GROUNDWATER PROTECTION AT BRITTAS, CO. DUBLIN: A DETAILED HYDROGEOLOGICAL ASSESSMENT AROUND THE PUBLIC WATER SUPPLY WELL

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Abstract
The source of water at the village of Brittas, South Co. Dublin is a well abstracting groundwater from a fractured bedrock aquifer overlain by glacial drift. Previously, it was unknown how well the shallow (drift) and the deep (bedrock) aquifers are hydraulically connected. Discharges from septic tanks near the abstraction well could potentially have been impacting the groundwater quality of the shallow aquifer. No groundwater Source Protection Areas are currently defined for the Brittas well and very little geological information is available for the Brittas area.

Mouchel undertook a comprehensive hydrogeological study of the Brittas drinking water supply well to provide advice on groundwater vulnerability, quality protection and future water resource availability in light of a commitment in the Brittas development plan to investigate water availability. A geophysical and intrusive ground investigation was undertaken followed by groundwater sampling and monitoring and hydrogeological testing (pumping test) to achieve the above objectives.

The extensive dataset obtained from the investigation allowed the development of a detailed conceptual model of the site, which formed the basis of a numerical groundwater flow model (Visual Modflow) representing the hydrogeological regime around the Brittas well. This in turn allowed the definition of an Inner Source Protection Area for the well based on the modelled 100 day travel time which was used to assess whether the septic tanks near the well are posing a risk to the public supply well.
The investigation revealed the deep and shallow aquifers to be hydraulically connected but the site to be overlain by a clay layer which is expected to offer a reasonable degree of protection to the bedrock aquifer from contamination. The model showed that potential discharges from the septic tanks will take more than 100 days to intercept the well. Therefore the drift overlying the bedrock aquifer appears to offer reasonable protection from sewage and bacterial contamination.

The suite of investigation assessment techniques adopted here is an excellent example of how to address difficult hydrogeological issues in particular related to groundwater risk assessments and source protection in the context of planning and development.

1. Introduction
The well supplying the village of Brittas, South Co. Dublin abstracts groundwater from a fractured bedrock aquifer overlain by glacial drift deposits. At the beginning of this work the degree of connectivity between deep bedrock and shallow drift aquifers and the proportion of the abstracted groundwater originating in the shallow aquifer were unknown. Septic tanks are located near the abstraction well, discharges from which could potentially impact the groundwater quality of the shallow aquifer, and ultimately the deep aquifer depending on the degree of hydraulic connectivity between the two. No Groundwater Source Protection Areas were defined for the Brittas well and little detailed geological information was available specifically for the Brittas area.

Mouchel undertook a Cryptosporidium risk assessment of the public supply well at Brittas for South Dublin County Council in 2006 which determined a HIGH Cryptosporidium risk level for the well due to a combination of the rural setting, agricultural practices and principally uncertainty regarding the hydrogeology and borehole construction.

The South Dublin County Council 2004-2010 Development Plan includes a Specific Local Objective to carry out a planning study of the Brittas Village Area, which would include an assessment of infrastructural provision in the area (including water supply). In order to fulfil the objective to investigate water availability and also to reduce the uncertainty regarding the well condition and hydrogeology, Mouchel was commissioned by South Dublin County Council to undertake a hydrogeological investigation in 2007/2008. The objectives of this investigation were as follows:

- To assess the potential impacts of septic tanks on water quality and define a Source Protection Area for the well;
- To comment on the potential to increase the yield of the abstraction well;
- To provide an updated Cryptosporidium risk assessment incorporating the site data using the new EPA guidance, 2008.

This paper details the scope of works undertaken to achieve the above objectives and the conceptual understanding gained from the results of the investigation. This in turn allowed the development of a numerical groundwater flow model through which a Source Protection Area for the well was defined and the well yield assessed.

2. Site Information

The village of Brittas is located on the N81 road between Tallaght and Blessington, 17km to the south west of Dublin city centre, at grid reference 30325 21700. Brittas is set in the floor of a broad valley at an altitude of about 220m OD. The predominant land use in the area around the village is agricultural grassland, primarily used for grazing beef cattle. The Brittas stream flows through the village in a southerly direction and intercepts the Brittas River approximately 400m south of the village.

The geological map for the Kildare-Wicklow area[1] indicates the geology in the area to be drift deposits (tills and fluvioglacial sands and gravels) of 10-30m thick overlying bedrock of Palaeozoic age, predominantly greywackes, shales, siltstone, slate and quartzite.

According to information supplied by South Dublin County Council, the Brittas borehole was installed to a depth of approximately 60m, with a diameter of 150mm and with a steel liner to a depth of 17m. The hole is presumed to be open below a depth of 17m. The pump is a 2.2Kw Brooks pump set at a depth of 36m.

3. Hydrogeological Site Investigation

The hydrogeological site investigation was undertaken in 2007/2008, and comprised the following scope of works.

(a) Geophysical investigation and CCTV

Optical imaging and CCTV surveys were carried out to assess borehole condition (casing integrity, bedrock fracturing) followed by temperature and conductivity logging, calliper logging and flowmeter logging to locate potentially productive fractured zones and water inflow zones.

(b) Intrusive ground investigation

An intrusive ground investigation to gain an understanding of the geology and hydrogeology; 14 boreholes were drilled of which 9 were installed as groundwater monitoring wells. In order to allow monitoring of groundwater in both the upper and lower aquifers, boreholes BH15, BH12, BH6, BH4 and BH9 were screened in the upper (drift) aquifer and BH 10 in the lower (bedrock) aquifer.

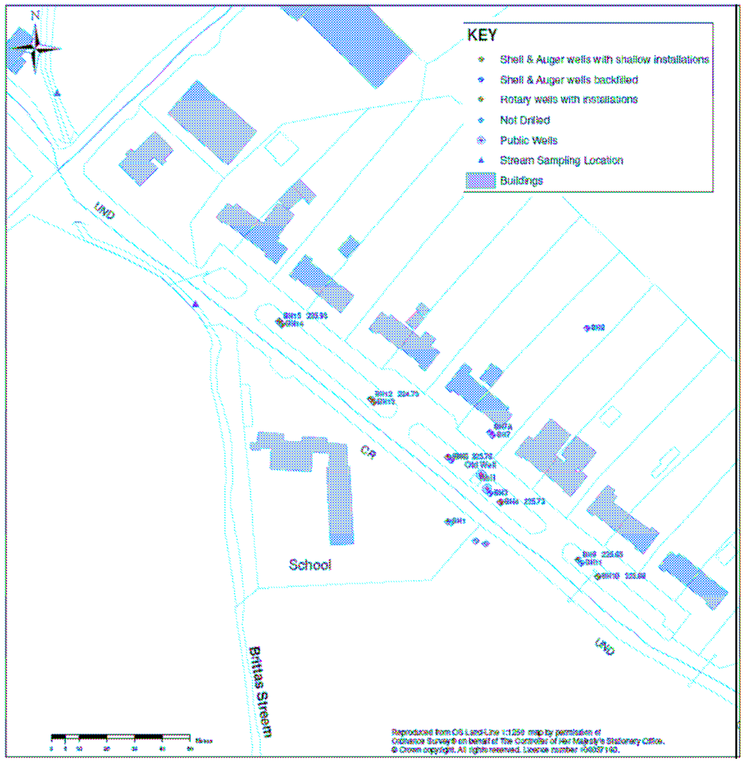

Figure 1: Site layout and borehole location plan

(c) Pumping Test

A pumping test was undertaken to assess the hydraulic properties of the aquifer whereby the well was pumped at a constant rate and the response in the aquifer monitored, which allowed aquifer properties to be calculated and, the extent of the hydraulic continuity between the shallow and the deep groundwater evaluated.

The pumping test had two components: a recovery test and a drawdown test. The well was pumped at a steady rate of 11.4m^3/hr (typical pumping rate 2.5-6m^3/hr) for 19 hours prior to the test to ensure the water level was constant at the start of the test. The pump was then switched off and the change (rise) in water level in the pumped well and monitoring wells monitored for 23.5 hours. The pump was then turned on (pumping rate 9-12m^3/hr) and the drawdown in the pumped well and monitoring wells measured for 28 hours. The data from the recovery test was used in the assessment of the aquifer hydraulic properties as it was not possible to maintain a constant pumping rate during the drawdown test.

(d) Groundwater monitoring

Groundwater level monitoring and sampling and chemical analysis of the Brittas stream and the groundwater were undertaken to gain a better understanding of the hydrogeological regime at the site, particularly the interaction of shallow and deep groundwater. In-situ measurements of pH, electrical conductivity, total dissolved solids and temperature were taken on all groundwater samples at the site. Groundwater and surface water samples were tested in the laboratory for major ions, nitrate, nitrite, ammonium, boron, phosphate, orthophosphate, pH, electrical conductivity and additionally Total Coliforms and Escherichia Coli.

3. Hydrogeological Site Investigation Results

(a) Geophysical investigation and CCTV

Optical imaging and CCTV surveys were carried out which confirmed the presence of a 150mm liner in good condition to 15 m depth and an open borehole to a final depth of 65m. The surveys revealed the bedrock to be locally heavily fractured, in particular between 16 and 25m and around 40mbgl, as shown in Figure 2.

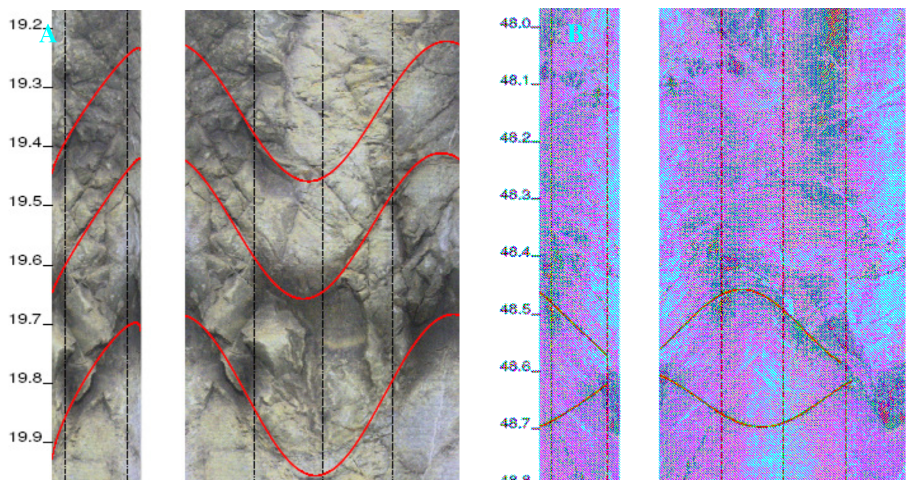

Figure 2: Optical images of (A) Fractured bedrock and (B) Unfractured bedrock. (Depth given in metres, red lines indicate fractures).

Geophysical testing (undertaken to a depth of 36m) did not indicate a specific zone of groundwater inflow, although it was expected that the highest proportion of groundwater inflow comes from the heavily fractured top zone of the bedrock (i.e. just below the liner).

(b) Ground investigation: geological and hydrogeological conditions

The ground investigation confirmed the presence of an upper clayey gravel aquifer and deeper bedrock aquifer. The upper gravel aquifer is overlain by a clay layer (5-7m thick) encountered in all boreholes across the site. At the northwestern end of the site the two aquifers are separated by a silty clay, 2-3m thick, thinning to the southeast of the site where the upper gravel and the weathered top of the bedrock (silty gravel) are expected to be directly hydraulically connected. Solid bedrock was encountered at 15m, composed of green mudstone underlain by a harder black shale at 21.5m.

(c) Pumping Test

The pumping test revealed a good degree of hydraulic conductivity/transmissivity both horizontally in the upper (fractured) part of the bedrock and also vertically between the deep and shallow aquifers. The most responsive monitoring well was that screened in the upper bedrock (BH10), indicating a good horizontal conductivity in the upper part of the bedrock.

The monitoring wells screened in the upper gravel aquifer (BH15, BH12, BH6, BH4 and BH9) all showed a change in water level during the test (3-7cm), the magnitude of which decreased as distance from the pumped well increased. Such a response would suggest there is some degree of hydraulic connectivity between the bedrock aquifer and the upper gravel layer. The exception to this is BH9, which, despite being the greatest distance from the pumped well (approximately 35m) had the greatest drop in water level of any of the shallow wells (7cm). This is similar to the response in the shallow bedrock seen in BH10 (10m away).

(**d**) Groundwater level and quality monitoring

Groundwater monitoring revealed the water levels in the shallow aquifer and the bedrock aquifer to be below the water level in the Brittas stream by approximately 2m. Hydrochemical testing of the groundwater and the Brittas stream revealed the shallow and deep groundwaters to be similar in composition, but to be quite different to the stream, as the selection of results presented in Figure 3 below illustrate.

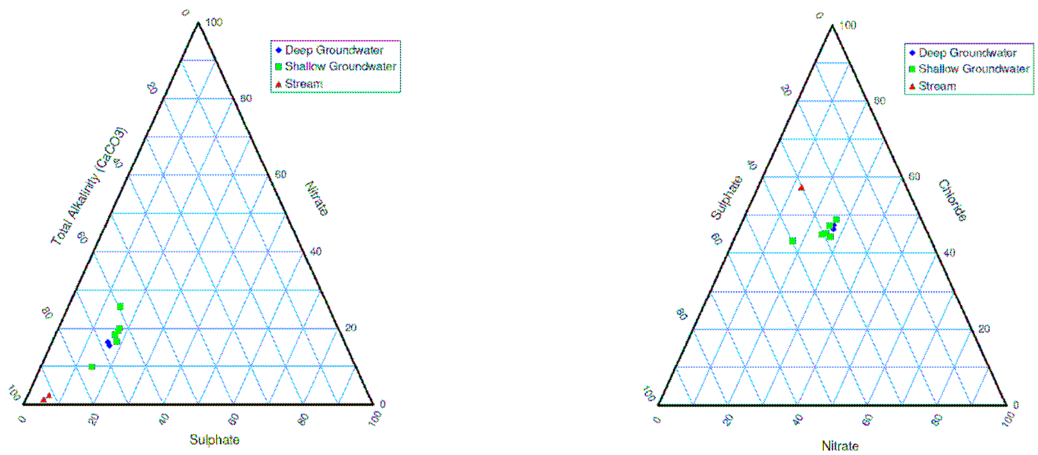

Figure 3: piper plots showing the contrast between surface water (red) and groundwater chemical compositions

4. Interpretation and conceptual model

The comprehensive hydrogeological investigation undertaken allowed a detailed conceptual understanding of the hydrogeological regime at a water supply well to be developed. The conceptual model is presented in Figure 4. This illustrates the hydrogeological regime in the vicinity of the borehole and identifies and characterises potential pollutant linkages and other risks pertinent to the site.

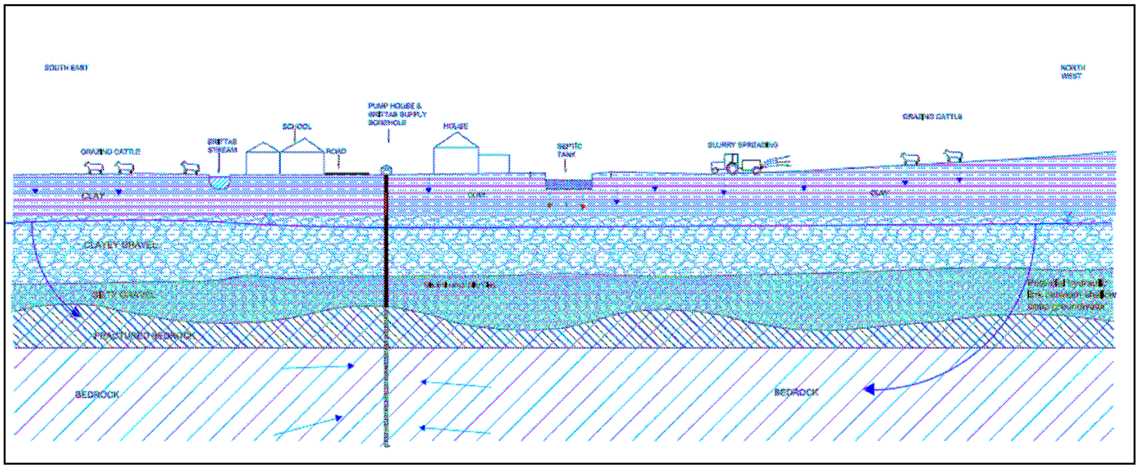

Figure 4: Conceptual Model

The shallow (clayey gravel) and deep (bedrock) aquifers are considered to be hydraulically linked, as evidenced by the concurrent responses in both the shallow and deep monitoring wells during the pumping test and additionally the results of the hydrochemical testing which demonstrate the shallow and deep groundwater to be of similar composition. The hydraulic connection is strongest at the southeastern end of the site where the silty clayey layer between the gravel and the weathered top of the bedrock in the western and central parts of the site is absent, potentially leading to higher vulnerability of the aquifer in this area..

The groundwater is hydraulically isolated from the Brittas stream. The stream flows on a clay layer (encountered in all boreholes during the ground investigation) which would restrict exchange between the stream and shallow groundwater. Groundwater levels are several metres below the stream and hydrochemically the two waters are of different composition, indicating little or no hydraulic interaction takes place between the surface and ground water.

The main potential sources of well contamination include septic tanks, slurry spraying, manure spreading and animals.

Possible significant pathways to the abstraction well could be:

- areas where the upper clay layer is absent or has been removed and the underlying gravel layer provides a quick flow path to the bedrock and as a result to the well, or
- contaminated run-off enters the well directly through the unsealed well cover.

However, both possibilities are considered unlikely as the clay overlying the entire site is expected to offer a reasonable degree of protection from contamination and the clay within the gravel below will reduce the effective porosity substantially. Together these features of the hydrogeological setting will act as a physical filter and to Cryptosporidium and provide a time delay between the ground surface and the well during which cryptosporidium will decay. Additionally, the CCTV and optical imaging surveys indicated that the well predominantly draws water from the deep bedrock aquifer rather than the overlying drift.

5. Delineation of Inner Source Protection Area and assessment of potential septic tank impact by numerical modelling

Based upon the conceptual model detailed above, a numerical groundwater flow model was constructed using the US Geological Survey flow modelling software MODFLOW 2000 within the Waterloo Hydrogeologic Inc. user interface package, Visual Modflow (Version 4.2).

Visual Modflow, a steady state, finite difference flow model, allows visualisation of groundwater flow paths (by the particle tracking tool) which also represent the pathways of potential contamination and it allows the calculation and visualisation of groundwater travel times from a defined start point to a groundwater receptor. The model may be run forwards (whereby particles representing contamination move in the direction of groundwater flow) or backwards (particles move opposite to the flow direction to allow their points of origin to be identified).

The Inner Source Protection Area is the area designed to protect against the effects of human activities that might have an immediate effect on the source and, in particular, against microbial pollution[(3)]. The area is defined by a 100-day time of travel from any point below the water table to the source. EPA guidance on the siting of new wastewater treatment systems (including septic tanks)[(4,5)] states that in an Inner Source Protection Area of moderate vulnerability, no water treatment system should be located within 60m of a public water supply source.

Particle tracking in Modflow was used to assess the 100 day travel time zone (i.e. Inner Source Protection Area) for the well in order to assess whether the septic tanks near the well are potentially posing a risk to the water quality in the abstraction well. The numerical model takes the variable hydraulic properties of the layered aquifer into account.

The model was designed to represent the groundwater flow in the vicinity of the public water supply well, not the entire Brittas area. The geology around the well is represented in the model by six layers representing the drift (3 layers) and the shallow and deep bedrock below (3 layers). The groundwater flow around the well has been calibrated based on the pumping test.

The findings of the numerical modelling are described below and shown in Figure 5.

Figure 5: A: Particle travel time from septic tanks to Brittas well
B: Particle tracking and delineation of Inner Source Protection Area

The septic tanks to the north-east of the Brittas well are predicted to be within the Inner Source Protection Area when the drift aquifer *is not* taken into account.
However, when the drift cover is taken into account the model shows that potential discharges from the septic tanks will take more than 100 days to travel to the well.
Therefore the drift overlying the bedrock aquifer appears to offer reasonable protection from sewage and bacterial contamination which is likely to be filtered out and therefore the risk of contamination of the well is considered to be low.

There are no requests for the installation of further septic tanks near the abstraction well, in particular not within 60m distance to the well. No evidence was found that the existing septic tanks, even if less than 60m from the well, pose a risk to the public water supply.

6. Assessment of the potential to increase the well yield

The output of the numerical modelling is based upon the average pumping rate of the Brittas well of 93m^3/d. The pumping test, which was carried out at ca. 270m^3/d showed that the groundwater abstraction rate can be increased. The lower groundwater table compared with the water level in the Brittas stream could be a sign of over-abstraction of the aquifer, but it is more likely to be a result of low recharge to the aquifer and relatively high permeabilities in the drift layers, which tie the groundwater elevations to the Brittas River elevation in the area. However, the development of the water table in the aquifer should be monitored regularly as over-abstraction and gradual lowering of the water table in the aquifer is a possibility.

The potential to increase the groundwater abstraction rate is dependent on the recharge rate and extent of the potential borehole catchment area. Based on a 210mm/a groundwater recharge rate and the current average pumping rate of 93m^3/d (around 34 Mio l/year) an area of around 162,000m^2 (i.e. an area of 400m x 400m) is required to provide the abstracted water volume by groundwater recharge. Based on the geology and the conceptual model it is likely that conditions in the aquifer are sufficient to sustain an increased abstraction from the well at around 120m^3/day.

The numerical groundwater model has demonstrated that an increase in pumping rate increases the travel time of groundwater to the well (i.e. increases the area of the Inner Source Protection Area) and therefore increases the risk of pollution of the well, as can be seen in Figure 6 below.

Figure 6: Influence of increasing well yield on groundwater flow velocities.
A: pumping rate of $93m^3/d$, **B**: pumping rate of $120m^3/d$

7. Cryptosporidium Risk Assessment

A Cryptosporidium risk assessment was undertaken according to amended screening methodology for Cryptosporidium issued by the EPA in 2008(6). Based upon the risk score calculated for the catchment, treatment, operational and management factors which were then population weighted, the final risk assessment score was LOW risk.

A substantial proportion of the risk assessment score is attributable to the geology and hydrogeology of the study area. The greater wealth of geological and hydrogeological information available following the hydrogeological investigation allowed a more accurate vulnerability rating to be attributed to the study area, which was key in lowering the risk assessment score.

8. Conclusions

A site-specific, diverse hydrogeological site investigation and risk assessment of the Brittas water supply well was undertaken by Mouchel in 2007/2008. The extensive, integrated dataset obtained facilitated detailed conceptualisation of the groudwater flow regime around the well through numerical modelling. This was used to assess the potential risk posed by septic tanks in the vicinity of the well and to define an Inner Source Protection Area for the well.

The findings of the investigation combined with the numerical modelling highlighted the importance of the drift overlying the bedrock aquifer, in particular the clay layer overlying the entire site. Should future development take place in the Brittas area it is recommended that this overlying clay layer is not removed. However, this clay layer limits groundwater recharge in the area, therefore should the well yield be increased the water balance should be taken into account and the potential exists for over abstraction due to the low permeability of the drift.

9. References

1 Geological Survey of Ireland (1995): Geological Map for the Kildare-Wicklow Area. Sheet 16.

2 Mouchel Parkman (2006): Cryptosporidium Risk Assessment, Brittas, Co. Dublin, Ireland.

3 Department of the Environment and Local Government, Environmental Protection Agency and Geological Survey of Ireland (1999): Groundwater Protection Schemes.

4 Environmental Protection Agency (2000): Wastewater Treatment Manuals. Treatment Systems for Single Houses.

5 Environmental Protection Agency (2000): Groundwater protection responses for on-site wastewater systems for single houses – summary.

6 Environmental Protection Agency (2008): Drinking Water Regulations Guidance Booklet No. 4. Risk Screening Methodology for Cryptosporidium

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