TECHNICAL MEMORANDUM

TO	Francesco Di Stefano, Environment Agency (EA)
FROM	Environmental Resources Management Limited (ERM)
DATE	11th November 2025
REFERENCE	0792240, Application reference EPR/CP3225SW/A001
SUBJECT	Aldbrough Hydrogen Pathfinder Permit Application – RFI Response – ALD1 Cavern

Response to EA Duly Making – Cavern Integrity and Risk Assessment

SSE Hornsea Limited (SSE) submitted a bespoke environmental permit application for the Aldbrough Hydrogen Pathfinder (AHP) facility, located at SSE's Albrough Gas Storage Site at Garton Road, East Riding of Yorkshire on 1st July 2025.

Following submission, the Environment Agency issued an information request as part of their duly making checks. Part of the request related to the **Cavern Integrity and Risk Assessment**. The specific requirements were listed in Point 5 of the request:

a) the geological setting of the salt cavern;

b) its dimensions, supported by 3D maps/drawings, and ideally a summary report of the latest sonar survey;

c) a high-level conceptual site model addressing potential interactions with groundwater and consideration of pathways for hydrogen emissions, along with a risk assessment and proposals for monitoring.

This technical note has been prepared by ERM on behalf of the SSE, to provide the information requested by the Environment Agency. In this note, reference is made to the following report:

- Atkins, June 2024, *Pathfinder Aldbrough 1 Rewatering – Cavern Rewatering Design Assessment*. Atkins ref. 5221963-ATK-ZZ-ZZ-TREP-CV-000001 (also provided in Attachment A).

HYDROGEN STORAGE CAVERN DESIGN

The AHP project proposes to re-purpose an existing underground natural gas storage cavern (known as 'ALD1') for hydrogen storage. This will include initial re-watering of the cavern (using water from licensed groundwater abstraction point, ref. NE/026/0033/011) to displace the natural gas currently stored in the cavern, followed by displacement of the water by hydrogen gas over a period of approximately 12 months.

The existing cavern was constructed in 1993 using solution mining techniques and is located at a depth of approximately 1,770 m – 1,850 m below ground level (bgl) within evaporite salts of the Permian Zechstein Group. The inherent properties of evaporite salts, including impermeability (gas tightness), plasticity ('self-healing', lack of fracturing) and chemical inertness, make them ideal for underground gas storage caverns.

The volume of the cavern is estimated at 267,193 m^3 with a maximum diameter of approximately 82 m (2023 data). The cavern has been in commercial use since 2009. Re-watering of the cavern is anticipated to increase the volume of the cavern to approximately 311,400 m^3, an increase of approximately 44,200 m^3 or 16.5 %.

According to Atkins' 2024 Rewatering Design Assessment report (Attachment A), cavern condition is generally described as 'stable' (i.e. the stability of the cavern is satisfactory; there is no requirement to carry out geomechanical investigations). Based on sonar surveys, minor roof falls are thought to have occurred between 2018 and 2023, reported to be potential evidence of cavern roof re-shaping into a state of equilibrium. Sufficient salt thickness (at least 30 m) remains above the roof of the cavern (2023 data).

There have been no reported concerns in relation to loss of natural gas, e.g. via seepage through the cavern walls, fracturing of the caprock or loss of integrity of the well bore since commencement of operation. Note that the well completion will be modified for AHP operations, to ensure it is appropriately designed and constructed for hydrogen service.

An updated geo-mechanical assessment of the cavern is proposed to be commissioned by SSE prior to re-purposing of the cavern for hydrogen storage to assess whether anticipated geometric changes in the cavern resulting from additional leaching of the cavern walls may compromise (or not) the geo-mechanical stability of the cavern roof and/or integrity of the Last Cemented Casing Shoe (LCCS) at the base of the well bore.

GEOLOGICAL SETTING

The geological sequence underlying the AHP site, based on British Geological Survey (BGS) mapping[1] and site-specific investigation data (see Attachment A) is summarised in Table 1, below, and shown schematically in Attachment B.

TABLE 1 - SUMMARY OF GEOLOGICAL SEQUENCE UNDERLYING AHP

Stratum	Approximate Depth to Top of Unit (m bgl)	Approximate Thickness (m)	General Description
Topsoil / Made Ground	0	0.3	Topsoil and/or engineered Made Ground.
Glacial Till	0.3	40	Clayey glacial deposits with some sand and gravel layers.
Chalk Group	40	550	White chalk with occasional chert bands, highly weathered towards the top.
Lias Group	590	130	Dark grey mudstone and siltstone.

[1] British Geological Survey 1:50,000 Map Sheet 73 (Hornsea, Solid & Drift, 1998) and 'GeoIndex' online mapping (https://mapapps2.bgs.ac.uk/geoindex/home.html), including available-to-view borehole records TA23NE4, TA23NE6, TA23NE7 and TA23NE13.

Stratum	Approximate Depth to Top of Unit (m bgl)	Approximate Thickness (m)	General Description
Penarth Group	720	20	Red-brown mudstone.
Mercia Mudstone	740	180	Red-brown mudstone and siltstone.
Sherwood Sandstone	920	670	Red sandstone with siltstone and mudstone towards the base.
Zechstein Group	1,590	340	Evaporite sequence comprising marl, halite, polyhalite, anhydrite (gypsum) and dolomite.
Cadeby Formation	1,930	90	Buff dolomitic limestone with occasional mudstone, siltstone and sandstone layers.

m bgl – metres below ground level

The ALD1 cavern is located entirely within the 'Z2 Fordon Evaporites' cycle of the Zechstein Group, which, based on site-specific geological and geophysical logs and sonar surveys provided in Attachment A, comprises:

- Z2 Evaporite (1,716 – 1,760 m bgl; c. 40 m in thickness) – alternating sequence of laminated anhydrite with bands of halite;
- Z2 Main Salt (1,760 – 1,908 m bgl; c. 150 m in thickness) – laminated halite with subordinate amounts of polyhalite, anhydrite and kieserite; and
- Z2 Polyhalite (>1,908 m bgl, at least 20 m in thickness) – laminated halite, anhydrite and polyhalite.

HYDROGEOLOGICAL SETTING

Chalk Group bedrock underlying the AHP site is highly productive and is classified as a Principal Aquifer. Given the significant thickness of Glacial Till overlying the chalk, the chalk aquifer is considered to be confined in the area of the AHP site. Reducing geochemical conditions are anticipated to prevail in the confined sections of the chalk aquifer[2].

Although the chalk aquifer is an important resource for potable supply at a regional scale, the AHP site is not located in a groundwater Source Protection Zone (SPZ). A licensed abstraction (ref. NE/026/0033/011) from the chalk aquifer is held by SSE for 'Petrochemicals: general use' at the Aldbrough Gas Storage facility. No further groundwater abstractions are identified within 1 km of the AHP site[3].

Due to the presence of dolomites, the wider Zechstein Group geological unit within which the cavern is located is classified by the British Geological Survey (BGS) as a highly productive

[2] British Geological Survey and Environment Agency, 2004, *Baseline Report Series: 10. The Chalk Aquifer of Yorkshire and North Humberside*. BGS ref. CR/04/128N and EA ref. NC/99/74/10.
[3] It is noted that a 2019 Hydrogeological assessment undertaken by Atkins also identified two private water supplies within 1 km of the AHP site. However, information provided by the Environment Agency and East Riding of Yorkshire Council in 2023 suggested that these abstractions no longer exist. It is, however, acknowledged that there may be the potential for other unlicensed, unrecorded abstractions to be present.

aquifer[4]. However, aquifer classifications generally apply to groundwater bodies in the upper approximately 400 m of the subsurface where groundwater is prioritised and protected through the WFD[5]; at the AHP site the Zechstein Group is located at a depth of approximately 1.6 km. At such depths, the resource value of groundwater is likely to be negligible, e.g. due to high salinity[6].

The Sherwood Sandstone, which directly overlies the Zechstein Group beneath AHP site, and Cadeby Formation, which underlies the Zechstein Group, are also classified as highly productive aquifers (where present at <400 m depth). However, the Lias Group, Penarth Group and Mercia Mudstone are not considered to be productive aquifers based on their predominantly low permeability strata (mudstones and siltstones).

Aquifer productivity of the geological units underlying the AHP site, based on BGS classifications, are shown on Attachment B.

POTENTIAL GROUNDWATER IMPACTS

No known adverse impacts have occurred on groundwater from the construction and use of the existing cavern for natural gas storage and the proposed re-purposing for hydrogen storage will not result in any significant changes to the location, construction or scale of the cavern.

However, it is recognised that if not appropriately designed, constructed and controlled potential impacts to groundwater could occur in relation to the AHP project, including to:

- Groundwater quantity, as a result of loss of potential water storage capacity in the location of the cavern; and
- Groundwater quality, as a result of potential chemical impacts to groundwater from the accidental release of hydrogen from the cavern or well bore.

1. Potential Impacts on Groundwater Quantity and Recharge Supply

Although the wider Zechstein Group within which the cavern is located is classified as a highly productive aquifer (where present at depths of <400 m, see above), the cavern is constructed entirely within the Z2 Fordon Evaporite horizon, which, based on its inherent physical properties (i.e. impermeability), acts as a non-aquifer[7]. The Z2 Fordon Evaporite would therefore not be anticipated to have the capacity to store significant volumes of groundwater.

In some cases, although deep groundwater itself maybe not be a viable resource, it may form a recharge supply for shallow aquifers, surface water baseflows or springs. However, in the case of the chalk aquifer in eastern England, recharge is primarily from shallow sources (i.e. infiltration of rainfall infiltration, surface water and lateral migration within the chalk)[2]. Vertical hydraulic connectivity of the chalk aquifer to deep underlying aquifers (i.e. Sherwood Sandstone, Zechstein Group and Cadeby Formation) is restricted by the presence of low permeability layers and confining strata in between (i.e. Lias Group, Penarth Group and Mercia Mudstone). As a

[4] British Geological Survey, *GeoIndex* online mapping. Available at: https://mapapps2.bgs.ac.uk/geoindex/home.html (accessed 14 October 2025).
[5] Environment Agency, October 2020, *Perspectives on Protection of Deep Groundwater.* EA ref. SC180015.
[6] UK Technical Advisory Group on the Water Framework Directive, March 2012, *Defining and Reporting on Groundwater Bodies*.
[7] The term 'non-aquifer' is equivalent to 'Unproductive Strata'. Although 'non-aquifer' was largely replaced, the terms are used interchangeably in technical sources referenced herein.

result, deep groundwater beneath the AHP site is not anticipated to contribute recharge to the shallow chalk aquifer.

2. Potential Impacts on Groundwater Quality

Potential contamination of groundwater resulting from underground hydrogen storage is very much an emerging field. Although hydrogen itself would not be anticipated to result in adverse effects on groundwater quality, escape of hydrogen from the cavern into surrounding deep groundwater may result in secondary effects on groundwater geochemistry as a result of microbial process which consume hydrogen, for example sulphate reduction, methanogenesis and acetogenesis[8]. Resulting changes in geochemistry include potential generation of hydrogen sulphide, methane and acetic acid, and subsequent changes in redox potential and pH, which can ultimately affect the mobility of metal species. As discussed below, escape of hydrogen through the cavern walls is anticipated to be extremely limited.

Microbes have been shown to exist at the depth of the ALD1 cavern[9], including within salt deposits, although potential presence of hydrogenotrophic microbes within the cavern at the AHP site has not been assessed at this time. However, the majority of the Z2 Fordon Evaporite deposits comprise halite (sodium chloride), which does not contain any appreciable concentrations of sulphate (required for sulphate reduction) or carbonate (required for methanogenesis and acetogenesis). The potential for generation of these compounds via hydrogen-driven microbial processes is therefore anticipated to be limited to locations of anhydrite (calcium sulphate) and kieserite (magnesium sulphate), which are present as subordinate layers within the Z2 Fordon Evaporite horizon. In addition, in the event that hydrogen was to escape from the well bore directly into the chalk aquifer, the presence of carbonates and potentially suitable reducing geochemical conditions may allow methanogenesis or acetogenesis to occur, subject to the presence of relevant microbial populations and substrates. The need for further assessments, sampling or studies of H_2S formation will be considered and incorporated into the design process, if required.

CONCEPTUAL SITE MODEL

ERM has considered potential Source → Pathway → Receptor (SPR) linkages associated with storage of hydrogen within the existing cavern, as summarised below, to develop a hydrogeological Conceptual Site Model (CSM).

In line with the EA's request for further information, the CSM considers groundwater receptors only. As described above, impacts to groundwater quantity (storage capacity) and recharge are not anticipated. Potential SPR linkages considered herein are therefore limited to those which may affect groundwater quality.

[8] A Clark, A Pathak, K Tinker, D Gulliver and S Sharma, *Microbial and Geochemical Characterization of Groundwater: Implications for Underground Hydrogen Storage Leakage*. AGU Conference 2024 presentation. Available online at: https://www.osti.gov/servlets/purl/2496267/

[9] R Beaver and J Neufeld, 2024, *Microbial Ecology of the Deep Terrestrial Subsurface*. In The ISME Journal – Multi-Disciplinary Journal of Microbial Ecology, Volume 18(1). Available online at: Microbial ecology of the deep terrestrial subsurface - PMC

Sources

- Hydrogen gas, proposed to be stored in an existing underground cavern at a depth of approximately 1.8 km.

Pathways

- Escape of hydrogen through cavern walls to pore space in surrounding strata, e.g. via gradual diffusion. However, based on the extremely low permeability of rock salt (on the order of 10^{-20} m^2, based on laboratory data[10]), the rate of diffusion of hydrogen within the surrounding salt strata would be so slow that the potential distance away from the cavern walls that hydrogen may migrate during the operational lifetime of the cavern would be negligible. . Furthermore, hydrogen release via fractures or discontinuities is considered unlikely given the physical properties of the surrounding salts.
- Escape of hydrogen via the LCCS and/or walls of the well bore between the cavern and ground surface.
- Vertical migration within surrounding strata towards the ground surface, if hydrogen gas escapes from well bore or cavern.

Receptors

- Groundwater within the Chalk Group (Principal Aquifer).

Identified SPR linkages are presented schematically in Attachment B.

PRELIMINARY HYDROGEOLOGICAL RISK ASSESSMENT

Groundwater Quantity

Based on the information presented above, there is anticipated to be **no adverse impact** on **groundwater quantity and recharge supply**, since:

- The Z2 Fordon Evaporite comprises evaporite salts which are essentially impermeable. The unit is therefore considered to be a non-aquifer and is not anticipated to contain significant quantities of deep groundwater;
- Although the cavern is anticipated to increase in volume by approximately 44,200 m^3 (16.5 %) compared to existing as a result of re-watering, the potential groundwater storage capacity of the surrounding strata is minimal given the non-aquifer status of the Z2 Lower Evaporite; and
- The shallow chalk aquifer underlying the AHP site is recharged by shallow inputs (rainwater infiltration etc.), and not by deep groundwater resources.

Groundwater Quality

The potential for adverse impacts to **groundwater quality** as a result of the proposed cavern re-purposing is considered to be **very low**, since:

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[10] MS Abuaisha and J Billiotte, 2021, A Discussion on Hydrogen Migration in Rock Salt for Tight Underground Storage with an Insight into Laboratory Setup. In the Journal of Energy Storage, volume 38, pp.102589. Available online at: https://www.sciencedirect.com/science/article/abs/pii/S2352152X21003273

- The potential for release of hydrogen from the cavern, and subsequent migration to water-bearing strata, via gradual diffusion or through fractures/discontinuities is considered negligible, as described above;
- The base of the bore (LCCS) was installed in accordance with oil and gas regulations and industry guidance (noting that construction pre-dated the current guidance)[11] and is subject to continuous annulus leakage monitoring. The base of the bore is located within the salt deposits, where gas tightness is higher compared to the overlying strata, and leakage is therefore less likely;
- The new well casing will be cemented in place and a mechanical integrity test undertaken to confirm well tightness, thereby minimising the potential for escape of hydrogen to surrounding strata between the cavern and the ground surface. If hydrogen were to escape from the (cemented) well bore within the surrounding chalk aquifer, there is the potential for suitable reducing geochemical conditions to be present such that sulphate reduction, methanogenesis or acetogenesis may occur, subject to the presence of relevant microbial populations and substrates, as well as associated changes to redox conditions, pH and metal concentrations. However, no integrity issues have been identified in relation to the existing well and cement in the 14 years of operation to date. Furthermore, continued operation of the re-purposed cavern will incorporate mitigation in line with relevant guidance (e.g. the general principles of EA's Approach to Groundwater Protection, 2018[12]) and industry best practice to reduce the potential for loss of hydrogen to the subsurface from the AHP site;
- The chalk aquifer is not used as a potable resource in the vicinity of the AHP site due to saline intrusion, so minor changes in aquifer geochemistry, if they were to occur, would be unlikely to have potentially significant adverse effects.

GROUNDWATER MONITORING PLAN

As part of the Environmental Permit application, the following pre-operational condition is proposed for consideration by the EA:

- A monitoring plan for commissioning activities will be developed and agreed with the EA prior to commissioning.

The permit is expected to require soil and groundwater monitoring to be undertaken where there is a credible pollution risk for the installation. The monitoring plan will likely entail groundwater monitoring of select boundary monitoring wells every 5 years and a repeat soil sampling exercise every 10 years. No groundwater monitoring for the gas storage itself is proposed as this would not be typical for a standalone gas storage facility.

In addition, a cavern and well inspection programme will be in place during operation to understand whether there has been any size or profile change between surveys. The proposed schedule of cavern surveys will be subject to extent of size and profile change and will be provided to the Environment Agency prior to operation if required.

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[11] The Offshore Installations and Wells (Design & Construction) Regulations (1996)

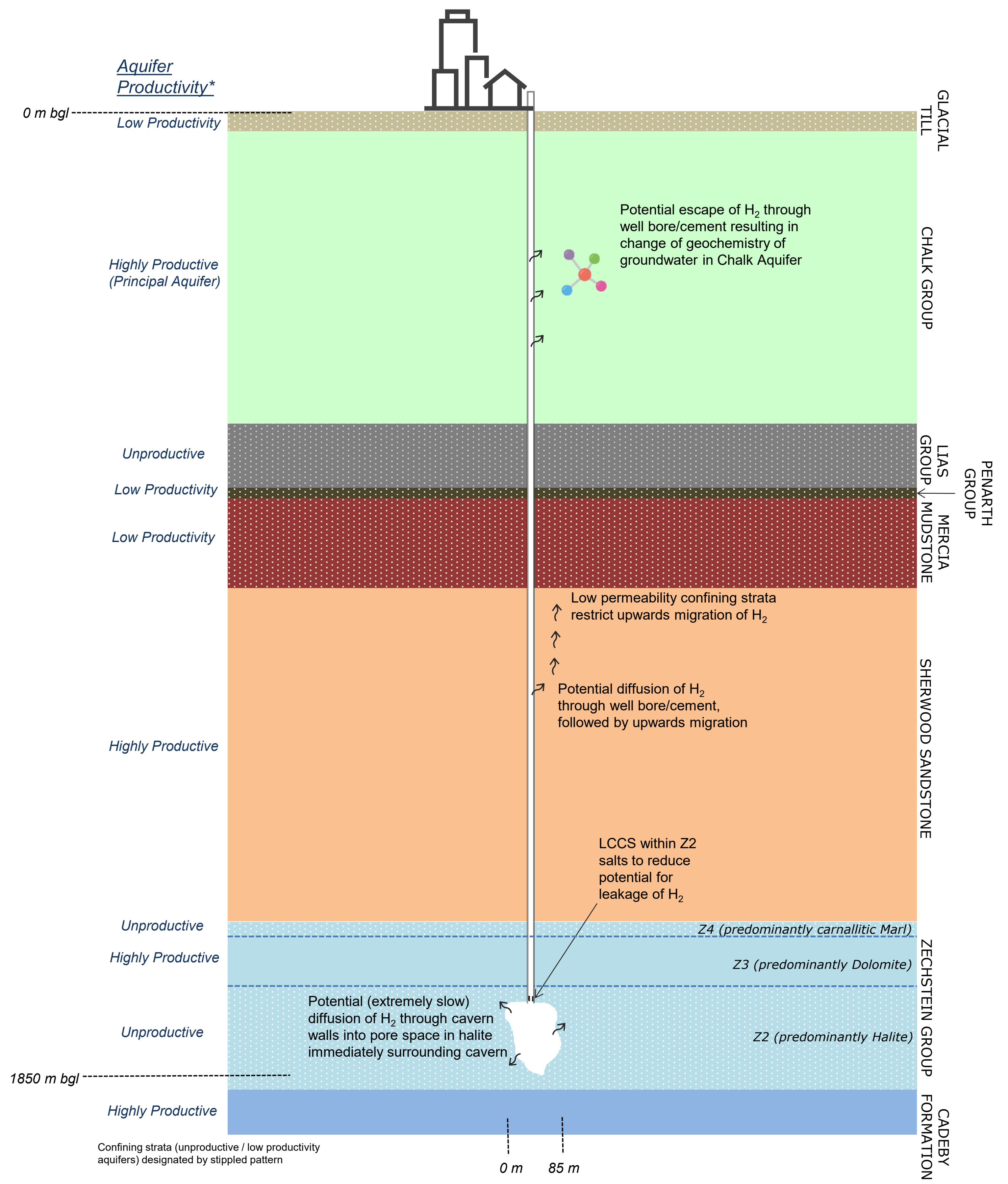
[12] Environment Agency, 2018, *Environment Agency's Approach to Groundwater Protection* (version 1.2). Available at: https://assets.publishing.service.gov.uk/media/5ab38864e5274a3dc898e29b/Envirnment-Agency-approach-to-groundwater-protection.pdf

SUMMARY

Based on the available information, and with the mitigation measures described above in place, the potential for adverse impacts to groundwater resources to occur from re-purposing of the existing ALD1 natural gas storage cavern for hydrogen storage is considered to be very low. Cavern integrity is considered to be good and hydrogen is not expected to result in the deterioration of the quality of groundwater.

ATTACHMENT A PATHFINDER ALDBROUGH 1 REWATERING – CAVERN REWATERING DESIGN ASSESSMENT (ATKINS, 2024)

ATTACHMENT B SCHEMATIC CONCEPTUAL SITE MODEL



Key

* Aquifer productivity based on BGS/EA classifications, where stratum is present at shallow (<400m) depth

Generalised aquifer classifications given for major geological groups, except Zechstein Group which is split into Z2, Z3 and Z4 horizons.

LCCS – Last Cemented Casing Shoe

SCALE: Not to Scale	VERSION: 02
SIZE: A4	DRAWN: KT
PROJECT: 0726717	CHECKED: RC
DATE: October 2025	APPROVED: RC

Figure 1: Schematic Conceptual Site Model

ERM

sse Thermal