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Materials Processing Institute

Version 1

Materials Processing Institute

SUMMARY

The Materials Processing Institute together with its project partners has the objective of achieving a systematic, long-term beneficial outcome from recovery and regeneration of Past Metallurgical Sites and Deposits (PMSD) in the INTERREG region of Europe under an EU funded REGENERATIS project. Its aims are the innovative circularity to recover raw materials while regenerating the polluted sites.

This report is submitted in fulfilment of the requirements of work package TI and deliverable D TI.1.1.1 for the collation of site-specific data sets for historical activities.

A compilation of the historical data from the South Tees Development Corporation Redcar site (Teesside PMSD 1) is presented based on a desktop review of historical records of site activities and extractive sampling comprising core and pit excavations.

The data has, as much as possible, been checked for its provenance and veracity.

Broad process knowledge of site activities has been elicited allowing contextual evidence to qualify the data further.

The amount of data available is extensive and this report does not purport to be a comprehensive record of all data sources. Some of the data is restricted at this time due to the ongoing process of the Compulsory Purchase Order of the land to the South Tees Development Corporation. Also, the impact of COVID-19 has limited the accessibility and timing of data procurement. For this reason, subsequent revisions of the report will be published as further data becomes available.

1 INTRODUCTION

The report provides a compilation of historical site data arising from the South Tees Development Corporation (STDC) site for use by the SMARTIX tool and the development of the DST (REGENERATIS deliverable TI.1.1.1).

The STDC site is a large site (1500 ha) with a 160-year history of iron and steel production and the processing of finished products. It comprises large areas of Redcar, Lackenby, Grangetown and South Bank to the South of the river Tees.

The site has been used, at varying periods of time, for the storage of feedstock, products, by-products and waste streams. Over the years, due to changes in ownership, regulatory controls and economic conditions, the materials have co-mingled with poor associated recording of the inventories of quantity and quality of materials. The materials have also co-mingled with natural ground materials. This includes dispersal in soil, rock, clay, silt and other materials arising from its tidal estuary location. The stratigraphy is, therefore, varied and complex.

Not all of the available site-specific data has been forthcoming due to the information being held by the Official Receiver for SSI UK and awaiting transfer of the intellectual property rights to the South Tees Development Corporation as part of the Compulsory Purchase Order. Contact details will be supplied to ensure that all relevant data is provided when the transition process is completed and the intellectual property has been transferred allowing release of data.

Release of data is also being delayed by other organisations e.g. Environment Agency due to COVID-19 as internal priorities have changed and manpower has been re-deployed.

2 PROJECT SCOPE

The land in ownership by the South Tees Development Corporation comprises approximately 224 ha land associated with ironmaking and 14 ha associated with the South Bank Coke Ovens. In addition, 26 ha is associated with the South Lackenby Effluent Management System (SLEMS). There is also a residual land area of 1084 ha. A large part of the land adjacent to the tidal estuary was reclaimed during the 19th and 20th centuries.

In several areas, the land for remediation and development lies near operational premises (Bolckow Trading Estate, Tees Dock, South Tees Freight Park, Redcar Bulk Terminal and the British Steel Lackenby works) and areas of recreational and special scientific interest (South Gare and Coatham Sands).

In addition to the large site area, manufacturing operations go back to the mid-1800s and accelerated when iron-ore was discovered in the nearby Eston hills.

Because the land area is so large and diverse, it is important to maximise available knowledge to provide contextual guidance for the recommended locations of geophysical surveying and sampling comprising bore holes and excavation pits. This knowledge has been sought from academics, research institutes, regional government departments, company archives and industrialists. Site specific process knowledge of the ironmaking, steelmaking and foundation industries (cement, aggregates, fertilisers) provides important clues to the material transfers both quantitatively and qualitatively.

This report details and collates site-specific data from historical records of ground excavations. During the Regeneratis project, the presentation of this data will subsequently be modified by the project partners into a form required for use by the SMARTIX tool and in the development of the DST.

Full information is provided in the reference source of the data.

3 THE PAST METALLURGICAL SITES AND DEPOSITS SOUTH TEES SITE

The Past Metallurgical Sites and Deposits (PMSD) site area is shown in Fig. 1 [1]. The significant areas of previous industrial activity are those of the Redcar works complex (comprising the blast furnace, coke ovens, sinter plant and materials handling areas), the Lackenby steelmaking complex (comprising the basic oxygen steel and continuous casting plants), the Grangetown Prairie (site of the Cleveland Iron Works), the zone designated as Landfill and Waste Management Facilities (comprising the SLEMS waste management facility, the High Tip Landfill and a metals recovery area) and the South Bank zone (site of the Clay Lane furnaces and the South Bank Coke Ovens). In addition, there are other smaller areas within the STDC area which are likely to contain significant quantities of waste products. In the area designated as the Teardrop site, the Redcar slag wool works was contemporaneous with the Redcar Iron and Steel works operating in the 1960s.

In terms of the Regeneratis project, the UK Teesside site is labelled PMSD-1.

The area covered by PMSD-1 has a long history of industrial activity dating from the mid-19th century. On the South of the river Tees there were 91 blast furnaces at its peak.

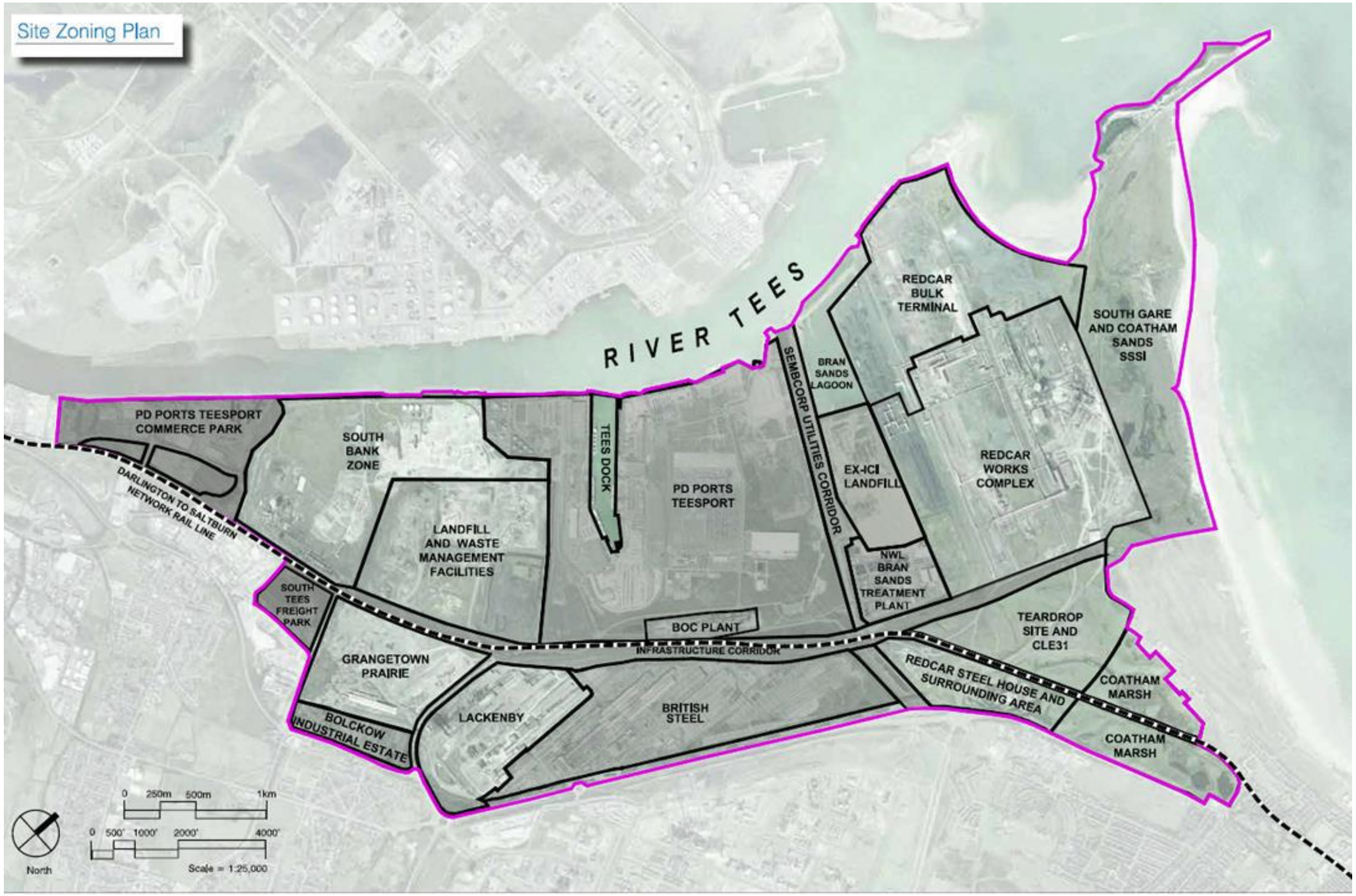


FIG. 1: PMSD-1 SITE ZONING PLAN

The ownership of assets in 2019 is given in Fig. 2 [1]. This has changed most significantly, with the transfer of ownership of SSI owned assets to South Tees Development Corporation in 2020.

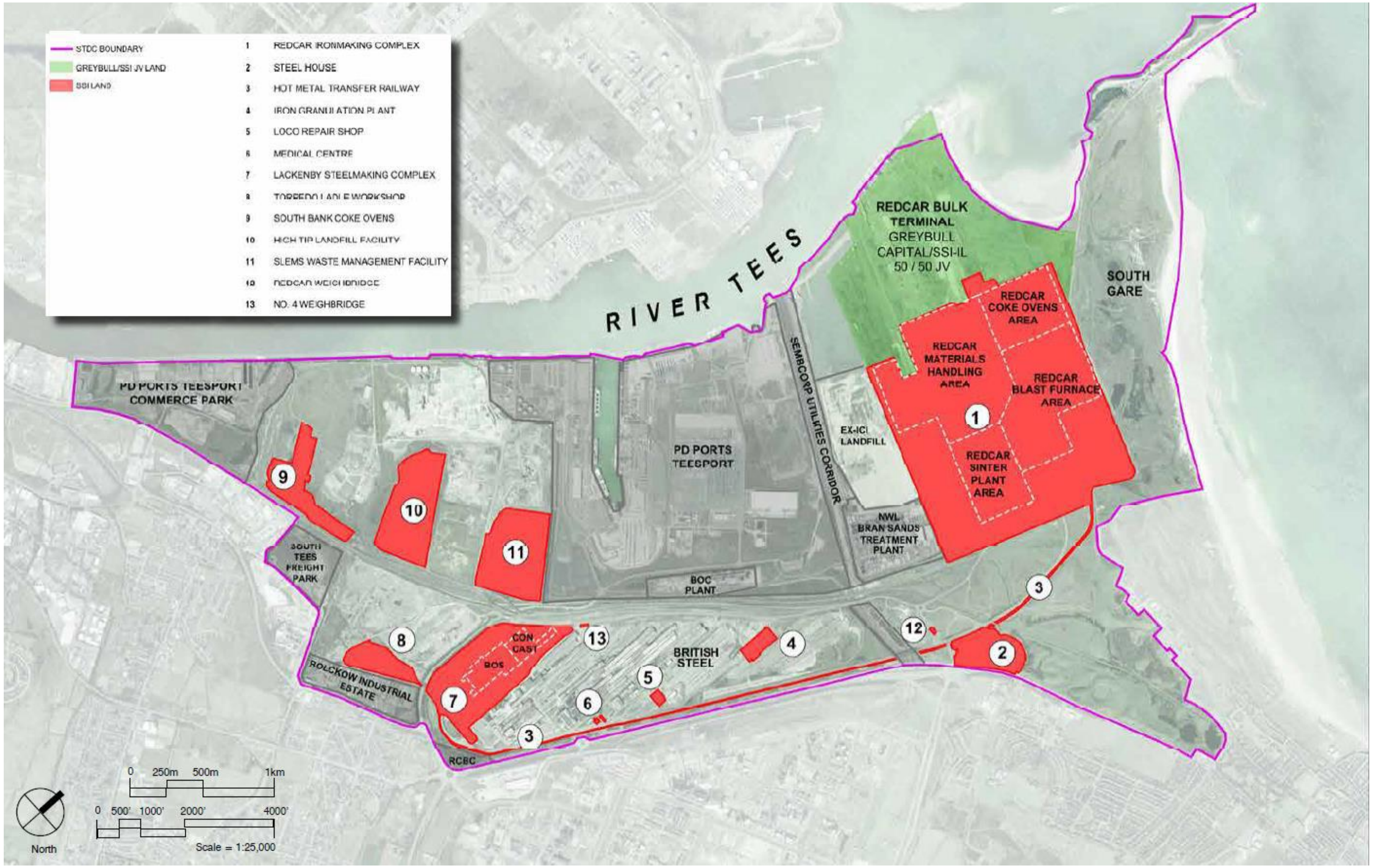


FIG. 2: OWNERSHIP OF ASSETS

The extent of the Teesside iron and steelmaking assets in 1966 is shown in Fig. 3.

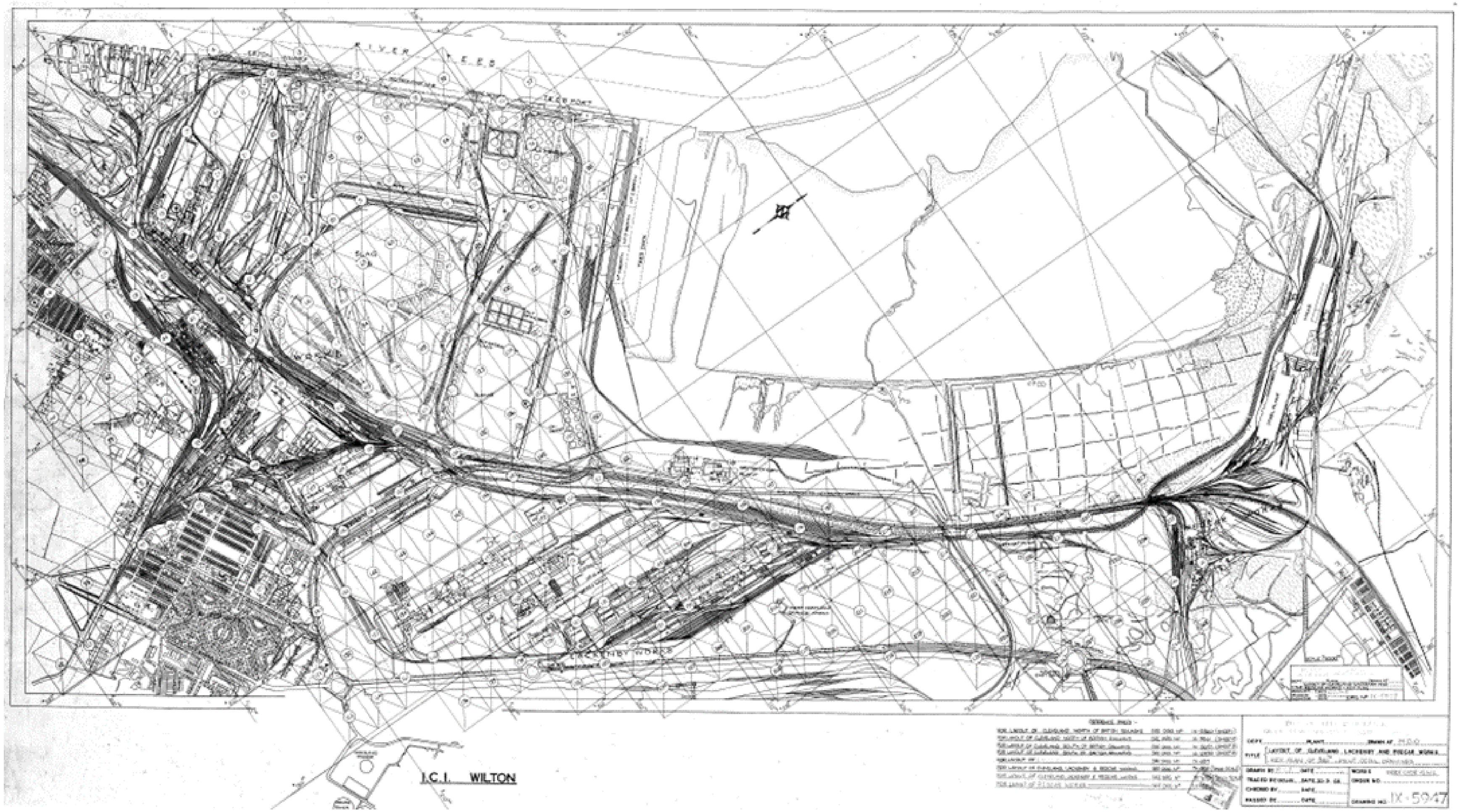


FIG. 3: CLEVELAND LACKENBY AND REDCAR WORKS 1966

3.1 THE GRANGETOWN PRAIRIE

In 1851, Bolckow and Vaughan built a blast furnace using iron ore from the Cleveland Hills.

The zone designated as the Grangetown Prairie has a long history of iron and steelmaking. Former uses were the Cleveland Iron and Steel Works, where coke ovens, iron and steelmaking were located along the western periphery with mills located in the central and eastern zone.

The Cleveland Iron works was established by Bolckow Vaughan Limited in 1875. The works comprised blast furnaces, coke ovens, Bessemer furnaces, steel mills and associated plant.

The existing Torpedo Ladle workshop was formerly home to a series of open-hearth furnaces.

Former activities have left a legacy of contamination, buried structures, abandoned utilities and chambers (voids) across the site.

The former coke ovens location, to the western side of the site, is likely to be heavily contaminated. The ground conditions beneath the site initially comprise up to 4 m of slag. Rock is at a depth of 6 - 15 m.

Dorman Long owned and operated iron and steelmaking sites from the 19th century. They took over the Bolckcow-Vaughan site at Grangetown, South Bank and Eston in the 1870s and the Redcar/Lackenby sites in the early 20th century [2].

The location of the Dorman Long plants in 1959 is shown in Fig. 4.

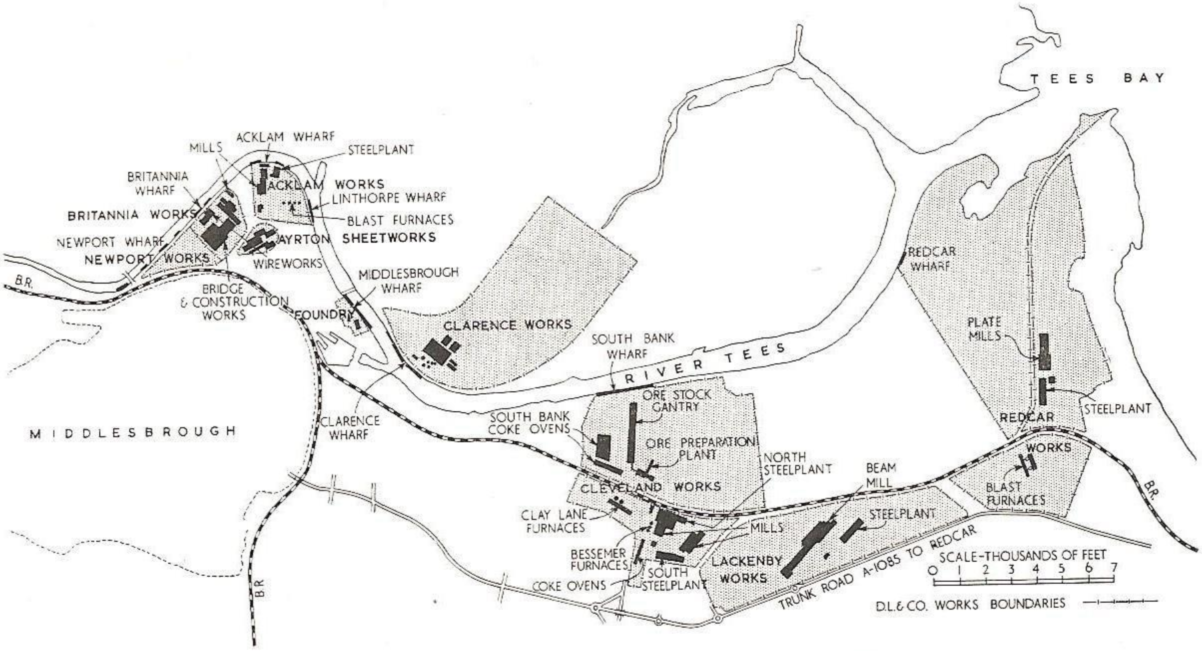


FIG. 4: THE LOCATION OF THE DORMAN LONG PLANTS IN 1959

3.2 THE SOUTHBANK ZONE

Immediately to the North of Middlesbrough Road East (Clay Lane) shown in Fig. 5 from the Ordnance Survey map from 1953-1955, the South Bank Steels Works were established from 1879. This comprised the pig iron furnaces and coke ovens.

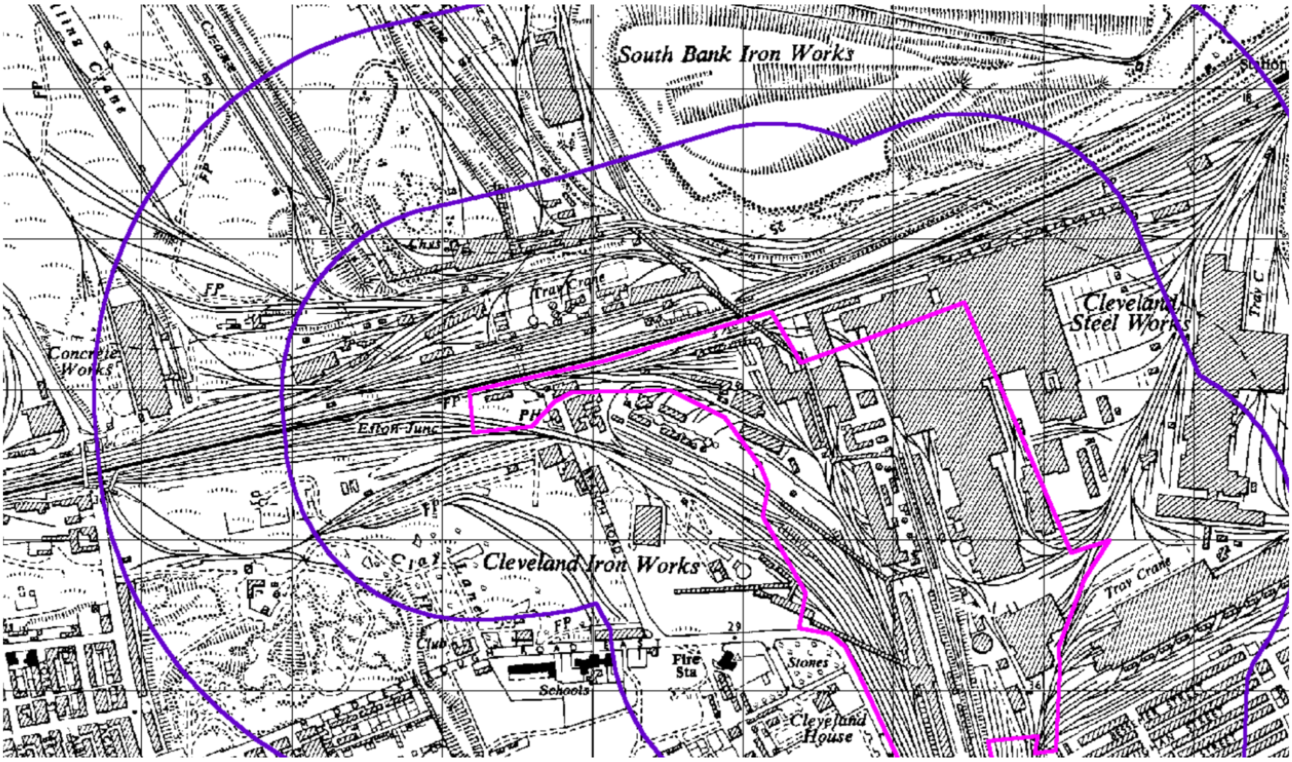


FIG. 5: CLAY LANE AREA SOUTH BANK (1955)

The land occupied by the estuary was reclaimed in the 1890s using slag as the steel works expanded. The land is up to 10 m thick with slag, is underlain by compressible soft and weak tidal flat deposits from the former estuary, and beneath that is the Tees laminated clay. The bedrock is the Mercia Mudstone at 18-25 m depth below ground, and the Boulby halite formation from which brine was historically extracted.

In 1900 Bolckow, Vaughan & Co Limited acquired the Clay Lane works and shifted production from iron to steel owning 21 of the 91 blast furnaces in the Cleveland area.

Previous residents of the land are Cleveland Saltworks, iron and steel works, galvanising works, concrete works, a fuel storage depot, coke ovens and by-products facilities. Residual coal-tar is stockpiled to the west of the by-products facility.

The production units in 1966 are shown in Fig. 6.

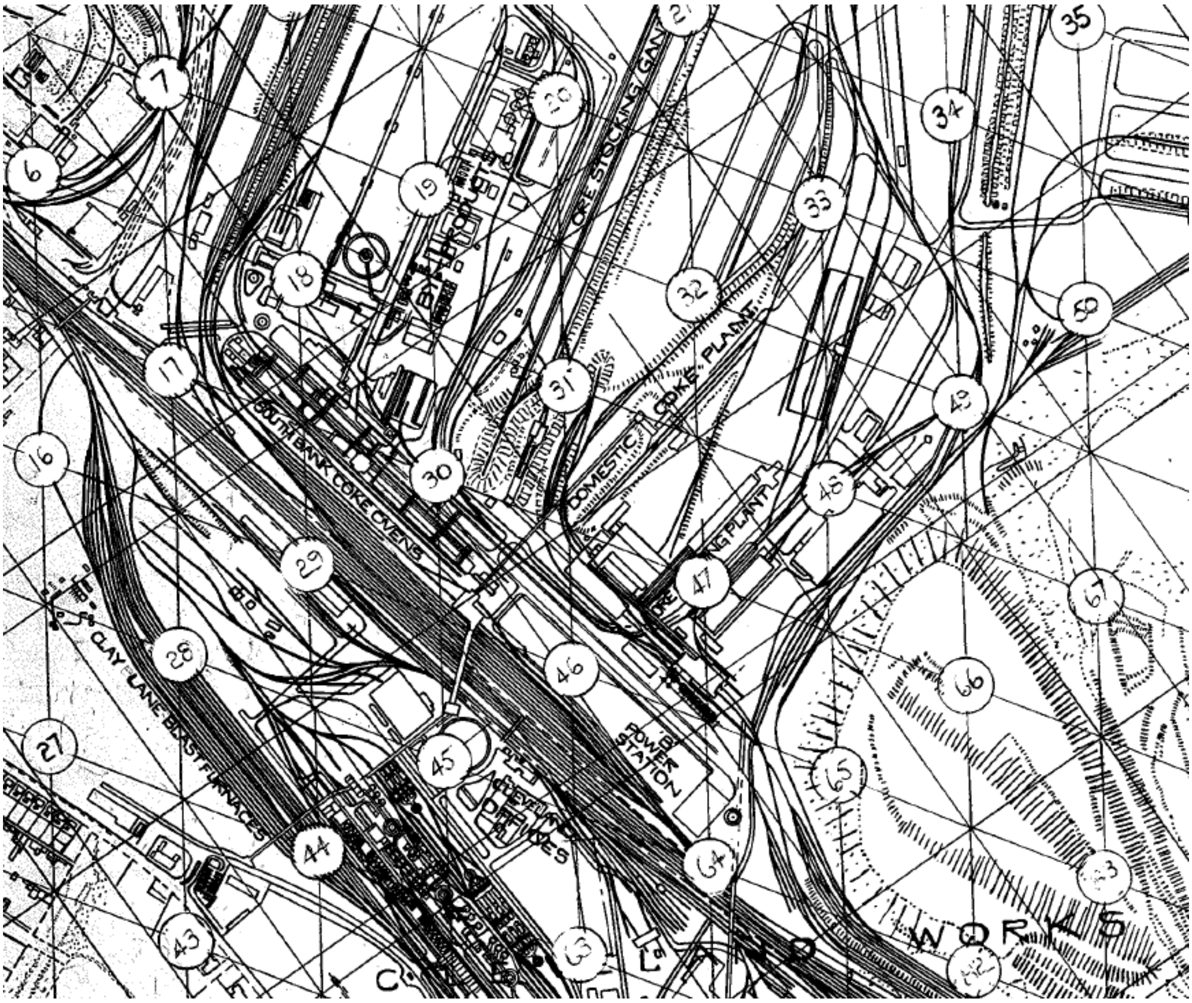


FIG. 6: SOUTH BANK PRODUCTION FACILITIES (1966)

Land remediation in the vicinity of the coke ovens and by-products facilities must be cognizant of the hazardous materials present in the ground as well as buried assets. Some of these materials are pyrophoric (e.g. iron sulphide).

The contaminants are contaminated coal, heavy fuel oil, benzole (benzene, toluene, xylene), creosote, absorbing oil, wash oil, coal tar (black viscous liquid denser than water comprising a complex mixture of condensed ring aromatic hydrocarbons, phenolic compounds, aromatic nitrogen bases, alkyl derivatives, paraffinic hydrocarbons, olefinic hydrocarbons), coal tar pitch (black solid residue from the distillation of coal tar).

There is also asbestos contamination of the soil.

No excavations are currently allowed due to the contaminants.

3.3 THE LANDFILL AND WASTE MANAGEMENT ZONE

The principal areas of landfill and waste management within the PMSD-1 area are shown in Fig. 7 [1].

The landfill and waste management area located at South Bank between the South Bank coke ovens and PD Ports Teesport comprises from West to East, the High Tip, the Impetus Tip and the SLEMS. This is shown in Fig. 8 in aerial image taken from North of the river Tees.

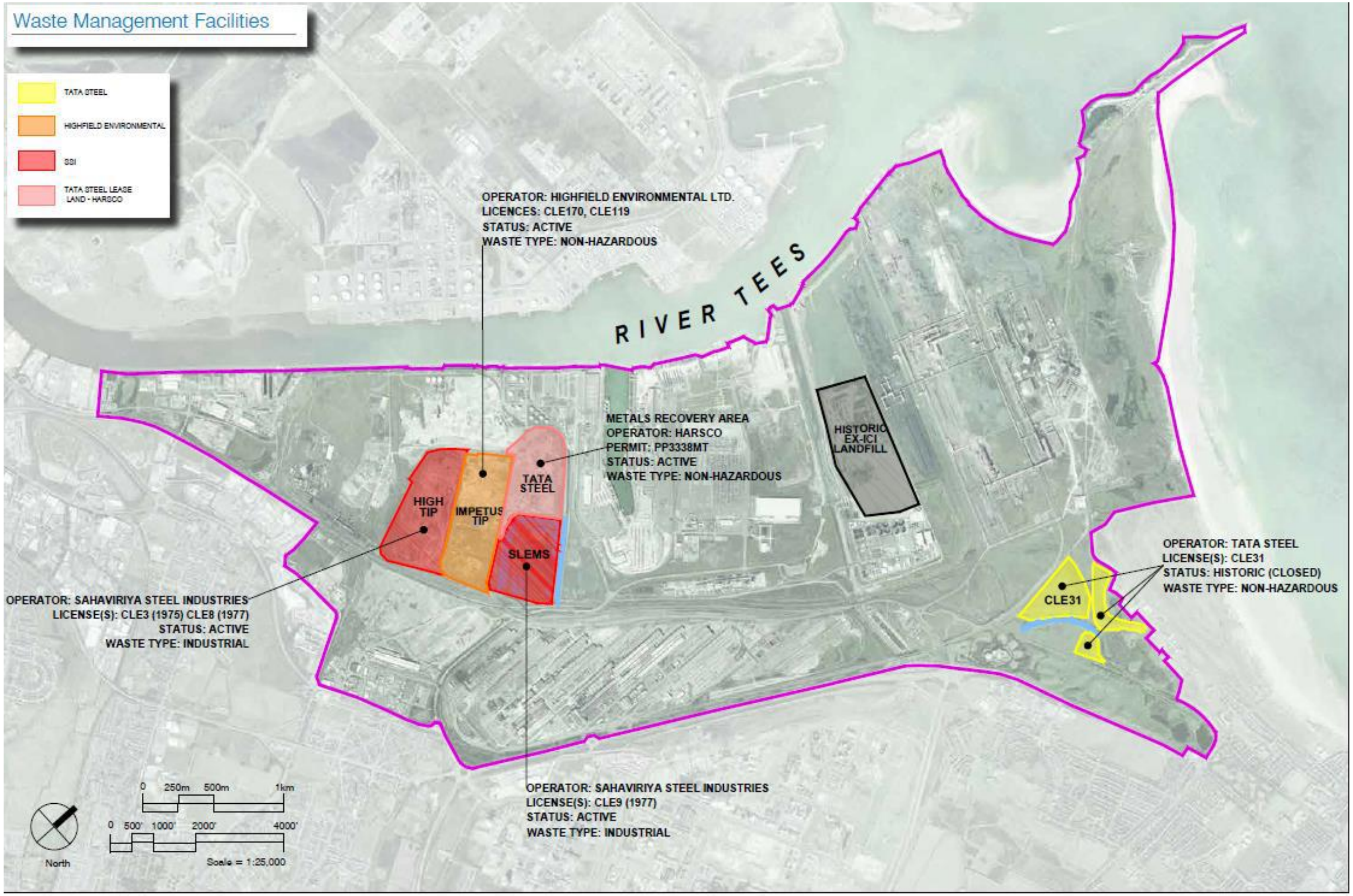


FIG. 7: WASTE MANAGEMENT FACILITIES WITHIN PMSD-1

FIG. 8: PRINCIPAL AREA OF LANDFILL AND WASTE MANAGEMENT AREAS

3.3.1 THE SSI HIGH TIP

An area of 25 hectares, this is a licenced facility used for disposal of by-products from iron and steelmaking operations.

The deposition of waste materials commenced between circa. 1865-1870.

The 1899 Ordnance Survey map is shown in Fig. 9. This shows that slag deposition had commenced to the west of the SLEMS area with the extent of the high tidal mark moved north.

Slag extractions from High Tip have occurred during various periods. In 1964 old slag material was extracted from the High Tip to provide land reclamation for the Shell Refinery within Teesport.

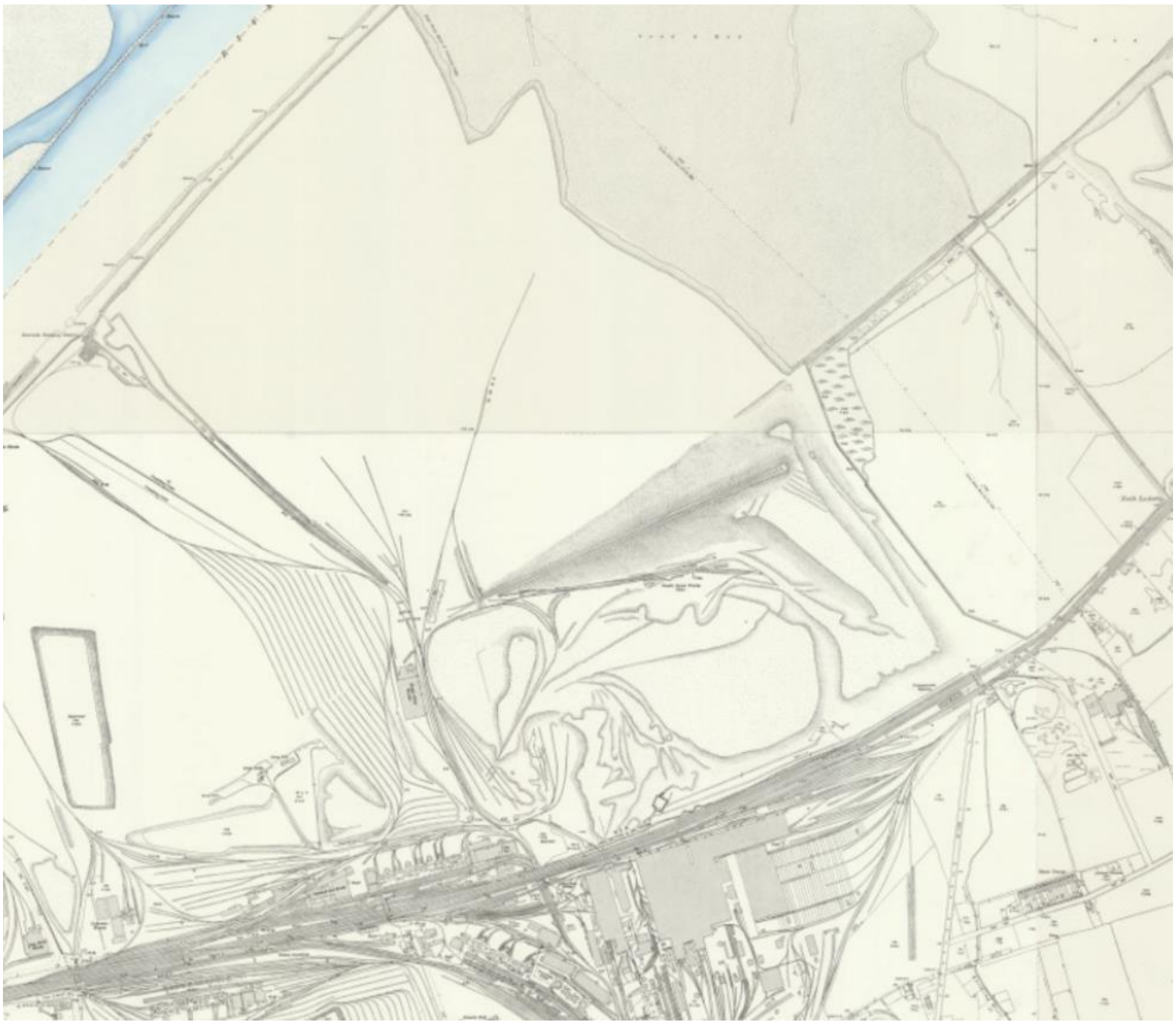


FIG. 9: 1899 ORDNANCE SURVEY MAP

3.3.2 THE SLEMS WASTE MANAGEMENT FACILITY

An area of 22 hectares, this is a waste handling and treatment facility for Basic Oxygen Steelmaking (BOS) oxide waste that is marketed for re-use in the cement industry.

It comprises a series of settling ponds in the southern section of the site. An aqueous suspension of BOS oxide and blast-furnace waste (slurry) was pumped from the BOS plant into these ponds.

The deposition of waste materials in the SLEMS is thought to have started in the late 1950s. A 1953-1955 Ordnance Survey map labels the SLEMS area as "Mud". A drawing from 1966 (Fig. 10) shows the SLEMS area. The site is labelled as a "silt extraction plant". This implies that a product is produced but no evidence has been obtained on the processes or markets supplied.

Settled material was dredged from the ponds and deposited in adjacent drying bays before being placed at a final deposition point within the landfill.

The landfill has an approximate maximum elevation of 15 m above surrounding ground.

BOS oxide is used in the manufacture of a wide range of construction materials.

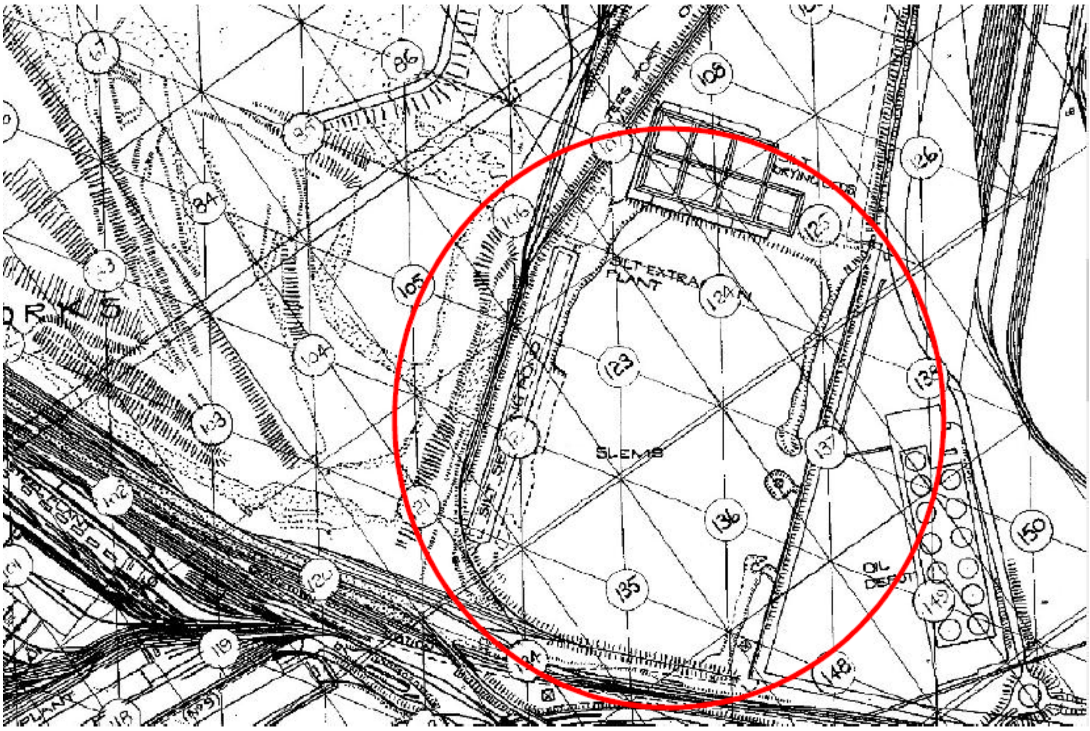


FIG. 10: EXCERPT FROM BRITISH STEEL DRAWING 1X5947 (1966)

A site plan is provided in Fig. 11 [3]

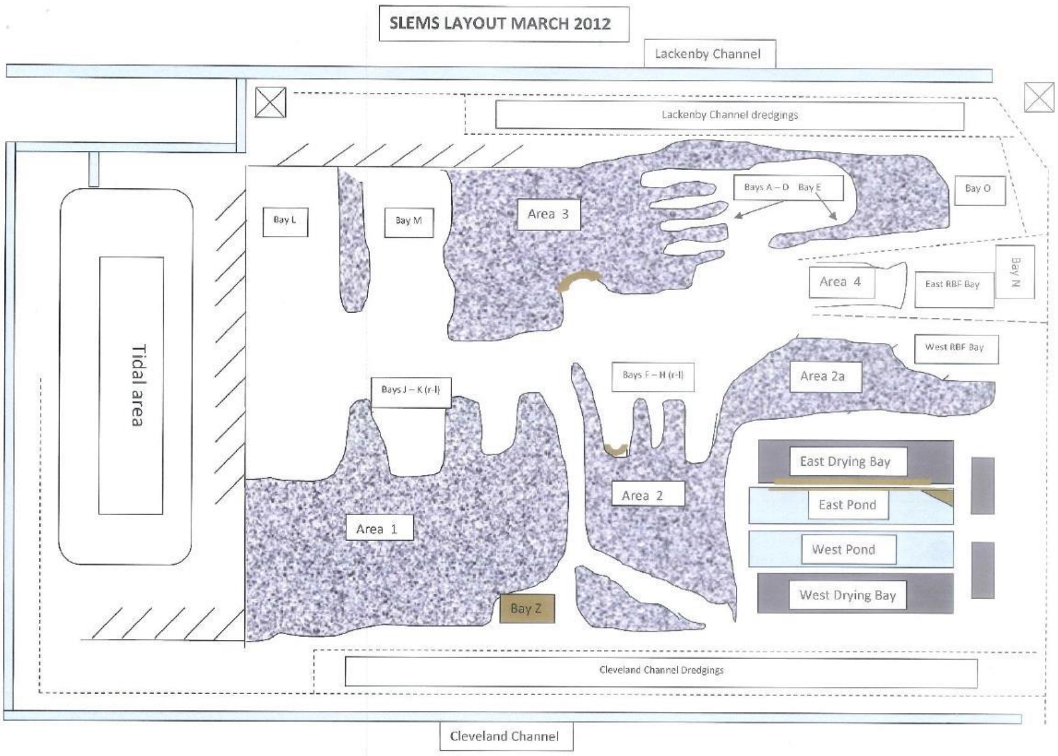


FIG. 11 SLEMS SITE PLAN

3.3.3 THE METALS RECOVERY AREA

This is an area leased by SSI from Tata Steel, that was previously leased from Harsco who have been engaged in recycling materials from iron and steelmaking for recovery of metals.

Harsco processed the slag from Lackenby steelworks and from legacy stockpiles by a series of physical impaction methods (including drum impactors), comminution, sieving, grading and magnetic separation of metallic material. The non-metallic material was supplied to Tarmac.

Waste deposits commenced in the 20th century as the tidal water mark completely covered this area as evidenced from the 1899 Ordnance Survey map.

3.3.4 HIGHFIELD ENVIRONMENTAL FACILITIES

Highfield operates various licenced landfill facilities along the central zone of this area, for both hazardous and non-hazardous wastes, that were previously designated as ICI landfills.

3.4 THE REDCAR COMPLEX

Iron making at Warrenby, Redcar commenced in the1860s.

The South Gare was constructed from slag between 1863-1888.

The Redcar Iron Works was opened in 1874.

In 1917, Dorman Long build a blast furnace at Redcar.

Land continued to be reclaimed from the estuary until the 1950s.
The former Redcar Iron Works occupied the south-eastern part of the Redcar site and included a tar plant.

In the 1960s, slag was recycled into bricks and slag wool (used for passive fire protection, sound insulation and the non-conducting linings of refrigerating chambers).

In 1979, all existing blast furnaces in the Cleveland area were closed with the opening by British Steel of a new blast furnace at Redcar and integrated steelmaking plant at Lackenby.

Post 1979, most of the materials of the steel plant wastes were recycled through sinter making, saving raw materials such as iron ore and limestone.

In 2015, the SSI assets of the Redcar blast furnace, the Redcar and South Bank coke ovens and the BOS plant at Lackenby closed.

Ground contamination is highly likely arising from the coke ovens by-products plants including coal tar, ammonia, phenol, naphthalene, light oil and sulphur removal from coke oven gas.

Other contaminants will arise from power generation (coal furnace bottom ash and fly ash, clinker) and from the sinter and pellet plants.

‘Made ground’ consists of slag up to 10 m thick. Rock lies at 15-25 m below ground level.

4 PROCESS KNOWLEDGE

4.1 IRON AND STEELMAKING PLANT

An understanding of the iron and steelmaking processes (both from recent and legacy assets) as well as the material handling activities of those assets provides a more informative view of the location, the chemical composition and quantities of the PMSD repositories.

The PMSD-1 site has a 170-year history, so spans a broad range of process technologies from pig iron foundries in the 19th century to a modern-integrated steelworks of the last 20 years.

Ironmaking blast furnace technology has changed significantly from the early blast furnaces of the 1850s (Grangetown Prairie) to the Redcar blast furnace first commissioned in 1979 (Redcar Works Complex).

Also, the quality of the iron ore has changed significantly. In the 19th century, local ironstone was used, which produced very large amounts of slag. The relatively small available markets for slag by-products resulted in large quantities being tipped onto the mud banks of the Tees.

The development of the River Tees estuary was instrumental to the industrial development of Teesside. Commencing in 1855, training walls were built to straighten the course of the river Tees [4]. Over 20 miles of training walls were built from slag. South Gare breakwater was created, built on a foundation of slag, to provide a harbour of refuge at the mouth of the river Tees.

Steelmaking technology started with the Bessemer blast furnace in the 1850s (pig iron contacted with air to remove carbon and silicon) to open hearth furnaces in the 1890s (Grangetown Prairie, Redcar Works Complex) and Basic Oxygen Steelmaking (BOS) in the latter half of the 20th century (Lackenby).

Process knowledge also extends to the change of use of the land occupation. This allows a better understanding of the present-day landforms (spoil tips and lagoons).

4.2 IRON AND STEELMAKING MATERIAL HANDLING

Understanding the chemistry, the physical and mechanical properties, storage and transport (mechanical handling) of the feedstocks, intermediates, products, by-products and waste streams allows a full picture.

A wide variety of scientific techniques can be used to investigate the materials and by inference the technologies employed in historic industries.

These comprise visual inspection, low power microscopy and high-power microscopy.

4.3 IRON AND STEELMAKING WASTE MATERIALS

The most significant waste materials arising from iron and steelmaking are blast furnace and BOS or steel slag.

Steel slag is much heavier than blast furnace slag with a specific gravity of 3.3 compared to 2.4 for blast furnace slag.

Visually, the slags can be distinguished by colour. After washing, the steel slag can be darker grey compared to the blast furnace slag which is a lighter grey.

Comparing slag pore size, the steel slag has larger pores than that of blast furnace slag.

Compositionally, there are also differences. The composition of iron slag is provided in Table 1 [5]. It is reported that older blast furnace slags have higher alumina content (up to 20%) [6].

The composition of blast furnace slag from the 19th century [7] is reported in Table 2 for Cleveland grey slag.
In comparison, BOS slag has 2-3% alumina. Also, older blast furnace slags have lower calcium oxide concentrations.

TABLE 1
IRON SLAG REDCAR BLAST FURNACE 2015

Component	Composition, %
Slag Fe (total)	0.22
FeO	0.28
SiO_2	37.16
CaO	40.76
MgO	7.32
Al_2O_3	12.62
TiO2	0.57
S	0.73
Mn	0.36
MnO	0.46
Na_2O	0.24
K_2O	0.59

Redcar 2015 blast furnace slag basicity ratios:
RI 1.10 CaO/SiO2
RII 0.97 (CaO+MgO)/(SiO2+Al2O3)

TABLE 2

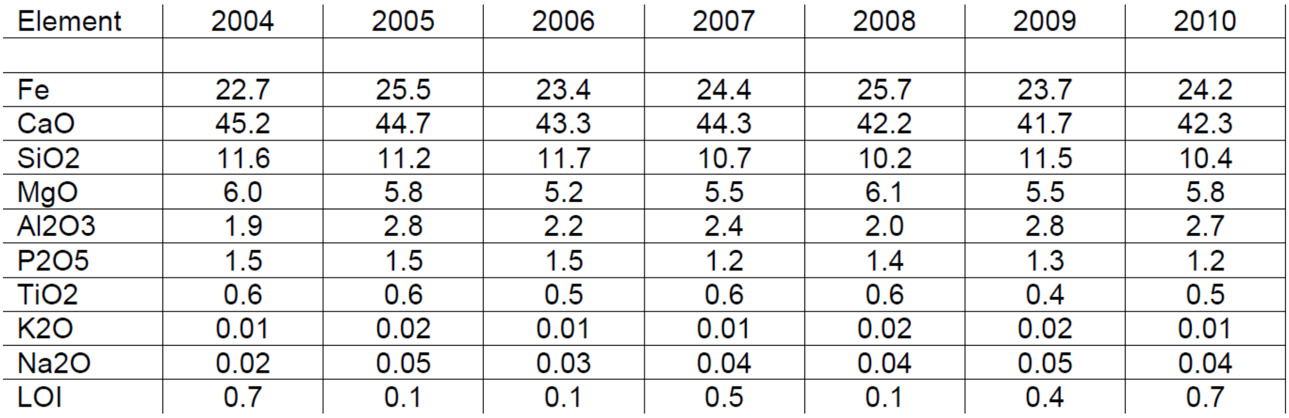
CLEVELAND GREY SLAG COMPOSITION 1867

Component	Composition, %
Silica (SiO_2)	38.25
Alumina (Al_2O_3)	22.19
Lime (CaO)	31.56
Magnesia (MgO)	4.14
Protoxide of Iron (FeO)	1.09
Sulphide of Calcium (CaS)	2.95
Manganese	trace
Total	100.16

The composition of steel slag is provided in Table 3. The data was supplied by Tarmac [8]

TABLE 3

STEEL SLAG COMPOSITION



Element	2004	2005	2006	2007	2008	2009	2010
Fe	22.7	25.5	23.4	24.4	25.7	23.7	24.2
CaO	45.2	44.7	43.3	44.3	42.2	41.7	42.3
SiO2	11.6	11.2	11.7	10.7	10.2	11.5	10.4
MgO	6.0	5.8	5.2	5.5	6.1	5.5	5.8
Al2O3	1.9	2.8	2.2	2.4	2.0	2.8	2.7
P2O5	1.5	1.5	1.5	1.2	1.4	1.3	1.2
TiO2	0.6	0.6	0.5	0.6	0.6	0.4	0.5
K2O	0.01	0.02	0.01	0.01	0.02	0.02	0.01
Na2O	0.02	0.05	0.03	0.04	0.04	0.05	0.04
LOI	0.7	0.1	0.1	0.5	0.1	0.4	0.7

The significant difference between the iron and steel slag is in the RI basicity ratio of CaO/SiO2. For BOS slag the RI is 4.0 compared to 0.05-1.15 for blast furnace slag.

5 PREVIOUS EXPLORATORY INVESTIGATIONS

5.1 WASTE MANAGEMENT FACILITIES

Enviros collated information of previous excavations on the periphery of the SLEMS site in 2004 [9].

A review of excavations undertaken by the British Geological Survey (BGS) data provided in Appendix A indicates that the area is underlain by tidal flat deposits of sand, silt and clay. Below this is glacial till predominantly a layer of gravelly clay. The underlying bedrock is Mercia mudstone.

Above the natural deposits is a varying thickness of slag. Other non-natural materials include refractory bricks, building rubble and oily/solvent contaminated peat.

Topographical surveys of the SLEMS have been undertaken by Corus (2002), AC Environmental Services (2011) and Arcadis (2018). The maximum elevation has been measured at approximately 20 m above ground level.

5.2 SLEMS GROUND CHARACTERISATION

Arcadis have reported (2018) excavation data in the SLEMS area based on a limited number of boreholes and trial pits. Only a limited number of boreholes was achieved due to the presence of impenetrable solid material. The excavation data is provided in Appendix B.

The ground was reported as comprising BOS oxide in the form of a slightly gravelly silt underlain with slag, refractory bricks and other wastes. Arcadis reported that the quantity of fine BOS oxide recovered was limited and as a result they may have overestimated the quantity of gravel and larger particles. The BOS oxide was generally found to be in the form of a black silt containing metallic dust but other deposits had varying degrees of colour variation (bluish grey, dark reddish brown, orange).

Another observation made was that the BOS oxide resides at different depths and layer thickness intermingled with layers of other materials most notably slag. The degree of randomness of layer composition and thickness would seem to indicate that waste deposition was undertaken with little attempt to segregate the type of waste material although any subsequent re-landscaping of the area would result in redistribution and mixing of materials between layers.

The slag was observed to be light grey to white in colour with voids filled with partially hydrated lime. Slag was also observed to be in the form of gravel often mixed in with refractory brick. Minor deposits of other waste including metal machine parts were also present.

Hydrocarbon odours were detected with solvent layers visible on surface water. It is unknown where this material has arisen from. However, hydrocarbons have been stored in the area for many decades and the area is a tidal mudflat with several natural water courses and man-made drainage cuts.

Groundwater was found at approximately 4.0 m depth in some of the excavation pits.
In the calculation of BOS oxide inventory, the boreholes were not included due to the likelihood of over-estimate of gravel quantities. Gravel is driven ahead by the boring tool with limited recovery of the BOS oxide.

The average BOS oxide content found was 63% and 37% slag.

The elemental analysis of the material is provided in Appendix C. A proportion of the material is saturated with water.

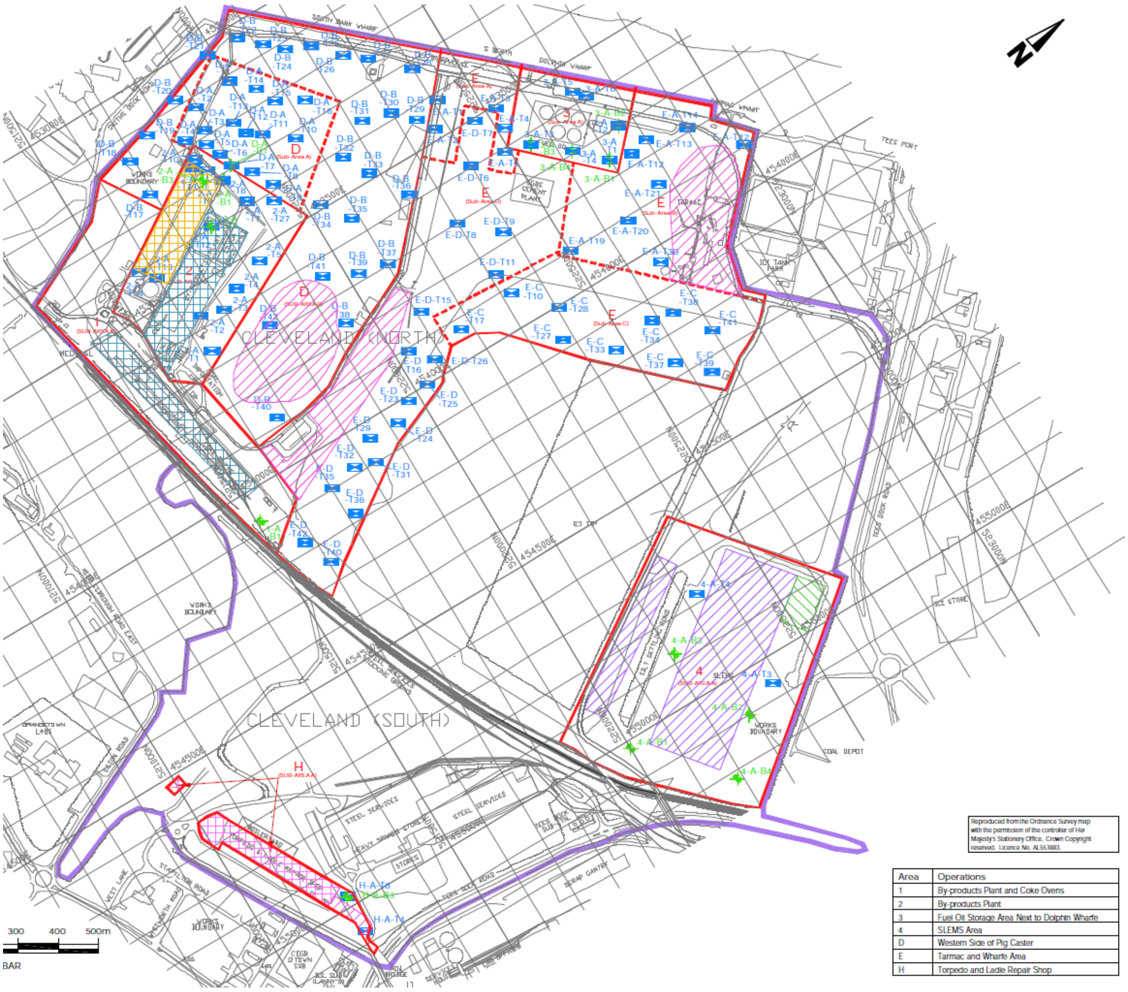
The elemental analysis indicates a large range of metallic species from 10-65 wt% metallics. These would be mainly present as oxides. The significant species present are iron, aluminium, chromium, vanadium, zinc and manganese.

The quantities of polycyclic aromatic hydrocarbons (PAHs) present also varies significantly with the maximum at 570 mg/kg.

The quantity of recoverable BOS oxide has been estimated at between 300,000 – 360,000 m3 based on the BOS oxide depth data (Appendix D), an estimated basal slag layer of 3.5 m (variation 2.5-3.5 m) and the height estimated from topographical data. Additionally, an assumption is made that 15% volume is unsuitable comprising slag, bricks, etc.

5.3 SOUTH BANK

Enviros undertook excavation work for Corus (2004) in the South Bank, Waste Management and Lackenby areas [10]. A plan of the boreholes and trial pits is shown in Fig. 12. The author has requested a copy of this report from the South Site Company Limited but this was declined on the basis of the on-going process of the Compulsory Purchase Order from SSI to STDC.



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Area	Operations
1	By-products Plant and Coke Ovens
2	By-products Plant
3	Fuel Oil Storage Area Next to Dolphin Wharfe
4	SLEMS Area
D	Western Side of Pig Caster
E	Tarmac and Wharfe Area
H	Torpedo and Ladle Repair Shop

FIG. 12: CORUS EXCAVATIONS (2004) - SOUTH BANK

5.4 REDCAR WORKS COMPLEX

Boreholes were taken around the site at the request for the Site Monitoring Protection Plan [11]. The author is currently in the process of obtaining this information from the Environmental Agency. Delays are expected due the COVID-19 and the prioritisation for urgent government work.

6 MADE LAND INVENTORY CALCULATIONS

The calculation of material arisings (deposits) to made land is particularly difficult due to the paucity of data available. In most cases the arisings originated at a time that pre-dated the statutory obligations of recording waste deposit transfers. This was certainly true prior to the Control of Pollution Act 1974. The pertinent UK environmental legislation is:

Control of Pollution Act 1974
Environmental Protection Act 1990
EU Landfill Directive 1999/31/EC
Hazardous Waste Regulations 2005
UK Waste Regulation 2015

Where records do not exist of arisings, these are estimated based on known hot metal production rates and typical by-product ratios at the time of operation.

6.1 SLAG AND REFRACTORY PRODUCTION RATES

The rate of slag production depended on the composition of the iron ore and the period in history (technology dependent).

The natural formation of Cleveland ironstone mined from the 1850s was iron carbonate (siderite) and barthierine (previously chamosite) [15]. This was mined extensively for fifty years but in reduced amounts in the 20th century due to the market demands of a changing steel composition. In 1881, 6 million tonnes of Cleveland ironstone were extracted.

Cleveland ironstone contained only 33% iron, so there was significant slag production from the production of pig iron. Typically, 1-2 tonne of slag was produced for every 1 tonne hot metal [6].

A large part of the slag was used for land reclamation which extended the dry land between the steel works and the high-water mark of the tidal estuary. At the South Gare, Redcar the land promontory is formed by slag from the nearby Warrenby Slag Works. Some of the slag was used for fertiliser (South Bank Antonien Works), slag wool for insulation and fire retardant (Redcar Slag Wool Works), brick manufacture (South Bank Brick Works) and for construction materials (South Bank Basic Slag Company).

In the 20th century, slag waste rates were reduced with more recycling of materials taking place.
The rate of production of blast furnace slag per tonne of hot metal (thm) from the most recent operations is typically in the range 150-350 kg/thm [16]. Of this approximately 95% can be re-used.

The rate of production of basic oxygen furnace slag is typically in the range 50-220 kg/thm [16]. Of this approximately 50% can be re-used.

The rate of production of refractory wastes is typically in the range 5-6.5 kg/thm [16]. Of this approximately 22% can be re-used. This is predominantly related to steelmaking rather than ironmaking.

6.2 REDCAR STEEL WORKS SLAG PRODUCTION RATES 1979-2015

During the period 1979-2015, 96.4 million tonnes of hot metal (thm) were produced [11].

The Redcar blast furnace from the 1970s had a hearth diameter of 14 m, a working volume of 4246 m_3 and a nameplate hot metal capacity of 11,000 t/day and pulverised coal injection rate of 240 kg/thm.

Blast furnace sludge arisings were 3-5 kg/thm [9] from the clarifier. Based on 4 kg/thm, the blast furnace sludge arisings for 1979-2015 were 385,600 te (i.e. 96,400,000 x 0.004).

The slag rate from the Redcar blast furnace owned by British Steel Corporation in 1989 was 282 kg/thm reported by Chatterjee et al [13]. All the blast furnace slag was taken by Tarmac for processing and sale as either cement or aggregate products [14]. The residual slag is estimated at 1.3 million tonnes based on a 95% re-use rate (i.e. 0.05 x 0.282 x 96,400,000).

6.3 LACKENBY STEELWORKS SLAG PRODUCTION RATES 1971-2015

A new Basic Oxygen Steelmaking plant was commissioned in 1971 by British Steel Corporation with an annual hot metal production capacity of 2.2 Mta after closure of steelmaking at Cargo Fleet in 1970. This was subsequently increased to 4.8 Mta in 1979 to take the increased iron from the Redcar blast furnace.

Basic oxygen steelmaking slag originated from three sources comprising desulphurisation process, from the BOS vessel itself, and from secondary processing (mixed product slag removal).

From 2000-2015 only the ladle slag was recovered by Tarmac.

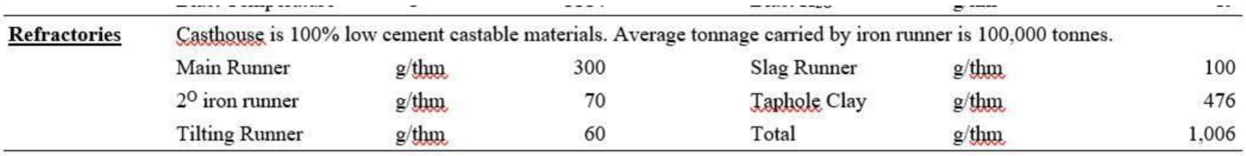
The estimated residual steelmaking slag is estimated as 10 million t based on a 50% re-use rate and an 80% overall equipment effectiveness (i.e. 0.8 x 0.5 x (2.2 x 8 + 4.8 x 36) x 0.135).

6.4 REFRACTORY PRODUCTION RATES 1971-2015

The Redcar blast furnace refractory consumption rates are provided in Table 4. All the tap hole clay ends up in the slag. Assume that 50% of the refractory ends up in the slag [12]. Therefore, the calculated refractory sent to landfill from 96.4 million thm is 25,046 t (0.5 x 530 x 96.4).

TABLE 4

REDCAR BLAST FURNACE REFRACTORY WEAR RATES



Refractories	Casthouse is 100% low cement castable materials. Average tonnage carried by iron runner is 100,000 tonnes.					
	Main Runner	g/thm	300	Slag Runner	g/thm	100
	2^{o} iron runner	g/thm	70	Taphole Clay	g/thm	476
	Tilting Runner	g/thm	60	Total	g/thm	1,006

The rate of production of refractory material is typically in the range 50-65 kg/thm [16]. Of this approximately 22% is reported to be re-used.

The refractory consumables from steelmaking is much higher than for ironmaking. This arises from vessel linings, tundish linings and continuous casting refractories.

For the Lackenby steelmaking site for 1971-2015, the estimated residual refractory is 0.6 million t based on a 22% re-use rate and an overall equipment effectiveness of 80% (2.2 x 8 + 4.8 x 36) x 0.0055 x 0.78 x 0.8).

6.5 COMBINED BLAST FURNACE SLAG REPOSITORY DEPOSITS 1850-2015

Historical records for Cleveland [17] show that by 1871 one million tonne per annum of pig iron was being produced at the South Tees ironmaking sites. By 1880 this had risen to 2 million tonne per annum. The reference does not include a detailed breakdown of districts, so the data has to be assumed as approximate. The pig iron data is broadly consistent with that the production data for iron ore based on a conversion rate of 3:1 iron ore to pig iron.

The production of iron in the 20th and 21st centuries varied significantly dependent on several strategic, economic and technological factors.

As iron as a finished product was superseded by steel for many applications requiring a highly level of ductility and tensile strength, the level of iron production tailed off in the latter part of the 19th century.

In 1902 the first integrated steel works opened at Cargo Fleet but this is further upstream on the river Tees and outside the PMSD-1 land area covered by the South Tees Company Site.

In 1917 the Redcar iron works opened.
In 1918 the Cleveland iron works opened.
In the 19th century, much of the slag had a limited market outlet. In 1899-1902 it is recorded as having a value of 1.3% steel product at 1.1 shilling/ton. Due to the high siderite content of Cleveland iron ore, the ores produced large amounts of slag.

In 1906, the South Bank Basic Slag Company Limited was formed which processed the slag for fertiliser. It operated until into the 1960s.

A conservative estimate of the average annual hot iron production for the period 1850-1910 is 2.0 Mt and 2.5 Mt for 1910-2015.

Assuming an average slag production rate of 80 wt% slag/thm and re-use percentage of 35% (author's estimate) for 60 years (1850-1910) followed by an average production rate of 35 wt% slag/thm and re-use percentage of 90% [16] for 105 years (1910-2015), the quantity of residual slag that did not find a market is 62 million t (60 x 2 x 0.8 x 0.65+ 105 x 2.5 x 0.35 x 0.1).

This compares with 2.7 million t for the period 1979-2015 (96.4 x 0.282 x 0.1) assuming 282 kg/thm [13].

6.5.1 CROSSCHECK CALCULATION

The average density of the slag is assumed to be 2.5 t/m3 [18]. Based on 62 Mt, this equates to a volume of 25 Mm3.

Based on an average slag thickness of 2.5 m, this equates to an area covered in slag of 10 km_2 or 1000 ha. By comparison with area measurement on Google Maps, the total area of potential slag waste deposition is approximately 1070 ha comprising Redcar (670 ha), South Bank (270 ha), Grangetown (70 ha) and Lackenby (160 ha).

By examining the maps between 1861 and 1993, development of the Tees river estuary has reduced the tidal flat area by 913 ha. A large part of this reclamation will have used waste products from the iron and steel industry.

The distribution of slag ground depth is not uniform with large variability between zero and 8 m. A significant determinant of slag depth is the requirement for land reclamation, particularly in the area of the tidal estuary. This would have been motivated by the need to create wharfing frontage for sea bearing cargo. Also, river frontage developments such as the oil refinery have required land reclamation from the mudflats and sandbanks.

6.6 COMBINED STEELMAKING SLAG REPOSITORY DEPOSITS 1850-2015

Bessemer furnace produced steel commenced from 1880 at 150,000 t per annum.

Steel production rose to 460,000 t (1890) and 1,350,000 t (1900).

A new open-hearth steel plant was opened in 1954 operating to 1971.

A new Basic Oxygen Steelmaking plant was commissioned in 1971 and operated until 2015.

The slag re-use percentage for steelmaking is much lower than that for ironmaking [16] due to the higher quantity of consumables - less than 50%. This is due to the steelmaking slag having less intrinsic value. This is mainly due to the higher hazardous material content e.g. heavy metals.

A conservative estimate of annual hot steel production for the period 1850-2015 is 1.7 Mt.

Assuming an average re-use percentage of 40% and 18 wt% slag/thm for the same period [16], the quantity of residual slag that did not find a market is 27 million t (150 x 1.7 x 0.18 x 0.6). This compares with 10 million t for the period 1979-2015 (36 years).

6.7 COMBINED REFRACTORY REPOSITORY DEPOSITS 1850-2015

Since the bulk of the consumable refractory waste arises from steelmaking rather than ironmaking, the calculation is based wholly on steel production.

Assuming, conservatively, an annual hot steel production for the period 1865-2015 is 1.7 Mt.

Assuming an average re-use percentage of 22% and 0.65 wt% refractory/thm for the same period [16], the quantity of residual refractory that did not find a market is 1.3 million t (150 x 1.7 x 0.0065 x 0.78). This compares with 0.6 million t for the period 1979-2015 (36 years).

7 CONCLUSIONS AND RECOMMENDATIONS

The Teesside PMSD has undergone significant change from the beginnings of industrial iron and steelmaking in the 19th century to the present day. The land mass has literally been shaped by those metallurgical industries (land reclamation from slag deposition). The ground composition varies significantly, from areas with little evidence of industrial activity to areas with a high degree of material deposition arising from metallurgical and chemical industrial activities.

7.1 HISTORICAL DATA

Historical data of site excavations comprising boreholes and pits has been collated.

Further data will be forthcoming once the ongoing Compulsory Purchase Order process reaches its conclusion and the SSI Official Receiver agrees to the transfer of the intellectual property to STDC.

The extent of ground excavation and sampling undertaken to date is a relatively small fraction of the total area used for iron and steelmaking activities (224 ha). Therefore, site surveying and the use of geophysics will be an important tool to employ in the overall evaluation process of the site for material recovery and land remediation.

7.2 STRATEGY FOR PMSD EVALUATION

The Regeneratis project has as its objective, the delivery of a generic model and its associated data that can be packaged in a form for use by organisations undertaking remediation projects of PMSDs in the future.

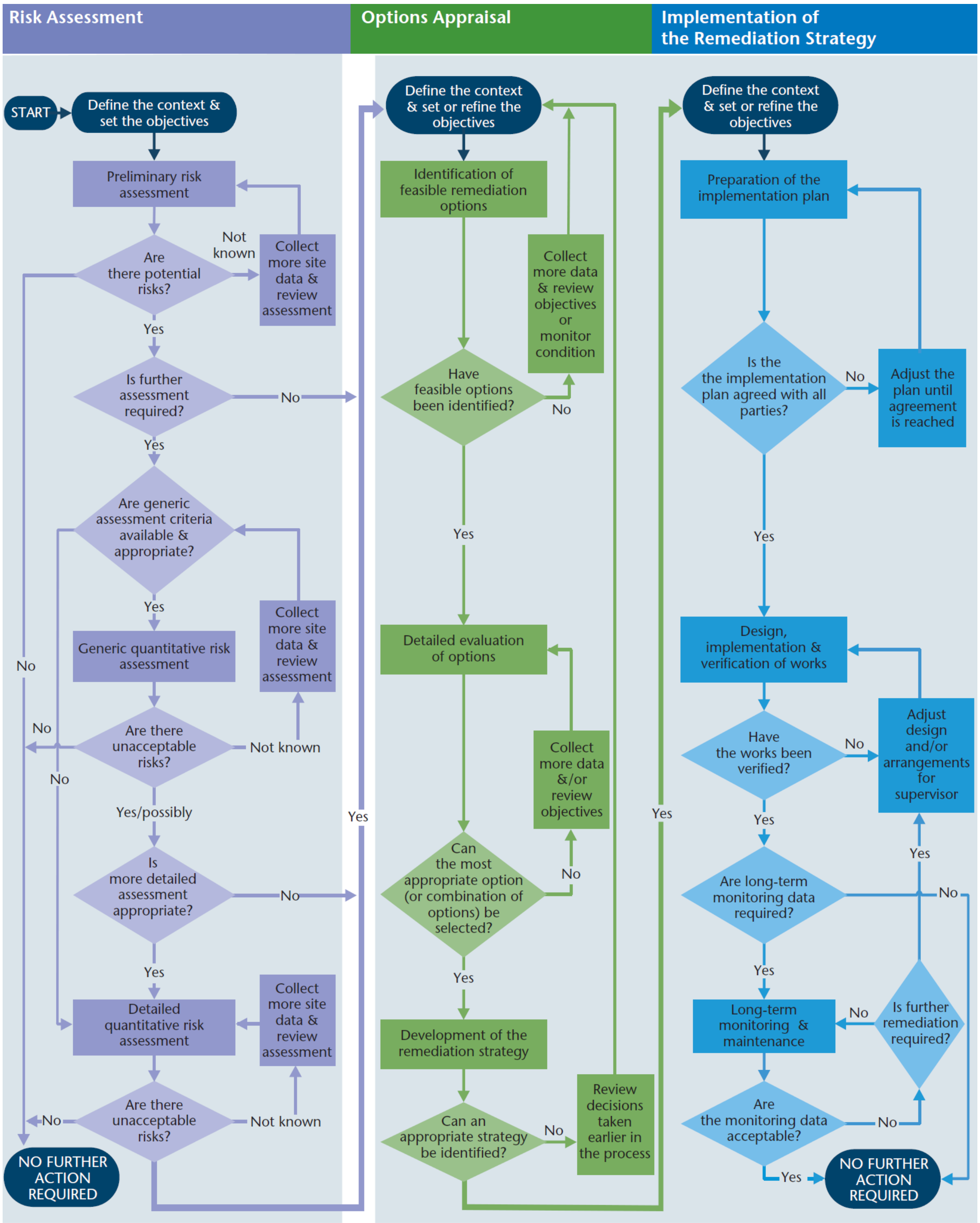
Generating the model and its associated data in an easily accessible form is a key requirement.

It will also be important to provide an indication of how easy it will be to recover the materials and how economically desirable. A detailed value in use assessment is required.

The key elements to a successful outcome will be the capture of material composition, morphology, ground structure, topography and stratigraphy data.

Because of the large site area, prior knowledge of the iron and steelmaking sites is vital to identifying those sites containing beneficially recoverable material to reduce the investigative effort.
Knowledge on the physio-chemical processes of material recovery is key to understanding the relevancy of site excavation data. This knowledge will be obtained as part of the Regeneratis project by the Materials Processing Institute and its partners.

A multi-phased environmental risk assessment is required that requires integration with the site overall assessment strategy. This is managed using the Model Procedures for the Management of Land Contamination [19]. The process of managing land contamination is shown in Fig. 13.



Note: The process may apply to one or more pollutant linkages each of which may follow a different route. For some linkages, it may be possible to stop at an early stage – others will progress all the way through the process. The level of complexity of each stage may also vary and in some cases may be very simple.

FIG. 13: THE PROCESS OF MANAGING LAND CONTAMINATION

7.3 RECOMMENDATIONS

There are many approaches undertaken to ensure a successful outcome of environmental regeneration projects. Many environmental assessment companies adopt in-house procedures that are part of a quality management system that can be audited against using recognised quality audit standards e.g. ISO9001 and ISO14001.

One approach is to use a flow chart to capture all the processes of the procedures. This is particularly useful for communicating the principles to a wide audience and shows how the various elements of the process relate to individuals. It is also good at specifying the decision points and the acceptance criteria on which decisions are based. It should be considered as a working document and will evolve in time as the project develops.

At present there is only limited knowledge of the pathways by which by-products and wastes were distributed. Further work is required to refine the material inventory calculations to include materials exported from site e.g. shipping records.

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APPENDIX A

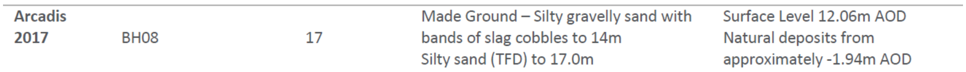
BRITISH GEOLOGICAL SURVEY EXCAVATION DATA

Reference	BH ID and Location	Depth (m bgl)	Ground Conditions (all depths m below ground level)	Elevation
BGS	Borehole NZ52SW315 (1967)Adjacent to northern boundary	10	Slag fill to 3.30m Silty sand (TFD) to 4.6m Firm silty clay (GL) to 5.8m Stiff gravelly clay (GT) to 10.05m Mercia Mudstone	Surface level 3.3m AOD Natural deposits from approximately 0.0m AOD
	Borehole NZ52SE13551/241 South east corner	4.6	Slag fill to 0.9m Gravel to 1.2m Very stiff Stony Clay (GT) to 4.6m	Not available
	4AB1 – See Figure 5	6.5	Slag fill – very sandy gravel to 3m Slag fill – very gravelly cobbles to 5.9m (oily) Made Ground – soft slightly gravelly clay to 6.5m (hydrocarbon odour), potentially natural.	Surface Level 7.1m AOD Potential natural deposits from approximately 1.6m AOD
	4AB2 – See Figure 5	6.5	Slag fill – clayey sandy gravel to 2m No recovery 2.0-4.0m Slag Fill – silty sandy gravel to 4.8m (hydrocarbon odour) Firm slightly gravelly clay to 6.5	Surface Level 4.82m AOD Natural deposits from approximately 0.02m AOD
	4AB3 – See Figure 5	7.1	Slag fill – clayey sandy gravel to 1.1m Slightly gravelly clay to 2.0m (hydrocarbon / solvent odour) Made Ground- soft blue/grey/brown clay to 6.3m (solvent odour) Soft brown clay to 7.1	Surface Level 7.17m AOD Natural deposits from approximately 0.87m AOD
	4AB4 – See Figure 5	6.7	Slag fill – clayey sandy gravel to 4.6m Stiff brown sandy gravelly clay to 6.7m	Surface Level6.64m AOD Natural deposits from approximately 2.04m AOD
	Trial pit 4AT3– See Figure 5	4	Slag fill of cobbles and boulders in a brown granular matrix including refractory bricks rubble and wood	Not available
	Trial pit 4AT4– See Figure 5	3.2	Slag Fill - Cobbles of slag in a grey slag dust to 0.8 Slag fill - Gravel cobbles and boulders in a brown clayey sand to 2.5 Slag Fill – Cobbles of slag in a very sandy clay matrix to 3.0m (hydrocarbon product) Made Ground – sandy clay with frequent organic peat to 3.2m (hydrocarbon odour)	Not available

APPENDIX B

ARCADIS 2018 EXCAVATION DATA

Borehole Made Ground Data

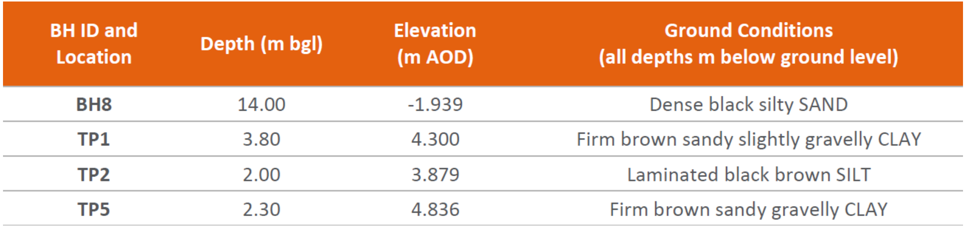


Arcadis 2017	BH08	17	Made Ground – Silty gravelly sand with bands of slag cobbles to 14m Silty sand (TFD) to 17.0m	Surface Level 12.06m AOD Natural deposits from approximately -1.94m AOD

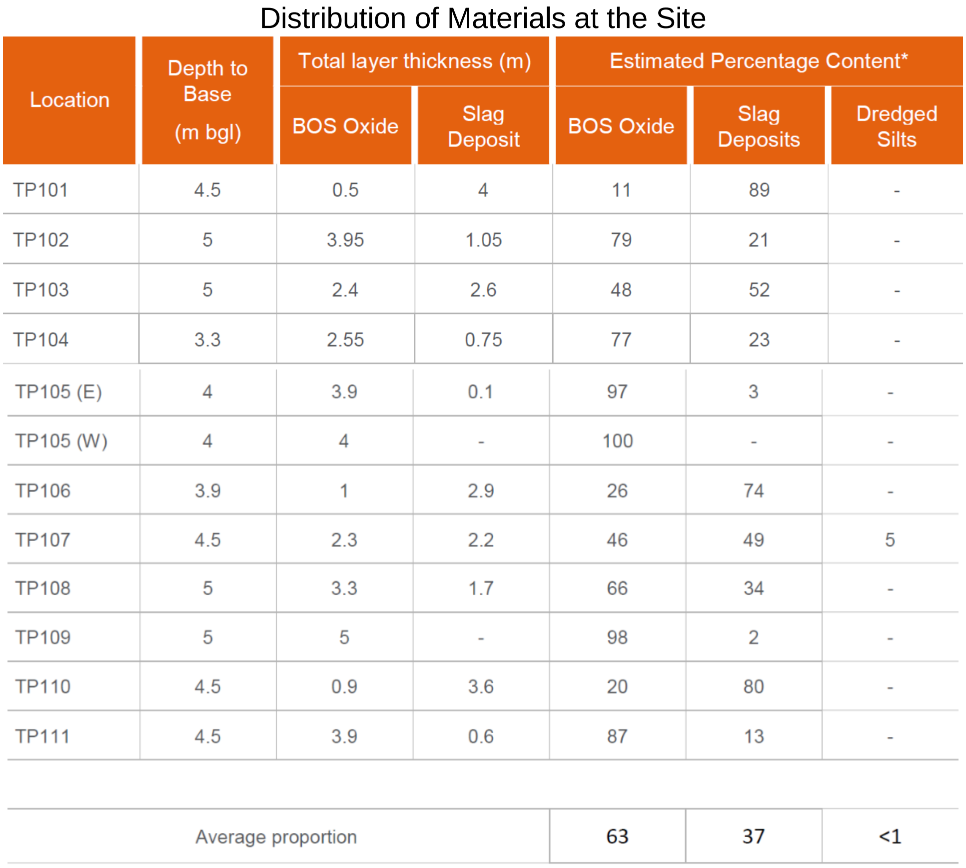
Trial Pit Made Ground Data

Variation	Locations
BOS Oxide Silt locally fused to a stiff to friable consistency.	TP106 (0.0m-0.3m bgl) TP108 (0.0m 1.4m bgl) TP109 (0.0m-5.0m bgl) TP110 (0.0m-0.9m bgl)
BOS Oxide Silt fused to extremely weak to very weak rock consistency.	TP102 3.4m-5.0m bgl TP104 (2.5m-3.3m bgl) TP108 (3.1m-3.7m bgl) TP106 (2.4m-3.1m bgl)
BOS Oxide Silt oxidised to dark reddish brown	TP104 (2.5m-3.3m bgl)
BOS Oxide Silt has light blue colour	TP105 (E) (0.1m-1.45m bgl)
BOS Oxide Silt oxidised to red to orange.	TP105 (W) (0.0m-5.0m bgl) Anecdotal information indicates this location was the site of a historical ground fire.
Mixed BOS Oxide and Slag	TP109 (3.8m-5.0m bgl) TP111 (1.6m-4.5m bgl)

Natural Geology Data



BH ID and Location	Depth (m bgl)	Elevation (m AOD)	Ground Conditions (all depths m below ground level)
BH8	14.00	-1.939	Dense black silty SAND
TP1	3.80	4.300	Firm brown sandy slightly gravelly CLAY
TP2	2.00	3.879	Laminated black brown SILT
TP5	2.30	4.836	Firm brown sandy gravelly CLAY



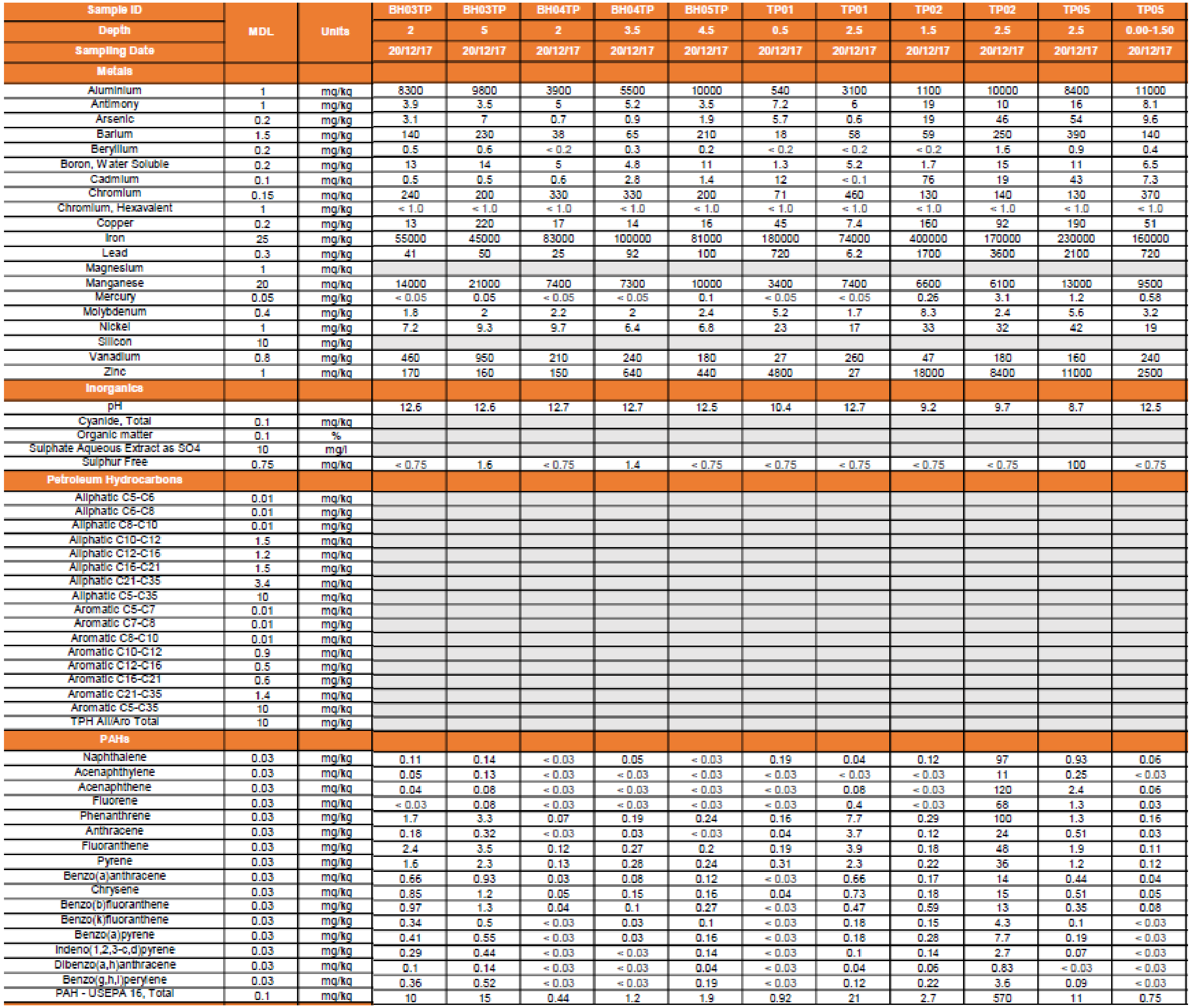
Distribution of Materials at the Site

Location	Depth to Base (m bgl)	Total layer thickness (m)		Estimated Percentage Content*		
		BOS Oxide	Slag Deposit	BOS Oxide	Slag Deposits	Dredged Silts
TP101	4.5	0.5	4	11	89	-
TP102	5	3.95	1.05	79	21	-
TP103	5	2.4	2.6	48	52	-
TP104	3.3	2.55	0.75	77	23	-
TP105 (E)	4	3.9	0.1	97	3	-
TP105 (W)	4	4	-	100	-	-
TP106	3.9	1	2.9	26	74	-
TP107	4.5	2.3	2.2	46	49	5
TP108	5	3.3	1.7	66	34	-
TP109	5	5	-	98	2	-
TP110	4.5	0.9	3.6	20	80	-
TP111	4.5	3.9	0.6	87	13	-
Average proportion				63	37	<1

APPENDIX C

CHEMICAL ANALYSIS ARCADIS 2018 EXCAVATIONS

Sample ID	MDL	Units	TP101	TP102	TP103	TP104	TP105	TP106	TP107	TP108	TP109	TP110
Depth			2	2.5	1	1	3	2.5	1	5	3.8	4.5
Sampling Date			28/03/18	28/03/18	28/03/18	27/03/18	28/03/18	27/03/18	28/03/18	27/03/18	27/03/18	28/03/18
Metals												
Aluminium	1	mg/kg	14000	8400	2900	2100	1800	6200	1800	8200	920	6400
Antimony	1	mg/kg	6.1	4.6	15	15	14	6.7	13	11	14	9.2
Arsenic	0.2	mg/kg	2	6.6	7.8	14	11	28	11	43	13	2.1
Barium	1.5	mg/kg	460	120	86	68	50	120	51	72	44	110
Beryllium	0.2	mg/kg	0.6	1	< 0.2	< 0.2	< 0.2	0.7	< 0.2	0.9	< 0.2	< 0.2
Boron, Water Soluble	0.2	mg/kg	0.9	7	0.9	1.6	2.6	1.6	1.2	6	2.9	3.2
Cadmium	0.1	mg/kg	0.4	26	25	94	58	28	31	75	37	3.1
Chromium	0.15	mg/kg	390	40	110	120	140	40	130	34	170	610
Chromium, Hexavalent	1	mg/kg	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Copper	0.2	mg/kg	20	20	94	140	170	42	130	26	160	22
Iron	25	mg/kg	130000	270000	470000	21000	620000	220000	520000	240000	560000	200000
Lead	0.3	mg/kg	36	1500	1000	1600	1200	2500	1100	3100	830	93
Magnesium	1	mg/kg	31000	11000	5300	4700	4900	6500	4600	7300	6700	31000
Manganese	20	mg/kg	33000	1200	5900	4500	6600	830	5800	1600	9300	18000
Mercury	0.05	mg/kg	< 0.05	0.42	0.13	0.35	0.1	0.54	0.15	0.29	0.1	< 0.05
Molybdenum	0.4	mg/kg	3	1.4	5.7	6.3	11	3.9	9	2.7	6.8	4.6
Nickel	1	mg/kg	8.8	23	34	27	54	23	47	44	46	60
Silicon	10	mg/kg	30000	36000	22000	500000	9200	25000	12000	34000	3200	45000
Vanadium	0.8	mg/kg	400	46	61	51	60	33	56	55	250	530
Zinc	1	mg/kg	190	9300	8700	21000	5500	17000	5800	23000	3800	440
Inorganics												
pH			12.6	8.5	9.2	9.1	10.6	8.4	9.3	8.6	9.6	12.6
Cyanide, Total	0.1	mg/kg	0.2	75	2	3.1	< 0.1	140	1.5	10	5	0.5
Organic matter	0.1	%	0.7	5.2	5.2	4.4	1	8.3	4.3	4.6	5	1.5
Sulphate Aqueous Extract as SO4	10	mg/l	15	1100	860	310	650	400	290	720	440	17
Sulphur Free	0.75	mg/kg										
Petroleum Hydrocarbons												
Aliphatic C5-C6	0.01	mg/kg	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.10	< 0.01
Aliphatic C6-C8	0.01	mg/kg	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.10	< 0.01
Aliphatic C8-C10	0.01	mg/kg	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.11	< 0.01	< 0.01	0.26	< 0.01
Aliphatic C10-C12	1.5	mg/kg	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5
Aliphatic C12-C16	1.2	mg/kg	< 1.2	< 1.2	< 1.2	< 1.2	< 1.2	< 1.2	< 1.2	< 1.2	< 1.2	2.7
Aliphatic C16-C21	1.5	mg/kg	2.2	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	5.6
Aliphatic C21-C35	3.4	mg/kg	14	< 3.4	< 3.4	< 3.4	< 3.4	58	< 3.4	< 3.4	< 3.4	29
Aliphatic C5-C35	10	mg/kg	17	< 10	< 10	< 10	< 10	59	< 10	< 10	< 76.3	38
Aromatic C5-C7	0.01	mg/kg	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.10	< 0.01
Aromatic C7-C8	0.01	mg/kg	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.10	< 0.01
Aromatic C8-C10	0.01	mg/kg	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.10	< 0.01
Aromatic C10-C12	0.9	mg/kg	< 0.9	< 0.9	< 0.9	< 0.9	< 0.9	< 0.9	< 0.9	< 0.9	< 0.9	< 0.9
Aromatic C12-C16	0.5	mg/kg	< 0.5	< 0.5	< 0.5	1.6	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	9.8
Aromatic C16-C21	0.6	mg/kg	1.3	< 0.6	< 0.6	15	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	25
Aromatic C21-C35	1.4	mg/kg	5.7	< 1.4	< 1.4	52	< 1.4	< 1.4	< 1.4	< 1.4	< 1.4	80
Aromatic C5-C35	10	mg/kg	< 10	< 10	< 10	70	< 10	< 10	< 10	< 10	< 34.3	120
TPH Ali/Aro Total	10	mg/kg	25	< 10	< 10	70	< 10	59	< 10	< 10	110	150
PAHs												
Naphthalene	0.03	mg/kg	< 0.03	0.22	0.07	0.17	< 0.03	0.37	< 0.03	0.39	1.4	< 0.03
Acenaphthylene	0.03	mg/kg	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.07
Acenaphthene	0.03	mg/kg	< 0.03	0.1	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	1.1	0.51
Fluorene	0.03	mg/kg	< 0.03	0.38	< 0.03	< 0.03	< 0.03	0.11	< 0.03	0.13	0.38	0.22
Phenanthrene	0.03	mg/kg	0.13	1.3	0.16	0.2	< 0.03	0.55	0.05	0.59	0.36	0.97
Anthracene	0.03	mg/kg	< 0.03	0.12	< 0.03	0.06	< 0.03	< 0.03	< 0.03	< 0.03	0.06	0.15
Fluoranthene	0.03	mg/kg	0.14	0.37	0.11	0.15	< 0.03	0.14	0.05	0.14	0.23	1.3
Pyrene	0.03	mg/kg	0.1	0.44	0.16	0.19	< 0.03	0.23	0.11	0.24	0.21	1.2
Benzo(a)anthracene	0.03	mg/kg	0.04	< 0.03	< 0.03	0.08	< 0.03	< 0.03	< 0.03	< 0.03	0.06	0.48
Chrysene	0.03	mg/kg	0.05	< 0.03	< 0.03	0.14	< 0.03	< 0.03	< 0.03	< 0.03	0.11	0.54
Benzo(b)fluoranthene	0.03	mg/kg	0.03	< 0.03	< 0.03	0.06	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.59
Benzo(k)fluoranthene	0.03	mg/kg	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.21
Benzo(a)pyrene	0.03	mg/kg	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.41
Indeno(1,2,3-c,d)pyrene	0.03	mg/kg	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.29
Dibenzo(a,h)anthracene	0.03	mg/kg	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.04
Benzo(g,h,i)perylene	0.03	mg/kg	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.31
PAH - USEPA 16, Total	0.1	mg/kg	0.49	2.9	0.5	1.1	< 0.10	1.4	0.21	1.5	3.9	7.2



Sample ID	MDL	Units	BH03TP	BH03TP	BH04TP	BH04TP	BH05TP	TP01	TP01	TP02	TP02	TP05	TP05
Depth			2	5	2	3.5	4.5	0.5	2.5	1.5	2.5	2.5	0.00-1.50
Sampling Date			20/12/17	20/12/17	20/12/17	20/12/17	20/12/17	20/12/17	20/12/17	20/12/17	20/12/17	20/12/17	20/12/17
Metals													
Aluminium	1	mg/kg	8300	9800	3900	5500	10000	540	3100	1100	10000	8400	11000
Antimony	1	mg/kg	3.9	3.5	5	5.2	3.5	7.2	6	19	10	16	8.1
Arsenic	0.2	mg/kg	3.1	7	0.7	0.9	1.9	5.7	0.6	19	46	54	9.6
Barium	1.5	mg/kg	140	230	38	65	210	18	58	59	250	390	140
Beryllium	0.2	mg/kg	0.5	0.6	< 0.2	0.3	0.2	< 0.2	< 0.2	< 0.2	1.6	0.9	0.4
Boron, Water Soluble	0.2	mg/kg	13	14	5	4.8	11	1.3	5.2	1.7	15	11	6.5
Cadmium	0.1	mg/kg	0.5	0.5	0.6	2.8	1.4	12	< 0.1	76	19	43	7.3
Chromium	0.15	mg/kg	240	200	330	330	200	71	460	130	140	130	370
Chromium, Hexavalent	1	mg/kg	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Copper	0.2	mg/kg	13	220	17	14	16	45	7.4	160	92	190	51
Iron	25	mg/kg	55000	45000	83000	100000	81000	180000	74000	400000	170000	230000	160000
Lead	0.3	mg/kg	41	50	25	92	100	720	6.2	1700	3600	2100	720
Magnesium	1	mg/kg											
Manganese	20	mg/kg	14000	21000	7400	7300	10000	3400	7400	6600	6100	13000	9500
Mercury	0.05	mg/kg	< 0.05	0.05	< 0.05	< 0.05	0.1	< 0.05	< 0.05	0.26	3.1	1.2	0.58
Molybdenum	0.4	mg/kg	1.8	2	2.2	2	2.4	5.2	1.7	8.3	2.4	5.6	3.2
Nickel	1	mg/kg	7.2	9.3	9.7	6.4	6.8	23	17	33	32	42	19
Silicon	10	mg/kg											
Vanadium	0.8	mg/kg	460	950	210	240	180	27	260	47	180	160	240
Zinc	1	mg/kg	170	160	150	640	440	4800	27	18000	8400	11000	2500
Inorganics													
pH			12.6	12.6	12.7	12.7	12.5	10.4	12.7	9.2	9.7	8.7	12.5
Cyanide, Total	0.1	mg/kg											
Organic matter	0.1	%											
Sulphate Aqueous Extract as SO4	10	mg/l											
Sulphur Free	0.75	mg/kg	< 0.75	1.6	< 0.75	1.4	< 0.75	< 0.75	< 0.75	< 0.75	< 0.75	100	< 0.75
Petroleum Hydrocarbons													
Aliphatic C5-C6	0.01	mg/kg											
Aliphatic C6-C8	0.01	mg/kg											
Aliphatic C8-C10	0.01	mg/kg											
Aliphatic C10-C12	1.5	mg/kg											
Aliphatic C12-C16	1.2	mg/kg											
Aliphatic C16-C21	1.5	mg/kg											
Aliphatic C21-C35	3.4	mg/kg											
Aliphatic C5-C35	10	mg/kg											
Aromatic C5-C7	0.01	mg/kg											
Aromatic C7-C8	0.01	mg/kg											
Aromatic C8-C10	0.01	mg/kg											
Aromatic C10-C12	0.9	mg/kg											
Aromatic C12-C16	0.5	mg/kg											
Aromatic C16-C21	0.6	mg/kg											
Aromatic C21-C35	1.4	mg/kg											
Aromatic C5-C35	10	mg/kg											
TPH Ali/Aro Total	10	mg/kg											
PAHs													
Naphthalene	0.03	mg/kg	0.11	0.14	< 0.03	0.05	< 0.03	0.19	0.04	0.12	97	0.93	0.06
Acenaphthylene	0.03	mg/kg	0.05	0.13	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	11	0.25	< 0.03
Acenaphthene	0.03	mg/kg	0.04	0.08	< 0.03	< 0.03	< 0.03	< 0.03	0.08	< 0.03	120	2.4	0.06
Fluorene	0.03	mg/kg	< 0.03	0.08	< 0.03	< 0.03	< 0.03	< 0.03	0.4	< 0.03	68	1.3	0.03
Phenanthrene	0.03	mg/kg	1.7	3.3	0.07	0.19	0.24	0.16	7.7	0.29	100	1.3	0.16
Anthracene	0.03	mg/kg	0.18	0.32	< 0.03	0.03	< 0.03	0.04	3.7	0.12	24	0.51	0.03
Fluoranthene	0.03	mg/kg	2.4	3.5	0.12	0.27	0.2	0.19	3.9	0.18	48	1.9	0.11
Pyrene	0.03	mg/kg	1.6	2.3	0.13	0.28	0.24	0.31	2.3	0.22	36	1.2	0.12
Benzo(a)anthracene	0.03	mg/kg	0.66	0.93	0.03	0.08	0.12	< 0.03	0.66	0.17	14	0.44	0.04
Chrysene	0.03	mg/kg	0.85	1.2	0.05	0.15	0.16	0.04	0.73	0.18	15	0.51	0.05
Benzo(b)fluoranthene	0.03	mg/kg	0.97	1.3	0.04	0.1	0.27	< 0.03	0.47	0.59	13	0.35	0.08
Benzo(k)fluoranthene	0.03	mg/kg	0.34	0.5	< 0.03	0.03	0.1	< 0.03	0.18	0.15	4.3	0.1	< 0.03
Benzo(a)pyrene	0.03	mg/kg	0.41	0.55	< 0.03	0.03	0.16	< 0.03	0.18	0.28	7.7	0.19	< 0.03
Indeno(1,2,3-c,d)pyrene	0.03	mg/kg	0.29	0.44	< 0.03	< 0.03	0.14	< 0.03	0.1	0.14	2.7	0.07	< 0.03
Dibenzo(a,h)anthracene	0.03	mg/kg	0.1	0.14	< 0.03	< 0.03	0.04	< 0.03	0.04	0.06	0.83	< 0.03	< 0.03
Benzo(g,h,i)perylene	0.03	mg/kg	0.36	0.52	< 0.03	< 0.03	0.19	< 0.03	0.12	0.22	3.6	0.09	< 0.03
PAH - USEPA 16, Total	0.1	mg/kg	10	15	0.44	1.2	1.9	0.92	21	2.7	570	11	0.75

Sample ID	MDL	Units	BH01TP	BH01TP	BH04	BH05	BH05	BH06	BH06	BH06	BH09	BH09	BH09
Depth			1	2	1.2	1	4	1	2.5	5.5	2.2	5.4	8.2
Sampling Date			18/12/17	18/12/17	18/12/17	18/12/17	18/12/17	18/12/17	18/12/17	18/12/17	18/12/17	18/12/17	18/12/17
Metals													
Aluminium	1	mg/kg	9600	8000	1600	14000	16000	2000	6000	8600	14000	5500	11000
Antimony	1	mg/kg	8.1	6.8	14	1.5	5.4	15	8.5	7.3	5.6	6.1	6.1
Arsenic	0.2	mg/kg	3.7	15	13	8.6	1.3	13	1.6	7.7	2.9	3.7	4.6
Barium	1.5	mg/kg	290	170	110	250	130	62	91	230	800	180	350
Beryllium	0.2	mg/kg	0.4	0.4	< 0.2	1	0.4	< 0.2	< 0.2	0.6	0.8	0.5	0.7
Boron, Water Soluble	0.2	mg/kg	5.4	3.4	1.7	2.5	7.8	1.8	4.8	7.2	43	9	6.6
Cadmium	0.1	mg/kg	3.9	9.7	66	1.3	3.8	52	0.6	4.3	0.6	5.7	1.1
Chromium	0.15	mg/kg	530	200	100	33	320	120	640	320	420	340	450
Chromium, Hexavalent	1	mg/kg	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Copper	0.2	mg/kg	35	150	120	36	23	140	16	100	18	33	28
Iron	25	mg/kg	160000	130000	460000	55000	120000	450000	170000	170000	110000	160000	150000
Lead	0.3	mg/kg	140	920	1200	100	110	1200	17	210	28	400	64
Magnesium	1	mg/kg											
Manganese	20	mg/kg	18000	6800	3600	840	11000	7100	16000	17000	42000	22000	38000
Mercury	0.05	mg/kg	< 0.05	0.94	0.27	0.07	< 0.05	0.19	< 0.05	< 0.05	< 0.05	0.07	< 0.05
Molybdenum	0.4	mg/kg	4.4	8	5.4	1.2	2.6	8	2.9	5.9	2.6	3.1	2.7
Nickel	1	mg/kg	16	90	25	36	8.1	38	3.7	22	8.8	8.2	10
Silicon	10	mg/kg											
Vanadium	0.8	mg/kg	460	200	65	34	270	61	500	780	390	2800	3300
Zinc	1	mg/kg	1000	2400	17000	310	780	14000	110	1400	180	2300	280
Inorganics													
pH			12.4	11.9	10	9.2	12.6	9.7	12.6	12.5	12.6	12.5	12.5
Cyanide, Total	0.1	mg/kg		170									
Organic matter	0.1	%		13									
Sulphate Aqueous Extract as SO4	10	mg/l		740									
Sulphur Free	0.75	mg/kg	< 0.75	870	6.9	< 0.75	< 0.75	< 0.75	< 0.75	< 0.75	1.7	< 0.75	2.4
Petroleum Hydrocarbons													
Aliphatic C5-C6	0.01	mg/kg		< 0.01									
Aliphatic C6-C8	0.01	mg/kg		< 0.01									
Aliphatic C8-C10	0.01	mg/kg		2.2									
Aliphatic C10-C12	1.5	mg/kg		220									
Aliphatic C12-C16	1.2	mg/kg		1700									
Aliphatic C16-C21	1.5	mg/kg		4700									
Aliphatic C21-C35	3.4	mg/kg		22000									
Aliphatic C5-C35	10	mg/kg		28000									
Aromatic C5-C7	0.01	mg/kg		14									
Aromatic C7-C8	0.01	mg/kg		7.9									
Aromatic C8-C10	0.01	mg/kg		6.6									
Aromatic C10-C12	0.9	mg/kg		3400									
Aromatic C12-C16	0.5	mg/kg		12000									
Aromatic C16-C21	0.6	mg/kg		6200									
Aromatic C21-C35	1.4	mg/kg		11000									
Aromatic C5-C35	10	mg/kg		33000									
TPH Ali/Aro Total	10	mg/kg		61000									
PAHs													
Naphthalene	0.03	mg/kg	< 0.03	3600	0.06	0.05	< 0.03	0.07	0.03	35	< 0.03	< 0.03	< 0.03
Acenaphthylene	0.03	mg/kg	< 0.03	370	0.05	< 0.03	< 0.03	< 0.03	< 0.03	10	< 0.03	< 0.03	< 0.03
Acenaphthene	0.03	mg/kg	0.04	3400	0.06	0.05	< 0.03	< 0.03	< 0.03	1	< 0.03	< 0.03	0.07
Fluorene	0.03	mg/kg	< 0.03	2100	0.1	0.07	< 0.03	< 0.03	< 0.03	8.9	< 0.03	< 0.03	0.11
Phenanthrene	0.03	mg/kg	0.14	1300	0.16	0.06	0.07	0.12	0.04	28	< 0.03	< 0.03	0.54
Anthracene	0.03	mg/kg	0.03	330	0.04	< 0.03	< 0.03	< 0.03	< 0.03	6.4	< 0.03	< 0.03	0.06
Fluoranthene	0.03	mg/kg	0.19	570	0.27	< 0.03	0.04	0.1	0.12	18	0.03	< 0.03	0.51
Pyrene	0.03	mg/kg	0.17	400	0.24	< 0.03	0.07	0.19	0.11	14	0.03	0.03	0.36
Benzo(a)anthracene	0.03	mg/kg	0.09	180	0.12	< 0.03	< 0.03	0.04	0.04	5.2	< 0.03	< 0.03	0.15
Chrysene	0.03	mg/kg	0.11	160	0.39	< 0.03	< 0.03	0.05	0.04	4.8	< 0.03	< 0.03	0.16
Benzo(b)fluoranthene	0.03	mg/kg	0.1	200	0.06	< 0.03	< 0.03	0.04	0.04	4.9	< 0.03	< 0.03	0.15
Benzo(k)fluoranthene	0.03	mg/kg	0.03	78	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	1.8	< 0.03	< 0.03	0.05
Benzo(a)pyrene	0.03	mg/kg	0.04	150	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	3.7	< 0.03	< 0.03	0.06
Indeno(1,2,3-c,d)pyrene	0.03	mg/kg	0.06	83	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	1.7	< 0.03	< 0.03	0.05
Dibenzo(a,h)anthracene	0.03	mg/kg	< 0.03	20	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.57	< 0.03	< 0.03	< 0.03
Benzo(g,h,i)perylene	0.03	mg/kg	0.08	110	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	2.1	< 0.03	< 0.03	0.06
PAH - USEPA 16, Total	0.1	mg/kg	1.1	13000	1.5	0.23	0.18	0.61	0.43	150	< 0.10	< 0.10	2.4

Sample ID	MDL	Units	TP03	TP04	TP04	BH01 (TP)	BH08	BH08	BH08	BH08	BH08	BH08
Depth			1	3	1.00-2.00	1.5	8	12	15	1	3	5
Sampling Date			18/12/17	18/12/17	18/12/17	18/12/17	06/12/17	13/12/17	13/12/17	30/11/17	01/12/17	01/12/17
Metals												
Aluminium	1	mg/kg	5500	790	1700		2200	6100	4900	2400	1400	890
Antimony	1	mg/kg	9.1	13	20		17	5.7	11	19	20	19
Arsenic	0.2	mg/kg	43	7.6	17	3.9	9.9	9.8	17	16	14	12
Barium	1.5	mg/kg	240	50	140		85	120	120	110	120	72
Beryllium	0.2	mg/kg	0.8	< 0.2	< 0.2		< 0.2	0.7	0.4	0.2	< 0.2	< 0.2
Boron, Water Soluble	0.2	mg/kg	2	1.2	1	5.7	2.3	2.9	2.9	1.1	1.1	1
Cadmium	0.1	mg/kg	87	21	73	3.7	34	25	27	47	48	29
Chromium	0.15	mg/kg	28	110	110	190	170	48	74	88	91	120
Chromium, Hexavalent	1	mg/kg	< 1.0	< 1.0	< 1.0		< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Copper	0.2	mg/kg	23	160	150	50	170	26	75	99	110	160
Iron	25	mg/kg	210000	420000	510000		420000	200000	280000	290000	440000	480000
Lead	0.3	mg/kg	7900	1700	1600	270	1800	2500	2400	1400	1200	1800
Magnesium	1	mg/kg										
Manganese	20	mg/kg	780	5200	4200		8000	1200	2500	3900	5600	8900
Mercury	0.05	mg/kg	1.4	0.1	0.19	0.15	0.07	0.28	0.24	0.19	0.13	0.15
Molybdenum	0.4	mg/kg	2.1	7.9	5.1		7.2	1.6	4.3	5.1	4.9	6.8
Nickel	1	mg/kg	22	39	27	38	42	18	26	23	23	43
Silicon	10	mg/kg										
Vanadium	0.8	mg/kg	58	75	47		140	43	53	49	48	49
Zinc	1	mg/kg	33000	8900	37000	960	11000	10000	12000	14000	22000	11000
Inorganics							11	10.3	10.3	9.1	9.5	9.6
pH			6.9	10.2	9.1	11.8						
Cyanide, Total	0.1	mg/kg				47						
Organic matter	0.1	%				3.7						
Sulphate Aqueous Extract as SO4	10	mg/l				110						
Sulphur Free	0.75	mg/kg	220	< 0.75	3		< 0.75	36	28	1.6	1	< 0.75
Petroleum Hydrocarbons												
Aliphatic C5-C6	0.01	mg/kg				< 0.01						
Aliphatic C6-C8	0.01	mg/kg				0.15						
Aliphatic C8-C10	0.01	mg/kg				1.1						
Aliphatic C10-C12	1.5	mg/kg				< 50.0						
Aliphatic C12-C16	1.2	mg/kg				380						
Aliphatic C16-C21	1.5	mg/kg				1100						
Aliphatic C21-C35	3.4	mg/kg				6200						
Aliphatic C5-C35	10	mg/kg				7700						
Aromatic C5-C7	0.01	mg/kg				4						
Aromatic C7-C8	0.01	mg/kg				3.8						
Aromatic C8-C10	0.01	mg/kg				4.1						
Aromatic C10-C12	0.9	mg/kg				460						
Aromatic C12-C16	0.5	mg/kg				1800						
Aromatic C16-C21	0.6	mg/kg				1300						
Aromatic C21-C35	1.4	mg/kg				2600						
Aromatic C5-C35	10	mg/kg				6200						
TPH Ali/Aro Total	10	mg/kg				14000						
PAHs												
Naphthalene	0.03	mg/kg	4.1	0.03	0.04	410	< 0.03	0.1	0.13	0.06	0.04	< 0.03
Acenaphthylene	0.03	mg/kg	0.07	< 0.03	< 0.03	62	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Acenaphthene	0.03	mg/kg	0.66	< 0.03	< 0.03	560	< 0.03	< 0.03	0.05	< 0.03	< 0.03	< 0.03
Fluorene	0.03	mg/kg	1.2	< 0.03	< 0.03	330	< 0.03	0.09	0.16	< 0.03	< 0.03	< 0.03
Phenanthrene	0.03	mg/kg	3.4	0.06	0.1	230	0.08	0.21	0.37	0.27	0.19	< 0.03
Anthracene	0.03	mg/kg	0.41	< 0.03	< 0.03	64	< 0.03	< 0.03	0.05	< 0.03	< 0.03	< 0.03
Fluoranthene	0.03	mg/kg	1.4	0.06	0.07	150	0.08	0.05	0.14	0.31	0.19	< 0.03
Pyrene	0.03	mg/kg	2.8	0.06	0.09	120	0.1	0.14	0.35	0.24	0.18	< 0.03
Benzo(a)anthracene	0.03	mg/kg	0.06	< 0.03	< 0.03	46	< 0.03	< 0.03	< 0.03	0.04	0.04	< 0.03
Chrysene	0.03	mg/kg	0.17	< 0.03	< 0.03	38	0.05	< 0.03	< 0.03	0.09	0.09	< 0.03
Benzo(b)fluoranthene	0.03	mg/kg	0.04	< 0.03	< 0.03	52	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Benzo(k)fluoranthene	0.03	mg/kg	< 0.03	< 0.03	< 0.03	20	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Benzo(a)pyrene	0.03	mg/kg	< 0.03	< 0.03	< 0.03	42	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Indeno(1,2,3-c,d)pyrene	0.03	mg/kg	< 0.03	< 0.03	< 0.03	20	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Dibenzo(a,h)anthracene	0.03	mg/kg	< 0.03	< 0.03	< 0.03	5.1	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Benzo(g,h,i)perylene	0.03	mg/kg	< 0.03	< 0.03	< 0.03	24	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
PAH - USEPA 16, Total	0.1	mg/kg	14	0.18	0.31	2200	0.31	0.6	1.3	1	0.72	< 0.10

APPENDIX D

SLEMS BOS OXIDE VOLUME ESTIMATE DATA

Location	Consultant	Year	Elevation (m AOD)	Made Ground Interface (m AOD)
BH 4 AB1	Environ	2004	7.10	Not recorded
BH 4AB2	Environ	2004	4.82	0.02
BH 4AB3	Environ	2004	7.17	0.87
BH 4AB4	Environ	2004	6.64	2.04
NZ52SW315 (off site to north)	BGS	1967	3.28	0
BH08	Arcadis	2017	12.06	-1.939
TP01	Arcadis	2017	8.1	4.3
TP02	Arcadis	2017	5.879	3.879
TP05	Arcadis	2017	7.136	4.836