Gruggies Burn Flood Alleviation Scheme

Seepage Analysis

March 2024

West Dunbartonshire Council

Balfour Beatty

SCAPE SCOTLAND CIVIL ENGINEERING

FAIRHURST

Gruggies Burn Flood Alleviation Scheme

Seepage Risk Analysis Report

March 2024

West Dunbartonshire Council

SCAPE SCOTLAND CIVIL ENGINEERING

Balfour Beatty

FAIRHURST

CONTROL SHEET

CLIENT: West Dunbartonshire Council
PROJECT TITLE: Gruggies Burn Flood Alleviation Scheme
REPORT TITLE: Seepage Risk Analysis Report
PROJECT REFERENCE: 153386
DOCUMENT NUMBER: GBFAS-FRH-ZZ-ZZ-RP-W-100003

Original Issue	Issue 1 FINAL	Name	Signature	Date
	Prepared by	Tommy Rae	Signed copy held on file	21/03/2024
	Checked by	Harris Tarnanas	Signed copy held on file	21/03/2024
	Approved by	Simon Shillington	Signed copy held on file	21/03/2024

Update Record	Issue	Date	Status	Description	Signature	
	2				Prepared By	
					Checked	
					Approved	
	3				Prepared By	
					Checked	
					Approved	
	4				Prepared By	
					Checked	
					Approved	

This document has been prepared in accordance with the Fairhurst Quality and Environmental Management System and in accordance with the instructions of the client, West Dunbartonshire Council for the client's sole and specific use. Any other persons who use any information contained herein do so at their own risk. Any information provided by third parties and referred to herein has not been checked or verified by Fairhurst unless otherwise expressly stated within this report.

Fairhurst is the trading name of Fairhurst Group LLP, a limited liability partnership registered in Scotland with the registered number SO307306 and registered office at 43 George Street, Edinburgh EH2 2HT.

CONTENTS

Table of Figures

Executive Summary

Fairhurst has completed a comprehensive seepage risk assessment as part of the Gruggies Burn Flood Alleviation Scheme (the Scheme) in Dumbarton. The purpose of the Scheme is to mitigate flooding of residential, non-residential and commercial property from the river Gruggies Burn and from extreme tidal events. This report aims to present an overview of the site's ground and groundwater conditions, as well as the methodology and results of the seepage analysis and an assessment of the potential seepage risks to flood defences structures.

A hydrogeological conceptual model was developed for the site based on online geological information and records from previous ground investigations. The conceptual model informed the development of the modelling cross-sections which were used for the seepage risk analyses.

Numerical seepage modelling was carried out using the SEEP/W software for selected cross-sections of the flood defences where the conditions were assessed as being at higher risk of seepage. The results of the multiple seepage analyses indicate that during the design flood event the tidal embankment and the flood walls prevent seepage from emerging on the dry side of the flood protections structures.

In conclusion, the seepage analysis indicates that no seepage issues are expected to arise from flooding at the Scheme based on current modelling parameters and assumptions. If changes are made to the Scheme’s design, location and properties that present more onerous conditions, the seepage analysis would have to be re-run

1. Introduction

1.1 Background

Fairhurst were commissioned by West Dunbartonshire Council to conduct a seepage risk assessment as part of the Gruggies Burn Flood Alleviation Scheme in Dumbarton (the Scheme). The Scheme is designed to mitigate flooding from the watercourse flows and from extreme tidal events through the use of flood walls along the river and a tidal embankment along the coastal front.

Assessing the risk of seepage is crucial due to its potential adverse impacts on the stability and reliability of flood protection structures. Seepage can cause erosion, weaken embankments, and pose risks of system failure, resulting in significant property damage and threats to human safety. There is a risk that the proposed flood defences increases the risk of groundwater seeping from the wet side to the dry side of the structure during the design flood event.

The purpose of this report is to provide an overview of the existing ground and groundwater conditions at the site and detail the methodology and results of the seepage analysis carried out at selected cross-sections along the flood defences. The assessment draws upon desk study findings, past site investigations, and seepage modelling utilising GeoStudio SEEP/W software.

1.2 Report Structure

This report consists of the following sections:

- Description of the site setting which includes details of the location, geology, hydrology, hydrogeology, nearby water features and known water quality;
- A summary of the results of previous Ground Investigations (GI);
- The development of a hydrogeological conceptualisation of the site;
- Detailing of the methodology of the seepage analysis;
- A presentation of the results of the seepage analysis;
- Conclusions and recommendations.

2. Site Location and Description

2.1 Location

As shown on the site location plans in **Appendix A,** the works were conducted in the town of Dumbarton adjacent to the existing course of Gruggies Burn.

The site is bordered by both residential and industrial properties as well as a number of green spaces/open parkland areas. The topography generally exhibits a gentle slope from the higher northern parts of the site to the southern edge where the foreshore meets the River Clyde.

2.2 Land Use

The site has a history of various industrial uses, including a mineral railway, the Leven shipbuilding yard, warehouses, the Glasgow Dumbarton and Helensburgh railway, a mill lade, a dam, High Mains Quarry, and a sand pit.

The site has undergone significant changes over time, with the current land use being a mix of residential, recreational, industrial, woodland, and agricultural land. The site includes a former gasholder land use, Lanarkshire and Dunbartonshire Railway, A814, A82, East End Park and residential areas.

Overall, the site has transitioned from primarily industrial use to a mix of different land uses, with an emphasis on residential and recreational areas in recent years.

2.3 Geology

2.3.1 Superficial Geology

The BGS geological mapping indicates that the superficial deposits vary along the site, with made ground and alluvium overlying raised marine deposits and glacial till, underlain by bedrock.

Made ground refers to soil or rock material that has been deposited or modified by human activities, such as construction, demolition, or landfill operations.

Alluvium refers to unconsolidated sediment or soil material that has been deposited by flowing water, such as rivers, streams, or floodplains. It can be composed of a range of particle sizes, from clay and silt to sand and gravel, and may also contain organic matter or debris.

Raised marine deposits refer to sediment or soil material that has been deposited by the sea, but has been uplifted above sea level due to tectonic processes or changes in sea level. They can be composed of a variety of sedimentary materials, including sand, gravel, clay, and silt, and may also contain layers of organic material.

Glacial till refers to unsorted and unstratified sediment or soil material that has been deposited by glaciers. It can be composed of a range of particle sizes, from clay and silt to sand, gravel, and boulders, and may also contain rock fragments and debris that were carried along by the glacier.

2.3.2 Bedrock Geology

The BGS geological mapping indicates that the bedrock geology underlying the site is composed of two distinct formations: the Kinnesswood Formation and the Ballagan Formation.

The Kinnesswood Formation is present in the central and southern areas of the site. It consists predominantly of purple-red, yellow, white and grey-purple, fine- to coarse-grained sandstones which are mostly cross-bedded and arranged in upward-fining units.

The Ballagan Formation is present in the northern section of the site. It is characterised by generally grey mudstones and siltstones, with nodules and beds (generally less than 0.3 m thick) of ferroan dolostone.

2.4 Hydrogeology

Two groundwater bodies have been identified by SEPA on the site: Loch Lomond and Leven Sand and Gravel groundwater body (ID: 150766) in the northern area of the site and the Dumbarton groundwater body (ID: 150505) in the southern section. Both groundwater bodies have an overall classification of ‘Good’ (SEPA, 2023).

The aquifer is classified by SEPA as a moderately productive 2B aquifer. The flow is virtually all through fractures and other discontinuities. It is summarised as a multi-layered aquifer with fracture flow yielding up to 10l/s.

A BGS Groundwater Vulnerability Map indicates the superficial deposits in the southern section of the site are a 'major or highly permeable aquifer' and the superficial deposits in the north western section of the site are a 'minor or moderately permeable aquifer'. The change in permeability is associated with the change is superficial geology, from the more permeable raised marine deposits to the less permeable glacial till.

2.5 Hydrology

According to the SEPA’s Water Environment Hub Map, no datasheet is available for Gruggies Burn. The nearest recorded surface water body is the Clyde Estuary, of which Gruggies Burn is a tributary. SEPA gave the Clyde Estuary an overall status of 'Moderate'.

2.6 Flooding

According to SEPA’s flood maps the site has the following:

- A medium to high risk of coastal flooding;
- A medium to high risk of river flooding;
- A medium to high risk of surface water.

2.7 Mining and Quarrying

Dumbarton is not listed as being in a Coal Authority Reporting Area and consequently the risk associated with mine workings/entries below the site is considered negligible.

2.8 Abstractions and Discharges

One discharge has been recorded by SEPA within a 1km radius. The discharge is sewage effluent to the River Clyde from a treatment system serving Castle Road, Dumbarton (G82 1JJ).

2.9 Designations

The area to the south of the site is designated as part of the inner Clyde Site of Special Scientific Interest (SSSI) and also a Special Protection Area (SPA).

The Inner Clyde regularly supports nationally important wintering populations of several species of waterfowl, including redshank, red-throated diver, cormorant, eider, goldeneye, red-breasted merganser and oystercatcher. Principal roosting sites are at Ardmore, Dumbarton, Cardross, Milton Island, Longhaugh Point to West Ferry, and Newshot Island.

3. Previous Ground Investigation (GI) Work

3.1 Causeway Geotech (on behalf of Balfour Beatty) – 2020

A previous GI at Gruggies Burn, Dumbarton was carried out by Causeway Geotech on behalf of Balfour Beatty in 2020. Site operations were conducted between July 30th and October 22nd 2020.

In-situ permeability tests were carried out in boreholes BH03, BH05, BH07, and BH09 by variable head permeability methods, following development of the boreholes. Testing was carried out in accordance with the guidance as set out in BS EN ISO 22282-2: 2012.

Following completion of site works, groundwater level monitoring was conducted over 6 monitoring rounds on 12 boreholes.

Key findings from the report relevant to the seepage assessment include the following:

- Four permeability tests carried out on boreholes on site suggest a **moderate/high soil permeability** (0.00045 – 5.194E-06 m/s);
- Six rounds of groundwater monitoring on 12 boreholes showed that there is a **shallow groundwater table** present in the superficial deposits on site at 0.54-3.13mbgl;
- Bedrock was encountered only at BH10 and BH11 at 9.50mbgl and 6.25mbgl respectively (this area is northeast of the FDS location and doesn't appear relevant to the works).

4. Conceptual Model

Two hydrogeological cross-sections of the site at the locations of the Scheme were developed, to assist in the conceptualisation of the ground and groundwater conditions at the site. The conceptual model of the site would be used to inform the development of the seepage modelling cross-sections.

The construction of these cross-sections involved an analysis of existing online geological maps, lithological information, and data extracted from 23 ground investigation boreholes from the 2020 GI, as well as online records. To ensure precision in depicting the landform, high-resolution topographic maps obtained through Light Detection and Ranging (Lidar) technology was used.

Schematic representations of the conceptual hydrogeological cross-sections are described below and are shown in **Appendix B**. The positions of the conceptual cross-section lines are also shown in the site layout map drawing in **Appendix A.** The hydrogeological units as depicted in the conceptual model of the site are summarised in **Table 1** below.

Table 1: Summary of Hydrogeology

Material	Description	Thickness	Location	Hydrogeology
Made Ground	Variable – ranging from gravel, sand with red brick to sandy clay with brick	from 0.2 up to 2.5 metres below ground level (mbgl)	Made ground is relatively extensive and was found in most borehole logs in the area	Permeability is highly variable due to the highly variable nature of this unit
Clay	Comprise fine-grained sediments predominantly composed of clay minerals, reflecting glacial activity and varying in thickness and composition across the region	From 0.2 mbgl to upper thickness unknown	More prominent in borehole logs in the east of the site	Permeability is likely to be low to moderate.
Sand	Consists of coarse to fine-grained sediments deposited by ancient river systems or marine processes, exhibiting variable thickness and composition throughout the site	From 0.2 mbgl to upper thickness unknown	Extensive across the site and found in all borehole logs	Permeability is likely to be relatively high
Gravel	Comprise coarse fragments of rock ranging in size from pebbles to boulders, often deposited by glacial meltwater or ancient river channels, exhibiting diverse compositions and	From 0.7mbgl to >5 metres mbgl	More prominent in the north of the site	Permeability is likely to be relatively high

Material	Description	Thickness	Location	Hydrogeology
	thicknesses across the site			

The presence of varying superficial deposits such as sands and gravels, alongside a shallow groundwater table, underscored the necessity for an extensive seepage assessment. These deposits introduce additional complexities that may influence seepage dynamics, further emphasising the need for a detailed examination to evaluate the extent and potential impact of seepage on the site.

5. Seepage Analysis Methodology

Numerical seepage modelling was carried out using GeoStudio SEEP/W which uses a finite element approach to solving the differential equations describing water flow through porous media. To assess the seepage risk of the Scheme transient seepage analyses were undertaken for the 200-year return period time-stage hydrograph provided.

Transient analyses were carried out at 4 sections of the proposed coastal defences and 3 sections of the proposed watercourse defences. Multiple cross-sections through the proposed Scheme were assessed to determine the most onerous geometries in relation to seepage risk. Modelling cross-sections were selected for the highest risk of seepage, based on the most onerous existing topography in relation to the Scheme and on the maximum height difference between peak flood level and ground elevation on the dry side. The positions of the modelling cross-section lines are also shown in the site layout map drawing in **Appendix A.**

This methodology section outlines the approach employed to conduct the seepage analysis of the proposed Scheme. The analysis integrates various components including hydraulic properties of all materials, flood defence design details, flood data, and groundwater monitoring information.

5.1 Hydraulic Properties of Materials

Hydraulic properties of subsurface materials, geological layers and proposed flood defence systems were determined to develop an accurate numerical model. The model accounts for the variability in soil permeability, porosity, and other relevant parameters to simulate seepage behaviour under various hydraulic loading conditions. The hydraulic properties used in the model of the subsurface materials, geological layers and proposed flood defence systems are summarised in **Table 2** below.

Table 2: Hydraulic Properties of Subsurface Materials, Geological Layers and Flood Defence Systems

Material	Hydraulic Conductivity (m/sec)	Saturated Water Content	Residual Water Content
Made Ground	0.000451	0.4	0.045
Clay	5.19E-06	0.5	0.068
Sand	4.30E-05	0.4	0.045
Silt	5.00E-06	0.5	0.034
Gravel	3.00E-03	0.35	0.04
Concrete	1.00E-10	0.15	0.05
Embankment	6.35E-05	0.45	0.05

5.2 Flood Data

The design flood event data for the Scheme was used in the transient modelling of seepage and is presented below in **Figure 1**. The tidal flood level data was used for the modelling of both the tidal embankment and the watercourse flood walls. The maximum peak flood level is at 4.32 mAOD for the design flood event.

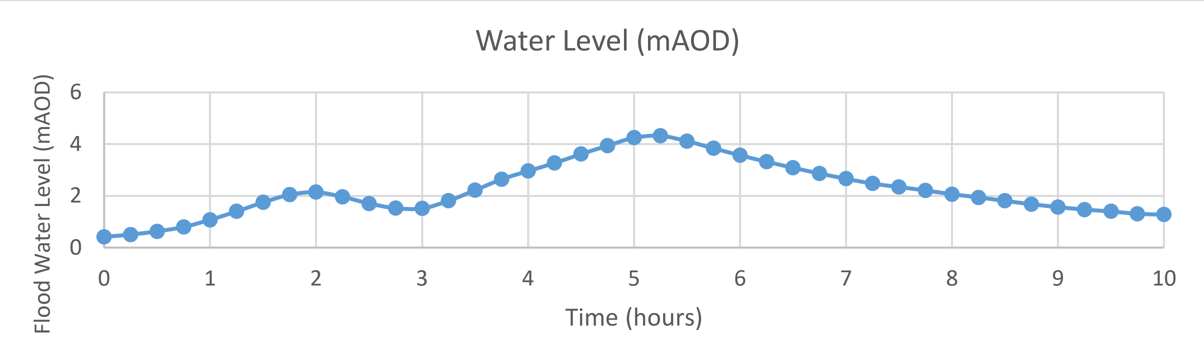


Figure 1: Design Flood Event Data

5.3 Groundwater Monitoring Data

Groundwater monitoring data was obtained from the GI monitoring boreholes and were applied to the relevant modelling cross sections, to estimate the local shallow water table in the superficial deposits. The groundwater level information can be found in **Table 3** below.

Table 3: Groundwater Monitoring Data

ID	Elevation (mAOD)	Screen (mbgl)	Unit	Rd 1	Rd 2	Rd 3	Rd 4	Rd 5	Rd 6	Permeability (m/s)
BH01	14.11	0.5-3.00	Made ground/clay	-	-	-	2.96	Dry	Dry	
BH03	4.76	3.0-6.0	Clay	2.7	2.75	2.68	2.72	-	-	5.19E-06
BH05	3.51	30.5-2.0	Made ground/Clay	0.95	1.07	1.11	1.02	-	-	4.51E-04
BH06	3.72	0.5-3.0		no access	no access	no access	no access	no access	no access	
BH07	3.34	0.5-3.0	Sand	1.4	1.45	1.44	1.44	-	-	4.30E-05
BH09	7.25	0.5-1.5	Made Ground/Clay	0.7	0.62	0.64	0.54	-	-	6.36E-05
BH14	10.72	3.5-10.0	Sand				1.68	1.58	1.81	
WS03	7.17	1.5-3.4	Gravel	1.9	1.85	1.52	1.34	-	-	
WS08	3.5	1.5-3.0	Slit/Gravel	0.8	0.85	1.51	1.24	-	-	
WS09	2.77	1.0-3.0	Sand	1.2	1.21	1.34	1.22	-	-	
WS10	4.24	0.5-5.0	Made Ground/Sand	1.6	1.63	2.21	2.26	-	-	
WS11	6.14	3.0-5.0	Gravel/Silt	2.3	2.3	3.13	3.08	-	-	

5.4 Proposed Flood Defences Design

The proposed Scheme will consist of a tidal embankment above the River Clyde, flood walls, a flow diversion culvert and a tidal flood gate. The proposed tidal embankment is to provide protection during extreme tidal events. The tidal embankment will be built to a height of 4.92mAOD to protect against the design tidal flood level and will have a side slope gradient of 2:1 or 3:1 dependent on where it is located on the site. Along the Gruggies Burn reach within the Scheme area, the flood walls will be constructed to stop flooding during high tides. The flood walls will comprise a 9m sheet pile (approximately 6m to 7m below ground and the balance above ground with cladding above ground to suit the local environment.

5.5 Modelling Assumptions

The following assumptions were made for the transient seepage analysis performed in SEEP/W.

- The assumption that soil/material properties (such as permeability, porosity, and hydraulic conductivity) are uniform and consistent throughout the model domain;
- It was assumed that the vertical permeability is assumed to be equivalent to horizontal permeability;
- It is assumed that the ground profile is laterally continuous. If less permeable ground, or an obstruction, is present within 5 to 10m of the wall on the defended side the water table may rise to above ground level;
- The default soil compressibility was used for all materials in the model as 1e-05 KPa;
- Simplified geometric representations of structures, embankments, and water bodies were constructed, which may not fully capture real-world complexities;
- Hydraulic continuity was assumed within the soil mass and across interfaces between different soil layers and structures; and
- The geological properties of the materials and stratigraphy were taken from limited borehole data, and making assumptions about soil layers and their properties based on nearby information.

6. Seepage Modelling Results

6.1 Embankment Seepage Risk Analysis

Four cross sections were analysed with SEEP/W for the tidal embankment of the Scheme (AA, BB, CC and DD) and their locations is shown in **Appendix A**.

The results indicate that during the design flood event, the embankment effectively prevents seepage both through and under its structure. At peak flood levels, as well as during the peak flux which commonly occurs a short while after, no seepage was observed to emerge from the wet side to the dry side across all examined cross sections. A summary of the analysis for each section is presented in **Table 4**. Graphical seepage outputs were generated for each cross-section depicting the model during the peak flood time and the subsequent peak flux time, which typically follows shortly after. The modelling outputs along with the model geometry used for each section are shown in **Appendix C.**

Table 4: Embankment Seepage Analysis Results Summary

Section	Embankment Geometry	Results
AA	Height 4.92, 1:2 Slopes	No seepage of water, water table 1mbgl on dry side at peak flood and 0.8 mbgl post peak flood
BB	Height 4.92, 1:2 Slopes	No seepage of water, water table 1.5 mbgl on dry side at peak flood and 1.4 mbgl post peak flood
CC	Height 4.92, 1:3 Slopes	No seepage of water, water table 1.4 mbgl on dry side at peak flood and 1.3 mbgl post peak flood
DD	Height 4.92, 1:3 Slopes	No seepage of water, water table 1.7 mbgl on dry side at peak flood and 1.7 mbgl post peak flood

6.2 River Walls Modelling Results

Floodwalls designed for the water course to the east of the site have also undergone modelling using SEEP/W software. Three cross sections were analysed (EE, FF and GG) and their locations are shown in **Appendix A**.

Similar to the embankment modelling, the results do not show any seepage occurring on the dry side of the walls during the design flood event. A summary of the analysis for each section is presented in **Table 5.** Graphical seepage outputs were generated for each cross-section depicting the model during the peak flood time and the subsequent peak flux time, which typically follows shortly after. The modelling outputs along with the model geometry used for each section are shown in **Appendix C.**

Table 5: Flood Walls Seepage Analysis Results Summary

Section	Defence Geometry	Results
EE	Sheet Plies, 3 metres above ground level and 6 mbgl	No seepage of water, water table 1.3 mbgl on dry side at peak flood and 1.3 mbgl post peak flood

Section	Defence Geometry	Results
FF	Sheet Plies, 3 metres above ground level and 6 mbgl	No seepage of water, water table 1.7 mbgl on dry side at peak flood and 1.7 mbgl post peak flood
GG	Sheet Plies, 3 metres above ground level and 6 mbgl	No seepage of water, water table 1.7 mbgl on dry side at peak flood and 1.6 mbgl post peak flood

7. Conclusion

Seepage risk analysis was conducted using SEEP/W software to perform transient modelling for critical sections of the Scheme. The modelling was based on a hydrogeological conceptualisation of the site which was developed based on a combination of desk study findings, previous site investigation results, and the proposed design.

A hydrogeological conceptual model was developed for the site based on online geological information and records from previous ground investigations. The conceptual model informed the development of the modelling cross-sections which were used in SEEP/W for the seepage risk analyses.

Seepage analyses were performed for the flood protection structures proposed to assess the potential seepage below the structures during the design flood event. Transient analyses were carried out at 4 cross- sections of the proposed tidal embankment and 3 cross- sections of the proposed flood walls using SEEP/W. The modelling sections were selected as being at highest risk of seepage based on the most onerous existing topography in relation to the Scheme and on the maximum height difference between peak flood level and ground elevation on the dry side.

The seepage analysis showed that there is no risk of water seepage from the wet side to the dry side of the structures across all examined cross sections during the design flood event.

In conclusion, the seepage analysis indicates that no seepage issues are expected to arise from flooding at the Scheme based on current modelling parameters and assumptions. The Scheme properties and position have a major influence on seepage flows and the analyses will need to re-run if any changes are made to the design that present more onerous conditions.

Appendix A

Site Layout / Cross Section Locations

Legend

- Modelling Cross Sections
- Flood Walls
- Tidal Embankments
- Conceptual Cross Section NWSE
- Conceptual Cross Section NESW

REV	SUIT	DATE	DESCRIPTION	BY	APP

West Dunbartonshire Council
Balfour Beatty FAIRHURST
SCAPE SCOTLAND CIVIL ENGINEERING

Gruggies Burn Flood Alleviation Scheme
153386
Site Location Plan
SCALE: 1:4500

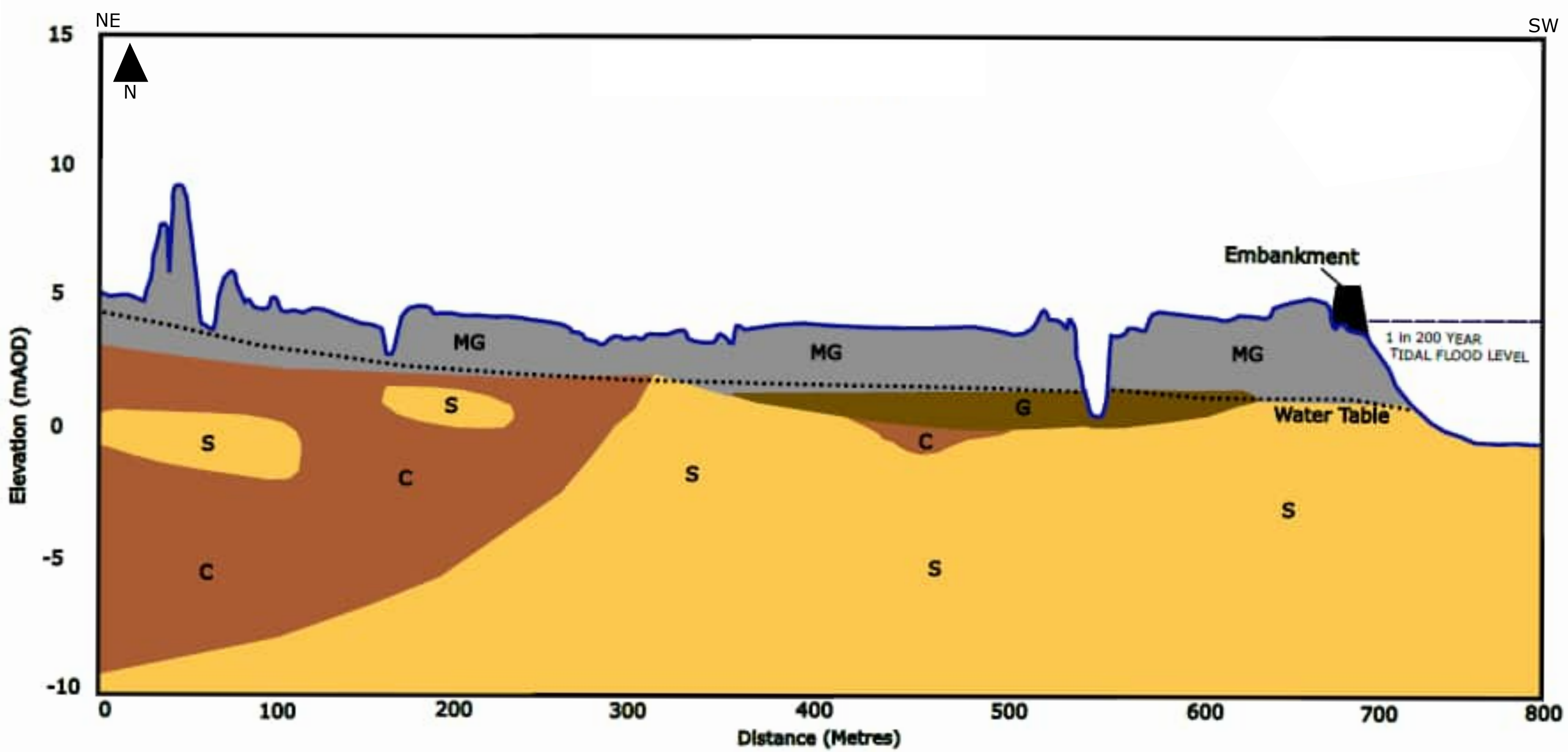
DESIGN: TR	DRAWN: TR	CHK: HT	APP: HT

DATE: 18/03/2024
PROJ: 153386
DWG: 153386/GIS/01

SHEET: 1 of 1	VERSION: 01

Appendix B

Conceptual Cross Sections



Legend

- MG - Made Ground
- G - Gravel
- C - Clay
- S - Sand

REV	SUIT	DATE	DESCRIPTION	BY	APP

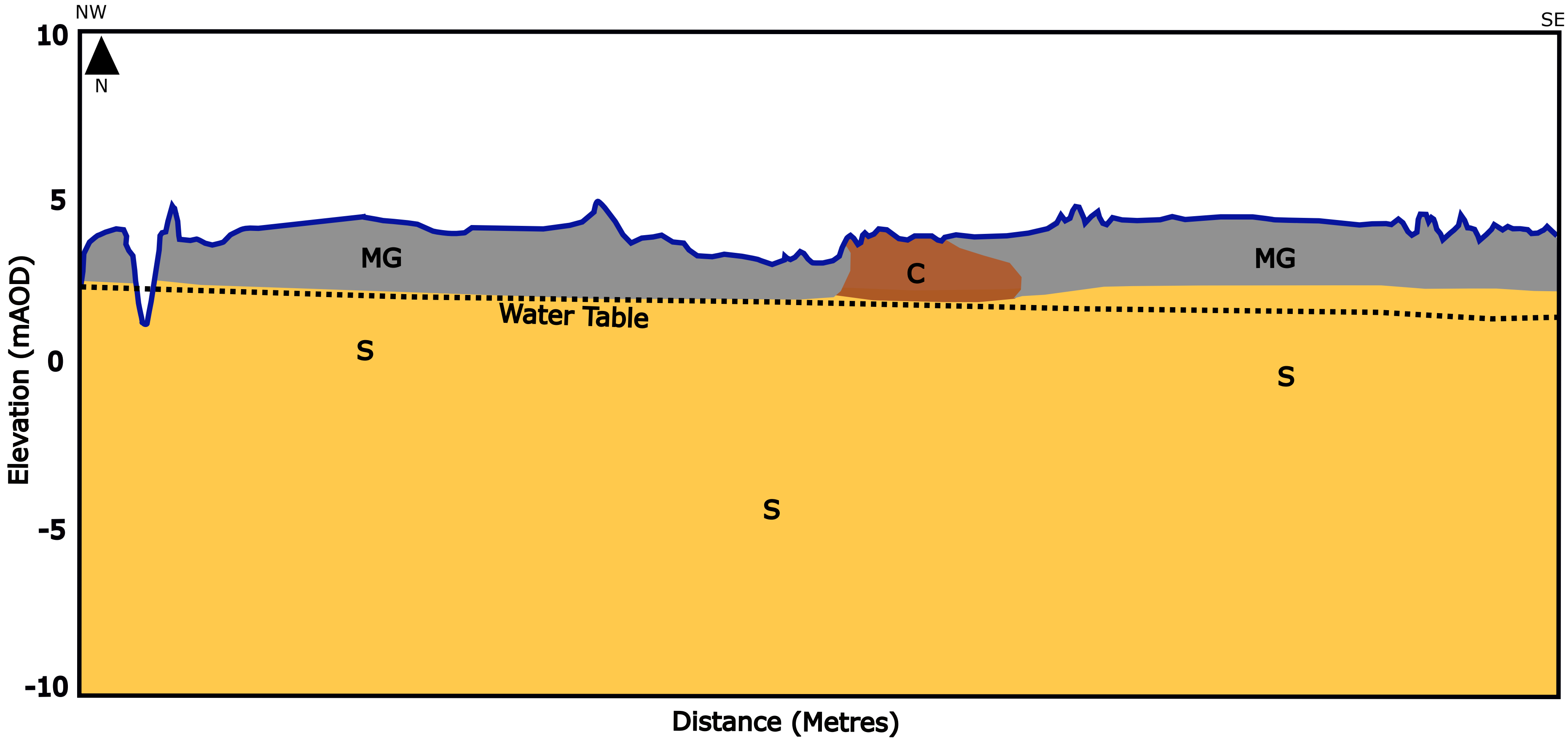
NESW Cross Section

Gruggies Burn Flood Alleviation Scheme
Conceptual Cross Section Drawings

DESIGN:	DRAWN:	CHK:	APP:
TR	TR	HT	HT

DATE: 18/03/2024
PROJ: 153386
DWG: 153386/02

SHEET:	VERSION:	STATUS: S0
1	1	



Legend

- MG - Made Ground
- G - Gravel
- C - Clay
- S - Sand

REV	SUIT	DATE	DESCRIPTION	BY	APP

NWSE Cross Section

Gruggies Burn Flood Alleviation Scheme
Conceptual Cross Section Drawings

DESIGN: TR	DRAWN: TR	CHK: HT	APP: HT

DATE: 18/03/2024
PROJ: 153386
DWG: 153386/03

SHEET: 1	VERSION: 1	STATUS: S0

Appendix C

Modelling Cross Sections

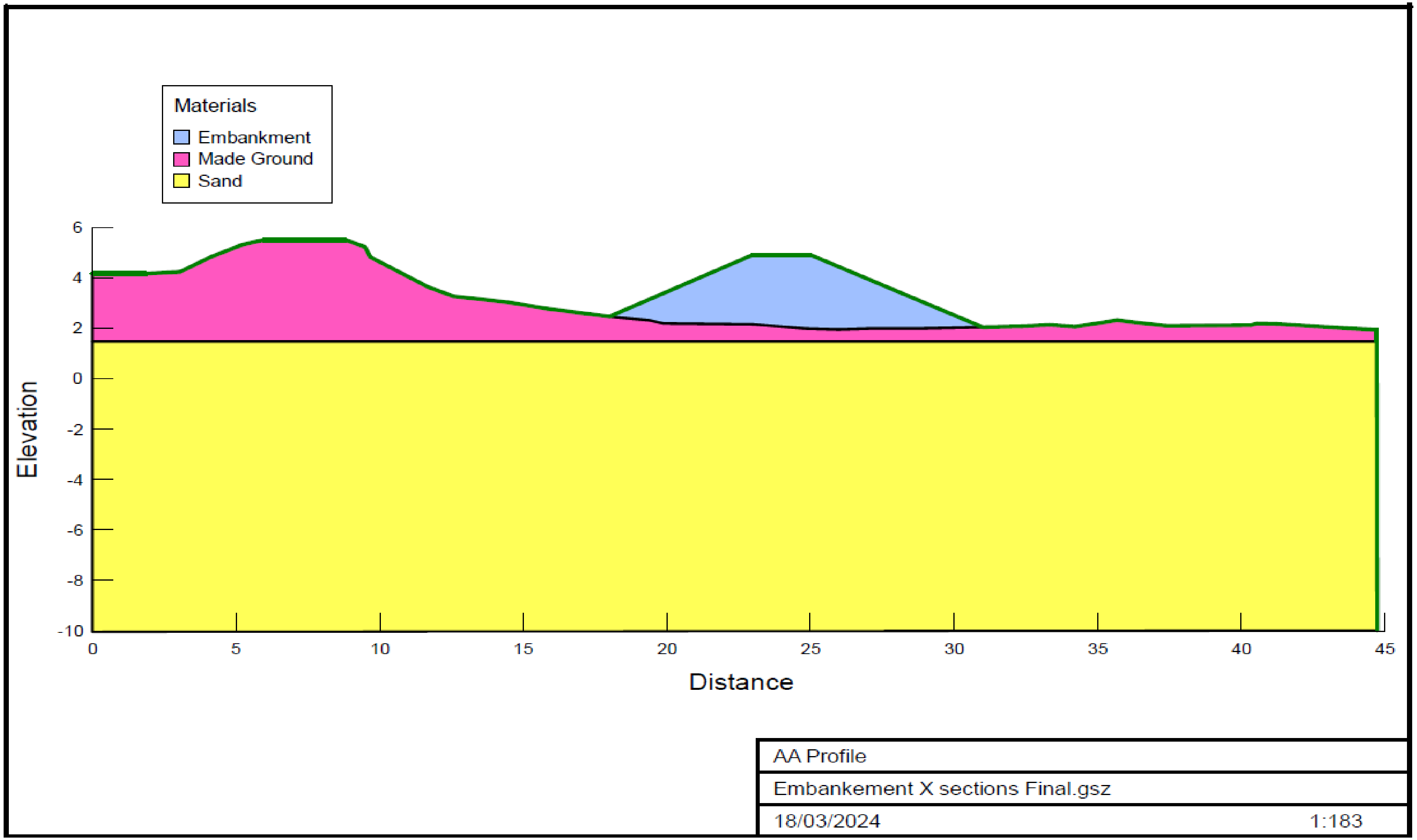


Figure 2:Cross-Section AA Model Geometry

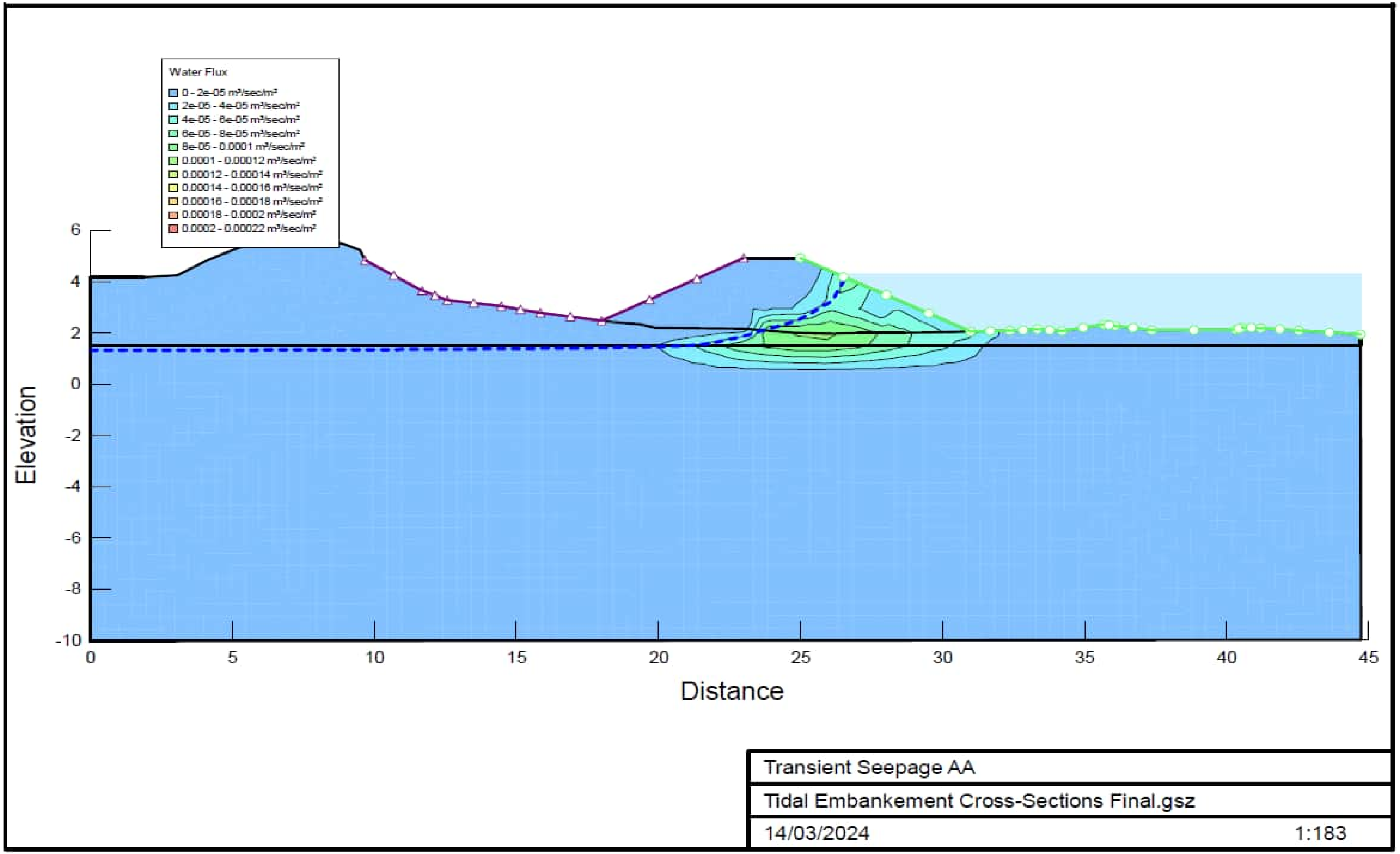


Figure 3: Cross-Section AA Groundwater Flux during Peak Tidal Flood.

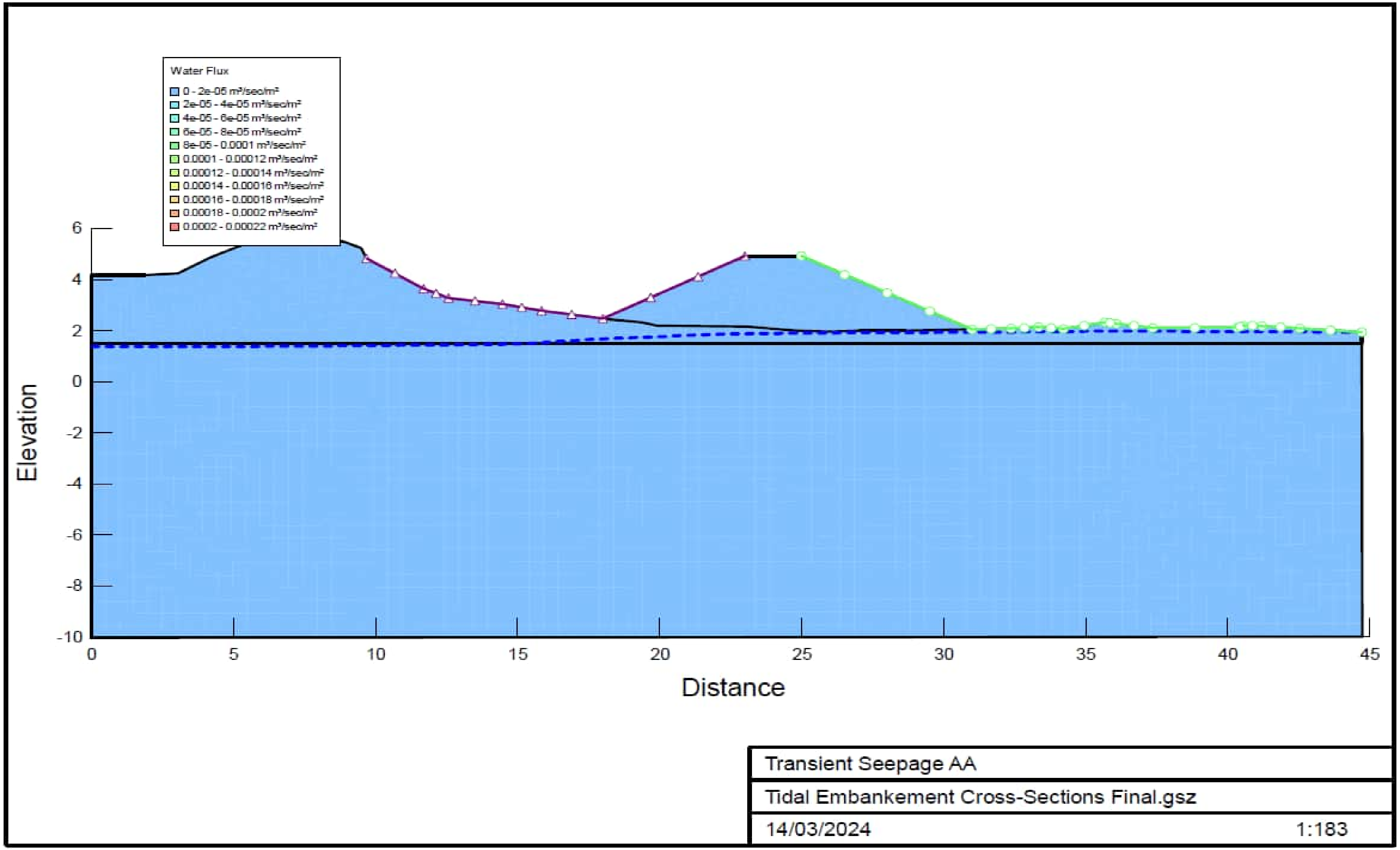


Figure 4: Cross-Section AA 5 hours post Peak Tidal Flood. No seepage on dry side of embankment.

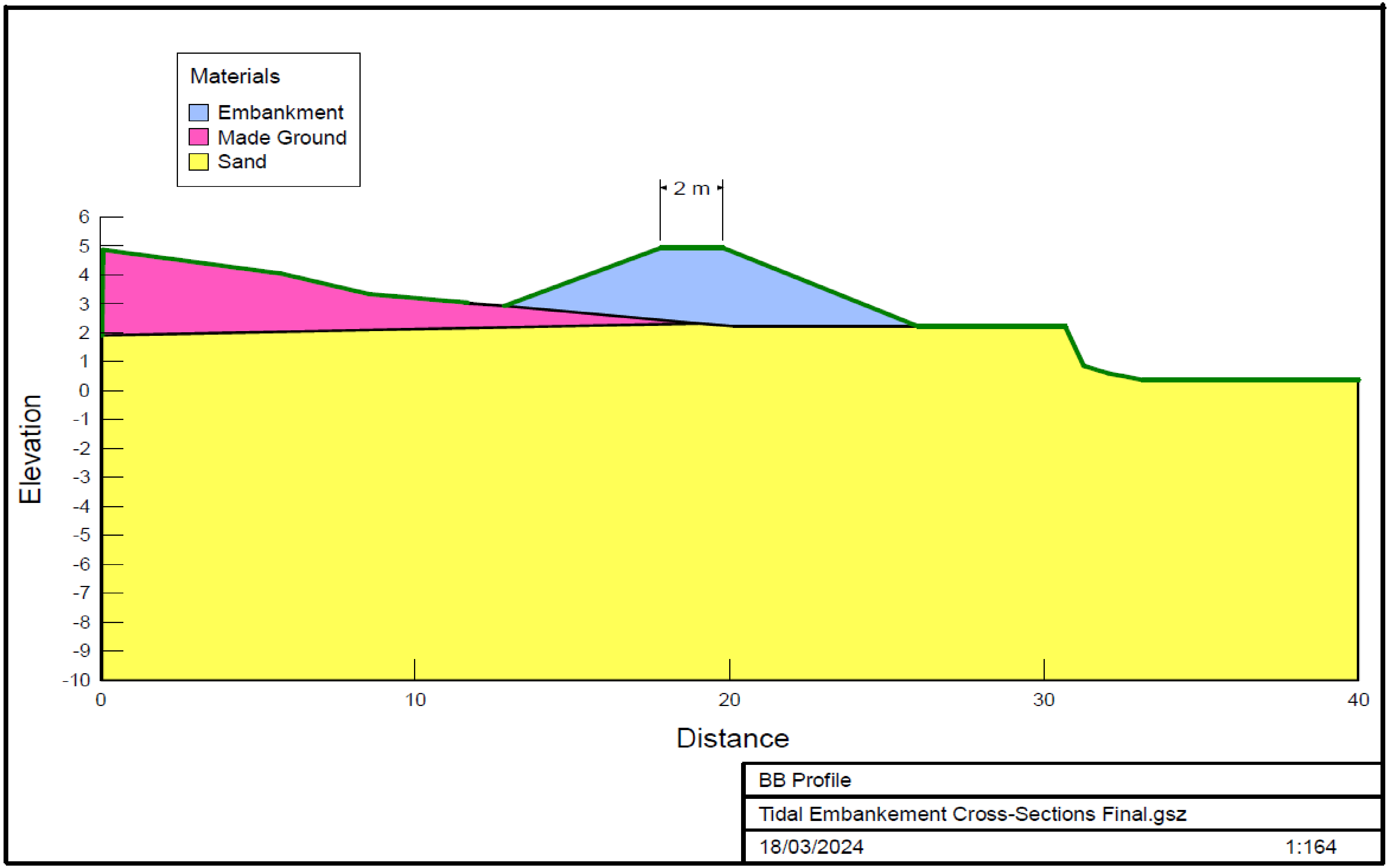


Figure 5: Cross-section BB Model Geometry.

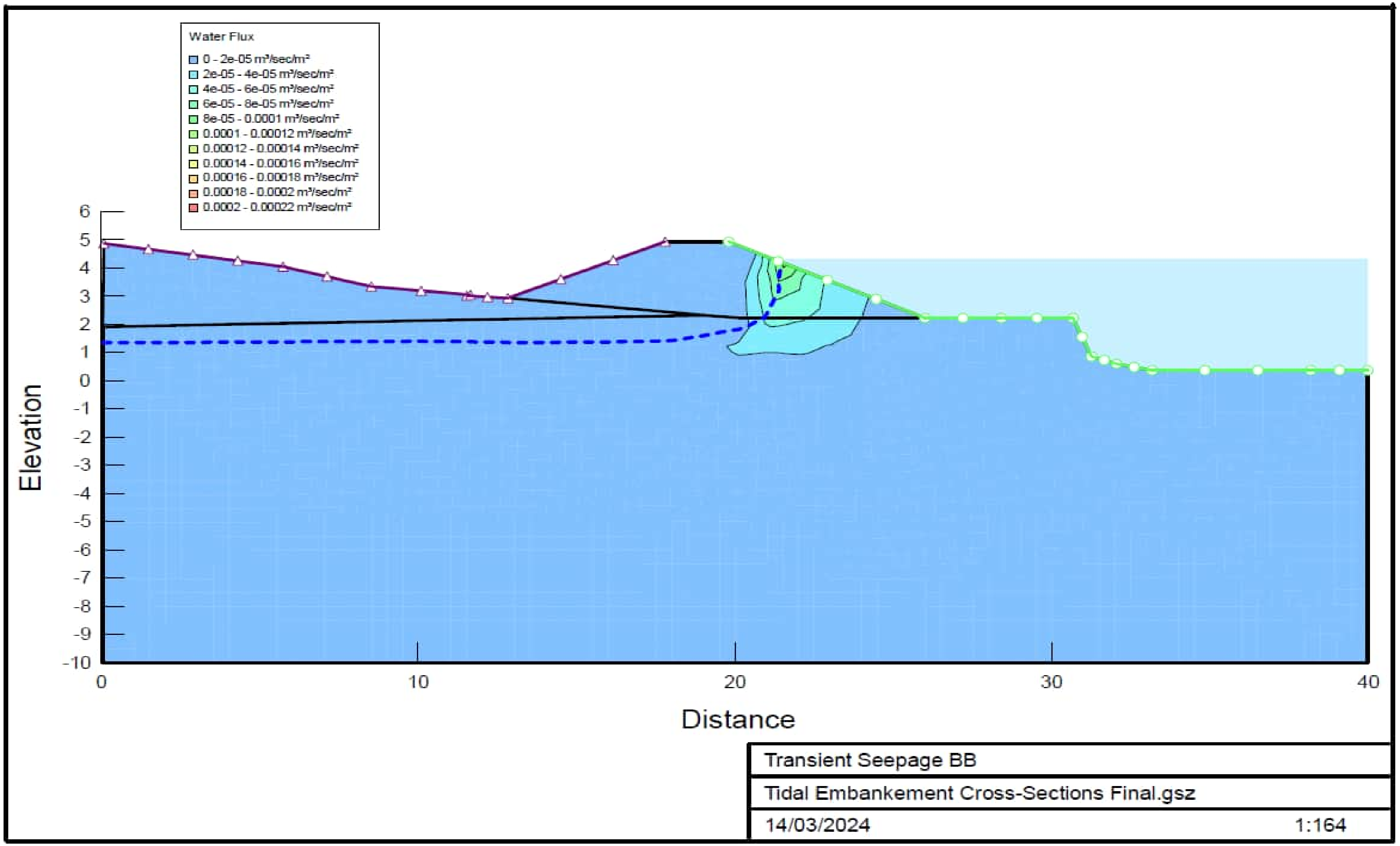


Figure 6:Cross-Section BB Groundwater Flux during Peak Tidal Flood

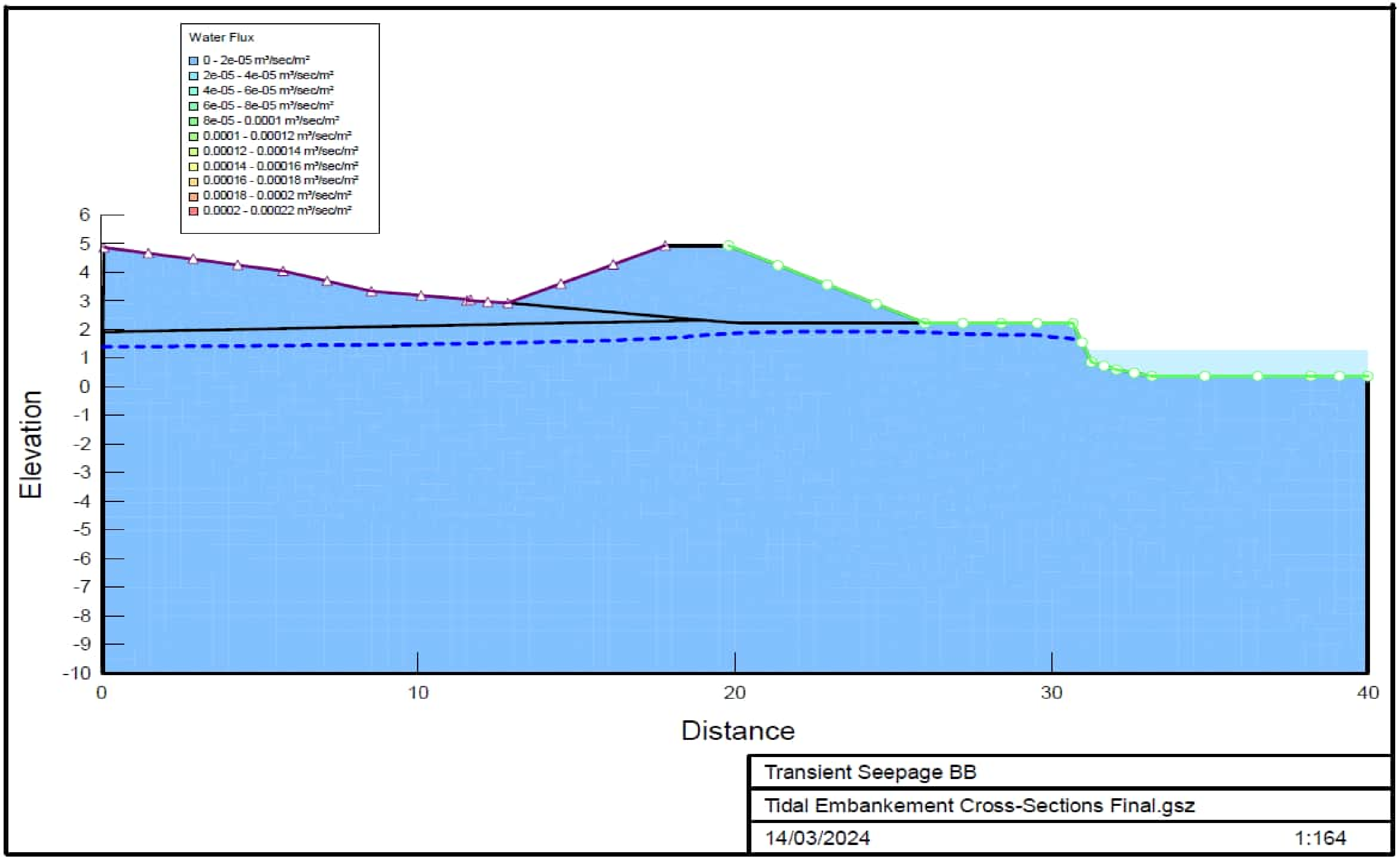


Figure 7:Cross-Section BB Groundwater Flux 5 hours post Peak Tidal Flood. No seepage on dry side of embankment

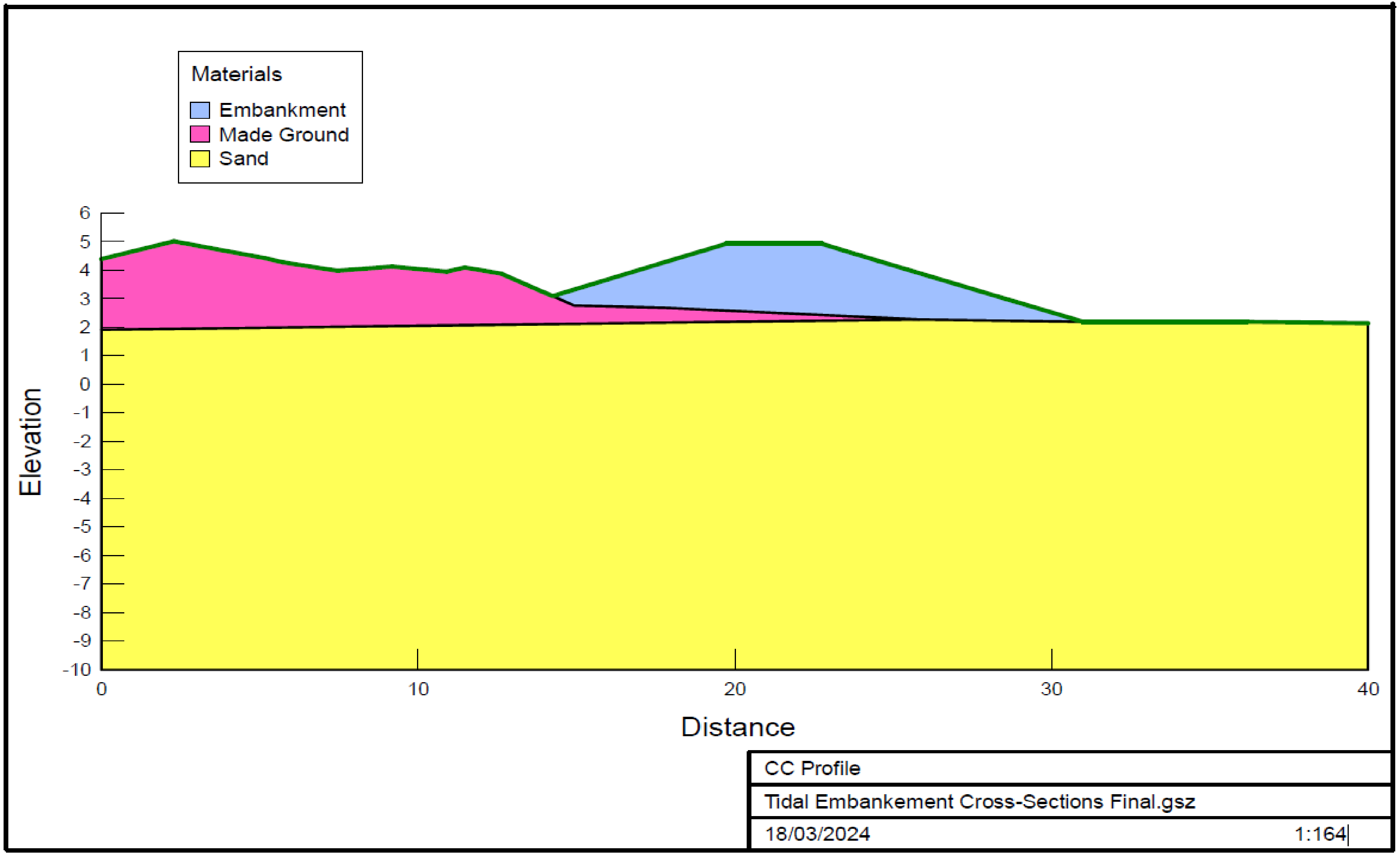


Figure 8:Cross-section CC Model Geometry

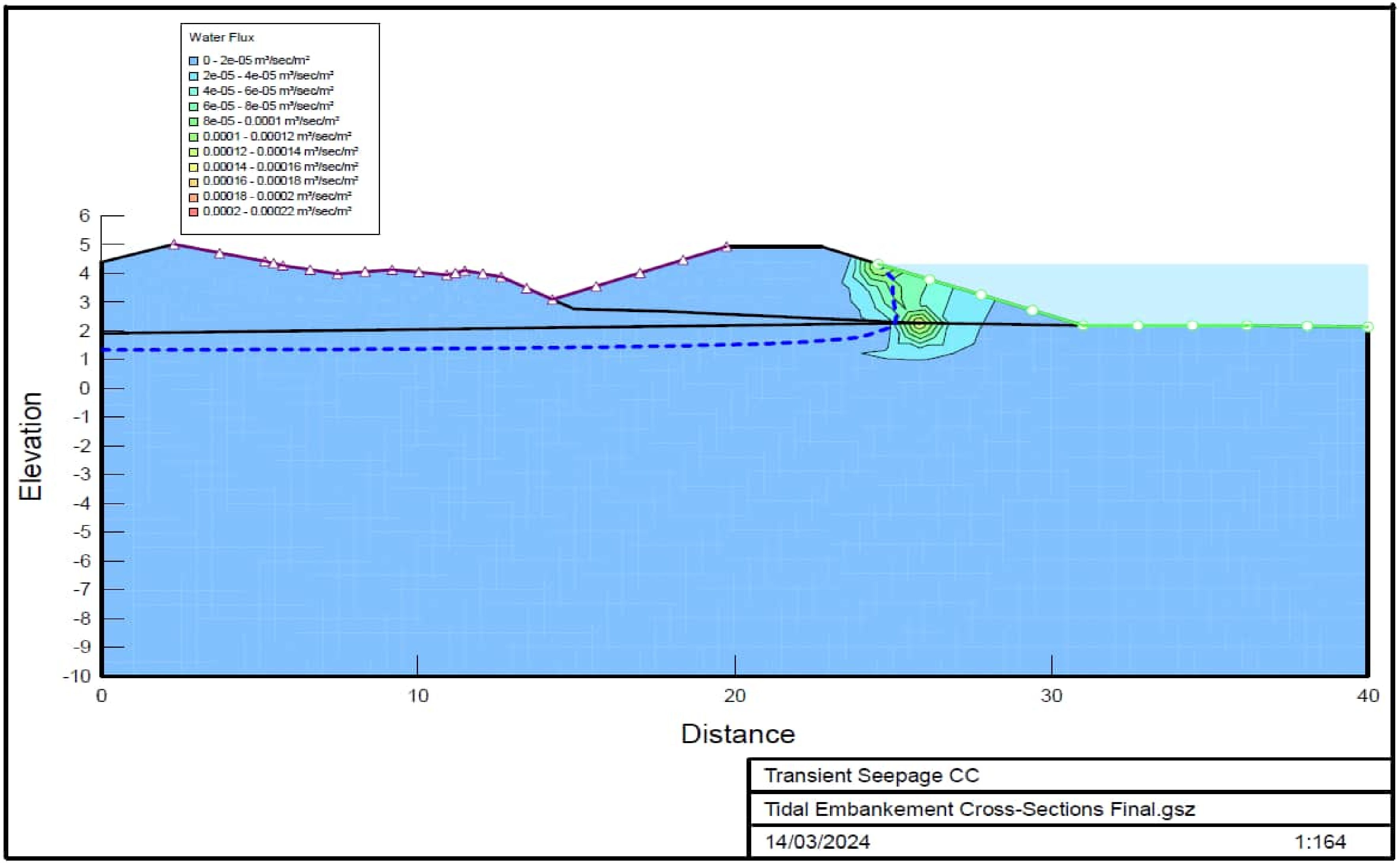


Figure 9:Cross-Section CC Groundwater Flux during Peak Tidal Flood

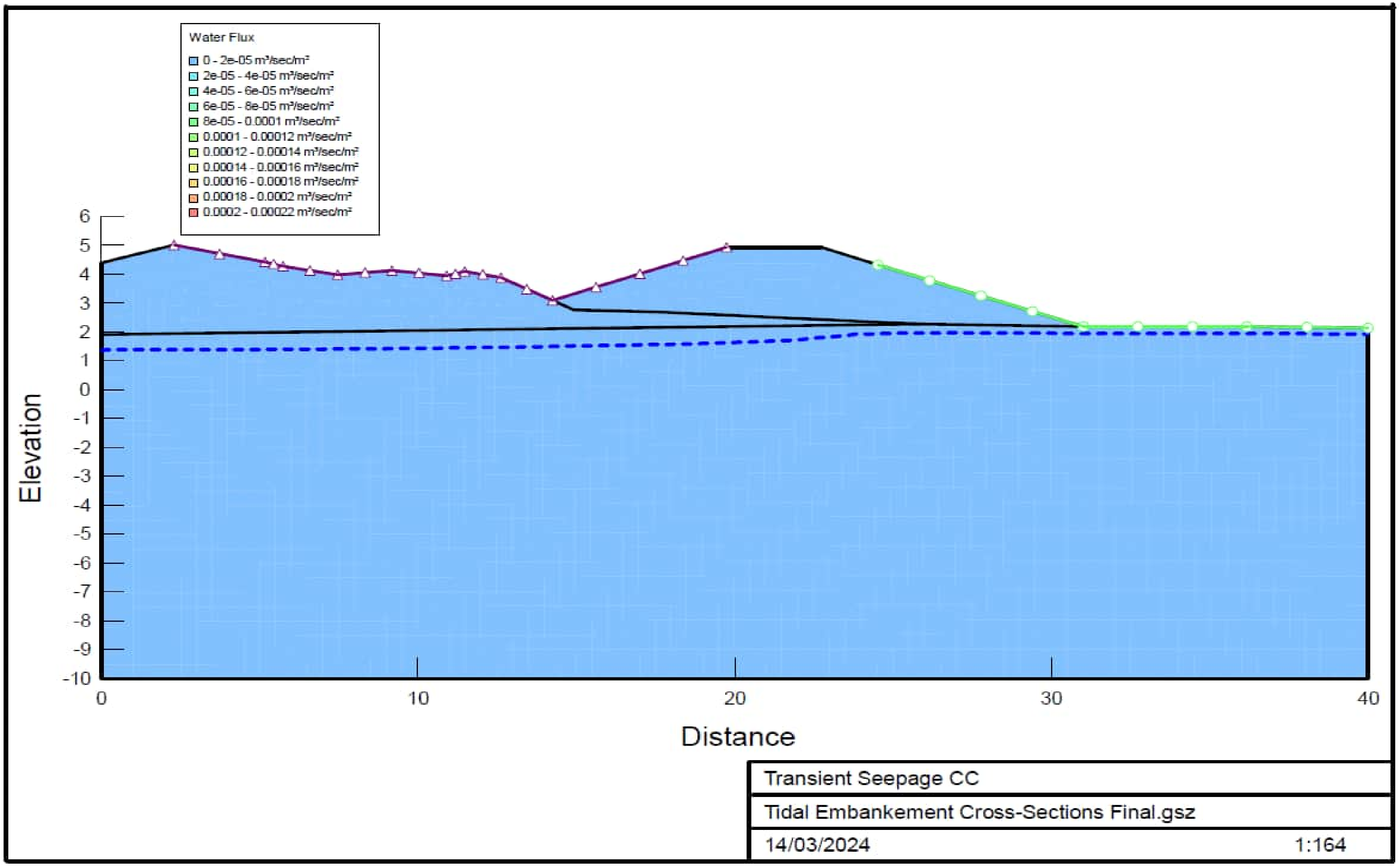


Figure 10:Cross-Section CC Groundwater Flux 5 hours post Peak Tidal Flood. No seepage on dry side of embankment

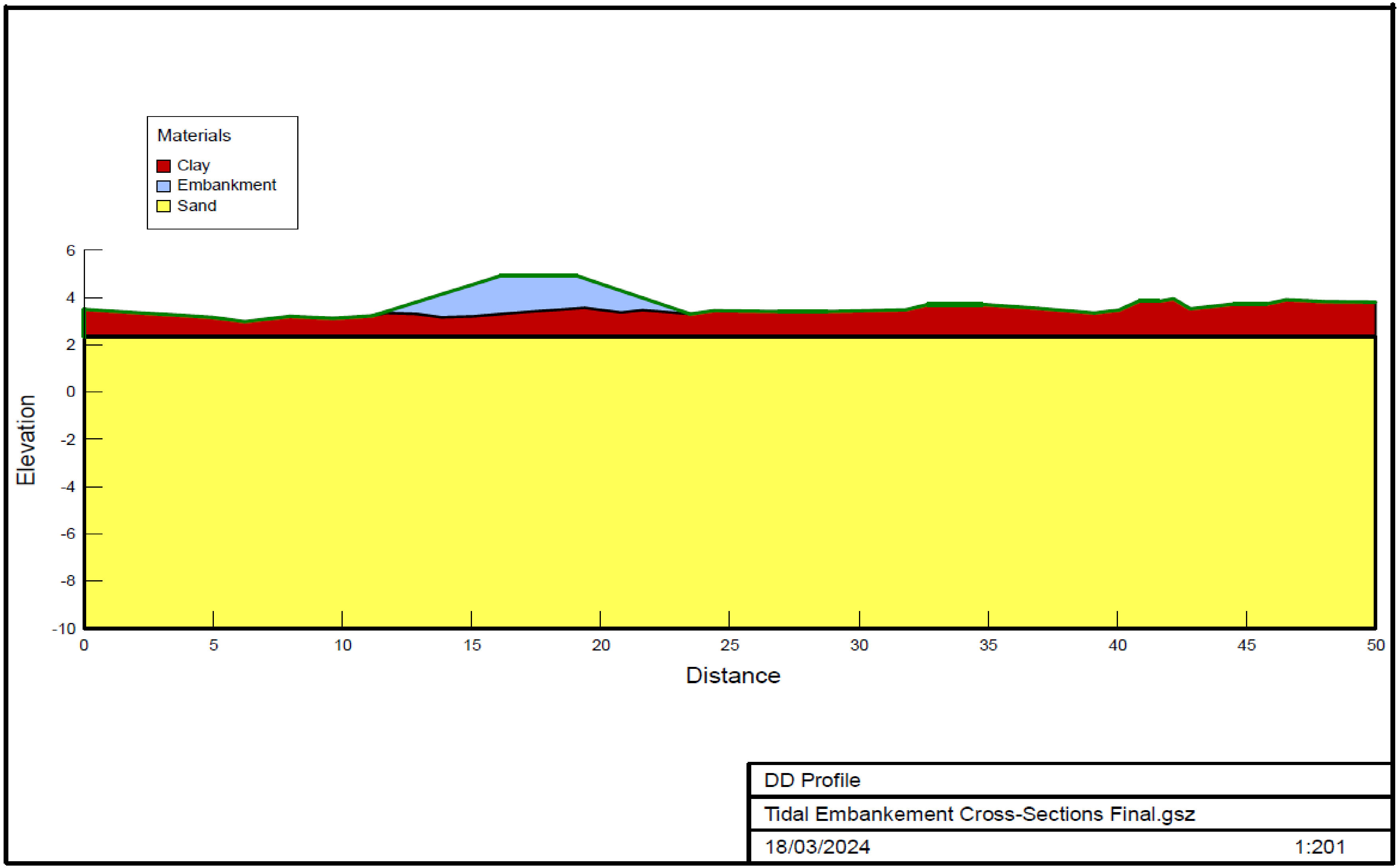


Figure 11:Cross-section DD Model Geometry

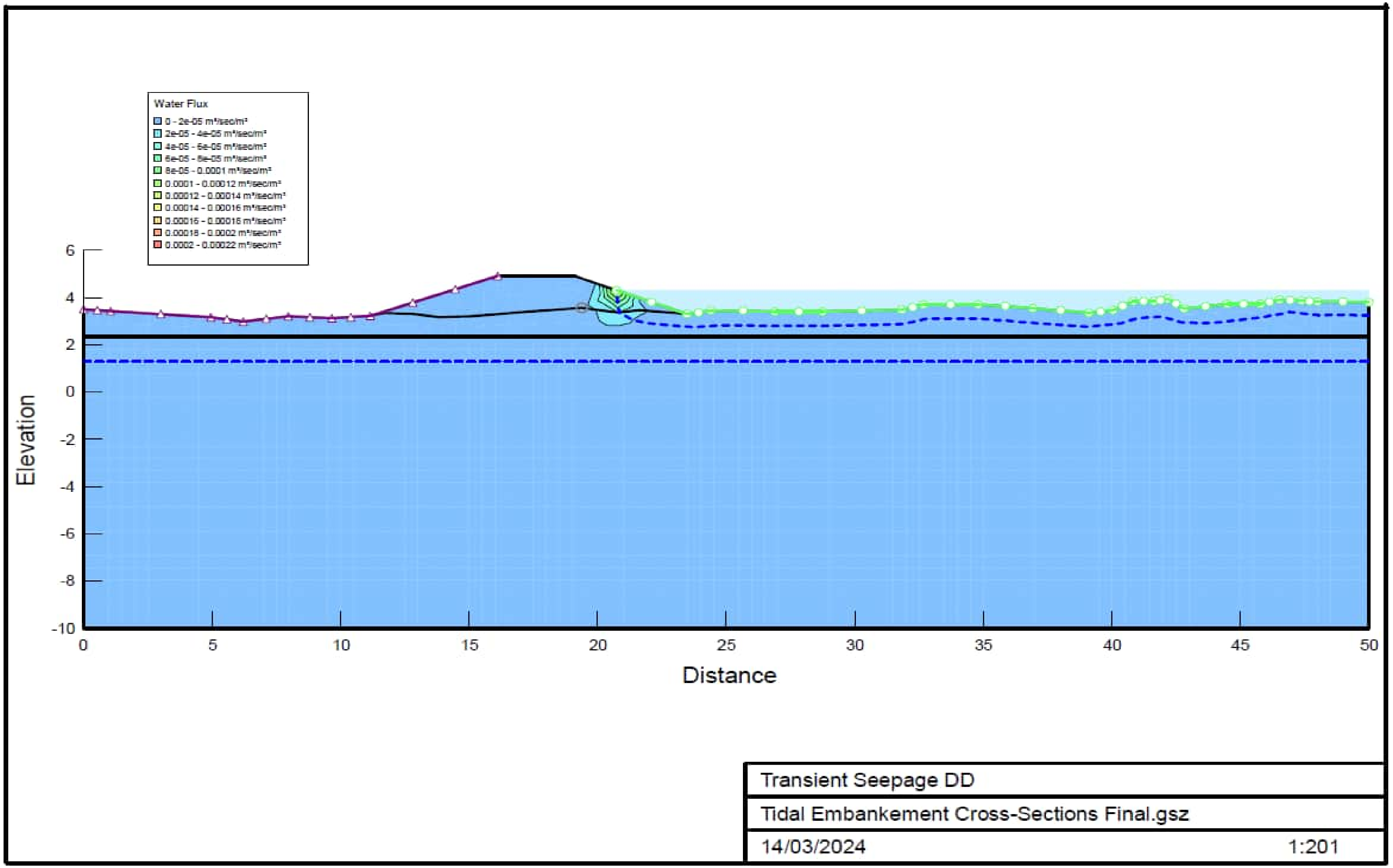


Figure 12:Cross-Section DD Groundwater Flux during Peak Tidal Flood

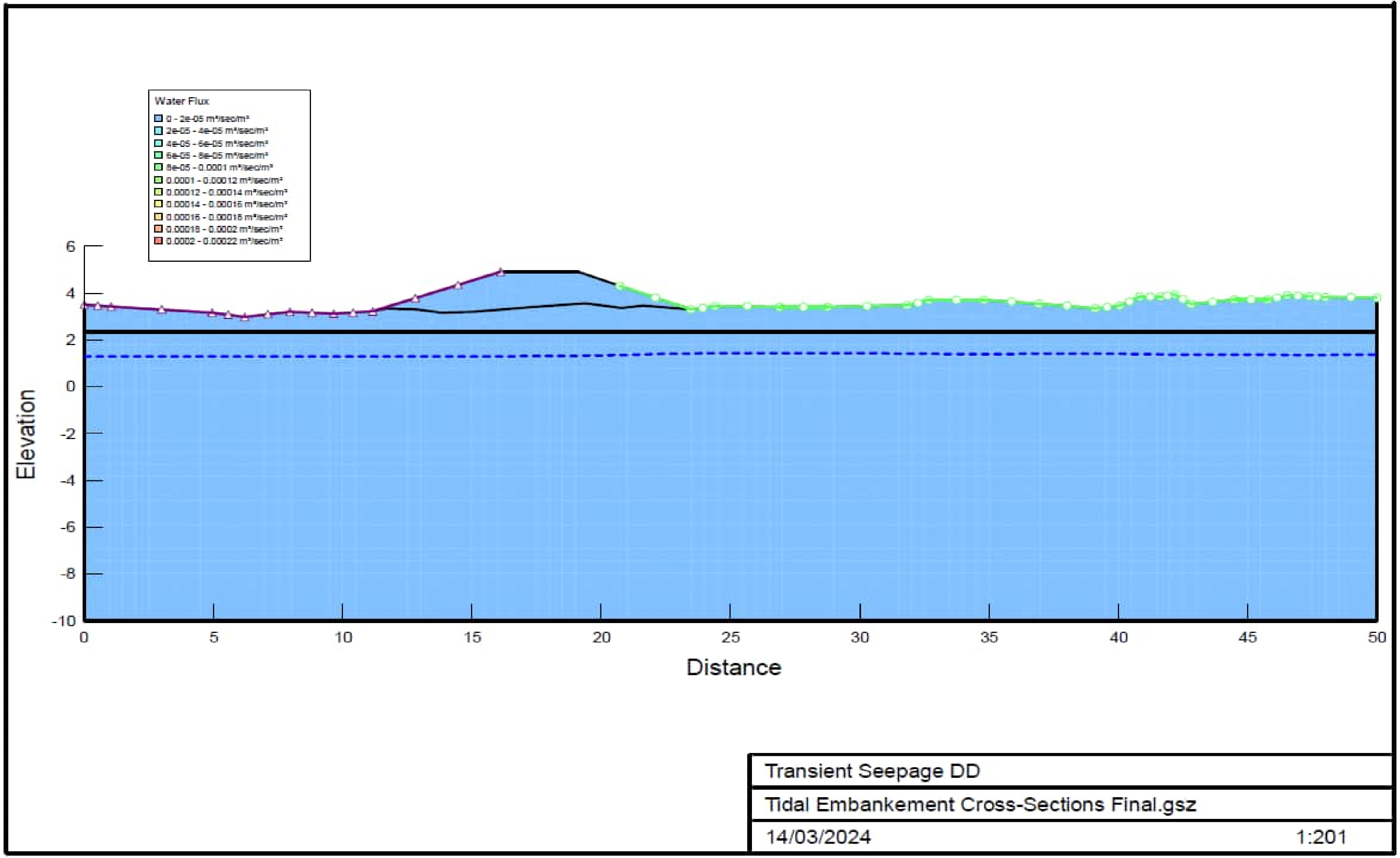


Figure 13:Cross-Section DD Groundwater Flux 5 hours post Peak Tidal Flood. No seepage on dry side of embankment

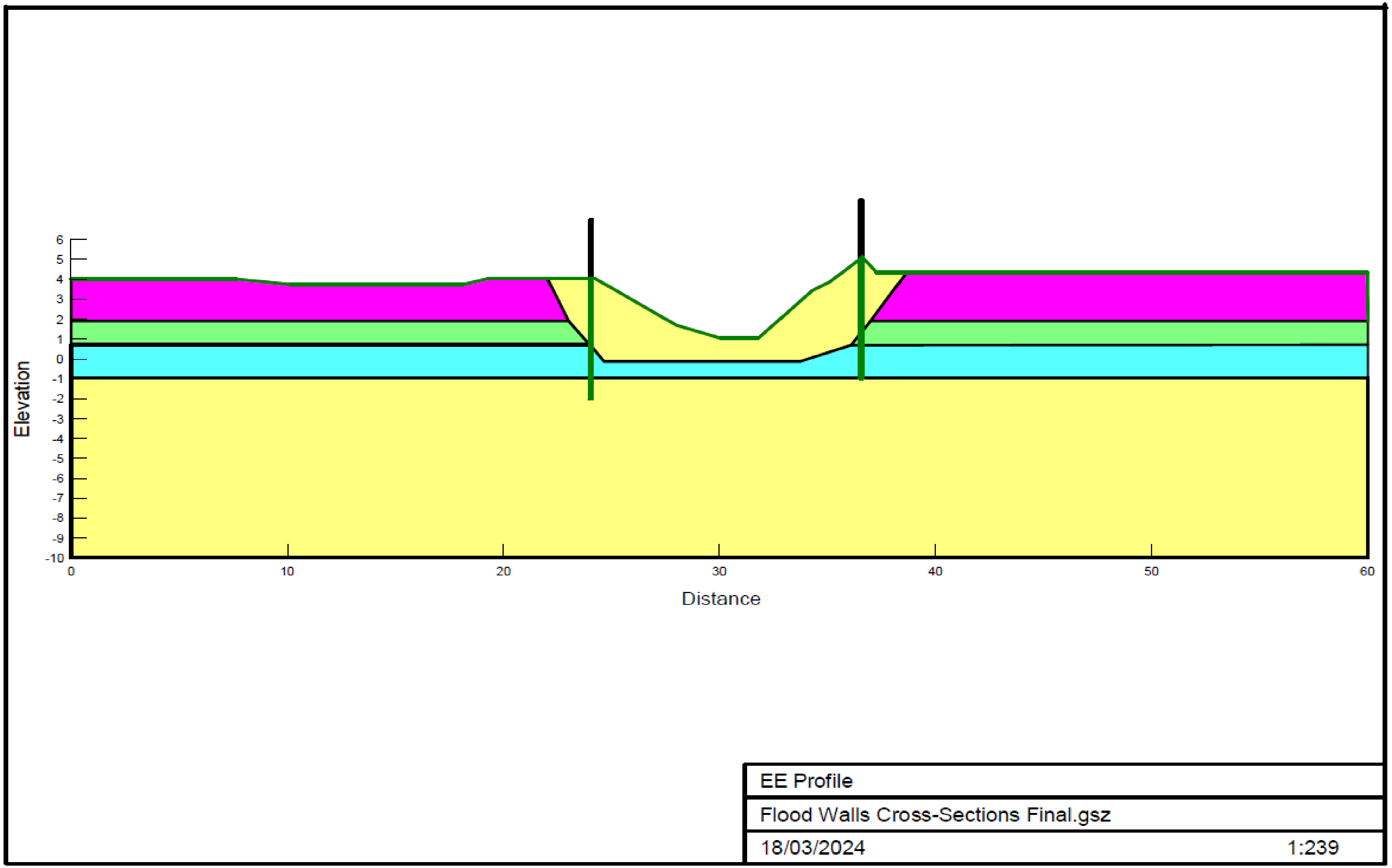


Figure 14:Cross-section EE Model Geometry

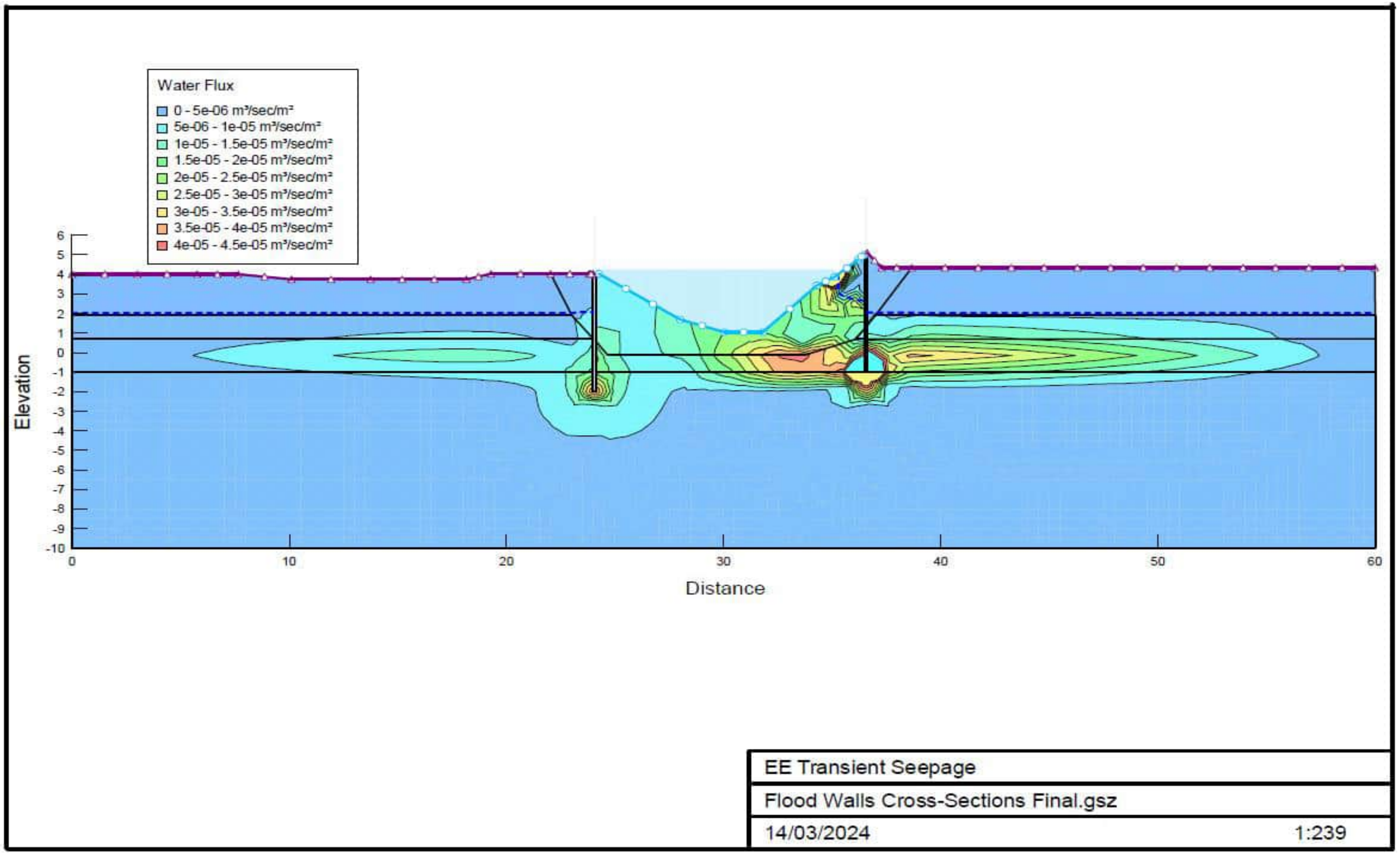


Figure 15:Cross-Section EE Groundwater Flux during Peak Tidal Flood

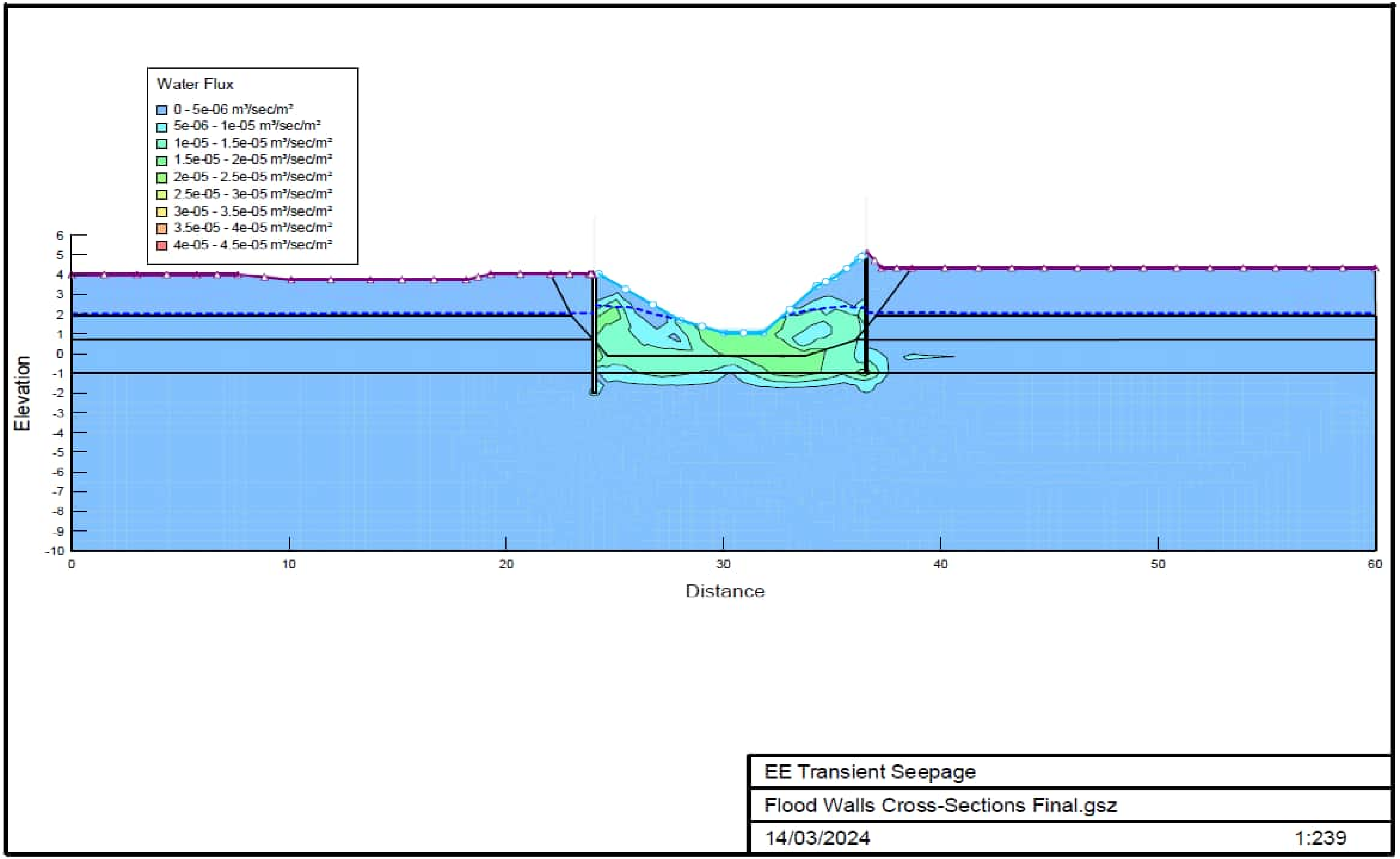


Figure 16:Cross-Section EE Groundwater Flux 5 hours post Peak Tidal Flood. No seepage on dry side of embankment

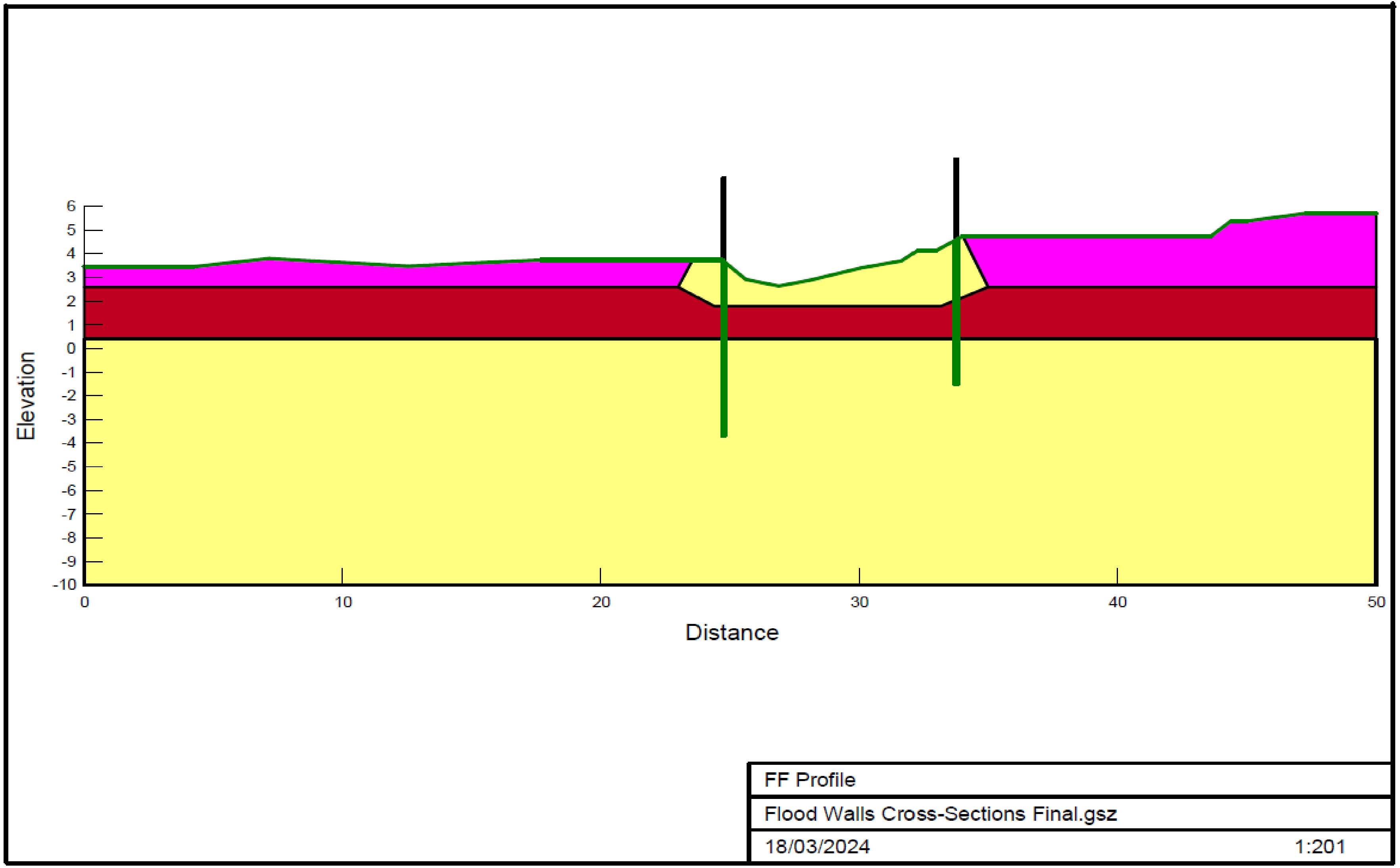


Figure 17:Cross-section FF Model Geometry

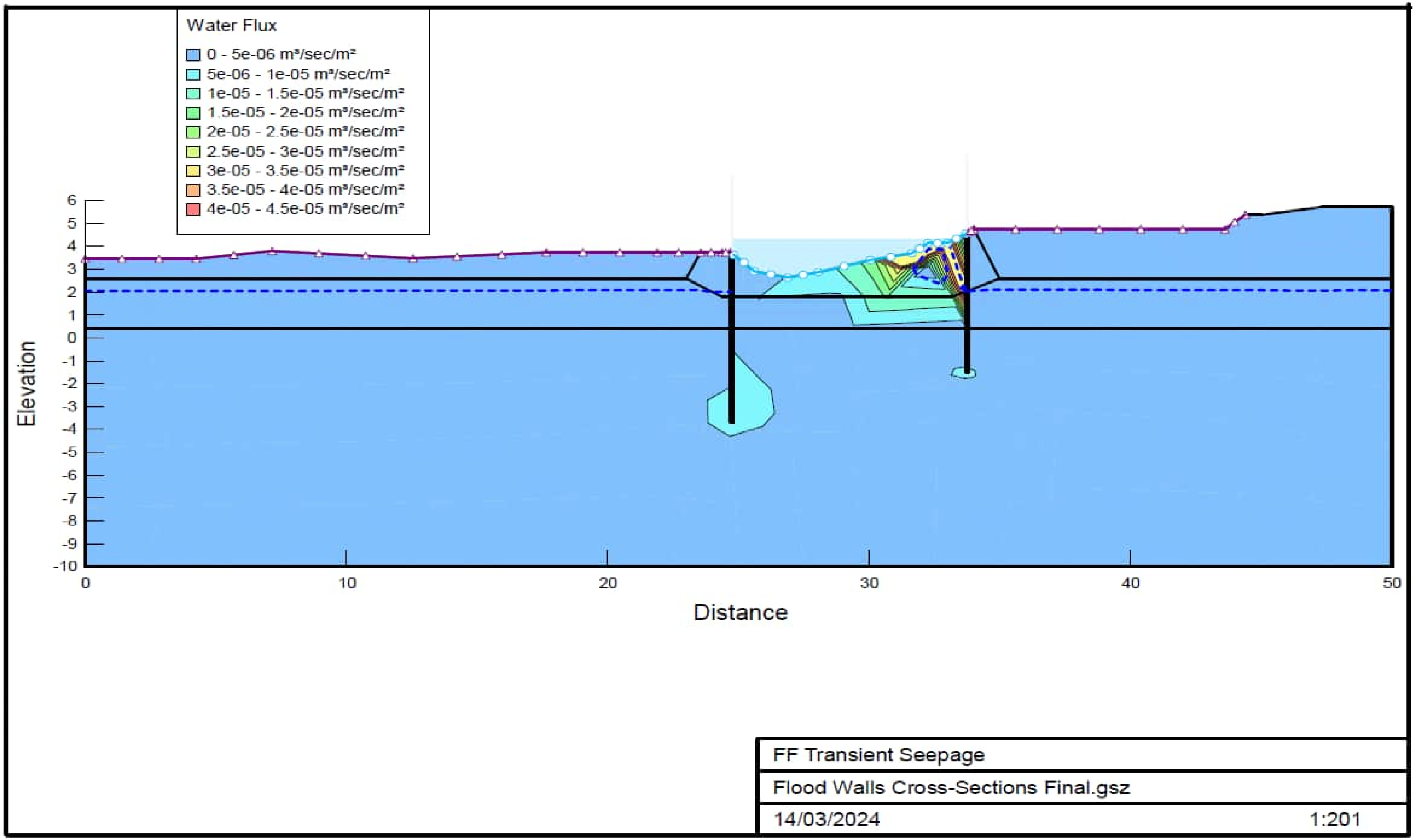


Figure 18:Cross-Section FF Groundwater Flux during Peak Tidal Flood.

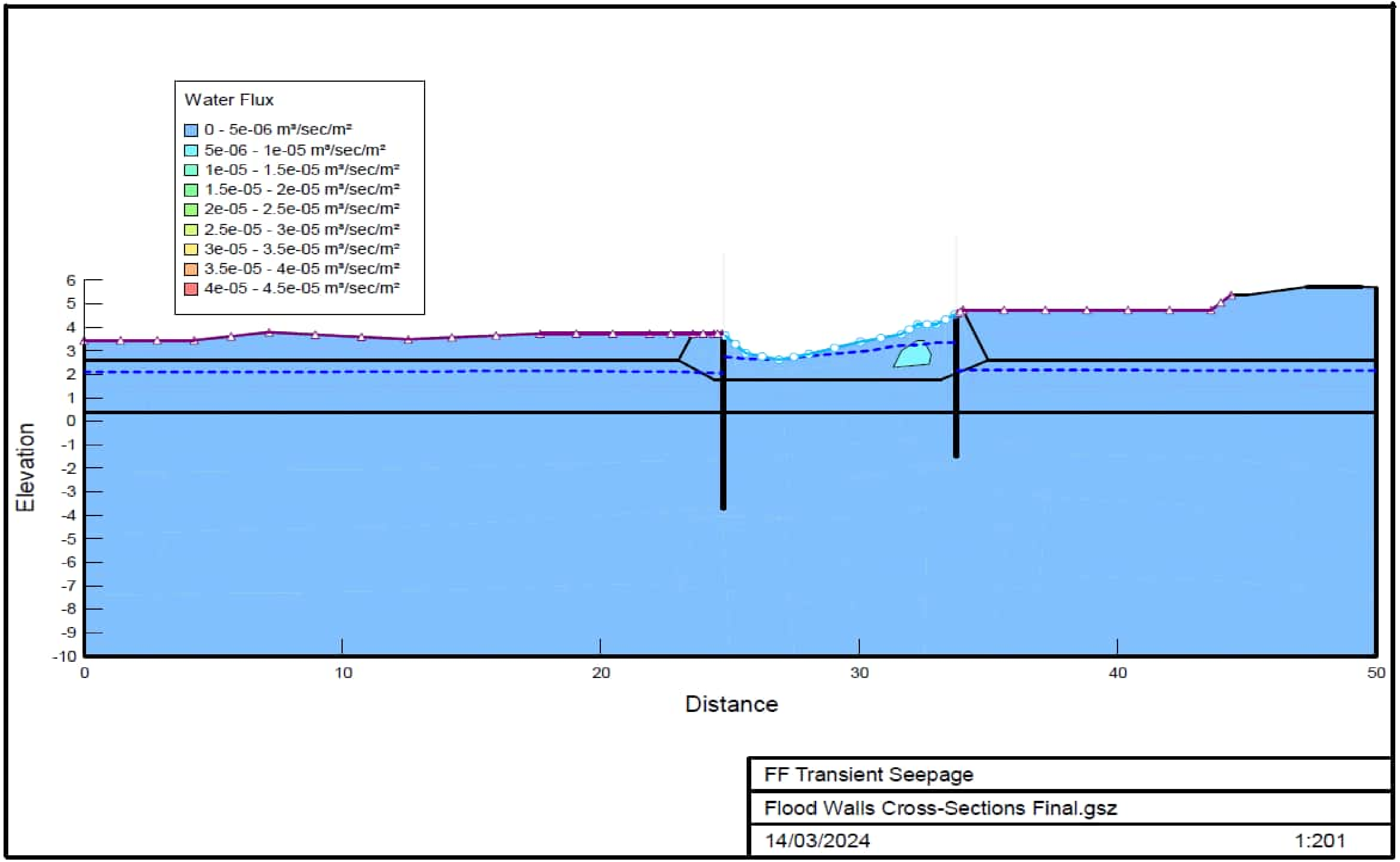


Figure 19:Cross-Section FF Groundwater Flux 5 hours post Peak Tidal Flood. No seepage on dry side of embankment

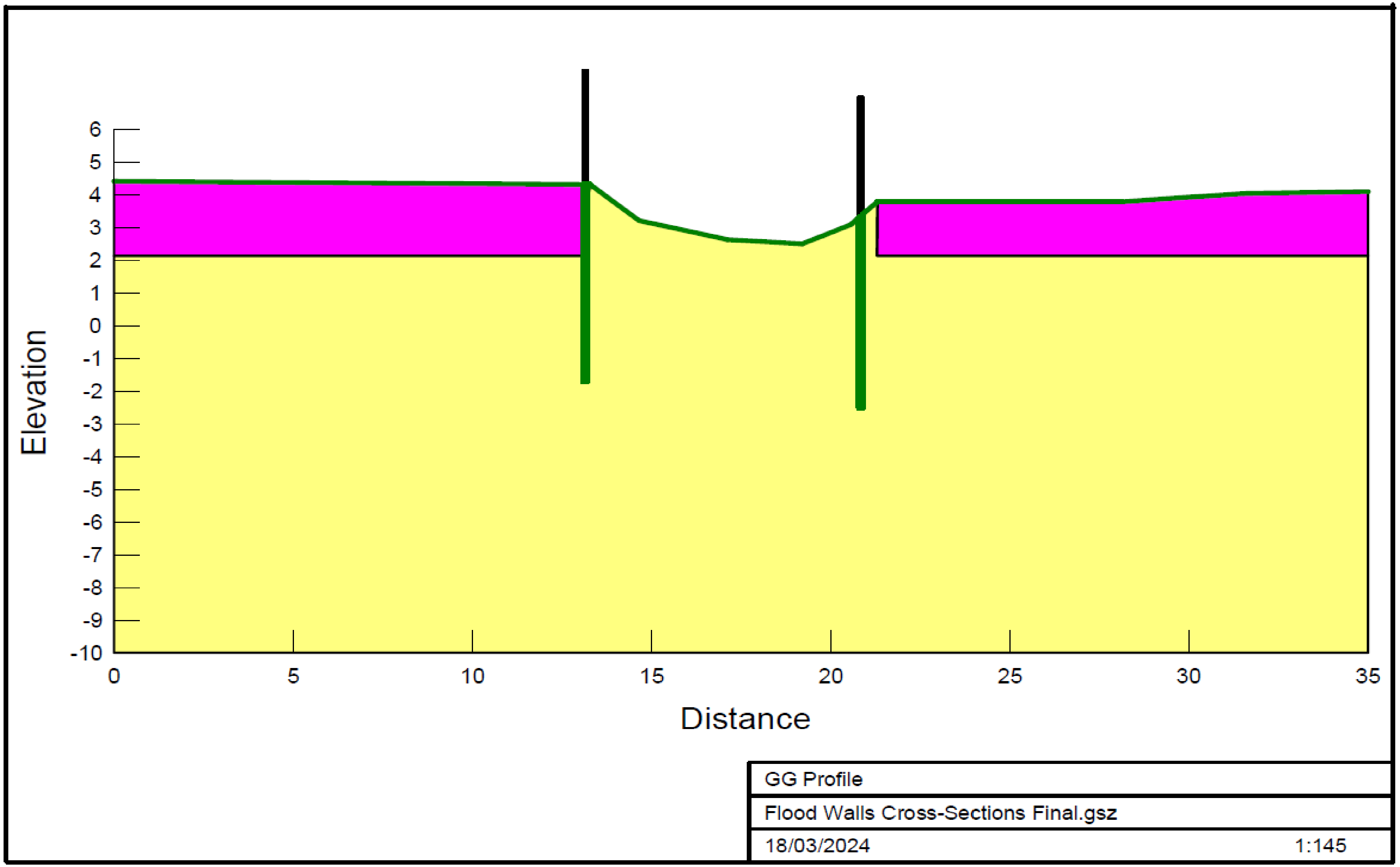


Figure 20:Cross-section GG Model Geometry.

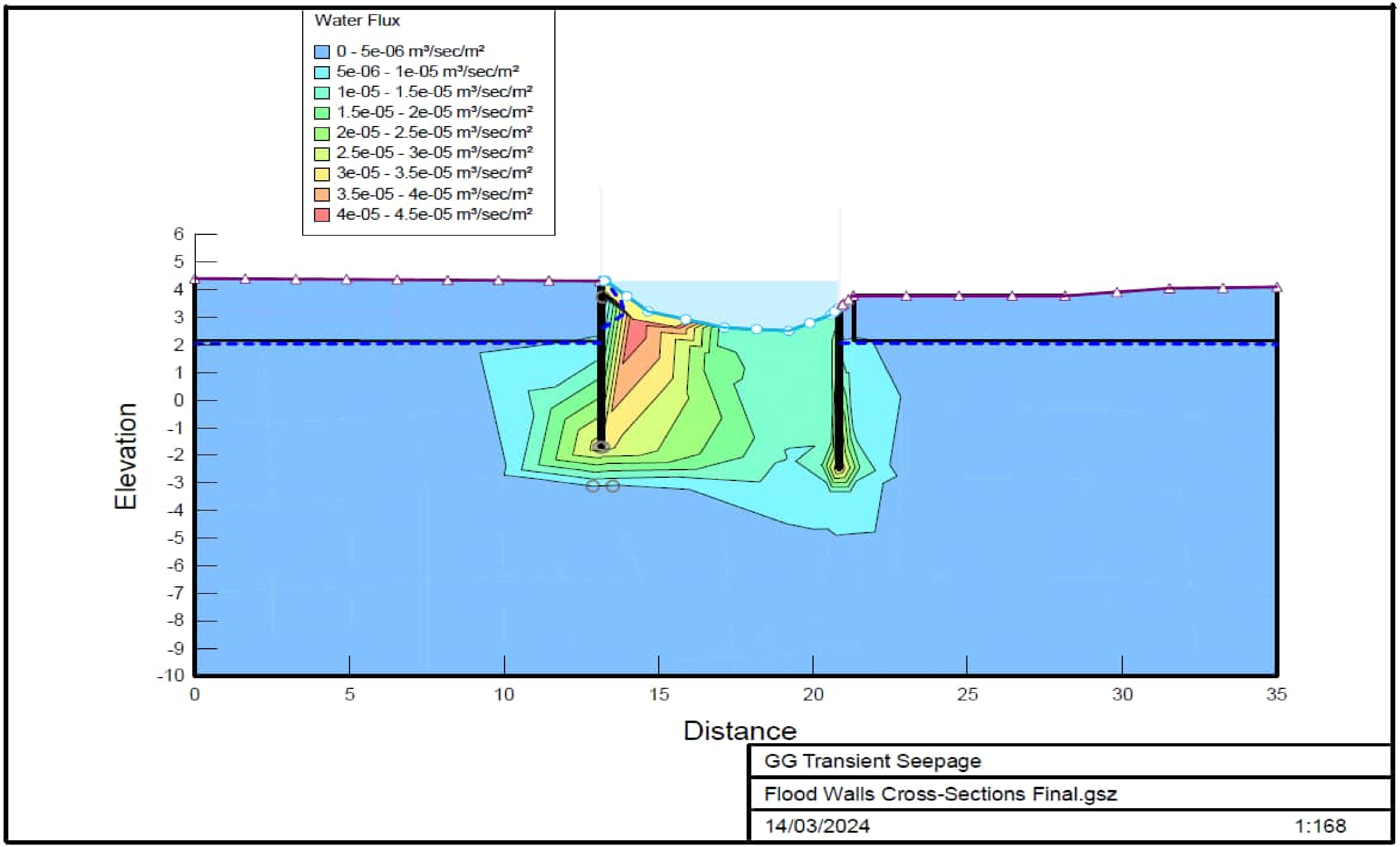


Figure 21:Cross-Section GG Groundwater Flux during Peak Tidal Flood

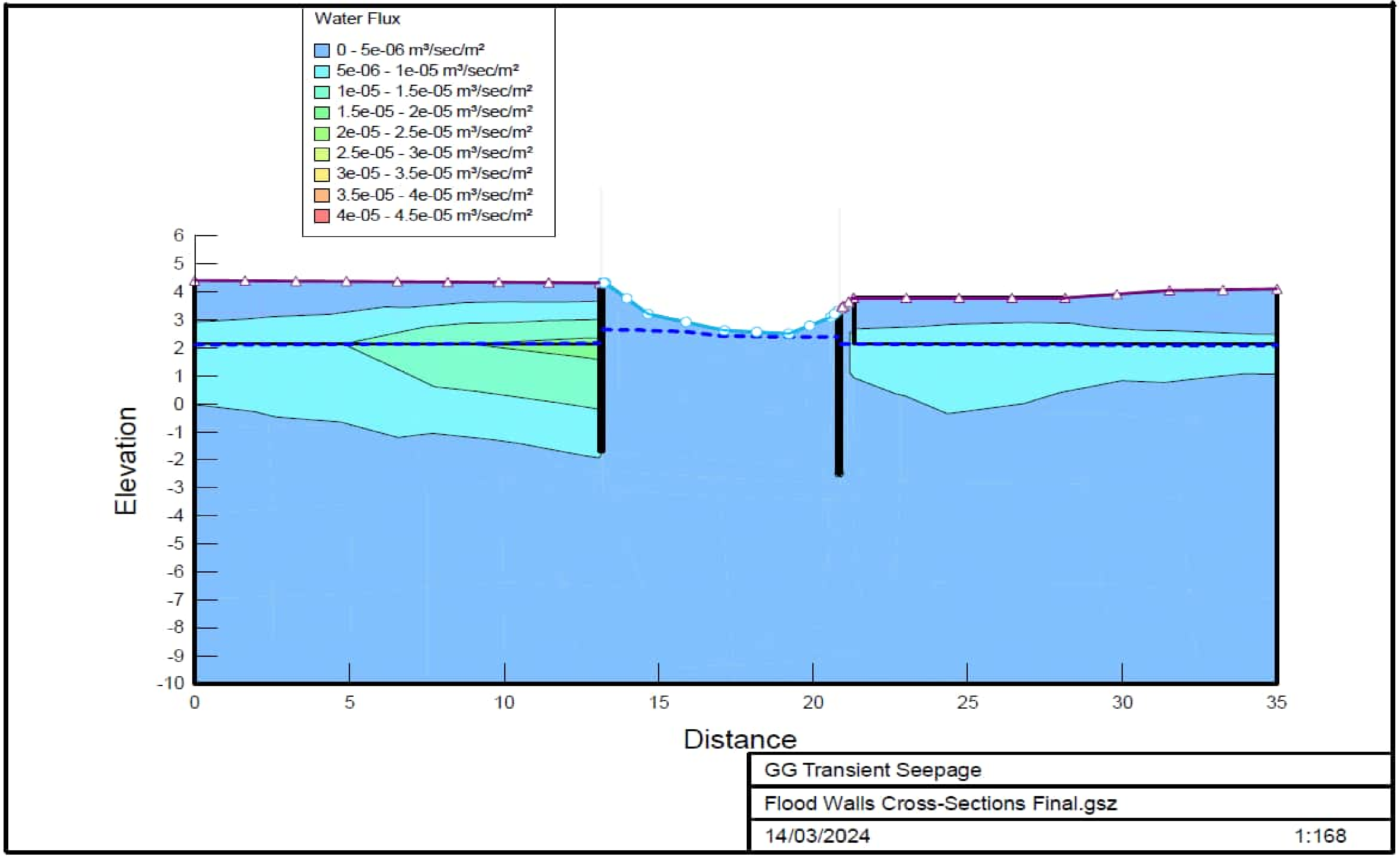


Figure 22:Cross-Section GG Groundwater Flux 5 hours post Peak Tidal Flood. No seepage on dry side of embankment

CIVIL ENGINEERING • STRUCTURAL ENGINEERING • TRANSPORTATION • ROADS & BRIDGES PORTS & HARBOURS • GEOTECHNICAL & ENVIRONMENTAL ENGINEERING • PLANNING & DEVELOPMENT • WATER SERVICES • HEALTH & SAFETY / CDM SERVICES

www.fairhurst.co.uk

Aberdeen
Aberdeen Westhill
Birmingham
Bristol
Dundee
Edinburgh
Elgin
Glasgow
Huddersfield
Inverness
Leeds
London
Newcastle upon Tyne
Plymouth
Sevenoaks
Taunton
Thurso
Watford

FAIRHURST