Technical Memorandum

To:	Sarah Senior	**From:**	Ian Walton
Company:	Natural Resources Wales	**SLR Consulting Limited**	
cc:	Anothony Allen (A & C Aggregates Limited)	**Date:**	15 January 2024
		Project No.	407.063401.00001

RE: Carew Mill Pond Water Levels

1.0 Background

This technical memorandum has been prepared in support of the Application (PAN-022378) for an abstraction licence (transfer licence) for the proposed dewatering of a Limestone aggregate quarry at Carew Quarry, Carew Cheriton (the Quarry) NGR: SN 04830 04277.

The Quarry is located c. 0.25km north of the tidal Carew River and Mill Pond (the Pond). The Pond provides a habitat for the Tentacled Lagoon Worm (*Alkmaria romijni*), which is designated a species of "principal importance" for the purpose of maintaining and enhancing biodiversity in relation to Wales. As such the Pond coastal lagoon feature designated as a Special Area of Conservation (SAC) feature as part of the Pembrokeshire Marine SAC.

In response to the Application and associated Hydrogeological Impact Appraisal (HIA), Natural Resources Wales (NRW) have requested further information (email from Sarah Senior NRW to Geoff Keenan SLR, attached as Annex A) to assist them in determining the application. The NRW have requested further information on the following issues:

1. Impact of the proposed abstraction on water levels in the Pond.
2. Increased risk of saline intrusion into the aquifer.
3. Further quantitative assessment of the impact of dewatering on groundwater and pond water levels (Tier 2 Intermediate or Tier 3 Detailed analysis[1]) to the assess the impacts described above.
4. Requirements for pump testing.
5. Effect of the lateral and vertical extension of the quarry.

These issues are considered in this technical memorandum.

Three approaches to considering the likely impact of the abstraction on water levels are set out in this memorandum:

- A simplistic, conservative, water balance;
- The impact of the dewatering of the quarry by the former owners; and
- The direct recharge of the dewatering water;

These are discussed in turm below.

[1] Environment Agency (April 2007) Hydrogeological Impact Appraisal for Dewatering Abstractions, ref: SC040020/SR1

2.0 Water Balance

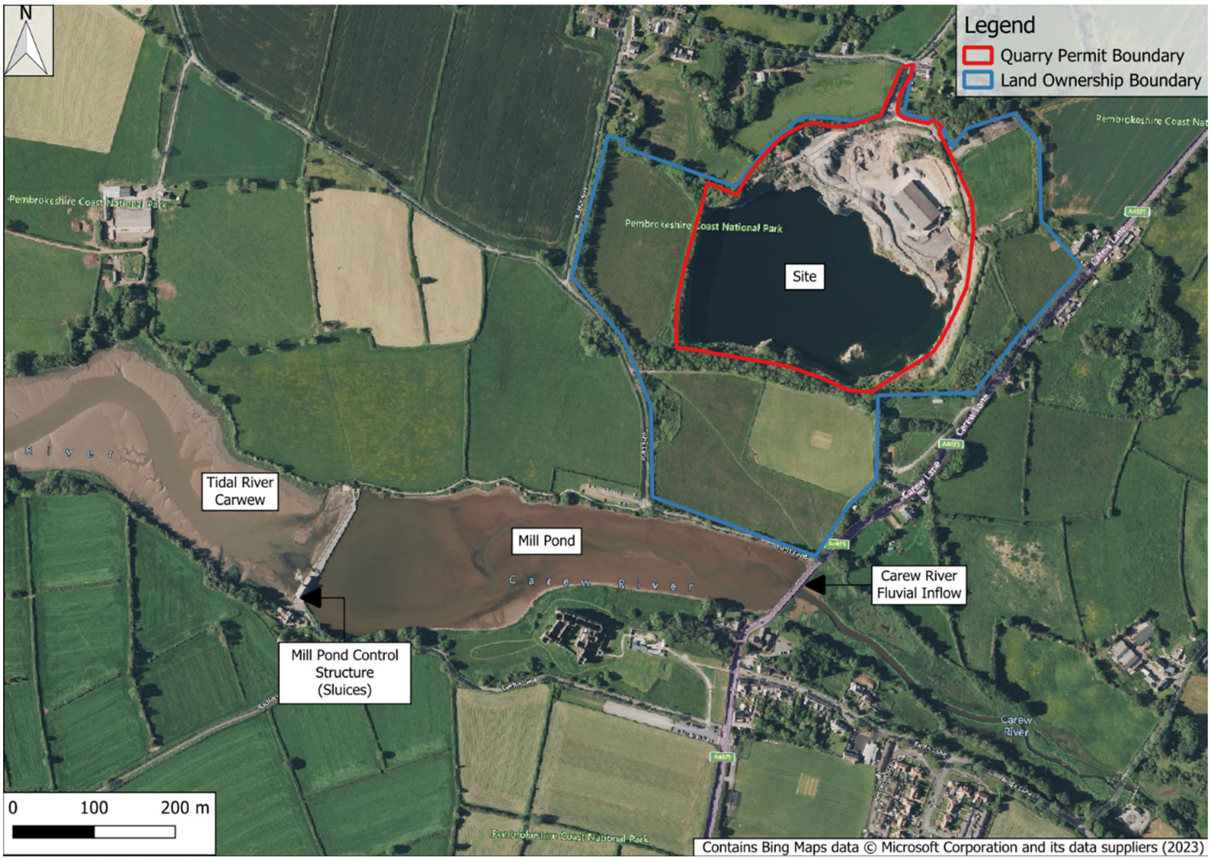
2.1 Background

This section presents the methodology and results of the analysis of the potential impact of the proposed dewatering of the Quarry on water levels in the Pond. It is based on a high-level water balance approach, i.e. considering the inputs to, and outputs from, the Pond and has been completed adopting the following worst-case conservative assumptions:

- The proposed maximum 10,000m^3day^{-1} is abstracted directly from the Pond. During periods of low flow corresponding to periods of low rainfall, the long-term dewatering rate is likely to be considerably lower than the maximum sought (see Section 3.0 for commentary on 'historic' abstraction rates)
- There is no groundwater inflow to the Pond.
- The lowest monthly average inflow (Q95 baseflow) into the Pond from the Carew River.

The location of the Quarry in relation to the Pond is shown by Figure 2-1.

Figure 2-1: Site Location



The dam that impounds the Pond was constructed in circa 1800 to power the Carew Tidal Mill[2]. During operation of the Mill, water was impounded on a rising tide and drained via a sluice to power the Mill's water wheels. The Mill operated until circa 1937.

Over the period of operation, water levels would therefore have varied will the filling and draining of the lagoon. However, it is understood that water levels in the Pond are now

[2] https://en.wikipedia.org/wiki/Carew_Tidal_Mill

supposed to be maintained and are only lowered to alleviate potential flooding in the Carew River.

The 19.5km^2 upstream catchment of the Carew River drains to the Pond providing a freshwater input. The resulting mixing of tidal, groundwater (ignored for the analysis) and fluvial inflows results in a brackish pond with a surface circa. 7.5ha.

The location of the Pond is shown by Figure 2-1.

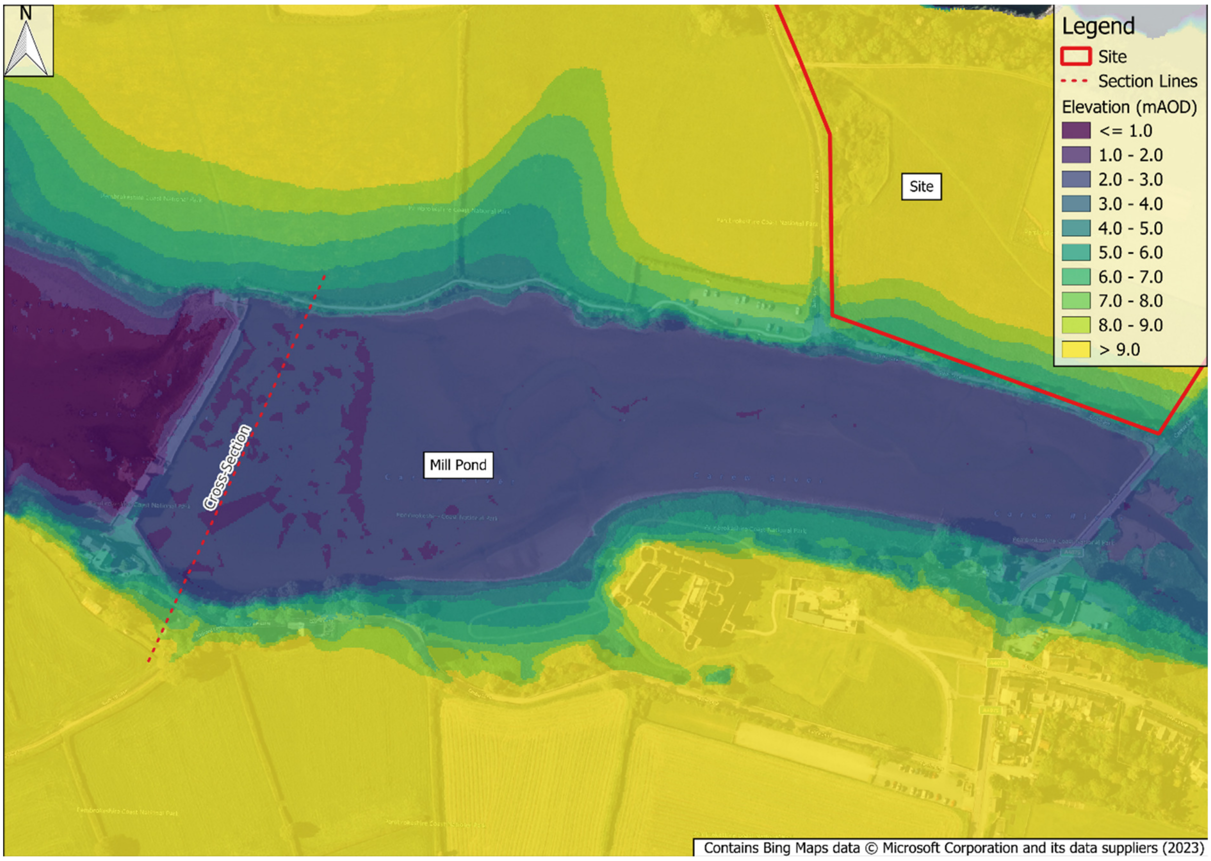
2.2 Topography of the Pond

The topography (bathymetry) of the pond has been derived from 1m resolution LiDAR DTM data[3] as shown in Figure 2-2. It is clear that when the topographic data was acquired, the Pond was not impounded and therefore provides a reasonable representation of the bed.

The cross-section shown in Figure 2-3 indicates that the bed level of the Pond is at circa. 2.0m above Ordnance Datum (AOD) and covers an area of approximately 7.5ha.

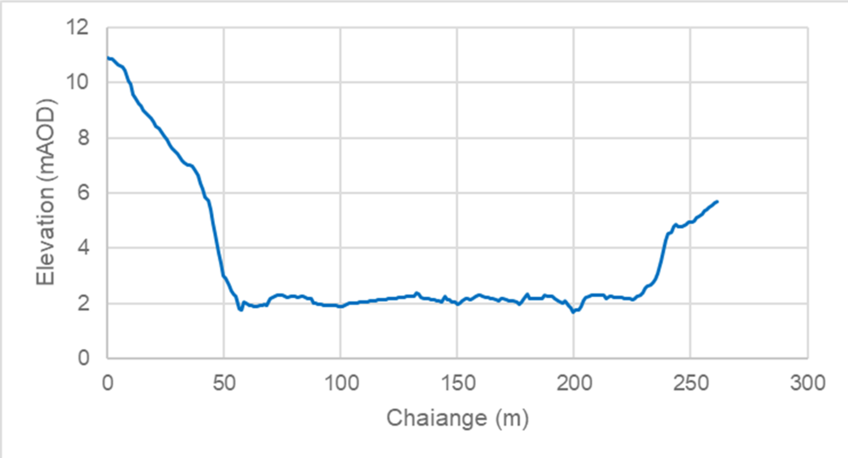
Maximum water levels in the Pond are governed by an overflow weir at the northern end of the dam. The invert level of the weir has recently been surveyed as 3.1mAOD and this has been used as the impounded top water level for the Pond in the analysis.

Figure 2-2: Local topography



[3] https://datamap.gov.wales/maps/lidar-viewer/

Figure 2-3: Mill Pond Cross-Section



2.3 Tidal Influence

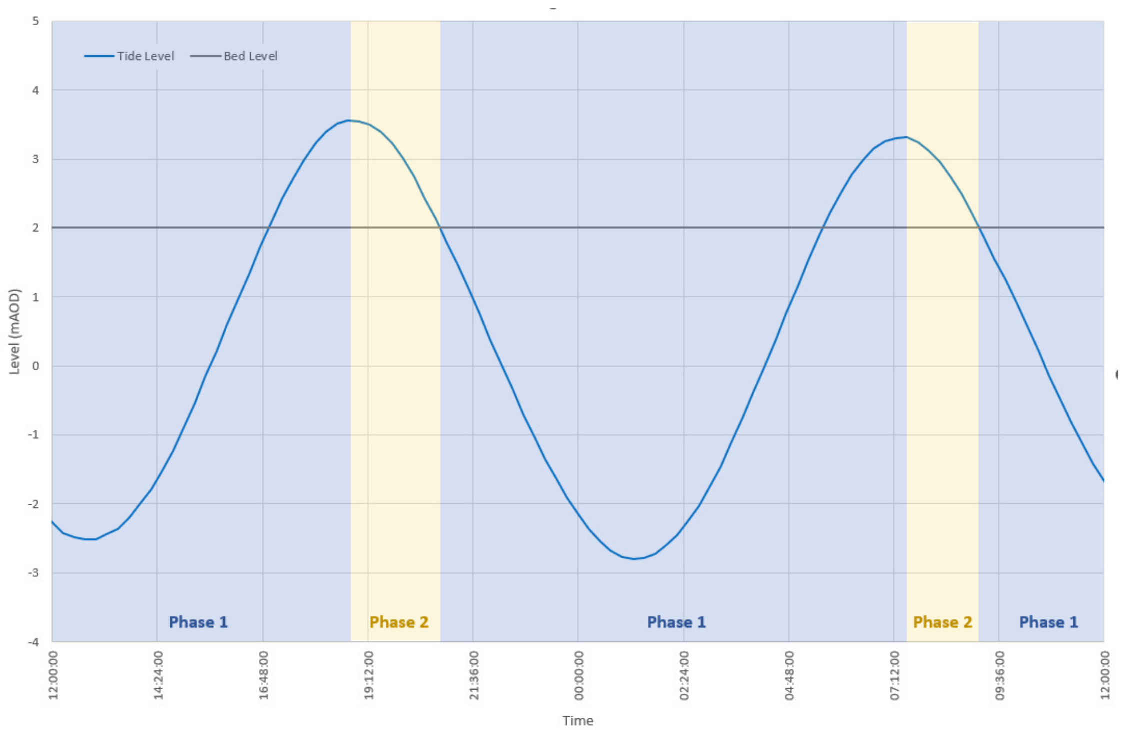
The tidal inflows to the Pond are controlled by sluice gate structures in the dam wall. They act as 'one-way' valves allowing tidal ingress when tide levels on the downstream side of the dam are higher that impounded levels in the Pond. This is conceptually a two-phase process

Phase 1 – During a rising tide, sea water flows through the sluices into the Pond. Water levels in the Pond equalise with the level of the tide.

Phase 2 – During a falling tide, the sluices are closed to retain water within the Pond below the level of the overflow weir. Water levels in the Pond are higher than in the tidal River Carew downstream of the dam.

These phases are shown conceptually by Figure 2-4.

Figure 2-4: Tidal Cycle Phases



2.4 Conceptual Water Balance Model

- As discussed in Section 2.1, a conservative approach has been adopted and
- Evaporation from the surface of the Pond
- Infiltration thorough the base of the Pond

These are discussed below.

Figure 2-5 illustrates the conceptual water balance model developed for this analysis.

The inflow and outflows are summarised a follows:

Inputs (sustaining water levels in the Pond)

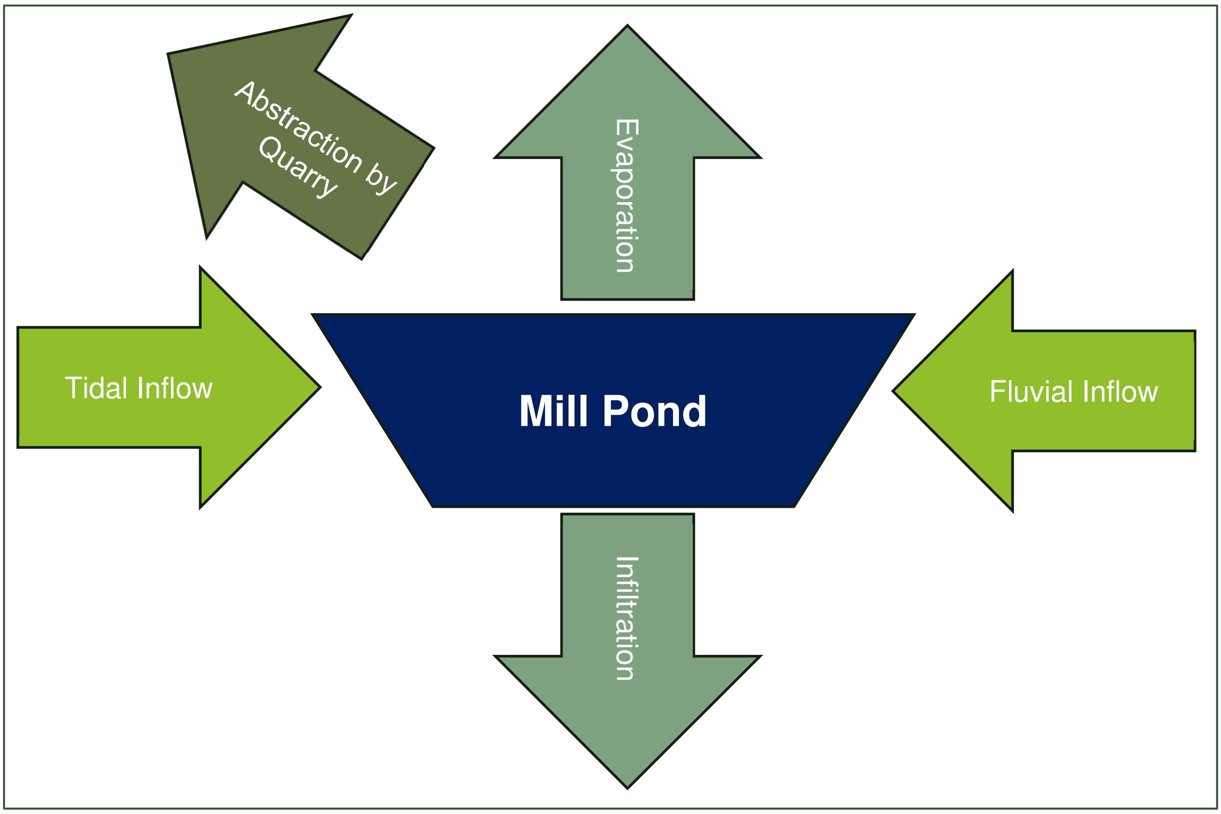
- Tidal inflow when tide level is greater than level in the Pond
- Fluvial inflows from the upstream catchment of the Carew River
- Groundwater inflows (not considered to provide a conservative assessment)

Losses (reducing water levels in the Pond)

- Abstraction from the Quarry (assumed to be a direct loss from the Pond)
- Evaporation from the surface of the Pond
- Infiltration thorough the base of the Pond

These are discussed below.

Figure 2-5: Mill Pond Conceptual Water Balance



2.4.1 Tidal Input

The nearest location for which tide level is published is Black Mixen Pool some 3.5km downstream of the dam. However, as gauge data is not available for the Black Mixen Pool, analysis of the tidal range at the Pond has been based on the gauge record from Milford Haven[4]. Comparison of high tide levels between Milford Haven and Black Mixen Pool confirms that there is no difference between the two.

2.4.2 Fluvial Input

An analysis of annual flow duration curves for the fluvial inflows to the Pond from the upstream River Carew catchment has been completed using the LowFlows2[5] software. The analysis indicates that the Annual Mean Flow is circa $0.38m^3s^{-1}$ with an Annual Mean Q95 flow (the flow rate which is expected to be exceeded for 95% of the year and is considered to represent 'baseflow'.) of $0.018m^3s^{-1}$.

The monthly Q95 flow was shown to be lowest during August where it was estimated to be $0.009m^3s^{-1}$. (9 ls^{-1}). This value has been conservatively adopted as the fluvial inflow during the analysis of Pond water levels.

2.4.3 Abstraction Losses

The 'losses' from the Pond due to the proposed dewatering have been conservatively assumed to be 10,000 m^3day^{-1} (115 ls^{-1}) based on the maximum permitted rate from the Quarry secured by the previous owners and sought by this application.

This is an extremely conservative (and unrealistic) assumption as it assumes in effect that the dewatering operations would be drawing water directly from the Pond with no recharge via groundwater inflows.

As noted in Section 2.1, the analysis assumes that there is no groundwater flow into the pond. This again is extremely conservative as there are several visible issues that discharge to the northern edge of the Pond.

Whilst consent is being sought to abstract groundwater from Quarry at a maximum rate of 10,000 m^3day^{-1}, it is anticipated that this will only be required to dewater the void. Once groundwater levels have been drawn down, the pumping rate to maintain the lowered levels is likely to be considerably less. Previous operational experience (see Section 3.0) suggest this will vary between 6,000 m^3day^{-1} during winter months and 3,000 m^3day^{-1} during summer months.

2.4.4 Evaporation Losses

To assess the likely worst case evaporation losses from the Pond during the summer months, the Environment Agency's (EA) Potential Evapotranspiration (PET) 1km grid dataset[6] was reviewed for the 2016-2020 water years. These values were converted to estimates of open water evaporation using the '*empirical factors method*' for MORECS grass PE as detailed in the EA's Estimation of Open Water Evaporation guidance[7].

Analysis of the data indicates that in general the highest evaporation occurs during June and July, when the average open water evaporation is $3.6mmday^{-1}$.

[4] https://rivers-and-seas.naturalresources.wales/Station/73039?parameterType=3
[5] https://www.hydrosolutions.co.uk/software/lowflows2/
[6] https://www.data.gov.uk/dataset/7b58506c-620d-433c-afce-d5d93ef7e01e/environment-agency-potential-evapotranspiration-dataset
[7] https://assets.publishing.service.gov.uk/media/5a74b4bae5274a3f93b4823a/sw6-043-hb-e-e.pdf

However, the Q95 open water evaporation rate for June and July (the daily evaporation is expected to be below this value for 95% of the month.) was 6.2mmday^{-1}. This value has therefore been conservatively adopted as the evaporation rate for the analysis of Pond water levels.

2.4.5 Infiltration Losses

As described previously there are unlikely to be significant losses via infiltration through the base of the Pond due to the low permeability of the tidal flat deposits within which it is founded. However, as a worst-case scenario, potential infiltration losses have been estimated.

Infiltration losses from the Pond have been based on the typical infiltration coefficients for '*silty clay loam*' provided by Table 25.1 of The SuDS Manual[8]. These are considered to be analogous to the tidal flat deposits with coefficients ranging between 1 x 10^{-8} ms^{-1} to 1 x 10^{-6} ms^{-1}. Given the evident significant siltation in the Pond, it is expected that infiltration rates will be at the lower end of the typical coefficients. However, a conservative central value of 1 x 10^{-7} ms^{-1} (8.6mmday^{-1}) has been adopted.

2.5 Analysis

As described previously, the water levels in the Pond are predominantly controlled by the tidal levels. The tidal influence has been separated into two phases described below:

Phase 1 – Tidal levels are rising between the bed of the Pond and high tide water level. During this phase it is assumed that the sluice gates are open and water levels in the Pond equalise with the tidal water level.

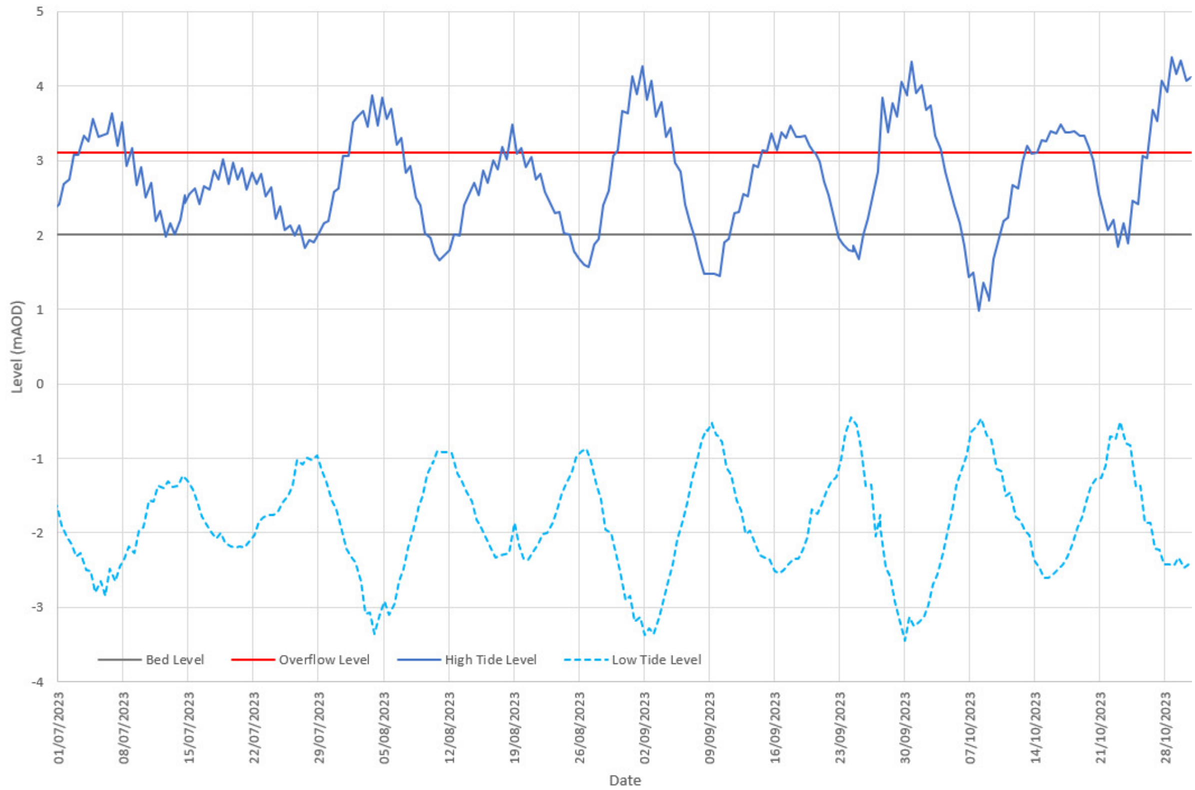
Phase 2 – Tidal levels are falling or are below the bed of the Pond. During this phase it is assumed the sluice gates are closed and water levels in the Pond below the level of the overflow weir change based on the water balance of the fluvial (freshwater) inflow and the evaporation, infiltration, and dewatering losses.

The water balance has been based on the tidal gauge record for Milford Haven over the 4-month period between 30 June 2023 to 30 October 2023 which provides a typical tidal range across several neap and spring tidal cycles.

The variation in tidal levels over this period in relation to the bed level and the overflow level of the Pond are shown by Figure 2-6. This shows that the high tide during several of the neap tidal cycles does not reach the level of the bed of the Pond and therefore there would be no tidal inflow.

8 CIRIA C753 The SuDS Manual, 2015.

Figure 2-6: Tidal Levels at the Pond



The August Q95 fluvial inflow and evaporation, infiltration, and dewatering losses have been converted to a rate of change of level in the Pond assuming an area of 7.5ha.

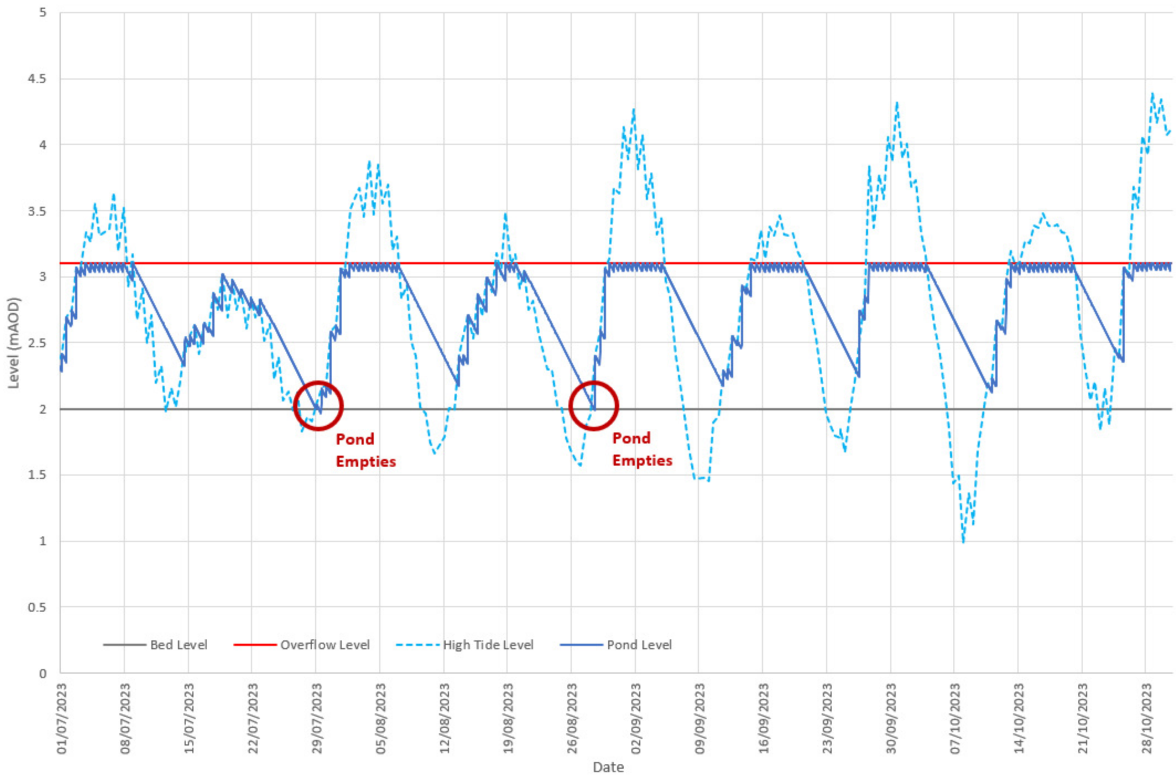
A summary of the inputs into the water balance assessment for Phase 2 of the water balance is provided in Table 2-1.

Table 2-1: Phase 2 Water Balance Inputs

Variable	Value
Pond area (m^2)	75,000
Pond Overflow Wier Level (mAOD)	3.1
Fluvial Inflow August Q95 (m^3/s)	0.009
Fluvial increase in Pond Level (mm/day)	10.4
Evaporation Pond Losses Q95 June / July (mm/day)	6.2
Infiltration Rate (m/s)	1×10^{-7}
Infiltration Pond Losses (mm/day)	8.6
Dewatering Abstraction Rate (m^3/day)	10,000
Dewatering Pond Losses (mm/day)	133.3
Total Phase 2 Reduction Rate in Pond Level (mm/day)	**137.7**

During the periods where there is no tidal inflow to the Pond, water levels will reduce if the combined loses are greater than the fluvial inflow (this is always the case where the August Q95 inflow is assumed). Figure 2-7 shows the effect of the losses exceeding the inflow during the neap tidal cycle on the water level in the Pond.

Figure 2-7: Milford Haven and Mill Pond Water Level Plot



The results of the analysis indicate that during the typical 4 month period assessed the Pond would be fully empty three times for periods of 1 hour 15 mins, 7 hours and 2 hours 45 mins; a total of some 11 hours. For the remainder of the 4 month period, 2,869 hours, water levels remain above the bed level of the Pond.

However, as discussed above, the analysis is extremely conservative in that no account of groundwater inflow to the pond has been considered and 10,000m^{3}day^{-1} is lost directly from the Pond due to the dewatering of the Quarry.

Clearly the draining of the Pond for a matter of hours would not result in the drying out of the tidal flats deposits and accumulated silt washed down from the upstream catchment.

It is also noted that when the Mill was operational, the Pond would have been emptied on a regular basis to power the water wheels. The most conservative assessment of the proposed dewatering of the Quarry set out here would therefore have considerably less impact on water levels in the Pond than the former operation of the Mill.

2.6 Conclusion

Even adopting the most conservative of assumptions, it is concluded that the proposed dewatering of the Quarry would not result in the drying out of the sediments in the Pond. Therefore, the habitat for the Tentacled Lagoon Worm (*Alkmaria romijni*) within the Mill Pond SAC, would not be detrimentally impacted by the proposed dewatering works.

3.0 Previous Operation of the Quarry

Quarrying at Carew commenced in 1919, initially as a source of lime for various lime kilns situated in the locality. Operations have continued since then, with the focus now on the supply of high-quality crushed limestone as an aggregate for the construction industry. The first planning permission was granted in 1947 followed by permissions for various extensions. In August 1997, a planning application was submitted to 'consolidate' theses permissions into one single permission.

A 15-year review require required by the Environment Act 1995 was submitted in December 2012 and the Periodic Review of Mineral Planning Permissions (ROMP) was granted in June 2019.

Quarrying by the former owner ceased in 2018 by which time the maximum permitted depth of -30mAOD had been reached in the south east corner of the Quarry. Up to the 2018 closure, the Quarry was being dewatered with the dewatering water discharged to a sinkhole to the south of the Quarry approximately mid-way between the southern run of the Quarry and the northern edge of the Pond. The application seeks to replicate the dewatering of the Quarry to this sinkhole.

The Appendix 3 to the ES that supported the 2012 ROMP included the results of flow monitoring for the discharge from the Quarry over a 4 year period between 2000 and 2004. This indicated that the maximum daily flow varied between 5,723m^3 in the winter and 2,793m^3 in the summer.

We are unaware of any adverse impact on the habitat of the Tentacled Lagoon Worm prior to the closure of the Quarry in 2018.

The maximum licenced daily discharge rate for the Quarry before the 2018 closure and now being sought by the current owners is 10,000m^{3}day^{-1}. In the short term, it is anticipated that groundwater will be abstracted at the maximum permitted rate to lower levels in the Quarry to allow quarrying of the remainder of the base to the permitted levels.

Assuming this is completed over the summer months, and assuming a net outflow from the Quarry of circa 7,000m^{3}day^{-1}, it would take 4 to 5 months to lower levels. Once levels have been reduced, it is anticipated that the daily discharge would be reduced to the range monitored between 2000 and 2004.

4.0 Impact on Water Level in the Mill Pond – Hydrogeology

Notwithstanding the conclusions of the water balance assessment described above, there are also hydrogeological considerations that will affect the potential impact of the proposals on the water levels in the Pond. The NRW has suggested that the applicant consider additional quantitative hydrogeological assessment to further asses the risk to the Pond. This could include undertaking a Tier 2 or 3 impact assessment and potentially a pumping test.

The appropriateness of these assessments has been considered further and it is concluded that they are unlikely to provide the additional understanding sought and the effort and cost is better directed elsewhere to verify the conclusions of the HIA and this technical memorandum. The rationale behind this conclusion is discussed below:

- Water abstracted from the Quarry will be discharged down hydraulic gradientto a sinkhole, between the Quarry and the Pond. There is likely to be a direct, karstic connection between the discharge location and the Pond. There is therefore only a negligible risk that the dewatering abstraction will significantly reduce the discharge of groundwater to the Pond.
- Potential impacts on the Tentacled Lagoon Worm relate to the lowering of water levels in the Pond and the subsequent drying out of the sediment. As described above in the water balance study, other than the issue noted on the northern bank, groundwater is unlikely to be a significant input to the Pond water balance. The base of the pond comprises fine grained Tidal Flat Deposits which will have a low permeability this further reduces the risk of a lowering of the water due to a reduction in groundwater levels beneath the Pond.
- Tier 2 Intermediate or Tier 3 Detailed analysis[1] would involve more sophisticated analytical solutions and/or two-dimensional steady state or time-variant numerical modelling. Appendix 3 of the guidance[1] states that where conduit flow is present, most analytical equations and conventional groundwater modelling strategies are inappropriate and, if they are used, predictions of impacts will be highly uncertain. Conduit flow is known to be the principal flow mechanism in the aquifer at the Quarry and Pond. The guidance recommends that the best approach in this situation is to ‘monitor and mitigate’. The mitigation is to recharge the water back to the aquifer down hydraulic gradient from the Quarry. It is therefore proposed that a groundwater monitoring borehole is installed between the Quarry and the Pond to demonstrate that this is effective.
- Conduit flow will also mean that pump testing will be of limited value and is not considered appropriate for this situation.
- The increased risk of saline intrusion into the aquifer is considered to be negligible for the same reasons as described above regarding the impact on water levels in the Pond. It is considered that in an aquifer dominated by conduit flow, resources are better directed towards mitigation and monitoring as described above.
- There are no proposals to increase the consented lateral footprint and vertical depth of the excavation. Dewatering will be undertaken from the same sump location in the southwestern part of the void and the water level will be at, or above, historical levels. There will therefore be no change to the historic impact of the Quarry, which we understand did not significantly affect water levels in the Pond.

5.0 Conclusions

The water balance assessment presented in this note demonstrates that water levels in the Pond are not dependant on groundwater flow, the principal control being the tidal inundation of the Pond and inflow from the Carew River. Groundwater is likely to be a relatively small component and a worst-case assessment assuming that all of the proposed abstraction of 10,000m^3day^{-1} is drawn from the Pond with no groundwater inflow demonstrates that even under theses conservative (unrealistic) assumptions, the sediment in the Pond would not dry out.

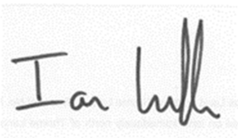
The hydrogeological conceptual model further reduces the risk as groundwater flow is via conduit flow and water will be discharged back to the conduit system mitigating any potential effects. The pond is also underlain by low permeability Tidal Flat Deposits which will severely restrict the leakage of water from the Pond, even if dewatering was to lower groundwater levels, which the assessment indicates it will not. For the same reason the dewatering of the Quarry will not significantly increase the risk of saline intrusion into the aquifer.

There are no proposals to increase the historic lateral footprint and vertical depth of the excavation. There will therefore be no change to the historic impact of the Quarry, which did not significantly affect water levels in the Pond.

More detailed analytical and/or numerical groundwater modelling is not appropriate in a karstic aquifer dominated by conduit flow. The guidance recommends that the approach should be to ‘monitor and mitigate’. Mitigation is the discharge of water to the conduit system between the Quarry and the Pond.

It is proposed to install a borehole between the Site and the Pond to monitor the impact and demonstrate that the assessment presented in this note and the HIA is correct, i.e. that the water level in the Pond will not be significantly affected by the dewatering of the Quarry and there will be no impact on the habitat of the Tentacled Lagoon Worm.

SLR Consulting Limited



Ian Walton BSc (Hons) MSc DIC MICE CEng
Technical Director

Attachments Annex A: Natural Resources Wales Request for Further Information (1st December 2023)

Annex A - Natural Resources Wales Request for Further Information (1st December 2023)

Geoff Keenan

From: Senior, Sarah <sarah.senior@cyfoethnaturiolcymru.gov.uk>
Sent: 01 December 2023 13:34
To: Geoff Keenan
Subject: PAN-022378 - Carew Quarry - Additional information required to support application

Importance: High

Good afternoon Geoff,
I am contacting you as we need to request further supporting information for application PAN-022378.

As you know, the quarry is sited next to Mill Pond (a coastal lagoon (SAC feature) forming part of the Pembrokeshire Marine SAC), which contains a species of conservation importance under the Environment (Wales) Act (the Tentacled Lagoon Worm). After consulting with my Geoscience colleague, the local Conservation Officer and a Specialist Advisor in Benthic Ecology, we have concerns that dewatering in the quarry could negatively impact this protected feature by lowering the water level in the Pond. Our invertebrate specialist has confirmed that this species is sensitive to fluctuating water levels so any activity that will cause water levels to lower in the Pond could disturb or cause a deterioration of the SAC feature. If we cannot rule out that an activity will adversely affect the integrity of a Natura 2000 site, then we would not normally issue a licence for that activity. At present, we do not have enough supporting information to rule out dewatering at Carew Quarry from adversely affecting the Tentacled Lagoon Worm.

We require further supporting information from you, in your HIA, to allow us to determine whether we can rule out the activity from having an adverse effect on a SAC feature. My Geoscience colleague has provided the following assessment of your HIA with a recommendation of what is still required.

> "The HIA produced was sufficient for normal applications (Tier 1 Basic as defined in Hydrogeological impact appraisal for dewatering abstractions - GOV.UK (www.gov.uk) , but given the complex sensitive receptors around the quarry (SAC features within the Mill Pond) and potential dewatering zone of influence (or drawdown area) more details and quantitative assessment are required (Tier 2 and 3 as define by HIA guidance). The current water level within the limestone (karstic) quarry is at a similar elevation to the water levels within the Mill Pond only 200 m from the site. Although we note that calculations done to date indicate a zone of influence from the dewatering drawdown to only be 100m, given that the quarry will be deepened beyond its current base depth and expanded laterally the zone of influence of drawdown has the potential to have a greater radius over time. A greater radius for the zone of influence of drawdown then has the potential to draw in groundwater from a wider area and start to affect the water level within the Mill Pond and lower the water levels within this feature. The SAC feature within the Mill Pond, the Tentacled Lagoon Worm, is sensitive to drying out which could occur if water levels within the Mill Pond are lowered by the dewatering. Needless to say a quantitative hydrogeological impact assessment (HIA) is required to support this application. Details on HIA requirements are define within the guidance Hydrogeological impact appraisal for dewatering abstractions - GOV.UK (www.gov.uk), in particular, Appendix 3 for karstic terrains and Box A3.1 and Box A3.2 are specific HIA methodology for karst."

We need you to undertake the higher tiers of an HIA, as noted above, to gain a better understanding of the hydraulic connectivity between groundwater and surface water at the site and the potential impact dewatering of the quarry could have on the water levels in Mill Pond. If you are unable to rule out connectivity, then we would need to know how the proposed abstraction would affect the water levels of Mill Pond, during the initial dewatering to drain the quarry and any dewatering required while the quarry is subsequently worked and the zone of influence potentially widens. My Geoscience colleague has suggested you may need to undertake a test pump, monitoring of groundwater levels and subsequent assessment, or modelling to generate the required information to add to your HIA. If you decided a test pump is required, then you would need to apply for a Groundwater Investigation Consent to undertake this work.

As part of our determination, we would also use the additional supporting data on hydraulic connectivity to assess the risk of further saline intrusion occurring and affecting the WFD status of the groundwater body.

I need to know from you how long you would need to generate the additional supporting data that we require for our determination of the application. (Note: we would normally only allow several weeks for an applicant to provide additional supporting information during determination and if this is not possible recommend the application is withdrawn, if as it stands we would not be able to issue a licence.)

If you would like to discuss any of the above before letting me know how long you will need to add to the HIA, then I can give you a call at your convenience (next week) and ,if it would be useful, bring in my Geoscience colleague too.
Thanks, Sarah

Enw / Name - Sarah Senior
Teitl swydd / Job title – **Swyddog Trwyddedu Adnoddau Dwr 2** / Water Resources Permitting Officer 2
Adran / Department – **Tystiolaeth, Polisi a Thrwyddedu** / Evidence, Policy & Permitting
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Rhagenwau / Pronouns – **hi** / she/her

Croesewir gohebiaeth yn Gymraeg a byddwn yn ymateb yn Gymraeg, heb i hynny arwain at oedi.
Correspondence in Welsh is welcomed, and we will respond in Welsh without it leading to a delay.