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Tier 2 Hydrogeological Risk Assessment: Belturbet Landfill

Location:	Rahaghan, Belturbet, Co. Cavan
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Introduction

The following hydrogeological risk assessment has been prepared by Patrick Breheny MSc (Hydrogeology), of Envirologic Ltd., on behalf of Cavan County Council. Envirologic was retained by Cavan County Council to undertake a Tier II hydrogeological assessment of a historic closed landfill site at Rahaghan, Belturbet, Co. Cavan. Following submission of a Tier I assessment for the site on the 20th September 2013 the Agency requested the following further information be gathered in order to adequately assess the site:

- Confirmation on the completion of drilling activities by an environmental drilling company
- Current trended results for contaminants of potential concern
- Proposed timeline for the submission of a Tier II hydrogeological risk assessment

The Tier I report submitted for the site proposed that a number of additional recommendations were to be carried out with a view to improving the overall understanding of the perceived risks to environmental receptors at the site. In the interim period site investigation works were carried out at the facility during November 2017. The data gathered during this phase of work was used to inform the Tier II risk assessment. The recent work included the following tasks:

Task 1 - Drilling and installation of two groundwater wells at the site (one upgradient of the site and one within the boundary of the site). The subsequent logging of soil cores extracted, and permeability testing of selected wells.

Task 2 - Collection and laboratory analysis of groundwater samples from the newly installed monitoring wells (in addition to the annual compliance monitoring locations).

Task 3 - Data interpretation, risk screening and the presentation of a summary report, to include an updated graphical conceptual site model for the closed facility.

Site Description

Site Location

The site location is indicated on Figure 1. Site area is equal to 0.67 ha. The site is located within the townland of Rahaghan, 4.5 km southwest of Belturbet, and 5.7 km southeast of Ballyconnell. The area lies within north County Cavan, 4.5 km from the national border at Fermanagh. The national road N87 (connecting Belturbet with Ballyconnell) passes in an east-west direction along the southern boundary of the site. The site is accessed from the N87 via a small laneway.

Topography is typical of a drumlin landscape, with pre-development elevation around 65 mOD. The drumlin ridges appear to be elongated generally along a northeast orientation, peaking between 90 - 110 mOD. Elevation decreases toward the site from a peak 400 m to the south. The site appears to straddle a minor ridge on a drumlin mid-slope position. Elevation decreases to the east toward Killynagher Lough, 170 m east of the site. The minor ridge continues from the site in a northern direction, with elevation on the western side of the site decreasing toward a small north-facing valley.

Depressions within this undulating landscape are generally occupied by bodies of water, connected by a dense network of streams and rivers.

Land use in the surrounding area is almost exclusively grassland, supporting dairy, beef and sheep agriculture of low to moderate intensity. Land quality in the topographically depressed areas is poor and not considered important in terms of agricultural production.

Housing density in the area is low, typical of one-off housing, though there is a linear cluster of houses toward a junction 400 m to the east, at Drumasladdy. The nearest house is 25 m to the south of the site.

Site Layout

A site layout map is presented in Figure 2. The site is approximately rectangular along a northeast-southwest orientation, with approximate width 70 m and length 100 m.

The site originally operated as a quarry, excavating composite limestone bedrock. Since 1979 the site has been used as a traditional landfill facility by Cavan County Council, closing in February 2002.

Between the period 1988 - 1994 the landfill annually accepted 20 tonnes of inert waste, 480 tonnes of non-hazardous waste, and minor quantities of hazardous waste. These volumes increased gradually between 1994-1999 to a total of 950 t yr^{-1}.

Natural topography is slightly higher than site topography on the western and northern boundaries, with an elevation drop of 1 metre. This drop is steep, and was clearly the limit of the quarry excavation as bedrock is exposed. Natural topography is 67.8 - 70.0 mOD on the western boundary, falling slightly to 67.6 - 65.6 mOD along the eastern boundary. Elevation continues to drop to 52.9 mOD in an open drain on adjacent lands, and further to 50.1 mOD at the lake shore to the east.

Landfill elevation is lowest on the boundaries, being generally even at 66 mOD, rising toward an apex of 69 mOD along the central north-south axis.

A covered french drain runs along the inside perimeter of the site boundary. This french drain was designed to discharge to an open drain on the privately owned lands 100 m east of the site, ultimately flowing into Killynagher Lough. Following discussions with Cavan Co Council the adjacent landowner refused permission to access the land.

Prior to closing the site a temporary cap was placed on the deposited waste material. The landfill was then permanently capped in 2011. A fully engineered and lined system was installed, consisting 5,805 m^3 uniaxial geogrids, surface water drainage, geocomposite layer, LLDPE liner and geocomposite gas collection layer. Works also included importation of inert fill material (construction and demolition waste), on top of which subsoil and topsoil were spread and seeded. The base of the landfill is unlined.

Desk Study

Soils

Drumlins consist of a thick cover of boulder clay deposited in the form of small hills, typically oval in plan. The drumlins stretch from Leitrim and Meath, through Cavan and Monaghan toward Belfast.

Figure 3 shows deep-poorly drained acidic mineral soils dominate the landscape, this soil unit occupying much of Cavan. It is classified by Gardiner and Radford (1980) as wet mineral and organic drumlin soil composed of an imperfectly to poorly drained surface water gley of loam to clay loam texture and of medium base status. Surface structure is a weak crumb, which becomes massive at about 30 cm, below which soil consistence is plastic and root penetration poor. Drainage impedance is attributed to the heavy texture. The retentive nature of the subsoil predisposes it to periodic water saturation, and a seasonal ‘perched’ water table results. The main soil (40%) in the association consists of a moderately well-drained acid brown earth of loam to clay loam texture. This soil is shallower and freer draining in places, almost exclusively on elevated ground.

The majority of the local surface water bodies appear to be underlain by alluvial material, which infers that they were naturally formed. Marginal areas around some water bodies are lacustrine clays, likely deposited when water levels were higher. Degradation of soils toward peat has occurred in isolated areas but is not prevalent.

We can assume that prior to quarrying and landfilling at the site, original soils were deep poorly-drained minerals.

Subsoils

Figure 4 shows that the heavy impermeable boulder clay tills are formed from Namurian shales and sandstones. Overburden has previously been described as stiff to hard, brown, clayey, sandy, gravelly silt. Subsoil depth is deeper in the valleys, thinning somewhat on elevated areas and steeper slopes.

It can be seen that the site itself is devoid of subsoils, with karstified limestone bedrock having been exposed at the surface.

Bedrock & Structural Geology

Figure 5 presents bedrock and structural geology. The site is underlain by the Vartry Limestone Formation, a dark fine-grained cherty limestone belonging to the Dinantian Pure Bedded Limestones.

A mapped fault running 200 m south of the site along a southeast-northwest orientation marks the surface contact between the Vartry Formation and the underlying Drumgesh Shale Formation, comprised of dark shale, fine-grained limestone. Structural faulting in the region is primarily southwest-northeast and west-east, with some perpendicular faulting. GSI bedrock data in the area is limited but shows that:

- bedrock assumed at 19 m at Clourney House, 900 m north of the site;
- bedrock met at 24 m at Drumasladdy PO, 600 m northeast of site;
- bedrock at 22.9 m in an agricultural/domestic well in Lismagratty, within 500 m of the site;
- bedrock at 29.3 in Unshinagh, 2.4 km northeast of the site.

This would imply that bedrock is dipping in all directions from the site. Bedrock was exposed on the northern boundary, with bedrock head about 1.7 m above landfill elevation, i.e. bedrock head approximately 67.6 mOD. Observed exposed bedrock was noted as being heavily weathered and fractured. Bedding planes were generally horizontal, with some dipping northwest by approximately 15°. The exposure is light brown/grey in colour, with the brown likely washed clay filling fractures and cavities. Fresh exposures have a grey appearance with some light silver marbling and calcification apparent. Rock is soft and slaty in texture.

During recent site investigation work which involved the installation of two groundwater monitoring wells at the site bedrock was encountered at 61.05 mOD (MW10) and 61.95 mOD (LMWC).

Aquifer Classification

The Dartry Limestones are classified as a regionally important bedrock aquifer, dominated by conduit flow. Karstification is the process whereby limestone is slowly dissolved away by percolating waters. It can often result in uneven distribution of permeability through solutionally enlarged conduits within the rock, and unique karst surface features (swallow holes, caves, etc.). Groundwater velocities through these fissures/conduits may be high and there may be a strong interconnection between surface water and groundwater. In these purer limestones most groundwater flows in an epikarst layer 2-3 m thick and in a zone of interconnected solutionally-enlarged fissures and conduits that extends approximately 30 m below this.

According to the GSI database, the nearest karst features are 13 km northwest of the site, in the Cuilcagh Mountains. The lack of karst features in the area would suggest bedrock flow is concentrated in the upper fractured and weathered zones (epikarst) and in the vicinity of fault zones. The aquifer is most likely unconfined.

The Vartry Limestones are bounded to the south by lower permeability rock, the Drumgesh Shale, which is a locally important aquifer, moderately productive in local zones. In an undisturbed state we would expect groundwater flow to be limited to the upper weathered zones of the Dartry limestones, with vertical bedrock flow limited upon encountering the underlying Drumgesh shales. The depth to the Drumgesh shales beneath the site is unconfirmed.

The site lies within the Rahaghan Groundwater Body (GWB), for which no interim report has been published. The Rahaghan GWB is surrounded by four GWB's: Derrylin, Clones, Killeshandra and Newtown-Ballyconnell,. Relevant points are taken from the latter two in the list which, not surprisingly, state that well yields and transmissivities are highly variable.

Groundwater Vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost extent of the saturated zone. The GSI classification (Figure 6) shows that vulnerability at the site itself is extreme (rock near surface or karst).

Vulnerability in the surrounding area is generally low to moderate, as a function of soil thickness. In places where depth to water table is less than 3 m, the vulnerability of groundwater becomes high to extreme, whilst the area between the site and Killynagher Lough is denoted as having high groundwater vulnerability.

There is a risk associated with discharging to an area with high to extreme groundwater vulnerability, due to the short vertical travel times and the minimal potential for attenuation of contaminants.

Landfill Vulnerability Classification

The GSI groundwater protection scheme includes a classification that assesses the site suitability of a landfill based on hydrogeological factors.

The input parameters at Belturbet for the response matrix for landfills are Extreme (E) vulnerability and Regionally important karstified aquifer (Rkc). This returns a value of R4 which by todays standards is deemed unacceptable for siting of a landfill. The landfill was initiated prior to this classification coming into force.

Recharge

Gridded rainfall data from Met Éireann (Walsh, 2012) 1981-2010 = 1059 mm yr^{-1}

PE (Clones, 21km northeast of site) = 438 mm yr^{-1}

AE (95%PE) = 416.4 mm yr^{-1}

ER (AAR-AE) = 1059 - 416 = 643 mm yr^{-1}

Recharge coefficients can be utilised to estimate the proportion of water infiltrating to bedrock, against that moving laterally as shallow subsurface flow and surface overland flow. The maps represent the site in its state following quarrying, that is karstified rock exposed as surface. This correlates to a recharge coefficient of 85%. As the landfill has been capped with approximately 1 m of imported subsoil, lithological profile is more likely to be represented by moderate permeability subsoil overlain by 'poorly drained' soil, which yields a recharge coefficient of 33%.

w = annual recharge, $m^3\ m^{-2}$ = 33% ER = 33% of 643 mm = mm = 0.212 $m^3\ m^{-2}$ = 0.0006 $m^3\ m^{-2}\ d^{-1}$

Source Protection Area (SPA)

The site does not appear within source protection areas to any groundwater abstractions, as mapped by the GSI or EPA. The closest SPA to the site is 12 km west at Bawnboy, deemed to be too far to be at risk of impact. This is expected, as most drinking water supplies in Cavan are sourced from surface waters.

Hydrology

Designated Areas

Killynagher Lough belongs to the Lough Oughter and Associated Loughs SAC, a complex of waterways, islands, small lakes and peninsulas. The Lough Oughter & Associated Loughs SAC describes 90 relatively small inter-drumlin lakes that cover a large area from Killeshandra 14 km south of the site, to the border with Northern Ireland, where this network discharges to Upper Lough Erne, 10 km northeast of the site.

Although falling within the SAC, Killynagher does not belong to the same major cluster of lakes that form Lough Oughter, but rather sits within part of a smaller separate set of lakes and rivers that enter the Rag River, which subsequently flows into Upper Lough Erne. The outflow system of Killynagher does not join the River Erne directly, this being the outflow channel for the main Lough Oughter series.

Catchment Delineation

It is important to consider the surface water catchment, and any other potential sources of contamination to Killynagher, and the fate of any potential contaminants downstream. Surface water levels were surveyed as part of the work plan during the Tier I report (see Figure 7) using RTK R4 VRS technique and referencing Malin as elevation datum. These levels, along with topographical contours, were used to define the upgradient and downgradient catchment.

The upgradient catchment to Killynagher is relatively small, with an area of 3.1 km^2, having it's headwaters 1.5 km to the southwest in the townland of Kilnaglare. A stream is formed in a valley between two northeast facing drumlin ridges, which flows northwards beneath the local N87, entering the southern side of Killynagher Lough 270 m east of the site.

Killynagher Lough discharges at it's northwestern corner to a stream which flows into Barn Lough. Surface waters move via a series of streams through Long Lough and into the Rag River. The Rag River flows into Upper Lough Erne 8 km northeast of the site.

Due to the hilltop nature of the site, there is a hydraulic gradient to the west also. The small valley to the west of the site contains a minor stream, which flows north into the stream that connects Clonamullig Lough with Barn Lough.

Flood Risk

Reference is made to the OPW Flood maps which shows there are no benefitting lands or floodplains within 1 km of the site. The nearest mapped flood event is 1 km to the northwest.

An OPW gauging station is positioned at the outfall of Tomkonroan Lough, 2.3 km north of the site. Water level was noted as 0.29 m on the day of the site visit, equivalent to 48.55 mOD (Poolbeg). However, there is no annual maxima data for the this gauging station.

The drainage network of local streams often appear to be deep, steep-sided channels, suggesting fluctuation in water levels. Site elevation is 66 - 69 mOD, 16-19 m above nominal lake level of approximately 50 mOD. The original survey followed a prolonged dry period, and judging by high water mark the maximum water level in Killynagher Lake may approach 51.50 mOD. The depth of waste material in the landfill becomes important here if seasonally high water levels intercept the waste material, and promote high hydraulic connectivity between baseflow and lake water.

Hydrogeology

Groundwater Wells

Summary details of existing on-site groundwater wells are presented in Table 1 (locations of which are shown in Figure 2). These wells were installed at different times for different reasons over a period of more than 10 years. Borehole design was specific to a particular application at that time. The available information shows;

- MW1, MW2, MW3 and MW4 were installed in January 1999. These boreholes were installed using a window sampler to bedrock. Depth to bedrock (and borehole depth) for these four wells were 1.0 m, 1.5 m, 0.8 m and 0.3 m, respectively. These wells are no longer in place (well logs included in Appendix A).

- In total there are six groundwater monitoring wells remaining at the site. All monitoring wells consists 50mm PVC casing that includes a screened section.

  - MW5 and MW6 penetrate the waste mass, on the north and west facing slopes (well logs included in Appendix A). MW5, installed in January 1999, was drilled to a depth of 31.5 m and screened between 7.5 m - 31.5 m below ground. Weathered bedrock was recorded at 3.4 m below surface, with composite limestone bedrock to the base. There is no record of water strikes or inflows on the drill log.

  - MW6 was also installed in January 1999 and was drilled to a depth of 11 m. Inert construction waste was logged to 2.7 m below surface, beneath which lies domestic waste to a depth of 10.8 m below surface. Composite limestone was recorded below the domestic waste, and the hole was ended at 11.0 m. The hole was plugged with bentonite between 10.5 and 11 m bgl.

  - MW7 is located at the site entrance, immediately outside the southwest boundary. MW9 is located on the southern boundary while MW8 is positioned on the southeastern boundary.

  - MW10, an upgradient monitoring well was drilled during November 2017 to a depth of 15m (well log included in Appendix A). The well was installed off-site to ascertain upgradient groundwater water level and quality data at the site.

There are three leachate wells:

- LMWA and LMWB are larger diameter boreholes and may have been installed to facilitate abstraction of leachate by borehole pumping. These leachate wells consist 0.31 m ID steel casing (0.325m OD) supporting 0.22 m ID PVC casing (0.27m OD). Logs for these leachate wells were not available.

- Leachate well LMWC was installed into the waste cell to gain information on leachate within the fill material (well log included in Appendix A). Bedrock was encountered at 6.9m bgl. No leachate was encountered during drilling of the well.

Table 1 - Well Details (figures in bold November 2017)

Borehole ID	Easting, m	Northing, m	Ground elevation, mOD	Top of Casing elevation, mOD	Well Depth	Depth to GW 27/11/17	Groundwater elevation, mOD	Inner Casing diameter, m
MW5	232014	315497	66.38	67.50	-	**9.35**	**58.15**	0.05
MW6	232011	315450	66.46	67.26	11	**9.42**	**57.84**	0.05
MW7	232011	315391	66.73	67.39	31.2	**-**	**-**	0.05
MW8	232062	315445	65.73	66.44	31.12	**5.46**	**60.98**	0.05
MW9	232055	315417	65.94	66.82	-	**5.36**	**61.46**	0.05
MW10	**631969**	**815346**	**65.151**	**65.55**	**15**	**3.65**	**61.9**	**0.05**
LMWA	231999	315496	66.00	67.04	-	-	-	0.22
LMWB	232034	315502	65.89	66.93	-	-	-	0.22
LMWC	**631988**	**815466**	**67.42**	**67.85**	**8.00**	**-**	**-**	**0.05**

Groundwater Levels & Flow Direction

A groundwater level survey was completed using data collected over the recent drilling program at the site (November 2017). These levels were used to compile a groundwater contour map (Figure 8).

The groundwater contour map shows that groundwater flow direction follows the regional pattern, that being northerly, towards Lough Erne. It is likely though that the interpretation of groundwater flow direction is limited by the density and spread of monitoring points. The piezometric map indicated that the old quarry excavation was acting as a local groundwater sump were groundwater movement in the area of the quarry was being collected radially and essentially held up. Previous historical reports have also indicated periods when the base of the quarry was flooded. Even though this void is now filled with waste, this material has much higher permeability than surrounding bedrock and so would still provide a hydraulic gradient to attract groundwater inflows.

A groundwater survey undertaken during the Tier I investigation was performed following a prolonged dry period, so groundwater levels are considered to be relatively low. Water level in MW6 on 25/07/13 was 55.36, whilst the base of the waste material is at 55.66 mOD. This would suggest that, under these conditions, all waste material is unsaturated. The most recent survey carried out during a wetter period (November 2017) confirmed that seasonal groundwater intercepts the base of the waste at the site. Groundwater elevation in MW6 during November 2017 was measured at 57.84 m OD. It is possible that a fracture in the bedrock facilitates outflow from the quarry sump, and prevents significant build up of water. Further monitoring of levels in MW6 is required to confirm this.

Although regional groundwater flow is to the north, given the topographical siting, and hydraulic gradients in other directions, it is likely that Killynagher Lough and the stream to the west of the site, serve as local sumps, receiving a proportion of localised baseflow. Surface water elevation in Killnagher Lough was 50.02 mOD.

Groundwater level in MW8 fluctuates over the range 59 - 63 mOD. It is possible that MW8 penetrates low permeability bedrock surface and is therefore more susceptible to changes in water table in response to rainfall.

The data also confirms that there is usually a hydraulic gradient to the east, from MW7, through MW9, to MW8. Presumably this continues beyond the site and confirms the local groundwater flow aspect toward Killynagher Lough.

Permeability testing was undertaken at newly installed well MW10 to estimate hydraulic conductivity of the underlying bedrock formation. Permeability values calculated within the upgradient bedrock well was approximately 0.5 meters per day (0.45 m d^{-1}). The permeability of the natural overburden soils although not tested would be expected to be an order of magnitude less.

The above bedrock permeability suggests a relatively narrow K range for the underlying bedrock aquifer, this being indicative of a low permeability system. Groundwater flow within this strata would be dominated by fracture flow.

Surface water falling on the cap drains to the surrounding french drain. This drain has not been connected to the local surface water network and as such water in this drain is believed to overtop, with water draining vertically and laterally through surrounding overburden. Although considered as point recharge this volume is not considered to be significant.

Hydrochemistry

There is a paucity of hydrochemical data in the pre-2008 period, apparently due to local land ownership issues. Since August 2010 groundwater and surface water quality data has been collected on a quarterly basis. The following list of surface water parameters are considered to be Contaminants of Potential Concern (CoPC) in both groundwater and surface water bodies at the facility;

- Ammonia; Ammonia is considered to be a good overall indicator of water quality impact attributable to unlined municipal landfills. It can be particularly useful where surface waters may be at risk, as it can be toxic to fish at low concentrations (1 mg l^{-1}).

- Chloride: Chloride is usually at elevated concentrations in leachate derived from landfills. Chloride is considered a mobile constituent in the aquatic environment and is often used as an indicator of contamination.

- Iron & Manganese: Manganese and iron are ubiquitous in the environment and occur naturally in soils, background concentrations vary with respect to local geology. Mobilisation of iron and manganese in the subsurface is controlled by pH levels. Metals which may be present in buried C and D waste/aggregates of treated timber products will become soluble in low pH leachate or groundwater.

Surface Water Quality

The Waste License stipulates that surface water samples shall be taken from 3 no. monitoring points: SW1, SW2 and SW3. SW1 refers to Killynagher Lake; SW2 refers to all surface waters collected from the capped landfill area; SW3 refers to all surface waters collected from hardstanding areas at the entrance area.

There is no hardstanding at the area so it is unclear what SW3 refers to. The surface water outfall to adjacent lands has not been competed as yet and there has been no collection of waters at SW2.

Surface water quality from the local Killynagher Lake has been recorded by Boylan Engineering since 2011. Trended results for dissolved parameters ammonia, chloride and COD are summarised in Graphs 4 to 6.

The available data shows that water quality at Kilynagher Lake is good and satisfies the Surface Water Regulations (2009 and as amended 2015). (The more recent 2010 - 2015 WFD status remains unassigned).

Groundwater Quality

The Waste License stipulates that there shall be monitoring at MW1, MW2, MW4, MW7, MW9 and MW10. Of these, only MW7 and MW9 are in existence.

Additional downgradient groundwater monitoring boreholes have been proposed in the past, however an agreement with local landowners to access the land in this area has not been reached. In the interim period it was decided to install two further boreholes at the site - MW10 (to the south, and upgradient, of the site) and a leachate well LMWC.

Newly drilled monitoring well MW10 was installed into bedrock upgradient of the waste cell and is screened within competent bedrock. During the installation of leachate well LMWC, bedrock was encountered at 6.9 m bgl; no water strikes were encountered during drilling.

Trended results for COPC's in groundwater at the above locations are illustrated in Graphs 1 - 3. The data set exists for quarterly monitoring of groundwater quality since August 2010. Of the data collected, trends in the hydrochemical parameters ammonia, chloride, iron and manganese will be looked at more closely. This is because these are considered to be reliable indicators of groundwater contamination from a municipal and C & D facility. Laboratory certificates for the dates 2011 - 2017 are available upon request.

Conductivity

In all boreholes, conductivity is higher than that at Killynagher Lough, and representative of groundwater. The lowest conductivities noted in MW7 (and potentially MW9) would confirm that it is indeed upgradient of the landfill. Conductivity levels of 700-800 µS cm^{-1} may indicate very slight radial migration toward MW7, but this is not deemed to be a significant amount.

Conductivity is elevated in MW5, MW6 and groundwater here is more typical of leachate. The increased conductivity represents a higher concentration of free ions, and promotion of ion-exchange and chemical processes associated with dissolution/precipitation as material comes into contact with groundwater. The highest variability is observed in MW6 and is most likely attributable to groundwater level, with increase in conductivity noted during high rainfall, where more waste is in contact with groundwater during infiltration, and as groundwater level rises.

The elevated conductivity in MW8 suggest it is within, or downgradient of, the waste cell. Conductivity in MW7 and MW8 appears to be stable over time.

All measured concentrations are below the 1875 µS cm^{-1} threshold value established under the Groundwater Regs (2010 and as amended 2016).

Ammonia

Ammonia is considered to be a good overall indicator of water quality impact attributable to unlined municipal landfills. It can be particularly useful where surface waters may be at risk, as it can be toxic to fish at low concentrations (1 mg l^{-1}). Historical trends (2011-2017) in ammonia concentrations at wells MW6, MW7, MW8, MW9 are presented in Graph 1. With the exception of well MW6 (which is considered to be more representative of a leachate) ammonia concentrations in MW7, MW8 and MW9 have been declining since monitoring began. Most recent reported concentrations for MW7 and MW8 (Q4, 2017) have declined below the Interim Guideline Value for Groundwater (IGV - 0.015 mg/l) to 0.005 mg/l and 0.036 mg/l respectively.

Concentrations in well MW9 going back to 2011 have generally been in a narrow range between 0.9 mg/l and 1 mg/l. During 2017 ammonia concentrations in this well have declined to 0.175 mg/l which is just above the IGV of 0.15 mg/l.

Ammonia concentrations in MW6, have been consistently elevated when compared with adjacent wells with the highest concentration being recorded during Q2, 2011 at 36.9 mg/l. Since that period concentrations, although sporadic, have exhibited an overall declining trend. Concentrations during Q4, 2017 were reported as 2.1 mg/l.

The ammonia spike in MW6 during May 2011 is attributed to disturbances during the capping process. It is likely that during this procedure the temporary capping was removed, during which time recharge to the landfill was greatly enhanced, facilitating greater mobilisation and leaching of ammonia. Wet conditions can establish methogenic conditions which leads to a leachate with high levels of ammonia. Since then, ammonia concentrations within the landfill appear to be declining, although sporadic spikes do occur. These spikes may be contributed to instances of heavy rainfall events, again likely as a function of dry waste coming into contact with infiltrating water and rising groundwater.

Ammonia concentrations in MW7 and MW8 appear to have stabilised. The elevated concentration in MW7 might suggest some radial migration within a short distance of the landfill. The observed low concentrations of ammonia in MW8 is unexpected given the location of the well, downgradient of the infilled area. The subsurface pathway controlling maximum groundwater levels may not be connected to MW8.

With the exception of historical ammonia levels in MW6 (2011), when comparing the most recent concentrations recorded across the site with typical leachate ammonia values, as observed in unlined landfills (EPA, 2010), concentrations at this facility may be considered quite low.

Chloride

Chloride is a mobile constituent which is often used as an indicator of contamination. Chloride concentrations in on-site wells during the monitoring period are shown in Graph 2. Historically concentrations in excess of the IGV of 30 mg/l have been observed in monitoring wells MW8 and MW9 during the period 2010 - 2017. Higher concentrations were observed in well MW8 between 75 mg/l and 250 mg/l as far back as Q1, 2011. Between Q1, 2011 and Q2, 2016 concentrations in this well remained in this higher range. In the interim period (Q2, 2016 to Q4, 2017), reported concentrations in this well have been in a lower range (140 mg/l - 10 mg/l, all be it sporadic). The most recent results for this well during Q4, 2017 concentrations dropped back below the IGV to 12 mg/l.

Ammonia levels in monitoring well MW6 during the period 2010 - 2017 have remained fluctuating in a narrow range between 19 mg/l and 71 mg/l. Total organic carbon concentrations were low, indicating that the chlorides are not organically linked. Chloride levels in the remaining monitoring wells MW7 and MW9 have remained below the IGV during the period of monitoring with similar low concentrations observed in both wells during Q4, 2017 at 12 mg/l.

Iron & Manganese

Dissolved iron is ubiquitous in the environment and occurs naturally in soils, background concentrations vary with respect to geology. Mobilisation of iron in groundwater is controlled by pH levels. As pH decreases metals which may be present in buried waste/aggregates of treated timber products will become soluble in low pH leachate or groundwater. Similarly to iron dissolved manganese can also be used as an indicator of contamination from unlined landfill site.

Data on manganese concentrations is limited to annual monitoring (three consecutive years available) a review of the laboratory data shows concentrations in all wells remaining below the IGV of 50 ug/l.

Dissolved iron is analysed annually as part of the monitoring program for the site, concentration trends for this parameter are illustrated in Graph 3. The highest historical iron concentrations at the site was observed in MW9 during Q3, 2013 at 1005 ug/l (1.05 mg/l). In comparison with quarterly data for this well this elevated spike in concentration seems to be an isolated occurrence. Concentrations in MW9 in the interim period (Q4, 2013) have in general remained below the laboratory limit of detection of 0.020 ug/l.

Sporadic changes of dissolved Iron concentrations in monitoring well MW8 have persisted since monitoring began at the site, generally levels are within a range between < 0.20 ug/l - 0.29 ug/l. The leachate from landfills (non-hazardous waste) may produce reducing conditions beneath the landfill, allowing the solution of iron and manganese from the underlying deposits and from C & D waste if present. At this site iron concentrations are generally at or below 0.2 mg/l. These sporadic spikes in concentration may be linked to seasonal changes in groundwater levels at the site where for short periods of time the base of the waste becomes saturated resulting mobilisation of dissolved iron.

Hydrogeological Conceptual Model

The hydrogeological assessment is guided by the source-pathway-receptor (S-P-R) model, as outlined below. The S-P-R model is used to identify the sources of water and potential contaminants, the environmental assets affected by such, and the pathways by which water and contaminants reaches those receptors. It is refined as the assessment evolves and more information is acquired.

A graphical interpretation of local hydrogeology can be derived and this is presented as Figure 9. The line of section is along an east-west plane through the landfill.

Preliminary S-P-R

Following desk study findings, historical data and site survey information, the preliminary conceptual source-pathway-receptor model is as follows:

source	pathways	receptors
hazardous landfill material	infiltrating water	groundwater quality: north, east and west
non-hazardous landfill material	leachate migration	Killynagher Lough and Lough Oughter SAC
precipitation	groundwater flow type (e.g karst) and velocities	stream to west of site
sediment bound contaminants	groundwater flow direction	karstified bedrock aquifer
dissolved contaminants	throughflow from surrounding lands	groundwater in downgradient farmland

- The site is located on a minor northward pointing drumlin ridge. Topography decreases to the west toward a minor valley, and to the east toward a lake, Killynagher Lough.
- An excavation resulting from historical quarrying of limestone bedrock was backfilled with a minimum of 10 m waste material, mostly obtained from local municipal sources.
- The landfill was completed to natural surface elevation on the southern and eastern sides. The landfill was completed to 1 m below natural surface elevation on the northern and western sides; bedrock faces are exposed on these boundaries.
- The site was closed in 2002, and capped with imported soil material in 2011. The capping material is designed to prevent infiltration to the landfill material, instead collecting precipitation and runoff in the french drain within the site perimeter. Whilst infiltration will over time assist in the gradual dilution of contaminant sources, in the short-medium term it can serve to mobilise potential contaminants. In this regard the capping process has been deemed successful in restricting infiltration.
- A number of existing groundwater monitoring boreholes are on site. There is one upgradient monitoring borehole outside the site boundary. There are no groundwater monitoring boreholes downgradient of the site (due to restricted land access).
- Groundwater flow is primarily north toward Lough Erne, with localised components flowing (i) east toward Killynagher Lake, (ii) west toward a minor stream.

- The base of the landfill is unlined so any water that does penetrate the capping layer can flow vertically through the waste layer,
- The lack of any subsoil beneath the discharge zone means there is little opportunity for biomat formation and associated attenuation.
- Infiltrating water will enter the karstified bedrock aquifer. Below the epikarst, fracture flow is likely to be the dominant groundwater pathway in the aquifer.
- Given the age of the landfill and observed concentrations of COPC's, conditions within the waste cell are now likely to be anaerobic. Concentration of substances will decline due to one or a combination of (i) half-life deterioration, (ii) dispersion by dilution, (iii) chemical precipitation (and by assumption immobilisation) onto ion receptors such as clay particles.
- Depth of overburden will likely increase approaching the surface water bodies in topographical depressions. There is potential for attenuation in this zone, as baseflow moves from the site toward streams and lakes.

Landfill Gas

The rate of decomposition of the emplaced waste will influence the production of gas within the waste mass. Gas levels have been monitored on a quarterly basis throughout the period 2011 - 2017, with results available for wells MW5, MW6 and MW9.

A review of this data shows variability in gas production levels and ratios across the waste cell. Levels of methane and carbon dioxide detected in wells MW5 and MW9 appear to be negligible in comparison to levels recorded at MW6. Levels of carbon dioxide at both these locations are generally recorded below 9% and methane levels generally below 1% by volume. These readings may suggest that organic waste is either not present or only present at minimal depths in these locations.

Methane and carbon dioxide levels are greater in monitoring well MW6 which is located centrally on the western side of the waste cell. The ratio of methane to carbon dioxide at this location is consistently 1:1 throughout the monitoring period (2011 - 2017), generally with both methane and carbon dioxide levels between 11 - 17% by volume. This would suggest that both methane and carbon dioxide gas production in this part of the site has stabilised over the monitoring period.

The variability of gas production at the site may be indicative of the variation of waste type across the site (e.g. waste segregation whereby more putrescible or organic waste was emplaced in a specified area or at a specified level during emplacement. The local authority have no detailed knowledge of historical landfilling practices at the site.

Risk Prioritisation

The risk screening tool as presented in the EPA Code of Practice "Environmental Risk Assessment for Unregulated Waste Disposal Sites" was applied to the site and is presented below. The key potential pollution linkages for the site are considered to be as follows:

- Vertical migration of leachate to the water table, followed by either:
    1. Lateral migration of dissolved phase COPCs via shallow groundwater flow in the weathered bedrock zone/overburden soils towards Killynaher Lake, downgradient of the eastern portion of the site.
    2. Lateral landfill gas migration to the domestic dwelling structure, southeast of the site (lateral migration to a human presence).
    3. Vertical migration of dissolved phase COPCs via overburden soils to the underlying bedrock aquifer followed by lateral migration of COPCs within the aquifer to downgradient receptors.

- Vertical Migration of landfill gas to the surface above the landfill.
- Lateral migration of landfill gas dissolved in groundwater along groundwater flow paths to downgradient receptors.

The most sensitive environmental receptors are considered to be the residential property (south east) and groundwater/ surface water receptors to the east of the site.

Source Area

The site covers an area of approximately 0.67 ha with approximately 90% of the area infilled with waste. The depth of the waste is understood to be 6-10 m. Table 1a and 1b below give the following Source Hazard Scores for leachate and landfill gas.

Table 1a: Leachate Hazard Score

Waste Type	Foot Print	Score
Municipal	>1	5

Table 1b: Landfill Gas Hazard Score

Waste Type	Foot Print	Score
Municipal	>1	5

Leachate Migration Pathway

The main leachate migration pathway is considered to be vertical flow to the bedrock aquifer and lateral flow within the bedrock aquifer.

Table 2a: Migration Pathway Vertical

Groundwater Vulnerability (Vertical flow)	Score
Extreme	3

Table 2b: Leachate Migration Pathway Horizontal

Groundwater Vulnerability (Horizontal flow)	Score
Karstified Groundwater Body	5

Surface Water Drainage

Surface water drains surrounds the landfill cap but it is not directly connected to local surface watercourses.

Table 2c: Leachate Migration Pathway Surface Water Drainage	
Direct connection between surface water drains and local surface water streams	Score
No	0

Landfill Gas Migration Pathway

There is a single residential dwelling approximately 25m southeast of the site, therefore only landfill gas Table 2d applies in this instance. Table 2d assumes that the waste has been sealed with a capping layer resulting in a risk of lateral gas migration through the bedrock/overburden geology. The risk assessment assumes that leachate and waste material are in direct contact with the underlying bedrock.

Table 2d: Landfill Gas Pathway	
Pathway material	Score
Clay, Alluvium, Peat	1

Leachate Migration Receptors (Human Health)

A number of private dwellings are located within 50m of the southeastern and site boundary. Following a recent survey of the dwellings it is believed that drinking water is supplied from an Irish Water or GWS mains network. For the purposes of the risk classification it is assumed that there is a potential risk that private wells may be used in the future.

Table 3a: Leachate Receptors	
Distance to dwelling	Score
On or within 50m from waste body	3

Aquifer Categorisation

The distance to the nearest public supply well is also considered in this section. The nearest dwelling that may be supplied by a water from a private well is located 25 m from the southeastern site boundary.

Table 3c: Aquifer Categorisation- Resource Potential	
Aquifer Type	Score
Regionally Important Bedrock Aquifer	5

Table 3d: Public Water supplies (other than private wells)	
Distance to PWS and aquifer type	Score
Greater than 1km karst aquifer	3

Leachate Migration Receptors (Ecological - Surface Water Bodies)

Table 3e below considered the risk to the closest surface water receptors. As stated Killynaher Lake is to the east of the site.

Table 3e: Leachate Migration Receptors- Surface Water Bodies	
Distance to Surface Water	Score
Greater than 50m but less than 250m	2

Landfill Gas Migration - Receptor

Based on the age of the site and type of waste deposited the site is considered to have the potential to generate landfill gas. The risk screening tool was applied as per the code of practice as follows.

Table 3f: Landfill Gas Migration Receptors	
Distance to Nearest Dwelling	Score
On site or within 50 m of the site boundary	5

Tier 2 Risk Calculations and Classifications

The source pathway receptor linkage prioritisation was applied as per the EPA's Code of Practice for Risk Assessment of Unregulated Waste Disposal Sites. Each viable S-P-R linkage is scored individually as presented below. The calculations reference the table numbers above and correspond directly to the table references used in the EPA Code of Practise. A risk percentage is presented which denotes the percentage risk for each SPR linkage normalised against the maximum possible score for each SPR linkage. Each linkage is banded into High risk Class A sites (S-P-R percentage >70% for any viable linkage), Medium risk Class B sites (S-P-R percentage 40 - 70 % for any viable linkage) and Low risk Class C sites (S-P-R linkage < 40% for all viable linkages).

SPR	Equation	Linkage Score and (max score)	Normalised score (as % of max)	Risk Classification
Vertical migration to bedrock aquifer	1a x (2a + 2b) x 3c	200 (400)	50%	Class B
Vertical migration to bedrock aquifer and migration to private well	1a x (2a + 2b) x 3a	120 (240)	50%	Class B
Leachate migration via groundwater and surface water drainage to the Killynaher Lough	1a x (2a + 2b) + 2c) x 3e	80 (300)	26%	Class C

SPR	Equation	Linkage Score and (max score)	Normalised score (as % of max)	Risk Classification
Leachate migration via surface water drainage to the Killynaher Lough	1a x 2c x 3e	20 (60)	33%	Class C
Landfill gas lateral migration to a human presence	1b x 2d x 3f	25 (150)	16%	Class C

As can be seen from the above risk categorisation table, the key potential linkages that classify this site as medium risk or within Class B are as follows;

- Vertical migration dissolved phase groundwater COPCs to bedrock aquifer and potential migration to off-site private wells;

In addition to the Class B pollution linkages identified there are also viable pollutant linkages that classify this site as a low risk Class C site:

- Lateral migration of dissolved-phase COPCs via shallow groundwater flow in the overburden soils towards the Killynaher Lake bordering the eastern portion of the site.
- Vertical migration of dissolved phase groundwater COPCs to the bedrock aquifer.
- Lateral migration of landfill gas to a human presence.

The most sensitive environmental receptor is considered to be Killynaher Lake along the eastern boundary of the site. Recent surface water quality monitoring results suggest that this risk ranking may overestimate the actual risk posed to the watercourse by the landfill. This is assumed to be due to the presence of low permeability gley soils surrounding the landfill to a depth of 6 m below surface which is impeding lateral shallow subsurface flow towards the lake. There is also limited risk of gas migration to the domestic dwelling south of the site.

Site Compliance (Groundwater Directive)

The site operated since late 1972 as a traditional landfill, accepting non-hazardous waste. During the lifetime of the facility the base of the site was unlined Prior to the site closure in 2002 a temporary cap was installed over the site. The landfill was then permanently covered in 2011 with a fully engineered and lined cap. The cap is designed to eliminate/reduce the ingress of rainfall entering the waste cell. Leachate production (prior to 2011) would have been associated with rainwater percolating directly into the waste. Monitoring has shown that the presence of the engineered cap prevents leachate production, limits vertical leachate migration and to some extent lateral migration. However seasonal variations in groundwater elevations at the site have the potential to increase production of leachate via lateral mixing of groundwater through the base of the cell. Deep groundwater beneath the site does not appear to be significantly impacted by COPC's associated with leachate impacted groundwater at the site. With the exception of ammonia, dissolved chloride and iron concentrations in deep groundwater are generally at or just below their respective IGV's. Ammonia concentrations although historically elevated have declined significantly over the past 7 years. Additionally nearby surface water receptors do not appear to be impacted by the presence of the historic Landfill.

In this regard the site is generally deemed to be compliant with the limit objectives of the Water Framework Directive and Groundwater Directive. The cap design limits the generation of leachate and potential for leachate to migrate off site and impact the local aquatic environment, thereby limiting the consequences of historical pollution at the location.

Recent intrusive site investigation has conformed the natural geology at the site (MW10) and LMWC); data gathered at these locations will be used to inform any future revision of the current CSM (revised CSM presented in Figure 9). The detailing of the engineered liner has also been amended to demonstrate how it prevents leachate generation from the waste cell. The CSM shall be updated in future as remedial measures are employed, and ongoing monitoring leads to advanced understanding of the hydrogeological regime beyond the current version.

Summary/Conclusions

A Tier 2 hydrogeological assessment has been carried out to assess risk to groundwater and surface water from a historic landfill facility in Belturbet, Co. Cavan. Results of this assessment are summarised below.

Prior to closing the site a temporary cap was placed on the deposited waste material. The landfill was then permanently capped in 2011 using a fully engineered and lined capping system. Works also included importation of inert fill material (construction and demolition waste), on top of which subsoil and topsoil were spread and seeded. The base of the landfill is believed to be unlined. A 300 mm toe drain collects surface runoff from the cap, the outfall of this drain is located in the eastern portion of the site where it flows indirectly into Killynaher Lake. Site elevation is 66 - 69 mOD, 16 -19 m above nominal lake level of approximately (50 mOD).

Two groundwater wells were recently installed: (i) upgradient of the site (MW10) and (ii) centrally on the site (LMWC). Installation of these wells confirmed the underlying geology at each location and the depth to bedrock. In addition these two installations have confirmed the flow direction of deep groundwater at the site.

A groundwater elevation survey carried out on site confirmed that seasonally groundwater elevations during wetter months may potentially intercept the base of the waste material resulting in limited leachate production at the site. The groundwater parameters considered to be the main COPC's at the site are ammonia, chloride, Iron and manganese, all of which are considered good indicators of landfill derived leachate. With the exception of ammonia, dissolved chloride and iron concentrations in deep groundwater are generally at or just below their respective IGV's. Ammonia concentrations although historically elevated have declined significantly over the past 7 years. Ammonia concentrations in MW7 and MW8 appear to have stabilised.

Similarly iron concentrations are generally reported (albeit intermittently) at or below 0.2 mg/l. These sporadic spikes in concentration may also be linked to seasonal changes in groundwater levels at the site where for short periods of time the base of the waste becomes saturated resulting in mobilisation of dissolved iron. A review of manganese data shows concentrations in all wells remained below the IGV of 50 ug/l. Additionally nearby surface water receptors do not appear to be impacted by the presence of the historic landfill.

When comparing the most recent concentrations recorded across the site with typical leachate ammonia values, observed in unlined landfills (EPA, 2010), concentrations at the site are considered quite low. These observed low concentrations may indicate that groundwater may be intercepting a layer of waste which has a lower organic content, possibly a reworked C & D or mixed waste layer. In general, long term concentrations of ammonia in groundwater across the site have been declining.

A CSM which was developed for the site during the initial Tier 1 assessment has been updated to include data gathered during the most recent site investigation. The EPA Code of Practice was subsequently applied and a risk calculation for the site was completed. Applying the above methodology the site is classified as a Class B - Moderate risk site. The Tier 2 assessment identified the primary potential risk drivers for the site as migration of leachate to the bedrock aquifer and leachate impacted shallow groundwater reaching the Killynaher Lake. Results from the bedrock aquifer and the Killynaher Lake suggest that risk may be overestimated.

The site is deemed to be compliant with the limit objectives of the Water Framework Directive and Groundwater Directive.

At this point in time a number of data gaps still exist in relation to the extent of bedrock contamination downgradient of the site. Cavan Co. Council has contacted a number of local land owners to request permission to access and install monitoring wells on adjacent lands. To date no agreement has be made to facilitate these works.

Technical Assessment Recommendations

The following additional measures are recommended to facilitate current data gaps within the Tier II Risk Assessment.

1. The focus of further work, and any future compliance monitoring, needs to take into account general groundwater status downgradient of the landfill, baseflow to local surface water bodies, and water quality of these surface waters.
2. Consider sampling of stream northwest of site as it is a potential surface water receptor. Sampling location is dependent on land access.
3. The inclusion of analysis for dissolved manganese on a quarterly basis for all groundwater and leachate wells currently sampled at the site (currently carried out annually since 2014), and
4. The inclusion of quarterly monitoring of nitrite/nitrate to assess nitrate flux

References

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Appendices

Appendix A - Well Logs

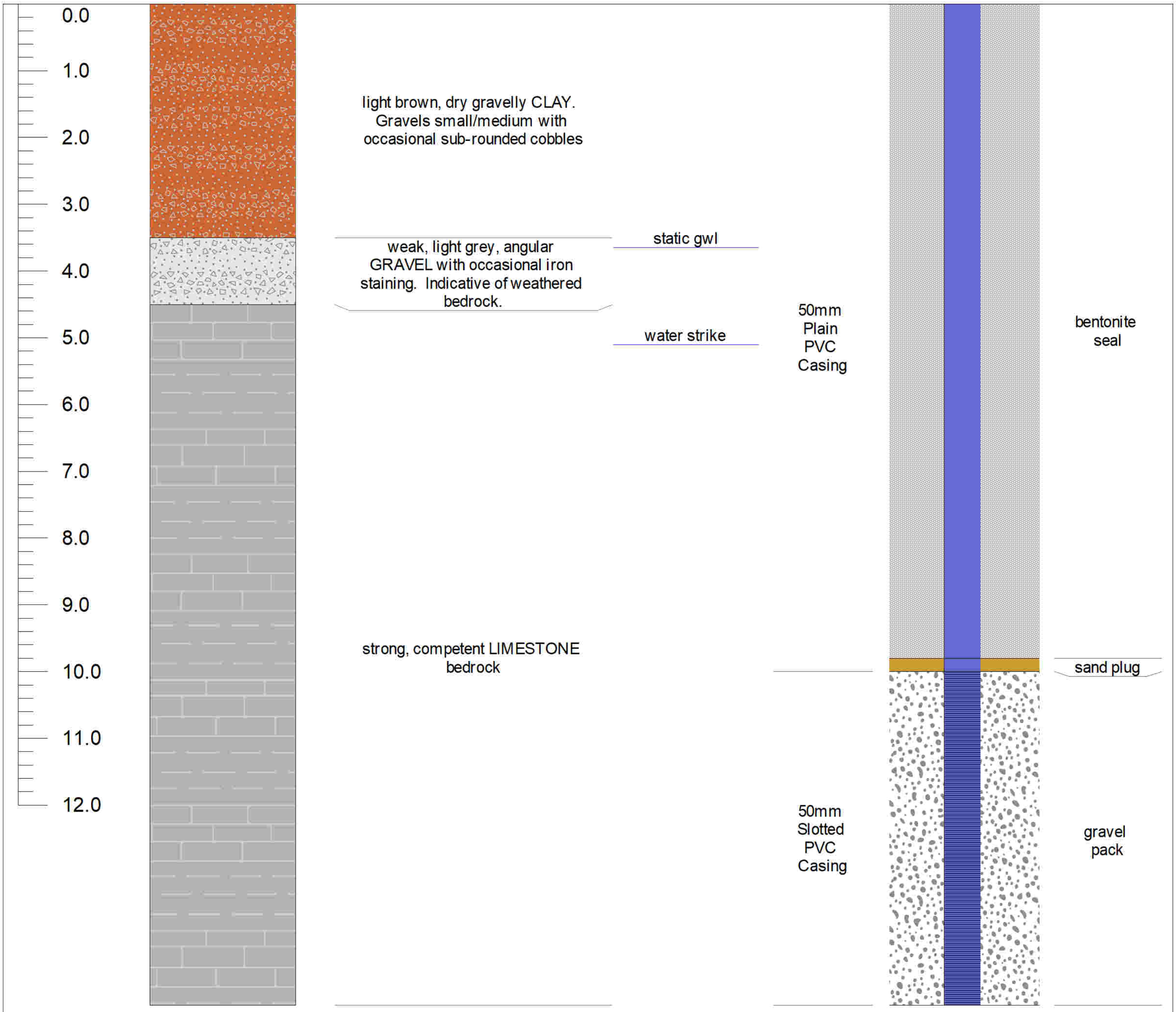
ENVIROLOGIC
HYDROGEOLOGICAL · HYDROLOGICAL CONSULTING

Client:	Cavan County Council
Project:	Hydrogeological Risk Assessment
Location:	Belturbet, Co. Cavan

Borehole No.
MW10

Coordinates:	631,969 / 815,346	Start Date:	15/11/17	Borehole Diameter:	140 mm
Ground Elevation:	65.15 mOD	End Date:	15/11/17	Screen :	50 mm PVC
Top of Casing Elevation:	65.55 mOD	Borehole Depth:	15.0 m	Depth to bedrock:	4.5 m below ground

DEPTH **DESCRIPTION** Static w.l.: 61.91 mOD **BOREHOLE CONSTRUCTION**

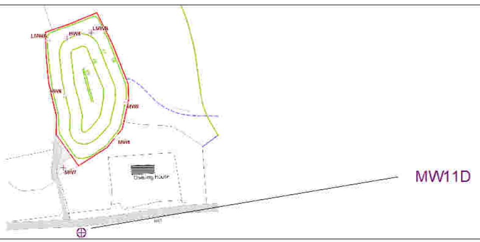


light brown, dry gravelly CLAY. Gravels small/medium with occasional sub-rounded cobbles

weak, light grey, angular GRAVEL with occasional iron staining. Indicative of weathered bedrock.

strong, competent LIMESTONE bedrock

Site Map



Driller:	Causeway Geotech Ltd.
Drilling Rig:	Beretta T41
Drilling Method:	Rotary Hammer
Supervision:	Envirologic: P. Breheny
Log drawn by:	C. O'Reilly
Project Ref.:	1525

ENVIROLOGIC
HYDROGEOLOGICAL · HYDROLOGICAL CONSULTING

Client: Cavan County Council
Project: Hydrogeological Risk Assessment
Location: Belturbet, Co. Cavan

Borehole No.
LMWC

Coordinates: 631,988 / 815,466
Ground Elevation: 67.42 mOD
Top of Casing Elevation: 67.85 mOD

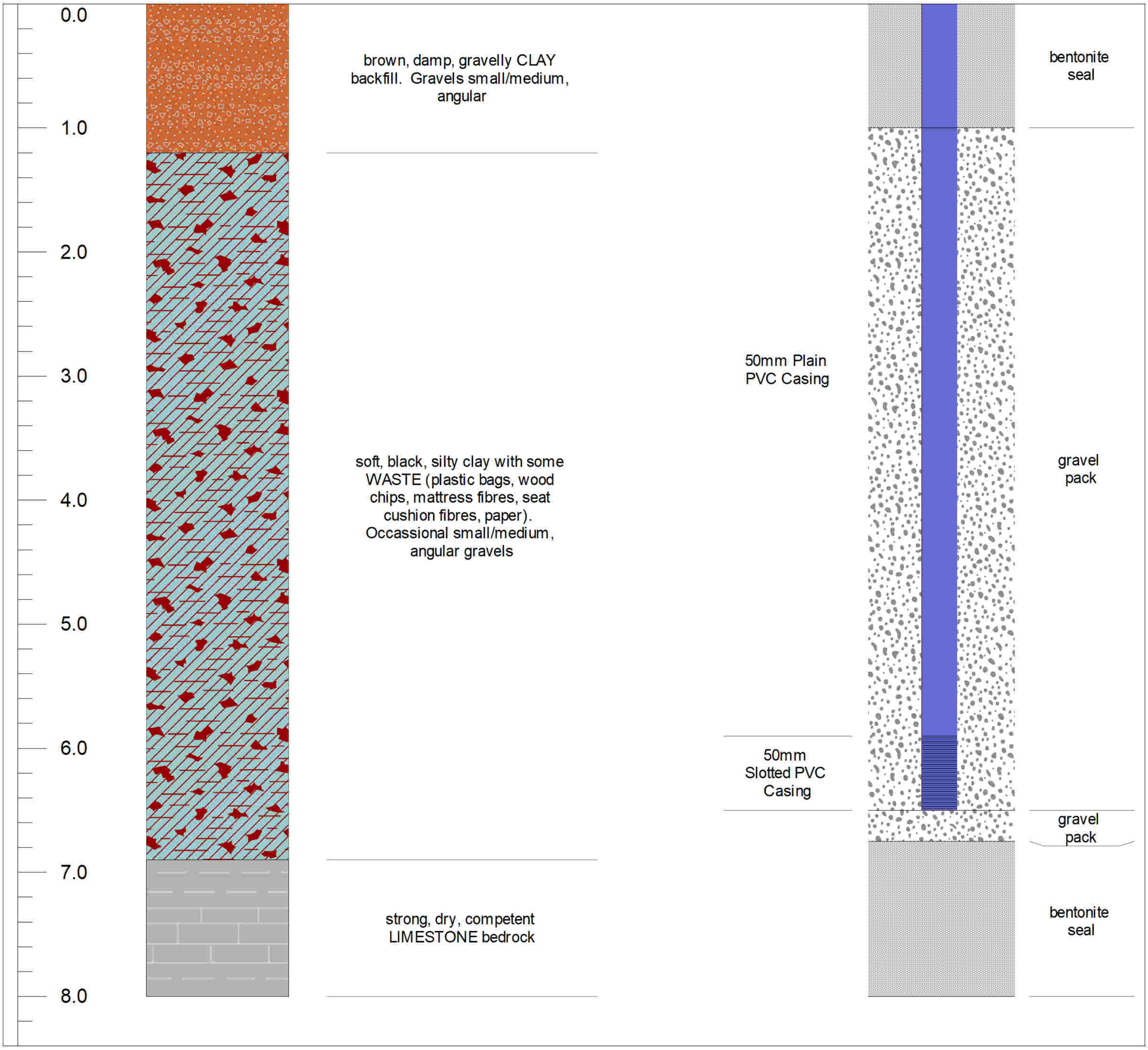
Start Date: 15/11/17
End Date: 15/11/17
Borehole Depth: 8 m

Borehole Diameter: 140 mm
Screen : 50 mm PVC
Depth to bedrock: 6.9 m below ground

DEPTH **DESCRIPTION**

Static w.l.: dry

BOREHOLE CONSTRUCTION

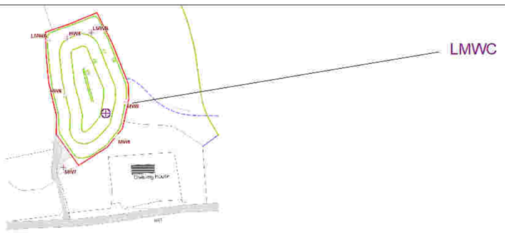


brown, damp, gravelly CLAY backfill. Gravels small/medium, angular

soft, black, silty clay with some WASTE (plastic bags, wood chips, mattress fibres, seat cushion fibres, paper). Occassional small/medium, angular gravels

strong, dry, competent LIMESTONE bedrock

Site Map



Driller: Causeway Geotech Ltd.
Drilling Rig: Beretta T41
Drilling Method: Rotary Hammer
Supervision: Envirologic: P. Breheny
Log drawn by: C. O'Reilly
Project Ref.: 1525

Monitoring Well Records

Project No. : 1892 **Location :** Belturbet Landfill **Date :** Jan. '99

Drilling Method : Window Sampling **Supervisor :** K.T. Cullen & Co. Ltd.

MW No. : 1

Geology :

0 - 1.0m Brown Soil

1.0m Rock

Screen : 0 - 1.0 m

Seal : Bentonite Seal at top

Water Entry :

Static Water : Dry

Total Depth : 1.0m

Comments : Rock at 1.0m

MW No. : 2

Geology :

0 - 1.5m Brown Soil

1.5m Rock

Screen : 0 - 1.5 m

Seal : Bentonite Seal at top

Water Entry :

Static Water : Dry

Total Depth : 1.5m

Comments : Rock at 1.5m

MW No. : 3

Geology :

0 - 0.8m Brown Soil

0.8m Rock

Screen : 0 - 0.8 m

Seal : Bentonite Seal at top

Water Entry :

Static Water : Dry

Total Depth : 0.8m

Comments : Rock at 0.8m

MW No. : 4

Geology :

0 - 0.3m Brown Soil

0.3m Rock

Screen : 0 - 0.3m

Seal : Bentonite Seal at top

Water Entry :

Static Water : Dry

Total Depth : 0.3m

Comments : Rock at 0.3m

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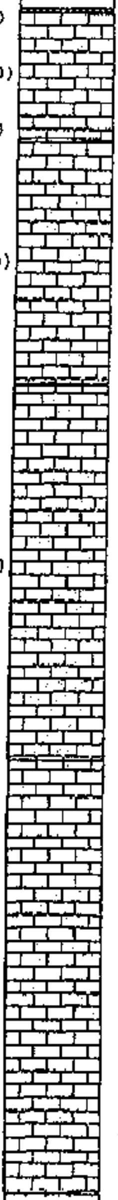
Boring Method Light Cable Percussion Boring.	**Dates** 26/01/99 - 27/01/99	**Client** K. T. CULLEN & CO	**Sheet** 1/1
Hole Diameters	**Location** AS PLAN	**Engineer**	**Ground Level (mOD)**
Site BELTURBET			**Borehole Number** Mw

Description	Depth m (Thickness)	Legend	Level (mOD)	Samples / Tests			Water Level *	Daily Progress
				Depth (m)	Sample	Test		
Hardcore and FILL	0.10							
Broken rock (CARBONIFEROUS LIMESTONE)	(3.40) 3.50							
Hard rock (CARBONIFEROUS LIMESTONE)	(6.50) 10.00							
ard rock (CARBONIFEROUS LIMESTONE)	(10.00) 20.00							
Hard rock (CARBONIFEROUS LIMESTONE)	(10.00) 30.00							
Hard rock (CARBONIFEROUS LIMESTONE)	(1.50) 31.50							27/01/99
END OF BOREHOLE AT 31.5m								

Remarks

2" HDPE screen installed from 31.5m to 7.5m.
2" HDPE plain installed from 7.5m to +0.4m.
vel filter pack installed from 31.5m to 6.5m.
tonite pellet seal from 6.5m to 0.7m.
Concrete and lockable cover fitted from 0.7m to 0.0m.

SAMPLE / TEST KEY

J	Disturbed Sample
B	Bulk Sample
U	Undisturbed Core Sample
P	Piston Sample
V	Field Vane Test
W	Water Sample
SPT	Standard Penetration Test
CPT	Cone Penetration Test
( )	Penetration < 300mm

Scale 1:200	**Logged By** fR
Figure No. [redacted]	
Borehole Number	MW5

Glover Site Investigations Ltd

Site	BELTURBET
Borehole Number	Mw
Boring Method	Light Cable Percussion Boring.
Dates	28/01/99 - 28/01/99
Client	K..T. CULLEN & CO
Sheet	1/2
Hole Diameters	
Location	AS PLAN
Engineer	
Ground Level (mC	

Description	Depth m (Thickness)	Legend	Level (mOD)	Samples / Tests			Water Level *	Daily Progress
				Depth (m)	Sample	Test		
CLAY cap	(0.50) 0.50	▩						
Builders rubble, FILL, bricks, wood etc.	(2.20) 2.70	▓						
DOMESTIC WASTE	(7.30) 10.00	▩						

Remarks

2" HDPE screen installed from 10.5m to 2.0m.
2" HDPE plain installed from 2.0m to +0.6m
ntonite seal installes from 11.0m to 10.5m.
vel filter pack installed from 10..5m to 2.0m.
ntonite seal installed from 2.0m to 0.0m.
Lockable cap fitted.

SAMPLE / TEST KEY

J	Disturbed Sample
B	Bulk Sample
U	Undisturbed Core Sample
P	Piston Sample
V	Field Vane Test
W	Water Sample
SPT	Standard Penetration Test
CPT	Cone Penetration Test
( )	Penetration < 300mm

Scale	1:50
Logged By	IR
Figure No.	[illegible]
Borehole Number	Mw6

Glover Site Investigations Ltd

Site BELTURBET			Borehole Number MW6
Boring Method Light Cable Percussion Boring.	Dates 28/01/99 - 28/01/99	Client K. T. CULLEN & CO	Sheet 2/2
Hole Diameters	Location AS PLAN	Engineer	Ground Level (mOD)

Description	Depth m (Thickness)	Legend	Level (mOD)	Samples / Tests Depth (m)	Samples / Tests Sample	Samples / Tests Test	Water Level *	Daily Progress
DOMESTIC WASTE	(0.80) 10.80	▨						
Hard rock (CARBONIFEROUS LIMESTONE)	11.00	▦						28/01/99
END OF BOREHOLE AT 11.0m								

Remarks

2" HDPE screen installed from 10.5m to 2.0m.
2" HDPE plain installed from 2.0m to +0.6m
tonite seal installes from 11.0m to 10.5m.
vel filter pack installed from 10..5m to 2.0m.
Bentonite seal installed from 2.0m to 0.0m.
Lockable cap fitted.

SAMPLE / TEST KEY

J	Disturbed Sample
B	Bulk Sample
U	Undisturbed Core Sample
P	Piston Sample
V	Field Vane Test
W	Water Sample
SPT	Standard Penetration Test
CPT	Cone Penetration Test
( )	Penetration < 200mm

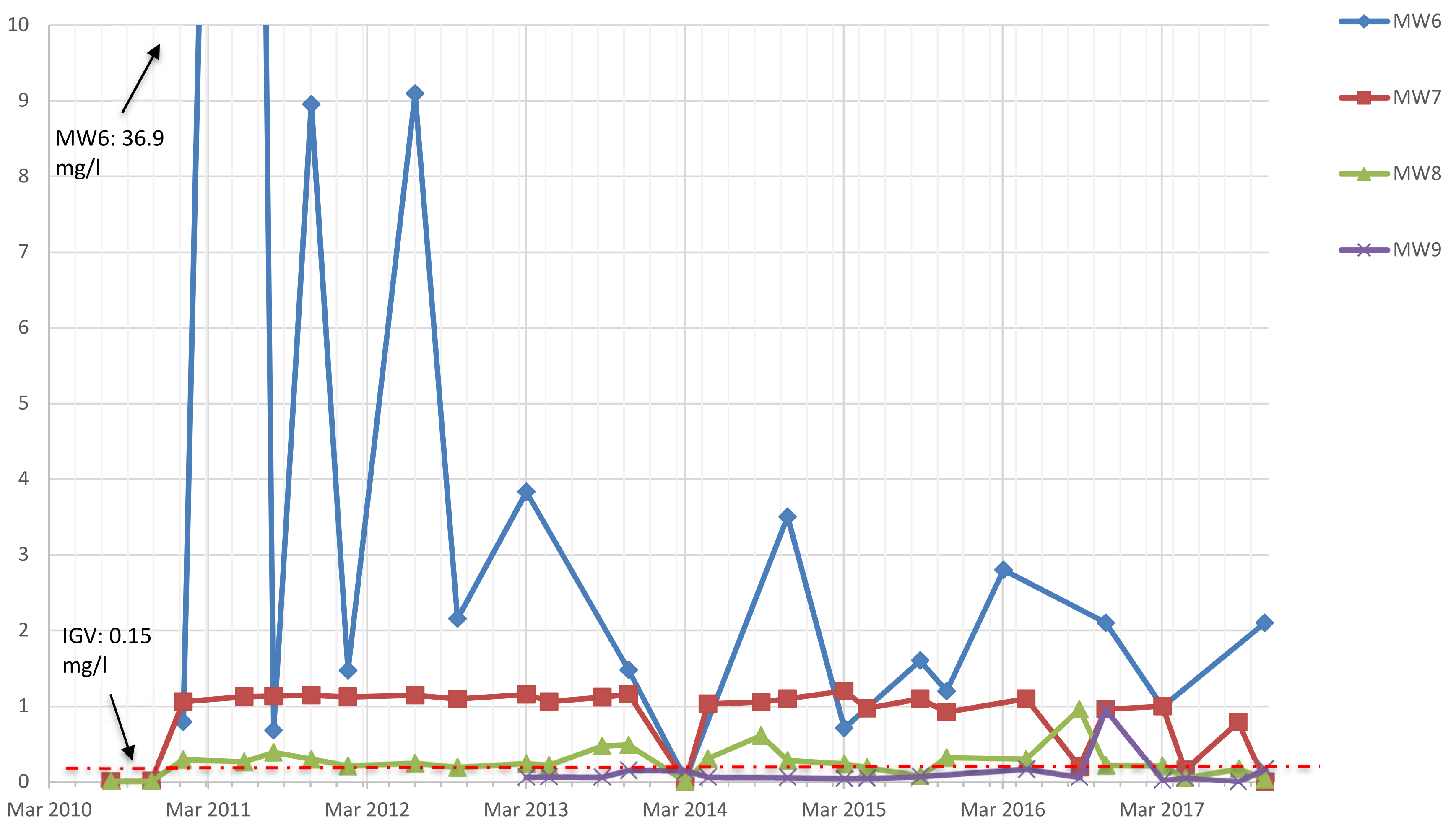
Scale 1:50

Logged By IR

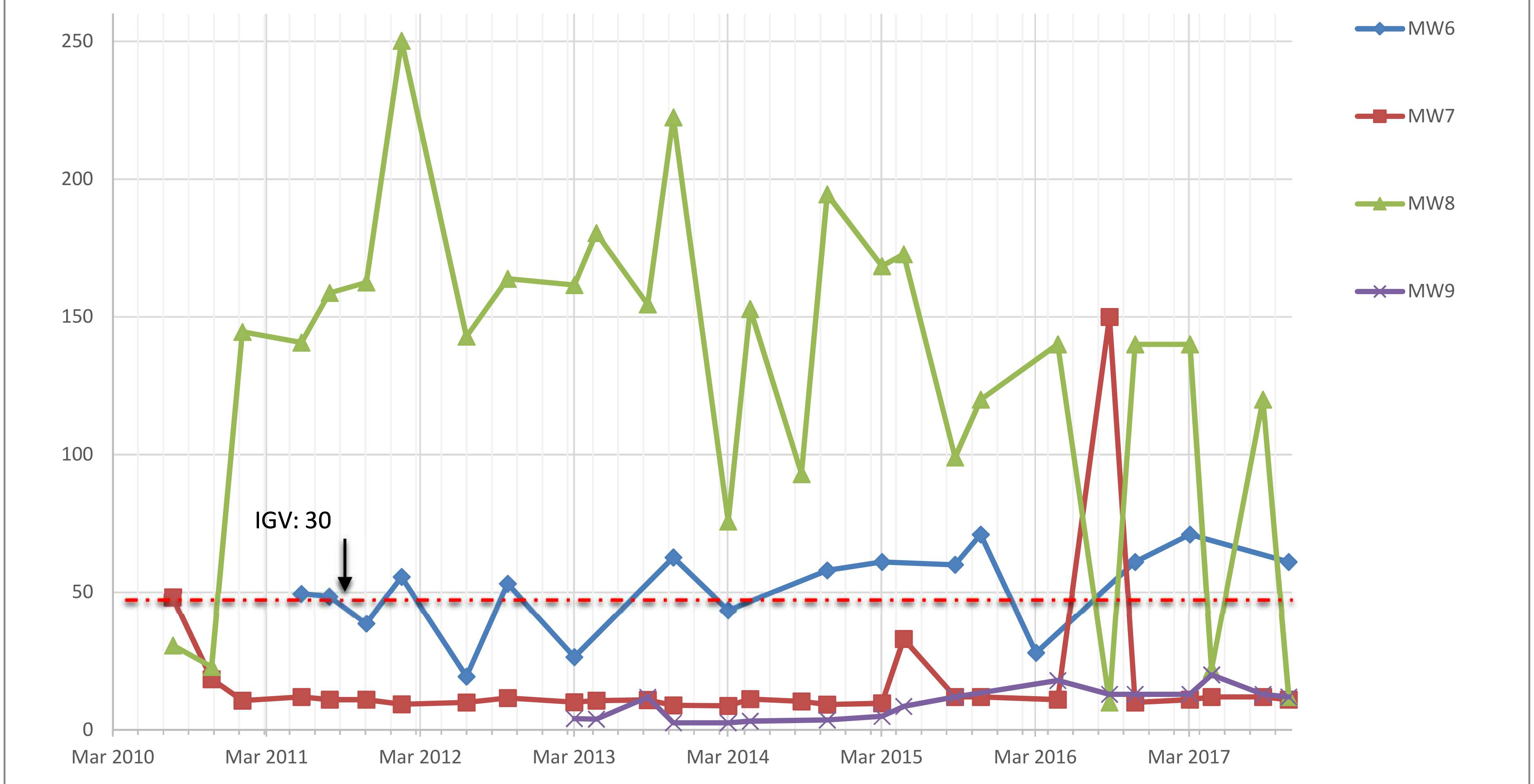
Figure No. 3[redacted]

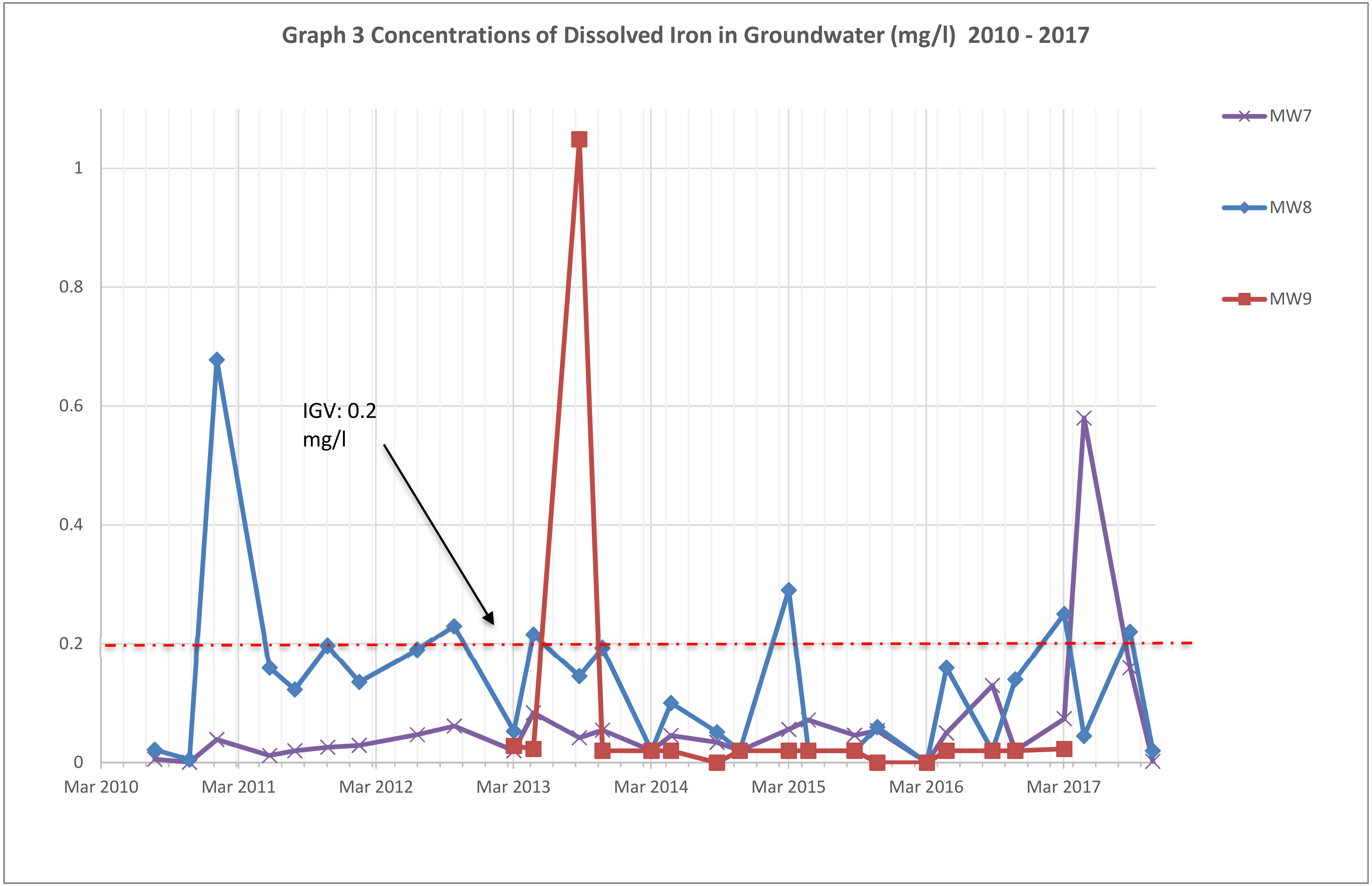
Borehole Number MW6

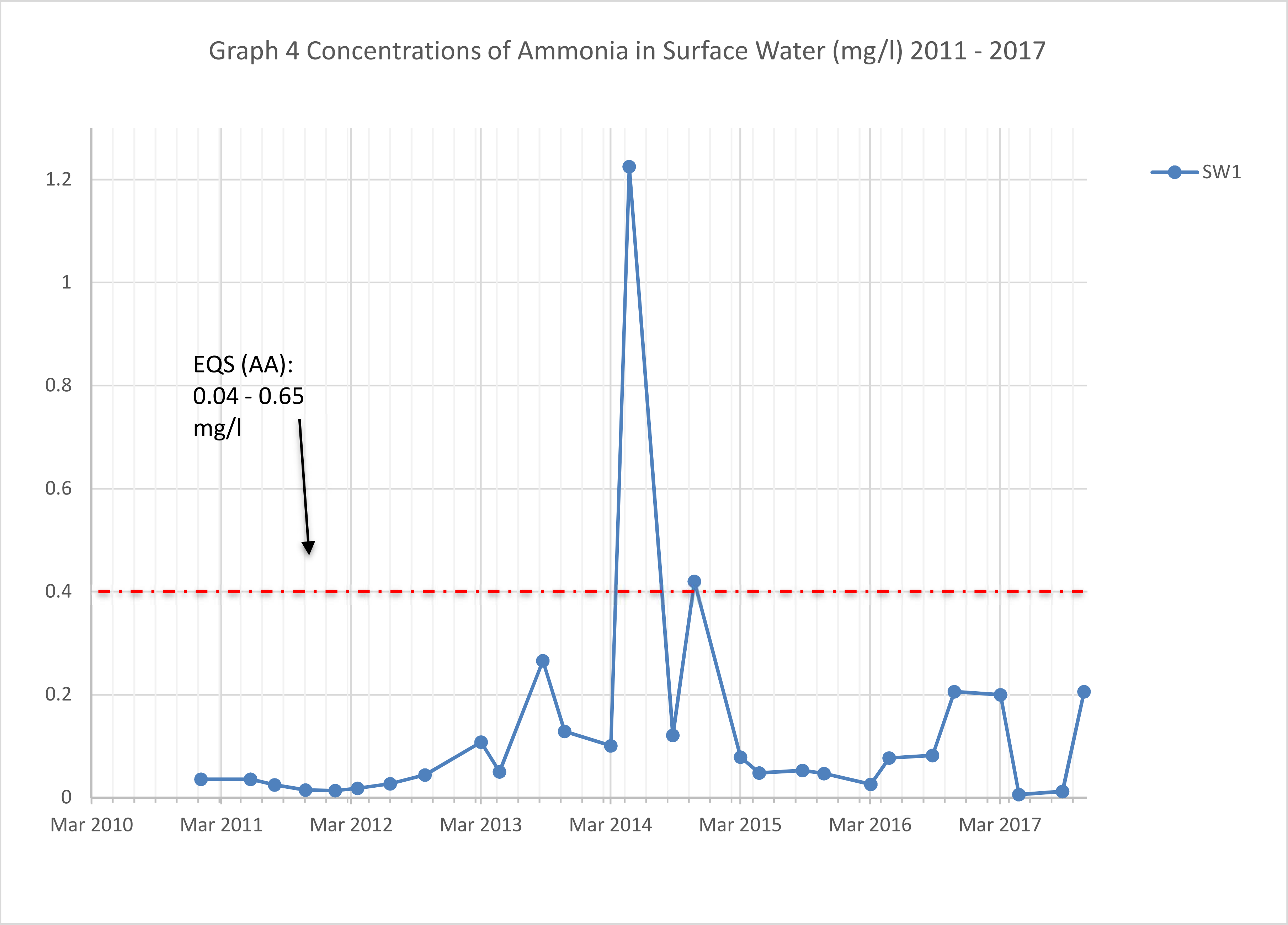
Graphs


Graph 1 Concentrations of Ammonia in Groundwater (mg/l) 2010 - 2017

Graph 2 Concentrations of Chloride in Groundwater (mg/l) 2010 - 2017

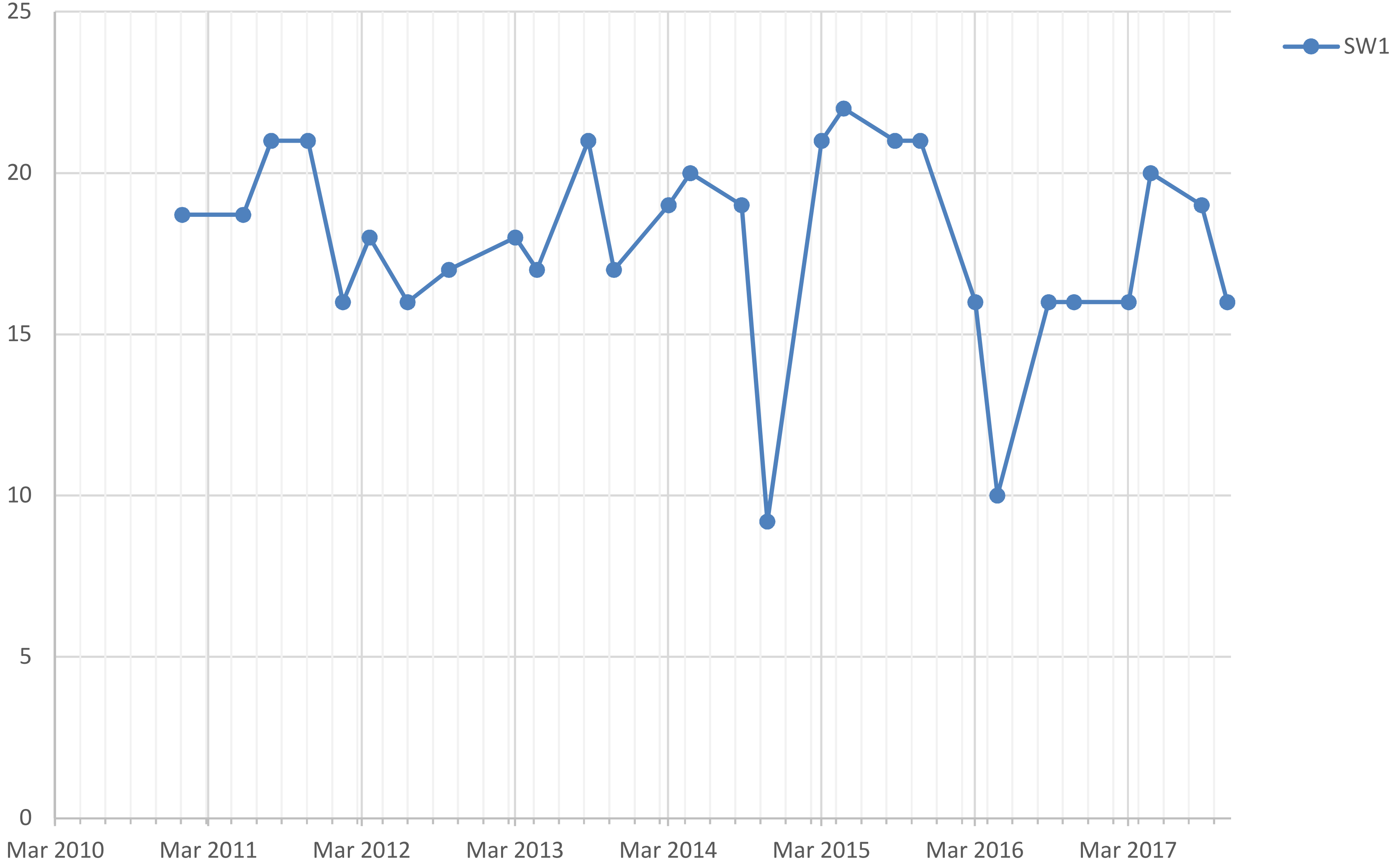


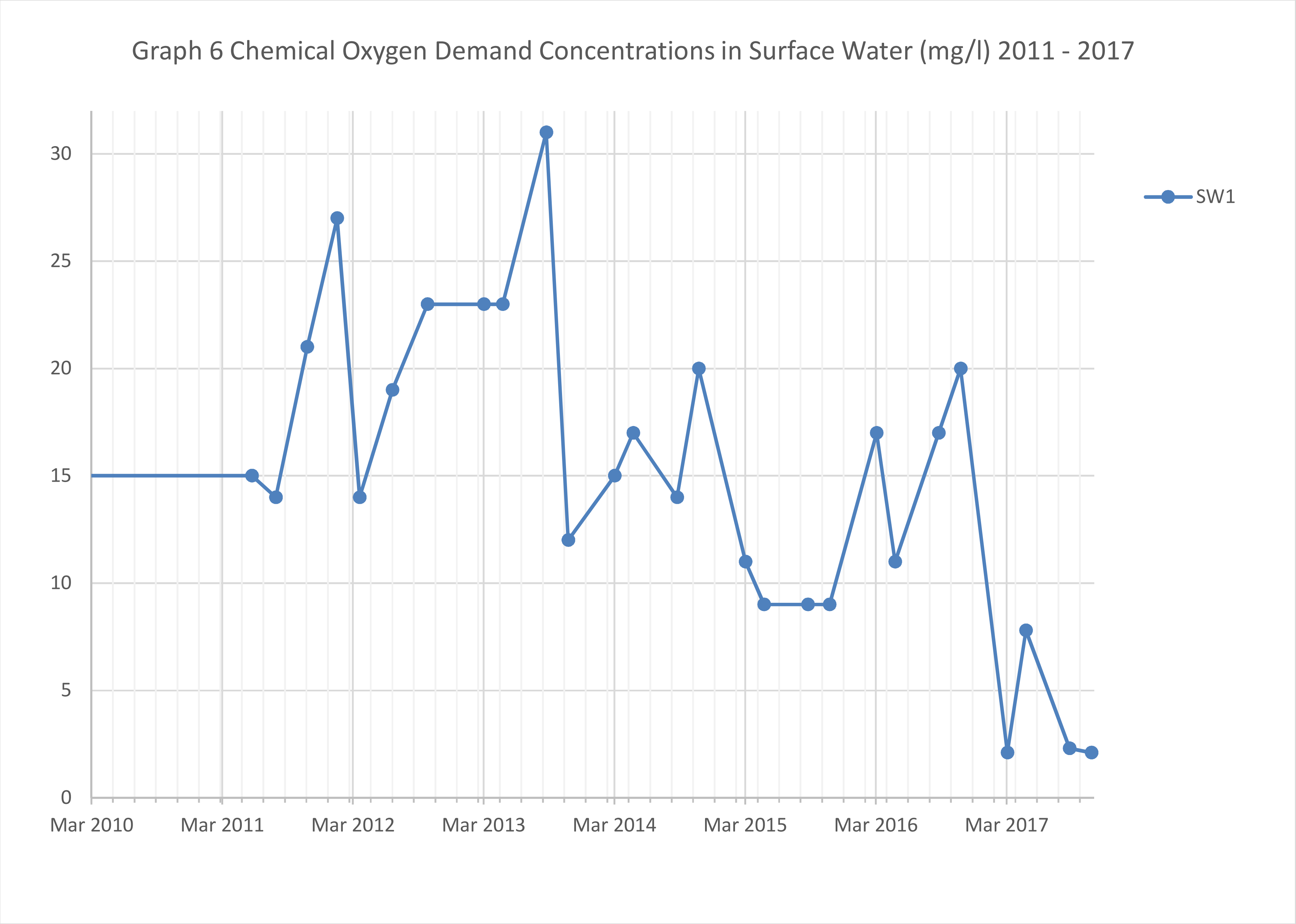

Graph 3 Concentrations of Dissolved Iron in Groundwater (mg/l) 2010 - 2017
1
0.8
0.6
0.4
0.2
0
Mar 2010
Mar 2011
Mar 2012
Mar 2013
Mar 2014
Mar 2015
Mar 2016
Mar 2017
IGV: 0.2 mg/l
MW7
MW8
MW9



Graph 4 Concentrations of Ammonia in Surface Water (mg/l) 2011 - 2017

Graph 5 Concentrations of Chloride in Surface Water (mg/l) 2011 - 2017




Graph 6 Chemical Oxygen Demand Concentrations in Surface Water (mg/l) 2011 - 2017
30
25
20
15
10
5
0
Mar 2010
Mar 2011
Mar 2012
Mar 2013
Mar 2014
Mar 2015
Mar 2016
Mar 2017
SW1

Figures