8.1.1 Drift (Superficial Deposits)

Till is a variable deposit of boulder clay and morainic drift. The principal lithology is unsorted stones of gravel, cobble and boulder within a silty clay matrix; however, in places lenses and more continuous bands of stratified sand and gravel are anticipated to be present. These predominantly granular lenses can act as localised perched aquifers however the main hydrogeological significance of till deposits is in limiting recharge to, and confining water within, underlying formations.

8.1.2 Solid (Bedrock)

The coal measures likely to be encountered beneath the site comprise rhythmic sequences of mudstones, siltstones, sandstones, grits, fireclays and coals. The South Wales Upper Coal Measures Formation (not shown to be present beneath the site) is known to contain large quantities of groundwater and form a multi-layered aquifer system with separate water bodies found within each sandstone horizon. The Middle and Lower Coal Measures (shown to be present beneath the site) tend to have lower porosities than the overlying Upper Measures with the highest values of porosity occurring in areas of intensive folding and faulting. However, the extensive disturbance and subsidence caused by mining in the South Wales region has resulted in hydraulic conductivity between the sandstone horizons comprising the South Wales Upper Coal Measures Formation and, locally, hydraulic conductivity exists between the Upper and Middle/Lower Coal Measures Formations.

The groundwater within the Middle and Lower Measures tends to contribute towards baseflow of rivers and usually emerges as springs at the bases of the subordinate sandstones. Groundwater yields from the Middle and Lower Coal Measures rarely exceeds 1l/s.

8.2 Aquifer Designations

The aquifer designations of the various geological strata identified to be present beneath the site have been ascertained through review of the Groundsure EnviroInsight report (refer to Appendix E).

The glacial till deposits shown to be present in the southern and western portion of the site are designated as a ‘Secondary Aquifer’. A ‘Secondary Aquifer’ designation is attributed to a stratum where it has not been possible to differentiate between a ‘Secondary (A)’ or ‘Secondary (B)’ designation. A ‘Secondary (A) Aquifer’ refers to a stratum defined as *“permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers”*. Whereas, a ‘Secondary (B) Aquifer’ refers to a stratum defined as *“predominantly lower permeability layers which may store and yield amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering”*. As identified on the hydrogeological mapping, granular lenses of sands and gravels within glacial till deposits can occasionally act as aquifers however, due to the cohesive nature of clays that are typical of glacial till, till deposits predominantly limit recharge to

and confine groundwater within underlying permeable stratum. It is therefore unlikely that the glacial till deposits located to the south of the site will form part of a large aquifer.

The deposits of peat shown to be present within the site are designated as 'unproductive strata'. Unproductive strata are defined as *"rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow"*.

The South Wales Coal Measures Formations (both Middle and Lower) shown to be present beneath the entirety of the site are both designated as 'Secondary (A) Aquifers' which are as defined above.

No principal aquifers are located beneath the site.

8.2.1 Abstraction Licenses

From review of the Groundsure EnviroInsight report, a singular groundwater abstraction license pertaining to a groundwater abstraction point ~800m to the northeast of the north-eastern boundary site is present. According to the date within the Groundsure report, this groundwater abstraction license is no longer active and the water abstracted was used for 'General Farming and Domestic' purposes.

However, it should be noted that opencast dewatering operations are known to be in operation which will be artificially lowering the groundwater level in the vicinity of the Nant Helen Extension opencast site.

A total of eight surface water abstraction licenses are held within a 700m radius of the northern boundary of the site. Six of these licenses pertain to abstraction points along the River Tawe or unnamed tributaries of the Tawe and are all designated as 'historical' suggesting that the licenses are no longer in effect. The remaining two surface water abstraction licenses pertain to two abstraction points from a reservoir at Gwaunclawdd Farm (not covered on the figures). These are also noted as 'historical' which suggest the licenses are no longer in effect.

8.3 Groundwater Levels

The groundwater levels beneath the site have been interpreted through review of ground investigation logs held by the BGS and through review of documents provided by Celtic Energy. It should be noted that the groundwater data presented on the logs held by the BGS is limited in nature and only pertains to the washery portion of the site.

Groundwater remarks presented on the BGS logs reviewed suggests that the groundwater level within the washery portion of the site sits between 3.45m and 7.2m below ground level. Shallower strikes and slight seepages were also noted as shallow as 1.0m bgl.

No indication of groundwater strikes were provided on the logs reviewed within the main body of the site. However, within the Environmental Statement submitted for the expansion of the Nant Helen Extension opencast site in 2011,

details regarding groundwater levels in the locale of the opencast area were provided (refer to Appendix H). It should be noted that these boreholes were not located within the boundary of the site.

Extensive exploratory drilling was undertaken by British Coal in the late 1990s in the location of the Nant Helen Extension opencast. It should be noted that these boreholes are located to the west of the western site boundary and do not pertain to the site directly. The boreholes were progressed through the known workings within the "Nine Feet" and "Brass" seams and the water levels within each were recorded. The groundwater level within these workings was recorded to be standing at approximately 126m AOD beneath the easternmost extent of the Nant Helen Extension opencast site and approximately 100m AOD at the westernmost extend of the Nant Helen Extension opencast site (refer to Appendix H). Based on current LiDAR elevation data, this would put the groundwater level between ~170m below current ground level (east) and ~50m below current ground level (west); the disparity in these levels is due to the existing Nant Helen Extension void in the west and the overburden storage area to the east.

These levels are corroborated by two piezometers which were also installed by British Coal during the ground investigation in the 1990s. These piezometers indicate that the groundwater level to the west of the Nant Helen Extension site was between 109m AOD and 99m AOD (refer to Appendix H).

Through consultation with Celtic Energy, it has been determined that current dewatering operations within the Nant Helen Extension opencast site aims to maintain the water levels at approximately 100m AOD. As highlighted in the Environmental Statement for the Nant Helen Extension opencast, the lowest projected level of excavation within the Nine Feet seam could be as low as 76m AOD (refer to Appendix H). As dewatering would be required to reach this depth, it is likely that the groundwater level would be locally reduced to a similar level. Post completion of opencast excavation in the area it is possible that the groundwater levels will re-bound to a similar level that was encountered within the boreholes progressed during the British Coal ground investigation in the 1990s (between ~100m AOD and ~120m AOD).

In addition, there are numerous adits that allowed access to workings within the Nine Feet and Brass seams to the west of the site. The lowest of which, the Cwm Du adit, underdrains the opencast workings within the Nant Helen Extension site. The Cwm Du adit has an invert level of 93.6m AOD where it discharges to the River Tawe (refer to Appendix H).

The hydrogeological regime beneath the site is anticipated to be complex and highly varied across the site. As highlighted in the 2011 Environmental Statement, there is evidence that the Nant Helen Extension site is under-drained by existing adits. This is likely to also be the case for the other areas of opencast working which have excavated through underground workings in the past; the groundwater levels within these regions is likely to be heavily dependent on the outflow capacity of the adits and secondary permeability of the underlying bedrock. In order to gain an appreciation for the groundwater levels in the various areas of opencast, identification of the likely under-draining adits (potentially through review of a comprehensive set of mine abandonment plans and/or a future site

visit) coupled with deep intrusive ground investigation including subsequent groundwater monitoring would likely be required.

It should also be noted that there are numerous surface water features that appear to originate within the site, particularly in the southern half. The levels (~250m AOD) of the ponds and the headwaters of the streams are unlikely to represent an overall piezometric surface for the site and instead are likely to represent locally perched groundwater controlled by areas of geology with low permeability (e.g. shallow impermeable bedrock or cohesive superficial deposits (both natural and made ground)).

9 Coal Mining

The entirety of the proposed site is situated within a Coal Authority 'Development High Risk Area'. A 'Development High Risk Area' is defined as an *"area which contains one or more recorded coal mining related features which have the potential for instability or a degree of risk to the surface from the legacy of coal mining operations"* [8]. These *"features"* typically include mine entries (shafts and adits) and shallow coal workings (recorded and probable).

New development in areas defined as high risk needs to demonstrate that the development will be safe and stable taking due account of former coal mining activities. This section of the report aims to highlight the particular features and constraints associated with mining activities in the area and identify 'risk zones' along the proposed route where the risk of subsidence on account of shallow workings is considered greatest. The features and risk zones are marked on Figures 8 and 9 which should be referred to throughout.

The sources reviewed during the preparation of this report are presented in Section 2 above; however, with regards to the information presented in this section of the report it should be noted that the basis of many of the findings is sourced from primary data sources such as BGS geological plans (various scale ranges), historical mapping sets and historical aerial imagery. The findings presented within the primary data sources have then been supplemented with data from secondary sources such as Coal Authority data and records provided by Celtic Energy.

9.1 Outcrops

As identified in the Published Geology section above, the site is primarily underlain by South Wales Middle and Lower Coal Measures Formations. Numerous coal seam outcrops associated with the aforementioned formations, both observed and inferred, have been identified from review of BGS published geological sources (refer to Figure 6). It should be noted that there is a discrepancy between the seam outcrops shown on the BGS published geological mapping and the seam outcrops shown on the Coal Authority online viewer. As the BGS published geological mapping is considered to be the primary data source, the locations of the seam outcrops shown on the BGS published geological mapping have been assumed to take precedence within this report.

The site is roughly split in half by the Pwllau Bach Fault along a north to south centrally located axis. Significant outcropping of seams within the South Wales Middle Coal Measure Formation is shown to the west of the Pwllau Bach Fault on the published geological mapping sources. The "Soap" seam is shown to outcrop along an east to west alignment from the Pwllau Bach Fault in the east to the site boundary in the west. Moving down through the Middle Coal Measures sequence, with the outcrops progressing northwards, and following a similar alignment, are shown for the "Stwrin", "Rock", "Little", "Four Feet", "Nine Feet" and "Brass" seams. To the north of the "Brass" seam the outcrop of the Amman Marine Band is shown to be located which marks the boundary between the Middle and Lower Coal Measures Formations. No outcrops are shown in the southern portion of the site to the west of the Pwllau Bach Fault. This is likely due to the dip of the solid geology (5° – 15°, WSW – SW) shown on the 1:10,560 geological mapping and the similar dip of the topography also towards the southwest.

Between the Pwllau Bach Fault and the Chapel Fault, the observed and partially inferred outcrops of the "Nine Feet" and "Brass" seams are shown on the published geological mapping reviewed. The outcrops of both are shown to follow a north to south alignment before turning 90° to run along an east to west alignment. To the south of the site within the bounds of the Pwllau Bach and Chapel faults, the inferred and partially observed outcrops of the "Cornish", "Lower Eighteen Feet" and "Stwrin" are shown to be present.

To the east of the Chapel fault (downthrow to the east) the "Nine Feet" and "Brass" seam outcrops are once again shown to be present within the site boundary. The alignments of both are shown as observed and are believed to have been mapped during the opencast mining activity located in the eastern half of the main portion of the site. The outcrops of the "Cornish" and "Stwrin" seams are shown to be located to the south of the site; the "Lower Eighteen Feet" outcrop is not shown to the east of the Chapel fault and instead the outcrops of the "Lower Four Feet" and "White Four Feet" seams are shown to be located between the outcrops of the "Cornish" (north) and "Stwrin" (south).

To the north of the Chapel fault in the north-eastern corner of the main portion of the site, the outcrops of the "Upper Bluers", "Middle", "Lower" and "Bryn" seams are shown to be present situated along an east to west alignment. An anticlinal axis is shown to manipulate the alignment of the "Upper Bluers" seam outcrop. All of these outcrops refer to seams located within the South Wales Lower Coal Measures Formation.

To the east of the Glyncorrwg Fault the inferred outcrops of the "Upper Bluers", "Grey" and "New" coal seams are shown to be present beneath the washery portion of the site. These inferred outcrops are shown to be situated along an approximate southeast to northwest alignment.

Through review of the BGS geological memoir for the site area (Sheet Memoir 231) and the Nant Helen old workings file provided by Celtic Energy, the anticipated sequencing of the seams within each formation has been determined and is presented in Table 3 below. In addition, from review of the various sources, inconsistency regarding naming of the various seams has been noted and so the other names (and deviations of the same seam, e.g. "Four Feet" and "Lower Four

Feet") associated with each seam are also noted in Table 3. Typical seam sections have been identified through review of the Nant Helen old workings file provided by Celtic Energy.

Table 3 – Interpreted coal seam sequencing

Seam	Other names	Typical seam section
South Wales Middle Coal Measures		
Soap	Two Feet-Nine	-
Stwrin	Two Feet-Nine	-
Four Feet	Upper Four Feet, Lower Four Feet, White Four Feet, White, Stwrin	0.9m
Eighteen Feet	Lower Eighteen Feet, Six Feet, Black	-
Cornish	Red Vein, Two Feet	0.76m
Harnlo	-	-
Nine Feet	Big	2.7 – 3.0m
Brass	Bute, Peacock	0.9 – 1.4m
South Wales Lower Coal Measures		
Yard	Lower Peacock, Lower Brass	-
Bluers	Blewers, Upper Bluers, Lower Bluers, Seven Feet	0.6 – 0.85m
Rhyd	Five Feet, Little Brass	0.75m
Grey	Gellideg	0.66m
Middle	Gellideg	0.63m
New	Lower	0.69m
Bryn	Gnapiog	0.5m

9.2 Collieries

The following information for each of the identified collieries has been gathered from the Welsh Coal Mines website [9]. The information contained is not necessarily complete but identifies the seams worked by each colliery and provides information regarding years of operation. A short paragraph is provided on each colliery before the seams worked are listed; the seams are listed from shallowest to deepest based on published geological sequencing.

The approximate locations of each colliery are shown on Figure 4. The locations of the collieries have been determined through a review of historical mapping and photographic sources and not from information presented on the Welsh Coal Mines website.

Abercrave Colliery

The Abercrave Colliery was opened in 1872 and predominantly worked the "Eighteen Feet" seam and lower measures seams beneath the site. By 1923 the colliery was working the "Big Vein" (also known as "Nine Feet"), "Four Feet" and "Peacock" seams. The Abercrave Colliery was closed in 1967 [9].

Operational years: 1872 - 1967

Seams worked:
Middle Coal Measures
Four Feet
Eighteen Feet
Big (Nine Feet)
Peacock (Brass)

Lower Coal Measures
*Lower measures seams**

**no distinction between indivual seams within the Lower Coal Measures is provided in the source material.*

International Colliery

Records suggest that the International Colliery was opened in 1893 and was operated by the French Anthracite Company. The colliery is shown to have worked the "Four Feet", "Nine Feet", "Peacock" and "White" seams. The International Colliery was absorbed into the Abercrave Colliery in 1913 and both were eventually closed in 1967 [9].

Operational years: 1893 - 1913

Seams worked:
Middle Coal Measures
White (Four Feet)
Nine Feet
Peacock (Brass)

Gwaunclawdd Colliery

The Gwaunclawdd ("Gwaun Clawdd" or "Gwaun-y-clawdd") Colliery was opened in 1864 as an anthracite drift mine. The colliery produced anthracite from the "Big" (also known as "Nine Feet"), "Lower", "Brass" and "Four Feet" seams. The colliery was closed in 1938 [9]. From review of historical mapping sources, the Gwaunclawdd Colliery moved from its original site to a new site approximately 500m to the east between 1877 and 1903, refer to Figure 4.

Operational years: 1864 - 1938

Seams worked:
Middle Coal Measures
Four Feet
Big (Nine Feet)
Brass

Lower Coal Measures
Lower (Gellideg)

Onllwyn Colliery

Developed in the 1840's, the Onllwyn Colliery was originally a collection of drift mines situated in the upper Dulais valley working the "Big" (also known as "Nine Feet"), "Red Vein" and "Peacock" seams. Detail suggesting working of the "Brass", "Eighteen Feet", "White" and "Bluers" seams is also provided on the Welsh Coal Mines website. The various drift mines were closed between 1962 and 1964 [9].

Operational years: circa 1840 - 1964

Seams worked:
Middle Coal Measures
White (Four Feet)
Eighteen Feet
Red Vein
Big (Nine Feet)
Peacock (Brass)

Lower Coal Measures
Bluers

Dulais Colliery

The Dulais Colliery (also referred to as Drym Colliery) was originally an anthracite slant (drift) mine built along the Neath and Brecon Railway; the colliery was located to the west of the Onllwyn Colliery. In 1905 a shaft was sunk to work the "Bluers" seam within the Lower Coal Measures. In 1930 the Dulais Colliery was working the "Peacock" seam and in 1935 the workings included the "New" seam. The drift mines associated with the "New" and "Bluers" seams were abandoned in 1917 and the "Nine Feet" seam was abandoned in 1926 (Note: no details regarding the initiation of workings within the "Nine Feet" seam are provided). The Dulais Colliery was closed prior to Nationalisation in 1947 [9].

Operational years: circa 1905 – circa 1947

Seams worked:
Middle Coal Measures
Nine Feet
Peacock (Brass)

Lower Coal Measures
Bluers
New (Gellideg)

Hendre Ladis Colliery – Ynyscedwyn Colliery

Note, neither of these collieries are shown on Figure 4. The Hendre Ladis Colliery was located approximately 1km to the west of the western site boundary and the Ynyscedwyn Colliery (which absorbed the Hendre Ladis) was located approximately 1.4km to the west of the western site boundary.

The Hendre Ladis Colliery, circa 1840, originally comprised a singular steeply inclined drift mine owned by the Ynyscedwyn Iron Company. No details of seams worked, whilst under the name "Hendre Ladis", are provided. Towards the end of the 19th century the colliery was absorbed by the Ynyscedwyn Colliery. The

'Ynyscedwyn Slant' (drift mine) worked the "Big" (also known as "Nine Feet") and "Peacock" seams. The Ynyscedwyn Colliery was closed by the National Coal Board in 1967/8 [9].

Operational years: circa 1840 - 1968

Seams worked: Middle Coal Measures
Big (Nine Feet)
Peacock (Brass)

Seven Sisters Colliery

The first of two shafts at the Seven Sisters Colliery was sunk in 1872. The two shafts were sunk to the "Nine Feet" seam which was encountered 183m below surface level. A list from 1923 shows that the "Four Feet" and "Brass" seams were being worked alongside the "Nine Feet" seam. The Seven Sisters Colliery was closed in 1963/4 [9].

Operational years: 1872 - 1964

Seams worked: Middle Coal Measures
Four Feet
Nine Feet
Brass

Glynllech Colliery – Cwm Tawe Colliery

Although no records of the Glynllech/Cwm Tawe Colliery are presented on the Welsh Coal Mines website, from review of historical mapping sources (Groundsure OS) the colliery is shown to be present to the north of the main site. The colliery is first shown on the 1914 mapping and is absent on the 1948 mapping suggesting a short period of operation.

Based on the location of the Glynllech Colliery and interpretation of published geological mapping, the Glynllech Colliery is anticipated to have worked the "Bluers", "Middle" and "Lower" seams; all of which sit within the South Wales Lower Coal Measures Formation.

9.3 Mine Entries

Based on review of the Coal Authority online viewer a total of 95No. mine entries have been identified within the site boundary. Sixty-four of the entries, both shafts and adits, are shown to be located within the main portion of the site. Thirty-one mine entry locations are shown to be present within the "washery" portion of the site [8]. The majority of the entry locations within the main portion of the site have been plotted on Figure 8 based on review of opencast completion plans and abandonment plans provided by Celtic Energy. However, the entry locations within the washery site were not shown on the source material provided by Celtic Energy.

In the north-western portion of the site a total of 24No. mine entries have been identified; seven of these entries are shown to be shafts (no depths provided) and the remaining seventeen are shown to be adits [8]. Based on the location, these

entries are anticipated to have been associated with the Abercrave and International Collieries; it should be noted that these entries have most likely been excavated out during the opencast mining activities associated with the Abercrave/Gwaunton opencast site (1973) and are therefore are unlikely to still be present (refer to Figure 9).

In the north-eastern portion of the site a total of 28No. mine entries are shown to have been present; nine of the entries have been identified as shafts and the remaining nineteen entries pertain to adits. Of the nine shafts identified, depths for three of the shafts were provided and range between 5.5m and 9.15m. Based on review of historical mapping, these entries are likely to have been associated with the Glynllech/Cwm Tawe Colliery. Two of the adits shown are located within the extent of the Abercrave/Gwaunton opencast site and have likely been excavated out. However, the majority are shown to be located in an area that has not been opencast and are therefore both the shafts and associated mine workings are still potentially present. No details on any 'treatment' (e.g. backfilling) of the entries in this location are provided on the Coal Authority online viewer.

A total of 12No. mine entries were identified to be present within the south of the site. Six of these entries pertained to shafts with known depths ranging between 3.6m and 4.6m and the remaining six entries were shown to be adits. These entries are likely to be associated with the Dulais Colliery and based on review of abandonment plans, the entries accessed the "Nine Feet" and "Brass" workings.

The presence of coal seams at shallow depth beneath the ground surface (both in the north and south of the site) means that they could be worked by bell pitting. Bell pitting as a method of extraction was often prevalent in areas where mineral deposits that are near-surface and shafts rarely extended beyond 10-12m in depth. From review of historical aerial photography from 1945, surface depressions have been identified that could be the result of bell pitting activities, see Figure 12 below.

Figure 12 Extract from 1945 aerial photography showing potential 'bell pitting'

A total of 31No. mine entries were identified to be present within the washery portion of the site. As the locations of these entries were not shown on any of the materials provided by Celtic Energy, the locations of these entries are not shown on Figure 8. The thirty-one entries within the zone include eight recorded shafts and twenty-three recorded adits. No depths were provided for the shafts identified on the Coal Authority viewer.

9.4 Underground Workings

Through review of abandonment plans provided by Celtic Energy (see Appendix F), the plan area extent and anticipated depth to workings for identified coal seams have been reviewed. It should be noted that the Coal Authority online viewer shows that the majority of the site is underlain by some form of underground workings. Abandonment plans held by the Coal Authority for these workings have not yet been acquired. (It is recommended that the available abandonment plans are acquired and reviewed as part of a more detailed desk study assessment).

Given the age and geographical location of the workings, 'partial extraction' methods are anticipated to have been used. As a result, residual voids associated with mining roadways and open stalls are likely to be present in the worked seams lying beneath the site.

Based on the '10t rule of thumb' (noted within CIRIA C758D) corresponding to 10 times the thickness (t) of an assumed unsupported high void/mining roadway [10]. If a 2m thick void is assumed – corresponding with the typical dimensions of a mining rowadway, the risk of subsidence associated with potential mining related voids is genrally considered to be sufficiently high to require mitigation or treatment when workings <20m below rockhead are anticipated to be present.

This bedrock cover value has been applied to the underground working plans reviewed to determine where the greatest risk of subsidence currently lies.

Table 4 – Underground workings summary table

ID	Description	Level (mAOD)	Depth to workings (m below current rock head)
A	Workings within the 'Nine Feet' seam anticipated to be associated with the Hendre Ladis/Ynyscedwyn Colliery.	Not provided	>>20 [1]
B	Workings within the 'Brass' seam anticipated to be associated with the Hendre Ladis/Ynyscedwyn Colliery.	Not provided	>>20 [1]
C	Workings within the 'Brass' seam anticipated to be associated with the Seven Sisters Colliery.	Not provided	>>20 [1]
D	Workings within the 'Nine Feet' seam anticipated to be associated with the Seven Sisters Colliery.	93.87	169

ID	Description	Level (mAOD)	Depth to workings (m below current rock head)
E	Workings within the 'Nine Feet' seam anticipated to be associated with the Dulais Colliery.	245.36 (Adit entry level)	<20 [2]
F	Workings within the 'Peacock' (Brass) seam known to be associated with the Dulais Colliery.	192.14 – 276.78	5 - 25
G	Unnamed adit believed to be associated with the Dulais Colliery. 'No Coal' notation on abandonment scan suggest it was a trial adit which was not progressed further.	243.84 (Adit entry level)	<20 [2]
H	Unnamed workings (assumed to be Bluers Seam within the Lower Coal Measures) anticipated to be associated with the Dulais Colliery.	143.43 – 176.78	87 - 97

Notes

1. Although depth to working and/or working levels were not provided on the plans used to identify these workings, based on the level provided on the plan to identify the level of working 'D', the depth to these workings is anticipated to be far greater than the 20m below rockhead range identified as highest risk within CIRIA C758D.
2. No in seam levels are provided. The depth to workings has been assumed to be less than 20m due to the limited plan area extent of the workings that spread from the adit entry points which are shown to be situated at surface level.

As highlighted in Table 4 above, underground workings at depths shallower than 20m below the current anticipated rock head are anticipated to be present. This particularly applies to workings 'E', 'F' and 'G' (refer to Figure 8).

It should be noted that cuttings (~10m) are currently proposed through the area that is anticipated to be underlain by workings 'E', 'F' and 'G'. These cuttings will lower the rock cover and in some instances underground workings may be encountered during excavation of the cuttings currently proposed (refer to Figure 11).

In these locations there is a risk of subsidence as a result of collapsed underground mine workings; in order to mitigate against the risk of subsidence, remedial actions such as grouting of voids may be required.

9.5 Open Cast Coal Mining

In addition to the extensive deep mine working continued beneath the site up until ~1966, the site has also been subject to extensive opencast coal mining activity from as early as 1946. From review of opencast completion plans (see Appendix G) and review of historical aerial photography, the various opencast sites have been identified and are shown on Figure 9.

A summary of the opencast sites identified is provided in Table 5 below; the operational years and an estimate of the maximum depth of excavation is also tabulated. The depth of excavation has been determined through review of opencast completion plans, where available, and current levels ascertained from online OS elevation data.

The depths of excavation provide indicative figures for the depth of fill material which is now present within the opencast sites that have been backfilled post completion of opencast activity. The backfill material is likely to comprise the non-coal bearing site won rock arisings which have been excavated during opencast working.

Table 5 – Opencast workings summary table

Name	Operational Years	Maximum depth of excavation
Onllwyn	1946 – 1949	~15m
Cefn Byrle [1, 2]	1952 – 1953	-
Abercrave / Gwaunton [1]	1963 – 1973	~40m
Onllwyn	1972 – 1982	~82m
Nant Helen	1986 – 1999	~130m
Nant Helen Extension	2002 - Present	~150m

Notes

1. Completion plans for the Cefn Byrle and Abercrave/Gwaunton opencast sites were not provided.
2. The existence of the Cefn Byrle opencast site has been determined through review of the 'History of Coal Mining' figure contained within the Nant Helen Extension Environmental Statement from 2011. Refer to Appendix H.

Refer to Figure 11 for an illustrative geological section which passes through the Onllwyn (1972-1982) and Nant Helen (1986-1999) opencast workings. The depths of the workings shown have been interpreted through review of the relevant opencast completion plans.

It should be noted that the extent of the Abercrave/Gwaunton opencast site shown on Figure 9 has been determined through review of figures provided within the Nant Helen Extension Environmental Statement (refer to Appendix H) rather than abandonment plans.

9.6 'Risk Zones'

A preliminary risk assessment has been undertaken in order to identify particular 'risk zones' along the proposed track route. The risk zones aim to highlight where the risk of subsidence as a result of shallow mine working collapse is highest. The

risk zoning has been primarily based on the areas that have are anticipated to have not been subject to opencast mining activity.

The risk zones are shown on Figures 8 and 9.

'Risk Zone A' is located in the south-eastern quarter of the main portion of the site. The zone covers the sections of proposed track from the western border of the second Onllwyn opencast site (1982) in the east to the eastern border of the Nant Helen opencast site (1999) centrally located within the site. There is a risk of subsidence in this zone due to the known presence of underground workings at shallow depth within the "Nine Feet" and "Brass" seams (see workings 'E', 'F' and 'G' on Figure 8); based on review of abandonment plans (provided by Celtic Energy), some of these workings are potentially as shallow as 5m below the current anticipated rock head and are therefore within the 20m below rockhead range which poses a crown-holing subsidence risk as determined from review of the CIRIA C758D guide. As highlighted in Section 9.4, as cuttings in the range of ~10m are proposed in this region of the site, the rock head cover is likely to be reduced and in some cases, workings are anticipated to be exposed by the proposed cuttings. In addition, potential 'bell pitting' activities have been identified within this zone from review of historical aerial photographs which further increases the risk of potential subsidence in this zone.

'Risk Zone B' is located in the north-eastern quarter of the main portion of the site. The zone covers the section of proposed track between the northern border of the second Onllwyn opencast site (1982) in the east to the eastern boundary of the Abercrave/Gwaunton opencast site (1973) located in the north of the site. There is a risk of subsidence in this zone due to the presence of numerous shaft and adit mine entries associated with the Glynllech/Cwm Tawe Colliery. Although a comprehensive set of abandonment plans for this region of the site have not yet been reviewed, there is the potential that shallow underground workings will be present in this area on account of the numerous shafts and adits; the depths of the shafts in this region (~5.5 – 9.15m) also indicate the potential presence of shallow workings within the 20m below rockhead range determined from review of the CIRIA C758D guide.

'Risk Zone C' is located in the south-western quarter of the main portion of the site. The zone covers the section of proposed track which runs from the southern border of the Nant Helen opencast site (1999) to the southern boundary of the Nant Helen Extension (2002 – present) located along the westernmost border of the site. There is a risk of subsidence in this zone due to the known presence of underground workings beneath the proposed track route. It should be noted that the risk of subsidence in this zone isn't considered to be as great as it is in zones 'A' and 'B' as the workings are anticipated to be much deeper than the 20m below rockhead range determined.

'Risk Zone D' covers the washery portion of the site. The zone has not been defined further as the exact locations of the shaft and adits identified to be present within the washery portion of the site could not be confirmed through review of opencast competition plans or abandonment plans provided by Celtic Energy. It is likely that Coal Authority data will have to be purchased in this region to cross

check the recorded locations of the mine entries shown on the Coal Authority online viewer.

It is recommended that a comprehensive set of abandonment plans are purchased and a ground investigation (including both intrusive and non-intrusive works) is scoped and undertaken to confirm the potential presence of shallow workings within the zones identified. If identified, remedial actions such as grouting of voids may be required in order to mitigate the risk of subsidence.

10 Sensitive Land Uses

Through review of information presented within the Groundsure EnviroInsight report, the following sensitive land uses have been identified within a 500m buffer of the site the site boundary. Refer to Figure 10 for the locations of the sensitive land uses identified.

Table 6 – Sensitive land uses

Sensitive Land Use	Name	Location
National Parks	Brecon Beacons	85m (NE)
Sites on Special Scientific Interest (SSSI)	Gorsllwyn, Onllwyn	19m (NE)
	Nant Llech	111m (N)
Ancient Woodland	Ancient semi natural woodland	On site
	Plantation on ancient woodland site	On site
Scheduled Ancient Monuments	"Tramroad at Ystradgunlais" *(a.k.a. Brecon Forest Tramroad – Claypons Extension)*	On site
	Bryn Llechwen ring cairn	90m (SW)

The border of the Brecon Beacons National Park is located approximately 85m to the NE of the northern site boundary.

The Gorsllwyn SSSI covers an area of approximately 40 hectares and comprises an upland mire located on a col between the Pyrddin and Dulais valleys. The peatlands within the mire are surrounded by an area of acidic grassland. The Gorsllwyn is deemed to be of interest as the mire landscape is rare with few other examples of this formation known in mid and south Wales.

The Nant Llech is a mountain stream that flows through a steep-sided valley of special interest on account of its rich variety of woodland species, cliff plant communities and Westphalian rock exposure. The site has been deemed critical for understanding the stratigraphy of the South Wales Coalfield due to the exposed sequence of over 120m of rock strata.

Through review of information presented within the Groundsure EnviroInsight report, multiple areas of 'ancient semi-natural woodland' and 'plantations on ancient woodland sites' have been identified. A small portion of the track route is shown to pass through an area of 'plantation on an ancient woodland site'. As set out in the National Planning Policy Framework (February 2019), *"development resulting in the loss or deterioration of irreplaceable habitats (such as ancient woodland…) should be refused, unless there are wholly exceptional reasons…"*. However, as the areas identified refer to areas of 'ancient semi-natural woodland' and 'plantations on ancient woodland sites', it is anticipated that these will have limited impact on the planning process for the future developments.

The 'Tramroad at Ystradgynlais' (also referred to as the Brecon Forest Tramroad – Claypon's Extension) is a Scheduled Ancient Monument and was built in the 1830s to link the Brecon Forest Tramroad and the Swansea Canal with the Drum Colliery.

The Bryn Llechwen ring cairn is also a Scheduled Ancient Monument and is located approximately 90m to the southwest of the western site boundary.

11 Preliminary Conceptual Site Model

The following section details a preliminary conceptual site model. The conceptual site model highlights the potential sources of contamination, identifies the potential receptors and sets out the potential pathways which would allow for a pollutant linkage to form.

11.1 Sources

The potential sources identified are highlighted in individual sub-sections below. It should be noted that the presence of potentially contaminated ground and groundwater beneath the site can only be confirmed through intrusive ground investigation and subsequent chemical analysis of geo-environmental samples gathered. The following identified contaminants for each identified source are purely indicative.

Made Ground

Based on review of the BGS online GeoIndex, review of borehole logs from previous ground investigations and from review historical mapping/photographs, made ground deposits are anticipated to be encountered beneath the majority of the proposed track route. The made ground materials are anticipated to comprise material used for infilling of the various opencast sites (refer to Figure 11). This material is likely to comprise gravels, cobbles and occasional boulders of mudstone, siltstone and sandstone (refer to photographs 3, 4, 5 and 6 in Appendix A).

No chemical testing on the made ground (fill) materials has been undertaken to date. This material is unlikely to be impacted by significant contamination; however, given the extensive usage of motorised plant in opencast mining

activities over the past 75 years there is the potential to encounter localised pockets of hydrocarbon (TPHs) contamination as a result of spillages.

As previously highlighted within this report, the site has been impacted by both sub-surface and surface coal mining activities. The Abercrave/Gwaunton opencast mine excavated the area previously occupied by the Abercrave, International and Gwaunclawdd Collieries. There is the potential that contaminants associated with coal mining activities could be encountered within the backfill in these locations. Contaminants arising from the coal mining infrastructure and activity in the area may be present; typical contaminants may include various metals, metalloids, sulphates, PAHs, TPHs and asbestos.

Rail/Tram Lines

The Neath and Brecon Railway (main and junction lines) have been identified to have run adjacent to the northern (junction line) and southern (main line) site boundaries through review of historical mapping and historical aerial photographs. In addition, three tramways (including the Brecon Forest Tramroad) have been identified to have crossed into the site through review of historical mapping and historical aerial photographs. Potential contaminants associated with rail/tram lines typically include various metals, TPHs, PCBs, PAHs, herbicides, ferrous residues, metal fines, ash, sulphates and asbestos.

Fuel Tanks

From review of site walkover photographs (see Photograph 7), a group of four large cylindrical tanks were identified to be present close to the site compound and offices centrally located within the site.

These tanks are likely to be fuel tanks or at the very least contain some form of hydrocarbon-based substance due to the nature of the flammable warning signs observed to be present. The tanks are above ground however, there is the potential that spillages and leakages may have occurred and as a result the soils and groundwater present in this location could potentially be impacted by hydrocarbon contamination.

Pollution Incidents

From review of the Groundsure EnviroInsight report, two pollution incidents have been recorded by the NRW within the site; an additional two pollution incidents were recorded <5m away from the site boundary taking the total to four. All four of the incidents were located within or within the direct vicinity of the washery portion of the site. The pollution incidents are detailed below.

In 2013 a pollution incident was recorded within the washery portion of the site (E: 283823, N: 210346). The pollutant was identified as ‘Coal’ and the impact to water was categorised as Category 2 (significant impact). No impact to land or air was recorded (both Category 4).

In 2001 a pollution incident was recorded within the washery portion of the site (E: 285452, N: 210250). The pollutant was identified as ‘Sewage Materials’ and the impact to water was categorised as Category 3 (minor impact). No impact to land or air was recorded (both Category 4).

In 2014 a pollution incident was recorded 1m to the south of the washery portion of the site (E: 285288, N: 210222). The pollutant was identified as 'Construction and Demolition Materials and Wastes' and the impact to both land and air was categorised as Category 3 (minor impact). The impact to water was not categorised.

In 2001 a pollution incident was recorded 4m to the northeast of the washery portion of the site (E: 285503, N: 210298). The pollutant was identified as 'Sewage Materials' and the impact to water was categorised as Category 3 (minor impact). No impact to land or air was recorded (both Category 4).

The pollution incidents presented above are anticipated to have had a localised impact to the soils and groundwater beneath the washery portion of the site. However, given the categorisation of these incidents the level of contamination is anticipated to be minor.

Landfills

No landfill sites have been identified within the site. From review of the Groundsure EnviroInsight report, the following historic landfills, see are located within 1km of the site boundary:

Table 7 – Historic Landfill sites – NRW Dataset

Name	Direction and distance from site	Type of Waste Accepted	Year of Closure
Moorside Villas	473m (NW)	Commercial Household	1974
Cowlbren	612m (N)	Unknown	Unknown

As neither of these landfills impact the site directly, the risk of encountering potential contamination associated with these two locations is considered to be negligible.

11.2 Receptors

The following potential receptors have been considered within the preliminary conceptual site model.

Human

- Construction workers/maintenance workers

  During the construction of the proposed cuttings and embankments, construction workers will be exposed to the soils and groundwater present beneath the site.

  Post construction, maintenance workers have the potential to be exposed to the soils and groundwater present beneath the site if works involving excavation activity is required.

- Site users

Post construction, site users are anticipated to include train drivers and maintenance workers carrying out works on the proposed test track. The train drivers are not considered to be vulnerable as they are highly unlikely to come into contact with soils and groundwater found beneath the site.

- Site neighbours

  Site neighbours includes people living in the various towns and villages that surround the site. This is particularly relevant to residents of Onllwyn which directly borders the site.

Environmental

- Surface Water

  Numerous surface water features have been identified to pass through the proposed site. These features are all small streams which are tributaries of the larger streams and rivers that surround the site.

- Groundwater

  The South Wales Coal Measures Formations that lie beneath the site are designated as Secondary (A) Aquifers. There are no known groundwater abstraction licenses within 500m of the site boundary however there may be unlicensed groundwater abstraction points surrounding the site.

11.3 Pathways – Pollutant Linkages

For a pollutant linkage to exist, an identified pathway has to be present to link a source to a receptor. The pathways identified have been split between human and environmental receptors and are presented below.

Human

- Ingestion of soils, soil dust and groundwater

  During construction, construction workers and site neighbours have the potential to come into contact with contaminated soils through ingestion of soils and soil dust.

  Post construction limited migration of soils and soil dust is anticipated to occur and therefore the likelihood of site neighbours to come into contact with potentially contaminated soils is negligible. However, maintenance workers have the potential to come into contract with contaminated soils through ingestion of soils and soil dust.

- Dermal exposure to soils, soil dust and groundwater

  During construction, construction workers are likely to experience dermal exposure to potentially contaminated soils, soil dust and groundwater. In addition, site neighbours also have the potential to experience dermal exposure to potentially contaminated soil dust that migrates from the site works.

  Post construction, maintenance workers are likely to experience dermal exposure to potentially contaminated soils, soil dust and groundwater.

- Inhalation of particulate matter and soil vapours

  During construction, construction workers and site neighbours have the potential to be impacted by contaminated soils through inhalation of particulate matter and soil vapours.

  Post construction, particulate matter and soil vapour is unlikely to migrate and therefore the risk of exposure to sit neighbours is considered to be negligible. However, there is a residual risk of exposure to maintenance workers.

Environmental

- Leaching and vertical/lateral migration

  The various excavation works currently proposed have the potential to introduce preferential flow paths for groundwater from the potentially contaminated superficial material (made ground) to the Secondary (A) Aquifer of the underlying solid geology.

- Surface run-off

  Breaking the ground, moving materials and formation of temporary storage stockpiles of made ground/fill may result in increased contaminant mobilisation due to increased exposure to rainfall. As this material has the potential to be contaminated, there is therefore the risk of surface run-off from the earthworks migrating migrate to the various surface water features that originate within the site.

- Direct discharge as a result of dewatering

  During the earthworks there may be a need to dewater the excavations. The removed water could be discharged to the wider site drainage or ground and, if contaminated, could potentially impact the receiving controlled water receptors.

12 Unexploded Ordnance

A preliminary risk assessment for the presence of buried unexploded ordnance (UXO) covering the site has been undertaken in accordance with CIRIA C681. The preliminary risk assessment has not been carried out by a UXO specialist and the assessment has been based on a desktop review of historical information regarding site location and previous site development.

12.1 The Site

The site is approximately 500 hectares in plan area. The site lies roughly ~20km to the northeast of Swansea and is bordered by the town of Ystradgynlais to the west and the village of Onllwyn to the east.

The site boundary roughly sits at around 250m AOD with the land rising towards the centre of the site. The majority of the central portion of the site is at around 295m AOD with localised artificially raised areas of land reaching 335m AOD. The “washery” portion of the site sits lower than the main portion of the site at roughly 230m AOD.

Based on review of current online aerial photography, the main portion of the site is shown to be a moorland type area with significant evidence of opencast mining activity. The majority of the active opencast evidence is present to the west of the main portion of the site although areas of land that appear to have been backfilled opencast sites are present in the east of the site. The centre of the main portion is shown to contain artificially raised "overburden storage area/layer-cake" spoil heaps. These areas of land are significantly raised compared to the surrounding area with the largest

The "washery" portion of the site is shown to contain a varied array of coal processing infrastructure with a limited network of rail lines running along an east to west alignment towards the north of the site. The land surrounding the coal processing infrastructure appears to be raised industrial scrubland with minimal vegetation cover.

12.2 Geology

Based on review of published geological sources, the site is shown to have a limited and discontinuous cover of superficial deposits. Glacial till deposits, covering a minimal plan area, are shown to be present along the southern and western boundaries of the site. Glacial till material tends to comprise a heterogenous mixture of predominantly clay sized material, with sand, gravel and larger cobble and boulder sized inclusions. In addition, a small peat deposit is shown to be present within the central portion of the site.

12.3 Proposed Works

The proposed earthworks include comprehensive cut and fill activities to form a range of embankments and cuttings; the embankments and cuttings are required to form the base for a rail test track facility. Based on current ground levels it is anticipated that cuttings of up to ~30m deep and embankments of up to ~40m high will likely be required. The majority of the cuttings proposed are through backfilled opencast sites with a few sections of rock cut anticipated.

12.4 Site History

Based on review of aerial photography from 1945, the main portion of the site is shown to be free from any major development and appears to comprise moorland with numerous small fluvial valleys originating from the centre of the site. Significant coal mining activity is shown along the northern boundary (Abercrave, Gwaun Clawdd and Ynyscedwyn Collieries) and the southern boundary (Onllwyn, Dulais and Seven Sisters Collieries). A linear alignment of minor cuttings and embankments is shown to cross along the southern boundary of the site. From review of historical mapping this alignment is labelled as an 'Old Tramway'; the tramway is labelled 'Old' on the earliest available historical mapping from 1876 which suggests that the tramway had long been disused at the time of WWII. The "washery" portion of the site contains the Onllwyn Washery with multiple rail lines and stockpiles present.

Post WWII, the site has undergone significant opencast mining activities. The progression of opencast activity has progressed from east to west with the earliest opencast site, Onllwyn (1949), being located beneath the eastern boundary of the main portion of the site and the most recent opencast site, Nant Helen Extension (2002 - present), being located beneath the western boundary of the site. The "washery" portion of the site appears to have remained relatively unchanged since WWII with a slight reduction coal processing infrastructure noted; a raised portion of the industrial scrubland to the north of the Onllywn Washery has possibly been formed from the stockpiles noted from the 1945 aerial photography.

12.5 Evidence of previous military land-use

The site located has historically been used for coal mining with no evidence of military use in the direct vicinity of the site. From a review of potential military sites collated on the Coflein website, no major military targets have been identified within a 10km radius of the site [18].

Swansea is located approximately 20km to the southwest of the site. Swansea was a target of major Luftwaffe bombing raids during WWII and was the most heavily bombed location in South Wales. However, given the distance, it is unlikely that the site will have been impacted by Luftwaffe bombing raids targeted at Swansea.

12.6 Potential for aerially delivered ordnance

The Zetica regional unexploded bomb risk map for Glamorgan shows that the site is located within a low bomb risk map. In addition to the regional unexploded bomb risk map, a bespoke unexploded bomb risk map for the site has been freely downloaded from the Zetica website, see Figure 13 below.

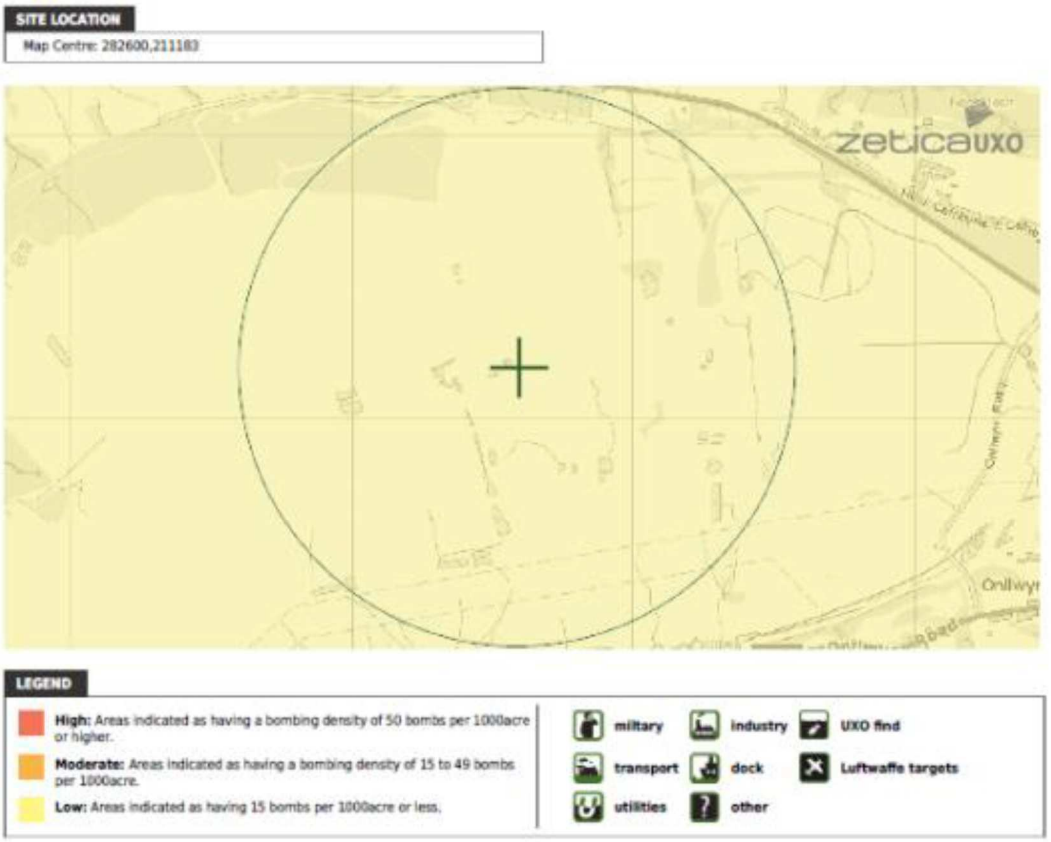

Figure 13 Zetica Unexploded Bomb Risk Map

As shown above, the site sits within a low risk area. A low risk area is defined as an *"area indicated as having 15 bombs per 1000 acres or less"*. As set out by Zetica, a low risk area suggests that there is no greater probability of encountering UXO than anywhere else in the UK. Therefore, the potential for aerially delivered ordnance is low.

12.7 Consideration of mitigating factors

The predominantly firm nature of the glacial till superficial geology and reported lack of superficial geology in some areas of the site, means that had any aerially delivered ordnance been dropped it is highly likely to have detonated upon impact. Also, given the general absence of soft superficial deposits, other than areas of peat in the central areas of the site it is likely that any UXO would have been discovered on the ground surface and dealt with.

No previous military land use was identified within a 10km radius of the site. The collieries and rail infrastructure present surrounding the site at the time of WWII do represent a potential target for WWII Luftwaffe bombing raids. However, given the localised nature of Luftwaffe bombing raids in Wales (primarily concentrated on Swansea, Cardiff and Milford Haven), it is unlikely that the collieries surrounding the site would have been targeted.

The extensive nature of post WWII development to the site, primarily regarding opencast mining activity, further reduces the risk of UXO encounter. This is particularly relevant when considering that the majority of cuttings currently

proposed pass through areas of previously backfilled opencast sites. The remaining cuttings are proposed through areas where superficial deposits are anticipated to be minimal. The areas of peat which were historically present will generally have been worked out during the open-casting operations that historically took place on the site.

12.8 Conclusions and recommendations

Based on the preliminary UXO risk assessment detailed above, the risk of UXO encounter beneath the site is considered negligible. As a result, a detailed UXO risk assessment is not deemed to be required.

13 Preliminary Engineering Assessment

From the information available, a preliminary geotechnical and geo-environmental assessment has been undertaken to identify the potential constraints at the site.

The engineering assessment has considered issues regarding settlement, the earthworks proposed, the potential for material re-use, issues regarding groundwater and potential foundation options for the structures proposed.

13.1 Settlement

A literature review regarding the estimation of settlement at the site was undertaken using the following documents:

- BRE Report – Building on Fill: Geotechnical Aspects (3rd edition)[13];
- BRE Information Paper IP 5/97 – Building on Fill: Collapse Compression on Inundation [14];
- BRE Information Paper IP 15/85[15];
- British Coal Opencast: State of the Art Review of The Compaction of Opencast Backfill. Report No. 90CPC/GEO/095 dated March 1997 by Scott Wilson Kirkpatrick (3 vols) [16];
- Building on uncompacted dumps in the Rhenish brown coal area of the Federal Republic of Germany. Lange S. 1986 [17].

For opencast backfills such as the ones on site, the mechanisms of ground movement include:

- long term creep settlement – most settlement occurs;
- settlement due to inundation;
- heave movements associated with inundation and/or stress relief;
- movements as a result of load imposition.

The primary factor affecting magnitude of these settlements is degree of compaction. Uncompacted fills (e.g. by end tipping in thick layers) show the most settlement. Other controlling factors which need to be considered include backfill properties (e.g. particle size and shape, grading, particle strength hydraulic properties), shape, depth and extent of excavation, location of spoil mounds, haulage roads and hydrogeological effects.

13.1.1 Creep settlement

Most settlement occurs during and soon after backfilling. Assuming that the majority of backfill is granular; major settlements are likely to have occurred almost immediately upon backfilling.

Further movement then occurs gradually and is known as long term creep settlement, the rate of movement decaying linearly when plotted on a log-time scale. The slope of the graph of movement versus log time is known as the logarithmic creep compression parameter, α.

For opencast backfills containing sandstone/mudstone rockfill, conservatively assumed to have been non-engineered (i.e. has had no systematic compaction), this parameter typically lies in the range 0.9% to 1.5% [13]. This range of α values have been used to determine the likely rate of creep settlement occurring in the areas of opencast that have since been backfilled.

In addition, following the BRE building on fill guidance [13], a less conservative logarithmic creep compression parameter value of 0.34% for the Nant Helen opencast site has been calculated for engineered (i.e. heavy vibrating roller compaction) sandstone/mudstone rockfill. The backfill has been assumed to be dry ($\therefore \sigma_v' = \sigma_v$).

Sandstone/mudstone rockfill	Heavy vibrating roller	0.13 σ'_v
Sandstone/mudstone rockfill	No systematic compaction	0.9–1.5

The creep settlement has been estimated for various values of a logarithmic creep compression parameter (α) using the equation below.

$$\alpha = \Delta s/[H \log (t_2/t_1)]$$

Where, 'Δs' refers to the settlement of an embankment of height 'H' between times 't_2' and 't_1'.

A general assessment of the magnitude and timescale of future movements, considered sufficient to establish the feasibility of development plans, has been made using desk study information on the geometry/depth, age, type and hydrogeological regime of the backfill, together with settlement monitoring records.

Refer to Figure 14 for the estimated rate of creep settlement for different α values for the Nant Helen opencast site. The Nant Helen opencast site was chosen to illustrate the potential rates of creep settlement as the site represents the deepest of the backfilled sites (~130m).

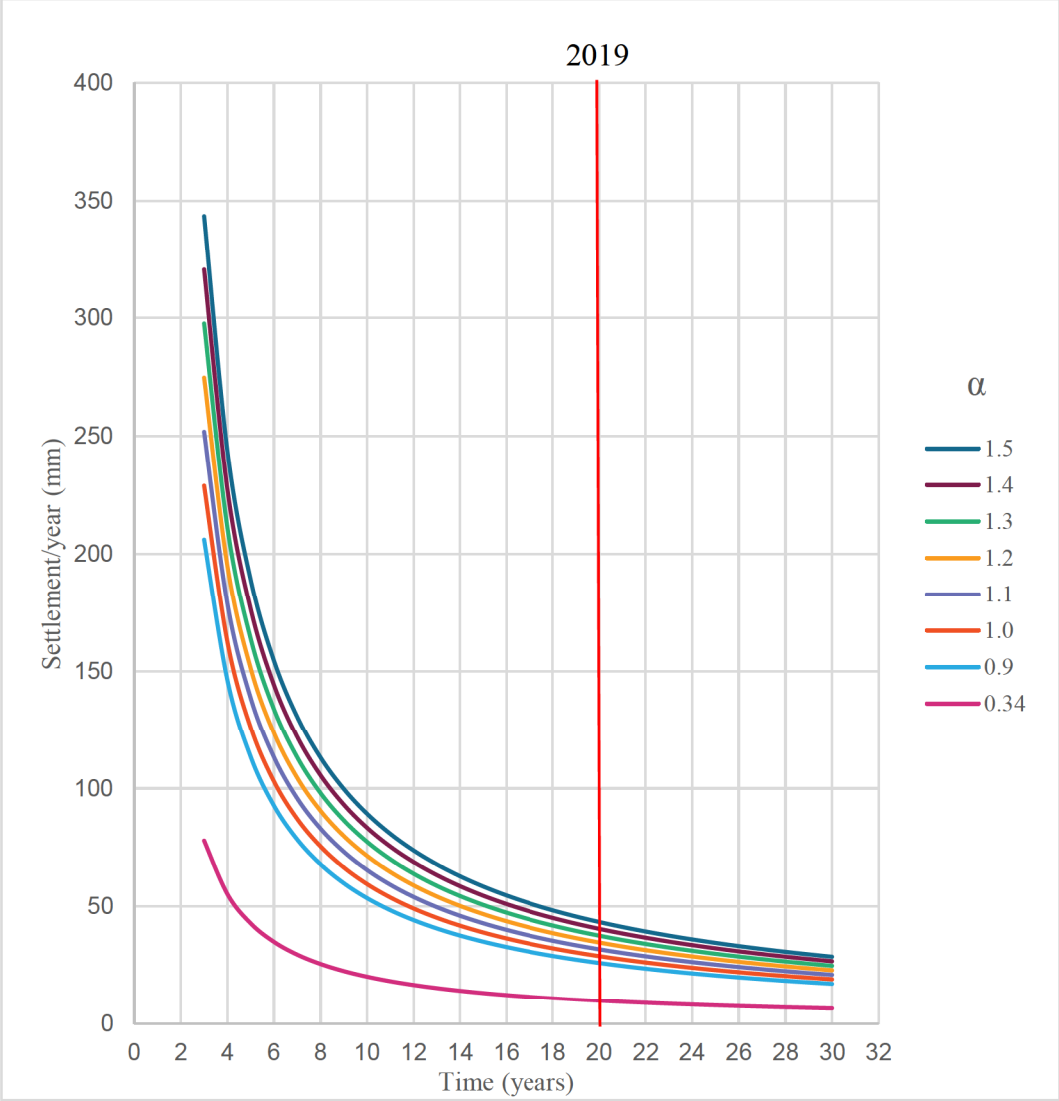

Figure 14 Creep settlement rate for different α values (Nant Helen 1999)

For all alpha values, based on this assessment the current creep settlement rate is anticipated to be in the range of 10-50mm per year.

As highlighted in Figure 14 above, the risk of creep settlement is considered to be greatest within the areas that have been recently been backfilled. This risk particularly pertains to the Nant Helen Extension site beneath the western boundary of the site where the opencast void is yet to be backfilled.

The detailed design of remediation works and foundation solutions will need to consider the effects of specific features such as spoil mounds, sloping sides of excavation, potential "hard spots" at edge of excavation and hydrological/ hydraulic features in the proposed development.

A suitable scope of ground investigation works will need to be undertaken to provide information on the detailed geotechnical properties of the backfill.

13.1.2 Inundation settlement of fill following the rebound of the groundwater level

Inundation settlement occurs relatively rapidly following inundation of susceptible fill materials by groundwater or surface water. Sensitivity to inundation settlement depends on air voids content prior to saturation. Inundation settlement is negligible when air voids are less than 5% and of small magnitude when air voids are less than 10%. On the other hand, linear strains of the order of 3% to 5% have been measured in many loose fills [14].

This is likely to affect the western part of the site mainly, where dewatering activities are currently being undertaken to allow for the excavations within the Nant Helen Extension opencast site. Once dewatering is ceased, the groundwater levels in this region will rebound to a certain level. Given the general lack in groundwater information for the site, this rebound will have to be monitored to determine the level to which groundwater will rise post completion of opencast working. This monitoring should be undertaken site wide; initially to gain an appreciation for the groundwater level currently beneath the site and to then measure the change in groundwater level, if any, that occurs once the dewatering measures are stopped.

As inundation settlement can be mitigated somewhat through control of air voids within the fill material, opportunities to minimise this risk during the filling of the current opencast voids located to the west of the site should be fully explored.

13.1.3 Potential differential

There is the potential for differential settlements to occur along the proposed track route. This is due to the fact that the areas of backfill will settle whereas the areas that have not been subject to opencast working are unlikely to settle.

There is likely to be a degree of differential settlement within the areas of backfill themselves. This is due to the fact that total settlement is dependent on the thickness of fill; as the thickness is not constant, the areas with greater thicknesses of fill will settle more than those with a shallower thickness.

In order to mitigate against differential settlements at the surface, improvement of near surface materials could be considered. It should be noted however that this would not eliminate total settlements. Improvement of near surface materials could be achieved by:

1. Excavating and recompacting
2. High Energy Impact Compactions (HEIC) (likely to improve the upper ~3m)
3. Dynamic Compaction (likely to improve the upper ~10m)
4. Surcharge
5. Grouting

Alternatively, a rigid base to track bed could be proposed. This would mitigate against the risk of minor differential settlements but would likely require comprehensive piled foundations, which would not be a feasible solution for the deeper areas of fill.

As settlement is likely to occur at the highest rate within the areas that have most recently been backfilled, altering the proposed alignment to avoid the most recent areas of opencast mining would minimise the risk of differential settlement. Ideally the alignment should be altered to avoid the areas of recently backfilled material where possible.

13.1.4 Heave

Elastic heave movements can occur when cuttings are formed through fill material or on removal of surcharge mounds. Heave can also result from the swelling of near surface deposits caused by water ingress and seasonal moisture content changes.

The risk of heave should be considered in any areas where removal of material from the large overburden storage areas is proposed or any areas where extensive cuttings are proposed.

13.2 Proposed Earthworks

The extent and size of cuttings and embankments required is dependent on the proposed track level. The slope angles of the cuttings and embankments are dependent on material. Based on the anticipated nature of the material used for the embankments and cuttings, and the anticipated groundwater regime across the site, the following slope gradients have been estimated to ensure stability with adequate factors of safety:

- Embankments – 1:3
- Cuttings (coal measures) – 1:1
- Cutting (backfill) – 1:2.5

It should be noted that the slope angles for the cuttings and embankments proposed here are indicative only, and should be verified following ground investigation on the basis of stratigraphy, material and mass properties and the results of groundwater monitoring.

13.2.1 Areas at Risk of Shallow Mine Workings

The risk zones identified in Section 9 of this report highlight the areas where opencast working has not been undertaken and shallow mine workings may be present. Within such areas of shallow mine workings, the development proposals may be susceptible to impacts from potential subsidence events. Excavation of cuttings would reduce the thickness of cover over the workings, increasing the risk that ‘crown hole’ collapse could propagate to the surface and affect the proposed development.

For example, in 'Risk Zone A' workings <20m below the existing rockhead are anticipated. Workings within this range present the highest risk of subsidence as a result of roadway collapse. Given the age of the workings, roadway collapse may occur due to the degradation of supports present at any time.

The cuttings are likely to reduce the depth to workings, and in some cases expose wokrings, due to the removal of material. This is likely to bring more workings within the 20m (particularly in 'Risk Zone A') range which has been highlighted as highest risk.

Engineering measures are likely to be required to effectively lower the risk of shallow working related subsidence within risk zones. This could include bulk infilling of mining voids such as grouting of voids (or use of gravel where drainage pathways need to be maintained), or use of high strength geogrids to temporarily or permanently span potential subsidence features.

13.3 Potential for Material Re-use

An assessment of the suitability of material re-use in the construction of the numerous embankments proposed will be necessary as part of the scope of ground investigation works. From review of the site walkover photographs, much of the made ground fill material anticipated to be encountered within the backfilled opencast sites is likely to comprise gravels, cobbles and occasional boulders of mudstone, siltstone and sandstone. This material is expected to be predominantly granular, predominantly comprising the non-coal bearing material that has been excavated during opencast working.

This material is also likely to be representative of the material that would be generated during the excavation of the cuttings required through areas of previously unworked Coal Measures Formations.

From a geotechnical perspective, this material is likely to be suitable for re-use subject to processing to reduce the maximum particle size and achieve a suitable grading, and removal of any coal that may still be present.

The glacial till natural superficial material is also likely to be geotechnically suitable for re-use in the formation of the embankments required.

The deposits of peat are likely to be unsuitable for reuse as a fill material. Furthermore, if present, it is likely that any peat present in at grade sections or beneath the proposed embankments will have to be excavated and removed from the areas or treated prior to construction.

The geotechnical suitability for material re-use, can only be confirmed through geotechnical sampling and subsequent testing of the materials present within the opencast areas that have been backfilled.

From a geo-environmental perspective, the potential contaminative nature of made ground fill material must be assessed in order to determine the suitability for re-use. Human health and controlled waters risk assessments will be required to determine the geo-environmental suitability for re-use.

13.4 Groundwater

As discussed in Section 13.1.2, further understanding of groundwater levels beneath the site is required to inform assessment of inundation settlements.

Groundwater has the potential to impact the settlement in the areas of backfill and affect the proposed cuttings. It is recommended that a ground investigation is undertaken to ascertain the groundwater level beneath the site.

13.5 Foundation Options – Structures proposed

In addition to the track loops, it is envisaged that a platform environment, facilities for rail storage, train decommissioning areas and other testing facilities may also be included as part of the developed works.

The proposals are likely to comprise the construction of numerous structures of various sizes. These structures may be located within the main area of the site and also within the washery portion of the site.

In the main portion of the site outside any areas of historical opencast activity it may be feasible to found buildings on pad or raft foundations with the glacial till or on top of the relatively shallow bedrock.

The layout of the development should consider the risks presented by ongoing settlement of the backfill.

It may be feasible to found buildings within the areas of previous opencast activity on pad and raft foundations. This is subject to future ground investigation of the ground conditions and careful consideration of the potential magnitude of settlements; in-particular, the differential settlement that may occur within the backfilled opencast workings. Understanding the location of the historical workings will be important for assessment of potential variations in settlement across the site.

Regardless of ongoing settlements, any heavily loaded buildings in these areas may require the use of piled foundations or some form of ground improvement to limit potential settlements under loading to acceptable limits.

As highlighted within the ground conditions section of this report, artificial material (made ground) overlying natural superficial material (predominantly glacial till, potential for peat) is likely to be encountered within the washery portion of the site. The depth to weathered rockhead is anticipated to vary, up to depths of 7.0m bgl based on the logs reviewed. The descriptions from boreholes progressed within the washery portion of the site suggest that the bedrock is comprised of mudstones and siltstones which are slightly to moderately weathered and are moderately weak to strong.

Based on the anticipated ground conditions in the washery portion of the site, it is possible that piled foundations may be required; however, it should be noted that the foundation type is highly dependent on the loading of the structures proposed. For example, smaller structures with lower loading may be able to be founded on pad or raft foundations.

The subsidence risks associated with shallow mine workings will need to be considered as part of the foundation selection regardless of the foundation type selected some form of mine workings treatment or mitigation is likely to be required within identified risk zones.

The extent of ground treatment and foundation selection will need to be reviewed once more detailed assessment of mining risks and ground investigations have been undertaken.

It is recommended that the development masterplan is developed to minimise risks associated with potential total and differential settlement associated with former backfilled opencast areas, potential mining related subsidence associated with shallow underground mine workings.