APPENDIX A

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WELL LOG

Well No.: TW1

Description: Trial Well

Client: Project Management

Location: Carranstown, Duleek

Driller: Tom Briody & Son

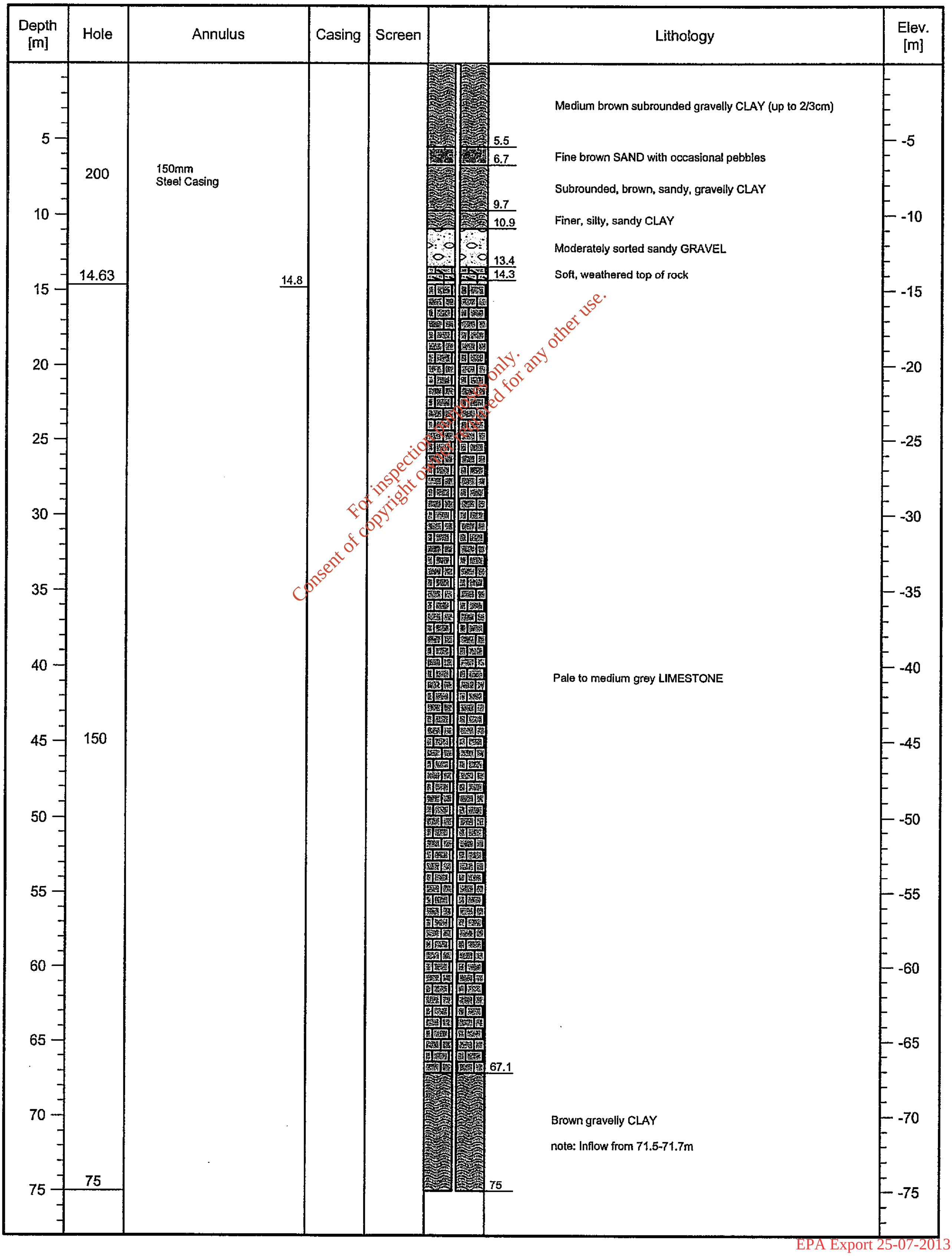
Date Drilled: 26/4/00

Water Level (mbtoc):

All diameters in mm
All depths in metres

Scale

Vertical	Horizontal
375.0	250.0



Medium brown subrounded gravelly CLAY (up to 2/3cm)

Fine brown SAND with occasional pebbles

Subrounded, brown, sandy, gravelly CLAY

Finer, silty, sandy CLAY

Moderately sorted sandy GRAVEL

Soft, weathered top of rock

Pale to medium grey LIMESTONE

Brown gravelly CLAY

note: Inflow from 71.5-71.7m

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WELL LOG

Well No.
MW1

Description
Overburden well

Client
Project Management

Location
Carranstown, Duleek

Driller
Tom Briody & Son

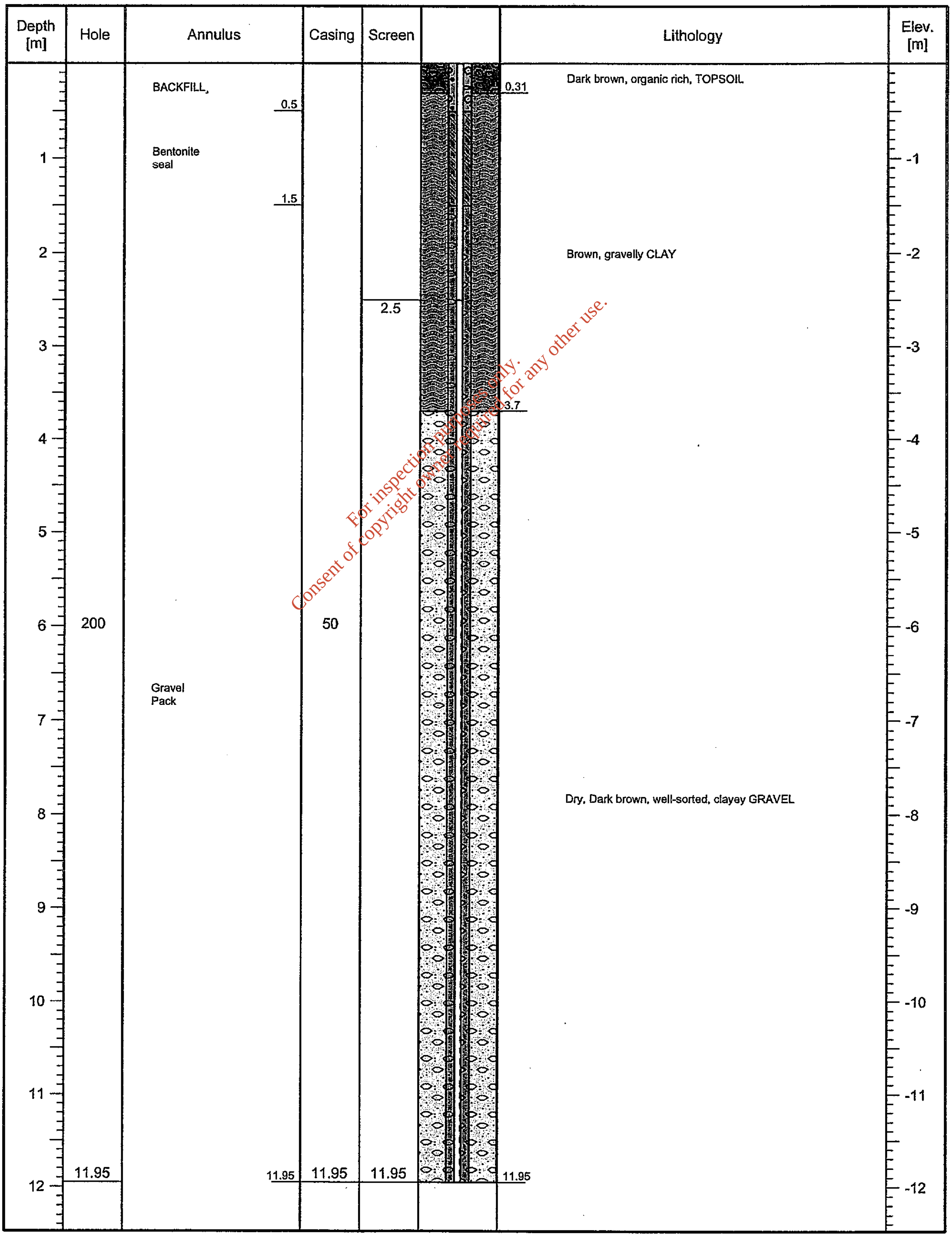
Date Drilled
2/5/00

Water Level (mbtoc)

All diameters in mm
All depths in metres

Scale

Vertical	Horizontal
60.0	50.0



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WELL LOG

Well No.
MW2

Description
Overburden well

Client
Project Management

Location
Carranstown, Duleek

Driller
Tom Briody & Son

Date Drilled
3/5/00

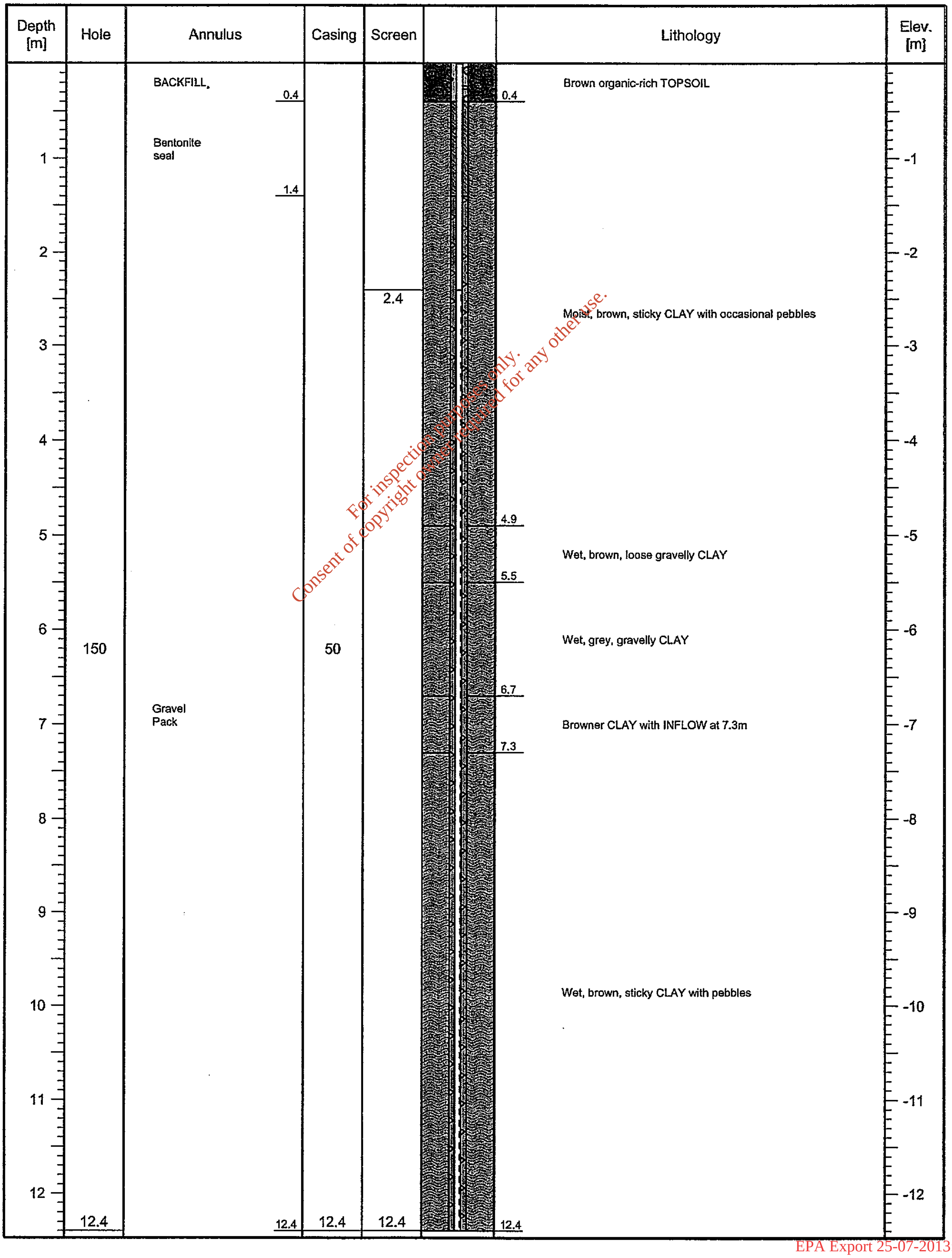
Scale

Vertical
60.0

Horizontal
50.0

Water Level (mbtoc)

All diameters in mm
All depths in metres



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WELL LOG

Well No.
MW3

Description
Overburden well

Client
Project Management

Location
Carranstown, Duleek.

Driller
Tom Briody & Son

Date Drilled
3/5/00

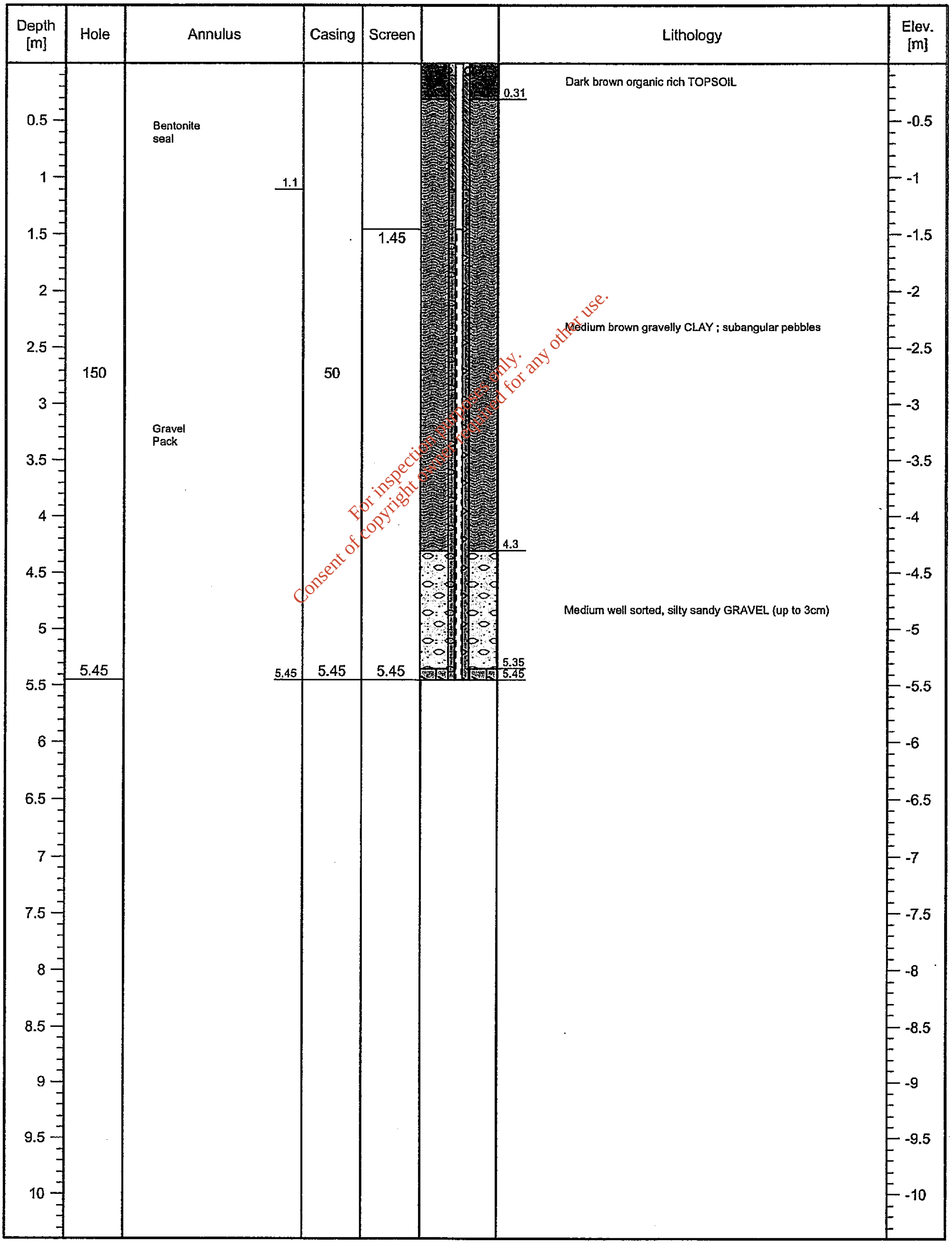
Scale

Water Level (mbtoc)

All diameters in mm
All depths in metres

Vertical
50.0

Horizontal
40.0



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WELL LOG

Well No. MW4	Description Bedrock monitoring Well	Client Project Management
	Location Carranstown, Duleek	Driller Tom Briody & Son

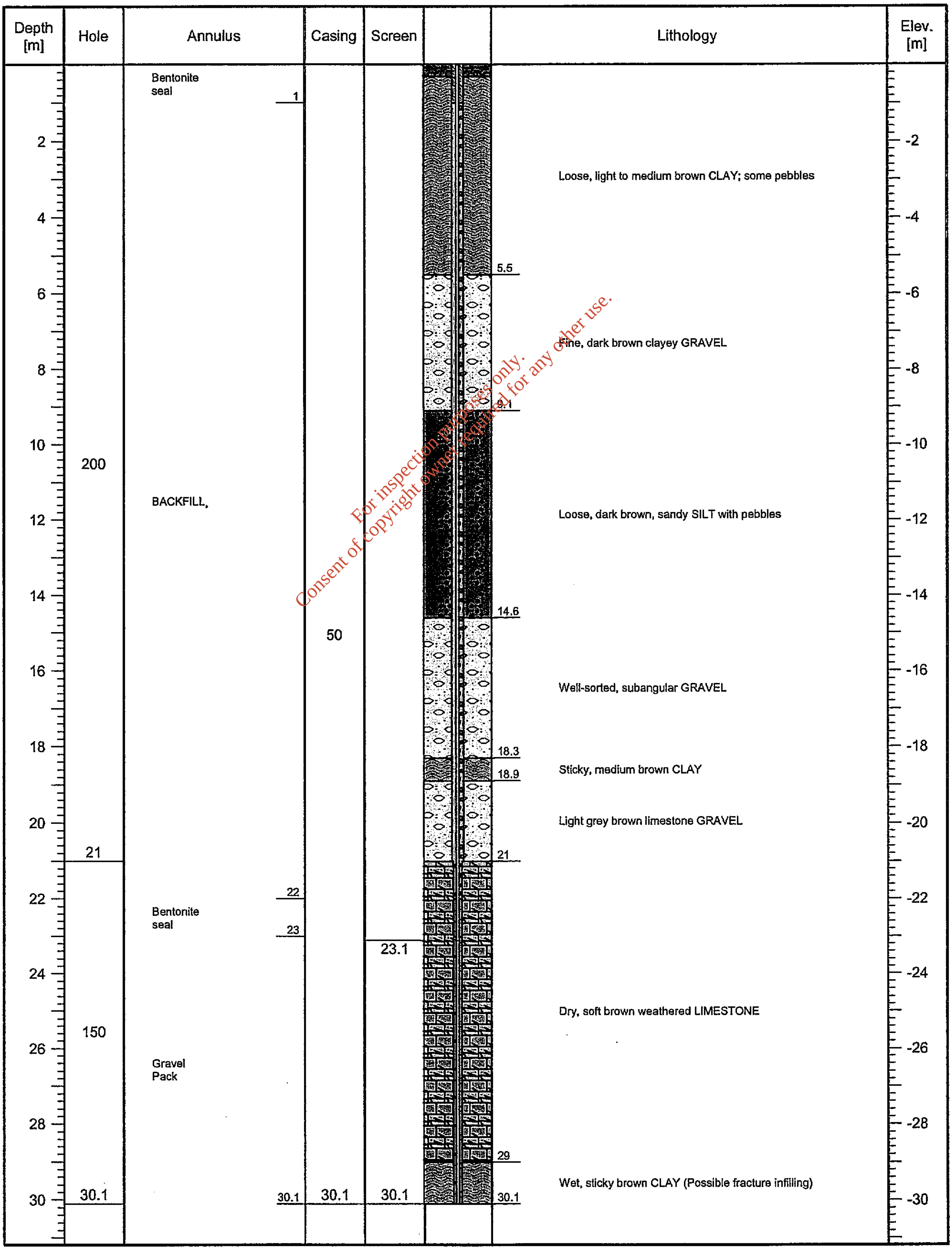
Date Drilled
5/4/00

Scale

Water Level (mbtoc)

All diameters in mm
All depths in metres

Vertical	Horizontal
150.0	100.0



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APPENDIX B

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Elapsed Time (MINS)	WATER LEVEL BELOW G.L. (m.)	DRAWDOWN (METRES)	YIELD (M3/DAY)
		TW 1	
0	20.73	0.00	0.0
0.5	22.65	1.92	504.0
1	22.71	1.98	504.0
1.5	22.82	2.09	504.0
2	22.89	2.16	504.0
2.5	22.94	2.21	504.0
3	22.96	2.23	504.0
3.5	23.04	2.31	504.0
4	23.06	2.33	504.0
4.5	23.08	2.35	504.0
5	23.10	2.37	504.0
6	23.13	2.40	504.0
7	23.15	2.42	474.8
8	23.17	2.44	474.8
9	23.20	2.47	474.8
10	23.21	2.48	474.8
12	23.26	2.53	474.8
14	23.29	2.56	474.8
16	23.29	2.56	474.8
18	23.30	2.57	474.8
20	23.32	2.59	474.8
22	23.33	2.60	481.7
24	23.35	2.62	481.7
26	23.36	2.63	481.7
28	23.37	2.64	481.7
30	23.38	2.65	481.7
35	23.40	2.67	481.7
40	23.41	2.68	481.7
45	23.42	2.69	481.7
50	23.43	2.70	481.7
55	23.44	2.71	481.7
60	23.44	2.71	481.7
75	23.46	2.73	481.7
90	23.44	2.71	470.4
105	23.45	2.72	470.4
120	23.45	2.72	470.4
150	23.46	2.73	470.4
180	23.49	2.76	470.4
210	23.48	2.75	470.4
240	23.49	2.76	468.0
300	23.50	2.77	470.4
360	23.50	2.77	470.4
420	23.51	2.78	470.4
480	23.53	2.80	470.4
540	23.54	2.81	470.4
600	23.54	2.81	468.0
720	23.56	2.83	470.4
840	23.57	2.84	470.4
960	23.59	2.86	471.6
1080	23.61	2.88	472.8
1200	23.65	2.92	470.4
1320	23.63	2.90	470.4
1440	23.65	2.92	470.4
1560	23.66	2.93	470.4
1680	23.64	2.91	474.8
1800	23.67	2.94	465.6
1920	23.70	2.97	469.2
2040	23.71	2.98	469.2
2160	23.71	2.98	474.8
2520	23.70	2.97	474.8
2880	23.72	2.99	470.4
3240	23.69	2.96	467.2
3600	23.69	2.96	467.2
3960	23.72	2.99	467.2
4230	23.72	2.99	468.3

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Time Drawdown Data from 70.5 hour Pumping Test on TW 1
at Carranstown, Co. Meath, May 2000

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Elapsed Time (Mins)	Drawdown (Meters)		
	IC	MW4	MW2
0	0.00	0.00	0.00
0.5	0.00	0.00	0.00
1	0.00	0.00	0.00
1.5	0.00	0.00	0.00
2	0.00	0.00	0.00
2.5	0.00	0.00	0.00
3	0.00	0.00	0.00
3.5	0.00	0.00	0.00
4	0.00	0.00	0.00
4.5	0.00	0.00	0.00
5	0.00	0.00	0.00
6	0.00	0.00	0.00
7	0.00	0.00	0.00
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
12	0.00	0.00	0.00
14	0.00	0.00	0.00
16	0.00	0.00	0.00
18	0.00	0.00	0.00
20	0.00	0.00	0.00
22	0.07	0.03	0.00
24	0.07	0.03	0.00
26	0.07	0.03	0.00
28	0.07	0.03	0.00
30	0.07	0.03	0.05
35	0.07	0.03	0.05
40	0.07	0.03	0.05
45	0.07	0.03	0.05
50	0.07	0.03	0.05
55	0.07	0.03	0.05
60	0.07	0.03	0.05
75	-0.03	0.01	0.04
90	-0.03	0.01	0.04
105	-0.03	0.01	0.04
120	-0.03	0.01	0.04
150	-0.03	0.01	0.04
180	-0.03	0.04	0.04
210	-0.03	0.04	0.04
240	-0.03	0.04	0.04
300	-0.03	0.04	0.04
360	-0.05	0.09	0.04
420	-0.05	0.09	0.04
480	-0.05	0.09	0.04
540	-0.05	0.09	0.04
600	-0.06	0.17	0.04
720	-0.06	0.17	0.04
840	-0.06	0.17	0.04
960	-0.07	0.22	0.05
1080	-0.07	0.22	0.05
1200	-0.07	0.22	0.05
1320	-0.08	0.26	0.06
1440	-0.08	0.26	0.06
1560	-0.08	0.30	0.06
1680	-0.08	0.30	0.06
1800	-0.09	0.32	0.06
1920	-0.09	0.32	0.06
2040	-0.09	0.32	0.06
2160	-0.09	0.36	0.06
2520	-0.89	0.40	-0.04
2880	-0.84	0.40	-0.04
3240	-0.74	0.42	-0.04
3600	-0.68	0.43	-0.03
3960	-0.61	0.45	-0.01
4230	-0.57	0.48	0.00

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Time drawdown data for Monitoring Wells MW2, MW4 and IC, Carranstown, Co Meath, May 2000

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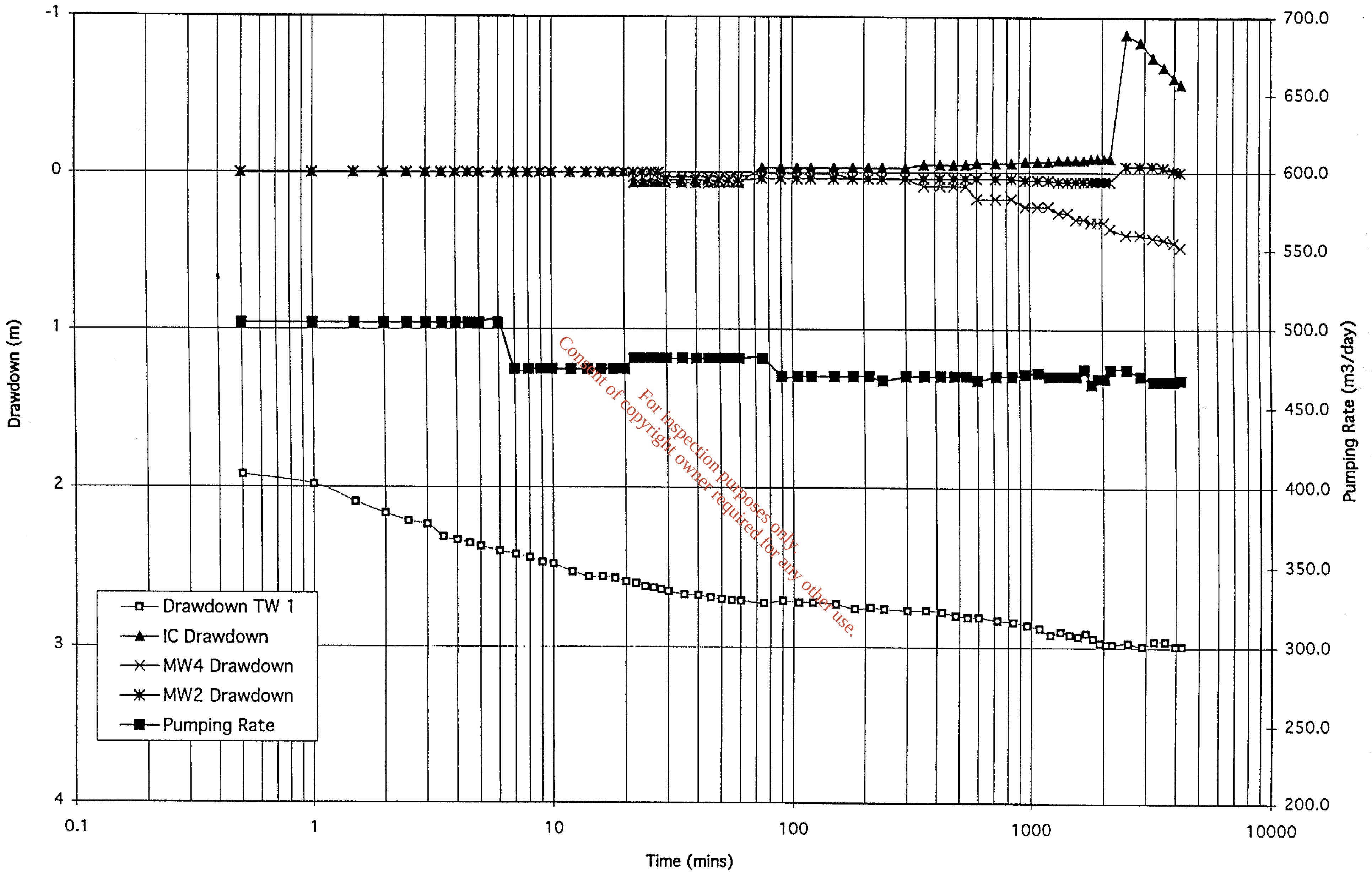

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Pumping Rate and Drawdown versus Time for TW 1 and Monitoring Wells 70hr Pumping Test,
at Carranstown, Co. Meath, May 2000

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TIME (MINS)	WATER LEVEL BELOW G.L. (m.)				RECOVERY (METRES)			
	TW1	IC	MW4	MW2	TW1	IC	MW4	MW2
0	23.72	18.84	21.69	1.87	2.99	-0.57	0.48	0.00
0.5	21.87	18.84	21.69	1.87	1.14	-0.57	0.48	0.00
1	21.77				1.04			
1.5	21.68				0.95			
2	21.61				0.88			
2.5	21.56				0.83			
3	21.53				0.80			
3.5	21.51				0.78			
4	21.47				0.74			
4.5	21.44				0.71			
5	21.42				0.69			
6	21.39				0.66			
7	21.36				0.63			
8	21.34				0.61			
9	21.32				0.59			
10	21.31				0.58			
12	21.27				0.54			
14	21.24				0.51			
16	21.22				0.49			
18	21.20				0.47			
20	21.18				0.45			
22	21.17				0.44			
24	21.16				0.43			
26	21.15				0.42			
28	21.14				0.41			
30	21.13				0.40			
35	21.11				0.38			
40	21.10				0.37			
45	21.09				0.36			
50	21.08				0.35			
55	21.07				0.34			
60	21.05	18.86	21.63	1.87	0.32	-0.55	0.42	0.00
420	-	18.89	21.54	1.87	-	-0.52	0.33	0.00

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Time Drawdown Recovery Data from TW 1 and monitoring wells at Carranstown, Co. Meath, May 2000

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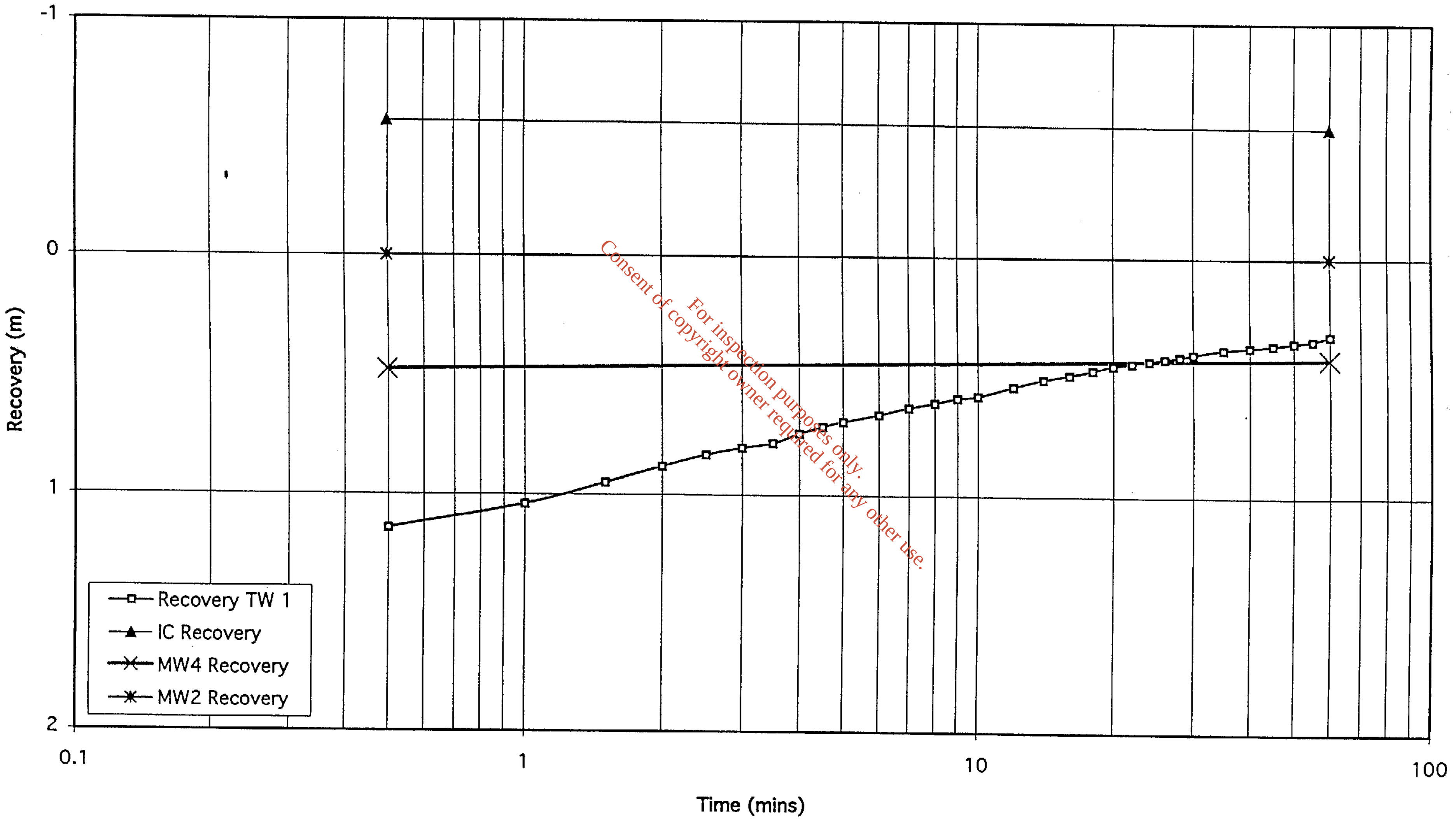

Time Recovery Graph from TW 1
at Carranstown, Co. Meath, May 2000

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APPENDIX C

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Trial Pit Records

Project No. : 2175 **Location :** Duleek, Co. Meath **Date :** 28/4/00

Drilling Method : JCB **Supervisor :** Amy Brennan

TRIAL PIT NO.1

Geology :

0 - 0.25	Dark brown organic-rich TOPSOIL
0.25 - 0.9	Medium brown silty CLAY with occasional subrounded pebbles.
0.9 - 3.0	Fine grained, homogeneous, brown SAND.
3.0 - 3.2	Brown BOULDER CLAY with occasional large limestone boulders
3.2 - 3.3	Stiff, black BOULDER CLAY

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Depth to Rock : >3.3m

Rock Type :

Water Entry : None

Static Water :

Total Depth : 3.3m

Comments : Composite soil samples taken; Dry deposits. No unusual colours o odours noted.

-

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Trial Pit Records

Project No. : 2175 **Location :** Duleek, Co. Meath **Date :** 28/4/00

Drilling Method : JCB **Supervisor :** Amy Brennan

TRIAL PIT NO.2

Geology :

0 - 0.2	Brown organic-rich TOPSOIL
0.2 - 1.1	Medium brown silty CLAY with occasional subangular pebbles.
1.1 - 1.6	Medium brown, silty BOULDER CLAY with large limestone boulders
1.6 - 3.4	Extremely coarse, clayey GRAVEL deposits (boulders up to 40 - 45cm), with water.

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Depth to Rock : >3.4m

Rock Type :

Water Entry : 3.2m

Static Water : 3.2

Total Depth : 3.4m

Comments : Water seen to be flowing in through the gravels. Composite soil sample taken. No unusual colours or odours noted.

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Trial Pit Records

Project No. : 2175 **Location :** Duleek, Co. Meath **Date :** 28/4/00

Drilling Method : JCB **Supervisor :** Amy Brennan

TRIAL PIT NO.3

Geology :

0 - 0.15	Dark brown organic-rich TOPSOIL
0.15 - 1.9	Dark brown, moderately well-sorted , dry, clayey, sandy GRAVEL.
1.9 - 3.4	Lighter brown, clayey SAND with occasional pebbles up to 3-4cm in size.

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Depth to Rock : >3.4m

Rock Type :

Water Entry : Seepage into the excavation from approx. 1.9m

Static Water :

Total Depth : 3.4m

Comments : Water was seen to be seeping in through the clayey SAND layer. Composite soil sample was taken. No unusual colours or odours.

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Trial Pit Records

Project No. : 2175 **Location :** Duleek, Co. Meath **Date :** 28/4/00

Drilling Method : JCB **Supervisor :** Amy Brennan

TRIAL PIT NO.4

Geology :

0 - 0.15	Brown organic-rich TOPSOIL
0.15 - 0.4	Medium brown subsoil.
0.4 - 1.25	Loose, light brown, silty, sandy, CLAY with occasional rounded pebbles.
1.25 - 3.45	Poorly sorted, subrounded, brown, clayey, sandy, GRAVEL with some black colouration due to presence od shaley fragments.

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Depth to Rock : >3.45m

Rock Type :

Water Entry : Gravels moist- Very small amount of seepage.

Static Water :

Total Depth : 3.45m

Comments : Gravel layer collapsing into the hole. No unusual colours or odours noted. Composite soil samples taken.

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Trial Pit Records

Project No. : 2175 **Location :** Duleek, Co. Meath **Date :** 28/4/00

Drilling Method : JCB **Supervisor :** Amy Brennan

TRIAL PIT NO.5

Geology :

0 - 0..12	Medium brown organic-rich TOPSOIL
0.12 - 1.3	Loose, light brown, sandy CLAY.
1.3 - 2.7	Loose, fine grained, homogeneous brown SAND.
2.7 - 3.4	Quite stiff, light brown BOULDER CLAY

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Depth to Rock : >3.4m

Rock Type :

Water Entry : Water seeping into the hole at approx 2.7m through the bottom of the sands.

Static Water : Not available. Hole filled up with sand.

Total Depth : 3.4m

Comments : Walls of the excavation very unstable and sand collapsing into the hole. No unusual colours or odours noted. Composite soil samples taken.

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Trial Pit Records

Project No. : 2175 **Location :** Duleek, Co. Meath **Date :** 28/4/00

Drilling Method : JCB **Supervisor :** Amy Brennan

TRIAL PIT NO.6

Geology :

0 - 0.15	Dark brown organic-rich TOPSOIL
0.15 - 0.6	Medium brown silty CLAY with only occasional subrounded pebbles.
0.6 - 1.85	Grey brown, loose, silty CLAY with boulders up to 25cm in size.
1.85 - 3.15	Moderately well sorted, clayey GRAVEL, with occasional large boulders (up to 30cm).

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Depth to Rock : >3.15m

Rock Type :

Water Entry : Spring seen to be flowing into the excavation at approx 1.85m

Static Water : 3.0m and rising

Total Depth : 3.15m

Comments : Spring flowing in from the northern side of the excavation, quite quickly. No unusual colours or odours. Composite soil sample taken.

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Trial Pit Records

Project No. : 2175 **Location :** Duleek, Co. Meath **Date :** 28/4/00

Drilling Method : JCB **Supervisor :** Amy Brennan

TRIAL PIT NO.7

Geology :

0 - 0.3	Dark brown organic-rich TOPSOIL & subsoil
0.3 - 0.95	Dark brown, clayey, sandy, SILT with occasional pebbles
0.95 - 3.1	Moderatley well-sorted, dark brown, sandy, clayey, GRAVEL
3.1 - 3.3	Tight, dark brown BOULDER CLAY .

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Depth to Rock : >3.3m

Rock Type :

Water Entry : None

Static Water :

Total Depth : 3.3m

Comments : Composite soil samples taken; Dry deposits. No unusual colours or odours noted.

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APPENDIX D

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Monitoring Well Sampling Log

Site Location : Carranstown, Duleek

Project No. : 2175

Well No. : MW-2

Date : 16/5/00

Sampler : Amy Brennan

TOC Elevation (msl) :

Stickup :

Water Level (BTOC) :

Well Depth : 12.4m

Head :

Well ID : 10cm

Volume in Well :

Volume Purged :

Rope Type :

Bailer Type : Teflon

Decon. Procedure : Triple rinse with de-ionised water and Decon 90

FIELD PARAMETERS

Colour : Slight brown tint

Odour : None

Temperature : 21.5°C

Conductivity : 550µs/cm

pH : 7.25

ANALYSIS REQUESTED	CONTAINER TYPE/VOL.	PRESERVED
Full baseline parameters		

Comments :

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T.Cullen & Co. Ltd.
Hydrogeological & Environmental Consultants

NOTE : 5cm ID = 1.962 litres/m

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Monitoring Well Sampling Log

Site Location : Carranstown, Duleek

Project No. : 2175

Well No. : MW-4

Date : 16/5/00

Sampler : Amy Brennan

TOC Elevation (msl) :

Stickup :

Water Level (BTOC) :

Well Depth : 30.0m

Head :

Well ID : 10cm

Volume in Well :

Volume Purged :

Rope Type :

Bailer Type : Teflon

Decon. Procedure : Triple rinse with de-ionised water and Decon 90

FIELD PARAMETERS

Colour : Clear

Odour : None

Temperature : 16.1°C

Conductivity : 624µs/cm

pH : 7.0

ANALYSIS REQUESTED	CONTAINER TYPE/VOL.	PRESERVED
Full baseline parameters		

Comments :

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K.T.Cullen & Co. Ltd.
Hydrogeological & Environmental Consultants

NOTE : 5cm ID = 1.962 litres/m

APPENDIX E

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3. Land Surface Zoning for Groundwater Protection

3.1 Information and Mapping Requirements for Land Surface Zoning

The **groundwater resources protection zone map** is a land-use planning map, and therefore is the most useful map for the decision-making process. It is the ultimate or final map as it is obtained by combining the **aquifer** and **vulnerability maps.** The **aquifer map** boundaries, in turn, are based on the **bedrock map** boundaries and the **aquifer categories** are obtained from an assessment of the available **hydrogeological data**. The **vulnerability map** is based on the **subsoils map**, together with an assessment of relevant **hydrogeological data**, in particular indications of permeability and karstification. This is illustrated in Figure 3.

Similarly, the **source protection zone maps** result from combining **vulnerability** and **source protection area maps**. The **source protection areas** are based largely on assessments of **hydrogeological data**. This is illustrated in Figure 4.

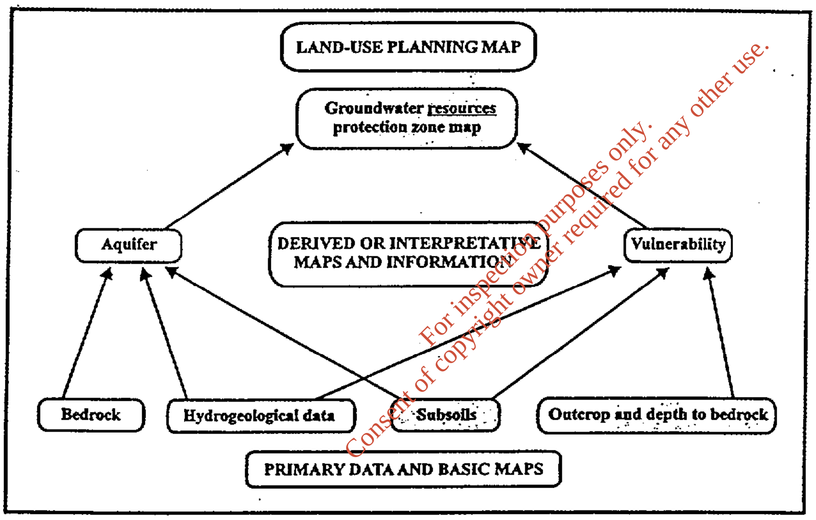

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Figure 3. Conceptual framework for production of groundwater <u>resource</u> protection zones, indicating information needs and links

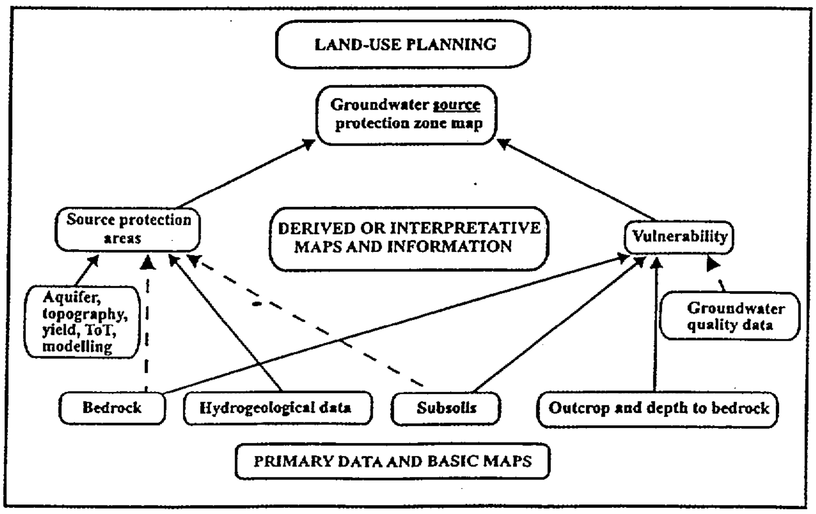

Figure 4. Conceptual framework for production of groundwater <u>source</u> protection zones, indicating information needs and links

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3.2 Vulnerability Categories

Vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities.

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. As all groundwater is hydrologically connected to the land surface, it is the effectiveness of this connection that determines the relative vulnerability to contamination. 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 subsoils 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.

In general, little attenuation of contaminants occurs in the bedrock in Ireland because flow is almost wholly via fissures. Consequently, the subsoils (sands, gravels, glacial tills (or boulder clays), peat, lake and alluvial silts and clays), are the single most important natural feature influencing groundwater vulnerability and groundwater contamination prevention. Groundwater is most at risk where the subsoils are absent or thin and, in areas of karstic limestone, where surface streams sink underground at swallow holes.

The geological and hydrogeological characteristics can be examined and mapped, thereby providing a groundwater vulnerability assessment for any area or site. Four groundwater vulnerability categories are used in the scheme - **extreme (E)**, **high (H)**, **moderate (M)** and **low (L)**. The hydrogeological basis for these categories is summarised in Table 1 and further details can be obtained from the GSI. The ratings are based on pragmatic judgements, experience and available technical and scientific information. However, provided the limitations are appreciated, vulnerability assessments are essential when considering the location of potentially polluting activities. As groundwater is considered to be present everywhere in Ireland, the vulnerability concept is applied to the entire land surface. The ranking of vulnerability does not take into consideration the biologically-active soil zone, as contaminants from point sources are usually discharged below this zone, often at depths of at least 1m. However, the groundwater protection responses take account of the point of discharge for each activity.

Vulnerability maps are an important part of groundwater protection schemes and are an essential element in the decision-making on the location of potentially polluting activities. Firstly, the vulnerability rating for an area indicates, and is a measure of, the likelihood of contamination. Secondly, the vulnerability map helps to ensure that a groundwater protection scheme is not unnecessarily restrictive on human economic activity. Thirdly, the vulnerability map helps in the choice of preventative measures and enables developments, which have a significant potential to contaminate, to be located in areas of lower vulnerability.

In summary, the entire land surface is divided into four vulnerability categories - extreme (E), high (H), moderate (M) and low (L) - based on the geological and hydrogeological factors described above. This subdivision is shown on a groundwater vulnerability map. The map shows the vulnerability of the first groundwater encountered (in either sand/gravel aquifers or in bedrock) to contaminants released at depths of 1-2 m below the ground surface. Where contaminants are released at significantly different depths, there will be a need to determine groundwater vulnerability using site-specific data. The characteristics of individual contaminants are not taken into account.

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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.

Table 1. Vulnerability Mapping Guidelines

3.3 Source Protection Zones

Groundwater sources, particularly public, group scheme and industrial supplies, are of critical importance in many regions. Consequently, the objective of source protection zones is to provide protection by placing tighter controls on activities within all or part of the zone of contribution (ZOC) of the source.

There are two main elements to source protection land surface zoning:

- Areas surrounding individual groundwater sources; these are termed source protection areas (SPAs)
- Division of the SPAs on the basis of the vulnerability of the underlying groundwater to contamination.

These elements are integrated to give the source protection zones.

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3.3.1 Delineation of Source Protection Areas

Two source protection areas are recommended for delineation:

- Inner Protection Area (**SI**);
- Outer Protection Area (**SO**), encompassing the remainder of the source catchment area or ZOC.

In delineating the inner (SI) and outer (SO) protection areas, there are two broad approaches: first, using arbitrary fixed radii, which do not incorporate hydrogeological considerations; and secondly, a scientific approach using hydrogeological information and analysis, in particular the hydrogeological characteristics of the aquifer, the direction of groundwater flow, the pumping rate and the recharge.

Where the hydrogeological information is poor and/or where time and resources are limited, the simple zonation approach using the arbitrary fixed radius method is a good first step that requires little technical expertise. However, it can both over- and under-protect. It usually over-protects on the downgradient side of the source and may under-protect on the upgradient side, particularly in karst areas. It is particularly inappropriate in the case of springs where there is no part of the downgradient side in the ZOC. Also, the lack of a scientific basis reduces its defensibility as a method.

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There are several hydrogeological methods for delineating SPAs. They vary in complexity, cost and the level of data and hydrogeological analysis required. Four methods, in order of increasing technical sophistication, are used by the GSI:

(i) calculated fixed radius;

(ii) analytical methods;

(iii) hydrogeological mapping; and

(iv) numerical modelling.

Each method has limitations. Even with relatively good hydrogeological data, the heterogeneity of Irish aquifers will generally prevent the delineation of definitive SPA boundaries. Consequently, the boundaries must be seen as a guide for decision-making, which can be reappraised in the light of new knowledge or changed circumstances.

3.3.1.1 Inner Protection Area (SI)

This area is designed to protect against the effects of human activities that might have an immediate effect on the source and, in particular, against microbial pollution. The area is defined by a 100-day time of travel (TOT) from any point below the water table to the source. (The TOT varies significantly between regulatory agencies in different countries. The 100-day limit is chosen for Ireland as a relatively conservative limit to allow for the heterogeneous nature of Irish aquifers and to reduce the risk of pollution from bacteria and viruses, which in some circumstances can live longer than 50 days in groundwater.) In karst areas, it will not usually be feasible to delineate 100-day TOT boundaries, as there are large variations in permeability, high flow velocities and a low level of predictability. In these areas, the total catchment area of the source will frequently be classed as SI.

If it is necessary to use the arbitrary fixed radius method, a distance of 300m is normally used. A semi-circular area is used for springs. The distance may be increased for sources in karst aquifers and reduced in granular aquifers and around low yielding sources.

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3.3.1.2 Outer Protection Area (SO)

This area covers the remainder of the ZOC (or complete catchment area) of the groundwater source. It is defined as the area needed to support an abstraction from long-term groundwater recharge i.e. the proportion of effective rainfall that infiltrates to the water table. The abstraction rate used in delineating the zone will depend on the views and recommendations of the source owner. A factor of safety can be taken into account whereby the maximum daily abstraction rate is increased (typically by 50%) to allow for possible future increases in abstraction and for expansion of the ZOC in dry periods. In order to take account of the heterogeneity of many Irish aquifers and possible errors in estimating the groundwater flow direction, a variation in the flow direction (typically ±10-20°) is frequently included as a safety margin in delineating the ZOC.

A conceptual model of the ZOC and the 100-day TOT boundary is given in Figure 5.

If the arbitrary fixed radius method is used, a distance of 1000m is recommended with, in some instances, variations in karst aquifers and around springs and low-yielding wells.

The boundaries of the SPAs are based on the horizontal flow of water to the source and, in the case particularly of the Inner Protection Area, on the time of travel in the aquifer. Consequently, the vertical movement of a water particle or contaminant from the land surface to the water table is not taken into account. This vertical movement is a critical factor in contaminant attenuation, contaminant flow velocities and in dictating the likelihood of contamination. It can be taken into account by mapping the groundwater vulnerability to contamination.

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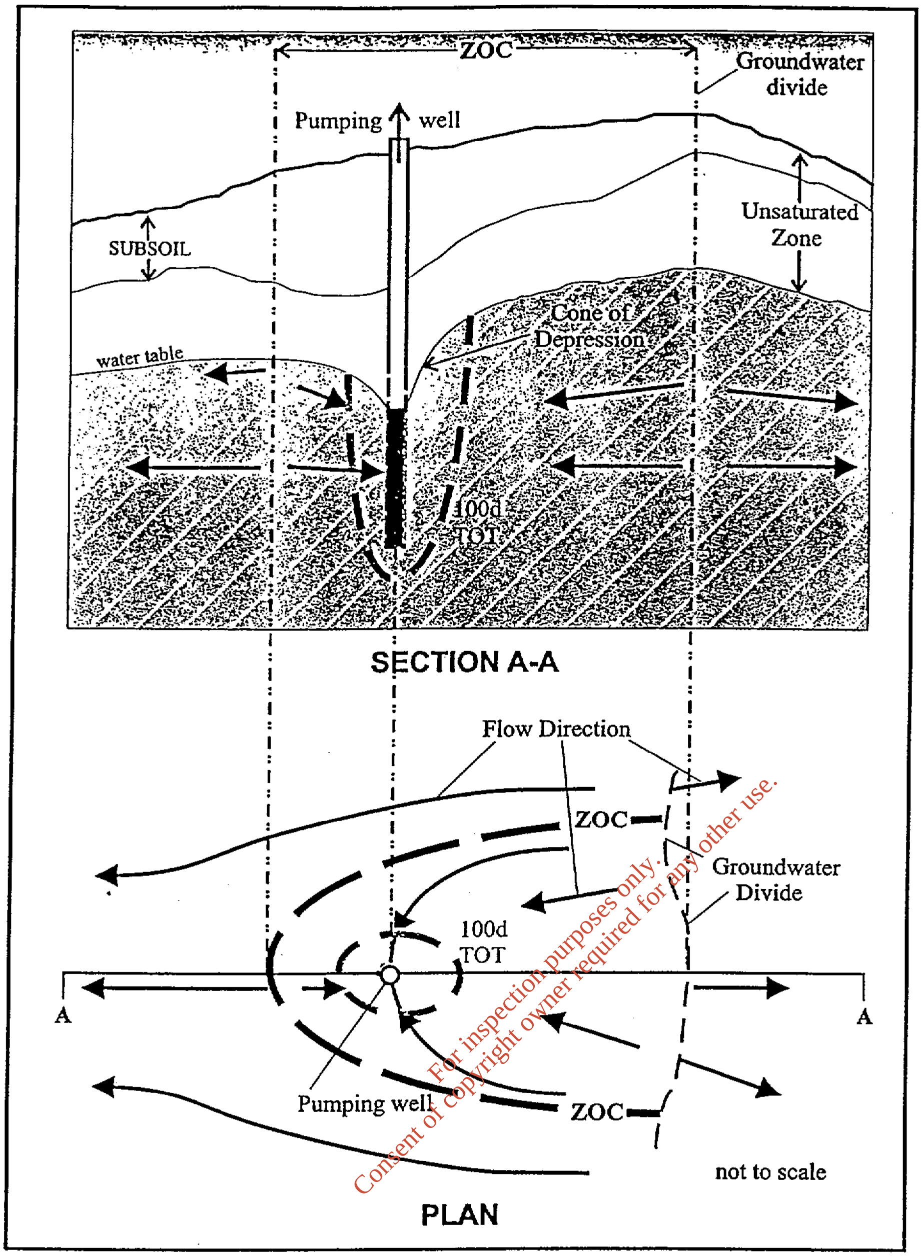

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Figure 5. Conceptual Model of the Zone of Contribution (ZOC) at a Pumping Well (adapted from US EPA, 1987)

3.3.2 Delineation of Source Protection Zones

The matrix in Table 2 below gives the result of integrating the two elements of land surface zoning (SPAs and vulnerability categories) – a possible total of eight source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SO/H**, which represents an <u>Outer Source Protection area</u> where the groundwater is <u>highly</u> vulnerable to contamination. The recommended map scale is 1:10,560 (or 1:10,000 if available), though a smaller scale may be appropriate for large springs.

VULNERABILITY RATING	SOURCE PROTECTION ZONE	
	Inner (SI)	**Outer (SO)**
Extreme (E)	SI/E	SO/E
High (H)	SI/H	SO/H
Moderate (M)	SI/M	SO/M
Low (L)	SI/L	SO/L

Table 2. Matrix of Source Protection Zones

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All of the hydrogeological settings represented by the zones may not be present around each groundwater source. The integration of the SPAs and the vulnerability ratings is illustrated in Figure 6.

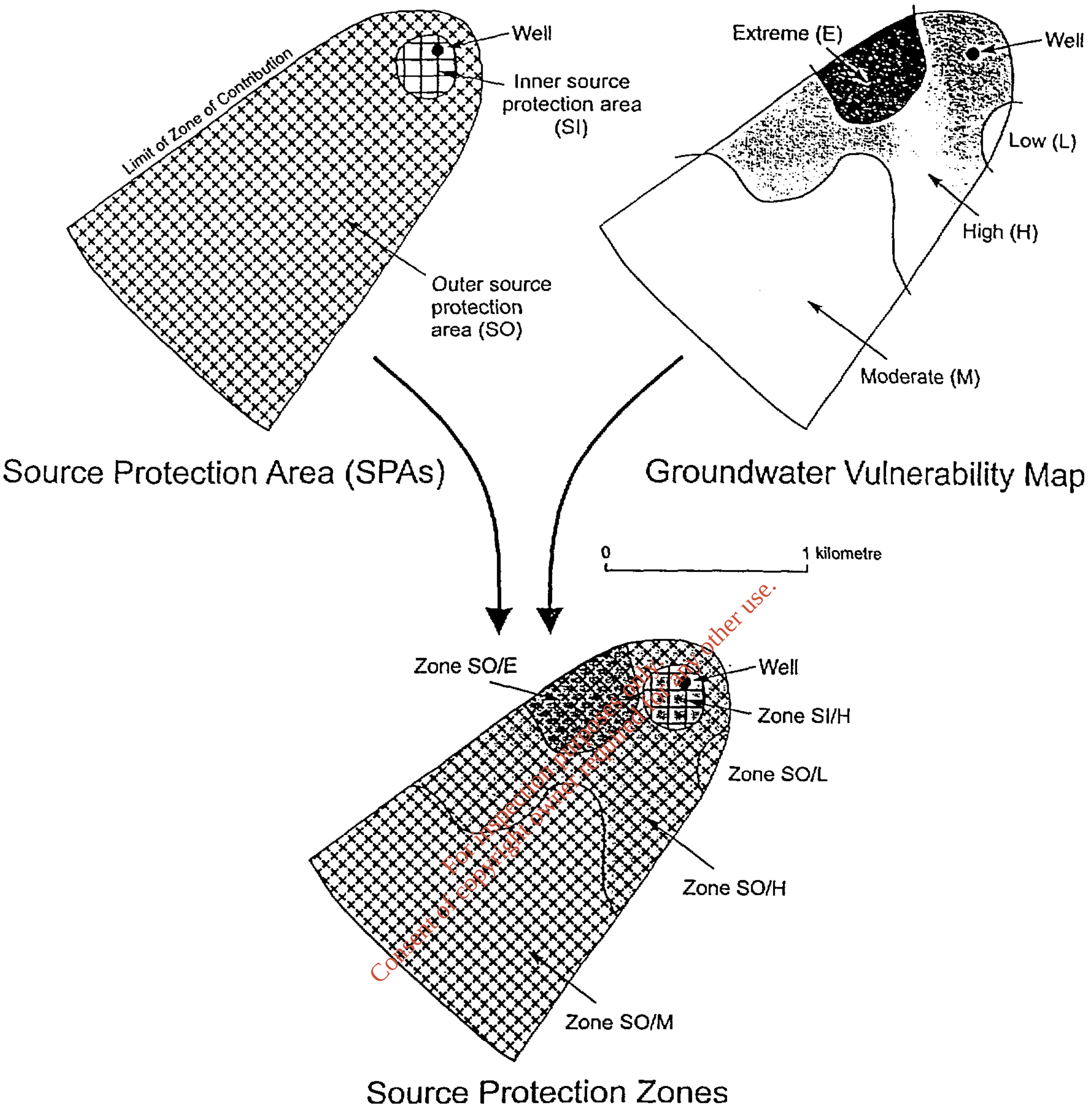

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Figure 6. Delineation of source protection zones around a public supply well from the integration of the source protection area map and the vulnerability map.

3.4 Resource Protection Zones

For any region, the area outside the SPAs can be subdivided, based on the value of the resource and the hydrogeological characteristics, into eight aquifer categories:

Regionally Important (R) Aquifers

(i) Karstified aquifers (Rk)

(ii) Fissured bedrock aquifers (Rf)

(iii) Extensive sand/gravel aquifers (Rg)

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Locally Important (L) Aquifers

(i) Sand/gravel (**Lg**)

(ii) Bedrock which is Generally Moderately Productive (**Lm**)

(iii) Bedrock which is Moderately Productive only in Local Zones (**Ll**)

Poor (P) Aquifers

(i) Bedrock which is Generally Unproductive except for Local Zones (**Pl**)

(ii) Bedrock which is Generally Unproductive (**Pu**)

These aquifer categories are shown on an aquifer map, which can be used not only as an element of a groundwater protection scheme but also for groundwater development purposes.

The matrix in Table 3 below gives the result of integrating the two regional elements of land surface zoning (vulnerability categories and resource protection areas) – a possible total of 24 resource protection zones. In practice this is achieved by superimposing the vulnerability map on the aquifer map. Each zone is represented by a code e.g. **Rf/M**, which represents areas of regionally important fissured aquifers where the groundwater is moderately vulnerable to contamination. In land surface zoning for groundwater protection purposes, regionally important sand/gravel (**Rg**) and fissured aquifers (**Rf**) are zoned together, as are locally important sand/gravel (**Lg**) and bedrock which is moderately productive (**Lm**). All of the hydrogeological settings represented by the zones may not be present in each local authority area.

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VULNERABILITY RATING	RESOURCE PROTECTION ZONES					
	Regionally Important Aquifers (R)		Locally Important Aquifers (L)		Poor Aquifers (P)	
	Rk	Rf/Rg	Lm/Lg	L1	P1	Pu
Extreme (E)	Rk/E	Rf/E	Lm/E	L1/E	P1/E	Pu/E
High (H)	Rk/H	Rf/H	Lm/H	L1/H	P1/H	Pu/H
Moderate (M)	Rk/M	Rf/M	Lm/M	L1/M	P1/M	Pu/M
Low (L)	Rk/L	Rf/L	Lm/L	L1/L	P1/L	Pu/L

Table 3. Matrix of Resource Protection Zones

3.5 Flexibility, Limitations and Uncertainty

The land surface zoning is only as good as the information which is used in its compilation (geological mapping, hydrogeological assessment, etc.) and these are subject to revision as new information is produced. Therefore a scheme must be flexible and allow for regular revision.

Uncertainty is an inherent element in drawing geological boundaries and there is a degree of generalisation because of the map scales used. Therefore the scheme is not intended to give sufficient information for site-specific decisions. Also, where site specific data received by a regulatory body in the future are at variance with the maps, this does not undermine a scheme, but rather provides an opportunity to improve it.

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