8.0 WATER

8.1 Introduction

8.1.1 Background

This chapter provides an assessment of the potential impacts of proposed recommencement of mining at the former Galmoy Mine (the Proposed Development) on the surrounding hydrological and hydrogeological environment. The development proposes to recommence mining of zinc and lead ore from underground using methods that were previously employed at the mine, to a depth of ca. 150 m bgl (below ground level).

Dewatering of the previous Galmoy underground mine began in 1996 and ceased in 2013. The main orebodies ("zones") cover a geographical area of around 0.5 km² and occur between approximately 40 and 150 m bgl.

In order to supplement local private water supplies during the previous period of active dewatering, two water supply scheme wells (RWSS – Replacement Water Supply Scheme) were installed to the west and northwest of the K Orebody (Figure 8.1). Production water supply well (WW1A) and reserve water supply well (WW2B) were installed by Galmoy Mine in 1996 in compliance with planning conditions for the previous mining. The scheme, now known as the Galmoy-Rathdowney Public Water Supply (GRPWS), is owned and operated by Irish Water.

Recommencement of mining will occur beneath the water-table. Groundwater entering the underground workings will be pumped to surface for treatment and discharged to the River Goul via the existing Goul Discharge Pipeline (Figure 8.1). The existing water management and treatment facilities on-site will be replaced with a new water treatment plant as part of the development. In the early stages of dewatering, groundwater may be abstracted from the aquifer by a number of temporary wells and the existing ventilation shafts.

Returning to a previously closed (or flooded) underground operation has a number of precedents around the world, including:

- Pomorzany, Olkusz, Poland;
- Katanga, Democratic Republic of Congo;
- McArthur River, Northern Territory, Australia;
- Bulga Coal, New South Wales, Australia;
- Naica, Chihuahua, Mexico;
- San Antonio, Chihuahua, Mexico;
- Cigar Lake, Saskatchewan, Canada;
- Carr Fork (Bingham Canyon), Utah, USA;
- Bunker Hill, Idaho, USA;
- Golden Sunlight, Montana, USA;
- Libby, Montana, USA; and
- Bisbee, Arizona, USA.

8.1.2 Available Data

There is a good pre-mining hydrogeological dataset (since about 1988) available for the Galmoy mining district and the Garrylaun Project. This includes both surface water and groundwater. The original pre-mining dataset was used to help develop the dewatering programme for the original Galmoy mine, with the mine being dewatered in 1996, and ceasing dewatering in 2013.

The baseline hydrogeology studies were carried out to a high standard by KT Cullen and are reported in Hydrogeology and Dewatering of the Galmoy Mine (November 1992). The original surveys were carried out in early 1988. A further monitoring programme was carried out in 1992.

In addition to the pre-mining data, there is an extensive monitoring database available throughout the entire period of mine development, operations and closure of the previous Galmoy mine. The monitoring programme was carried out through to 2017. Additional monitoring and sampling was implemented by Shanoon Resources Limited in 2018 and more recently in 2020 and 2021 using existing sampling locations.

The objectives of the hydrological and hydrogeological assessment for the proposed recommencement of mining at the Site are to:

- Identify any potential impacts of the Proposed Development on the surface water and groundwater environments during the development, operation and restoration phases of the Project;
- Identify mitigation measures to avoid, remediate or reduce significant adverse impacts; and,
- Assess significant residual impacts and cumulative impacts of the proposed recommencement of mining at the Site.

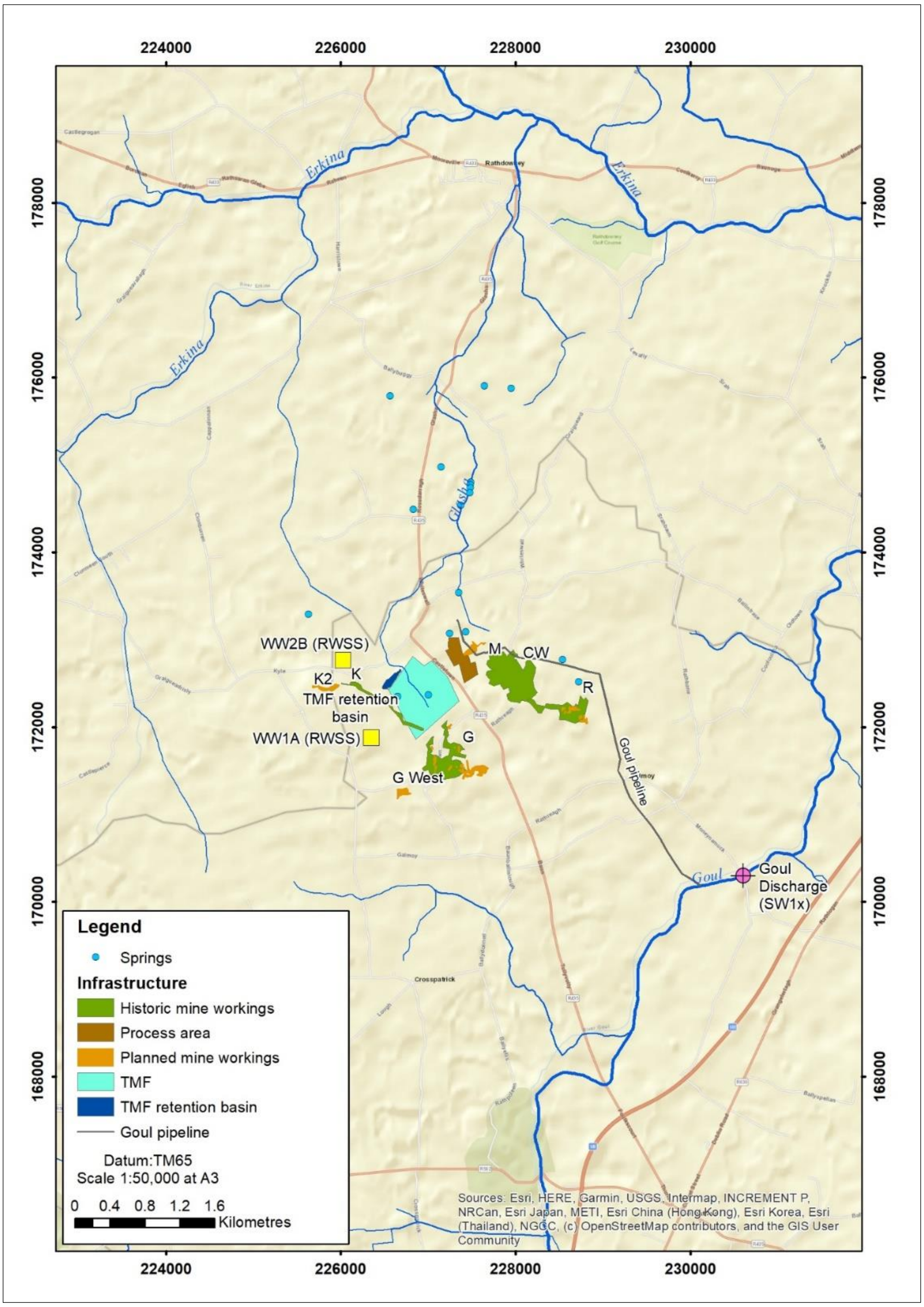


Figure 8.1: Location of GRPWS (RWSS) wells and Goul Discharge Point

8.2 Legislative and Policy Context

The following statutory instruments are referenced in this assessment as follows:

- 'Groundwater regulations' – S.I. No. 366/2016 - European Union Environmental Objectives (Groundwater) (Amendment) Regulations 2016;
- 'Surface water regulations' – S.I. No. 272/2009 - European Communities Environmental Objectives (Surface Waters) Regulations 2009 and S.I. No. 77/2019 - European Union Environmental Objectives (Surface Waters) (Amendment) Regulations 2019; and
- 'Drinking water regulations' – S.I. No. 122/2014 - European Union (Drinking Water) Regulations 2014.

8.3 Assessment Methodology and Significance Criteria

The assessment methodology used in this chapter of the EIAR follows the Guidelines for the Preparation of Soils, Geology and Hydrogeology Chapters of Environmental Impact Statements (Institute of Geologists of Ireland (IGI), 2013). The IGI (2013) assessment criteria, as outlined in Table 8.1 to Table 8.4 have been adopted for this assessment. The categories and descriptions may differ slightly from methodologies used in other chapters.

Table 8.1: Environmental Value (Sensitivity) and Descriptions (based on IGI, 2013)

Value (sensitivity) of receptor / resource	Typical description	Example
Extremely High	Attribute has a high quality or value on an international scale	Supports river, wetland or surface water body ecosystem protected by EU legislation e.g. SAC or SPA status
Very High	Attribute has a high quality or value on a regional or national scale	Regionally Important Aquifer with multiple wellfields. Supports river, wetland or surface water body ecosystem protected by national legislation – e.g. NHA status. Regionally important potable water source supplying >2500 homes Inner source protection area for regionally important water source. WFD designation of 'Good'. Floodplain protecting >50 residential or commercial properties or nationally important infrastructure (e.g. motorways/national roads) from flooding.
High	Attribute has a high quality or value on a local scale	Regionally Important Aquifer. Groundwater provides large proportion of baseflow to local rivers. Locally important potable water source supplying >1000 homes. Outer source protection area for regionally important water source. Inner source protection area for locally important water source. WFD designation of 'Moderate'. Floodplain protecting between >5 residential or commercial properties or regionally important infrastructure (e.g. regional roads) from flooding.
Medium	Attribute has a medium quality or value on a local scale	Locally Important Aquifer Potable water source supplying >50 homes. Outer source protection area for locally important water source. WFD designation of 'Poor'. Floodplain protecting between >1 residential or commercial properties or locally important infrastructure (e.g. local roads) from flooding.
Low	Attribute has a low quality or value on a local scale.	Poor Bedrock Aquifer. Potable water source supplying <50 homes. Floodplain protecting a residential or commercial properties from flooding.

The hydrological and hydrogeological impacts associated with the proposed recommencement of mining at the Application Site were assessed by means of a desk study of the project area (i.e. a review of available information and reports from the Site generated over a 25 year period), a number of freely available technical references (including Geological Survey of Ireland (GSI) and Environmental Protection Agency (EPA) online publications), consultations with previous employees and statutory bodies; and site work (including water quality sampling).

Table 8.2: Magnitude of Impact and Typical Descriptions (based on IGI, 2013)

Magnitude of impact (change)	Typical description	Example
Large Adverse	Results in loss of attribute and/or quality and integrity.	Removal of large proportion of aquifer or surface water system. Changes to aquifer or unsaturated zone resulting in extensive change to existing water supply springs and wells, river baseflow or ecosystems. Potential high risk of pollution to water body. Risk of serious pollution incident >2% annually.
Moderate Adverse	Results in impact on integrity of attribute or loss of part of attribute.	Removal of moderate proportion of aquifer or surface water system. Changes to aquifer or unsaturated zone resulting in moderate change to existing water supply springs and wells, river baseflow or ecosystems. Potential medium risk of pollution to water body. Risk of serious pollution incident >1% annually.
Small Adverse	Results in minor impact on integrity of attribute or loss of small part of attribute.	Removal of small proportion of aquifer or surface water system. Changes to aquifer or unsaturated zone resulting in minor change to water supply springs and wells, river baseflow or ecosystems. Potential low risk of pollution to water body. Risk of serious pollution incident >0.5% annually.
Negligible	Results in an impact on attribute but on insufficient magnitude to affect either use or integrity.	Risk of serious pollution incident <0.5% annually.

Table 8.3:Significance Classification (from IGI, 2013)

Significance	Typical description
Imperceptible	An impact capable of measurement but without noticeable consequences
Slight	An impact which causes noticeable changes in the character of the environment without affecting its sensitivities
Moderate	An impact that alters the character of the environment in a manner consistent with existing and emerging trends
Significant	An impact, which by its character, magnitude, duration or intensity alters a sensitive aspect of the environment
Profound	An impact which obliterates sensitive characteristics

Table 8.4: Significance Matrix (based on IGI, 2013*)

	Magnitude of Impact (Degree of Change)				
Environmental value (Sensitivity)		Negligible	Small Adverse	Moderate Adverse	Large Adverse
	Extremely High	Imperceptible	Large	Profound	Profound
	Very High	Imperceptible	Large / Moderate	Profound / Large	Profound
	High	Imperceptible	Moderate / Slight	Large / Moderate	Profound / Large
	Medium	Imperceptible	Slight	Moderate	Large
	Low	Imperceptible	Imperceptible	Slight	Slight / Moderate

* note, for consistency with other chapters 'Large' significance has been used instead of the IGI term 'Significant'

8.4 Baseline Conditions

8.4.1 Precipitation and Evaporation

Climate conditions are an important factor in the planning for the proposed recommencement of mining at the Application Site and by association, the management of water throughout the life of the mine, because it is the primary factor that controls groundwater recharge. For the previous Galmoy mine, most water pumped from the mine workings was derived from rainfall and recharge. Groundwater storage formed only a minor component of the mine water pumping volume, with the exception of the very early stages of mine dewatering. The same was true at the nearby Lisheen mine.

Consequently, the two most important factors that will control the mine dewatering rate for the proposed recommencement of mining are: (i) the size of the drawdown area that develops around the mine workings, and (ii) the amount of rainfall during the preceding three months. Experience at both Galmoy and Lisheen shows that, when antecedent rainfall is low, the mine dewatering rate reduces. Conversely, very wet periods can produce large peaks in the mine dewatering rate (Figure 8.2).

Annual precipitation data from Parknahown, Cullahill, 7 km east of the Application Site shows a range of 710 to 988 mm over the last ten years (Table 8.5). The mean is about 835 mm/year.

Total evaporation from Oak Park synoptic station around 50 km east of the Application Site shows a range of 698 to 813 mm between 2017 and 2020, with a mean of 767 mm (Table 8.6). Around 71% occurs between the five months, April to August. During the summer months, there is usually a moisture deficit within the soil. Except during very wet periods where the soil moisture deficit reduces to near zero, summer rainfall does not contribute to groundwater recharge. This is illustrated using effective precipitation in Table 8.7 (precipitation minus evaporation). It shows that, for an average year, there is typically no effective precipitation from April to July. Effective precipitation peaks in November and December, averaging 72 mm and 95 mm, respectively.

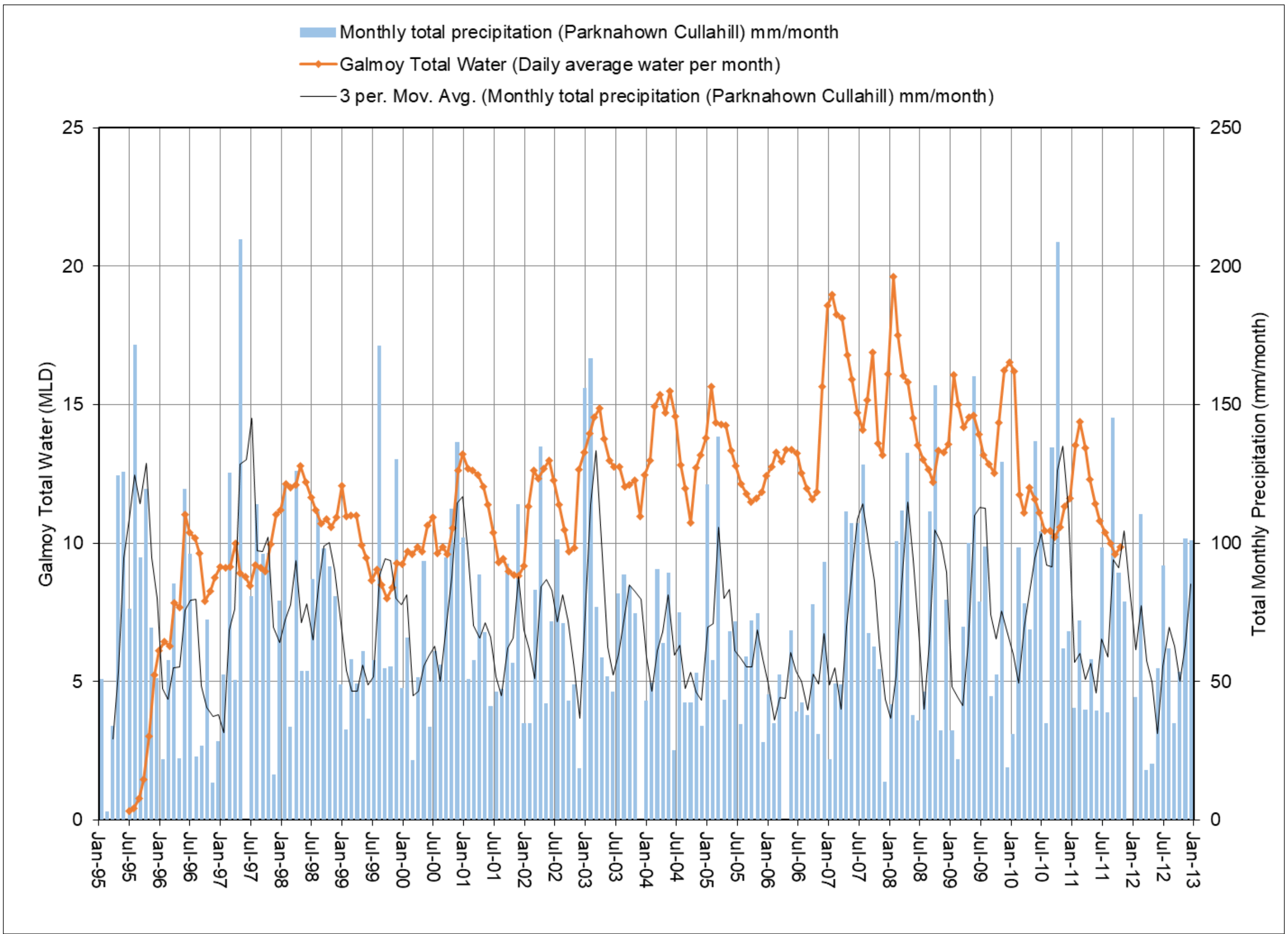


Figure 8.2: Long-term Dewatering Rate at Galmoy with Monthly and 3-Monthly Precipitation

Table 8.5: Monthly Precipitation Data from Parknahown Cullahill

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2010	68	41	72	40	58	39	98	39	145	89	79	N/A	**> 769**
2011	44	111	18	20	55	92	62	35	54	102	101	76	**769**
2012	N/A	23	26	63	48	196	107	105	41	100	80	72	**> 860**
2013	82	33	61	46	39	47	39	47	38	151	37	113	**733**
2014	127	177	65	38	66	52	26	83	41	104	129	80	**988**
2015	79	45	61	41	107	20	57	82	41	49	125	209	**915**
2016	95	91	49	53	53	79	30	46	88	33	30	64	**710**
2017	33	41	97	14	99	88	56	84	83	79	53	106	**833**
2018	140	39	86	80	23	25	38	38	59	51	112	139	**829**
2019	38	27	120	70	7	62	32	89	94	79	113	77	**807**
2020	52	194	55	33	17	61	73	122	49	92	75	110	**934**
Mean	**76**	**75**	**65**	**45**	**52**	**69**	**56**	**70**	**67**	**84**	**85**	**105**	**835**

Table 8.6: Monthly Total Evaporation Data from Oak Park

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2017	15	25	71	114	122	120	93	64	36	14	12	12	**698**
2018	18	24	44	77	119	149	142	100	70	38	18	15	**813**
2019	17	29	56	75	107	115	127	106	70	36	15	14	**767**
2020	16	34	60	92	142	109	108	93	69	38	18	12	**789**
Mean	**16**	**28**	**57**	**89**	**122**	**123**	**118**	**91**	**61**	**31**	**16**	**13**	**767**

Table 8.7: Monthly Effective Precipitation Data (Parknahown Cullahill precipitation minus Oak Park evaporation)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2017	18	16	26	0	0	0	0	20	47	66	41	95	**328**
2018	122	15	42	3	0	0	0	0	0	14	94	124	**413**
2019	22	0	64	0	0	0	0	0	24	43	97	63	**313**
2020	37	160	0	0	0	0	0	29	0	54	57	98	**435**
Mean	**49**	**48**	**33**	**1**	**0**	**0**	**0**	**12**	**18**	**44**	**72**	**95**	**372**

8.4.2 Understanding Gained from Previous Mining Operations at the Site

8.4.2.1 Available Information

A comprehensive surface water and groundwater monitoring programme was undertaken throughout the life of the Galmoy mining operation, including dewatering flows, groundwater levels, groundwater chemistry and receiving water flows and chemistry. An excellent dataset is available. The primary objective of monitoring was to confirm that no unpredicted impacts to the surface and groundwater system, or to local receptors, was occurring as a result of mine operations. The dataset includes:

- Existing groundwater wells in the Galmoy district, water levels and water quality;
- Purpose drilled monitoring wells (installed by the mine), water levels and water quality;
- RWSS/GRPWS wells pumping flow rates, water levels and water quality;
- Surface water tributaries of the Glasha Stream (water quality);
- Mine dewatering flows, flow rates and water quality;
- Performance of the water treatment plant (WTP), flow rates and water quality;
- Discharge water to the River Goul - including flow rates, sediment and water quality; and
- Receiving waters of the River Goul upstream and downstream of the discharge point – including flows rates, sediment and water quality.

8.4.2.2 Dewatering Rate

Dewatering of the previous Galmoy mine workings commenced in 1996 and ceased in March 2013. Following the early removal of groundwater storage from the Waulsortian limestone, the pumping was generally stable, varying only with rainfall and groundwater recharge patterns. Figure 8.3 shows that the pumping rate was mostly within the range 11.5 to 15.5 MLD (million litres per day).

The dewatering rate was mostly a function of rainfall in the preceding 3 months. Following periods of high rainfall and recharge, the dewatering rate occasionally approached 20 MLD (or 20,000 m^3/d). A close correlation between pumping rate and rainfall can be seen both seasonally and annually (Figure 8.2). The 'dry' years (such as 2004 to 2006 and 2011) show lower dewatering rates while the wet winter of 2006-07 shows a large increase in dewatering rate.

The drainable porosity of the Waulsortian limestone is known to be low (< 0.015), with much of the storage occurring within the upper weathered (epikarst) zone. The unweathered formation contains relatively few joints and fractures and contains relatively little groundwater in storage. Most of the deeper bedrock groundwater storage was contained in the joints and cavity zones at the ore horizon, such as those encountered along the Main Fissure. However, the actual storage in these features was limited because of sediment fill. It can be approximated that the total overall bedrock groundwater storage contained within the competent bedrock prior to mining would have been no more than about 1 million m^3.

Following the early groundwater storage removal from the Waulsortian in the first years of dewatering, most of the groundwater pumped was derived from on-going recharge. Additional contribution occurred due to local-scale shallow lateral flow and drawdown in the overburden around the margins of the block.

Figure 8.3 also illustrates a similar response of the dewatering rate to recharge at the Lisheen mine, where most of the groundwater was also abstracted from the Waulsortian limestone, except for the F2/F3 zone in the decline, which is fed by groundwater from the Lisduff Oolite. Although the flow rate at Lisheen is almost an order of magnitude higher (because the size of the Waulsortian block is approximately an order of magnitude greater), the figure generally shows a good correlation between the two sets of pumping data. The peaks in pumping at Galmoy coincide with the peaks in pumping at Lisheen.

In particular, the period of high recharge during the wet winter of 2006-07 is evident at both mines. The effect of this was magnified at Lisheen because it coincided with the period when Bog Zone was being opened up. The reasonably high recharge periods in the three following years (2007-08, 2008-09 and 2009-10) are also evident on the graph. Both plots show very low flow conditions during 2011 because of the dry weather and low groundwater recharge that occurred during the spring period of 2011.

The similarity between the Galmoy and Lisheen pumping graphs is also an indication that most of the water pumped from the workings was derived from on-going groundwater recharge rather than from groundwater storage. Although there may be zones of strong jointing and cavity development (often full of sediment), the low drainable porosity of the Waulsortian limestone, means that the formation itself naturally contains relatively little groundwater in storage.

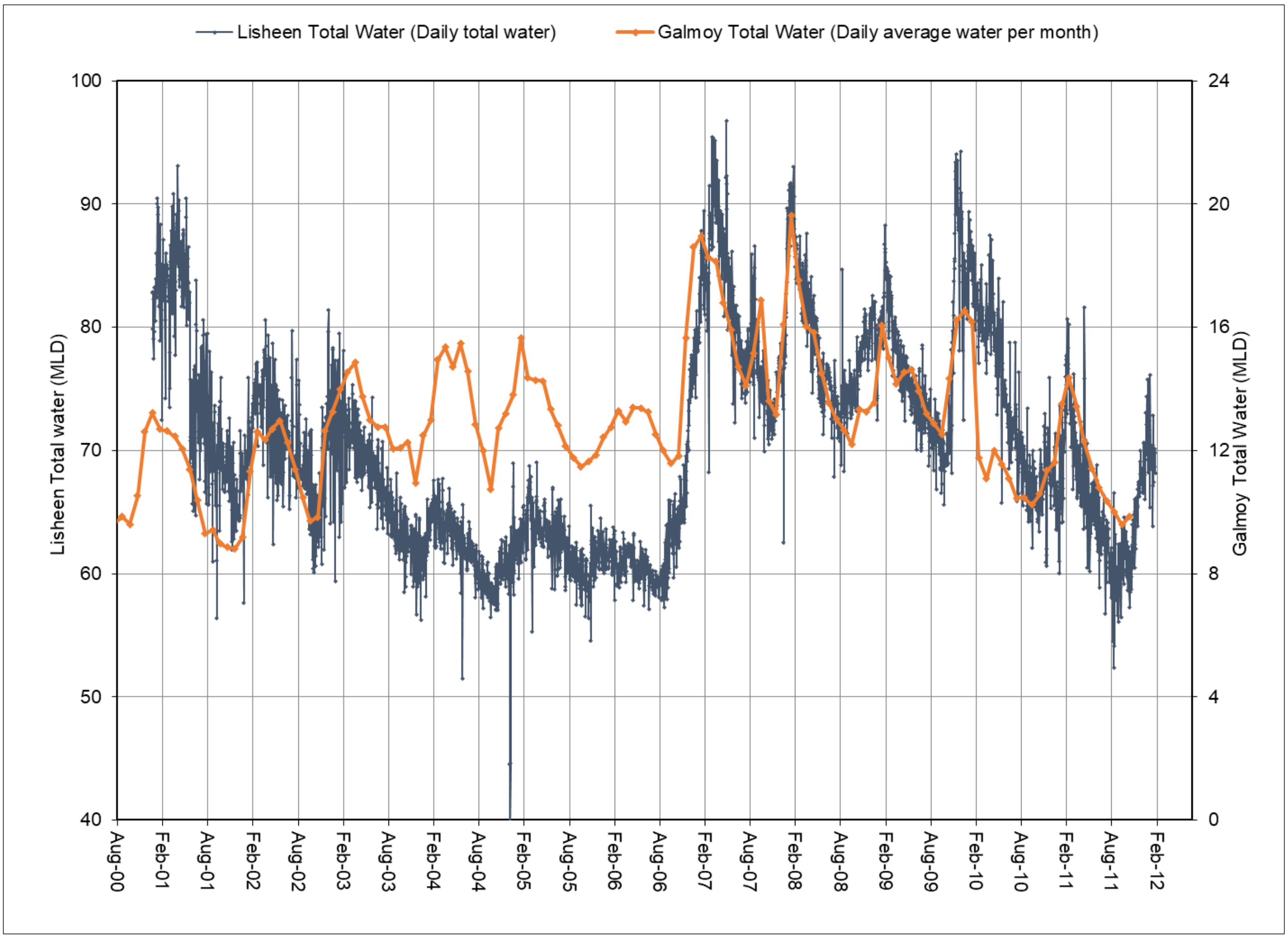


Figure 8.3: Long-term Dewatering Rate at Galmoy (Brown) showing a Similar Behaviour to Lisheen

8.4.2.3 Area of Drawdown

Once the drawdown became established by the initial pumping in the late 1990s, the area of drawdown (around 18 km²) did not change significantly as the mine was progressively developed. Galmoy Mine prepared a series of 6-montlhy drawdown maps which showed that the area of drawdown influence showed little change with time. This is also reflected in the long-term hydrographs (Figure 8.4) and is indicative of a strongly-bounded groundwater system. The conceptual model developed for Galmoy is presented in Figure 8.5.

The total area of drawdown consisted of a zone of high drawdown in the Waulsortian limestone, covering an area of about 8 to 10 km². Around the periphery of this area, minor drawdown was observed in the bedrock to the west and east of prominent fault boundaries.

A decoupled response was observed between the groundwater levels within the superficial deposits and the groundwater levels in the underlying bedrock. The superficial deposits stayed saturated across most of the dewatered area, even though the underlying bedrock became dewatered. This decoupled response between shallow and deep groundwater levels was also observed at Lisheen. It is typical of many mine dewatering operations where the underlying hard rock is overlain by more porous materials. At Galmoy, the actual amount of drawdown that occurred within the superficial materials was small.

Many of the observed changes in the six-monthly drawdown maps occurred around the periphery of the dewatered area. The precise extent of the drawdown area is difficult to determine because the magnitude of drawdown around the periphery of the drawdown area was less than a metre, which is within the normal range of seasonal water table fluctuation. Therefore, changes in the drawdown area were generally associated with the amount of rainfall and the season, rather than from pumping from the mine.

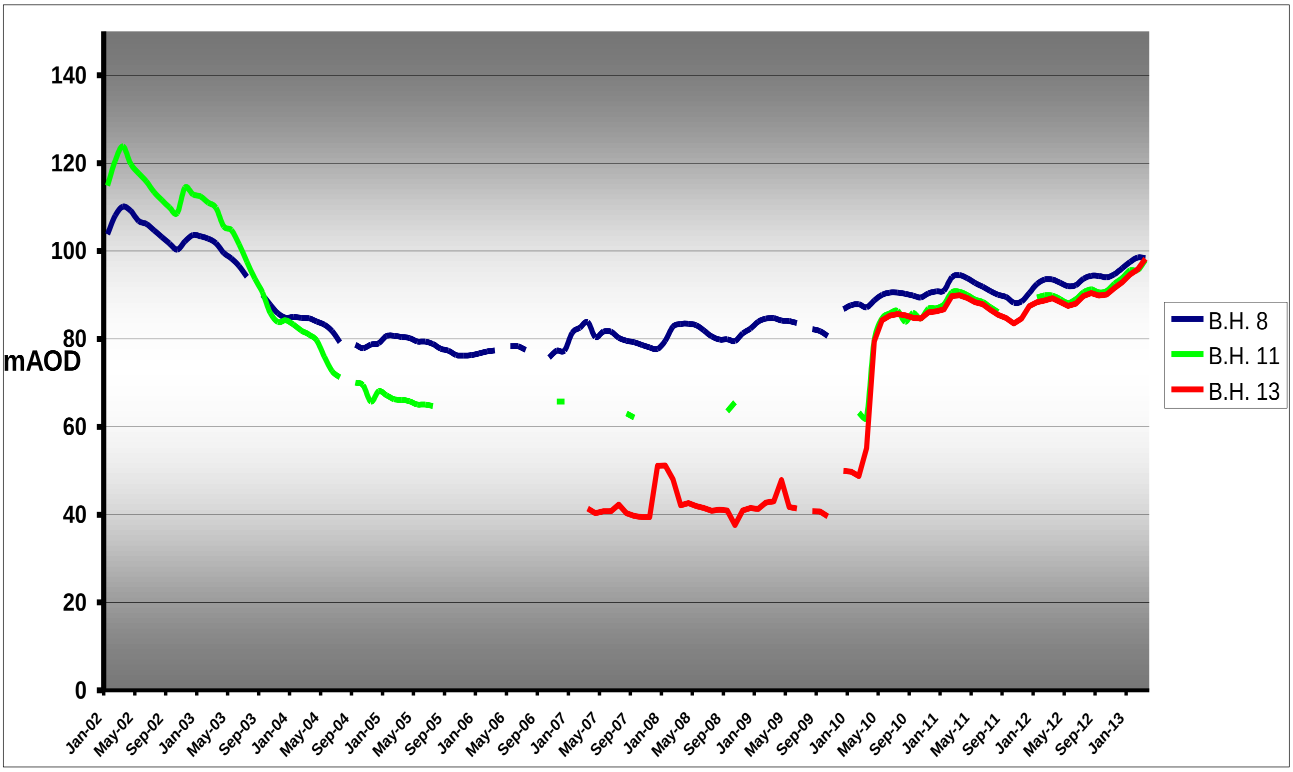


Figure 8.4: Observation Well Hydrographs from Galmoy Mine

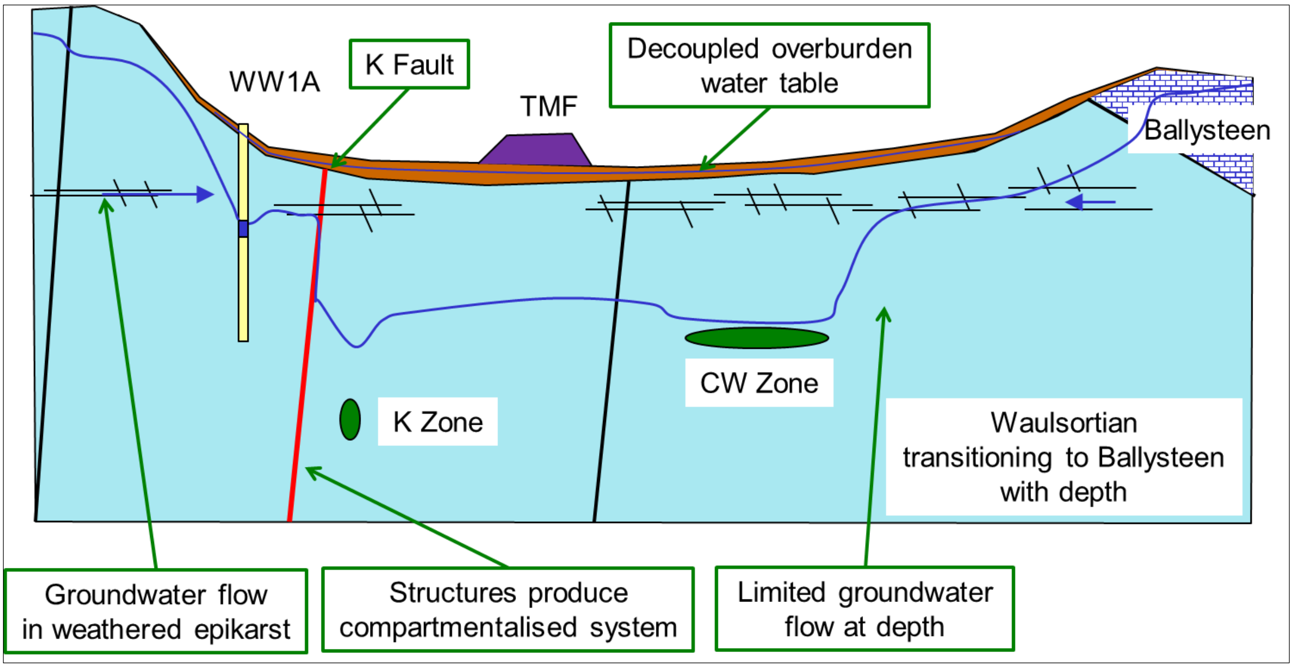


Figure 8.5: Conceptual Groundwater Model cross section during Galmoy Dewatering

8.4.2.4 Mine Water Chemistry

Underground Samples

The water pumped from the Galmoy Mine was highly buffered. There is no indication of any acid generating conditions. Most reported bicarbonate alkalinity values for the Waulsortian groundwater are within the range

300 to 450 mg/L, which provides excellent buffering capacity. The majority of reported pH values from within the mine workings are within the range 6.8 to 7.7.

Figure 8.6 to Figure 8.10 show trend plots of nitrate, sulphate, zinc, lead and ammonia, respectively, for the composite water pumped from the previous Galmoy workings. In general, the monitoring results showed relatively good water quality being pumped from the workings. The post-2006 monitoring results showed much less variability in reported parameter values than the earlier results; this reflects improved underground water management practices that were adopted around this time. From around 2009, the water quality improves further due to a reduction in mining activity (fewer active mining faces) towards the end of mine life.

Values of nitrate were mostly stable and within the general range of pre-mining groundwater values. Values of sulphate were slightly more variable, with values typically ranging between 50 and 400 mg/L. Zinc was generally within the range 0.2 to 4.5 mg/L, with no consistent trends over the dewatering period. Lead was generally within the range 0.005 to 0.5 mg/L, again with no consistent trends. The reported ammonia values were more variable with time but, again, with no consistent trend, and most values falling within the range < 0.01 to 0.5 mg/L.

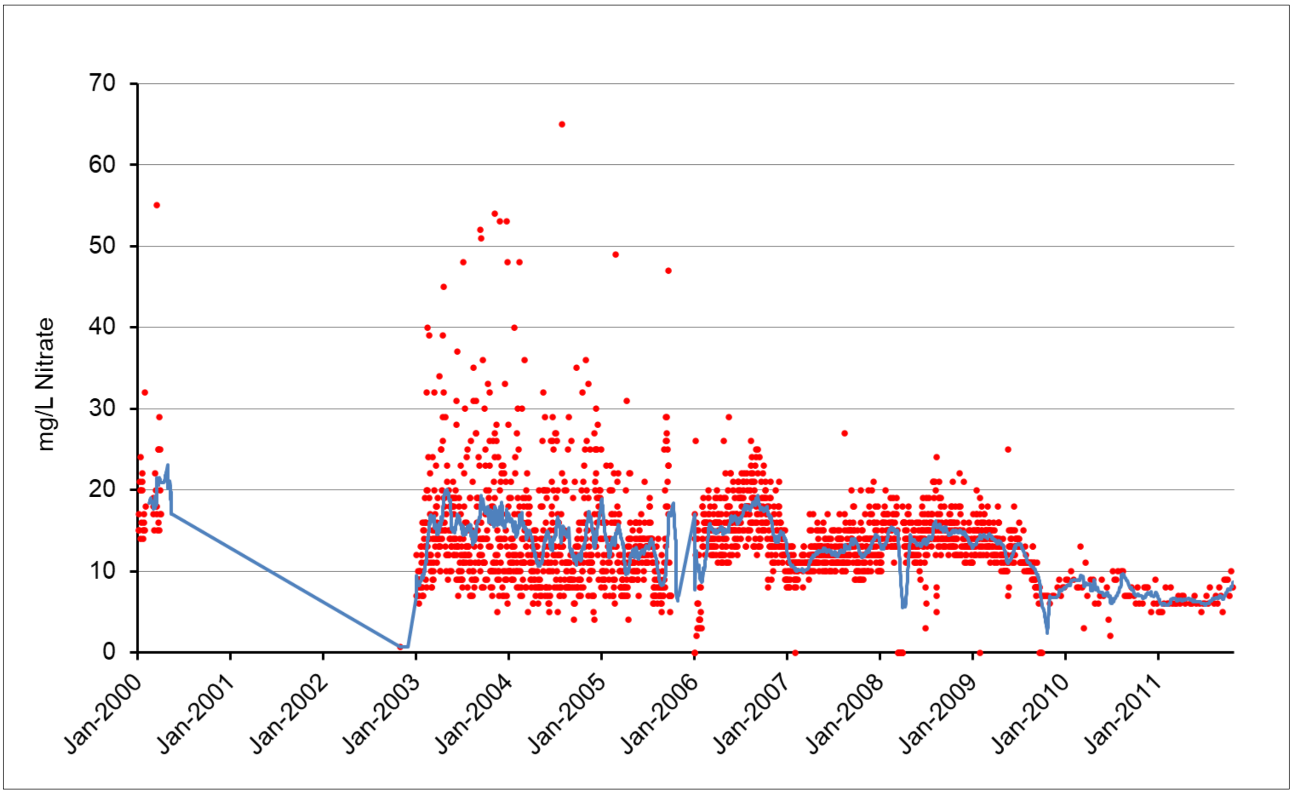


Figure 8.6: Nitrate Concentration in the Composite Pumped Mine Water with 30 day Running Mean

A seasonal trend was evident in the operational dataset at several monitoring locations. Higher values were often reported in April and May. Lower values were more evident in samples taken in late summer and autumn. This may have reflected seasonal recharge and mobilisation of some parameters while the mine was in a dewatered state.

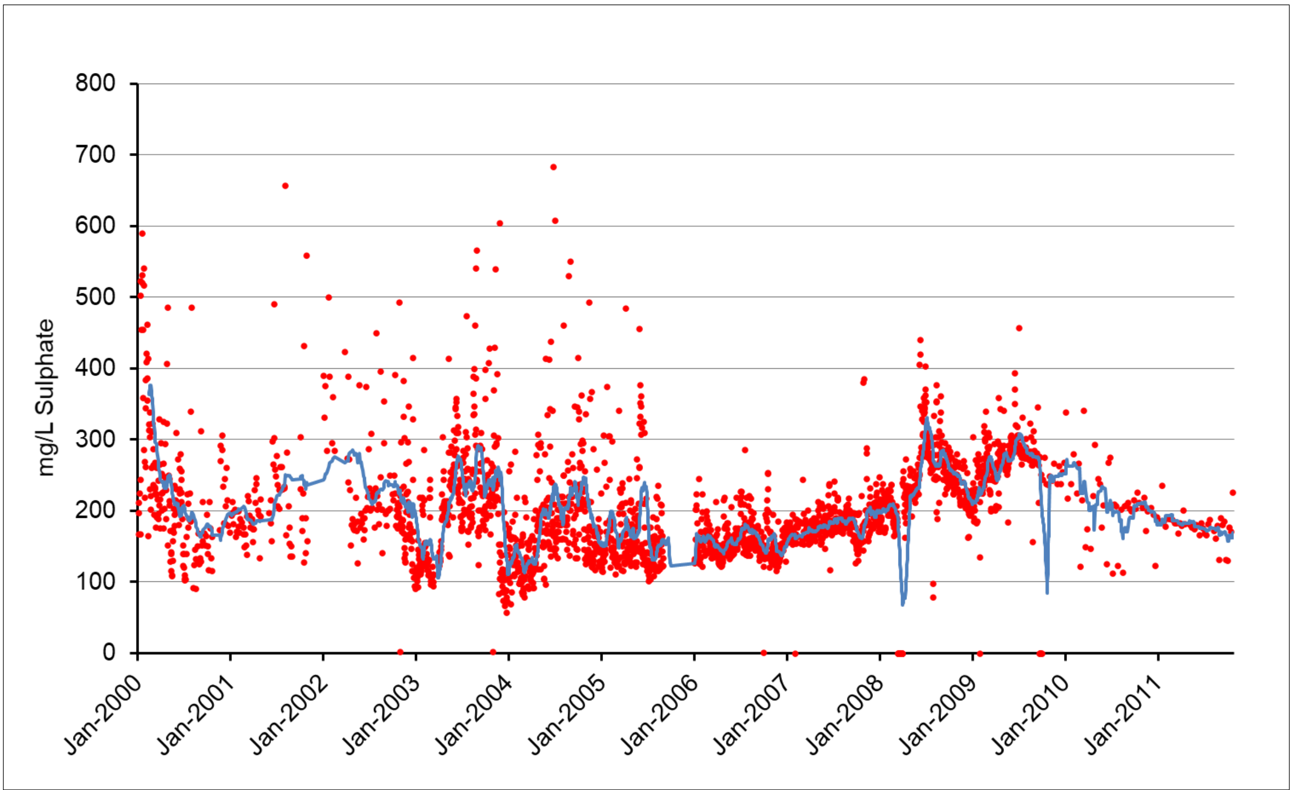


Figure 8.7: Sulphate Concentration in the Composite Pumped Mine Water with 30 day Running Mean

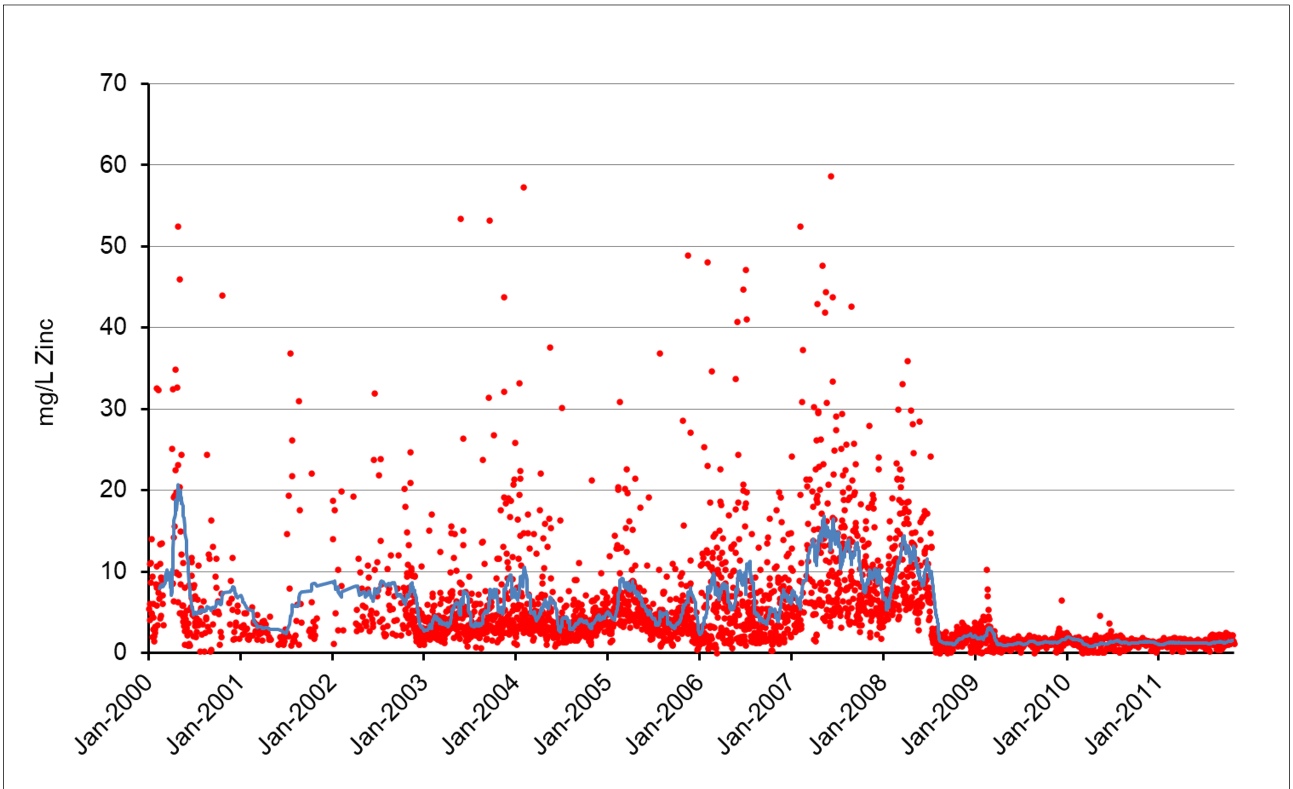


Figure 8.8: Zinc Concentration in the Composite Pumped Mine Water with 30 day Running Mean

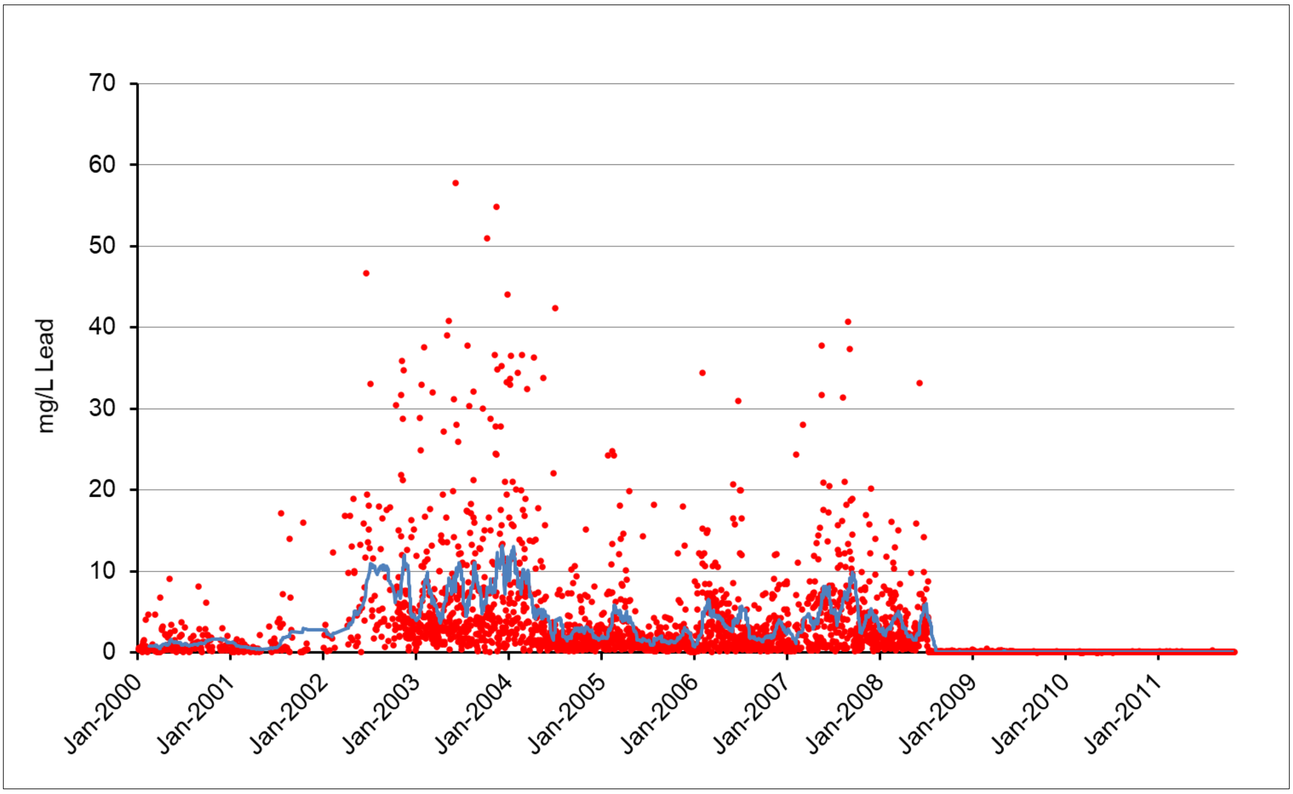


Figure 8.9: Lead Concentration in the Composite Pumped Mine Water with 30 day Running Mean

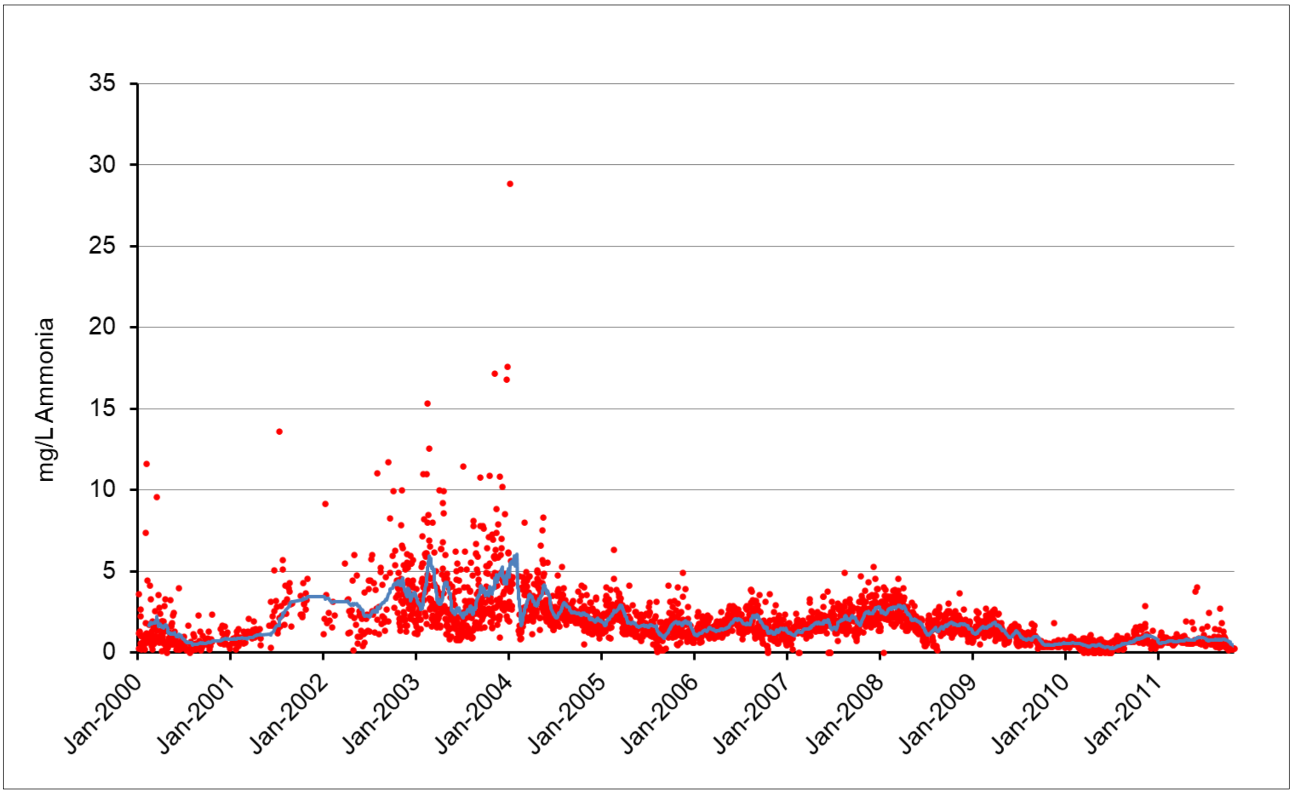


Figure 8.10: Ammonia (as N) Concentration in the Composite Pumped Mine Water with 30 day Running Mean

Water chemistry data from sampling points R vent shaft, RD 14, K access, K5 hanging box, and G E access for 2009 are shown in Table 8.8 to Table 8.12, respectively. The monitoring locations show the following results.

- **R Vent Shaft:** Operational data for the R vent shaft shows a pH range of 6.8 to 7.2, electrical conductivity (EC) values of 1,098 to 1,166 µS/cm, chemical oxygen demand (COD) results of 8 to 15 mg/L, nitrate values of < 1 to 21 mg/L, sulphate values of 336 to 359 mg/L, ammonia within the range 1.85 to 4.03 mg/L, lead values within the range 0.011 to 0.017 mg/L, zinc values of 0.41 to 0.68 mg/L, and iron values of 0.91 to 17 mg/L (most likely reflecting the presence of fine grained colloidal iron material).
- **R D 14 Sampling Point:** Data from the R D 14 sampling point showed broadly similar values to the R vent shaft, with a higher pH range (7.3 to 8.0), slightly higher EC values of 1,206 to 1,310 µS/cm, COD of < 5 to 12 mg/L, nitrate values within the range 1 to 8 mg/L, sulphate values between 403 and 442 mg/L, ammonia within the range < 0.05 to 0.15 mg/L, lead values of 0.006 to 0.028 mg/L and zinc values of 0.40 to 0.58 mg/L. Reported iron values were within the range 0.004 to 0.039 mg/L.
- **K5 Access:** The data from the R sampling points showed a higher range of sulphate values than the K5 access samples, but generally lower values of lead and zinc. The K5 access showed a pH range of 6.9 to 7.6, EC values of 733 to 892 µS/cm, COD within the range < 5 to 11 mg/L, relatively high nitrate values (26 to 35 mg/L), low reported sulphate (103 to 212 mg/L), but higher lead (0.07 to 0.065 mg/L) and zinc (0.13 to 1.3 mg/L) than the R sampling points. There was no reported ammonia in the K5 access samples, and iron values were within the range 0.001 to 0.021 mg/L.
- **K Hanging Box:** The K hanging box also showed low EC (797 to 842 µS/cm) and low sulphate (129 to 177 mg/L), with no reportable ammonia, but relatively high nitrate (18 to 23 mg/L). The pH range of the samples was 7.4 to 7.9, COD was < 5 to 6 mg/L, lead values were 0.007 to 0.019 mg/L, zinc was within the range 0.21 to 0.25 mg/L, and iron values were 0.001 to 0.019 mg/L.
- **G E Access:** The G E access samples show a pH range of 7.0 to 7.2, EC of 593 to 619 µS/cm, COD values of < 5 to 7 mg/L, low values of nitrate (1 to 3 mg/L), very low sulphate (35 to 47 mg/L) and no reportable ammonia. Lead values were elevated in the range 0.029 to 0.042 mg/L, and zinc values were also relatively elevated, within the range 1.6 to 1.9 mg/l. Reported iron values were < 0.001 to 0.035 mg/l.

Table 8.8: Water Chemistry data for the R Vent shaft

	DO	pH	EC	TSS	COD	Ortho Phos.	Nitrate	Nitrite	Sulphate	T. Ammonia	Lead	Zinc	Calcium	Sodium	Magnesium	Iron
Date	mg/L		µS/cm	mg/L	mg/L O2	mg/L P	mg/L NO_3	mg/L NO_2	mg/L SO_4	mg/L NH_3	µg/L Pb	µg/L Zn	mg/L Ca	mg/L Na	mg/L Mg	µg/L Fe
31/03/2009		7.19	1135	19	11		2	<0.01	336	1.85	14	456	218	13.7	30	914
10/04/2009		6.91	1141	4	8		21	<0.01	352	2.5	16	412	2650	165	394	5590
06/05/2009		6.95	1124	11	15	<0.02	<1	<0.01	346	2.68	17	562	5580	363	1070	4850
12/06/2009	8.52	6.84	1119	17	13		4	<0.01	359	4.03	16	679	224	14.5	54	4730
08/07/2009	9.16	6.95	1098	10	9	<0.02	4	<0.01		2.01	11	638	300	14.4	47	16600
31/08/2009	8.97	6.83	1166	11	10	<0.02	5	<0.01		2.76	13	464	245	23.4	37	5070
Drinking Water Regulations							50	0.5	250	0.5	10			200		200
Salmonid Waters Regulations				<25												
Surface Water Regulations					40							300				

Table 8.9: Water Chemistry data for the RD 14

	DO	pH	EC	TSS	COD	Ortho Phos.	Nitrate	Nitrite	Sulphate	T. Ammonia	Lead	Zinc	Calcium	Sodium	Magnesium	Iron
Date	mg/L		µS/cm	mg/L	mg/L **O2**	mg/L **P**	mg/L **NO_3**	mg/L **NO_2**	mg/L **SO_4**	mg/L **NH_3**	µg/L **Pb**	µg/L **Zn**	mg/L **Ca**	mg/L **Na**	mg/L **Mg**	µg/L **Fe**
31/03/2009		8.02	1264	2	6		4	0.04	403		16	496	245	16.3	32	4
10/04/2009		7.51	1225	1	<5		6	0.03	428	0.09	28	401	280	18.6	30	17
06/05/2009		7.54	1219	<1	10	<0.02	1	0.03	442	<0.05	10	502	266	18.7	53	11
12/06/2009	8.96	7.27	1211	1	12		8	0.02	430	0.06	13	583	253	17.5	58	5
08/07/2009	9.57	7.23	1206	2	7	<0.02	6	0.02		<0.05	8	556	261	19.2	46	39
31/08/2009	9.86	7.3	1310	5	11	<0.02	6	0.03		0.15	6	474	283	29.1	43	32
Drinking Water Regulations							50	0.5	250	0.5	10			200		200
Salmonid Waters Regulations				<25												
Surface Water Regulations					40							300				

Table 8.10: Water Chemistry data for the K5 Access

	DO	pH	EC	TSS	COD	Ortho Phos.	Nitrate	Nitrite	Sulphate	T. Ammonia	Lead	Zinc	Calcium	Sodium	Magnesium	Iron
Date	mg/L		µS/cm	mg/L	mg/L O2	mg/L P	mg/L NO_3	mg/L NO_2	mg/L SO_4	mg/L NH_3	µg/L Pb	µg/L Zn	mg/L Ca	mg/L Na	mg/L Mg	µg/L Fe
31/03/2009		7.58	804	4	6		26	0.01	116	<0.05	22	225	130	8.8	37	1
10/04/2009		7.07	793	< 1	< 5		32	< 0.01	116	<0.05	25	204	280	18.6	30	3
06/05/2009		7.28	892	24	11	<0.02	28	0.23	212	0.06	65	1250	155	11.3	74	6
12/06/2009	8.72	6.96	736	1	7		32	<0.01	103	<0.05	12	270	124	8.9	67	3
08/07/2009	9.93	7.06	733	<1	<5	<0.02	31	<0.01		<0.05	7	224	119	9.23	49	21
31/08/2009	9.65	6.92	747	3	<5	<0.02	35	<0.01		<0.05	8	125	133	13.5	47	35
Drinking Water Regulations							50	0.5	250	0.5	10			200		200
Salmonid Waters Regulations				<25												
Surface Water Regulations					40							300				

Table 8.11: Water Chemistry data for the K5 Hanging Box

	DO	pH	EC	TSS	COD	Ortho Phos.	Nitrate	Nitrite	Sulphate	T. Ammonia	Lead	Zinc	Calcium	Sodium	Magnesium	Iron
Date	mg/L		µS/cm	mg/L	mg/L O2	mg/L P	mg/L NO_3	mg/L NO_2	mg/L SO_4	mg/L NH_3	µg/L Pb	µg/L Zn	mg/L Ca	mg/L Na	mg/L Mg	µg/L Fe
31/03/2009		7.89	814	<1	<5		18	0.01	126	<0.05	14	239	121	15.7	44	1
10/04/2009		7.78	831	<1	<5		21	<0.01	129	<0.05	13	214	138	17	31	2
06/05/2009		7.68	842	<1	6	<0.02	20	<0.01	156	<0.05	19	249	135	17.7	77	4
12/06/2009	9.61	7.71	736	<1	<5		23	0.01	177	<0.05	13	273	124	16.3	82	1
08/07/2009	10.59	7.72	797	<1	<5	<0.02	22	0.01		<0.05	9	230	129	18.4	67	19
31/08/2009	10.6	7.44	839	3	<5	<0.02	21	0.01		<0.05	7	247	123	21	56	19
Drinking Water Regulations							50	0.5	250	0.5	10			200		200
Salmonid Waters Regulations				<25												
Surface Water Regulations					40							300				

Table 8.12: Water Chemistry data for the G E Access

	DO	pH	EC	TSS	COD	Ortho	Nitrate	Nitrite	Sulphate	T. Ammonia	Lead	Zinc	Calcium	Sodium	Magnesium	Iron
Date	mg/L		µS/cm	mg/L	mg/L **O2**	mg/L **P**	mg/L NO_3	mg/L NO_2	mg/L SO_4	mg/L NH_3	µg/L **Pb**	µg/L **Zn**	mg/L **Ca**	mg/L **Na**	mg/L **Mg**	µg/L **Fe**
31/03/2009		7.17	600	<1	<5		1	0.32	46	<0.05	42	1730	95	7.2	26	<1
10/04/2009		7.14	611	<1	<5		3	0.36	35	<0.05	35	1550	107	7.9	34	<1
06/05/2009		7.05	616	1	<5	<0.02	1	0.4	47	<0.05	34	1740	104	8.2	53	8
12/06/2009	6.42	7.05	593	<1	7		1	0.31	43	<0.05	29	1700	96	7.7	51	4
08/07/2009	7.34	7.07	595	<1	7	<0.02	3	0.34		<0.05	41	1930	95	7.56	38	19
31/08/2009	5.98	7	619	4	<5	<0.02	2	0.33		<0.05	36	1690	133	13.5	47	35
Drinking Water Regulations							50	0.5	250	0.5	10			200		200
Salmonid Waters Regulations				<25												
Surface Water Regulations					40							300				

Monitoring Wells

Galmoy carried out a six-monthly sampling survey for a number of wells surrounding the mine area as part of the Planning Conditions. There were no long-term trends evident for any of the parameters that were monitored. However, a number of elevated parameter values were evident for several wells and, in particular, several reported lead and nitrate values were above the drinking water regulations of 0.01 mg/l and 50 mg/l, respectively.

During the period of previous mine operations, it is not expected that the mine workings would have influenced the surrounding groundwater chemistry in any way. During the entire period of mining operations, the workings themselves acted as a hydrogeological sink, and all groundwater flow within the surrounding district was always towards the workings.

8.4.3 Understanding Gained from Previous Mining Closure at the Site

8.4.3.1 Closure Schedule

The closure schedule for the previous Galmoy mining was carried out as follows:

- 26th March 2010: Two K Zone plugs installed and closed;
- 21st October 2012: R Zone pumps shut down;
- 8th February 2013: G Zone plugs installed;
- 19th February 2013: G Zone pumps shut down;
- 11th March 2013: Shut down of the pumps in the CW/R Zone – termination of all dewatering; and
- March 2014: Full recovery of the groundwater system to the pre-mining level of around 130 m OD.

A revised hydrogeological monitoring programme was implemented for the mine closure phase. The phased closure approach allowed interactive monitoring to be carried out to confirm that conditions were as predicted and allowed interactive adjustments to be made as the closure programme was advanced.

The monitoring programme focussed on the measurement of the recovering groundwater levels, plus the key parameters which were considered to have the greatest potential to impact groundwater quality (arsenic, lead, nickel, zinc, nitrate, ammonia and sulphate). The sampling frequency was progressively reduced as the closure programme progressed and as the hydraulic gradients towards the mine reduced.

Table 8.13 and Figure 8.11 show the monitoring locations used for the latter stages of the closure period. The locations were chosen based upon their historic monitoring record and their suitability for providing representative data. It should be noted that, for consistency, most of the closure monitoring locations were retained for the baseline survey for the current Application and are proposed to be used in the operational monitoring programmes for the Proposed Development.

Table 8.13: Closure Phase Monitoring Locations for Galmoy Mine

Sample	Area (relative to mine site)	TM65 Irish Grid		Water Source	2015 Measurement Frequency
		Easting	Northing		
G South	Mine workings	227152	171367	Groundwater	Monthly
CW West	Mine workings	227670	172478	Groundwater	Monthly
K Vent	Mine workings	226446	172323	Groundwater	Monthly
TMW8	Mine workings	226858	172746	Groundwater	Monthly
TMW13	Mine workings	226994	171905	Groundwater	Monthly
WW1A	GRPWS wells	226352	171875	Groundwater	Monthly
WW2B	GRPWS wells	226025	172766	Groundwater	Monthly
PD	Northern district well	228610	173695	Groundwater	Monthly
KN	Northern district well	228092	173614	Groundwater	Monthly
GM	Western district well	225410	170950	Groundwater	Monthly
KS	Southern district well	227211	170851	Groundwater	Monthly
JP	Eastern district well	229982	172612	Groundwater	Monthly
Duggans Bridge	Surface water	226952	173719	Surface water	Monthly
Glasha Crossroads	Surface water	227102	176013	Surface water	Monthly
Whiteswall	Surface water	228809	172915	Surface water	Monthly

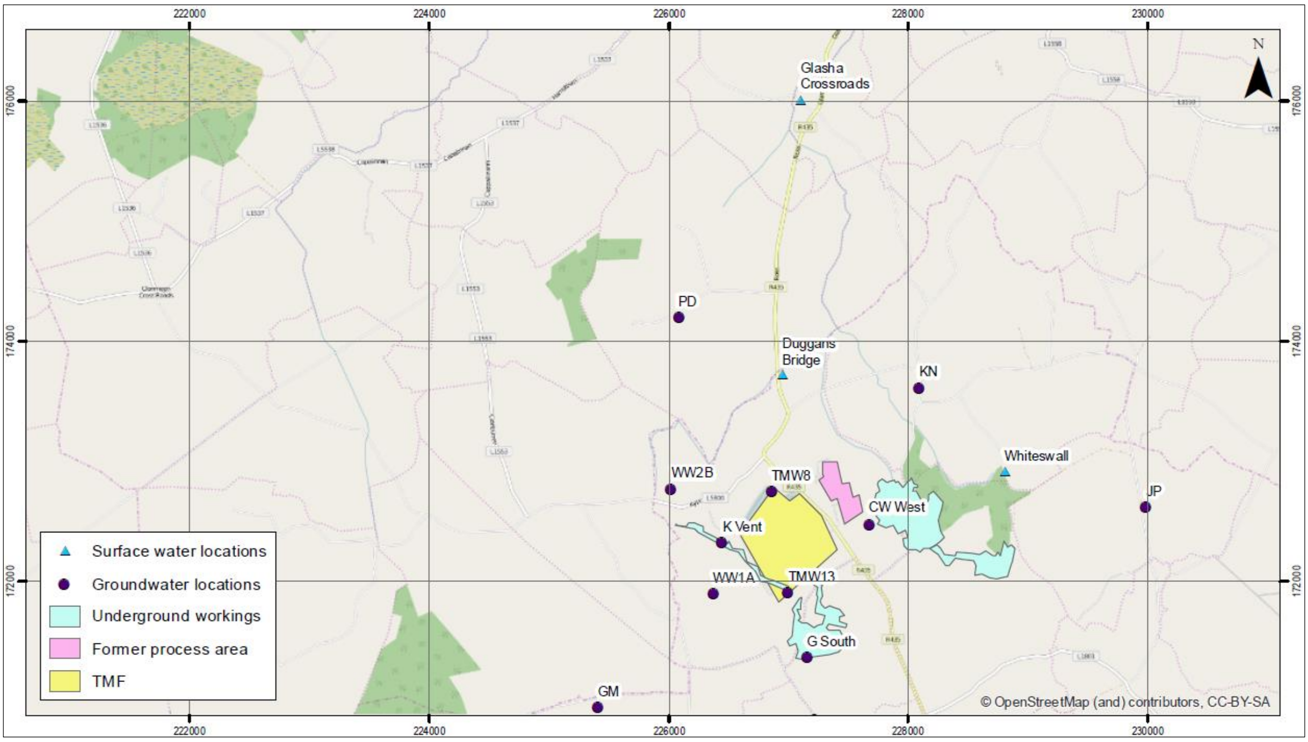


Figure 8.11: Closure Phase Monitoring Locations for Galmoy Mine (from SWS, 2015)

8.4.3.2 Initial flooding of the K Zone

K Zone Flooding

As part of the initial period of mine closure, two plugs were installed to isolate the K Zone workings and prevent water in the K Zone from entering the remaining operational parts of the mine. The plugs were activated on 26th March 2010 and about 35 to 40 m of head of water was allowed to build up behind the plugs, flooding the K

Zone workings. The K Zone workings were sealed off by the installation of two plugs: one located towards the southern end of K Zone; and the second further east just to the north of G Zone.

The re-flooding caused a local rebound of the water table by about 45 m in the western area of the mine which showed that the zone of enhanced drawdown to the bottom of the workings (105 m depth) was only very localized immediately around the K Zone area. This provides further evidence that most active groundwater flow likely occurs in the upper 20 to 30 m bgl. The full rebound occurred within a time period of about 2 to 3 months.

Although the flooding of the K Zone caused a fall in the dewatering rate for a period of 2 to 3 months, there was no effect on the overall long-term pumping rate for the mine (Figure 8.3). This helps illustrate that the overall dewatering rate is determined by recharge over the entire area of drawdown, rather than by local conditions around the workings.

Monitoring of the water chemistry in the flooded K Zone workings was carried out at the K-vent and the K-plug sampling stations. Most of the pH values were between 6.9 and 7.3. In general, the monitoring results were broadly consistent with the observed chemistry results during operations.

Monitoring Well Water Quality

The following sampling points in the vicinity of the K Zone were routinely monitored during flooding:

- RWSS/GRPWS well WW1A;
- Reserve RWSS/GRPWS well WW2B;
- Monitoring well TMW13, located adjacent to the K Zone workings; and
- GM, located to the west of the K Zone workings

At WW1A, zinc values were typically within the range from the detection level up to 0.13 mg/L, but with some elevated values up to 0.46 mg/L between March and April 2011 (generally occurring at the time of seasonal recharge). Values showed a rise post-2007, which was most likely related to the drawdown within the production well itself. There was no apparent change in the reported values following flooding of the K Zone. The higher values may reflect the influence of seasonal recharge mobilising sediment rather than flooding.

Lead values for production well WW1A were typically <0.001 to 0.004 mg/L, with no apparent trends following flooding of the K Zone. Nitrate values showed a general slight increase after 2007 to about 23 to 28 mg/L. Sulphate values showed a slight peak between 2008 and 2010 but subsequently decreased to 10 to 12 mg/L.

WW2B is located close to the northern limit of the K Zone workings. Zinc values at WW2B were typically within the range 0.1 to 0.45 mg/L, but subsequently declined. Lead values at WW2B varied between < 0.001 mg/L and 0.005 mg/L. Nitrate values were mostly within the range 25 to 30 mg/L. Sulphate values were stable from about 2007, generally within the range 9 to 10 mg/L.

The location of TMW13 is close to the K Zone. Zinc values were non-detect through May 2010, with one value (2009) reported as 0.015 mg/L. Following flooding, values were between 0.01 and 0.03 mg/L. It was therefore apparent that changes to the chemistry occurred post-flooding, which was expected because of the close proximity of the sampling point to the flooded K Zone workings.

Zinc values at GM were mostly at or close to the detection limit. There were a number of reported values between 0.2 and 0.3 mg/L during 2010 and early 2011, but all values were lower after the flooding of the K Zone workings.

Overall, the water quality results for the surrounding monitoring stations showed relatively stable water chemistry following the K Zone flooding. Any chemistry changes that may potentially be attributable to flooding were only seen in TMW13, which is located very close to the K Zone workings.

8.4.3.3 Recovery of Groundwater Levels

Figure 8.12 shows the recovery of the groundwater levels following cessation of dewatering at Galmoy Mine. The key phases of the groundwater recovery were as follows:

- March-June 2013: Rapid recovery of the locally dewatered zone immediately above the CW/R ore zone;
- July 2013-March 2014: Regional recovery of the groundwater levels throughout the Galmoy mining area;
- January-March 2014: Rapid water level rebound resulting from extreme rainfall and recharge;
- March 2014: Groundwater level recovers to just above 130 m OD, and local springs start flowing; and
- March 2014-October 2014: Seasonal groundwater regression.

The original predicted time for full recovery was 18 months. However, pre-mining (baseline) groundwater conditions became re-established in March 2014, about 12 months after dewatering ceased. The flooding time was quicker than expected because of extremely high rainfall and groundwater recharge that occurred in January and February 2014. Groundwater flow to the north resumed in the area of the mine, towards the Glasha Stream. Local baseflow (groundwater discharge) to the Glasha and its tributaries was re-established.

The groundwater system in the Galmoy district became fully stabilised after the previous mining. The greatest variation in water level is seen in WW2B due to effects of pumping for water supply, reducing the water level, as opposed to an impact from mining. PD also shows effects from pumping but to a lesser degree. The remaining locations all exhibit the expected season variation typical of Irish groundwater systems: highest during spring and lowest during autumn. The water level in PD in April 2015 is lower than the pre-mining level, also because of the pumping of the well for water supply.

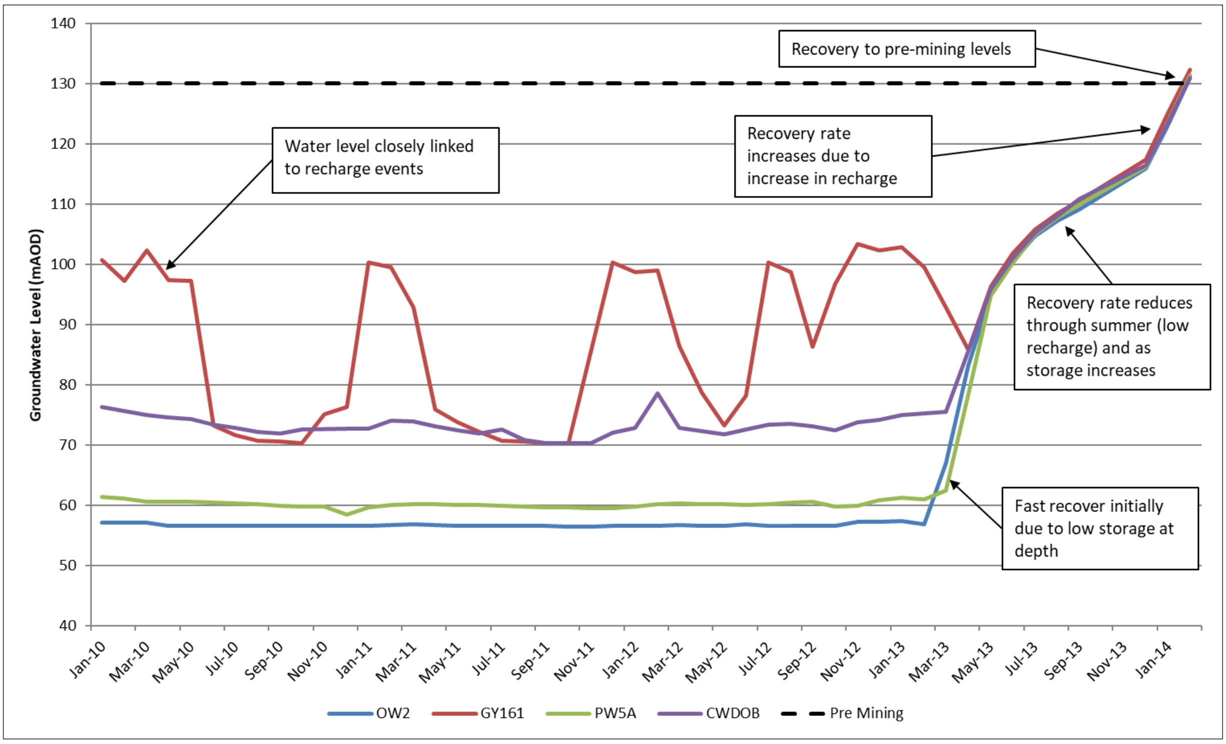


Figure 8.12: Groundwater Recovery following Termination of Dewatering at Galmoy Mine (from SWS, 2014)

8.4.3.4 Post-recovery Water Quality

Flooded Workings

Since full groundwater recovery was completed in March 2014, the water quality in the workings has been predominantly stable for pH, most major ions, metals and nutrients. Most reported water quality results consistently comply with drinking water regulations and groundwater regulations. Arsenic, nickel, zinc and sulphate showed more variable results, as would be expected, but the groundwaters of the mining area are not impacting surrounding groundwater-related receptors. Pre-Galmoy mining baseline survey water quality analysis (Section 8.4.4.7) also shows some localised areas of elevated zinc values.

Figure 8.13 shows that arsenic trends were generally stable but with occasional spikes. During 2015, the drinking water regulation (0.01 mg/L) was only exceeded once (0.011 mg/L in TMW13 in July). A spike was also seen in K-vent at the same time. The K-vent sampling location is close to TMW13. Both locations showed a return to typical lower values for the next samples in August 2015.

Nickel levels (Figure 8.14) were also stable, but there were two locations (CW west vent and G south vent) that have historically been above the groundwater guideline values. Immediately after closure, values were elevated in the workings. These declined over the next year or two across all sampling locations so that by 2015 levels has stabilised to the closure compliance value of 0.02 mg/L.

Zinc trends (Figure 8.15) during 2015 were stable for the all the mine workings locations except for K-vent. TMW13 and G south vent continued to show a gradual decline in levels since 2013. G south vent was consistently below 0.5 mg/L for all of 2015 while TMW13 was stabilising at a values close to the groundwater standard. K-vent did not show a consistent decline but, during 2015, had levels between 1.5 and 2.3 mg/L. Fluctuations in concentration are consistent with seasonal variation and did not influence the water quality in the nearby WW1A. This is because the zone of contribution for WW1A is to the west, whereas K Zone is located downgradient of the well to the east.

Values of sulphate in CW west vent showed consistent decline since 2013 (Figure 8.16) and were below the groundwater standard of 250 mg/L by May 2015. All other locations were stable below the groundwater standard, with little variability over the last two years of monitoring.

GRPWS Wells

The group scheme wells WW1A and WW2B are both upgradient from the mine workings. Monitoring data for both wells through 2017 demonstrate that all chemical parameters in the wells were stable and complied with the drinking water regulations. The slightly elevated zinc recorded in K-vent did not impact either WW1A or WW2B. The flooded mine workings are not within the zone of contribution for either well. Further details of the GRPWS water quality are provided in Section 8.4.4.7.

Private Water Supply Wells

Monitoring data from the private water supplies show that the chemistry remained stable and below compliance values. The two exceptions were zinc in the wells of GM and JP. The monitoring data from GM well shows a spike in zinc during September 2015 where the value increases to 1.05 mg/L. August and September results were below detection limit (0.005 mg/L). Therefore, this is assumed to be a sampling or analytical error.

A trend of increasing zinc is evident in JP well from in mid-2013. The JP well is upgradient of the mine, and so the elevated levels were a not caused by water migrating from the workings. Furthermore, the closest mine workings (CW West) have significantly lower zinc levels than recorded in the well. Therefore, localised contamination is the most likely reason for the increased zinc levels. Coincident with increasing zinc is an increase in ammonia. This suggests that the source of the elevated parameter values is locally derived.

Further details of the private water supply well water quality is provided in Section 8.4.4.7.

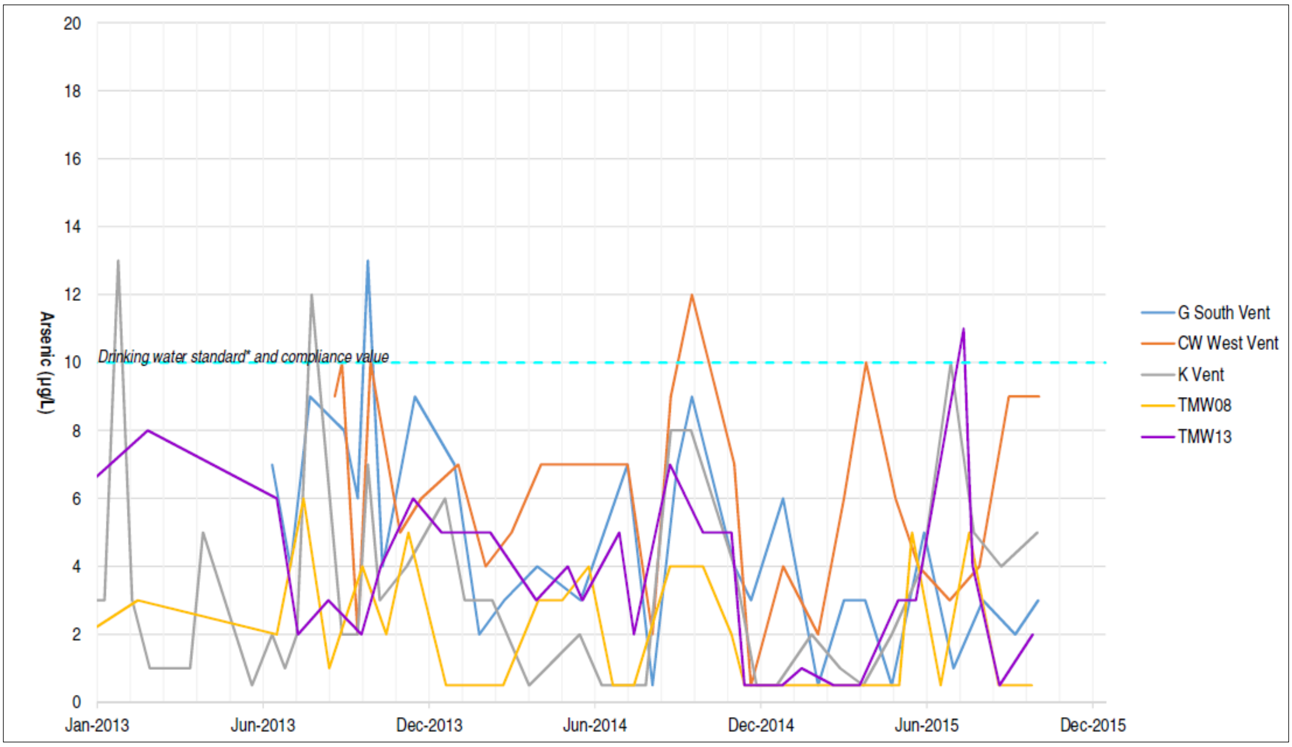


Figure 8.13: Arsenic concentration during and flowing closure of Galmoy Mine (from SWS, 2016)

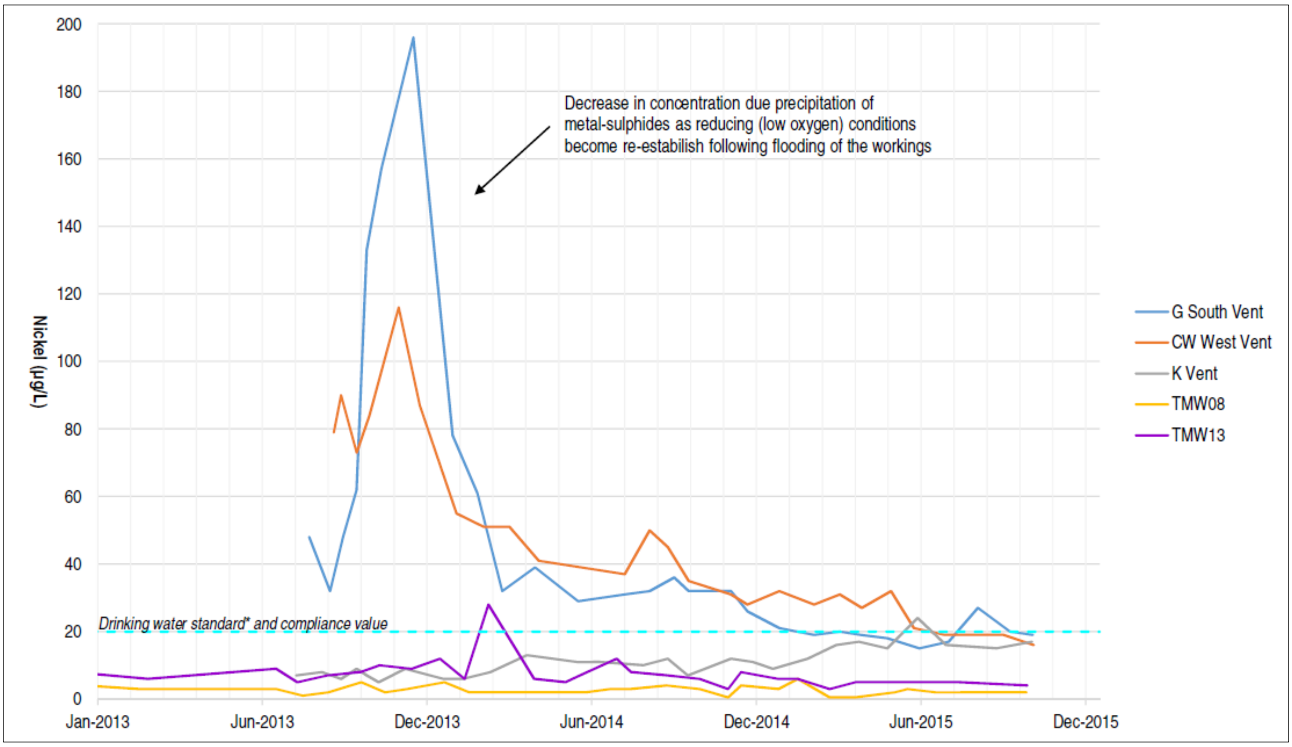


Figure 8.14: Nickel concentration during and flowing closure of Galmoy Mine (from SWS, 2016)

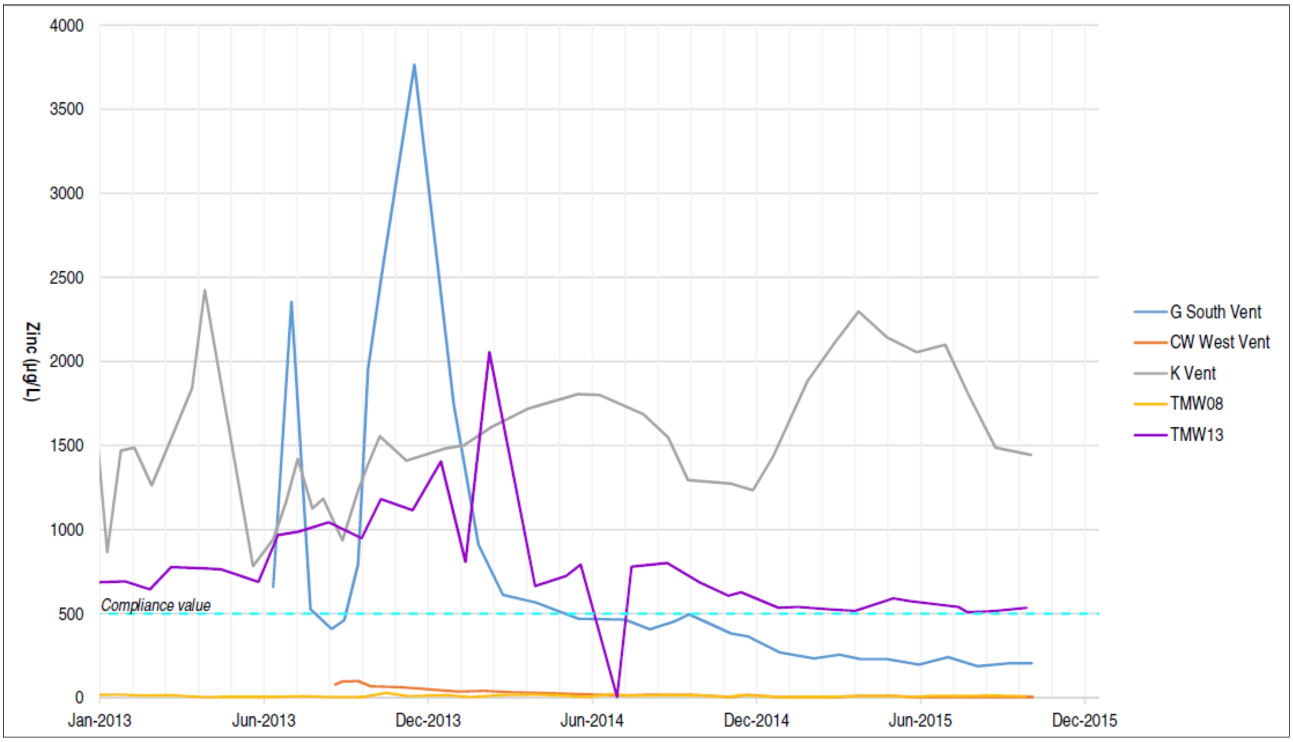


Figure 8.15: Zinc concentration during and flowing closure of Galmoy Mine (from SWS, 2016)

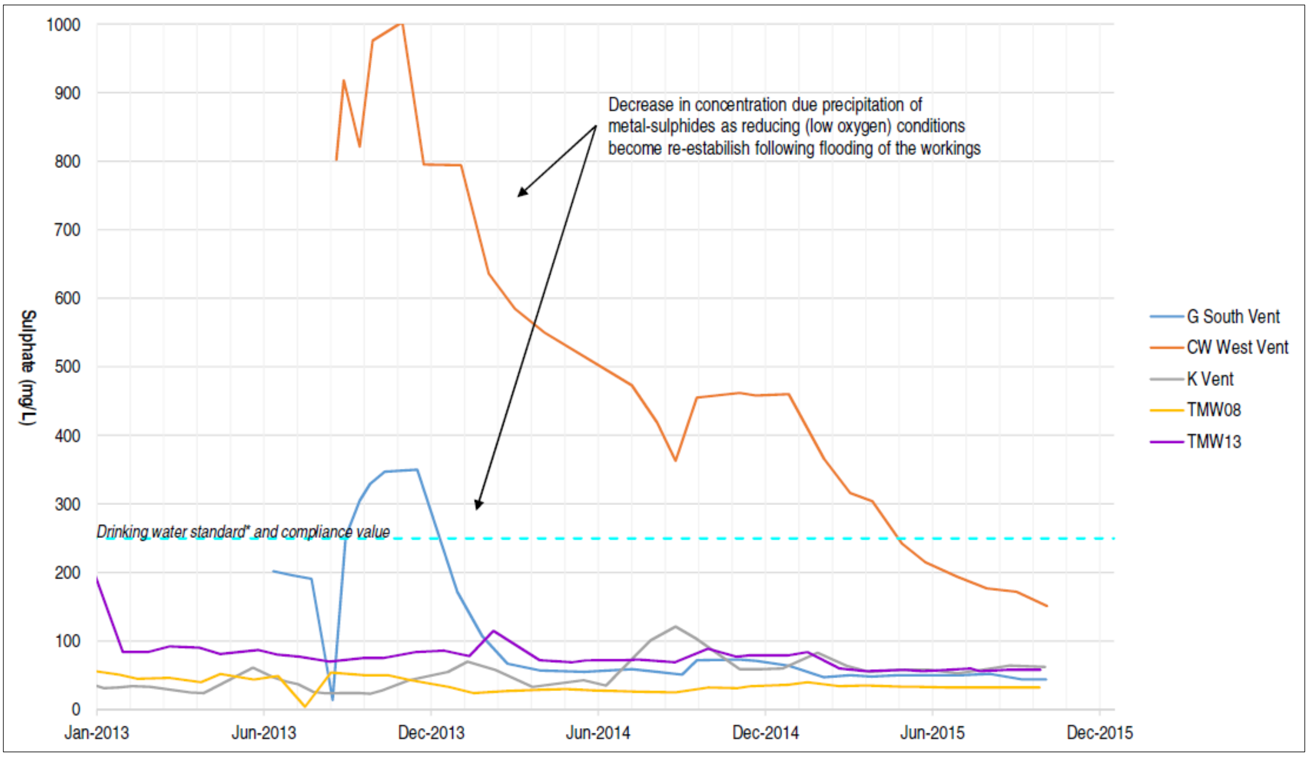


Figure 8.16: Sulphate concentration during and flowing closure of Galmoy Mine (from SWS, 2016)

Surface Water

Monitoring data from the downstream surface water locations show that the chemistry of the key parameters remained stable and below Galmoy compliance values and Irish surface water regulations.

Glasha Crossroads has continued to show a seasonal variation in pH, EC and some metals (such as iron, manganese and zinc). The seasonal variations are typical of groundwater-fed baseflow streams in Ireland with increased dissolved solids during the summer when the greatest contribution to the streams is from groundwater. During winter the dissolved solids reduce as the contribution of rainfall-runoff to the stream increases. Therefore, the water quality in the middle of summer is a good proxy for the groundwater quality entering the streams. In general, the quality of groundwater entering the streams is good.

8.4.4 Groundwater – Hydrogeology

8.4.4.1 Geology and Hydrogeological Units

The geology of the Application Site is described in Chapter 7. The geology (lithology and structures) provides the basis for defining the primary hydrogeological units of the area, as outline below and in Figure 8.17. All of the Proposed Development's orebodies and mining horizons are located towards the base of the Waulsortian limestone.

Waulsortian Limestone Formation

Where the Waulsortian limestone is dolomitised, it is considered a regionally important karstified bedrock aquifer. In undolomitised areas, it is considered a locally important aquifer. The upper zone, nearest the surface, is weathered and exhibits epikarst conditions which have an associated high transmissivity. Consequently, most natural groundwater movement occurs within this upper epikarst zone.

The GRPWS wells penetrate the Waulsortian limestone and have recorded good yields, particularly from the upper weathered part of the formation. In addition, there are a number of local domestic wells that draw groundwater from the upper epikarst zone of the Waulsortian.

Ballysteen Formation

Ballysteen Formation, as it is known locally, is Argillaceous Bioclastic Limestone (ABL) and occurs directly beneath the Waulsortian. In some areas, is considered a locally important aquifer. However, experience at both the Galmoy and Lisheen mines, and in several limestone quarries in Co. Laois, indicates this is a tight formation (aquitard) and yields little groundwater (except along localised highly transmissive fissure zones). In the Galmoy and Lisheen mines, it was seen to form a low permeability base to the overlying Waulsortian and forms a barrier between the Waulsortian and the Lisduff Oolite. Hydrogeology data and monitoring results from the nearby Lisheen mine are consistent with the observations during previous mining at Galmoy.

Lisduff Oolite

The Lisduff Oolite Formation is interbedded within the Ballysteen formation. The oolite is considered a locally important aquifer. The oolite is known to be fractured and to yield groundwater in the vicinity of the main geological structures.

The degree of fracturing and groundwater flow in the oolite away from the main structural zones is uncertain. At Lisheen, mining in the oolite to the south of the Killoran Fault (in Main Zone South) was undertaken without experiencing any major groundwater inflow.

Upper Weathered Zone

Enhanced bedrock weathering (including epikarst) is seen up to about 20 to 30 m bgl. Data from several sources suggest that the epikarst was formed by the dissolution of the carbonate rock during the Tertiary period. Drill logs show a greater frequency of joints and sediment-filled cavities within the upper weathered horizon of the Waulsortian, and also deeper cavities at the level of the ore horizon (to about 80 m depth).

In general, the exploration borehole logs indicate that there are relatively few cavities in the intervening rock between the upper weathered zone and the mining horizon, even where large regional structures have been identified. Cavities that are encountered are usually choked with sediments.

Most natural groundwater movement occurs within the upper weathered zone.

Overburden

The region is overlain by Quaternary superficial glacio-alluvial sediments. The sediments are mostly between about 4 and 8 m thick in the Application Area, and generally thin to the north. However, there are areas in proximity to the mining area where small limestone outcrops are exposed.

Locally, the superficial deposits mostly comprise glacial till, with isolated and discontinuous sand and gravel lenses, and with some cutover peat present. Some pockets up to 15 m thickness of glacial material occur locally, for example in borehole GY136. The glacial till is predominantly composed of limestone clasts within a clay matrix.

There are no overburden (gravel) aquifers defined by the GSI within 10 km of the Application Site.

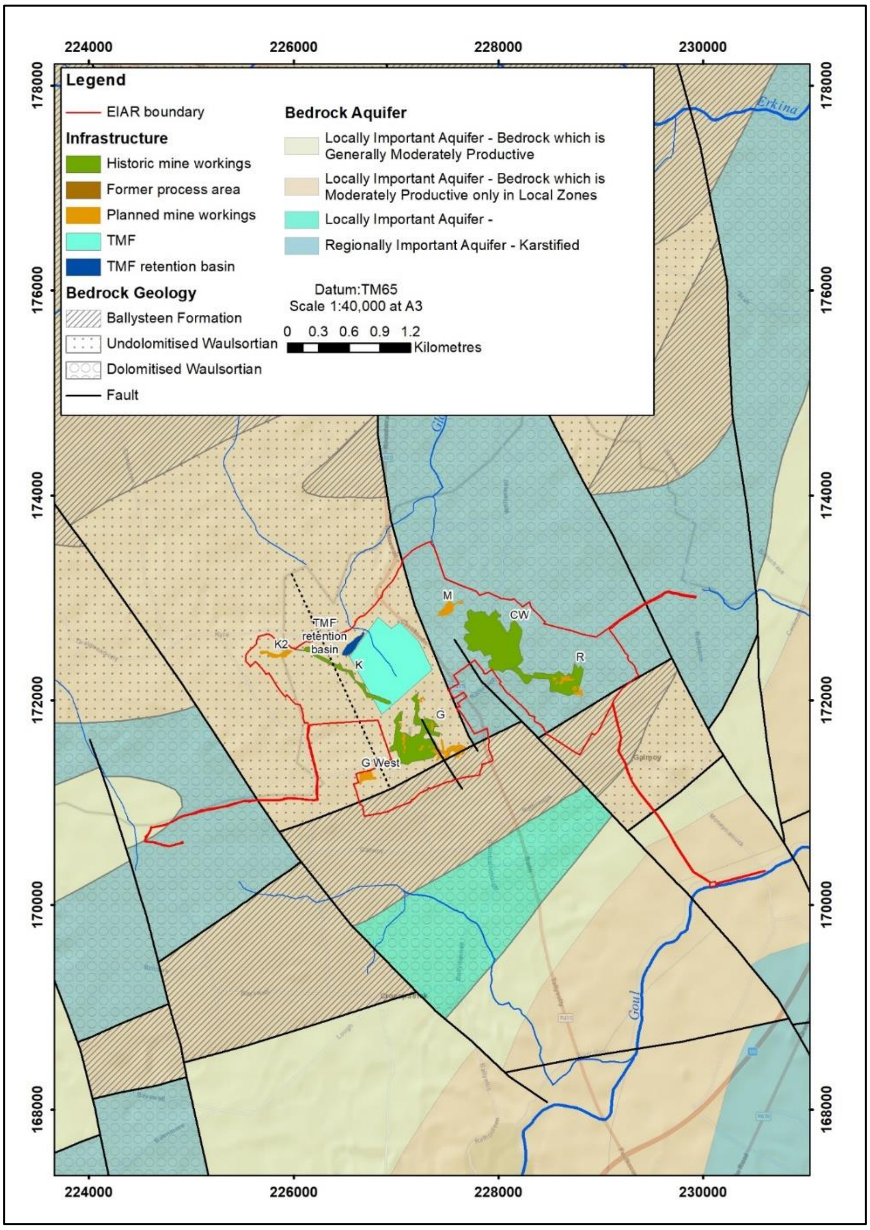


Figure 8.17: GSI Bedrock Groundwater Classification and Lithology of the Mine Area

8.4.4.2 Groundwater Bodies

GSI Groundwater Bodies

Groundwater bodies (GWB) have been defined by the GSI to determine the catchment areas and divides within areas, in a similar fashion to the river basins defined for surface water features. The Application Site occurs within the Rathdowney (IE_SE_G114) and Shanahoe (IE_SE_G_119) GWBs. The Rathdowney GWB is characterised by a 'poorly productive bedrock' and the Shanahoe GWB is characterised by a 'karstic' bedrock. The 'initial characterisation' details are provided in Appendix 8.1.

Galmoy Block

All geology interpretation and hydrogeology monitoring results indicate that the Application Site (including all of the orebodies) occurs within a well bounded block of Waulsortian Formation limestone, reference here as the 'Galmoy Block'. The boundaries of the Galmoy Block have acted to localise the area of drawdown during dewatering of Galmoy Mine.

The Galmoy Block is about 8 to 10 km² in extent. The boundaries of the block are interpreted as follows.

- To the south, the block is bounded by the G Zone Fault and the contact between the Waulsortian and Ballysteen. This is a similar situation to the Main Zone and the Killoran Fault at Lisheen. At both mines, the fault contact to the south of the workings was seen to be a significant hydrogeological boundary;
- To the west, the block is bounded by a NNW-SSE trending structure. This was defined by the baseline studies for Galmoy and has proven to be accurate. It was particularly evident for separating the bedrock drawdown around the Galmoy mining area with the GRPWS wells (WW1A, WW2B) located immediately to the west and northwest of the mining area;
- To the east, the block is bounded by a NNE-SSW structure, with a Ballysteen high, including sub-cropping Ballysteen; the eastern boundary was less well defined by the baseline studies; and
- To the north, the block is bounded by the thinning Waulsortian and by transition to the Ballysteen Formation.

The existing Galmoy workings and proposed new Garrylaun mining areas occur towards the southern end of the Galmoy Block, reasonably close to the G Zone Fault.

8.4.4.3 Groundwater Levels and Flow

Figure 8.18 shows groundwater contours for the Application Area from July 1992, before mining of Galmoy (KT Cullen, 1992). They show relatively flat hydraulic gradients across the orebodies, indicating a good local hydraulic connection. Figure 8.19 shows groundwater contours post-mining of Galmoy with additional spot-measurements of groundwater elevation from baseline monitoring in October 2020. It shows that the groundwater elevations remain consistent with baseline conditions prior to the mining of Galmoy, although CW West and G South values are around 5 m lower than would have been anticipated. This is due to drilling in the area at the time of sampling combined with normal seasonal low levels at the end of the summer.

Baseline groundwater levels are interpreted as follows.

- Along the southern and eastern margin of the block (across the G Zone Fault), there is a step down (to the south) in groundwater levels of about 10 m. Groundwater levels in the Waulsortian to the north of the fault (on the hangingwall side) were about 128 to 135 m OD. Groundwater levels in the Ballysteen to the south of the fault (on the footwall side) were about 120 m OD.

- On the west side of the block, the western boundary was characterised by a stepped increase in groundwater levels. The western boundary represents both the groundwater divide and the surface water divide with the headwaters of the River Drish to the west.
- The northern margin of the block is characterised by a gradual steepening of the pre-mining groundwater table as a result of thinning of the Waulsortian and the transition Ballysteen Formation. Going to the north, the pre-mining groundwater levels drop by about 10 m (to 120 m OD) over a distance of about 1.5 km.

In the immediate area of the orebodies, groundwater levels are typically around 130 mOD, which is between 0 and about 10 m below the ground surface, depending on local topographic variations. The pre-mining groundwater levels were consistent with the observed elevation of local springs (see Section 8.4.4.6), which area also about 130 mOD. The springs represent the natural discharge points of the local groundwater system.

Groundwater flow throughout the district is dominated by fracture flow conditions. All groundwater movement in the limestone bedrock units occurs by fracture flow. Groundwater flow paths are irregular and tend to follow discrete interconnected fracture zones and pathways and consequently significant inflows are confined to discrete areas.

The magnitude of flow within the limestone is controlled by the inter-connectivity of the fracture zones and the ability of the groundwater to cross lithological or fault boundaries, rather than by the local-scale permeability of the formation. The pre-mining groundwater levels suggested the fracture interconnections show enhanced anisotropy in a north northwest-south southeast (NNW-SSE) direction. Monitoring during the period of Galmoy mine operations and closure has proven this to be the case. A similar NNW-SSE pattern in groundwater anisotropy was also observed at nearby Lisheen.

Most natural groundwater movement occurs within the upper weathered zone (20 to 30 m bgl) comprising of epikarst. Groundwater discharge is predominantly to the northwest of the Application Area as springs and baseflow to the Glasha Stream. Although groundwater levels are also lower to the south, monitoring data and presence of the northeast-southwest-trending ‘G-Fault’ indicate that groundwater flow to the southeast is limited.

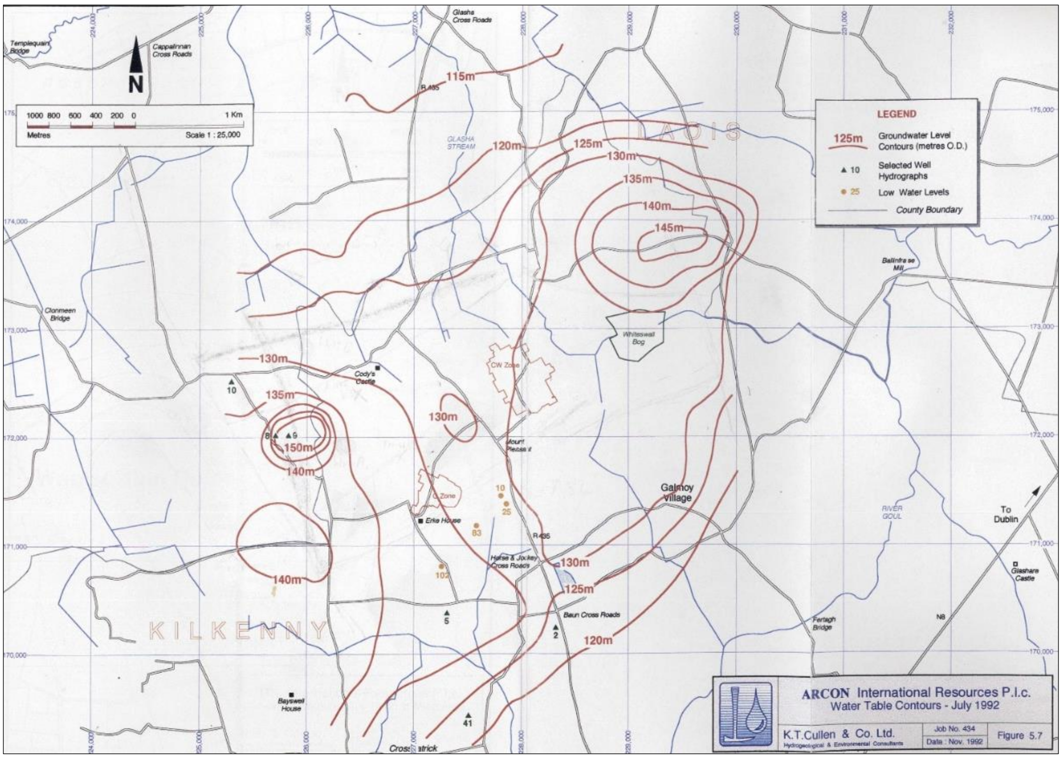


Figure 8.18: 1992 Baseline Groundwater Contours before Mining of Galmoy (from KT Cullen, 1992)

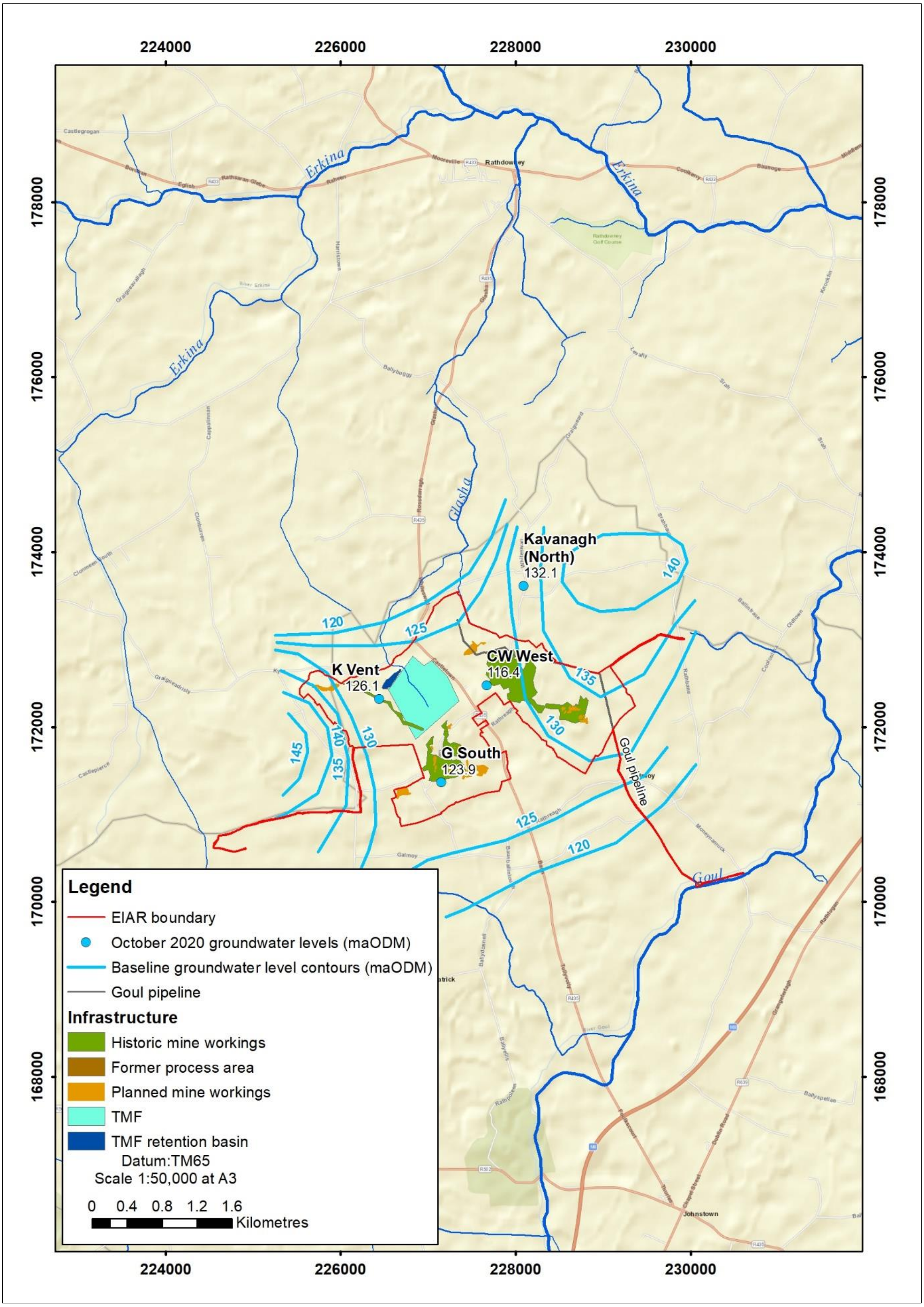


Figure 8.19: 2020 Baseline Groundwater Contours

8.4.4.4 Groundwater Vulnerability

The vulnerability of groundwater depends on: (i) the time of travel of infiltrating water (and contaminants); (ii) the relative quantity of contaminants that can reach the groundwater; and (iii) the contaminant attenuation capacity of the geological materials through which the water and contaminants infiltrate. Groundwater that readily and quickly receives water (and contaminants) from the land surface is considered to be more vulnerable than groundwater that receives water (and contaminants) more slowly and in lower quantities. The travel time, attenuation capacity and quantity of contaminants are a function of the following natural geological and hydrogeological attributes of any area:

i. The sub-soils that overlie the groundwater;
ii. The type of recharge - whether point or diffuse; and
iii. The thickness of the unsaturated zone through which the contaminant moves.

Four vulnerability categories are defined by the GSI (Table 8.14): extreme (E), high (H), moderate (M) and low (L) - based on the geological and hydrogeological factors described above.

Groundwater vulnerability at the Application Site has been defined as 'Moderate', 'Extreme' and 'High' with bedrock near to surface over much of the Site to the east and west (Figure 8.20).

Table 8.14: Extract from 'Groundwater Protection Schemes', Department of the Environment and Local Government, Environmental Protection Agency, Geological Survey of Ireland, 1999.

Vulnerability Rating	Hydrogeological Conditions				
	Subsoil Permeability (Type) and Thickness			Unsaturated Zone	Karst Features
	High permeability (sand/gravel)	Moderate permeability (e.g. Sandy subsoil)	Low permeability (e.g. Clayey subsoil, clay, peat)	(Sand/gravel aquifers only)	(<30 m radius)
Extreme (E)	0 - 3.0m	0 - 3.0m	0 - 3.0m	0 - 3.0m	-
High (H)	>3.0m	3.0 - 10.0m	3.0 - 5.0m	>3.0m	N/A
Moderate (M)	N/A	>10.0m	5.0 - 10.0m	N/A	N/A
Low (L)	N/A	N/A	>10.0m	N/A	N/A

Notes: (1) N/A = not applicable.
(2) Precise permeability values cannot be given at present.
(3) Release point of contaminants is assumed to be 1-2 m below ground surface.

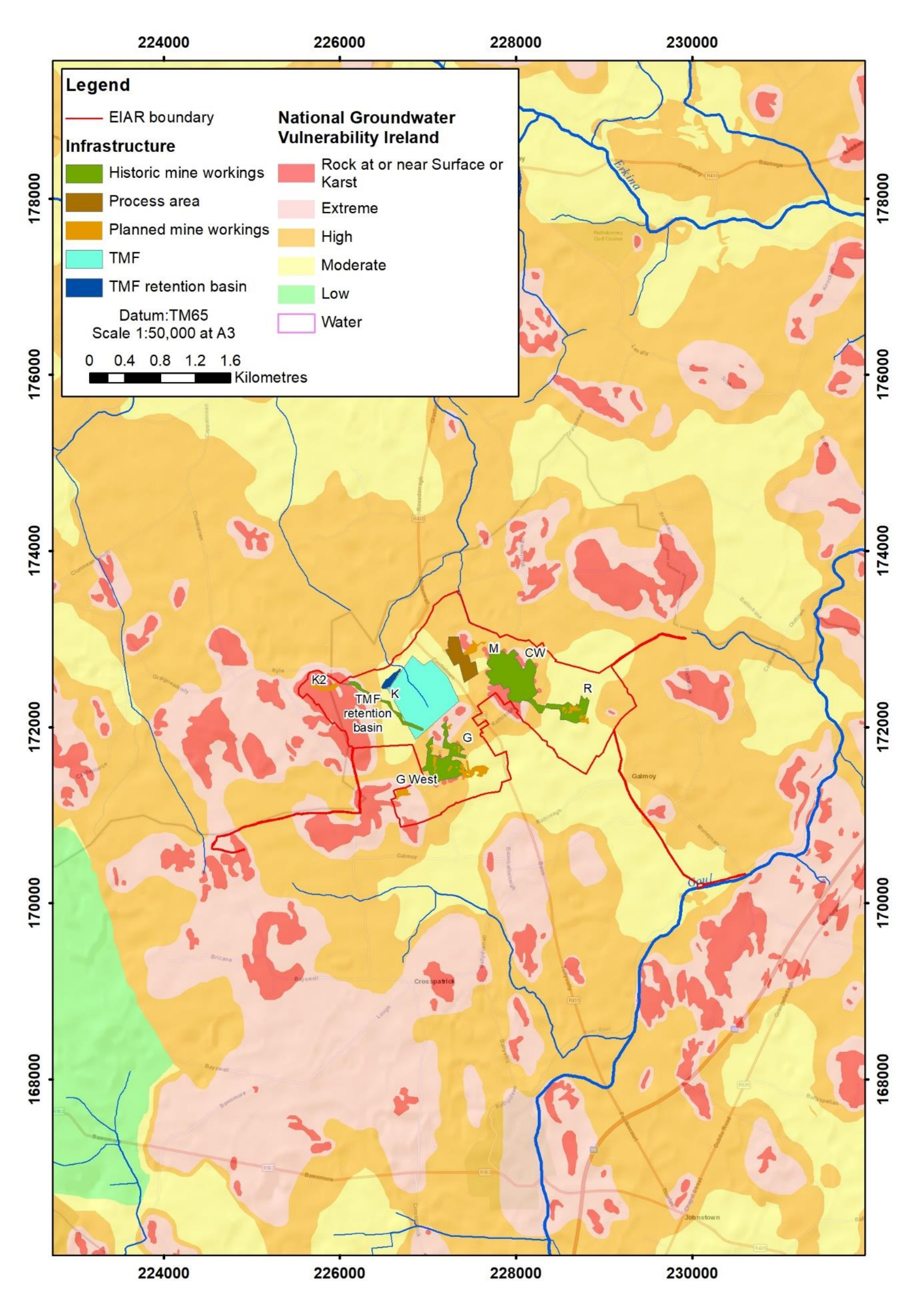


Figure 8.20: GSI Groundwater Vulnerability Map

8.4.4.5 Groundwater Recharge

Groundwater recharge to the Galmoy Block is mostly derived from infiltration of precipitation and local runoff. Meteorological data (Section 8.4.1) indicates that, for an average year between April and July, the effective rainfall (and therefore recharge) is zero. August and September also typically have low effective precipitation, with some years historically also having zero (Table 8.7).

A typical seasonal cycle of the soil moisture balance and recharge is as follows.

- Summer: High rate of evapotranspiration and soil moisture removal; increasing soil moisture deficit; rainfall events cause near-surface infiltration, but the water is removed from the soil profile by evapotranspiration.
- Autumn: High soil moisture deficit, which has been gradually built up over the summer months; infiltration from rainfall events is stored in the near-surface soils, even though evapotranspiration rates are low; little water percolates downward below the extinction depth and becomes recharge.
- Winter: The soil moisture deficit that was built up during the summer months becomes progressively replenished by on-going infiltration due to precipitation events. At some point, the soil moisture deficit is used up and breakthrough occurs, and the percolating water moves downward below the capture zone of the root system; the water is able to move downward below the extinction depth and become recharge to the groundwater system.
- Spring: The soils are fully saturated, and any rainfall is transmitted rapidly downward below the root zone to become recharge. Late winter or spring is usually the period of high water availability, so most or all of the annual recharge may occur during this period. As ambient air temperatures increase, so evapotranspiration rates also rise, and the soil moisture deficit starts to build up as summer approaches.

It should be appreciated that both the annual rainfall amounts, and the seasonal pattern of rainfall, is highly variable, so the actual recharge in any one year is likely to significantly vary year-on-year. For example, in 2011 there was abnormally low rainfall recorded during the late winter and spring, at the time when most of the groundwater recharge would normally be expected to occur. Therefore, the actual groundwater recharge in 2011 was low. Consequently, low groundwater levels in pumping wells and observation wells (and low pumping rates from Galmoy and Lisheen mines) were reported throughout much of Ireland during the summer of 2011.

Previous monitoring results from Galmoy Mine indicate mean annual recharge within the Galmoy Block is around 275 mm/yr. The area of the block is 8 to 10 km^2, which corresponds to a recharge 'flow' of 7.5 MLD. Under active dewatering conditions (as noted in Section 8.4.4.3 above), a minor amount of recharge was also likely derived due to inward (eastward) leakage across the western boundary of the block. This was estimated at the time, based on the water balance and pumping rate from Galmoy, to be about 1 MLD.

At its maximum extent, the total area of the drawdown influence from Galmoy Mine dewatering was about 18 km^2. Around the margins of the block, a relatively small amount of drawdown occurred in the overburden (and also in the bedrock to the west), which created additional capture area. It can be estimated that the recharge potential over the marginal area (8 km^2) would be about 4.5 MLD (assuming a lower non-dewatered recharge rate of 200 mm/yr).

Therefore, based on data from Galmoy Mine, natural recharge of the area (under non-dewatering conditions) is likely to average 200 mm/yr. Recharge over the Galmoy Block during active dewatering is likely to be higher at around 275 mm/yr. However, recharge will vary significantly between years as well as seasonally.

8.4.4.6 Groundwater Discharge

Natural

Based on the geological interpretation provided in Section 8.4.4.3, the interpreted natural groundwater discharge path from the Galmoy Block is to the north, towards the headwaters of the Glasha Stream and the River Erkina. The groundwater contribution to the Glasha occurs from the bedrock and/or superficial deposits as springs and diffuse discharge along the tributary stream channels and ditches, much of which evaporates during the summer months. Discharge is typically most evident in the late summer months when streamflow contributions from surface water are low and when groundwater baseflow forms a larger proportion of the total streamflow.

This interpretation is based on site observations and monitoring data. It corroborates with a pre-Galmoy mining baseflow analysis that was carried out for the River Goul at Ballyboodin Mills near its confluence with the River Erkina. The analysis indicated the baseflow was about 250 to 300 mm, which is considered to be quite high.

In the immediate area of the Application Site, there are two prominent springs, both of which occur at a topographic elevation of about 130 m OD. Both springs were observed to be flowing prior to the start of Galmoy mining (to the Glasha). However, the flow ceased as soon as mine dewatering commenced. Following cessation of mining and recovery of the dewatering system, the springs started to flow again as soon as the recovering groundwater levels reached 130 m OD.

The local springs represent part of the discharge system for the Galmoy Block to the Glasha (Figure 8.1). When the springs flow, the groundwater system is 'full' to 130 m OD. Local recharge to the groundwater block discharges through the springs. As local groundwater levels become lowered, the water table drops below the invert level of the springs, so groundwater discharge and spring flow ceases.

Abstractions – Public Water Supply

The existing GRPWS production wells WW1A and WW2B, both around 500 m away and located to the west and north of K Zone (Figure 8.21), were operated successfully throughout the entire period of mining at Galmoy. There was some drawdown due to the previous dewatering, associated with drawdown in the weathered zone, but it did not significantly affect the operation of the wells.

Groundwater monitoring during the previous period of mine operations and closure showed that the deep groundwater system in the area of the GRPWS wells was separated from the immediate mine area by a hydrogeological boundary, the north-northwest trending K Fault. Figure 8.22 shows a map of the incremental change in groundwater levels between May and June 2013, during the period of groundwater recovery following the previous period of mining. The red contours around WW1A and WW2B indicate summer drawdown due to water supply (GRPWS) pumping. At the same time, the green contours show on-going recovery around the mine area. The two systems appear to be separated by a north-northwest trending structure. The geological structure causes the groundwater flow system to be compartmentalised, and means that the groundwater around the GRPWS wells behaved independently of the recovering groundwater levels above the mine (see conceptual cross section in Figure 8.5).

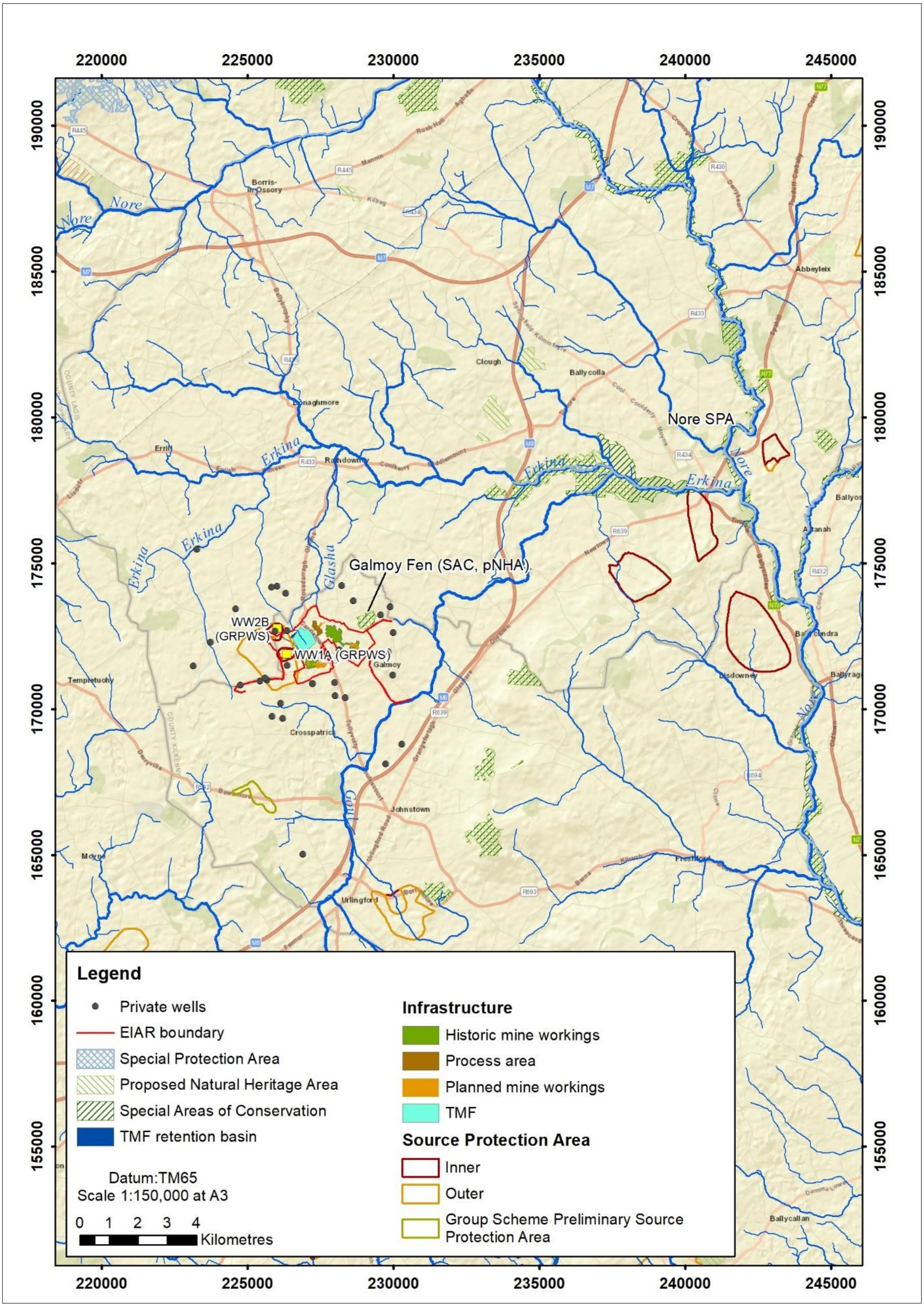


Figure 8.21: Public and Private Abstractions and Protected Areas in the vicinity of the Site

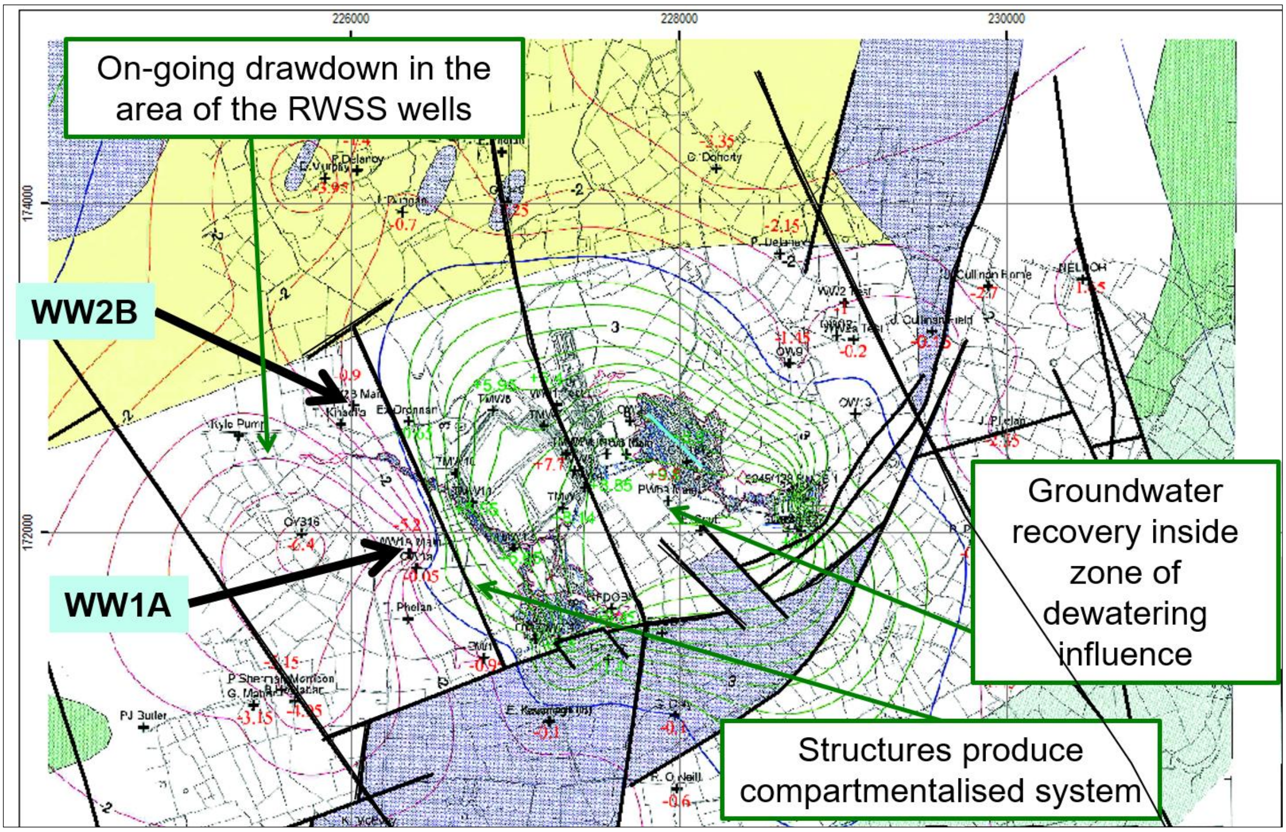


Figure 8.22: Map showing the Change in Groundwater Levels between May and June 2013

Abstractions – Group Water Schemes

Four groundwater-supplied Group Water Schemes occur within the region of the Site. However, all are comfortably outside of any projected area of impact and are therefore not considered within this impact assessment. The schemes are:

- Baunmore 5 km to the south;
- Errill 7 km to the west;
- Ballacolla 9 km to the north; and
- Balief 9 km to the southeast.

Abstractions – Private Domestic Wells

A large number of houses and farms in the area have domestic wells (Figure 8.21). However, prior to mining at Galmoy all affected third parties were provided with a potable water supply via the network now known as GRPWS (previously the RWSS). A recent survey has identified properties in the predicted area of drawdown which are not connected to the GRPWS (Figure 8.23).

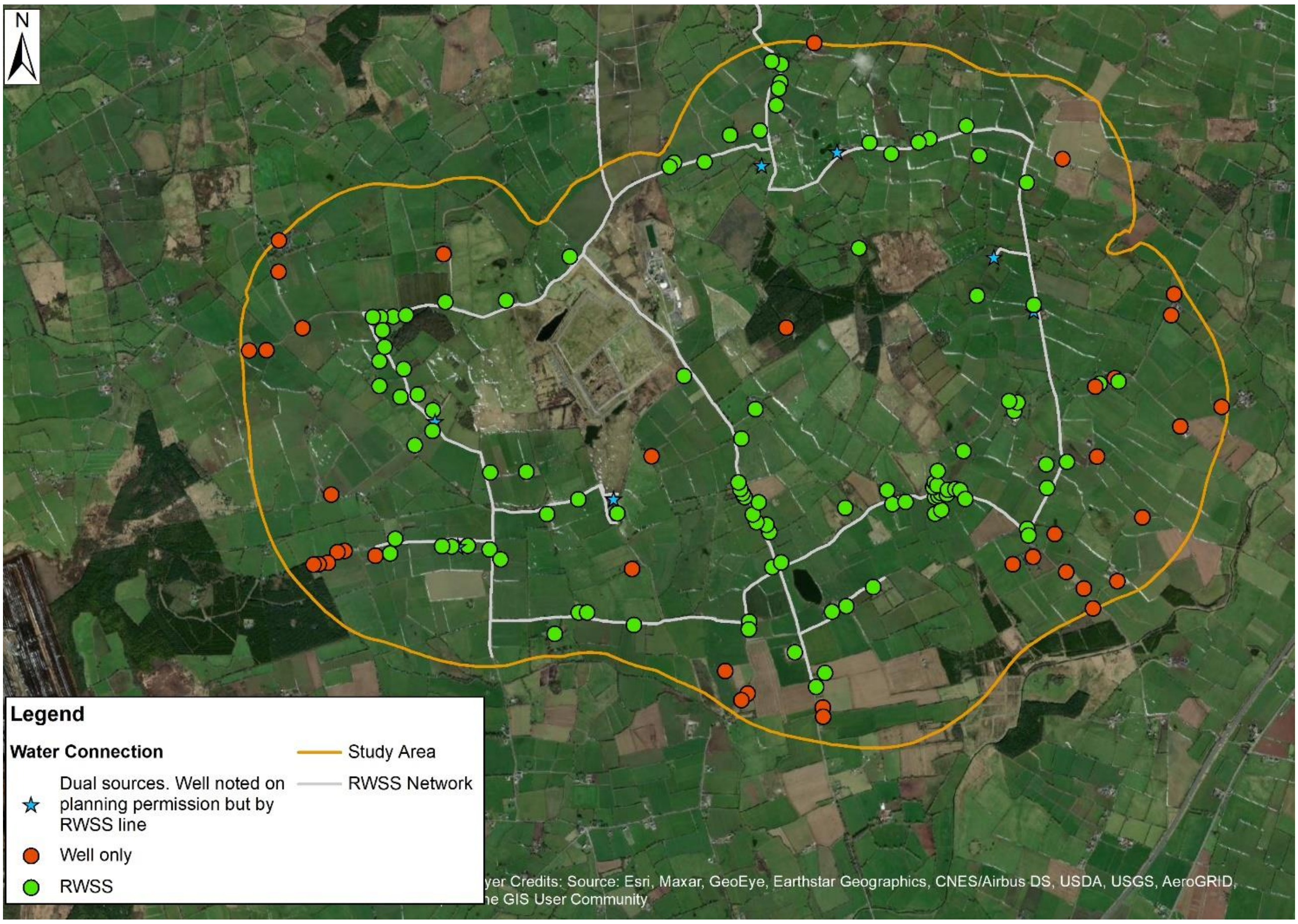


Figure 8.23: Properties within the Predicted Area of Drawdown which are Not Connected to the GRPWS (Red Spots)

Groundwater-Surface Water Interactions

The previous period of mining impacted two bedrock springs, feeding the Glasha, within the immediate area of the mine. These springs occur at a topographic elevation of about 130 m OD and form part of the natural groundwater discharge system for the Galmoy Block.

Groundwater Dependent Terrestrial Ecosystems

Galmoy Fen SAC and pNHA (also known as Whiteswall Bog) is located 1 km northeast of the Site (Figure 8.21). Monitoring of water levels in the fen during operations at Galmoy demonstrated that there was no impact to the wetland area and the SAC.

8.4.4.7 Groundwater Chemistry

1992 baseline

Baseline groundwater quality sampling was completed in 1990 and 1991 as part of the planning for Galmoy Mine (KT Cullen, 1992). Overall, the pre-mining water quality dataset shows that the key elevated parameters in the groundwater system were nitrate, sulphate, zinc and lead, with minor values of copper and barium. Many of the wells with elevated pre-mining constituent concentrations, and particularly the deeper bored wells that penetrated the Waulsortian bedrock, were located in the area immediately to the north of the orebodies. It can be inferred they are located downgradient of the orebodies. The results showed the following.

- Elevated zinc values were reported in some bedrock wells with a range of values between 0.35 and 1.2 mg/L, this is attributed to natural mineralisation of the area. Two shallow overburden wells also reported values greater than 3 mg/L; this is unlikely to be directly associated with mineralisation but may be mineralised sediment in the overburden or associated with materials used in the well construction.

- For those wells with reported zinc values:
  - There was no detectable lead (all reported lead values were <0.05 mg/L);
  - Copper was detected with a range 0.02 to 0.35 mg/L;
  - Barium values were within the range 0.035 to 0.13 mg/L
  - Iron values were low <0.01 to 0.1 mg/L; and
  - Nickel, arsenic, manganese and aluminium were all below detection limit.
- All baseline groundwater samples reported cadmium values of <0.005 mg/L.
- Most lead values in groundwater were below the method detection limit, but some values of up to 0.014 mg/L were reported in the baseline.
- Sulphate values reported in the groundwater system were variable, but generally within the range <5 to 48 mg/L. Values reported for the oolite were often lower than the values reported for wells drilled into the Waulsortian. The sulphate values did not show correlation with the reported zinc values.
- Nitrate values in the groundwater were generally within the range <1 to 20 mg/L. With variations commonly seen in agricultural areas.
- Baseline ammonia also showed variability, from below detection limit to over 5 mg/L at Derryville Bog to the southwest of the Application Area. These variations area attributed to both agriculture and naturally occurring ammonia sources within and adjacent to areas of peat.

Galmoy environmental monitoring

Galmoy mine operated a large groundwater sampling network through operations and into closure, including domestic wells and monitoring wells. The findings showed further evidence for natural groundwater quality in the area being generally good quality, with the exception of nitrogen-species (nitrate and ammonia). The source of these is most likely to be agricultural (animal or land spreading), human waste disposal (septic tanks) and natural (areas of peat).

Despite elevated concentrations of metals and sulphate in the mine workings during initial flooding, once the groundwater system stabilised in and around the workings, the groundwater within the workings became depleted of oxygen (reducing conditions). This prevented any further oxidation of sulphide minerals (the primary source of the metals and sulphate) and, due to the neutral pH of the water, sulphides precipitated from the water, removing these elements from the water. As a result, there is no migration of poor quality water away from the Galmoy mine workings.

2020 and 2021 baseline

Further baseline groundwater sampling was completed in late 2020 and early 2021. The groundwater sampling locations comprised Galmoy ventilation shafts and domestic wells, as shown in Figure 8.24 and Table 8.15.

The mean results from three sampling rounds are presented in Table 8.16 and full results in Appendix 8.2. They show that all parameters analysed for comply with groundwater regulations, with the exception of the following.

Ventilation Shafts

- Arsenic in G South had a value of 0.0083 mg/L against a groundwater regulation of 0.0072 mg/L. All remaining samples from the ventilation shafts were below regulation values, and most were below the detection limit.
- Zinc was below detection limit in both samples from CW West, but over the groundwater regulation value of 0.075 mg/L consistently in both G South and K Vent, with values up to 0.519 mg/L and 1.35 mg/L, respectively. The high zinc is associated with the orebody and does not precipitate from solution as readily as other metals under reducing (zero oxygen) conditions.
- Ammonia was below detection limit in both samples from G South, but over the groundwater regulation value of 0.065 mg/L in both CW West and K Vent, with values up to 0.09 mg/L and 0.07 mg/L, respectively. Ammonia was below detection limit in G South, but G South was the only location to have elevated nitrate at up to 11.4 mg/L N (against a regulation of 8.25 mg/L N).

Domestic Wells

None of the domestic wells sampled are currently used for potable supply.

- Arsenic was equal to the groundwater regulation of 0.0075 mg/L in GM for the November 2020 sample. All other samples from all other wells were below the regulation value.
- Zinc is elevated in JP for both samples at over 4 mg/L compared to a regulation value of 0.0075 mg/L. This corresponds with observations from Galmoy’s monitoring of the same well, when it was believed to be related to mobilisation of naturally occurring sediment or construction materials used in the well. Iron is also high in this well which suggests that the source of zinc may be fine grained particulates from sediment.
- Ammonia exceeds the regulation value (0.065 mg/L) in both samples from GM and JP, and in one of the samples from KN. Values in JP were over 2 mg/L, further suggesting the integrity of the well has been compromised. Ammonia has been elevated in these wells historically (throughout the operation of Galmoy) and when it was attributed to land spreading and/or waste disposal.

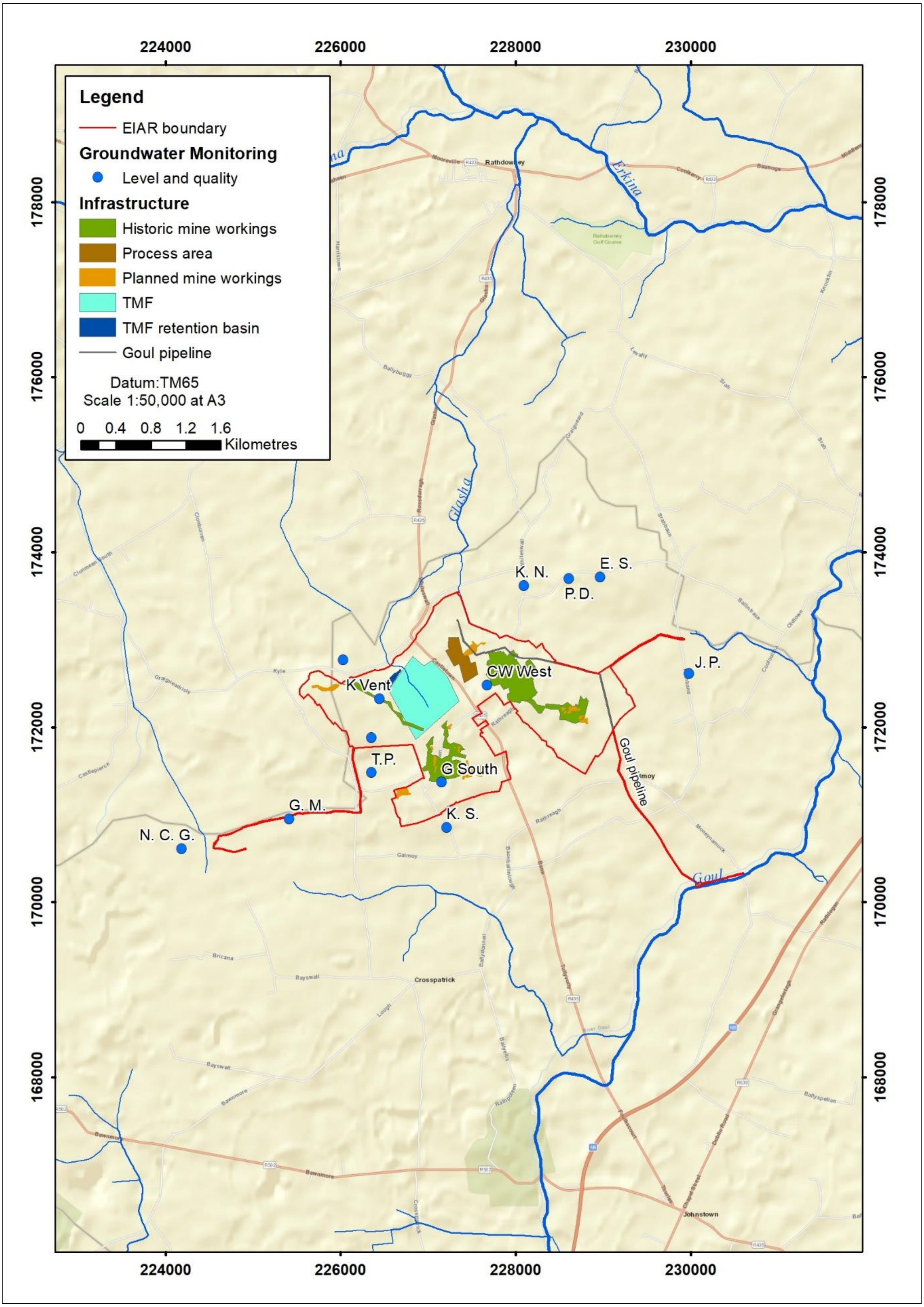


Figure 8.24: 2020 and 2021 Baseline Groundwater Sampling Locations

Table 8.15: 2020 and 2021 Baseline Surface Water and Groundwater Sampling Locations

Location	Area (relative to mine site)	TM65 Irish Grid		Water Source
		Easting	Northing	
G South	Mine workings	227152	171367	Groundwater
CW West	Mine workings	227670	172478	Groundwater
K Vent	Mine workings	226446	172323	Groundwater
PD	Northern district well	228610	173695	Groundwater
KN	Northern district well	228092	173614	Groundwater
ES	Northern district well	228964	173713	Groundwater
GM	Western district well	225410	170950	Groundwater
TP	Western district well	226348	171478	Groundwater
NCG	Western district well	224180	170610	Groundwater
KS	Southern district well	227211	170851	Groundwater
JP	Eastern district well	229982	172612	Groundwater
Goul Discharge (SW1x)	Goul	230610	170304	Surface water
Ballinfrase (15041)	Goul	231582	173535	Surface water
Glasha Discharge	Glasha	227350	173565	Surface water
Coadys Castle (SW2)	Glasha	226570	172703	Surface water
Duggans Bridge	Glasha	226971	173722	Surface water
Glasha Crossroads (nr 15042)	Glasha	227107	176009	Surface water
Coneyburrow Bridge (15056)	Erkina d/s of Glasha	229081	178396	Surface water
Durrow Ft Br (15005)	Erkina d/s of Goul	240541	177475	Surface water
River Nore	Nore u/s of Erkina	241518	178596	Surface water

Table 8.16: 2020 and 2021 Baseline Mean Groundwater Quality

Parameter	Unit	Groundwater Regulations	CW West	G South	K Vent	ES	GM	JP	KN	KN	NCG
Groundwater Level	Mbrp		17.13	22.46	3.22			7.48	3.70	10.51	7.23
DO	%		3.6	7.3	5.9	60	14	5.4	63	53	100
Electrical Conductivity Field	µS/cm		770	1000	820	820	1100	790	890	800	800
Electrical Conductivity Lab	µS/cm		790	1000	840	800	1000	800	860	890	780
pH Field	pH units		7.1	6.6	6.9	7	6.8	7.1	6.9	7	7.1
Temperature	°C		11	11	12	11	11	11	11	11	10
pH Lab	pH units		7.8	7.5	7.6	7.8	7.5	7.7	7.7	7.7	8.2
ORP	mV		0.6	210	77	150	210	-90	140	360	360
Total Dissolved Solids	mg/l		500	710	550	530	730	460	540	560	490
Total Hardness as $CaCO_3$	mg/l		370	500	470	410	520	370	420	440	10
Total Suspended Solids	mg/l		<10	<10	<10	<10	<10	11	29	<10	<10
Turbidity	NTU		18	18	2.1	-2	1.4	7.2	3.4	33	-2
Bicarbonate Alkalinity as $CaCO_3$	mg/l		340	450	400	380	470	400	380	380	340
Chloride	mg/l	24 — 187.5	22	29	14	20	48	29	34	34	34
Dissolved Aluminium	mg/L	0.15	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Dissolved Arsenic	mg/L	0.0075	0.002	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.005
Dissolved Cadmium	mg/l		<0.00003	0.0002	0.00009	<0.00003	<0.00003	<0.00003	<0.00003	<0.00003	<0.00003
Dissolved Calcium	mg/l		83	140	120	130	160	88	120	120	2.1
Dissolved Chromium	mg/L		<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
Dissolved Copper	mg/L		<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	0.01
Dissolved Iron	mg/L		0.11	<0.02	0.05	<0.02	<0.02	4.5	0.04	<0.02	<0.02
Dissolved Lead	mg/L	0.0075	<0.005	<0.005	<0.005	<0.005	<0.005	0.007	<0.005	<0.005	<0.005
Dissolved Magnesium	mg/l		39	36	39	19	32	35	25	31	1.1
Dissolved Manganese	mg/L		0.008	0.19	0.17	<0.002	<0.002	0.27	0.04	<0.002	<0.002
Dissolved Mercury	mg/l	0.00075	<0.00001	0.0003	0.0002	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Dissolved Nickel	mg/L		0.004	0.02	0.01	<0.002	<0.002	0.003	<0.002	<0.002	<0.002
Dissolved Phosphorus	mg/L		0.005	0.005	0.003	0.02	<0.005	<0.005	0.02	0.005	0.003
Dissolved Potassium	mg/l		22	28	2	9.7	15	19	3.2	3.1	0.9
Dissolved Silicon	mg/L		4.2	4.5	2	2	2.9	4.1	3.3	3	2.8
Dissolved Sodium	mg/l		12	12	6.9	9.8	21	12	19	18	190
Dissolved Zinc	mg/L	0.075	0.002	0.4	1.2	0.006	0.007	4.3	0.02	0.01	0.005
Fluoride	mg/l		0.6	<0.3	0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Sulphate as SO_4	mg/l	187.5	50	59	64	15	22	21	18	18	17
Total Alkalinity as $CaCO_3$	mg/l		340	450	400	380	470	400	380	380	340
Ammoniacal Nitrogen as N	mg/l	0.065 — 0.175	0.08	<0.03	0.07	<0.03	0.21	2.9	0.07	<0.03	<0.03
Fats Oils and Grease	mg/l		<4	<4	<4	<4	<4	<4	<4	<4	<4
Nitrate as N	mg/l	8.3	2.5	8.6	0.33	8.9	11	0.03	6.5	8.9	4.8
Nitrite as N	mg/l	0.11	0.04	0.08	<0.006	<0.006	0.04	<0.006	<0.006	<0.006	<0.006

Note, values reported as being below detection limit by the laboratory, are reported here as being half of the detection limit.

8.4.5 Surface Water – Hydrology

8.4.5.1 Watercourses

Lands overlying the very southern and eastern mine workings of the Application Area are drained by the River Goul (Figure 8.27). The Goul flows through counties Kilkenny, Tipperary and Laois from its source in the Slieveardagh Hills, ca. 6 km south of Urlingford. It flows north between Johnstown and Galmoy into County Laois, where it joins the River Erkina, a tributary of the River Nore, several kilometres from Durrow.

The remainder of the Application Area, including all surface infrastructure, is drained by a series of small headwater streams that flow northward to the Glasha Stream and eventually join the Erkina River (see above). The local stream baseflows are mostly fed by groundwater, as described in Section 8.4.4.6.

EPA flow duration curves for locations downstream of the Application Site discharge points are presented in Figure 8.26. In the vicinity of the mine, the Goul has a catchment area of ca. 110 km² and a median flow of ca. 110 MLD. The Glasha has a catchment area of ca. 3 km² and a median flow of ca. 10 MLD.

Under natural conditions, both the Goul and Glasha include gaining reaches. They both receive groundwater from sand and gravel layers within the glacial deposits and shallow weathered (epikarst) limestone, both of which are sustained by infiltration within the local area. While Galmoy was operating, two of the ephemeral springs in the Glasha temporarily ceased flowing. No apparent losses were observable from the Goul during the period of mine dewatering, but it did receive the treated water discharged from the mine. Going forward, the same discharge location would be used for the Proposed Development.

8.4.5.2 Water Body Information

The Application Site is drained by a series of small headwater streams that flow northward to the Glasha (Figure 8.25) and eventually join the Erkina River, a tributary of the River Nore. The local stream baseflows are mostly fed by groundwater (Figure 8.1).

The Glasha and Goul are within the South Eastern River Basin District (SERBD) (IESE17). This is an administrative area for managing the Water Framework Directives (WFD) objectives and monitoring for all rivers in the southeast of Ireland. The SERBD is responsible for dividing the surface water catchments into ‘water management units’ and creating an action plan for meeting the objectives of the WFD as defined in the Regulations.

The Goul is part of the WFD Goul subcatchment (Goul_SC_010). According to the Subcatchment Assessment for the Goul (EPA, 2019a; Appendix 8.3), there are eight river waterbodies within the subcatchment (Figure 8.25 and Table 8.17). The Goul pipeline (the proposed discharge point for the Site) joins the Goul on the GOUL_040 reach. GOUL_020, GOUL_030 and GOUL_040 are upstream of the Site. Although the sampling station for GOUL_040 is downstream of the discharge location (Station Fertagh Br RS15G020300). Further downstream of the discharge point, GOUL_050 and GOUL_060 appear to show deteriorating water quality over time. Both had ‘Good’ status in the 2007-09 assessment but in the latest (2013-2018) assessment both are ‘Moderate’ (Figure 8.25 and Table 8.17). The reason for the deterioration is not stated.

The Erkina WFD Subcatchment (Erkina_SC_010) includes the Glasha Stream, referred to as the Rathdowney Stream, and six other river waterbodies (EPA, 2019b) (Appendix 8.3). The two headwater streams of the Glasha that originate within the Site are both considered as the RATHDOWNEYSTREAM_010 reach. The quality of this reach has deteriorated over time from ‘Moderate’ in both 2007-09 and 2010-12 assessments, to ‘Poor’ in 2012-15. The reason for the deterioration is not stated. This reach joins the Erkina at ERKINA_030. The ERKINA_030 reach includes approximately 750 m of the river upstream of the confluence with the Glasha (Rathdowney Stream). The WFD status for ERKINA_030 shows the same deterioration in quality as RATHDOWNEYSTREAM_010.

There are no lake waterbodies within the Goul or Erkina subcatchments. Both the Goul and Glasha catchments have shown a deterioration in status over time. Pressures identified within both subcatchments are stated as including agriculture, forestry, anthropogenic pressures and urban wastewater.

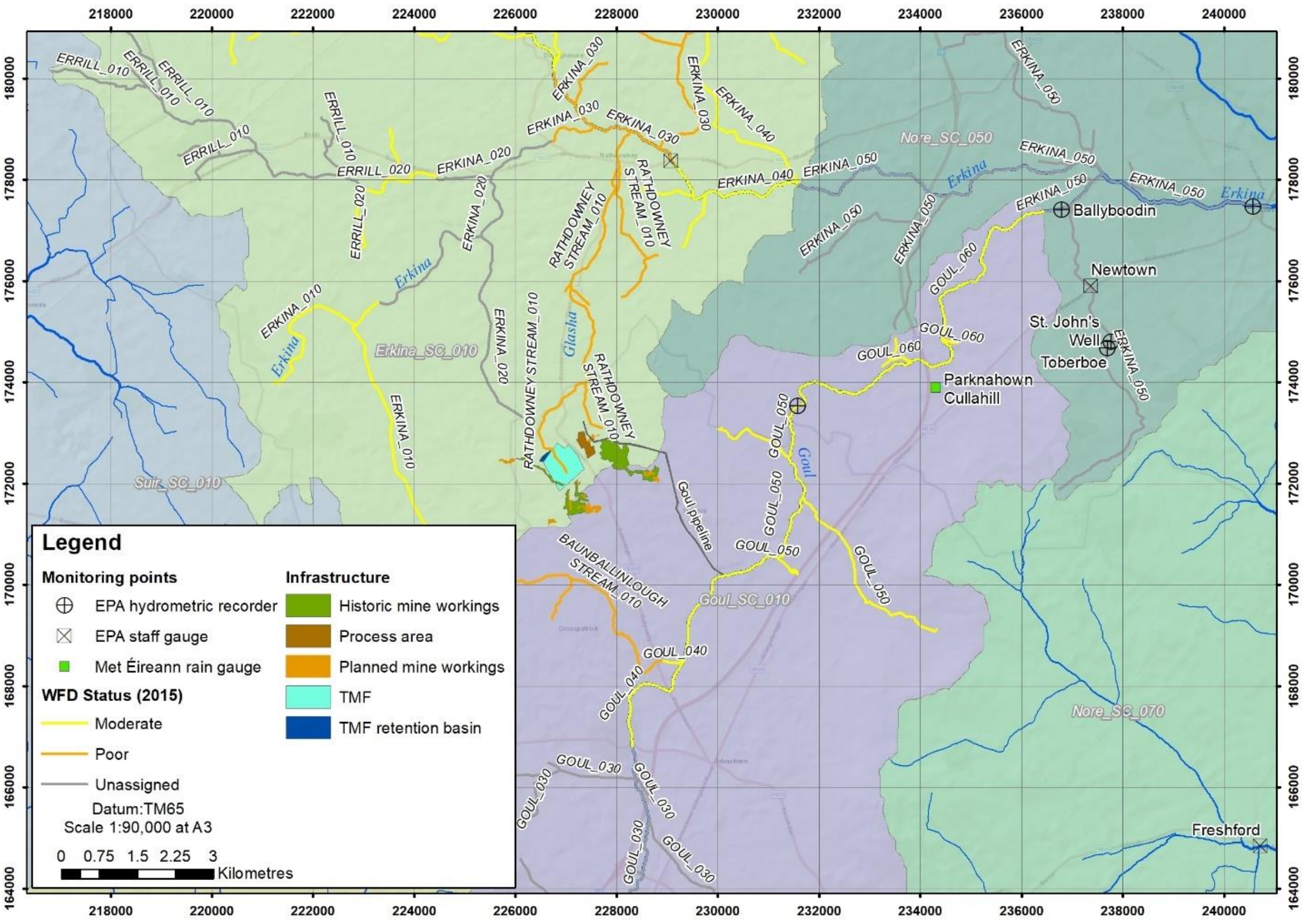


Figure 8.25: WFD River Waterbodies and 2010-15 Status

Table 8.17: WFD River Waterbodies and Status

WFD Code	WFD Name	Status		
		2007-09	2010-12	2012-15
Goul Subcatchment (Goul_SC_010)				
IE_SE_15B120080	BAUNBALLINLOUGH STREAM_010	Moderate	Poor	Poor
IE_SE_15G020060	GOUL_010	Unassigned	Unassigned	Unassigned
IE_SE_15G020110	GOUL_020	Unassigned	Unassigned	Unassigned
IE_SE_15G020200	GOUL_030	Unassigned	Unassigned	Unassigned
IE_SE_15G020300	GOUL_040	Moderate	Poor	Moderate
IE_SE_15G020360	GOUL_050	Good	Moderate	Moderate
IE_SE_15G020500	GOUL_060	Good	Good	Moderate
IE_SE_15A030960	ARDREAGH_010	Unassigned	Unassigned	Unassigned
Erkina Subcatchment (Erkina_SC_010)				
IE_SE_15D030700	DONAGHMORE STREAM_010	Moderate	Moderate	Moderate
IE_SE_15E010040	ERKINA_010	Moderate	Moderate	Moderate
IE_SE_15E010200	ERKINA_030	Moderate	Moderate	Poor
IE_SE_15E010300	ERKINA_040	Moderate	Moderate	Moderate
IE_SE_15E030500	ERRILL_020	Moderate	Moderate	Moderate
IE_SE_15R031100	RATHDOWNEY STREAM_010	Moderate	Moderate	Poor
IE_SE_15E010100	ERKINA_020	Unassigned	Unassigned	Unassigned

8.4.5.3 Surface Water Flow

Publicly Available Data

Flow duration curves for the Goul (at the proposed discharge location) and Glasha (at the former Galmoy discharge location) have been obtained from the River Flow Estimates – Hydrotool website. The locations are shown in Figure 8.26. They show that the flow in the Goul flow ranges between 0.266 m^3/s (23 MLD) at Q95 (i.e. 95% of flow is greater than 0.266 m^3/s) and 3.599 m^3/s (311 MLD) at Q5, with median flow of 1.269 m^3/s (110 MLD). Flow in the Glasha ranges between 0.03 m^3/s (2.6 MLD) at Q95 and 0.393 m^3/s (34 MLD) at Q5, with median flow of 0.115 m^3/s (10 MLD).

Flow duration curves for the Goul and Glasha suggest both are steady (i.e. non-flashy) systems. The curves have relatively shallow slopes that maintain flow throughout the year, suggesting permeable catchments which absorb winter precipitation and have a contribution from baseflow in the summer.

Baseline Flow Monitoring

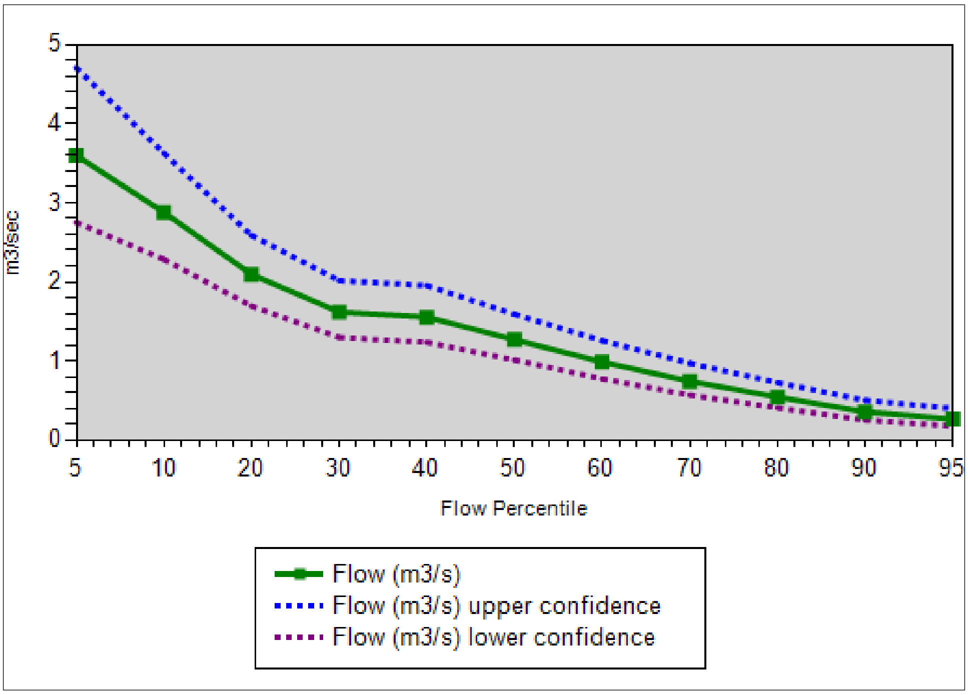
Flow monitoring was carried out at the monitoring points (Figure 8.27) between September 2020 and February 2021 as part of the baseline water quality surveys (Table 8.18). Duggans Bridge, Glasha Discharge (Whiteswall Stream) and Glasha Crossroads (nr 15042) are flow and quality monitoring points on the Glasha and its tributaries. Goul Discharge (SW1x) and Ballinfrase (15041) are on the Goul. Coneyburrow Bridge (15056) is on the River Erkina, downstream of the confluence with the Glasha Stream. Durrow Foot Bridge (15005) is downstream of Coneyburrow Bridge on the River Erkina, in the town of Durrow. The River Nore is monitored approximately 1 km north of the confluence with the River Erkina.

The objective of the baseline monitoring was to measure flow and take water quality samples under a range of flow conditions. Most of the watercourses were in flood during February 2021 and measurement of flow was not safe to complete.

The Glasha showed high variability on flows, with observed flows at Duggans Bridge between 1.7 MLD and 31.4 MLD. At Glasha Discharge (Whiteswall Stream), flows ranged from 0.9 MLD to 12.7 MLD. Downstream of the confluence of these points at Glasha Crossroads (nr 15042), flows were between 6 MLD and 56.8 MLD.

The Goul showed more modest variations in flow. Flows varied between 67.4 MLD and 82.9 MLD at Goul Discharge (SW1x) and between 47.5 MLD and 59.6 MLD at Ballinfrase (15041).

At Coneyburrow Bridge (15056) on the Erkina downstream of the confluence with the Glasha, the maximum measured flow was 73.4 MLD. Observed flow in the River Nore was between 424.2 MLD and 526.2 MLD.



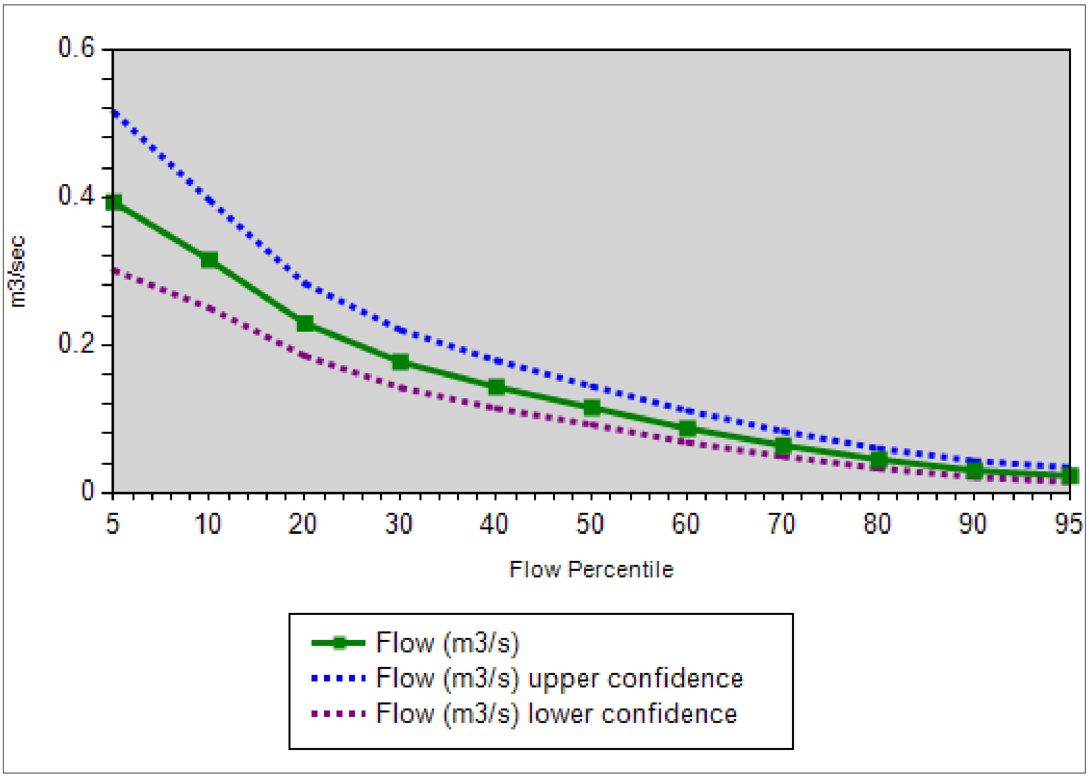


Figure 8.26: EPA flow duration curves for River Goul (top) and Glasha Stream (bottom)

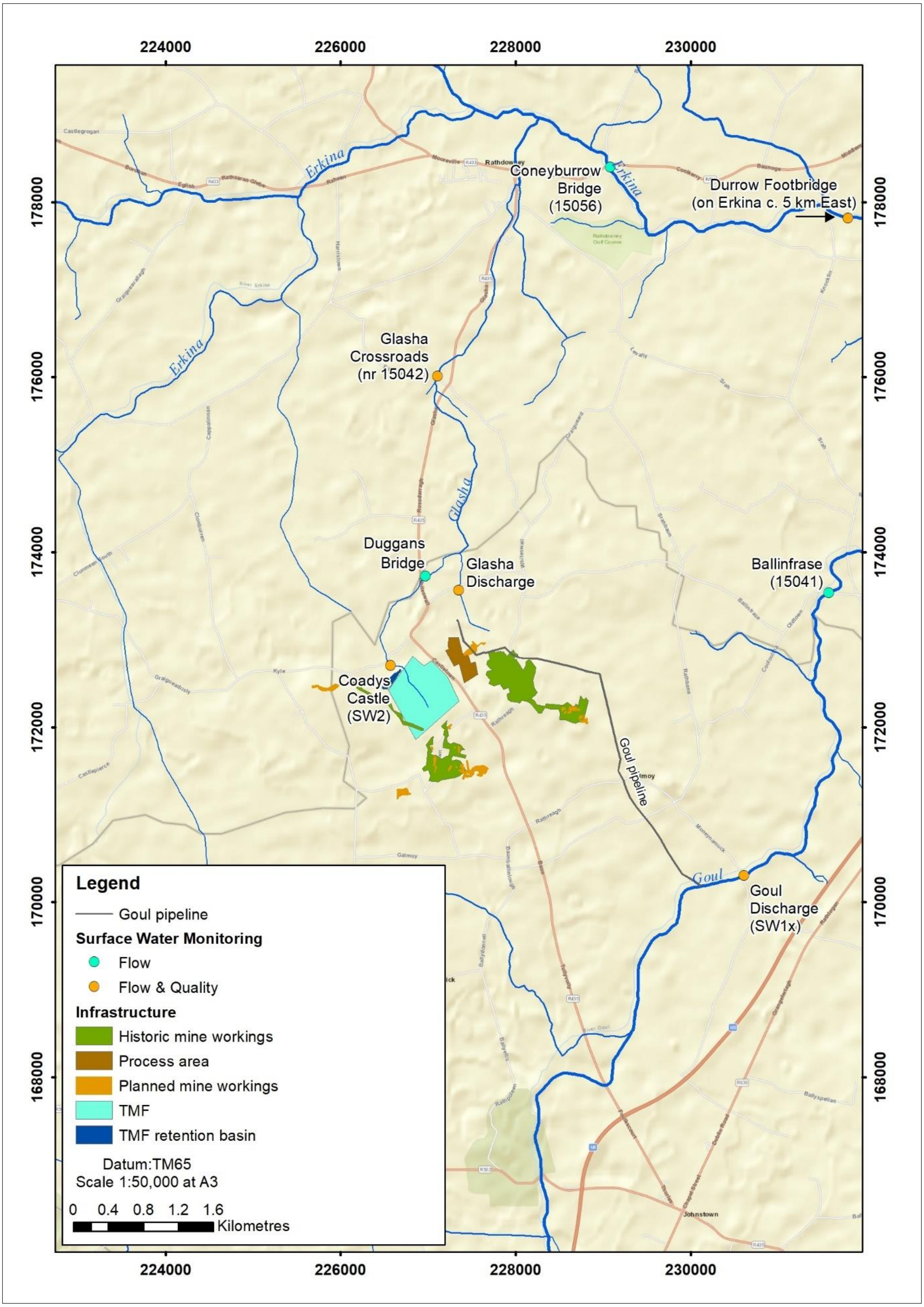


Figure 8.27: 2020 and 2021 Baseline Surface Water Sampling Locations

Table 8.18: 2020 and 2021 Baseline Surface Water Flow Measurements

Location	Flow Rate (MLD)		
	Sep-20	Nov-20	Feb-21
Ballinfrase (15041)	47.5	59.6	In flood
Coadys Castle (SW2)	0.9	2.4	23.3
Coneyburrow Bridge (15056)	58.8	73.4	In flood
Duggans Bridge	1.7	7.9	31.4
Durrow Ft Br (15005)	190.9	235.9	In flood
Glasha Crossroads (nr 15042)	6.0	25.7	56.8
Glasha Discharge (Whiteswall Stream)	0.9	1.9	12.7
Goul Discharge (SW1x)	67.4	82.9	-
River Nore	424.2	526.2	-

8.4.5.4 Surface Water Chemistry

1992 Baseline

Baseline groundwater quality sampling was completed in 1990 and 1991 as part of the planning for Galmoy Mine (KT Cullen, 1992). These are summarised below.

- Reported nitrate values for surface water were within the range 5 to 25 mg/L.
- Sulphate values were within the range 5 to 55 mg/L, with the highest values often reported for the tributary streams immediately to the north of the Galmoy area. Variably elevated sulphate was evident throughout the entire baseline dataset.
- Reported zinc values were within the range <0.01 to 0.17 mg/L. The highest reported pre-mining values were 0.17 mg/L and 0.12 mg/L, both of which are from locations located on headwater tributaries of the Glasha Stream immediately north of the Galmoy orebodies and sampled during low flow (baseflow) periods. This is consistent with the concept of discharge of naturally mineralised groundwater into the surface water system.
- The only reported pre-mining detection of lead was 0.8 mg/L, at the Whiteswall Bog. However, it should be noted that the detection level used for many of the early lead analyses was high (0.05 mg/L), so low level values may have been below the detection level.
- There was no detectable copper in the surface water baseline.
- Total ammonia (as NH_4) was variably present in the baseline dataset.

Galmoy Environmental Monitoring

The chemistry of the water discharge to the River Goul during previous mine operations is summarised Table 8.19. During the period of previous mine operations, the average reported value of ammonia in the upstream water was 0.06 mg/L NH_3. The reported upstream values were variable, peaking at 0.58 mg/L. The reported concentrations appear to follow a seasonal cycle in the river, generally highest in the spring and dropping later in the year. A number of reported ammonia values were above 0.3 mg/L, particularly in 2004 and between 2011 and 2013. The average concentration of ammonia in the Galmoy Mine discharge water was about 1 mg/L NH_3, leading to generally higher ammonia concentrations downstream of the previous mine discharge location.

Table 8.19: Summary of Goul and Discharge Water Quality data from Galmoy Mine

Parameter	Unit	Upstream of the discharge point	Downstream of the discharge point	Mine discharge water
pH		7.68	7.77	8.23
Conductivity	µS/cm	615.73	599.16	998.65
DO	mg/L O_2	9.33	9.59	10.45
Total hardness	mg/l $CaCO_3$	371.97	390.02	947.62
Total alkalinity	mg/l $CaCO_3$	329.23	314.43	-
Suspended solids	mg/L Solids	5.53	5.93	9.62
O-Phosphate	mg/L P	0.01	0.01	-
Nitrate	mg/L NO3-	15.80	15.89	19.32
Nitrite	mg/L NO2-	0.08	0.14	0.57
Sulphate	mg/L $SO_4$2-	14.01	66.18	437.39
Total Ammonia	mg/L NH3	0.06	0.13	1.03
Lead	µg/L Pb	5.76	7.77	23.45
Zinc	µg/L Zn	13.76	32.23	149.32
Cadmium	µg/L Cd	0.51	0.50	0.10
Copper	µg/L Cu	1.35	1.54	10.01
Iron	µg/L Fe	53.06	58.67	114.23
Arsenic	µg/L As	1.92	3.22	13.48
Calcium	mg/L Ca	42.92	39.77	-
Sodium	mg/L Na	12.94	19.95	-
Magnesium	mg/L Mg	22.73	27.47	68.55
Aluminium	µg/L Al	27.12	31.35	36.70
Potassium	mg/L K	4.67	5.37	-

Average nitrate values were about 15.8 mg/L in the upstream waters during the previous period of mine operations. Values about 20 mg/L were frequently reported prior to 2010, particularly during periods of lower flow in the river. The observed changes in nitrate between the upstream and downstream monitoring points was also small.

Values of sulphate in the upstream waters were low (mostly less than 40 mg/L). There were numerous elevated reported values of zinc (up to 0.158 mg/L). High reported values of total suspended solids (TSS) were also reported, mostly during periods of high streamflow. Variable values of lead were reported in the upstream waters prior to 2012.

The average conductivity of the Galmoy Mine discharge water was about 990 µS/cm. However, the average conductivity value at the upstream point is slightly higher than reported average downstream value. Dissolved Oxygen (DO) reported for the Galmoy Mine discharge water was also slightly higher than the River Goul as a result of the slow nature of the natural river flows during the summer months.

The mean TSS concentration in the Galmoy Mine discharge water was 9.6 mg/L, which resulted in a slight increase in average TSS in the downstream waters relative to the upstream. Concentrations of zinc in the Galmoy Mine discharge water were elevated in comparison with the Goul, but zinc concentrations declined since 2008. This was due to improved underground water management procedures and a reduction in active mining faces (see Section 8.4.2).

Reported sulphate values in the Galmoy Mine discharge water averaged 437 mg/L, but with a significant reduction in the reported concentrations after 2008. Sulphate values in the downstream waters were consistently below 250 mg/L from 2007 onward. Sulphate showed a strong seasonality, usually peaking in late summer and showing lowest values in December.

2018, 2020 and 2021 Baseline

Baseline surface water sampling was completed in 2018, late 2020 and early 2021. The surface water sampling locations are shown in Figure 8.27 and Table 8.15.

The mean results from these sampling rounds are presented in Table 8.20, with full results provided in Appendix 8.4. The results show that all parameters analysed are below the annual average value required for compliance with the surface water regulations, with the exception of the following.

- Zinc in one sample from Glasha Stream in March 2018 at a value of 0.126 mg/L against a regulation of 0.1 mg/L.
- Ammonia exceeded the surface water regulations of 0.065 mg/L N in all samples taken in February 2021 except for Durrow Bridge. In addition, the regulations were exceeded at Coadys Castle (Mar-2019), Glasha Crossroads (Sep-2020) and Nore (Nov-2020). The highest value recorded was 0.1 mg/L N at Coadys Castle in February 2021. Only one sample from 23 taken was below the detection limit of 0.03 mg/L N. Widespread elevated ammonia in the river network indicates that potentially naturally occurring sources and agricultural runoff across the region are impacting the river network.

In addition to these exceedances, the following observations are made.

- Sulphate concentrations are generally low (< 50 mg/L) as would be expected in surface water. However, Coadys Castle shows values of 10 to 219 mg/L. The higher values are most likely associated with discharge from the TMF retention basin, which is fed by the wetland on top of the TMF.
- There is a background level of nitrate around 5 mg/L (as N) in the Glasha, Goul and Erkina. Only the Nore had consistent levels below 2 mg/L N across all sampling events. This also indicates agricultural impact on these rivers.

Table 8.20: 2018, 2020 and 2021 Baseline Mean Surface Water Quality

Parameter	Unit	Surface Water Regulations	Coadys Castle (SW2)	Glasha Discharge (Whiteswall Stream)	Glasha Crossroads (nr 15042)	Goul Discharge (SW1x)	Durrow Ft Br (15005)	River Nore
DO Field	%	80 to 120	85.9	65.6	91.8	98.7	85.7	87.3
Electrical Conductivity Field	µS/cm		811	900	823	699	696	465
Electrical Conductivity Lab	µS/cm		815	906.7	813	712.67	700	487.5
pH Field	pH units	6 to 9	7.48	7.32	7.6825	7.66	7.71	7.7225
pH Lab	pH units	6 to 9	7.99	7.88	8.0925	8.09	8.21	8.1475
Temperature Field	°C		9.7	10.3	9	9.9	9.2	9.175
ORP	mV		176.78	105.07	171.18	173.67	198.17	172.78
Total Dissolved Solids	mg/L		515.75	602	514	436	441	288.25
Total Hardness as $CaCO_3$	mg/L		419.5	477	413	351	336	219
Total Suspended Solids	mg/L		<10	<10	<10	<10	<10	<10
Turbidity	NTU		23.955	14.7	2.85	3.11	1.31	5.22
Bicarbonate Alkalinity as $CaCO_3$	mg/L		293	343.5	338	326.5	301	178.67
Chloride	mg/L		12.95	16.2	18.675	20.17	22	16.2
Dissolved Aluminium	mg/L		<0.02	<0.02	<0.02	<0.02	<0.02	0.025
Dissolved Arsenic	mg/L	0.025	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025
Dissolved Cadmium	mg/L		<0.00003	0.00018	<0.00003	<0.00003	<0.00003	0.00013
Dissolved Calcium	mg/L		117	142.9	127.9	106.8	112.1	77.7
Dissolved Chromium	mg/L	0.0.0034	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	0.00096
Dissolved Copper	mg/L	0.03	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Dissolved Iron	mg/L		0.033	0.079	0.036	0.032	0.042	0.124
Dissolved Lead	mg/L	0.0072	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Dissolved Magnesium	mg/L		30.25	28.5	22.13	20.17	13.3	5.875
Dissolved Manganese	mg/L		0.0155	0.076	0.016	0.008	0.006	0.023
Dissolved Mercury	mg/L		<0.00072	<0.00072	<0.00072	<0.00072	<0.00072	<0.00072
Dissolved Nickel	mg/L	0.02	0.0018	0.004	0.0025	<0.002	<0.002	<0.002
Dissolved Phosphorus	mg/L		0.023	0.0085	0.024875	0.029	0.026	0.0205
Dissolved Potassium	mg/L		3.975	3.2	3.85	2.9	4.1	2.675
Dissolved Silicon	mg/L		2.26	1.891	1.938	2.042	2	1.7
Dissolved Sodium	mg/L		11.3	9.57	9.3	9.1	9.6	7.8
Dissolved Zinc	mg/L	0.1	0.0198	0.061	0.0253	0.0025	0.0027	0.0023
Fluoride	mg/L		<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Sulphate	mg/L		84.725	125.3	65.1	19	24.4	19.1
Total Alkalinity as $CaCO_3$	mg/L		352	376	349	345	320	205
Ammoniacal Nitrogen as N	mg/L	0.065	0.0625	0.057	0.056	0.057	0.047	0.073
Apparent Colour	mg/L PtCo		85	53	56	47	61	120
BOD (Settled)	mg/L	1.3	<1	<1	<1	<1	1	<1
COD (Settled)	mg/L		25	18.5	22.875	23.17	26.5	36
Fats Oils and Grease	mg/L		<4	<4	<4	<4	<4	<4
Nitrate as N	mg/L		3.16	1.54	5.06	4.89	4.48	1.905
Nitrite as N	mg/L		<0.006	<0.006	<0.006	<0.006	0.019	<0.006
Total Organic Carbon	mg/l		6.25	3.7	7	4.33	7.3	10
Ortho Phosphate as PO_4	mg/L		<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
MRP Ortho Phosphate as P	mg/L	0.035	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03

Note, values reported as being below detection limit by the laboratory, are reported here as being half of the detection limit.

8.5 Characteristics of the Proposed Development

8.5.1 Supplementary Wellfield

The GRPWS production wells WW1A and WW2B continued to supply water to the scheme with limited impact from the mining and dewatering activities of Galmoy. However, although the risk of impacting these wells remains low, a supplementary groundwater supply will be developed as part of the Proposed Development. A trial well drilling programme has been completed outside of the predicted 1.5 m area of drawdown (Appendix 8.5). This has demonstrated that a water resource of suitable quantity and quality exists in that area to supplement (or replace) the existing production wells in the event that mining does have an impact on their ability to provide sufficient supply to the scheme.

Abstracting water from the supplementary wellfield would reduce groundwater levels in the area. This has, therefore, been included in the impact assessment for the Site.

8.5.2 Mine Water Management System

8.5.2.1 Water Balance

For the purposes of this assessment, the mine water management system and associated facilities are described in three categories:

- Water inflows and/or chemical mass addition;
- Water storage; and
- Water treatment, mass removal and discharge.

A water balance flow diagram for the Application Site is presented in Figure 8.28. It shows that the underground dewatering system dominates the water management system and the MWTP has been sized to accommodate a maximum flow of 24 MLD.

Treated water will be used for service water underground (which will be returned via the dewatering system) and for ore washing (which will evaporate, become moisture for backfill or return to the water treatment plant). Water used for backfill will also come from the water treatment plant sludge. Further details of the mine water balance and flows are presented in the following subsections.

8.5.2.2 Water inflows and/or chemical mass addition

Underground workings

The underground workings extend to depths of up to 150 m bgl. Water inflows to the underground workings comprises of groundwater and recirculated water for services underground (including drilling). The backfill used will also include some water, but this will remain locked in storage within the backfill, rather than 'discharge' to produce an inflow of water to the workings (see Section 8.5.2.3). All water from the underground workings will be pumped to surface.

Chemical mass additional occurs underground through two mechanisms.

1) Oxidation of sulphide material – the orebody and associated sulphide material is currently submerged beneath the water table and so remains stable in a reducing (zero oxygen), neutral pH environment. Dewatering of the sulphide material will lead to oxidation of the sulphides, therefore producing a chemical mass flux of primarily sulphate and trace metals into the water being abstracted from the workings to surface; and

2) Blast residues – explosives used for mining typically contain nitrogen species. If these become washed out pre-blast (uncommon in underground mining), ammonium nitrate can be released into the water.

Oxides of nitrogen, including nitrate and nitrite are produced from blasting and post the blast these can be impinged in mine water.

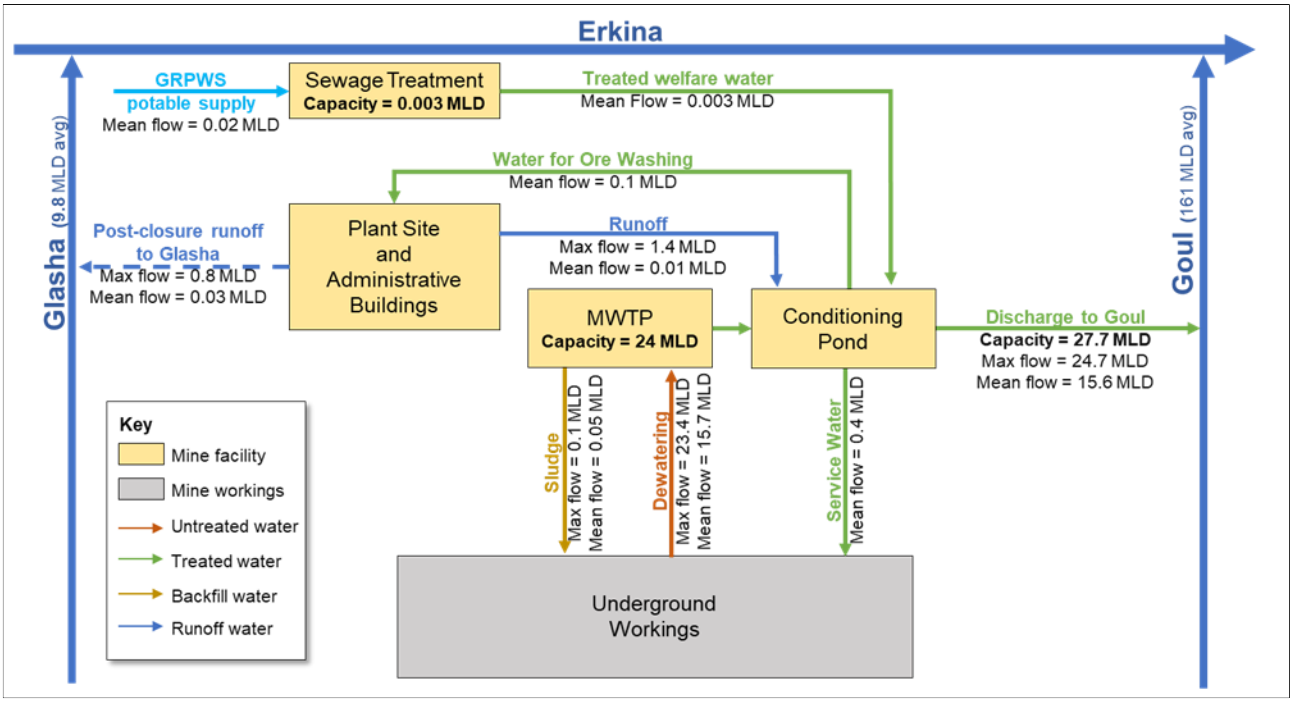


Figure 8.28: Water Balance Flow dDagram for the Application Site

Surface water inflow

Ore handling areas within the Plant Site are the only areas where 'contact' runoff water (water in contact with mine facilities) may be generated. The surface runoff flows have the potential to contain trace metals and suspended solids. Runoff generated within these areas will be routed to the mine water treatment plant (MWTP) for treatment.

Runoff generated within 'non-contact' areas of the Plant Site, such rooftops and the car park, will be collected by the storm water system routed to the Conditioning Pond for discharge with treated water.

Potable water will be supplied to the sanitary facilities, etc. at the Application Site. The water will be supplied by the Irish Water supply network (GRPWS).

Service water

Service water requirements on site are primarily:

- Drilling underground;
- Dust suppression of the material handling system and haul roads;
- Washing of ore; and
- Washdown of mine vehicles.

Total service water flows are anticipated to be very small (< 0.5 MLD) and will utilise mine dewatering water as the supply source. All water will be recirculated or routed to the MWTP for treatment (except for dust suppression on haul roads which will evaporate).

8.5.2.3 Water storage

Site water will only be stored in the MWTP balance tank and conditioning pond (receiving treated water).

Water will be permanently bound within the backfill used underground. Runoff from the Plant Site area (described in Section 8.5.2.2 above) will contribute water to the mine water management system.

8.5.2.4 Water treatment, mass removal and discharge

Two water treatment plants will be used at the Application Site.

The MWTP will be commissioned to manage all groundwater and contact surface water inflows generated at the Site. The treatment technology used will be a pH modification and precipitation system (Section 3.4.6.1 of this EIAR), the same technology previously used for both Galmoy and Lisheen Mines. Treated water will be discharged to the River Goul via the existing 'Goul pipeline' previously used by Galmoy Mine. Sludge water will be dewatered to a cake and mixed with rock as part of the cemented rock fill (CRF) process and used as backfill material.

Waste water from the sanitary facilities will be treated in a site sewage treatment plant and the treated water routed to the MWTP conditioning pond for discharge via the Goul pipeline.

8.5.3 Dewatering Plan

8.5.3.1 Predicted Dewatering Rate

Overall Dewatering Rate

Figure 8.1 presents the current mine plan for the Application Site. There are five planned mining zones:

- M Zone is a new mining area to the north of the existing CW Zone;
- R Zone is mostly within the existing mined R Zone footprint area, extending slightly to the east;
- G Zone is within the existing footprint area as well as extending further to the east;
- G West is a new area to the southwest of G the existing G Zone; and
- K2 Zone extends to the west of the existing K Zone mining area.

All underground access will use existing tunnels and infrastructure. All of the new mining areas are within the defined Galmoy Block (see Section 8.4.4.2). G West and K2 zones will mine through the K Fault; this structure was not previously mined past by Galmoy. While the area to the west of the K Fault is within the Galmoy Block, during the dewatering of Galmoy, drawdown was limited to the base of the weathered zone (Figure 8.5). Mining through the K Fault at depth (below the weathered zone) may have the potential to create greater drawdown in the area to the west of the fault than occurred during dewatering of Galmoy. This includes the area where GRPWS production well WW1A abstracts water.

It is anticipated that dewatering requirements will be almost identical to those of required when Galmoy Mine was operating, with the exception of potential additional inflows from the area to the west of the K Fault. A breakdown of dewatering rates is provided below. Figure 8.29 presents the range of predicted dewatering rates for the Application Site. In any given year, flow rates are expected to range seasonally between 12 and 20 MLD, as experienced when Galmoy was actively dewatering, although rates will be higher or lower depending upon the preceding 3 month of precipitation (Figure 8.2).

Dewatering of Recharge Inflows

The historical dewatering rate for Galmoy Mines was mostly within the range 11 to 15 MLD (Figure 8.3). Once the initial groundwater storage has been removed, a similar dewatering rate can be expected for the planned Garrylaun workings.

Based on experience from dewatering at Galmoy (see Section 8.4.2.2), the dewatering rate will be mostly a function of rainfall in the preceding 3 months. The maximum dewatering rate seen at Galmoy was just over

19 MLD in early 2008. The dewatering rate fell below 10 MLD in the summer of 2011. The normal ‘dry-year’ dewatering rate for the Galmoy mine (baseflow rate 2004 to 2006) was about 12 MLD. A dewatering rate approaching 20 MLD can potentially be expected following periods of very high rainfall and recharge.

The new MWTP has been conservatively sized to manage the worst-case scenario of 24 MLD.

Initial Dewatering

For initial dewatering of the mine, it will be necessary to lower the water table from the current elevation of about 130 m OD. To achieve this, there will be a need to remove groundwater storage, and also the water in the decline and the flooded workings, in addition to the on-going recharge. If the water level is pumped down over a 6-month period, the drawdown rate will be about 0.3 m/d, which should provide enough time for the water pressures in the wall rocks to equalise with the falling groundwater level.

Assuming the current void volume of the underground workings above the elevation of the Garrylaun workings is about 150,000 m^3, and that the volume of groundwater storage that requires removal is about 350,000 m^3 (both conservative), there would be a requirement to pump an additional 3 MLD of storage during mine re-opening (assuming that pumping out the mine occurred within a period of 6 months). If possible, the initial dewatering will be carried out during the summer months to minimise the potential for removal of the groundwater storage to coincide with a period of high groundwater recharge.

Placement of Bulkheads

Bulkheading within the workings is being considered to reduce the volume of initial storage removal and therefore minimise the short-term inflow peak. Exclusion of initial water from the deeper parts of the CW & R-Zones will be considered as part of the detailed design stage. A bulkhead may be placed close to the bottom of the existing decline to minimise short term inflows from the deeper eastern part of the existing mine footprint area.

In addition, the existing K Zone plugs will be inspected and reinforced, as required, to minimise short term inflows from K Zone during the initial mining period of the Garrylaun orebody.

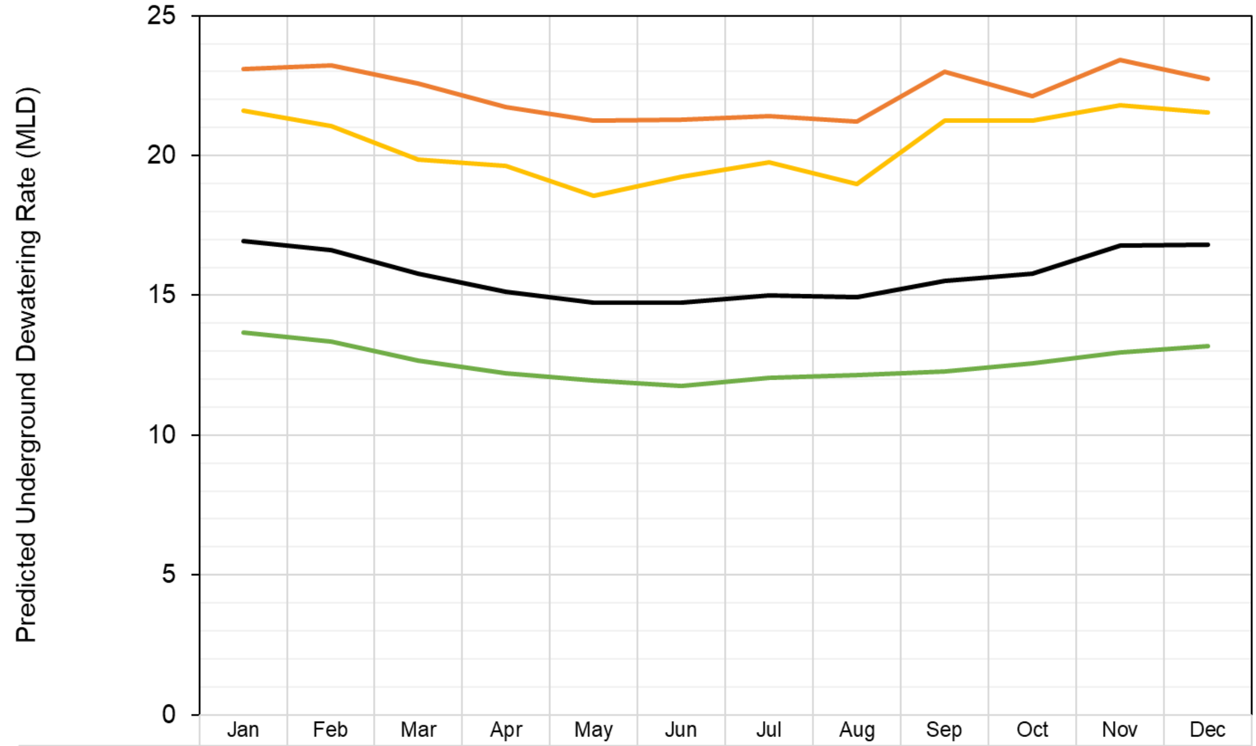
While the placement of bulkheads may lead to a reduction in the initial volume of pumped storage, it would not significantly influence the long-term dewatering rate, which is controlled by recharge over the full area of the Galmoy Block.

K Zone Bulkheads

The short-term benefit of bulkheading the workings was previously demonstrated in the early stages of Galmoy closure (see Section 8.4.3.2). The K Zone plugs led to a reduction in mine water inflows for a period of 2 to 3 months immediately following the shutdown of pumping in the K Zone. There was reduction in pumping rate of 2 to 3 MLD as the inflowing groundwater replenished the storage within and immediately surrounding the K-zone. Once the recovery of local groundwater levels above the K Zone had been completed, the presence of the plugs did not change the overall mine inflow rate, which was controlled by the wider-scale groundwater recharge over the Galmoy Block.

Mining through the K Fault

Mining of the K2 and GW West zones extends the workings beyond the K Fault; Galmoy did not previously mine past this fault. During Galmoy dewatering, groundwater flow occurred from the west of the K Fault, but the drawdown was limited to the base of the weathered epikarst zone (as demonstrated in monitoring data from WW1A and WW2B, Section 8.4.2.3; and in the conceptual model cross section, Figure 8.5. This was because the K Fault acted as a hydraulic barrier to flow from the deeper, competent bedrock. GRPWS production well WW1A abstracts water from below the weathered zone to the west of the K Fault, so there is potential for larger inflows as the fault is mined through. This also has the potential of impacting the GRPWS wells. Cover grouting will be undertaken as K Fault is mined through (in both K2 and G West zones). This involves cover drilling in advance of mining to identify zones of potential groundwater inflow. These zones will then be pressure grouted from underground to minimise any inflows when mined. This is a common method of underground mining and, for example, is normal procedure in some areas of Tara Mines.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum (MLD)	13.7	13.3	12.7	12.2	11.9	11.8	12.1	12.1	12.3	12.6	12.9	13.2
Median (MLD)	16.9	16.6	15.8	15.1	14.7	14.8	15.0	14.9	15.5	15.8	16.8	16.8
Maximum (MLD)	21.6	21.1	19.9	19.6	18.6	19.3	19.8	19.0	21.2	21.3	21.8	21.5
Worst Case (MLD)	23.1	23.2	22.6	21.7	21.3	21.3	21.4	21.2	23.0	22.1	23.4	22.7

Figure 8.29: Predicted Dewatering Rates for the Underground Workings, excluding the Initial Storage Removal

8.5.3.2 Dewatering Sequence

It is expected that the dewatering sequence will be as follows.

- Achieve initial dewatering using sump pumps as the decline is progressively developed, possibly in conjunction with pumping from ventilation shafts and/or dewatering wells.
- Re-establish the permanent pumping station at a convenient location close to the bottom of the decline. The capacity of the pumping station would be about 350-400 kW, to lift the water up the decline to the MWTP balance tank. The operating capacity would be capable of pumping 24 MLD with a total dynamic head of about 90 m.
- Establish staged collector sumps (including underground dewatering wells/drains where beneficial) as the workings are gradually extended outwards. The collector sumps would have low head transfer pumps to route the water to the permanent pumping station. It is likely that initial development will be towards G-North and G-South ventilation shafts, to allow a ventilation system to be set up as soon as possible.
- Adopt a programme of cover grouting for the K2 Zone and G West Zone.

8.5.3.3 Pumped Water Chemistry

The pumped water chemistry needs to be considered for:

- The initial period of mine development as the water in the existing flooded workings is pumped out; and
- Long-term pumping during dewatered conditions for production mining.

The initial pumped water chemistry is expected to be similar to the water currently within the mine workings, as described in Section 8.4.4.7. For the purposes of planning, the maximum water quality seen during the baseline sampling of the ventilation shafts has been used for the prediction of quality (Table 8.21). This shows there may be a water treatment requirement for zinc from the start of mining to ensure compliance with the EPA Emission Limit Values (ELVs).

Table 8.21: Predicted Water Quality of Underground Dewatering Pre-Treatment

Parameter	Unit	Surface Water Regs	Initial Water Quality	Maximum Long Term Water Quality
pH	mg/L	6 to 9	7.4	8.7
Al	mg/L		0.01	6.4
Alkalinity	mg/L		460	460
As	mg/L	0.025	0.001	1
Ca	mg/L		140	140
Cd	mg/L		0.0003	0.19
Cl	mg/L		26	38
Cu	mg/L	0.03	0.004	0.19
Fe	mg/L		0.01	17
F	mg/L	0.5	0.15	0.17
Hg	mg/L		0.0005	0.56
K	mg/L		25	25
Mg	mg/L		36	120
Na	mg/L		11	11
Ni	mg/L	0.02	0.02	0.02
NH_3 as N	mg/L	0.065	0.6	1
NO_2 as N	mg/L		0.08	1.0
NO_3 as N	mg/L		7	23
Pb	mg/L	0.0072	0.003	14
SO_4	mg/L		300	330
Zn	mg/L	0.1	0.5	19

Grey shading indicates value exceeds the surface water regulations[1]. Conservative values for sulphate and ammonia assured in the initial pumped water.

As the water level is pumped down and the workings become dewatered, on-going recharge will become mixed with the existing water storage. The pumped water chemistry is expected to become similar to that pumped during later years of previous production mining at Galmoy, as described in Section 8.4.2.4. Table 8.21 presents the predicted long-term water quality based on the Galmoy monitoring data.

[1] Surface water regulations provide limit values that must be complied with by Member States to achieve good status in surface waters. Emission limit values will be set by the EPA to ensure the achievement of these limits is not impacted by mining. ELVs may take into account assimilative capacity of the receiving water.

The ore geochemistry of the planned future mining extensions is similar to the ore geochemistry of the existing workings, so there is no basis for predicting different future water chemistry in the dewatering flows.

8.5.4 Surface Water Runoff

Surface water flows will be generated from the Plant Site including administration buildings area (ca. 8.6 ha).

Maximum daily runoff values from these areas have been derived using a GoldSim site wide water balance model (Appendix 8.6). It has been assumed that the process/admin area will be located on impermeable land cover (concrete, tarmac and roofs), so a curve number of 99 was assigned.

Given that the mine life is anticipated to be between 7 to 10 years, the peak flows from the facilities have been assessed using a 1-in-25 year return period. The annual maximum daily flow rates from the Plant Site is predicted to be 1.4 MLD. Median and maximum predicted mean monthly surface flows from the Plant Site are presented in Figure 8.30. Flows are expected to vary seasonally between around 0.05 MLD in summer and 0.15 MLD in winter. Maximum (mean monthly) summer flows are expected to be around 0.15 MLD and winter maximum flows around 0.3 MLD. Runoff water that has not contacted mineralised material on surface will be directed to the Storm Water Pond prior to discharge to the Goul with treated MWTP water. A small amount of runoff will generated from the ore handling and sorting area. This runoff will have contact with mineralised material and will therefore be routed to the MWTP. For the purposes of a conservative MWTP capacity assessment, it was assumed that all Plant Site runoff would report to the MWTP.

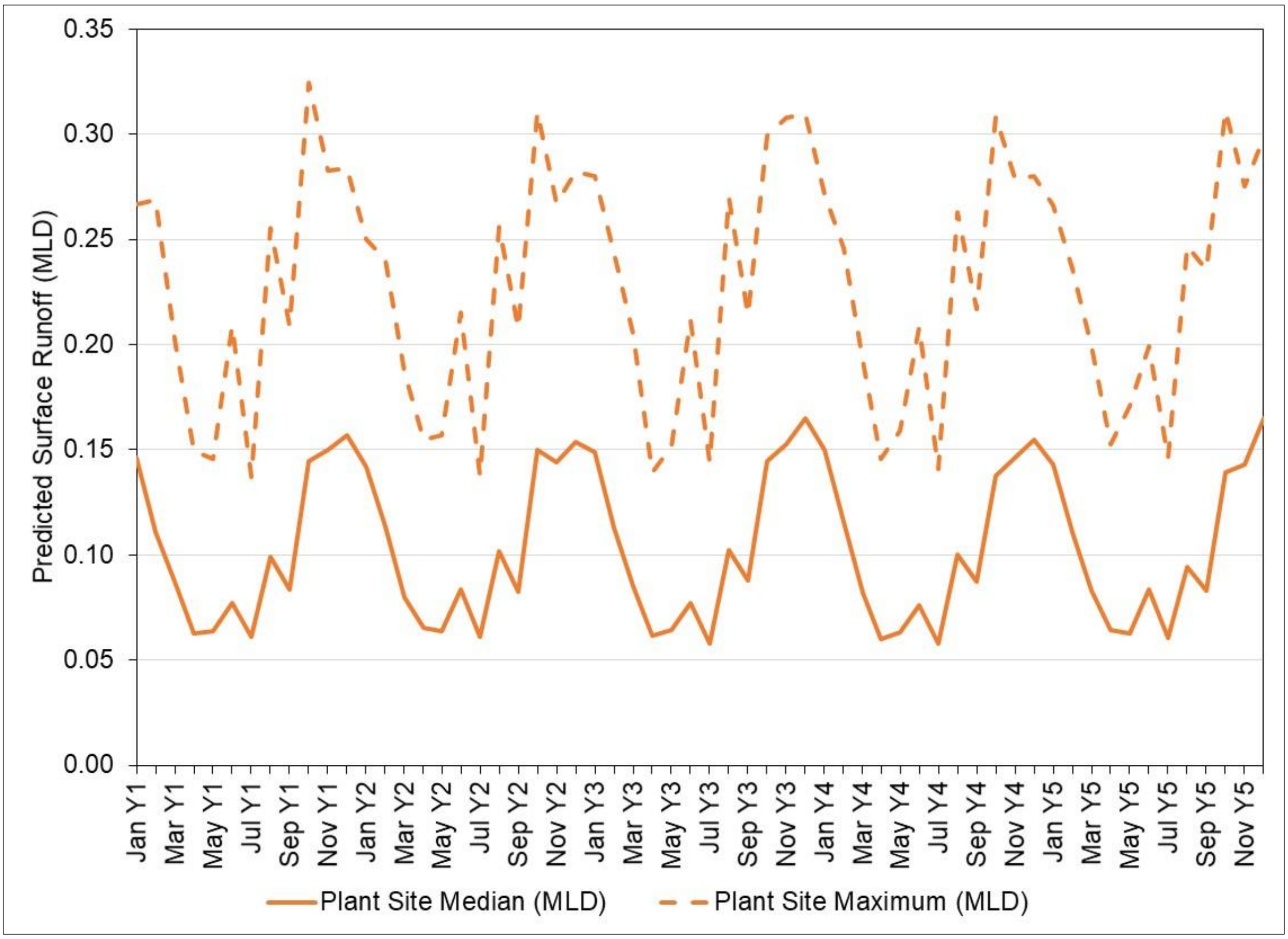


Figure 8.30: Predicted Surface Runoff Rates for the Plant Site including the Administrative Area

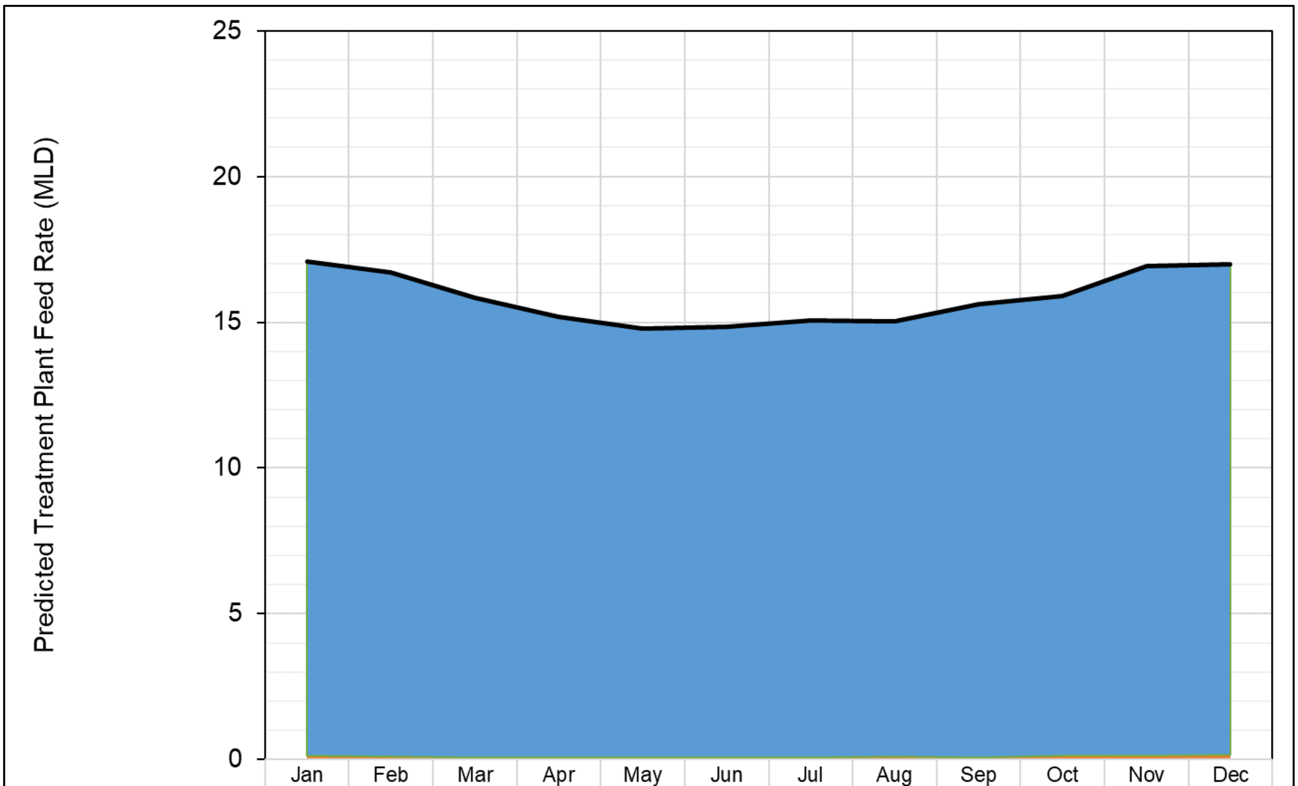
8.5.5 Water Treatment Requirements

8.5.5.1 Mine Water

A new water treatment plant will be commissioned based on similar technology as previously used at Galmoy and Lisheen Mines (i.e. pH adjustment and precipitation). Settlement of precipitates will be completed in a clarifier and a settlement pond prior to discharge. The goal of the treatment system will be to reduce values of constituents in the water to ensure compliance with ELVs and ensure there is no negative impact on the receiving water WFD status.

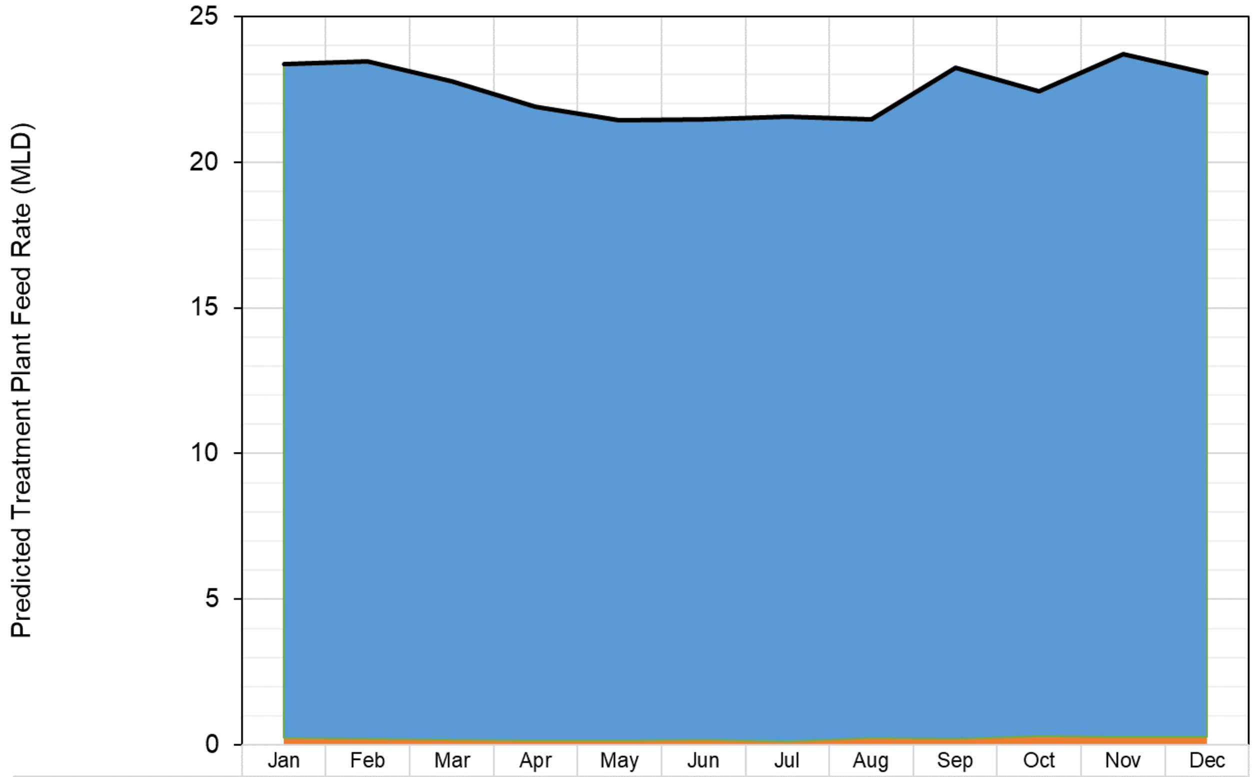
The MWTP will treat mine dewatering water and a small amount of runoff from the ore handling and sorting area. Figure 8.31 and Figure 8.32 show the dominance of dewatering water on the water management system, with over 99% of all water being derived from the underground. Feed rates are expected to range seasonally between 12 and 20 MLD, as experienced when Galmoy was actively dewatering, although rates will be higher or lower depending upon the preceding 3 months of precipitation (Figure 8.2).

The Application Site does not have a water storage facility available to buffer large inflows of water (Galmoy and Lisheen used their TMF supernatant ponds to do this). Therefore, the new treatment plant will be designed to treat up to 24 MLD – the maximum 'worst case' predicted treatment requirement from underground and ore handling and sorting area.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dewatering (MLD)	16.9	16.6	15.8	15.1	14.7	14.8	15.0	14.9	15.5	15.8	16.8	16.8
Plant Site Runoff (MLD)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
TOTAL (MLD)	17.1	16.7	15.9	15.2	14.8	14.8	15.1	15.0	15.6	15.9	16.9	17.0

Figure 8.31: Predicted Median Feed Rates to the MWTP in Year 5 of Mine Life



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dewatering (MLD)	23.1	23.2	22.6	21.7	21.3	21.3	21.4	21.2	23.0	22.1	23.4	22.7
Plant Site Runoff (MLD)	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.3	0.3	0.3
TOTAL (MLD)	23.4	23.5	22.8	21.9	21.4	21.5	21.6	21.5	23.2	22.4	23.7	23.0

Figure 8.32: Predicted Maximum Feed Rates to the MWTP in Year 5 of Mine Life

8.5.5.2 Domestic Sewage

A proprietary sewage effluent treatment system will be installed with a capacity of 2.7 m³/d (0.003 MLD) to meet the needs of the Site. This is a population equivalent (PE) of 30 for the organic load, although a PE41 plant will be installed for greater integrity of the system. The treated effluent will be pumped into the MWTP conditioning pond for discharge down the existing Goul pipeline.

8.5.6 Discharge of the Pumped Water

Primary Discharge Point

The primary route for treated mine water discharge will be through the existing pipeline into the River Goul, as shown on Figure 8.1.

The proposed discharge point is not located within any Special Protection Area (SPA) or Special Area of Conservation (SAC).

Discharge Point – Post Mine Closure

A discharge point post mine closure is proposed to manage storm water runoff from the Plant Site to the Glasha Stream, immediately to the north of the Site. The exact location of this discharge point will be agreed with the EPA as part of the Site's CRAMP (Closure, Restoration and Aftercare Management Plan).

8.5.7 Closure

The closure of the Application Site will occur in two phases:

- Active Closure – where mining has ceased but activities continue on site to close the mine, such as backfilling, and restoration works; and
- Passive Closure – once all closure works have been completed and the Site is stable and not impacting the environment.

Active closure will include the following activities:

- Removal of all underground infrastructure which has the potential to impact groundwater quality;
- Removal of all hazardous materials (oils greases etc.);
- Termination of dewatering to allow groundwater levels to rebound;
- Maintaining a functioning MWTP to treat any contact surface water generated during rehabilitation works;
- Removal of all surface infrastructure that is not being retained for site redevelopment;
- The removal of any contaminated soil and hard standing areas; and
- Monitoring of the groundwater and surface water network to ensure closure predictions are being met.

Two metrics will be used to determine whether, from a water perspective, closure is complete:

1) Groundwater levels in monitoring wells near the workings have returned to their baseline elevations; and
2) Water quality in the monitoring boreholes have returned to the typical range of baseline water quality.

8.6 Potential Effects

8.6.1 Methodology

The identification of potential effects has been completed using the Source-Pathway-Receptor model. An effect can only occur if all three elements of the Source-Pathway-Receptor model are present. Potential effects were defined based on experience from Galmoy Mine and the 'Activities/Environments Matrix' provided in the IGI (2013) guidelines. These comprise:

- Lowering of groundwater levels due to **dewatering** (drawdown) affecting other groundwater abstractions or surface water-groundwater interactions;
- **Discharge to groundwater** (water quality) of mine-impacted water or hydrocarbons from the plant;
- **Discharge to surface water** (flow and water quality) from the MWTP; and
- Dewatering-induced **sinkhole development and reactivation of palaeokarst**.

The latter of these, sinkhole development and reactivation of palaeokarst, has been evaluated through a separate quantitative risk assessment (QRA) detailed in Appendix 8.7 and summarised in Section 8.6.6.

For the former three potential effects, potential receptors have been defined through baseline surveys, prior experience from Galmoy Mine and publicly available sources including the EPA, GSI, OPW and NPWS. These have been identified as:

- Public water supply including source protections zones – the **GRPWS production wells** (WW1A and WW2B);
- Group water schemes including source protections zones – none, due to their distance from the Site;
- Private water supply – **domestic water wells**;

- Groundwater dependent terrestrial ecosystems – none (Galmoy Fen was shown to have not been impacted during previous dewatering of Galmoy Mine);
- Surface water – **Glasha Stream** and **Goul River** (tributaries of the **Erkina** and Nore); and
- **Public and private property** (subsidence evaluation only).

Pathways between the potential impacts and receptors are defined through the conceptual groundwater model, numerical groundwater modelling and surface water flow characterisation.

Dewatering-induced sinkhole development and/or reactivation of palaeokarst is outlined in a separate section: Section 8.6.6.

8.6.2 Potential Effects

8.6.2.1 Lowering of Groundwater Levels due to Dewatering

Once groundwater storage removal was completed during the previous dewatering of Galmoy, the area of drawdown did not vary significantly, as described in Section 8.4.2.3. This is because dewatering is controlled by recharge to a discrete structurally-controlled groundwater block (the Galmoy Block). The area of drawdown was around 18 km², with the greatest drawdown restricted to an area of 8 to 10 km² (the Galmoy Block). Drawdown outside the Galmoy Block was restricted to the shallow weathered zone and some areas of overburden.

It is anticipated that the future maximum extent of drawdown for the Site will be almost identical to the previous area of drawdown. However, because mining through the K Fault has the potential to create additional groundwater inflows, without mitigation measures in place, the future dewatering of the Site may have the potential to have a greater impact on the GRPWS wells than during the previous dewatering.

A numerical groundwater model was constructed (Appendix 8.8) to predict the 'worst case scenario' drawdown (i.e. if no cover grouting is completed in K2 or G West Zones). The predicted area of the 1.5 m drawdown contour is around 22 km² (compared to the estimated 18 km² for the Galmoy Mines area of drawdown). Figure 8.33 shows that drawdown may be elongated to the west and south compared to the previous drawdown area. This is partly because the drawdown area is defined through automatic kriging of limited monitoring data, and partly due to the mining through the K Fault. With cover grouting in place, the simulated area is reduced to 20 km², primarily due to the greater area of drawdown to the east of the Site, which was poorly constrained by monitoring data for Galmoy (i.e. with grouting, the area of drawdown would be similar to previous).

8.6.2.2 Discharge to Groundwater

During operational dewatering, there will be no discharge to groundwater and dewatering will induce a hydraulic gradient towards the mine workings. All 'potential contamination' at the Site will be captured by the mine dewatering system. Therefore, no sources of potential impact will develop.

During closure, as water levels recover and natural (baseline) groundwater flow gradients re-establish, there is the potential for poor quality water in the workings to enter to the surrounding groundwater system. Therefore, discharge to groundwater as a potential effect is only considered for the mine closure phase.

8.6.2.3 Discharge to Surface Water

The zinc and lead orebodies being mined are also naturally elevated in other metals, primarily aluminium, arsenic, cadmium and nickel; as well as sulphate. Along with blasting residues from mining (nitrite and ammonia), these have the potential, without treatment, to be discharged to surface water as a result of mine dewatering.

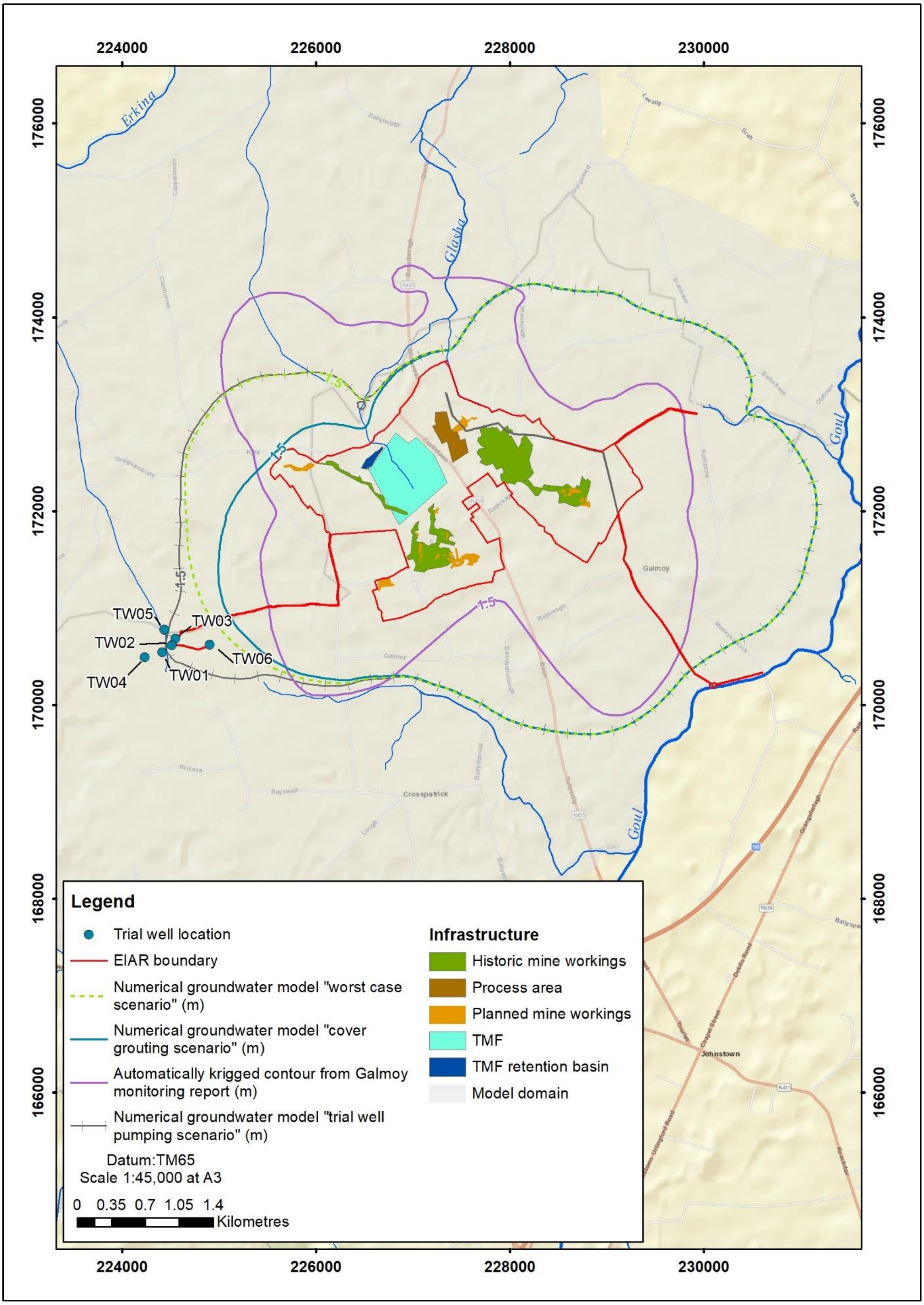


Figure 8.33: Estimated Area of Drawdown from Previous Mining at Galmoy and 'Worst Case' Drawdown resulting from Future Dewatering

8.6.3 Receptor Importance

The importance (sensitivity) of a receptor has been assigned based on the IGI (2013) guidelines outlines in Table 8.1.

- GRPWS – **Medium** Importance: approximately 640 properties are supplied by the scheme.
- Domestic wells – **Low** Importance: fewer than 50 homes have domestic wells as their primary water supply.
- Goul – **Medium** Importance: the river is of local value, has a WFD status of Moderate and the lower reach comprises part of the 'The Curragh and Goul River Marsh' pNHA; the Nore SPA; and the 'River Barrow and River Nore' SAC.
- Glasha – **Low** Importance: the stream is of local value and has a WFD status of Poor; and
- Erkina – **High** Importance: the river comprises a substantial part of the 'The Curragh and Goul River Marsh' pNHA; the Nore SPA; and the 'River Barrow and River Nore' SAC.

8.6.4 Significance Rating

The inputs used to define the significance rating are outlined in Table 8.22, together with the final definition. This assumes that the preventative and mitigation measures outlined below have been put in place as part of the planned development. It shows that any impacts are assessed to be **Slight** or **Imperceptible**. The Slight impacts are drawdown effects on the GRPWS, and the Glasha and surface water discharge to the Goul.

Table 8.22: Significance Rating of Receptors

Receptor	Importance	Potential Effect	Magnitude of Impact	Impact Rating
GRPWS	Medium	Drawdown	Small Adverse	Slight
		Discharge to Groundwater	Negligible	Imperceptible
Domestic wells	Low	Drawdown	Small Adverse	Imperceptible
		Discharge to Groundwater	Negligible	Imperceptible
Goul	Medium	Drawdown	Negligible	Imperceptible
		Discharge to Surface Water	Small Adverse	Slight
Glasha	Low	Drawdown	Moderate Adverse	Slight
Erkina	High	Drawdown	Negligible	Imperceptible
		Discharge to Surface Water	Negligible	Imperceptible

8.6.5 'Do Nothing Scenario'

Under a Do Nothing scenario where the mine is not developed, it is anticipated that baseline conditions will continue to prevail within the seasonal and inter-annual variations discussed in this chapter. No significant changes to surface water or groundwater flow/level or quality are anticipated.

It is understood that the GRPWS WW2B well may require rehabilitation. These works, which may form part of the supplementary water supply plan, would need to be completed by IW under a do-nothing scenario.

8.6.6 Dewatering-induced Sinkhole Development from Reactivation of Palaeokarst

8.6.6.1 Objective

A QRA for the development of sinkholes from the potential reactivation of palaeokarst features due to the dewatering of the underground workings at Garrylaun was undertaken. Full details of the QRA are provided in Appendix 8.7. This section provides a summary of the approach and findings. Consolidation-related subsidence, due to dewatering and/or rock extraction, is assessed separately in Chapter 7.

The QRA is primarily a desk-based assessment, with site-specific knowledge and data from previous mining at Galmoy. Furthermore, a sinkhole developed above the Galmoy mine workings (CW Orebody) after closure, in February 2014, following a period of extreme wet weather. The data and subsequent investigation into this provide important empirical data for the assessment.

8.6.6.2 Development Mechanisms

'Karst' is used to describe geological features formed by the dissolution of rock. The most common rock types for karst to occur in are carbonates (e.g. limestone or dolomite); although the presence of carbonate rocks does not mean that karst features will occur. Karst features include turloughs, caves, some springs and sinkholes (also known as dolines). Sinkholes are enclosed depressions that may have a wide range of size and depth. In Ireland, they are the most common landform in karst areas.

Natural sinkholes may occur as isolated features or in clusters causing a pock-marked land surface. They can form due to a large number of mechanisms; however, six main types are commonly referred to: solution, collapse, dropout, buried, caprock and suffosion. Only dropout dolines and suffosion dolines have the potential to develop due to dewatering-induced reactivation of palaeokarst.

For the purposes of the QRA, the likelihood of a sinkhole developing was based on the following assumptions.

- There is a general 'very unlikely' background potential for sinkhole development due to the limestone lithology and bedrock geomorphology in the area.
- Periods of extreme rainfall (weeks to months scale) increase the likelihood for sinkhole development across the whole region due to: (i) increased unsaturated flow potentially mobilising sediments, and (ii) additional weight in the overburden.
- A sinkhole is most likely to develop when a 'choked' geological structure is 'cleaned out'; causing overburden material to wash into the structure.
- Mine workings intersecting a structure may accelerate the 'cleaning out' of structures because they may enhance conditions for unsaturated (turbulent) flow to mobilise sediment, and the workings may act as a sink for the 'cleaned out' sediment to be transported away from the structure. However, where sub-vertical structures and mine workings intersect, these areas have been supported by a combination of wire mesh and shotcrete, or fibre reinforced shotcrete or steel arches, thus minimising the potential movement of sediment into the mine workings at those locations.
- Major structures in the area are steeply dipping (> 75°), but a structure intersected at depth within the workings may daylight at surface away from the workings footprint. Therefore, an additional 50 m buffer zone has been applied to the workings based on intersecting an unmapped 65° structure at 100 m depth.
- Reduction in the water table due to dewatering (but away from mining activity) increases the likelihood of sinkhole development but not significantly because, although it produces the conditions for unsaturated flow, it does not produce a sink for sediment removal.

- Localised mapping of the likelihood for sinkhole development can therefore be undertaken by cross referencing the projected surface outcrop of mapped geological structures from underground, where they intersect underground workings within the area of predicted drawdown due to dewatering.

8.6.6.3 Consequences of Sinkhole Development

The consequence of sinkhole development was defined based on the land use which broadly summarises: (i) the frequency of use; (ii) the potential for loss of life; and (iii) the potential for negative environmental impact. Domestic and public access lands have the greatest consequences and scrub land the lowest.

8.6.6.4 Risk Assessment

The risk of dewatering-induced sinkhole development following the reactivation of palaeokarst for Garrylaun was determined by cross-referencing the likelihood and the consequence. Five risk categories were defined as follows:

- Extreme – hazardous and the area should be evacuated;
- High – elevated risk which must be closely monitored;
- Medium – elevated risk requiring periodic evaluation;
- Low – acceptable risk; and
- Negligible – safe.

The QRA shows that the majority of the Garrylaun area is determined to have *Insignificant* or *Low* risk of dewatering-induced sinkhole development. There are no areas of *Extreme* risk. Very limited areas of *High* risk and *Medium* risk were identified, as follows.

- High risk – 180 m of major road (R435) and associated public water network, a 200 m section of public water network along the L5805 and a discrete location of minor road (L5804).
- Medium risk – 1.54 km of minor roads (L5804 and L5805) and one agricultural building.

Where elevated risks have been identified, these can be:

- Prevented through a suitable monitoring network and associated TARPs; and
- Mitigated through the development of contingency plans and good interaction with the local community.

8.6.7 Cumulative Impacts

The cumulative effects of both dewatering the mine and abstracting water from the GRPWS (existing and supplementary wells) has been undertaken as part of the impact assessment outlined above.

The EPA mapping of various ‘pressures’ identifies both the Goul and the Glasha as having ‘River Agriculture Pressures’. In addition, a ‘Groundwater Agriculture Pressures’ area is identified on the eastern side of the Goul, over 1 km east of the proposed Goul discharge. No other pressures were identified within 10 km of the Site or within the Goul or Glasha catchments.

Agricultural pressures may contribute to additional nitrogen species in the rivers. With this exception, no cumulative impacts on the surface water or groundwater environments are anticipated as a result of the recommencement of mining at the Site. There are no extractive industry sites located in the immediate vicinity of the development and no industrial discharges to surface water within 10 km of the site. Dawn Meats Ireland t/a Meadow Meats (Licence No. P0183) in Rathdowney is the only other licenced industry adjacent to the Glasha. There are no facilities adjacent to the Goul.

One wind turbine permitted for construction is located within the predicted area of drawdown. The presence of a wind turbine is not anticipated to impact the extent drawdown and the drawdown is not anticipated to impact the stability of the turbine.

8.7 Mitigation and Management

8.7.1 Construction and Operations

8.7.1.1 General

From a water perspective, construction and operational activities are the same. The mitigation and management requirements are, therefore, outlined together.

Maintaining good housekeeping during operations and adhering to best mining practices will significantly reduce the potential effects on the surrounding water environment. It is proposed that the following mitigation measures will be used at the Site.

- A water management system will be maintained and a MWTP constructed for the purposes of water treatment and management on, and from, the Site (see Section 8.7.1.5);
- Cover drilling and cover grouting (where required) will be completed in mining operations that cross the K Fault, including in the K2 and G West Zones;
- All topsoil, subsoil and overburden stockpiles will be covered (i.e. vegetated) to minimise the risk of rain / wind erosion;
- Chemical, fuel and oil stores will be bunded as per regulatory requirements. Explosives will be stored in a purpose-built facility with appropriate pollution protection;
- Mobile plant will use refuelling facilities. Static plant or tracked excavators will refuel over a drip tray with an absorbent mat;
- All mobile plant shall be regularly maintained, and where plant is damaged or leaking it will be fixed or replaced immediately, as part of the ongoing operational management of the mine to reduce the risk of leaks;
- No storage of hydrocarbons will take place underground;
- Emergency spill kits (including absorbers) will be available for use in the event of an accidental spill underground or in the ore storage areas;
- Filters and bunds placed with the sumps, balance tank conditioning pond and MWTP clarifier will be used to collect hydrocarbons within the water pumping circuit;
- All site sewage water will be treated by a dedicated sewage treatment plant and the treated water discharged to Goul via the existing pipeline;
- Regular monitoring of groundwater (levels and quality) will continue to take place using monitoring boreholes based on best practice and in compliance with EPA licence requirements; and
- Regular monitoring of surface (mine) water discharge to the Goul will be undertaken to take in compliance with EPA licence requirements.

8.7.1.2 GRPWS

8.7.1.2.1 Cover Grouting

No significant changes to the operation of the GRPWS wells are expected in the future. Although development of the K2 and GW Zones will occur as part of the future mine plan, cover grouting is planned for these areas to prevent any additional groundwater inflows to the workings, and therefore to prevent any additional impacts to the groundwater system. The planned programme of cover grouting will isolate the underground mining from the groundwater in the surrounding Waulsortian.

Monitoring data for both wells (WW1A and WW2B) through 2017 demonstrate that all chemical parameters continue to be stable and to comply with the drinking water regulations. No changes to water quality in the GRPWS wells are expected as a result of the planning mining operation.

8.7.1.2.2 Supplementary Water Supply

Background

At the request of Irish Water, a supplementary groundwater supply system will be constructed prior to commencing the mine dewatering programme. The intention is to provide a production wellfield the provides a water supply of comparable quantity and quality to the existing supply. This supplementary supply may then be used to supplement the two existing GRPWS production wells should mining have an impact on their ability to provide sufficient supply to the scheme.

A trial well drilling programme has been completed on private land (referred to here as the ‘Rathpatrick site’) to the west of the Site outside the predicted 1.5 m area of drawdown. Constant rate pumping tests carried out simultaneously on two wells (TW03 and TW06) demonstrated that a supply of at least 70 m^3/hr (1.2 MLD – the current daily GRPWS supply) could be developed at the site, with water quality that: (i) complies with drinking water standards; and (ii) is comparable to the existing supplies. Appendix 8.5 provides details of the completed trial well drilling and testing programme.

Existing Production Wells

The supplementary production wellfield will be constructed and commissioned before dewatering activities are initiated. This includes the drilling and construction of production wells, pump installation, disinfection, headworks, fencing, pipelines and connection to the existing GRPWS reservoir. In addition, rehabilitation of WW2B may be undertaken, although this will be through consultation with IW.

However, it is anticipated that the exiting GRPWS wells will continue to be the sole supply to the scheme through mine life and closure of the Proposed Development. Impacts on the existing wells are predicted to be identical to the impacts seen during dewatering of Galmoy (Figure 8.34). The lowering of the pump was required in WW1A to maintain the yield. These works will be repeated if necessary, because the pump has subsequently been raised to its original level since full groundwater recovery.

Site Selection

The Rathpatrick site is located 1.5 km to the southwest of the current reservoir (Figure 8.35). It was identified as the area in which to focus the trial well drilling programme for the following reasons.

- It is located outside of the 1.5 m drawdown contour defined during Galmoy Mine’s dewatering programme. Subsequent numerical modelling demonstrates that it is also predicted to be outside of the 1.5 m drawdown contour for Garrylaun dewatering. The 1.5 m contour was used because this is the typical seasonal variation for groundwater in the area.
- It is located on the same side of the mine as the GRPWS reservoir, minimising the length of any pipeline between the two locations. This reduces the impact of installing the pipeline as well as reducing the operational (head losses) and maintenance costs.

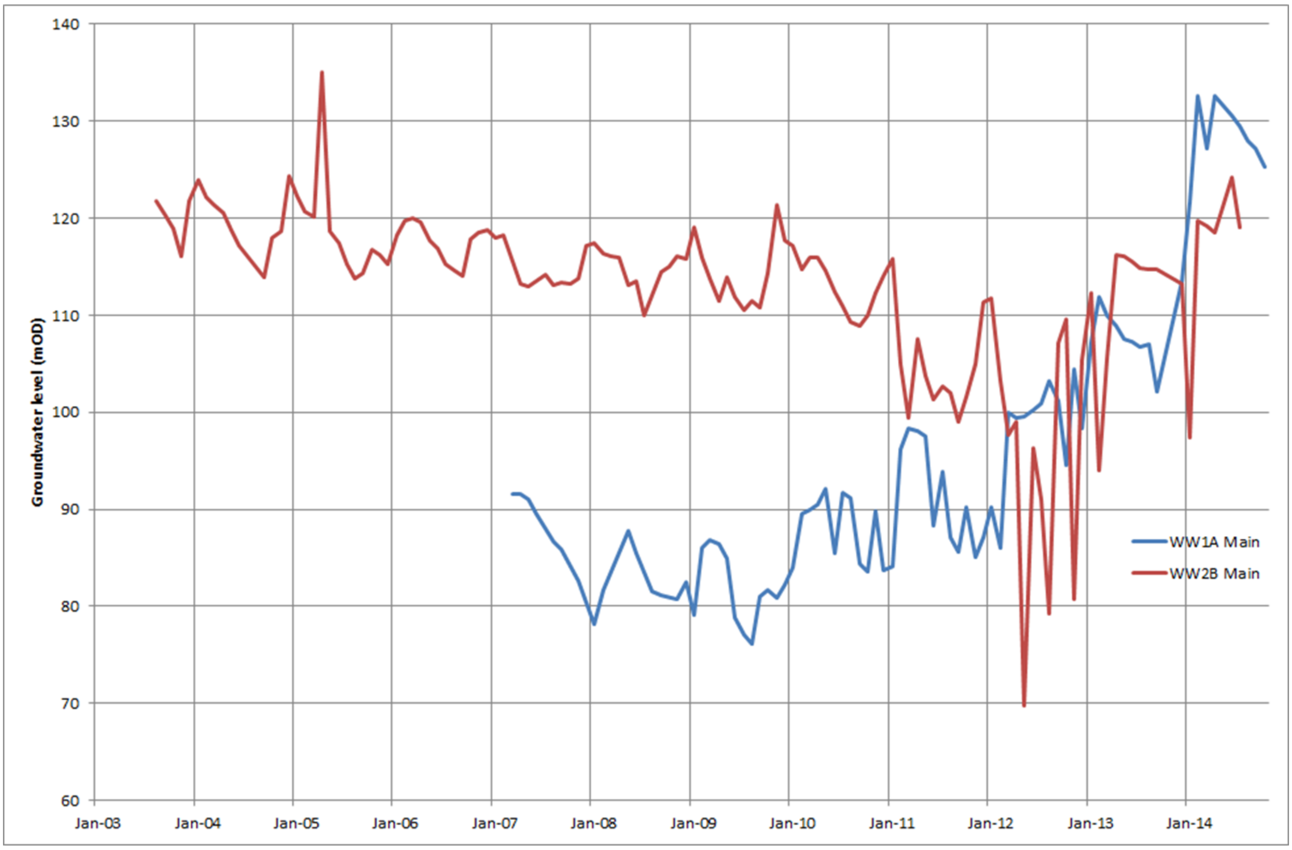


Figure 8.34: Water Levels in WW1A and WW2B during and after Mine Dewatering Operations at Galmoy (courtesy of Galmoy Mines)

- The Rathpatrick site is currently leased to Coillte, who allowed access to their rented ground to explore for water.
- The site straddles the geological formations of Crosspatrick to the west and Waulsortian to the east and has a mapped sub vertical fault unit within it. The Crosspatrick Formation is classified by the Geological Survey of Ireland (GSI) as a 'Locally Important Aquifer – Bedrock which is generally moderately productive'. The Waulsortian Formation is a 'Regionally Important Aquifer – Karstified (Diffuse)'.
- The site is largely forested and covers ca.70 hectares of land, which is favourable in terms of source protection restrictions, by restricting potential point and diffuse sources of contamination outside a 50 m radius from well targets.
- The water drilling rig weighs ca. 25 tonnes and the established roadways within the Rathpatrick site are designed and built for such traffic (and supporting vehicles), making planned water exploration work accessible, efficient and safe.
- Well maintenance and operation would be cost efficient as the wells could be drilled adjacent to the forestry roads; and are also in close proximity to power lines and the public access road which also provides a piping route option.

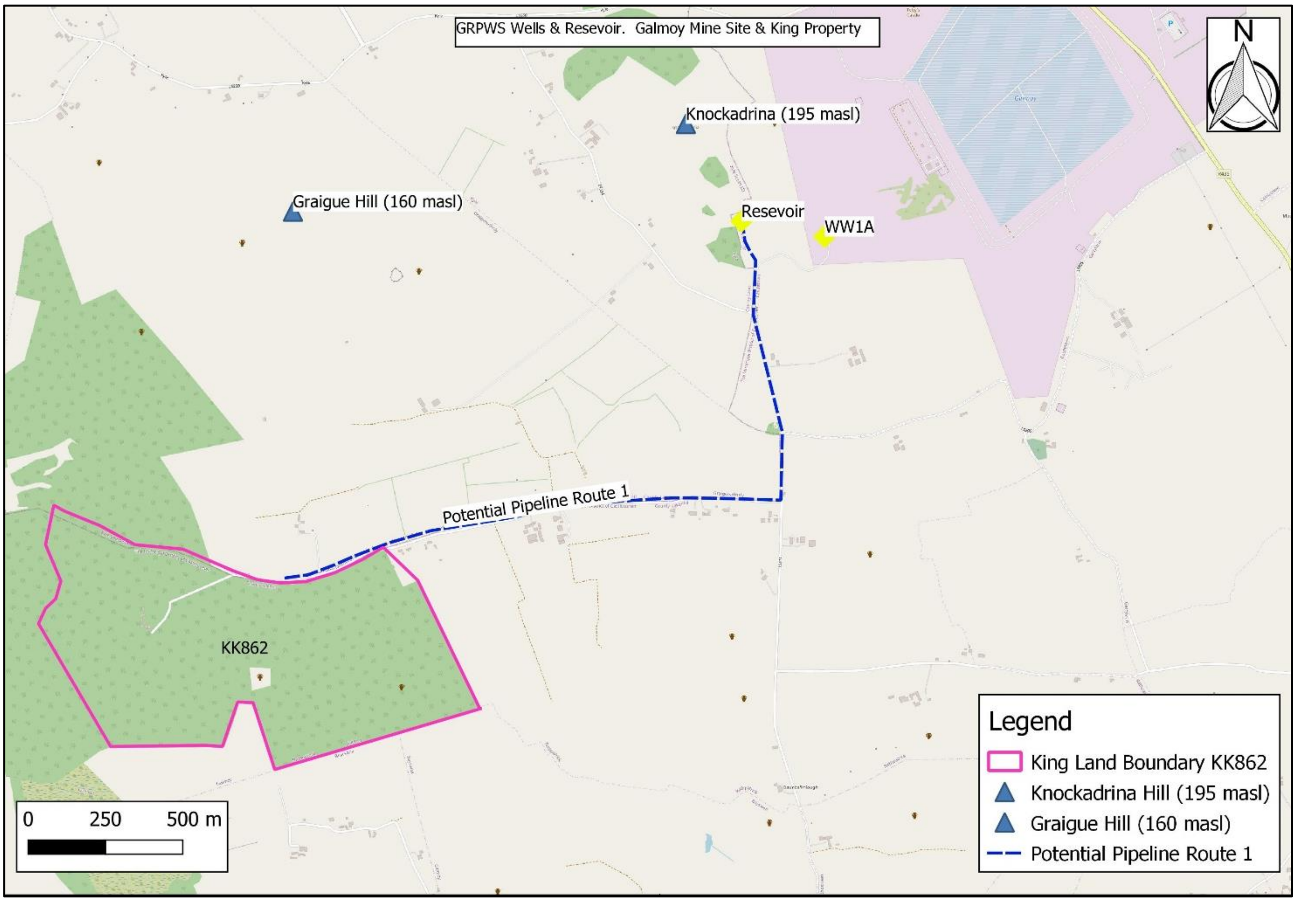


Figure 8.35: GRPWS Wells and Reservoir with the Rathpatrick Site (pink boundary)

Triggers for Utilising the Supplementary Supply

The supplementary supply will be utilised if and when it is deemed that the existing production wells (WW1A and WW2B) are approaching a point that they may not be able to meet the demands of the scheme. Two triggers will be defined based on yield and water level within the production wells: Preparation and Pumping. The actual trigger levels used will be defined through consultation with IW. Water level, yield and turbidity data will be reviewed on a weekly basis initially then on a monthly basis once the initial dewatering phase is completed. The frequency would be increased if the triggers are being approached and when mining activity occurs through the K Fault.

- Preparation Trigger – the first trigger will identify that the supplementary supplies may be required in the coming weeks. It allows testing, maintenance, flushing and disinfection of the supplementary network in readiness for use as a supply.
- Pumping Trigger – the second trigger will identify when the supplementary supply will be needed to supplement the two existing wells. The balance of different supplies will be defined by IW depending upon the amount the existing supplies can efficiently produce.

Area of Drawdown

Section 8.6.2 defines the predicted are of drawdown for the Application Site. This includes a scenario where the supplementary supply is pumping at 70 m³/hr (1.2 MLD), which is the current GRPWS requirement. It shows that the mining dewatering and the supplementary wellfield drawdown areas may coalesce. However, the extent of drawdown around the supplementary wells is very limited and the impact on production rates would be very small. The primary inflow to both wells is over 40 m below ground level and, during trial well testing, there was sufficient available drawdown at the end of the test to mitigate against an additional 1 to 2 m of 'regional' drawdown. Additionally, there is good evidence from WW1A and WW2B that a reduction in 'regional' groundwater levels does not prevent the wells from being a viable supply.

The benefits of the Rathpatrick site's location (outlined above) are considered to outweigh the small impact that may possibly occur due to the interaction with the mine's area of drawdown.

8.7.1.3 Domestic Wells

During previous mining of Galmoy, all properties with wells potentially impacted by mining (i.e. locations within the predicted area of drawdown) were provided with a connection to the GRPWS (or RWSS as it was known at the time). As part of this Application, an additional number of residences have been identified within the new predicted area of drawdown which currently do not have a connection to the GRPWS (Figure 8.23). Almost all of these wells are at the periphery of the area of drawdown and are therefore unlikely to see any drawdown outside the typical seasonal variation.

8.7.1.4 Glasha Springs and Baseflow

No mitigation measures are proposed for the reduction in spring flow and base flow to the Glasha caused by dewatering, as the natural spring discharges in the summer were seen to evaporate prior to previous mining operations.

8.7.1.5 Water Treatment

Future mitigation for the mine water discharge will consist of sediment removal (as required), water treatment and monitoring. Following the start of the proposed future mining operation, all mine water will be routed through the MWTP to ensure compliance with metals and suspended solids for discharge (Sections 3.4.6.1 and 8.5.5.1). The operating plan for the MWTP is based on similar Galmoy and Lisheen plants (pH adjustment and clarification), with the associated 'experience learned' from both operations. Settlement of precipitates will be completed in a clarifier and a settlement pond prior to environmental discharge. The goal of the treatment system will be to reduce values of constituents in the water to ensure compliance with ELVs and ensure there is no negative impact on the receiving water WFD status.

A summary of Galmoy discharge quality, upstream and downstream Goul quality has been provide in Table 8.19 for reference. Improvements were made to water quality management at Galmoy over the mine life and those experiences will be built upon for the current application. This underground water management to reduce the amount of ammonia entering the dewatering stream. Galmoy had limited treatment capacity for ammonia, but this did not negatively impact the WFD status of the Goul which was 'Good' while Galmoy was operational but has recently be classified as 'Moderate' (Table 8.17).

An important factor with respect to ammonia is the link to production. The primary source of ammonia in the dewatering stream was residue from ammonium nitrate based explosive emulsion. There was a direct correlation between tonnes mined and explosives used. Garrylaun will produce on the order of half the tonnage of the Galmoy Mine and therefore, conservatively, it is expected explosive usage for Garrylaun will be half the usage for Galmoy, with much lower potential to add ammonia loading to the water. It is also expected that the non-production (development blasting) at Garrylaun will be less than Galmoy, as much of the primary development (access tunnels, etc) is already completed. Based on Galmoy's experience, the expected concentration of ammonia in the dewatering will be between 0.3 and 0.6 mg/L.

Techniques are available for removing ammonia from water, including from mine water. The challenge for mine water treatment for ammonia at most mines is that it is often not possible to treat all mine water with such techniques given the quantity of water and the relatively small loading of ammonia. However, there are opportunities to use these techniques in discrete applications where flows will be smaller and concentrations higher (e.g. individual headings underground). Techniques may include the use of zeolite. For example, it may be possible to pass all water coming from a heading where a blast face is being charged with explosive through a zeolite filter so that, in the event of a failure of underground controls, the water in the heading can be scrubbed using the zeolite. Other methods include the use of natural attenuation techniques within the waterbodies on site.

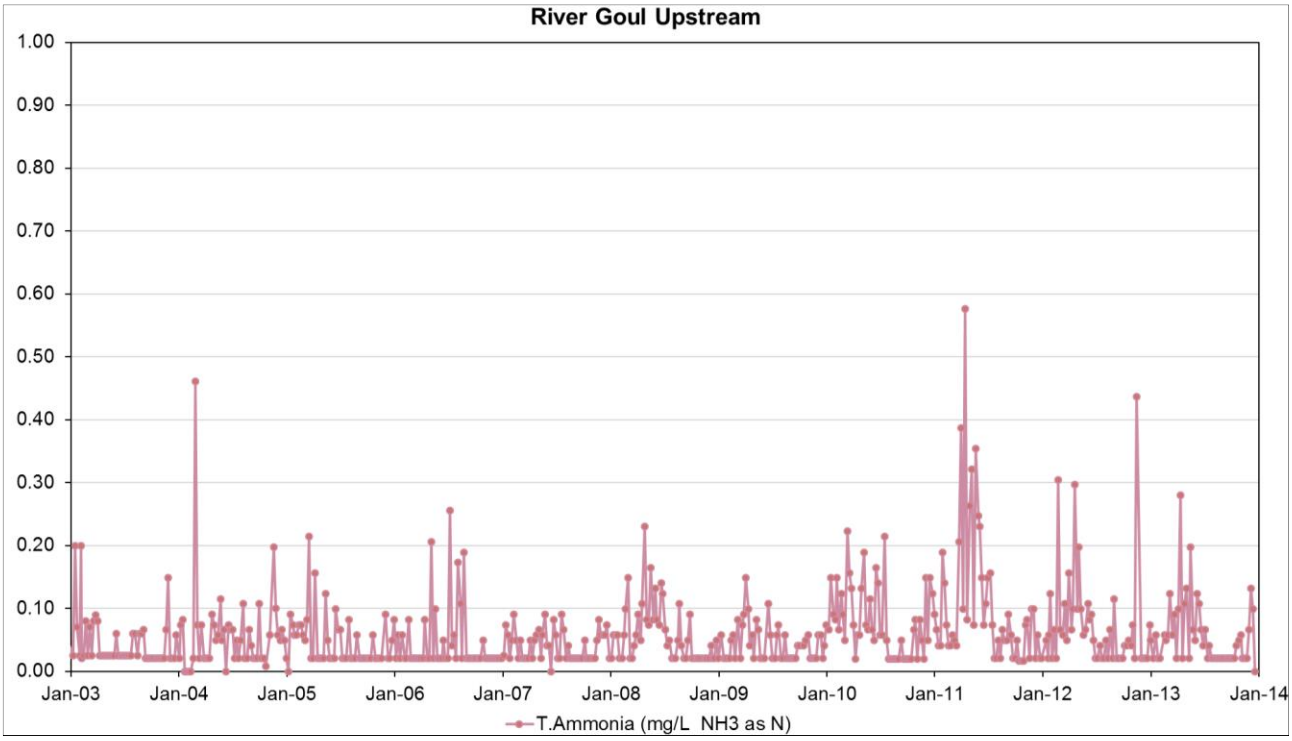


Figure 8.36: Ammonia (as N) Concentrations in the Goul Upstream of the Galmoy Discharge

8.7.2 Mine Closure

The previous closure of Galmoy Mines provides a significant understanding of the conditions expected once dewatering of the underground is terminated. Before dewatering activities end, the following will be undertaken:

- Removal of all underground infrastructure which has the potential of impacting groundwater quality;
- Removal of all hazardous materials (oils greases etc.);
- Removal of all surface infrastructure that is not being retained for site redevelopment; and
- The removal of any contaminated soil and hard standing areas.

The MWTP will remain operational while surface works are undertaken in case there is a requirement to treat surface runoff. Once surface rehabilitation is complete, the MWTP will also be decommissioned (and a mobile treatment plant made available, if required, during MWTP decommissioning).

While the groundwater system is recovering, the full surface water and groundwater monitoring programme will continue to be implemented. The primary objective will be to identify whether any unpredicted impacts to the surface and groundwater system, or to local receptors, is occurring.

8.7.3 Monitoring

8.7.3.1 General

A comprehensive monitoring programme was undertaken throughout the entire period of previous mining. The primary objective was to determine the potential impacts to the surface and groundwater system, and to local receptors, and to ensure that mitigation plans could be implemented; thereby ensuring no actual impact. If required, committees may be set up to allow the communication of monitoring information between the mine, local community, regulators and other third parties.

The previous monitoring has shown that there are only a limited number of potentially elevated water quality parameters in the mine water system. Future monitoring should therefore focus on the key parameters, which are considered to be pH, total dissolved solids (TDS), total suspended solids (TSS), sulphate, nitrate, ammonia, lead, zinc, arsenic and nickel. These parameters would form the proposed indicator suite.

8.7.3.2 Components of the Monitoring Plan

The key components of the monitoring plan for future development are:

- Groundwater flowing from each active mining zone; flow, chemistry, suspended solids (underground monitoring);
- The overall mine dewatering rate; flow, chemistry and suspended solids;
- Input and output (overflow and underflow) to the water treatment plant; flow and chemistry;
- Mine water discharge; flow, chemistry and suspended solids;
- Upstream and downstream surface water locations in the River Goul and Erkina River (as necessary), for stage, chemistry and suspended solids; and
- Groundwater levels and water quality in existing wells.

8.7.3.3 Sampling Suites

The monitoring programme will utilise two sampling suites, as follows.

- **Indicator suite:**
  - Field measurement – temperature, electrical conductivity, pH, dissolved oxygen and redox; and
  - Laboratory measurement – total dissolved solids (TDS), total suspended solids (TSS), sulphate, nitrate, ammonia, lead, zinc, arsenic and nickel.
- **Full suite:**
  - Field measurement – temperature, electrical conductivity, pH, dissolved oxygen and redox; and
  - Laboratory measurement – TDS, TSS, sodium, potassium, calcium, magnesium, sulphate, nitrate, nitrite, ammonia, alkalinity, plus the standard suite of trace metals.

All groundwater samples will be analysed for the dissolved fraction and will therefore be field-filtered. Surface water samples will be analysed for both total and dissolved fractions.

The plan for future mining does not include any mineral processing, addition of reagents or tailings deposition. Therefore, the sampling suites do not include any organic parameters, biological oxygen demand, or chemical oxygen demand.

8.7.3.4 Mine, Dewatering and Treatment

Underground Monitoring

Inflows to active mining zones will be monitored as follows:

- Instantaneous pumping rate measured at least daily;
- Cumulative pumped volume totalled weekly;

- Weekly sampling for the indicator suite; and
- Daily sampling for any identified parameters of concern based on interactive analysis of the monitoring results.

Overall Dewatering Flow

The overall mine dewatering flow will be monitored as follows:

- Instantaneous pumping rate measured at least daily;
- Cumulative pumped volume totalled weekly;
- Daily sampling of any key parameters;
- Weekly sampling for the indicator suite, plus suspended solids; and
- Monthly sampling for the full suite.

Water Treatment Plant

Inflows and outflows (overflow and underflow) to the water treatment plant will be monitored daily for flow and chemistry, as required.

Mine Water Discharge

The mine water discharge will be monitored at the outfall as follows:

- Instantaneous pumping rate measured daily;
- Cumulative pumped volume totalled weekly;
- Daily sampling for the indicator suite; and
- Monthly sampling for the full suite.

8.7.3.5 Surface Waters

Discharge Points

The Goul discharge will be monitored with one upstream monitoring point, and one downstream monitoring point (Table 8.23). The monitoring frequency will be as follows:

- River stage continuously;
- Weekly sampling for the indicator suite; and
- Monthly sampling for the full suite.

Other Surface Waters

Monitoring will be undertaken for additional surface water monitoring points as shown in Table 8.23. The monitoring frequency will be as follows:

- Monthly river stage;
- Monthly sampling for the indicator suite; and
- Six-monthly sampling for the full suite during summer low flow period.

8.7.3.6 Groundwater Monitoring

The proposed general groundwater monitoring locations are shown in Table 8.23. The locations have been chosen based upon their historic monitoring record, use as baseline locations and suitability for providing representative data. At the present time, it is not anticipated that any additional groundwater monitoring points will be required. Monitoring will be at least monthly for water level, quarterly for the indicator suite and annually for the full suite.

It is currently understood that all required monitoring of the GRPWS wells, including the new supplementary wells, will be undertaken by Irish Water.

Table 8.23: Proposed General Monitoring Locations

Location	Area (relative to mine site)	TM65 Irish Grid		Water Source	Measurement Frequency
		Easting	Northing		
G South	Mine workings	227152	171367	Groundwater	Monthly
CW West	Mine workings	227670	172478	Groundwater	Monthly
K Vent	Mine workings	226446	172323	Groundwater	Monthly
TMW8	Mine workings	226858	172746	Groundwater	Monthly
TMW13	Mine workings	226994	171905	Groundwater	Monthly
PD	Northern district well	228610	173695	Groundwater	Monthly
KN	Northern district well	228092	173614	Groundwater	Monthly
GM	Western district well	225410	170950	Groundwater	Monthly
KS	Southern district well	227211	170851	Groundwater	Monthly
JP	Eastern district well	229982	172612	Groundwater	Monthly
Goul upstream	Surface water	228762	168547	Surface water	Monthly
Goul downstream	Surface water	230610	170304	Surface water	Monthly
Duggans Bridge	Surface water	226952	173719	Surface water	Monthly
Glasha Crossroads	Surface water	227102	176013	Surface water	Monthly
Whiteswall	Surface water	228809	172915	Surface water	Monthly

8.8 Residual Effects

It is expected that rewatering/flooding and closure of the planned future mining operations will be similar to the previous Galmoy closure plan. Furthermore, the geochemistry of the orebodies is similar to the previous mine orebody geochemistry, so the previous water quality monitoring results can be used as a direct analogue. The previous closure was thoroughly monitored and therefore provides the understanding required for mine closure, without the requirement for 'modelling' of potential future conditions.

Understanding gained from the previous mine closure is provided in Section 8.4.3, and is summarised below. Following the previous phase of mining at Galmoy, flooding of the underground workings was carried out between March 2013 and March 2014. The monitoring results show that:

- Baseline groundwater flow conditions were re-established in March 2014;
- Mine closure was carried out without impacting groundwater-related receptors, and there is a low risk of future impact;
- Post-closure groundwater level data are consistent with pre-mining conditions and exhibit the expected seasonal variation typical of Irish groundwater systems: highest during spring and lowest during autumn;

- Water chemistry within the flooded workings is generally stable, with values for most parameters being consistently below that of the compliance values (groundwater and drinking water regulations);
- Post-closure surface water quality data remain stable and below Galmoy compliance values and surface water regulations;
- Groundwater discharges to the surface water system (baseflows) to the Glasha also comply with surface water regulations; and
- Groundwater quality results for monitoring wells and for the GRPWS wells have mostly remained consistent and stable and below compliance values.

8.9 Difficulties Encountered

During the preparation of this impact assessment, COVID-19 restrictions impacted the trial well drilling programme for the supplementary GRPWS supply. The Rathpatrick site had been identified as the preferred drilling location in November 2020, but drilling activity could not start until March 2021.

8.10 Summary and Conclusions

The previous operation and closure of Galmoy Mines provides significant understanding of the conditions that will be encountered during the proposed mining and closure of the Proposed Development. Most of the existing (Galmoy) workings will utilised by Garrylaun and the most mining will occur within orebodies previously mined. From a water perspective, there a number of primary differences between the previous operation at Galmoy and the proposed Garrylaun operations, as follows.

- Mining of K2 and G West orebodies – these orebodies mine through the K Fault which has been identified from historical monitoring data as a barrier to deep groundwater into the mine workings. Mining of K2 will be closer to the existing GRPWS wells. The effects of this will be mitigated by cover drilling and pressure grouting, a technique used by many underground mine operators (including Tara Mines) to reduce inflows to the workings.
- No tailings facility – Galmoy produced a tailings stream as part of the ore processing. This was manged by spigotting on the TMF. The TMF was a sink of water (holding water in the pore space of the tailings mass) and the supernatant pond on top of the TMF provided a ‘buffer’ to manage high flows of water. Therefore, without the TMF, water needs to be treated and discharged from site immediately. For this reason, the water treatment plant has been designed to have a capacity equal to the ‘worst case scenario’ inflow rate.
- GRPWS supplementary supply wells – at the request of IW, a supplementary water supply will be provided. A trial well drilling programme to the southwest of the site has identified a resource of comparable quantity and quality to the existing water supply.
- The mining rate at Garrylaun (ca. 310,000 t/a) will be considerably lower than it was previously (ca. 500,000 t/a). This will reduce the impact on the quality of mine water being pumped from the mine compared to Galmoy Mine, as there will be less explosives used, and therefore less ammonia being produced from blasting. Evidence for this can be seen in the improvement in water quality data from 2009 onwards as mining rates at Galmoy where reduced.
- Following extensive assessment of the existing MWTP it was decided to construct a new treatment plant, as the existing plant is hydraulically constrained in relation to the volume of water it can treat. The existing plant is in fact a collection of individual plants, each with their own reagent dosing and control systems all of which would have to be calibrated and maintained. The complete replacement of the existing MWTP,

with a new treatment plant that is sized to treat in excess of the maximum predicted flow de-risks the Project with respect to potential water quality issues.

This impact assessment has identified three *Slight* impacts: drawdown effects on the GRPWS and the Glasha stream; and surface water discharge to the Goul. All other impacts are assessed to be *Imperceptible*, provided that the mitigation measure outlined above are put in place.

8.11 References

8.11.1 Referenced Documents

- EPA, 2019a. WFD Cycle 2: Goul_SC_010 Subcatchment Assessment. Environmental Protection Agency.
- EPA, 2019b. WFD Cycle 2: Erkina_SC_010 Subcatchment Assessment. Environmental Protection Agency.
- IGI, 2013. Guidelines for the Preparation of Soils, Geology and Hydrogeology Chapters of Environmental Impact Statements. Institute of Geologist of Ireland.
- KT Cullen, 1992. Hydrogeology and Dewatering of the Galmoy Mine. November 1992.
- SWS, 2014. Galmoy Mine – Analysis of groundwater recovery following completion of mining. Schlumberger Water Services. Report number 51471R3v2. August 2014.
- SWS, 2015. Galmoy Mine – Analysis of 2015 monitoring data. Schlumberger Water Services. Report number 51471R5v2. April 2016.

8.11.2 General References

- Guidelines on the Information to be contained in Environmental Impact Statement. Environmental Protection Agency, Johnstown Castle Estate, Co. Wexford, Ireland. EPA. 2002.
- Advice Notes on Current Practice in the preparation of Environmental Impact Statements (Environmental Protection Agency, 2003).
- Department of the Environment, Quarries and Ancillary Activities, Guidelines for Planning Authorities 2004.
- Environmental Management in the Extractive Industry: Guidelines for Regulators 2006.
- Guidelines for Planning Authorities and An Bord Pleanála on carrying out Environmental Impact Assessment (Department of Environment, Community and Local Government, 2013).
- Draft - Revised Guidelines on the Information to be contained in Environmental Impact Statements. EPA 2015.
- gis.epa.ie/EPAMaps Environmental Protection Agency – online water quality and surface water monitoring mapping.
- www.gsi.ie Geological Survey of Ireland – online geological and hydrogeological mapping.
- www.met.ie Met Éireann – online precipitation and evaporation data.
- www.npws.ie National Parks & Wildlife Service – online protected sites mapping.

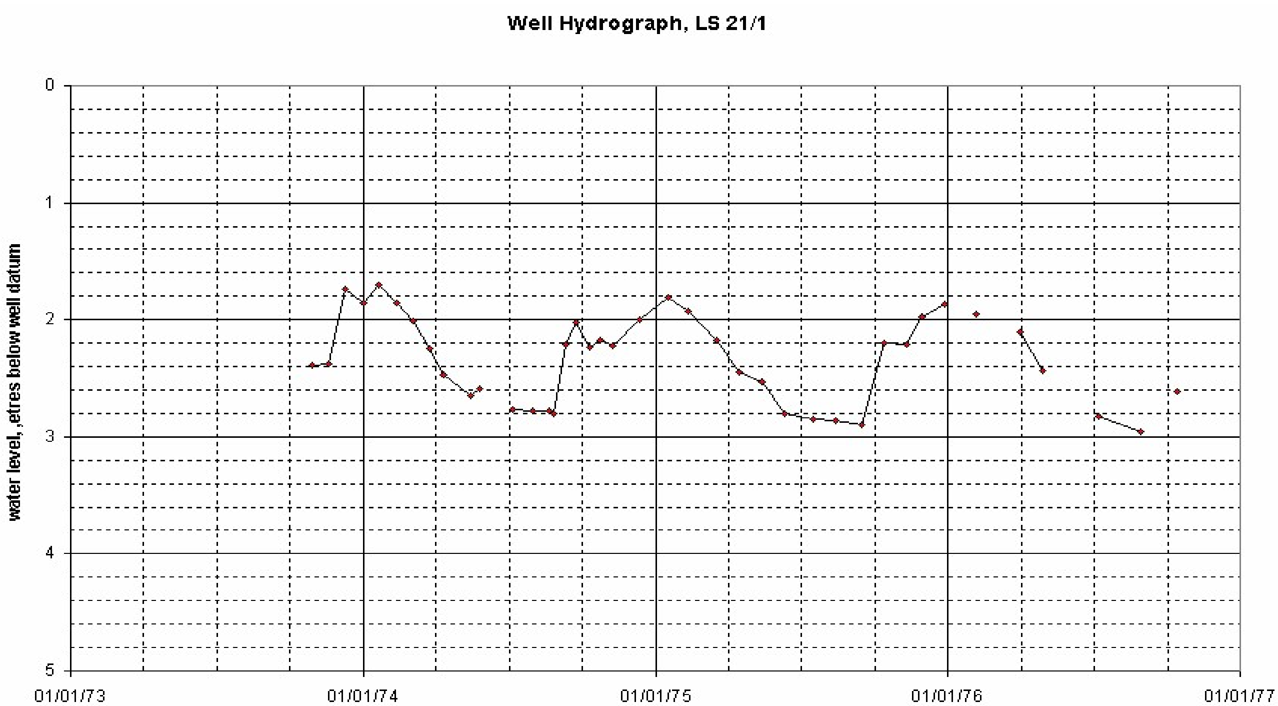
APPENDIX 8.1

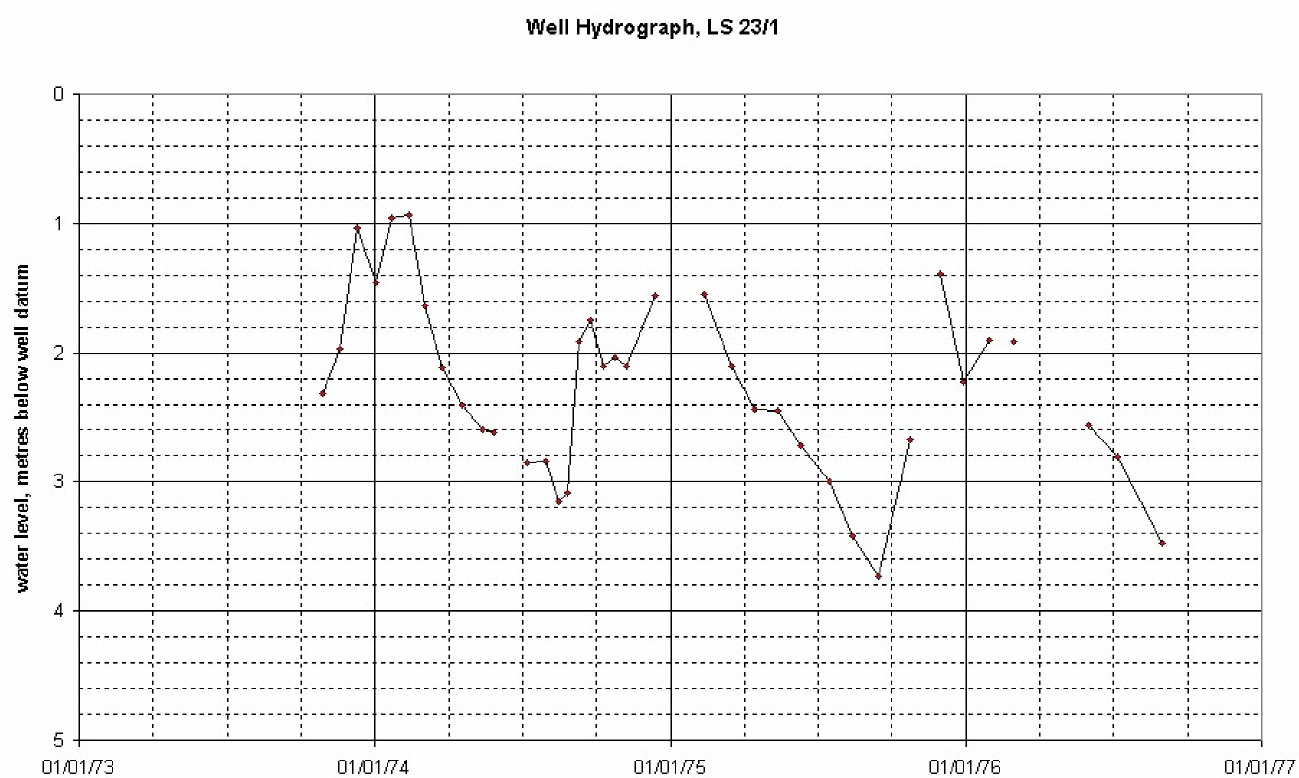
Groundwater Bodies Initial Characterisation Sheets

Rathdowney GWB: Summary of Initial Characterisation.

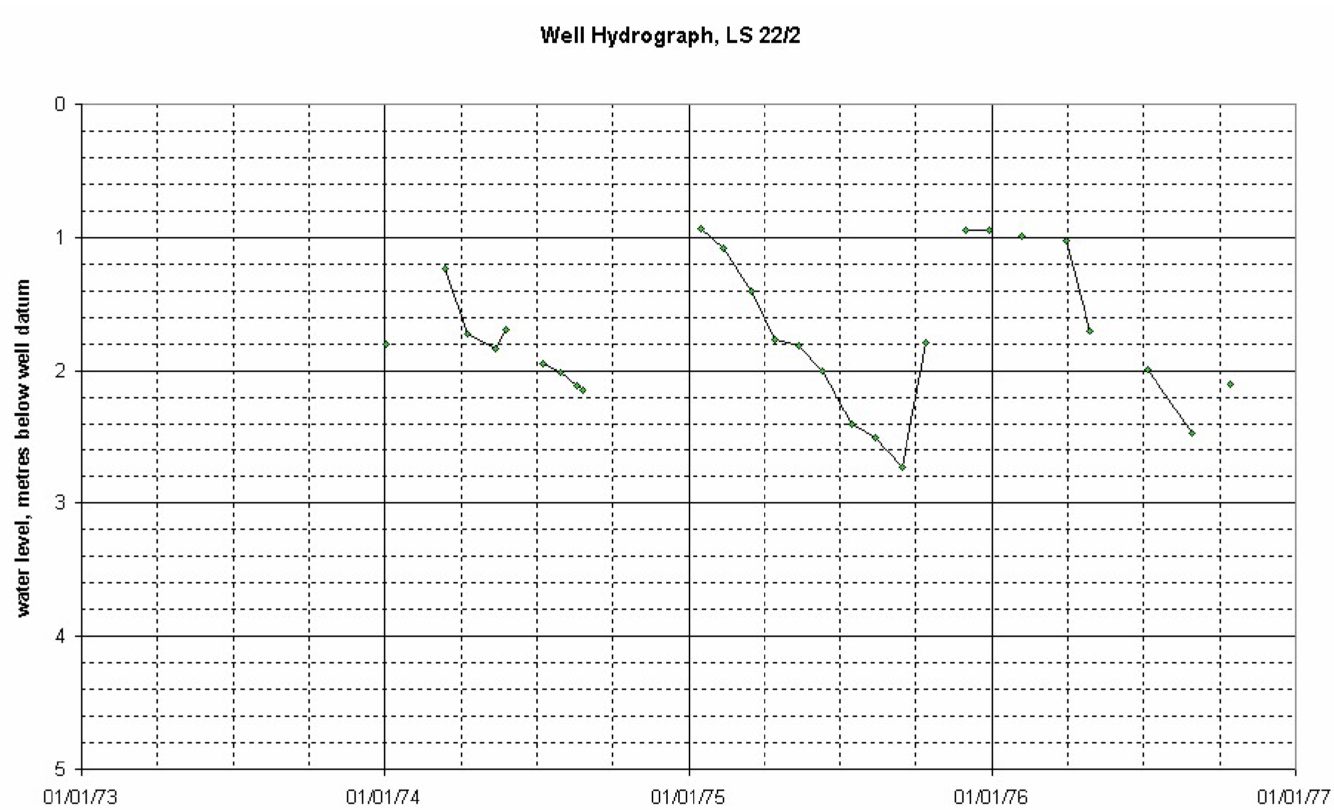
Hydrometric Area Local Authority		Associated surface water bodies	Associated terrestrial ecosystems	Area (km^2)
15 – Nore Laois Co Co Kilkenny Co Co		Nore, Tonet, Delour, Mountrath, Cappanacloghy, Ballytarsna, Ballyroan, Gully, Donaghmore Stream, Erkina, Rathdowney Stream, Goul,	Monaincha Bog/Ballaghmore Bog, Coolrain Bog, Knockacoller Bog, Forest House Wood, Mannin Wetland, Shanahoe Marsh, Cuffsborough, Grantstown Wood and Lough, Galmoy Fen, River Nore / Abbeyleix Woods Complex, The Curragh and Goul River Marsh	503
Topography		The highest elevations in this groundwater body are to the north on the lower slopes of Slieve Bloom. The source of the River Nore is found in the northwest of this groundwater body where initially it flows north and then makes a broad about turn around Castletown where it flows south. This occurs because of a slightly elevated area between Rathdowney and Borris in Ossory, which forces the Nore northwards, before Slieve Bloom forces it southwards again. The overall topography of the area can be considered as a gently undulating upland area.		
Geology and Aquifers	Aquifer type(s)	**Ll** – Locally Important Aquifer, moderately productive only in local zones		
	Main aquifer lithologies	BA - Ballysteen Formation - Fossiliferous dark-grey shaly limestone WA – Waulsortian Limestones - Massive unbedded limestone DW - Durrow Formation - Shaly fossiliferous & oolitic limestone AG - Aghmacart Formation - Dark shaly fine-grained limestone		
	Key structures.	Groundwater flow is affected by the anticline located at the southwest of the body; there is also a greater degree of faulting in this area.		
	Key properties	A pumping test in the Durrow Formation near Ballyragget shows a specific capacity of 40 m^3/day/m. Analysis of data from this test (Jacob method) provided a transmissivity estimate of 15 m^2/d. Using a conservative aquifer thickness estimate of 10 m, a permeability of 1.5 m/day has been derived from the transmissivity estimate. A porosity of 0.01 has been assumed for the Durrow **'Ll'** aquifer on the valley floor. This is at the lower end of the typical range used by the GSI for bedrock aquifers (0.025 to 0.01) and reflects the belief that fracturing is not particularly dense in this portion of the aquifer.		
	Thickness	Given common weathering patterns, most flow is thought to be relatively shallow; concentrating in the top 10 m to 30 m of the rock profile		
Overlying Strata	Lithologies	To the southwest the subsoil type is mainly limestone-derived till. In the northeast there are widespread gravel deposits which are thin and therefore not considered to be aquifers.		
	Thickness	Typically between 1 and 3m, subsoil is thinner in the south.		
	% area aquifer near surface	Low - 20%		
	Vulnerability	Mostly HIGH with small areas of EXTREME and fewer areas of LOW. The proportion of the area that is EXTREME increases to the south		
Recharge	Main recharge mechanisms	Most recharge is expected to occur locally; there is no evidence of swallow holes or sinking streams. Diffuse recharge will enter the groundwater body directly from the surface where subsoil is thinnest or most permeable.		
	Est. recharge rates	*[Information will be added at a later date]*		
Discharge	Springs and large known abstractions	Clonakenny (23), Derrin (Borris-in-Ossory WS) (500), Townparks (Borris-in-Ossory WS) (193), Colrain Co-Op, Donoghmore GWS (90), Raheen GWS (13), Donaghmore Co-Op Creamery (90), Meadow Irish Meats (273), Fermoyle PWS, Urlingford / Johnstown (966),		
	Main discharge mechanisms	Discharge from this groundwater body is to the local rivers, which appear to be in hydraulic connectivity with the groundwater body. There some springs located with in the groundwater body but evidence suggests these are not karst features.		
	Hydrochemical Signature	The bedrock strata of this groundwater body are **calcareous**. The limited data available show the groundwaters are "very hard" and have a calcium bicarbonate signature. The groundwaters have typical electrical conductivity of 700 µs/cm.		
Groundwater Flow Paths		Fracture flow is expected to be dominant. Flows are expected to be concentrated in fractured and weathered zones. Faulting and associated fracturing are likely to be a focus for groundwater flow. Due to the likely low permeability of the Durrow Formation, groundwater gradients are probably similar to topographic gradients, and are estimated to range from 0.004 (1 in 250) to 0.02 (1 in 50).		
Groundwater & surface water interactions		Groundwater will discharge locally to streams and rivers crossing the aquifer and also to small springs and seeps. Owing to the poor productivity of the aquifers in this body it is unlikely that any major groundwater - surface water interactions occur. Baseflow to rivers and streams is likely to be relatively low.		

Conceptual model	This groundwater body in north Kilkenny and south Laois consists of the locally important aquifers of the Ballysteen Limestone and the "Calp-like" limestones of the Durrow and Aghmacart formations. Most groundwater flow is considered to take place within the top 15m from the surface where the bedrock is fractured. The borehole water level data suggest the aquifer may be more developed towards the south, where we find deeper groundwater flow with a higher fluctuation in water level which is more typical of a karstic flow regime..
Attachments	(Figure 1 – 9) Borehole Hydrographs (Figure 10) Durov Plot of chemical data
Instrumentation	Stream gauge: 15008, 15035, 15027, 15007, 15010, 15041, 15052, 15048, 15051, 15038, 15042, 15030, 15033, GSI - Borehole Hydrograph: LS 21/1, LS 16/1, LS 23/1, LS 22/2, LS 28/1, LS 28/168, LS 29/2 (LAO064), EPA Representative Monitoring boreholes: <u>Laois</u> - Clonakenny GWS (#81 – S120820), Donoghmore (#37 – S260850), Fermoyle (#39 – S361791) <u>Kilkenny</u> - Spring Toberpatrick Urlingford (#34 – S300635)
Information Sources	Buckley, R. & Fitzsimons, V (2002) Urlingford and Johnstown Public Supply, Groundwater Source Protection Zones.
Disclaimer	Note that all calculation and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae



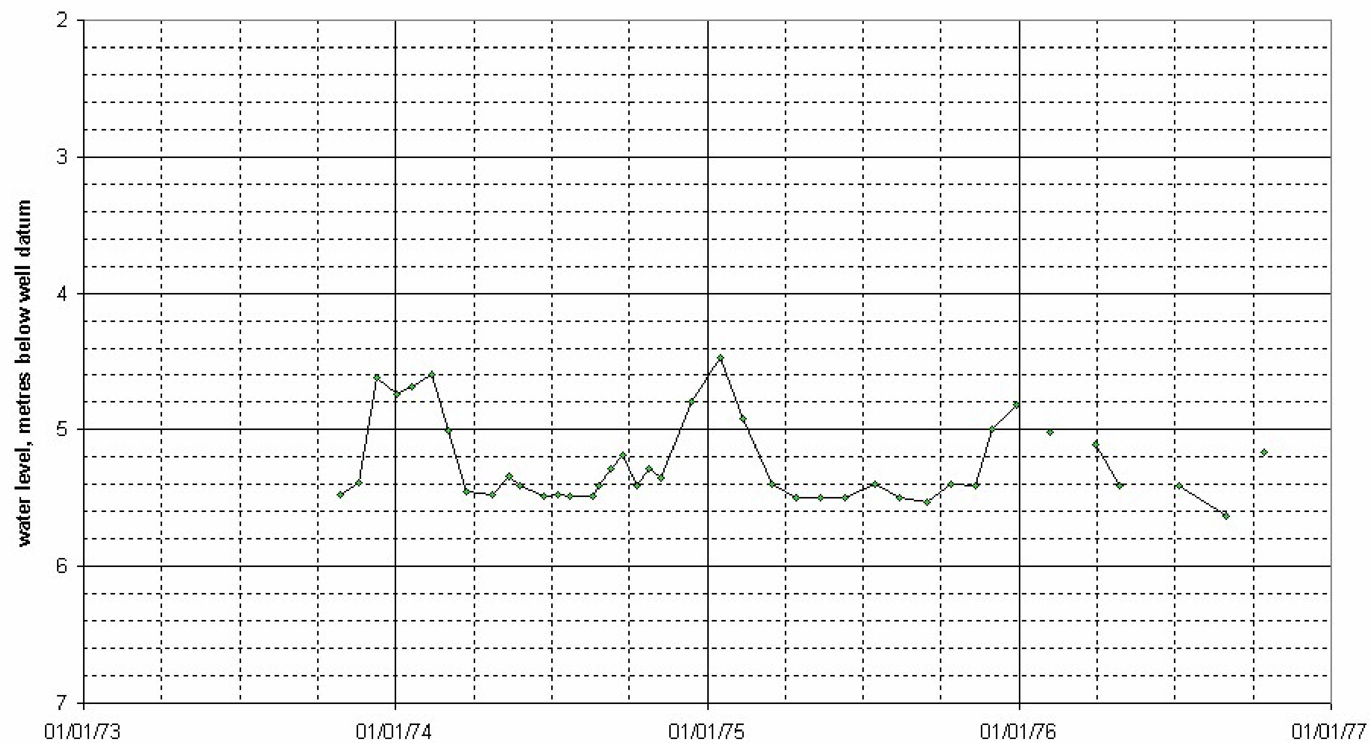


Well Hydrograph, LS 23/1
water level, metres below well datum
0
1
2
3
4
5
01/01/73
01/01/74
01/01/75
01/01/76
01/01/77

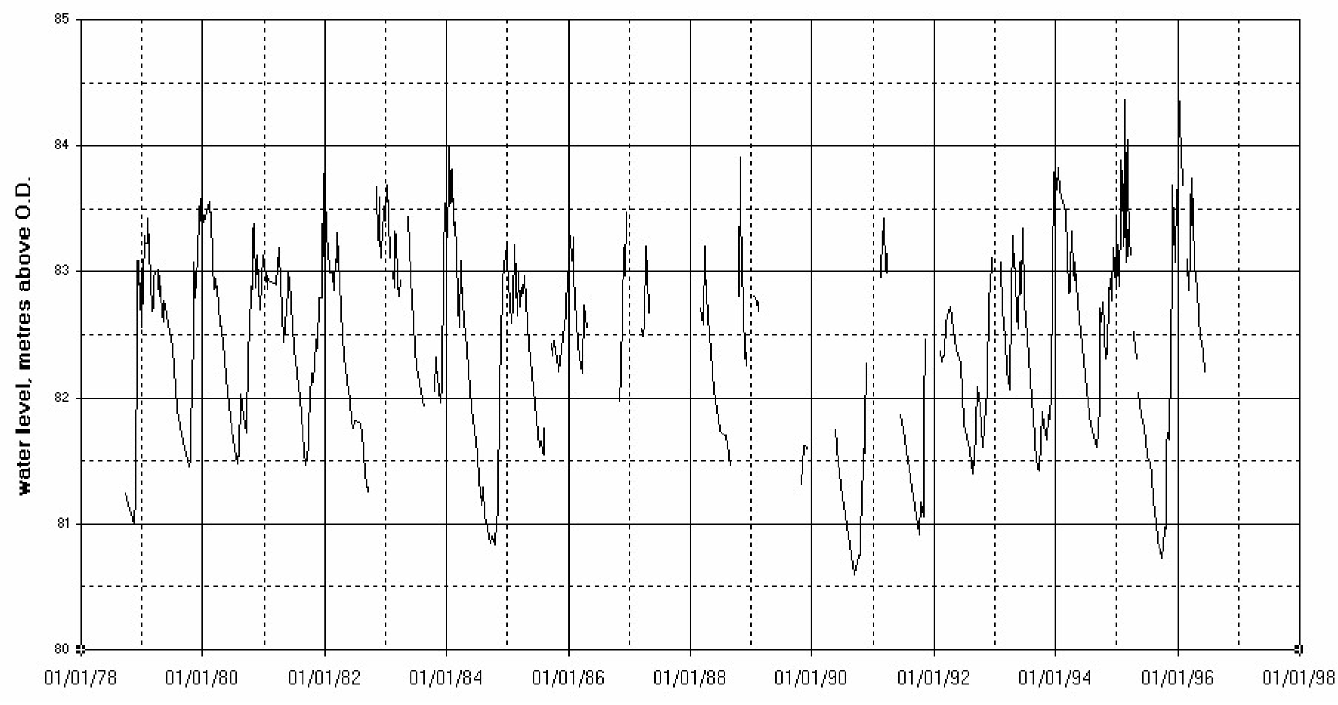


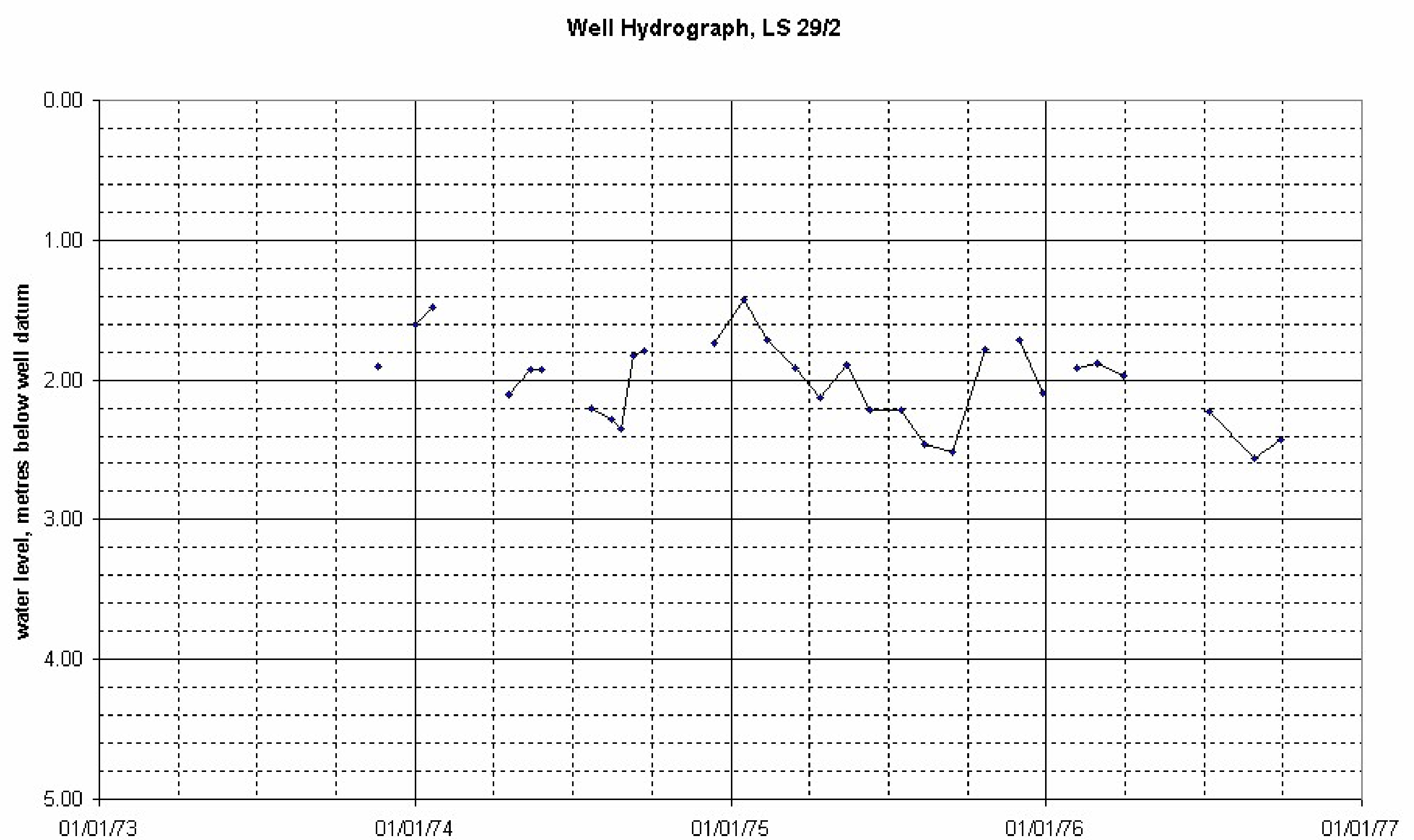
Well Hydrograph, LS 22/2
water level, metres below well datum
0
1
2
3
4
5
01/01/73
01/01/74
01/01/75
01/01/76
01/01/77

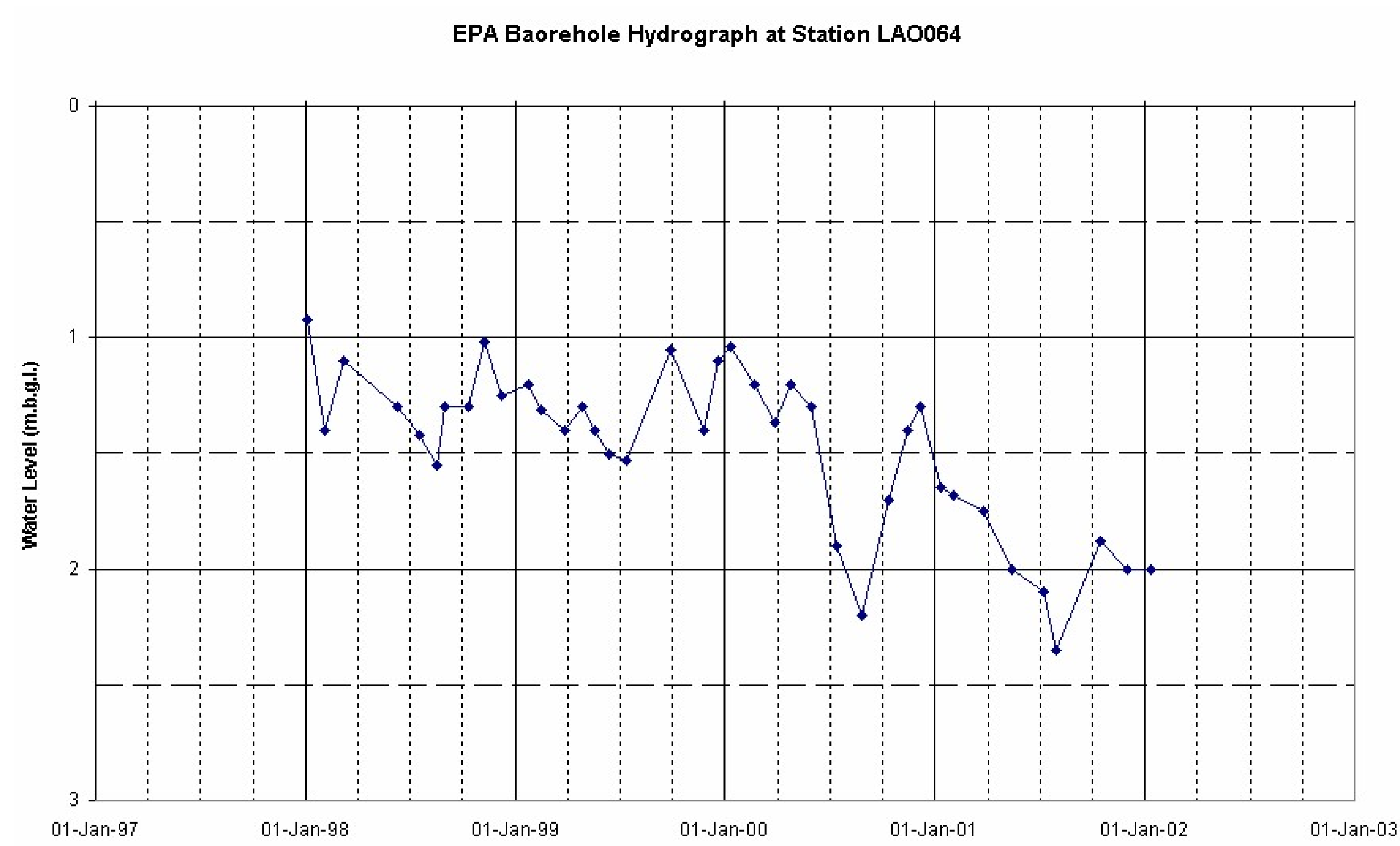
Well Hydrograph, LS 28/1

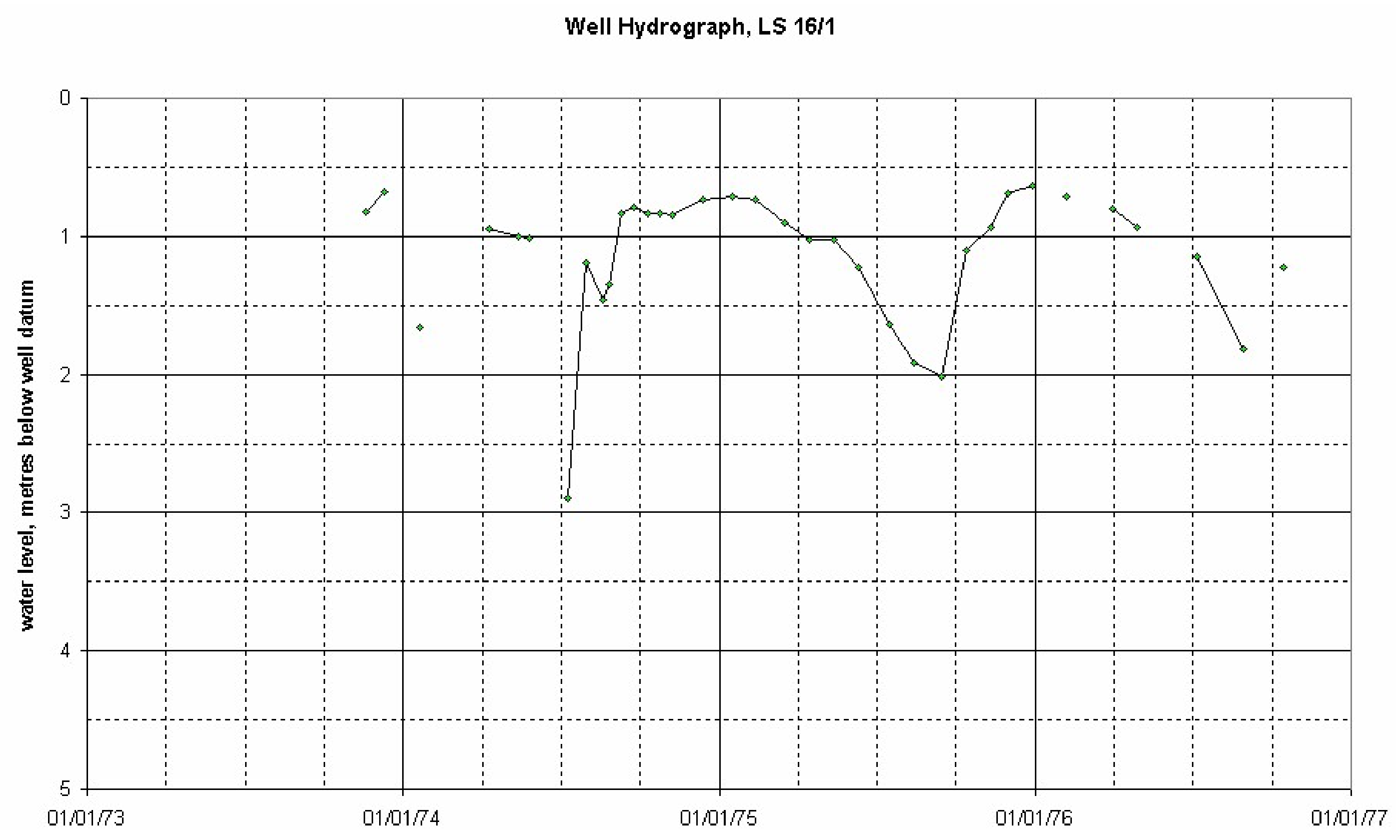


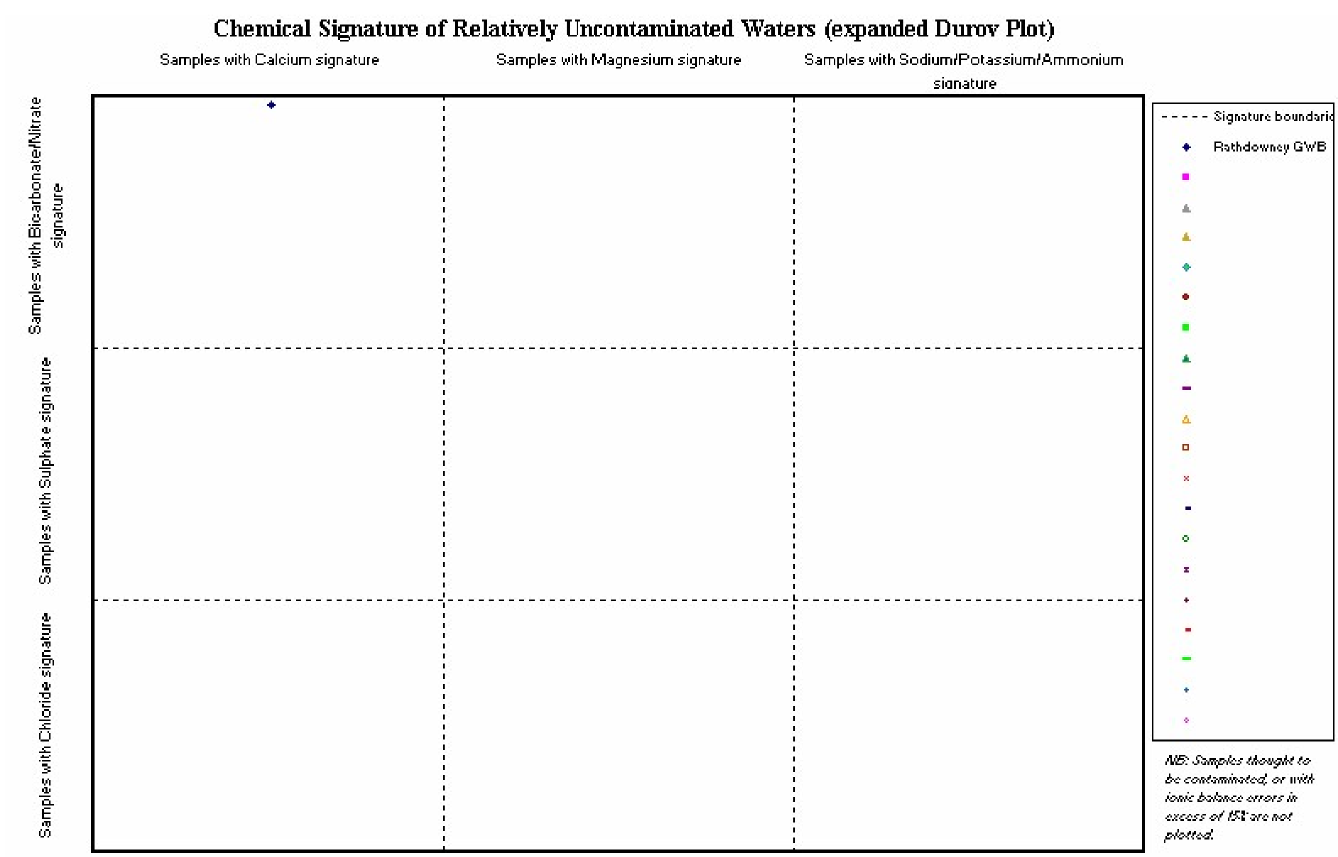
Well Hydrograph, Granston Manor, Durrow, Co. Laois,
(LS 28/168) NGR S 339 785; 30m deep borehole
in dolomitised Crosspatrick (limestone) Formation




Well Hydrograph, LS 29/2
water level, metres below well datum
0.00
1.00
2.00
3.00
4.00
5.00
01/01/73
01/01/74
01/01/75
01/01/76
01/01/77


EPA Baorehole Hydrograph at Station LAO064
Water Level (m.b.g.l.)
0
1
2
3
01-Jan-97
01-Jan-98
01-Jan-99
01-Jan-00
01-Jan-01
01-Jan-02
01-Jan-03


Well Hydrograph, LS 16/1
water level, metres below well datum
0
1
2
3
4
5
01/01/73
01/01/74
01/01/75
01/01/76
01/01/77


Chemical Signature of Relatively Uncontaminated Waters (expanded Durov Plot)
Samples with Calcium signature
Samples with Magnesium signature
Samples with Sodium/Potassium/Ammonium signature
Samples with Bicarbonate/Nitrate signature
Samples with Sulphate signature
Samples with Chloride signature
Signature boundaric
Rathdowney GWB
NB: Samples thought to be contaminated, or with ionic balance errors in excess of 15% are not plotted.

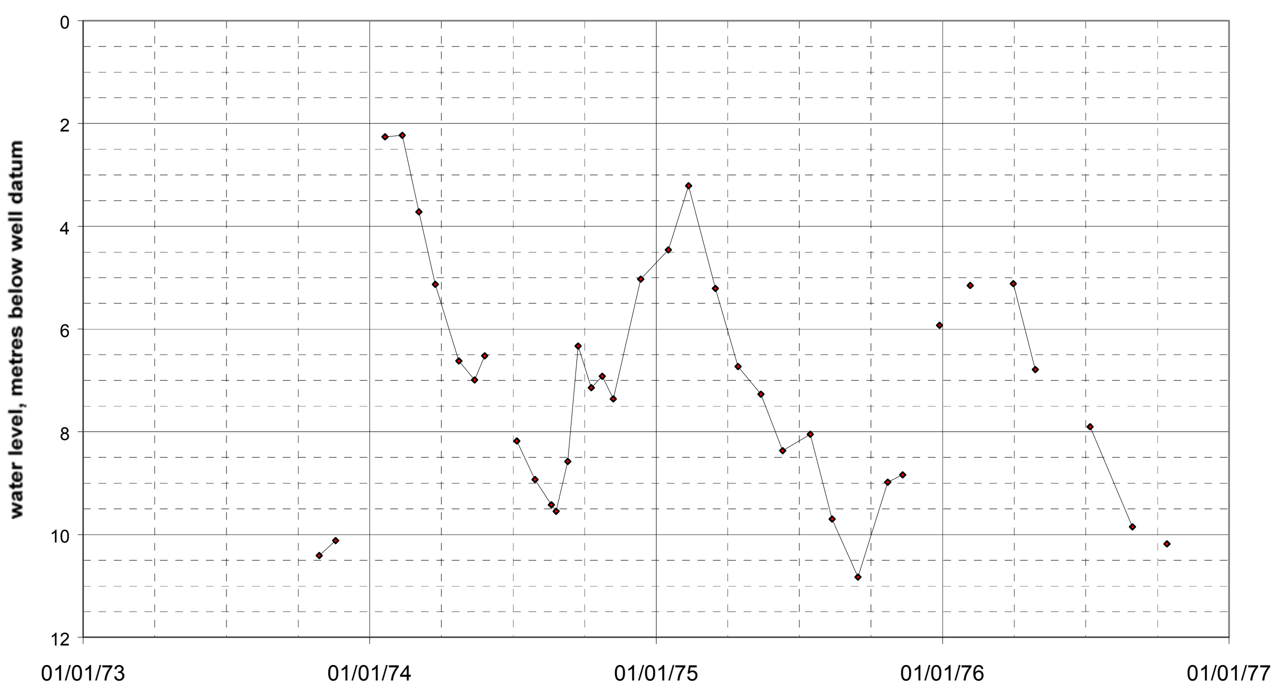
Shanahoe GWB: Summary of Initial Characterisation.

Hydrometric Area Local Authority	Associated surface water bodies	Associated terrestrial ecosystems	Area (km^2)
15 – Nore Laois Co Co Kilkenny Co Co S. Tipperary Co Co	Goul, Rathdowney Stream, Erkina, Gully, Nore, Ballytarsna, Ballyroan	Galmoy Fen, Coolacurragh Wood, Grantstown Wood And Lough, River Nore/Abbyleix Woods Complex, Shanahoe Marsh.	89.8

Topography		The highest elevations found in the area of this groundwater body are at the boundary between the Nore and Suir basins just southwest of Urlingford. Drainage here is to the north until the small streams meet the Erkina and Goul river where the river courses turn to the east. Moving further north the drainage is continuously east or southeast where are hills and troughs that cross cut the area of the groundwater body.
Geology and Aquifers	Aquifer type(s)	**Rf**: Regionally Important Fractured Aquifer. **Lm** : Locally Important Aquifer, generally moderately productive
	Main aquifer lithologies	WAdo: Dolomitised Waulsortian limestone CS : Crosspatrick Formation - Pale grey cherty crinoidal limestone
	Key structures.	A large number of faults are likely to have an effect on the rate and direction of groundwater flow at the southern end of this groundwater body.
	Key properties	Trasmissivities in the dolomite range from 50 – 500m^2/d and Permeabilities from 0.5 – 10m/d. The storage coefficient is in the order of 10^{-3} – 10^{-4}. The wide range of transmissivity values are largely due to the variability in the intensity of dolomitisation.
	Thickness	The effective thickness of the aquifer is very variable and depends on the intensity of dolomitisation in a given area. Dolomitisation is not just a near surface phenomenon, consequently significant permeability has been found at depths greater than 100m. In cross section, it becomes apparent that the two bands form the ends of a large U-bend structure (part of the central syncline of Kilkenny), which runs underneath the Slieveardagh Hills and the Castlecomer Plateau at depths of over 300m.
Overlying Strata	Lithologies	There is a large area of gravels in the southwest of Laois, part of which overlies this groundwater body. These gravels are considered to be too thin to be an aquifer. To the north there are more areas overlain by till, of which there are two types; till dominated by gravel and till derived from limestone.
	Thickness	The thickness of subsoil is generally less than 5m; there are also smaller areas to the south where there is rock close to surface. The thickest subsoil sections are to be found in the northern area of the groundwater body.
	% area aquifer near surface	There are areas of outcrop to the southern area of the groundwater body.
	Vulnerability	The overall vulnerability for the area is MODERATE with isolated areas of EXTREME. To the north there is a significant area of LOW vulnerability where there is an increase in subsoil thickness.
Recharge	Main recharge mechanisms	Most recharge to this aquifer is likely in the areas to the south where there is increased elevation and thinner subsoil, which appears to be permeable gravels.
	Est. recharge rates	*[Recharge rates will be calculated at a later date]*
Discharge	Springs and large known abstractions (m^3/d)	Rathbeg, Inchirourke (320) Dairyhill (Ballacolla GWS) (142), Whitehall (Rathdowney WS) (450),
	Main discharge mechanisms	In the Urlingford – Mountrath Lowlands the aquifer discharges to the Erkina and the Nore and to smaller streams often via small springs (frequently ephemeral).
	Hydrochemical Signature	Dolomite areas in the Nore are indicated to be very hard waters with high Mg/Ca ratio. Waters have a Calcium/Magnesium Bicarbonate type. The bedrock strata of this aquifer are **Calcareous**.
Groundwater Flow Paths		This is the one aquifer in the Nore River Basin where significant amounts of deep (>200m) groundwater flow may occur. The following area cited as evidence (1) This aquifer is continuous at depths under the centre of the basin. (2) There is significant permeability at depth (3) There is a head difference of more than 30m between the discharge levels in the two lowlands, which could provide the hydraulic drive. (4) The large springs at Callan – Bennettsbridge Lowlands (5) the slightly elevated temperature of some of the discharge waters from this aquifer in the Callan – Bennettsbridge lowlands.
Groundwater and Surface water interactions		Some karst features such as caves, a turlough, highly permeable zones and surface solution are found in parts of this aquifer. In areas where the aquifer is close to the surface, the drainage density is low.

Conceptual model	This groundwater body is defined to the north by the extent of dolomitised Waulsortian limestone and to the south by the Crosspatrick Limestone. The southwestern boundary is defined by the Nore/Suir catchment boundary. The dolomitisation of the original limestones has resulted in increased porosity. Subsequently other processes such as faulting, development of joints and karstification enhanced this porosity. The end product is a rock that is quite porous and permeable and which has been reduced in some places to the consistency of sand. Groundwaters in the outcrop areas of this aquifer are unconfined except for a number of small, generally low-lying areas where it is confined by till or peat big.
Attachments	(Figure 1) GSI Borehole Hydrograph at Middlemount
Instrumentation	Stream gauge: 15043, 15044 GSI Borehole Hydrograph: Middlemount (LS 28/2 - S326788) EPA Representative Monitoring boreholes: Bawnmore GWS (#50 - S558661), Galmoy GWS (#17 - S302712),
Information Sources	Buckley, R. & Fitzsimons, V (2002) Kilkenny Co Co Groundwater Protection Scheme. Daly, E. P. (1993) Hydrogeology of the Dolomite Aquifer in the Southeast of Ireland. Geol. Surv. Ire. Unpubl. Rep. Daly, E.P. (1994) Groundwater resources of the Nore River Basin. Geol. Surv. Ire. Unpubl. Rep.
Disclaimer	Note that all calculation and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae

Well Hydrograph at Middlemount LS 28/2



APPENDIX 8.2

Baseline Groundwater Monitoring Results

Parameter	Unit	SI No 366/2016	ES	Ex-D	GM	GM	GM	JP
			18 November 2020	07 March 2018	03 March 2018	14 October 2020	18 November 2020	03 March 2018
Physicochemical								
Groundwater Level	mbrp							
DO Lab	%		60.4			18	9.2	
Electrical Conductivity Field	µS/cm		823			1068	1074	
Electrical Conductivity Lab	µS/cm		800	796	1100	1054	1043	711
pH Field	pH Units		7.01			6.7	6.82	
pH Lab	pH units		7.75	7.39	7.03	7.49	7.5	7.05
Temperature	°C		11.2			11	10.7	
Total Dissolved Solids	mg/L		534			741	718	
Total Hardness Dissolved (as CaCO3)	mg/L		413	394	528	528	519	368
Total Suspended Solids	mg/L		<10	<10	<10	<10	<10	<10
Turbidity	NTU		-1.98			4.43	-1.68	
Major ions and metals								
Bicarbonate Alkalinity as CaCO3	mg/L		384			470	472	
Chloride	mg/L	24 — 187.5	19.6	22.4	56.1	49.4	46.9	27.3
Dissolved Aluminium	mg/L	0.15	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Dissolved Arsenic	mg/L	0.0075	0.0044	<0.0025	<0.0025	<0.0025	0.0075	<0.0025
Dissolved Cadmium	mg/L		<0.00003	<0.0005	<0.0005	<0.0005	0.00004	0.0038
Dissolved Calcium	mg/L		132.5	131.3	165.5	156.7	154.4	89.3
Dissolved Chromium	mg/L	0.0375 (Cr Total); 0.0075 (Cr-VI)	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
Dissolved Copper	mg/L		<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Dissolved Iron	mg/L		<0.02	<0.02	<0.02	<0.02	<0.02	0.038
Dissolved Lead	mg/L	0.0075	<0.005	<0.005	<0.005	<0.005	<0.005	0.007
Dissolved Magnesium	mg/L		19.4	15.7	27.2	32.4	31.6	34.5
Dissolved Manganese	mg/L		<0.002	<0.002	<0.002	<0.002	<0.002	0.166
Dissolved Mercury	mg/L	0.00075	<0.00001	<0.001	<0.001	<0.001	<0.00001	<0.001
Dissolved Nickel	mg/L		<0.002	<0.002	<0.002	0.002	<0.002	0.002
Dissolved Phosphorus	mg/L		0.019			0.015	<0.005	
Dissolved Potassium	mg/L		9.7	26.2	33.7	14.3	16	14.6
Dissolved Silicon	mg/L		1.952			2.976	2.871	
Dissolved Sodium	mg/L		9.8	16.4	22.1	21	20	10.5
Dissolved Zinc	mg/L	0.075	0.006	<0.003	<0.003	0.012	<0.003	8.389
Fluoride	mg/L		<0.3			<0.3	<0.3	
Sulphate as SO4	mg/L	187.5	14.9	19.3	23.9	22.4	21.7	22.5
Total Alkalinity as CaCO3	mg/L		384	364	498	470	472	360
Miscellaneous								
Ammoniacal Nitrogen as NH3	mg/L	0.065 — 0.175	<0.03	<0.03	0.96	0.25	0.17	0.07
Fats Oils and Grease	mg/L		<4			<4	<4	
Nitrate as N	mg/L	8.25	8.93	53.3	55.8	10.66	10.67	9
Nitrite as N	mg/L	0.1125	<0.006	<0.02	0.04	0.054	0.032	0.12
ORP	mV		146.6			100.4	329.1	
Ortho Phosphate as PO4	mg/L		<0.06	<0.06	<0.06	<0.06	<0.06	<0.06

Parameter	Unit	SI No 366/2016	JP	JP	KN	KN	KN	KS
			14 October 2020	18 November 2020	03 March 2018	14 October 2020	18 November 2020	03 March 2018
Physicochemical								
Groundwater Level	mbrp		10.7	7.48		5.17	3.45	
DO Lab	%		3.8	7		63	63	
Electrical Conductivity Field	µS/cm		802	785		907	878	
Electrical Conductivity Lab	µS/cm		839	752	856	834	879	581
pH Field	pH Units		6.88	7.32		6.82	7.01	
pH Lab	pH units		7.63	7.72	7.22	7.6	7.7	7.08
Temperature	°C		11	11		10.8	10.7	
Total Dissolved Solids	mg/L		486	442		518	559	
Total Hardness Dissolved (as CaCO3)	mg/L		371	362	371	420	412	316
Total Suspended Solids	mg/L		<10	17	<10	53	<10	40
Turbidity	NTU		8.39	5.99		6.72	0.1	
Major ions and metals								
Bicarbonate Alkalinity as CaCO3	mg/L		422	368		414	348	
Chloride	mg/L	24 — 187.5	29.8	27.4	65.4	24.9	42.1	19.8
Dissolved Aluminium	mg/L	0.15	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Dissolved Arsenic	mg/L	0.0075	<0.0025	0.0048	0.0026	<0.0025	0.0043	0.0031
Dissolved Cadmium	mg/L		0.0006	0.00008	<0.0005	<0.0005	<0.00003	<0.0005
Dissolved Calcium	mg/L		89.2	87.5	110.4	127.1	121.9	97.5
Dissolved Chromium	mg/L	0.0375 (Cr Total); 0.0075 (Cr-VI)	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
Dissolved Copper	mg/L		<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Dissolved Iron	mg/L		3.509	5.443	0.063	0.068	<0.02	0.067
Dissolved Lead	mg/L	0.0075	<0.005	0.012	<0.005	<0.005	<0.005	<0.005
Dissolved Magnesium	mg/L		35.3	34	22.7	24.3	25.5	17.3
Dissolved Manganese	mg/L		0.239	0.294	<0.002	0.071	<0.002	0.041
Dissolved Mercury	mg/L	0.00075	<0.001	<0.00001	<0.001	<0.001	<0.00001	<0.001
Dissolved Nickel	mg/L		0.002	0.003	<0.002	<0.002	<0.002	<0.002
Dissolved Phosphorus	mg/L		0.015	<0.005		0.046	<0.005	
Dissolved Potassium	mg/L		19.9	17.9	5.5	2.1	4.3	3
Dissolved Silicon	mg/L		4.274	3.94		3.048	3.596	
Dissolved Sodium	mg/L		12.5	11.8	37.8	11.5	26.7	11.5
Dissolved Zinc	mg/L	0.075	4.393	4.246	0.048	0.017	0.017	0.013
Fluoride	mg/L		<0.3	<0.3		<0.3	<0.3	
Sulphate as SO4	mg/L	187.5	20	21.1	19.3	19.6	16	18.3
Total Alkalinity as CaCO3	mg/L		422	368	366	414	348	322
Miscellaneous								
Ammoniacal Nitrogen as NH3	mg/L	0.065 — 0.175	3.19	2.55	<0.03	0.12	<0.03	0.04
Fats Oils and Grease	mg/L		<4	<4		<4	<4	
Nitrate as N	mg/L	8.25	<0.05	<0.05	39	1.35	11.65	8.3
Nitrite as N	mg/L	0.1125	<0.006	<0.006	<0.02	<0.006	<0.006	0.03
ORP	mV		-84.9	-100.6		149.8	135.8	
Ortho Phosphate as PO4	mg/L		<0.06	<0.06	<0.06	<0.06	<0.06	<0.06

Parameter	Unit	SI No 366/2016	KS	KS	NCG	PD
			14 October 2020	18 November 2020	18 November 2020	03 March 2018
Physicochemical						
Groundwater Level	mbrp			11.81	7.37	
DO Lab	%		16.4	88.7	118.3	
Electrical Conductivity Field	µS/cm		779	820	798	
Electrical Conductivity Lab	µS/cm		975	806	782	761
pH Field	pH Units		6.86	7.09	7.09	
pH Lab	pH units		7.61	7.76	8.19	7.15
Temperature	°C		11.1	10.3	10.1	
Total Dissolved Solids	mg/L		626	502	488	
Total Hardness Dissolved (as CaCO3)	mg/L		435	439	10	400
Total Suspended Solids	mg/L		<10	<10	<10	<10
Turbidity	NTU		66.8	-1.62	-2.13	
Major ions and metals						
Bicarbonate Alkalinity as CaCO3	mg/L		374	392	344	
Chloride	mg/L	24 — 187.5	50.3	17.3	33.8	40
Dissolved Aluminium	mg/L	0.15	<0.02	<0.02	<0.02	<0.02
Dissolved Arsenic	mg/L	0.0075	<0.0025	0.0055	0.0054	<0.0025
Dissolved Cadmium	mg/L		<0.0005	0.00023	<0.00003	<0.0005
Dissolved Calcium	mg/L		129.7	116.7	2.1	109.4
Dissolved Chromium	mg/L	0.0375 (Cr Total); 0.0075 (Cr-VI)	<0.0015	<0.0015	<0.0015	<0.0015
Dissolved Copper	mg/L		<0.007	<0.007	0.01	<0.007
Dissolved Iron	mg/L		<0.02	<0.02	<0.02	<0.02
Dissolved Lead	mg/L	0.0075	<0.005	<0.005	<0.005	<0.005
Dissolved Magnesium	mg/L		26.4	35.1	1.1	30.2
Dissolved Manganese	mg/L		<0.002	<0.002	<0.002	<0.002
Dissolved Mercury	mg/L	0.00075	<0.001	<0.00001	<0.00001	<0.001
Dissolved Nickel	mg/L		<0.002	<0.002	<0.002	<0.002
Dissolved Phosphorus	mg/L		0.007	<0.005	<0.005	
Dissolved Potassium	mg/L		4.6	1.5	0.9	5.1
Dissolved Silicon	mg/L		3.699	2.314	2.795	
Dissolved Sodium	mg/L		28.4	8.2	191	16.6
Dissolved Zinc	mg/L	0.075	0.014	0.009	0.005	0.004
Fluoride	mg/L		<0.3	<0.3	<0.3	
Sulphate as SO4	mg/L	187.5	15.2	19.8	16.6	38.1
Total Alkalinity as CaCO3	mg/L		374	392	344	396
Miscellaneous						
Ammoniacal Nitrogen as NH3	mg/L	0.065 — 0.175	<0.03	<0.03	<0.03	<0.03
Fats Oils and Grease	mg/L		<4	<4	<4	
Nitrate as N	mg/L	8.25	11.88	5.88	4.83	30.4
Nitrite as N	mg/L	0.1125	<0.006	<0.006	<0.006	<0.02
ORP	mV		40.8	672.6	356.6	
Ortho Phosphate as PO4	mg/L		<0.06	<0.06	<0.06	<0.06

Parameter	Unit	SI No 366/2016	CW West	CW West	CW West	G South	G South	G South
			14 October 2020	17 November 2020	03 March 2018	14 October 2020	17 November 2020	03 March 2018
Physicochemical								
Groundwater Level	mbrp		18.56	17.86		24.13	21.33	
DO Lab	%		6.4	0.8		5.4	1.9	
Electrical Conductivity Field	µS/cm		795	735		994	1032	
Electrical Conductivity Lab	µS/cm		851	738	621	1057	1022	920
pH Field	pH Units		6.94	7.23		6.42	6.87	
pH Lab	pH units		7.72	7.84	7.45	7.44	7.51	7.14
Temperature	°C		10.8	10.7		10.8	11.2	
Total Dissolved Solids	mg/L		559	439		713	673	
Total Hardness Dissolved (as CaCO3)	mg/L		398	345	251	505	496	484
Total Suspended Solids	mg/L		<10	<10	<10	<10	<10	<10
Turbidity	NTU		26.94	8.91		20.3	19.07	
Major ions and metals								
Bicarbonate Alkalinity as CaCO3	mg/L		370	314		462	438	
Chloride	mg/L	24 — 187.5	21.7	21.5	23.9	26.3	33.5	24.6
Dissolved Aluminium	mg/L	0.15	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Dissolved Arsenic	mg/L	0.0075	<0.0025	0.0036	<0.0025	<0.0025	0.0083	0.0031
Dissolved Cadmium	mg/L		<0.0005	<0.00003	<0.0005	<0.0005	0.00003	<0.0005
Dissolved Calcium	mg/L		91.7	73.5	56.5	142	139.7	134.3
Dissolved Chromium	mg/L	0.0375 (Cr Total); 0.0075 (Cr-VI)	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
Dissolved Copper	mg/L		<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Dissolved Iron	mg/L		0.1	0.12	0.476	<0.02	<0.02	<0.02
Dissolved Lead	mg/L	0.0075	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Dissolved Magnesium	mg/L		40.1	38.4	26.1	35.8	34.9	35.4
Dissolved Manganese	mg/L		0.005	0.011	0.008	0.182	0.208	0.05
Dissolved Mercury	mg/L	0.00075	<0.001	<0.00001	<0.001	<0.001	<0.00001	<0.001
Dissolved Nickel	mg/L		0.004	0.003	0.003	0.02	0.01	0.008
Dissolved Phosphorus	mg/L		0.008	<0.005		0.006	<0.005	
Dissolved Potassium	mg/L		20.3	23.4	22.1	25	33	29
Dissolved Silicon	mg/L		4.639	3.716		4.258	4.986	
Dissolved Sodium	mg/L		11.3	12.5	22.5	11.4	14	12.6
Dissolved Zinc	mg/L	0.075	0.003	<0.003	<0.003	0.519	0.153	0.103
Fluoride	mg/L		0.3	0.9		<0.3	<0.3	
Sulphate as SO4	mg/L	187.5	42.1	56.9	122.4	66.7	41.9	40.4
Total Alkalinity as CaCO3	mg/L		370	314	206	462	438	478
Miscellaneous								
Ammoniacal Nitrogen as NH3	mg/L	0.065 — 0.175	0.07	0.09	0.23	<0.03	<0.03	0.08
Fats Oils and Grease	mg/L		<4	<4		<4	<4	
Nitrate as N	mg/L	8.25	4.91	0.16	<0.2	7.19	11.38	34.1
Nitrite as N	mg/L	0.1125	0.01	0.064	<0.02	0.083	0.064	<0.02
ORP	mV		-3.1	4.3		259.3	80	
Ortho Phosphate as PO4	mg/L		<0.06	<0.06	<0.06	<0.06	<0.06	<0.06

Parameter	Unit	SI No 366/2016	K Vent	K Vent	K Vent	TMW8	TMW13
			14 October 2020	17 November 2020	07 March 2018	07 March 2018	07 March 2018
Physicochemical							
Groundwater Level	mbrp		5.9	1.95			
DO Lab	%		3.5	3.9			
Electrical Conductivity Field	µS/cm		795	852			
Electrical Conductivity Lab	µS/cm		852	833	661	958	879
pH Field	pH Units		6.81	6.98			
pH Lab	pH units		7.58	7.55	7.58	7.3	7.45
Temperature	°C		11.9	11.5			
Total Dissolved Solids	mg/L		561	544			
Total Hardness Dissolved (as CaCO3)	mg/L		447	476	379	559	536
Total Suspended Solids	mg/L		<10	<10	<10	<10	<10
Turbidity	NTU		6.7	0.57			
Major ions and metals							
Bicarbonate Alkalinity as CaCO3	mg/L		394	422			
Chloride	mg/L	24 — 187.5	14.8	13	17.2	14.2	15.9
Dissolved Aluminium	mg/L	0.15	<0.02	<0.02	<0.02	<0.02	<0.02
Dissolved Arsenic	mg/L	0.0075	<0.0025	0.0049	<0.0025	0.0026	<0.0025
Dissolved Cadmium	mg/L		<0.0005	<0.00003	<0.0005	<0.0005	<0.0005
Dissolved Calcium	mg/L		117	123.2	100.9	144.8	139.1
Dissolved Chromium	mg/L	0.0375 (Cr Total); 0.0075 (Cr-VI)	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
Dissolved Copper	mg/L		<0.007	<0.007	<0.007	<0.007	<0.007
Dissolved Iron	mg/L		0.022	0.059	<0.02	<0.02	<0.02
Dissolved Lead	mg/L	0.0075	<0.005	<0.005	<0.005	<0.005	<0.005
Dissolved Magnesium	mg/L		36.8	40.1	30.2	46.9	44.8
Dissolved Manganese	mg/L		0.158	0.176	0.065	<0.002	<0.002
Dissolved Mercury	mg/L	0.00075	<0.001	<0.00001	<0.001	<0.001	<0.001
Dissolved Nickel	mg/L		0.013	0.014	<0.002	<0.002	<0.002
Dissolved Phosphorus	mg/L		0.005	<0.005			
Dissolved Potassium	mg/L		2	2	4.9	1.8	2.4
Dissolved Silicon	mg/L		1.882	2.053			
Dissolved Sodium	mg/L		6.8	7	8.1	21.1	7.9
Dissolved Zinc	mg/L	0.075	1.351	1.112	<0.003	0.008	0.478
Fluoride	mg/L		0.3	0.3			
Sulphate as SO4	mg/L	187.5	46.7	71.8	34.6	138.2	75.4
Total Alkalinity as CaCO3	mg/L		394	422	330	420	432
Miscellaneous							
Ammoniacal Nitrogen as NH3	mg/L	0.065 — 0.175	0.07	0.07	0.24	<0.03	<0.03
Fats Oils and Grease	mg/L		<4	<4			
Nitrate as N	mg/L	8.25	0.58	0.2	<0.2	14.3	19.7
Nitrite as N	mg/L	0.1125	<0.006	<0.006	<0.02	<0.02	<0.02
ORP	mV		54.6	80			
Ortho Phosphate as PO4	mg/L		<0.06	<0.06	<0.06	<0.06	<0.06

APPENDIX 8.3

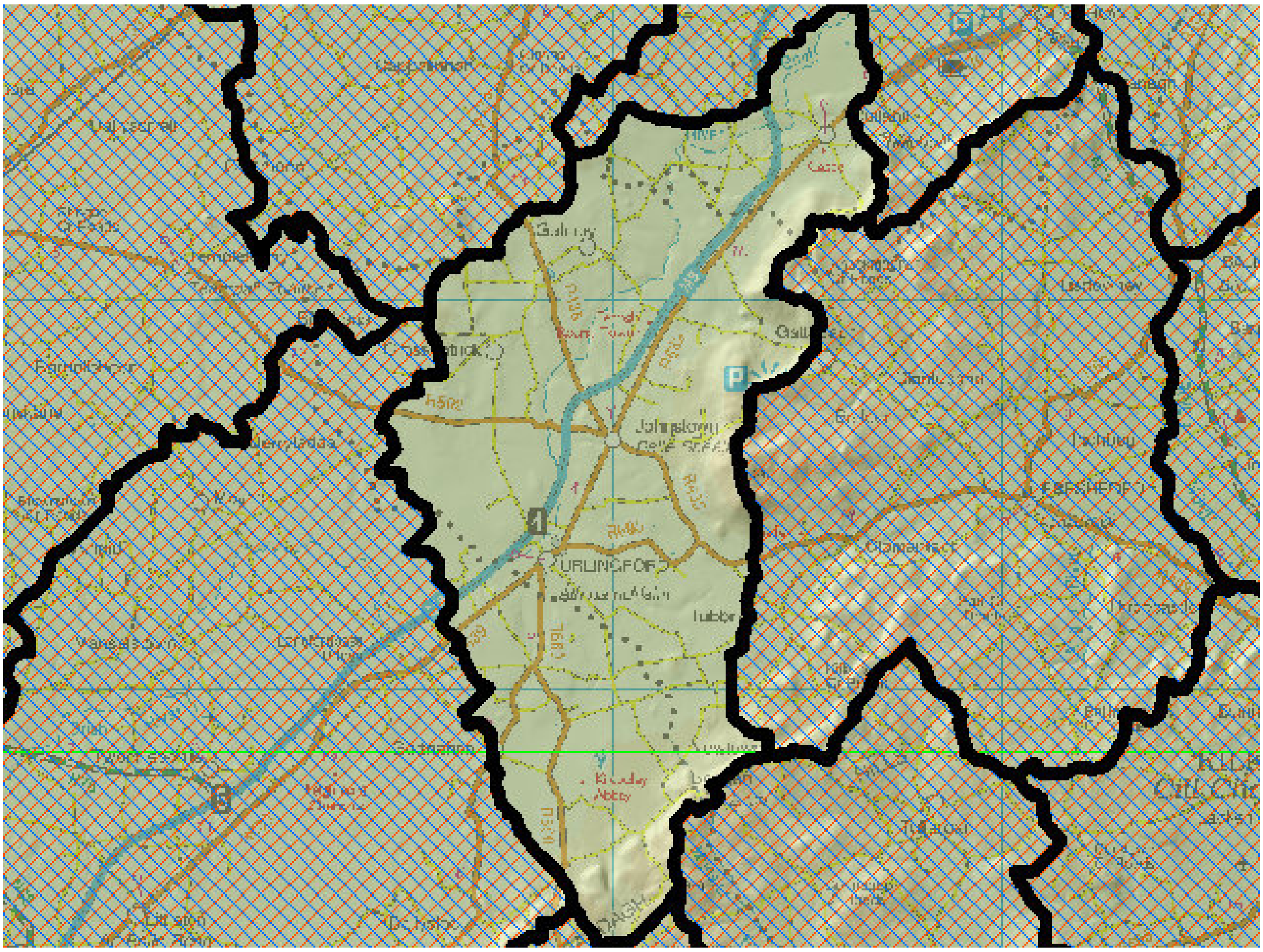
Surface Water WFD Cycle 2 Assessments

WFD Cycle 2

Catchment Nore

Subcatchment Goul_SC_010

Code 15_15



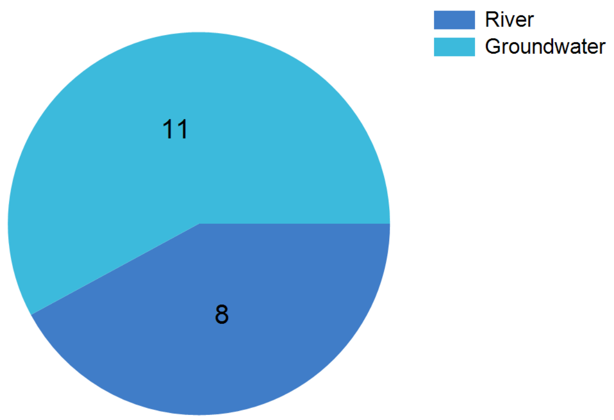
Generated on: 04 Jan 2019

Assessment Purpose

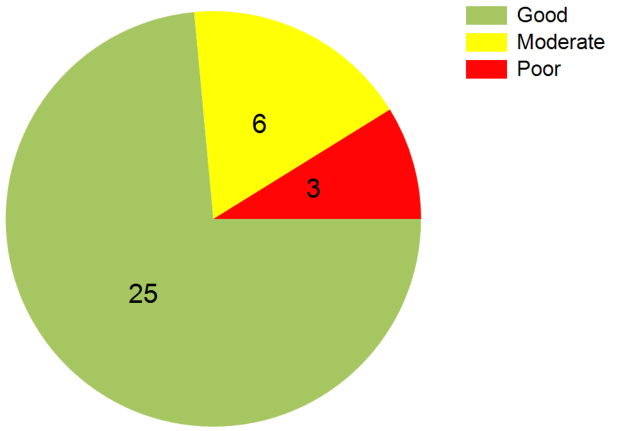
This assessment has been produced as part of the national characterisation programme undertaken for the second cycle of Water Framework Directive river basin management planning. It has been led by the EPA, with input from Local Authorities and other public bodies, and with support from RPS consultants.

The characterisation assessments are automatically generated from the information stored in the WFD Application. They are based on information available to the end of 2015 but may be subject to change until the final 2018-21 river basin management plan is published. Users should ensure that they have the most up to date information by downloading the latest assessment before use.

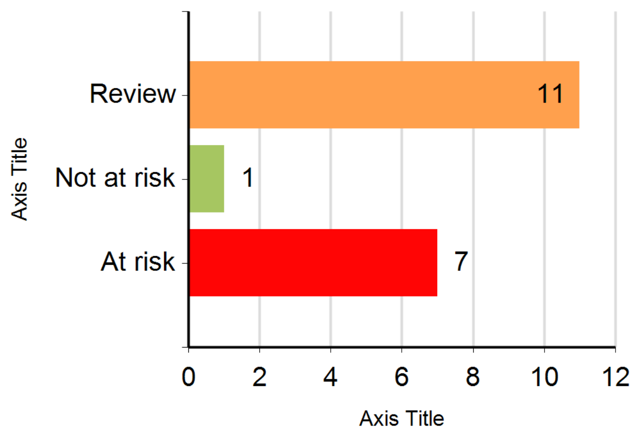
Waterbodies



Water Quality Status (Monitored)



WFD Risk



Water Quality - High Ecological Status

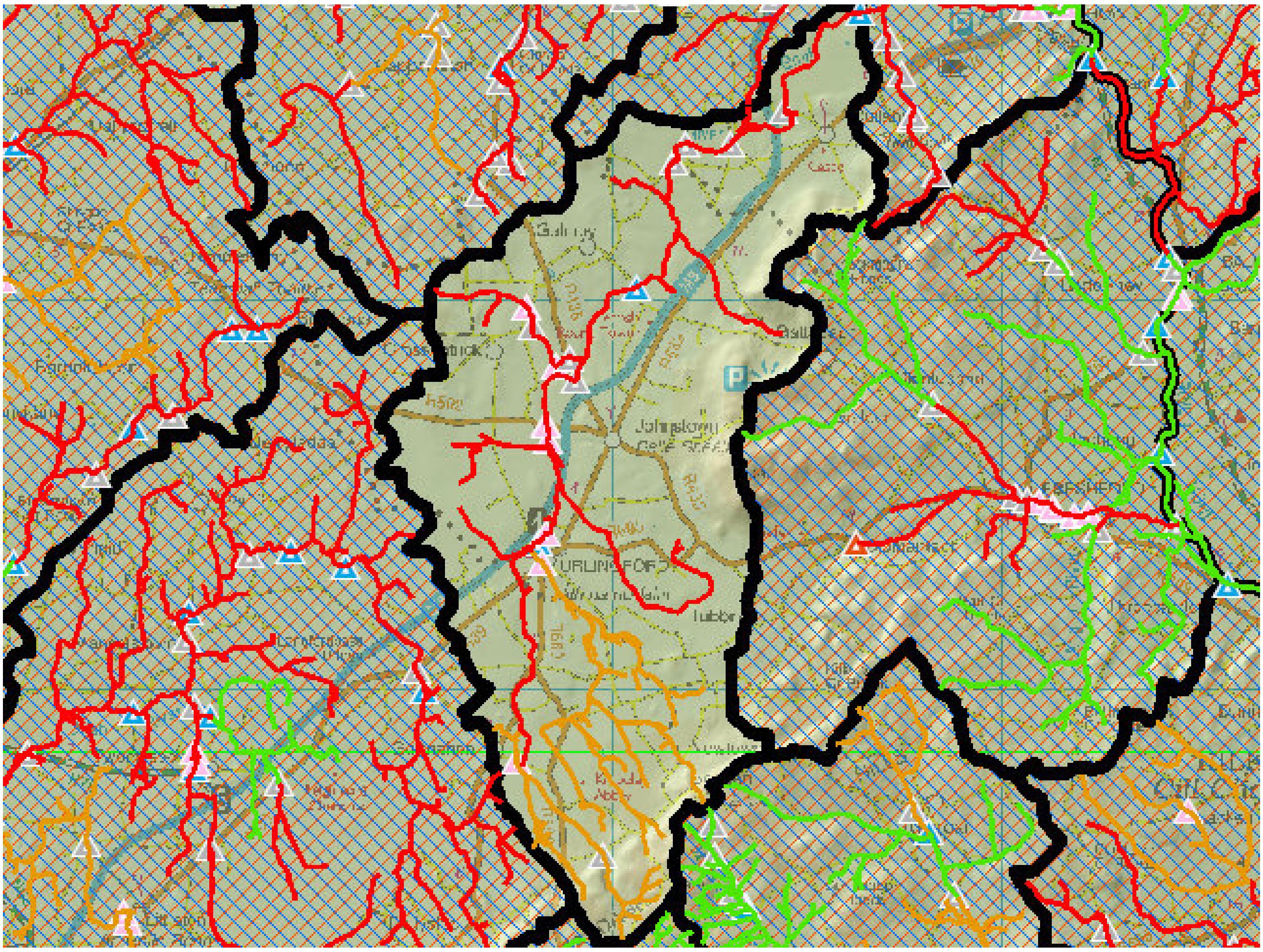
No Data Available

Evaluation of PrioritySubcatchment Issues

Ecological status is unassigned in the upper reaches of the subcatchment and less than Good status in the middle and lower reaches; ecological status is Moderate on Goul_040, Goul_050 and Goul_060, and Poor on Baunballinlough Stream_010. Concentrations of phosphate and ammonia are elevated on Goul_020 and Goul_030.

On Goul_010 and Goul_020 the significant pressures are agriculture and a Certificate of Authorisation for urban wastewater discharge. On Goul_030 two urban wastewater treatment plants are the significant pressures. On Goul_040, agriculture is the significant pressure at the upstream monitoring station and forestry is the significant pressure at the downstream monitoring station. On Baunballinlough_010, Goul_050 and Goul_060, agriculture is the significant pressure; all three subbasins are predominantly well drained and, therefore, sources of nutrients are likely to be via small point sources and groundwater. Diffuse input of nutrients in the lower reaches of the subcatchment are due to a lack of adequate buffer strips adjacent to the water bodies.

Map Subcatchment Risk Map

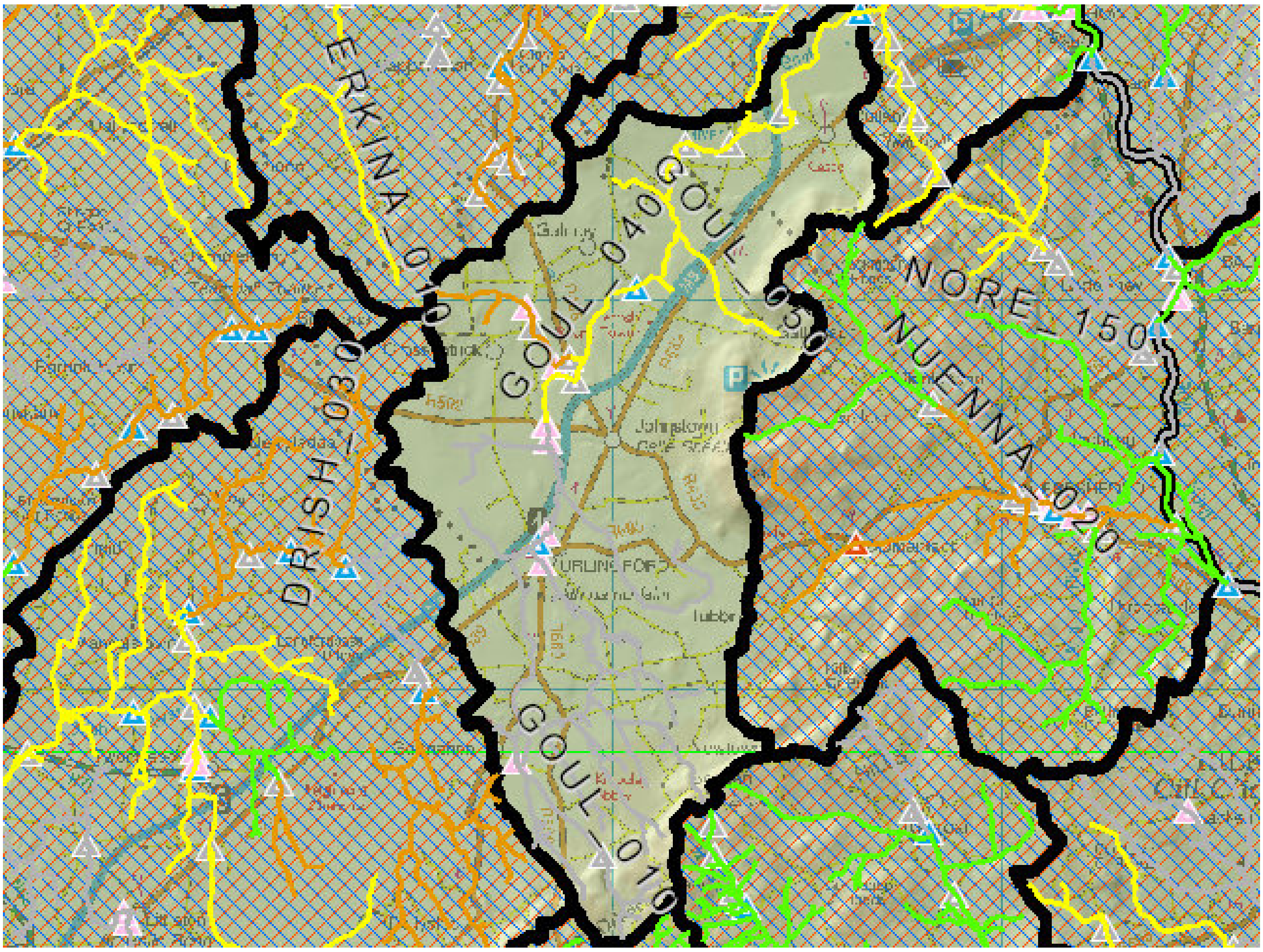


River And Lake Waterbodies: WFD Risk

The following river and lake waterbodies are in the subcatchment.

Code	Name	Type	WFD Risk	Significant Pressure
IE_SE_15B120080	BAUNBALLINLOUGH STREAM_010	River	At risk	Yes
IE_SE_15G020110	GOUL_020	River	At risk	Yes
IE_SE_15G020200	GOUL_030	River	At risk	Yes
IE_SE_15G020300	GOUL_040	River	At risk	Yes
IE_SE_15G020360	GOUL_050	River	At risk	Yes
IE_SE_15G020500	GOUL_060	River	At risk	Yes
IE_SE_15A030960	ARDREAGH_010	River	Review	Yes
IE_SE_15G020060	GOUL_010	River	Review	Yes

Map Subcatchment Water Quality Status Map



River And Lake Waterbodies: Water Quality Status

The water quality status of river and lake waterbodies in the subcatchment is as follows.

Code	Name	Type	2007-09	2010-12	2010-15
IE_SE_15A030960	ARDREAGH_010	River	Unassigned	Unassigned	Unassigned
IE_SE_15B120080	BAUNBALLINLOUGH STREAM_010	River	Moderate	Poor	Poor
IE_SE_15G020060	GOUL_010	River	Unassigned	Unassigned	Unassigned
IE_SE_15G020110	GOUL_020	River	Unassigned	Unassigned	Unassigned
IE_SE_15G020200	GOUL_030	River	Unassigned	Unassigned	Unassigned
IE_SE_15G020300	GOUL_040	River	Moderate	Poor	Moderate
IE_SE_15G020360	GOUL_050	River	Good	Moderate	Moderate
IE_SE_15G020500	GOUL_060	River	Good	Good	Moderate

Potentially Dependent Transitional and Coastal Waterbodies

The Transitional and Coastal waterbodies listed below intersect spatially with river and lake waterbodies in the subcatchment …

Code	Name	Type	Local Authority	WFD Risk

Potentially Dependent Groundwater Waterbodies

The groundwaters listed below interset spatially with river and lake waterbodies in the subcatchment …

Code	Name	Type	Local Authority	WFD Risk
IE_SE_G_009	Ballingarry	Groundwater	Kilkenny County Council	Review
IE_SE_G_040	Clonmel	Groundwater	Tipperary County Council	Review
IE_SE_G_081	Killenaule	Groundwater	Tipperary County Council	Not at risk
IE_SE_G_088	Lisdowney	Groundwater	Kilkenny County Council	Review
IE_SE_G_114	Rathdowney	Groundwater	Laois County Council	Review
IE_SE_G_119	Shanahoe	Groundwater	Laois County Council	Review
IE_SE_G_126	Slieveardagh Hills	Groundwater	Tipperary County Council	Review
IE_SE_G_131	Templemore	Groundwater	Tipperary County Council	Review
IE_SE_G_134	GWDTE-The Loughlans Turlough (SAC000407)	Groundwater	Kilkenny County Council	Review
IE_SE_G_156	Durrow	Groundwater	Kilkenny County Council	At risk
IE_SE_G_158	Thurles	Groundwater	Tipperary County Council	Review

Protected Areas intersecting River and Lake Waterbodies

The Protected Areas listed below intersect spatially with river and lake waterbodies in the subcatchment …

Code	Name	Type	Waterbody Name	Association Type
IE0002162	River Barrow And River Nore SAC	SAC	GOUL_060	Overlapping / partly within Protected Area

Pressures

Below is a list of all significant pressures identified in the subcatchment.

Code	Name	WFD Risk	Pressure Category	Pressure Sub Category
IE_SE_15B120080	BAUNBALLINLOUGH STREAM_010	At risk	Agriculture	Agriculture
IE_SE_15G020110	GOUL_020	At risk	Agriculture	Pasture
IE_SE_15G020110	GOUL_020	At risk	Urban Waste Water	Agglomeration PE < 500
IE_SE_15G020200	GOUL_030	At risk	Urban Waste Water	Agglomeration PE of 1,001 to 2,000
IE_SE_15G020200	GOUL_030	At risk	Urban Waste Water	Agglomeration PE of 500 to 1,000
IE_SE_15G020300	GOUL_040	At risk	Agriculture	Agriculture
IE_SE_15G020300	GOUL_040	At risk	Industry	IPC
IE_SE_15G020300	GOUL_040	At risk	Forestry	Forestry
IE_SE_15G020360	GOUL_050	At risk	Agriculture	Agriculture
IE_SE_15G020500	GOUL_060	At risk	Agriculture	Arable
IE_SE_15G020500	GOUL_060	At risk	Agriculture	Pasture
IE_SE_G_156	Durrow	At risk	Agriculture	Agriculture
IE_SE_15A030960	ARDREAGH_010	Review	Forestry	Forestry
IE_SE_15A030960	ARDREAGH_010	Review	Agriculture	Pasture
IE_SE_15G020060	GOUL_010	Review	Urban Waste Water	Agglomeration PE < 500
IE_SE_15G020060	GOUL_010	Review	Agriculture	Pasture
IE_SE_G_009	Ballingarry	Review	Anthropogenic Pressures	Unknown
IE_SE_G_040	Clonmel	Review	Anthropogenic Pressures	Unknown
IE_SE_G_088	Lisdowney	Review	Anthropogenic Pressures	Unknown
IE_SE_G_114	Rathdowney	Review	Anthropogenic Pressures	Unknown
IE_SE_G_119	Shanahoe	Review	Anthropogenic Pressures	Unknown
IE_SE_G_126	Slieveardagh Hills	Review	Anthropogenic Pressures	Unknown
IE_SE_G_131	Templemore	Review	Anthropogenic Pressures	Unknown
IE_SE_G_134	GWDTE-The Loughlans Turlough (SAC000407)	Review	Anthropogenic Pressures	Unknown
IE_SE_G_158	Thurles	Review	Anthropogenic Pressures	Unknown

Further Characterisation Actions

The following further characterisation actions have been identified. These are necessary to help understand more fully issues in the subcatchment and their likely cause.

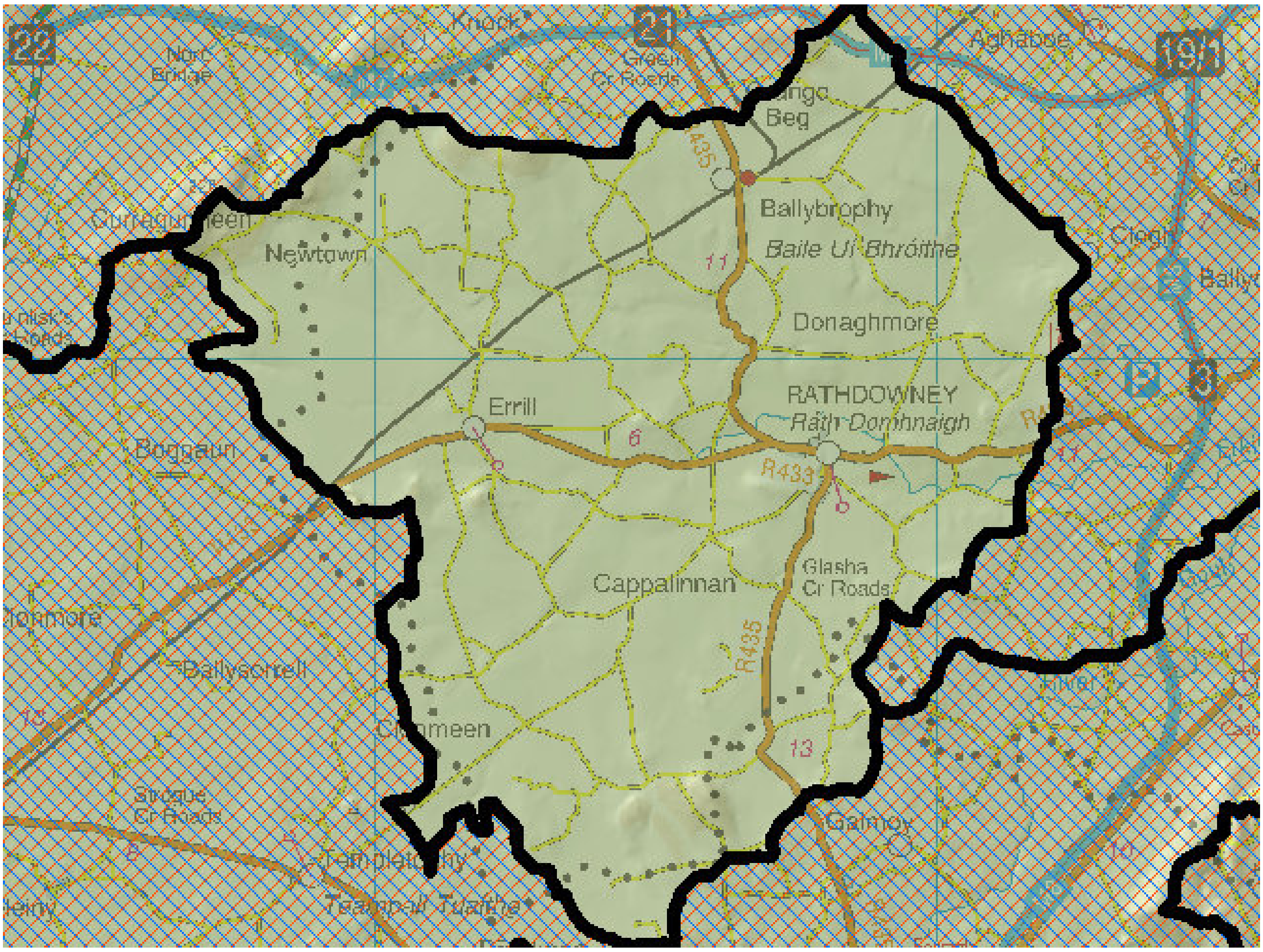
Code	Name	Action	Responsible Organisation
IE_SE_15G020060	GOUL_010	IA3 Determination of Water Quality (unassigned waterbody)	Tipperary County Council
IE_SE_15G020200	GOUL_030	IA1 Provision of Information	Environmental Protection Agency
IE_SE_15B120080	BAUNBALLINLOUGH STREAM_010	IA7 Multiple Sources in Multiple Areas	Kilkenny County Council
IE_SE_15G020300	GOUL_040	IA1 Provision of Information	Environmental Protection Agency
IE_SE_15G020500	GOUL_060	IA7 Multiple Sources in Multiple Areas	Laois County Council
IE_SE_15G020300	GOUL_040	IA7 Multiple Sources in Multiple Areas	Wexford County Council
IE_SE_15G020360	GOUL_050	IA7 Multiple Sources in Multiple Areas	Laois County Council
IE_SE_15G020110	GOUL_020	IA7 Multiple Sources in Multiple Areas	Tipperary County Council
IE_SE_15A030960	ARDREAGH_010	IA3 Determination of Water Quality (unassigned waterbody)	Tipperary County Council

WFD Cycle 2

Catchment Nore

Subcatchment Erkina_SC_010

Code 15_14



Generated on: 04 Jan 2019

Assessment Purpose

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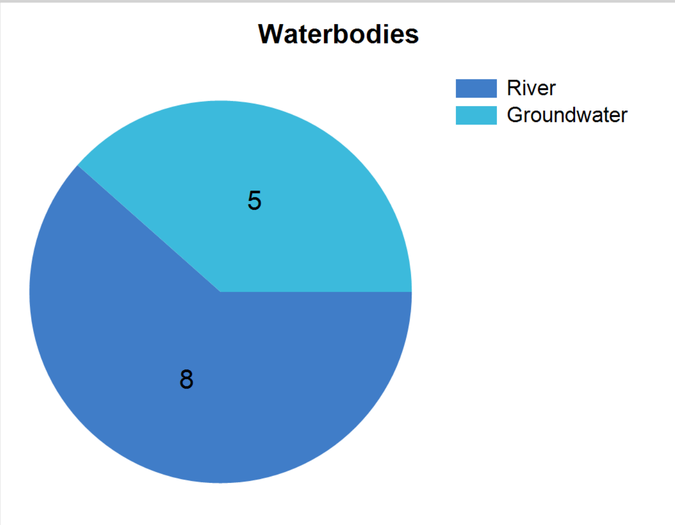
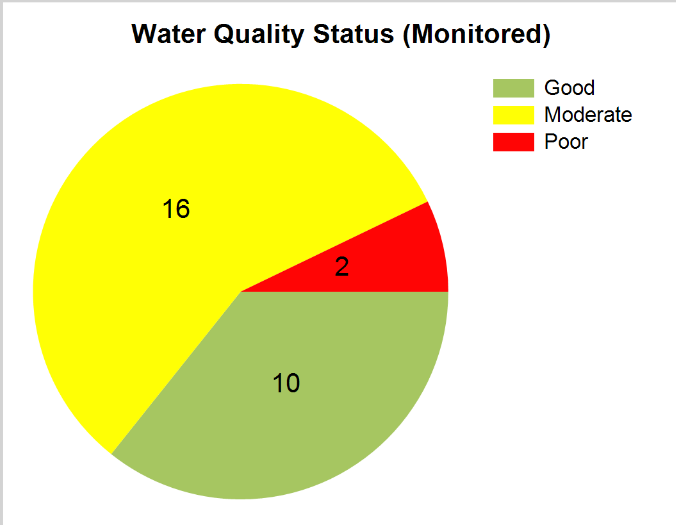
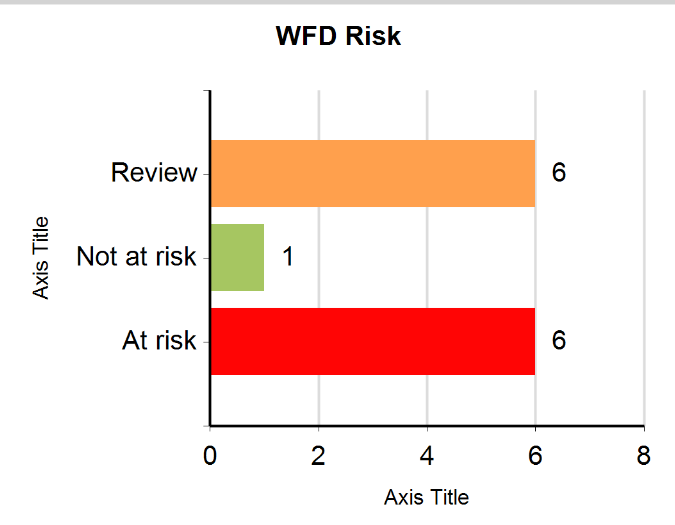






Water Quality - High Ecological Status

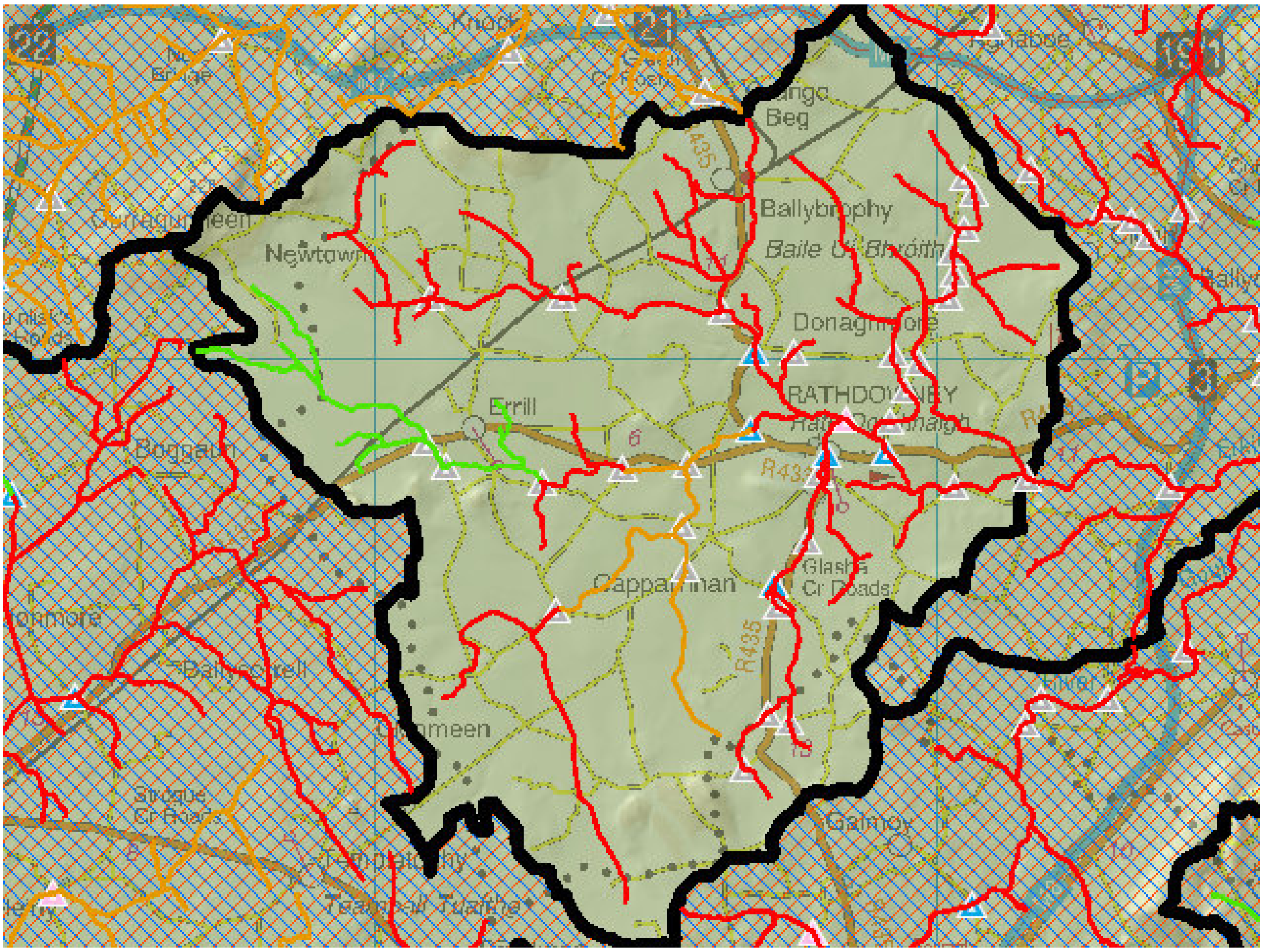
No Data Available

Evaluation of PrioritySubcatchment Issues

Six out of eight river water bodies within this subcatchment are AT RISK: Donaghmore Stream_010, Errill_020, Erkina_010 and Erkina_040 due to Moderate biological status; Erkina_030 due to Poor biological status, elevated phosphate concentrations and failing oxygenation conditions and; Rathdowney Stream_010 due to Poor biological status. Note that biology status was driven by invertebrate status. Erkina_020 is under REVIEW due to its unassigned status but elevated phosphate concentrations.

The significant pressure is unknown in Erkina_010. Agriculture (both diffuse and point) is a significant pressure Errill_020, Rathdowney Stream_010 and Donaghmore Stream_010. Waste water treatment may be a significant issue within Erkina_020. A licensed facility and waste water treatment may be impacting water quality and hence biology within Erkina_030. The pressures within this water body may also be impacting the downstream water body, Erkina_040.

Map Subcatchment Risk Map

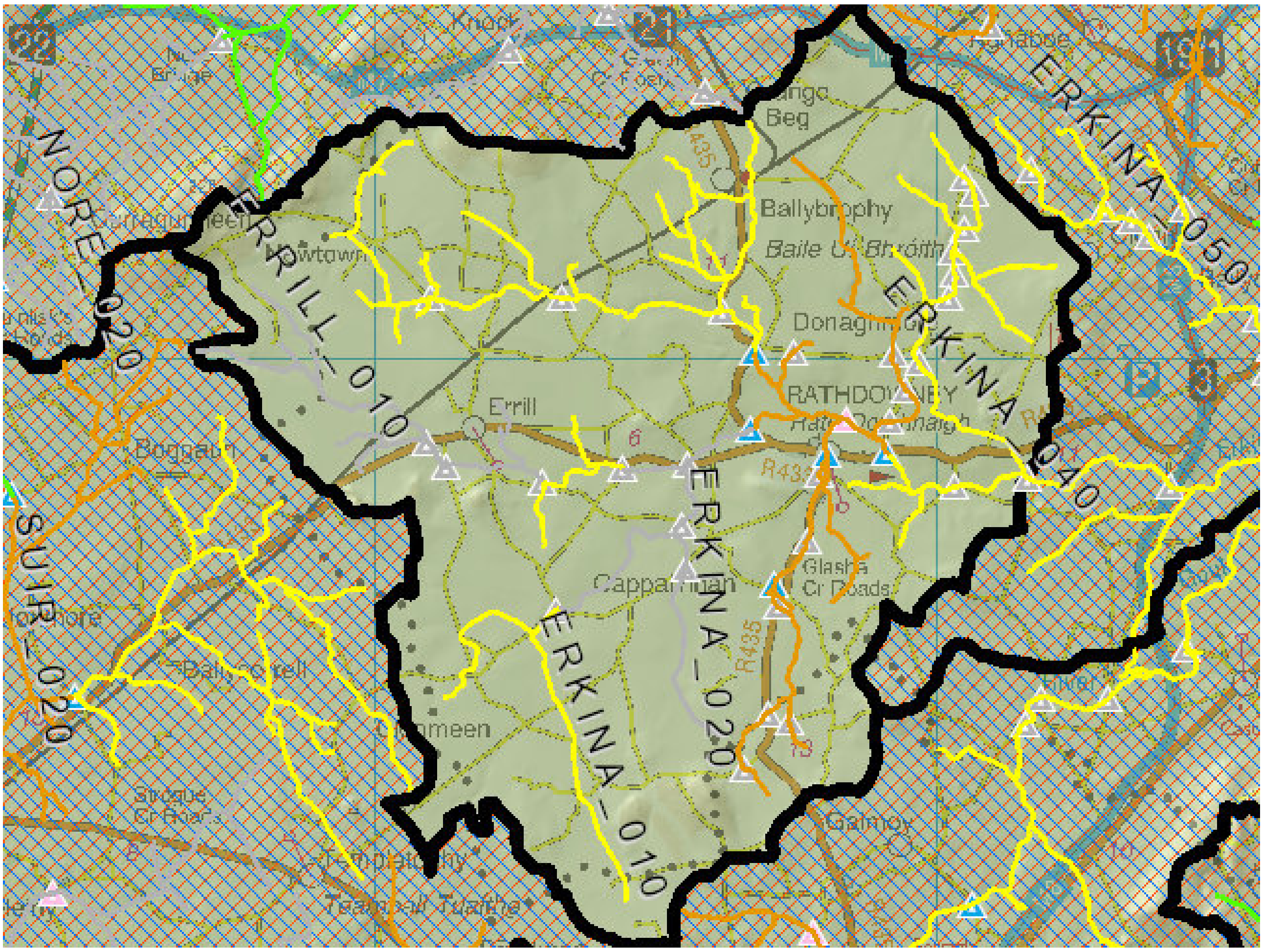


River And Lake Waterbodies: WFD Risk

The following river and lake waterbodies are in the subcatchment.

Code	Name	Type	WFD Risk	Significant Pressure
IE_SE_15D030700	DONAGHMORE STREAM_010	River	At risk	Yes
IE_SE_15E010040	ERKINA_010	River	At risk	Yes
IE_SE_15E010200	ERKINA_030	River	At risk	Yes
IE_SE_15E010300	ERKINA_040	River	At risk	Yes
IE_SE_15E030500	ERRILL_020	River	At risk	Yes
IE_SE_15R031100	RATHDOWNEY STREAM_010	River	At risk	Yes
IE_SE_15E010100	ERKINA_020	River	Review	Yes

Map Subcatchment Water Quality Status Map



River And Lake Waterbodies: Water Quality Status

The water quality status of river and lake waterbodies in the subcatchment is as follows.

Code	Name	Type	2007-09	2010-12	2010-15
IE_SE_15D030700	DONAGHMORE STREAM_010	River	Moderate	Moderate	Moderate
IE_SE_15E010040	ERKINA_010	River	Moderate	Moderate	Moderate
IE_SE_15E010100	ERKINA_020	River	Unassigned	Unassigned	Unassigned
IE_SE_15E010200	ERKINA_030	River	Moderate	Moderate	Poor
IE_SE_15E010300	ERKINA_040	River	Moderate	Moderate	Moderate
IE_SE_15E030400	ERRILL_010	River	Unassigned	Unassigned	Unassigned
IE_SE_15E030500	ERRILL_020	River	Moderate	Moderate	Moderate
IE_SE_15R031100	RATHDOWNEY STREAM_010	River	Moderate	Moderate	Poor

Potentially Dependent Transitional and Coastal Waterbodies

The Transitional and Coastal waterbodies listed below intersect spatially with river and lake waterbodies in the subcatchment …

Code	Name	Type	Local Authority	WFD Risk

Potentially Dependent Groundwater Waterbodies

The groundwaters listed below interset spatially with river and lake waterbodies in the subcatchment …

Code	Name	Type	Local Authority	WFD Risk
IE_SE_G_051	Donaghmore	Groundwater	Laois County Council	Review
IE_SE_G_114	Rathdowney	Groundwater	Laois County Council	Review
IE_SE_G_119	Shanahoe	Groundwater	Laois County Council	Review
IE_SE_G_131	Templemore	Groundwater	Tipperary County Council	Review
IE_SE_G_158	Thurles	Groundwater	Tipperary County Council	Review

Protected Areas intersecting River and Lake Waterbodies

The Protected Areas listed below intersect spatially with river and lake waterbodies in the subcatchment …

Code	Name	Type	Waterbody Name	Association Type

Pressures

Below is a list of all significant pressures identified in the subcatchment.

Code	Name	WFD Risk	Pressure Category	Pressure Sub Category
IE_SE_15D030700	DONAGHMORE STREAM_010	At risk	Agriculture	Agriculture
IE_SE_15E010040	ERKINA_010	At risk	Anthropogenic Pressures	Unknown
IE_SE_15E010200	ERKINA_030	At risk	Industry	IE
IE_SE_15E010200	ERKINA_030	At risk	Urban Waste Water	Agglomeration PE of 2,001 to 10,000
IE_SE_15E010300	ERKINA_040	At risk	Urban Waste Water	Agglomeration PE of 2,001 to 10,000
IE_SE_15E010300	ERKINA_040	At risk	Industry	IE
IE_SE_15E030500	ERRILL_020	At risk	Agriculture	Pasture
IE_SE_15R031100	RATHDOWNEY STREAM_010	At risk	Agriculture	Pasture
IE_SE_15R031100	RATHDOWNEY STREAM_010	At risk	Industry	IPC
IE_SE_15E010100	ERKINA_020	Review	Urban Waste Water	Agglomeration PE of 2,001 to 10,000
IE_SE_G_051	Donaghmore	Review	Anthropogenic Pressures	Unknown
IE_SE_G_114	Rathdowney	Review	Anthropogenic Pressures	Unknown
IE_SE_G_119	Shanahoe	Review	Anthropogenic Pressures	Unknown
IE_SE_G_131	Templemore	Review	Anthropogenic Pressures	Unknown
IE_SE_G_158	Thurles	Review	Anthropogenic Pressures	Unknown

Further Characterisation Actions

The following further characterisation actions have been identified. These are necessary to help understand more fully issues in the subcatchment and their likely cause.

Code	Name	Action	Responsible Organisation
IE_SE_15E010300	ERKINA_040	IA3 Determination of Water Quality (unassigned waterbody)	Laois County Council
IE_SE_15E010200	ERKINA_030	IA1 Provision of Information	Laois County Council
IE_SE_15E010040	ERKINA_010	IA7 Multiple Sources in Multiple Areas	Laois County Council
IE_SE_15E030500	ERRILL_020	IA7 Multiple Sources in Multiple Areas	Laois County Council
IE_SE_15D030700	DONAGHMORE STREAM_010	IA5 Multiple Sources in defined rural area (1km) or waterbody or rural town	Laois County Council
IE_SE_15R031100	RATHDOWNEY STREAM_010	IA7 Multiple Sources in Multiple Areas	Laois County Council
IE_SE_15E010100	ERKINA_020	IA1 Provision of Information	Laois County Council
IE_SE_15E010300	ERKINA_040	IA1 Provision of Information	Laois County Council

APPENDIX 8.4

Baseline Surface Water Monitoring Results

Parameter	Unit	SI No272/2009	Coadys Castle (SW2)	Coadys Castle (SW2)	Coadys Castle (SW2)	Coadys Castle (SW2)	Duggans Bridge
			03 March 2018	21 September 2020	16 November 2020	02 February 2021	07 March 2018
Physicochemical							
Average depth of surface water	m				0.212	0.22	
Surface Water Flow	m^3/sec			0.01	0.0282	0.27	
DO Lab	%	>80% to <120%		90.07	69.6		
DO Field	mg/L	>80% to <120%				86.4	
Electrical Conductivity Field	µS/cm			782	899	785	
Electrical Conductivity Lab	µS/cm		770	785	899	748	1297
pH Field	pH units	6.0< pH < 9.0		7.47	7.7	7.24	
pH Lab	pH units	6.0< pH < 9.0	7.64	8.01	8.05	7.85	7.6
Temperature Field	°C			11.2	9	7.4	
Total Dissolved Solids	mg/L			479	640	492	
Total Hardness Dissolved (as CaCO3)	mg/L		455	427	449	368	463
Total Suspended Solids	mg/L		<10	<10	<10	21	<10
Turbidity Field	NTU			0.73	0.33	86.9	
Major ions and metals							
Bicarbonate Alkalinity as CaCO3	mg/L				276	309	
Chloride	mg/L			12.5	13.5	13.4	
Dissolved Aluminium	mg/L		<0.02	<0.02	<0.02	<0.02	<0.02
Dissolved Arsenic	mg/L	0.025	<0.0025	<0.0025	<0.0025	<0.0025	0.0032
Dissolved Cadmium	mg/L		<0.0005	<0.0005	<0.00003	<0.0005	<0.0005
Dissolved Calcium	mg/L			116.5	117.5	115.4	
Dissolved Chromium	mg/L	0.0047 (Cr-III); 0.0034 (Cr-VI)		<0.0015	<0.0015	<0.0015	
Dissolved Copper	mg/L	0.03	<0.007	<0.007	<0.007	<0.007	<0.007
Dissolved Iron	mg/L		0.034	<0.02	0.044	0.068	0.024
Dissolved Lead	mg/L	0.0072	<0.005	<0.005	<0.005	<0.005	<0.005
Dissolved Magnesium	mg/L		25.5	32.4	36.9	18.9	24.7
Dissolved Manganese	mg/L			<0.002	0.023	0.037	
Dissolved Mercury	mg/L			<0.001	<0.00001	<0.001	
Dissolved Nickel	mg/L	0.02		<0.002	0.002	0.003	
Dissolved Phosphorus	mg/L			0.008	0.02	0.054	
Dissolved Potassium	mg/L		3.6	2.4	6.9	4.1	3.6
Dissolved Silicon	mg/L				2.725	1.798	
Dissolved Sodium	mg/L		11.3	5.9	24.6	8.6	9.9
Dissolved Zinc	mg/L	0.1	0.017	0.022	0.013	0.021	0.013
Fluoride	mg/L			<0.3	<0.3	<0.3	
Sulphate as SO4	mg/L		140.8	11.5	219.4	97.4	114.4
Total Alkalinity as CaCO3	mg/L		346	410	276	309	354
Miscellaneous							
Ammoniacal Nitrogen as NH3	mg/L	≤0.065 (mean) or ≤0.140 (95%ile)	0.07	0.05	0.05	0.1	0.06
Apparent Colour	mg/L PtCo			<15	79	245	
BOD (Settled)	mg/L	≤ 1.3 mean or ≤ 2.2 95%ile		<1	2	<1	
COD (Settled)	mg/L			<7	33	60	
Fats Oils and Grease	mg/L			<4	<4	<4	
Nitrate as N	mg/L		13.6	4.57	0.29	3.19	15.6
Nitrite as N	mg/L		<0.02	<0.006	<0.006	<0.006	<0.02
ORP	mV			211.4	120.4	169.2	
Total Organic Carbon	mg/L			<2	12	11	
MRP Ortho Phosphate as P	mg/L			<0.03	<0.03	<0.03	
Ortho Phosphate as PO4	mg/L		<0.06	<0.06	<0.06	0.11	0.06

Parameter	Unit	SI No272/2009	Durrow Ft Br (15005)	Durrow Ft Br (15005)	Durrow Ft Br (15005)	G01	Glasha Crossroads (nr 15042)
			21 September 2020	16 November 2020	02 February 2021	07 March 2018	03 March 2018
Physicochemical							
Average depth of surface water	m						
Surface Water Flow	m^3/sec		2.21	2.73			
DO Lab	%	>80% to <120%	94.8	76.6			
DO Field	mg/L	>80% to <120%			91.9		
Electrical Conductivity Field	µS/cm		725	711	652.2		
Electrical Conductivity Lab	µS/cm		761	709	629	647	783
pH Field	pH units	6.0< pH < 9.0	7.61	7.86	7.67		
pH Lab	pH units	6.0< pH < 9.0	8.17	8.19	8.28	7.88	7.82
Temperature Field	°C		12.2	8.5	7		
Total Dissolved Solids	mg/L		485	449	389		
Total Hardness Dissolved (as CaCO3)	mg/L		367	347	294	365	451
Total Suspended Solids	mg/L		<10	<10	<10	<10	<10
Turbidity Field	NTU		2.6	-1.23	2.55		
Major ions and metals							
Bicarbonate Alkalinity as CaCO3	mg/L			346	256		
Chloride	mg/L		25.4	20.4	18.8		
Dissolved Aluminium	mg/L		<0.02	<0.02	<0.02	<0.02	<0.02
Dissolved Arsenic	mg/L	0.025	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025
Dissolved Cadmium	mg/L		<0.0005	<0.00003	<0.0005	<0.0005	<0.0005
Dissolved Calcium	mg/L		116.4	119	100.8		
Dissolved Chromium	mg/L	0.0047 (Cr-III); 0.0034 (Cr-VI)	<0.0015	<0.0015	<0.0015		
Dissolved Copper	mg/L	0.03	<0.007	<0.007	<0.007	<0.007	<0.007
Dissolved Iron	mg/L		0.026	0.051	0.05	0.044	0.031
Dissolved Lead	mg/L	0.0072	<0.005	<0.005	<0.005	<0.005	<0.005
Dissolved Magnesium	mg/L		18.2	11.9	9.9	20.5	24.4
Dissolved Manganese	mg/L		0.007	0.007	0.005		
Dissolved Mercury	mg/L		<0.001	<0.00001	<0.001		
Dissolved Nickel	mg/L	0.02	<0.002	<0.002	<0.002		
Dissolved Phosphorus	mg/L		0.022	0.032	0.024		
Dissolved Potassium	mg/L		4.2	5	3.2	2.5	3.4
Dissolved Silicon	mg/L			2.369	1.634		
Dissolved Sodium	mg/L		12	8.5	8.3	12.1	10
Dissolved Zinc	mg/L	0.1	<0.003	0.005	<0.003	<0.003	0.034
Fluoride	mg/L		<0.3	<0.3	<0.3		
Sulphate as SO4	mg/L		23.7	29.2	20.3	19.6	79.5
Total Alkalinity as CaCO3	mg/L		350	346	263	322	372
Miscellaneous							
Ammoniacal Nitrogen as NH3	mg/L	≤0.065 (mean) or ≤0.140 (95%ile)	0.05	0.04	0.05	0.05	0.05
Apparent Colour	mg/L PtCo		32	82	68		
BOD (Settled)	mg/L	≤ 1.3 mean or ≤ 2.2 95%ile	<1	<1	2		
COD (Settled)	mg/L		<7	26	50		
Fats Oils and Grease	mg/L		<4	<4	<4		
Nitrate as N	mg/L		5.1	4.27	4.06	18.3	21.6
Nitrite as N	mg/L		0.046	0.006	0.006	<0.02	<0.02
ORP	mV		197.6	197.8	199.1		
Total Organic Carbon	mg/L		5	9	8		
MRP Ortho Phosphate as P	mg/L		<0.03	<0.03	<0.03		
Ortho Phosphate as PO4	mg/L		<0.06	<0.06	<0.06	<0.06	<0.06

Parameter	Unit	SI No272/2009	Glasha Crossroads (nr 15042)	Glasha Crossroads (nr 15042)	Glasha Crossroads (nr 15042)	Glasha Discharge (Whiteswall Stream)	Glasha Discharge (Whiteswall Stream)
			21 September 2020	16 November 2020	03 February 2021	03 March 2018	21 September 2020
Physicochemical							
Average depth of surface water	m			0.56	0.88		
Surface Water Flow	m³/sec		0.07	0.298	0.657		0.01
DO Lab	%	>80% to <120%	98.1	85.5			69.7
DO Field	mg/L	>80% to <120%			80		
Electrical Conductivity Field	µS/cm		850	882	779		1063
Electrical Conductivity Lab	µS/cm		890	878	728	925	1112
pH Field	pH units	6.0< pH < 9.0	7.95	7.79	7.45		7.41
pH Lab	pH units	6.0< pH < 9.0	8.05	8.14	8.09	7.47	7.92
Temperature Field	°C		12.8	9.4	6.9		12.3
Total Dissolved Solids	mg/L		527	580	479		767
Total Hardness Dissolved (as CaCO3)	mg/L		463	451	369	551	599
Total Suspended Solids	mg/L		<10	<10	<10	<10	<10
Turbidity Field	NTU		0.7	-1.97	6.84		33.5
Major ions and metals							
Bicarbonate Alkalinity as CaCO3	mg/L			378	314		
Chloride	mg/L		19.1	19.7	19		18.3
Dissolved Aluminium	mg/L		<0.02	<0.02	<0.02	<0.02	<0.02
Dissolved Arsenic	mg/L	0.025	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025
Dissolved Cadmium	mg/L		<0.0005	<0.00003	<0.0005	<0.0005	<0.0005
Dissolved Calcium	mg/L		134.4	141.9	117.7		175
Dissolved Chromium	mg/L	0.0047 (Cr-III); 0.0034 (Cr-VI)	<0.0015	<0.0015	<0.0015		<0.0015
Dissolved Copper	mg/L	0.03	<0.007	<0.007	<0.007	<0.007	<0.007
Dissolved Iron	mg/L		<0.02	0.035	0.051	0.102	<0.02
Dissolved Lead	mg/L	0.0072	<0.005	<0.005	<0.005	<0.005	<0.005
Dissolved Magnesium	mg/L		30.2	22.8	17.8	34	38.5
Dissolved Manganese	mg/L		0.006	0.019	0.019		0.041
Dissolved Mercury	mg/L		<0.001	<0.00001	<0.001		<0.001
Dissolved Nickel	mg/L	0.02	0.003	<0.002	0.003		0.004
Dissolved Phosphorus	mg/L		0.008	<0.005	0.047		0.008
Dissolved Potassium	mg/L		2.8	4.1	4.3	3.2	3.6
Dissolved Silicon	mg/L			2.157	1.819		
Dissolved Sodium	mg/L		9.9	9.6	8.9	11.6	11.3
Dissolved Zinc	mg/L	0.1	0.01	0.027	0.032	0.126	0.034
Fluoride	mg/L		<0.3	<0.3	<0.3		<0.3
Sulphate as SO4	mg/L		64.4	75	60.1	182.8	178.4
Total Alkalinity as CaCO3	mg/L		380	378	314	402	440
Miscellaneous							
Ammoniacal Nitrogen as NH3	mg/L	≤0.065 (mean) or ≤0.140 (95%ile)	<0.03	0.04	0.09	0.04	0.04
Apparent Colour	mg/L PtCo		<15	50	81		22
BOD (Settled)	mg/L	≤ 1.3 mean or ≤ 2.2 95%ile	<1	<1	<1		<1
COD (Settled)	mg/L		<7	26	31		<7
Fats Oils and Grease	mg/L		<4	<4	<4		<4
Nitrate as N	mg/L		5.05	5.81	4.7	11.2	1.53
Nitrite as N	mg/L		<0.006	<0.006	<0.006	<0.02	<0.006
ORP	mV		136.4	51.6	255.1		130.1
Total Organic Carbon	mg/L		4	6	8		4
MRP Ortho Phosphate as P	mg/L		<0.03	<0.03	<0.03		<0.03
Ortho Phosphate as PO4	mg/L		<0.06	<0.06	0.07	<0.06	<0.06

Parameter	Unit	SI No272/2009	Glasha Discharge (Whiteswall Stream)	Glasha Discharge (Whiteswall Stream)	Goul Discharge (SW1x)	Goul Discharge (SW1x)	Goul Discharge (SW1x)
			16 November 2020	02 February 2021	21 September 2020	16 November 2020	02 February 2021
Physicochemical							
Average depth of surface water	m		0.245	0.34			
Surface Water Flow	m³/sec		0.022	0.147	0.78	0.96	
DO Lab	%	>80% to <120%	61.4		122	75.3	
DO Field	mg/L	>80% to <120%		84.1			89.7
Electrical Conductivity Field	µS/cm		976	662.1	737	708	652.6
Electrical Conductivity Lab	µS/cm		965	643	799	708	631
pH Field	pH units	6.0< pH < 9.0	7.27	7.29	7.89	7.59	7.49
pH Lab	pH units	6.0< pH < 9.0	7.78	7.94	8.21	8	8.07
Temperature Field	°C		9.9	8.7	12.6	9.4	7.7
Total Dissolved Solids	mg/L		655	383	472	453	383
Total Hardness Dissolved (as CaCO3)	mg/L		526	305	389	362	303
Total Suspended Solids	mg/L		<10	<10	<10	<10	15
Turbidity Field	NTU		-1.83	12.5	3.03	-1.11	7.42
Major ions and metals							
Bicarbonate Alkalinity as CaCO3	mg/L		442	245		356	297
Chloride	mg/L		17.9	12.3	22	20	18.5
Dissolved Aluminium	mg/L		<0.02	<0.02	<0.02	<0.02	<0.02
Dissolved Arsenic	mg/L	0.025	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025
Dissolved Cadmium	mg/L		0.00003	<0.0005	<0.0005	<0.00003	<0.0005
Dissolved Calcium	mg/L		159.6	94.1	112.5	112.9	94.9
Dissolved Chromium	mg/L	0.0047 (Cr-III); 0.0034 (Cr-VI)	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
Dissolved Copper	mg/L	0.03	<0.007	<0.007	<0.007	<0.007	<0.007
Dissolved Iron	mg/L		0.131	0.096	<0.02	0.045	0.04
Dissolved Lead	mg/L	0.0072	<0.005	<0.005	<0.005	<0.005	<0.005
Dissolved Magnesium	mg/L		30.3	16.7	25.7	19.1	15.7
Dissolved Manganese	mg/L		0.143	0.043	0.005	0.01	0.009
Dissolved Mercury	mg/L		<0.00001	<0.001	<0.001	<0.00001	<0.001
Dissolved Nickel	mg/L	0.02	0.005	0.004	<0.002	<0.002	<0.002
Dissolved Phosphorus	mg/L		<0.005	0.015	0.016	0.029	0.043
Dissolved Potassium	mg/L		3.2	2.8	2.6	3.1	3
Dissolved Silicon	mg/L		2.261	1.521		2.187	1.897
Dissolved Sodium	mg/L		10.1	7.3	10	8.8	8.5
Dissolved Zinc	mg/L	0.1	0.085	0.063	<0.003	0.003	0.003
Fluoride	mg/L		<0.3	<0.3	<0.3	<0.3	<0.3
Sulphate as SO4	mg/L		120.7	76.9	17.1	23.6	16.3
Total Alkalinity as CaCO3	mg/L		442	245	382	356	297
Miscellaneous							
Ammoniacal Nitrogen as NH3	mg/L	≤0.065 (mean) or ≤0.140 (95%ile)	0.05	0.08	0.05	0.04	0.08
Apparent Colour	mg/L PtCo		39	98	15	61	65
BOD (Settled)	mg/L	≤ 1.3 mean or ≤ 2.2 95%ile	<1	1	<1	<1	1
COD (Settled)	mg/L		12	40	<7	30	36
Fats Oils and Grease	mg/L		<4	<4	<4	<4	<4
Nitrate as N	mg/L		1.86	1.24	5.1	5.17	4.39
Nitrite as N	mg/L		<0.006	<0.006	<0.006	<0.006	0.009
ORP	mV		81.8	103.3	194.7	151.2	175.1
Total Organic Carbon	mg/L		4	3	<2	8	4
MRP Ortho Phosphate as P	mg/L		<0.03	<0.03	<0.03	<0.03	<0.03
Ortho Phosphate as PO4	mg/L		<0.06	<0.06	<0.06	<0.06	0.09

Parameter	Unit	SI No272/2009	River Nore	River Nore	River Nore
			21 September 2020	16 November 2020	02 February 2021
Physicochemical					
Average depth of surface water	m				
Surface Water Flow	m³/sec		4.91	6.09	
DO Lab	%	>80% to <120%	93.8	84.4	
DO Field	mg/L	>80% to <120%			93.2
Electrical Conductivity Field	µS/cm		586	451.1	371.4
Electrical Conductivity Lab	µS/cm		677	454	364
pH Field	pH units	6.0< pH < 9.0	7.95	7.59	7.62
pH Lab	pH units	6.0< pH < 9.0	8.19	8.05	8.3
Temperature Field	°C		12.6	9.1	6.2
Total Dissolved Solids	mg/L		361	284	221
Total Hardness Dissolved (as CaCO3)	mg/L		302	211	155
Total Suspended Solids	mg/L		<10	<10	<10
Turbidity Field	NTU		11.4	1.08	7.42
Major ions and metals					
Bicarbonate Alkalinity as CaCO3	mg/L			198	144
Chloride	mg/L		18.8	15.9	14.1
Dissolved Aluminium	mg/L		<0.02	0.031	0.03
Dissolved Arsenic	mg/L	0.025	<0.0025	<0.0025	<0.0025
Dissolved Cadmium	mg/L		<0.0005	<0.00003	<0.0005
Dissolved Calcium	mg/L		104	75.8	55.9
Dissolved Chromium	mg/L	0.0047 (Cr-III); 0.0034 (Cr-VI)	<0.0015	<0.0015	<0.0015
Dissolved Copper	mg/L	0.03	<0.007	<0.007	<0.007
Dissolved Iron	mg/L		0.045	0.153	0.15
Dissolved Lead	mg/L	0.0072	<0.005	<0.005	<0.005
Dissolved Magnesium	mg/L		9.9	5	3.7
Dissolved Manganese	mg/L		0.038	0.019	0.016
Dissolved Mercury	mg/L		<0.001	<0.00001	<0.001
Dissolved Nickel	mg/L	0.02	<0.002	<0.002	<0.002
Dissolved Phosphorus	mg/L		0.017	0.019	0.024
Dissolved Potassium	mg/L		2.6	2.8	2.3
Dissolved Silicon	mg/L			1.799	1.47
Dissolved Sodium	mg/L		9.5	7.3	7.1
Dissolved Zinc	mg/L	0.1	<0.003	0.003	<0.003
Fluoride	mg/L		<0.3	<0.3	<0.3
Sulphate as SO4	mg/L		20.2	21.7	12.8
Total Alkalinity as CaCO3	mg/L		276	198	152
Miscellaneous					
Ammoniacal Nitrogen as NH3	mg/L	≤0.065 (mean) or ≤0.140 (95%ile)	0.04	0.09	0.08
Apparent Colour	mg/L PtCo		43	151	141
BOD (Settled)	mg/L	≤ 1.3 mean or ≤ 2.2 95%ile	<1	<1	<1
COD (Settled)	mg/L		12	34	62
Fats Oils and Grease	mg/L		<4	<4	<4
Nitrate as N	mg/L		2.28	1.84	1.67
Nitrite as N	mg/L		<0.006	<0.006	<0.006
ORP	mV		140.2	190.3	181.8
Total Organic Carbon	mg/L		4	12	10
MRP Ortho Phosphate as P	mg/L		<0.03	<0.03	<0.03
Ortho Phosphate as PO4	mg/L		<0.06	<0.06	<0.06

APPENDIX 8.5

Trial well drilling and testing programme for the GRPWS supplementary water supply

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FILE: TM05v1.0_ContingencyTrialWells.docx

TECHNICAL MEMORANDUM

DATE: 3rd July 2021

TO: Alan Buckley

FROM: James Lalor and Simon Sholl

RE: **Garrylaun Mine: Trial well drilling and testing programme for the GRPWS supplementary water supply**

1. INTRODUCTION

The Galmoy Rathdowney PWS (GRPWS) has two wells, both of which are located within the area of expected drawdown for the Garrylaun Project. Both wells were previously installed by Galmoy Mines.

WW1A is located 270 m west of the Irish Water (IW) reservoir and WW2B located 850m north of the IW reservoir (Figure 1). For IW to give their consent as part of the Garrylaun planning process, they have requested that a contingency water supply (equivalent in capacity and quality to the current GRPWS supply) is proven, outside of the predicted area of drawdown for Garrylaun.

The objective of this memorandum is to provide a factual account of the trial well drilling and testing programme. The conclusions of the programme are included in the water chapter of the environmental risk assessment report (EIAR).

2. SITE SELECTION

A desktop study was completed to identify potential drilling locations based on the hydrogeology of the area, proximity to the existing GRPWS infrastructure and the area of drawdown defined during the previous dewatering of Galmoy Mine.

The King property at Rathpatrick (the 'Rathpatrick site') was identified as the area in which to focus the trial well drilling programme for the following reasons.

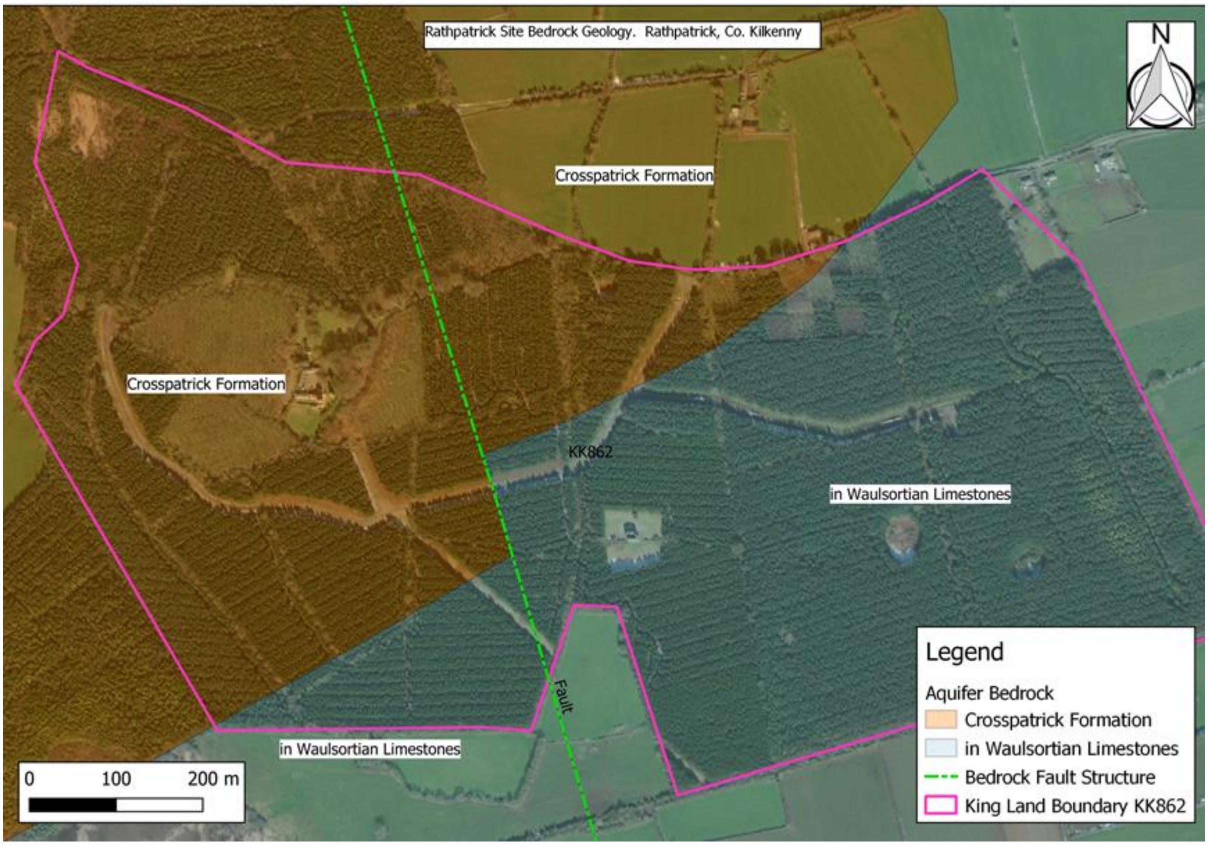
- It is located outside of the 1.5 m drawdown contour defined during Galmoy Mine's dewatering programme. Subsequent numerical modelling demonstrates that it is also predicted to be outside of the 1.5 m drawdown contour for Garrylaun dewatering. The

1.5 m contour was used because this is the typical seasonal variation for groundwater in the area.

- It is located on the same side of the mine as the GRPWS reservoir, minimising the length of any pipeline between the two locations. This reduces the impact of installing the pipeline as well as reducing the operational (head losses) and maintenance costs.
- The Rathpatrick site is currently leased to Coillte, who allowed access to their rented ground to explore for water.
- The site straddles the geological formations of Crosspatrick to the west and Waulsortian to the east and has a mapped sub vertical fault unit within it (Figure 2). The Crosspatrick Formation is classified by the Geological Survey of Ireland (GSI) as a 'Locally Important Aquifer – Bedrock which is generally moderately productive'. The Waulsortian Formation is a 'Regionally Important Aquifer – Karstified (Diffuse)'.
- The site is largely forested and covers c.70 hectares of land, which is favourable in terms of source protection restrictions, by restricting potential point and diffuse sources of contamination outside a 50 m radius from well targets.
- The water exploration rig weighs c.25 tonnes and the established roadways within the Rathpatrick site are designed and built for such traffic (and supporting vehicles), making planned water exploration work accessible, efficient and safe.
- Well maintenance and operation would be cost efficient as the wells could be drilled adjacent to the forestry roads and also be in close proximity to power lines and the public access road which also provides a piping route option.

Figure 1: GRPWS wells & reservoir in relation to the Rathpatrick site (Folio No. KK862)

Figure 2: Bedrock geology of the Rathpatrick site (from GSI)



3. CALENDAR OF EVENTS

The primary site activities undertaken as part of the trial well drilling program are outline in Table 1 below.

Table 1: Site activities completed at the Rathpatrick site

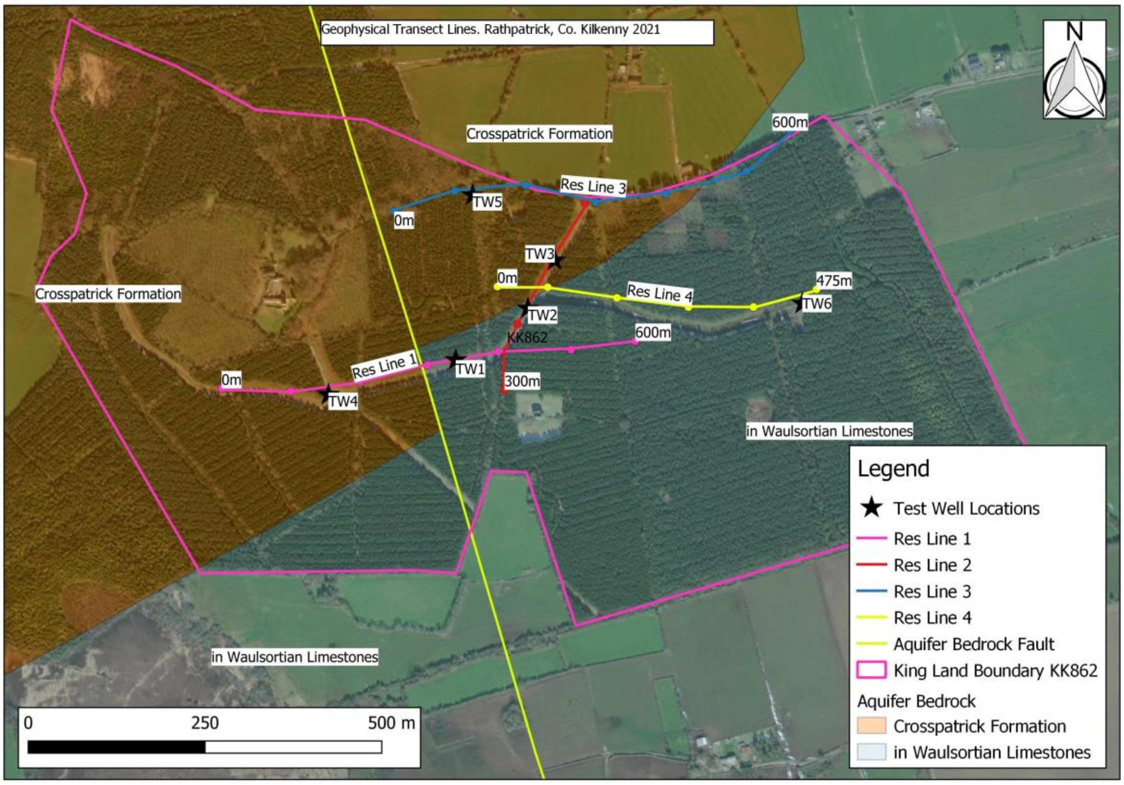
Date	Action	Comment
Nov-20	Rathpatrick site identified	Coillte site 2 km southwest of IW reservoir.
Nov-20	First Resistivity Survey	Two transects run, Transect 1, 600 m west to east; Transect 2, 300 m north to south.
Dec-20	Permission to Access Land	Permission granted by J. King to access land (rented to Coillte)
Mar-21	Establish comms with Coillte	Permission granted by Coillte to explore the site. Fogarty drilling completes induction on March 8th 2021.
11-Mar-21	TW01 Complete	Drilled to 39 mbgl. Drilling stopped due to excessive sedimentation and cavitation around borehole.
19-Mar-21	TW02 Complete	Drilled to 30 mbgl. Drilling stopped due to excessive sedimentation and cavitation around borehole.
17-Mar-21	TW03 Complete	Drilled to 92mgl. Drilling stopped due water ingress at 40.8 to 47.5m , depth and borehole collapsing.
24-Mar-21	TW04 Complete	Drilled to 142 mbgl. Drilling stopped due to insufficient water, <2 L/s
12-Apr-21	Step Test and CRT on TW03 complete.	TW3 was the only well feasible after initial drilling exploration work, pumped at 50 m³/hr for 4 days.
27-Apr-21	Second Resistivity Survey	Two transects run, Transect 3, 600 m west to east; Transect 4, 475 m west to east.
13-May-21	TW05 Complete	Drilled to 37 mbgl. Drilling stopped due to excessive sedimentation and cavitation around borehole.
22-May-21	TW06 Complete	Drilled to 92 mbgl. Drilling stopped due to discreet water ingress between 84 to 86 m.
02-Jun-21	TW06 Step Test Complete	TW6 step tested at increments of 20, 30 and 40 m³/ hr
03-Jun-21	CRT at TW03 and TW06	Each well to be pumped at 35 m³/hr for 7 days.

4. GEOPHYSICAL SURVEY

Two geophysical surveys were undertaken at the Rathpatrick site, using the existing road infrastructure as transect corridors. Electrical Resistivity Imagery (ERI) surveys, referred to as ‘res lines’, were completed by Golder Associates. Res Lines 1 and 2 were surveyed in November 2020; and Res Lines 3 and 4 in April 2021. Locations of the surveys can be seen in Figure 3 below which also includes trial well locations and geology of the site.

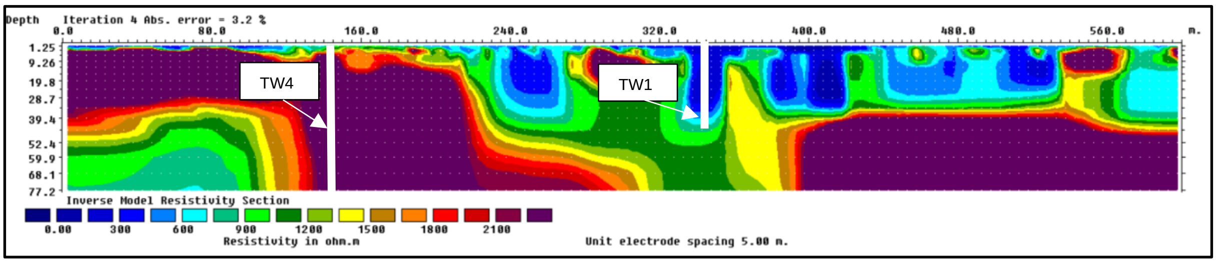
The four res line sections are described below with reference to the trial wells drilled along the transects. Full details of the trial well drilling are provided in Section 5.

Figure 3: ERI transect lines and trial well locations



Trial wells TW01 and TW04 were sited on Res Line 1 as indicated in Figure 4 running west to east in orientation. TW01 targeted a sub vertical fault feature, while TW04 aimed to intersect the contact between the Crosspatrick and Waulsortian formations at depth.

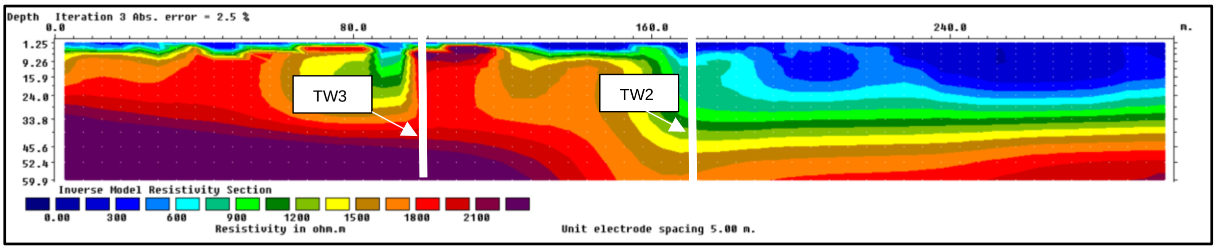
Figure 4: Res Line 1 and associated trial wells



Trial wells TW02 and TW03 were sited on Res Line 2 as indicated in Figure 5, running north to south in orientation. TW02 targeted a potential sub-horizontal feature (possible epikarst) up to 50 m below ground level. TW03 aimed to intersect the contact between the Crosspatrick and Waulsortian formations.

Poor ground conditions were encountered when drilling TW01, TW02 and TW03 including cavitation around TW01 and TW02 due to outwash of sediment. TW03 ground conditions improved with depth, yielding clean water following development.

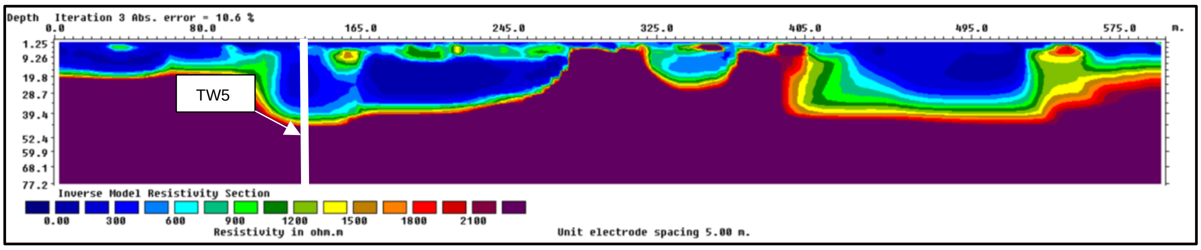
Figure 5: Res Line 2 and associated trial wells



A second round of geophysical surveying was undertaken on 27th April 2021. This involved surveying two more transects, Res Line 3 and Res Line 4 from west to east in orientation using existing roadways as survey routes and allowing both transect lines to intersect Res Line 2.

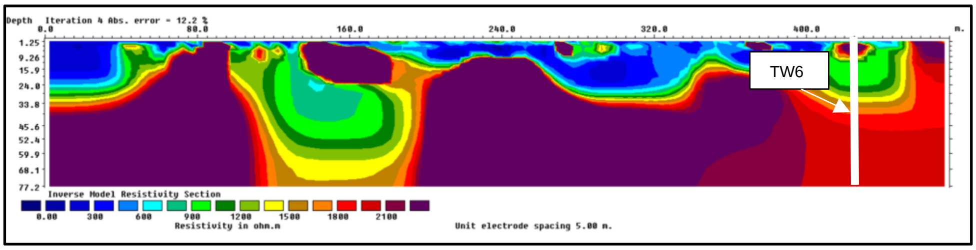
TW05 located on Res Line 3 (Figure 6) attempted to intercept the contact of the Crosspatrick and Waulsortian at lower elevations to that of TW03 and TW02. The ground conditions however where not conducive to either good drilling or favourable hydrogeological formation and the hole had to be abandoned.

Figure 6: Res Line 3 and associated trial well



TW06 located on Res Line 4 was targeting the Waulsortian Formation in an attempt to move away from the challenging ground conditions encountered at TW01 to TW03 and TW05. The geology at the location of TW06 was very competent, yielding very little water until 88mbgl when a clean, discreet, water bearing fracture was encountered.

Figure 7: Res Line 4 and associated trial well

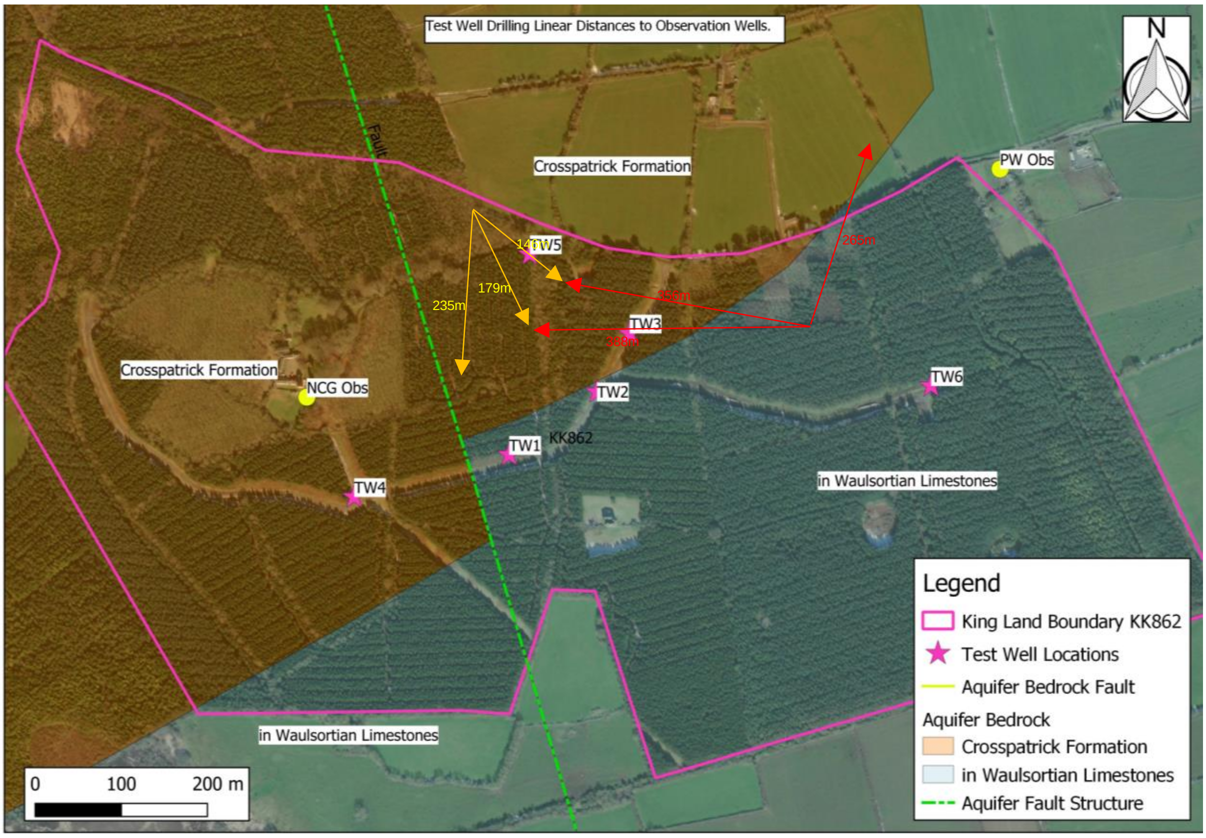


5. TRIAL WELL DRILLING

Drilling was undertaken by Fogarty Drilling Ltd, Gowran, Co. Kilkenny using conventional rotary percussion method. Drilling was undertaken at six locations on the site in two phases as described in Section 4 above. Four wells were drilled between 10th and 24th March following the first round of geophysical surveying. Two further wells were drilled between 6th May and 22nd May following the second round of geophysical surveying. The well locations can be seen in Figure 8 and detailed well logs in Appendix 1.

The poor drilling conditions encountered while drilling identified the highly weathered and highly localised nature of the upper 30 to 50 m of both the Waulsortian and Crosspatrick formations at the Rathpatrick site. Monitoring of water levels in the wells as drilling continued also showed the high degree of connectivity of the shallow (<30 m) groundwater across the site.

Figure 8: Trial well locations (arrows indicate distances between some wells



6. STEP TESTS

6.1. Overview

Pumping step tests were conducted on two of the six wells drilled at the Rathpatrick site (TW03 and TW06) by TQ Electrical Engineering, Thurles. The objective of the step tests was to estimate well efficiency and to identify a potential yield for the longer duration Constant Rate Tests (CRT).

6.2. TW03

Two step tests were performed on TW03. The first step test was completed on 1st April 2021 and the second 'extended step test' on 6th April 2021. The well was tested based on a final blow yield following drilling indicating that the well had estimated potential of 47 m³/hr. The first step test flow rates and corresponding drawn of the borehole water level can be seen in Table 2.

Table 2: TW03 first step test drawdown and abstraction rate

Step	Drawdown (Sw)	Abstraction Rate (Q)
Units	**(m)**	**(m³/hr)**
Step 1	11.86	27
Step 2	15.46	30
Step 3	19.03	35
Step 4	24.02	40

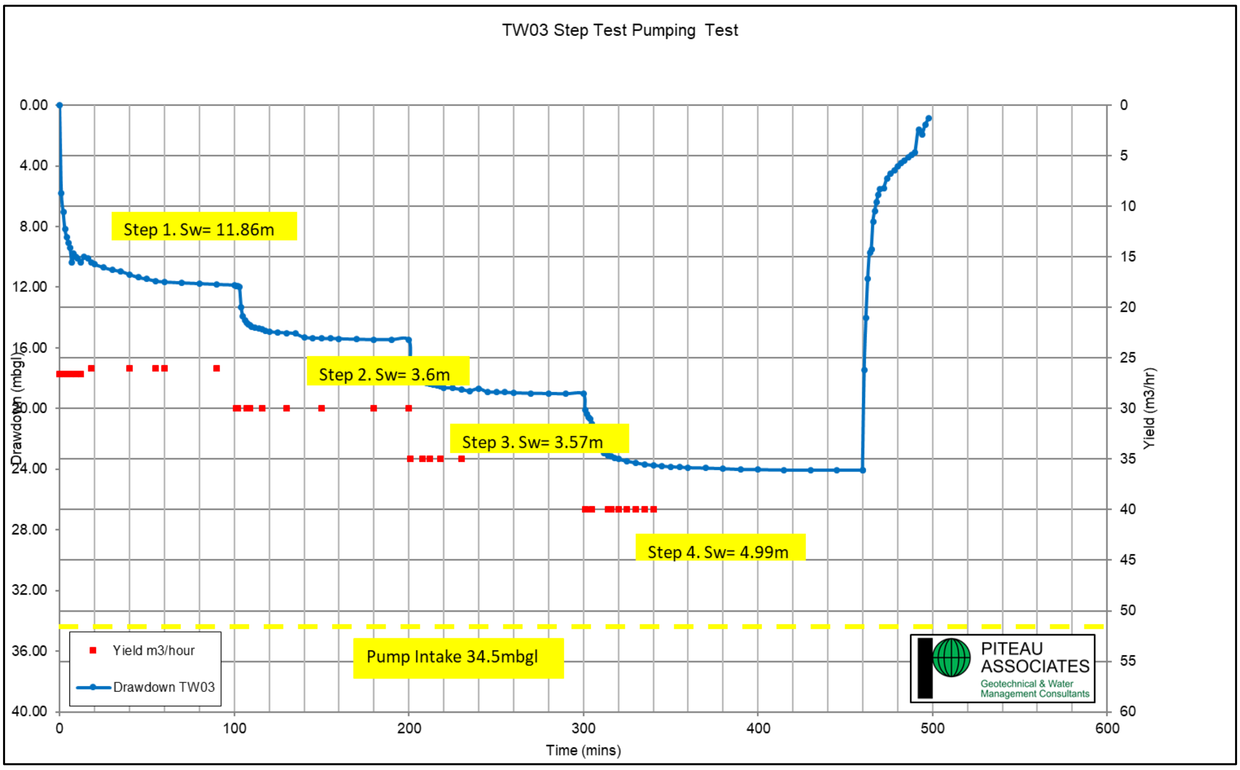
A graph representing the data collected for the step test is shown in Figure 9. Steady state conditions were achieved at the end of each step. The well is calculated to be pumping at 70% efficiency which is considered good. Over 95% recovery occurred within 45 minutes of ending the test.

On 6th of April, an extended step test was undertaken at TW03: a step test followed by a CRT. The steps were used to determine whether the abstraction rate could be increased above the 40 m³/hr of the final step in the first test. The test involved initially four 100 minute steps using discharge rates of 40, 45, 50 and 55 m³/hr, then allowing the fourth step to run for a planned 7,200 minutes (120 Hours), as shown in Figure 11. However, the final pumping rate of 55 m³/hr was not sustainable and after 77.5 hours of pumping, a water sample was collected for analysis and pumping terminated.

Drawdown observed in TW02 was just over 1 m at the end of the CRT and nearly 40 cm in NCG Obs (Figure 12).

The results of the water quality sample are discussed in Section 10.

Figure 9: TW03 first step test drawdown against abstraction rate



Monitoring of TW02 and NCG Obs (a domestic well, see Figure8) showed limited drawdown (< 20 cm) impact during the first step test, as shown in Figure 10.

Figure 10: Monitoring well water levels during the TW03 first step test

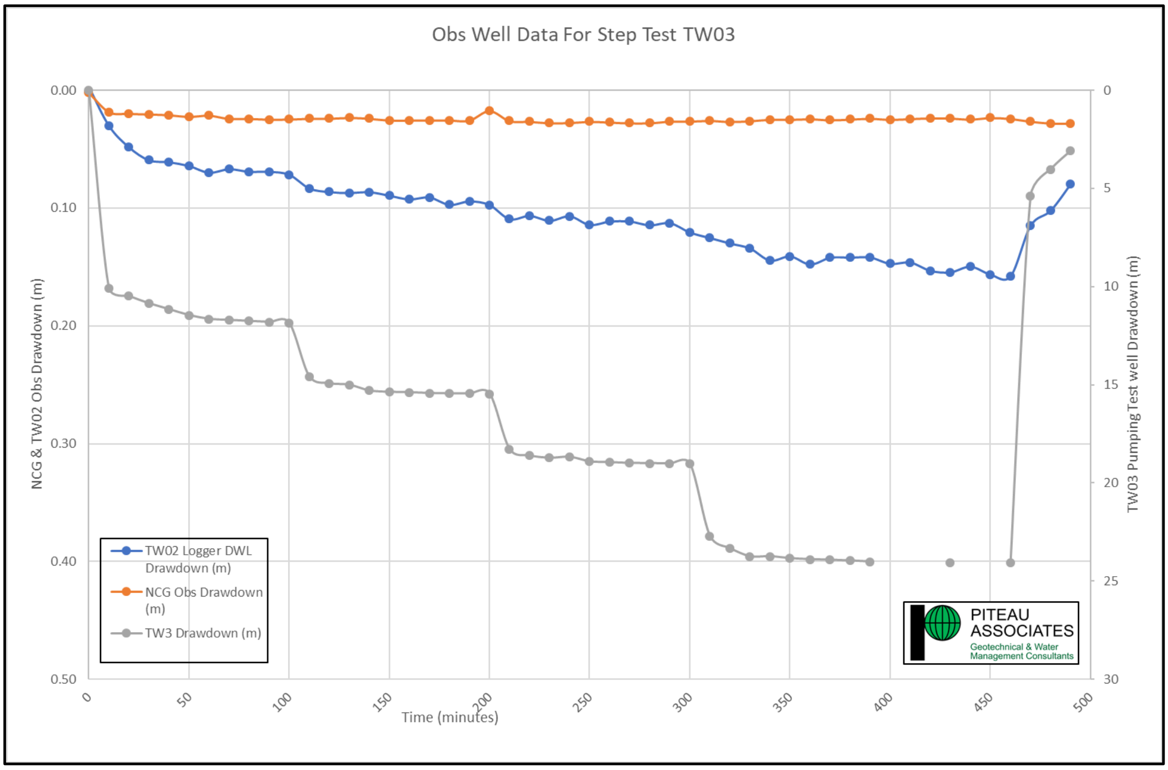


Figure 11: TW03 extended step test drawdown against abstraction rate

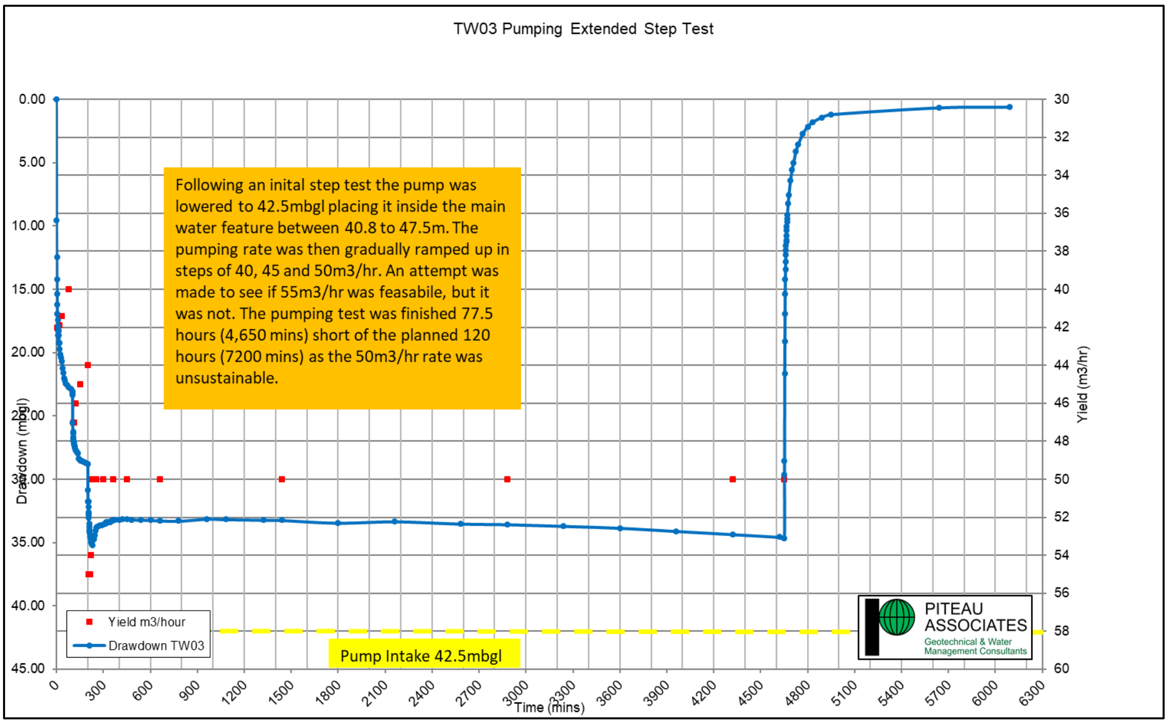
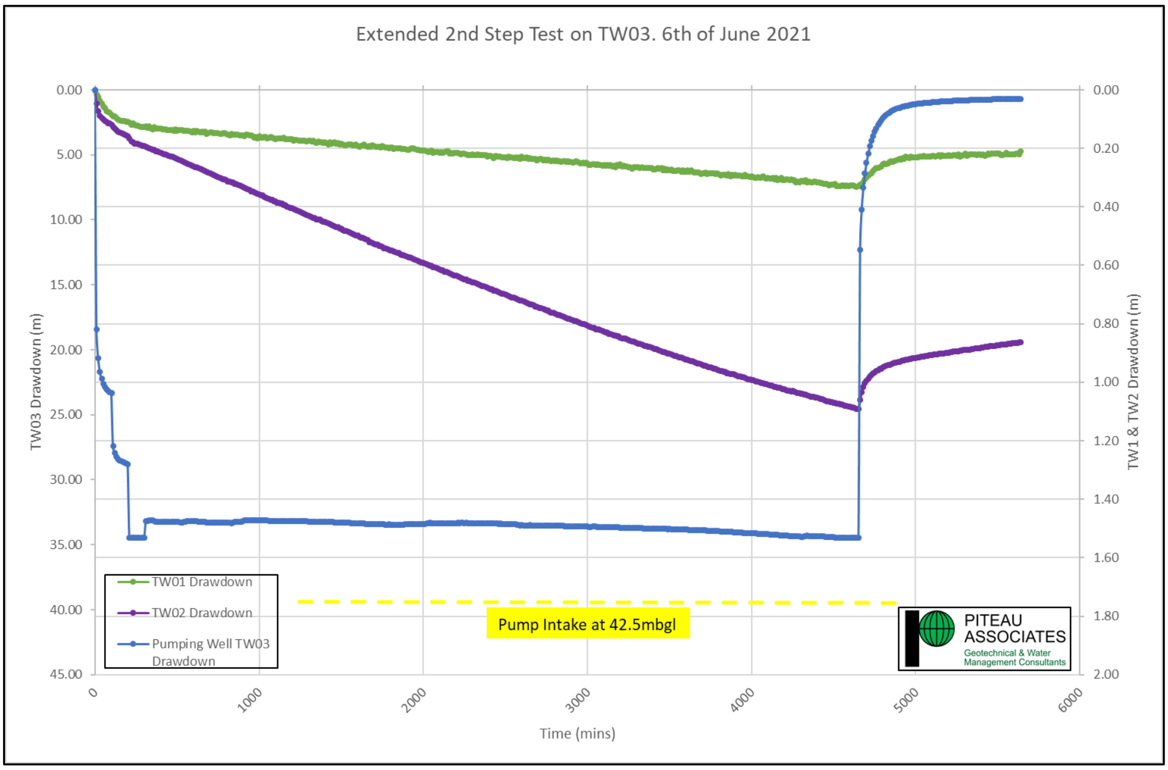


Figure 12: Monitoring well water levels during the TW03 extended step test



6.3. TW06

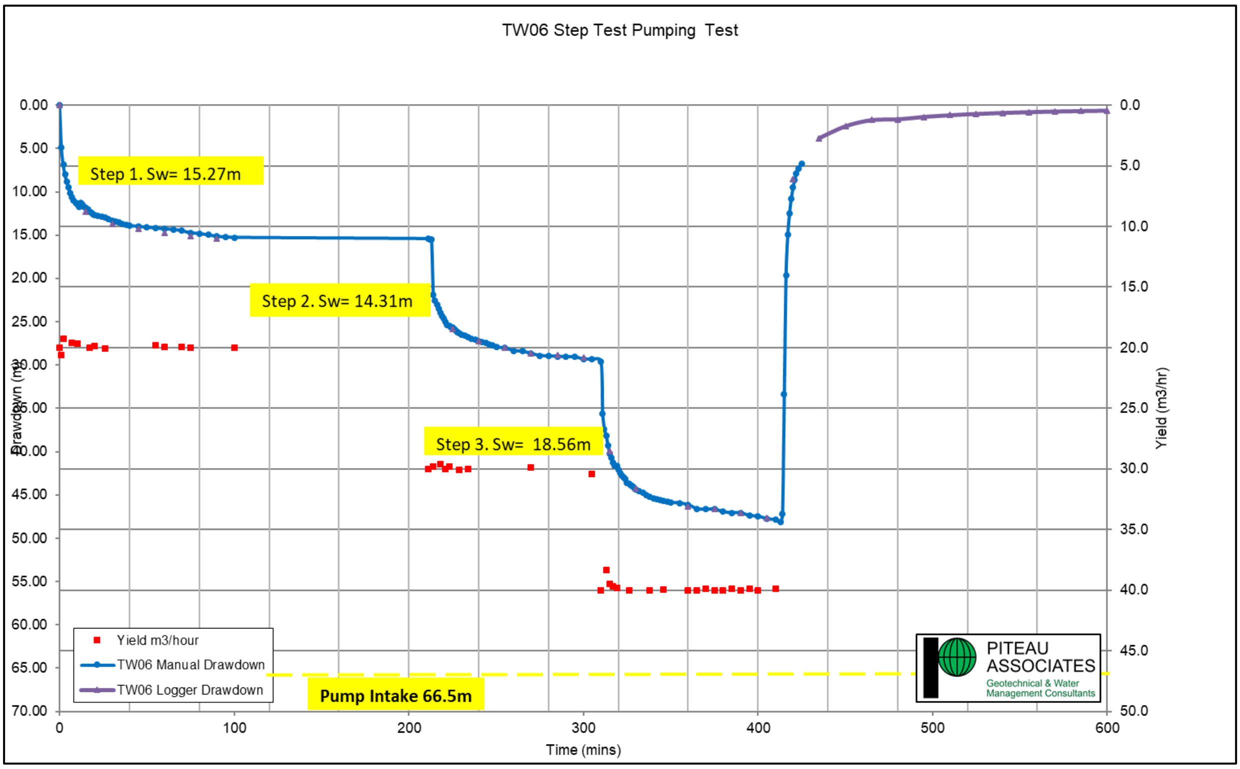
A step test was completed at TW06 on 1st June 2021. The well was tested based on an estimated final yield following drilling indicating that the well had a potential of between 40 to 50 m³/hr. A blow yield test was not possible due to the orientation of the borehole to the side of the drilling pad and a deep drain. Only three steps were possible at this well owing to the generator having mechanical issues and a delayed start. The step flow rates and corresponding drawdown of the borehole water level can be seen in Table 3 below.

Table 3: TW06 step test drawdown and abstraction rate

Step	Drawdown (Sw)	Abstraction Rate (Q)
Units	**(m)**	**(m³/hr)**
Step 1	15.27	20
Step 2	29.58	30
Step 3	48.14	40

Figure 13 shows that steady state conditions were achieved at the end of the first step. Water levels were continuing to fall at the end of the second and third steps. The well is calculated to be pumping at 58% efficiency which is considered reasonably good. Over 95% recovery occurred within the first 45 minutes.

Figure 13: TW06 step test drawdown against abstraction rate



7. CONSTANT RATE TESTS

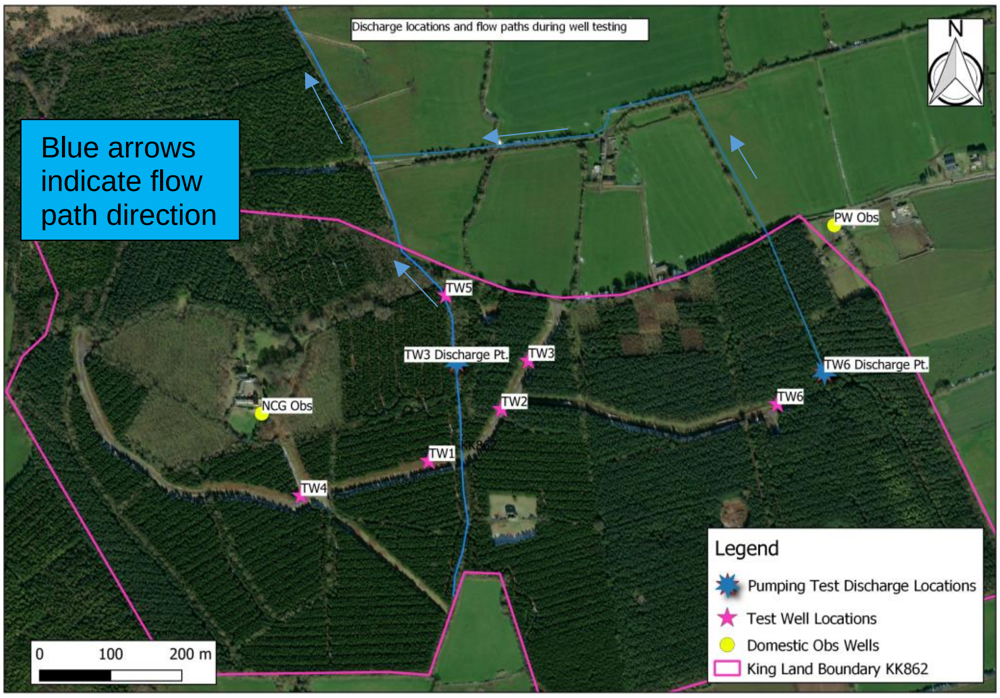
7.1. Overview

Simultaneous pumping tests were carried out on TW03 and TW06 starting on 3rd June 2021. Each well was pumped at 35 m³/hr, giving a combined output of 70 m³/hr.

The remaining four trial wells were used as observations wells for the duration of the test, as well as two domestic wells. During the step tests and the constant rate tests, water discharge was pumped into established watercourse drains in the forestry area that flow into the Erkina river.

TW06 had a discharge distance of 82m downgradient from the trial well to the watercourse; TW03 had a distance of 103m (Figure 14).

Figure 14: Discharge locations for TW03 and TW06



Test on both wells were affected by generator breakdowns during the testing cycle. The generator broke down at TW06 on Saturday 5th June at 03:30 and Sunday 6th June at 07:30. The generator broke down on TW03 on Friday 11th June at 14:36.

7.2. TW03

The CRT commenced at 11:00 hrs on 3rd June 2021 to Friday 11th June at 14:36. The pump at TW03 was an 18 kW pump running at 32Hz; which is 64% of its full capacity. The test was terminated prematurely due to generator breakdown. However, the planned termination time was only 24 minutes later at 15:00 the same day.

The test was operational for 11,736 minutes (8 days, 5 hours and 36 minutes). Total drawdown at the end of the test was 23.17m (Figure 15), with a final water level of 28.96mbgl. Pump intake was 42.5mbgl, resulting in a further available drawdown of 11m. The drawdown increased by 0.1m from 23:00 on 10th June to the pumping discharge termination of the test at 14:36 on 11th June. The pumping rate remained consistently at 35 m³/hr for the duration of the test.

Physiochemical water quality readings were recorded throughout the test using an Insitu AquaTROLL 500 multi probe and will be discussed in the Section 10 (water quality).

The log linear graph of the CRT for TW03 (Figure 16) shows the continued reduction in drawdown over time, even at the end of the test. This can be extrapolated to indicate that continued pumping at 35 m³/hr for 70 days (100,000 minutes) would result in 26m of drawdown, an increase in drawdown of 2.8m compared to the end of the CRT.

Figure 15: TW03 constant rate test drawdown against abstraction rate

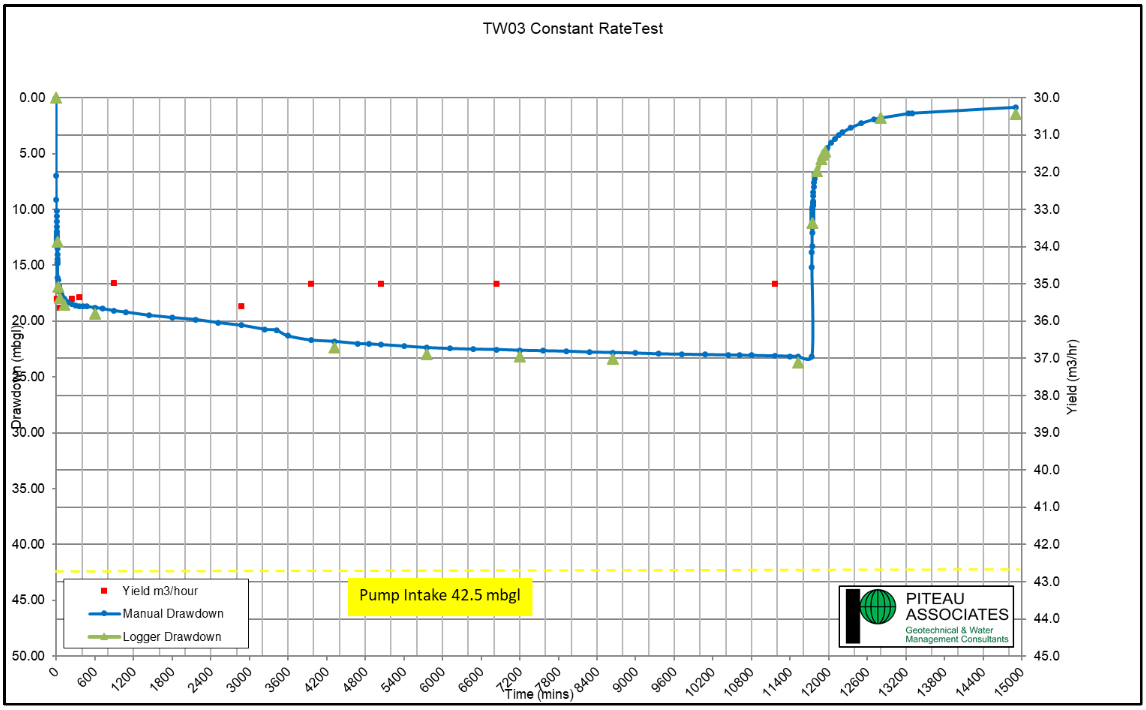
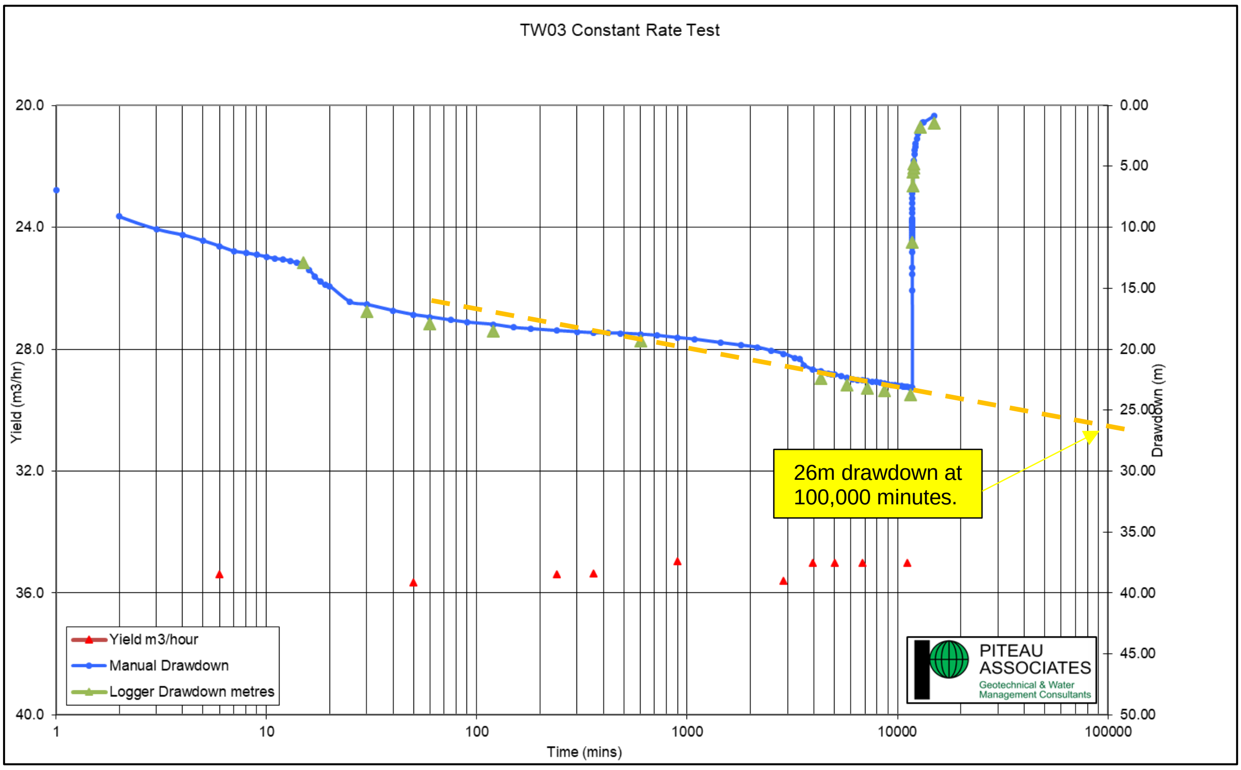


Figure 16: TW03 constant rate test log-linear drawdown over time



7.3. TW06

TW06 CRT commenced at 10:00 hrs on 3rd June 2021 until Friday 11th June at 16:30. The pump at TW06 was a 22kW pump running at 36Hz; which is 72% of its full capacity. The test was hampered by two breakdowns on the 5th and 6th of June, but pumping resumed quickly to a steady drawdown level.

The test was operational for 11,910 minutes (8 days, 6 hours and 30 minutes). Total drawdown was 45.73m at the end of the test (Figure 17), with a final water level of 50.82mbgl. Pump intake was 66.5mbgl, resulting in 10m of available drawdown at the end of the test. The drawdown increased by 0.03m between 23:00 on 10th June and 16:30 on 11th June when pumping was terminated. The pumping rate remained consistently at 35 m³/hr for the duration of the test.

Physiochemical water quality readings were recorded throughout the test using a Insitu AquaTROLL 500 multi probe and will be discussed in Section 10 (water quality).

The log linear graph of the CRT for TW06 (Figure 18) shows the continued reduction in drawdown over time, even at the end of the test. This can be extrapolated to indicate that continued pumping at 35 m³/hr for 70 days (100,000 minutes) would result in 46.5m of drawdown, an increase in drawdown of 0.8m compared to the end of the CRT.

Figure 17: TW06 constant rate test drawdown against abstraction rate

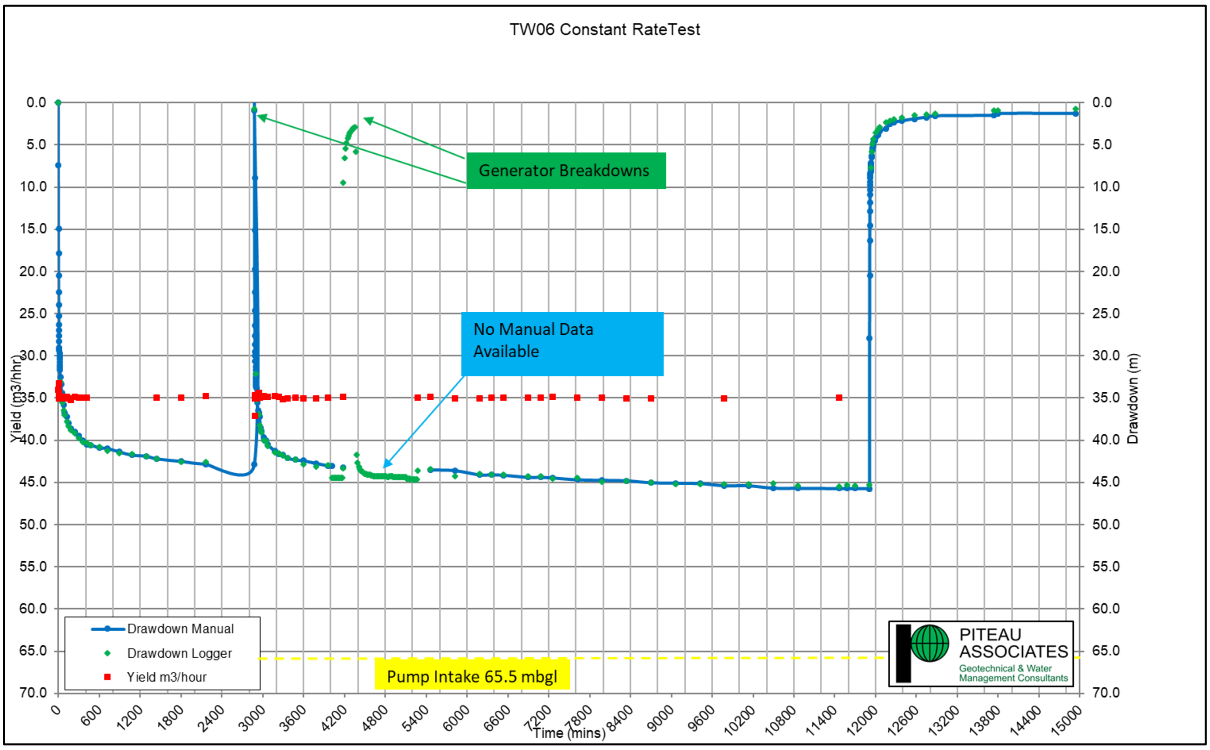
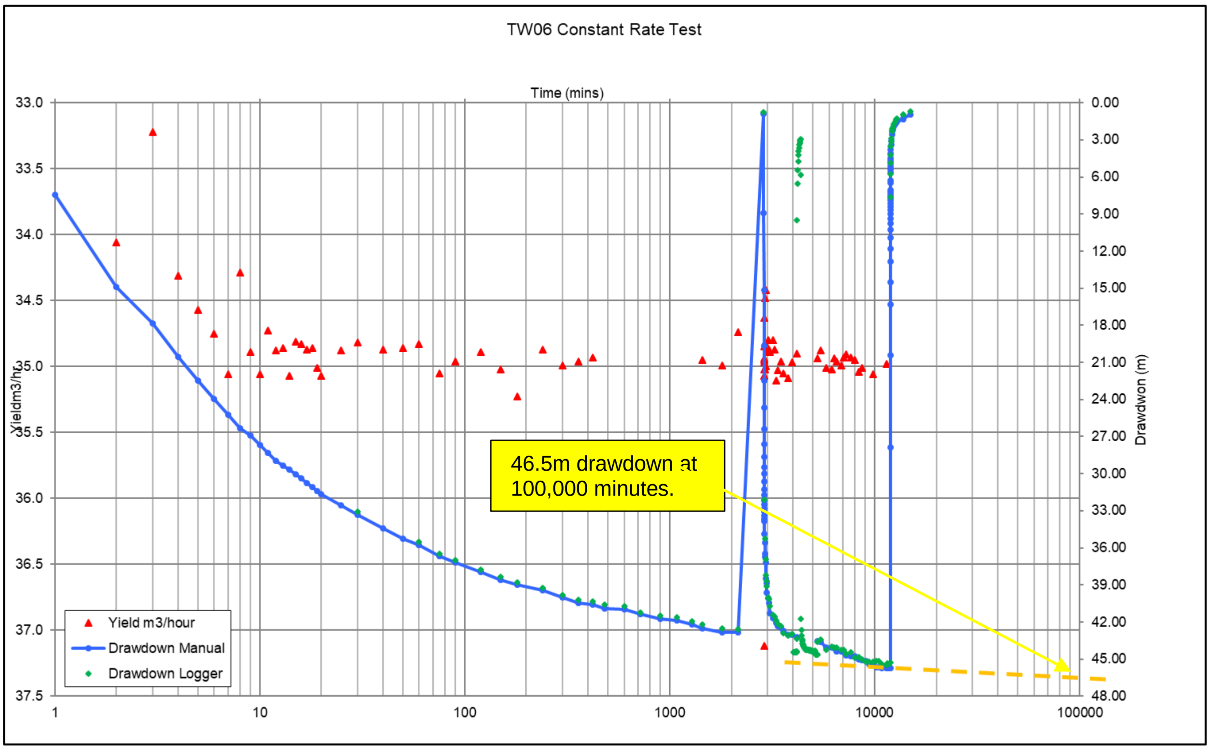


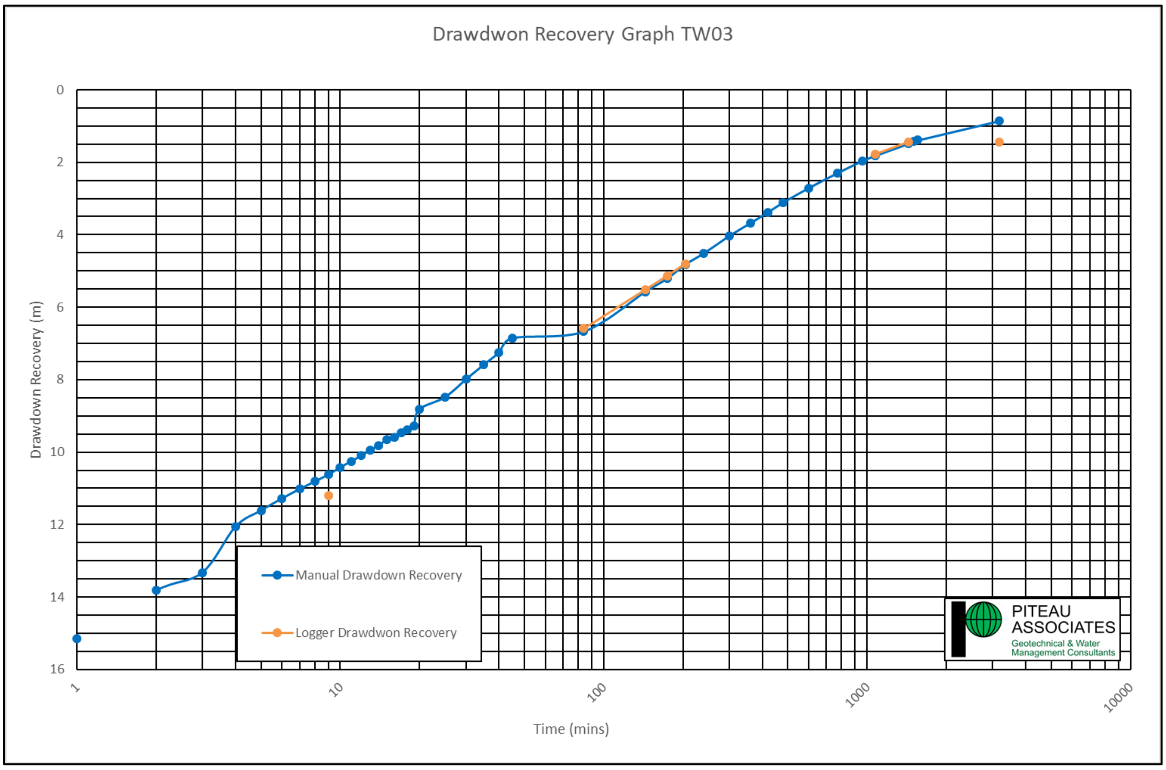
Figure 18: TW06 constant rate test log-linear drawdown over time



8. RECOVERY TESTS

The recovery of TW03 commenced at 14:36 on 11th June 2021. The drawdown had recovered 87% after 24 hours' recovery from a SWL of 5.79 mbgl at 11:00 on the 3rd June 2021 when testing began (Figure 19).

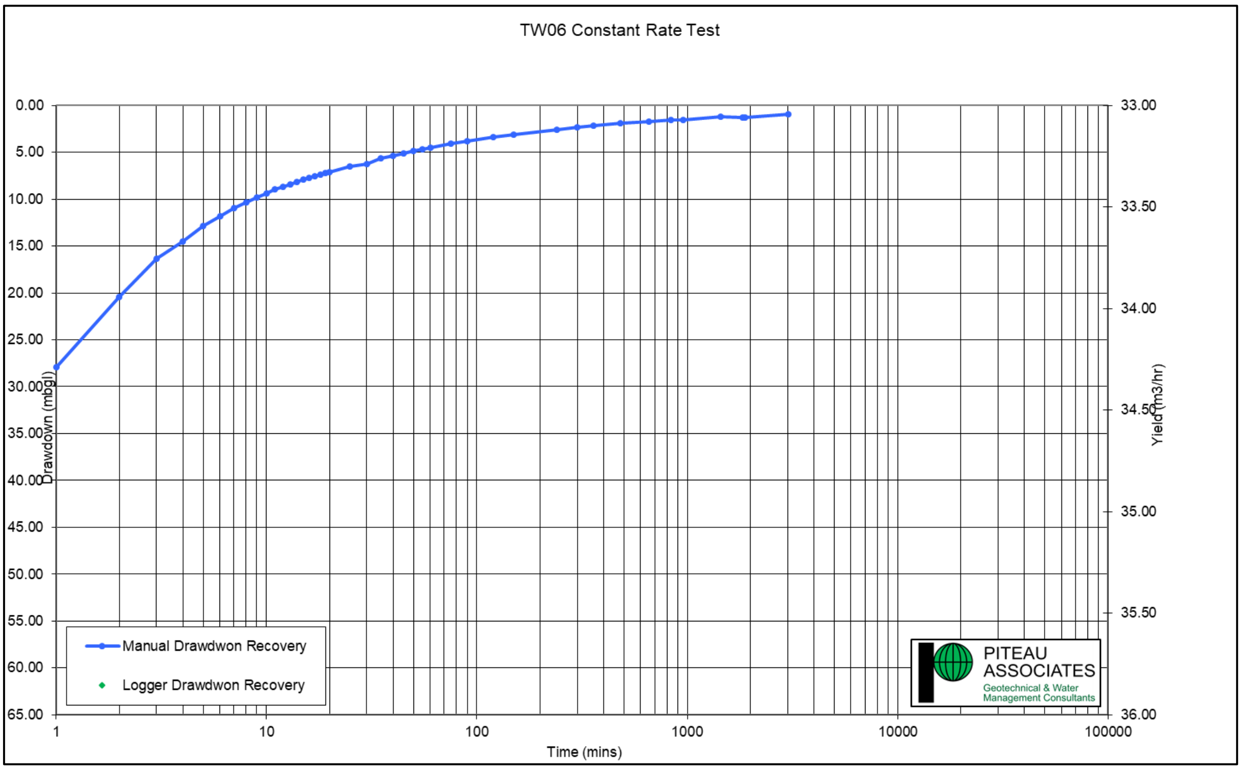
Figure 19: TW03 recovery test log-linear drawdown over time



The recovery of TW06 commenced at 16:30 on 11th June 2021. The drawdown had recovered 76% after 24 hours' recovery from a SWL of 5.09 mbgl at 10:00 on 3rd June 2021 when testing began (Figure 20).

The recovery test results show that both boreholes were pumping sustained inflows as opposed to groundwater storage. However, TW06 showed a reduction in recovery rate over time indicating some loss to storage.

Figure 20: TW06 recovery test log-linear drawdown over time



9. OBSERVATION WELL DISCUSSION

Observation well behaviour is important in the assessment of drilling and aquifer impact. Monitoring well behaviour indicates wider aquifer behavioural characteristics and contributes data for more in depth aquifer analysis.

Step test data from TW06, indicates that pumping did not induce a drawdown response in TW03 (Figure 21). This may be due to the distance between TW06 and TW03, or because the two wells are drilled into unconnected (poorly connected) groundwater units.

During the simultaneous pumping test of TW03 and TW06, the remaining four trial wells were used as observation wells along with two domestic wells as shown in Figure 14 and Table 4.

Table 4: Domestic wells used for observation of the simultaneous test

Name	X	Y	Status	Depth	Age	Hydrogeological Formation	Owner
NCG Obs	624129	670641	Pump Active	N/A	N/A	Crosspatrick	Nigel Croft Greene
PW Obs	624934	670906	Pump Active	N/A	N/A	Waulsortian	Paul Webster

The drawdown induced by the CRT on all monitoring wells is less than 2.5 m, as presented in Figure 22 below. PW Obs located in the Waulsortian Formation has a very contrasting behavioural pattern to that of all the other observation wells located in the on the mapped edge of the Crosspatrick Formation and within it. This is primarily because PW Obs is also an abstraction well so the monitoring data show both pumping and non-pumping levels. The greatest drawdown is seen in TW02 due to its proximity to TW03.

Figure 21: Monitoring well water levels during the TW06 step test

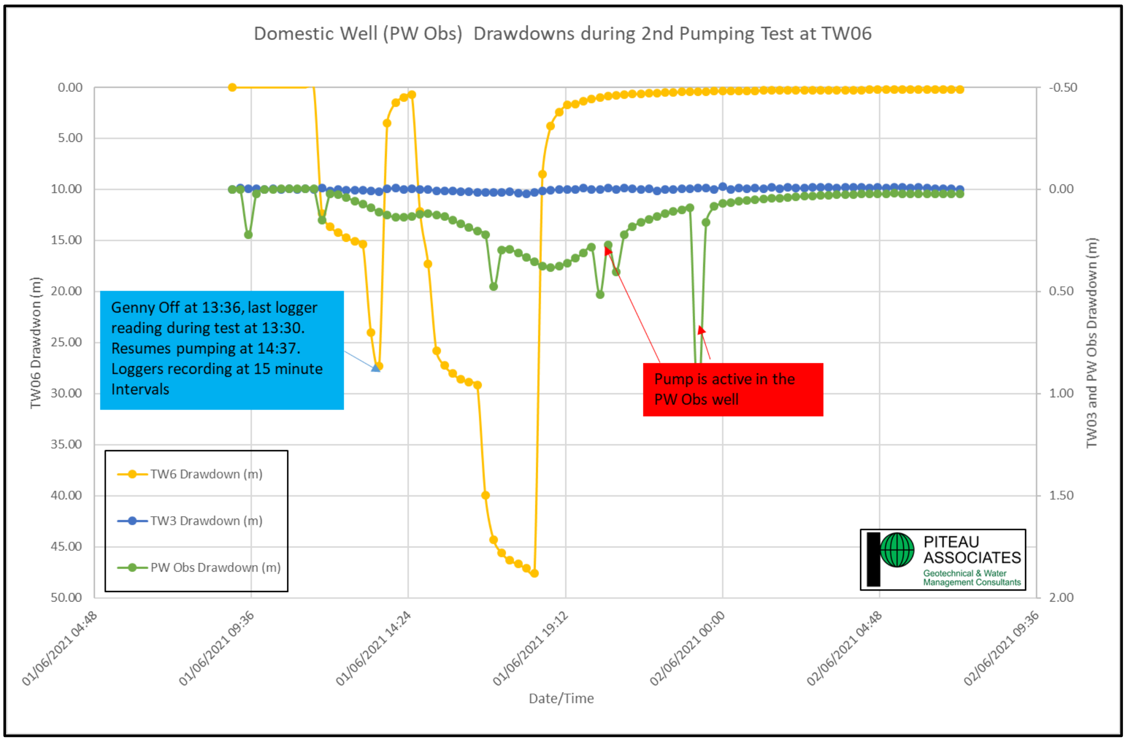
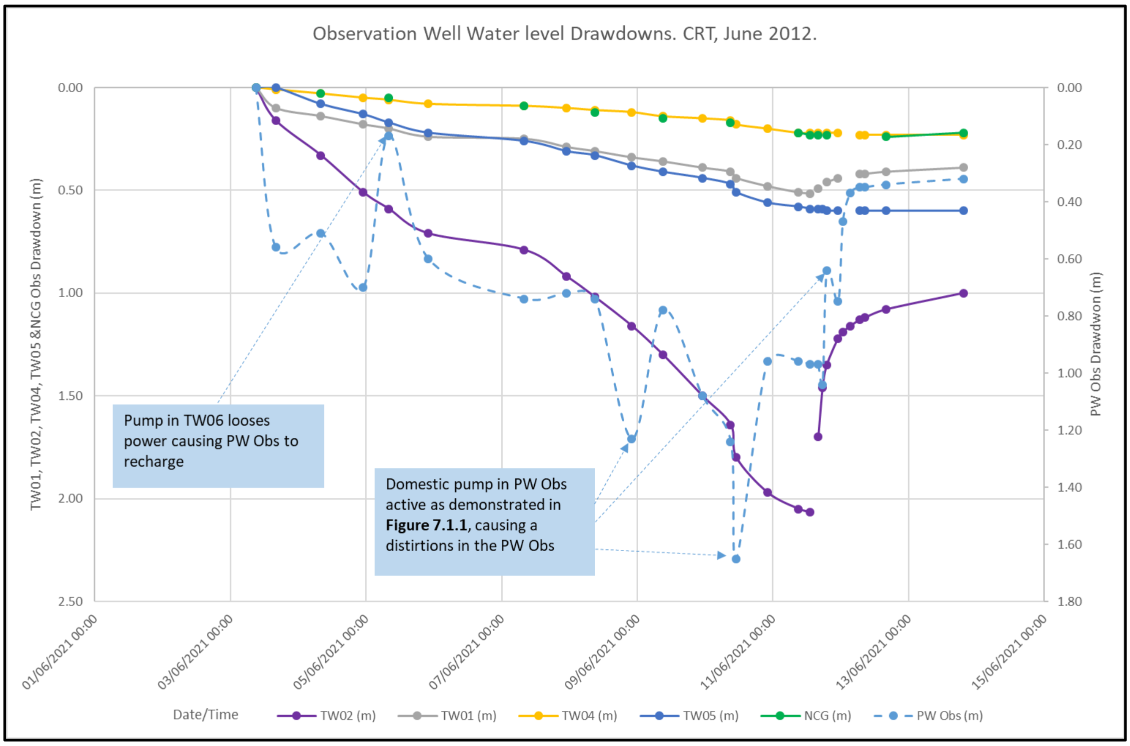


Figure 22: Monitoring well drawdown during the TW03 and TW06 CRT



10. WATER QUALITY

10.1. TW03 extended step test

Samples were collected for the EU Drinking Water Suite following the extended step test (CRT) on TW03. During the extended step test, field parameters were monitored, including temperature, conductivity, pH and turbidity. The average temperature and conductivity were 10.3°C and 537 µS/cm, respectively. Average pH was recorded at 7.2 units. The average turbidity was 27.1 NTU. The extended test was commenced on 6th April 2021 at 10:00 and was completed on 9th April 2021 at 15:30. The full EU audit suite sample was collected on 8th April 2021 at 11:00. Lab samples were collected via a sampling tap at the head works according to best practice and sent to an accredited laboratory for analysis. For the duration of this project, Fitz Scientific Laboratories, Drogheda, Co. Louth was used (www.fitzsci.ie).

No bacteria were detected in the sample. All parameters were found to be within threshold values, except aluminium and turbidity were both slightly elevated. It is likely the elevated turbidity was caused by over-stressing the borehole to below the level of the main contributing fracture zone. This elevated aluminium is associated with the turbidity. Table 5 presents all of the water quality results. The full laboratory report can be found in Appendix 3.

10.2. Simultaneous CRT

The simultaneous CRT was undertaken on both TW03 and TW06 commencing on 3rd June and continuing until the 11th June 2021. Over the course of CRT, physiochemical field parameters were recorded using an Insitu AquaTROLL 500 Multiparameter Sonde. The instrument was fully calibrated prior to the testing program. Table 6 presents the physiochemical values of TW03 discharge over the course of the CRT; Table 7 presents TW06. The turbidity in both wells decreases over the duration of the test suggesting that the pumping is developing the wells. All other parameters remain relatively consistent (or within a range) over the duration of the test, indicating stable conditions.

Full EU audit suite samples were collected on 9th June 2021. Lab samples were collected via a sampling tap at the head works according to best practice and sent to Fitz Scientific Laboratories for analysis. The full laboratory report for all the analysis can be found in Appendix 3 and summarised in Table 5.

The results of the sampling demonstrate during that turbidity and aluminium were lower than the TW03 extended step test and neither exceed drinking water standards. This provides further indication that the turbidity was caused by over-stressing the borehole with pumping and that the aluminium is associated with the turbidity.

TW03 and TW06 had counts of 116 and 14 cfu/100ml of enterococci. Clostridium perfringens was recorded as 1 cfu/100ml in TW03; all other micro parameters (e. coli, total coliforms and colony counts) were zero for both wells. Also, at the end of the extended step test at TW03, there was zero counts of enterococci. Enterococci are indicators of the presence of faecal material in water. Given the low counts of all other microbial parameters, it is likely the results are due to contamination of the sample. The closest septic tank to TW03 is 384m away. The domestic well at this address showed a drawdown of 0.23m. In the case of TW06, the closest septic tank is 263m away, and the domestic well at this address shows a drawdown of 0.97m.

A set of samples filtered (with a 45-micron filter) on site was collected in conjunction with the full audit suite. The aim is to identify whether any potential exceedances are due to suspended solids. Iron, manganese and nickel are higher in TW06, but both samples were within regulation values with no exceedances' (Table 8).

Table 5 Water quality results for TW03 and TW06 compared to WW1A and WW2B

Parameter	Unit	SI No. 122 of 2014 - EU Drinking Water Regulations 2014	TW03 Extended Step Test	TW03 CRT	TW06 CRT	WW1A (Oct-2019 to Dec-2015)		WW2B (Oct-2019 to Dec-2015)	
			08-Apr-2021	09-Jun-2021	09-Jun-2021	50th Percentile	90th Percentile	50th Percentile	90th Percentile
Microbiological Parameters									
E. coli	cfu/100 mL	0	0	0	0				
Enterococci	cfu/100 mL	0	0	116	14				
Chemical Parameters									
Antimony	µg/L	5	<2	<2	<2				
Arsenic	µg/L	10	<2	<2	<2	1	3.8	0.5	3
Benzene	µg/L	1	<0.34	<0.34	<0.34				
Benzo(a)pyrene	µg/L	0.01	<0.01	<0.01	<0.01				
Boron	mg/L	1	0.033	<0.02	<0.02				
Bromate	µg/L	10	<2.4	<2.4	<2.4				
Cadmium	µg/L	5	<1	<1	<1	<1	<1	<1	<1
Chromium	µg/L	50	<4	<4	<4	<1	<1	<1	<1
Copper	mg/L	2	<0.003	<0.003	<0.003	< 0.002	0.0021	0.0005	0.0005
Cyanide	µg/L	50	<5	<5	<5				
1,2-dichloroethane	µg/L	3	<0.82	<0.82	<0.82				
Fluoride (naturally occurring fluoride)	mg/L	1.5	0.14	0.09	0.1				
Lead	µg/L	10	1	<1	<1	1	2	<1	3
Mercury	µg/L	1	<0.15	<0.15	<0.15	<1	<1	<1	<1
Nickel	µg/L	20	2	<2	4	3	5	2.5	3.1
Nitrate	mg/L as NO_3	50	24.22	25.04	15.46	24	26	25	29
Nitrite	mg/L as NO_2	0.5	<0.099	<0.099	0.187	0.01	0.025	0.015	0.02
Pesticides - Total	µg/L	0.5	<0.5	<0.5	<0.5				
Polycyclic aromatic hydrocarbons	µg/L	0.1	<0.01	<0.01	<0.01				
Selenium	µg/L	10	<3	<3	<3				
Tetrachloroethene and Trichloroethene	µg/L	10	<2.32	<2.32	<2.32				
Trihalomethanes - Total	µg/L	100	<100	<100	<100				
Indicator Parameters									
Aluminium	µg/L	200	821	9	<9	<9	9	<9	12
Ammonium	mg/L as NH_4	0.3	0.08	0.07	0.07				
Chloride	mg/L	250	20.8	17.3	14.3	15	16.2	11	15
Clostridium perfringens	cfu/100 mL	0	0	1	0				
Colour	PtCo Units	acceptable to consumer	22	<11	12	2.5	21	2	4
Conductivity	µs/cm at 20ºC	2500	686.0	693	660	625.5	701.5	616	702.4
Hydrogen ion concentration	pH Units	> 6.5 and < 9.5	7.23	7.13	7.1	7.33	7.61	7.44	7.72
Iron	µg/L	200	132	<14	59	7	2.1	3	10
Manganese	µg/L	50	28	<3	47	<10	<10	<10	<10
Odour	TON	acceptable to consumer	No Odour	No Odour	No Odour				
Sulphate	mg/L as SO_4	250	11	15	15	12	16	10	12.3
Sodium	mg/L	200	7.8	8.3	7.4	7.62	8.77	7.81	9.74
Taste	FTN	acceptable to consumer	No Taste	-	-				
Colony count 22deg		no abnormal change	138	>300	>300				
Coliform bacteria	cfu/100 mL	0	0	0	0				
Total organic carbon (TOC)	mg/L	no abnormal change	<0.8	<0.7	0.7				
Turbidity	NTU	acceptable to consumer	22.3	0.2	0.4	0.4	2.248	0.8	13.46

Table 6: Physiochemical values for TW03 CRT

Date Time	Conductivity (µS/cm)	SPC (µS/cm)	Salinity (PSU)	TDS (ppt)	Temp (°C)	RDO Conc (mg/L)	RDO Sat (%Sat)	pH (units)	ORP (mV)	Turbidity (NTU)	Comments
03/06/2021	527.67	741.17	0.36	0.48	9.92	7.5	67.39	7.13	128.64	12.01	TW3 WQ1
03/06/2021	527.24	742.02	0.36	0.48	9.85	7.34	64.95	7.13	139.91	2.85	TW3 WQ2
04/06/2021	522.35	727.57	0.35	0.47	10.23	7.39	66.42	7.18	120.75	2.32	TW3 WQ3
05/06/2021	512.56	715.04	0.35	0.46	10.17	7.17	64.28	7.1	116.71	1.34	TW3 WQ4
07/06/2021	523.25	730.79	0.36	0.48	10.13	7.1	63.65	7.15	135.57	1.03	TW3 WQ5
08/06/2021	532.48	739.56	0.36	0.48	10.34	7.27	65.64	7.2	101.35	1.18	TW3 WQ6
09/06/2021	530.33	740.76	0.36	0.48	10.13	7.28	65.62	7.13	125.7	0.75	TW3 Lab Sample
Average	***525.13***	***733.84***	***0.36***	***0.48***	***10.11***	***7.29***	***65.42***	***7.15***	***124.09***	***3.07***	
Max	***532.48***	***742.02***	***0.36***	***0.48***	***10.34***	***7.5***	***67.39***	***7.2***	***139.91***	***12.01***	
Min	***512.56***	***715.04***	***0.35***	***0.46***	***9.85***	***7.1***	***63.65***	***7.1***	***101.35***	***0.75***	

Table 7: Physiochemical values for TW06 CRT

Date Time	Conductivity (µS/cm)	SPC (µS/cm)	Salinity (PSU)	TDS (ppt)	Temp (°C)	RDO Conc (mg/L)	RDO Sat (%Sat)	pH (units)	ORP (mV)	Turbidity (NTU)	Comments
03/06/2021	520.55	723.62	0.35	0.47	10.31	3.34	29.84	7.07	54.81	4.47	TW6 Demo Test 1
03/06/2021	520.25	723.58	0.35	0.47	10.29	3.17	28.78	7.03	27.02	3.36	TW6 Demo Test 2
03/06/2021	520.23	723.39	0.35	0.47	10.3	3.15	28.6	7.01	27.23	2.86	TW6 Demo Test 3
03/06/2021	520.23	723.23	0.35	0.47	10.3	3.14	28.47	7	30.2	6.15	TW6 Demo Test 4
03/06/2021	511.39	708.37	0.35	0.46	10.44	3.77	34.22	7.1	44.74	2.91	TW 6 WQ 5
04/06/2021	510.93	705.45	0.34	0.46	10.56	4.45	40.36	7.1	29.42	2.61	TW6. WQ6
05/06/2021	510.69	707.3	0.34	0.46	10.45	3.8	34.31	7.08	41.35	8.86	TW 6 WQ 7
05/06/2021	508.48	706.38	0.34	0.46	10.33	3.57	32.07	7	37.14	1.66	TW6 WQ 8
07/06/2021	496.62	687.38	0.33	0.45	10.47	3.78	34.15	7.12	32.97	0.86	TW6 WQ 9
09/06/2021	458.72	635.67	0.31	0.41	10.43	3.26	29.64	6.92	49.23	0.68	TW6 Lab Sample
Average	***507.809***	***704.437***	***0.341***	***0.46***	***10.388***	***3.543***	***32.044***	***7.043***	***37.411***	***3.442***	
Max	***520.55***	***723.62***	***0.35***	***0.47***	***10.56***	***4.45***	***40.36***	***7.12***	***54.81***	***8.86***	
Min	***458.72***	***635.67***	***0.31***	***0.41***	***10.29***	***3.14***	***28.47***	***6.92***	***27.02***	***0.68***	

Table 8: Comparison of dissolved parameters in TW03 and TW06

Filtered Parameter	Unit	TW03	TW06
Aluminium	ug/L	<9	<9
Antimony	ug/L	<2	<2
Arsenic	ug/L	<2	<2
Boron	mg/L	<0.02	<0.02
Cadmium	ug/L	<1	<1
Chromium	ug/L	<4	<4
Copper	mg/L	<0.003	<0.003
Iron	ug/L	<14	59
Lead	ug/L	<1	<1
Manganese	ug/L	<3	45
Mercury	ug/L	<0.15	<0.15
Nickel	ug/L	<2	3
Selenium	ug/L	<3	<3

11. CONCEPTUAL UNDERSTANDING

The extensive groundwater exploration of the Rathpatrick site has significantly improved the understanding hydrogeological conditions. Figures 22 and 23 present a plan and conceptual cross section of the site area. The GSI map shows two separate formations on site, the Crosspatrick to the west and overlying the Waulsortian in the east. Both units dip gently to the west.

Geophysics and drilling data collected as part of the trial well drilling programme show that there are substantial areas of weathered epikarst in both mapped formations, although this is not extensive across the site, as evident in competent ground encountered at TW04 (Crosspatrick) and TW06 (Waulsortian).

The contact zone of the Crosspatrick and Waulsortian also appears to be highly weathered. This is evident where it outcrops (around TW02) but also where it is encountered at depth (TW03).

The data indicate TW06 is not hydraulically connected to the other trial wells and is located in a separate hydrogeological unit related to the Waulsortian Formation.

The water quality of the area is good with most parameters below detection limit and in compliance with drinking water standards.

Figure 23: Map indicating location of cross section A – A'

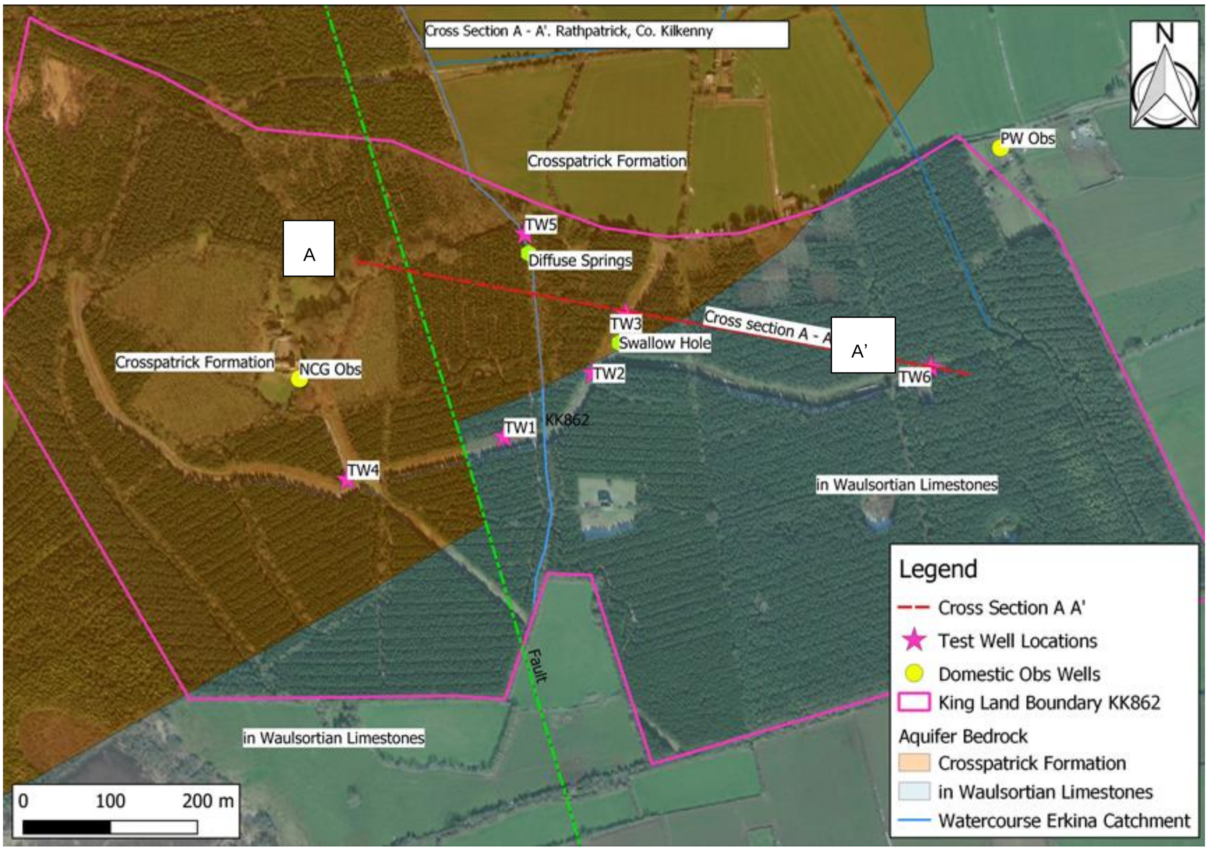
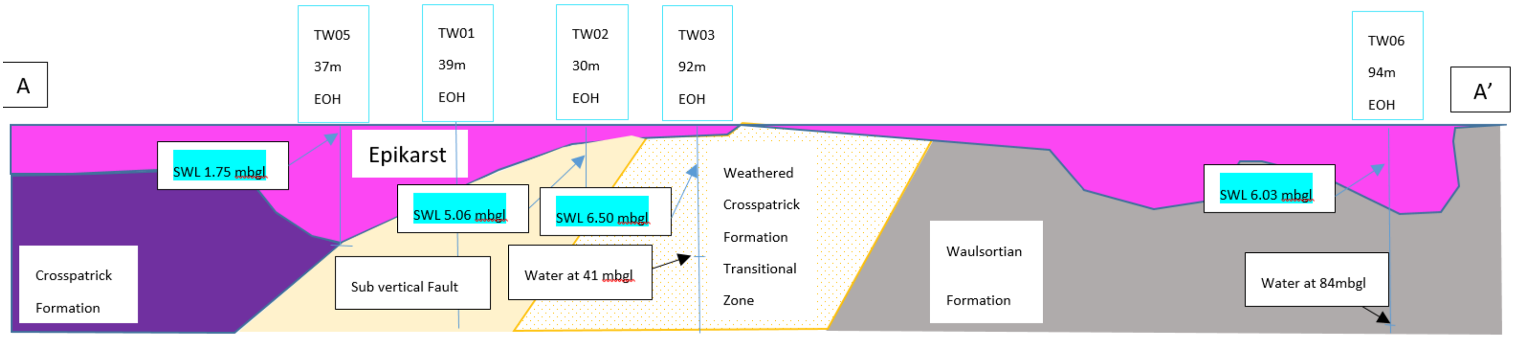


Figure 24: Conceptual cross section A – A'



APPENDIX 1
BOREHOLE LOGS

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

Test Well No.1

Project:	**TW Drilling Rathpatrick, Co. Kilkenny**	**Borehole ID:**	
Supervisor:	**James Lalor**	**Norting: 624364,**	**Start** / **Finish**
Date:	**11/03/2021** **Shift: Day**	**Easting: 670574**	**10/03/2021** / **11/03/2021**
Compiled by: James Lalor. Driller Tom Fogarty		**Elevation: 132 masl**	
Location:	**Rathpatrick, Co. Kilkenny**	**Rig ID:**	

TW01.

Depth (m)			Lithology
0.00	to	2.00	CLAY. Dark brown, peaty soils. Vegitative layer.
2.00	to	4.60	TILL. Limestone till boulder clays.
4.60	to	7.70	WEATHERED LIMESTONE. Buff/pale brown colour, with silt, cobbles and some boulders.
7.70	to	10.50	LIMESTONE. Pale grey. Cherty. Sharp fragments. Hard. Fractures at 8.4 and 9.8m. Some water.
10.50	to	12.00	LIMESTONE. Partly Dolomitised.
12.00	to	12.80	SAND. Buff coloured. Well sorted. Fine to medium grain sand.
12.80	to	14.50	LIMESTONE. Dolomitised limestone. Discreet fisures water ingress.
14.50	to	17.50	LIMESTONE. Fractured limestone with increased water/sand in samples.
17.50	to	22.00	LIMESTONE. Partly Dolomitised. Competent.
22.00	to	22.40	LIMESTONE. Fractured limestone increase in water/sand content in sample.
22.40	to	24.00	LIMESTONE. Partly Dolomitised. Competent. EOH @24m. 10/3/21
24.00	to	25.40	LIMESTONE. Weathered limestone. Pale grey/buff. Coarse sand. Poorly sorted.
25.40	to	26.60	LIMESTONE. Fracture cavaity. Water/sand ingress noted. Very dirty.
26.60	to	27.00	CAVITY. Sand/water filled cavity.
27.00	to	28.00	LIMESTONE. Weathered limestone. Broken.
28.00	to	30.00	LIMESTONE. Partly Dolomitised. Competent.
30.00	to	32.00	LIMESTONE. Soft weathered. Fractured. Buff coloured, poorly sorted sands.
32.00	to	37.00	LIMESTONE. Weathered, fractured. Incresed yield of dirty water. Very sandy.
37.00	to	38.00	LIMESTONE. Hard, competent limestone.
38.00	to	39.00	CAVITY. Sand/water filled cavity. Flow appears strong into settlement pit from borehole, however, water emerging from the pit (post settlement) is actually small. Hole not suitable to drill further due to rig stabilisation concerns and water qaulity/yield concerns.

DRILLING DETAILS

From :	0	to	10m	12"
To	10	to	39m	8"
Total :				

Waterlevel at the begining of the shift (m): 3m — From ground level
Waterlevel at the end of the shift (m): N/A

DRILLING METHOD:

Conventional DTH hammer
10.4m of 10" casing
14m of 120mm slotted PVC

COMMENTS / OBSERVATIONS

Unable to get propper flow rate due to the presence of sands in the well.
TW01 has been converted to a monitoring well - MW01
During drilling 15m3 of sediment produced from hole in 2 hours.
14m of 120mm slotted PVC casing installed with lockable lid.

Observations are a combination of drillers notes and sample logging.

Flows during development

Time	From	To	Flow l/sec	Pression PSI

Fields parameters:

PH , T (ºC) , CE (µS)

MATERIAL

10.5m of 10" (255mm) casing installed.
14m of 205mm slotted PVC

Client:

EQUIPMENT USED	Qty

Supervisor Piteau
James Lalor

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

Test Well No.2

Project:	**TW Drilling Rathpatrick, Co. Kilkenny**	**Borehole ID:**	
Supervisor:	**James Lalor**	**Norting: 624466**	**Start** / **Finish**
Date:	**15/03/2021** **Shift:**	**Easting: 670647**	**15/03/2021** / **16/03/2021**
Compiled by: James Lalor. Driller Tom Fogarty		**Elevation: 128m**	
Location:	**Rathpatrick, Co. Kilkenny**	**Rig ID:**	

TW02.

Depth (m)			Lithology
0.00	to	1.40	CLAY. Vegitative layer. BROWN dark peaty clays.
1.40	to	2.50	TILL. Pale Grey, silty gravel.
2.50	to	4.20	LIMESTONE. Weathered, with soft brown clay fill.
4.20	to	5.20	LIMESTONE. Weathered Limestone. No cuttings from 0.to 6m. Minor water Ingress.
5.20	to	6.20	LIMESTONE. Competent L'stone. Pale grey and buff coloured limestone.
6.20	to	9.40	LIMESTONE. Competent L'stone. Pale grey and buff coloured limestone.
9.40	to	10.00	LIMESTONE. Weathered limestone with boulder clay infill.
10.00	to	17.40	LIMESTONE. Fractured and weathered limestone. Sediment content and water.
17.40	to	20.40	LIMESTONE. Fractured and weathered limestone. Sediment content and water.
20.40	to	20.80	LIMESTONE. Cavity with sediment infill.
20.80	to	24.00	LIMESTONE. Competent, high sediment content, connected to upper cavity units wash out.
24.00	to	24.20	LIMESTONE. Weathered. Water and sediment.
24.20	to	30.00	LIMESTONE. Weathered. Water and sediment. Loosing pressure, well collapsing. Increase sedimer
			Incresed sediment and water. Hole compromised.

DRILLING DETAILS

From :	0	to	6.2m	12"
To	6.2	to	30m	8"
Total :				

DRILLING METHOD:
Conventional DTH hammer
6.6m of 10" casing

Waterlevel at the begining of the shift (m): From ground level
Waterlevel at the end of the shift (m): N/A

Flows during development

Time	From	To	Flow l/sec	Pression PSI

MATERIAL
6.6m of 10" (255mm) casing installed.

EQUIPMENT USED	Qty

COMMENTS / OBSERVATIONS
Unable to get propper flow rate due to the presence of sands in the well.

Observations are a combination of drillers notes and sample logging.
Began to loose pressure around rig through ground (bubbles) and up the side of the casing.

Fields parameters:
PH , T (ºC) , CE (µS)

Client:

Supervisor Piteau
James Lalor

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

Test Well No.3

Project:	**TW Drilling Rathpatrick, Co. Kilkenny**	**Borehole ID:**	
Supervisor:	**James Lalor**	**Norting: 624504**	**Start** / **Finish**
Date:	**22/03/2021** **Shift:**	**Easting: 670715**	**18/03/2021** / **19/03/2021**
Compiled by: James Lalor. Driller Tom Fogarty		**Elevation: 131m**	
Location:	**Rathpatrick, Co. Kilkenny**	**Rig ID:**	

TW03.

Depth (m)			Lithology
0.00	to	1.00	CLAY. Brown and peaty.
1.00	to	2.40	TILL. Buff brown, weathered pebbles and coarse sand.
2.40	to	17.50	LIMESTONE. Pale Dolomitised Limestone. Cherty. Competent. Hard drilling.
17.50	to	18.20	LIMESTONE. Weathered vein with minor water. <1ltr/sec
18.20	to	37.00	LIMESTONE. Pale Dolomitised Limestone. Cherty. Competent. Hard drilling.
37.00	to	38.40	LIMESTONE. Weathered vein with increased water. <1ltr/sec
38.40	to	40.80	LIMESTONE. Weathered fractures. Coarse sand. Increased water.
40.80	to	47.50	LIMESTONE. Weathered fissure. Sand and gravel infil. Increased water. C.13 ltr/sec
47.50	to	58.50	LIMESTONE. Dark grey. Fine grained. Poorly sorted. Continuing gravel from upper fracture zone.
58.50	to	61.00	LIMESTONE. Dark grey. Fine grained limestone. Yield incresing gradually with depth.
			Change hammer from 8" to 6" at 61m. On running collapse was noted at 44.5, 50 and 55m.
			3m of sediment in base of well prior to drilling on 19/3/21. SWL 4.66 mbtoc
			Flow test on 19/3/21 = 16ltrs/sec
61.00	to	62.00	LIMESTONE. Dark grey. Fine grained. Poorly sorted. Continuing gravel from upper fracture zone.
62.00	to	92.00	LIMESTONE. Dark grey. Fine grained. Poorly sorted. Continuing gravel from upper fracture zone.
			Further water bearing fractures at 65.4, 75.6, 79.5, 85.2 and 87.8m adding 3 to 4ltrs/sec

DRILLING DETAILS

From :	0	to	3.5	12"
To	3.5	to	61	8"
Total :	61	to	92	6"

DRILLING METHOD: Conventional DTH hammer

Waterlevel at the begining of the shift (m): 4.36 From ground level

Waterlevel at the end of the shift (m): N/A

Flows during development

Time	From	To	Flow l/sec	Pression PSI

MATERIAL

4.0m of 10" Casing

EQUIPMENT USED	Qty

COMMENTS / OBSERVATIONS

Tagged again on Monday 22/3/21.

Bridging at 44.5, 51.2 and 55.8mbgl. (similar to previous notes of collapse).

Sediment at base of well, tagged at 5m.

Well developed for 1.5 hours on 22/3/21 and rig demobilised.

Observations are a combination of drillers notes and sample logging.

Fields parameters:

PH , T (ºC) , CE (µS)

Client:

Supervisor Piteau
James Lalor

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

Test Well No.4

Project:	**TW Drilling Rathpatrick, Co. Kilkenny**	**Borehole ID:**	
Supervisor:	**James Lalor**	**Norting: 624184**	**Start** / **Finish**
Date:	**24/03/2021** **Shift:**	**Easting: 670525**	**22/03/2021** / **24/03/2021**
	Compiled by: James Lalor. Driller Tom Fogarty	**Elevation: 124**	
Location:	**Rathpatrick, Co. Kilkenny**	**Rig ID:**	

TW04.

Depth (m)			**Lithology**
0.00	to	0.60	CLAY. Brown Peaty soft.
0.60	to	1.80	TILL. Boulders and cobbles. Poorly sorted grey.
1.80	to	2.70	CLAY. Brown clay. Possibly ground that was disturbed by forestry in the past.
2.70	to	6.00	LIMESTONE. Slghtly weathered. Brownish grey. Minor water ingress noted.
6.00	to	18.80	LIMESTONE. Pale grey, dolomitised, cherty. Competent.
18.80	to	30.00	LIMESTONE. Alternate layers of hard l'stone and discreet dry weathered bands. Minor water increase
30.00	to	30.20	LIMESTONE. Small fissure, minor increased yield noted.
30.20	to	56.00	LIMESTONE. Alternate layers of hard l'stone and discreet dry weathered bands. Mostly hard l'stone.
			Weathered veins noted at 45.5m, 47.6m and 50m.
56.00	to	62.00	LIMESTONE. Weathered unit, very occasional calcite. Minor water increase
62.00	to	92.00	LIMESTONE. Variations between dark grey to black. Fne grain. Competent. Partially weathered 84 to 86m
92.00	to	142.00	LIMESTONE. Fne grain. Varying between pale and dark grey, slightly weathered.

DRILLING DETAILS

0	to	6	12"
6	to	55	8"
55	to	142	6"

DRILLING METHOD:
Conventional DTH hammer

Waterlevel at the begining of the shift (m): 4.36 From ground level
Waterlevel at the end of the shift (m): N/A

Flows during development

Time	From	To	Flow l/sec	Pression PSI

MATERIAL
6.5m of 8" casing nstalled, not 10" as on other holes.

EQUIPMENT USED	Qty

COMMENTS / OBSERVATIONS
Very little variation of rock units during drilling. Formation very tight.
Observations are a combination of drillers notes and sample logging.

Flow Yield measured at 114m = 1.6 ltrs/sec
Flow Yield measured at 122m = 1.9 ltrs/sec
Penetration rates:
124m to 130m = 27 mins.
130m to 136m = 28 mins
136m to 144m = 27 mins

Fields parameters:
PH , T (ºC) , CE (μS)

Client:

Supervisor Piteau
James Lalor

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

Test Well No.5

Project:	**TW Drilling Rathpatrick, Co. Kilkenny**	**Borehole ID:**	
Supervisor:	**James Lalor**	**Norting: 624388**	**Start** / **Finish**
Date:	**13/05/2021** **Shift:**	**Easting: 670807**	**06/05/2021** / **13/05/2021**
	Compiled by: James Lalor. Driller Tom Fogarty	**Elevation: 131m**	
Location:	**Rathpatrick, Co. Kilkenny**	**Rig ID:**	

TW05.

Depth (m)			Lithology
0.00	to	0.40	Humus. Dark Brown. Soft Peat. Vegitative layer.
0.40	to	4.20	Gravels. Buff colour. Very soft. Water at 1.8m (alligned to springs in drains close by)
4.20	to	5.50	Clay. Dark grey to buff colour. Silty texture. Possibly broken weathered rock head with clay infill
5.50	to	7.30	Pale Limestone.
7.30	to	10.00	Limestone. Weathered, poorly sorted cuttings. Coarse sands and gravels. High clay till content.
10.00	to	21.50	Limestone. Clay content increasing. Sand to cobble size pieces some associated with clays. Water
			Drilling with 8" hammer and pushing 10" into hole with relative ease to support hole.
			Shallow inflows being sealed out, more water between 20 to 24m
21.50	to	26.50	Clay. Unconsolidated clay fill with weathered calp.
26.50	to	27.70	Limestone. Hard Limestone shelf.
27.70	to	29.20	Cavity. Sand and Water.
29.20	to	30.80	Limestone. Soft to drill. Water and sand continue to increase yield.
30.80	to	34.00	Limestone. Competent.
34.00	to	35.70	Limestone Weathered. Soft.
35.70	to	37.00	Cavity. Sand and Water.
			Changed 8" hammer to 10" to ream out from 24.5 to 31m.

DRILLING DETAILS

From :	0	to	7.3	12"	
To	7.3	to	37	8"	
Total :	24.5	to	31	10"	

DRILLING METHOD: Conventional DTH hammer

Reamed out.

Waterlevel at the begining of the shift (m): 2.5 From ground level

Waterlevel at the end of the shift (m): N/A

Flows during development

Time	From	To	Flow l/sec	Pression PSI

MATERIAL

7.8	m	10" Casing	(6/5/21)
4	m	10" Casing	(7/5/21)
1.5	m	10" Casing	(7/5/21)
4	m	10" Casing	(10/5/21)
4	m	10" Casing	(10/5/21)
4	m	10" Casing	(12/5/21)
6	m	10" Casing	(13/5/21)
31.3	m	10" Casing	(Start of 13/5/21)

EQUIPMENT USED	Qty

COMMENTS / OBSERVATIONS

Lots of sand. Unable to do approapriate well development due to sediment management challenges on a small site and proximity to road and drainage channel.

24hours after finishing work on well, the sand had collapsed and moved to 23mbgl inside casing rendering the hole inoperable. Plans to test pump the exposed aquifer section had to be halted.

Observations are a combination of drillers notes and sample logging.

Fields parameters:

PH , T (ºC) , CE (μS)

Client:

Supervisor Piteau
James Lalor

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

Test Well No.6

Project:	**TW Drilling Rathpatrick, Co. Kilkenny**	**Borehole ID:**	
Supervisor:	**James Lalor**	**Norting: 624854**	**Start** / **Finish**
Date:	**22/05/2021** **Shift:**	**Easting: 670654**	**20/05/2021** / **22/05/2021**
	Compiled by: James Lalor. Driller Tom Fogarty	**Elevation: 129m**	
Location:	**Rathpatrick, Co. Kilkenny**	**Rig ID:**	

TW05.

Depth (m)			**Lithology**
0.00	to	2.60	Made Ground. Drill pad ballast stone.
2.60	to	18.00	Limestone. Weathered. Pale grey, sharp. Massive. Minor water @ 5.4 and9.6m
18.00	to	27.00	Limestone. Pale grey, massive. Intermitant units of hard and soft rock.
27.00	to	40.50	Limestone. Pale grey, massive. Hard Rock. Competent. < 2 ltrs/sec
40.50	to	49.30	Limestone. Pale grey, massive. Softer band of Waulsortian.
			Minor fissure with calcite at 45m
49.30	to	53.50	Limestone. Pale grey, massive. Hard Rock. Competent. < 2 ltrs/sec.
			Minor Fissure with calcite at 54.4m
53.50	to	61.00	Limestone. Pale Grey, massive.
61.00	to	82.70	Limestone. Dark Grey, massive. <2 ltrs/sec
			Minor Fissure with calcite at 69.3m
82.70	to	84.00	Limestone. Pale Grey, massive. <2 ltrs/sec. Weathered.
84.00	to	86.00	Limestone. Pale Grey, massive. Weathered. 10 to 15 ltrs/sec. Little associated clays and/or sands.
86.00	to	94.00	Limestone. Pale grey, massive. Hard Rock. Competent.
			Development of water features for about 2 hours. Velocity of water and material ejecting from
			well undermine 4m of 10" casing at surface and cause wash out. Extra casing to be installed.
			EOH at 94m

DRILLING DETAILS

From :	0	to	6	12"
To	0	to	70	8"
Total :	70	to	94	6"

DRILLING METHOD:
Conventional DTH hammer
Reamed out.

Waterlevel at the begining of the shift (m):
Waterlevel at the end of the shift (m): N/A

Flows during development

Time	From	To	Flow l/sec	Pression PSI

MATERIAL

5m of 10"
Open Hole 6m to 94m
Reamed out to 70m at 8".
70m to 94m @ 6"

0 m 10" Casing (Start of 13/5/21)

EQUIPMENT USED	**Qty**

COMMENTS / OBSERVATIONS
Very discreet fractures between 84 - 86m (possibly 3 zones) yield most of the water. <2 ltrs/sec up to 80m. Very clean fractures, no sand or clay.

Observations are a combination of drillers notes and sample logging.

Fields parameters:
PH , T (ºC) , CE (µS)

Client:

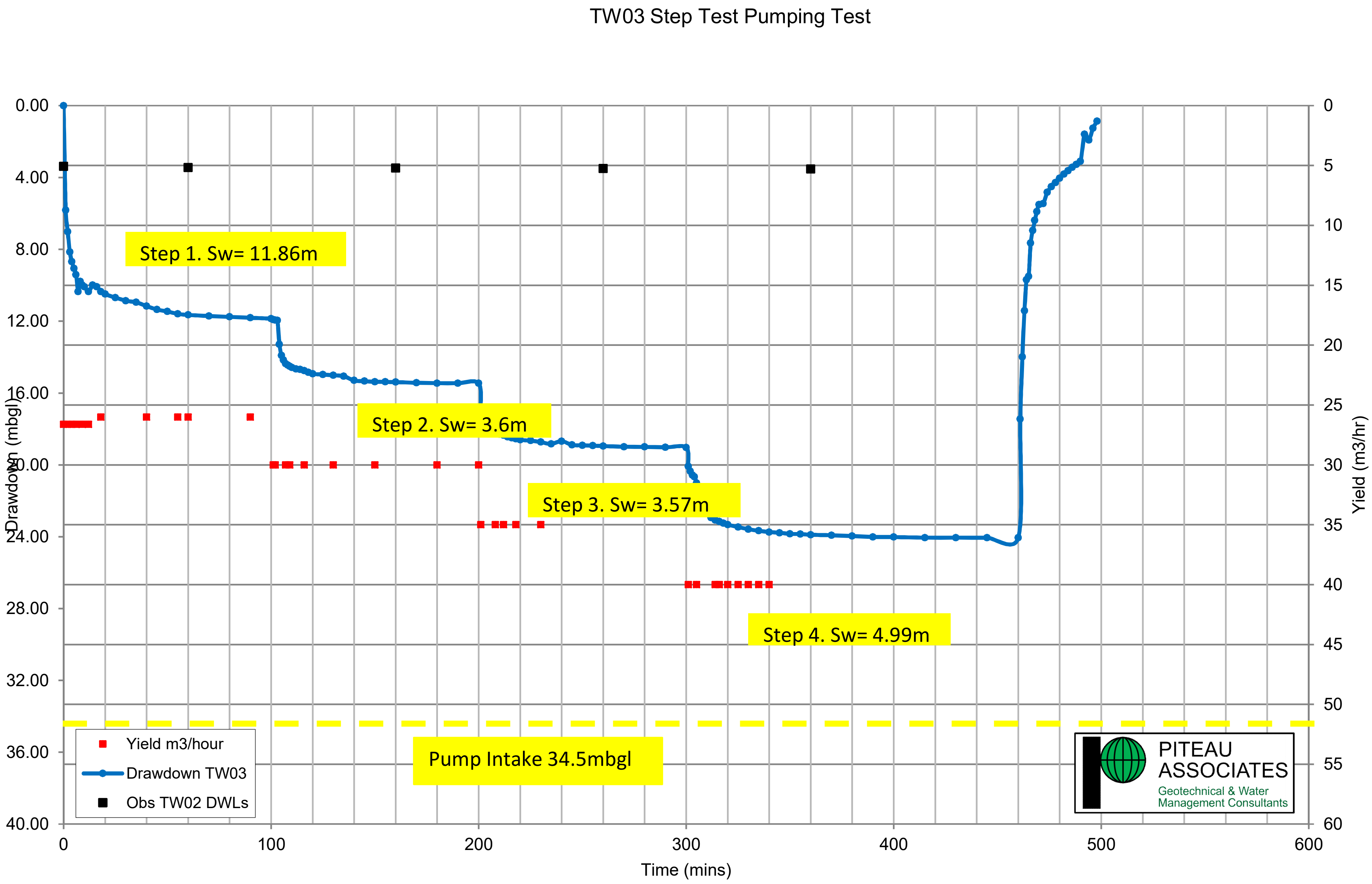
Supervisor Piteau
James Lalor

APPENDIX 2
PUMPING TEST DATA & GRAPHS
STEP RATE TESTS

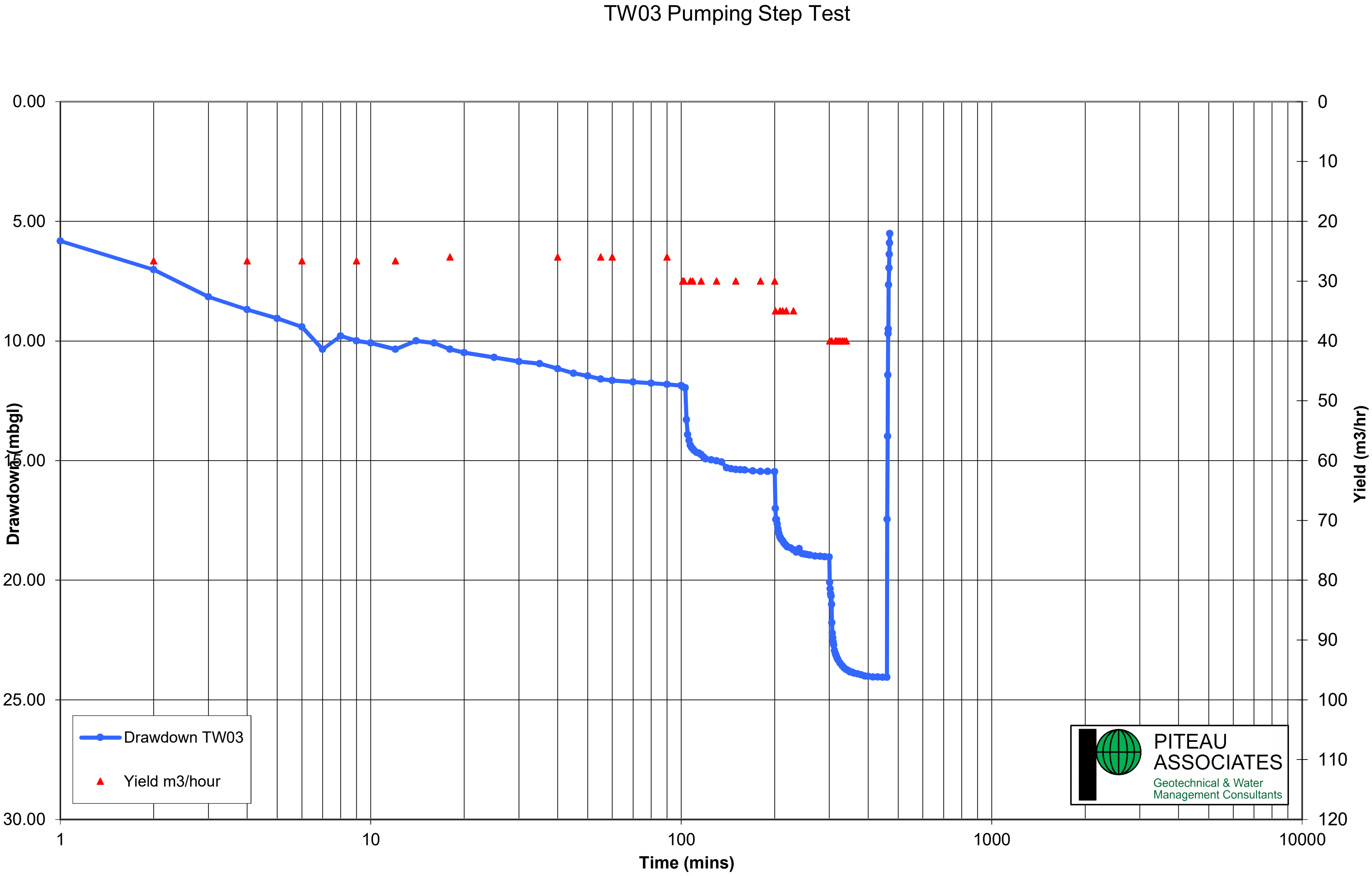
Actual Time	Time (Mins)	Water Level (m.b.g.l)	Drawdown TW03 metres	Yield m3/hour	Obs TW02 DWLs (mbtoc)	Comments
1/4/21 10:30:00	0	4.63	0.00	27	3.38	Step 1 Start
1/4/21 10:31:00	1	10.45	5.82			
1/4/21 10:32:00	2	11.65	7.02	27		
1/4/21 10:33:00	3	12.78	8.15			
1/4/21 10:34:00	4	13.32	8.69	27		
1/4/21 10:35:00	5	13.69	9.06			
1/4/21 10:36:00	6	14.04	9.41	27		
1/4/21 10:37:00	7	14.98	10.35			
1/4/21 10:38:00	8	14.42	9.79			
1/4/21 10:39:00	9	14.62	9.99	27		
1/4/21 10:40:00	10	14.71	10.08			
1/4/21 10:42:00	12	14.98	10.35	27		
1/4/21 10:44:00	14	14.62	9.99			
1/4/21 10:46:00	16	14.71	10.08			
1/4/21 10:48:00	18	14.98	10.35	26		
1/4/21 10:50:00	20	15.12	10.49			
1/4/21 10:55:00	25	15.32	10.69			
1/4/21 11:00:00	30	15.49	10.86			
1/4/21 11:05:00	35	15.58	10.95			
1/4/21 11:10:00	40	15.79	11.16	26		
1/4/21 11:15:00	45	15.98	11.35			
1/4/21 11:20:00	50	16.09	11.46			
1/4/21 11:25:00	55	16.22	11.59	26		
1/4/21 11:30:00	60	16.28	11.65	26	3.45	
1/4/21 11:40:00	70	16.34	11.71			
1/4/21 11:50:00	80	16.39	11.76			
1/4/21 12:00:00	90	16.44	11.81	26		
1/4/21 12:10:00	100	16.49	11.86			Step 2 Start
1/4/21 12:11:00	101	16.54	11.91	30		
1/4/21 12:12:00	102	16.57	11.94	30		
1/4/21 12:13:00	103	16.58	11.95			
1/4/21 12:14:00	104	17.92	13.29			
1/4/21 12:15:00	105	18.54	13.91			
1/4/21 12:16:00	106	18.79	14.16			
1/4/21 12:17:00	107	18.99	14.36	30		
1/4/21 12:18:00	108	19.08	14.45			
1/4/21 12:19:00	109	19.14	14.51	30		
1/4/21 12:20:00	110	19.21	14.58			
1/4/21 12:22:00	112	19.29	14.66			
1/4/21 12:24:00	114	19.32	14.69			
1/4/21 12:26:00	116	19.38	14.75	30		
1/4/21 12:28:00	118	19.48	14.85			
1/4/21 12:30:00	120	19.56	14.93			
1/4/21 12:35:00	125	19.60	14.97			
1/4/21 12:40:00	130	19.64	15.01	30		
1/4/21 12:45:00	135	19.69	15.06			
1/4/21 12:50:00	140	19.93	15.30			
1/4/21 12:55:00	145	19.97	15.34			
1/4/21 13:00:00	150	20.00	15.37	30		
1/4/21 13:05:00	155	20.01	15.38			
1/4/21 13:10:00	160	20.02	15.39		3.48	
1/4/21 13:20:00	170	20.06	15.43			
1/4/21 13:30:00	180	20.08	15.45	30		
1/4/21 13:40:00	190	20.08	15.45			
1/4/21 13:50:00	200	20.09	15.46	30		Step 3 Start
1/4/21 13:51:00	201	21.63	17.00	35		
1/4/21 13:52:00	202	22.09	17.46			
1/4/21 13:53:00	203	22.09	17.46			
1/4/21 13:54:00	204	22.28	17.65			
1/4/21 13:55:00	205	22.49	17.86			
1/4/21 13:56:00	206	22.62	17.99			
1/4/21 13:57:00	207	22.72	18.09			
1/4/21 13:58:00	208	22.83	18.20	35		
1/4/21 13:59:00	209	22.87	18.24			
1/4/21 14:00:00	210	22.92	18.29			
1/4/21 14:02:00	212	22.98	18.35	35		
1/4/21 14:04:00	214	23.07	18.44			
1/4/21 14:06:00	216	23.13	18.50			
1/4/21 14:08:00	218	23.18	18.55	35		

Time Drawdown Data From Step Test On TW03, Rathpatrick, Co. Kilkenny. April 2021.

Actual Time	Time (Mins)	Water Level (m.b.g.l)	Drawdown TW03 metres	Yield m3/hour	Obs TW02 DWLs (mbtoc)	Comments
1/4/21 14:10:00	220	23.24	18.61			
1/4/21 14:15:00	225	23.28	18.65			
1/4/21 14:20:00	230	23.36	18.73	35		
1/4/21 14:25:00	235	23.46	18.83			
1/4/21 14:30:00	240	23.31	18.68			
1/4/21 14:35:00	245	23.52	18.89			
1/4/21 14:40:00	250	23.54	18.91			
1/4/21 14:45:00	255	23.56	18.93			
1/4/21 14:50:00	260	23.58	18.95		3.50	
1/4/21 15:00:00	270	23.62	18.99			
1/4/21 15:10:00	280	23.63	19.00			
1/4/21 15:20:00	290	23.65	19.02			
1/4/21 15:30:00	300	23.66	19.03			Step 4 Start
1/4/21 15:31:00	301	24.72	20.09	40		
1/4/21 15:32:00	302	24.99	20.36			
1/4/21 15:33:00	303	25.20	20.57			
1/4/21 15:34:00	304	25.30	20.67			
1/4/21 15:35:00	305	25.64	21.01	40		
1/4/21 15:36:00	306	26.41	21.78			
1/4/21 15:37:00	307	26.85	22.22			
1/4/21 15:38:00	308	27.04	22.41			
1/4/21 15:39:00	309	27.22	22.59			
1/4/21 15:40:00	310	27.34	22.71			
1/4/21 15:42:00	312	27.57	22.94			
1/4/21 15:44:00	314	27.70	23.07	40		
1/4/21 15:46:00	316	27.78	23.15	40		
1/4/21 15:48:00	318	27.88	23.25			
1/4/21 15:50:00	320	27.96	23.33	40		
1/4/21 15:55:00	325	28.09	23.46	40		
1/4/21 16:00:00	330	28.21	23.58	40		
1/4/21 16:05:00	335	28.30	23.67	40		
1/4/21 16:10:00	340	28.37	23.74	40		
1/4/21 16:15:00	345	28.41	23.78			
1/4/21 16:20:00	350	28.47	23.84			
1/4/21 16:25:00	355	28.48	23.85			
1/4/21 16:30:00	360	28.52	23.89		3.53	
1/4/21 16:40:00	370	28.55	23.92			
1/4/21 16:50:00	380	28.59	23.96			
1/4/21 17:00:00	390	28.64	24.01			
1/4/21 17:10:00	400	28.65	24.02			
1/4/21 17:25:00	415	28.68	24.05			
1/4/21 17:40:00	430	28.68	24.05			
1/4/21 17:55:00	445	28.69	24.06			
1/4/21 18:10:00	460	28.69	24.06			Recovery Start
1/4/21 18:11:00	461	22.08	17.45			
1/4/21 18:12:00	462	18.62	13.99			
1/4/21 18:13:00	463	16.05	11.42			
1/4/21 18:14:00	464	14.32	9.69			
1/4/21 18:15:00	465	14.13	9.50			
1/4/21 18:16:00	466	12.28	7.65			
1/4/21 18:17:00	467	11.58	6.95			
1/4/21 18:18:00	468	11.01	6.38			
1/4/21 18:19:00	469	10.53	5.90			
1/4/21 18:20:00	470	10.14	5.51			
1/4/21 18:22:00	472	10.08	5.45			
1/4/21 18:24:00	474	9.45	4.82			
1/4/21 18:26:00	476	9.14	4.51			
1/4/21 18:28:00	478	8.91	4.28			
1/4/21 18:30:00	480	8.67	4.04			
1/4/21 18:32:00	482	8.44	3.81			
1/4/21 18:34:00	484	8.26	3.63			
1/4/21 18:36:00	486	8.07	3.44			
1/4/21 18:38:00	488	7.90	3.27			
1/4/21 18:40:00	490	7.73	3.10			
1/4/21 18:42:00	492	6.22	1.59			
1/4/21 18:44:00	494	6.54	1.91			
1/4/21 18:46:00	496	5.89	1.26			
1/4/21 18:48:00	498	5.50	0.87			



Time Drawdown Graph From Step Test on TW03, Rathpatrick, Co. Kilkenny. April 2021. *(Linear Format)*



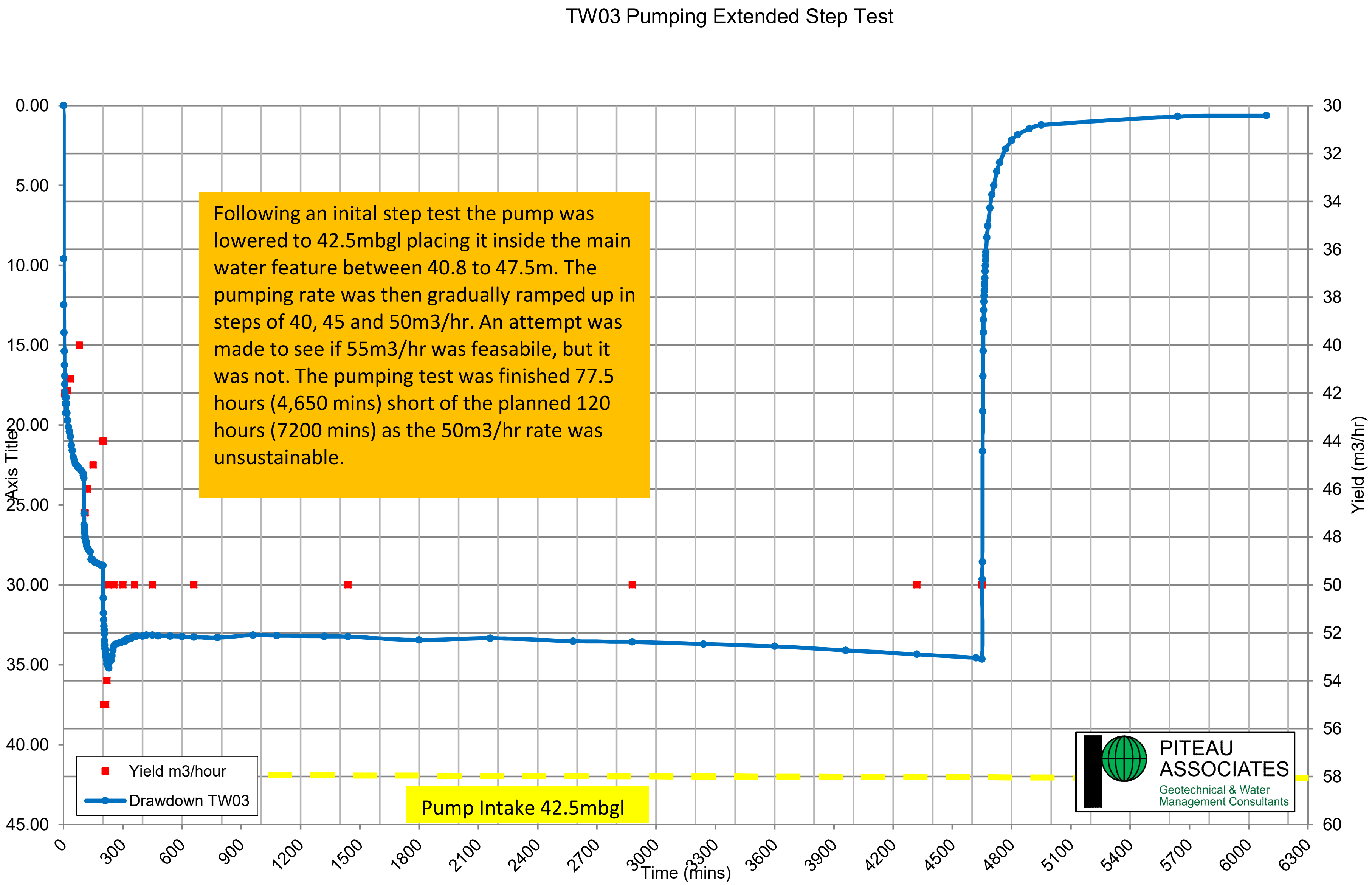
Time Drawdown Graph From Step Test on TW03. Rathpatrick, Co. Kilkenny. March 2021 *(Log-Linear Format)*

Actual Time	Time (Mins)	Drawdown TW03 metres	Yield m3/hour	Drawdown TW02 metres	Comments
6/4/21 10:00:00	0	0.00		0.00	Step 1 Start
6/4/21 10:01:00	1	9.58			
6/4/21 10:02:00	2	12.46			
6/4/21 10:03:00	3	14.21			
6/4/21 10:04:00	4	15.38			
6/4/21 10:05:00	5	16.23			
6/4/21 10:06:00	6	16.92	42		
6/4/21 10:07:00	7	17.43			
6/4/21 10:08:00	8	17.92			
6/4/21 10:09:00	9	18.27			
6/4/21 10:10:00	10	18.66			
6/4/21 10:12:00	12	19.23			1.04
6/4/21 10:14:00	14	18.27			
6/4/21 10:16:00	16	18.66			24.82
6/4/21 10:18:00	18	19.23			
6/4/21 10:20:00	20	19.70	42		
6/4/21 10:25:00	25	20.12			
6/4/21 10:30:00	30	20.41			
6/4/21 10:35:00	35	20.71	41		
6/4/21 10:40:00	40	21.26			
6/4/21 10:45:00	45	21.59			
6/4/21 10:50:00	50	21.99			
6/4/21 10:55:00	55	22.23			
6/4/21 11:00:00	60	22.43			
6/4/21 11:10:00	70	22.59			
6/4/21 11:20:00	80	22.72	40		
6/4/21 11:30:00	90	22.85			
6/4/21 11:40:00	100	23.03			Step 2 Start
6/4/21 11:41:00	101	23.14			
6/4/21 11:42:00	102	23.19			
6/4/21 11:43:00	103	23.32			
6/4/21 11:44:00	104	25.52			
6/4/21 11:45:00	105	26.25	47		
6/4/21 11:46:00	106	26.40			
6/4/21 11:47:00	107	26.65			
6/4/21 11:48:00	108	26.77			
6/4/21 11:49:00	109	26.96			
6/4/21 11:50:00	110	27.10	47		
6/4/21 11:52:00	112	27.18		0.14	
6/4/21 11:54:00	114	27.28			
6/4/21 11:56:00	116	27.38			
6/4/21 11:58:00	118	27.55			
6/4/21 12:00:00	120	27.68	46		
6/4/21 12:05:00	125	27.77			
6/4/21 12:10:00	130	27.88			
6/4/21 12:15:00	135	27.94			
6/4/21 12:20:00	140	28.40			
6/4/21 12:25:00	145	28.42			
6/4/21 12:30:00	150	28.47	45		
6/4/21 12:35:00	155	28.54			
6/4/21 12:40:00	160	28.58			
6/4/21 12:50:00	170	28.63			
6/4/21 13:00:00	180	28.70			
6/4/21 13:10:00	190	28.76			
6/4/21 13:20:00	200	28.79	44		Step 3 Start
6/4/21 13:21:00	201	30.83			
6/4/21 13:22:00	202	31.77			
6/4/21 13:23:00	203	31.77	55		
6/4/21 13:24:00	204	32.19			
6/4/21 13:25:00	205	32.58			
6/4/21 13:26:00	206	32.81			
6/4/21 13:27:00	207	33.06	55		
6/4/21 13:28:00	208	33.50			
6/4/21 13:29:00	209	33.78			
6/4/21 13:30:00	210	34.00			
6/4/21 13:32:00	212	34.16			
6/4/21 13:34:00	214	34.34	55		
6/4/21 13:36:00	216	34.52			
6/4/21 13:38:00	218	34.70			
6/4/21 13:40:00	220	34.95	54		Turbulance c2m above pump
6/4/21 13:45:00	225	35.07			Cut back to 50m3/hr
6/4/21 13:50:00	230	35.20	50		
6/4/21 13:55:00	235	34.81			
6/4/21 14:00:00	240	34.74			

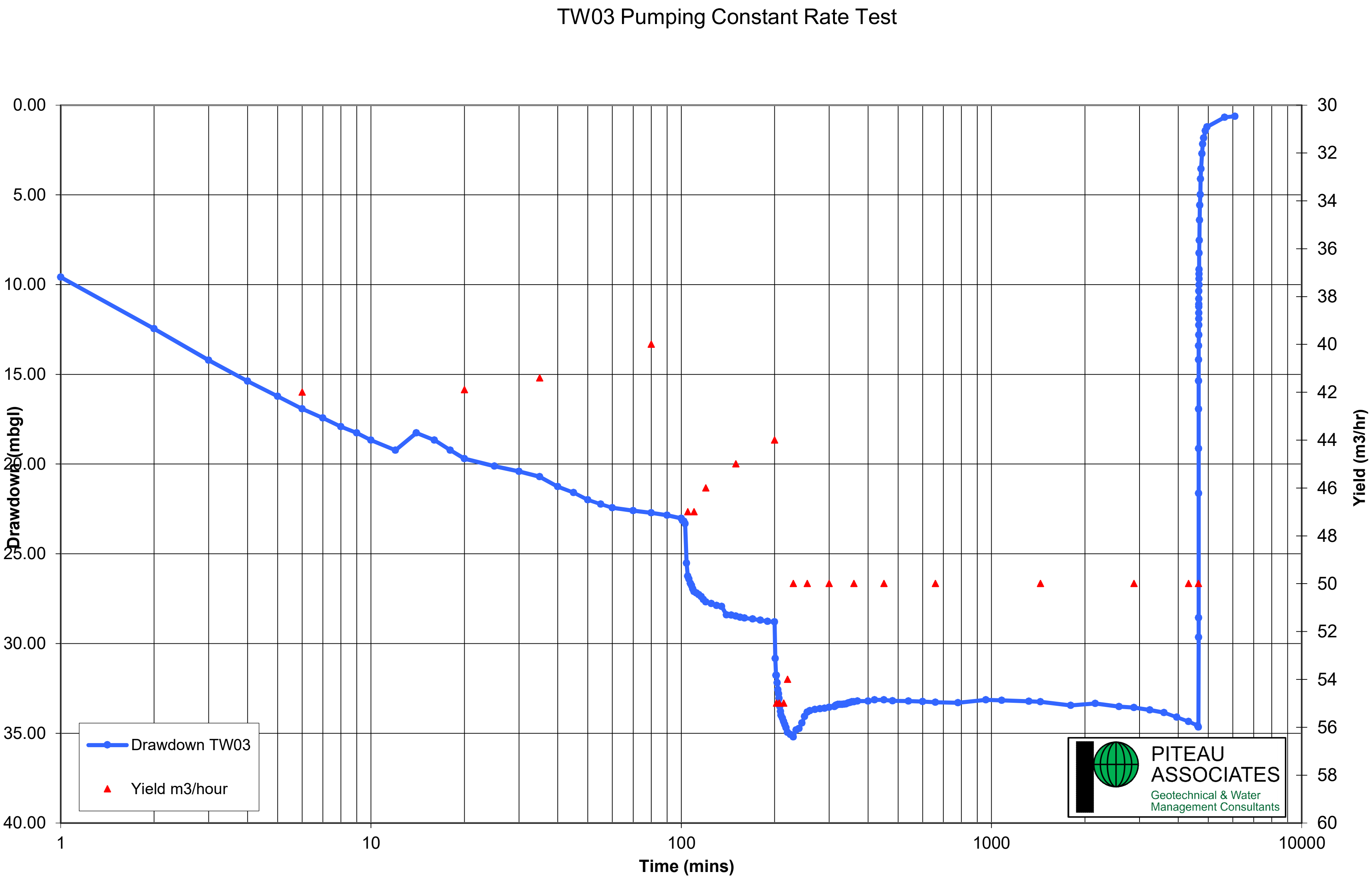
Time Drawdown Data From Extended Step Test On TW03, Rathpatrick, Co. Kilkenny. April 2021.

Actual Time	Time (Mins)	Drawdown TW03 metres	Yield m3/hour	Drawdown TW02 metres	Comments
6/4/21 14:05:00	245	34.43			
6/4/21 14:10:00	250	34.07			
6/4/21 14:15:00	255	33.83	50		
6/4/21 14:20:00	260	33.74			
6/4/21 14:30:00	270	33.67			
6/4/21 14:40:00	280	33.64			
6/4/21 14:50:00	290	33.61			
6/4/21 15:00:00	300	33.55	50		Step 4 Start
6/4/21 15:12:00	312	33.52			
6/4/21 15:14:00	314	33.47			
6/4/21 15:16:00	316	33.44			
6/4/21 15:18:00	318	33.42			
6/4/21 15:20:00	320	33.40			
6/4/21 15:25:00	325	33.39		0.21	
6/4/21 15:30:00	330	33.39			
6/4/21 15:35:00	335	33.38			
6/4/21 15:40:00	340	33.37			
6/4/21 15:45:00	345	33.31			
6/4/21 15:50:00	350	33.29			
6/4/21 15:55:00	355	33.25			
6/4/21 16:00:00	360	33.24	50		
6/4/21 16:10:00	370	33.20			
6/4/21 16:40:00	400	33.20			
6/4/21 17:00:00	420	33.14			
6/4/21 17:30:00	450	33.14	50		
6/4/21 18:00:00	480	33.19			
6/4/21 19:00:00	540	33.21			
6/4/21 20:00:00	600	33.23			
6/4/21 21:00:00	660	33.27	50		
6/4/21 23:00:00	780	33.30			
7/4/21 2:00:00	960	33.14			
7/4/21 4:00:00	1080	33.17			
7/4/21 8:00:00	1320	33.22			
7/4/21 10:00:00	1440	33.24	50	0.47	
7/4/21 16:00:00	1800	33.45			
7/4/21 22:00:00	2160	33.34			
8/4/21 5:00:00	2580	33.52			
8/4/21 10:00:00	2880	33.57	50	0.80	
8/4/21 16:00:00	3240	33.70			
8/4/21 22:00:00	3600	33.85			
9/4/21 4:00:00	3960	34.10			
9/4/21 10:00:00	4320	34.35	50	1.05	
9/4/21 15:00:00	4620	34.57			
9/4/21 15:30:00	4650	34.65	50	1.20	Pumping Stopped.
9/4/21 15:31:00	4651	29.65			
9/4/21 15:32:00	4652	28.56			
9/4/21 15:33:00	4653	21.63			
9/4/21 15:34:00	4654	19.13			
9/4/21 15:35:00	4655	16.93			
9/4/21 15:36:00	4656	15.36			
9/4/21 15:37:00	4657	14.19			
9/4/21 15:38:00	4658	13.41			
9/4/21 15:39:00	4659	12.80			
9/4/21 15:40:00	4660	12.26			
9/4/21 15:41:00	4661	11.91			
9/4/21 15:42:00	4662	11.58			
9/4/21 15:43:00	4663	11.24			
9/4/21 15:44:00	4664	11.10			
9/4/21 15:45:00	4665	10.79			
9/4/21 15:46:00	4666	10.36			
9/4/21 15:47:00	4667	10.01			
9/4/21 15:48:00	4668	9.68			
9/4/21 15:49:00	4669	9.41			
9/4/21 15:50:00	4670	9.16			
9/4/21 15:55:00	4675	8.25			
9/4/21 16:00:00	4680	7.53			
9/4/21 16:10:00	4690	6.41			
9/4/21 16:20:00	4700	5.57			
9/4/21 16:30:00	4710	4.99			
9/4/21 16:45:00	4725	4.11			
9/4/21 17:00:00	4740	3.55			
9/4/21 17:30:00	4770	2.70			
9/4/21 18:00:00	4800	2.17			
9/4/21 18:30:00	4830	1.83			
9/4/21 19:30:00	4890	1.43			
9/4/21 20:30:00	4950	1.21			
10/4/21 8:00:00	5640	0.68		0.88	
10/4/21 15:30:00	6090	0.62		0.84	

Time Drawdown Data From Extended Step Test On TW03, Rathpatrick, Co. Kilkenny. April 2021.



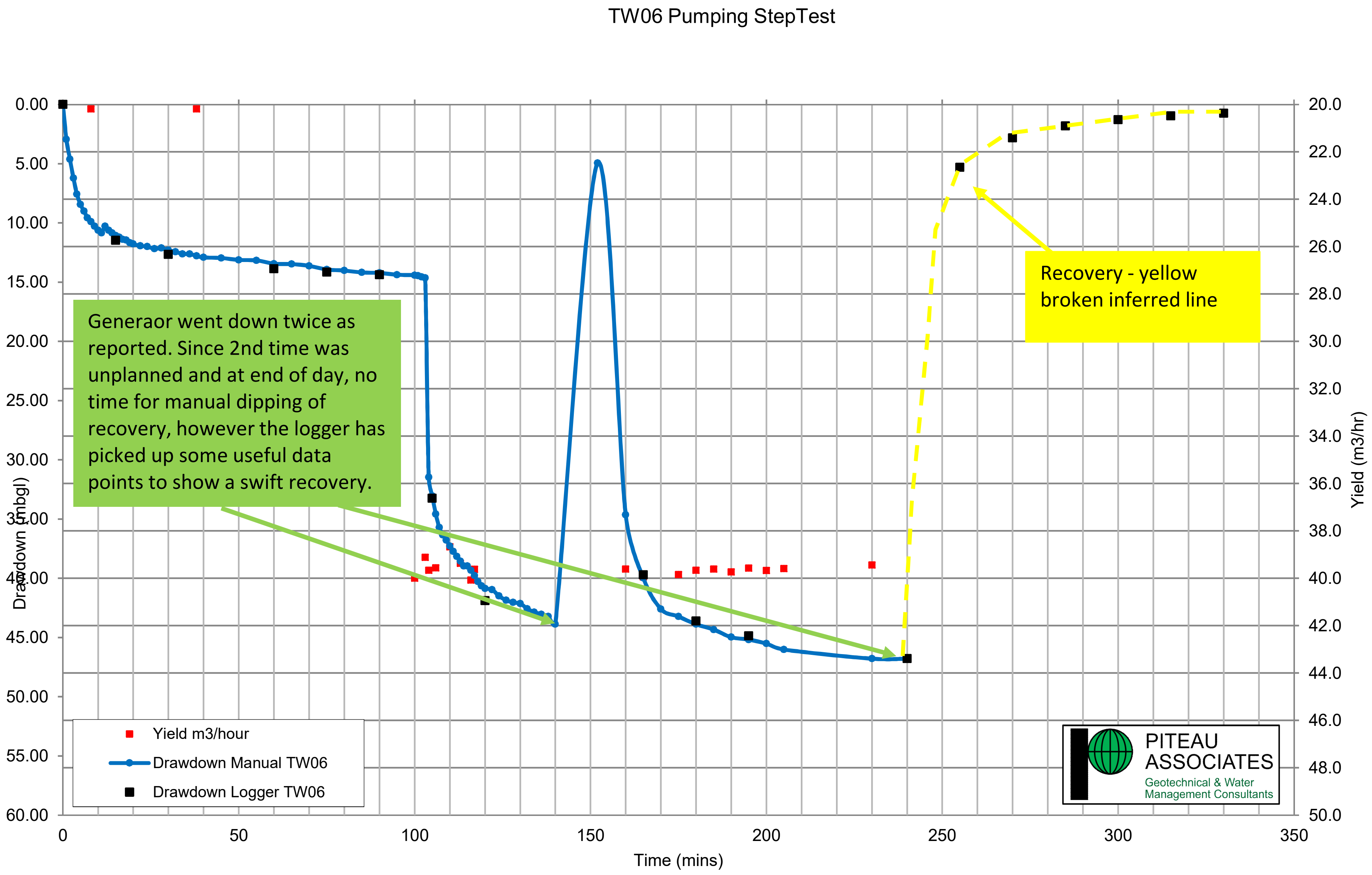
Time Drawdown Graph From Step Test on TW03, Rathpatrick, Co. Kilkenny. April 2021. *(Linear Format)*



Time Drawdown Graph From Step Test on TW03. Rathpatrick, Co. Kilkenny. March 2021 *(Log-Linear Format)*

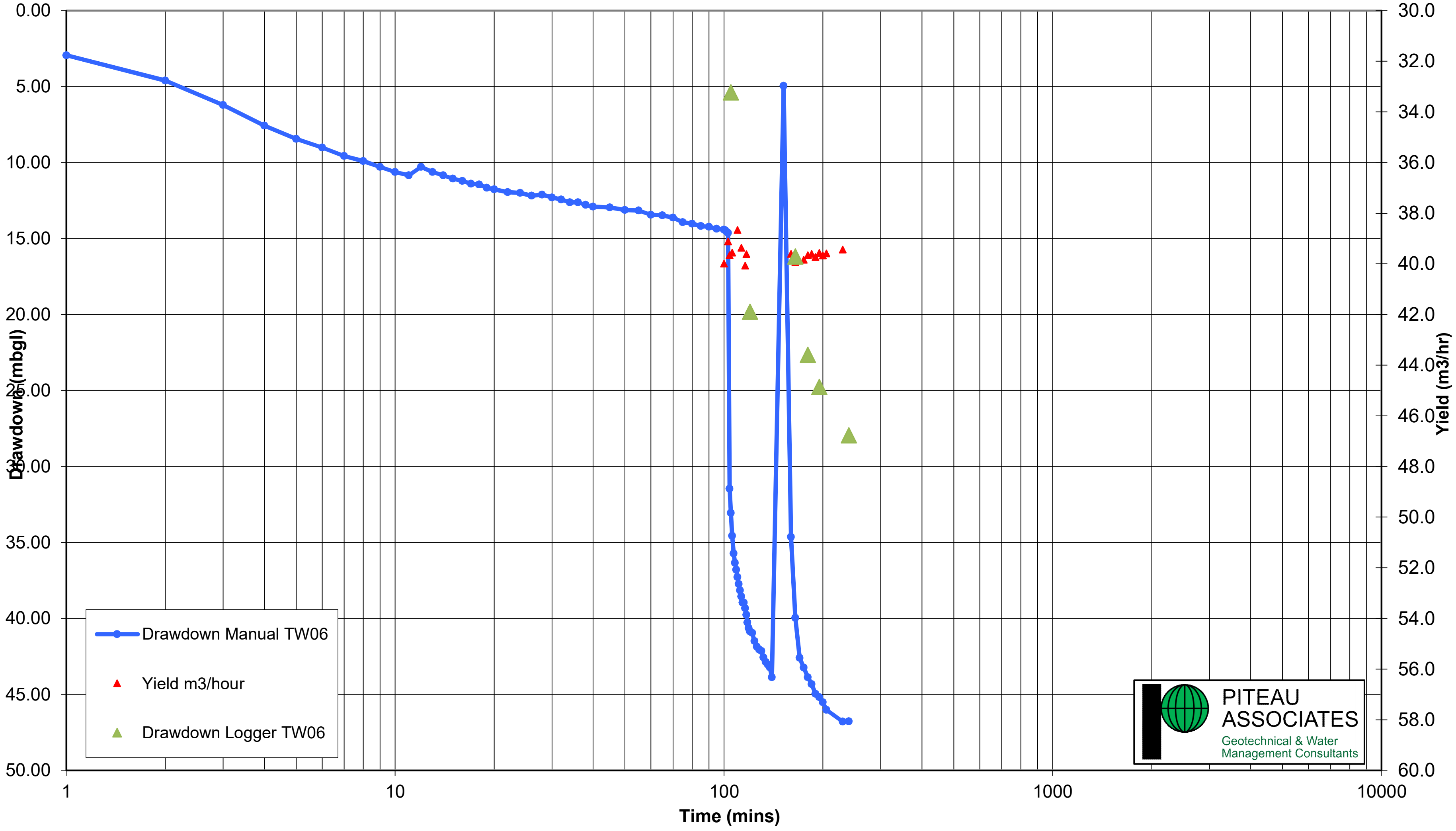
Actual Time	Time (Mins)	Water Level (m.b.g.l)	Drawdown Manual TW06 metres	Yield m3/hour	Drawdown Logger TW06 (m.b.g.l)	Comments
31/5/21 12:00:00	0	5.04	0.00	13.5	0.00	Step 1 Start
31/5/21 12:01:00	1	7.98	2.94			
31/5/21 12:02:00	2	9.65	4.61	18.5		
31/5/21 12:03:00	3	11.26	6.22	19.7		
31/5/21 12:04:00	4	12.61	7.57	19.9		
31/5/21 12:05:00	5	13.48	8.44			
31/5/21 12:06:00	6	14.05	9.01			
31/5/21 12:07:00	7	14.60	9.56			
31/5/21 12:08:00	8	14.94	9.90	20.2		
31/5/21 12:09:00	9	15.32	10.28			
31/5/21 12:10:00	10	15.66	10.62			
31/5/21 12:11:00	11	15.88	10.84	20.0		
31/5/21 12:12:00	12	15.32	10.28			
31/5/21 12:13:00	13	15.66	10.62			
31/5/21 12:14:00	14	15.88	10.84			
31/5/21 12:15:00	15	16.10	11.06		11.47	
31/5/21 12:16:00	16	16.25	11.21			
31/5/21 12:17:00	17	16.43	11.39			
31/5/21 12:18:00	18	16.49	11.45			
31/5/21 12:19:00	19	16.70	11.66			
31/5/21 12:20:00	20	16.81	11.77			
31/5/21 12:22:00	22	16.98	11.94			
31/5/21 12:24:00	24	17.03	11.99			
31/5/21 12:26:00	26	17.22	12.18			
31/5/21 12:28:00	28	17.16	12.12			
31/5/21 12:30:00	30	17.34	12.30		12.65	
31/5/21 12:32:00	32	17.47	12.43			
31/5/21 12:34:00	34	17.66	12.62			
31/5/21 12:36:00	36	17.66	12.62			
31/5/21 12:38:00	38	17.82	12.78	20.2		
31/5/21 12:40:00	40	17.95	12.91			
31/5/21 12:45:00	45	18.00	12.96			
31/5/21 12:50:00	50	18.16	13.12			
31/5/21 12:55:00	55	18.20	13.16			
31/5/21 13:00:00	60	18.48	13.44		13.88	
31/5/21 13:05:00	65	18.51	13.47			
31/5/21 13:10:00	70	18.66	13.62	19.9		
31/5/21 13:15:00	75	18.97	13.93		14.15	
31/5/21 13:20:00	80	19.06	14.02			
31/5/21 13:25:00	85	19.22	14.18			
31/5/21 13:30:00	90	19.26	14.22	19.9	14.38	
31/5/21 13:35:00	95	19.41	14.37			
31/5/21 13:40:00	100	19.45	14.41	40.0		Step 1 Finish, Step 2 Start
31/5/21 13:41:00	101	19.50	14.46			
31/5/21 13:42:00	102	19.60	14.56			
31/5/21 13:43:00	103	19.67	14.63	39.1		
31/5/21 13:44:00	104	36.50	31.46	39.7		
31/5/21 13:45:00	105	38.09	33.05		33.24	
31/5/21 13:46:00	106	39.61	34.57	39.6		
31/5/21 13:47:00	107	40.76	35.72			
31/5/21 13:48:00	108	41.38	36.34			
31/5/21 13:49:00	109	41.83	36.79			
31/5/21 13:50:00	110	42.32	37.28	38.7		
31/5/21 13:51:00	111	42.78	37.74			
31/5/21 13:52:00	112	43.19	38.15			
31/5/21 13:53:00	113	43.60	38.56	39.4		
31/5/21 13:54:00	114	44.00	38.96			
31/5/21 13:55:00	115	44.00	38.96			
31/5/21 13:56:00	116	44.36	39.32	40.1		
31/5/21 13:57:00	117	44.81	39.77	39.6		
31/5/21 13:58:00	118	45.31	40.27			
31/5/21 13:59:00	119	45.68	40.64			
31/5/21 14:00:00	120	45.90	40.86		41.90	
31/5/21 14:02:00	122	46.00	40.96			Genny Down @ 14:22 Hrs
31/5/21 14:04:00	124	46.53	41.49			
31/5/21 14:06:00	126	46.90	41.86			
31/5/21 14:08:00	128	47.08	42.04			
31/5/21 14:10:00	130	47.18	42.14			
31/5/21 14:12:00	132	47.61	42.57			
31/5/21 14:14:00	134	47.90	42.86			
31/5/21 14:16:00	136	48.08	43.04			
31/5/21 14:18:00	138	48.26	43.22			
31/5/21 14:20:00	**140**	48.92	43.88			
31/5/21 14:32:00	152	9.99	4.95			
31/5/21 14:40:00	160	39.68	34.64	39.6		
31/5/21 14:45:00	165	45.01	39.97	40.0	39.71	
31/5/21 14:50:00	170	47.63	42.59			
31/5/21 14:55:00	175	48.27	43.23	39.8		
31/5/21 15:00:00	180	48.92	43.88	39.7	43.60	
31/5/21 15:05:00	185	49.37	44.33	39.6		
31/5/21 15:10:00	190	50.01	44.97	39.7		
31/5/21 15:15:00	195	50.22	45.18	39.6	44.86	
31/5/21 15:20:00	200	50.55	45.51	39.7		
31/5/21 15:25:00	205	51.06	46.02	39.6		
31/5/21 15:50:00	230	51.83	46.79	39.4		Genny Down @ 16:02 Hrs
31/5/21 16:00:00	240	-1.06	46.78		46.78	Recovery
31/5/21 16:15:00	255				5.29	Recovery
31/5/21 16:30:00	270				2.81	Recovery
31/5/21 16:45:00	285				1.80	Recovery
31/5/21 17:00:00	300				1.28	Recovery
31/5/21 17:15:00	315				0.96	Recovery
31/5/21 17:30:00	330				0.74	Recovery

Time Drawdown Data From Step Test On TW06, Rathpatrick, Co. Kilkenny. May 2021.



Time Drawdown Graph From Step Test on TW06, Rathpatrick, Co. Kilkenny. May 2021. *(Linear Format)*

TW06 Pumping Step Test



Time Drawdown Graph From Step Test on TW06. Rathpatrick, Co. Kilkenny. May 2021 *(Log-Linear Format)*

Actual Time	Time	TW6	TW06	Yield	TW06	Comments
		Water Level	Manual Drawdown	TW06	Logger Drawdown	
	(Mins)	(m.b.g.l)	metres	m3/hour	(m)	
1/6/21 11:30:00	0	5.06	0.00	20.0	0.00	Step 1 Start
1/6/21 11:31:00	1	9.98	4.92	20.6		
1/6/21 11:32:00	2	11.88	6.82	19.3		
1/6/21 11:33:00	3	13.05	7.99			
1/6/21 11:34:00	4	13.85	8.79			
1/6/21 11:35:00	5	14.51	9.45			
1/6/21 11:36:00	6	15.22	10.16			
1/6/21 11:37:00	7	15.63	10.57	19.6		
1/6/21 11:38:00	8	16.08	11.02			
1/6/21 11:39:00	9	16.32	11.26			
1/6/21 11:40:00	10	16.52	11.46	19.7		
1/6/21 11:41:00	11	16.78	11.72			
1/6/21 11:42:00	12	16.32	11.26			
1/6/21 11:43:00	13	16.52	11.46			
1/6/21 11:44:00	14	16.78	11.72			
1/6/21 11:45:00	15	16.90	11.84		12.34	
1/6/21 11:46:00	16	17.08	12.02			
1/6/21 11:47:00	17	17.33	12.27	20.0		
1/6/21 11:48:00	18	17.45	12.39			
1/6/21 11:49:00	19	17.62	12.56			
1/6/21 11:50:00	20	17.77	12.71	19.9		
1/6/21 11:52:00	22	17.83	12.77			
1/6/21 11:54:00	24	17.96	12.90			
1/6/21 11:56:00	26	18.03	12.97	20.1		
1/6/21 11:58:00	28	18.21	13.15			
1/6/21 12:00:00	30	18.37	13.31		13.67	
1/6/21 12:02:00	32	18.53	13.47			
1/6/21 12:04:00	34	18.60	13.54			
1/6/21 12:06:00	36	18.77	13.71			
1/6/21 12:08:00	38	18.83	13.77			
1/6/21 12:10:00	40	18.97	13.91			
1/6/21 12:15:00	45	19.05	13.99		14.23	
1/6/21 12:20:00	50	19.17	14.11			
1/6/21 12:25:00	55	19.24	14.18	19.8		
1/6/21 12:30:00	60	19.35	14.29	20.0	14.72	
1/6/21 12:35:00	65	19.40	14.34			
1/6/21 12:40:00	70	19.57	14.51	20.0		
1/6/21 12:45:00	75	19.80	14.74	20.0	15.10	
1/6/21 12:50:00	80	19.89	14.83			
1/6/21 12:55:00	85	20.03	14.97			
1/6/21 13:00:00	90	20.21	15.15		15.37	
1/6/21 13:05:00	95	20.28	15.22			
1/6/21 13:10:00	100	20.33	15.27	20.0		
1/6/21 15:00:00	210	20.47	15.41	30.0		Step 2
1/6/21 15:01:00	211	20.47	15.41	30.0		
1/6/21 15:02:00	212	20.52	15.46			
1/6/21 15:03:00	213	20.57	15.51			
1/6/21 15:04:00	214	26.91	21.85	29.8		Generator went down at 13:36, generator operational by 14:37. Resumed pumping to get back to a drawdown of 20.33mbgl and continue testing, hence discrepency in timeline.
1/6/21 15:05:00	215	27.64	22.58			
1/6/21 15:06:00	216	28.08	23.02			
1/6/21 15:07:00	217	28.55	23.49			
1/6/21 15:08:00	218	29.02	23.96	29.6		
1/6/21 15:09:00	219	29.37	24.31			
1/6/21 15:10:00	220	29.67	24.61			
1/6/21 15:11:00	221	30.08	25.02	30.0		
1/6/21 15:12:00	222	30.41	25.35			
1/6/21 15:13:00	223	30.53	25.47	29.8		
1/6/21 15:14:00	224	30.76	25.70			
1/6/21 15:15:00	225	30.76	25.70		25.82	
1/6/21 15:16:00	226	30.87	25.81			
1/6/21 15:17:00	227	31.06	26.00			
1/6/21 15:18:00	228	31.28	26.22			
1/6/21 15:19:00	229	31.39	26.33	30.1		
1/6/21 15:20:00	230	31.60	26.54			
1/6/21 15:22:00	232	31.69	26.63			
1/6/21 15:24:00	234	31.80	26.74	30.0		
1/6/21 15:26:00	236	32.04	26.98			
1/6/21 15:28:00	238	32.13	27.07			
1/6/21 15:30:00	240	32.36	27.30		27.27	
1/6/21 15:32:00	242	32.42	27.36			
1/6/21 15:34:00	244	32.48	27.42			
1/6/21 15:36:00	246	32.68	27.62			
1/6/21 15:38:00	248	32.74	27.68			
1/6/21 15:40:00	250	32.99	27.93			
1/6/21 15:45:00	255	33.10	28.04		28.04	
1/6/21 15:50:00	260	33.40	28.34			

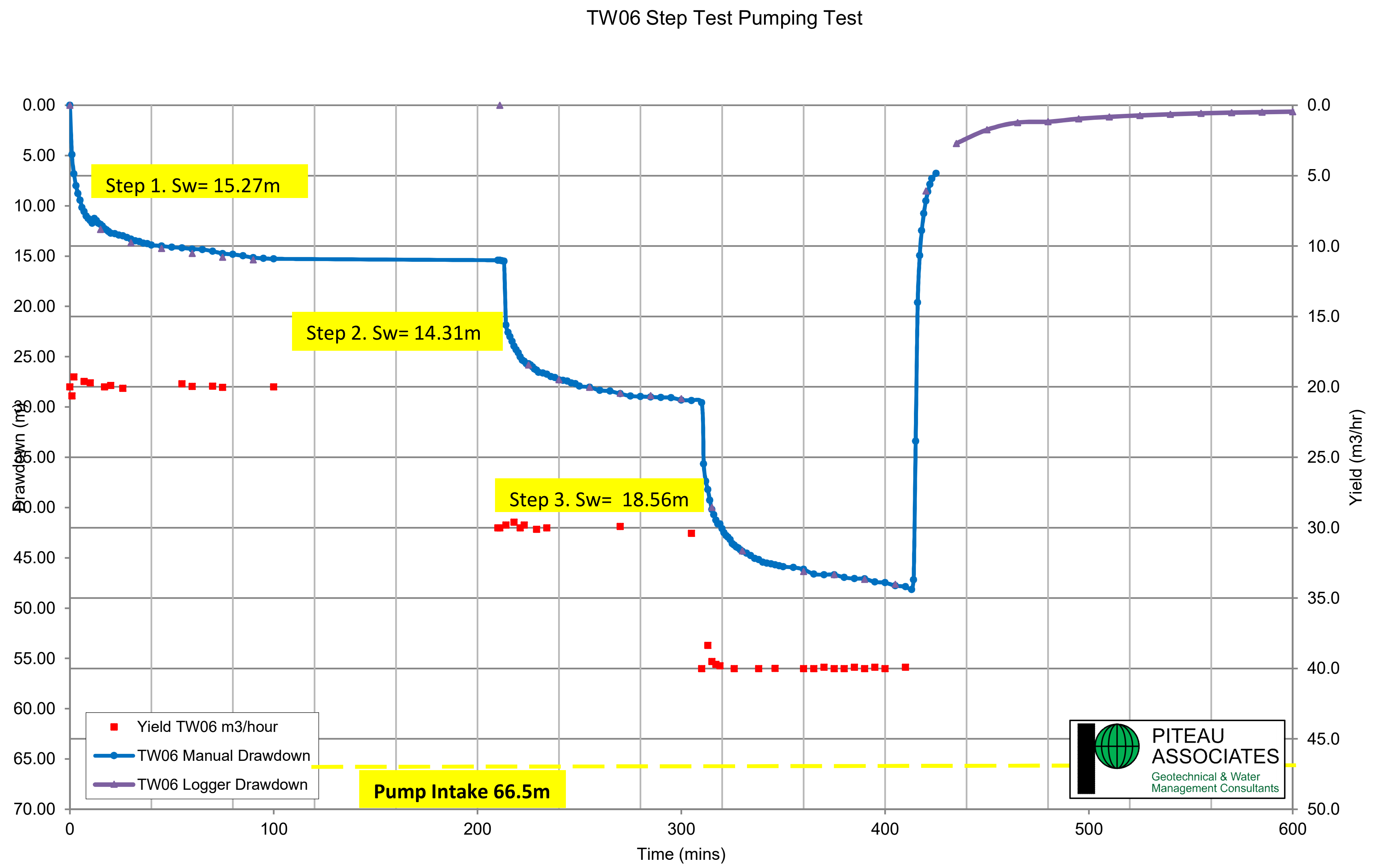
Time Drawdown Data From 2nd Step Test On TW06, Rathpatrick, Co. Kilkenny. June 2021.

Actual Time	Time	TW6	TW06	Yield	TW06	Comments
		Water Level	Manual Drawdown	TW06	Logger Drawdown	
	(Mins)	(m.b.g.l)	metres	m3/hour	(m)	
1/6/21 15:55:00	265	33.48	28.42			
1/6/21 16:00:00	270	33.73	28.67	29.9	28.63	
1/6/21 16:05:00	275	33.97	28.91			
1/6/21 16:10:00	280	34.02	28.96			
1/6/21 16:15:00	285	34.06	29.00		28.87	
1/6/21 16:20:00	290	34.11	29.05			
1/6/21 16:25:00	295	34.13	29.07			
1/6/21 16:30:00	300	34.37	29.31		29.18	
1/6/21 16:35:00	305	34.41	29.35	30.4		
1/6/21 16:40:00	310	34.64	29.58	40.0		Step 3 Start
1/6/21 16:41:00	311	40.72	35.66			
1/6/21 16:42:00	312	42.45	37.39			
1/6/21 16:43:00	313	43.26	38.20	38.4		
1/6/21 16:44:00	314	44.32	39.26			
1/6/21 16:45:00	315	45.25	40.19	39.5	39.99	
1/6/21 16:46:00	316	45.77	40.71			
1/6/21 16:47:00	317	46.31	41.25	39.7		
1/6/21 16:48:00	318	46.68	41.62			
1/6/21 16:49:00	319	46.68	41.62	39.8		
1/6/21 16:50:00	320	47.16	42.10			
1/6/21 16:51:00	321	47.56	42.50			
1/6/21 16:52:00	322	47.85	42.79			
1/6/21 16:53:00	323	48.01	42.95			
1/6/21 16:54:00	324	48.25	43.19			
1/6/21 16:55:00	325	48.65	43.59			
1/6/21 16:56:00	326	48.79	43.73	40.0		
1/6/21 16:57:00	327	48.97	43.91			
1/6/21 16:58:00	328	49.08	44.02			
1/6/21 16:59:00	329	49.27	44.21			
1/6/21 17:00:00	330	49.41	44.35		44.29	
1/6/21 17:02:00	332	49.59	44.53			
1/6/21 17:04:00	334	49.82	44.76			
1/6/21 17:06:00	336	50.11	45.05			
1/6/21 17:08:00	338	50.23	45.17	40.0		
1/6/21 17:10:00	340	50.50	45.44			
1/6/21 17:12:00	342	50.58	45.52			
1/6/21 17:14:00	344	50.66	45.60			
1/6/21 17:16:00	346	50.76	45.70	40.0		
1/6/21 17:18:00	348	50.85	45.79			
1/6/21 17:20:00	350	50.95	45.89			
1/6/21 17:25:00	355	51.01	45.95			
1/6/21 17:30:00	360	51.21	46.15	40.0	46.35	
1/6/21 17:35:00	365	51.67	46.61	40.0		
1/6/21 17:40:00	370	51.73	46.67	39.9		
1/6/21 17:45:00	375	51.73	46.67	40.0	46.66	
1/6/21 17:50:00	380	52.01	46.95	40.0		
1/6/21 17:55:00	385	52.13	47.07	39.9		
1/6/21 18:00:00	390	52.14	47.08	40.0	47.13	
1/6/21 18:05:00	395	52.45	47.39	39.9		
1/6/21 18:10:00	400	52.53	47.47	40.0		
1/6/21 18:15:00	405	52.83	47.77		47.63	
1/6/21 18:20:00	410	52.93	47.87	39.9		
1/6/21 18:23:00	413	53.20	48.14			Recovery Manual
1/6/21 18:24:00	414	52.23	47.17			Recovery Manual
1/6/21 18:25:00	415	38.45	33.39			Recovery Manual
1/6/21 18:26:00	416	24.67	19.61			Recovery Manual
1/6/21 18:27:00	417	20.00	14.94			Recovery Manual
1/6/21 18:28:00	418	17.53	12.47			Recovery Manual
1/6/21 18:29:00	419	15.83	10.77			Recovery Manual
1/6/21 18:30:00	420	14.58	9.52		8.51	Recovery Manual
1/6/21 18:31:00	421	13.65	8.59			Recovery Manual
1/6/21 18:32:00	422	12.91	7.85			Recovery Manual
1/6/21 18:33:00	423	12.35	7.29			Recovery Manual
1/6/21 18:35:00	425	11.83	6.77			Recovery Manual
1/6/21 18:45:00	435	8.70			3.80	Recovery Logger
1/6/21 19:00:00	450	7.33			2.43	Recovery Logger
1/6/21 19:15:00	465	6.62			1.72	Recovery Logger
1/6/21 19:30:00	480	6.54			1.64	Recovery Logger
1/6/21 19:45:00	495	6.25			1.35	Recovery Logger
1/6/21 20:00:00	510	6.05			1.15	Recovery Logger
1/6/21 20:15:00	525	5.91			1.01	Recovery Logger
1/6/21 20:30:00	540	5.80			0.90	Recovery Logger
1/6/21 20:45:00	555	5.71			0.81	Recovery Logger
1/6/21 21:00:00	570	5.63			0.73	Recovery Logger
1/6/21 21:15:00	585	5.58			0.68	Recovery Logger
1/6/21 21:30:00	600	5.53			0.63	Recovery Logger
1/6/21 21:45:00	615	5.49			0.59	Recovery Logger
1/6/21 22:00:00	630	5.45			0.55	Recovery Logger

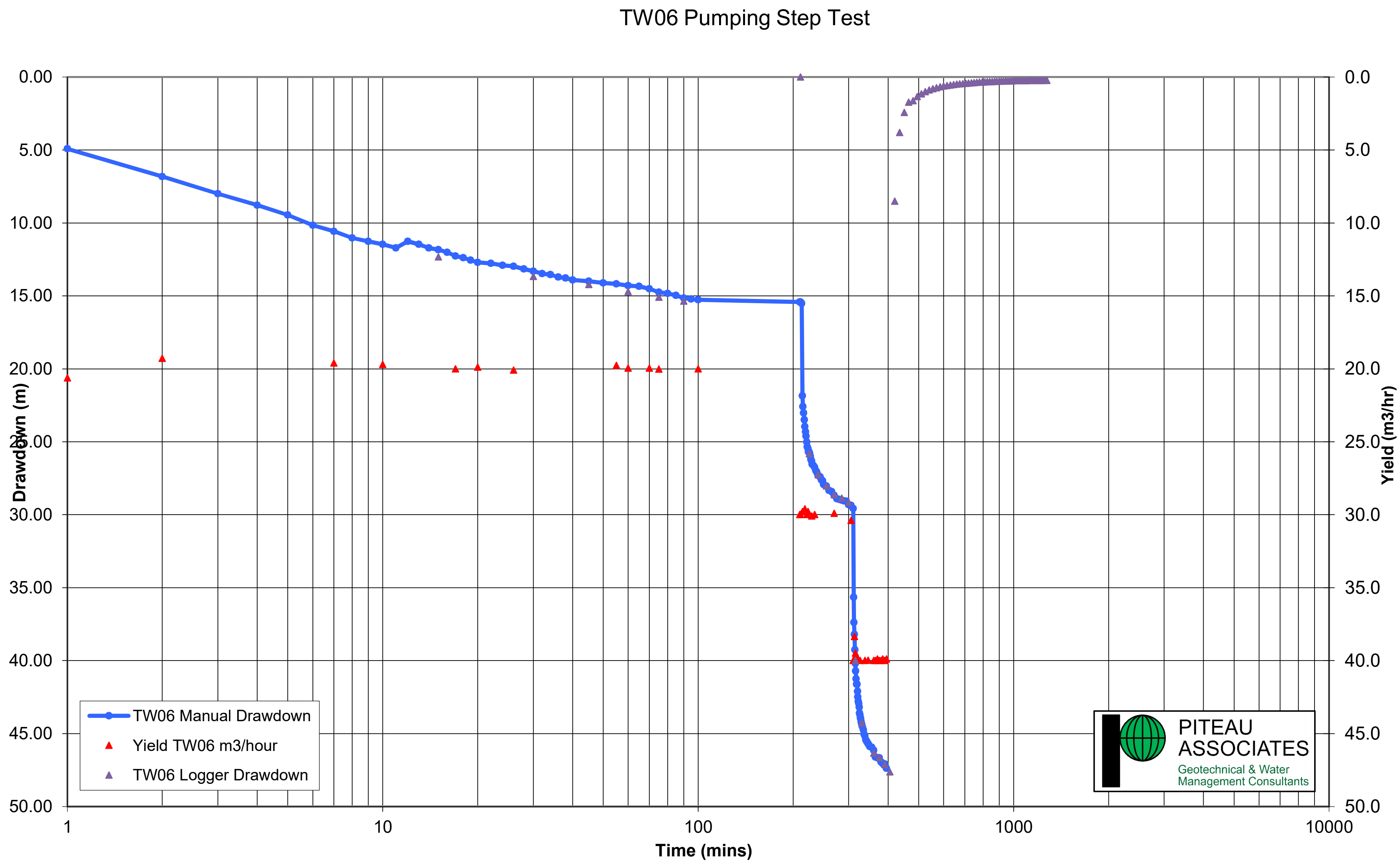
Time Drawdown Data From 2nd Step Test On TW06, Rathpatrick, Co. Kilkenny. June 2021.

Actual Time	Time	TW6	TW06	Yield	TW06	Comments
		Water Level	Manual Drawdown	TW06	Logger Drawdown	
	(Mins)	(m.b.g.l)	metres	m3/hour	(m)	
1/6/21 22:15:00	645	5.42			0.52	Recovery Logger
1/6/21 22:30:00	660	5.40			0.50	Recovery Logger
1/6/21 22:45:00	675	5.37			0.47	Recovery Logger
1/6/21 23:00:00	690	5.35			0.45	Recovery Logger
1/6/21 23:15:00	705	5.33			0.43	Recovery Logger
1/6/21 23:30:00	720	5.32			0.42	Recovery Logger
1/6/21 23:45:00	735	5.30			0.40	Recovery Logger
2/6/21 0:00:00	750	5.29			0.39	Recovery Logger
2/6/21 0:15:00	765	5.27			0.37	Recovery Logger
2/6/21 0:30:00	780	5.26			0.36	Recovery Logger
2/6/21 0:45:00	795	5.25			0.35	Recovery Logger
2/6/21 1:00:00	810	5.24			0.34	Recovery Logger
2/6/21 1:15:00	825	5.23			0.33	Recovery Logger
2/6/21 1:30:00	840	5.22			0.32	Recovery Logger
2/6/21 1:45:00	855	5.21			0.31	Recovery Logger
2/6/21 2:00:00	870	5.21			0.31	Recovery Logger
2/6/21 2:15:00	885	5.20			0.30	Recovery Logger
2/6/21 2:30:00	900	5.19			0.29	Recovery Logger
2/6/21 2:45:00	915	5.19			0.29	Recovery Logger
2/6/21 3:00:00	930	5.18			0.28	Recovery Logger
2/6/21 3:15:00	945	5.18			0.28	Recovery Logger
2/6/21 3:30:00	960	5.17			0.27	Recovery Logger
2/6/21 3:45:00	975	5.17			0.27	Recovery Logger
2/6/21 4:00:00	990	5.17			0.27	Recovery Logger
2/6/21 4:15:00	1005	5.16			0.26	Recovery Logger
2/6/21 4:30:00	1020	5.16			0.26	Recovery Logger
2/6/21 4:45:00	1035	5.16			0.26	Recovery Logger
2/6/21 5:00:00	1050	5.15			0.25	Recovery Logger
2/6/21 5:15:00	1065	5.15			0.25	Recovery Logger
2/6/21 5:30:00	1080	5.15			0.25	Recovery Logger
2/6/21 5:45:00	1095	5.15			0.25	Recovery Logger
2/6/21 6:00:00	1110	5.15			0.25	Recovery Logger
2/6/21 6:15:00	1125	5.14			0.24	Recovery Logger
2/6/21 6:30:00	1140	5.14			0.24	Recovery Logger
2/6/21 6:45:00	1155	5.14			0.24	Recovery Logger
2/6/21 7:00:00	1170	5.14			0.24	Recovery Logger
2/6/21 7:15:00	1185	5.14			0.24	Recovery Logger
2/6/21 7:30:00	1200	5.13			0.23	Recovery Logger
2/6/21 7:45:00	1215	5.14			0.24	Recovery Logger
2/6/21 8:00:00	1230	5.13			0.23	Recovery Logger
2/6/21 8:15:00	1245	5.13			0.23	Recovery Logger
2/6/21 8:30:00	1260	5.13			0.23	Recovery Logger
2/6/21 8:45:00	1275	5.13	0.07		0.23	Recovery Logger

Time Drawdown Data From 2nd Step Test On TW06, Rathpatrick, Co. Kilkenny. June 2021.



Time Drawdown Graph From Step Test 2 on TW06, Rathpatrick, Co. Kilkenny. June 2021. *(Linear Format)*



Time Drawdown Graph From Step Test on TW06. Rathpatrick, Co. Kilkenny. June 2021 *(Log-Linear Format)*

APPENDIX 2
PUMPING TEST DATA & GRAPHS
CONSTANT RATE TESTS

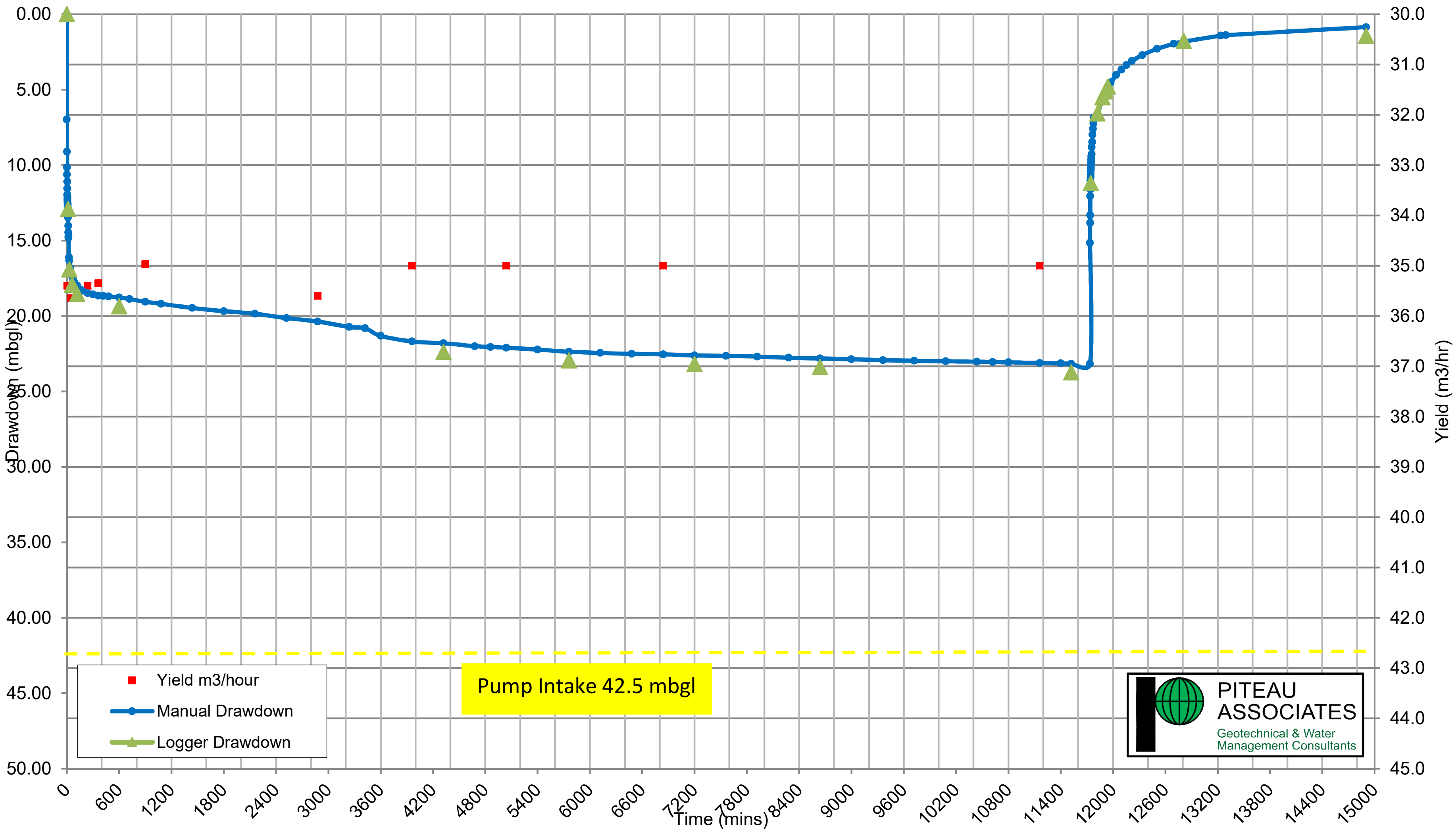
Time	Time	Water Level	Manual Drawdown	Logger Water level	Logger Drawdown	Yield	Comments
		TW03					
Hrs/Mins/Secs	(Mins)	(m.b.g.l)	metres	(m.b.g.l)	metres	m3/hour	
3/6/21 11:00:00	0	5.79	0.00	5.21	0.00		at zero minutes on totaliser
3/6/21 11:01:00	1	12.77	6.98				
3/6/21 11:02:00	2	14.91	9.12				Pump intake 42.5mbgl
3/6/21 11:03:00	3	15.94	10.15				
3/6/21 11:04:00	4	16.42	10.63				
3/6/21 11:05:00	5	16.89	11.10				
3/6/21 11:06:00	6	17.34	11.55			35.4	
3/6/21 11:07:00	7	17.74	11.95				
3/6/21 11:08:00	8	17.90	12.11				
3/6/21 11:09:00	9	18.05	12.26				
3/6/21 11:10:00	10	18.21	12.42				
3/6/21 11:11:00	11	18.36	12.57				
3/6/21 11:12:00	12	18.43	12.64				
3/6/21 11:13:00	13	18.55	12.76				
3/6/21 11:14:00	14	18.72	12.93				
3/6/21 11:15:00	15	18.72	12.93	18.12	12.91		
3/6/21 11:16:00	16	19.27	13.48				
3/6/21 11:17:00	17	19.82	14.03				
3/6/21 11:18:00	18	20.26	14.47				
3/6/21 11:19:00	19	20.50	14.71				
3/6/21 11:20:00	20	20.61	14.82				
3/6/21 11:25:00	25	21.91	16.12				
3/6/21 11:30:00	30	22.13	16.34	22.13	16.92		
3/6/21 11:40:00	40	22.62	16.83				
3/6/21 11:50:00	50	22.96	17.17			35.7	
3/6/21 12:00:00	60	23.15	17.36	23.15	17.94		
3/6/21 12:15:00	75	23.40	17.61				
3/6/21 12:30:00	90	23.58	17.79				
3/6/21 13:00:00	120	23.77	17.98	23.77	18.56		
3/6/21 13:30:00	150	24.01	18.22				TW3 WQ1. 13:32
3/6/21 14:00:00	180	24.12	18.33				
3/6/21 15:00:00	240	24.27	18.48			35.4	
3/6/21 16:00:00	300	24.37	18.58				
3/6/21 17:00:00	360	24.45	18.66			35.4	
3/6/21 18:00:00	420	24.47	18.68				
3/6/21 19:00:00	480	24.49	18.70				TW3 WQ2. 19:38
3/6/21 21:00:00	600	24.57	18.78	24.57	19.36		
3/6/21 23:00:00	720	24.67	18.88				
4/6/21 2:00:00	900	24.85	19.06			35.0	
4/6/21 5:00:00	1080	24.98	19.19				
4/6/21 11:00:00	1440	25.26	19.47				TW3 WQ3. 10:50
4/6/21 17:00:00	1800	25.47	19.68				
4/6/21 23:00:00	2160	25.64	19.85				
5/6/21 5:00:00	2520	25.93	20.14				
5/6/21 11:00:00	2880	26.16	20.37			35.6	
5/6/21 17:00:00	3240	26.52	20.73				TW3 WQ4. 16:49
5/6/21 20:00:00	3420	26.60	20.81				
5/6/21 23:00:00	3600	27.11	21.32				
6/6/21 5:00:00	3960	27.48	21.69			35.0	
6/6/21 11:00:00	4320	27.60	21.81	27.60	22.39		
6/6/21 17:00:00	4680	27.79	22.00				
6/6/21 20:00:00	4860	27.84	22.05				
6/6/21 23:00:00	5040	27.89	22.10			35.0	
7/6/21 5:00:00	5400	28.02	22.23				
7/6/21 11:00:00	5760	28.16	22.37	28.16	22.95		TW3 WQ5. 10:58
7/6/21 17:00:00	6120	28.24	22.45				
7/6/21 23:00:00	6480	28.30	22.51				
8/6/21 5:00:00	6840	28.33	22.54			35.0	
8/6/21 11:00:00	7200	28.40	22.61	28.40	23.19		
8/6/21 17:00:00	7560	28.44	22.65				TW3 WQ6. 14:29
8/6/21 23:00:00	7920	28.48	22.69				
9/6/21 5:00:00	8280	28.56	22.77				
9/6/21 11:00:00	8640	28.60	22.81	28.60	23.39		Averaging 34.55 for full test
9/6/21 17:00:00	9000	28.65	22.86				
9/6/21 23:00:00	9360	28.72	22.93				
10/6/21 5:00:00	9720	28.75	22.96				
10/6/21 11:00:00	10080	28.79	23.00				
10/6/21 17:00:00	10440	28.82	23.03				
10/6/21 20:00:00	10620	28.84	23.05				
10/6/21 23:00:00	10800	28.86	23.07				
11/6/21 5:00:00	11160	28.9	23.11			35	
11/6/21 9:00:00	11400	28.93	23.14				
11/6/21 11:00:00	11520	28.95	23.16	28.95	23.74		TW3 Lab Sample. 11:05
11/6/21 14:36:00	11736	28.96	23.17				Genny Breaks down.
11/6/21 14:37:00	11737	20.94	15.15				Recovery starts
11/6/21 14:38:00	11738	19.61	13.82				
11/6/21 14:39:00	11739	19.11	13.32				
11/6/21 14:40:00	11740	17.85	12.06				
11/6/21 14:41:00	11741	17.4	11.61				
11/6/21 14:42:00	11742	17.07	11.28				
11/6/21 14:43:00	11743	16.81	11.02				
11/6/21 14:44:00	11744	16.6	10.81				
11/6/21 14:45:00	11745	16.41	10.62	16.41	11.20		
11/6/21 14:46:00	11746	16.21	10.42				
11/6/21 14:47:00	11747	16.04	10.25				
11/6/21 14:48:00	11748	15.89	10.1				
11/6/21 14:49:00	11749	15.73	9.94				
11/6/21 14:50:00	11750	15.6	9.81				
11/6/21 14:51:00	11751	15.45	9.66				
11/6/21 14:52:00	11752	15.37	9.58				

Time Drawdown Data From Constant Rate Test TW03, Rathpatrick, Co. Kilkenny (June 2021).

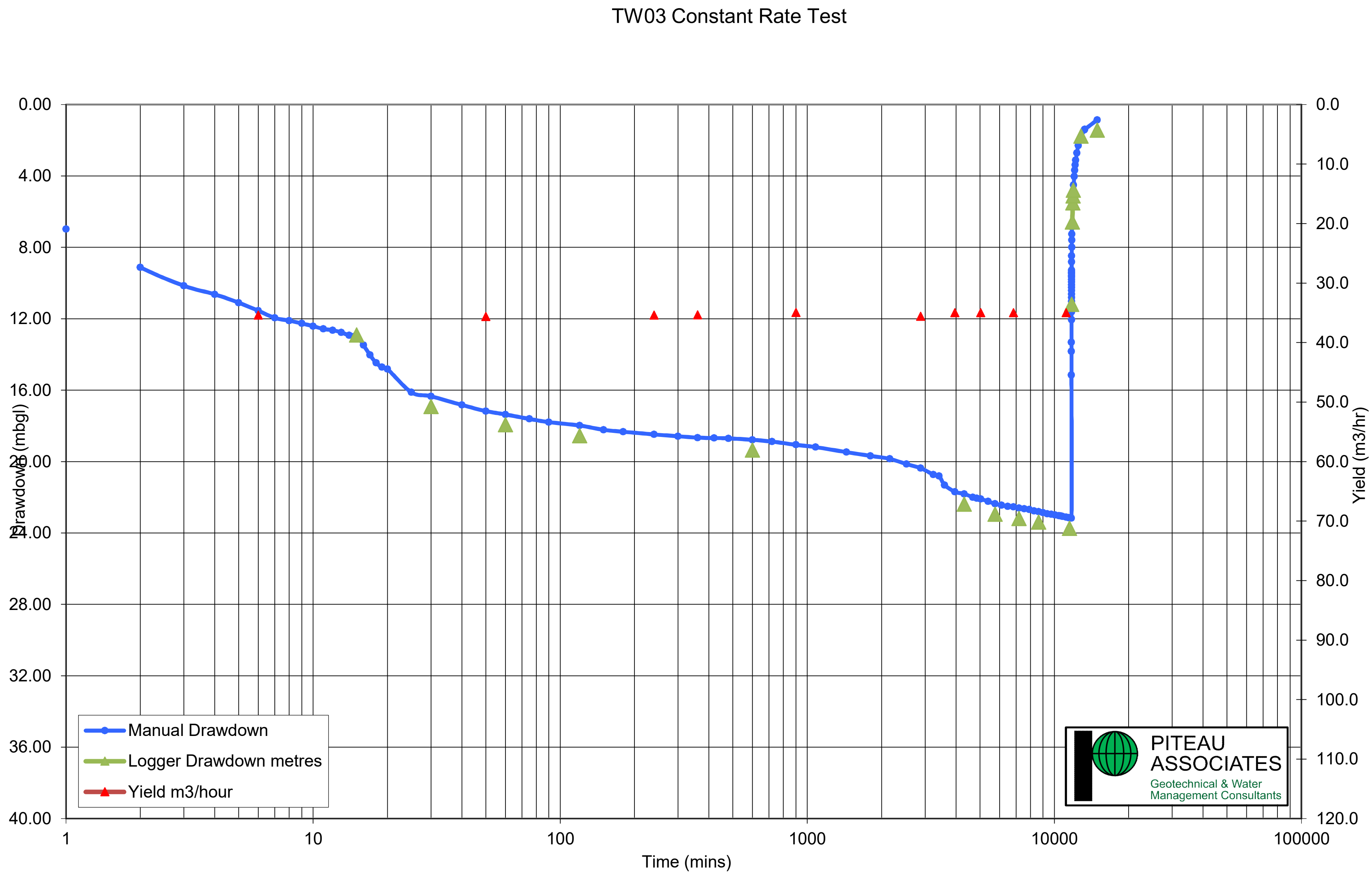
Time	Time	Water Level	Manual Drawdown	Logger Water level	Logger Drawdown	Yield	Comments
		TW03					
Hrs/Mins/Secs	(Mins)	(m.b.g.l)	metres	(m.b.g.l)	metres	m3/hour	
11/6/21 14:53:00	11753	15.25	9.46				
11/6/21 14:54:00	11754	15.18	9.39				
11/6/21 14:55:00	11755	15.07	9.28				
11/6/21 14:56:00	11756	14.6	8.81				
11/6/21 15:01:00	11761	14.27	8.48				
11/6/21 15:06:00	11766	13.78	7.99				
11/6/21 15:11:00	11771	13.38	7.59				
11/6/21 15:16:00	11776	13.04	7.25				
11/6/21 15:21:00	11781	12.64	6.85				
11/6/21 16:00:00	11820	12.46	6.67	11.80	6.59		
11/6/21 17:00:00	11880	11.36	5.57	10.72	5.51		
11/6/21 17:30:00	11910	11.00	5.21	10.34	5.13		
11/6/21 18:00:00	11940	10.61	4.82	10.01	4.80		
11/6/21 18:36:00	11976	10.30	4.51				
11/6/21 19:36:00	12036	9.82	4.03				
11/6/21 20:36:00	12096	9.47	3.68				
11/6/21 21:36:00	12156	9.17	3.38				
11/6/21 22:36:00	12216	8.9	3.11				
12/6/21 0:36:00	12336	8.5	2.71				
12/6/21 3:26:00	12506	8.09	2.3				
12/6/21 6:36:00	12696	7.75	1.96				
12/6/21 8:30:00	12810	7.61	1.82	6.99	1.78		
12/6/21 15:36:00	13236	7.21	1.42				
12/6/21 16:36:00	13296	7.18	1.39				
13/6/21 19:23:00	14903	6.65	0.86	6.65	1.44		

Time Drawdown Data From Constant Rate Test TW03, Rathpatrick, Co. Kilkenny (June 2021).

TW03 Constant RateTest



Time Drawdown Graph From Constant rate Test at TW03 Rathpatrick, Co. Kilkenny. June 2021. *(Linear Format)*



Time Drawdown Graph Constant Rate Test for TW03. Rathpatrick, Co. Kilkenny. June 2021. *(Log-Linear Format)*

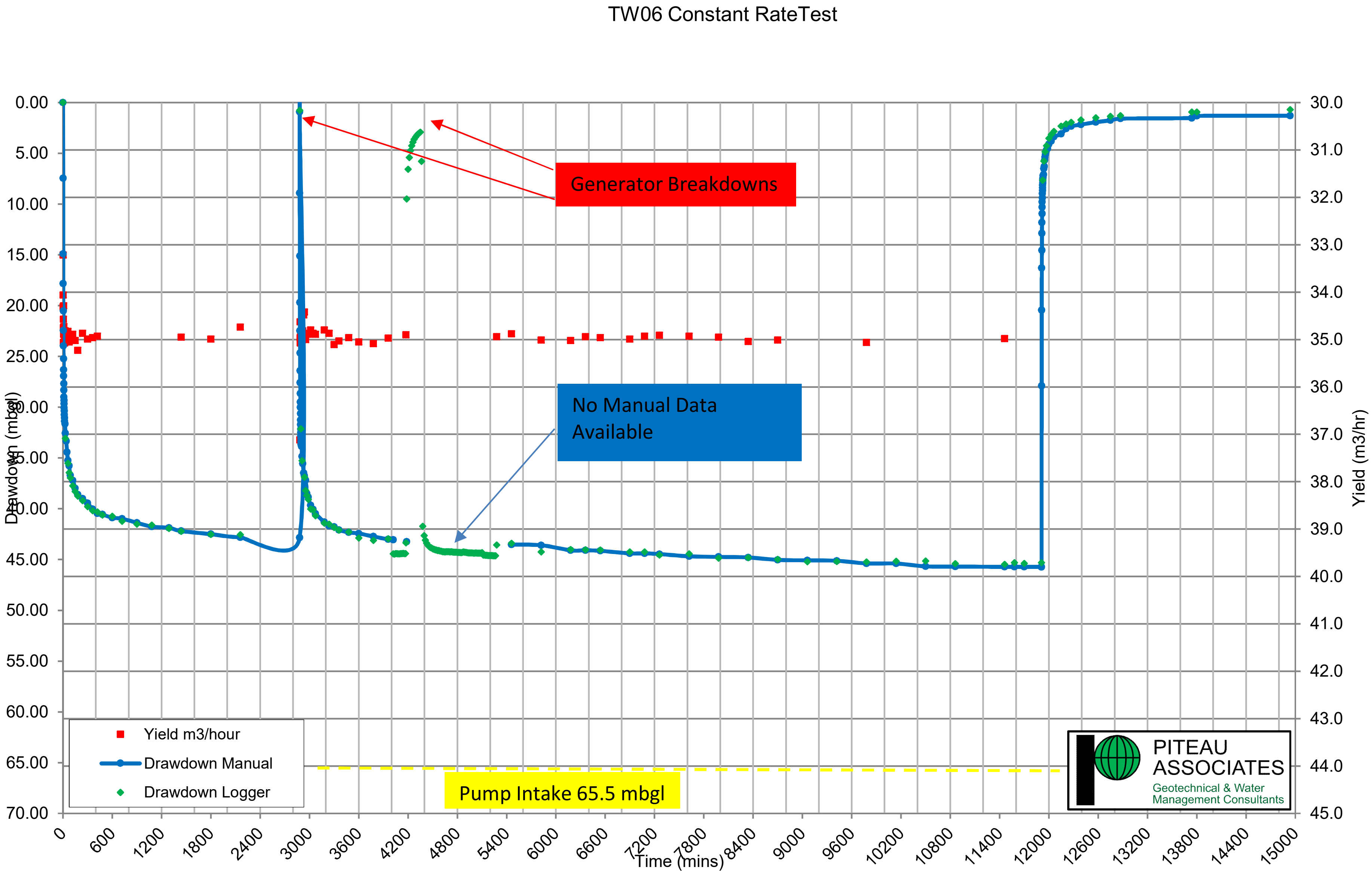
Date/Time Hrs/Mins/Secs	Time (Mins)	Water Level Manual (m.b.g.l)	Drawdown Manual metres	Water Level TW6 Logger (m.b.g.l)	Drawdown Logger metres	Yield m3/hour	Comments
3/6/21 10:00:00	0	5.09	0.00	4.25	0.00		
3/6/21 10:01:00	1	12.54	7.45				
3/6/21 10:02:00	2	19.99	14.90			34.1	
3/6/21 10:03:00	3	22.91	17.82			33.2	
3/6/21 10:04:00	4	25.61	20.52			34.3	
3/6/21 10:05:00	5	27.54	22.45			34.6	
3/6/21 10:06:00	6	29.04	23.95			34.8	
3/6/21 10:07:00	7	30.32	25.23			35.1	
3/6/21 10:08:00	8	31.40	26.31			34.3	
3/6/21 10:09:00	9	32.02	26.93			34.9	
3/6/21 10:10:00	10	32.76	27.67			35.1	
3/6/21 10:11:00	11	33.40	28.31			34.7	
3/6/21 10:12:00	12	34.08	28.99			34.9	
3/6/21 10:13:00	13	34.43	29.34			34.9	
3/6/21 10:14:00	14	34.75	29.66			35.1	
3/6/21 10:15:00	15	35.15	30.06			34.8	
3/6/21 10:16:00	16	35.47	30.38			34.8	
3/6/21 10:17:00	17	35.84	30.75			34.9	
3/6/21 10:18:00	18	36.15	31.06			34.9	
3/6/21 10:19:00	19	36.48	31.39			35.0	
3/6/21 10:20:00	20	36.73	31.64			35.1	
3/6/21 10:25:00	25	37.64	32.55			34.9	
3/6/21 10:30:00	30	38.42	33.33	37.33	33.08	34.8	
3/6/21 10:40:00	40	39.51	34.42			34.9	
3/6/21 10:50:00	50	40.35	35.26			34.9	
3/6/21 11:00:00	60	40.86	35.77	39.79	35.54	34.8	
3/6/21 11:15:00	75	41.79	36.70	40.71	36.46	35.1	
3/6/21 11:30:00	90	42.30	37.21	41.23	36.98	35.0	
3/6/21 12:00:00	120	43.07	37.98	41.99	37.74	34.9	
3/6/21 12:30:00	150	43.68	38.59	42.57	38.32	35.0	
3/6/21 13:00:00	180	44.08	38.99	43.02	38.77	35.2	WQ 1 to 4. 13:00 to 13:30
3/6/21 14:00:00	240	44.54	39.45	43.46	39.21	34.9	
3/6/21 15:00:00	300	45.13	40.04	44.05	39.80	35.0	
3/6/21 16:00:00	360	45.56	40.47	44.46	40.21	35.0	
3/6/21 17:00:00	420	45.65	40.56	44.57	40.32	34.9	WQ5. 17:17
3/6/21 18:00:00	480	45.97	40.88	44.87	40.62		
3/6/21 20:00:00	600	46.07	40.98	45.00	40.75		
3/6/21 22:00:00	720	46.47	41.38	45.48	41.23		Genny stops at 7:34
4/6/21 1:00:00	900	46.85	41.76	45.77	41.52		
4/6/21 4:00:00	1080	46.97	41.88	45.87	41.62		631m3.
4/6/21 7:30:00	1290	47.28	42.19	46.20	41.95		
4/6/21 10:00:00	1440	47.59	42.50	46.47	42.22	35.0	WQ6 10:10
4/6/21 16:00:00	1800	47.90	42.81	46.78	42.53	35.0	
4/6/21 22:00:00	2160	47.93	42.84	46.82	42.57	34.7	Twist in dip meter fixed
5/6/21 10:00:00	2880	6.01	0.92	5.03	0.78		Generator breaks down
5/6/21 10:01:00	2881	14.00	8.91				
5/6/21 10:02:00	2882	20.21	15.12				
5/6/21 10:03:00	2883	24.77	19.68			37.1	
5/6/21 10:04:00	2884	27.56	22.47				
5/6/21 10:05:00	2885	29.75	24.66				
5/6/21 10:06:00	2886	31.50	26.41			34.6	
5/6/21 10:07:00	2887	32.68	27.59			35.0	
5/6/21 10:08:00	2888	33.73	28.64				
5/6/21 10:09:00	2889	34.59	29.50			35.0	Flow increased
5/6/21 10:10:00	2890	35.10	30.01			35.1	.22 for 38 minutes and started fa
5/6/21 10:11:00	2891	35.72	30.63			35.1	
5/6/21 10:12:00	2892	36.36	31.27				
5/6/21 10:13:00	2893	36.80	31.71				
5/6/21 10:14:00	2894	37.25	32.16				
5/6/21 10:15:00	2895	37.59	32.50	36.38	32.13		
5/6/21 10:16:00	2896	37.92	32.83			34.9	
5/6/21 10:17:00	2897	38.19	33.10				
5/6/21 10:18:00	2898	38.48	33.39			35.0	
5/6/21 10:19:00	2899	38.77	33.68				
5/6/21 10:20:00	2900	38.95	33.86				
5/6/21 10:25:00	2905	39.94	34.85			34.9	
5/6/21 10:30:00	2910	40.64	35.55	39.53	35.28	35.0	
5/6/21 10:40:00	2920	41.57	36.48			34.8	
5/6/21 10:50:00	2930	41.85	36.76			34.5	
5/6/21 11:00:00	2940	42.28	37.19	41.16	36.91	34.4	
5/6/21 11:15:00	2955	43.59	38.50	42.47	38.22	35.0	
5/6/21 11:30:00	2970	43.95	38.86	42.94	38.69	34.9	
5/6/21 11:45:00	2985	44.74	39.65	43.35	39.10	34.9	
5/6/21 12:15:00	3015	45.16	40.07	44.29	40.04	34.8	
5/6/21 12:45:00	3045	45.58	40.49	44.38	40.13	34.9	
5/6/21 13:15:00	3075	46.39	41.30	44.95	40.70	34.9	
5/6/21 15:00:00	3180	46.77	41.68	45.67	41.42	34.8	WQ7 14:30
5/6/21 16:00:00	3240	46.86	41.77	45.78	41.53	34.9	
5/6/21 17:00:00	3300	47.18	42.09	46.11	41.86	35.1	
5/6/21 18:00:00	3360	47.42	42.33	46.37	42.12	35.0	
5/6/21 20:00:00	3480	47.52	42.43	46.56	42.31	35.0	WQ8 19:52
5/6/21 22:00:00	3600	47.82	42.73	47.15	42.90	35.1	
6/6/21 1:00:00	3780	48.10	43.01	47.37	43.12	35.1	
6/6/21 4:00:00	3960	48.14	43.05	47.21	42.96	35.0	Generator breaks down at 07:34
6/6/21 5:00:00	4020			48.69	44.44		
6/6/21 5:15:00	4035			48.71	44.46		

Time Drawdown Data From Constant Rate Test TW06, Rathpatrick, Co. Kilkenny (June 2021).

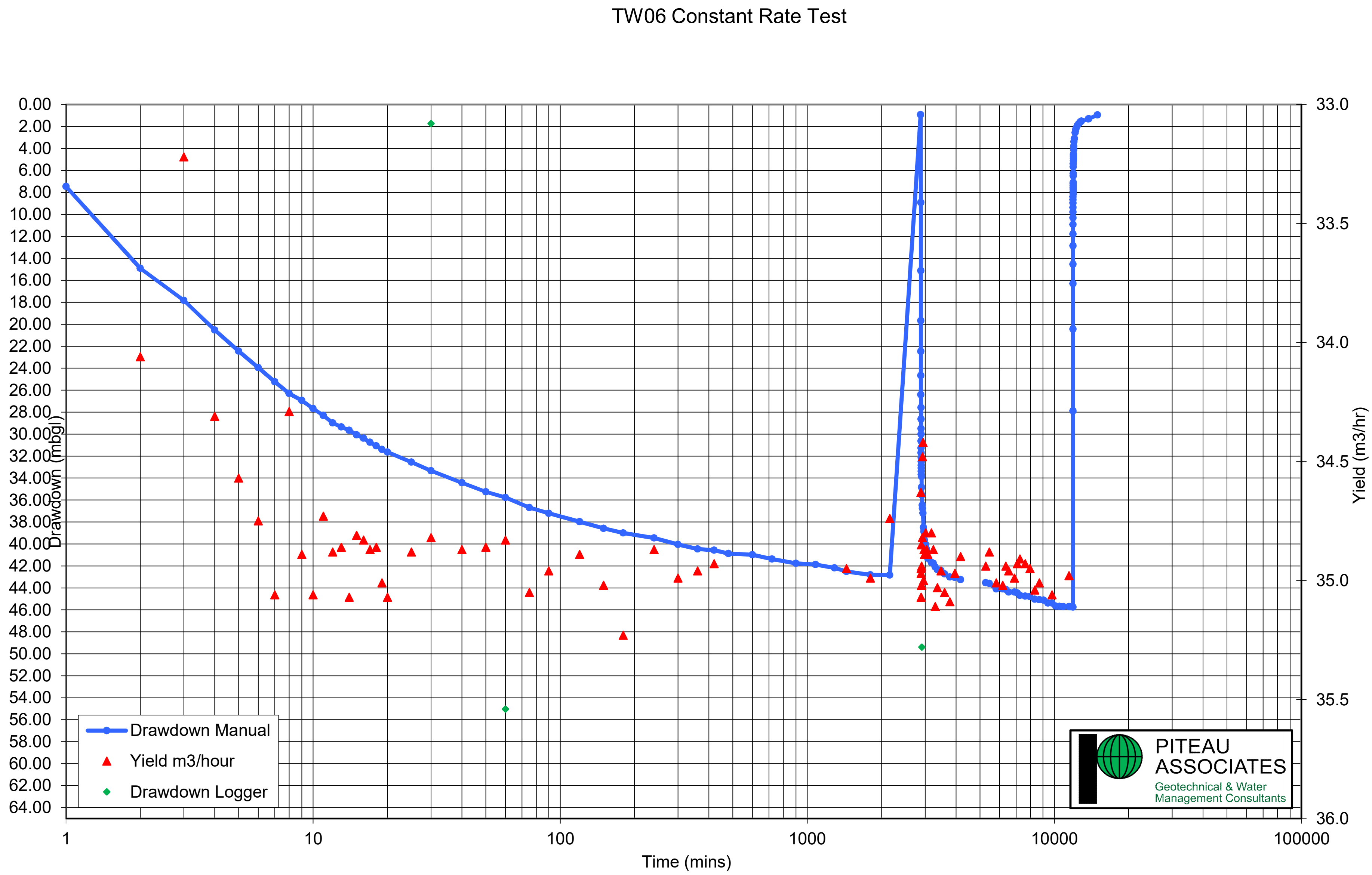
Date/Time	Time	Water Level	Drawdown	Water Level TW6	Drawdown	Yield	
		Manual	Manual	Logger	Logger		
Hrs/Mins/Secs	(Mins)	(m.b.g.l)	metres	(m.b.g.l)	metres	m3/hour	Comments
6/6/21 5:30:00	4050			48.68	44.43		
6/6/21 5:45:00	4065			48.68	44.43		
6/6/21 6:00:00	4080			48.69	44.44		
6/6/21 6:15:00	4095			48.69	44.44		
6/6/21 6:30:00	4110			48.68	44.43		
6/6/21 6:45:00	4125			48.67	44.42		
6/6/21 7:00:00	4140			48.66	44.41		
6/6/21 7:15:00	4155			48.66	44.41		
6/6/21 7:30:00	4170			48.66	44.41		
6/6/21 7:35:00	4175	48.34	43.25	47.60	43.35	34.9	
6/6/21 7:45:00	4185			13.74	9.49		
6/6/21 8:00:00	4200			10.82	6.57		
6/6/21 8:15:00	4215			9.67	5.42		
6/6/21 8:30:00	4230			8.98	4.73		
6/6/21 8:45:00	4245			8.51	4.26		
6/6/21 9:00:00	4260			8.15	3.90		
6/6/21 9:15:00	4275			7.88	3.63		
6/6/21 9:30:00	4290			7.67	3.42		
6/6/21 9:45:00	4305			7.50	3.25		
6/6/21 10:00:00	4320			7.37	3.12		
6/6/21 10:15:00	4335			7.26	3.01		
6/6/21 10:30:00	4350			7.18	2.93		
6/6/21 10:45:00	4365			10.06	5.81		
6/6/21 11:00:00	4380			45.98	41.73		
6/6/21 11:15:00	4395			46.90	42.65		
6/6/21 11:30:00	4410			47.35	43.10		
6/6/21 11:45:00	4425			47.64	43.39		
6/6/21 12:00:00	4440			47.82	43.57		
6/6/21 12:15:00	4455			47.96	43.71		
6/6/21 12:30:00	4470			48.05	43.80		
6/6/21 12:45:00	4485			48.11	43.86		
6/6/21 13:00:00	4500			48.20	43.95		
6/6/21 13:15:00	4515			48.25	44.00		
6/6/21 13:30:00	4530			48.29	44.04		
6/6/21 13:45:00	4545			48.31	44.06		
6/6/21 14:00:00	4560			48.36	44.11		
6/6/21 14:15:00	4575			48.37	44.12		
6/6/21 14:30:00	4590			48.41	44.16		
6/6/21 14:45:00	4605			48.44	44.19		
6/6/21 15:00:00	4620			48.48	44.23		
6/6/21 15:15:00	4635			48.49	44.24		
6/6/21 15:30:00	4650			48.51	44.26		
6/6/21 15:45:00	4665			48.49	44.24		
6/6/21 16:00:00	4680			48.47	44.22		
6/6/21 16:15:00	4695			48.48	44.23		
6/6/21 16:30:00	4710			48.51	44.26		
6/6/21 16:45:00	4725			48.49	44.24		
6/6/21 17:00:00	4740			48.51	44.26		
6/6/21 17:15:00	4755			48.52	44.27		
6/6/21 17:30:00	4770			48.53	44.28		
6/6/21 17:45:00	4785			48.53	44.28		
6/6/21 18:00:00	4800			48.54	44.29		
6/6/21 18:15:00	4815			48.54	44.29		
6/6/21 18:30:00	4830			48.56	44.31		
6/6/21 18:45:00	4845			48.57	44.32		
6/6/21 19:00:00	4860			48.56	44.31		
6/6/21 19:15:00	4875			48.52	44.27		
6/6/21 19:30:00	4890			48.54	44.29		
6/6/21 19:45:00	4905			48.56	44.31		
6/6/21 20:00:00	4920			48.59	44.34		
6/6/21 20:15:00	4935			48.60	44.35		
6/6/21 20:30:00	4950			48.60	44.35		
6/6/21 20:45:00	4965			48.60	44.35		
6/6/21 21:00:00	4980			48.60	44.35		
6/6/21 21:15:00	4995			48.62	44.37		
6/6/21 21:30:00	5010			48.62	44.37		
6/6/21 21:45:00	5025			48.61	44.36		
6/6/21 22:00:00	5040			48.61	44.36		
6/6/21 22:15:00	5055			48.62	44.37		
6/6/21 22:30:00	5070			48.61	44.36		
6/6/21 22:45:00	5085			48.62	44.37		
6/6/21 23:00:00	5100			48.58	44.33		
6/6/21 23:15:00	5115			48.82	44.57		
6/6/21 23:30:00	5130			48.82	44.57		
6/6/21 23:45:00	5145			48.83	44.58		

Date/Time	Time	Water Level Manual	Drawdown Manual	Water Level TW6 Logger	Drawdown Logger	Yield	
Hrs/Mins/Secs	(Mins)	(m.b.g.l)	metres	(m.b.g.l)	metres	m3/hour	Comments
7/6/21 0:00:00	5160			48.84	44.59		
7/6/21 0:15:00	5175			48.87	44.62		
7/6/21 0:30:00	5190			48.86	44.61		
7/6/21 0:45:00	5205			48.86	44.61		
7/6/21 1:00:00	5220			48.85	44.60		
7/6/21 1:15:00	5235			48.89	44.64		
7/6/21 1:30:00	5250			48.89	44.64		
7/6/21 1:45:00	5265			48.89	44.64		
7/6/21 2:00:00	5280	48.62	43.53	47.83	43.58	34.9	
7/6/21 5:00:00	5460	48.68	43.59	47.67	43.42	34.9	
7/6/21 11:00:00	5820	49.18	44.09	48.51	44.26	35.0	WQ9 10:31
7/6/21 17:00:00	6180	49.18	44.09	48.27	44.02	35.0	
7/6/21 20:00:00	6360	49.23	44.14	48.30	44.05	34.9	
7/6/21 23:00:00	6540	49.48	44.39	48.32	44.07	35.0	
8/6/21 5:00:00	6900	49.48	44.39	48.51	44.26	35.0	
8/6/21 8:00:00	7080	49.55	44.46	48.50	44.25	34.9	
8/6/21 11:00:00	7260	49.77	44.68	48.81	44.56	34.9	
8/6/21 17:00:00	7620	49.83	44.74	48.70	44.45	34.9	
8/6/21 23:00:00	7980	49.88	44.79	49.13	44.88	35.0	
9/6/21 5:00:00	8340	50.12	45.03	49.08	44.83	35.0	
9/6/21 11:00:00	8700	50.17	45.08	49.25	45.00	35.0	Lab Sample WQ
9/6/21 17:00:00	9060	50.21	45.12	49.48	45.23		
9/6/21 23:00:00	9420	50.47	45.38	49.44	45.19		
10/6/21 5:00:00	9780	50.48	45.39	49.49	45.24	35.1	
10/6/21 11:00:00	10140	50.76	45.67	49.42	45.17		
10/6/21 17:00:00	10500	50.78	45.69	49.39	45.14		
10/6/21 23:00:00	10860	50.81	45.72	49.67	45.42		
11/6/21 9:00:00	11460	50.81	45.72	49.74	45.49	35.0	
11/6/21 11:00:00	11580	50.81	45.72	49.56	45.31		
11/6/21 13:00:00	11700	50.82	45.73	49.63	45.38		
11/6/21 16:30:00	11910	50.84	45.75	49.56	45.31		Recovery Starts at 16:30
11/6/21 16:31:00	11911	32.99	27.90				
11/6/21 16:32:00	11912	25.54	20.45				
11/6/21 16:33:00	11913	21.39	16.30				
11/6/21 16:34:00	11914	19.63	14.54				
11/6/21 16:35:00	11915	17.95	12.86				
11/6/21 16:36:00	11916	16.89	11.80				
11/6/21 16:37:00	11917	16.02	10.93				
11/6/21 16:38:00	11918	15.39	10.30				
11/6/21 16:39:00	11919	14.87	9.78				
11/6/21 16:40:00	11920	14.46	9.37				
11/6/21 16:41:00	11921	14.05	8.96				
11/6/21 16:42:00	11922	13.74	8.65				
11/6/21 16:43:00	11923	13.48	8.39				
11/6/21 16:44:00	11924	13.23	8.14				
11/6/21 16:45:00	11925	13.00	7.91	11.91	7.66		
11/6/21 16:46:00	11926	12.78	7.69				
11/6/21 16:47:00	11927	12.63	7.54				
11/6/21 16:48:00	11928	12.47	7.38				
11/6/21 16:49:00	11929	12.29	7.20				
11/6/21 16:50:00	11930	12.18	7.09				
11/6/21 16:55:00	11935	11.59	6.50				
11/6/21 17:00:00	11940	11.38	6.29	10.02	5.77		
11/6/21 17:05:00	11945	10.75	5.66				
11/6/21 17:10:00	11950	10.47	5.38				
11/6/21 17:15:00	11955	10.20	5.11	9.10	4.85		
11/6/21 17:20:00	11960	9.97	4.88				
11/6/21 17:25:00	11965	9.78	4.69				
11/6/21 17:30:00	11970	9.61	4.52	8.51	4.26		
11/6/21 17:45:00	11985	9.20	4.11				
11/6/21 18:00:00	12000	8.89	3.80	7.79	3.54		
11/6/21 18:30:00	12030	8.47	3.38	7.41	3.16		
11/6/21 19:00:00	12060	8.18	3.09	7.11	2.86		
11/6/21 20:30:00	12150	7.65	2.56	6.59	2.34		
11/6/21 21:30:00	12210	7.42	2.33	6.37	2.12		
11/6/21 22:30:00	12270	7.26	2.17	6.21	1.96		
12/6/21 0:30:00	12390	7.02	1.93	5.97	1.72		
12/6/21 3:30:00	12570	6.84	1.75	5.75	1.50		
12/6/21 6:30:00	12750	6.67	1.58	5.62	1.37		
12/6/21 8:30:00	12870	6.61	1.52	5.54	1.29		
12/6/21 23:00:00	13740	6.40	1.31	5.19	0.94		
13/6/21 0:00:00	13800	6.39	1.30	5.19	0.94		
13/6/21 18:57:00	14937	6.03	0.94	4.96	0.71		

Time Drawdown Data From Constant Rate Test TW06, Rathpatrick, Co. Kilkenny (June 2021).



Time Drawdown Graph From Constant rate Test at TW06 Rathpatrick, Co. Kilkenny. June 2021. *(Linear Format)*



Time Drawdown Graph Constant Rate Test for TW06. Rathpatrick, Co. Kilkenny. June 2021. *(Log-Linear Format)*

APPENDIX 3
HYDRO CHEMICAL LAB ANALYSIS

APPENDIX 3
TW03 EXTENDED STEP TEST
HYDRO CHEMICAL LAB ANALYSIS

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Customer supplied information appear in italics.

Customer	*James Lawlor* *Piteau Associates UK* *Canon Court West* *Abbey Lawn* *Shrewsbury* *SY2 5DE,UK*	*Lab Report Ref. No.*	2071/001/01
		Date of Receipt	09/04/2021
		Sampled On	*08/04/2021*
		Date Testing Commenced	09/04/2021
		Received or Collected	Courier: DPD
		Condition on Receipt	Acceptable
Customer PO		*Date of Report*	11/05/2021
Customer Ref	*TWO3*	*Sample Type*	*Drinking Water*
Ref 2	*08/04/21 10:30*		
Ref 3			

CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
1,2-Dichloroethane (Potable Water)	154	GCMS	3	<0.82	ug/L	UKAS
2,3,6-Trichlorobenzoic Acid (Potable)	543	LC-MS-MS	0.1	<0.017	ug/L	UKAS
2,4-D (Potable)	543	LC-MS-MS	0.1	<0.004	ug/L	UKAS
2,4-DB (Potable)	543	LC-MS-MS	0.1	<0.01	ug/L	UKAS
Aluminium (Potable Water)	177	ICPMS	200	821	ug/L	UKAS
Ammonium (Potable Water as NH4)	114	Colorimetry	0.3	0.08	mg/L as NH4	UKAS
Antimony (Potable Water)	177	ICPMS	5	<2	ug/L	UKAS
Arsenic (Potable Water)	177	ICPMS	10	<2	ug/L	UKAS
Atrazine (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Bentazone (Potable)	543	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Benzene (Potable Water)	154	GCMS	1	<0.34	ug/L	UKAS
Benzo(a)pyrene (GCMS)	200	GCMS	0.01	<0.01	ug/L	
Benzo(b)fluoranthene (GCMS)	200	GCMS	-	<0.01	ug/L	
Benzo(g,h,i)perylene (GCMS)	200	GCMS	-	<0.01	ug/L	
Benzo(k)fluoranthene (GCMS)	200	GCMS	-	<0.01	ug/L	
Boron (Potable Water) mg/L	177	ICPMS	1	0.033	mg/L	UKAS
Boscalid (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Bromate (Potable water)	125	IC	10	<2.4	ug/L	UKAS
Bromodichloromethane (Potable Wat	154	GCMS	-	<1.2	ug/L	UKAS

Signed :

Date : 11/05/2021

Aoife Harmon - Laboratory Supervisor

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	Canon Court West	*Sampled On*	*08/04/2021*
	Abbey Lawn	*Date Testing Commenced*	09/04/2021
	Shrewsbury	*Received or Collected*	Courier: DPD
	SY2 5DE,UK	*Condition on Receipt*	Acceptable
Customer PO		*Date of Report*	11/05/2021
Customer Ref	*TWO3*	*Sample Type*	*Drinking Water*
Ref 2	*08/04/21 10:30*		
Ref 3			

CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
Bromoform (Potable Water)	154	GCMS	-	<2.6	ug/L	UKAS
Cadmium (Potable Water)	177	ICPMS	5	<1	ug/L	UKAS
Chlorfenvinphos (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Chloride (Potable Water)	100	Colorimetry	250	20.8	mg/L	UKAS
Chloroform (Potable Water)	154	GCMS	-	<5.5	ug/L	UKAS
Chlorpropham (Potable)	542	GC MS MS	0.1	<0.007	ug/L	UKAS
Chlortoluron (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Chromium (Potable Water)	177	ICPMS	50	<4	ug/L	UKAS
Clopyralid (Potable)	543	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Clostridia perfringens(Potable)P	161	Anaerobic Incubation	0	0	cfu/100ml	UKAS
Coliforms Total (Potable)P	157	Filtration/Incubation	0	0	cfu/100ml	UKAS
Colour Apparent (Potable Water)	108	Colorimetry	-	22	PtCo Units	UKAS
Conductivity (Potable Water at 20C)	112	Electrometry	2500	686.0	µscm -1@20C	UKAS
Copper (Potable Water) mg/L	177	ICPMS	2	<0.003	mg/L	UKAS
Cyanide (Free)	138	Colorimetry	50	<5	ug/L	
Cypermethrin (Potable)	542	GC MS MS	0.1	<0.01	ug/L	
Diazinon (Potable)	540	LC-MS-MS	0.1	<0.02	ug/L	UKAS
Dibromochloromethane (Potable Wat	154	GCMS	-	<1.4	ug/L	UKAS
Dicamba (Potable)	543	LC-MS-MS	0.1	<0.003	ug/L	UKAS

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Customer	*James Lawlor*	*Lab Report Ref. No.*	2071/001/01
	Piteau Associates UK	*Date of Receipt*	09/04/2021
	Canon Court West	*Sampled On*	*08/04/2021*
	Abbey Lawn	*Date Testing Commenced*	09/04/2021
	Shrewsbury	*Received or Collected*	Courier: DPD
	SY2 5DE,UK	*Condition on Receipt*	Acceptable
Customer PO		*Date of Report*	11/05/2021
Customer Ref	*TWO3*	*Sample Type*	*Drinking Water*
Ref 2	*08/04/21 10:30*		
Ref 3			

CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
Dichlobenil (Potable)	542	GC MS MS	0.1	<0.033	ug/L	
Dichlorprop (Potable)	543	LC-MS-MS	0.1	<0.0036	ug/L	UKAS
Dieldrin (Potable)	542	GC MS MS	0.03	<0.010	ug/L	UKAS
Diflufenican (Potable)	540	LC-MS-MS	0.1	<0.01	ug/L	UKAS
Diuron (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
E. coli (Potable)P	157	Filtration/Incubation	0	0	cfu/100ml	UKAS
Enterococci (Potable)P	153	Filtration/Incubation	0	0	cfu/100ml	UKAS
Epoxiconazole (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Fluoride (Potable Water)	115	Colorimetry	0.8	0.14	mg/L	UKAS
Fluoroxypyr (Potable)	543	LC-MS-MS	0.1	<0.01	ug/L	UKAS
Indeno(1,2,3-cd)pyrene (GCMS)	200	GCMS	-	<0.01	ug/L	
Iron (Potable Water)	177	ICPMS	200	132	ug/L	UKAS
Isoproturon (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Lead (Potable Water)	177	ICPMS	10	1	ug/L	UKAS
Linuron (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Manganese (Potable)	177	ICPMS	50	28	ug/L	UKAS
MCPA (Potable)	543	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Mecoprop (Potable)	543	LC-MS-MS	0.1	<0.0037	ug/L	UKAS
Mercury (Potable water)	178	ICPMS	1	<0.15	ug/L	UKAS

Signed : A Harmon

Date : 11/05/2021

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Customer supplied information appear in italics.

Customer	*James Lawlor*	*Lab Report Ref. No.*	**2071/001/01**
	Piteau Associates UK	*Date of Receipt*	**09/04/2021**
	Canon Court West	*Sampled On*	***08/04/2021***
	Abbey Lawn	*Date Testing Commenced*	**09/04/2021**
	Shrewsbury	*Received or Collected*	**Courier: DPD**
	SY2 5DE,UK	*Condition on Receipt*	**Acceptable**
Customer PO		*Date of Report*	**11/05/2021**
Customer Ref	*TWO3*	*Sample Type*	***Drinking Water***
Ref 2	*08/04/21 10:30*		
Ref 3			

CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
Metazachlor (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Nickel (Potable Water)	177	ICPMS	20	2	ug/L	UKAS
Nitrate (Potable Water as NO3)	103	Colorimetry	50	24.22	mg/L as NO3	UKAS
Nitrite (Potable Water as NO2)	118	Colorimetry	0.5	<0.099	mg/L as NO2	UKAS
Odour	239	Olfactory Panel	-	No Odour	TON	
PAH (sum of 4)	200	GCMS	0.1	<0.01	ug/L	
Pendimethalin (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Pentachlorophenol (Potable)	543	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Pesticides Total (Potable)	0	Calculation	0.5	0.000	ug/L	
pH (Potable Water)	110	Electrometry	6.5 - 9.5	7.23	pH Units	UKAS
Picloram (Potable)	543	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Propyzamide (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Selenium (Potable Water)	177	ICPMS	10	<3	ug/L	UKAS
Simazine (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Sodium (Potable Water)	184	ICPMS	200	7.8	mg/L	UKAS
Sulphate (Potable Water)	119	Colorimetry	250	11	mg/L as SO4	UKAS
Taste	238	Taste Panel	-	No Taste	FTN	
TBC @ 22˚C (Potable)	493	Spread plate/Incubation	-	138	cfu/mL	UKAS
Tetrachloroethene & Trichloroethene	154	GCMS	10	<2.32	ug/L	UKAS

Signed : A Harmon

Date : 11/05/2021

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UKAS TESTING 2802

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Customer	*James Lawlor*	*Lab Report Ref. No.*	2071/001/01
	Piteau Associates UK	*Date of Receipt*	09/04/2021
	Canon Court West	*Sampled On*	*08/04/2021*
	Abbey Lawn	*Date Testing Commenced*	09/04/2021
	Shrewsbury	*Received or Collected*	Courier: DPD
	SY2 5DE,UK	*Condition on Receipt*	Acceptable
Customer PO		*Date of Report*	11/05/2021
Customer Ref	*TWO3*	*Sample Type*	*Drinking Water*
Ref 2	*08/04/21 10:30*		
Ref 3			

CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
THM Total (Potable Water)	154	GCMS	100	0.0	ug/L	UKAS
TOC (Potable Water)	316	TOC Analyser	-	<0.8	mg/L	UKAS
Triclopyr (Potable)	543	LC-MS-MS	0.1	<0.004	ug/L	UKAS
Turbidity (Potable Water)	109	Turbidimetry	-	22.3	NTU	UKAS

Signed : A Harmon

Date : 11/05/2021

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APPENDIX 3
CRT FULL DRINKING WATER SUITE AUDIT RESULTS
HYDRO CHEMICAL LAB ANALYSIS

APPENDIX 3
CRT ONSITE FILTERED SAMPLE RESULTS
HYDRO CHEMICAL LAB ANALYSIS

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Customer	***James Lalor***	***Lab Report Ref. No.***	**2071/002/03**
	Piteau Associates UK	***Date of Receipt***	**10/06/2021**
	Canon Court West	***Sampled On***	***09/06/2021***
	Abbey Lawn	***Date Testing Commenced***	**10/06/2021**
	Shrewsbury	***Received or Collected***	**Courier: DPD**
	SY2 5DE,UK	***Condition on Receipt***	**Acceptable**
Customer PO		***Date of Report***	**23/06/2021**
Customer Ref	***TW3 Filtered***	***Sample Type***	***Drinking Water***
Ref 2	***09/06/21 10:00***		
Ref 3			

CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
Aluminium (Potable Water)	177	ICPMS	200	<9	ug/L	UKAS
Antimony (Potable Water)	177	ICPMS	5	<2	ug/L	UKAS
Arsenic (Potable Water)	177	ICPMS	10	<2	ug/L	UKAS
Boron (Potable Water) mg/L	177	ICPMS	1	<0.020	mg/L	UKAS
Cadmium (Potable Water)	177	ICPMS	5	<1	ug/L	UKAS
Chromium (Potable Water)	177	ICPMS	50	<4	ug/L	UKAS
Copper (Potable Water) mg/L	177	ICPMS	2	<0.003	mg/L	UKAS
Iron (Potable Water)	177	ICPMS	200	<14	ug/L	UKAS
Lead (Potable Water)	177	ICPMS	10	<1	ug/L	UKAS
Manganese (Potable)	177	ICPMS	50	<3	ug/L	UKAS
Mercury (Potable water)	178	ICPMS	1	<0.15	ug/L	UKAS
Nickel (Potable Water)	177	ICPMS	20	<2	ug/L	UKAS
Selenium (Potable Water)	177	ICPMS	10	<3	ug/L	UKAS

Signed : A Harmon

Date : 23/06/2021

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Customer	***James Lalor***	**Lab Report Ref. No.**	**2071/002/04**
	Piteau Associates UK	**Date of Receipt**	**10/06/2021**
	Canon Court West	**Sampled On**	***09/06/2021***
	Abbey Lawn	**Date Testing Commenced**	**10/06/2021**
	Shrewsbury	**Received or Collected**	**Courier: DPD**
	SY2 5DE,UK	**Condition on Receipt**	**Acceptable**
Customer PO		**Date of Report**	**23/06/2021**
Customer Ref	***TW6 Filtered***	**Sample Type**	***Drinking Water***
Ref 2	***09/06/21 11:00***		
Ref 3			

CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
Aluminium (Potable Water)	177	ICPMS	200	<9	ug/L	UKAS
Antimony (Potable Water)	177	ICPMS	5	<2	ug/L	UKAS
Arsenic (Potable Water)	177	ICPMS	10	<2	ug/L	UKAS
Boron (Potable Water) mg/L	177	ICPMS	1	<0.020	mg/L	UKAS
Cadmium (Potable Water)	177	ICPMS	5	<1	ug/L	UKAS
Chromium (Potable Water)	177	ICPMS	50	<4	ug/L	UKAS
Copper (Potable Water) mg/L	177	ICPMS	2	<0.003	mg/L	UKAS
Iron (Potable Water)	177	ICPMS	200	59	ug/L	UKAS
Lead (Potable Water)	177	ICPMS	10	<1	ug/L	UKAS
Manganese (Potable)	177	ICPMS	50	45	ug/L	UKAS
Mercury (Potable water)	178	ICPMS	1	<0.15	ug/L	UKAS
Nickel (Potable Water)	177	ICPMS	20	3	ug/L	UKAS
Selenium (Potable Water)	177	ICPMS	10	<3	ug/L	UKAS

Signed : A Harmon

Date : 23/06/2021

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ilac-MRA UKAS TESTING 2802

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Customer supplied information appear in italics.

Customer	***James Lalor***	**Lab Report Ref. No.**	**2071/002/01**
	Piteau Associates UK	**Date of Receipt**	**10/06/2021**
	Canon Court West	**Sampled On**	***09/06/2021***
	Abbey Lawn	**Date Testing Commenced**	**10/06/2021**
	Shrewsbury	**Received or Collected**	**Courier: DPD**
	SY2 5DE,UK	**Condition on Receipt**	**Acceptable**
Customer PO		**Date of Report**	**25/06/2021**
Customer Ref	***TW3***	**Sample Type**	***Drinking Water***
Ref 2	***09/06/21 10:00***		
Ref 3			

CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
1,2-Dichloroethane (Potable Water)	154	GCMS	3	<0.82	ug/L	UKAS
2,3,6-Trichlorobenzoic Acid (Potable)	543	LC-MS-MS	0.1	<0.017	ug/L	UKAS
2,4-D (Potable)	543	LC-MS-MS	0.1	<0.004	ug/L	UKAS
2,4-DB (Potable)	543	LC-MS-MS	0.1	<0.01	ug/L	UKAS
Aluminium (Potable Water)	177	ICPMS	200	9	ug/L	UKAS
Ammonium (Potable Water as NH4)	114	Colorimetry	0.3	0.07	mg/L as NH4	UKAS
Antimony (Potable Water)	177	ICPMS	5	<2	ug/L	UKAS
Arsenic (Potable Water)	177	ICPMS	10	<2	ug/L	UKAS
Atrazine (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Bentazone (Potable)	543	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Benzene (Potable Water)	154	GCMS	1	<0.34	ug/L	UKAS
Benzo(a)pyrene (GCMS)	200	GCMS	0.01	<0.01	ug/L	
Benzo(b)fluoranthene (GCMS)	200	GCMS	-	<0.01	ug/L	
Benzo(g,h,i)perylene (GCMS)	200	GCMS	-	<0.01	ug/L	
Benzo(k)fluoranthene (GCMS)	200	GCMS	-	<0.01	ug/L	
Boron (Potable Water) mg/L	177	ICPMS	1	<0.020	mg/L	UKAS
Boscalid (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Bromate (Potable water)	125	IC	10	<2.4	ug/L	UKAS
Bromodichloromethane (Potable Wat	154	GCMS	-	<1.2	ug/L	UKAS

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CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
Bromoform (Potable Water)	154	GCMS	-	<2.6	ug/L	UKAS
Cadmium (Potable Water)	177	ICPMS	5	<1	ug/L	UKAS
Chlorfenvinphos (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Chloride (Potable Water)	100	Colorimetry	250	17.3	mg/L	UKAS
Chloroform (Potable Water)	154	GCMS	-	<5.5	ug/L	UKAS
Chlorpropham (Potable)	542	GC MS MS	0.1	<0.007	ug/L	UKAS
Chlortoluron (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Chromium (Potable Water)	177	ICPMS	50	<4	ug/L	UKAS
Clopyralid (Potable)	543	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Clostridia perfringens(Potable)P	161	Anaerobic Incubation	0	1	cfu/100ml	UKAS
Coliforms Total (Potable)P	157	Filtration/Incubation	0	0	cfu/100ml	UKAS
Colour Apparent (Potable Water)	108	Colorimetry	-	<11	PtCo Units	UKAS
Conductivity (Potable Water at 20C)	112	Electrometry	2500	693.0	µscm -1@20C	UKAS
Copper (Potable Water) mg/L	177	ICPMS	2	<0.003	mg/L	UKAS
Cyanide (Free)	138	Colorimetry	50	<5	ug/L	
Cypermethrin (Potable)	542	GC MS MS	0.1	<0.01	ug/L	
Diazinon (Potable)	540	LC-MS-MS	0.1	<0.02	ug/L	UKAS
Dibromochloromethane (Potable Wat	154	GCMS	-	<1.4	ug/L	UKAS
Dicamba (Potable)	543	LC-MS-MS	0.1	<0.003	ug/L	UKAS

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Customer Ref	*TW3*	*Sample Type*	*Drinking Water*
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Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
Dichlobenil (Potable)	542	GC MS MS	0.1	<0.033	ug/L	
Dichlorprop (Potable)	543	LC-MS-MS	0.1	<0.0036	ug/L	UKAS
Dieldrin (Potable)	542	GC MS MS	0.03	<0.010	ug/L	UKAS
Diflufenican (Potable)	540	LC-MS-MS	0.1	<0.01	ug/L	UKAS
Diuron (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
E. coli (Potable)P	157	Filtration/Incubation	0	0	cfu/100ml	UKAS
Enterococci (Potable)P	153	Filtration/Incubation	0	116	cfu/100ml	UKAS
Epoxiconazole (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Fluoride (Potable Water)	115	Colorimetry	0.8	0.09	mg/L	UKAS
Fluoroxypyr (Potable)	543	LC-MS-MS	0.1	<0.01	ug/L	UKAS
Indeno(1,2,3-cd)pyrene (GCMS)	200	GCMS	-	<0.01	ug/L	
Iron (Potable Water)	177	ICPMS	200	<14	ug/L	UKAS
Isoproturon (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Lead (Potable Water)	177	ICPMS	10	<1	ug/L	UKAS
Linuron (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Manganese (Potable)	177	ICPMS	50	<3	ug/L	UKAS
MCPA (Potable)	543	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Mecoprop (Potable)	543	LC-MS-MS	0.1	<0.0037	ug/L	UKAS
Mercury (Potable water)	178	ICPMS	1	<0.15	ug/L	UKAS

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Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
Metazachlor (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Nickel (Potable Water)	177	ICPMS	20	<2	ug/L	UKAS
Nitrate (Potable Water as NO3)	103	Colorimetry	50	25.04	mg/L as NO3	UKAS
Nitrite (Potable Water as NO2)	118	Colorimetry	0.5	<0.099	mg/L as NO2	UKAS
Odour	239	Olfactory Panel	-	No Odour	TON	
PAH (sum of 4)	200	GCMS	0.1	<0.01	ug/L	
Pendimethalin (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Pentachlorophenol (Potable)	543	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Pesticides Total (Potable)	0	Calculation	0.5	0.000	ug/L	
pH (Potable Water)	110	Electrometry	6.5 - 9.5	7.13	pH Units	UKAS
Picloram (Potable)	543	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Propyzamide (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Selenium (Potable Water)	177	ICPMS	10	<3	ug/L	UKAS
Simazine (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Sodium (Potable Water)	184	ICPMS	200	8.3	mg/L	UKAS
Sulphate (Potable Water)	119	Colorimetry	250	15	mg/L as SO4	UKAS
Taste	238	Taste Panel	-	See micro	FTN	
TBC @ 22˚C (Potable)	493	Spread plate/Incubation	-	>300	cfu/mL	UKAS
Tetrachloroethene & Trichloroethene	154	GCMS	10	<2.32	ug/L	UKAS

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Customer Ref	*TW3*	*Sample Type*	***Drinking Water***
Ref 2	*09/06/21 10:00*		
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CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
THM Total (Potable Water)	154	GCMS	100	0.0	ug/L	UKAS
TOC (Potable Water)	316	TOC Analyser	-	<0.7	mg/L	UKAS
Triclopyr (Potable)	543	LC-MS-MS	0.1	<0.004	ug/L	UKAS
Turbidity (Potable Water)	109	Turbidimetry	-	0.2	NTU	UKAS

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	Abbey Lawn	***Date Testing Commenced***	**10/06/2021**
	Shrewsbury	***Received or Collected***	**Courier: DPD**
	SY2 5DE,UK	***Condition on Receipt***	**Acceptable**
Customer PO		***Date of Report***	**25/06/2021**
Customer Ref	***TW6***	***Sample Type***	***Drinking Water***
Ref 2	***09/06/21 11:00***		
Ref 3			

CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
1,2-Dichloroethane (Potable Water)	154	GCMS	3	<0.82	ug/L	UKAS
2,3,6-Trichlorobenzoic Acid (Potable)	543	LC-MS-MS	0.1	<0.017	ug/L	UKAS
2,4-D (Potable)	543	LC-MS-MS	0.1	<0.004	ug/L	UKAS
2,4-DB (Potable)	543	LC-MS-MS	0.1	<0.01	ug/L	UKAS
Aluminium (Potable Water)	177	ICPMS	200	<9	ug/L	UKAS
Ammonium (Potable Water as NH4)	114	Colorimetry	0.3	0.07	mg/L as NH4	UKAS
Antimony (Potable Water)	177	ICPMS	5	<2	ug/L	UKAS
Arsenic (Potable Water)	177	ICPMS	10	<2	ug/L	UKAS
Atrazine (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Bentazone (Potable)	543	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Benzene (Potable Water)	154	GCMS	1	<0.34	ug/L	UKAS
Benzo(a)pyrene (GCMS)	200	GCMS	0.01	<0.01	ug/L	
Benzo(b)fluoranthene (GCMS)	200	GCMS	-	<0.01	ug/L	
Benzo(g,h,i)perylene (GCMS)	200	GCMS	-	<0.01	ug/L	
Benzo(k)fluoranthene (GCMS)	200	GCMS	-	<0.01	ug/L	
Boron (Potable Water) mg/L	177	ICPMS	1	<0.020	mg/L	UKAS
Boscalid (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Bromate (Potable water)	125	IC	10	<2.4	ug/L	UKAS
Bromodichloromethane (Potable Wat	154	GCMS	-	<1.2	ug/L	UKAS

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Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
Bromoform (Potable Water)	154	GCMS	-	<2.6	ug/L	UKAS
Cadmium (Potable Water)	177	ICPMS	5	<1	ug/L	UKAS
Chlorfenvinphos (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Chloride (Potable Water)	100	Colorimetry	250	14.3	mg/L	UKAS
Chloroform (Potable Water)	154	GCMS	-	<5.5	ug/L	UKAS
Chlorpropham (Potable)	542	GC MS MS	0.1	<0.007	ug/L	UKAS
Chlortoluron (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Chromium (Potable Water)	177	ICPMS	50	<4	ug/L	UKAS
Clopyralid (Potable)	543	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Clostridia perfringens(Potable)P	161	Anaerobic Incubation	0	0	cfu/100ml	UKAS
Coliforms Total (Potable)P	157	Filtration/Incubation	0	0	cfu/100ml	UKAS
Colour Apparent (Potable Water)	108	Colorimetry	-	12	PtCo Units	UKAS
Conductivity (Potable Water at 20C)	112	Electrometry	2500	660.0	µscm -1@20C	UKAS
Copper (Potable Water) mg/L	177	ICPMS	2	<0.003	mg/L	UKAS
Cyanide (Free)	138	Colorimetry	50	<5	ug/L	
Cypermethrin (Potable)	542	GC MS MS	0.1	<0.01	ug/L	
Diazinon (Potable)	540	LC-MS-MS	0.1	<0.02	ug/L	UKAS
Dibromochloromethane (Potable Wat	154	GCMS	-	<1.4	ug/L	UKAS
Dicamba (Potable)	543	LC-MS-MS	0.1	<0.003	ug/L	UKAS

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Customer Ref	***TW6***	***Sample Type***	***Drinking Water***
Ref 2	***09/06/21 11:00***		
Ref 3			

CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
Dichlobenil (Potable)	542	GC MS MS	0.1	<0.033	ug/L	
Dichlorprop (Potable)	543	LC-MS-MS	0.1	<0.0036	ug/L	UKAS
Dieldrin (Potable)	542	GC MS MS	0.03	<0.010	ug/L	UKAS
Diflufenican (Potable)	540	LC-MS-MS	0.1	<0.01	ug/L	UKAS
Diuron (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
E. coli (Potable)P	157	Filtration/Incubation	0	0	cfu/100ml	UKAS
Enterococci (Potable)P	153	Filtration/Incubation	0	14	cfu/100ml	UKAS
Epoxiconazole (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Fluoride (Potable Water)	115	Colorimetry	0.8	0.10	mg/L	UKAS
Fluoroxypyr (Potable)	543	LC-MS-MS	0.1	<0.01	ug/L	UKAS
Indeno(1,2,3-cd)pyrene (GCMS)	200	GCMS	-	<0.01	ug/L	
Iron (Potable Water)	177	ICPMS	200	59	ug/L	UKAS
Isoproturon (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Lead (Potable Water)	177	ICPMS	10	<1	ug/L	UKAS
Linuron (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Manganese (Potable)	177	ICPMS	50	47	ug/L	UKAS
MCPA (Potable)	543	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Mecoprop (Potable)	543	LC-MS-MS	0.1	<0.0037	ug/L	UKAS
Mercury (Potable water)	178	ICPMS	1	<0.15	ug/L	UKAS

Signed :

Date : 25/06/2021

Aoife Harmon - Laboratory Supervisor

Acc. : Accredited Parameters by ISO/IEC 17025:2017
PVL - Parametric Value Limit as per EU (Drinking water) Regulations (SI 122 2014)
For bacterial analysis a result of 0 means none detected in volume examined
All organic results are analysed as received and all results are corrected for dry weight at 104 C
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Results contained in this report relate only to the samples tested (P) : Presumptive Results

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Customer supplied information appear in italics.

Customer	*James Lalor*	Lab Report Ref. No.	2071/002/02
	Piteau Associates UK	Date of Receipt	10/06/2021
	Canon Court West	Sampled On	*09/06/2021*
	Abbey Lawn	Date Testing Commenced	10/06/2021
	Shrewsbury	Received or Collected	Courier: DPD
	SY2 5DE,UK	Condition on Receipt	Acceptable
Customer PO		Date of Report	25/06/2021
Customer Ref	*TW6*	Sample Type	*Drinking Water*
Ref 2	*09/06/21 11:00*		
Ref 3			

CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
Metazachlor (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Nickel (Potable Water)	177	ICPMS	20	4	ug/L	UKAS
Nitrate (Potable Water as NO3)	103	Colorimetry	50	15.46	mg/L as NO3	UKAS
Nitrite (Potable Water as NO2)	118	Colorimetry	0.5	0.187	mg/L as NO2	UKAS
Odour	239	Olfactory Panel	-	No Odour	TON	
PAH (sum of 4)	200	GCMS	0.1	<0.01	ug/L	
Pendimethalin (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Pentachlorophenol (Potable)	543	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Pesticides Total (Potable)	0	Calculation	0.5	0.000	ug/L	
pH (Potable Water)	110	Electrometry	6.5 - 9.5	7.10	pH Units	UKAS
Picloram (Potable)	543	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Propyzamide (Potable)	540	LC-MS-MS	0.1	<0.007	ug/L	UKAS
Selenium (Potable Water)	177	ICPMS	10	<3	ug/L	UKAS
Simazine (Potable)	540	LC-MS-MS	0.1	<0.003	ug/L	UKAS
Sodium (Potable Water)	184	ICPMS	200	7.4	mg/L	UKAS
Sulphate (Potable Water)	119	Colorimetry	250	15	mg/L as SO4	UKAS
Taste	238	Taste Panel	-	See micro	FTN	
TBC @ 22˚C (Potable)	493	Spread plate/Incubation	-	>300	cfu/mL	UKAS
Tetrachloroethene & Trichloroethene	154	GCMS	10	<2.32	ug/L	UKAS

Signed : A Harmon

Date : 25/06/2021

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Customer supplied information appear in italics.

Customer	***James Lalor***	**Lab Report Ref. No.**	**2071/002/02**
	Piteau Associates UK	**Date of Receipt**	**10/06/2021**
	Canon Court West	**Sampled On**	***09/06/2021***
	Abbey Lawn	**Date Testing Commenced**	**10/06/2021**
	Shrewsbury	**Received or Collected**	**Courier: DPD**
	SY2 5DE,UK	**Condition on Receipt**	**Acceptable**
Customer PO		**Date of Report**	**25/06/2021**
Customer Ref	***TW6***	**Sample Type**	***Drinking Water***
Ref 2	***09/06/21 11:00***		
Ref 3			

CERTIFICATE OF ANALYSIS

Test Parameter	SOP	Analytical Technique	PVL	Result	Units	Acc.
THM Total (Potable Water)	154	GCMS	100	0.0	ug/L	UKAS
TOC (Potable Water)	316	TOC Analyser	-	0.7	mg/L	UKAS
Triclopyr (Potable)	543	LC-MS-MS	0.1	<0.004	ug/L	UKAS
Turbidity (Potable Water)	109	Turbidimetry	-	0.4	NTU	UKAS

Signed : A Harmon

Date : 25/06/2021

Aoife Harmon - Laboratory Supervisor

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APPENDIX 8.6

GoldSim Model Construction, Calibration and Simulation

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FILE: TM06v1.0_WaterBalance.docx

TECHNICAL MEMORANDUM

DATE: 5th July 2021

TO: Alan Buckley

FROM: Lara Belton and Simon Sholl

RE: **Garrylaun Mine: GoldSim water balance model construction, calibration and simulation**

1. OBJECTIVES

A dewatering and site-wide water balance model was developed in GoldSim for the Garrylaun Project, to produce probabilistic predictions of underground dewatering requirement, surface runoff and resultant water treatment capacity. The model also includes chemical mass balance functionality to evaluate the treatment efficiency as part of the feasibility study.

Dewatering flows of Galmoy and Lisheen mines are mostly a function of rainfall in the preceding months. Therefore, to provide a reliable assessment of likely groundwater conditions over a wide range (and return period) of precipitation conditions, a probabilistic model with a stochastic precipitation generator was required.

The water balance was built in parallel with the numerical groundwater model for the Garrylaun Project, allowing the development to be an iterative process.

2. MODEL DEVELOPMENT

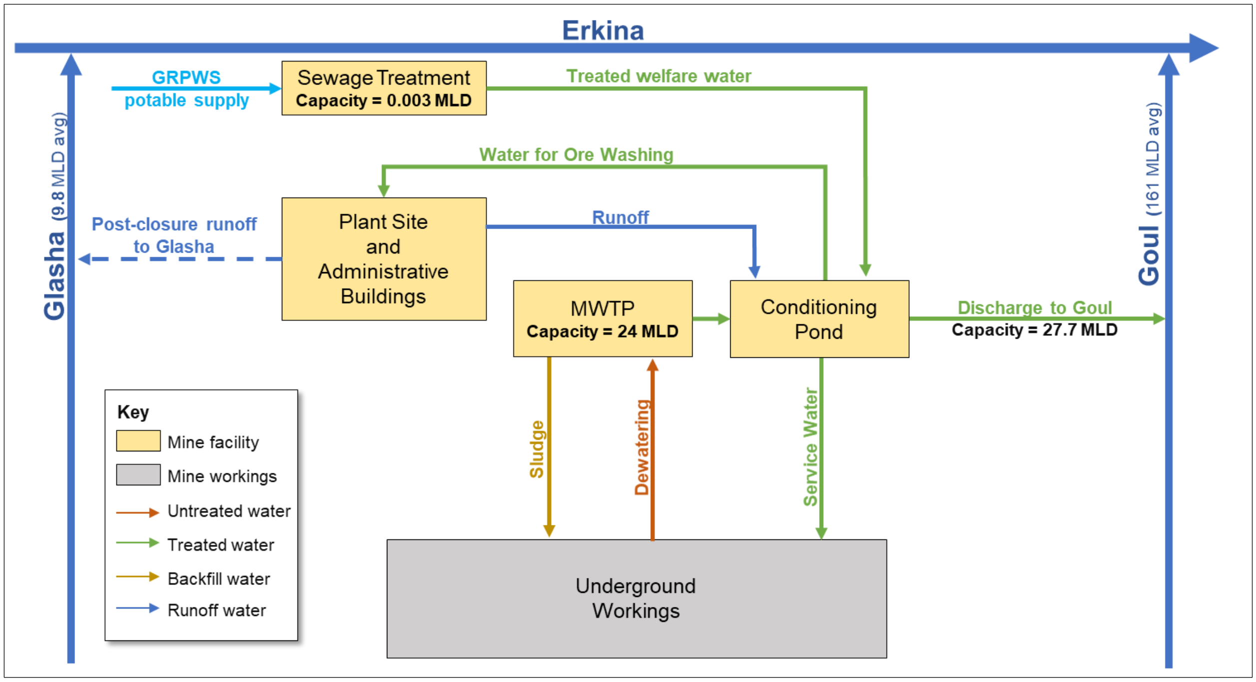
2.1. GoldSim simulation software platform

The Garrylaun site-wide water and mass balance model is constructed in the GoldSim™ software platform (GoldSim Technology Group, 2017). GoldSim is an analytical modelling package which allows the simulation of highly dynamic flow network systems. The system is simulated using empirical or mathematical representation, the scope of which depends upon: i) the complexity of the system (or sub-system) being simulated; ii) the level of understanding or available data for the system; and iii) the level of precision required.

A GoldSim model is constructed using 'elements', each of which can provide graphic output including a time-series and probability distribution. A large library of elements performing different functions is available, presented as images with inter-relationships between elements displayed to provide a graphical view of the model structure. This ensures that the model can be scrutinised by users with limited GoldSim experience.

The mine water management system flow diagram used to construct the model is presented in Figure 1.

Figure 1: Schematic diagram of the mine water management system



2.2. Simulation settings

The model can be adjusted to run for any time period or any number of Monte-Carlo probabilistic simulations as desired. However, the model for Garrylaun has specifically been designed to start on 5 years before mining and step forward in daily increments.

The model is configured to run for 125 realisations when run probabilistically. This is appropriate to establish probabilistic results between the 4th and 96th percentiles (equivalent to up to a 1-in-25 year return period).

2.3. Model layout

GoldSim models are typically organised hierarchically, using 'Container' elements to organise the function elements in a logical manner. The top level of the model comprises four principal containers: Meteorology, Hydrology, Water Balance and Results.

- **Meteorology** – observed and stochastic precipitation and pan evaporation inputs (see Section 3).

- **Hydrology** – natural catchment and on-site hydrological algorithms defining runoff and actual evapotranspiration (see Section 4).
- **Water Balance** – the physical water balance comprising mine facility and catchment modules (see Section 5).
- **Results** – collated time series graphs of key information (primarily water flows and quality) to allow ease of access and quick comparisons with results from different areas of the model.

3. METEOROLOGY

3.1. Stochastic precipitation generator

Modules using a second-order Markov chain derived from the WGEN model (USDA, 1984[1]) were developed in GoldSim for stochastic precipitation generation. This includes i) a Boolean probability distribution to predict the occurrence of rain on a particular day; and ii) a probabilistic distribution to express the amount of rain on any given day; both are generated using a Monte Carlo simulation. The WGEN model has been shown to adequately simulate precipitation trends in climates subject to infrequent precipitation, high-intensity storms, or multiple/successive days of precipitation.

For the Garrylaun stochastic precipitation generator, input values are assigned on a monthly basis (Table 1) derived from the Met Éireann Parknahown Cullahill daily total precipitation data from the 26-year record (1982 to 2008). The last 10 years of data is presented in Table 2.

Table 1: Inputs to the GoldSim stochastic precipitation generator

Month	Boolean probability distribution inputs to define the occurrence of rain on a particular day			Gamma probability distribution inputs to define the amount of rain on any given day	
	Probability of a wet day following a dry day	Probability of two wet days following a dry day	Probability of three consecutive wet days	Mean wet day precipitation (mm/d)	Standard deviation wet day precipitation (mm/d)
January	0.5532	0.8077	0.8142	8.21	10.02
February	0.5000	0.9000	0.8364	9.72	13.35
March	0.5227	0.7826	0.8393	6.61	9.93
April	0.5161	0.6875	0.8932	13.72	16.02
May	0.7059	1.0000	0.8919	10.86	11.48
June	0.4615	0.7500	0.9011	10.66	13.33
July	0.5484	0.8235	0.8272	11.03	12.05
August	0.5102	0.8000	0.7101	9.17	13.27
September	0.3418	0.7407	0.5455	6.35	9.91
October	0.2473	0.6522	0.6154	6.45	8.34
November	0.4247	0.6774	0.6719	7.77	10.35
December	0.5000	0.7692	0.8319	8.62	9.11

[1] USDA, 1984. WGEN: A model for generating daily weather variables. United States Department of Agriculture.

Table 2: Monthly precipitation data from Parknahown Cullahill

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2010	68	41	72	40	58	39	98	39	145	89	79	N/A	**> 769**
2011	44	111	18	20	55	92	62	35	54	102	101	76	**769**
2012	N/A	23	26	63	48	196	107	105	41	100	80	72	**> 860**
2013	82	33	61	46	39	47	39	47	38	151	37	113	**733**
2014	127	177	65	38	66	52	26	83	41	104	129	80	**988**
2015	79	45	61	41	107	20	57	82	41	49	125	209	**915**
2016	95	91	49	53	53	79	30	46	88	33	30	64	**710**
2017	33	41	97	14	99	88	56	84	83	79	53	106	**833**
2018	140	39	86	80	23	25	38	38	59	51	112	139	**829**
2019	38	27	120	70	7	62	32	89	94	79	113	77	**807**
2020	52	194	55	33	17	61	73	122	49	92	75	110	**934**
Mean	**76**	**75**	**65**	**45**	**52**	**69**	**56**	**70**	**67**	**84**	**85**	**105**	**835**

To validate the stochastic precipitation generator, the model was run for 1,000 years and the results compared to the Parknahown Cullahill rain gauge data to ensure that the precipitation generated is representative of the observed dataset. Three key validation comparisons were made: i) wet days per month; ii) monthly precipitation at varying percentiles; and iii) annual maximum daily precipitation. These are presented in Figure 2 to Figure 4.

Figure 2 presents a comparison of wet days per month with error bounds of ±2.5%. It shows that the Boolean probability generator is able to replicate the mean number of wet days per month seen in the observed data.

Figure 3 presents a comparison of monthly total precipitation at the 25th, 50th, 75th and 95th percentiles. It shows that the stochastic precipitation generator is able to replicate the variation in monthly total rainfall seen in the observed data.

Figure 4 presents a comparison of annual maximum daily precipitation for a range of return periods. It shows that the stochastic precipitation generator is able to replicate storm events of comparable magnitude to those predicted by Gumbel extreme value distribution analysis.

Figure 2: Observed and simulated mean wet days per month

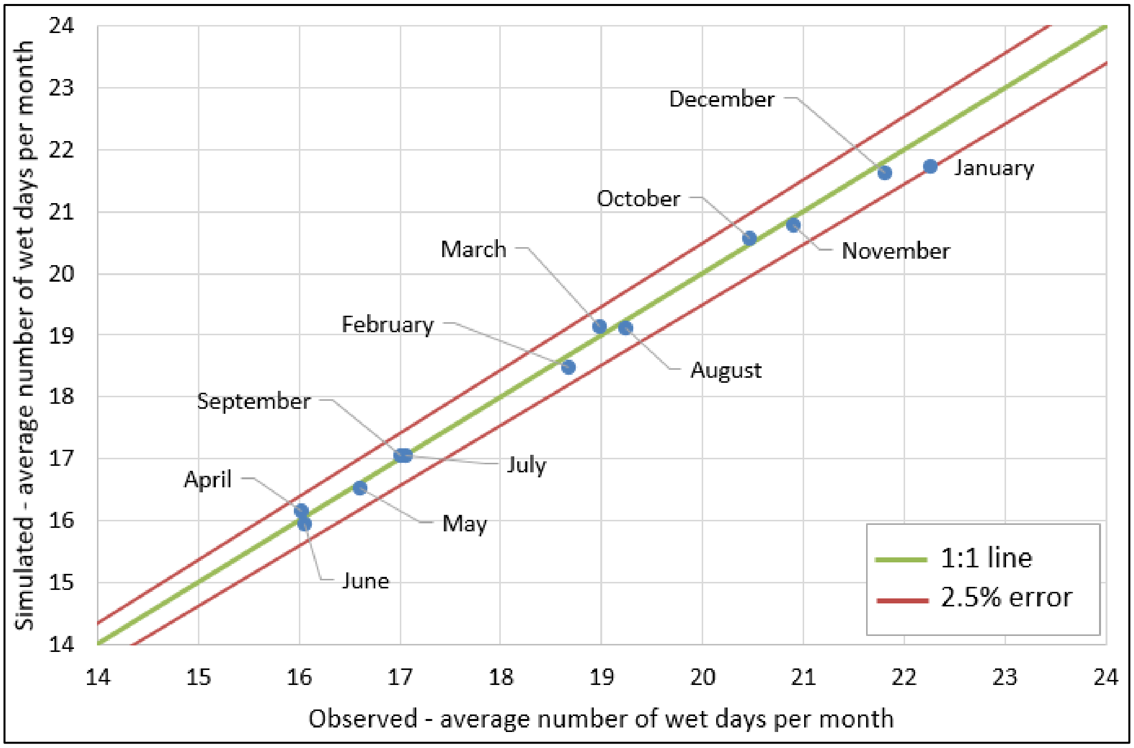


Figure 3: Observed and simulated total monthly precipitation

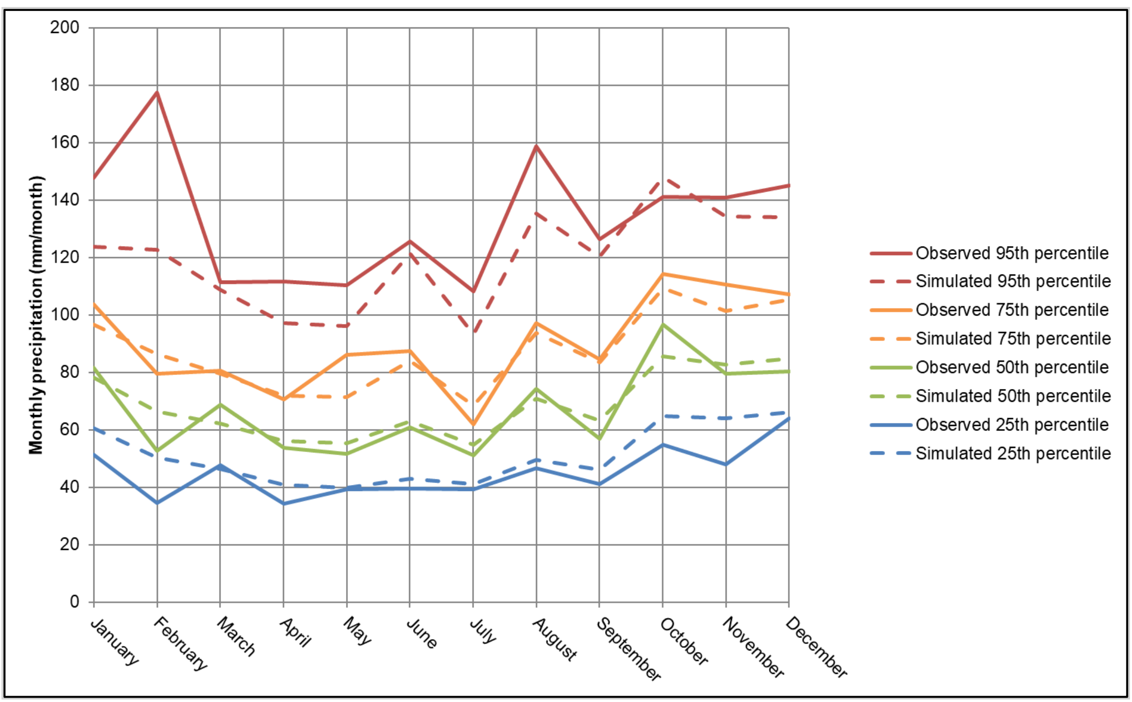
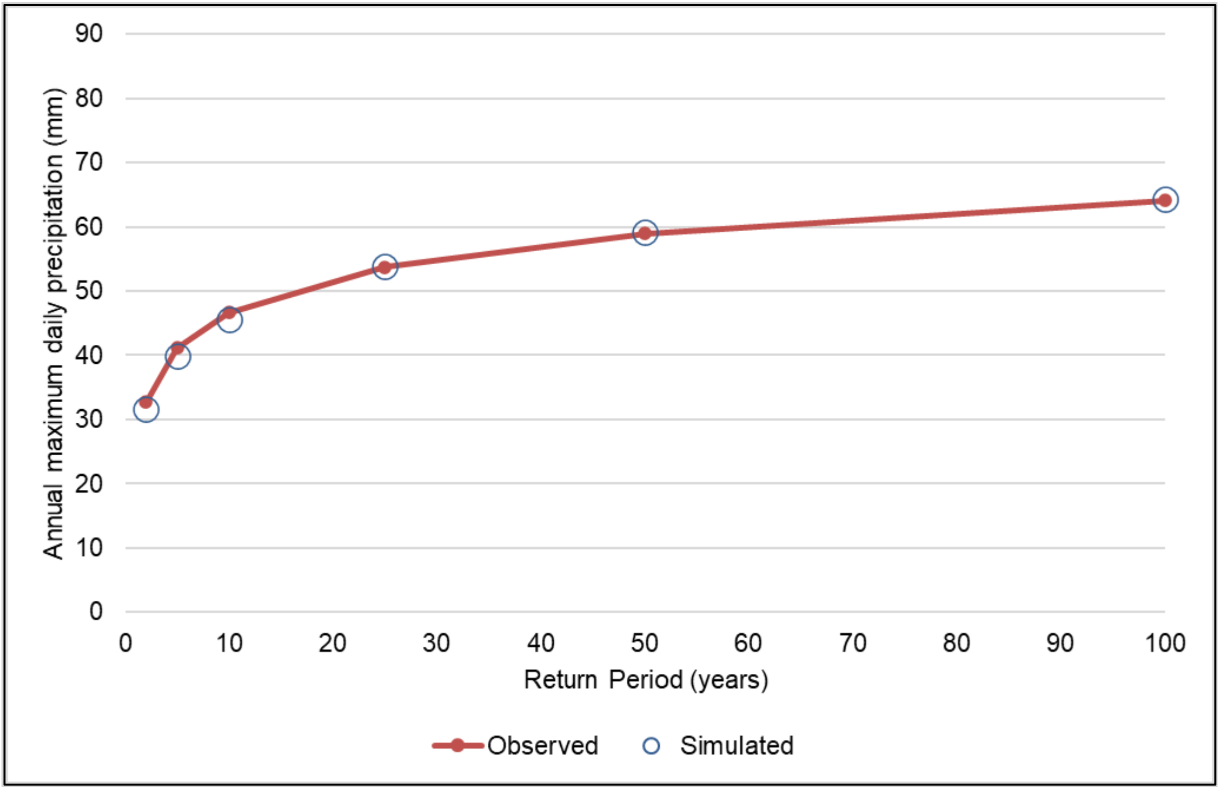


Figure 4: Derived and simulated annual daily maximum precipitation



3.2. Evaporation

Total evaporation from Oak Park synoptic station around 50 km east of the Garrylaun shows a range of 698 to 813 mm between 2017 and 2020, with a mean of 767 mm. Around 71% occurs between the five months, April to August.

Evaporation has less variability than precipitation and, therefore, has less of an impact on the water balance. Therefore, the mean monthly evaporation (Table 3) is used as the input. However, the model has been constructed so that, if a weather station or evaporation pan are installed on the site, daily evaporation data can be easily uploaded via the input Excel spreadsheet.

Table 3: GoldSim pan evaporation dataset (from Met Éireann, 2021)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2017	15	25	71	114	122	120	93	64	36	14	12	12	**698**
2018	18	24	44	77	119	149	142	100	70	38	18	15	**813**
2019	17	29	56	75	107	115	127	106	70	36	15	14	**767**
2020	16	34	60	92	142	109	108	93	69	38	18	12	**789**
Mean	**16**	**28**	**57**	**89**	**122**	**123**	**118**	**91**	**61**	**31**	**16**	**13**	**767**

4. HYDROLOGY

4.1. Catchment areas

A full review of the site surface water catchment and management system was completed. The review included cataloguing the situation on site during Galmoy operations, as well as proposed changes for the period of operations for Garrylaun. Figure 5 presents the catchments used for Garrylaun. The areas for each catchment are:

- Goul Discharge (SW1x) = 109.5 km^3;
- Ballinfrase (15041) = 16.6 km^2 addition to Goul Discharge;
- Coadys Castle (SW2) = 2.6 km^2;
- Glasha discharge = 2.1 km^2 (including 0.09 km^2 of the Garrylaun plant site); and
- Glasha crossroads = 5.2 km^2 addition to both Coadys Castle and Glasha discharge.

The methods applied allow the surface runoff and river flows to be simulated probabilistically using the stochastic precipitation generator. The following sub-sections describe how the hydrological processes of these catchments are simulated.

4.2. Natural catchments

River flow in the Goul and Glasha is simulated using continuous soil moisture accounting (SMA) methodology patterned after Leavesley's Precipitation Runoff Modelling System. This is a commonly used algorithm available in the United States Army Corps of Engineers, Hydrologic Engineering Center – Hydrological Modeling System (HEC-HMS). This method accumulates and releases moisture from several layers within the vegetative, surficial and upper soil profile.

The SMA method was developed to predict short term daily runoff, mid-term interflow and longer-term base flow discharge volumes from the surface and vadose-zone regimes. The model addresses water release, evaporative losses, and changes in storage in response to daily precipitation using a number of parameters to describe physical and hydraulic properties of the various layers.

Parameters for inclusion in the Garrylaun model were developed by iterative calibration against observed flow at the EPA Ballinfrase flow gauge (Figure 6) and the EPA flow duration curve for the Glasha stream, north of the site (
Figure 7). Both figures show that the calibration is excellent for flows below Q30 (i.e. the lower 70% of flows). Higher flows are not well simulated, but the focus of the assessment is for the impact at low flows, therefore this was evaluated to be acceptable.

Calibrated input values are presented in Table 4.

Figure 5: Simulated surface water catchment area

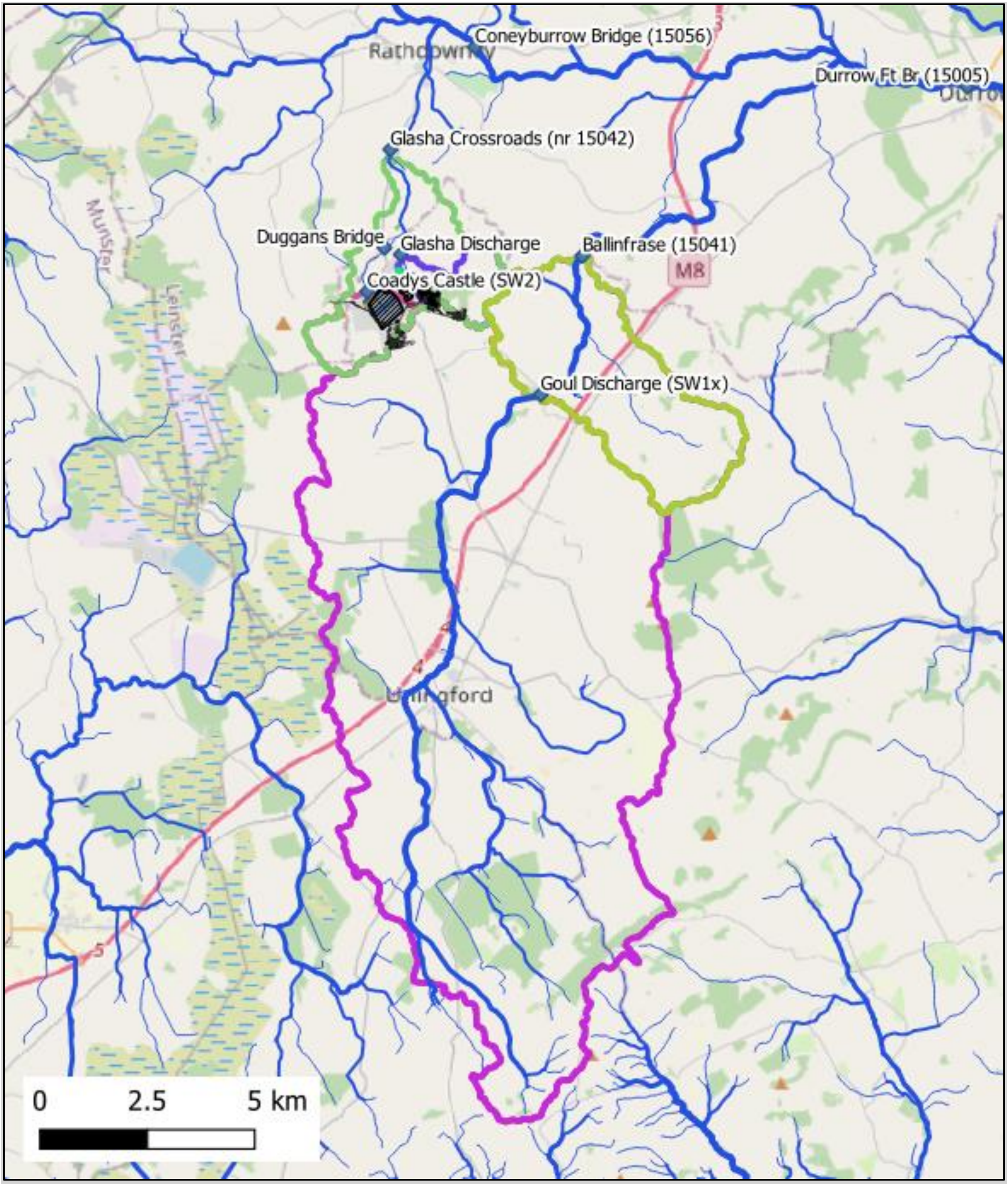


Figure 6: Observed and calibrated flow for the EPA Ballinfrase flow gauge

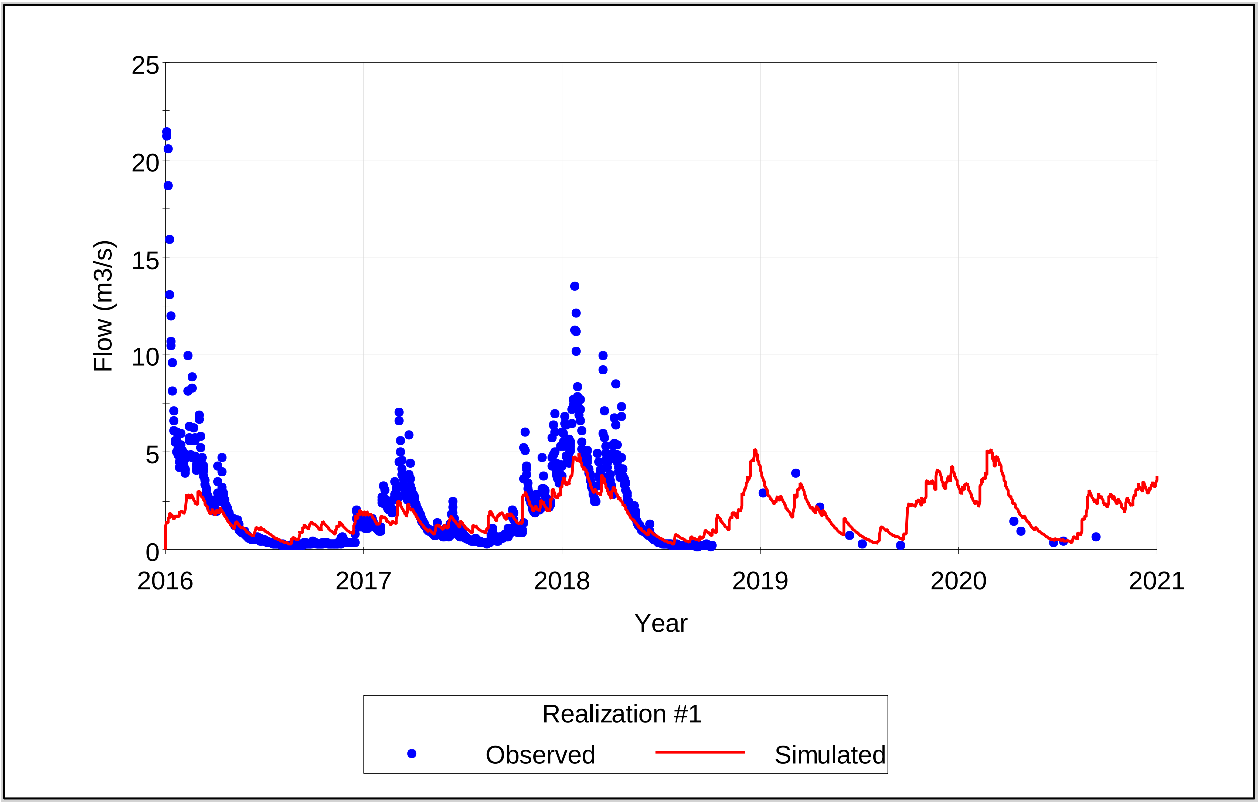


Figure 7: Observed and calibrated flow duration curve for the Glasha stream

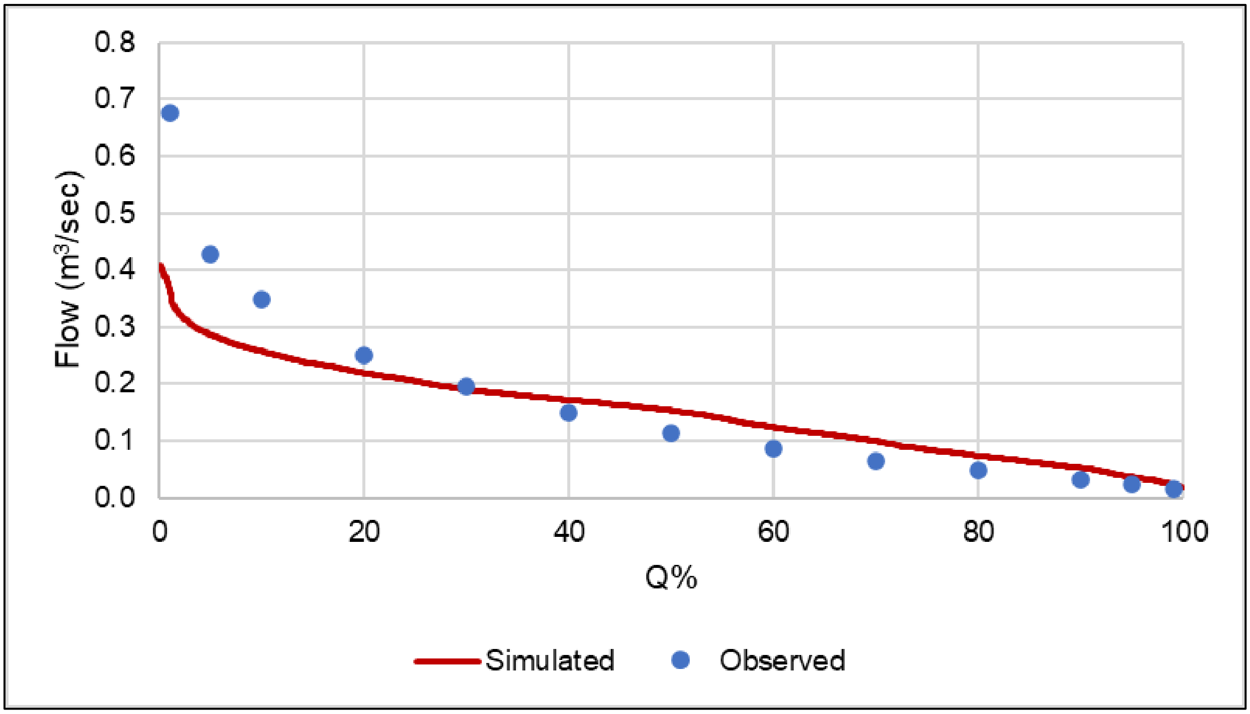


Table 4: HEC-HMS input parameters for Goul and Glasha flow simulation

Parameter	Value	Parameter	Value
Canopy_Max_Storage (mm)	0	GW1_Coefficient (d)	3.6
Surface_Max_Storage (mm)	1	GW2_Max_Storage (mm)	50
Max_Infiltration (m/s)	0.02	Max_Percolation_Deep (m/s)	0.07
Soil_Max_Storage (mm)	2	GW2_Coefficient (d)	98
Tension_Storage (mm)	10	GW1_Baseflow_Coefficient (d)	66
Max_Percolation_GW1 (m/s)	0.05	GW2_Baseflow_Coefficient (d)	5.3
GW1_Max_Storage (mm)	100	Runoff_Transform_Coefficient (d)	37
Max_Percolation_GW2 (m/s)	0.06		

4.3. Disturbed catchments

Runoff from the plant site, including the administration buildings and car park is simulated using the United States Soil Conservation Services Curve Number (CN) method. The method is widely accepted for hydrological simulation and was developed to predict daily runoff volumes from a variety of different soils and vegetation types in response to daily precipitation using a single descriptive number ranging between 40 and 100. The benefit of curve numbers over runoff coefficients is that curve numbers allow antecedent conditions and rainfall depth to be accounted for when defining the proportion of precipitation which becomes runoff. Therefore, proportionally more runoff is generated if the previous days or weeks have been wet and/or more precipitation has fallen. For example, a 10 mm event occurs in the dry season may produce no runoff (runoff coefficient equivalent of 0.0), but the same event in the wet season may produce 1.5 mm runoff (runoff coefficient of 0.15). Likewise, under the same wet season conditions, a 15 mm event may produce 4 mm of runoff (runoff coefficient of 0.27). The unit runoff is calculated using the equation:

$$RO = (P - Ia)^2 \div (P - Ia + S)$$

Where: RO is unit runoff (in/d); P is precipitation (in/d); S = 1000/CN-10 and is the potential maximum soil moisture retention after runoff begins (in); and Ia = 0.2S and is the initial abstraction, which relates to the volume intercepted by vegetation or which infiltrates into the soil. If P is less than or equal to 'Ia', then RO is equal to zero. The curve number method uses imperial units of inches, GoldSim automatically converts precipitation from mm/d to in/d, then unit runoff from in/d to mm/d for use in the model.

Areas where runoff is low, such as highly vegetated areas, curve numbers are low. Conversely, areas where runoff is high, such striped surfaces (pit walls) or infrastructure (concrete, roofs and roads where infiltration is low), the curve number is high. The plant site has been conservatively simulated with a curve number of 99 based on the large covering of tarmac and buildings.

5. WATER BALANCE AND RESULTS

5.1. Inflows

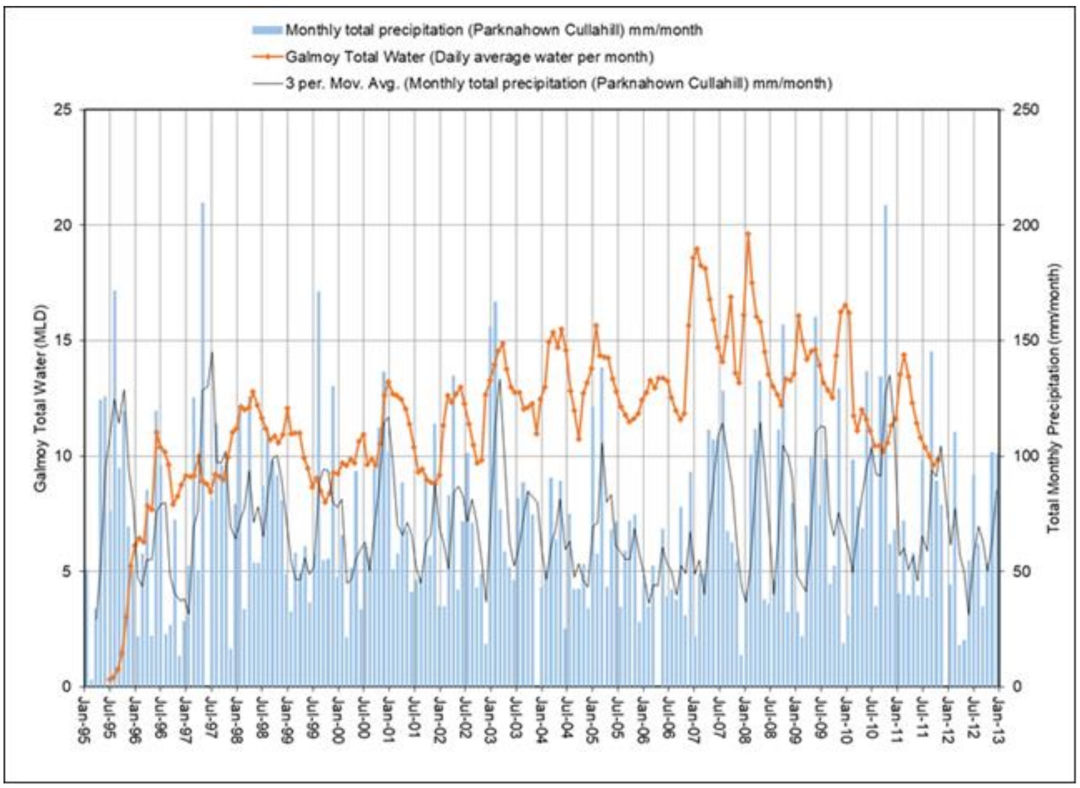
Mine dewatering

Dewatering of the previous Galmoy Mine workings was mostly within the range 11.5 to 15.5 MLD. The dewatering rate was mostly a function of rainfall in the preceding 1 to 3 months (Figure 8). Following periods of high rainfall and recharge, the dewatering rate occasionally approached 20 MLD (in 2007 and 2008). A close correlation between pumping rate and rainfall can be seen both seasonally and annually. The 'dry' years (such as 2004 to 2006 and 2011) show lower dewatering rates while the wet winter of 2006-07 shows a large increase in dewatering rate.

The comprehensive groundwater monitoring dataset from the dewatering of Galmoy, and predicative numerical modelling completed as part of this project indicate that the area of drawdown for Garrylaun is going to be up to 10% larger than Galmoy. This is due to mining through the K Fault into a new deeper block. This will be mitigated by cover grouting. Conceptually, groundwater inflows to Garrylaun may also increase by up to 10% compared to Galmoy, so potentially up to 22 MLD.

Mine dewatering is simulated in the water balance using an algorithm developed by correlating historical Galmoy dewatering rates with the precipitation record and input from the numerical groundwater model. The algorithm calculates a running mean of precipitation over a 30 day period. A conversion factor is applied based on the area of drawdown and a baseflow component is added. The factor and baseflow were calibrated against the Galmoy data to achieve a good correlation between historical and simulated values.

Figure 8: Galmoy Mine dewatering rates with monthly and 3-monthly precipitation

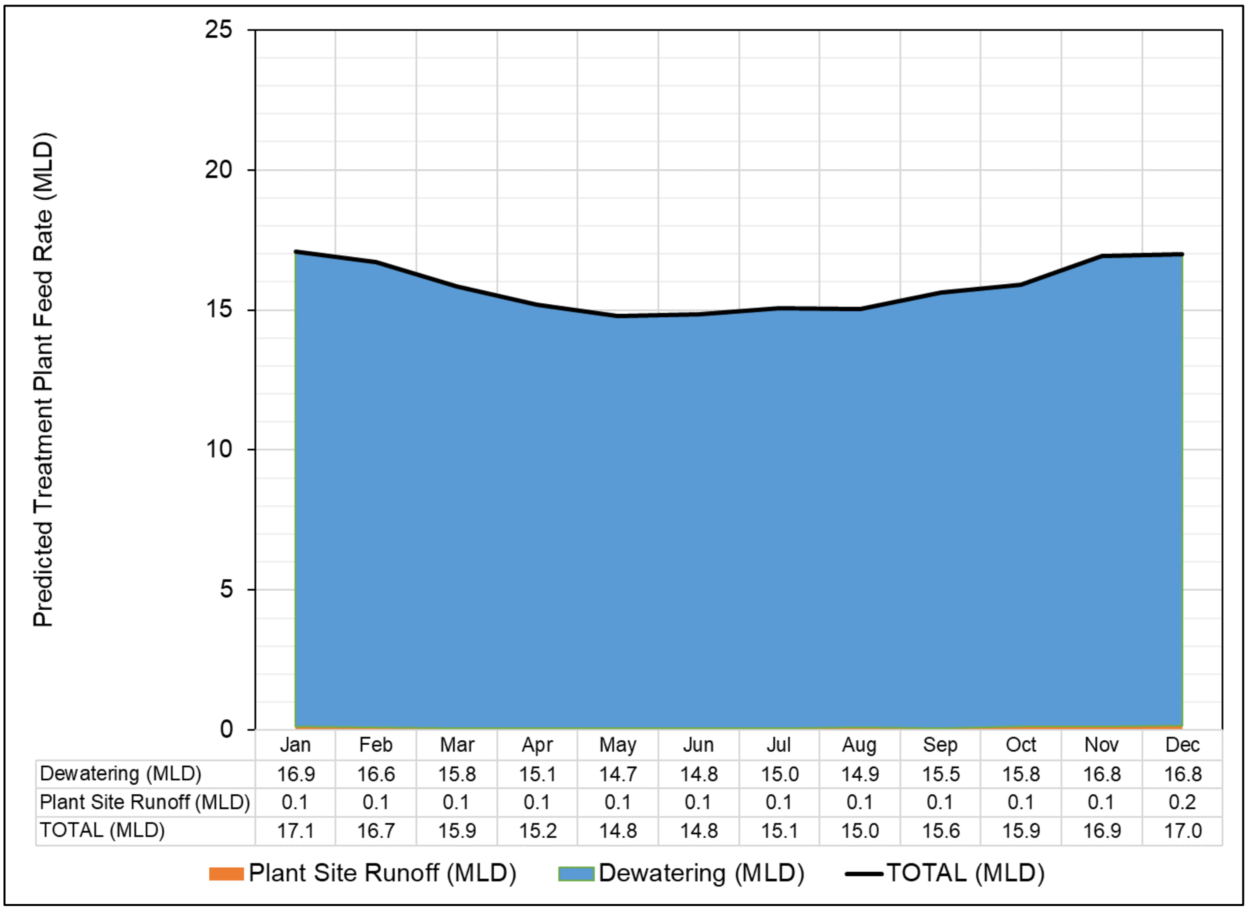


A 'baseflow' of 10 MLD is applied for dewatering once the area of drawdown has been established. Short-term (30-day) recharge-driven precipitation is calculated by multiplying the area of drawdown and applying a factor of 15%. This method allows dewatering rates to be simulated stochastically using outputs from the precipitation generator. It can therefore account for a very wide range of potential precipitation scenarios including very long wet (and dry) periods with return periods of up to 1-in-25 years.

An additional 0.4 MLD of water is added to the groundwater inflow component to represent service water for drilling, etc. underground. This is a conservative value.

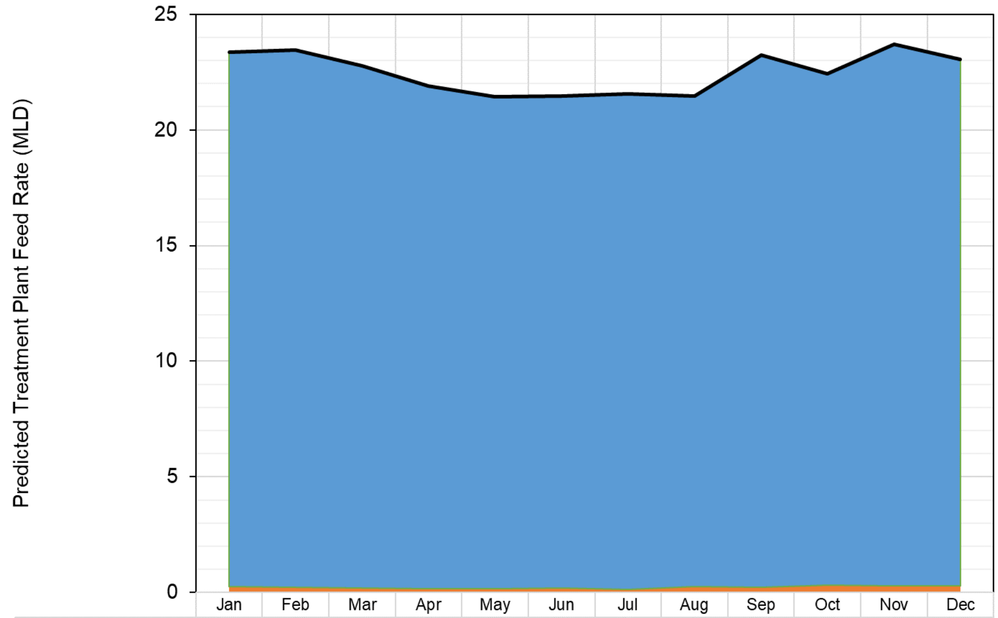
The model shows that, once the area of drawdown has become established, dewatering requirement will range seasonally. Average flows are expected to be highest in January at 16.9 MLD, and lowest in May at 14.7 MLD (Figure 9). Maximum inflows, after prolonged periods of wet weather, are expected to range between 21.2 MLD and 23.4 MLD (Figure 10). It should be noted that these latter maximum flows are not long-term projections of the dewatering system but an indication of what short-term (3 to 6 weeks) pumping may be required at different times of the year in response to prolonged wet periods.

Figure 9: Predicted median feed rates to the MWTP in Year 5 of mine life



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dewatering (MLD)	16.9	16.6	15.8	15.1	14.7	14.8	15.0	14.9	15.5	15.8	16.8	16.8
Plant Site Runoff (MLD)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
TOTAL (MLD)	17.1	16.7	15.9	15.2	14.8	14.8	15.1	15.0	15.6	15.9	16.9	17.0

Figure 10: Predicted maximum feed rates to the MWTP in Year 5 of mine life



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dewatering (MLD)	23.1	23.2	22.6	21.7	21.3	21.3	21.4	21.2	23.0	22.1	23.4	22.7
Plant Site Runoff (MLD)	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.3	0.3	0.3
TOTAL (MLD)	23.4	23.5	22.8	21.9	21.4	21.5	21.6	21.5	23.2	22.4	23.7	23.0

Site runoff

Site runoff is generated using the Curve Number methodology described in Section 4.3. The annual maximum daily flow for a 1-in-25 year return period is predicted to be 1.4 MLD.

Median and maximum predicted mean monthly surface flows from the site are expected to vary seasonally between around 0.05 MLD in summer and 0.15 MLD in winter. Maximum (mean monthly) summer flows are expected to be around 0.15 MLD and winter maximum flows around 0.3 MLD. Most runoff water will be direct to the storm water management system and sent to the conditioning pond for discharge to the Goul with treated MWTP water.

Ore handling areas within the Plant Site are the only areas where ‘contact’ runoff water (water in contact with mine facilities) may be generated. The surface runoff flows have the potential to contain trace metals and suspended solids. The small volumes of runoff generated within these areas will be routed to the mine water treatment plant (MWTP) for treatment.

For the purposes of a conservative MWTP capacity assessment, it was assumed that all Plant Site runoff would report to the MWTP.

Potable supply

A nominal potable supply from the Galmoy Rathdowney Public Water supply (GRPWS) of 0.02 MLD (20 m³/d) has been assumed. Most of this will be used as services water (e.g. vehicle washdown) and will report to the storm water management system. Around 0.003 MLD (2.7 m³/d) will be used as welfare water (e.g. showers, toilets and kitchens).

5.2. Water treatment and flow routing

Flow routing

A schematic diagram of the water balance is presented in Figure 11. Two water treatment plant will be used on site: the mine water treatment plant (MWTP) and a sewage treatment plant (STP).

The model assumes that all underground dewatering generated is pumped directly to the MWTP along with any additional contribution from runoff. No pump or pipeline capacity is applied to either flow assuming that the system will be engineered based on the findings of the model.

Treated water is routed through balance tank, then the conditioning pond, where it is joined with treated effluent from the STP. A small amount of water from the conditioning pond will be used on site:

- 0.4 MLD for service water underground;
- 0.05 MLD for cemented rock fill (CRF) and pumped underground; and
- 0.1 MLD for ore washing (this is the net requirement, ore washing will typically recirculated with a bleed back to the MWTP).

MWTP

A new MWTP will be commissioned based on similar technology as previously used at Galmoy and Lisheen mines (i.e. pH adjustment and precipitation). Settlement of precipitates will be completed in a clarifier and a settlement pond prior to discharge. The goal of the treatment system will be to reduce values of constituents in the water to ensure compliance with ELV's and ensure there is no negative impact on the receiving water WFD status.

Typical feed rates are expected to range seasonally between 12 and 20 MLD, although rates will be higher or lower depending upon the preceding 3 months of precipitation.

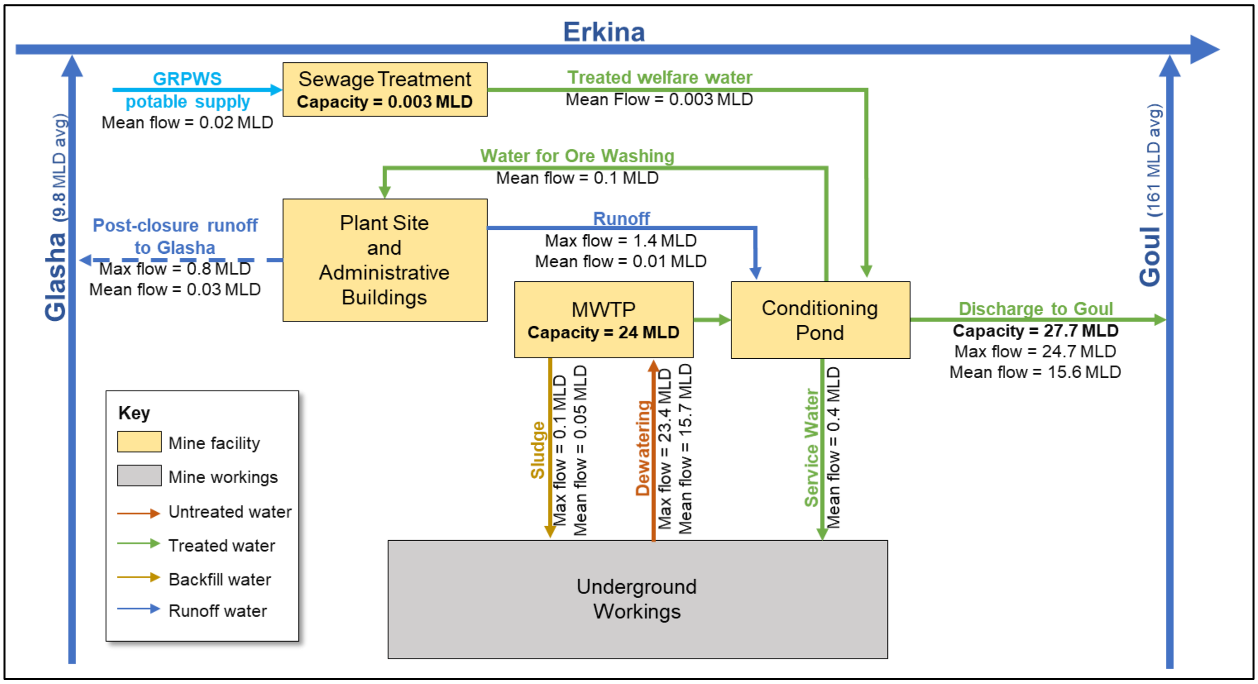
The site will not have a water storage facility available to buffer large inflows of water (Galmoy and Lisheen used their TMF supernatant ponds to do this). Therefore, the new MWTP will be designed to treat up to 24 MLD – the maximum 'worst case' predicted treatment requirement from underground.

The sludge generated will be dewatered to a cake and mixed with rock as part of the CRF process and pumped underground.

STP

A proprietary STP will be installed with a capacity of 2.7 m³/d (0.003 MLD) to meet the needs of the site. The treated effluent will be pumped into the MWTP conditioning pond for discharge down the Goul pipeline.

Figure 11: Predicted average and maximum flow rates within the mine water management system



5.3. Discharge and losses

Most treated water will be sent to the Goul via the existing pipeline along with treated sewage effluent. The pipeline is understood to have a capacity of up to 27.7 MLD.

A limited amount of water from the MWTP will be pumped back underground as water in the CRF. This water is a 'loss' from the system because it will be permanently bound within the paste underground.

APPENDIX 8.7

Quantitative Risk Assessment for Subsidence Resulting from Dewatering of the Underground Mine

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FILE: TM04v4.0_SubsidenceRA.docx

TECHNICAL MEMORANDUM

DATE: 8th July 2021

TO: Barry Balding

FROM: Simon Sholl

Garrylaun Mine: Quantitative Risk Assessment for Potential Reactivation of Palaeokarst and Sinkhole Development from Dewatering and Rewatering of the Underground Mine

1. INTRODUCTION

This report been produced by Piteau Associates as part of the Shanoon Resources Limited (SRL) planning application and Environmental Impact Assessment Report (EIAR) for the recommencement of mining at the former Galmoy Mine, Co. Kilkenny (the 'Garrylaun Project').

The objective of this report is to provide a quantitative risk assessment (QRA) for the development of sinkholes from the potential reactivation of palaeokarst features due to the dewatering (and rewatering) of the underground mine workings at Garrylaun. Consolidation-related subsidence, due to rock extraction, is assessed separately in Chapter 7, Appendix 7.1 of the EIAR.

The QRA is primarily a desk-based assessment, albeit with the knowledge and data from previous mining at Galmoy. Furthermore, a sinkhole developed above the Galmoy mine workings (CW Orebody) after closure, in February 2014, following a period of extreme wet weather. The data and subsequent investigation into this provide important empirical data for this assessment.

Prevention and mitigation measures are provided, as well as possible follow up site investigations to improve an understanding of the likelihood for potential sinkhole development at locations of potentially higher risk.

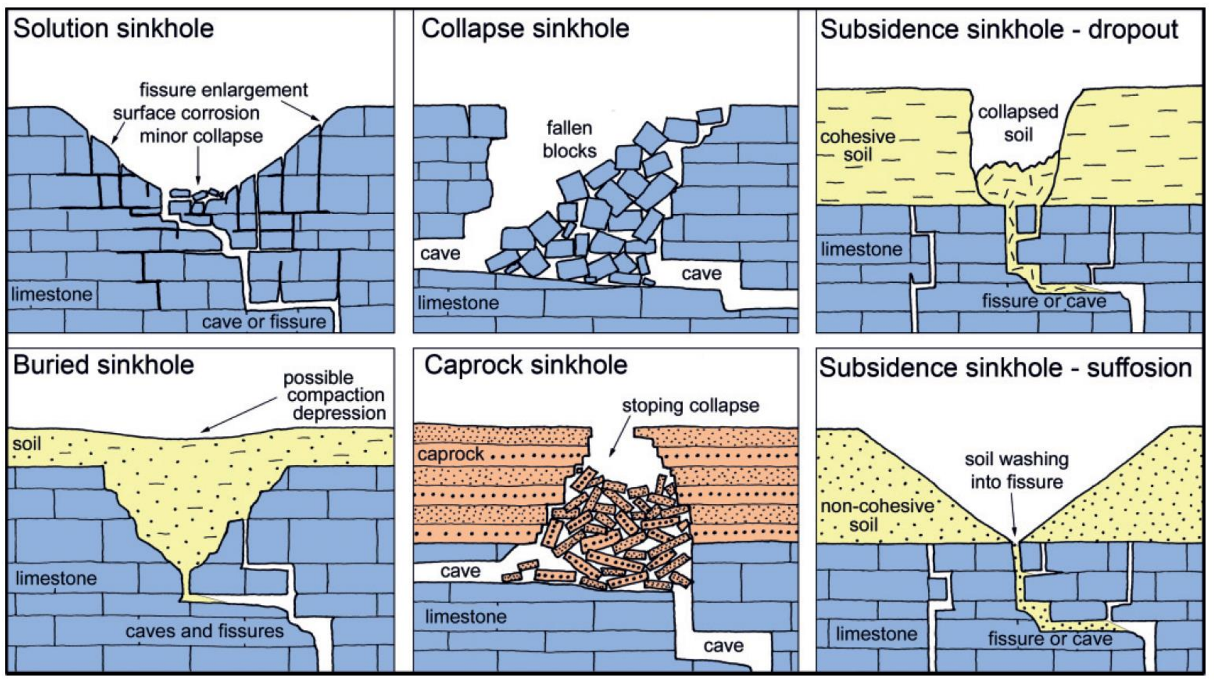
2. SINKHOLE CHARACTERISTICS

'Karst' is used to describe geological features formed by the dissolution of rock. The most common rock types for karst to occur in are carbonates (e.g. limestone or dolomite); although the presence of carbonate rocks does not mean that karst features will occur. Karst features include turloughs, caves, some springs and sinkholes (also known as dolines).

Sinkholes are enclosed depressions that may have a wide range of size and depth. In Ireland, they are the most common landform in karst areas. Natural sinkholes may occur as isolated features or in clusters causing a pock-marked land surface. They can form due to a large number of mechanisms; however, six main types are commonly referred to: solution, collapse, dropout, buried, caprock and suffosion (Figure 1).

Approximately 50% of the Republic of Ireland is underlain by limestone, the majority of which is Carboniferous in age (ca. 300 to 360 million years old). For this reason, karst features are a common occurrence – there are estimated to be over 6,000 sinkholes (Hickey, 2013).

Figure 1: Six main types of sinkhole (from Waltham, *et al*., 2008)



Epikarst, the upper, most-weathered zone of carbonate rocks, is common in the region around Garrylaun and typically occurs within the upper 20 to 30 m of weathered limestone bedrock. The epikarst zone is evident in many of the local limestone quarries in Laois, Kilkenny, and Tipperary. No cave systems have been identified within the Garrylaun area.

Sinkholes are a natural phenomenon although they are sometimes induced or accelerated by human activities. The initial karst feature may be only a few centimetres across and the downward transport of sediment from the soil zone may be very slow, so the void may take many tens or hundreds of years to form. The acceleration of the process is commonly the result of drawdown of the water table which may be due to water supply abstraction, quarrying or mining. Waltham (2016) states that, *“New subsidence sinkholes (both dropout and suffosion) formed within the soil cover constitute the main karst geohazard. Nearly all are induced by increased drainage inputs or by water table decline, and control of the drainage is the primary* *means of reducing their hazard".* Above the water table, there is often: (i) a greater thickness of unsaturated material where turbulent flow, piping and transport of sediment may occur, and (ii) remobilisation and transport of sediment which may already be filling the joints, fractures or conduits in the underlying limestone rock as a result of earlier erosion and transport.

3. FEBRUARY 2014 SINKHOLE

3.1. Description

Overnight between the 14th and 15th February 2014 (one year after all dewatering had ceased at Galmoy Mine), a 'subsidence sinkhole – dropout' appeared in a field above the CW Orebody. This provides an excellent case study to understand the primary factors affecting sinkhole development in the area and, therefore, the primary characteristics and findings following the event are provided below. The sinkhole was successfully remediated by backfilling in April 2014.

No further subsidence occurred in, or around, the sinkhole during the 2 month period between appearance and backfilling works. Over the period before the sinkhole was backfilled, and in the period to today since backfilling, there is no evidence of any cracking or ground movement in the surrounding area. The centre of the sinkhole was immediately above a major geological structural zone (Figure 2) – termed the 'Main Fissure'. The sinkhole was elliptical in plan with the long axis in alignment with the Main Fissure. The dimensions were: long axis 13 m, short axis 8 m, depth 7 m and approximate volume of 730 m^3.

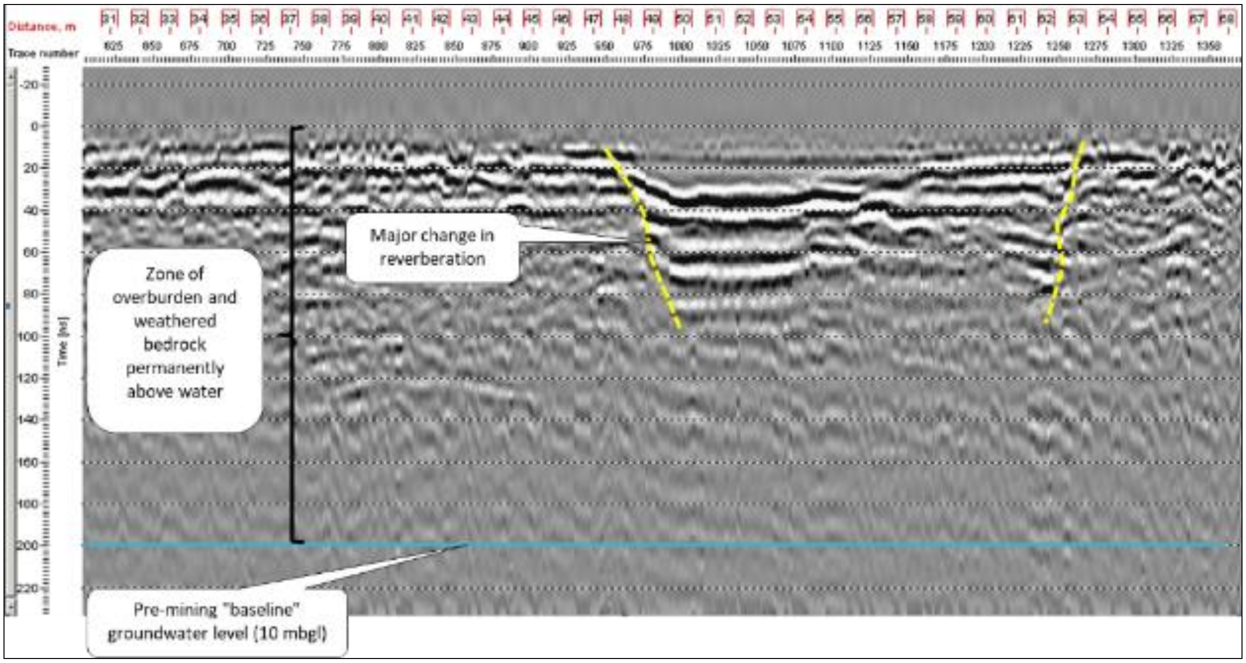
The Main Fissure was the largest NNW-SSE trending sub-vertical geological structure encountered at Galmoy Mine, and consists of a sub-vertical fracture/fissure zone which pinches and swells in width, both along dip and strike. As with the majority of the fissures and associated palaeokarst features encountered when mining at Galmoy, the Main Fissure is essentially 'choked' with debris from weathering and erosion of the limestone and dolomite bedrock during Tertiary times, and the subsequent deposition of superficial deposits during Quaternary glacial episodes (evidence for this exists where peat was recorded in a choked conduit intersected during the development of the Main Access Decline to the mine). Few conduits or cavities were recorded from drilling and mining at Galmoy and, where they were encountered, they were choked with debris.

Figure 2: Location of sinkhole relative to the Main Fissure

The 2014 sinkhole was steep-sided with no bedrock visible in the walls or base, both of which were composed of glacial till. Following the formation of the sinkhole, a minor amount of water was present in the base of the hole. This is unlikely to have been groundwater because levels in the area were estimated to be between 10 and 15 mbgl (metres below ground level) at the time (approximately between 125 and 130 mAOD). Therefore it is likely to have been standing water, indicating that the till was saturated at the time. Saturation of the till was also evident in the walls of the sinkhole below about 4 mbgl (due to a recent period of prolonged heavy rainfall).

Around 100 m southeast of the sinkhole and close to the line of the Main Fissure, there is an enclosed surface depression (Figure 2). It is approximately 15 m in diameter and 1 m deep at its centre. As part of the 2014 sinkhole investigation, Golder Associates (2014) carried out a ground penetrating radar (GPR) survey across this feature (Figure 3). A major change in the character of the reflector is apparent within the depression, giving the impression of a steep sided feature approximately 5 m deep. This has been interpreted to be a potential buried sinkhole (in palaeokarst) of comparable size and geometry to the February 2014 sinkhole, demonstrating that sinkholes have previously occurred in the region of the Main Fissure.

Figure 3: Ground penetrating radar section across the 'enclosed depression' (based on Golder Associates, 2014)



3.2. Mechanism for Sinkhole Development

The morphology of the February 2014 sinkhole strongly suggests that it is a dropout sinkhole (also known as dropout or cover collapse sinkhole) – illustrated in Figure 1. Such features are characterised by vertical or steep-sided collapses, with a very sharp break in slope and no bedrock exposure in the walls or base.

Dropout sinkholes occur when the soil (in this case boulder clay and overlying subsoil and topsoil) collapses into a void within the soil itself. They are common in Ireland because the prerequisites are cohesive soils (such as glacial till) overlying karst features. The generalised formation of a typical dropout sinkhole is as follows:

1. Water percolates through the soil.
2. The underlying bedrock surface provides a low permeability barrier to downward flow, so the water moves laterally downslope at the base of the soil to an area of higher permeability (the karst feature).
3. Concentration of percolation water occurring within the unsaturated zone (above the main water table), causes the flow to become non-Darcian (commonly referred to as 'turbulent'), i.e. capable of carrying sediment. The high velocities increase the potential for piping (internal erosion of the soil grains), transport of sediment and formation of an internal void above the karst feature. At the surface, there are often no visible signs of this occurring.
4. Void formation often concentrates the water seepage, thus accelerating the internal erosion process.

5. The eroded soil material is transported downwards into the karst feature and into interconnected joints, fractures or conduits within the underlying limestone bedrock. The connecting conduits are present because of the gradual dissolution of the limestone due to percolating water over long periods of geological time, primarily during the Tertiary period. In the limestone areas of the Irish Midlands, the upper part of the bedrock may be strongly weathered (epikarst) and contain interconnected conduits at greater depths which were formed when the water table was lower than it is currently (palaeokarst).
6. A critical point is reached where the soil can no longer support its own mass and it suddenly collapses.

The soil collapse often occurs during or following periods of heavy rainfall when the percolating water adds more weight to the overlying soil, triggering the collapse.

In summary, dropout sinkholes can form early-on during a dewatering event. At Galmoy this did not happen, because the existing palaeokarst system was 'choked' and there was nowhere for sediment to move to.

However, dewatering and subsequent mining into the Main Fissure at the orebody horizon provided a pathway for sediment to move downwards through the system throughout the life of mine. The bedrock depression associated with the Main Fissure provided a drainage point into the structure for water ingress.

Following cessation of mining, while the recovering water table was still below baseline levels, a period of extremely high rainfall occurred over the period of two months. This allowed for increased fluid flow through conduits that had become un-choked during the period of mining, and this coupled with the development of open voids within the boulder clay (soils) due to washout of material through conduits in the upper parts of the bedrock above the Main Fissure, increased the weight of the boulder clay (soils) and acted as the trigger for collapse into a void which formed the sinkhole.

3.3. Contributing Factors

The February 2014 sinkhole is a natural feature; however, it is likely that the following factors contributed to its formation:

- The presence of the Main Fissure.
- The geomorphology of the bedrock surface and local topography allowed infiltrating and percolating water to become concentrated above the Main Fissure at the specific location where the sinkhole occurred.
-
- The shallow pre-mining water table in the bedrock (approximately 8 to 10 m below the ground surface) meant that percolation, internal erosion and transport of soil material from the overlying soils (boulder and soils) could have been occurring for many years prior to the sinkhole development – assuming open conduits were present for sediment to move into.

- The mine dewatering potentially contributed to an increased void space and sediment sink in the upper weathered bedrock into which the in-situ unconsolidated material could be transported. This is because dewatering potentially caused an increase in recharge flow velocity (sufficient to carry sediment) within the unsaturated zone of the upper bedrock. Dewatering may have caused consolidation of material that filled existing joints, fractures and bedrock cavities in the palaeokarst zone below the level of the sinkhole.
- The extremely high rainfall from December 2013 to February 2014, which added weight to the soil above the void provided the trigger for the collapse. Whilst a void may develop over a period of decades, the final collapse of its roof to form a dropout sinkhole commonly occurs during or after periods of high rainfall.

4. LIKELIHOOD OF A SINKHOLE DEVELOPING

4.1. Likelihood Definitions

The likelihood of sinkhole development is a combination of many factors including natural topography, underlying geology and precipitation. Five likelihood categories are used:

- Very unlikely – may occur but only under exceptional circumstances;
- Unlikely – could occur but doubtful;
- Moderate – might occur at some time in the future;
- Likely – known to have occurred in the past; and
- Very likely – expected to occur.

4.2. Potential Subsidence Mechanisms

The focus of this QRA is dewatering-induced or mining-induced reactivation of palaeokarst features (i.e. sinkholes). Consolidation-related subsidence, due to dewatering and/or rock extraction, is assessed separately in Chapter 7 of the EIAR.

Figure 1 illustrates the six primary sinkhole types. These have been assessed to determine the potential to develop at Garrylaun.

- Solution Sinkhole – Very unlikely. Dissolution rates in the area are very low due to the neutral pH of the soil water. Some acid water may be generated within the mine workings as sulphide material is oxidised, however, this will be rapidly neutralised by 'background' alkalinity from the recharging groundwater system.
- Collapse Sinkhole – Very unlikely. Although some palaeokarst cavities are present in the area all evidence from Galmoy mine and exploration drilling indicates that these are 'choked' and very limited in size, so unlikely to cause a collapse sinkhole as a collapse sinkhole can only occur where there is a large open bedrock void close to the surface.
- Subsidence (Dropout) Sinkhole – Likely. This mechanism was the likely cause of the February 2014 sinkhole, where unconsolidated material collapsed into a previously choked conduit (the 'Main Fissure') over the life of the underlying mining operation.

- Buried Sinkhole – Likely. The 'enclosed depression' near the February 2014 sinkhole is likely to be a buried (palaeokarst) sinkhole. These features are common in areas of Irish lowland karst where they are associated with sub-vertical conduits. Compaction subsidence is possible at these locations as well as mobilisation of soil leading to a dropout sinkhole (above).
- Caprock Sinkhole – Very unlikely. By definition, caprock sinkholes occur in a caprock over the limestone and there is no caprock in this area.
- Subsidence (Suffosion) Sinkhole – Unlikely. Suffosion sinkholes only form in non-cohesive superficial deposits and the deposits in this area are cohesive.

4.3. Effects of Extreme Rainfall

Approximately two thirds of dewatering water at Galmoy Mine can be attributed to seasonal recharge; the remaining third being primarily derived from lateral inflows from the area. The same conditions are, therefore, expected when dewatering Garrylaun. Periods of above average rainfall, particularly over weeks or months, will produce increased recharge. More recharge means a larger volume of water percolating through the unsaturated zone, increasing the potential for sediment transport. In addition, greater saturation of the soil zone during or immediately following prolonged periods of extreme rainfall increases the weight of the soil, thereby providing a likely trigger for sinkhole formation.

This was a key contributor to the February 2014 sinkhole. The winter of 2013-2014 was exceptionally wet. Between December 2013 and February 2014, 460 mm of rain was recorded at Oakpark, Co. Carlow (45 km east of Garrylaun). This is 2.4 times higher than the long-term (1996 to 2013) average of 194 mm for the same period.

4.4. Effects of Geology

Lithology

Sinkholes are common in Irish limestones (Hickey 2013), but with the exception of the February 2014 dropout sinkhole (now remediated), the only known sinkhole in the mine area is the enclosed depression shown on Figure 3, which is probably a buried sinkhole. Based on observations in other parts of Ireland there is a potential for other buried dolines to be present.

Regional geological structures

Regional geological features, such as the 'Main Fissure' underlying the February 2014 sinkhole, define zones where there is natural increased potential for groundwater flow, weaker rock (from drilling records) and a sediment sink. Hence, the presence of such features increases the potential for sinkhole development. However, these features typically pinch and swell along their plane (i.e. laterally along the strike and vertically along the dip). This produces isolated zones of enhanced flow potential (the swells) separated by zones of limited flow potential (the pinches). Therefore, while the potential for sinkhole development exists, the size or extent would be limited to discrete sections of such structures, rather than producing linear subsidence along the strike. In addition, the geological structures (fractures and fissures) and palaeokarst features associated with the dolomitised Waulsortian limestone at Galmoy tend to be choked with sediment, limiting the flow of groundwater and the potential for sinkhole development.

With the exception of the G Zone Fault, located ca. 500 m to the south of the 2014 sinkhole (which is much shallower dipping and has the low permeability Ballysteen Formation as its footwall), the ‘Main Fissure’ was the largest geological structure discovered during mining of Galmoy. There are no other known major sub-vertical structures at Galmoy, thus reducing the potential for similar sinkhole mechanisms occurring elsewhere close to the mining area.

During the Galmoy Tailings Management Facility (TMF) design process, Golder (1992) undertook an assessment (including geophysical surveys and intrusive ground investigations) into the potential for karst to cause near-surface stability issues. The assessment showed that: (i) the palaeokarst system in the TMF area is immature, (ii) the system is filled with in-situ derived residual material (i.e. ‘choked’), and (iii) it is highly unlikely that a system of continuous conduits occurs underneath TMF footprint area.

The likelihood for potential sinkhole development increases where sub-vertically linked open conduits intersect underground mine workings. However, where conduits/palaeokarst features intersect underground workings in the Galmoy area these features are typically choked with sediment and are quickly supported to prevent the movement of bulk sediment into the mine excavation, while still allowing water to drain from the conduit in a controlled manner. For the purposes of the QRA to delimit the likelihood of subsidence, a 10 m buffer zone (i.e. 20 m across) is applied to the surface-expression of major mapped structures in the area. This is considered conservatively wide because of the limited lateral extent associated with dropout sinkhole formation.

Bedrock surface geomorphology and local topography

Recharge percolating downwards under unsaturated flow conditions will flow along the line of least resistance through the epikarst, concentrating the flow of water into vertical conduits that commonly develop at fracture intersections. This can facilitate the capture of water in depressions within the bedrock surface, focusing the flow of water and increasing the potential for turbulent (non-Darcian) flow. Depressions are more likely to occur near geological structures where the bedrock may be weaker, such as at the intersection of fractures.

The bedrock surface geomorphology has not been mapped in detail in the area as it is covered by a layer of boulder clay (glacial till), with little bedrock exposure occurring in the vicinity of the mine, therefore, **geomorphology has not been included as part of the QRA.**

4.5. Mine Dewatering

The reduction in the water table elevation has the potential to dewater palaeokarst features and some of the (shallower) epikarst. This can cause unsaturated groundwater flow (i.e. movement of water above the water table) through interconnected joints, fractures, and conduits. Unsaturated flow is likely to be turbulent; thus facilitating erosion and increasing sediment-carrying potential. Therefore, mine dewatering has the potential to mobilise material accumulated in these void spaces (joints, fractures and cavities) in the upper bedrock if open conduits occur. This has the potential effect of ‘cleaning out’ the void space and producing a greater sink for sediment further ‘upgradient’, assuming open, connected conduits exist. Therefore, sediment is mobilised from a greater and greater distance over time.

Dewatering of Garrylaun will decrease the level of the water table in the area of the mine workings by around 60 to 80 m. However, most mining activity will be below the present (predewatering) water table. Therefore, unsaturated (turbulent) flow into the mine (the primary sediment sink) will only occur where conduits intersecting the mine workings are unsupported and become unchoked. By supporting the conduits shortly after they are intersected, the movement of bulk sediment into the mining workings can be prevented. Experience and evidence from previous mining does not support a rapid connection between the sediment-filled (choked) conduits at the mining horizon and conduits (also choked) in the upper part of the bedrock, provided that the conduits at depth are supported where they intersect the mine workings. Any flow or transport of sediment between the two zones appears to be diffuse and likely to have a complex and tortuous flow pathway.

Reduction of the water table can increase the potential for Sinkhole development, particularly dropout sinkholes. Therefore, for the purposes of determining likelihood, the maximum predicted drawdown extent (both laterally and vertically) has been discretised into the following zones.

- **< 3 m – groundwater remains within the zone of natural seasonal level change and therefore does not increase the likelihood for sinkhole development.**
- **3 to 10 m – drawn down bedrock water table elevation assumed to remain within the soil and unconsolidated sediments, slightly increasing the likelihood for void formation and ultimately sinkhole development.**
- **>10 m – drawn down bedrock water table below the base of the unconsolidated sediments causing unsaturated flow conditions between the base of the unconsolidated sediments and the dewatered water level. This increases the likelihood for void formation and ultimately sinkhole development by a moderate amount.**

4.6. Likelihood assessment

This QRA covers the two elements in the formation of a dropout sinkhole: (1) the slow growth of a void in the soil material that overlies the solid bedrock, and (2) the very rapid appearance of a sinkhole at surface as the roof of the void collapses.

1. There is a general ‘very unlikely’ background potential for a void to form in the soil material as this requires downwards removal of sediment and the underlying palaeokarst system in the area being is known to be immature and choked.
2. A void is most likely to develop in the soil when a ‘choked’ or sediment filled structure at depth is ‘cleaned out’ allowing material from above to wash into the newly opened bedrock void thereby forming a new void in the soil material.
3. Mine workings that intersect a structure have the greatest likelihood of ‘cleaning it out’ because they produce conditions for unsaturated (turbulent) flow to mobilise sediment, and a sink for the ‘cleaned out’ sediment to be transported away from the structure. However, where sub-vertical structures and mine workings intersect, these areas have been supported by a combination of wire mesh and shotcrete, or fibre reinforced shotcrete or

steel arches, thus minimising the potential movement of bulk sediment into the mine workings at those locations.

4. Major structures in the area are steeply dipping (> 75°), but a structure intersected at depth within the workings may daylight at surface away from the workings footprint. Therefore, an additional 50 m buffer zone has been applied to the workings based on intersecting an unmapped 65° structure at 100 m depth.

5. Reduction in the water table due to dewatering (but away from mining activity) increases the likelihood of a void forming in the soil but not significantly because, although it produces the conditions for unsaturated flow, it does not produce a sink for bulk sediment removal.

Localised mapping of the likelihood for sinkhole development can therefore be undertaken by cross referencing the projected surface outcrop of mapped geological structures from underground, where they intersect underground workings within the area of predicted drawdown due to dewatering. The cross reference matrix is presented in Table 1 and the mapped likelihood areas in

6. Figure 4.

7. A void may form in the soil without ever growing to a size that is sufficient for collapse to occur resulting in the appearance at surface of a dropout sinkhole. Prolonged or intense rainfall events that saturate, and thereby increase the weight, of the material that forms the roof of the void, are common triggers for collapse.

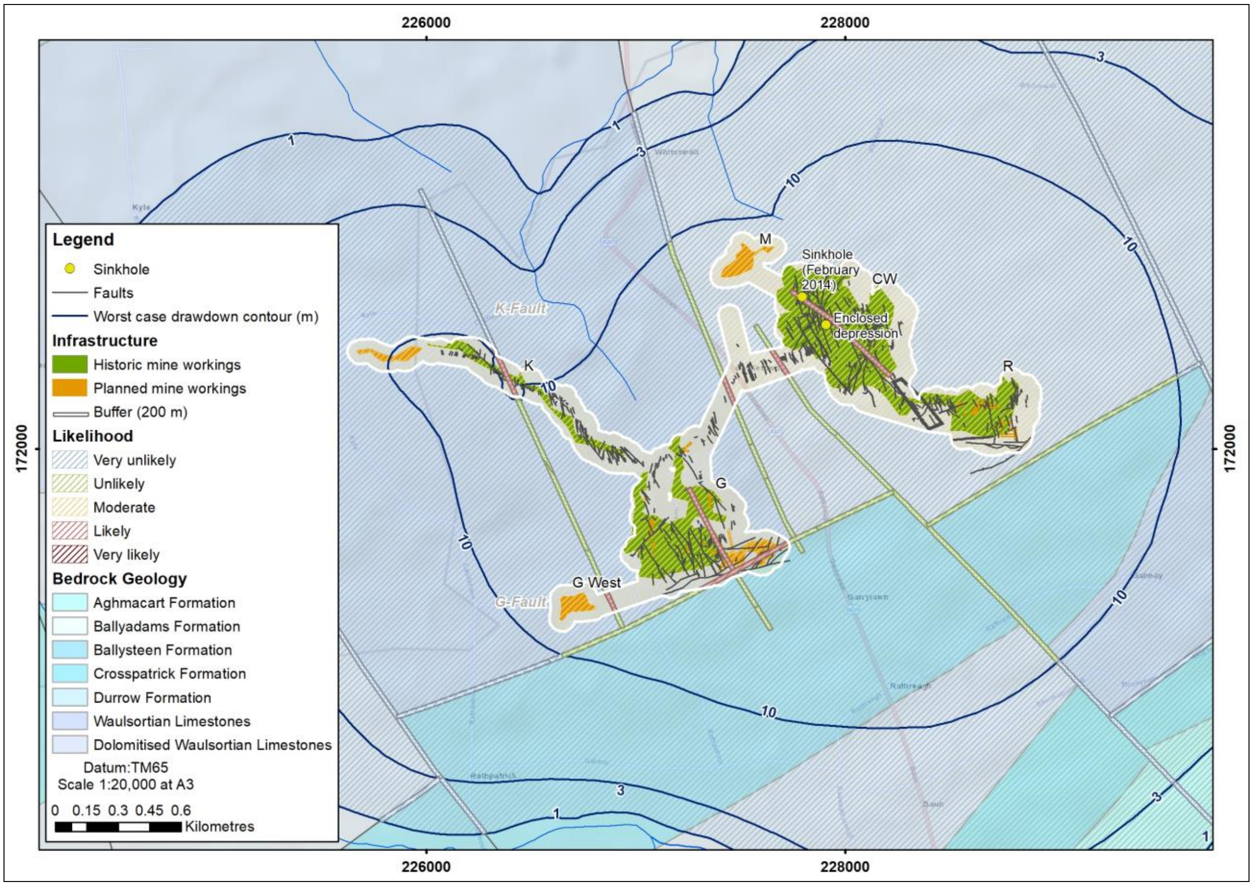
The likelihood for sinkhole development remains the same as outlined above during the period of active closure, when mine dewatering is ceased, and the water table allowed to recover to baseline conditions.

Post-closure (once baseline conditions have been achieved), the likelihood for sinkhole development returns to 'very unlikely' because there is no mechanism in place for the transport of sediment to a 'sink'.

Table 1: Matrix for defining the likelihood of a void developing in the soil based on the intersection of sub-vertical structures and underground workings due to dewatering

		Geological Structures	
		Outside Workings Buffer	**Inside Workings Buffer**
Dewatering-induced drawdown	**< 3m drawdown**	Very Unlikely	Unlikely
	3-10m drawdown	Very Unlikely	Unlikely
	>10m drawdown	Unlikely	Likely

Figure 4: Likelihood of sinkhole development based on the intersection of geological structures with mine workings with the predicted area of drawdown due to dewatering

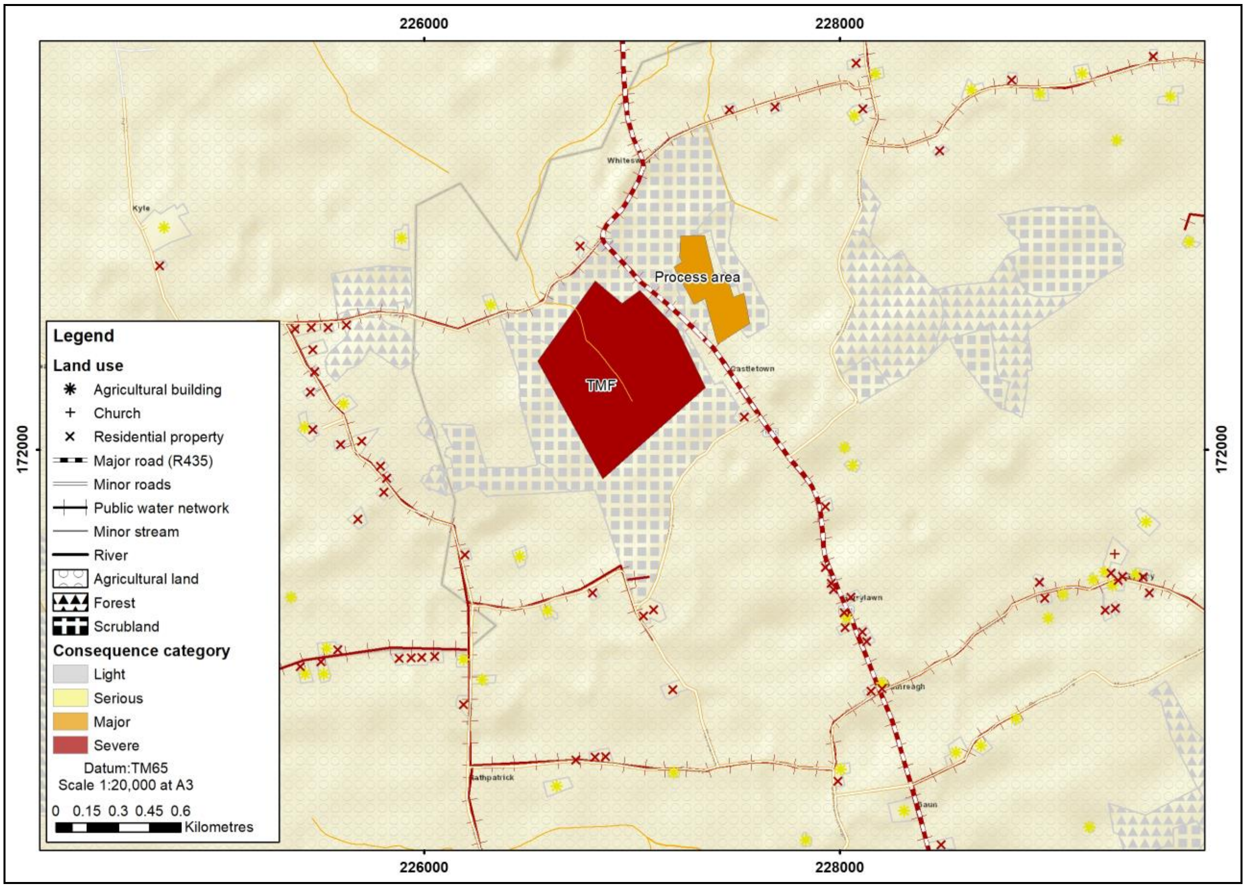


5. CONSEQUENCE OF A SINKHOLE DEVELOPING

The consequence of sinkhole development is defined based on the land use which broadly summarises the frequency of use, the potential for loss of life and the potential for negative environmental impact. Therefore, domestic and public access lands have the greatest consequences and scrub land the lowest. Each land use has been assigned to a consequence factors as outlined below and illustrated in Figure 5.

- Light consequence – agricultural, forestry, wildlife or scrub land;
- Serious – agricultural buildings;
- Major – mine property (excluding TMF), minor public road and streams; and
- Severe – residential property, electricity supply grid, drinking water supply network, public access land, TMF, major public road and rivers.

Figure 5: Consequence of sinkhole development based on land use



6. QUANTATIVE RISK ASSESSMENT

6.1. Objective

The objective of the QRA is to assess the area around Garrylaun for the likelihood of the reactivation of palaeokarst features (and the development of sinkholes) due to mine dewatering and the consequence that any subsidence might have. These categories are then combined to determine the risk of sinkhole development at any given location.

The area of assessment for the QRA is the maximum area predicted to have more than 1 m of drawdown under the ‘worst case scenario’ for dewatering (where no cover grouting is undertaken).

The QRA allows monitoring and mitigation measures to be applied to areas at greatest risk of potential sinkhole development following reactivation of palaeokarst features. Five risk categories have been defined as follows:

- Extreme – hazardous and the area should be evacuated;
- High – elevated risk which must be closely monitored;

- Medium – elevated risk requiring periodic evaluation;
- Low – acceptable risk; and
- Negligible – safe.

6.2. Risk matrix

The risk of sinkhole development is determined by cross-referencing the likelihood and the consequence, as presented in Table 2.

Table 2: Matrix for determining the risk of a sinkhole developing

		Likelihood				
		Very Unlikely	**Unlikely**	**Moderate**	**Likely**	**Very Likely**
Consequence	**Light**	Insignificant	Low	Low	Low	Medium
	Serious	Low	Low	Medium	Medium	High
	Major	Low	Medium	Medium	High	High
	Severe	Low	Medium	High	High	Extreme

The likelihood of sinkhole development due to the reactivation of palaeokarst is dependent upon a number of factors including topography, geology and precipitation. These factors have been discussed in Section 4 together with an assessment of the likelihood for the Garrylaun area.

The consequence is primarily defined by the land use, as outlined in Section 5.

6.3. Risk assessment

The majority of the Garrylaun area is determined to have *Insignificant* or *Low* risk of sinkhole development following reactivation of palaeokarst features (Figure 6). Areas where risk is greater than this during active dewatering and post-closure groundwater recovery periods are as follows.

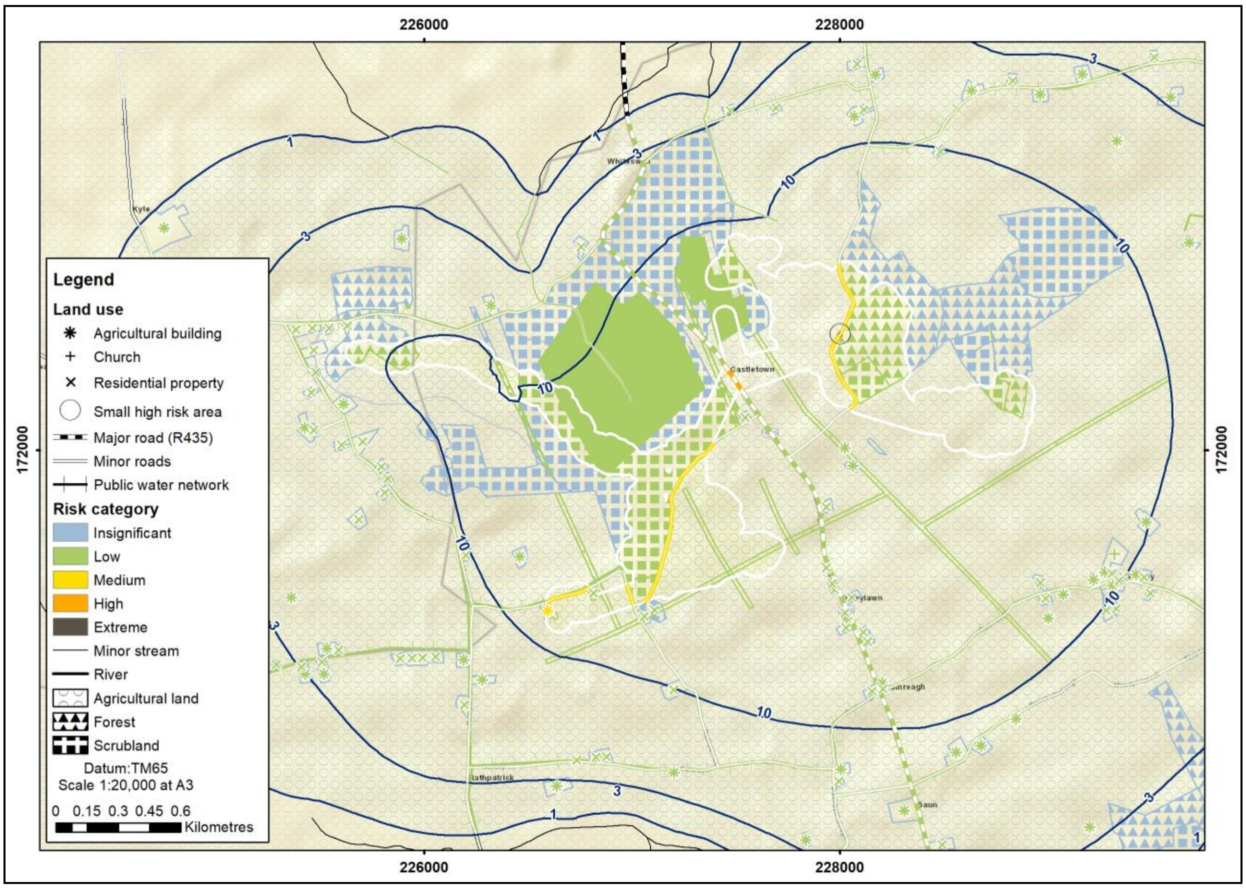
- Extreme risk – there are no areas of extreme risk.
- High risk:
  - 180 m of the R435 where it crosses the mine buffer zone;
  - 180 m of public water network along the R435;
  - 200 m of public water network along the L5805; and
  - one discrete 20 m location on the L5804 where it crosses the Main Fissure.
- Medium risk:
  - 760 m of the L5804 where it crosses the CW Orebody;
  - 780 m of the L5805 (in three sections) where it crosses the G and G West orebodies and three geological structures; and

- one agricultural building towards the edge of the G West Orebody.

Once the water table has recovered to baseline conditions after closure, the risk for sinkhole development is *Insignificant* across the whole mine area.

The QRA is primarily a desk-based assessment. However, the current study is considered to be robust because of the existing detailed knowledge of the area, the long period of pre-mining, operational and post-mining monitoring, and the knowledge and data from previous mining at Galmoy and the February 2014 sinkhole and subsequent investigation.

Figure 6: Risk of sinkhole development due to dewatering-induced water table drawdown



6.4. Prevention and mitigation

For the purposes of this QRA, the following definitions are used:

- **Prevention –** reducing the likelihood of a sinkhole developing (i.e. moving further to the left in Table 2); and
- **Mitigation** – reducing the consequence of a sinkhole developing (i.e. moving further up in Table 2).

Prevention measures

- Monitoring systems should be implemented for:
    - Precipitation (and tracking against long-term trends);
    - Regional subsidence stations;
    - Regional groundwater levels;
    - Reporting of significant inflows of water or water with a high-sediment content underground (parameters to be agreed with the regulator); and
    - Frequent liaison with local community members.
- Increase the monitoring frequency during and after periods of above average precipitation.
- Development of Trigger Action Response Plans (TARPs) which use monitoring data to identify when the likelihood of sinkhole development increases, and define what action need to be taken to reduce the likelihood again.
- Carry out underground cover drilling, where feasible, to identify any potential significant inflows and allow them to be grouted up in advance of mining.
- Restricting or grouting any major underground groundwater inflow or water with a high-sediment content. Reducing the inflow to the workings will reduce the erosion of sediment, a potential trigger to sinkhole development.
- Annual geophysical surveys be conducted (GPR) on surface above areas where mine workings intersect water bearing conduits underground with the aim of identifying any near surface voids in the superficial deposits.
- Regularly monitor locations where mine workings intersect water bearing conduits underground to measure turbidity, allowing a database of areas in which sediment movement can be mapped and monitored.

Mitigation measures

- Any private property at medium risk, provide awareness of the risk to the property owner through community relations.
- For public access lands at high risk, provide signage warning of the risks, particularly during or just after periods of above average precipitation.
- For all infrastructure (roads, electricity, water supply networks), creation of ‘diversion plans’ to reroute traffic, electricity or power through alternative routes should a sinkhole develop.
- Revise and agree the Cautionary Zone Map with the relevant authorities.

7. CONCLUSION

The risk of dewatering-induced sinkhole development following the reactivation of palaeokarst for Garrylaun has been determined by cross-referencing the likelihood and the consequence. The QRA shows that the majority of the Garrylaun area is determined to have *Insignificant* or *Low* risk of dewatering-induced sinkhole development. There are no areas of *Extreme* risk and limited areas of potentially *High* risk.

180 m of major road (R435) and associated public water network, a 200 m section of public water network along the L5805 and a discrete location of minor road (L5804) have been identified as being at high risk.

1.54 km of minor roads (L5804 and L5805) and one agricultural building have been identified as medium risk.

Where elevated risks have been identified, these can be:

- Prevented through a suitable monitoring network and associated TARPs; and
- Mitigated through the development of contingency plans and good interaction with the local community.

Once the water table has recovered to baseline conditions after closure, the risk for sinkhole development is *Insignificant* across the whole mine area.

8. REFERENCES

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9. CLOSING

We trust the above is adequate for your current needs. If you have any questions regarding the above, or we can be of further service, please do not hesitate to contact us.

Respectfully submitted,

PITEAU ASSOCIATES

Simon Sholl, Hydrogeologist

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APPENDIX 8.8

Numerical Groundwater Model Construction, Calibration and Simulation

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FILE: TM07v1.0_NumericalGroundwaterModel.docx

TECHNICAL MEMORANDUM

DATE: 8th July 2021

TO: Alan Buckley

FROM: Lara Belton and Simon Sholl

Garrylaun Project: Numerical groundwater model construction, calibration and simulation

1 INTRODUCTION

A site-wide 3D numerical groundwater model was constructed for the Garrylaun Project using the FEFLOW code. The model is configured to simulate the groundwater system over a domain area which encompasses the historic Galmoy mining area and the planned Garrylaun workings.

The model domain is extended outward from these mining areas to the major bounding rivers of the Erkina to the north, and the Goul to the east. Catchment subdivisions were used to define the western and southern domain boundaries. Groundwater in the mine area is considered unlikely to flow beyond these boundaries (

Figure 1) and they may thus be regarded as reasonably defining the area of potential groundwater impact.

2 MODEL CONSTRUCTION

2.1 Grid and layers

A triangular grid was used throughout the model with cell widths varying between 3 m and 230 m. Smaller cells were used to discretise features of interest (mine workings, rivers and geological structures).

The model domain was divided into 10 layers with thicknesses between 1 m and 137 m. The model was constructed using an elevation of Malin plus 1000 m. It extends from a maximum elevation of 1190 mRL (190 maODM) to a minimum elevation of 636 mRL (-364 maoDM). The surface of Layer 1 was defined using local topography that spliced together available datasets from:

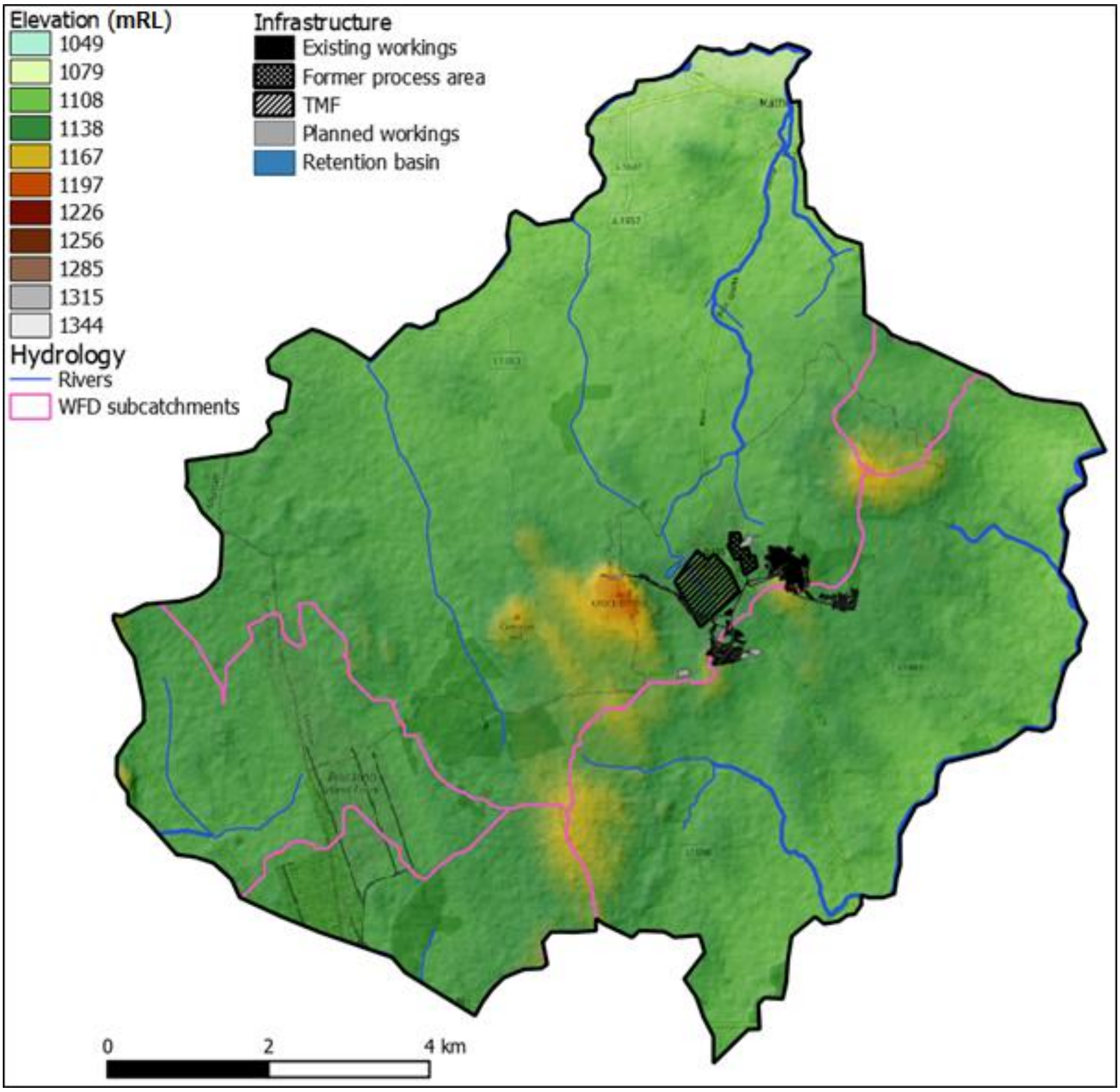
- High resolution: site survey data (Master Survey Jan 28 2021.dwg and 01 – OGL From Cad – Malin.dwg); and

- Low resolution: NASA Shuttle Radar Topography Mission (SRTM) data at 1-arcsecond resolution.

The geological drillhole database was used to define the base of the overburden and Waulsortian limestones and the remaining layers were split from these.

Surface water catchment, sub-catchment and river flow network data from the EPA were used to define model domain boundaries.

Figure 1: Groundwater model domain



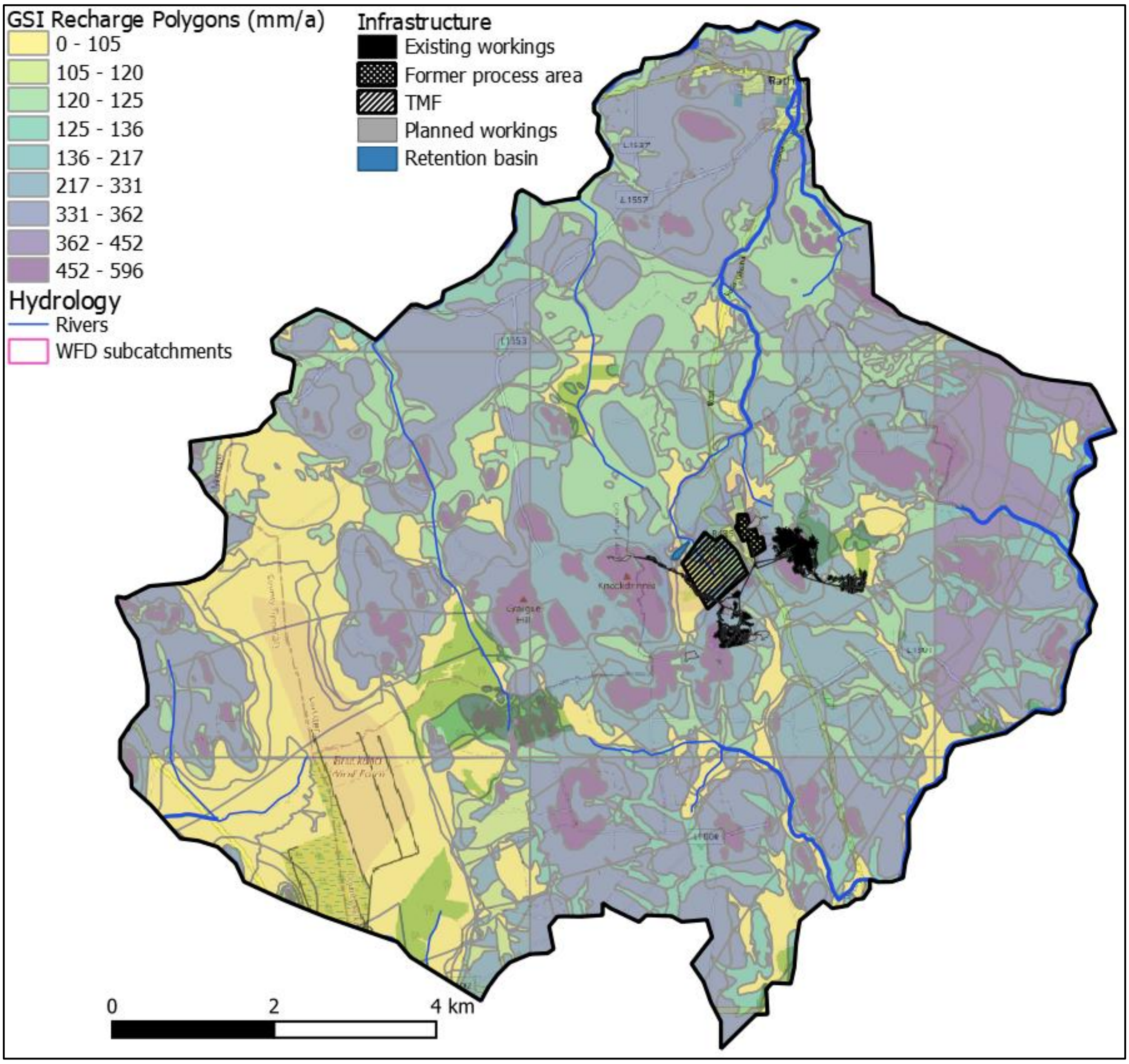
2.2 Boundary conditions

Precipitation and recharge

Daily precipitation is recorded by Met Éireann at the Parknahown Cullahill rain gauge approximately 7 km east of the site. The annual average rainfall for the 1982 to 2019 period was 835 mm/yr. Monthly total pan evaporation and evapotranspiration data are collected at the Oak Park synoptic station approximately 50 km east of the site.

Recharge polygons are available from the Geological Survey of Ireland (GSI) for the model area (Figure 2) and provide a recharge rate based on parameters including soil properties, depth to groundwater and groundwater vulnerability. Recharge rates assume annual average precipitation and evapotranspiration. A factor was applied to the GSI recharge rate by dividing annual average precipitation and monthly precipitation to produce a time series of recharge polygons that better reflects the seasonal variation seen in Irish groundwater systems.

Figure 2: Recharge polygons



Discharge and dewatering

The primary natural discharge mechanism for groundwater in the model area is to the surface drainage system. This occurs where natural topography, river valleys or drainage ditches intersect the water table, allowing groundwater to flow into streams and rivers as baseflow or as springs and wetlands.

Discharge is represented in the groundwater model using seepage nodes which correspond to a 'hydraulic head' boundary condition with a flow constraint. Seepage nodes are distributed along the axes of streams in the model domain (Figure 3). The applied boundary condition generates a stream by the combination of conductance of the surrounding elements and the difference between the groundwater level and the ground level. Seepage nodes are established in the FEFLOW model such that only discharge may occur, with reverse flow precluded.

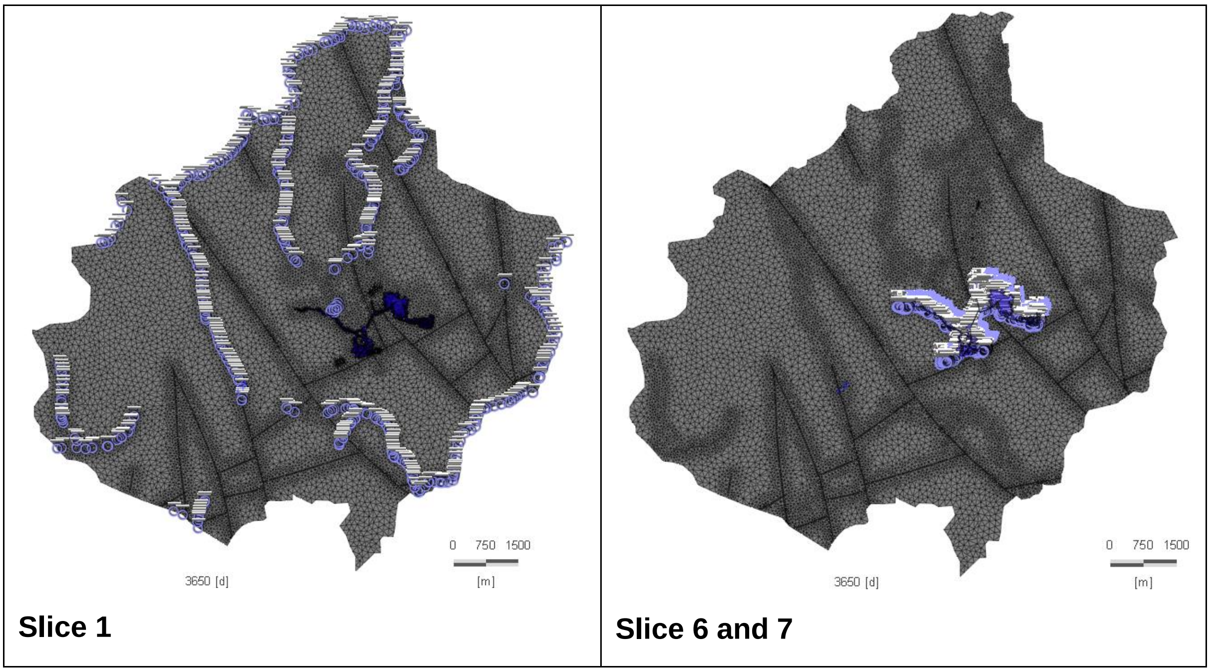
Groundwater discharge to the underground workings (i.e. mine dewatering) was also simulated using seepage nodes in Layer 6 (Slice 6 and 7).

A constant head boundary condition was used to simulate the retention basin north of the closed TMF in Slice 1.

Public water abstraction

The Galmoy and Rathdowney Public Water Supply (GRPWS) production wells WW1A and WW2B are both located around 500 m west and north of the underground workings. Both wells were operated successfully throughout the entire period of mining at Galmoy. The wells were simulated assuming only WW1A was abstracting at a rate of 70 m³/hr (1,700 m³/d), the long-term average pumping rate for this well. WW2B is a standby well and is infrequently pumped, so it was not included in the model.

Figure 3: Hydraulic head boundary conditions



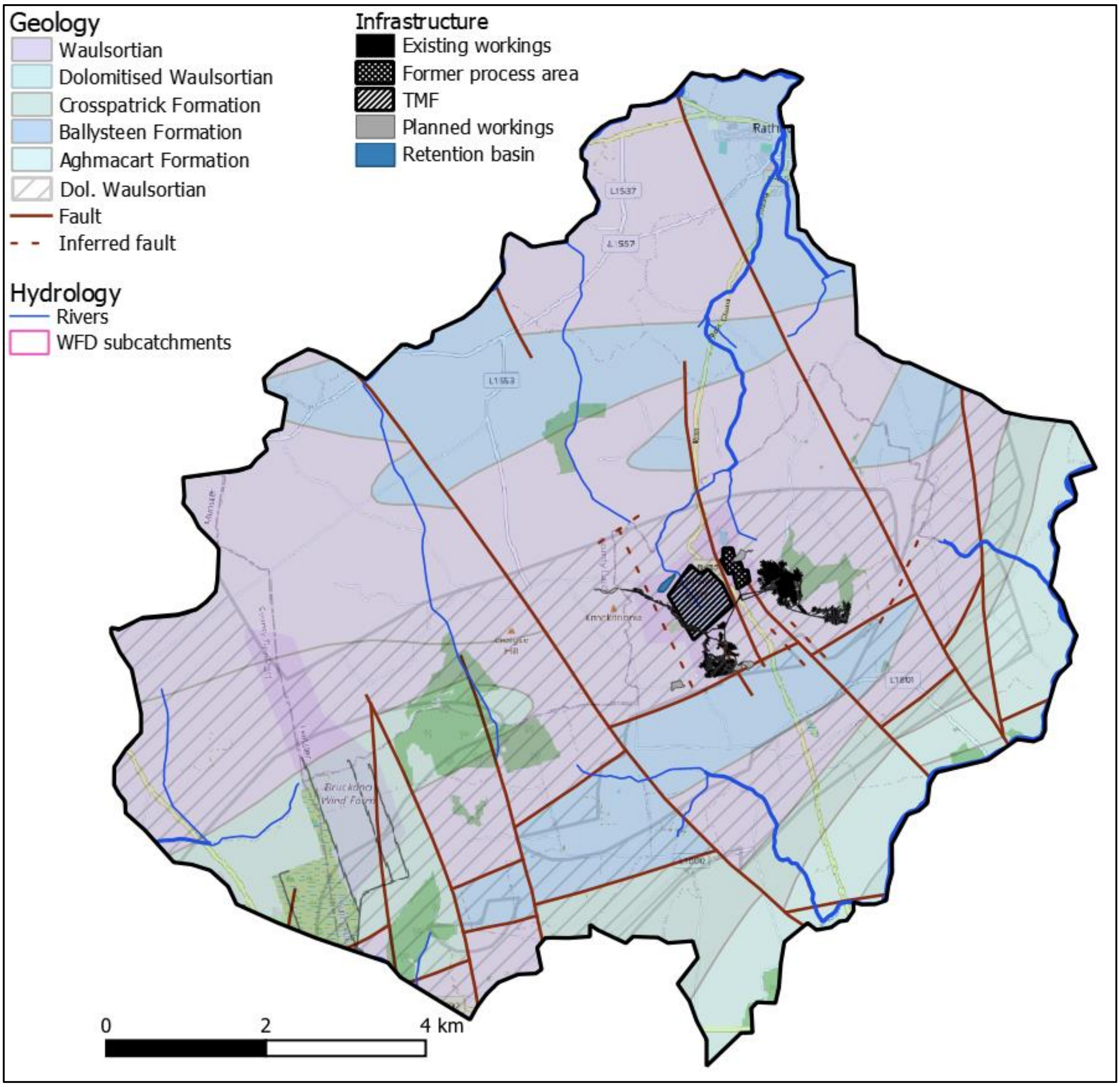
2.3 Hydraulic properties

The bedrock lithologies within the model domain are dominated by limestones (Figure 4), primarily:

- **Dolomitised Waulsortian Limestone:** regionally important karstified bedrock aquifer;
- **Undolomitised Waulsortian Limestone:** locally important aquifer with lower permeability than the Dolomitised Waulsortian Limestone;
- **Ballysteen Formation:** or Argillaceous Bioclastic Limestone (ABL) which underlies the Waulsortian and is often low permeability apart from localised highly transmissive interbedded oolites;
- **Crosspatrick Formation:** Crinoidal limestone, locally important aquifer; and
- **Aghmacart Formation:** dark shaly micrite and peloidal limestone, locally important aquifer.

The entire domain is overlain by Quaternary superficial alluvial deposits with thickness between 4 and 8 m. Most bedrock groundwater flow occurs in the upper weathered zone (20 to 30 mbgl) which includes epikarst. Groundwater flow within the bedrock units occurs as fracture flow; primary permeability is essentially zero. As is the standard procedure, the groundwater flow system is simulated using an equivalent porous medium approach, where the bulk hydraulic properties in the model represent the average hydraulic properties of any structures and host rock.

Figure 4: Model geology



Bedrock hydraulic conductivity of the Garrylaun model domain was estimated to be between 10^{-4} and 10^{-2} m/d (Table 1) based on calibration of the groundwater flow model in steady-state and transient conditions against observed groundwater levels and the groundwater recovery following cessation of mining at Galmoy. Faults are hydraulic barriers to flow and have therefore been assigned a hydraulic conductivity of 10^{-7} m/d. The specific storage of the groundwater system was estimated as being 0.0001 1/m based on calibration of the groundwater flow model under transient conditions against the observed groundwater levels and recovery.

Table 1: Hydraulic properties of main hydrogeological units

Unit	Hydraulic conductivity (m/d)	Drainable porosity	Specific storage (1/m)
Overburden	10	0.025	0.0001
Epikarst	1	0.0025	
Faults (perpendicular to strike)	10^{-7}	0.0001	
Dolomitised Waulsortian	10^{-2}	0.0001	
Undolomitised Waulsortian	10^{-3}	0.0001	
Ballysteen Formation	10^{-4}	0.0001	
Workings voids	10	0.85	
Workings backfill	10^{-4}	0.001	

3 GROUNDWATER FLOW MODEL CALIBRATION

3.1 Steady state calibration

The groundwater flow model was first calibrated in steady-state against measured groundwater levels in domestic and mine boreholes monitored during active Galmoy dewatering (Figure 5). The available borehole locations for steady-state calibration comprised 31 holes in the vicinity of the mine, and 26 domestic wells. During mine operations, groundwater levels varied seasonally in most domestic wells by up to 8 m in response to rainfall patterns. Monitoring wells within the area of influence of the Galmoy workings showed deeper groundwater levels with little seasonal fluctuation in comparison to available pre-mining water levels. As the best monitoring data available was during mine operations and the recovery post-closure, the operating period was chosen for steady-state calibration.

Figure 6 shows the steady state calibration as a scatter plot of simulated versus observed groundwater levels. The overall root mean square (RMS) residual is 17 m (i.e. 18% of the observed range in groundwater levels), however, the points on the scatter plot generally fall close to the 1 : 1 diagonal line (points falling exactly along this line indicate a perfect match) with the exception of some outliers near the TMF.

Figure 5: Groundwater monitoring network

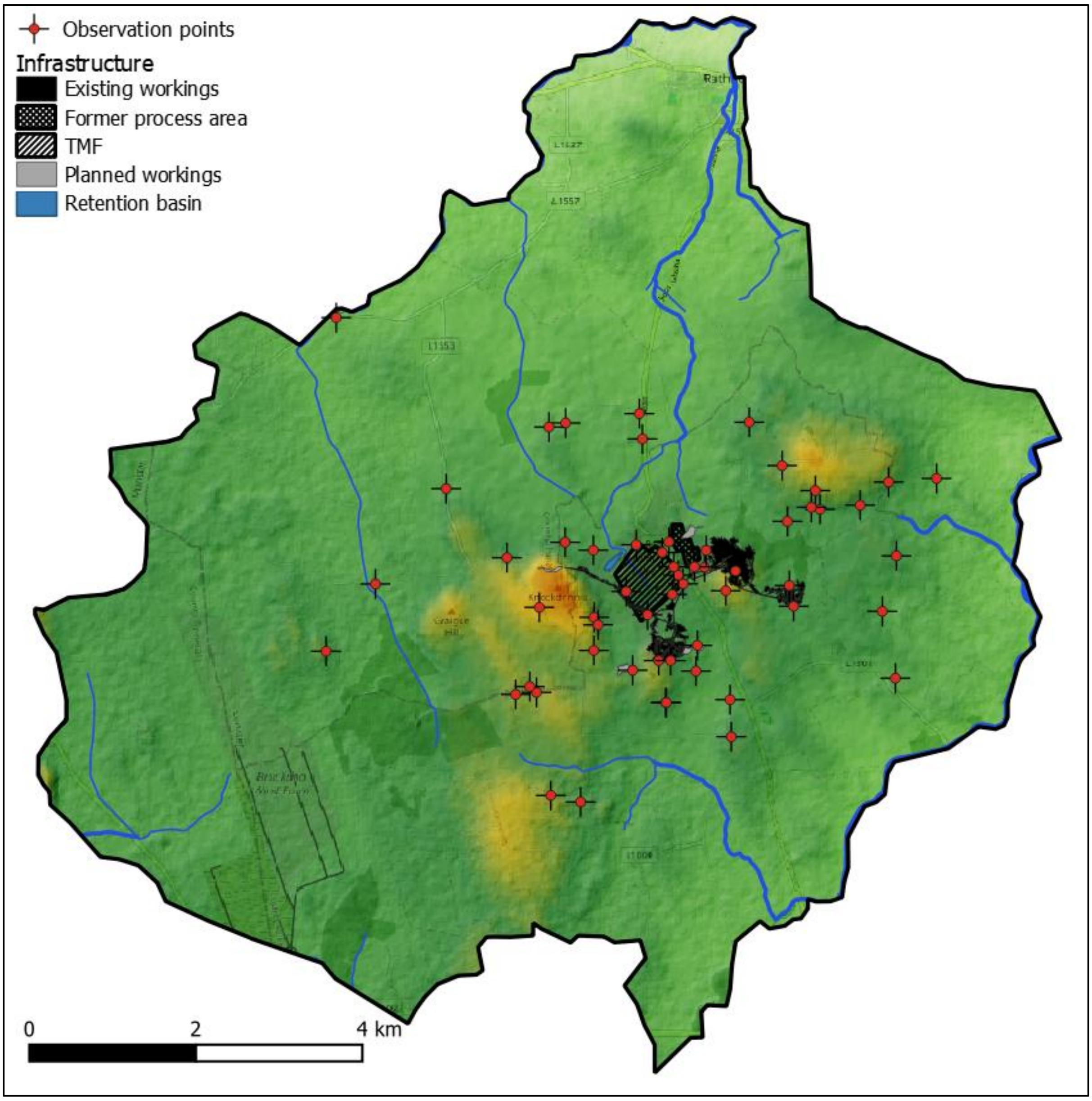
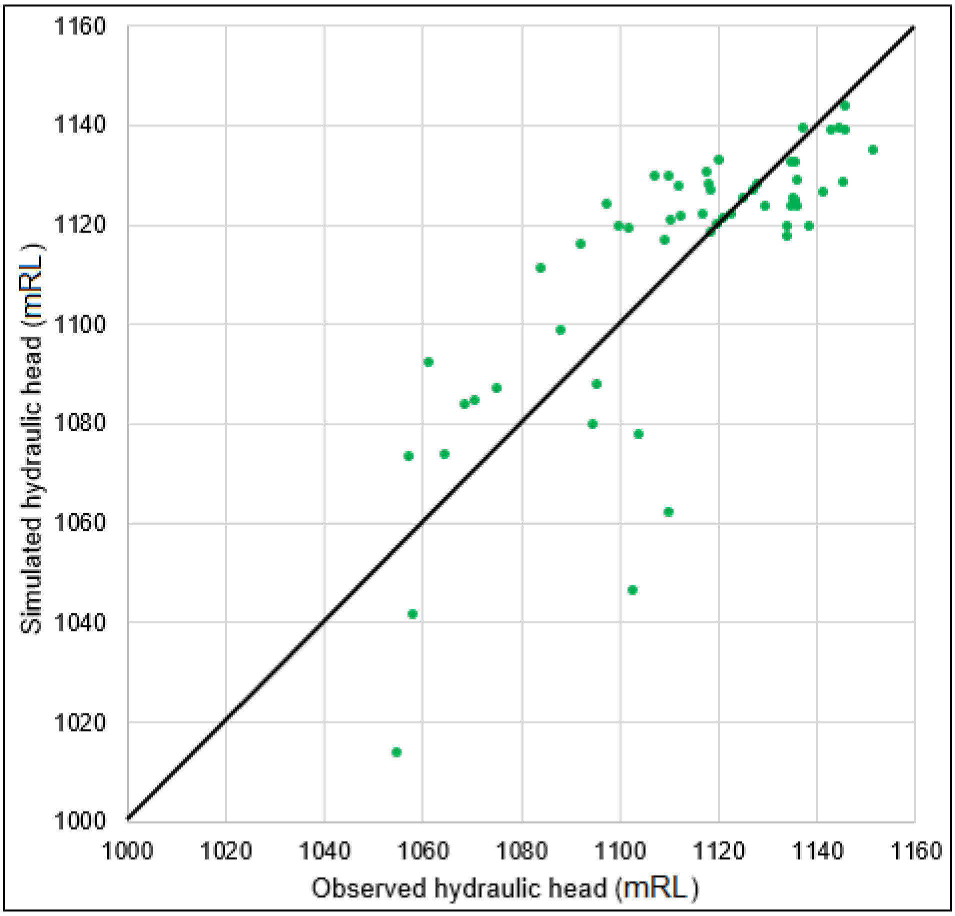


Figure 6: Steady state calibration residuals



3.2 Transient calibration

Transient model calibration was undertaken against groundwater elevation data for the period January 2013 to March 2014, during the groundwater recovery following the closure of the Galmoy mine. Simulated seasonal fluctuations in groundwater levels in the domestic wells generally match well with observed fluctuations (Figure 7). A period of enhanced recharge occurred in February and March 2014 during a prolonged period of high rainfall. The effect of elevated recharge during this period was observed through a step-change increase in groundwater levels around Galmoy and a significant increase in pumping rates at the nearby Lisheen mine.

Figure 7: Observed and simulated transient groundwater levels for domestic wells

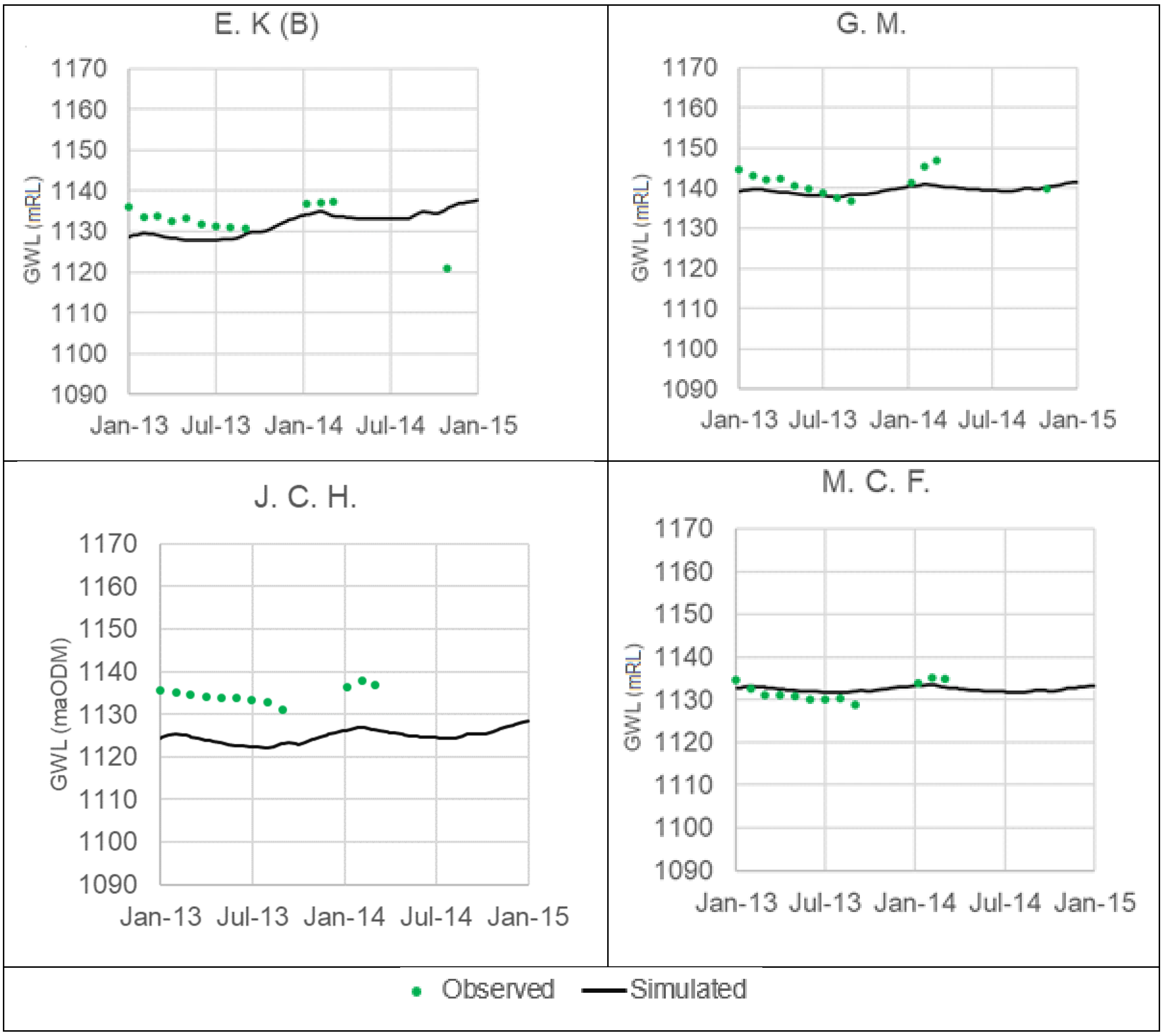
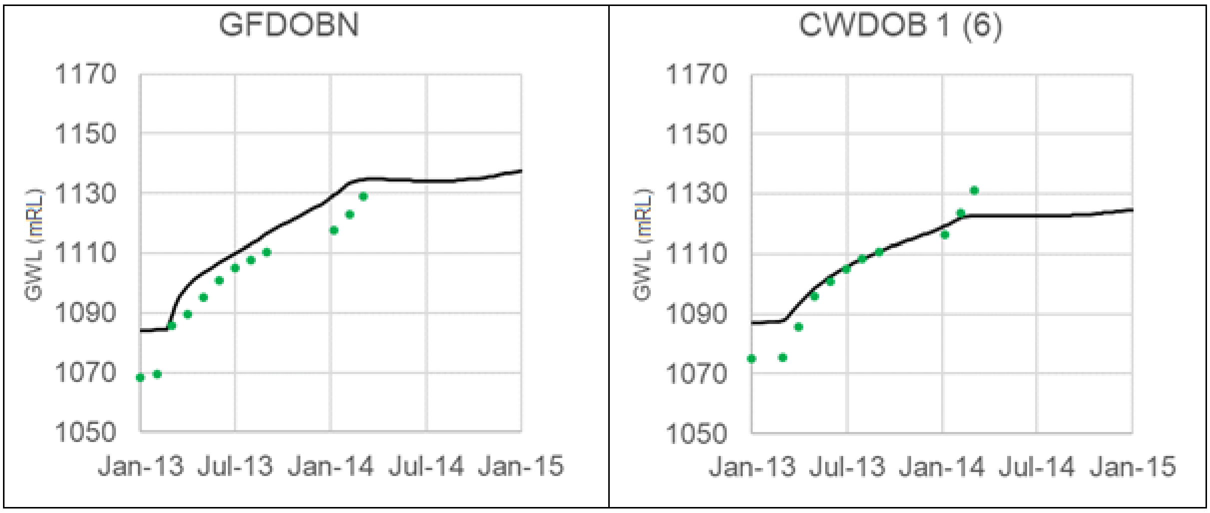
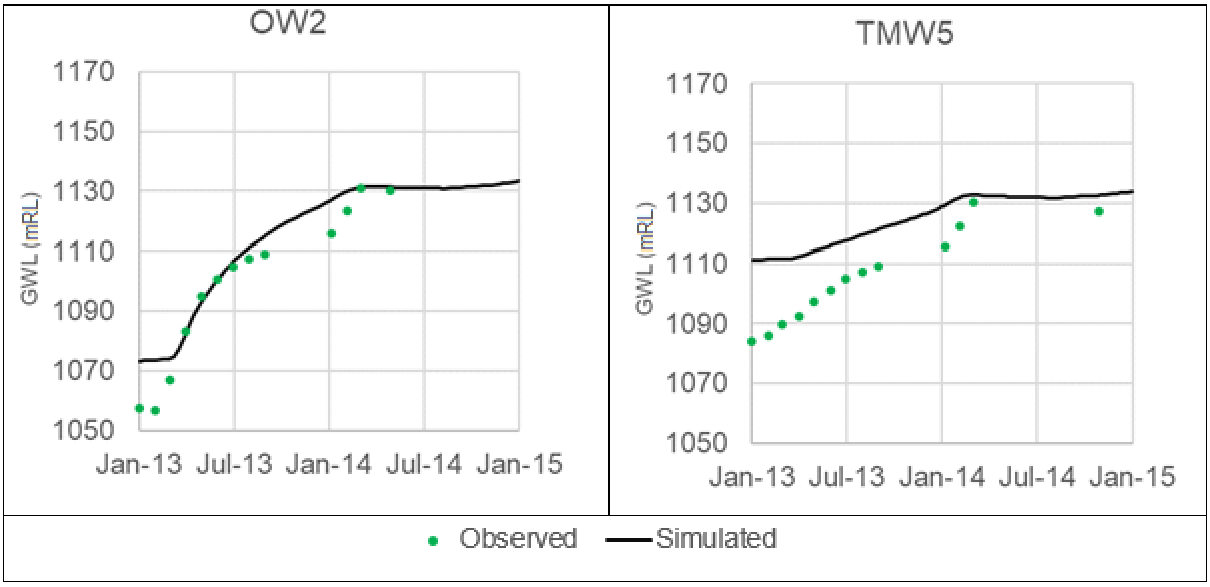


Figure 8: Observed and simulated transient groundwater levels for mine wells





4 PREDICTIVE SIMULATIONS

The following predictive runs were set up using the calibrated transient model:

- Worst case: includes planned Garrylaun mining areas with no cover grouting of the K2 workings following mining through the K-fault;
- Cover grouting: includes planned Garrylaun mining areas with simulation of cover grouting in the K2 zone; and
- Contingency wellfield: includes the cover grouting but also an abstraction of 70 m^3/hr from the proposed GRPWS contingency wellfield at the 'Rathpatrick site' southwest of the mine (Figure 9).

The 'worst case' scenario was simulated using seepage node boundary conditions across the entire planned K2 workings area. For the 'cover grouting' scenario, the seepage nodes were removed from the planned K2 workings area. A comparison between drawdown extents is shown in Figure 9 and a comparison between inflows to the mine workings for an 'average year' is shown in Figure 10. This excludes the groundwater inflow that occurs in response to 1 to 3 month periods of high rainfall (see water balance appendix). Cross sections through the mine workings and GRPWS well WW1A for the 'worst case' and 'cover grouting' scenarios are presented in Figure 11 and Figure 12, respectively. They demonstrate that cover grouting is an effective option for reducing groundwater inflows to the mine workings and minimising any impact on WW1A.

Under the 'contingency wellfield scenario, the drawdown areas associated with the mine dewatering and the contingency wellfield coalesce (Figure 9). However, the extent of drawdown around the contingency wells is limited and the impact on production rates would be small. The primary inflow to both wells is over 40 mbgl (simulated in Layer 6) and, during trial well testing, there was sufficient available drawdown at the end of the test to mitigate against an additional 1 to 2 m of 'regional' drawdown.

Figure 9: Drawdown comparison between "worst case", "cover grouting" and "contingency wellfield" scenarios

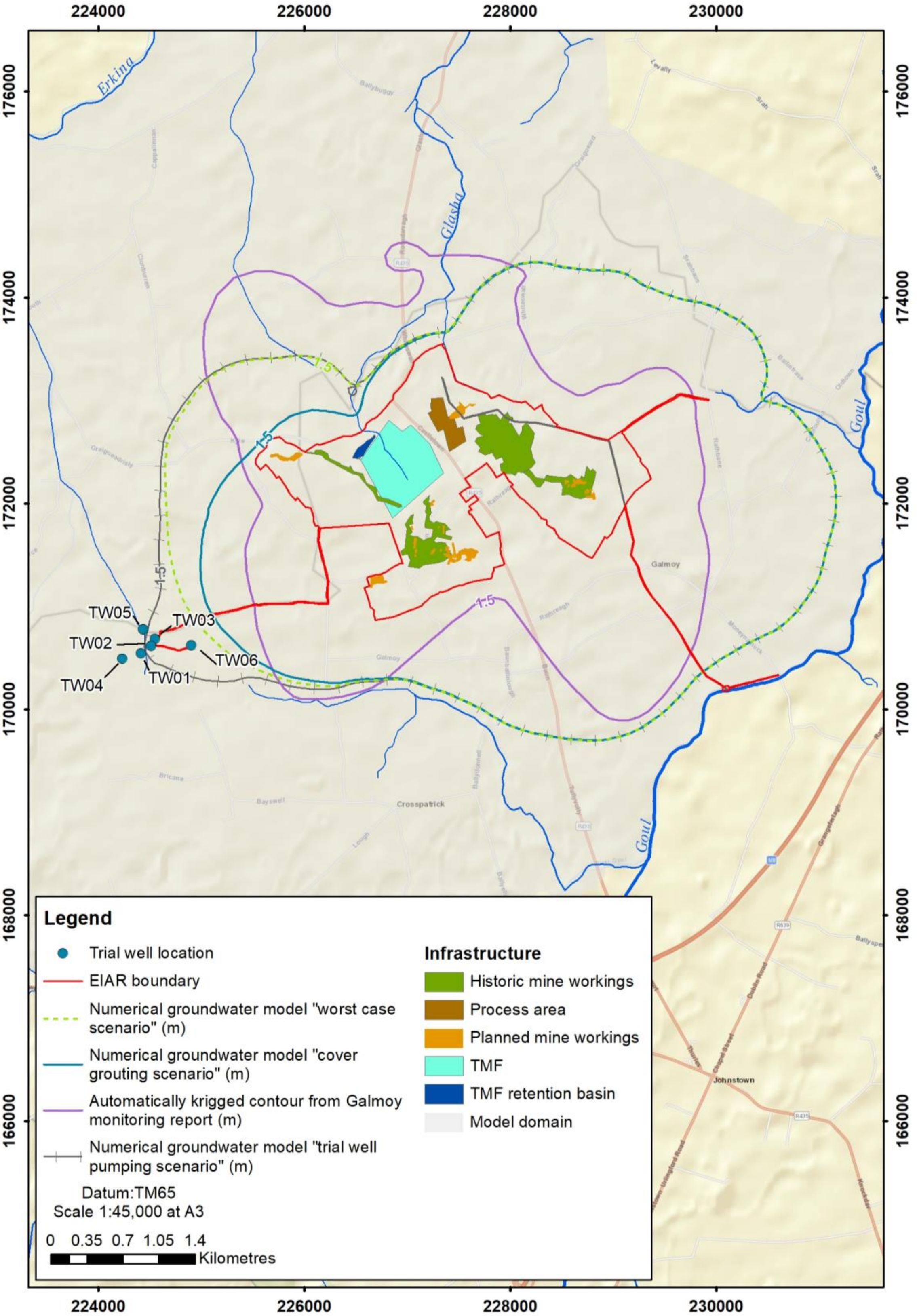


Figure 10: 'Average year' inflow comparison between 'worst case' and 'cover grouting' scenarios

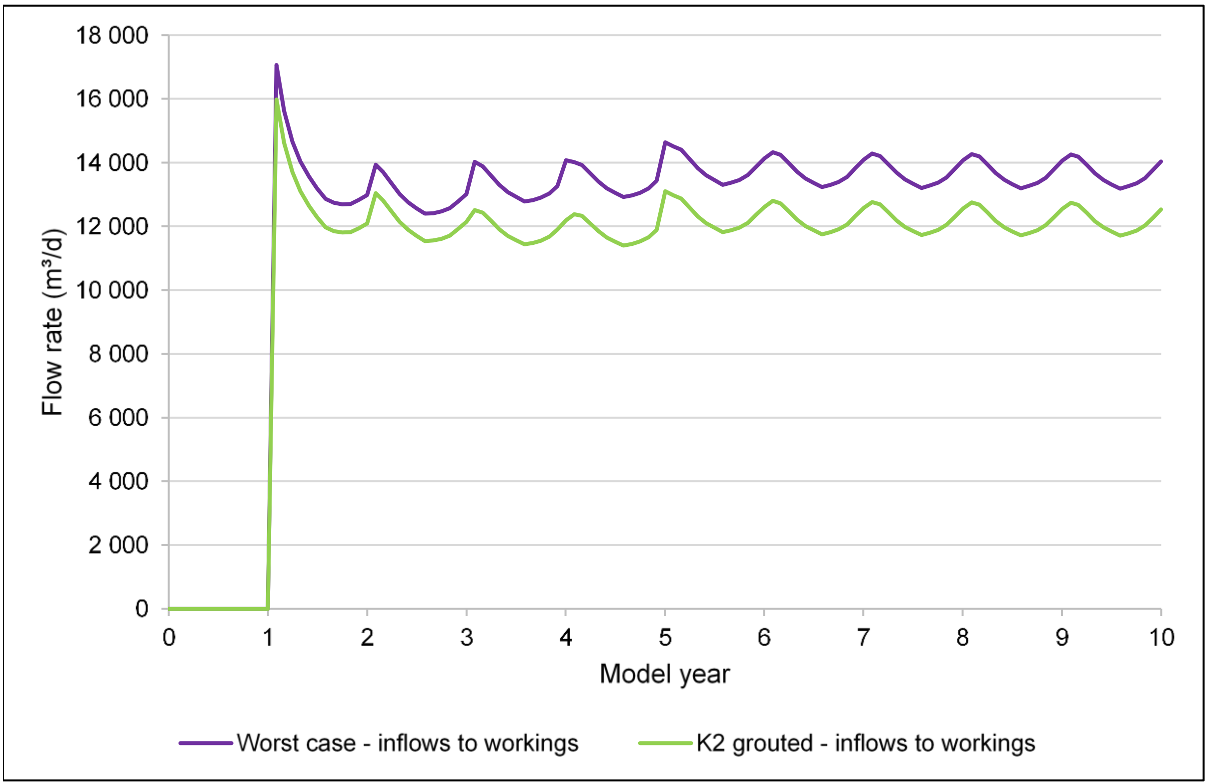


Figure 11: Cross section through WW1A and mine workings showing simulated drawdown ('worst case' scenario)

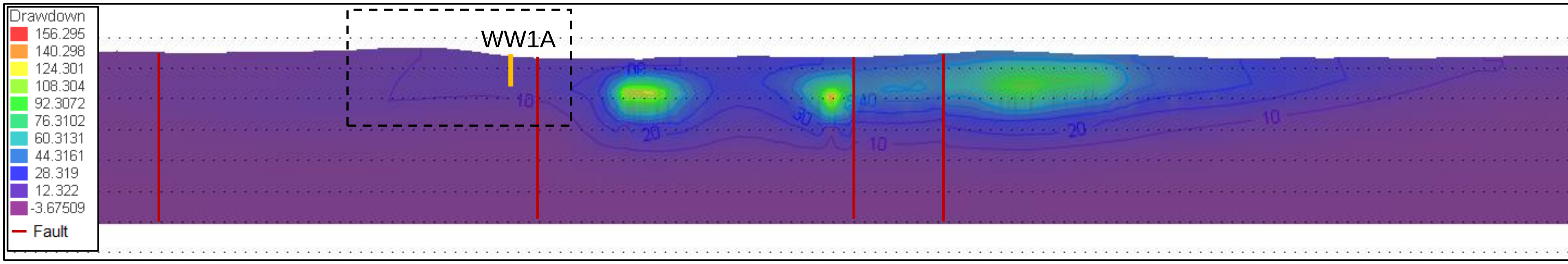


Figure 12: Cross section through WW1A and mine workings showing simulated drawdown ('cover grouting' scenario)