Construction-phase dewatering hydrogeological impact assessment: Parc Awen, Llanelli

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1. Introduction

1.1. Instruction

Englobe regeneration (UK) Ltd (Englobe; the Client) are providing specialist remediation contracting services to Bouygues (UK) Ltd (BUK), who are the Main Contractor responsible for the development of Parc Awen Wellness and Life Sciences project in Llanelli, Carmarthenshire (the Site).

As part of their ongoing role, Englobe have been asked to provide support to the dewatering that is required in order to reduce the elevation of the groundwater table sufficiently to enable construction of the new swimming pools, and to provide help with the treatment of any other incidental waters that require management on the Site. Yellow Sub Geo Ltd (Yellow Sub) has been employed by Englobe to provide technical support in assessing the potential hydrogeological impacts of the dewatering, in order to support the application for an Environmental Permit for the dewatering works.

1.2. Scope

The scope of works was agreed between Englobe and Yellow Sub, and comprises:

- Undertaking a review of the information available from the suite of documents that have already been compiled on the ground and groundwater conditions beneath the Site, by a range of parties, as part of the support of the planning application for the Site's redevelopment. These documents and their contents are discussed further in Section 2.
- Attending Site to undertake a water features survey of the Site and its environs. The findings of the water features survey are discussed in Section 3.
- Undertaking a hydrogeological modelling exercise, modelling the potential impacts of the dewatering activity on the environment, with particular focus on surface water features. This modelling is reported upon in Section 4.
- Using the results of the above to undertake a hydrogeological risk assessment of the proposed dewatering works. This assessment is provided in Section 5.

1.3. Limitations

This report is subject to the Report Conditions provided in Appendix A.

2. Site information

In order to inform the subsequent assessment work, a desk-based review of the available documents was undertaken, to identify and collate the information pertaining to the proposed works and the groundwater and ground conditions beneath the Site. The results of this work are summarised in the following paragraphs:

2.1. Documents reviewed

The following documents were provided by Englobe for review, or obtained via a search of the Carmarthenshire County Council planning portal:

- Curtins Drawing Ref. C-92001 Proposed drainage layout. Issue P07 dated 25th October 2022.
- Curtins Drawing Ref. S-21501 Sections. Issue P08 dated 7th January 2021.
- Curtins Drawing Ref. C-92031 Drainage Details. Issue P01 dated 15th July 2022.
- Arup Remediation Strategy and Remediation, Implementation and Verification Plan. Ref. LWLSV-ARUP-ZZ-XX-RP-CG-0002 dated 20th May 2020.
- Curtins Remediation Strategy & Verification Plan. Ref. LWLSV-CUR-XX-XX-SP-G-00002-Remediation_Strategy-S2 issue P04 dated 21st September 2022.
- Arup Geotechnical and Geo-environmental Interpretative Report, Phase 1. Ref. LWLSV-ARUP-ZZ-XX-RP-CG-0001. Dated 15th May 2020.
- Curtins Phase 2 Ground Investigation Report. Ref. LWLSV-CUR-XX-XX-RP-G-00001-Phase_2_GI _REPORT-S2 dated 26th August 2022.
- WYG Factual Ground Investigation Report. Ref. A112372. Dated February 2020.

2.2. Site description

The Site lies to the south of the town of Llanelli. It lies within a former industrial area that has been the subject of a series of land regeneration projects over the previous decades. It forms a roughly triangular area, bounded by the B4304 to the south, Dafen Inlet to the north and a light industrial estate to the east.

The Site is broadly level and its ground level (beneath the piling mat) is approximately 7 metres above Ordnance Datum (m aOD). At the time of Yellow Sub's water features survey on 13th March 2023, the majority of the Site was covered by a granular piling mat, which had been formed with a geotextile mesh beneath and covered the majority of the Site. The south-western corner of the Site was covered by a tarmac car parking area and site cabins. The far east of the Site was occupied by a series of soil stockpiles. The far northern and eastern edges of the Site remained at previous ground level, some 1m to 1.5m beneath the surface of the piling mat. These areas were covered in rough grass vegetation with areas of ponded water as a result of recent heavy rainfall events.

The northern Site boundary comprises the southern edge of Dafen Inlet. It was viewed from the northern side of the Inlet and was noted to primarily be comprised of a stone wall, which is the remains of a former quay. This stone wall is in varying states of repair, but is in-tact. The far south-eastern corner of the Inlet/ far north-eastern edge of the Site does not have a quay wall present, and the boundary here is a grassed bank down to the Inlet.

The piling mat and active construction site did not extend all the way to the northern Site boundary. A strip of land approximately 20m wide was excluded from the development site. This is understood to be coincident with a 16m wide easement associated with a trunk sewer beneath.

2.3. Site history

The Site has a long industrial history. The southern portion of the Site is recorded as Brick Field Clay Mill and Brick Fields (chemical) Works on 1880 Ordnance Survey (OS) mapping. The chemical works produced sulphuric acid, arsenic and iron sulphate.

The northern portion of the Site was occupied by the South Wales Works, an iron, steel and tin plate works. A terrace of houses, Dock Terrace, was present on Site in between the chemical works to the south and steel works to the north. A series of railway sidings were present between the north of the steel works and the Dafen Inlet, which is shown to have an engineered southern edge with loading stages on the 1880 and 1916 mapping.

A reservoir was present in the southern portion of the Site associated with the chemical works.

The chemical works burnt down in 1913 and a locomotive repair shop was constructed in its footprint.

Much of the industry was demolished between 1953 and 1971, during which period the reservoir was also infilled.

2.4. Site redevelopment details

2.4.1. Site development description

The Site is in the process of being redeveloped to create a wellness and life sciences village. Phase 1 of the works, to which this report pertains, comprises a wellness centre with two wings. The western wing will provide dry sports provision, whereas the eastern wing will provide wet sports provision. This eastern wing will have two swimming pools constructed within it, positioned end-to-end in a broadly north-north-east to south-south-west orientation.

The proposed development is predominantly to be constructed above ground, based on driven pile foundations. The exception to this is the swimming pools, which are discussed further below:

2.4.2. Swimming pool excavations

In order to construct the two swimming pools, an excavation shall need to be formed. The swimming pool location is presented in Figure 2-1 below. A cross sections of the pools are presented in Figure 2-2 and Figure 2-3 below.

Figure 2-1: Proposed development plan (excerpt from Powell Dobson Drawing No. LWLSV-PDA-XX-00-DR-A-05011)

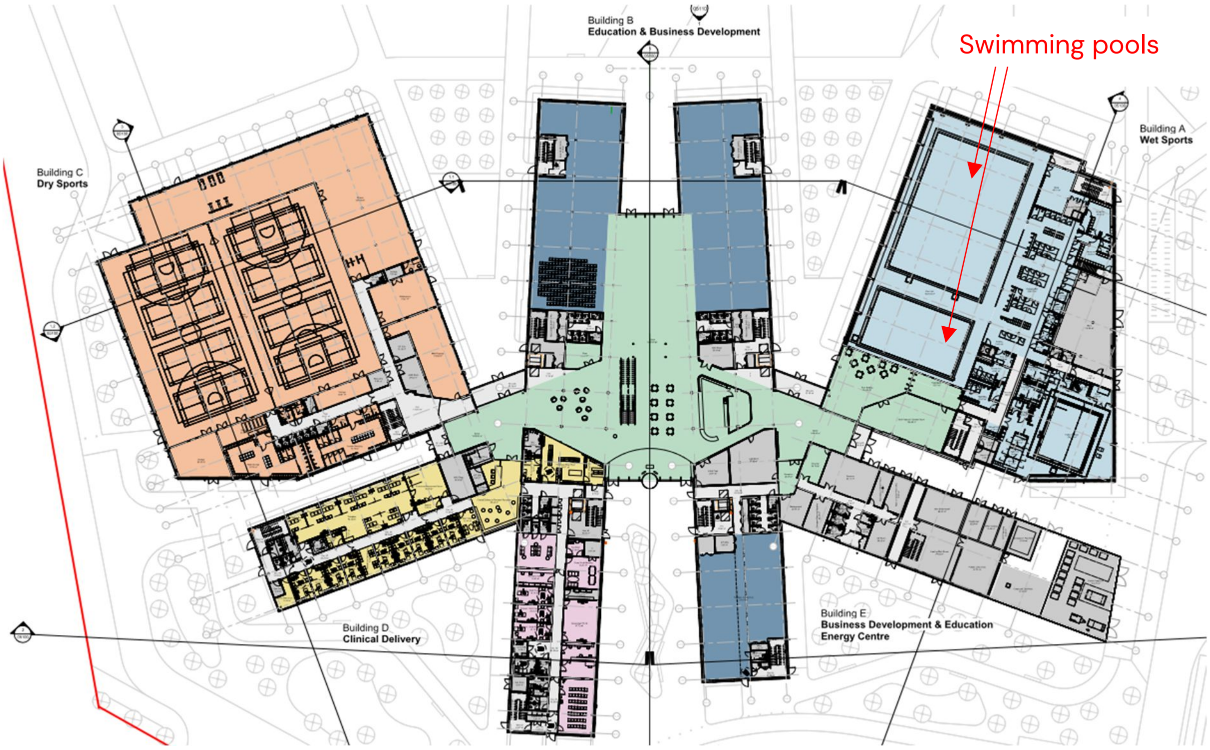

Figure 2-2: Longitudinal cross section through the swimming pools (excerpt from LWLSV-CUR-BA-ZZ-DR-S-21501-P08)

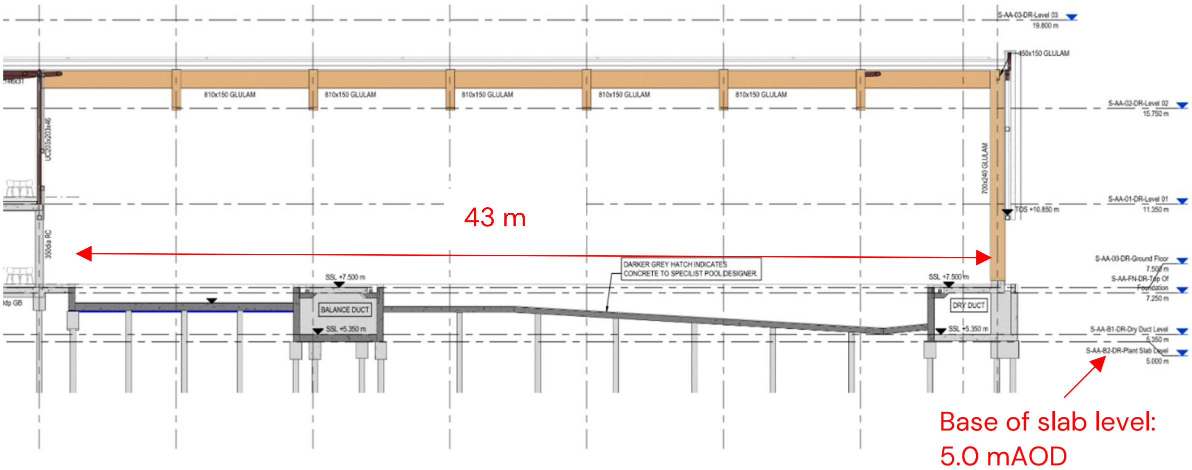

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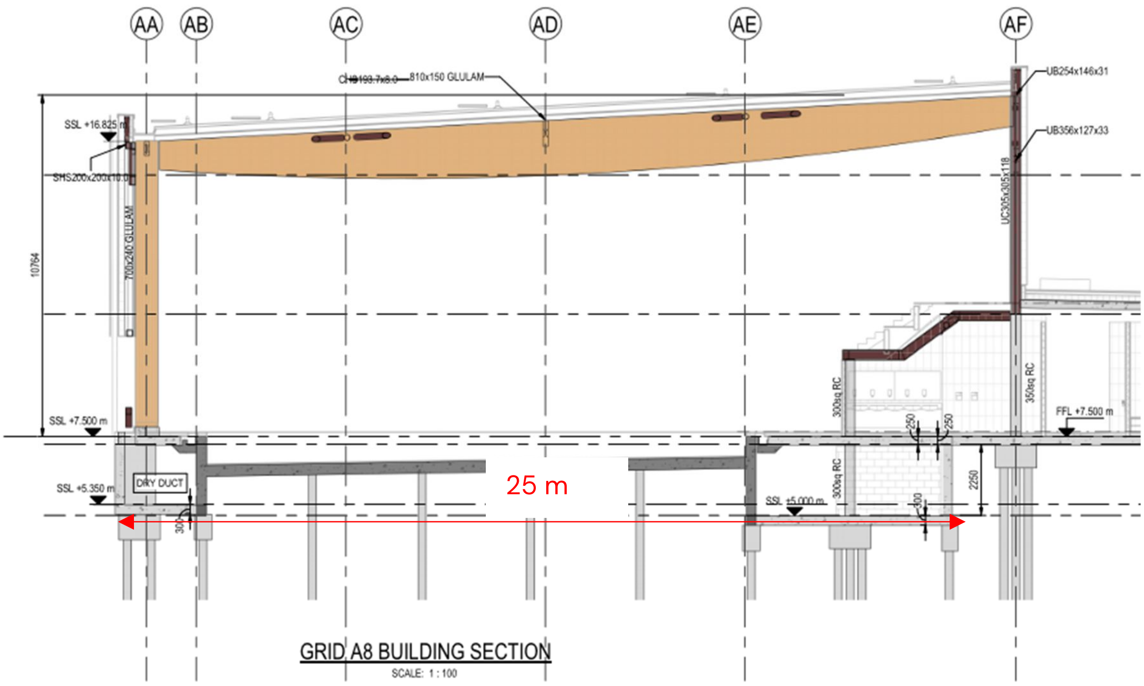
Figure 2-3: Latitudinal cross section through the swimming pools (excerpt from LWLSV-CUR-BA-ZZ-DR-S-21501-P08)



2.4.3. Dewatering proposals

In order to construct the swimming pool, it will be necessary to excavate soils to create the necessary void. This excavation shall need to be sized such that it is larger than the combined footprint of the two swimming pools plus surrounding areas of below-ground ducts. Based upon the cross sections and ground floor plans, the dimensions of the required void are 43m in length and 25m in width. It can be assumed that an additional working area will be required beyond this, such that the overall void size may be in the order of 50m x 30m.

The base of the slab beneath the swimming pool is at a depth of approximately 2.5 metres below finished ground level (m bgl) at 5.0m aOD. In order to facilitate the placement of sufficient blinding and sub-base layers, and to form the pile mat and pile cap, it is anticipated that the excavation shall need to be approximately 1m deeper than this, so extending to approximately 3m bgl.

In anticipation of dewatering being required, BUK have approached Welsh Water (WW) in order to seek approval for discharge of pumped water into the foul sewer that is present beneath the Site. We understand that WW have refused permission for this operation.

An alternative solution to the need to discharge water is therefore required. Two options remain 1) to discharge the water into the Dafen Inlet under an appropriate Environmental Permit, or 2) to discharge the water back to ground, also under an Environmental Permit.

Whilst the groundwater quality is assessed by previous works to not be materially impacted by contamination, it is considered unlikely that discharge to the Dafen Inlet would be preferred, in part because the Inlet discharges directly into the environmentally sensitive Carmarthen Bay and Estuaries Special Area for Conservation (SAC). This is of particular note due to the fact that a number of the special features of the SAC will be sensitive to water quality.

The preferred option is therefore considered likely to be to discharge the water back to ground, under an Environmental Permit. Bouygues has identified an area of the Site along its eastern boundary that may be suitable to form an infiltration trench, which could be used to return the pumped water to ground.

The water pumped from the excavation shall be processed through the following system:

The system will treat the water via the following processes as standard:

- Settlement of suspended solids via a storage Lagoon;
- Settlement of suspended solids via a baffled settlement tank;
- Filtration of suspended solids through sand filters and Granular Activated Carbon (GAC);
- Sorption of dissolved phase hydrocarbons and through GAC vessels; and
- If required, use of zeolite vessels.
- Dependent on influent concentrations of suspended solids, dosing may also be required therefore the system also have these capabilities, should additional treatment processes be.
- Non-aqueous phase liquids (NAPL) are not expected to enter the system; however, the system also incorporates oil-water separation through gravity separation, with drums or IBC to be used for storage of any recovered NAPL.

As a result of this filtration and treatment, it is anticipated that the water that is returned to ground will be lower in contaminant concentration and therefore less contaminated than the current status quo. Therefore the operation will, in effect, deliver a betterment with respect to groundwater quality.

2.5. Ground conditions

The ground profile beneath the Site has been characterised by numerous phases of ground investigation, the most recent of which are reported in WYG (2020) and Curtins (2022). The general ground profile comprises:

- Dark grey granular made ground typically comprising a sand or gravel with varying silt, cobble and boulder content, over;
- Greyish brown to brownish grey Raised Beach Deposits, which are locally present immediately to the south of the Dafen Inlet. These typically comprise a silty gravel with some sand and cobble content. The Raised Beach Deposits are not present in a continuous layer, with the overlying made ground sitting directly on the underlying Tidal Flat Deposits across much of the Site.
- Soft grey sandy silty clay of the Tidal Flat Deposits, over;

- Glacial Till, over;
- Hughes Member sandstone bedrock.

Table 2-1 below provides a summary of the ground conditions beneath the proposed swimming pool and infiltration trench areas, in the form of extracts from the lithological logs provided by WYG (2020).

Table 2-1 Summary of ground conditions beneath the swimming pool area (from WYG 2020).

BH306

Strata Description	Legend	Depth (m)	Reduced Level (mAOD)
Grey sandy slightly silty GRAVEL. Gravel is fine to coarse sub-angular to angular of limestone and sandstone (MADE GROUND)		0.10	6.89
Medium dense dark greyish black sandy slightly silty GRAVEL. Gravel is fine to coarse angular to rounded of siltstone and sandstone, brick fragments, slag and rare glass (MADE GROUND)		3.00	3.99
Medium dense orangish brown mottled with very dark grey very sandy GRAVEL. Gravel is fine to coarse sub-rounded to rounded of sandstone and siltstone with occasional clay rich nodules (5cm diameter) and rare shell fragments. Sand is fine to coarse (MADE GROUND)		5.00	1.99
Loose light brownish grey very sandy silty GRAVEL. Gravel is fine to coarse sub-angular to sub-rounded of sandstone and siltstone. Sand is fine and medium. Pockets of very sandy silt (RAISED BEACH DEPOSITS)		5.45	1.54
Loose light brownish grey sandy slightly silty GRAVEL. Gravel is fine to coarse angular to rounded of quartzite and sandstone with abundant shell fragments. Sand is fine and medium (RAISED BEACH DEPOSITS)		6.95	0.04
Loose grey sandy slightly silty GRAVEL. Gravel is fine to coarse angular to well rounded of sandstone, quartzite, mudstone and siltstone with abundant shell fragments. Sand is fine to coarse (RAISED BEACH DEPOSITS)		8.00	-1.01
Soft grey slightly gravelly sandy silty CLAY. Rare coarse gravel of sub angular sandstone odour. Gravel is fine and medium angular to sub-angular of sandstone and siltstone. Sand is fine and medium. (ESTUARINE ALLUVIUM)		8.50	-1.51
Soft dark grey brown and black mottled silty organic CLAY. (ESTUARINE ALLUVIUM)			

Approx. depth to base of slab beneath pool

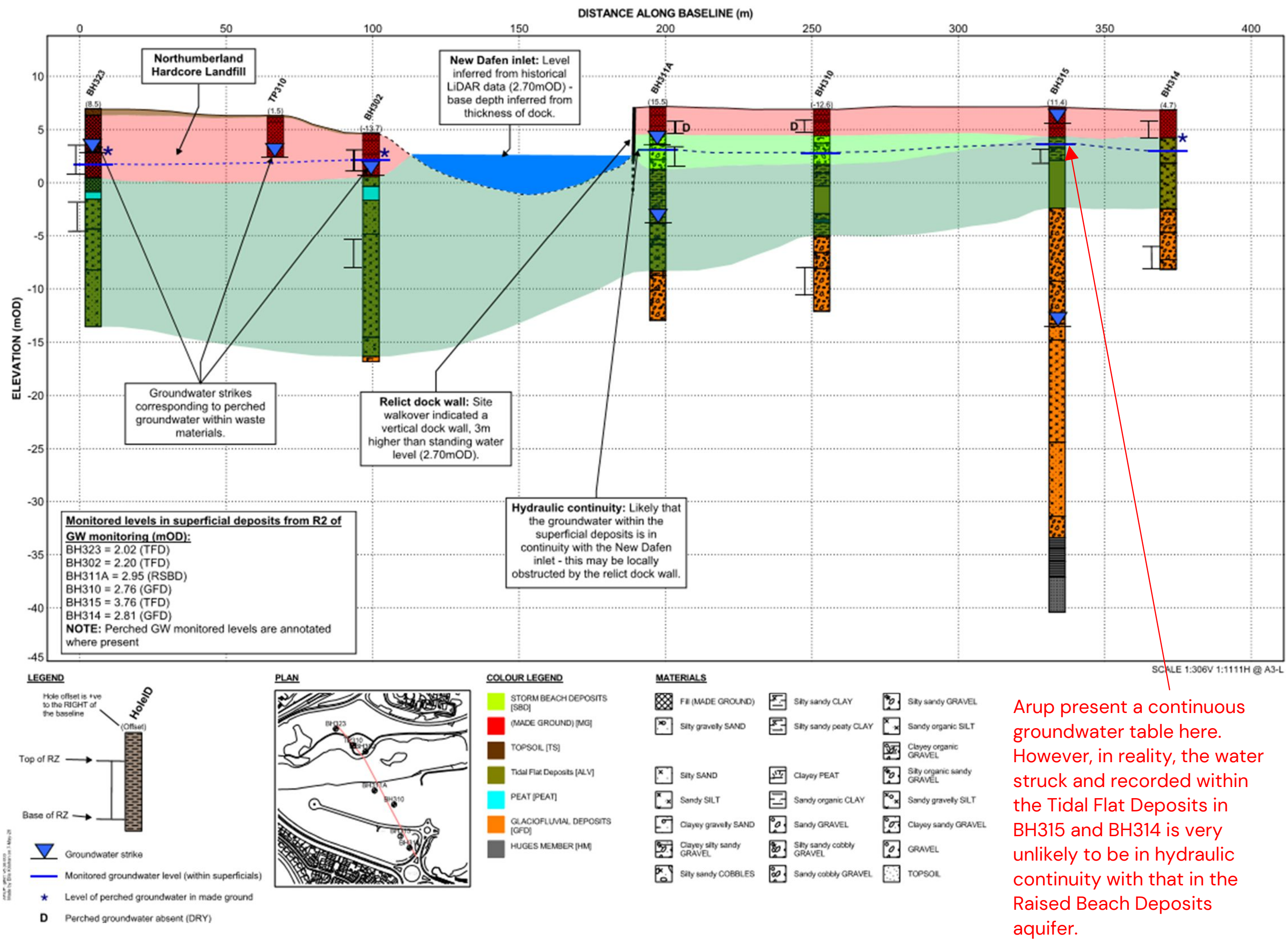
Estimated depth of required excavation

BH305

Strata Description	Legend	Depth (m)	Reduced Level (mAOD)
TOPSOIL TOP		0.10	6.91
Medium dense dark grey sandy clayey cobbly GRAVEL. Sand is fine to coarse. Gravel is fine to coarse sub-angular and sub-rounded of brick, slag, concrete and limestone with frequent wood fragments. Cobbles are sub-angular and sub-rounded of chert and sandstone. (MADE GROUND)		1.50	5.51
Dark greyish brown gravelly silty SAND. Sand is fine to coarse. Gravel is fine to coarse sub-angular and sub-rounded of brick, slag, chert and sandstone and occasional glass fragments. (MADE GROUND)		2.00	5.01
Loose greyish brown and orangish brown gravelly silty SAND. Sand is fine to coarse. Gravel is fine to coarse sub-rounded of sandstone with occasional shell fragments (MADE GROUND)		2.50	4.51
Medium dense greyish brown slightly silty cobbly GRAVEL. Sand is fine to coarse. Gravel and cobbles are fine to coarse sub-angular and sub-rounded of sandstone (RAISED BEACH DEPOSITS)		4.00	3.01
Medium dense orangish brown sandy cobbly GRAVEL. Sand is fine to coarse. Gravel is sub-angular and sub-rounded of mudstone, chert, sandstone and quartz. Cobbles are sub-angular and sub-rounded of sandstone and chert (RAISED BEACH DEPOSITS)		7.50	-0.49
Soft grey occasionally mottled greyish brown sandy silty CLAY with occasional shell fragments. Sand is fine to coarse (ESTUARINE ALLUVIUM)			

A generalised sequence of the geology at play beneath the Site is summarised by Arup (2020) in a stylised geological cross section which is reproduced in Figure 2-4. This cross section has been drawn through the western wing of the proposed wellness centre. Comparison of the available exploratory hole logs from beneath the eastern wing (where the swimming pool excavation will be required) confirm that the ground conditions are broadly similar (as per Table 2-1).

Figure 2-4: Stylised geological cross section through ground beneath the western wing of the proposed new wellness centre (from Arup 2020)



2.6. Contamination

Soil and groundwater contamination has been the subject of a significant body of work by previous authors, culminating in the remediation strategies drafted by Arup (Arup 2020) and

Curtins (Curtins 2022a). It is outside of the scope of this document to reproduce or discuss the contamination encountered. Notwithstanding this, the following bullet points provide some salient summary points from the remediation strategies:

- Groundwater and soil-derived leachate data has been gathered from two main phases of ground investigation and compared against generic acceptance criteria (GAC) protective of the aquatic environment. This has identified a series of contaminants which are present in excess of the GACs, but to a limited degree.
- As a result, both Arup and Curtins have concluded that there is insufficient pollutant linkage present to necessitate remediation activity focussed on protecting the aquatic environment.
- It is recommended that a programme of groundwater monitoring be undertaken during the piling programme in order to monitor impact on the groundwater regime. This is ongoing at the time of drafting this report.

3. Water features survey

A water features survey has been undertaken, using a combination of a Site walkover inspection (undertaken on 13th March 2023) and a desk-based assessment of the available data on surface water and groundwater.

3.1. Surface water conditions

OS mapping and aerial photography confirm that the closest surface water feature to the Site is the New Dafen River and Dafen Inlet. The New Dafen River flows into Llanelli from the north, through the Dafen area of the town and into the section of the watercourse that lies immediately to the east of the Site. That section of the New Dafen River nearest to the Site flows through part of the footprint of a former scouring basin. A scouring basin is used to impound tidal water at a higher level, then release it rapidly in order to scour the channel downstream and hence help maintain the channel's depth for navigable craft. The majority of this basin has since been filled in, but the New Dafen River's channel here remains overly wide for the scale of the river.

The New Dafen River flows into the Dafen Inlet through a culvert at the south-eastern end of the Inlet. This is just beyond the far north-eastern corner of the Site. The actual culvert could not be seen during the walkover survey, and is assumed to have been permanently flooded following the impoundment of the Dafen Inlet (see below).

The Dafen Inlet is recorded on historical mapping to have previously been tidal, and used as a harbour with quays and landing stages to facilitate the transfer of goods to the steel works and to other surrounding industrial facilities. At some point a sluice has been installed across the entrance of the Inlet, impounding the waters of the Dafen and separating them from the tidal influence that is still seen in the Afon Lliedi and Loughor Estuary. Anecdotal evidence quoted by Arup (2020a) suggests that the sluice is no longer operational, but that the water levels within he Inlet remain relatively static due to leakage through and over the sluice.

Data collected by land survey in 2016 is reported by Arup, placing the water elevation within the Inlet at 3.13m aOD. LiDAR information from 2001 places it at 2.7m aOD. During the water features survey undertaken by Yellow Sub, an estimate of the difference in elevation between the top of the former quay wall (surveyed by Arup to be between 6.6m aOD and 6.1m aOD) and the water in the inlet placed the difference between approximately 3.0m and 3.5m. This places the impounded water within the Inlet at approximately 3m aOD. There had been heavy rainfall for approximately 18 hours prior to this, and hence this may be towards the upper end of the range.

During the walkover survey, Yellow Sub inspected the Site for any other surface water features, such as wells, ditches, land drains or other feature. No such features were identified, and the New Dafen River/ Dafen Inlet were confirmed to be the closest surface water receptor.

The Dafen Inlet discharges into the Afon Lliedi. The waters of the Afon lliedi are tidal, with a range of between 0.58m aOD and 6.6m aOD recorded at the Llanelli Tidal Monitoring station, situated immediately adjacent to the Dafen Inlet sluice. The Afon Lliedi is, in turn, part of the larger Loughor Estuary. The local areas of the Loughor Estuary are protected as Burry Inlet and Loughor Estuary Site of Special Scientific Interest (SSSI), Burry Inlet Special Protection Area (SPA), Burry Inlet North Shellfish Waters Protected Areas (CEFAS) and Carmarthen Bay and Estuaries/ Bae

Caerfyrddin ac Aberoedd Special Area of Conservation (SAC). The boundary of these two designations lies at the mouth of the Afon Lliedi, some 350m from the sluice at the mouth of the Dafen Inlet.

The SSSI and SAC are both notified for marine and tidal assemblages and species that are sensitive to water quality. Habitats that are protected include sea inlets, tidal rivers, estuaries, mud flats, sand flats, lagoons (including saltwork basins), salt marshes, salt pastures, salt steppes, shingle, sea cliffs and islets. The sand and mud flats have large numbers of bivalve molluscs including the edible cockle. There are a great variety of marine invertebrates. The saltmarshes have biodiverse communities of glasswort (Salicornis species), dwarf eelgrass (Zostera noltei), sea rush (Juncus maritimus) and marsh-mallow (Althaea officinalis) and all the wildlife they support. A primary reason for the listing is the presence in the bay of the twait shad, a migratory fish. The SPA is protected for its community of wading birds, some of which will rely on the shellfish that are protected under the CEFAS protection.

A further water body, Machynys Ponds, are located approximately 350m to the south of the Site. These are also protected as Pyllau Machynys (Machynys Ponds) SSSI. This SSSI is designated for its standing-water and swamp habitats, which are of interest of themselves, but also support a diverse and rich species mix. Of special note is the presence of 14 species of dragonfly and damselfly found at the ponds.

3.2. Groundwater conditions

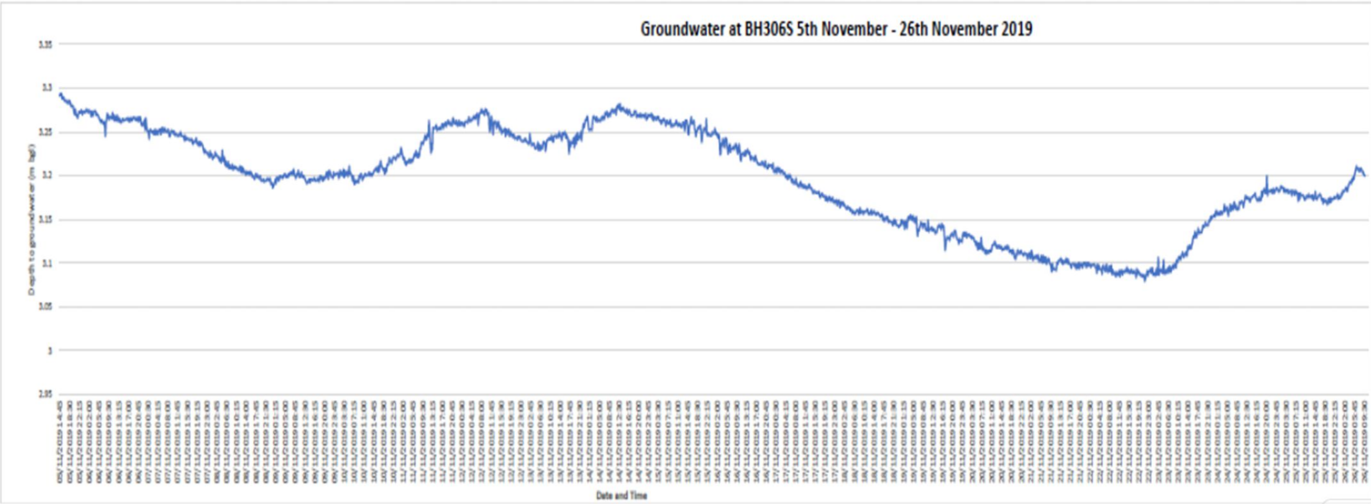
Arup and Curtins provide groundwater monitoring data from the numerous wells installed into the ground across the Site. These wells comprise some installed within the shallow made ground, some within the Raised Beach Deposits, some within the Tidal Flat Deposits and a few within the deep Glacial Till and sandstone bedrock. The conclusions of both Arup and Curtins are as follows:

- Whilst some groundwater strikes were recorded within the made ground, follow-up monitoring rounds routinely recorded made ground wells to be dry.
- There is a continuous groundwater body within the Raised beach Deposits, which is in continuity with the overlying made ground.
- The Tidal Flat Deposits act as an aquitard or even an aquiclude, separating the groundwater within the Raised Beach Deposits above from that within the Glacial Till and Sandstone bedrock beneath. Water is present within peaty, more permeable layers within the Tidal Flat Deposits, but this is very stratified, with little if any vertical connectivity.
- Therefore, there is no meaningful natural pathway between the shallow Raised Beach Deposits/ made ground aquifer and the deeper water bodies.

Yellow Sub have undertaken a high-level review of the groundwater data, and concur with the assessments of Arup and Curtins.

Arup have previously deployed a datalogger within the monitoring well in BH306 that has been constructed to monitor groundwater within the Raised Beach Deposits. This well is within the footprint of the proposed swimming pool excavation. The resultant hydrograph is presented as Figure 3-1 below. The groundwater elevations show no tidal signal, and are seen to vary from approximately 3.1m to 3.3m aOD.

Figure 3-1: Hydrograph of groundwater elevations in BH306, (from Arup 2020a)



This groundwater elevation is broadly analogous with, and slightly higher than, the impounded water levels within the Dafen Inlet. It is therefore likely that the two water bodies are in hydraulic continuity. The freedom with which water flows between the Raised Beach Deposits/ made ground aquifer and the Inlet may be inhibited to some degree by the presence of the former quay wall. The wall is conjectured by Arup to extend to approximately 11m below ground level (m bgl). Whether this is correct or not, it is certainly likely to extend deeper than the top of the Raised Beach Deposits aquifer, and may therefore hamper flow to some degree.

The Raised Beach Deposits/ made ground aquifer can be assumed to extend from groundwater surface down to the base of the deposits, where it overlies the much lower permeability Tidal Flat Deposits, at approximately -1 m aOD, or 8m bgl.

Curtins undertook three permeability tests within the Raised Beach Deposits during drilling of boreholes. The results are summarised in Table 3-1 below:

Table 3-1: Permeability test results (from Curtins, 2022).

Borehole	Test depth mbgl (stratum)	Permeability (m/s)
BH101	3.0 – 3.3 (made ground – silty sandy gravel)	1.4×10^{-6}
BH106	4.5 (Raised Beach Deposits – clayey sandy gravel)	8.2×10^{-6}
BH110	3.8 – 4.0 (Raised Beach Deposits, sandy gravelly clay)	5.8×10^{-7}

The depth to groundwater was recorded in BH306, within the swimming pool footprint, on four occasions by WYG (WYG 2020). This well is constructed with the response zone within the Raised Beach Deposits. The results are summarised in the following table:

Table 3-2: Groundwater elevations in BH306, within the swimming pool footprint (data from WYG 2020)

	Round 1	Round 2	Round 3	Round 4	Average
Date	August 2019	September 2019	October 2019	November 2019	
Depth to groundwater (m bgl)	3.51	3.68	3.14	3.20	3.38
Groundwater elevation (m aOD)	3.48	3.31	3.85	3.79	3.61

4. Conceptual model and dewatering assessment

4.1. Hydrogeological conceptual model

The proposed excavation works are to be dewatered by means of a sump and pump arrangement, with the pumped water to be discharged back to ground via an infiltration trench within the Site boundary. In order to inform an assessment of the effect that this dewatering and discharge may have on water bodies on the Site, a hydrogeological conceptual model has been compiled, as discussed below.

4.1.1. Impacts of dewatering and discharge

The action of dewatering the area of the swimming pool excavation and of the infiltration of the arising water back to ground is considered to be two-fold:

- Firstly, the act of pumping and infiltration may alter the groundwater regime, by altering the direction and or volume of groundwater flow through the aquifer. The area of pumping will draw groundwater towards the excavation, thus creating a hydraulic head and inducing groundwater flow inwards towards the excavation. The inverse will occur in the area of infiltration, where the increased input of water will lead to an outwards flow of groundwater due to the localised increase to hydraulic head.
- Secondly, any induced change in direction and volume of groundwater flow may lead to the mobilisation and migration of dissolved phase contamination within the aquifer. This impact is considered feasible, but will be limited to a notable degree by the fairly limited groundwater or soil leachate impact recorded by both Arup and Curtins. Indeed, both such previous workers have assessed the groundwater to be of sufficiently acceptable quality as to not require any remediation as part of the development. We understand that on this basis, the Remediation Strategy and Verification Plan produced by Curtins (Curtins 2022) has been used in support of the successful discharge of planning conditions.

In both cases, the impact is considered to be temporary, as they would only continue for the period during which pumping and infiltration is occurring. Potential impacts may be considered to be longer term with respect to the potential inducement of contaminant migration, were a significant degree of contamination to be present within the aquifer. The data and assessments of previous works indicates that this is not the case however.

4.1.2. Sensitive environmental receptors

The nearest sensitive receptor is considered to be the Dafen Inlet and New Dafen River. These abut the Site on its northern and eastern boundaries respectively. The two water bodies are assessed as a single receptor in this assessment, due to the fact that the river discharges directly into the inlet via culvert, and due to the fact that the two water bodies both appeared to be at the same elevation during the walkover survey.

The Burry Inlet and Loughor Estuary SSSI, Carmarthen Bay and Estuaries SAC, Burry Inlet Special Protection Areas (SPA), Burry Inlet North Shellfish Waters Protected Areas (CEFAS) and Machynys Ponds SSSI are also considered to be sensitive receptors. Whilst they are a greater distance from the Site, their protected special features are considered to be particularly sensitive to change associated with the dewatering and discharge activities.

The Secondary A Aquifer within the Hughes Member sandstone bedrock at depth is not considered to be a viable receptor with respect to the dewatering activities. This is because it is separated from the shallow groundwater by a significant thickness (in excess of 20m) of low permeability Tidal Flat Deposits. This vertical hydraulic separation is corroborated by groundwater elevation data collected by both Arup and Curtins. The Hughes Member aquifer is therefore not considered further herein.

The aquifer within the Raised Beach Deposits/ made ground aquifer has also been considered with respect to whether it represents a sensitive receptor. The aquifer is extremely local in its extent, with the Raised Beach Deposits only being present within that area of the Site beneath the vicinity of the wellness building footprint itself. Outside of this area, the made ground lies directly on the Tidal Flat Deposits. The aquifer therefore is not considered to represent a viable resource with respect to economic or social value. However, it does likely provide some recharge to the New Dafen River and Dafen Inlet. It is therefore of very localised importance. Whilst this aquifer does represent a controlled water body (as defined under the Water Resources Act 1990), it is not considered to be a sensitive receptor. It has been taken forward for further consideration however, due to the degree of impact that the proposed dewatering activity is anticipated to have on it.

4.1.3. Connectivity

The comparative elevation of the groundwater within the Raised Beach Deposits/ made ground aquifer and the Dafen Inlet suggests that there is a degree of hydraulic connectivity between the two. It is anticipated that flux between the two will be limited to some degree by the presence of the former quay wall, but that some degree of connectivity should be assumed.

The same degree of connectivity is not considered likely to be present between the same aquifer and the Machynys Ponds SSSI. The ground investigation data indicates that the Raised Beach Deposits that are present in the northern part of the Site do not continue as far southwards as the Site boundary. At the southern end of the Site, nearest to the ponds, the made ground sits directly on the upper surface of the Tidal Flat Deposits at an elevation of approximately 5m aOD. This is some two metres higher than the groundwater level within the aquifer, thus suggesting that there is no meaningful aquifer body present in this area. Hence there is considered unlikely be a meaningful pathway for groundwater movement between the Site and the ponds.

There is a degree of connectivity between the Site and the Afon Lliedi (and therefore the SSSI, SPA, CEFAS and SAC), via groundwater flow into the Dafen Inlet, and discharge of surface water from the Inlet into the Afon Lliedi via the sluice. This pathway is only considered viable with respect to contaminant migration. It is feasible, albeit unlikely, that contamination entering the Inlet may continue to migrate through dispersion in the surface water, and enter the Afon Lliedi via the sluice. The dilution effect within the Inlet would be significant however, and there would then be even further dilution within the tidal cycle of the Lliedi. The pathway between the Raised

Beach Deposits/ made ground aquifer beneath the Site and the SSSI/ SPA/ CEFAS/ SAC in the Loughor Estuary is therefore considered to be present, but to be very minimal.

Any induced change in the groundwater flow into the Inlet is considered likely to be inconsequential in comparison with the volume of water within the Inlet and the flow of water from the New Dafen River. Hence this pathway is not considered to be material with respect to the impact of a change in water flow.

The critical pathway by which the dewatering and infiltration activity may impact receptors beyond the Raised Beach Deposits/ made ground aquifer is that whereby the effects within that aquifer occur over a sufficiently wide area as to effect groundwater recharge into the Dafen Inlet/ New Dafen River. The Inlet itself then provides the extension of the pathway to the SSSI, SPA, CEFAS and SAC within the Loughor Estuary. It is this pathway that has therefore been focussed on by means of groundwater modelling.

4.2. Groundwater modelling

In order to assess the impact that the dewatering and infiltration may have on the aquifer, two models have been constructed; a dewatering model and a groundwater mounding model. The first simulates the drawdown effect on the aquifer that will result from locally lowering the groundwater table to provide a dry excavation for construction work. The second simulates the local increase in groundwater elevation that can be expected at the point of recharge to the aquifer from the infiltration trench.

The purpose of the modelling is to ascertain the radius of influence over which each activity will have an effect. This in turn can then be compared with the distance to the Dafen Inlet/ New Dafen River at its closest point to both the area of dewatering (the swimming pool excavation) and the point of infiltration (the infiltration trench).

The following table summarises the input parameters used in the two models:

Table 4-1: Groundwater modelling input parameters

Parameter	Value	Rationale
Hydraulic conductivity (k), m/sec	$1.4x10^{-6}$	The largest of the three values collected by in situ permeability testing by Curtins.
Aquifer thickness (b), m	5	Difference between water table at approximately 3m aOD and the base of the Raised Beach Deposits is at approx. 8m aOD.
Storativity (S), dimensionless	2	Median value for typical range
Time period for dewatering (days)	100	Assumed 3 month period for construction of swimming pool basement.

Parameter	Value	Rationale
Drawdown required to provide dry excavation, m	0.85 (rounded up to 1 m)	Difference between shallowest recorded elevation of groundwater in BH306 (3.85m aOD) and anticipated required depth of dewatering (base of floor slab minus 2m = 3m aOD)
Specific yield (Sy) dimensionless	0.3	Assumed representative value for gravel aquifer.

4.2.1. Dewatering model

The Theis equation (Theis, 1935) can be used to estimate the drawdown inducted by pumping in a confined aquifer, as follows:

$$s = \frac{Q}{4\pi T} \mathrm{w}(u) \quad \text{and} \quad u = \frac{r^2 S}{4Tt}$$

s = drawdown (m)
Q = pumping rate (m^3/day)
T = Transmissivity (m^2/day)
w = Theis well function
S = Storativity (dimensionless)
r = radius of influence (m)
t = duration of pumping (days)

The results of the Theis equation can be adjusted to account for unconfined conditions using the Jacobs correction (Jacobs, 1944):

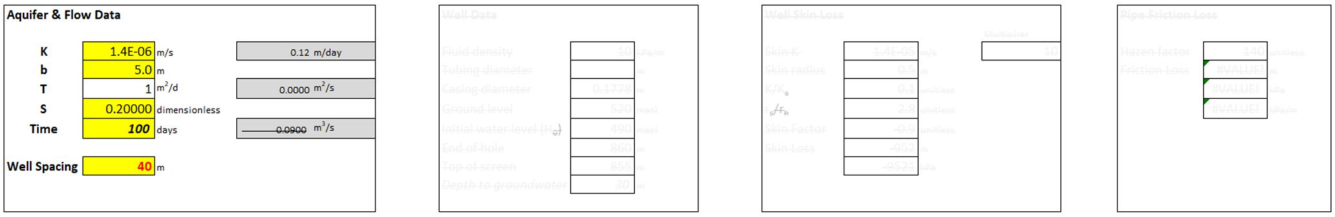
$$s' = s - s^2/2b$$

s' = corrected drawdown
s = observed drawdown
b = saturated aquifer thickness.

A spreadsheet was used to calculate the drawdown that might be expected at a theoretical monitoring well 40m distant from the swimming pool excavation. 40m is the approximate distance from the proposed excavation to the Dafen Inlet at its closest point, and so this was modelled to represent the drawdown that might be seen in the aquifer at the point where it drains to the Inlet. The pumping to dewater the excavation was modelled as two abstraction wells, at each end of the swimming pool excavation, 40m apart.

The results of this modelling are summarised in Figure 4-1 below. In the figure, abstraction wells are W1 and W2, highlighted in green. Monitoring wells are W3, W4, W5 in blue.

*Figure 4-1: Results of the Theis modelling process**



Aquifer & Flow Data

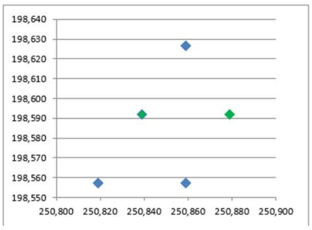
K	1.4E-06	m/s	0.12 m/day
b	5.0	m	
T	1	m^2/d	0.0000 m^2/s
S	0.20000	dimensionless	
Time	100	days	~~0.0900~~ m^3/s
Well Spacing	40	m	

CALCULATION: Change in Head including effect of neighbouring wells

Q (L/s)	Q (m^3/d)	Well ID	W1	W2	W3	W5	W4
0.015	1.296	W1	1.11	0.02	0.02	0.00	0.02
0.015	1.296	W2	0.02	1.11	0.02	0.02	0.02
0	0	W3	0.00	0.00	0.00	0.00	0.00
0	0	W5	0.00	0.00	0.00	0.00	0.00
0	0	W4	0.00	0.00	0.00	0.00	0.00
0	3		↓	↓	↓	↓	↓
		Total Δ Head	1	1	0	0	0

CALCULATION: Idealised well spacing (from separate sheet)

Well ID	W1	W2	W3	W5	W4
W1	1	40	40	69	40
W2	40	1	40	40	40
W3	40	40	1	40	69
W5	69	40	40	1	80
W4	40	40	69	80	1



* Calculations representing the effect of well design are not used, to simulate the pumping from open excavation/ sump. Hence the greyed out sections.

As can be seen above, a pumping rate of 0.015L/sec or 1.2096m^3/day is required to induce a drawdown of 1.11m within the excavation. This drawdown needs to be corrected using the Jacobs correction in order to represent the unconfined nature of the aquifer. With a drawdown of 1.11m and a saturated aquifer depth of 5m, the corrected drawdown is 0.987m, or approximately 1 m.

Therefore, in an unconfined aquifer, a pumping rate of 1.296m^3/day is modelled to be required to achieve the required approximately 1 m drawdown in the excavation.

In all wells 40 m distant from the excavation, the anticipated drawdown associated with this pumping is modelled as approximately 2cm. That is, the aquifer may be approximately 2cm lower adjacent to the Dafen Inlet during pumping. This is considered to be negligible, given the temporary nature of the pumping.

4.2.2. Groundwater mounding model

In order to model the effect of recharge to the aquifer from the infiltration trench, the Hantush equation (Hantush, 1967) can be used to model the effect. This has been undertaken using the spreadsheet model from the United States Geological Survey (Carleton, 2010). This requires three additional input parameters to those listed in Table 4-1. These are as follows:

- The width and length of the infiltration basin. A 100m^2 square basin has been assumed.
- The assumed rate of infiltration in m/day. This has been assumed to equal the total rate of pumping from the excavation (2.592 m^3/day, divided by the cross sectional area of the infiltration basin (100m^2) = 0.02592 m/day.

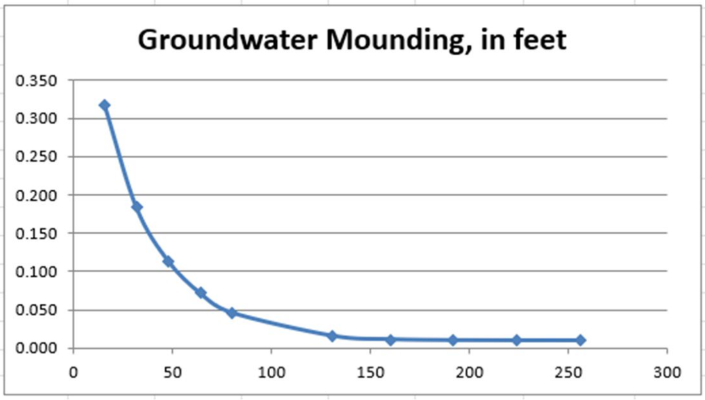
Figure 4-2 below provides a summary of the results.

Figure 4-2: Results of modelling using the Hantush equation (Hantush, 1967) using the USGS spreadsheet (Carleton, 2010).

Input Values		
0.0850	*R*	Recharge (infiltration) rate (feet/day)
0.300	Sy	Specific yield, Sy (dimensionless, between 0 and 1)
0.40	K	Horizontal hydraulic conductivity, Kh (feet/day)*
5.000	x	1/2 length of basin (x direction, in feet)
5.000	y	1/2 width of basin (y direction, in feet)
100.000	t	duration of infiltration period (days)
16.400	hi(0)	initial thickness of saturated zone (feet)
17.015	h(max)	maximum thickness of saturated zone (beneath center of basin at end of infiltration period)
0.615	Δh(max)	maximum groundwater mounding (beneath center of basin at end of infiltration period)

Ground-water Mounding, in feet	Distance from center of basin in x direction, in feet
0.317	16
0.183	32
0.113	48
0.071	64
0.046	80
0.015	131
0.011	160
0.010	192
0.009	224
0.009	256

Re-Calculate Now



At a distance of approximately 25m (80feet), the mounding effect is less than 1.5cm. At 40m (131feet), the mounding effect is less than 0.5cm. Positioning the infiltration basin at least 40m from the Dafen Inlet should therefore enable any effect on the recharge of groundwater to the inlet to be minimal.

4.2.3. Temporary works considerations

Whilst an infiltration rate equivalent to the pumping rate has been assumed for the purposes of this assessment, this may not be achievable, as the ground may not be permeable enough to accept the discharged water at this rate. It may therefore be necessary to increase the size of the infiltration basin dependent upon an assessment of the ground's ability to infiltrate.

Note that any such increase in basin size would not impact upon the findings of this study, as the groundwater mounding model herein assumes infiltration rate = pumping rate (i.e. spreading this pumped water across a wider area will decrease infiltration rate to keep the volume of infiltrating water the same).

The assessment undertaken herein assumes that there are no preferential pathways for migration of groundwaters between either the excavation or the infiltration basin. Should any potential preferential pathways be encountered during excavation of either of these features (e.g. redundant drainage runs, redundant service trenches, relic structures), these will have to be either infilled, bunged or removed and backfilled in order to prevent preferential migration of water.

The assessment herein has been undertaken in order to inform a hydrogeological impact assessment and is considered appropriate for this purpose only. The results presented herein are not suitable for use in informing temporary works design and should not be used for that purpose.

5. Impact assessment

The results of the assessment in Section 4 have been used to refine and inform an assessment of the potential effects that may be associated with the impacts caused by the proposed dewatering activity. This is summarised in the following table:

Table 5-1: Hydrogeological impact assessment

Impact	Receptor	Likelihood	Severity	Effect
Dewatering and infiltration causes an alteration to the direction or volume of water flow within the receptor	Raised Beach Aquifer	Likely	Low	Minor
	Dafen Inlet/ New Dafen River	Very Low	Very Low	Negligible
	Carmarthen Bay and Estuaries SAC/ Burry Inlet and Loughor Estuary SSSI/ Burry Inlet Special Protection Areas (SPA) Burry Inlet North Shellfish Waters Protected Areas (CEFAS)	Very Low	Very Low	Negligible
	Machynys Ponds SSSI	Very Low	Very Low	Negligible
Dewatering and infiltration causes migration of contamination and an alteration to the chemistry of water within the receptor	Raised Beach Aquifer	Likely	Low	Minor beneficial
	Dafen Inlet/ New Dafen River	Very Low	Very Low	Negligible
	Carmarthen Bay and Estuaries SAC/ Burry Inlet and Loughor Estuary SSSI/ Burry Inlet Special Protection Areas (SPA) Burry Inlet North Shellfish Waters Protected Areas (CEFAS)	Very Low	Very Low	Negligible
	Machynys Ponds SSSI	Very Low	Very Low	Negligible

The conclusion of the works presented herein is that the proposed dewatering and infiltration required to enable the excavation to form the swimming pool will have:

- A minor adverse effect on the groundwater behaviour within the Raised Beach Deposits/ made ground aquifer. This effect will be very localised to within 40m of the operations.

- A minor beneficial effect on the groundwater chemistry within the Raised Beach Deposits/ made ground aquifer. This is due to the betterment that will be provided to the water quality due to the filtration and treatment of the water as it is circulated from the pumps to the infiltration basin.
- A negligible effect on the flow of water between the aquifer and the Dafen Inlet, New Dafen River and, by extension, the local SSSIs, SPA, CEFAS and SACs.
- A concomitant negligible effect on the water chemistry within the Dafen Inlet, New Dafen River and, by extension, the local SSSIs, SPA, CEFAS and SACs.

As a result, the overall effect on the environment associated with the proposed dewatering and infiltration is considered to be acceptable.

6. References

Arup 2020 Llanelli Wellness and Life Science Village Remediation Strategy and Remediation, Implementation and Verification Plan. Report Ref. LWLSV-ARUP-ZZ-XX-RP-CG-0002

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Jacob, C.E., 1944. Notes on determining permeability by pumping tests under water-table conditions, U.S. Geological Survey, 25p.

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WYG 2020 Llanelli Wellness Village Factual Ground Investigation Report. Report Ref. A112372.

Appendix A: Report conditions

Report Conditions

This report has been prepared by Yellow Sub Geo Ltd. (Yellow Sub Geo) in its professional capacity as soil and groundwater specialists, with reasonable skill, care and diligence within the agreed scope and terms of contract and taking account of the manpower and resources devoted to it by agreement with its client and is provided by Yellow Sub Geo solely for the internal use of its client.

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