INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS

Irish Group

Proceedings of the 29th Annual Groundwater Conference

Tullamore, 21st & 22nd April 2009

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS
(IRISH GROUP)

PRESENTS

GROUNDWATER: A NEW FRAMEWORK

Proceedings of the 29th Annual Groundwater Conference

Tullamore Court Hotel
Tullamore
County Offaly

21st & 22nd April 2009

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“Groundwater – A New Framework”

29th Annual Groundwater Conference

International Association of Hydrogeologists
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Programme Day 1

Day 1 Session 1: New Regulation & Water Framework Directive 1

8.15 am	Conference Registration
9.30 am	Welcome: Paul Johnston, Trinity College Dublin & President IAH Irish Group.
9.35 am	Conference Opening: John Chilton, Executive Manager, IAH Secretariat, IAH International.
9.50 am	The New Groundwater Regulations 2009 Dr. Colin Byrne, Water Inspectorate, Department of Environment, Heritage and Local Government.
10.20 am	Chemical and Quantitative Status of Groundwater Bodies: A measure of the present; a signpost to the future Donal Daly & Matthew Craig, Hydrometric & Groundwater Section, EPA.
11.10 am	Coffee & Tea: Visit Exhibitor Stands
11.40 am	Practical implementation by Local Authorities of the WFD with respect to Groundwater Ray Spain (SERBD, Carlow County Council), Grace Glasgow & Kieran Fay (RPS Consulting Engineers).
12.00	The Water Framework Directive and the Groundwater Information Renaissance Natalya Hunter Williams (GSI), Donal Daly (EPA), Matthew Craig (EPA), Monica Lee (GSI).
12.20	Discussion, Questions & Answers
12.45	Lunch

Day 1 Session 2: Water Framework Directive 2: Outputs

2.00 pm	Technical Guidance Towards Groundwater Abstraction Licensing in Ireland Henning Moe (CDM)
2.20 pm	Status Classification of Groundwater Bodies Containing Closed Mine Sites for the Water Framework Directive Eibhlín Doyle & Gerry Stanley (GSI)
2.40 pm	Spring into Action - Spring and Streamflow Monitoring to Meet Water Framework Directive and Related Hydrometric Requirements. Stewart Child, Hydro-Logic
3.00 pm	Groundwater Classification – How Does It Influence Regulation at a Site Scale? Vincent Fitzsimons & Malcolm Roberts (SEPA)
3.20 pm	Discussion, Questions & Answers
3.40 pm	Coffee & Tea: Visit Exhibitor Stands

Day 1 Session 3: On Site Wastewater Treatment & Discharge to Groundwater

4.15 pm	Large Scale Discharges to Groundwater: Risk Mapping & Framework for Site Assessments. Paddy Kavanagh, Tommy Bree & Rose Walsh (ESBI & WRBD)
4.40 pm	The new “Code of Practice Wastewater Treatment & Disposal Systems Serving Single Houses”. Margaret Keegan, EPA.
5.05 pm	Discussion, Questions & Answers. Close day 1.
7.30 pm	IAH sponsored Meal & Traditional Music Session at Wolftrap Bar & Restaurant, William St., Tullamore.

"Groundwater – A New Framework"

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Programme Day 2

Day 2 Session 4: Karst Hydrogeology

9.30 am	Some Aspects of the Hydrogeology of the Carboniferous Limestone in Ireland Dr. David Drew, Trinity College Dublin
9.55 am	Origin, transport & monitoring of particles and microbial contaminants in karst aquifer systems Dr. Nico Goldscheider, University of Neuchâtel, Switzerland
10.15 am	Groundwater Dependent Terrestrial Ecosystems 1: Hydrology & Hydrogeology of Turloughs: How Turloughs Fill & Drain Presented by Paul Johnston, Trinity College Dublin Authors: Naughton, O., Gill, L. & Johnston, P., (Trinity College Dublin) 2: Turlough Water Quality and Implications for Groundwater Management Presented by Dr. Catherine Coxon, Trinity College Dublin Authors: Pereira, H., Coxon, C. & Allott, N. (Trinity College Dublin)
10.45 am	Discussion, Questions & Answers
11.00 am	Coffee & Tea: Visit Exhibitor Stands

Day 2 Session 5: Groundwater as a Source of Water Supply

11.30 am	Protecting the Source: Challenges for Communities in Groundwater Zones Brian MacDonald, National Federation of Groundwater Schemes
11.50 am	Determining the Sustainable Yield of Groundwater Supplies Gerry Baker, WYG Ireland
12.10	Has Groundwater a Role In Supplying Dublin's Water Needs? Kevin T. Cullen, Consultant
12.30	Discussion, Questions & Answers
12.45	Conference Closing Address
13.00	Lunch

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Session I

THE PROPOSED GROUNDWATER ENVIRONMENTAL OBJECTIVES REGULATIONS

Dr. Colin Byrne.
Water Inspectorate. Department of Environment, Heritage and Local Government, Custom House, Dublin 1.

ABSTRACT

The first Groundwater Directive (80/68/EEC) on the protection of groundwater against pollution caused by certain dangerous substances will be repealed by 2013 under the Water Framework Directive (2000/60/EC). However, it will remain as a legal instrument for preventing or limiting pollution until this date, and will then be replaced by the new Groundwater Directive (2006/118/EC). The new Groundwater Directive is in the process of being transposed into National legislation.

The original Groundwater Directive (80/68/EEC) requires the prevention of direct or indirect inputs of high priority pollutants into groundwater and the limiting of inputs of other pollutants into groundwater so as to avoid pollution of groundwater by such substances. However, the directive was limited in scope, focussing on the control of emissions of substances from industrial and urban sources.

During the 1990's the European Parliament and the Council recognised the need for further action to avoid long-term deterioration of quality and quantity of all freshwater resource in Europe, including groundwater, and subsequently requested the Commission to establish a framework for a European water policy. This request led to the adoption of the Water Framework Directive (WFD) in October 2000.

For the first time, under the WFD groundwater is treated in an integrated manner with surface water systems such as rivers, lakes and wetlands. Also, for the first time, the WFD requires groundwater to be protected for its environmental value in addition to its protection as a valuable resource with multiple uses.

The WFD includes groundwater in the river basin management planning process, and sets clear milestones for groundwater bodies in terms of delineation, economic analysis, characterisation (analysis of pressures and impacts), monitoring, and the design of programmes of measures. The WFD requires the establishment of environmental objectives for all waters – surface, coastal, transitional, and ground waters – to be achieved by the end of 2015. For groundwater this essentially means that, by the end of 2015, each groundwater body should have a sufficient quantity of groundwater of good chemical status.

The quantitative status objectives for groundwater are clear in the WFD. The aim is to ensure a balance between abstraction and recharge of groundwater. However, the chemical status criteria are more complex and were not fully resolved at the time the WFD was adopted. The European Parliament and the Council, therefore, requested that the Commission develop a proposal for a "daughter" directive clarifying the criteria for good chemical status, as well as, criteria and specifications related to the identification and reversal of pollution trends. This new Groundwater Directive (2006/118/EC) was adopted in December 2006.

The new Groundwater Directive establishes a regime, which sets underground water quality standards and introduces measures to prevent or limit inputs of pollutants into groundwater. The directive establishes quality criteria that take into account local characteristics and allows for further improvements to be made based on monitoring data and new scientific knowledge. It requires the

assessment of chemical status of groundwater and the identification and reversal of significant and sustained upward trends in pollutant concentrations. Each Member State must establish quality standards (threshold values) at the most appropriate level and take into account local or regional conditions.

NOTES

CHEMICAL AND QUANTITATIVE STATUS OF GROUNDWATER BODIES: A MEASURE OF THE PRESENT, A SIGNPOST TO THE FUTURE

Donal Daly & Matthew Craig
Hydrometric & Groundwater Section
Environmental Protection Agency

ABSTRACT

Implementation of the Water Framework Directive (WFD) is challenging; it is a complex Directive, with interconnected concepts and articles, many of which need careful interpretation. However, it is also a visionary Directive, requiring an integrated, holistic approach to catchment management, with groundwater as a core component and with its own (Daughter) Groundwater Directive (GWD). In implementing both Directives, the national geosciences datasets and maps have greatly improved, as has our understanding of groundwater in Ireland. Considerable investment of time and resources has enabled the national groundwater quality and level networks to be upgraded. The interim status of the groundwater bodies has been determined, with 14% of the country classed as poor status; status provides not only a snapshot of the present situation but also a signpost to future requirements. The implementation of measures required to return these areas to good status will have environmental benefits, but may also have social and economic costs. In addition to achieving good status, identification and reversal of sustained upward pollution trends together with measures to prevent or limit inputs of pollutants complete the means of protecting groundwater (and surface water). Multi-sectoral and multi-disciplinary cooperation, hard work and vision will be required if success is to be achieved in the coming years.

THE WFD –WHERE ARE WE NOW?

INTRODUCTION

Since the adoption of the WFD in 2000 considerable resources have been expended, much discussion has taken place and significant progress has been made towards its implementation. The changing views, work undertaken and outputs are summarised as follows:

- The WFD requires an integrated, holistic approach to management and protection of water thereby increasing the effectiveness of river basin management in Ireland. Groundwater is, therefore, at the core of the WFD. While the focus in the past has been mainly concerned with its use for drinking water, now the WFD requires that it also be considered in terms of the link with, and contribution to, ecosystems.
- The "groundwater body (GWB)" term has been added to the vocabulary of hydrogeologists, as GWBs are the groundwater management units of the WFD.
- GWBs were delineated and characterised, and reported to the EC in 2005.
- Up-dated groundwater level and quality monitoring networks became operational in 2006, and further improvements have continued since then.
- The interim chemical and quantitative status classification of GWBs was completed in December 2008.

GROUNDWATER – MORE THAN JUST A DRINKING WATER SOURCE

Until recently, the focus on groundwater mainly concerned its use as drinking water; about 75% of European Union residents and 25% of Republic of Ireland residents depend on groundwater for their water supply. However, the environmental value of groundwater, as well as its value as a water supply reservoir, has been recognised by the ecological objectives of the WFD. Groundwater plays an essential role in the hydrological cycle and is critical for maintaining wetlands, river flows and surface water ecosystems. In most rivers in Ireland, more than 30% of the annual average flow is derived from groundwater. In low flow periods, this figure can rise to more than 90%. Therefore, reductions in groundwater input, particularly in dry weather periods, or deterioration in groundwater quality may directly affect related surface water and terrestrial ecosystems. For instance, since surface waters receive inflowing groundwater, groundwater quality will ultimately be reflected in the quality of surface waters. Therefore, the effect of human activity on groundwater quality will eventually impact on the quality of associated aquatic ecosystems and directly dependent terrestrial ecosystems if natural attenuation reactions such as biodegradation and adsorption in the subsurface are not sufficient to remove the contaminants.

THE 'GROUNDWATER BODIES' CONCEPT

Virtually all of the requirements of the WFD concerning groundwater relate specifically to 'groundwater bodies' (GWBs) rather than to 'aquifers' (Daly, 2002). According to Article 2 of the WFD, *"Body of groundwater" means a distinct volume of groundwater within an aquifer or aquifers.*

The concept of 'Groundwater Bodies' embraces:

- groundwater that can provide for the abstraction of significant quantities of water and should be managed to ensure sustainable, balanced and equitable water use, and groundwater of satisfactory quality.
- groundwater that is in continuity with surface ecosystems, can place them at risk, and should be managed to prevent environmental impacts on them arising from human activity, either through the transmission of pollutants or by unsustainable abstraction.

The **Groundwater Body is consequently the groundwater management unit under the WFD** that is necessary for the subdivision of large geographical areas of aquifer in order for them to be effectively managed (see Figure 1). They are used for characterisation, monitoring and reporting, and where they are in close proximity and have similar hydrogeological properties, may be grouped together for these purposes.

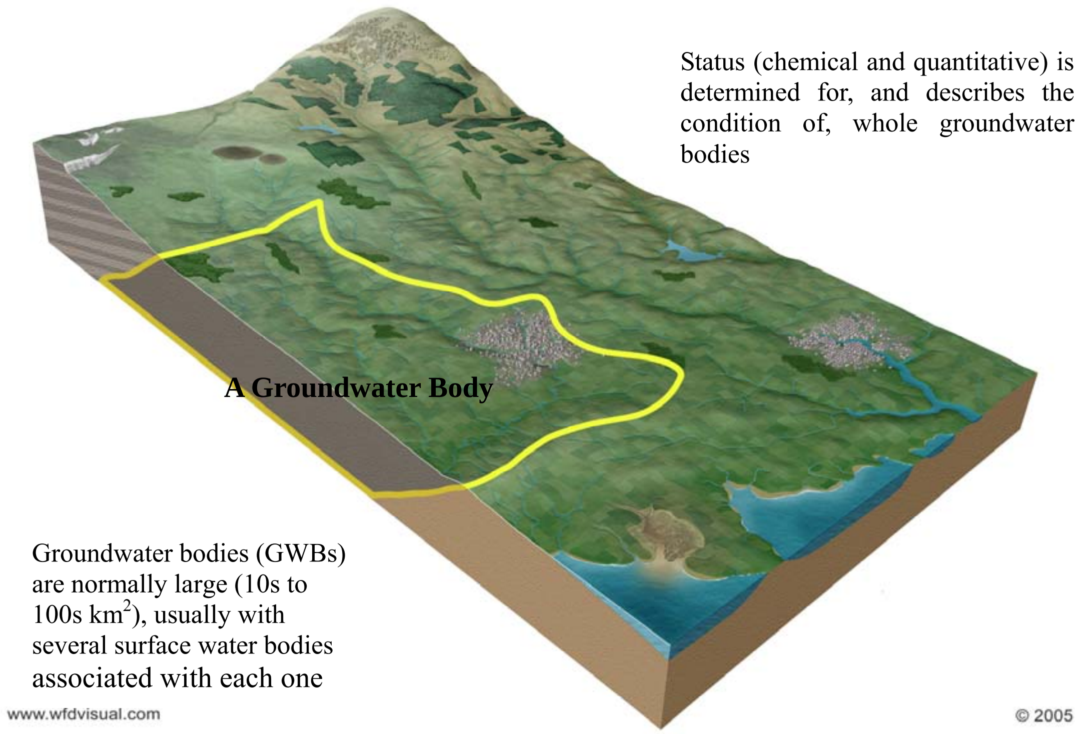

Figure 1 A groundwater body as a 3-D entity; illustrating the association with geology, topography and surface water bodies

ENVIRONMENTAL CHARACTERISATION AND RISK ASSESSMENT

The characterisation process involved two elements: physical characterisation and risk characterisation. Physical characterisation provides relevant information on groundwater receptors and on the geological pathways that link pressures and receptors. The physical characterisation process required collection of new data, mapping, compilation and assessment of existing data, and production of relevant maps in a digital format and accompanying reports – see paper by Hunter Williams *et al* in these Proceedings.

In general, Ireland has a diverse, complex bedrock and subsoils geology. Consequently, the groundwater flow regime varies from intergranular flow in subsoils to fissure flow in bedrock and karstic (conduit flow) in pure limestones. This influences not only groundwater abstraction but also pollutant movement and attenuation, and interactions with surface water. Therefore, GWBs were apportioned to four groundwater flow regime types (see Table 1): karstified limestone, productive fissured bedrock, poorly productive bedrock and sand/gravel.

Table 1 Summary of groundwater bodies based on flow regimes

Groundwater body types based on flow regime	Number of groundwater bodies	% of number	% area of country
Karstified limestone	202	26.7	19.6
Productive fissured bedrock	109	14.4	7.4
Sand/gravel	70	9.2	2
Poorly productive bedrock	376	49.7	71

(from Daly, 2005)

While 71% of the country is underlain by bedrock that is considered to be generally ‘poorly productive’, these areas are capable of providing significant groundwater supplies from zones (usually narrow – metres to 10s metres) of high transmissivity. In addition, due to the presence of an upper weathered and fractured zone, groundwater in these areas provide a substantial component of stream flow, particularly during wet periods, and acts as an important pathway for contaminants from the land surface to rivers.

The risk assessment process, which was completed and reported to the EC in March 2005 as a requirement of Article 5 of the WFD, concluded that 458 GWBs (60.6%), comprising 26.7% of the area of the country, were classed in the category *at risk*. While the larger number (295) were at risk due to point source pollution, diffuse source pollution affected the greater area – 24.6%. Nitrate from agricultural activities entering groundwater was considered to pose a threat in the south-east and south, while phosphate from agricultural activities was considered to pose a threat to surface water and terrestrial ecosystems in the karstified limestone areas of the west. Unlike most other European countries, groundwater abstraction was not considered a major threat.

GROUNDWATER MONITORING

The implementation of the Water Framework Directive (WFD) required that comprehensive groundwater quality and water level programmes should be operational by 22nd December 2006. This requirement necessitated a review of the existing networks, followed by the establishment of carefully-selected new networks (Figure 2). The main features of the networks are as follows:

- Three elements are included:
  - A quantitative monitoring network (based on the assessment of water levels and water balance estimations);
  - A surveillance and operational water quality monitoring network;
  - Appropriate monitoring to support the achievement of Protected Area objectives, e.g. Drinking Water and Habitats Protected Areas.
- The lead monitoring authority is the EPA, supported by local authorities and the National Parks and Wildlife Service.

- The networks take account of the relationship with surface water, in particular groundwater-surface water interactions, and thus encourage an integrated, holistic approach to monitoring and environmental assessment.
- Pre-screening of all monitoring points (e.g. checking well construction) has been undertaken to ensure that they are suitable for monitoring purposes.
- Representativity analyses have been undertaken to ensure that the monitoring points in combination represent both the variation in hydrogeological settings and the pressures.
- Springs are an important feature in Ireland, particularly in karstified limestone areas. Over 50 springs are now included in the groundwater quality network; weirs or other flow measurement structures have been installed at half of these springs, thereby enabling a comprehensive assessment and understanding of pollutant movement in the underground environment.
- In poorly productive aquifers, where flowpaths are short and meeting representativity requirements is not readily achievable, monitoring points were focussed in fault zones (vertical zones of high transmissivity). In addition, 60 multi-level piezometers (wells) have been installed in five hydrogeologically-different 'type' settings – Galway granite, Pre-Cambrian rocks of north Mayo, Pre-Cambrian rocks in a cross-border groundwater body in Donegal, Lower Palaeozoic rocks in Louth, Old Red Sandstone in Cork and impure limestones in Meath.
- In early 2009, the water quality network consisted on 275 wells, with sampling taking place every three months. A comprehensive suite of parameters are analysed, including pesticides. Data loggers have been installed on 100 wells and springs (with a further 60 being installed this year), with water level readings taken every 15 minutes.

CLASSIFICATION OF GROUNDWATER BODIES

INTRODUCTION

For groundwaters, the overall aim is to achieve 'good status' in all bodies of groundwater by 2015, as well as preventing deterioration in those waters that have been classified as "good". The process of classifying groundwater bodies follows logically from the characterisation and risk assessment process undertaken for Article 5 of the WFD. The risk assessments have been further refined in 2008 based on improved information.

In general terms, the main threats to groundwater are posed by inputs of pollutants and water level drawdown due to groundwater abstraction. Therefore, for each body of groundwater, both the chemical status and the quantitative must be determined. Both have to be classed as either 'good' or 'poor'. Groundwater bodies that are "not at risk" are automatically classed as good status. The WFD sets out a series of criteria that must be met for a body to be classed as good chemical and quantitative status. The criteria for good chemical status are further elaborated in the Groundwater (Daughter) Directive (GWD) and are summarised in the following section.

The EPA, assisted by River Basin District Project consultants, completed the interim classification of groundwater bodies in December 2008. The classification will be finalised in December 2009, following a consultation process.

STATUS DEFINITION

Classification of groundwater bodies differs from that undertaken for surface water bodies, in that the surface water standards relate to ecological status and these standards define the classification boundaries. Groundwater status does not directly assess ecology, but the classification process takes account of the ecological needs of the relevant rivers and terrestrial ecosystems that depend on contributions from groundwater (GWDTEs). Another key component of the groundwater classification is assessment of the impact of pollution on the uses (or potential uses) of groundwater from the groundwater body, e.g. for water supply.

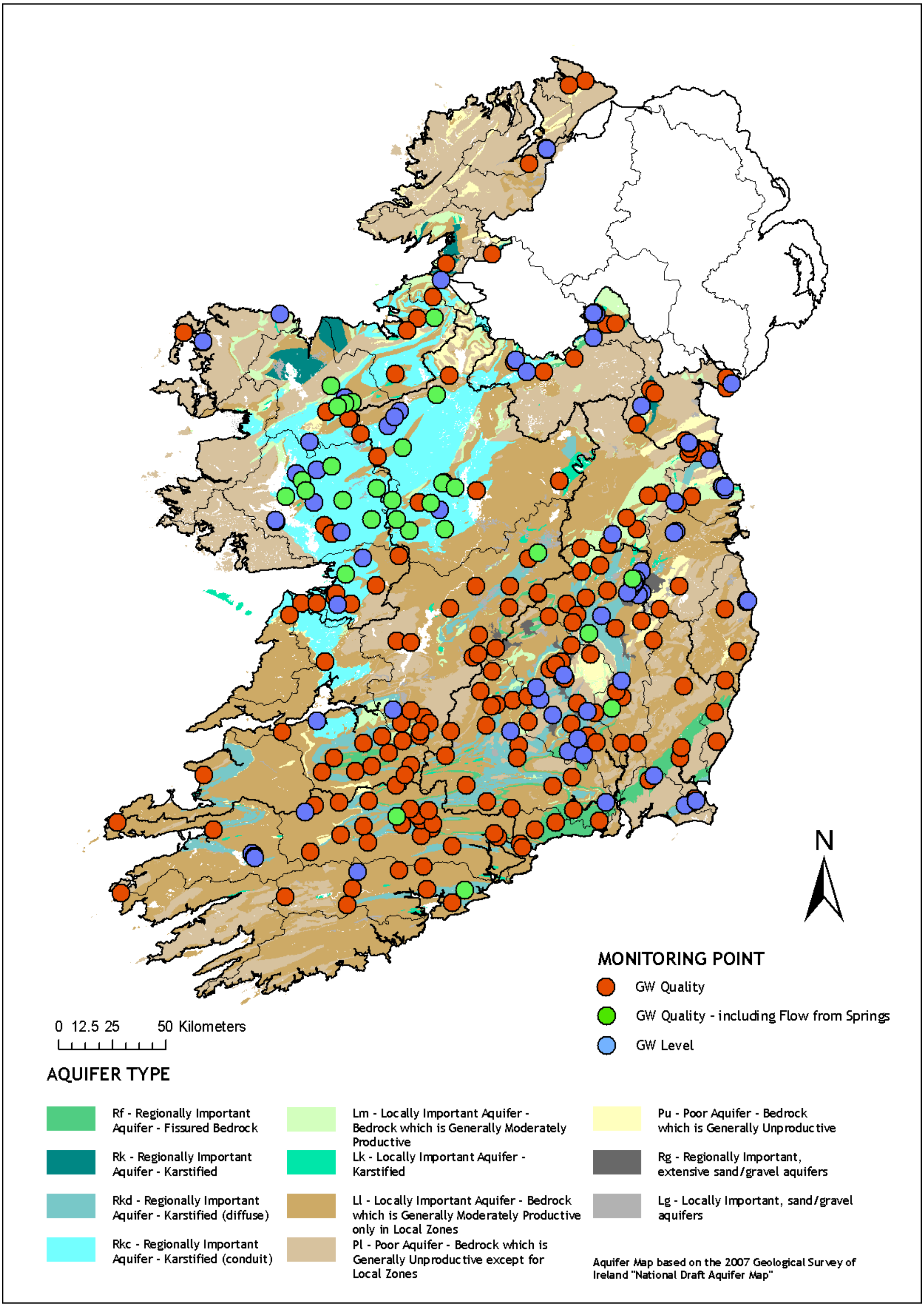

Figure 2 Groundwater level and quality monitoring networks

The groundwater body classification is based on the "objectives" defined in Annex V of the Water Framework Directive and Annexes I – III of the Groundwater Daughter Directive (GWD). These objectives are:

1. No saline or other intrusions;
2. Achieving the objectives of the Water Framework Directive for dependent surface waters including no deterioration in status;
3. No damage to any wetlands that depend on the groundwater body;
4. No impact on Drinking Water Protected Areas;
5. No significant impairment of human uses of groundwater.

The key principles for groundwater classification that are identified in EC (2009) and UKTAG (2007) have been applied in the classification process. The guidance requires undertaking a number of tests as a means of determining status. These are summarised in Figure 3. The tests are intended to be applied where a risk to the achievement of good chemical and quantitative status is identified, and are used to assess whether those identified risks have affected the chemical and quantitative status of groundwater. Where no risks are identified, a water body can be classed as good status without undertaking the more detailed investigations required by the tests.

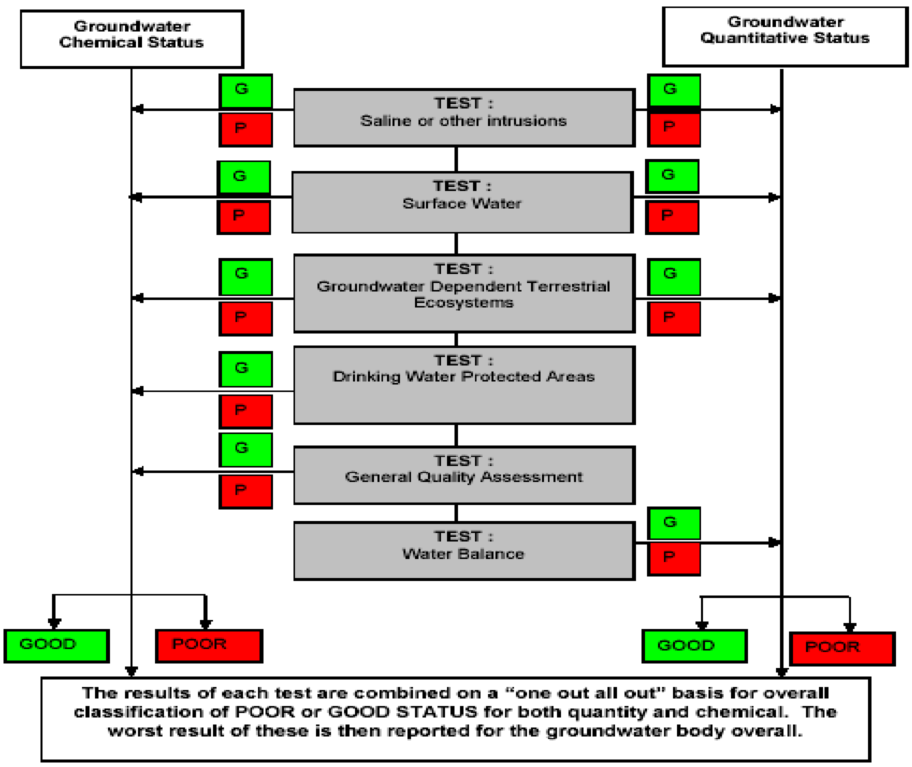

Figure 3 Overall procedure of classification tests for assessing groundwater status (UK TAG, 2007)

The variety of classification elements, the volume and precision of monitoring data, and the uncertainties in our understanding of groundwater flow and quality, contribute to uncertainty in the classification process. A weight of evidence approach, with monitoring data complemented by conceptual understanding and data on risk assessment, is essential to ensure the reliable classification of groundwater bodies and subsequent proper targeting of measures in River Basin Planning. However, the data and information available to assess damage to GWDTEs were generally inadequate. For instance, information on the environmental supporting conditions (flow, level and chemistry) needed to maintain GWDTEs, particularly those 'at risk', in a favourable state is required to enable status to be determined. As this information was not generally available, the status tests were undertaken for only a small number of GWDTEs. This situation will need to be rectified in the next River Basin Management Plan.

If a groundwater body fails any of the classification tests, then the groundwater body is at poor status. The five chemical and four quantitative tests applied by the EPA for groundwater bodies in the Republic of Ireland are summarised below.

CHEMICAL STATUS TESTS

Articles 3 and 4 of the GWD, together with associated Annexes, lay down the criteria for assessing groundwater body chemical status. Groundwater quality standards are set in the GWD for two pollutants: 50 mg/l for nitrates, and 0.1 µg/l and 0.5 µg/l (total) for active substances in pesticides, including their relevant metabolites, degradation and reaction products. "Threshold values" have been developed for Irish groundwater bodies by the EPA for substances that are leading to (or likely to lead to) chemical and/or ecological status failures – see Table 2. Threshold Values (TVs) are annual average concentrations, rather than Maximum Admissible Concentrations (MACs) and different TVs have been derived for different chemical status tests, e.g. for the surface water test the TV is the surface water EQS, whilst for use based status tests (Drinking Water and General tests), the TV is 75% of the Drinking Water standard for appropriate determinands. In order to ensure that peak concentrations remained below the Drinking Water MAC, 75% of the MAC was taken to be the TV, because Drinking Water standards are MACs, and TVs are average values. However, it should be noted that these Member State defined quality standards are used as triggers for further investigation to determine whether or not the conditions for good chemical status are met, and do not by themselves define the actual boundary between good and poor status.

Five tests are relevant to the assessment of groundwater body chemical status; these are summarised below.

Test: Assessment for the Presence of Saline or other Intrusions

Key Concept

Determined through an assessment of trends in Electrical Conductivity (EC) or other relevant indicator substances. The test is designed to detect the presence of an intrusion that is induced by the pumping of groundwater.

Threshold values

Set at the upper limit of the natural background range for key determinands: for example, EC = 800 µS/cm; Cl = 24 mg/l.

Threshold values are only used in combination with trend assessment.

Criteria for poor groundwater chemical status

Threshold values are exceeded **and** there is <u>either</u> a significant and sustained rising trend in one or more key determinands at relevant monitoring points <u>or</u> there is an existing significant impact on a point of abstraction as a consequence of an intrusion.

Results

0 GWBs at poor status

Test: Assessment of adverse impacts of the chemical inputs from groundwater on associated surface water bodies

Key Concept

Status is determined through a combination of surface water classification results and an assessment of chemical inputs from groundwater bodies into surface water bodies. The surface water bodies can comprise rivers, standing waters and transitional waters. The test is designed to determine whether the contribution from groundwater quality to surface water quality or any consequent impact on surface water ecology is sufficient to threaten the WFD objectives for these associated water bodies.

Threshold values

Surface water quality standards adjusted by dilution and, where appropriate, attenuation factors.

Examples: MRP = 35 µg/l P; NH_4 = 65 µg/l N.

Criteria for poor groundwater chemical status

An associated surface water body does not meet its objectives, threshold values are exceeded and groundwater contributes more than 50% of the pollutant load required to cause poor status in the surface water body, i.e. cause the EQS to be exceeded.

Results
101 GWBs at poor status (13.3% of area) mainly in the karstic aquifers in the west of Ireland due to presence of phosphate in groundwater.

Test: Assessment of adverse impacts of the chemical inputs from groundwater on groundwater dependent ecosystems (wetlands)

Key Concept
Status is determined through a combination of the assessment of the condition of wetlands and an assessment of the chemical inputs from groundwater bodies into wetlands.

Threshold values
An appropriate percentage of a prescribed standard; however, to-date no specific standards have been derived for GWDTEs.

Criteria for poor groundwater chemical status
There is evidence of significant damage to a wetland caused by pollution and the pollutants responsible for that damage are judged to have reached the wetland via groundwater.

Results
0 GWBS at poor status.

Test: Assessment of whether groundwater intended for human consumption in drinking water protected areas is impacted by pollutants and/or is showing a significant and sustained rise in pollutant levels

Key Concept
Good chemical status requires an assessment, at the point of abstraction for water intended for human consumption, of whether there is deterioration in groundwater quality due to anthropogenic influences that could lead to an increase in purification treatment. This test has been applied to the drinking water sources that are part of the national groundwater quality network (201 sources).

Threshold values
75% of Drinking Water Standards. Examples: NO_3 = 37.5 mg/l as NO_3; total pesticides = 0.375 μg/l.

Criteria for poor groundwater chemical status
The threshold values are exceeded at the point of abstraction and there is a significant and sustained rising trend in one or more key determinands.

Results
2 GWBs at poor status (0.3% of area) due to presence of nitrates.

Test: Assessment of the general quality of groundwater in the body in terms of whether its ability to support human uses has been significantly impaired by pollution

Key Concept
Status is determined through an assessment of the areal extent of a groundwater body exceeding a TV for a pollutant. It is only conducted for determinands where: a) the EU prescribed standard is set; or b) the risk characterisation process has indicated that pollutants may cause significant impairment of human uses.

Threshold values
An appropriate percentage of the EU prescribed standards for nitrates and pesticides or a use-related standard that is appropriate for existing or planned use of the groundwater.

Criteria for poor groundwater chemical status
Threshold values are exceeded at individual monitoring points, and a representative aggregation of the monitoring data at the groundwater body scale indicates that there is a significant environmental risk or a significant impairment of human uses of the groundwater body.

Results
9 GWBs at poor status (1.2% of area); 5 due to historic mines, 3 to contaminated land and 1 due to urbanisation.

QUANTITATIVE STATUS TESTS

The classification scheme for groundwater quantity is divided into four tests. As the saline intrusion test is common to both chemical and quantitative status assessments (as abstraction causes chemical impacts) and has been described above, the remaining three tests are summarised below.

Test: Water balance

Key Concept

This is a body-wide test, which considers the cumulative effects of abstraction across the body. It takes account of the available groundwater resource and water levels. The available groundwater resource is estimated by subtracting the groundwater contribution needed to support rivers and ecosystems from recharge. Conditions for good quantitative status are not met if the long-term average abstraction exceeds the available resource.

Criteria for poor groundwater quantitative status

a) The annual average volume of water abstracted from the groundwater represents more than 80% of the long-term annual volume of recharge (i.e. water that replenishes the groundwater); <u>or</u>

b) The annual average volume of water abstracted from the groundwater represents more than 20% of the long-term annual volume of recharge in bedrock groundwater bodies (30% in gravel bodies) and there is evidence of a long-term drop in groundwater levels in the body of groundwater; <u>or</u>

c) A Groundwater Dependent Terrestrial Ecosystem (GWDTE) is damaged and the annual average volume of water abstracted from the groundwater represents more than 5% of the long-term annual volume of recharge in the groundwater body containing the GWDTE and there is evidence of a long-term drop in groundwater levels in the groundwater body.

Results

2 GWBs at poor status (0.3% of area); one each in north County Dublin and County Cork.

Test: Assessment of adverse impacts of groundwater abstraction on associated surface water bodies

Key Concept

This test is applied at the surface water body (SWB) scale and is only undertaken when the SWB is considered to be at less than ‘good’ status. Information on the surface water flow standards is required.

Criteria for poor groundwater quantitative status

a) An applicable river flow standard for 'good status' is failed in an associated river water body; <u>and</u>

b) The total volume of groundwater abstractions in the surface water catchment associated with the failing river are greater than 50 % of the required surface water flow standard.

Results

As no surface water bodies were classed as less than good due to abstractions, there are no GWBs classed as poor status.

Test: Assessment of groundwater abstraction on groundwater dependent ecosystems (wetlands)

Key Concept

Status is determined through a combination of the assessment of the condition of wetlands and an assessment of the effects on wetlands of changes in groundwater levels in associated GWBs. In particular, the test estimates whether the changes in water levels or flows are sufficient to cause ‘significant damage’.

Criteria for poor groundwater quantitative status

There is evidence of significant damage to a wetland caused by insufficient water availability and the major reason for the insufficient water availability is judged to be alterations to groundwater levels resulting from human activities.

Results

2 GWBs at poor status due to impact of lowering of groundwater levels at Pollardstown Fen.

OVERALL GROUNDWATER STATUS RESULTS

For each groundwater body, the lowest classification from the five chemical tests has been reported as the overall chemical status (Figure 4), and the lowest classification from the four quantitative tests have been reported as the overall quantitative status (Figure 5). If either the chemical or the quantitative assessment is poor, then a "one out all out" approach is used to determine the overall classification.

The summary results are given in Table 3. The overall results depicted in Table 3 show that 85% of the groundwater bodies are at Good Status and 15% (which relates to 14.2% of the total land area) are at Poor Status.

Table 3 Summary of classification results

Status	**Chemical**		**Quantitative**		**Overall**	
	Number (% of total)	% area	Number (% of total)	% area	Number (% of total)	% area
Good	646 (85.3)	86.1	753 (99.5)	99.7	642 (84.8)	85.8
Poor	111 (14.7)	13.9	4 (0.5)	0.3	115 (15.2)	14.2
Total	757		757		757	

The status results are somewhat surprising. Microbial pathogens, potentially indicated by the presence of faecal bacteria, and nitrate have been regarded as the most important pollutants in groundwater in Ireland. However, no GWBs are at poor status due to pathogens as they are not a parameter considered by the WFD. Only 0.3% of the country is at poor status due to the presence of high nitrate concentrations in the vicinity of groundwater supply abstraction points. Also, pesticides in groundwater have not resulted in any GWBs being at poor status. In contrast, 13.3% of the country is at poor status due to the presence of phosphate in groundwater. This outcome is due to two factors: firstly, to the sensitivity of surface water ecosystems to phosphate; and secondly, to the impact of groundwater input and quality on surface water ecosystems, particularly in the karstified limestone aquifers, where the groundwater flow contribution to surface water is usually more than 60% and the vulnerability of these rocks (with shallow soils and subsoils, and sinking streams) results in high average phosphate concentrations in the groundwater (typically mean MRP concentrations are >30 μg/l P).

TREND IDENTIFICATION AND REVERSAL

Article 5 of the GWD concerns the identification of sustained upward pollution trends and their reversal. This is the second "pillar" of the GWD (EC, 2008), which stipulates that such trends will have to be identified for any pollutants characterising groundwater as being at risk. The EPA will undertake the identification of these trends in 2009.

The reversal obligation establishes that any significant and sustained upward trend will have to be reversed when reaching 75% of the values of the groundwater quality standards and/or threshold values, although local circumstances may justify different values. The WFD programmes of measures are intended of providing the means of reversing trends.

MEASURES TO PREVENT OR LIMIT POLLUTANT INPUTS

This is the third 'pillar' of the GWD (EC, 2008). While this issue is covered by the existing Groundwater Directive (EC, 1980), new elements, which are covered by other directives, such as the Landfill Directive, make the existing Groundwater Directive redundant in some aspects in relation to the WFD programmes of measures. Consequently, the 1980 Directive is being repealed in 2013. Prevention applies to hazardous substances, whereas the limit requirement applies to non-hazardous substances.

In principle, prevent or limit measures are the first line of defence in preventing unacceptable inputs of pollutants to all groundwater (and thereby avoiding pollution) (UK TAG, 2007). In contrast, the assessment of status provides a six yearly review of the condition of groundwater bodies, with updated characterisation and risk assessments used to identify future non-compliance with the WFD and related Directives in future planning cycles. The characterisation and risk assessment, status and prevent or limit requirements are therefore complimentary. Provided that sufficient time is allowed to enable the historical legacy of prior pollutant releases to be degraded or dispersed, and if all prevent or limit requirements are met everywhere within a groundwater body, the body would be at good chemical status. Future regulatory measures will be based predominantly upon the ‘prevent or limit’ objective rather than classification results, as in practice this is the most restrictive requirement (UK TAG, 2007).

CONCLUSIONS

In general terms, the implementation of the WFD to-date has enabled the following benefits:

- ♦ It has required an integrated, holistic approach to management and protection of water for the first time, thereby increasing the effectiveness of river basin management in Ireland.
- ♦ By improving the geosciences datasets and maps, it has helped advance the understanding of groundwater in Ireland.
- ♦ As the existing groundwater monitoring networks had to be upgraded, improved representative level and quality monitoring networks have been installed.
- ♦ The chemical and quantitative status of groundwater bodies has been determined, providing a snapshot of the current situation and a signpost to future requirements.

The interim classification of GWBs has resulted in 14.2% of the land area as being poor status; this is likely to be relatively low in comparison to other EU countries. By far the greater proportion of this area is caused by the input of pollutants, mainly phosphate, probably from agricultural activities, although on-site wastewater treatment systems may also be a minor source. Abstraction of groundwater was not shown to be a significant issue. While the implementation of measures, which are required to return these areas to good status, will have environmental benefits, they are also likely to have some social and economic costs. Therefore a good scientific basis is needed to justify the measures and to focus them on the critical areas; this will be challenging. Multi-sectoral and multi-disciplinary cooperation will be critical to achieving success.

The work described in this paper has been undertaken primarily to enable compliance with the WFD and the GWD. However, even without requirements set by the EC, the work undertaken is generally beneficial and justifiable as the approach and outcomes provide a good, sensible basis for water management in Ireland.

ACKNOWLEDGEMENTS

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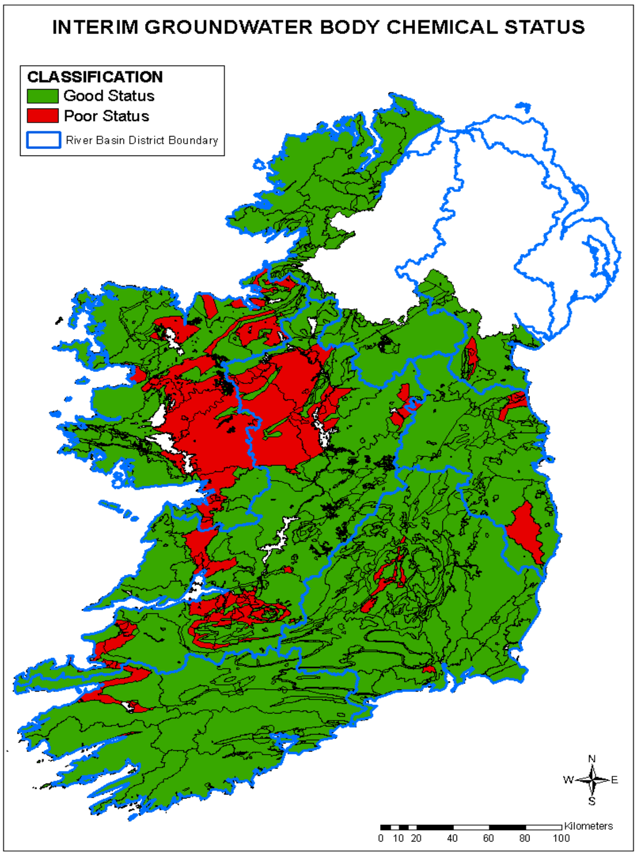

Figure 4 Overall chemical status of Ireland's groundwater bodies

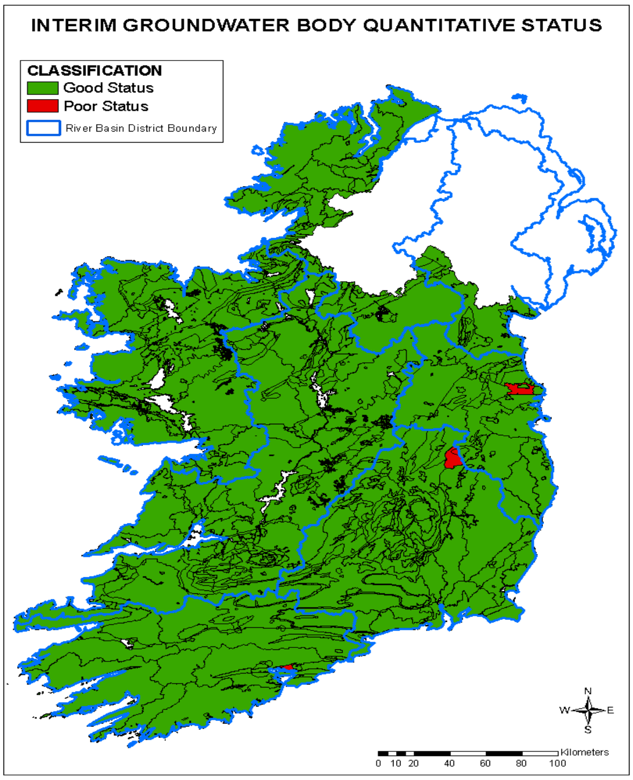

Figure 5 Overall quantitative status of Ireland's groundwater bodies.

Parameter	Units	TVs arising from Chemical Status Tests				Overall Threshold Value Range
		Test: assessment for the presence of saline or other intrusions	Test: Assessment of adverse impacts of the chemical inputs from groundwater on associated surface water bodies	Test: Assessment of whether groundwater intended for human consumption in drinking water protected areas is impacted by pollutants and/or is showing a significant and sustained rise in pollutant levels	Test: Assessment of the general quality of groundwater in the body in terms of whether its ability to support human uses has been significantly impaired by pollution	
Inorganic & Metals						
Electrical Conductivity	µS/cm	800	-	1875	-	800 - 1875
Molybdate Reactive Phosphorus	µg/l P	-	35	-	-	35
Ammonium	µg/l N	-	65	175	175	65 – 175
Nitrite	µg/l NO_2	-	-	375	-	375
Nitrate	mg/l NO_3	-	-	37.5	37.5	37.5
Chloride	mg/l Cl	24	-	187.5	-	24 – 187.5
Sulphate	mg/l SO_4	-	-	187.5	187.5	187.5
Sodium	mg/l Na	-	-	150	-	150
Boron	µg/l B	-	-	750	750	750
Chromium	µg/l Cr	-	-	-	37.5	37.5
Arsenic	µg/l As	-	-	-	7.5	7.5
Lead	µg/l Pb	-	-	-	18.75	18.75
Nickel	µg/l Ni	-	-	-	15	15
Mercury	µg/l Hg	-	-	-	0.75	0.75
Cadmium	µg/l Cd	-	-	-	3.75	3.75
Copper	µg/l Cu	-	-	-	1500	1500
Aluminium	µg/l Al	-	-	-	150	150
Cyanide	µg/l Cn	-	-	-	37.5	37.5
Pesticides						
Atrazine	µg/l	-	-	0.075	0.075	0.075
Simazine	µg/l	-	-	0.075	0.075	0.075
MCPA	µg/l	-	-	0.075	0.075	0.075
Lindane	µg/l	-	-	0.075	0.075	0.075
Diuron	µg/l	-	-	0.075	0.075	0.075
4,4 - DDT	µg/l	-	-	0.075	0.075	0.075
Dieldrin	µg/l	-	-	0.075	0.075	0.075
Cypermethrin	µg/l	-	-	0.075	0.075	0.075
Bentazone	µg/l	-	-	0.075	0.075	0.075
Glyphosate	µg/l	-	-	0.075	0.075	0.075
Chlortoluron	µg/l	-	-	0.075	0.075	0.075
Mecoprop	µg/l	-	-	0.075	0.075	0.075
Isoproturon	µg/l	-	-	0.075	0.075	0.075
2,4 Dichlorophenoxyacetic acid	µg/l	-	-	0.075	0.075	0.075
Total Pesticides	µg/l	-	-	0.375	0.375	0.375
Organics						
1,2-Dichloroethane	µg/l	-	-	-	2.25	2.25
Vinyl Chloride	µg/l	-	-	-	0.375	0.375
Total Tetrachloroethene & Trichloroethene	µg/l	-	-	-	7.5	7.5
Benzene	µg/l	-	-	-	0.75	0.75
Benzo(alpha)pyrene	ng/l	-	-	-	7.5	7.5
Total Polycyclic Aromatic Hydrocarbons	µg/l	-	-	-	0.075	0.075
Total Trihalomethanes	µg/l	-	-	-	75	75

Table 2 Groundwater Threshold Values

(1) The calculation of the arithmetic mean and the analytical method used must be in accordance with the proposed Directive adopting technical specifications for chemical monitoring and quality of analytical results in accordance with Directive 2000/60/EC of the European Parliament and of the Council, including how to apply an EQS where there is no appropriate analytical method meeting the minimum performance criteria.

Notes

[1] No specific threshold values have been developed for the assessment of Groundwater Dependent Terrestrial Ecosystems.

[2] The surface water EQS for metals in surface water allow natural background concentrations to be considered when establishing a standard. Therefore it has not been possible to derive a threshold value.

PRACTICAL IMPLEMENTATION OF THE WATER FRAMEWORK DIRECTIVE WITH RESPECT TO GROUNDWATER BY LOCAL AUTHORITIES

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ABSTRACT

The Water Framework Directive (WFD) uniquely embraces the management of surface waters and groundwaters together. It sets objectives for the protection and where necessary improvement of groundwater quantity and pollution status. The implementation of the WFD is at a critical stage: in December 2008 draft river basin management plans where produced for each of Ireland's districts. These plans contain information about the status, objectives and management actions proposed for our waters. The draft plans aim to enable stakeholder and wider-public consultation on the management proposals so that these views can be considered prior to finalising the plans by December 2009. This paper highlights the proposals for a strengthened focus on the management of groundwater and in particular sets out the responsibilities and practical implications for Local Authorities. The key messages are that groundwater cannot be taken for granted; it must be more closely monitored; and the emphasis of future management most move towards prevention.

INTRODUCTION

A figure which has always struck me as odd here in Ireland is our dependence on surface waters as a source of drinking water. Throughout Europe, groundwater is dominant with approximately 75% of their drinking water been sourced from groundwater supplies, while here in Ireland it is the opposite with only 20% coming from groundwater. We need to understand this phenomenon before we can commence to address the implications for Local Authorities of the WFD on groundwater.

Its not as if we have a shortage of groundwater resources compared with the rest of Europe. Our potential groundwater resources are reasonably well documented but to date are under utilised. Historically, groundwater was the dominant resource, every house in the country side had its own well or springs, as a considerable proportion still do today. Towns and villages had the "village pump" which also served as the central meeting place for people as they went about their daily lives. We have in Ireland, many holy springs and wells which were treated with reverence by the population. Groundwater was looked at almost mystically. Before modern science developed enough to tell us that surface waters contained numerous pathogens compared to groundwaters, people already understood that it was safer to drink from wells and springs. Maybe this is part of the reason they were held in high esteem.

So why did the balance shift in favour of surface waters? I think some of this was due to the lack of understanding of groundwater, its fragile nature in terms of continuity of supply, it could not be quantified, it could get contaminated but from where, you could not see it. There was also the Broad Street pump public health incident in London which was written about widely in professional and academic journals at the turn of the last century which did not help the "press" groundwater received. There were too many un-answered questions about groundwater which surface water was not open to and despite many of these questions being answerable today, often the first port of call when a local authority is seeking to increase the supply of drinking water is surface water.

A side effect of the WFD maybe to swing the pendulum in favour of groundwater resources and to explain this we need to look at some specific objectives of the WFD. The WFD seeks to achieve good status for all our waters ecologically, chemically and in quantitative terms and also importantly no deterioration in existing status. The quantitative objective is often overlooked and requires us to maintain a minimum ecological flow in our surface waters and levels in groundwaters. The WFD process has identified surface waters which are been over abstracted or are at risk of over abstraction. At present this only amounts to a handful of locations but with our ever increasing population and the effects of climate change the potential of surface waters to supply the greater portion of our drinking water resources is diminishing. The climate change scenario is maybe of most concern, as our summers become longer and drier, rainfall events become less frequent and more intense, we may reach a situation where we cannot continue to abstract even at existing daily rates because of the need to maintain a minimum ecological flow. Of course groundwater is subject to the same quantitative objective but we have significant resources which we have not yet commenced to exploit.

It is worth reiterating at this point that the WFD is an objective led directive as opposed to an emissions led directive. One of it's underwriting objectives is sustainability in terms of water quality status but also in allowing all those, both man and beast, equal access to waters, to grow and develop into the future. The 'no deterioration' objective also brings prevention to the forefront for the first time. This could be considered to be the most difficult objective to achieve not only in terms of the technical requirements but also the change in institutional practice that will be needed. Traditionally, a reactive approach was taken to pollution issues but with prevention, a proactive approach is required. Prevention requires risk assessment to develop an operational plan which must be flexible and reviewed regularly to respond to the changing land use patterns within the catchment and also requires the continual influence of professionals. For groundwaters, the core objectives are to improve quantity and chemical quality where necessary to achieve good status and reverse increasing pollution trends.

So what are the specific implications today for local authorities in terms of groundwater arising from the WFD ? Given below is a synopsis of what we consider to be the significant arisings from the WFD in terms of groundwater for local authorities.

ABSTRACTIONS

It is expected that a new authorisation system for abstraction will be introduced by way of Regulation. Different levels of technical assessment will be required based on abstraction rates and location relative to sensitive receptors. It is expected that local authorities will be assigned this task with local authorities applying to the EPA for their own abstractions. Groundwater abstraction impacts, consumptive usage and other relevant data is not captured at present. The proposed authorisation process mentioned above is expected to contain a requirement for local authorities to capture this information and maintain a register of abstractions.

Monitoring under the WFD shows that groundwater resources are generally in good condition with only a few abstractions considered to be unsustainable. These are associated with public supply, mining, quarrying or a combination of these. More detailed studies will be required in these areas and if it is found that abstraction results in a water body being designated at less than good status, remediation schemes will need to be considered.

Though not directly related to the WFD, the Water Services Act 2007 has a provision in it, which has not yet been commenced, requiring Group Water Schemes to apply to local authorities for a licence to operate. Conditions may be attached to such licences requiring measures to protect risk to human health or the environment and measures to prevent source contamination.

GROUNDWATER PROTECTION SCHEMES

In 1999 the GSI, DoEHLG and EPA launched "Groundwater Protection Schemes" a document which set out a methodology to delineate groundwater source protection zones. It was envisaged that these would then form the foundation for local authorities to establish pollution prevention action plans for groundwater sources.

There are 614 groundwater abstractions for public water supply in Ireland and from Table 1 you can see that only 128 or 21% of these have had source protection zones delineated. The "Good Agricultural Practice for Protection of Waters" Regulations provides for varying setback distances from groundwater sources of drinking water for the spreading of organic fertiliser. These setback distances take the form of circles with radii of 200m, 100m and 25m from the source depending on population usage figures. This is a crude methodology and should only be seen as an interim measure pending the establishment of source protection zones using the "Groundwater Protection Schemes" document.

Table 1		County Groundwater Protection Scheme	Individual Source Protection Zones
1	Cavan	N	3
2	Clare	Y	4
3	Cork	Y	14
4	Donegal	Y	6
5	Galway	N	1
6	Kildare	Y	7
7	Kilkenny	Y	8
8	Laois	Y	5
9	Limerick	Y	18
10	Meath	Y	7
11	Monaghan	Y	2
12	Offaly	Y	24
13	Roscommon	Y	7
14	Tipperary South	Y	
15	Tipperary North	Y	9
16	Waterford	Y	8
17	Wicklow	Y	5
			128

SEPTIC TANKS

Over the years the issue of septic tanks, or as they are called now on-site wastewater treatment systems, has received considerable attention including at previous IAH conferences. They still remain one of the significant pressures on our groundwaters and while a lot of work and guidance has gone into mitigating the effects of new installations, there still remains the legacy of the historical inventory of systems. Cavan County Council probably lead the way in tackling this legacy with the introduction of specific bye-laws in 2004 and an active enforcement system. The following figures were obtained from the CSO and make for some interesting reading.

Table 2	**Households**	
	%	**No.**
Not stated	3.2%	47,791
Public scheme	63.3%	956,239
Individual septic tank	27.7%	418,033
Individual treatment not septic tank	2.0%	29,685
Other	0.5%	6,979
No sewerage facility	0.3%	4,179
		1,510,087

Table 2 shows that there are 447,718 household with OSWTS in Ireland or 1.3m, 28% of the population, dispose of their wastewater to groundwater, or to put it another way 230 million litres every day. Cavan County Council in their work found that 36% of OSWTS were defective and causing pollution. If such large volumes of wastewater were entering a surface water body there would be a public outcry but with groundwater; out of sight out of mind!

The European Commission have initiated a case against Ireland (under Article 226) about individual wastewater treatment systems – the Commission contend that domestic waste water is a category of waste that falls under the Waste Directive and that measures implemented by Ireland do not amount to measures pursuing the same objectives of the Directive, or resulting in an equivalent level of protection. This case is at the European Court of Justice awaiting a hearing. Judgement on this case is likely to issue before summer 2009. A task force has now been established within the Department to consider the options available in the event of a ruling against Ireland comprising a number of sections in the Department with an interest in this Case, and also liaising with the CCMA as the work of the Group progresses.

USE OF SEWAGE SLUDGE IN AGRICULTURE

The primary objective of the *Use of Sewage Sludge in Agriculture Regulations* is safety of public health. Sludge is required to be to be spread in accordance with a nutrient management plan with soil and sludge analysis for heavy metals. There is no specific objective in the regulation in relation to groundwater other than Article 4 which requires that the quality of soil, of surface water and of groundwater is not impaired. The 'no deterioration' objective of the WFD implies that in addition to the specific obligations of the regulation a risk analysis for water pollution is also required. In relation to groundwater this means a detailed vulnerability assessment on a field by field bases and that sludge be spread in accordance with "Groundwater Protection Schemes".

SAFE GUARD ZONES – SURFACE WATER

A methodology will be developed to protect surface water sources of drinking water. An element of this will cover the groundwater body within the surface water catchment and require an understanding of surface water – groundwater interaction.

SUSTAINABLE URBAN DRAINAGE SYSTEMS (SUDS)

For this exercise we shall include drainage from roads under this heading. The concept of SUDS fits in perfectly with the objectives of the WFD, protecting water quality and reducing runoff. It seeks to achieve a 'no impact state' where water behaves the same way as it did prior to construction of the "urban" area. A cursory glance at a SUDS leaves one thinking that these are a rather simple design that anyone could have a shot at and in there simplest application this may be true; a "swail" (infiltration gallery) by the side of the road or a water feature (attenuation pond) in a business park. However when scale is increased, storm events and groundwater vulnerability taken into account these become the preserve of specialist designers.

A core element of their design is to allow rainwater infiltrate to groundwater but this introduces risk to groundwater quality, as the rainwater is now contaminated by pollutants which have accumulated on roads and streets and the disturbance of the natural ground conditions during the construction of the infiltration galleries may lead to increase vulnerability. At a small scale and where space is limited we see the use of underground infiltration galleries constructed of "milk crates". Advertising for these "milk crate" soak pits expound their invisibility below ground. These are often located under green space or car parking and design criteria submitted to local authorities in the planning process often only considers rate of infiltration with no mention of water quality. A small spill of oil on the road or car park could lead to significant groundwater contamination and all this occurring out of sight out of mind!

AUTHORISATION OF DISCHARGES TO GROUNDWATERS

Current legislation controlling the myriad of discharges to groundwater are considered inadequate and it is proposed that a new authorisation system will be introduced. This system will prohibit direct discharge of pollutants to groundwater and require prior authorisation for reinjection of waters for specific activities such as dewatering for mining, exploration for oils and injection for storage of gas. Construction or civil engineering works that could influence the water table will also require authorisation as will groundwater geothermal heat extraction systems.

Ireland's existing Wastewater Discharge Regulations prohibit discharge of certain dangerous substances to groundwater and they also provide controls for discharges of other substances by water services authorities by way of Environmental Protection Agency licenses. Additional regulatory requirements and further guidance will be incorporated into Irish controls under *Groundwater Environmental Objectives Regulations* to be made in 2009 when transposing the Groundwater Directive. The new regulations will set criteria for status and trends and require measures to prevent or limit inputs of pollutants into groundwaters.

CONTAMINATED LAND

Although currently no national survey has been carried out to identify and register contaminated sites in Ireland, industrial activities applying to the EPA for an IPPC licence are required to give details on all known historical pollution incidents which have occurred on-site. In these instances, the industries are required to provide an assessment of ground and groundwater contamination of the site. From this information, contaminated land sites were identified at licensed facilities that have had historical contamination (e.g. a spillage of chemicals) and where remediation is not planned to be complete before 2015. For these sites, an assessment of groundwater status was carried out for WFD purposes and three groundwater bodies were classed as having "poor status" due to the concentration of contaminants remaining in the groundwater.

In addition, there are sites throughout the country that although do not affect the larger groundwater body, have contamination issues at a localised level. Such sites have been identified and specific measures will be placed on the activities via the IPPC licensing system to ensure that groundwater at these sites remain at good status. The EPA may then require remediation of the site, or attach conditions to the licence to remediate the site to reduce and/or eliminate the risk of contamination. Although, there currently is no specific legislation in Ireland for dealing with contaminated land, the regulator's (Local Authorities and EPA) approach to such incidences involves integrating pollution prevention, the polluter pays principle and the precautionary principle.

LANDFILLS

Historic landfills which were in operation prior to 1997 and were not in breach of national legislation, do not fall under the Waste Management Licensing Regulations (1997) as amended. Risk assessment of such sites has already commenced in some local authority areas. In 2005 the EPA estimated that there were approximately 400 closed unregulated local authority landfills in Ireland. A Ministerial Direction (WIR 04/05) was issued on the 3rd May 2005 under Section 60 of the Waste Management Acts 1996 to 2005. It reminded local authorities of their responsibilities under Section 22 of the Waste Management Acts, 1996 - 2005 requiring them to carry out an inventory and risk assessment of all landfill facilities, both authorised and unauthorised, where disposal or recovery activities have taken place.

In 2007 a Code of Practice was published by the EPA to assist local authorities to comply with the requirements of Section 22 and 26 of the Waste Management Acts 1996 to 2005 (WMAs), the Ministerial Direction and any possible subsequent regulations. On foot of the Ministerial Direction, regulations have been drafted which when published will require all local authorities to comply with the requirements of the WMA though the application of the Code of Practice guidance document.

Many local authorities have already commenced the process of identifying unregulated closed landfill sites and to date the EPA indicates that up to 250 such sites have been registered. Follow on assessments have started for a small number of sites but sufficient information to assess risk in the context of the WFD will not be available before the commencement of the 2009- 2015 planning cycle.

QUARRIES

Best Practice Guidelines for quarries have been developed by the EPA "*Environmental Management in the Extractive Industry*" and the Irish Concrete Federation Environmental Code 2005. These guidelines have been referenced in the Department of the Environment, Heritage and Local Governments Guidelines for Planning Authorities document "*Quarries and Ancillary Activities*". It is envisaged that the application of best practice as outlined in these guidelines by quarry operators and the requirements for planning conditions to be met based on the application of best practice will result in a substantial improvement in the environmental performance of quarries in the future. The application of these guidelines by operators and regulators alike combined with a programme of registration of abstractions is considered to be the most effective programme of measures to address any impacts resulting in the future from the quarrying industry.

Some local authorities have granted planning permission/registration but have specified conditions which require a more comprehensive assessment of the potential impacts of quarry operations on the environment, including impacts in relation to dewatering on off-site receptors. Other conditions include requirements to install groundwater monitoring wells to assess impacts on water level and quality and measurement of abstraction rates.

It is recommended that for all proposed quarry developments or expansions where dewatering will be required at rates greater than $250m^3$/day that an assessment of the potential impact on the chemical and quantitative status of the GWB in which the development is proposed be undertaken and reported to the Environmental Protection Agency Groundwater Section. It is recommended that for all new quarry developments or expansions where a Groundwater Dependent Terrestrial Ecosystem (GWDTE) is located within 250m of the quarry that an assessment of the potential impact on the GWDTE be undertaken by an appropriately qualified environmental scientist. For such developments in karst limestone areas where the quarry is within 1km of the site such an assessment is also recommended.

GROUNDWATER LINK TO SURFACE WATER

In situations where a surface water body is of less than good status a test is applied to the underlying groundwater body (GWB) to determine whether the chemical inputs from groundwater are significantly contributing to the less than good status of the surface water body. The conditions for good chemical status are not met when the Surface Water Body (SWB) is at “less than good” status, and the relevant threshold value is exceeded in the groundwater body and groundwater is contributing 50% or more of the surface water EQS. The test focuses on pollutants that cause river / lake / transitional water bodies to be “at risk”.

As a result 101 groundwater bodies were classed as poor status and these are mainly in Galway, Roscommon and Limerick. This reflects the hydrogeology in areas with good regional flow and high vulnerability due to poor cover of soils and subsoils. Any pressures on the ground in these areas can result in nutrients easily making their way into the groundwater from there transported to by horizontal flow in the aquifer to discharge zones such as streams and rivers. In these areas, the surface water body status will not achieve “good status” if measures are focused only on the rivers. Focus also needs to be placed on groundwater as a pathway for nutrients to surface waters and measures placed on activities on the ground in these areas.

LOCAL AUTHORITY ACTION / IMPLEMENTATION PLAN

If River Basin Management Plans are not to sit on the shelf gathering dust, local authorities will have to develop action plans for their implementation. These plans will need to be developed individually by local authorities to match their resources and the particular pressures within their functional areas. Cross county boundary issues will require coordination and the action plan will also require integration with the RCMEI (Recommended Minimum Criteria for Environmental Inspections) Plan. The plan will require the input of groundwater professionals and coordination with other WFD stakeholders through a management process.

CONCLUSIONS

As can be seen from the foregoing, local authorities have considerable responsibilities and objectives in relation to groundwater under the WFD. However local authorities will not be in a position to achieve these objectives without significant input and coordination of actions with all other bodies involved in the WFD process. It is this coordination role which may prove to be the biggest challenge for local authorities and indeed other public bodies and NGO's as historically, coordination of actions has not been pursued.

THE EU WATER FRAMEWORK DIRECTIVE IN IRELAND AND THE GROUNDWATER INFORMATION RENAISSANCE

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ABSTRACT

The WFD has acted as a catalyst for the completion and initiation of many datasets and information sources. The information sources fall into three general categories: maps, reports and monitoring data.

During the 'Initial Characterisation' phase of the WFD (2001-2004), the focus was on mapping, for use in general characterisation and initial risk assessments. Documentation from the 'Initial Characterisation' phase concentrated on implementation guidance, and what was reported on the first risk assessment. Existing monitoring networks were assessed and upgraded.

In the 'Further Characterisation' phase of the WFD (2005-2009), new monitoring data have come on-stream. Several important studies, designed for more in-depth investigations into specific groundwater risks, have concluded.

In summary, in the last eight years there has been a wealth of new, highly relevant and useful information created. However, many in the groundwater community are unaware of these resources. It is the aim of this paper, therefore, to describe the outputs of relevance to groundwater practitioners, and give details of how to find the information. It focuses on information generated to meet the WFD's requirements for groundwater, but also details relevant information from other disciplines, such as hydrology. It also indicates how groundwater information has been crucial in meeting the WFD's requirements in other areas, such as hydrology and limnology.

INTRODUCTION

The introduction of the EU Water Framework Directive in December 2000 (2000/60/EC) acted as a catalyst for the acquisition and processing of new data, creation of new datasets, and commissioning of new studies, in order to meet its requirements. In the last eight years, State and semi-State organisations and the private sector have been working together to meet the goals set by the WFD implementation timetable. The work programme had many milestones, but comprised three main phases: the 'Initial Characterisation' (IC) phase of the WFD (2001-2005), the 'Further Characterisation' (FC) phase of the WFD (2006-present) and the interim classification of groundwater bodies (2008). Combined, these phases make up the first River Basin Cycle. We will be entering the second River Basin Cycle in 2010.

In the groundwater sphere, many organisations and people have contributed to the increased body of knowledge.

State and semi-State organisations providing data include the Geological Survey of Ireland (GSI, primary geological and hydrogeological mapping, hydrogeological databases), Teagasc (primary soils and subsoils mapping), the Environmental Protection Agency (EPA, monitoring data, guidance), Local Authorities and River Basin Districts (RBDs).

The Working Group on Groundwater (WGW) has played a key part in establishing the methodologies that have underpinned how, in practice, the WFD has been implemented. The WGW was established under the aegis of the WFD Technical Co-ordination Group to assist in the technical interpretation of the Directive, and to provide guidance for River Basin Projects on the delivery and implementation of work strategies to meet the groundwater requirements of the WFD. The organisations and companies contributing to the work of the WGW include the EPA, GSI, the Geological Survey of Northern Ireland (GSNI), National Parks and Wildlife Service (NWPS), Department of Heritage and Local Government (DEHLG), Teagasc, consultants from each of the RBDs, and academic staff from TCD and QUB.

The RBDs were managed by representatives from Local Authorities, with much of the work being undertaken by consultants from the private sector reporting to the RBD co-ordinators. The RBD consultants have been critical in creating groundwater information, in both Initial and Further Characterisation phases. At an RBD level, they collated much of the additional information required, such as abstraction data. At a national level, they undertook some of the Initial Characterisation studies and many of the Further Characterisation studies.

In terms of the new information available, it is important to remember that it is not only ‘conventional’ groundwater information that is of use. There is much of use from other areas, such as river flows and river water quality from the upgraded hydrology network.

Broadly, the information sources fall into three general categories, with a fourth category defined by how the information is accessed:

1. groundwater-related map data,
2. groundwater-related monitoring data,
3. groundwater-related documents and other information,
4. information and data delivery.

The datasets are described briefly in the sections below.

GROUNDWATER-RELATED MAP DATA

The majority of new maps created for use in meeting WFD requirements were generated or completed during the Initial Characterisation phase of the WFD. In this phase, the focus was on general characterisation and initial risk assessments. The production of relevant spatial data played a key part in achieving these objectives. Table 1 summarises the key groundwater datasets.

The datasets listed in Table 1 have been crucial in both the Article 5 Risk Assessment and Further Characterisation studies. Many of the data have also been used in surface water studies. For example, the calcareous/non-calcareous map was created to allow characterisation of lakes for which no physico-chemical data were available. The basic hydrogeological maps (i.e. aquifer, vulnerability, subsoil permeability) maps were used, together with other data, in deriving low flows (Q_{95}) in ungauged catchments.

Table 1: Key groundwater-related map data

Data Type	Name	Data origin	Description	Availability
National Map	Rock Unit Group map	GSI	Simplified bedrock geology map – basis of bedrock aquifer map.	Follow links from GSI website – **http://www.gsi.ie/Mapping.htm** or access online maps directly from **http://spatial.dcenr.gov.ie/imf/imf.jsp?site=Groundwater**
	Bedrock and Sand/Gravel Aquifer maps		As named.	
	Interim Groundwater Vulnerability map	GSI & RBD consultants	Full (GSI) and interim (GSI/RBD consultant) mapping. Interim maps delineate only extreme and high-low vulnerability areas.	
	Subsoils map	Teagasc	Describes subsoil type and origin. Incorporates much of GSI Quaternary and outcrop mapping.	
	Soils map		Based on soils map. Shallow/deep acid/basic/peat/alluvium soils delineated. Also, wet/dry soils.	From EPA website **http://www.epa.ie/** or access directly from **http://maps.epa.ie/InternetMapViewer/mapviewer.aspx**
	Subsoil permeability map	GSI	Map of subsoil permeability units, with high, moderate or low categories.	Will be hosted on the GSI's Webmapping site. **http://spatial.dcenr.gov.ie/imf/imf.jsp?site=Groundwater**
	Groundwater recharge map	GSI/EPA/ Compass Informatics/ WGW	Map created for Abstraction Risk Assessment. Based on recharge coefficients in documents GW5 and GW8 (see Table 3) and input maps.	
	Calcareous/non-calcareous aquifer map	GSI	Map created to assist in lake characterisation. See document GW3 (Table 3) for details.	
	Groundwater Body map	GSI & RBD consultants	A GWB is a management unit that subdivides large geographical areas of aquifer so they can be effectively managed. The reports contain descriptions of the areas, related data, and simple hydrogeological conceptual models.	From EPA website **http://www.epa.ie/** Will shortly be hosted on **http://www.gsi.ie/Mapping.htm**
	Groundwater Body reports			GWB descriptions available as PDFs from **http://www.gsi.ie/Programmes/Groundwater/Projects/Groundwater+Body+Descriptions.htm** Will be hyperlinked to GWB map on GSI site.
	Groundwater-dependent terrestrial ecosystems (GWDTEs)	NPWS	As named.	Contact NPWS. Additional GWDTEs are to be delineated in the next RBMP
	Pressures (livestock units, tillage, location of point source pressures)	EPA& RBD consultants	Corine landcover (1990, 2000), Forest cover, Rural Environmental Protection Scheme; Active IPPC and Waste Enforcement licenses	Follow link from EPA website **http://www.epa.ie/** or access maps directly from **http://maps.epa.ie/InternetMapViewer/mapviewer.aspx**
	Article 5 Risk Assessments	EPA & RBD consultants	All water bodies were assessed and given a score based on the likelihood of them achieving or retaining good status by 2015. See Article 5 RA documentation listed in Table 3.	
	'Watermaps'	DELHG	Presents data on waterbody status, risks, objectives and measures, shows colour coded maps linking to detailed waterbody reports.	**http://watermaps.wfdireland.ie/** and **http://www.wfdireland.ie/maps.html**

In addition to the data layers described above that were employed directly in WFD risk assessments, monitoring point representativity analysis and hydrological studies, there are further relevant data available on the Department of Communications, Energy and Natural Resources webmapper (**http://spatial.dcenr.gov.ie/imf/imf.jsp?site=GSI_Simple**), such as EMD's minerals investigation boreholes database, GSI's karst tracing, geotechnical investigation data and reports, bedrock boreholes, groundwater boreholes. The EPA's website also has considerably more information than listed in the tables in this paper, with numerous reports and databases available for download, and maps displayed through their online mapviewer.

GROUNDWATER-RELATED MONITORING DATA

A critical assessment of the groundwater quality and water level monitoring network was made during the Initial Characterisation phase, with new potential monitoring locations identified by each of the RBDs.

The EPA is tasked with implementing the National Groundwater Monitoring Programme. Upgraded groundwater quality and level monitoring networks have been developed, by applying representativity criteria established by the WGW to fundamental hydrogeological map data. In some cases, entirely new monitoring locations have been established, and new data, such as weir-measured spring flows, have been acquired. In December 2006, these updated networks were reported to the EC. Improvements have continued since then and, in early 2009, the networks consist of:

- 215 groundwater quality sampling locations (the majority of which are existing water supplies with abstractions >100 m^3/d);
- 60 boreholes that have been installed (at different depths) to facilitate groundwater quality and level monitoring in five different "poorly productive" bedrock catchments. These boreholes have been installed in Galway granites, Pre-Cambrian rocks of north Mayo, Pre-Cambrian rocks in a cross-border GWB in Donegal, Lower Palaeozoic rocks in Louth, Old Red Sandstone in Cork and impure limestones in Meath.
- 75 groundwater level locations (with data loggers recording water level at 15 minute intervals installed);
- Weirs and equipment that have been installed at 25 springs to record water level and flow (these sites are a subset of the groundwater quality network);
- Additional monitoring data from selected point source monitoring, e.g. from IPPC licensed activities, GSI mine surveys etc. have been utilised for the assessment of point source pressures within groundwater bodies;
- Additional groundwater level and quality monitoring is planned at selected wetlands (GWDTEs) during the next planning cycle of the WFD.

Environmental data, including groundwater quality data, will be collected through the Environmental Data Exchange Network (EDEN). EDEN is a centralised information exchange for environmental monitoring data. Contributors to the EDEN system include the EPA, RBDs, DEHLG, Department of Agriculture, Local Authorities, Private Labs, Marine Institute, Central Fisheries Board and Health Boards. EDEN provides a central portal to submit environmental data remotely and to exchange this data with all parties authorised for environmental monitoring.

In the future, the EPA will provide supplementary information on groundwater monitoring points on its website, with folders containing basic hydrogeological information on each monitoring site and water quality and water level data.

Basic information on the EPA's national monitoring programme is available on the EPA website: http://www.epa.ie/whatwedo/monitoring/water/groundwater/. Table 2 summarises the available groundwater-related monitoring data, and how it is accessed.

Table 2: Key groundwater-related monitoring data

Data Type	Name	Data origin	Description	Availability
Database	Groundwater Monitoring Network	EPA/LAs	Groundwater quality and groundwater level monitoring	**http://www.epa.ie/downloads/pubs/water/other/wfd/**
Webviewer	Groundwater Monitoring Network	EPA/LAs	Groundwater quality and groundwater level locations	**http://maps.epa.ie/InternetMapViewer/mapviewer.aspx**
Database	Groundwater Quality data	EPA/LAs	Groundwater quality data (samples every 3 months) for selected determinands	Phase II of EDEN database development to include groundwater (once completed, GW data will be uploaded to EDEN). Data currently available on request from EPA
Database	Groundwater Level and Flow from springs data	EPA/LAs	15 min interval data logger records, historical GWL dips and digitised GSI chart data (for selected sites)	Data currently available on request from EPA (with the view that the data will be available on EPA website in the future)
Files	Monitoring site folders	RBD consul-tants	Site information on each of the monitoring sites	Being updated. Once completed, data will be uploaded to EPA website for download
Web-based data portal	EDEN data repository	DEHLG	Web-based data hub for uploading & downloading water data generated by EPA, DEHLG, LA & relevant stakeholders	**https://www.edenireland.ie/Home/Home.aspx**

In addition to specific groundwater monitoring data, the EPA provide the following online data that are useful for groundwater studies:

- Hydrometric data via EPA HydroNet (http://hydronet.epa.ie/introduction.htm). These data comprise surface water levels and flows. The locations of the hydrometric stations can be downloaded in tabular format, or viewed through the EPA webviewer.
- The OPW also provide hydrometric data, which can be accessed at http://www.opw.ie/hydro/index.asp.
- River and lake water quality data, which can be accessed through the EPA webviewer. The Q Value system is used, which quantitatively describes the relationship between water quality and the macroinvertibrate community.
- Results of lake and river water Article 5 risk assessments can also be accessed through the EPA webviewer.

GROUNDWATER-RELATED DOCUMENTS AND OTHER INFORMATION

Documentation from the Initial Characterisation phase focussed on implementation guidance, and reported on the first risk assessment (the ‘Article 5’ risk assessment). The Further Characterisation phase saw the initiation of several important studies that were designed to investigate in more detail certain risks posed to groundwater. These studies have concluded and reported on. Key reports are listed below and summarised in Table 3.

- Eleven Guidance documents were produced by, or on behalf of, the WGW during Initial Characterisation. They provided guidelines to RBDs on how the WFD requirements should be implemented for groundwaters. There was particular emphasis on the technical aspects of the Article 5 Risk Assessment, although one report focussed on groundwater chemistry;
- ‘Article 5’ Risk Assessments were completed in early 2005, with the production of reports and maps. These are, in the main, predictive risk assessments for groundwaters and surface waters of the likelihood of them achieving or retaining good status by 2015;

- During Further Characterisation, more detailed studies were undertaken on a variety of themes that were felt to be important for groundwater quality and quantity, or where inadequate information existed at the Initial Characterisation phase. Study themes included the risk to groundwater from: diffuse mobile organics; historic mining activities; and unsewered wastewater treatment systems. The conclusions and recommendation from these studies will be used to inform the Programmes of Measures (POMs) implemented in the next River Basin cycle;
- In 2007, Significant Water Management Issues (SWMI) booklets were produced for each RBD. The reports were for information and consultation, with the aim of encouraging active involvement of all interested parties in the WFD. They were issued two years before the beginning of the river basin management plan;
- Draft River Basin Management Plans (RBMPs) were published at the end of 2008, and are open for consultation until 22nd June 2009. The draft plans provide an assessment of the current status of our water bodies, propose the environmental objectives to be achieved, and suggest the measures that will be required in order to achieve these objectives. The measures proposed in the draft plans include a range of existing measures (e.g. implementation of the Nitrates Regulations), and also a range of supplementary measures for consideration;
- In addition to reports, images visualising some of the complex processes underpinning the water environment and its management under the WFD were created. The images go under the banner ‘WFDVisual’, and were created on behalf of SNIFFER, EA, GSI, and EPA.

Table 3: Key reports

Data Type	**Name**	**Data origin**	**Description**	**Availability**
Guidance Document	Technical requirements for groundwater and related aspects (GW1)	WGW, 2002-2004	Interpretation of the WFD requirements as applied to groundwater.	Follow links from **http://www.wfdireland.ie/WFDCharRep.htm**
	Approach to delineation of Groundwater Bodies (GW2)		Outlines the approach to delineating groundwater bodies.	
	The Calcareous/ Non-Calcareous (“siliceous”) classification of bedrock aquifers in the Republic of Ireland (GW3)		Indicator of the susceptibility of surface water to acidification as a function of groundwater buffering capacity.	
	Guidance on pressures and impacts methodology (GW4)		Pressures and impacts ‘risk assessment’ approach to decide whether water bodies are ‘at risk’ of failing to meet the WFD’s environmental objectives.	
	Guidance on the assessment of the impact of groundwater abstractions (GW5)		Abstraction impacts on GWBs and on groundwater dependent terrestrial ecosystems (GWDTEs). Has table outlining recharge coefficients.	
	Advice on the implementation of guidance on monitoring groundwater (GW6)		Provides technical interpretation and guidance for the monitoring of groundwater in Ireland.	
	Point source pressure risk assessment for groundwaters (GW7)		Sets out the data requirements and criteria for deciding whether a groundwater body is at risk of failing to achieve environmental objectives due to point source pressures.	
	Methodology for risk characterisation of Ireland’s groundwater (GW8)		Detailed methodology and criteria for undertaking the risk characterisation of groundwater in Ireland.	

Data Type	Name	Data origin	Description	Availability
	Guidance on the assessment of pressures and impacts on groundwater dependent terrestrial ecosystems Risk Assessment Sheet GWDTERA2a – Turloughs (GW9)		Assessment of risk to turlough GWDTEs from phosphate.	
	Verifying the predictive risk assessment methodology for mobile diffuse inorganic pollutants (NO_3) (GW10)		Describes the development and verification of the predictive risk assessment methodology for Risk Assessments that consider the impact of diffuse inorganics (such as nitrate) on the chemical status of the groundwater bodies.	
	Guidance on the application of groundwater risk assessment sheets SWRA 1-6 and GWDTERA 1-9 to areas designated for the protection of habitats and species (GW11)		Assessment of risk to areas designated for the protection of habitats and species from groundwater abstraction and diffuse and point source pollutants.	
Initial Charac-terisation Report	Article 5 – The Characterisation and Analysis of Ireland's River Basin Districts	EPA/RBDs/ LAs, 2005	Comprehensive assessment of all waters (groundwater, rivers, lakes, transitional and coastal waters). Established baseline and identified priority actions for subsequent stages in the river basin planning cycle.	Follow links from **http://www.wfdireland.ie/WFDCharRep.htm**
Significant Water Management Issues (SWMI)	'Water Matters' reports	RBDs/ LAs/ EPA, 2007	Interim overview of the significant water management issues in the river basin, made available for public and users comment over 6 month consultation period. Complies with Article 14 of the WFD.	**http://www.wfdireland.ie/docs/13_WaterMattersBookletsAndBackgroundDocs/**
Further Characterisation Report	Establishing Natural Background Levels for groundwater in Ireland	Southeastern RBD & O'Callaghan Moran Assoc., 2007.	Establishes Natural Background Levels (NBL) for Irish groundwaters. Part of larger process involving the establishment of Environmental Quality Standards (EQS) for all waters.	Available on request from EPA.
	Risk to groundwater from diffuse mobile organics	Eastern RBD & CDM, 2008	Develops and implements revised risk assessment methodology for national assessment of risk to groundwater from diffuse mobile organics.	**http://www.wfdireland.ie/docs/25_DiffuseMobileOrganics/**
	An integrated approach to quantifying groundwater and surface water contributions to stream flow	Southwestern RBD & RPS, 2008	Estimate contribution of groundwater to surface waters, esp. river flows. Results input to GW quality thresholds for chemical parameters that are linked to SW body EQS requirements.	**http://www.wfdireland.ie/docs/18_SurfacewaterGroundwaterInteraction/**
	Groundwater Abstractions Pressure Assessment	Eastern RBD & CDM, 2009	Updates national register of groundwater abstractions and national risk assessment of groundwater abstractions; Develops technical guidance towards establishing future GW abstraction licensing system.	**http://www.wfdireland.ie/docs/24_Abstractions/**
	Groundwater Urban Pressure Assessment	Eastern RBD & CDM, 2009	Explores environmental risk and impact to groundwater from urban pressures.	**http://www.wfdireland.ie/docs/28_UrbanPressures/**

Data Type	Name	Data origin	Description	Availability
	Unsewered Wastewater Treatment Systems. National Study	Western RBD & ESBI, 2008	Risk assessment decision support tool, providing pressure layer information, pathway risk mapping and receptor sensitivity mapping. Allows LAs to evaluate the potential impact of existing systems and to predict the potential impact of proposed systems.	**http://www.wfdireland.ie/docs/23_UnseweredWasteWaterTreatmentSystems/**
	WFD Risk Assessment Update	South Eastern RBD, 2008	Summarises the results of updates on foot of FC studies, and provides a revised overall risk assessment.	**http://www.wfdireland.ie/docs/WFD%20Risk%20Assesment%20Update.pdf**
	Further Characterisation Study Historic Mining Activities	ShIRBD & GSI, 2009	In preparation	Will be hosted on **www.wfdireland.ie/docs/**
RBMPs	Draft River Basin management Plans for • Eastern, • North Eastern, • North Western, • Neagh Bann, • Shannon, • South Eastern, • South Western and • Western RBDs	RBDs/ LAs/ EPA, 2008	Provide an assessment of the current status of our water bodies, propose the environmental objectives to be achieved, and suggest the measures which will be required in order to achieve these objectives.	**http://www.wfdireland.ie/docs/1_DraftRiverBasinManagementPlans/**
	Draft River Basin Management Plans: National summary of programme of measures	Western RBD & ESBI, 2008	Report prepared to inform the development of River Basin Management Plans for RBDs	**http://www.wfdireland.ie/docs/National%20Summary%20Programme%20of%20Measures.pdf**
Visual-isation	WFD Visual	EA/GSI/EPA/ GSNI/ SNIFFER	Library of images depicting groundwater concepts and its management.	**http://www.wfdvisual.com**

There are more documents than listed above available through WFD Ireland (**www.wfdireland.ie/**), and it is worth having a browse through the various sub-sections. There has also been a number of related papers presented in recent years at national and international conferences. The papers presented at the IAH (Irish Group) Conference and at the National Hydrology Seminar are listed in Section 8, below (References/Bibliography).

INFORMATION DISSEMINATION

A significant part of the WFD implementation is concerned with public participation and consultation. Hence, easy access to data and information is a central aim. As can be seen from the preceding tables, a key medium for providing information is via the internet.

Information on the Water Framework Directive, and its implementation in Ireland, can be found at http://www.wfdireland.ie. This is the vehicle for many of the documents described in Section 3. It is also a portal for links to the individual RBD websites, and State bodies who have contributed to the WFD implementation over the last eight years.

The main mapping websites are those from the GSI, EPA and NPWS. Key websites for relevant WFD information are given in Table 4.

Table 4 Useful web-based resources

Name	URL	Information type
WFD Ireland	**http://www.wfdireland.ie/**	Documents, 'Watermaps'.
EU WFD	**http://europa.eu.int/comm/environment/water/water-framework/index_en.html.**	Documents.
RBDs	Eastern: **http://www.erbd.ie/**; Southeastern: **http://www.serbd.ie/**; Southwestern: **http://www.swrbd.ie/**; Western: **http://www.wrbd.ie/** ; Shannon International: **http://www.shannonrbd.com/**; Northwestern International: **http://www.nwirbd.com/**; Neagh Bann International: **http://www.nbirbd.com/**; Northeastern: **http://www.nerbd.com/**.	Reports, consultation documents, presentations, data.
EPA	**http://www.epa.ie/**	Map data, groundwater quality and level data, hydrometric data, surface water quality data.
DEHLG	**http://www.environ.ie/en/Environment/Water/WaterQuality/WaterFrameworkDirective/**	Overview, legislation, updates.
GSI	**http://www.gsi.ie/**	Map data, Documents.
Teagasc	**http://www.teagasc.ie/**	Map data.
NPWS	**http://www.npws.ie/**	Map data, Documents.
WFDVisual	**http://www.wfdvisual.com/**	Images.

FUTURE

Although a vast amount has been achieved in the last eight years, work is still ongoing in terms of data and information generation and acquisition. Of particular note are:

- The planned completion of the GSI's groundwater vulnerability mapping by consultants, facilitated by National Development Plan funding. This will feed into greater coverage of Groundwater Protection Scheme maps, the subsoil permeability map and the groundwater recharge map;
- Ongoing monitoring by the EPA of water quality and levels, including installation of new boreholes and spring weirs;
- Improved delineation of source protection zones around EPA monitoring points;
- Updated physical and risk characterisation of groundwater bodies by the EPA in 2011;
- In 2009, identification by the EPA of sustained upward trends in pollution;
- Academic studies at QUB and TCD utilising the new monitoring network in poorly productive fissured aquifers, which will contribute to improved understanding of groundwater flow in these aquifers. Multi-annual research funding comes from the GSI's Griffiths Awards and the EPA's STRIVE Programme.
- Improved webmapping content and delivery from both the GSI and EPA.

SUMMARY

This paper has described the outputs of relevance to groundwater practitioners, and given details of how to find the information. The main focus of this paper is on information generated to meet the WFD's requirements for groundwater. It has also highlighted relevant information from other disciplines, such as hydrology, and indicated how groundwater information has been crucial to meeting the WFD's requirements in other areas, such as hydrology and limnology.

In the last eight years, there has been a wealth of new, highly relevant and useful groundwater information created, with the aim of helping Ireland to meet the objectives of the WFD. As we approach the end of the first River Basin Cycle, the rate of creation of new datasets and information sources is decreasing. However, there are still exciting developments ongoing, such as: the planned completion of the GSI's groundwater vulnerability mapping; ongoing monitoring by the EPA of water quality and levels, including upgraded monitoring locations (e.g. spring weirs) and monitoring point characterisation; EPA- and GSI-funded academic studies utilising the new monitoring network in poorly productive aquifers and continuously improving webmapping resources.

ACKNOWLEDGEMENTS

Many people within and allied to the groundwater community have contributed significantly to the increase in groundwater information in the last eight or so years. They include staff from the State bodies, Local Authorities and consultants to the RBDs. Due to space constraints, individuals are not listed here; consultation of many of the documents described in this paper will indicate authorship or contributors, however. The consultants to each of the RBDs are as follows:

Shannon International RBD: RPS KMM, Golder (UK).
Eastern RBD: CDM, Compass Informatics.
South Eastern RBD: RPS, Mott McDonald, O'Callaghan Moran & Associates.
South Western RBD: RPS, Mott McDonald, Jacob Babties, O'Callaghan Moran & Associates.
Western RBD: ESBI, O'Neill Groundwater Engineers, WYG, WRC plc.
North Western RBD: RPS KMM, O'Callaghan Moran & Associates, Jennings O'Donovan, Compass Informatics, TCD, UU Coleraine.
Neagh Bann RBD: RPS KMM, Jennings O'Donovan, Compass Informatics, TCD.

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The EU Water Framework Directive
James Hunt, Environment Agency (England and Wales)
The EU Water Framework Directive in Ireland
David Moore, DELG

22nd Annual IAH Seminar: GROUNDWATER QUALITY: CURRENT ISSUES AND CONCERNS
16-17 April 2002, Tullamore Court Hotel, Co. Offaly
Water Framework Directive – An Overview of Groundwater Aspects
Donal Daly, GSI

25th Annual IAH Conference: GROUNDWATER IN IRELAND ~ 25TH ANNIVERSARY CONFERENCE
19-20 April 2005, Tullamore Court Hotel, Co. Offaly
River Basin Districts – Overview of scope and results from all components of the work

Grace Glasgow, Kirk McClure Morton
Physical characterisation and risk characterisation of river basin districts: groundwater aspects
Donal Daly, Geological Survey of Ireland.
Groundwater monitoring for implementation of the Water Framework Directive; initial results and assessment
Sean Moran and Gerry Baker, O'Callaghan Moran Associates.
River Basin Districts – The Future – monitoring, classification and programme of measures
Pat Duggan, Department of Environment and Local Government

26th Annual IAH Conference: "It doesn't just go away, you know…" SUDS and Groundwater Monitoring
25-26 April 2006, Tullamore Court Hotel, Co. Offaly
The Draft EU Directive on the Protection of Groundwater Against Pollution: a Summary and an Assessment of the Likely Implications
Donal Daly, Geological Survey of Ireland, Matthew Craig, Environmental Protection Agency, Garrett Kilroy, EPA Research Fellow, Trinity College, Dublin.
Screening Methodology for the Water Framework Directive Water Quality Monitoring Network
Matthew Craig, Environmental Protection Agency, Dublin, Henning Moe, CDM Ireland Ltd., Dublin, Natalya Hunter Williams, Geological Survey of Ireland, Dublin.
Establishing Natural Background Levels for Groundwater in Ireland
Gerry Baker, Donal Crean and Sean Moran, O'Callaghan Moran & Associates, Cork.

27th Annual IAH Conference: Groundwater: Opportunities and Pressures
24-25 April 2007, Tullamore Court Hotel, Co. Offaly
Agricultural Pressure – farm and national scale case studies & risk assessment
Monica Lee & Pamela Bartley, GSI & Hydro-G
A national assessment of groundwater abstraction pressures
Henning Moe & Donal Daly, CDM & EPA

National Hydrology Seminar: Hydrology Applications – Modelling – Data Issues
13 November, 2007, Tullamore Court Hotel, Co. Offaly
An Integrated Approach to Quantifying Groundwater and Surface Water Contributions of Stream Flow, GIS (Geographic Information Systems)
Jennings, S., Elsaesser, B., Baker, G., Bree, T., Daly, D., Fitzpatrick, J., Glasgow, G., Hunter Williams, N.

National Hydrology Seminar: Hydrology and Spatial Planning
13 November, 2008, Tullamore Court Hotel, Co. Offaly
Groundwater Vulnerability Mapping
Lee, M., Hunter Williams, N., Meehan, R., Kelly, C., Kabza, M., Murphy, O. and Spillane, M.

Session II

TECHNICAL GUIDANCE TOWARDS GROUNDWATER ABSTRACTION LICENSING IN IRELAND

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ABSTRACT

Primary legislation to cover groundwater abstraction licensing in Ireland does not yet exist. A recently completed national study on groundwater abstraction pressures (CDM, 2009) has explored a potentially suitable licensing framework modelled on recent legislation in Northern Ireland and Scotland. The framework is risk-based, whereby environmental risk increases with higher abstraction rates and proximity to groundwater users, receptors, and seawater. The consideration of a future abstraction licensing system is in direct response to the EU Water Framework Directive (WFD) which specifically requires that member states introduce abstraction controls that include a Register of abstractions and a system of "prior authorisation".

This paper summarises the technical contents of a proposed licensing framework, and addresses water management topics that are central to the WFD, notably: availability of groundwater resources; environmental supporting conditions of groundwater dependent terrestrial ecosystems; groundwater-surface water interactions; and saline intrusion. Abstraction thresholds and distance criteria are proposed which trigger different levels of impact assessment during the licensing process.

Future licensing would have implications for all participants in the process, and the roll-out of a new licensing system will need to be accompanied by training programmes geared towards local authorities and practitioners within the groundwater industry, including drillers. Proper well construction practices are strongly promoted within the licensing framework.

INTRODUCTION

Growing water demands across Ireland highlights the need for an updated regulatory framework for water resources management. The increasing use and reliance on groundwater implies a need for improved controls on new and planned abstraction schemes. As well, Article 11.3(e) (Programme of Measures) of the WFD specifically requires:

"controls over the abstraction of fresh surface water and groundwater, and impoundment of fresh surface water, including a register or registers of water abstractions and a requirement for prior authorisation for abstraction and impoundment. These controls shall be periodically reviewed and, where necessary updated. Member states can exempt from these controls, abstractions and impoundments which have no significant impact on water status."

The current practice of "prior authorisation" in Ireland is linked to two primary sets of regulations:

- Statutory Instrument (S.I.) No. 93 of 1999 (EC (EIA) (Amendment) Regulations, 1999); and
- Planning and Development Regulations, 2001.

The existing legislation does not fully meet WFD requirements. First, registers are not consistently kept or maintained. Second, the current system of prior authorisation tends to be implemented only for larger schemes. Third, current practice does not explicitly consider the technical elements that are integral to water resources management under the WFD. A consistent system of abstractions licensing is regarded as a suitable mechanism to ensure that relevant water management topics are adequately explored and quantified as part of WFD implementation. As such, the introduction of a future licensing system would be a significant measure in the context of WFD implementation in Ireland.

WFD STATUS OBJECTIVES

The overall WFD status objective is to achieve "good" status of all water types and associated ecosystems by 2015. This applies to both water quantities and quality. In the context of abstractions, the WFD objective is to achieve "good" *quantitative* status, as defined in Annex V of the WFD. Ireland, like all EU member states, will be required to report on groundwater body status nationally every 6 years. Thus, WFD status objectives must be integrated into the licensing guidance.

An initial status classification was recently undertaken by the EPA (EPA, 2008). In classifying Irish groundwater bodies, EPA applied a set of 'tests' that were carried out against specific criteria and thresholds that define good status (UKTAG, 2007) and which relate to the following water management topics:

- Water balances (of groundwater bodies);
- Groundwater and surface water interactions – i.e., groundwater abstraction impacts to surface water bodies;
- The environmental supporting conditions of groundwater dependent terrestrial ecosystems (GWDTEs); and
- Saline intrusion.

Assessment of water balance components are complex, and require knowledge of all (cumulative) abstractions in relation to the "available groundwater resource" within a groundwater body. Per EPA's test methodology (UKTAG, 2007), good quantitative status objectives are met when the "available groundwater resource is not exceeded by the long term annual average rate of abstraction". The "available groundwater resource" is defined as:

"the long-term annual average recharge over the groundwater body less the long-term annual rate of flow required to achieve the ecological quality objectives for associated surface water……, to avoid any significant diminution in the ecological status of such waters, and to avoid any significant damage to associated terrestrial ecosystems".

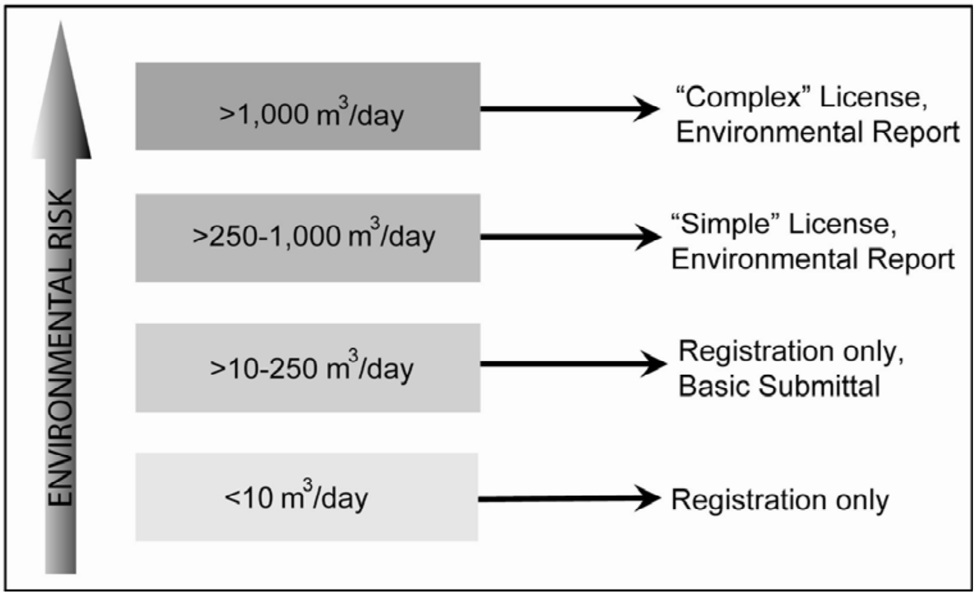
The status tests therefore take into account the ecological needs of rivers (e.g., flow requirements) and the environmental supporting conditions of GWDTEs within the groundwater body.

The need to define ecological flows and environmental supporting conditions of rivers and GWDTEs poses a particular challenge to hydrologists, aquatic ecologists, and fisheries officials alike, as these are frequently not known without considerable study or measurement.

PROPOSED LICENSING FRAMEWORK

The proposed groundwater abstraction licensing framework is shown in Figure 1, and is modelled on recent legislation in Scotland and Northern Ireland. A risk-based approach would be adopted whereby licensing requirements and levels of impact assessment increase in detail and complexity with higher abstraction rates and proximity to important groundwater users, receptors or saline waters.

Figure 1:



Proposed Licensing Framework

Potential impacts of groundwater abstractions would initially be screened against a set of basic criteria and thresholds, as follows:

- Total abstraction rate of the proposed scheme;
- Distance of individual abstraction points from rivers or lakes;
- Distance of individual abstraction points from a GWDTE or a special area of conservation (SAC) with qualifying interests;
- Distance of individual abstraction points from the coastline or other saline water body.

A groundwater abstraction scheme is defined by the sum total abstraction rate (m^3/day) and ultimately, the total number of wells or springs that provide the total quantity to be supplied from the same scheme. A scheme consisting of multiple abstraction points would be assessed in its totality unless hydrogeologic reasoning dictates that the scheme can be justifiably divided into different components.

The screening process is shown schematically in Figure 2. An application would initially be screened to flag potential issues that may have to be looked at in closer detail with study, monitoring and technical assessment. While it is envisaged that the majority of applications can be processed swiftly from initial screening, larger schemes or those involving sensitive receptors will require site-specific assessment.

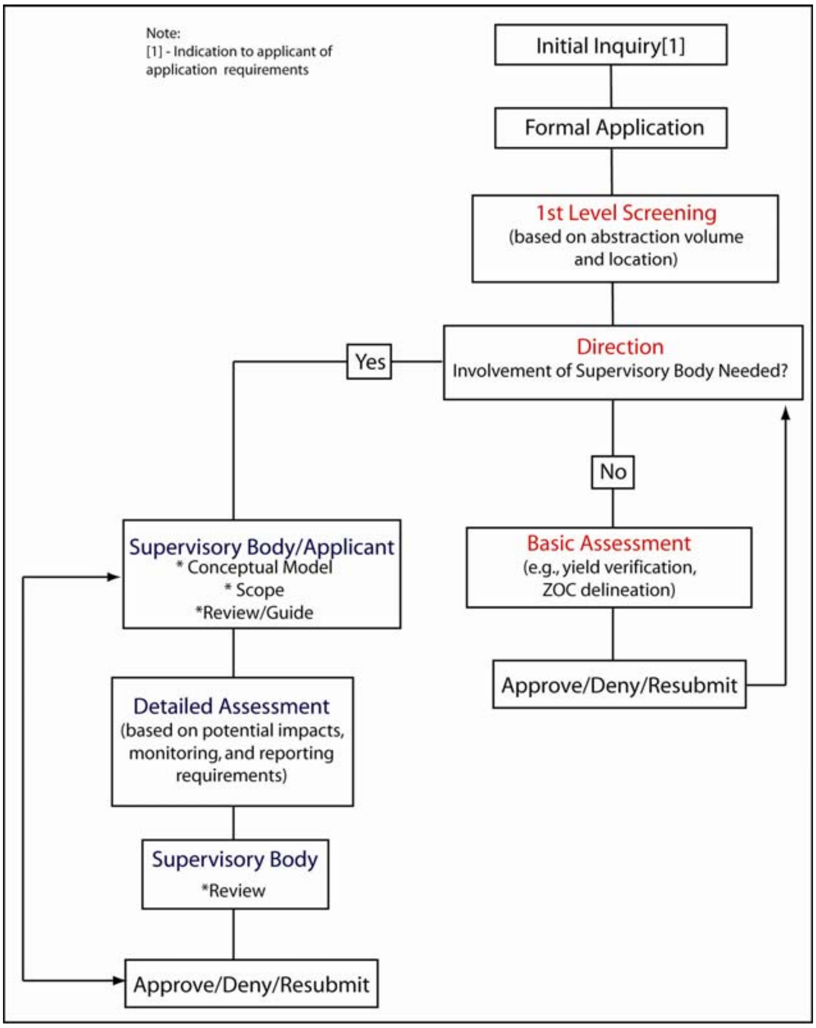


Figure 2: Proposed Screening Process

All applications would be screened and processed on an individual basis. The licensing body would check each application in context of other users and groundwater receptors within the same groundwater body. Uncertain or conflicting matters would be flagged by the licensing body and referred to a supervisory body for review and further decision-making.

During initial screening, applications would be checked against EPA's status classification of water bodies that are associated with the proposed abstraction scheme. If the related groundwater body or associated groundwater receptor is flagged as being at less than good status due to abstraction pressures, then the application would be deferred to the supervisory body to clarify the specific reason for the poor status classification. It is expected that subsequent processing of the application would be led by the supervisory body.

Poor quantitative status of a groundwater body does not necessarily impose a ban on additional groundwater abstractions. Because many groundwater bodies in Ireland are very large, and a particular poor status case may be caused by a localised problem, further groundwater abstraction in another area of the same groundwater body may be permitted.

If initial screening indicates that a higher degree of complexity is involved, the intent would be to ensure that qualified individual or organisations are involved in defining the level of ecological and hydrogeological assessment that may be necessary. It is therefore important to ensure that the initial screening process captures the essential technical requirements needed to assess impact. In certain defined cases, it is envisaged that the supervisory body would assist in the scoping, review and approval of technical study and assessment (and ultimately approval of a licence).

ABSTRACTION THRESHOLDS AND SCREENING CRITERIA

The proposed abstraction thresholds that would be used in the screening process were shown in Figure 1 and are summarised in Table 1.

Table 1: Proposed Abstraction Thresholds for Screening of Abstraction Schemes

Abstraction Threshold (m^3/day)	Action from Screening	% of Known Abstractions in Present Abstraction Register
<10	Approval, Registration only	36
>10-250	Approval in most cases, Registration only. Abstractions >100 m^3/day and <250 m from a GWDTE or SAC boundary would require an Environmental Report.	46
>250-1,000	Environmental Report required, “simple” licence	12
>1,000	Environmental Report required, “complex” licence	6

Abstractions <10 m^3/day would be automatically approved, and the abstractions would simply be registered with an x,y-location, name, and intended use. The same is true for abstractions >10-250 m^3/day, except in situations where the proposed scheme exceeds 100 m^3/day and is located within 250 m of a GWDTE boundary or a special area of conservation (SAC) with qualifying interests (Peer Review Group, 2008).

Abstraction schemes <250 m^3/day are generally not expected to result in significant impact (Peer Review Group, 2008). Abstractions >250 m^3/day would require impact assessment and the submittal of an Environmental Report under screening criteria which are summarised in Table 2.

PROPOSED LEVELS OF ASSESSMENT

The proposed levels of assessment for the different abstraction categories are summarised below. Higher abstraction rates imply an increased level of assessment and greater complexity in study, monitoring and reporting.

Abstraction Category >10-250 m^3/day

Abstraction schemes >10-250 m^3/day would be deemed authorised without a prescribed level of environmental assessment, with the exception of the scenario defined in Table 2. Registration is required and the following basic information would be submitted to EPA and local authorities as good practice:

- Well construction diagrams;
- Aquifer test data;
- Water quality results.

All abstraction schemes >100 m^3/day would be subject to annual reporting of the volumes of water pumped.

Table 2: Abstraction Categories Requiring Environmental Reports

Abstraction Category	Conditions Requiring an Environmental Report	Conditions Requiring and Environmental Report and Consultation with the Supervisory Body
100 – 250 m^3/day		
GWTDE	--	If <250 m from a designated or mapped GWDTE, or an SAC with qualifying interests
250-1,000 m^3/day		
River or Lake	If >500 m from a river or lake of good quantitative or ecological status	If <500 m from a river or lake of good quantitative and ecological status, or if downgradient river/lake is of poor status
GWTDE	If >1 km of a designated or mapped GWDTE, or an SAC with qualifying interests	If <1 km of a designated or mapped GWDTE, or an SAC with qualifying interests
Saline Intrusion	If >1 km from source of saline water for PPAs*; > 5 km for other aquifer types	If <1 km from source of saline water for PPAs*; >5 km for other aquifer types
Existing Abstraction Schemes (>10 m^3/day)	If >3 km from the estimated ZOC of the existing abstractor	If <3 km from the estimated ZOC of the existing abstractor
>1,000 m^3/day		
All applications are referred automatically to the supervisory body.		

Note:
*PPA = poorly productive aquifers (GSI aquifer categories Pl, Pu, Ll)

Abstraction Categories >250 m^3/day

Abstraction schemes >250 m^3/day would require the applicant to prepare and submit an Environmental Report (ER). The ER should contain all information and data that is relevant to decision making. Proposals have been made for the "minimum" content of an ER (CDM, 2009) and it is acknowledged that each ER will be a stand-alone document that addresses site-specific characteristics. Because of the site-specific nature of hydrogeology and the groundwater dependence of different types of ecosystems, assessing hydraulic responses to pumping will vary from one location to another, and will require some degree of monitoring.

Rule-based decision-making is not regarded as appropriate for abstraction schemes >1,000 m^3/d. For this reason, it is proposed that all applications for new or expanded schemes >1,000 m^3/d be directed automatically to the supervisory body for initial consultation on the type and level of assessment that may be required. A conceptual model of the abstraction scheme and the associated hydrogeological setting should be prepared and submitted by the applicant prior to the scoping meeting, as a basis for discussion. In this way, the licensing process takes immediate stock of relevant topics and expertise that may be needed to steer the impact assessment in the right technical direction.

Public or private supply schemes that are intended for human consumption, directly or indirectly (e.g., food processing) would require the development of Source Protection Areas following the guidance established (principally) by the GSI (GSI/DELG/EPA, 1999). Such schemes would also have to prove compliance with drinking water standards.

All schemes >250 m^3/day would be required to maintain and submit annual reports of quantities of water pumped, and where applicable, related environmental monitoring data and reports as stipulated by licence conditions.

OTHER MEASURES

In context of future WFD implementation in Ireland and improved water resources management generally, the national groundwater abstractions pressure assessment study (CDM, 2009) has identified high-priority topics that are licensing-related and that merit future consideration, as described below.

Improvements to the National Register of Abstractions

The existing national Register of groundwater abstractions has been significantly improved with the implementation of river basin district projects in Ireland, but considerable data gaps remain with respect to private non-domestic and industrial abstractions. As future licensing is not likely to apply retro-actively, it is recommended that targeted abstraction surveys be carried out in the following sectors of users: food and drinks industry; golf courses, quarries, and manufacturing.

Well Construction Practices

There are presently no statutory regulations or comprehensive guidelines concerning the drilling industry in Ireland. As a result, there are inconsistent standards of construction and decommissioning of boreholes. New abstraction and associated monitoring wells should be constructed such that they provide reliable data from the aquifer and hydrogeological setting they represent. Improperly constructed wells can provide misleading data resulting in false or erroneous interpretations of local hydrogeology.

Proper well construction practices would therefore be formally promoted in the licensing framework. A mandatory well construction code is regarded as a necessary means of achieving good construction practice. It is therefore proposed that the well construction documentation available through the IGI (IGI, 2007) be used as a starting point towards establishing a code of good well construction practice. Non-compliance could result in licences not being granted.

The introduction of a well construction code would have to be accompanied with an awareness and training programme that would not be limited to well drilling firms, but also local authority personnel and water supply practitioners.

A registration or certification programme of well drilling firms would be another means of promoting good construction standards, but this would require an entirely different level of effort and approach, and would hold further (financial and operational) implications for well drillers.

Information Management

The potential introduction of a licensing system for groundwater abstractions would generate a wealth of new data and information. There are five broad classes of information that would have to be deposited, processed and maintained: Licence applications; Environmental reports; Monitoring data; Licence decisions (and terms and conditions); and a Register of abstractions.

The submittal and processing of licence applications should be managed through an appropriate information management system (IMS). Similarly, monitoring data and environmental reports would be processed and accessed through a database linked to a national Register of abstraction as well as a repository of reports that can be accessed for any given abstraction scheme, whether a licence is granted or not.

It is envisaged that an IMS could be accessible to both the applicant and the licensing or supervisory body, each in different ways. The IMS would be web-based and could be a single application or a combination of applications between different sources of information. The functionality that is assigned to the IMS could have a tremendous impact on water resources management practices and the general dissemination of water related information to the public and professionals alike.

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STATUS CLASSIFICATION OF GROUNDWATER BODIES CONTAINING CLOSED MINE SITES FOR THE WATER FRAMEWORK DIRECTIVE

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Geological Survey of Ireland

ABSTRACT

The GSI (Geological Survey of Ireland) carried out a review of the status of GWBs (Groundwater Bodies) containing closed mine sites to determine if the mines were having an impact on groundwater quality, in the context of the Water Framework Directive. In all, 11 former mine sites were investigated using the General Chemistry Test devised for the purpose by the EPA (Environmental Protection Agency). In addition to determining the status of the GWB, an assessment of whether the GWBs were at risk was made.

*The following GWBs were found to be at '**Poor**' Status (and therefore are also "At Risk") and it is recommended that they be put forward as candidates for LSO (Less Stringent Objective).*

Mine	***GWB Name(s)***	***GWB Code(s)***
Avoca	*Wicklow Central (Avoca Mine)*	*IE_EA_G_007*
Glendalough	*Wicklow Central (Avoca Mine)*	*IE_EA_G_007*
Silvermines	*Nenagh_1*	*IE_SH_G_178*
GL2	*IE_SH_G_094*	
Tynagh	*Tynagh*	*IE_SH_G_236*
Tynagh 1	*IE_SH_G_237*	

INTRODUCTION

The Minerals Section of the Geological Survey of Ireland (GSI) carried out a classification of Groundwater Bodies (GWB) which were potentially contaminated as a result of former mining activity for the Water Framework Directive. The GSI appliedthe General Geochemical Test to GWB for point sources of contamination as represented by Closed Mines.

The following information or decisions had been developed by others for the seven River Basin Districts, including:

a. 4,460 Surface Water Bodies (delineated by the EPA).

b. 757 Groundwater Bodies ('parent' GWBs delineated by GSI; 'daughter' GWBs delineated by River Basin District (RBD) consultants).

c. Eleven closed mine sites (Table 1) identified as potential point sources of pollution of the GWBs within which they are situated (identified by RBD consultants, with advice from EMD and GSI Minerals Section).

d. A General Chemical Test (Section 3) for determining the Status and Risk Designation of GWBs (developed by the EPA).

e. Hydrochemical data for the GWBs within which the closed mine sites are situated (provided by the EPA).

Mine or Mine District	Minerals Extracted
Abbeytown	Zinc - lead
Avoca	Copper and pyrite
Clare phosphates	Phosphates
Connaught	Coal
Glendalough	Lead
Gortdrum	Copper and mercury
Kanturk	Coal
Leinster	Coal
Silvermines	Zinc - lead
Slieve Ardagh	Coal
Tynagh	Zinc - lead

Table 1 The eleven closed mine sites drawn up as potential pollution sources

THE GENERAL CHEMICAL TEST

The General Chemical test was to be applied so as to classify the potentially affected GWB as either "**Good Status**" or "**Poor Status**". Those GWBs that classified as "**Poor Status**" would become potential candidates for LSO **(Less Stringent Objectives)** under the Water Framework Directive. The GWBs were also to be designated with respect to the risk posed by the former mine sites.

OUTLINE OF THE TEST

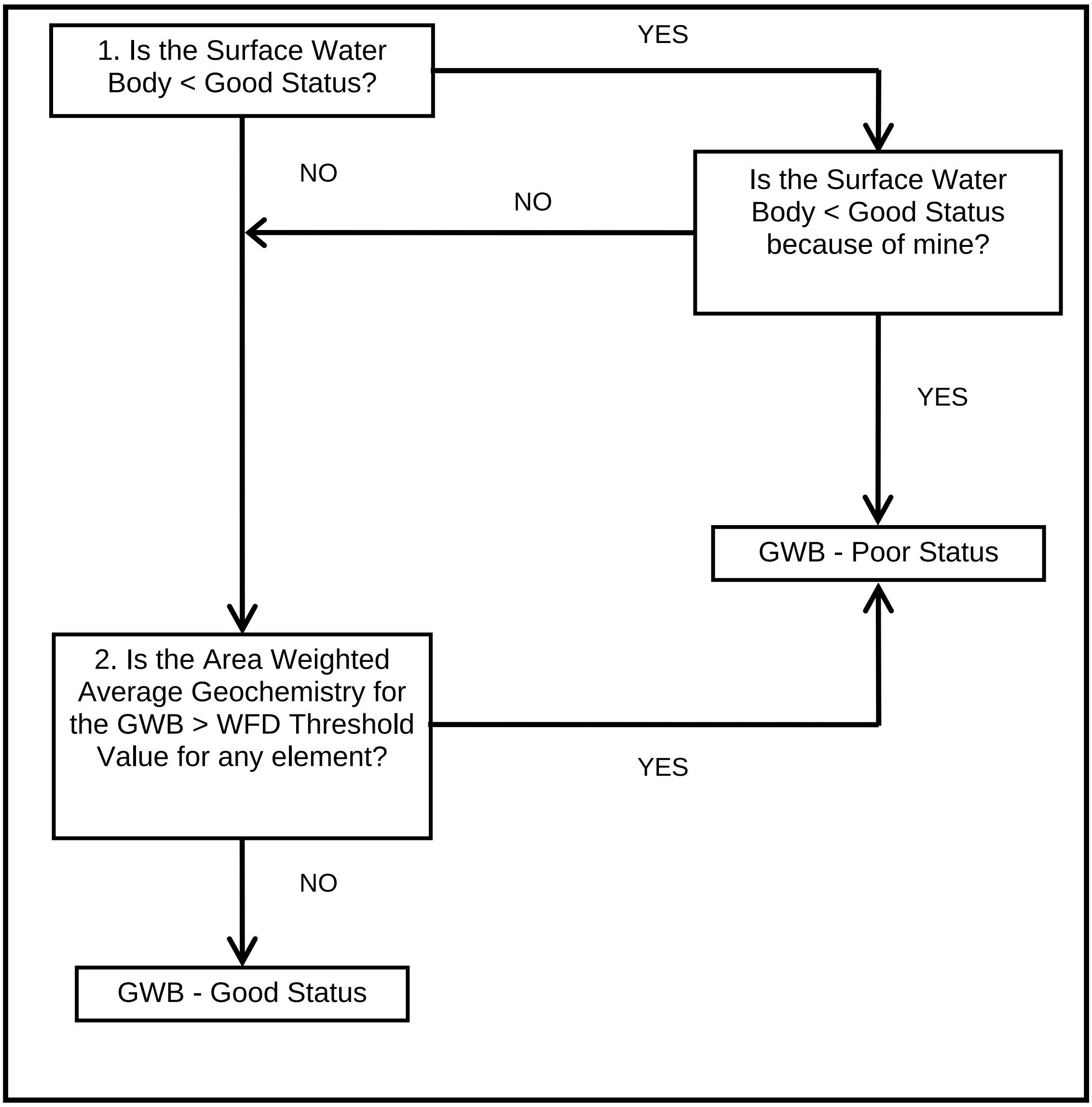
The General Chemical Test as applied to mines is depicted graphically in Figure 1.

Simply, the General Chemical Test asks two questions. The first seeks to know if the Surface Water Body (SWB) within which the closed mine site lies is at "Less than Good Status because of mining activities", i.e. it is not at "Less than Good Status" for diffuse physico-chemical or biological reasons. If YES then the GWB is at POOR STATUS. If NO then the second question is put.

The second question asks whether the weighted GWB-wide average concentration of any pollutant that can be related to the closed mine is greater than the national threshold value (TV) set by the EPA (these are calculated as 75% of the standard set in the Drinking Water Standards). If the answer to the question is YES then the GWB within which the closed mine site lies will be at "POOR STATUS" and the GWB is a potential candidate for LSO. If the answer to this question is NO then the GWB is classified as at "GOOD STATUS".

In terms of assessing whether the GWB is At Risk or Not at Risk the guidance in Table 2 was received from the EPA:

Figure 1 The General Chemical Test.



Status	Risk Designation	Criterion for assessing Risk Designation
POOR	At Risk – High Confidence	Significant known impacts
GOOD	At Risk – High Confidence	Mine impacting on the entire GWB
GOOD	At Risk – Low Confidence	Local impact from mine
GOOD	Not at Risk – Low Confidence	No real impact on the GWB
GOOD	Not at Risk – High Confidence	No mine in the GWB

Table 2 Guidance for assigning Risk Status to Groundwater Bodies.

INFORMATION REQUIREMENTS

In order to apply the test the following data are required:

Question 1:

Status Classification of the SWB
Reason for Classification of the SWB

Question 2:
Hydrochemistry
a. GWB hydrochemistry within the potential contaminated area
OR
b. Discharge water chemistry from closed mine sites
OR
c. Leach Test results from samples from closed mine sites
AND
GWB hydrochemistry outside the potential contaminated area

2. Areas
a. Potential Contaminant Plume
AND
b. Remainder of GWB

In addition the Threshold Values are required.

The Status Classification of SWBs has been determined by the consultants to the seven River Basin Districts in consultation with the Environmental Protection Agency (EPA) with the reason for this classification clearly recorded. This is all that is required for Question 1.

For Question 2 the hydrochemical data that are required to assess for the potentially contaminated mine areas have been assembled by the Minerals Section of the GSI as part of the Historic Mine Sites – Inventory Risk Classification (HMS-IRC) project. The HMS-IRC project is being carried out jointly between the Department of Communications, Energy and Natural Resources (DCENR) and the EPA. The HMS-IRC project is being carried out, in part, to comply with Article 20 of Directive 2006/21/EC of the European Parliament and of the Council on the management of waste from extractive industries and amending Directive 2004/35/EC. In addition analyses were made available from the Avoca and Silvermines former mine sites, which are the subject of additional work by the Department of Communications, Energy and Natural Resources.

Three options are possible for GWB hydrochemistry within a potentially contaminated area: either GWB hydrochemistry from wells OR discharge water chemistry from adits OR leach test results from samples. These are in order of preference from closed mine sites. Groundwater sampled from wells within the potentially contaminated area is the preferred information source. If these data do not exist then adit discharges from mines is the next preferred data source. Adit discharges represent groundwater which is channelled through underground mine workings and which exit from the mine workings via a mine adit. If these do not exist then the results from a leach test are used. Groundwater chemistry is simulated by taking a sample of mine waste, immersing it in distilled water, agitating the water with the mine waste for a specified time and then analysing a filtered sample of the water. Water generated in this way simulates rain water falling onto a waste pile which becomes groundwater by infiltration into the waste pile.

In the case of the elements Fe (iron) and Mn (manganese) contamination may arise from a number of sources, both natural and anthropogenic, including mining. However, as it is not practical to determine the actual source of either Fe or Mn, it was decided to remove these elements from the analysis, on the advice of the EPA.

Hydrochemical data for uncontaminated areas of GWBs were provided by the EPA.

In this study the area of the potential contamination within the GWB for each closed mine site was drawn by the GSI with the assistance of staff from the EPA and the Shannon RBD Team. This took

account of the mine site and groundwater flow to adjacent surface water bodies, and was measured in a GIS environment.
The area of the uncontaminated GWB was obtained by subtracting the area of the potentially contaminated GWB from the total area of the GWB as provided by the EPA.

APPLYING THE TEST

The test was applied to all eleven sites. The GWBs in Table 3 are of '**Good'** status based on the General Chemistry Test as applied in this study.

Mine	GWB Name(s)	GWB Code(s)	Risk Designation
Abbeytown	Carrowmore West	IE_WE_G_0040	At risk – low confidence
Castlecomer, Leinster Coalfield	Newtown Newtown-A Castlecomer Castlecomer-A Castlecomer-B Castlecomer-C	IE_SE_G_104 IE_SE_G_105 IE_SE_G_034 IE_SE_G_035 IE_SE_G_036 IE_SE_G_037	At Risk – Low Confidence
Clare Phosphates	Milltown Malbay Slieve Elva	IE_SH_G_167 IE_SH_G_212	Not at Risk – low confidence
Connaught East Coalfield	Lough Allen Uplands_4 Anierin-Cuilcagh East	IE_SH_G_161 IEGBNI_NW_G_035	Not at Risk – low confidence
Connaught West Coalfield	Lough Allen Uplands Lough Allen Uplands-1	IEGBNI_SH_G_002 IE_SH_G_158	At Risk – Low Confidence
Gortdrum	Slieve Phelim Slieve Phelim_7	IE_SH_G_213 IE_SH_G_220	At risk – low confidence
Kanturk	Kanturk	IE_SW_G_039	Not at risk – low confidence
Slieve Ardagh Coalfield	Slieve Ardagh Hills Ballingarry Killenaule	IE_SE_G_126 IE_SH_G_022 IE_SE_G_081	At risk – low confidence

Table 3 GWBs determined as being at **Good** status based on the General Chemical test and their Risk designations.

The GWBs in Table 4 are of '**Poor'** status based on the General Chemistry Test as applied to Closed Mine Sites in this study and are therefore potential candidates for LSO.

Mine	GWB Name(s)	GWB Code(s)
Avoca	Wicklow Central (Avoca Mine)	IE_EA_G_007
Glendalough	Wicklow Central (Avoca Mine)	IE_EA_G_007
Silvermines	Nenagh_1 GL2	IE_SH_G_178 IE_SH_G_094
Tynagh	Tynagh Tynagh 1	IE_SH_G_236 IE_SH_G_237

Table 4 GWBs determined as being at 'Poor' status based on the General Chemistry Test. Note: all GWBs determined to be at '**Poor**' status are designated **At Risk – High Confidence**.

RECOMMENDATION

It is recommended that the following GWBs be put forward as candidates for LSO:

Mine	GWB Name(s)	GWB Code(s)
Avoca	Wicklow Central (Avoca Mine)	IE_EA_G_007
Glendalough	Wicklow Central (Avoca Mine)	IE_EA_G_007
Silvermines	Nenagh_1	IE_SH_G_178
GL2		IE_SH_G_094
Tynagh	Tynagh	IE_SH_G_236
Tynagh 1		IE_SH_G_237

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SPRING INTO ACTION – SPRING AND STREAMFLOW MONITORING TO MEET WFD AND RELATED HYDROMETRIC REQUIREMENTS

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ABSTRACT

As part of a number of European Framework initiatives the Republic of Ireland embarked on a programme of works to rehabilitate its springflow monitoring network. Historically the springflow monitoring network consisted mainly of a combination of rated sections, informal controls and thin plate weirs. Many of the existing structures had fallen into a state of disrepair and needed reconstruction; other important springflow sources had not been previously monitored on a continuous basis. Problems caused by unstable natural controls, aquatic weed growth, poor foundation conditions and non-modular flows at structures were given due consideration. The final rehabilitated network consisting of 23 gauging stations consists of a combination of thin plate and flat-v weirs, rated sections and the use of acoustic flow monitoring technologies. The uncertainties in flow data were considered at the investigation and the design stage. It is generally believed that the network is capable of obtaining flow data to uncertainty levels of within 10 – 15% at 95% confidence level at the majority of the new and rehabilitated gauging stations at all but the most extreme low flows.

1.0 INTRODUCTION

As part of the European Framework Directive 2000/06/EC to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater throughout Europe, surface water monitoring is required. In the Republic of Ireland part of the programme involved the improvement of continuous monitoring at a number of spring sources throughout the country. At many of the sites, flow monitoring infrastructure already existed, while at other locations no continuous monitoring had been previously undertaken. Where infrastructure already existed it was generally in a poor state of repair or inadequate for purpose. The springflow monitoring project was administered on behalf of the River Basin Districts in Ireland and the Environmental Protection Agency (EPA) by Carlow County Council. This paper describes some of the work that has been undertaken in the implementation of the surface water monitoring programme, including some of the hydrometric issues encountered, the solutions adopted and a consideration of the potential uncertainties in the derived flow data.

2.0 SPRING FLOW MONITORING IN IRELAND

2.1 BACKGROUND

The physical nature of the Irish bedrock means that it is very difficult to develop a representative borehole network. Therefore, the borehole network development has concentrated on monitoring points with relatively large zones of contribution. The density of monitoring points in the EPA national water level and quality networks is far lower than the average for the other EU countries. However, relative to other European countries there are many large springs in the regionally important aquifers. Therefore, the EPA wished to develop a high quality network of spring monitoring sites. These have relatively large catchments which are far larger on average than the wells in the monitoring network. Therefore the springs have the potential to provide monitoring data representative of relatively large areas. The direct measurement of the flow from the springs will supplement the understanding of groundwater transport and when used in conjunction with water quality data, provides vital information on pollutant loading to surface water

Responsibility for spring flow monitoring in the Republic of Ireland is shared between the EPA and the councils. The former tend to be responsible for the data collection while the latter look after the maintenance of the monitoring infrastructure, including aquatic vegetation clearance. At many of the important spring sources in Ireland monitoring infrastructure has been installed and maintained in the past. However, some of the installations had reached the end of their design life and entered into a state of disrepair. For example some of the existing flow measurement structures were found to be leaking very badly. Increasing demands on water supplies dependent on spring sources, while at the same time not compromising the aquatic environment, resulted in the need to re-establish and improve the earlier springflow monitoring programme. The springflow monitoring rehabilitation programme took place between August 2007 and early 2009. A total of 35 sites were investigated and 23 were subsequently implemented.

The site investigations were usually undertaken by a team consisting of a hydrologist and a civil engineer. They included detailed topographic/cross-sectional surveys, current meter gauging flow measurements, a visual inspection of ground and other conditions such as aquatic vegetation growth, ease of access and health and safety assessments. Hydraulic analysis was undertaken for most of the sites to assist with technique selection and to try and assess the impact of the proposed installations on upstream water levels. This sometimes included the use of simple 1D models. Provisional assessments of the likely uncertainties in the flow determinations associated with the techniques under consideration. The relevant hydrometric staff from the EPA were involved throughout the project from the initial site visits, through the design and construction phases to the final signing off of the sites. Their contributions and local site knowledge was invaluable and greatly appreciated by all concerned with the implementation of the project.

2.2 SPRING CHARACTERISTICS

The physical characteristics of the springs vary considerably. Therefore it was not possible to adopt a single, or even several standard designs. Each spring had to be considered on its own merits. Some of the characteristics that were of importance in designing the monitoring installations are summarised as follows:

1. Flow range: There were no continuous flow data readily available for the spring sources. However, the EPA undertook several spot gaugings at the majority of the sites through the summer of 2007. These coupled with additional gaugings undertaken at the detailed site survey stage were used to aid the selection and design of the monitoring method. The lowest gauged flows at the sites varied from less than 10 ls^{-1} to of the order of 200 ls^{-1} but at some of the sites flows of the order of 1000 l/s had been gauged.
2. Location of water supplies relative to monitoring points: The impact of the proposed monitoring, installation on upstream water levels, particularly if flow monitoring structures were being considered was assessed.
3. Foundation conditions: Quite a number of the springs were located at sites where the receiving watercourse bed material and surrounding channels was relatively deep peat. At such locations it is often difficult to construct flow measuring structures that will remain stable within a reasonable budget.
4. Aquatic vegetation growth: Many of the sites experience rapid and dense aquatic weed growth. Aquatic plants and hydrometry are not good companions. There is no easy solution to dealing with watercourses which experience aquatic weed growth. However, whenever possible the chosen solution was selected to try and help mitigate the problems of weed growth.
5. Health and safety and access considerations.

3.0 POTENTIAL FLOW MONITORING TECHNIQUES

3.1 STREAMFLOW MEASUREMENT IN IRELAND

The main methods used for continuous streamflow measurement, including springs, in the Republic of Ireland have been:

1. Rated sections: stage (water level) – discharge relationships derived by current meter gauging. The problem with rated sections is that they require considerable gauging effort and the stage-discharge relationships can be unstable due to seasonal changes in vegetation growth and other variable backwater affects.
2. Informal controls: these are either structures that have been installed for another purpose e.g. mill weir, or those that have been installed to aid flow measurement by stabilising the stage-discharge relationship. They also usually need considerable calibration effort.
3. Purpose built flow measurement structures that comply with the relevant International Standard: Rectangular thin plate weirs and v-notches are the type of structure that has been used most regularly for springflow measurement Ireland. Provided they are well maintained, constructed in accordance with the relevant standard and operated within their design range, flow measurement structures are capable of producing good quality flow data. However, design process requires that the modular limit (see Section 3.2.2) is maximised while the amount of afflux is minimised.

In recent years acoustic streamflow monitoring technologies have been used more extensively throughout the world as alternatives to the more conventional techniques listed above. At the outset of the springflow measurement project the use of acoustic technologies was avoided since the EPA had little previous experience of these devices. However, it became apparent as the investigations progressed that there could be significant advantages in utilising acoustic technologies at some of the sites.

3.2 FLOW MEASUREMENT STRUCTURES

3.2.1 Structures considered

Three types of flow measurement structure were preferred:

1. Rectangular thin plate weirs (ISO 1438:2008);
2. V-notches (ISO 1438:2008);
3. Flat-v weirs (ISO 4377:2002).

In addition to the above compound thin plate weirs (combinations of 1 & 2) were also designed and constructed. Consideration was given to other types of structure including triangular profile horizontal crested (Crump) weirs, broad-crested weirs and flumes. These were not considered further for a number of reasons including low flow sensitivity (accuracy) and modular limits.

V-notches were generally the preferred structure at smaller springflow sites. At some locations compound thin plate weirs had already been installed. Where appropriate these were replaced with structures with similar dimensions and crest levels so as to maintain the status quo. Flat-v weirs were installed where it was necessary to measure quite a wide range of flows. The v-shaped crest gives far better low flow sensitivity than a horizontal crested structure. In addition flat-v weirs with 1:2 upstream and 1:5 downstream slopes have quite high modular limits (see below).

3.2.2 Modular and non-modular flows

If the upstream water level or stage at a structure is influenced by downstream water levels the structure becomes non-modular. If the flow is non-modular and the standard formula is used to derive the discharge, the flow will be overestimated. Downstream water levels can rise due to the influence of high flows in the downstream channel(s) or due to dense aquatic weed growth. It is rare in natural watercourses to be able to construct a flow measurement structure that can accommodate the full range of flows within the modular limit. A number of the sites investigated were observed to experience very dense aquatic weed growth. Therefore when site conditions allowed the weir crests were kept as high as possible to try and minimise the amount of downstream channel clearance. Nevertheless, it is essential that the downstream aquatic vegetation growth is controlled.

Flat-v weirs with 1:2 upstream and 1:5 downstream slopes have relatively high modular limits. In addition, there is a methodology for adjusting flows if flat-v weirs go non-modular using downstream water level measurements [Ackers, et al (1978) & ISO 4377, (2002)]. The discharge equation for a flat-v is normally expressed in terms of the total head (H_1) as follows:

$$Q = C_{DE}(\sqrt{g})mZ_H H_{1e}^{\frac{5}{2}} \qquad \text{Equation 1}$$

where:

C_{DE} = effective coefficient of discharge in the modular range

m = mean crest slope

Z_H = shape factor = 1 when the flow is within the v.

H_{1e} = effective upstream total head

$$H_{1e} = H_1 - k_h = h_1 + \frac{\alpha v_1^2}{2g} - k_h \qquad \text{Equation 2}$$

Where v_1 = velocity in the approach channel

h_1 = stage/upstream water level

k_h = head correction factor

When the flow at a flat-v weir gauging station is non-modular the discharge can be determined using:

$$Q = C_{DE}C_{dr}(\sqrt{g})mZ_H H_{1e}^{\frac{5}{2}} \qquad \text{Equation 3}$$

where C_{dr} is the drowned flow reduction factor

The drowned flow reduction factor can be estimated using downstream water levels using equations of the following form:

$$C_{dr} = fn\left(\frac{H_{2e}}{H_{1e}}\right) \qquad \text{Equation 4}$$

Where H_{2e} = total downstream head

The modular limit for a flat-v weir occurs when the downstream stage measured relative to the lowest crest level reaches about 70% of the stage. Therefore, if downstream water level recorders are installed at flat-v weirs it is possible to ascertain when the weir goes non-modular. The downstream stage data can also be used to calculate the non-modular flow adjustment factor. Once the weir becomes totally submerged, i.e. there is no discernible head difference across the structure it is no longer possible to undertake the adjustment.

Provision has been made at several of the flat-v weir installations for the installation of downstream water level recorders. At the very least, the operation of a downstream water level recorder allows the user to identify when the flow goes non-modular and flag the suspect data accordingly.

3.2.4 The impact of algae growth

The build up of algae growth on structures should be avoided. Experiences of practised hydrometrists in the south of England has shown that on some watercourses it is not unusual to get about 10 mm of algae growth over a 1 – 2 month period. It is therefore essential to clean the crests and throats of flow measurement weirs and flumes on a regular basis. Figure 1 shows the potential errors that can occur at a flat-v weir with 1:10 cross slopes, due to 5 mm and 10 mm of algae growth respectively. From this it can be seen that when the discharge is the design minimum of about 13 ls^{-1}, corresponding to the minimum recommended stage of 60 mm, the flow could be overestimated by nearly 50% if the head is raised by 10 mm due to algae growth.

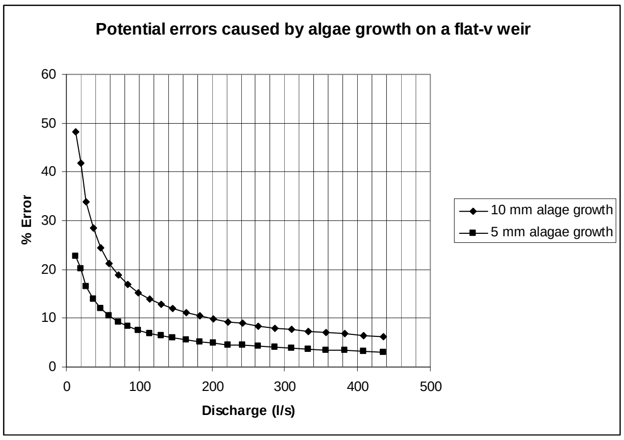

Figure 1: Graph illustrating the impact of algae growth on the performance of a flat-v weir

3.3 ACOUSTIC FLOW MEASUREMENT TECHNIQUES

3.3.1 Alternatives

As the investigations progressed it was realised that there could be some significant advantages in utilising acoustic flow monitoring techniques. There are four main categories of acoustic technologies that are currently used for velocity, and thus flow, determination. Acoustic flow monitoring techniques include:

1. Bed mounted devices that are based on the Doppler shift principle – these only sample a portion of the channel. The portion sampled is usually unknown.
2. More sophisticated range gated devices based on acoustic Doppler current profiler (ADCP) technology
3. Echo correlation devices - these look like bed mounted Dopplers but are based on a somewhat different principle.
4. Time of flight/transit time ultrasonic.

Following the investigations and detailed discussions with the EPA it was decided that the use of both time of flight/transit time ultrasonic and echo correlation devices would be appropriate for some of the sites. The devices have been used where the cost of structures was prohibitive, it was not possible to generate sufficient head loss for a structure, significant variable, backwater conditions prevailed or the ground conditions were unsuitable for construction.

3.3.2 Time of flight/transit time ultrasonic

Transit time ultrasonic river gauging is based upon the principle that the time taken for sound pulses to be transmitted through flowing water over a known distance, is different to the time taken for the pulse to travel the same distance when that water is stationary (ISO6416:2004). When pulses are transmitted at an angle to the direction of flow the speed of the pulse in the downstream direction will be enhanced by the flow of water whilst, returning in the upstream direction, the speed of the pulse will be impeded by the flow. The difference in the travel times in each direction between the same points will be proportional to the component of water velocity along the "flight path" taken by the signal. The timing difference referred to is very small (of the order of millionths of a second) but can be measured accurately electronically and the resolved component of mean velocity of water along the flight path calculated. A level sensor is also incorporated into the system. This technology has been successfully used in streamflow measurement since the nineteen seventies.

Using such systems velocities can be measured at different levels or paths. If there are sufficient paths operating within the cross-section and these are well distributed throughout the water column these devices are capable of returning accurate determinations of flow with little calibration effort. They work particularly well in clear water which is a problem with some of the Doppler technologies which require particles or reflectors in the water to function. However, significant weed growth can be a problem with time of flight systems since it can impede the transmission of the sound pulses from one bank to the other. Nevertheless this is common to all flow monitoring techniques and the amount of channel clearance required is often less than for a flow measurement structure. Time of flight ultrasonic systems can often be best installed under bridges. These can often provide a good measuring section, the abutments provide a ready made fixing support for the transducers and the shade provided often inhibits aquatic vegetation growth.

3.3.3 Echo correlation devices

The acoustic (echo) correlation method (draft ISO 15769:2009) is a relatively new development. In some ways it is similar to the ultrasonic Doppler technique. Pulses of ultrasound are transmitted from the sensor and these are reflected back off particles and disturbances in the water and the reflected echo is received as a characteristic pattern. The echo patterns from the first scan are digitally stored. A second scan is undertaken between 0.5 to 4 μs later the received echoes from which are also analysed. The cross-correlation method used by the system analyses the transmitted and received echoes. From these it is possible to determine the movement of the particle or disturbance, which can be converted directly into flow velocity.

The system divides the sampled water profile into 16 cells. Therefore the instrument defines the velocity profile in front of the sensor. Like ultrasonic Doppler devices it does not sample the full width of the channel but nevertheless provides a good estimate of what it measures. This can be used as an index velocity to determine the mean velocity in the measuring section. This is sometimes referred to as the velocity index technique (see Section 3.4). The system also has an in-built water level sensor.

These bed mounted echo correlation devices tended to be used on the springs project where there was insufficient depth for a time of flight system. Nevertheless at several sites the water level had to be raised artificially by means of cheap, simple downstream constructions e.g. rocks, to raise the water level in the measuring section.

3.4 THE USE OF VELOCITY INDEX TECHNIQUES

Velocity index techniques such as the Echo Correlation technology are velocity area methods. Discharge is therefore determined using the continuity equation,

$$Q = \overline{V} \times A \qquad \text{Equation 5}$$

Where

Q = discharge (m^3s^{-1})
$\overline{V}$ = mean velocity at instrument measuring section (ms^{-1})
A = cross-sectional area at instrument measuring section (m^2)

For many installations the velocity determined by the instrument will not be the same as the mean velocity in the measuring section since in most channels the instrument will not sample the whole of the flowing cross-section. The mean velocity is determined undertaken by using a relationship between the mean velocity and the instrument velocity, usually referred to as the index velocity. Velocity index relationships can take the following general forms:

$$\overline{V} = fn(V_i) \qquad \text{Equation 6}$$

$$\overline{V} = fn(V_i, h) \qquad \text{Equation 7}$$

Where

V_i = instrument/index velocity (ms^{-1})
h = stage (m)

The cross-sectional area is determined using a relationship between stage and cross-sectional area. This can be determined by cross-sectional survey.

The computation process is summarised as follows:

1. Mean velocity is determined from the velocity index rating, using the measured velocity and, for more complex ratings, also the stage;
2. The cross-sectional area is determined from the stage via a stage area relationship or look-up table or direct calculation from cross-sectional survey data directly input into the instrument;
3. The corresponding mean velocity and cross-sectional are multiplied to obtain the discharge.

4.0 UNCERTAINTIES IN DISCHARGE DATA

4.1 GENERAL

As stated in the EN ISO 25377:2007 'Hydrometric Uncertainty Guidance'

"All measurements of a physical quantity are subject to uncertainties.....The result of a measurement is only an estimate of the true value of the measured quantity and therefore is only complete when accompanied by a statement of its uncertainty."

And

"The discrepancy between the true and measured values is the measurement error. The error, which cannot be known, causes uncertainty about the correctness of the result."

Hydrometry is not a precise science and it is important that the users of hydrometric data are made aware of the uncertainties in the flow determinations. The uncertainty in a streamflow measurement is a combination of a number of individual measurement and assumption uncertainties. The individual uncertainties are normally combined in quadrature.

4.2 UNCERTAINTIES IN FLOWS DETERMINED USING MEASUREMENT STRUCTURES

The uncertainty (U^*_c) for a flow measurement structure is a combination of the combined uncertainties in the discharge coefficient (C_e), the structure geometry and the stage. The uncertainty in the geometry for a rectangular notch is the uncertainty in the width. For a v-notch the uncertainty in the geometry is the uncertainty in $tan(\alpha/2)$ where α equals the notch angle The stage uncertainty is a combination of instrument and gauge zero uncertainties. The uncertainty for a v-notch is given by the following equation:

$$U_c^*(Q)_v = \sqrt{u^*(C_e)^2 + u^*(tan(\alpha/2))^2 + (2.5u^*(h_e))^2} \qquad \text{Equation 9}$$

An uncertainty curve for a ½ 90^o v-notch operating within its design range is shown in Figure 2. It has been assumed that the uncertainty in the stage measuring instrument is 3 mm and the gauge zero uncertainty is 1 mm. The minimum recommended operating stage for a v-notch is 60 mm which corresponds to a discharge of 0.65 l/s for which the estimated uncertainty at the 95% confidence level is about 13.25%.

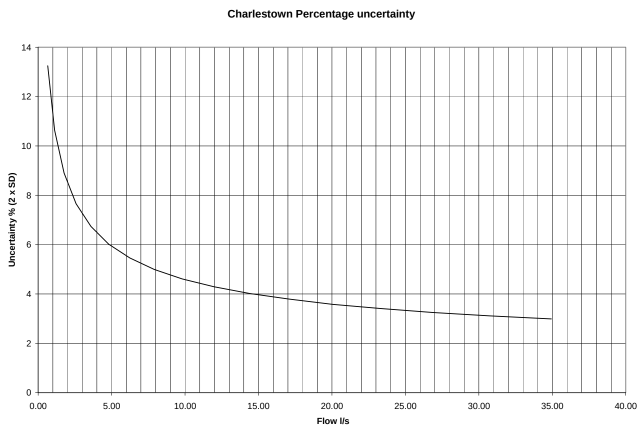

Figure 2: Example of an uncertainty curve for a thin plate weir.

By far the most significant source of overall uncertainty is the uncertainty in the stage measurement. At the majority of the spring sites float and counterweight sensors linked to shaft encoders will be used. Provision has been made in the design of the stilling wells for the use of a large diameter float (200 mm) since the error in the water level measurement is inversely proportional to float size.

Generally a well constructed and maintained flow measurement structure operating within its design range should be capable of delivering flow data to within 5 – 10% at the 95% confidence level (two standard deviations).

4.3 UNCERTAINTIES FOR OTHER TECHNIQUES

4.3.1 Velocity index techniques

The overall uncertainty can be obtained by combining the component uncertainties in quadrature. The component uncertainties are those related to the velocity index rating, the index/instrument/measured velocity, the cross-sectional area/stage area relationship and the overall uncertainty in the stage. The largest source of uncertainty is generally in the velocity index rating. Provided this is relatively stable and is defined by a reasonable amount of gaugings (min. 10 – 15) over the target flow range, it should be possible to determine discharge to within 10%.

4.3.2 Time of flight/transit time ultrasonic

The overall uncertainty is a function of uncertainties due to the limited number of paths (pairs of transducers) and their distribution in the vertical, the instrument calculated velocity, the width measurement and the stage or depth measurement. The largest source of uncertainty is likely to be the former. However, with a four path system with a well distributed array of transducers it should be possible to determine discharge at the 95% confidence level to within 5 – 10%.

4.3.3 Rated sections

The uncertainties associated with rated sections are a function of the stability and sensitivity of the control, the number of gaugings that have been used to derive the stage-discharge relationship and the overall uncertainty in the stage measurement. For stable controls a minimum of 15 gaugings is usually recommended (ISO1100-2:1998) over the target flow range. For stable controls it should be possible to determine discharges to within 10 – 15% but where variable backwater occurs due to variations in seasonal weed growth the uncertainties could be significantly larger.

5.0 REHABILITATED SPRINGFLOW NETWORK

5.1 SUMMARY

The rehabilitated springflow network consists of a mixture of flow measurements structures, rated sections, time of flight ultrasonic and echo correlation gauging stations and is summarised in Table 1 below. This network should be capable of providing flow data with uncertainties of within 10 – 15% at the 95% confidence level at all but the most extreme high flows provided the stations are operated in accordance with good hydrometric practice. However, in order to achieve this level of uncertainty it is essential as for all hydrometric networks a regular maintenance programme is agreed and implemented

Table 1: Summary of gauging station types

Gauging station type	No.
Thin plate weir	10
Flat-v weir	3
Rated section	3
Echo correlation device	3
Time of flight ultrasonic	4
TOTAL	23

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GROUNDWATER CLASSIFICATION – HOW DOES IT INFLUENCE REGULATION AT A SITE SCALE?

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Malcolm Roberts, Scottish Environmental Protection Agency

ABSTRACT

The Water Framework Directive sets-out distinct but complimentary local and water-body scale objectives for groundwater. The requirement to "prevent or limit" the input of pollutants complements status and trend objectives. Notwithstanding the time needed to enable the historical legacy of releases to degrade or disperse, if all the "prevent or limit" requirements were met everywhere within a groundwater body, point source inputs would not cause failure of good chemical status. Regulation of new and existing pollutant inputs to the level required by prevent or limit would also prevent new and halt and reverse existing upward trends in pollutant concentration.

For groundwater quality, the objectives that refer to status are complemented by the objective to "prevent or limit" the input of pollutants, and by the objective to reverse rising trends. In operating at a larger scale, status tests are "harder to fail" than those for local pollution or local over-abstraction. In this respect they will usually not be the limiting factor driving the setting of local permit values. However, they provide a valuable tool in identifying areas which are already impacted. Sitting within the River Basin Planning framework, status tests can be incorporated into catchment-scale assessments of priorities for restoration.

1 INTRODUCTION

The classification of groundwater bodies is a requirement of the Water Framework Directive (2000/60/EC) which came into force in the year 2000. Certain groundwater objectives of Article 4 of the Directive were clarified by the adoption in 2006 of an additional Groundwater Directive (2006/118/EC) for the protection of groundwater against pollution and deterioration. There is by now a widespread understanding amongst hydrogeologists of the requirements to achieve good groundwater status and ensure no deterioration of status, and of the criteria set-down in Annex V of the Water Framework Directive and in the 2006 Groundwater Directive. In fact, most hydrogeologists with 2-5 years experience have been learning about these requirements since university.

Unfortunately, dissemination of what groundwater classification actually means in practice has been much less widespread amongst regulators, developers, and other water professionals. In the experience of the authors, this has led to the development of misconceptions and uncertainty. This is particularly the case for activities such as indirect discharges to land, landfills and remediation of land contamination, which have traditionally required controls at a site specific level. For these activities, the relationship is not intuitive between conditions on individual permits and thresholds applied to groundwater bodies as a whole. Similarly, the Directives do not make it immediately obvious how permit conditions should, or shouldn't, be influenced if a site happens to lie within poor status groundwater body.

The link between the site scale and groundwater body scale objectives of the Water Framework Directive has been the subject of some discussion amongst UK and Ireland agencies and at European level. These discussions have been placed on a formal footing by the publication of the 2006 Groundwater Directive. Greater confidence is also possible since the publication of the first draft River Basin Management Plans for consultation in 2009 (SEPA, 2009). The discussions have been focused primarily through groups such as the Groundwater Task Team of the UK Technical Advisory

Group which includes members from agencies in the Republic of Ireland (EPA), Northern Ireland (EHSNI), Scotland (SEPA), and England & Wales (EA).

This paper aims to help explain what groundwater classification actually means in practice for regulators and developers, by explaining the link between the site scale and groundwater body scale objectives of the Water Framework Directive. It is aimed at hydrogeologists and other water specialists working in the private sector or for regulatory agencies and with an interest in groundwater and the Water Framework Directive. A general understanding of the concepts of the Water Framework Directive is assumed.

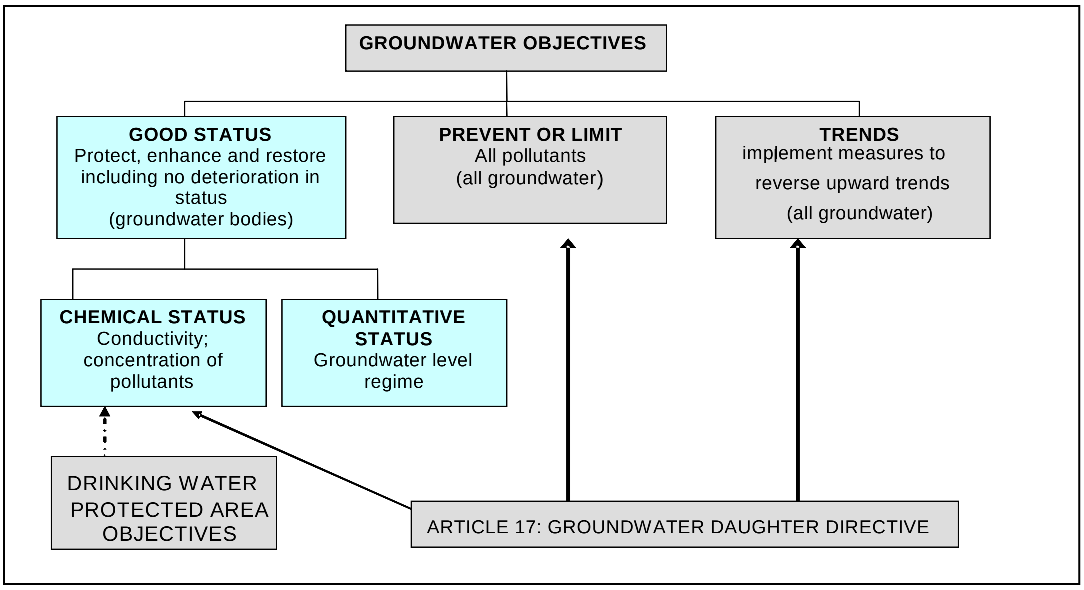
To provide some practical context the paper draws heavily on the work of the Groundwater Task Team and on the draft River Basin Management Plan for the Scotland River Basin District. Where possible, reference is also made to formal directions to SEPA by the Scottish Government. However, it is stressed that the opinions expressed in this paper are those of the authors and do not necessarily reflect the view of the Scottish Environment Protection Agency, or Scottish or UK Government policy unless specific reference is made to this policy.

2 WATER FRAMEWORK DIRECTIVE OBJECTIVES FOR GROUNDWATER

The Water Framework Directive came into force in 2000. Article 4 (1) (b) sets three key objectives for groundwater (Figure 1):

1. Achieve good status and ensure no deterioration of status;
2. "Prevent or limit" the input of pollutants; and,
3. Take measures to reverse any significant and sustained upward trends in pollutant concentrations.

Figure 1: Water Framework Directive Objectives for Groundwater



Two of these objectives (status and trends) are new – there has been no previous requirement to classify groundwater bodies into good or poor status or identify upward trends in pollutants before. “Prevent or Limit” is not new – a similar regime is already established by the original Groundwater Directive (80/68/EEC).

3. REGULATORY BACKGROUND

3.1 REGULATION OF GROUNDWATER ABSTRACTIONS

The Groundwater Task Team guidance on the application of standards to regulation (UKTAG, 2007a) states that, since the impacts of quantitative pressures (abstractions) spread widely and quickly through a groundwater body in response to changes in hydraulic pressure within the aquifer, the standards applied to individual permits will tend to closely reflect the standards required to meet good quantitative status.

3.2 REGULATION OF INPUTS OF POLLUTANTS

Following entry a pollutant is usually subject to dilution and attenuation along the groundwater flow path. The rate and direction of movement and degree of dilution and attenuation varies according to the physical and chemical characteristics of the geological strata but these factors combine to invariably lead to a gradual decrease in concentration away from the source. It can be seen that inputs may result in localised pollution by causing harm to nearby receptors but will have a much reduced or no impact on the more distant parts of the groundwater body. Point source inputs are therefore invariably regulated to protect nearby receptors.

Article 6(1) of the 2006 Groundwater Directive requires Member States to implement measures necessary to:

- Prevent *hazardous* substances from entering groundwater; and
- Limit inputs of *non-hazardous* substances into groundwater so as to ensure that such inputs do not cause deterioration, or significant and sustained upward trends in the concentration of pollutants in, groundwater.

The requirement to prevent the entry of hazardous substances is very similar to the existing requirement to prevent the entry of List I substances under 1980 Groundwater Directive (80/68/EEC). Member States are required to determine which substances are hazardous. The Groundwater Task Team guidance on the application of standards to regulation has proposed the use of List I as a starting point for this purpose.

The limit objective requires that the input of non-hazardous substances to groundwater must not cause significant and sustained upward trends and any deterioration. The Groundwater Task Team in its guidance on the application of standards to regulation has interpreted this to mean that pollution by non-hazardous substances should be prevented.

The Water Framework Directive defines pollution as "*the direct or indirect introduction, as a result of human activity, of substances or heat into the air water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems, which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment*." The Groundwater Task Team in its guidance on the application of standards to regulation has interpreted that the mere entry into, or slight deterioration in quality of groundwater, is not in itself pollution, and, for pollution to occur, there needs to be some actual or likely harmful effect to a receptor. The definition of harm encompasses the obvious receptors like groundwater dependent ecosystems or drinking water abstractions. However, the definition of harm has also been interpreted by the Groundwater Task Team to include the impairment of potential future uses of groundwater.

Subject to enabling legislation, the agencies will apply the revised prevent or limit requirements to all regulatory regimes within their control, e.g. Pollution Prevention and Control, landfill, discharges to ground, etc. In addition the requirements of the Water Framework Directive apply to other inputs of pollutants to groundwater, such as those arising from diffuse sources. Clearly, controls are required across a broad programme of measures and these are described later in this paper.

4. OUTLINE GROUNDWATER CLASSIFICATION

The design of a groundwater status classification methodology must be based on the criteria set out in Annex V of the Water Framework Directive and, for chemical status, in the 2006 Groundwater Directive. To paraphrase these requirements, groundwater is considered to be at poor status where its function as a resource for human use or for providing support to surface ecosystems is impaired. The Groundwater Task Team has recommended that status assessment be undertaken as a series of separate tests, which are generally designed to test specific impacts on receptor types (UKTAG 2007b and 2007c). The tests assess whether a groundwater body meets all the criteria set-out for good status.

In summary, there are five chemical and four quantitative tests which are applied to the groundwater body as a whole. The worst classification from the five chemical tests is reported as the overall chemical status, and the worst classification from the four quantitative tests would be reported as the overall quantitative status. An estimate of the confidence of the assigned status class is also reported.
Though the chemical tests are quite different in detail, the same general steps are followed in each test:

i. Identify risk and key pollutants.
ii. Monitor and re-evaluate risk.
iii. Set threshold value. These are set either for individual groundwater bodies or collectively at member state level.
iv. Identify if the threshold is exceeded in at least one monitoring location. If the threshold is not exceeded, the groundwater body is at good status.
v. If the threshold is exceeded, we must undertake further investigation to assess if the groundwater body is at poor status.

The nature of the further investigation is different for each chemical test, but they all use a weight of evidence approach, whereby a simple exceedence of the threshold is insufficient to classify a groundwater body as being at poor status. Examples of the chemical tests are provided below:

Drinking Water Protected Areas: The test is failed if a) a threshold value is exceeded in the raw water of at least one abstraction for "water intended for human consumption" (as defined in the Drinking Water Directive), <u>and</u> b) there is a significant and sustained rising trend in one or more key determinands at this point. Clearly, the criteria for pollution of a potable supply (refer to Section 3.2) can be exceeded more easily than these status criteria. This is not least because many private supplies will not be large enough to be considered under the Drinking Water Directive and will therefore not be considered as receptors under this status test.

Surface water ecosystems: The test is failed if a) an associated surface water body does not meet its objectives, b) threshold values are exceeded in at least one monitoring point, <u>and</u> c) groundwater contributes at least 50% of the relevant surface water standard in the river. Given that river water bodies have catchments in excess of 10 km^2, it is clear that the load from groundwater must be considerable if the test is to be failed. Note that a burn may be too small to be considered a water body, but may still be polluted in accordance with the definition set-out in Section 3.2.

For quantitative status, the Water Framework Directive does not have the same explicit requirements for setting formal thresholds and undertaking further investigation. However, in effect the method recommended by Groundwater Task Team (UKTAG, 2007c) uses a similar set of principles, being based on an overall weight of evidence approach.

Individual agencies in UK and Ireland have applied these tests in slightly different ways, largely as a function of differing hydrogeological regimes and differing amounts of available historical data. That being said, UK and Ireland agencies have worked together to ensure implementation has been as consistent as possible across these islands. In Scotland, public consultations occurred in 2008 on the methods used in the draft classification (Scottish Government 2008a), and on the threshold values (Scottish Government 2008b) The outcome of this consultation will be captured in a formal Direction from Scottish Ministers, which is expected to be published in 2009.

A fundamental point to emphasise is that groundwater bodies cannot be poor status through a simple local exceedence of a threshold. It is therefore quite possible to have localised pollution within a groundwater body that is at good chemical status. The standards and conditions that are applied to environmental permits reflect other groundwater objectives of the Water Framework Directive, including the requirements to "prevent or limit" the input of pollutants (Section 3). This means that the particular standards and conditions used in permits to control the input of pollutants to groundwater are separate from and different to the standards and threshold values used for classification of water bodies as a whole.

Though considered separately by the Water Framework Directive, the trends objective is very closely aligned to status. In effect, the requirement to reverse trends is aimed at ensuring that groundwater bodies will not fail status in the future.

5. GROUNDWATER STATUS AND RIVER BASIN PLANNING

The key groundwater quality objectives of the Water Framework Directive are to ensure the progressive reduction of pollution, and prevent future pollution, so as to provide a sufficient supply of good quality groundwater as needed for sustainable, balanced, and equitable use. Status assessment addresses the need to establish overall quality in groundwater bodies. The Water Framework Directive requires that objectives should be set and measures introduced to achieve good status for all groundwater bodies and that status, objectives, and measures must be brought together in River Basin Plans. In Scotland only two River Basin Districts (RBD) have been designated, the Scotland RBD and the Solway Tweed RBD. As noted in the Introduction, SEPA has recently published draft River Basin Plans for these districts for public consultation (SEPA, 2009). These contain the first estimates of the relevant objectives for groundwater bodies.

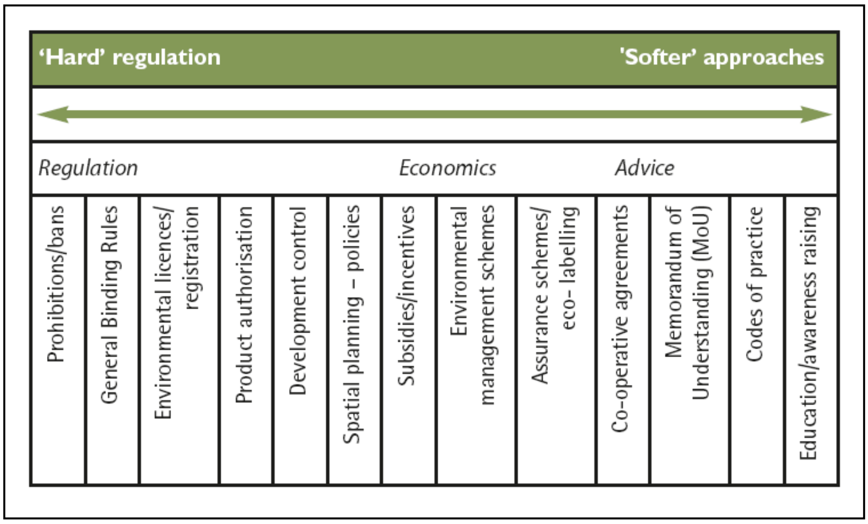
Attention has been focused on designing measures and setting objectives for water bodies that are at less than good status. For groundwater, the objectives are, in effect, simply a date at which poor status bodies will return to good. These dates correspond with the end of three six yearly river basin cycles; 2015, 2021, and 2027. Any groundwater bodies which are at poor status by 2027 will require less stringent objectives and rigorous justification to the European Commission that options for earlier improvement are disproportionately costly or technically infeasible.

However, it is important to recognise that a key objective, in fact arguably a more important objective, is to ensure that those groundwater bodies already at good status do not deteriorate. Measures consist of a range of actions which can be taken to either:

- Prevent deterioration in water body status or the condition of protected areas by ensuring existing water uses are appropriately managed and, where possible, ensure new water uses include appropriate mitigation and are located where the water environment can accommodate them; and/or
- Improve the status of water bodies or the condition of protected areas by reducing, modifying or removing the reasons for failure.

The permits described in Section 3 are an example of “hard” measures but there are other measures that use different “softer” approaches. Figure 3 provides examples of types of measures.

Figure 3: An example of the range of measures that can be applied in River Basin Planning (adapted from SEPA 2007d)



The following discussion considers different types of measures, and is based closely on the Draft River Basin Plan (SEPA, 2009).

5.1 NO DETERIORATION MEASURES

These are measures that prevent a water body from deteriorating from its current status including mitigating the impacts of new pressures. They also include measures that prevent any deterioration in the condition of protected areas. 'No deterioration' measures may be achieved by simply observing best practice, following a General Binding Rule or implementing existing licence conditions. Many are ongoing actions ensuring the water environment remains at good status.

These often unnoticed actions are carried out by land and water managers and represent a significant contribution to maintaining the quality of the water environment. Ensuring no deterioration in status is a clear priority of the Water Framework Directive.

Two classic examples of existing measures which are focussed on the prevention of deterioration are:

- Regulatory regimes arising out of the prevent and limit requirements of the Groundwater Daughter Directive (refer to Section 3); and
- Action Programmes developed under Nitrates Directive (91/676/EEC).

In Scotland, the transposing legislation for the former is the Controlled Activities Regulations (Scottish Government, 2005) usually referred to as CAR, as amended. SEPA is the competent authority for enforcement of these regulations.

The Nitrates Directive has been transposed into Scots Law by the Scottish Government via the Protection of Water against Agriculture Pollution (Scotland) Regulations 1996, by designation of Nitrate Vulnerable Zones, and by introduction of an action programme (Scottish Government, 2008c).

Where existing measures will not deliver the level of protection or the scale of improvement required by the Water Framework Directive, new measures must be introduced. In Scotland, these are called 'RBMP' measures. For groundwaters in Scotland, an obvious example of a regulatory RBMP measure is the abstraction licensing regime implemented through the CAR.

5.2 IMPROVEMENT MEASURES

Where a water body is at less than good status, it is necessary to develop a programme of measures that actively improves its condition. Similar action is required where a protected area does not achieve the required conditions. Improvement measures can involve a mix of regulatory and voluntary measures. In some instances the land or water manager responsible for implementing the measures will work with other agencies and voluntary bodies to ensure the improvements take place as quickly and as effectively as possible. One of the main functions of the Area Advisory Groups set-up under River Basin Planning in Scotland is to develop the partnerships necessary to support land and water managers.

For groundwater, a classic example of an improvement measure would be the remediation of land contamination. This can occur through “Part IIA” (Scottish Government, 2000), a legislative (and hence “hard”) regime for which Local Authorities are the primary regulators. However, it is generally recognised that improvements are most often achieved through the “softer” means of control of redevelopment under the planning regime.

6. SUMMARY

In the context of the Water Framework Directive, regulation of the groundwater quantitative resource is based upon the Directive’s status and protected area objectives. Standards derived for quantitative status are directly applicable to the regulation of abstractions.

For groundwater quality, status and regulation are less clearly linked as the relationship is not intuitive between conditions on individual permits and thresholds applied to groundwater bodies as a whole. Similarly, the Directives do not make it immediately obvious how permit conditions should, or shouldn’t, be influenced if a site happens to lie within poor status groundwater body. In addition, regulation of groundwater quality cannot be based primarily on the requirements to meet good chemical status as there are other, more stringent objectives for groundwater in the Water Framework Directive and the 2006 Groundwater Directive. Regulatory measures for groundwater quality and in particular the conditions on permits will be based predominantly upon “prevent or limit”, as in practice this is the most restrictive requirement as it requires protection of local receptors.

Compared with the requirements for good status, the "prevent or limit" objective provides protection to all groundwater, to a wider range of receptors, and at a more local scale. "Prevent or limit" measures are the first line of defence in preventing pollution. For groundwater quality, the objectives that refer to status are complemented by the objective to "prevent or limit" the input of pollutants, and by the objective to reverse rising trends. Full implementation of the "prevent or limit" objective will ensure there is no deterioration in status as a result of new contamination. This would also ensure, in due course, that upward trends are reversed.

In operating at a larger scale, status tests are “harder to fail” than those for local pollution or local over-abstraction. In this respect they may not be the limiting factor driving the setting of local permit values. However, they provide a valuable tool in identifying areas which are already impacted or may be at risk of failure. Sitting within the River Basin Planning framework, they can be incorporated into catchment-scale assessments of priorities for restoration.

Standards and thresholds derived for chemical status definition will not be directly applied to meet the prevent or limit objective as they are be based on different compliance regimes which may not provide sufficient protection to local receptors. In contrast it is a requirement of the “limit” objective that inputs do not cause deterioration of good chemical status or significant and sustained rising trends in pollutants. So, in the overall hierarchy of measures within a River Basin Plan, regulatory and other “softer” measures that control local pollution will often take a high priority.

However, status tests provide a valuable tool in identifying areas which are already impacted. Sitting within the River Basin Planning framework, they can be incorporated into catchment-scale assessments of priorities for improvement.

7 CONCLUSIONS

For pollution, the "prevent or limit" objective acts at a more local scale than the objectives expressed in terms of status. Compared with the requirements for good status, the "prevent or limit" objective provides protection to all groundwater, to a wider range of receptors, and at a more local scale. "Prevent or limit" measures are the first line of defence in preventing pollution.

In operating at a larger scale, status tests are “harder to fail” than those for local pollution or local over-abstraction. In this respect they will not generally be the limiting factor driving the setting of local permit values. However, they provide a valuable tool in identifying areas which are already impacted or may be at risk of failure. Sitting within the River Basin Planning framework, they can be incorporated into catchment-scale assessments of priorities for restoration.

For groundwater quality, the objectives that refer to status are complemented by the objective to "prevent or limit" the input of pollutants, and by the objective to reverse rising trends. Notwithstanding the time needed to enable the historical legacy of releases to degrade or disperse, if all the "prevent or limit" requirements were met everywhere within a groundwater body, it would be at good chemical status. Full implementation of the "prevent or limit" objective will ensure there is no deterioration in status as a result of new contamination. This would also ensure, in due course, that upward trends are reversed.

ACKNOWLEDGEMENTS

The authors would like to thank the members of UK Technical Advisory Group’s Groundwater Task Team for their hard work in drafting a number of the documents upon which this paper relies. By the same token, the authors would also like to thank the authors of Scotland’s Draft River Basin Plan, along with members of SEPA’s policy Directorate for their help in reviewing the drafts of the paper.

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Session III

LARGE SCALE DISCHARGES TO GROUNDWATER: RISK MAPPING & FRAMEWORK FOR SITE ASSESSMENTS

Patrick Kavanagh, Thomas Bree & Rose Walsh, ESBI and Western River Basin District

ABSTRACT

Advances in our understanding of the risks of unsewered systems point to particular risks from large systems, where water quantity, water quality and ecosystem constraints require careful consideration. Procedures for incorporating these constraints into pathway risk mapping are addressed and situations are described where the constraints can prohibit large discharges in many settings.

Hydrogeological and geotechnical issues are to the fore, combined with topography, water quality, ecology, meteorology, and surface water hydrology in a multidisciplinary approach.

While many issues are common to both large and small discharges, large systems involve a more detailed risk assessment undertaken both at local scale, in the form of a comprehensive site investigation, and at a wider scale, through consideration of water body and catchment impacts. The Water Framework Directive and Groundwater Directive classification, status and risk methodologies support site assessment procedures.

INTRODUCTION

Large discharges to groundwater constitute a significant pressure on water quantity, water quality and ecosystems. The number of large discharges has increased in recent years, notably from wastewater treatment systems of commercial, industrial and housing clusters. Large onsite treatment can involve technologies that are more complex than conventional systems and they may incorporate pumping, aeration, high volumes of sludge, integrated wetlands, etc, fitted with polishing filters or conventional percolation trenches discharging to subsoil.

Clusters of houses may have a single large treatment and discharge system. Similarly, high-density clusters with individual conventional systems can be considered to act together as a large discharge, imposing an equivalent pressure on groundwater status and on downstream surface water status.

The Water Framework Directive (WFD) Programme of Measures and the Draft River Basin Management Plans were published in December 2008. Supporting documents will contribute to assessment of large discharges, notably the unsewered wastewater systems study[7], undertaken by ESBI/Western RBD with a Steering Group comprising EPA, GSI, DoEHLG and a number of Local Authorities.

Specific recommendations have been developed for local site investigation and hydrogeological assessment of large systems by Wexford County Council[15] for 3 to 7 houses (less than 5 m^3/d) and for 8 or more houses (greater than 5 m^3/d). In USA, Minnesota Pollution Control Agency[9] has published design guidance for systems greater than 50 houses (38m^3/d). Many issues that are common to small systems are dealt with in the new "Code of Practice Wastewater Treatment Systems for Single Houses (PE<10), Consultation Draft"[3] and are not repeated here.

PRESSURES AND PATHWAYS

Flowrate

A critical issue for large systems is the flowrate. If the permeability of the subsoil cannot take the peak flowrate in addition to rainfall, the system will backup, interfering with the treatment system and causing ponding of untreated effluent. In addition, the water table may rise locally where the saturated horizontal permeability cannot discharge the additional flow from the system.

Nitrogen

The percolation process converts nitrogen from organic matter and ammonia almost entirely into nitrite and then to nitrate. When nitrate reaches the ground water, it moves freely. Reduction of nitrate concentrations in ground water occurs primarily through dispersion and dilution in groundwater.

Phosphorus

Excessive Phosphorous load is a major contributing factor to nutrient enrichment of waters and to loss of natural ecology. Contamination of surface waters will generally occur in areas with low permeable soils overlying poorly productive aquifers such as granites. It may also occur in areas of extreme vulnerability over karst aquifers, through a primary pathway to groundwater and subsequently through a rapid pathway to surface water such as emerging springs.

Pathogens

Pathogens (pathogenic organisms) are a serious health hazard and organisms such as E. coli, streptococci and faecal coliforms, with the same enteric origin as pathogens, indicate whether pathogens may be present or not in wastewater. The sizes of bacteria range from 0.2 to 5 microns; thus, physical removal through filtration occurs when unsaturated sand filters and subsoil micropores are smaller than this.

Specific effluent flow pathways from sand filters, percolation areas and integrated wetlands include:

(a) to groundwater by infiltration – where particularly nitrogen, but in the case of vulnerable karst and other shallow rock areas, other pollutants such as phosphate and particularly microbial pathogens, will also persist;

(b) to surface water via soil interflow, particularly on wet low-permeability subsoils and shallow groundwater (also to surface water via deep groundwater flow particularly in karst areas); and

(c) to surface water directly overland, where the percolation rate is inadequate - the effluent will pond; it may back up into the system and impair the operation of the wastewater system, even when the water table is well below the percolation area – particularly pathogens and phosphorus.

REGIONAL RISK ASSESSMENT

Sources of information are available for pressure mapping, pathway risk mapping and receptor sensitivity mapping, as illustrated in Figure 1. This sets the context for the wider-scale assessment.

Large discharges require consideration of all pressures acting together on a groundwater or surface water body catchment. With regard to existing unsewered wastewaters, the WFD study prepared maps throughout the country with information on existing systems based on:

- An Post GeoDirectory providing the location of households and buildings,
- Maps of all sewered areas, so that these households and buildings could be excluded from existing unsewered pressure.

Simplified Pathway Risk Maps

The concept of pathway susceptibility (i.e. the likelihood of pollutants being transmitted to a receptor) describes the movement of pollutants vertically and horizontally and is a factor of soil and subsoil

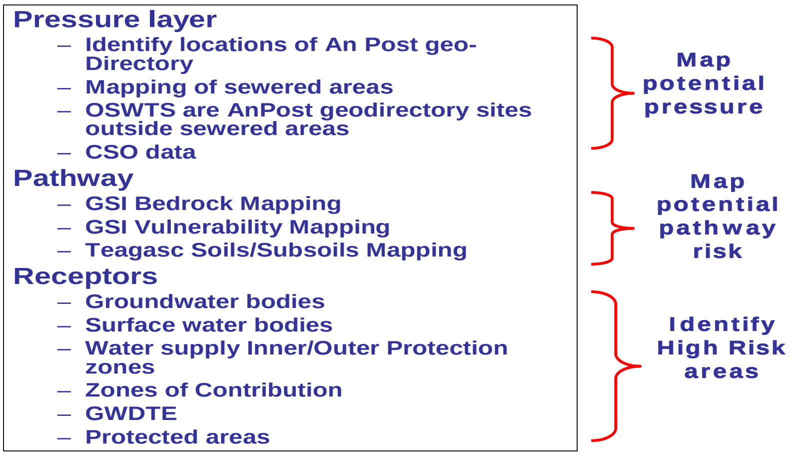

Figure 1. Regional Pressure- Pathway-Receptor Approach

type, aquifer type and vulnerability. Specified ranges of subsoil depth, of subsoil permeability and types of aquifers are defined nationally. These categories were applied in an assessment of risk to groundwater and risk to surface water. Two categories of subsoil depth are critical, i.e. where depth is less than one metre and less than three metres, and in these areas the permeability of the subsoil is not important and is not used. Where the depth is more than three metres, categories of subsoil permeability are important.

Risk assessment matrices were developed with varying weights for different soils, soil depths, permeabilities and aquifer types, to map the potential pathway risk to both surface water and groundwater for pathogens, for phosphorus and for percolation impairment (the nitrate potential impact pathway has been considered separately by the WFD National Groundwater Working Group).

The resulting five national simplified risk maps are:

1. Risk to Groundwater – Pathogens
2. Risk to Groundwater – Phosphorous
3. Risk to Surface Water – Pathogens
4. Risk to Surface Water – Phosphorous
5. Likelihood of Inadequate Percolation

Maps 1 and 2 are shown in Figure 2. In Figure 3, map 5 for the Dereen Catchment is shown, with the existing systems pressure layer.

Receptors

The Receptor factor must be considered for both groundwaters and surface waters. Receptors include aquatic ecosystems, groundwater dependent terrestrial ecosystems, groundwater bodies, groundwater wells and drinking water protected areas. Receptors have different requirements and sensitivities. Particular care needs to be taken with certain sensitive receptors, such as small rivers, high status water bodies (surface and groundwater) and downgradient wells. The GSI groundwater protection response for on-site wastewater treatment systems, and the well and karst datasets will all be useful.

Apart from these water-related receptors, there may be landscape, ecological, heritage and other features that depend on the waterbody. These should also be considered as receptors.

Consideration could be given to increasing the minimum separation distances for receptors for large discharges as against those for single-house systems, such as doubling the distances for surface water soakaways to 10m, watercourses/streams to 20m, lakes to 100m, and increasing the distance to any dwelling house to 50m.

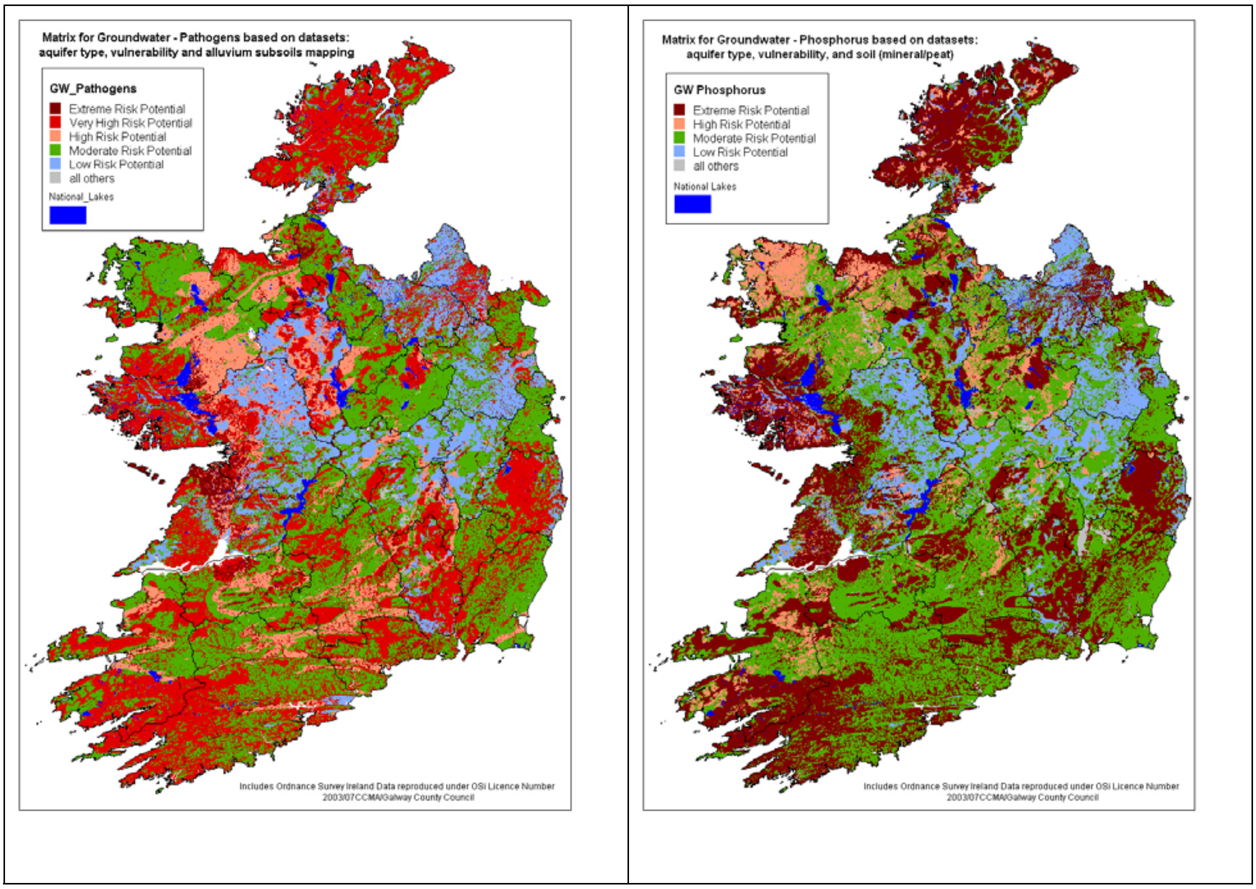

Figure 2. Simplified Risk Maps to Groundwater from Pathogens and Phosphorous

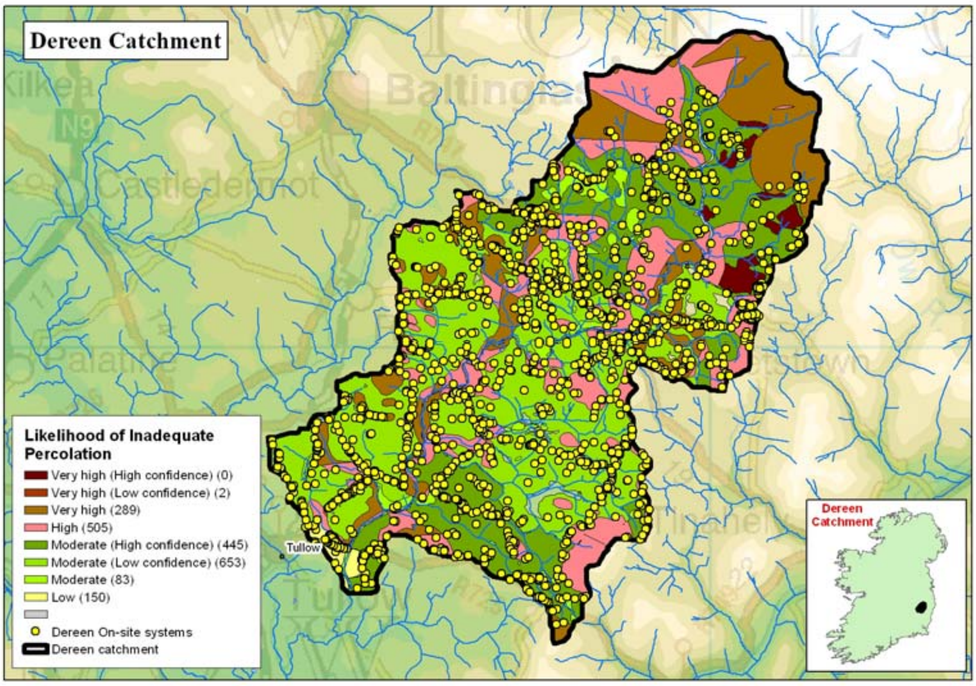

Figure 3. Simplified Catchment Risk Map for Inadequate Percolation, with Households Layer, Dereen Catchment

The extent of the upstream 'recharge area' and the recharge may be estimated based on the soils and geology information, based on the approach outlined in WFD Groundwater Working Group Guidance

Document No. GW5[8], particularly Section 6.3.4 and Table1. Meteorological information in the region should be identified.

The drainage patterns of the area being examined are critical, and reference should be made to the OPW website www.flooding.ie containing information on historical flood events and some areas with flood risk maps.

Potential impact on the status of the groundwater body must be assessed. Groundwater body classification is based on:

1. No saline or other intrusions;
2. Achieving the objectives of the Water Framework Directive for dependent surface waters including no deterioration in status;
3. No damage to any wetlands that depend on the groundwater body;
4. No impact on Drinking Water Protected Areas;
5. No significant impairment of human uses of groundwater.

Calculation of nitrate concentrations is discussed below. With regard to item 2 above, a large discharge to groundwater may contribute to the failure of a biological or physicochemical standard for 'good status' in an associated surface water body. Geological conditions that support "gaining streams" (streams fed by ground water during low-flow conditions) might result in nutrient or pathogen impacts on surface waters if siting or design criteria fail to consider these conditions. The test is where the total inputs via groundwater contribute greater than 50 % of the surface water standard in the surface water body.

This test can be investigated using the procedures and methods of two WFD supporting studies:

- An integrated approach to quantifying groundwater contribution to surface water, Joint RPS/Jacobs/MottMcDonald/ESBI[11]
- Low flow estimation for ungauged catchments, unpublished joint ESBI/EPA study[6].

In most cases, flow records will not be available. One or more analogue catchments may be chosen from those studied in these two reports, and a system for forming a pooling group based on catchment descriptors for soils, subsoils and aquifers is described in the second report above.

Assimilative capacity calculations for the downstream surface water body will need the appropriate receiving water flow values, i.e., Dry Weather Flow for dangerous or toxic substances, median flow for Ortho-phosphate and 95%ile flow for other substances. A useful tool for risk assessment on small streams is the Small Stream Risk Score[5] rapid field method for risk assessment based solely on macro invertebrates.

LOCAL SITE INVESTIGATION AND ASSESSMENT

The regional assessment will allow a decision to be made to progress to costly site investigation only if it is considered that the site appears to be suitable.

The analysis and design of the geotechnical aspects are site specific and therefore the investigation should be undertaken by an experienced hydrogeologist. Essentially, the soil permeability would be estimated using trial hole and borehole soil classification and percolation tests. The investigation should be in accordance with BS5930 Code of Practice for Site Investigations and should be targeted to provide:

- for vertical flow below the polishing filter, the required depth of unsaturated suitable subsoil for effluent attenuation and
- for horizontal flow at the water table, the variation in water table levels and hydraulic gradient during high flows for analysis of horizontal groundwater flow.

Where geology and hydrogeology are simple and there is no heterogeneity, it is suggested that the minimum investigation would comprise:

- Three boreholes located near the percolation area and with at least one downgradient of the percolation area (allowing characterisation of soil and rock, in-situ permeability testing of overburden and rock, recovery of samples for particle size distribution analysis (sieve and hydrometer) and the construction of groundwater monitoring/sampling installations)
- Trial pits in a grid at 100m centres (allowing characterisation and sampling of subsoil). Trial pits are assumed machine excavated to the maximum safe excavatable depth – minimum of 3m, depending on the point of release of discharge)
- T tests as per EPA 'Waste Water Treatment Manual – Treatment Systems for Single Houses' in a grid at 50 m centres and at appropriate depths.
- Monitoring of groundwater levels monthly for three months (this will generally require recording of winter water levels) and the taking of water samples on two occasions at minimum 1 month interval. Sampling should be in accordance with standard procedures.

It should be noted that most sites will not have simple homogenous geology and hydrogeology and more extensive investigation would be required. Water samples shall be tested for a suite of determinands that at a minimum shall include pH, nitrate, phosphorous, ammoniacal nitrogen, major ions, faecal and total coliforms.

To avoid any accidental damage, site investigation and testing should not be undertaken in areas, which are at or adjacent to significant sites (e.g. NHAs, SACs, SPAs, Archaeological Sites, Groundwater Dependent Terrestrial Ecosystems, etc.), without prior advice from the National Parks and Wildlife Service or other relevant bodies.

Soil	**Subsoil**	**Bedrock**	**Hydraulic**
Permeability Slope of land surface Vegetation	Particle Size Distribution and Permeability (Falling Head Test, (example, Butler, 1997)) Thickness Variations in permeability with depth (layering) Vulnerability of groundwater	Slope General groundwater flow regime Permeability of bedrock (Packer, Falling Head Test) Variations in permeability of bedrock with depth (Packer) Lateral Groundwater Movement	Water table (Winter water levels) Depth to water table & fluctuations Hydraulic gradient Recharge estimates for area – updated from regional study to site investigation Local Recharge (as an indicator of vertical pathway)

Table 1. Site Investigation Parameters

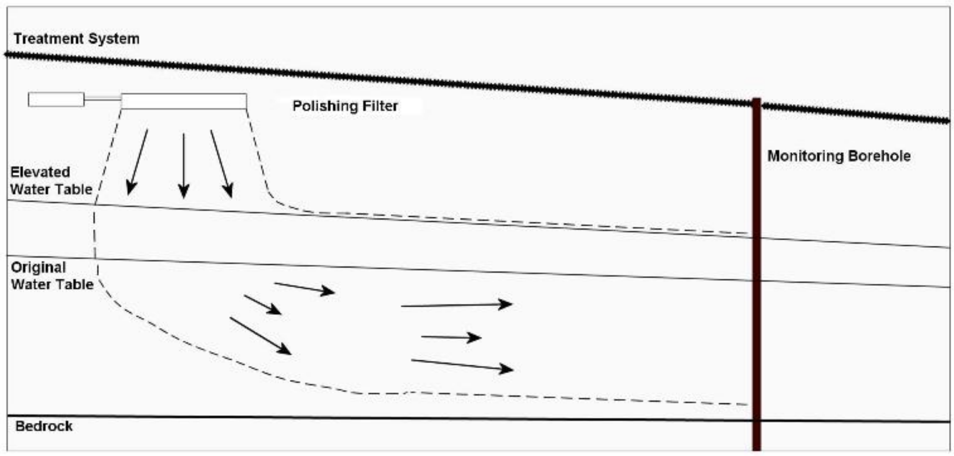

Figure 4. Schematic of Mixing Zone

Pathways and associated hydraulic gradients should be shown on a cross-section derived from the geotechnical investigation.

Hydraulic Load

The hydraulic load analysis involves calculations that determine the total permissible flow into the subsoil below the polishing filter, per square metre, and this may be used to provide the required area of the polishing filter, the permissible number of houses and the extent of the development. The total permissible flow is calculated for each of two limiting scenarios as stated below, and the smaller of the two limits is chosen.

Rainfall over the site must be take into account, bearing in mind the limited recharge to poorly productive aquifers. Separate surface water and sewage systems must be used. The investigations will need to address the quantities from both systems.

The scenarios address the questions:

1. Is there adequate vertical permeability in the unsaturated subsoil between the discharge point and the water table to allow the effluent to flow vertically under gravity toward the water table?
2. Is there sufficient horizontal permeability to enable the hydraulic load to get away to the discharge zone (stream) below the water table or downgradient, such that the water table will not rise causing ponding and interference with the operation of the polishing filter?

One or other of these two scenarios on its own may prevent proper attenuation of contaminants in the polishing filter and may cause ponding at the surface.

Vertical Flow

The subsoil in and around the polishing filter must remain unsaturated, even during heavy rain.

Using as inputs the measured or estimated *saturated permeability* and the depth to the water table, Darcy's Equation or more complex models may again be used to find the permissible vertical flow that allows attenuation to occur and prevents ponding at the surface. Contribution of rainfall should be added. In a layered subsoil, the lowest unsaturated permeability among the layers is used in the calculation, together with the depth to this layer. The flow is assumed to apply across all of the area of the polishing filter.

Horizontal Flow

Using as inputs the measured permeability in the subsoil and bedrock, which shall include a safety margin, and the measured slope of the water table, Darcy's Equation or more complex models are applied to calculate as output the increase in slope of the water table due to the increase in groundwater flow due to the total additional flow in the aquifer. The total horizontal flow used in the calculation includes the flow derived or observed during the geotechnical investigation, plus:

- the OSWTS effluent;
- the additional upstream hardsurface runoff during a design rainstorm;
- direct infiltration to the subsoil from the design rainstorm; and
- any other potential contributions to flow that were not present when the permeabilities were measured.

It may be appropriate to complete this analysis with two figures for water table slope, the first being that measured locally and the second extending the slope to the nearest surface downstream waterbody.

Dilution of Nitrate Pollutant Load

A simple mass balance approach can be applied to examine the relative local impact of the development. This considers the dilution effect of local groundwater recharge, without further attenuation within the local groundwater body. Thus it provides an upper limit for the longterm average concentrations in the groundwater downstream of the site.

The calculation may be made assuming initially that the effluent remains within the total width of the percolation area as it migrates downstream, without lateral diffusion. The calculation will demonstrate the order of magnitude of the local impact. It can be repeated for, say, a width of twice the percolation area to account for typical lateral diffusion. There are many more complex modelling systems for effluent migration that might be considered.

When the effluent passes into the saturated zone, flow occurs in response to a positive pressure gradient. Mixing may be limited at the water table where the subsoil or bedrock are homogeneous subsoil because ground water flow usually is laminar. As a result, treated laminar water can remain as a distinct plume at the ground water interface for some distance from its source.

The overall annual mass balance equation used to predict nitrate-nitrogen (or other soluble pollutant) concentrations in ground water and surface waters is:

$$\text{Nitrate-nitrogen (mg/l)} = \frac{\text{Annual nitrogen loading from all sources in mg}}{\text{Annual water recharge volume from all sources in litres}}$$

This may be applied to check local dilution. Prior to the discharge, the equation allows the loading to be calculated from the measured concentration and the recharge (this can be checked against nitrate runoff estimates for upstream landuses and point sources). This annual loading is increased by adding the annual loading from the development, and the annual water recharge is increased by the annual flow of the discharge to groundwater in litres. The new concentration is found by dividing the new loading by the new recharge.

Although nitrogen removal rates can range between 10 and 20 percent (Van Cuyk et al., 2001) for soil-based systems, this effect is ignored.

In layered and more complex soil and bedrock systems, such as those with preferential flow, the geotechnical results may provide the component of flow in each pathway. The contribution of each component to the rise in water table can then be derived. In some cases, weighted average permeabilities may be used.

Monitoring

Suitable monitoring points may be located at:

- Outlet of sewage treatment plant
- Extremity of site (down gradient from polishing filter)
- Wells and boreholes (dependent on nature of groundwater body)
- Downstream surface water body.

The compliance point shall be in the soil and bedrock, at the site boundary, down-gradient from the discharge to groundwater.

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THE NEW "CODE OF PRACTICE: WASTEWATER TREATMENT & DISPOSAL SYSTEMS SERVING SINGLE HOUSES"

Ms. Margaret Keegan

Office of Environmental Enforcement, Environmental Protection Agency

ABSTRACT

Ireland enjoys a high quality environment and the conservation and enhancement of our environment is a key objective for the future. It is correspondingly vital that the protection of our environment, and specifically water quality, is a central objective in the assessment, design, installation and maintenance of new wastewater disposal systems for single houses in unsewered areas.

The 2006 census indicated that around 40% of the population of Ireland lived outside of the main cities and towns. Unlike other more urbanised European countries, around a third of the population of Ireland lives in the open countryside in individual dwellings not connected to a public sewer. The wastewater from rural settlement patterns is disposed of to systems of various types designed to treat the wastewater at or near the location where it is produced. Such systems are often referred to as on-site wastewater treatment systems.

The EPA issued a draft Code of Practice: Wastewater Treatment Systems for Single Houses, for public consultation in July 2007 and plan to publish the code of practice (CoP) in 2009. The CoP establishes an overall framework of best practice in relation to the development of wastewater treatment systems, in unsewered rural areas, for protection of our environment and specifically water quality.

The CoP replaces previous guidance issued by the EPA on wastewater treatment systems for single houses (EPA 2000) and incorporates the requirements of new European guidelines, recent research findings and submissions and comments received during the consultation process.

THE CODE OF PRACTICE SETS OUT THE FOLLOWING**:**

- An assessment methodology for the determination of site suitability for an on-site wastewater treatment system and identification of the minimum environmental protection requirements.
- A methodology for the selection of a suitable wastewater treatment system for sites in unsewered rural areas.
- Information on the design and installation of septic tank systems; filter systems and mechanical aeration systems.
- Information on tertiary treatment systems.
- Maintenance requirements for the above systems.

The overall regulatory and policy framework at national level is clear on the need for the application of high standards in the assessment of, provision and maintenance of effective on-site wastewater disposal systems for new housing development in rural areas and this code of practice presents comprehensive recommendations for the attainment of such high standards in line with the regulatory and policy frameworks.

NOTES

Session IV

ASPECTS OF THE HYDROGEOLOGY OF THE CARBONIFEROUS LIMESTONES OF IRELAND

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ABSTRACT

Carboniferous limestone is both the most extensively outcropping rock in Ireland and also the most important aquifer. However, its hydrogeological characteristics vary greatly, the major controls being the degree of karstification that has occurred, the lithological and structural characteristics of the limestone and topographic situation.

INTRODUCTION

This paper does not represent original research. Rather it is a synthesis and an interpretative summary of available, though sometimes inaccessible, material relating to the hydrogeology of Irish limestones. Furthermore, the contents relate only to the character of the Carboniferous limestone aquifers and not to the dynamics (recharge, flow systems and discharge) of the aquifers.

Limestone of Carboniferous age is the outcrop or near-outcrop rock across more than 50% of the Republic of Ireland but has a much less extensive outcrop in Northern Ireland (Sevastopulo & Wyse-Jackson 2001). Extensive areas of upland karst are confined to the Burren of Co. Clare and the plateaux of Sligo, Leitrim, Cavan and Fermanagh in the northwest. In excess of 90% of the limestone outcrop is in a lowland situation with elevations less than 150m a.s.l. and over much of the midland and western outcrop elevations are less than 100m a.s.l.. The Carboniferous limestone comprises the principal aquifer in the Republic of Ireland and because of its predominantly lowland occurrence it coincides with the most productive land, the areas of greatest economic activity and the areas having the greatest demand for water resources (Drew 1990, 2008).

Figure 1 shows the distribution of the limestone outcrop in Ireland. ‘Pure’ and ‘Impure’ limestones are differentiated though the distinction between them is not precise. Commonly ‘pure’ limestone is comprised of >95% calcite and dolomite, though in practice carbonate minerals regularly constitute >99% of the rock. Impure limestones (including several lithologies which are distinguished later in this paper), are located mainly in the midlands and the east whilst purer limestones predominate west of the River Shannon and in the south.

KARSTIFICATION

Pure limestone is more susceptible to karstification than impure limestone and it is karstification that gives the limestone the hydrogeological characteristics that distinguish it from fractured rock aquifers. However, karst features have been reported from 80-85% of the area underlain by limestone including appreciable areas of impure limestone so it is probably safe to assume that all limestones have developed or potentially may develop, some degree of enhanced secondary permeability due to selective solutional enlargement of fissures (Drew, Burke & Daly 1996).

Karstification has taken place whenever limestone bedrock has been exposed at or close to the land surface. Widespread karstification occurred during the Tertiary (Drew & Jones 2000), whilst Quaternary glacial episodes destroyed some karst features, infilled others, such as dolines and caves and blocked or partly blocked karstic drainage systems. During the Holocene new karst drainage systems have developed, particularly in the upland limestone areas and blocked drainage systems have been re-excavated and re-activated to some extent, for example Ballyglunin Cave in Co. Galway (Drew 1973).

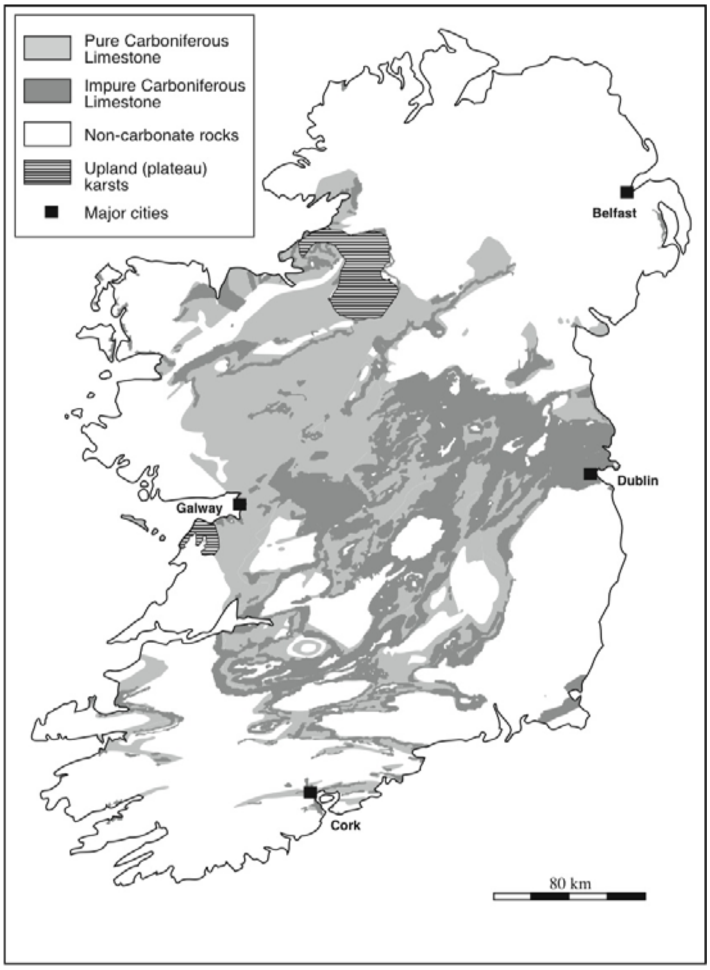

Figure 1 The distribution of Carboniferous limestone outcrop or near outcrop in Ireland.

Areas of impure limestone are indicated as are the upland (plateau) karsts.(Data from Geological Survey of Ireland).

The hydrogeological characteristics of the Carboniferous limestone are primarily a function of the degree and type of karstification it has undergone and in turn the karstification is determined by a variety of factors:

- The lithology (primarily purity)
- Fracturing - density, vertical extent, interconnectedness of fissures,
- Faulting – barriers or conductors (compartments or extensive aquifers)
- The presence of non-soluble rocks such as chert and shale as layers in the limestone
- Bedding frequency
- Diagenetic changes to the limestone e.g. secondary dolomitisation - enhanced permeability (often around faults)
- Topographic and geologic setting e.g. steep gradients, allogenic recharge
- Impounded or freeflow conditions
- Subsoils – confining, semi-confining, buffering and reservoir functions
- Degree of infilling of fissure/conduit systems
- Old sea levels and palaeo-topography
- Intensified solution of the limestone, for example via sulphuric acid generated by adjacent sulphide rich rocks such as shale

The intensity and importance of each of the above factors varies areally as do their combinations and, therefore, it is difficult to predict with any certainty the water bearing character of any particular limestone from any one factor such as lithology.

Groundwater conditions in the Carboniferous limestone range from those typical of a conventional fractured rock aquifer with distributed flow to wholly conduit flow systems in which recharge is conducted to a limited number of point discharge locations (springs) via a hierarchy of highly integrated flow routes. A spectrum of part-distributed part-concentrated flow systems exists between these two extremes. The more conduit dominated the flow system (as on the upland karsts) the more localised and therefore unpredictable the occurrence of water is. However, seemingly, all Irish limestones can be productive and unproductive locally. For example, on Aughinish Island in the River Shannon estuary, 18 wells were drilled to a depth of 40-45m (35-45m below the water table) in some instances spaced only a few metres apart. Seven of the wells were dry and the remaining 11 were productive in varying degrees. This is in a very restricted and apparently uniform low-lying outcrop of limestone (Hartwell et al 1979).

The depth to which karstification and hence groundwater circulation occurs is uncertain. Daly (1995) suggests that 75-80% of groundwater in the limestones of central Ireland is confined to 20-30m below the summer position of the water table, with 60% in the uppermost 10m and only 4% below 100m. The deepest water is considered to be mainly in faults. Epikarst is widely developed in Irish limestones and ranges from 0.5 to 3m in thickness. It functions not only as a perched reservoir but also to concentrate and localise recharge to the main aquifer.

A schematic model of the vertical distribution of permeability in Irish limestones as a function of depth and lithology is shown in Figure 2 (Fitzsimons et al 2005). A productive zone of weathered rock with interconnected fissures extends to <30m depth in pure limestones and <15m in others (except where faulted). Below may be more isolated fissures faults up to a depth of 150m or to 200m in dolomite. However, the rock between the fissures may be dry. Major active karst conduits with cross-sectional areas <50m^2 are known to exist at considerable depth in some areas. For example in the Gort – Kinvara area of Co. Galway conduits have been explored at a depth of 35m below sea level (50m below the watertable, and at Pollatoomary spring in Co. Mayo to a depth of 60m below sea level (110m below the watertable). There is a non-linear relationship between depth and transmissivity. Permeability in the top layer is similar for all lithologies but there are large differences at depth between productive and unproductive aquifers. This is an idealised model and in practice local factors may greatly modify hydraulic characteristics.

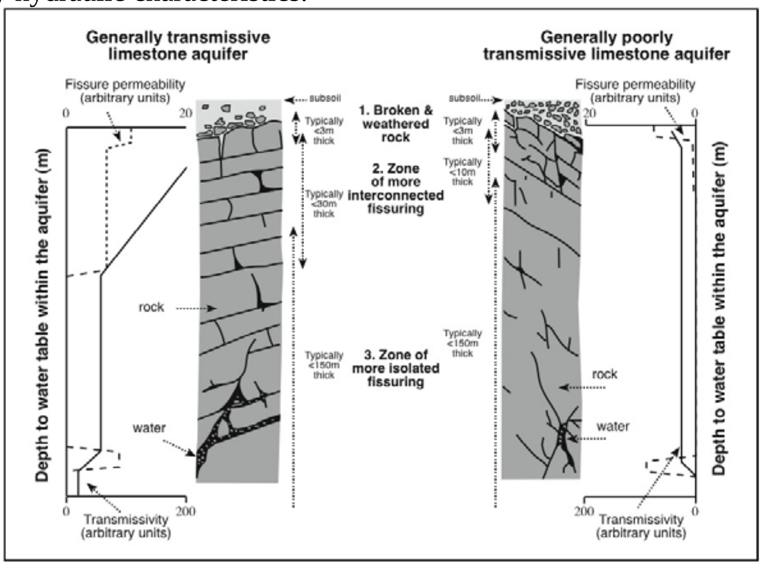

Figure 2 A schematic model of the vertical distribution of permeability in Irish limestone (after Fitzsimmons et al 2005)

Consistency of hydraulic characteristics can only be realised with a Representative Elemental Volume (REV) of several cubic km in volume but not locally and certainly not at the scale of boreholes as the

Aughinish data demonstrate. Thus, most limestone aquifers in Ireland are not amenable to many standard investigative techniques of groundwater assessment. For example, there are problems in determining transmissivity values when the functional saturated thickness is uncertain, whilst permeability becomes a meaningless concept where flow systems are conduit dominated. Porosity is almost entirely in secondary openings with mean values of 2.5% (S.Y. 2.4%) for pure limestones and 1% (S.Y. 0.9%) for impure limestones.

With increasing karstification the relationship between surface river systems and groundwater becomes increasingly tenuous and in the extreme, surface drainage systems are replaced by wholly sub-surface drainage systems. Irish limestones exhibit the full spectrum of such relationships. For example, Figure 3 shows surface and groundwater flow systems in two contrasting areas. Figure 3A depicts the Nuenna catchment in Co. Kilkenny where a close relationship exists between rivers, valleys and groundwater flow systems, though some degree of karstification exists as is apparent from the presence of springs and segments of dry valley. The Dunkellin-Lavally catchments in eastern Co. Galway (Figure 3B) show little relationship between surface and groundwater. For much of the time the rivers sink underground leaving the middle and lower reaches of channel dry. Groundwater flow systems are focussed on coastal springs in this highly karstified aquifer.

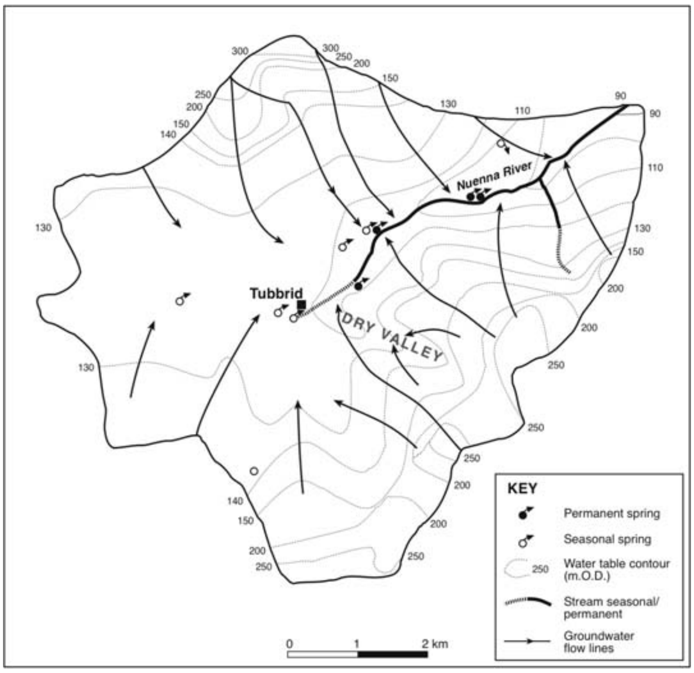

Figure 3A The potentiometric surface and groundwater flow lines in relation to surface drainage under low stage conditions (A) The Nuenna catchment, Co. Kilkenny (adapted from Daly 1995)

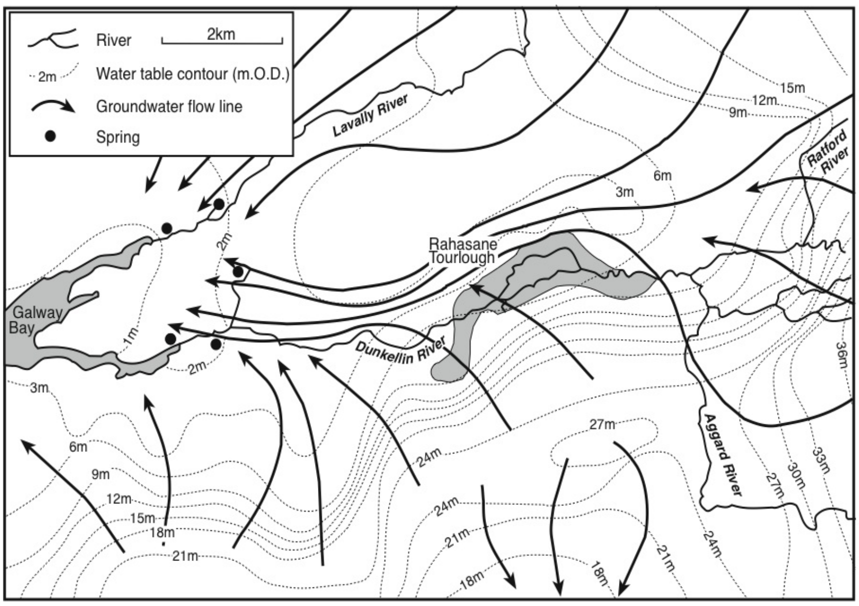

Figure 3B The potentiometric surface and groundwater flow lines in relation to surface drainage under low stage conditions (B) The Dunkellin-Lavally catchments Co. Galway (adapted from Drew and Daly 1993)

Overviews of the carbonate aquifers in Ireland are given in GSI (in press) and Drew (2008) while examples of detailed hydrogeological studies at local level of a county with almost exclusively limestone aquifers (Roscommon) are given in Hickey (2008) and Lee & Daly (2002).

LITHOLOGICAL AND STRUCTURAL INFLUENCES

As was remarked in the preceding section there, is rarely a consistent and unambiguous relationship between hydrogeological and geological conditions in the Carboniferous limestone. However, some degree of generalisation is possible, particularly with respect to the degree of purity of the limestone. Figure 4 shows histograms for borehole productivity (determined from well discharge and Specific Capacity relationships) for a range of types of Carboniferous limestones compared to values for a high yielding sand and gravel aquifer. In the sand and gravel aquifer most wells are high yielding (category I) with progressively fewer wells with lower yields. Impure limestones show a mirror-image distribution of yields with fewest wells in categories I and II. The Burren pure limestone has a bimodal distribution of yields with significant numbers of both high and low yielding wells, suggesting that pure limestone means better karstification but more variable yields because of the high degree of heterogeneity of the aquifer.

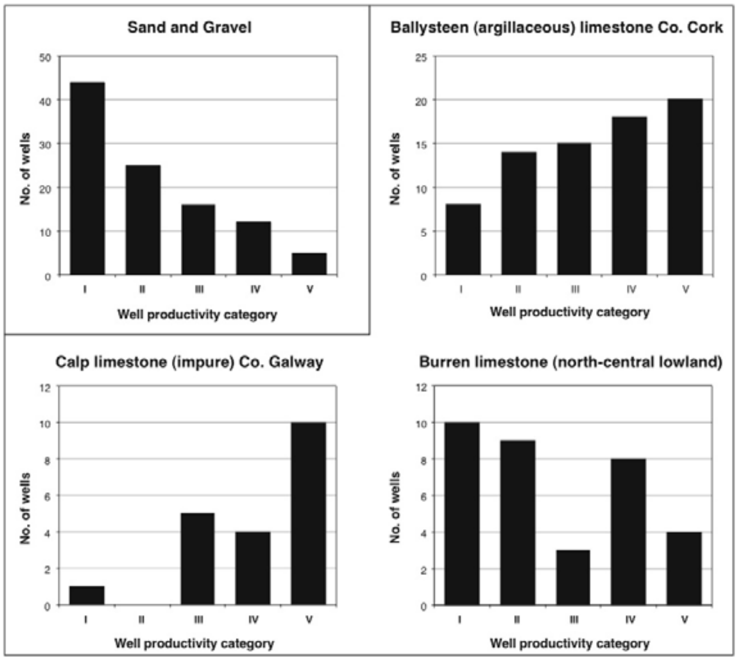

Figure 4 Borehole productivity for selected aquifers in Ireland (adapted from Wright 2000). I represents the highest productivity, IV the lowest.

However, if constituent lithologies within the 'impure limestones' are considered the picture becomes more complex. The Calp limestone (for example the Ballysteen Formation) is widely considered to be too argillaceous to develop significant karstification yet stream sinks occur in south Co. Cork, springs are known (for example, at Fore, Co. Westmeath) though spring discharges rarely exceed 3000m3/day and many are less than $100m^3$/day and karstification seems to be confined to the uppermost 10m. Figure 5 illustrates the considerable degree of hydrogeological variation within a single lithology, the Calp. The histograms of well productivity at five locations in eastern and central Ireland are all skewed towards lower productivity categories but the distribution for the Kilkenny-Laois-Tipperary example is almost a normal distribution whilst Meath-north Dublin has high yields, which contrast to the remaining locations which have consistently low yields.

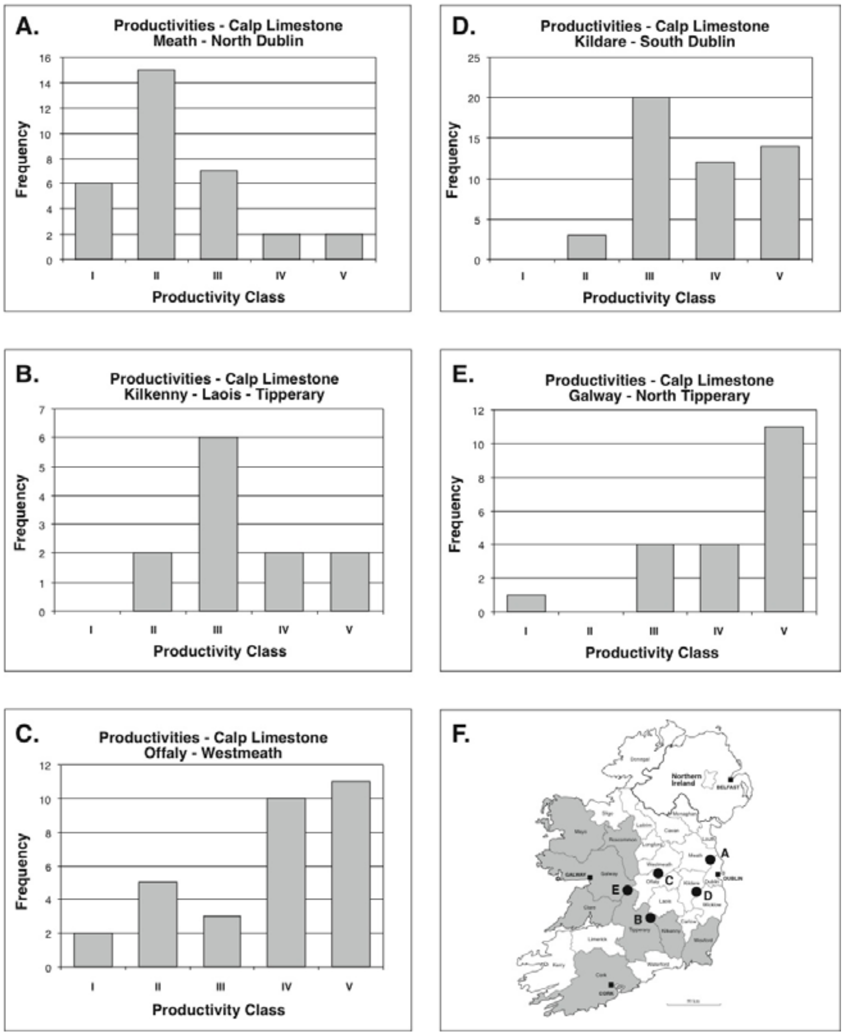

Figure 5 Well productivities in the Calp (Lucan Formation) in various localities in Ireland (adapted from Geological Survey of Ireland, in press)

Thus, even 'impure' limestones can be locally productive, presumably a function of fracturing and faulting, and behave as fissured aquifers but with great heterogeneity in terms of transmissivity.

Waulsortian limestones, usually have a high degree of purity and are commonly fine-grained, massive and unbedded with well-developed jointing only if they are located close to faults or folds. Outcrop of these limestones are most widespread in the midlands and in the valleys of counties Cork, Tipperary and Waterford. It is the southern outcrop with folded limestones that is more productive of groundwater, presumably because of the increased karstification in the fractured rock. For example, near Dungarvan in Co. Waterford transmissivity values are <3000m^2/d with permeabilities of 0.5-200m/d. Large springs are associated with fractured Waulsortian limestones, for example the Kedrah spring near Clonmel (baseflow of 0.25m^3/s) and the River Suir between Ardfinnan and Thurles receives large inflows from a series of springs issuing from Waulsortian limestone.

Thus, the hydrogeological character of a specific pure limestone lithologies may be significantly affected by the occurrence or otherwise of potentially karstifiable secondary openings. Dolomitised limestones outcrop primarily in the central and eastern midlands and in south Co. Wexford. Dolomitisation appears to significantly affect the water bearing character of limestones in Ireland. Particularly in pure limestones, increasing degrees of dolomitisation are associated with increasing permeability and well yields. Table 1 shows the occurrences per meter of overall fractures and fractures with flow for various lithologies for Waulsortian limestones in Co. Limerick. The increase in both overall fracturing and productive fractures with increased dolomitisation is apparent.

Table 1 Fissure occurrence relative to lithology, Co. Limerick (adapted from Jones et al 1999).

Fractures per metre	Limestone	Dolomite	Dolomitised limestone	Sucrositic limestone
Overall fractures	0.67	0.95	7.03	1.94
Flowing fractures	0.13	0.02	2.1	1.7

Overall, well yields from dolomitised rock are markedly skewed to high yields with relative high transmissivities, a more distributed permeability and possibly bimodal permeability in some locations as compared with even pure limestones.

Even within pure limestones, impurities are common and may impact on the character of the aquifer. Shale/clay bands, even when only a few cm in thickness, may hinder vertical movement of groundwater and encourage lateral flow along bedding planes, specially where the strata are near-horizontal for example, in the Burren, Co. Clare and on the Aran Islands. Chert lenses, even where they are discontinuous have a similar barrier function in the limestone aquifer. The plateau limestones of the northwest and the Derravarragh limestones of eastern Co. Westmeath exhibit strong groundwater flow influences due to the presence of extensive chert. All of these impurities commonly function as inception horizons for karst conduits.

Folded limestones, in addition to having well-developed fracture sets, form semi-impounded aquifers where they comprise synclinal valley-floor outcrops in the south of Ireland and these are often high yielding aquifers, possibly because of the distributed nature of karstification. In the flat-lying pure limestones that stretch from south Clare into south Mayo and Co. Roscommon groundwater is abundant but highly localised. In the limestones of the midlands, compartmentalisation of the limestone into hydrogeological blocks is widespread. Adjacent blocks with volumes of several cubic kilometres, may have different transmissivities and groundwater levels and so have stepped hydrogeological boundaries, precluding the occurrence of extensive aquifers. The blocks are often bounded by faults, although individual faults/lineaments may be barriers or transmitting zones or may change character along their length. The termination of a dolomitised zone of limestone may also function as a hydrogeological barrier. There is also some evidence of vertical compartmentalisation of the midland limestones due to the occurrence of less permeable strata.

Although, as noted previously, it seems that permeability and transmissivity decline sharply with depth below ground level, quantitative data are limited. In the dolomitic and undolomitised pure limestone of south Wexford Cullen (1980) reports 20% of inflow occurring within the uppermost 5m, 64% in the first 30m with no flows recorded below 94m. Similarly, in Limerick, dolomitic limestone fissure density in the upper 45m b.g.l. was tenfold that between 45 and 155 b.g.l., (Jones et al 1999). Evidence for deeper flows in the limestones is largely confined to isolated evidence from the midlands for example, the large mines in Tipperary and Laois. Figure 6 shows the fissure frequency (derived from 637 boreholes) from the surface to -360m in the vicinity of the Lisheen Mine; some 20% of boreholes had no fissuring.

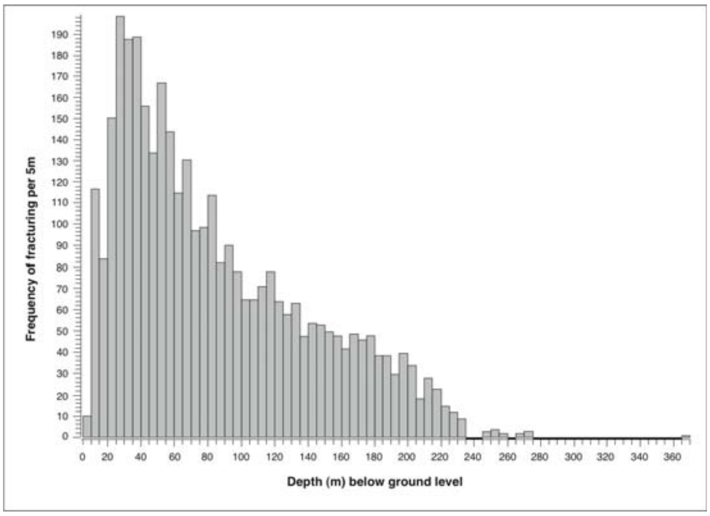

Figure 6 Fracture frequency in relation to depth below ground level, Lisheen Mine (adapted from Jones et al 1999)

CONCLUSIONS

The complex interaction of factors that determine the aquifer characteristics of the Carboniferous limestone make water yield prediction difficult for any particular locale, except in general terms. No one variable (e.g. purity of the limestone, fracture density, topographic and geological setting) can be relied upon as a predictor of water yield.

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ORIGIN, TRANSPORT AND MONITORING OF PARTICLES AND MICROBIAL CONTAMINANTS IN KARST AQUIFER SYSTEMS

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ABSTRACT

Sediments and suspended particles/colloids of different types and origin play crucial roles for the formation and dynamics of karst aquifer systems, and for the transport and attenuation of contaminants, including faecal and pathogenic microorganisms (FPM). Particles in karst groundwater either originate from the soil and sinking surface streams (allochthonous) or from within the aquifer (autochthonous). FPM are allochthonous and display highly variable concentration levels in karst spring water. Long periods of good water quality are occasionally interrupted by relatively short but intense contamination events, often following intense rainfall. These contaminations are difficult to identify, because FPM cannot be monitored online. This study is consequently aimed at the identification of easy-to-measure parameters that indicate the possible presence of FPM. Turbidity alone turned out not to be a reliable indicator, because autochthonous turbidity is generally not contaminated with FPM. Continuous measurements of particle-size distribution (PSD) using a portable particle counter allowed differentiation of autochthonous and allochthonous turbidity: The first consists of a mixture of different particle sizes; the second is mainly composed of very fine particles/colloids. High correlation between 1-µm particles and E. coli was found (R^2 = 0.92) in allochthonous turbidity. PSD monitoring can thus be used as an "early-warning system" for microbial contamination of karst spring water.

INTRODUCTION

Microbial pathogens in drinking water are a major threat to human health, causing several billion occurances of disease and millions of deaths per year worldwide. Most waterborne disease outbreaks occur in poor countries (Montgomery and Elimelech 2007), but faecal and pathogenic microorganisms (FPM) are also a problem for water suppliers in rich countries (e.g. Herwaldt et al. 1992). Karst aquifers contribute an estimated 25% to global drinking water supply (Ford and Williams 2007) but are highly vulnerable to contamination. Contaminants can easily enter the aquifer via swallow holes or thin soils, and rapidly spread in the conduit network, often together with suspended sediment particles.

A major challenge in the use of karst water sources lies in the variability of water quality. Prolonged periods of good water quality are interrupted by short but intense contamination events. Pathogens in drinking water (viruses, bacteria, protozoan cysts) are difficult to detect. Therefore, monitoring of water quality relies on faecal indicator bacteria (FIB), such as *E. coli*. The idea is that the presence of FIB indicates the possible presence of pathogens, while their absence means that pathogens are also absent (which is not always true). However, FIB monitoring requires water sampling and subsequent laboratory analysis, which typically takes 24 hours – often too late for highly variable karst springs.

Contamination of karst springs often occurs during or after storm rainfall, which also causes increased levels of turbidity. Therefore, both turbidity and discharge have been proposed as indicators for water quality (Auckenthaler et al. 2002; Nebbache et al. 1997; Ryan and Meiman 1996). However, the relationship between these parameters and microbial water quality is not straightforward. Microbial contamination originating from the land surface sometimes arrives at the spring several days after storm rainfall, during recession periods, while the spring water discharging during high-flow periods sometimes includes high levels of turbidity without being contaminated (Pronk et al., 2006).

Therefore, a research project was set up to obtain a better understanding of the origin, transport and dynamics of suspended particles in karst systems and how they relate to faecal and pathogenic microorganisms (FPM) in spring water. The practical goal was to identify an early-warning system for microbial contamination, i.e. an easy-to-measure parameter that indicates the possible presence of FPM. Particles and sediments are also relevant for the transport and attenuation of other contaminants and for the formation and behaviour of karst systems. Consequently, this study has broader implications than the immediate use for microbial water quality monitoring. This paper presents selected results of this project. A more complete presentation can be found in Pronk et al. (2006, 2007). The project also included experiments in the unsaturated zone (Goldscheider et al. 2008; Pronk et al. 2009b) and research on microbial biocenoses (Goldscheider et al. 2006; Pronk et al. 2009a).

TEST SITE, MATERIAL AND METHODS

The study area is a karst system near the city of Yverdon, Switzerland. It is located between two major geological and landscape units: The folded Jura Mountains reaching an altitude of 1588 m in the region, and the Molasse Basin, forming the Swiss Plateau (430–600m). The forested SE slope of the Jura Mountains, where Upper Jurassic (Malm) and Cretaceous limestones outcrop, is the principal diffuse, autogenic recharge area. Further to the SE, due to a complex arrangement of folds and faults, limestone is exposed in two hydrogeologic windows within low-permeability molasse sediments, which confine the aquifer. At the western window, a stream sinks into the *Feurtille* swallow hole at ~600m (F in Fig. 1). As the stream drains agricultural land, it frequently contains high levels of turbidity, organic matter, nitrate and bacteria. About 4km to the east, at the base of the second window, two large karst springs at ~450m are located at the contact between the low-permeability sediments and the Cretaceous limestone: The *Moulinet* spring (M) consists of eight individual orifices with identical physicochemical and microbial characteristics. The *Cossaux* spring (C) is captured by eight inclined drillings and contributes to the water supply of the city.

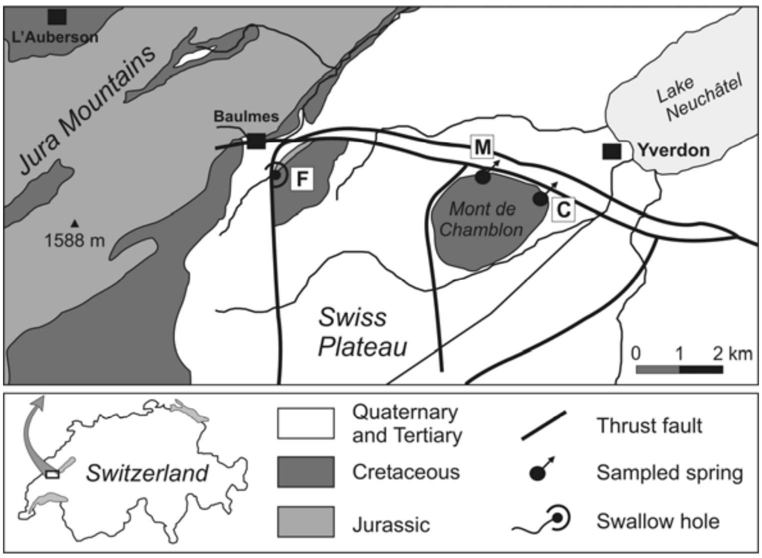

Fig. 1: Hydrogeologic map of the Yverdon karst system. The Feurtille swallow hole (F) drains agricultural land and is connected to two karst springs, Moulinet (M) and Cossaux (C), the latter is used for drinking water supply (Pronk et al. 2007).

Discharge, temperature (T), specific electrical conductivity (SEC), turbidity and total organic carbon (TOC) were monitored continuously at the swallow hole and springs, using weirs and pressure probes (DL/N 64, STS), SEC-T probes (Cond 340i, WTW) coupled with data loggers (DT50, dataTaker) and flow-through field fluorometers (GGUN-FL30, P.A. Schnegg). Precipitation data from three nearby stations were collected (MeteoSwiss). Particle-size distribution (PSD) was measured continuously using a portable particle counter (Abakus mobil fluid, Klotz) that counts suspended particles in the range of 0.9–139 µm and groups them into up to 32 definable size classes.

For detailed hydrochemical and microbiological analyses during selected events, water samples were collected hourly using auto-samplers (6712C, ISCO) with sterilised bottles, transported to the laboratory in cooling boxes and processed within 6 h (for the latest sample) to 30 h (for the earliest sample). Samples were analysed for major ions using ion chromatography (DX-120, Dionex), and for FIB, including total coliforms, heterotrophic plate counts, enterococci and *E. coli*, using standard cultivation techniques; only *E. coli* results are discussed here.

In order to better characterise the connection between the swallow hole and the springs, four tracer tests were carried out, using 1kg of uranine per test. Dye concentrations were continuously recorded with the abovementioned field fluorometer. Control samples were collected with auto-samplers and analysed in the laboratory using a spectral fluorometer (LS 50 B, PerkinElmer).

RESULTS AND DISCUSSION

The four tracer tests made it possible to better characterise contaminant transport between the swallow hole and the springs. Transit times varied between 24 hours during high-flow conditions and 12 days during low-flow conditions (Fig. 2). With increasing discharge, tracer recoveries increase at the Moulinet spring but decrease at the Cossaux spring, while total recovery remains nearly constant at ~29 %, indicating that Moulinet acts as an overflow of the Cossaux spring.

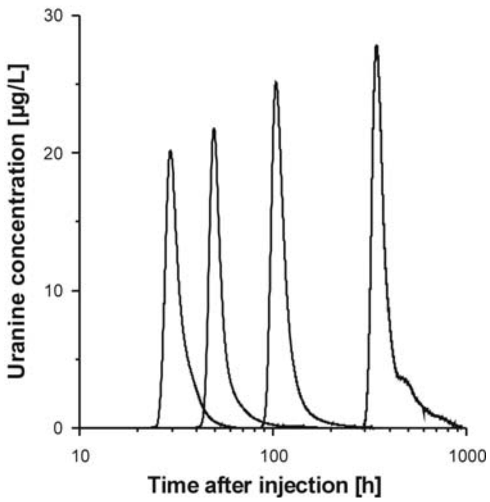

Fig. 2: Uranine breakthrough curves monitored at Moulinet spring. Transit times (first detection) vary between 24 hours and 12 days, depending on the hydrologic conditions.

Two types of turbidity were observed at the two karst springs during and after storm rainfall (Fig. 3): A primary turbidity signal occurred shortly after rainfall, during the rising limb of the spring hydrograph. This turbidity is explained by the remobilisation of sediments from karst conduits due to a hydraulic pressure pulse; it is thus referred to as autochthonous or pulse-through turbidity. A secondary turbidity signal occurs 1 to 12 days later and is explained by the arrival of turbid water from the swallow hole; it is thus referred to as allochthonous or flow-through turbidity. The range of transit times of this second turbidity and its dependency on the hydrologic conditions coincides with the transit times obtained by the tracer tests. During the first turbidity signal, TOC remains constant and low at pre-storm levels; the second turbidity signal coincides with a significant increase of TOC (Fig.

3). As TOC typically originates from the soil, land surface and (sinking) streams, this observation supports the allochthonous origin of the second turbidity signal (Pronk et al. 2006).

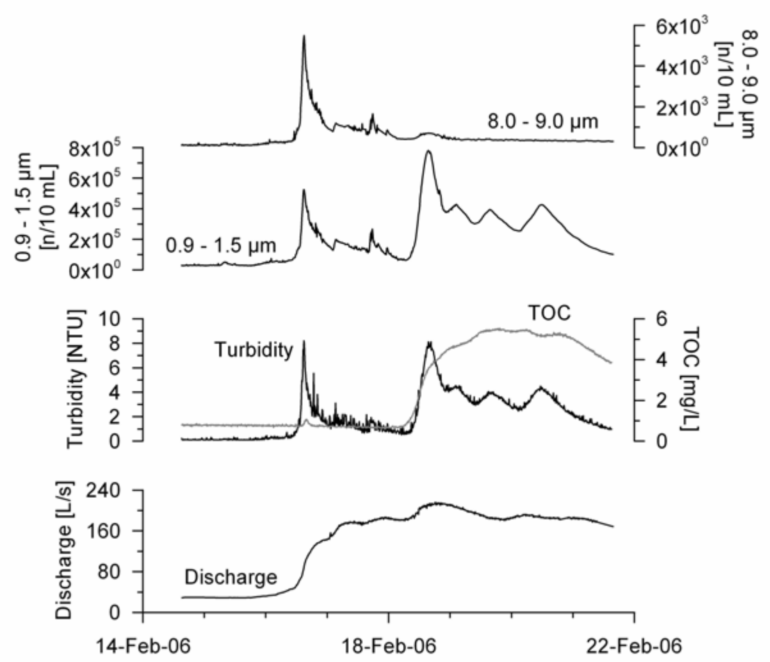

Fig. 3: Variability of discharge, turbidity, TOC and two different particle-size classes at the Moulinet spring. The primary turbidity signal consists of a mixture of fine and large particles; the secondary signal is mainly composed of fine particles (0.9–1.5 µm) and characterised by high TOC levels.

PSD monitoring allowed further differentiation of the two turbidity signals (only two size-classes are shown in Fig. 3): While the primary turbidity signal consists of a broad mixture of fine and large particles, the secondary turbidity signal is predominantly composed of very fine particles/colloids, with an equivalent spherical diameter of 0.9–1.5 µm. The explanation for this observation can be found in the classical Hjulström diagram, which describes the relationship between flow velocity and erosion, transport and deposition of sediment particles of different sizes. The increased flow velocities during the rising limb of the spring hydrograph (hydraulic pressure pulse) mobilise a mixture of clay and silt (and even sand) particles, but only the very fine particles are transported from the swallow hole to the spring, while larger particles are removed by sedimentation.

Fig. 4 presents monitoring results from the Moulinet spring following two intense rainfall events: Two primary, autochthonous turbidity signals (T1a, T1b) were observed shortly after the two rainfalls events, when spring discharge was rapidly increasing. These two turbidity signals consist of a mixture of fine and larger particles and are characterised by stable and very low levels of *E. coli* and TOC. Two secondary, allochthonous turbidity signals (T2a, T2b) occurred several days later. These turbidity signals are mainly composed of very fine particles (0.9–1.5 µm). TOC increases in two steps, and *E. coli* display two distinct peaks, highly correlated to the evolution of fine particles (R^2 = 0.92). All this clearly indicates the arrival of water from the swallow hole, which contains high levels of TOC, faecal bacteria, and probably pathogenic microorganisms. All larger particles have been removed from the water by sedimentation between the swallow hole and the springs, while bacteria, TOC and fine particles are transported inside the aquifer without significant attenuation.

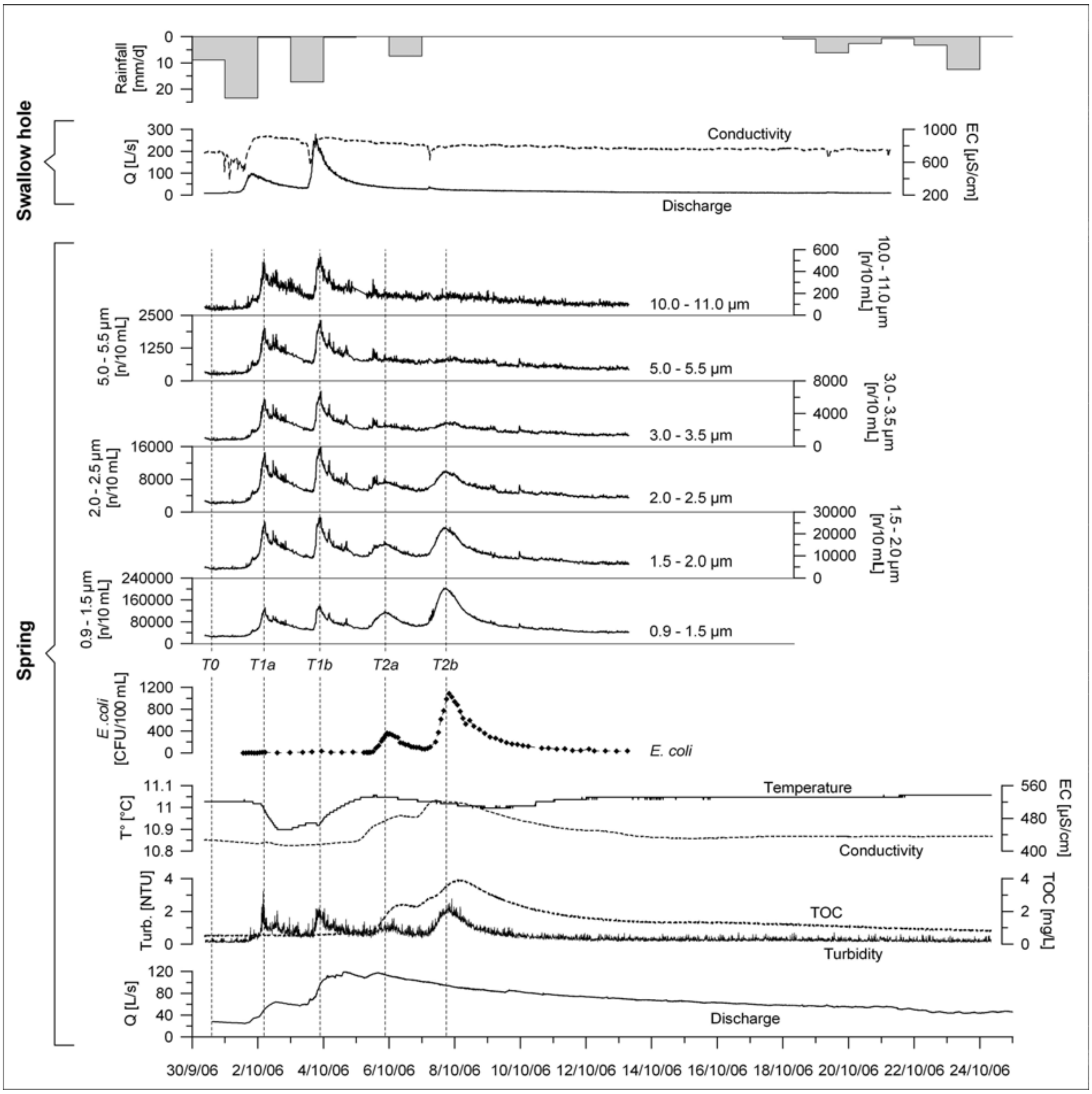

Fig. 4: Variability of particle-size distribution, *E. coli* and various hydrologic and physicochemical parameters at the Moulinet karst spring following a double rainfall event (Pronk et al. 2007).

These findings were confirmed by several other high-flow events monitored at this test site and another karst aquifer system (Noiraigue, Switzerland), and by monitoring and a combined irrigation-tracer test at an unsaturated zone experimental site (Pronk et al. 2009). Although there are many differences in the detail, it is generally possible to differentiate autochthonous and allochthonous turbidity. Allochthonous turbidity is often characterised by increased levels of TOC and FIB, and can be identified by an overproportional increase of fine particles (~ 1 µm) with respect to larger ones.

CONCLUSIONS AND OUTLOOK

Turbidity in karst groundwater has two principal origins: Autochthonous turbidity results from the mobilisation or remobilisation of sediments in karst conduits, while allochthonous turbidity originates from the soil zone, land surface or sinking surface streams (Fig. 5). Monitoring of particle-size distribution (PSD) makes it possible to characterise and differentiate the two turbidity types: Autochthonous turbidity consists of a broad mixture of different particle-size classes. In the allochthonous turbidity, most large particles have been removed by sedimentation in the system and so this turbidity is predominantly composed of fine particles.

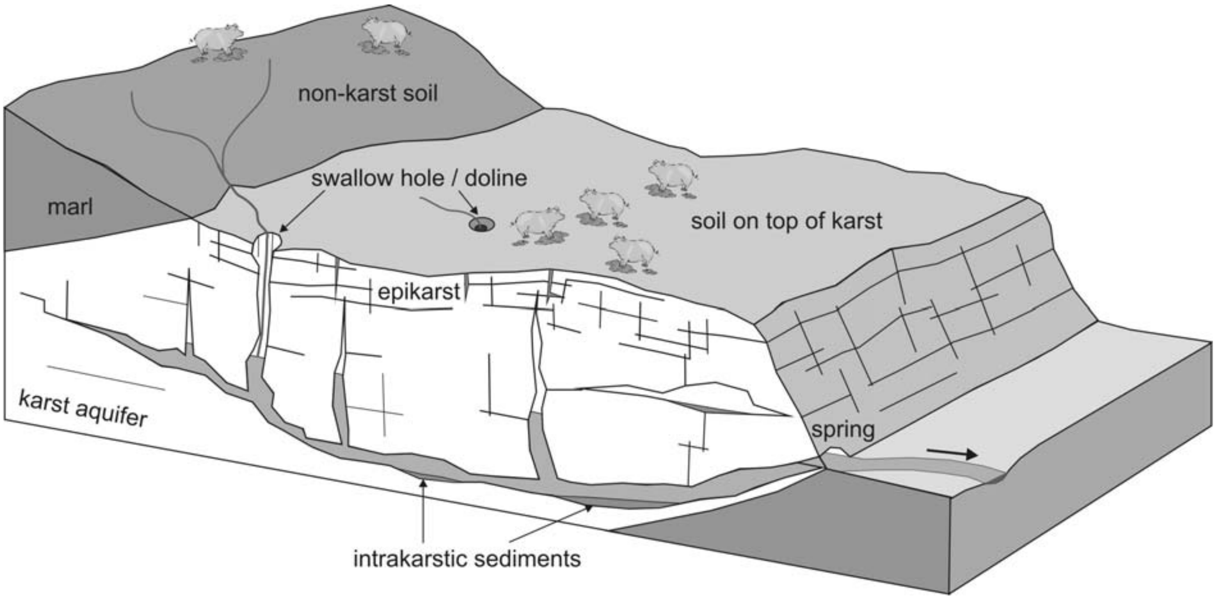

Fig. 5: Block diagram of a karst aquifer illustrating different origins of sediment particles and faecal and pathogenic microorganisms (FPM) in spring water. Particles either originate from remobilisation of intrakarstic sediments (autochthonous) or from the soil and sinking streams, often including high levels of FPM and organic carbon (allochthonous) (after Goldscheider and Drew 2007).

TOC and faecal and pathogenic microorganisms (FPM) also originate from the land surface or sinking streams, i.e. they are also allochthonous (Fig. 5). Therefore, the differentiation of autochthonous and allochthonous turbidity has practical implications for spring water quality monitoring. Two alternative “early-warning systems” for the possible presence of (FPM) can be proposed:

- The simultaneous increase of turbidity and TOC;
- The relative increase of fine particles (0.9–1.5 µm) with respect to larger particles.

Very probably, these early-warning systems only work for microbial contamination resulting from agricultural activities on the land surface, while direct and permanent wastewater injections into sinking streams or groundwater are likely to cause permanent spring water contamination (as demonstrated by means of comparative tracer tests with solute and particulate tracers, Göppert and Goldscheider, 2008), without distinct TOC or PSD variations.

Besides the use for microbial water quality monitoring, a better understanding of sediments and suspended particles in karst systems is also relevant for many other applied and research questions. The transport and attenuation of other types of contaminants is also related to sediment and particle transport. Intrakarstic sediments can act as storage reservoirs for toxic metals, due to adsorption (Vesper and White 2004). During turbulent storm-flow conditions, these sediments are mobilised and the contamination reaches the spring (Vesper and White 2003) – in this case, autochthonous turbidity is problematic for water quality. DNAPLs also accumulate in conduit sediments, due to their high density, and can be remobilised during storm flow (Loop and White 2001).

Sediment transport is also relevant for the formation of karst aquifers. Most carbonate rocks include mineralogical impurities, such as clay and silt. While the carbonate components are removed by chemical dissolution, residual minerals have to be removed by mechanical erosion, otherwise karstification will stop. While much research has been done on the chemical aspects of karstification (e.g. Dreybrodt 1990), the removal of sediments from evolving karst aquifers requires further research, taking into consideration relevant threshold events, such as the threshold between laminar and turbulent flow (Herman et al. 2008).

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HYDROLOGY AND HYDROGEOLOGY OF TURLOUGHS AS WETLANDS

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ABSTRACT

This study quantifies the hydrological regime of a set of turloughs and suggests a conceptual model to explain turlough operation. Hourly water levels were recorded in 22 turloughs over a 2 year period beginning in November 2006. Stage – volume relations were derived using digital terrain models generated from detailed topographic surveys. These were then combined to give volume time series. A range of turlough response and recession characteristics were observed with some having multiple flood events in the course of a year whereas others show a single event with a slow recession. Maximum flow capacities were derived through analysis of the volume recessions. The hydrological behaviour observed led to the development of a conceptual model for the operation of turloughs. Together with ecological and management data this model will aid in the evaluation of turlough conservation status as groundwater dependent terrestrial ecosystems. Application of such a model to historic rainfall records would provide details of long term turlough hydrological regimes and so could be used to partially explain existing ecosystems.

INTRODUCTION

DEFINITION
Turloughs are one of the characteristic features of the Irish karst landscape (Drew and Daly 1993). They are ephemeral lakes resulting from a combination of relatively high rainfall and groundwater levels in topographic dips in the karst. Thus, a turlough is effectively a hydrogeological feature which may formally be defined as "A topographic depression in karst which is intermittently inundated on an annual basis, mainly from groundwater, and which has a substrate and/or ecological communities characteristic of wetlands." (Tynan et al. 2005)

ECOLOGICAL IMPORTANCE
By their nature, turloughs support many characteristic flora and fauna species (Reynolds 1996). Under the Water Framework Directive (2000/60/EC), turloughs are classified as Groundwater Dependent Terrestrial Ecosystems (GWDTEs) and as a Priority Habitat in Annex 1 of the EU Habitats Directive (92/43/EEC). Consequently, under national legislation, many have been designated Special Areas of Conservation (SAC), that is, areas of ecological importance which are afforded the highest level of protection as 'natural' sites. Both EU directives necessitate the monitoring and management of these habitats to ensure favourable conservation and groundwater status is achieved. In particular, the Water Framework Directive
requires a good understanding of the hydrological linkage between the turlough wetland, its ecological functioning and the connected groundwater body. Development of a conceptual model for the hydroecology and hydrochemistry of turloughs is currently the subject of a major research project being carried out by Trinity College on behalf of the National Parks and Wildlife Service of the Department of the Environmentt in aid of a management strategy for these wetlands.

HYDROLOGY

Turloughs are at the interface between groundwater and surface water. They fill mainly by rising groundwater levels through estavelles and springs together with surface runoff; they ultimately empty through estavelles and swallow holes (Coxon 1986). Filling normally occurs in late autumn due to periods of intense or prolonged rainfall. Emptying typically occurs from April onwards. The karst flow system, of which a turlough is a surface expression, possesses a flow capacity which is defined by the size and connectivity of the flow paths present within the rock. Rainfall of insufficient duration or intensity can be accommodated by subsurface flow paths; hence no surface flooding is visible in the turlough basin during these dry periods. However once the required combination of rainfall intensity and duration occurs the storage of the system is exceeded and flooding begins (Fig. 1).

(a) ***(b)***

Figure 1 Blackrock turlough in (a) June and (b) December 2007

The level, duration and extent of flooding vary greatly among turloughs. Maximum flood depths of between 3 and 14m and flooded areas of over 60 hectares were recorded during the monitoring period of this project. A range of turlough response and recession characteristics also exist with some having multiple flood events in the course of a year whereas others show a single event with a slow recession (Fig 2). The nature of the response not only depends on the physical constraints at flow entry and exit but also on the particular rainfall pattern during the year.

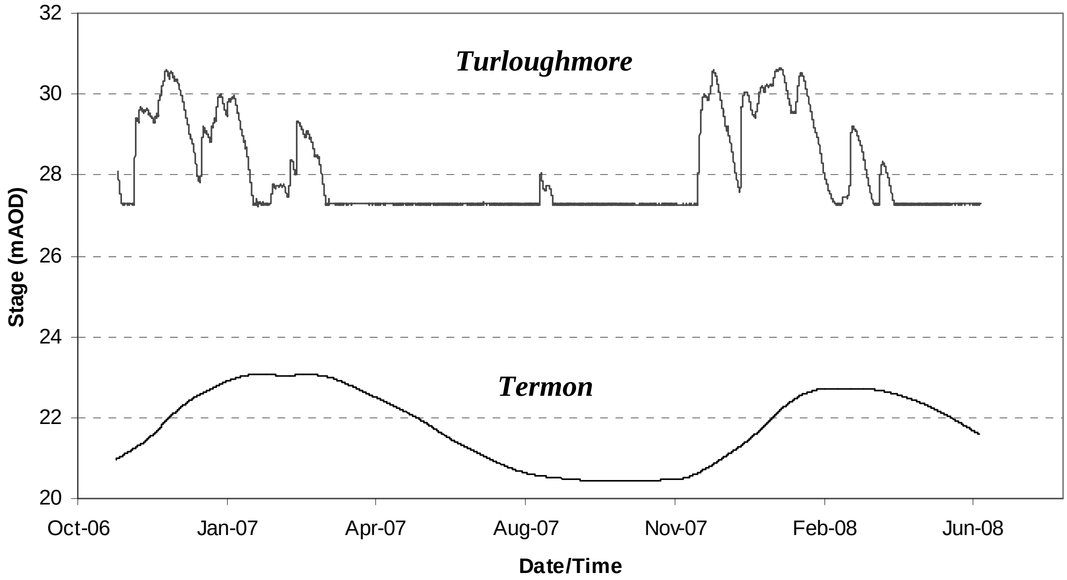

Figure 2 Contrasting Turlough Hydrological Regimes of Turloughmore, Co. Clare and Termon, Co. Galway

GEOLOGY

Turloughs are found in areas of thin, relatively permeable subsoil on well-bedded, pure grey calcarenite. They occur predominantly on Dinantian pure bedded limestone due to its purity and well developed bedding (Coxon 1987). Turloughs were originally considered hollows in glacial drift with underlying karst drainage systems (Williams 1964). However, Drew asserted that turloughs invariably lie in bedrock hollows (Drew 1976). These solutional features require a far longer period to develop than has passed since the last glaciation and it was therefore inferred that turloughs could not be solely glacial features. Coxon and Coxon (1997) later suggested that turloughs are polygenetic with both processes playing a part in their formation. The presence of lacustrine marl in the basin of many turloughs also provides evidence that the flood regime has altered over time (Coxon 1994). Moreover, where turloughs occur, it has been postulated that there may be more than one period of karstification involved, both Pleistocene and Tertiary.

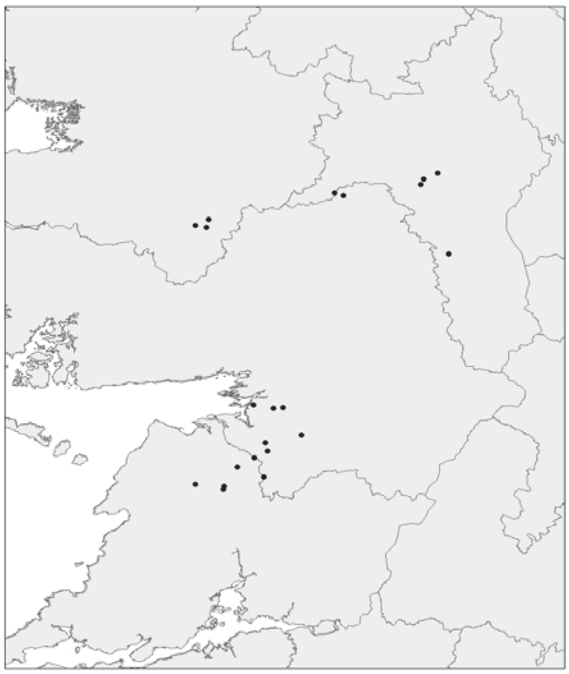

Figure 3 Turlough study sites

METHODS

HYDROLOGY

The behaviour of a turlough as a wetland is fundamentally driven by its hydrology, essentially groundwater but with some surface water interaction that includes direct rainfall. Discharges through turloughs are notoriously difficult to assess because of the often uncertain location and nature of the inflow and outflow points. Thus, the only realistic hydrological measures are based on water level. Semi-permanent water level monitoring stations were established in twenty-two selected turloughs using ‘Divers’, proprietary pressure transducer-based instruments. Time series of water levels were collected using Divers installed at or near the lowest point of each turlough and recorded on an hourly basis. Sites were instrumented in early November 2006 and monitoring will continue until summer 2009.

In addition sixteen Divers were equipped with temperature probes and recorded water temperature at hourly intervals. An array of temperature probes was also installed in an active estavelle in Caranavoodaun turlough to measure variation of temperature with depth.

To supplement long term Met Eireann data, three rain gauges were installed in Kilchreest and Francis Gap in Co. Galway and Ballintober in Co. Roscommon. Rainfall was measured using an ARG100 tipping bucket rain gauge which recorded cumulative rainfall at 15 minute intervals.

Water samples were taken for chemical and 18O isotope analysis from 5 turloughs in the Gort – Kinvarra chain, three contributing rivers to the karst flow system as well as the springs in Kinvarra.

TOPOGRAPHY

In the absence of direct measurement of flows in or out of a turlough, the approach was taken to estimate net flows by determining the volume of the turlough and deriving flows from a combination of time changes in stage related to the relevant volume at that stage. Thus a depth-volume relationship for each turlough was essential to determining flow.

A detailed topographic survey was carried out on each turlough using Trimble differential GPS equipment with better than one centimeter accuracy in the vertical. An average of over 900 points was taken per turlough with a mean horizontal point spacing of 12m. The locations of karst features such as springs and swallow holes were recorded during the field surveys, and smaller grid spacing was used to map such features.

Using this extensive topographic dataset, digital terrain models (DTM) were generated (Fig. 4). To determine turlough volume and net flow rates the relationship between stage and volume in each turlough basin was established. This was achieved by calculating the volume between the lower surface of the turlough and an upper horizontal surface representing a specific water level at 20mm intervals over the recorded range. Applying this relation allowed time series of volumes and associated flow rates to be obtained from recorded water levels for each turlough.

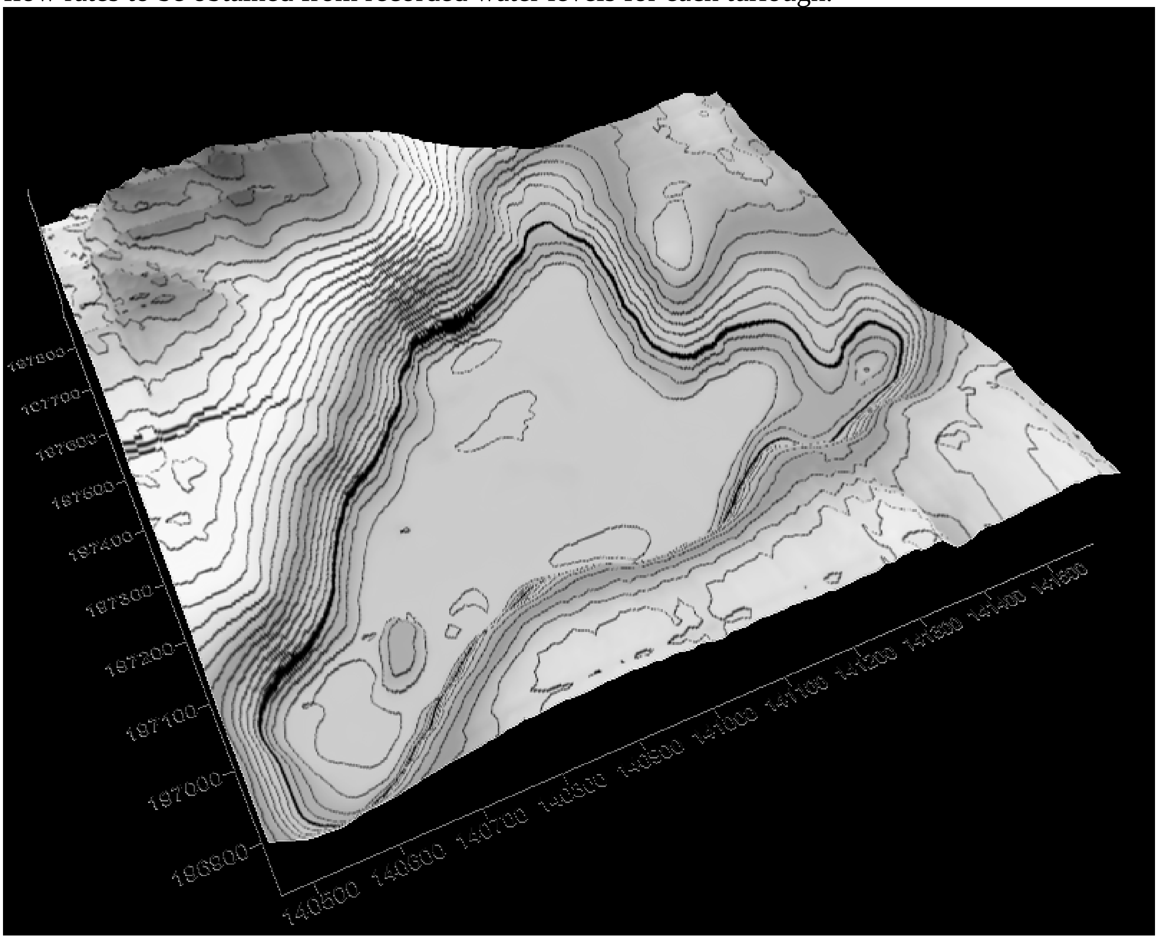

Figure 4 Digital Terrain Model for Termon, Co. Galway (Flooding extent highlighted in bold)

DISCUSSION

Upon applying stage – volume relationships to recorded hydrographs a common characteristic was observed across the set of turloughs. During the emptying phase the net outflow did not vary with changing head as might be expected if the turlough were conceived as a bucket with a hole in the bottom. Instead net outflow remained constant for a large part of the recession, the outflow only reducing at low water levels. This implied that there exists a maximum rate at which each turlough can drain, a rate which is independent of water level within the turlough. By applying linear regression to the recession curves the maximum drainage capacity could be derived (Fig 5).

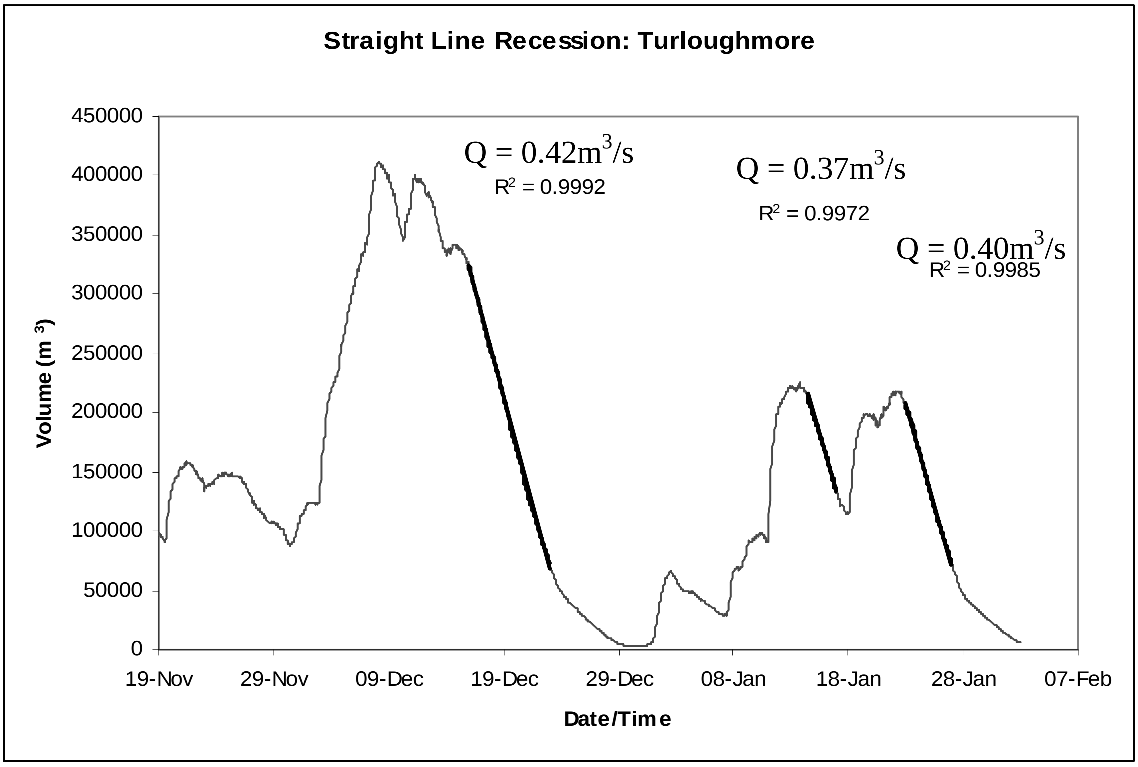

Figure 5 Straight Line Recessions for Turloughmore turlough

The constant flow rate during recession is only clearly defined when there is little or no rainfall during the recession period. Recharge from rainfall events causes water levels in the catchment to rise thus slowing the rate of emptying of the turlough. It also enters the turlough directly via surface flow and direct rainfall. In an attempt to limit this effect, regression analysis was carried out on data from mid March to early April 2007, a period where little or no rainfall fell. A few fast responding sites such as Turloughmore and Lough Aleenaun on the Burren had multiple recessions before this period and so regression analysis was carried out on all available recessions and the highest recorded rate taken as the maximum flow rate.

The recession behaviour observed from 2 years of hydrological data led to the development of a conceptual model for the operation of turloughs. As the turloughs are typically empty during summer months despite rainfall events, there exists a flow system capable of carrying this recharge without surface flooding. When the rainfall on the catchment exceeds the capacity of this system, it becomes surcharged and flooding occurs. This process is represented by the pipe flow system shown in fig. 6.

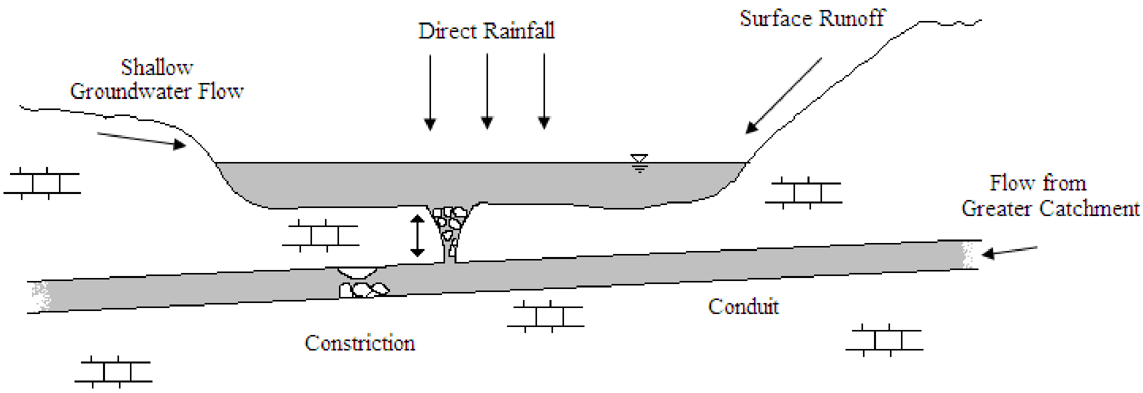

Figure 6 Schematic for a Turlough Conceptual Model

The conduit represents an actual conduit or a system of interconnected fractures. The turlough is represented by a pond with depth – volume characteristics derived from the digital terrain model (DTM) fitted to the topographic survey data. Two catchments are defined in the model. The first is the greater catchment area which drains via the conduit system beneath the turlough. The second is a smaller local catchment which supplies water to the turlough via direct rainfall, surface runoff and shallow groundwater flow. Rainfall on the greater catchment enters the turlough via the conduit flow system; the capacity of which is controlled by the restriction. During recession periods flow through the conduit system does not enter the turlough. Instead it controls the rate of release of water from the turlough by varying the pressure in the pipe. By modeling the hydrological response of turloughs to rainfall events in this way, the required contributing area can be quantified in a hydraulic sense for the first time.

The hydrological data so far collected has also confirmed the basic modus operandi of a turlough as a ‘surge tank’ in a hydraulic sense and that most turloughs operate through a single or a few restricted entry points rather than behaving as ‘flow through’ devices where the surrounding boundaries are all permeable. Once a turlough fills, it has very little mixing association with the underlying groundwater. This model has particular implications for interpretation of potentially polluting pressures and on the management of associated risks.

CONCLUSIONS

The main basis for assessing pressures, pathways and therefore risk is the Zone of Contribution (ZOC) or catchment area of the turlough as envisaged by the Water Framework Directive. Identifying a catchment area, while conceptually straightforward on the conventional basis of catchment topography, is difficult in practice because of the karstic nature of a turlough and its surroundings often stretching the catchment beyond the topographic divide. By fitting the conceptual model proposed here to individual turloughs the the magnitude of the zone of contribution can be defined. By taking into account surrounding geology, topography and any other relevant data, this area can then be fitted to define the turlough catchment.

Together with ecological and management data this model will aid in the evaluation of turlough conservation status as groundwater dependent terrestrial ecosystems. For the first time the role turloughs occupy within the karst groundwater system will be defined and subsequently the risk posed to these protected ecosystems can be evaluated and quantified. From water level records and the DTM for a turlough appropriate measures for hydroecological risk are being established. For example, frequency-duration curves for different stages in the turlough are uniquely related to characteristic ecological communities (Tynan et al, 2005). For invertebrates, the relevant hydrological measure may be the rate at which the area of inundation spreads, as the turlough fills or empties, again derivable quantities from the stage volume relationship for the turlough.

Application of such a model to historic rainfall records would provide details of long term turlough hydrological regimes and so could be used to partially explain existing ecosystems. There is also scope for its use as a predictive model to investigate potential changes to hydrological regime, and so potential risk due to changing rainfall patterns associated with climate change.

ACKNOWLEDGEMENTS

This research is funded by a grant from the National Parks and Wildlife Service (Department of the Environment, Heritage and Local Government). This research forms a part of the large interdisciplinary project on Assessing the Conservation Status of Turloughs, being carried out in Trinity College Dublin in 2006-2010, funded by the National Parks and Wildlife Service of the Department of the Environment (see Pereira *et al.*., 2009, this volume). We are also grateful to Patrick Veale for his field assistance.

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TURLOUGH WATER QUALITY AND IMPLICATIONS FOR GROUNDWATER MANAGEMENT

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ABSTRACT

This paper describes some preliminary findings from a research project on turlough hydrochemistry and algal dynamics. Monthly samples were collected from 22 turloughs during the 2006-07 flooding season. Mean total phosphorus values from each site over the flooding season ranged between 4.0 and 82.1 µg/L. Algal biomass (measured by chlorophyll a) showed seasonal mean values similar to annual mean values observed in Irish permanent lakes, despite the absence of water during the summer months when algal biomass would normally reach a peak. The majority of turloughs (17 of 22) showed a linear relationship of total phosphorus with chlorophyll a, implying that algal growth was limited by phosphorus. Four turloughs that did not conform to this relationship (having high phosphorus levels values but relatively low values of chlorophyll a), lie along major karst conduit flow paths through the Gort Lowlands fed by allogenic (non-limestone) water. Any future decisions on quality standards for turlough waters, which will have implications for the quality status of their associated groundwater bodies and hence for catchment management, must take into account this varying relationship between nutrients and turlough trophic status.

BACKGROUND

This paper describes some preliminary findings from research on turlough hydrochemistry and algal dynamics which is currently being undertaken as a Ph.D. project by the first author. This research forms a part of the large interdisciplinary project on Assessing the Conservation Status of Turloughs, being carried out in Trinity College Dublin in 2006-2010, funded by the National Parks and Wildlife Service of the Department of the Environment (see Naughton & Johnston., 2009, this volume).

The research project involved the collection and analysis of water samples from 22 turloughs (see Naughton & Johnston, Figure 3). A nested approach was taken, with an initial broad overview of all sites during the first flooding season followed by a more detailed investigation of a subset of turloughs with contrasting nutrient status and algal populations in the second flooding season. This paper outlines some of the results from the first year's sampling, focussing particularly on phosphorus, nitrogen and algal biomass.

AIMS

Turloughs are depressions in karstic areas that flood seasonally (mostly by groundwater), and that support soils and ecological communities characteristic of wetlands (Working Group on Groundwater, 2004). They are important ecosystems which are potentially vulnerable in a number of ways. Pressures include arterial drainage, which has severely impacted approximately a third of Ireland's largest turloughs (Coxon, 1987; Drew & Coxon, 1988), land management changes within the turlough, which may have a direct effect on turlough soils, vegetation and water quality (Sheehy Skeffington *et al*., 2006), and land management changes within the catchment, which may have an impact on the turlough due to changes in quality of water entering the turlough. This paper focuses particularly on the latter pressure.

Turloughs are identified as priority habitats under EU Habitats Directive (EEC, 1992), and seventy-one Irish turloughs are protected within Special Areas of Conservation (SACs) under this directive. These SACs are also designated as protected areas under the Water Framework Directive (EC, 2000). For the purposes of the Water Framework Directive, turloughs are defined as groundwater-dependent terrestrial ecosystems (GWDTE). However, given that they generally consist of an open water body for several months each year, they also have affinities with lakes. In seeking to manage turloughs and to maintain good ecological status, a question to be answered is to what extent their aquatic phase can be treated as a freshwater body subject to the same environmental quality objectives as permanent lakes. The aim of this research, therefore, is to investigate the relationship between the two important nutrients that normally influence the trophic status of water bodies, (i.e. phosphorus and nitrogen), and the algal biomass of the turlough (measured as concentration of chlorophyll a), and to compare these relationships with those observed in permanent lakes.

Given that the main water inputs to turloughs are of groundwater from the underlying karst aquifer, entering the turlough via springs and estavelles, an understanding of nutrient relationships and trophic status of the turlough has important implications for the associated groundwater body. Karst groundwater can provide a significant pathway of phosphorus transfer to surface waters (Kilroy *et al*., 2001; Kilroy & Coxon, 2005). Many groundwater bodies in western Irish karst aquifers have recently been classed at poor status because of their contribution of phosphorus to rivers, for which an environmental quality standard of 35 µg/L molybdate reactive phosphorus is proposed in draft legislation (see Daly & Craig, 2009, this volume). It is therefore important to consider how the protection of turloughs relates to this situation.

METHODS

The 22 sites were sampled monthly from October 2006 until emptying in April to June 2007, by throwing a weighted 5 L plastic bottle, attached to a rope, from the shore to an area of open water. Analyses undertaken included total phosphorus, soluble reactive phosphorus, total nitrogen, total oxidised nitrogen, chlorophyll a, pH, alkalinity and colour. This paper focuses on the phosphorus and chlorphyll a data.

Samples were analysed colorimetrically for total phosphorus (TP) after acid persulphate digestion and for soluble reactive phosphorus (SRP) after Whatman GF/C filtration (Eisenreich *et al.*, 1975). Chlorophyll a (Chl a) was determined colorimetrically by methanol extraction of the Whatman GF/C filters (Standing Committee of Analysts, 1983).

RESULTS

The turloughs varied considerably in the measured levels of nutrients and chlorophyll a. Mean values were calculated for each turlough from the monthly samples from October till emptying in April-June: mean TP values from the 22 sites ranged between 4.0 and 82.1 µg/L, with 16 sites (73%) having a mean TP of less than 35 µg/L and 4 sites (18.2%) less than 10 µg/L. Mean SRP values ranged from 1 to 42 µg/L, with the mean being below 10 µg/L in 17 of the 22 sites. Mean Chl a ranged from 1.1 to 18.4 µg/L (excluding one outlier of 33.5 µg/L). (Note that the full results will be published at a later date (Pereira *et al*., in prep.)).

Total phosphorus showed a statistically significant positive linear relationship with chlorophyll a ($p < 0.001$). Four notable outliers in this relationship are Blackrock, Lough Coy, Garryland and Caherglassaun turloughs, which have high values of both total phosphorus and soluble reactive phosphorus, but relatively low values of chlorophyll a.

Table 1 shows the values for mean TP, mean chlorophyll a and maximum chlorophyll a found in the 22 turloughs, compared with values from studies of Irish lakes.

Table 1: Comparison of turlough water quality from the present study with data from a number of Irish lakes reported in the literature
Means are average annual means in the case of lakes, and means from the flooding season in case of the turloughs. TP = total phosphorus, Chl a = chlorophyll a. All concentrations are in µg/L. In parenthesis are extreme values that occurred as outliers from the bulk of the data.

Reference	Number of lakes	Mean TP	Mean Chl a	Max Chl a
Turloughs	*22*	*4-52 (82)*	*1.1-18.4 (33.5)*	*2.0-110.5*
Champ 1998	10	4-20 (44)	1.7-8.3 (36.2)	3.5-110.8
Irvine et al. 2001	31	<4-91 (530)	1.1-35 (58.1)	2.1-184.9

DISCUSSION

It can be seen from Table 1 that the turloughs exhibited values of chlorophyll a similar to those of Irish permanent lakes. This is perhaps surprising, given that turlough water bodies exist predominantly in winter when temperatures and light levels are low; means based on samples taken from October to April-June might be expected to be significantly lower than annual means from permanent lakes.

In their study of trophic status of 492 Irish lakes based on maximum chlorophyll a, Toner *et al*. (2005) classified 51.5% of the lakes as oligotrophic, 35% as mesotrophic, 11.2% as eutrophic and 2.4% as hypertrophic. Applying the same classification to the turlough data would indicate 27.2% of the turloughs (6 sites) as oligotrophic, 54.5% (12 sites) as mesotrophic, 13.6% (3 sites) as eutrophic and 4.5% (1 site) as hypertrophic. Alternatively, by applying the OECD (1982) classification based on mean TP and mean Chl a to the values obtained in turloughs, 4 of the turloughs are classed as oligotrophic, 8 as mesotrophic, 3 as eutrophic, and 7 have an ambiguous classification (conflicting between that based on TP and on Chl a).

Phosphorus has long been recognised as the most important limiting nutrient for algal growth in lakes (e.g. Reynolds, 1984). Consequently, many studies of lakes have found P to be positively correlated with algal biomass (e.g. Phillips *et al*., 2008). It is notable that the majority of turloughs (17 of the 22) also show this linear relationship of P with algal biomass, implying that their algal growth is limited by phosphorus. The four main outliers in this relationship (Blackrock, Lough Coy, Garryland and Caherglassaun turloughs), which had high phosphorus values but relatively low values of chlorophyll a, lie along major karst conduit flow paths through the Gort Lowlands, which receive allogenic (non-limestone) point recharge from sinking streams from the Slieve Aughty mountains (Drew *et al*., 1997; Southern Water Global, 1997). The majority of turloughs receive their recharge from diffuse recharge and autogenic point recharge generated within the limestone area, and it appears that this hydrological difference has an influence on the relationship between nutrients and algal biomass. Further studies are required, but one factor may be water colour (with highly coloured peaty waters from the Slieve Aughtys suppressing algal growth owing to light attenuation) while another contributing factor might be a rapid flushing rate in the turloughs.

Agricultural activities in the turlough catchments are expected to be the major contributors of nutrients to turlough waters. However, another potential source would be nutrient inputs to soils in the actual turlough basins from grazing animals during the summer months. The possibility of release of nutrients from the soil to the water following inundation is currently under investigation. Nevertheless, it is evident that input of nutrients from groundwater is an important factor. Therefore any future decisions on quality standards for turlough waters will have implications for the qualitative status of their associated groundwater bodies under the Water Framework Directive, and resultant management plans could have repercussions for catchment agricultural activities. So it is important that any future management strategies should be based on a clear understanding of the relationship between nutrients and turlough trophic status, and a recognition that this relationship is not the same at all sites.

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Session V

PROTECTING THE SOURCE: CHALLENGES FOR COMMUNITIES IN GROUNDWATER ZONES

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ABSTRACT

Draft plans prepared under the Water Framework Directive (WFD) acknowledge that public support will be required to achieve and maintain at least good status in our surface waters and aquifers. However, despite the best efforts of those driving the consultation process, take-up by the public has been disappointingly low.

This lack of engagement by 'the plain people of Ireland' doesn't augur well for the future, because, whatever about a need for consultation in formulating plans, public participation in implementing those plans will be essential. Without it, we will be left with enforcement alone and we can be sure there will be public representatives who will portray the WFD as another stick to beat the poor farmer. Indeed, this charge has already been levelled by a councillor in my own county. Humbug, no doubt, but if such misinformation is to be countered, then the WFD will need friends and activists who are embedded in rural communities. This presentation is intended to explain why community-owned group water schemes can and will provide such friends, if others are prepared to work with them on a basis of partnership. This would have major implications in groundwater zones. While the ratio of source types for drinking water supplies is usually given as 70% surface water and 30% groundwater, that ratio is more than reversed in community-owned group water scheme supplies. Taken together, borewells and springs account for 75% of GWS source types, while only 25% of schemes get their supply from lakes and rivers. Yet, despite their reliance on groundwater supplies, group water scheme committees would be the first to acknowledge that they know precious little about their source. Some sampling will undoubtedly have been carried out to determine raw water quality, but as to the nature of their aquifer – its length, direction of flow, overlay, recharge capacity, points of vulnerability etc. – they are in the dark and no one seems to think that it would be a good idea to enlighten them! For all that they have legal responsibilities in regard to their sources, group schemes have no enforcement powers and truth be told, they have been largely by-passed in the formulation of policy. Apart from the environmental considerations, group schemes have a direct financial incentive in ensuring that their sources are free of contamination. For this reason alone, they are potentially a useful and willing ally in any initiative designed to improve water sources. More than that, they represent the best hope of securing the co-operation of the communities they serve (and of which they are part) in shaping source protection as a process of voluntary participation by citizens.

NOTES

DETERMINING THE SUSTAINABLE YIELD OF GROUNDWATER SUPPLIES

Gerry Baker

WYG Ireland

ABSTRACT

There is currently no available guidance in Ireland to determine the sustainable yield of a groundwater supply. To ensure sustainable development of Ireland's groundwater resource guidelines or regulations are needed to act as a support tool for the hydrogeological community and for a reference document for water managers. The introduction of an abstraction licensing system has been proposed as part of the WFD and it is recommended that guidelines and/or regulations should be incorporated into any new abstraction licensing system. Suitable guidelines are available from other countries. The leading international approaches adopt the capture principle in assessing sustainability of groundwater supplies. It is crucial that an oversimplified approach to regulation is not adopted which would needlessly restrict development or overexploit aquifers. The application of such guidelines is shown by examples of groundwater development completed in Co. Wicklow by WYG.

INTRODUCTION

At the present time, many Local Authority water supply infrastructures are stretched to their limits and there is a significant lag time between completion of new regional water infrastructure developments and the growing demand. Where new private developments are planned they must source their own water supply and in many cases development can be limited by the sustainable yield of the water supply developed on site.

Currently there are no guidelines available in Ireland to determine the sustainable yield of groundwater abstractions. Typically the hydrogeologist will be asked to drill some wells, conduct a pumping test and define the sustainable yield of the supply. When complete the results and assessment are submitted to the Local Authority generally as part of a planning submission. There is no standardised methodology used by hydrogeologists to define the potential yield of the borehole or how to address its potential impact on the environment. There is no standard for the Local Authority personnel to judge the quality of assessment. This has led in some cases for Local Authorities to place very conservative restrictions on the amount of water that may be abstracted. It is not uncommon for some Local Authorities to only allow 50% or even 25% of the yield recommended by the hydrogeologist to be abstracted. This is an understandable approach when there are no guidelines for the Local Authority to reference.

Much needed developments should not be limited by lack of confidence in the hydrogeological community's practices. It is therefore crucial that some guidance/regulation is provided to act as a support tool for hydrogeologist and also for a benchmark for local authorities. Article 11.3(e) of the Water Framework Directive (WFD) requires that abstraction controls be introduced which include a register of abstractions and a requirement for "prior authorisation". It is recommended under current proposed approach for an abstraction licensing system (CDM 2009) that Environmental Reports are completed as part of the licence for large supplies. There is an opportunity here to incorporate clear and informative guidelines on the approach to such an Environmental Report. The aim of this paper is to address the key issues which must be considered in defining sustainable yield of groundwater supplies and review some guidelines already developed in other countries.

DEFINING SUSTAINABLE YIELD

There are innumerable definitions of the term sustainable yield. For a summary of the most widely used of these see Kalf et al (2005). Alley and Leake (2004) chart the development of the concept in detail from the term 'safe yield' first documented in 1915. It must be recognised that there are two facets incorporated with the sustainable yield of a supply. Firstly is the determination of the amount of water that can be permanently abstracted from the well without continuing depletion of the storage in the aquifer. Secondly is some assessment of how sustainable this yield is in terms of its impacts on environmental receptors, other water supplies and water quality of the supply.

The UK Water Industry Research provides useful guidance in defining these two aspects as Potential Yield and the Deployable Output (UKWIR 1995). The UKWIR defines Potential Yield as "*The yield of a commissioned source or group of sources as constrained only by well and/or aquifer properties for specified conditions and demands*" and Deployable Output (DO) as "*the output of a commissioned source or group of sources or of bulk supply as constrained by: licence, if applicable, water quality, environment, treatment, raw water mains and/or aqueducts, pumping plant and/or well/aquifer properties transfer and/or output main, for specified conditions and demands.*"

There are established methodologies available for considering both the Potential Yield (Wright 1985) and the Deployable Output (Environment Agency 2007) of a groundwater abstraction.

THE CAPTURE PRINCIPLE

The assessment of quantitative status of groundwater bodies (GWB) has recently been completed (CDM 2009). The status has been defined by comparing the total groundwater abstraction in the GWB to the recharge. Where a certain percentage of recharge is exceeded the status of the GWB is reduced (GWG 2005). The definition of quantitative status also considers any observed impacts on surface water bodies or groundwater dependant terrestrial ecosystems (GWDTE). A relatively small number of GWB have been defined as being at less than good status following a detailed assessment.

The approach of defining the available resource in an aquifer by comparing it to the long term recharge has been defined in the literature as the *Water Budget Myth* (Bredehoft et al 1982). It can be shown that this approach is not suited to determining the sustainable yield for individual abstractions.

Theis (1940) defined the source of water to well as follows - "*Under natural conditions...previous to development by wells, aquifers are in a state of approximate dynamic* *equilibrium. Discharge by wells is thus a new discharge superimposed upon a previously stable system, and it must be balanced by an increase in the recharge of the aquifer, or by a decrease in the old natural discharge, or by loss of storage in the aquifer, or by a combination of these".*

In this case recharge can be in the form of: downward flow though the unsaturated zone, lateral and/or vertical flow from other aquifer systems, induced flow from nearby surface water bodies, artificial recharge e.g. infiltration points. Discharge could be to streams, lakes, wetlands, saltwater bodies, and springs or via evapotranspiration. The sum of increase in recharge and decrease in discharge is referred to as **Capture** (Lohman et al 1972).

Some logical consequences of the principle of capture when an aquifer system is subject to development are:

- Some groundwater must be removed from storage before the system can be brought into equilibrium – i.e. water levels dropping during pumping
- The time that is required to bring a hydrological system into equilibrium depends on the rate at which discharge can be captured
- The rate at which discharge can be captured is a function of the characteristics of the aquifer system and the placement of the pumping wells – spacing, distance to recharge zones, distance to discharge zones, rate of expansion of the cone of depression (CoD)
- Equilibrium is reached only when pumping is balanced by capture. In many cases this may take quite some time!!

Perhaps the most important implication of the capture principle is that antecedent recharge does not determine sustainability. Sustainability is determined by what induced recharge is created and existing discharge is captured. This can be clearly displayed in water budget format (Lohman, 1972):

The equilibrium condition before any pumping occurs is:

$$R = D \qquad (1)$$

Where – R = Antecedent Recharge, D = Antecedent Discharge. With the addition of pumping Theis (1940) tell us this becomes:

$$R + \Delta R = D + \Delta D + Q + S\ \Delta h/\Delta t \qquad (2)$$

Where ΔR is the change in recharge caused by pumping, ΔD is the change in discharge caused by pumping, Q is the abstraction rate and $S\ \Delta h/\Delta t$ is the rate of change of storage. When the system is in equilibrium the recharge will equal discharge (R=D) and there are no changes in storage over time ($S\ \Delta h/\Delta t=0$). Substituting D in Eqn 2 for R and allowing $S\ \Delta h/\Delta t = 0$ the resulting equation is:

$\Delta R = \Delta D + Q$, or:

$Q = \Delta R + \Delta D$

Thus these equations conceptually confirm that it is the change in recharge and discharge caused by pumping that determine the sustainability of the abstraction. The groundwater abstracted from a well is captured from one of the following sources;

- Reduction in groundwater contribution to baseflow
- Drying up of Springs

- Reduction in yields from boreholes on adjacent properties
- Reduction in supply to Groundwater Dependant Terrestrial Ecosystems (GWDTE)
- Induced flow from surface water bodies such as rivers flowing close to the source
- Capture of groundwater from adjacent aquifers
- Increased recharge due to the acceptance of previously rejected recharge.
-

ACHIEVING EQUILIBRIUM

The relationship between reduced storage, decreased discharge and induced recharge as a result of an abstraction are shown in Figure 1 (Leake 2001). The system returns to equilibrium when the increased inflow and decreased outflow equal the rate of abstraction.

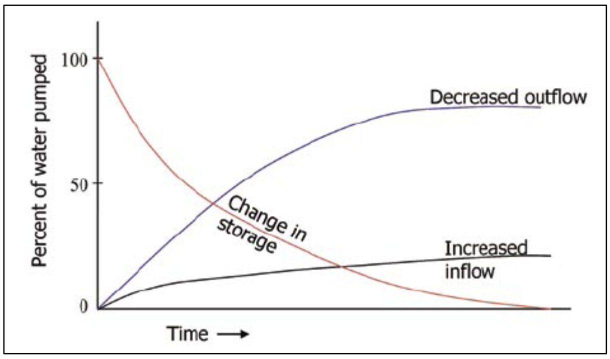


Figure 1 – Effects on pumping on inflow, outflow and storage.

The sustainability of the supply can only be fully assessed once the change in storage has reduced to nil. In practical terms this is when the water level in the borehole stops dropping. During this initial phase of a pumping test the cone of depression is expanding. The equation for groundwater flow to wells (Thies 1935) tells us that the cone will continue to expand and levels continue to drop indefinitely! The cone of depression will only cease to stop and the water levels cease to drop once the abstraction rate is equalled by capture.

The response of a groundwater system depends on the aquifer parameters (transmissivity & storage coefficient), boundary conditions and the positioning of the abstraction. The Cooper-Jacob distance drawdown method (Cooper & Jacob 1946) clearly shows (Equation 3) that the rate of propagation of the cone of depression is not determined by the pumping rate, rather the duration of pumping (t), transmissivity (T) and storage coefficient (S) are the key properties. The response of some Irish aquifers based on WYG experience of aquifer parameters is shown in Table 1 below.

$$S = \frac{2.25\ Tt}{r_0^2} \therefore r_o = \sqrt{\frac{2.25\ Tt}{S}} \qquad (3)$$

Table 1 - Propagation of Cone of Depression in Irish Aquifers

Aquifer Type	T (m^2/d)	S	24hrs	72hrs	Day 7	Day 14	Day 30	Day 60	Day 90
			Extent of Cone of Depression - R_o(m)						
Rf / Rkd	200	0.02	150	260	397	561	822	1,162	1,423
Rg	200	0.2	47	82	125	177	260	367	450
Ll	20	0.01	67	116	177	251	367	520	636
Pl	2	0.01	21	37	56	79	116	164	201
Ll *Confined*	20	0.0002	474	822	1,255	1,775	2,598	3,674	4,500

The speed of propagation of the cone of depression (CoD) is not proportional to the productivity of the aquifer. These values should be considered in the light of typical groundwater flow path lengths and drainage densities in the aquifers in question (Fitzsimons 2005). Flow path lengths in Regionally Important Karst Aquifers (Rkd) can be over a kilometre. From the example in Table 1 it would take approximately 14days for the diameter of the cone of depression in the Rkd scenario to reach 1km. The range in size for the 72hr test for unconfined aquifers is quite small (37 - 260m).

Using typical recharge values as an indication of though flow in unconfined aquifer types, it is possible to estimate how much flow is captured within each aquifer type based on the size of CoD in Table 1. The table shows very limited abstractions may be captured in poorly productive aquifers even after 7 days of pumping.

Table 2 - Flow Captured within Cone of Depression

Aquifer Type	Recharge (mm/yr)	24hrs	72hrs	Day 7	Day 14	Day 30	Day 60	Day 90
		Flow Captured within this period (m^3/d)						
Rf/Rkd	500	97	290	678	1,356	2,905	5,810	8,715
Rg		10	29	68	136	290	581	871
Rf/Rkd	300	58	174	407	813	1,743	3,486	5,229
Rg		6	17	41	81	174	349	523
Ll	150	6	17	41	81	174	349	523
Pl	100	0.4	1	3	5	12	23	35

ALLOWING FOR DROUGHT CONDITIONS

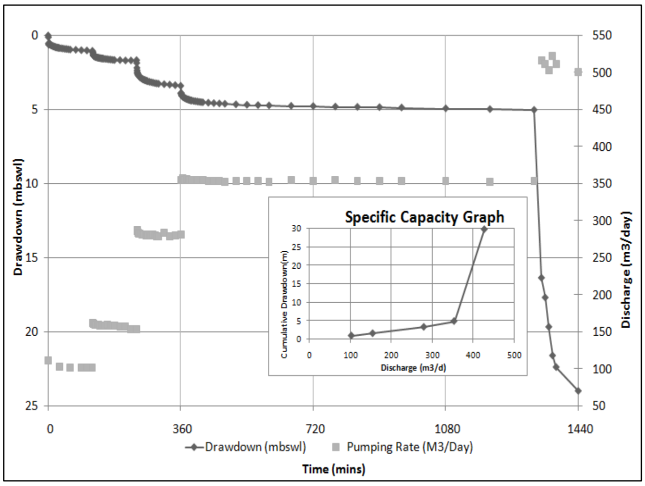
Another aspect of defining the sustainable yield of a well is how to allow for drought conditions. It is common policy to extend the size of the Zone of Contribution (perhaps by 50%) to allow for drier conditions (DoELG/EPA/GSI 1999). During drought conditions there is no recharge to the aquifer but discharge continues e.g. baseflow in rivers, as a result storage is reduced and groundwater levels fall. This reduction in levels means a reduction in the gradient and in an unconfined aquifer a reduction in the saturated thickness which would result in a reduction in flow through the aquifer. This reduction in flow means the area required to capture the yield of the well must increase.

Testing a well at 150% of the required yield does not represent the response of the aquifer in drought conditions. When storage in an unconfined aquifer as a whole has been reduced the transmissivity and response of the aquifer to pumping could be quite different. Entire fissures may become dewatered and in karst aquifers flow directions can change completely. This cannot be represented by pumping one well at a higher rate during a wet season. Pumping at this higher rate may not be suitable or efficient based on the borehole construction and limiting a supply on this basis is a false positive.

It is recommended (Besson et al. 1997) to extrapolate pumping test results to 200 days using the response of the well during the pumping test and the Cooper-Jacob equation (or similar depending on suitability). The increased drawdown over this period can be incorporated in an impact assessment. It should be noted that this methodology is not suitable where levels have stabilised during the pumping test and that it ignores heterogeneity and boundaries in the aquifer.

DEFINING POTENTIAL YIELD

A method for determining the optimal yield of wells was provided by Wright (1985). The author recommends a step test is completed for the supply and a specific capacity graph is developed. Figure 2 shows the typical well response to incremental pumping rates. Where there is a clear change in the response, as indicated by a break in the slope of the graph, the well should not be pumped higher than the abstraction in the step before the break in slope.



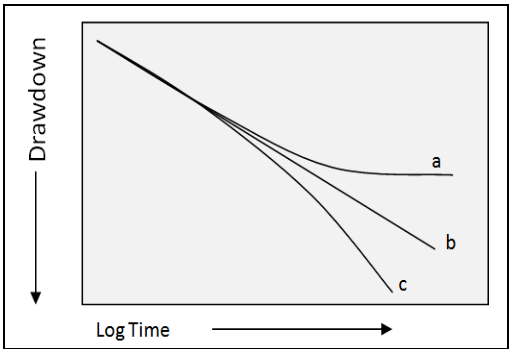


Fig 2 a&b – Step test & Constant Rate Test

The break in slope is indicative of a marked change in well efficiency (Biershenk 1963) which may be related to the borehole construction or productivity of the aquifer. It is best to use a wide range of pumping rates for the step test. WYG recommend using at least five steps range from a fraction to the drillers yield estimate to the maximum output of the pump. The steps should be continued until the drawdown has stabilised preferably for an hour. When the step test is complete the well should be allowed to recover (typically overnight) and a constant rate test conducted at the optimised abstraction rate.

The constant rate test should be conducted for as long as feasible. The time drawdown graph is plotted on a semi-log graph. The results will fall into one of three typical responses. In Example A after a certain time the water table ceases to drop. This implies the CoD has ceased to expand and the well has captured enough flow. In Example B the CoD is still expanding and a longer test is needed. In Example C a boundary has been encountered or a significant water bearing fissure has been dewatered and the well cannot capture the required amount within the aquifer, storage will continue to be depleted until the water level drops below the pump.

Once these tests have been completed for long enough, the hydraulic capabilities of the borehole should be well understood. Longer tests may be required where equilibrium has not been achieved. Just because equilibrium has not been achieved within the timeframe of the pumping test does not imply the abstraction rate is unsustainable. Rather it means a longer test is needed.

A complete understanding of the functioning of an aquifer cannot be achieved during a 72hr or 7 day test. There is a need for an adaptive, iterative assessment of the aquifer. Hydrogeologists in Ireland are commonly requested to define the sustainable yield of a supply based on a (typically) short pumping test due to cost issues for longer term tests. The results of pumping tests can only apply to the conditions they are conducted in. Project timelines may not always allow for pumping tests to be completed in late summer when groundwater levels are generally expected to be at their lowest.

It is therefore recommend that an initial conservative estimate of the potential yield of the well is derived from the pumping tests. This should be followed by a review of well response to pumping after one full year of operation. This will allow the well response under a variety of conditions to be examined. UKWIR provide an excellent methodology for the use of operational data to determine Potential Yield and Deployable Output (UKWIR 2000, Beeson *et al*. 1997). This could be adopted as a requirement for licensing of new supplies.

HYDROGEOLOGICAL IMPACT APPRAISAL

Once the potential yield of the well has been defined an assessment of the potential impact on environmental receptors and other supplies is required. The Environment Agency in the UK has developed an excellent methodology for this purpose – *Hydrogeological Impact Appraisals for Groundwater Abstractions (2007)*. The method has been developed with the Capture Principle and adaptive management at its heart. The methodology identifies the need to address the overall quantitative status of the GWB and to develop a conceptual model of the aquifer and site.

Importantly it distinguishes between *flow impacts* and *dewatering impacts*. The capture principle leads to an understanding that all groundwater abstractions are capturing flow which would have ultimately discharge to a surface water body or GWDTE. The cone of depression does not need to extend to the receptor for this reduction in discharge and *flow impact* to occur. Therefore risk assessments based on the distance to the receptor are not valid. All groundwater abstractions should be therefore considered in light of the quantitative status, low flow conditions (e.g. 95%ile) and ecological requirements of the associated surface water bodies.

Drawdown impacts will occur where the CoD extends to the receptor. It is important to note that the CoD extends beyond the zone of contribution to the well. GWDTEs can be very sensitive to drawdown (e.g. Pollardstown Fen cSAC 396) and appropriate monitoring needs to be considered (Kilroy & Dunne 2008). Impact on a GWDTE may often need considerable assessment due to the lack of available information/studies on the habitat requirements. Where drawdown occurs at a receptor and it is within the Zone of Contribution (ZoC) there will be direct flow from the receptor (e.g. river) to the abstraction point and the implications for the water quality of the abstraction point need to be considered accordingly. The proportion of contribution from the contributing water body should be assessed and this can be completed using standard hydrogeological methods e.g. image well theory (Kruseman & de Ridder 1994).

The guidance requires that appropriate monitoring and mitigation measure are developed where a significant impact is identified and these are revised when monitoring information has provided an improved conceptual model for the system.

CASE STUDIES

WYG has been involved in developing groundwater supplies in County Wicklow for a number of years. The supplies have been developed in a range of hydrogeological environments. There are no regionally important aquifers located in County Wicklow and the potential to develop significant groundwater resources is quite limited. In this light the yield from the resources developed must be optimised.

Example 1 – Bedrock Aquifer adjacent to a GWDTE

In the first example a groundwater supply is required for proposed residential development. The development is located on a steeply sloping bedrock aquifer (Kilmacrea Fmt – Ordovician Metasediments -Ll). Geophysics and bedrock mapping indicated the location of potential water bearing faults towards the lower elevations on the site. Three trial wells were drilled to 90m at 150mm diameter. A 24hr step test was conducted on each well, followed by a combined 72hr test.

The results show that there is a distinct change in well response above 300m^3/d (Figure 3a). The pumping rate for the constant rate test is chosen as 300m^3/d. The drawdown during the constant rate test plots a straight line up to the first day of pumping (1,440 minutes). The level then stabilises suggesting either the CoD has extended to capture sufficient flow in the aquifer or a recharge boundary has been encountered. An assessment of water features in the area identifies the presence of a GWDTE (Arklow Marsh SAC1931). It is recommended that a longer test is conducted at the well during which standpipes should be installed at various locations in the marsh and the water level monitored during the test. The aquifer properties and distance to the feature suggest it is possible that the CoD could extend this far in one day.

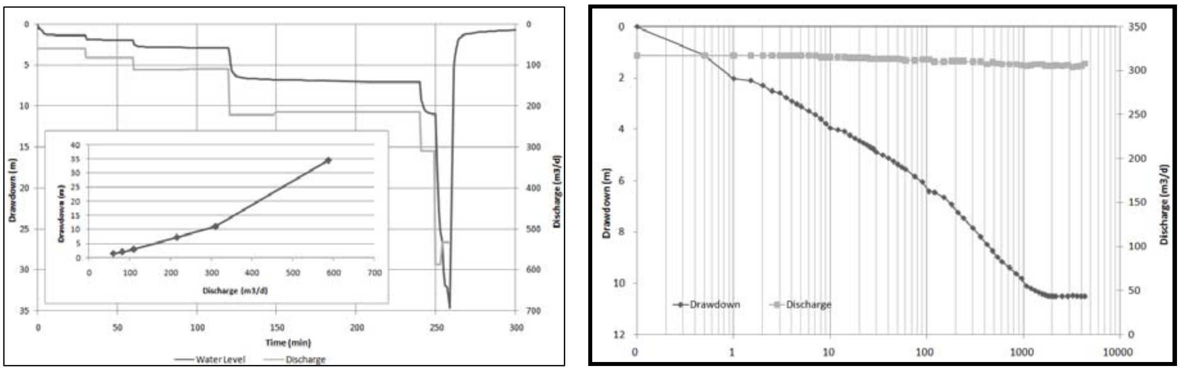


Figure 3a &b - Example 1 Pumping Tests

In summary there will inevitably be a *flow impact* on the marsh as the wells will capture discharge to the feature. This must be considered in the context of the ecological requirements of the marsh. Further testing is required to determine if there will be a *drawdown impact* on the marsh.

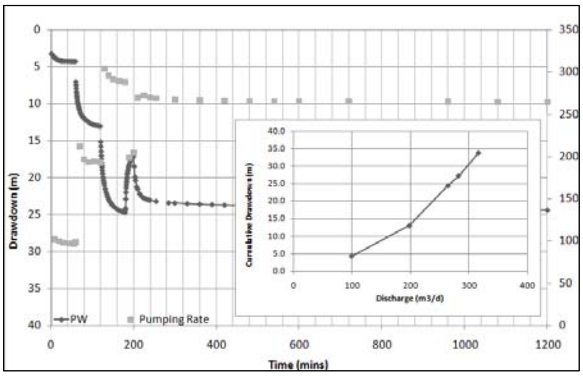
Example 2 – Bedrock Aquifer

The second example is a groundwater development for a public supply. The well, one of three in the area, is located in a bedrock aquifer (Oaklands Fmt - Ordovician Metasediments - Ll) which is overlain by a considerable thickness of till but there is highly variable till thickness in the area.

The wells are drilled to 90m at a thickness of 200mm. The well is located quite close (70m) to an upland stream. The steps used in the step test were relatively high for this aquifer and there was no stabilisation at the higher steps. An abstraction rate of 200m^3/d was selected for the constant rate test.

The constant rate graph shows four distinct slopes (Figure 4b). The first slope (0-11mins) is steeper than the second slope (12 – 1,920mins). The break in slope occurs at 13m drawdown is roughly coincident with the thickness of subsoils at the well. The third slope (1,920 – 3,960mins) is much flatter and water levels appear to have stabilised, however minor reductions in level continue. From 3,960mins to the end of the test (13,680mins) the level starts to drop again.

Based on the aquifer parameters (Transmissivity 13m^2/d, Storage Coefficient 0.004) the CoD should have extended to the river within approximately 1 day (1,440 minutes). This could be coincident with the third, flatter slope. However clearly the recharge available at this boundary is insufficient to satisfy the full requirement of the well and the storage becomes depleted again. The total duration of the test was 7 days and the pumping rate selected does not appear to be sustainable.



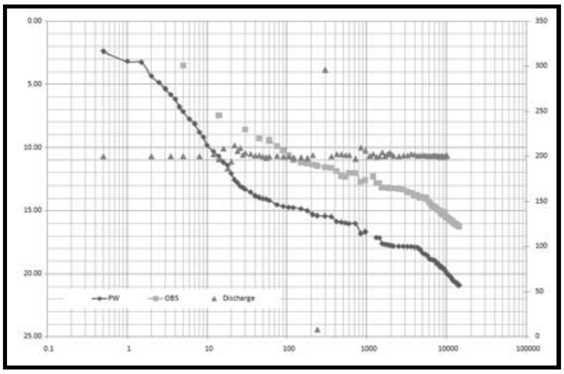
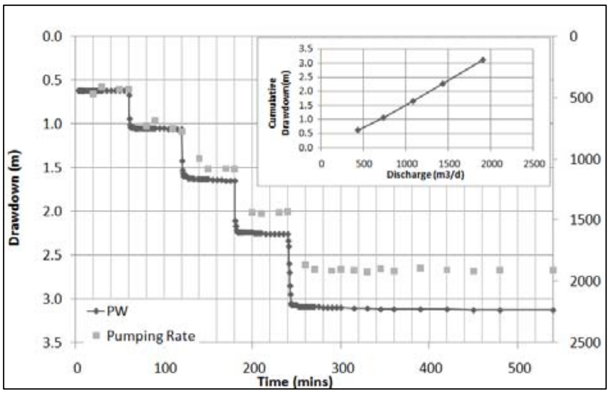


Figure 4a&b - Example 2 Pumping Tests

The wells are located in a small upland catchment and it appears the topographic catchment to the well may only provide in the order of 400m^3/d in annual average recharge. The bedrock permeability is quite poor and although the cone of depression may have intercepted the river, the ability of the aquifer to transmit this water to the wells is limited. In this case the capture requirement cannot be met due to the low permeability and throughput in the aquifer. A lower pumping rate is more suitable at this location.

Example 3 – Sand & Gravel Aquifer

There are small fluvial sand & gravel aquifers located within the steeply dipping bedrock valleys in County Wicklow. These aquifers are not extensive and represent a locally important resource. In this example 4 wells have been located in close proximity in one of these aquifers. The aquifer is 17m thick and the gravels are poorly sorted and tend to have occasional layers of clay. The initial testing of the wells suggests the aquifer is highly productive and large yields are available (~2,000m^3/d).



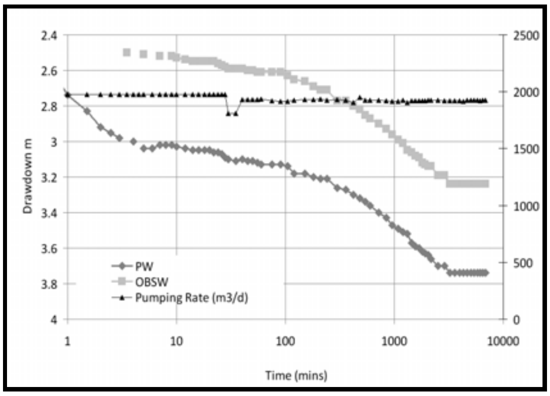


Figure 5a&b - Example 3 Pumping Test Results

The results of the step test showed a very high productivity and well efficiency with little drop in efficiency (80%) while pumping at highest rates (c. 2,000m^3/d) The wells were tested at the maximum pump output for the constant rate test and stabilisation occurred in all wells after c. 2 days (3,240mins). The aquifer parameters (Transmissivity - 500m^2/d, Storage Coefficient - 0.015) suggest the cone of depression should have extended 125m in this time. This agrees well with the distance of from the wells to the river.

The gravel aquifer is restricted (250m wide, saturated thickness 12m) and is recharged by direct rainfall but also from runoff and discharge from the up-gradient bedrock aquifer. The recharge to the well field based on the topographic catchment and suitable recharge coefficients is estimated to be 1,450m^3/d. The four wells developed produce 6,500m^3/d. In this case, where atmospheric recharge alone used to determine the sustainability the well field would appear be unsustainable. However, the total abstraction represents 4% of the river 95 percentile flow (1.75m^3/s) and therefore there is little danger of dewatering the river.

As there is a direct contribution from the river the influence of this quality must be assessed. Initial groundwater modelling indicated that c. 77% of the water may be contributed from the river; this agrees well with the recharge calculations. Groundwater quality results during the testing indicate good water quality. It is thought that Bank Filtration (Hiscock 2002) is acting as a natural filter and treatment process in the aquifer. To prove sustainability of the supply, it is hoped to conduct longer-term testing and more detailed modelling to develop a more confident understanding of the aquifer/surface water interaction.

CONCLUSIONS

There is currently no available agreed guidance in Ireland to determine the sustainable yield of a groundwater supply. Guidelines and/or Regulations could be incorporated into any new Abstraction Licensing system. Suitable guidelines are available from other countries. The leading international approaches adopt the capture principle in assessing sustainability of groundwater supplies. It is crucial that an oversimplified approach to regulation is not adopted which would needlessly restrict development or overexploit aquifers. In particular long term recharge should not be the sole benchmark used to define the sustainability of groundwater abstractions. In summary – **Things should be made as simple as possible, but not simpler.** (Einstein 1934).

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HAS GROUNDWATER A ROLE IN SUPPLYING DUBLIN'S WATER NEEDS?

EurGeol Kevin T. Cullen PGeo.

ABSTRACT

Of course groundwater has a role in supplying Dublin's water needs. The degree to which it does eventually will be determined by the availability of alternative water sources, policy and timing. To date, Dublin has been able to call upon the water resources that are either located in or drain from its neighbouring counties to meet the capital's water requirements. Today Dublin gets its water from the Vartry, Dodder and Liffey catchments. A very small percentage of Dublin's water demand is met by groundwater, possibly as low as 1%, with the Bog of the Ring abstraction at Balbriggan being the only abstraction of any significance.

It is projected that the greater Dublin area needs a further 300ML/d (66Mg/day) to meet the 2031 demand. A recent study has concluded that the groundwater resources within 80kms of the city might at best supply 125Ml/day or c. 40% of the projected 2031 requirement. However, as the groundwater option was deemed as not having sufficient capacity to meet Dublin's supply needs it was not considered further in the environmental assessments. Those with the responsibility of developing Dublin's water demands will now go on to assess the surface water sources that have being identified with a single abstraction from the Shannon Catchment appearing to be the preferred option. In fairness to the Working Group charged with the task of securing the next stage of the capital's water needs, a single abstraction from the Shannon has endless engineering benefits. A single large abstraction allows for economies of scale, predictable water quality and limited piping. Unfortunately life is never than simple and there are those who feel that such a large scale abstraction from the Shannon is unsustainable both environmentally and commercially. Critically, there are many who believe that not enough consideration was given to the other options identified by Working Group.

It is likely that these objectors will bring their concerns and arguments to the planning process. The promoters of the Shannon abstraction will then be obliged to satisfy the regulator that the selection process was well founded, robust and lacked bias towards the preferred option. For example, was a mix of groundwater and surface given serious consideration with groundwater contributing say 25% of the 2031 shortfall? Such a scenario would significantly reduce the required Shannon abstraction. Was groundwater given due consideration in the security of the capital's water supply in the context of the near 100% reliance on surface water abstractions. This was an important recommendation of the Groundwater Report commissioned by the Working Group.

The debate may also inquire into the concept that groundwater beneath the city was considered as not being potable. This might sound strange when a surface water source such as the Liffey River which receives farm, domestic and industrial waste water discharges is considered suitable as a safe source of potable water, after treatment of course. Also, a statement in the Groundwater Report that the northern side of the Dublin Region is not particularly well served

with groundwater resources appears to ignore the near total reliance of the country's market gardening industry on groundwater and which is located in north county Dublin.

I recall that a planned, but contentious, abstraction from the River Slaney at Rathvilly in County Carlow in the late 1980's ended up in the courts. In that case, if I recall correctly, the Geological Survey of Ireland was called upon to provide independent expert evidence on groundwater availability. I wonder will the current Shannon proposal have a similar fate?

NOTES

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David Ball

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