N4 Collooney to Castlebaldwin, *Proposed Road Development*

APPENDIX NO. 14.1

Hydrological study of Tawnagh Lake, Tawnagh, County Sligo

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1 INTRODUCTION

1.1 Context

Tawnagh Lake in Co. Sligo is located within the area for which an EIS for the proposed realignment of the N4 road has being prepared by Minerex Environmental Ltd. (MEL) on behalf of Sligo County Council. The objective of this study of the lake is to characterise the lake hydrologically (its flooding regime), define the catchment of the lake (its hydrological contributing area) and assess any likely effects of the proposed road route and alignment on the hydrological regime of the Tawnagh Lake catchment.

1.2 Turlough Definition

Although there are a number of Turlough definitions emphasising either hydrological or ecological factors, a turlough can be broadly defined as:

> *A topographic depression in karst which is intermittently inundated on an annual basis, mainly from groundwater, and which has a substrate and/or an ecology characteristic of wetlands.*

This definition was developed to take account of the fact that a turlough is an integrated hydro-ecological entity. A relationship exists between the water quality, the flooding regime, the morphology and substrate of the turlough, and the composition and distribution of its plant and animal communities, which are adapted to survive fluctuating hydrological conditions. Turloughs exhibit a range of hydrological, morphological and substrate parameters that are associated with a characteristic range of ecologies (Ref. 1).

The occurrence of flooding is a function of the climatic regime and of the hydrological functioning of the turloughs and the karstic limestone system of which they are an integrated part. Western Ireland, where almost all turloughs occur, has high rainfall, on average 1000mm per annum. The predominantly seasonal pattern of flooding observed in turloughs results from high rainfall in winter, and less rainfall, with higher evapotranspiration, in summer. Similarly derived landforms in Yugoslavia (poljes), are glacial hollows on Carboniferous limestone, but do not flood, sometimes for many years due to a different climatic regime, in addition to having a thick layer of sediments on the basin floor (Ref. 2). Turloughs within the same climatic environment have different patterns of seasonal flooding due to differences in their hydrological functioning, specifically their capacity for filling and emptying. A small number of upland turloughs have been reported to have short term filling and emptying, in response to individual rainfall events, even in summer. These reported turloughs all occur on the Burren plateau. The majority of lowland turloughs flood seasonally, filling sometime in September/October and emptying (apart from residual pools) in the April to June period. The speed of filling and emptying varies among turloughs, as does the modality of increase and decrease in water levels during the flooded period. Analysis of rainfall data for the Gort area of Co. Galway (Ref. 3), where turloughs are associated with conduit flow type hydrology, showed that intensive flooding was always associated with high winter rainfall amounts, specifically when cumulative rainfall during the December through February period exceeded 550mm. Recent work has shown that a range of lake hydrology types from turloughs that empty and fill several times a year to more permanent lakes on limestone bedrock that empty every few years or every decade or so can also be classified as types of turlough or at least, turlough-like in their hydrology (Ref. 4).

2 MONITORING AND SURVEY WORK

2.1 Monitoring and surveying has comprised:

i) Initial field visit. The site was visited on 13/1/11 to install the monitoring equipment. An extensive walkover of the site and adjacent lands was also conducted at this time. Photographs were taken of the lake and nearby karst features.

ii) Installation of monitoring equipment.

Two Van Essen Micro Divers which records water level at hourly intervals were installed in a protective casing and weighted with steel weights connected to a line so as to identify the location under flood conditions and to permit recovery, as necessary. The monitoring system was installed on 13/1/2011 at grid reference In the centre of the Turlough at Grid Ref 173896, 317326. The location is in the deepest part of the Turlough as identified onsite during the installation process. Two Primelog Xilogger data loggers were also installed in boreholes BH31 and BH32. The Groundwater data from the boreholes was used in conjunction with the lake level data to analyse the relationship between groundwater and surface water at the site and to examine the relative response of the groundwater system and the surface water systems to rainfall events during the monitoring period.

iii) The monitoring equipment was removed from the lake and boreholes on 1/6/11 in dry conditions.

iv) A Magellan Differential GPS (DGPS) topographic survey system was used to survey the parts of the lake basin and karst features during 2011. The Magellan DGPS is accurate to 10mm in the z direction (elevation) and 5mm in the x and y directions. It was not possible to survey the entire lake basin as the lake did not drain during the study period.

3 RESULTS OF MONITORING AND SURVEY

The results of the water monitoring are presented graphically below. The water level data, which is recorded as mbar of pressure above the diver base, was subject to compensation using barometric pressure recorded locally at hourly intervals, to give a result of cm of water above the diver base. The water level has been corrected to maOD, as have the water levels in BH31 and BH32 which are also shown below. Also shown with the monitoring data are daily rainfall values at Markree Castle, located 1km outside Collooney, the closest reliable meteorological station to Tawnagh which records daily rainfall.

4 CATCHMENT DELINEATION

4.1 Characteristics of Tawnagh lake and the surrounding area

4.1.1 Bedrock Geology

The geology of the area is comprised of Carboniferous limestones. The lake is situated in the Bricklieve limestone formation which consists of medium to thick bedded grey bioclastic limestones, generally wackestones and packestones devoid of internal bedding features. Much of the formation is thick bedded and featureless. Chert occurs in a great variety of forms and is abundant throughout much of the succession, forming up to 70% of the rock towards the top of the succession, (MacDermot, Long and Harney 1996). The formation is divided into the Upper Bricklieve and Lower Bricklieve divisions, the turlough itself being located within the Lower Bricklieve limestones. The clean , thick bedded nature of these limestones, along with the presence of abundant chert renders them very susceptible to karstification. The presence of chert acts to concentrate flow into pathways around the highly resistant material, thus enhancing the process of karstification. The Bricklieve limestones are classified by the GSI as a regionally important karstified aquifer. The Bricklieve limestone is underlain by the older Lisgorman shale formation which is exposed to the southwest of the Bricklieve at Tawnagh. The Lisgorman shale comprises calcareous shales interbedded with very fine grained limestones, with the limestone beds being less than 20cm in thickness. Karstification does not develop in such shale dominated formations. The Lisgorman shale is classified as a locally important aquifer, moderately productive only in local zones.

The Bricklieve limestones are the youngest of a series of Carboniferous limestones and sandstones exposed in the Ballymote syncline which has a north east south west axis, closing to the south west. A northeast-southwest trending fault which along the southern side of Tawnagh Lake is mapped on the 1:100,000 scale bedrock map. Such faults, where they occur in clean, thick bedded, limestones such as the Bricklieve formation, can act as a focus for karstification by concentrating flow through the high transmissivity conditions associated with them. This potentially results in a zone of highly karstified limestone within and around the fault zone. At the northern end of Tawnagh Lake there are up to 10 swallow holes/depressions running in a line towards the field boundary, whose occurrence may be related to a zone of highly karstified limestone extending from the mapped fault. As in the case of the Turloughmore Turlough near Tubbercurry, lithological and structural conditions are therefore such as to result in karstification of the Bricklieve limestone across the extent of its occurrence in the area of the Ballymore syncline. The turlough catchment is bounded within the area of the karstified Bricklieve limestones and cannot extend into the unkarstified Lisgorman shale formation to the southwest.

4.1.2 Topography

Tawnagh Lake is located in a shallow basin with a minimum height of 59 m ODMalin. It is surrounded to the east and west by topographic high points. Loughymeenaghan is located to the south of, and flows into Tawnagh Lake. A dry valley is located to the north of Tawnagh Lake, and St. Patricks well is located approximately 0.5km north of the lake at the bottom of the dry valley. The general surrounding area is comprised of nw-se trending drumlins and Lough Arrow is located 3kms southeast of Tawnagh Lake. The Arrow or Unshin River flows north to Riverstown where it receives the discharge from St. Patricks well. Local topographic high points are provided by the drumlins which reach an average height of 90-100m ODMalin.

4.1.3 Regional Hydrology

The regional groundwater gradient in the area in which the lake is located, is from south to north, with water from the karst aquifer providing baseflow to the Unshin River. Karst groundwater flow systems however, do not necessarily mirror completely the topography and its associated surface water catchment. Non co-incidence with the topography occurs most frequently with conduit type karst systems, where recharge to the system may be by both point and diffuse recharge, and the conduit flow system may traverse topographic catchment boundaries. Thus, it is common for the hydraulic catchment of a turlough or turlough-type lake not to be coincident with the topographic catchment.

4.1.4 Turlough Hydrology

Tawnagh Lake was full when the January site visit was carried out. As the depth of water in the middle of the lake was relatively shallow, it was possible to install divers at the base of the deepest part of the lake. The water depth at installation was 0.317m (water surface = 59.9maOD) and the water temperature was 5.67º. The water depth recorded on 1/6/11 when the divers were removed was 0.209m deep (water surface = 59.73) with a temperature of 12.68 ºCelcius. The maxima and minima water levels and temperatures recorded during the monitoring period were 1.09m (60.61maOD) , 0.108m (59.63maOD), 19.7 ºCelcius and 3.03 ºCelcius. The water depths in the turlough are typically <1m depth and thus water temperatures (measured near the base of the turlough at the location of the Diver) will be affected to some extent by solar heating. Nevertheless, the temperatures are somewhat lower than would be expected if significant bedrock groundwater inflow was taking place.

Electrical conductivity of the water in the surface water stream flowing into Tawnagh Lake was 414 µS/cm (at 20 ºCelcius)and that of the water flowing into the swallow hole at the northern end of the lake was 398 µS/cm when the divers were installed. If karstic groundwater was discharging into the lake in significant volumes relative to the surface water input from Loughymeenaghan, then the lake outflow would be expected to be at least as high, if not higher than the surface water in the influent stream.

Water flow in the stream flowing into the lake was approximately 15 l/s and the volume of water flowing into the swallow hole at the northern end of the lake was similar. Precision in measuring such flows is difficult but the difference between the surface inflow and swallow hole outflow of the lake is relatively small in any case, indicating that groundwater discharge was not providing the majority of inflow to the lake.

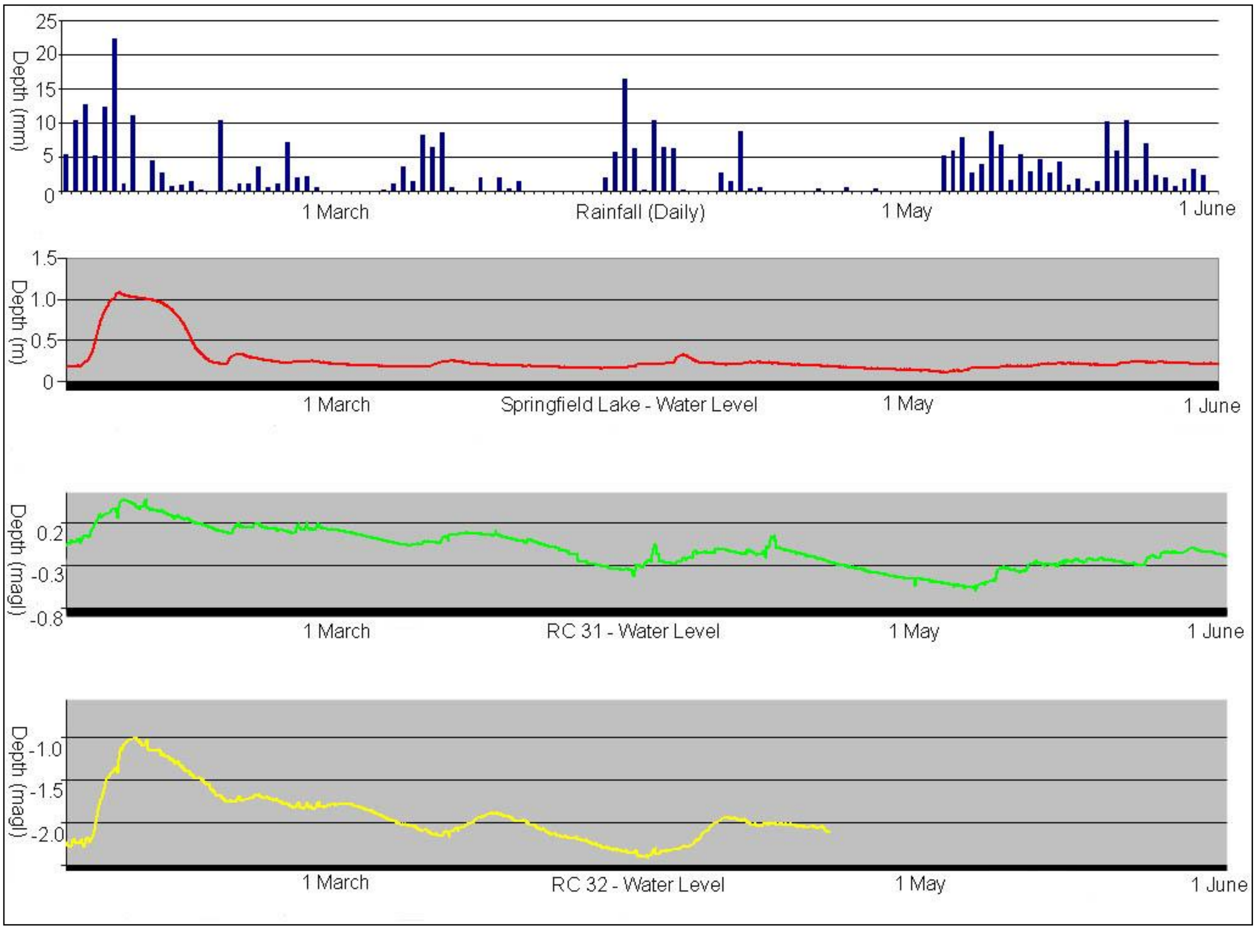
The convex shape of the hydrograph recession, as the lake level recedes in January 2011, could indicate several possibilities (see graph below). It could result from relatively shallow source (low residence time) subsurface water inflows to the lake, or it could be caused by the elongated nature of the surface catchment upstream of the lake and the buffering effects of Loughymeenaghan.

The lake surface reacts to rainfall inputs generally within 24 hours of a rainfall event. Increased lake levels in response to rainfall persist in the lake before receding and, as outlined above, the recession curve of the hydrograph tends to display a convex characteristic which is most easily explained by the linear nature of the upstream surface catchment and the resulting lag time between rainfall and peak flow arrival into the lake (see graphs below). The water level in RC31 and RC32 (see graphs below) react to rainfall in different ways. The water level in RC32 appears to be 'flashier' than that in RC31, indicating that there is heterogeneous groundwater flow in the area which is indicative of a karst aquifer. There is no clear lag between the reaction of groundwater levels and/or levels in Tawnagh lake following rainfall events. However, any relationship that may exist between the water level in the lake and the local groundwater levels is probably masked by the hydrograph response caused by surface water inputs into the lake. The data logger in RC32 was broken by cattle two-thirds of the way through the monitoring period and thus a complete data record is not available for this borehole.

Anecdotal evidence recorded from local farmers indicates that during times of flood, the lake used to flood the road to the north. This is now avoided as a result of the construction of a drainage channel under the road which carries floodwaters away to the north. It is possible that this flooding is caused either by the water table rising above the ground level in the area north of the site, or possibly by the drainage capacity of the swallow holes at the north of the lake being exceeded during times of high rainfall which cause the karst system to be bypassed and surface flow to occur. It is difficult to say definitively which scenario operates at the site without groundwater level recordings at the north end of the lake during such high rainfall events.

The first edition 6 inch map shows a swallow hole but no lake at the present site of Tawnagh lake, south of the currently functioning swallow holes. This suggests that the lake may have formed during the past 170 years due to collapse and infilling of the swallow hole that used to exist on the western side of the current lake. It also suggests that the water table at the site of the lake is below the lakebed for at least part of the year, as a swallow hole could not function if the watertable was higher than the base of the lake. This supports the likelihood of Tawnagh lake being predominantly fed by surface water from Loughymeenaghan.

However, this feature may be an estavelle, i.e. a two-way flow feature that functions as a swallow hole or a spring depending on the height of the watertable. If this is the case, then Tawnagh Lake marks the point at which the water table intersects the land surface. The water level recorded in RC34 supports this theory, as it was measured at 69.64 in early June 2011. This would mean there is a hydraulic gradient of 0.03 between the water table in this borehole and the surface of Tawnagh Lake. Such a hydraulic gradient is high by the standards of lowland karst aquifers in Ireland (typically 0.01-0.001).



4.2 Catchment Area

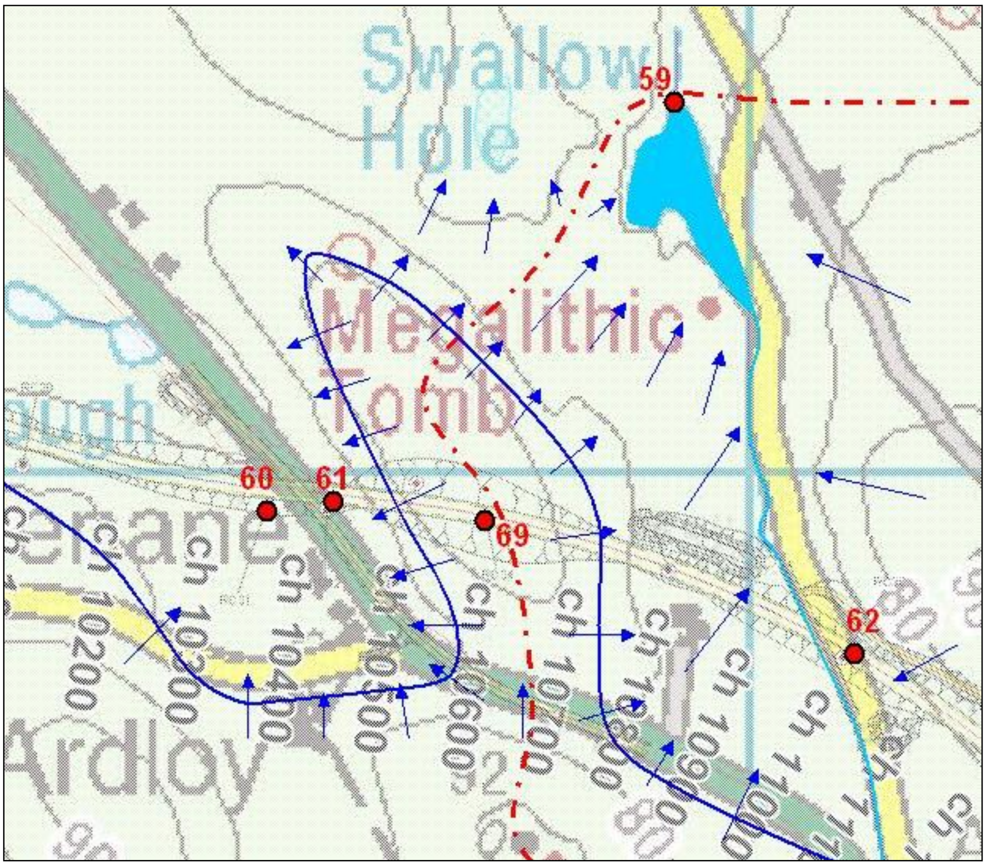
The surface catchment area of Tawnagh Lake is approximately 1.9 km². This area extends to the topographic highs around the lake and approximately 2km to the south, including the catchment of Loughymeenaghan. Discharge from the lake was recorded as approximately 15 l/s during the site visit, equating to 7.8 l/s/km², which is relatively low. This could be due to the fact that it had not rained heavily in the time running up to or during the site visit, or it could possibly indicate that the surface drainage system in the catchment is losing water to the groundwater system. It does not indicate that groundwater discharge from outside the surface catchment is discharging into Tawnagh Lake and there is no reason to assume that the lake has a larger catchment area than the known area of contribution as defined topographically.

4.3 Catchment Location

A topographic catchment to Tawnagh Lake was delineated. This has an area of approximately 1.9 km2 and is considered to be an appropriate catchment boundary location based the interpretation of the site data and conceptual model of the lake hydrology.

The boundaries of the karstic groundwater catchment under the lake are difficult to definitively delineate in a drumlin area such as this as they are likely to be controlled to some extent by the elevation of rockhead beneath the unconsolidated deposits and by the orientation of local bedrock faulting and jointing. However, results of rotary coring undertaken as part of the Collooney to Castlebaldwin N4 Realignment indicate that many of the drumlins in the area contain a core of limestone bedrock. Assuming that this is generally the case in the Tawnagh Lake catchment then it is likely that the contributing area to the lake can be roughly defined by its topographic catchment. This assumption is corroborated by the fact that the volume of water flowing into Tawnagh Lake via the surface channel and out of the lake via the swallow hole are similar.

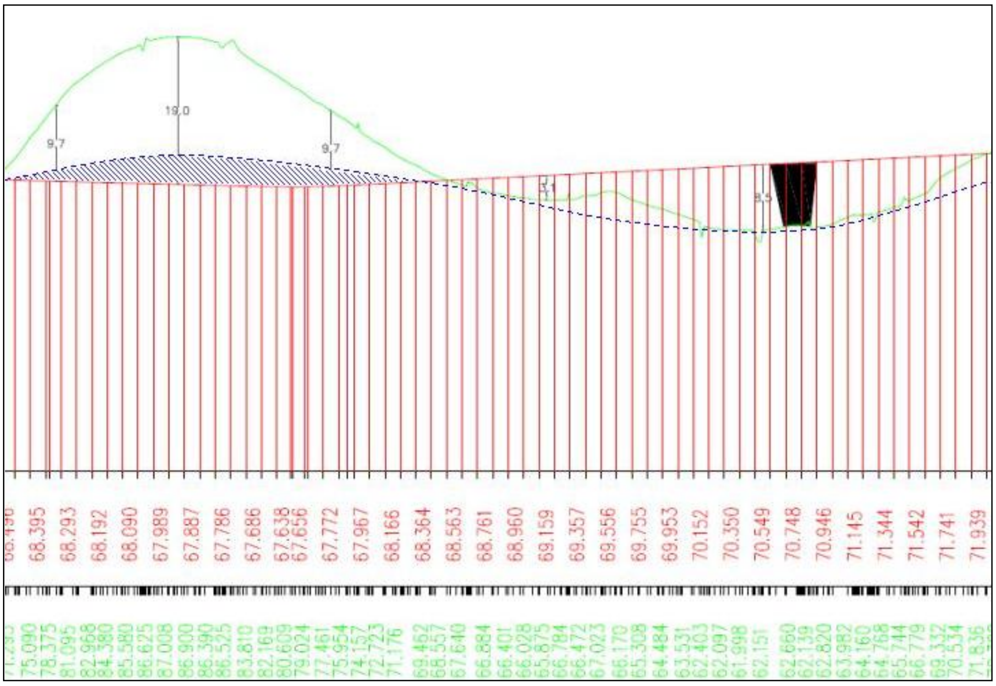
The map below shows recorded groundwater levels in site investigation boreholes. The likely current position of the 67maOD groundwater contour was extrapolated from these (the level of the base of the cut). The groundwater flow arrows show the likely groundwater flow routes (although in reality these will be different to some degree due to bedrock structural control of local groundwater flow direction in karst aquifers). The broken red line shows the likely current position of the groundwater catchment boundary for Tawnagh Lake.



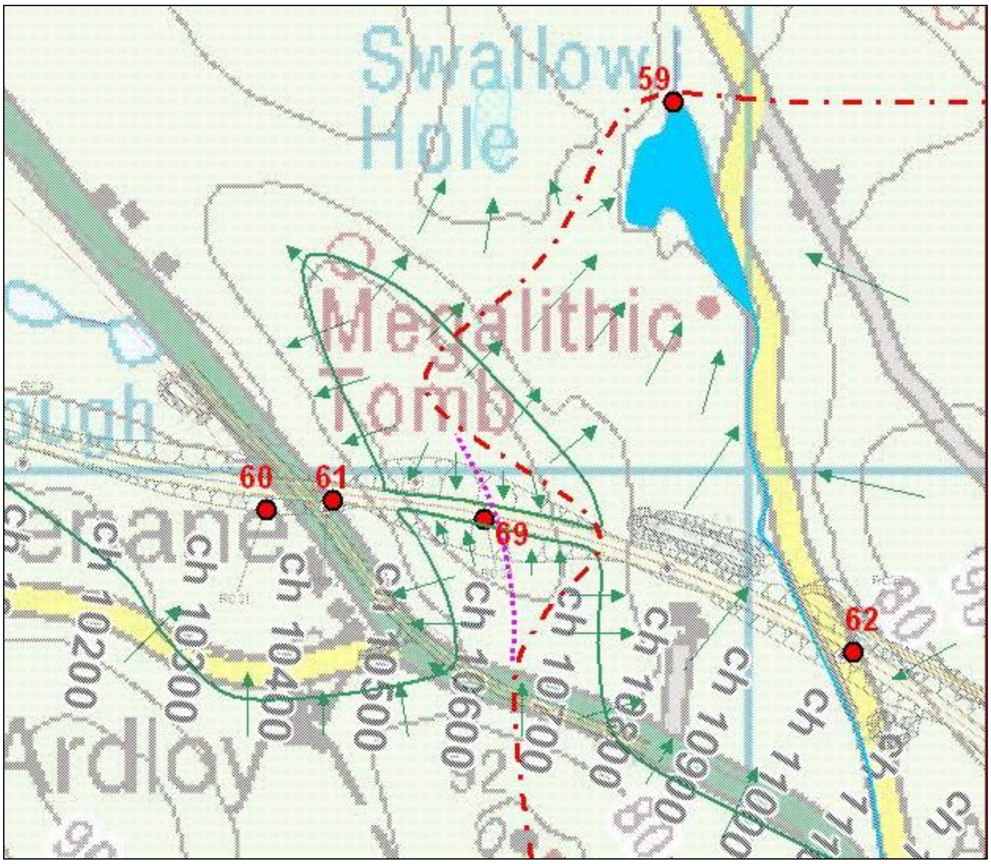
Map showing the existing groundwater catchment (red line) of Tawnagh Lake with borehole locations (red dots), groundwater levels (red numbers), the 67maOD groundwater contour (blue line), groundwater flow direction (blue arrows).

5 POTENTIAL IMPACTS OF THE ROAD RE-ALIGNMENT ON TAWNAGH LAKE AND MITIGATION MEASURES

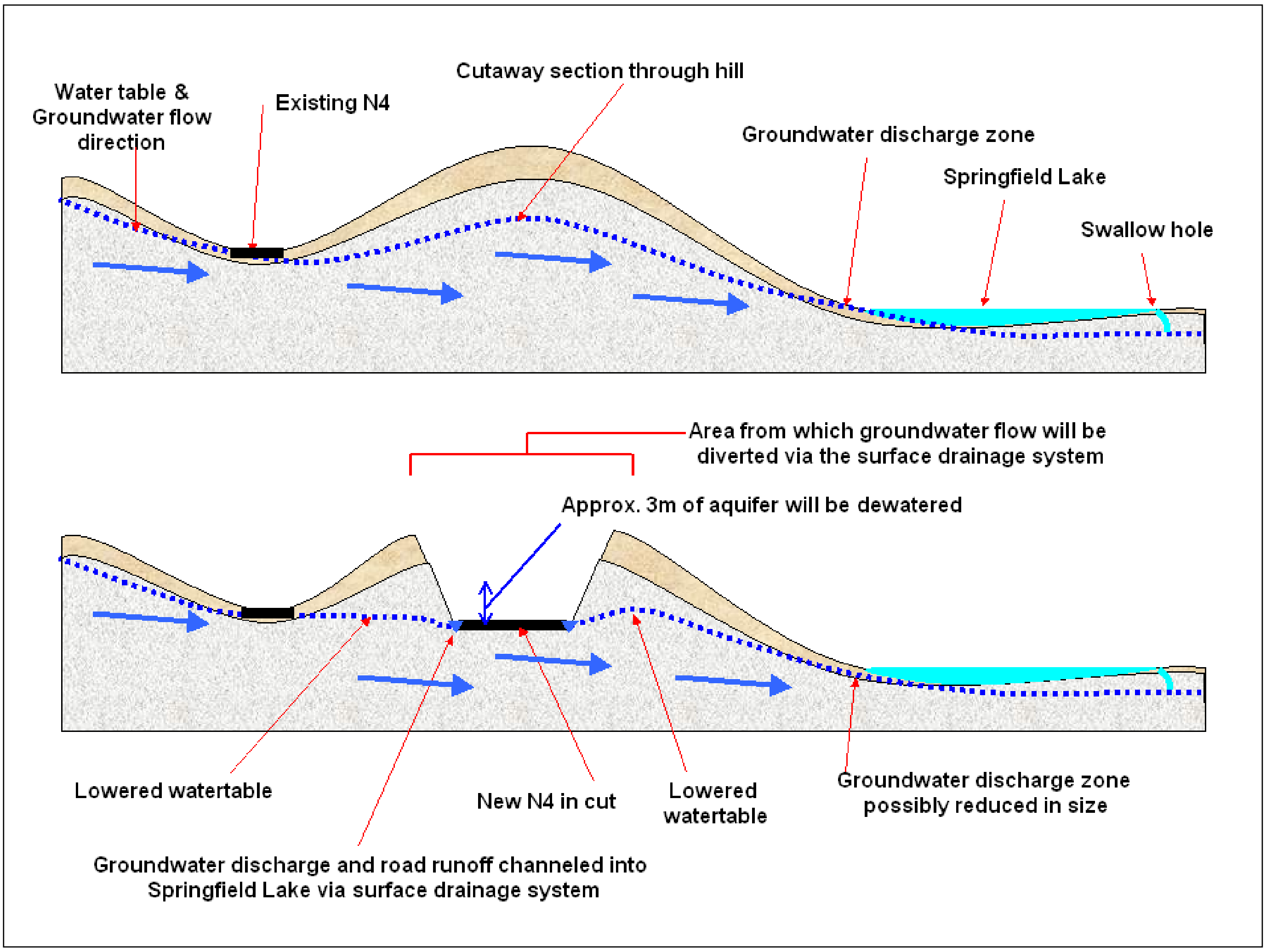
There is a potential impact for the road realignment to reduce the volume of groundwater flowing to Tawnagh Lake from the southwest. This is due to the 19m deep cut (cut 9) which is likely to intersect 3-4m of saturated bedrock (potentially 5m+ in winter months) (see cross-sectional schematic below). Cut 9 would essentially create a valley which would cut off a vertical section of saturated aquifer up to 600 m², of which 826m² (a conservative estimate based on a length of 295m and an average saturated thickness of 2.8m although the actual area in question is likely to be smaller) is situated within the Tawnagh lake catchment. The effect of the cut on the 67maOD groundwater contour and local groundwater flow conditions can be observed by comparing the blue line and arrows in the map in Section 4 with the green line and arrows contained in the map below. The Groundwater catchment of Tawnagh Lake would be reduced by approximately 0.03 km² or 1.6% by the cut and by 0.17km² by other sections of the route realignment. The horizontal extent of the aquifer likely to be affected by the cut is difficult to accurately predict due to the heterogeneity of karst aquifers where permeabilities commonly vary by an order of magnitude or more over short distances (<10m). The nearest borehole for which an estimate of permeability exists is RC32 with an estimated permeability of 0.99 m/day. A hydraulic gradient of 0.05 may be considered appropriate based on the local topography. If this was taken as the average permeability across the cross-sectional area of the saturated zone in cut 9 that contributes to Tawnagh lake, then using Darcy's law an estimate of up to 40m³/day or 0.5 l/s could be diverted into the road cut, although this is likely to be an overestimation of the actual likely volume.



Vertical section through cut 9 showing the existing land surface (green line), finished road surface (red line), likely current position of the water table (broken blue line) and area of cut section that is likely to be dewatered by the road cut (hatched blue area).



Map showing the likely groundwater conditions post-construction with groundwater catchment (red line) of Tawnagh Lake with borehole locations (red dots), groundwater levels (red numbers), the 67maOD groundwater contour (green line), groundwater flow direction (green arrows).



Section (South-North) through the area of the road cut showing pre and post construction conditions.

5.1 Mitigation Measures

A mitigation measure, if feasible, would be to design the road drainage system to ensure that all seepage from the bedrock faces of cut 9 and all paved areas within the topographically delineated catchment of Tawnagh Lake as it currently exists are directed to outfall 13 following appropriate treatment to ensure acceptable water quality. This outfall drains into Tawnagh Lake and this mitigation measure would ensure that any groundwater that was diverted (by the road cut) from flowing to the lake (via the karst aquifer) would continue to reach the lake (via the surface drainage system) once the road was completed.

6 REFERENCES

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