

Appendix 14.2

Detailed Site Assessment

Irish Water

**Arklow Wastewater Treatment
Plant Project**

Detailed Site Assessment for the
Wastewater Treatment Plant

247825-00_30.08.2018_DSA_Final.

Issue | 30 August 2018

This report takes into account the particular instructions and requirements of our client.

It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

Job number 247825-00

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Contents

	Page
Executive Summary	3
1 Introduction	5
1.1 Project contractual basis	5
1.2 Project objectives	5
1.3 Scope of work	5
1.4 The proposed development	6
1.5 Personnel involved	6
1.6 Guidance	7
2 Summary of the findings of the PSA	8
3 Ground investigation	9
3.1 Rationale & strategy	9
3.2 Non-intrusive methods	9
3.3 Intrusive investigation	10
4 Results and discussion of ground investigation	17
4.1 Site Geology	17
4.2 Site Hydrogeology	23
4.3 Radiological Survey	24
4.4 Chemical Test Results	25
4.5 Conceptual Site Model	26
5 Generic quantitative risk assessment (GQRA)	28
5.1 Generic assessment criteria (GACs)	28
5.2 Results of generic quantitative risk assessment	33
6 Remediation strategy	13
7 Summary, Conclusions and Recommendations	13
7.1 Summary and Conclusions	13
7.2 Recommendations	14
8 References	16

Figures

Figure 1: Site Location

Figure 2: Site Investigation Locations

Figure 3: Ground Gas, Groundwater and Surface Water Monitoring Locations

Figure 4: Location of Asbestos in the Made Ground

Figure 5: Location of Gun Cotton (Nitrocellulose) Observed in the Soil at the
WwTP

Figure 6: Radioactive Materials

Figure 7: Groundwater and Surface Water Hydrograph

Figure 8: Groundwater Flow Direction – Low Tide

Figure 9: Groundwater Flow Direction – High Tide

Figure 10: Conceptual Site Model

Figure 11: Remedial Strategy

Executive Summary

Arup was commissioned by Irish Water to prepare a detailed assessment of the potential for land contamination at the wastewater treatment plant site (WwTP) which is part of the Arklow WwTP Project.

This report presents a Detailed Site Assessment (DSA) of the current land contamination risks and the potential land contamination risks associated with the use of the site following the proposed development.

In summary, the findings of the PSA are:

“The site is underlain by a substantial thickness of made ground which was placed to reclaim the land from the Avoca River and the Irish Sea between 1845 and 1885, during the re-routing of the outfall of the Avoca River. The site was then used as a chemicals factory, munitions factory and finally a gypsum plasterboard factory.”

Based on the results of the PSA, a ground investigation was designed by Arup in November 2017. The ground investigation was carried out between January and February 2018 by Causeway Geotech Ltd (Causeway).

The ground investigation found that site geology consists generally of made ground overlying two layers of sand and gravel separated by a thin clay layer. Beneath the sand and gravel layers is a thicker clay layer overlying bedrock. Based on the groundwater flow patterns the groundwater in the sand and gravel flows generally to the east but only discharges to the Irish Sea during low tide. While the River is in hydraulic continuity with the sand and gravel aquifer, the flow within the river is not fed by the groundwater (base flow), and groundwater under the WwTP does not flow discharge into the Avoca River.

Contamination was seen in the made ground, and groundwater beneath. In summary, this comprises:

- Made ground, likely to have been derived from mine spoil containing heavy metals (arsenic in one discrete location and lead between approximately 0.4m to 2.5m below ground level across the site);
- An area in the north which is considered to comprise an infilled pond has elevated level of PAH's;
- Nitrocellulose (also referred to as guncotton) at four discrete locations around the site between approximately 0.4m to 2.5m below ground level;
- Asbestos containing materials in four discrete locations around the site; and
- Nickel, zinc, lead, cadmium, barium, phosphate and ammoniacal nitrogen are present in the groundwater beneath the site.

The contamination was assessed against the proposed development and it was found that the modifications that will occur on site as part of the construction of the WwTP will break the exposure pathways or remove part of the source. Hence

the is considered that from the proposed WwTP design there is no significant risk to site users from the contamination noted on site.

There are residual risks to construction workers who could be exposed to the soils during the excavation. Measures are proposed to manage these risks. These include:

- During construction of the WwTP it will be necessary to have a watching brief to identify and segregate NC so that it can be stored and disposed of safely;
- There will be a need to manage risk from the ground water contamination during the excavation for the WwTP. This is likely to be done by minimising the groundwater ingress, treating small amounts of groundwater and discharging to the Irish Sea under a Section 4 licence. An options appraisal for managing groundwater during construction is appended to this DSA (Appendix C).
- It will be necessary for to manage the risks to construction workers from dust and enclosed space containing levels of radiation above background. This is likely to comprise standard measures such as dust suppression and site monitoring;
- Future work which involves exposure of the soils at the site, including during the construction of the proposed WwTP beneath the slab should consider the risks to site users and appropriate measure implemented to minimise exposure. These are likely to include good hygiene and suitable personal protective equipment.
- Prior to construction and as part of the detailed design it will be necessary to confirm the conclusions of ground gas risk assessment by undertaking additional gas monitoring in accordance with best practice.

1 Introduction

1.1 Project contractual basis

Arup was commissioned by Irish Water to prepare a detailed assessment of the potential for land contamination at the wastewater treatment plant site (WwTP) which is part of the Arklow WwTP Project.

This assessment comprises an appendix to the Environmental Impact Assessment Report that supports the planning application for the Arklow WwTP Project.

The site for the WwTP is at Ferrybank, Arklow, Co. Wicklow and is the location of the currently derelict Wallboard Factory. The proposed WwTP, subject of this assessment (the site), is delimited by the yellow line presented on Figure 1 together with the planning boundary for the Arklow WwTP Project (red line).

1.2 Project objectives

This report presents a Detailed Site Assessment (DSA) of the current land contamination risks and the potential land contamination risks associated with the use of the site following the proposed development.

The DSA includes findings of a detailed intrusive site investigation and subsequent monitoring of groundwater and ground gases. The report discusses the potential land contamination risks associated with the proposed use for the wastewater treatment plant. It has taken account of the site specific Preliminary Site Assessment (PSA) [1] previously prepared for the Arklow WwTP.

Potential contamination risks associated with the demolition of the existing buildings are not covered by this PSA. These are covered by the construction strategy and Construction Environmental Management Plan (CEMP) which are appended to the Environmental Impact Assessment Report.

1.3 Scope of work

The scope of works includes:

- Review and interpretation of the results of the site investigation carried out in January and February 2018 and subsequent monitoring of groundwater, surface water and ground gases.
- Review the Source-Pathway-Receptor (SPR) linkages on site for the current situation and the proposed development.
- Undertake a Generic Quantitative Risk Assessment of any Source-Pathway-Receptor (SPR) linkages, where such linkages exist; and
- Assess the impact of the proposed WwTP on any land contamination present.

1.4 The proposed development

The proposed Arklow WwTP Project comprises the following:

- A new WwTP of 36,000 population equivalent (PE) and associated infrastructure including an inlet pumping station, a storm water storage tank, preliminary and secondary treatment facilities, sludge thickening and dewatering facilities, a pump sump and tank to discharge excess storm water flows as well as site administration facilities and associated landscaping (all located at the site of the Old Wallboard factory at Ferrybank);
- Interceptor sewers along North Quay, South Quay and under the Avoca River (including associated manholes and vent stacks) that would tie in with the existing wastewater network and bring the untreated wastewater to the WwTP;
- A combined sewer overflow (CSO) and storm water storage tank to the west of River Walk on a vacant site locally referred to as ‘the Alps’;
- A short sea outfall pipeline (that terminates at the toe of the revetment) to discharge excess storm water flows to the Irish Sea;
- A long sea outfall pipe (approximately 900m in length) to discharge the treated wastewater effluent to the Irish Sea; and
- An upgrade to the existing revetment on the coastal side of the Wallboard Factory.
- A landscaped area with additional native planting will be provided to the north-west of the WwTP site. Upon commissioning, this landscaped area will be handed over to the Wicklow County Council as a continuation and contribution to the public realm of the area.

The subject of this assessment includes the Arklow WwTP and the area of the revetment. The area of the Arklow WwTP project and the Arklow WwTP are shown on Figure 1.

1.5 Personnel involved

The personnel working on the project are summarised in **Table 1**.

Table 1: Personnel

Personnel	Experience
EurGeol Eoin Wyse, BSc, PGeo,	Eoin Wyse has 14 years’ experience in contaminated land. He has extensive experience in site assessment and the management of contaminated land. He is a Professional Geologist and is on the IGI Register of Professional Qualified Geoscientists / Competent (in respect of environmental risk assessment for regulated and unregulated waste disposal and contaminated land).
Mr Christopher Newton MSci, CGeol	Mr C Newton, lead project hydrogeologist, has ten years’ experience in hydrogeological issues associated with contaminated land. He is on the IGI Register of Professional Qualified Geoscientists / Competent (in respect of

Personnel	Experience
	environmental risk assessment for regulated and unregulated waste disposal and contaminated land).
Ms Laura McGrath, BSc, MSc	Laura is the graduate hydrogeologist for the project. She has two years' experience working on hydrogeology, water quality and contaminated land projects.

1.6 Guidance

At present, there is no statutory or regulatory guidance on the assessment of land contamination in Ireland, except where the site is operated under an EPA regulated licence [2] e.g. Industrial Emission Licence (IEL) or Integrated Pollution Control (IPC) permit. This 2013 EPA [2] guidance document presents a summary of the processes to be followed and clearly sets out the documents to be prepared at each stage. The 2013 EPA guidance follows a similar international guidance on the assessment of land contamination (CLR11). In the absence of a directly relevant guidance the 2013 EPA guidance has been followed.

This Detailed Site Assessment has been prepared in accordance with the EPA Detailed Site Assessment template within the EPA's guidance document on management of contaminated land [2].

2 Summary of the findings of the PSA

In summary, the findings of the PSA are:

“The site is underlain by a substantial thickness of made ground which was placed to reclaim the land from the Avoca River and the Irish Sea between 1845 and 1885, during the re-routing of the outfall of the Avoca River. The site was then used as a chemicals factory, munitions factory and finally a gypsum plasterboard factory.

Data from previous site investigations suggest that the made ground and groundwater are contaminated with heavy metals, hydrocarbons and asbestos, particularly in the made ground. The nature of the interaction with the Irish Sea and the extent of the tidal effects on the groundwater are uncertain. Also, the impact on the Avoca River and Irish Sea have not been assessed previously.

The desk study has highlighted that the site of the proposed WwTP was used to manufacture Cordite, (an explosive) and handled phosphogypsum a material naturally enriched radioactive elements. The extent of the contamination by these two has not been assessed previously.

As well as being reclaimed from the sea, the area around the site also has a history of industrial use and part of the area was used as a landfill. These are all up hydraulic gradient of the proposed WwTP. Consequently, there is the potential for the groundwater quality under the site to be affected by contamination from up hydraulic gradient of the site. In addition, the area of landfill could be a potential source of ground gas. Based on limited monitoring data, the ground gas flows and concentrations are low. However, the response zones of the boreholes are unknown hence the validity of the monitoring is uncertain.”

The PSA includes a preliminary conceptual site model which was used to assess the potential source-pathway-receptor linkages. The PSA highlighted that the areas of potential contamination may pose a risk to site users and to the water quality of the underlying water bearing strata and the adjacent Avoca River and Irish Sea.

A detailed ground investigation was proposed in the PSA to fill in data gaps and to gain a better understanding of the ground conditions of the site.

3 Ground investigation

Based on the results of the PSA, a ground investigation was designed by Arup in November 2017. The ground investigation was carried out between January and February 2018 by Causeway Geotech Ltd (Causeway).

3.1 Rationale & strategy

The GI comprised a targeted geo-environmental site investigation to assess impacts of the previous site use on the soils at the site and to confirm the results of the previous site investigation.

In summary, the strategy comprised:

- a non-intrusive investigation survey to confirm the presence of elevated levels of radiation;
- trial pits to investigate and sample shallow made ground;
- boreholes to investigate and sample the deeper made ground and natural soils beneath;
- installation of monitoring pipes in the natural strata beneath the site to monitor groundwater quality and flow direction;
- installation of monitoring pipes in the unsaturated shallow made ground to monitor ground gases.
- sampling groundwater and surface water over a range of climatic conditions to assess the impacts of the site on the surrounding aquatic environment;

3.2 Non-intrusive methods

3.2.1 Geophysical survey

Prior to the intrusive investigation, a geophysical investigation was carried out in March 2016 by Minerex Geophysics Limited across the site to support and supplement the results of the intrusive investigation, investigate the presence of any anomalies and investigate the nature of the subsoils beyond the site boundary. Results of this investigation are presented in Appendix A of this DSA and the locations of the geophysical survey sections are presented on Figure 2. The geophysics included:

- 2D-Resistivity
- Seismic refraction (p-wave)
- Multichannel analysis of surface wave (MASW) (s-wave)

The 2D-resistivity survey covered the full length of the eastern and western sections of the site to provide information on bulk resistivity to highlight any

anomalies. Two smaller seismic refraction and MASW surveys were carried out in the north-west and south-east of the site to provide information on the depth and extent of the made ground.

3.2.2 Radiological survey

The radiological survey was recommended in the PSA due to the site's history. A radiological survey was carried out on the 8th and 9th of January 2018 by Radman Associates whose report is presented in Appendix L of the Causeway Geotech Ground Investigation Report (Appendix B) [4].

The survey was carried out using a hand-held solid-state scintillation detector (Georadis RT-30, serial no. 1997). The instrument identified soils emitting gamma emitting radionuclides in the surface or immediate subsurface (to a depth of ~200 mm). The instrument recorded its position using a GPS logger, hence any elevated readings could be related to a geographical position.

3.3 Intrusive investigation

The intrusive ground investigation was carried out by Causeway Geotech Ltd (Causeway).

Causeway excavated 27 trial pits with a tracked excavator and drilled 15 cable percussive holes, including three with rotary core follow on. Causeway also undertook Standard Penetration Tests (SPT), well monitoring installation, well development and soil and water quality sampling.

Logging of the arisings was carried out by Causeway according to BS5930:2015 [4]. The ground investigation was supervised by Arup. Copies of the logs are presented in Appendix B of the Causeway ground investigation report presented in Appendix B of this DSA. A plan showing the locations of the borehole and trial pits is presented at Figure 2.

3.3.1 Trial pits

The depth of the trial pits excavated ranged from a minimum depth of 0.8mBGL to a maximum depth of 3.10mBGL.

3.3.2 Boreholes

Twenty-two boreholes were drilled using cable percussion. Of these only fourteen were drilled to 1m into the clay layer to prove the full thickness of the sand and gravel aquifer (BH01, BH02C, BH03, BH04, BH05, BH06A, BH07B, BH08, BH09, BH10B, BH11, BH17, BH18 and BH19). Eight boreholes (BH02, BH02A, BH02B, BH06, BH07, BH07A, BH10 and BH10A) were terminated at a shallow depth due to obstructions in the shallow layers. Three boreholes (BH04, BH05 and BH11) were deepened by rotary coring methods up to 26.5mBGL collect approximately five meters of bedrock.

3.3.3 Monitoring installations

Groundwater monitoring standpipes were installed in all boreholes. The base of the borehole up to the base of the targeted response zone was backfilled with bentonite grout in BH01, BH02 and BH03. However, this design could not be installed successfully in the remainder of the boreholes due to the high permeability of the sand and gravel. As an alternative, the remainder of the holes were backfilled with clean arisings from the base of the hole up to 1.1m below the base of the response zone. Then bentonite pellets were added from approximately 1.1m to 0.1m below the base of the targeted response zone in the sand and gravel aquifer. This was then followed by a 0.1m gravel layer.

A 50mm slotted standpipe was installed from the top of the gravel layer to between 7.5m and 1.5m below ground level followed by a plain pipe to 0.4m above the surface. A gravel pack was installed around the slotted standpipe up to 0.7m above the slotted section and up to 0.8m below the base of the made ground. Approximately 0.3m sand layer was placed above the gravel pack and the remainder was backfilled with bentonite pellets up to below ground level.

Gas monitoring standpipes were installed in three boreholes in the northern section of the site to target potential ground gas from deep areas of made ground with organic soils and a landfill north of the site. These were installed in the unsaturated made ground only. A 0.1m gravel layer was placed over bentonite pellets. A 19mm internal diameter slotted standpipe was installed between 2.5mBGL and 0.5mBGL gravel and plain standpipe to the surface. A gravel surround was installed up to 0.2m above the slotted section followed by bentonite pellets to the surface. A gas tap was inserted in the top of the standpipe.

Following the site work, all locations were surveyed relative to Ordnance Datum.

Following well development, falling head tests were carried out in five boreholes (BH02C, BH04, BH05, BH07B and BH10B) across the site to assess the permeability of the aquifer.

3.3.4 Soil Sampling

To give a robust understanding of the nature of contamination within the made ground in vertical and lateral extent, small disturbed samples were taken at 1m intervals and from every change of strata in the made ground. The first 1m of the underlying sand/gravel was also sampled to confirm if any contamination had migrated into the natural soils.

Samples were collected in dedicated soil pots and jars as specified and supplied by the analytical laboratory. Samples were taken in accordance with methods specified and referenced in the Investigation of potentially contaminated sites - Code of practice (BS 10175:2011+A1:2013) [6].

In addition, a sub-sample from each environmental sample was tested for volatile organic carbons using a calibrated portable Photo-Ionisation Detector (PID) with a 10.6eV bulb on-site. A subset of the samples was sent to an accredited analytical laboratory and tested for the analytical suites of contaminants highlighted in Table 4 of the PSA (chemicals of concern). The subset was selected based on the PID

readings and visual and olfactory observations. Only the samples which were considered to be the most contaminated from each pit and the natural ground below them were sent for testing. The results of the PID are presented in the logs in Appendix B of the Causeway ground investigation report presented in Appendix B of this DSA.

3.3.5 Water and ground gas monitoring

Following the completion of the site investigation, a campaign of monitoring was carried out comprising:

- Continuous monitoring of water levels in five groundwater boreholes (BH02, BH03, BH08, BH18 and BH20) for approximately one month using level loggers.
- Three occasions of manual groundwater level monitoring in all boreholes.
- Three occasions of groundwater quality sampling and surface water quality sampling at high tide and low tide.
- Three occasions of gas monitoring.
- Laboratory analysis of water samples.

The ground gas, groundwater and surface water monitoring locations are presented in Figure 3. Additional surface water samples were collected upstream of the site on the River Avoca. Their location is shown in Appendix A of the ground investigation report presented in Appendix B of this DSA. Water samples were collected from all boreholes using dedicated bailers in accordance with “Water quality - Sampling. Guidance on sampling of groundwater” (BS ISO 5667-11:2009 **Error! Reference source not found.** Surface water samples were collected at high and low tide at four locations south and east of the site from the Avoca River and in the Irish Sea (Figure 3).

The sample containers used were provided by the laboratory.

A number of field analytical tests were carried out including pH, Electrical Conductivity (EC), Dissolved Oxygen (DO) and Redox. The results of the field monitoring are presented in Appendix H of the ground investigation report (Appendix B). These were measured using a Hanna Instruments HI-98194 Multiparameter Waterproof Meter.

Samples were only collected once three consecutive pH, EC and DO readings were observed within 10% of each other. After sampling, the samples were stored in cool boxes with ice packs before being sent to the laboratory.

3.3.6 Gas monitoring

Gas monitoring was carried out in all boreholes containing a gas monitoring installation using calibrated, ATEX approved equipment to measure methane, carbon dioxide and oxygen as a percentage by volume and borehole gas flow rate in litres per hour. The monitoring was carried out in accordance with the methods

stated in CIRIA C665 [7] and BS 8576:2013 [8]. Gas monitoring was undertaken on three occasions throughout a period of five weeks.

3.3.7 Laboratory Analysis

All samples were analysed within the laboratory recommended holding time to prevent the samples degrading.

Chemtest Ltd. undertook the analysis of ninety-one (91 no.) soil samples and fifty-seven (57 no.) water samples, including twenty-four surface water samples and thirty-three groundwater samples.

Chemtest Ltd. carries a high level of accreditation for the analysis of the determinands analysed and have accreditation to ISO 17025:20005 [9]. The parameters chosen for analysis were based on the consideration of the past site activities and related potential contaminants as identified in the PSA [1]. The samples were tested for the contaminants highlighted in Table 8 of the PSA.

Copies of the tables from the specification presenting the suites of determinands to be tested for in the soils and water are presented in Table 2 and Table 3 below.

Table 2: Soil testing suite

TEST	METHOD DETECTION LIMIT
Leachate Sample	
CEN Leachate Generation L/S 10: 1	0.02mg/kg
As	0.5mg/kg
Ba	0.004mg/kg
Cd	0.5mg/kg
Cr	0.5mg/kg
Cu	0.0005mg/kg
Hg	0.05mg/kg
Mo	0.1mg/kg
Ni	0.5mg/kg
Pb	0.05mg/kg
Sb	0.05mg/kg
Se	0.5mg/kg
Zn	0.5mg/kg
Chloride	10mg/kg
Fluoride	0.1mg/kg
Sulphate Soluble	30mg/kg
Total Phenols by HPLC	0.10mg/kg
Dissolved Organic Carbon	20mg/kg
Total Dissolved Solids	500mg/kg
Soil Sample – Total Pollutant Content	

TEST	METHOD DETECTION LIMIT
Asbestos Screen – confirmation of presence, quantification if present	N/A
Total organic Carbon	0.10%
PCB (7 congeners)	1 ug/kg
Total Petroleum Hydrocarbons with BTEX and MBTE – Criteria Working Group (TPH – CWG) (with banding)	Low level
PAH (Speciated 17) by GC MS, including Coronene	1ug/kg
LOI	0.1%
Metals:	
As	Low level
Ba	Low level
Cd	Low level
Cr (III and VI speciated)	Low level
Cu	Low level
Hg	Low level
Mo	Low level
Ni	Low level
Pb	Low level
Sb	Low level
Se	Low level
V	Low level
Zn	Low level
Sulphide	Low level
Complex cyanide	Low level
Free cyanide	Low level
pH	
Volatiles– Modified USEPA 8260 (10ug/I) including tentatively identified compounds	Low level
SVOC– Modified USEPA 8270 (10ug/I) including tentatively identified compounds	Low level
Suite of potentially explosive substances including: Nitrocellulose, Nitroglycerine, Picric Acid	≤1 mg/l
Radionuclides (U ²³⁸ , U ²³⁴ , Th ²³⁴ , Th ²³⁰ , Pr ²³⁴ , Rm ²²⁶ , Radon ²²² , Polonium ²¹⁸ , Pb ²¹⁴ , Pb ²¹⁰ , Pb ²⁰⁶ , Bismuth ²¹⁴ , Bismuth ²¹⁰ , Polonium ²¹⁴ and Polonium ²¹⁰)	1mg/kg
Higher resolution gamma spectrometry (all gamma)	Low level
Gross alpha / beta (all alpha and beta)	100Bq/kg

Table 3: Water testing site

TEST	METHOD DETECTION LIMIT
To be tested in the field	
pH	Between 1.0 and 14.0 pH units
Electrical Conductivity (EC)	Between 10µS/cm and 30,000mS/cm
Dissolved Oxygen	<0.1mg/l and 0.1% [Both to be recorded]
Redox	<1eV
To be tested in an analytical laboratory	
Ca	0.05mg/l
Mg	0.05mg/l
Sodium	0.2mg/l
Potassium	0.2mg/l
Alkalinity	1 mg/l
Chloride	1 mg/l
Sulphate	3mg/l
Mn	1ug/l
Fe	1ug/l
Ammoniacal Nitrogen	0.2mg/l
Hexavalent Chromium	0.03mg/l
Nitrate	0.3mg/l
Phosphate	0.03mg/l
As	low level
Ba	low level
Cd	low level
Cr (III)	low level
Cu	low level
Hg	low level
Mo	low level
Ni	low level
Pb	low level
Sb	low level
Se	low level
Zn	low level
Hg	low level
V	low level
BTEX/PRO incl. MTBE by GC-FID*	10ug/l

TEST	METHOD DETECTION LIMIT
Total Petroleum Hydrocarbons with BTEX and MTBE – Criteria Working Group (TPH – CWG) (with banding)	0.01mg/l
BOD	2mg/l
COD	15mg/l
Complex cyanide	Low level
Free cyanide	Low level
Total Dissolved Solids	50mg/l
Total Suspended Solids	10mg/l
Additional items (see BoQ item I2i)	
Volatiles + TIC's – Modified USEPA 8260 (10ug/l) including tentatively identified compounds	1ug/l
SVOC + TIC's– Modified USEPA 8270 (10ug/l) including tentatively identified compounds	1ug/l
Additional items (see BoQ item)	
PCB (7 congeners)	Low level
Suite of potentially explosive substances including: Nitrocellulose, Nitroglycerine and Picric Acid	≤10µg/l
Radionuclides (U ²³⁸ , U ²³⁴ , Th ²³⁴ , Th ²³⁰ , Pr ²³⁴ , Rm ²²⁶ , Radon ²²² , Polonium ²¹⁸ , Pb ²¹⁴ , Pb ²¹⁰ , Pb ²⁰⁶ , Bismuth ²¹⁴ , Bismuth ²¹⁰ , Polonium ²¹⁴ and Polonium ²¹⁰)	1 mg/l
Higher resolution gamma spectrometry (all gamma)	Low level
Gross alpha/beta (all alpha and beta)	0.1Bq/l

4 Results and discussion of ground investigation

4.1 Site Geology

The site geology consists generally of made ground overlying two layers of sand and gravel separated by a thin clay layer. Beneath the sand and gravel layers is a thicker clay layer overlying bedrock. A summary of the strata proven at the site is summarised in Table 4. This information is compiled from the borehole and trial pit logs from the site investigation as presented in Appendix B, Appendix D and Appendix F of the site investigation report produced by Causeway Geotech [3] presented in Appendix B of this DSA. The strata proven is consistent with the regional geology and generally consistent with findings from previous site investigations for the site presented in the PSA.

Table 4: Site geology

Lithology	Description	Location	Depth (mBGL)	Thickness (m)
Made Ground	<p>Made ground – Brown sand and gravel</p> <p>Loose or Medium dense fine to coarse brown or grey, occasionally reddish-brown sand or gravel with anthropogenic materials such as red brick and cement and structures such as brick culverts.</p>	Across the site	0 to 3.3	0.2 to 2.5
	<p>Made ground – Phosphogypsum deposits</p> <p>White silt</p>	In the north of the site	0 to 2.0	1 to 2.0
	<p>Made ground – Infilled pond</p> <p>Medium dense purplish-brown to reddish-brown sand and gravel with organic material such as reeds.</p>	North west of the site	0 to 4.4	2.8 to 3.0
Sand and Gravel	<p>Very loose to medium dense yellowish-brown to brownish-grey silty sand and gravel with shell fragments present in places.</p>	Across the site	0.3 to 17.2	7.9 to 15.2
	<p>Contains a band of soft to stiff brownish grey slightly sandy slightly gravelly clay layer.</p>	South and centre of the site	10.6 to 13.4	0.2 to 1.1

Lithology	Description	Location	Depth (mBGL)	Thickness (m)
Clay	Soft to very stiff brownish grey slightly sandy slightly gravelly silty clay.	Across the site except the south west	14.0 to 21.9 (where proven)	0.6 to 7.8 (where proven)
Gravel	Dense to very dense brown sandy angular to subangular fine to coarse gravel	Across the site	15.40 to 19.50 (where proven)	1.5 to 2.9 (where proven)
Bedrock	Medium strong to strong grey massive medium grained sandstone or dolerite.	Across the site	17.8 to 26.5 (base not proven)	4.6 to 7.0 (base not proven)

The made ground is present in all boreholes and trial pits on the site. It was found to be highly variable on a local scale but across the site the made ground can be generally be divided into four subgroups which include brown sand and gravel, phosphogypsum deposits, infilled pond and black sand and gravel (Table 4).

The thickness of the made ground varies between 0.9m in TP10 to 4.4m in BH09, both of which are in the north of the site, although typically the thickness of the made ground is approximately 1.5m.

4.1.1 Made ground – brown sand and gravel

The brown sand and gravel is present throughout the site from ground level and varies in thickness. Typically, this layer is thicker in the north and west of the site and thinner in the east and south of the site. This soil group is rich in anthropogenic materials, primarily red brick and cement.

Often the colour of the sand and gravel is recorded as black and is associated with hydrocarbon and chemical odours. This was typically observed in the centre of the site. Despite the olfactory observations, volatile organic compound (VOC) readings taken using a hand-held field photo ionization detector (PID) are low (refer to Section 2.3.1).

Green, orange and red staining of these deposits was noted across the site and is likely due to metal contamination. White staining was seen in the south of the site, however the radiological survey discounted this as a phosphogypsum deposit.

The thickness of the made ground varies throughout the site. It is thickest in the north (4.4mBGL) and north-west of the site where land was reclaimed from the old Avoca River channel. The made ground is thinnest in the west and south of (0.5mBGL), where on the historical maps prior to the redirection of the Avoca River the land was shown above the level of the Irish Sea.

Potential asbestos containing materials

Potential asbestos sheeting was identified in two trial pits (TP1 and TP3) and a suspected asbestos pipe was identified in TP15. As the pipe was not damaged no sample was taken from the pipe. A sample was collected from TP1 and sent to the laboratory for analysis and confirmed by the laboratory to contain asbestos. The laboratory results are reviewed in detail in Section 5. Once the potential asbestos sample was taken the trial pit was backfilled to prevent disturbing any further potential buried asbestos.

The location of asbestos identified in the made ground is presented in Figure 4.

Plate 1: TP03A. Made Ground brown sand and gravel soil including suspected asbestos cement sheets (right hand side of the plate).



Explosive materials

Suspected nitrocellulose (guncotton) was identified in three trial pits (TP5, TP9 and TP11). A sample was collected from TP5 and sent to a laboratory for analysis. Nitrocellulose was confirmed in a shallow sample at 0.4mBGL in the south of the site outside of the factory area; at 1.5mBGL and 1.7mBGL in the north and north-west of the site and is associated with infilled ponds; and at 2.5mBGL in a yard area.

The location of nitrocellulose (guncotton) identified in the made ground is presented in Figure 5.

4.1.2 Made ground – phosphogypsum deposits

Phosphogypsum deposits were identified as white silt and were only present in the fenced area north of the site (TP24, TP25 and TP26). The ground level in this area is approximately 0.5m to 1.0m higher than the ground level immediately south of the fence, suggesting that phosphogypsum deposits were stockpiled here. Brown sand and gravel was proven beneath the phosphogypsum.

The location of the phosphogypsum deposits is presented in Figure 6.

Plate 2: Phosphogypsum deposits in TP25 (note the vegetation and topsoil around the pit were removed to allow the excavator to access location).



4.1.3 Made ground – infilled ponds

Historical maps presented in the Preliminary Site Assessment identified a potential pond feature in the north-west section of the site [1]. Deep made ground with organic and silty soils were proven in areas that correspond with these ponds identified in BH09, BH11 and TP21. The deposits were thickest (up to 3m in BH09) in the north of the site. The deposits were not identified in the east of the site.

4.1.4 Natural Strata

Layers of sand and gravel underlying the made ground was present throughout the site. These are likely to be estuarine deposits in the area of the old Avoca River channel in the northern area of the site and beach deposits in the centre and south of the site. Intact oyster shells were observed in the upper two meters of sand below the made ground in the south and west of the site. Shell fragments were noted in deeper sand layers in the south and east of the site between 7.7mBGL (-4.55mOD) and 13mBGL (-9.85mOD).

Deeper sand and gravel deposits were proven between 16.2mBGL and 19.5mBGL (-13.16 and -16.99mOD). These are more angular and less well sorted than the shallower sand and gravel deposits and are likely to be fluvial or glacial deposits.

Isolated patches of green to orange staining was observed in the upper two meters of natural ground between 0.8mBGL and 2.8mBGL (between 2.2mOD and -0.41mOD) across the site. Orange staining was observed within sand deposits (TP05 and TP10) with green staining observed within sand deposits and in shells (TP06, TP15 – TP17) (plate 5 and plate 6). The colours seen in the natural strata are likely to be due to metals leaching, probably from the upper made ground layer.

Plate 5: TP16 showing orange staining of natural deposits beneath the grey brown made ground and green staining beneath.



Plate 6: Spoil from TP16 (1.7mBGL) showing green staining of natural deposits



4.2 Site Hydrogeology

During the site investigation in general only the sand and gravel was found to be water bearing. Where depth of the base of the made ground was below the water table it was also seen to be water bearing, but no perched water was observed in the made ground.

Fifteen boreholes were installed with responses zones in the sand and gravel under the made ground. Water levels in the boreholes were recorded between April and May 2018 using transducers in a subset of five borehole and manually in all boreholes on three occasions. The data from the transducers and manual readings are presented on a series of hydrographs in Appendix D and in Figure 7.

The variations in water level in the aquifer and Arklow Harbour were monitored over a five-week period. The water level varied during this period between approximately 0.6mOD (2.1mBGL) in BH18 in the north east of the WwTP to approximately -0.6mOD (3mBGL) in BH03 (Figure 7). During this period, the maximum and minimum tides recorded were approximately 0.9mOD and -1mOD respectively indicating that the groundwater is in continuity with the Irish Sea and

follows the tide in a suppressed manner (Figure 7). The groundwater levels in the north of the site are generally around the level of the daily high tide and the water levels in the south of the site are above or around the level of the low tide.

Groundwater elevations and flow nets at low tide (04:00 on 30/04/2018) and high tide (11:00 on 17/04/2018) are presented in Figure 8 and Figure 9. The water level monitoring data is presented in Appendix E.

At low tide, the groundwater levels varied between 0.0mOD (2.6mBGL) in the west of the site to -0.6mOD (3.0mBGL) in the east of the site. During low tide (Figure 8) the groundwater flows in a west to east or south-east direction and toward the Irish Sea.

During high tide, the groundwater levels across the site varied between 0.6mOD (2.0mBGL) in the north of the site to 0.0mOD (2.4mBGL) in the south-east of the site. During high tide (Figure 9) the direction of groundwater flow from the north-north-west to the south-east direction.

This change in flow direction reflects the movement of the sea water into the sand and gravel aquifer during high tide as the water level along the coastline rises above the water level in the aquifer and vice versa during low tide. Hence the groundwater quality in the sand and gravel close to the Irish Sea is strongly affected by the water quality in the Irish Sea.

4.3 Radiological Survey

The walkover survey identified radiation slightly above background levels (0.1 μ Sv/h):

- in the fenced area in the north of the site;
- at two open pipes in the north side of the main factory building; and
- in a small stockpile in the south of the site.

The areas identified are shown on Figure 6.

Following the non-intrusive survey, an intrusive investigation was arranged to investigate the source of the elevated readings and sample the soils in the north and south of the site. During the intrusive investigation monitoring was carried out by the radiological surveyor from Radman Associates.

The monitoring comprised measuring the radioactivity using the handheld meter from the spoil and the working area during the excavation and before anyone approached the trial pit. The radiological surveyor confirmed that all the samples had sufficiently low readings ($\ll 1000\mu$ Sv/h) to allow them to be sampled but advised that dust masks be worn as a precaution. In addition, he verbally confirmed that the risk to the site users during the investigation were sufficiently low to allow the area of the phosphogypsum to be accessed and that there was no risk at the site boundary.

Results of the intrusive investigation showed that:

“...phosphogypsum was easily identifiable in TP24, TP25 and TP26 by the characteristic white chalky appearance...Readings up to 550 cps were recorded in close proximity to the phosphogypsum from all three trial pits. The maximum dose rate recorded in this area was 0.3 μ Sv/h.

The maximum dose rate recorded on site was in the area of the phosphogypsum deposits. The report stated that:

“...it would take over 3330 hours to reach the annual dose limit for a member of the public (1 mSv) within Article 10 of the Radiological Protection Act 1991 (Ionising Radiation) Order 2000.”

This is equivalent to exposure over a continuous time period of approximately 89 weeks consisting of a 37.5-hour work week.

It also states that: *“Material from TP27 gave elevated readings up to 400 csp (0.2 μ Sv/h) but no obvious phosphogypsum was observed. The elevated readings may be due to other material containing NORM [naturally occurring radioactive materials] e.g. bricks and rubble which was present in the area.”*

These samples that were collected were sent for high resolution gamma spectroscopy to determine the contaminant activity concentrations. The results are presented in Appendix F and reviewed below in Section 5.

The area around the open pipes (Figure 6) gave readings up to 350 cps (0.2 μ Sv/h). The report recommends this area should be investigated further to determine the type and extent of radiological contamination. This was not undertaken during the ground investigation due to limited access to the buried pipes.

4.4 Chemical Test Results

In accordance with the EPA template for Detailed Site Assessment report, the following section presents a summary of the results of the analysis of the soil, water and ground gas.

4.4.1 Soil Analysis

Soil results taken from the boreholes and trial pits are presented in Appendix F to this DSA. A summary of the soil sample results are as follows:

- Asbestos was confirmed in four samples of the eighty-seven samples analysed and detected at 0.09% to 4.5% by weight;
- Photo-Ionisation Detector readings carried out on-site generally recorded low levels at or around the instrument detection limit (<0.1ppm to 1.8ppm);
- Elevated concentrations of metals were recorded across the site in the brown sand and gravel made ground and hydrocarbon compounds were recorded in the black part of the sand and gravel made ground.
- The phosphogypsum was recorded to emit low levels of radiation but at levels higher than background.

- Nitrocellulose (guncotton) was found at four discrete locations around the site between approximately 0.4m to 2.5m below ground level.

4.4.2 Water quality

Water quality results are presented in Appendix G to this DSA.

The main findings of the water quality analysis are as follows:

- elevated levels of metals (nickel, zinc, lead, cadmium, barium) were recorded in all the groundwater samples from the sand and gravel aquifer.
- phosphate and ammoniacal nitrogen are present in the groundwater beneath the site.
- The water quality beneath the site is influenced by the Irish Sea.

4.4.3 Ground Gas

Ground gas monitoring results are presented in Appendix H1 to this DSA.

The main findings of the ground gas monitoring are as follows:

- Low concentrations of methane and carbon dioxide are present in the site.
- The borehole gas flows recorded are low.

4.5 Conceptual Site Model

An initial conceptual model; was presented in the PSA which raised a number of site uncertainties which have been addressed through the DSA. Figure 10**Error! Reference source not found.** illustrates the conceptual model and shows a summary of the information collected.

Below is a summary of the CSM in which the site has been subdivided into sources, pathways and receptors and key source pathway receptor (SPR) linkages are highlighted.

4.5.1 Source

In the PSA, the following potential sources were highlighted:

- Uncontrolled fill of the Avoca River and made ground used to reclaim the site from the sea;
- Cordite;
- Phosphogypsum;
- Asbestos containing materials in the soil; and
- Others (electricity substation and above ground oil storage tanks).

With the exception of the substation and the above ground oil storage tanks, based on the ground investigation information there is sufficient evidence to consider the likelihood for all the other potential sources to pose a risk.

4.5.2 Pathways

The principal pathways highlighted in the PSA were:

- direct exposure of contamination in the made ground (ingestion, inhalation and dermal contact);
- percolation of recharge through the unsaturated made ground to the groundwater;
- percolation of liquid contaminants through the made ground;
- movement of groundwater in the made ground (below the water table) into the sand and gravel;
- groundwater movement through the made ground and sand and gravel; and
- movement of ground gas through the unsaturated made ground and sand and gravel.

Based on the results of the ground investigation these are all considered relevant pathways.

4.5.3 Potential receptors

The principal receptors highlighted in the PSA are:

- Demolition and construction workers;
- site users (current and future Irish Water site operators);
- proposed buildings associated with the WwTP;
- groundwater in the sand and gravel;
- groundwater in the locally important bedrock aquifer;
- Avoca River; and
- Irish Sea.

Based on the results of the ground investigation these are all considered relevant.

4.5.4 Source-pathway-receptor linkages

Considering the CSM outlined above and presented in Figure 10, the following plausible SPR linkages are highlighted for the current and proposed development of the site.

Table 5: Identified Source -Pathway -Receptors

Source	Pathway	Receptor
Historic channel of Avoca River and land reclaimed from the sea, above ground storage tanks and infilled ponds	Direct contact (ingestion, inhalation and dermal contact)	Demolition and construction workers, Irish Water site operators and current site users
	Migration of ground gas through the permeable unsaturated zone	Current buildings, demolition and construction workers and the proposed WwTP
	Percolation of dissolved phase or liquid contaminants	Groundwater in the sand and gravel
	Groundwater in the sand and gravel	Avoca River and Irish Sea
Phosphogypsum (solid stored above ground and escaped from buried pipes)	Direct contact (ingestion, inhalation and dermal contact)	Demolition and construction workers, Irish Water site operators and current site users
	Percolation of dissolved phase or liquid contaminants	Groundwater in the sand and gravel
	Groundwater in the sand and gravel	Avoca River and Irish Sea
Shallow surface contamination of made ground with cordite	Direct contact (ingestion, inhalation and dermal contact)	Demolition and construction workers, Irish Water site operators and current site users
Adjacent landfill (ground gases)	Diffusion through the subsurface permeable made ground to the surface	Site buildings and, demolition and construction workers

Considering the receptors highlighted above, human health criteria for the soils and environmental quality standards for the groundwater are considered as part of a generic quantitative risk assessment (GQRA). The GQRA has been carried out for the contaminants identified in Section 4.4

5 Generic quantitative risk assessment (GQRA)

5.1 Generic assessment criteria (GACs)

5.1.1 Soil

There are no Irish soil quality standards for assessing risk of contaminated soils to site users. EPA guidance states that:

“EPA recommends the use of GAC, based on the UKEA Contaminated Land Exposure Assessment (CLEA) model, either produced by the UKEA itself (known as Soil Guideline Values/SGVs) or values generated using the CLEA model by reputable third-party organisations such as Land Quality Management (LQM) or Contaminated Land: Applications in Real Environments (CL:AIRE). Where GAC have not been published or if practitioners don't use human health GAC publications, values should be generated by appropriately qualified and experienced professionals using the CLEA model to ensure consistency with the EPA approach”

Consistent with the EPA guidance limits this GQRA refers to C4SL's (Category 4 Screening Levels) derived using CLEA and as an output from the UK Department for Environment, Food and Rural Affairs (DEFRA) research project SP1010 and which incorporate feedback from the project's Steering Group and the wider contaminated land community. The project's Steering Group included individuals from the following organisations:

- Department for Environment, Food and Rural Affairs (Defra)
- Department for Communities and Local Government (DCLG)
- Welsh Government (WG)
- Environment Agency (EA)
- Natural Resources Wales (NRW)
- Public Health England (PHE, formerly the Health Protection Agency)
- Food Standards Agency (FSA) and
- Homes and Communities Agency (HCA)

Where no C4SL is available, the LQM's S4UL's (suitable for use limits) have been derived using the CLEA model by a group of contaminated land consultants and members of academia. These have been endorsed in the UK by the Chartered Institute of Environmental Health (CIEH). The S4UL's are relatively conservative and do not take account of individual exposure pathways at each site or the local soil type.

Where no S4UL is available, Generic Assessment Criteria developed by Arup using the same method and software (CLEA) as the S4UL's have been used. Where, no C4SL, S4UL or Arup standards are available, values from the other countries have been used. These have not been derived using the CLEA model and can incorporate different risk levels to values derived using the CLEA model.

In the GQRA the soil assessment criteria are collectively referred to as GAC.

Although all standards used in this assessment were not specifically derived for Irish soil, the large factor of safety built into the CLEA model makes them a suitable conservative assessment criteria in the absence of Irish soil standards. They are also commonly used in Northern Ireland.

GAC have been derived for several site uses. Hence the standards used should relate to the proposed use of the site. In this assessment, the GAC for commercial site use has been used as the site will not generally be accessible to the public. A

small strip of land to the north will comprise landscaping along Mill Road in this area the GAC for public open space (park) has been used.

The soil GAC used are taken for a soil with a soil organic matter content of 2.5%. This was calculated for the soil based on the total organic carbon measured in the made ground. The conversion was carried out by multiplying the soil total organic carbon by a factor of 1.72 [10]. The soil organic matter concentrations range from 0.3% to 46.4%, with an average concentration of 3.6%. Organic matter concentrations are higher in areas of pond infill.

The comparison of the soil results with the GAC is presented in Section 5.2.

5.1.1.1 Asbestos

Currently, there is no Irish or UK GAC for asbestos and any level of asbestos is potentially harmful. In this assessment it has been assumed that if the laboratory limit of detection is not exceeded, no asbestos is present in the sample.

However, even if asbestos was not observed in the tested sample, there still remains the possibility that it could be present in concentrations less than the laboratory detection limit. Hence soils with recorded concentrations of asbestos below the detection limit could still present an risk.

5.1.1.2 Explosives materials

There are no national Irish or UK CLEA derived GAC's for explosives. However, BAE Systems [11] & [12] and provided in Appendix F, a private company with specialist knowledge of explosives have produced a number of short reports for Arup summarising the key toxicological data and physiochemical properties for a number of explosives including nitrocellulose and nitro-glycerine. These reports include a detailed review of international standards, toxicological literature and physiochemical properties that has been published relevant to individual explosives. Should it be necessary it is possible to derive GACs using the CLEA model. Where necessary, in the absence of CLEA derived GAC these documents have been referred to.

The comparison of the soil results with GAC derived from the BAE systems reports is presented in Section 5.2.

5.1.1.3 Radioactive materials

Radioactive materials are regulated in Ireland under the Radiological Protection Act (RPA), 1991 (Ionising Radiation) Order, 2000 [13]. This presents national standards in relation to the concentration of radioactivity above which workers and members of the public should not be exposed to. These are measured in milli-Sieverts per year (mS/annum) and relate to the exposure from all the radionuclides in a material. The results of the site survey were collected in mS/annum and have been compared to these values.

Where a material contains radionuclides above a limit the material should be controlled under a licence. The results of the ground investigation have been

compared to the standards in the RPA to confirm if the materials are below this limit. The standards comprise individual standards for specific radionuclides (which considers their daughter products). In addition, where there is a mixture of radionuclides, the sum of the ratios (measured concentration against the RPA standard) has been determined to establish if it is less than 1.

In addition to the national standards the soil concentrations have also been screened against the human health criteria for radioactive soils calculated using CLEA presented in a UK Department for the Environment, Farming and Rural Affairs (DEFRA) guidance for assessing risks from radioactive soils [14]. This provides individual GAC for radionuclides and an overall all assessment level. These results have been compared to both.

The comparison of the soil results with the radiological GAC is presented in Section 5.2.

5.1.2 Water

Based on the SPR linkages highlighted in Section 4.5.4 there is no significant exposure pathway to humans from water and this assessment does not consider this risk any further.

The water in the gravel is seen to be in continuity with the fluctuating tide level and is potentially discharging to the Irish Sea during low tide.

The EQSs are prepared by the European Union to assess the quality of water within the member states of the Union [15][16][17]. They are not statutory requirements for land owners but exceedances of the standards are considered to comprise pollution as they could affect the quality status of the water body.

Where no surface water EQS are available, in order of preference, groundwater quality standards [17] and then older EPA interim guideline values (IGV) [18] have been used to provide a qualitative assessment levels. An exceedance of a groundwater standard or IGI value does not necessarily denote that the water quality is unacceptable, but highlights that the concentration could be unacceptable and requires additional consideration.

If water quality beneath the site is seen to exceed the EQS value, this could be either due to an on-site contamination source or an off-site source. Potential contamination up hydraulic gradient of the site is likely to impact on water quality under the site. To determine if any exceedances of the EQS are caused by the potential contamination off site and up-hydraulic gradient, water quality in the boreholes on the eastern side of the site (down-hydraulic gradient) was compared to water quality in the boreholes on the western side of the site (up-hydraulic gradient). Sea water quality collected at low tide and high tide along the coastline on the eastern and southern sides of the site was also compared to groundwater quality.

This is considered an appropriate methodology as it allows for natural variation in water quality and considers the possibility that water quality is naturally higher than the standards. The comparison of the water quality results for the site with the EQS values and up hydraulic water quality is presented in Section 5.3.

5.1.3 Ground Gas

Bulk gases which were monitored for on the proposed WwTP site were the bulk ground gases methane (CH₄) and carbon dioxide (CO₂).

Ground gasses are assessed in relation to their risk to causing damage to buildings by accumulating above explosive limits in basements by use of the Generic Screening Values from BS8485 [19]. According to the BS8485 guidance, the maximum borehole flow rate (l/hr) is to be multiplied by the maximum gas concentration (%) to calculate the gas screening value (GSV). These are then compared to Table 2 of BS8485 presented below.

Table 6: Table 2 from BS8485

CS	Hazard potential	Site characteristic GSV ^{A)} L/h	Additional factors
CS1	Very low	<0.07	Typically <1% methane concentration and <5% carbon dioxide concentration (otherwise consider an increase to CS2)
CS2	Low	0.07 to <0.7	Typical measured flow rate <70 L/h (otherwise consider an increase to CS3)
CS3	Moderate	0.7 to <3.5	–
CS4	Moderate to high	3.5 to <15	–
CS5	High	15 to <70	–
CS6	Very high	>70	–

^{A)} The figures used in this column are empirical.

NOTE The CS is equivalent to the characteristic GSV in CIRIA C665 [6].

NOTE 2 The results from the models can be used to determine the scope of gas protection measures needed for a building and to design any necessary underfloor ventilation.

NOTE 3 This approach is of particular use where gas migrates through the ground from a source adjacent to the site (e.g. where landfill gas migration occurs).

NOTE 4 Further information on detailed quantitative risk assessment is provided in the Ground Gas Handbook [4].

Using the characteristic situation from Table 8.5, the level of the gas protection measures required can be specified once the final design of the building is known.

In addition to the risks to buildings, ground gases pose a risk to human health and potentially in limits which would cause an explosion. Ground gas concentrations have been compared with the Irish Occupational Exposure Limits published by the Health and Safety Authority (HSA) [20].

5.2 Results of generic quantitative risk assessment

5.2.1 Soils

The results of the testing include the potential chemicals of concern (PCOC) presented in the PSA. The testing included an extensive number of compounds. A full set of all the results screened against the relevant GAC is presented in Appendix F. Two summary tables presented below highlighting the PCOC which exceed the relevant GAC. Table 7 presents the results for the area of the site within proposed fence line for which commercial GAC are relevant. Table 8 presents the results for the area to the north of the site that will be under the ownership of Irish Water but will be landscaped and accessible by the public. Public open space (park) GAC have been used for this area.

Table 7: Maximum parameter concentrations and number of exceedances in soil samples S4ULs and GACs for a site for commercial use

Determinand	Unit	LOD	GAC (commercial)	Samples	Exceedances	Location of the exceedance (depth in metres below ground level)
Asbestos	% (weight)	0.001	-	4	-	TP2 (1.2m), TP3A (, 0.5m & 1.5m) TP27 (0.1)
Arsenic	mg/kg	1.0	640	27	1	TP2 (1.5)
Lead	mg/kg	0.50	1100	27	25	TP1 (0.5m & 1.5m), TP2 (0.5m & 1.5m), TP3A (0.5m), TP4 (0.5m), TP5 (1.0m), TP6 (0.5m), TP7 (1.5m), TP8 (1.0m), TP9 (0.5m, 1.5m & 2.5m), TP12 (1.5m & 2.3m), TP14 (0.5m & 1.6m), TP15 (0.5m), TP16 (0.4m), TP18 (0.5m), TP21 (0.5m), TP23 (1.5m), TP27 (0.1m)
Nitrocellulose (NC)	mg/kg	5000	-	25	-	TP5 (2.5), TP19 (1.7), TP11 (1.5), TP16 (0.4)

Table 8: Maximum parameter concentrations and number of exceedances in soil samples S4ULs and GACs for a site for public open space – park use

Determinand	Unit	LOD	GAC (park)	Samples	Exceedances	Location of the exceedance (depth in metres below ground level)
Arsenic	mg/kg	1.0	170.00	13	3	TP09 (0.5m & 2.5m), TP12 (2.3m)
Mercury	mg/kg	0.10	30.00	13	2	TP09 (2.5m), TP12 (2.3m)
Lead	mg/kg	0.50	580.00	13	13	TP09 (0.5m, 1.5m & 2.5m), TP11 (0.5m), TP12 (0.5m, 1.5m & 2.3m), TP19 (0.5m), TP20 (0.5m & 1.5m), TP21 (0.5m & 1.5m) and BH09 (3.0m)
Benzo[b-]fluoranthene	mg/kg	0.010	13.2	12	1	TP09 (0.5m)
Benzo[a]-pyrene	mg/kg	0.010	10.8	13	1	TP09 (0.5m)
Dibenz(a,h)-Anthracene	mg/kg	0.010	1.15	9	1	TP09 (0.5m)
Nitrocellulose (NC)	mg/kg	5000	N/A	25	4	TP09 (1.7m) and TP11 (1.5m)

Based on the results of the soil testing presented in Appendix F, except for lead and arsenic on one occasion, the determinands are below the (commercial) GAC limit. These also exceed the public open space (park) GAC together mercury and a few polycyclic aromatic hydrocarbons (PAH's). Figure 10 shows the distribution of exceedances for these GAC is across the site. The exceedances for lead are throughout the site in or just below the brown sand and gravel made ground and up to a depth of 3m.

It is likely that these elevated lead and arsenic concentrations relate to the mine spoil, hence the brown sand and gravel is likely to be mostly mine spoil.

The exceedances for PAH's were observed in a shallow depth (0.5m) in TP9, which is considered to be located in the area of the infilled pond. The PAH's are likely to relate to materials used to fill in the old pond and are likely to be fairly limited in extent.

5.2.1.1 Asbestos

Asbestos was recorded in 4 no. soil samples at varying depths (See Figure 4). The occurrence ranged from suspected asbestos containing materials such as the broken asbestos cement sheet seen in TP01 to microscopic loose fibre at 0.025% mass. The asbestos containing material recorded by the laboratory includes asbestos cement, lagging and fibres/ clumps. The types of asbestos recorded by the laboratory include chrysotile, and crocidolite.

Asbestos was used in the construction of the current derelict buildings still standing on the site. It is likely that during the construction of the current building off cuts and waste asbestos sheets and lagging from insulation was used with soil to fill buried features such as the brick filled channels in TP1 and TP3. Asbestos

was not seen in the brown sand and gravel at depth. Consequently, the asbestos in the made ground is probably limited to discrete area where fill was needed.

No samples of the topsoil or hardstand present at the site were tested during this investigation, however, considering the state of the building it is likely that there is also shall contamination of the top soil and surface in the vicinity of the building.

5.2.1.2 Explosive material

The only explosive that was suspected and proven by laboratory analysis to be present on site is nitrocellulose (NC). This was produced in the Kynoch plant on the site of the proposed WwTP. Nitro-glycerine (NG) was also produced in the plant. It was noted in the PSA that NC is very resistant to biodegradation, hence the lack of any NG is probably due to the complete breakdown over the past 100 years since the cordite production stopped. NC is not toxic hence there is no GAC, however it remains a physical hazard as it is explosive when dry. Two samples of NC taken from soil at the WwTP were tested for flammability and were reported to burn vigorously.

The NC was seen in a small number of locations and at various depths. The locations have been compared with the position of the old factory buildings on Figure 5 to determine the source of the NC. Figure 5 shows that the NC recorded at a shallow depth (TP18) in the south outside the old buildings. Hence is likely to have been present as litter on the then floor level, perhaps dispersed after the site had been demolished. Two deeper samples located in the north close to the pond and a ditch associated with it, were confirmed to contain NC. These ponds were likely to have been used as onsite areas for waste disposal. The forth sample with NC was seen at 2.4mbgl to the north, in the centre of the site, in between former buildings. It is not clear how the presence of NC at this depth relates to the former operation of the cordite factory.

5.2.1.3 Radioactive material

Based on the non-intrusive survey, radioactive materials were limited to the area of phosphogypsum identified in the north of the site. The readings observed were below the relevant limits stated in the RPA.

The samples of phosphogypsum were all tested for radionuclides and all shown to contain levels of radiation below the threshold which requires a licence and below the human health GAC (refer to Figure 6).

5.2.2 Water Quality

Water quality results recorded in the sand and gravel aquifer and from surface water taken during the three monitoring visits are presented in Table 9 together with the EQS values.

Footnote 3 of Table 10 of the Surface Water Regulations (2009) [16] states that *'values for all metals, except Chromium VI, are as added values to background concentrations'*.

This allows for the EQS for Arsenic, Chromium III, Copper and Zinc set out in the regulations to be increased by the background concentration for each determinand. The background concentration for this assessment was estimated based on the average concentration recorded in the River Avoca upstream of the WwTP site. The EQS used for Chromium III is based on the Groundwater Quality Regs (2016) [17] so remained unchanged.

To aid interpretation, boreholes were grouped into up hydraulic gradient and down hydraulic gradient groups. In addition, surface water samples have been grouped into samples from the Avoca Rives and samples from the Irish Sea (at high and low tide).

Based on the groundwater flow patterns the groundwater in the sand and gravel flows generally to the east but only discharges to the Irish Sea during low tide. While the River is in hydraulic continuity with the sand and gravel aquifer, the flow within the river is not fed by the groundwater (base flow), and groundwater under the WwTP does not flow into it. The River Avoca outfalls to the Irish Sea.

Table 9: Comparison of the water quality results with the GAC

Determinand	Units	LOD	GAC ¹	River Avoca			Groundwater Upgradient			Groundwater Downgradient			Irish Sea High Tide			Irish Sea Low Tide		
				Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max
Electrical Conductivity	µS/cm	1	N/A	280	825	2900	1500	12183	50000	2500	18718	34000	49000	49333	50000	4700	34589	50000
Sulphate	mg/l	1	187.5	15	46.67	130	510	1251	1700	54	1109	2400	2500	2600	2800	2500	2578	2700
Potassium	mg/l	0.5	N/A	1.70	7.60	29	13	76.88	170	94	184.86	250	290	343.33	400	300	341.67	380
Magnesium	mg/l	0.5	50.00	3.60	17.32	57	19	173.	530	0.50	320	770	930	1290	1800	980	1376	2100
Sodium	mg/l	0.5	150.00	8.70	128.39	500	59	1443.25	4500	440	3285.45	6600	6100	8377.78	11000	5200	8411.11	11000
Arsenic	µg/l	1	22.30 [^]	1	3.81	8.3	2.40	18.03	32	5	31.00	72	62	101.89	150	59	90.78	130
Copper	µg/l	1	14.60 [^]	7.40	11.63	17	6.80	33.76	120	22	61.73	130	110	272.22	470	130	313.33	780
Chromium (III)	µg/l	20	37.50	20	61.08	160	20	41.33	140	20	95.91	210	230	380.00	670	150	324.44	500
Mercury	µg/l	0.01*	0.05	0.01	0.10	0.66	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.06	0.16	0.01	0.48	2.2
pH	pH Units	N/A	9.00 ^(upper limit)	7.3	8.03	9.0	7.1	8.19	12.8	6.9	9.63	12.9	7.8	7.99	8.3	7.8	8.06	8.3
Barium	µg/l	5	100.00	5	6.01	8	24	40.67	75	27	266.36	1600	5	8.24	12	5	6.79	10
Phosphate	µg/l	20*	40.00	20	177.25	630	20	25.50	51	40	119.33	230	20	20.00	20	26	28.67	34
Calcium	mg/l	5	200.00	7.2	12.52	29	260	509.17	730	60	560.00	1200	280	405.56	570	290	422.22	620
Cadmium	µg/l	0.08	0.20	0.09	0.18	0.32	0.08	8.44	42	0.08	12.67	120	0.08	0.08	0.1	0.08	0.08	0.092
Manganese	µg/l	1	300.00	11	42.08	82	7.9	1507.49	3900	1.2	665.66	2500	1	6.48	13	1	5.51	12
Lead	µg/l	1	1.30	1	1.56	2.9	1	1.24	2	1	7.76	38	1	1.06	1.5	1	1.00	1
Chromium (VI)	µg/l	0.1*	0.60	0.10	0.10	0.10	0.10	0.10	0.13	0.10	40.08	190	0.10	0.10	0.10	0.10	0.10	0.10
Nickel	µg/l	1	8.60	1	1.90	8	3	17.97	41	2.4	9.74	22	4.6	7.76	9.9	3.9	7.18	10
Iron	µg/l	20	1000.00	130	190.00	330	420	851.67	1300	86	1375.09	5700	740	1015.56	1600	690	970.00	1400
Zinc	µg/l	1	101.90 [^]	40	68.33	100	34	5252.00	32000	14	259.27	1100	43	70.11	94	40	67.33	84
Ammoniacal Nitrogen	mg/l	0.05	0.07	0.05	0.53	5.2	0.05	1.49	3	0.21	0.99	1.6	0.7	0.85	1	0.69	0.85	1

¹ The GAC comprise groundwater quality standards (black text) [17], surface water quality standards (green text) [15][16] and EPA IGV (red text) [18].

^ The EQS for arsenic, copper and zinc are summarised below:

	Surface Water Regs EQS ($\mu\text{g/l}$)	Average background concentration based on concentrations in the River Avoca upstream of the WwTP site ($\mu\text{g/l}$)	New EQS
Arsenic (Dissolved)	20	2.3	22.3
Copper (Dissolved)	5	9.6	14.6
Zinc (Dissolved)	40	61.9	101.9

* The Limit of Detection for Chromium VI, Cyanide and Phosphate was higher for monitoring round 1 in comparison to monitoring round 2 and monitoring round 3:

Chromium = $20\mu\text{g/l}$

Phosphate = 0.2mg/l

Mercury = $0.05\mu\text{g/l}$

In general, the water quality in the groundwater beneath the site is poor and the water quality in the surrounding water bodies River Avoca and Irish Sea is also poor. Numerous compounds exceed their relevant standards especially metals which are likely to be attributable to the mine spoil. However, there is no trend of high concentrations under the WwTP together with high concentrations in the low tide. Hence despite the poor groundwater quality under the WwTP there is no obvious trend of the groundwater impacting the low tide sea water quality.

High sulphate, magnesium and sodium concentrations are highlighted in the above table but are not of concern as these relate to the mixing of sea water with the groundwater.

Concentrations of arsenic, copper and trivalent chromium are elevated in the groundwater samples but are in higher concentrations in seawater samples. With the exception of arsenic there are also concentrations above the GAC values in the Avoca River. Their presence in the groundwater is likely to be strongly influenced by the seawater and is not considered to comprise contamination from the WwTP site.

Mercury concentrations were elevated during monitoring round three in the sea water samples at high and low tide and in the river sample at high tide. Exceedances in the groundwater was noted in BH08 during monitoring round three only. The presence on this exceedance is not considered to comprise contamination by the soils at the site

Calcium concentrations in the groundwater are slightly higher than concentrations in sea water. No calcium exceeding the GAC was detected in river samples. The elevated levels of calcium are not considered significant as calcium denotes high levels of water hardness and do not present a risk to groundwater quality.

Hexavalent chromium was elevated in BH02 and BH04 only and was below detection limits at every other monitoring location.

Cadmium, lead and manganese concentrations were elevated across the WwTP site during each monitoring round. Cadmium and lead GAC were marginally exceeded downstream (SW04) and upstream (SW05) in the River Avoca at high and low tides during monitoring round three. Lead was marginally exceeded in SW05 at high and low tide during monitoring round one, and in SW03 at low tide during monitoring round three.

Iron concentrations in sea water were exceeded during monitoring round one only. No exceedances in the River Avoca were recorded. Groundwater concentrations were exceeded across the site during monitoring rounds one and three, with maximum concentrations recorded in BH02 and BH05.

Nickel concentrations in groundwater were exceeded throughout the site in monitoring round one and three. Concentrations in sea water were slightly above the GAC both in the high tide and low tide during these monitoring rounds also. No nickel was detected above the GAC in the River Avoca samples, hence the exceedance in the sea water could be attributable to background concentrations.

Zinc concentrations were significantly elevated during each monitoring round, with maximum concentrations noted in BH06A. GAC exceedances were noted in

the groundwater samples, which were an order of magnitude greater than the surface water samples.

Concentrations exceeding the respective GAC for barium, pH and total petroleum hydrocarbons (TPH), (aliphatics C16 to C35, aromatics C8 to C12 and C21 to C35), were noted in boreholes BH01, BH02 and BH19. These boreholes were sealed above the response zone and to the surface using grout which is considered to be the cause of the elevated pH. TPH concentrations in these boreholes were noted during monitoring round two only. No TPH was identified in BH19 during monitoring round three and none was recorded in the Irish Sea at low tide, hence this is not considered to be significant.

Ammoniacal nitrogen is present above the GAC within the groundwater, sea water and the River Avoca. Highest concentrations under the WwTP site were noted down hydraulic gradient of the capped landfill in BH10, BH11 and BH19. Concentrations were lowest in the River Avoca at SW04. SW05 had the maximum concentration during monitoring round 3 at high tide, suggesting a source of ammoniacal nitrogen in the River Avoca other than the capped landfill.

Phosphate also exceeds the standards in the River Avoca and to a lesser extent in the groundwater under the WwTP. This is likely to be attributable to sources of phosphate entering the river from upstream and which could have flowed into the groundwater from the Avoca River.

A number of samples around the phosphogypsum stockpile were tested for the radioactivity to confirm that the radionuclides were not leaching. All sample results were seen to be below the detection limit. Also, a small number of samples were tested for dissolved phase explosive but the samples also did not have any concentrations above the laboratory detection limit.

5.2.3 Ground Gas

Manual ground gas monitoring was carried out in three boreholes with standpipes installed in the made ground (BH10B, BH11 and BH19) on three occasions between April and May 2018.

The gas results show low concentrations of methane and carbon dioxide and low gas flow in each borehole. Concentrations and flow remained low throughout the sampling period.

Conservatively, the results from all the ground gas monitoring were considered against the gas screening values using the guidance outlined in BS8485:2015 [19]. According to the guidance, the maximum borehole flow rate (l/hr) is to be multiplied by the maximum gas concentration (%) to calculate the gas screening value (GSV). A summary of the results is presented in Table 10.

Table 10: Summary of concentrations of CH₄ and CO₂, gas flow rates and screening values in April and May 2018

	CH ₄ (%)	CO ₂ (%)	Gas flow (l/hr)	CH ₄ gas screening value	CO ₂ gas screening value
Minimum	0.1	0.9	0	-	-
Average	0.18	1.19	0.09	0.02	0.11
Maximum	0.2	1.5	0.2	0.04	0.30

From the three rounds of monitoring data, the highest maximum gas screening value is 1.5 for CO₂ and 0.2 for CH₄. Based on BS8485:2015 these correspond with a characteristic gas situation CS 1. To further support this, the GSV values were calculated for each borehole and monitoring period. These show that the CS 1 value (GSV < 0.07) is periodically exceeded but the CS 2 value (GSV > 0.07, < 0.7) is not exceeded.

The ground gas monitoring suggests that potential gas from the infilled ponds or landfill north of the site may be coming onto the site. As the fill materials are over 40 years old, most of the decomposition is likely to already have happened. As the volume of organic material which can decompose is depleted the gas generated also decreases. Throughout the lifetime of any development on the site the concentrations of methane and carbon dioxide are likely to decrease and the risk posed by ground gases will decrease also.

In addition to the gas screening values the gas results have been compared with the occupational exposure limits (OELs) and are presented in Table 11. Based on the comparison the concentrations of ground gases methane and carbon dioxide do not exceed the OEL's.

Table 11: OEL Limits

Determinand	Max Conc. %	Max. Conc. ppm	Occupational Exposure Limit		Comments
			8-hour ppm	15-minute ppm	
Methane	0.2	2000	-	-	Asphx
Carbon Dioxide	1.5	15000	5000	15000	IOELV

Notes: Asphx = Gaseous chemical substance which may not produce significant physiological effects in the exposed employee, but when present in high concentrations will act as a simple asphyxiant.

IOELV = Indicative occupational exposure limit values based on health based limits set under the Chemical Agents Directive 98/24/EC.

Based on the comparison with the OELs the ground gas's methane and carbon dioxide do not exceed the respective thresholds.

It should be noted that this data set is a minimal data set hence the results are indicative. Prior to construction and as part of the detailed design it will be necessary to confirm the conclusions of this assessment by undertaking additional gas monitoring in accordance with best practice.

5.2.4 Updated Potential Pollution Linkages

The results of the GQRA have been compared to the SPR linkages highlighted outlined in Section 3 the following linkages are highlighted for the current and proposed development of the site and are assessed in the following sections:

Table 12: Updated potential pollution linkages base in the GQRA results

Source	Result of GQRA	Modification of the site as part of the standard construction	Change to the S to P to R linkage	Residual risk	Remedial measure required
Made ground contamination - historic channel infill of Avoca River and land reclaimed from the sea, above ground storage tanks and infilled ponds.	Soils exceed human health criteria	Partial excavation and covering with hardstanding or a suitable thickness of cover soil in areas of landscaping	Break pathway / partly remove source	Future work which involves exposure of the soils at the site, including during the construction of the proposed WwTP beneath the slab should consider the risks to site users and appropriate measure implemented to minimise exposure.	These are likely to include good hygiene and suitable personal protective equipment
	Ground gas concentrations are very low	Current buildings contain numerous measures to protect against ground gases	Modify receptor	None	None
	Groundwater under the site is contaminated by the made ground	Covering large areas of the site will reduce infiltration and the contamination reaching the ground water	Break pathway	There will be a need to manage risk from the ground water contamination during the excavation.	This is likely to be done by minimising the groundwater ingress, treating small amounts of groundwater and discharging to the Irish Sea under a Section 4 licence. An options appraisal from managing groundwater during construction is appended to this DSA

Source	Result of GQRA	Modification of the site as part of the standard construction	Change to the S to P to R linkage	Residual risk	Remedial measure required
					(C1Appendix C)
	Groundwater is not considered to impact on nearby surface water quality.	Avoca River and Irish Sea	-	-	-
Phosphogypsum (solid stored above ground and escaped from buried pipes)	The phosphogypsum does not pose a significant risk to site users.	Demolition and construction workers, Irish Water site operators and current site users	-	It will be necessary for to manage the risks to construction workers from dust and enclosed space containing levels of radiation above background..	This is likely to comprise standard measures such as dust suppression and site monitoring.
	Groundwater is not affected by the phosphogypsum	-	-	-	-
Electrical substation and above ground oil storage tanks	No evidence seen of contamination of soils or groundwater	-	-	-	-
Shallow surface contamination of made ground with cordite	Small amounts of NC were recorded. While not toxic the NC is flammable when dry	Partial excavation and covering with hardstanding or a suitable thickness of cover soil in areas of landscaping	Break pathway / partial removal of the source	During construction, it will be necessary to have a watching brief to identify and segregate NC so that is can be stored and disposed of safely	None
Adjacent landfill (ground gases)	Ground gas concentrations are very low	Current buildings contain numerous measures to protect against ground gases	Modify receptor	None	None

A conceptual site model illustrating updated pollutant linkages is presented in Figure 10.

Figure 11 shows a summary of the information collected and the refinement of the CSM from the PSA based on the site information collected as part of the DSA and the way that the construction strategy effectively breaks the SPR linkages.

6 Remediation strategy

The soils on the site present a risk to site users, however the construction of the proposed development will ensure that this risk is minimised, by either removing those contaminated soils from the excavations, or ensuring soils are covered, thus breaking the source-pathway-receptor linkage. This would be undertaken and managed by conventional construction practices:

- Construction of buildings and hardstanding would provide a hard barrier that would prevent exposure.
- In areas of landscaping a c. 300mm depth of made ground would be removed to allow clean topsoil to be placed on the areas of landscaping. The topsoil would be underlain by a geotextile material to limit mixing of the underlying made ground with the topsoil. This would also prevent made ground from being exposed at the surface. Soft landscaping would include planting of low lying vegetation with shallow roots. Where larger plants are proposed e.g. gorse, they would be planted in mounds of clean topsoil to provide them with a greater depth of topsoil and avoid the excavation of any contaminated soils.

7 Summary, Conclusions and Recommendations

7.1 Summary and Conclusions

Arup was commissioned by Irish Water to prepare a detailed assessment of the potential for land contamination at the wastewater treatment plant site (WwTP) which is part of the Arklow WwTP Project.

This report presents a Detailed Site Assessment (DSA) of the current land contamination risks and the potential land contamination risks associated with the use of the site following the proposed development.

In summary, the findings of the PSA are:

“The site is underlain by a substantial thickness of made ground which was placed to reclaim the land from the Avoca River and the Irish Sea between 1845 and 1885, during the re-routing of the outfall of the Avoca River. The site was then used as a chemicals factory, munitions factory and finally a gypsum plasterboard factory.”

Based on the results of the PSA, a ground investigation was designed by Arup in November 2017. The ground investigation was carried out between January and February 2018 by Causeway Geotech Ltd (Causeway).

The ground investigation found that site geology consists generally of made ground overlying two layers of sand and gravel separated by a thin clay layer. Beneath the sand and gravel layers is a thicker clay layer overlying bedrock. Based on the groundwater flow patterns the groundwater in the sand and gravel flows generally to the east but only discharges to the Irish Sea during low tide.

While the River is in hydraulic continuity with the sand and gravel aquifer, the flow within the river is not fed by the groundwater (base flow), and groundwater under the WwTP does not flow discharge into Avoca River.

Contamination was seen in the made ground, and groundwater beneath. In summary, this comprises:

- Made ground, likely to have been derived from mine spoil containing heavy metals (arsenic in one discrete location and lead between approximately 0.4m to 2.5m below ground level across the site);
- An area in the north which is considered to comprise an infilled pond has elevated level of PAH's;
- Nitrocellulose (also referred to as guncotton) at four discrete locations around the site between approximately 0.4m to 2.5m below ground level;
- Asbestos containing materials in four discrete locations around the site; and
- Nickel, zinc, lead, cadmium, barium, phosphate and ammoniacal nitrogen are present in the groundwater beneath the site.

The contamination was assessed against the proposed development and it was found that the modifications that will occur on site as part of the construction of the WwTP will break the exposure pathways or remove part of the source. Hence the is considered that from the proposed WwTP design there is no significant risk to site users from the contamination noted on site.

There are residual risks to construction workers who could be exposed to the soils during the excavation. Measures are proposed to manage these risks.

7.2 Recommendations

A number of residual risk remain following the standard construction of the proposed WwTP. These include:

- During construction of the WwTP it will be necessary to have a watching brief to identify and segregate NC so that it can be stored and disposed of safely;
- There will be a need to manage risk from the ground water contamination during the excavation for the WwTP. This is likely to be done by minimising the groundwater ingress, treating small amounts of groundwater and discharging to the Irish Sea under a Section 4 licence. An options appraisal from managing groundwater during construction is appended to this DSA (Appendix C);
- It will be necessary for to manage the risks to construction workers from dust and enclosed space containing levels of radiation above background. This is likely to comprise standard measures such as dust suppression and site monitoring;

- Future work which involves exposure of the soils at the site, including during the construction of the proposed WwTP beneath the slab should consider the risks to site users and appropriate measure implemented to minimise exposure. These are likely to include good hygiene and suitable personal protective equipment.
- Prior to construction and as part of the detailed design it will be necessary to confirm the conclusions of ground gas risk assessment by undertaking additional gas monitoring in accordance with best practice.

8 References

- [1] Arup, 2018. Arklow Waste Water Treatment Plant, Preliminary Site Assessment. Report reference 247825-00_PSA_31-07-2017
- [2] Environmental Protection Agency, 2013. Management of Contaminated Land & Groundwater at EPA licensed sites. ISBN: 978-1-84095-511-8. Available at:
<https://www.epa.ie/pubs/advice/waste/contaminatedland/contaminatedland/>
- [3] Causeway Geotech, 2018. Arklow WwTP Land – Ground Investigation. Report No. 17-1455.
- [4] British Standards Institute, 2015. Code of practice for site investigation. BS5930:2015.
- [5] British Standards Institute, 2013. Investigation of potentially contaminated sites. Code of practice. BS10175:2011+A1:2013.
- [6] British Standards Institute, 2009. Water Quality – Sampling. Part 11: Guidance on sampling of groundwaters. Code of practice. BS ISO 5667-11:2009
- [7] CIRIA, 2007, Assessing risks posed by hazardous ground gases to buildings. CIRIA C665.
- [8] British Standards Institute, 2013. Guidance on investigations for ground gas. Permanent gases and Volatile Organic Compounds (VOCs). Code of Practice: BS 8576:2013
- [9] General requirements for the competence of testing and calibration laboratories. ISO 17025:2005
- [10] Soil Quality, 2011. Soil Quality for Environmental Health, Indicators, Total Organic Carbon. Available at:
http://www.soilquality.org/indicators/total_organic_carbon.html
- [11] BAE Systems Environmental, 2005. Collation of Toxicological and Physiochemical Data for Nitroglycerine. Report Ref: A0469-00-R6-A.
- [12] BAE Systems Environmental, 2005. Collation of Toxicological and Physiochemical Data for Nitrocellulose. Report Ref: 1.
- [13] Radiological Protection Act, 1991 (Ionising Radiation) Order 2000. S.I. No. 125/2000. Available at:
<http://www.irishstatutebook.ie/eli/2000/si/125/made/en/print#article1>
- [14] CLR-13, 2006. RCLEA, Using RCLEA – the Radioactively Contaminated Land Exposure Assessment Methodology. Draft. Available

at: <https://www.ihsti.com/temping/5C41C95-PICIS888614800280642.pdf>

- [15] Statutory Instruments (S.I. No. 386 of 2015) European Union Environmental Objectives (Surface Waters) (Amendment) Regulations 2015
- [16] Statutory Instruments (S.I. No. 272 of 2009) European Communities Environmental Objectives (Surface Waters) Regulations 2009
- [17] Statutory Instruments (S.I. No. 366 of 2016) European Union Environmental Objectives (Groundwater) (Amendment) Regulations 2016
- [18] Environmental Protection Agency, 2003. Towards Setting Guideline Values for the Protection of Groundwater in Ireland. Available: http://www.epa.ie/pubs/advice/water/ground/EPA_proposed_interim_values_protection_groundwater_guidelines.pdf
- [19] British Standards Institute, 2015. Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings (incorporating corrigendum No. 1). BS8485:2015.
- [20] Health and Safety Authority, 2018. 2018 Code of Practice for the Chemical Agents Regulations. The Metropolitan Building, James Joyce Street, Dublin 1. Available at: https://www.hsa.ie/eng/Publications_and_Forms/Publications/Chemical_and_Hazardous_Substances/Chemical_Agents_COP_2018.pdf
- [21] Arup, 2016. Arklow Sewerage Scheme – Process Design Review Report – Wastewater Treatment Plant. Report No. 247825-00 DRR-TP
- [22] Irish Water, 2016. Particular Specification for LOT 1 – Intrusive Site Investigation Works. Arklow Sewerage Scheme Land Based Site Investigation. Invitation to Tender Document.
- [23] Environmental Protection Agency, 2007. Code of Practice Environmental Risk Assessment for unregulated waste disposal sites
- [24] Environmental Protection Agency Act, 1992. Number 7 of 1992, Irish Statute Book. Available from: <http://www.irishstatutebook.ie/eli/1992/act/7/enacted/en/print#sec2>
- [25] Soil Quality for Environmental Health, 2011. Indicators, Total Organic Carbon. Available at: http://www.soilquality.org/indicators/total_organic_carbon.html. Accessed on 11 June 2018.
- [26] RPS, 2005. Environmental Soil and Groundwater Investigation Report. Ferrybank, Arklow EIS. Document No. MDC0186

- [27] Arup, 2007. Former IGB Site: Closure Restoration and Aftercare Management Plan Draft 1.
- [28] Minerex Geophysics Limited, 2016. Geophysical Survey. Site at Ferrybank, Arklow County Wicklow. Report Status: Draft. MGX File Ref: 6049d-005.doc. Confidential Report to Arup
- [29] Radiological Protection Institute of Ireland, 1994. Report to Ove Arup & Partners Ireland no Analysis of Samples for the Arklow By-pass Project Taken on the 27th of April 1994.
- [30] British Standards Institute, 2013. Investigation of potentially contaminated sites. Code of practice. BS10175:2011+A1:2013.
- [31] British Standards Institute, 2013. Guidance on investigations for ground gas – Permanent gases and Volatile Organic Compounds (VOCs)
- [32] UKAS Testing, 2017. Schedule of Accreditation issued by United Kingdom Accreditation Service. Chemtest Ltd, Issue No: 091.
- [33] Natura 2000, 2000. Natura 200 – Standard Data Form for Special Protection Areas (SPA), Proposed Sites for Community Importance pSCI, Sites of Community Importance (SCI) and for Special Areas of Conservation for South Dublin Bay SAC. Site IE0000210.
- [34] CL:AIRE, 2014. SP1010 – Development of Category 4 Screening Levels for Assessment of Land Affected by Contamination Final Project Report (Revision 2).
- [35] Nathaniel, C.P.; McCaffrey, C.; Gillett, A.G.; Ogden, R.C. & Nathaniel, J.F., 2015. The LQM/CIEH S4ULs for Human Health Risk Assessment. Land Quality Press, Nottingham.
- [36] Health and Safety Authority, 2016. Code of Practice for the chemical reagent regulations
- [37] United States Environmental Protection Agency, WHEN. Soil Guideline Values.

Figures

Figure 1: Site Location

Figure 2: Site Investigation Locations

Figure 3: Ground Gas, Groundwater and Surface Water Monitoring Locations

Figure 4: Location of Asbestos in the Made Ground

Figure 5: Location of Gun Cotton (Nitrocellulose) Observed in the Soil at the WwTP

Figure 6: Radioactive Materials

Figure 7: Groundwater and Surface Water Hydrograph

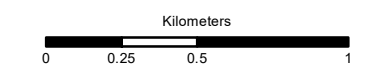
Figure 8: Groundwater Flow Direction – Low Tide

Figure 9: Groundwater Flow Direction – High Tide

Figure 10: Conceptual Site Model



- Legend**
- ▶ Generalised Groundwater Flow Direction
 - WwTP Site Boundary
 - Proposed Development Planning Boundary
 - Arklow WwTP Site 2km Buffer



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Client
Irish Water

Job Title
Wastewater Treatment Plant for the Arklow Wastewater Treatment Plant Project

Site location	
Scale at A3	1:25,000
Job No 247825-00	Drawing Status For Information
Drawing No 001	Issue 11

D1	2017-12-19	LM	CN	EW
Issue	Date	By	Chkd	Appd



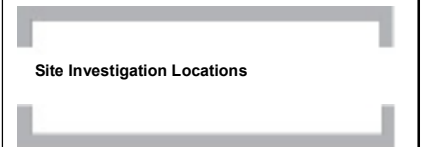
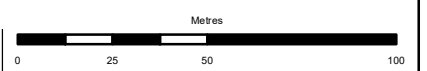
Legend

- Proposed Development Planning Boundary
- WwTP Site boundary
- Site Investigation Locations**
- + Borehole
- x Trial Pit
- Area of Radiological Survey
- 2D-Resistivity Profile
- Seismic Refraction/MASW Profile

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Job Title				
Arklow WWTP				
D1	2018-08-22	LM	CN	CN
Issue	Date	By	Chkd	Appd



Scale at A4
1:2,000

Job No 247825-00	Drawing Status For Information
Drawing No 002	Issue I1



Legend

- + Ground Gas and Groundwater Monitoring
- + Groundwater Monitoring
- ▲ Surface Water Sampling Locations
- Proposed Development Planning Boundary
- WwTP Site boundary

ARUP

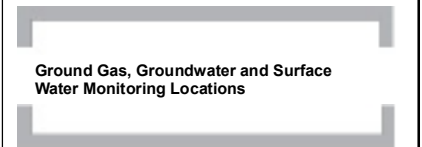
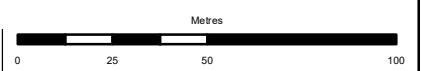
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Client
Irish Water

Job Title
Arklow WWTP

D1	2018-08-22	LM	CN	CN
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Issue	Date	By	Chkd	Appd



Scale at A4
1:2,000

Job No 247825-00	Drawing Status For Information
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Drawing No 003	Issue I1
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Legend

- Soil Exceedances
- Proposed Development Planning Boundary
- Proposed Buildings
- WwTP Site Boundary

ARUP

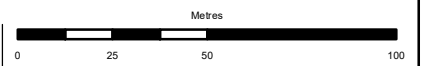
50 Ringsend Road
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 Tel +353 (0)1 233 4455 Fax +353 (0)1 668 3169
 www.arup.com

Client
Irish Water

Job Title
Arklow WWTP

F1	2018-08-24	LM	CN	CN
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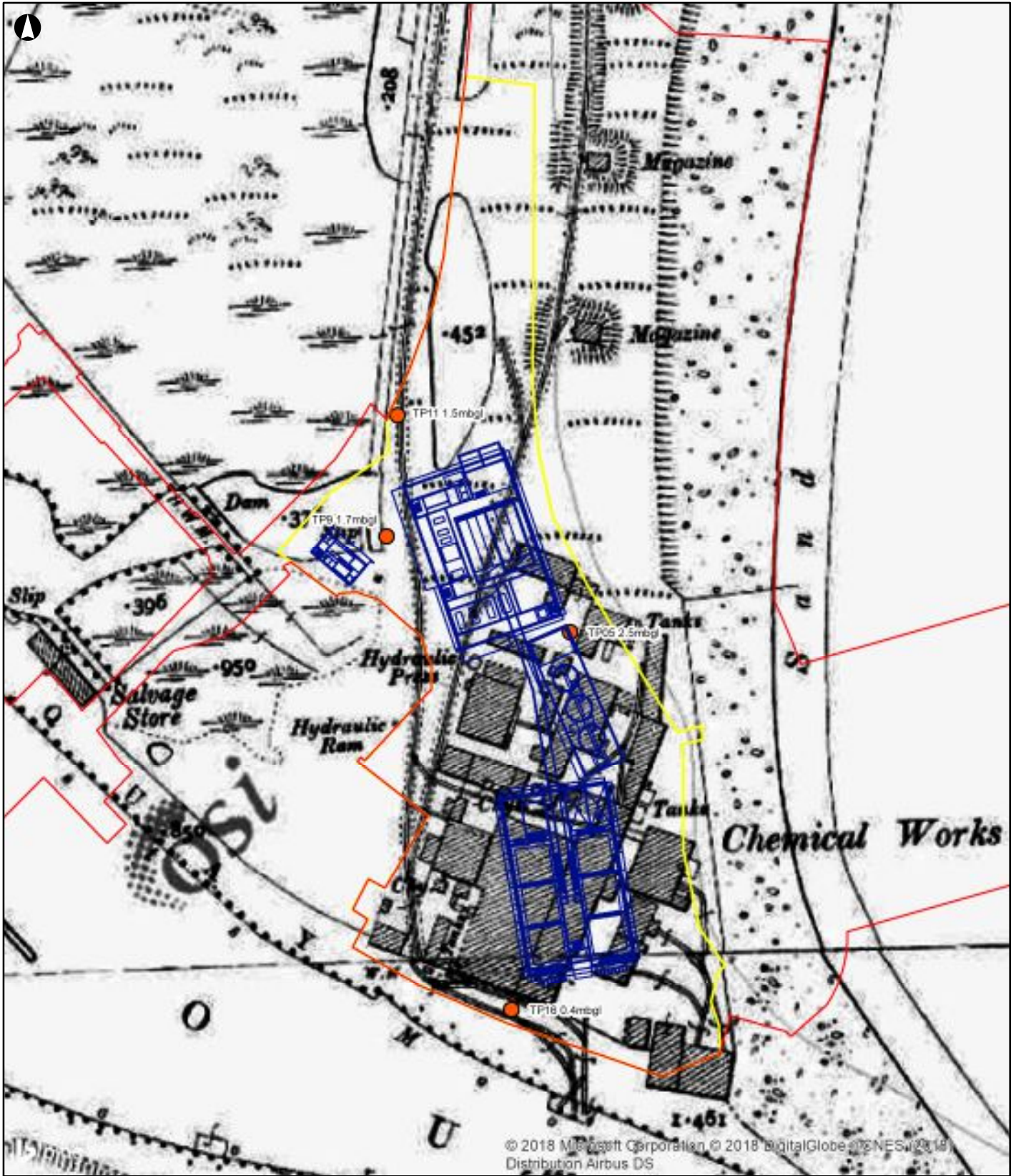
Issue	Date	By	Chkd	Appd



Scale at A4
1:2,000

Job No 247825-00	Drawing Status For Information
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Drawing No 004	Issue I1
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Legend

- Proposed Development Planning Boundary
- Proposed Buildings
- WwTP Site Boundary
- TP16 0.4mbgl Location ID and depth of which sample was taken

Concentrations reported by laboratory for all samples is Nitrocellulose >5000mg/kg

ARUP

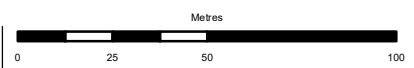
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Client
Irish Water

Job Title
Arklow WWTP

F1	2018-08-24	LM	CN	CN
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Issue	Date	By	Chkd	Appd
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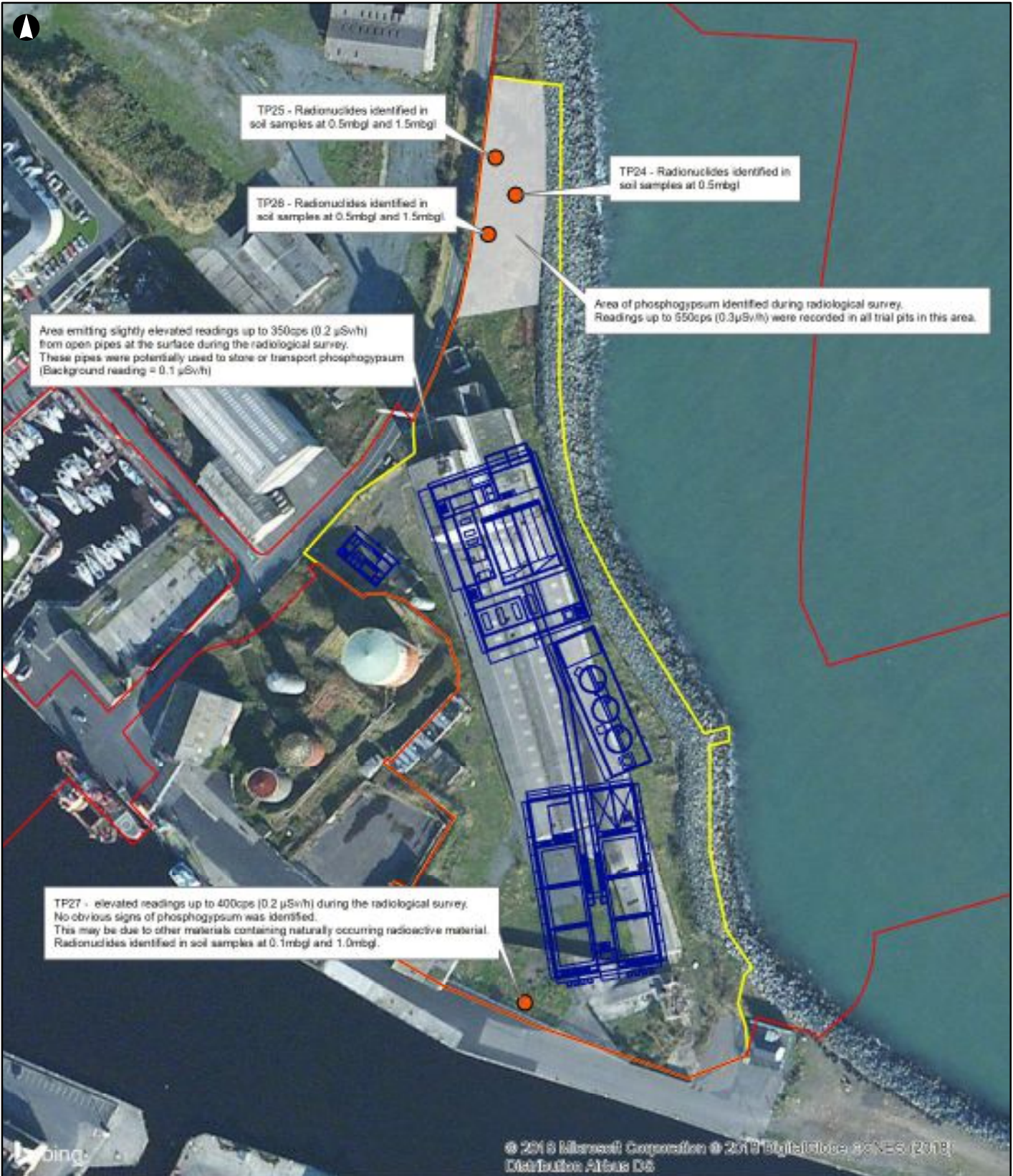


Locations of gun cotton (Nitrocellulose) observed in the soil at the WwTP

Scale at A4
1:2,000

Job No 247825-00	Drawing Status For Information
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Drawing No 005	Issue 11
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Legend

- Trial pit containing radionuclides
- Proposed Development Planning Boundary
- Proposed Buildings
- WwTP Site Boundary

ARUP

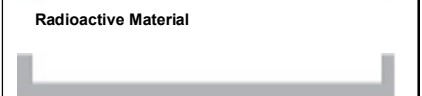
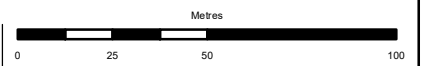
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Client
Irish Water

Job Title
Arklow WWTP

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Issue	Date	By	Chkd	Appd

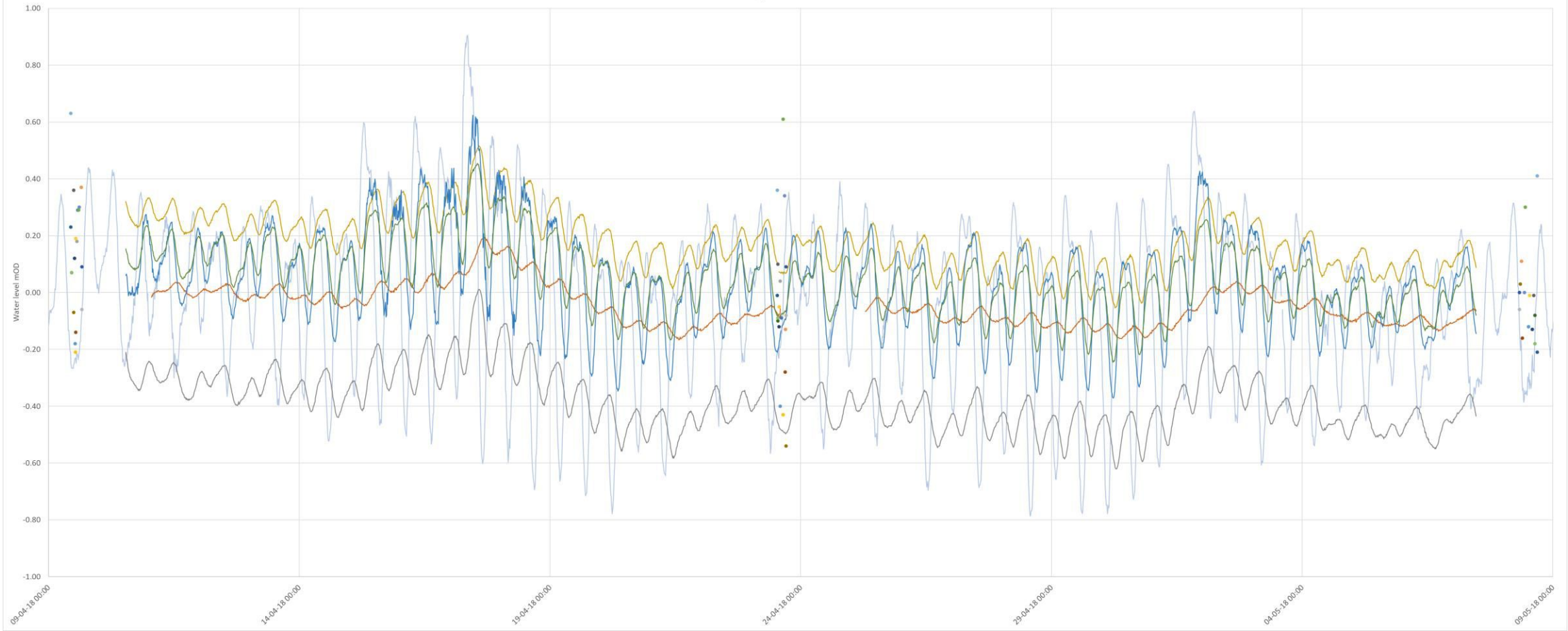


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Job No 247825-00	Drawing Status For Information
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Drawing No 006	Issue I1
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Groundwater Level Dips vs Tide Level in Arklow Harbour



Legend

- Arklow Harbour Tidal Variation
- BH02C
- BH03
- BH08
- BH18
- BH20
- BH01
- BH02C
- BH03
- BH04
- BH05
- BH06A
- BH07B
- BH08
- BH08
- BH09
- BH10B - Aquifer
- BH10B - Made Ground
- BH11 - Aquifer
- BH11 - Made Ground
- BH17
- BH18
- BH19 - Aquifer
- BH19 - Made Ground
- BH20

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Issue	Date	By	Chkd	Appd

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Client
Irish Water

Job Title
Arklow WwTP Detailed Site Assessment

Groundwater and Tide Levels
April to May 2018

Job No
247859-00

Drawing Status
For Information

Drawing No
007

Issue
I1



Legend

- + Groundwater Monitoring
- ▲ Surface Water Sampling Locations
- Proposed Development Planning Boundary
- WwTP Site Boundary
- ➔ Indicative direction of groundwater flow
- Indicative groundwater contour

Low tide data presented was recorded at 04:00 on 30/04/2018

ARUP

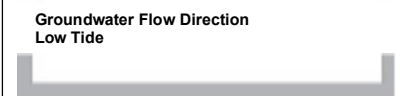
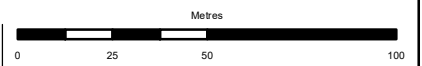
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Client
Irish Water

Job Title
Arklow WWTP

D2	2018-08-23	LM	CN	CN
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Issue	Date	By	Chkd	Appd



Scale at A4
1:2,000

Job No 247825-00	Drawing Status For Information
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Drawing No 008	Issue I1
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Legend

- + Groundwater Monitoring
- ▲ Surface Water Sampling Locations
- Proposed Development Planning Boundary
- WwTP Site Boundary
- ➔ Indicative direction of groundwater flow
- Indicative groundwater contour

High tide data presented was recorded at 11:00 on 17/04/2018

ARUP

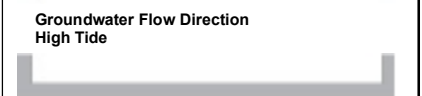
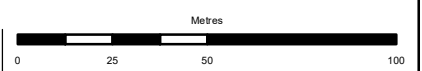
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Client
Irish Water

Job Title
Arklow WWTP

D2	2018-08-23	LM	CN	CN
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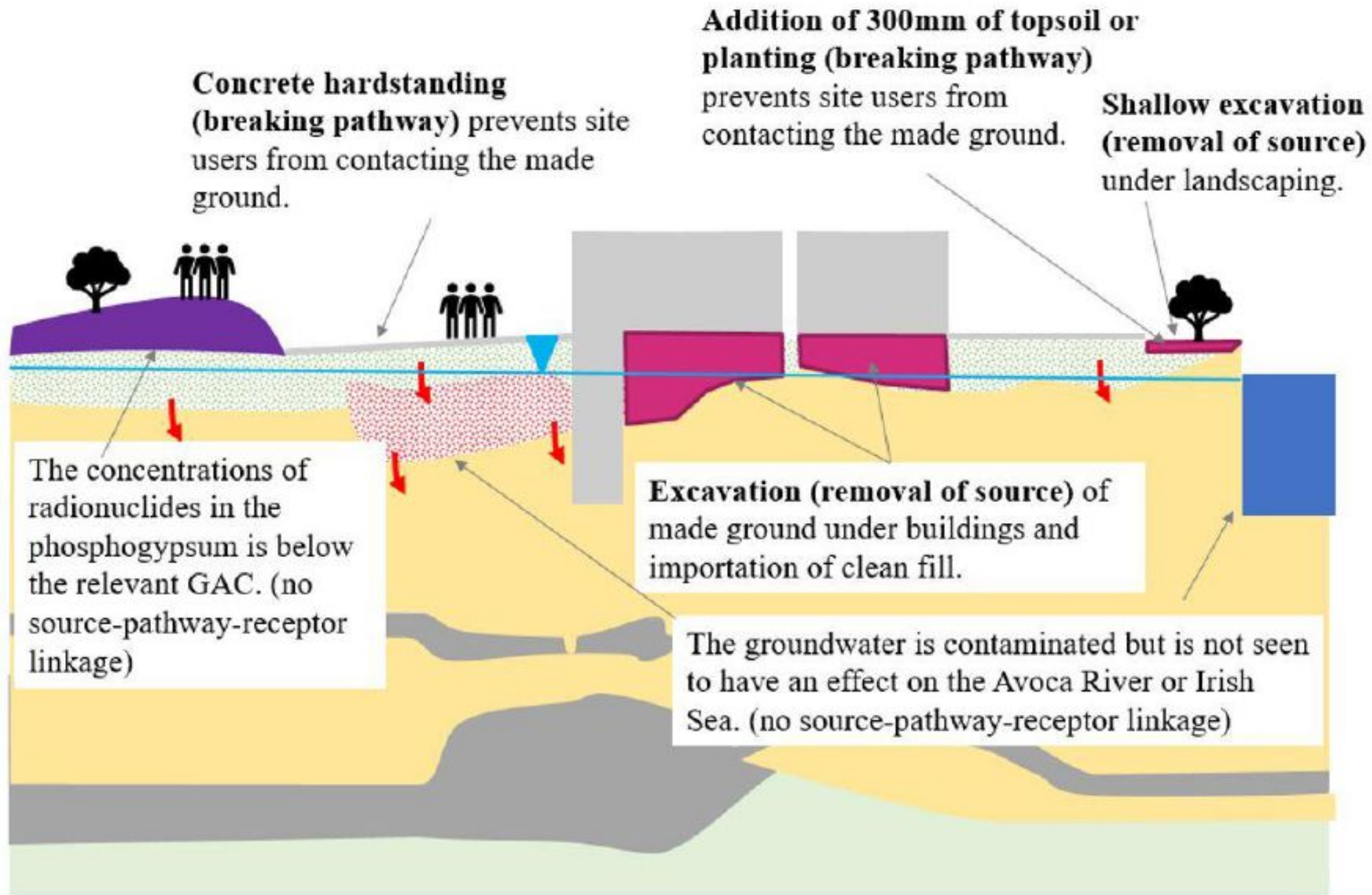
Issue	Date	By	Chkd	Appd



Scale at A4
1:2,000

Job No 247825-00	Drawing Status For Information
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Drawing No 009	Issue I1
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- Legend**
- Phosphogypsum
 - Brown Sand and Gravel (Made Ground)
 - Pond Infill (Made Ground)
 - Sand and Gravel
 - Clay
 - Bedrock
 - Imported Clean Soil

U	2011-09-28	DN	TR	TR
Issue	Date	By	Checked	Approved

ARUP

Client
Irish Water

Job Title
Arklow WWT, DSA

Conceptual Site Model - WwTP

Scale: 1:100
NTS

Job No. 247859-00	Drawing Status For Information
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Appendix A

Minerex Geophysical Ltd
Geophysical Survey Report
(March 2016)

A1 Minerex Geophysical Ltd Geophysical Survey Report (March 2016)

Site at Ferrybank, Arklow
County Wicklow
Geophysical Survey

Report Status: Draft

MGX Project Number:6049

MGX File Ref: 6049d-005.doc

14th March 2016

Confidential Report To:

Arup
Arklow SS
H5 Centrepoint Business Park
Oak Road
Dublin 12

**Report submitted by :
Minerex Geophysics Limited**

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Issued by:

Ruth Jackson (Senior Geophysicist)

Hartmut Krahn (Senior Geophysicist)



Subsurface Geophysical Investigations

EXECUTIVE SUMMARY

1. Minerex Geophysics Ltd. (MGX) carried out a geophysical survey consisting of 2D-Resistivity, seismic refraction (p-wave) and MASW (s-wave) surveying for the preliminary ground investigation at a site at Ferrybank, Arklow, Co. Wicklow.
2. The site is a former wallboard factory and the site is currently for sale. The client is considering to purchase the site and to use parts of the construction of a waste water treatment plant.
3. The main objectives of the survey were to determine ground conditions, estimate the depth to rock and overburden thickness and to determine the strength of subsurface materials.
4. The survey was carried out along the two long sides of the existing long factory building.
5. The resistivity survey showed that the ground under the site has saline conditions and that the ground is therefore corrosive.
6. The shallow overburden is made up of topsoil, fill material and made ground consisting predominantly of blocks and gravel.
7. The deeper overburden (Layer 2 in the seismic interpretation) has a firm stiffness and is interpreted as sandy and gravelly overburden (marine sediments).
8. Layer 3 interpreted from the seismic refraction as weathered rock or very compact overburden has a high stiffness or compaction and seems suitable to carry piled foundations for structures with heavy loads. This layer occurs at a depth of approx. 10m at S1 and 15 to 20m on S2.
9. The MASW method determined shear moduli between 71 and 336 MPa for depths of 1.1 to 10.6 m bgl.
10. Future ground investigation should consist of trial pits for the overburden and of rotary coring (Geobore-S method) to investigate the layer 3.

CONTENTS

1. INTRODUCTION	1
1.1 Background.....	1
1.2 Objectives.....	1
1.3 Site Description.....	1
1.4 Geology.....	1
1.5 Report.....	2
2. GEOPHYSICAL SURVEY	3
2.1 Methodology.....	3
2.2 2D-Resistivity.....	3
2.3 Seismic Refraction.....	3
2.4 MASW (Multichannel Analysis of Surface Waves).....	4
2.5 Site Work.....	4
3. RESULTS AND INTERPRETATION.....	5
3.1 2D-Resistivity Models.....	5
3.2 Seismic Refraction Models.....	5
3.3 Interpretation of Seismic Refraction.....	6
3.4 Results for MASW Survey.....	7
4. CONCLUSIONS AND RECOMMENDATIONS.....	8
5. REFERENCES.....	9

List of Tables, Maps and Figures:

Title	Pages	Document Reference
Table 1: Summary of Results and Interpretation	In text	In text
Table 2: MASW S-Wave Velocity and Shear Modulus	1 x A4	6049d_Tab2.xls
Map 1: Geophysical Survey Location Map	1 x A3	6049d_FigsMaps.dwg
Figure 1: Models of Geophysical Survey	1 x A3	6049d_MapsFigs.dwg
Figure 2: Interpretation of Geophysical Survey	1 x A3	6049d_MapsFigs.dwg
Figure 3: MASW Results	1 x A3	6049d_MapsFigs.dwg

1. INTRODUCTION

1.1 Background

Minerex Geophysics Ltd. (MGX) carried out a geophysical survey at the site of a disused wallboard factory at Ferrybank in Arklow, Co. Wicklow. The site is currently for sale and the client is considering to purchase the site and construct a waste water treatment plant. The survey consisted 2D-Resistivity, seismic refraction (p-wave) and MASW (s-wave) measurements. The survey was commissioned by Arup acting on behalf of Irish Water and Wicklow County Council.

The survey employed various geophysical methods that complement each other and improve the interpretation. The role of geophysics as a non-destructive fast method is to generate an initial ground model that can be later improved by direct ground investigations.

1.2 Objectives

The main objectives of the geophysical survey were:

- To determine the ground conditions under the site
- To determine the depth to rock and overburden thickness
- To estimate the strength/stiffness/compaction of overburden materials and the quality of rock
- To detect lateral changes within the geological layers

1.3 Site Description

The site is located at Ferrybank in Arklow. The site is dominated by the long building of the disused factory. The site is close to a sea wall made from large blocks. The ground is generally very flat with elevations of 2.3 to 2.8 m OD. At the northern end of profile R1 the ground is uneven and large blocks of reinforced concrete are visible.

1.4 Geology

The shallow overburden geology consists of made ground and fill. Historical maps on the Ordnance Survey of Ireland webpage indicate that the Avoca River was meandering under the factory in historical times. The Avoca River is now flowing straight to the sea south of the site under investigation.

The deeper overburden is likely to consist of marine sediments like silt, sand and gravels.

The bedrock geological map of Carlow-Wexford (GSI, 1995) indicates that the southern survey area is underlain by the Maulin Formation described as dark blue-grey Slate, Phyllite and Schist. The northern part is underlain by the Kilmacrea formation described as dark grey slate and minor pale grey sandstone.

1.5 Report

This report includes the results and interpretation of the geophysical survey. Maps, figures and tables are included to illustrate the results of the survey. More detailed descriptions of geophysical methods and measurements can be found in GSEG (2002), Milsom (1989) and Reynolds (1997).

The client provided maps of the site and the digital version was used as the background map in this report. Elevations were surveyed on site and are used in the vertical sections.

The interpretative nature and the non-invasive survey methods must be taken into account when considering the results of this survey and Minerex Geophysics Limited, while using appropriate practice to execute, interpret and present the data, give no guarantees in relation to the existing subsurface.

2. GEOPHYSICAL SURVEY

2.1 Methodology

The methodology consisted of using 2D-Resistivity Profiles, Seismic Refraction and MASW profiles. The survey locations are indicated on Map 1.

All geophysical surveys are acquired, processed and reported in accordance with British Standards BS 5930:1999 +A2:2010 'Code of Practice for Site Investigations'.

2.2 2D-Resistivity

Two 2D-Resistivity profiles were surveyed with electrode spacing of 5m, up to 64 electrodes per set-up and a length of 315m for R1 and 205 m for R2. The readings were taken with a Tigre Resistivity Meter, Imager Cables, stainless steel electrodes, laptop and ImagerPro acquisition software. The survey was done along green strips of ground to avoid hardstanding surfaces.

During 2D-Resistivity surveying data is acquired in the form of linear profiles using a suite of metal electrodes. A current is injected into the ground via a pair of electrodes while a potential difference is measured across a second pair of electrodes. This allows for the recording of the apparent resistivity in a two-dimensional arrangement below the profile. The data is inverted after the survey to obtain a model of subsurface resistivities. The generated model resistivity values and their spatial distribution can then be related to typical values for different geological materials.

2.3 Seismic Refraction

The seismic survey consisted of p-wave seismic refraction profiling at the locations shown on Map 1. Each of the profiles consisted of 24 geophones with 3 m spacing, resulting in lengths of 69m for S1 and 63m for S2. The recording equipment consisted of a 24 Channel GEOMETRICS ES-3000 engineering seismograph with 4.5 Hz vertical geophones. The seismic energy source consisted of a hammer and plate. A zero delay trigger was used to start the recording. Seven shot points per p-wave profile were used.

In the seismic refraction survey method a p-wave is generated by a source at the surface resulting in energy travelling through surface layers directly and along boundaries between layers of differing seismic wave velocities. Processing of the seismic data allows geological layer thicknesses and boundaries to be established.

Seismic Refraction generally determines the depth to horizontal or near horizontal layers where the compaction/strength/rock quality changes with an accuracy of 10 – 20% of depth to that layer. Where low velocity layers or shadow zones are present (e.g. below solid ground surface) or where layers dip with more than 20 degrees angle the accuracy becomes much less.

In areas with thick concrete, tarmac or blocks a low velocity layer exists for the seismic waves below the solid surface layer. This makes it less certain or impossible to pick first breaks from geophones near the source and therefore no velocity determination for the shallow subsurface is possible. This results in larger deviations in the modelling and borehole results are required for a final calibration of the results.

2.4 MASW (Multichannel Analysis of Surface Waves)

The seismic shear wave velocity was determined by active MASW surveying. MASW (Multi-Channel Analysis of Surface Waves) determines the bulk seismic shear wave velocity versus depth. The velocities are used to determine the small strain shear modulus.

The MASW method was acquired along with the seismic refraction survey though the shots were done individually with a larger time window. The recording equipment consisted of a 24 Channel GEOMETRICS ES-3000 engineering seismograph with 4.5 Hz vertical geophones. The seismic energy source consisted of a hammer and plate. A zero delay trigger was used to start the recording. The shot points were located at the ends of the profiles.

Many constrains exist for the MASW method and the main factors on this site that affect the methods are strong vertical velocity gradients and changing velocity structure and layer thicknesses along the profiles.

2.5 Site Work

The data acquisition was carried out on the 10th of March 2016. The weather conditions were fair throughout the acquisition period. Health and safety standards were adhered to at all times.

The locations and elevations were surveyed with a TRIMBLE RTK-GPS to accuracy < 0.05m.

3. RESULTS AND INTERPRETATION

The interpretation of geophysical data was carried out utilising the known response of geophysical measurements, typical physical parameters for subsurface features that may underlay the site, and the experience of the authors.

3.1 2D-Resistivity Models

The 2D-Resistivity data was positioned and inverted with the RES2DINV inversion package. Overlapping and roll-along profiles were concatenated for a joint inversion. The programme uses a smoothness constrained least-squares inversion method to produce a 2D model of the subsurface model resistivities from the recorded apparent resistivity values. Three variations of the least squares method are available and for this project the Jacobian Matrix was recalculated for the first three iterations, then a Quasi-Newton approximation was used for subsequent iterations. The resulting models were colour contoured with the same resistivity scale for all profiles and they are displayed as cross sections (Figure 1).

The resistivities cover a large range typical for materials from dry made ground and rock or gravel fill to saline ground conditions.

Very low resistivity values (<20 Ohmm (orange to red colours) indicate saline ground conditions that are caused by saline sea water intruding under the site. These intrusions were expected before the survey. The resistivity proved these saline conditions to be true and therefore the ground under the site has to be treated as corrosive. This means that future possible structures, foundations and underground pipes/cables have to be rated to withstand corrosive conditions. This can be a cost factor for a proposed development.

The shallow ground to a few meters of depth is characterised by high resistivities (> 80 Ohmm) indicating fill and made ground made mainly from rock or gravel fill. There does not seem to be a large amount of clay in the fill material.

The saline ground conditions do not make it possible to interpret the data further other than to state that the ground is intruded by saline water. Therefore the ground must be permeable for water and it could be made up from weathered rock or sandy gravelly overburden. The purpose of the resistivity survey was to establish the amount of saline ground and to check if the ground is corrosive.

3.2 Seismic Refraction Models

The seismic refraction data was positioned and processed with the SEISIMAGER software package to give a layered model of the subsurface. The numbers of layers has been determined by analysing the seismic traces and four layers were used in the models. All seismic profiles were subject to a standardised processing sequence which consisted of a topographic correction which was based on integrated elevation data, first break picking, tomographic inversion, travel-time computation via ray-tracing and velocity modelling. Residual deviations of < 2 msec RMS have been obtained for each profile. Following each processing stage QC procedures were adhered to. The resulting layer boundaries are shown as thick lines

overlaid on the 2D-Resistivity cross sections (Figure 1). The average seismic velocities obtained within the layers are annotated on the sections as bold black numbers.

The p-wave seismic velocity is closely linked to the density of subsurface materials and to parameters like compaction, stiffness, strength and rock quality. The higher the density of some subsurface materials the higher the seismic velocity. Similarly for the other parameters it is generally valid that a stronger material will have a higher seismic velocity. For rock the seismic velocity is higher when the rock is stronger and less weathered. If the rock is more weathered broken fractured or fissured then the seismic velocity will be reduced compared to that of intact fresh rock.

Because of the above relation the seismic refraction method and seismic velocities are suitable to investigate ground where the layers get denser, more compacted and stronger with depth. A disadvantage is that some materials have the same seismic velocity: A very stiff or very dense highly consolidated overburden and a weathered rock can have the same seismic velocity range (as is the case in the layer 3 below).

Layer 1a has a thickness of 1 – 2 m and seismic velocities of 270 - 300 m/s. This overburden is interpreted as topsoil and soil with a soft or loose stiffness or compaction.

Layer 1b was modelled with a velocity range of 600 – 1100 m/s and a thickness of 6 – 9 m. The velocity and the hard ground on site indicate fill material and made ground.

Layer 2 velocities of 1500 – 1700 m/s indicate predominantly overburden which is saturated by water.

Layer 3 velocities of 2800 – 2900 m/s indicate a weathered rock or very compact overburden. The elevation of the top of this layer varies between – 5 to – 7 mOD on S1 and around -15 mOD on S2.

3.3 Interpretation of Seismic Refraction

Table 1 summarises the interpretation. The stiffness/compaction and the rock strength/quality have been estimated from the seismic velocity. Interpreted cross sections are shown in Figure 2. The interpretation has been made from and for the seismic refraction profiles only.

Table 1: Summary of Results and Interpretation

Layer	General Seismic Velocity Range (m/sec)	Stiffness/ Compaction or Rock Strength/ Quality	Interpretation
1a	270 – 300	Soft or loose	Topsoil
1b	600 - 1100	Dense	Fill Material/Made Ground
2	1500 - 1700	Firm or dense	Overburden
3	2800 - 2900	Fair Rock or very dense Overburden	Weathered Rock or very compact Overburden

3.4 Results for MASW Survey

The MASW profiles were positioned, processed, analysed and modelled with the SEISIMAGER/SW software package. The objective is to obtain a profile of shear wave velocity versus depth and to calculate the small strain shear modulus G_{max} from the shear wave velocities. Two opposed shot points from each profile set-up were acquired and were analysed. One end shot for each profile showed a good dispersion curve while the other did not show a useful curve. This can happen on build up sites and has been observed before on other sites. The good shots were used for further processing:

Following processing steps are done to achieve this:

1. Edit the shot point geometry and display the shot points for each profile
2. Edit traces and/or apply filters to improve the shot record for the next step
3. A dispersion curve (phase velocity versus frequency plot or dispersion image) is computed
4. For each shot the maximum amplitude at each frequency of the dispersion image is selected and then the picks for the dispersion curve are truncated (frequency gate), smoothed and brought forward into the modelling process
5. An initial model of shear-wave velocity versus depth V_s is computed
6. An inversion is carried out to create the final V_s curve (Shear wave versus depth). The valid depth range is noted and the data saved in a file
7. For stable repeatable results the shear wave velocity versus depth is extracted and the depth range covered by the real survey data is then listed in Table 2.
8. The small strain shear modulus (also named G_{max}) for each shot point and depth is computed by using a density of 2000kg/m^3 typical for consolidated overburden (Eq. 1)

$$\text{(Eq. 1)} \quad G = V_s^2 * \rho * 10^{-6}$$

where G = Shear Modulus (MPa)

V_s = Seismic Shear Wave Velocity (m/s)

ρ = Density (kg/m^3)

The results are tabulated in Table 2 and the models of the shear wave velocity versus depth are shown on Figure 3.

Shear modules between 71 and 336 MPa have been derived for depths of 1.1 to 10.6m.

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made:

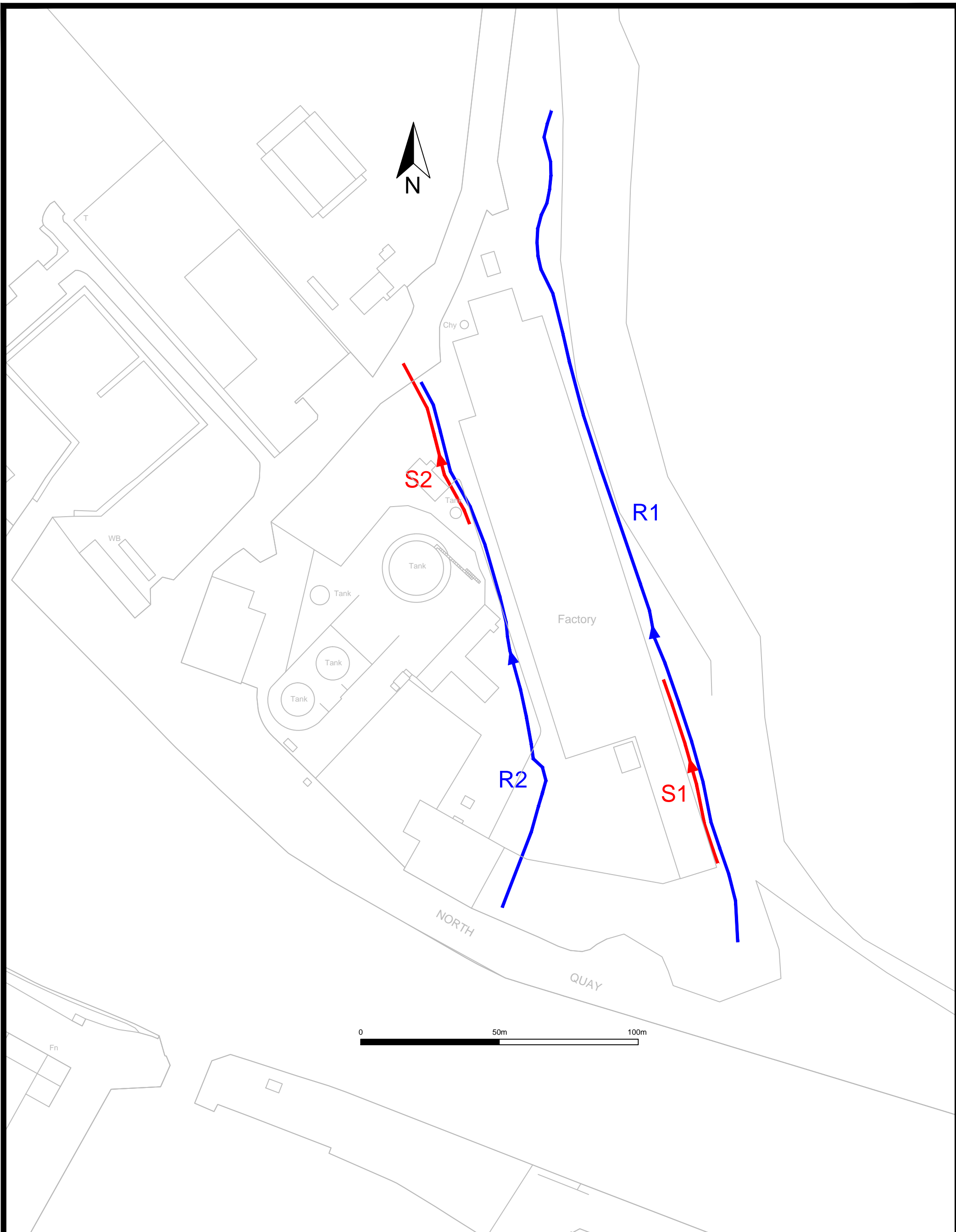
- The geophysical survey carried out at the Ferrybank site showed the following results:
- The resistivity survey showed that the ground under the site has saline conditions and that the ground is therefore corrosive. This will have an impact in the design of future structures, foundations and underground pipes/cables.
- The shallow overburden is made up of topsoil, fill material and made ground. Historical maps indicate that the ground has been filled over a previous river bed of the Avoca River. When grounding electrodes is was noted that the ground is very rocky and stony along the factory building. The seismic velocities on profile S1 at the south-eastern end of the site indicate solid fill layers that could be made up from blocks and gravel.
- The deeper overburden (Layer 2 in the seismic interpretation) has a firm stiffness as derived from the MASW results. It is likely sandy and gravelly overburden that are marine sediments and they are saturated as indicated by the p-wave velocity.
- Layer 3 interpreted from the seismic refraction as weathered rock or very compact overburden has a high stiffness or compaction and seems suitable to carry piled foundations for structures with heavy loads. This layer occurs at a depth of approx. 10m at S1 and 15 to 20m on S2. This depth does not seem too bad for a coastal site where the marine sediments can reach thicknesses of several 10 m.
- The MASW method determined shear moduli between 71 and 336 MPa for depths of 1.1 to 10.6 m bgl.
- The seismic p-wave velocities for layer 3 allow a rough estimate of shear moduli of 2000 – 4500 MPa for this layer.
- Future ground investigation should consist of trial pits for the overburden and of rotary coring (Geobore-S method) to investigate the layer 3. Cable percussive borehole would be likely to refuse at a shallow depth.
- The recommendations above should not preclude any other site investigation that may be carried out based on geological, geotechnical or engineering considerations.

5. REFERENCES

1. **GSEG 2002.** Geophysics in Engineering Investigations. Geological Society Engineering Geology Special Publication 19, London, 2002.
2. **GSI, 1995.** Geology of Carlow-Wexford. Geological Survey of Ireland 1995.
3. **Milsom, 1989.** Field Geophysics. John Wiley and Sons.
4. **Reynolds, 1997.** An Introduction to Applied and Environmental Geophysics. John Wiley and Son.

Table 2: MASW S-Wave Velocity and Shear Modulus



MASW Profile	Interpretation/Comment (Note: The density used for computing the Shear Modulus is 2000 kg/m ³)	Depth (m)	S-Wave Velocity (m/s)	Gmax - Shear Modulus in MPa
S1	The dispersion image shows a well defined curve for the depth range 2.3 to 10.6 m bgl.	2.3	222.0	98
		3.0	236.5	111
		3.8	243.8	118
		4.6	271.7	147
		5.5	302.1	182
		6.4	306.3	187
		7.4	340.3	231
		8.4	348.1	242
		9.5	356.6	254
		10.6	410.1	336
S2	The dispersion image shows a well defined curve for the depth range 1.7 to 10.6 m bgl.	1.1	188.9	71
		1.7	201.2	80
		2.3	220.0	96
		3.0	236.3	111
		3.8	246.3	121
		4.6	263.1	138
		5.5	263.4	138
		6.4	281.1	158
		7.4	292.2	170
		8.4	295.1	174
		9.5	309.7	191
		10.6	313.4	196



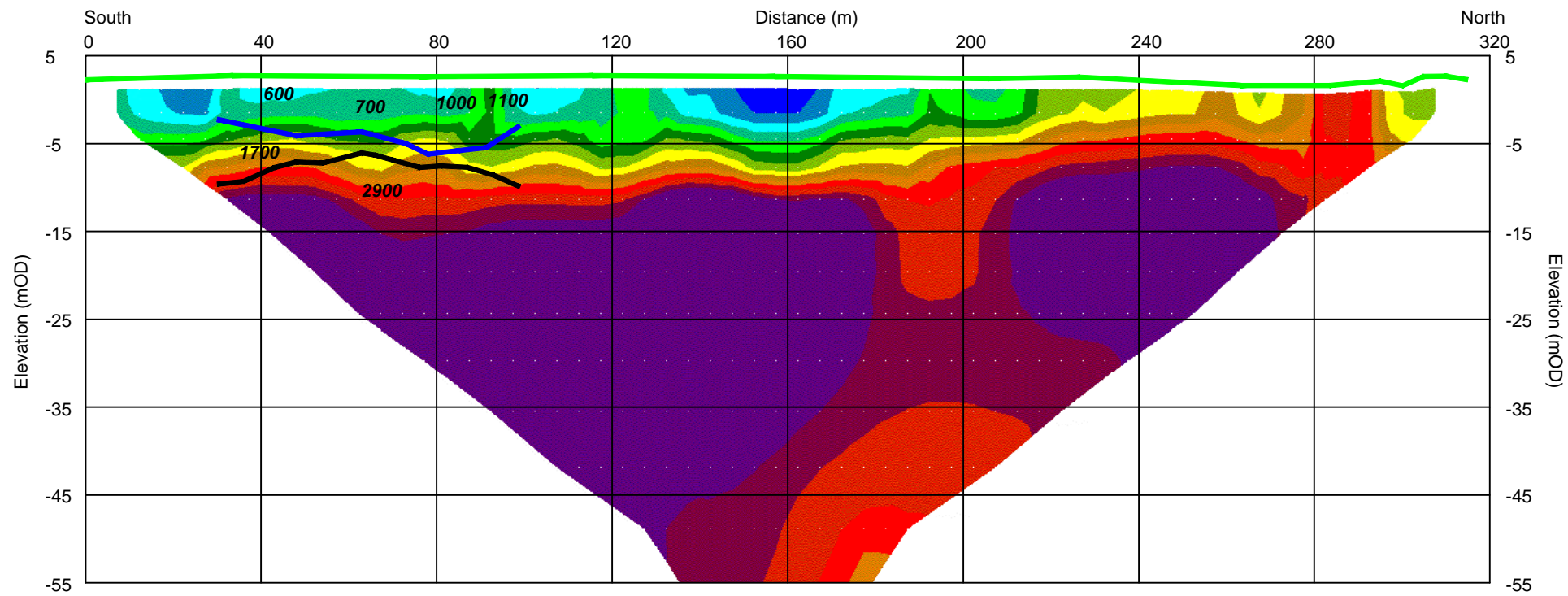

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CLIENT	Irish Water Arup
PROJECT	Site at Ferrybank, Arklow Geophysical Survey
TITLE	Map 1: Geophysical Survey Location Map

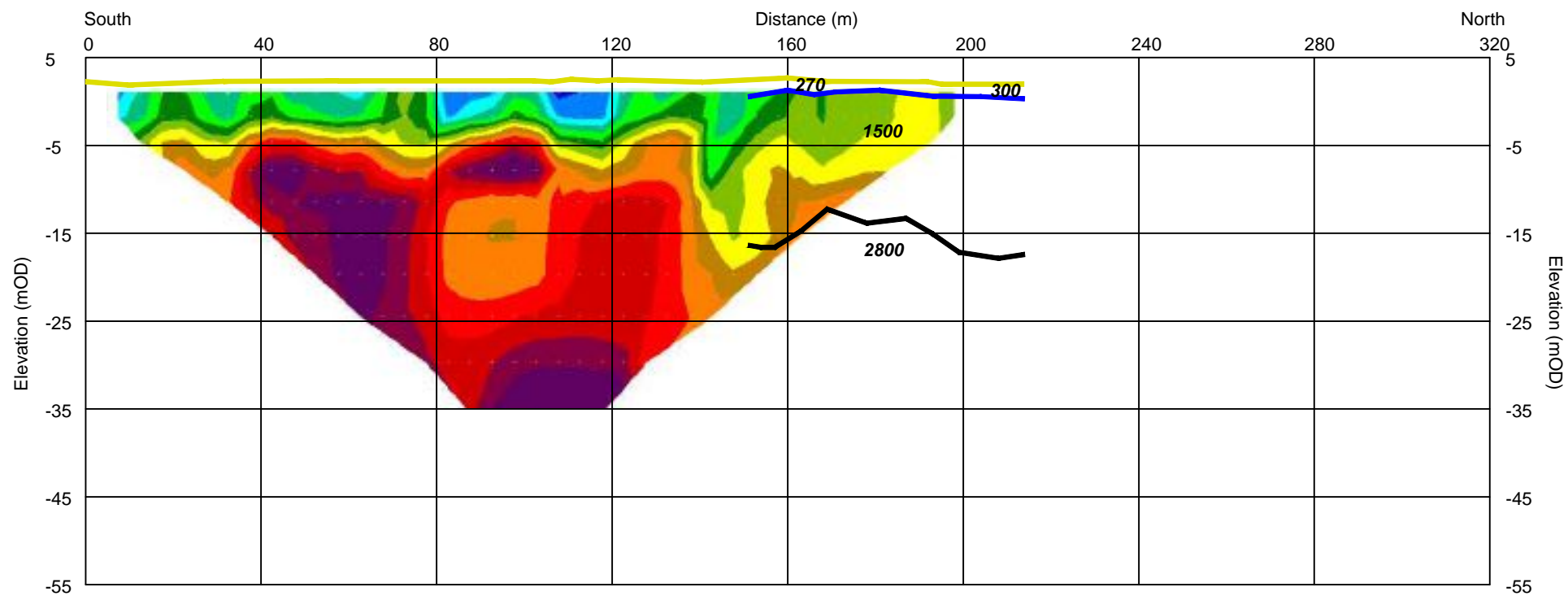
SCALE:	1:1250 @ A3
PROJECT:	6049
DRAWN:	HK
DATE:	14/03/2016
MGX FILE:	6049d_MapsFigs.dwg
STATUS:	Draft

LEGEND: **Geophysical Survey Locations:**
 **R2** 2D-Resistivity Profile
 **S1** Seismic Refraction/MASW Profile

2D-Resistivity Profile R1 and Seismic Refraction Profile S1 Model



2D-Resistivity Profile R2 and Seismic Refraction Profile S2 Model



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CLIENT Irish Water
 Arup
 PROJECT Site at Ferrybank, Arklow
 Geophysical Survey
 TITLE Figure 1: Models of
 Geophysical Survey

SCALE: NTS @ A3, VE x 2
 PROJECT: 6049
 DRAWN: HK
 DATE: 14/03/2016
 MGX FILE: 6049d_MapsFigs.dwg
 STATUS: Draft

LEGEND: Layers from Seismic Refraction Model:

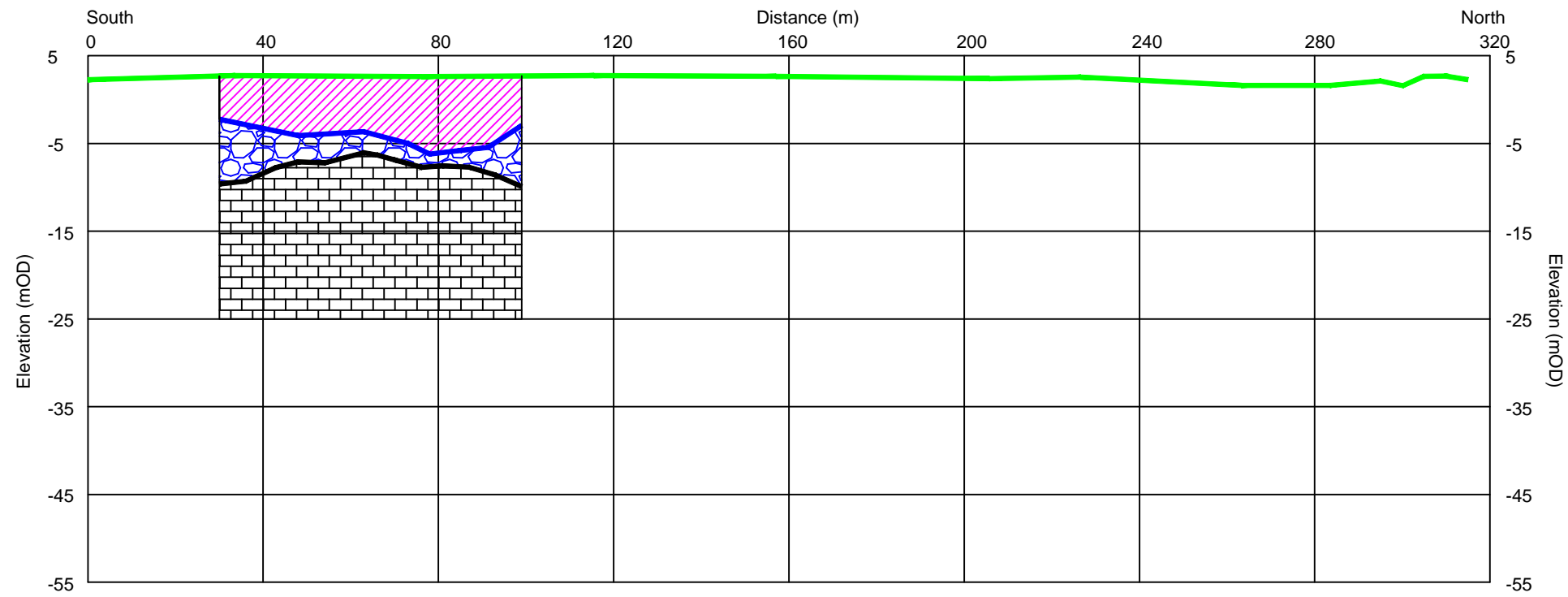
- Ground Surface/Top of Layer 1a (270 - 300 m/s)
- Ground Surface/Top of Layer 1b (600 - 1100 m/s)
- Top of Layer 3 (1500 - 1700 m/s)
- Top of Layer 3 (2800 - 2900 m/s)

1800 Seismic Velocity in m/s

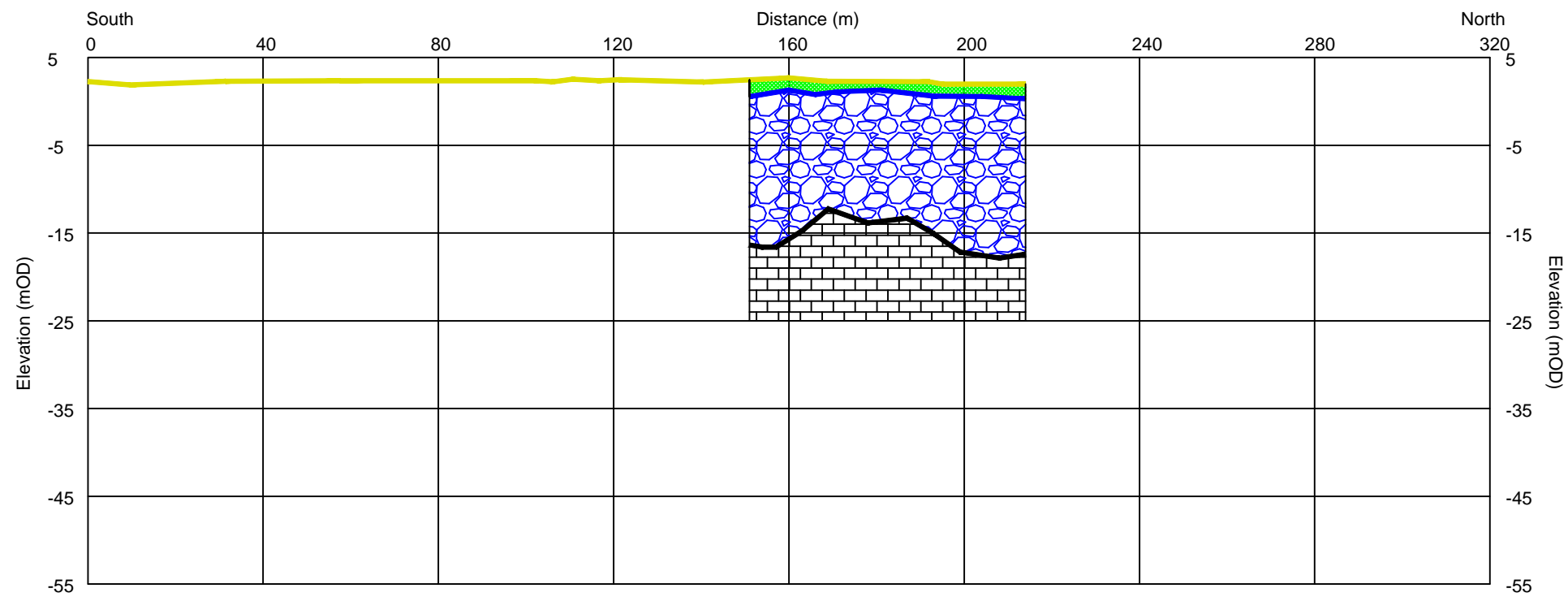
Resistivities (Ohm-m) for 2D-Resistivity Model

5.00	10.0	20.0	40.0	80.0	160	320	640		

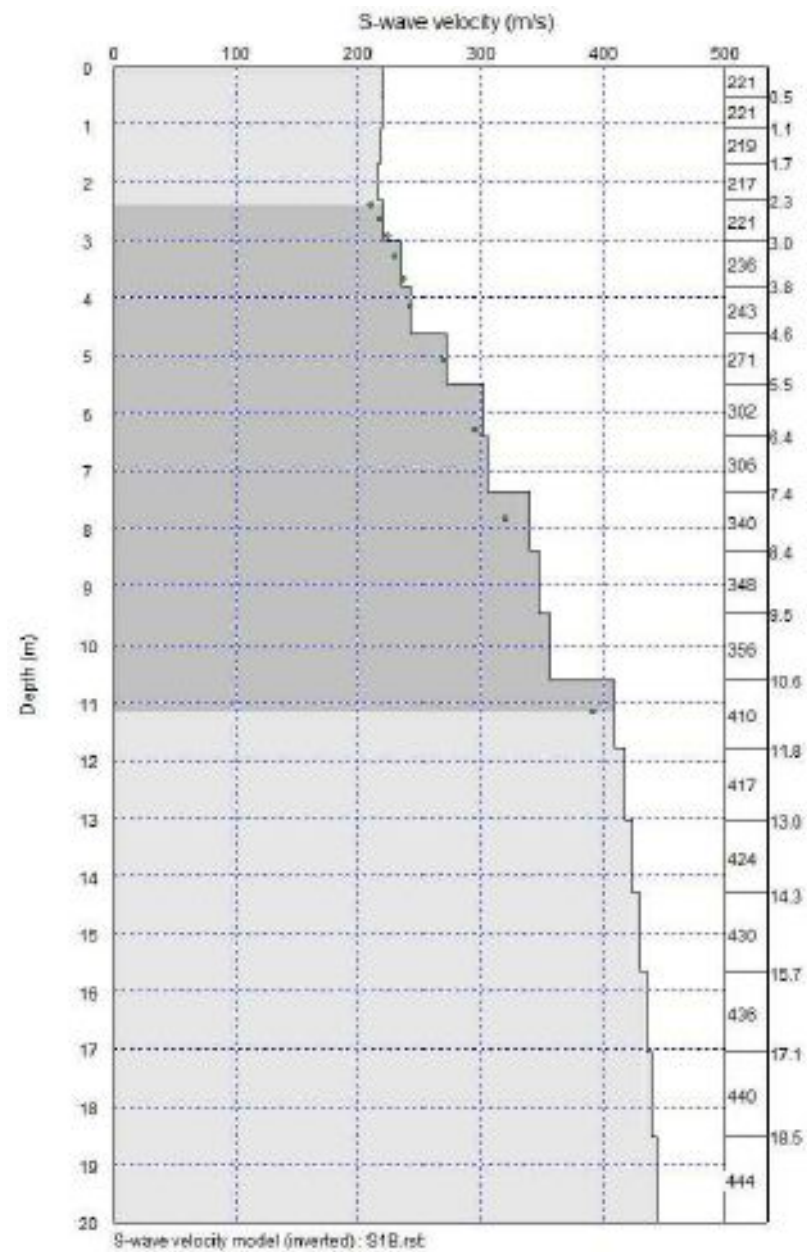
2D-Resistivity Profile R1 and Seismic Refraction Profile S1 Interpretation



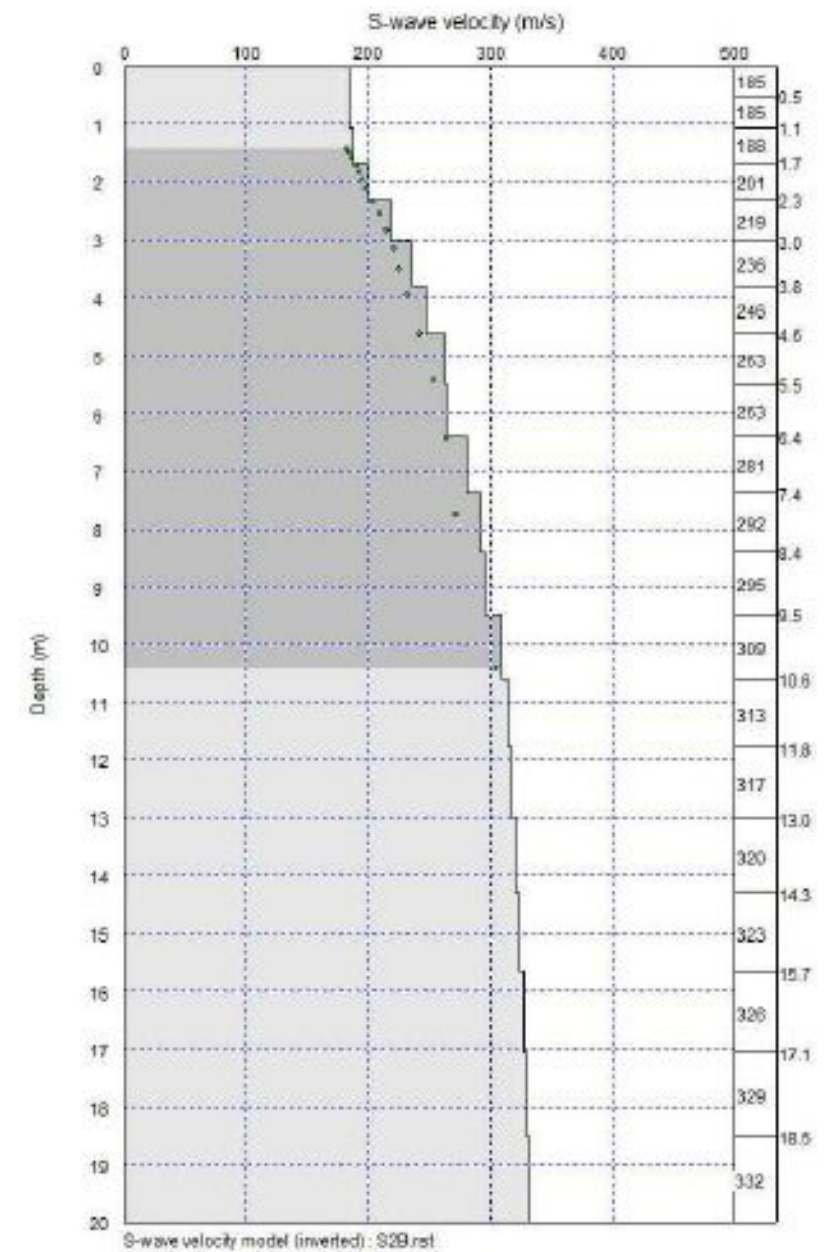
2D-Resistivity Profile R2 and Seismic Refraction Profile S2 Interpretation



Shear Wave Velocity (m/s) versus Depth (m) for S1



Shear Wave Velocity (m/s) versus Depth (m) for S2



Appendix B

Causeway Geotech Ltd. Ground
Investigation Report (July 2018)

B1 Causeway Geotech Ltd. Ground Investigation Report (July 2018)

See Chapter 14, Land and Soils,
Appendix 14.5

Causeway Ground Investigation Report,
Arklow Wastewater Treatment Plant,
Land - Ground Investigation, 17-1455,
18 July 2018.

Appendix C

Dewatering Options Appraisal

C1 Dewatering Options Appraisal

Dewatering options appraisal

Dewatering option	Likely groundwater ingress rate	Treatment methodology	Advantages		Disadvantages		Summary
			Effect	Consequence of an effect on option	Effect	Consequence	
Abstraction of groundwater by sump pump/perimeter well field with or without sheet piles to partly exclude groundwater flow from the sand and gravel but not keyed into a clay layer.	>1000m ³ /day	On site treatment and temporary discharge to the Irish Sea treatment options are likely to comprise dosing.	1. This provide the most flexibility for a potential design and build contractor as he can seek opportunities to reduce the abstraction rate.	M	<p>1. The hydraulic conductivity of the strata is high (>1 x 10⁻⁴m/s) and the final abstraction rate could be an order of magnitude or more higher than the volume estimated. Hence it could be technically challenging and expensive to achieve the required drawdowns. In strata with hydraulic conductivity greater than 1 x 10⁻³m/s and where drawdown exceeds 2m groundwater control by pumping is not recommended (CIRIA 750).</p> <p>2. High ground water flow rates in the sand and gravel around the sheet piles could destabilise them.</p> <p>3. High abstraction rates could cause settlement around the excavation area which, although this could be managed by sequencing the dewatering.</p> <p>4. The groundwater is contaminated and will require onsite treatment prior to discharge. Treatment of high volumes of effluent will be expensive.</p> <p>5. Treatment of large amounts of water requires a large foot print on site for the treatment facility (potentially >2,000m²) and will require large amounts of power and generate considerable waste e.g. contaminated sludge which could be hazardous.</p> <p>6. The surface water discharge will need to be subject of a Section 4 licence from Wicklow County Council in accordance with the Local Government (Water Pollution) Acts, 1977 – 2007. Treatment will require careful monitoring to ensure that the discharge is compliant, could need to be switched off causing delays to the project.</p>	H M L M H M / H	This is considered an unfavourable option. It is not certain that it can be achieved and will be technically challenging in a number of ways.
		Off site treatment	In addition to 1 (above) 2. No need to manage treatment on site	H M	In addition to 1, 2 and 3 (above) 7. The volume of tankers movements would be large. Assuming that each tanker has a volume of 35m ³ , the abstraction rate would	H	

Dewatering option	Likely groundwater ingress rate	Treatment methodology	Advantages		Disadvantages		Summary
			Effect	Consequence of an effect on option	Effect	Consequence	
			3. No need to obtain and manage a Section 4 licence		require up to 30 vehicles a day. This would have an impact on the local traffic. If the abstraction rate increased then the vehicle numbers could significantly increase.		in a number of ways. Also there is uncertainty that tankering is viable due to the large number of vehicles required.
		Reinjection of groundwater without treatment	In addition to 1, 2 and 3 (above) 4. No need to allow for additional vehicle movements, power or temporary storage areas on site. 5. Typically, reinjection is undertaken exempt from regulatory requirements. However, this subject to the requirements of Wicklow County Council. 6. Less sensitive to higher permeability – if extraction volume increase, injection rates also likely increase	M M L	In addition to 1, 2 and 3 (above) 9. Reinjection of high volumes of contaminated groundwater could affect the groundwater flow regime and cause the contaminated groundwater discharge to Irish Sea at a higher rate that it does currently. This could cause the concentrations in the Irish Sea to exceed the surface water quality standards. 10. Reinjection would also impact on construction operations/areas available for Contractor. Abstracted water will need to be treated for sediment and pipes would need to be laid across the site from the abstraction wells to the treatment area and then to the reinjection wells. While the space requirement is relatively small the system will need to be monitored and maintained continuously.	H M	Overall this is considered an unfavourable option. It is not certain that it can be achieved and will be technically challenging in a number of ways and the rejection at high flow rates could contaminate the Irish Sea.
Groundwater exclusion by sheet piling	Minimal. Conservatively it is estimated that the volume for treatment could be as high as 250m ³ /day to allow for management of rainfall and small amounts of seepage.	On site treatment and temporary discharge to the Irish Sea treatment options are likely to comprise dosing.	7. Treatment of small volumes of water will be incur reduced treatment costs and require a smaller foot print and have a smaller energy requirement. 8. Reduced volumes of abstraction will simplify the groundwater management making it less technically challenging.	M H	11. The groundwater is contaminated and will require treatment prior to discharge. Treatment of minimal or small volumes of effluent will be but less expensive that high volumes. 12. Treatment of minimal or small amounts of water requires a medium foot print on site for the treatment facility (potentially 500m ²) and will require power and generate waste. 13. The surface water discharge will need to be subject of a Section 4 licence from Wicklow County Council in accordance with the Local Government (Water Pollution) Acts, 1977 – 2007. Treatment will require careful monitoring	M/L M/L M/L	This is considered a more favourable option however if sheet piles failed to totally exclude groundwater the volume for treatment would increase

Dewatering option	Likely groundwater ingress rate	Treatment methodology	Advantages		Disadvantages		Summary
			Effect	Consequence of an effect on option	Effect	Consequence	
					<p>to ensure that the discharge is compliant with and could need to be switched off. With minimal ingress rates it may be more manageable to store water and there is less risk of a delay to the construction.</p> <p>14. There is a risk that sheet piling will not be effective in totally excluding groundwater. Hence there would be a need to handle higher volumes of groundwater ingress. If treating the water there would be an increased cost if the plant size needed to be increased.</p>	H	
		Off site treatment	<p>See 2, 3 and 7 (above)</p> <p>9. Smaller abstraction rates will require less vehicle movements (<7/day).</p>	M	<p>15. The cost of the provision of the tankers is likely to be more expensive than the onsite treatment.</p> <p>16. The additional traffic will impact on the local area and increase burden on the local roads.</p>	M M	This is considered a favourable option although the cost of tanking is likely to make it uneconomic.
		Reinjection of groundwater without treatment	See 1, 2, 3, 4 and 5 (above)		17. Reinjection of minimal or small volumes of contaminated groundwater could affect the groundwater flow regime and cause minimal or small amounts of contaminated groundwater discharge to Irish Sea at a higher rate than it does currently. This could cause the concentrations in the Irish Sea to exceed the surface water quality standards but is not likely to be significant.	M	Overall this is considered a potentially favourable option. The rejection at high flow rates could contaminate the Irish Sea and would need to be assessed in detail.
Groundwater exclusion by grouting	Minimal. Conservatively it is estimated that the volume for treatment could be as high as 250m ³ /day to allow for management of rainfall and small amounts of seepage.	On site treatment and temporary discharge to the Irish Sea treatment options are likely to comprise dosing.	<p>See 7, 8 and 9 (above)</p> <p>10. Grouting is more likely to form a water tight seal hence there would be a lower risk of high inflows.</p>	H	<p>See 11, 12, 13, and 14 (above)</p> <p>Grouting may not be successful in a highly permeable environment should it not be successful it would be necessary to rely on sheet pile to exclude groundwater</p> <p>Requires on-site trials to achieve suitable level of performance. Due to permeable nature of soils, grout takes could be high – hence high cost. Difficult to quantify this (typically grouting contractors only provide unit rates, not lump sums)</p>	M	This is considered a potential favourable option although it would need to be confirmed that the ground conditions will allow effective grouting.
		Off site treatment	See 2, 3, 7 and 9 (above)		See 15 and 16 (above)		This is considered a potential favourable option although it would need to be confirmed that the ground conditions will allow effective grouting.

Dewatering option	Likely groundwater ingress rate	Treatment methodology	Advantages		Disadvantages		Summary
			Effect	Consequence of an effect on option	Effect	Consequence	
		Reinjection of groundwater without treatment	See 1, 2, 3, 4 and 5 (above)		See 17		This is considered a potential favourable option although it would need to be confirmed that the ground conditions will allow effective grouting.

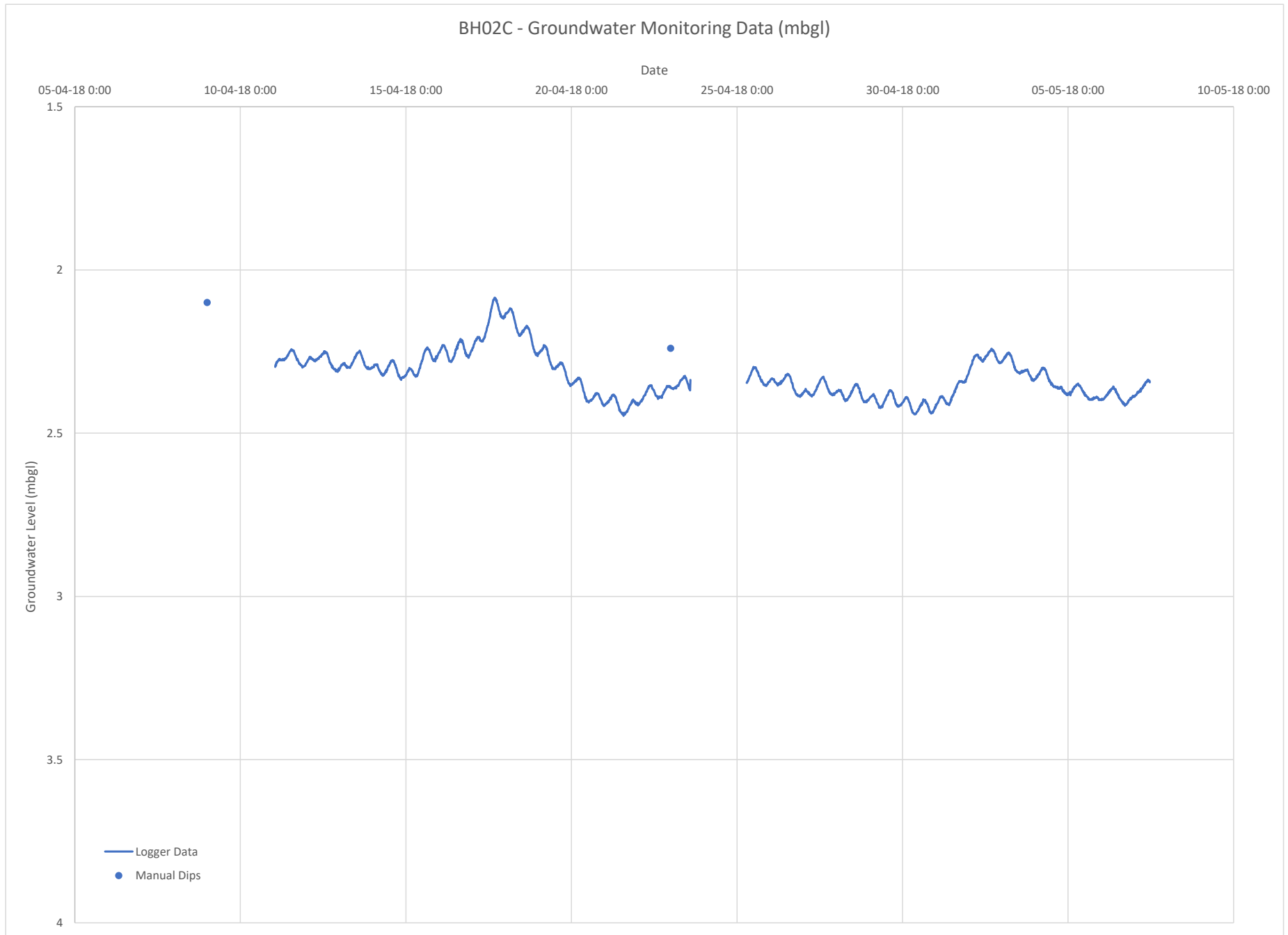
Note

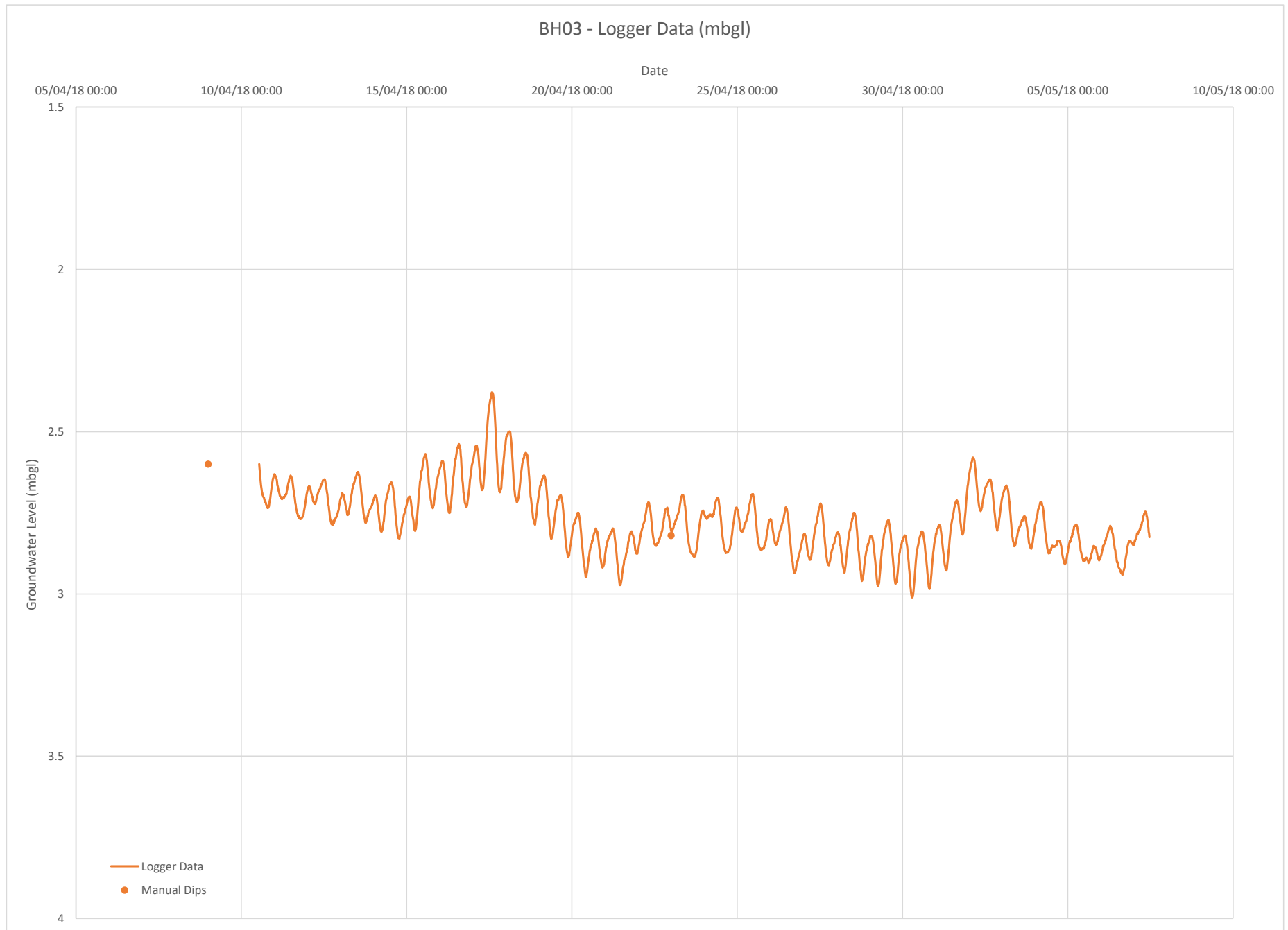
L, M, H in the 'consequence of an effect on option' column refers to the qualitative assessment of the consequence of the effect on the proposed option. L denotes a low consequence, M a medium consequence and H and high consequence. The consequence of effect on option should be considered in the context of the effect, as an advantage effect with a high consequence is a favourable effect but a disadvantage with a high effect is an unfavourable effect.

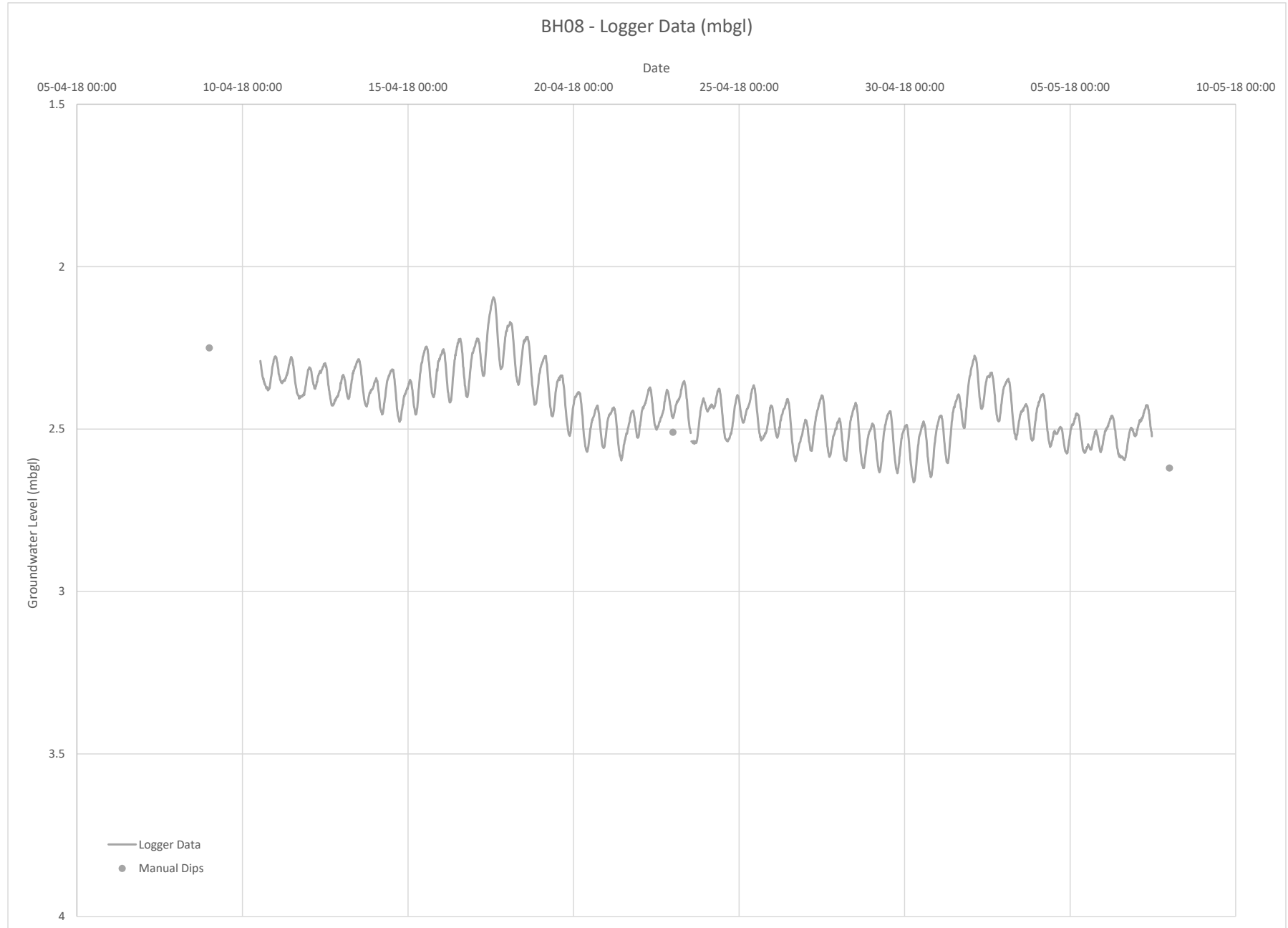
Appendix D

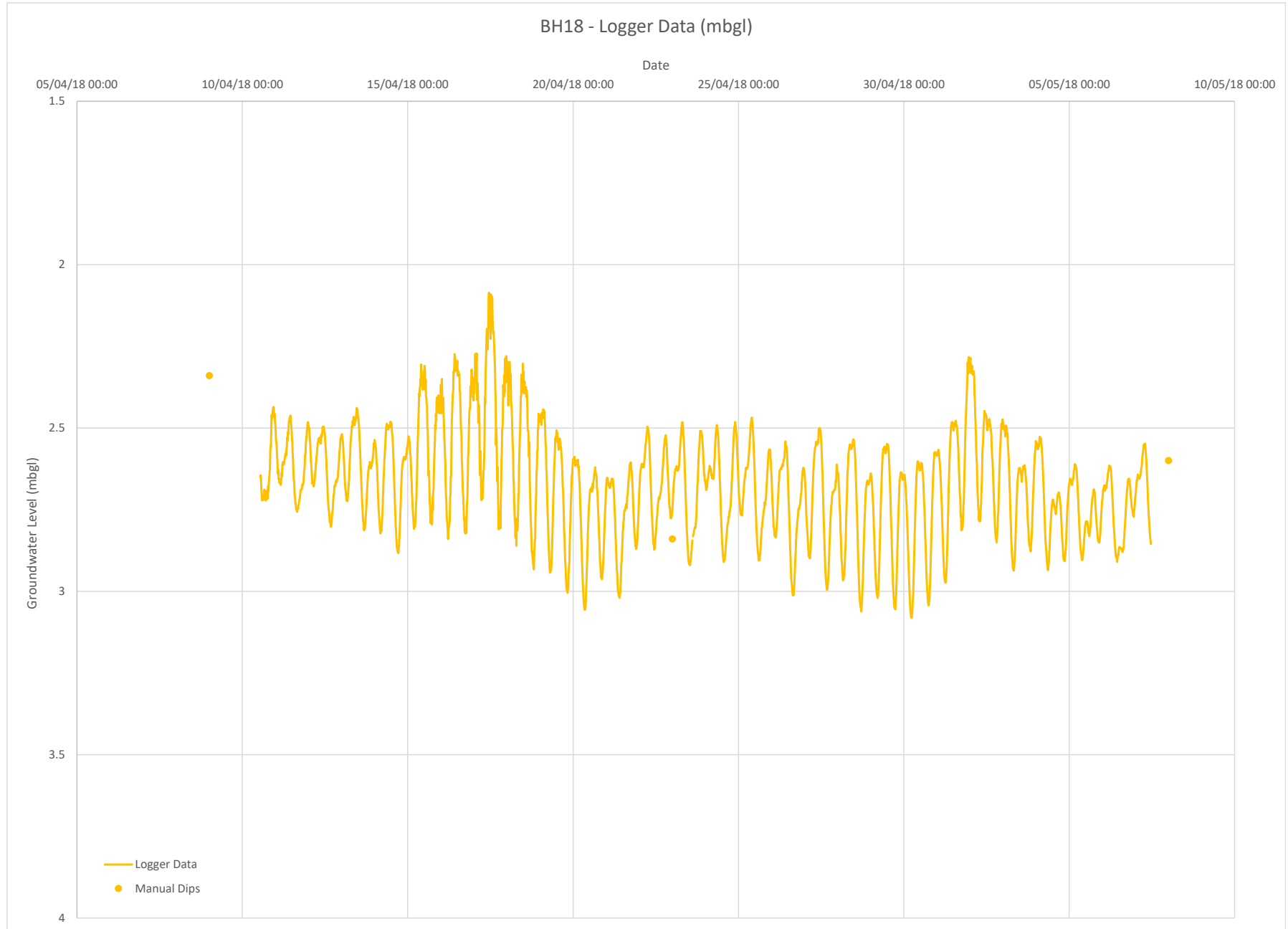
Groundwater Monitoring -
Hydrographs of Transducer
Logger and Manual Dip Data

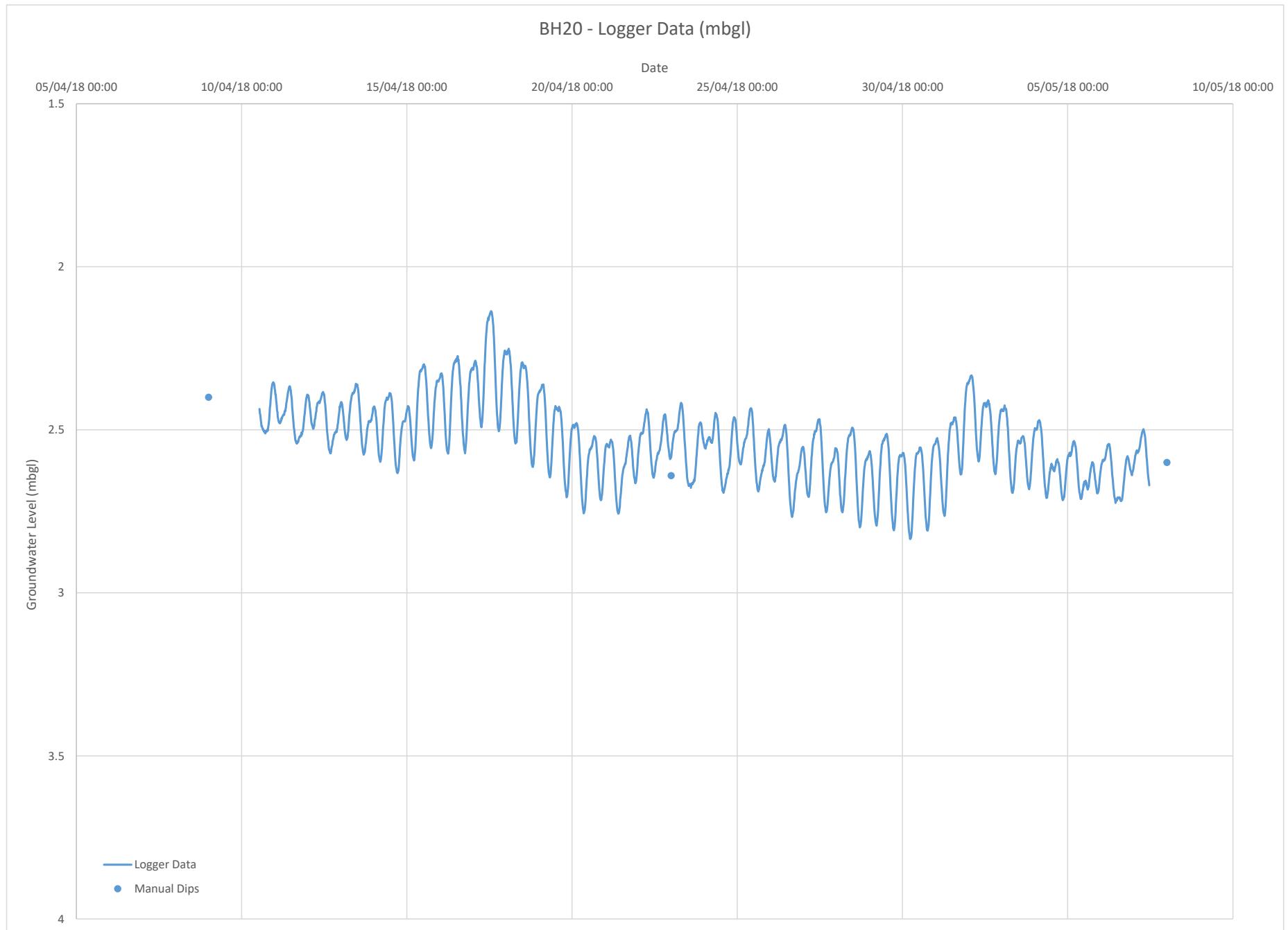
D1 Groundwater Monitoring - Hydrographs of Transducer Logger and Manual Dip Data











Appendix E

Groundwater Monitoring – Transducer Logger Data and Manual Dip Data

E1 Groundwater Monitoring – Transducer Logger Data and Manual Dip Data

BH02

Table with columns: Date and Time, Level Depth To Water (m), Level Depth To Water (m(CD)). Rows 1-300 for BH02.

BH03

Table with columns: Date and Time, Level Depth To Water (m), Level Depth To Water (m(CD)). Rows 1-300 for BH03.

BH04

Table with columns: Date and Time, Level Depth To Water (m), Level Depth To Water (m(CD)). Rows 1-300 for BH04.

BH14

Table with columns: Date and Time, Level Depth To Water (m), Level Depth To Water (m(CD)). Rows 1-300 for BH14.

BH20

Table with columns: Date and Time, Level Depth To Water (m), Level Depth To Water (m(CD)). Rows 1-300 for BH20.

Table with 16 columns: Date and Time, Level Depth To Water (mDC), BH02, Date and Time, Level Depth To Water (mDC), BH03, Date and Time, Level Depth To Water (mDC), BH04, Date and Time, Level Depth To Water (mDC), BH05, Date and Time, Level Depth To Water (mDC), BH06, Date and Time, Level Depth To Water (mDC), BH07. The table contains multiple rows of data for each BH station, showing time-series measurements.

Main data table with columns for Date and Time, Level Depth To Water (mDC), and Level Depth To Water (mC). It is divided into 12 sections labeled B5C2 through B5C13.

Table with columns for BH02, BH03, BH04, and BH05. Each column contains two sub-columns: 'Date and Time' and 'Level Depth To Water (mDC)'. The data consists of multiple rows of numerical values representing depth and time measurements for various points in the system.

Borehole Information		BH01		BH02C		BH03		BH04		BH05		BH06A		BH07B		BH08		BH09	
Irish National Grid Easting		325397.02		325307.25		325375.11		325340.14		325357.99		325298.79		325339.93		325296.01		325316.01	
ING Northing		173032.78		173049.67		173083.98		173091.76		173138.45		173112.12		173208.08		173182.39		173273.21	
Depth (m)		15.00		18.20		15.70		25.00		25.00		15.00		14.80		12.90		17.00	
Ground level mOD		2.54		2.28		2.39		2.51		3.14		2.52		2.59		2.61		2.21	
Statistics	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	
Max	4.33	0.29	5.13	0.18	4.25	-0.21	2.91	-0.12	2.85	0.61	2.65	0.12	2.87	-0.14	2.62	0.36	2.75	0.03	
Min	2.25	-1.79	2.10	-2.85	2.60	-1.86	2.63	-0.40	2.53	0.29	2.40	-0.13	2.73	-0.28	2.25	-0.01	2.18	-0.54	
Median	2.63	-0.09	2.24	0.04	2.82	-0.43	2.69	-0.18	2.84	0.30	2.64	-0.12	2.75	-0.16	2.51	0.10	2.28	-0.07	
Mean	3.07	-0.53	3.16	-0.88	3.22	-0.83	2.74	-0.23	2.74	0.40	2.56	-0.04	2.78	-0.19	2.46	0.15	2.40	-0.19	
Quartile 1 (25%)	2.44	-0.94	2.17	-1.41	2.71	-1.15	2.66	-0.29	2.69	0.30	2.52	-0.13	2.74	-0.22	2.38	0.04	2.23	-0.31	
Quartile 3 (75%)	3.48	0.10	3.69	0.11	3.54	-0.32	2.80	-0.15	2.85	0.46	2.65	0.00	2.81	-0.15	2.57	0.23	2.52	-0.02	
Interquartile Range	1.04	1.04	1.52	1.52	0.83	0.83	0.14	0.14	0.16	0.16	0.13	0.13	0.07	0.07	0.19	0.19	0.29	0.29	
Date	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	
09-04-18	2.25	0.29	2.10	0.18	2.60	-0.21	2.69	-0.18	2.85	0.29	2.40	0.12	2.73	-0.14	2.25	0.36	2.28	-0.07	
23-04-18	2.63	-0.09	2.24	0.04	2.82	-0.43	2.91	-0.40	2.53	0.61	2.64	-0.12	2.87	-0.28	2.51	0.10	2.75	-0.54	
08-05-18	4.33	-1.79	5.13	-2.85	4.25	-1.86	2.63	-0.12	2.84	0.30	2.65	-0.13	2.75	-0.16	2.62	-0.01	2.18	0.03	

Borehole Information		BH10B - Aquifer		BH10B - Made Ground		BH11 - Aquifer		BH11 - Made Ground		BH17		BH18		BH19 - Aquifer		BH19 - Made Ground		BH20	
Irish National Grid Easting		325274.99		325274.99		325253.12		325253.12		325346.90		325326.00		325298.06		325298.06		325324.98	
ING Northing		173233.01		173233.01		173206.01		173206.01		173173.67		173239.66		173286.91		173286.91		173120.91	
Depth (m)		20.00		20.00		26.50		26.50		15.90		15.00		18.00		18.00		16.20	
Ground level mOD		2.23		2.23		1.72		1.72		3.15		2.71		1.34		1.34		2.59	
Statistics	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	
Max	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Median	2.24	-0.01	1.82	0.41	1.80	-0.08	1.81	-0.09	2.83	0.32	2.60	0.11	1.40	-0.06	1.25	0.09	2.60	-0.01	
Mean	2.23	0.00	1.76	0.47	1.76	-0.04	1.79	-0.07	2.83	0.32	2.59	0.12	1.41	-0.07	1.25	0.09	2.55	0.04	
Quartile 1 (25%)	2.12	-0.11	1.71	0.39	1.73	-0.09	1.73	-0.14	2.82	0.31	2.47	-0.01	1.40	-0.07	1.25	0.09	2.50	-0.03	
Quartile 3 (75%)	2.34	0.11	1.85	0.52	1.81	-0.01	1.86	-0.01	2.84	0.33	2.72	0.24	1.41	-0.06	1.25	0.09	2.62	0.09	
Interquartile Range	0.22	0.22	0.14	0.14	0.09	0.09	0.13	0.13	0.02	0.02	0.25	0.25	0.01	0.01	0.00	0.00	0.12	0.12	
Date	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	mbgl	mOD	
09-04-18	2.00	0.23	1.60	0.63	1.65	0.07	1.65	0.07	2.85	0.30	2.34	0.37	1.40	-0.06	1.25	0.09	2.40	0.19	
23-04-18	2.24	-0.01	1.87	0.36	1.82	-0.10	1.81	-0.09	2.81	0.34	2.84	-0.13	1.42	-0.08	1.25	0.09	2.64	-0.05	
08-05-18	2.44	-0.21	1.82	0.41	1.80	-0.08	1.90	-0.18	N/A	N/A	2.60	0.11	1.40	-0.06	Dry	Dry	2.60	-0.01	

Appendix F

Soil Quality Results

F1 Soil Quality Results

Soil Quality Results - Site for Public Open Space Park Use

Table with columns: Element, Unit, LQ, DAC, No. Samples Tested, No. Exceedances, and 24 sampling points (SP1-SP24). The table lists various soil parameters including heavy metals (Cadmium, Chromium, Copper, Lead, Manganese, Nickel, Zinc), nutrients (Nitrogen, Phosphorus, Potassium), and hydrocarbons. Values are presented as ranges (min-max) or specific measurements.

Unless otherwise stated the
following values are for
Public Open Space Park use
CAS - S80-1400* CASL range
SAC:
Irish DAC
Dutch Intervention Values
REA 2000 Limits

Appendix G

Water Quality Results

G1 Water Quality Results

Table with columns for Determiand, Accred, S, P, U, L, O, and a grid of data points for various sampling locations (SW01-LW, SW01-HW, SW02-LW, SW02-HW, SW03-LW, SW03-HW, SW04-LW, SW04-HW, SW05-LT, SW05-HT) across 13 dates from 24-Apr-2018 to 03-May-2018.

Determinand	Accred.	SOP	Units	LOD	EQS	SW01 LW			SW01 HW			SW02 LW			SW02 HW			SW03 LW			SW03 HW			SW04 LW			SW04 HW			SW05 LT			SW05 HT		
						1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
						09-Apr-2018	24-Apr-2018	07-May-2018	09-Apr-2018	24-Apr-2018	07-May-2018	09-Apr-2018	24-Apr-2018	07-May-2018	09-Apr-2018	24-Apr-2018	07-May-2018	09-Apr-2018	24-Apr-2018	07-May-2018	09-Apr-2018	24-Apr-2018	07-May-2018	09-Apr-2018	24-Apr-2018	07-May-2018	09-Apr-2018	24-Apr-2018	07-May-2018	09-Apr-2018	24-Apr-2018	07-May-2018	10-Apr-2018	24-Apr-2018	07-May-2018
Ra-226	S		Bq/L	N/A		<94	<30	<27	<93	<29	<28																								
Ac-228	S		Bq/L	N/A		<17	<7.2	<7.6	<19	<6.6	<7.9																								
Pb-234	S		Bq/L	N/A		<740	<180	<210	<700	<200	<220																								
Th-234	S		Bq/L	N/A		<78	<26	<27	<79	<26	<26																								
U-238	S		Bq/L	N/A		<5.9	<1.9	<1.7	<5.8	<1.8	<1.8																								
Am-241	S		Bq/L	N/A		<5.2	<2.5	<2.4	<5.3	<2.5	<2.4																								
Gross Alpha as Pu-242	S		Bq/L	N/A		<2.8		<3.5	<6		<5.6																								
Gross Beta as Cs-137	S		Bq/L	N/A		11.7 ± 5.3		14.1 ± 6.1	10.6 ± 4.4		<12																								
VOC TIC	N	1760	µg/l	N/A	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	
SVOC TIC	N	1760	µg/l	N/A	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected	None Detected		
Explosives High Level Suite (Subcon)	SN		mg/l	N/A		Below reporting limit		Below reporting limit		Below reporting limit		Below reporting limit		Below reporting limit		Below reporting limit		Below reporting limit		Below reporting limit		Below reporting limit		Below reporting limit		Below reporting limit		Below reporting limit		Below reporting limit		Below reporting limit			

*LOD was higher for monitoring round 1:
Chromium = 20µg/l
Cyanide (free) and Cyanide (complex) = 0.05mg/l
Phosphate = 0.2mg/l
Mercury = 0.5µg/l

EUROPEAN UNION ENVIRONMENTAL OBJECTIVES (SURFACE WATERS) (AMENDMENT) REGULATIONS 2015. Statutory Instruments, SI No. 386 of 2015. Available: <http://www.irishstatutebook.ie/eli/2015/si/386/made/en/pdf> Accessed: 02/05/2018
 EUROPEAN UNION ENVIRONMENTAL OBJECTIVES (SURFACE WATERS) REGULATIONS 2009. Statutory Instruments, SI No. 272 of 2009. Available: <http://www.irishstatutebook.ie/eli/2009/si/272/made/en/pdf> Accessed: 03/05/2018
 Surface Water AA EQS
 Surface Water MAC EQS

S.I. No. 366/2016 - European Union Environmental Objectives (Groundwater) (Amendment) Regulations 2016. Available: <http://www.irishstatutebook.ie/eli/2016/si/366/made/en/pdf> Accessed: 02/05/2018
 EPA, 2003. Towards Setting Guideline Values For the Protection of Groundwater in Ireland. Available: http://www.epa.ie/pubs/advice/water/ground/EPA_proposed_interim_values_protection_groundwater_guidelines.pdf Accessed: 02/05/2018

Table with columns: Parameter, Method, Unit, LOD, DOB, and a grid of data points for monitoring points BH01 through BH19. The grid contains numerical values, some with units, and some with status indicators like '10^{-1}'.

Table with columns for chemical name, unit, and 32 monitoring points (BB01 to BB20). Data values are numerical or categorical (e.g., Not Detected, Below detection limit).

***LOD was higher for monitoring round 1:**

Chromium = 25µg/l

Cyanide (free) and Cyanide (complex) = 0.05mg/l

Phosphate = 0.2mg/l

Mercury = 0.5µg/l

EQS References:

EUROPEAN UNION ENVIRONMENTAL OBJECTIVES (SURFACE WATERS) (AMENDMENT) REGULATIONS 2015. Statutory Instruments, SI No. 386 of 2015. Available: <http://www.irishstatutebook.ie/eli/2015/si/386/made/en/pdf> Accessed: 02/05/2018EUROPEAN UNION ENVIRONMENTAL OBJECTIVES (SURFACE WATERS) REGULATIONS 2009. Statutory Instruments, SI No. 272 of 2009. Available: <http://www.irishstatutebook.ie/eli/2009/si/272/made/en/pdf> Accessed: 03/05/2018[Surface Water AA EQS](#)[Surface Water MAC EQS](#)S.I. No. 366/2016 - European Union Environmental Objectives (Groundwater) (Amendment) Regulations 2016. Available: <http://www.irishstatutebook.ie/eli/2016/si/366/made/en/pdf> Accessed: 02/05/2018EPA, 2003. Towards Setting Guideline Values For the Protection of Groundwater in Ireland. Available: http://www.epa.ie/pubs/advice/water/ground/EPA_proposed_interim_values_protection_groundwater_guidelines.pdf Accessed: 02/05/2018

Appendix H

Gas Quality Results

H1 Gas Quality Results

Determinand	Units	BH10B			BH11			BH19			Statistics		
		09-Apr-2018	23-Apr-2018	08-May-2018	09-Apr-2018	23-Apr-2018	08-May-2018	09-Apr-2018	23-Apr-2018	08-May-2018	Max	Average	Min
Methane	Steady % by vol	0.2	0.10	0.10	0.2	0.20	0.10	0.2	0.10	0.10	0.20	0.14	0.10
	Peak % by vol	0.20	0.20	0.20	0.20	0.20	0.10	0.20	0.10	0.20	0.20	0.18	0.10
Carbon Dioxide	Steady % by vol	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.20	0.12	0.10
	Peak % by vol	1.10	0.90	1.10	1.50	1.20	1.30	1.40	1.30	0.90	1.50	1.19	0.90
Oxygen	Steady % by vol	21.20	21.40	20.90	21.10	21.30	20.70	21.00	21.10	20.10	21.40	20.98	20.10
	Peak % by vol	20.10	20.40	20.10	19.40	19.70	19.90	19.3	19.60	19.60	20.40	19.79	19.30
Flow	Steady l/hr	-0.10	0.10	0.00	0.00	0.00	0.00	-0.10	-0.10	0.10	0.10	-0.01	-0.10
	Peak l/hr	0.10	0.20	0.10	0.00	0.10	0.10	0.00	0.00	0.20	0.20	0.09	0.00