Establishment of Groundwater Source Protection Zones

Killasser Group Water Supply Scheme:

Killasser Springs

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Project description

Since the 1980's, the Geological Survey of Ireland (GSI) has undertaken a considerable amount of work developing Groundwater Protection Schemes throughout the country. Groundwater Source Protection Zones are the surface and subsurface areas surrounding a groundwater source, i.e. a well, wellfield or spring, in which water and contaminants may enter groundwater and move towards the source. Knowledge of where the water is coming from is critical when trying to interpret water quality data at the groundwater source. The Source Protection Zone also provides an area in which to focus further investigation and is an area where protective measures can be introduced to maintain or improve the quality of groundwater.

The project "Establishment of Groundwater Source Protection Zones", led by the Environmental Protection Agency (EPA), represents a continuation of the GSI's work. A CDM/TOBIN/OCM project team has been retained by the EPA to establish Groundwater Source Protection Zones at monitoring points in the EPA's National Groundwater Quality Network.

A suite of maps and digital GIS layers accompany this report and the reports and maps are hosted on the EPA and GSI websites (www.epa.ie; www.gsi.ie).

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1 Introduction

Groundwater Source Protection Zones (SPZ) have been delineated for the Killasser GWS according to the principles and methodologies set out in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999) and in the GSI/EPA/IGI Training course on Groundwater SPZ Delineation.

The Killasser Group Water Scheme (GWS) is supplied from three springs in the townland of Cartronmacmanus, Co. Mayo. In 2010, the GWS distributed an estimated 900 m^3/d on average to approximately 400 households, of which 50% are cattle farms. The overall abstraction from the springs is expected to decrease in 2011 in line with ongoing network improvement works and the introduction of water meters to GWS customers.

The objectives of this report are as follows:

- To outline the principal hydrogeological characteristics of the area surrounding the boreholes.
- To delineate source protection zones for the production wells in the GWS.
- To assist the Environmental Protection Agency and Mayo County Council in protecting the water supply from contamination.

The protection zones are intended to provide a guide in the planning and regulation of development and human activities to ensure groundwater quality is protected. More details on protection zones are presented in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

The maps produced are based largely on the readily available information in the area, a field walkover survey, water level monitoring during normal pumping operations, and on mapping techniques which use inferences and judgements based on experience at other sites. As such, the maps cannot claim to be definitively accurate across the whole area covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

2 Methodology

The methodology applied to delineate the SPZ consisted of data collection, desk studies, site visits, field mapping of geological exposures, well audits, water level recording, as well as subsequent data analysis and interpretation. An initial interview with the caretaker, and site and local area inspection, was undertaken in mid-July 2010. Further interviews and site visits were carried out in August and October, 2010, and in January 2011.

3 Location, site description and spring protection

As shown in **Figure 1**, the sources of water for the Killasser GWS are located approximately 3.5 km to the NNW of the Killasser village. The GWS is sourced from three separate springs, referred to in this report as Springs 1, 2 and 3. The layout of the collection and conveyance system is illustrated in **Figure 2** and key features of the system are included in Photographs 1 through 7.

Each spring is enclosed in a concrete chamber. Water from each chamber is conveyed via 3-inch diameter PVC pipes to a 5-inch diameter PVC water main which transmits the water, also by gravity, to a 136 m^3 reservoir in the townland of Carrowmore.

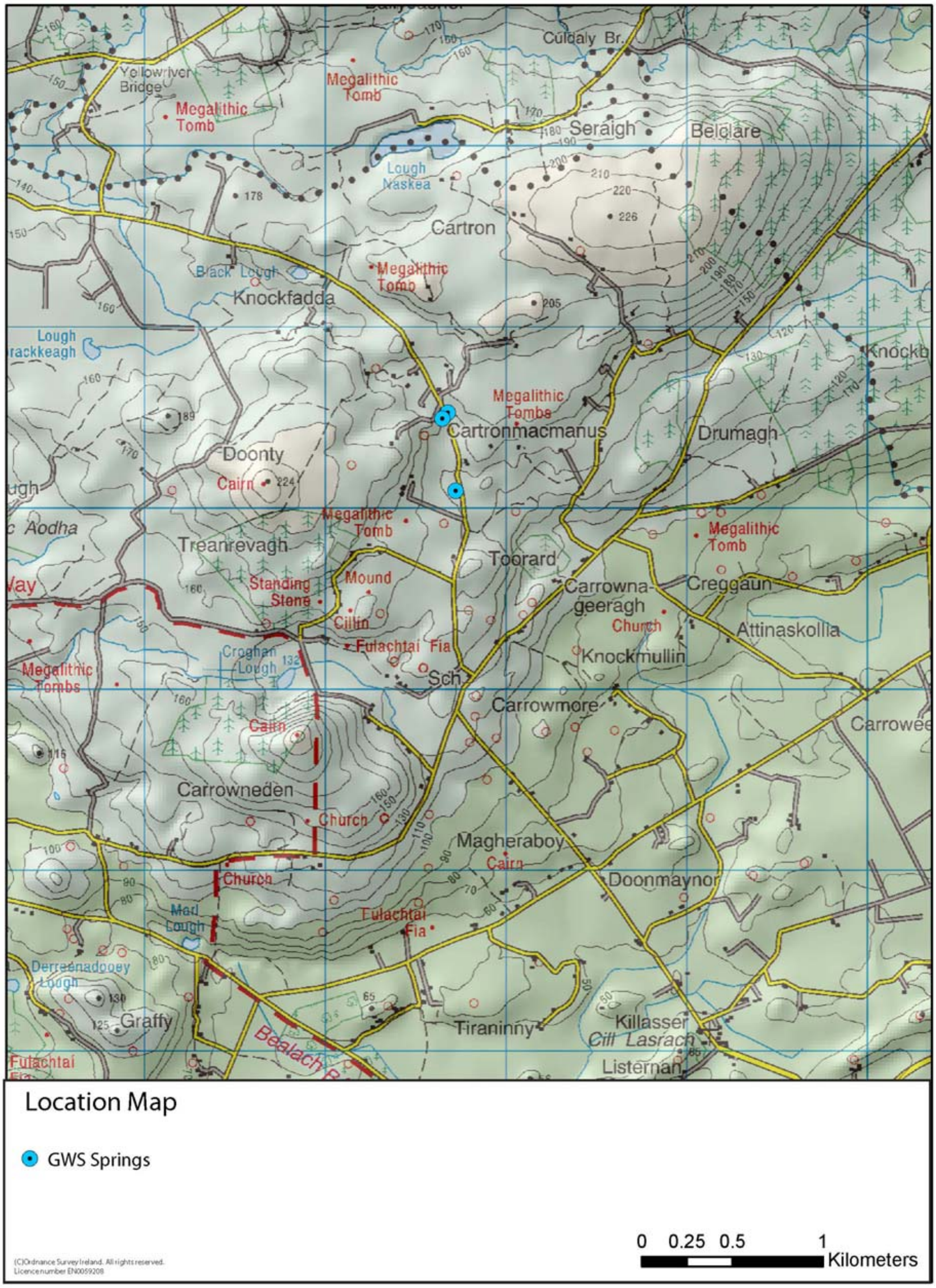


Figure 1: Location Map

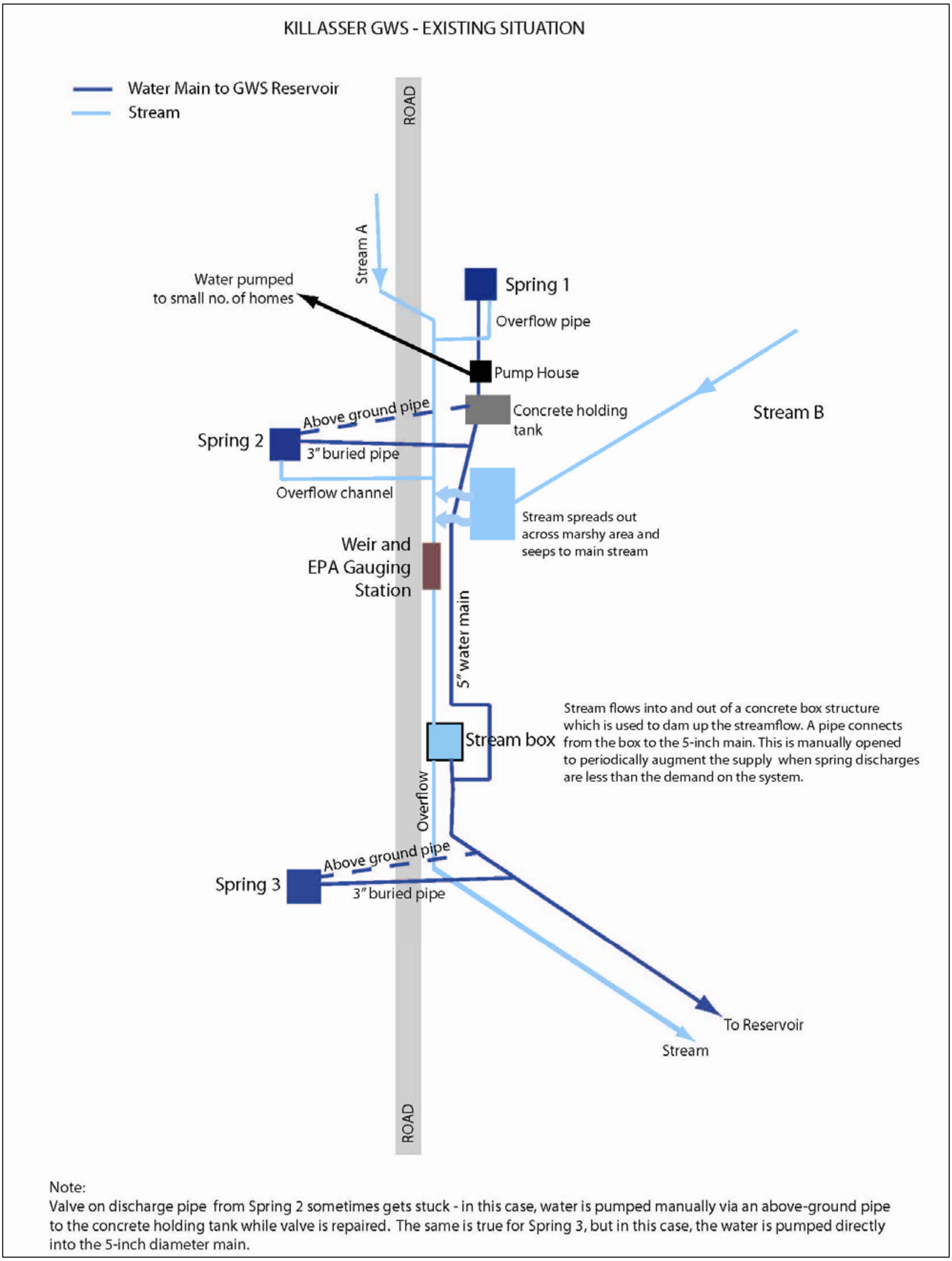


Figure 2: GWS Layout


Photo 1: Spring 1 with overflow pipe


Photo 2: Spring 2


Photo 3: Spring 3 with above-ground pipe


Photo 4: EPA weir and gauging station

Photo 5: Concrete holding tank and pump house near Spring 1

Photo 6: "Stream box" damming up stream (new reservoir in background)

Photo 7: New water treatment plant and reservoir under construction

When the combined discharges from the three springs are lower than the demand from the reservoir, spring water is augmented with surface water. As indicated in **Figure 2**, two streams, referred to as Streams A and B in this report, merge and flow into a concrete "box" (photo 6) which overflows and then directs water back into the natural surface water course that flows past the springs. The box is equipped with a 3-inch diameter valved pipe which connects to the 5-inch water main that runs parallel to the merged stream towards the reservoir. The valve is infrequently opened, usually only in late summer.

The group water scheme has recently been upgraded. The upgrade includes a new reservoir with a capacity of 327 m^3 and a water treatment facility near Spring 3.

A metering project has been underway for some time which, according to the caretaker, has resulted in a reduction in average total demand on the reservoir from 900 m^3/d in 2010 to approximately 780-800 m^3/d in February 2011. The GWS has been undertaking a leak detection survey in the distribution network in the summer of 2011. With preliminary estimates of network losses of up to 60% in 2010, the leak detection survey and subsequent network upgrades are expected to further reduce demand from the reservoir.

4 Summary of sources

Table 1 provides a summary of the springs as currently known.

Table 1: Spring Details

	Spring 1	Spring 2	Spring 3
Reporting Code	IE_WE_G_0034_16_011		
Groundwater Body	Foxford (IE_WE_G_0034)		
Grid reference	135673E 307527N	135654E 307439N	135714E 307094N
Townland	Cartronmacmanus	Cartronmacmanus	Cartronmacmanus
Source type	Spring	Spring	Spring
Owner	Killasser GWS		
Elevation (Ground Level - GPS)	c. 159 mOD	c. 160 mOD	c. 148 mOD
Depth of chamber	1.75m	1.98m	1.25m
Dimension of chamber	1.6 x 1.6 m	1.6 x 1.6 m	1.7 x 1.2 m
Depth to rock	At surface	At surface	<2 m
Estimated yield (m^3/d)*	<500*	<450*	<250*

Note
**- inferred from pump tests (TOBIN, 2001).*

Historical records of spring discharges and overflows do not exist. The combined gravity-fed inflow to the reservoir is also not metered. The range of seasonal discharges associated with the three sources is, therefore, poorly quantified to date. In late-August 2010, there were no overflows on account of the exceptionally dry weather experienced during the summer of 2010. In the same period, the caretaker reported some disruptions or "shortfalls" in the supply, and little or no streamflow available to augment the supply.

The reported average supply from the reservoir in 2010 was 900 m^3/d, and according to the caretaker, historical supply has rarely been less than 800 m^3/d or greater than 1,100 m^3/d. The way the GWS is designed and constructed, an approximate balance is maintained between inflow to the reservoir and outflow to the distribution network. On this basis, it is inferred that the combined discharge from the springs during late-August 2010, when no overflows occurred, was less than 800 m^3/d.

Using data on the relative elevations of springs and the diameters of existing pipes, the estimated free-flow from the springs into the reservoir would not exceed 21 l/s, or 1,800 m^3/d, under ideal conditions (no back-pressure or pipe losses). This is the theoretical 'capacity' of the inflow system, and therefore represents a maximum theoretical flow that would not result in overflows at the springs. The reality, of course, is different. The inflow to the reservoir is controlled with a level indicator and a back-pressure is maintained on the inflow at most times. Spring overflows are, therefore, a function of both the natural discharges at the springs and the magnitude of the back-pressures in the 5-inch water main.

Following heavy rains in September and the early parts of November, overflows from Spring 1 and 2 were measured at 368 m^3/d and 345 m^3/d, respectively, on November 26th, 2010 (see **Appendix 1**). Using the average supply of 900 m^3/d (equal to the inflow to the reservoir), combined with total measured overflows of 713 m^3/d, the estimated total discharge from the three springs was approximately 1,613 m^3/d on that day.

There was no overflow from Spring 3 on November 26th. Due to the way that the spring chamber is constructed, overflows simply flood the surrounding land. There was no flooding on the day of measurement.

The measurements of November 26th were a repeat of measurements on November 16th, when overflows of 1,230 m^3/d and 350 m^3/d for Springs 1 and 2, respectively, were measured. The measurement from Spring 2 is consistent between the two dates, but the overflow from Spring 1 is significantly higher and potentially erroneous. Overflow from Spring 1 discharges from a pipe into Stream A (see **Figure 2**). The overflow was estimated by measuring the streamflow immediately upstream and downstream of the overflow pipe discharge point. On the day of the measurement, the stream (basically a culvert at this location) was running full and fast. Due to suspected errors in measurement on November 16th, the measurements were repeated on November 26th as a check. November 26th data are considered more reliable.

At Spring 2, the overflow was measured in a 60 m long flat and partially vegetated channel which links the spring to Stream A. The land surrounding the overflow channel was water logged on the days of measurement and there may be surface water contributions over the length of the overflow channel. Overflows volumes were consistent on the two measurements days, 345 and 350 m^3/d.

Estimates of spring discharges were also undertaken in 2001 as part of a design effort to upgrade the GWS facilities (TOBIN, 2001). "Pumping tests" were undertaken at each spring to estimate their relative "yields". Heavy rains were reported in the week preceding the tests. The tests are reproduced in **Appendix 2** and summarised below:

- Spring 1 was pumped for 24 hours at 570 m^3/d without measurable drawdown inside the concrete chamber (and no overflow).

- Spring 2 was pumped for 26 hours at 505 m^3/d. The maximum drawdown was 0.19 m and the recovery was almost instantaneous, within 3 minutes.

- Spring 3 was pumped for a total of 95 hours at different rates. The initial pump rate was set at 272 m^3/d for 50 minutes and the maximum drawdown stabilized early at 0.08 m. The pump rate was increased to 431 m^3/d between 50 and 72 minutes which increased the drawdown to 0.14 m. After 72 minutes the pump rate was increased to 520 m^3/day with a maximum drawdown of 0.79 m. This rate resulted in dewatering of the spring chamber.

The tests were partly successful in establishing relative "yields", however a cautionary note was included in the reporting, basically that responses to pumping may have been partly influenced by surface water (e.g. from land drains which link to the overflow channel at Spring 2).

On the basis of the test results, respective yields are inferred to be approximately 500 m^3/d (Spring 1); 450 m^3/d (Spring 2); and 250 m^3/d (Spring 3). These figures are approximations as it is not known if the tests were influenced by any potential surface water contributions during pumping.

5 Topography, surface hydrology, landuse

The spring sources of the GWS are located at a relatively high elevation (150-160 mOD) in the foothills of the Slieve Gamph Mountains. The surface catchment of the springs rises to 225 mOD at both Doonty in the west and Cartron in the NE. The terrain is rolling, and as shown in Photographs 8-11, contains numerous small topographic depressions that collect surface runoff and from which water subsequently infiltrates to ground.

The topographic catchment of the GWS ultimately drains to the River Moy at Creggatalagh, approximately 5 kms due south of the GWS springs. The main stream that runs past the three GWS springs is unnamed, but is referenced herein as the "Killasser stream" on account of its association with the GWS. It originates as a small (1 l/s) seep/rise to the west of Spring 1 (labelled as Stream A in **Figure 2)** and as an outflow from a blanket bog and a series of field drains to the east of Spring 1 (labelled as Stream B in **Figure 2)**.

The Killasser stream is gauged by the EPA (see photograph 4). The gauged flow represents the combined flows from Stream A and Stream B as well as the overflows from Springs 1 and 2. Data from the EPA indicates that the Killasser stream responds rapidly to rainfall. As shown in **Figure 3**, the min, max, and mean flows for the period May 2009 – March 2011 were 0.003 m^3/s, 1.04 m^3/s, and 0.038 m^3/s respectively. The flashy nature of the stream is primarily due to the significant surface runoff contribution of Stream B which cascades across steep gradients before joining the Killasser stream upslope from the gauging station (see photographs 12-15).

The relative contribution from overflows at Springs 1 and 2 is small compared to the contribution from surface runoff. On November 26th, the overflow was 713 m^3/d or 0.008 m^3/s. This corresponds to 11 % of the recorded flow (0.07 m^3/s) at the gauging station on the same day.

Land use in the area is mainly agricultural, livestock pasture dominating the hillsides surrounding the spring. Coniferous forests are found in upland areas of both Doonty and Cartron, as well as near Spring 3. There are several farmyards and one-off houses with septic tanks in the area. Two farmyards are located directly within the surface catchments of the main springs, and slurry is spread on land immediately adjacent to Springs 1 and 3.

6 Hydrometeorology

Establishing groundwater source protection zones requires an understanding of general hydrometeorological patterns across the area of interest. This information was obtained from Met Eireann.

Annual rainfall: 1,450 mm. The contoured data map of rainfall in Ireland (Met Éireann website, data averaged from 1961–1990) shows that the source is located between the 1,400 mm and the 1,500 mm average annual rainfall isohyets.

Annual evapotranspiration losses: 494 mm. Potential evapotranspiration (P.E.) is estimated to be 520 mm/yr (based on data from Met Éireann). Actual evapotranspiration (A.E.) is estimated as 95% of P.E., to allow for seasonal soil moisture deficits.

Annual Effective Rainfall: 956 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge to groundwater is therefore equivalent to this, or 956 mm/year.

Reference is made to Section 10 on recharge which estimates the proportion of effective rainfall that enters the groundwater system that discharges at the springs.

Photos 8 -11: Examples of internal topographic depressions holding surface water

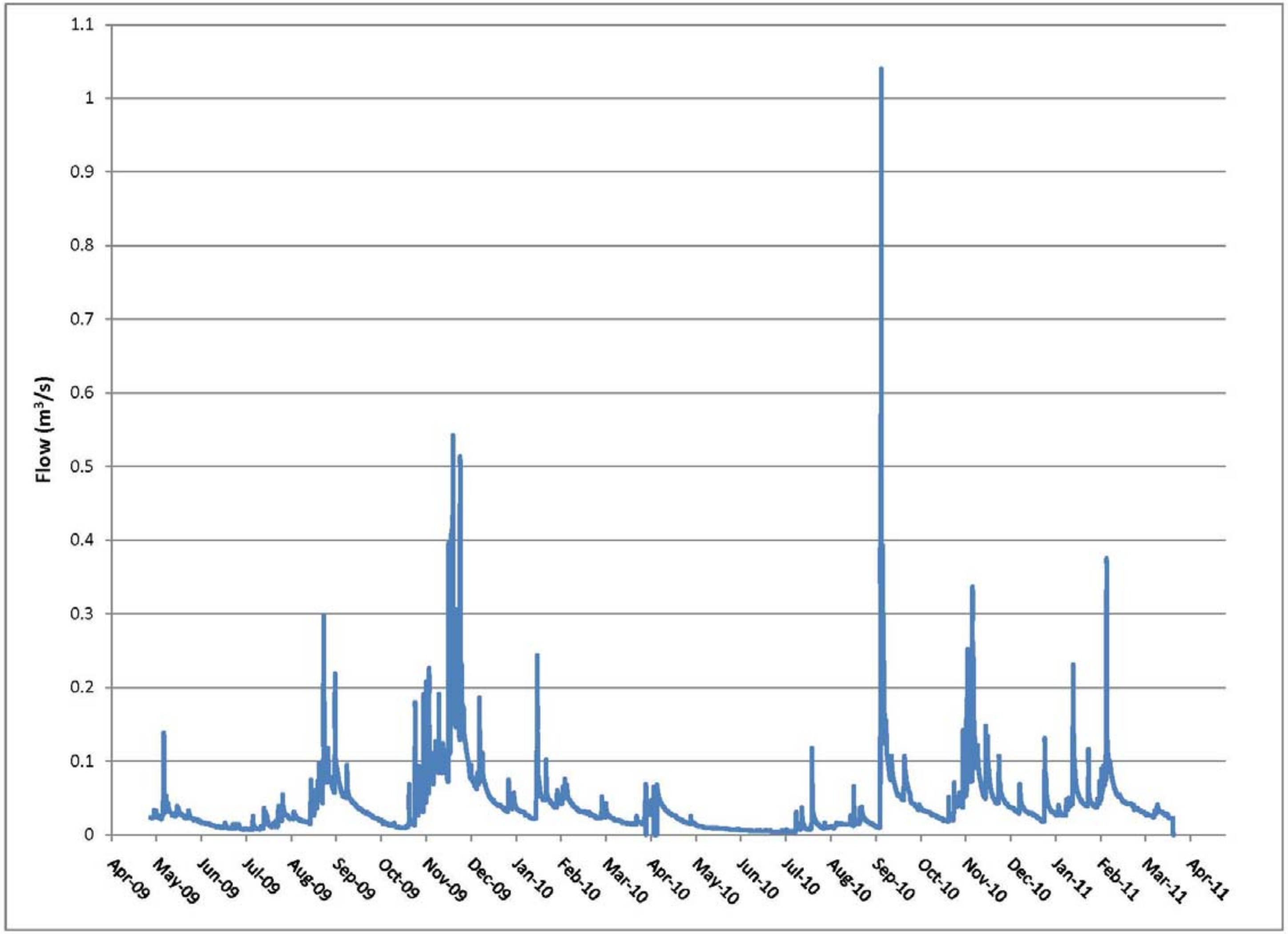


Figure 3: Killasser Stream Hydrograph May 2009 – March 2011

Photos 12-15: Stream B

7 Geology

This section briefly describes the relevant characteristics of the geological materials that underlie the area surrounding the GWS. It provides a framework for the assessment of groundwater flow and source protection zones. The geological information is based on:

- Geology of Sligo - Leitrim. Bedrock Geology 1 : 100,000 Map series, Sheet 7, Geological Survey of Ireland (MacDermott et al, 1996);
- Report 'Hydrogeological Investigation of Group Water Scheme Sources at Cartronmacmanus, Killasser Co. Mayo' (TOBIN, 2001);
- Field mapping of bedrock outcrops during site visits;
- Groundwater vulnerability mapping by the GSI in 2010.

7.1 Bedrock

As indicated in **Figure 4**, the bedrock in the study area comprises metamorphic quartzites and schists. These rocks are part of the Dalradian Supergroup and are geologically distinguishable by their mineralogies, "grain size" and feldspathic contents. Hydrogeologically, the quartzites and schists are very similar in nature (see Section 10).

The metasedimentary rocks are part of a succession of rocks that developed as a major sheer zone and into which the Slieve Gamph Igneous Complex intruded (consisting of granites and granodiorites). Strain partitioning in the sheer zone resulted in "tectonic slides" (type of fault) which divide the schist and quartzite sequence into NE-SW trending geological "slices". These tectonic slides may be hydrogeologically significant (see Section 10).

In the immediate vicinity of the GWS springs, two such slides (synmetamorphic faults) are mapped (see **Figure 5**); one separates schists of the Meelick Member (MM) from schists of the Lower Lismoran Formation (LLF) to the south. The other separates the MM from the quartzite of the Leckee Quartzitic Formation (LQ) to the north.

The three springs are located within 100 m of the fault that separates the MM from the LLF. Groundwater flow could therefore be structurally related to the fault. Rocks of the MM generally dip steeply (>70º) to the NW whereas rocks of the LLF dips steely (>80º) to the SE.

In stark contrast to the schists and quartzites, the local geology includes a previously unmapped exposure of marl near Toorard, approximately 3 kms SE of the GWS springs. Here, flat-lying marls lie unconformably on the bedrock. Shown in Photographs 16-22, these deposits contain abundant bioclasts as well as cm-scale "micro-caves" with polished dripstone structures. These distinctly layered deposits may represent lacustrine and tufa strata where the latter would have precipitated from calcareous waters. Fossil structures, including shells, bryophytes and roots are present in clusters. From the existing GSI bedrock mapping, the deposits occur near the contact between the Callow Formation (metavolcanics) and the LLF (schist). The origins and geological context of the deposits have not yet been studied.

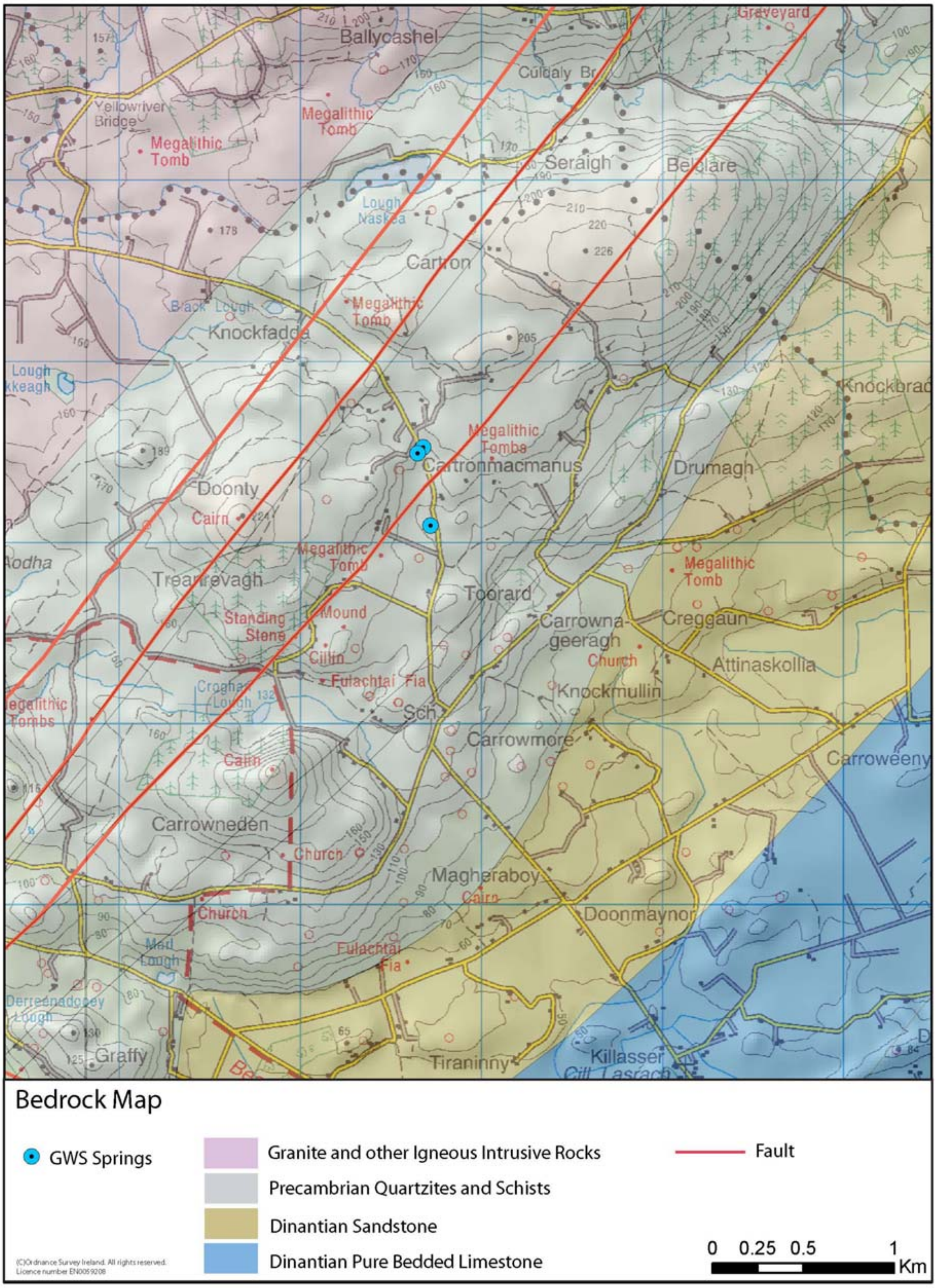
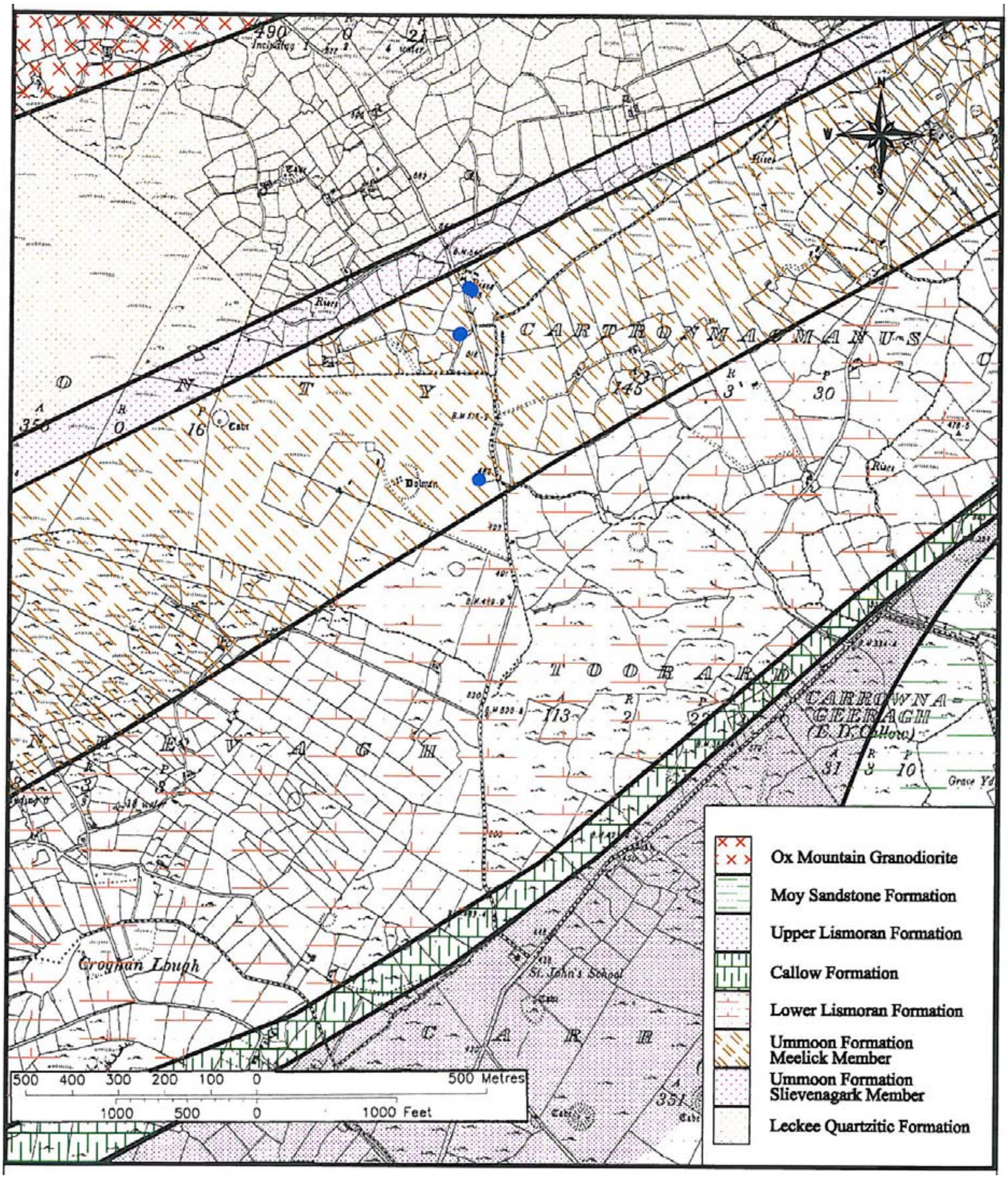


Figure 4: Bedrock/Rock Unit Map



Source: Tobin, 2001

Figure 5: Rock Formation in Study Area

Photos 16-22: Marl and tufa deposits near Toorard

7.2 Soil and subsoil geology

Mapped soils surrounding the GWS springs, see **Figure 6**, include deep, poorly drained mineral soils (AminDW) and shallow, well drained mineral soils (AminSW). The area also includes shallow, peaty mineral soil (AminSRPT) soils as well as blanket peat and cutaway peat.

The glacial till of the area, whose distribution is shown in **Figure 7**, is derived from the underlying metamorphic rocks (TMp). Blanket peat (BktPt) and cutover raised peat (cut) is also present in the area.

There are numerous small internal drainage basins within the study area that have clayey subsoils at their base. The subsoil is partly represented by glacial till and overlying organic-rich clay layers referred to locally as “blue adobe”.

7.3 Depth to bedrock

Bedrock is exposed or is close (<3m) to the ground surface within most of the study area, although there are internal drainages and depressions where subsoil thickness may be several metres thick locally.

Bedrock (schist) outcrops at both Spring 1 and Spring 2. At Spring 3, bedrock is estimated to be <2 m below ground surface.

8 Groundwater vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater ‘target’, which in the case of the GWS means that vulnerability relates primarily to the permeability and thickness of the subsoil. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999) and in the draft GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination (Fitzsimons et al, 2003).

An interim groundwater vulnerability map for Co. Mayo has been developed by the GSI (dated March 2011). As shown in **Figure 8**, the vulnerability in the area surrounding the GWS is mostly High. Small areas of Extreme vulnerability (characterised by bedrock outcrops and thin subsoils less 1 m thick) occur near the springs, and smaller areas of Low vulnerability (thick and/or low permeability subsoils) are associated with blanket peat.

9 Hydrogeology

This section describes the current understanding of the hydrogeology in the vicinity of the GWS. Hydrogeological and hydrochemical information was obtained from the following sources:

- GSI and EPA websites and databases;
- County Council Staff and drinking water returns;
- Met Eireann rainfall and evapotranspiration data;
- Report: Tobin (2001).

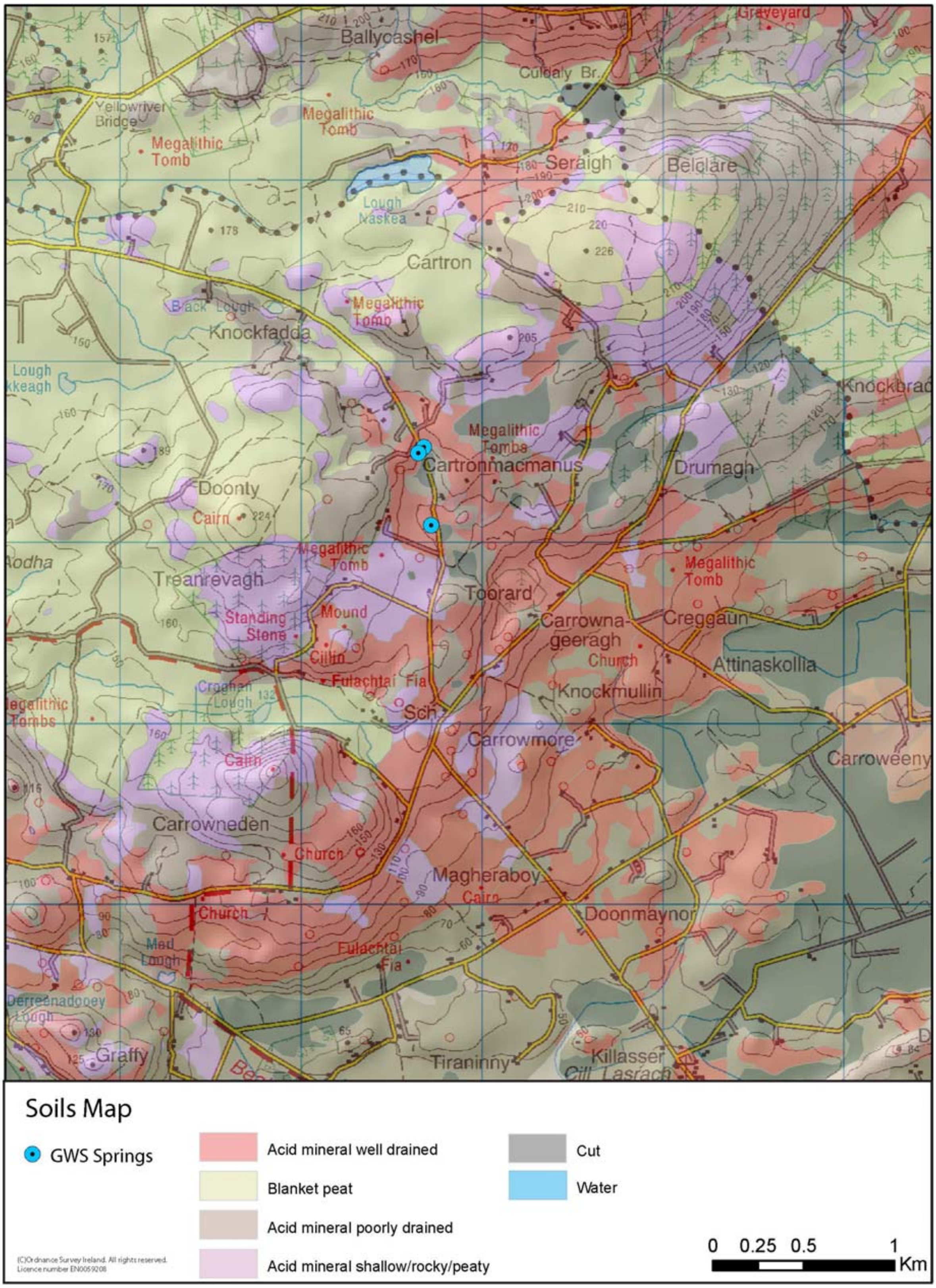


Figure 6: Soils Map

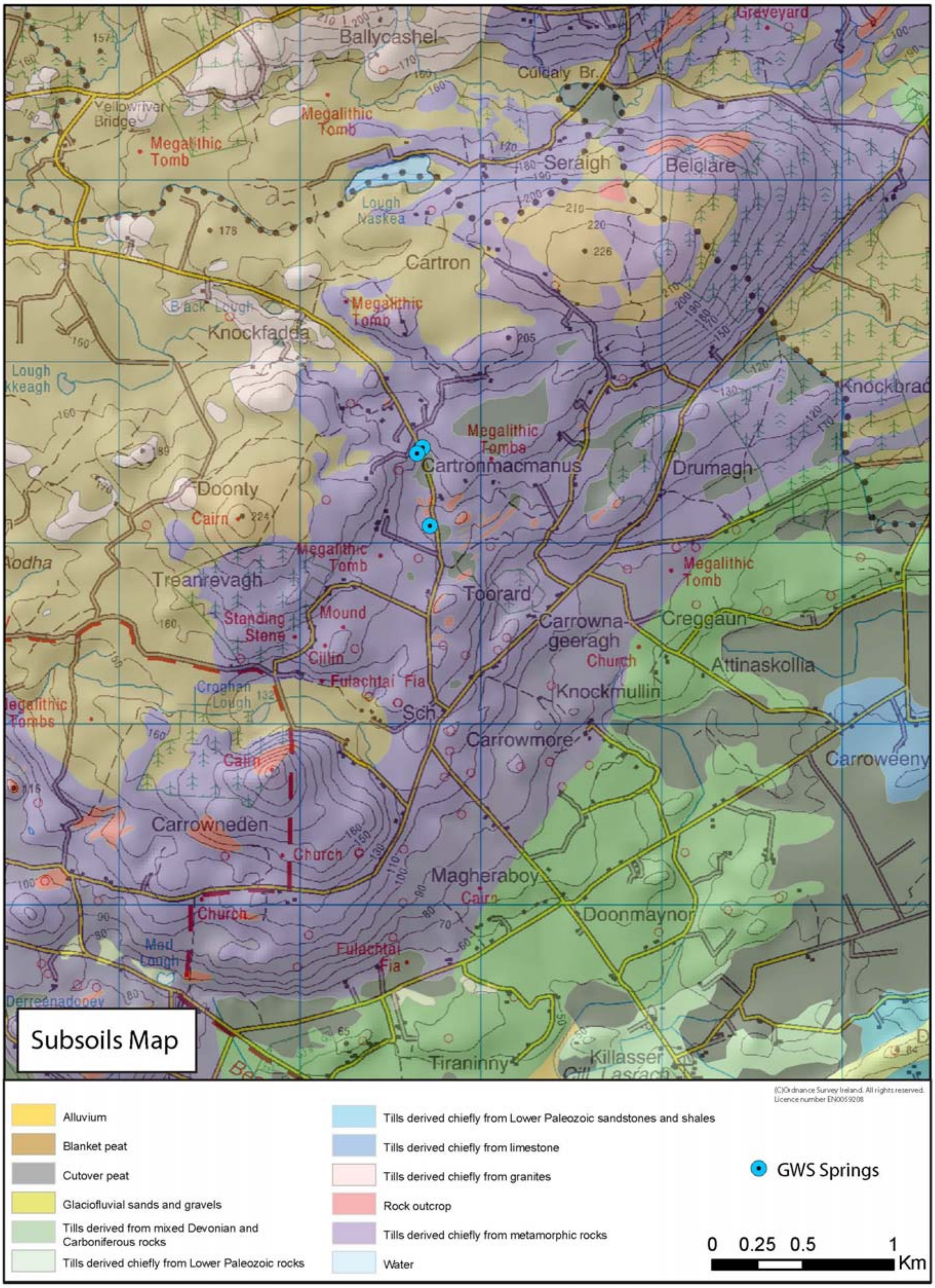


Figure 7: Subsoils Map

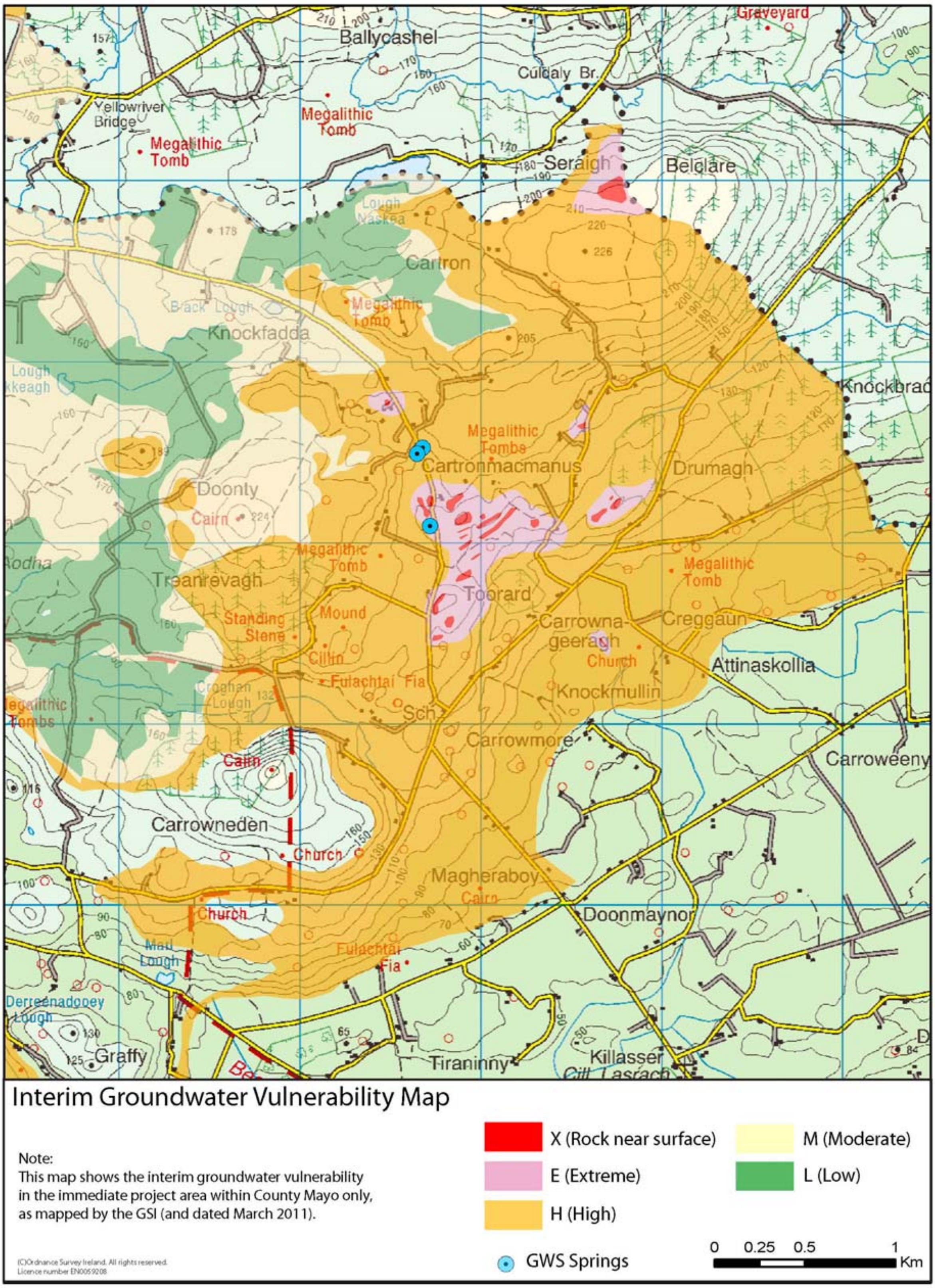


Figure 8: Interim Groundwater Vulnerability Map

9.1 Groundwater body and status

The GWS and its surrounding area is located within the Foxford groundwater body (GWB) which has been classified by the EPA as being of "Good" status. The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the Water Framework Directive website: www.wfdireland.ie/maps.html.

9.2 Groundwater levels, flow directions and gradients

The three source springs emerge at elevations ranging from 150 to 160 mOD. There are other, much smaller groundwater seeps at similar elevations elsewhere in the study area, especially to the northeast of Cartron. There is only one known borehole within the GWS valley (not used) and a groundwater flow map cannot, therefore, be developed from water levels in boreholes. However, given the fractured and weathered nature of the bedrock, groundwater flow directions are expected to follow topography towards the established springs and seeps.

In the context of the GWS springs, the main structural trend of the bedrock formations and faults (tectonic slides) is NE-SW, and flow patterns are expected to be influenced by this trend. Due to the poorly productive nature of the bedrock (see Section 10), flow systems are expected to localised whereby groundwater discharges quickly into the local streams and via springs. Near-surface and shallow groundwater flow paths are expected to dominate.

There are no site-specific empirical data available to establish groundwater flow gradients within the study area, but on the basis of similar hydrogeological settings elsewhere in Ireland, gradients on the order of 0.01 or greater can be expected.

9.3 Hydrochemistry and water quality

Field measurements of electrical conductivity were taken during site visits in September and November 2010 from both springs and surface water features. **Table 2** provides results on September 6th from the locations shown on **Figure 9**.

Table 2: Field Measurements of Electrical Conductivity

No.	Location	Conductivity (µS/cm)	Comments
1	Stream A - 1	318	Spring rise of Stream A
2	Stream A - 2	254	Just upstream of Spring 1
3	Spring 1	460	Inside concrete chamber
4	Stream A - 3	413	d/s of Spring 1 and Stream A (at this point referred to as Killasser stream)
5	Spring 2	576	Inside concrete chamber
6	Stream B	363	200 m u/s of weir location
7	Stream A+B - Weir location	432	Combined Spring 1, Spring 2 and Stream A and B at location of weir
8	Spring 3	515	Inside concrete chamber
9	Ponding in field near Spring 3	484	Possible groundwater seep

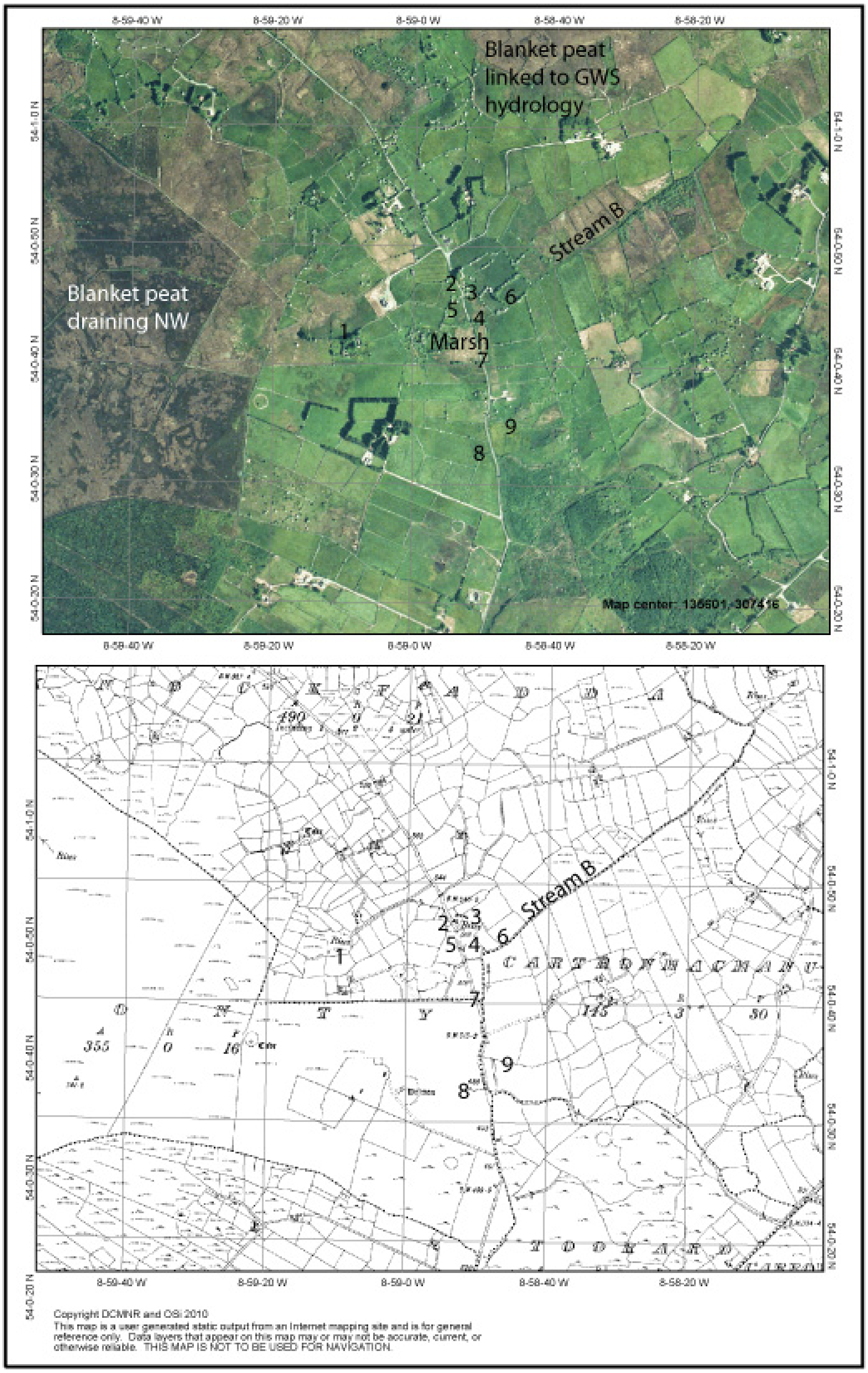


Figure 9: Field Measurement Locations

Samples that represent spring overflows show a slightly higher EC (460-576 ųS/cm) compared to stream samples (Streams A and B, 318 and 363 ųS/cm, respectively). Stream A is also influenced by surface runoff and has a conductivity of 254 ųS/cm just upstream of Spring 1. Finally, the overflows from Springs 1 and 2 raise the conductivity of the Killasser stream where they discharge into the stream.

Killasser GWS has been included in the EPA operational chemical network since 2007. The sample point is at the reservoir prior to chlorination. Existing laboratory results have been compared to these thresholds or standards: EU Drinking Water Council Directive 98/83/EC Maximum Admissible Concentrations (MAC); the European Communities Environmental Objectives (Groundwater) Regulations 2010, which were recently adopted in Ireland under S.I. No. 9 of 2010. The data are summarised graphically in **Figures 10 to 12**, representing 10 samples in total. Recognising that the data may occasionally represent a mix of spring water and surface water (i.e. when stream water augments flow to the reservoir), results are highlighted as follows:

- The water quality is hard (average 280 mg/l $CaCO_3$). Alkalinity ranges from 24 to 344 mg/l as $CaCO_3$. The average field conductivity is 512 µS/cm and pH is around 7.4. The hydrochemical signature of the water is calcium bicarbonate.
- Faecal coliforms were present in 70% of the samples, with gross contamination on two occasions (greater than 100 faecal coliforms per 100 ml). Potential sources include agriculture and septic tanks systems. The concentrations were highly variable and could not be correlated with seasons. No ammonium values greater than the Water Framework Directive Drinking Water Status Threshold value (0.175 mg/l as N) established by the EPA were recorded.
- The concentration of nitrate ranges from <0.3 mg/l to 4.6 mg/l with a mean of 3.25 mg/l (as NO_3). These values are well below the EU Drinking Water Directive maximum admissible concentration (MAC) of 50 mg/l or the EPA threshold value of 37.5 mg/l.
- Chloride can be a constituent of organic wastes and levels higher than threshold value 24 mg/l may indicate contamination, with levels higher than the MAC value 250 mg/l usually indicating significant contamination. Chloride concentrations range from 12.5 mg/l to 15.3 mg/l with a mean of 14.2 mg/l which is below the threshold value.
- The sulphate, potassium, sodium, magnesium and calcium levels are within normal ranges. The potassium/sodium ratio is low at less than 0.18. The concentration of iron and manganese is also within normal ranges. The concentration of all other trace metals are low and/ or below laboratory detection limits. The concentrations of all organic compounds are also below the laboratory limits of detection.

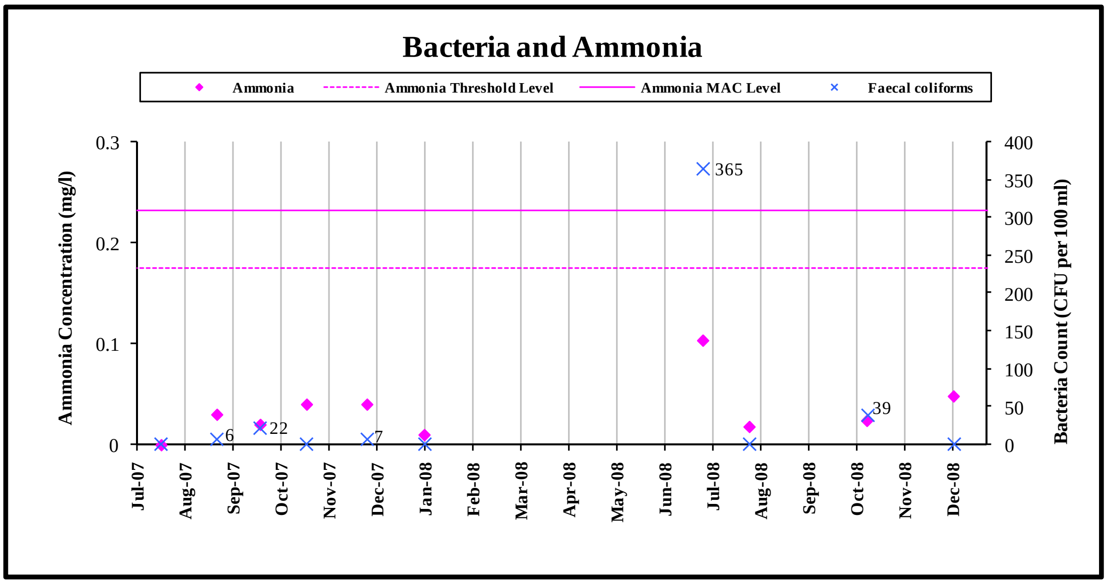


Figure 10: Bacteria Counts and Ammonia Concentrations

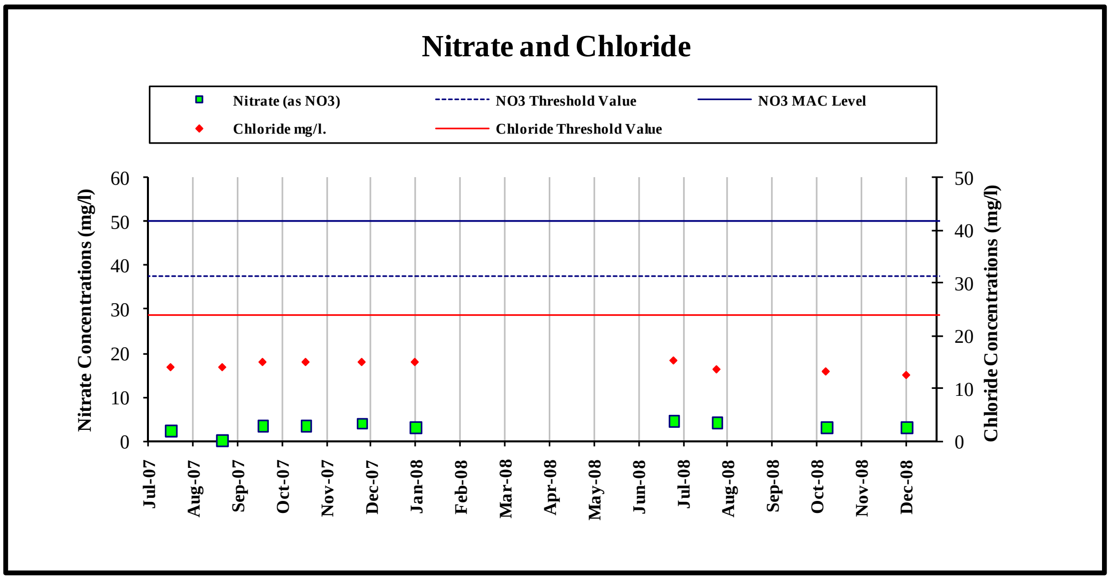


Figure 11: Nitrate and Chloride Concentrations

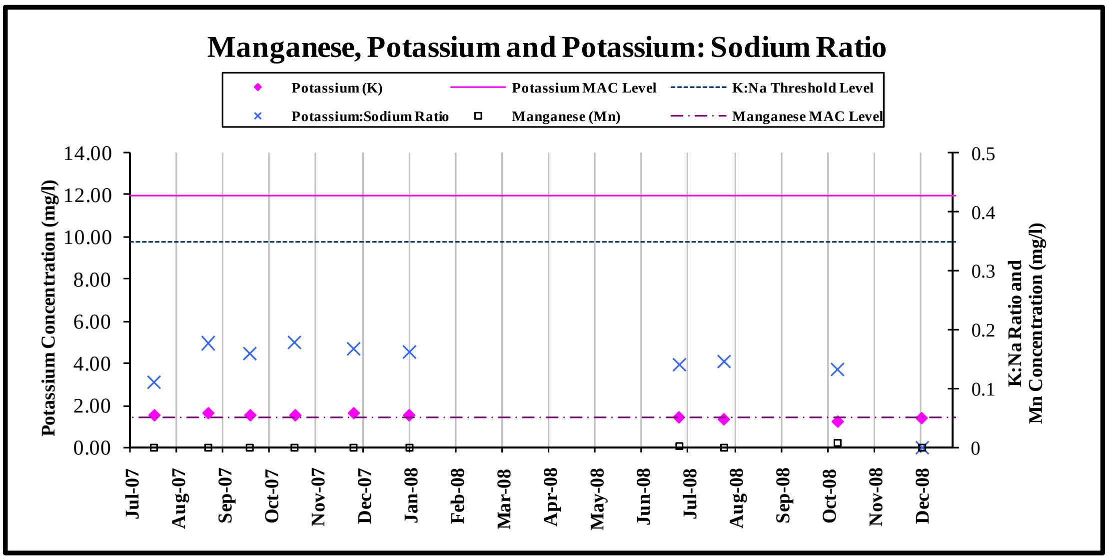


Figure 12: Manganese and Potassium Concentrations and K/Na Ratios

Knowing that the results may occasionally reflect a blend of surface water and groundwater, a single round of additional and discrete samples were collected on November 16, 2010 from the three springs and three surface water locations to see if any significant changes in water quality could be detected in dedicated samples. Results are shown in **Table 3**, and do not suggest any dramatic overall differences in water quality between the springs and surface water sources.

In summary, groundwater quality at the GWS is generally good, although data indicate periodic impact from bacterial pollution. The hardness of the waterm Ca-HCO_3 chemical signature and conductivity are all higher than would usually be expected in Precambrian rocks and indicate a potential influence from carbonates, which is not immediately apparent in the mapped geology. However, the presence and origins of marls and tufa less than 3 kms from the GWS springs indicates that the rocks of the Slieve Gamph should be explored further.

Table 3: Water Quality, November 16, 2010.

Sample Number		S1	S2	S3	S5	S6	S4
Location	**Unit**	**Spring 1**	**Spring 2**	**Spring 3**	**Stream A**	**Stream B**	**Stream - Weir**
Conductivity (20°C)	µS/cm	459	513	515	412	484	487
pH	pH	7.3	7.2	7.2	7.9	7.9	7.4
Total Alkalinity	$mgCaCO_3/l$	261	281	282	225	262	264
Total Hardness	$mgCaCO_3/l$	253	281	281	217	269	277
TON	mg/l as N	0.60	0.98	1.69	0.35	0.56	0.63
Nitrate	mg/l as N	0.60	0.98	1.69	0.35	0.56	0.63
Nitrite	mg/l as N	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ammonia	mg/l as N	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Total Phosphorus	mg/l as P	0.08	<0.01	<0.01	<0.01	<0.01	<0.01
Phosphorus (React)	mg/l as P	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Sulphate	mg/l	5	5	5	4	6	5
Aluminium	µg/l	4	4	3	2	21	3
Chromium	µg/l	0.9	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4
Boron	µg/l	< 32	< 32	< 32	< 32	< 32	< 32
Cadmium	µg/l	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Calcium	mg/l	97.7	121.5	123.2	85.0	106.4	106.9
Copper	µg/l	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Sodium	mg/l	7.1	8.0	7.9	7.9	8.1	7.7
Iron	µg/l	7	3	2	3	66	7
Lead	µg/l	< 3	< 3	< 3	< 3	< 3	< 3
Magnesium	mg/l	3.1	3.5	3.3	2.8	3.3	3.3
Manganese	µg/l	< 0.4	1.0	0.8	2.0	15.0	5.0
Nickel	µg/l	< 2	< 2	< 2	< 2	< 2	< 2
Potassium	mg/l	1.1	1.2	1.1	1.0	1.1	1.2
Zinc	µg/l	38	37	44	12	35	37

9.4 Aquifer characteristics

The GWS springs are situated close to a GSI-mapped fault. Groundwater flow is therefore inferred to be associated with fracture permeability of a fault zone. As shown in **Figure 13**, the bedrock from which the springs discharge is classified by the GSI as a *Pl* aquifer - *generally unproductive except for local zones* - in this case, the local zone is represented by the fault.

Site-specific values for bedrock aquifer properties are not available (the bedrock does not appear to have been tested or quantified in the immediate area). Information from other locations in the Foxford GWB (GSI, 2005) indicate transmissivity values in the range 0.1-10 m^2/d, where higher values apply to fault zones. Storativity is expected to be low, generally <1 %.

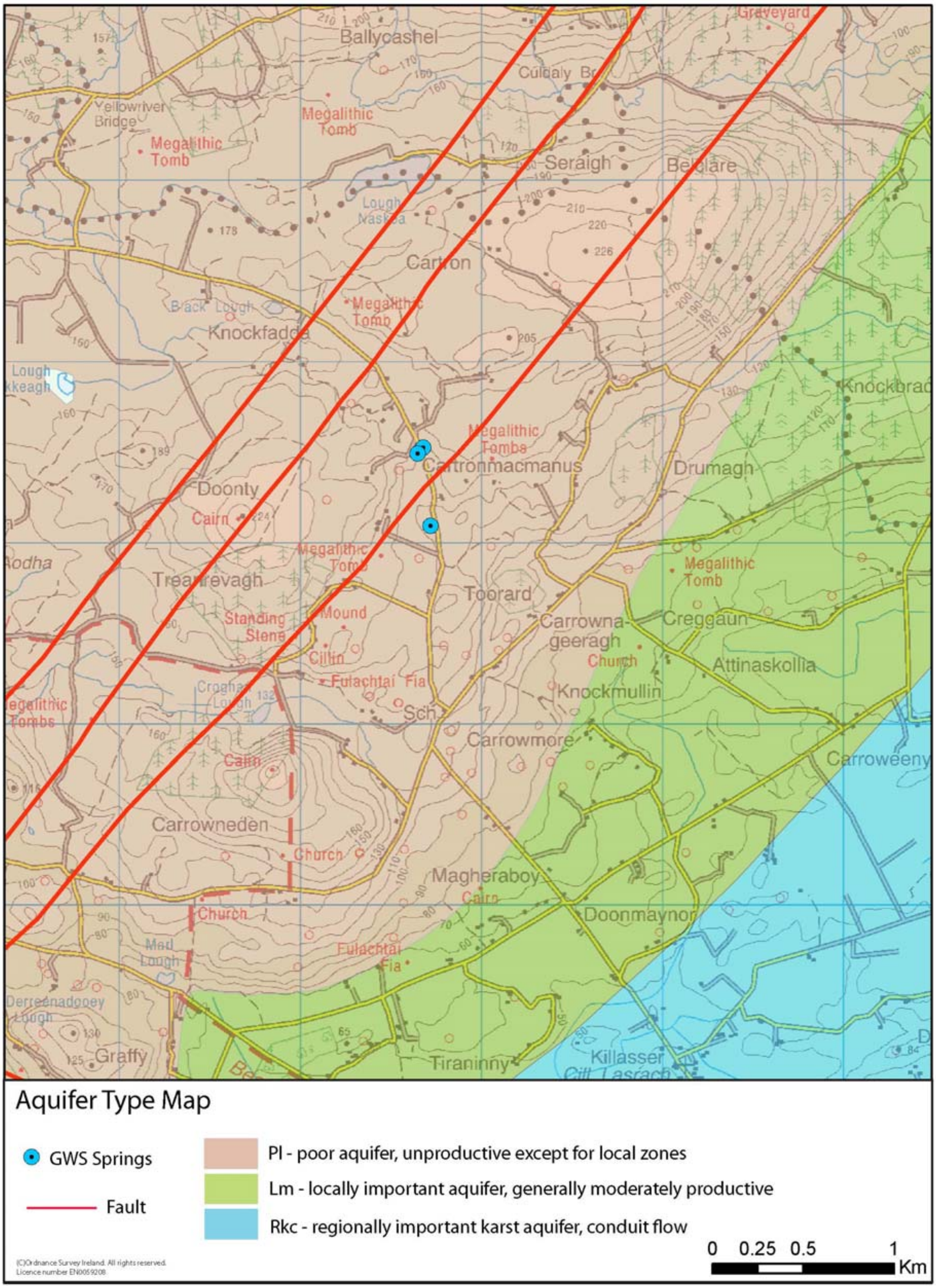


Figure 13: Aquifer Map

For a transmissivity of 10 m^2/d, the corresponding bulk permeability (K) of the Pl aquifer can be estimated by dividing the transmissivity by the saturated thickness of the aquifer. The saturated thickness is not known, but in Pl aquifers, most of the groundwater flux is likely to be in a zone of interconnected fissures some 10-15 m thick, although along fault zones, this can be greater. Assuming a thickness of 15 m across the bulk of the contributing area to the springs, the estimated K is 0.67 m/d.

Using the K value, the approximate velocity of groundwater flow towards the springs can be estimated from the following equation:

$$\text{Velocity (v)} = (\text{K x Groundwater Gradient (i)}) / \text{effective porosity } (n_e)$$

The natural gradient is naturally steep and assumed to be 0.05, a reasonable value for a Pl aquifer. The effective porosity of the fractured aquifer is taken to be 1% (0.01).The bulk groundwater velocity is therefore estimated to be 3.35 m/d or 1,223 m/yr, although it is acknowledged that velocity can be higher in individual fractures or fracture zones.

10 Zone of Contribution

The Zone of Contribution (ZOC) is the hydrogeological catchment areas of the sources that are required to support a natural discharge from a spring or an abstraction from a borehole from long-term recharge. The size and shape of the ZOC is controlled by: (a) the total discharge or abstraction, (b) groundwater flow directions and gradients, (c) subsoil and rock permeabilities, and (d) the recharge in the area.

10.1 Conceptual model

Illustrations of the conceptual hydrogeological model of the Killasser sources are provided in **Figures 14 and 15.** The GWS is sourced from three springs that discharge from bedrock in vicinity of a NE-SW trending fault. The springs discharge from a bedrock aquifer which is classified as a *Pl* aquifer - *generally unproductive except for local zones* - in this case, the local zone is represented by a fault (zone). Groundwater in the Pl bedrock aquifer flows through fractures and fissure, driven by fracture geometry and prevailing hydraulic gradients. The Pl aquifer designation infers that flow paths are shallow and short, and that flow systems are localised. Away from the mapped faults, the aquifer comprises low transmissivity bedrock where most of the groundwater flux occurs in a shallow, broken and weathered zone to a few metres depth. This zone, sometimes referred to as the “transition zone” (Moe et al, 2010) is evident in several exposures in the general Killasser area, and is considered to be a potentially important shallow groundwater pathway for the Killasser catchment.

Towards the faults, fracture density and fracture permeability is expected to be greater. Accordingly, groundwater flow may also be deeper. As such, the faults would act as preferred hydraulic conduits and thereby exert a hydraulic influence on groundwater flow patterns. Springs 1 and 2 are located along a mapped fault and are located at approximately the same elevation. They are, therefore, considered to be part of the same flow system. The smaller Spring 3 also discharges from bedrock, albeit at a lower elevation.

Outside the fault zone, the general low permeability nature of the bedrock would tend to limit the quantities of rainwater that can physically infiltrate. Bulk recharge as a proportion of effective rainfall is, therefore, expected to be quite low. For this reason, most of the effective rainfall discharges rapidly to nearby streams and small springs. Streamflows have a high surface runoff component as evidenced by a “flashy” response to rainfall.

Groundwater vulnerability across most of the study area is mapped by the GSI as mostly High. Exceptions are Low vulnerability pockets of blanket peat and internal drainage basins lined with lower permeability sediments, and small windows of Extreme vulnerability where bedrock outcrops. Slow recharge from internal drainage areas provides recharge to the groundwater system during dry periods, whereas outcrop areas provide localized increased recharge. The GWS springs have never reportedly dried up, although the supply may suffer during extremely dry weather periods, such as that experienced during the summer of 2010.

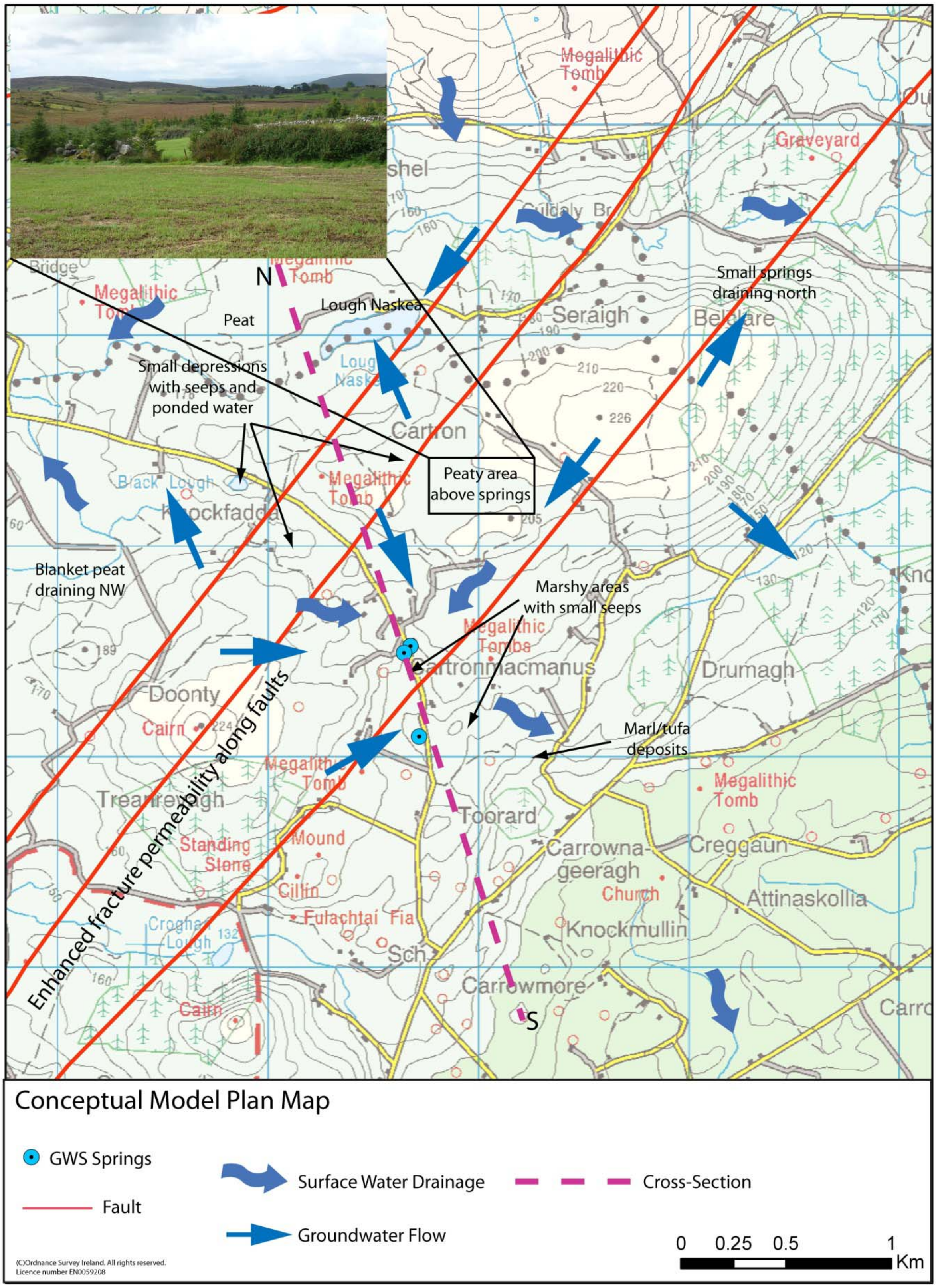


Figure 14: Conceptual model - plan view

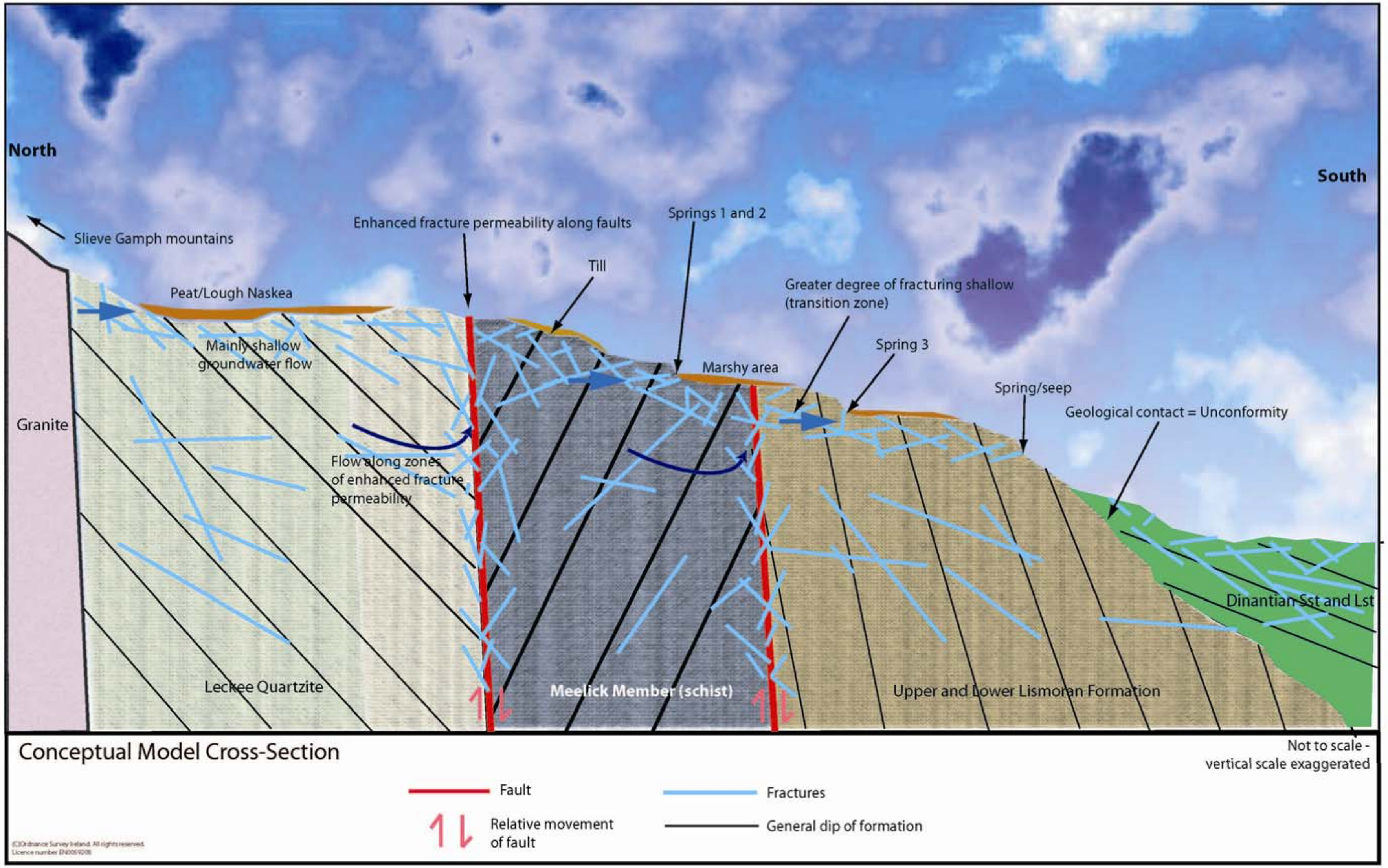


Figure 15: Conceptual model – cross-section

10.2 Boundaries

Groundwater flows to the springs by gravity. All areas at higher elevation than the springs are, therefore, potentially contributing areas. The obvious areas to be considered for ZOC delineation are the hilly areas at Doonty and Cartron which align roughly with the NE-SW trending faults referenced earlier.

The delineated ZOCs for the Killasser springs are shown in **Figure 16.** Guided by topography, ZOCs were delineated from a water balance approach by estimating the recharge areas that would be needed to supply the measured spring discharges described in Section 4. Although discharges up to 1,600 m^3/d were measured in November 2010, the discharge of 1,200 m^3/d is considered more “representative” as it based on test pumping of individual spring chambers under reasonably wet conditions.

Using an estimated average recharge rate of 182 mm (see Section 10.3), the combined recharge area required to discharge a total of 1,200 m^3/d from the three springs is 2.4 km^2.As indicated by **Figure 16**, the ZOC for Spring 3 is differentiated from that of Springs 1 and 2 on the basis of its lower elevation and position within the general (spring) valley.

ZOC - Spring 3

Spring 3 is the smallest of the three springs, with a demonstrated discharge of at least 250 m^3/d. The inferred ZOC covers an area of 0.5 km^2 and incorporates the eastern slope of the hill at Doonty. The ZOC boundaries are shaped by topography and drainage towards the spring. The southern boundary has been extended to include a small mound to the west of Toorard, from which there is a slight surface drainage gradient towards the spring, and the ZOC is considered to be conservatively large.

ZOC – Springs 1 and 2

Springs 1 and 2 are situated at an elevation of approximately 160 mOD, which is approximately 10 m higher than Spring 3. The inferred ZOC covers an area of approximately 1.9 km^2. Along its eastern boundary, the ZOC is drawn parallel to the 165 mOD contour, in other words, it includes areas that are marginally at higher elevations than the springs. The northern boundary extends to the peak of Cartron hill, but not beyond, as there are several smaller springs along the northern slope of Cartron hill which drain northward to the Bellamenean River. The (north)western boundary is influenced by drainage considerations towards Lough Naskea, Black Lough, and the peaty area surrounding Lough Nambrackkeagh. The southern ZOC boundary adjoins the ZOC for Spring 3.

The inferred total ZOC area of 2.4 km^2 for the three springs is based on the discharge value of 1,200 m^3/d. As demonstrated in Section 4, the total discharge can periodically be greater and was estimated (measured) at 1,600 m^3/d in November 2010. This implies one or both of the following two alternatives:

- The ZOC areas are larger than those shown (mainly for Springs 1 and 2); and/or
- Recharge may periodically be greater than 180 mm/yr (see Section 10.3), basically, the groundwater flow system is capable of transporting larger quantities of water within the confines of the delineated ZOCs during wet weather conditions.

Whereas the ZOC boundaries of Springs 1 and 2 are reasonably well defined to the south, east and north, there is topographic room for ZOC expansion to the west/northwest. However, this alternative is not favoured due to drainage considerations for surface water features to the north and west of Doonty and Cartron hills, respectively. As such, the ZOC for Springs 1 and 2 is considered to be topographically constrained to the west/northwest. Consequently, the enhanced recharge alternative is considered to be a more plausible explanation for the discharges in excess of 1,200 m^3/d.

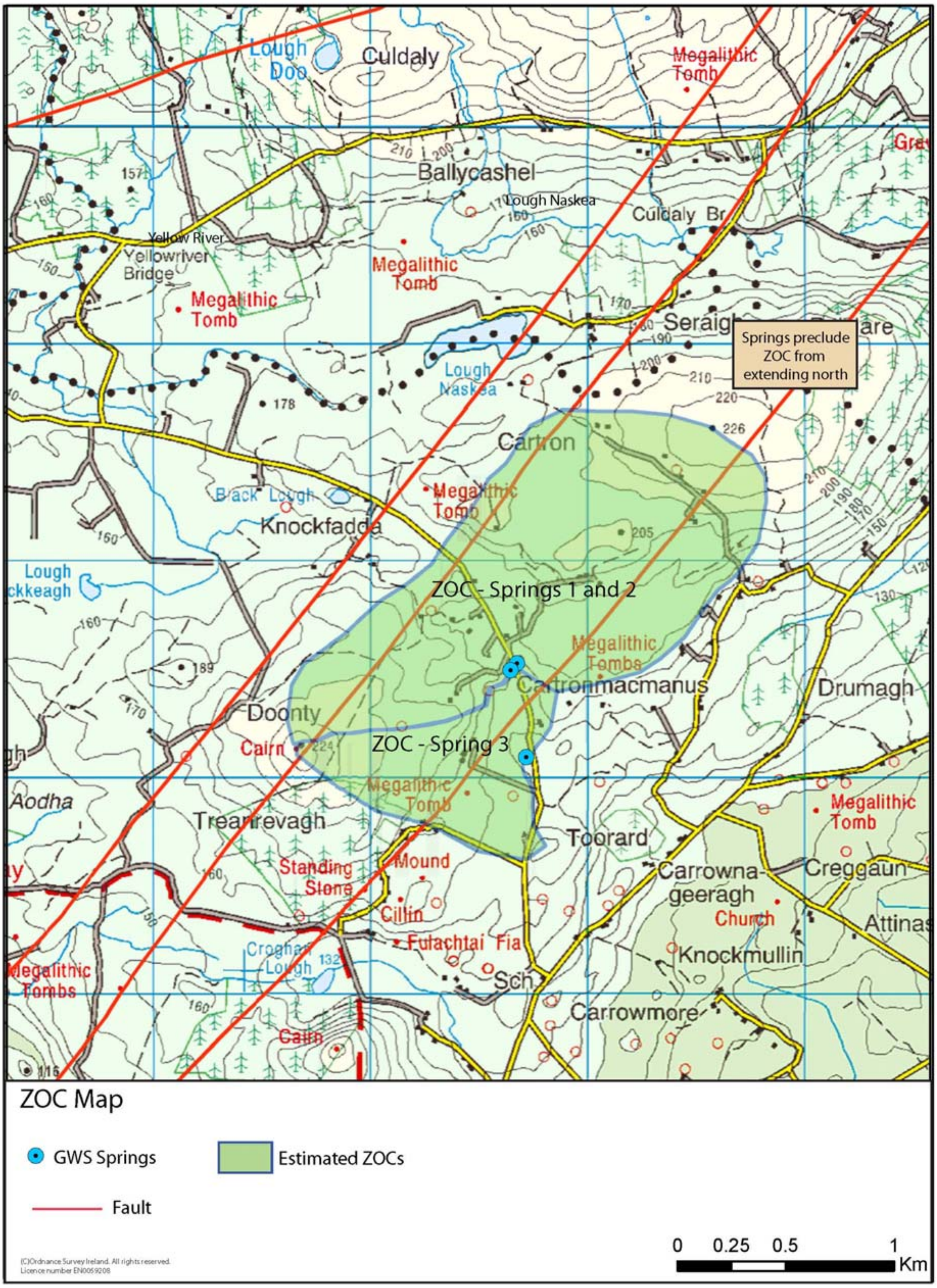


Figure 16: Estimated Zone of Contribution

10.3 Recharge and water balance

The term 'recharge' refers to the amount of water that replenishes the groundwater flow system. The recharge rate is usually stated as an annual average, and is assumed to consist of input (*i.e*. annual rainfall) less water loss prior to entry into the groundwater system (*i.e*. annual evapotranspiration and runoff).

The estimation of a realistic recharge rate is important in source protection delineation, as it will dictate the size of the ZOC to the source and, therefore, the Outer Source Protection Area. At Killasser, the main parameters involved in recharge rate estimation are annual rainfall; actual annual evapotranspiration and a recharge coefficient (Rc). The recharge coefficient is estimated using Guidance Document GW5 (Groundwater Working Group, 2005).

The general catchment areas of the three springs comprise relatively steep-sided hills that are covered by glacial till and/or blanket peat. Subsoils, as currently mapped by the GSI, are mostly of moderate permeability and greater than 3 m in thickness across the ZOCs. On account of general catchment characteristics, a bulk recharge coefficient (Rc) of 30% is considered reasonable for respective ZOCs and the average annual recharge rate to the groundwater system is calculated to be 287 mm/yr, as follows:

Average annual rainfall (R) (see Section 5)	1450 mm
Estimated P.E. (see Section 5)	520 mm
Estimated A.E. (95% of P.E.)	494 mm
Effective rainfall (ER = R-AE)	956 mm
Potential recharge (equal to ER)	956 mm
Bulk recharge coefficient	30%
Annual recharge rate	287 mm

A recharge rate of 287 mm/yr is conceptually quite high for a Pl aquifer. However, for the ZOC area indicated in Section 10.2, it results in a combined discharge rate of 1,892 m^3/d, which is only 18% higher than the highest estimated (measured) discharge to date of 1,600 m^3/d. If the recharge coefficient is lowered slightly from 30% to 25%, the resulting discharge would be 1,576 m^3/d. The suggested recharge coefficient is consistent with hydrogeological observations in the catchment and given the fact that peak discharges are historically not well quantified (measured), a potential recharge rate of 287 mm/yr cannot be discounted.

The equivalent recharge rate for the discharge of 1,200 m^3/d is 182 mm/yr, which is considered to be entirely plausible for the Killasser hydrogeological setting. Given the topographic constraints on the estimated ZOCs for Springs 1 and 2 especially, it is inferred that recharge to the Killasser spring system exceeds 182 mm/yr during wet weather conditions (when total discharges also exceed 1,200 m^3/d).

Recharge of this magnitude is accommodated periodically during episodic rainfall events via enhanced shallow groundwater pathways as suggested by the conceptual model of the springs (i.e. enhanced fracture permeability associated with fault zones and an active transition zone).

A suggested recharge rate of 182 mm/yr (from Section 10.2) would account for 19% of effective rainfall whereas surface runoff losses would account for the remaining 81%, which is consistent with the flashy nature of the Killasser stream hydrograph.

11 Source Protection Zones

The Source Protection Zones are a landuse planning tool which enables an objective, geoscientific assessment of the risk to groundwater to be made. The zones are based on an amalgamation of source protection areas and the aquifer vulnerability. The source protection areas represent the horizontal groundwater pathway to the source, while the vulnerability reflects the vertical pathway. Two source protection areas have been delineated, the Outer Source Protection Area (SO) and the Inner Source Protection Area (SI).

The Outer Protection Area (SO) encompasses the entire ZOC to the GWS springs. The SI is defined by a 100-day time of travel to the source and is designed to protect the source from microbial and viral contamination (DELG/EPA/GSI 1999). From Section 9.4, the groundwater velocity is inferred to be on the order of 3 m/d and hence the 100-day time of travel distance is 300 m. The Inner Protection Area is illustrated in **Figure 17**.

The resulting groundwater Source Protection Zones are shown in **Figure 18.** These are based on the interim groundwater vulnerability mapping described in Section 8, and should, therefore, also be regarded as interim in nature. The SPZs would need to be revised should the final vulnerability map for County Mayo, once published by the GSI, show any changes to that indicated in **Figure 8**.

The majority of the SO is designated as SO/H and SO/M, and significantly, more than 90% of the SI is designated as either SI/E or SI/H, reflecting the Extreme and High groundwater vulnerability of the immediate area surrounding the springs.

12 Potential pollution sources

The springs are covered to protect against the direct ingress of polluted surface water, however, at Spring 3, the cover is flush with the ground surface and at Spring 2, the cover is built up only slightly. Both covers have gaps through which surface runoff may enter.

The primary land use within the SI is pasture for grazing animals. Landspreading of organic fertilizer takes place in some of the fields adjacent to the springs, even on steep slopes.

The majority of land within the SO is agricultural grassland and commonage, as well as blanket peat and raised bogs. There is some forestry in upland areas. There are only a few scattered farms and therefore few septic tanks and animal slurry storage areas.

The main pollution source to be considered is therefore regarded to be landspreading and cattle grazing in the fields immediately surrounding each spring, Microbial pollution has been detected frequently in the untreated water. Given the predominantly High and Extreme vulnerability within the SI, the potential risk from pollution, including cryptosporidium and viruses, is considered high.

13 Conclusions

The Killasser springs discharge from a Pl aquifer characterised by flow through fissures and fractures and which appear to be associated with nearby fault zones. There is some uncertainty around estimates of total spring discharges due to a general lack of historical records. Best available data indicate that the total discharge from the three springs can range from 800 m^3/d during dry periods to 1,600 m^3/d or greater during wet weather. Because historical records do not exist, a detailed analysis of discharges, including regression analysis, is not possible.

The combined ZOCs for the three springs cover an area of approximately 2.4 km^2 and is based on a “representative” discharge of 1,200 m^3/d. Topography and water balance considerations places constraints on the ZOC delineation in terms of area available for recharge, and a recharge rate of 182 mm/yr is considered realistic for the discharge of 1,200 m^3/d. This recharge rate is exceeded during very wet weather conditions, and the groundwater flow system is considered to be capable of transporting larger volumes of water during wet weather events via shallow groundwater pathways associated with fault zones.

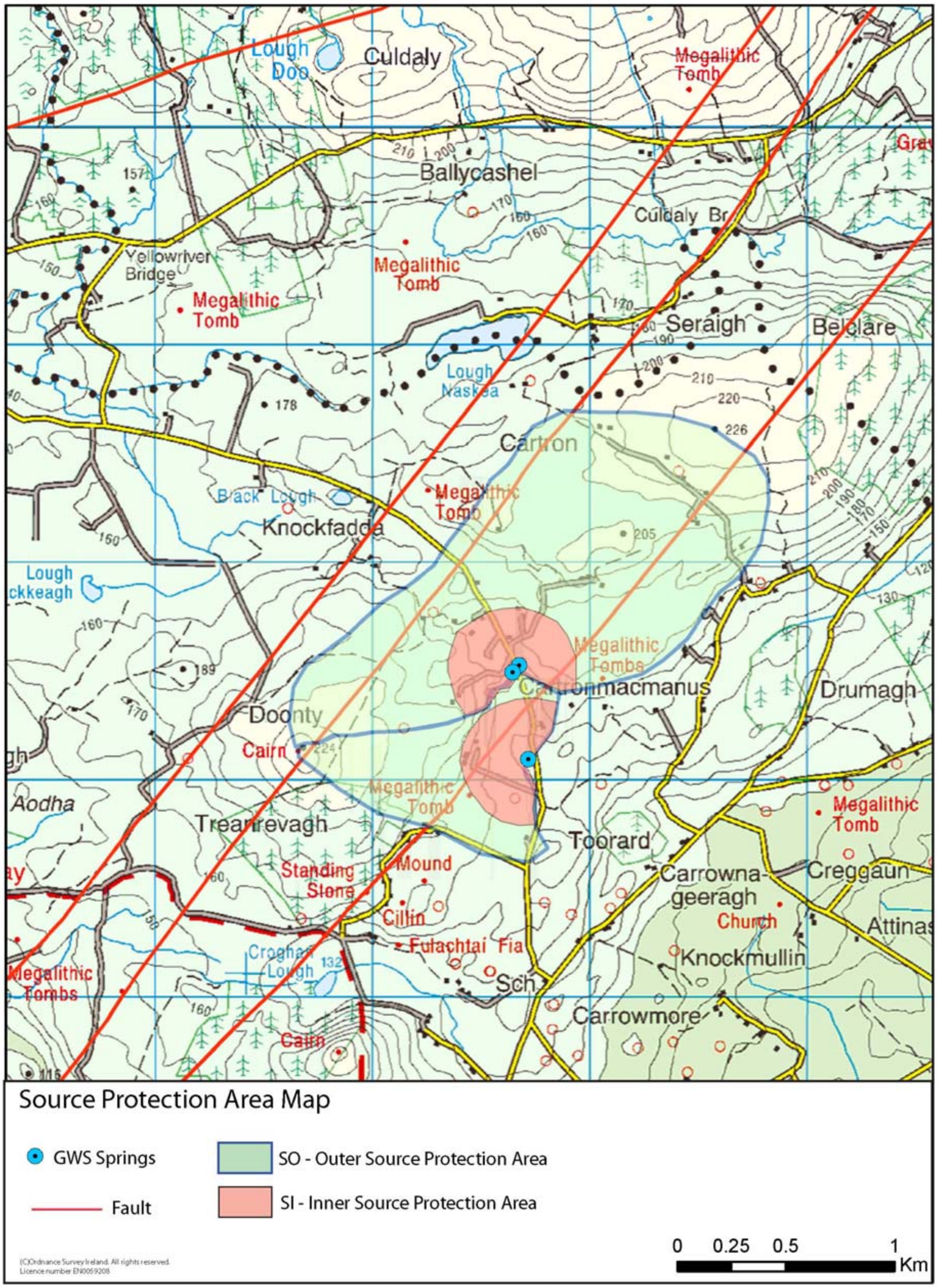


Figure 17: Inner and Outer Source Protection Areas

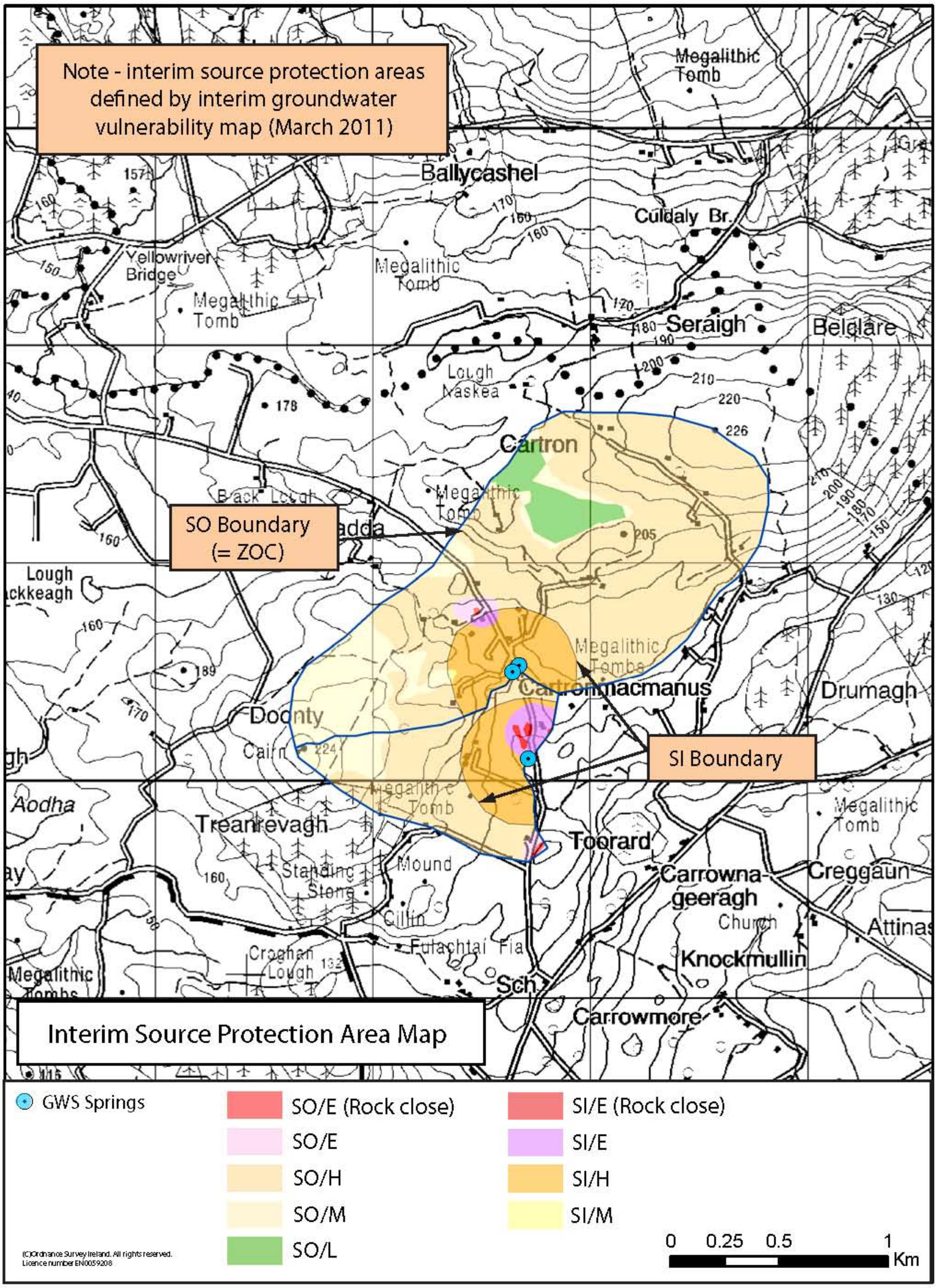


Figure 18: Source Protection Zones

The groundwater vulnerability within the Inner Source Protection Areas is mostly High and Extreme. Water quality is generally good but is periodically impacted by microbial pollution. The hardness and Ca-HCO_3 chemical signature of the spring water appears to be influenced by a source of carbonates which on the basis of existing geological mapping is not immediately obvious.

14 Recommendations

Improved protection of each spring is needed, and it is recognised that construction measures have already been taken to secure the spring chambers at Springs 1 and 2. However, Spring 2 is still considered vulnerable in an area that floods and Spring 3 needs improved physical protection.

Current landspreading and cattle grazing activities should be reviewed with local farmers and solutions found to minimize the risk of impact on spring quality.

Simple measures should be taken to improve the understanding of spring flows by installing metres on discharge pipes and overflows. This should be implemented immediately in the context of current GWS upgrades.

The current understanding of the ZOC is based on the available data, and should be revised on the basis of improved and additional flow measurements from the springs.

The current EPA gauging station on the Killasser stream measures flow and stage that represents both spring overflows and surface water runoff. In the context of stream gauging, a concrete box that is used as a "holding tank" for augmentation of supply to the reservoir (and that is located just 50-60 m downstream from the gauging station) should be eliminated as it backs up the streamflow and therefore raises the stream level in an upgradient direction. Whether or not this influences the gauging data is unknown and should be investigated.

15 References

DELG/EPA/GSI, 1999. Groundwater Protection Schemes. Dept. of the Environment & Local Government; Environmental Protection Agency; Geological Survey of Ireland.

EPA website. www.epa.ie

European Communities (Drinking Water) Regulations (2000). S.I. No. 439 of 2000.

Fitzgerald, D. and F. Forrestal, 1996. Monthly and annual averages of rainfall for Ireland 1961 to 1990. Meteorological Service Climatological Note No. 10. Glasnevin Hill, Dublin 9.

GSI website. www.gsi.ie

GSI, 2004. Foxford Groundwater Body – Water Framework Directive Initial Characterisation Summary – 1st Draft. Geological Survey of Ireland.

GWWG 2005. Guidance on the Assessment of the Impact of Groundwater Abstractions. Guidance Document No.GW5. Intergovernmental Working Group on Groundwater.

Long, B., Mac Dermot, C.V., Morris, J.H., Sleeman, A.G., Tietzsch-Tyler, D., (1992). A geological description to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 6, North Mayo. Geological Survey of Ireland Map Series Report.

Moe, H., Craig M., and Daly, D. (2010). Poorly Productive Aquifers – Monitoring Installations and Conceptual Understanding. Published by the Environmental Protection Agency.

Tobin, 2001. Hydrogeological Investigations of Group Water Scheme Sources at Cartronmacmanus, Killasser, Co. Mayo. Prepared for the Killasser Group Water Scheme, April 2001.

APPENDIX 1

Flow Measurements at Killasser Spring Sources

Flow Measurement (16/11/10)

Location	Q l/s	Comments
Spring A - rise	1.21	At higher elevation
Stream A u/s Spring 1	9.54	Groundwater seeps add to flow and surface water runoff from road
Spring 1 overflow pipe	14.27[1]	Difficult to get reliable reading due to construction works and site layout.
Stream – d/s Spring 1	23.81	By marsh, d/s of inflow point from Spring 2 overflow
Spring 2 overflow pipe	4.00[2]	Overflow channel with vegetation.
Spring B	4.5[3]	Flow measurement taken before small waterfall. Turbulent flow in stream. Flow at base of waterfall could not be taken – water 'diffuses' into surrounding marshy area.
Stream – d/s of weir	53.66	This equals flow from Spring A and B and Overflow from Spring 1 and 2 (total 32.32 l/s). The missing flow (21.35 l/s) is believed to be from error in Stream B flow measurement and small groundwater seeps by marshy area upstream of weir (where all flows merge).

Note:
1 – In all likelihood an overestimate. Measurement redone on 26/11/10, with an estimate of 4.3 l/s
2 – approximate – overflow channel well defined but partly overgrown, attempts made to remove vegetation for measurement. New measurement on 26/11/10 also gave 4 l/s.
3 – In all likelihood a significant underestimate.

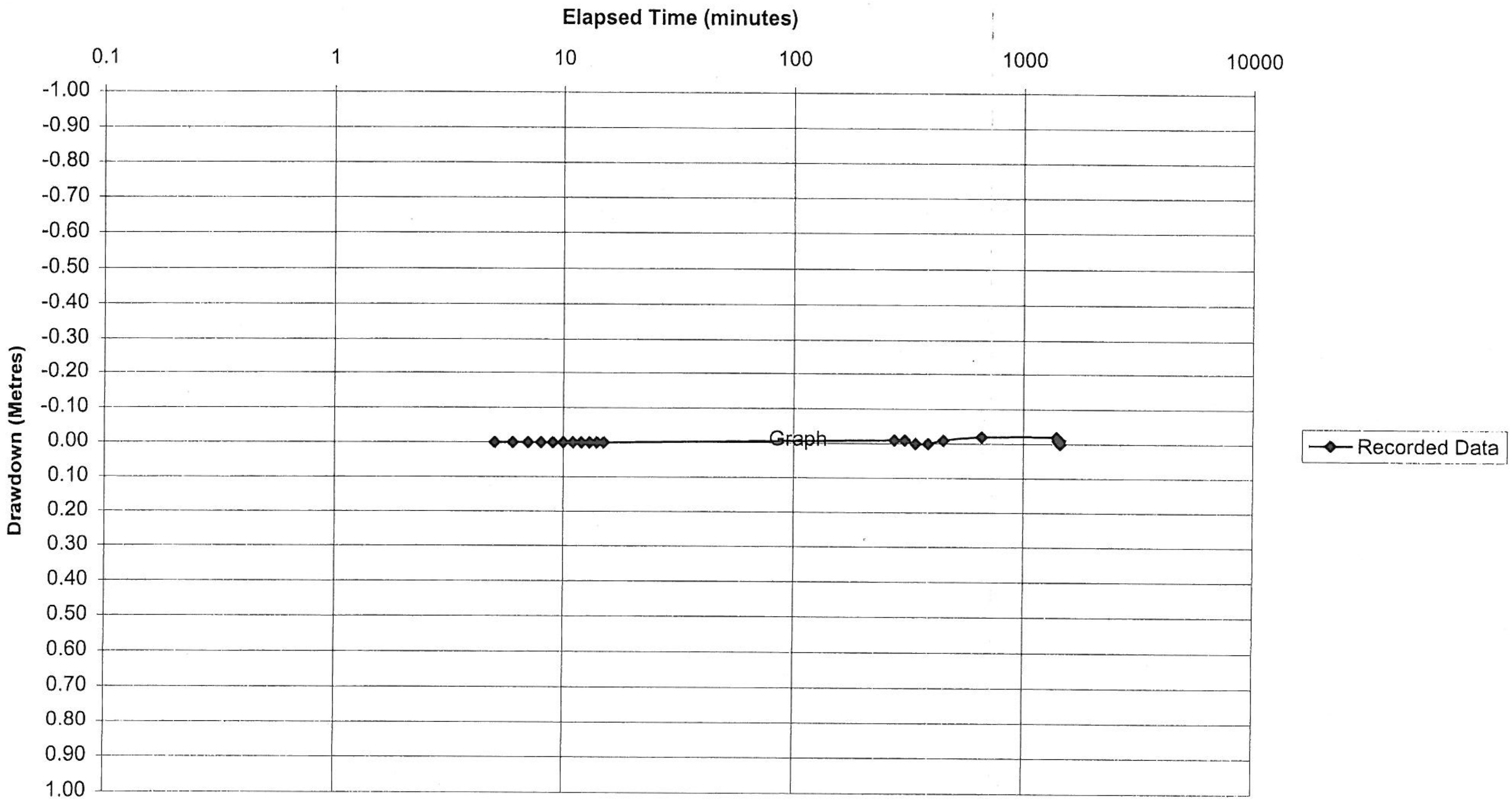
APPENDIX 2

Pump Tests of Killasser Spring Sources

Killasser Group Water Scheme SOURCE NO. 1
Constant Yield - Drawdown Test

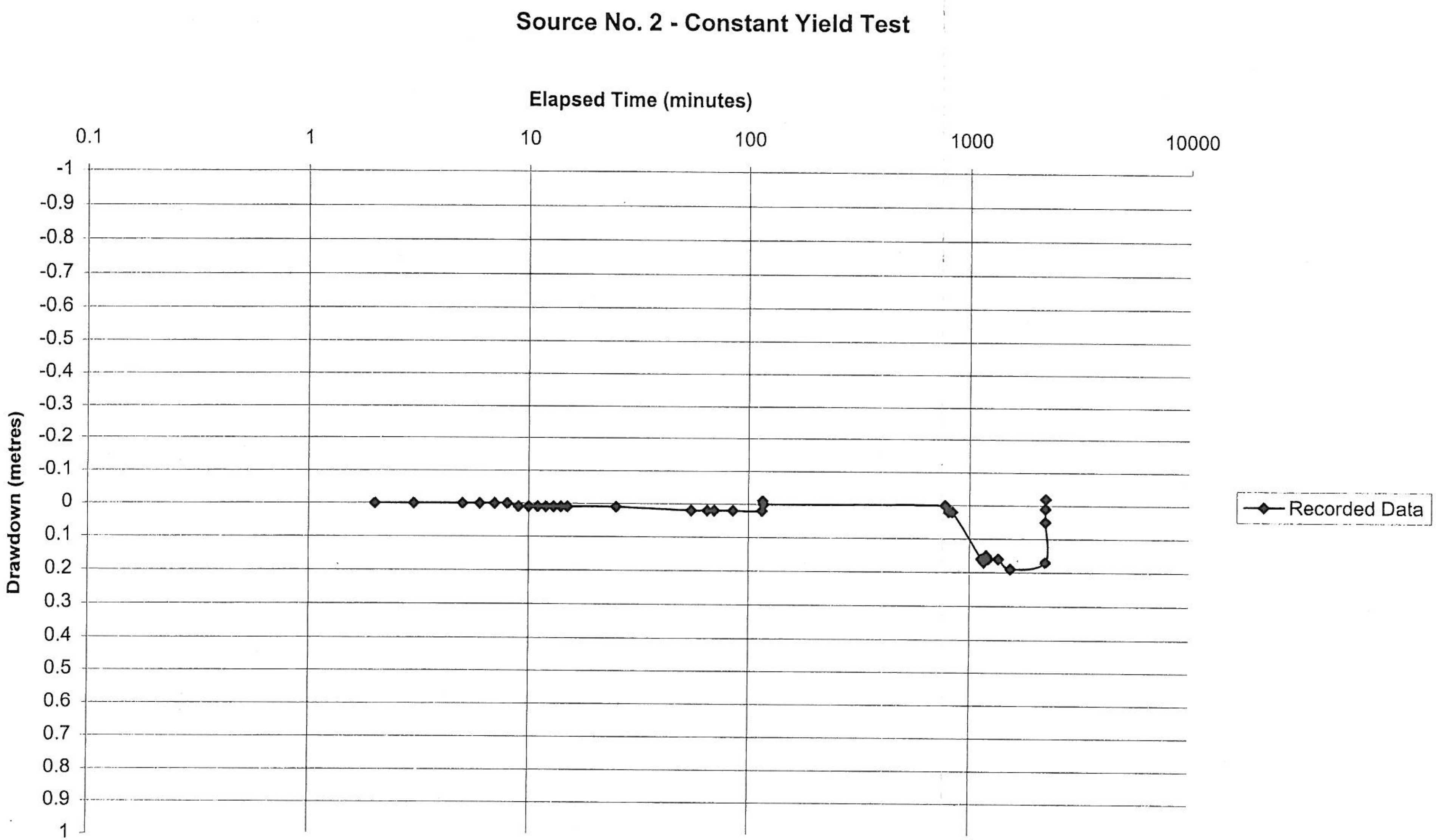
Date	Time (GMT)	Elapsed Time (minutes)	Water Level (metres below casing)	Drawdown (metres)	Yield m^3/day	Comments
14-Feb-01	10.15	0	0.81	0.00	570	Source outfall sealed
14-Feb-01	10.20	5	0.81	0.00	570	
14-Feb-01	10.21	6	0.81	0.00	570	
14-Feb-01	10.22	7	0.81	0.00	570	
14-Feb-01	10.23	8	0.81	0.00	570	
14-Feb-01	10.24	9	0.81	0.00	570	
14-Feb-01	10.25	10	0.81	0.00	570	Water clear
14-Feb-01	10.26	11	0.81	0.00	570	
14-Feb-01	10.27	12	0.81	0.00	570	
14-Feb-01	10.28	13	0.81	0.00	570	
14-Feb-01	10.29	14	0.81	0.00	570	
14-Feb-01	10.30	15	0.81	0.00	570	
14-Feb-01	14.50	275	0.80	-0.01	570	Water clear
14-Feb-01	15.20	305	0.80	-0.01	570	
14-Feb-01	15.55	340	0.81	0.00	570	
14-Feb-01	16.40	385	0.81	0.00	570	
14-Feb-01	17.45	450	0.80	-0.01	570	
14-Feb-01	21.15	660	0.79	-0.02	570	Water clear.
15-Feb-01	9.30	1395	0.79	-0.02	570	
15-Feb-01	9.45	1410	0.80	-0.01	570	
15-Feb-01	10.20	1445	0.80	-0.01	570	
15-Feb-01	10.21	1446	0.81	0.00	570	Samples taken S1 - Pump switched off
15-Feb-01	10.22	1447	0.81	0.00		Recharge
15-Feb-01	10.23	1448	0.81	0.00		Recharge

Source No. 1 - Constant Yield Test



Killasser Group Water Scheme SOURCE NO. 2
Constant Yield - Drawdown Test

Date	Time (GMT)	Elapsed Time (minutes)	Water Level (metres below casing)	Drawdown (metres)	Yield m^3/day	Comments
12-Feb-01	19.35	0	0.42	0.00		Outlet partially blocked, inlet clamped as tight as possible
12-Feb-01	19.37	2	0.42	0.00	505	
12-Feb-01	19.38	3	0.42	0.00	505	Water clear
12-Feb-01	19.40	5	0.42	0.00	505	Water cloudy brown
12-Feb-01	19.41	6	0.42	0.00	505	Water cloudy brown
12-Feb-01	19.42	7	0.42	0.00	505	Water brown from outflow pipe
12-Feb-01	19.43	8	0.42	0.00	505	Water brown
12-Feb-01	19.44	9	0.43	0.01	505	Water brown
12-Feb-01	19.45	10	0.43	0.01	505	Water brown
12-Feb-01	19.46	11	0.43	0.01	505	Water brown
12-Feb-01	19.47	12	0.43	0.01	505	
12-Feb-01	19.48	13	0.43	0.01	505	Water brown/clearing
12-Feb-01	19.49	14	0.43	0.01	505	
12-Feb-01	19.50	15	0.43	0.01	505	Water clear with particles from outflow pipe
12-Feb-01	20.00	25	0.43	0.01	505	
12-Feb-01	20.30	55	0.44	0.02	505	
12-Feb-01	20.40	65	0.44	0.02	505	
12-Feb-01	20.45	70	0.44	0.02	505	
12-Feb-01	21.00	85	0.44	0.02	505	
12-Feb-01	21.30	115	0.44	0.02	505	Pump switched off
12-Feb-01	21.31	116	0.41	-0.01	505	Pump switched off
12-Feb-01	21.32	117	0.42	0.00	505	Recharge
13-Feb-01	8.30	775	0.42	0.00	505	Recharge
13-Feb-01	9.00	805	0.44	0.02	505	Test Start - Pump switched on
13-Feb-01	9.30	835	0.44	0.02	505	
13-Feb-01	14.30	1135	0.58	0.16	505	
13-Feb-01	15.00	1165	0.59	0.17	505	
13-Feb-01	15.30	1195	0.57	0.15	505	
13-Feb-01	16.00	1225	0.58	0.16	505	
13-Feb-01	18.10	1355	0.58	0.16	505	
13-Feb-01	21.15	1540	0.61	0.19	505	
14-Feb-01	8.30	2215	0.59	0.17	505	Samples taken S2 - Pump switched off
14-Feb-01	8.31	2216	0.47	0.05		Recharge
14-Feb-01	8.32	2217	0.43	0.01		Recharge
14-Feb-01	8.33	2218	0.40	-0.02		Recharge
14-Feb-01	8.34	2219	0.40	-0.02		

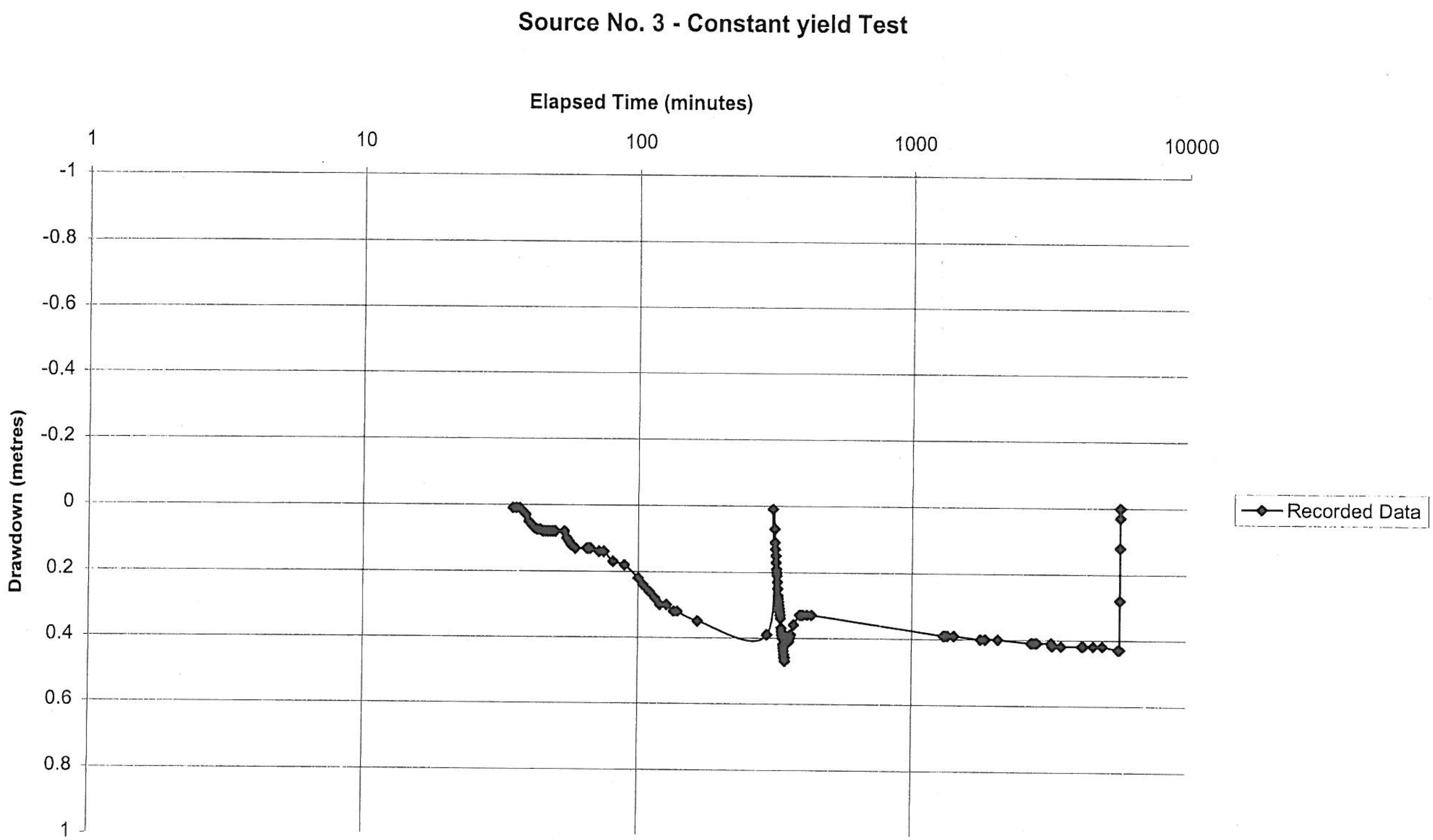

Source No. 2 - Constant Yield Test
Elapsed Time (minutes)
0.1
1
10
100
1000
10000
Drawdown (metres)
-1
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Recorded Data

Killasser Group Water Scheme SOURCE NO. 3
Constant Yield - Drawdown Test

Date	Time (GMT)	Elapsed Time (minutes)	Water Level (metres below casing)	Drawdown (metres)	Yield m^3/day	Comments
8-Feb-01	11.00	0	0.35	0.00	272	Outlet valve @ Source 3 closed
8-Feb-01	11.35	35	0.36	0.01	272	Water clear
8-Feb-01	11.36	36	0.36	0.01	272	Pump started
8-Feb-01	11.37	37	0.36	0.01	272	
8-Feb-01	11.38	38	0.37	0.02	272	
8-Feb-01	11.39	39	0.38	0.03	272	Water clear
8-Feb-01	11.40	40	0.40	0.05	272	
8-Feb-01	11.41	41	0.41	0.06	272	
8-Feb-01	11.42	42	0.42	0.07	272	
8-Feb-01	11.43	43	0.43	0.08	272	Water clear
8-Feb-01	11.44	44	0.43	0.08	272	
8-Feb-01	11.45	45	0.43	0.08	272	
8-Feb-01	11.46	46	0.43	0.08	272	
8-Feb-01	11.47	47	0.43	0.08	272	Water clear
8-Feb-01	11.48	48	0.43	0.08	272	
8-Feb-01	11.49	49	0.43	0.08	272	Water clear
8-Feb-01	11.50	50	0.43	0.08	272	
8-Feb-01	11.54	54	0.43	0.08	431	
8-Feb-01	11.55	55	0.45	0.10	431	Pump rate increased
8-Feb-01	11.56	56	0.46	0.11	431	Water clear
8-Feb-01	11.57	57	0.47	0.12	431	
8-Feb-01	11.59	59	0.48	0.13	431	
8-Feb-01	12.05	65	0.48	0.13	431	Water clear
8-Feb-01	12.06	66	0.48	0.13	431	
8-Feb-01	12.07	67	0.48	0.13	431	
8-Feb-01	12.12	72	0.49	0.14	431	
8-Feb-01	12.15	75	0.49	0.14	520	
8-Feb-01	12.21	81	0.52	0.17	520	Pump rate increased
8-Feb-01	12.29	89	0.53	0.18	520	
8-Feb-01	12.40	100	0.57	0.22	520	Water clear
8-Feb-01	12.44	104	0.59	0.24	520	Water clear
8-Feb-01	12.50	110	0.61	0.26	520	
8-Feb-01	12.55	115	0.63	0.28	520	Water clear
8-Feb-01	13.00	120	0.65	0.30	520	
8-Feb-01	13.07	127	0.65	0.30	520	
8-Feb-01	13.15	135	0.67	0.32	520	
8-Feb-01	13.19	139	0.67	0.32	520	Water clear

Date	Time (GMT)	Elapsed Time (minutes)	Water Level (metres below casing)	Drawdown (metres)	Yield m^3/day	Comments
8-Feb-01	13.45	165	0.70	0.35	520	
8-Feb-01	15.56	296	0.74	0.39	520	Water clear
8-Feb-01	16.10	310	0.36	0.01	520	Stop pump to adjust fuel supply
8-Feb-01	16.15	315	0.42	0.07	520	
8-Feb-01	16.16	316	0.46	0.11	520	Pump started
8-Feb-01	16.17	317	0.48	0.13	520	
8-Feb-01	16.18	318	0.50	0.15	520	
8-Feb-01	16.19	319	0.52	0.17	520	
8-Feb-01	16.20	320	0.54	0.19	520	
8-Feb-01	16.21	321	0.55	0.20	520	
8-Feb-01	16.22	322	0.56	0.21	520	
8-Feb-01	16.23	323	0.58	0.23	520	
8-Feb-01	16.24	324	0.60	0.25	520	
8-Feb-01	16.25	325	0.62	0.27	520	
8-Feb-01	16.26	326	0.63	0.28	520	
8-Feb-01	16.27	327	0.64	0.29	520	
8-Feb-01	16.28	328	0.65	0.30	520	
8-Feb-01	16.29	329	0.66	0.31	520	Water clear
8-Feb-01	16.30	330	0.67	0.32	520	
8-Feb-01	16.31	331	0.68	0.33	520	
8-Feb-01	16.32	332	0.69	0.34	520	Water clear
8-Feb-01	16.34	334	0.72	0.37	520	Stream dry
8-Feb-01	16.35	35	0.73	0.38	520	
8-Feb-01	16.36	336	0.74	0.39	520	
8-Feb-01	16.38	338	0.75	0.40	520	
8-Feb-01	16.39	339	0.77	0.42	520	
8-Feb-01	16.40	340	0.78	0.43	520	
8-Feb-01	16.41	341	0.79	0.44	520	
8-Feb-01	16.42	342	0.80	0.45	520	
8-Feb-01	16.43	343	0.81	0.46	520	
8-Feb-01	16.44	344	0.81	0.46	520	
8-Feb-01	16.45	345	0.82	0.47	520	
8-Feb-01	16.57	357	0.76	0.41	520	
8-Feb-01	16.59	359	0.75	0.40	520	
8-Feb-01	17.00	360	0.75	0.40	520	Well experiencing recharge
8-Feb-01	17.01	361	0.74	0.39	520	
8-Feb-01	17.02	362	0.74	0.39	520	
8-Feb-01	17.11	371	0.71	0.36	520	Refuel honda
8-Feb-01	17.30	390	0.68	0.33	520	
8-Feb-01	17.35	395	0.68	0.33	520	
8-Feb-01	17.41	401	0.68	0.33	520	
8-Feb-01	17.55	415	0.68	0.33	520	

Date	Time (GMT)	Elapsed Time (minutes)	Water Level (metres below casing)	Drawdown (metres)	Yield m^3/day	Comments
8-Feb-01	18.11	431	0.68	0.33	520	
9-Feb-01	8.45	1305	0.74	0.39	52	
9-Feb-01	9.00	1320	0.74	0.39	520	
9-Feb-01	9.30	1350	0.74	0.39	520	
9-Feb-01	10.45	1425	0.74	0.39	520	
9-Feb-01	16.45	1785	0.75	0.40	520	Sample taken S3
9-Feb-01	18.00	1860	0.75	0.40	520	
9-Feb-01	21.30	2070	0.75	0.40	520	
10-Feb-01	8.30	2730	0.76	0.41	520	Heavy rain throughout night
10-Feb-01	8.50	2750	0.76	0.41	520	
10-Feb-01	9.03	2763	0.76	0.41	520	
10-Feb-01	10.05	2825	0.76	0.41	520	Water clear
10-Feb-01	10.45	2865	0.76	0.41	520	
10-Feb-01	16.50	3230	0.76	0.41	520	
10-Feb-01	17.20	3260	0.77	0.42	520	
10-Feb-01	21.30	3510	0.77	0.42	520	Weather - dry and mild.
11-Feb-01	8.30	4170	0.77	0.42	520	Foot valve cleaned. Refueled. Dry mild, lightning
11-Feb-01	9.30	4230	0.77	0.42	520	Water clear
11-Feb-01	15.35	4595	0.77	0.42	520	Refuel
11-Feb-01	21.35	4955	0.77	0.42	520	Water clear
12-Feb-01	9.15	5655	0.78	0.43	520	Weather - dry and mild. Refuel
12-Feb-01	10.00	5700	0.78	0.43	520	Sample taken S3
12-Feb-01	10.15	5715	0.78	0.43	520	Pump switched off
12-Feb-01	10.16	5716	0.63	0.28		Recharge
12-Feb-01	10.17	5717	0.47	0.12		Recharge
12-Feb-01	10.18	5718	0.38	0.03		Recharge
12-Feb-01	10.19	5719	0.35	0.00		Recharge
12-Feb-01	10.20	5720	0.35	0.00		Recharge
12-Feb-01	10.21	5721	0.35	0.00		
12-Feb-01	10.22	5722	0.35	0.00		


Source No. 3 - Constant yield Test
Elapsed Time (minutes)
1
10
100
1000
10000
Drawdown (metres)
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Recorded Data