Newcastle University
Newcastle LTC
Ground Risk Report

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1 Introduction

Newcastle University proposes to develop part of the Science Central Development site as a lecture building referred to as the Learning and Teaching Centre (LTC). The Science Central site is located on the site of the former Scottish and Newcastle Brewery, to the west of the city centre in Newcastle upon Tyne, which underwent a site wide reclamation between 2011 and 2014 to remove contamination hotspots and extract two shallow coal seams. Following the reclamation works, the LTC site has been used as a contractor's compound and was used as a fan zone for the 2015 Rugby World Cup. Infrastructure works have also taken place across the wider site area, as well as development works commencing on adjacent plots. Some or all of these activities may have changed the ground conditions at the LTC site following the completed reclamation works.

Arup have been commissioned by Newcastle University to undertake a review of the ground related risks associated with the development of the LTC in light of the site history, pre and post-reclamation ground conditions, and interfaces with existing/proposed infrastructure and buildings in the vicinity.

Arup have undertaken a review of selected desk studies, previous ground investigation reports, reclamation works reports, reclamation validation reports, monitoring reports and design documents for the LTC site and adjacent sites within the wider Science Central Development provided by the client. No information was available on the post-reclamation activities on the site at the time of writing, and as such these have not been considered in this review.

This report summarises the findings of the review and divides ground risks to the LTC site into three categories: mining, geotechnical and contamination risks. It also presents a risks and opportunities register and proposes measures to further investigate, reduce or eliminate these risks to the new development.

This report takes into account the specific instructions and requirements of Newcastle University. It is not intended for, and should not be relied upon by, any third party, and no responsibility is undertaken to any third party.

2 Information Reviewed

A number of reports for the Science Central Development were made available during the production of this report by Newcastle University. These include desk studies, ground investigation reports, interpretative reports, completion and validation reports and health and safety files as listed below. This information was supplemented with records held by Arup for the Science Central Development site.

Desk Studies

- Geotechnical Desk Study Tyne Brewery Development. Mott Mac Donald, 1993. [1]
- Desk Study Tyne Brewery Site Development. Connell Mott MacDonald, 2005. [2]

Investigation Reports

- Site Investigation Report, Tyne Brewery Site Development, Exploration Associates,1994. [3]
- Report on Ground Investigation at Scottish and Newcastle Brewery, Newcastle. Norwest Holst Soil Engineering Limited, 2005. [4]
- Investigation of Hazards & Mining Risks, Gallowgate, Newcastle-Upon-Tyne. Donelly, C., 2006. [5]
- Report on Ground Investigation at the Former Tyne Brewery, Sites 1 and 2. Norwest Holst, 2009. [6]
- Ground Investigation Report Science Central Infrastructure Phase 1. Allied Exploration and Geotechnics, 2011. [7]

Validation and Completion Reports

- Health and Safety File Introduction: Newcastle Breweries Demolition. Atkins, 2009. [8]
- Asbestos Monitoring Report. Hall Construction Services. WSP, 2014. [9]
- Remediation Completion Report. Hall Construction Services. WSP, 2014. [10]
- Earthworks Completion Report. Hall Construction Services. WSP, 2014.[11]
- Health and safety file for the Science Central Enabling works, Hall Construction, 2014. [12]
- Completion Report: Treatment of Mine Workings, Drilling and Grouting of Mine Entries for Hall Construction Services. Groundshire, April 2014. [13]

Monitoring Reports

- Post Restoration Settlement Monitoring, Science Central, Enabling Works, Mot MacDonald, Jul 2015. [14]
- Post Restoration Settlement Monitoring, Science Central, Enabling Works, Mot MacDonald, Jan 2016. [15]

USB Building Design Related Documents

- Geotechnical Interpretive Report Newcastle University USB. BuroHappold Engineering, April 2015. [16]
- Movement and Tolerances report, Newcastle University USB, BuroHappold, May 2015. [17]
- Specification for Piling, Newcastle University USB, BuroHappold, June 2015. [18]
- Specification for Drilling and Grouting Treatment of Mine Workings, Newcastle University USB, BuroHappold, June 2015. [19]
- Drainage Specification, Newcastle University USB, BuroHappold, Nov 2015. [20]
- Factual Report: Probing, Locating, Drilling and Treatment of Shallow Mine Workings. Van Elle, 2016 [21] (included within the Coal Authority submission prepared by Mott MacDonald for the USB building, March 2016). [23]
- CFA Bearing Pile Design, Newcastle University USB, Van Elle, Feb 2016 [22] (included within the Coal Authority submission prepared by Mott MacDonald for the USB building, March 2016). [23]

3 The Site

3.1 Site Location

The site of the LTC is located within the Science Central Development in Newcastle-Upon-Tyne, at approximate Grid Reference NZ 240 643. The location of the site is shown in Figure 1. Its location with regards to the Science Central Development is shown on Figure 2.

3.2 Site Description

The following site description is based upon a review of readily available maps and aerial photographs, supplemented by findings of a site walkover undertaken on the 14th July 2016.

The Science Central Development covers an area of approximately 9 hectares and the post reclamation works show a general fall in levels from 77mOD in the northwest to 58mOD in the southeast [11]. The LTC site is broadly rectangular in shape, covering an area of approximately 0.5 hectares. The site narrows to the north and is approximately 70m wide in an east-west direction and 70m long in a north-south direction. At the time of the site walkover, the site surface was undulatory and gently sloped upwards towards the north and east of the site. The post reclamation works [11] indicate the site to range from approximately 62mOD in the southeast to 67mOD in the northwest however, this trend in fall across the site is not consistent with the findings of the site walkover.

The LTC site is bounded in all directions by the Science Central Development, with the Urban Sciences Building (USB) currently under construction to the north of the site. Unoccupied development plots, paths and small areas of hard and soft landscaping are present in all other directions surrounding the site.

At the time of the site walkover, the LTC site comprised an open area of soft landscaping with a strip of dense and more mature vegetation along the southern boundary. A gravel land drain approximately 0.5m wide was present parallel to the southern boundary. Service manholes were identified in the southeast and southwest corners. An electricity feeder pillar was also located in the south east corner of the site.

3.3 Proposed Development

The wider Science Central Development is being regenerated to provide research, business, living and leisure facilities.

The proposed LTC development will comprise a multi-storey building (up to four-storey high) incorporating a 750 seat column free auditorium and exhibition space on the ground floor, with teaching and learning facilities on the upper floors. The building will be arc shaped in plan and will be connected to the adjacent USB building by a link bridge from the second floor. The roof is anticipated to provide external plant space and will also incorporate a green roof above the auditorium

[24]. It is currently proposed to found the building on rock socketed piles, in a similar fashion to the USB building.

The site will be bounded by Fry Richardson Avenue to the East, Draymans Way to the South and Knowledge Square to the West, an area of public open space. A large water attenuation retention tank is proposed to be placed beneath Knowledge Square. The square will comprise an area of open hard and soft landscaping at ground level [24].

3.4 Site History

3.4.1 Pre-Reclamation

The Science Central Development site has been subject to numerous desk studies and site investigations prior to reclamation works. A summary of the site history is presented below. Further details can be gained from the Mott Macdonald Desk Study completed in July 2005 [2].

- The Science Central site was in industrial use from the mid-nineteenth century to the late twenty first century. Works on the site included a tobacco factory, brick works, colliery and more recently the Scottish and Newcastle brewery [2].
- The brewery buildings were demolished in 2007 and the site regraded in preparation for reclamation works. The Demolition Health and Safety File [8] states that asbestos clearance certificates and validation certificates for recycled crushed materials were obtained for this site.
- The North Elswick Colliery was situated to the north of the LTC site. Historical maps and records indicate the colliery was operational until the mid 1940s. This colliery records workings within the Low Main, Beaumont, Three Quarter and Brockwell seams at depths between 80m and 230m [2] [5].
- Abandoned mine workings have been positively identified during previous ground investigations on the site. The following coal seams are known to be present at shallow depth (<40m below ground level). High Main, Metal, Five Quarter and Main. The 1993 Mott MacDonald Desk Study [1] contains a Mining Report that recommends the site is stripped and inspected for signs of old mineshafts and adits, or collapsed features.

3.4.2 Reclamation

Hall Construction Services Limited were appointed to remediate the Science Central site. Due to the presence of potentially worked shallow coal seams beneath the site, their proposed reclamation design involved large-scale excavation works to a depth of up to 16m to remove these seams. The works were undertaken between 2011 and 2014. The extent of the excavation area in relation to the LTC site is shown on Figure 3.

The geotechnical elements of the earthworks were advised by WSP including the testing regime, with Mott Macdonald providing technical advice on behalf of the client. The Earthworks Completion Report [11] states the site was excavated in a series of eighteen cuts, commencing in the southeast corner and extended north by progressively spiralling west, however, dates of validation testing within each cut suggest some variation to this method occurred between July and October 2013, see Figure 3. The report and earthworks plans also suggest that the base of each cut was excavated to allow surface water to fall towards a sump.

The proposed LTC building sits over six of the cuts excavated as part of the reclamation works, see Figure 3. The open cast cuts were backfilled in parallel with excavation progressing using engineered site won fill to the original ground level, predominantly comprising fine grained rock (sandstone, and siltsone), weathered mudstone and smaller quantities of cohesive made ground, glacial till and recycled aggregate. A capping layer of site won clean material was placed on the site surface. Details of the works undertaken on and surrounding the LTC site are provided in the Earthworks Completion Report [11]. In summary the reclamation works comprised:

- Remediation of localised contamination hotspots,
- Removal of soil and rock overburden to enable extraction of coal from shallow seams,
- Inspection and treatment of any identified mine shafts through grouting and capping,
- Infilling opencast excavation with suitable site won materials as an engineered fill to the earthworks specification to make up levels back to a required profile,
- Stabilisation by drill and grout methods of worked coal seams outside the opencast excavation. (A total of 3277No. probe holes around the perimeter of the opencast excavation were completed by Groundshire [13]), and
- Monitoring of gas/groundwater levels in the installations surrounding the opencast excavations.

3.4.3 Post-Reclamation

Following completion of the reclamation works, the LTC site is understood to have been used as a contractor's compound during the construction of the CORE building and site wide infrastructure contracts and as a fan zone during the 2015 Rugby World Cup. The information received and reviewed to date does not provide any coverage of how materials were managed on site during these events.

The undulating surface noted during the site walkover survey, and the discrepancies with the finishing levels reported in the Health and Safety File for the enabling works [11] [12] support the fact that works have been undertaken on the site post-reclamation.

3.5 Published Geology

The 1:50,000 series geological map of the area Sheet 20, dated 1992 [25], shows the site to be underlain by boulder clay overlying Pennine Middle Coal Measures overlying sandstone. The 1:10,000 geological map NZ26SW [26] shows the site to be in the area of multiple coal seams: the High Main, Metal and Five Quarter. The High Main is shown to subcrop across the north of the LTC site. However, coal seam subcrop locations shown on the map in this area have been proven to be inaccurate by the excavation works on the site.

The site is also shown to be within an area of multiple east-west trending faults downthrown to the southern side. One fault is shown to underlie the LTC site. A previous study [7] suggests the fault has caused a 3m down throw and is present between the Hutton seam at depth and the surface, however, there is limited evidence to suggest offset within the upper coal seams.

Following site reclamation, the anticipated stratigraphy under the LTC site is engineered fill/made ground overlying middle coal measures including interbedded layers of mudstones, sandstones, siltstones and coal seams.

3.6 Hydrology and Hydrogeology

The closest surface water feature identified by aerial image is understood to be Leazes Park Lake, located approximately 600m to the northeast of the site. The River Tyne is located approximately 1300m to the south of the site.

Envirocheck reports obtained for previous desk studies indicate the site to overly a Minor Aquifer and soils of low leaching potential.

Groundwater levels reported pre and post-reclamation works at the LTC site and its vicinity are presented in Figure 4 and discussed below.

3.6.1 Pre-Reclamation Groundwater Levels

Pre-reclamation investigations on the Science Central site encountered perched water or confined water within the superficial deposits. This has been linked to surface water infiltration, which was confined to a certain degree by the cohesive glacial clay directly overlying bedrock [7]. From the instruments installed within the shallow deposits the following observations are made:

- Groundwater was recorded at 62.95mOD (1m bgl) at BH48A, located some 100m to the east of the LTC site, at 66.16mOD (4.06m bgl) at BH80 located 100m to the south of the site, and at 67.61mOD (3m bgl) at BH65 located 50m south of the LTC site during the Norwest Holst 2005 investigation [4].
- During the Norwest Holst 2009 investigation, six out of eleven instruments installed at shallow depths (<5m) were reported to be dry throughout the monitoring period [6]. The five that encountered groundwater were located in the centre of the Science Central site, in the vicinity of the LTC site, with groundwater recorded between 57.8mOD

and 67.6mOD (1.78m and 3.48m bgl). BH304 located some 80m to the east of the LTC site was subsequently monitored during the AEG 2011 investigation and groundwater levels were generally recorded at 59.9mOD (1.45m bgl).

- Perched water was reported at the interface between made ground and glacial deposits within the AEG 2011 ground investigation [7]. Shallow groundwater levels reported in BH809, located to the east of the LTC site, indicated the water table to range between 60.45m and 61.94mOD (2.54 to 4.0m bgl) throughout the monitoring period.

Pre-reclamation investigations on the Science Central site generally encountered deeper groundwater within bedrock at levels varying between:

- 46.28mOD and 58.17mOD (15.4m bgl to 22.5m bgl) over a six month period during the 1994 Exploration Associates investigation [3], with the highest levels reported to the southwest of the Science Central site,
- 51.42mOD and 66.48mOD (4.65m bgl to 11.83m bgl) over a six week period during the Norwest Holst 2005 investigation [4]. BH62 located on the LTC site recorded average groundwater levels at 57mOD (10.35m bgl) and BH39 located 30m north of the site recorded average groundwater levels of 57.28mOD (10.27m bgl), with generally higher groundwater levels recorded to the northwest of the Science Central site,
- 50.16mOD and 70.77mOD (5.01m bgl to 12.93m bgl) over a three week monitoring period during the Norwest Holst 2009 investigation [6], with generally higher groundwater levels recorded to the southwest of the Science Central site, and
- 50.12mOD and 55.47mOD (5.89m bgl and 11.83m bgl) during the 2011 AEG investigation [7]. BH807 located 50m north of the site recorded average groundwater levels of 55.47mOD (11.83m bgl).

Pre-reclamation groundwater levels in the bedrock show potential groundwater rebound occurred between 1994 and 2005 of approximately 5m. It is interpreted that this may relate to regional groundwater level rebound in the area associated with the cessation of mine groundwater pumping.

Locally higher pre-reclamation groundwater levels in the deeper aquifer are noted within instruments located to the west and southwest of the Science Central site. Lower groundwater levels were generally noted along the east, on holes located close to Wellington Street.

3.6.2 Groundwater Levels during Reclamation

The Earthworks Completion Report states that a sump pump was used during excavation to prevent fill materials being placed in standing water. However, no further details on dewatering during reclamation works were available at the time of writing [11] .

Monitoring conducted by WSP during the reclamation works was carried out in 26 holes around the perimeter of the Science Central site, between October 2012 and June 2014. These showed groundwater levels to vary between:

- 55mOD and 75mOD (1m and 4m bgl) in the shallow deposits (SP1, SP5, SP9, SP11, SP13, SP15, SP17, SP21, SP23, SP25); and
- 54mOD and 70mOD (2m to 17m bgl) in the bedrock. To the east of the LTC site groundwater levels were reported to vary between 54mOD and 55mOD (7m and 10mbgl) on SP6 and SP8. [10].

Generally higher groundwater levels were recorded to the southwest of the Science Central site decreasing eastwards.

3.6.3 Post-Reclamation Groundwater Levels

Post-reclamation monitoring conducted by Mott MacDonald for the Science Central site between June 2014 and October 2015 indicated groundwater at GW3 (located closest to the LTC site) to range between 56.3mOD and 56.8mOD (11.2 m bgl and 11.8mbgl), towards the base of the fill materials [15].

Post-reclamation monitoring conducted by AEG for the USB building between February and April 2015 indicated groundwater to range between 54.4mOD and 56.4mOD (11.05m bgl and 12.79m bgl). Six instruments installed at shallow depths of 1m to 5m depth were dry throughout the monitoring period. The BuroHappold GIR for the USB site however, states that “the groundwater table is predicted to rise following the remediation works” and recommends a design groundwater level of 1m bgl [16].

The post-reclamation groundwater levels in the deeper aquifer recorded to the north of the LTC site, around the USB development, are generally consistent with pre-reclamation levels. However, regional groundwater rebound is noted to be still occurring. Furthermore, it is considered that infiltration rates may be altered by the site wide development and these may effect groundwater levels in the deeper aquifer due to the removal of glacial deposits that previously confined surface water. Therefore there is potential for groundwater in the deeper aquifer to rise beyond pre-reclamation levels.

3.7 Historic Ground Investigations

A number of previous ground investigations have been conducted on the Science Central site both prior and post-reclamation works. Figure 5 shows the location of exploratory holes on or near the LTC site and identifies the coal seams where potential workings were identified.

A summary of the investigations carried out on site are presented below with emphasis given to the type and depth of the investigation, and its findings with regards to coal seams and potential workings. Encountered ground conditions and the results of in-situ and laboratory test results are not described in detail here. These will be covered in detail in the Ground Investigation Report that is to be produced for the LTC development.

3.7.1 Pre-Reclamation

Exploration Associates, 1994 [3]

The investigation was conducted for the brewery extension under the instruction of Mott MacDonald. It comprised:

- 26No. cable percussive holes, 17No. of which were extended by rotary drilling to depths up to 30m.
- 21No. trial pits to depths between 2m and 4m bgl, and
- 2No. trial trenches.

Of the above, 2No. trial pits and 1No. borehole were located on the northern boundary of the LTC site. Groundwater levels in bedrock were monitored as part of the investigation.

Mott MacDonald interpreted that potential workings were identified in the High Main seam between 65.69mOD and 67.59mOD in close proximity to the LTC site as black coal and soft mudstone with loss of flush, and in the Metal seam between 54.69mOD and 56.29mOD as a void with a thin layer of made ground. The Five Quarter seam was encountered at 45.60mOD to 45.90mOD on the northern boundary of the LTC site, with no evidence of workings reported.

Norwest Holst, 2005 [4]

The investigation was conducted to investigate future development opportunities by Newcastle City Council. This investigation comprised:

- 37No. cable percussive boreholes, 20No. of which were extended by rotary drilling to depths between 15m and 33m.
- 39No. window sampler probe holes, and
- 2No. concrete cores were also conducted.

Of the above 5No. boreholes and 3No. window sampler holes were located on the LTC site. Groundwater levels in made ground and bedrock were monitored as part of the investigation.

The High Main, Metal and Five Quarter seams were encountered within the upper 20m of the bedrock. The High Main was encountered in one borehole within the LTC site at 65.09mOD to 66.39mOD. The Metal seam was also encountered within the LTC site as two seams approximately 0.2m thick between 52.82mOD and 56.23mOD. No coreloss, voids, loss of flush or broken ground were encountered within the LTC site, however zones of core loss were encountered within the High Main and Metal seams in the vicinity of the LTC site.

Norwest Holst, 2009 [6]

The investigation was conducted to investigate development opportunities by Newcastle City Centre. It comprised of:

- 10.No cable percussion boreholes, 6No. of which were extended by rotary drilling to depths of 18m to 26m bgl, and
- 31.No trial pits to depths up to 4.5m bgl.

Of the above, no boreholes were located on the LTC site. Groundwater levels in made ground, glacial till and bedrock were monitored as part of the investigation.

Zones of core loss, loss of flush or possible packed waste were encountered in both the High Main between 66.40mOD and 68.86mOD and Metal seam between 55.73mOD and 56.72mOD, and 53.03mOD and 53.73mOD in the vicinity of the LTC site. The Five Quarter was encountered as two intact thin seams between 41.99mOD and 44.62mOD.

Allied Exploration and Geotechnics, 2011 [7]

The investigation was conducted to investigate development opportunities for the 'Science Central' development site. It comprised:

- 9No. cable percussive boreholes with rotary continuation to depths approximately 25m bgl.

No exploratory holes were located on the LTC site. Groundwater levels in made ground, glacial till and bedrock were monitored as part of the investigation.

The Metal seam was encountered as a split seam between 46.01mOD and 54.89mOD, the average combined thickness of the two seams was 1.35m. Potential workings were identified in the Metal seam as coal and soft clay and sandstone boulders. The Five Quarter seam was encountered between 33.87mOD and 42.91mOD as a split seam with the top seam on average 0.41m thick and the bottom seam on average 0.18m thick with potential workings identified as an area of poor recovery and gravelly clay.

The Main seam was encountered in three boreholes in the south and east of the site at 33.9mOD ± 2.5m and on average 0.25m thick. One borehole approximately 150m east of the LTC site encountered poor recovery, broken ground and clay materials between 32.35mOD and 34.30mOD consistent with the level of the Main. It also encountered a 0.05m thick seam identified as the Main 1.1m below the area of potential workings, indicating the seam may be formed from multiple leaves in this area. The ground investigation report states that where encountered, the Main was noted to be impoverished and in places potentially washed out.

3.7.2 Reclamation

A series of reports were produced by WSP to summarise the reclamation earthworks and remediation. In addition an asbestos monitoring report was produced. A summary of the reports are presented below.

WSP, Earthworks Completion Report 2014 [11]

The Earthworks Completion Report indicates the excavation was conducted in a series of eighteen cuts excavated in series from the southwest corner moving

westwards and spiralling to the north, see Figure 3. Evidence from testing dates however, does not support this cutting sequence.

The earthworks were designed with the intention of excavating to the base of the Metal seam. Beneath the LTC site, the base of excavation is shown to range from 55.3mOD in the south of the site to 53.4mOD in the north, locally to 50.16mOD in the area of an unrecorded mine shaft. It is considered likely that the High Main and Metal seams were completely removed in the area of the LTC site. As discussed in section 3.4.2 the excavation was backfilled with site won materials to a maximum depth of 16m within the LTC site. The backfill materials predominantly comprised sandstone, siltstone, weathered mudstone, glacial till, cohesive made ground, granular made ground and recycled aggregate.

The proposed LTC building sits over six of the cuts excavated as part of the reclamation works. It is understood that backfill material varied from cut to cut. The Earthworks Completion Report [11] highlights the following regarding the backfilling operations:

- There was significant variation across the site in grain size of Fine Grained Rock (FGR), which comprised the majority of backfill materials. Frequent boulders (>330mm) were incorporated within fill materials, however, later on in the works the FGR was crushed using excavators and mechanical crushing machines. It is therefore understood that cuts undertaken prior to August 2013 may contain oversized particles and the report suggests cuts 5-9 and 18 to contain oversized particles. However, dates from validation tests undertaken during backfilling suggest more cuts, including 3, 4 and 5 in the south of the LTC site to have been backfilled prior to August 2013.
- Loose edges remained on the edge of previously backfilled layers forming a narrow wedge of generally oversized uncompacted fill which could not be rolled. The report states that this problem was dealt with by cutting back loose material with a tracked blade and incorporating loose material into the new fill layer.
- Delays in validation test results meant some areas were already covered by the time a non-compliance was identified.

A reclamation validation investigation was conducted by WSP as geotechnical advisors to Hall Construction Services Limited for the reclamation of the Science Central site. WSP provided full-time geotechnical engineer attendance between October 2012 and March 2014 during the earthworks. A summary of the classification tests on the general fill outlined in the Earthworks Specification as included in their Completion Report is reproduced below:

- Particle Size Distribution (PSD): 1 per 5,000 m3;
- Optimum moisture content (OMC), dry density (4.5kg or 2.5kg compaction): 1 per 5,000 m3 up to a maximum of 5 samples per material type;
- Moisture content (MC): 1 per 5,000 m3;

- Plasticity Index (PI): 1 per 5,000 m3 (cohesive soils only).

The results of the classification tests are provided within the Completion Report [11], and summary tables are presented within Appendix A.

Compliance tests on the general fill were to be carried out at the following frequency:

- Nuclear Density Test (NDT)/core cutter – 1 per 1,125 m2 for each 500mm thickness of fill placed;
- Sand Replacement Test (SRT) - 1 per 11,250 m2 for each 500mm thickness of fill placed;
- Plate bearing test (PBT) – 1 per 10,000m2 for each 500mm thickness of fill placed;
- CBR (California Bearing Ratio) capping layer only – 1 per 4,000 m2 for each 500mm thickness of fill placed.

It is understood that the Earthworks Specification stated that the average relative density must exceed 95% maximum density with no individual result below 90%. The results of classification tests and resulting maximum dry densities are reproduced in Appendix A. The average air voids across the site was required to be less than 5% and no individual result was permitted above 10% for general made ground and 5% for cohesive made ground. A minimum stiffness of 15MPa (undrained) and 5MPa (drained) was also required.

The fill materials were placed at set thicknesses ranging from 250mm to 500mm dependent upon the material type, determined from compaction trials. A smooth wheeled vibratory roller was used to compact materials, with a minimum of six passes required. Figures 6 and 7 show the compaction test results available for the cuts that underlie the LTC site.

WSP's Completion Report notes that the overall frequency of testing was maintained during the works however, fewer tests were conducted within the Fine Grained Capping layer than were previously outlined in the Earthworks Specification. It also states that "an average relative density of more than 95% was achieved for all material types (with the exception of the processed demolition rubble), with an overall average for all fills placed of 98 % (measured using NDT methods) or 99% measured using SRT methods".

During reclamation works nine recorded and twelve un-recorded mine shafts were encountered across the Science Central Development site. One recorded and one un-recorded shafts were encountered on the LTC site:

- Shaft 6 was located close to its recorded location in the north of the site. The base of the shaft was proven to 53.19mOD and was backfilled with site won materials as part of the wider reclamation works.
- Shaft 13 was un-recorded and was encountered during excavation works. The base of the shaft was found by excavation at 50.16mOD

(below the Metal seam) and was also backfilled as part of the wider reclamation works.

A recorded shaft known as Shaft 7 was encountered approximately 20m east of the LTC site. This shaft was reportedly capped and grouted prior to the excavation works on the site. This cap was removed during excavation works, and shaft proven to extend beyond the Metal seam. Due to previous grouting works conducted on this shaft it was considered that further grouting was not required. A new shaft cap was installed at the base of the excavation at 53mOD.

WSP, Asbestos Monitoring Report 2014 [9][10]

It is understood that materials from the demolition of industrial buildings previously present across the Science Central Development site were processed for use as recycled aggregate. The Asbestos Monitoring Report indicates that pre-excavation a stockpile of recycled aggregate, and recycled aggregate distributed across the surface of the site were proven to contain amosite and chrysotile asbestos. The report states that:

- 26No. tests were conducted, of which 8No. identified amosite or chrysotile.
- Only 5No. asbestos quantification tests were carried out on samples where asbestos was identified, all of which recorded <0.001%.

At the request of the Contaminated Land Officer the use of recycled aggregate materials as backfill material was only permitted at depths greater than 2.5m. The Asbestos Monitoring Report states the likely cause of asbestos within these materials was due to incomplete removal of asbestos containing materials prior to demolition and processing of materials.

Airborne fibre monitoring was conducted during the site works following the identification of asbestos containing material. The results of all the monitoring returned results lower than the lower limit of quantification and were therefore considered satisfactory.

WSP, Remediation Completion Report 2014 [10]

The report summarises the remedial strategy and validation contamination testing conducted on site. The following remedial works were reported:

- Removal of three contamination hot spots that exceeded human health thresholds to a 5m radius and depth of 0.5m below the identified contaminant.
- Removal of eight contamination hot spots that exceeded the hazardous waste threshold to a 2m radius and depth of 0.5m below contaminant.
- Placement of 1.5m thick layer of clean cover soils at the surface.

Areas of localised contamination, called “hot spots” by WSP, were identified from previous ground investigations using assessment criteria suitable for residential land use with plant uptake. The remediation report suggests that the

remedial works aimed to place a clean cover suitable for residential end use. The validation criteria used during the earthworks are provided in Appendix B.

Upon excavation of hot spots further validation testing took place. Where concentrations exceeded the assessment criteria this material was disposed of off site. Materials shown by testing to have contaminant concentrations below the assessment criteria were used as backfilling materials below the 1.5m clean cover materials.

A hotspot located adjacent to Corporation Street was not removed due to being located beneath or in close proximity to existing concrete basement which was left in place after demolition. The full radius of excavation was not achieved in some areas due to nearby structures or services, however, it is understood that no hot spots were located on the LTC site.

Upon completion of the works, 64 No. samples were collected from the clean cover layer. One sample identified asbestos within a sample of siltstone. A retest of this sample recorded no fibres present and a quantification test did not identify asbestos above the limit of detection (0.001%). Therefore no remedial action was taken. All other validation samples tested met the validation testing criteria.

Gas and groundwater monitoring was undertaken in 26 No. holes on the perimeter of the site during and after grouting works between October 2012 and June 2014. The WSP report indicates no elevated levels of hazardous gas that would cause concern were encountered, with the exception of one borehole SP07 which recorded 100% methane during grouting works, and gradually reduced to original levels over the course of a week.

Recorded groundwater levels in the shallower deposits ranged from 55mOD to 75mOD around the perimeter of the excavation, and between 54mOD and 70mOD in the bedrock. Generally higher groundwater levels were recorded to the southwest of the Science Central site decreasing eastwards. Groundwater levels were reported to be generally stable with no significant variation within instruments recorded during monitoring. Some short term variation was noted in some instruments considered to be due to dewatering of the opencast excavation.

3.7.3 Post-Reclamation

AEG 2015 [16]

The investigation was conducted to investigate ground conditions at the site of the USB development, located immediately north of the LTC site on behalf of Newcastle University. It comprised:

- 9No. cable percussive boreholes, of which 5No. were continued by rotary coring to depths between 5m and 50m.
- 9No. Cone Penetration Tests (CPT)

Groundwater was monitored in the bedrock and fill material and was reported to be close to the base of the excavation.

The engineered fill was described as variable composition but generally described as a medium dense clayey sandy gravel becoming a sandy gravelly clay of low plasticity at depth. These descriptions are generally consistent with the CPT test results, however, the friction ratio indicates granular material to comprise silty sand. Particle size distribution tests indicate the material is well graded, with silt and clay content increasing to 40% at depth. SPT N values within fill material typically showed values between 10 and 30, and a design value of 13 was chosen, indicating a medium dense material.

The High Main and Metal seams were absent except in boreholes outside of the open cast excavation. The Five Quarter seam was encountered as a single seam approximately 0.5m thick in the east at approximately 43mOD, and split into two thin seams in the west, in between approximately 42mOD and 45.8mOD. The Main seam was encountered in the east of the site in BH03 at 31.4mOD as three thin layers <0.15m. No workings or grout were encountered within any seams beneath the site.

Post Restoration Settlement Monitoring [14][15]

Following completion of reclamation works, instrumentation was installed under the instruction of Mott MacDonald. This comprised:

- 4No. groundwater monitoring standpipes. 2No. of these were lost during construction works on the site.
- 27No. settlement monitoring points. 19No. of these have been lost due to construction works.
- 10No inclinometers were installed across the site, however 5No. of these have been lost due to construction works.
- 17 No. extensometers, of which 7No. have been lost or damaged.

Of the above, 4No. settlement monitoring points, 2No. extensometers and 1No. groundwater monitoring well were located on the LTC site, but all of these have been lost or damaged.

Ground surface monitoring across the wider site indicate an initial period of rapid movement during April 2014. A gap in monitoring between May and November 2014 is noted in the data. Of the remaining 8No. settlement monitoring points, 2No. showed heave of up to 2mm between November 2014 and October 2015, while the other 6No. showed a trend of gradual creep settlement of up to 3mm during the same period. Extensometers surveying indicate various magnitudes of settlement/heave of up to 240mm being recorded at depth however, there is significant scatter and no apparent trend on these results. Inclinometer readings also suggest that movement is still occurring within the backfill wedge adjacent to the high wall.

The report concludes that settlement and heave has taken place, with internal ground movements being significantly larger than those manifested at the ground surface. The report suggests that settlement could be ongoing for a significant number of years.

3.8 Summary of Ground and Groundwater Conditions

3.8.1 Anticipated Ground Conditions

Based on the findings of the reclamation reports and previous ground investigations, the anticipated stratigraphy under the LTC site comprises approximately 10m to 16m of engineered fill/made ground, locally deeper in the area of Shaft 13, overlying Middle Coal Measures including interbedded layers of mudstones, sandstones, siltstones and coal seams. The High Main and Metal seams are understood to be absent under the site.

The engineered fill placed beneath the LTC site predominantly comprises fine grained rock (sandstone, and siltstone), weathered mudstone and smaller quantities of cohesive made ground, glacial till and recycled aggregate.

It is unclear if the capping layer of clean material placed on the site surface on completion of remedial works is still present, due the more recent use of the site as a fan zone for the 2015 Rugby World Cup, and as a site compound during the construction of the CORE building.

3.8.2 Anticipated Groundwater Levels

The post-reclamation groundwater levels in the deeper aquifer recorded to the north of the LTC site, around the USB development, are generally consistent with pre-reclamation levels varying between 54mOD and 57.28mOD. However, regional groundwater rebound is noted to be still occurring.

It is considered that infiltration rates may be altered by the site wide development and these may effect groundwater levels in the deeper aquifer due to the removal of glacial deposits that previously confined surface water. Therefore there is potential for groundwater in the deeper aquifer to rise beyond pre-reclamation levels.

4 Mining Risk Assessment

4.1 Introduction

This section identifies the hazards associated with the coal seams beneath the site, and assesses the risks they pose to the proposed development.

4.2 Hazard Identification

The principal hazards associated with mining on the LTC site are ground movements associated with potential mine workings within shallow seams, the presence of mine shafts both recorded and unrecorded, and mine gas migration.

Anticipated details of the shallower seams have been identified from selected previous ground investigations and desk studies and are outlined below:

- High Main – 66.5mOD 0.4m to 1.4m thick (subcropped on site) approximately 0.5mbgl
- Metal– 52mOD to 55mOD two leaves approximately 0.2-0.3m thick approximately 10-12mbgl.
- Five Quarter – 45mOD to 46mOD, approximately 0.6m thick approximately 20-21mbgl
- Main – approximately 27m – 32mOD in three thin seams 0.2m thick approximately 35mbgl.

4.3 Hazard Assessment

4.3.1 High Main and Metal Seams

A review of the base of excavation drawing from the reclamation works carried out by Hall Construction Services Limited [12] identified that the reduced levels achieved by the excavation were consistently below the level of the base of the Metal seam identified in historic borehole information. As such it is considered that both the Metal seam and the High Main seam, where present, have now been removed. This is also supported by the absence of these seams in the post-reclamation grouting carried out as part of the USB development in 48 No. holes[21].

Previous desk studies and the geological map indicate the seams to be downthrown to the south by faulting, however, based upon historic ground investigations and inspections carried out during the earthworks there is little evidence to suggest the fault offset has propagated to the surface.

Based on this assessment it is considered that the remediation works have mitigated the risk posed by shallow mineworkings within the High Main and Metal seams.

4.3.2 Five Quarter Seam

Previous ground investigations located on the LTC site did not reach the Five Quarter seam. Nearby pre-reclamation boreholes encountered the Five Quarter seam at 47.6mOD approximately 20m to the south (BH74); at 46.29mOD approximately 30m to the west (BH3); at 45.6mOD on the northern boundary (BH6A) and at 42.14mOD approximately 10m to the northeast of the site (BH8). Based on this information, it is anticipated that the Five Quarter seam will be at an approximate depth of 46mOD in the south of the LTC site to approximately 44mOD in the north. Ground investigation information indicates the seam to be approximately 0.6m thick, and locally present as two separate seams.

No workings were identified within boreholes in the vicinity of the site, however approximately 100m southeast of the site, potential workings were identified between 42.9mOD and 43.3mOD in one borehole (BH805) and in two thin areas of no recovery 0.9m thick in another borehole (BH201) between 44.83mOD and 47.53mOD. These were recorded as assumed zones of core loss and described as collapsed workings by the drillers, indicating the Five Quarter may be worked and comprise two seams in this area.

The Groundshire grouting report [13] indicates no workings were identified in the Five Quarter seam and no loss of flush recorded during drilling. This is also supported by the grouting works undertaken for the USB development to the north of the LTC site which encountered the Five Quarter seam between 22m and 24m depth. No workings were identified during the USB grouting works and no grout uptake was recorded [21].

4.3.3 Main Seam

Previous ground investigations located on the LTC site did not reach the Main seam due to their limited depth of investigation. Boreholes from the AEG 2011 investigation [7], located approximately 100m southeast of the site encountered the top of the Main between 32mOD and 34mOD. A borehole from the USB investigation to the north of the site (BH 03) indicates the Main to be present as three thin seams, each approximately 0.2m thick between 26mOD and 32mOD [16]. Based on this information, it is anticipated that the top of the Main seam will be encountered at approximately 30mOD under the LTC site.

A borehole (BH203) located approximately 150m south of the site encountered a zone of core loss described by the driller as collapsed workings between 34.72mOD and 36.12mOD. A borehole located 150m southeast of the LTC site (BH231) encountered core loss described by the driller as borehole collapsing between 39.61mOD and 40.91mOD and very stiff mudstone between 37.81mOD and 38.91mOD, which may be concordant with the level of the Main in this area. A borehole located approximately 150m east of the LTC site (BH802A) encountered suspected workings as poor recovery of coal and clay between 32.4mOD and 34.4mOD. Intact coal was recorded in another borehole (BH806) at 33.5m to 33.8mOD approximately 100m southeast of the LTC site. This information indicates the Main to be variable and potentially locally worked in the southeast of the Science Central site.

A review of mining hazards conducted for the site by Donelly in 2006 [5] describes the Main seam as impoverished and therefore unlikely to be worked.

The Groundshire grouting report [13] indicates no workings were identified within the Main seam, however, based on the depth of probe holes it is unlikely that the Main seam was encountered in the majority of holes.

4.3.4 Mine Shafts

The Earthworks Completion Report [11] indicates that Shafts 6 and 13 were previously located on the LTC site, and were excavated out as part of the reclamation works. Shaft 7 located approximately 20m east of the site was reportedly capped and grouted prior to opencast mining on the site. This cap was removed during excavation works, and the shaft proven to extend beyond the Metal seam. Due to previous grouting works conducted on this shaft it was considered that further grouting was not required. A new shaft cap was installed at the base of the excavation at 53mOD.

4.3.5 Mine Gas

No ground gas monitoring has taken place on the LTC site, however monitoring has been undertaken in other areas of the Science Central site prior, during and after the reclamation works.

- Ground gas monitoring was conducted prior to reclamation in four boreholes to the southeast of the LTC site by AEG in 2011 [7]. The AEG report states that negligible concentrations of methane were encountered and levels of oxygen and carbon dioxide fluctuated significantly. Gas flows recorded by AEG were generally low, peaking at 2.5l/h in BH806 located approximately 100m southeast of the LTC site.
- During and post-reclamation works, no elevated levels of hazardous gas that would cause concern were encountered, with the exception of one borehole SP07 which recorded 100% methane during grouting works, and gradually reduced to original levels over the course of a week [11].

4.4 Risk Estimation

The risks posed by mining works to the LTC development are discussed below:

- Possible workings within the Five Quarter and Main seams pose a risk to the LTC foundations by resulting in **reduced pile capacity and performance**. There is currently insufficient data to assess the likelihood of this event, however due to the fact there is evidence of workings (although limited) in the vicinity of the LTC site, this risk is considered **high**. Further ground investigation targeting these seams is recommended to further assess this risk and to derive ground parameters for pile design.
- Possible workings within the Five Quarter and Main seams also pose a risk to the LTC building by resulting in **excessive surface settlement** due to subsidence. This risk is considered **low** as the ratio of seam thickness to

rock overburden is understood to range between 10 and 13 across the site based upon the extrapolated depth of the seam and reported depths of excavation. Further ground investigation targeting the Five Quarter and Main seams is recommended to further assess this risk.

- The risk of **mine shafts** beneath and in close proximity to the building is considered **low** based on the records of previous shaft treatment. It is considered that any unrecorded mineshafts would have been encountered during the reclamation excavation. Shafts 6 and 13 within the LTC site have reportedly been excavated to the base, and shaft 7 close to the site was reportedly capped at the base of the excavation.
- The risk of **mine gas migration** from within the coal measures to the surface and into the building is considered **moderate** based on the nature of the engineered fill, the limited available ground gas monitoring data, the absence of shafts within the LTC site, and presence of the capped Shaft 7 approximately 20m east of the site. Further ground investigation including monitoring of ground gas is recommended to further reduce this risk. Mitigation measures such as installation of a gas membrane may be required.

In order to better estimate the risks posed by mining to the LTC development, a development specific ground investigation is recommended with specific focus on proving the depths and thicknesses of the Five Quarter and Main seams, and identifying the presence of potential workings.

5 Geotechnical Risk Assessment

5.1 Introduction

This section identifies the hazards associated with the engineered fill placed as part of the reclamation works and assesses the risks it poses to the proposed development.

5.2 Hazard Identification

The reclamation reports indicate the anticipated stratigraphy under the LTC site to comprise between approximately 10m and 16m of engineered fill/made ground, locally deeper in the area of Shaft 13, overlying middle coal measures. The engineered fill predominantly comprises fine grained rock (sandstone and siltsone), weathered mudstone and smaller quantities of cohesive made ground, glacial till and recycled aggregate.

The BRE Digest 427 [28] defines the primary hazard associated with structures founded on fill as the long term movement brought by volume change rather than by inadequate bearing capacity. These movements may be caused by:

- Compression due to self-weight.
- Compression due to weight of buildings/ applied load on fill.
- Compression due to inundation.

5.3 Hazard Assessment

5.3.1 Compression Due to Self-Weight

Compression due to self-weight of the fill material is often a major cause of long term settlement. Compressibility of fill depends on its nature and composition, particle size distribution, degree of compaction, existing stress levels, stress increment and moisture content [28]. The immediate compression, which occurs during the earthmoving operations has no practical effect on the proposed structures [29]. However, creep movements that occur under conditions where moisture content and applied stress do not change can have an impact on future buildings and surrounding infrastructure. The rate and magnitude of creep settlement, α, due to self-weight is known to decrease rapidly with time.

Figures 6 and 7 summarise the findings of a review of reclamation test results available on and within the vicinity of the LTC site, and highlight areas of limited testing. Results from Nuclear Density Gauge tests carried out within the LTC site suggest densities to range from 91.65% to 110.44% of calculated maximum dry density. Void ratios are shown to range from negative values to 14.54% with an average of 1.5%. The greatest variation in void ratio was observed within the Fine Grained Rock, in which the average void ratio was found to be 5.91%, highlighting the variability in the compaction of these materials. A limited number

of Sand Replacement tests were conducted on the site and reflect results consistent with the Nuclear Density Gauge tests. In addition, a limited number of Plate Bearing Tests were conducted, all tests exceeded the target stiffness.

Ground surface monitoring, conducted on the wider Science Central Development since shortly after reclamation works were completed, indicate an initial period of rapid movement during April 2014 [15]. Of 27No. settlement monitoring points installed, 6No. showed a settlement trend of up to 13mm, while the rest recorded heave of up to 13mm. A gap in monitoring between May and November 2014 was noted in the data. Only 8No. settlement monitoring points remained beyond November 2014. Of these, 2No. showed heave of up to 2mm between November 2014 and October 2015, while the other 6No. showed a trend of gradual creep settlement of up to 3mm during the same period. None of the remaining points were located on the LTC site.

Extensometers surveying across the wider site indicate various magnitudes of settlement/heave of up to 240mm being recorded at depth however, there is significant scatter and no apparent trend on these results. Inclinometer readings also suggest that movement is still occurring within the backfill wedge adjacent to the high wall [15].

An assessment conducted by Van Elle for the USB building estimates settlements in the order of 48mm to 81mm, after 10 to 24 months since completion of reclamation works [22]. These estimates are understood to relate to backfill depths of 8m to 13.5m and are based on rates reported by the BRE [28] [29] for open cast coal mining backfill.

The BRE has also published α values for heavily compacted sandstone and mudstone fill embankments, and correlations to the effective weight of the overburden [29]. Based on a fill height of 16m the following long term settlements are estimated. See Table 5.1 below.

Table 5.1 –Anticipated Settlement with Time based on Published Creep Rates

Fill Type	Settlement after 2yr (mm)	Settlement after 50yr (mm)	Settlement after 100yr (mm)
Heavily Compacted Sandstone and Mudstone (calculated from effective vertical stress) (α = 0.04%)	2	11	13
Heavily Compacted Sandstone and Mudstone (as monitored by Charles [29]) (α = 0.17%)	8	46	54
Open Cast Mining Backfill (α = 0.74%)	36	204	240

The recorded creep settlement of 3mm between November 2014 and October 2015 on 6No. out of 27No. settlement monitoring points installed across the Science Central site, indicate creep rates α in the order of 0.04% which appear to be in the order of those reported for heavily compacted Sandstone and Mudstone. However, it must be noted that this is based on very limited monitoring data on variable ground conditions, none of which is located within the LTC site.

5.3.2 Compression due to the Applied Load on Fill

The BRE Digest 427 [28] states that most of the compression due to imposition of a structural load on fill material will occur almost immediately after the load is applied (as in the case of settlement due to self-weight). The long-term creep component of the settlement is of particular significance and can seriously damage a structure. Damage to finishes (for example partitions or plasterwork) is reported to be caused mainly by long-term movements.

External areas of hard and soft landscaping, which are likely to involve local earthworks will be susceptible to ground movements induced by long term settlement.

It is currently proposed to found the LTC building on rock socketed piles, in a similar fashion to the USB building to the north of the site. As such, ground deformations caused by the weight of a building should be negligible, as the building loads will be transferred to the bedrock through the piles, but changes to site wide levels during construction are likely to result in additional ground settlement.

5.3.3 Compression due to Inundation

Inadequately compacted or dry placed materials usually undergo a reduction in volume when their moisture content is increased. This phenomenon is commonly termed collapse compression or collapse settlement and can occur without any increase in applied stress. Unlike other forms of settlement, the potential for inundation settlement does not decrease with time.

The increase in moisture content can be caused by either downward infiltration of surface water (for example through deep excavated drainage trenches) or by rising of groundwater. The rate of settlement can be variable, depending on moisture content, degree of compaction and particle size distribution. From the literature, it is understood that above 95% relative compaction up to 2.0% volume change may occur on submergence for a soil compacted 5% dry of optimum [29].

Figures 6 and 7 summarise the findings of a review of reclamation test results available on and within the vicinity of the LTC site, and highlight areas of limited testing. From the figures it can be seen that the achieved densities range from 91.65% to 110.44% and void ratios are shown to range from negative values to 14.54%. Therefore there is a risk that localised inundation settlements may occur.

The post-reclamation monitoring report prepared by Mott MacDonald for the Science Central [15] states that there is no evidence that limited or full inundation settlement has occurred across the site, and that such settlements could still occur in the future as and when groundwater levels rise.

As noted in Section 3.6.3, post-reclamation monitoring conducted immediately north of the LTC site indicates groundwater levels in the deeper aquifer to be consistent with pre-reclamation levels. However, the potential for groundwater in the deeper aquifer to rise beyond pre-reclamation levels due to groundwater rebound, changes to infiltration regime and removal of the glacial deposits has been identified.

5.4 Risk Estimation

The risks posed by the engineered fill placed during reclamation works at the site of the LTC development are discussed below:

- Compression due to creep settlement caused by self-weight and inundation settlement pose a risk of **excessive surface settlement of external ground levels**. There is currently insufficient data to assess the magnitude of movement that will occur. This risk is considerate **high**, particularly with regards to potential inundation settlements which are difficult to quantify. Further ground investigation including density tests, groundwater monitoring and settlement monitoring for as long as possible, is recommended.
- Compression due to creep settlement caused by self-weight and inundation settlement pose a risk to the proposed piled foundations, as these settlements result in an additional load into the piles known as **negative skin friction.** This risk is considerate **high**. Further ground investigation of the engineered fill is recommended to derive ground parameters for pile design.
- The transition from the LTC building, which will be piled, to external non-piled areas posed the risk of **differential settlement** between the elements**.** There is currently insufficient data to assess the magnitude of movement that will occur. This risk is considerate **high**. Selection of flexible materials and connections for example the inclusion of "rocker" pipes in drainage is recommended to reduce this risk. Further ground investigation to assess variability of backfill material between adjacent cuts is recommended. Also, adoption of site wide design creep rates for the Science Central Development are recommended to inform the design of any site infrastructure interfaces with individual plots.
- There is also a risk of **differential settlement** along the link bridging the USB and the LTC buildings. This risk is considerate **moderate**.

In order to better estimate the geotechnical risks posed by the engineered fill to the LTC development, a development specific ground investigation is recommended with specific focus on variability of backfill material, identification of areas of poor compaction, and assessment of long term settlement rates and groundwater table fluctuations.

6 Contamination Risk Assessment

6.1 Introduction

Ground contamination can present a risk to site development through the potential risk to human health, Controlled Waters and the wider environment, as well as presenting commercial risks and liabilities associated with any requirements for remediation of the site. Ground contamination is regulated through Part 2A of the Environmental Protection Act (1990) [30], planning and various other pieces of legislation relating to water resources and pollution control.

In line with the Environment's Agency CLR11 document [31], the assessment of the impacts arising from potentially contaminated land is based upon considerations of pollution linkages (source-pathway-receptor) between contamination sources and sensitive receptors. This section identifies the hazards associated with ground contamination and provides an understanding of potential pollutant linkages to assess the risks they pose to the proposed development.

6.2 Hazard Identification

6.2.1 Historic Land Uses and Contamination Sources

A review of available reports has identified the site and the surrounding area to have a history of potentially contaminative uses associated with the former tobacco factory and brewery on the site. Such land uses have the potential to result in a range of contaminants being present, including hydrocarbons, acids and inorganic contaminants and localised asbestos.

Pre-reclamation ground investigations [4][6] identified generally very low levels of contamination, with localised "hotspots" identified of total and polyaromatic hydrocarbons, lead and asbestos.

Prior to the reclamation works, the brewery buildings were demolished, and it is understood that the demolition materials were distributed across the Science Central Development site. The demolition works included the removal and disposal of all materials with the exception of clean brickwork, blockwork and concrete. The Health and Safety File states that asbestos clearance and validation certificates were provided [8].

Pre-reclamation gas monitoring recorded generally relatively low concentrations and flows of ground gas, however, concentrations within coal seams/ workings were locally recorded up to 38.8% Methane, 7% Carbon Dioxide, with flows up to 10.2l/hr [4].

6.2.2 Reclamation and Post- Reclamation Works

The Remediation Completion Report [10] indicates that contamination remediation works were carried out as part of the site wide reclamation, including:

- Removal of 3No. contamination hot spots that are stated to have exceeded human health thresholds to a 5m radius and 0.5m below identified contaminant (Lead, Benzo(a)pyrene and Dibenzo(ah)anthracene).
- Removal of 8No. contamination hot spots that exceeded the hazardous waste threshold to a 2m radius and a depth of 0.5m below identified contaminant.
- Placement of a 1.5m thick layer of clean cover soils at the surface, suitable for residential land use, Appendix B.

An underground fuel tank located to the west of the site, was also decommissioned and removed by Hall Construction Services and no evidence of ground contamination was recorded according to the Validation Report [10]. Some areas of contamination were reportedly not removed due to their proximity to pavements and structures that were not due to be removed around the perimeter of the Science Central site.

The WSP Remediation Completion Report [10] states that the reclamation works were considered to be performed in general accordance with the Employer's Requirements and Remediation Method Statement and that based on the available information it was considered that "the remediation objectives agreed for the site were satisfactorily completed". It should be noted however that there were some variations to the method during the works to account for specific conditions.

The potential sources of contamination at the LTC site are discussed below:

<u>Engineered Fill</u>

- It is understood that the demolition materials were processed for use as recycled aggregate and used as fill materials across the Science Central Development site.
- Asbestos containing materials (from demolition material) were identified within the recycled aggregate [9].
- The records of the reclamation works indicate that the materials arising from contamination hotspots, with contaminant concentrations below the assessment criteria were placed at depth within the backfilled excavation, including the identified asbestos. To minimise the risk of any residual asbestos, no demolition materials were to be placed within 2.5m of the ground surface.
- It is understood that in some areas the contamination "hot spots" were not excavated due to their location being below concrete bases, which were not removed. It is understood that none of these hotspots were located within the LTC site.

<u>Clean Capping Layer</u>

- The clean capping layer generally included natural strata comprising mudstone, sandstone, siltstone or glacial till. This was generally placed across the entirety of the site with the exception of a localised strip along

the site hoarding and utilities and footpaths, due to the need to avoid disturbing these areas. It is understood that all areas of the LTC site were within the deep excavation and therefore all made ground materials were excavated and clean cap placed on the top 1.5m. The Earthworks Completion Report [11] indicates some finishing levels were subsequently changed and excavations were backfilled with up with 500mm of clean cover. It is understood that the material may not be natural strata in these areas.

- One sample of clean near surface capping material outside the LTC site was identified to contain asbestos, however, additional localised soil removal and replacement and further validation sampling was carried out in these areas. Subsequent testing did not detect asbestos and was hence compliant with the validation testing criteria.
- Validation works of the clean cover layer indicated generally low levels of residual contamination in the near surface materials. Monitoring is stated to have identified minimal impact to groundwater quality by the reclamation works.
- It is understood that post-reclamation the site has recently been used as a contractor's compound during nearby construction works, and formed part of the "Fan Zone" for the Rugby World Cup in 2015. It is possible that localised contamination may have occurred as a result of the above, for example due to stockpiling of materials, fuel spillages or the placement of fill materials which do not meet the chemical criteria for the capping layer.

Ground gas

- Post-reclamation gas monitoring recorded generally relatively low concentrations and flows of ground gas within the main backfilled excavation. On one occasion, during the reclamation works, very high levels of methane were recorded in one of the perimeter boreholes around the site installed in rock.
- Post reclamation gas monitoring has been conducted by Mott MacDonald around the perimeter of the site, and by AEG on the USB site immediately to the north.
- Monitoring conducted for the USB development was interpreted by BuroHappold to indicate a Characteristic Situation 2, based upon GSVs of 0.0007l/hr methane and 0.0105l/hr carbon dioxide [16]. They state that no direct comparison can be made with the previous site investigation as the material has been removed and replaced.

6.3 Hazard Assessment

The proposed development is understood to comprise a Learning and Teaching Centre, with lecture theatres and office space. Due to the current levels on the site it is anticipated that excavation will be required to create a level development platform. These excavation works will extend through the clean capping into the

general fill below, potentially to depths greater than 2.5m. The foundation solution for the development is anticipated to comprise piles. The majority of the site is anticipated to be hard landscaped with minor areas of soft landscaping.

Based on the findings of the review of previous investigations on the site, it is considered that there is a low likelihood of significant widespread contamination being present on the site. However, low levels of contamination may be present locally. There is also a potential for contamination to be present at depth within site won fill materials which may be close to the finished surface as a result of required excavation works on the site.

Potential pollutant linkages (source-pathway-receptor) based on a conceptual site model developed for the LTC site are summarised in Table 6.1.

Table 6.1 – Summary of Potential Receptors and their Associated Exposure Pathways

Receptor	Potential Pathways
Construction Workers	Inhalation of dust, gas or any vapours, direct dermal contact and ingestion of any contaminated soils, dust or groundwater, particularly during excavations that exceed the depth of the clean cover and through pile arisings.
Site End-Users	Inhalation of dust, gas or any vapours, direct dermal contact and ingestion of any contaminated soil or groundwater. Exposure likely to be most significant in any areas of soft landscaping, however, due to the nature of the development it is considered that such exposure is unlikely. Inhalation/ explosion of ground gas due to migration through/around piles and mineworkings.
Adjacent Site-Users	Inhalation of dust, most notably during construction works or from areas of soft landscaping after construction. The likelihood of exposure after construction is likely to be significantly lower than that during construction.
Building Materials	Direct contact with any aggressive contaminants within soil or groundwater. This could potentially result in degradation of building materials such as buried concrete.
Controlled Waters	Leaching of any mobile soil contaminants, lateral and vertical groundwater migration through infill materials into the underlying aquifer or nearby surface water.
Vegetation	Direct root uptake. It should be noted that no evidence of distressed vegetation was noted during the site walkover.

6.4 Risk Estimation

Based on the development proposals, it is considered that a number of potential pollutant linkages could feasibly occur between any contamination present and construction workers, building materials, end site users, adjacent site users and controlled waters. It is however, considered **unlikely that the potential pollutant linkages are to pose a significant constraint to the proposed development**. The risk associated with each of these linkages would be dependent on the actual nature and distribution of any contamination present and the final development proposal.

A brief review of the soil contamination testing within the clean fill materials indicates levels below those protective of human health for commercial land use according to a generic assessment criteria developed by Arup.

Based on the remedial works conducted and the validation reports, it is considered that the potential risk of **significant widespread contamination** being present across the site is **low**. Localised areas of contamination may, however, be present at depth within site won backfill materials. It is understood that asbestos containing material are present below 2.5m depth across the site, potentially resulting in exposure in shallow excavations and pile arisings. The potential presence of asbestos and the associated risk can be further investigated through a site specific ground investigation.

In order to better estimate the risks posed by contamination to the LTC development, it is recommended that a site specific ground investigation is carried out to confirm the actual levels of any contamination present and enable the risks associated with the identified pollutant linkages to be appropriately assessed. This should include investigation of:

- General levels of contamination in the cover and reworked materials at depth.
- Potential mine and soil gas associated with shallow mine workings and thick backfill material.
- General levels of near surface materials associated with use as a construction depot depot and “Fan Zone”.

7 Risk and Opportunities Register

Hazard	Risk/ Opportunity	Consequence	Mitigation
Possible workings in Five Quarter seam.	R-Reduced pile capacity.	Excessive pile movement beyond permitted settlement criteria.	Investigate presence and thickness of working within this seam through ground investigation. Assess likelihood of impact on piling works. Ignore contribution of base resistance above coal seam on pile design. Undertake a grouting exercise to consolidate the workings.
Possible workings in Five Quarter seam.	R- Excessive surface settlement.	Subsidence.	Investigate presence and thickness of working within this seam through ground investigation. Assess likelihood of impact on piling works. Undertake a grouting exercise to consolidate the workings.
Possible workings in Main seam.	R -Excessive surface settlement.	Subsidence.	Investigate presence and thickness of working within this seam through ground investigation. Assess likelihood of impact on piling works and surface settlements. Undertake a grouting exercise to consolidate the workings.

Hazard	Risk/ Opportunity	Consequence	Mitigation
Compression due to creep settlement.	R- Excessive surface settlement of ground levels. O – Current programme gives opportunity for installation and monitoring of ground instrumentation.	Aesthetics. Frequent maintenance required.	More accurately estimate rate and magnitude of predicted settlement through interpretation of monitoring results. Re-engineering of upper made ground or ground improvement measures to reduce magnitude of future movements. Accommodate differential settlement mitigation into building design – door thresholds, external appearance, use of soft landscaping.
Compression due to creep settlement.	R - Rupture of service connections.	Risk to end-users and site wide development.	As above. Provide flexible service connections to building to accommodate anticipated settlement. Pile services to avoid settlement.
Compression due to creep settlement.	R - Negative skin friction.	Settlement of fill material in relation to the piles results in additional load into the piles.	Make an allowance for negative skin friction in pile design.

Hazard	Risk/ Opportunity	Consequence	Mitigation
Compression due to inundation.	R - Large ground settlements as a result of downward infiltration or rise of groundwater.	Surface settlements, localised damage to services.	Re-engineering of upper made ground or ground improvement measures to reduce magnitude of future movements. Use of geogrids to reduce impact of localised movements. Use piled slabs in external areas.
Bridge linking the USB and the LTC buildings.	R- Differential settlement in excess of defined tolerances. O – Adopt piled foundations for both buildings.	Damage to bridge structure.	Review pile design assumptions made for the USB building. Design of bridge connection to accommodate movement.
Ground gas.	R - Migration of ground gases into the building.	Risk to end-users.	Investigate and monitor concentration of ground gas as part of ground investigation. Including appropriate gas protection measures if required.
Potential asbestos identified in recycled aggregate.	R- Asbestos can be harmful to human health.	Risk to construction workers and end-users Increased cost of groundworks.	Further investigation of recycled aggregate to assess risk. Contractor to adopt asbestos control measures during site works. Specialist advice may be necessary.

Hazard	Risk/ Opportunity	Consequence	Mitigation
Backfill contains contaminated material.	R – Exposure of construction workers to excavated materials from excavations and pile arisings.	Risk to construction workers Increased cost of groundworks.	Investigate potential for contaminated materials within backfill as part of ground investigation. Appropriate safe working practice. Provide sufficient clean cover to protect end users.
Capping layer may be absent or may have been contaminated due to post-reclamation site uses.	R - Exposure of construction workers and end-users to potentially contaminated material	Risk to construction workers and end-users Increased cost of groundworks.	Investigate potential for contamination in near surface materials as part of ground investigation. Appropriate safe working practice. Provide sufficient clean cover to protect end users.

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Figures

A3

Legend

Site Location

05/08/2016 11:52:29

Issue	Date	By	Chkd	Appd
P1	05-08-2016	SB	MSL	JMB

Metres
0 135 270 540

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Client

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Job Title

Newcastle LTC

Site Location Plan

Scale at A3

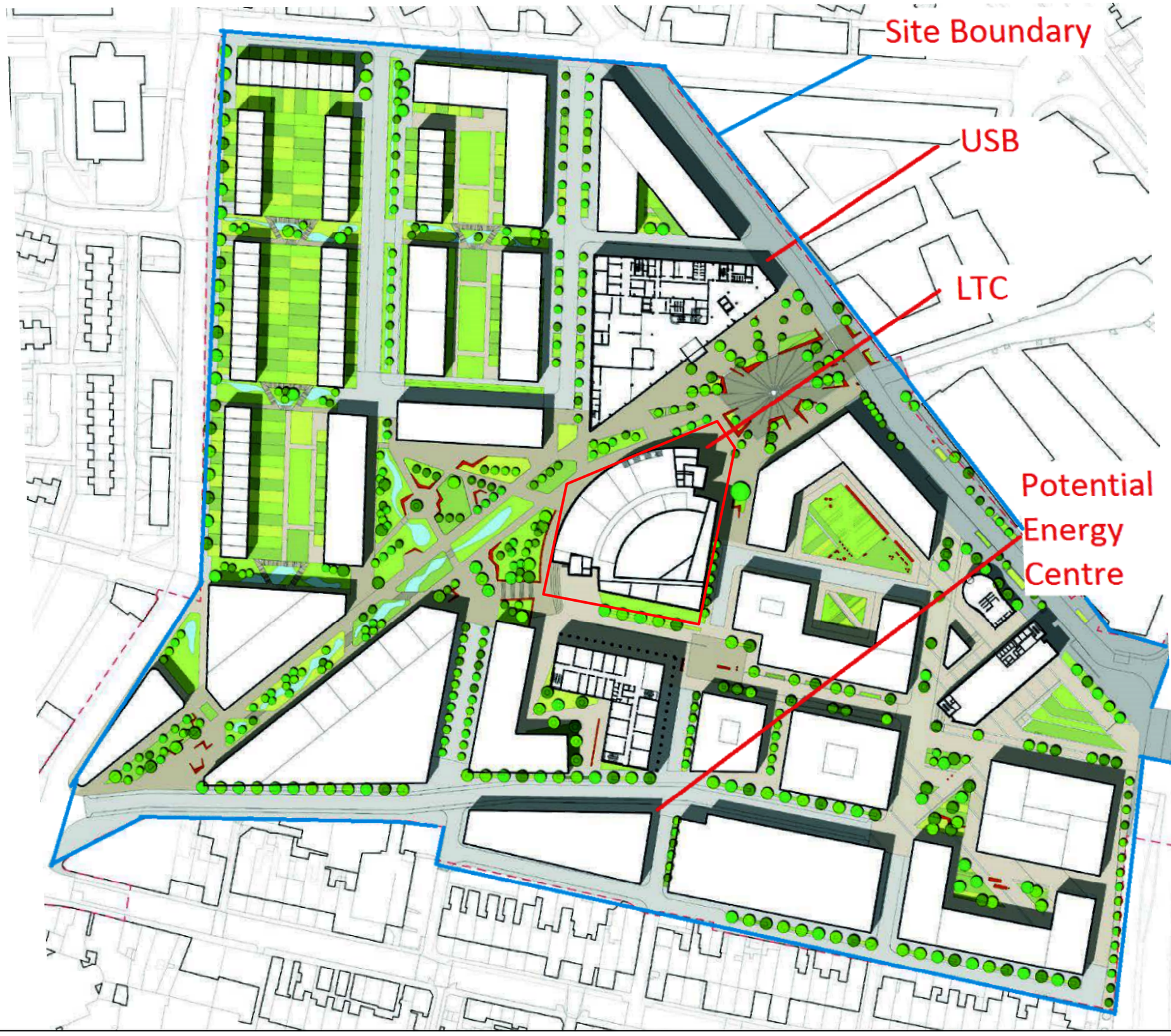
1:10,000

Job No	Status	Issue
244267	For Information	**P1**

FIGURE 1

MXD Location

A3



Legend

Learning and Teaching Centre

Science Central Site

05/08/2016 11:56:15

Note:
Map with outline of relevant buildings
(Map data 2016 Google)

Issue	Date	By	Chkd	Appd
P1	05-08-2016	SB	MSL	JMB

Metres
0 20 40 80

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Science Central Development Proposals

Scale at A3

1:1,500

Job No	Status	Issue
244267	For Information	**P1**

FIGURE 2

MXD Location

A3

Legend

- Learning and Teaching Centre
- Excavation Boundaries
- Cross Sections
- (July '13) Date base of excavation validated

Note:
-Cut locations provided by Hall Construction drawing 2031_DD235_Rev A_Revised Opencast Excavation.

- Date of base of excavation validation from Hall Construction drawing "Base of Excavation Validation".

Issue	Date	By	Chkd	Appd
P1	05-08-2016	SB	MSL	JMB

Metres
0 20 40 80

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Extent of Reclamation Area

Scale at A3
1:1,500

Job No
244267

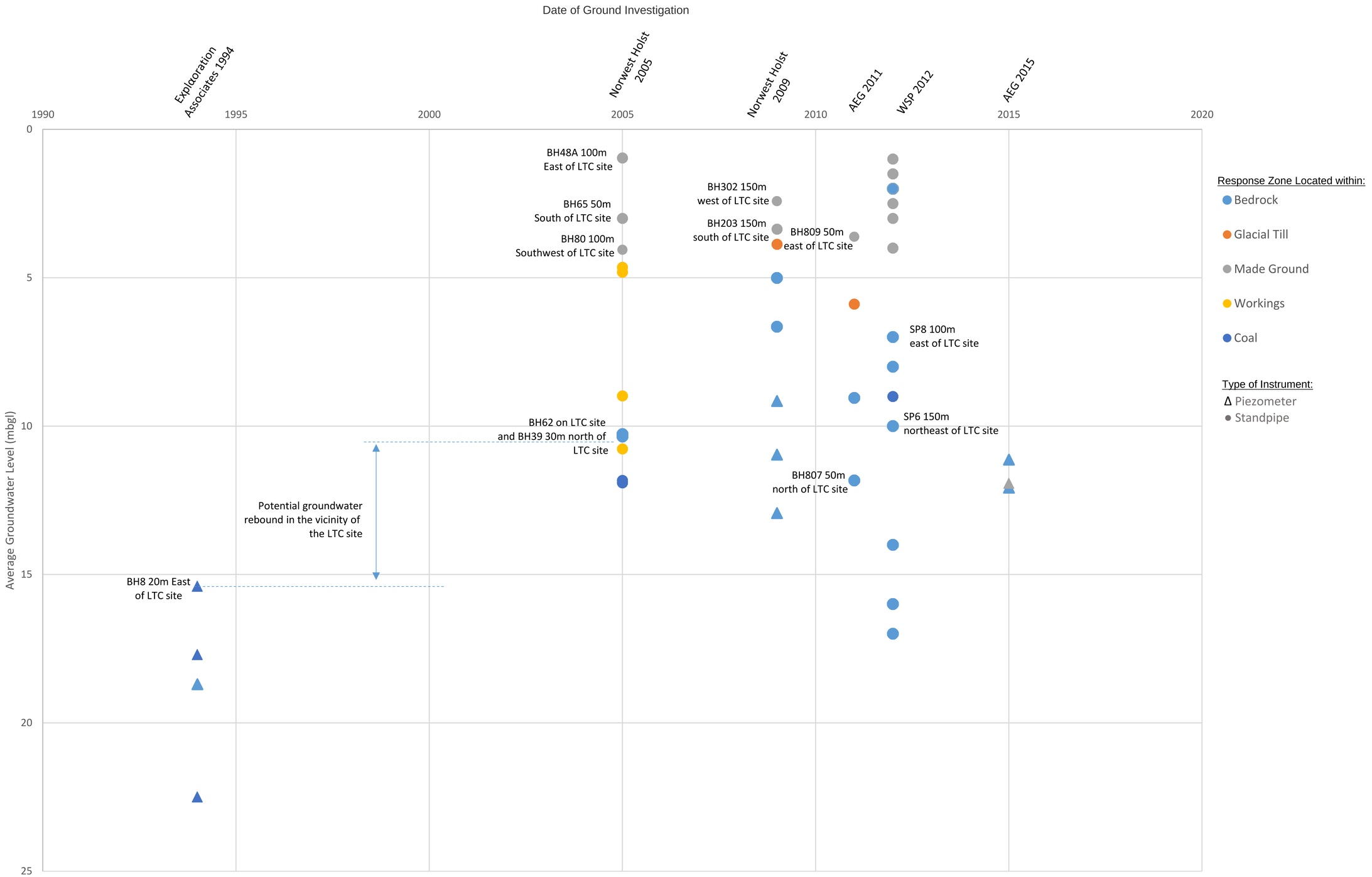
Status
For Information

Drawing No
FIGURE 3

Issue
P1

05/08/2016 14:38:06

MXD Location



Issue	Date	By	Chkd	Appd
P1	05-08-2016	SB	MS	JB
P0	19-07-2016	SB	MS	JB

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Job Title: Newcastle LTC

Figure Title: Groundwater Levels Monitored During Previous Ground Investigation

Discipline

Figure Status: For Information

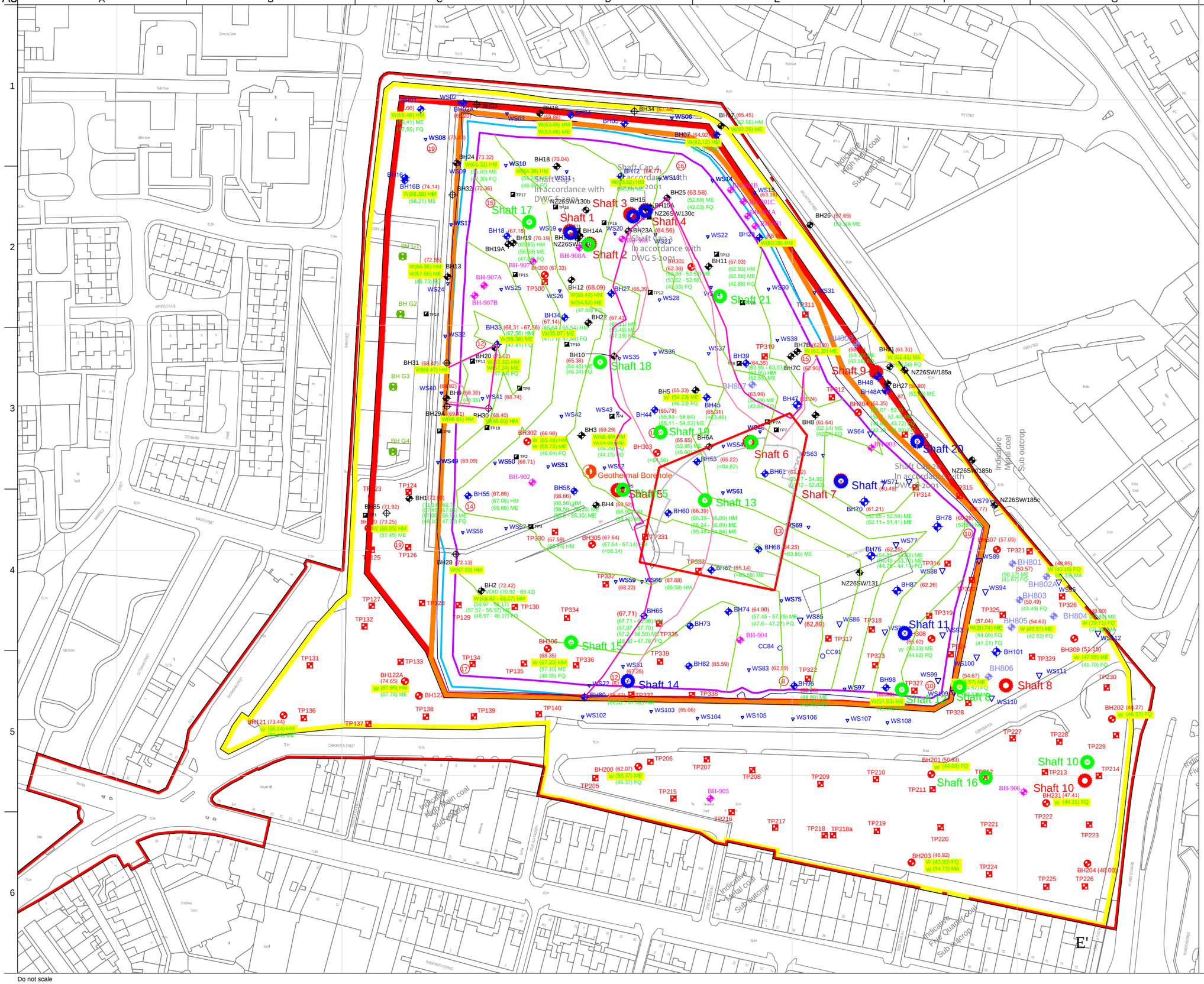
Job No: 244267

Issue: P1

Drawing No: FIGURE 4

Do not scale

A3



Known Mineshaft
BH G1 Groundshire 2013 Borehole
BH-907A AEG 2012 Borehole
BH808 AEG 2011 Borehole
BH300 Norwest Holst 2009 Borehole
TP300 Norwest Holst 2009 Trial Pit
BH53 Norwest Holst 2005 Borehole
WS25 Norwest Holst 2005 Window Sample
BH33 Exploration Associates 1994 Additional GI Borehole
BH13 Exploration Associates 1994 GI Borehole
TP1 Exploration Associates 1994 GI Borehole
NZ26SW/185a British Geologogical Survey Archive Information
Geothermal Borehole
Learning and Teaching Centre Site
Anticipated LTC Building Layout

Coal Seam (Reduced Level)

HM High Main
ME Metal
FQ Five Quarters
MA Main

Note
-Hole Locations and coal seam levels provided from Hall Construction drawing 20131_SS246_Rev A_Revised Opencast Excavation

Issue	Date	By	Chkd	Appd
P1	05-08-2016	SB	MS	JB

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Job Title
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Reduced Level of Coal Seams and Workings

Scale at A3 1:1000

Discipline GEO

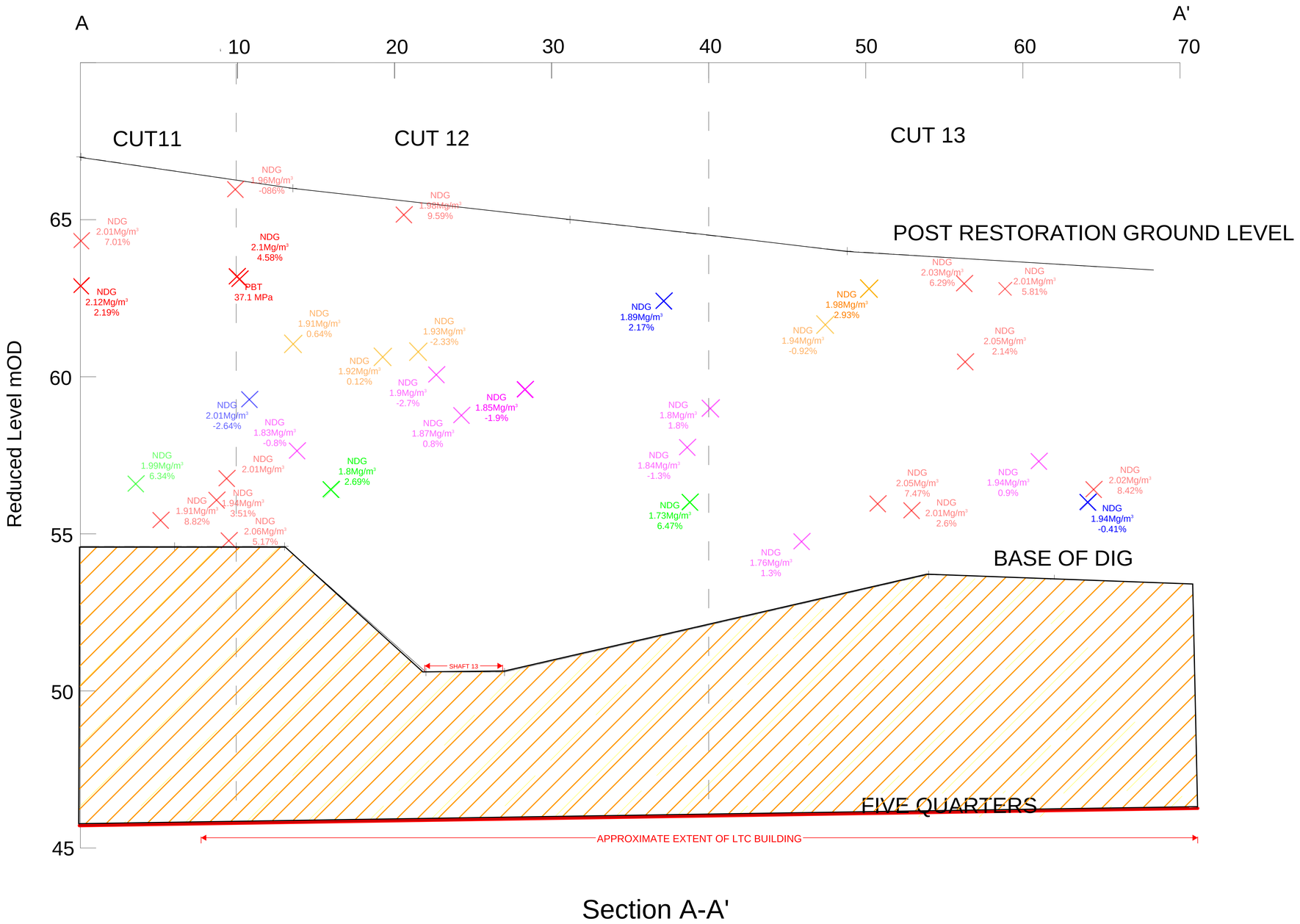
Job No **244267-00**

Status For Information

Issue P1

FIGURE 5

Do not scale



Section A-A'

Key

PBT (Plate Bearing tests)
Stiffness MPa

NDG (Nuclear Density Gauge)
Measured Density Mg/m³
Void Ratio 1.37%

Test within 10m of section line

Test within same cut as section line

Weathered Mudstone

Glacial Till

Fine Grained Rock

Cohesive Made Ground

Recycled Aggregate

Notes:
- Base of dig level, post restoration ground level and validation tests provided from Hall Construction drawings
- Level of Five Quarters estimated from pre-reclamation ground investigation

Issue	Date	By	Chkd	Appd
P1	05-08-2016	SB	MS	JB
Issue	Date	By	Chkd	Appd
P0	19-07-2016	SB	MS	JB

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Job Title: Newcastle LTC

Figure Title: Earthworks Test Results Section A-A'

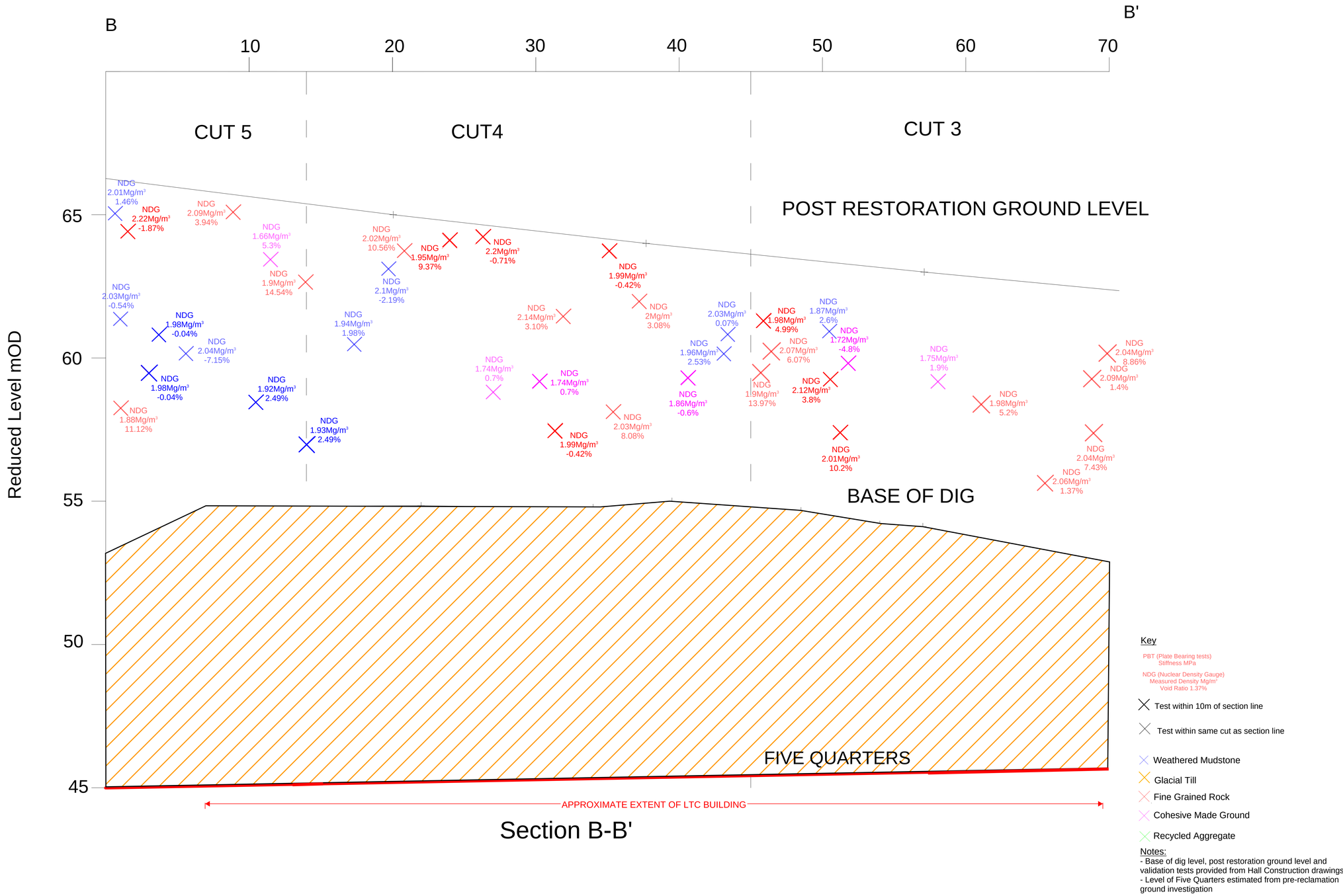
Discipline

Figure Status: For Information

Job No: 244267

Issue: P1

Drawing No: **FIGURE 6**



Section B-B'

Key

PBT (Plate Bearing tests)
Stiffness MPa

NDG (Nuclear Density Gauge)
Measured Density Mg/m³
Void Ratio 1.37%

Test within 10m of section line

Test within same cut as section line

Weathered Mudstone

Glacial Till

Fine Grained Rock

Cohesive Made Ground

Recycled Aggregate

Notes:
- Base of dig level, post restoration ground level and validation tests provided from Hall Construction drawings
- Level of Five Quarters estimated from pre-reclamation ground investigation

Issue	Date	By	Chkd	Appd
P1	05-08-2016	SB	MS	JB
P0	19-07-2016	SB	MS	JB

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Figure Title: Earthworks test results Section B-B'

Discipline

Figure Status: For Information

Job No: 244267

Issue: P1

FIGURE 7

Appendices

Appendix A

Geotechnical Classification of Backfill Materials

Classification Test Summary Tables

Table A1: Summary of Classification Tests on FGR

Test	Number of tests	Results
4.5kg Compaction Tests	8	Maximum Dry Density (MDD): Range= 1.79 – 2.22 Mg/m^3. Average = 2.04 Mg/m^3. OMC: Range = 6.1-14%. Average = 9%
Particle Size Distribution	44	27 of the samples indicate Class 1C grading, 14 indicate Class 1B and three samples indicate Class 2C.
Moisture Content	37	Range = 4 - 19% Average = 8%
Particle Density	8	Range = 2.59 – 2.7 Mg/m^3 Average = 2.65 Mg/m^3
LA Coefficient* (Siltstone)	6	Range = 33 – 40% Average = 36%

Table A2: Summary of Classification Tests on Weathered Mudstone.

Test	Number of tests	Results
4.5kg Compaction Tests	8	Maximum Dry Density MDD: Range= 1.88 – 2.08 Mg/m^3, Average = 2.03 Mg/m^3 OMC: Range = 7-11%, Average = 9%
Particle Size Distribution	19	Thirteen of the samples indicate a Class 1B grading, one indicates a class 1C and five indicate a class 2C.
Moisture Content	17	Range = 5 - 12% Average = 8%
Particle density	8	2.35 – 2.66 Mg/m^3. Average = 2.57 Mg/m^3

Table A3: Summary of Classification Tests on Glacial Till.

Glacial Till	Number of tests	Results
4.5kg Compaction Tests	3	Maximum Dry Density MDD: Range = 1.97 – 2.02 Mg/m^3, Average =2.00 Mg/m^3 OMC: Range = 8 - 10%, Average = 9%
2.5kg Compaction Tests	4	Maximum Dry Density MDD: Range = 1.85-2.03 Mg/m^3, Average = 1.92 Mg/m^3 OMC Range 9.6 - 12% (average 11%)
Particle Size Distribution	13	All tests demonstrate a 2C grading.

Moisture Content	8	Range = 7-26%. Average = 13%
Particle density	6	Range= 2.6 – 2.68Mg/m^3 Average 2.64Mg/m^3
Plasticity Index	7	Range = 15 - 21% Average = 18%

Table A4: Summary of Classification Tests on Recycled Aggregate

Test	Number of tests	Results
4.5kg Compaction Tests	5	Maximum Dry Density MDD: Range = 1.81 -1.88 Mg/m^3, Average = 1.84 Mg/m^3 OMC: Range = 12-14 %, Average = 13%
Particle Size Distribution	12	Ten samples indicate a Class 6F2 grading and one indicates a Class 2C.
Moisture Content	10	Range = 10 -17% Average = 13%
Particle density	5	Range = 2.49 – 2.58 Mg/m^3 Average = 2.55 Mg/m^3
LA Coefficient	4	Range = 38-40% Average = 39%

Table A5: Summary of Classification tests on Cohesive Made Ground.

Test	Number of tests	Results
2.5kg Compaction Tests	2	Maximum Dry Density MDD: Range= 1.63 – 1.71 Mg/m^3, Average = 1.67 Mg/m^3 OMC: Range = 7-12%, Average =9.4%
Particle Size Distribution	2	Both tests indicate a Class 2C grading.
Moisture Content	23	Range = 10 - 19%. Average = 15%
Particle density	2	2.08-2.18 Mg/m^3 Average 2.13 Mg/m^3

Table A6: Summary of Classification tests on Processed Demolition Rubble

Test	Number of tests	Results
4.5kg Compaction Tests	2	Maximum Dry Density MDD: Range = 1.95 – 1.98 Mg/m^3, Average = 1.97Mg/m^3 OMC: Range = 10 %, Average = 10%
Particle Size Distribution	2	Both tests indicate a 1C grading.
Moisture Content	2	Both results were 13%.

Particle density	2	2.6 – 2.61 Mg/m^3 Average 2.60 Mg/m^3

Table A7: Summary of Classification tests on Weathered Coarse Grained Rock

Test	Number of tests	Results
4.5kg Compaction Tests	6	Maximum Dry Density MDD: Range = 1.99 – 2.08 Mg/m^3, Average = 2.03 Mg/m^3 OMC: Range = 7-10%, Average = 8%
Particle Size Distribution	6	Three of the tests indicate a Class 2C and two indicate a Class 1B. One test is close to the grading requirements of Class 1C but contains slightly more fines (<63mm) than required (<15%).
Moisture Content	6	Range = 9-13%. Average = 11%
Particle density	6	Range = 2.46 – 2.69 Mg/m^3 Average 2.57 Mg/m^3

Table A8: Summary of Classification tests on Granular Made Ground

Test	Number of tests	Results
4.5kg Compaction Tests	2	Maximum Dry Density MDD: Range = 1.96 -2.01 Mg/m^3, Average = 1.985 Mg/m^3 OMC Range 8.7-9.4% (average 9.1%)
Particle Size Distribution	4	Two samples indicate a Class 1C grading, one shows a Class 6F2 and one a Class 1B grading.
Moisture Content	4	Range = 5-13%. Average = 9%
Particle density	2	Range = 2.61-2.65 Mg/m^3 Average= 2.63 Mg/m^3

Table A9: Summary of Classification tests on Fine Grained Rock (Capping Layer)

Test	Number of tests	Results
4.5kg Compaction Tests	2	Maximum Dry Density MDD: Range = 1.96 -2.01 Mg/m^3, Average = 1.985 Mg/m^3 OMC Range 8.7-9.4% (average 9.1%)
Particle Size Distribution	4	Two samples indicate a Class 1C grading, one shows a Class 6F2 and one a Class 1B grading.
Moisture Content	4	Range = 5-13%. Average = 9%
Particle density	2	Range = 2.61-2.65 Mg/m^3 Average= 2.63 Mg/m^3

Appendix B

Chemical Assessment Criteria

The following assessment criteria were provided in Appendix C of the draft version of WSP Remdiation Completion report [10].

Determinand		
Arsenic	32	mg/kg
Cadmium	10	mg/kg
Chromium	3000	mg/kg
Copper	2330	mg/kg
Lead	450	mg/kg
Mercury	1.0	mg/kg
Nickel	130	mg/kg
Selenium	350	mg/kg
Vanadium	75	mg/kg
Zinc	3750	mg/kg
Asbestos	No fibres detected	-
TPH Screen	15	mg/kg
TPH Aliphatic C5-C6	30	mg/kg
TPH Aliphatic C6-C8	73	mg/kg
TPH Aliphatic C8-C10	19	mg/kg
TPH Aliphatic C10-C12	93	mg/kg
TPH Aliphatic C12-C16	740	mg/kg
TPH Aliphatic C16-C35	75000	mg/kg
TPH Aromatic C5-C7	65	mg/kg
TPH Aromatic C7-C8	120	mg/kg
TPH Aromatic C8-C10	27	mg/kg
TPH Aromatic C10-C12	69	mg/kg
TPH Aromatic C12-C16	140	mg/kg
TPH Aromatic C16-C21	250	mg/kg
TPH Aromatic C21-C35	890	mg/kg
PAH Screen	0.5	mg/kg
Acenaphthene	210	mg/kg
Acenaphythlene	170	mg/kg
Anthracene	2300	mg/kg
Benzo(a)anthracene	2.5	mg/kg
Benzo(a)pyrene	0.60	mg/kg
Benzo(b)fluoranthene	3.5	mg/kg
Benzo(g,h,i)perylene	70	mg/kg
Benzo(k)fluoranthene	6.8	mg/kg
Chrysene	2.6	mg/kg
Dibenzo(a,h)anthracene	0.76	mg/kg
Fluoranthene	52	mg/kg
Fluorene	27	mg/kg

Determinand		
Indeno(1,2,3-cd)pyrene	3.2	mg/kg
Naphthalene	1.5	mg/kg
Phenanthrene	92	mg/kg
Pyrene	560	mg/kg