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Tier 2 Hydrogeological Risk Assessment: Ballyjamesduff Landfill

Location:	Derrylurgan, Ballyjamesduff, Co. Cavan
Prepared for:	Cavan County Council
Prepared by:	Pat Breheny MSc (Hydrogeology)
Prepared by:	Colin O'Reilly PhD (Hydrology)
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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 Ltd was retained by Cavan County Council to undertake a Tier 2 hydrogeological assessment of a historic closed landfill facility at Derrylurgan, Ballyjamesduff, County Cavan. Following submission of a Tier I hydrogeological 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:

- Tier II hydrogeological risk assessment report, including figures and appendices;
- Provide a clear statement on whether the site is compliant with the 'prevent' or 'limit' objectives of the Water Framework Directive and Ground Water Directive;
- Current Trended results for Contaminants of Potential Concern (CoPC);
- Clarification on if there are any domestic wells in the vicinity of the facility.

The Tier 1 report submitted for the site proposed that a number of additional recommendations were to be carried 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 2 risk assessment. This work included the following tasks:

- **Task 1** - Drilling and installation of two deep groundwater monitoring wells downgradient of the site, subsequent logging of soil cores extracted. and undertake permeability testing of selected wells;
- **Task 2** - Collection and laboratory analysis of groundwater samples from the newly installed monitoring wells MW19D, MW20D (in addition to the annual compliance monitoring locations);
- **Task 3** - Data interpretation and presentation of a summary report, to include an updated graphical conceptual site model.

Site Description

Site Location

The site location is indicated on Figure 1. Site area is equal to 1.42 ha. The site is located within the townland of Derrylurgan, 0.5 km north of Ballyjamesduff, a medium sized rural town in south County Cavan. A local road on the western site boundary connects Ballyjamesduff with the N3 at Killygrogan. The regional road R196 connecting Ballyjamesduff with New Inn passes 130 m east of the site at its closest point.

Topography is typical of a drumlin landscape, with pre-development elevation at the site around 92 - 94 mOD. The drumlin ridges appear to be elongated generally along a southeast orientation, peaking between 120 - 180 mOD. The site is located on a minor valley floor between the toe-slope of a drumlin ridge immediately west, and a more rounded drumlin hill to the immediate east.

Depressions within this undulating landscape are generally occupied by bodies of water, connected by a dense network of streams and rivers. A south-flowing stream runs adjacent to the eastern site boundary. The narrow valley within which this stream flows gradually widens out to the southwest approaching Lough Sheelin.

Land use in the surrounding area north of the site is almost exclusively grassland, supporting dairy, beef and sheep agriculture of low to moderate intensity. Land quality in the topographically depressed areas is poor in terms of agricultural production. Housing density north of the site is typical of one-off rural housing.

Development considered part of Ballyjamesduff starts immediately south of the site with a cluster of derelict sheds, south again of which is a housing estate. On the eastern side of the stream adjacent to the site is a large industrial facility (Cavan Box Ltd.). A linear cluster of houses run parallel to the local road 170 m to the west of the site.

Site Layout

A site layout map is presented in Figure 2. The site is approximately rectangular along a northwest-southeast orientation, with approximate length 140 m and width 100 m. The site boundary is defined by a steel fence.

Activities on the site prior to the landfill are assumed to be agricultural grassland. Ballyjamesduff Landfill has been operated as a waste disposal facility by Cavan County Council since the late 1960s, and was closed in March 2002. It is believed that the site was selected due to the underlying peat bog which it was believed would promote attenuation, dilution and dispersal, and the protection offered to groundwater by site lithology.

The site was operated as a traditional landfill. Between the documented period 1988 - 1994 the landfill accepted on average, annually, 70 tonnes of inert waste, 530 tonnes of non-hazardous waste, and minor quantities of hazardous waste. These volumes increased gradually between 1994-1999 to a total of 1,500 tonnes per annum. Total quantity of waste deposited over the lifetime of the landfill is estimated to be 65,000 tonnes. Based upon previous reports it has been assumed that infilling of waste took place from north to south, and that there is up to 2 m of waste below the original ground surface.

Elevation at the site perimeter is relatively flat and marginally higher (~93 mOD) than the natural surrounding low-lying lands. The banks of the waste cell are relatively steep-sided toward a maximum elevation of 101.8 mOD at the top, which is a small, reasonably level plateau. Access from the road is at the northwest corner, where there is a small flat area, used for temporary parking; this area has a gravel surface. There is no hardstanding within the site.

Inside the perimeter is a 300 mm toe drain to collect surface runoff from the landfill cap. The outfall of this drain to the south-flowing Pound River is in the southeastern corner of the site. The south-flowing Pound River runs parallel to the eastern boundary, with a small separation distance of 7-10 m.

Prior to closing the site in 2002 a temporary cap was placed on site. The landfill was then permanently capped in 2006. A fully engineered and lined system was installed, consisting:

- an upper component consisting of 150 mm of topsoil on
- an 850 mm layer of subsoil on
- a geo-composite surface water drainage layer on
- an LDPE liner on
- a geo-composite gas collection layer on
- 250 mm regulation layer (where necessary) on
- re-graded landfill surface or filled waste.

Desk Study

Soils

Drumlins are a glacial feature consisting a thick cover of boulder clay deposited in the form of small hills, typically oval in plan. The drumlins stretch from Leitrim and Longford, through Cavan and Monaghan, towards Down.

Figure 3 shows deep-poorly drained acidic mineral soils dominating the landscape, this soil unit occupying much of Cavan. It is classified by Gardiner and Radford (1980) as a 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 this 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. Between Nadrageel Lough, to the north of the site, and Ballyjamesduff, the Pound stream is mapped in peats, rather than alluvial deposits, which infers it may have been installed as part of an OPW drainage scheme.

The site is located within the southern extent of these same peat deposits that occupy topographically depressed ground between two drumlin ridges. Peats are apparent when previously submerged lake beds dry out, or previously dry soils have degraded due to seasonal or more persistent waterlogging.

Subsoils

Figure 4 shows that the heavy impermeable boulder clay tills are formed from Namurian shales and sandstones. Subsoil depth is deeper in the valleys, thinning somewhat, in some cases enough to expose bedrock, on elevated areas and steeper slopes. The site itself is predominately underlain by peat and low permeability clayey gravels (base of peat).

Bedrock & Structural Geology

Figure 5 presents bedrock and structural geology. The site is underlain by the Oghill Formation, a sandstone and microconglomerate belonging to the bedrock group Silurian metasediments and volcanics. The massive nature of this formation means it is unlikely to have dense fracture networks or weathered zones that will promote permeability.

The main structural features have a southwest-northeast trend, with northwest trending cross faults highlighting displacement of some formations. A mapped fault to the south of the site separates the Oghill Formation from the Castlerahan Formation, comprised of black shales of Lower Palaeozoic age. These formations form part of the geological structure known as the Longford-Down Massif and are known to be of low permeability.

GSI bedrock data in the area is limited but shows that the depth of glacial overburden is highly variable:

- bedrock met at approx. 40 m in a 55 m deep borehole, 1500 m north of the site;
- bedrock met at 19.5 m in a 40 m deep borehole at Ballyjamesduff Co-Op (estimated yield 87.2 $m^3 d^{-1}$);
- bedrock at 7 m in an unspecified well used for industrial supply, within 500 m of the site;
- bedrock at 4.9 m in Kilmore, within 1 km northeast of the site.

During recent site investigation works which involved the installation of two deep groundwater monitoring wells at the site (MW19D and MW20D) bedrock was encountered at approximately 8.5 m below ground level at both locations. No bedrock exposures were observed close to the site.

Aquifer Classification

The Oghill Sandstones are classified as a poor bedrock aquifer, moderately productive only in local zones. The aquifer is capable of supplying small abstractions. Groundwater flow occurs predominantly through a limited and poorly connected network of fractures, fissures and joints, and the permeability through these tends to decrease with depth. A shallow zone of increased permeability may exist along the top few metres of fractured/weathered rock. Overall permeability, storage capacity, recharge acceptance, length of flow path and baseflow are likely to be low. Groundwater discharge to streams as baseflow can significantly decrease during drier periods.

There are no karstified limestones in the area. The nearest karst features to the site mapped 20 km to the south, at Fore.

The site lies within the Inny GWB. The Inny GWB is large, and extends to Lough Ree. Given the scale of this groundwater body there is no relevant hydrogeological data specific to the Oghill sandstones. Relevant information in the adjacent Bailieboro GWB is also limited.

Historical drilling records from Liffey Meats reported exceptionally poor yields (K.T. Cullen, 1999).

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 moderate, derived from a 5-10 m thick layer of low permeability subsoil (in this case peat) overlying bedrock. On raised ground, and as a function of decreasing subsoil depth, vulnerability increases to High through to Extreme.

Recent site investigation works at the site confirmed that the bedrock aquifer is overlain by peat deposits up to 6 m deep in undisturbed areas and borehole logs will be used to establish site-specific vulnerability.

Landfill Vulnerability Classification

The GSI groundwater protection scheme operates a classification scheme that assesses the site suitability of a landfill based on hydrogeological factors. Based on a poor aquifer (Pl), and moderate vulnerability, Ballyjamesduff Landfill is assigned a response matrix R2[1]. This is deemed to be acceptable subject to the condition:

- *special attention should be given to checking for the presence of high permeability zones. If such zones are present then the landfill should only be allowed if it can be proven that the risk of leachate movement to these zones is insignificant. Special attention must be given to existing wells downgradient of the site and to the projected future development of the aquifer.*

Recharge

Gridded rainfall data from Met Éireann (Walsh, 2012) 1981-2010 = 1036 mm yr^{-1}

PE (Clones, 35 km north of site) = 438 mm yr^{-1}

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

ER (AAR-AE) = 1036 - 416 = 620 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 recharge coefficient applicable to moderate vulnerability and basin peat is 4%, with this representing infiltration below the waste material. As the landfill has been capped with approximately 1 m of imported subsoil, there may be a separate recharge coefficient at the ground surface, represented by moderate permeability subsoil overlain by 'poorly drained' soil, yielding a recharge coefficient of 33%.

w = annual recharge to waste material, $m^3 m^{-2}$ = 33% ER = 33% of 620 mm = 0.2046 $m^3 m^{-2}$ = 0.0006 $m^3 m^{-2} d^{-1}$

w = annual recharge to bedrock, $m^3 m^{-2}$ = 4% of 0.2046 $m^3 m^{-2}$ = 0.008 $m^3 m^{-2}$ = 0.00002 $m^3 m^{-2} d^{-1}$

Source Protection Area (SPA)

The site does not appear within source protection areas to any public groundwater abstractions, as mapped by the GSI or EPA. The closest SPA to the site is 15 km southwest at Finea, 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

Catchment Delineation

It is important to consider the surface water catchment, and any other potential upgradient sources of contamination to the Pound Stream, and the fate of any potential contaminants downstream.

The upgradient catchment to the Pound Stream where it passes adjacent to the site is approximately 14.5 km^2. The headwaters of the catchment, as shown in Figure 7A, originate in the townland of Aghadreenagh, 7 km north of the site. From here the stream flows directly south toward the site, through a fairly narrow contributing area, as defined by the ridges and valleys flanking it on either side. The upgradient catchment to the site consists of agricultural lands and farmhouses, with a small number of pig-rearing facilities.

A large pair of loughs, referred to as the singular Lough Nadrageel are located 1.3 km north east of the site. These waterbodies are separated by a small canal, and this appears to define a catchment divide, with only the western lough draining to an outflow point in its southwestern corner, that joins the Pound Stream. The contributing area to the inflow of this western lough would seem relatively small. Lough Nadrageel west is the source for the Ballyjamesduff Regional Water Supply scheme. The population served under this scheme is 2900.

Figure 7B shows the surface hydrology in the immediate vicinity of the site. The stream is relatively straight and slow moving as it flows south by the eastern site boundary. The separation distance between the infill area and the stream is between 10 - 20 m. Stream gradient along this section is very shallow.

The local road 170 m west of the site (Cavan Road) represents a drumlin ridge top. Elevation west of this road falls toward the site, steeply at first to the rear of a linear arrangement of local houses, before flattening out to a wet, boggy area opposite the site. This area is drained by a series of open field drains, some of which have silted up, These drains flow into another very slow moving collector drain on the western side of the local road, opposite the site. This cut-off drain prevents surface waters generated on fields to the west from entering the site. This drain is diverted east through a culvert and flows east along the northern site boundary. This is also a cut-off drain that prevents surface waters from fields to the north from entering the site, and enters the Pound stream adjacent to the northeast site corner. The site survey was preceded by a dry period, though these drains all contained surface water. This high water table would confirm the poorly drained nature of the area.

Inside the perimeter is a 300 mm toe drain to collect surface runoff from the waste cell. The outfall of this drain to the Pound Stream is in the southeast corner of the site. A minor subsurface drain is also mapped as entering the site along the southern boundary. This also originates on lands on the opposite side of the local road.

Cavan Box manufacturing facility is on the eastern side of the stream and downgradient of the site, while the urban section of the town borders the stream further south.

Figure 7C shows the downgradient route of the Pound Stream, which initially flows through the centre of Ballyjamesduff, where it has been recently upgraded as part of a community scheme.

The primary sources of contamination in this area would be Liffey Meats, Ballyjamesduff Co-Op and the urban wastewater treatment plant discharge. Ballyjamesduff wastewater treatment works are located 300 m east of the town centre. It treats a population equivalent of 1930, and normally discharges 395 m^3 d^{-1}.

Stream gradient for the first 1 km downgradient of the town is steep, leveling out thereafter. A number of tributaries enter the Pound Stream, as it flows toward Mountnugent 6 km southwest of the site, before it outfalls to Lough Sheelin, 7.5 km southwest of the site.

Designated Areas

Lough Sheelin is a Special Protected Area and proposed Natural Heritage Area. Sheelin is a medium to large sized lake, that lies near the top of the catchment of the Inny River, a main tributary of the River Shannon. The lake has suffered from significant pollution in the past.

Flood Risk

The OPW Flood maps show that the site, adjoining areas, and the low-lying parts of the upgradient catchment are all classified as benefitting lands. This infers that the OPW may have performed restoration works as part of a drainage maintenance scheme. Much of these works took place in the 1960s - 70s. It may also indicate that the low-lying areas are artificially drained. The pFRA maps also show an area liable to be at risk of 1 in 100 year flooding to closely match this area of benefitting lands.

The OPW Flood Maps show the centre of Ballyjamesduff as being prone to flooding after heavy rainfall, due to the Pound Stream overflowing its banks. This occurs approximately every second year and properties and sewerage works are affected.

The 2012 AER makes a reference to flooding in the south east corner of the site which prevented a sample being retrieved from the cap discharge point.

Low Flows

Low flows in the Pound stream as it passes through Ballyjamesduff are given as 0.02 and 0.006 m^3 s^{-1} for 95%ile and dry weather flow, respectively.

Surface Water Flows

There are no long term records of flow or surface water elevation in the Pound Stream as it passes the site. Consideration should perhaps be given to installing a staff gauge in the stream which would facilitate recording surface water elevation, along with groundwater levels, at each monitoring visit.

Hydrogeology

Groundwater Wells

Summary details of existing on-site groundwater wells are presented in Table 1. These wells wells were installed at different times for different reasons over a period of more than then years. Borehole design was specific to a particular application at that time. The available information shows:

- MW1-MW7 were installed in 1999 using a window sampler. Borehole depth is 2.0 m in each case, and wet peat was recorded below 0.5 m topsoil. Static water table was in the range 0.55 - 1.30 m btoc in these boreholes.

- MW8 was also installed during 1999 using shell and auger. This borehole is 3.0 m deep. A 2.2 m thick layer of domestic waste was recorded above a peat layer.
- MW9, MW10, MW11S, MW11D were installed between 1999 and 2001.
- MW16S, MW16D, MW17S, MW17D and MW18D were installed in 2009, to replace wells that had been lost during local road restoration works.
- MW19D and MW20D were installed along the eastern boundary of the site in November 2017.

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, m	Depth to water table 20/08/13	Static water table, mOD
MW1	252021	291352	93.15	94.19	2.4	2.26	91.93
MW2	252083	291378	92.59	92.59	2.0	0.77	91.82
MW3	252110	291369	93.17	93.94	2.77	1.99	91.95
MW4	252139	291315	92.49	92.79	2.30	borehole blocked	
MW5	252144	291290	92.30	92.60	2.0	borehole blocked	
MW6	252073	291281	99.57	100.47	2.7	tape refused @ 2.60	
MW7	252054	291292	96.33	97.30	2.73	dry	
MW8	252042	291347	95.42	96.18	5.30	4.10	92.08
MW9	252104	291370	94.48	95.37	4.50	3.41	91.96
MW10	252129	291310	92.86	93.51	3.40	1.65	91.86
MW11S	251835	291289	106.44	106.44	5.00	2.90	103.54
MW11D	251835	291289	106.44	106.44	30.00	11.91	94.54
MW12	252110	291237	93.20	94.13		1.49	92.64
MW13	252043	291293	93.53	94.47		1.92	92.55
MW14	252132	291264	97.38	98.35		tape refused @ 3.62	
MW15	252148	291281	92.41	92.88		1.10	
MW16S	252077	291175	93.90	93.90	5.00	0.89	93.01
MW16D	252077	291173	94.05	94.05	10.00	0.00	94.05
MW17S	251997	291377	93.45	93.45	5.00	1.20	92.25
MW17D	251998	291376	93.48	93.48	15.00	0.31	93.17
MW18	251987	291405	93.37	93.37	21.00	artesian	>93.37
MW19D	252133	291297	**92.345**	**92.89**	**12.00**	**artesian**	**93.32**
MW20D	252111	291379	**92.587**	**92.98**	**12.00**	**artesian**	**93.15**

Borehole logs for recently installed wells MW19D - MW20D are presented in Appendix A. Depth to bedrock in both wells was confirmed at approximately 8.5 m below ground level. A summary of the underlaying geology at both locations indicates a deep layer of peat from 0 - 6 metres, a thin layer of marl type clay underlain by gravelly clay. Weathered bedrock was noted from 6 - 8.5 m bgl (approximately). Both wells were advanced into bedrock to a depth of approximately 12.0 m (bgl) and screened at the base of each well. A bentonite seal was installed above the screened sections to prevent shallow groundwater mixing with deep groundwater within the aquifer. Artesian groundwater conditions were observed at both well installations. Static groundwater level was determined by installing a length of temporary casing to a height above potentiometric groundwater level.

Similarly, to facilitate permeability testing on wells displaying artesian behaviour (MW17D & MW16D), remedial works were carried out at each location which involved temporarily extending casing height above ground level by attaching extra vertical casing (ensuring watertight conditions), to a height that will facilitate recording of a potentiometric groundwater level.

Permeability testing was undertaken at MW17D and MW16D to estimate the hydraulic conductivity of the underlying bedrock formation. Permeability values within the bedrock ranged between 0.3 m/day (3.5 x 10^{-6} m s^{-1}) and 0.37 m/day (4.3 x 10^{-6} m s^{-1}). The permeability of the overburden geology was previously calculated as 5 x 10^{-7} m s^{-1} (0.04 m/day).

The above bedrock permeability suggests a relatively narrow K range for the underlying bedrock aquifer, the range indicative of a low permeability system. Groundwater flow within this strata would be dominated by fracture flow (indicated as water strikes on borehole logs).

An additional leachate well was scheduled as part of the drilling programme. However, due to the steep nature of the landfill side slopes and the wet conditions at time of site works, the drilling rig could not access the top of the waste cell. It is intended that installation of this additional leachate well be scheduled during spring/summer 2018.

Well Survey

A third party well survey was completed previously during the Tier 1 Assessment for the site. Cavan Box which is located southeast of the site was visited, where the site caretaker confirmed that the facility is supplied by mains water and not an on-site groundwater source. All local houses within 400 m of the site are supplied by mains supply, believed to be sourced from Lough Nadrageel. The farmyard north of Cavan Box was visited but the owner of the holding was absent. Ballyjamesduff Co-Op appeared in the well search as having a groundwater supply. However this is on the opposite side of the Pound River and was therefore not included in the well survey.

Groundwater Levels & Flow Direction

A review of the most recent recorded groundwater levels was undertaken (see Table 1). These levels were used to compile a groundwater contour map of shallow and deep groundwater flow at the site. The shallow (overburden) groundwater contour map shows that groundwater flow direction follows surface topography, flowing generally west to east. The lack of boreholes between MW11S and the road adjacent to the landfill gives the appearance of a relatively uniform hydraulic gradient. The hydraulic gradient shallows as one approaches the toe-slope of the local east facing drumlin slope. The groundwater elevation at MW1 skews the lowest contour slightly, this likely resulting from its proximity to the cutoff drain. Groundwater elevation recorded in the eastern site boreholes are approximately level with surface water elevation in the Pound Stream, suggesting these flows may be in continuum with one another.

It is worth noting that there is some peripheral drawdown of water along the western and northern site boundaries, toward the cutoff drains. These flows will be very localised but may result in migration of a small amount of leachate into these drains. Once in the cutoff drains, any pollutants will be carried around to the Pound Stream.

Groundwater flows within the bedrock aquifer are illustrated in Figure 8B, groundwater flow within the aquifer flows generally from southwest to northeast from the local topographic high towards the Pound stream.

Static bedrock groundwater levels are higher than those observed in overburden, at the same locations. The data infers that the bedrock aquifer is confined, with recharge to the aquifer likely to be occurring on higher ground where soil depth is thinner and is composed of overburden with drainage characteristics typically better than those attributed to peats. This bedrock groundwater is then held under the peat layers, which can create a rise in bedrock piezometric head.

Since the landfill was permanently capped groundwater level has been consistently measured at the following boreholes: MW3, MW4, MW9, MW10, MW11S, MW11D, MW16S, MW17S, MW17D. The following boreholes remain suitable for monitoring groundwater level: MW1, MW2, MW8, MW12, MW13, MW15;

The range of water table levels across all boreholes in the vicinity of the landfill is narrow, and water table appears to be close to natural surface level. It can be concluded that there is little response to rainfall. A review of shallow groundwater levels in the vicinity of the site suggests that groundwater flow beneath (and potentially through the lower parts of the waste cell) the site is from lands to the west of the site, eastwards toward the Pound Stream. Peats located on the eastern side of the waste cell, to a depth of 6 m, may inhibit shallow subsurface flow towards the stream.

Hydrochemistry

There is a reasonably good monitoring infrastructure at Ballyjamesduff landfill, and there has been close monitoring since 2000, with data 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. Chlorine 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.

Groundwater Quality

The Waste License stipulates that there shall be monitoring at MW1, MW2, MW4, MW7, MW9 and MW10. Of these wells MW1 and MW2 have not been monitored, likely due to difficulties in purging and recovering sufficient amounts of water. Recorded data for the remaining wells is incomplete, with intermittent time intervals missing from the record.

For the purposes of interpretation wells within close proximity to the waste cell shall be referred to as “landfill wells” and wells upgradient/downgradient of the waste cell referred to as “peripheral wells”, with groupings as follows:

Landfill Wells:

- MW3, MW7, MW8, MW9, MW10 are all positioned on the waste mound and therefore considered to be within the waste cell and more representative of leachate impacted wells.

Peripheral Wells:

- MW16D, MW17D and MW18D are bedrock monitoring boreholes, upgradient of the landfill; MW16S and MW17S are upgradient boreholes positioned in the overburden. MW4 is downgradient of the waste cell and positioned in the overburden.
- Newly installed groundwater wells MW19D and MW20D are downgradient bedrock monitoring boreholes.

Trended results for COPC’s at the above locations are illustrated in Graphs 1 - 6 (Appendix B). Monitoring wells MW11D and MW11S are significantly upgradient of the landfill site. Elevated chloride levels observed in these wells has been attributed to the storage of silage bales at this location, and the leaching of silage effluent from same. Given that top of casing is below ground level it is probable that the well is susceptible to pollution from silage effluent. The borehole is on third party lands and there is little scope to increase top of casing elevation as a mitigation measure. In its current state, MW11S is not considered a good representation of upgradient shallow groundwater quality. There is no benefit in sampling MW11S in future. For the purposes of the Tier 2 assessment water quality data from both locations has been omitted from the trended figures

Conductivity

Conductivity is elevated (800 - 1300 µS cm^{-1}) in MW3, MW8, MW9 and MW10 and is typical of a leachate. The increased conductivity represents a higher concentration of free ions, promotion of ion-exchange and chemical processes associated with dissolution/precipitation as material comes into contact with groundwater. There appears to be a slight decrease in conductivity over time in these boreholes and this may infer that the lack of large variation in water table though the waste cell is not mobilising ions from fresh material.

Ammonia

Landfill Wells:

Ammonia is considered to be a good overall indicator of water quality impact attributable to unlined municipal landfills. Trends in ammonia concentrations at the site are presented in Graphs 1 and 2. With the exception of a spike in concentrations at well MW10 (Nov 2014), ammonia concentrations within the landfill wells appears to be within an elevated range of between 10 - 66 mg/l. Data suggests that ammonia concentrations within leachate impacted wells MW9 and MW10 have increased when compared with pre-capping concentrations. Given that these boreholes are positioned on the waste mound, it is likely that they were altered in some way as part of the capping process.

Ammonia concentration in MW8, representing leachate quality has been consistently elevated since 2000, with the most recent value equal to 38 mg l^{-1} (Q4, 2017). Concentrations in MW3 have declined while MW9 and MW10 are consistently elevated, typically between 20 - 40 mg l^{-1} (Graph 1). When compared with typical leachate ammonia values, observed in unlined landfills (EPA, 2010), concentrations in this range are consider low.

Peripheral Wells:

Ammonia concentrations within upgradient boreholes MW17D and MW17S appear to be intermittently elevated when compared to adjacent upgradient wells MW16 and MW18. However since Q2 2016 concentrations in both wells have declined markedly to a range below 2 mg/l. The most recent concentration of ammonia in MW17D during 2017 was 0.007 mg l^{-1} (Graph 2).

With the exception of a spike in concentration during Q2, 2015, ammonia levels in downgradient well MW4 appear to have declined consistently back to 0.59 mg/l (Q3, 2016).

Ammonia was below the IGV of 0.15 mg/l in both newly installed deep downgradient borehole MW19D and MW20D at 0.035 mg/l and 0.011 mg/l respectively. This suggests that any leachate generated is not penetrating to the bedrock aquifer.

Chloride

Landfill Wells: Chloride is a mobile constituent which is often used as an indicator of contamination. Historically elevated concentrations in excess of the IGV of 30 mg/l, were observed in MW3, MW8, MW9 and MW10 during the period 2011 - 2017 (Graph 3). Higher concentrations were observed in well MW10, between 100 - 140 mg/l as far back as Q2 2012; in the interim period spikes in ammonia concentrations at this location appear to be decreasing. The most recent result for this well during Q4 2017 concentrations dropped back below the IGV to 13 mg/l. Chloride concentrations in well MW3 have also exhibited elevated ammonia levels over time, during the most recent monitoring round levels in this well increased to 95 mg/l.

Peripheral wells: In general chloride concentrations within peripheral wells appear to be within a narrow range between 10 - 25 mg/l (Graph 4). Historic elevated spikes have been noted in wells MW17D, MW18D and MW4 between the period 2014 -

2015. With the exception of well MW16S (Q4 2012 = 32 mg/l), concentrations in the remaining peripheral wells including the newly installed well MW20D were below the IGV of 30 mg/l.

Chloride concentrations in well MW19D were elevated at 30 mg/l. The origin of this elevated result may be linked to contamination of upgradient deep well MW11D, where elevated chloride has also been recorded previously. As deep groundwater has been shown to be confined it may pass from MW11D to MW19D with no interaction with the landfill. The lack of chloride in MW20D suggests connection between MW11D and MW19D may be via discrete fracture flows. If this high chloride result was in some way linked to the migration of landfill-derived leachate to bedrock groundwater, elevated concentrations of ammonia would also be present in this well (MW19D).

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. 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. Iron and manganese data is collected annually as part of the monitoring program for the site, concentration trends for both parameters are illustrated in Graphs 5 - 8.

The highest iron concentrations are observed in the on-site boreholes: MW3, MW9, MW10, all of which are located on the landfill. Concentrations in these wells vary between 1 - 38 mg/l. Concentrations in MW10 peaked during Q2 2016 at 38 mg/l. These values were higher than would be expected from background geological or peat formations and typical of unlined landfill leachate. During the most recent monitoring round concentrations in this well dropped back to 2.8 mg/l.

With the exception of monitoring well MW17S concentrations of iron in peripheral wells is in a narrow range between 0.1 and 7.1 mg/l. Iron concentrations were as expected in the upgradient roadside boreholes except for MW17S, this may suggest that shallow groundwater in this location may be impacted with contaminated water associated with landfill waste.

Manganese concentrations in wells situated on the landfill: MW3, MW9, MW10, have exhibited high concentrations of manganese in the past (Graph 7). Concentrations within monitoring well MW10 remain high while levels in MW3 and MW9 have declined below 0.50 mg/l.

With the exception of MW4 which is slightly downgradient of the waste cell, manganese concentrations in peripheral wells have consistently declined towards a narrow range between 0.77 mg/l - 0.25 mg/l.

Other Parameters

Observations from other parameters measured are summarised as:

- pH conditions in overburden groundwater is generally neutral, or showing marginal acidity, attributed to the peat;
- pH conditions in bedrock are more clearly alkaline tending toward pH of 8;
- there are some detections of phenols in the on-site boreholes, these were all confined to 2010. Monitoring of phenols appears sporadic and consideration should be given to re-introducing this to the quarterly list of parameters for analysis.

Surface Water Quality

Surface water samples are taken at two monitoring points on a bi-annual basis, SW1 and SW2. SW1 is an upgradient monitoring point on the Pound Stream; SW2 refers to a downgradient monitoring point on the Pound Stream approximately 50 m south of the southern boundary.

Surface water quality trends (2005 - 2017) for COPCs, primarily ammonia and chloride at both the upgradient and downgradient sampling points, are presented in Graphs 9 and 10 (Appendix B). With the exception of the most recent spikes of ammonia in SW1 (May 2014 and May 2016) and SW2 (May 2015 and May 2016), long term trends in ammonia concentrations are within a relatively low range of (0 - 0.2 mg/l). The incidence of elevated concentrations as mentioned appear to have occurred during early summer months where it is possible that locally impacted groundwater in the vicinity of the landfill may be contributing increased baseflow to the stream during dryer periods (increased hydraulic gradient as stream level falls). Surface water quality may also be influenced by artesian flow from deep groundwater monitoring boreholes. Historical Data of COPC's including ammonia, orthophosphate and BOD concentrations indicate that historical landfill activity (operational phase) had a negative effect on the Pound River. In recent years overall concentrations of COPC's (with the exception of the aforementioned seasonal spikes) show a long term declining trend (Graphs 9 - 10).

It is clear from all of the graphs that there is no significant difference in surface water quality between the upgrading and downgradient sampling points. This would suggest one of two scenarios is occurring:

1. Surface water quality is controlled only by upgradient activities in the catchment, and the landfill is not effecting water quality in any way. This is considered unlikely. Confirmation is required from the local authority regarding the actual sampling locations and access.

2. The surface water quality monitoring points are too close to each other, and too close to the landfill. Migration of pollution from the landfill to the stream is occurring radially, or perpendicular to the entire eastern boundary. If this is the case, then a different surface water sampling strategy is required to detect any impact that the landfill is having on the stream. This may include extending the distance between the landfill and the upgradient and downgradient monitoring points, and adding an extra sampling point, adjacent to the midway point of the eastern site boundary. The upgradient surface water sampling point must be upgradient of the northern cutoff drain. Any extension of the downgradient sampling point could be at risk of introducing other downgradient contaminant sources so care is required when selecting this location (this may be difficult given the abrupt change to an urban environment downstream).

In summary:

- ammonia concentrations are satisfactory, generally around 0.1 mg l^{-1}, and below the 0.2 mg l^{-1} threshold value;
- conductivity values are in the range 100 - 300 µS cm^{-1};
- BOD values since 2007 have been less than or equal to 4, although the final value in 2012 showed a temporary increase to 5 and 6 in the upgradient and downgradient samples, respectively;
- with the exception of unexplained spikes (SW1) recorded chloride concentrations in surface water are showing a declining trend.

The recorded spikes in concentrations of COPCs during 2009/2010 have been attributed to the disturbance and likely sediment losses that occurred during, and immediately after, the capping process. Since 2010 there has been a general decline in concentrations of indicative parameters, which would suggest that the capping process was successful in the protection of surface water quality. Any future pollution of the stream along this stretch is therefore more likely to be associated with contaminants mobilised by overburden groundwater flow beneath the site toward the stream, or artesian flow from deep groundwater monitoring boreholes.

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 a west-east 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	Pound Stream
non-hazardous landfill material	leachate migration	Lough Sheelin SPA
precipitation	groundwater flow type and velocities	cutoff drains
sediment bound contaminants	groundwater flow direction	overburden groundwater
dissolved contaminants	throughflow from surrounding lands	bedrock groundwater

- The site is located in a minor drumlin valley, tucked between an elongated south tending drumlin ridge to the west, and a more typical drumlin hill to the east. The site is positioned on the western side of a slow moving river (Pound Stream) that drains the valley.
- Although the base elevation of the waste material is not confirmed, available literature suggests that it is not more than a couple of metres below ground level.
- The waste essentially sits on top of a 2-5 m thick peat deposit that occupies the valley floor underlain by approximately 1-3 m of low permeability glacial clay till.
- Bedrock is microconglomerate derived from shales and volcanics, with very low permeabilities of 1×10^{-6} m s^{-1}.
- The landfill exists as a mound, with a maximum height of around 10 m, and an overall footprint of 100 by 140 m.
- The site was closed in 2002 and a capping procedure took place between 2006-2009. 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, and there are several on the periphery of the site.

- Boreholes that penetrated bedrock returned static water level higher than those penetrating overburden only. This suggests the bedrock aquifer is confined.
- Overburden groundwater flow direction is generally to the east toward the Pound Stream. Peripheral cutoff drains designed to prevent shallow subsurface flow from passing beneath the waste cell have the effect of lowering water table, and thus draining the outer margins of the waste cell.
- There is no evidence that the landfill is lined. However the low permeability peat restricts vertical infiltration to bedrock. In addition to this there is no evidence to suggest that a head difference exists between the leachate and localised shallow groundwater outside of the waste cell. The negligible hydraulic head and low hydraulic conductivity of the peat seems to be preventing lateral migration of impacted water east towards the river. The low permeability peat also reduces the potential for natural attenuation.
- Permeability is so low in the peats that lateral flow rates will be minimal, and confined to the upper couple of metres. Any infiltration excess will flow as surface water runoff to adjacent drains.
- The main groundwater discharge is to the east toward the Pound Stream. The presence of a high water table, coupled with the low permeability of the overburden and bedrock, suggests most of the potential recharge will re-emerge in the local drainage network.
- The low range in seasonal water table means there is unlikely to be any prolonged immersion of fresh waste in groundwater in future years. This means there are no mechanisms that would promote an increase in pollution from the landfill in future.
- There is unlikely to be significant infiltration to bedrock. Using existing data, bedrock groundwater flow direction appears to be west to east also. The two recently installed downgradient bedrock boreholes have confirmed this.
- Groundwater vulnerability may be considered to be low, given that the depth of low permeability peat is greater than 3 m. Shallow subsurface water may be at risk given the high water table.
- With the exception of MW19D, groundwater quality taken from bedrock samples are generally good which reinforces the concept that there appears to be no vertical migration of leachate to the bedrock aquifer beneath the waste cell; (It is recommended to continue monitoring at MW19D to determine any trends of chloride concentration in this well).
- The risk of migrating leachate emerging in local surface water sinks is greater than risk of vertical migration to the bedrock aquifer.
- The surface water drain which conveys both runoff from the adjacent roadway and rainwater from the engineered cap has the potential to act as a pathway for impacted shallow groundwater reaching the stream.

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 overburden soils towards the Pound Stream bordering the eastern portion of the site.
    2. 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 Pound Stream and surface water drains bordering the site.

Source Area

The site covers an area of approximately 1.42 ha with approximately 80% of the area infilled with waste. The depth of the waste (above ground) is understood to be at least 6m in places. 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<5ha	7

Table 1b: Landfill Gas Hazard Score		
Waste Type	Foot Print	Score
Municipal	>1<5ha	7

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
Moderate	1

Table 2b: Leachate Migration Pathway Horizontal	
Groundwater Vulnerability (Horizontal flow)	Score
Poorly Productive Bedrock	1

Surface Water Drainage

Surface water drains border the site to the east and are considered to drain to the local watercourse.

Table 2c: Leachate Migration Pathway Surface Water Drainage	
Direct connection between surface water drains and local surface water streams	Score
Yes	2

Landfill Gas Migration Pathway

There are no permanent residential dwellings on the site, therefore landfill gas Table 2d only applies in this instance. The closest dwelling is within 150 m south of the site. A commercial premises is situated approximately 100m southeast of the site on the opposite bank of the Pound Stream. The risk assessment assumes that leachate and waste material are in direct contact with the underlying peat.

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 100 to 250 m of the southwestern and southern site boundary. Following a recent survey of the dwellings it is believed that drinking water is supplied via an Irish Water mains water scheme. 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
Greater than 50 but less than 250m from waste body	2

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 160 m from the northwestern site boundary.

Table 3c: Aquifer Categorisation- Resource Potential	
Aquifer Type	Score
Poor Bedrock Aquifer	1

Table 3d: Public Water supplies (other than private wells)	
Distance to PWS and aquifer type	Score
Greater than 1km-non karst aquifer	0

Leachate Migration Receptors (Ecological - Surface Water Bodies)

Table 3e below considered the risk to the closest surface water receptors. As stated an unnamed stream borders the site to the east.

Table 3e: Leachate Migration Receptors- Surface Water Bodies	
Distance to Surface Water	Score
Within 50m of site boundary	3

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	3

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	14 (400)	3.5%	Class C
Vertical migration to bedrock aquifer and migration to private well	1a x (2a + 2b) x 3a	28 (240)	11.6%	Class C
Leachate migration via groundwater and surface water drainage to the Pound Stream	1a x (2a + 2b) + 2c) x 3e	84 (300)	28%	Class C
Leachate migration via surface water drainage to the Pound Stream	1a x 2c x 3e	42 (60)	70%	Class A

SPR	Equation	Linkage Score and (max score)	Normalised score (as % of max)	Risk Classification
Landfill gas lateral migration to a human presence	1b x 2d x 3f	21 (150)	14%	Class C

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

- Lateral migration of dissolved-phase COPCs via shallow groundwater flow in the overburden soils towards the Pound stream bordering the eastern boundary of the site.

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

- Vertical migration of dissolved phase groundwater COPCs to the bedrock aquifer;
- Vertical migration dissolved phase groundwater COPCs to bedrock aquifer and potential migration to off-site private wells;
- Vertical and lateral migration of leachate via groundwater and surface water drainage to the local unnamed stream.

The most sensitive environmental receptor is considered to be the Pound Stream 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 peat layer surrounding the landfill to a depth of 6 m below surface which is impeding lateral shallow subsurface flow, and thereby leachate.

Site Compliance (Groundwater Directive)

The site operated since late 1960 as a traditional landfill, accepting non-hazardous waste. During the lifetime of the facility the base of the site was unlined, though it is mapped by the GSI as being underlain by low permeability peat. Prior to the site closure in 2002 a temporary cap was installed over the site. The landfill was then permanently covered in 2006 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 2002) would have been associated with rainwater percolating directly into the waste. The engineered cap has proven effective at limiting the production of leachate. It is possible that there is an indirect discharge to groundwater through the base of the waste cell. Monitoring has shown that the presence of low permeability peats beneath the waste cell, in combination with the engineered liner, limits vertical leachate migration and to some extend lateral migration. Deep groundwater beneath the site does not appear to be impacted by COPC's associated with leachate impacted groundwater at the site. In this regard the site is deemed to be compliant with the limit objectives of the Water Framework Directive and Groundwater Directive. The 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 (MW19D and MW20D), data gathered at these locations will be used to inform a 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 an historic landfill facility in Ballyjamesduff. Results of this assessment are summarised as follows;

Prior to closing the site in 2002 a temporary cap was placed on site. The landfill was then permanently capped in 2006. A fully engineered and lined system was installed. Inside the perimeter is a 300 mm toe drain to collect surface runoff from the site. The outfall of this drain is located in the southeastern portion of the site where it flows into the Pound River.. The south-flowing Pound River runs parallel to the eastern boundary, with a small separation distance of 7-10 m.

Two deep groundwater wells were recently installed on the eastern boundary of the site. Installation of these wells confirmed the underlying geology as being predominately low permeability peat to a depth of approximately 6 m below ground level. Based upon previous reports it has been assumed that infilling of waste took place from north to south, and that there is up to 2 m of waste below the original ground surface. Given the waste is deposited to a depth of 2 m bgl the remaining confirmed overburden (low permeability peat and clayey gravels) is considered to be an impediment to vertical and lateral migration of leachate to the underlying bedrock aquifer. In addition these two installations have confirmed the flow direction of deep groundwater at the site. A planned installation of an additional leachate monitoring well on top of the cap was postponed due to unsafe ground conditions.

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. A low-lying area to the southeast of the landfill cap appears to be impacted by COPC's associated with migration of leachate to surface water. An elevated chloride result was observed within newly installed deep well MW19D which is located in this area. The source of this chloride in deep groundwater in most likely linked to contamination at the upgradient bedrock MW11D. Given the artesian nature of MW19D and the concentrations of the remaining COPC's in this sample suggest that the source of elevated chloride is not as a result of leachate derived contamination. Future monitoring at this location should confirm this.

A Conceptual Site Model which was developed for the site during the initial Tier 1 assessment, the CSM has been updated to include data gathered during the most recent site investigation. The EPA Code of Practice was applied and a risk calculation for the site was completed. Applying the above methodology the site is classified as a Class A - High 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 Pound River. Results from the bedrock aquifer and the Pound River suggest that risk may be overestimated.

Recent intrusive investigations in close proximity and downgradient of the waste cell has shown that deep groundwater does not appear to be impacted by the presence of leachate within the waste cell. Future monitoring of bedrock wells MW19D and MW20D should confirm this. However, artesian flow from these and other deep groundwater monitoring wells may be impacting surface water quality.

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 shallow contamination on the eastern boundary of the site. Further information on the construction and condition of the culvert drain to the southeast of the site is may rule out the possibility that this structure is acting as a pathway for shallow groundwater reaching the River. Rehabilitation of MW4 which was not possible in November 2017 due to waterlogged conditions is also recommended. This can only be done manually in spring/summer conditions. Given that the area surrounding MW4 is surrounded by surface water from the Pound Stream during long-term winter flooding conditions, and given its proximity to MW10 and the river, it may be prudent to remove MW4 from the sampling schedule. It may be useful to install an additional surface water monitoring point, SW3, adjacent to MW4.

Technical Assessment Recommendations

The following additional measures are recommended to facilitate current data gaps within the Tier 2 Risk Assessment.

1. Install leachate monitoring borehole as outlined in previous subsection. Once installed the data collected can be used to assess the current decomposition phase of the waste within the cell. This will be done during spring/summer 2018.

2. It was recommended in the Tier 1 report that 'the distance of the upgradient and downgradient surface water monitoring points from the site is increased, and that another surface water monitoring point is installed adjacent to the mid-point of the eastern site boundary.

   Surface water quality at SW1 and SW2 does not appear to show significant difference. Clarification was requested from the local authority regarding the actual surface water sampling points being used. Following communication with the local authority it was confirmed that they have explored the feasibility of the Tier 1 recommendation, with the following outcome. The upgradient distance to SW1 could not be increased due to (i) land access restrictions, (ii) livestock in field posing risk to sampler, and (iii) flooding which makes underfoot conditions dangerous. The downgradient distance to SW2 could not be increased due to proximity of Cavan Box industrial facility on opposite of river.

   Surface water quality has been identified as the receptor most at risk. Detailed analysis of surface water quality trends over time has shown that it is generally of good quality and shows no deterioration as it passes the waste cell. Intermittent spikes in ammonia and chloride may be due to artesian flow from deep groundwater wells. Recommendation 3 aims to address this possible source of contamination. Following implementation of Recommendation 3 surface water sampling will proceed as per current regime to see if this measure eliminates the intermittent spikes in ammonia and chloride.

3. Raise inner PVC casing on all bedrock monitoring wells exhibiting artesian conditions to prevent direct flow of groundwater into surface watercourses.

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Appendix A: 2017 Borehole Logs

ENVIROLOGIC

HYDROGEOLOGICAL · HYDROLOGICAL CONSULTING

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

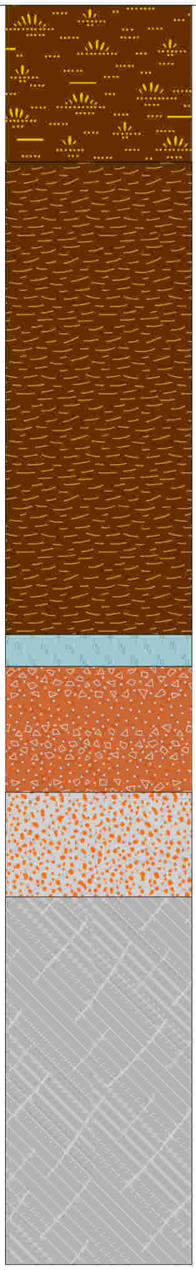
Borehole No.

MW19D

Coordinates:	252,133 / 292,297	Start Date:	14/11/17	Borehole Diameter:	140 mm
Ground Elevation:	92.35 mOD	End Date:	14/11/17	Screen :	50 mm PVC
Top of Casing Elevation:	92.89 mOD	Borehole Depth:	12.0 m	Depth to bedrock:	8.5 m below ground

DEPTH **DESCRIPTION** Static w.l.: 93.32 mOD **BOREHOLE CONSTRUCTION**

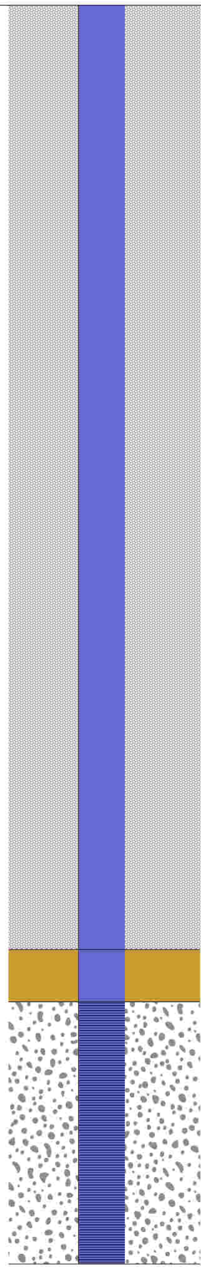
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0



Description
very soft, wet black spongy PEAT with some degraded plastic
damp, very soft , black spongy PEAT
very soft, damp, grey/blue CLAY
stiff, dark brown, damp gravelly (fine to medium, angular) CLAY
weak, angular GRAVEL. Gravels small to medium, slightly damp with iron staining on face of gravels
strong, competent SHALE bedrock

static gwl

water strike



50mm Plain PVC Casing

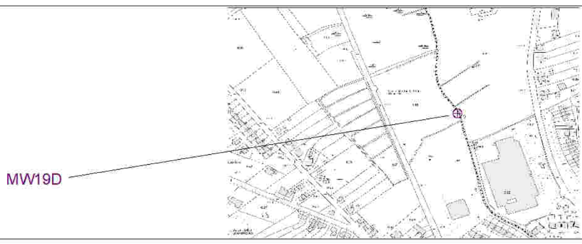
bentonite seal

sand plug

50mm Slotted PVC Casing

gravel pack

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.:	1524

ENVIROLOGIC

HYDROGEOLOGICAL · HYDROLOGICAL CONSULTING

Client: Cavan County Council

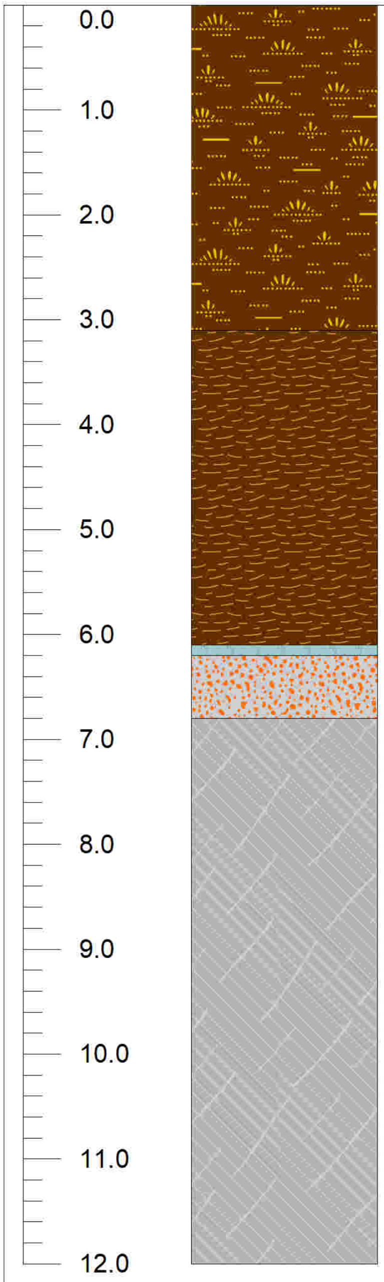
Project: Hydrogeological Risk Assessment

Location: Ballyjamesduff, Co. Cavan

Borehole No. **MW20D**

Coordinates:	252,111 / 291,379	Start Date:	13/11/17	Borehole Diameter:	140 mm
Ground Elevation:	92.59 mOD	End Date:	13/11/17	Screen :	50 mm PVC
Top of Casing Elevation:	92.98 mOD	Borehole Depth:	12.0 m	Depth to bedrock:	6.8 m below ground

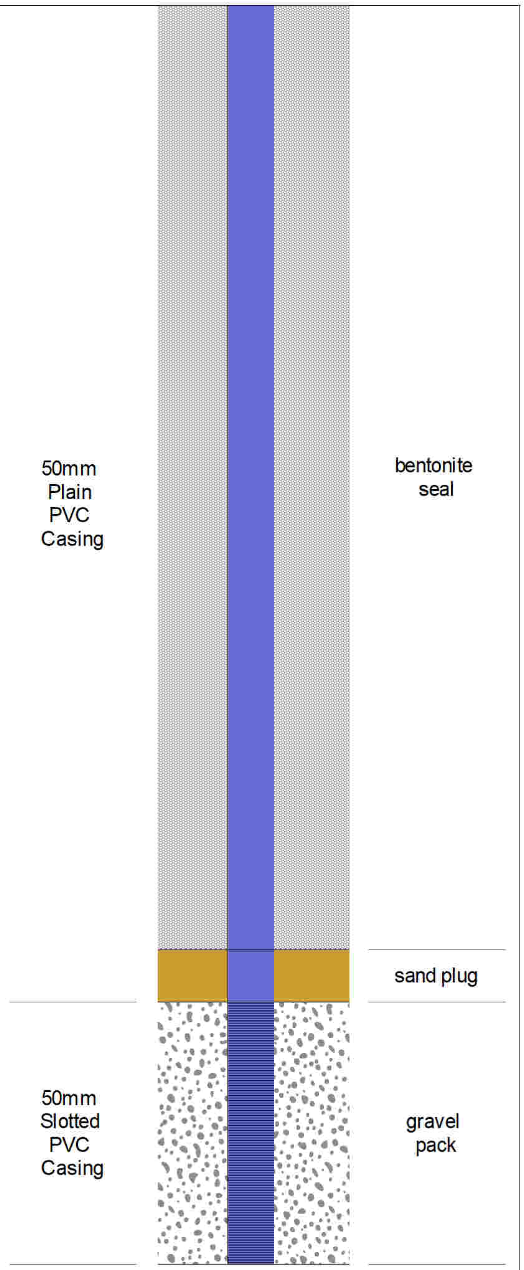
DEPTH | **DESCRIPTION** | Static w.l.: 93.15 mOD | **BOREHOLE CONSTRUCTION**



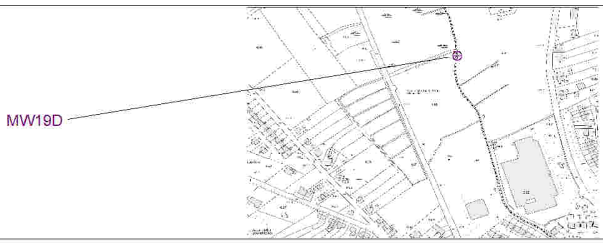
	Description
0.0 – 3.1	very soft, damp, black spongy PEAT with some waste between 0.6 - 2.0 m
3.1 – 6.1	damp, very soft , black spongy PEAT
6.1 – 6.2	very soft, damp, grey/blue CLAY
6.2 – 6.8	weak, angular GRAVEL. Gravels small to medium, slightly damp with iron staining on face of gravels (weathered bedrock)
6.8 – 12.0	strong, competent SHALE bedrock

static gwl

water strike



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.:	1524

Appendix B: COPC Water Quality Trends

Ammonia - Groundwater

Figure 1 - Ammonia Concentrations (mg/l) in Landfill Wells v Time (2010 - 2017)

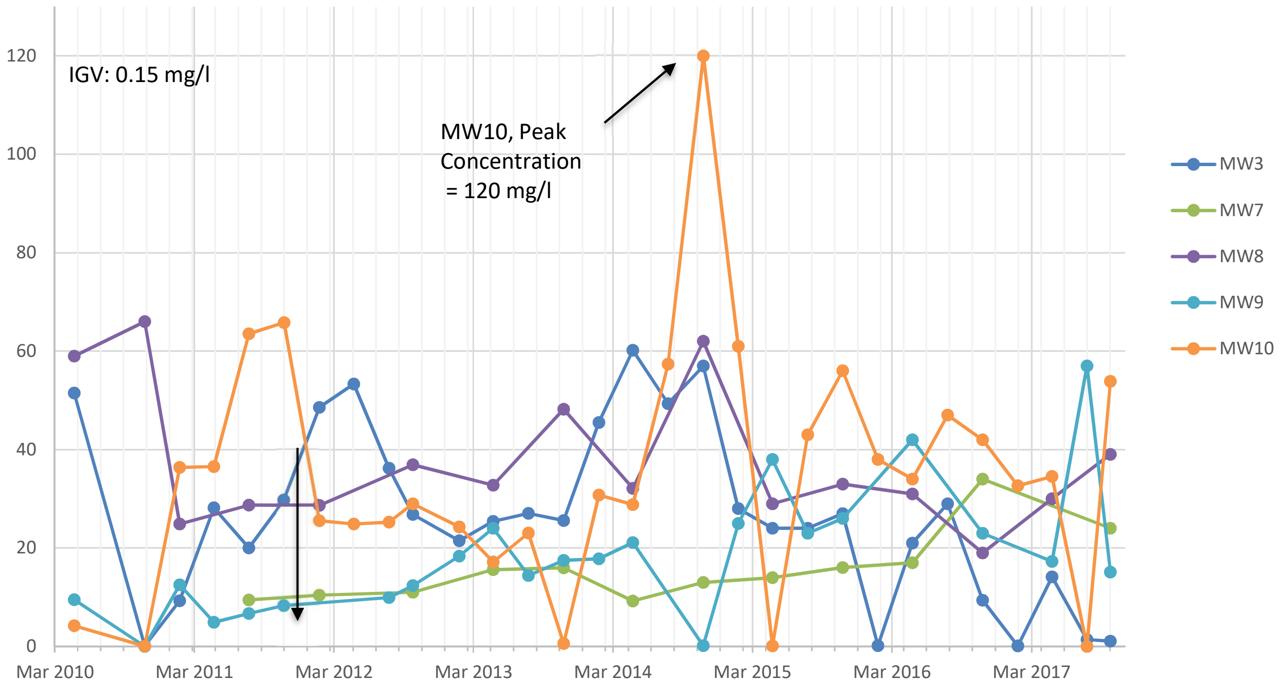
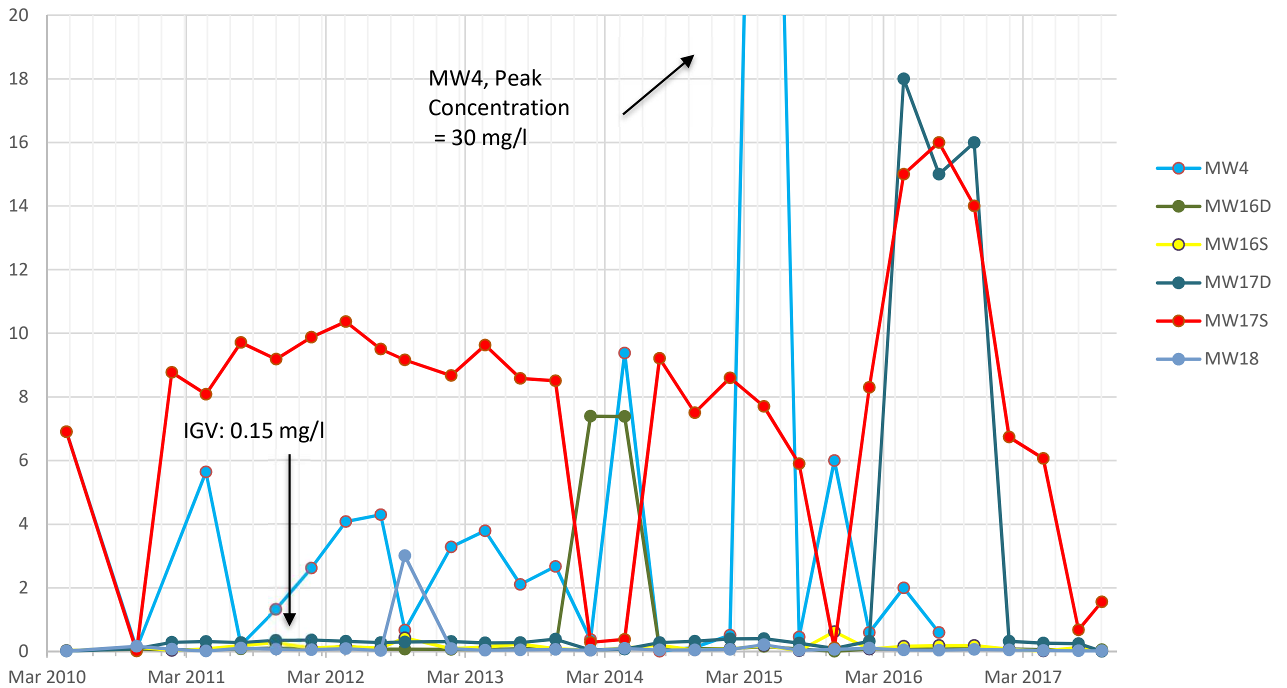


Figure 2 - Ammonia Concentrations (mg/l) in Peripheral Wells v Time (2010 - 2017)



Chloride - Groundwater

Figure 3 - Chloride Concentrations (mg/l) in Landfill Wells v Time (2010 - 2017)

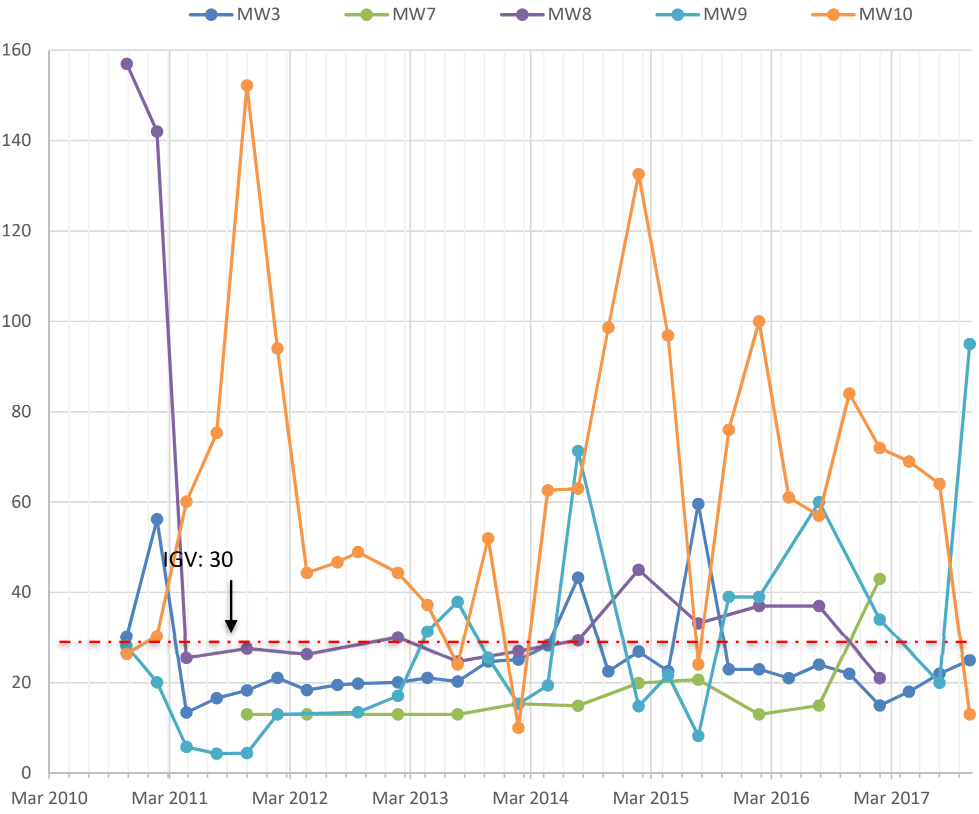
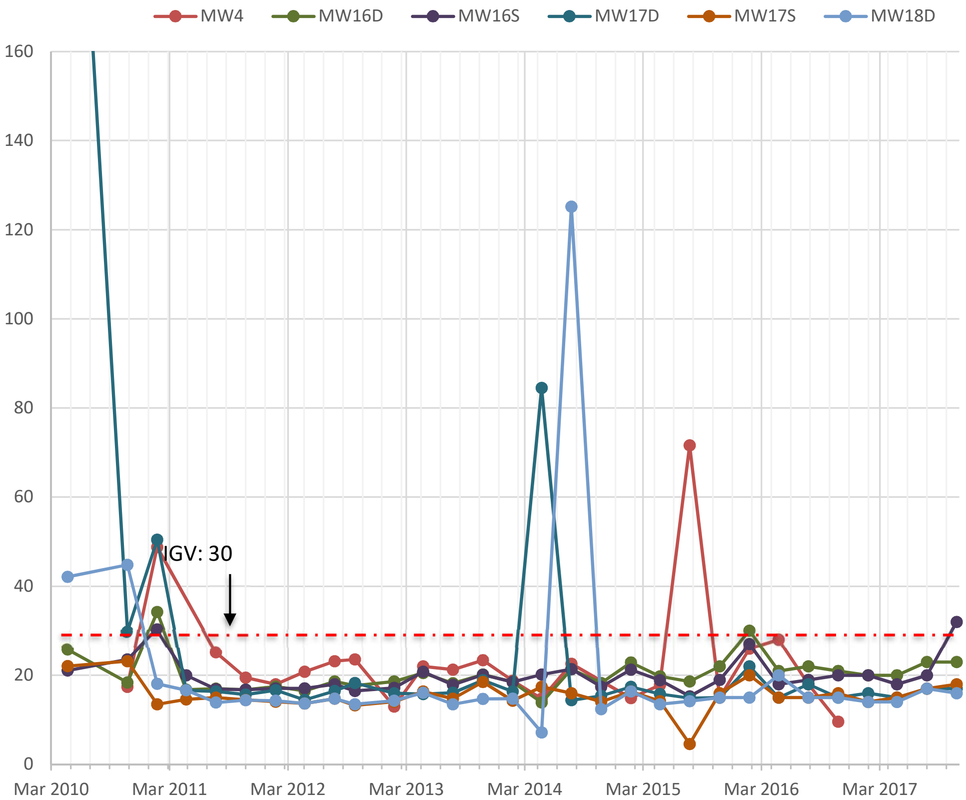
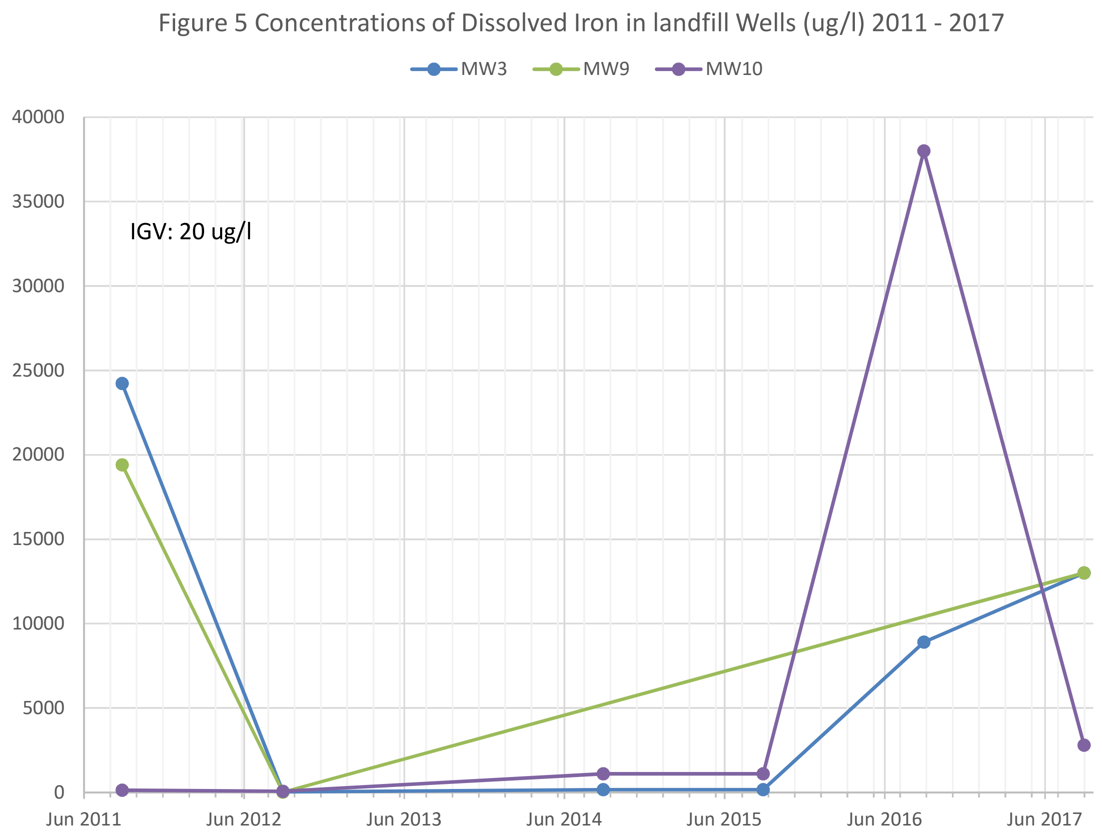
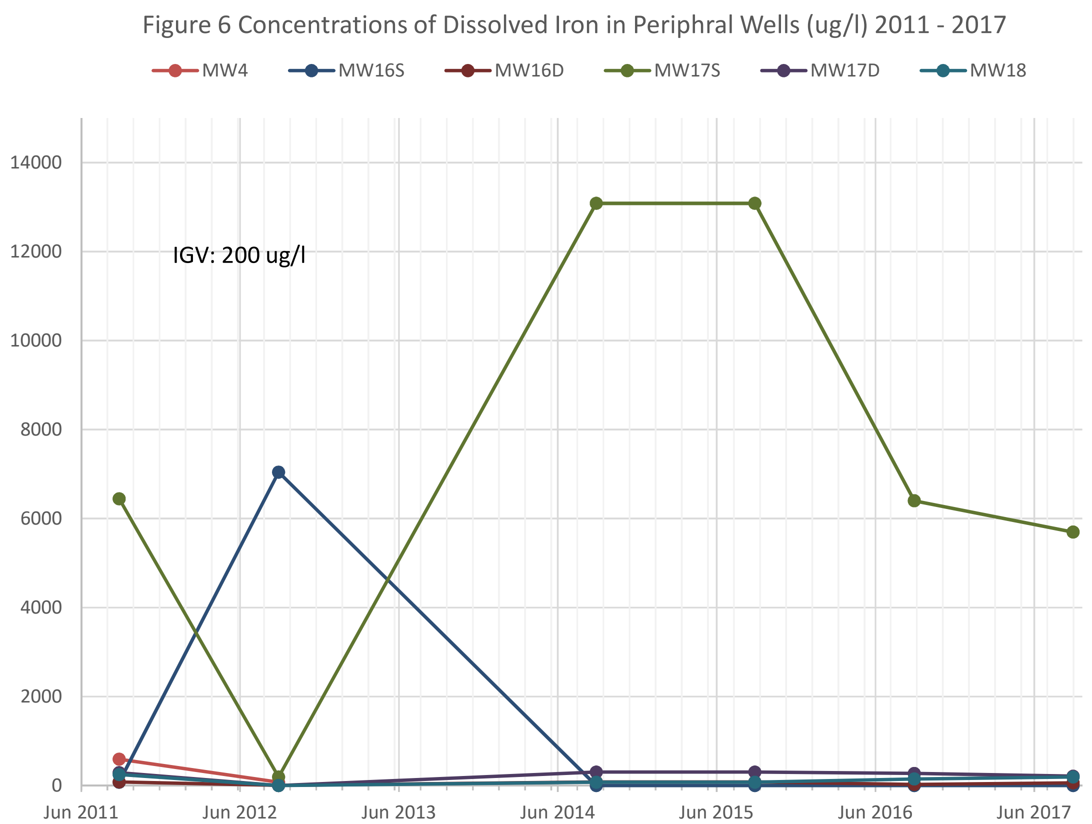


Figure 4 - Chloride Concentrations (mg/l) in Peripheral Wells v Time (2010 - 2017)

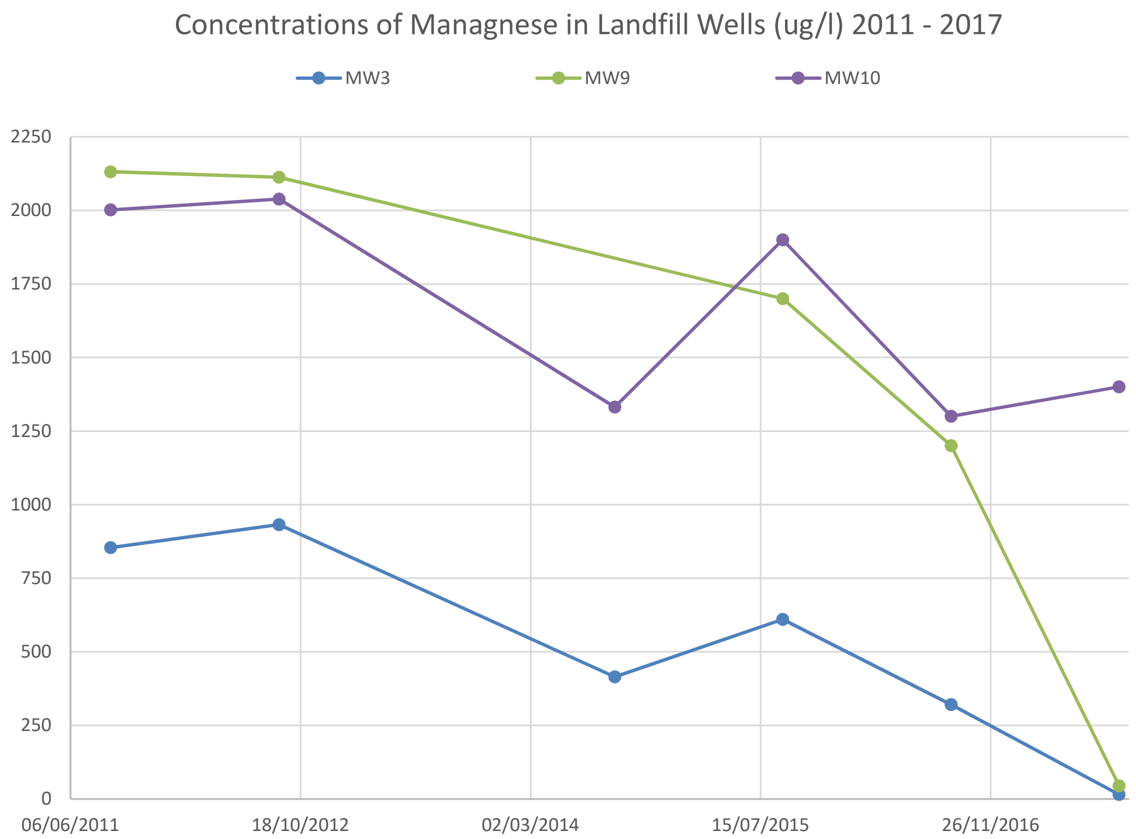


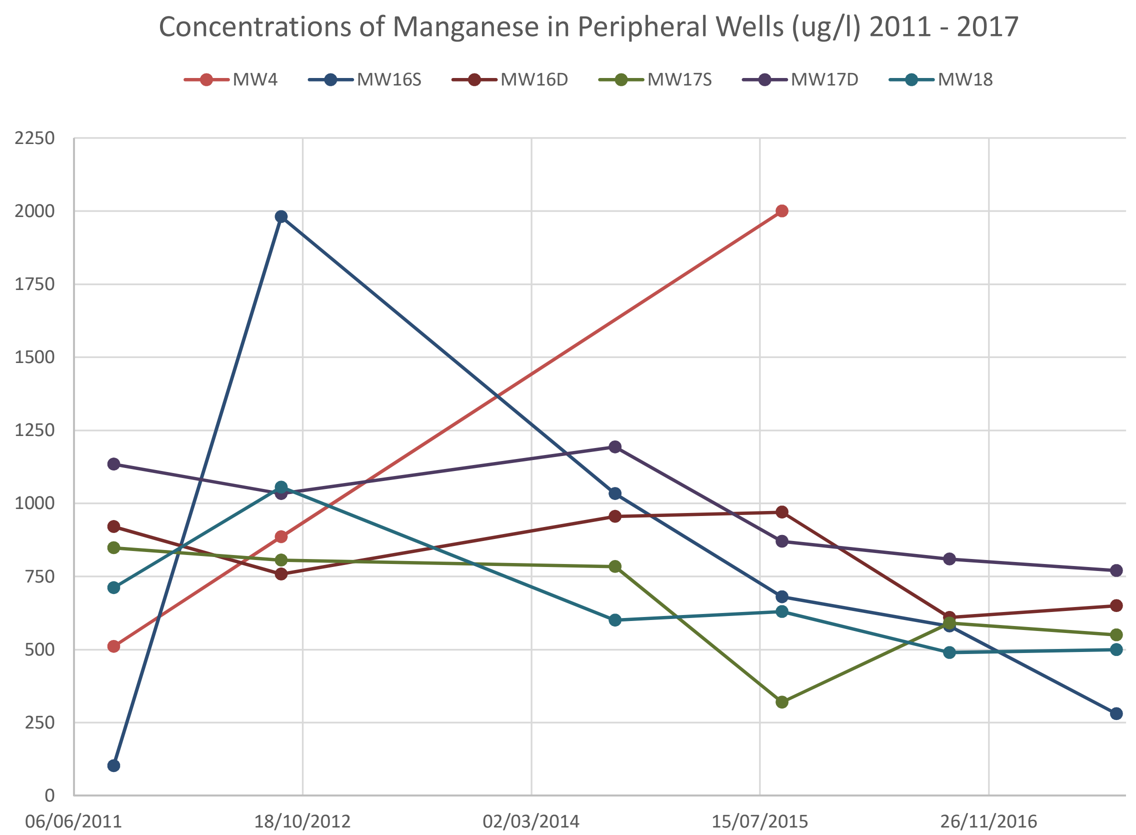
Dissolved Iron - Groundwater





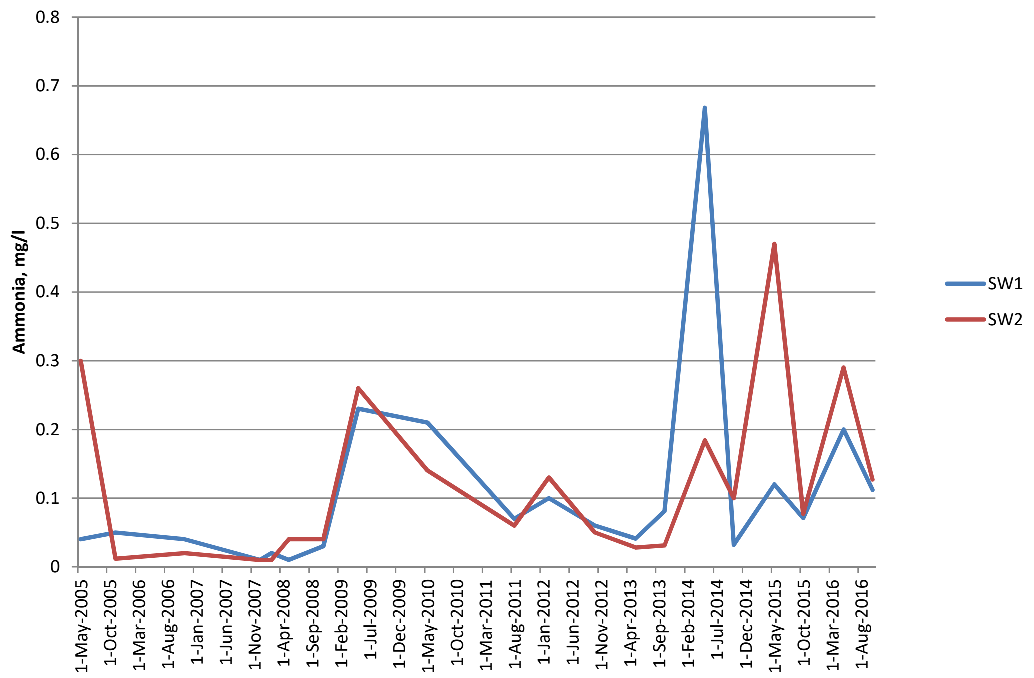
Dissolved Manganese - Groundwater





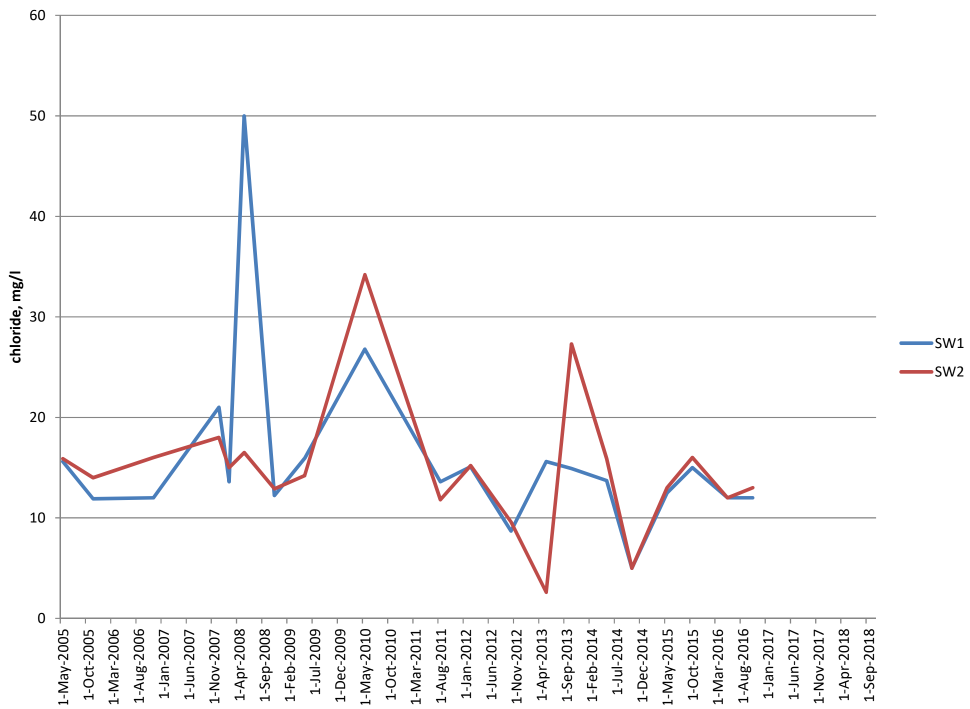
Ammonia - Surface Water

Figure 9 Concentrations of Ammonia in SW mg/l (2005 - 20017)



Chloride - Surface Water

Figure 10 Chloride Concentrations in SW mg/l (2005 - 2017)



Figures