Former Gasworks
Dock Road, Limerick

Quantitative Risk Assessment, Options Appraisal and Remediation

March 2010

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Prepared by

mouchel

Rowan House
Lloyd Drive
Ellesmere Port
South Wirral
CH65 9HQ

T 0151 356 5555
F 0151 356 8960

For Bord Gais Eireann

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New information, changed practices or new legislation may necessitate revised interpretation of the report after the date of its submission.

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Executive Summary

Appointment	Mouchel were appointed by Bord Gais Eireann on 31st March 2009 to provide engineering consultancy services for the assessment and remediation of the former gasworks site at Limerick, Ireland. This report presents the findings of a Detailed Quantitative Risk Assessment (DQRA), a Remediation Options Appraisal and Remedial Strategy, which have been undertaken to assess risks to identified receptors and to derive Remediation Target Values (RTV's) for soils and groundwater.
Location	The 1.4ha site is located in the City of Limerick approximately 100m south-east of the River Shannon. It is roughly rectangular and generally level but drops from approximately 8m MHD (Malin Head Datum) at the south-eastern boundary to approximately 5m MHD at the north-western boundary (adjacent to the Dock Road). The site is currently derelict although the former Bord Gais offices are still present with an electricity sub-station (near the boundary with O'Curry Street) and a former Generator Building (No. 5 Stores). The Generator Building and the Dock Road wall have Protected Status.
Site History	In the 1830's, a limestone quarry was situated in the eastern part of the site, with a small gas works located to the north-west. In 1872, the gas works occupied the majority of the site. The quarry had been backfilled by 1938 with the gasworks operations now covering this area. Coal gas manufacture had ceased in 1974 and the works became an oil gas plant until 1986 when natural gas was introduced. Demolition and site clearance took place between 1988 and 1995.
Geology	Published Geological maps identify the bedrock beneath the site to comprise Visean Limestone of the Lower Carboniferous Period. The rockhead in places is close to the surface with little or no drift cover. Where cover is present, it comprises made ground used as backfill in the construction of the gasworks, infill to the quarry, underground tanks etc or recent alluvium associated with the River Shannon.
Ground Investigations	The site has been subject to five ground investigations undertaken in 1995 (O'Conner Sutton Cronin), 1996 (Arups), 2001 and 2003 (both by Parkman) and in 2009 (Mouchel). The most recent investigation was the most comprehensive and comprised the excavation of 132 sonic drilled boreholes on a 10x10m grid across the whole site. All boreholes penetrated a depth of 1-2m into rock and samples were retrieved at 1m intervals for subsequent laboratory analysis to allow a detailed physical and chemical characterisation of the site to be undertaken. The investigations concur with the published geological maps with Made Ground (up to 10m deep in the former quarry area) overlying a thin layer of alluvial deposits (identified at the north-western boundary adjacent to the Dock Road) overlying limestone bedrock (which outcrops at the south- eastern boundary. Groundwater levels are generally 2-3m below existing ground level and do not appear to be tidally influenced. The limestone bedrock is weathered near its surface (approximately 2m) but is recorded as 'massive' beneath. The hydraulic conductivity of the limestone is assumed to be 1×10^{-7}m/s. Significant free phase product was identified within underground tanks and the former quarry. Assessment of the site has identified that groundwater beneath the site appears to have been impacted with dissolved phase phenols, PAHs (naphthalene in particular), cyanides, sulphate, ammonia, BTEX, TPH and heavy metals. In addition to the organic contaminants in soil and water, visual evidence of spent oxide was encountered in the central area of the site (old quarry area) with associated elevated cyanide levels and soil samples over the majority of the site contained high concentrations of sulphate, ammonia and metals, particularly lead with minor components of arsenic, chromium, nickel, copper and zinc.

Proposed Development Options	It is proposed that the site could be developed for commercial, residential (apartments) or public open space end uses.
Potential Pollutant Linkages	The Potential Pollutant Linkages with respect to human health are assessed to comprise:- • Ingestion/ direct contact of soil for future site occupiers • Inhalation/ ingestion/ direct contact of soil dust for future site occupiers and adjacent site occupiers, and • Inhalation of soil gas/ volatiles for future site occupiers and adjacent site occupiers. The potential pollutant linkages with respect to water are assessed to comprise:- • Soil (including free phase hydrocarbons) leaching to groundwater impacting the River Shannon, and • Groundwater (dissolved and free phase contaminants) impacting the River Shannon.
Human Health Detailed Quantitative Risk Assessment (DQRA)	Remediation Target Values (RTV's) have been derived using generic assessment parameters, considered to be protective of human health, for each of the three development options being considered using the UK EA/ DEFRA's CLEA (Contaminated Land Exposure Assessment) and Dutch methodologies. In addition, a potential vapour pathway has been modelled whereby volatile organic contaminants in the soil and groundwater could represent a risk to future site occupiers and adjacent offsite occupiers. This potential pollutant linkage has been analysed using a RISC4 model as the CLEA analysis does not model the risk of vapours from groundwater/ free phase liquids or to offsite receptors.
Groundwater/ Surface Water Quantitative Risk assessment	A Tier 3 Quantitative Risk Assessment has been undertaken using the UK EA's R & D Publication 20 to derive Remediation Target Values (RTV's) for contaminants in soils and groundwater that are protective of water resources at specified compliance points. In this case, the River Shannon, approximately 100m from the site, has been used. The risk assessment identifies that although a theoretical risk exists in respect to the River Shannon, this is unlikely to be realised due to the timescales required for contaminants to flow to the receptor and the presence of the wet dock and graving docks (with significant walls) impeding flow. It is also noted that cohesive alluvial deposits may be present in the vicinity of the river further impeding any groundwater flow directly into the river. It is concluded that the limestone aquifer is not productive due to the brackish nature of the groundwater and the thin water bearing stratum (in the near surface weathered zone). There are also no abstractions within the vicinity of the site.
Remediation Options Appraisal	A detailed appraisal of the available remediation options was undertaken in two stages. The first comprised a technical pre-screening to determine a shortlist of feasible solutions to address the risks identified. It was concluded that all seven general remediation option methods (civil engineering, biological, chemical, physical, solidification/ stabilisation, thermal and monitored natural attenuation) could be applicable to the contaminants identified on site and were consequently considered at the second stage. Stage 2 identified eleven evaluation criteria to test the ability of each feasible remediation option to meet specific remediation, management and other technical objectives. The preferred remediation options were identified as:- • Pump and treat • Solidification/ stabilisation (ex-situ or in-situ) • Thermal based technology
Remediation	The preferred remediation options have been adopted to produce a remediation

Strategy	strategy using a two phase approach. Phase 1 comprises the removal of free phase liquids, predominantly dense non-aqueous phase liquids (DNAPL) by Pump and Treat techniques. One such method comprises the installation of wells to intercept the DNAPL, generally spaced at 4-5m centres. Water is heated and pumped into some of the wells and extracted through others over a period of several weeks. The extracted mixture of water and DNAPL is separated with the DNAPL being collected in IBC's (intermediate bulk containers) or large tanks prior to removal from site for recycling or disposal (possibly incineration). Water is cleaned and reused. The whole system is closed and hence release of odours is minimal. It is estimated that a volume of approximately 200m^3 of DNAPL requires removal from site for recycling or disposal. Phase 2 comprises the ex-situ stabilisation/ solidification of the uppermost 3m of made ground (or shallower where rock is encountered) to RTV's for surface soils are achieved and to remove the majority of underground structures and remnant free product from site. Sophisticated plant is available to allow thorough mixing of excavated materials with appropriate binders to ensure that the stabilised materials comply with specified leachate criteria. It is estimated that a volume of approximately 32,500m^3 of soil requires stabilisation/ solidification. A number of Site Constraints have been identified which will need to be addressed at detailed design stage. These include unstable boundary walls/ slopes, structures to be retained on site, known underground tanks and the former quarry.
Recommendations	1. Undertake some further preparatory works on site prior to remediation works commencing. These include demolition of the Governer House, Booster House and connecting internal walls, relocation of the AGI (Above Ground Installation) off-site and construction of a DRI (District Regulator Installation) together with the relocation of the ESB sub-station near the boundary with O'Curry Street. 2. Undertake some further sampling of soils in the vicinity of the AGI once it has been relocated off site to complete the detailed characterisation information. 3. Obtain some large bulk samples of contaminated soils to undertake bench trials to allow selection of an appropriate binder for the stabilisation/ solidification works. 4. Early Liaison with regulators including the EPA and the Local Authority to obtain approval in principle to the proposals and to determine whether a Waste Licence and planning consents are required.

1 Introduction

1.1 Brief

Mouchel were appointed by Bord Gais Eireann, on 31st March 2009, to provide engineering consultancy services for the assessment and remediation of the former gasworks site, on Dock Road, Limerick, Ireland. Mouchel (formerly known as Parkman) have had an involvement with the site extending over a period of some nine years having previously undertaken ground investigations at the site.

This report presents the findings of a detailed Quantitative Risk Assessment (DQRA), a remedial options appraisal and remedial strategy, which have been undertaken to assess risks to identified receptors.

1.2 Methodology

Mouchel, based on previous investigations and a recent characterisation exercise, have assessed the potential for harm posed by contaminants on and under the site to future potential users of the site. This approach has also been applied to the potential for harm to the River Shannon which is 100m from the site boundary. The assessment of risk has followed good practice, guidance and legislation applicable to this site to assess what type of remedial options may be suitable to address any risks identified. The remedial methodologies assessed are considered within this report.

Free phase light and dense non-aqueous phase liquids are considered to present the greatest risk of migration from site and residual liability. Therefore, the risk assessment methodology is based on the assumption that all major sources of free product will be removed from the site. This is generally recognised as international best practice.

1.3 Legislative Considerations

Currently the enforcement of environmental law in Ireland is predominately shared between the EPA and local authorities, although certain other bodies play a role in enforcement under specific environmental legislation e.g. the Fisheries Boards under the Fisheries Acts 1959-2003. The planning regime includes some environmental provision, and this comes under the Department of the Environment, Heritage & Local Government, and thus the local authorities. Legislation already makes provision for notification of pollution incidents, most notably under the IPPC and Waste Management Licensing regime where conditions to this effect are imposed, however historic soil contamination does not fall into either sets of legislation, but is mostly tied in with the planning rules.

The Environmental Liability Directive[1] was supposed to be implemented by member states by 30 April 2007, however is not likely to come into effect in Ireland until April 2010. The ELD will cover damage to:

- Protected species and natural habitats covered by the Habitats Directive (92-43-EEC)[2] and the Wild Birds Directive (79-409-EEC)[3].
- Water covered by the Water Framework Directive (2000/60/EC)[4].
- Land.

The Directive is not retrospective. The ELD when transposed into Irish Law will not cover liability for "historic" damage. Instead it will apply to all environmental damage occurring after April 2009.

Local Authorities, and at appeal or for major infrastructure projects, An Bord Pleanála, deal with contamination under the planning regime. The primary Irish legislation is the Planning and Development Act 2000[5]. This Act consolidated all planning legislation from 1963 to 1999 and codified much of what had grown up in custom and practice during that time, clarifying and simplifying the overall legislation. However there have been amendments in 2002, 2004 and 2006.

This enables planning conditions to be imposed on a development such as regard to air and noise pollution, and to impose site investigation, to be followed if required, by remedial measures.

Although, no definitive Irish framework for assessing contaminated land exists, a risk based approach (as laid done by the EU) is followed. In the case of Ireland, both Dutch guidance and UK guidance has been utilised. Both risk based strategies follow the source-pathway-receptor tiered approach. Therefore soil or water can be compared to generic end-uses or standards, followed by a more site specific approach (Detailed Quantitative Risk Assessment) if required.

2 Basis of Site information

2.1 Summary of Previous Investigations

The site has been subject to five main phases of investigation; 1995 (O'Connor, Sutton, Cronin), 1996 (Arup), 2001 (Parkman), 2003 (Parkman) and 2009 site characterisation (Mouchel). These investigations are reported in the following documents, which have been reviewed for this risk assessment:

Summary Report on Limerick Site – O' Conner, Sutton, Cronin, August 1995[6];

Site Investigation Report: Volume 1 Report - Ove Arup, April 1996[7];

Site Investigation Report: Volume 2 Factual Site Investigation Data - Ove Arup, April 1996[8];

Desk Study Phase 1 Report – Parkman, April 2001 (report reference 25837/OR/01B)[9];

Site Investigation Factual Report Volumes 1A and B – Parkman October 2001 (report reference 25827/OR/03B)[10];

Site Investigation General Report Volume 2 – Parkman October 2001(report reference 25837/OR/04B)[11]; and

Ground Investigation into Boundary Conditions and Quarry Backfill – Parkman 2003 (report reference 25837/R/11A)[12].

Limerick Gasworks 2009 Site Characterisation Factual Report 1021927/R/02 February 2010- Mouchel[13]

The findings of these reports have been used to determine the conceptual site model in Section 3. Reference to the original reports should be made if further detail is required.

2.2 Limerick Main Drainage Scheme

The Limerick Main Drainage Scheme was undertaken in 2002-2003 and involved the construction of a number of interceptor sewers, new pumping stations and a new wastewater treatment plant. The main interceptor sewer is the Inner Southern Interceptor Sewer (Lower), which is 2.7 km in length and was constructed in a tunnel of diameter 1.8 m to 2.7 m. The tunnel runs along the Dock Road and passes adjacent to the Limerick Gasworks site, where it has been constructed in limestone rock.

At the request of John Boylan of Bord Gais, Piers Sadler of Mouchel accompanied him during a visit to the Limerick Main Drainage site offices on 7th April 2003, to discuss the tunnelling with Russell Naylor, Senior Resident Engineer, Limerick

Main Drainage. The objectives of the discussions were to obtain information on the tunnelling operations in the immediate vicinity of the site, in particular relevant geological and chemical data gained during the related site investigations for the sewer. The data obtained has not been warranted to Mouchel or Bord Gais. Therefore it has only been used for guidance purposes and to support the conceptual model.

From discussions with Russell Naylor, the following information was obtained:

tunnelling was undertaken using a Tunnel Boring Machine (TBM) at a diameter of either 1.8 m or 2.7 m depending on location;

adjacent to the site, the tunnel invert level is –8.5 to –8.9 m MHD (Malin Head Datum). This section of the tunnel was constructed using the TBM in open mode due to the low water ingress. Generally in this area water ingress was low and the limestone was described as massive;

adjacent to the northern part of the site an oily smell in the groundwater was interpreted as a result of contaminated groundwater seepage. However no corroborating evidence such as observed increased inflows or direct observation of fractured rock was reported;

whilst undertaking works adjacent to the site a number of service runs were encountered. These were generally cut and sealed off with concrete. The largest was a 600mm concrete pipe containing tar;

low permeability conditions were found where the limestone was massive and where tunnelling or shaft sinking intercepted alluvium. Water ingress along the tunnel was greatly increased where the tunnel passed through the upper weathered zone in the limestone; and

shaft 6, sunk adjacent to the site, was essentially dry, whilst Shaft 7 some 500 m south west of the site experienced inflows of approximately 120 l/sec. In this area the rock head was deeper relative to the tunnel level and consequently tunnelling occurred within the weathered zone of the limestone.

The following reports were also reviewed:

Limerick Main Drainage, Contract 3.1 Inner Southern Interceptor Sewer (Lower), Dock Road Tunnel, Geotechnical Summary Report – Dr Eric Farrell and Bernard Murphy Associates[14];

Limerick Main Drainage, Contract 3.1 Inner Southern Interceptor Sewer (Lower), Dock Road Tunnel, Site Investigation Factual Report, S O'Sullivan, J Barry and Partners, Gibson O'Connor and Michael Punch and Partners[15]:

Volume 1 Boreholes and In Situ Test Results; and

Volume 3 Water Permeability and Environmental Test Results.

In reviewing these reports the focus was on assessing conditions adjacent to the site and comparing these with adjacent areas. The aim was to provide supporting information for the site conceptual model.

Data viewed included borehole engineering sections, borehole logs, permeability data and water quality data.

2.3 Historic Data Use Assumptions

Analytical data for soils from all site investigations was used in the human health risk assessment presented in this report. QA data from some of the previous investigations (1995[6] and 1996[7]) with regard to laboratory results was not forth-coming, therefore more reliance has been placed on the Parkman investigations (2001[10,11] and 2003[12]) that do include this.

Details of the site plan and location of previous exploratory holes are identified on Figure 3.

Groundwater data from the 2003[12] investigation was used to investigate current and future risks associated with the groundwater as this is considered to be the most reliable of the historic data sets.

Only soils and waters have been assessed in the risk assessment. As stated in section 1.2, tars and other free phase hydrocarbon contamination have not been included in the assessment. It has been assumed that all visible tars will be removed from site. In addition it should be noted that the 2001[10,11]/2003[12] investigations were designed to fill in the gaps left by the highly targeted previous investigations, and as such did not encounter 'worst-case' contamination. However, all areas were investigated during the 2009 characterisation investigation[13], and thus the 2009 investigation provides the most definitive data set.

2.4 2009 Site Characterisation – Summary of site works

The Site Characterisation was undertaken to supplement the information gained from the previous investigations undertaken at the site and was designed to test for a wider range of determinands and provide a more comprehensive dataset of physical and chemical characteristics of the site.

The investigation was designed to provide sufficient data to allow: -

- A more accurate conceptual ground model, specifically delineation of the former quarry area and underground structures

- Identify significant pollutant linkages in respect to human health and groundwater
- Update the quantitative risk assessments to assess risks to identified receptors
- Update remediation target values for soils and groundwater, as required.
- Provide an improved data set for remedial options appraisal.
- Allow for the formulation of a robust remediation strategy.

Sonic drilling was used for the majority of the site works as this technique is fast and provides good core recovery which is useful to define strata changes and facilitate reliable sample collection. The sonic drills are able to progress through obstructions such as concrete slabs, which may not be penetrated by other methods. Sonic drilling is also generally a cleaner and safer technique than cable percussion drilling.

Window sampling was undertaken in areas that could not be accessed by the sonic rigs (inside buildings and some areas along the site boundary).

The exploratory hole location plan is displayed as Figure 2.

Table 2.1: Summary of Site Activities

Activity	Dates Undertaken	Exploratory Hole Reference	Maximum Depth
Sonic drilled boreholes	4th November – 24th November	132 locations referenced by alpha-numeric 10 x 10 m grid cell reference (A1, A2…)	12m bgl
Window sample holes	25th November – 27th November	13 locations (C12AWS, C12BWS, D12WS, E12WS, F9WS, F10WS, F12WS, L11WS, L12WS, L1WS, M1WS, N1WS, N2WS)	4.0m bgl
Trial pits	9th November – 10th November	3 locations (TP1, TP2, TP3)	5.0m bgl
Soak away pits	9th November	1 location ("soakaway")	2.1m bgl

Samples were selected at approximately 1m intervals, or significant strata changes, and submitted for subsequent chemical analysis.

A full record of the 2009 Site Characterisation findings is presented in the 2009 Site Investigation Factual Report[13].

Data from the 2009 Site Investigation has been collated to form the base data set for this report and its findings. The data from the 2009 investigation has been compared against data from the previous investigations. Where relevant, data from the previous investigations has been incorporated into the main dataset.

It is noted that the total volume of made ground estimated from the results of the characterisation works is in the order of 60,000m^3.

3 Conceptual Site Model

3.1 Conceptual Site Model

A conceptual model for the site, which takes into account the following information, is presented as Figure 9, A site photographic log is presented as Figure 13.

3.2 Location and Description

The 1.4 ha site is located in the City of Limerick approximately 100 m south east of the River Shannon and immediately south east of the Dock Road. The national grid co-ordinates for the site are E156950 N156650. A location plan is included as Figure 1.

The site, roughly rectangular in shape, is generally level at about 5 m MHD but rises to approximately 8 m MHD towards the south and east boundaries.

The site is surrounded by housing and light industry to the northeast and housing to the southeast and southwest. To the northwest some commercial properties are present and beyond this are a Graving Dock, Wet Dock and the River Shannon.

The site is currently not in use and access is managed by Bord Gais. The site includes a two-storey office block and other ancillary buildings (booster house and No 5. store), none of which are used on a permanent basis (see Figure 12). The No. 5 store (generator building) and the masonry wall at the Dock Road boundary are protected structures and will need to be retained. It is also our understanding that Bord Gais would wish to retain the existing 2-story office building if possible.

3.3 Summary of Site History

The site history is summarised below:

- in the 1830's a limestone quarry was situated in the eastern part of the site, with a small gas works located to the north west;
- by 1872 the gas works occupied the majority of the site, with a water feature located within the remaining quarry;
- the quarry had been backfilled by 1938, and an electricity substation was located along the north east boundary;
- coal gas manufacture ceased in 1974 and the works became an oil gas plant until 1986 when natural gas was introduced; and
- demolition and site clearance took place between 1988 and 1995.

Some recent site clearance (2009) was undertaken to facilitate access for the characterisation works undertaken in November 2009. Works also included the placement of gabion baskets along a short length of the south boundary wall (grid cells G12, H12,and I12 and grid cells L10, L11 and L12) as it was considered to be unstable. Shoring was also provided to the Dock Road wall.

Former gasholder wells/ tar tanks etc are identified and numbered (T1, T2, T3 etc) on Figure 12.

3.4 Proposed Development

It is our understanding that three potential development options may be considered for the site:

commercial;

apartments (residential without plant uptake); or

parkland/public open space.

For the purposes of the risk assessment the site has been appraised assuming any of the above land-uses could be utilised in future on the site.

3.5 Geology

The Geological Survey of Ireland, Sheet 17, Limerick, 1:100,000 Scale[16]; the Geological Survey of Ireland publication “Geology of the Shannon Estuary”[17] and the local geological memoir were consulted and indicated that the bedrock beneath the site comprises the Visean Limestones of the Lower Carboniferous Period. The limestones are mainly oolitic, occasionally containing clay ‘wayboards’ which formed following exposure of the platform above sea level and accumulation of volcanic ash. The limestone often contains chert nodules (siliceous concretions) and thin interbedded shales. The Visean Limestone is also known as ‘Clean Shelf Limestone’. The total thickness of the limestone is more than 800 m. It lies conformably on the Waulsortian Limestone, described as a massive unbedded lime mudstone representing a deeper marine depositional environment.

Beneath the site, the beds dip approximately 8° to the north. The site is located on the southern limb of an east-west trending syncline.

The rockhead, in places, is close to the surface with little or no drift cover. Where cover is present, it comprises made ground used as backfill in the construction of the gasworks, infill to the quarry or recent alluvium associated with the River Shannon flood plain. Wider from the site, the EPA classify the soils in and adjacent to Dock Road and O’Curry Street as ‘Made’, comprising Made Ground, based on soils mapping completed in May 2006 by the EPA[18], Teagasc, Forest

Service and Geological Survey of Ireland. A small area of lithosol/ regosol (code: AminSW) was identified bounding on the north east corner of the site, stretching across O'Curry Street and beyond Windmill street, adjacent to Dock Road. Much of the soil to the west of the site and downstream comprises marine estuarine sediments.

3.5.1 Site Specific Geology

From the four previous site investigations[6,7,10,11,12] and the 2009 characterisation[13], the general sequence of ground conditions comprised; Made ground underlain by limestone, with localised alluvium around the site boundary extending from the north west to the south west of the site.

The sequence encountered is summarised in Table 3.1.

Table 3.1 Summary of encountered ground conditions during the 2009 Site characterisation

Stratum	Range of depth strata encountered (m bgl)	Average thickness (m)
Made Ground	0 – 10	4.3
Alluvium	0 – 5.5	1.8
Limestone	0 - 10	-

The thickest made ground was found in the former quarry (0-10m bgl). Extensive depths of made ground were also encountered in areas of former tanks and gas holders (Gas holder 2 – cell C07 @ 0-6.5m bgl, pre 1840 and 1872 structures – cells E07, E08 and E09 @ 0-6.0m bgl, Tar tank 7 – cell H09 @ 0-4.2m bgl, around Gasholder 5 – cells K04, K05, K06, K07, L04, L05, L06, M05, M06 @ 0-9m bgl).

Made ground over much of the site was predominantly granular in nature comprising sand, ash, limestone gravel with bricks and concrete. The made ground within the former quarry area was predominantly clay with brick and concrete fragments and large pockets of sand and layers of ashy material were recorded in the eastern section of the site and around the former quarry. The made ground was often contaminated with tarry liquid and occasionally had a strong phenolic odour. See Figure 4 (cross-sections) and Figure 11 (made ground depths).

A localised area of natural clay (with an average thickness of 1.5m) was reported around the Bord Gais offices in cells C11, C12, D10, D11, D12, E10, E11, E12. The clay was directly underlain by limestone bedrock. The clay was generally described as a stiff grey slightly gravely CLAY. Further alluvial deposits are thought to be present in the north west to south west sections of the site adjacent to Dock

Road, although these have been disturbed by foundation construction and hence are often generally described as Made Ground. They comprise loose to medium dense brown-grey sandy gravels and brown soft silty clays with gravels and occasional cobbles and boulders. The 2003 investigation logs[12] often reported shells were present within these deposits.

The bedrock surface was found to be very uneven due to previous quarrying activities and excavation for underground tanks and tank foundations. The natural slope of the bedrock is from approximately 8m MHD near the southern corner (Cell L08) to 1m MHD at the north western boundary with Dock Road (Cell A6). Rockhead was encountered at a maximum depth of 10m bgl (-2.5m MHD) in cell G4 at the base of the former quarry which is shown on the historical map for 1872. The quarry appears to have a steep face to the north-west, with its base rising more gently to the east. Rock head was encountered at ground level at the sites eastern to southern boundaries and in cells I10, J09, K08, K09, K10, L08, L09 and L10, Figure 5 shows the topography of rock-head.

From the previous investigation data, the top of the limestone was encountered between approximately 0.4 to at least 9.6m bgl. On average around the top 1.5m (based on 2003 data[12]) of limestone was found to be weathered, consisting of gravel through to cobbles and boulders of limestone, becoming more competent but highly fractured. This was largely comparable with conditions experienced in the 2009 investigation[13]. The bedrock comprised grey, coarse grained, massive to bedded limestone. Total Core Recoveries (TCR) from the previous investigations were in the range of 14% to 100% with an average of 76%. Rock Quality Designation (RQD) values were also in range of 14% to 100% with an average of 64%. The rock head was often described as "stained with black tar" over a depth of up to 3m (Parkman 2001 report). During the 2009 investigation some thin layers of clay were identified, interbedded with the limestone.

Twelve Fraction of Organic Carbon (FOC) tests were carried out, eight on samples of the superficial and four on samples of rock in the 2003 investigation[12]. These were undertaken as FOC is a critical input parameter for risk assessments. Results in the made ground ranged between 0.003 to 0.062, with an average of 0.021 and no visible variation between granular and cohesive deposits. Results on the rock vary between 0.001 and 0.023 with an average of 0.007. No additional FOC tests were undertaken as part of the 2009 investigation.

3.6 Hydrology

The site is situated on the southern side of the River Shannon estuary, which flows westerly into the Atlantic. At the site, the estuary is approximately 200 m in width and subject to tidal influence.

The average rainfall for the area is 850 mm/yr.

The site currently comprises approximately 60 % hard cover and 40 % free draining material (with many underground structures that may impinge on the infiltration and flow of rainwater/perched water through the made ground). There is a fall in the site level from the south east (8 m MHD) to the west and north west (5 m MHD), directing surface run-off in this direction. The River Shannon's water level is typically 0 m MHD near to the site. The mean high and low waters at spring tide vary from 3.10 to -2.6m MHD, with the neap tides fluctuating between 1.6 and -1.8m MHD, giving the mean tidal level at the Dock as being -0.1m MHD.

Drainage of the site has historically been to the city's sewers, which historically discharged into the river via a main sewer on Dock Road. It is our understanding that the drainage from the site has now been incorporated into the new Limerick Main Drainage Scheme, although some drains have reportedly been sealed by the scheme.

The 1996 Ove Arup Site Investigation Report[7,8] recorded that storm water flooding had occurred in the past along the Dock Road at its junctions with O'Curry Street and St Alphonsus Street, i.e. close to the site. The maximum recorded flood level for the City was reported as 4.25 m MHD.

Along this length of the River Shannon, the site is separated from the River by the Wet Dock and the Graving Dock. The Graving Dock (a dry dock that could be flooded from the wet dock), is partially infilled, but by its nature would have had low permeability dock walls of stone or brick. The Wet Dock is in continuity with the river, but is likely to be similarly lined, decreasing continuity between groundwater and river.

3.7 Hydrogeology

The Groundwater Protection Maps for County Limerick (Maps 1-6)[18] indicate that the Clean Shelf Limestone is a 'Locally Important Aquifer' that is generally Moderately Productive (40-100 m^3/d). The hydraulic properties of the aquifer are dominated by fissure flow and well-developed karst features have been observed in the area. The nearest abstraction well is 6 km to the south east of the site. The oolitic limestones of the Limerick Syncline are known to have relatively high permeabilities. The aquifer is classified as 'Vulnerable' due to the lack of impermeable cover or thick unsaturated zone.

There are no recorded active wells or boreholes in the vicinity of the site; although the historical site plan dated 1977 shows a well 5 m to the north west of Gasholder No.3 (T11). This may or may not have been grouted up and may form a pathway for surface contamination to groundwater.

3.7.1 Site Specific Hydrogeology

Occasional pockets of perched water were encountered in trial pits in the made ground during the investigations undertaken at the site. However, these were not generally reported in any of the boreholes in any investigation. During the excavation of the trial pits in the 2009 investigation several pockets of perched water were encountered. As the excavations progressed in some instances the water drained away quickly, indicating the presence of impermeable obstructions within the made ground which have created localised areas of perched water.

One soakaway pit was excavated in the 2009 investigation in cells J4/J5 (see Figure 2). The pit was dug in the made ground which was described as a sandy gravely clay. No water was encountered whilst digging the pit however when filled with water, as part of a falling head permeability test, it dissipated very slowly over a period of several hours. The strata appeared to be relatively impermeable.

Localised pockets of 'tarry liquid' were identified by Arups (1996)[7,8]. During the 2009 investigation a 'tarry / hydrocarbon' dense non aqueous phase liquid (DNAPL) was recorded in several locations and within some monitoring wells. Figure 7 and 8 show areas of free phase contamination in the made ground and within the fractured limestone bedrock during the recent (2009) and previous investigations respectively.

Generally hydraulic continuity exists between the Made Ground and the bedrock due to the granular nature of the made ground, and therefore the groundwater potentially acts as one body.

The findings of the 2009 investigation were similar to the findings from the previous investigations. The water table falls from approximately 7.8m MHD in cell K5 and the south eastern section of the site, to approximately 2.7m MHD in cells A11, A3 and A4 on the sites boundary with Dock Road. The general groundwater flow direction appears to be in an approximate westerly direction (See Figure 6).

The groundwater data implies that there may be two sources of groundwater entering the site.

Source 1 – Originating from the southern corner of the site from within the rock outcrop (picked up by monitoring well J10).

Source 2 – Originating from the south east section where water is draining into the site (picked up by monitoring well K5).

These two sources seem to be partially split by the bedrock which is located at the surface around cells I10, J09, K08, K09, K10, L08, L09 and L10.

The water appears to accumulate in the quarry area and flow towards the south west (A11 / corner of Dock Road and St. Alphonsus Street) and to the west (A3 –

A4 / Dock Road). Flow is therefore in an approximately westerly direction as would be expected close to the river (the angle of flow will be to the river (west north west) but with a vector in the direction of river flow, i.e. westerly.

Table 3.2 Summary of historic water monitoring points

BH No.	Date drillled	Response zone strata	Response zone depth (m bgl)	Water Level m MHD August 2003
BH7	1996	Limestone bedrock	6.00-9.10	4.66
BH31	2001	Limestone bedrock	1.85-5.25	2.59
BH32	2001	Limestone bedrock	1.85-4.85	2.60
BH33	2001	Limestone bedrock	1.45-8.45	5.71
BH35	2003	Limestone bedrock	6.60-8.60	4.35
BH35A	2003	Limestone bedrock	8.50-13.50	4.31
BH36	2003	Limestone bedrock	2.80-5.10	3.32
BH36A	2003	Limestone bedrock	5.30-10.30	3.03
BH37	2003	Limestone bedrock	3.80-6.80	4.15
BH37A	2003	Limestone bedrock	7.10-12.05	4.15
BH38	2003	Limestone bedrock	4.25-6.65	3.33
BH38A	2003	Limestone bedrock	6.00-11.50	2.69
BH39D	2003	MG – silty gravel	1.00-7.00	4.41
BH40	2003	MG – clay rubble	1.00-6.00	4.95
BH41C	2003	MG – gravel	1.00-5.00	4.43
BH42	2003	MG - clay fill	1.00-4.50	7.30
BH43	2003	MG – clay fill	1.00-2.65	5.10

Borehole locations are identified on Figure 3.

Table 3.3 Summary of 2009 investigation water monitoring points

BH No.	Response zone strata	Response zone depth (m bgl)	Water level m MHD (DNAPL level m MHD)	
			10th-11th Dec 2009	14th – 15th Jan 2010
A3	Limestone bedrock	3.0 - 4.5	2.80	2.75
A4	Limestone bedrock	2.5 - 4.5	2.73	2.67
A11	Limestone bedrock	1.9 - 2.9	2.70	2.68

BH No.	Response zone strata	Response zone depth (m bgl)	Water level m MHD (DNAPL level m MHD)	
			10th-11th Dec 2009	14th – 15th Jan 2010
B8	Made ground	1.0 - 4.5	3.69 (2.24)	3.64 (2.79)
C7	Limestone bedrock	6.0 - 7.5	4.00 (-1.98)	3.75 (-1.17)
C11	Natural clay	1.0 - 2.5	3.11	3.07
D1	Limestone bedrock	6.0 - 7.5	4.26	4.06
D5	Made ground	1.0 - 3.0	5.30	5.20
E8	Made ground	1.0 - 6.0	5.04	4.84
F11	Limestone bedrock	3.5 - 5.0	5.10	5.22
G2	Limestone bedrock	10.0 - 11.5	5.20	4.84
G3	Made ground	1.0 - 9.0	5.22	4.87
G4	Limestone bedrock	10.0 - 12.0	5.15 (-1.55)	4.85 (2.15)
G5	Made ground	1.0 - 9.0	5.24	4.90
G8	Limestone bedrock	1.0 - 2.5	6.94	6.95
H12	Limestone bedrock	3.0 - 4.5	5.71	5.72
J10	Limestone bedrock	1.0 - 3.0	6.87	6.85
K1	Made ground	1.0 - 4.5	6.04	5.90
K5	Made ground	1.0 - 6.0	7.87	7.67
L7	Limestone bedrock	2.0 - 3.5	<5.85*	<5.85*
M3	Limestone bedrock	5.0 - 6.5	5.44	5.06

*Installation was dry during monitoring visit, depth has been calculated at base of well.

Borehole locations are identified on Figure 2.

The results equate to the following estimates of hydraulic gradient across the site:

Visit 1
G8 – E8 (approximately 1.9m / 13.5m) = 0.141

G3 – A3 (approximately 2.42m / 59.9m) = 0.040

F11 – A11 (approximately 2.37m / 47.15m) = 0.050

Average across the three = 0.077

Visit 2

G8 – E8 (approximately 2.11m / 13.5m) = 0.156

G3 – A3 (approximately 2.12m / 59.9m) = 0.035

F11 – A11 (approximately 2.54m / 47.15m) = 0.054

Average across the three = 0.075

Therefore the average over the recent characterisation (2009/2010) visits was 0.076. The previous (2003) groundwater results indicated a hydraulic gradient of approximately 0.06, and thus this is very similar. All visits indicate a shallower hydraulic gradient towards the Dock Road as the groundwater exits the site in a westerly direction.

The proximity of the site to the Shannon Estuary would suggest the potential for the groundwater on site to be tidally affected, however tidal monitoring undertaken over a 13 hour period in 2003 on boreholes 31, 32, 33, 34 and 11 showed little fluctuation. Most of the boreholes increased in water level over this period by 4 to 6cm, and therefore did not show a 6 hour tidal fluctuation. As the River Shannon is only 100m away, this would indicate that the hydraulic connectivity with the river is low, and therefore the hydraulic conductivity is low in this area.

The hydraulic conductivity of the various units has been estimated from falling head tests undertaken in the boreholes. The hydraulic conductivity within the made ground was recorded during the Parkman site investigation in four boreholes (BH31-34) and found to be 2.1×10^{-8} m/s; 1.3×10^{-8} m/s; 3.7×10^{-8} m/s and 1.8×10^{-10} m/s respectively. In 2009 Mouchel carried out a soakaway test in the made ground, although tests in trial pits are less representative than boreholes, an approximate hydraulic conductivity of 4.11×10^{-6} was calculated. The hydraulic conductivity within the limestone was recorded in the same four boreholes and found to be 1.2×10^{-8} m/s; 1.3×10^{-8} m/s, 3.7×10^{-8} m/s and 2.9×10^{-6} m/s. Arup carried out two packer tests near the surface of the bedrock, identifying a hydraulic conductivity of 9×10^{-6}m/s and $<10^{-12}$m/s. Bedrock was described as a strong, medium grey coarse grained bedded limestone (RQD 87-89%).

The hydraulic conductivity of both the made ground and the limestone are potentially highly variable and therefore the values obtained from a small number of tests should be used with care. The values obtained for the made ground would appear to reflect mainly cohesive conditions, whilst in some areas where the made ground may be more granular, higher hydraulic conductivities may be applicable (as found in the 2009 soakaway test). However the logs mainly suggest a highly granular made ground of limestone and brick rubble, but with a clay matrix decreasing permeability.

For the groundwater risk assessment the hydraulic conductivity of the limestone is important. The test results reflect the variability of the limestone and probably represent rock with either limited fracturing, limited interconnected fractures or filled fractures. However, weathered limestone in the area is reported as being much more permeable (Limerick Main Drainage – verbal communication, see section 2.2). Results of testing of the limestone from the 2.5 km stretch of the new sewer are reported to range approximately from $1x10^{-3}$ m/s to $1x10^{-9}$ m/s. Typical results of packer tests (more accurate than falling head tests) undertaken along the route of the sewer are as follows:

weathered limestone: $1x10^{-5}$ to $1x10^{-6}$ m/sec;

massive rock: $1x10^{-8}$ to $1x10^{-9}$ m/sec.

Adjacent to the site along the Dock Road the Limerick main drain works reported that the limestone was of good quality with very little fracturing, and little water ingressed the works. Based on this observation and the Parkman falling head test results (2003)[12], it would seem reasonable to adopt a figure at the lower end of the permeability range. However, in the interests of maintaining conservatism and because of residual uncertainties a value representing the mean of the overall data set has been selected.

The geometric mean (appropriate for variables with a logarithmic distribution such as hydraulic conductivity) of the full range of permeability data obtained for the limestone is $1x10^{-7}$ m/s. Based on data known to have been obtained from just the weathered horizon, this would appear to be $1x10^{-6}$m/s. This accords with a value from the UK Aquifer Properties database for moderately karstified limestone of 3.3 x 10^{-6} m/s (0.285 m/day). Within the groundwater modelling the geometric mean ($1x10^{-7}$ m/s) was used. As a result, groundwater flow velocities averaging between 50 and 150 m/year can be expected.

One soakaway pit was excavated during the 2009 site characterisation. The material in the pit (a predominantly clayey made ground) appeared to be relatively impermeable as the water level only drained 10cm in three hours. An infiltration rate (f-value) of 0.00025 m/min was calculated from this data. The soakaway log and f-value calculations are presented in the 2009 Site Characterisation Factual Report[13].

3.8 Potential Pollutant Linkages

3.8.1 Characterisation Identified Sources

The 2009 investigation identified several areas of extensive NAPL and ash material and one localised deposit of spent oxide ('Blue Billy').

Based upon visual and olfactory evidence gained during the investigation works, the major primary sources of NAPL encountered during the 2009 investigation have been outlined in the table below (ref Figure 2 and 12) .

Table 3.4 Primary areas of NAPL contamination

General area of site	Cell location	Visually Contaminated horizon from borehole logs (m MHD)	Thickness of heavily contaminated soil (m)	Predominant horizon type	Max Measured thickness of NAPL in BH installation (m)	Approx depth of groundwater (m MHD)
Deep Limestone feature (under Gasholder 2 (T12) and surrounds)	B05	1.48 to 0.98*	0.50	MG: Gravelly clay	-	3.7
	B06	2.65 to 1.45	1.20	MG: Gravelly clay	-	3.7
	B07	2.49 to 1.99	0.50	MG: Gravelly clay	-	3.6
	B08	3.69 to 0.99	2.70	MG: Gravelly clay	-	3.7
	C05	6.37 to 5.87	0.50	MG: Gravelly clay	-	4.5
	C06	4.35 to -0.65*	5.00	MG: Gravelly clay	-	4.1
	C07	4.45 to -0.45*	4.90	MG: Gravelly clay	1.78	4.0
	C08	4.68 to 2.38*	2.30	MG: Clayey gravel	-	3.9
	D05	-	0	-	-	5.2
	D06	-	0	-	-	4.7
	D07	4.60 to 2.30*	2.30	MG: Gravelly clay	-	4.3
			Ave = 1.81			
Pre 1872 tank (T23)	D08	6.22 to 4.22	2.00	MG:Gravelly clay/ gravel	-	4.3
	D09	-	0	-	-	4.1
	E08	-0.16 to -1.16	1.00	Limestone Bedrock	-	4.8
	E09	3.92 to -0.08*	4.00	MG: sandy gravel	-	4.7
			Ave = 1.75			
Former quarry area	E03	3.12 to 1.07	2.05	MG: clayey gravel	-	4.9
	E04	6.10 to 4.68	1.42	MG: oils	-	5.0
	F03	1.35 to 0.35	1.00	MG: gravelly clay	-	5.0
	F06	5.76 to 5.06	0.70	MG: sandy gravel	-	5.5
	F07	6.82 to 6.22	0.60	MG: gravelly clay	-	5.5
	G04	-1.55 to -4.55	3.00	Limestone Bedrock	1.24	5.2
	G05	-0.26 to -3.76*	3.50	Limestone Bedrock	-	5.3
	G06	5.20 to 3.70*	1.50	MG: gravelly sand	-	5.9
	G07	4.24 to 1.24*	3.00	MG: clayey sand	-	6.4
	H06	5.45 to 3.95	1.50	MG: clayey gravel	-	6.5
	I06	6.91 to 1.36*	5.55	MG: clays and gravel	-	6.9
	I07	5.04 to 2.04	3.00	MG: Gravelly clay	-	7.1
			Ave = 2.20			
Booster House	F08	6.98 to 6.48	0.50	MG: gravelly silt	-	6.3
	F09	7.17 to 6.67	0.50	MG: gravelly silt	-	6.1
	F10 WS	6.52 to 6.27	0.25	MG: cobbles	-	5.3
			Ave = 0.4			
Tar tank 7 (T28)	H08	4.15 to 2.95	1.20	MG: gravelly sand	-	6.8
	H09	5.65 to 3.65	0	MG:clayey gravel	-	6.8
	I08	4.11 to 2.81	1.30	MG: gravelly clay	-	7.1
	I09	4.15 to 3.45	0.7	MG: gravelly clay	-	7.0
			Ave = 0.80			
Gasholder 3 (T11) and surrounds	J06	3.48 to 1.98	1.50	MG: cobbles	-	7.4
	K04	1.88 to 0.88	1.00	MG: gravelly clay	-	7.0
	K05	7.64 to 2.64	5.00	MG: gravelly clay	-	7.8
	K06	6.82 to 4.62	2.20	MG: gravelly clay	-	7.6
	L03	3.51 to 2.51	1.00	MG: gravelly clay	-	6.1
	L04	5.26 to -0.74	6.00	MG: cobbles–L'stone	-	6.6
	L05	6.91 to 2.41*	4.50	MG: gravelly clay	-	7.2
	L06	6.91 to 1.61*	5.30	MG: gravelly clay	-	7.3
	M05	2.35 to 0.35	2.00	MG: gravelly clay	-	6.7
			Ave = 3.2			
Pre 1840 tank (T13)	D05	-	0	-	-	5.2
	D06	-	0	-	-	4.7
	E05	-	0	-	-	5.2
	E06	4.83 to 2.83*	2.00	MG: gravelly clay	-	5.3
			Ave = 0.5			
Bord Gais office	F12 WS	0.50 to 1.2	0.70	MG: gravelly clay	-	5.2

*Free phase intermittent throughout stated depth MG = made ground

During the investigation it was apparent that dissolved phase and free phase product may have been transported from these primary sources across the site. Hydrocarbon staining and odours were noted in the majority of locations at the site. Both dissolved and free phase is known to have migrated into the fractured and weathered limestone. This is shown on site photographs obtained during the 2009 site characterisation[13] A basic visual / olfactory assessment of the contamination status of the material encountered was performed during the 2009 site characterisation by IGSL and is reported in the exploratory logs in the 2009 Site Characterisation Factual Report[13]. Where no contamination was identified the logs were annotated with "NEC" – No Evidence of Contamination. These comments are meant as a guide only. The extent of contamination will be assessed in detail in Section 4, using the chemical analytical results.

Based upon visual and olfactory evidence gained during the investigation works, the major primary sources of ash and cinders encountered during the 2009 investigation have been outlined in the table below.

Table 3.5 Primary areas of ash contamination

General area of site	Cell locations where a loose white/cream/grey fine clayey sand (possible ash) was encountered	Cell locations where a loose black/brown clayey sand and gravel (possible cinders) was encountered
Former quarry area	G04, H02, H05, I02, J01, J02, J04, K03	G04, I02, J02, J04, J07, K03. K04
No. 5 stores	L01 WS, M01 WS, N01 WS, N02 WS	L01WS
Bord Gais offices	C12A WS, C12B WS, D12WS	

Localised pockets of ash and cinders were recorded within the top several metres of the site. The most extensive deposits of ash were encountered in cell J02 where a loose black/grey/white (layered) clayey gravel (possible ash and cinders) was recorded from 0.2 – 2.0 m bgl, and in M01 WS where a firm white/grey clay (possible ash) was recorded from 0.5 – 3.9 m bgl.

One localised deposit of suspected 'Blue Billy' was recorded in the soakaway pit (Cells J04/J05) at 1.70 – 2.10m bgl.

3.8.2 Historic Identified Sources

The general findings of the previous investigations were similar to the findings of the recent 2009 site characterisation. The major primary sources of contaminants identified during the historic site investigations were the underground tanks and gas holder wells, in addition to the backfill material within the former quarry. Secondary sources are sorbed phase contaminants in soil, free phase product that has leaked from the primary sources into the soil, or pooled there, dissolved phase contamination in groundwater, and free phase contaminates in groundwater. Both dissolved and free phase is known to have migrated into the fractured and weathered limestone.

Of particular note was Borehole BH7 (1995)[6] which encountered 2m of DNAPL in the groundwater, Borehole BH38A (2003)[12] which encountered 0.54m of DNAPL in the groundwater adjacent to Gas Holder 2 and Borehole BH42 (2003)[12] at Gas Holder 3 that contained 0.18m of DNAPL. Visual evidence of spent oxide ("blue billy") was encountered in the central area of the site (old quarry area), with associated elevated cyanide levels (TP's 33, 39 and 49) see Figure 3.

Identified contaminants typically correlate with the presence of gasworks-derived tars, liquors, TPH, naphthalene and other waste materials located within underground tanks, structures and made ground, together with material used to backfill the quarry.

Degradable fill such as wood may also potentially act as a source of methane and carbon dioxide through its degradation along with biodegradation of the above organic contaminants. Monitoring for these two gases was undertaken during both the Arup (1996[7,8]) and Parkman (2001[10,11] and 2003[12]) site investigations. Elevated methane was recorded in the Arup investigation. However, this was attributed to a leaking gas pipe. No significantly elevated concentrations of methane were recorded in the Parkman Investigations, although elevated concentrations of carbon dioxide were recorded in both investigations. Therefore this was not repeated during the 2009 investigation.

3.8.3 Receptors

The main receptors for contamination at the site are as follows:

Human health

- Current site users including trespassers
- Neighbouring properties
- Future site workers (construction etc)
- Future site occupants

There is no defined scenario for trespassers. However, the US EPA region 4 (south east)[19] considers the typical trespasser to be an adolescent aged 7-16 (10 year exposure duration) with a body weight of 45 kg as representative of this age range. Trespasser exposure frequency should consider site-specific factors such as distance from the site to residences and the attractiveness of the site to the trespasser. Although the site is close to properties it is surrounded by a high wall or palisade fencing, decreasing the opportunity to trespass. Existing site boundaries are summarised below.

Table 3.6 Existing site boundary wall details

Location	Height and type
North east (O' Curry St)	2 – 3.5m high masonry (limestone) wall
South east (Garda training centre)	6m high rock face with 2m high masonry (limestone) wall
South east (residential properties)	3m high brick retaining wall
South west (commercial properties)	2.5m high brick wall
North west (Dock Road)	Up to 6m high masonry (limestone) wall

The boundaries are considered generally secure at present, and although trespassers can gain access over a low wall along O'Curry Street or via the gates on O'Curry Street, there are regular checks on the site by security guards employed by Bord Gais. However, once remediation is completed trespassers will no longer be at risk.

Offsite receptors are the neighboring properties. These comprise commercial properties (offices and pubs) on Dock Road and along St Alphonsus Street. Residential properties including houses with private gardens are found to the south of the site. These are up the hydraulic gradient, and there is no evidence that the gasworks ever extended beyond its boundary. Therefore these houses are not considered a risk. Care should however be exercised during remediation to prevent dust entering these properties or the gardens and contaminating this receptor. Good working practices will prevent this.

Whilst remediation is ongoing there will be construction workers on site. These are covered by health & safety legislation, although the types of contaminants and their risk phrases are required for COSHH assessment. These have not been considered further at this time, as appropriate PPE should be worn coupled with good hygiene practices. We would recommend CIRIA report 132 *'A Guide to Safe Working on contaminated sites'* (1996)[20] should be followed.

Future site occupants could include users of the land as public open space commercial workers, or residents (apartments). Therefore, the risk assessment has considered both a UK standard commercial end-use and residential but without plant uptake (no private garden for vegetable growing and consumption, but the possibility of communal green space), and public open space (a non-standard land use).

Water

- Groundwater in the limestone aquifer below the site
- The River Shannon

The Visean limestone is a locally important aquifer. The area was historically extensively quarried, which will have affected both quality and quantity. Information obtained from the drainage scheme (section 2.2), indicates that the limestone is massive with little groundwater flow at depth, however both the drainage works and the onsite boreholes indicate a weathered zone with fracturing which will transmit water and tars. There are no local abstractions in the area, and due to its closeness to the Shannon, the water quality is brackish.

As stated earlier, the site is only 100m south east of the River Shannon. The river is tidal at this point and saline, therefore all assessments have assumed that it is a marine environment, and where appropriate marine Environmental Quality Standards have been chosen.

3.8.4 Pathways

Human Health

With regard to the future site occupiers whether general public, commercial or residential, the main exposure pathways are:

- Direct contact (dermal) with contaminated soil/dust either indoors or outdoors
- Ingestion of soil and dust derived from site soils either outside, or tracked back into the building to become dust
- Inhalation of dust either inside or outside
- Inhalation of vapours either indoors or outdoors.

The inhalation of dust, ingestion and dermal contact will depend on the amount of hardstanding (tarmac, turf, buildings, etc) and thus the lack of potential for bare soil to be exposed. Such dust primarily poses a risk to future site users, but could potentially impact adjacent residents albeit in very low concentrations during remediation works.

Vapour generation can occur from the more volatile hydrocarbons as well as cyanide and ammonia. This pathway additionally applies to ground gases (carbon dioxide and methane) generated through biodegradation of putrescent material if present within the infilled area, and biodegradation of hydrocarbons. Vapours can migrate through soils and along service ducts into foundations and buildings to accumulate in living and working spaces. Vapours can migrate to outdoor, ambient air, but due to dilution rarely pose a risk in this situation. Vapours can be sourced from soil, free product (e.g. tars) and from dissolved and free phase product associated with the groundwater.

Water

The main pathways for water contamination at the identified receptors are as follows:

- Leaching of contaminants from soils and infiltration into groundwater;
- Leakage of free phase hydrocarbon liquids and dissolution into migrating groundwater;
- Leaching of contaminants directly into groundwater from sources below the water table, particularly in the area of the former quarry;
- Migration of groundwater which is already impacted.

In each case, groundwater contaminants may migrate down hydraulic gradient and potentially migrate off site to impact groundwater and the River Shannon.

Pathways are all likely to be shallow within the limestone since it has been logged as massive at depth, and fractured in the weathered zone. Between the Shannon and the site is the graving dock and the wet dock. The graving dock will have been built to be water tight and therefore flow through the walls towards the Shannon will be prevented or at least impeded. Assuming the wet dock is constructed similarly, this wall may also impede flow and may impact the local groundwater flow pattern.

3.9 Risk Evaluation

Risks associated with the identified potential pollutant linkages are discussed briefly below in the context of the current site condition and future development.

3.9.1 Human Health

Under current conditions the site poses a potential risk to current site users through direct contact with made ground soils and contact with dust (dermal, ingestion and inhalation). The site is however only currently used occasionally by Bord Gais personnel, security and possible rare trespassers. Any screening protective of future site users, will be protective of current Bord Gais users and occasional users.

As stated above, remediation and construction contractors are not considered further as they are covered by Health & Safety legislation, and will wear appropriate PPE. The risks to future site workers are therefore considered to be low.

The site is currently being considered as a public open space, commercial or residential apartments. In a residential scenario, the receptor may have access to communal gardens, but is unlikely to grow and consume their own vegetables there. As they have access to gardens they could be exposed to soils in landscaped areas through dermal contact and incidental ingestion, plus inhalation of dust from bare (unturfed, no hardstanding) soil, and could also be exposed to vapour inhalation, although this would be diluted within the air. This scenario also applies to public open space use. However, residential occupiers would also be exposed indoors to contaminated soil brought in as dust and vapours entering the building.

Based on the discussion above, potential pollutant linkages which require more detailed consideration through quantitative risk assessment have been identified. These are listed in Table 3.7.

Table 3.7 Pollutant linkages requiring further consideration (human health)

Source	Pathway	Receptor
Soil	Ingestion Direct contact	Future site occupiers
Soil dust	Inhalation and ingestion Direct contact	Future site occupiers Adjacent site occupiers
Soil gas / volatiles	Inhalation	Future site occupiers Adjacent site occupiers

3.9.2 Water

Pollution of the Shannon could have a potential effect on freshwater/marine life and potentially on the human environment in respect of contact through swimming or accidental ingestion.

Pollution of the groundwater aquifer may relate either to pollution of the aquifer as a potential resource, or where abstractions or discharges from that aquifer occur, potentially resulting in a secondary impact on either human health or the environment.

The conceptual hydrogeological model is illustrated as part of Figure 9, and shows the potential pollutant linkages associated with groundwater and the River Shannon.

The aquifer is believed to be brackish at this point (based on historic water results[12]) and is not used as a resource, partially due to its low hydraulic conductivity and the water bearing strata being relatively limited (the limestone is massive at depth), therefore for the purposes of assessment, given the close proximity of the River Shannon, the river is considered the receptor and the groundwater a pathway only.

The risk of contamination from the site having a quantifiable effect on the River Shannon itself is negligible due to the extremely high dilution, which the river will provide. In addition, the presence of structures such as the graving dock and the wet dock walls will impact water movement from the site to the river, and may provide a barrier beyond which contamination cannot pass. However, if groundwater at the river bank is considered as a compliance point at which water quality should be suitable for drinking or aquatic life in the river, then both the aquifer and the river will be protected.

Based on the discussion above, potential pollutant linkages which require more detailed consideration through quantitative risk assessment have been identified. These are listed in Table 3.8.

Table 3.8 Pollutant linkages requiring further consideration (water)

Source	Pathway	Receptor
Soil (including free phase hydrocarbons) leaching to groundwater	Groundwater	River Shannon
Groundwater (dissolved & free phase contaminants)	Groundwater	River Shannon

A schematic conceptual site model providing a representation of identified significant pollutant linkages and risks is presented as Figure 9.

4 Human Health Quantitative Risk Assessment

4.1 Introduction

Initially this section presents a description of the derivation of generic screening values, considered to be protective of human health, for each of the three development options being considered (commercial, public open space and residential).

A tier 1 assessment was conducted using the UK EA / DEFRA's CLEA (Contaminated Land Exposure Assessment) and Dutch methodologies.

In addition a tier 2 assessment was conducted, by modelling a potential vapour pathway whereby volatile organic contaminants in the soil and groundwater could represent a risk to future site occupiers and adjacent offsite occupiers. This potential pollutant linkage has been analysed using a RISC4 model as the CLEA analysis does not model the risk of vapours from groundwater/ free phase liquids or to offsite receptors.

4.2 Tier 1 – Human health screening

4.2.1 Methodology

The soil results for 2001[11], 2003[12] and 2009[13] have been compared against generic screening values considered protective of human health.

If the results are lower than the screening values, then the site conditions are considered to be acceptable to end-users; if the site concentrations exceed the screening values then the site may pose a risk. It is assumed that all free phase hydrocarbons will be cleaned up for human health grounds.

With regard to the Dutch methodology, RIVM have published the Dutch Intervention Values (DIVs) (most up to date 2001[21]). In the UK, the Environment Agency & DEFRA have published Soil Guideline Values (SGVs) or Generic Assessment Criteria (GAC), the most up to date SGVs being released April-August 2009[22]. Both represent an *Intervention Value* for <u>chronic</u> health risks above which, a *potential* significant risk to human health exists. This however, does not mean a risk actually exists at this time – there may be site-specific conditions that prevent the risk. They therefore provide a value of soil contamination above which *intervention* should be undertaken to make sure that human health is protected; intervention may be further investigation or remediation. They are not statutory standards that must not be exceeded. Although an SGV is an authoritative, scientifically based value published by the UK Environment Agency, a GAC has no less science applied; it is however derived by a non-Environment Agency source. The Dutch Intervention Values in their turn are also considered authoritative, scientifically based values in the Netherlands.

Due to the large data set created by the 2009 SI, it was impossible to fit every sample on one excel spreadsheet. Therefore, the data had to be split across two spreadsheets One spreadsheet included all samples from rows A-G , the second included all samples from H-L. The mean values of the UCL95s for each spreadsheet were used to produce the UCL95 for the whole site. This same approach was used on the Arup 1996 dataset.

4.2.2 Screening Value Selection

The screening values are generated using generic assessment parameters. In the case of the DIVs, a lifetime (70years) of residential end-use, in the case of the UK SGV/GACs, a child residential end-use or an adult commercial end-use. There is no 'standard' land-use scenario for public open space; therefore Mouchel have used a modified allotment scenario; a child accesses the site for 3 hours a day for 130 days per year, but doesn't live there. The vegetable uptake pathway is not included. These three scenarios are seen as a good starting point to identify if the site could potentially pose a risk to human health, and are all considered conservatively protective.

The UK guidance relies on - "Human health toxicological assessment of contaminants in soil" (SR2)[23] and "Updated technical background to the CLEA model" (SR3)[24]. DEFRA and the Environment Agency have withdrawn all the previous CLR 7-10 documents since these no longer fully reflect the revised approach. CLR7 contained information that is now addressed elsewhere or is covered by other guidance that is available; guidance on statistical analysis has been published by CL:AIRE and CIEH[25]. The Environment Agency has also published a database of chemical information "Compilation of Data for Priority Organic Pollutants for Derivation of Soil Guideline Values" (SR7)[26]. The Dutch guidance relies on RIVM reports 711701 025[21], "Re-evaluation of human-toxicological maximum permissible risk levels", 2001 and report 711701 023, "Technical Evaluation of the Intervention Values for Soil/sediment and groundwater", 2001[27].

Tier 1 screening against recognised generic scenarios was therefore carried out against UK residential without plant uptake (0-6 year old female child living on site), UK commercial worker (16-65 year old female office worker) and the Dutch Intervention Value (0-70 year old residential occupier). Public Open space (a non-standard use) was also included. Therefore the combination of different land uses could be compared as well as the contaminants of concern.

The UK residential scenario assumes that for children up to school age all their time is spent at home, whereas a child of 4 or above will spend 7 hours at school during term time. SR3 therefore assumes that for a 0 to 4 year old, 1 hour is spent in the garden and 23 hours indoors, whereas the 4 to 6 year old spends 19 hours/day indoors and 1 hour in the garden. Surface cover equates to 75%; 25% bare soil. All exposures are for 365 days/year with the exception of the 0 to 1 year old. It is assumed that for the first 6 months of life babies are in cots, thus no dermal contact or ingestion is included. SR3[24] notes that UK research indicates that a usual working week in the UK for the commercial scenario may be more than 45 hours. SR3[24] assumes 45 hours/week as a default with a one hour lunch break that could be eaten away from the desk (possibly outside) for approximately 8.5 months a year; therefore out of a 9 hour day, given the lunch break is outside for only part of the year, a weighted average of 8.3 hour/day is given for indoor exposure and 0.7hour/day for outdoor exposure. The exposure frequency for indoor exposure is therefore deemed to be 230 days a year (5 day week, an assumed period of 20 days holiday plus bank holidays, plus a small 'sick' allowance). Hardstanding and cover is assumed to be 80%, with 20% bare soil.

The Dutch scenario assumes a resident living on site as a child and then an adult for 70 years and eating vegetables grown in their garden, although the scenario does not assumes self sufficiency. The scenario assumes the receptor is outdoors for longer than the UK scenario (1.14 to 2.86 hours per day), but does not assume that this is everyday. The exposure pathways are similar, although it is assumed that the soil contamination can impact groundwater, therefore vapours from contaminated groundwater during showering/bathing and ingestion of water is also included.

The Mouchel Public Open Space scenario, based on a modified UK allotment scenario, again assumes the most vulnerable receptor, the 0-6 year old female child and assumes they visit the site for 3 hours a day for 130 days, decreasing to 65 days as they reach school age. They are exposed to outdoor dust, therefore there is dermal contact, incidental soil ingestion and outdoor inhalation of dust and vapours. It is assumed there is no exposure to contaminants at home.

In all cases it was assumed that free phase will be removed. Where CLEA calculates a value in excess of the soil saturation limit (i.e. the limit at which the soil contaminant is so concentrated that it forms free phase), then the soil saturation limit, is seen as the screening value.

A risk based approach to dealing with contaminated land is based on removing the source, blocking the pathway, or removing the receptor. The different Tier 1 outputs can therefore be used to consider a change of receptor as a remedial option. The analysis was carried out on 321 number of data points form 2009 and 83 historic data points for the majority of inorganics, cresols and PAHs, but not including free phase concentrations. BTEX and TPH/TPHCWG/TPH banding was carried out on all the 2009 data[13], and approximately 60 samples from the historic data set. Depth was not considered since many of the organic contaminants are volatile, and thus could pose a risk from below 1m depth. In addition, the use of the site and therefore the final levels are not confirmed; soil from deeper than 1m could therefore forseeably be encountered at ground level if any excavation or cut is carried out.

4.2.3 Commercial Scenario

The derived human health screening values for a commercial end use was compared with the upper 95% confidence limits (UCL 95) for the chemical test data. Contaminants were the UCL 95 was greater than the screening value indicating site wide exceedances are summarized in table 4.1 below, and screening tables for all analytes are presented in Appendix A.

Table 4.1 Comparison of 2009 human health screening - commercial site wide exceedances

Type	Analyte	Human Health Screening Value (mg/kg)	Upper 95th of mean (mg/kg) (UCL 95)
TPH	Aliphatic C12-16	59	397
PAH	Naphthalene	183	1447
	Acenaphthylene	212	225
	Benzo(a)pyrene	14	80
	Benzo(a)anthracene	95	103

In addition to the site wide contamination identified above by the statistical analysis, the following contaminants were found in excess of screening levels in over half the localities tested:

- PAHs – Dibenzo(ah)anthracene
- PAHs – Benzo(b)fluoranthene
- Benzene

There were also hotspots of the following contaminants:

TPH (aliphatic C5-6, Aliphatic C8-10, Aliphatic C10-12, aromatic C16-21, aromatic C21-35), PAHs (acenaphthene, chrysene, benzo(k)fluoranthene, indeno(123-cd)pyrene), Trichloroethene and lead.

Of these, to note were 2 hotspots and statistical outliers of trichloroethene (TCE) at F09 (123mg/kg) and L05 (41700mg/kg); TCE was not noted elsewhere above the screening value on site. Lead was found above screening at a number of locations, but a statistical outlier were found at H02 (16200mg/kg).

Historic site investigation data showed there appeared to be site wide exceedances of the heavier molecular weight PAHs such as benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, dibenzo(ah)anthracene, (as above), and also benzo(k)fluoranthene, and indeno(123-cd)pyrene. However, statistically, a number of site wide exceedances may be due to only sampling PAHs in the heavier contaminated areas, as much of the sampling was targeted in such areas. The lighter, volatile naphthalene PAH was also found as an exceedance at many of the sample locations. Hotspots of benzene and lead were identified. Hydrocarbons were generally not speciated, however where they were, the exceedances appear to relate again to the mid range aliphatic.

4.2.4 Public Open Space Scenario

The derived human health screening values for a public open space end use were compared with the UCL 95s for the chemical test data. Contaminants where the UCL 95 was greater than the screening value indicating site wide exceedances are summarized in table 4.2 below, and screening tables for all analytes are presented in Appendix A.

Table 4.2 Comparison of 2009 human health screening – public open space site wide exceedances

Type	Analyte	Human Health Screening Value (mg/kg)	Upper 95th of mean (mg/kg) (UCL 95)
PAH	Dibenzo(ah)anthracene	3.9	10.6
	Chrysene	36	79
	Benzo(a)pyrene	4.1	80
	Benzo(a)anthracene	26	103
	Benzo(b)fluoranthene	28	96.4
	Indeno(123-cd)pyrene	17	38

In addition to the site wide contamination identified above by the statistical analysis, the following contaminants were found in excess of screening levels in over half the localities tested:

- PAHs – Naphthalene
- PAHs – Benzo(k)fluoranthene
- TPH – aromatic C21-35
- TPH – aliphatic C10-12

There were also hotspots of the following contaminants:

TPH(aliphatic C8-10, aromatic C12-35), PAHs (phenanthrene, benzo(ghi)perylene), benzene, xylene, lead, arsenic, cyanide, polychlorinated biphenyls (PCBs) and TCE.

Of these, to note were 1 hotspot and statistical outlier of TCE at L05 (41700mg/kg). Lead was found above screening at a number of locations, but a statistical outlier were found at H02 (16200mg/kg), and an arsenic outlier was identified at N01 (370mg/kg). A PCB outlier was identified at J02 (0.00478mg/kg). Cyanide was found at 4 locations only, cells C06, C07, I03 and I05.

Historically the cyanide was identified in TP13, TP22 and TP39 only, and again there were a number of lead exceedances.

The historic PAHs, identified exceedances of benzo(a)pyrene, phenanthrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, dibenzo(ah)anthracene, benzo(k)fluoranthene, benzo(ghi)perylene and indeno(123-cd)pyrene. The lighter, volatile naphthalene PAH was also found as an exceedance only in a small number of samples during the 2003 investigation. Hydrocarbons were generally not speciated, however where they were there were no exceedances.

4.2.5 Residential Without Plant Uptake Scenario

The derived human health screening values for a residential without plant uptake end use was compared with the UCL 95s for the chemical test data. Contaminants were the UCL 95 was greater than the screening value indicating site wide exceedances are summarized in table 4.3 below, and screening tables for all analytes are presented in Appendix A.

Table 4.3 Comparison of human health screening – residential without plant uptake site wide excedances

Type	Analyte	Human Health Screening Value (mg/kg)	Upper 95th of mean (mg/kg) (UCL 95)
TPH	Aliphatic C12-16	59.1	397
	Aliphatic C16-35	21.2	983
	Aliphatic C35-44	21.2	62
PAH	Benzo(b)fluoranthene	7.3	96
	Benzo(k)fluoranthene	10	41
	Benzo(a)pyrene	1	80
	Benzo(a)anthracene	5.2	103
	Indeno(123-cd)pyrene	4.4	38
	Dibenzo(ah)anthracene	0.91	10.6
BTEX	Benzene	0.49	45

The following contaminants are statistically identified as site wide, but in fact are found in just over half the sampling points:
TPH – aromatic C8-10
TPH – aromatic C12-16
TPH – aromatic C16-21
TPH – aromatic C21-35
PAH – naphthalene
PAH – Acenaphthylene
PAH – Fluorene
Methyl phenol - cresol

In addition to the site wide contamination identified above by the statistical analysis, the following contaminants were found in excess of screening levels in over half the localities tested:

- PAHs – Chrysene
- PAHs – Benzo(ghi)perylene
- Xylene
- TPH – aliphatic C5-6
- TPH - aliphatic C8-10
- TPH – aliphatic C10-12

There were also hotspots of the following contaminants:
The PAHs, acenaphthene, phenanthrene and fluoranthene were found as fairly common hotspots, along with cyanide and lead. There was occasional hotspots of TPH(aromatic C35-44), arsenic, 1,2dichloroethane, TCE and carbon disulphide.

Of these, to note were 2 hotspots and statistical outliers of trichloroethene (TCE) at F09 (123mg/kg) and L05 (41700mg/kg); TCE was not noted elsewhere above the screening value on site, and 1,2 dichloroethane at E07 (0.15mg/kg). Lead was found above screening at a number of locations, but a statistical outlier were found at H02 (16200mg/kg), and arsenic was found as two statistical outliers in N01 (370mg/kg) and M04 (127mg/kg). A carbon disulphide outlier was identified at F05 (4.86mg/kg) and there were occasional exceedances elsewhere on site. Cyanide was restricted to the flowing cells C06, C07, F02, F03, F06, F07, F09, G05, G07, H05, I03, I05, I06, J03, J06, L06 and M05.

Historically there appeared to be site wide exceedances of the following PAHs; benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, dibenzo(ah)anthracene, benzo(k)fluoranthene, and indeno(123-cd)pyrene. In addition, most samples exceeded for the more volatile naphthalene. In localities where the PAHs were elevated, there were also exceedances of cresol.

There were additionally localised benzene hotspots, failures of mid to heavy end hydrocarbons and cyanide in the following locations; TP13, TP22, TP24, TP27, TP55, TT54 and BH41.

4.2.6 Dutch Intervention Values – Residential Scenario

The derived human health screening values for a residential without plant uptake end use was compared with the UCL 95s for the chemical test data. Contaminants were the UCL 95 was greater than the screening value indicating site wide exceedances are summarized in table 4.4 below, and screening tables for all analytes are presented in Appendix A.

Table 4.4 Comparison of human health screening – residential (Dutch) Intervention Values site wide exceedances

Type	Analyte	Human Health Screening Value (mg/kg)	Upper 95th of mean (mg/kg) (UCL 95)
PAH	Sum of 10 PAHs	40	2852
BTEX	Benzene	1	45
	Xylenes	25	137
Inorganics	Cyanide	70	473

The following contaminants are statistically identified as site wide, but in fact are found in just over half the sampling points:

- Methyl phenol – cresol
- Phenol
- Mineral oil (sum of TPHCWG)

Lead was found in many sample points in excess of the screening value, but was not site wide. Hotspots were noted of copper, arsenic, zinc, toluene and ethylbenzene. There was additionally a TCE hotspot.

4.2.7 Summary of Tier 1 Human Health Risk Assessment

Potential risks posed to future site users (general public, residents and workers) fundamentally differ to those posed to any current site users, in that future risks can be actively managed during the development of the site by placement of hard cover/ capping layers and incorporation of appropriate venting measures for buildings, as well as by remediation activities. Additionally, using such screening values is conservative for most scenarios since the site conceptual models used in their calculation assume such things as no more than 80% hard cover end-use and long term exposure (in the case of the Dutch Intervention Values – 70 years).

The historic results and the characterisation results found similar contaminants posing an unacceptable risk to each land use. All indicated a risk posed by some or all PAHs, often TPH (although the fraction posing a risk varied), and occasional risks from benzene and cresol, with identifiable areas of the site contaminated by cyanide.

Hotspots of lead were identified and rare exceedances of TCE, carbon disulphide, arsenic, zinc, copper, toluene and xylene. Only the Dutch Intervention Values noted a number of phenol exceedances.

Generally, the degree of clean up increases with the increased intensity and sensitivity of use. Thus the lower volatility PAHs pose a risk for Public Open Space, removing the need to consider the vapour inhalation pathway. However contaminants that are volatile are identified as causing a potential risk for both the commercial and residential pathways.

The metals and inorganic contaminants, the less volatile PAHs (PAHs excluding naphthalene), and the heavier fraction hydrocarbons (C16 and above) could all be addressed by blocking the pathway (i.e. hardstanding, capping layers). Notwithstanding the above, however, risks posed to future site users by volatile compounds in particular, require addressing due to the large quantities of free-phase product identified at the site.

4.3 Tier 2 - Quantitative Vapour Modelling

Qualitative assessment of the site has identified the existence of complete pollutant linkages which can not be significantly mitigated by covering the site with hardstanding or capping layers. Volatile organic contaminants identified in the unsaturated zone (made ground and shallow natural ground) and saturated zone (groundwater) beneath the site could give rise to significant risks to human health for future site users and adjacent offsite occupiers. The CLEA screening takes into account migration of vapours from onsite sources to receptors with regard to indoor and ambient air.

This assumes that the primary pathways of concern are the vertical migration and inhalation of volatile contaminants in outdoor air with a degree of dilution according to windspeed and site area, and indoor air via migration through the floor slabs of future buildings should they be built without appropriate venting and prior remediation of the site. Calculated risks for outdoor air assume that no hard cover is present on the site. However, CLEA does not consider the risk of vapours from groundwater, or the risk from free phase, and does not consider offsite migration of vapours. Therefore, quantitative human health risk assessment modelling has been undertaken using $RISC_4$ (Risk-Integrated Software for Clean-Ups, PB Amoco Oil, 2001), which uses algorithms similar to those present in Risk Based Corrective Action Applied at Petroleum Release Sites (RBCA) for calculating human exposure to contaminants.

4.3.1 Data Input and Assumptions

Chemical data was obtained from the Environment Agency publication SR7[26], 'Compilation of Data for Priority Organic Pollutants for Derivation of Soil Guideline Values', 2008. Where not available, sources recommended within this publication were used to obtain data and the TPHCWG publications, volume 1-5, 1997-99[28]. Toxicity data used within the model for contaminants of concern were obtained from the US Environmental Protection Agency[29], UK Environment Agency[30], TPHCWG[28], RIVM[21,27] and others. Model input data such as soil type, distance from source to receptor, groundwater depth, wind speed, receptor exposure duration, etc. were based on site-specific data where available and on guidance given in the DEFRA/EA publication SR3[24].

Based on the risk assessment for soils (human health) the contaminants of concern as an amalgam of all scenario's with regard to volatility were:

Benzene, Xylene, Naphthalene, TPH (aliphatic C5-6, C8-10, C10-12, C12-16, C16-35, and aromatic C8-10, C12-16, C16-21).

The groundwater monitoring also indicated elevated levels of toluene and ethylbenzene, TPH (as above plus aliphatic C6-8, aromatic C6-7, C7-8, C10-12), but it was not known if these would pose a vapour risk, so these were also conservatively included in the vapour modelling.

Free phase contaminants have been identified within the groundwater beneath the site, primarily in the form of DNAPL and possibly NNAPL (neutral non aqueous phase liquids) tarry materials. Given that DNAPL/NNAPL will require dissolution into the aqueous phase prior to volatilisation into the overlying unsaturated zone it is considered appropriate to model the vapour risks using RISC4, using standard volatilisation equations.

As per SR3[24], for the residential without plant uptake scenario and the commercial worker, the exposure durations were 6 years and 49 years respectively. No vapour risk was identified for the public open space user.

In accordance with the TPH Criteria Working Group Volume 5 report, 1999[28], only non-carcinogenic risks have been calculated for the TPH fractions. Carcinogenic risks associated with volatile TPH compounds have been modelled for benzene only.

The aromatic TPH fraction C5-C7 comprises solely of benzene and has been included to take account of non-carcinogen effects whilst carcinogenic effects only are considered for benzene itself. The aromatic TPH fraction C7-C10 has not been included as it comprises toluene, ethylbenzene, and xylenes; their individual non-carcinogenic effects are calculated separately. This fraction also includes styrene, which has not been identified as a contaminant of concern at the site, the exclusion of which from the modelling is not considered to be significant. The volatile non-carcinogenic PAH, naphthalene is calculated both as the individual compound and within the TPH aromatic >C10-C12 fraction. Xylene is calculated as the meta isomer (*m*-Xylene), as 45-70% of xylene associated with coal tar is this isomer. No TPH fractions greater than equivalent carbon16 have been included due to their low volatility.

Table 4.5 Maximum Source Concentrations

VOC	Status	Maximum Soil Concentration (mg/kg)	Maximum Aqueous Phase Concentration (mg/l)
Benzene	carcinogen	1200	22.8
Toluene	toxic	913	9.1 (1008)
Ethylbenzene	toxic	1050	0.4 (176)
Xylenes	toxic	6010	3.9 (1590)
Naphthalene	toxic	32100	7.3 (23.2)
TPH Aliphatic >C5-E6	toxic	787	0.467
TPH Aliphatic >C6-C8	toxic	220	9.56
TPH Aliphatic >C8-C10	toxic	353	2.96
TPH Aliphatic >C10-C12	toxic	505	9.17
TPH Aliphatic >C12-C16	toxic	10600	1.66
TPH Aromatic >C5-C7	toxic	854	18.9
TPH Aromatic >C10-C12	toxic	758	13.8
TPH Aromatic >C12-C16	toxic	33600	4.23

All readings relate to 2009 data except bracketed readings () = 2003

It should be noted that calculated risks for the site do not take into account the presence of low permeability cover material or hard-standing, which would have the effect of mitigating the migration of volatile contaminants to indoor and outdoor air. Calculated risks for future site use may therefore be conservative, but are dependent upon the form and nature of the development.

4.3.2 Risk Modelling Results

Site specific target levels have been calculated for residential and commercial future users indoors and outdoors from vapours.

Based on inhalation from groundwater approximately 2m below ground level as a conservative assumption, there may be risks to residential children if vapours build up indoors for BTEX, naphthalene and the aromatic hydrocarbons C5-12, and for benzene out of doors. However for the commercial worker, the majority of clean-up values are set at soil saturation, i.e. as long as no free phase is present, there will be no unacceptable risk, with the exception of benzene indoors. It should be noted that the groundwater is flowing offsite in a west direction, albeit slowly, and therefore these risks may also be posed offsite in this direction.

Table 4.6 Site Specific Target Levels (SSTLs) for groundwater (mg/l)

	Benzene	Toluene	Ethylbenzene	Xylenes	Naphthalene
Residential indoor	0.57	640	110	31	2.2
Residential outdoor	730	SOL	SOL	SOL	SOL
Commercial indoor	57	SOL	SOL	SOL	SOL
Commercial outdoor	SOL	SOL	SOL	SOL	SOL

	Aliphatic					Aromatic		
	C5-6	C6-8	C8-10	C10-12	C12-16	C5-7	C10-12	C12-16
Residential indoor	SOL	SOL	SOL	SOL	SOL	20	16	SOL
Residential outdoor	SOL	SOL	SOL	SOL	SOL	SOL	SOL	SOL
Commercial indoor	SOL	SOL	SOL	SOL	SOL	SOL	SOL	SOL
Commercial outdoor	SOL	SOL	SOL	SOL	SOL	SOL	SOL	SOL

NB :Highlighted cells are solubility limits

Assuming that all soil concentrations are identified at 1m bgl (0.85m below building) there is a risk to residential children for indoor air and a risk outdoors from residual benzene, even after all visual free phase saturated soil is removed.

Table 4.7 Site Specific Target Levels for soil (mg/kg)

	Benzene	Toluene	Ethylbenzene	Xylenes	Naphthalene
Residential indoor	0.13	390	120	44	14
Residential outdoor	150	SAT	SAT	SAT	SAT

	Aliphatic					Aromatic		
	C5-6	C6-8	C8-10	C10-12	C12-16	C5-7	C10-12	C12-16
Residential indoor	20	52	13	64	SAT	7.9	120	7100
Residential outdoor	SAT	SAT	SAT	SAT	SAT	SAT	SAT	SAT

NB :Highlighted cells are above saturation limits (i.e. free phase)

4.4 Summary

Intrusive investigations have identified widespread contamination of the site, typically associated with by-products and waste products produced during the former use as a coal-gasification gasworks i.e. TPH, BTEX, PAHs (predominantly associated with coal tars) cyanides and heavy metals.

Qualitative assessment of the pollutant linkages for the site has identified potentially significant risks to future site users and adjacent premises. A tier 1 quantitative risk assessment has been undertaken for onsite future residents (assuming apartments), public open space use and commercial workers and has identified potentially significant risks to site users via dermal contact and ingestion of shallow made ground contaminants across the site and inhalation of dust (and vapours for residential and commercial users), assuming that the free phase is not present (it is remediated/removed). If the site is however used for parkland, the public open space users are potentially at risk via dermal contact, ingestion of shallow soils and inhalation of dust only, if there is no break layer introduced.

A tier 2 quantitative vapour risk assessment has identified risks to onsite receptors, and thus potentially adjacent receptors. Assuming:

a) all free phase within soil and on the groundwater is removed; and

b) the surface soil is capped,

then the risk drivers are primarily for indoor air which can be mitigated with gas protection measures on site.

Offsite properties located down the hydraulic gradient (west / south west) are primarily commercial. Therefore, if free phase is removed and the SSTL for benzene for a commercial land use is adopted (57mg/l) then the risks to adjacent offsite properties should be acceptable.

However, if the current site was used for residential properties, then the following clean-up levels are recommended. These would also reduce long term liabilities associated with the site, and prevent vapour exposure to offsite properties:

Table 4.8 Site Specific Target Levels for soil and groundwater – Residential without plant uptake scenario

Analyte	Soil (mg/kg)	Groundwater (mg/l)
Benzene	0.13	0.57
Toluene	390	640
Ethylbenzene	120	110
Xylene	44	31
Naphthalene	14	2.2

Analyte	Soil (mg/kg)	Groundwater (mg/l)
Aliphatic C5-6	20	SOL
Aliphatic C6-8	52	SOL
Aliphatic C8-10	13	SOL
Aliphatic C10-12	64	SOL
Aromatic C5-7	7.9	20
Aromatic C10-12	120	16
Aromatic C12-16	419	SOL

NB :Highlighted cells are solubility limits

Based upon the findings of the Tier 1 and Tier 2 assessment, the derived Remediation Target Values (RTVs) for soil in respect to human health, for the three development options being considered, are presented in the tables below

Table 4.9 RTVs for soil at ground level for various land-uses

The RTVs assume removal of free phase hydrocarbons. Where the analyte is labelled “SAT” this indicates if free phase is removed this is sufficiently protective of human health.

Analyte	POS (mg/kg)	Commercial (mg/kg)	Residential (mg/kg)
	Removal of Free Phase Hydrocarbons		
Naphthalene	1600	SAT	14
Acenaphthylene	18000	SAT	SAT
Benzo(a)pyrene	4.1	14	1
Benzo(a)anthracene	26	95	5.2
Dibenzo(ah)anthracene	3.9	13	0.91
Benzo(b)fluoranthene	28	100	7.3
Benzo(k)fluoranthene	42	140	10
Chrysene	36	140	97
Indeno(123-cd)pyrene	17	61	4.4
Benzene	75	50	0.13
Toluene	SAT	SAT	390
Ethylbenzene	SAT	SAT	120
Xylenes	SAT	SAT	44
Cresol	3400	2900	12
Phenol	2300	3200	420
Aliphatic C5-6	SAT	SAT	20
Aliphatic C6-8	SAT	SAT	52
Aliphatic C8-10	SAT	SAT	13
Aliphatic C10-12	SAT	SAT	64
Aromatic C5-7	SAT	SAT	7.9
Aromatic C8-10	SAT	SAT	81

Analyte	POS (mg/kg)	Commercial (mg/kg)	Residential (mg/kg)
Aromatic C10-12	6430	SAT	120
Aromatic C12-16	6600	37000	SAT
Aromatic C16-21	5000	28000	1300
Aromatic C21-35	5000	28000	1300
Cyanide	2900	16000	70

Table 4.10 RTVs for soil at depth for various land-uses

Soil at depth is described as material deeper than 1m bgl or material underlying hardstanding. The RTVs assume removal of free phase hydrocarbons. Where the analyte is labelled "SAT" this indicates if free phase is removed this is sufficiently protective of human health.

Analyte	POS		Commercial		Residential	
	Soil mg/kg	Water mg/l	Soil mg/kg	Water mg/l	Soil mg/kg	Water mg/l
Naphthalene	SAT	SAT	SAT	SAT	14	22
Benzene	SAT	SAT	SAT	57	0.13	0.57
Toluene	SAT	SAT	SAT	SAT	390	640
Ethylbenzene	SAT	SAT	SAT	SAT	120	110
Xylenes	SAT	SAT	SAT	SAT	44	31
Aliphatic C5-6	SAT	SAT	SAT	SAT	20	SAT
Aliphatic C6-8	SAT	SAT	SAT	SAT	52	SAT
Aliphatic C8-10	SAT	SAT	SAT	SAT	13	SAT
Aliphatic C10-12	SAT	SAT	SAT	SAT	64	SAT
Aromatic C5-7	SAT	SAT	SAT	SAT	7.9	SAT
Aromatic C8-10	SAT	SAT	SAT	SAT	81	20
Aromatic C10-12	SAT	SAT	SAT	SAT	120	16

5 Groundwater / Surface Water Quantitative Risk Assessment

5.1 Methodology

The EPA[31] classify the Shannon as a transitional water (tidal freshwater), and under the Water Framework Directive[4] (WFD) have identified it 'at risk from not achieving good status'. Its current water quality classification for eutrophication is intermediate. Prior to 1999 the River Shannon at this point was classified as unpolluted. Downstream of the site opposite the Corkanree Industrial estate, the river is a WFD species/habitat area. There is no bathing quality data for this area.

The majority of the ground water is hard, containing calcium bicarbonate (Ca $(HCO_3)_2$). The Parkman 2001 desk study[9] reported iron and manganese have been found in elevated concentrations west of Limerick. Elevated nitrates have been encountered in some locations due to agricultural activities. Groundwater quality of smaller, shallower sources is generally poorer than the larger, deeper sources, so a good water quality in this area was not expected. It is also known to be brackish.

Assessment of the site has identified that groundwater beneath the site within the limestone aquifer has been significantly impacted with dissolved phase phenols, PAHs (naphthalene in particular), cyanides, sulphate, ammonia, BTEX, TPH and heavy metals. Localised chlorinated solvents were identified. Contaminants identified in site soils and free product identified within structures, made ground, quarry fill and groundwater are considered to be the most likely source of this contamination. Free phase hydrocarbons were not tested for within the water samples; therefore the assessment is based on dissolved phase contaminants only.

As the groundwater is considered a receptor, consideration has been given to the EC Groundwater Directive (80/68/EEC)[32] and both its and member states associated Drinking Water Standards (DWS). Member States are obliged to take specific measures to prevent List I substances from entering groundwater and to restrict the entry of List II substances so as to prevent pollution. Under the Groundwater Directive there is a need to undertake "prior investigation" before authorisations to release List I and II substances to ground are granted, and there should also be "requisite surveillance" of groundwater to assess the impact of Authorised discharges. In addition, the European Drinking Water Directive (98/83/EC)[33] was published on the 25 December 1998. This replaces the Drinking Water Quality Directive 80/778/EEC[34]. The requirements of this directive have been transposed into local legislation as Statutory Instruments[35] 81/1988 and 439/2000, 106/2007, 278/2007 and also the document '*Towards Setting Guideline Values for the Protection of Groundwater in Ireland, Interim Report*', EPA[31]. This guidance has been considered with regard to carrying out risk to the aquifer. Where local or EU drinking water standards are not available, World Health Organisation (WHO) values[36] have been considered.

Since the River Shannon is within 100m of the site, groundwater that could potentially migrate and impact the river has additionally been assessed on Environmental Quality Standards (EQS) and associated standards.

Under the EC Surface Water Directive (75/440/EEC)[37] member states are required to lay down Imperative (I) and Guide (G) values for sampling points in rivers where water is abstracted for drinking. Member states must also monitor surface waters to ensure that 95% of surface water samples meet the I values laid down and that 90% of samples meet the G value. In the case of the River Shannon we have not taken account of this in detail due to its tidal nature, however have based the majority of screening on the new EU EQS legislation, 2008/105/EC[38], transposed into Irish legislation by Statutory Instrument 272/2009[39] Where this does not include contaminants of concern, we have referenced the previous Surface Water Directive which was transposed into local legislation by Statutory Instrument 12, Water Quality (Dangerous Substances) Regulations, 2001. Guidance on EQS is also given in the '*Interim Rep*ort' quoted above and in the July 1997 EPA document *'Proposed EQS for specific relevant pollutants in surface water in Ireland, report to the EQS steering group'*.[31]

Where EQS were not available, the EC Freshwater Fish Directive (78/659/EEC)[40] which requires member states to designate freshwaters needing protection or improvement in order to support fish life, has only been considered with regard to ammonium. Where EQS is not available from Irish or EU sources, the Canadian Environment Agency values for aquatic life (CCME)[41] have been considered. This is based on the large body of research work carried out by CCME after Exxon Valdez and also their research work on flooding valleys for Hydro-electric Power.

5.2 Tier 1 Groundwater screening

The dissolved phase contamination was assessed from boreholes across the site, based on groundwater concentrations obtained in 2003 and 2009 only. Due to the proximity of the River Shannon, and the limestone aquifer, screening has been carried out to both DWS and EQS standards.

5.2.1 EQS

Assuming that all groundwater can reach the River Shannon, site wide hydrocarbons, PAHs, cyanide, ammonium, copper and selenium pose a risk to waters, although the latter three only have screening values set for freshwater, rather than marine environments. A large proportion of samples containing the BTEX, phenol, sulphate and chromium also failed for fresh and marine environments, with hotspots identified where arsenic, nickel, zinc and chlorinated volatiles exceeded screening values.

The volatiles generally consisted of the methylated and chlorinated BTEX, however a number of solvents were identified such as tetrachloroethene, trichloroethene, 1,2 Dichloroethane, styrene, 1,1,1 & 1,1,2 Trichloroethane etc. These were predominantly found in K5 in gasholder 3. Styrene was detected during the second monitoring visit at B8 to C7.

With the exception of the chlorinated solvents that were previously not assessed, the 2003 results were consistent with the 2009 monitoring rounds.

Waters were all identified as alkali, as would be expected for limestone groundwater.

5.2.2 DWS

The aquifer rock is relatively thick, however evidence from on site and within Dock Road, suggest that the actual aquifer horizon is relatively thin, being within the more fractured, weathered upper horizons. Electrical Conductivity results obtained historically were high compared to drinking water standards; this may have been due to the brackish nature of the groundwater, or due to the organic contamination.

The phenols, PAH, TPH, cyanide, benzene, sulphate and ammonium values exceeded DWS for the majority of samples.

Many samples contained toluene, ethylbenzene and xylene, but this was not site wide. Within the historic data, the BTEX exceedances were identified spread across the majority of the site, although, there did not appear to be BTEX in the corner of the site with O'Curry Street and the No. 5 stores area (north east corner), where the limestone is very shallow/close to ground level.

It should be noted that both in 2003 and 2009, cyanide values were spread fairly consistently across the site, however, there is less evidence that they are present close to the south-western boundary (towards St Alphonsus Street). A similar pattern for was identified for sulphate and ammonium in 2003, but was less clear within the 2009 results.

Localised arsenic, nickel and selenium were identified as hotspots across the site, with chlorinated solvents as above.

5.3 Tier 2 / 3 Quantitative Risk Assessment

Groundwater risk assessment was undertaken using the UK Environment Agency 'new P20' spreadsheets, which are based on the updated version of the R&D Publication 20 document[42]. This methodology derives Remedial Target Values

(RTVs) for contaminants in soils and in the groundwater that are protective of water resources at specified compliance points.

The approach adopted for the risk assessments is summarised as follows:

- determine appropriate screening values based on the most sensitive pollutant linkages identified in the conceptual model – given the closeness of the tidal river the EQS (marine) was chosen;
- identify potential pollutant linkages to be modelled;
- based on the conceptual model develop model inputs for Tiers 2 and 3;
- compare modelled soil RTVs for soils;
- compare modelled groundwater RTVs to groundwater concentrations; and
- develop risk management strategy to alleviate risks posed by the site.

Due to the brackish nature of the groundwater and the thin (approx. 2m) water bearing (weathered) zone (observed on site and offsite during the drainage work, section 2.2), it was assessed that the aquifer was unlikely to be productive. Furthermore no abstractions had been identified in the vicinity. Therefore the screening value chosen was the EQS, based on the marine value where possible as the river is tidal.

The contaminants considered in the model include those commonly associated with gasworks sites and taking into account those contaminants that failed the initial screening.

Each tier of the model calculates a Remedial Target Value (RTV) for soil or groundwater. Soil RTVs are calculated for Tiers 2 and 3 of the model. Identified free phase product is also likely to exceed soil and groundwater RTVs for the site. Therefore locations where significant quantities of free phase product were observed or contaminants identified within underground tanks have been excluded from the assessment, and clean up assumed. Therefore the RTVs provide values to which residual (dissolved phase) contamination should be cleaned up to.

Groundwater RTVs are calculated for Tier 3 only.

Contaminants, which exceed Tier 3 RTVs, pose a risk for water resources, however in some cases travel times are excessive. For many contaminants, although the RTV is exceeded, the attenuation and retardation that occurs, means that degradation will occur before this contaminant can reach the compliance point 100m away. For those contaminants that will migrate readily, the response is then to consider additional modelling using more site-specific data, or consider remediation options that will remove the source or block the pathway.

Since a good spatial distribution of groundwater contaminant concentrations can be provided for the investigation area, a focus on the exceedences of RTVs for groundwater rather than for soil RTVs is followed, since groundwater is the transport medium for the contaminants.

5.4 Modelling Scenarios

The absence of permeability barriers or confining layers beneath the site, combined with the presence of made ground below the water table suggest that mobile contaminants released from the surface soils will undergo relatively unimpeded vertical migration to the water table. Upon reaching the groundwater, the general direction of transport will be towards the River Shannon, as supported by water table elevations recorded in monitoring wells installed in the limestone aquifer. As such, the model considered the made ground as the unsaturated zone and the limestone as the saturated zone, with site specific parameters used where available. This was then applied to following groundwater scenarios:

- Soil contamination leaching to pore-water and then the leachate in the near surface soils (made ground and natural strata) impacting on the groundwater table and migrating to the River Shannon (Tier 2-3 Soil spreadsheets in Appendix B); and
- dissolved contaminants already detected in the aquifer migrating to the River Shannon (Tier 3 Groundwater spreadsheets in Appendix B).

The distance to the River Shannon is approximately 100 m and therefore a compliance point is proposed within the groundwater at a distance of 100 m from the site. This will, in effect, protect water resources within the limestone aquifer and the river.

5.5 Modelling Input Parameters

Input parameters for the physical properties of the site are provided in Appendix B. These cover the range of parameters required by the spreadsheets to model each tier of the soil and groundwater assessments.

Where possible, site specific parameters were utilised to provide a representative assessment of the local conditions. In the absence of these, reference has been given to published generic parameters in the first instance, with conservative values based on professional judgement adopted only in the absence of more appropriate information.

Specific inputs, which warrant further consideration, are discussed below:

site dimensions - it was assumed that the entire site area formed the contaminant source. In comparison, the conceptual model highlights the former quarry and holder bases as providing the main sources of contaminants, with supplementary contributions from other points of the gasworks infrastructure. Since multiple sources are not considered by the model and the structures are site wide, the entire site dimensions were applied to the models;

infiltration – according to the Geological Survey of Ireland report on the Geology of the Shannon Estuary (report accompanying Sheet 17)[16], annual average rainfall in lowland areas is 850 mm/yr. Infiltration was then estimated to be 7.5% of this, being mid-way in the 5-10% range suggested by Conner *et al*, 1996[43] for sandy soils, based on a 'short-grass' scenario. This number is therefore suitable for Public Open Space, but is conservative if the future use of the site is potentially development as commercial/residential with limited areas of raised gardens and hard cover, which would further reduce infiltration;

hydraulic conductivity – based on the previous data from the site and local environs a hydraulic conductivity of 1 x 10^{-7} m/sec (0.01279 m/day) has been used for the modelling. Even though locally higher conductivities are possible (especially in the karstified limestone), this value is considered reasonable for the average condition;

effective porosity – matrix effective porosity in limestone aquifers is often negligible, in which case interconnected fractures provide by far the main contribution to groundwater flow. Since accurate measurements of fracture porosity are hard to establish, reference was given to BGS Technical Report WD/97/34[44] and a value for bulk porosity (0.012) utilised in the QRA;

distribution coefficient (Kd) –A literature value was chosen (EA SR7[26] database or RBCA database). For organic compounds literature values were used for Koc and the Kd calculated as Koc x foc. For other compounds a Kd of zero was assumed.

5.6 Results

5.6.1 Soil Targets

The model spreadsheets for all contaminants and all Tiers are presented in Appendix B.

Geotechnical assessment has identified two distinct types of soil at the site; granular made ground (generally less than 3 m deep) across the majority of the site and deeper clayey or sandy fill material within the quarry (generally deeper than 3 m). However, at this time, only the granular material has been considered. The majority of the soil and water clean-up values are onerous compared to those for human health, however in many cases the likely travel times are long, enabling further dilution, dispersion, chemical oxidation and biodegradation. The contaminants run at Tier 2 and Tier 3, were all identified as potential sources of concern at Tier 1. Although the PAHs as a group were identified, only Naphthalene was considered as this is significantly more soluble than the other PAHs.

Table 5.1 Tier 3 Soil & Water RTVs

Analyte	RTV Soil (mg/kg)	RTV water (mg/l)	Travel Time to Shannon (years)
Arsenic	21.7	0.0401	310000*
Cyanide	0.217	0.038	6140*
Copper	2.75	0.038	78800*
Chromium	333	0.122	2980000*
Nickel	21.7	0.076	310000*
Zinc	1.8	0.152	12800*
Selenium	0.109	0.0038	31000*
Ammonium	1.39	3.8	313
Benzene	0.17	0.1	297
Toluene	0.096	0.0201	890*
Ethylbenzene	0.206	0.0201	1940*
Xylene	0.206	0.0201	1940*
Naphthalene	0.0356	0.00241	2810*
Fluoranthene	0.828	0.00201	78800*
Phenols	0.188	0.175	364
TPH Aliphatics (C5-6)	0.0575	0.0201	82.2
TPH Aliphatics C6-8))	0.0897	0.0201	162
TPH Aliphatics (C8-10)	0.156	0.0201	394
TPH Aliphatics (C10-12)	0.272	0.0201	965*
TPH Aliphatics (C12-16)	1.1	0.0201	3530*
TPH Aromatics (C5-7)	0.00713	0.0201	39.9
TPH Aromatics (C7-8)	0.00768	0.0201	44.6
TPH Aromatics (C8-10)	0.0149	0.0201	110
TPH Aromatics (C10-12)	0.0169	0.0201	134
TPH Aromatics (C12-16)	0.0215	0.0201	179
TPH Aromatics (C16-21)	0.0334	0.0201	293
TPH Aromatics (C21-35)	57.2	0.0201	546000*

** contaminants in blue cells where the travel time is in excess of 500 years – degradation is likely to have occurred within that time*

The results in the above table indicate that there are likely to be risks to groundwater posed by the presence of elevated concentrations of benzene, in particular, TPH (aliphatics C5 to 10 and aromatics C5 to 21), phenols and ammonium.

The transport of the metals is limited by the hydro-chemical conditions (pH, redox) in the groundwater. Precipitation or co-precipitation of the metals as the dominating process in the aquifer is not considered in the P20 calculations. RTVs calculated for metals are therefore likely to be conservative. Similarly biodegradation of hydrocarbons is not considered and again the RTV's will be conservative; anything with a travel time in excess of 500 years is likely to degrade before reaching the river. It should be noted that travel times are less than 100 years for only three contaminants.

The primary risk to controlled waters is therefore considered to be the presence of benzene, phenol, ammonium and lighter phases of TPH (aliphatic C5-10, aromatic C5-21) identified within the soils and groundwater across the majority of the site.

5.6.2 Groundwater Targets

Major focus is given to the exceedence of the RTVs for groundwater, as it represents the transport medium responsible for the spread of contaminants across the site and towards the critical receptor. It is considered that this approach results in a more realistic evaluation of groundwater quality.

5.7 Discussion of the RTV results

The groundwater risk assessment represents a relatively simplified means of predicting the development of groundwater quality down hydraulic gradient of the site. As stated in section 5.3, groundwater as a receptor was not considered further due to its brackish nature, the thickness of the actual aquifer horizon in the limestone (approximately 2m) and the lack of abstractions. Since the risk assessment has been based on data collected principally from the site but evaluates the potential behaviour of contaminants between the site and the receptor, there is inherent significant uncertainty in the process. Key areas of uncertainty are as follows:

- the natural, extent and orientation of fracturing in the limestone;
- the nature of any fracture infill in the limestone;
- the presence and thickness of the alluvium;
- the likely rates of biodegradation;
- dilution occurring between the site and the river through infiltration;
- the effects of the dock walls.

In general these uncertainties have been accounted for by making conservative assumptions for the model input parameters including: hydraulic conductivity, fraction of organic carbon, hydraulic gradient, and effective porosity. Based on the permeability testing at site, borehole logs and the discussion in the report prepared by Parkman in 2001[10,11], it has been assumed that the fracturing within the limestone only impacts approximately the top 2m of bedrock and the fracturing is not open and continuous; a highly karstic aquifer would exhibit higher permeabilities. Therefore it is not envisaged that there would be large open fractures running between the site and the river as preferential pathways. This is also borne out by the tidal monitoring within the above mentioned Parkman 2001 report; over 13 hours the site did not indicate any tidal influence within the borehole water levels.

The Limerick Main Drainage work additionally provides evidence on the low permeability nature of the limestone adjacent to the site where shaft 6 was sunk. Water was not encountered. The drainage works notes that the massive limestone and alluvium was of low permeability and the water bearing zone was the weathered, upper limestone horizon.

The Tier 2 and Tier 3 modelling assumes unimpeded flow towards the River Shannon and does not consider any dilution on entering the river. As the groundwater table leaves the site at Dock Road, the water table is within the made ground, and based on borehole data, the saturated zone includes the top of the limestone; presumably in the fractured weathered zone. Based on the borehole logs for the site, limestone may be 1.5m to 2m below Dock Road, with the water table between 2m and 2.5m bgl. At this depth it is unlikely to encounter services providing preferential pathways, although previously there was a large sewer in this area. The more recent Limerick Main Drainage Scheme works has constructed a new sewer below sea level, and this encountered massive limestone with no groundwater flow in this area. However invert levels are between -8.5 and -8.9m MHD in this area.

Groundwater flow is in a westerly direction and would encounter the graving dock after passing under Dock Road. Although partially infilled at the north-eastern end, this dock was a water tight dock for ship repairs, which could have been flooded from the wet dock to allow ships to leave once repaired. Based on general graving dock design (approximately 5m deep) and the extrapolation of the water table, this suggests that the top of the water table is approximately half the way down the water-tight dock walls. Therefore this is an impediment to flow. Although a component of flow may be below the graving dock, depending on the fracture size and spacing, only dissolved phase contamination is likely to migrate via this route; any LNAPL will build up along the dock wall or migrate westerly towards the wet dock.

Assuming a south westerly flow, or flow patterns being altered by the graving dock, the next potential impediment to groundwater flow is the wet dock. Potentially, groundwater enters the River Shannon at this point. A detailed study of the dock wall has not been conducted, but it appears to have been constructed of limestone blocks as per the Graving Dock. The dock walls may be of low permeability although they may contain drains or weep holes to allow groundwater to exit.

Thus there may be an outlet for groundwater, through the walls however this is currently not proven. It is likely if weep holes exist then there would be anecdotal evidence of hydrocarbons and tars being identified in the dock. If the walls are of low permeability, groundwater will continue to flow south westerly parallel to the River Shannon until it can exit into the river downstream. Thus it is likely that the flow path of site to river is greater than 100m.

Any increase in flow path will increase dispersion, attenuation and degradation by biological or chemical means, and travel times will be in excess of those calculated for the 100m compliance point. The transport of metals in the groundwater to the receptor in significant concentrations is therefore considered unlikely, since pH and redox conditions in the aquifer are likely to precipitate the metals. Precipitation of metals is not considered in the Tier 3 risk model, nor is dilution between source and receptor, or the effects of adsorption on contaminant mass flux (steady state simulation), hence, the results are considered to be conservative.

For the main contaminants which degrade (organics), the calculated RTVs are highly sensitive to changes in hydraulic and chemical parameters. The most significant parameters are kd, the amount of organic carbon in the bedrock/fractures, bacteria in the groundwater (biodegradation) and contaminant half life, which is dependent on groundwater aerobic/anaerobic conditions. Given the unconfined nature of the aquifer, conditions are likely to be aerobic, increasing the potential for degradation.

Furthermore, contamination has been present at the site for up to 130 years. The groundwater travel time between the site and the receptor is approximately 3 years and 4 months (3.38 years), based on the hydraulic gradient and conductivity. It is therefore unlikely that there is a plume of contamination migrating towards the receptor which has not yet reached it. As yet there has been no noticeable, reported effect on the river quality. It also follows that with regard to pollution of groundwater and surface water by contamination in the ground, the current situation is also the worst-case scenario.

5.8 Summary

The initial groundwater assessment identified that there could be potentially significant risks posed to the River Shannon and the limestone aquifer by the presence of benzene, phenol, ammonium, hydrocarbons (aliphatics C5-10, aromatics C5-8) and to a lesser extent the other lighter aromatic hydrocarbons (C8-21), identified in site soils and groundwater beneath the site.

The hydraulic conductivity and gradient however, suggest that groundwater will take 3.38 years to migrate the 100m, and thus contamination will in most cases take longer, thus allowing for increased degradation and dilution. In addition, the docks (wet dock and graving dock) are likely to impede the flow of groundwater directly to the River Shannon, altering the flow path in a longer, more westerly direction. Thus the travel time will increase allowing for more degradation. Finally, it is possible that the alluvial deposits (predominantly cohesive) encountered near the Dock Road boundary may extend towards the river and be present beneath the river further impeding groundwater flow directly into the river. Therefore although a theoretical risk has been identified, it is unlikely that the site poses an actual risk due to contaminant degradation and increased travel times.

6 Remedial Options Appraisal

6.1 Methodology for Comparative Assessment and Scoring

The conceptual site model outlined in Section 3 and the risk assessments described in Sections 4 and 5, conclude that potentially significant pollutant linkages exist at the Limerick former Gasworks site. Section 5 concludes that although a calculated theoretical risk to the River Shannon exists, it is unlikely to be realised due to contaminant degradation and increased travel distances caused by obstructions such as the dock walls and lower permeability alluvium. Figure 10 identifies contamination levels above the Remedial Target Levels derived from the human health risk assessments (Table 4.9).

There are a multitude of potential remedial methods and techniques available to target the identified pollutants and pathways. The assessment of the most appropriate method for the site has been undertaken using a rigorous and systematic approach based on the process outlined in the Environment Agency Contaminated Land Report 11[45].

The appraisal of the available options has been undertaken in two stages:

Stage 1: Technical pre-screening to arrive at a shortlist of feasible solutions to the risks posed overall and for variously affected parts of Limerick Gasworks. This ensures that detailed consideration is confined to those technical options that are appropriate to the remediation required and the nature of the site.

Stage 2: Detailed appraisal of the shortlist of options.

6.2 Stage 1: Technical Pre-screening

6.2.1 Available Technologies

There are seven fundamentally different technologies available to treat contaminated land. Any assessment of options for Limerick gasworks must therefore start with a pre-screening of these available technologies.

Some technologies involve what is referred to as “in situ” treatment as opposed to “ex situ” which most require. The former means treatment of material in the ground without the need for excavation. The latter requires excavation of the material before feeding it through a process or otherwise disposing of it to a licensed facility.

It should be noted that, many of these technologies are unlikely to present a solution in themselves but might be considered in combination with each other.

The seven technology groups available are as follows:-

Civil Engineering Methods

Capping: This seeks to break the pathway between source and receptor by the introduction of an engineered barrier. It can take the form of a simple capping layer or a fully lined cell totally surrounding the source material. The latter is generally applied where there is a concern about ground water pollution. In the case of a capping layer the source may remain in situ, although sometimes redistribution or regrading of material is required before application of the cap. Generally speaking, a Waste Licence is likely to be required. Surrender of the licence can be difficult to achieve, often only after a prolonged period of monitoring. Other considerations include the durability of the barrier system, which may have a limited design life, after which further remediation work may be necessary.

Excavation and Replacement: This has until very recently been the most common approach in the UK. Contaminated soil is removed and disposed of off site, and replacing it with, in effect, a clean cap. This avoids the potential problem of raised ground levels that the simple cap solution presents. Excavation and replacement also has the advantage that it can be implemented in a shorter time than many other technologies some of which can take months to achieve the required treatment targets. The extent of removal of contamination can be validated as can the quality of replacement imported material. The material removed is most likely to be subjected to another form of treatment, but at another location.

Biological Based Technologies

These are only effective against organic contaminants ie carbon based such as oil or tar. They rely on the ability of these substances to degrade with time and seek to impose the optimum conditions for this natural process. They can be conducted both in situ and ex situ. In the former nutrients are injected into the ground and this is most effective in dealing with leaks from oil tanks etc. The latter is used on soils containing heavier oils or tars.

The three main drawbacks of these technologies are that they take a long time to be effective, may have difficulty in achieving target levels and are not effective against inorganic contaminants such as metals.

The ex situ technique involves excavating soil, placing it in stockpiles and turning these over regularly in order to keep the piles aerated. The stockpiles are regularly tested to see if they are being effective in reducing the organic contamination and by how much. The technique also needs a lot of space and a system to intercept leachate and rain water runoff. Sometimes the stockpiling area has to be roofed or even tented to control ambient temperatures, moisture etc. and prevent odour emissions.

Chemical Based Technologies

This form of treatment involves the use of chemicals to neutralise contamination or make it less mobile. By its very nature it is targeted towards a specific contaminant and so it rarely represents a total solution in itself. Many sites, such as Limerick contain a cocktail of different contaminants and so do not lend themselves to such a limited form of treatment.

Other concerns include whether the chemicals used might themselves be considered contaminants especially if their application might generate dust or odour.

The chemicals need to be thoroughly mixed into the contaminated soil to be effective. The process would require a Waste Licence.

Physical Based Technologies
These are essentially mechanical separation processes and their effectiveness relies on the fact that contaminants are usually present within the fine grained (ie. silt or clay) fraction of soils. They therefore represent a recovery process separating the clean sands and gravels from the dirtier silts and clays. They are less effective on soils consisting primarily of clays or silts.

A common example is referred to as soil washing which is a separation process enhanced by the use of water to recover the cleaner generally coarser materials. The fine fraction is usually disposed of to landfill. It is likely that this process will become a standard form of pre-treatment as required by the European Landfill Directive as a means of reducing tonnages to landfill. The recovered clean sands and gravels can be returned to site or used as construction material elsewhere. The wash water is usually recycled within the plant many times before requiring treatment and disposal.

Soil washing plants are usually designed as genuinely mobile and can be set up on the site requiring treatment. The plant does require a lot of space however and the contaminated and clean materials need to be transported to and from the plant.

Solidification and Stabilisation
This consists of the use of a substance to lock in contaminants rendering them immobile. Examples would be cement stabilisation or vitrification. Sometimes the former is used as a means of physically improving the engineering properties of soils. Recent studies have identified that stabilised soils can remain durable over many years[46].

Vitrification is the surrounding of contaminants by inert glass. It is very expensive and is used in the nuclear industry.

Thermal Based Technologies
Although incineration is sometimes used on tars and the like this group of technologies does not necessarily involve burning. Some soils containing organic contaminants can be effectively treated by a process called low temperature thermal desorption. This is usually done in a fixed plant and the material from the site needs to be transported to the plant which is most likely to be located on the continent. The soil is treated in a large drum (kiln) which is heated and which drives

off the organics. The plants have a sophisticated air quality monitoring system and a major part of the plant is designed to maintain clean air emissions.

The process is expensive and is more commonly used on mainland Europe than in the UK and Ireland.

Monitored Natural Attenuation.
This is an essentially 'do nothing' option in which the products of the processes of nature are carefully monitored so as to be able to predict when certain targets can be reached without direct intervention. The most common situation where this is applied is where organic solvents are present in ground water but the rate of transport is such that they are degrading sufficiently before reaching the receptor, (e.g. a nearby stream). By monitoring the quality of ground water at several positions the aim is to predict whether this situation will persist and therefore if the receptor will remain safe.

6.2.2 Basis of the Technical Pre-screening Matrix

The technical pre-screening matrix contains summary information on the potential applicability of a range of remediation options to particular contaminant–media type combinations.

Remediation options are grouped according to the relevant scientific or technical basis; media type (i.e. whether contaminants are present in soils, made ground or sediments, or in waters); and contaminant type (i.e., whether organic or inorganic substances are being considered).

The matrix gives an indication of the broad capabilities of remediation options. To determine whether a particular option is feasible to apply, and how effective it is likely to be in practice, requires consideration of a wide variety of site-specific factors and a greater understanding of the technical merits and limitations of each option (this is carried out during the detailed options appraisal in Stage 2).

The matrix is based on information contained in Volumes IV to IX (SP 104 to SP 109) of the CIRIA publication, Remedial treatment data sheets, as published by the Environment Agency, other Environment Agency publications on remediation and information sources published by CL:AIRE (Contaminated Land: Applications In Real Environments) (these documents and a comprehensive list of key information sources can be found in part 3 of CLR11[45]).

The matrix covers methods that are commercially available in the UK, Ireland and on mainland Europe at the time of publication – other methods may emerge over time.

The Stage 1 technical pre-screening matrix is included in Appendix C.

6.2.3 Technical Pre-screening Matrix First Stage Elimination

Technical pre-screening indicates that each of the seven general remediation option categories contain methods that are potentially applicable to the primary and secondary contaminants identified at the Limerick Gasworks site.

Therefore, all seven general remediation option categories are to be taken forward to the Stage 2 detailed remedial options appraisal.

It is emphasised that several of the technologies might not be suitable for use on site but might be deployed on the excavated material at another location.

6.3 Stage 2: Detailed appraisal of the shortlist of options

6.3.1 Basis of the appraisal of options

Detailed evaluation criteria are used to test the ability of each feasible remediation option to meet specific remediation, management and 'other' technical objectives.

Since objectives are determined on a site- specific basis, it follows that detailed evaluation criteria should also be specific to the site, although many will be common to most sites.

The scoring categories table below details the definitions of the evaluation criteria (a to k), and the scores (+2 to -2), used for the appraisal of remedial options at the Limerick former Gasworks site.

Table 6.1 Detailed options Appraisal – Scoring Categories

LIMERICK GASWORKS REMEDIATION: STAGE 2 DETAILED OPTIONS APPRAISAL- SCORING CATEGORIES					
SCORE	**+2**	**+1**	**0**	**-1**	**-2**
GENERAL DEFINITION	**Makes a significant contribution to positive outcomes under this criterion and/or provides a very low risk of adverse consequences**	**Makes a generally positive contribution under this criterion or provides a positive balance of outcomes**	**Has little or no direct effect or wider impact on this criterion**	**Some negative impact and/or risk to positive outcomes under this criterion**	**Significant negative impact and/or significant risk to positive outcomes under this criterion**
a) Track Record for former Gasworks sites	Well proven record, used extensively on gasworks	Good record of use on gasworks	Some use on gasworks	Limted use on gasworks	Very limited or no track record
b) Site Constraints (size of site, access, services location, structures on site etc)	None	Few constraints easily resolved	Some constraints, can be resolved	Some constraints difficult to resolve	Significant constraints, dificult to resolve
c) Effectiveness of Remediation Technology (in relation to the treatment of primary and secondary contaminants and the physical nature of the material) Given a x2 weighting.	Very effective in dealing with all contaminants	Effective in dealing with most contaminants	Effective for some contaminants ineffective for others	Ineffective for most contaminants	Ineffective for all contaminants
d) Technical Constraints: availability of technology and other physical resources.	Excellent availability	Good availability	Some availability	Limited availability	Poor availability
e) Durability of Remediation Technology	Excellent durability, no long term issues	Good durability	Some durability	Limited durability	Not durable
f) Validation and Auditability	Very easy to validate and audit	Easy to validate and audit	Some difficulties to validate and audit	Difficult to validate and audit	Very difficult to validate and audit
g) Adverse Environmental Impacts (Safety, Health & Environment)	Insignificant impacts	Few impacts	Some impacts	Many impacts	Significant impacts
h) Regulatory Constraints (permits, licenses, planning etc)/ likely view of EPA. Given a x2 weighting.	No constraints/very postive view from EPA	Few constraints/positive view from EPA	Some constraints/neutral view from EPA	Many constraints/negative view from EPA	Significant constraints/very negative view from EPA
i) Cost. Given a x2 weighting.	Very Low (no plant required)	Low (some plant needed e.g. in-situ methods)	Medium (simple ex-situ methods)	High (complex in-situ methods)	Very High (remove and export)
j) Time Constraints	Very Short (less than a month)	Short (1-3 months)	Medium (4-6 months)	Long (7-11 months)	Very Long (more than 12 months)
k) Carbon footprint (as a measure of sustainability)	Very Low (low/no plant usage or import of material)	Low (some plant needed e.g. in-situ methods)	Medium (simple ex-situ methods)	High (complex in-situ methods)	Very High (remove and export)

6.3.2 Weighting of Scores

Where particular site specific evaluation criteria are considered to have a significant bearing on the suitability of a remediation option, these criteria are given a ‘weighting’, i.e. the scores for that criteria are multiplied by a factor considered appropriate for the importance of that criteria.

In the case of the Limerick former gasworks site, the following evaluation criteria have been given a weighting factor of two;

c) Effectiveness of Remediation Technology (in relation to the treatment of primary and secondary contaminants and the physical nature of the material)

h) Regulatory Constraints (permits, licenses, planning etc)/ likely view of EPA.

i) Cost

The complete Stage 2 detailed options appraisal matrix is included in Appendix C.

6.3.3 Preferred Remediation Options

The detailed options appraisal concludes that the following remediation options are the most appropriate for the Limerick former Gasworks site (highlighted green in the matrix)-

- Pump and Treat
- Solidification/ Stabilisation Ex-situ
- Solidification/ Stabilisation In-situ
- Thermal Based Technologies (Thermal desorption or incineration)

The preferred options are taken forward and developed in Section 7 'Remedial Strategy'.

7 Remediation Strategy

7.1 Introduction

The risk assessment as described in the Sections 4 and 5 has identified likely significant risks posed to future site users (public open space, commercial and/or residential without gardens) from shallow soil contaminants and toxic and carcinogenic volatile organic contaminants beneath the site. Remedial Target Values (RTV's) have been derived as identified in Tables 4.9 and 4.10 for shallow soils and deep soils respectively. It is noted that free phase hydrocarbons were not tested for within the water samples; therefore this assessment has been based on dissolved phase contaminants and any free phase liquids will need to be removed as part of the remedial works.

The remedial options appraisal described in Section 6 has determined that one or a combination of pump and treat, solidification/ stabilisation and thermal treatment techniques should be adopted to mitigate the identified risks and require the removal of significantly contaminated areas (i.e. free phase contaminants in the Made Ground and within underground structures).

The following sub-sections discuss specific site constraints which must be considered in designing remediation works, present details of the proposed remediation processes and describe the likely sequencing of the remediation activities.

It is anticipated that the works would be undertaken in accordance with a Waste Licence to be obtained from the EPA. Planning permission may also be required although it is possible that such permission would not be required for the remediation works themselves if any demolition works had already been undertaken.

7.2 Site Constraints

The following site constraints have been identified as requiring due allowance in the design of the remediation works. Reference should be made to Figure 12 identifying the locations of all identified site constraints.

- **Unstable Boundary walls/ steep slopes**

  A significant proportion of the boundary walls are considered to be unstable. These include the following:-

1) Dock Road wall (north western boundary) - this is constructed of masonry limestone blocks and is up to 6m in height. It has Protected Status. It is currently being stabilised by the use of buttresses placed on the site side of the wall.

2) Brick boundary walls (south western and south-east) – these are currently being stabilised by the use of gabion baskets covered in 'shotcrete' placed on the site side of the walls (Grid cells G12, H12, I12, L12, L11 and L10). The walls vary in height between approximately 2 and 4m.

3) O'Curry Street wall (north eastern boundary) – this acts as a retaining wall to the pavements/ services on O'Curry Street and has a steep slope in front of it on the site side of the wall (Grid cells H1, I1 and J1)

Further temporary works may be required to provide additional support to these walls prior to excavation works in their vicinity depending on the depth of excavation required. If deep excavations are required, then some form of retaining structure may be necessary. Options would include sheet piling (although this would not be appropriate where rock is shallow) or the placement of gabion baskets or other form of supporting structure. For shallower excavations, it may be possible to excavate up to the toe of the slope in short panels, backfilling one panel before starting to excavate the next.

- **Restricted Access**

It is possible that access to and from the Dock Road may be problematic due to heavy traffic and visibility issues. The traffic issue may be relieved by the opening of a new tunnel transferring traffic away from the city Centre prior to the remediation works commencing. The only other available access is from O'Curry Street and this road isn't particularly wide.

- **Retained Structures**

Several structures will need to be retained on site and works will need to be designed to allow any remediation required to be undertaken as close as possible to the structures. It is assumed that most existing structures on-site such as the Governer House, Booster House and some internal walls will be demolished prior to remedial works commencing. It is also anticipated that the AGI (Above Ground Installation) will be relocated off site but that a new DRI (District Regulator Installation) and a new ESB sub-station (to replace the existing one) will be cited at the boundary with O'Curry Street. Therefore, the retained structures will comprise:-

1) ESB electricity sub-station & DRI (District Regulator Installation) – to be located at the boundary with O'Curry Street. It is anticipated that contaminated materials will be removed to a depth of 1m beneath these structures and in the adjacent grid cells C1, D1, E1 and F1, prior to backfilling with clean imported granular fill. Significant contamination was not identified beneath 1m depth.

2) No. 5 Store (Generator Building) - a Protected Status. This is a large masonry building which has a large underground tank associated with it which extends to the south-west of the building. Significant contamination has been identified in the vicinity of this structure.

3) Bord Gais offices - .No significant contamination was identified during the characterisation works undertaken in December 2009 and consequently these two storey offices are proposed to be retained for use as site accommodation during the remediation works.

- **Known Underground Tanks**

Numerous underground tanks are known to be present on site; the significant ones are highlighted on Figure 12. Details of the tanks are presented below. All these tanks with the exception of T34 are known to be backfilled with materials predominantly contaminated with coal tars (sometimes as free phase). T34 is known to be partially backfilled with standing water present. Approximate volumes of free product have been calculated by using an estimate of the depth of free product encountered in exploratory holes and assuming a voids ratio of 30%. Estimated depths of free product are calculated in Table 3.4. Where no holes have been positioned within a tanks boundary, volumes of free product have been estimated assuming a voids ratio of 30% of the volume of the tank.

Table 7.1 Details of significant underground tanks

Tank Number & Age	Approximate Diameter	Approximate Depth of tank (source of data)	Approximate Volume of tank	Backfill?	Void space within soils where free product could be present * (source of data)
T7 (pre-1919)	6m	1m (Arup 1996 TP14)	30m^3	yes	0m^3 (Arup 1996 TP14)
T11 (Pre-1902) Assumed 'dumpling' at base	25m	6.0m (Mouchel 2009 J06, K04, K05, K06, L04, L05, L06, M05, M06)	4200m^3	yes	250m^3 (Mouchel 2009 ave of J06, K04, K05, K06, L03, L04, L05,L06,M05)
T13 (Pre -1840)	10m	3.2m (Mouchel 2009 E06)	250m^3	yes	50m^3 (Mouchel 2009 E06)

Tank Number & Age	Approximate Diameter	Approximate Depth of tank (source of data)	Approximate Volume of tank	Backfill?	Void space within soils where free product could be present * (source of data)
T14 (Pre-1840)	3m	2m (professional judgment)	21m^3	unknown	10m^3 (assuming 30% void ratio)
T15 (Pre – 1840)	10m	4.8m (Mouchel 2009 E07)	375m^3	yes	0m^3 (Mouchel 2009 E07)
T23 (Pre -1872)	19m	5m (Mouchel 2009 E08, E09)	1420m^3	yes	150m^3 (Mouchel 2009 D08,E08, E09)
T28 (Pre-1872)	16m	4m (Mouchel 2009 H09, I08, I09)	800m^3	yes	50m^3 (Mouchel 2009 H09, I08, I09)
T34 (Pre-1919)	4m x 13m (rectangular tank)	>2.3m (O'Connor 1995) 3m (professional judgment)	156m^3	partial	top 2.3m bgl = 0m^3 (O'Connor 1995) >2.3m blg Unknown as base of tank not found (no gross contamination expected)
				Total	**510m^3**

*Estimated depths of heavily contaminated material are presented in Table 3.4

Based on this assessment the likely volumes of 'pumpable' free product will be in the order of 60m^3

- **Former Quarry and Deep Limestone Feature**

An extensive former quarry is known to be present over the eastern half of the site as indicated on Figures 4, 5, 11 and 12. The quarry is up to 10m deep and backfilled with predominantly cohesive material. Free product is present at its base (grid cells F03, F06, F07, G04, G05, G06, G07, H06, I06 and I07). The quarry is shown as extending outside the boundary of the site in historical maps which appeared to be confirmed during the characterisation investigation as the edge of the quarry could not be located near the O'Curry Street boundary.

A deep area of made ground was identified by the ground investigations under the former large gasholder no. 2 (T12) although this is known to have been an above ground gasholder. It appears that a deep limestone feature is present at this location and free product has been identified at the base of the made ground in grid cells B05, B06, B07, B08, C05, C06, C07, C08, D05, D06 and D07).

Volumes of voids where free product could be present within the former quarry and deep limestone feature are estimated to be 800m^3 and 450m^3 respectively assuming a 30% voids ratio. However, volumes of 'pumpable' free product are likely to be in the order of 80m^3 and 60m^3 respectively.

- **Limestone Outcrops**

It is noted that limestone outcrops near the south-eastern and north-western boundaries of the site and is identified on Figure 12. In particular, a limestone face, up to 8m in height, is present along parts of the south-eastern and north-western boundaries.

7.3 Phase 1 Remediation Works

It is anticipated that the first phase of any remediation works will require the removal of free phase liquids. These liquids generally comprise coal tars (predominantly dense non-aqueous phase liquids (DNAPL)) and are present at the base of several underground tanks, within the quarry area and the deep limestone feature. The preferred option for removal of the DNAPL has been identified as pump and treat technology.

One such technique, which has a proven track record on former gasworks sites, involves the installation of wells, generally spaced at 4-5m centres, to intercept the DNAPL. Direct pumping may be possible depending on the viscosity of the DNAPL but it is probable that heating of the DNAPL will be required which reduces its viscosity and facilitates removal by pumping. Water heated to approximately 70^{o}C is pumped into some of the wells and extracted through others over a period of several weeks. The extracted mixture of water and DNAPL is separated in oil/ water separation tanks. The DNAPL is placed in IBC's (intermediate bulk containers) or similar prior to removal from site. It is possible that this material can be recycled and this has been successful at some sites in the UK or it will require disposal which would generally be undertaken using a thermal process (incineration). The water is 'cleaned' through a water treatment process prior to either reuse or disposal to foul sewer under an appropriate licence. It is anticipated that approximately 90% of free phase liquids can be removed using this process; the remaining 10% would be the most viscous fraction and hence the likelihood of any migration of remnant materials would be extremely small. The whole process is closed and hence the release of odours is minimal.

There are other pump and treat technologies available and the advice of specialist contractors should be sought to assess the suitability of their proprietary techniques to the contaminants identified on site.

Approximate quantities of DNAPL present within underground structures are presented in Table 7.1 above.

It is estimated that a total volume of DNAPL requiring removal from site for recycling/ disposal (including DNAPL within the former quarry/ deep limestone feature) will be approximately 200m^3.

7.4 Phase 2 Remediation Works

In order to comply with the Remediation Target Values (RTV's) for surface soils as calculated by the human health risk assessment and presented in Table 4.9, it will be necessary to provide a form of cover layer to the site.

The options appraisal has identified that the preferred solution to comply with this requirement would comprise some form of stabilisation/ solidification technique. It is proposed that this technique should treat the uppermost 3m across the entire site except where site constraints preclude its use or limestone is encountered at shallower depth. This would ensure that the majority of underground structures are removed to facilitate the possible future redevelopment of the site. It would also identify and allow other free product present within this 3m depth to be removed. Any remaining obstructions could be surveyed to record their exact locations for future reference. These underground structures/ foundations etc would be crushed and reused, where possible, as a clean capping layer. It is anticipated that this may be some 0.5m deep and would have the benefit of allowing potential future services to be placed in clean fill. In addition, any future commercial/ residential (apartments) development requiring an underground car park would only need to remove stabilised material although appropriate disposal options would need to be considered.

Any groundwater encountered during the excavation process would need to pass through a water treatment plant prior to disposal to foul sewer under an appropriate discharge licence obtained from the drainage authority.

Excavations would be undertaken on a grid by grid basis using the chemical analysis results obtained from the characterisation works to determine treatment streams. These may include 'clean' material requiring no treatment (which could be used as a capping layer together with crushed material), material requiring stabilisation/ solidification or possibly highly contaminated material. In the case of the highly contaminated material, it may be more cost effective to remove this material from site for disposal/ treatment rather than add large quantities of binder to try to stabilise them. Likely treatment options for coal tar contaminated material would involve low temperature thermal desorption.

The volume of material requiring stabilisation/ solidification is estimated to be in the order of 32,500m^3.

Sophisticated stabilisation/ solidification plant is now available and has been used in the UK and Ireland. The plant allows excavated contaminated soils to be placed on conveyor belts, weighed and mixed thoroughly (using paddle mixers) with appropriate binders prior to replacement in the excavations. The binder has to be designed by specialist contractors but would usually comprise cement, pfa (pulverised Fuel ash) or a mixture, added by approximately 5-10% by weight. The strength of the stabilised material can also be designed to provide good geotechnical properties. Granular materials re usually easier to treat than cohesive materials as thorough mixing of the binder is more easily achieved and this may be problematic for the quarry backfill which is predominantly cohesive. It is possible that mixing of the granular and cohesive materials may be required prior to introducing the binder.

It is noted that odour emissions during the mixing process are generally low as a 'hood' fits over the mixing tank where air is extracted from the process and passed through carbon filters prior to minimise any odour emissions. Furthermore, as the majority of free product will have already been removed during the Phase 1 works, odour emissions from excavations will also be reduced.

In-situ stabilisation/ solidification is considered more problematic than an ex-situ process due the large number of obstructions present in the made ground, identified during the previous ground investigations undertaken.

Testing of the capping material would be undertaken to check that soil RTV's (as detailed in Table 7.2 below) are achieved. Likewise, stabilised material would be tested to check that leachate RTV's (also detailed in Table 7.2 below) are achieved. The leachate values quoted directly correlate to the leachate potential of the soil concentrations in accordance with the Remedial Targets Methodology; Hydrogeological Risk Assessment for Land Contamination (2006) published by the Environment Agency[42].

Table 7.2 RTV's at Ground Level for various land uses

	POS		Commercial		Residential	
	Soil (mg/kg)	Leachate (mg/l)	Soil (mg/kg)	Leachate (mg/l)	Soil (mg/kg)	Leachate (mg/l)
Benzene	75	47.8	50	32	0.13	0.08
Toluene	1920	432.8	1920	433	390	88
Ethylbenzene	1220	128	1220	128	120	13
Xylene	1120	118	1120	118	44	4.6
Phenol	2300	1218	3200	1695	420	222
Cresol	3400	4065	2900	3467	12	14.4

	POS		Commercial		Residential	
	Soil (mg/kg)	Leachate (mg/l)	Soil (mg/kg)	Leachate (mg/l)	Soil (mg/kg)	Leachate (mg/l)
Naphthalene	1600	117	183	13.4	14	1
Fluorene	12000	202	69000	1163	76.5	1.3
Fluoranthene	3800	10	23000	60.2	990	2.6
Phenanthrene	3700	32	22000	190	930	8.1
Pyrene	9100	26.71	54000	159	2400	7.04
Anthracene	90000	761	540000	4568	2200	18.6
Acenaphthylene	18000	469	212	5.5	212	5.5
Benzo(ghi)perylene	210	0.02	660	0.08	47	0.005
Benzo(a)pyrene	4.1	0.0015	14	0.005	1	0.00037
Benzo(a)anthracene	26	0.0159	95	0.058	5.2	0.00319
Dibenzo(ah)anthracene	3.9	0.001	13	0.003	0.91	0.00023
Benzo(b)fluoranthene	28	0.0127	100	0.046	7.3	0.00332
Benzo(k)fluoranthene	42	0.0135	140	0.045	10	0.003
Chrysene	36	0.0312	140	0.121	97	0.084
Indeno(123-cd)pyrene	17	0.009	61	0.033	4.4	0.002
Ammonium	18#	30**	18#	30**	18#	30**
Sulphate	-	1400*	-	1400*	-	1400*
Chloride	-	2000**	-	2000**	-	2000**
Cyanide	2900	289	16000	1593	70	7
Arsenic	130	0.26	640	1.3	35	0.07
Cadmium	290	2.9	230	2.3	84	0.84
Chromium III	43000	9	30400	6.3	3000	0.62
Chromium VI	120	6.6	35	1.9	4.3	0.24
Copper	38000	380	71700	716	6200	62
Lead	450	0.2	750	0.3	450	0.2
Mercury (inorganic)	960	2	3600	7.2	240	0.48
Nickel	2900	5.8	1800	3.6	130	0.26
Zinc	150000	3940	665000	17435	40000	1049
Aliphatic C5-6	558	210	558	210	20	7.5
Aliphatic C6-8	322	77.7	322	78	52	12.6
Aliphatic C8-10	190	26.4	190	26	13	1.8
Aliphatic C10-12	118	9.4	118	9.4	64	5.1
Aliphatic C12-16	16000	315	59	1.2	59	1.2
Aliphatic C16-35	320000	0.027	1800000	0.15	21.2	0.000002
Aromatic C5-7	2260	6858	2260	6858	7.9	24
Aromatics C7-8	1920	5412	1920	5412	1300	3664
Aromatic C8-10	1500	2182	1500	2182	1500	118
Aromatic C10-12	6430	8250	899	1154	120	154
Aromatic C12-16	6600	6640	37000	37221	419	1610
Aromatic C16 - 21	5000	3242	28000	18152	1300	843
Aromatic C21-35	5000	1.9	28000	11	1300	0.49

odour thresholds
Shaded – Saturation Limit

*BRE, 2005, 'Concrete in Aggressive Ground', Special Digest 1,Third edition. Based on concrete classification of DC-2

** EA/BRE, 2000 'Risks of contaminated land to buildings, building materials and services: A literature review', Report P331, quotes both ammonium at <30mg/l as slightly aggressive (quoted from an original source of BS EN 206-1, and chloride at 2000mg/l.

7.5 Sequence of Operations

In fulfilling the Remediation Strategy, the scope of the work to be carried out by the Contractor shall include the following:-

- Provision of safe access/ egress from the site with appropriate signage.
- Further temporary works to support the site boundary walls/ fencing.
- Set up site accommodation, wheel wash etc.
- Phase 1 remediation works comprising the extraction and disposal of DNAPL from underground tanks, former quarry area and deep limestone feature (as described in Section 7.3 above).
- Provision of any additional support to existing unstable walls and groundwater control measures required to enable excavation/remediation to the desired depth (approximately 3m).
- Excavation and crushing of old foundations and slabs (crushing may be permitted off site at a suitably licensed facility).
- Excavation, screening and sorting of soils on site into suitable and unsuitable materials. Some mixing of cohesive and granular materials may be required to obtain a suitable material for stabilisation.
- Phase 2 Remediation works to stabilise suitable materials from the uppermost 3m (as described in Section 7.4 above)
- Disposal of any contaminated materials unsuitable for stabilisation/ solidification.
- Treat waters from the site and dispose to sewer, under licence.
- Backfilling using suitable material from site, plus imported fill, if required.
- All necessary control of noise, dust, odours etc emanating from the works. It is anticipated that odour nuisance will be minimised by the remediation techniques being proposed.
- All necessary monitoring, geotechnical and chemical proof testing.
- All necessary Safety, Health and Welfare measures.
- Compliance with the Conditions of the Waste Licence.
- Obtaining and comply with permits for waste collections.
- Obtaining and comply with any other permits, licences etc., necessary.

8 Conclusions/Recommendations

8.1 Conclusions

1. The site has been subject to five ground investigations undertaken between 1995 and 2009[6-13]. The most recent investigation was the most comprehensive and comprised the excavation of 132 sonic drilled boreholes on a 10 x10m grid across the whole site. All boreholes penetrated 3m into limestone bedrock and samples were retrieved at 1m intervals for laboratory analysis. This allowed a comprehensive model to be developed of the physical and chemical conditions present on site.

2. Significant free phase product was identified within underground tanks and the former quarry. Assessment of the site has identified that groundwater beneath the site within the made ground and limestone aquifer has been significantly impacted with dissolved phase phenols, PAHs (naphthalene in particular), cyanides, sulphate, ammonia, BTEX, TPH and heavy metals. In addition to the organic contaminants in soil and water, visual evidence of spent oxide was encountered in the central area of the site (old quarry area), with associated elevated cyanide concentrations, and soil samples over the majority of the site contained high concentrations of sulphate, ammonia and metals, particularly lead with minor components of arsenic, chromium, nickel, copper and zinc.

3. Potential Pollutant Linkages with respect to human health have been assessed to comprise:-
   - Ingestion/ direct contact of soil for future site occupiers
   - Inhalation/ ingestion/ direct contact of soil dust for future site occupiers and adjacent site occupiers, and
   - Inhalation of soil gas/ volatiles for future site occupiers and adjacent site occupiers.
4. Potential Pollutant Linkages with respect to water have been assessed to comprise:-
   - Soil (including free phase hydrocarbons) leaching to groundwater impacting the River Shannon, and
   - Groundwater (dissolved and free phase contaminants) impacting the River Shannon.

5. A human health risk assessment has derived Remediation Target Values (RTV's) using generic assessment parameters, for each of the three development options being considered (commercial, public open space and residential apartments). The assessment has included consideration of a potential vapour pathway whereby volatile organic contaminants in the soil and groundwater could represent a risk to future site occupiers and adjacent offsite occupiers.

6. A groundwater risk assessment has been undertaken which concludes that, although a theoretical risk exists in respect to the River Shannon, this is unlikely to be realised due to the timescales required for contaminants to flow to the receptor, the presence of the underground obstructions (dock walls etc) and the possible presence of cohesive alluvial deposits in the vicinity of the river. It is concluded that the limestone aquifer is not productive due to the brackish nature of the groundwater, the thin water bearing stratum (in the near surface weathered zone) and the lack of any abstractions within the vicinity of the site. Free phase hydrocarbons were not tested for within the water samples; therefore this assessment has been based on dissolved phase contaminants only.

7. A Detailed Options Appraisal identified that the three preferred remediation options to address the risks identified by the risk assessments are:-
   - Pump and treat
   - Solidification/ stabilisation (ex-situ or in-situ)
   - Thermal based technology an options

8. The preferred remediation options have been adopted to produce a remediation strategy using a two phase approach.

   Phase 1 comprises the removal of free phase liquids, predominantly dense non-aqueous phase liquids (DNAPL) by Pump and Treat techniques. One such method comprises the installation of wells to intercept the DNAPL whereby water is heated and pumped into some of the wells and extracted through others over a period of several weeks. The extracted mixture of water and DNAPL is separated with the DNAPL being collected in IBC's (International bulk carriers) or similar prior to removal from site for recycling or disposal (possibly incineration). Water is cleaned and reused. The whole system is closed and hence release of odours is minimal.

   Phase 2 comprises the ex-situ stabilisation/ solidification of the uppermost 3m of made ground (or shallower where rock is encountered) to achieve RTV's for surface soils and to remove the majority of underground structures and remnant free product from site. Sophisticated plant is available to allow thorough mixing of excavated materials with appropriate binders to ensure that the stabilised materials comply with specified leachate criteria.

   A number of Site Constraints have been identified which will need to be addressed at detailed design stage. These include unstable boundary walls/ slopes, structures to be retained on site, known underground tanks and the former quarry.

   It is estimated that a volume of some 200m^3 of DNAPL will require removal from site for recycling/ disposal with a volume of some 32,500m^3 requiring stabilisation/ solidification.

8.2 Recommendations

1. Undertake some further preparatory works on site prior to remediation works commencing. These include:-
   - Demolition of the Governor House, Booster House and connecting internal walls.
   - Relocation of the AGI (Above Ground Installation) off-site.
   - Construction of a DRI (District Regulator Installation) together with the relocation of the ESB sub-station near the boundary with O'Curry Street. Some preparatory works may be required at these locations.
2. Undertake some further sampling of soils in the vicinity of the AGI once it has been relocated off site to complete the detailed characterisation information. This area has previously been inaccessible for ground investigation. Excavations could be undertake by trial pitting or window sampling techniques.
3. Obtain some large bulk samples of contaminated soils to undertake bench trials to allow selection of an appropriate binder for the stabilisation/ solidification works. It is possible that this work could be undertaken concurrently with the Phase 1 Pump and Treat works.
4. Early Liaison with regulators including the EPA and the Local Authority to obtain approval in principle to the proposals and to determine whether a Waste Licence and planning consents are required.

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http://www.irishstatutebook.ie/2000/en/si/0439.html
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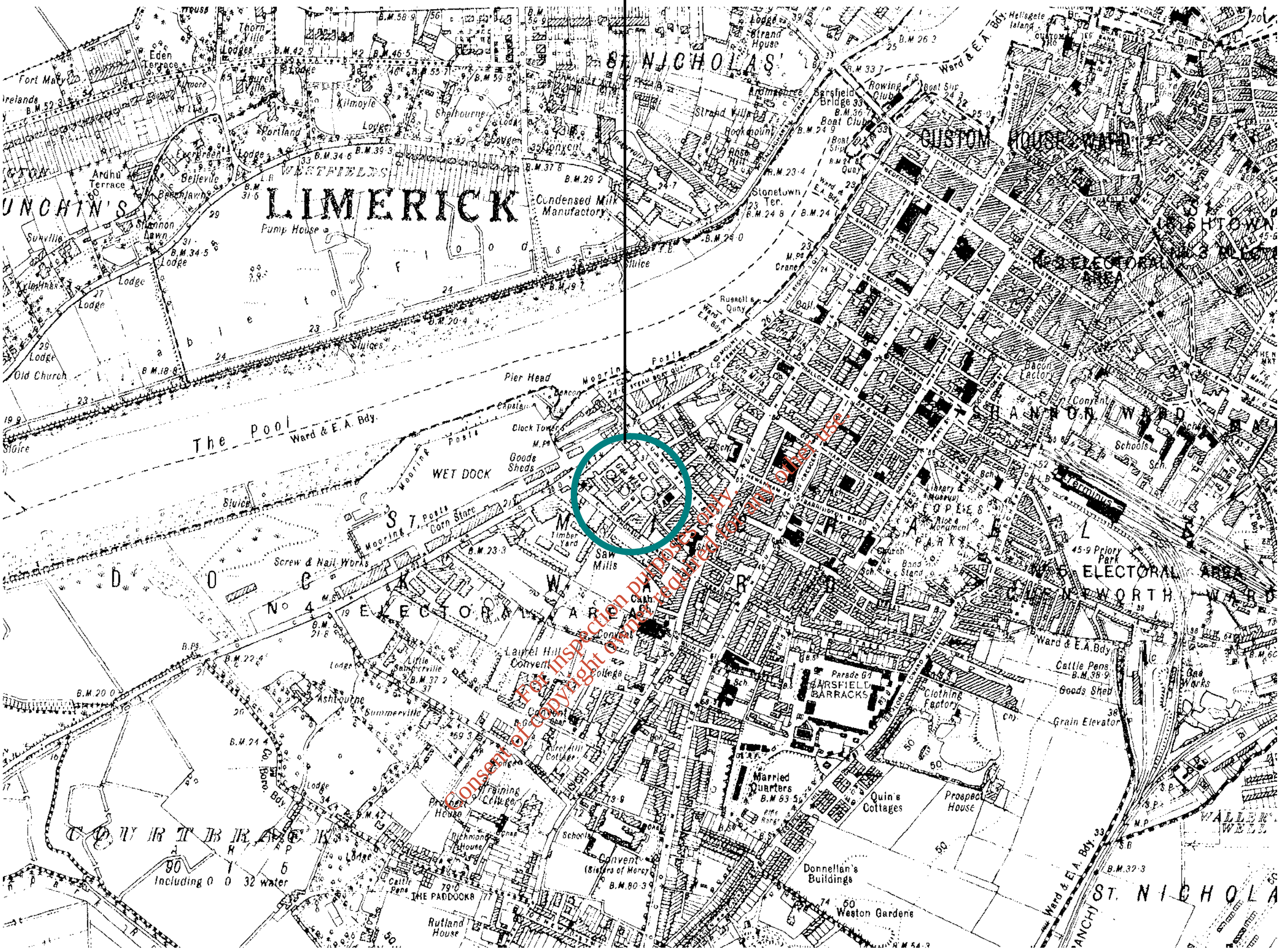
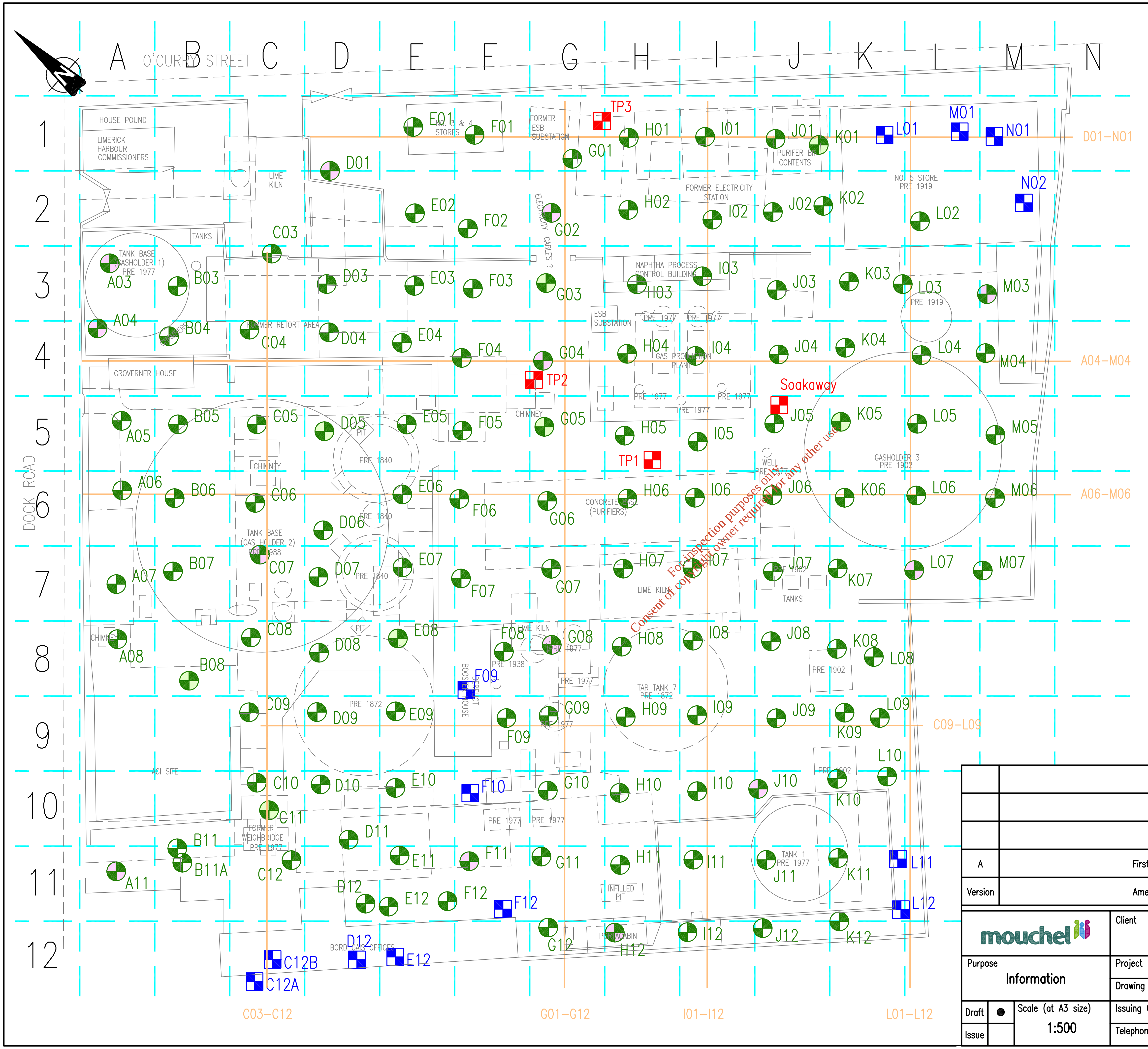
Site Location



mouchel	Client	Bord Gáis Éireann
	Project	Limerick Gas Works
	Title	Figure 1) Site Location Plan
Purpose: Report	Draft / Issue ●	Scale (at A4): Not to scale
Issuing Office: Cheshire	Drawing number: 1021927/R03/001	Version: A
Telephone: 0151 356 5555		



Key

Approximate Location of Former Structure

2009 Site Investigation

Sonic Drilled Boreholes

10m Grid

Window Sample Location

Trial Pit

Installation in made ground

Installation in limestone rock

Cross Sections (see figure 4)

A	First Issue	K.Hodgkinson 13/01/10	D.Megson 13/01/10	D.Watts 21/01/10
Version	Amendment	Originated by and date	Checked by and date	Approved by and date

mouchel

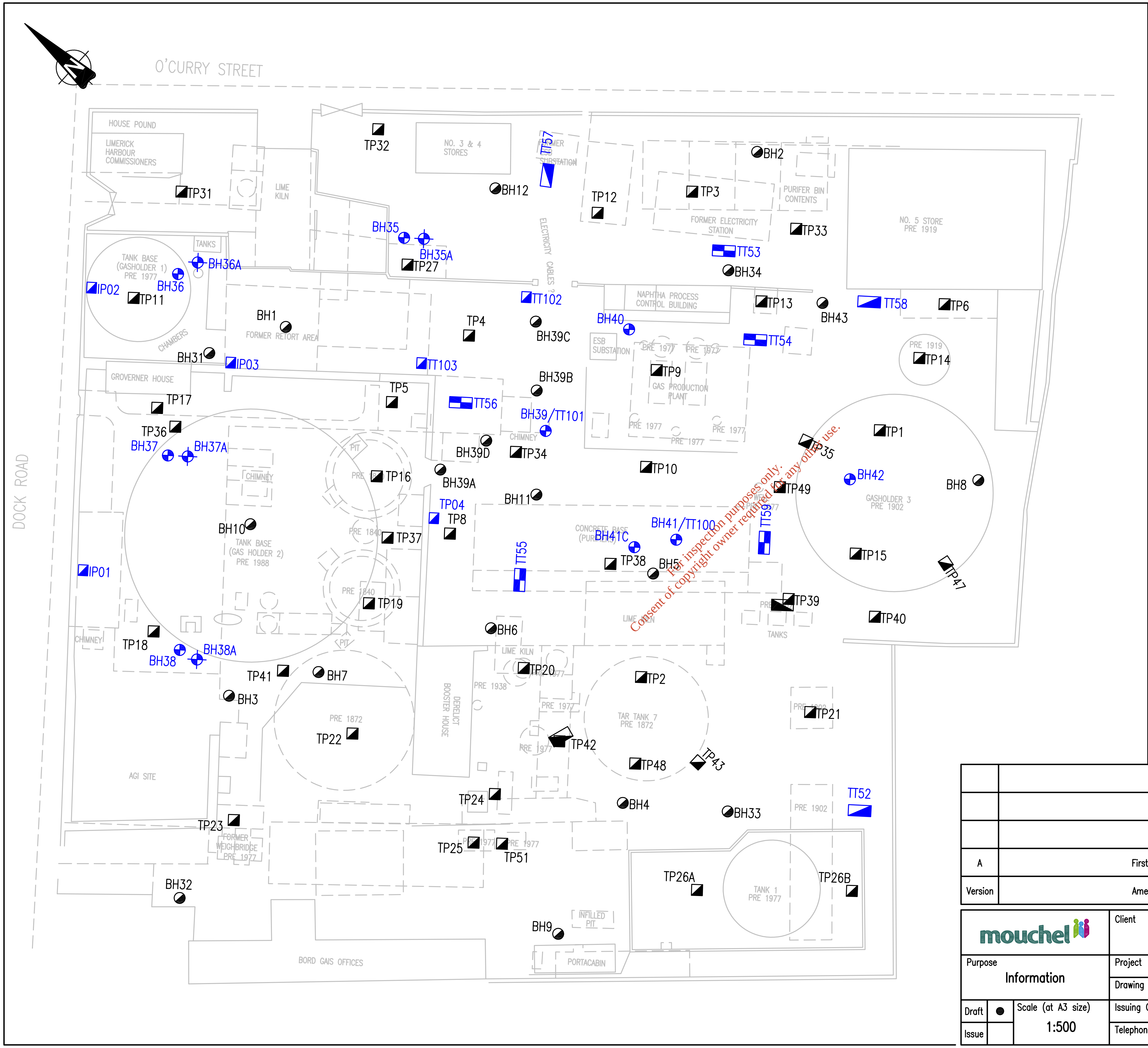
Client: BORD GÁIS

Purpose: Information

Project: Limerick Gasworks

Drawing Title: Figure 2 2009 SI – Exploratory Hole Location Plan

Draft	●	Scale (at A3 size) 1:500	Issuing Office: Ellesmere Port	Drawing number: 1021927/R03/002	Version: A
Issue			Telephone: 0151 356 5555		



Key

- Approximate Location of Former Structure
- Trial Pits 1996, 1995, 2001 SI
- Boreholes 1996, 1995, 2001 SI
- Cable Percussion Borehole, 2003 S.I.
- Rotary Borehole, 2003 S.I.
- Trial Trench TT52–59, 2003 S.I.

Version	Amendment	Originated by and date	Checked by and date	Approved by and date
A	First Issue	N.Henrys 26/01/10	D.Field 26/01/10	Tony Brown 26/01/10

mouchel

Client: BORD GÁIS

Purpose: Information

Project: Limerick Gasworks

Drawing Title: Figure 3 Previous Investigation Borehole Location Plan

Draft ● | Issue

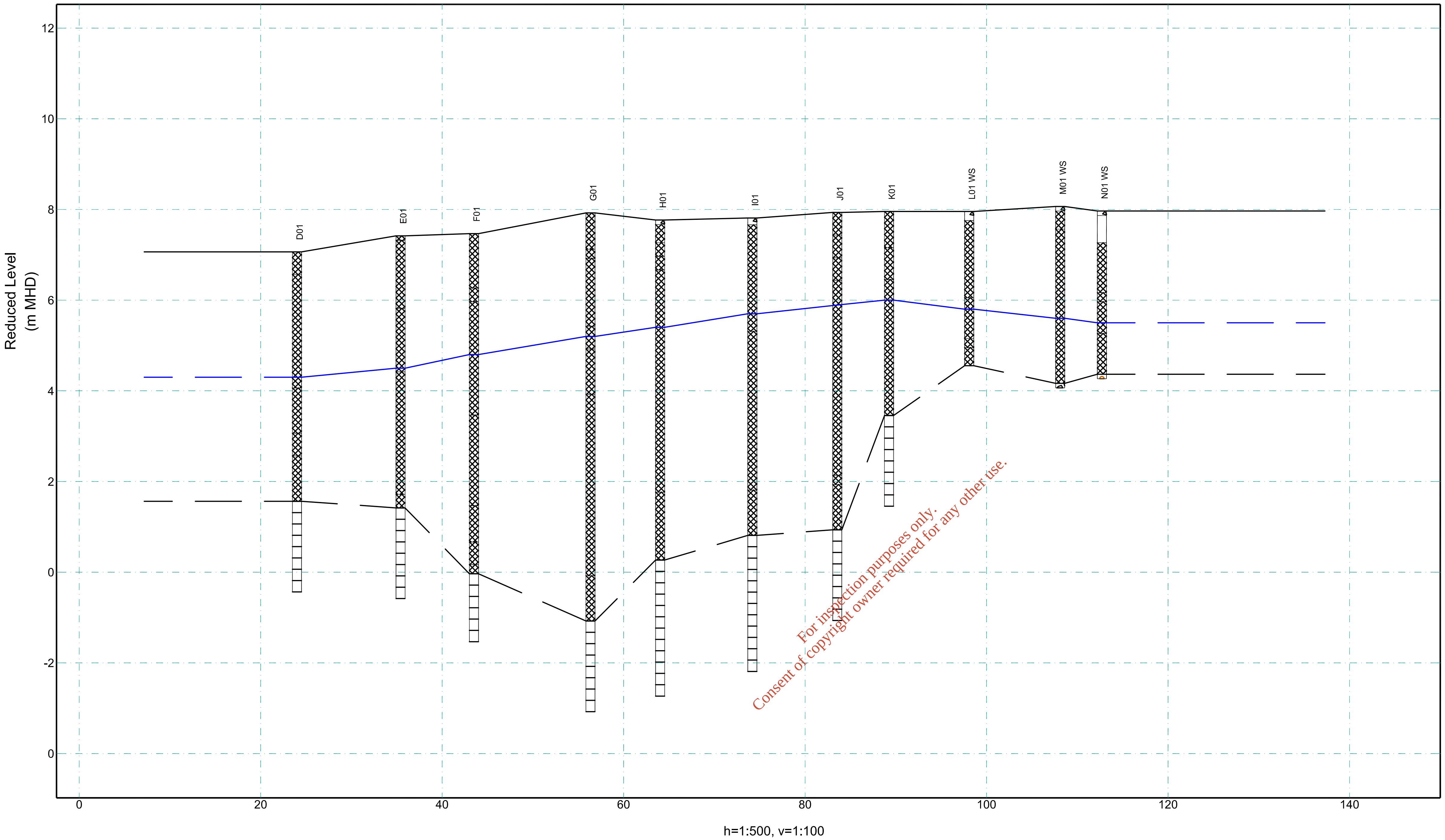
Scale (at A3 size): 1:500

Issuing Office: Ellesmere Port

Telephone: 0151 356 5555

Drawing number: 1021927/R03/003

Version: A



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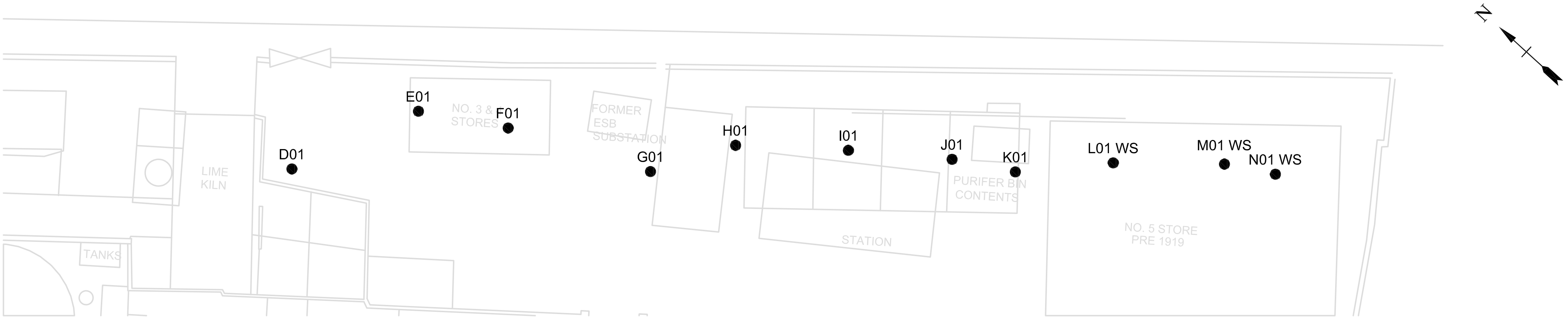

KEY

MADE GROUND	Ground Level
CONCRETE	Made Ground Boundary
GRAVEL	Groundwater Level
COBBLES	
LIMESTONE	

REF	DATE	REVISIONS	INITIALS

AMENDMENTS

CLIENT

BORD GÁIS

CONSULTANT

mouchel

SUB CONSULTANT

PROJECT TITLE

Limerick Gas Works

DRAWING TITLE

Figure 4a) D1 - N1

Design By	D. Megson	Checked By	D. Watts
Design Date	12/01/10	Checked Date	18/01/10
Drawn By	N. Appleton	Approved By	D. Watts
Drawn Date	15/01/10	Approved Date	22/01/10

DRAFT | PRELIMINARY | TENDER | CONTRACT

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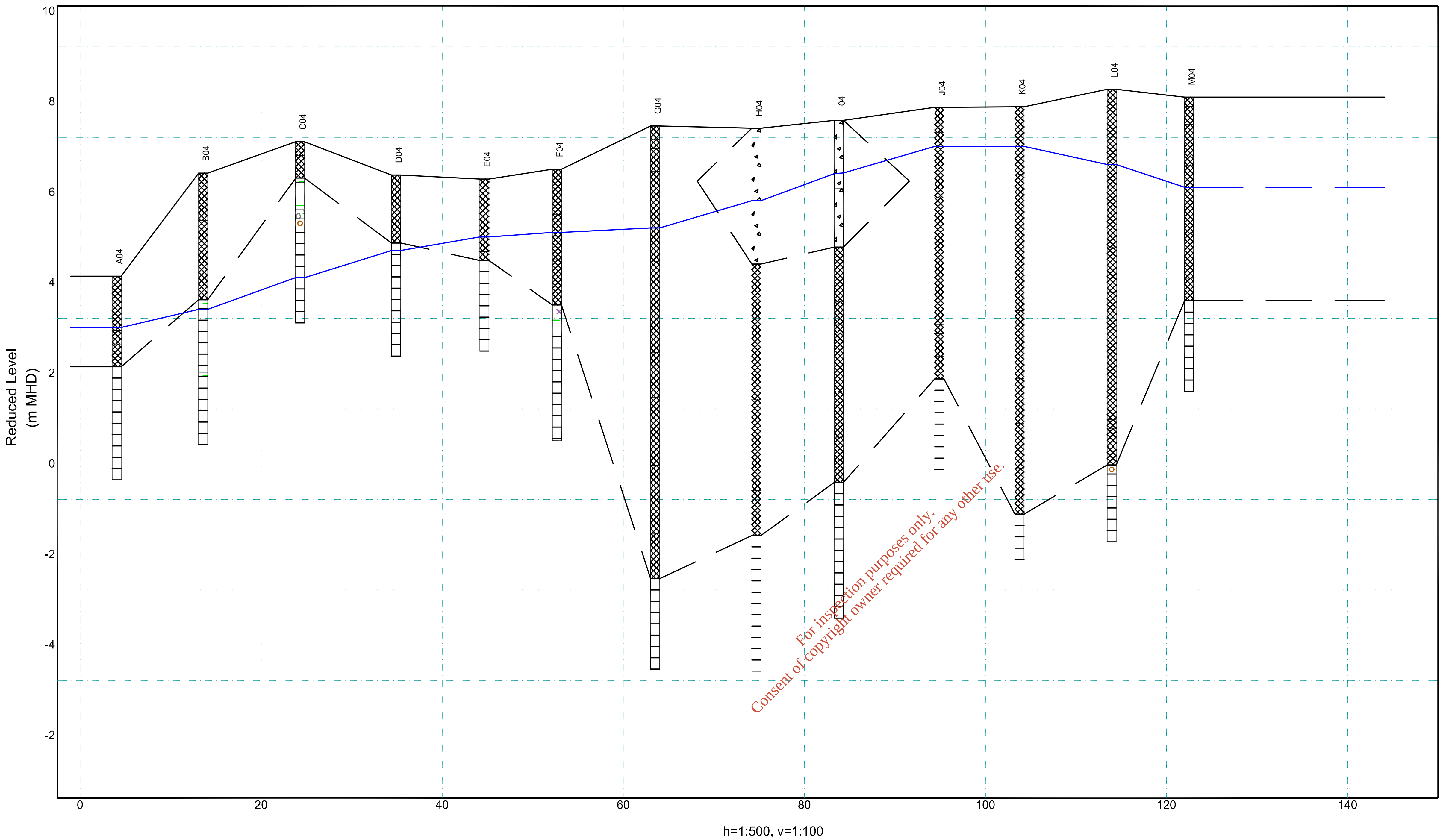

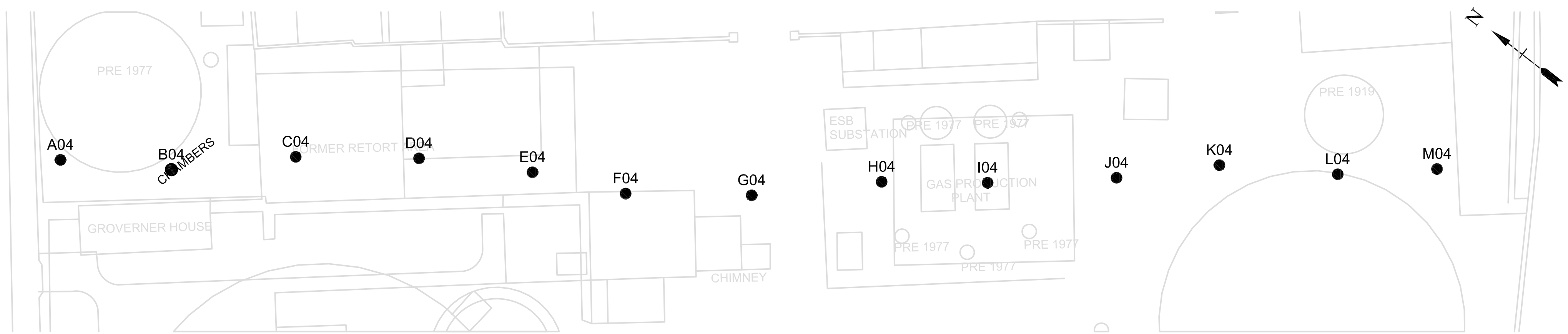

KEY

MADE GROUND	Ground Level
CONCRETE	Made Ground Boundary
CLAY	Groundwater Level
Gravelly clayey SAND	
Sandy CLAY	
Silty sandy Clay	
Very clayey sandy GRAVEL	
Gravelly sandy CLAY	
Limestone	

REF	DATE	REVISIONS	INITIALS

AMENDMENTS

CLIENT

BORD GÁIS

CONSULTANT

mouchel

SUB CONSULTANT

PROJECT TITLE

Limerick Gas Works

DRAWING TITLE

Section 4b) A04 - M04

Design By	D. Megson	Checked By	D. Watts
Design Date	12/01/10	Checked Date	18/01/10
Drawn By	N. Appleton	Approved By	D. Watts
Drawn Date	15/01/10	Approved Date	22/01/10

DRAFT	PRELIMINARY	TENDER	CONTRACT

SCALE	DRAWING NO	REV
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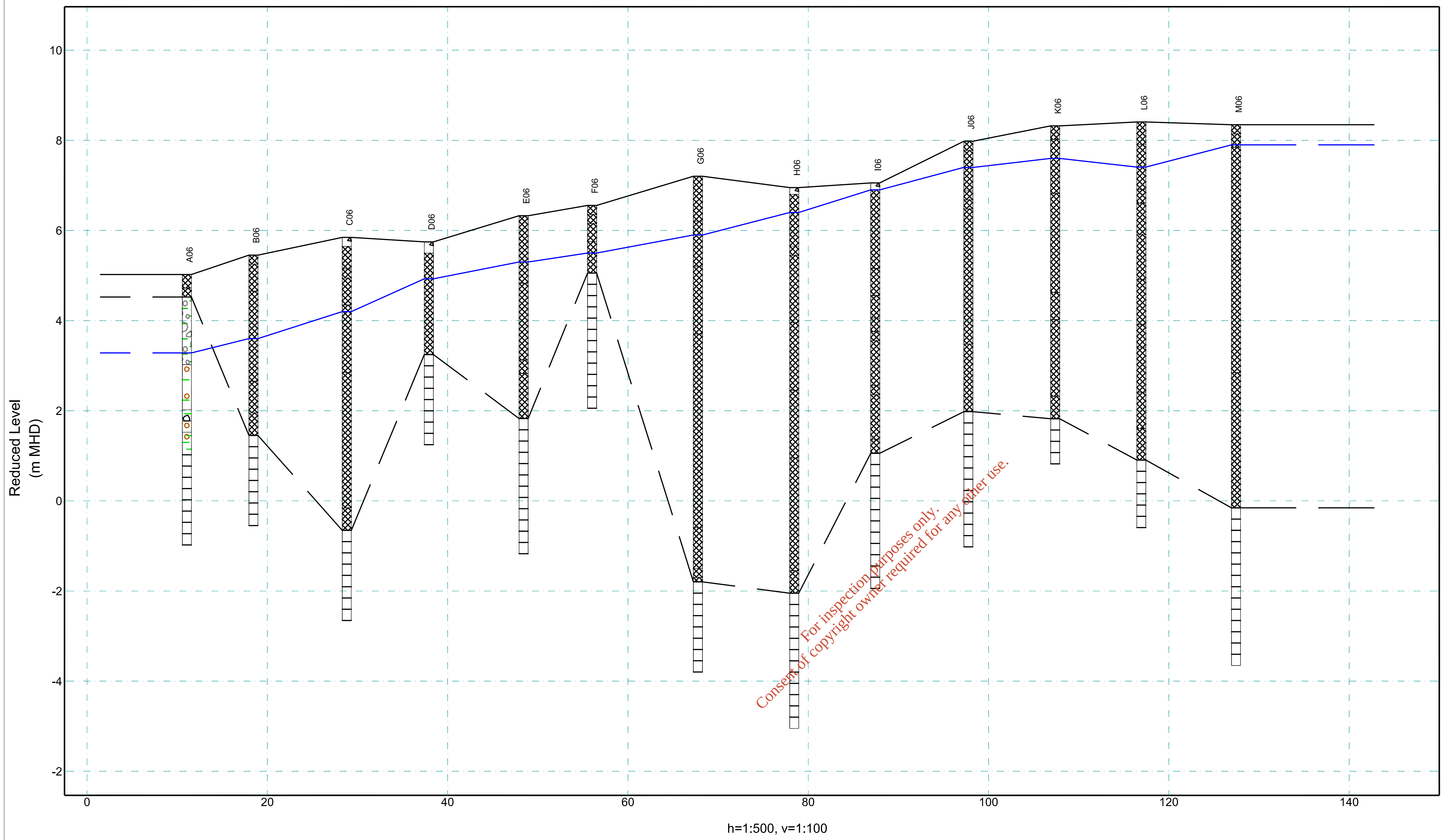
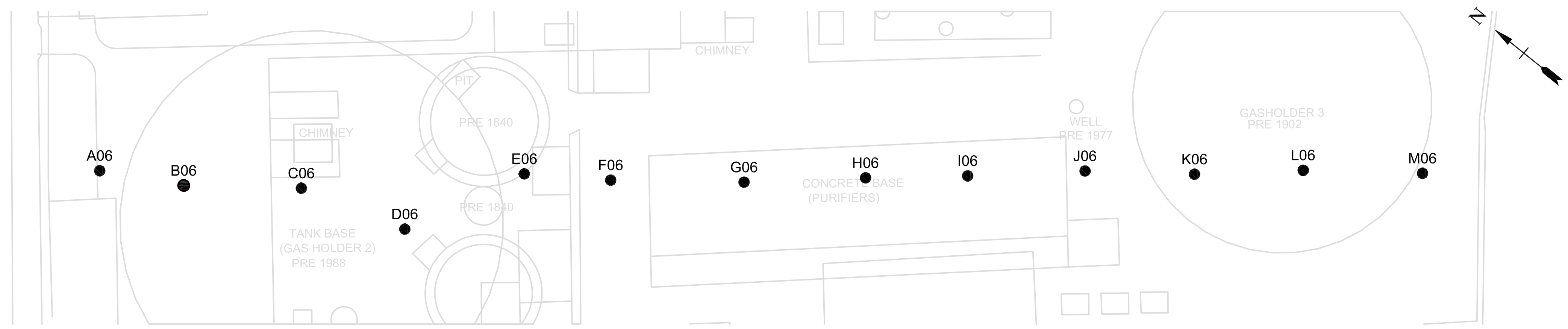


KEY

- MADE GROUND
- CONCRETE
- Gravelly sandy CLAY
- Gravelly CLAY
- Very clayey sandy GRAVEL
- Clayey GRAVEL
- Limestone
- Ground Level
- Made Ground Boundary
- Groundwater Level



REF	DATE	REVISIONS	INITIALS

AMENDMENTS

CLIENT

BORD GÁIS

CONSULTANT

mouchel

SUB CONSULTANT

PROJECT TITLE

Limerick Gas Works

DRAWING TITLE

Section 4c) A06 - M06

Design By	D. Megson	Checked By	D. Watts
Design Date	12/01/10	Checked Date	18/01/10
Drawn By	N. Appleton	Approved By	D. Watts
Drawn Date	15/01/10	Approved Date	22/01/10

DRAFT	PRELIMINARY	TENDER	CONTRACT

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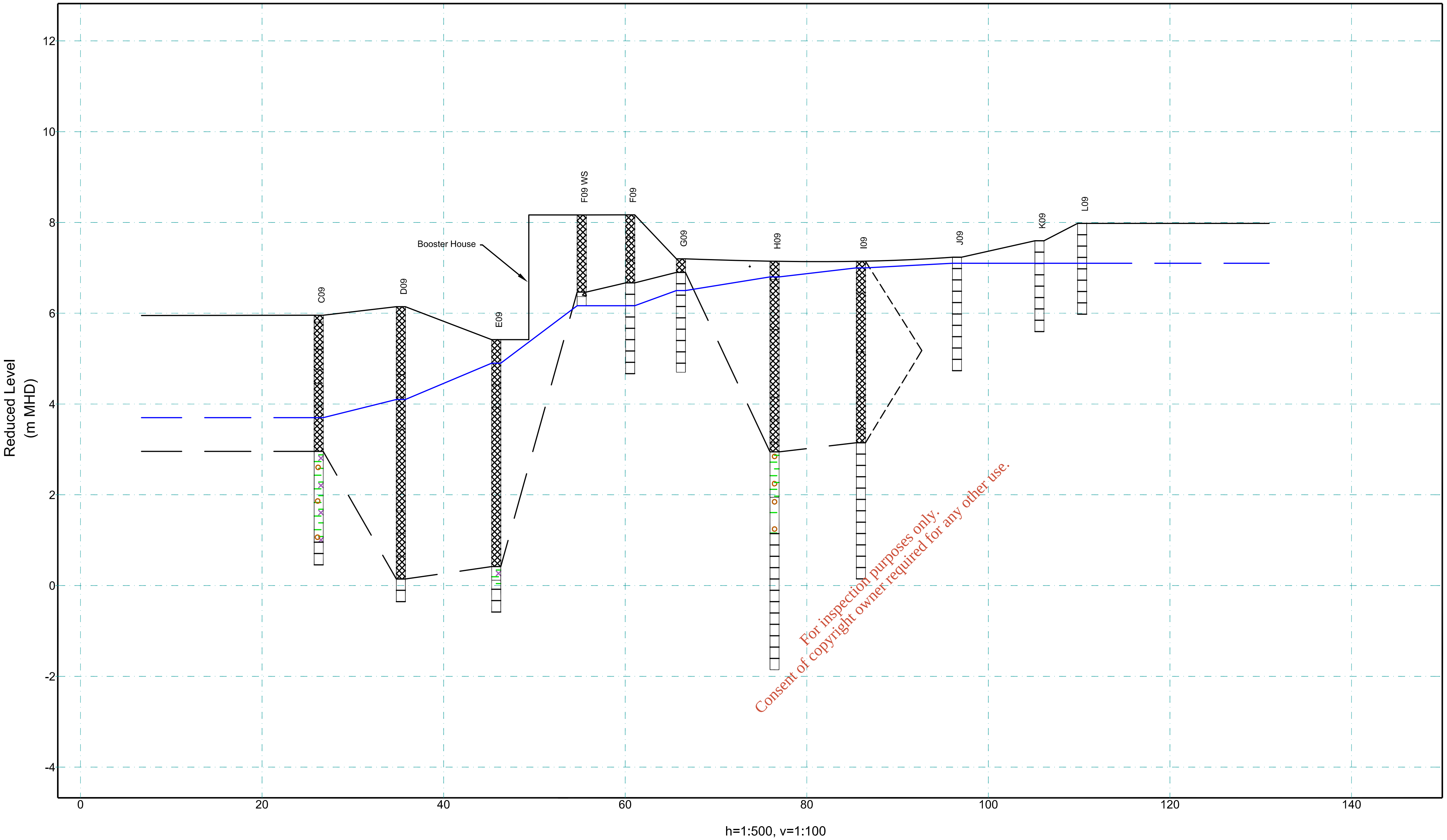

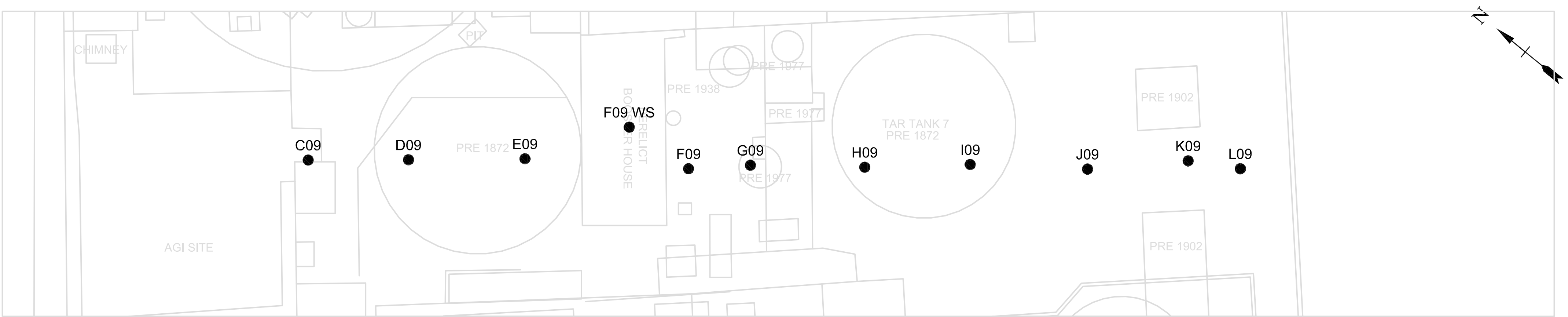

KEY

MADE GROUND	Ground Level
Clayey SAND	Made Ground Boundary
Gravelly sandy CLAY	Groundwater Level
Gravelly CLAY	
CLAY	
Silty CLAY	
CLAY with Cobbles	
Limestone	

REF	DATE	REVISIONS	INITIALS

AMENDMENTS

CLIENT

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PROJECT TITLE

Limerick Gas Works

DRAWING TITLE

Section 4d) C09 - L09

Design By	D. Megson	Checked By	D. Watts
Design Date	12/01/10	Checked Date	18/01/10
Drawn By	N. Appleton	Approved By	D. Watts
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DRAFT	PRELIMINARY	TENDER	CONTRACT

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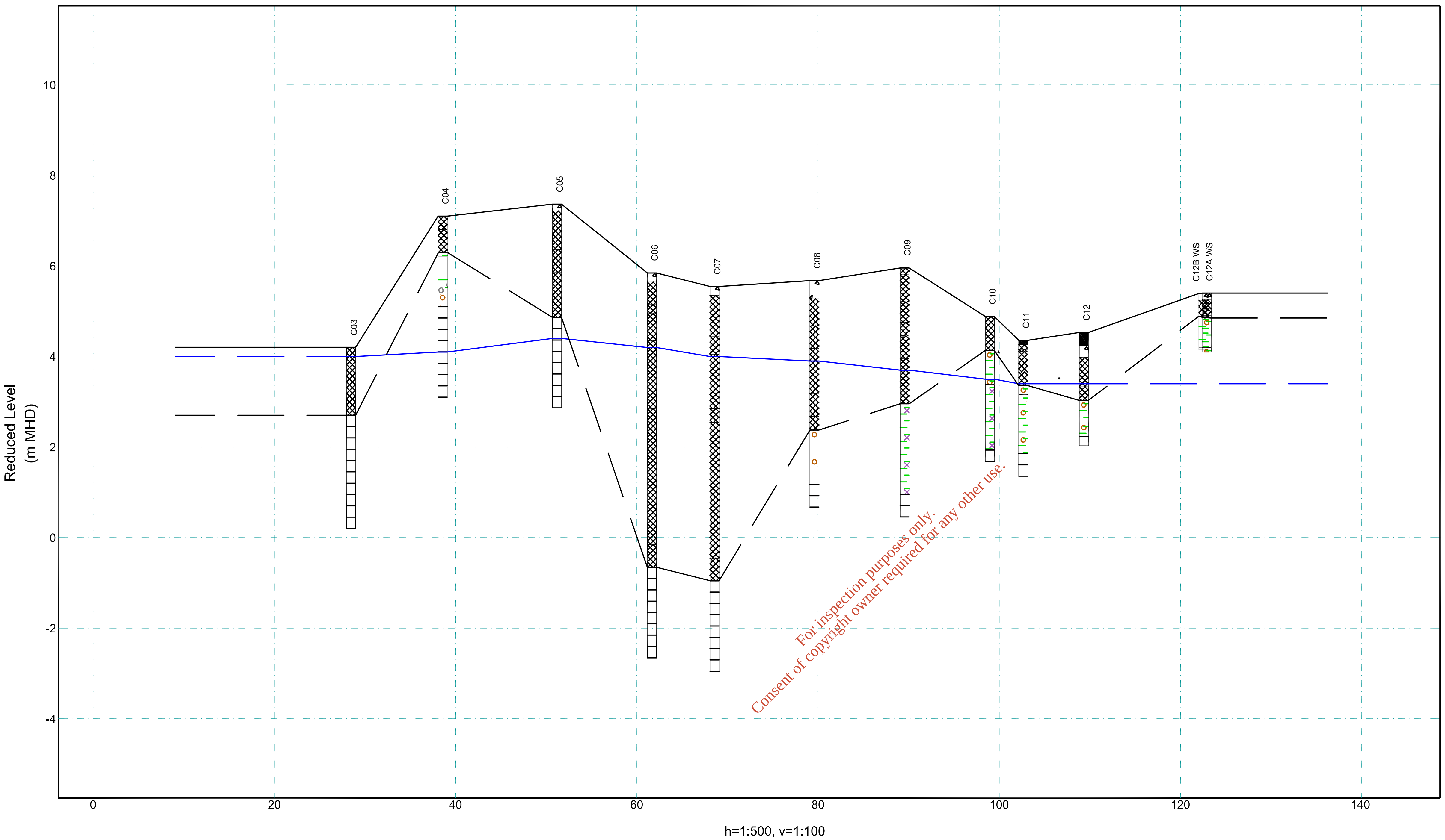

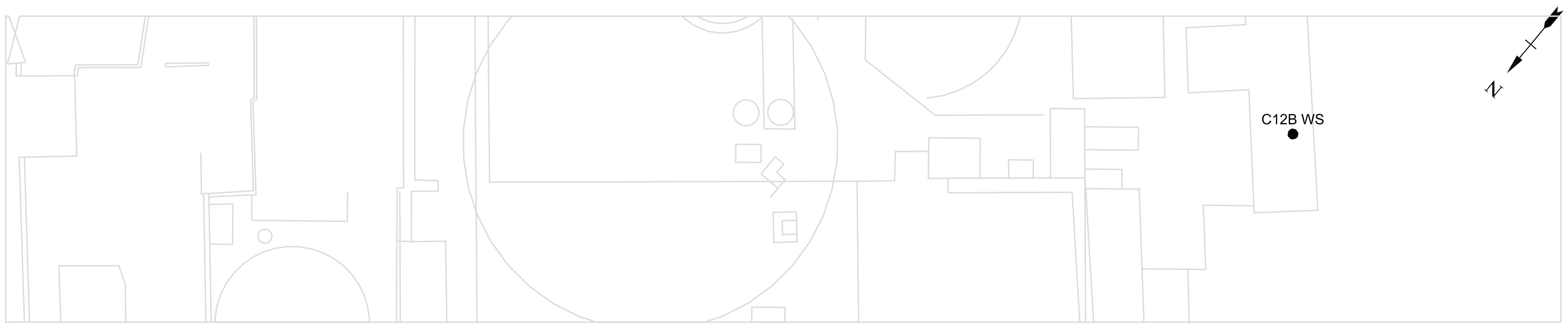

KEY

- MADE GROUND
- CONCRETE
- Gravelly Clayey SAND
- Gravelly sandy CLAY
- Gravelly CLAY
- Sandy CLAY
- Silty CLAY with rare gravel
- Very clayey sandy GRAVEL
- GRAVEL
- Limestone
- Ground Level
- Made Ground Boundary
- Groundwater Level

REF	DATE	REVISIONS	INITIALS

AMENDMENTS

CLIENT

BORD GÁIS

CONSULTANT

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SUB CONSULTANT

PROJECT TITLE

Limerick Gas Works

DRAWING TITLE

Section 4e) C3 - C12

Design By	D. Megson	Checked By	D. Watts
Design Date	12/01/10	Checked Date	18/01/10
Drawn By	N. Appleton	Approved By	D. Watts
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DRAFT | PRELIMINARY | TENDER | CONTRACT

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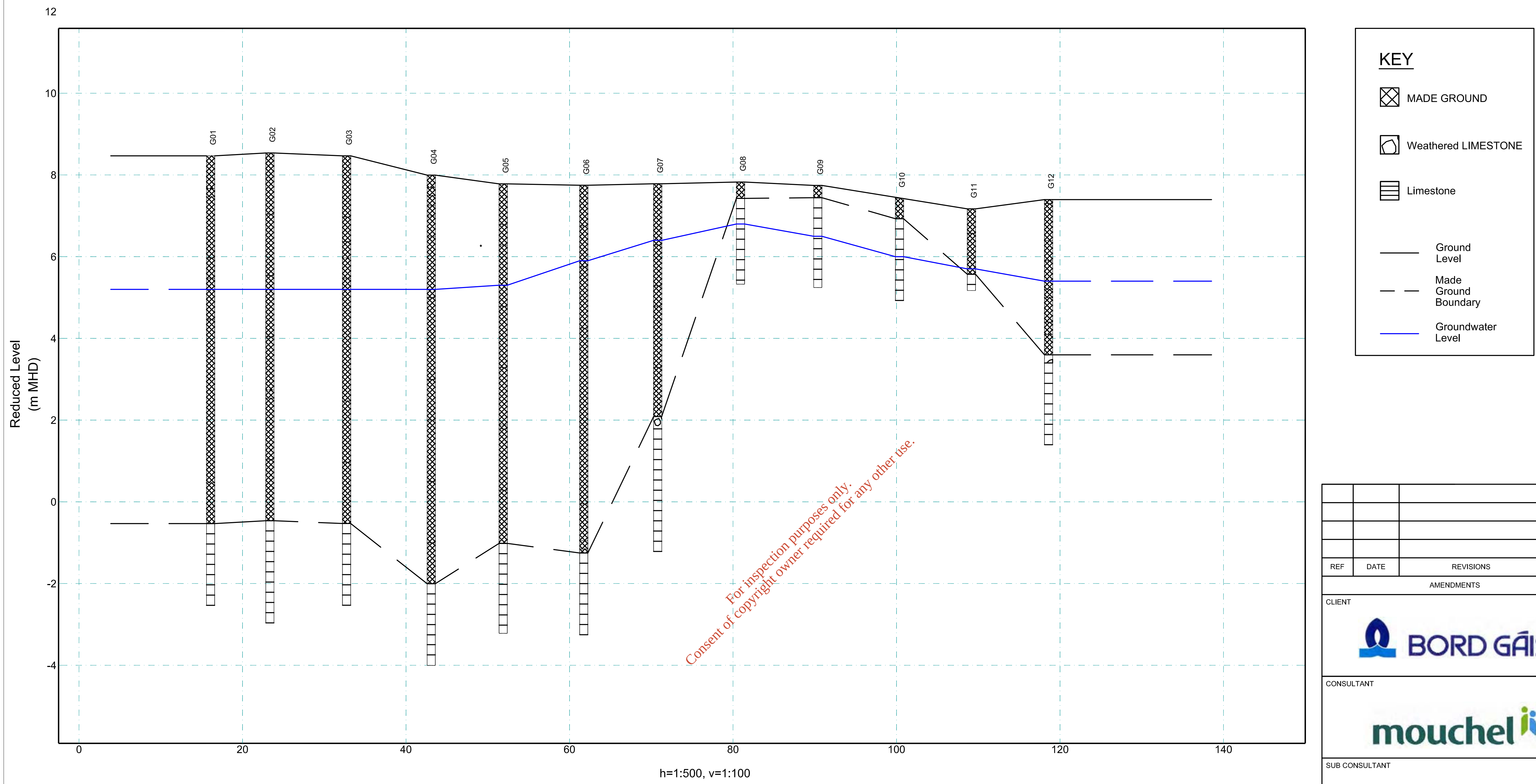

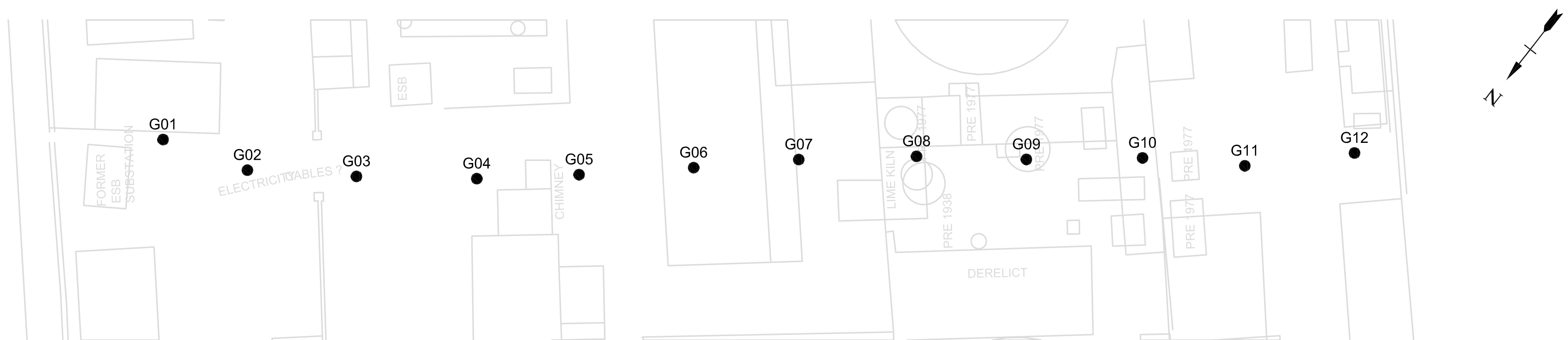

REF	DATE	REVISIONS	INITIALS

AMENDMENTS

CLIENT

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CONSULTANT

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SUB CONSULTANT

PROJECT TITLE

Limerick Gas Works

DRAWING TITLE

Section 4f) G1 - G12

Design By	D. Megson	Checked By	D. Watts
Design Date	12/01/10	Checked Date	18/01/10
Drawn By	N. Appleton	Approved By	D. Watts
Drawn Date	15/01/10	Approved Date	22/01/10

DRAFT | PRELIMINARY | TENDER | CONTRACT

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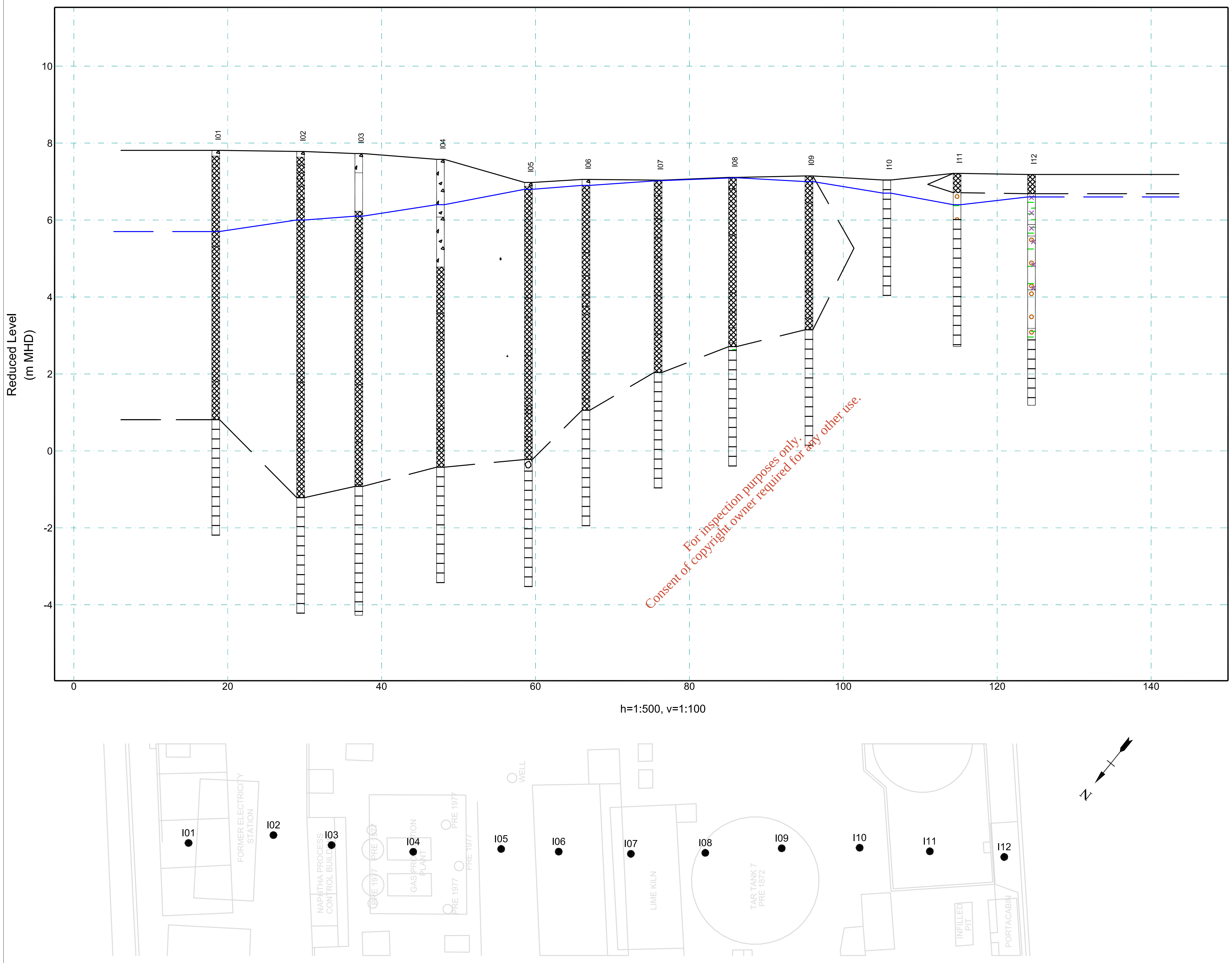

KEY

MADE GROUND	Ground Level
CONCRETE	Made Ground Boundary
Sandy CLAY	Groundwater Level
Gravelly CLAY	
Gravelly sandy CLAY	
Slightly silty sandy gravelly Clay	
Slightly gravelly CLAY/SILT	
Weathered Limestone	

REF	DATE	REVISIONS	INITIALS

AMENDMENTS

CLIENT

BORD GÁIS

CONSULTANT

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SUB CONSULTANT

PROJECT TITLE

Limerick Gas Works

DRAWING TITLE

Section 4g) I01 - I12

Design By	D. Megson	Checked By	D. Watts
Design Date	12/01/10	Checked Date	18/01/10
Drawn By	N. Appleton	Approved By	D. Watts
Drawn Date	15/01/10	Approved Date	22/01/10

DRAFT | PRELIMINARY | TENDER | CONTRACT

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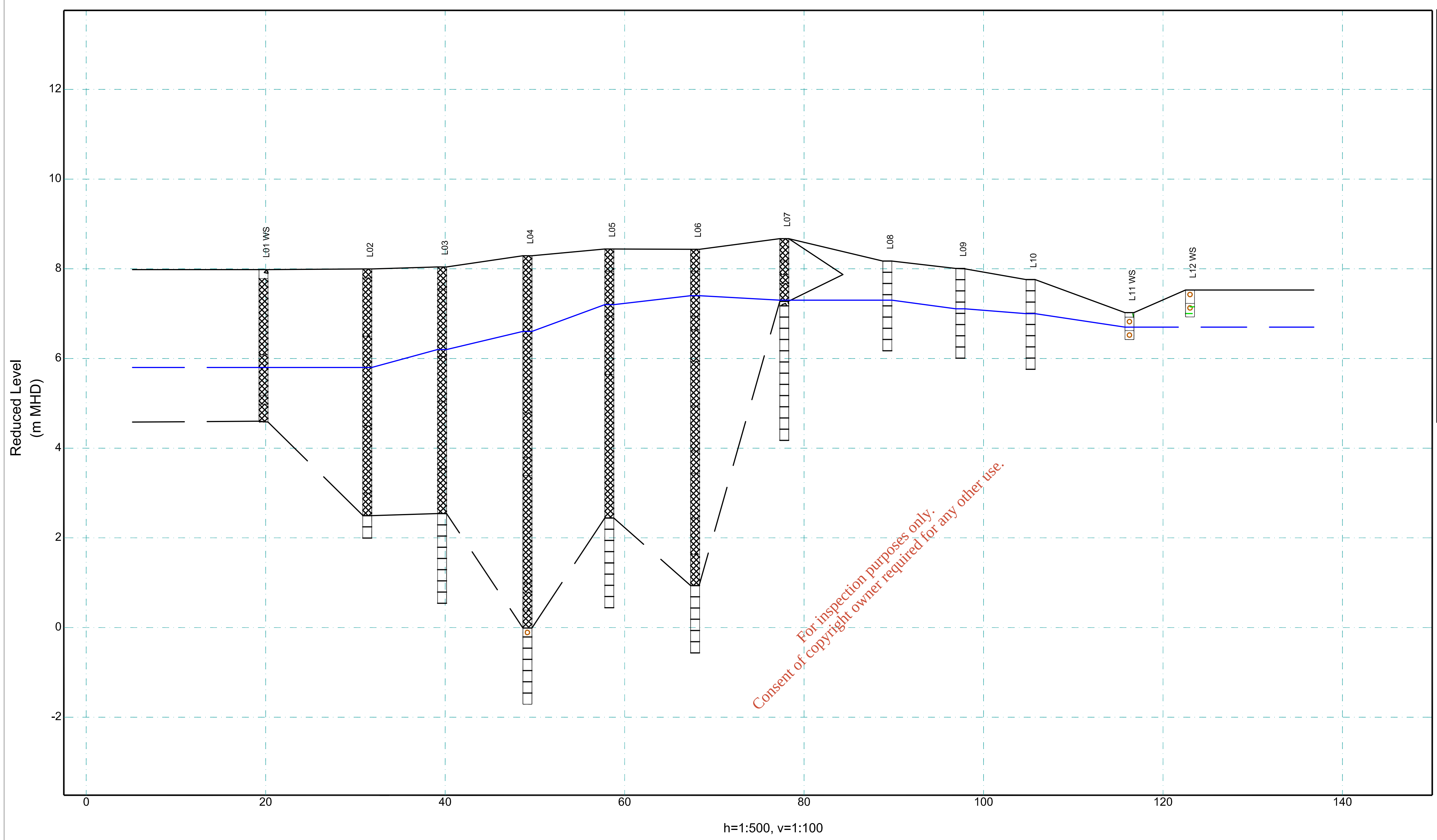

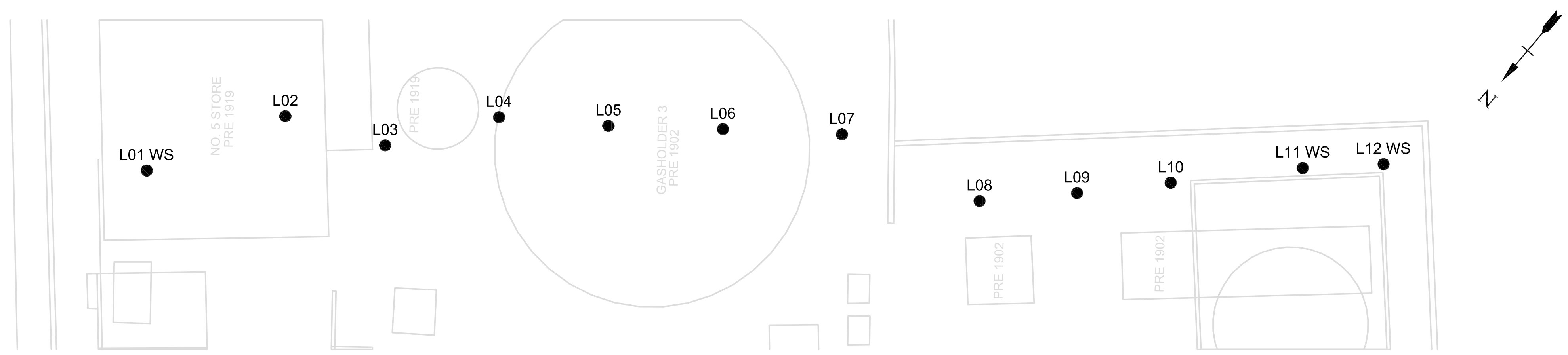

KEY

TOPSOIL	Ground Level
MADE GROUND	Made Ground Boundary
CONCRETE	Groundwater Level
Gravelly sandy CLAY	
Limestone	
Gravelly CLAY	
Weathered LIMESTONE	

REF	DATE	REVISIONS	INITIALS

AMENDMENTS

CLIENT: BORD GÁIS

CONSULTANT: mouchel

SUB CONSULTANT

PROJECT TITLE: Limerick Gas Works

DRAWING TITLE: Section 4h) L01 - L12

Design By	D. Megson	Checked By	D. Watts
Design Date	12/01/10	Checked Date	18/01/10
Drawn By	N. Appleton	Approved By	D. Watts
Drawn Date	15/01/10	Approved Date	22/01/10

DRAFT | PRELIMINARY | TENDER | CONTRACT

SCALE	DRAWING NO	REV
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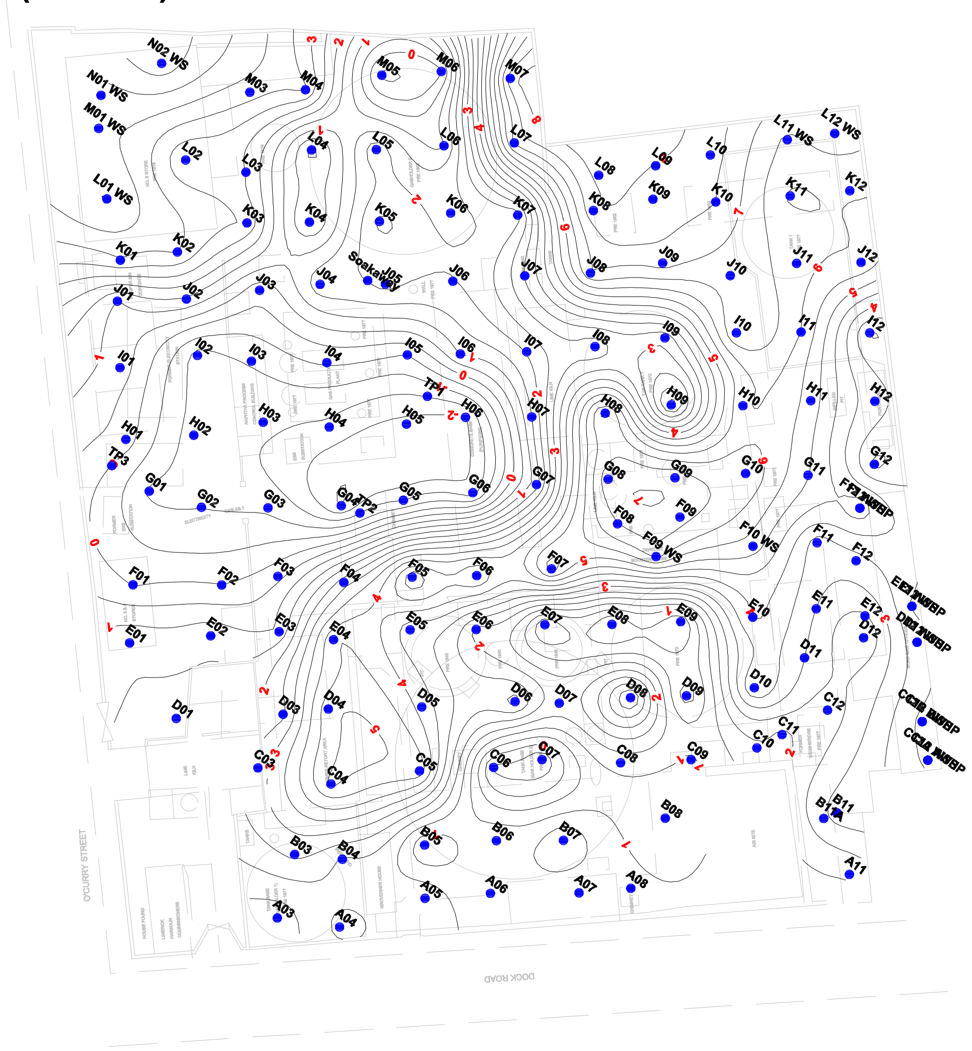
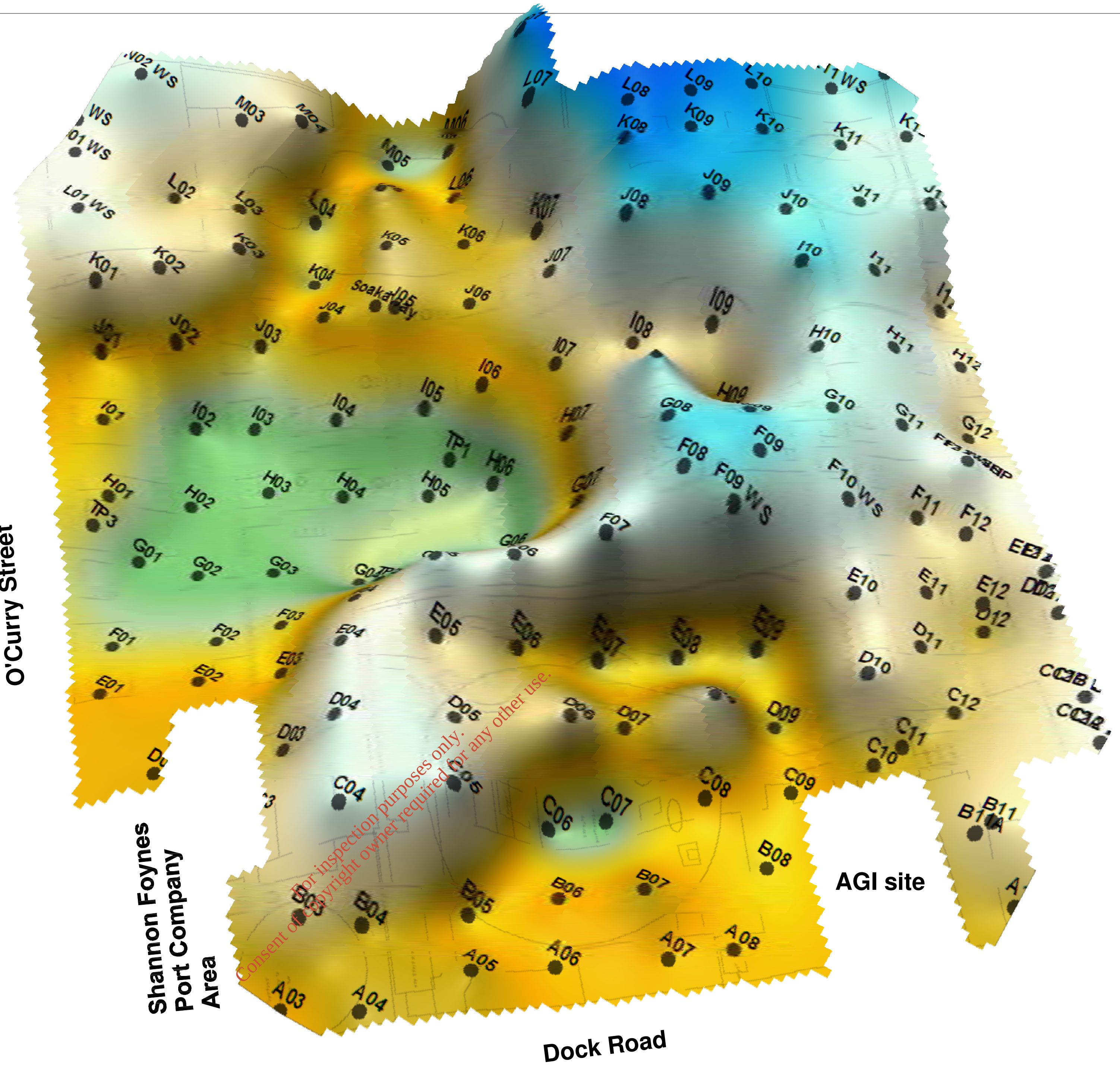
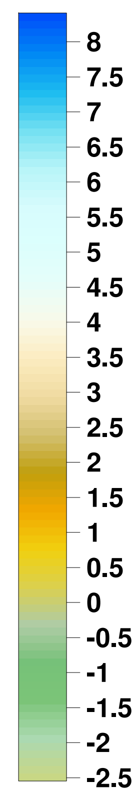
North

Approximate rock head contours (m MHD)





Approximate Rock head level (m MHD)

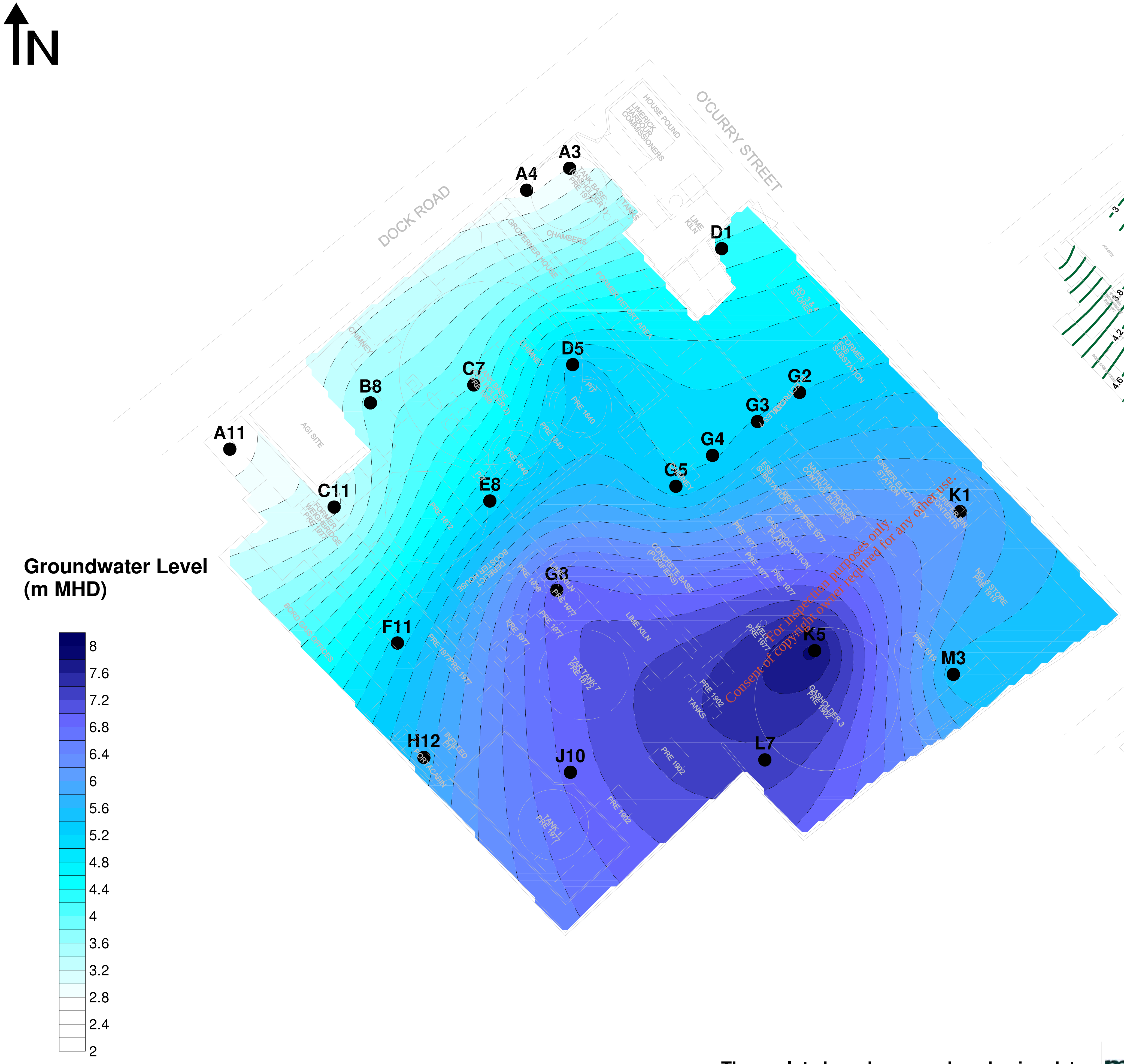


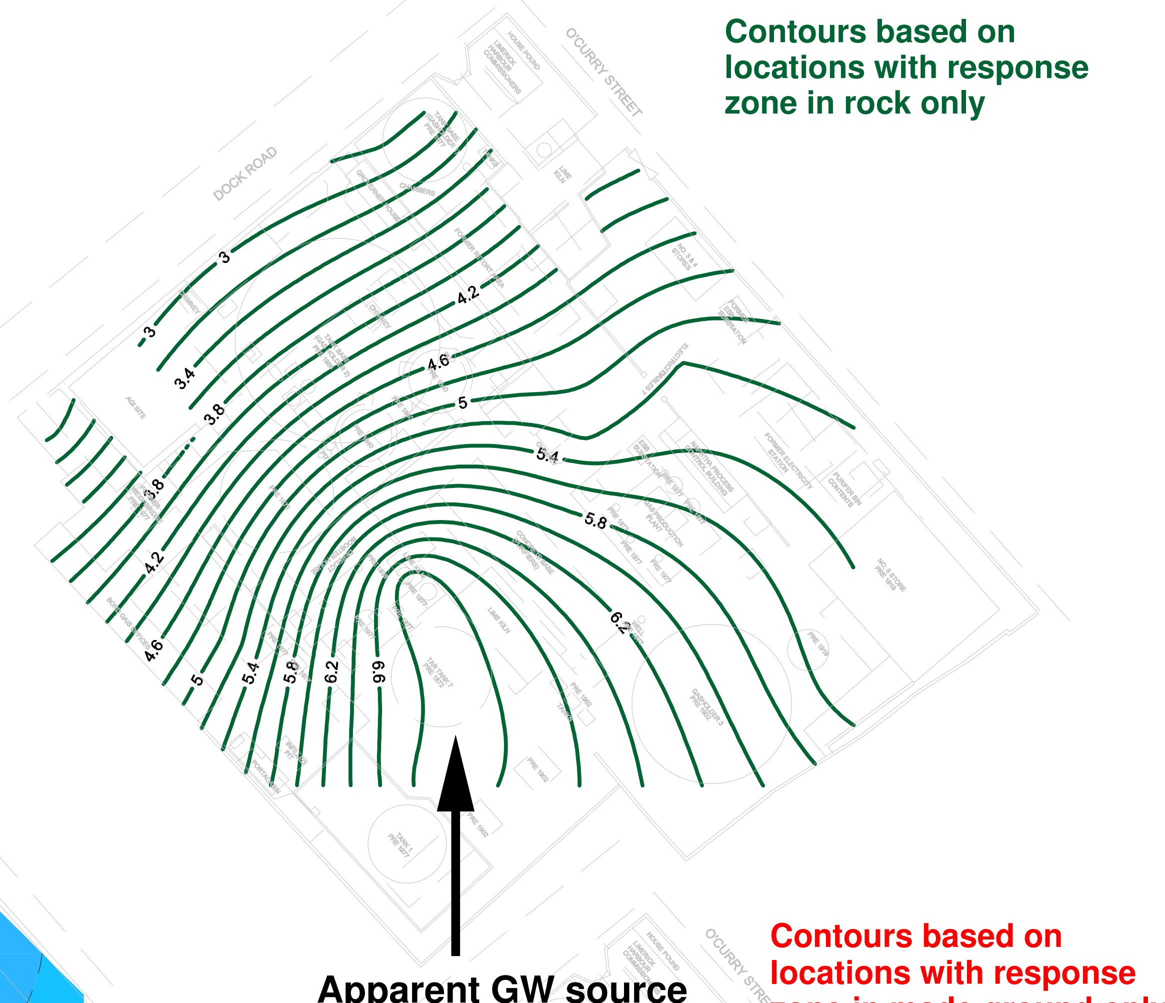
This plot was produced using data obtained from the 2009 Site Investigation. Contours were plotted using the Kriging method based upon a 1m x 1m grid

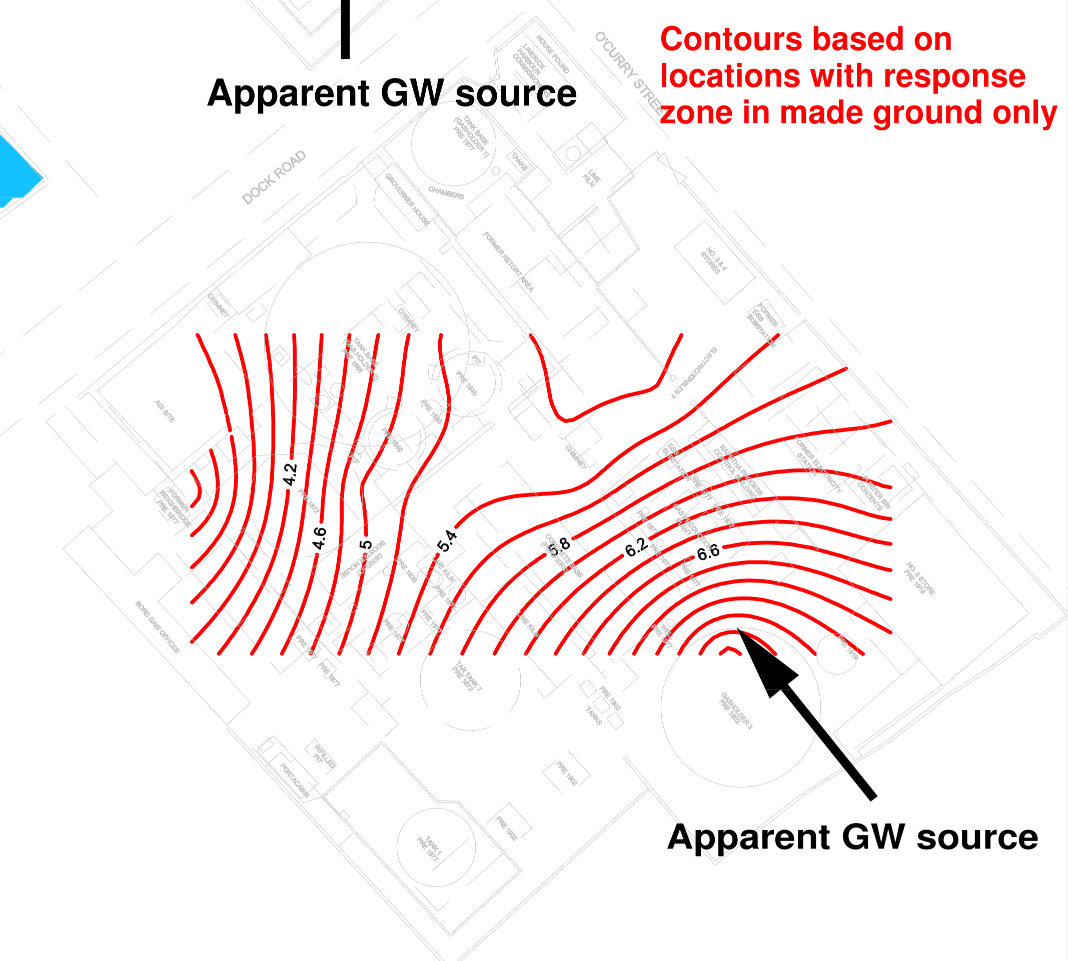
Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

mouchel

Client	Bord Gais
Project	Limerick Gasworks
Drawing Title	Figure 5) Topography of rock-head
Purpose	Information
Scale	Not to scale
Issuing Office	Ellesmere Port
Telephone	0151 356 5555
Drawing Number	1021927/R03/005
Version	A







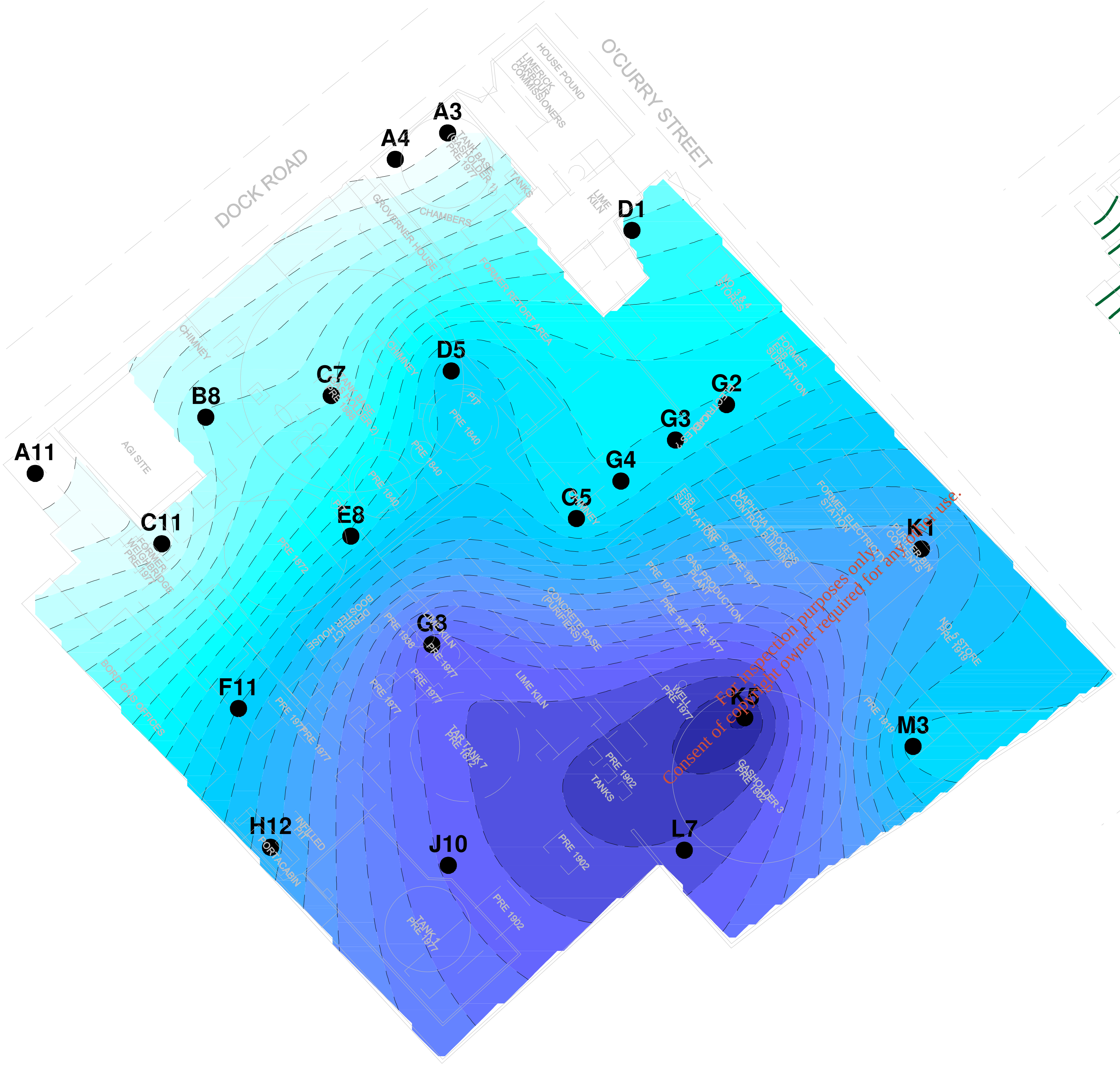
These plots have been produced using data obtained from the groundwater monitoring visit undertaken on 10-11/12/2009. Contours were plotted using the Kriging method based upon a 1m x 1m grid

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	SD	DW

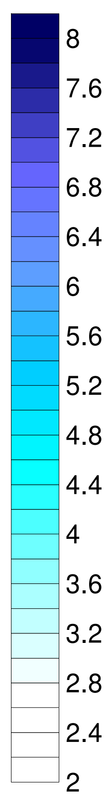
mouchel

Purpose	Information
Scale	Not to scale
Client	Bord Gais
Project	Limerick Gasworks
Drawing Title	Figure 6a) Groundwater levels 10-11/12/2009
Issuing Office	Ellesmere Port
Telephone	0151 356 5555
Drawing Number	102192/R03/006a
Version	A

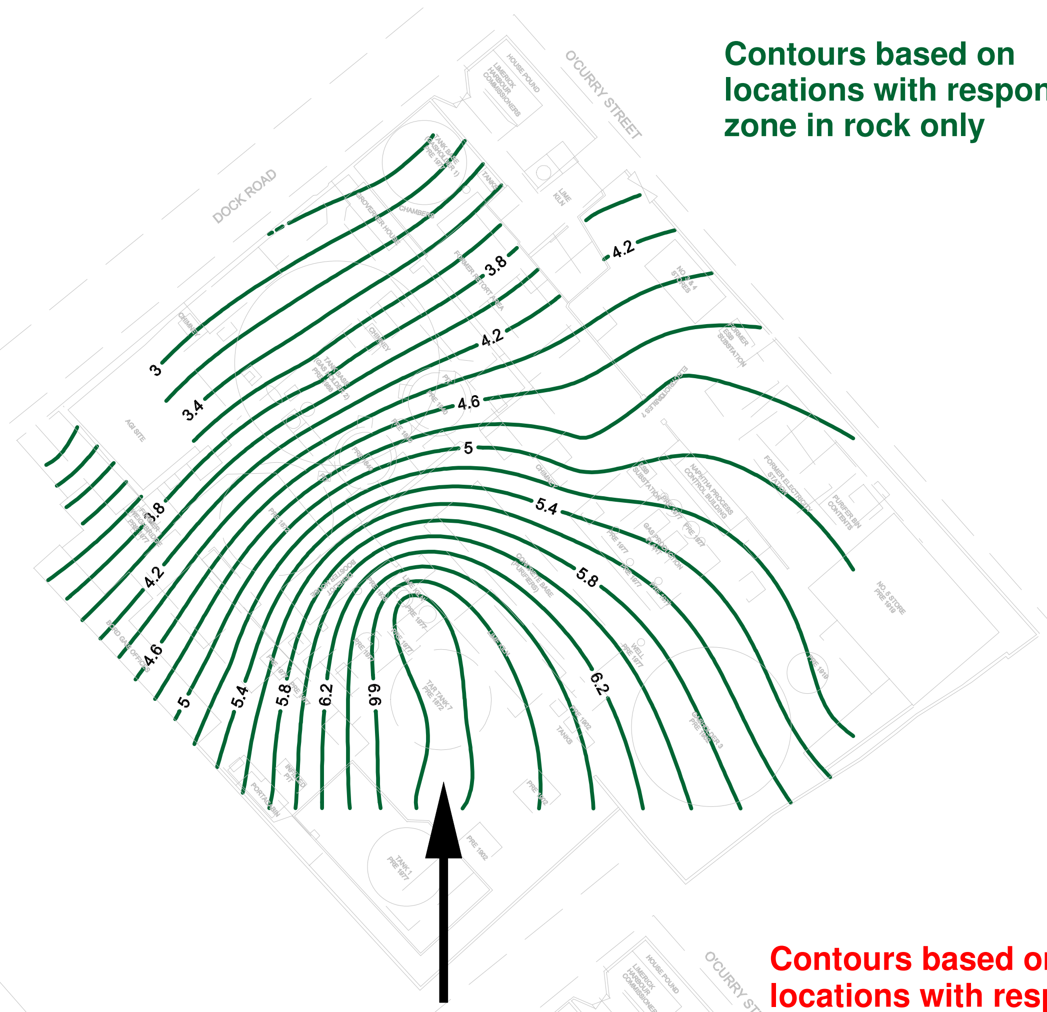
N



Groundwater Level (m MHD)

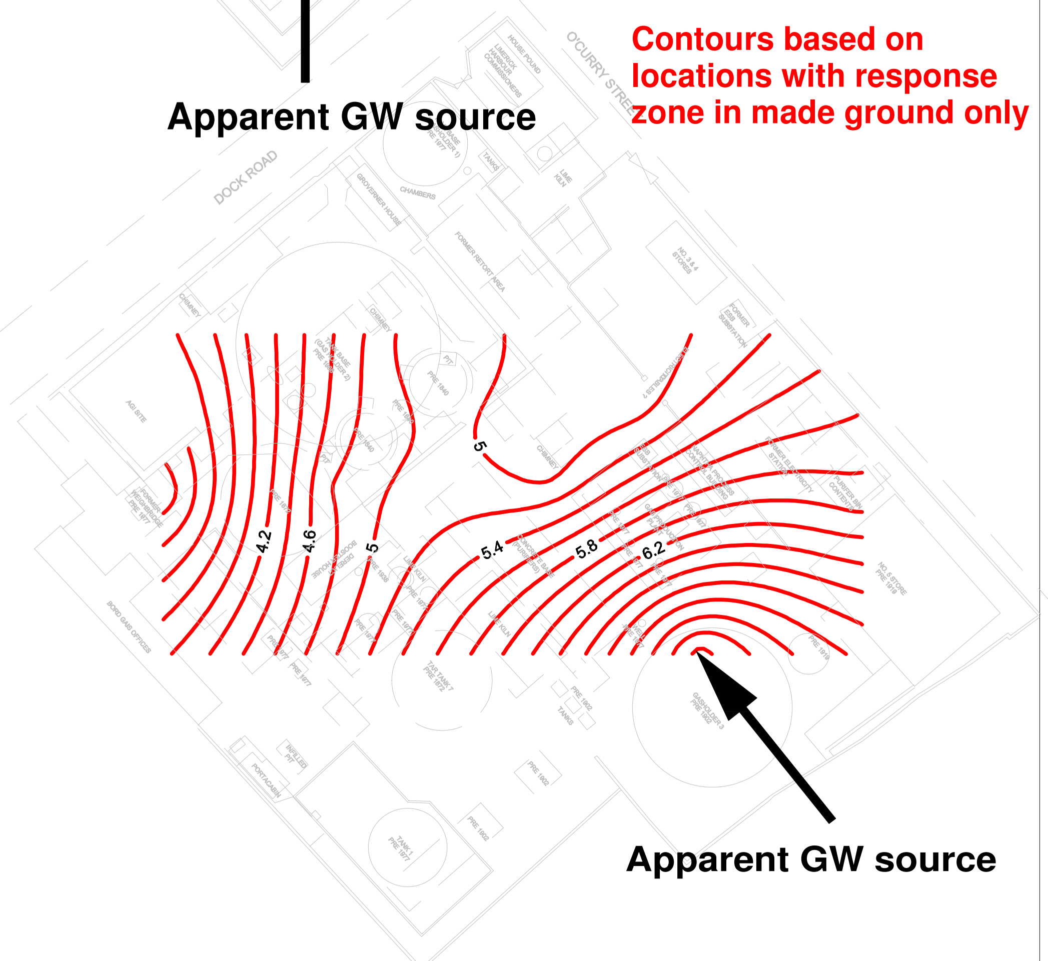


Contours based on locations with response zone in rock only



Apparent GW source

Contours based on locations with response zone in made ground only



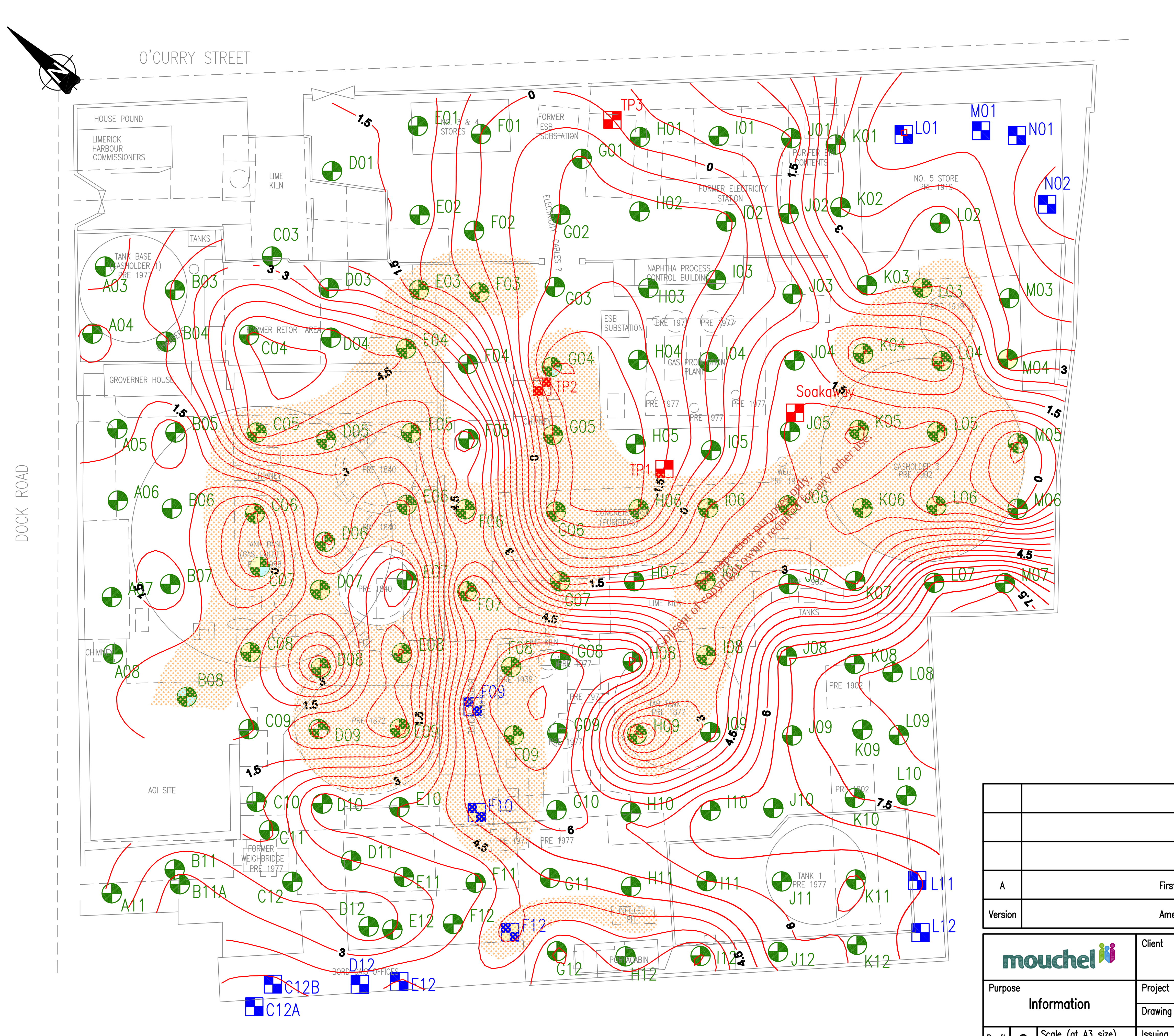
Apparent GW source

These plots have been produced using data obtained from the groundwater monitoring visit undertaken on 14-15/01/2009. Contours were plotted using the Kriging method based upon a 1m x 1m grid

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	SD	DW

mouchel

Purpose	Information
Scale	Not to scale
Client	Bord Gais
Project	Limerick Gasworks
Drawing Title	Figure 6b) Groundwater levels 14-15/01/2010
Issuing Office	Ellesmere Port
Telephone	0151 356 5555
Drawing Number	1021927/R03/006b
Version	A



Key

Approximate Location of Former Structure

2009 Site Investigation

- Sonic Drilled Boreholes
- Window Sample Location
- Trial Pit
- Extensive free phase observed during 2009 SI
- Free phase observed during groundwater monitoring
- Free phase observed during 2009 SI and groundwater monitoring
- Predicted extent of free phase
- Rock head contour (mMHD)

A	First Issue	K.Hodgkinson 26/01/10	D.Megson 26/01/10	D.Watts 26/01/10
Version	Amendment	Originated by and date	Checked by and date	Approved by and date

mouchel

Client: BORD GÁIS

Purpose: Information

Project: Limerick Gasworks

Drawing Title: Figure 7 Encountered Free Phase product

Draft ●

Issue

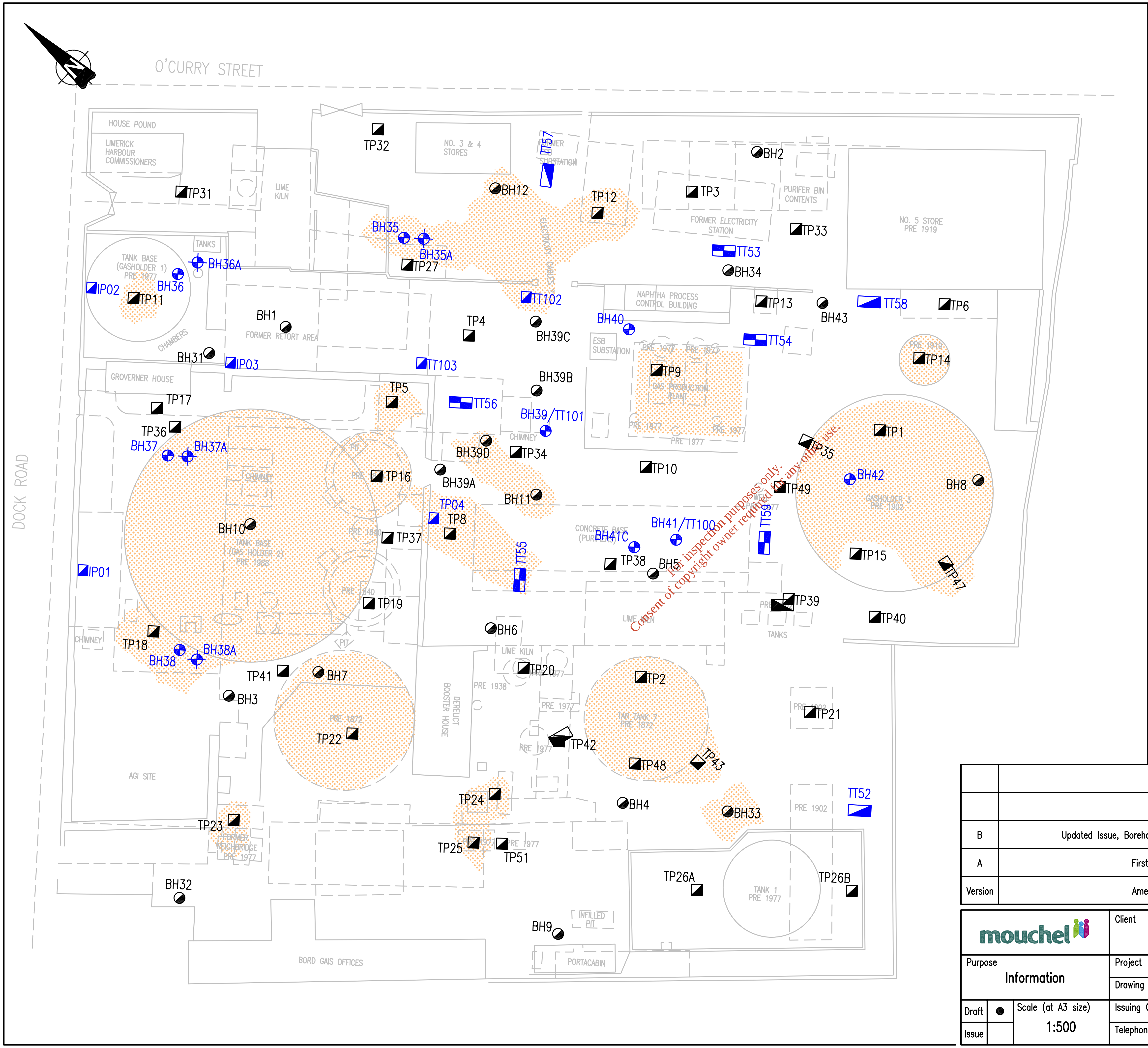
Scale (at A3 size): 1:500

Issuing Office: Ellesmere Port

Telephone: 0151 356 5555

Drawing number: 1021927/R03/007

Version: A



Key

- Approximate Location of Former Structure
- Trial Pits 1996, 1995, 2001 SI
- Boreholes 1996, 1995, 2001 SI
- Cable Percussion Borehole, 2003 S.I.
- Rotary Borehole, 2003 S.I.
- Trial Trench TT52–59, 2003 S.I.
- Locations of free phase NAPL in made ground and limestone

Version	Amendment	Originated by and date	Checked by and date	Approved by and date
B	Updated Issue, Boreholes and Trial Pits added	N.Henrys 03/04/09	T Brown 03/04/09	T Brown 03/04/09
A	First Issue	5/11/03	D.Field 5/11/03	Tony Brown 5/11/03

mouchel

Client: BORD GÁIS

Purpose: Information

Project: Limerick Gasworks

Drawing Title: Figure 8 Encountered Free Phase Product (Historic)

Draft ● / Issue

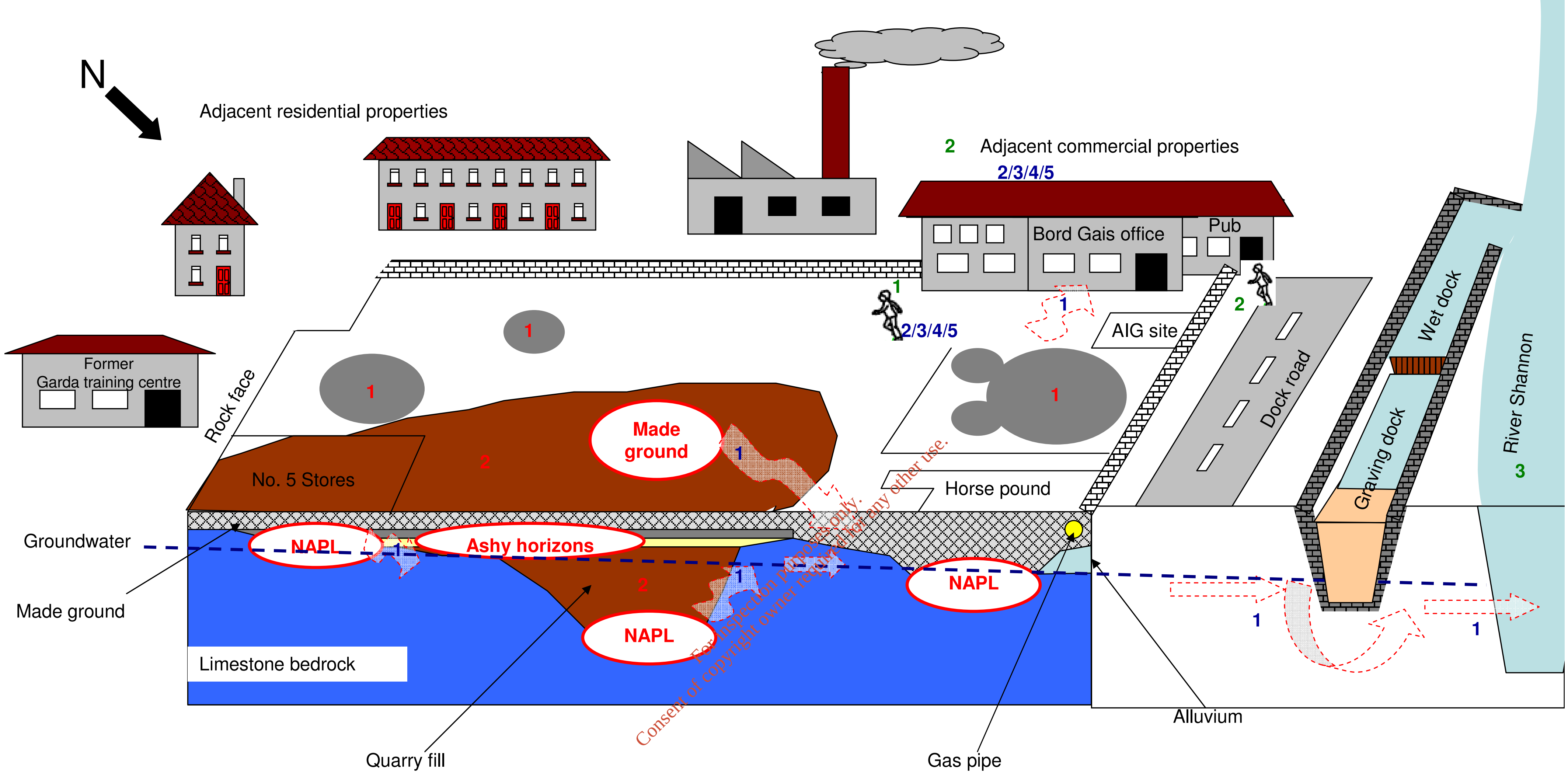
Scale (at A3 size): 1:500

Issuing Office: Ellesmere Port

Telephone: 0151 356 5555

Drawing number: 1021927/R03/008

Version: B



Source

Primary sources:

1) Underground tanks / gasholders

2) Backfilled quarry

Which are evident from
Made ground
NAPLs
Ashy Horizons

Pathway

1) Contaminant mobilisation and migration

2) Direct human contact with soil/dust (indoors and outdoors)

3) Ingestion of soil/dust (indoors and outdoors)

4) Inhalation of dust (indoors and outdoors)

5) Inhalation of vapours (indoors and outdoors)

Receptor

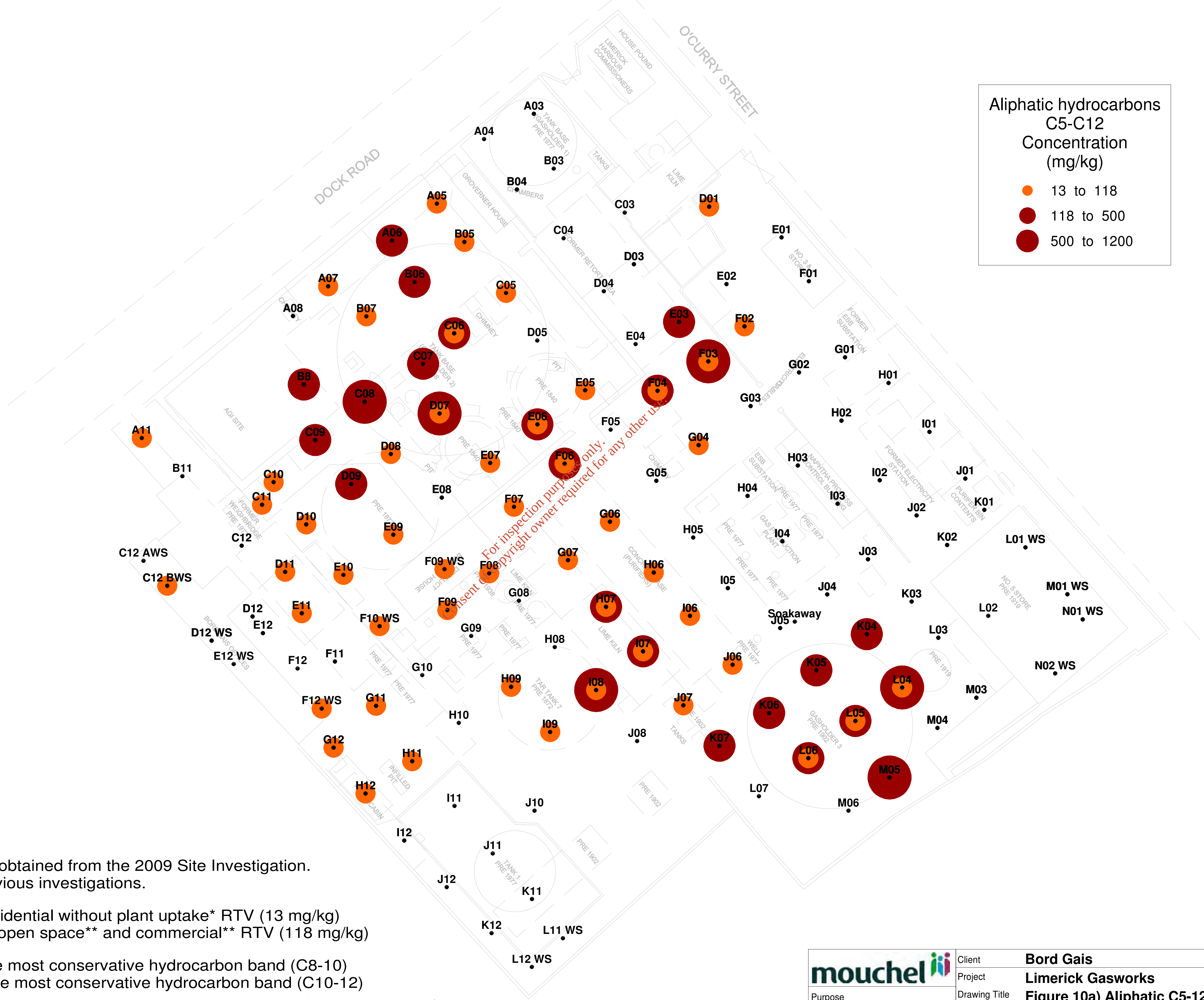
1) Future site users

2) Adjacent site users

3) River Shannon

mouchel	Client: Bord Gais		
	Project: Limerick Gasworks		
	Title: Figure 9) Conceptual site model		
Purpose Report	Draft		Not to scale
	Issue	●	
Issuing Office: Ellesmere Port	Drawing number: 1021927/R03/009		Version A
Telephone: 0151 356 5555			

N



This plot was produced using data obtained from the 2009 Site Investigation.
No data was included from the previous investigations.

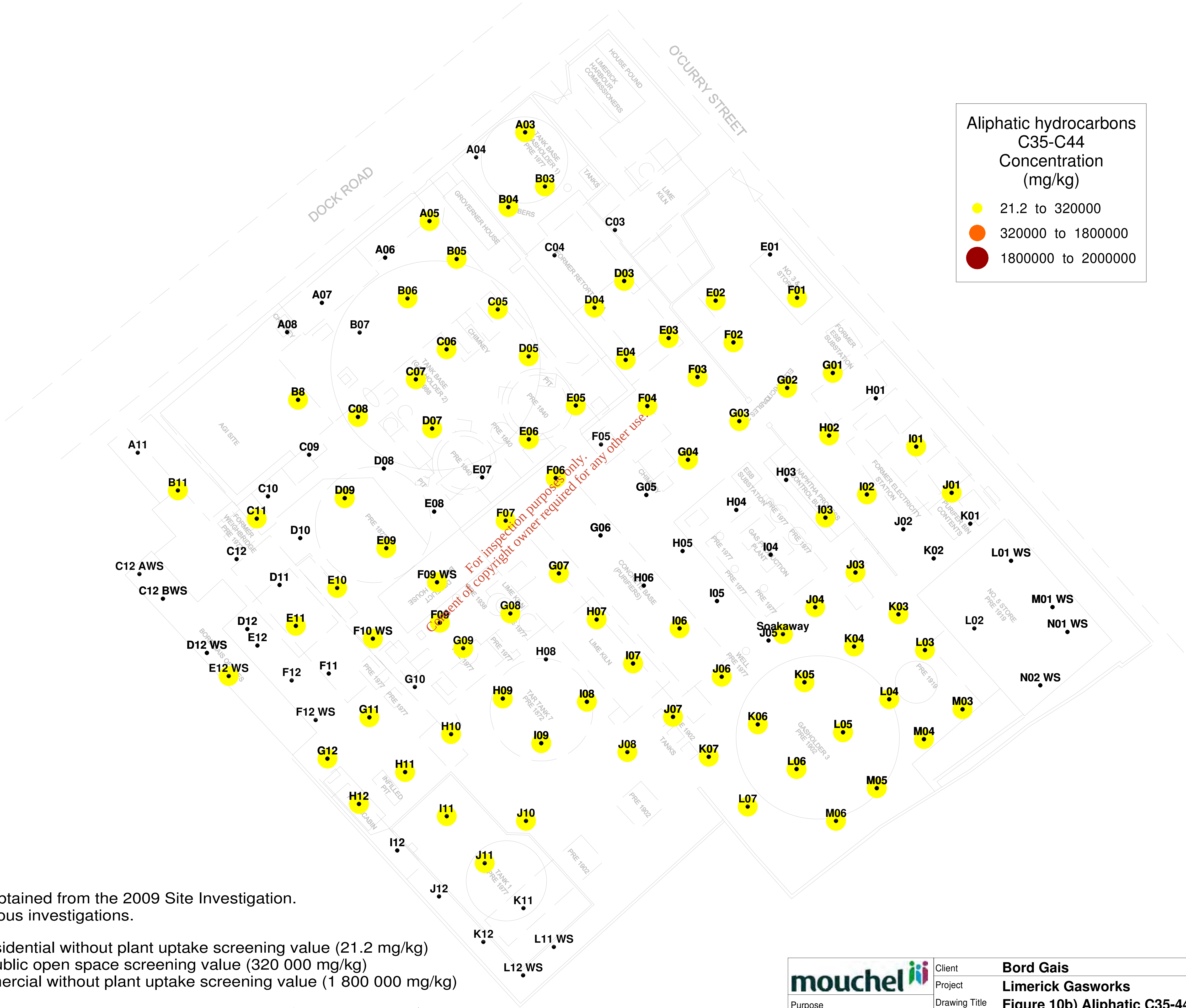
Locations in orange exceed the residential without plant uptake* RTV (13 mg/kg)
Locations in red exceed the public open space** and commercial** RTV (118 mg/kg)

*Screening value is based upon the most conservative hydrocarbon band (C8-10)
**Screening value is based upon the most conservative hydrocarbon band (C10-12)

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

mouchel

Client	Bord Gais
Project	Limerick Gasworks
Drawing Title	Figure 10a) Aliphatic C5-12
Purpose	Information
Scale	Not to scale
Issuing Office	Ellesmere Port
Telephone	0151 356 5555
Drawing Number	1021927/R03/010a
Version	A



Aliphatic hydrocarbons C35-C44 Concentration (mg/kg)

- 21.2 to 320000
- 320000 to 1800000
- 1800000 to 2000000

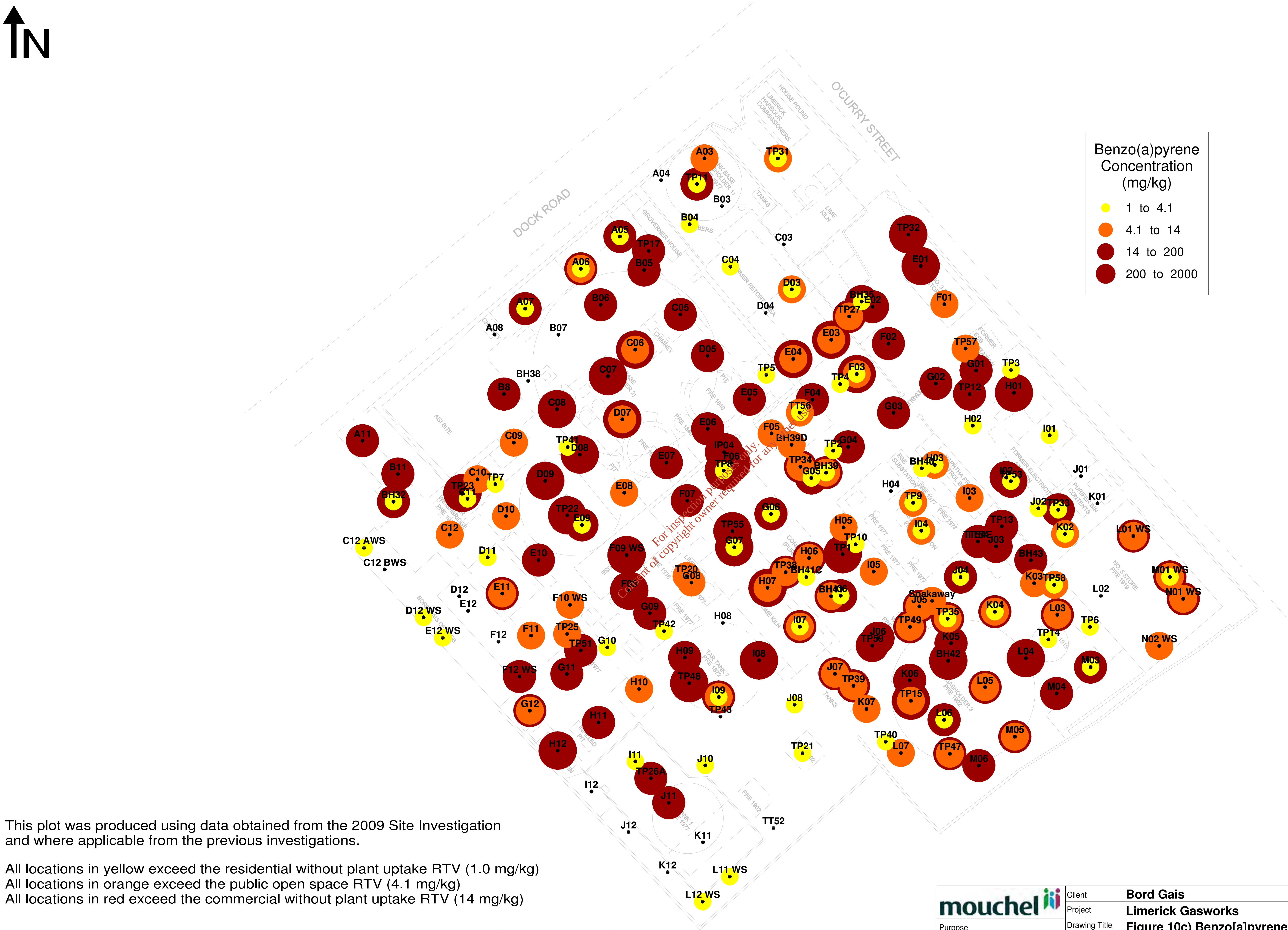
This plot was produced using data obtained from the 2009 Site Investigation.
No data was included from the previous investigations.

All locations in yellow exceed the residential without plant uptake screening value (21.2 mg/kg)
All locations in orange exceed the public open space screening value (320 000 mg/kg)
All locations in red exceed the commercial without plant uptake screening value (1 800 000 mg/kg)

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

mouchel

Purpose	Information
Client	Bord Gais
Project	Limerick Gasworks
Drawing Title	Figure 10b) Aliphatic C35-44
Scale	Not to scale
Issuing Office	Ellesmere Port
Telephone	0151 356 5555
Drawing Number	1021927/R03/010b
Version	A



This plot was produced using data obtained from the 2009 Site Investigation and where applicable from the previous investigations.

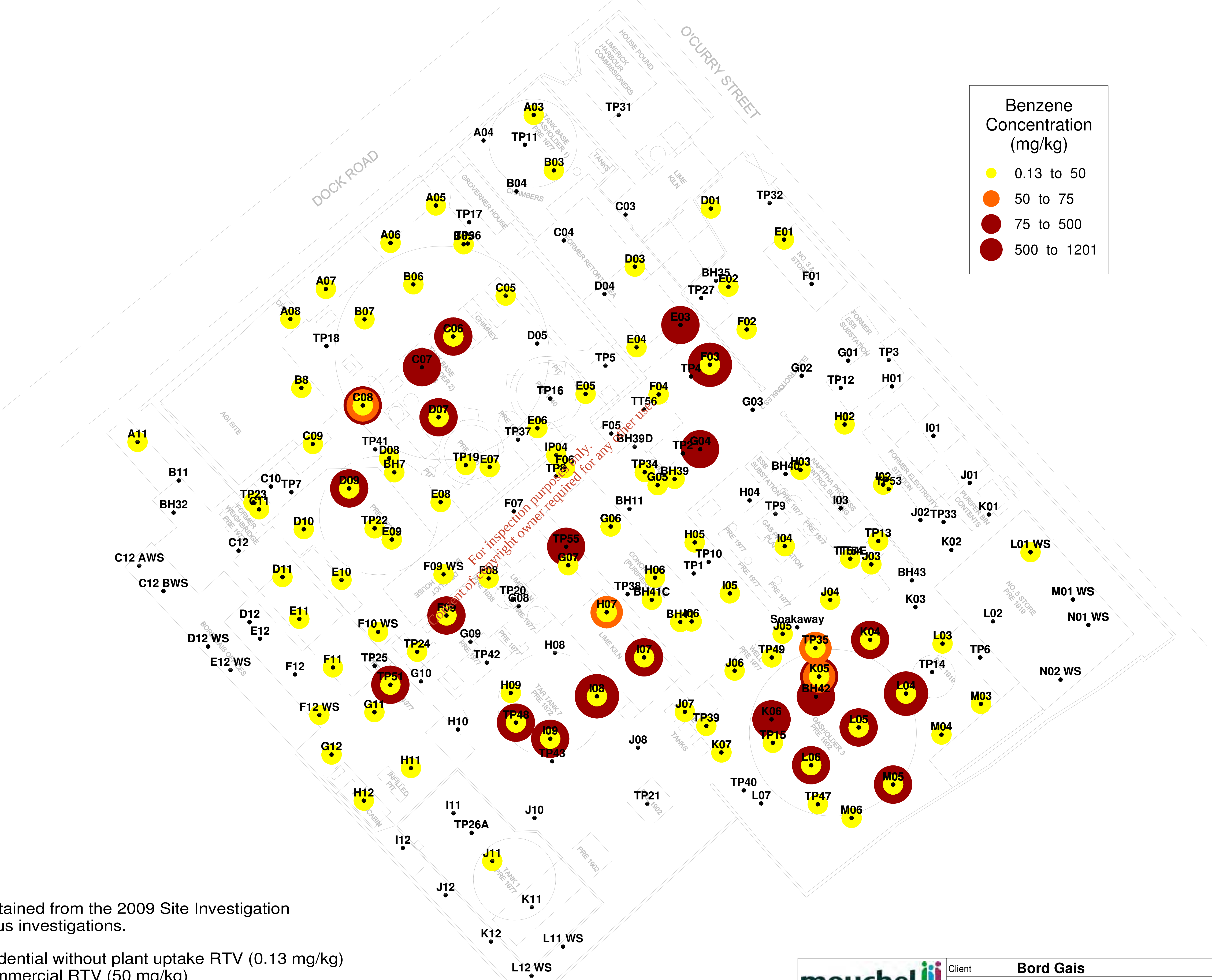
All locations in yellow exceed the residential without plant uptake RTV (1.0 mg/kg)
All locations in orange exceed the public open space RTV (4.1 mg/kg)
All locations in red exceed the commercial without plant uptake RTV (14 mg/kg)

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

mouchel

Client	Bord Gais
Project	Limerick Gasworks
Drawing Title	Figure 10c) Benzo[a]pyrene
Purpose	Information
Scale	Not to scale
Issuing Office	Ellesmere Port
Telephone	0151 356 5555
Drawing Number	1021927/R03/010c
Version	A

N



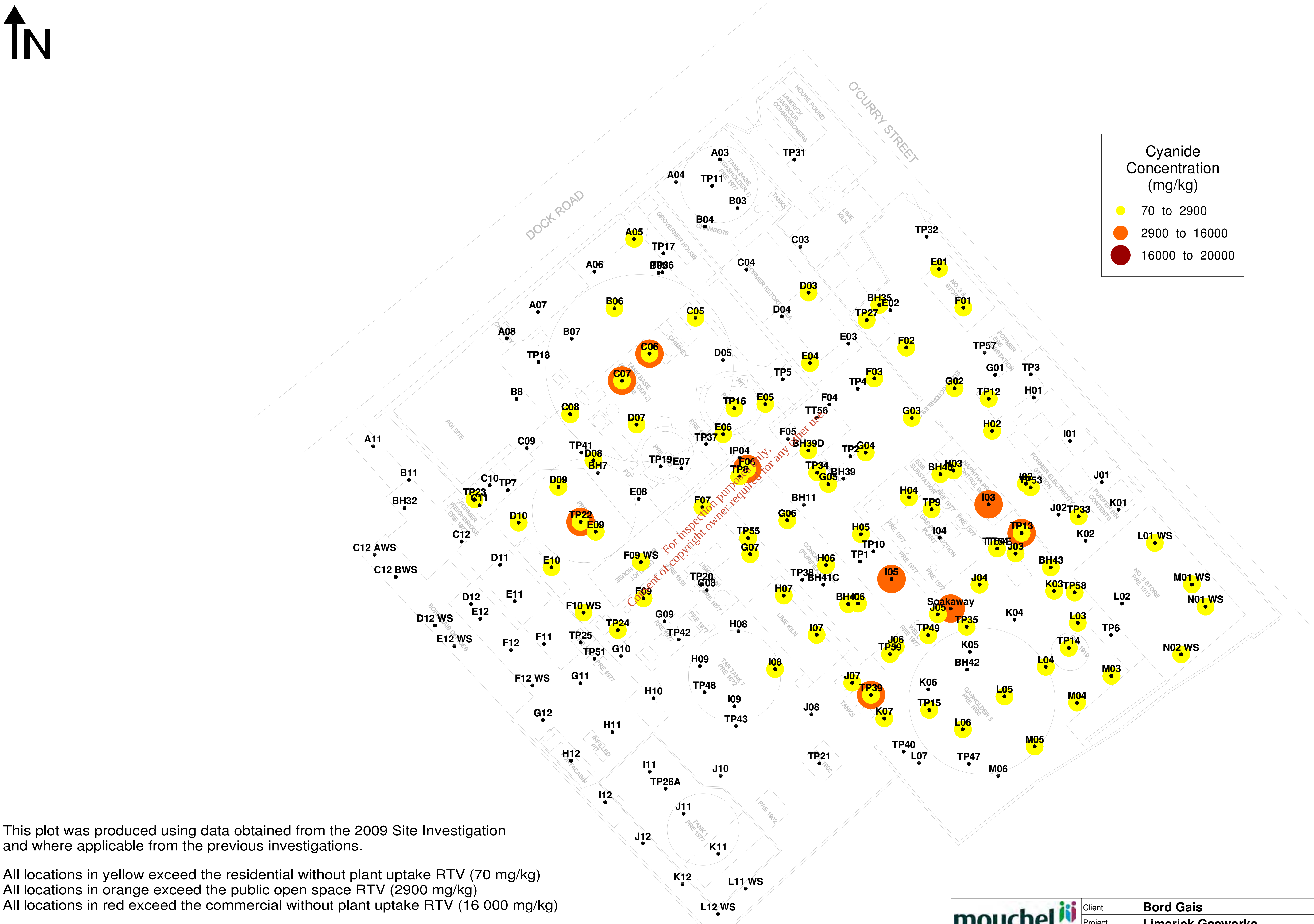
This plot was produced using data obtained from the 2009 Site Investigation and where applicable from the previous investigations.

All locations in yellow exceed the residential without plant uptake RTV (0.13 mg/kg)
All locations in orange exceed the commercial RTV (50 mg/kg)
All locations in red exceed the public open space without plant uptake RTV (75 mg/kg)

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

mouchel

Purpose: Information	Client: Bord Gais		
	Project: Limerick Gasworks		
	Drawing Title: Figure 10d) Benzene		
Scale: Not to scale	Issuing Office: Ellesmere Port	Drawing Number: 1021927/R03/010d	Version: A
	Telephone: 0151 356 5555		



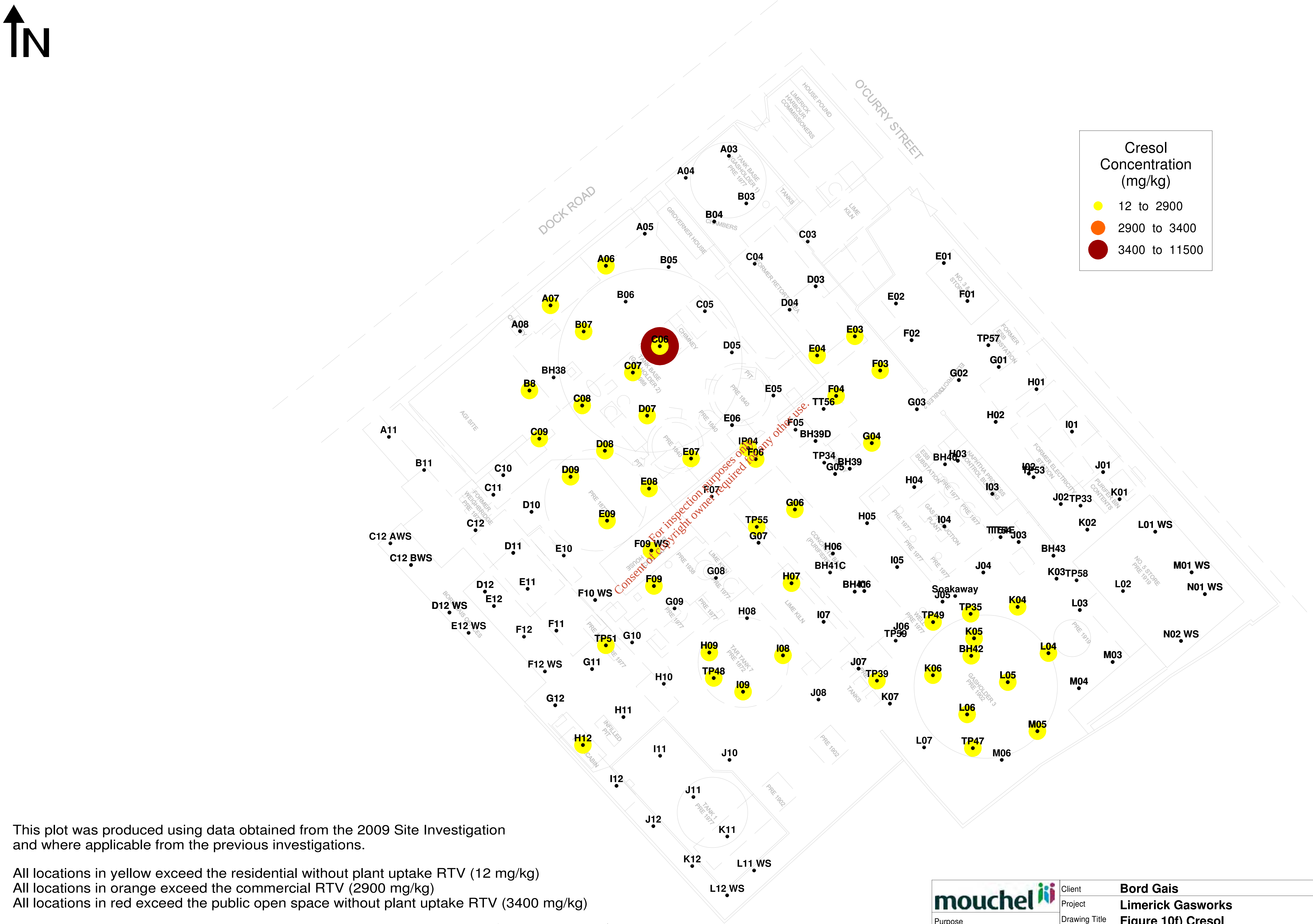
This plot was produced using data obtained from the 2009 Site Investigation and where applicable from the previous investigations.

All locations in yellow exceed the residential without plant uptake RTV (70 mg/kg)
All locations in orange exceed the public open space RTV (2900 mg/kg)
All locations in red exceed the commercial without plant uptake RTV (16 000 mg/kg)

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

mouchel

Purpose: Information	Client	Bord Gais
	Project	Limerick Gasworks
	Drawing Title	Figure 10e) Cyanide
Scale: Not to scale	Issuing Office	Ellesmere Port
	Telephone	0151 356 5555
Drawing Number: 1021927/R03/010e	Version	A



Cresol Concentration (mg/kg)

- 12 to 2900
- 2900 to 3400
- 3400 to 11500

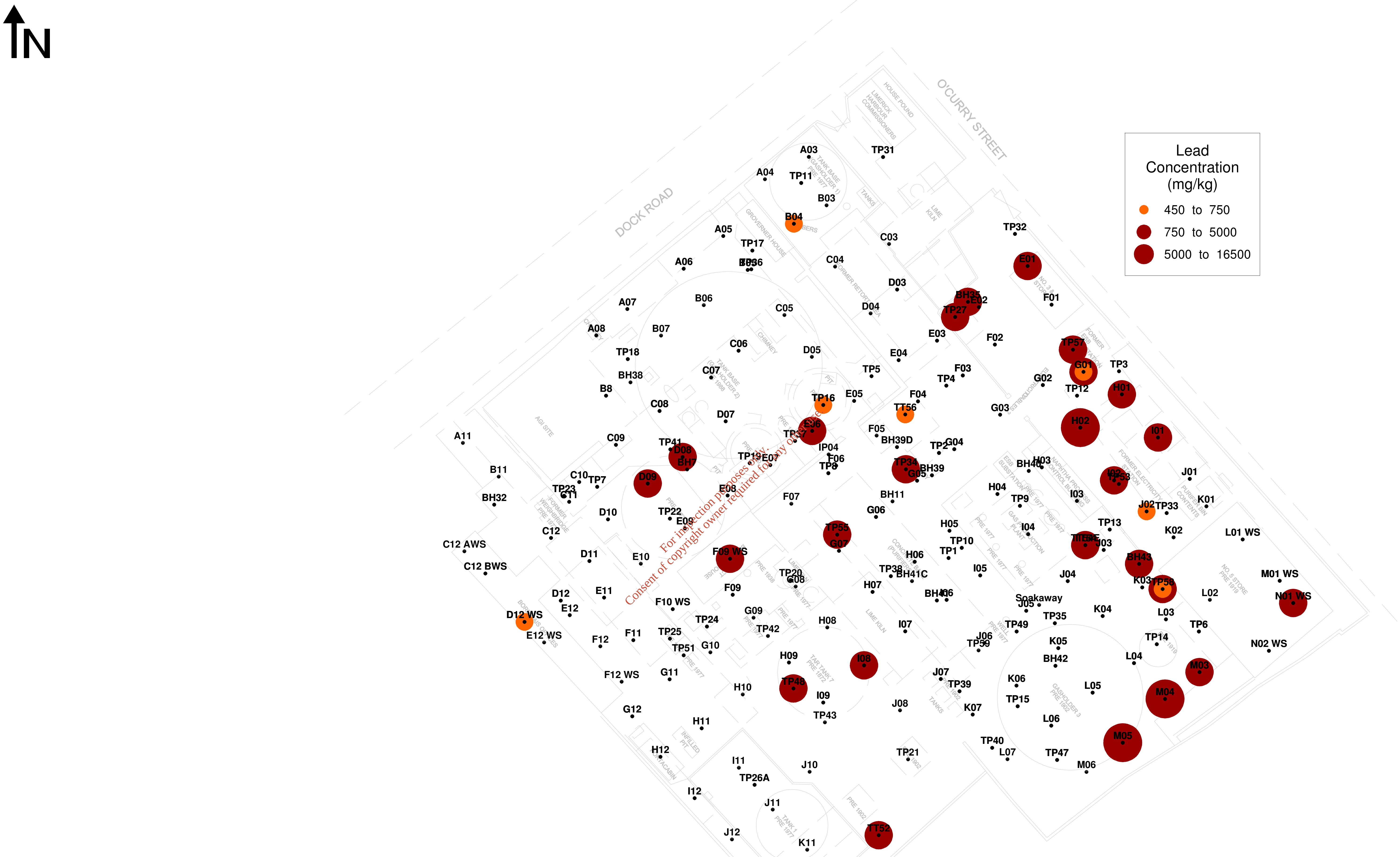
This plot was produced using data obtained from the 2009 Site Investigation and where applicable from the previous investigations.

All locations in yellow exceed the residential without plant uptake RTV (12 mg/kg)
All locations in orange exceed the commercial RTV (2900 mg/kg)
All locations in red exceed the public open space without plant uptake RTV (3400 mg/kg)

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM		

mouchel

Client	Bord Gais
Project	Limerick Gasworks
Drawing Title	Figure 10f) Cresol
Purpose	Information
Scale	Not to scale
Issuing Office	Ellesmere Port
Telephone	0151 356 5555
Drawing Number	1021927/R03/010f
Version	A



This plot was produced using data obtained from the 2009 Site Investigation and where applicable from the previous investigations.

Locations in orange exceed the residential without plant uptake and public open space RTV (450 mg/kg)
Locations in red exceed the and commercial RTV (750 mg/kg)

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

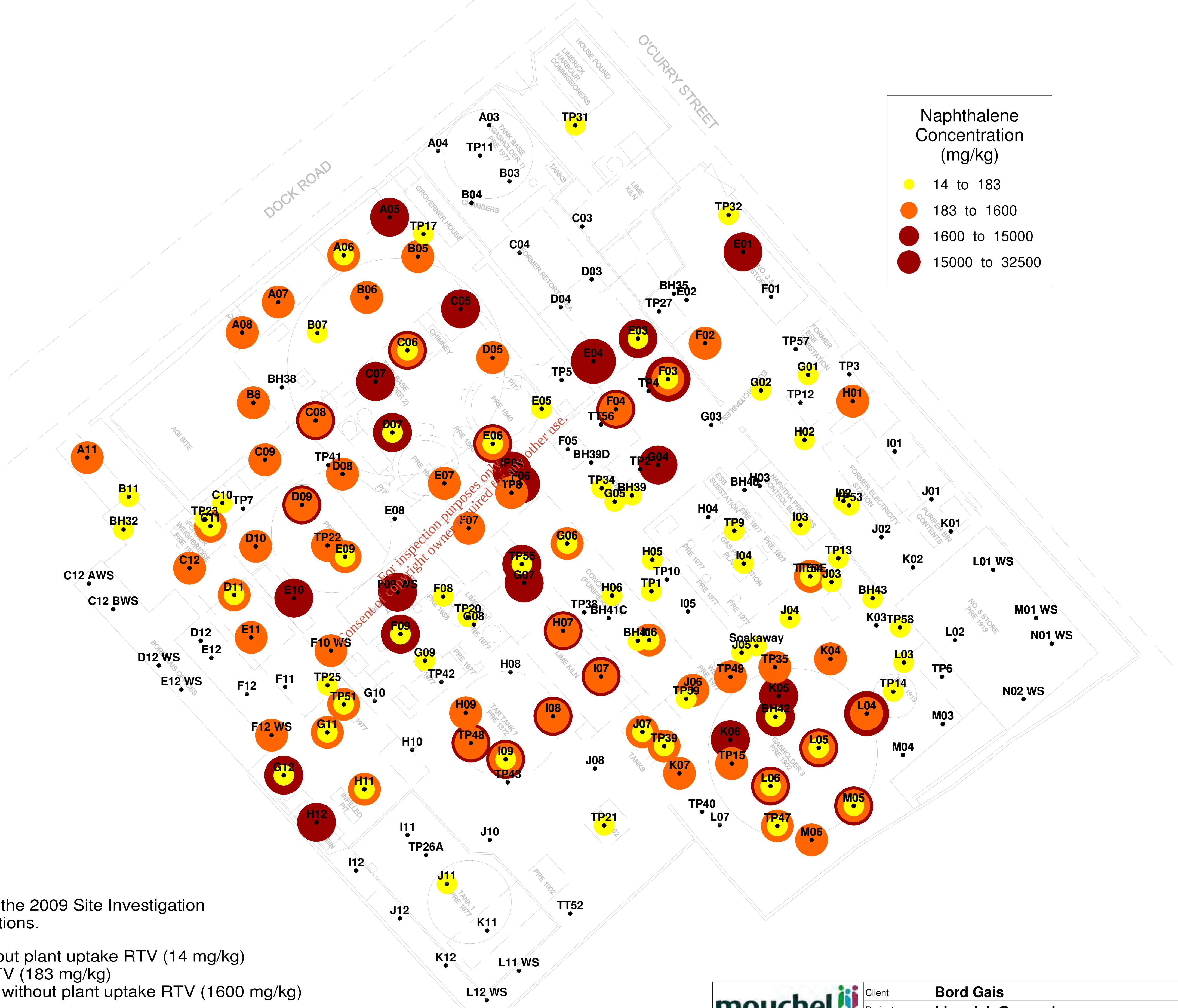
mouchel

Purpose: Information

Scale: Not to scale

Client: Bord Gais
Project: Limerick Gasworks
Drawing Title: Figure 10g) Lead
Issuing Office: Ellesmere Port
Telephone: 0151 356 5555
Drawing Number: 1021927/R03/010g
Version: A

N



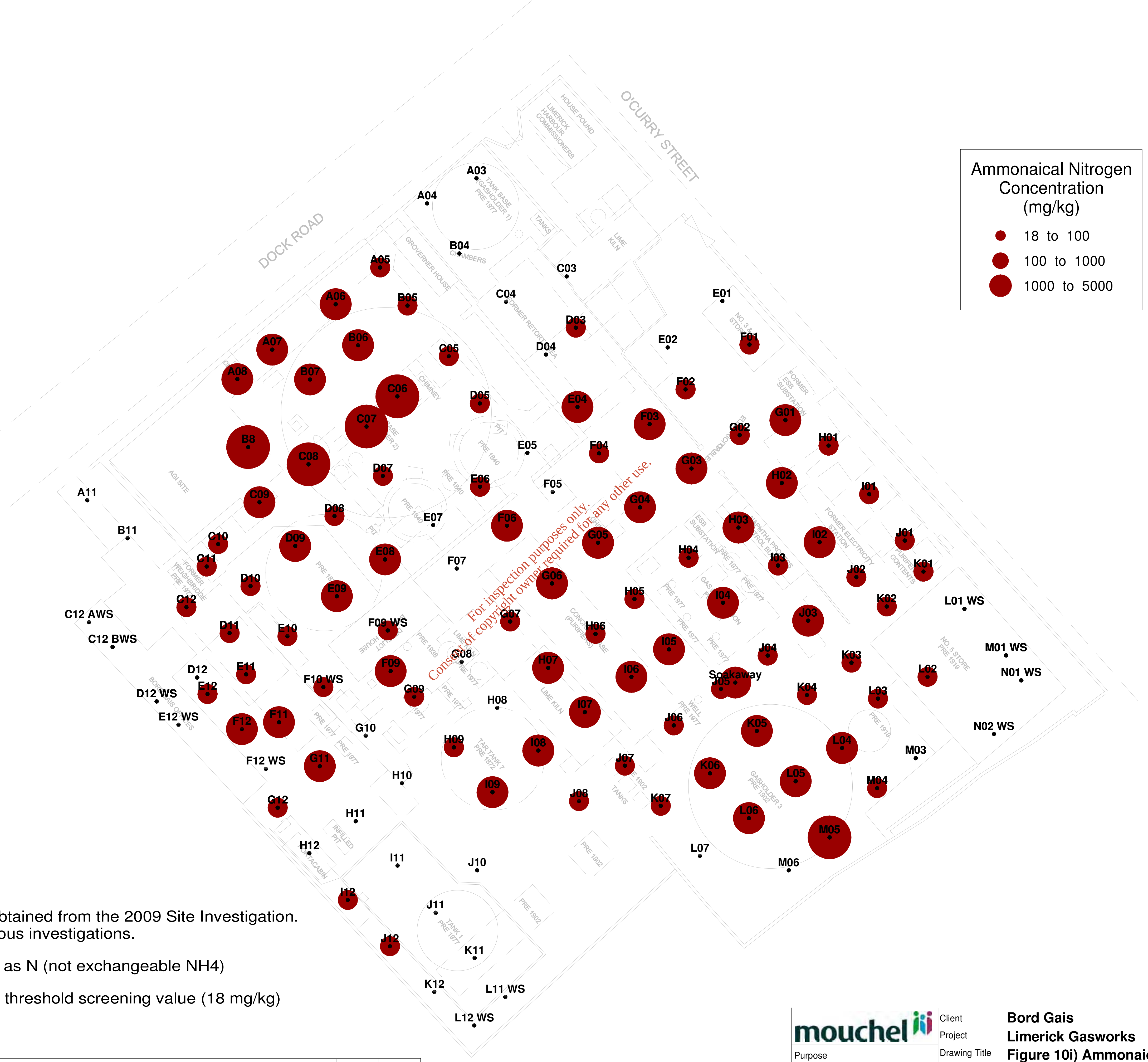
This plot was produced using data obtained from the 2009 Site Investigation and where applicable from the previous investigations.

All locations in yellow exceed the residential without plant uptake RTV (14 mg/kg)
All locations in orange exceed the commercial RTV (183 mg/kg)
All locations in red exceed the public open space without plant uptake RTV (1600 mg/kg)

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

mouchel

Client	Bord Gais
Project	Limerick Gasworks
Drawing Title	Figure 10h) Naphthalene
Purpose	Information
Scale	Not to scale
Issuing Office	Ellesmere Port
Telephone	0151 356 5555
Drawing Number	1021927/R03/010h
Version	A



This plot was produced using data obtained from the 2009 Site Investigation.
No data was included from the previous investigations.

Results are for ammonaical nitrogen as N (not exchangeable NH4)

All locations in red exceed the odour threshold screening value (18 mg/kg)

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

mouchel

Purpose: Information

Client: Bord Gais

Project: Limerick Gasworks

Drawing Title: Figure 10i) Ammonaical Nitrogen

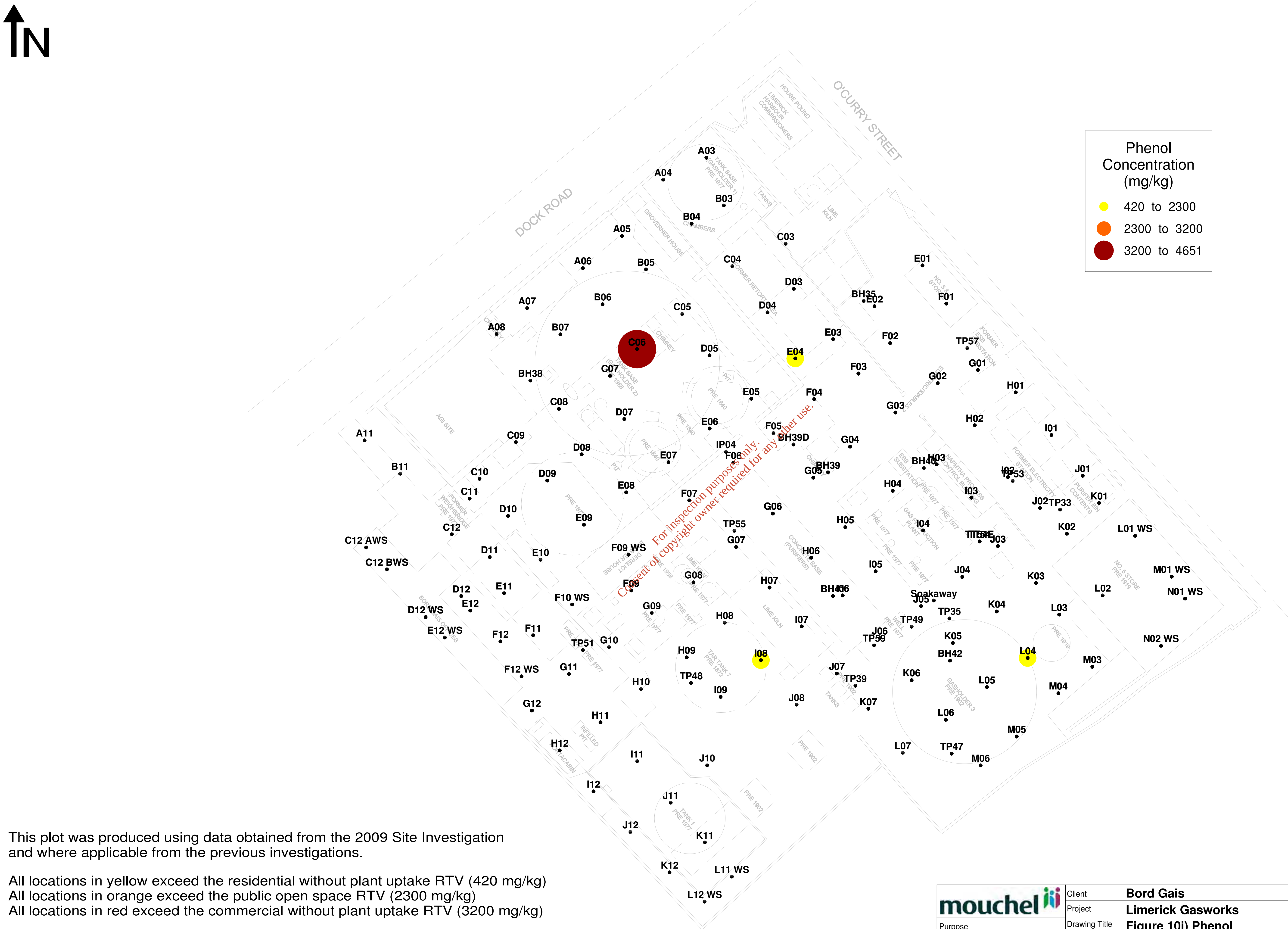
Scale: Not to scale

Issuing Office: Ellesmere Port

Telephone: 0151 356 5555

Drawing Number: 1021927/R03/010i

Version: A



This plot was produced using data obtained from the 2009 Site Investigation and where applicable from the previous investigations.

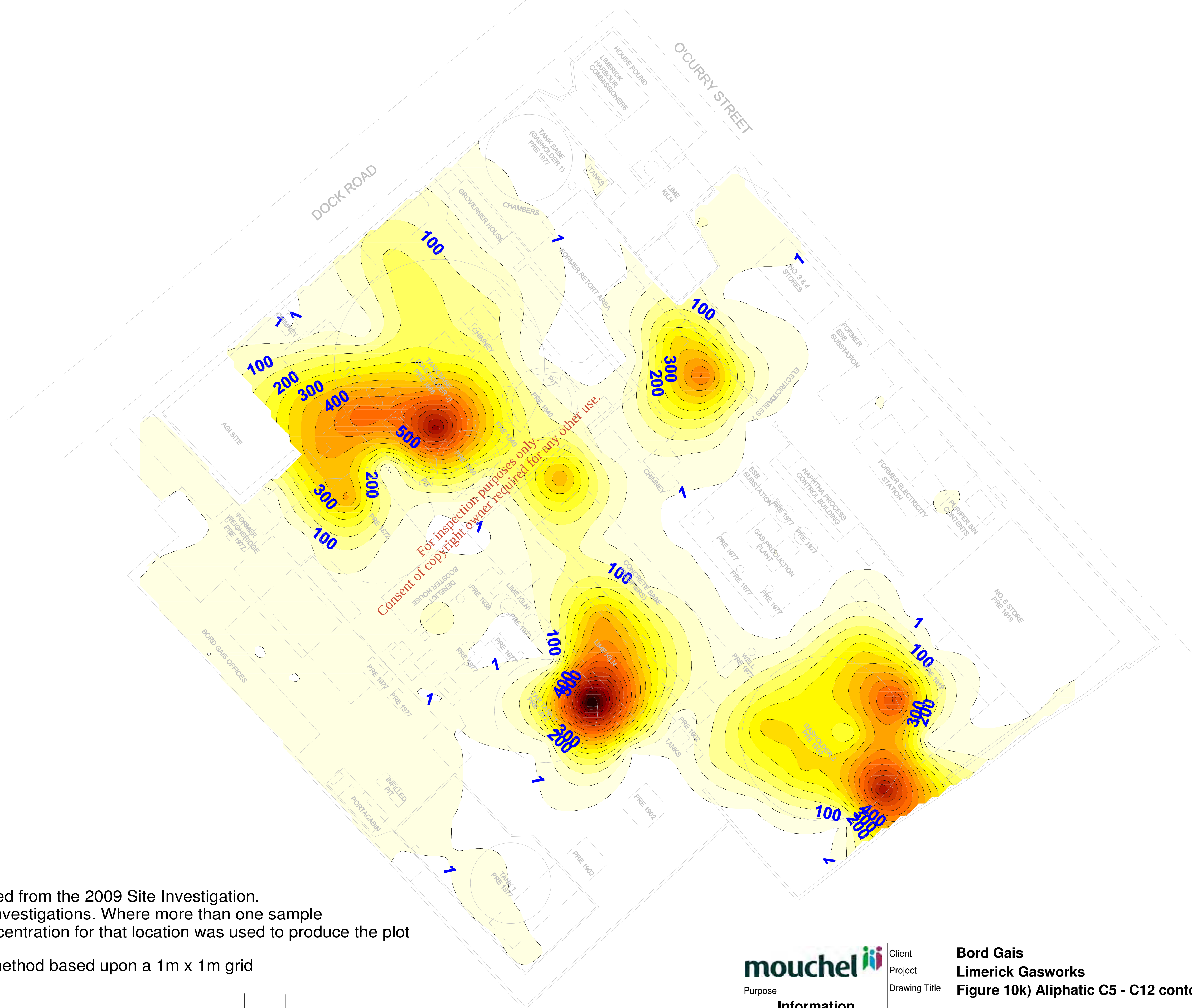
All locations in yellow exceed the residential without plant uptake RTV (420 mg/kg)
All locations in orange exceed the public open space RTV (2300 mg/kg)
All locations in red exceed the commercial without plant uptake RTV (3200 mg/kg)

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

mouchel

Client	Bord Gais
Project	Limerick Gasworks
Drawing Title	Figure 10j) Phenol
Purpose	Information
Scale	Not to scale
Issuing Office	Ellesmere Port
Telephone	0151 356 5555
Drawing Number	1021927/R03/010j
Version	A

N



Aliphatic C5-C12 Concentration (mg/kg)

1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
1

This plot was produced using data obtained from the 2009 Site Investigation.
No data was included from the previous investigations. Where more than one sample was obtained from a hole the highest concentration for that location was used to produce the plot

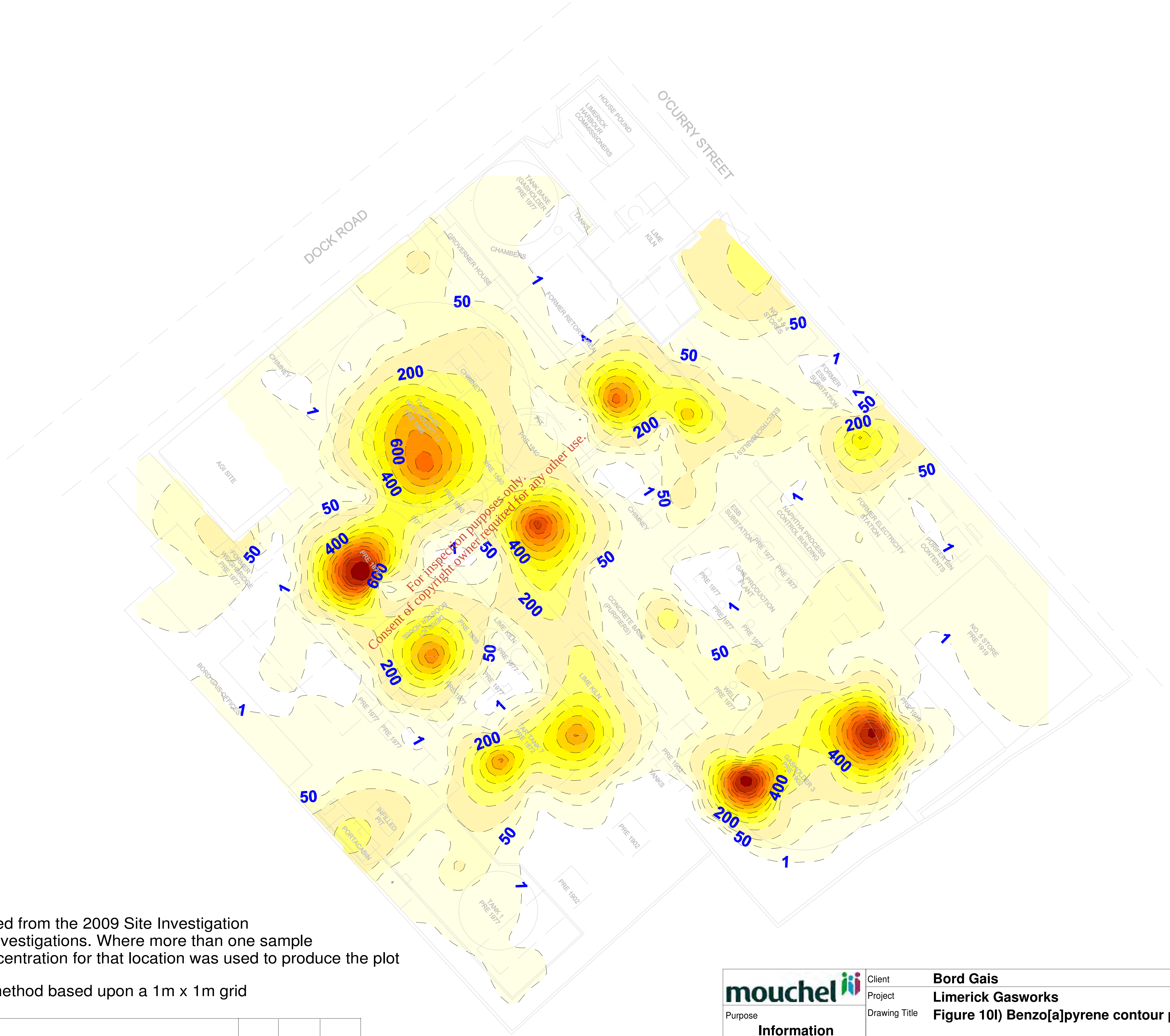
Contours were plotted using the Kriging method based upon a 1m x 1m grid

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

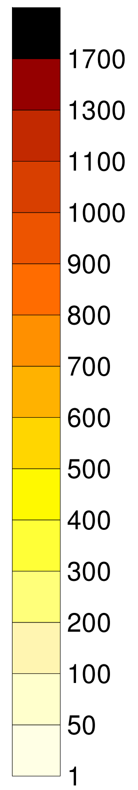
mouchel

Purpose	Information
Scale	Not to scale
Client	Bord Gais
Project	Limerick Gasworks
Drawing Title	Figure 10k) Aliphatic C5 - C12 contour plot
Issuing Office	Ellesmere Port
Telephone	0151 356 5555
Drawing Number	1021927/R03/010k
Version	A

N



Benzo[a]pyrene Concentration (mg/kg)



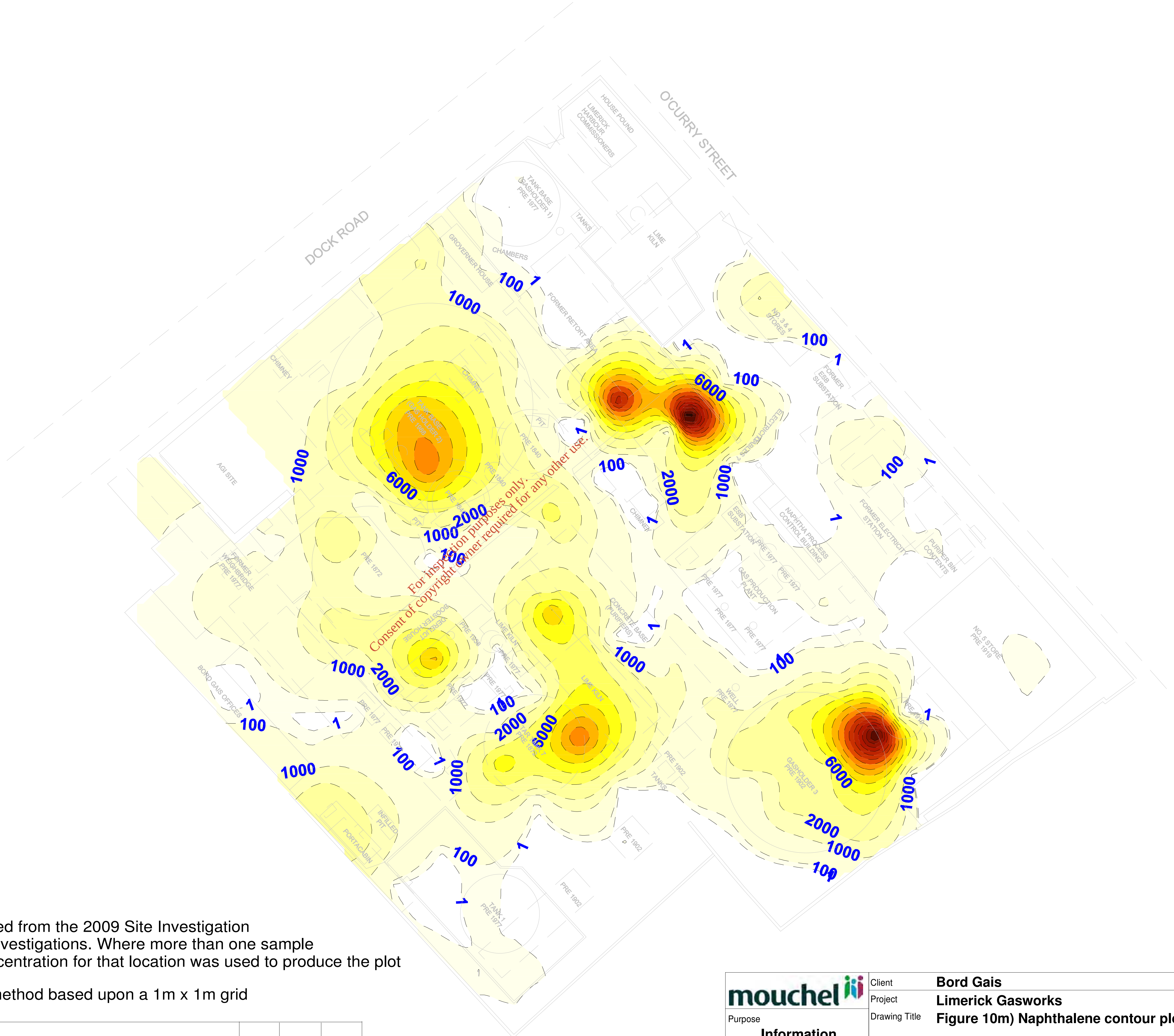
This plot was produced using data obtained from the 2009 Site Investigation and where applicable from the previous investigations. Where more than one sample was obtained from a hole the highest concentration for that location was used to produce the plot

Contours were plotted using the Kriging method based upon a 1m x 1m grid

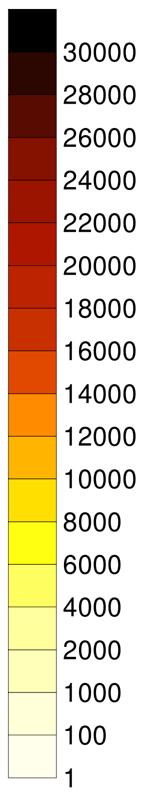
Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

mouchel

Client	Bord Gais		
Project	Limerick Gasworks		
Drawing Title	Figure 10l) Benzo[a]pyrene contour plot		
Purpose	Information		
Scale	Not to scale		
Issuing Office	Ellesmere Port	Drawing Number	1021927/R03/010l
Telephone	0151 356 5555	Version	A



Naphthalene Concentration (mg/kg)



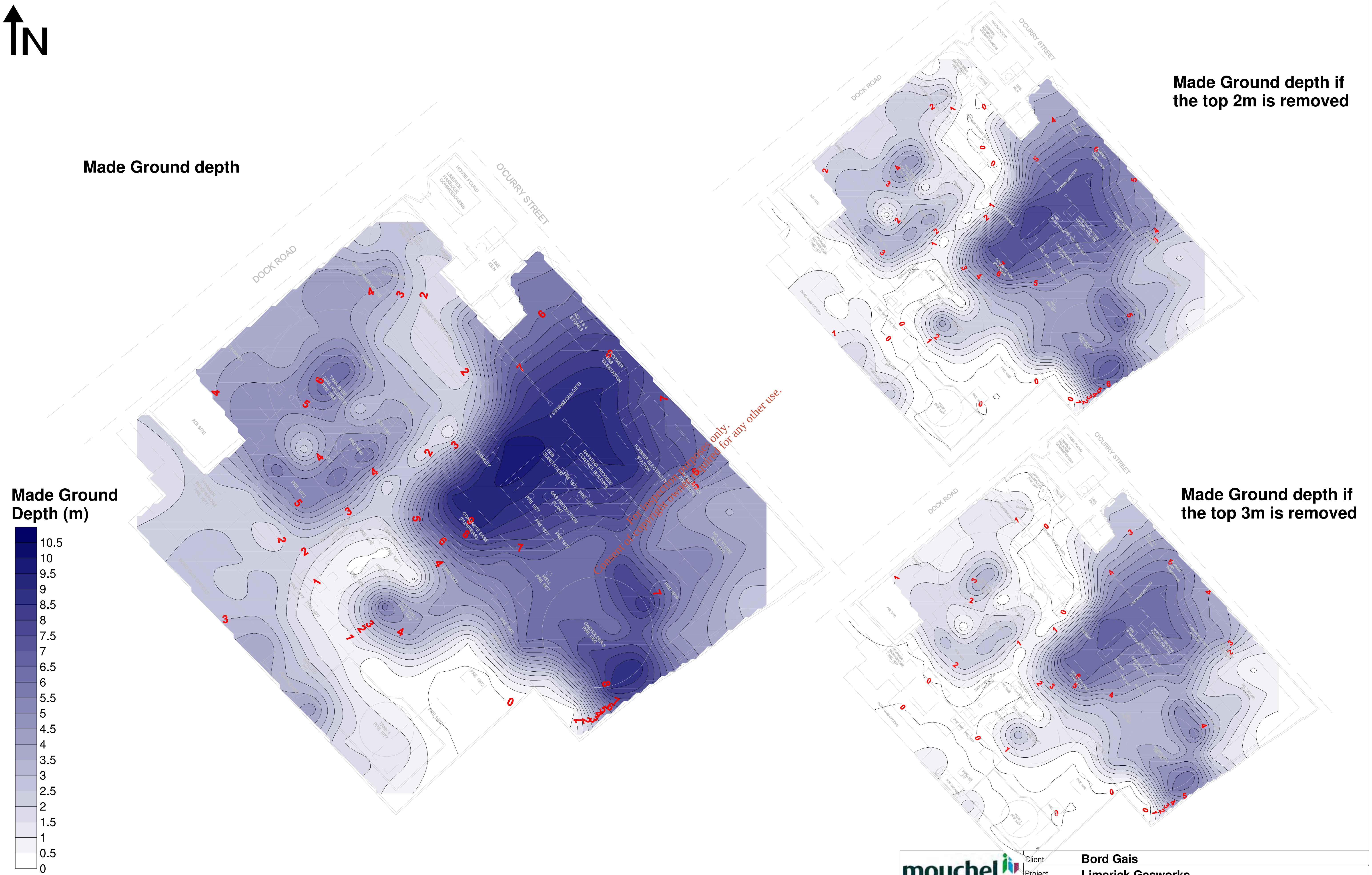
This plot was produced using data obtained from the 2009 Site Investigation and where applicable from the previous investigations. Where more than one sample was obtained from a hole the highest concentration for that location was used to produce the plot

Contours were plotted using the Kriging method based upon a 1m x 1m grid

Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

mouchel

Purpose	Information
Client	Bord Gais
Project	Limerick Gasworks
Drawing Title	Figure 10m) Naphthalene contour plot
Scale	Not to scale
Issuing Office	Ellesmere Port
Telephone	0151 356 5555
Drawing Number	1021927/R03/010m
Version	A

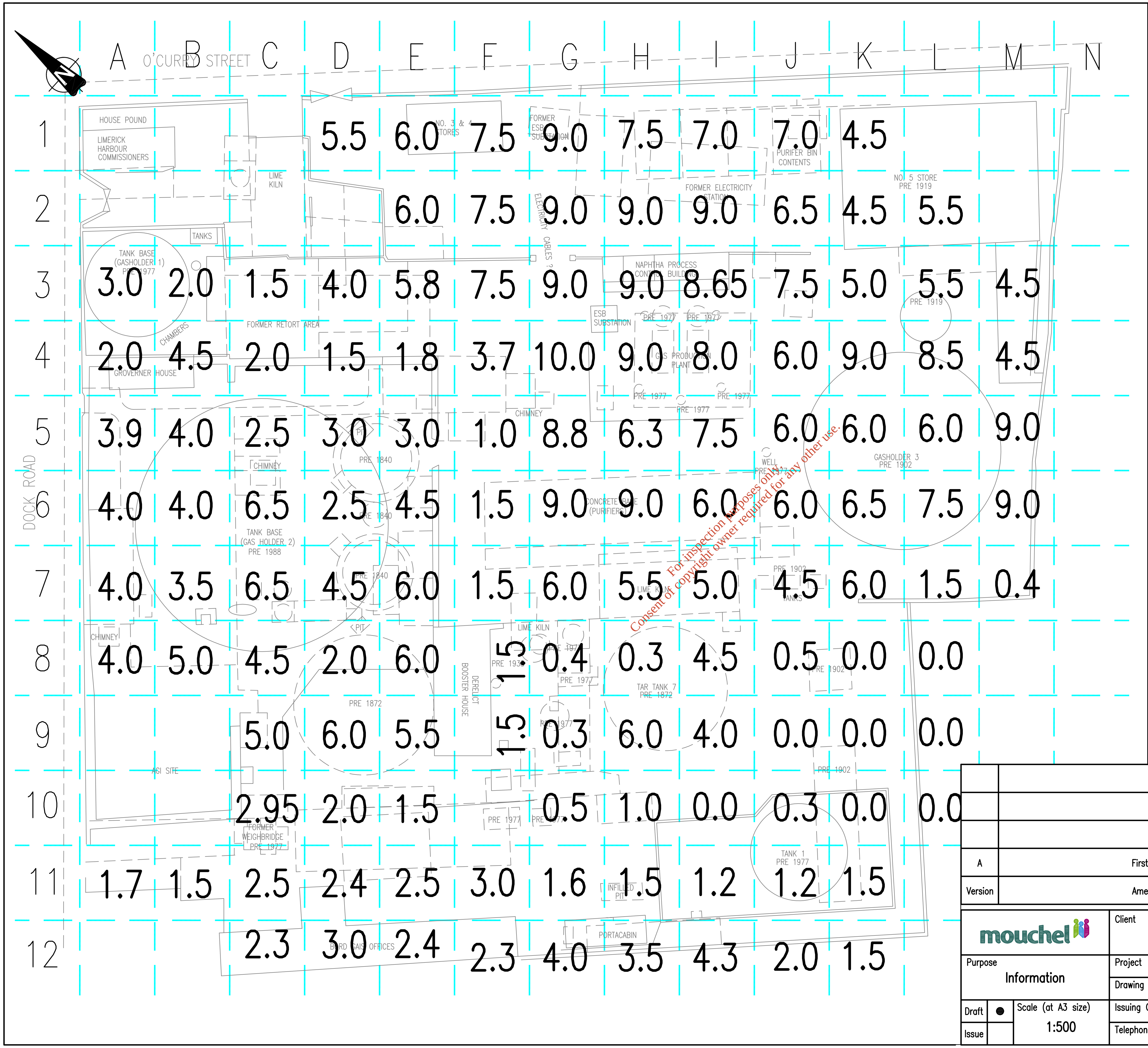


Version	Ammendment	Originated	Checked	Approved
A	First Issue	DM	DM	DW

This plot was produced using data obtained from the 2009 Site Investigation. Contours were plotted using the Kriging method based upon a 1m x 1m grid

mouchel

Purpose	Information
Scale	Not to scale
Client	Bord Gais
Project	Limerick Gasworks
Drawing Title	Figure 11a) Made ground depth contour plot
Issuing Office	Ellesmere Port
Telephone	0151 356 5555
Drawing Number	1021927/R03/011a
Version	A



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				5.5	6.0	7.5	9.0	7.5	7.0	7.0	4.5			
2					6.0	7.5	9.0	9.0	9.0	6.5	4.5	5.5		
3	3.0	2.0	1.5	4.0	5.8	7.5	9.0	9.0	8.65	7.5	5.0	5.5	4.5	
4	2.0	4.5	2.0	1.5	1.8	3.7	10.0	9.0	8.0	6.0	9.0	8.5	4.5	
5	3.9	4.0	2.5	3.0	3.0	1.0	8.8	6.3	7.5	6.0	6.0	6.0	9.0	
6	4.0	4.0	6.5	2.5	4.5	1.5	9.0	9.0	6.0	6.0	6.5	7.5	9.0	
7	4.0	3.5	6.5	4.5	6.0	1.5	6.0	5.5	5.0	4.5	6.0	1.5	0.4	
8	4.0	5.0	4.5	2.0	6.0	1.5	0.4	0.3	4.5	0.5	0.0	0.0		
9			5.0	6.0	5.5	1.5	0.3	6.0	4.0	0.0	0.0	0.0		
10			2.95	2.0	1.5		0.5	1.0	0.0	0.3	0.0	0.0		
11	1.7	1.5	2.5	2.4	2.5	3.0	1.6	1.5	1.2	1.2	1.5			
12			2.3	3.0	2.4	2.3	4.0	3.5	4.3	2.0	1.5			

Key

Approximate Location of Former Structure

10m Grid

Version	Amendment	Originated by and date	Checked by and date	Approved by and date
A	First Issue	K.Hodgkinson 13/01/10	D.Megson 13/01/10	D.Watts 21/01/10

mouchel

Client: BORD GÁIS

Purpose: Information

Project: Limerick Gasworks

Drawing Title: Figure 11b Depth of Made Ground

Draft ● | Issue

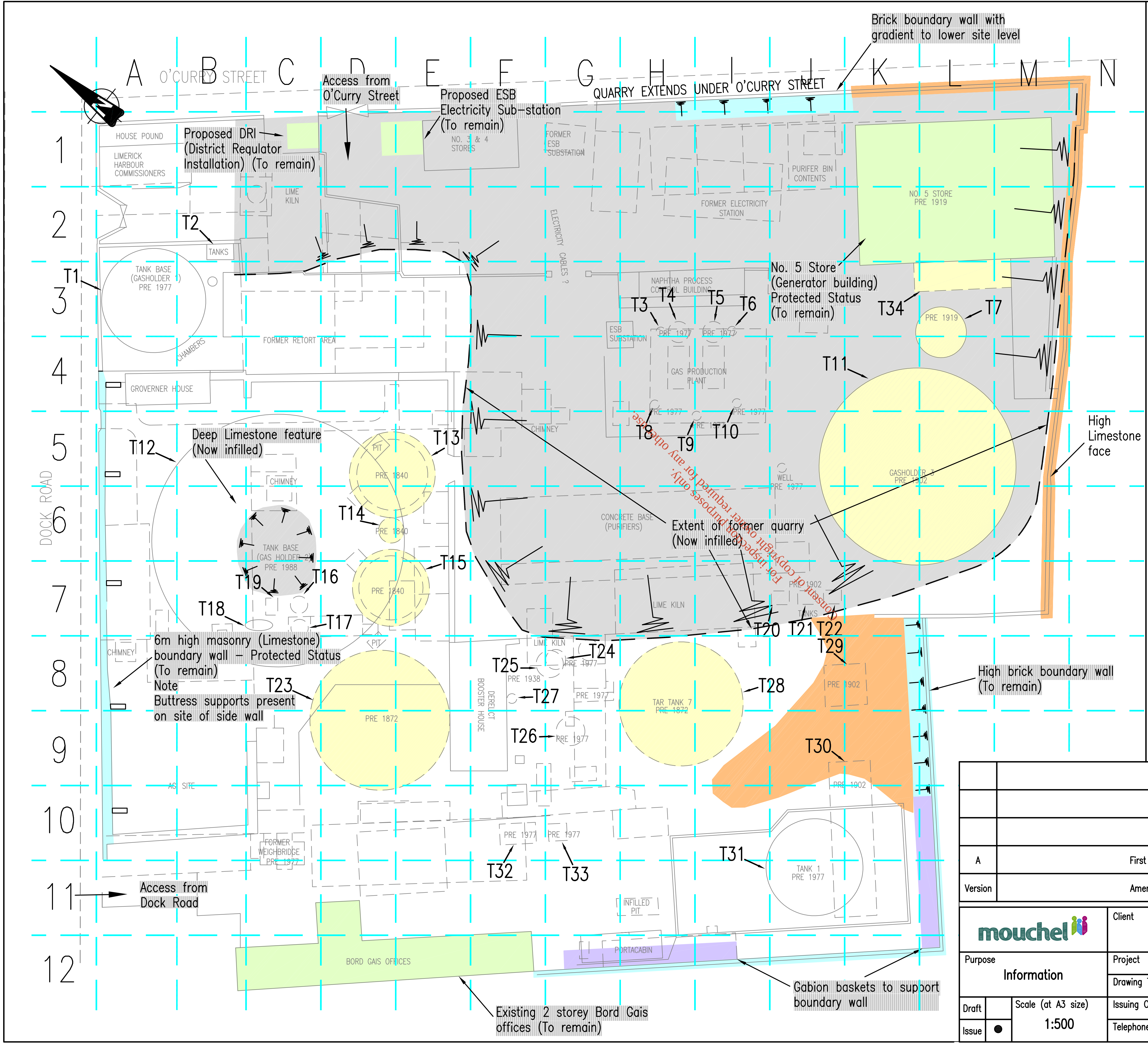
Scale (at A3 size): 1:500

Issuing Office: Ellesmere Port

Telephone: 0151 356 5555

Drawing number: 1021927/R03/11b

Version: A



KEY

- Potentially unstable boundary wall/slopes
- Above ground structures (to be retained)
- Limestone outcrop/rock face
- Known significant underground tanks
- Former Quarry/Deep Limestone Feature (now backfilled)

Version	Amendment	Originated by and date	Checked by and date	Approved by and date
A	First Issue	K.Hodgkinson 26/01/10	D.Field 26/01/10	Tony Brown 26/01/10

mouchel

Client: BORD GÁIS

Purpose: Information

Project: Limerick Gasworks

Drawing Title: Figure 12 Constraints Plan

Draft / Issue ●

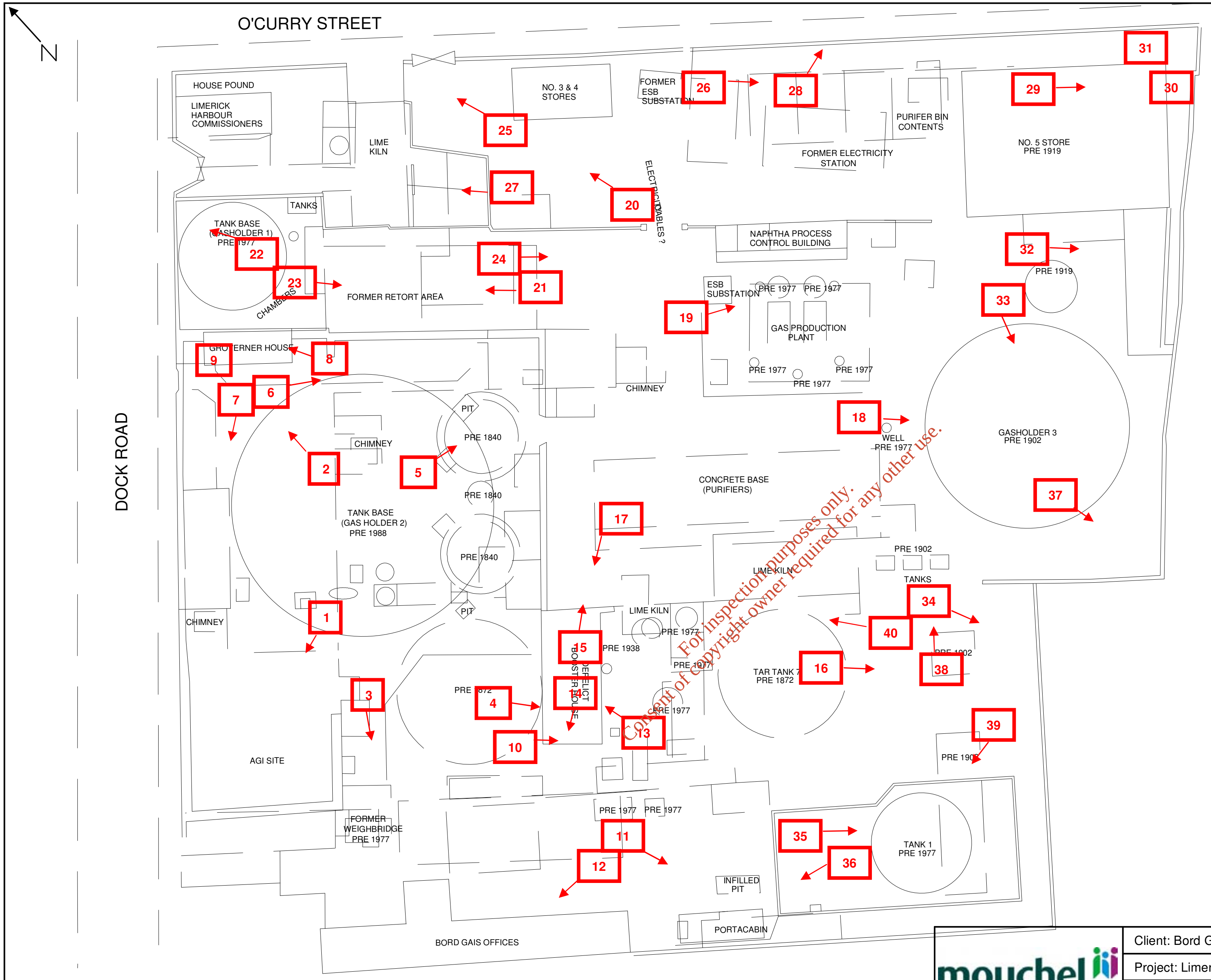
Scale (at A3 size): 1:500

Issuing Office: Ellesmere Port

Telephone: 0151 356 5555

Drawing number: 1021927/R03/012

Version: B



mouchel

Client: Bord Gais

Project: Limerick Gasworks

Title: Figure 13) Site photographic log

Purpose	Draft		Scale (at A3)
Report	Issue	●	Not to scale

Issuing Office: Cheshire	Drawing number	Version
Telephone: 0151 356 5555	1021927/R03/013	A

Limerick Gasworks - Site Photographs, July 2009

Photo 1) AGI site

Photo 2) Gasholder 2 and Grovener house

Limerick Gasworks - Site Photographs, July 2009

Photo 3) Bord Gais offices

Photo 4) Back wall of booster house

Limerick Gasworks - Site Photographs, July 2009

Photo 5) Looking west from Gasholder 2

Photo 6) Gasholder 2

Limerick Gasworks - Site Photographs, July 2009

Photo 7) Gasholder 2 and AGI

Photo 8) Groverner house

Limerick Gasworks - Site Photographs, July 2009

Photo 9) Inside manhole

Photo 10) Booster house slab

Limerick Gasworks - Site Photographs, July 2009

Photo 11) Corner of tank 1 bund

Photo 12) Bord Gais offices

Limerick Gasworks - Site Photographs, July 2009

Photo 13) Booster house

Photo 14) Inside booster house

Limerick Gasworks - Site Photographs, July 2009

Photo 15) Inside Booster house

Photo 16) Excavated wall

Limerick Gasworks - Site Photographs, July 2009

Photo 17) Booster house

Photo 18) View towards Gasholder 3

Limerick Gasworks - Site Photographs, July 2009

Photo 19) No. 5 stores

Photo 20) North east site boundary

Limerick Gasworks - Site Photographs, July 2009

Photo 21) View towards Gasholder 1

Photo 22) Gasholder 1

Limerick Gasworks - Site Photographs, July 2009

Photo 23) Former retort area

Photo 24) View towards ESB substation

Limerick Gasworks - Site Photographs, July 2009

Photo 25) O' Curry St site entrance

Photo 26) No. 5 Stores

Limerick Gasworks - Site Photographs, July 2009

Photo 27) Harbour commissioners land

Photo 28) North eastern boundary

Limerick Gasworks - Site Photographs, July 2009

Photo 29) Inside No. 5 stores

Photo 30) Behind No. 5 stores

Limerick Gasworks - Site Photographs, July 2009

Photo 31) Limestone behind No. 5 stores

Photo 32) South west side of No.5 stores

Limerick Gasworks - Site Photographs, July 2009

Photo 33) Gasholder 3

Photo 34) Exposed wall

Limerick Gasworks - Site Photographs, July 2009

Photo 35) Tank 1 bund

Photo 36) Tank 1 bund

Limerick Gasworks - Site Photographs, July 2009

Photo 37) Site corner from Gasholder 3

Photo 38) Exposed limestone bedrock

Limerick Gasworks - Site Photographs, July 2009

Photo 39) Tank 1 bund exterior

Photo 40) View west across the site