

Tynagh Mine Groundwater Issues

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Abstract Description of the geological and hydrogeological setting of the Tynagh Mine in east Galway, Ireland. Groundwater chemical data presented in the context of physical and regulatory environment.

Key Words Tynagh, groundwater, chemistry, fault structure

Introduction

A significant lead-zinc deposit of approximately 9.9 million tonnes (MT) of economic grade mineralisation was discovered near the village of Tynagh in east County Galway in 1961, representing the first major discovery of metalliferous minerals in Ireland (Kearns 1976; fig. 1). A mining lease operated at the site from December 1962 until November 1983, with open pit and underground mining conducted between 1965 and 1982 (Brogan 2003). Approximately 7.9 MT of ore grade mineralization was extracted during the life of mine (Johnston 1999). The mine site covers an area of approximately 115 hectares. Some limited remediation work was undertaken at the site upon completion of mining activity (Dallas & Good 1995).

Following consultation with interested parties

the Environmental Protection Agency (EPA) undertook a study of the area reporting on the distribution of heavy metals in streams, sediments and tailings around the mine site (Brogan 2003). Groundwater was not investigated but one of the recommendations of the report was that a detailed groundwater study be completed.

The purpose of this contribution is to detail the work completed to date in characterising the hydrogeology of the area and to suggest possible linkages between groundwater chemistry and the structural geology. This represents the first detailed assessment of groundwater around the Tynagh mine site which involved identifying, mapping and surveying well head locations and elevations, recording of water levels and sample recovery and analysis. Data are presented and the findings are discussed in the context of geology, structure, mineralization as well as in the regulatory framework.

Site Description

Bedrock Geology & Mineralisation

Zinc-lead mineralisation in the Irish midlands is hosted in Mississippian (Carboniferous) carbonate rocks (Wilkinson 2010). In the Tynagh area (fig. 2) Mississippian limestones overlie (upper Devonian) Old Red Sandstone (ORS), which in turn unconformably overlie Lower Palaeozoic greywackes and shales of possible volcanoclastic origin (Schultz 1968).

The ORS sediments consist of conglomerates, mudstones and sandstones. A granitic source has been proposed for the latter, with a moderate to high energy, shallow water depositional palaeoenvironment (Clifford *et al.* 1986). The Lower Limestone Shale (LLS) is a transitional unit and consists of sandstones and shales, grading progressively upward to mudstones and thin limestones. This is overlain by a series of dark, well-bedded argillaceous calcarenites with laminated calcareous shales (Ballysteen Formation (BA)). This unit becomes increasingly muddy towards the top (Gately *et al.* 2005). The overlying Waulsortian (WA) Formation is predominantly a carbonate mudbank facies, composed of massive biomi-

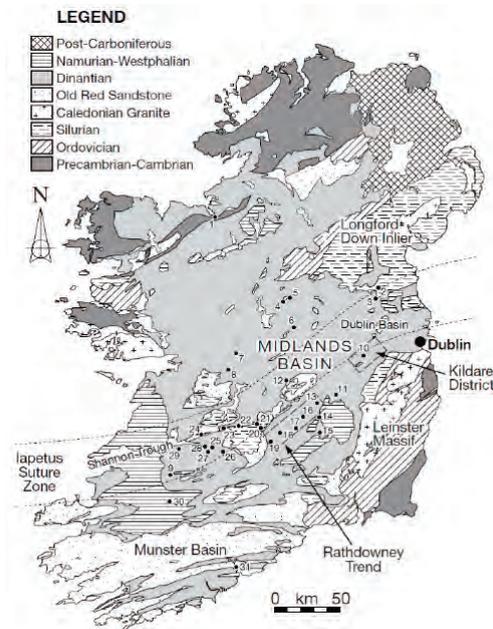


Figure 1 Geological map of Ireland showing the location of base metal deposits. 8: Tynagh Mine. Modified after Everett *et al.* 2003.

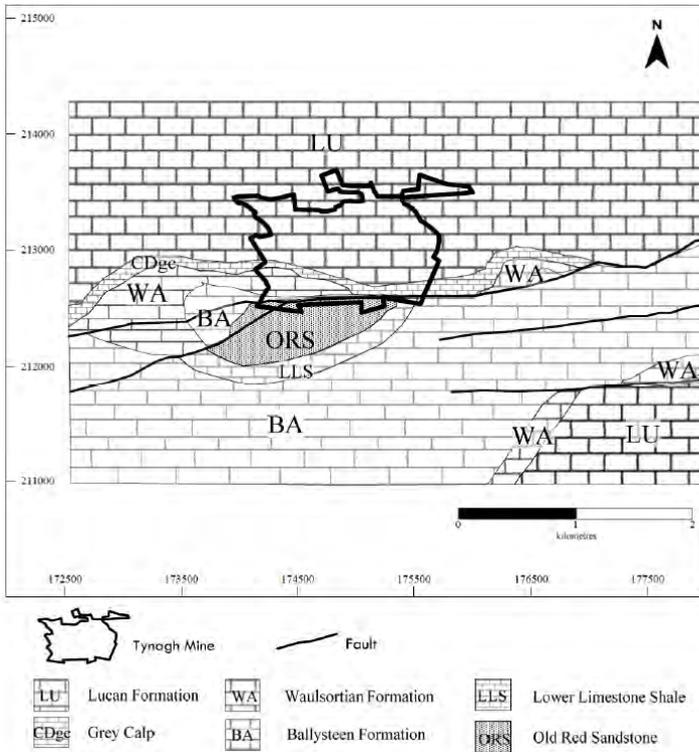


Figure 2 Geology of the Tynagh Mine.

crites. These limestones form the host-rock for the main orebodies at Tynagh. The succeeding Lucan Formation [LU] is characterised by thinly-bedded, graded, intraclastic skeletal packstones and grainstones which are interbedded with shales and micrites.

The LU was weathered and karstified subsequent to deposition leading to its decalcification and collapse adjacent to a major fault in the area (fig. 2). This unconsolidated material occupied an area approximately 600m long and 50m wide (Gately *et al.* 2005). A residual orebody (rich in lead, zinc, copper and silver oxides and sulphides) developed in this weathered material (Clifford *et al.* 1986). This graded down to bedrock to an underlying zone of massive sulphide mineralization hosted in the WA, this extended for approximately 900m along fault in the northerly hanging wall of the easterly trending North Tynagh fault (Clifford *et al.* 1986). The deposit thinned out rapidly within 120m north of the fault (Williams & Brown 1986).

The principal minerals are sphalerite, barite and galena, and the major minerals mined were lead, zinc, copper, silver and barium sulphide (Brogan 2003). It has been noted by several authors that Irish type base metal deposits are typically stratabound in lower Carboniferous carbonates formed in a marine transgressive sequence that

overlies the late-Devonian ORS (Garven *et al.* 1999). The Irish deposits are closely associated with faults which penetrate into the Lower Palaeozoic basement (Murphy *et al.* 2008). Post depositional normal faulting facilitated the migration of ore-forming solutions upwards from the ORS (Johnston *et al.* 1996; Garven *et al.* 1999; Wilkinson 2010). The faults are thought to have allowed convectively driven metal-rich brines to flow from the underlying rock into the carbonates where mineralisation occurred.

Hydrology & Hydrogeology

The entire area is part of the River Shannon catchment. Surface drainage is from west to east to the Kilcrow River (fig. 3). As part of this study 39 wells in the area were surveyed and mapped and water levels have been recorded at these wells and flow maps derived, showing that groundwater flow direction is coincident with surface water patterns (west to east).

Aquifer Classification

The Geological Survey of Ireland (GSI) class the ORS and LLS as being Poor Aquifers because of their low conductivities (10^{-2} m/d; Gately *et al.* 2005). All of the remaining limestones in the area are classed as being Locally Important

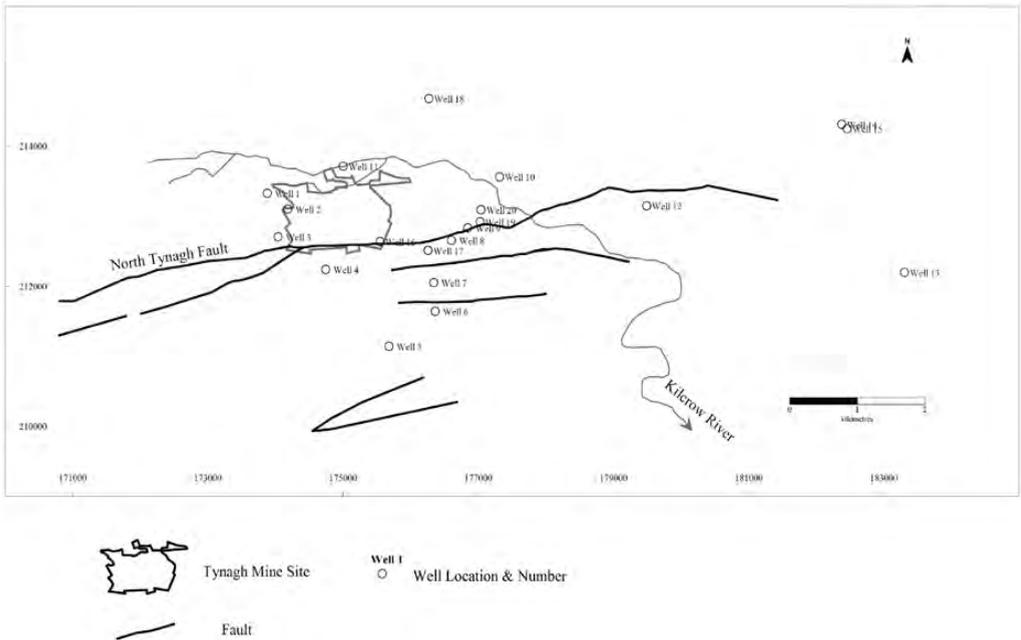


Figure 3 Sample Well Locations

Aquifers, moderately productive only in local zones (LI; WFD Ireland 2005). The GSI report that groundwater developments in the BA and the Lu formations are rarely successful (Gately *et al.* 2005). Yields are low due to the presence of muds and fines in the rocks. The WA tends to be relatively pure and therefore susceptible to karstification; however, in this area there is little evidence of extensive karstification of the limestone. Indeed the classification is reflected by the well-developed surface drainage pattern in the area, suggesting the relative importance of stream discharge. This classification is based on a regional approach; local variations (or localised regional variations) are not accounted for in this scheme. While the majority of the wells tested in this work are poorly to moderately productive, reflecting the classification, structural controls on groundwater flows are evident. Five of the wells tested in this work are deep, bored wells (greater than 50m deep), all of which are associated with the North Tynagh fault; Well 3 is west of the mine site, while Wells 9, 16, 19 and 20 are found to the east. These wells are very productive and have yields more commonly associated with Regionally Important Aquifers.

In the recently published Shannon International River Basin Management Plan (ShIRBD 2010) the region is almost entirely classed as being of Good Water Status in relation to groundwater, under the terms of the Water Framework Directive

(WFD) (European Parliament 2000). The area immediately north of the mine area is classed as Poor Water Status in relation to groundwater. This classification is based on a desk study and on surface water sampling carried out by the EPA in 2003; in fact the mine site is classed as being of Good Water Status. The zone identified as being of Poor Water Status is bounded by the two small streams running along the northern boundary of the mine (fig. 3) and was delineated by surface drainage patterns and chemistry.

Groundwater chemistry

General

Younger and Adams (1999) suggest that the behaviour of flooded, abandoned mine voids display marked similarities to karstified limestones. While the footprint of the Tynagh site is relatively small there were approximately 84 kilometres of underground workings excavated during the life of the mine (Brogan 2003). Following backfilling it is now estimated that 13 kilometres remains open. The open pit has flooded and remains flooded. Acid Mine Drainage (AMD) is considered the primary mechanism of groundwater contamination associated with mining (Younger & Adams 1999). Contaminated groundwater may be carried in the direction of the local or regional groundwater flow. The pollutant concentration, which has been in contact with the mine workings, is determined principally by the geology and

hydrology of the area. The long-term chemistry of the groundwater leaving the site is governed by the recharge chemistry, the relative abundance of acid-generating and buffering mineral assemblages (Younger & Banwart 2002). In the case of Tynagh the buffering capacity of the local limestones is demonstrated by the relatively satisfactory surface water quality downstream of the site (Brogan 2003). There is no indication that groundwater quality has been affected by AMD based on the results of the current work. Groundwater may also be at risk of contamination from leaching of wastes from the TMF and other surface storage facilities. There is some indication of uncontrolled runoff from the TMF during wet periods and there is potential for groundwater to be contaminated from this source.

Water sampling

Twenty (20) wells were selected based on a number of selection criteria: their location relative to the Tynagh mine site; their location relative to the mapped Tynagh North Tynagh fault; well type (bored wells and dug wells); and location relative to groundwater flow direction (fig. 3). Several wells were sampled on a number of occasions over a two-year period (labelled a, b, c and d). Samples were recovered as per the USGS Water Quality Field Manual (Wilde & Radtke 1998).

Groundwater analysis

The results of the analyses are presented in Table 1. Figures 4 and 5 graphically represent the surface water samples taken by the EPA in 2003 and the groundwater samples taken as part of this work, respectively. The EPA values (fig. 4) are all surface water samples and they reflect the sample points. The values with high SO₄ levels are located on the mine site or in the immediate vicinity of the mine

site. Samples recovered from streams upstream and downstream of the site are calcium and bicarbonate waters showing little indication of contamination. The surface waters leaving the mine site are enriched but are buffered almost immediately on leaving the site. The groundwater samples (fig. 5) are predominantly calcium-bicarbonates, with one distinct outlier (Well 2) sourced from a shallow dug well located within 10 metres of the tailings facility (fig. 3).

Groundwater Threshold Values (GTV) have been established in Irish law under SI No 9 of 2010 (as required under EC Directive 2006/118/EC (European Parliament 2006)). Prior to publication of the Directive the Geological Survey of Ireland (GSI) and the EPA published Guideline Values (IGV) as suggested target values (EPA 2003).

In reference to the samples recovered as part of this study, dissolved trace elements were dominated by iron, manganese, zinc, copper, barium, nickel and arsenic and the range of values is shown in Table 1, all of which were found in concentrations that exceed both the GTV and the IGV. The exceedences are in elements that are associated with the mineralisation in the area or are associated with limestones in Ireland. Only one elemental exceedence (for arsenic) has significant implications in terms of human health.

Well 2 is a shallow dug well located within 10 metres of the TMF and susceptible to direct runoff from the mine site. Well 15 is a deep (>100m) well sited several kilometres east of the mine site. The elevated levels of Fe, Ba, Mn and As in samples recovered from Wells 3, 9, 16, 19 and 20 exceed GTV and IGV. Arsenic can occur in several oxidation states in the environment but the predominant form in groundwaters is arsenic (III) (Lemmo *et al.*1983; Welch *et al.*1988). This was one of the principal ore minerals present at Tynagh in the form

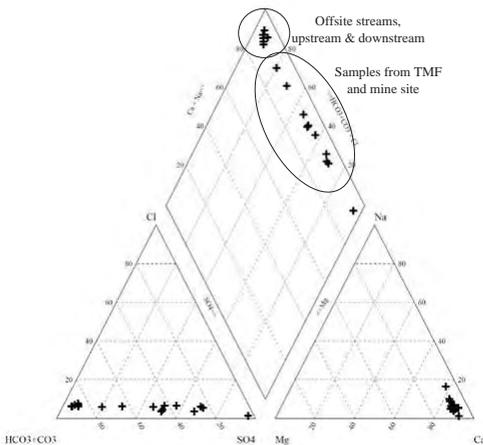


Figure 4 EPA Surface Water Samples (2003)

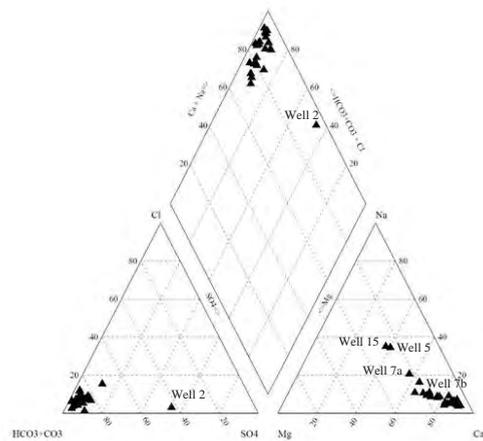


Figure 5 Groundwater samples

Table 1 Groundwater analysis results for wells in Tynagh catchment

Well No	TDS mg/l	EC µS/cm	Cl mg/l	SO ₄ mg/l	NO ₃ mg/l	NO ₂ mg/l	NH ₄ mg/l N	Na mg/l	K mg/l	Mg mg/l	Ca mg/l	Cu µg/l	Fe µg/l	Mn µg/l	Zn µg/l	Cr µg/l	Pb µg/l	Ba µg/l	Cd µg/l	Ni µg/l	As µg/l
1	325	700	12.4	12.1	2.19	<0.013	0.27	9.9	2.1	6	146.3	6.1	<5	<1	21.9	<1.0	<0.3	5.7	<0.1	2.8	<0.2
2	600	947	15.4	296	0.832	0.086	0.014	12.3	2	5.9	209.5	4.3	166.2	134.7	152.7	<1.0	5.4	26	<0.1	0.8	0.3
3a	290	437	22.9	6.1	0.172	<0.013	0.141	11.1	3	7.8	79.9	<3.0	3302	54.32	24.2	<1.0	4	35	<0.1	1	0.5
3b	205	415	21.3	5.44	<0.12	<0.013	0.11	10.8	2.5	8.2	75.6	<3.0	1880	20.7	6.7	<1.0	0.4	26.8	<0.1	0.8	0.3
3c	195	432	16.4	3.16	<0.12	<0.013	<0.007	9.3	2.6	7.8	70.6	<3.0	2394	40.8	4.9	<1.0	0.7	35.1	<0.1	1	<5.0
4	240	690	21.4	15.2	2.94	<0.013	0.171	10.9	9.6	5.7	115.4	5.6	18.3	3	9.4	<1.0	0.7	402.9	<0.1	0.8	0.4
5	595	534	21.5	24.1	<0.12	<0.013	0.154	50.5	2.6	18.9	50.2	2.4	103.2	5.5	6.7	<1.0	0.4	15.5	<0.1	0.8	0.6
6	330	597	16.5	5.12	0.742	<0.013	0.135	9.3	8.4	4.6	123.4	23.5	23.4	19.1	133	<1.0	1.2	97.7	<0.1	3.9	0.2
7a	410	590	16.5	11	<0.12	<0.013	0.17	34.9	2.1	19.1	80.6	7.5	1855	51.4	19.8	<1.0	<0.3	271.8	<0.1	0.7	0.4
7b	290	552	17.1	21.7	<0.12	<0.013	0.036	23.4	1.9	13.9	76.7	<3.0	120	52.9	4.9	<1.0	0.5	73.2	<0.1	0.5	11.3
8	220	595	28	13.4	2.97	<0.013	0.202	12.5	0.9	5.9	135.4	<3.0	9.7	2.7	24	<1.0	2.3	381.3	<0.1	1.3	<0.2
9a	210	540	15.1	22.5	<0.12	<0.013	0.089	14.5	1.8	14	99.4	<3.0	10200	88.9	91.1	0.7	20.2	140.9	<0.1	5.2	299.2
9b	215	447	14.2	14.6	<0.12	<0.013	0.115	13.8	1.7	13.1	73.6	<3.0	12800	392.8	58.4	<1.0	1.9	97.4	<0.1	4.2	113.7
9c	320	553	13.5	20.1	<0.12	<0.013	0.163	14.1	1.7	14.4	97.2	5	512	196	3.2	<1.0	0.4	123.4	<0.1	3.99	54.2
9d	270	539	12.8	17.4	<0.12	<0.013	<0.007	13.5	1.9	13.4	82.8	<3.0	5330	40.2	40.9	<1.0	0.4	116	<0.1	2.1	14.7
10	285	695	18.2	30.6	2.41	<0.013	0.125	10.9	5	7.3	149	22.7	48.3	<1.0	17.2	<1.0	1	174	<0.1	6.6	0.5
11	305	571	18.9	21.8	0.267	<0.013	0.215	18.2	1.7	20.2	88.4	<3.0	474	90.4	12.6	<1.0	0.4	105.8	<0.1	3.2	3.6
12	230	597	16.6	28.1	0.326	<0.013	0.066	10.1	0.9	9.9	131.3	4.1	33200	1565	40.5	2.4	1.6	222.5	0.2	17.6	0.3
13	200	432	12.3	24.5	5.31	<0.013	0.154	10.6	8.5	4.4	77.8	10.4	247.9	18.7	9.4	2.2	0.8	19.2	<0.1	1.8	0.4
14	340	706	16.4	15.7	6.35	<0.013	0.089	8.5	2.5	5.8	149.4	34	<5.0	<1.0	12.7	<1.0	1	11	<0.1	1.3	<0.2
15	335	572	20.9	30	<0.12	<0.013	0.194	5.5	1.4	21.9	50	<3.0	<5.0	16.7	2.3	<1.0	<0.3	90.4	<0.1	<0.5	<0.2
16	315	497	16.4	7.9	<0.12	<0.013	0.287	8.6	0.8	8.1	97	4	697.9	120.3	40.2	3.8	1.5	328.3	<0.1	25.8	48.7
17	340	630	26.4	12.2	0.708	<0.013	0.096	13.3	2.1	4.1	131	5.9	250.2	40.1	19.8	8	11.8	405.7	0.3	25.5	0.9
18	380	780	35.8	3.5	6.01	<0.013	0.122	20.3	7.3	8.8	159	<3.0	10	2.8	7.1	<1.0	<0.3	23.3	<0.1	3.1	0.3
19	320	585	39.5	36.9	0.38	<0.013	<0.007	21	2.2	16.3	99.3	8	1044	145.1	28.5	<1.0	3.9	467.6	3.5	3.2	17.8
20	385	739	15.6	91.7	1.04	<0.013	0.059	9.5	0.9	8.2	185.1	10	28580	2474	389.8	<1.0	7.9	537.2	<0.1	249.6	15.6

Groundwater Threshold Values: 800-1875 24-187.5 187.5 37.5 3.75 0.065-0.175 150 1500 30 200 50 100 30 10 10 5 20
 Values: 1000 30 200 25 0.1 0.15 150 5 50 200 30 200 50 100 30 10 10 5 20
 IGV: Irish Groundwater Values; Statutory values in Irish law (SI No 9 of 2010)
 Groundwater Threshold Values, Statutory values in Irish law (SI No 9 of 2010)
 IGV: Irish Groundwater Values produced by EPA & GSI before publication of EC Directive 2006/118/EC

of arsenopyrite (FeAsS; Brogan 2003). Arsenic levels are below the GTV (7.5 µg/L) in all but four wells. DeHay *et al.* (2004) noted a relationship between elevated arsenic and iron concentrations in groundwaters in the Picher Mining District in Oklahoma and they suggest that the source of the arsenic might be the dissolution of iron-containing sulphide or oxy-hydroxide minerals.

Conclusions

Groundwater recovered from the wells for analysis is reflective of the bedrock geology and is largely described as CaCO₃ (calcite, dolomite) water. While a small number of wells were sampled up-gradient of the mine site, the main focus of the sampling in this study was on the wells down-gradient of the mine site.

Well 2 is a shallow, dug well that is located within two metres of the mine site boundary. This well is not used for any domestic or agricultural purpose. A large number of exceedences are recorded for this well and these are most likely associated with uncontrolled surface water runoff from the adjacent mine site. Elevated sulphate levels are associated with the processing of the main minerals recovered from the wells (galena, sphalerite, chalcopyrite, tetrahedrite and bornite (Brogan 2003)). Wells 3, 9, 16, 19 and 20 are deep, bored wells all of which are finished on the north side of the North Tynagh fault and it is likely that all intersect it. During the sampling phase in this work limited drawdowns of water level were achieved during the purging process.

The North Tynagh fault acts as a conduit for groundwater flows, and while providing excellent quantities of water to wells the quality of the water is affected by mineralisation associated with the fault and by recharge to the fault zone. While it is not possible from the current study to positively identify the specific source of these ele-

vated concentrations it is likely that they result from a combination of natural and anthropogenic sources (the naturally occurring mineralization, the underground workings, the TMF and other surface storage of mine waste).

The North Tynagh fault has been extensively mapped and it facilitated the precipitation of economic deposits of minerals. During the underground mining phase at Tynagh large inflows of water occurred in localised zones associated with the North Tynagh fault. It would appear that there is an association between groundwater chemistry, well depth, well location, mine location and structural geology in the area. Further, more detailed work will be have to be undertaken to determine, if possible, the specific sources of dissolved metals in the local groundwater. It should be noted, however, that it may not be possible to absolutely isolate the sources of these metals. However, it would appear that any future assessment such as that recommended by the EPA and GSI in 2010 (Stanley *et al.* 2010) must be based on the recognition of the intimate relationship between groundwater, geology and structure and that existing management plans should be amended to recognise these relationships.

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