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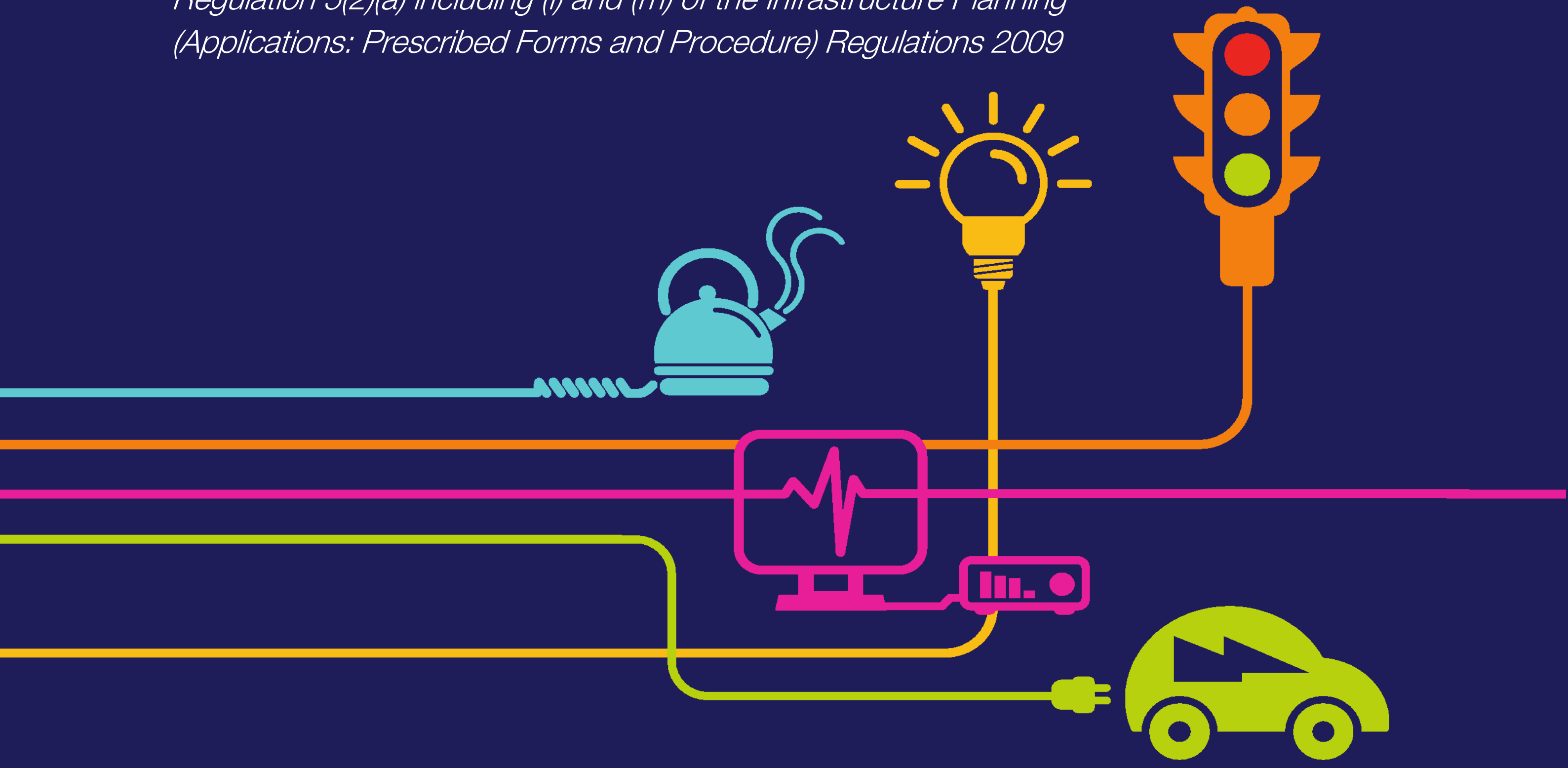
Shaft and Tunnel Groundwater Inflow

Chapter 11 – Appendix 8

National Grid (North Wales Connection Project)

Regulation 5(2)(a) including (l) and (m) of the Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009



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National Grid
National Grid House
Warwick Technology Park
Gallows Hill
Warwick
CV34 6DA

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<tr><td colspan="2">Author</td><td colspan="2">Claire Howarth (Principal Engineering Hydrogeologist)</td></tr>
<tr><td colspan="2">Reviewed by</td><td colspan="2">Gareth Mason (Principal Engineering Geologist)</td></tr>
<tr><td colspan="2">Approved by</td><td colspan="2">Keithley Johnson (Project Manager)</td></tr>
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1 Introduction

1.1 OVERVIEW

1.1.1 The Proposed Development includes a tunnel approximately 4 km long with a 4 m internal diameter connecting the Braint shaft (approximately 75m deep) and the Tŷ Fodol shaft (approximately 90 m deep). A description of the Proposed Development is set out in Chapter 3, Description of the Proposed Development (**Document 5.3**) and Chapter 4, Construction, Operation, Maintenance and Decommissioning of the Proposed Development (**Document 5.4**).

1.1.2 A likely construction method for both shafts comprises a wet caisson excavation method through the superficial deposits, switching to open excavation (drill and blast) through bedrock to final depth with subsequent spraying of a concrete primary lining. Grouting would also be undertaken as required from within the shafts and it is considered unlikely that dewatering external to the shaft will be required. Dewatering external to the shaft of the glacial deposits or bedrock would not be the preferred method. However, there would be removal of groundwater trapped inside the caisson rings and from the ingress of groundwater from the bedrock by sump pump (‘internal dewatering’).

1.1.3 As part of the design of the tunnel and shafts, potential groundwater seepage rates have been estimated. This document summarises the technical assessments that have been undertaken to estimate groundwater inflow into the tunnel and shafts during the construction and operational stages of the Proposed Development.

1.2 SCOPE OF WORKS

1.2.1 The scope of works for this assessment has comprised a conceptual hydrogeological review, combined with a conservative analytical assessment to estimate potential seepage rates. No numerical modelling of tunnel or shaft seepage during construction or operation has been undertaken as part of this assessment. More detailed analysis may be possible once additional ground investigation has been undertaken within the Menai Strait.

1.2.2 This document summarises the following:

- hydrogeological conceptual model and engineering design assumed for this assessment.
- methodology used to carry out the assessments; and
- assessment results and discussion.

1.3 STUDY LIMITATIONS

1.3.1 The limitations of this technical assessment include:

- groundwater monitoring locations and temporal groundwater level data are limited along the length of the route. Conservative maximum recorded groundwater levels have been used within the assessment, potentially resulting in an over-estimation of potential seepage rates.
- no numerical modelling has been undertaken as part of this assessment. Analytical equations assume a uniform, homogeneous, isotropic groundwater system. The fractured bedrock strata is heterogeneous, anisotropic and potentially fault–controlled, which would have an impact on actual seepage rates encountered during construction. Additional investigation is required within the Menai Strait to determine the presence and nature of a potential geological fault in this area.
- this document is based on information obtained in previous or recent ground investigations and these investigations can only examine a fraction of the subsurface conditions.

2 Hydrogeological Conceptual Model

2.1 OVERVIEW

2.1.1 The following overview represents a summary of the conceptualisation of the hydrogeology and detailed consideration of hydraulic properties of the proposed shafts and tunnel.

2.1.2 Both shaft sites are characterised by superficial deposits, predominantly comprising Glacial Till (with an anticipated thickness of 11m at the Braint shaft site and 4m at the Tŷ Fodol shaft site) overlying bedrock. At the Braint site, the shaft would be constructed into the Central Anglesey Berw and Shear Zone (Mica Schist) bedrock, depth likely to be in the order of approximately 75 m. At the Tŷ Fodol site, the shaft would be excavated into the Padarn Tuff Formation bedrock (Tuff Felsic), depth likely to be in the order of approximately 90 m.

2.1.3 The tunnel would be constructed through the:

- Central Anglesey Berw and Shear Zone (mica schist);
- Loggerheads Limestone and Menai Strait Formation (limestone / mudstone / siltstone / sandstone / breccia / conglomerate);
- Minffordd Formation (sandstone / conglomerate / tuff); and the
- Padarn Tuff Formation (tuff).
- It would also pass through several mapped fault zones and unmapped igneous dykes.

2.1.4 The groundwater flow characteristics, and Natural Resource for Wales (NRW) aquifer designation, of strata likely to be encountered during the construction of the Proposed Development are summarised in Table 2.1 below.

Table 2.1: Aquifer characterisation

Strata (abbreviation)	Groundwater Flow Type	NRW Designation
Alluvium / peat	Perched / intergranular	Secondary A
Glacial Till	Intergranular	Within Ynys Môn, this is designated as a Secondary B aquifer. Within Gwynedd, this is undesignated.
Marine Deposits	Intergranular	Undesignated
Carboniferous Limestone (Clwyd / Loggerhead) (LGHL)	Fracture	Principal
Menai Strait Formation (MEST)	Fracture	Secondary A
Minffordd Formation (MINF) and Allt Lwyd Formation (ALL)	Fracture	Secondary A
Padarn Tuff (PDT)	Fracture	Secondary A
Pre-Cambrian schists (CABSZ)	Fracture	Unproductive

2.1.5 The potential characteristic of the superficial deposits aquifer is that flow is likely to be intergranular, with the volume of flow being dependent on lithology. Superficial deposits which have a lower clay content e.g. sands and gravels and a higher permeability have greater flow compared to superficial deposits with a higher clay content and hence lower permeability, such as clays and silts.

2.1.6 Interbedded lower permeability mudstones within the Carboniferous Limestone Series may also confine groundwater locally. As such there is the potential for multi-layered aquifer units across the study area. Significant faults within the study area have the potential to lead to compartmentalisation of groundwater flow units (if acting as a barrier), or enhanced flow routes.

2.1.7 The scale of interaction/hydraulic connection vertically between the intergranular superficial deposits and fractured bedrock has not been quantified. However, with lower groundwater levels within the schist/tuff bedrock (see section 2.3), when compared to groundwater levels recorded in the superficial deposits, the hydrogeological system would appear to be under-drained with a downward vertical hydraulic gradient and with minimal direct hydraulic continuity between the superficial deposits and the bedrock. This may indicate the potential for a hydraulic disconnection between the superficial deposits and bedrock, which conceptually would not be unexpected where a greater proportion of clay is present within the anticipated, low permeability Glacial Till.

2.2 PERMEABILITY

2.2.1 The composition of Glacial Till is heterogeneous, potentially containing; clay, silt, sand, gravel, cobbles, and boulders. The permeability of a till deposit is expected to be less than $1x10^{-6}$ m/s[1]; however, due to the variable nature of the Glacial Till, permeabilities will vary considerably across the site and could be as high as $1x10^{-4}$ m/s within a clean sand horizon[2]. Analysis of results from two Particle Size Distribution tests on samples from superficial deposits estimate a permeability of $5x10^{-6}$ m/s. However, both samples were from gravels, and as such the permeability estimate would not be applicable to more cohesive deposits found within the Glacial Till on site.

2.2.2 Soakaway tests were undertaken within the superficial deposits at both the Braint and Tŷ Fodol shaft sites. At the Braint shaft site, soakaway tests did not result in a significant change in water levels (and in some cases noted a rise), potentially indicative of a lower permeability Glacial Till. At the Tŷ Fodol shaft site, infiltration rates ranged from $1x10^{-5}$ to $4x10^{-4}$m/s. [3]

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[1] Domenico & Schwartz (1997), Table 3.2 ‘till’ permeability ranges from $1x10^{-12}$ m/s to $1x10^{-6}$ m/s.

[2] Domenico & Schwartz (1997), Table 3.2 ‘sand’ permeability ranges from $2x10^{-7}$ m/s to $2x10^{-4}$ m/s.

[3] Infiltration rate is not the same as permeability but has been used as an indicator of permeability.

2.2.3 Rising and falling head tests were undertaken within borehole standpipe installations and the results are presented on Image 2.1.

2.2.4 The range of in-situ bedrock permeabilities measured (via borehole packer testing over 5m depth intervals) during the ground investigation is summarised in Table 2.2.

Table 2.2: In-situ borehole permeability range recorded in ground investigation

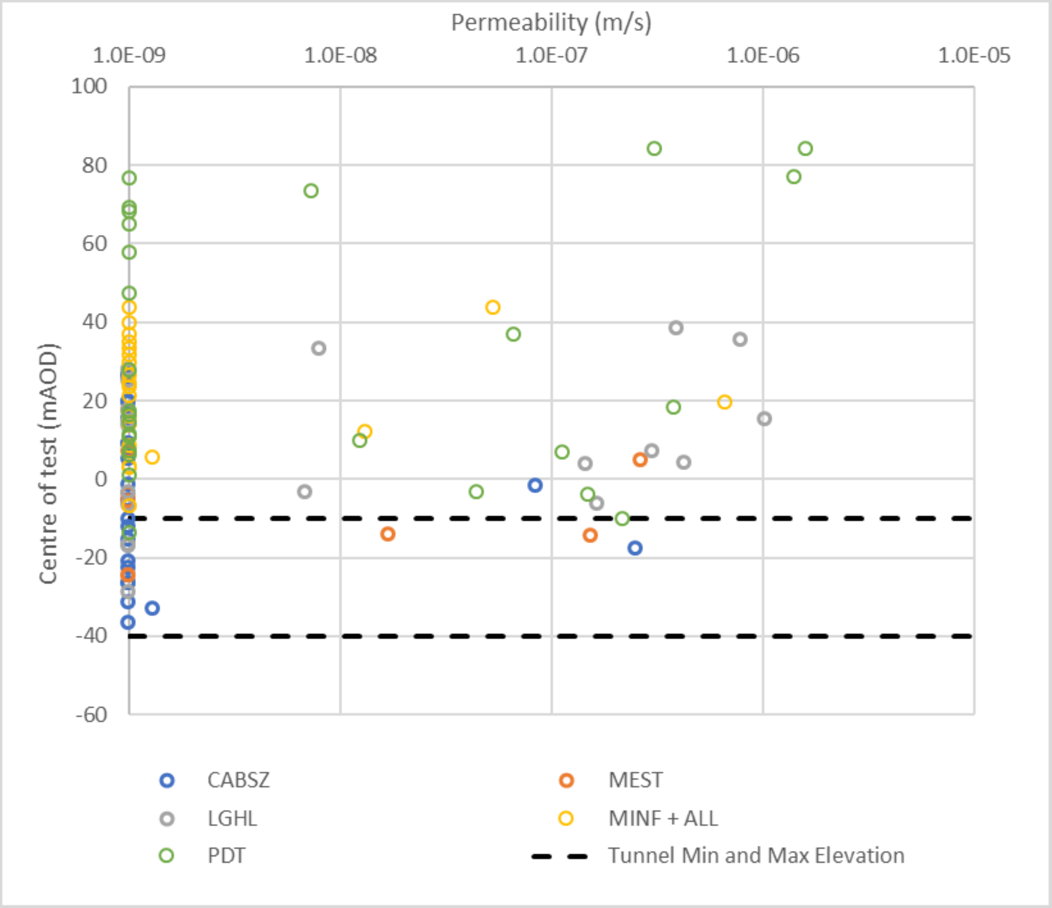
Strata	Nr. successful tests	Nr. zero flow packer or non-standard tests	Mean (m/s)	Max (m/s)	Min (m/s)
CABSZ	4	19	5.1×10^{-8}	2.5×10^{-7}	1.3×10^{-9}
MEST	2	6	6.7×10^{-8}	2.6×10^{-7}	1.7×10^{-8}
LGHL	8	10	1.3×10^{-7}	1.0×10^{-6}	6.9×10^{-9}
MINF/ALL	3	19	2.8×10^{-8}	6.6×10^{-7}	1.3×10^{-9}
PDT	11	16	7.2×10^{-8}	1.4×10^{-6}	4.7×10^{-9}

Note – The mean values do not include the “zero flow” tests.

2.2.5 The permeability of the bedrock is controlled by fractures, and fractures would be expected to be more open within the shallow subsurface and closed at depth (leading to a reduction in permeability with depth) – as illustrated in Image 2.1 below, which includes packer and rising/falling head test results. The majority of packer tests did not record any flow, which indicates very low permeability ($<1 \times 10^{-9}$m/s) at those test horizons.

2.2.6 However, it is noted that in-situ borehole testing only investigates a limited area local to the borehole, or individual fractures. The mass permeability of a fractured system is dependent upon the interconnectivity, and openness of fractures / faults. As such there is potential for higher permeability fractures and flow zones, particularly within the Carboniferous Limestone and fault zone areas. Advanced probing for identification of potentially high yielding fractures / flow zones can be undertaken during excavation in bedrock, with subsequent grouting of any significant features identified, to minimise groundwater ingress.

Image 2.1: Rock permeability with elevation

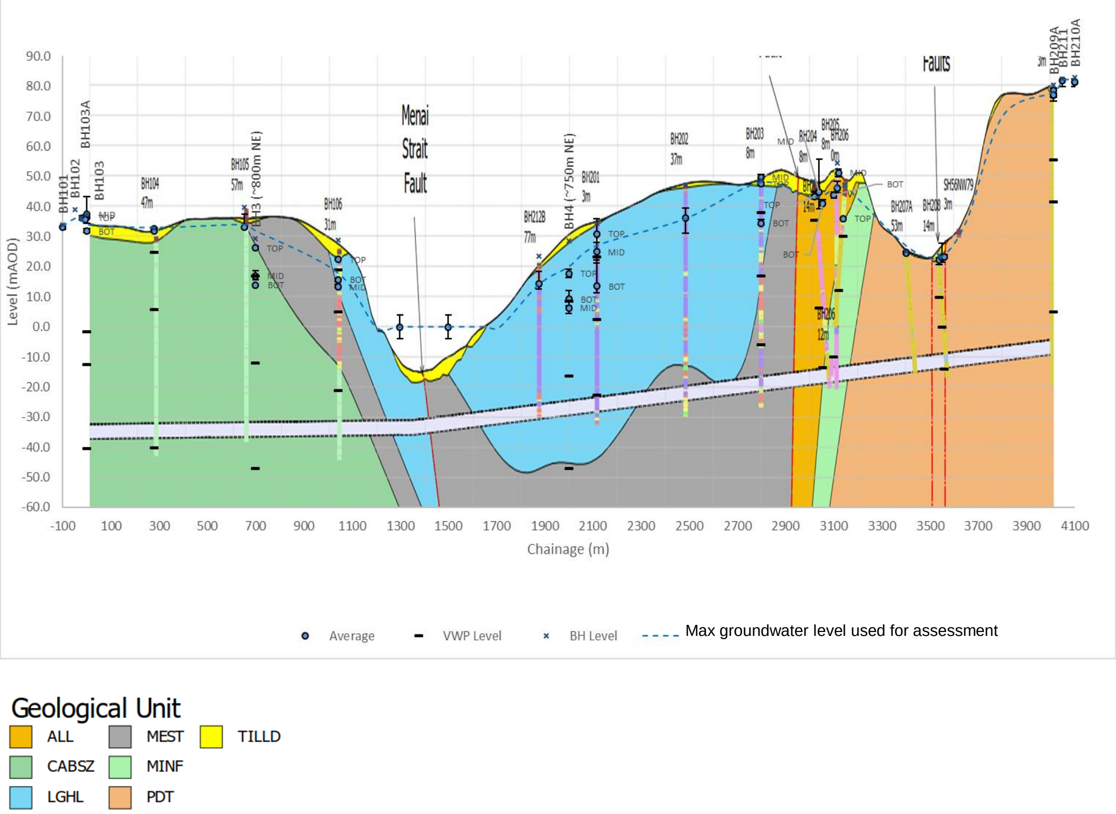


Note – Zero flow results recorded during packer tests have been plotted at 1x10^{-9}m/s.

2.3 GROUNDWATER LEVELS

2.3.1 Ground and groundwater conditions recorded within the Phase 2 Ground Investigation Factual Report Appendix 11.7 (**Document 5.11.2.7**) are illustrated in Image 2.2.

Image 2.2 – Tunnel long section showing groundwater conditions



Note – Upper and lower bound tick marks indicate maximum and minimum groundwater levels.
Groundwater levels measured at approx. monthly intervals for >1 year.
Groundwater monitoring points include VWP = Vibrating wire piezometer and multi-level standpipes. BH = Borehole. TOP, MID and BOT = Top, middle and bottom VWPs.

2.3.2 At individual monitoring locations, groundwater levels within shallow (superficial deposit) and deeper (bedrock) standpipes / vibrating wire piezometers were consistently different (as illustrated in Table 2.3) with the groundwater level in the Glacial Till being above that in the underlying bedrock.

Table 2.3: Groundwater levels at shaft locations

Shaft Site	Location	Ground Level (mAOD)	Install Depth (mBGL)	Install level (mAOD)	Min GWL (mAOD)	Max GWL (mAOD)	Average GWL (mAOD)	Geological Strata at install depth
Braint	BH103A	33.96	2 to 10.15	31.96 to 23.81	33.20	33.26	33.23	Glacial Till
	BH103 TOP	33.96	39	-5.04	32.50	32.96	32.71	Schist
	BH103 MIDDLE	33.96	50	-16.04	32.35	32.81	32.56	Schist
	BH103 BOTTOM	33.96	78	-44.04	28.00	28.48	28.25	Schist
Tŷ Fodol	BH210A	82.85	1 to 5	81.85 to 77.85	80.15	80.28	80.23	Glacial Till / Weathered Tuff
	BH209A TOP	81.27	25	56.27	79.36	79.79	79.57	Tuff
	BH209A MIDDLE	81.27	39	42.27	77.53	78.01	77.77	Tuff
	BH209A BOTTOM	81.27	75.5	5.77	77.54	78.27	77.92	Tuff

2.3.3 An absence of groundwater monitoring data exists immediately adjacent to, and beneath, the Menai Strait. Therefore, the groundwater levels within the Carboniferous Limestone aquifer and the extent of tidal influence / degree of hydraulic connection between the Menai Strait and the underlying groundwater cannot be confirmed. For the purposes of this assessment, it is assumed that there is hydraulic connection with the Menai Strait acting as a source of recharge to groundwater locally.

2.4 ENGINEERING OVERVIEW

2.4.1 The following text briefly outlines shaft and tunnel engineering proposals, pertinent to the assessment of potential groundwater seepage rates and drawdown estimation.

2.4.2 Both 15 m internal diameter shafts would be constructed using a wet caisson method (to 11 m depth at Braint, and 20 m depth at Tŷ Fodol) through the superficial deposits (and more fractured weathered Tuff bedrock at the Tŷ Fodol shaft) into unweathered bedrock. This will act as a groundwater cut-off for the superficial system and fractured weathered Tuff bedrock. Shaft excavation would then progress using drill and blast (D&B) through the bedrock to full depth. Probing and grouting of the rock would be undertaken as excavation progresses to reduce permeability of the strata locally surrounding the shafts to $\leq 1x10^{-7}$ m/s.

2.4.3 The shaft will be excavated sequentially, with a primary lining installed during each cycle of excavation made up of sprayed concrete and rock bolts. Following completion of the shaft excavation, tunnel excavation can commence. The shaft secondary lining will not be installed until the tunnelling works are complete. This lining will be “waterproof” to the required level. Residual water pressure behind the secondary lining could be made to dissipate by drainage into the shaft base through a control mechanism such as weep holes.

2.4.4 The 4 km long tunnel (4 m internal diameter) would be excavated by either Tunnel Boring Machine (TBM) or Drill & Blast (D&B) technique. In the case of the TBM method, the permanent lining would be installed as the TBM progresses.

2.4.5 In the case of drill and blast, open-face excavation for the entire length of the tunnel would be undertaken prior to the installation of the secondary tunnel lining. Probing and grouting and other ground treatments of the rock would be undertaken as excavation progresses to reduce permeability to $\leq 1x10^{-7}$ m/s, particularly in areas of higher ingress risk (such as the Carboniferous Limestone and fault zones).

2.4.6 Drill and blast excavation and secondary lining is estimated to take approximately 17 months from Braint and 13 months from Tŷ Fodol, commencing from both shafts, with 150 day delay from Tŷ Fodol. The drill and blast tunnels would theoretically meet at tunnel chainage CH2824m based on assumed progress rates. The tunnel gradient would fall towards the Braint shaft.

2.4.7 Secondary lining installation would start from the Tŷ Fodol shaft at a rate of approximately 12 m/ day, but could also start from the Braint shaft. It is assumed that the tunnel secondary lining would commence 14 days after tunnel excavation is complete.

2.4.8 For the purposes of this groundwater ingress assessment it is assumed that potential poor quality groundwater (influenced by the Menai Strait) would be encountered within the tunnel from chainage CH1000 to CH1900 (refer to design plan DCO_DE/PS/07_01). These chainages are presented for the purposes of determining a theoretical volume of poor quality groundwater inflow with exceedances in water quality levels, which may need additional treatment or removal, when compared to the groundwater quality tests from boreholes. The chainage locations are based on the following assumptions:

- The chainage positions are >150 m horizontally from the mean high-water mark of the Menai Strait.
- Groundwater sample laboratory tests from borehole BH212B and natural springs on the Menai Strait shoreline indicate that the groundwater is not saline (refer to results included in Phase 2 Ground Investigation Factual Report Appendix 11.7, Document 5.11.2.7).
- It is acknowledged that poor quality groundwater (associated with depth and age of groundwater) may exist in areas outside these chainages but are unlikely to require significant treatment to meet water quality standards for discharge, based on groundwater quality test results from boreholes.

2.4.9 Temporary sumps and groundwater pumping could be used within the tunnel during construction to separate saline and fresh water inflows, which could reduce the amount of groundwater needing additional treatment or removal, if significant volumes of poor quality groundwater are encountered.

3 Methodology and assumptions

3.1 SHAFT CONSTRUCTION STAGE

3.1.1 A steady state groundwater inflow rate has been conservatively estimated analytically using the Darcy equation[4]. Horizontal flows through the open face shaft walls, together with an estimate of vertical flow through the base of the shaft, have been aggregated.

3.1.2 With the presence of caisson rings cutting off the superficial deposits, it is assumed that only the depth of shaft below the caisson rings is open to groundwater ingress (Images 3.1 and 3.2). Conservatively it has been assumed that seepage would occur over the full depth of open face, albeit given the nature of a fractured bedrock, flow horizons are likely to be limited to a smaller number of elevations.

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[4] Q = KiA, where Q = flow (m^3/s); K = permeability (m/s); i = hydraulic gradient; A = cross-sectional area(m^2) through which flow occurs (equal to shaft perimeter multiplied by depth of open face in this assessment).

Image 3.1 – Braint shaft cross section showing groundwater

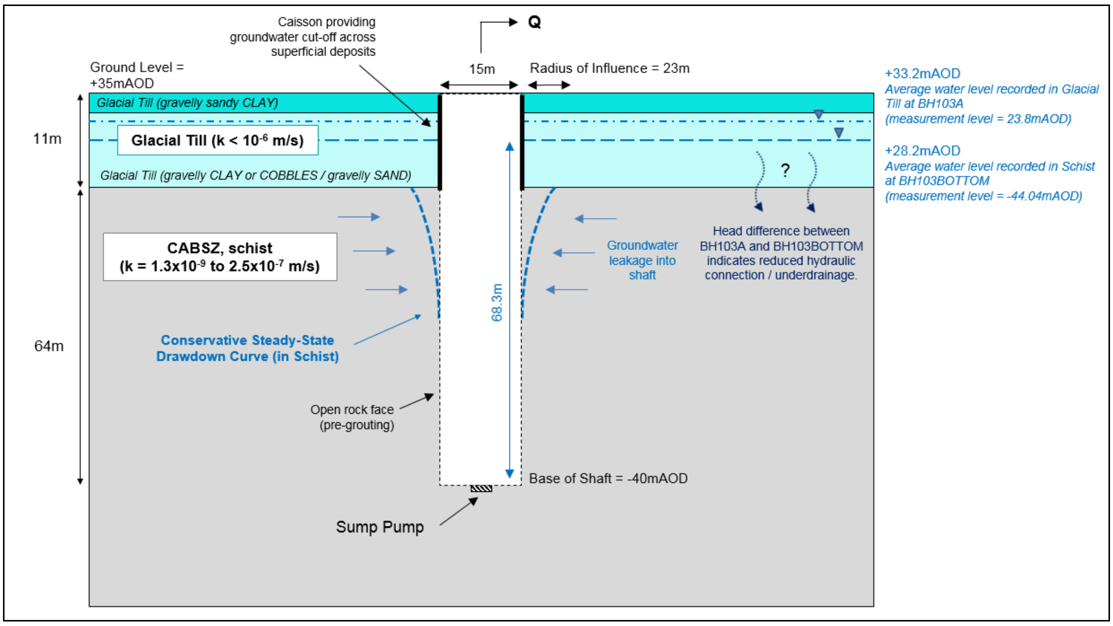
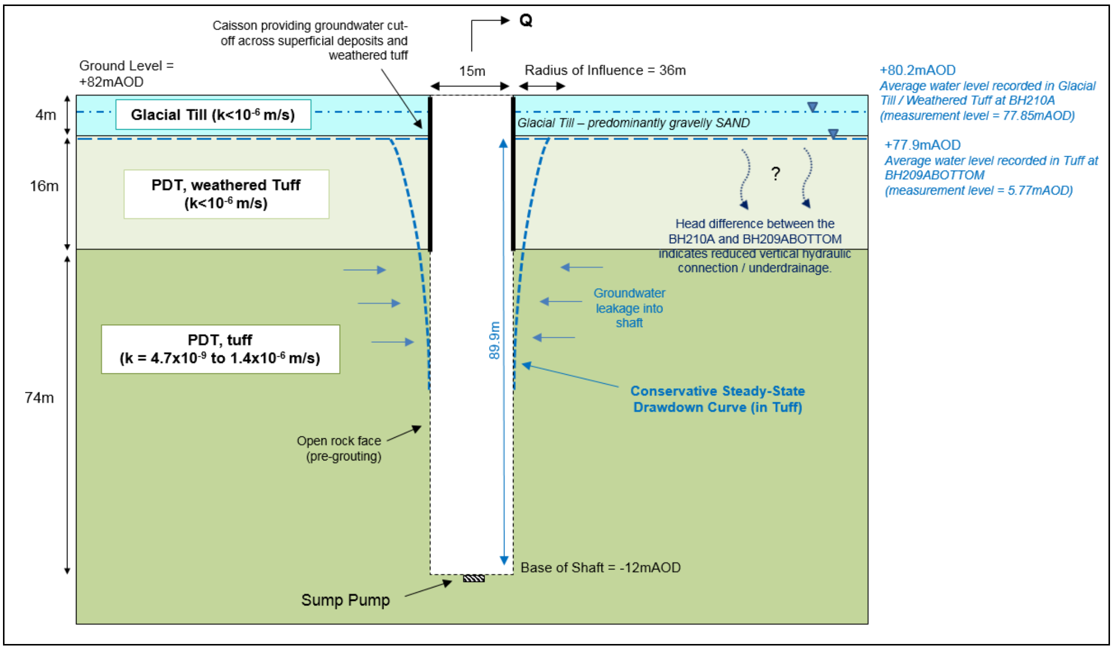


Image 3.2 – Tŷ Fodol shaft cross section showing groundwater



3.1.3 To reflect the anticipated decline in permeability with depth, within the assessment the open face has been sub-divided into three equal depth zones – each assigned a different permeability:

- Zone 1 = $1x10^{-7}$ m/s[5]
- Zone 2 = $1x10^{-8}$ m/s[6]
- Zone 3 = $1x10^{-9}$ m/s

3.1.4 Vertical permeability is set to be 1/10th of the horizontal permeability.

3.1.5 With respect to hydraulic gradient, conservatively the maximum groundwater level recorded in bedrock strata has been used. Within the shaft the depressed groundwater level is assumed to be 1 m below the base of shaft (reflective of potential sump depth). For steady state conditions, it has been assumed that the difference in groundwater levels external and internal to shaft is dissipated over the radius of drawdown influence.

3.1.6 The conservative steady state radius of influence has been estimated using the Sichardt empirical formula (CIRIA Guidance C750).

$$R_o = Cs\sqrt{k}$$

R_0 = radius of drawdown influence (m)

C = factor (3,000 used as worst case)

s = drawdown (m) within the shaft.

k = permeability (m/s)

3.1.7 It should be noted that the Darcy and Sichardt steady state assessment approaches are both conservative in that they assume homogeneous,

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[5] Reflecting proposed grouting of any zones where potential permeabilities higher than $1x10^{-7}$ m/s are identified during probing.

[6] Reflective of average permeability recorded in ground investigation.

isotropic, uniform conditions and an infinite aquifer extent. As discussed in Section 2, given the fractured / faulted nature of the bedrock the actual conditions are likely to be heterogeneous, anisotropic with the potential for faults compartmentalising aquifer blocks or providing preferential pathways for groundwater flow.

3.2 SHAFT OPERATIONAL STAGE

3.2.1 The shaft lining may allow pressure relief and therefore the groundwater inflow determined for the construction stage has been assumed during the operational stage based on the grouted permeability of the rock.

3.3 TUNNEL CONSTRUCTION STAGE

3.3.1 If the tunnel is constructed by TBM, the permanent tunnel lining would be installed as the TBM progresses. As such the groundwater inflow rate would be the same as that of the operational stage.

3.3.2 For a drill and blast tunnel, the conservative groundwater inflow rate for each 100 m length of tunnel has been estimated using the Goodman equation (as outlined in Goodman, Moye, Schalkwyk, & Javandel, 1965).

$$Q = 2\pi K \frac{H}{2.3 log\,(\frac{2h}{r})}$$

Q = seepage rate over 1m length of tunnel (m^3/s)

K = permeability of host rock (m/s) [7]

H = hydraulic head (m) above central axis elevation[8]

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[7] Either average bedrock permeability (if less than $1x10^{-7}$ m/s) or $1x10^{-7}$ m/s grouted permeability in bedrock with a natural permeability greater than $1x10^{-7}$ m/s).

[8] Conservatively taken as maximum extrapolated average groundwater level recorded (Image 2.2), or 0m AOD under Menai Strait. Monitoring results indicate that average deeper groundwater levels may be less, as such analytical results may over-estimate actual seepage rates encountered during excavation.

h = depth to tunnel axis (m)

r = radius of tunnel (m)[9]

3.3.3 Seepage estimates for 1 m lengths of tunnel are scaled up across 100 m lengths of tunnel. As excavation progresses, seepages from the increasingly exposed face are aggregated; assumed to reach a cumulative peak when the tunnels meet and prior to installation of the permanent lining.

3.4 TUNNEL OPERATIONAL STAGE

3.4.1 For both shaft and tunnel the permitted groundwater leakage rate through the tunnel lining is based on British Tunnelling Society - Specification for Tunnelling, 2010 for 'Capillary Dampness' (0.1 litres/m^2/day).

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[9] Approx. outside diameter of tunnel = 5m, therefore radius = 2.5m.

4 Summary of Analysis Results

4.1 SHAFT CONSTRUCTION STAGE

4.1.1 Table 4.1 summarises the results of the Sichardt steady state analysis for internal dewatering within the shafts to estimate the lateral extent of groundwater level drawdown within the bedrock.

Table 4.1: Estimated radius of influence within the bedrock due to internal dewatering

Shaft Site	Drawdown at shaft (s)	In-Situ Permeability (k)	Estimated Steady State Radius of Influence (Ro)
Braint Shaft	34m	$5x10^{-8}$ m/s (geometric mean)	23m
Tŷ Fodol	46m	$7x10^{-8}$ m/s (geometric mean)	36m

Water assumed to drawdown to 30m into bedrock
R_o estimated based on Sichardt equation (assuming C = 3000 as worst-case)

4.1.2 Owing to the fact that the groundwater flow to the shaft is cut-off by the caissons within the superficial deposits (and the weathered Tuff in the case of the Tŷ Fodol shaft), in order for dewatering within the bedrock to impact on groundwater levels in the overlying superficial deposits, the reduction in groundwater levels at depth would need to transmit upwards through the bedrock to the superficial deposit. This is dependent on:

- The vertical permeability of the bedrock.
- The hydraulic connection between the bedrock and the Glacial Till.
- The vertical permeability of the Glacial Till.

4.1.3 The composition of the Glacial Till is highly variable and is predominantly described as a gravelly clay (with significant sand horizons) at the Braint site and as a gravelly sand at the Tŷ Fodol site. A reduced hydraulic connection vertically between the intergranular superficial deposits and fractured bedrock is suggested by the head difference between the Glacial Till and the bedrock. In combination with the decline in permeability within the bedrock, the groundwater drawdown within the bedrock (locally around the shaft) is considered conceptually unlikely to transmit upwards through the bedrock to the overlying superficial deposits.

4.1.4 Table 4.2 summarises the results of the steady state seepage assessment (utilising the Darcy equation outlined in Section 3).

Table 4.2: Estimated shaft seepage rates

Shaft Site	Depth of shaft below caisson (m)	External groundwater level (mAOD)	Dissipation distance (m)	Hydraulic gradient	Permeability (m/s) Depth below caisson in brackets, m	Q (m^3/s)
Braint (Anglesey)	59.7	+28.25	23	2.78	1x10^{-7} (0-20m)	2.6x10^{-4}
					1x10^{-8} (20-40m)	2.6x10^{-5}
					1x10^{-9} (40-60m)	2.9x10^{-6}
Horizontal flow (sub-total)						2.9x10^{-4}
Vertical flow at base						4.2x10^{-7}
Total estimated seepage rate (m^3/s)						2.9x10^{-4}
Total estimated seepage rate (m^3/d)						25.2 m^3/d
Tŷ Fodol (Gwynedd)	68.7	+77.92	36	2.35	1x10^{-7} (0-20m)	2.2x10^{-4}
					1x10^{-8} (20-40m)	2.2x10^{-5}
					1x10^{-9} (40-69m)	3.2x10^{-6}
Horizontal flow (sub-total)						2.5x10^{-4}
Vertical flow at base						4.2x10^{-}

Table 4.2: Estimated shaft seepage rates

	7
Total estimated seepage rate (m^3/s)	$2.5x10^{-4}$
Total estimated seepage rate (m^3/d)	21.4 m^3/d

4.1.5 Based on the above assessment, an allowance of approximately 30 m^3/day groundwater inflow to each shaft has been assumed.

4.2 SHAFT OPERATIONAL STAGE

4.2.1 Operationally the shaft lining itself would comply with British Tunnelling Society seepage limits. However, based on a conservative estimate that the water build up behind the permanent lining is released at the base of the slab, then the construction stage flows are used for assessment of flows during the operational stage.

4.2.2 An allowance of approximately 30 m^3/day groundwater inflow to each shaft has been assumed.

4.3 TUNNEL CONSTRUCTION STAGE

4.3.1 A summary of estimated groundwater inflow rates per bedrock strata / chainage length of tunnel excavated by drill and blast have been outlined in Table 4.3, based on the Goodman equation in section 3.3. These groundwater inflow rates represent the maximum anticipated during construction and will reduce as the “waterproof” secondary lining is installed.

Table 4.3: Estimated tunnel seepage rates during construction for drill and blast excavation

Strata	Chainage (m)	Groundwater level assumed (range, mAOD)	Hydraulic head range (m)	Assumed mass permeability (m/s)	Inflow across each section (m^3/d)
CABSZ	0 to 1128	0 to 34	28.6 to 63.7	$1x10^{-8}$	90

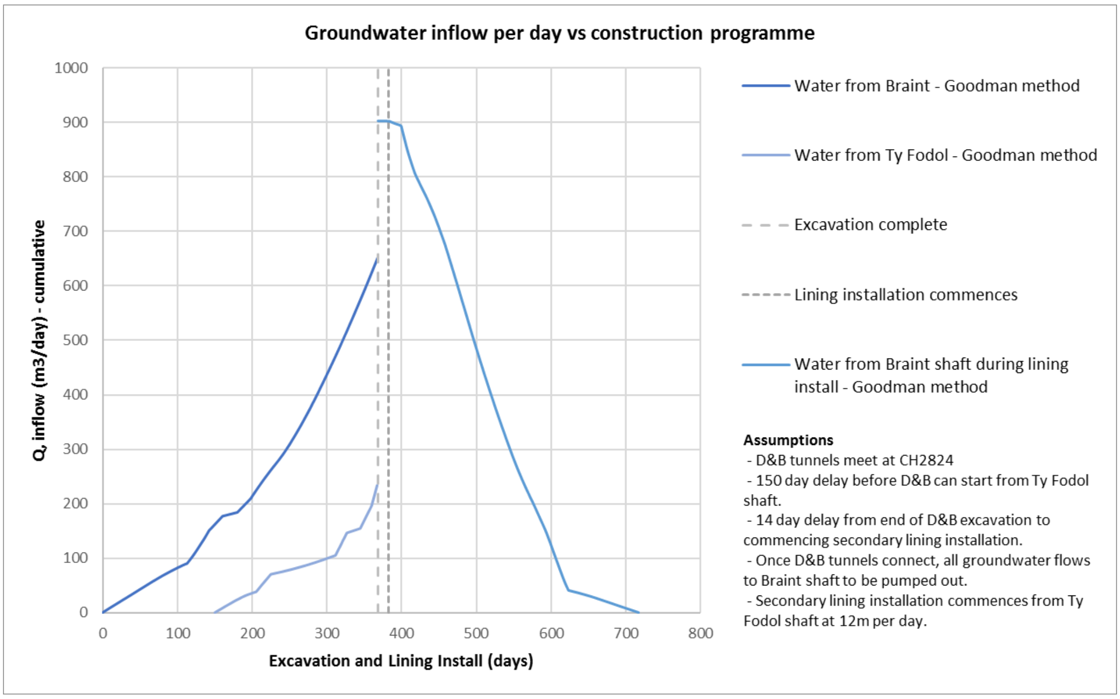
Table 4.3: Estimated tunnel seepage rates during construction for drill and blast excavation

Strata	Chainage (m)	Groundwater level assumed (range, mAOD)	Hydraulic head range (m)	Assumed mass permeability (m/s)	Inflow across each section (m^3/d)
LGHL & MEST	1128 to 1363	0	28.1 to 28.6	$5x10^{-8}$	60
Menai Strait Fault Zone	1363 to 1465	0	27.9 to 28.1	$1x10^{-7}$ (grouted)	59
LGHL & MEST	1465 to 2824	0 to 48	24.6 to 61.9	$5x10^{-8}$	443
Dinorwic Fault Zone	2824 to 2994	48	60.0 to 61.7	$1x10^{-7}$ (grouted)	91
MINF	2994 to 3219	40.3 to 48.0	50.0 to 60.0	$1x10^{-8}$	18
PDT	3219 to 3514	22.5 to 40.3	29.4 to 50.0	$1x10^{-8}$	17
BGS Fault Zone	3514 to 3579	23.0 to 25.5	29.5 to 31.6	$1x10^{-7}$ (grouted)	32
PDT	3579 to 4021	25.5 to 78.0	31.6 to 79.7	$1x10^{-8}$	38

Note – Grouting may be required in any strata.
The assumed mass permeability values have been estimated with reference to the test values described in section 2.2.

4.3.2 Graphically the results are presented in Image 4.1.

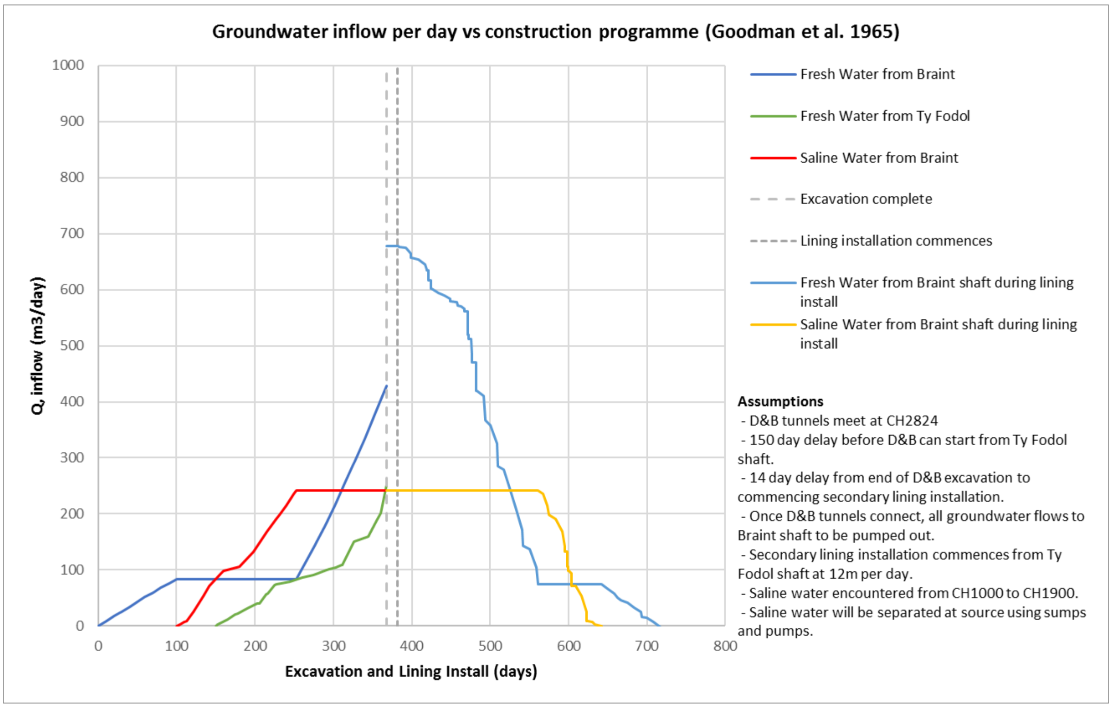
Image 4.1 – Groundwater inflow per day during construction



Assumptions
- D&B tunnels meet at CH2824
- 150 day delay before D&B can start from Ty Fodol shaft.
- 14 day delay from end of D&B excavation to commencing secondary lining installation.
- Once D&B tunnels connect, all groundwater flows to Braint shaft to be pumped out.
- Secondary lining installation commences from Ty Fodol shaft at 12m per day.

4.3.3 The results of the groundwater inflow assessment have also been presented in Image 4.2, which assumes a split between poor quality groundwater associated with the Menai Strait between CH1000 and CH1900 (refer to design plan DCO_DE/PS/07_01).

Image 4.2 – Groundwater inflow (saline and fresh) per day during construction



Assumptions
- D&B tunnels meet at CH2824
- 150 day delay before D&B can start from Ty Fodol shaft.
- 14 day delay from end of D&B excavation to commencing secondary lining installation.
- Once D&B tunnels connect, all groundwater flows to Braint shaft to be pumped out.
- Secondary lining installation commences from Ty Fodol shaft at 12m per day.
- Saline water encountered from CH1000 to CH1900.
- Saline water will be separated at source using sumps and pumps.

4.3.4 For the TBM tunnelling technique, it is assumed that the permanent tunnel lining is installed as the TBM progresses, and therefore the groundwater inflow has been estimated to be the same as during the operational stage.

4.4 TUNNEL OPERATIONAL STAGE

4.4.1 The allowable groundwater leakage rate through the tunnel lining is based on British Tunnelling Society, Specification for Tunnelling, 2010 for 'Capillary Dampness' (0.1litres/m^2/day).

4.4.2 For a 4 km tunnel with internal diameter of 4 m, the groundwater inflow rate would be estimated to be ~5m^3/day.

5 References

1. Preene, M., Roberts, T., & Powrie W. (2016). Groundwater control: design and practice. *CIRIA Guidance C750 (2nd Edition).*

2. Goodman, R., Moye, D., Schalkwyk, A., & Javandel, I. (1965). Groundwater inflows during tunnel driving. *Bulletin Association Engineering Geologists*, 35-56.

3. British Tunnelling Society / Instituition of Civil Engineers (2010). Specification for Tunnelling, Third Edition.

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