08	BH5
2	1.2 - 2	2.66	0.8	Made Ground: slightly clayey very gravelly fine-coarse sand	1.16E-04	0.28	0.39	0.11	BH5
3	2 - 2.7	1.96	0.7	Slightly clayey, gravelly fine-coarse sand	1.15741E-05	0.28	0.39	0.11	BH5
4	2.7 - 3.3	1.36	0.6	Gravelly very sandy clay	1.15741E-07	0.1	0.42	0.32	BH5
5	3.3 - 3.45	1.21	0.15	Peat	1.00E-06	0.44	0.92	0.48	BH5
6	3.45 - 3.80	0.86	0.35	Slightly silty fine-med sand with occasional gravel	1.15741E-05	0.25	0.41	0.16	BH5
7	3.8 - 5.5	-0.85	1.7	Very sandy fine-coarse gravel	0.001157407	0.25	0.34	0.09	BH5
8	5.5 - 8.25	-3.6	2.75	Slightly sandy slightly gravelly clay with low cobble content	1.15741E-07	0.05	0.41	0.36	BH5
9	8.25 - 9.3	-4.65	1.05	Slightly clayey, gravelly fine-coarse sand with low cobble content	0.000115741	0.28	0.39	0.11	BH5
10	9.3 - 10	-5.35	0.7	Gravelly very sandy clay with low cobble content	1.15741E-07	0.1	0.42	0.32	BH5
11	10 - 10.5	-5.85	0.5	Gravelly fine-med sand	0.000115741	0.28	0.39	0.11	BH5
12	10.5+			Sandstone	5.80E-05		0.33		BH5

Table B4: Section 4 Model Layer Properties

Model Layer	Depth (mbgl)	Thickness (m)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
1	0 - 1	1	Made ground: gravelly fine coarse sand	0.0001157	0.28	0.39	0.11	CDR2
2	1 - 3.5	2.5	Sandy fine- coarse gravel of sandstone	0.0011574	0.24	0.32	0.08	CDR2
3	3.5 - 6.6	3.1	Silt, sand and clay, some gravel	1.157E-07	0.12	0.43	0.31	BH2 and 28
	6.6 - 10	3.4	Sandy gravelly clay	1.157E-07	0.12	0.42	0.3	BH28
4	10+		Sandstone	5.80E-05		0.33		Unconfirmed, BH only completed to 10 m as that was scheduled depth

Table B5: Section 5 Model Layer Properties

Model Layer	Depth (mbgl)	Layer base (mAOD)	Thickness (m)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
1	0 - 2	1.88	2	Slightly clayey, gravelly fine-coarse sand, some cobbles	0.000116	0.28	0.39	0.11	BH28
2	2 - 2.4	1.48	0.4	Peat		0.44	0.92	0.48	BH28
3	2.4 - 3	0.88	0.6	Clayey gravelly fine-coarse sand	0.000116	0.28	0.39	0.11	BH28
4	3 - 3.5	0.38	0.5	Slightly sandy silt	1.16E-07	0.08	0.46	0.38	BH28
	3.5 - 10	-6.12	6.5	Slightly sandy, slightly gravelly clay	1.16E-07	0.12	0.42	0.3	BH28
5	10+			Sandstone	5.80E-05		0.33		Unconfirmed, BH only completed to 10 m as that was scheduled depth

Table B6: Section 6 Model Layer Properties

Model Layer	Depth (mbgl)	Thickness (m)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
1	0 - 3.2	3.2	Made ground: clayey, gravelly, fine to coarse sand	1.16E-05	0.28	0.39	0.11	BH1a
2	3.2 - 4.6	1.4	Organic silt, some laminations of fine/med sand and occasional fine/coarse gravel	1.16E-07	0.08	0.46	0.38	BH1a
3	4.6 - 5.1	0.5	Slightly clayey fine-med sand	1.16E-05	0.23	0.43	0.2	BH1a
4	5.1 - 5.6	0.5	Peat		0.44	0.92	0.48	BH1a
5	5.6 - 5.8	0.2	Slightly clayey, gravelly fine-coarse sand	1.16E-05	0.28	0.39	0.11	BH1a
6	5.8 - 6.5	0.7	Slightly gravelly sandy clay	1.16E-07	0.03	0.42	0.39	BH1a
	6.5 - 7	0.5	Very sandy silt	1.16E-07	0.12	0.45	0.33	BH1a
	7 - 9.5	2.5	Slightly sandy slightly gravelly clay	1.16E-07	0.03	0.42	0.39	BH1a
9	9.5 - 10	0.5	Clayey, gravelly fine-coarse sand	1.16E-05	0.28	0.39	0.11	BH1a
10	10+		Sandstone	5.80E-05		0.33		BH1a

Table B7: Section 7 Model Layer Properties

Model Layer	Depth (mbgl)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
1	0 - 0.3	Made ground slightly gravelly slightly clayey fine to medium sand	1.16E-04	0.25	0.39	0.14	BH21a
2	0.3 - 1.2	Made ground slightly gravelly clayey fine to coarse sand	1.16E-04	0.25	0.4	0.15	BH21a
3	1.2 - 2	Slightly clayey slightly gravelly fine to medium sand	1.16E-04	0.25	0.39	0.14	BH21a
4	2 - 3.3	Slightly silty very sandy fine to coarse gravel	1.00E-05		0.32		BH21a
5	3.3 - 4	Very silty fine sand	1.05E-07		0.44		BH21a
6	4 - 4.4	Slightly gravelly sandy silt	1.60E-09		0.46		BH21a
7	4.4 - 6.35	Slightly sandy slightly gravelly clay	1.00E-09		0.42		BH21a
8	6.35 - 10	Slightly gravelly fine to coarse sand	1.16E-03		0.34		BH21a

Table B8: Section 8 Model Layer Properties

Model Layer	Depth (mbgl)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
1	0 - 0.3	Slightly clayey gravelly fine to coarse sand, possible made ground	1.16E-04	0.25	0.4	0.15	BH22
2	0.3 - 1.2	Slightly clayey gravelly fine to coarse sand	1.16E-04	0.25	0.4	0.15	BH22
3	1.2 - 2.1	Sandy gravelly clay	5.00E-08	0.03	0.42	0.39	BH22
4	2.1 - 2.8	Slightly clayey very sandy fine to coarse gravel	1.00E-05	0.27	0.32	0.05	BH22
5	2.8 - 3.1	Sandy gravelly clay	5.00E-08		0.42		BH22
6	3.1 - 3.4	Slightly clayey very sandy fine to coarse gravel	1.15E-05		0.31		BH22
7	3.4 - 9.2	Slightly sandy slightly gravelly clay	1.00E-09		0.42		BH22
8	9.2 - 10.45	Very sandy fine to coarse gravel	1.15E-03		0.31		BH22

Table B9: Section 9 Model Layer Properties

Model Layer	Depth (mbgl)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
1	0 - 0.3	Slightly gravelly clayey fine to medium sand, topsoil	1.16E-04	0.28	0.39	0.11	BH23
2	0.3 - 1.2	Slightly gravelly silty fine to medium sand	1.16E-04	0.26	0.44	0.18	BH23
3	1.2 - 2.4	Slightly silty sandy gravel	3.75E-04				BH23
4	2.4 - 3.3	Slightly sandy slightly gravelly clay	1.00E-07				BH23
5	3.3 - 3.7	Clayey gravelly fine to coarse sand	1.16E-04				BH23
6	3.7 - 4	Slightly gravelly sandy silt	1.60E-09				BH23
7	4 - 5	Slightly sandy slightly gravelly clay	1.00E-09				BH23

Table B10: Section 10 Model Layer Properties

Model Layer	Depth (mbgl)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
	0 - 0.2	Made ground					BH14
	0.2 - 0.4	Made ground, fine to coarse gravel					BH14
1	0.4 - 1.2	Slightly gravelly, fine to medium sand	1.16E-03	0.28	0.39	0.11	BH14
2	1.2 - 2.3	Silty gravelly, fine to coarse sand	1.60E-05	0.15	0.43	0.28	BH14
3	2.3 - 3	Slightly sandy slightly gravelly clay	5.00E-08		0.43		BH14
4	3 - 3.4	Slightly gravelly clayey sand	5.79E-05		0.43		BH14
5	3.4 - 3.75	Sandy gravelly clay	1.00E-07		0.42		BH14
6	3.75 - 5	Clayey fine to coarse sand	5.80E-07		0.43		BH14
7	5 - 7.5	Sandstone	5.80E-05		0.33		BH14

Table B11: Section 11 Model Layer Properties

Model Layer	Depth (mbgl)	Layer base (mAOD)	Thickness (m)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
1	0 - 2.35	2.99	2.35	Clayey gravelly fine-coarse sand with low-med cobble content	0.000116	0.28	0.39	0.11	BH6
2	2.35 - 2.7	2.64	0.35	Slightly sandy clay	1.16E-06	0.03	0.42	0.39	BH6
3	2.7 - 3.8	1.54	1.1	Gravelly fine-coarse sand	0.000116	0.27	0.39	0.12	BH6
4	3.8 - 4.15	1.19	0.35	Sandy slightly gravelly clay	1.16E-06	0.05	0.42	0.37	BH6
5	4.15 - 9	-3.66	4.85	Gravelly clayey fine-med sand	0.000116	0.25	0.41	0.16	BH6
6	9+			Sandstone	5.80E-05		0.33		BH6

Table B12: Section 12 Model Layer Properties

Model Layer	Depth (mbgl)	Layer base (mAOD)	Thickness (m)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
1	0 - 2	8.49	2	Made ground: slightly clayey gravelly fine-coarse sand	0.000116	0.28	0.39	0.11	BH24
	2 - 3	7.49	1	Silty gravelly fine-coarse sand	0.000116	0.28	0.39	0.11	BH24
2	3 - 4.3	6.19	1.3	Slightly sandy silt	1.16E-07	0.1	0.46	0.36	BH24
	4.3 - 10	-0.4	4.73	Slightly gravelly sandy clay	1.16E-07	0.06	0.42	0.36	BH25 BH24 & BH22
3		-1.7	1.3	Sandy fine-coarse gravel	0.001157	0.24	0.32	0.08	BH22
4		plus		Sandstone	5.80E-05		0.33		A number of surrounding locations

Table B13: Section 13 Model Layer Properties

Model Layer	Depth (mbgl)	Layer base (mAOD)	Thickness (m)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
	0 - 0.5	10.68	0.5	Clayey gravelly fine-med sand	0.00012	0.23	0.41	0.18	BH29
1	0.5 - 2.6	8.58	2.1	Slightly gravelly very clayey fine-med sand	1.16E-05	0.2	0.42	0.22	BH29
2	2.6 - 3.4	7.78	0.8	Interlaminated slightly gravelly clay and fine sand	1.2E-06	0.13	0.42	0.29	BH29
3	3.4 - 4.7	6.48	1.3	Slightly clayey very gravelly fine-coarse sand	0.00012	0.28	0.39	0.11	BH29
4	4.7 - 6.5	4.73	1.75	Slightly sandy slightly gravelly clay	1.2E-07	0.03	0.42	0.39	BH29
5		4.33	0.4	Slightly clayey gravelly fine-coarse sand	0.00012	0.28	0.39	0.11	BH25
6		-0.4	4.73	Slightly gravelly sandy clay	1.2E-07	0.06	0.42	0.36	BH25 BH24 & BH22
7		-1.7	1.3	Sandy fine-coarse gravel	0.00116	0.24	0.32	0.08	BH22
8		plus		Sandstone	5.80E-05		0.33		A number of surrounding locations
N.A.				Fill	0.00012	0.24	0.32	0.08	Based on description of materials

Table B14: Section 14 Model Layer Properties

Model Layer	Depth (mbgl)	Layer base (mAOD)	Thickness (m)	Material	K (m/s)	Specific Yield	Porosity	Residual Water Content	Source of Information
	0 - 0.1	8.84	0.1	Made ground: asphalt					BH13
	0.1 - 0.25	8.69	0.15	Made ground: concrete					BH13
1	0.25 - 1.2	7.74	0.95	Made ground: very gravelly fine-med sand	0.00116	0.25	0.39	0.14	BH13
2	1.2 - 2	6.94	0.8	Slightly clayey gravelly fine-coarse sand with low cobble content	0.00012	0.28	0.39	0.11	BH13
	2 - 3	5.94	1	Slightly gravelly silty fine-med sand	1.2E-05	0.23	0.43	0.2	BH13
3	3 - 4.7	4.24	1.7	Slightly clayey very gravelly fine-coarse sand	0.00012	0.25	0.39	0.14	BH13
4	4.7 - 5.5	3.44	0.8	Slightly gravelly sandy clay	1.2E-07	0.1	0.42	0.32	BH13
5	5.5 - 6.7	2.24	1.2	Gravelly fine-med sand	0.00012	0.28	0.39	0.11	BH13
6	6.7 - 9	-0.06	2.3	Clayey sandy gravel with low-medium cobble content	0.00116	0.25	0.34	0.09	BH13
7	9+			Sandstone	5.80E-05		0.33		BH13

C Model Results

Table C-1: Section 1

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
1	1.9	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	-	-
		Piping Conditions Encountered	No	-
		Ground Water Flooding Encountered	-	Yes
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	-	-
		Hydraulic Gradient Zone 2	-	-
		Hydraulic Gradient Zone 3	-	-
	1.3	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	-	-
		Piping Conditions Encountered	Yes	-
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	0.978	-
		Hydraulic Gradient Zone 2	-	-
		Hydraulic Gradient Zone 3	-	-
	4	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	NA
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	6.85E-09	3.70E-07
		Hydraulic Gradient Zone 1	0.07	<0
		Hydraulic Gradient Zone 2	<0	0.0014
		Hydraulic Gradient Zone 3	0	0

Table C-2: Section 2

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
2	0.8	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	-	-
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	-	-
		Hydraulic Gradient Zone 2	-	2.3
		Hydraulic Gradient Zone 3	-	-
	1.3	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	-	-
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	-	-
		Hydraulic Gradient Zone 2	-	1.3
		Hydraulic Gradient Zone 3	-	-
	2	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	-	-
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	No	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	-	-
		Hydraulic Gradient Zone 2	-	1.93
		Hydraulic Gradient Zone 3	-	-
	2.9	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	No
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	1.39E-07	1.06E-04
		Hydraulic Gradient Zone 1	0.0004	0.37
		Hydraulic Gradient Zone 2	<0	0.72
		Hydraulic Gradient Zone 3	0.0004	0.46

Table C-3: Section 3

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
3	4.2	Scour Included	-	-
		Rock Armour Included	Yes	-
		Drain Included Behind Defences	No	-
		Piping Conditions Encountered	Yes	-
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	1.33	-
		Hydraulic Gradient Zone 2	-	-
		Hydraulic Gradient Zone 3	-	-
	5.2	Scour Included	-	-
		Rock Armour Included	Yes	-
		Drain Included Behind Defences	No	-
		Piping Conditions Encountered	Yes	-
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	1.33	-
		Hydraulic Gradient Zone 2	-	-
		Hydraulic Gradient Zone 3	-	-
	6.2	Scour Included	-	-
		Rock Armour Included	Yes	Yes
		Drain Included Behind Defences	Yes	NA
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	3.88E-08	3.68E-08
		Hydraulic Gradient Zone 1	0.39	0.25
		Hydraulic Gradient Zone 2	<0	0.31
		Hydraulic Gradient Zone 3	<0	<0
	6.2	Scour Included	Yes	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	-
		Piping Conditions Encountered	Yes	-
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	0.86	-
		Hydraulic Gradient Zone 2	-	-
		Hydraulic Gradient Zone 3	-	-
	7.2	Scour Included	Yes	Yes
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	NA

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	3.88E-08	5.72E-08
		Hydraulic Gradient Zone 1	0.46	0.21
		Hydraulic Gradient Zone 2	<0	0.13
		Hydraulic Gradient Zone 3	0.16	<0

Table C-4: Section 4

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
4	1.7	Scour Included	Yes	Yes
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	NA
		Piping Conditions Encountered	No	-
		Ground Water Flooding Encountered	NA	Yes
		Flow Rate Under Sheet Pile (m3/s)	1.33E-07	1.37E-03
		Hydraulic Gradient Zone 1	NA	NA
		Hydraulic Gradient Zone 2	NA	1.4
		Hydraulic Gradient Zone 3	-1.5	0.05
	4.6	Scour Included	Yes	Yes
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	NA
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	NA	No
		Flow Rate Under Sheet Pile (m3/s)	2.83E-08	7.40E-09
		Hydraulic Gradient Zone 1	0.34	<0
		Hydraulic Gradient Zone 2	<0	0.92
		Hydraulic Gradient Zone 3	0.08	<0
	5.3	Scour Included	Yes	Yes
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	NA
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	NA	No
		Flow Rate Under Sheet Pile (m3/s)	1.91E-08	6.18E-09
		Hydraulic Gradient Zone 1	0.45	-
		Hydraulic Gradient Zone 2	NA	0.48
		Hydraulic Gradient Zone 3	NA	0.49
	2.7	Scour Included	-	-
		Rock Armour Included	Yes	Yes
		Drain Included Behind Defences	No	-
		Piping Conditions Encountered	Yes	-
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	2.3	-
		Hydraulic Gradient Zone 2	<0	-
		Hydraulic Gradient Zone 3	7.5	-
	3.8	Scour Included	-	-
		Rock Armour Included	Yes	Yes
		Drain Included Behind Defences	No	-
		Piping Conditions Encountered	Yes	-

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	2.3	-
		Hydraulic Gradient Zone 2	<0	-
		Hydraulic Gradient Zone 3	7.5	-
	4.6	Scour Included	-	-
		Rock Armour Included	Yes	-
		Drain Included Behind Defences	Yes	NA
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	2.38E-08	4.41E-08
		Hydraulic Gradient Zone 1	0.49	<0
		Hydraulic Gradient Zone 2	<0	0.44
		Hydraulic Gradient Zone 3	0.13	<0

Table C-5: Section 5

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
5	0.8	Scour Included	-	-
		Rock Armour Included	Yes	Yes
		Drain Included Behind Defences	No	NA
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	1.30E+07	1.12E-05
		Hydraulic Gradient Zone 1	0.01	<0
		Hydraulic Gradient Zone 2	<0	0.05
		Hydraulic Gradient Zone 3	0.01	5.8
	1.4	Scour Included	-	-
		Rock Armour Included	Yes	Yes
		Drain Included Behind Defences	No	NA
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	1.30E+07	1.12E-05
		Hydraulic Gradient Zone 1	0.003	<0
		Hydraulic Gradient Zone 2	<0	3.77
		Hydraulic Gradient Zone 3	0	0.05
	1.4	Scour Included	-	-
		Rock Armour Included	Yes	Yes
		Drain Included Behind Defences	No	NA
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	1.30E+07	3.73E-05
		Hydraulic Gradient Zone 1	0.006	<0
		Hydraulic Gradient Zone 2	<0	1.35
		Hydraulic Gradient Zone 3	0	0.128
	2	Scour Included	-	-
		Rock Armour Included	Yes	Yes
		Drain Included Behind Defences	Yes	NA
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	Yes	No
		Flow Rate Under Sheet Pile (m3/s)	1.73E-08	-
		Hydraulic Gradient Zone 1	0.16	<0
		Hydraulic Gradient Zone 2	<0	3.15
		Hydraulic Gradient Zone 3	0.1	0.02
	2.7	Scour Included	-	-
		Rock Armour Included	Yes	Yes
		Drain Included Behind Defences	Yes	NA
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	Yes	No
		Flow Rate Under Sheet Pile (m3/s)	1.07E-08	5.61E-08
		Hydraulic Gradient Zone 1	0.27	<0
		Hydraulic Gradient Zone 2	<0	1.05
		Hydraulic Gradient Zone 3	0.04	<0

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
	3.5	Scour Included	-	-
		Rock Armour Included	Yes	Yes
		Drain Included Behind Defences	Yes	NA
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	Yes	No
		Flow Rate Under Sheet Pile (m3/s)	7.41E-09	3.47E-08
		Hydraulic Gradient Zone 1	0.02	<0
		Hydraulic Gradient Zone 2	<0	0.45
		Hydraulic Gradient Zone 3	0.1	<0
	3.5	Scour Included	Yes	Yes
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	NA
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	Yes	No
		Flow Rate Under Sheet Pile (m3/s)	1.60E-08	1.27E-07
		Hydraulic Gradient Zone 1	0.13	<0
		Hydraulic Gradient Zone 2	<0	1.8
		Hydraulic Gradient Zone 3	0.13	0.4
	4	Scour Included	Yes	Yes
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	NA
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	Yes	No
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	-	-
		Hydraulic Gradient Zone 2	-	0.98

Table C-6: Section 6

Section ID	Cutoff Length	Parameter	Steady	Transient
6	4	Scour Included	Yes	Yes
		Rock Armour Included	-	-
		Drain Included Behind Defences	-	-
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	-	1.5
		Hydraulic Gradient Zone 2	-	-
		Hydraulic Gradient Zone 3	-	-
	5.5	Scour Included	Yes	Yes
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	-
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	2.38E-08	5.90E-08
		Hydraulic Gradient Zone 1	0.41	<0
		Hydraulic Gradient Zone 2	<0	0.75
		Hydraulic Gradient Zone 3	0.2	0.28
	1.5	Scour Included	-	-
		Rock Armour Included	Yes	Yes
		Drain Included Behind Defences	No	-
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	-	<0
		Hydraulic Gradient Zone 2	-	1.79
		Hydraulic Gradient Zone 3	-	0.18
	2.6	Scour Included	-	-
		Rock Armour Included	Yes	Yes
		Drain Included Behind Defences	Yes	-
		Piping Conditions Encountered	Yes	-
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	1.54	-
		Hydraulic Gradient Zone 2	-	-
		Hydraulic Gradient Zone 3	-	-
	3.6	Scour Included	-	-
		Rock Armour Included	Yes	Yes
		Drain Included Behind Defences	Yes	-
		Piping Conditions Encountered	No	No

Section ID	Cutoff Length	Parameter	Steady	Transient
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	5.62E-08	1.00E-07
		Hydraulic Gradient Zone 1	0.55	<0
		Hydraulic Gradient Zone 2	<0	0.17
		Hydraulic Gradient Zone 3	0.0013	0.0008

Table C-7: Section 7

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
7		Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	No
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	1.34E-07	3.04E-05
		Hydraulic Gradient Zone 1	NA	<0
		Hydraulic Gradient Zone 2	NA	0.003
		Hydraulic Gradient Zone 3	NA	<0

Section C-8: Section 8

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
8	1.2	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	No
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	-	-
		Hydraulic Gradient Zone 2	-	-
		Hydraulic Gradient Zone 3	-	1.99
	1.7	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	No
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	-	<0
		Hydraulic Gradient Zone 1	-	2.9
		Hydraulic Gradient Zone 2	-	1.06
		Hydraulic Gradient Zone 3	-	-
	2.5	Scour Included	-	-

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	-
		Piping Conditions Encountered	No	Yes
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	0.038	-
		Hydraulic Gradient Zone 2	<0	2.37
		Hydraulic Gradient Zone 3	0.01	0.08
	3.1	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	-
		Piping Conditions Encountered	Yes	-
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	2.59	-
		Hydraulic Gradient Zone 2	<0	-
		Hydraulic Gradient Zone 3	0.0002	-
	4.1	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	-
		Piping Conditions Encountered	Yes	-
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	1.04	-
		Hydraulic Gradient Zone 2	<0	-
		Hydraulic Gradient Zone 3	-	-
	5.5	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	Yes
		Piping Conditions Encountered	No	Yes/No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	1.70E-10	1.70E-10
		Hydraulic Gradient Zone 1	0.49	3.38
		Hydraulic Gradient Zone 2	<0	<0
		Hydraulic Gradient Zone 3	0.13	0

Table C-9: Section 9

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
9	1.1	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	-
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	1.35E-07	4.44E-05
		Hydraulic Gradient Zone 1	0.006	<0
		Hydraulic Gradient Zone 2	<0	0.75
		Hydraulic Gradient Zone 3	<0	0.34

Table C-10: Section 10

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
10	2.9	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	No
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	1.12E-07	3.51E-07
		Hydraulic Gradient Zone 1	0.72	<0
		Hydraulic Gradient Zone 2	<0	0.26
		Hydraulic Gradient Zone 3	0.58	0.29
	2.5	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	-
		Piping Conditions Encountered	Yes	-
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	0.95	-
		Hydraulic Gradient Zone 2	<0	-
		Hydraulic Gradient Zone 3	0.45	-
	3.1	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	No
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	1.25E-08	3.52E-07
		Hydraulic Gradient Zone 1	0.7	<0
		Hydraulic Gradient Zone 2	<0	0.21
		Hydraulic Gradient Zone 3	0	<0

Table C-11: Section 11

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
11		Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	-	-
		Piping Conditions Encountered	-	-
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	-	-
		Hydraulic Gradient Zone 2	-	-
		Hydraulic Gradient Zone 3	-	-

Table C-12: Section 12

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
12	1.4	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	-	-
		Piping Conditions Encountered	No	-
		Ground Water Flooding Encountered	-	Yes
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	-	-
		Hydraulic Gradient Zone 2	-	-
		Hydraulic Gradient Zone 3	-	-
	2.1	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	-
		Piping Conditions Encountered	No	yes
		Ground Water Flooding Encountered	-	-
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	0.2	<0
		Hydraulic Gradient Zone 2	<0	1.63
		Hydraulic Gradient Zone 3	0.02	<0
	2.6	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	Yes	-
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	3.30E-09	2.09E-08
		Hydraulic Gradient Zone 1	0.07	<0
		Hydraulic Gradient Zone 2	<0	0.36
		Hydraulic Gradient Zone 3	0.01	<0

Table C-13: Section 13

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
13	0.8	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	-	-
		Piping Conditions Encountered	No	-
		Ground Water Flooding Encountered	-	yes
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	-	-
		Hydraulic Gradient Zone 2	-	-
		Hydraulic Gradient Zone 3	-	-
	0.8	Scour Included	-	-

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	No
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	1.43E-07	7.40E-06
		Hydraulic Gradient Zone 1	0.007	<0
		Hydraulic Gradient Zone 2	<0	0.15
		Hydraulic Gradient Zone 3	-	0.56

Table C-14: Section 14

Section ID	Cutoff Length (m)	Parameter	Steady State	Transient State
14	2.4	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	-	-
		Piping Conditions Encountered	No	yes
		Ground Water Flooding Encountered	-	No
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	0.07	-
		Hydraulic Gradient Zone 2	-	1.07
		Hydraulic Gradient Zone 3	-	-
	3.5	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	-
		Piping Conditions Encountered	No	yes
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	1.34E-07	1.53E-05
		Hydraulic Gradient Zone 1	0.002	<0
		Hydraulic Gradient Zone 2	<0	0.93
		Hydraulic Gradient Zone 3	<0	0.03
	4	Scour Included	-	-
		Rock Armour Included	-	-
		Drain Included Behind Defences	No	-
		Piping Conditions Encountered	No	No
		Ground Water Flooding Encountered	No	No
		Flow Rate Under Sheet Pile (m3/s)	-	-
		Hydraulic Gradient Zone 1	0.0028	<0
		Hydraulic Gradient Zone 2	<0	0.8
		Hydraulic Gradient Zone 3	<0	0.22

D Maps

E Manual Piping Analysis

Table E-1 : Manual Steady State Piping Analysis

Section Name	Model Name	Dryside Head (mAOD)	Wet Side head (mAOD)	Base of Piling (mAOD)	River bed (mAOD)	H	D	H/2D	2D/H	Seep gradient
Section 4	SH-JBA-01-03-M2-GE-0001_ section 4_5.3m	3.1	2.2	-1.5	-0.5	0.9	1	0.45	2.222	0.45
	SH-JBA-01-03-M2-GE-0001_ section 4_6.3m	3.1	2.2	-2.5	-0.5	0.9	2	0.23	4.444	1.45
	SH-JBA-01-03-M2-GE-0001_ section 4_RM_4_6m	3.1	2.2	-0.8	1.8	0.9	2.6	0.17	5.78	0.49
Section 5	SH-JBA-01-04-M2-GE-0001_ section 5_RA_3.5m	2.4	2.2	-0.8	1.6	0.2	2.4	0.04	24.00	0.02
	SH-JBA-01-04-M2-GE-0001_ section 5_Scour_4.5m	2.6	2.2	-1.8	-0.8	0.4	1	0.20	5.00	0.17
Section 3	SH-JBA-01-09-M2-GE-0001_ section 3_RA_6.2m	4	2.9	-1.5	2.3	1.1	3.8	0.14	6.91	0.39
	SH-JBA-01-09-M2-GE-0001_ section 3_Scour_7.2m	4	2.9	-2.5	-0.1	1.1	2.4	0.23	4.36	0.46
Section 1	SH-JBA-01-15-M2-GE-0001_ section 1_4m	6.8	6.76	4.6	6.3	0.04	1.7	0.01	85.00	0.07
Section 14	SH-JBA-01-17-M2-GE-0002_ section 14_4m	6.85	6.8	4.5	6.3	0.05	1.8	0.01	72.00	0.0028

Section Name	Model Name	Dryside Head (mAOD)	Wet Side head (mAOD)	Base of Piling (mAOD)	River bed (mAOD)	H	D	H/2D	2D/H	Seep gradient
Section 9	SH-JBA-02-03-M2-GE-0001_ section 9-1-1m	8.02	8	7.9	7.8	0.02	-0.1	-0.10	-10	0.0006
Section 12	SH-JBA-02-04-M2-GE-0001_section 12_2-6m	9.2	9.1	6.8	8.7	0.1	1.9	0.03	38.00	0.07
Section 6	SH-JBA-04-01-M2-GE-0001_ section_6_5.5m	2.6	1.7	-2.2	-0.7	0.9	1.5	0.30	3.333	0.41
	SH-JBA-04-01-M2-GE-0001_ section_6_RA_3_6m	2.6	1.7	-0.7	1.6	0.9	2.3	0.20	5.11	0.55
Section 2	SH-JBA-01-10-M2-GE-0001_ section 2_2_9m	2.9601	2.96	2.2	2.8	0	0.6	0.00	12000	0
Section 13	SH-JBA-02-06-M2-GE-0001_ section 13_Pile_0-8m	9.81	9.75	9.5	9.31	0.06	-0.2	-0.16	-6.33	0.0007
Section 8	SH-JBA-02-04-M2-GE-0001_ section 8_SS_6	8	6.7	3.3	6.7	1.3	3.4	0.19	5.23	0.49
Section 10	SH-JBA-01-17-M2-GE-0001_ section 10_3	7.3	6.7	5.2	6.3	0.6	1.1	0.27	3.667	0.7
Section 11	SH-JBA-01-12-M2-GE-0001_ section 11_imperm_wall_4.1m	3.5	3.43	0.8	2.8	0.07	2	0.02	57.14	1.7

Note - green indicates situation where the river is remote from the wall therefore D calculated not valid

Offices at

Coleshill

Doncaster

Dublin

Edinburgh

Exeter

Haywards Heath

Limerick

Newcastle upon Tyne

Newport

Saltaire

Skipton

Tadcaster

Thirsk

Wallingford

Warrington

Registered Office
South Barn
Broughton Hall
SKIPTON
North Yorkshire
BD23 3AE

t:+44(0)1756 799919
e:info@jbaconsulting.com

Jeremy Benn Associates Ltd
Registered in England
3246693

Visit our website
www.jbaconsulting.com