COG MOORS WWTW

Hydrogeological Impact Appraisal

AUGUST 2018

Incorporating

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Cog Moors WWTW

Hydrogeological Impact Appraisal

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1 Introduction

1.1 Background

Cog Moors Waste Water Treatment Works (‘the site’) is currently being upgraded by Skanska UK Construction Ltd (Skanska) on behalf Dŵr Cymru Welsh Water. As part of the upgrade works, excavations below the water table are required to construct a new pumping station and trenches for buried pipelines and a culvert. These excavations will take place over a period of approximately 2 years, commencing in autumn/winter 2018.

Current legislation requires a water abstraction licence for dewatering operations lasting more than 28 days. Therefore, Skanska is applying to Natural Resources Wales (NRW) for a water abstraction licence and Environmental Permit (discharge consent). This report is a Hydrogeological Impact Appraisal (HIA) in support of the water abstraction licence application.

Arcadis Consulting (UK) Limited (Arcadis) has prepared this HIA with reference to latest guidance (Environment Agency, 2007).

1.2 Site setting and proposed dewatering activities

The site is an operational wastewater treatment works (WWTW), approximately 5.65ha in area and located within the Vale of Glamorgan at National Grid Reference (NGR) 316120, 169660. The site is within the broad, almost flat floodplain of Sully Brook with low hills rising to the north, west and south (Figure 1).

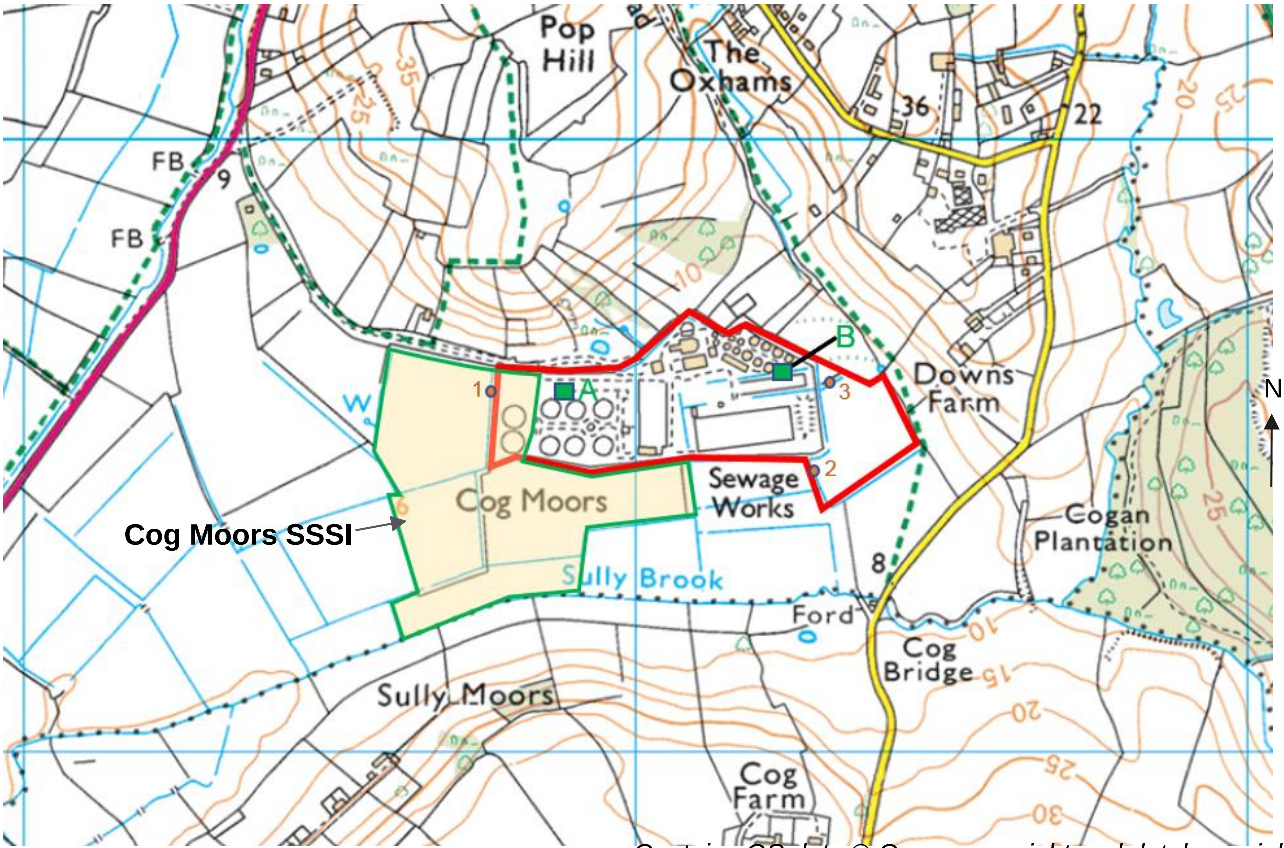

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Figure 1 Location of site and proposed water collection points

Cog Moors Site of Special Scientific Interest (SSSI) is immediately adjacent to the site. This SSSI is a marsh area which is of special interest for its *“large continuous area of damp mesotrophic (neutral) semi-natural grassland, which is associated with several stands of tall sedges, and for populations of two uncommon plant species”* (CCW, 2000). Note the SSSI area within the western boundary of the WwTW has been translocated as part of previous work at the site (see section 2.2).

A summary of the excavations and proposed dewatering relevant to the HIA is given below.

A Final Effluent (FE) pumping station will be constructed in the western part of the site (point A on Figure 1). Construction will include an excavation with dimensions of 5 m x 5 m x 4.7 m (length x width x depth). Ground support will be provided by a sheet pile wall. The excavation is likely to remain open for approximately 1 month, although a concrete base slab will be installed as early as possible in that period, which will reduce groundwater seepage through the base of the excavation. Groundwater that seeps into the excavation (and rainfall directly into the excavation) will be diverted to a collection point within the excavation and pumped out and discharged into a nearby drainage ditch (point 1 on Figure 1).

Trenches will be excavated in the eastern and central parts of the site to install pipelines and services, and to install a culvert to divert one of the drainage ditches within the southeast corner of the site. These trenches will be excavated in sections of 15 m length x 1m width. Once a section of pipeline/culvert has been installed, the trench will be backfilled and the next trench section excavated. The depth of the trenches for pipelines and services will vary from 0.8 m to a maximum depth of 4 m below ground level. The excavation for the reen diversion will be a depth of 2 m along its entire 122 m length.

The total construction period for the trenches is anticipated to be 18 months. The trenches will be excavated outwards from a central (deepest) point and the base of the trenches will be backfilled with a permeable gravel bed. Groundwater that seeps into the trenches (and rainfall directly into the excavation) will be allowed to flow back through the permeable gravel bed to the central collection point (point B on Figure 1). This collection point will have dimensions of approximately 0.6 m diameter and 4 m depth. Water will then be pumped out of this collection point and discharged into the drainage ditches at points 2 and 3 on Figure 1.

Locations of the proposed abstraction (collection points) and discharge points are shown in Appendix A.

A detailed dewatering method statement has been written by Skanska (Appendix B) and a summary of the main points relevant to the HIA are given below:

Any nuisance water that enters the excavations (rain water/ groundwater), will be directed into a collection point. From here it will be pumped from the excavation through to its treatment process location, which will be a Siltbuster settlement tank (or equivalent) to remove any suspended solids. After treatment, the nuisance water, will be allowed to discharge into the drainage ditches identified and be subject to regular discharge quality reviews to ensure silty water is not being pumped into them.

If at any time, the turbidity of the water being discharged is silty and causing a visible silty slick in any of the drainage ditches, the pumps will be switched off immediately, works will cease, the NRW will be notified and arrangements to rectify the situation will commence.

At the proposed discharge locations, the end point of the hose will have a silt sock/ dirt bag (if required) which will be contained with a hay bale to act as the final silt removal point and to remove some of the energy from the water so not to damage the integrity of the ditch.

1.3 Limitations

This report has been prepared for Skanska in accordance with the terms and conditions of appointment. Arcadis cannot accept any responsibility for any use of or reliance on the contents of this report by any third party. The copyright of this document shall remain the property of Arcadis.

This report has been compiled from a number of sources, which Arcadis believes to be trustworthy. However, Arcadis is unable to guarantee the accuracy of information provided by others. The report is based on information available at the time of writing. Additional information may become available in the future which may have a bearing on the conclusions of this report and for which Arcadis cannot be responsible.

Ground investigations by nature only reveal a small percentage of the ground conditions present beneath the site. The possibility of significant variation in ground conditions existing between sampling locations cannot be discounted. Groundwater conditions are based on observations made at the time of the investigation and during monitoring visits and may be subject to significant variation due to atmospheric, seasonal or other effects.

2 Hydrogeological assessment

2.1 Geology and hydrogeology

The geological sequence at the site comprises made ground and superficial deposits of alluvium, which are underlain by weathered and intact Mercia Mudstone Group bedrock (BGS, 1988) . Figure 2 shows borehole locations from a site-specific ground investigation (Arcadis, 2018), in relation to the proposed dewatering collection points.

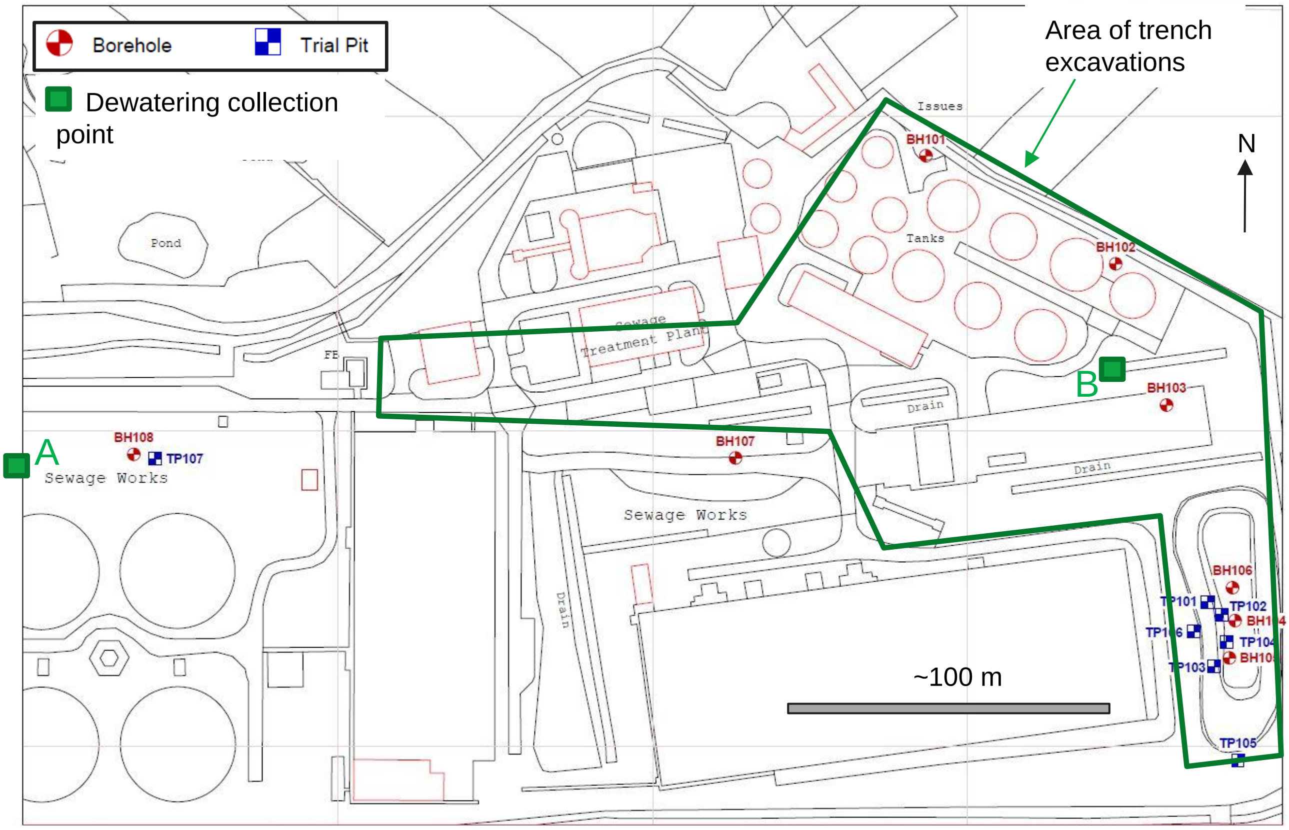


Figure 2 Site plan showing borehole locations and dewatering collection points

Boreholes from the ground investigation indicate the made ground typically consists of variable amounts of clay, sand and gravel with fragments of concrete, brick, plastic, wood and metal. These fragments were most evident within exploratory holes BH104 to BH106 and TP101 to TP106 all of which are located within the area known as 'the mound', a raised area presumably created from previously excavated material. The thickest made ground deposits (5.70 m) were encountered in BH105. Made ground deposits elsewhere across the site where found up to 1.60 m thickness.

Alluvium was recovered from all borehole positions, with the exception of BH101 in the northern part of the site. The alluvium was generally described as soft to firm blue grey slightly silty slightly sandy CLAY and occasionally described as slightly organic fibrous clay. The recorded thickness of the alluvium ranges from 0.9 m in BH102 (eastern part of site) to 2 m in BH108 (western part of site).

Figure 3 is an extract from historical borehole records available from the British Geological Survey's GeoIndex website[1]. This map shows contours on the base of the alluvium using the borehole logs shown on the map. This indicates the alluvium becomes deeper and thicker (up to 3.0 m) in the middle of the valley, along the southern part of the site and beneath Cog Moors SSSI.

[1] http://mapapps2.bgs.ac.uk/geoindex/home.html

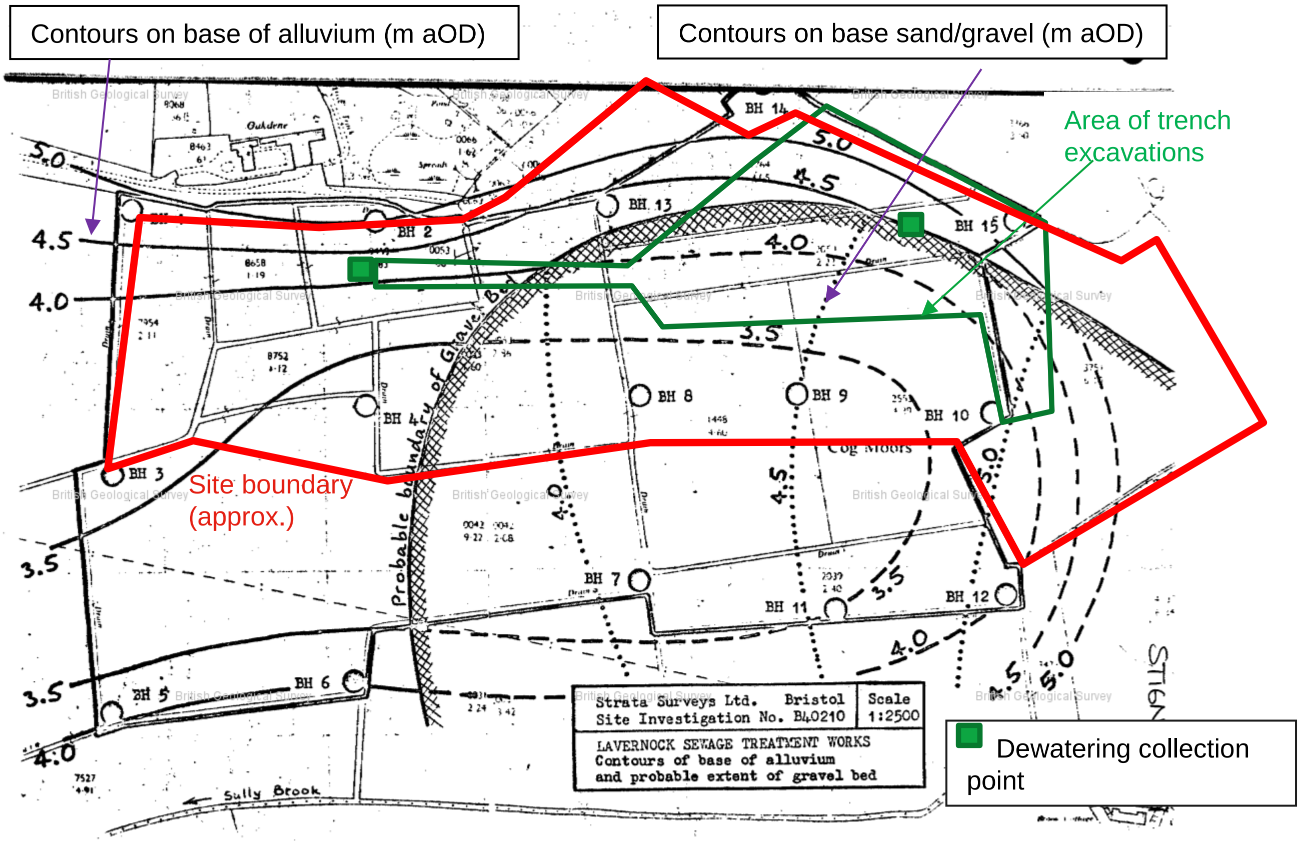


Figure 3 Extract from BGS historical borehole records ref: ST16NE14

A weathered horizon of clays, silts, sands and gravels associated with the Mercia Mudstone Group bedrock was recovered from all borehole positions at various depths and compositions. The sequence is typically a clay/silt layer overlying a sand/gravel layer. In terms of hydrogeology, a distinction can be made between clay/silt (which are likely to have low permeability) and sand/gravel (which are likely to have higher permeability).

The silt clay layer is generally described as reddish brown slightly sandy gravelly CLAY/SILT. The recorded thickness of the silt/clay layer was between 2.4 m to 7.0 m; thickest in the northeastern part of the site; BH101.

The sand/gravel layer is generally described as loose to very dense reddish brown clayey slightly sandy GRAVEL and very dense reddish brown clayey slightly gravelly SAND. This was recorded in all boreholes from the Arcadis (2018) ground investigation with thicknesses ranging from 0.5 m to 4.6 m. The recorded depth to the base of the clay/silt layer and the top of the sand/gravel layer varied from 6 m to 9 m below ground level (bgl).

However, BGS historical borehole records indicate that the sand/gravel layer rises to around 5 m aOD (approximately 2.1 m bgl) in the eastern part of the site, as shown on Figure 3. It is also interesting to note that BH2 and BH4 shown in Figure 3 (BGS borehole ref: ST16NE8 and ST16NE10) did not record a sand/gravel layer, whereas BH108 (located between these two boreholes adjacent to collection point A) recorded 3.5 m of gravel. This suggests the sand/gravel layer may be discontinous within the valley.

Intact Mercia Mudstone bedrock was recovered from all borehole positions. It was typically described as very weak to medium strong, (generally increasing in strength with depth), and was generally described as brown micaceous mudstones, often with calcite vugs and sometimes containing siltstone laminations. The base of the strata was not proven but commenced from a depth between 9.20 m bgl and 13.20 m bgl.

2.1.1 Groundwater levels

All eight boreholes on site were completed with standpipe installations for groundwater level monitoring. The screened section (response zone) of the standpipes in all boreholes is within the weathered mudstone and typically overlaps the sand/gravel layer and clay/silt layer. Boreholes on the mound (BH105 and BH106) have their response zones through the made ground, alluvium and weathered mudstone. Therefore, the data are a composite of the groundwater level(s) in these layers. The response zone for BH104 is only within the sand/gravel layer.

Groundwater levels were recorded on three occasions following completion of the boreholes. The results are summarised in Table 1 and Figure 4. Note that the lines connecting data points on Figure 4 are included for clarity and do not indicate that groundwater levels were recorded continuously.

Table 1 Summary of groundwater level monitoring

Exploratory position	Response zone (m bgl)	Groundwater level (m aOD) 25/08/2017	Groundwater level (m aOD) 03/10/2017	Groundwater level (m aOD) 17/10/2017
BH101	3 to 9	2.15	6.78	4.77
BH102	3 to 9	2.16	6.32	3.66
BH103	3 to 8	1.18	5.82	3.63
BH104	6.9 to 11	4.24	5.72	7.97
BH105	3 to 9.5	4.16	5.68	7.63
BH106	1 to 9.5	4.3	5.67	7.74
BH107	3 to 9	1.93	5.23	4.25
BH108	6 to 10.5	0.96	5.26	4.19

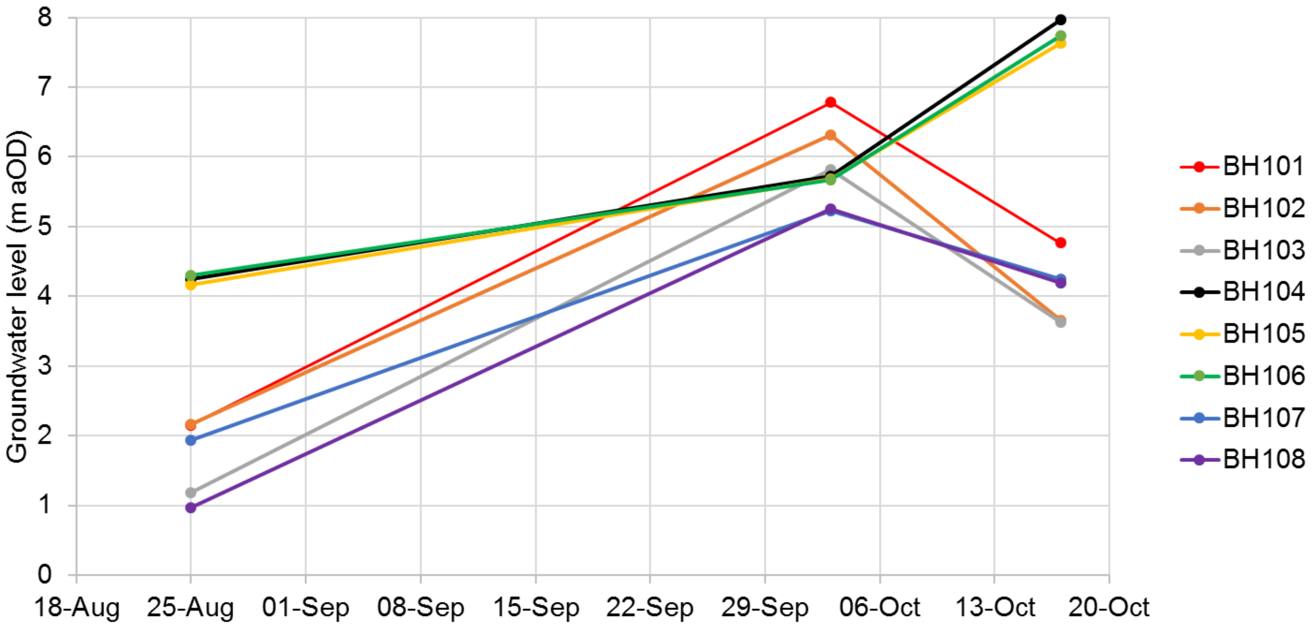


Figure 4 Groundwater levels recorded on 25/08/2017, 03/10/2017 and 17/10/2017

These data indicate the following:

- Groundwater levels on each date are higher in BH101 than in BH102, followed by BH107, BH103 and BH108. This hydraulic gradient indicates groundwater flow is broadly south towards the Sully Brook, as would be expected.
- Groundwater levels beneath the mound (BH104 to BH106) are typically 2 to 3 m higher than groundwater levels across the rest of the site. This may be due to a greater thickness of made ground in the mound which could store or perch groundwater. BH105 and BH106 are screened through the made ground, as well as the alluvium and weathered mudstone.
- Groundwater levels across the site (excluding the mound) rose by around 4 m on average between 25th August and 3rd October. Groundwater levels subsequently fell by 0.98 m to 2.66 m between 3rd October and 17th October. This is likely to be due to variations in rainfall during the monitoring period.
- Groundwater levels beneath the mound continued to rise throughout the monitoring period. Again, this may reflect the presence of thicker made ground in this area, which may delay the response to rainfall.

Figure 5 shows schematic borehole logs with response zones and groundwater levels.

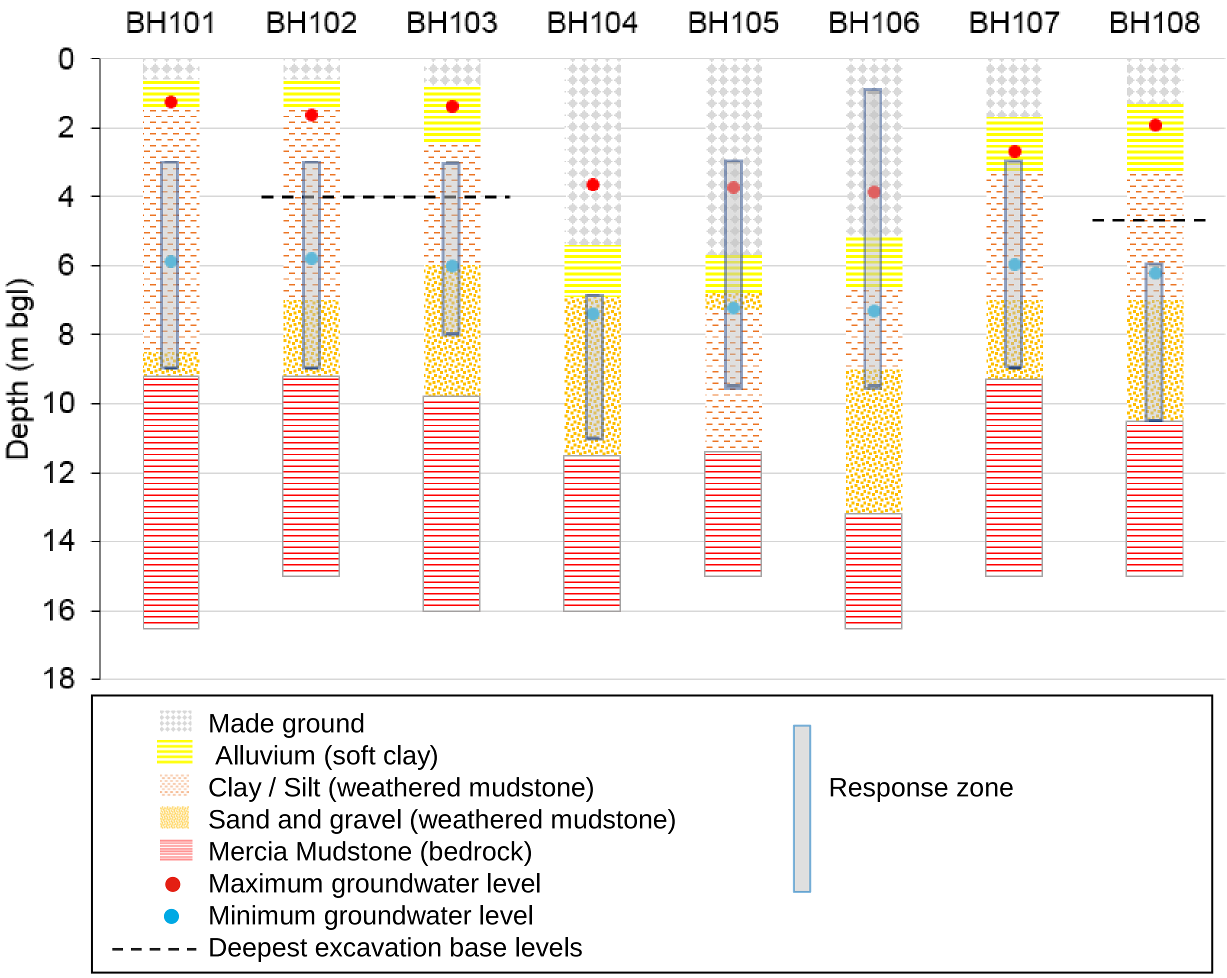


Figure 5 Schematic borehole logs showing groundwater levels

BH108 is closest (approx. 40 m distance) to the FE pumping station excavation (collection point A). Figure 5 shows that groundwater level was 1.5 m below the excavation base (4.7 m bgl) on 25th August 2017. Adjacent to BH108, Trial pit TP107 was excavated to a depth of 3.5 m bgl through made ground and alluvium (clay) on 15th August 2017. No groundwater was encountered.

BH102 and BH103 are closest (40 m and 20 m distance) to collection point B, which will be used for trench dewatering. Groundwater levels in BH102 and BH103 were 1.78 m and 2.01 m below the base of collection point B (4 m bgl) on 25th August 2017.

These data indicate that during dry periods groundwater levels in the weathered mudstone will be below the depth of collection points A and B, and therefore little or no dewatering will be required for these excavations during dry periods.

Figure 5 shows that recorded maximum (shallowest) groundwater levels are above the deepest excavation levels. Groundwater will therefore, at times, seep into the excavations and dewatering will be required. Given that the site is immediately adjacent to a marsh (Cog Moors SSSI), we would anticipate groundwater levels to be close to ground level during wet periods, especially in winter when there will be little evapotranspiration.

2.1.2 Permeability estimates

In the absence of in-situ permeability testing we have made some estimates of permeability based on particle size distribution (PSD) data from samples of made ground and weathered bedrock (sand and gravel). Permeability values were calculated using the Kozeny-Carman formula.

There are no PSD data for samples from the alluvium or silt/clay layers of the weathered bedrock. However, water strikes during borehole drilling were typically encountered in the clay/silt weathered bedrock layer. Groundwater strike levels and the water level after 20 minutes were recorded. We have used this data to estimate permeability values using the rising head test analysis (velocity graph method) as described in British Standard 22282-2:2012.

Our estimates of permeability values are summarised in Table 2.

Table 2 Summary of permeability estimates from PSD data and water strikes

Test Location	No. of samples/ tests	Geometric mean permeability (m/s)	Minimum permeability (m/s)	Maximum permeability (m/s)
Made Ground	17	2.05×10^{-4}	1.62×10^{-5}	2.77×10^{-3}
Weathered bedrock (clay/ silt)	7	7.69×10^{-6}	3.90×10^{-6}	1.96×10^{-5}
Weathered bedrock (sand and gravel)	5	1.10×10^{-4}	1.92×10^{-5}	7.21×10^{-4}

It is acknowledged that there are several assumptions and potential biases within each of these methods. However, the estimated values are within the range of published estimates for similar sediment types (e.g. Freeze and Cherry, 1979) and are therefore considered valid for this level of assessment.

It is worth restating that the sand/gravel layer is generally described as a clayey sand/gravel and is derived from weathering of the mercia mudstone. Therefore, this layer is not a well sorted river gravel that would be expected to have a very high permeability.

2.2 Water resource and environmental constraints

The superficial deposits at the site are designated a Secondary A aquifer. The bedrock is designated a Secondary B aquifer. Secondary aquifers may be important water sources for small-scale water supplies and baseflow to rivers.

According to the Geo-environmental report (Arcadis, 2018) the closest licenced abstraction is approximately 600 m northeast of the site. The superficial deposits beneath Cog Moors WWTW are not present at the location of this abstraction, and it is therefore very unlikely to be affected by the proposed dewatering. We have contacted NRW to confirm the location of this abstraction. At the time of writing we are awaiting confirmation from NRW.

Vale of Glamorgan Council were consulted regarding Private Water Supplies. The Council told us there are no private water supplies within 1 km of the site[2], and we await written confirmation of this. Also, the site does not lie within a Source Protection Zone (SPZ). All this evidence indicates there are no potable groundwater supplies that rely on the aquifer beneath Cog Moors WWTW.

[2] Telecon with Mr R Morgan, Specialist Services Officer

The Ordnance Survey map shows a well (marked 'W') approximately 200 m west of the site (Figure 1). Although we are not aware of the status of this well, our assessment indicates it is unlikely to be affected by the proposed dewatering (Figure 8).

Cog Moors SSSI is located immediately adjacent to the site as shown in Figure 6. The SSSI citation for Cog Moors (CCW, 2000) and information on the NRW website[3] states the following:

"Cog Moors SSSI consists of a group of fields on low-lying land. The fields are situated on almost flat ground and are separated by ditches, bordered by hedges or rows of hawthorn trees. In some winters much of the site is under water for several weeks."

"Cog Moors SSSI is of special interest for its large continuous area of damp mesotrophic (neutral) semi-natural grassland, which is associated with several stands of tall sedges, and for populations of two uncommon plant species."

"Because of the damp, clayey soils and high water table, the neutral grassland here is not typical. The grassland at Cog Moors represents an example of coastal and floodplain grazing marsh."

Previous extension works were undertaken at Cog Moors WwTW in 2007 (Arup, 2007). These works extended into an area of Cog Moors SSSI at the western end of the WwTW. As part of the Environmental Action Plan, this area of SSSI was translocated into the Cog Moors Site of Importance for Nature Conservation (SINC) with a management and monitoring plan put in place. The receptor site for the SSSI habitat is located to the south of the existing WwTW (outside of the planning application boundary for the proposed Development) and should therefore remain undisturbed as part of these works. Figure 6 shows the area of Cog Moors SSSI that was translocated.

In addition, There is one non-statutory designated site within the proposed Development site, Cog Moors Site of Importance for Nature Conservation (SINC), which is designated for its series of species-rich rush pastures and presence of Tubular Water-Dropwort.

[3] https://naturalresources.wales/guidance-and-advice/environmental-topics/wildlife-and-biodiversity/find-protected-areas-of-land-and-seas/sites-of-special-scientific-interest-sssis/?lang=en

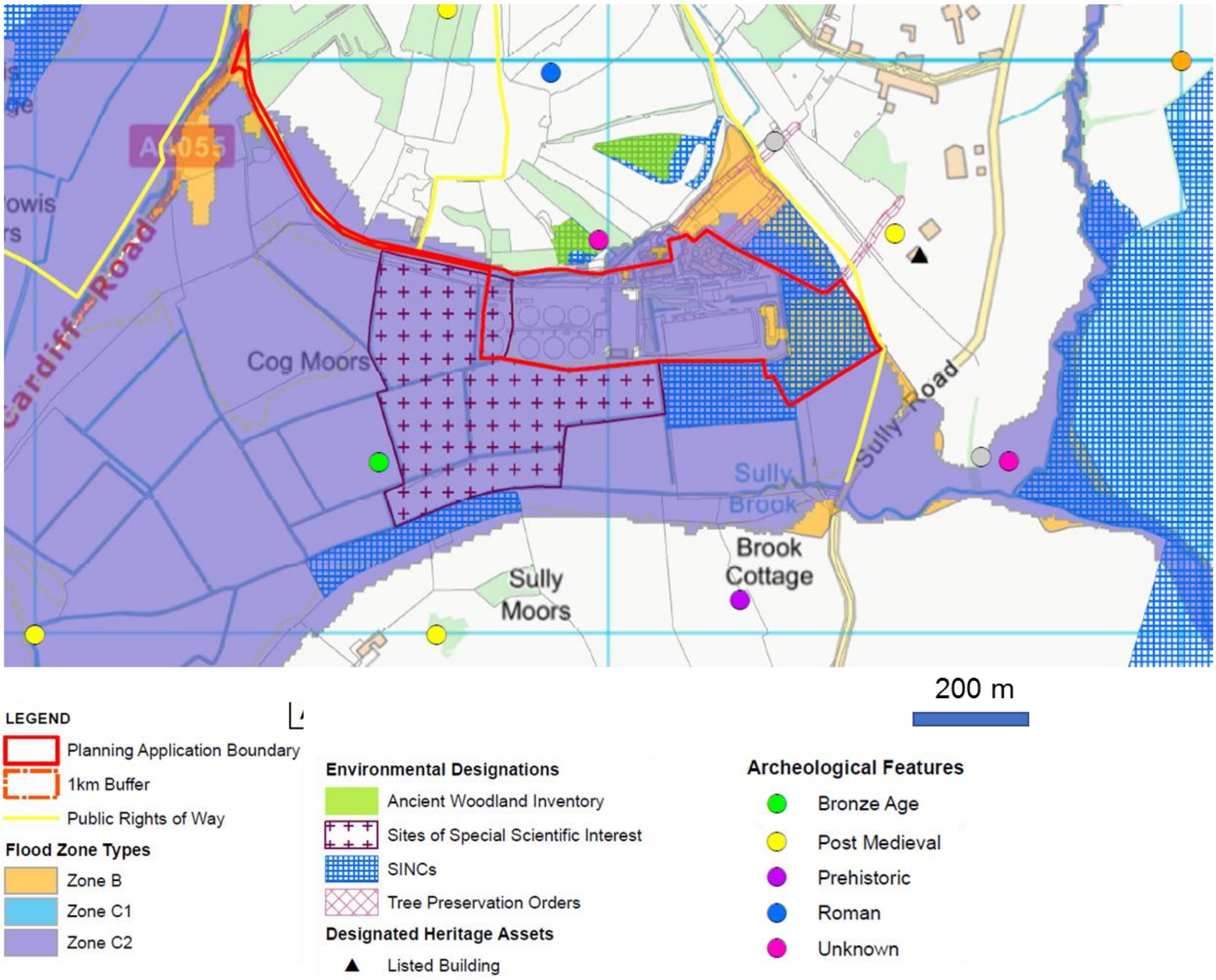


Figure 6 Environmental constraints

2.3 Conceptual site model

Figure 7 shows a hydrogeological cross section through the site (north – south orientation). The geological sequence is based on ground investigation boreholes and BGS historical borehole records as described in section 2.1.

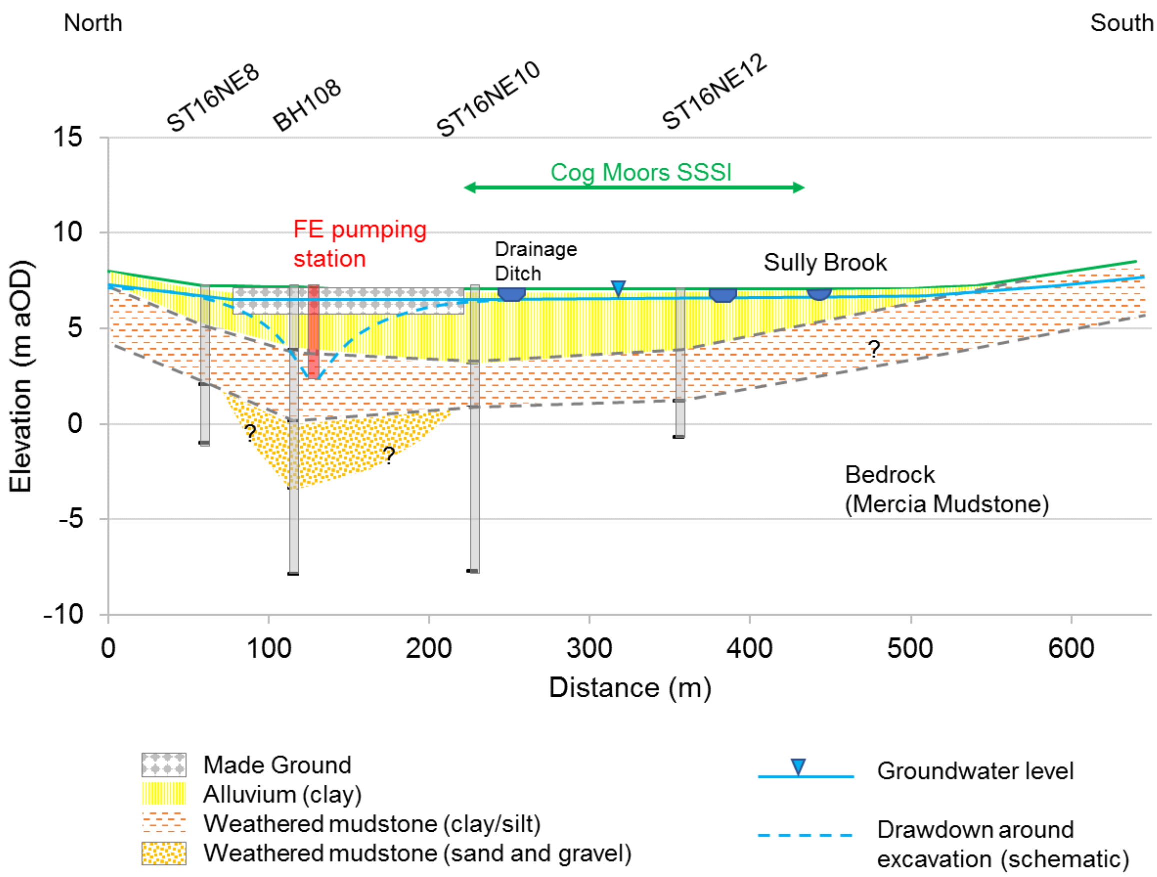


Figure 7 Schematic hydrogeological cross section (north – south)

The key features of the conceptual model are:

- Excavations for the FE pumping station (collection point A) and collection point B for trench dewatering are likely to encounter made ground, alluvium (soft to stiff clay), and weathered mudstone (silt/clay).
- Groundwater levels are likely to be close to ground level during wet periods, especially in winter when there will be little evapotranspiration. Groundwater will therefore, at times, seep into the excavations and dewatering will be required.
- However, groundwater levels in weathered mudstone layers vary significantly. During dry periods it is likely that groundwater level will be below the excavations and little or no dewatering will be required.
- Made ground is likely to be resricted to the site and therefore dewatering of this layer is unlikely to impact any off-site sensitive areas (Cog Moors SSSI).
- Alluvium and weathered mudstone (silt/clay) layers are likely to have low to very low permeabilities.
- The weathered mudstone (sand/gravel) layer is likely to have a higher permeability. This layer seems to be discontinuous and is likely to be below the maximum depth of excavations for collection point A and B.
- However, BGS historical boreholes recorded the top of the sand and gravel layer to be present from 2.1 to 2.5 m bgl in the eastern part of the site (Figure 3). Therefore, it is likely that trenches in this area excavated to depths greater than ~2 m will encounter this more permeable water-bearing sand and gravel layer.

- Cog Moors SSSI is immediately adjacent to the site. The presence of low permeability clay soils on low-lying land, suggests the water balance is likely to be dominated by direct rainfall and flow / flooding of Sully Brook and drainage ditches. We anticipate that groundwater flow into the SSSI would be small and of relatively minor significance to the designated features. However, groundwater level (a high water table) is clearly important in maintaining the marsh conditions.
- It is uncertain whether there is a hydraulic connection between the weathered mudstone (sand/gravel) and any (perched?) water within the alluvium. Based on the typical description of the alluvium as soft clay and the variation in groundwater levels observed in the weathered mudstone it would suggest that the marsh conditions / saturated ground are likely to be maintained by seasonal flooding of the Sully Brook and ditches onto slow-draining clay soils, rather than perennial groundwater upflow from the weathered mudstone.

2.4 Radius of influence

For the purposes of a dewatering impact appraisial, the radius of influence defines the area in which groundwater levels will be lowered (impacted). The radius of influence depends on the strata that are being dewatered, their hydraulic properties (permeability), and drawdown in the excvation (the vertical distance between rest water level and the excavation base level). The radius of influence for dewatering can be calculated using the Sichardt formula:

$$R_0 = Cs\sqrt{K}$$

Where:

R_0	the radius of influence
C	an empirical calibration factor
S	the maximum drawdown in the excavation
K	the hydraulic conductivity (permeability)

If s and K are in m and m/s respectively, C is usually taken as 3000 for radial flow (Somerville, 1986).

2.4.1 Collection point A (FE pumping station)

The maximum depth of excavation for the FE pumping is 4.7 m bgl. The geological sequence recorded in borehole BH108 indicates that the excavation is likely to made ground, alluvium and weathered mudstone (clay), with the permeable sand/gravel layer more than 2 m beneath the maximum depth of excavation.

Estimated permeability values for the weathered bedrock (clay/silt) based on water strike data from the site are summarised in section 2.1.2. The maximum permeability based on water strike data is estimated to be 1.96×10^{-5} m/s (Table 2). As a conservative adjustment for this impact assessment we have used 5×10^{-5} m/s as the maximum estimate of permeability for the weathered bedrock (clay/ silt) to match the higher values of published estimates for silt (Freeze and Cherry, 1979). There are no data with which to estimate the permeability of the alluvium, however this is antipated to have a similar or lower permeability than the weathered bedrock, so the calculations are conservative. As discussed above, made ground is likely to be resricted to the site and therefore dewatering of this layer is unlikely to impact any off-site sensitive areas.

For the puposes of this impact assessment we have also conservatively assumed that the groundwater level will be at ground level (i.e. saturated ground during wet periods). Therefore drawdown is equal to the full depth of excavation, 4.7 m.

Results shown in Table 3 indicate a radius of influence of approximately 40 m based on the expected (geometric mean) permeability value from site data. The radius of influence may extend almost 100 m if the maximum permeability estimate (5.0 x 10^{-5} m/s) is more representative.

Table 3 Radius of influence calculations for the FE pumping station excavation

Parameter	Expected	Minimum estimate	Maximum estimate
Maximum drawdown in excavation (*s*)	4.7 m	4.7 m	4.7 m
Permeability (*K*) m/s	7.69 x 10^{-6}	3.90 x 10^{-6}	5.0 x 10^{-5}
Radius of influence (R_0)	39.1	27.8	99.7

2.4.2 Collection point B (for trench dewatering)

Trenches will be excavated across the eastern and central part of the site to install pipelines and services, as shown on Figure 2. The trenches will be excavated outwards from a central (deepest) point and the base of the trenches will be backfilled with a permeable gravel bed. Groundwater that seeps into the trenches (and rainfall directly into the excavation) will be allowed to flow back through the permeable gravel bed to the central collection point B. This collection point for trench dewatering will have dimensions of approximately 0.6 m diameter and 4 m depth.

Groundwater levels will be lowered to, and therefore drawdown will occur around i) the base of collection point B, and ii) the base of the trench sections.

2.4.2.1 Collection point B

The geological sequence recorded in boreholes BH102 and BH103 indicates that collection point B is likely to encounter made ground, alluvium and weathered mudstone (clay), similar to collection point A.

Results shown in Table 4 indicate a radius of influence of approximately 33 m based on the expected (geometric mean) permeability value from site data. The radius of influence may extend almost 85 m if the maximum permeability estimate (5.0 x 10^{-5} m/s) is more representative.

Table 4 Radius of influence calculations for collection point B (trench dewatering)

Parameter	Expected	Minimum estimate	Maximum estimate
Maximum drawdown in excavation (*s*)	4.0 m	4.0 m	4.0 m
Permeability (*K*) m/s	7.69 x 10^{-6}	3.90 x 10^{-6}	5.0 x 10^{-5}
Radius of influence (R_0)	33.3	23.7	84.9

2.4.2.2 Trenches and reen diversion

The geological sequence recorded in BGS historical boreholes (ST16NE14, ST16NE15, ST16NE16 and ST16NE2) recorded the top of the weathered mudstone (sand/gravel) was encountered from 2.1 to 2.5 m bgl in the eastern part of the site. Therefore, it is likely that trenches in this area excavated to depths greater than ~2 m bgl will encounter this more permeable water-bearing sand and gravel layer. However, it should be noted that only certain sections of trenches will be excavated below 2 m depth. The trench sections being constructed across the site are summarised below:

- Cable Ducting ~400 m at 1.5 m depth
- Pressurised pipelines ~950 m at average of 2 m depth
- Gravity fed pipelines ~250 m at average of 2 m depth
- HV Cable ~130 m at 1.2 m depth
- Drainage ~800 m at 2.5 m depth

Results shown in Table 5 indicate a radius of influence of approximately 126 m based on the expected (geometric mean) permeability value from site data. The radius of influence may extend over 320 m if the maximum permeability estimate (7.21 x 10^{-4} m/s) is more representative.

Table 5 Radius of influence calculations for trenches

Parameter	Expected	Minimum estimate	Maximum estimate
Maximum drawdown in excavation (*s*)	4.0 m	4.0 m	4.0 m
Permeability (*K*) m/s	1.1 x 10^{-4}	1.92 x 10^{-5}	7.21 x 10^{-4}
Radius of influence (R_0)	125.7	52.6	322.1

The reen (drainage ditch) within the southeast corner of the site will be diverted to enable part of the upgrade works. The excavation depth will be 2 m bgl. Therefore, seepage through the base of this excavation, and hence some drawdown, cannot be ruled out. As the maximum drawdown would be 2 m, the radius of influence would be half that listed in Table 5.

It is anticipated that during most of the construction period, only one trench section will be open at any one time. There may occasionally be a requirement to have two trench sections open at the same time. However, this is unlikely to have a significant effect on the radius of influence because the objective is to maintain a lower water level, not to maintain a flow rate. In other words, if the permeability is high, the drawdown around the ‘first’ trench will lower the water level at the ‘second’ trench, and less will need to be pumped from the second trench. If the permeability is low, the radius of influence around each trench will be towards the minimum estimate.

2.5 Impact appraisal

Figure 8 shows the 'worst-case' extents of cones of depression surrounding the proposed collection points and trenches, based on the maximum estimated radii of influence.

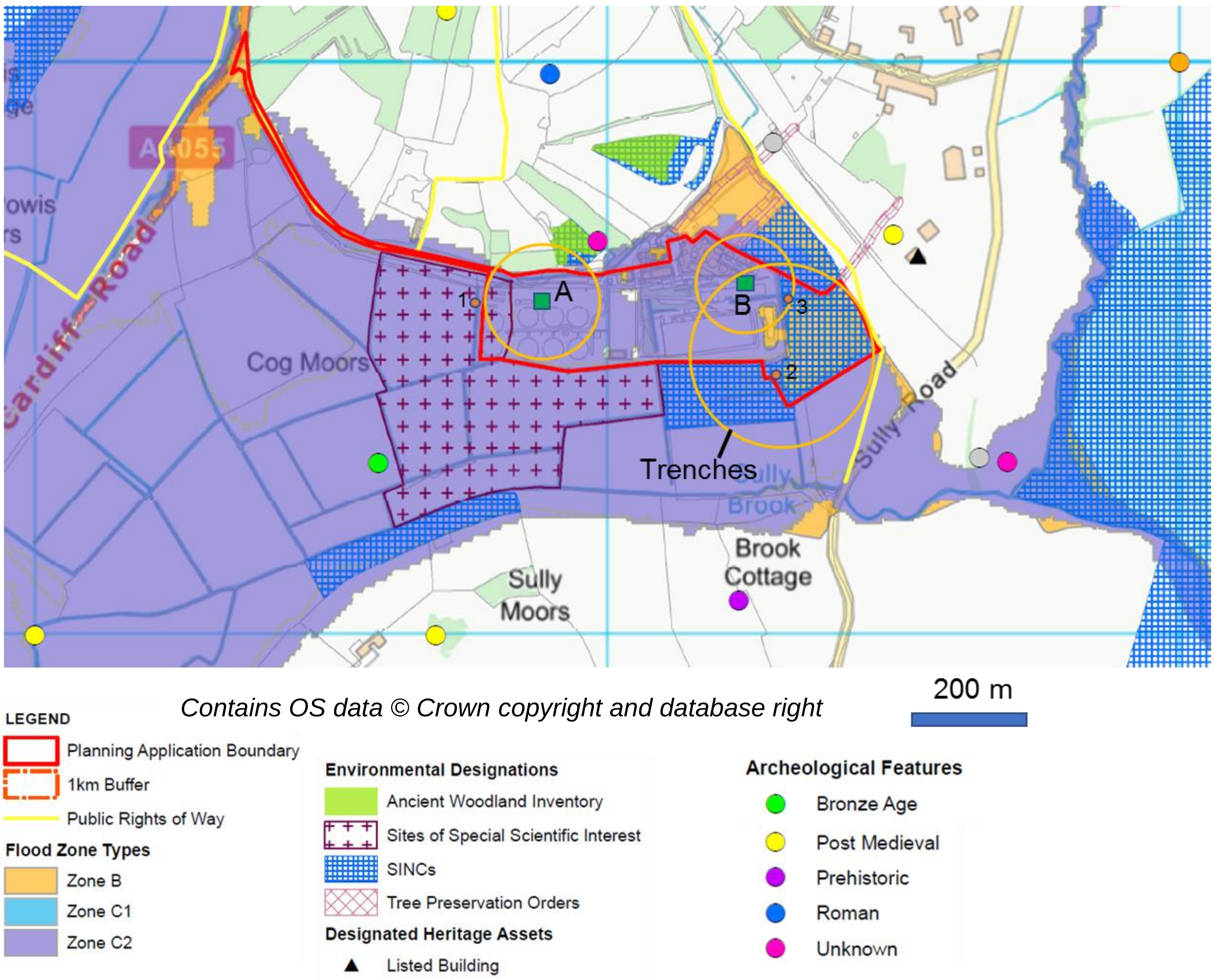


Figure 8 Cones of depression (maximum estimates) surrounding proposed collection points and trenches

The cone of depression around collection point A extends into Cog Moors SSSI, but only to the area which has been already translocated. The cones of depression for collection point B and the trenches extend into Cog Moors SINC, but not the SSSI wetlands. The cone of depression for the trenches is centred on the eastern part of the site where the weathered mudstone (sand/gravel) layer is most likely to be encountered. It is acknowledged that the cones of depression for collection point B and the trenches overlap and therefore there will be superposition effects (i.e. additional drawdown). However, the calculations and conceptual model are conservative in several other ways:

- The calculations are a worst-case scenario which use the maximum permeability estimates and assumes groundwater level is at ground surface. However, as shown in Figure 5, groundwater level data indicate that during dry periods groundwater levels will be below the depth of excavations, and therefore no dewatering will be required. Hence there will be no impact on groundwater levels during these periods.
- As noted in section 1.2, the FE pumping station excavation is likely to remain open for only 1 month therefore drawdown will be temporary. This excavation is currently scheduled to be in October / November 2018. Groundwater levels in shallow aquifers are typically at the lower levels of the range in autumn, following summer recession, especially given the current hot, dry weather (June / July 2018).

- Drawdown will reduce with distance from the excavation. For a 322 m distance of influence around the trenches (4 m deep), drawdown would be less than 0.8 m at a distance of 160 m from the excavation i.e. 20% of the drawdown at 50% of the radius of influence, as shown in CIRIA guidance R113 (Somerville, 1986). At the small area of SINC on the northeastern edge of the cone of depression for collection point A (Figure 8), drawdown is likely to be only a few centimetres.
- Figure 5 also shows that the range of groundwater level is at least 4 m in the weathered mudstone, hence the drawdown outside of the site will be well within natural variation in groundwater level.
- Only certain sections of trenches will be excavated below 2 m depth and therefore not all trenches will encounter the permeable sand and gravel layer. In those areas the radius of influence will be significantly reduced.
- It is proposed that any water drawn from the collection points will be discharged into the nearby drainage ditches, which flow into Cog Moors SINC and SSSI. Therefore, there will be no net loss of water from the catchment.

In summary we conclude that there is a low risk of significant impact from dewatering on water features outside of the site boundary including Cog Moors SSSI.

2.6 Dewatering rate estimates

Estimates of the dewatering rates are given below based on the Theim-Dupuit equation for steady-state flow to a well in an unconfined aquifer:

$$Q = \pi K \frac{(H^2 - h^2)}{\ln(\frac{R_0}{r})}$$

Where:

Q	flow rate into the well (or excavation)
K	hydraulic conductivity (permeability)
H	height of the water table above the base of the aquifer at the radius of influence
h	height of the water table above the base of the aquifer at the well (excavation)
R_0	radius of influence
r	radius of the well (or equivalent radius of excavation)

Table 6 lists the parameters and results of dewatering rate calculations for the combined weathered mudstone and alluvium layers.

Table 6 Parameters and results of dewatering calculations from the alluvium and weathered mudstone

Parameter	Collection point A	Collection point B	
		Collection point	Trenches (per 15 m section)
K (m/s)	5.0×10^{-5}	5.0×10^{-5}	7.21×10^{-4}
H (m)	10.5	9.8	11.5
h (m)	5.8	5.8	7.5
R_0 (m)	39.1	33.3	125.7
r (m)	2.82	0.3	2.2
Q (l/s)	4.6	2.1	49.1

The calculations use maximum permeability (*K*) values for the strata being dewatered, as listed in Table 3, Table 4 and Table 5. Values for *H* and *h* use the base of the weathered mudstone from the borehole logs as the base of the aquifer. The radii of influence (R_0) are taken from the calculations in section 2.4. In all cases the values used are conservative i.e. these are likely to predict the maximum dewatering flow rates.

In addition to groundwater seepage from the weathered mudstone, nuisance water may enter the excavations from seepage from the made ground and direct rainfall.

Seepage from the made ground is estimated to be up to 1 l/s based on the Theim-Dupuit equation using the maximum permeability estimate of 2.77 x 10^{-3} m/s and a thickness of 1.6 m as listed in section 2.

Rainfall may enter the excavation directly or via runoff. The site is almost flat and therefore it is anticipated that runoff into the excavation can be minimised by simple methods e.g. sand bags and diversion to drains. However, as a conservative estimate we have taken an area of 25 m x 25 m surrounding the excavation. A very significant storm event (1 in 30 year) might deliver 70 mm of rainfall in 6 hours, which equates to an instantaneous flow rate of 2 l/s.

Table 7 combines the dewatering rates from Table 6 with the estimated seepage from made ground and rainfall and runoff to give total rates of removal of nuisance waters from each collection point. As stated in section 2.4.2.2, it is anticipated that during most of the construction period, only one trench section will be open at any one time. However, there may occasionally be a requirement to have two trench sections open at the same time. The totals are rounded up to the nearest 10 l/s as it likely to be difficult to closely control the flow rate of pumps.

Table 7 Instantaneous dewatering rate estimates in litres per second

Parameter	Collection point A	Collection point B	
		Collection point	Two trench sections
Groundwater seepage from alluvium and weathered mudstone	4.6	2.1	85.1
Seepage from made ground	1	1	2
Rainfall and runoff	2	2	4
Totals	7.6	96.2	
Totals rounded up to nearest 10 l/s	10	100	

The instantaneous dewatering rate estimates given above are conservative in that they use maximum permeability estimates and assume groundwater levels are at ground surface. We are unable to specify daily or annual volumes. Dewatering will only occur when necessary. When groundwater levels naturally fall below the excavations in dry summer periods, there will be no requirement to dewater. Data from the site indicates groundwater levels vary significantly and likely to be rainfall dependant. It is therefore anticipated that long term (annual) dewatering rates will be significantly lower than the equivalent of instantaneous rates.

As an upper estimate, the annual dewatering rate is unlikely to exceed groundwater recharge. The area of superficial deposits upstream of the site is estimated to be 317,845 m^2. Annual average rainfall at the site is approximately 1100 mm. The presence of clay soils likely restricts the recharge to around 30% of rainfall. Therefore, total annual recharge to the superficial deposits around the site is likely to be no more than 104,889 m^3.

To reiterate, it is proposed that any water drawn from the collection points will be discharged in to the nearby drainage ditches, which flow in to Cog Moors SSSI. Therefore, there will be no net loss of water from the catchment.

3 Discharge assessment

3.1 Discharge rate

Scoping calculations have been undertaken to estimate the capacity of the land drainage ditches around Cog Moors WWTW. These calculations are required so that the capacity of these ditches to accept flows from dewatering activities during construction works can be assessed. A summary of the calculations is given below and the full calculation sheets are presented in Appendix C.

The following key features of the land drainage ditches have been estimated from site visit observations (undertaken 13/06/2018) and a review of available data:

- Channel shape - trapezoidal
- Height to top of bank – 1 m
- Channel bed width – 1 m
- Trapezoidal channel side slope - 1:2 gradient.
- Channel roughness - Manning's value of 0.05. This is representative of a straight channel that has a relatively high degree of vegetation.
- Channel gradient – 0.0005 m/m. Lidar data shows that the land in this area is very flat, so a low gradient has been adopted.

It was not possible to obtain detailed channel measurements during the site visit and a walkover of the entire drainage network was not undertaken. Therefore, the above channel details are high level estimates only, however, they are considered to be conservative estimates and appropriate for this assessment.

The capacity within the land drainage ditches to accept de-watering discharges will vary depending on the existing water levels. The water levels in the ditches would be expected to vary, for example, due to seasonal variation, weather conditions, etc. Therefore, for the purposes of this study, we have estimated the maximum capacity within the ditch i.e. dry prior to the discharge (note: this was the condition at the time of the site visit) and if the ditch was already half full.

The Manning's open channel flow equation has been used to estimate flow capacity within the land drainage channels.

The channel capacity estimates, as detailed in the attached calculation sheet, are detailed below:

- Maximum channel capacity – 0.40 m^3/s (400 l/s)
- Available capacity when channel is already half full – 0.28 m^3/s (280 l/s)

When compared to the maximum estimated peak dewatering rates of 10 l/s and 100 l/s for collection points A and B respectively, this indicates that the ditches have the capacity to convey water from the dewatering.

3.2 Water quality

Eight groundwater samples, one from each borehole, were obtained during the ground investigation (Arcadis, 2018). Laboratory testing results were either recorded below the relevant screening values or below the laboratory limit of detection for PAHs, TPH CWG, BTEX and volatile organic compounds. Minor exceedances of the Environmental Quality Standards (EQS) for some metals are listed in Table 8.

Table 8 Summary of water quality results

Determinand	Min (µg/l)	Max (µg/l)	EQS-AA (µg/l)	Number of exceedances	Boreholes with exceedances
Chromium (total)	<0.2	16	4.7	1	BH103
Chromium VI	<5	19	3.4	1	BH103
Copper	1.7	6.6	1	8	All boreholes
Zinc	2.2	13	10.9	2	BH101, BH104

In considering the potential impact of these minor exceedances, it should be noted that dewatering and discharge of groundwater is likely to occur during wet periods when the flow in drainage ditches and Sully Brook is likely to provide significant dilution of the discharged water.

Chromium was only found in one borehole and zinc in two, indicating low level contamination is isolated to a few locations. Therefore, it is likely there will be some dilution of these metals within the excavation dewatering itself, prior to discharge.

4 Summary and conclusions

Cog Moors Waste Water Treatment Works (‘the site’) is currently being upgraded by Skanska UK Construction Ltd (Skanska) on behalf Dŵr Cymru Welsh Water. As part of the upgrade works, excavations below the water table are required to construct a Final Effluent (FE) pumping station and trenches for buried pipelines and a culvert. These excavations will take place over a period of approximately 2 years, commencing in autumn/winter 2018.

The FE pumping station will be constructed in the western part of the site and trenches will be excavated in sections, mostly in the eastern and central part of the site. Any nuisance waters that enter the excavations, which will include groundwater, will be channelled towards two collection points (A and B) and then discharged to nearby drainage ditches. Nuisance water will be treated through a settlement tank to reduce suspended solids and regular visual checks will be made to ensure water is not turbid.

Cog Moors SSSI is immediately adjacent to the site and Cog Moors SINC is within the site boundary. The presence of low permeability clay soils on low-lying land suggests the water balance of these conservation sites is likely to be dominated by direct rainfall and flow / flooding of Sully Brook and drainage ditches. We anticipate that groundwater flow into the SSSI and SINC would be small and of relatively minor significance to the designated features. However, groundwater level (a high water table) is clearly important in maintaining the marsh conditions.

Excavations for the FE pumping station (collection point A) and collection point B for trench dewatering are likely to encounter made ground, alluvium (soft to stiff clay), and low permeability weathered mudstone (silt/clay). Calculations indicate the cone of depression (the area in which groundwater levels will be lowered (impacted)) is unlikely to extend more than 100 m from these excavations. It is likely that trenches in the eastern part of the site excavated to depths greater than ~2 m are likely to encounter a higher permeability weathered mudstone (sand/gravel) layer. Calculations indicate this layer is likely to have a relatively high permeability and the cone of depression may extend over 320 m around a trench section.

The maximum estimated extent cone of depression around collection point A extends into Cog Moors SSSI, but in the area which has already been translocated. The maximum estimated cones of depression for collection point B and the trenches extend into Cog Moors SINC, but not the SSSI. The proposed dewatering is unlikely to have a significant impact on water features outside of the site boundary including Cog Moors SSSI and SINC. Key factors are:

- Construction (and dewatering) activity will be temporary, lasting approximately 1 month for collection point A and 18 months for collection point B for the trenches;
- The dewatering calculations are conservative in that they use the maximum permeability estimates and assume groundwater level is at surface. Monitoring data indicate groundwater levels in weathered mudstone layers vary significantly. During dry periods it is likely that groundwater level will be below the excavations and little or no dewatering will be required;
- Drawdown will reduce with distance from the excavation, and it is likely that drawdown within the weathered mudstone outside of the site boundary will be well within the natural variation of groundwater levels;
- It is proposed that any water drawn from the collection points will be discharged in to the nearby drainage ditches, which flow in to Cog Moors SSSI and SINC. Therefore, there will be no net loss of water from the catchment;
- It is uncertain whether there is a hydraulic connection between the weathered mudstone and any (perched?) water within the alluvium. The site setting and description of Cog Moors SSSI (CCW, 2000) and SINC suggests that seasonal flooding of the Sully Brook and ditches onto slow-draining clay soils is responsible for maintaining the marsh conditions (saturated ground), rather than perennial groundwater upflow from the weathered mudstone. Therefore, interception of groundwater is unlikely to have a significant impact on the SSSI or SINC.

5 References

Arcadis (2018) Cog Moors WWTW Geotechnical and Geo-environmental Interpretive Report. Report No 4793-S-203-HYD-XX-XX-RP-GX-20002. February 2018.

Arup (2007) Cog Moors Waste Water Treatment Works. Mitigation/Environmental Action Plan.

British Geological Survey (1988), BGS Geological Map Series Sheet 263 Cardiff.

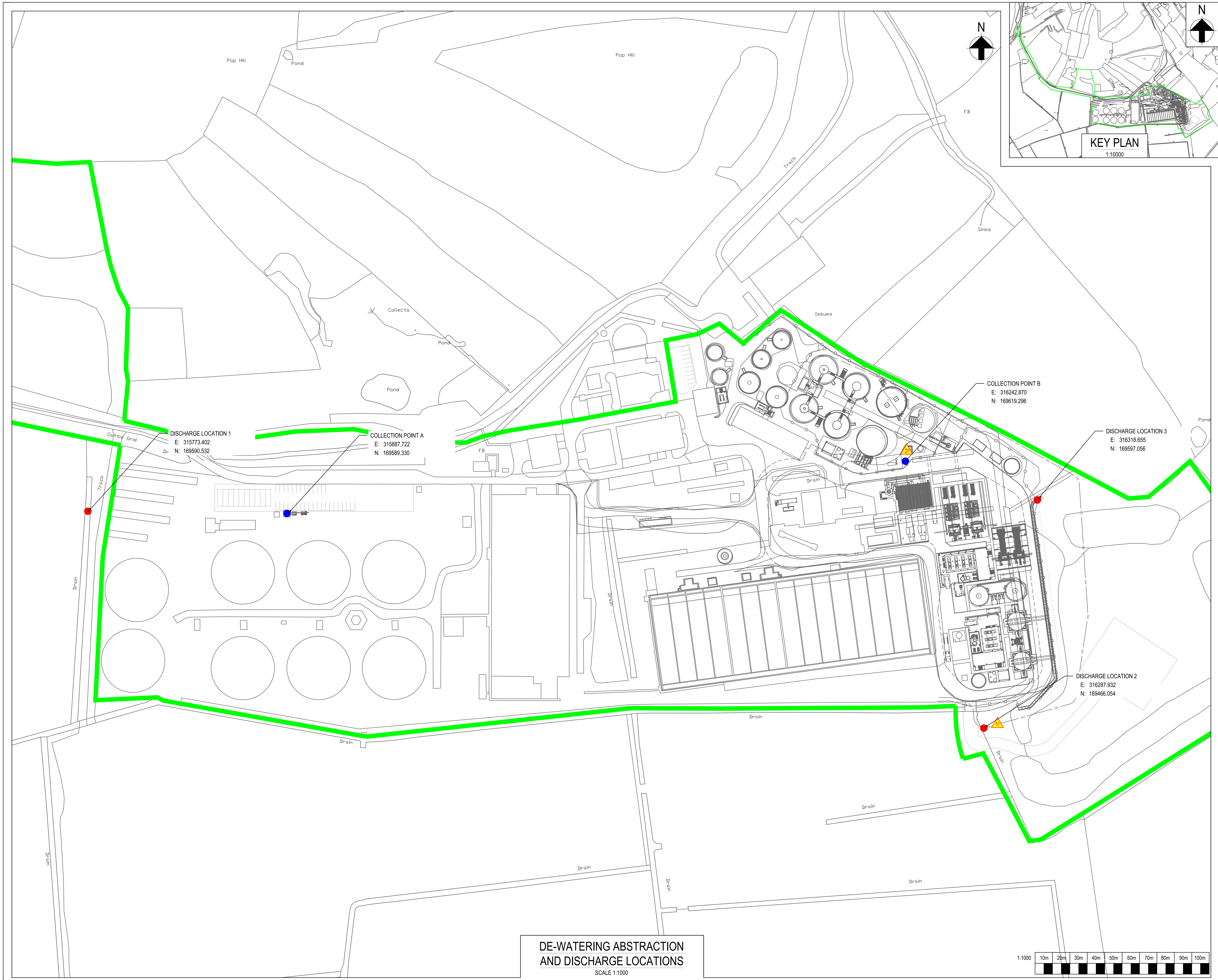
Countryside Council for Wales (CCW) (2000) Cog Moors Site of Special Scientific Interest Citation.

Environment Agency (2007) Hydrogeological impact appraisal for dewatering abstractions. Science Report – SC040020/SR1.

Somerville (1986) Control of groundwater for temporary works. CIRIA report R113.

APPENDIX A

Site plan showing abstraction (collection points) and discharge points



DE-WATERING ABSTRACTION
AND DISCHARGE LOCATIONS
SCALE 1:1000

A1

NOTES:
1. ALL DIMENSIONS ARE IN MILLIMETERS UNLESS OTHERWISE STATED.
2. ALL LEVELS ARE IN METERS RELATIVE TO AOD.
3. DO NOT SCALE FROM THIS DRAWING.
4. CONSULT TOPOGRAPHICAL INOFORMATION AND CONDUCT TRIAL HOLES BEFORE BREAKING ANY GROUND

LEGEND:
- PROPOSED DISCHARGE LOCATION TO DITCH
- PROPOSED COLLECTION POINT
- PLANNING APPLICATION BOUNDARY

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING:

CONSTRUCTION
1 PROPOSED HV CABLE
2 EXISTING AND PROPOSED LIQUOR RETURN PIPELINES

MAINTENANCE / CLEANING / OPERATION

DECOMMISSIONING / DEMOLITION

REFER TO THE DESIGN RISK REGISTER FOR FURTHER DETAILS. IT IS ASSUMED THAT ALL THE WORKS ON THIS DRAWING WILL BE CARRIED OUT BY A COMPETENT CONTRACTOR WHO HAS CARRIED OUT A COMPREHENSIVE RISK ASSESSMENT.

Rev.	Date.	Drawn.	Description.	Chkd.	Appd.	Date.
P01	23/07/18	TH	FOR INFORMATION	MJ	SS	23/07/18

Capital Delivery Alliance
Cynghrair Cyflawni Cyfalaf

Ty Awen, Spooner Close, Coed Kernew, Newport, NP10 8FZ

Project Name. COG MOORS WwTW AAD

Drawing Title. PROPOSED DE-WATERING ABSTRACTION AND DISCHARGE LOCATIONS

Suitability. FOR INFORMATION
Suitability Code. S2

Originator. SS
Designer. TH
Date. 23/07/17

Internal Project Number. UA007902
Scale. 1:1000
Rev. P01

Drawing Number. 4793-S-203-HYD-XX-XX-DR-CX-00502

APPENDIX B

Dewatering method statement

SKANSKA

Dewatering Construction Method Statement for Works within the Floodplain at Cog Moor WwTW

Contract:	Cog Moor WwTW	Method Statement No:	1
Name of Author:	Simon Hazel	Date:	03/07/2018
Name of Approver:	Andrew Bowen	Date:	05/07/2018
Revisions:	1		

No:	Reason	Author	Date	Approved	Date
1	For Comment	Simon Hazel	03/07/2018	Andrew Bowen	05/07/2018
2	Minor tweaks	Stephen Smith	25/07/2018	Simon Hazel	25/07/2018

1.0 References

Relevant drawings attached:

- Cog Moor WwTW Site Layout Plan;
- Cog Moor WwTW Environmental Constraints Plan.

Relevant documents attached:

- Environmental Screening Report;
- Dewatering Construction Method Statement;
- Permit to Pump Form;
- Project Environmental Management Plan;
- Control of Sediment Run Off Plan;
- Discharge of Groundwater Plan;
- Pollution Prevention Plan;
- Environmental Incident Response Plan;
- Environmental Generic Risk Assessment;
- PPG 1 – Pollution Prevention Guidelines;
- PPG 5 - Works in or near a watercourse
- PPG 6 – Pollution Prevention Guidelines for Working at Construction and Demolition Sites;
- PPG 7 – Refuelling Facilities Guidelines;
- PPG 13 – Vehicle Washing and Cleaning.

2.0 Scope of Work

Cog Moor WwTW will require excavations and driving piles to facilitate the construction of the AAD Plant upgrade. Due to the site location, there will be a need to undertake the dewatering of nuisance waters from these excavations to facilitate the works. A key challenge is a high groundwater table, flood plain and tidal effects, and so alternative discharge locations other than onto land need to be considered.

It is proposed that for excavations a collection point and pump system will be used for the dewatering, and for the water to be pumped through pumps – the flows then split into two (if required – dependant on volumes) – through a groundwater treatment system such as settlement tanks (which will be large enough to cater for the predicted volumes). At the proposed discharge locations, the end point of the hose will have a silt sock/ dirt bag (if required) which will be contained with a hay bale to act as the final silt removal point and to remove some of the energy from the water so not to damage the integrity of the ditch.

This method statement and attached appendices (which are available on request) represent the environmentally friendly systems of work associated with the scheme.

Should the scope of work change, first make contact with the Environmental Advisor to ensure compliance, record any emails and ensure handwritten amendments are made to this method statement and risk assessment.

2.1 Competence

All Skanska staff and sub-contractors to be competent and to hold the relevant certifications required for the tasks in hand, and to follow all Skanska and DCWW site procedures, Risk Assessments and Method Statements & CIRIA Tool Box Talks guidance.

3.0 Principal Environmental Considerations

3.1 Significant hazards

- Working adjacent to a watercourse;
- Working compliantly to the consents and permit for the project;

3.2 Definition of Significant

Contamination of the watercourse and flood plain from silts, fuel, stored materials and plant etc in the working area within the flood plain, could lead to bad PR and prosecution from the Regulator: NRW. It is absolutely imperative that these risks are briefed out to all Site Staff and Visitors. Any breaches must be reported to the Site Manager and Environmental Advisor immediately.

4.0 Methodology

Setting up of the Dewatering Operation

Following a number of sites visits, it has been agreed that the proposed discharge points will be as identified on the plan (red dots) below, with another option identified by the orange circle when the culvert is completed.

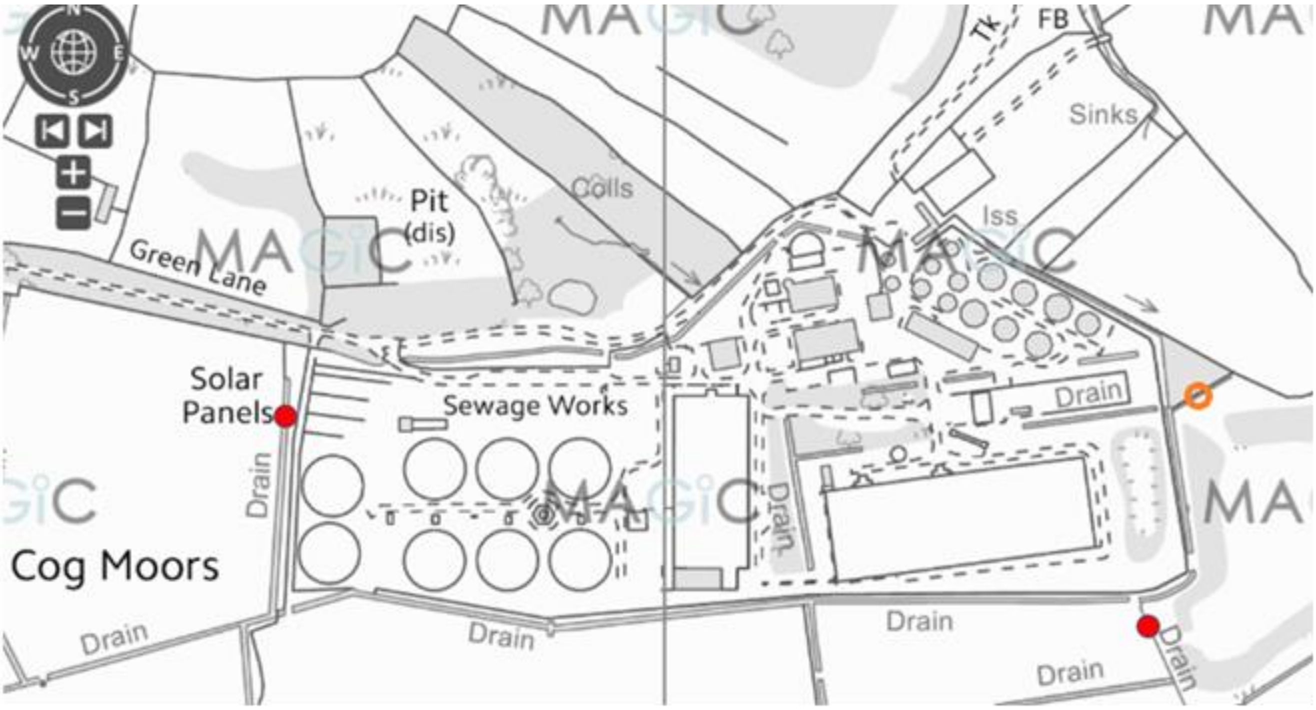


Figure 1: Location of proposed discharge points in relation to Cog Moor WwTW, identified by two red dots and the orange circle

Before any site works commence, the Project Management Team will ensure that they have signed up via twitter, Facebook or mobile for alerts from the NRW/EA for Flood Warning alerts (this has been done already), and display on site the Meteorological Office's 5 Day Weather Forecast to monitor the flood risk for the site that week, and to ensure perishable materials, fuels and chemicals and plant are moved to higher ground.

Before anyone commences work on site, they will have a site induction which will include a comprehensive section on the environment, especially monitoring ditch level flows, pollution prevention and controlling and monitoring of silty surface water from excavations and controlling sediment run off.

Monitoring and Management of the Dewatering Activities for the Excavation(s)

- Any nuisance water that enters the excavations (rain water/ overland surface water/ possible drainage ditch/ groundwater), will be directed into a collection point. From here it will be pumped from the excavation through to its treatment process location, which will be a Siltbuster settlement tank (or equivalent) to remove any suspended solids. After treatment, the nuisance water, will be allowed to discharge into the drainage ditches identified and be subject to regular discharge quality reviews to ensure silty water is not being pumped into them.

Turbidity will be measured by using a clear tube roughly 600mm tall with a circumference of 25 mm, which has a rule down one side which measures from 500 at the bottom then rises to 5 at the top of the tube. There is a black cross at the bottom of the tube which if the water is clear i.e. drinking water, you should be able to see the cross through the water in the tube from the measurement of 5. If the water is extremely dirty you will not see the cross from 500.

Regular monitoring of this water will take place, and only water where the cross can be seen will be permitted to be discharged into the drainage ditches.

Figure 7: Tubes to monitor Turbidity compliance

Silt/ sediment Filtration Processes

- All dewatering of excavations will require filtration in the form of a collection point and pump system, through a Siltbuster (or equivalent) and silt socks (if required

The proposed plan is as follows:

1. Collection points set up within the excavations on site;

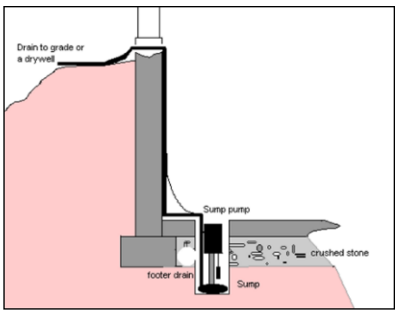


Figure 8: Proposed example of a collection point set up

2. Flows pumped up to the Siltbuster – flows split to go through Siltbuster Settlement Tanks (HB50 or equivalent) and a pH adjustment process, to remove the fines and neutralise the flows.

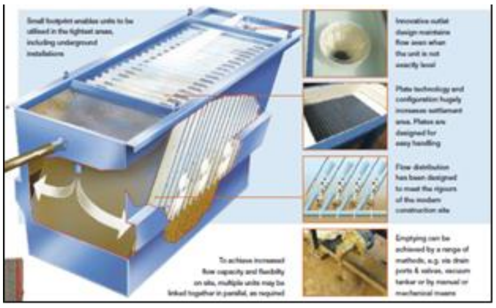


Figure 9: Set of the silt filtration units: flows split into two and through an HB50 or equivalent settlement system

3. A silt sock will (if required) be placed over the end of the discharge hose which will be located within a temporary fixed point at the discharge point.

4. Carry out regular checks using the permit to pump checklist.

- If the excavations determine that we need to use well-point dewatering, then we will ensure this method is followed to ensure the silt/ sediment filtration processes are not overloaded at the point of discharge.

<u>Environmental/ Water Quality Monitoring of the Discharges</u>

- A bespoke permit to pump form will be used for each discharge point, with a written record of any observations made each day, and un-recorded informal checks carried out during the day. As part of the induction and subsequent on-site training the emphasis will be on everybody working on site to have responsibility for checking the outfalls and to report any issues to their Supervisor;

- Whoever is carrying out the recorded and un-recorded checks will be looking out to see that ***"the discharge must have no adverse visible effect on the receiving water, the bed of the watercourse or any plants or animals within the watercourse";***
- Photographs will be taken upstream and downstream of the discharge points to demonstrate that the dewatering discharge points are creating 'no adverse visual effect' on the receiving watercourses on a daily basis.

Emergency Procedure for the Discharges

- If at any time, the turbidity of the water being discharged is silty and causing a visible silty slick in any of the drainage ditches, the pumps will be switched off immediately, works will cease, the NRW will be notified and arrangements to rectify the situation will commence.

Precautions to be taken at the End of the Working Shift

- At the end of the working day all plant and equipment should be positioned and immobilised so that it is safe and does not interfere or obstruct other contractors – this will be either in the site compound or the working area. Small items of plant should be isolated and left in a safe position with a drip tray or plant nappy underneath;
- All fuel points or bowsers are to be secured and positioned as to reduce the risk from theft or vandalism;
- The site manager will review the weather forecast, monitor any flood alerts and discuss the appropriate action to be taken with the Environment Advisor.

APPENDIX C

Channel capacity calculations

ARCADIS Design & Consultancy for natural and built assets	DOCUMENT No. (Project/Doc.)	SHEET No. 1

SUBJECT COG MOOR DITCH CAPACITY CALCULATIONS

REF	CALCULATIONS	OUTPUT

FULL CAPACITY

$$A = \frac{1+2}{2} \times 1 = 1.5\ m^2$$

$$P = 1 + 2(1)\sqrt{1+0.5^2} = 3.24\ m$$

$$Q = \frac{1}{0.05} \times \frac{(1.5)^{5/3}}{(3.24)^{2/3}} \times 0.0005^{1/2} = \underline{0.40\ m^3/s}$$

HALF CAPACITY

$$A = \frac{1+1.5}{2} \times 0.5 = 0.625\ m^2$$

$$P = 1 + 2(0.5)\sqrt{1+0.5^2} = 2.118\ m$$

$$Q = \frac{1}{0.05} \times \frac{(0.625)^{5/3}}{(2.118)^{2/3}} \times 0.0005^{1/2} = \underline{0.12\ m^3/s}$$

CAPACITY FOR ABSTRACTION

FULL CAPACITY − HALF CAPACITY = $0.40 - 0.12 = \underline{0.28\ m^3/s}$

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