MASON EVANS

Geo-Environmental Consultants

ROTTERDAM WHARF,

PORT DUNDAS,

GLASGOW

REPORT ON

SITE INVESTIGATIONS

DATE

March 2024

CLIENT

Scottish Opera

Scottish Opera

Rotterdam Wharf,

Port Dundas,

Glasgow

Report on Site Investigations

Date of Issue:	March 2024
Report Status:	1st Edition
Project Reference:	P22/271
Prepared by:	Scott Armstrong – Principal Geo-Environmental Engineer
Reviewed and Approved by:	Andrew McGuire – Associate

Mason Evans Partnership Limited
100 Brand Street
Glasgow
G51 1DG

Revision History			
Issue Reference:	*Date:*	*Revision Detail:*	*By:*
1st Edition	March 2024	Initial issue	S. Armstrong

C O N T E N T S

LIST OF DRAWINGS

LIST OF APPENDICES

EXECUTIVE SUMMARY

Client	Scottish Opera.
Site	Rotterdam Wharf, Port Dundas, Glasgow.
Proposed Development	A five-storey extension to the existing Scottish Opera building, plus the development of two multi-storey (one 15 and another 20 storeys) residential flatted developments within the northern and southern site areas. In addition, two pedestrian bridges are being proposed to connect the newly extended Scottish Opera building to the existing canal footpath to the east.
Project Objectives	▪ To investigate the possible presence of ground contamination associated with the historical uses of the site and any potential associated risks. ▪ To investigate the ground conditions and provide recommendations on foundation and infrastructure design. ▪ To investigate the mineral conditions below the site. ▪ To provide recommendations (if any) for additional works / remediation required.
Topography and Surface Cover	The site was predominantly surfaced in hardstanding (tarmac or concrete) with occasional vegetated areas, particularly within the southern area. The site topography was relatively flat across the site, with a steep step in topography up to the concrete yard area with a large retaining wall along the eastern boundary. Surface levels were recorded to range between 35 mAOD (within the car park area) and 41 mAOD (within the concrete yard area).
Site History	Based on a review of information obtained from historical ordnance survey maps, it is indicated that the site has been used for several developments including a timber yard until approximately 1870, an iron works until approximately 1895, an electricity generating station until approximately 1970, a maintenance depot until approximately 1990 and a Scottish Opera production studio, which remains to the present day. The immediate surrounding area was noted to be heavily developed from earliest records including roads, houses, local industrial businesses, schools, and a hospital. We therefore consider the site to be 'brownfield' in nature.
Recorded Ground Conditions	The ground conditions recorded MADE GROUND generally described as brown or black, clayey, gravelly sand with extraneous materials including plastic, metal, ceramic, timber and ash fragments plus frequent bricks, proven to between 0.70 m and 3.30 m thick, underlain by natural glacial soils described as firm, brown, sandy, gravelly (weathered) CLAY underlain by stiff, grey, slightly sandy, slightly gravelly (unweathered) CLAY, proven to between 6.80 m and 15.80 m depth. Sedimentary bedrock was encountered at rockhead depths of between 6.40 m and 15.80 m bgl, described as either moderately strong, grey SANDSTONE or weak, dark grey MUDSTONE with occasional coal seams. Rockhead levels ranged between 30.09 mAOD and 24.97 mAOD and were noted to generally become deeper below the eastern / south-eastern areas of the site. A shallow pervasive water table was not recorded below the site. However, pockets of groundwater do exist, though will likely be localised, perched and not of significant volume, the result of surface water infiltration.

EXECUTIVE SUMMARY (Continued)

Assessment of Risks to Human Health, Vegetation and the Water Environment	Due to the presence of toxic and phytotoxic contaminant exceedances within the shallow made ground soils, we recommend that all future gardens and areas of soft landscaping (underlain by made ground materials) should be underlain by an environmental capping layer consisting of 600 mm clean, inert topsoil / subsoil further underlain by a high-visibility geotextile (i.e. an anti-dig layer). In addition, due to the presence of localised asbestos at high concentrations (i.e. >0.1%) we recommend that the made ground soils (from between approx. 0.25 m and 3.60 m depth) in proximity to BH02 will require to be further delineated and locally excavated and removed off-site prior to future development. Importantly, all future site staff (e.g. construction workers and maintenance personnel) should remain vigilant to the risk of encountering contaminated material (**in particular asbestos fibres**) when working on-site. Prior to any works starting, a detailed method statement and risk assessment should be implemented to mitigate the risk of toxic contaminants to future groundworkers, including: ▪ Use of appropriately qualified personnel for the task; ▪ Use of appropriate PPE; ▪ Provision of on-site washing facilities and maintenance of a high standard of basic hygiene; and ▪ A non-smoking and eating policy within the working area, with designated clean areas set aside for these activities. Based on results from soil leachate and groundwater analyses plus our detailed risk assessment, it was concluded that the shallow soils do not pose a risk to the wider water environment.

EXECUTIVE SUMMARY (Continued)

Assessment of Ground / Mine Gas and Radon	Methane (up to 4.9%) was recorded at elevated levels below the site. We consider the gas source to be associated with mine gas within the bedrock. From the site characteristic hazardous gas flow rate as calculated, based on a worst-case scenario, the ground / mine gas regime was classified as '*Characteristic Situation 2*' whereby gas protection measures are considered necessary. In addition, future abnormal foundations (i.e. piles) could provide an additional pathway for ground gas migration below the building footprints (further owing to the requirement of gas protection). Taking into account the building types (Type B and Type C) this corresponded to required solution scores of 3.5 points (for the proposed flatted residential developments) and 2.5 points (for the proposed commercial development). Following the determination of the minimum gas protection score, a combination of: 1) structural barrier of the floor slab, and / or; 2) ventilation measures, and / or; 3) a gas resistant membrane should be implemented in order to achieve an adequate score. Furthermore, we would recommend that vented street furniture be implemented where applicable. Radon gas or hydrocarbon vapour barriers are not considered necessary.
Assessment of the Built Environment	Recommended concrete (ACEC) Classification is AC-2s with a Design Sulphate Class for the site of DS-2. Given the results from the preliminary UKWIR analysis (which recorded elevated SVOC concentrations) plus the recorded ground conditions (i.e. thick made ground containing ash), we would recommend that barrier (PE-AL-PE) water supply pipes be utilised within the site. Furthermore, due to the presence of asbestos, all future pipes should be laid in widened trenches (approximately 1.00 m wide) and backfilled with clean, inert material.

EXECUTIVE SUMMARY (Continued)

Off-Site Disposal	The results from the HazWaste Online© assessment generally classified the soils as 'non-hazardous', in terms of off-site disposal. However, one of the made ground samples (BH07 at 0.30 m) was classed as 'hazardous waste' due to an elevated total TPH concentration of 3,000 mg/kg. In addition, due to high levels of asbestos encountered within the made ground in proximity to BH02 at 0.50 m and 2.50 m depth, these soils would be also considered as 'hazardous waste' and if disturbed at any point during the development works, these soils would require to be taken off-site. Should any materials be required to be taken off-site as part of future development works, we would recommend that further testing be undertaken (on specific materials identified to go off-site) in order to confirm its waste classification and to provide a more accurate assessment.
Foundation Construction	*Proposed 5-Storey Extension to Existing Scottish Opera Building* Based on existing site levels, the stiff (or better) natural (unweathered) clay subsoils may be suitable for use as a foundation bearing horizon (via piled foundations). These soils would provide an allowable bearing capacity of 150 kN/m^2 between depths of approximately 2.00 m and 7.20 m bgl (33.78 mAOD and 36.08 mAOD). Alternatively, the underlying bedrock could be used as a foundation bearing horizon. *Proposed Multi-Storey Residential Blocks* Based on the likely loading requirements for the proposed development (which includes for 15 and 20 storey buildings) we would recommend piled foundations be utilised, end bearing onto the sedimentary bedrock at depths between approximately 6.40 m to 15.80 m bgl (approx. 30.09 mAOD to 24.97 mAOD). Based on the results from the laboratory UCS testing, the bedrock would provide an allowable bearing capacity of approximately 5.0 MN/m^2. Detailed discussions with specialist contractors and the structural engineer should be undertaken with regard to the final design of the piled foundations.

EXECUTIVE SUMMARY (Continued)

Mining and Quarrying	Intrusive mineral investigations recorded shallow mine workings within the southern site area between 8.40 m and 9.10 m depth, described as 'packed waste'. We have conjectured these mine workings to be associated with the Upper Possil Coal (0.70 m thick), as was shown on the BGS solid geology map to outcrop within this vicinity. As such, we consider that this area is minerally unstable and therefore recommend that grouting consolidation works be undertaken prior to any future development. Note that additional mineral bores would be beneficial at a later date to further delineate the extent of the workings. The northern and central site areas did not record any evidence of shallow mine workings, and therefore, we consider these areas of the site to be minerally stable. The Coal Authority did not record any mine entries within the site or immediate surrounding area. However, it should be highlighted that as in all areas of historical mining, unrecorded mine entries could exist. During future earthworks if any mine shafts or similar looking features are encountered, we should be immediately consulted for further advice. Finally, there was no evidence of any historical quarrying activity within the site.
Road Design	Due to the presence of thick and variable made ground, we would recommend a full capping layer (i.e. 600 mm thick) be used below all future roads and parking areas.
Invasive Plant Species	A specialist survey identified the presence of non-native invasive species 'Cotoneaster' within the site. As such, we recommend the infestation be appropriately managed prior to future development.
Flood Risk	SEPA did not indicate any risk from river or coastal flooding on the site. However, localised areas of the site in the north were noted to be at a low to medium risk of surface water flooding. In addition, the Forth and Clyde Canal to the immediate east was also noted to be at potential low to medium risk of surface water flooding. If further information is required, we would recommend a detailed flood risk assessment be undertaken.
Service Information	Buried BT cables were noted to underlie the western site boundary running north to south feeding the current Scottish Opera Building. In the south buried BT cables were recorded to run east to west along the site boundary connecting to the southern end of the Scottish Opera building. In addition, high voltage buried Scottish Power cables were recorded below southern boundary running west to east. There were also high voltage cables running north to south along the western site boundary. A low-pressure Scottish gas main was recorded on site running from Corn Street in the south of the site to the south of the existing Scottish Opera building. No services operated by Scottish Water were recorded within the site. Though, fresh and wastewater pipes were indicated in the immediate surrounding area.

1.0 INTRODUCTION

1.1 Commission

1.1.1 Mason Evans Partnership were commissioned by Scottish Opera (the Client) to undertake ground investigations in connection with the proposed development at a site (1.72 Ha) titled 'Rotterdam Wharf, Scottish Opera Glasgow' (Drawing Nos. P22/271/SI/R/F/01 and 02).

1.1.2 It is understood that the development proposal is to consist of a five-storey extension to the existing Scottish Opera building, plus the development of two multi-storey (one 15 and another 20 storeys) residential flatted developments within the northern and southern site areas. In addition, two pedestrian bridges are being proposed to connect the newly extended Scottish Opera building to the existing canal footpath to the east. A proposed development layout plan is shown in Drawing No. P22/271/SI/R/F/03.

1.1.3 This report should be read in conjunction with our Phase 1 Desk Study Report (included in Appendix 01).

1.2 Investigation Proposals

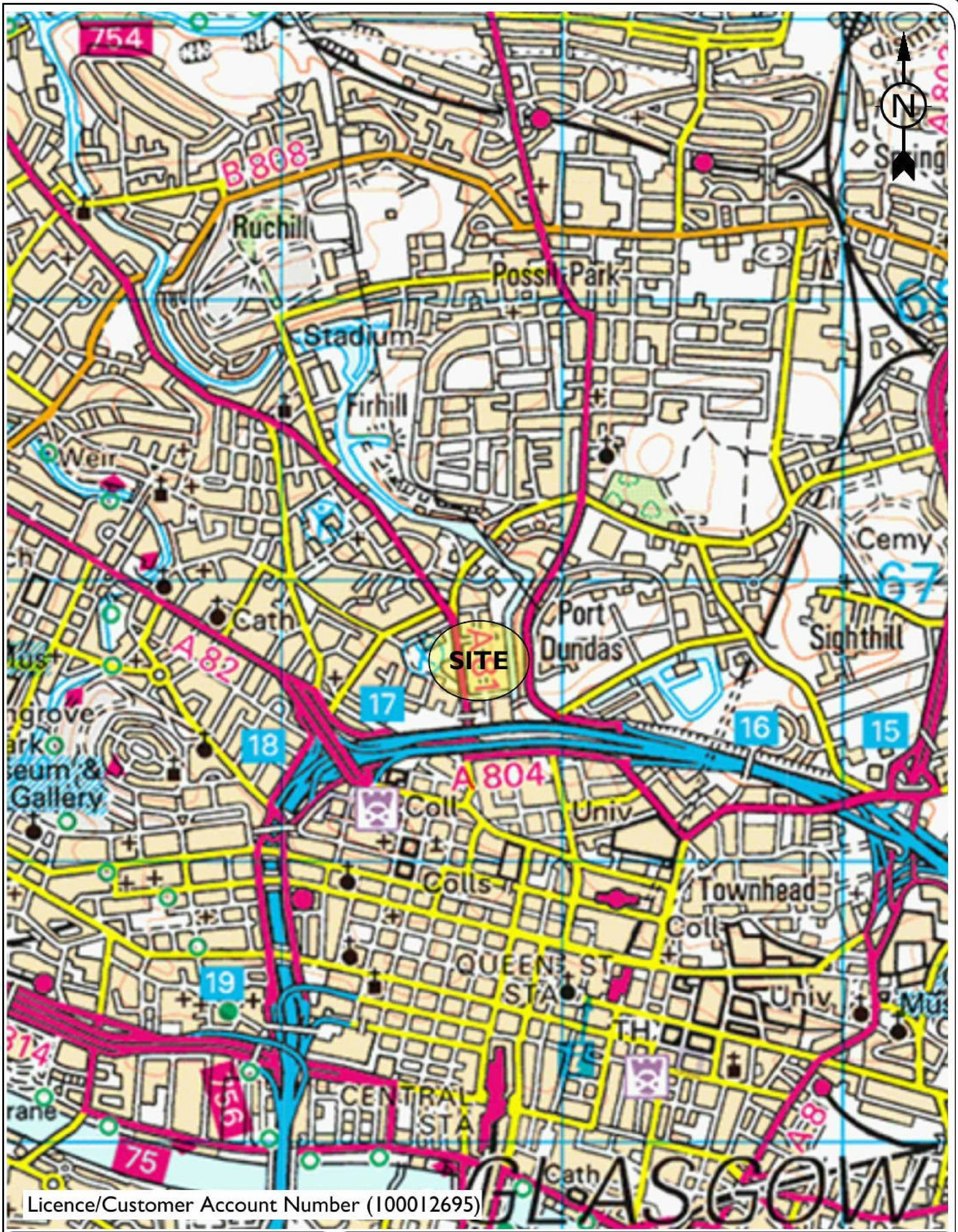
1.2.1 The intention of the ground investigations was to provide information on the following:

- Soil, groundwater and rockhead profiles.
- Chemical contamination conditions.
- Ground gas emissions.
- Geotechnical characteristics of the materials.
- Foundation bearing characteristics.
- Mining and quarrying constraints.
- Existence of invasive plants.

1.3 Limitations

1.3.1 Our interpretations of the ground conditions are based on the information retrieved from the soil bores within the site during the recent investigations. While we have carried out interpretation of the ground conditions between the exploratory locations, it should be recognised that soil and groundwater conditions can vary from point to point. As such, ground conditions at variance with those indicated by the exploratory pits / bores may exist in areas not investigated.

1.3.2 It should be recognised that this report is prepared in accordance with current recommended practice and existing legislation. It is written in the context of a proposed five-storey extension to the existing Scottish Opera building, plus the development of two multi-storey (one 15 and another 20 storeys) residential flatted developments within the northern and southern site areas. Should there be any alternative end-use, it would be prudent to consult us further to ensure the continued pertinence of the recommendations advised



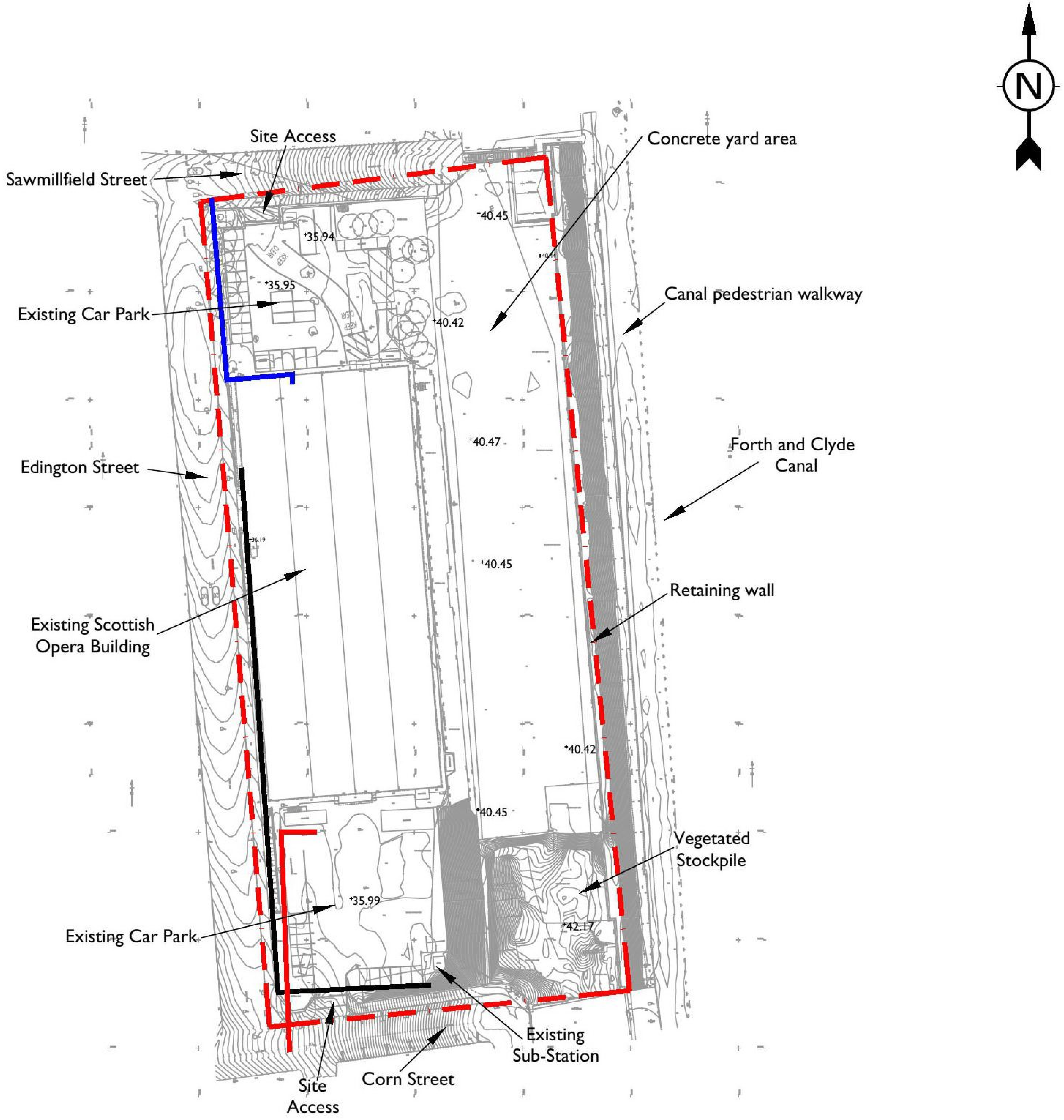
MASON EVANS
A PHENNA GROUP COMPANY
Geo-Environmental Consultants
t: 0141 420 2025 e: mail@masonevans.co.uk
100 Brand Street, Glasgow, G51 1DG

client details: SCOTTISH OPERA
39 ELMBANK STREET
GLASGOW, G2 4PT

project title:	drawing title:
ROTTERDAM WHARF PORT DUNDAS, GLASGOW	SITE LOCATION PLAN

project no:	drawing no:	revision:	date:	drawn by:	approved by:	scale:
P22/271	P22/271/SI/R/F/01		11.03.24	AC	SA	Not to Scale

A4 border: 277 x 190



NOTES

- Approximate site boundary
- SP Energy cables
- Scottish Gas pipe
- Buried BT cable

REV	DATE	DETAILS

SCOTTISH OPERA
39 ELMBANK STREET
GLASGOW
G2 4PT

PROJECT TITLE

ROTTERDAM WHARF
PORT DUNDAS, GLASGOW

DRAWING TITLE

TOPOGRAPHIC
SURVEY

DRAWN BY	CHK'D BY	APP'D BY	DATE	SCALES
AC	SA	SA	11.03.24	1:1000 @ A3

PROJECT No.	DRAWING No.	REVISION
P22/271	P22/271/SI/R/F/02	

MASON
EVANS
A PHENNA GROUP COMPANY
Geo-Environmental Consultants
t: 0141 420 2025 e: mail@masonevans.co.uk
100 Brand Street, Glasgow, G51 1DG

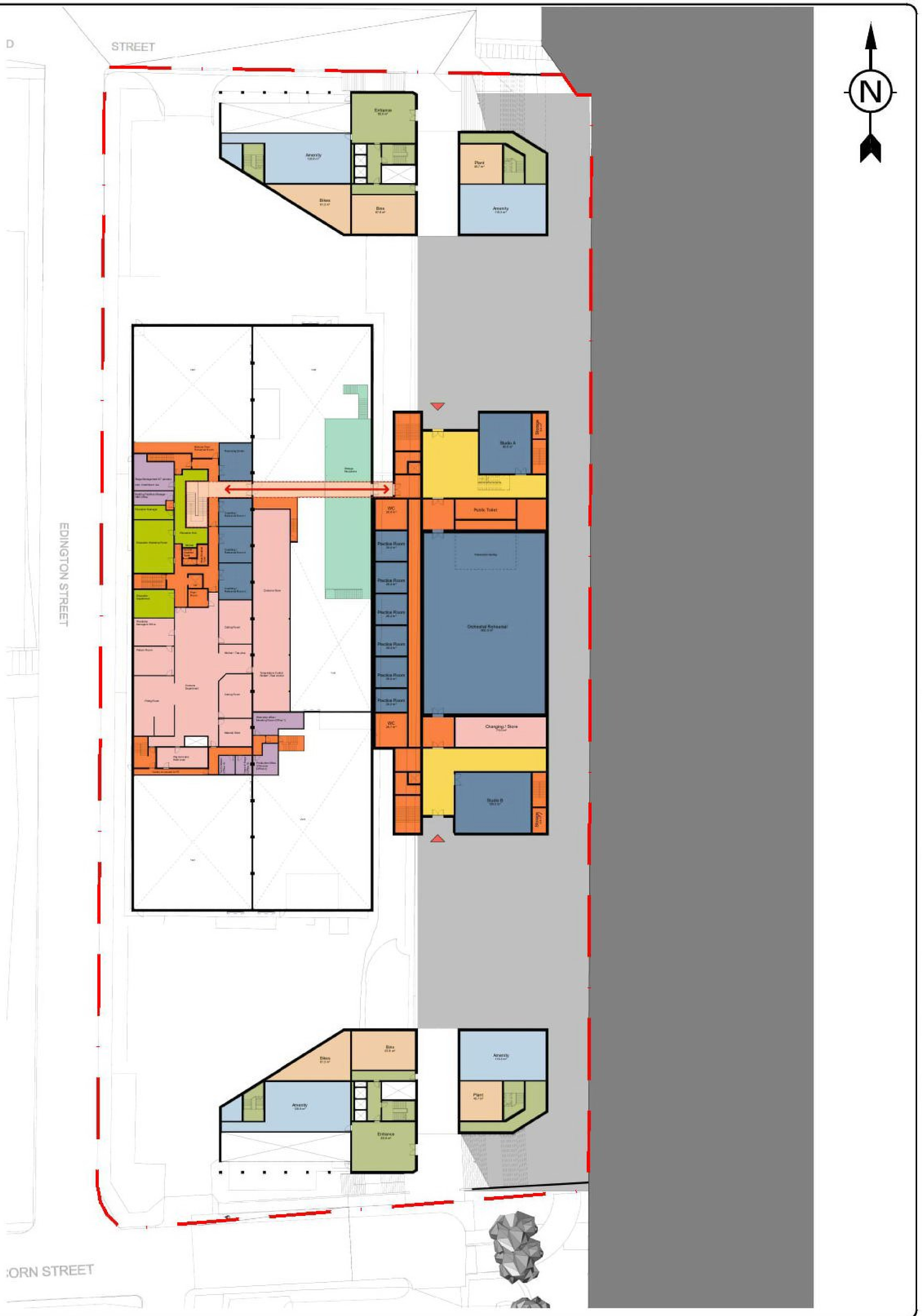
A3 border: 400 x 273

Scottish Opera

- Office Space
- Education
- Practice/Rehearsal Room
- Cafe / Entrance (Public - Semi-public)
- Technical Areas / Workshops
- Wardrobe / Wig Department
- Circulation / Support

PBSA Residential

- Circulation / Entrance
- Support / Office
- Internal Amenity
- External Amenity
- Accommodation Room



NOTES

Approximate site boundary

REV	DATE	DETAILS

SCOTTISH OPERA
39 ELMBANK STREET
GLASGOW
G2 4PT

PROJECT TITLE

ROTTERDAM WHARF

DRAWING TITLE

PROPOSED DEVELOPMENT LAYOUT PLAN

DRAWN BY	CHK'D BY	APP'D BY	DATE	SCALES
TR	JSA	AMcG	14.09.23	Not to Scale

PROJECT No.	DRAWING No.	REVISION
P22/271	P22/271/SI/R/F/03	

MASON EVANS
Part of the CTS Group
Geo-Environmental Consultants
t: 0141 420 2025 e: mail@masonevans.co.uk
The Piazza, 95 Morrison Street, Glasgow, G5 8BE

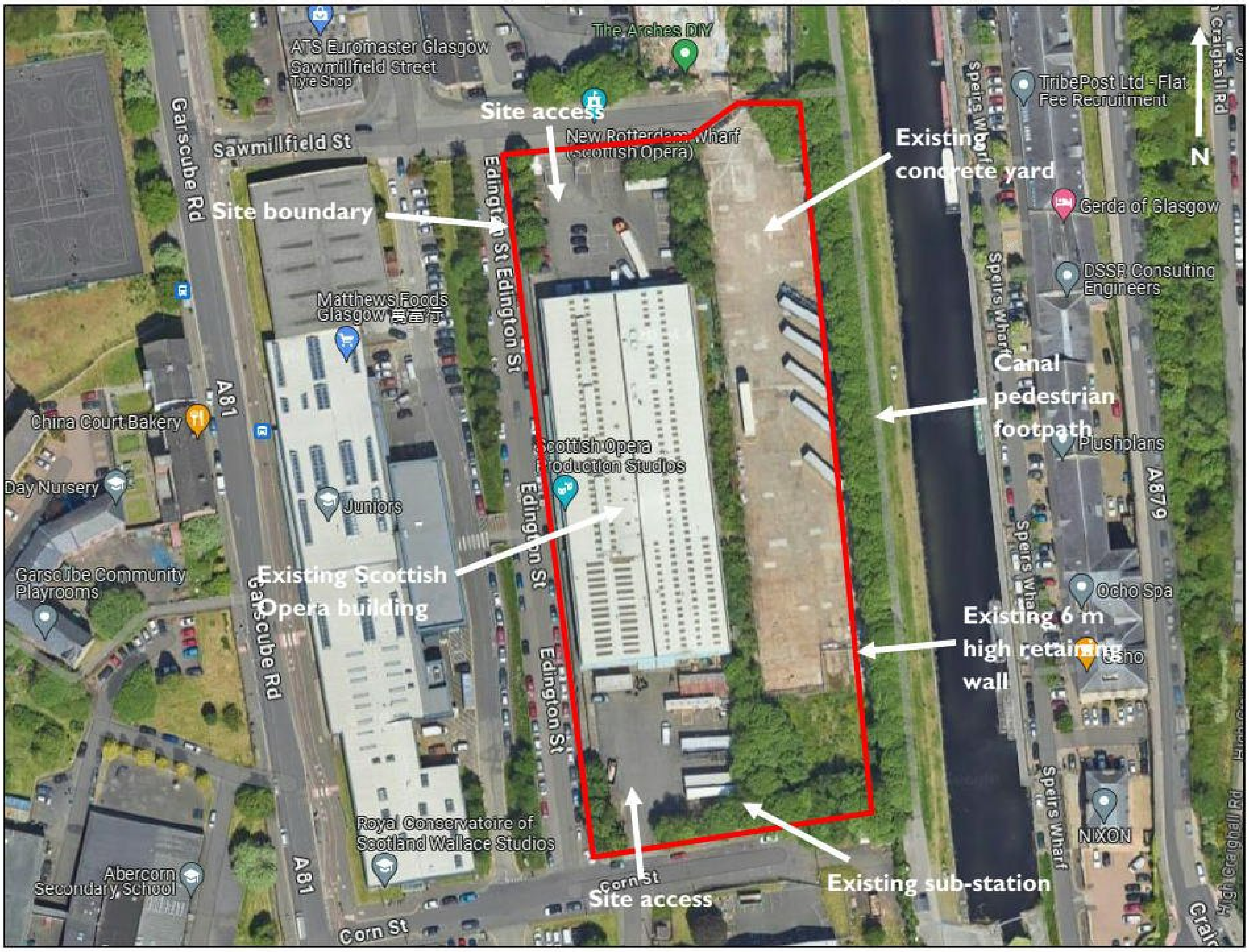
A3 border: 400 x 273

2.0 DESK STUDY INFORMATION

2.1 The Site

2.1.1 The context of the site (1.72 Ha) is indicated on Plate 01, which shows it to be bound by roads and industrial units to the north, south and west, with a (approx. 6 m high) retaining wall to the east with the Forth and Clyde Canal beyond. The main access routes into the site were from both Sawmillfield Street to the north or Corn Street to the south, as shown below.

Plate 01 – Aerial Photograph of the Site (courtesy of Google Maps)



2.2 Summary

2.2.1 In September 2023, Mason Evans issued a detailed Phase 1 Geo-Environmental Desk Study Report at the site (a copy of the text and drawings is included in Appendix 01), a summary of which is included below:

<u>*Existing Site Conditions*</u>

2.2.2 The site was predominantly surfaced in hardstanding (tarmac or concrete) with occasional vegetated areas, particularly within the southern area.

2.2.3 The site topography was relatively flat across the site, with a steep step in topography up to the concrete yard area with a large retaining wall along the eastern boundary. Surface levels were recorded to range between 35 mAOD (within the car park area) and 41 mAOD (within the concrete yard area).

Site History

2.2.4 Based on a review of information obtained from historical ordnance survey maps, it is indicated that the site has been used for several developments including a timber yard until approximately 1870, an iron works until approximately 1895, an electricity generating station until approximately 1970, a maintenance depot until approximately 1990 and a Scottish Opera production studio, which remains to the present day.

2.2.5 The immediate surrounding area was noted to be heavily developed from earliest records including roads, houses, local industrial businesses, schools, and a hospital.

2.2.6 Following these researches, we consider the site to be 'brownfield' in nature.

Geology and Mining

2.2.7 It is considered that MADE GROUND deposits will exist below the site associated with previous historical development. The British Geological Survey (BGS) indicated the natural soils below the site to consist of glacial till (i.e. boulder CLAY), with thicknesses ranging between approximately 5 m and 20 m (becoming thicker from north-west to south-east).

2.2.8 The BGS indicated the underlying solid strata to belong to the Carboniferous aged Limestone Coal Group comprising sequences of SANDSTONE, SILTSTONE and MUDSTONE with seams of COAL and IRONSTONE.

2.2.9 The Upper Possil Coal (sometimes referred to as the Davy Coal) was conjectured to outcrop within the southern site area aligned south-west to north-east and dipping towards the south-east (i.e. below the site) with an indicated thickness of 0.80 m. The Upper Possil Ironstone or Garscube Wee Coal was conjectured to outcrop to the north of the site and is recorded to dip below the site to the south-east with an indicated thickness of 0.70 m. Furthermore, whilst not shown to outcrop on the geological map, the Batchie Ironstone or Coal was indicated on the stratigraphic column to exist between the Upper Possil / Davy Coal and the Upper Possil Ironstone / Garscube Wee Coal seams with an indicated thickness of up to 0.70 m, and therefore is considered to underlie the site at shallow depth.

2.2.10 A site-specific report obtained from The Coal Authority Report stated that there are no records of any past underground mine workings below the site.

2.2.11 Importantly however, The Coal Authority did indicate that there was a potential for unrecorded workings at shallow depth (i.e. < 30 m depth) below the site. We consider that any shallow mineral extraction would be associated with The Upper Possil Ironstone or Garscube Wee Coal (0.80 m thick), the Batchie Ironstone or Coal (up to 0.70 m thick) and / or the Upper Possil / Davy Coal (0.70 m thick) which were indicated to exist below the site at shallow depths.

2.2.12 The Coal Authority did not record any mine entries within the site or immediate surrounding area. However, it should be highlighted that as in all areas of past mining, unrecorded mine entries could exist.

2.2.13 The Coal Authority also did state any known mine gas emissions within 500 m of the site. However, it should be noted that any unrecorded mine workings below the site could contribute to mine gas and this will therefore require to be further investigated.

2.2.14 A review of the historical OS maps did not indicate the presence of historical quarrying activity within the site, or the immediate surrounding area.

2.2.15 To conclude, we consider the site to be at potential risk of ground instability as a result of unrecorded shallow mine workings. Therefore, mineral ground investigations are recommended in order to confirm (or otherwise) the presence of any shallow mine workings below the site.

Hydrology and Flooding

2.2.16 The nearest surface water body to the site was the Forth and Clyde Canal located to the east of the site. Given that the canal is topographically higher than the site and is separated by a significant retaining wall, and that the canal is a man-made contained body of water which will be lined, and therefore there would be no risk of contaminants from the site entering into this surface water feature, we do not consider this to be a sensitive receptor in relation to the proposed development. No other surface water bodies were recorded within 1 km.

2.2.17 SEPA did not indicate an aquifer to exist within the superficial deposits below the site. However, SEPA did record the 'Glasgow and Motherwell' bedrock aquifer to exist below the site (at depth). At this stage, this is considered to be the most sensitive water receptor in relation to the site.

2.2.18 The SEPA flood map did not indicate any risk from river or coastal flooding on the site. However, localised areas of the site in the north were noted to be at a low to medium risk of surface water flooding. In addition, the Forth and Clyde Canal to the immediate east was also noted to be at potential low to medium risk of surface water flooding. If further information is required, we would recommend a detailed flood risk assessment be undertaken.

Invasive Plants

2.2.19 A specialist survey undertaken in December 2023 identified the presence of non-native invasive species 'Cotoneaster' within the site. As such, we recommend the infestation be appropriately managed prior to future development.

2.2.20 A copy of the report is included in Appendix 02.

Services

2.2.21 Buried BT cables were noted to underlie the western site boundary running north to south feeding the current Scottish Opera Building. In the south buried BT cables were recorded to run east to west along the site boundary connecting to the southern end of the Scottish Opera building.

2.2.22 In addition, high voltage buried Scottish Power cables were recorded below southern boundary running west to east. There were also high voltage cables running north to south along the western site boundary.

2.2.23 A low-pressure Scottish gas main was recorded on site running from Corn Street in the south of the site to the south of the existing Scottish Opera building.

2.2.24 No services operated by Scottish Water were recorded within the site. Though, fresh and wastewater pipes were indicated in the immediate surrounding area.

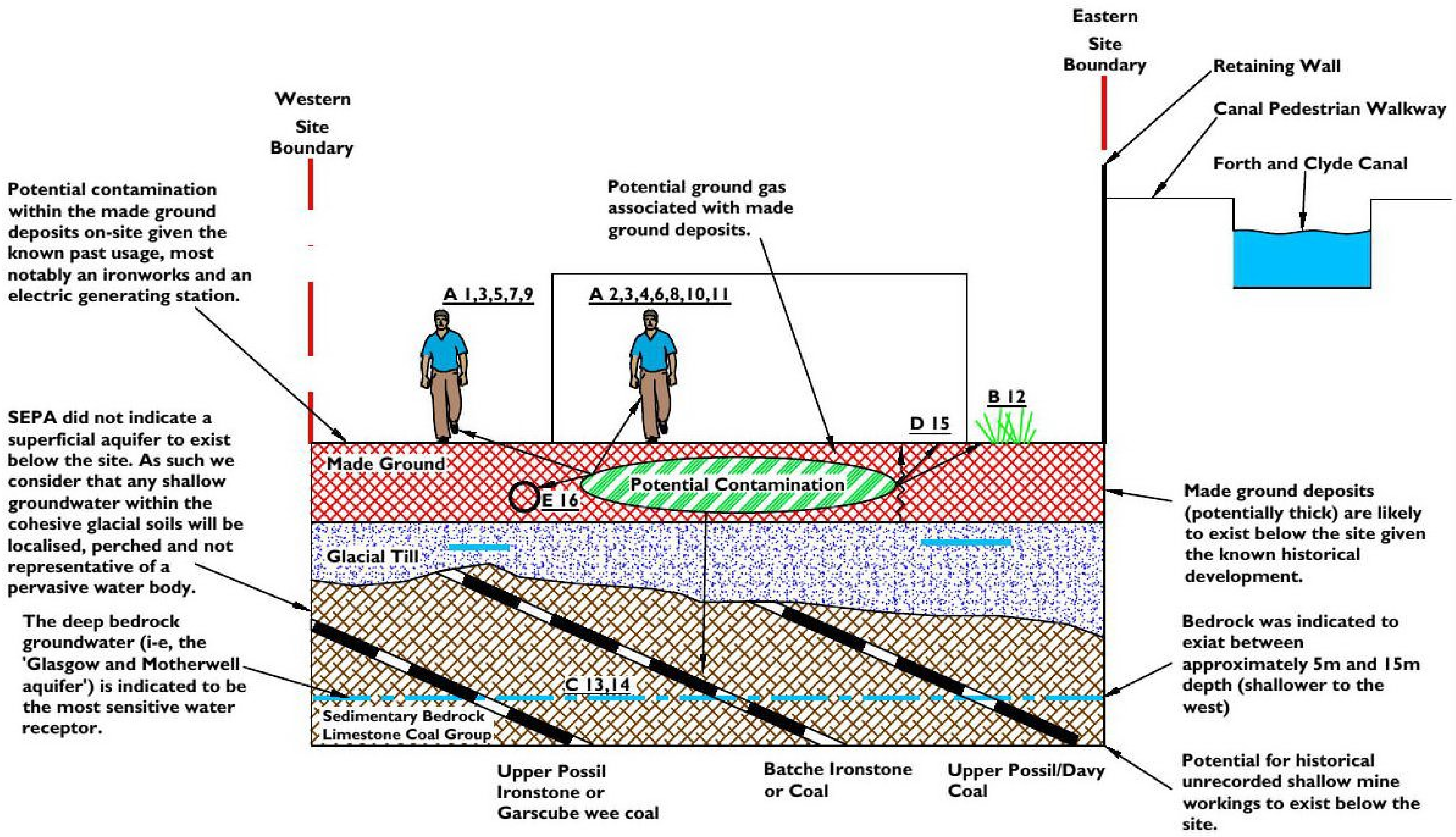
2.2.25 Finally, the potential for unrecorded local services should not be discounted.

Preliminary Conceptual Site Model

2.2.26 Based on the information from the desk study, we have designed our ground investigations to target the following receptors which we consider to be relevant to this site:

- Humans – site end users and construction workers (outdoor),
- Humans – site end users (indoor),
- Buildings and services,
- Water Environment (deep bedrock groundwater aquifer),
- Vegetation / fauna.

2.2.27 The potential source-receptor-pathway linkages identified for this site are illustrated within our Preliminary Conceptual Site Model (Drawing No. P22/271/SI/R/F/04) and on Tables 1A and 1B. Site investigations were required to confirm or otherwise the existence of such linkages in addition to providing further confirmation of the geological and geotechnical conditions.



Potential Source

- Made ground (containing toxic/phytotoxic contaminants and acting as a source of ground gas)
- Mine workings (acting as a source of mine gas)

Potential Exposure Pathways

1. Outdoor ingestion of dust.
2. Indoor ingestion of dust.
3. Consumption of homegrown vegetables.
4. Ingestion of soil attached to vegetables.
5. Skin contact with outdoor soil.
6. Skin contact with indoor dust.
7. Outdoor inhalation of dust.
8. Indoor inhalation of dust.
9. Outdoor inhalation of soil vapour.
10. Indoor inhalation of soil vapour.
11. Inhalation of ground gases.
12. Contaminant uptake by vegetation.
13. Leaching of contaminants to the groundwater.
14. Contaminant migration in the groundwater.
15. Detrimental effects on buried concrete.
16. Permeation of plastic water supply pipes.

Potential Receptors

A. Site users / construction personnel.
B. Vegetation / fauna.
C. Groundwater.
D. Buried concrete (Service and foundations)
E. Plastic water supply pipes.

NOTES

An invasive plant species survey recorded the presence of non-native species 'Cotoneaster' within the site.

REV	DATE	DETAILS

SCOTTISH OPERA
39 ELMBANK STREET
GLASGOW
G2 4PT

PROJECT TITLE

ROTTERDAM WHARF
PORT DUNDAS, GLASGOW

DRAWING TITLE

PRELIMINARY CONCEPTUAL SITE MODEL

DRAWN BY	CHK'D BY	APP'D BY	DATE	SCALES
AC	SA	SA	11.03.24	Not to Scale

PROJECT No.	DRAWING No.	REVISION
P22/271	P22/271/SI/R/F/04	

MASON EVANS
A PHENNA GROUP COMPANY
Geo-Environmental Consultants
t: 0141 420 2025 e: mail@masonevans.co.uk
100 Brand Street, Glasgow, G51 1DG

Table 1A – Preliminary Qualitative Risk Assessment – On-Site

Source	COCs	Pathway	Receptors (s)	Assessment	Further Investigation Required
1. Made ground (containing toxic / phytotoxic contaminants and acting as a source of ground gas). 2. Shallow mine workings (generating mine gas emissions).	Metals, semi-metals and non-metals: As, Cd, Cr, Ni, Zn, Cu, Hg, Pb Organics: Hydrocarbons, PAH, Fuel oil, Phenol Miscellaneous: Asbestos, Sulphate, PCBs Ground / mine gasses: CO_2, CH_4.	Dermal contact, ingestion, inhalation	Human – site workers Humans – end users (outdoor)	Spillage/leakage of contaminants impacting near surface soils. Contaminated materials may have been deposited within the site.	Yes
		Leaching through soil or direct migration	The water environment - groundwater	Contaminants may be leached and potentially mobilised from the soil by percolation and / or shallow groundwater movement.	Yes
		Direct contact, leaching through soil, groundwater migration	Buildings and services	Potential for aggressive chemical environments for concrete due to sulphate and acidic conditions. Presence of contaminants in soil that may permeate water supply pipes.	Yes
		Gas / vapour inhalation, vertical/lateral migration	Buildings and services Humans – end users (indoor)	Contamination may include gas/vapour producing materials or compounds that could vertically migrate into overlying buildings producing a potentially asphyxiating or explosive environment.	Yes
		Direct contact, uptake	Plants	Direct contact or uptake of contamination from the soil or groundwater could adversely affect any plants grown.	Yes

Table 1B – Preliminary Qualitative Risk Assessment – Off-Site

Source	COCs	Pathway	Receptors (s)	Assessment	Further Investigation Required
1. Made ground (containing toxic / phytotoxic contaminants and acting as a source of ground gas). 2. Shallow mine workings (generating mine gas emissions).	Metals, semi-metals and non-metals: As, Cd, Cr, Ni, Zn, Cu, Hg, Pb Organics: Hydrocarbons, PAH, Fuel oils, Phenols Miscellaneous: Asbestos, Sulphate, PCBs Ground / mine gasses: CO_2, CH_4.	Dermal contact, ingestion, inhalation	Human – site workers Humans – end users (outdoor)	Spillage/leakage of contaminants impacting near surface soils. Contaminated materials may have been deposited within the site.	Yes
		Leaching through soil or direct migration	The water environment - groundwater	Contaminants may be leached and potentially mobilised from the soil by percolation and / or shallow groundwater movement.	Yes
		Direct contact, leaching through soil, groundwater migration	Buildings and services	Potential for aggressive chemical environments for concrete due to sulphate and acidic conditions. Presence of contaminants in soil that may permeate water supply pipes.	Yes
		Gas / vapour inhalation, vertical/lateral migration	Buildings and services Humans – end users (indoor)	Contamination may include gas/vapour producing materials or compounds that could vertically migrate into overlying buildings producing a potentially asphyxiating or explosive environment.	Yes
		Direct contact, uptake	Plants	Direct contact or uptake of contamination from the soil or groundwater could adversely affect any plants grown.	Yes

3.0 SITE INVESTIGATIONS

3.1 General

3.1.1 The scope and location of works was non-targeted. Site works undertaken were implemented generally in accordance with BS5930:2015 + A1:2020 and BS10175:2011 + A2:2017. The proposed scope of works was discussed with Glasgow City Council prior to any works commencing on site.

3.1.2 The following investigation works were undertaken:

Table 02 – Site Investigations

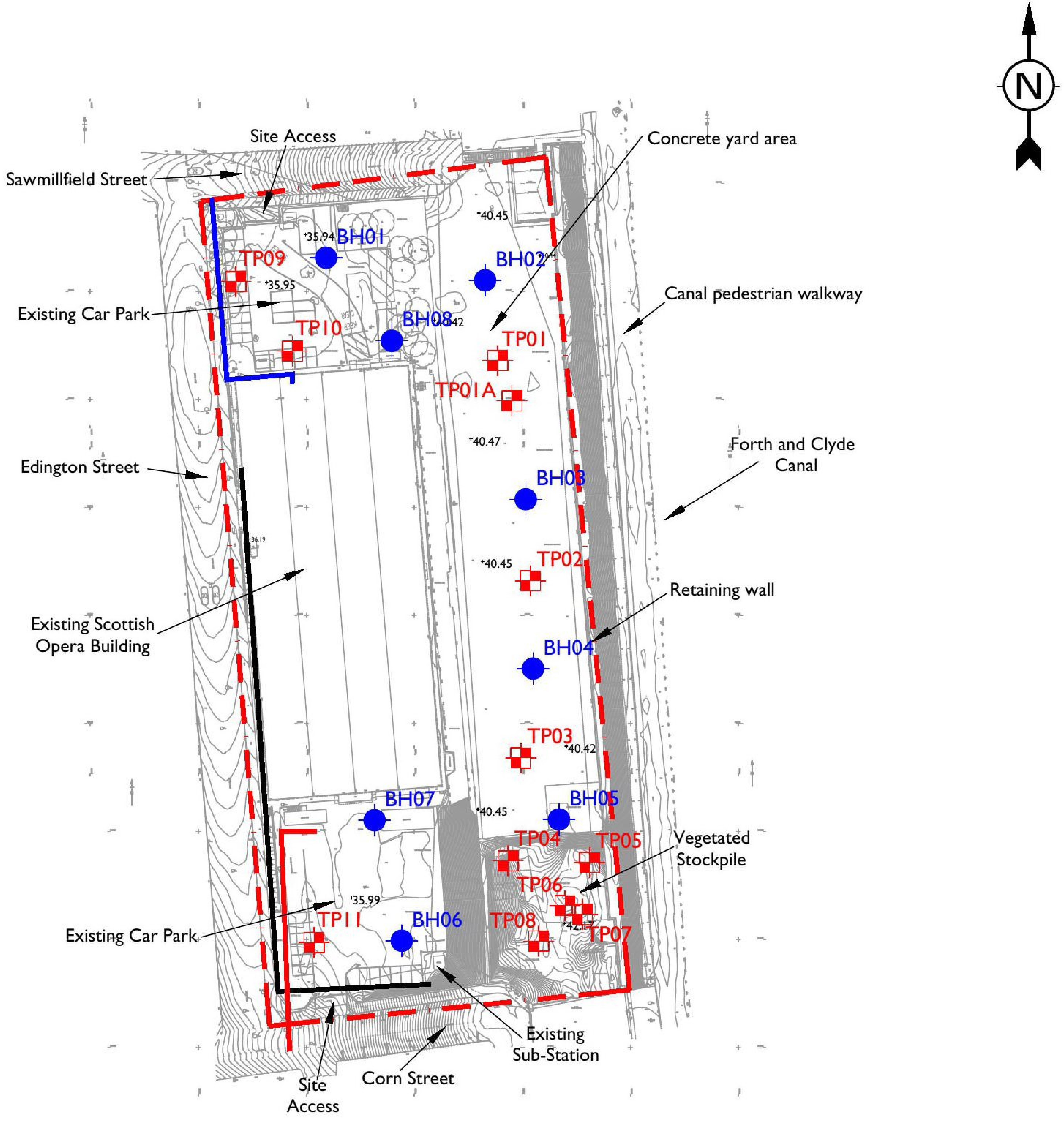
Trial Pits (December 2023)	11 No. trial pits (TP01 to TP11) were excavated mechanically, extended to depths of up to 3.70 m bgl and logged by a competent field geologist. Logs are included in Appendix 03.
Soil Boreholes (December 2023)	8 No. soil boreholes (BH01 – BH08) were sunk from ground level to depths of up to 15.80 m bgl. Gas and groundwater monitoring wells were installed in each borehole. Logs are included in Appendix 04.
Rotary Boreholes (December 2023)	6 No. rotary boreholes (R01 to R06) were sunk up to 38.50 m bgl to determine depth to rockhead, the underlying bedrock lithology and to investigate any potential underground shallow mining. Logs are included in Appendix 05.
Chemical Testing	38 No. soil samples, 26 No. leachate samples and 5 No. groundwater samples were tested for a comprehensive range of potential contaminants. Soil and water chemical analysis results are included in Appendix 06.
Groundwater / Gas Monitoring	6 No. ground gas / water monitoring visits have been undertaken at the site. Results are included in Appendix 07.
Geotechnical Testing	In-situ SPT tests were undertaken in all soil boreholes sunk on site. In addition, geotechnical analyses were undertaken on selected soil samples. Results are included in Appendix 08.

3.1.3 The exploratory holes were intended to provide geotechnical and hydrogeological data of site areas associated with the proposed development, and to facilitate soil and water sampling (if available) for chemical contamination and geotechnical testing, where required.

3.1.4 Representative samples of the soils encountered were obtained and tested for an appropriate suite of testing including metals, hydrocarbons, PCBs (due to former electric generating station on-site) plus asbestos.

3.1.5 Exploratory hole locations are indicated on Drawing No. P22/271/SI/R/F/05.

3.1.6 The co-ordinates and levels of each exploratory hole were surveyed in by Mason Evans Partnership.



NOTES

- Approximate site boundary
- SP Energy cables
- Scottish Gas pipe
- Buried BT cable
- TP01 to TP11 — Trial pit excavated by Mason Evans (December 2023)
- BH01 to BH08 — Soils borehole sunk by GD Drilling (December 2023)

REV	DATE	DETAILS

SCOTTISH OPERA
39 ELMBANK STREET
GLASGOW
G2 4PT

PROJECT TITLE

ROTTERDAM WHARF
PORT DUNDAS, GLASGOW

DRAWING TITLE

LOCATION OF EXPLORATORY HOLES

DRAWN BY	CHK'D BY	APP'D BY	DATE	SCALES
AC	SA	SA	11.03.24	1:1000 @ A3

PROJECT No.	DRAWING No.	REVISION
P22/271	P22/271/SI/R/F/05	

MASON EVANS
A PHENNA GROUP COMPANY
Geo-Environmental Consultants
t: 0141 420 2025 e: mail@masonevans.co.uk
100 Brand Street, Glasgow, G51 1DG

A3 border: 400 x 273

3.2 Investigation Rationale

3.2.1 Our intrusive investigation has sought to be generally compliant with BS5930:2015 + A1:2020 and BS10175:2011 + A2:2017. We have implemented the following site practices:

- The drilling works have been undertaken by a suitably accredited sub-contractor.
- The geological succession at each exploratory hole location has been logged by an experienced field specialist and samples taken for laboratory analysis together with a visual assessment, made of geological character and potential contaminant impact if present.
- In selecting the appropriate samples for testing, we have taken cognisance of a number of factors, including the proposed site use. Sampling rationale has been determined in accordance with R&D Technical Report P5-066 / TR Secondary Model Procedure for the Development of Appropriate Soil Sampling Strategies for Land Contamination, as indicated in the table below.

Table 03 – Sampling Strategy

Rationale for Sampling at Different Depths	
Depth Range	**Rationale**
Ground Level – 1.0 m	To assess: • Human/ animal intake arising from ingestion and dermal contact. • Potential for wind entrainment leading to inhalation (of contaminated soils and dusts) or deposition onto neighbouring land. • Surface water run-off (e.g. due to flash flooding). • Uptake by shallow rooting plants (e.g. crops, ornamental and wild species). • Surface leaching to groundwater.
>1.0 m in made or natural ground	To assess: • Intake via ingestion/ inhalation/ dermal contact arising from 'abnormal' (or unpredicted) excavation (e.g. children digging dens) or for other purposes such as swimming pools, ponds, house extensions. • Uptake by deep rooting shrubs or trees. • Intake by or arising from the activities of burrowing animals. • Intake arising from construction/ maintenance of buildings and services, for example: a. Foundations (usually within 2.0 m of final formation level). b. Water supply pipes, telecommunications, gas and power (0.5 m to 1.0 m of final formation levels). c. Sewers (from 0.5 m to >1.0 m of final formation level). • To locate perched water of groundwater. • To confirm depth of made ground. • To locate possible lateral pathways for gas or vapour migration in made ground. • To establish the extent of any leaching of soluble constituents from superficial soils. • To detect 'deep' contamination (e.g. gas generating materials, leachable materials, dense solvents located above an impermeable stratum). • To obtain information on 'background' soil properties. • To locate 'natural' lateral migration pathways.

- The scope of the testing implemented considered the interpreted origin of the materials in association with their description. This is consistent with best practice under current contaminated land guidance. The chemical condition of these materials was assessed for a wide spectrum of potential contaminants, comprising a broad range of common organic and inorganic substances primarily of a toxic or phytotoxic nature.
- During sample collection, relevant information such as notes of field observations has been logged before transferring the samples to laboratory-prepared sample containers of appropriate type. Care was also taken to minimise the aeration of samples during transfer to the containers.

3.2.2 At the generic assessment stage it should be assumed that all pathways, contained within the generic model applied, will be active. In reality, unless a contaminant is volatile (e.g. organic), exposure by direct contact is likely to be mitigated by the depth of the contaminant or available surface cover. Generally, direct contact with contaminants at greater than 600 mm depth, or under hardstanding is highly unlikely to occur, unless the ground is to be disturbed through removal of surfacing or earthworks.

Monitoring Well Design Justification

3.2.3 In order to target ground gases and groundwater at various depths and strata types, the monitoring wells were designed as per the below:

- BH01 – plain pipe installed to 1.00 m followed by a slotted pipe to 7.00 m to target the made ground and natural clay strata (for ground gas monitoring) and for possible water sampling (albeit no strikes recorded).

- BH02 – plain pipe installed to 12.00 m followed by a slotted pipe to 20.00 m to target the solid strata (for mine gas monitoring) and to target the bedrock groundwater for possible sampling.

- BH03 – plain pipe installed to 3.00 m followed by a slotted pipe to 13.00 m to target the natural clay strata (for ground gas monitoring) and for possible water sampling (albeit no strikes recorded).

- BH04 – plain pipe installed to 16.00 m followed by a slotted pipe to 24.00 m to target the solid strata (for mine gas monitoring) and to target the bedrock groundwater for possible sampling.

- BH05 – plain pipe installed to 1.00 m followed by a slotted pipe to 7.00 m to target the made ground and natural weathered clay strata (for ground gas monitoring) and for possible water sampling (albeit no strikes recorded).

- BH06 – plain pipe installed to 8.00 m followed by a slotted pipe to 9.50 m to target the solid strata where evidence of mine workings was recorded (for mine gas monitoring).

- BH07 – plain pipe installed to 0.50 m followed by a slotted pipe to 2.50 m to target the made ground strata (for ground gas monitoring) and for possible water sampling (albeit no strikes recorded).

- BH08 – plain pipe installed to 0.50 m followed by a slotted pipe to 4.00 m to target the natural weathered clay strata (for ground gas monitoring) and for possible water sampling (albeit no strikes recorded).

Groundwater Purging

3.2.4 All purging of groundwater and subsequent sampling was undertaken using 1 m long plastic bailers. Once a minimum of three total well volumes had been purged, this was immediately preceded by water sampling into suitably sized glass and plastic bottle containers, adhering to the BS 10175+A1:2013 guidance. In addition, separate bailers were used within each bore to prevent any potential cross-contamination.

Deviations in the Soil Samples

3.2.5 With regards to BH02 and BH03 (cert ref: 23-29383), these samples were deviating due to pH, conductivity and (within BH02 at 2.00 m only) VOC holding time exceedances. However, it is considered that these did not have an impact on the results or our recommendations as these parameters were not actively used as part of our human health risk assessment.

Deviations in the Groundwater Samples

3.2.6 With regards to certificates 23-29937, 24-01406 and 24-02529 these samples had deviation codes associated with pH and conductivity (due to a one day holding time exceedance). However, and similar to the few deviations within the soil analyses, it is considered that these did not have an impact on the results or our risk assessment as these parameters were not actively used as part of our water environment risk assessment.

3.2.7 Therefore, it is considered that the recorded deviation codes from both the soil and groundwater analyses do not pose an adverse impact on our geo-environmental risk assessments.

4.0 INVESTIGATION RESULTS

4.1 Ground Conditions

4.1.1 The ground conditions recorded during the investigations were consistent with the anticipated sequence of strata. The soils were noted to comprise MADE GROUND underlain by natural glacial CLAY deposits, further underlain by SEDIMENTARY BEDROCK.

Table 04 – Summary of Ground Conditions

Strata Type	Depth Range (m bgl)	Visual Description
Surface Covering	0.00 to 0.20	Concrete or tarmac.
Made Ground	From 0.20 to between 0.70 and 3.30 (thicker to the south)	Brown or black, clayey, gravelly sand with extraneous materials including plastic, metal, ceramic, timber and ash fragments plus frequent bricks.
Glacial Till	From 0.70 to between 6.40 and 15.80	Firm, brown, sandy, gravelly (weathered) CLAY underlain by stiff, grey, slightly sandy, slightly gravelly (unweathered) CLAY.
Sedimentary Bedrock	6.40 – 15.80 (rockhead depths)	SANDSTONE or MUDSTONE with occasional seams of COAL.

4.2 Strata Encountered

Surface Covering

4.2.1 The site was predominantly surfaced in either reinforced CONCRETE or TARMAC, both of which were approximately 0.20 m thick. Within the south-eastern corner of the site, a stockpile consisting of MADE GROUND material was present, which was surfaced in rough vegetation and elevated approx. 1.50 m above the underlying concrete.

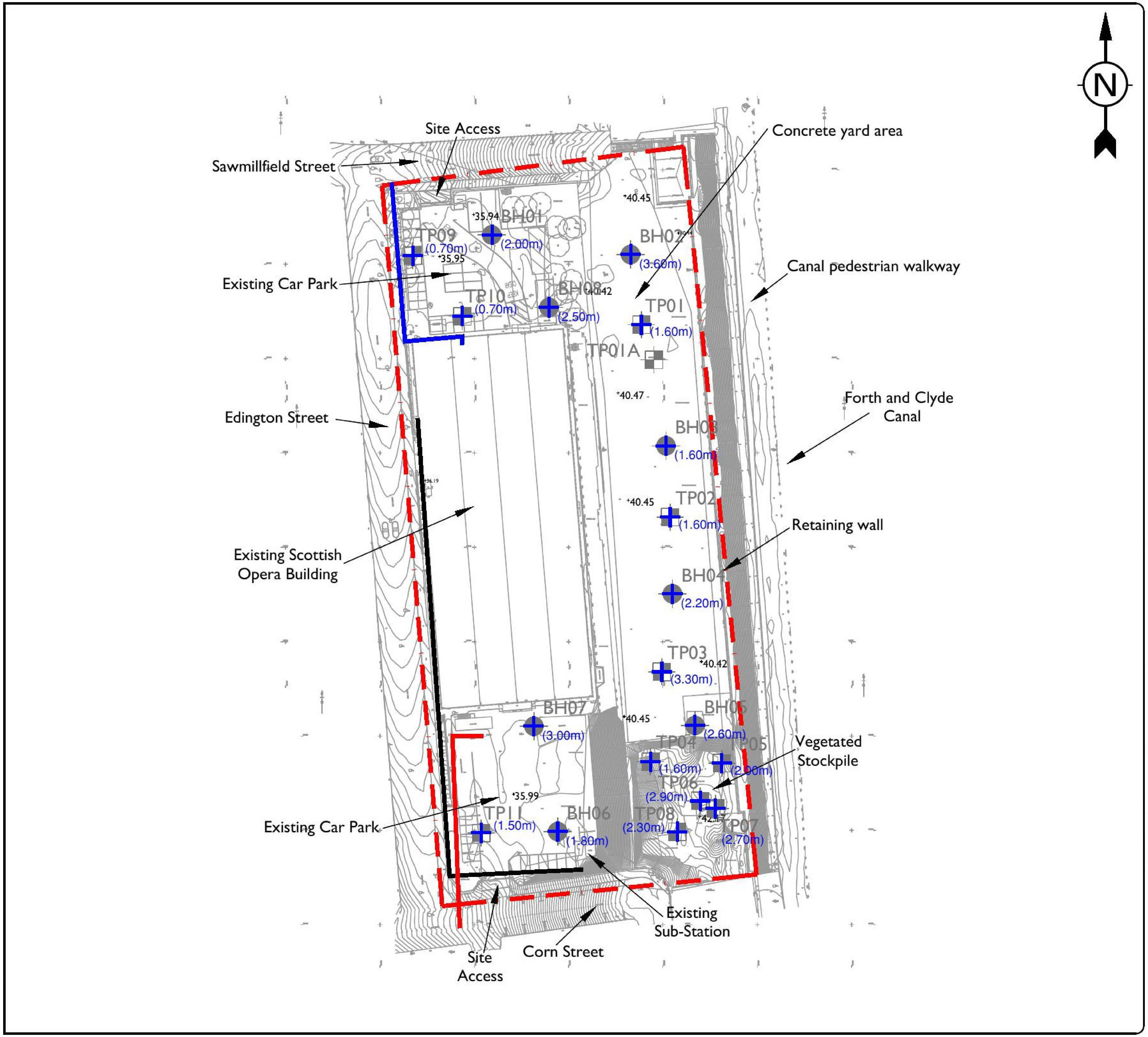
Made Ground

4.2.2 MADE GROUND deposits were encountered from the base of the concrete / tarmac and generally described as brown or black, clayey, gravelly sand with extraneous materials including plastic, metal, ceramic, timber and ash fragments plus frequent bricks.

4.2.3 The stockpile in the south-eastern site area was similarly described.

4.2.4 The made ground composition was of variable nature from point to point and was noted to be thicker below the southern area of the site (up to 3.30 m) and thinner below the northern area (approx. 0.70 m).

4.2.5 The recorded made ground thicknesses are indicated on Drawing No. P22/271/SI/R/F/06.



NOTES

- Approximate site boundary
- SP Energy cables
- Scottish Gas pipe
- Buried BT cable
- TP01 to TP11 — Trial pit excavated by Mason Evans (December 2023)
- BH01 to BH08 — Soils borehole sunk by GD Drilling (December 2023)
- (1.60m) — Recorded made ground thickness (m)

REV	DATE	DETAILS

SCOTTISH OPERA
39 ELMBANK STREET
GLASGOW
G2 4PT

PROJECT TITLE

ROTTERDAM WHARF
PORT DUNDAS, GLASGOW

DRAWING TITLE

RECORDED MADE GROUND THICKNESS

DRAWN BY	CHK'D BY	APP'D BY	DATE	SCALES
AC	SA	SA	11.03.24	1:1000 @ A3

PROJECT No.	DRAWING No.	REVISION
P22/271	P22/271/SI/R/F/06	

MASON EVANS
A PHENNA GROUP COMPANY
Geo-Environmental Consultants
t: 0141 420 2025 e: mail@masonevans.co.uk
100 Brand Street, Glasgow, G51 1DG

A3 border: 400 x 273

Glacial Till

4.2.6 Encountered from the base of the made ground, generally described as firm, brown, sandy, gravelly (weathered) CLAY underlain by stiff, grey, slightly sandy, slightly gravelly (unweathered) CLAY, proven to between 6.80 m and 15.80 m depth.

4.2.7 The recorded depths and levels to stiff (or better) natural cohesive subsoils are indicated on Drawing No. P22/271/SI/R/F/07.

Rockhead

4.2.8 Sedimentary bedrock was encountered at rockhead depths of between 6.40 m (R06) and 15.80 m (R05) bgl, generally described as either moderately strong, grey SANDSTONE or weak, dark grey MUDSTONE with occasional coal seams. Rockhead levels ranged between 30.09 mAOD and 24.97 mAOD and were noted to generally become deeper below the eastern / south-eastern areas of the site.

4.2.9 The recorded depths and levels to rockhead are indicated in Drawing No. P22/271/SI/R/F/08.

4.3 Visual / Olfactory Evidence of Contamination

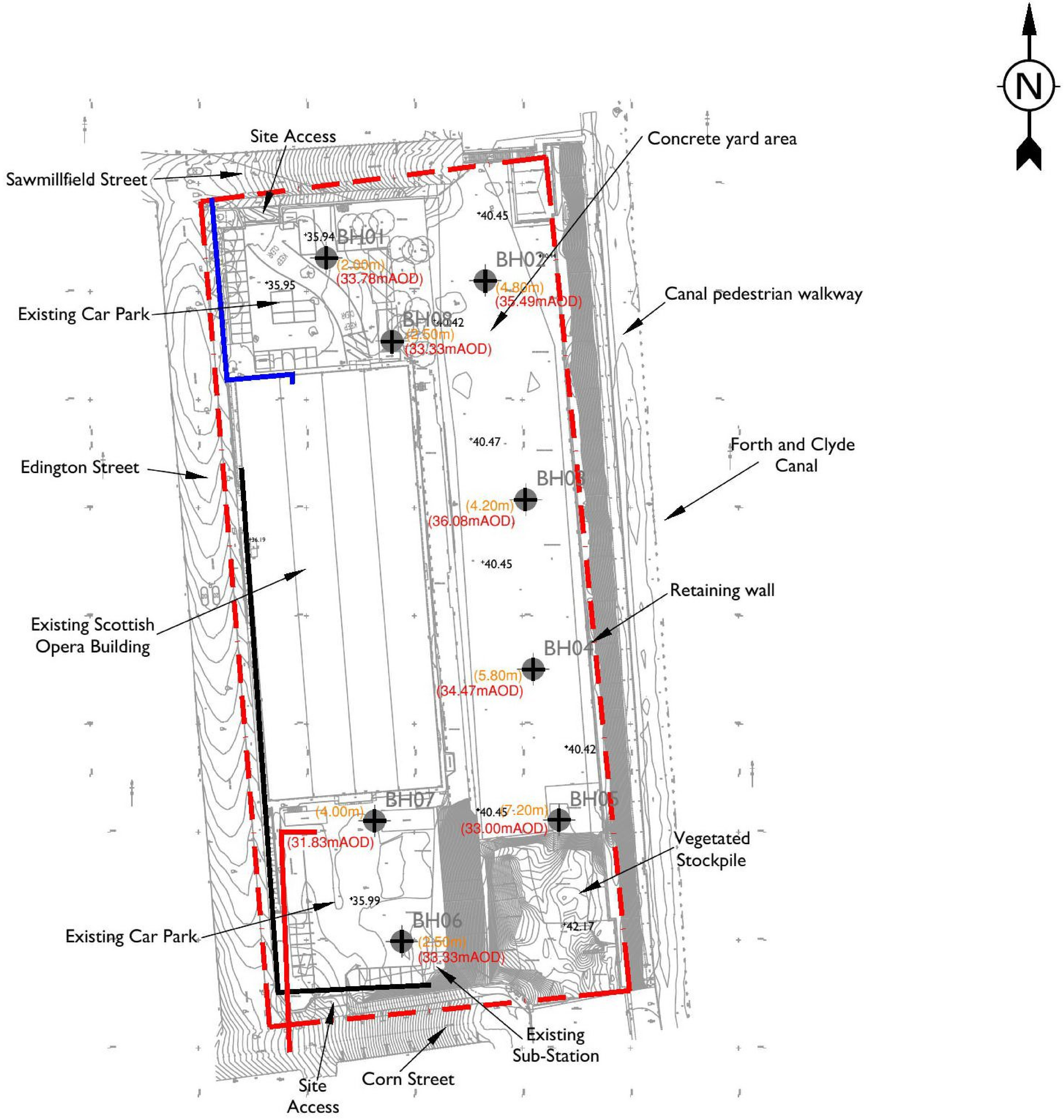
4.3.1 No obvious visual or olfactory evidence of contamination (e.g. hydrocarbons) was recorded within the soils below the site.

4.4 Obstructions

4.4.1 During the site works, obstructions were recorded in the form of concrete (conjectured to be representative of remnant floor slab fragments from previous on-site development) within the north-eastern site area (refer to TP01 and TP01A logs). Importantly, there is the potential for additional unencountered obstructions to be present due to the known historical development within the site. Vigilance should be maintained for such features during future development works.

4.5 Side Wall Stability

4.5.1 It should be highlighted that the majority of the trial pits were recorded to have unstable side walls within the shallow made ground strata (extending to 3.30 m depth). As such, this should be taken into consideration for future development / construction works.



NOTES

- Approximate site boundary
- SP Energy cables
- Scottish Gas pipe
- Buried BT cable
- BH01 to BH08 — Soils borehole sunk by GD Drilling (December 2023)
- (2.00m) (33.78mAOD) + — Recorded depth and level to stiff (or better) natural soils.

REV	DATE	DETAILS

SCOTTISH OPERA
39 ELMBANK STREET
GLASGOW
G2 4PT

PROJECT TITLE

ROTTERDAM WHARF
PORT DUNDAS, GLASGOW

DRAWING TITLE

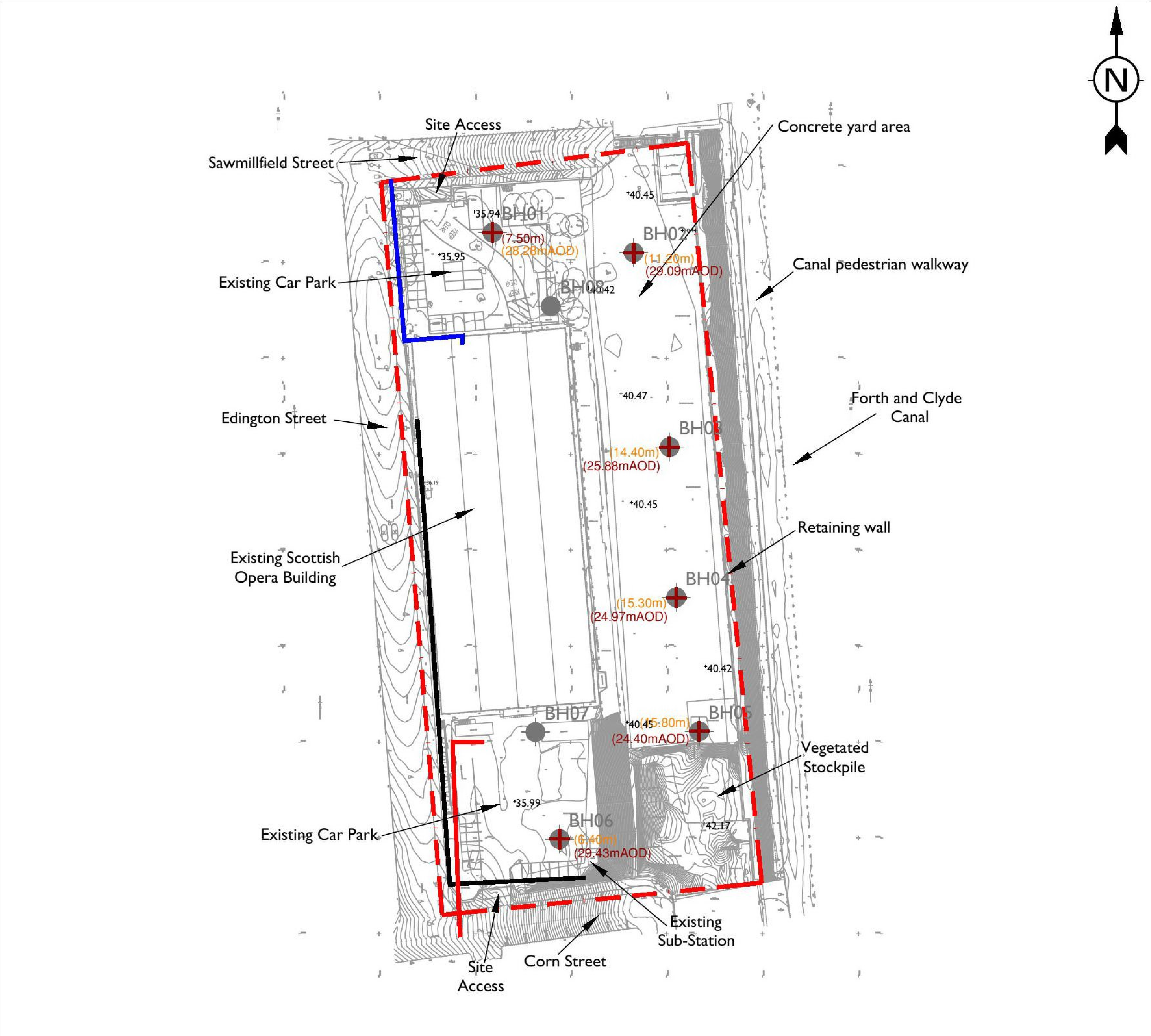
RECORDED DEPTH AND LEVEL TO STIFF (OR BETTER) NATURAL SOILS

DRAWN BY	CHK'D BY	APP'D BY	DATE	SCALES
AC	SA	SA	11.03.24	1:1000 @ A3

PROJECT No.	DRAWING No.	REVISION
P22/271	P22/271/SI/R/F/07	

MASON EVANS
A PHENNA GROUP COMPANY
Geo-Environmental Consultants
t: 0141 420 2025 e: mail@masonevans.co.uk
100 Brand Street, Glasgow, G51 1DG

A3 border: 400 x 273



NOTES

- Approximate site boundary
- SP Energy cables
- Scottish Gas pipe
- Buried BT cable
- BH01 to BH08: Soils borehole sunk by GD Drilling (December 2023)
- (7.50m) (28.28mAOD): Recorded depth and level to rockhead.

REV	DATE	DETAILS

SCOTTISH OPERA
39 ELMBANK STREET
GLASGOW
G2 4PT

PROJECT TITLE

ROTTERDAM WHARF PORT DUNDAS, GLASGOW

DRAWING TITLE

RECORDED DEPTH AND LEVEL TO ROCKHEAD

DRAWN BY	CHK'D BY	APP'D BY	DATE	SCALES
AC	SA	SA	11.03.24	1:1000 @ A3

PROJECT No.	DRAWING No.	REVISION
P22/271	P22/271/SI/R/F/08	

MASON EVANS
A PHENNA GROUP COMPANY
Geo-Environmental Consultants
t: 0141 420 2025 e: mail@masonevans.co.uk
100 Brand Street, Glasgow, G51 1DG

A3 border: 400 x 273

4.6 Groundwater

4.6.1 During the site works, no groundwater strikes were recorded within any of the trial pits, though occasional water strikes were recorded within the shallow made ground soils between 0.20 m and 3.00 m depth.

4.6.2 To provide a more accurate assessment of groundwater behaviour, monitoring wells were installed within each borehole. Please refer back to section 3.2.3 for the justification on each well install design.

4.6.3 Groundwater monitoring has been undertaken at the site on 6 No. occasions (results included in Appendix 07). The results of the groundwater depth monitoring are summarised in Table 05 below.

Table 05 – Summary of Groundwater Monitoring Results

Location	Minimum Depth (m bgl)	Maximum Depth (m bgl)	Minimum Level (m AOD)	Maximum Level (m AOD)	Depth of Well (m bgl)	Well Level at Base (m AOD)	Recharge
BH01A	3.15	3.40	32.63	32.38	6.70	29.08	No
BH02	5.10	10.35	35.19	29.94	19.00	21.29	Variable
BH03	2.25	4.30	38.03	35.98	11.60	28.68	Variable
BH04	7.00	11.35	33.27	28.92	22.80	17.47	Variable
BH05	2.30	2.90	37.90	37.30	7.65	32.55	Yes
BH06	6.90	8.00	28.93	27.83	10.60	25.23	Variable
BH07	Dry	Dry	33.43	33.43	2.40	33.43	N/A
BH08	2.55	3.95	33.28	31.88	4.00	31.83	No

4.6.4 The information obtained during site works and from the well monitoring (i.e. inconsistent water strike depths and levels with variable recharge during purging), plus the presence of cohesive glacial soils (which recorded a fines content of up to 51% - refer to Appendix 08) which would unlikely be susceptible to lateral groundwater migration, indicated that a pervasive groundwater table does not exist within the shallow soils.

4.6.5 However, pockets of groundwater do exist, though these are considered to be localised and perched, likely as a result of surface water infiltration.

5.0 CONTAMINATION RISK ASSESSMENT

5.1 Human Health and Groundwater Risk Assessment Screening Criteria

5.1.1 Consideration of analytical results against applicable, conservative risk-based screening criteria has been used to provide an assessment of risk. A tiered risk-based approach comprises:

- Preliminary Risk Assessment (e.g. establishing potential pollutant linkages);
- Generic Quantitative Risk Assessment (GQRA) (e.g. the comparison of contaminant concentrations against Soil Guideline Values (SGV) or other Generic Assessment Criteria (GAC)); and
- Detailed Quantitative Risk Assessment (DQRA) (e.g. the comparison of contaminant concentrations against site specific assessment criteria).

5.1.2 A GQRA has been carried out as part of this assessment. Soil chemical analysis data has been assessed in terms of risks to human health and vegetation while leachate and groundwater data has been assessed in terms of risks to the water environment. The GACs utilised are the published Suitable 4 Use Levels (S4ULs) derived by LQM/CIEH, based on the exposure parameters, outlined in the DEFRA publication SP1010 (Category 4 Screening Levels (C4SLs), March 2014). The S4ULs are derived in accordance with current UK legislation, and national policy using the most recent version of the CLEA software (v1.06). Normally the CLEA software utilises the default exposure pathways and land use assumptions outlined in SR3 (Environment Agency 2009b).

5.1.3 The derived S4ULs are based on the concept of minimal tolerable risk as described in SR2 (Environment Agency 2009a) which underpins all previous EA SGVs and other GACs. Please note that S4ULs do not incorporate any toxicological parameter changes to the CLEA base model, however recent toxicological data has been incorporated into the contaminant databases. Furthermore, S4UL GACs are considered to be equivalent to the previously published Environment agency SGVs, and previous iterations of LQM/CIEH GACs and as such are suitable for use in generic quantitative risk assessments under both planning and Part IIa regimes.

5.1.4 In this case we have utilised S4UL values appropriate to the 'residential without gardens' end-use, with an average soil organic matter (SOM) concentration 2.5% (given that an average of 3.36% was recorded).

5.2 Statistical Analysis of Data

5.2.1 Where appropriate, chemical data for soils can be considered statistically in general accordance with the guidelines given in the Chartered Institute of Environmental Health Publication *Guidance on comparing Soil Contamination Data with a Critical Concentration* (May 2008).

5.2.2 For this project, statistical analysis has not been required.

Sample Depths

5.2.3 At the generic assessment stage, it should be assumed that all pathways contained within the generic model applied will be active. In reality, unless a contaminant is volatile (e.g. organic), exposure by direct contact will likely be mitigated by the depth of the contaminant or available surface cover. Generally, direct contact with contaminants at greater than 600 mm depth or under hardstanding is highly unlikely to occur unless the ground is to be disturbed through removal of surfacing or earthworks.

5.3 Ground / Mine Gas Assessment

5.3.1 The potential presence of carbon dioxide and methane at the target site have been appraised in compliance with CIRIA document, *Assessing Risks Posed by Hazardous Gases to Buildings (Report C665)* and BS 8485, *Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings (June 2015)*. In addition, a recent CL:AIRE publication entitled; 'Good Practice for Risk Assessment for Coal Mine Gas Emissions, dated October 2021' has also been consulted during our assessment, with reference made to the 'Design Support Tool for Mine Gas Risk Assessment'. These documents detail site investigations methodologies and risk assessment procedures for assessing the results from such investigations.

5.4 Building Materials Assessment

5.4.1 BRE Special Digest 1 'Concrete in Aggressive Ground' (3rd Edition, 2005) has been used to determine an appropriate concrete class for the development.

6.0 HUMAN HEALTH RISK ASSESSMENT

6.1 Contaminants in Soils

6.1.1 38 No. soil samples (28 from within the made ground and 10 from within the natural subsoils) were retrieved from the (1.72 Ha) site and analysed for a range of metals, hydrocarbons and asbestos contaminants. In addition, 9 No. samples were tested for a range of various polychlorinated biphenyls (PCBs) based on the known historical site usage (most notably as an electricity generating station). We have compared the results with soil guideline values for a 'Residential without Gardens' end land use, with an average of 2.5% soil organic matter (given that an average of 3.36% was recorded).

6.1.2 The laboratory test certificates are included in Appendix 06, whilst an overview of the results is shown in Table 06 below.

Table 06 – Exceedance of Guideline Levels (Residential without Gardens)

Contaminant	Effect	Measured Concentrations in Excess of SGV/GSV/SSTL (mg/kg)		Measured Exceedance Concentrations (mg/kg)		SGV/GSV/SSV (mg/kg)	Source
		Made Ground	Natural	Made Ground	Natural		
Metals							
Arsenic	Toxic	2 of 28	0 of 10	87 (TP03) 93 (TP03)	-	40	LQM/CIEH S4ULs (2015)
Boron	Toxic	0 of 28	0 of 10	-	-	11,000	LQM/CIEH S4ULs (2015)
Cadmium	Toxic	0 of 28	0 of 10	-	-	85	LQM/CIEH S4ULs (2015)
Chromium III	Toxic	0 of 28	0 of 10	-	-	910	LQM/CIEH S4ULs (2015)
Chromium VI	Toxic	0 of 28	0 of 10	-	-	6	LQM/CIEH S4ULs (2015)
Copper	Toxic	0 of 28	0 of 10	-	-	7100	LQM/CIEH S4ULs (2015)
Lead	Toxic	4 of 28	0 of 10	410 (BH05) 370 (TP01) 590 (TP03) 630 (TP03)	-	300	C4SL (DEFRA SP1010) (2014)
Mercury (Inorganic)	Toxic	0 of 28	0 of 10	-	-	56	LQM/CIEH S4ULs (2015)
Nickel	Toxic	0 of 28	0 of 10	-	-	180	LQM/CIEH S4ULs (2015)
Selenium	Toxic	0 of 28	0 of 10	-	-	430	LQM/CIEH S4ULs(2015)
Zinc	Toxic	0 of 28	0 of 10	-	-	40,000	LQM/CIEH S4ULs (2015)
Petroleum Hydrocarbons							
Aliphatic C5-C6	Toxic	0 of 28	0 of 10	-	-	78	LQM/CIEH S4ULs (2015)
Aliphatic C6-C8	Toxic	0 of 28	0 of 10	-	-	230	LQM/CIEH S4ULs (2015)
Aliphatic C8-C10	Toxic	0 of 28	0 of 10	-	-	65	LQM/CIEH S4ULs (2015)
Aliphatic C10-C12	Toxic	0 of 28	0 of 10	-	-	330	LQM/CIEH S4ULs (2015)
Aliphatic C12-C16	Toxic	0 of 28	0 of 10	-	-	2400	LQM/CIEH S4ULs (2015)
Aliphatic C16-C21	Toxic	0 of 28	0 of 10	-	-	92,000	LQM/CIEH S4ULs (2015)
Aliphatic C16-C35	Toxic	0 of 28	0 of 10	-	-	92,000	LQM/CIEH S4ULs (2015)
Aliphatic C21-C35	Toxic	0 of 28	0 of 10	-	-	92,000	LQM/CIEH S4ULs (2015)
Aromatic C5-C7	Toxic	0 of 28	0 of 10	-	-	690	LQM/CIEH S4ULs (2015)
Aromatic C7-C8	Toxic	0 of 28	0 of 10	-	-	1800	LQM/CIEH S4ULs (2015)
Aromatic C8-C10	Toxic	0 of 28	0 of 10	-	-	110	LQM/CIEH S4ULs (2015)
Aromatic C10-C12	Toxic	0 of 28	0 of 10	-	-	590	LQM/CIEH S4ULs (2015)
Aromatic C12-C16	Toxic	0 of 28	0 of 10	-	-	2300	LQM/CIEH S4ULs (2015)
Aromatic C16-C21	Toxic	0 of 28	0 of 10	-	-	1900	LQM/CIEH S4ULs (2015)
Aromatic C21-C35	Toxic	0 of 28	0 of 10	-	-	1900	LQM/CIEH S4ULs (2015)
PAHs							
Naphthalene	Toxic	0 of 28	0 of 10	-	-	5.6	LQM/CIEH S4ULs (2015)
Acenaphthylene	Toxic	0 of 28	0 of 10	-	-	4600	LQM/CIEH S4ULs (2015)
Acenaphthene	Toxic	0 of 28	0 of 10	-	-	4700	LQM/CIEH S4ULs (2015)
Fluorene	Toxic	0 of 28	0 of 10	-	-	3800	LQM/CIEH S4ULs (2015)
Phenanthrene	Toxic	0 of 28	0 of 10	-	-	1500	LQM/CIEH S4ULs (2015)
Anthracene	Toxic	0 of 28	0 of 10	-	-	35,000	LQM/CIEH S4ULs (2015)
Fluoranthene	Toxic	0 of 28	0 of 10	-	-	1600	LQM/CIEH S4ULs (2015)
Pyrene	Toxic	0 of 28	0 of 10	-	-	3800	LQM/CIEH S4ULs (2015)

Benzo(a)anthracene	Toxic	0 of 28	0 of 10	-	-	14	LQM/CIEH S4ULs (2015)
Chrysene	Toxic	0 of 28	0 of 10	-	-	31	LQM/CIEH S4ULs (2015)
Benzo(b)fluoranthene	Toxic	0 of 28	0 of 10	-	-	4.0	LQM/CIEH S4ULs (2015)
Benzo(k)fluoranthene	Toxic	0 of 28	0 of 10	-	-	110	LQM/CIEH S4ULs (2015)
Benzo(a)pyrene	Toxic	2 of 28	0 of 10	4.9 (TP05) 4.1 (TP08)	-	3.2	LQM/CIEH S4ULs (2015)
Indeno(1,2,3-c,d)pyrene	Toxic	0 of 28	0 of 10	-	-	46	LQM/CIEH S4ULs (2015)
Dibenzo(a,h)anthracene	Toxic	2 of 28	0 of 10	0.8 (TP05) 0.5 (TP08)	-	0.32	LQM/CIEH S4ULs (2015)
Benzo(g,h,i)perylene	Toxic	0 of 28	0 of 10	-	-	360	LQM/CIEH S4ULs (2015)
Other							
Asbestos	Toxic	19 of 28	4 of 10	0.225% (BH02) 0.215% (BH02) 0.002% (BH03) 0.001% (BH03) 0.064% (BH04) 0.048% (TP01) 0.004% (TP02) 0.019% (TP03) 0.087% (TP03) <0.001% (TP04) 0.001% (TP04) <0.001% (TP05) <0.001% (TP06) 0.021% (TP07) <0.001% (TP07) <0.001% (TP08) 0.012% (TP08) <0.001% (TP09) 0.001% (TP11)	0.024% (BH02) 0.001% (BH04) 0.009% (BH05) <0.001% (TP06)	Detection	HSE
PCB 12 congeners	Toxic	0 of 8	0 of 1	-	-	0.01	Limit of Detection

6.1.3 The GQRA identified elevated toxic metal (arsenic and lead) and poly aromatic hydrocarbon (benzo(a)pyrene and dibenzo(a,h)anthracene) contaminants within the shallow made ground soils (between 0.40 m and 2.20 m depth), which pose a risk to human health.

6.1.4 In addition, asbestos fibres were frequently encountered within the shallow made ground deposits (within 67% of the samples) between 0.40 m and 4.00 m depth. Subsequent quantification analyses recorded the total mass percentage of asbestos to range between <0.001% (i.e. very low) and 0.225% (i.e. high). Note that whilst four samples of the identified asbestos were recorded within the natural subsoil, we consider this to be representative of cross-contamination from the overlying made ground (in where asbestos was frequently recorded), and not representative of the natural subsoil below the site. As such, it is considered that the asbestos within the made ground poses a toxic risk to human health (refer to recommended 'Mitigation Measures' in section 10.3 for further detail).

6.1.5 Importantly, two of the samples taken from BH02 at 0.50 m and 2.50 m depth recorded high levels of asbestos, where >0.1% quantification was recorded. As such, if disturbed, these soils would be considered as 'hazardous waste' (refer to section 10.5 for further detail).

7.0 WATER ENVIRONMENT RISK ASSESSMENT

7.1 Water Environment Vulnerability

7.1.1 Based on the desk study researches, interpretation of the ground conditions following investigative works and the results from groundwater monitoring, we consider the main water environment receptors with regards to the site to be the deep bedrock groundwater (i.e. the 'Glasgow and Motherwell' aquifer).

7.1.2 The nearest surface water body to the site was the Forth and Clyde Canal located to the east of the site. However, due to this canal being a lined body of water which is topographically higher than the site, we do not consider this to be a sensitive receptor in relation to the proposed development as there would be no risk of contaminants from the site entering into this feature. No other surface water bodies were recorded within 1 km.

7.2 Assessment of Water Environment

7.2.1 Following SEPA Position Statement WAT-PS-10-01, *'Assigning Groundwater Assessment Criteria for Pollutant Inputs'* (August 2014), the following assessment should be carried out for potential pollutant linkages to the water environment:

1) Assess which receptors (including surface / coastal waters, wetlands, potable water extractions, and future drinking water potential) may be affected by contamination sources.
2) For potential pollutant linkages, assess contaminant concentrations against relevant screening values at the recommended assessment point, taking into consideration mixing and upstream/upgradient concentrations, where appropriate.
3) Evaluate whether remedial measures would be either disproportionately costly, a risk to other receptors, or cause deterioration of the natural environment.

7.2.2 Leachate (including metals, TPH and PAH) analysis was carried out on 26 No. samples collected from across the site to determine the risks posed, if any, by the on-site conditions (if any) to the water environment.

7.2.3 Additionally, 5 No. groundwater samples were able to be recovered from BH02, BH03, BH04, BH05 and BH06. The groundwater samples were tested for a suite of analysis including metals, TPHs and PAHs, and the results are included in Appendix 06.

7.2.4 Note that the groundwater samples were able to be retrieved as a result of perched static groundwater sourced from surface water infiltration and not due to there being a shallow pervasive water table present.

7.2.5 All leachate and groundwater results have been compared to appropriate guideline values. As groundwater was considered a primary risk, Minimum Reporting Values (MRVs) and Resource Protection Values (RPVs) have been used, obtained from SEPA position statement WAT-PS-10-01 (August 2014). In the absence of any SEPA published MRVs and RPVs we have reverted to World Health Organisation's (WHO) Guidelines for Drinking Water Quality (4^{th} Edition, 2011), CL:AIRE Petroleum Hydrocarbons in Groundwater (2017) and then WHO: Petroleum Products in Drinking Water (2005), and finally in the absence of these guidelines we have reverted to the laboratory limits of detection (LoD).

7.2.6 It should be noted that in the absence of appropriate threshold values for a number of the PAHs, the LoD value was used as a threshold. The exceedance of the LoD value merely confirms that the contaminant is above the detection limit but is not based on, nor indicative of any toxicological risk.

7.2.7 The leachate test results are summarized on Table 07 below.

Table 07 – Analysis of Leachate Samples Compared with RPV / MRV

Potential Contaminant	RPV/MRV (µg/l)	WHO (4th Edition, 2011) (ug/l)	WHO (Petroleum Products in Drinking Water (2005)) (µg/l)	CL:AIRE (Petroleum Hydrocarbons in Groundwater (2017) (µg/l)	(MEP) Limit of Detection (µg/l)	No of Samples Above Assessment Levels	Range of Concentrations which Exceeded Relevant Guidelines (µg/l)
Metals							
Arsenic	10	-	-	-	-	0 out of 26	-
Cadmium	0.1	-	-	-	-	0 out of 26	-
Chromium	50	-	-	-	-	0 out of 26	-
Copper (toxic)		2000	-	-	-	0 out of 26	-
Lead	10	-	-	-	-	0 out of 26	-
Mercury (inorganic)	0.01	-	-	-	-	19 out of 26	0.40 (BH02) 0.07 (BH02) 0.17 (BH03) 0.038 (BH03) 0.056 (BH04) 0.017 (BH04) 0.049 (BH05) 0.028 (BH05) 0.017 (BH01A) 0.048 (BH06) 0.058 (TF03) 0.022 (TF04) 0.05 (TF06) 0.05 (TF06) 0.03 (TF07) 0.21 (TF08) 0.026 (TF10) 0.022 (TF11) 0.023 (TF11)
Nickel (toxic)	20	-	-	-	-	0 out of 26	-
Selenium	10	-	-	-	-	0 out of 26	-
Zinc (toxic)	-	3000	-	-	-	0 out of 26	-
Total Petroleum Hydrocarbons (TPHs)							
Aliphatic C5-C6	-	-	-	15000	-	0 out of 23	-
Aliphatic C6-C8	-	-	-	15000	-	0 out of 23	-
Aliphatic C8-C10	-	-	-	300	-	0 out of 23	-
Aliphatic C10-C12	-	-	-	300	-	0 out of 23	-
Aliphatic C12-C16	-	-	-	300	-	0 out of 23	-
Aliphatic C16-C21	-	-	300	-	-	0 out of 23	-
Aliphatic C21-C35	-	-	300	-	-	0 out of 23	-
Total Aliphatic C5-C35	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Aromatic C5-C7	-	-	-	10	-	0 out of 23	-
Aromatic C7-C8	-	-	-	700	-	0 out of 23	-
Aromatic C8-C10	-	-	-	300	-	0 out of 23	-
Aromatic C10-C12	-	-	-	90	-	0 out of 23	-
Aromatic C12-C16	-	-	-	90	-	0 out of 23	-
Aromatic C16-C21	-	-	-	90	-	0 out of 23	-
Aromatic C21-C35	-	-	-	90	-	0 out of 23	-
Total Aromatics C5-C35	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Aliphatics and Aromatics C5-C35	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene*	-	-	-	-	0.05	11 out of 23	0.84 (BH07) 0.33 (BH07) 0.13 (BH07) 0.52 (BH08) 0.07 (BH03) 0.55 (BH03) 0.10 (BH04) 0.24 (BH05) 0.11 (BH01A) 0.08 (TF08) 0.20 (TF11)

Table 07 – Analysis of Leachate Samples Compared with RPV / MRV continued…

Acenaphthylene*	-	-	-	-	0.01	4 out of 23	0.12 (BH07) 0.04 (BH07) 0.02 (BH07) 0.36 (BH08)
Acenaphthene*	-	-	-	-	0.01	11 out of 23	0.11 (BH07) 0.08 (BH07) 0.02 (BH07) 0.10 (BH08) 0.04 (BH03) 0.02 (BH04) 0.13 (BH05) 0.05 (BH01A) 0.02 (TF04) 0.04 (TF08) 0.05 (TF11)
Fluorene*	-	-	-	-	0.01	10 out of 23	0.07 (BH07) 0.04 (BH07) 0.13 (BH08) 0.02 (BH03) 0.02 (BH03) 0.05 (BH05) 0.03 (BH01A) 0.02 (TF04) 0.02 (TF08) 0.02 (TF11)
Fhenanthrene*	-	-	-	-	0.01	21 out of 23	0.08 (BH07) 0.13 (BH07) 0.02 (BH07) 0.21 (BH08) 0.03 (BH02) 0.02 (BH02) 0.10 (BH03) 0.11 (BH03) 0.04 (BH04) 0.02 (BH04) 0.16 (BH05) 0.03 (BH05) 0.11 (BH01A) 0.02 (BH06) 0.02 (TF01) 0.06 (TF02) 0.20 (TF04) 0.02 (TF06) 0.02 (TF07) 0.07 (TF08) 0.04 (TF11)
Anthracene*	-	-	-	-	0.01	10 out of 23	0.02 (BH07) 0.04 (BH07) 0.03 (BH08) 0.03 (BH03) 0.06 (BH04) 0.05 (BH05) 0.02 (BH01A) 0.10 (TF04) 0.02 (TF08) 0.02 (TF11)
Fluoranthene	0.1	-	-	-	-	4 out of 23	0.12 (BH07) 0.14 (BH05) 0.28 (TF04) 0.15 (TF08)

Table 07 – Analysis of Leachate Samples Compared with RPV / MRV continued…

Pyrene*	-	-	-	-	0.01	21 out of 23	0.08 (BH07) 0.12 (BH07) 0.02 (BH07) 0.05 (BH08) 0.06 (BH02) 0.03 (BH02) 0.06 (BH03) 0.08 (BH03) 0.04 (BH04) 0.02 (BH04) 0.10 (BH05) 0.02 (BH05) 0.08 (BH01A) 0.05 (BH06) 0.04 (TF01) 0.08 (TF02) 0.23 (TF04) 0.04 (TF06) 0.04 (TF07) 0.17 (TF08) 0.08 (TF11)
Benzo(a)anthracene*	-	-	-	-	0.01	15 out of 23	0.03 (BH07) 0.04 (BH07) 0.05 (BH02) 0.02 (BH02) 0.03 (BH03) 0.03 (BH03) 0.05 (BH05) 0.03 (BH01A) 0.02 (BH06) 0.03 (TF02) 0.11 (TF04) 0.02 (TF06) 0.02 (TF07) 0.06 (TF08) 0.02 (TF11)
Chrysene*	-	-	-	-	0.01	17 out of 23	0.04 (BH07) 0.06 (BH07) 0.05 (BH02) 0.02 (BH02) 0.03 (BH03) 0.03 (BH03) 0.02 (BH04) 0.06 (BH05) 0.03 (BH01A) 0.03 (BH06) 0.02 (TF01) 0.03 (TF02) 0.13 (TF04) 0.02 (TF06) 0.02 (TF07) 0.09 (TF08) 0.03 (TF11)
Benzo(b)fluoranthene	0.1	-	-	-	-	2 out of 23	0.13 (TF04) 0.13 (TF08)
Benzo(k)fluoranthene	0.1	-	-	-	-	0 out of 23	-
Benzo(a)pyrene	0.01	-	-	-	-	12 out of 23	0.06 (BH07) 0.06 (BH07) 0.04 (BH02) 0.03 (BH01A) 0.03 (BH06) 0.02 (TF01) 0.04 (TF02) 0.13 (TF04) 0.02 (TF06) 0.03 (TF07) 0.09 (TF08) 0.03 (TF11)
Indeno(123-cd)pyrene	0.1	-	-	-	-	0 out of 23	-
Dibenzo(ah)anthracene*	-	-	-	-	0.01	0 out of 23	-
Benzo(ghi)perylene	0.1	-	-	-	-	0 out of 23	-
Total PAH's	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* Most conservative Limit of Detection value used as no reporting value was available in the WAT-PS-10 (Aug 2010), WHO Document (2005, 2008 or 2011) or CL:AIRE Document (2017)

7.2.8 Utilising current guideline values (RPV / MRV), the leachate testing recorded very marginal (i.e. <1.0 µg/l over the guideline value / laboratory limit of detection) exceedances of mercury plus various PAH contaminants.

7.2.9 The groundwater test results are summarized on Table 08 below.

Table 08 – Analysis of Groundwater Samples Compared with RPV / MRV

Potential Contaminant	RPV/MRV (µg/l)	WHO (4th Edition, First Addendum 2017) (µg/l)	WHO (2004 (mg/l))	WHO (Petroleum Products in Drinking Water (2005)) (µg/l)	CL:AIRE (Petroleum Hydrocarbons in Groundwater (2017) (µg/l)	(MEP) Limit of Detection (µg/l)	No of Samples Above Assessment Levels	Range of Concentrations which Exceeded Relevant Guidelines (µg/l)
Metals								
Arsenic	10	-	-	-	-	-	0 out of 5	-
Boron (water soluble)	1000	-	-	-	-	-	0 out of 5	-
Cadmium	0.1	-	-	-	-	-	1 out of 5	0.14 (BH02)
Chromium	50	-	-	-	-	-	0 out of 5	-
Copper	-	2000	-	-	-	-	0 out of 5	-
Mercury (inorganic)	0.01	-	-	-	-	-	0 out of 5	-
Nickel	20	-	-	-	-	-	0 out of 5	-
Lead	10	-	-	-	-	-	0 out of 5	-
Selenium	10	-	-	-	-	-	1 out of 5	15 (BH04)
Zinc	-	3000	-	-	-	-	0 out of 5	-
Inorganics								
Sulphate as S04	-	-	250	-	-	-	2 out of 5	340 (BH02) 320 (BH04)
Total Cyanide	50	-	-	-	-	-	0 out of 5	-
Total Petroleum Hydrocarbons (TPHs)								
Aliphatic C5-C6	-	-	-	-	15000	-	0 out of 5	-
Aliphatic C6-C8	-	-	-	-	15000	-	0 out of 5	-
Aliphatic C8-C10	-	-	-	-	300	-	0 out of 5	-
Aliphatic C10-C12	-	-	-	-	300	-	0 out of 5	-
Aliphatic C12-C16	-	-	-	-	300	-	0 out of 5	-
Aliphatic C16-C21	-	-	-	300	-	-	0 out of 5	-
Aliphatic C21-C35	-	-	-	300	-	-	0 out of 5	-
Total Aliphatic C5-C35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Aromatic C5-C7	-	-	-	-	10	-	0 out of 5	-
Aromatic C7-C8	-	-	-	-	700	-	0 out of 5	-
Aromatic C8-C10	-	-	-	-	300	-	0 out of 5	-
Aromatic C10-C12	-	-	-	-	90	-	0 out of 5	-
Aromatic C12-C16	-	-	-	-	90	-	0 out of 5	-
Aromatic C16-C21	-	-	-	-	90	-	0 out of 5	-
Aromatic C21-C35	-	-	-	-	90	-	0 out of 5	-
Total Aromatics C5-C35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Aliphatics and Aromatics C5-C35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Polycyclic Aromatic Hydrocarbons (PAHs)								
Naphthalene*	-	-	-	-	-	0.05	2 out of 5	0.10 (BH02) 0.12 (BH06)
Acenaphthylene*	-	-	-	-	-	0.01	0 out of 5	-
Acenaphthene*	-	-	-	-	-	0.01	1 out of 5	0.02 (BH02)
Fluorene*	-	-	-	-	-	0.01	2 out of 5	0.05 (BH02) 0.03 (BH06)
Phenanthrene*	-	-	-	-	-	0.01	4 out of 5	0.23 (BH02) 0.06 (BH04) 0.20 (BH06) 0.02 (BH03)
Anthracene*	-	-	-	-	-	0.01	0 out of 5	-
Fluoranthene	0.1	-	-	-	-	-	0 out of 5	-
Pyrene*	-	-	-	-	-	0.01	4 out of 5	0.07 (BH02) 0.03 (BH04) 0.04 (BH06) 0.02 (BH03)
Benzo(a)anthracene*	-	-	-	-	-	0.01	2 out of 5	0.03 (BH02) 0.02 (BH06)
Chrysene*	-	-	-	-	-	0.01	2 out of 5	0.03 (BH02) 0.02 (BH06)
Benzo(b)fluoranthene	0.1	-	-	-	-	-	0 out of 5	-
Benzo(k)fluoranthene	0.1	-	-	-	-	-	0 out of 5	-
Benzo(a)pyrene	0.01	-	-	-	-	-	2 out of 5	0.03 (BH02) 0.02 (BH06)
Indeno(123-cd)pyrene	0.1	-	-	-	-	-	0 out of 5	-
Dibenzo(ah)anthracene*	-	-	-	-	-	0.01	0 out of 5	-
Benzo(ghi)perylene	0.1	-	-	-	-	-	0 out of 5	-
Total PAH's	N/A	N/A	-	N/A	N/A	N/A	N/A	N/A
Phenols								
Phenol*	-	-	-	-	-	0.5	0 out of 5	-

* Most conservative Limit of Detection value used as no reporting value was available in the WAT-PS-10 (Aug 2010), WHO Document (2005, 2008 or 2011) or CL:AIRE Document (2017)

7.2.10 The groundwater testing recorded elevated concentrations of metals cadmium and selenium (0.04 to 5.0 µg/l over the guideline value) plus very marginal (i.e. <1.0 µg/l over the guideline value / laboratory limit of detection) exceedances of various PAH contaminants.

7.2.11 Given the exceedances recorded in the analyses, and as part of our sensitivity analyses which takes cognisance of the guidance document EA RMT: Hydrogeological Risk Assessment for Land Contamination, we have modelled to an assessment point of 250 m. This is in line with SEPA guidance sourced from WAT-PS-10-01 which states that '*where present or planned future land-use limited the exploitation of the groundwater resource for the foreseeable future. The most likely example is the presence of sewered urban areas, forestry, or major infrastructure development. In this instance, the assessment point should be located at the downgradient extent of the limiting land use, subject to a maximum distance of 250 m. SEPA considers that a distance of 250 m represents a reasonable balance between the need to allow sustainable development and need to protect the potential future human use of groundwater*'.

7.2.12 As such and given the present land-use (i.e. a built-up area with no abstraction wells recorded within a 2 km radius) it is considered that there would be no exploitation of the groundwater and therefore an appropriate compliance point for the groundwater risk assessment would be 250 m.

7.2.13 We have utilised Remedial Targets Methodology R&D P20 (v3.2) published by the Environment Agency in our assessment and a copy of the models are included in Appendix 09.

7.2.14 The model was run for the maximum elevated concentrations of cadmium, mercury, selenium, sulphate, naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, and benzo(a)pyrene, which were indicated to pose the highest risk of contamination to the groundwater environment. The results of the modelling are shown in Table 09.

Table 09 – Results of P20 Groundwater Modelling (RPV / MRV)

Contaminants	Max Elevated Contaminant Concentration (µg/l)	Target Value (µg/l)	Source	Final concentration (µg/l)
Cadmium	0.14	0.10	RPV / MRV	0.0687
Mercury	0.40	0.01	RPV / MRV	0.196
Selenium	15	10	RPV / MRV	7.37
Total Sulphate	340 (mg/l)	250 (mg/l)	WHO	167 (mg/l)
Naphthalene	0.84	0.05	LoD	0.00
Acenaphthylene	0.36	0.01	LoD	0.00
Acenaphthene	0.13	0.01	LoD	0.00
Fluorene	0.13	0.01	LoD	0.00
Phenanthrene	0.23	0.01	LoD	0.00

Table 09 – Results of P20 Groundwater Modelling (RPV / MRV) continued…

Contaminants	Max Elevated Contaminant Concentration (µg/l)	Target Value (µg/l)	Source	Final concentration (µg/l)
Anthracene	0.10	0.1	LoD	0.00
Fluoranthene	0.28	0.1	RPV / MRV	0.00
Pyrene	0.23	0.01	LoD	0.00
Benzo(a)anthracene	0.11	0.01	LoD	0.00
Chrysene	0.13	0.01	LoD	0.00
Benzo(b)fluoranthene	0.13	0.1	RPV / MRV	0.00
Benzo(a)pyrene	0.13	0.01	RPV / MRV	0.00

7.2.15 Within each of the elevated contaminants modeled, the final concentration of each of the contaminants were below the recommended guidelines or laboratory limits of detection (i.e. the target values). The only exception was mercury which was recorded to be 0.186 µg/l above the laboratory limit of detection. However, given the extremely marginal nature of this exceedance coupled with the absence of a shallow pervasive water body and presence of low permeable glacial till deposits, we do not consider that this poses a risk to the water environment, with the most sensitive receptor considered to be the bedrock aquifer at depth.

7.2.16 In addition, given that post-development the majority of the site will be surfaced in buildings with associated hardstanding areas, infiltration of surface water will be reduced and therefore no significant source-pathway-receptor linkages will exist.

7.2.17 We therefore conclude that the shallow soils are not adversely impacting the wider water environment.

7.2.18 For clarity, justification of the P20 Model inputs utilised in our assessment are recorded in Table 10 overleaf.

Table 10 – Justification of P20 Model Inputs

Input Parameters	Value	Source of Parameter Value	Justification
Level 3 Groundwater			
Initial contaminant concentration in groundwater at plume core	Variable	Laboratory test results	Maximum recorded concentration of contaminant at the site (from both groundwater and leachate)
Half-life for degradation of contaminant in water.	Variable	Handbook of Environmental Degradation Rates *Howard et al (dated 2019)*	Reputable source of contaminant half-life information. High groundwater half-life utilised
Width of possible plume in aquifer at source (perpendicular to flow)	175 m	Site measurement	Maximum width of possible plume (no groundwater table was recorded)
Plume thickness at source	7.5 m	Assumed value	This represents 50% of the measured saturated aquifer thickness
Saturated aquifer thickness	15 m	Thickness of superficial recorded at the site	Maximum thickness of flooded superficial soils recorded across the site
Bulk density of aquifer materials	2.11 g/cm^3	MATtest certificate	Average value derived from soil geotechnical results
Effective porosity of aquifer	0.50	Freeze and Cherry (1979) Table 2.4	Average porosity within range for sandy clay soils
Hydraulic gradient	0.001	Calculation	Representative value used given the absence of a pervasive water body
Hydraulic conductivity of aquifer materials in which dilution occurs.	0.00000864 m/day	Freeze and Cherry (1979) Table 2.2 (10^{-3} cm/s converted to m/day)	Average hydraulic conductivity within range for sandy clay soils, as indicated by PSD Test results (section 11.2)
Distance to compliance point (groundwater assessment)	250 m	Section 7.3 of SEPA document WAT-PS-10-01	Built-up rural area with no potential for groundwater exploitation
Organic carbon partition coefficient	Variable	Total Petroleum Hydrocarbon Working Group Series Volume 3 (1997)	Reputable source of information

8.0 GROUND / MINE GAS EMISSIONS

8.1 General

Ground Gas

8.1.1 A ground gas risk assessment has been undertaken to assess the risk associated with carbon dioxide, methane gas and radon, to new buildings and their users. The identified sources of ground gas below the site were the made ground soils (locally up to 3.30 m thick) with total organic carbon (TOC) values of up to 6.3%. As such, we considered it prudent to undertake ground gas monitoring to confirm (or otherwise) the presence of ground gas emissions below the site.

8.1.2 As part of our risk assessment, we have also taken into consideration any potential drivers for gas migration and correlation, including changing atmospheric pressures and changing groundwater levels in the future. This is further discussed in sections 8.3.11 to 8.3.14.

8.1.3 The assessment of risk due to ground gases has been further discussed in publications for CIRIA and BRE, which have indicated a number of 'characteristic situations' depending on the concentrations and flow rates of gas. This classification system has been further developed by Wilson and Card (1999), and Boyle and Witherington (2006) and a revised industry guidance has been provided within CIRIA Report C665 (2007).

Mine Gas

8.1.4 The recent CL:AIRE publication entitled; 'Good Practice for Risk Assessment for Coal Mine Gas Emissions, dated October 2021' has also been consulted during our assessment, with reference made to the 'Design Support Tool for Mine Gas Risk Assessment'.

8.1.5 In accordance with the preliminary assessment procedures outlined in Figure 13.1 CL:AIRE, October 2021, we have assessed the site as being within a '*high risk zone*', given that previous shallow mining activities have taken place (refer to section 13.0 for further detail).

8.1.7 The superficial soils which underlie the site were recorded to be cohesive glacial till (sandy, gravelly CLAY). The glacial till deposits were encountered to rockhead, proven to depths typically between 6 m and 16 m bgl. Glacial till typically has a hydraulic conductivity of between 10^{-11} m/sec to 10^{-16} m/sec (sourced from Freeze and Cherry, 1979) and although not impervious to ground gas, would act as a preclusive barrier to reduce the potential risk of any mine gases migrating to the surface.

8.1.8 The shallowest mine workings below the site were encountered between 8.40 m and 9.10 m depth within the southern area at the level of the Upper Possil Coal. No mine workings were encountered within the northern or central site areas, proven to 38.50 m depth.

8.1.9 In addition, there are no records of mine entries within site.

8.1.10 It should be noted that Gas Screening Values (GSV's) and the design and specification for identifying suitable mitigation measures, as described in BS8485 (2015) + A1:2019 should be used with extreme caution in mine gas risk assessments. As noted within the CL:AIRE guidance, the methods utilised within this guidance may not be appropriate for sites with complex conceptual site models (CSM's) or affected by high risk factors, except as one strand in a multiple lines of evidence approach (CL:AIRE, October 2021).

8.2 Ground / Mine Gas – Results

8.2.1 Ground gas monitoring of the installations had been undertaken at the site on six occasions. The monitoring was undertaken using a portable gas meter and the data is presented below.

8.2.2 The rationale for monitoring was adapted from CIRIA C665 (Tables 5.5a and 5.5b), with a low to moderate-sensitivity development (i.e. commercial and flats) with a low generation potential (which we have assessed based on BS8576, Figure 6). Based on this, monitoring would be required on six occasions, over a period of approximately 3 months.

8.2.3 Measurements were taken during over a variety of atmospheric conditions, **including periods of low atmospheric pressure**, with barometric pressures ranging from 987 to 1012 mb.

- Oxygen (O_2) concentrations were recorded to range from 5.5% to 21.1%.
- Carbon dioxide (CO_2) concentrations were recorded to range from 0.0% to 2.3% vol.
- Methane (CH_4) concentrations were recorded to range between 0.0% to 4.9% vol.
- Steady state flow rates were recorded to range between 0.0 to 3.1 litres / hour over the monitoring period (though generally were consistent at 0.0 litres / hour).

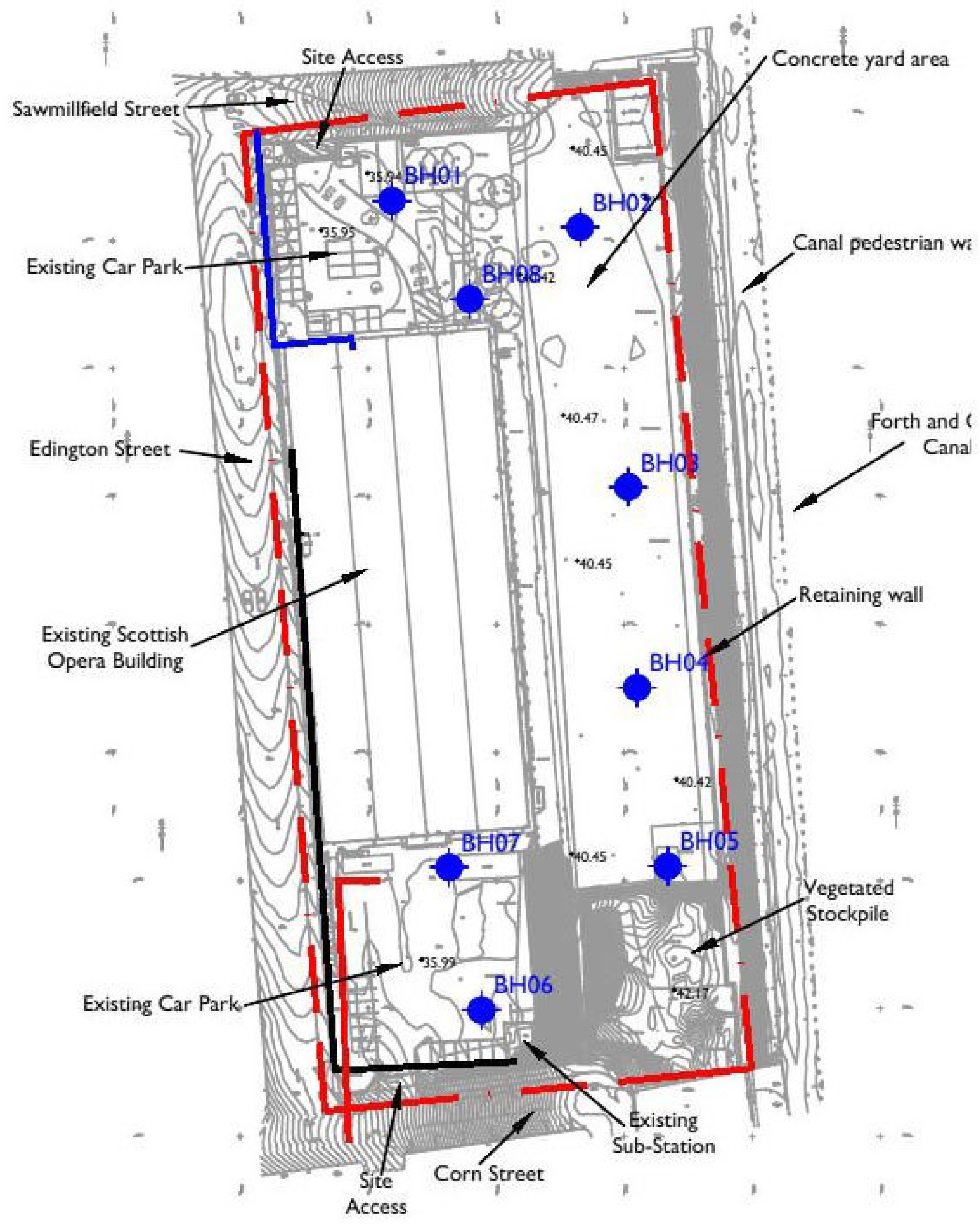
8.2.4 As previously discussed (refer to section 3.2.3) response zones within the made ground deposits, natural soils and the bedrock were targeted with slotted pipes.

8.2.5 A review of available atmospheric pressure details preceding each monitoring round have been reviewed from the nearest station located at Glasgow Airport approximately 6.5 miles to the west. The general trend for each round was as follows:

- Visit 01 18/12/23 – Falling pressure from 15th December until 21st December.
- Visit 02 09/01/24 – High and steady pressure from 8th January to 10th January.
- Visit 03 22/01/24 – Low and rising pressure from 21st January to 27th January.
- Visit 04 05/02/24 – Falling pressure from 3rd February to 6th February.
- Visit 05 19/02/24 – Rapidly falling pressure from 19th February to 21st February.

8.2.6 Whilst the available online data is consistent with our data, is considered that our data collected at the start and end of the monitoring rounds represents more accurate and appropriate data for our assessment, than the available online records. A copy of the historical atmospheric pressure details is included in Appendix 10.

8.2.7 The location of the monitoring wells, and a summary of the results is included in Drawing No. P22/271/SI/R/F/09. The results of the gas monitoring are included in Appendix 07.



Borehole BH01						
Date.	CH_4 % Vol.	CO_2 % Vol.	O_2 % Vol.	Ave Flow (l/h)	Atmos. Pressure (mb)	G/Water Depth (m)
18.12.23	0.0	0.0	5.5	0.0	1011	3.15
09.01.24	0.0	0.0	17.7	0.0	1010	3.40
22.01.24	-	-	-	-	978	-
05.02.24	-	-	-	-	1004	-
19.02.24	0.0	0.8	7.2	0.0	1017	-
04.03.24	-	-	-	-	1003	-

Borehole BH02						
Date.	CH_4 % Vol.	CO_2 % Vol.	O_2 % Vol.	Ave Flow (l/h)	Atmos. Pressure (mb)	G/Water Depth (m)
18.12.23	0.0	0.3	18.5	0.0	1011	6.20
09.01.24	0.0	0.0	20.1	0.0	1010	9.90
22.01.24	0.0	0.3	13.7	0.0	978	5.10
05.02.24	2.4	0.2	17.7	0.0	1004	10.35
19.02.24	1.0	0.4	15.1	0.0	1017	9.80
04.03.24	0.0	0.3	15.5	0.0	1003	9.95

Borehole BH03						
Date.	CH_4 % Vol.	CO_2 % Vol.	O_2 % Vol.	Ave Flow (l/h)	Atmos. Pressure (mb)	G/Water Depth (m)
18.12.23	0.0	0.0	17.0	0.0	1011	2.25
09.01.24	0.0	0.0	19.7	0.0	1010	2.30
22.01.24	0.0	0.0	17.2	0.0	978	2.30
05.02.24	0.0	0.1	18.1	0.0	1004	2.35
19.02.24	0.0	0.0	17.5	0.0	1017	4.30
04.03.24	0.0	0.0	18.0	0.0	1003	2.55

Borehole BH04						
Date.	CH_4 % Vol.	CO_2 % Vol.	O_2 % Vol.	Ave Flow (l/h)	Atmos. Pressure (mb)	G/Water Depth (m)
18.12.23	0.0	0.0	17.6	0.0	1011	7.20
09.01.24	0.0	0.0	21.1	0.0	1010	7.00
22.01.24	0.0	0.0	17.7	0.0	978	9.15
05.02.24	0.0	0.1	16.8	0.0	1004	-
19.02.24	0.0	0.1	10.2	0.0	1017	11.35
04.03.24	0.0	0.0	11.2	0.4	1003	11.20

Borehole BH05						
Date.	CH_4 % Vol.	CO_2 % Vol.	O_2 % Vol.	Ave Flow (l/h)	Atmos. Pressure (mb)	G/Water Depth (m)
18.12.23	0.0	0.2	19.5	0.0	1011	2.30
09.01.24	0.0	0.2	20.1	0.0	1010	1.10
22.01.24	-	-	-	-	978	2.25
05.02.24	0.0	0.1	19.8	0.0	1004	2.30
19.02.24	0.0	0.1	19.0	0.0	1017	2.30
04.03.24	0.0	0.0	19.4	0.0	1003	2.45

Borehole BH06						
Date.	CH_4 % Vol.	CO_2 % Vol.	O_2 % Vol.	Ave Flow (l/h)	Atmos. Pressure (mb)	G/Water Depth (m)
18.12.23	1.9	1.1	14.6	0.0	1011	7.90
09.01.24	0.0	0.0	19.0	0.0	1010	8.00
22.01.24	1.5	2.2	11.6	0.0	978	7.85
05.02.24	1.5	1.6	11.0	3.1	1004	-
19.02.24	1.9	2.3	8.4	0.0	1017	7.90
04.03.24	1.4	2.1	10.4	0.0	1003	8.00

Borehole BH07						
Date.	CH_4 % Vol.	CO_2 % Vol.	O_2 % Vol.	Ave Flow (l/h)	Atmos. Pressure (mb)	G/Water Depth (m)
18.12.23	0.0	0.3	17.9	0.0	1011	Dry
09.01.24	0.0	0.0	20.1	0.0	1010	Dry
22.01.24	0.0	1.0	16.3	0.0	978	Dry
05.02.24	0.6	0.6	18.3	0.0	1004	Dry
19.02.24	0.0	0.9	17.0	0.0	1017	Dry
04.03.24	0.0	0.4	19.2	0.0	1003	Dry

Borehole BH08						
Date.	CH_4 % Vol.	CO_2 % Vol.	O_2 % Vol.	Ave Flow (l/h)	Atmos. Pressure (mb)	G/Water Depth (m)
18.12.23	0.0	1.5	13.8	0.0	1011	2.90
09.01.24	0.0	0.0	21.1	0.0	1010	2.90
22.01.24	0.0	0.5	18.6	0.0	978	3.10
05.02.24	-	-	-	-	1004	-
19.02.24	0.0	0.2	19.3	0.0	1017	2.90
04.03.24	0.0	0.9	18.0	1.2	1003	2.55

NOTES

- Approximate site boundary
- SP Energy cables
- Scottish Gas pipe
- Buried BT cable
- BH01 to BH08 — Soils borehole sunk by GD Drilling (December 2023)

REV	DATE	DETAILS

SCOTTISH OPERA
39 ELMBANK STREET
GLASGOW
G2 4PT

PROJECT TITLE

ROTTERDAM WHARF
PORT DUNDAS, GLASGOW

DRAWING TITLE

GROUND GAS
EMISSIONS SURVEY

DRAWN BY	CHK'D BY	APP'D BY	DATE	SCALES
AC	SA	SA	11.03.24	1:1000 @ A3

PROJECT No.	DRAWING No.	REVISION
P22/271	P22/271/SI/R/F/09	

MASON EVANS
A PHENNA GROUP COMPANY
Geo-Environmental Consultants
t: 0141 420 2025 e: mail@masonevans.co.uk
100 Brand Street, Glasgow, G51 1DG

A3 border: 400 x 273

8.3 Ground / Mine Gas – Assessment

8.3.1 Gas Screening Values have been calculated in line with CIRIA 665 and BS8485 (2015) guidance.

8.3.2 This is done by calculating a Q_{hg} for each monitoring point, for each monitoring event. Hazardous gas flow rate Q_{hg} (in lh^{-1}) is calculated using the following:

$$Q_{hg} = C_{hg}/100 \times q$$

Where:
C_{hg} is the measured hazardous gas concentration (in percentage volume-by-volume).
q is the flow rate (in litres per hour) of combined gasses from the standpipe found by direct measurement.

8.3.3 Hazardous gas flow rates were calculated for each monitoring point during each event. An absolute 'worst-case' scenario was realised on 5th February 2024, in BH02 where CH_4 was 4.9% and a gas flow rate of 3.1 l/hr was recorded (within BH06). The resultant hazardous gas flow rate is therefore as follows:

$$Q_{hg} = 4.9/100 \times 3.1$$

$$Q_{hg} = 0.1519$$

8.3.4 The value derived above is the highest hazardous gas flow rate calculated over the duration of the gas monitoring.

8.3.5 Based on the BS 8485 (2015) guidance, the calculated monitoring data and GSV corresponds to 'Characteristic Situation 2' whereby gas protection measures are required, as per Table 11 below.

Table 11 – Assessment of Gas Characterisation

Characteristic Situation	Hazard Potential	Gas Screening Value (GSV) (l/hr)	Additional Limiting Factors
1	Very Low	<0.07	Methane not to exceed 1% by volume and carbon dioxide not to exceed 5% by volume.
2	**Low**	**0.07 to <0.7**	**Borehole air flow not to exceed 70 l/hr, otherwise increase to CS3.**
3	Moderate	0.7 to <3.5	None
4	Moderate to High	3.5 to <15	None
5	High	15 to <70	None
6	Very High	>70	None

8.3.6 The construction and use of the building, together with the control of future structural changes to the building and its maintenance (the building's management) should be assessed, since potential risks posed by ground gases are strongly influenced by these factors. The assessment should lead to the categorization of the building as a whole, or each different part of the building, into one of four building types: Type A, Type B, Type C or Type D, as outlined in Tables 12A and 12B overleaf.

8.3.7 New buildings should be categorized in accordance with Tables 12A and 12B, as outlined in BS 8485 (2015).

Table 12A – Building Types and Descriptions (BS 8485 – 2015) – Proposed Flatted Residential

Building Type	Description
A	Private ownership with no building management controls on alterations to the internal structure, the use of rooms, the ventilation of rooms or the structural fabric of the building. Some small rooms present. Probably conventional building construction (rather than civil engineering). Examples include private housing and some retail premises.
B	**Private or commercial property with central building management control of any alterations to the building or its uses but limited or no central building management control of the maintenance of the building, including the gas protection measures. Multiple occupancy. Small to medium size rooms with passive ventilation of rooms and other internal spaces throughout ground floor and basement areas. May be conventional building or civil engineering construction. Examples include managed apartments, multiple occupancy offices, some retail premises and parts of some public buildings (such as schools, hospitals, leisure centers) and parts of hotels.**
C	Commercial building with central building management control of any alterations to the building or its uses and central building management control of the maintenance of the building, including the gas protection measures. Single occupancy of ground floor and basement areas. Small to large size rooms with active ventilation or good passive ventilation of all rooms and other internal spaces throughout ground floor and basement areas. Probably civil engineering construction. Examples include offices, some retail premises, and parts of some public buildings (such as schools, hospitals, leisure centers and parts of hotels).
D	Industrial style building having large volume internal space(s) that are well ventilated. Corporate ownership with building management controls on alterations to the ground floor and basement areas of the building and on maintenance of ground gas protective measures. Probably civil engineering construction. Examples are retail park sales buildings, factory shop floor areas, warehouses. (Small rooms within these style buildings should be separately categorized as Type B or Type C).

Table 12B – Building Types and Descriptions (BS 8485 – 2015) – Commercial

Building Type	Description
A	Private ownership with no building management controls on alterations to the internal structure, the use of rooms, the ventilation of rooms or the structural fabric of the building. Some small rooms present. Probably conventional building construction (rather than civil engineering). Examples include private housing and some retail premises.
B	Private or commercial property with central building management control of any alterations to the building or its uses but limited or no central building management control of the maintenance of the building, including the gas protection measures. Multiple occupancy. Small to medium size rooms with passive ventilation of rooms and other internal spaces throughout ground floor and basement areas. May be conventional building or civil engineering construction. Examples include managed apartments, multiple occupancy offices, some retail premises and parts of some public buildings (such as schools, hospitals, leisure centers) and parts of hotels.
C	**Commercial building with central building management control of any alterations to the building or its uses and central building management control of the maintenance of the building, including the gas protection measures. Single occupancy of ground floor and basement areas. Small to large size rooms with active ventilation or good passive ventilation of all rooms and other internal spaces throughout ground floor and basement areas. Probably civil engineering construction. Examples include offices, some retail premises, and parts of some public buildings (such as schools, hospitals, leisure centers and parts of hotels).**
D	Industrial style building having large volume internal space(s) that are well ventilated. Corporate ownership with building management controls on alterations to the ground floor and basement areas of the building and on maintenance of ground gas protective measures. Probably civil engineering construction. Examples are retail park sales buildings, factory shop floor areas, warehouses. (Small rooms within these style buildings should be separately categorized as Type B or Type C).

8.3.8 From the identified Characteristic Situation and taking account of the proposed development, the minimum gas protection score should be calculated, in accordance with Table 13 below.

Table 13 – Gas Protection Score by Characteristic Situation and Type of Building

Characteristic Situation (CIRIA 149)	MINIMUM GAS PROTECTION SCORE (POINTS)			
	High Risk		Medium Risk	Low Risk
	Type A Building	Type B Building	Type C Building	Type D Building
1	0	0	0	0
2	3.5	**3.5**	**2.5**	1.5
3	4.5	4	3	2.5
4	6.5	5.5	4.5	3.5
5	-	6.5	5.5	4.5
6	-	-	7.5	6.5

8.3.9 To conclude, the site was classified as 'Characteristic Situation 2'. Taking into account the building types (Type B for flatted area and Type C for the extension) this corresponded to required solution scores of 3.5 for the proposed flatted residential developments, and 2.5 for the proposed extension to Scottish Opera.

8.3.10 Notably, the elevated methane readings were recorded within the wells with slotted pipes within the bedrock, indicating that the gas source is a result of mine gas emissions.

8.3.11 As part of our gas risk assessment, we have also taken into consideration the effects of natural events (such as global warming) and on-site preferential pathways may have on the gaseous conditions below the site.

8.3.12 In regard to preferential pathways, due to the poor ground conditions recorded below the site, the foundation proposals will likely consist of piles onto a suitable formation, which may potentially create additional preferential pathways for ground gases to migrate vertically (further owing to the requirement of gas protection).

8.3.13 Furthermore, as discussed earlier in the report, the site is not underlain by a pervasive shallow water table and therefore would not contribute to any significant hydraulic action, with the only known underground aquifer being within the bedrock at depth and so any increase in future groundwater levels will not pose an impact on the site. This was indicated during our gas monitoring visit on 22/01 which recorded low atmospheric pressure, yet still no discrepancies in the recorded ground gas readings (such as flow readings or higher CO_2 / CH_4 concentrations).

8.3.14 Finally, upon completion of the gas monitoring that each borehole well should be removed and appropriately backfilled in line with SEPA guidance prior to development, to limit any existing pathways existing where possible.

8.3.15 Following the determination of the minimum gas protection score, a combination of two or more of: 1) structural barrier of the floor slab, and / or; 2) ventilation measures, and / or; 3) a gas resistant membrane should be implemented in order to achieve an adequate score. The protection measures along with relevant scores are outlined in Tables 14, 15 and 16.

Table 14 – Gas Protection Scores for the Structural Barrier

Floor and Substructure Design	Score
Precast suspended segmented subfloor (i.e. beam and block).	0
Cast in situ ground-bearing floor slab (with only nominal mesh reinforcement)	0.5
Cast in situ monolithic reinforced ground-bearing raft or reinforced cast in situ suspended floor slab with minimal penetrations	1 or 1.5
Basement floor and walls conforming to BS 8102:2009 Grade 2 Waterproofing	2
Basement floor and walls conforming to BS 8102:2009 Grade 3 Waterproofing	2.5

Table 15 – Gas Protection Scores for Ventilation Protection Measures

Protection Element / System	Score	Comments
(a) Pressure relief pathway (usually formed of low fines gravel or with a thin geocomposite blanket or strips terminating in a gravel trench external to the building)	0.5	Whenever possible a pressure relief pathway (as a minimum) should be installed in all gas protection measures systems. If the layer has a low permeability and/or is not terminated in a venting trench (or similar), then the score is zero.
(b) Passive sub floor dispersal layer: Very good performance: Good performance: Media used to provide the dispersal layer are: ▪ Clear void. ▪ Polystyrene void former blanket. ▪ Geocomposite void former blanket. ▪ No-fines gravel layer with gas drains. ▪ No-fines gravel layer.	 2.5 1.5	The ventilation effectiveness of different media depends on a number of different factors including the transmissivity of the medium, the width of the building, the side ventilation spacing and type and the thickness of the layer.
(c) Active dispersal layer, usually comprising fans with active abstraction (suction) from a subfloor dilution layer, with roof level vents. The dilution layer may comprise a clear void or be formed of geocomposite or polystyrene void formers	1.5 to 2.5	This system relies on continued serviceability of the pumps, therefore alarm and response systems should be in place. There should be robust management systems in place to ensure the continued maintenance of the system, including pumps and vents. Active ventilation should always be designed to meet at least "good performance".
(d) Active positive pressurization by the creation of a blanket of external fresh air beneath the building floor slab by pumps supplying air to points across the central footprint of the building into a permeable layer, usually formed of a thin geocomposite blanket.	1.5 to 2.5	This system relies on continued operation of the pumps, therefore alarm and response systems should be in place. The score assigned should be based on the efficient "coverage" of the building footprint and the redundancy of the system. Active ventilation should always be designed to meet at least "good performance".
(e) Ventilated car park (floor slab of occupied part of the building under consideration is underlain by a basement or undercroft car park).	4	Assumes that the car park is vented to deal with car exhaust fumes, designed to Buildings Regulations 2000, Approved Document F[9].

Table 16 – Gas Protection Scores for the Gas Resistant Membrane

Protection Element / System	Score	Comments
Gas resistant membrane meeting all of the following criteria: ▪ Sufficiently impervious to the gases with a methane gas transmission rate <40.0 ml/day/m2/atm (average) for sheet and joints (tested in accordance with BS ISO 15105-1 manometric method); ▪ Sufficiently durable to remain serviceable for the anticipated life of the building and duration of gas emissions; ▪ Sufficiently strong to withstand in-service stresses (e.g. settlement if placed below a floor slab); ▪ Sufficiently strong to withstand the installation process and following trades until covered (e.g. penetration from steel fibres in fibre reinforced concrete, penetration of reinforcement ties, tearing due to working above it, dropping tools, etc); ▪ Capable, after installation, of providing a complete barrier to the entry of the relevant gas; ▪ Verified in accordance with CIRIA C735.	2	The performance of membranes is heavily dependent on the quality and design of the installation, resistance to damage after installation and integrity of joints. If a membrane is installed that does not meet all the criteria in column 1 then the score is zero.

8.3.16 From the site characteristic hazardous gas flow rate as calculated the ground gas regime was classified as 'Characteristic Situation 2'. Therefore, ground gas preclusion measures are required (3.5 points for the proposed flatted residential development and 2.5 points for the proposed commercial development), as set out in Tables 14, 15 and 16.

8.4 Hydrocarbon Vapours

8.4.1 In addition to the ground gas monitoring, Photoionization Detection (PID) monitoring was carried out in all well installations. The monitoring has been carried out on three occasions and results consistently recorded a value 0.0 ppm on each occasion. This was consistent with the recorded ground conditions which did not record any significant evidence of hydrocarbons.

8.4.2 As such, we do not consider hydrocarbon vapour preclusion measures to be necessary as part of future development.

8.5 Instrument Calibration

8.5.1 The calibration certificates for the gas monitoring instruments (including the PID instrument) used throughout our monitoring visits are included in Appendix 11.

8.6 Radon

8.6.1 The Envirocheck Report (refer to desk study report included in Appendix 01) stated that the site is located within a 'lower probability radon area' and therefore radon gas protective measures are not considered necessary in the construction of new developments.

8.7 Conclusions

8.7.1 Methane (up to 4.9%) was recorded at elevated levels below the site.

8.7.2 We consider the gas source to be associated with mine gas within the bedrock.

8.7.3 From the site characteristic hazardous gas flow rate as calculated, based on a worst-case scenario, the ground / mine gas regime was classified as '*Characteristic Situation 2*' whereby gas protection measures are considered necessary.

8.7.4 In addition, future abnormal foundations (i.e. piles) could provide an additional pathway for ground gas migration below the building footprints (further owing to the requirement of gas protection).

8.7.5 Taking into account the building types (Type B and Type C) this corresponded to required solution scores of 3.5 points (for the proposed flatted residential developments) and 2.5 points (for the proposed commercial development).

8.7.6 Following the determination of the minimum gas protection score, a combination of: 1) structural barrier of the floor slab, and / or; 2) ventilation measures, and / or; 3) a gas resistant membrane should be implemented in order to achieve an adequate score.

8.7.7 Radon gas or hydrocarbon vapour barriers are not considered necessary.

9.0 RISKS TO CONSTRUCTED DEVELOPMENT

9.1 Sulphate Attack on Construction Materials

9.1.1 Laboratory testing was undertaken on selected soil samples, in order to determine the sulphate content and acidity, and hence the concrete class required for buried concrete.

9.1.2 We consider that a shallow water table does not exist below the site, and as such, any shallow groundwater encountered is considered to be static.

Table 17 – Sulphate and pH Summary

Determinant	Range	DS Class	ACEC Class
Sulphate as SO_4 (%) in Groundwater	42 – 340 (mg / l)	DS-2	AC-2s
Sulphate as SO_4 (%) in Leachate	2.7 – 53.0 (mg / l)		
pH (soil and groundwater)	7.1 – 11.2		
Total Sulphate as SO_4 (%) in Soil	0.02 – 1.1		
Average of Highest 20% of Total Sulphate as SO_4 (%) in Soil	0.4725		

9.1.3 In accordance with BRE Special Digest '1:2005 Concrete in Aggressive Ground', given that there were >10 No. soil samples analysed, the mean of the highest 20% of the sulphate test results was taken as the characteristic value. As such, our recommendation for concrete is 'Aggressive Chemical Environment' for Concrete (ACEC) Classification AC-2s with a design sulphate class for the site of DS-2.

9.2 Phytotoxicity

9.2.1 Guidance on the effects of metal contamination on plant growth is provided within the British Standard 'BS3882:2015 - Specification for Topsoil' and similar guidance issued by the Scottish Agricultural College (SAC). A summary of test results versus the recommended phytotoxic screening criteria is provided below:

Table 18 – Summary of Soil Results vs Phytotoxic Screening Criteria

Contaminant	Screening Value (mg/kg)	Measured Exceedance Concentrations (mg/kg)	Conc > BS 3882 Screening Value
Zinc	300	500 (BH05) 460 (TP01) 840 (TP03) 890 (TP03)	Yes
Copper	200	370 (BH05) 210 (TP03) 220 (TP03) 540 (TP04)	Yes
Nickel	110	140 (TP03) 150 (TP03)	Yes

Note – screening value based on average pH of >7.0 (Ref BS3882:2015).

9.2.2 Within the shallow made ground soils, exceedances of BS3882:2015 screening values for phytotoxic zinc, copper and nickel were recorded. As such, the shallow made ground soils are considered to pose a phytotoxic risk to future plant life (refer to recommended 'Mitigation Measures' in section 10.3 for further detail).

9.3 Water Supply Pipes

9.3.1 UK Water Industry Research (UKWIR) document, '*Guidance for the Selection of Water Supply Pipes to be Laid in Brownfield Sites*', ref 10/WM/03/21, states that on brownfield sites, MDPE/HDPE water supply pipes could be at risk from organic contaminants including mineral oils, VOC's and SVOC's, if the pipes are laid within 15 m of recorded contamination. Additionally, UKWIR states that where metallic pipes are being considered for use, conductivity, pH and redox state of the soil should be assessed to determine if the pipes are at risk of being corroded.

9.3.2 4 No. soil samples (taken from 1.00 m to 2.00 m depth) were sent for laboratory analysis. Testing was undertaken for the mandatory parameters outlined in the UKWIR guidance, to provide comment on the water supply pipe material most likely to be suitable for use within the site. The test results (included in Appendix 03) are summarised in the following tables:

Table 19 – UKWIR Test Results

Laboratory Name: DETS Ltd		Dates: 2nd to 5th January 2024	Cert Nos. 23-29036, 23-29383, 23-29501, 23-29505		
Group No.	**Parameter Group**	**Depths: 1.00 m to 2.00 m bgl**	**Maximum Concentrations Detected**		
		Units	**Detection Limit**	**Concentration**	**Sample Code/ Hole**
1	Extended VOC suite (with TIC)	mg/kg	0.01	<0.01	All samples
1a	• BTEX + MTBE	mg/kg	0.01	<0.01	All samples
2	Extended SVOC suite (with TIC)	mg/kg	0.1	<0.1 to 3.5	All samples
2e	• Phenols	mg/kg	0.5	<0.1	All samples
2f	• Cresols and chlorinated phenols	mg/kg	0.5	<0.1	All samples
3	Mineral Oils C11-C20	mg/kg	10	<10	All samples
4	Mineral Oils C20-C40	mg/kg	10	<10	All samples
5	Corrosive (Conductivity, Redox and pH)				
	Conductivity	µS/cm	1	430 to 2100	All samples
	Redox Potential	mV	0.1	89 to 220	All samples
	pH	-	-	8.5 to 11.2	All samples
Specific suite if identified relevant					
2a	• Ethers	-	-	N/D	All samples
2b	• Nitrobenzene	-	-	N/D	All samples
2c	• Ketones	-	-	N/D	All samples
2d	• Aldehydes	-	-	N/D	All samples
6	Amines	-	-	N/D	All samples

Table 20 – UKWIR Screening Guideline Values

Parameter Group		Pipe Material – All Threshold Concentrations are in mg/kg					
		PE	PVC	Barrier Pipe (PE-Al-PE)	Wrapped Steel	Wrapped Ductile Iron	Copper
1	Extended VOC suite by purge and trap or head space and GC-MS with TIC	0.5	0.125	Pass	Pass	Pass	Pass
1a	+ BTEX + MTBE	0.1	0.03	Pass	Pass	Pass	Pass
2	SVOCs TIC by purge and trap or head space and GC-MS with TIC (aliphatic and aromatic C5 – C10)	2	1.4	Pass	Pass	Pass	Pass
2e	+ Phenols	2	0.4	Pass	Pass	Pass	Pass
2f	+ Cresols and chlorinated phenols	2	0.04	Pass	Pass	Pass	Pass
3	Mineral oil C11-C20	10	Pass	Pass	Pass	Pass	Pass
4	Mineral oil C21-C40	500	Pass	Pass	Pass	Pass	Pass
5	Corrosive (Conductivity, Redox and pH)	Pass	Pass	Pass	Corrosive if pH < 7 and conductivity > 400µS/cm	Corrosive if pH < 5, Eh not neutral and conductivity > 400µS/cm	Corrosive if pH <5 or >8 and Eh positive
Specific suite identified as relevant following Site Investigation							
2a	Ethers	0.5	1	Pass	Pass	Pass	Pass
2b	Nitrobenzene	0.5	0.4	Pass	Pass	Pass	Pass
2c	Ketones	0.5	0.02	Pass	Pass	Pass	Pass
2d	Aldehydes	0.5	0.02	Pass	Pass	Pass	Pass
6	Amines	Fail	Pass	Pass	Pass	Pass	Pass

Table 21 – Pipe Material Selection

Parameter Group		Pipe Material – All Threshold Concentrations are in mg/kg					
		PE	PVC	Barrier Pipe (PE-AL-PE)	Wrapped Steel	Wrapped Ductile Iron	Copper
1	Extended VOC suite by purge and trap or head space and GC-MS with TIC	✓	✓	Pass	Pass	Pass	Pass
1a	+ BTEX + MTBE	✓	✓	Pass	Pass	Pass	Pass
2	SVOCs TIC by purge and trap or head space and GC-MS with TIC (aliphatic and aromatic C5 – C10)	×	×	Pass	Pass	Pass	Pass
2e	+ Phenols	✓	✓	Pass	Pass	Pass	Pass
2f	+ Cresols and chlorinated phenols	✓	✓	Pass	Pass	Pass	Pass
3	Mineral oil C11-C20	✓	Pass	Pass	Pass	Pass	Pass
4	Mineral oil C21-C40	✓	Pass	Pass	Pass	Pass	Pass
5	Corrosive (Conductivity, Redox and pH)	Pass	Pass	Pass	✓	✓	×
2a	Ethers	N/D	N/D	Pass	Pass	Pass	Pass
2b	Nitrobenzene	N/D	N/D	Pass	Pass	Pass	Pass
2c	Ketones	N/D	N/D	Pass	Pass	Pass	Pass
2d	Aldehydes	N/D	N/D	Pass	Pass	Pass	Pass
6	Amines	N/D	Pass	Pass	Pass	Pass	Pass
	Pipes that pass chemical thresholds	×	×	✓	✓	✓	×

*N/D – Not Detected

9.3.3 The results from the preliminary UKWIR analysis recorded elevated SVOC concentrations. In addition, given the recorded ground conditions (i.e. thick made ground containing ash), it is recommended that barrier (PE-AL-PE) water supply pipes be utilised within the site.

9.3.4 Furthermore, due to the presence of asbestos, these should be laid in widened trenches (approximately 1.00 m wide) and backfilled with clean, inert material.

9.3.5 Ultimately, further UKWIR testing can be undertaken along the pipe alignment at relevant depths / levels (once known) to confirm the most suitable pipe specification.

10.0 REVISED CONCEPTUAL SITE MODEL

10.1 Contamination Sources / Receptors

Human Health:	The GQRA has identified toxic exceedances of arsenic, lead, benzo(a)pyrene, dibenzo(a,h)anthracene, plus asbestos (including locally at high concentrations) within the shallow made ground soils, which pose a risk to human health.
Plant Life:	Phytotoxic contaminant exceedances of zinc, copper and nickel were recorded within the shallow made ground soils which pose a risk to future vegetation.
Water Environment:	We conclude that the shallow soils underlying the site do not pose a risk to the water environment.
Ground / Mine Gas:	Our gas monitoring and detailed risk assessment indicated that the ground / mine gas regime conforms to 'Characteristic Situation 2', whereby gas protection measures are deemed necessary (3.5 points for the proposed flatted residential developments and 2.5 points for the proposed commercial development). Radon gas preclusion measures are not required.
Built Environment:	Representative samples analysed for pH and sulphate indicate ACEC Classification AC-2s with a design sulphate class for the site of DS-2. Based on the recorded ground conditions and results from the preliminary UKWIR analyses, we would recommend barrier (PE-AL-PE) water supply pipes be utilised.
Invasive Plants:	A survey recorded the presence of invasive species 'Cotoneaster' within the site.

10.2 Pollutant Linkage Assessment

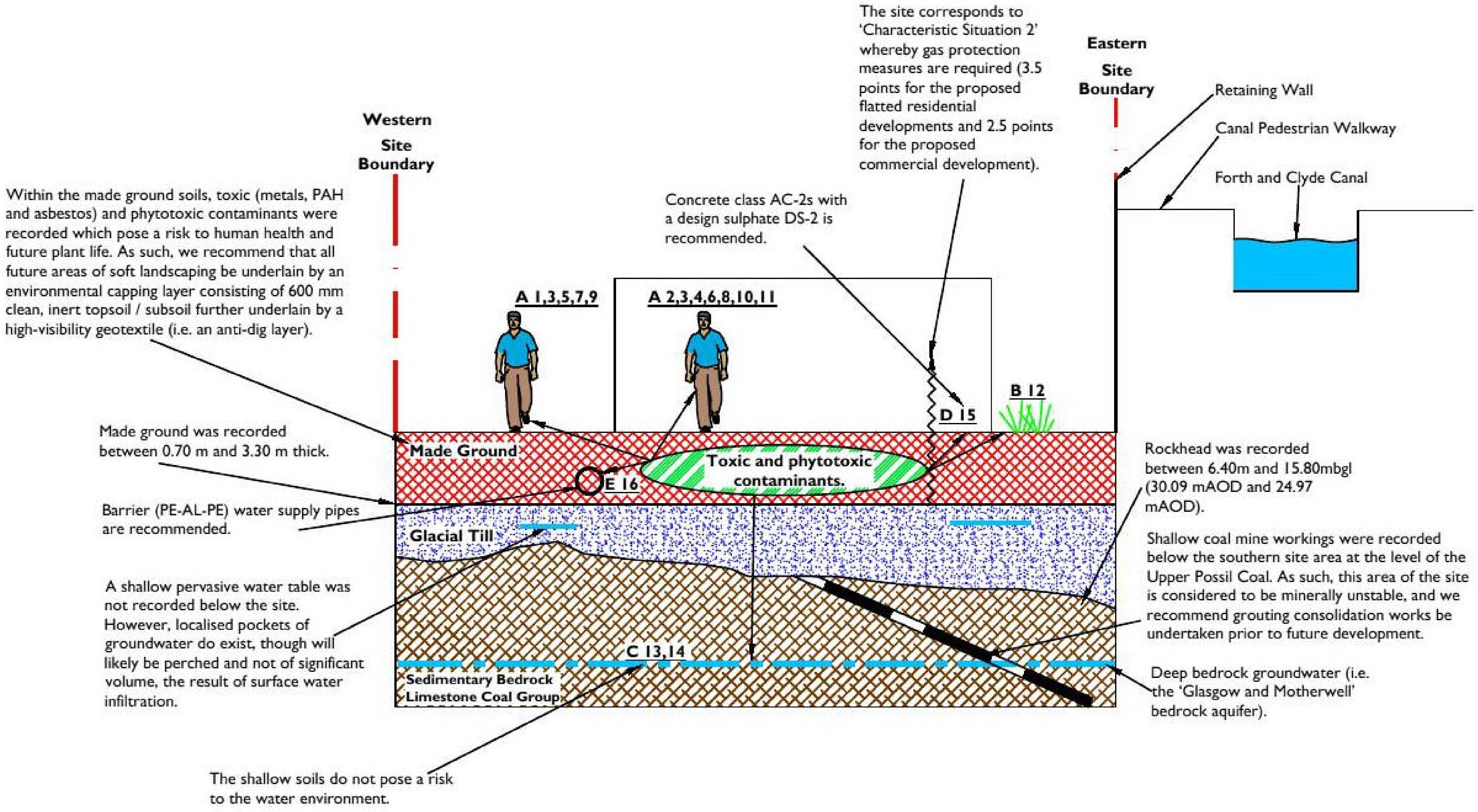
10.2.1 Based on the environmental investigation results and interpretations, our revised conceptual site model is indicated on Drawing No. P22/271/SI/R/F/10.

10.3 Mitigation Measures

Soil Contamination to Human Health and Future Plant Life

10.3.1 Due to the presence of toxic and phytotoxic contaminant exceedances within the shallow made ground soils, we recommend that all future gardens and areas of soft landscaping (underlain by made ground materials) should be underlain by an environmental capping layer consisting of 600 mm clean, inert topsoil / subsoil further underlain by a high-visibility geotextile (i.e. an anti-dig layer).

10.3.2 In addition, due to the presence of localised asbestos at high concentrations (i.e. >0.1%) we recommend that the made ground soils (from between approx. 0.25 m and 3.60 m depth) in proximity to BH02 will require to be further delineated and locally excavated and removed off-site prior to future development. Note that these soils will be classed as 'hazardous waste' in terms of off-site disposal to landfill (refer to section 10.5 for further detail).



Source

- Made ground (containing toxic/phytotoxic contaminants and acting as a source of ground gas)
- Mine workings (acting as a source of mine gas)

Exposure Pathways

1. Outdoor ingestion of dust.
2. Indoor ingestion of dust.
3. Consumption of homegrown vegetables.
4. Ingestion of soil attached to vegetables.
5. Skin contact with outdoor soil.
6. Skin contact with indoor dust.
7. Outdoor inhalation of dust.
8. Indoor inhalation of dust.
9. Outdoor inhalation of soil vapour.
10. Indoor inhalation of soil vapour.
11. Inhalation of ground gases.
12. Contaminant uptake by vegetation.
13. Leaching of contaminants to the groundwater.
14. Contaminant migration in the groundwater.
15. Detrimental effects on buried concrete.
16. Permeation of plastic water supply pipes.

Receptors

A. Site users / construction personnel.
B. Vegetation / fauna.
C. Groundwater.
D. Buried concrete (Service and foundations)
E. Plastic water supply pipes.

NOTES

- A survey identified invasive plant species 'Cotoneaster' within the site. As such, we would recommend an appropriate management programme be put in place prior to future development.
- Given that the made ground soils are known to contain asbestos (including locally at hazardous concentrations) all future site staff (e.g. construction workers and maintenance personnel) should remain vigilant to the risk of encountering contaminated material when working on-site. Prior to any works starting, a detailed method statement and risk assessment should be implemented to mitigate the risk of toxic contaminants to future groundworkers, including:
  - Use of appropriately qualified personnel for the task;
  - Use of appropriate PPE;
  - Provision of on-site washing facilities and maintenance of a high standard of basic hygiene; and
  - A non-smoking and eating policy within the working area, with designated clean areas set aside for these activities.

REV	DATE	DETAILS

SCOTTISH OPERA
39 ELMBANK STREET
GLASGOW
G2 4PT

PROJECT TITLE

ROTTERDAM WHARF
PORT DUNDAS, GLASGOW

DRAWING TITLE

REVISED CONCEPTUAL SITE MODEL

DRAWN BY	CHK'D BY	APP'D BY	DATE	SCALES
AC	SA	SA	11.03.24	Not to Scale

PROJECT No.	DRAWING No.	REVISION
P22/271	P22/271/SI/R/F/10	

MASON EVANS
A PHENNA GROUP COMPANY
Geo-Environmental Consultants
t: 0141 420 2025 e: mail@masonevans.co.uk
100 Brand Street, Glasgow, G51 1DG

A4 border: 297 X 210

10.3.3 Importantly, all future site staff (e.g. construction workers and maintenance personnel) should remain vigilant to the risk of encountering contaminated material (**in particular asbestos fibres**) when working on-site. Prior to any works starting, a detailed method statement and risk assessment should be implemented to mitigate the risk of toxic contaminants to future groundworkers, including:

- Use of appropriately qualified personnel for the task;
- Use of appropriate PPE;
- Provision of on-site washing facilities and maintenance of a high standard of basic hygiene; and
- A non-smoking and eating policy within the working area, with designated clean areas set aside for these activities.

10.3.4 In addition, should previously unidentified contaminated material be encountered, we should be immediately contacted for further advice.

The Water Environment

10.3.5 Based on results from soil leachate and groundwater analyses plus our detailed risk assessment, it was concluded that the shallow soils do not pose a risk to the wider water environment (with the most sensitive receptor considered to be the deep bedrock groundwater).

Ground / Mine Gas

10.3.6 The site has been classified as '*Characteristic Situation 2*', whereby gas preclusion measures are considered necessary, due to the presence of methane (up to 4.9%). We consider the gas source to be associated with mine gas within the bedrock. In addition, future abnormal foundations (i.e. piles) could provide an additional pathway for ground gas migration below the building footprints (further owing to the requirement of gas protection).

10.3.7 Taking into account the building types (Type B and Type C) this corresponded to required solution scores of 3.5 points (for the proposed flatted residential developments) and 2.5 points (for the proposed commercial development). Following the determination of the minimum gas protection score, a combination of: 1) structural barrier of the floor slab, and / or; 2) ventilation measures, and / or; 3) a gas resistant membrane should be implemented in order to achieve an adequate score.

10.3.8 Radon gas or hydrocarbon vapour barriers are not considered necessary.

The Built Environment

10.3.9 Concrete class DS-2, AC-2s is considered sufficient to protect buried concrete from pH and sulphate levels in the soils and groundwater.

10.3.10 Given the results from the preliminary UKWIR analysis (which recorded elevated SVOC concentrations) plus the recorded ground conditions (i.e. thick made ground containing ash), we would recommend that barrier (PE-AL-PE) water supply pipes be utilised within the site.

10.3.11 Furthermore, due to the presence of asbestos, all future pipes should be laid in widened trenches (approximately 1.00 m wide) and backfilled with clean, inert material.

Invasive Plant Species

10.3.12 A specialist survey identified the presence of non-native invasive species 'Cotoneaster' within the site. As such, we recommend the infestation be appropriately managed prior to future development.

10.4 Waste Management Legislation

10.4.1 Should materials be removed and disposed off-site, the developer has a statutory responsibility under the Duty of Care Regulations of the Environmental Protection Act 1990 to ensure that contaminated soil and water is disposed of off-site to a suitably licensed waste management facility in a safe and approved manner.

10.4.2 Should development plans include the removal of materials; the proposed remedial strategy plan should include details of proposed frequency and assessment standards for the waste disposal strategy.

10.4.3 In the event that material, uncharacteristic to that which has been previously identified within the site is encountered, we would recommend that a suitably qualified engineer/scientist obtain samples of the suspect material for chemical analysis, thus determining how the material should be managed.

10.5 Off-Site Waste Disposal

10.5.1 38 No. samples were screened using HazWaste Online© in order to classify the soils as hazardous or non-hazardous waste (refer to Appendix 12).

10.5.2 The results from the HazWaste Online© assessment generally classified the soils as 'non-hazardous', in terms of off-site disposal.

10.5.3 However, one of the made ground samples (BH07 at 0.30 m) was classed as 'hazardous waste' due to an elevated total TPH concentration of 3,000 mg/kg.

10.5.4 In addition, due to hazardous levels of asbestos encountered within the made ground in proximity to BH02 at 0.50 m and 2.50 m depth, these soils would be also considered as 'hazardous waste' and if disturbed at any point during the development works, these soils would require to be taken off-site.

10.5.5 Should any materials be required to be taken off-site as part of future development works, we would recommend that further testing be undertaken (on specific materials identified to go off-site) in order to confirm its waste classification and to provide a more accurate assessment.

10.5.6 Ultimately the results from the HazWaste Online© should be provided to specialist waste disposal contractors for review and costs for off-site disposal to landfill.

10.5.7 In the event that material, uncharacteristic to that which has been previously identified within the site is encountered, we would recommend that a suitably qualified engineer / scientist obtain samples of the suspect material for chemical analysis, thus determining how the material should be managed.

10.6 Contingent Liabilities

10.6.1 Assessments of the site include the determination of contingent liabilities in respect of current and future ownerships subsequent to remedial measures. These consider the impact of the environmental conditions on the study area and surrounding areas on site users, properties and also the liability of the site owners.

10.6.2 With regard to site users, considerations in relation to liability are inherent in the development of a suitable remedial strategy. In the site-specific circumstances presented by the identified conditions, the risk levels suggest minimal liability on ownership due to the environmental conditions, subsequent to development.

10.6.3 The potential for liability arising from site conditions impacting on the surrounding environment largely considers the potential for migration of pollutants beyond the site boundary normally associated with groundwater. Based on the soil and water analyses and a risk assessment, we consider the potential for liability arising from the site conditions to be low.

10.6.4 In the event that more definitive advice is required, we would recommend that the Client seeks specific advice on the liabilities incumbent on ownership from their legal advisors.

11.0 GEOTECHNICAL ASSESSMENT

11.1 General

11.1.1 Visual assessment of soils during the sinking of boreholes was supplemented by in-situ standard penetration tests (SPT's). It should be recognised that SPT testing of cohesive soils will only provide an indicative assessment of soils strength, although testing of granular soils will provide more reliable test data.

11.1.2 Geotechnical test results are included in Appendix 08.

11.2 Natural Cohesive Soils

11.2.1 The natural subsoils below the site were described as firm, brown, sandy, gravelly (weathered) CLAY underlain by stiff, grey, slightly sandy, slightly gravelly (unweathered) CLAY, proven to between 6.80 m and 15.80 m depth.

11.2.2 8 No. samples of these soils were sent for testing, providing comment on particle size distribution, moisture content, plasticity and shear strength. The results of laboratory testing are summarised in Tables 22 to 24 below.

Table 22 – Summary of Particle Size Distribution (PSD) Testing

Sample	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	On-Site Description
BH01A 3.00 – 3.45 m	26	25	39	10	Stiff becoming very stiff, dark grey, slightly silty, slightly sandy, gravelly CLAY
BH02 5.00 – 5.45 m	18	27	39	16	Firm becoming stiff, dark grey, slightly silty, slightly sandy, gravelly CLAY
BH03 11.50 – 11.95 m	20	28	29	23	Firm becoming stiff, dark grey, slightly silty, slightly sandy, gravelly CLAY
BH04 3.00 – 3.45 m	20	24	38	18	Firm, brown, slightly silty, slightly sandy, gravelly CLAY
BH05 4.00 – 4.45 m	21	29	33	17	Firm, brown, slightly silty, slightly sandy, gravelly CLAY
BH05 12.60 – 13.05 m	22	29	31	18	Stiff, dark grey, slightly silty, slightly sandy, gravelly CLAY
BH06 4.00 – 4.45 m	18	31	36	15	Stiff becoming very stiff, dark grey, slightly silty, slightly sandy, gravelly CLAY
BH08 3.00 – 3.70 m	21	23	45	11	Firm becoming stiff, brown, slightly silty, slightly sandy, gravelly CLAY

11.2.3 The results from the PSD testing were generally consistent with the visual descriptions on-site, though the geotechnical results did record a higher sand value (approx. 35%) than what was visually observed (i.e. slightly sandy).

Table 23 – Summary of Atterberg Testing

Sample	Moisture Content (%)	Liquid Limit (%)	Plasticity Index (%)	Remarks
BH01A 3.00 – 3.45 m	24.4	34	18	Clay with Low Plasticity
BH02 5.00 – 5.45 m	15.5	31	14	Clay with Low Plasticity
BH03 11.50 – 11.95 m	12.7	28	12	Clay with Low Plasticity
BH04 3.00 – 3.45 m	15.0	30	14	Clay with Low Plasticity
BH05 4.00 – 4.45 m	12.7	28	12	Clay with Low Plasticity
BH05 12.60 – 13.05 m	13.4	30	12	Clay with Low Plasticity
BH06 4.00 – 4.45 m	11.9	27	12	Clay with Low Plasticity
BH08 3.00 – 3.70 m	13.9	29	13	Clay with Low Plasticity

Table 24 – Summary of Multi-Stage Tri-axial Compression Testing

Sample	Avg. undrained Shear Stress (kPa)	Cohesion (kPa)
BH01A 3.00 – 3.45 m	39.0	32.9
BH02 5.00 – 5.45 m	99.6	70.0
BH03 11.50 – 11.95 m	88.3	76.4
BH04 3.00 – 3.45 m	26.6	22.7
BH05 4.00 – 4.45 m	41.3	31.8
BH05 12.60 – 13.05 m	34.3	22.2
BH06 4.00 – 4.45 m	97.0	67.2
BH08 3.00 – 3.70 m	26.6	20.9

11.2.4 Within the glacial deposits, the results from the plasticity and shear strength testing recorded 'clay with low plasticity' with average undrained shear stress values ranging between 26.6 kPa and 99.6 kPa. Note that we consider the low shear stress values to be associated with the high sand content resulting in a subsequently low cohesion, meaning that these results are not necessarily representative of soft cohesive soils.

11.2.5 In addition, moisture content values were generally recorded to be ≤15.0% (i.e. relatively low).

11.2.6 SPT's were undertaken within the natural subsoils at depths of between 1.20 m and 14.45 m bgl. The shallow natural soils recorded un-corrected N values of between 7 and 37, generally indicative of firm becoming stiff glacial soils, supporting the observations made on-site.

11.2.7 Results are summarised in Tables 25 and 26 overleaf.

Table 25 – SPT Results

SPT Depth (m bgl)	Recorded (un-corrected) N values							
	BH01A	BH02	BH03	BH04	BH05	BH06	BH07	BH08
1.20 – 1.65	45 (MG)	8 (MG)	12 (MG)	-	-	36 (MG)	8 (MG)	11 (c)
2.00 – 2.45	27 (c)	10 (MG)	7 (c)	-	-	27 (c)	11 (MG)	12 (c)
3.00 – 3.45	-	9 (MG)	-	-	13 (c)	28 (c)	11 (c)	15 (c)
4.00 – 4.45	32 (c)	10 (c)	14 (c)	11 (c)	-	-	-	27 (g)
5.00 – 5.45	-	-	-	-	13 (c)	33 (c)	-	-
6.50 – 6.95	37 (c)	17 (c)	16 (c)	24 (c)	-	Sedimentary Bedrock	Sedimentary Bedrock	-
8.00 – 8.45	Sedimentary Bedrock	-	-	-	19 (c)	Sedimentary Bedrock	Sedimentary Bedrock	-
9.00 – 9.45	Sedimentary Bedrock	25 (c)	-	-	-	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock
9.70 – 10.15	Sedimentary Bedrock	-	-	25 (c)	-	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock
10.00 – 10.45	Sedimentary Bedrock	Sedimentary Bedrock	24 (c)	-	-	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock
11.00 – 11.45	Sedimentary Bedrock	Sedimentary Bedrock	-	-	23 (c)	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock
13.00 – 13.45	Sedimentary Bedrock	Sedimentary Bedrock	24 (c)	-	-	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock
13.80 – 14.25	Sedimentary Bedrock	Sedimentary Bedrock	-	24 (c)	-	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock
14.00 – 14.45	Sedimentary Bedrock	Sedimentary Bedrock	-	-	27 (c)	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock
15.50 – 15.95	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock	Sedimentary Bedrock

*Red line denotes made ground / natural soils boundary.

Table 26 – N Value Classification

Cohesive Soils (c)		Granular Soils (g)	
N Values	Classification	N Values	Classification
0 - 4	Very Soft	0 - 4	Very Loose
4 - 8	Soft	4 - 10	Loose
8 - 16	Firm	10 - 30	Medium Dense
16 - 32	Stiff	30 - 50	Dense
>32	Very Stiff	>50	Very Dense

11.3 Bedrock

11.3.1 Sedimentary bedrock was encountered at rockhead depths of between 6.40 m (R06) and 15.80 m (R05) bgl, generally described as either moderately strong, grey SANDSTONE or weak, dark grey MUDSTONE with occasional coal seams. Rockhead level ranged between 30.09 mAOD and 24.97 mAOD and were noted to generally become deeper below the eastern / south-eastern areas of the site.

11.3.2 The recorded depths and levels to rockhead are indicated in Drawing No. P22/271/SI/R/F/08.

11.3.3 Rock core samples were retrieved from each of the rotary bores (R01 to R06) at depths from between 6.50 m and 25.50 m bgl.

- Total core recovery was reported to be between 78% and 100% (though generally 100%).
- Solid core recovery was noted to vary between 77% and 100%.
- Rock quality designations were recorded between 17% and 90%.

11.3.4 A copy of the rock core logs and photographs are included in Appendix 08.

11.3.5 Representative samples of the rock cores were sent for unconfined compressive strength (UCS) testing (within sections where the core recovery was suitable for this type of testing). The results of UCS tests are summarized on Table 27.

Table 27 – Summary of Unconfined Compressive Strength (UCS) Testing

Sample	Depth (m bgl)	Rock Type	Rock Class Grouping*	Water Content (%)	UCS (MPa)	Strength Description	ABC** (MN/m²)
R01	8.00	SANDSTONE	Group 2	1.8	25.1	Moderately Strong	10.0
R01	13.50	SANDSTONE	Group 2	1.7	8.9	Moderately Weak	5.0
R01	16.40	SANDSTONE	Group 2	1.2	41.4	Moderately Strong	10.0
R02	12.20	SANDSTONE	Group 2	4.0	11.7	Moderately Weak	5.0
R02	15.60	SANDSTONE	Group 2	5.9	25.3	Moderately Strong	10.0
R02	20.00	SANDSTONE	Group 2	2.2	20.4	Moderately Strong	10.0
R03	15.50	SANDSTONE	Group 2	7.3	25.6	Moderately Strong	10.0
R03	22.25	SILTSTONE	Group 2	7.4	19.4	Moderately Strong	10.0
R04	16.30	SANDSTONE	Group 2	8.3	28.3	Moderately Strong	10.0
R04	19.90	SILTSTONE	Group 2	8.2	25.9	Moderately Strong	10.0
R05	17.60	SANDSTONE	Group 2	0.5	25.7	Moderately Strong	10.0
R05	21.50	SANDSTONE	Group 2	7.0	35.6	Moderately Strong	10.0
R06	12.00	SANDSTONE	Group 2	5.3	26.5	Moderately Strong	10.0

* Taken from BS 8004:1986, Table 04
** ABC: Allowable Bearing Capacity

11.3.6 The unconfined compressive strength results were recorded to range between 8.9 MPa to 41.4 MPa (though generally >20 MPa), which generally moderately strong bedrock (BS5930:2015), with a presumed allowable bearing capacity of approximately 5.0 MN/m².

11.3.7 A copy of the rock core testing results are included in Appendix 08.

11.4 Road Design

11.4.1 Due to the presence of thick and variable made ground, we would recommend a full capping layer (i.e. 600 mm thick) be used below all future roads and parking areas.

12.0 FOUNDATION RECOMENDATIONS

12.1 Proposed Development

12.1.1 The development proposals for the site are understood include for a proposed five-storey extension to the existing Scottish Opera building, plus the development of two multi-storey (one 15 and another 20 storeys) residential flatted developments within the northern and southern site areas.

12.2 Foundations

12.2.1 The ground conditions on-site recorded MADE GROUND generally described as brown or black, clayey, gravelly sand with extraneous materials including plastic, metal, ceramic, timber and ash fragments plus frequent bricks, proven to between 0.70 m and 3.30 m thick, underlain by natural glacial soils described as firm, brown, sandy, gravelly (weathered) CLAY underlain by stiff, grey, slightly sandy, slightly gravelly (unweathered) CLAY, proven to between 6.80 m and 15.80 m depth.

12.2.2 Sedimentary bedrock was encountered at rockhead depths of between 6.40 m and 15.80 m bgl, generally described as either moderately strong, grey SANDSTONE or weak, dark grey MUDSTONE with occasional coal seams. Rockhead levels ranged between 30.09 mAOD and 24.97 mAOD and were noted to generally become deeper below the eastern / south-eastern areas of the site.

12.2.3 A shallow pervasive water table was not recorded below the site. However, pockets of groundwater do exist, though will likely be localised, perched and not of significant volume, the result of surface water infiltration.

<u>Proposed 5-Storey Extension to Existing Scottish Opera Building</u>

12.2.4 Based on existing site levels, the stiff (or better) natural (unweathered) clay subsoils may be suitable for use as a foundation bearing horizon (via piled foundations). These soils would provide an allowable bearing capacity of 150 kN/m^2 between depths of approximately 2.00 m and 7.20 m bgl (33.78 mAOD and 36.08 mAOD).

12.2.5 The recorded depths and levels to stiff (or better) natural cohesive subsoils are indicated on Drawing No. P22/271/SI/R/F/07.

12.2.6 Alternatively, the underlying bedrock could be used as a foundation bearing horizon.

<u>Proposed Multi-Storey Residential Blocks</u>

12.2.7 Based on the likely loading requirements for the proposed development (which includes for 15 and 20 storey buildings) we would recommend piled foundations be utilised, end bearing onto the sedimentary bedrock at depths between approximately 6.40 m to 15.80 m bgl (approx. 30.09 mAOD to 24.97 mAOD).

12.2.8 Based on the results from the laboratory UCS testing, the bedrock would provide an allowable bearing capacity of approximately 5.0 MN/m^2.

12.2.9 Detailed discussions with specialist contractors and the structural engineer should be undertaken with regard to the final design of the piled foundations.

12.2.10 The recorded depth and level to bedrock is indicated on Drawing No. P22/271/SI/R/F/08.

13.0 MINERAL INVESTIGATIONS

13.1 General

13.1.1 Given that our Phase I desk study researches highlighted the potential for coal seams to outcrop below the site in which may have been previously worked, we supervised mineral investigations to confirm (or otherwise) the presence of historical shallow underground mining activities.

13.2 Background Geological and Mining Information

13.2.1 The BGS geology maps conjectured the Upper Possil Coal (sometimes referred to as the Davy Coal) to outcrop within the southern site area aligned south-west to north-east and dipping towards the south-east (i.e. below the site) with an indicated thickness of 0.80 m. In addition, the Upper Possil Ironstone or Garscube Wee Coal was conjectured to outcrop to the north of the site and was recorded to dip below the site with an indicated thickness of 0.70 m. Furthermore, whilst not shown to outcrop on the geological map, the Batchie Ironstone or Coal was indicated on the stratigraphic column to exist between the Upper Possil / Davy Coal and the Upper Possil Ironstone / Garscube Wee Coal seams with an indicated thickness of up to 0.70 m, and therefore is considered to underlie the site at shallow depth.

13.2.2 A site-specific consultant's report obtained from The Coal Authority Report stated that there are no records of any past underground mine workings below the site.

13.2.3 Importantly however, The Coal Authority did indicate that there was a potential for unrecorded workings at shallow depth (i.e. < 30 m depth) below the site. We consider that any shallow mineral extraction would be associated with The Upper Possil Ironstone or Garscube Wee Coal (0.80 m thick), the Batchie Ironstone or Coal (up to 0.70 m thick) and / or the Upper Possil / Davy Coal (0.70 m thick) which were indicated to exist below the site at shallow depths.

13.2.4 There were no records of any mine shafts located within the site.

13.3 Intrusive Mineral Investigations

13.3.1 In December 2023, 6 No. mineral bores (R01 to R06) were sunk within the site (refer to Drawing No. P22/271/SI/R/F/05).

13.3.2 The bores recorded rockhead between 6.40 m and 15.80 m bgl (generally become deeper below the eastern / south-eastern areas of the site), with the rock strata described as either SANDSTONE or MUDSTONE with occasional seams of COAL, proven to 38.50 m bgl.

13.3.3 A copy of the mineral bore logs are included in Appendix 05.

13.3.4 A summary of the mineral bore investigations is shown in Table 28 overleaf.

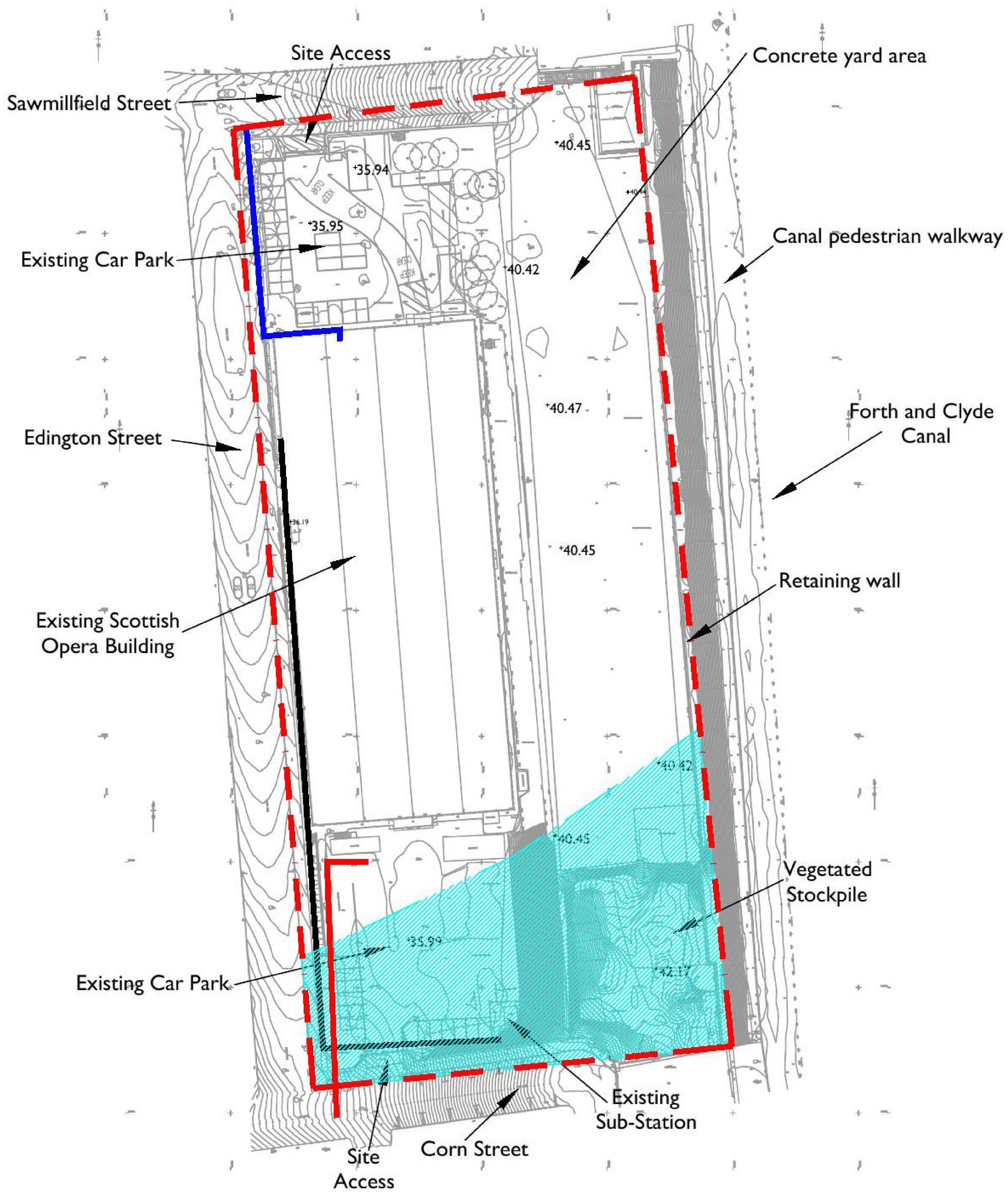
Table 28 – Summary of Mining Conditions

Borehole	Depth Encountered (m bgl)	Thickness (m)	Comments
R01	0.00	7.50	Superficial Deposits
	7.60	0.20	**Coal (intact)**
	The intervening rock strata was indicated to be SANDSTONE and MUDSTONE, proven to 31.00 m bgl.		
R02	0.00	11.20	Superficial Deposits
	13.80	0.40	**Coal (intact)**
	16.95	0.10	**Coal (intact)**
	The intervening rock strata was indicated to be SANDSTONE and MUDSTONE, proven to 37.50 m bgl.		
R03	0.00	14.40	Superficial Deposits
	17.80	0.40	**Coal (intact)**
	20.20	0.30	**Coal (intact)**
	22.40	0.10	**Coal (intact)**
	23.10	0.15	**Coal (intact)**
	The intervening rock strata was indicated to be SANDSTONE and MUDSTONE, proven to 38.00 m bgl.		
R04	0.00	15.30	Superficial Deposits
	20.20	0.40	**Coal (intact)**
	23.45	0.60	**Coal (intact)**
	The intervening rock strata was indicated to be SANDSTONE and MUDSTONE, proven to 38.50 m bgl.		
R05	0.00	15.80	Superficial Deposits
	23.35	0.45	**Coal (intact)**
	The intervening rock strata was indicated to be SANDSTONE and MUDSTONE, proven to 38.50 m bgl.		
R06	0.00	6.40	Superficial Deposits
	8.40	0.70	**Packed Waste (i.e. workings)**
	The intervening rock strata was indicated to be SANDSTONE and MUDSTONE, proven to 12.50 m bgl.		

13.3.5 Shallow mine workings were recorded within one of the mineral bores (R06) between 8.40 m and 9.10 m bgl, described as 'packed waste'. We have conjectured these mine workings to be associated with the Upper Possil Coal, as is shown on the BGS solid geology map to outcrop within this vicinity. Furthermore, a historical borehole record (ref: NS56NE/497) to the south of the site recorded workings within this same coal seam, consistent with the findings from our mineral investigations.

13.3.6 The northern and central site areas did not record any evidence of shallow mine workings, and therefore, we consider these areas of the site to be minerally stable.

13.3.7 Based on information from the mineral bores, the Upper Possil Coal (approx. 0.70 m thick) has been worked below the southern site area at shallow depth. As such, we consider that this area is minerally unstable and therefore recommend that grouting consolidation works be undertaken prior to any future development (refer to Drawing No. P22/271/SI/R/F/11). Note that additional mineral bores would be beneficial at a later date to further delineate the extent of the workings.



NOTES

Red dash-dot line	Approximate site boundary
Blue line	SP Energy cables
Red line	Scottish Gas pipe
Black line	Buried BT cable
Cyan area	Conjectured area of instability.

- Based on conjectured outcrop of the Upper Possil Coal as indicated by the BGS.
- Note that additional mineral bores would be beneficial to confirm a more accurate zone of instability, in relation to future grouting design works.

REV	DATE	DETAILS

SCOTTISH OPERA
39 ELMBANK STREET
GLASGOW
G2 4PT

PROJECT TITLE

ROTTERDAM WHARF
PORT DUNDAS, GLASGOW

DRAWING TITLE

CONJECTURED AREA OF INSTABILITY

DRAWN BY	CHK'D BY	APP'D BY	DATE	SCALES
AC	SA	SA	11.03.24	1:1000 @ A3

PROJECT No.	DRAWING No.	REVISION
P22/271	P22/271/SI/R/F/11	

MASON EVANS
A PHENNA GROUP COMPANY
Geo-Environmental Consultants
t: 0141 420 2025 e: mail@masonevans.co.uk
100 Brand Street, Glasgow, G51 1DG

A3 border: 400 x 273

13.3.8 The Coal Authority did not record any mine entries within the site or immediate surrounding area. However, it should be highlighted that as in all areas of historical mining, unrecorded mine entries could exist. During future earthworks if any mine shafts or similar looking features are encountered, we should be immediately consulted for further advice.

14.0 CONCLUSIONS AND RECOMMENDATIONS

14.1 General

14.1.1 Intrusive investigations have been undertaken to identify ground related risks that have the potential to impact on the proposed development at the site.

14.1.2 The site was predominantly surfaced in hardstanding (tarmac or concrete) with occasional vegetated areas, particularly within the southern area. The site topography was relatively flat across the site, with a steep step in topography up to the concrete yard area with a large retaining wall along the eastern boundary. Surface levels were recorded to range between 35 mAOD (within the car park area) and 41 mAOD (within the concrete yard area).

14.1.3 The ground conditions recorded MADE GROUND generally described as brown or black, clayey, gravelly sand with extraneous materials including plastic, metal, ceramic, timber and ash fragments plus frequent bricks, proven to between 0.70 m and 3.30 m thick, underlain by natural glacial soils described as firm, brown, sandy, gravelly (weathered) CLAY underlain by stiff, grey, slightly sandy, slightly gravelly (unweathered) CLAY, proven to between 6.80 m and 15.80 m depth.

14.1.4 Sedimentary bedrock was encountered at rockhead depths of between 6.40 m and 15.80 m bgl, generally described as either moderately strong, grey SANDSTONE or weak, dark grey MUDSTONE with occasional coal seams. Rockhead levels ranged between 30.09 mAOD and 24.97 mAOD and were noted to generally become deeper below the eastern / south-eastern areas of the site.

14.1.5 A shallow pervasive water table was not recorded below the site. However, pockets of groundwater do exist, though will likely be localised, perched and not of significant volume, the result of surface water infiltration.

14.2 Chemical Contamination and Gas Emissions

14.2.1 Within the shallow made ground soils, the GQRA has identified toxic metal (arsenic and lead), PAH (benzo(a)pyrene and dibenzo(a,h)anthracene) and asbestos contaminants, which are considered to pose a risk to human health. In addition, phytotoxic zinc, copper and nickel contaminants were recorded which pose a risk to future plant life.

14.2.2 As such, we recommend that all future gardens and areas of soft landscaping be underlain by an environmental capping layer consisting of 600 mm clean, inert topsoil / subsoil further underlain by a high-visibility geotextile (i.e. an anti-dig layer).

14.2.3 In addition, due to the presence of localised asbestos at high concentrations (i.e. >0.1%) we recommend that the made ground soils (from between approx. 0.25 m and 3.60 m depth) in proximity to BH02 will require to be further delineated and locally excavated and removed off-site prior to future development. Note that these soils will be classed as 'hazardous waste' in terms of off-site disposal to landfill.

14.2.4 Importantly, all future site staff (e.g. construction workers and maintenance personnel) should remain vigilant to the risk of encountering contaminated material (in particular asbestos fibres) when working on-site. Prior to any works starting, a detailed method statement and risk assessment should be implemented to mitigate the risk of toxic contaminants to future groundworkers, including:

- Use of appropriately qualified personnel for the task;
- Use of appropriate PPE;
- Provision of on-site washing facilities and maintenance of a high standard of basic hygiene; and
- A non-smoking and eating policy within the working area, with designated clean areas set aside for these activities.

14.2.5 Based on results from soil leachate and groundwater analyses plus our detailed risk assessment, it was concluded that the shallow soils do not pose a risk to the wider water environment.

14.2.6 Ground gas monitoring and risk assessment has indicated that gas protection measures are required. From the site characteristic hazardous gas flow rate, as calculated and based on a worst-case scenario, the ground gas regime was classified as 'Characteristic Situation 2', which corresponds to a required solution score of 3.5 points (for the proposed flatted residential developments) and 2.5 points (for the proposed commercial development).

14.2.7 Following the determination of the minimum gas protection score, a combination of: 1) structural barrier of the floor slab, and / or; 2) ventilation measures, and / or; 3) a gas resistant membrane should be implemented in order to achieve an adequate score.

14.2.8 Radon gas or hydrocarbon vapour barriers are not considered necessary.

14.3 The Built Environment

14.3.1 Concrete class DS-2, AC-2s is considered sufficient to protect buried concrete from pH and sulphate levels in the soils and groundwater.

14.3.2 Given the results from the preliminary UKWIR analysis (which recorded elevated SVOC concentrations) plus the recorded ground conditions (i.e. thick made ground containing ash) we would recommend that barrier (PE-AL-PE) water supply pipes be utilised within the site.

14.3.3 Furthermore, due to the presence of asbestos, all future pipes should be laid in widened trenches (approximately 1.00 m wide) and backfilled with clean, inert material.

14.4 Off-Site Disposal

14.4.1 The results from the HazWaste Online© assessment generally classified the soils as 'non-hazardous', in terms of off-site disposal.

14.4.2 However, one of the made ground samples (BH07 at 0.30 m) was classed as 'hazardous waste' due to an elevated total TPH concentration of 3,000 mg/kg.

14.4.3 In addition, due to high levels of asbestos encountered within the made ground in proximity to BH02 at 0.50 m and 2.50 m depth, these soils would be also considered as 'hazardous waste' and if disturbed at any point during the development works, these soils would require to be taken off-site.

14.4.4 Should any materials be required to be taken off-site as part of future development works, we would recommend that further testing be undertaken (on specific materials identified to go off-site) in order to confirm its waste classification and to provide a more accurate assessment.

14.5 Road Design

14.5.1 Due to the presence of thick and variable made ground, we would recommend a full capping layer (i.e. 600 mm thick) be used below all future roads and parking areas.

14.6 Invasive Plant Species

14.6.1 A specialist survey identified the presence of non-native invasive species 'Cotoneaster' within the site. As such, we recommend the infestation be appropriately managed prior to future development.

14.7 Foundation Recommendations (Based on Existing Site Levels)

Proposed 5-Storey Extension to Existing Scottish Opera Building

14.7.1 Based on existing site levels, the stiff (or better) natural (unweathered) clay subsoils may be suitable for use as a foundation bearing horizon (via piled foundations). These soils would provide an allowable bearing capacity of 150 kN/m^2 between depths of approximately 2.00 m and 7.20 m bgl (33.78 mAOD and 36.08 mAOD).

14.7.2 Alternatively, the underlying bedrock could be used as a foundation bearing horizon.

Proposed Multi-Storey Residential Blocks

14.7.3 Based on the likely loading requirements for the proposed development (which includes for 15 and 20 storey buildings) we would recommend piled foundations be utilised, end bearing onto the sedimentary bedrock at depths between approximately 6.40 m to 15.80 m bgl (approx. 30.09 mAOD to 24.97 mAOD).

14.7.4 Based on the results from the laboratory UCS testing, the bedrock would provide an allowable bearing capacity of approximately 5.0 MN/m^2.

14.8 Mining and Quarrying

14.8.1 Intrusive mineral investigations recorded shallow mine workings within the southern site area between 8.40 m and 9.10 m depth, described as 'packed waste'. We have conjectured these mine workings to be associated with the Upper Possil Coal (0.70 m thick), as was shown on the BGS solid geology map to outcrop within this vicinity. As such, we consider that this area is minerally unstable and therefore recommend that grouting consolidation works be undertaken prior to any future development. Note that additional mineral bores would be beneficial at a later date to further delineate the extent of the workings.

14.8.2 The northern and central site areas did not record any evidence of shallow mine workings, and therefore, we consider these areas of the site to be minerally stable.

14.8.3 The Coal Authority did not record any mine entries within the site or immediate surrounding area. However, it should be highlighted that as in all areas of historical mining, unrecorded mine entries could exist. During future earthworks if any mine shafts or similar looking features are encountered, we should be immediately consulted for further advice.

14.8.4 Finally, there was no evidence of any historical quarrying activity within the site.

14.9 Consultation with Glasgow City Council

14.9.1 It should be noted that various local authority departments (within Glasgow City Council) will become involved in the review of the site conditions. While measures proposed are consistent with conventional practice, we would advise that before design works are advanced to any considerable stage appropriate approvals are received from the relevant Council departments. We would be pleased to liaise with the Council's representatives in this regard.

We trust that this will meet with your current requirements. However, should you require any further information, please do not hesitate to contact us.

[redacted] [redacted]

Scott Armstrong
Principal Geo-Environmental Engineer

Andrew McGuire
Associate