[redacted]

INDEPENDENT HYDROGEOLOGICAL ASSESSMENT

JULY 2021

PROJECT NO. 21220054

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Report researched and produced by B. A. Hydro Solutions Limited (BAHS Ltd) on the instruction of the Wardens Trust.

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Executive Summary

[redacted], formerly known as Tea House (until 1945), consisting of an old farmhouse, cottages and a large museum building that was converted around 15 years ago into an Outings Centre for physically and mentally handicapped people of all ages, plus camping and outdoor spaces for activities. The community sources all of its water from a well, there are no other sources of water available for potable water supply.

Locally the groundwater flow direction is in an easterly direction towards the coast, though flow will be distorted in the immediate vicinity of the well when it is operating. Seasonal changes in rainfall recharge will affect groundwater levels resulting in a fluctuation in groundwater flow out to sea. During dry and drought periods there is the possibility of saline intrusion into the aquifer due to local groundwater abstractions reversing the hydraulic gradient. There are no records of this having happened although chloride (a signature of sea water) has been measured at high concentrations in the well.

As part of an offshore wind farm(s), it is proposed to bring onto land new power and communications cables a short distance south of Ness House. The cables shall be brought onto shore via horizontal directionally drilled holes that could be up to 3km long. The holes shall be drilled at least 85 metres, and most likely much further inland at an angle so that they pass well below the base of the existing cliff [below sea/groundwater level] in order to avoid disturbing the cliff and also to allow for future retreat of the cliff line.

It is feared that the drilled holes shall introduce low permeability grout into the groundwater flow horizon that sustains the [redacted] Well. This Assessment considers the risk of the drilled holes forming a groundwater barrier limiting the water available for abstraction, distorting groundwater flow and increasing the risk of saline intrusion.

The trenching route for the cables onshore passes very close to the Well across ground already proven to have a close hydraulic link with the well. Thus, representing a risk of contamination entering the ground during construction, the installation and operation of the cables.

This Assessment's hydrogeological conceptualisation of the area and the well concludes the groundwater source exists in a very fine balance within this environment. The abstraction is already vulnerable to being contaminated by surface activities, coastal erosion and sea level rise, drought and unforeseeable effects of climate change.

Numerical modelling of groundwater levels and movement indicates that groundwater moves from west to east. The source induces a drawdown in water levels that extends beneath the directional drill area and although it does not draw water from that area at present, it is likely that a change in ground conditions would change the source area from which the well draws.

This Assessments concludes the emplacement of a low permeability barrier running west to east around 200 metres south of the well in association with the installation of the cables; could starve the well of water, could distort groundwater flow and result in a measurably larger proportion of sea water being drawn into the well, affecting quality.

The evidence of past land use affecting the quality of water drawn from the well shows it is vulnerable to surface activities in the local area. As there would be a long build duration affecting the land surrounding Ness House there is a risk the disturbance to the ground would affect the quality (chemically, microbiological and physically such as turbidity) during and for many years after the installation. This would be in addition to any effects from changing the hydrogeological setting.

The combination of changing the hydrogeological setting through the drilling, with the risk posed from surface and subsurface work all around Ness House; in addition to coast erosion, sea level rise, drought effects and climate change means the proposal represents an existential threat to the Well.

It is our professional opinion that the very limited, basic and relatively poor-quality hydrogeological work completed to date are inadequate. They have not started to accurately characterise or quantify the hydrogeological setting. They have not identified the Ness House Well as a reception at risk. They have provided woefully inadequate information on which stakeholders can make no meaningful assessment forcing them to conduct their own investigation and deduce, from the experience of professional hydrogeologists, the true nature and impact their water supply is at risk of.

The hydrogeological work presented by ScottishPower Renewables should be rejected as incomplete and inadequate. No approval for any of the activities in the vicinity of Ness House should be granted. If the proposal is still to be sought, an extended period of data collection, ground investigation, hydrogeological monitoring, ground modelling and cooperation with the local stakeholders is essential before permission is considered. The directional drill design must be developed urgently so that the true impacts can be assessed before stakeholders are next asked to comment.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

B. A. Hydro Solutions Ltd. (BAHS Ltd.) has been commissioned to complete an Independent Hydrogeological Assessment [desk study report] on conditions present at Ness House and the potential implications of undertaking direction drilling and installation of a new buried power cable close to an operational well on the site. Information collected, interpreted and analysed within this report provides details on the hydrogeological setting, and shall assist in assessing the potential threat posed to the private water supply.

The site location is illustrated in the following figure; for the purpose of considering geological strata and depths to each stratum, the elevation of the Ness House borehole, has been adopted throughout this report, as listed below:

Site Address:	Ness House			
	Sizewell			
	Leiston			
Postcode:	IP16 4UB			
Drill position NGR:	TM 47550 61213			
Elevation range:	11.5	to	13	maOD
Elevation adopted:	12.2			maOD

Table 1: Site details

2 Background & Objectives

2.1 Background

Ness House, formerly known as Tea House (until 1945), consisting of an old farmhouse, cottages and a large museum building that was converted around 15 years ago into an Outings Centre for physically and mentally handicapped people of all ages, plus camping and outdoor spaces for activities. The community sources all of its water from a well, there are no other sources of water available for potable water supply.

No construction details are available for the well; however, it is thought to be around 13.1 metres deep. At such a depth, the strata penetrated by the well are likely to comprise 6 to 9 metres of Lowestoft Till Formation underlain by Crag Group (at least 4 metres) to the base of the shaft. The Lowestoft Till Formation at Ness House is likely to be unsaturated and as such does not contribute to the yield of the well, instead acting as a conduit for recharge to the underlying Crag

Group. The yield of the well (<20 cubic metres a day) is sourced from the Crag Group; a high permeability aquifer with intergranular flow and storage.

As part of an offshore wind farm(s), it is proposed to bring onto land new power and communications cables a short distance south of Ness House. The cables shall be brought onto shore via horizontal directionally drilled holes that could be up to 3km long. The holes shall be drilled at least 85 metres, and most likely further inland at an angle so that they pass well below the base of the existing cliff in order to avoid disturbing the cliff and also to allow for future retreat of the cliff line.

It is feared that the drilled holes shall introduce low permeability grout into the groundwater flow horizon that sustains the Ness House Well. This Assessment considers the risk of the drilled holes forming a groundwater barrier limiting the water available for abstraction, distorting groundwater flow and increasing the risk of saline intrusion.

The trenching route for the cables onshore passes very close to the Well across ground already proven to have a close hydraulic link with the well. Drainage plans include the use of soakaways which risk the rapid introduction of inferior quality water into the aquifer. Thus, representing a risk of contamination entering the ground during construction, the installation and operation of the cables.

2.2 Objectives

This Assessment seeks to fulfil the following objectives:

- Document field work and monitoring completed local to Ness House.
- Confirm the geological sequence.
- Define the hydrogeological setting.
- Consider where groundwater is present.
- Document current and historical groundwater abstractions from the same horizon the Ness House abstraction likely draws from.
- Develop a conceptual hydrogeological model of the Ness House site.
- Develop a basic groundwater flow model, in order to test different scenarios.
- Discuss the risk posed to the private water supply from the proposed cable installation.

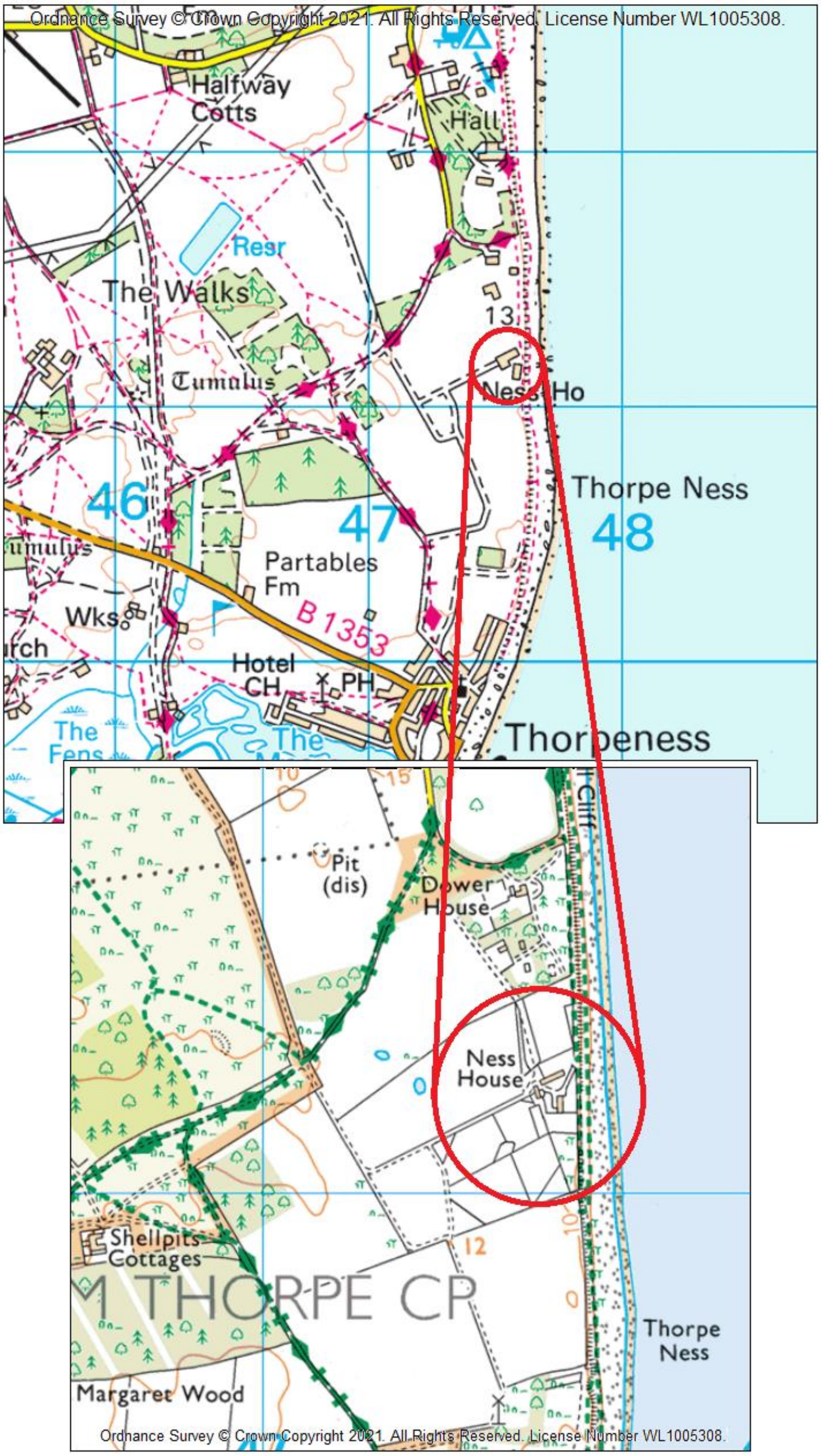


Figure 1: Location Map

3 Geological Setting

3.1 Geology

The following discussion of the geology beneath the site is based on a site-specific literature review and historical borehole records that have been obtained for the purpose of predicting the geological unit thickness, nature and depths. As geological units are not laterally continuous, vary in thickness and are not homogeneous, the predicted thickness and depths may differ slightly if or when proved by drilling. Unfortunately, there are no geological records for the existing well.

The geology and thicknesses reported are based on the assumption that the well was installed at the National Grid Reference (NGR) listed in Table 1 from the elevation stated.

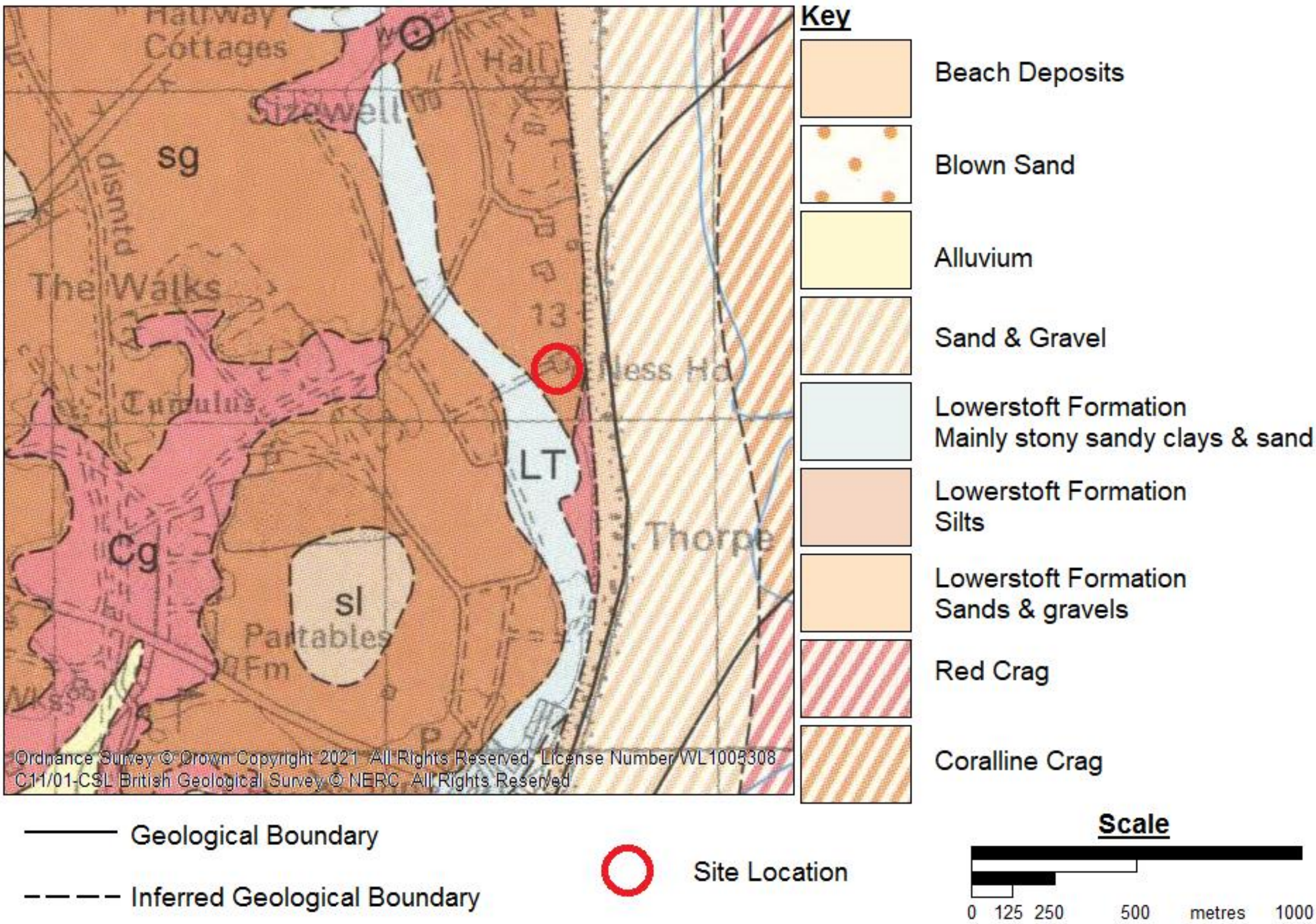


Figure 2: Geological Map

The geology mapped at ground level across the local area is illustrated in Figure 2; the location of the site is outlined in red, the following table summarises the strata present, their names, lithological nature and range of thicknesses as seen regionally.

Geological Group	Geological Formation	Lithological Nature	Range of thickness (metres)
-	Soil, made ground	Loamy soils	<1
-	Lowestoft Till Formation	Sand, gravel, silts and stony clays	Up to 30
Crag Group	Norwich Crag Formation	Sand, silt and clay	Up to 70
Crag Group	Red Crag Formation	Sand	Up to 40
Thames Group	Harwich Formation	Siltstone and mudstone	Up to 13

Table 2: Summary of Geological Sequence

3.2 Structure

The main geological structures present and affecting the ground beneath the site are listed below. The tectonic events and the sequences leading to the resulting structures are not considered by this Assessment as such detail does not affect the conclusions drawn by this study.

- There are no faults mapped in the local area that could affect the strata or hydrogeology of the local area,
- The shallow strata beneath the site have experienced limited tectonic deformation since their deposition, as a result the shallow strata considered within this report are not folded or significantly tilted,
- The Crag sequence and underlying strata dip gently to the south-east.
- None of the geological structure is anticipated to have a measurable effect on the presence, abundance or movement of groundwater beneath this site.
- Geomorphology is expected to have a strong influence on groundwater, including the slope of the sea cliff, the coastal margin and the gentle undulation of the land.

4 Lithological Characterisation

4.1 *Drift*

Soil underlying the site is characterised as freely draining, slightly acid and sandy. The soil is, in turn, underlain by the Lowestoft Till Formation. Regionally, the Formation forms an extensive sheet of chalky till, together with outwash sands and gravels, silts and clays.

Beneath the Ness House site, the clays are largely absent, the Lowestoft Till Formation being represented by glacial sands and gravels. A narrow strip of more clayey till is mapped to the west and south of the site, running through the course of the new power cable route.

Beneath the Ness House site, the Lowestoft Till Formation is anticipated to be 6 to 9 metres thick.

4.2 *Crag Group*

The Crag Group dominantly comprises fine- to coarse-grained micaceous sands. Where these are unweathered, below the water table, they are dark green in colour owing to their high glauconite content. However, where they are seen in a weathered state the sands are yellowish to reddish brown in colour. The weathered sands may contain beds of ferruginous concretions (iron pan), formed from the iron oxides and hydroxides released by the weathering of glauconite.

The Crag Group is divided into two Formations; the Red Crag Formation at the base overlain by the Norwich Crag Formation. The Red Crag Formation comprises poorly sorted, cross-bedded, medium- to coarse-grained shelly sands, with a gradual coarsening-upward trend. A basal bed containing a high proportion of phosphate pebbles is present in some areas. North of Aldeburgh, two units have been distinguished within the Red Crag.

The lower, the Sizewell Member, comprises some 13 metres of medium- and coarse-grained greyish green shelly sands interbedded with clays containing thin silt and sand laminae. The sands are moderately to poorly sorted and contain much glauconite and shell debris as well as quartz. The overlying Thorpeness Member is 20 to 30 metres thick and comprises two coarsening-upwards cycles of shelly fine- to medium-, and rarely, coarse-grained sand with a few laminae and thin beds of silty clay.

The *Norwich Crag Formation* comprises an extensive sheet of well-sorted fine- to medium-grained sand, with isolated beds of clay (Chillesford and other clays) and gravel ('Westleton Beds'). Between Aldeburgh and Sizewell, the Norwich

Crag sands (sometimes referred to as the Chillesford Sand Member) are dark yellowish orange, moderately to well sorted and fine- to medium-grained, with isolated shelly lenses, silty clay laminae and clay intraclasts.

Local boreholes document up to 12.5 metres of the Norwich Crag Formation, represented by the Chillesford Sand Member, overlying the Red Crag Formation (up to 40 metres thick). The Red Crag Formation is recorded as locally comprising shelly, poorly sorted, greyish orange becoming olive grey, fine- to coarse-grained sand with thin clays. A unit of clays, up to 7 metres thick, with fine sand and silt laminae, interbedded with fine- and medium-grained sands and shelly sands, is noted toward the base of the formation. Beneath the Ness House site, the Crag Group is anticipated to be around 45 to 50 metres thick.

4.3 Harwich Formation (Thames Group)

The Harwich Formation in East Anglia comprises mainly bioturbated silty clays and sandy clayey silts with subordinate sandy silts and silty sands, some of which are glauconitic. There is a notable component of volcanic ash, both disseminated and in discrete beds. The formation is divided into two members, the Hales Clay Member and the overlying Harwich Member. The *Hales Clay Member* comprises clay and silt with variable amounts of sand and sporadic volcanic ash layers. The *Harwich Member* comprises olive-grey to greyish brown sandy siltstones, sporadically glauconitic, with numerous basaltic ash layers.

Locally the Harwich Formation is anticipated to be around 10 metres thick.

5 Historical Groundwater Abstraction and Water Levels

BAHS have completed an appraisal of current and historic groundwater abstractions passing through comparable ground to that anticipated at the site. The records have been assessed as part of the data collection process; where possible, water level, abstraction rates, pumped water levels and any test data have been analysed. A total of 26 boreholes/wells/shafts at 9 sites have been identified within a radius of approximately 2.5 kilometres of the proposed borehole locations, see table below.

Ref No	Easting	Northing	Site name	Depth (m)	Year	Aquifer
1	646670	259850	Windmill Well, Thorpeness	13.7	1920	CG
2	647470	260530	Ted’s Barn, Thorpeness	13.7	1921	LF, CG
3	647310	260000	New Well, Thorpeness	12.2	1935	LF, CG
4	645330	260580	Church Lane, Aldringham	11.5	u/k	LF, CG
5	647500	262300	Cliff House, Sizewell	12.2	u/k	LF, CG
6	646800	263000	Thorpeness Estates	10	u/k	CG
7	646200	260300	Thorpeness Holt	9	u/k	CG
8	646500	261200	Aldringham Cum Thorpe (well point system)	10	u/k	CG
9a-l	647500	263200	Sizewell dewatering, 1-18	7.4-39.3	1961	CG

LF = Lowestoft Till Formation, CG = Crag Group, u/k = unknown
Table 3: Summary of local groundwater abstraction

The locations are plotted in the following figure and show good spatial distribution around Ness House. With the exception of the dewatering boreholes at Sizewell, the boreholes are all less than 14 metres in depth. Map Refs. 1 to 5 are large diameter shafts rather than boreholes, with diameters of up to 1829 mm, some having headings leading off them. Map Refs 6, 7 and 8 are well point systems; a series of closely spaced small diameter boreholes, connected via a header pipe to a pump.

Figure 3: Map of local groundwater abstractions

An assessment of water level and abstraction records for the local boreholes/wells has allowed the local range of transmissivity (T value) to be derived. Most of the records only provide limited water level and abstraction records, typically dating from the time of construction and consisting of a rest water level, a pumped water level and an abstraction rate. Consequently, only limited analysis can be completed with these; BAHS use Logan's Approximation to generate an estimate of the T value for the borehole or well. For three of the sites (Map Refs 6,7 and 8), the Environment Agency have previously undertaken analyses of test pumping data to derive values of transmissivity (and storativity), these are used in the report.

It is important to consider the origin of this data and whether there may be any bias in the figures which may distort the T value(s) being predicted from analysis of local boreholes. Most of the records assessed as part of this study originate from the British Geological Survey (BGS) and reflect logs submitted for projects. The BGS estimate they hold records for around 30% of boreholes drilled in the UK, this Assessment is thus based on data from less than half of the boreholes drilled locally.

Additionally, most drilling contractors do not record boreholes they abandon due to low yield or some form of failure. Abandoned and failed holes may be due to there being no/little water where they drilled, but commonly it is due to a lack of geological awareness, poor preparation, material failure and contractor shortcomings. BAHS is not aware of any working having been completed by the BGS to assess what proportion of the boreholes missing from their database would be the unproductive/abandoned holes through to holes with a varying degree of productivity.

It is reasonable to assume that good and high yielding boreholes will have become licensed for use overtime, and consequently ended up on the BGS database due to inter-agency sharing of data/records, even if they were not registered by the customer/driller at the time of construction as is required. It is the professional opinion of BAHS that the low and non-yielding boreholes are likely to represent the majority not registered with the BGS. Of these it is reasonable to assume that 50% would be low yielding and 50% failed due to inadequate design/planning and/or contractor failures.

To account for the approximate 70% of records that are missing from the BGS database, BAHS assume that half would not be hydrogeologically informative as they represent avoidable failures. This leaves a missing half (35% of all boreholes and wells drilled) which are likely to represent low yielding or non-licensed boreholes (abstractions of less than 20 m^3/day). These holes may not have been pumped at over 20 m^3/day but may still have had potential to yield greater than 20 m^3/day so would be informative if the records were available.

The missing records that may have been hydrogeologically informative, represent approximately the same number of holes as are registered. While they may have a similar statistical distribution of T values to those for which there are records, it is safer to assume they represent low yielding boreholes and those with a low(er) T value. To account for this BAHS have weighted the T value derived from the available records so that the lower values account more than the high T values.

Calculated and previously assessed Environment Agency data for the local sites give a T range from 40 to 1800 m^2/day, with an average of 330 m^2/day (
Figure 4). A short duration pump test completed on the Ness House well on the 16th June 2021 found a drawdown of 0.64 metres was maintained with an abstraction rate of 1.8 m^3/hour. A transmissivity value of 80 to 100 m^2/day has been calculated from the data with a correction for the estimated 900mm

diameter of the well. Storativity values have been calculated using data from the local borehole with a range of 0.03 to 0.1, consistent with an unconfined aquifer.

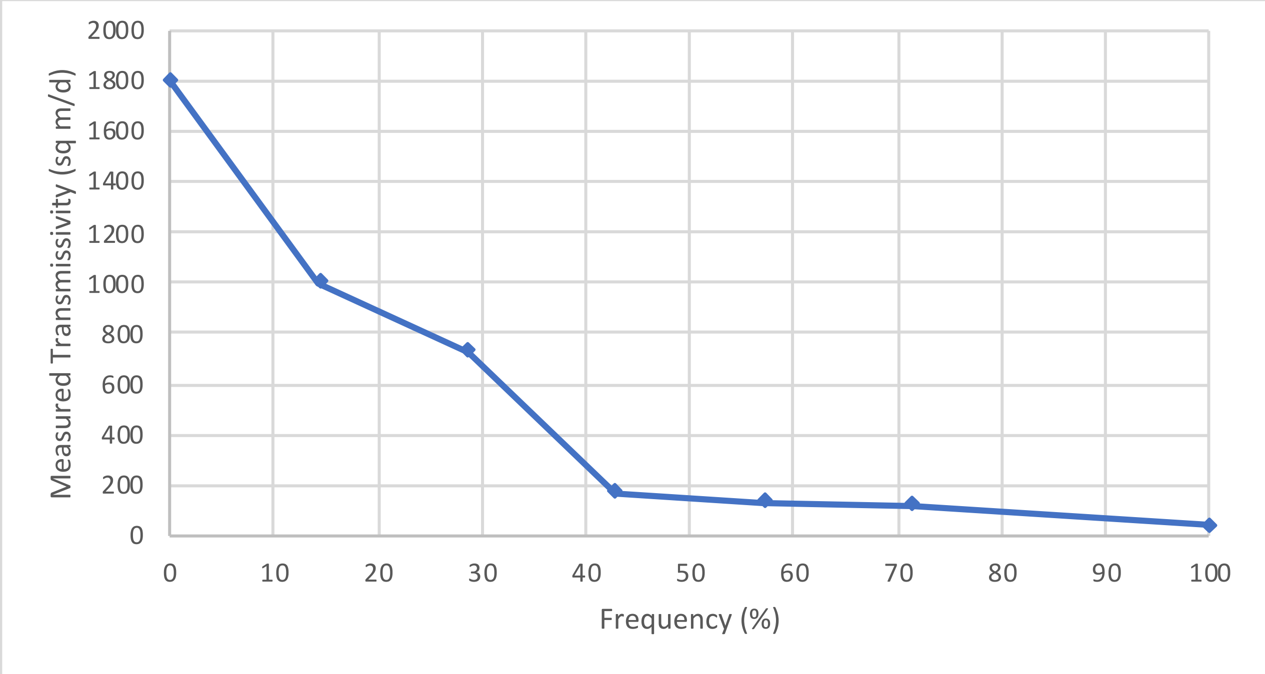


Figure 4. Graphical plot of T value frequencies

A report published by the British Geological Survey, in conjunction with the Environment Agency, entitled The Physical Properties of Minor Aquifers in England and Wales, documents calculated transmissivity values for the Crag Group of East Anglia based on data from 179 sites. The published range of transmissivity is 1.75 to 4231 m^2/day, with an average of 605 m^2/day, a median of 412 m^2/day, and an interquartile range of 238 to 772 m^2/day; the values derived in this hydrogeological assessment are consistent with these published values.

Section 6 discusses the properties of each hydrogeological unit with depth below the site. A range of T values for each unit is provided based on published ranges for the unit, local data (summarised above) and other records obtained in the production of this Assessment. A conservative T range for the Crag Group of 100 to 330 m^2/day has been used in this report.

6 Hydrology and Hydrogeology

6.1 Hydrology

The following table summarises the nearest water features to Ness House:

Water Feature	Direction (N/E/S/W)	Distance (km)	Hydraulic Connection?
Large pond or reservoir (Artificial)	W	1.2	Likely to be lined, no hydraulic connection with underlying strata
Surface drains/ channels leading to The Meare	SW	1.1	Likely hydraulic connection with Lowestoft Till Formation (sand and gravel) and Crag Group
The Meare (boating lake)	S	1.7	May be naturally perched, fed by, and drains to, Hundred River
Hundred River, The Fens	SW	2.5	Likely hydraulic connection with Lowestoft Till Formation (sand and gravel) and Crag Group
Surface drains/ channels north-east of Sizewell	N	1.5	Likely hydraulic connection with peat deposits and Crag Group

Table 4: Hydrology Summary

The Environment Agency's flood designation for the site is summarised below, this Assessment is not, and cannot be used as part of a flood risk assessment.

Is there a risk of flooding?	No
Flood Risk Level	Very low risk (less than 0.1% annual chance of flooding)
Nature of flood risk	Coastal, river, surface water

Table 5: Flood Designation

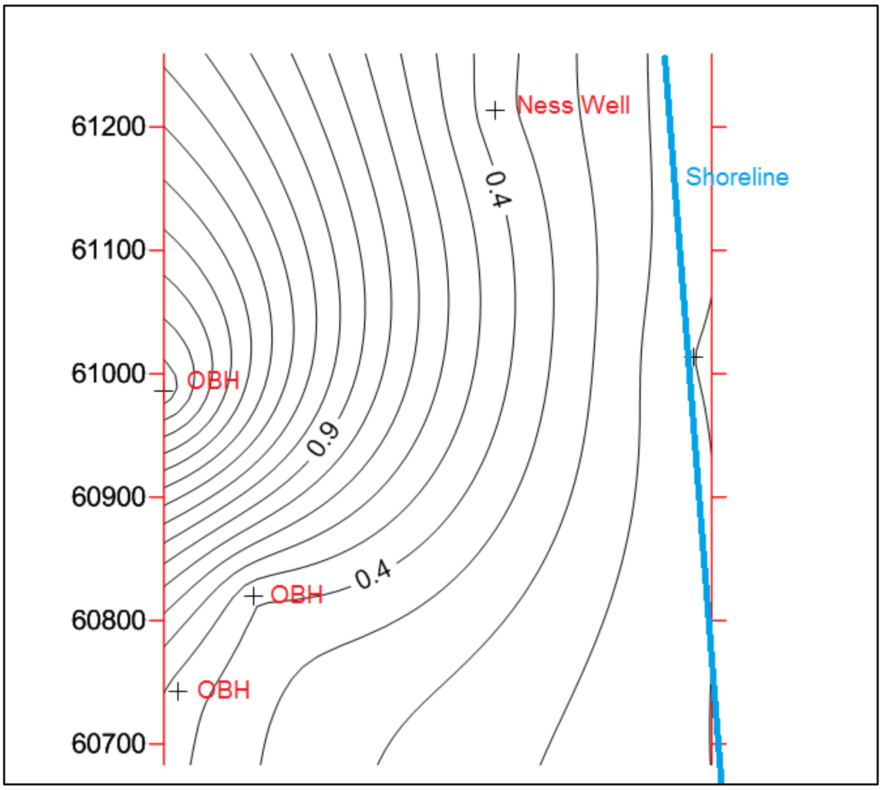
6.2 Hydrogeology

In this section the ground beneath the site is divided into hydrogeological units which are in turn considered in terms of the presence, abundance and movement of groundwater. Each unit is considered as it is reached with depth below the site.

The study has considered the different strata present beneath the site in terms of their hydrogeological conditions to develop a conceptual model for the site and determine likely parameters for a hydrogeological model. Where there are no boreholes or abstractions locally which can be used directly to judge the properties of the ground, BAHS Ltd use information derived from representative abstractions completed into comparable hydrogeological settings.

Lowestoft Till Formation Minor-aquifer	The glacial sands and gravels of the Lowestoft Till Formation provide small-scale aquifers. Generally, they directly overlie the Crag Group and are in direct hydraulic continuity with it. They are highly permeable, allowing nearly all effective rainfall to percolate through to storage within the Crag. Locally, the Lowestoft sands and gravels are thin (6 to 9 metres) and are likely to sit above the water table.	Water Level (maOD): N/A (unsaturated) Transmissivity: N/A
Crag Group Minor-aquifer	The Crag Group is considered to be a single water-bearing unit, although clay-rich layers may produce perched water levels in places. The strata are highly permeable and groundwater flow through the aquifer is intergranular, with yields depending on the coarseness of the sand and gravel fraction and on the degree of sorting. Seasonal fluctuations in water level are less than 1 metre due to the high storage coefficient of the aquifer. The unconsolidated, fine-grained nature of the Crag means that boreholes are liable to sand ingress and silting-up if not properly designed and constructed.	Water Level (maOD): 0.0 -0.5 Transmissivity: 100 – 330 m^2/day
Harwich Formation Non-aquifer	The clay rich, low permeability Harwich Formation acts as a confining layer to the overlying Crag Group, restricting downward movement of groundwater.	Water Level (maOD): N/A Transmissivity: N/A

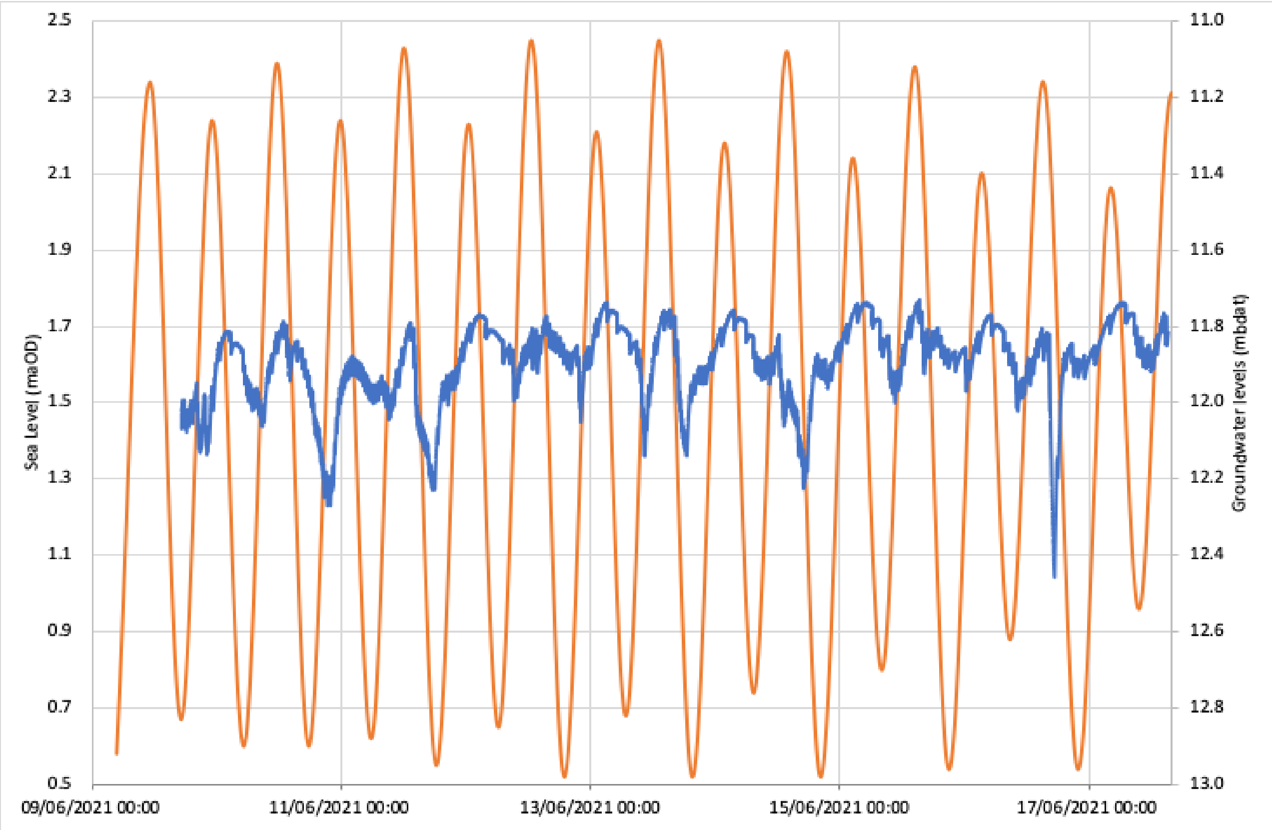
During the June 2021 site visit to the local area, groundwater levels in a number of observation boreholes, and the Ness House well itself, were measured. These have been used to generate groundwater contours (note groundwater levels are assumed to be 0 maOD at the shoreline). The rest water level in the Ness House well was recorded as 0.34 maOD (11.82 metres below ground level). Based on the contours, the general groundwater flow direction in the vicinity of the well is to the east, toward the shoreline.



Note: elevations (maOD) are approximate

Figure 5. Groundwater contours in the vicinity of Ness House well, June 2021

Being in close proximity to the coast, some tidal influence on groundwater levels is to be expected. Water levels within the Ness House well were monitored over the course of 8 days, these are plotted along with sea level as published for the Sizewell area, see Figure 6. There is a clear tidal influence on groundwater levels with the Ness House well, regular peaks in water level occurring just after high tide. The fluctuation in groundwater level associated with the tides is around 0.2 metres; larger drops in level seen on the plot are likely associated with the pumping of the well.



Orange = Sea Level, Blue = Groundwater level

Figure 6. Ness House well groundwater levels plotted against sea level

The fluctuation in groundwater levels as a result of tidal changes, approximately 150 metres inland from the line of low water [low tide level] shows the sensitivity of the well to activities some distance away. The directional drill site is 200 metres from the well at its closest point. It is therefore reasonable to conclude that there would likely be an influence on water levels, water quality and the availability of water to the well as a result of changes in/to the ground in the vicinity of the directional drill location.

7 Water Quality

The well was sampled in June 2021 and analysed, the results are presented in the table below, UK values are the Drinking Water Standards.

Parameter	Range [Median]	UK Limit	Units
Alkalinity	194 [N/A]	-	mg/l
Aluminium	<20 [N/A]	200	µg/l
Ammonium	7.2 - 2.0 [13]	500	µg/l
Antimony	<0.08 - 0.19 [0.17]	5	µg/l
Arsenic	0.023 - 0.043 [0.23]	10	µg/l
Boron	30 - 60 [36]	1000	µg/l
Bromate	<0.99 [N/A]	10	µg/l
Cadmium	<0.017 - 0.55 [0.019]	5	µg/l
Calcium	154.4 [N/A]	-	mg/l
Chloride	14 - 400 [260]	250	mg/l
Chromium	<0.083 - 0.58 [0.083]	50	µg/l
Copper	5.1 - 7.6 [240]	2000	µg/l
Cyanide	<10 [N/A]	50	µg/l
Fluoride	49 - 230 [139.5]	1500	ug/l
Dissolved Iron (Fe II)	<10 [N/A]	-	µg/l
Total Iron (FeII+FeIII)	<1.2 - 850 [1.4]	200	µg/l
Lead	0.54 - 1.9 [0.65]	10	µg/l
Magnesium	4.374 [N/A/]	-	mg/l
Manganese	0.25 - 62 [0.405]	50	µg/l
Mercury	<0.022 [N/A]	1	µg/l
Nickel	0.34 - 6.7 [1.2]	20	µg/l
Nitrate	9 - 191 [35]	50	mg/l
Nitrite	<15 - 52 [52]	500	µg/l
Phosphate	<0.05 [N/A]	-	mg/l
Potassium	<5 [N/A]	-	mg/l
Selenium	<0.83 [N/A]	10	µg/l
Sodium	26 - 140 [79]	200	mg/l
Sulphate	0.56 - 55.9 [0.9]	250	mg/l
Sulphide	<0.1 [N/A]	-	mg/l
Zinc	0.023 [N/A]	-	mg/l
Electrical Conductivity	170 - 1507.93 [1000]	2500	µS/cm
Hardness, Calcium Ca	386 [N/A]	-	mg/l
Hardness, Total, as CaCO3	404 [N/A]	-	mg/l
Hardness, Magnesium Mg	18 [N/A]	-	mg/l
pH	6.43 - 7.49 [7.31]	6.5-9.5	pH units
Total Dissolved Solids	752.45 [N/A]	-	mg/l
Turbidity	0.065 - 1.4 [0.12]	4	NTU
Colour	1 - 3.3 [0.965]	20	mg/l Pt/Co

Odour	0 - 5 [N/A]	-	-
Taste	0 - 5 [N/A]	-	-
E.coli	0 - 0 [N/A]	0	cfu/100ml
Total Coliforms	0 - 18 [N/A]	0	cfu/100ml
Enterococci	0 - 0 [N/A]	0	cfu/100ml
Pseudomonas spp.	0 - 0 [N/A]	-	cfu/100ml
TVC 3 at 22°C	>5000 [N/A]	-	cfu/ml
TVC 2 at 37°C	0 - 528 [N/A]	-	cfu/ml

Table 6: Indicative water quality

Analysis of the water by BAHS is provided along with the range of concentrations measured between July 2015 and June 2021. The median value is provided in brackets.

The water quality is good with the exception of nitrate which exceeds the UK prescribed concentration for drinking water and occasionally raised levels of chloride, total iron, manganese and a one-off measurement of a very low pH. This is in line with regionally reported raised levels of iron and manganese in groundwater from the Crag Group. The raised levels of chloride on occasion must be due to the proximity to the coast, as a marker of saline intrusion and/or influence from the sea.

BAHS have established that changes in nitrate and nitrite can be linked to different patterns of farming on the land further inland from the well. Over the last circa 20 years there have been periods when pigs have been on the land to the rear of Ness House (up to around 2018); in subsequent years there have been raised levels of nitrate detected in the well. Treatment has been installed which lowers the concentration to below UK limits, nevertheless, nitrate concentrations in the raw water continues to be in excess of 190 mg/l.

The long-lasting effect of the pig manure on groundwater quality from a distance of 50 to 400 metres from the well demonstrates there to be a link between surface activities and groundwater. The proposed installation of the power cable(s) and directional drilling that would involve below ground activities and trenching would therefore represents a significant risk to the quality, if not quantity of water the well will access in the short and long term.

The absence of microbiological contamination within the well demonstrates the source is free from, and historically clear of, such contamination. This indicates the rainfall recharge passes through a sufficient thickness of drift that delays its arrival to the water table long enough for the bacteria to die. This means that rainfall recharge must typically take longer than a few days to reach groundwater.

8 Groundwater Modelling

The following sections assess the potential impact on the existing abstraction well at Ness House from the proposed underground power line and directionally drilled landfall. A simple model has been developed as there is insufficient data to develop and calibrate a complex model. Simple does not mean, however, that it is ineffective or crude, as modelling is a viable method of evaluating and predicting the changes in water levels induced by a groundwater abstraction in response to changes that may occur to/in the aquifer. All modelling has been completed using AquiferWin32 modelling software.

A hydrogeological model was first created based on the hydrogeological conditions reported as a result of fieldwork and onsite pump testing (June 2021). The model was configured to simulate conditions within an area of approximately 5 kilometres by 3 kilometres, centred on the site.

This model area was set to allow it to be as sensitive and detailed as possible at the existing borehole at Ness house, but also large enough to minimise the potential for model artefacts which can begin to appear close to model boundaries, as the assumptions made for the model begin to break down. This is a factor of any model, and so needs to be addressed in the building of the site conceptual model and following hydrogeological modelling.

The effective aquifer thickness was set at 47 metres as this is representative of the effective thickness of the Crag Group and provides sufficient space within the model to reduce boundary effects. A low hydraulic gradient was used within the model; based on measurements in the well and assuming the water table reaches zero at sea level.

8.1 Model Input Parameters & Assumptions

8.1.1 Input Parameters

The key input parameters needed to populate the model are listed in Table 2. The initial values represent conservative values drawn from records associated with local boreholes and wells, those published and documented in Section 5 and Section 6 of this document.

Transmissivity is the ability of a substance to allow transmission through it. For an aquifer, this is water through pore spaces and fractures to a borehole/well in general. The storage coefficient, S, or storativity, refers to the volume of water released from ‘storage’ per unit decline in water level within the aquifer, per unit area of the aquifer. Porosity is the “space” within rock as a whole, the spaces between rock grains within the rock matrix. This space can be filled with water or other material, so is not the same as effective porosity, which refers to generally a lower volume of space, as some pores may be blocked, or pathways cemented up, which cannot be accessed for storage or abstracted.

Parameters	Value	Unit
Solution	Neuman, 1972 (Unconfined Aquifer)	-
Transmissivity	80	m^2/d
Aquifer Thickness	47	m
Storage Coefficient	0.03	-
Specific Yield	0.1	-
Beta/(r*r)	0.0001	-
Porosity	25	%
Reference Head (at shoreline)	0	maOD
Gradient	0.002 [East]	maOD

Table 7: List of key model input parameters pre calibration

Specific yield refers to the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the water table. It is effectively a ratio of the volume of water that saturated rock may yield by gravity to the total volume of the rock. This is usually expressed as a percentage or decimal.

8.1.2 Model Assumptions

In generating and running this type of computer-based model, it is necessary to make a number of assumptions which are listed below:

- The model assumes that the aquifer area is isotropic and homogeneous
- The model assumes that hydrogeological values are consistent over the entire area
- The model assumes there are no barriers to flow within the modelled area
- The model assumes groundwater flow is horizontal and occurs in an infinite aquifer.
- The reference head is constant seasonally
- The model allows the reference head to change to reflect abstraction and injection of groundwater
- The boreholes are assumed to be perfectly efficient (no well losses).

8.2 Model Calibration

Before the model was used to assess the spatial influence/impact of the Ness House Well, it was calibrated against the drawdown and abstraction rates measured and reported in a short duration pump test carried out on the well. Through an iterative process the model was run repeatedly with input values adjusted until the model was able to accurately predict the abstraction rate and drawdown in water levels observed in the Well. Figure 7 provides an illustration of the drawdown modelled.

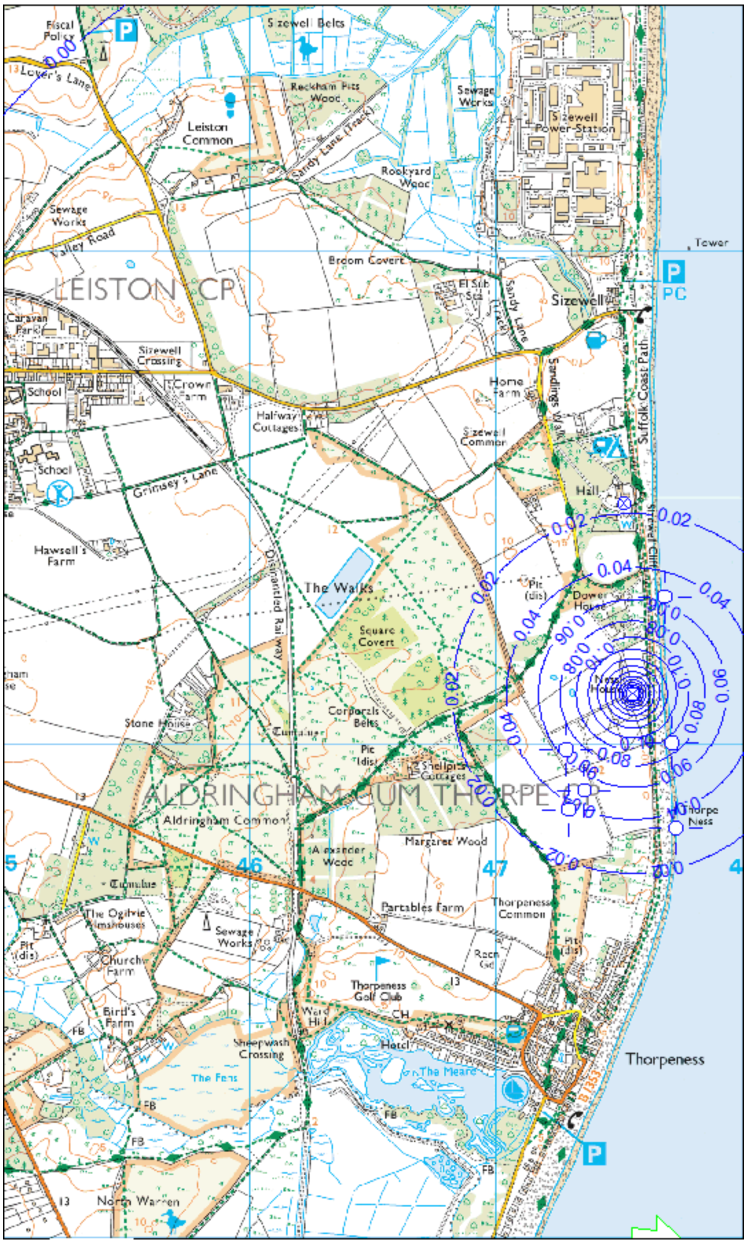


Figure 7: Modelled drawdown in calibrated model

The table below lists the final model input values found to best allow the model to replicate observed reality. The model, whilst fairly simple but effective, uses individual input parameters which are applied across the whole modelled area, not specific zones [there is insufficient data available to support spatial variations to be modelled] as can be afforded in larger models such as regional models. Nevertheless, the approximation provided by the model provides a valuable insight and tool to assist with the design of the proposed system and to assess the likely sustainability of the scheme.

Parameters	Value	Unit
Solution	Neuman, 1972 (Unconfined Aquifer)	-
Transmissivity	84.4	m^2/d
Aquifer Thickness	47	m
Storage Coefficient	0.03	-
Specific Yield	0.1	-
Beta/(r*r)	0.0001	-
Porosity	25	%
Reference Head	0.35	maOD
Gradient	0.002	maOD

Table 8: List of key model input parameters post calibration

The sensitivity of the model to various parameters was also tested and evaluated to ensure that the response to any of these was not disproportional to another and was representative of the actual site. The sensitivity analysis found that the model was most sensitive to changes in transmissivity. Calibration of the model resulted in a change in transmissivity value, which are still representative of the Crag Group and a sensible value compared to the local hydrogeological properties and within the range derived from pump test analysis of test data from the borehole.

8.3 Hydrogeological Model Scenarios

The hydrogeological model was used to simulate a number of scenarios to investigate the potential effects of the new power cable(s) and directional drilling. The following section documents the outputs from these scenarios.

9 Model Outputs

The model was allowed to run for 365 days at a rate of 0.833 m^3/hour from the abstraction borehole for 24 hours a day, this represents the maximum that might be abstracted from the Well now or in the future as it is not a licensed abstraction. The following Figure illustrates the theoretical change in groundwater contours induced by the abstraction borehole. The model predicting drawdown of 0 metres at 2 kilometres from the site.

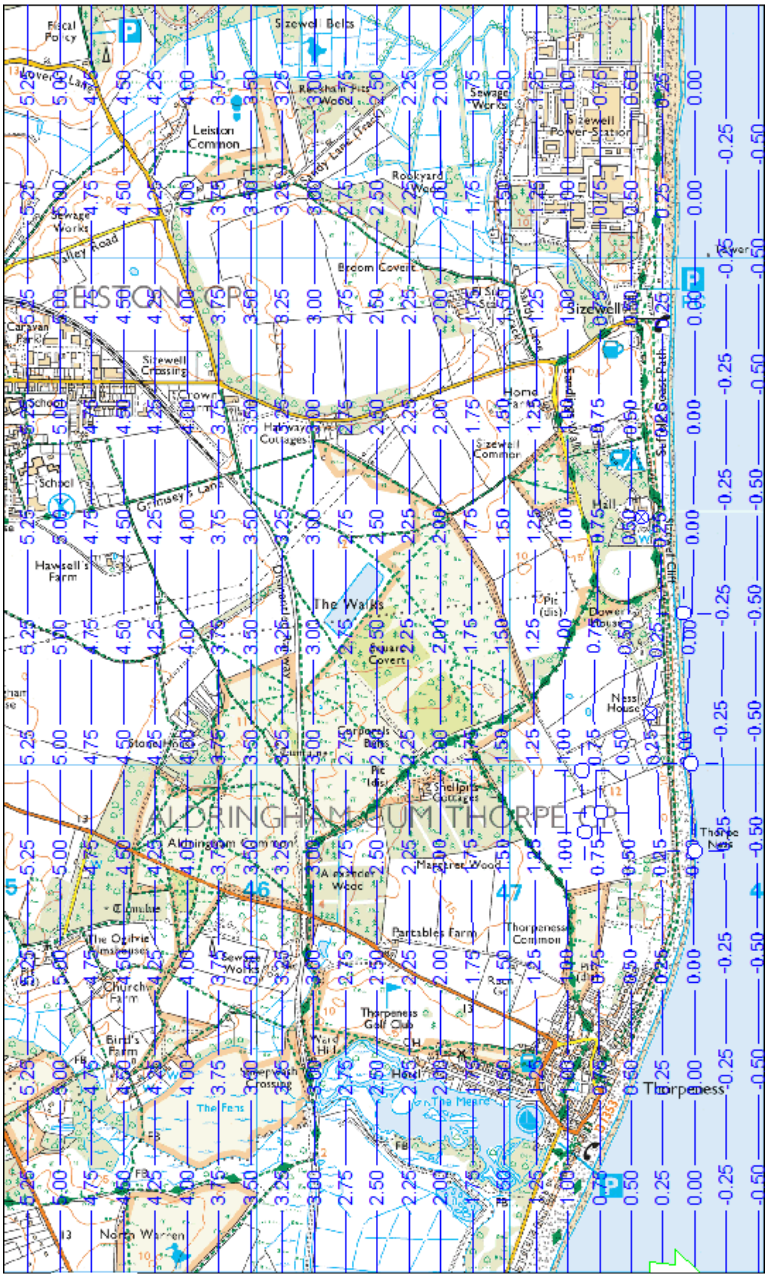


Figure 8: Modelled groundwater contours

The model was then allowed to run for 3 years at a rate of 0.833 m^3/hour from the abstraction borehole for 24 hours a day. A line of particles was added to the model along the length of the proposed cable(s) to simulate the pathway any contamination would follow if released to the ground along the installation route. Figure 9 illustrates the particle traces showing particles moving from the line of the cable(s) encroach on the Well after 3 years.

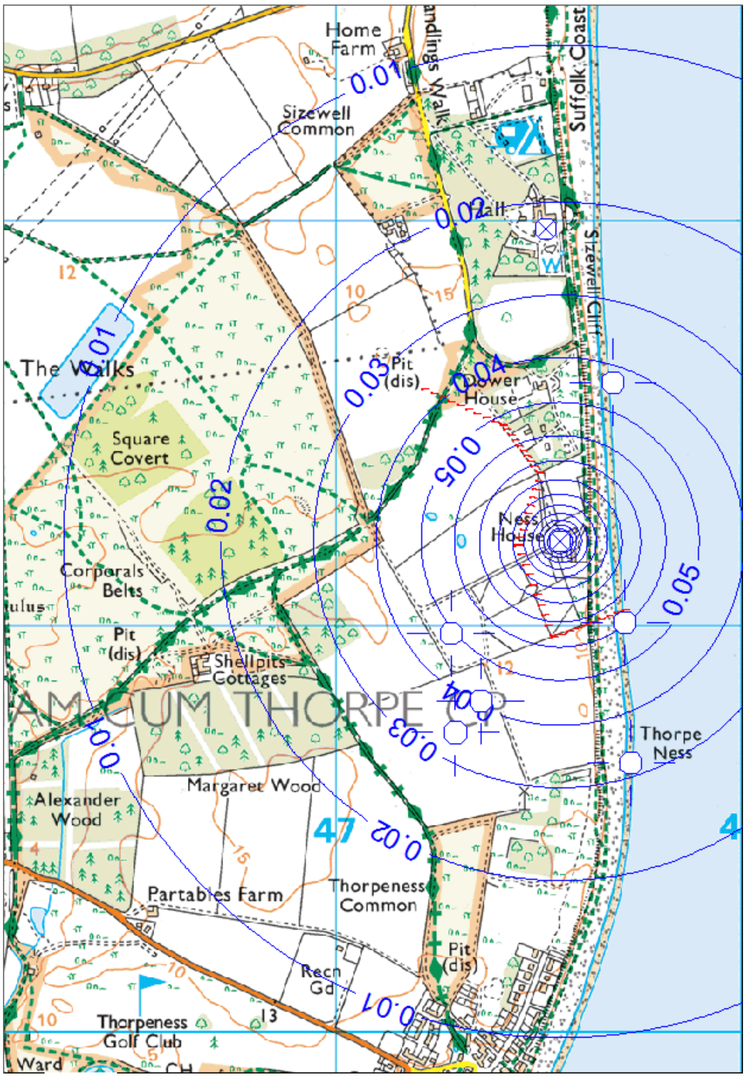


Figure 9: Modelled particle traces

This output shows the Well would be vulnerable to disturbance to the ground along the line of the cables where it passes nearby and any contamination that may enter the ground. The model suggests there would be limited movement of groundwater from the directional drill location to the Well while there is free movement of groundwater in the aquifer. This model cannot, unfortunately, simulate what might happen if the directional drill was to result in an east-west barrier to groundwater flow. As the radius of drawdown is shown to extend to beyond the directional drill area, any change in the ground's ability to store and transmit groundwater in that area will distort natural and abstraction induced groundwater flow directions. That would then result in a change in the source/recharge area that sustains the Ness House abstraction.

To understand the current source area that sustains the Ness House well a circle of particles has been modelled at 50 metres from the borehole to give an indication of how water behaves around the borehole. The results of this after 3+ years can be seen in Figure 10. This shows that most flow comes from up hydraulic gradient and that groundwater down gradient is slowed but over the long term still continues towards the sea. This explains why there is little, or no, sea water seen in the Well.

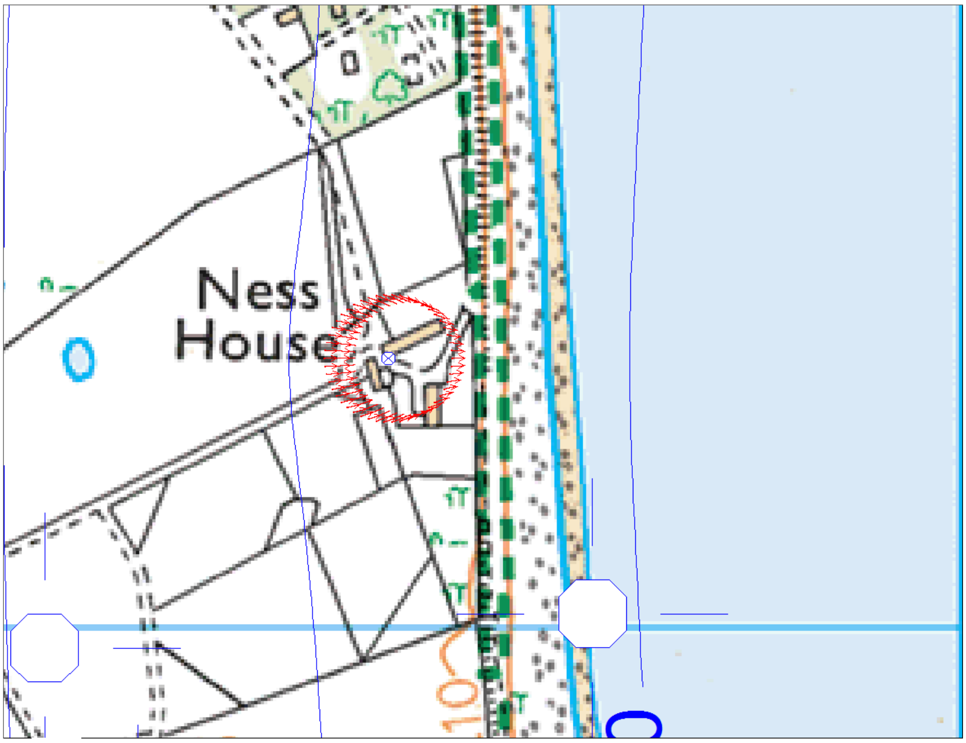


Figure 10: Modelled circular particle traces after 3+ years

If the recharge/source area is at all changed, as a result of the permeability/transmissivity reducing due to grout loss from directional drilling, then the source/recharge area will change. That could result in a reverse in groundwater flow between the Well and the shore if there is less water available from elsewhere in the aquifer to sustain the abstraction. Modelling thus shows the well and groundwater quality could be vulnerable to shallow ground works near the boundary and the amount of groundwater as a result of works to the south of the Well, leading to an imbalance in the saline/fresh water interface and problems with water quality.

10 Discussion

Based on the geology mapped and this Assessment's interpretation it is likely that the Ness House well draws water from the Crag beneath the drift. When groundwater levels rise in wet and winter periods water will also be received from the drift.

The head works of the well are well maintained with a steel cover, an accessible but still protected upstand through which the pump is installed. The well is with a locked brick-built room that houses the water treatment and pump controls.

Coastal erosion between 1985 and 2000 resulted in approximately 10 metres of ground being lost to the sea. The well now sits at around 150 metres from the low tide line. Erosion has stabilised in recent years, nevertheless this coast is expected to recede further which will threaten the quality of water that can be drawn from the well as the fresh water - sea water interface edges closer to the Well.

The well has historically provided a reliable source of water. This is most likely due to it being completed down to or just above sea level. The level of water measured within the well shows it can have a limited level from which to draw. Water quality analysis shows there have been occasions when more saline water has been abstracted. Thus, demonstrating the vulnerable nature of the source to loss of land and rises in sea level.

Quality data also demonstrates a link between farming activities across the fields and the quality of groundwater. Raised levels of nitrate highlight the hydraulic link between surface activities across the surrounding field and quality with a time lag between pig farming, for example, and rises in the well that also persist for years after the farm activity has stopped (>3 years).

This Assessment's hydrogeological conceptualisation of the area and the well concludes the groundwater source exists in a very fine balance within this environment. The abstraction is already vulnerable to being contaminated by surface activities, coastal erosion and sea level rise, drought and unforeseeable effects of climate change.

Numerical modelling of groundwater levels and movement indicates that groundwater moves from west to east. The source induces a drawdown in water levels that extends beneath the directional drill area and although it does not draw water from that area at present, it is likely that a change in ground conditions would change the source area from which the well draws.

Directional drilling involves the use of low permeability grout to stabilise, flush and seal the drilled holes. In the absence of detailed design (making it very hard to comment objectively on the proposal) it has to be assumed the drill will reach and go below sea level/the water table some distance before reaching the current cliff line.

This assumption is made as it is our professional opinion that the design will assume there to be a continued loss of land to the sea, thereby necessitating a design that would keep the drilled cables well below sea level an extended distance back from the current cliff line. This means the drill line will pass at a level equivalent to or marginally below the base of the well along a west to east line forming a low permeability barrier at exactly the level the well needs to communicate with the wider aquifer.

The directional drill cable runs will therefore change the hydrogeological regime. The effects are difficult to predict due to a lack of site specific data and the work carried out on behalf of ScottishPower Renewables has not recognised this threat, has not adequately characterised the local conditions or done anything to address the very real risk to the well.

This Assessment concludes the emplacement of a low permeability barrier running west to east around 200 metres south of the well could starve the well of water, could distort groundwater flow and result in a measurably larger proportion of sea water being drawn into the well affecting quality.

The evidence of past land use affecting the quality of water drawn from the well shows it is vulnerable to surface activities in the local area. As there would be a long build duration affecting the land surrounding Ness House there is a risk the disturbance to the ground would affect the quality (chemically, microbiological and physically such as turbidity) during and for many years after the installation. This would be in addition to any effects from changing the hydrogeological setting.

The draft construction method statement proposes the use of a soakaway type system of drainage. This would not be appropriate given the known water quality risk posed to the well as a result of rain/surface water infiltration (historical from land use). While soakaway systems would work well in this setting they pose a significant risk to the well therefore are not appropriate. Even with interceptors, control over what can be discharged and careful management, the risk would be too great to the private water supply.

The combination of changing the hydrogeological setting through the drilling, with the risk posed from surface and subsurface work all around Ness House; in addition to coast erosion, sea level rise, drought effects and climate change means the proposal represents an existential threat to the Well.

It is our professional opinion that the very limited, basic and relatively poor-quality hydrogeological work completed to date are inadequate. They have not started to accurately characterise or quantify the hydrogeological setting. They have not identified the Ness House Well as a reception at risk. They have provided woefully inadequate information on which stakeholders can make no meaningful assessment, forcing them to conduct their own investigation and deduce, from the experience of professional hydrogeologists the true nature and impact their water supply is at risk of.

The hydrogeological work presented by ScottishPower Renewables should be rejected as incomplete and inadequate. No approval for any of the activities in the vicinity of Ness House should be granted. If the proposal is still to be sought an extended period of data collection, ground investigation, hydrogeological monitoring, ground modelling and cooperation with the local stakeholders completed. The directional drill design must be developed so that the true impacts can be assessed before stakeholders are next asked to comment.

Recommendations

The following recommendations have been drawn from the desk study, fieldwork and informative outputs from the groundwater modelling:

- Work is needed to collect and appraise substantially more hydrogeological data/information as the limited information available is insufficient to develop a reliable and robust hydrogeological model/understanding of the local area.
  In the absence of reliable data and it only being possible to construct a limited hydrogeological conceptual model it is not possible to conclude there would be no impact from the proposal.
- Shallow groundwater monitoring boreholes need to be drilled and hydraulically tested at strategic positions in order to characterise the geology beneath and surrounding Ness House and so that they can form part of a permanent groundwater monitoring network.
  In the absence of reliable data and it only being possible to construct a limited hydrogeological conceptual model it is not possible to conclude there would be no impact from the proposal.
- Work is needed to establish a network of groundwater monitoring points so that the local groundwater regime can be continuous captured in terms of water level changes over at least one year.
  In the absence of reliable data and it only being possible to construct a limited hydrogeological conceptual model it is not possible to conclude there would be no impact from the proposal.
- Work is needed to collect and analyse groundwater samples from multiple sampling points over at least one year so that the spatial and temporal quality of groundwater can be better understood.
  In the absence of reliable data and it only being possible to construct a limited hydrogeological conceptual model it is not possible to conclude there would be no impact from the proposal.
- Tracer tests should be completed with the release of tracer(s) in newly drilled boreholes around Ness Well with monitoring within the Well.
  This is needed to understand and demonstrate groundwater flow paths, travel times and thus the vulnerability of the well to point and dispersed contamination.
- The cabling scheme design needs to be developed and shared prior to any decision being made so that it can be thoroughly and adequately appraised.
  In the absence of a detailed design, it is not possible to accurately and reliably appraise the risk, to ascertain whether sufficient work has been done to ascertain the risk, to assess what else needs to be done and/or for permission to be granted for such a scheme.
- Once the detailed design has been shared, local hydro-geological data has been collected along with at least one year of water level and quality measurements, a detailed groundwater model can be developed to simulate and test the potential impacts from the proposal and any mitigation measures that may be proposed.

Without completing this, it is not possible to conclude with any confidence that there would be no impact on Ness House, all evidence suggests there would be an existential threat to the private water supply.

- Mitigation measures need to be developed and proposed to protect the Ness House abstraction and in the event of an impact, to provide a reliable, practical and sustainable permanent alternative private water supply.
  The only mitigation that has been offered is placement of a temporary water bowser without any details as to the quality standard, volume, connection to the wellhead or duration for which it will be used. Whether this is solely drinking water supply, or would be connected to all header tanks for baths/showers should be explained. Those dependant on the supply currently have no way of judging whether they would be prepared to accept the alternative. It may not be acceptable in terms of volume, quality or reliability.
- There needs to be engagement with, and understanding of, the genuine concerns of those dependant on the Ness House private water supply, and the wider local community that wants to retain their right and ability to develop a private water supply if/when they choose. Private boreholes and wells have been identified locally, all owners expressed a desire to utilise their point of abstraction in the future. The quality and quantity of groundwater available to them, and potentially threatened by the proposal, must be taken into account in a substantive way.
  The current level of engagement and recognition of the concerns of those dependent on the private water supply has not been adequate.
- Climate change and coast erosion needs to be considered in conjunction with the potential impact from the proposal so that any impacts that might be acceptable/mitigatable now are not exasperated and magnified in the near future.
  None of the work presented to dates accounts for how the proposal might affect the private water supply with climate change and coast erosion overlayed.
- No soakaway drainage should be allowed anywhere on site until the above recommendations have been completed allowing the identification of safe places to discharge clean runoff to ground with interceptors and appropriate management systems in place.
  Discharge of water to ground in the wrong locations could rapidly introduce and/or mobilise inferior quality water into the aquifer that would affect Ness House.

Disclaimer – [redacted]

Information within this Hydrogeological Report has been gathered from all sources available to B. A. Hydro Solutions Ltd. Discussion and interpretation is the professional opinion of B. A. Hydro Solutions Ltd. based on information and data provided by the client plus the best available information collected specifically for this study.

If the client wishes to drill a borehole based on the information contained within this report B. A. Hydro Solutions Ltd. must stress no guarantee can ever be given that groundwater will be present, or that the quantity or quality of groundwater required will be available for abstraction. B. A. Hydro Solutions Ltd. cannot guarantee the ground conditions discussed/used (as drawn from research undertaken) are directly comparable to the ground beneath the site. Groundwater quantities/qualities, ground properties including thermal potentials can vary seasonally and as a result of external factors beyond our control and not foreseen by this study.

July 2021

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Hydrogeological Terms

The hydrogeological properties of strata and the ground as a whole is a function of its permeability and the ease at which water is able to move through the various strata. The ground can broadly be divided into three hydrogeological rock types, the aquifers which contain water, aquitards which can contain water but restrict the movement of water and aquicludes which do not contain water and act as a barrier to groundwater movement.

Groundwater moves through the ground via either pore spaces in the rocks, fractures and joints which dissect the strata or sometimes through solution features such as caves. The interconnectivity of the pores, joints, fractures and solutions features determines the amount of water which can accumulate and the ability of the ground to transmit.

The storage potential of the ground is described by its *storativity* [S] which is a dimensionless value ranging from zero up to one. The larger the number the greater the proportion of the saturated ground, in terms of total volume, which can be drained by lowering the water table. If the storativity was one it would be space entirely filled with water and no rock.

When the storativity is very low or zero there is no space in which water can accumulate or none of the water in the ground can be abstracted by lowering the water table. Due to the number of observations needed to quantify the storativity of the ground it is uncommon to be able to derive such values from historical data.

The grounds ability to transmit water is measured by its *transmissivity* [T], the larger the number the easier the water is able to move through the rocks. Theoretically there is no maximum T value, practically it is limited by the aquifer thickness, the volume of water in the aquifer and the capacity of the borehole and pump used to test the ground conditions.

The productivity of boreholes is simplistically measured by its *specific yield* [Sy] which is a measure of the sustainable yield a borehole can deliver per day per metre the water table is lowered. This can easily be derived from measurements recorded during pump tests or reported steady state yield and drawdown values.