Water Framework Directive (WFD)
River Basin District Management Systems

ADVICE ON THE IMPLEMENTATION OF GUIDANCE ON MONITORING GROUNDWATER

Paper by the Working Group on Groundwater

Guidance document no. GW6

This is a guidance paper on the **Implementation of Guidance on Monitoring Groundwater**. It documents the principles to be adopted by River Basin Districts and authorities responsible for implementing the Water Framework Directive in Ireland.				
REVISION CONTROL TABLE				
Status	**Approved by National Technical Co-ordination Group**	**WFD Requirement**	**Relevant EU Reporting Sheets**	**Date**
Final	March 2005	Monitoring	GWPI 11	October 2004

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1. Introduction

The National Groundwater Working Group set up a sub-working group on Groundwater Monitoring to assist in the technical interpretation of monitoring requirements and to provide advice and guidance where appropriate in the area of groundwater monitoring. The subgroup consists of the following members:

Organisation	**Representative**
Environmental Protection Agency	Margaret Keegan (convenor) Micheal MacCarthaigh
Geological Survey of Ireland	Donal Daly Geoff Wright
Department of Environment, Heritage and Local Government	Pat Duggan
South Eastern RBD	Gerry Baker (O'CM)
Shannon RBD	Kieran Fay (KMM)
Eastern RBD	Alan Hooper (CDM) Eoghan O'Brien (CDM)
Western RBD	Shane O'Neill (OGE)

2. Purpose

The purpose of this paper is to provide technical interpretation and guidance for the monitoring of groundwater in Ireland. It provides specific information with respect to Irish conditions. It is intended that the National Technical Co-ordination Group will approve this guidance and that it will be applied in a consistent manner across the RBDs. The reader should note that in all cases the Directive is the definitive document.

3. Background

In interpreting the Directive, the UK Technical Advisory Group (TAG) has produced 'Guidance on Monitoring Groundwater'. This guidance has general applicability to Ireland and therefore is included as Appendix 1. It covers general issues, which are not repeated in this paper. However, this paper includes points of clarification and interpretation specific to Irish conditions, and therefore it has precedence where necessary. Some of the additional guidance provided here has been taken from: *Interim Report of Working Group on Groundwater: Technical Requirements for Groundwater and Related Aspects*, 2001.

4. Conceptual Models

Conceptual models are very useful elements in the development of a monitoring programme. The conceptual model/understanding is required at two scales – regional and local. Regional conceptual models have been developed by and are available from the GSI for each type of groundwater body. However, at a local scale information has to be obtained to assist in the development of the local conceptual understanding; such information would include, for instance, a visual appraisal of the recharge area (Table 1) and information on pressures, flow direction etc.

5. Representative Monitoring Points

The WFD requires the establishment of monitoring networks to determine the quantitative and chemical status of groundwater bodies or groups of bodies. Monitoring points are not necessarily required in all groundwater bodies but they must be located so that they are ***representative*** of all groundwater bodies within a river basin district.

In Ireland, some locally important aquifers and virtually all poor aquifers, due to their hydrogeological conditions, have short flow paths, and the zones of contribution associated with monitoring sites are small. Therefore the usefulness of monitoring sites in terms of being representative of the waters within a groundwater body must always be assessed.

During initial and further characterisation the information from the existing groundwater chemical and water level monitoring network will be reviewed to assist in the preliminary identification of groundwater bodies at risk. The historic and current data obtained from the existing networks will be used to assist in the verification of the risk assessment methodology. Therefore it is critical that the monitoring points used for this verification are representative of the groundwater body.

5.1 Quantitative Assessment

In terms of quantitative assessment, the distribution of monitoring points must ensure that the spatial and temporal variability of the groundwater surface can be sufficiently well recorded within a groundwater body. Pumped wells are not normally suitable for use as water level monitoring points. Disused LA abstraction sites that have been assessed against the factors in Table 1 may prove to be suitable for use. An integrated approach to quantitative monitoring means that additional surface water hydrometric stations may be required.

5.2 Qualitative Assessment

For chemical assessment two networks shall be established – surveillance and operational monitoring. Monitoring may be considered representative if:

- The quality of the groundwater recorded is considered typical of a wider area, or
- The monitored groundwater body is considered to be characteristic of a wider area in terms of the hydrogeological regime and the existing land use and risks in the recharge area.

In order to be representative of the groundwater quality over a significant area, a monitoring borehole must be pumped for sufficient time to develop a substantial Zone of Contribution (ZOC) in the order of 10–100 ha (discharge rates greater than $100m^3$/day). Monitored springs should have catchment areas of at least comparable size.

If the monitoring site is deemed to have microbial pathogens, ammonia, phosphorus or potassium present at elevated levels, which are indicative of a local pollution problem, it is questionable as to whether or not the monitoring point represents regional conditions and therefore a decision on its inclusion in the monitoring programme has to be made.

The existing EPA groundwater monitoring programme sites (chemical and water level) as well as any other potential monitoring sites (e.g. LA sites) should be screened against the factors outlined in Table 1 (below). The information in Table 1 should be used to screen the monitoring points in terms of

whether they represent the groundwater body itself. This information and expert judgement should be used in deciding on the inclusion or otherwise of the monitoring points for verification of the risk assessment or for future use in the monitoring programmes. Decisions to discard monitoring points should be transparent and well documented. Appendix 2 contains sample data sheets being used by the SE RBD to assess if the existing monitoring points are representative. Nationally it is desirable to have a consistent datasheet for all the monitoring points; a sample datasheet (based on that used in the SE RBD and Table 1) is included in Appendix 2.

Table 1: Monitoring point information – essential and desirable factors

Factor	Chemical monitoring points	Quantitative monitoring points
Aquifer(s) monitored	E	E
Location (grid reference), name of monitoring point and unique identifier	E	E
Groundwater body that monitoring point is within	E	E
Purpose(s) of monitoring site	E	E
Type of monitoring point – farm borehole, industrial borehole, spring, etc	E	E
Depth and diameter(s) of boreholes/wells	E	E
Description of headworks – grouting integrity, slope of ground around borehole	E	E
Depth of screened/open sections of boreholes/wells	D	D
Vulnerability or indication of subsoil thickness and type at monitoring point	E	D
Visual appraisal of recharge area (including land use and pressures, potential sources of point pressures)	E	D
Daily flow rate		#
Amount abstracted or discharge flow rate	E	#
Pumping regime (qualitative description – e.g., intermittent, continuous, overnight, etc.)	D	#
Drawdown (pumped water level)	D	#
Zone of contribution/recharge area	D	D
Pump depth	D	D
Static or rest water level	D	E
Datum elevation and description of datum	D	E
Artesian/ overflowing	E	E
Borehole log (geological and construction details)	D	D
Aquifer properties	D	D

E- Essential
D- Desirable – it is intended that for all new (future) monitoring sites that this information will be deemed to be essential.
 # Pumped wells should not be used for water level monitoring in Ireland.

6. Monitoring Parameters

The selection of monitoring points and parameters must be based on sound conceptual models. The groundwater bodies shall be monitored for the following minimum set of parameters in all cases:

- Oxygen content
- pH value
- Electrical Conductivity
- Nitrate
- Ammonium

Field measurements for Temperature, DO, EC, pH should be undertaken in all cases. In addition, groundwater bodies that have been identified as being at significant risk of failing to meet the objectives shall be monitored for those parameters which are indicative of the risk. In the case of

cross-border groundwater bodies, they shall be monitored for those parameters which are relevant for the protection of all of the uses supported by the groundwater flow.

On an interim basis the Working Group recommends that the draft EPA list of parameters and guideline values be used for the characterisation of a groundwater body for the purpose of river basin projects. The determinands to be monitored should take account of information on the types of potential pollutants found in the area. The guidance on the selection of monitoring parameters will be elaborated upon following the risk assessment process and a review of water quality data

Appendix 2 of the TAG guidance sets out guidance on the selection of determinand suites of parameters. It relates parameters to land use activities and a similar indicative list of parameters related to land use may be developed through the ongoing risk assessment work.

The scope of parameters to be measured for 'operational monitoring' will generally include those required for 'surveillance monitoring' but will be extended as necessary to include those additional parameters that are indicative of the identified risks.

7. Frequency of Monitoring

General guidance is given in the Directive and elaborated in the UK TAG document in Appendix 1 and below on the frequency of monitoring. This will be elaborated upon following the risk assessment process and a review of water quality data. In addition, work currently being undertaken by the SERBD on groundwater monitoring will assist in the elaboration of guidance on the frequency for the different types of groundwater bodies.

7.1 Surveillance Monitoring

The frequency of monitoring shall allow assessment of the chemical status of each groundwater body and satisfy the requirements stated above. The frequency will depend on the hydrogeological conditions (vulnerability and flow regime) of the groundwater body. The monitoring frequency for surveillance monitoring should be a minimum of twice per year (spring and autumn, or high and low water table). Groundwater bodies comprising unconfined regionally important aquifers should be monitored more frequently. In addition, monitoring sites that demonstrate strong fluctuations of concentrations over the period of the year should be examined more often. In karstic aquifers subject to large fluctuations in water quality at times of flooding, continuous monitoring may be required for certain parameters. The minimum frequency set out in Table 2 should be used as a guide.

Table 2: Proposed minimum monitoring frequencies for surveillance monitoring

		Aquifer Flow Type				
		Confined	**Unconfined**			
			Intergranular flow significant		**Fracture flow only**	**Karst flow****
			Significant deep flows common	**Shallow flow**		
Initial frequency* – core & additional parameters		Twice per year	Quarterly	Quarterly	Quarterly	Quarterly
Long term frequency – core parameters	**Generally high-mod transmissivity**	Every 2 years	Annual	Twice per year	Twice per year	Twice per year
	Generally low transmissivity	Every 6 years	Annual	Annual	Annual	Twice per year
Additional parameters (on-going validation)		Every 6 years	Every 6 years	Every 6 years	Every 6 years	-

* Initial frequency period is defined as a minimum of two years.
** Continuous temperature and conductivity measurements at selected representative sites.

7.2 Operational Monitoring

Operational monitoring shall be carried out (i) at a minimum of once per year and (ii) between the sampling dates of the surveillance monitoring programme. As stated above for the surveillance monitoring programme, the frequency of monitoring shall allow assessment of the chemical status of each groundwater body and satisfy the requirements stated above. The frequency will depend on the hydrogeological conditions and on the vulnerability and flow regime of the groundwater body. Table 3, below, sets out minimum frequency requirements.

Table 3: Proposed minimum sampling frequencies for operational monitoring

		Flow Type				
		Confined	Unconfined			
			Intergranular flow significant		Fracture flow only	Karst flow
			Significant deep flows common	Shallow flow		
Higher vulnerability groundwater	Continuous pressures	-	Twice per year	Twice per year	Quarterly	Quarterly
	Seasonal/intermittent pressures	-	Annual	As appropriate	As appropriate	As appropriate
Lower vulnerability groundwater	Continuous pressures	Annual	Annual	Twice per year	Twice per year	Quarterly
	Seasonal/intermittent pressures	Annual	Annual	As appropriate	As appropriate	As appropriate
Trend assessments		Annual	Twice per year	Twice per year	Twice per year	-

7.3 Surveillance and Operational Monitoring

Surveillance monitoring is carried out in order to:

- Supplement and validate the procedure for the assessment of pressures and impacts; and
- Provide information for use in the assessment of long-term trends both as a result of changes in natural conditions and through anthropogenic activity.

The surveillance monitoring programme must provide a coherent and comprehensive overview of groundwater chemical status for each groundwater body or group of bodies. The network shall be designed to detect at an early stage any changes in chemical status and to register long term quality trends and establish their causes (natural or anthropogenic). Representative monitoring may suffice for 'not-at-risk' groundwater bodies of similar types (in terms of hydrogeological regime and risks located in the recharge area).

The existing EPA monitoring sites should be assessed to determine their suitability for inclusion in the surveillance monitoring programme.

The results of the surveillance monitoring programme, combined with the Risk Assessment, will be used to establish an operational monitoring programme for the River Basin Districts.

Operational monitoring must be undertaken in the periods between surveillance monitoring in order to:

- Establish the chemical status of all groundwater bodies determined as being 'at risk', and
- Establish the presence of any long-term anthropogenically induced upward trend in the concentration of any pollutant.

The operational monitoring programme will be carried out for all groundwater bodies or groups of bodies that have been identified, through characterisation and/or surveillance monitoring, as being 'at risk' of failing to meet the objectives under Article 4. Surveillance monitoring points may also be used as operational monitoring points, i.e. the monitoring networks are not mutually exclusive. Surveillance monitoring sites that indicate increased pollutant concentrations or long-term anthropogenic upward trends should also be used for operational monitoring purposes. The operational network can be extended to other sites. If a surveillance point is also used for operational monitoring then core determinands plus the selective determinands should be monitored.

8. Calculation of Parameter Values

The WFD states that 'in assessing status, the results of individual monitoring points within a groundwater body shall be aggregated for the body as a whole'. It goes on to state that for good status to be achieved for a groundwater body, for those chemical parameters for which environmental quality standards have been set:

- *the mean value of the results of monitoring at each point in the groundwater body or group of groundwater bodies shall be calculated, and*
- *in accordance with Article 17 these mean values shall be used to demonstrate compliance with good status.*

An EU funded project 'Statistical aspects of the identification of groundwater pollution trends, and aggregation of monitoring results' (2001) co-ordinated by the Federal Environment Agency – Austria, stated that if the GW-body is hydrogeologically heterogeneous and if a spatially homogeneous monitoring network is not feasible or sensible the monitoring has to be developed in a hydrogeologically representative way and the spatial mean should be estimated with identical weights (AM).

The above implies that in order to express the monitored data for a certain parameter for a GWB that this is done by calculating the "Average of Averages" for the parameter values in the GWB. This would include:

1. For a particular monitoring point calculate the average parameter value e.g. NO_3.
2. For a GWB calculate the average NO_3 values of all monitoring point average values. This new value is the average of averages.

There are obvious shortcomings in this methodology. In order to improve this it was suggested by the Groundwater Working Group that the monitoring points should be weighted according to their abstraction. This is because larger monitoring points with larger abstractions will have a larger ZOC and hence be representative of a larger portion of the aquifer. Appendix 3 sets out this methodology.
To maximise the representativity of the data it is also suggested not to use data from a monitoring point that abstracts less than $100m^3/d$. Also, only data collected after 2000 are to be used for verification of the risk assessment because our Pressure data are also based on more recent data.

9. Conclusions

This paper provides general guidance and a framework within which all RBDs should operate in terms of groundwater monitoring. It is critical that all groundwater monitoring sites are screened to determine whether or not they are representative of the groundwater body prior to the data from these sites being used to verify the risk assessment methodology. While the monitoring programme is not required until 2006, work will be undertaken, following the identification of groundwater bodies at risk, on monitoring parameters and frequency. The sub-group on groundwater monitoring will therefore develop further guidance in this area in 2005.

10. Membership of the Working Group on Groundwater

Organisation	Representative(s)
Geological Survey of Ireland (GSI)	Donal Daly (Convenor) Geoff Wright Vincent Fitzsimons Coran Kelly Taly Hunter Williams Monica Lee
Camp Dresser McKee (CDM)	Henning Moe
Compass Informatics Ltd.	Paul Mills
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Environment and Heritage Service/ Geological Survey of Northern Ireland (EHS/GSNI)	Peter McConvey
Environmental Protection Agency (EPA)	Margaret Keegan Micheal McCarthaigh
Kirk McClure Morton (KMM)	Grace Glasgow Kieran Fay
O'Callaghan Moran (OCM)	Sean Moran Gerry Baker
O'Neill Groundwater Engineering (OGE)	Shane O'Neill
Shannon Pilot River Basin – EPA/TCD Research Fellow	Garrett Kilroy
Southeastern River Basin District (SERBD)	Colin Byrne
Teagasc	Karl Richards
Trinity College, Dublin (TCD)	Paul Johnston Catherine Coxon

11. References

Groundwater Working Group (2001) Guidance Document GW1. *Water Framework Directive (WFD) River Basin District Management Systems: Technical Requirements for Groundwater and Related Aspects*. Interim Report of Working Group on Groundwater, 32 pp.

UK Task Action Group Task 12(a) (draft) *Guidance on Monitoring Groundwater (Groundwater Task Team)*

WFD-GW (2001) *The EU Water Framework Directive: Statistical aspects of the identification of groundwater pollution trends, and aggregation of monitoring results*. WFD-GW Trend/ Federal Ministry of Agriculture and Forestry, Austria.

Appendix 1 UKTAG 12(a) Guidance on Monitoring Groundwater (Groundwater Task Team)

UK Technical Advisory Group
On the Water Framework Directive

UKTAG Task 12(a) Guidance on Monitoring Groundwater
(Groundwater Task Team)

1. Purpose and scope

1.1. This paper provides guidance on establishing groundwater monitoring programmes to meet the requirements of the Water Framework Directive (WFD). These programmes include both quantitative and chemical (quality) monitoring for status and trend assessment and monitoring to support (ground)water body characterisation, 'prevent and limit' obligations and Drinking Water Protected Area (DWPA) objectives.

1.2. The establishment of high quality long-term monitoring programmes is essential if the implementation of the WFD is to be effective. Inadequate investment in monitoring, including network infrastructure and data quality and management will result in a significant risk of failure to meet the WFD's environmental objectives.

1.3. Implementation of the guidance provided in this paper will lead to consistent monitoring across the UK and the Republic of Ireland. The guidance will enable networks to be developed and maintained at high standards and thereby provide the necessary information to assess (ground)water status, identify trends in pollutant concentrations, support establishment and assessment of programmes of measures and the effective targeting of economic resources.

2. Background

2.1. Article 8 of the WFD establishes a requirement for establishing programmes for the monitoring of groundwater. They must provide information to enable the Article 4 environmental objectives to be met, in particular the assessment of groundwater quantitative status, chemical status and significant, long-term pollutants trends resulting from human activity. Programmes to meet these requirements must be operational by 22 December 2006 at the latest. In addition, programmes are needed to provide any additional monitoring requirements relevant to Protected Areas (e.g. Drinking Water Protected Areas) and to support validation of the Annex II risk assessment procedures.

2.2. The WFD sets out the requirements for the different groundwater monitoring programmes in Annex V (2.2 and 2.4) and Annex II (2.3).

2.3. The groundwater monitoring programmes must include:

- A quantitative monitoring network to supplement and validate the Annex II characterisation and risk assessment procedure with respect to risks of failing to achieve good groundwater quantitative status in all groundwater bodies, or groups of bodies. Its principal purpose is therefore to enable quantitative status assessment.

- A 'surveillance monitoring network' to: (a) supplement and validate the Annex II characterisation and risk assessment procedure with respect to the risks of failing to achieve good groundwater chemical status and (b) provide information for use in the assessment of long-term trends in natural conditions and in pollutant concentrations resulting from human activity.

- An ‘operational monitoring network’ to: (a). Establish the status of all groundwater bodies, or groups of bodies, determined as being ‘at risk’ (UKTAG Task 7(i) - Guidance on Pollution Pressures on Groundwater) , and (b). Establish the presence of significant and sustained upward trends in the concentration of pollutants.

- Monitoring to support the achievement of Drinking Water Protected Area (DWPA) objectives.

2.4. The results of the monitoring must be used to:

- establish the chemical and quantitative status of groundwater bodies;
- assist in further characterisation of groundwater bodies;
- validate the risk assessments carried out under Article 2;
- assist the design of programmes of measures;
- evaluate the effectiveness of programmes of measures;
- demonstrate compliance with DWPA and other protected area objectives
- characterise the natural quality of groundwater including natural trends (baseline) and;
- identify anthropogenically induced trends in pollutant concentrations and their reversal.

3. General Principles

3.1. Role of conceptual models.

3.1.1. Conceptual models are simplified representations, or working descriptions, of the hydrogeological system being investigated. Their development underpins much of the work carried out as part of the characterisation process. As the amount of, and confidence in, the available environmental information increases, the accuracy and complexity of the model improves, so that they become more effective and reliable descriptions of the system.

3.1.2. In this paper, two types of conceptual model/understanding are used;

- the regional conceptual model – an understanding of the groundwater body/aquifer scale factors that identifies the need to establish a monitoring network/point and how the data will be used.

- the local conceptual model – an understanding of the local factors influencing the behaviour, both in chemical and quantitative terms, of individual monitoring points;

3.1.3. A regional conceptual understanding/model will identify the specific requirement for establishing a monitoring network and the degree of monitoring, in terms of number of sites and frequency of monitoring, required. This model will be consistent with that developed and used as part of the characterisation and risk assessment process. Figure 3.1 outlines the principles and relationship of the model to the monitoring programme.

3.1.4. The design and operation of monitoring programmes should be informed by:

- the objectives applying to the body;
- the characteristics of the groundwater body, or group of bodies;
- the existing level of understanding (i.e. the confidence in the conceptual model/understanding and) of the particular groundwater system;
- the type, extent and range of the pressures on the body, or group of bodies;
- the confidence in the assessment of risk from pressures on the body, or group of bodies; and
- the level of confidence required in the assessment of risk.

3.1.5. The amount of monitoring that is required will be proportional to the difficulty in judging (a) the status of a groundwater body, (b) the presence of adverse trends, (c) the implications of errors

in such judgements and (d) the effectiveness of the Programme of Measures including those in relation to DWPA.

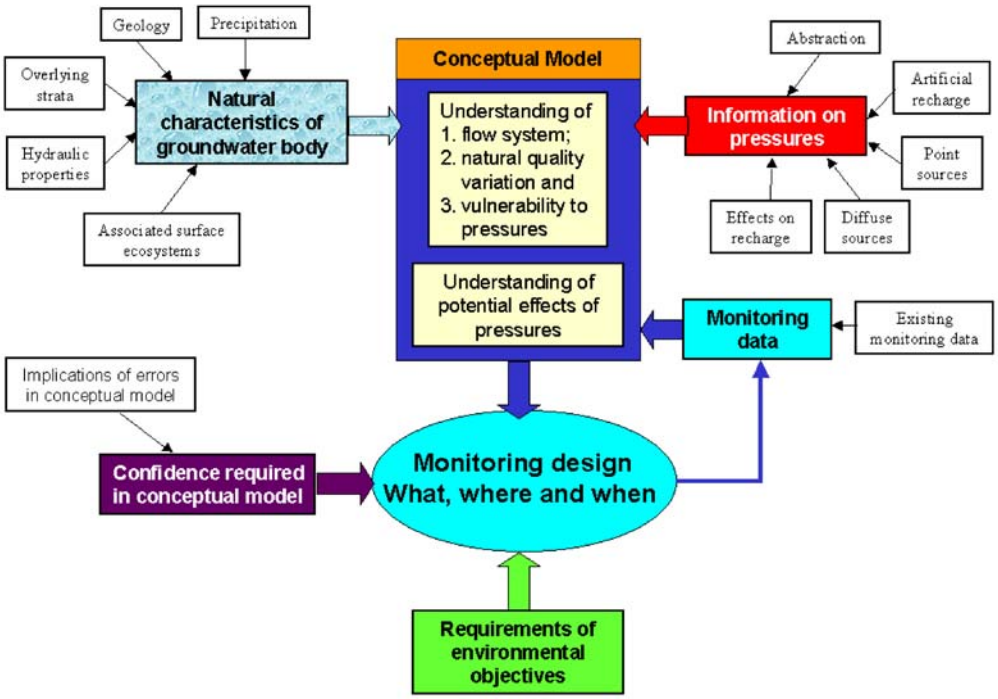

Figure 3.1. The conceptual model will represent the current understanding of the groundwater system based on the knowledge of its natural characteristics, perceived pressures and knowledge of impacts.

3.1.6. Designing the monitoring programmes on the basis of the conceptual model ensures that they will be appropriate to the hydrogeological characteristics of the system and, where relevant, the behaviour of pollutants in the groundwater system.

3.1.7. The selection of groundwater monitoring points also requires knowledge of the local environment within close proximity of the monitoring point. This enables an assessment to be made of the point's suitability for providing representative information and data to support the objectives of the monitoring programme. This conceptual understanding is vital for the effective operation of the monitoring programme.

3.1.8. In developing the local conceptual understanding, information on local hydrogeological and environmental conditions is required. This information includes:

- Monitoring point details;
- Hydrogeological setting;
- Understanding of recharge patterns;
- Local groundwater flow pattern(s) and regime within zone of contribution [1](ZOC)
- Abstraction impacts
- Approximate size of ZOC;
- Land use and pressures within ZOC.

3.1.9. The inclusion of a monitoring point in the relevant monitoring programme or network, e.g. quantitative status assessment network, chemical status assessment network or DWPA network, requires that a minimum level of information is known about the site for quality

[1] Zone of contribution refers to the area of land surface and/or volume of aquifer surrounding a monitoring point within which natural conditions and human activities may influence the quality of groundwater.

assurance (QA) purposes. The information needs are summarised in Appendix 1. In some cases a monitoring site may satisfy the requirements of one programme but not the others. A failure to meet a minimum level of information will exclude the monitoring point from one or more of the programmes.

3.2. Integrated Monitoring

3.2.1. The WFD considers the water environment as a continuum. This is reflected in the groundwater status definitions and through the recognition of the role played by groundwater in maintaining the flow, quality and ecology of dependent surface waters. Monitoring must be able to provide an understanding and assessment relating to groundwater flows between GWBs & SWBs and between GWBs and Terrestrial Ecosystems (TES).

3.2.2. Monitoring programmes for surface water and groundwater should therefore be designed and operated in an integrated way to assist in: (a) maximising the information that can be derived; (b) increasing confidence in the conceptual understanding of the interaction between groundwater and surface water and; (c) reducing the uncertainty associated with risk and status assessment. Data from both programmes can be used to inform and support interpretation of results. In particular the monitoring must be sufficient to allow the calculation or estimation of the GW flux and the degree of 'abstraction impact' on GW supported SWBS (lakes, rivers & estuaries) and GW dependant TES (terrestrial wetlands).

3.2.3. In designing both surface water and groundwater monitoring programmes, the requirements of each must be taken into account. This will contribute significantly to cost-effective monitoring. For example, when designing surface water monitoring programmes in fractured fast flow aquifers, which provide significant baseflow to surface waters and maintain terrestrial ecosystems, groundwater monitoring requirements must be taken into account. In many cases, the correct location of a surface water sampling point, e.g. close to an aquifer discharge point, may function as both a monitoring point for both programmes.

3.3. Grouping of Groundwater Bodies

3.3.1. Groundwater bodies may be grouped for monitoring purposes provided that the monitoring information obtained provides for a reliable assessment of the status of each body in the group and the confirmation of any significant upward trends in pollutant concentrations.

3.3.2. In grouping groundwater bodies, the monitoring programmes must be designed and operated to ensure that the environmental and monitoring objectives for each of the component bodies making up the group can be achieved with adequate confidence.

3.3.3. Where groundwater bodies are determined to be "not at risk" according to the characterisation process, bodies maybe grouped if they are sufficiently similar in terms of aquifer characteristics, pathway susceptibility(ies), pressure(s) and confidence in the risk assessment(s). In undertaking the grouping:

- bodies do not necessarily need to be adjacent to each other;
- a monitoring point is not required in each of the component bodies within the group provided there is sufficient overall monitoring in the group as a whole to meet the requirements of operational surveillance, quantitative or protected area monitoring, as appropriate;
- surface water monitoring may be used to verify risk classification.

3.3.4. Where groundwater bodies are determined to be "at risk" according to the characterisation process, bodies may be grouped if they are sufficiently similar in terms of aquifer characteristics, pathway susceptibility(ies), pressure(s) and confidence in the risk assessment(s). In undertaking the grouping:

- bodies must be adjacent to each other except in exceptional circumstances (e.g. islands);

- each component body must have at least one monitoring point to determine the relationship between the bodies;
- operational Monitoring may be focussed in one or more component bodies selected on the basis of the conceptual model, e.g. the most sensitive body(ies). This prioritised monitoring is designed to deliver cost-effective targeted environmental monitoring.

3.4. Aquifer Types

3.4.1 A diverse range of geological settings is found across the UK and Ireland. Correspondingly, this has produced a wide variety of aquifer types.

3.4.2 The Water Framework Directive definition of an aquifer is such that many materials previously described as *'poor' yielding'* or *'non aquifer'* now qualify as aquifers within which groundwater body management units must be delineated and subsequently monitored.

3.4.3 Whilst systematic monitoring within the major water supply aquifers is generally well established, the purpose of monitoring at specific boreholes/springs is sometimes uncertain. For minor water supply aquifers and aquifers not previously monitored, there is greater uncertainty regarding what type and density of monitoring is necessary to provide representative samples of groundwater to support the WFD objectives. For all aquifer areas, there is a need to consider the characteristics of the strata forming the aquifer with regard to flow type, storage, unsaturated zone thickness, etc, before determining the most appropriate means of monitoring. For each monitoring point, knowledge of the local hydrogeological setting around that point is required so that data collected can be interpreted in its proper context. Selected monitoring sites will be used as baseline monitoring points against which the status of groundwater bodies and the success or otherwise of future land use/water resource management strategies will be assessed. This information, and in particular any change observed, is required to be reported to Europe over several decades; hence a clear understanding of what each monitoring point is representing is needed.

3.4.4 The range of aquifer settings found across the UK and Ireland and some of the implications for monitoring is provided in Appendix 3.

4. Quantitative Monitoring

4.1 Introduction

4.1.1 A Quantitative monitoring network is required to assist in characterisation, to determine the quantitative "status of groundwater bodies, and to support the design and evaluation of the programme of measures.

4.1.2 A groundwater body will be at good quantitative status if:

- the available groundwater resource is not exceeded by the long-term annual average rate of abstraction, AND;
- the groundwater levels and flows are sufficient to meet environmental objectives for associated surface waters and groundwater dependent terrestrial ecosystems, AND;
- alteration to flow direction resulting from level change does not cause saline or other intrusion.

4.1.3 As with other networks, the monitoring design should be based on a conceptual understanding of the groundwater system and the pressures. The key elements of the quantitative conceptual understanding will be:

- assessments of recharge and the water balance, and/or;
- the degree of interaction between groundwater and related surface and terrestrial ecosystems.

4.1.4 The development of a quantitative monitoring network can be iterative; data collected from new monitoring points being used to enhance and refine the conceptual model used to locate each monitoring point and the operation of the quantitative monitoring programme.

4.2 Monitoring Parameters

4.2.1 Although the Directive identifies groundwater level as the metric for determining quantitative status, in practice, the requirements of status assessment mean that additional supporting information will be required. Recommended parameters for the purposes of quantitative assessment of groundwater include:

- groundwater levels in boreholes or wells;
- spring flows;
- flow characteristics and/or stage levels of surface water courses;
- stage levels in significant groundwater dependant wetlands and lakes.

The selection of the monitoring point and parameter must be based on a sound conceptual model of the water body to be monitored.

Additional monitoring to support groundwater characterisation and classification may also include:

- chemical monitoring for saline or other intrusions;
- rainfall and the components required to calculate evapotranspiration (to calculate GW recharge);
- ecological monitoring of groundwater dependent terrestrial ecosystems (including ecological indicators);
- groundwater abstraction (and artificial recharge).

Specific requirements for the supporting monitoring data, to supplement the knowledge gained from groundwater level monitoring, will largely be determined by the tools/methods that will be employed to support the assessment of risk or status and the confidence required in this assessment.

4.2.2 Key to parameter selection is how representative the parameter is of the hydrogeological setting being monitored and the significance of its role in determining risk or status.

4.2.3 In some hydrogeological settings monitoring groundwater levels in a borehole maybe inappropriate for the purposes of the Directive. In these circumstances the flow characteristics of associated watercourses or springs may provide better data with which to undertake an assessment. This is most likely to be the case in low permeability/fractured aquifers.

4.3 Density of monitoring

4.3.1 Monitoring may be required at <u>two different scales</u> to meet the various requirements of the Article 4 objectives. Firstly, where possible, groundwater levels and flows across a groundwater body must be assessed. These may be related to the water balance assessment for the body as a whole. Secondly, more focussed 'local' monitoring of levels and flows that relate to relevant local groundwater supported receptors, i.e. surface water bodies (rivers, lakes, estuaries) and groundwater dependent terrestrial ecosystems, may be needed. The latter may include supporting information e.g. salinity monitoring (with respect to saline intrusions) or ecological monitoring (as evidence of impact on ecosystems from groundwater abstractions).

4.3.2 In groundwater bodies or groups of groundwater bodies assessed as being "not at risk", the monitoring can be minimised. Indeed, monitoring need not be located in each body within a group, provided that the groups are hydrogeologically comparable (Section 3.3).

4.3.3 In groundwater bodies or groups of groundwater bodies assessed as being “at risk”, the distribution of monitoring points will reflect the need to understand the hydrogeological conditions that relate to the receptors identified as being “at risk” and to their perceived importance.

4.4 Frequency of monitoring.

4.4.1 The amount and frequency of monitoring will be determined by the data needed to determine risk and status, and where necessary to support the design and assessment of a program of measures.

4.4.2 In general, daily monitoring would be preferred (particularly when measuring flows) while monthly monitoring would generally be the minimum acceptable standard.

4.4.3 Examples of situations where less frequent monitoring may be acceptable include:

- Situations of higher confidence or lower risk in higher storage intergranular or dominantly intergranular aquifers
- Ecological monitoring

4.4.4 Examples of situations where sampling frequencies in excess of daily may be required are:

- Flow monitoring
- Situations of lower confidence or higher risk in karstic aquifers.

5. Chemical Status and Trends Monitoring Programmes

5.1. Introduction

5.1.1. Groundwater monitoring programmes are required to provide a “coherent and comprehensive overview of water status within each river basin, detect the presence of long-term anthropogenically induced trends in pollutant concentrations and ensure compliance with Protected Area objectives.

5.1.2. A groundwater body will be at good chemical status if the following criteria are satisfied:

i. *General water quality*: The concentration of pollutants should not exceed the quality standards applicable under other relevant Community legislation in accordance with the new Groundwater Directive;

ii. *Impacts on ecosystems*: The concentration of pollutants should not be such as would result in failure to achieve the environmental objectives specified under Article 4 for associated surface waters nor any significant diminution of the ecological or chemical quality of such bodies nor in any significant damage to terrestrial ecosystems which depend directly on the groundwater body*;*

iii. *Saline intrusion*: The concentrations of pollutants should not exhibit the effects of saline or other intrusions as measured by changes in conductivity.

5.1.3. The WFD requires both surveillance and operational programmes to be established to provide the information required to support the assessment of chemical status and identification and monitoring of pollutant trends.

5.1.4. Monitoring programmes specifically for addressing prevent and limit objectives, Drinking Water Protected Area objectives and further characterisation are covered separately in Sections 6 and 7.

5.2. Design of the Surveillance Programme

5.2.1 A 'surveillance monitoring' programme is required to:

- *Validate risk assessments:* supplement and validate the characterisation and risk assessment procedure with respect to risks of failing to achieve good groundwater chemical status;
- *Classify groundwater bodies:* confirm the status of all groundwater bodies, or groups of bodies, determined as not being at risk on the basis of the risk assessments; and
- *Assess trends:* provide information for use in the assessment of long-term trends in natural conditions and in pollutant concentrations resulting from human activity. Surveillance monitoring should be undertaken in each plan period and to the extent necessary to adequately supplement and validate the risk assessment procedure for each body or group of bodies of groundwater.

5.2.2. Surveillance is required in bodies or groups of bodies both at risk and not at risk of failing WFD objectives.

5.2.3. Selection of Surveillance Determinands.

The core suite will comprise DO, pH, EC, nitrate, ammonium, temperature, a suite of major and trace ions.

Additional anthropogenic contaminants (e.g. sheep dip insecticides) will be required on an infrequent basis (see below) to provide additional validation of WFD risk assessments.

When assessing natural background levels, additional selective determinands (e.g. heavy metals and radionuclides) will be required for the purposes of characterising natural groundwater quality and trends.

Further information on both core and selective determinand suite selection is provided in Appendix 2.

Selection of Representative Surveillance Monitoring Sites.

The selection process will be based on 3 main factors:

- body grouping (Section 3.3), characterisation and conceptual model(s) including an assessment of aquifer, pathway susceptibility and receptor sensitivity;
- assessment of risk and the level of confidence in the assessment; including the distribution of key pressures and;
- practical considerations relating to suitability of individual sampling points. Sites need to be easily accessed, secure and be able to provide long-term access agreements. Further information is provided in Appendix 1.

Site selection factors must be assessed on a site by site basis, but key principles are as follows:

- *Suitable types of site:* Selection should be based on the conceptual model of the groundwater bodies (or group) and a review of existing and candidate monitoring sites. Surveillance monitoring is not, on its own, required to isolate the impact of individual pressures and the effectiveness of programmes of measures. Large abstractions and springs may therefore provide suitable sites as they draw water from a large area and volume of aquifer.
- *'At risk' bodies*: Locations should ideally coincide with operational monitoring points.
- *'Not at risk' bodies where confidence in the risk assessment is low*: The number of monitoring points should be sufficient to represent the range of pressure and pathway conditions in the GWB grouping and provide the data necessary to supplement the

risk assessment, i.e. increase confidence. The final distribution per grouping will depend on availability of suitable surveillance sites and the distribution of pressures, but, as a general guide, at least 3 points in the most suitable groundwater body per grouping are recommended, with at least one additional point in as many as possible of the remaining bodies in the group.

- *Body groupings where pressures are limited (low or absent):* In bodies that are defined as 'not at risk' and confidence in the risk assessment is high, sampling stations will be required primarily to assess natural background levels and natural trends. Locations should therefore be selected accordingly. As a general guide, at least 1 point per grouping will be required.

5.2.4. Monitoring frequency selection will generally be based on the characteristics of the aquifer and the conceptual model. Table 1 provides suggested surveillance monitoring frequencies for different aquifer types.

Table 1. Proposed minimum monitoring frequencies for surveillance monitoring

		Aquifer Flow Type				
		Confined	**Unconfined**			
			Intergranular flow significant		**Fracture flow only**	**Karst flow**
			Significant deep flows common	**Shallow flow**		
Initial frequency – core & additional parameters		Twice per year	Quarterly	Quarterly	Quarterly	Quarterly
Long term frequency – core parameters	**Generally high-mod transmissivity**	Every 2 years	Annual	Twice per year	Twice per year	Twice per year
	Generally low transmissivity	Every 6 years	Annual	Annual	Annual	Twice per year
Additional parameters (on-going validation)		Every 6 years	Every 6 years	Every 6 years	Every 6 years	-

5.3. Design of the Operational Programme

5.3.1. An 'operational monitoring' programme is required to establish:

- the status of all groundwater bodies, or groups of bodies, determined as being at risk; and
- the presence of significant and sustained upward trends in the concentration of any pollutant. Operational monitoring has to be carried out for the periods between surveillance monitoring. In contrast to surveillance monitoring, operational monitoring is highly focused on assessing the specific, identified risks to the achievement of the Directive's objectives

5.3.2. Operational programmes are required only in bodies 'at risk' of failing to meet WFD objectives.

5.3.3. Selection of operational monitoring determinands.

- In most cases, both core and selective determinands will be required at each sampling station.
- The selection of selective determinands will be based on the initial conceptual models, the ongoing risk assessments arising out of WFD risk characterisation and results of the ongoing monitoring programmes.
- Guidance on selection of core and selective determinands is provided in Appendix 2.

5.3.4. The selection process will be based on 3 main factors:

- Body grouping (Section 3.3), characterisation and conceptual model(s) including an assessment of aquifer, pathway susceptibility and receptor sensitivity.
- Assessment of risk and the level of confidence in the assessment; including the distribution of key pressures identified in the characterisation process and which may cause the body to be classified at poor status.
- Practical considerations relating to suitability of individual sampling points. Sites need to be easily accessed, secure and be able to provide long-term access agreements. Further information is given in Appendix 1.

5.3.5. Where risk issues relate to specific receptors such as ecosystems, sampling points can be focussed in areas that are representative of key receptors and key pressures. In these cases, sampling points will often be used to help isolate impacts from different pressure types, assess the aerial extent of impacts and determine contaminant fate and transport between the pressure and the receptor.

5.3.6. Multi-level sampling points may be required to allow sampling from different depths (or depth intervals) within the aquifer or aquifer sequence (e.g. within a drift aquifer at ~10m, and within the underlying bedrock aquifer at ~30m and ~60m). The primary purpose of these multi-level sites is to assess variations in contaminant concentrations and distribution within the aquifer and at different depths so as to provide an adequate level of confidence for status assessment, design of Programmes of Measures and assessment of the effectiveness of programmes of measures.

5.3.7. Where pressures and risk issues relate to the water body itself, e.g. diffuse pressures, sampling points will be more distributed across the body, and where necessary focusing on the most representative or sensitive combinations of pressures and groundwater susceptibility.

5.3.8. When selecting monitoring sites, their locations should be prioritised on the basis of:

- Potential linkages with existing/planned surface water monitoring sites.
- Availability of suitable existing sites that provide representative samples.
- Potential for multi-purpose monitoring, e.g. combining requirements for Nitrates Directive monitoring, Drinking Water Protected Area monitoring, and Groundwater Directive compliance.
- Potential for supporting different WFD monitoring programmes (e.g. suitable springs can act as quality, quantity and surface water sampling stations).

5.3.9. Monitoring Frequency selection will generally be based on the conceptual model and in particular, the characteristic of the aquifer and its susceptibility to pollution pressures. Table 2 provides suggested minimum frequencies for different aquifer types.

Table 2. Proposed minimum sampling frequencies for operational monitoring

		Aquifer Flow Type				
		Confined	**Unconfined**			
			Intergranular flow significant		**Fracture flow only**	**Karst flow**
			Significant deep flows common	**Shallow flow**		
Higher vulnerability groundwater	**Continuous pressures**	Annual	Twice per year	Twice per year	Quarterly	Quarterly
	Seasonal/intermittent pressures	Annual	Annual	As appropriate	As appropriate	As appropriate
Lower vulnerability groundwater	**Continuous pressures**	Annual	Annual	Twice per year	Twice per year	Quarterly
	Seasonal/intermittent pressures	Annual	Annual	As appropriate	As appropriate	As appropriate
Trend assessments		Annual	Twice per year	Twice per year	Twice per year	-

5.3.10. Sampling frequency and sample timing at each monitoring location may require adjustment, based on:

- Statutory requirements for trend assessment, where applicable. These requirements are not yet available and will be specified in the new Groundwater Directive.
- Whether the location is upgradient, directly below, or downgradient of the pressure. Locations directly below a pressure may require more frequent monitoring.
- The level of confidence in the WFD risk assessments, and changes in the assessments over time.
- Short term fluctuations in pollutant concentrations, e.g. seasonal effects.

5.3.11. Where seasonal and other short-term effects are likely to be encountered, it is essential that sampling takes place at the same time(s) each year to enable comparable data for trend assessment, accurate characterisation and status assessment.

6. Prevent And Limit Monitoring

6.1. Groundwater quality monitoring is required to assess the effectiveness of the measures introduced to prevent or limit the deterioration of the status of groundwater. Although surveillance and operational monitoring programmes will contribute significantly to this, there may be a need for specific additional monitoring programmes aimed at point source pressures. These programme requirements may already be defined by specific regulation aimed at preventing or limiting the input of pollutants to groundwater, e.g. Landfill Directive requirements for landfill monitoring or Groundwater Regulations requirement for requisite surveillance. It may also be designed specifically to investigate other localised issues, e.g. contaminated land, accidental spillages.

6.2. **Defensive monitoring** of this type is designed primarily at ensuring compliance with site conditions and authorisations in the cases of regulated activities or for site specific investigation, i.e. **compliance monitoring**, or for the purposes of characterising site specific impacts and designing and assessing remedial action programmes, i.e. **investigation monitoring**.

6.3. The information derived from defensive monitoring should be used for characterisation and the investigation of specific issues, as well as ensuring Programmes of Measures are being effective. It should not be used specifically for status and trend assessment although some monitoring sites may potentially be used for surveillance and/or operational monitoring. However, where such sites are used, they must fully conform to the quality assurance requirements of WFD monitoring programme sites. Where sites do not comply they must be rejected.

7. Drinking Water Protected Area Monitoring

7.1. The WFD requires that monitoring programmes are able to assess the achievement of Drinking Water Protected Area (DWPA) objectives defined under Article 7. Unlike surface water bodies defined as DWPAs, the WFD does not introduce any additional specific monitoring criteria for groundwater bodies that are also DWPAs. However, the DWPA objectives require that any monitoring in these bodies is also able to provide accurate and reliable data to support DWPA management and assessment. For example this information

will be needed to identify any deterioration in the quality of abstracted water that may potentially lead to an increase in the level of purification/treatment.

7.2. Monitoring in groundwater DWPAs should therefore be carried in accordance with the programmes set out for Surveillance and/or Operational monitoring as relevant to that body (see Section 5) in order to meet Article 4 objectives with the added requirement to ensure compliance with DWPA objectives (Article 7(3)) and the information requirements of Further Characterisation set out in Annex (Annex II (2.3c)).

7.3. The Article 7(3) objective to aim to prevent deterioration in the water quality of DWPAs in order to reduce treatment implies that there are background quality data for DWPAs at the date of implementation of this objective, against which any subsequent deterioration can be assessed. No specification for this is provided so it may be assumed that only monitoring sufficient to assess this objective is needed. It seems clear that raw water quality data are needed and it is logical to assume that this should be focused on potable abstraction sources.

7.4. Regular monitoring of all potable sources would not be practical, or necessary where the characterisation processes has indicated no risk. In water bodies or groups of bodies not at risk of meeting Drinking Water Protected Area Objectives it is recommended that there should be sufficient monitoring of a representative selection of significant potable sources (those to which the Drinking Water Directive applies – see note below[2]) to confirm the risk assessment. This should be incorporated into and may in practice already be part of the surveillance monitoring programme. The relevant criteria from surveillance monitoring therefore apply.

7.5. In water bodies at risk of not meeting Drinking Water Protected Area Objectives, it is recommended that significant potable sources[1] should be monitored, as a minimum, at least once before and at least once within each RBMP period. Where appropriate, this monitoring may be focussed on, or restricted to, areas where the pressures and/or impacts that are giving rise to the risk are relevant to the quality of abstracted water. Subject to transposition into UK legislation, safeguard zones may be used to focus such monitoring (and subsequently to focus any necessary protection measures).

7.6. In many cases potable abstraction sources will form part of the surveillance and operational monitoring programmes. In these cases, the specific requirements of these programmes will take precedence over the monitoring outlined in 7.5 above. Where sources are part of surveillance and/or operational monitoring programmes, more frequent data than indicated above will be available and should be used for assessing compliance with Article 7 objectives.

7.7. In some cases individual groundwater abstraction points may form part of a group of sources that effectively abstract water from the same zone of contribution or safeguard zone within the DWPA. In such cases, providing that the monitoring regime is consistent and representative, not all individual sources may need to be monitored to adequately assess compliance with the Article 7 objectives.

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[2] A significant potable source is defined as one intended for human consumption that comes within the requirements of the Drinking Water Directive (Directive 80/778/EEC as amended by Directive 98/83/EC). That is a source where;

- water abstracted from an individual supply provides 10 m³ a day or more as an average or serves at least 50 persons, unless supplied as part of a commercial or public activity in which cases the thresholds do not apply;

and that is not;:

- a natural mineral water recognised as such by the competent national authorities, in accordance with Council Directive 80/778/EEC of 15 July 1980 on the approximation of the laws of the Member States relating to the exploitation and marketing of natural mineral waters; or
- water which is a medicinal product within the meaning of Council Directive 65/65/EEC of 26 January 1965 on the approximation of provisions laid down by law, regulation or administrative action relating to medicinal products.

Tool Box

Appendix 1: Criteria for site selection and information requirements

Critical requirements for all sampling sites

- ✓ Detailed information on the site should be available and routinely reviewed. This information should be used to assess the suitability of the site and only if the site is suitable should it be used for the relevant monitoring programme.
- ✓ Monitoring sites should be designed or selected to produce data for many years. Sites must have easy access, be secure security from vandals and potentially facilitate long-term installation of expensive water level or other monitoring equipment.
- ✓ Long term access agreement with land owners must be secured for sites and installed equipment must be secure

Monitoring point information – essential and desirable factors

Factor	Chemical monitoring points	Quantitative monitoring points
Aquifer(s) monitored	E	E
Location (grid reference), name of monitoring point and unique identifier	E	E
Groundwater body that monitoring point is within	E	E
Purpose(s) of monitoring site	E	E
Type of monitoring point – farm borehole, industrial borehole, spring, etc	E	E
Depth and diameter(s) of boreholes/wells	E	E
Description of headworks – grouting integrity, slope of ground around borehole	E	E
Depth of screened/open sections of boreholes/wells	D	D
Vulnerability or indication of subsoil thickness and type at monitoring point	E	D
Visual appraisal of recharge area (including land use and pressures, potential sources of point pressures)	E	D
Amount abstracted or discharge flow rate	E	E
Pumping regime (qualitative description – e.g., intermittent, continuous, overnight, etc.)	D	E
Drawdown (pumped water level)	D	E
Zone of contribution/recharge area	D	D
Pump depth	D	D
Static or rest water level	D	E
Datum elevation and description of datum	D	E
Artesian/ overflowing	E	E
Borehole log (geological and construction details)	D	D
Aquifer properties	D	D

KEY

E- Essential
D- Desirable

Quantitative Monitoring Sites

- ✓ Monitoring points should not be pumped or should only be pumped for very short periods at well-defined times, such that measured water levels reflect natural conditions.
- ✓ The locations should be outside the immediate hydraulic influence of the pressure such that day-to-day variations in pumping will not be evident in the data.
- ✓ Large springs may be suitable where total flows are in excess of 1 litre/sec.

Note that data from stations which function as continuous abstraction wells may be acceptable if accompanied by detailed (e.g. hourly) pumping records.

Appendix 2: Initial Guidance on the Selection of Determinand Suites

A2.1 Surveillance Monitoring

The following core determinands are mandatory:

- oxygen content (DO);
- pH;
- conductivity (EC);
- nitrate;
- ammonium.

In addition, the WFD requires that this core determinand list must be supplemented by parameters that are indicative of the impact of pressures identified through the characterisation and risk assessment process.

Although not required specifically by the WFD, the core list should also be supplemented by suites of inorganic parameters to provide data for QA purposes and information on the natural quality (baseline) of groundwater and temperature.

Further generic indicator species may also be added to supplement the risk assessment process. These may include indicators of general industrial activity, e.g. TCE and PCE and urban areas, e.g. Zn and B.

For surveillance monitoring it is therefore recommended that:

- The core suite will comprise DO, pH, EC, nitrate, ammonium, temperature, a suite of major and trace ions plus, where appropriate, selected indicators.
- Parameters indicative of the risks to and impacts on groundwater from pressures identified through Annex II characterisation process were relevant.
- Temperature, DO, EC, pH should be measured in-situ (at the sampling point), while the other parameters should be measured/analysed in the laboratory.

A2.2 Operational Monitoring

In addition to the core parameters, selective determinands will need to be monitored at specific locations, or across groundwater bodies, where the risk assessments carried out as part of the characterisation process of groundwater bodies indicates that they are at risk of failing to achieve relevant objectives.

The selection of parameters will be selected on a case-by-case basis and be influenced by WFD characterisation work supplemented, where necessary, by other information including existing water quality data and local knowledge. The chemical monitoring suites must be reviewed on a regular basis to ensure that they provide representative information and data on groundwater quality and fully support the risk assessment process.

Broad land use/cover categories can be used as a basis for initial determinand selection. Table A1 provides an indication of the types of land use/cover that can be used and potential determinand types for each. Further sub-division, targeting and optimisation of determinand suites should be based on information from the characterisation process, local knowledge and pre-existing water quality data.

Table A1. Indicative determinand types for different land use/cover.

Land Use	Fungicides	Urea Herb	OPs	Acid Herb	VOCs	Pyrethroids	Organotin
Cereals	✓	✓	As needed	✓	✓	✓	
Fruit	✓	As needed	✓	As needed	As needed	✓	
Potatoes	✓	✓	As needed	✓	As needed		✓
Golf		✓		✓			
Grass		As needed		✓	As needed		
Woodland		As needed		As needed			
Sheep			✓			✓	
Amenity		✓		✓	✓		
Urban/Industrial		✓		✓	✓		As needed

Appendix 3: Aquifer settings/flow types and monitoring implications

Aquifer setting/flow type		Example areas	Monitoring considerations	Preferred monitoring
Regional Flowpaths	Intergranular	Kildare Gravels (Ireland) Thames Gravels (England)	• High rate abstraction sources boreholes generally available for 'bulk' chemistry sampling. • Regional flow patterns readily established from level monitoring boreholes. Generally low water level seasonal range.	1, 2, 4, 5
	Intergranular/ Fracture	Permo-Triassic Sandstones (Midlands/Scotland/N.Ireland) Chalk (South and East England)	• High rate abstraction sources generally available for 'bulk' chemistry sampling. • Regional flow patterns readily established from level monitoring boreholes. • Commonly confined down-gradient, concentrating monitoring in unconfined recharge areas. • Unsaturated zone storage resulting in 'slow' component of recharge –delayed response to land use changes.	1, 2, 3, 4, 5
	Fracture	Jurassic Limestones (Lincolnshire)	• High rate abstraction sources generally available for 'bulk' chemistry sampling. • Regional flow patterns readily established from level monitoring boreholes. Water level seasonal ranges can be significant. • Preferential flow zones possible.	1, 2, 3, 4, 5
	Karstic	Carboniferous Limestone (Ireland/Mendips)	• High rate abstraction boreholes available but may only be representative of preferential flow zone. • Large discharge springs available for 'bulk' chemistry sampling. • Recharge zones can be complex. • Low storage leading to rapid level/quality changes with implications for monitoring frequency/timing.	1, 2, 3
Intermediate Flowpaths	Intergranular	Glacial outwash and valley sand & gravels/alluvials (UK and Ireland)	• Perched water tables.	4, 5, 6
	Intergranular/ fracture	Devonian Sandstones (Scotland/Welsh Borders) Millstone Grit (England)	• Can be compartmentalised by faulting with associated complex flow patterns. • Boreholes may sample only discrete zones.	5, 6
	Fracture Fracture/ karstic	Palaeogene Basalts (N.Ireland) Carboniferous/Devonian (Ireland, N England)	• Can be compartmentalised by faulting with associated complex flow patterns. • Higher abstraction rate sources less common with possibility of monitoring boreholes being located in low/no flow zones. • Low storage leading to rapid level/quality changes with implications for monitoring frequency/timing. • Layered aquifer systems with vertical flow relationships increasing complexity of data interpretation.	4, 5, 6
Local Flowpaths	Fracture/ upper weathered zone	Ordovician/Silurian (Wales/N.Ireland) Metamorphic/Igneous (Scottish Highlands/Northern Ireland/Ireland/Cornwall)	• Higher abstraction rate sources for 'bulk' sampling unlikely. • Fast through-flow times and short flow paths. • Low storage leading to intermittent well/spring yields with implications for monitoring frequency/timing. • Possibility of boreholes being located in low/no flow zones. • Option for spring/surface water monitoring as representative of groundwater. • Increased significance of storage in overlying superficial deposits.	3, 6

Monitoring type

1 – High rate abstraction boreholes
2 – Large discharge springs
3 – Surface water
4 – Purpose drilled monitoring boreholes
5 – Private/low rate abstraction boreholes
6 – Low discharge springs

Appendix 2: Sample Data Sheets

Abstraction Well - Screening Log	
Name:	National Grid Reference:
Location:	Datum type and level:
Date inspected:	Logged by:
GW Body type:	LA or Other Contact:

Well Construction Details	**Details**
Borehole Log	Y / N (if yes, attach)
Construction Log	Y / N (if yes, attach)
Drilling Company	
Total Depth (m)	
Depth to bedrock (m bgl)	
Depth to static water level (m bgl)	
Diameter (m)	
Boring Method	
Liner present	Y / N
If yes - Liner type?	
Screened Area (m bgl)	
Casing depths (m bgl)	
Aquifer type:	
Subsoil type	
Vulnerability Rating (GWPS)	Extreme / High / Moderate / Low
Any other relevant remarks	

Level of wellhead protection	**Details**
Well installed in pump house	Y / N
Wellhead details	
Level of protection	Adequate / Inadequate
Any other relevant remarks	

Abstraction Information	**Details**
Pump testing details	Y / N (if yes, attach)
Depth of pump (m bgl)	
Daily Pumping Rate	
Pumping regime (qualitative description)	
Drawdown (pumped WL)	
Spring discharge	Y / N
Method of measurement of discharge – weir, data logger etc.?	
Existing data available	Y / N (if yes, attach)
Estimate area of zone of contribution/recharge area	
Any other relevant remarks	

Local Area reconnaissance	**Details**
Potential point sources of pollution within 500m *i.e., WWT systems, farmyards, silage/slurry storage, landfills, IPC facilities, Intensive agricultural units etc.*	
Potential diffuse sources of pollution within 500m *i.e., landspreading areas, forestry, etc.*	
Land use in local area *i.e., grassland, dairy, tillage forestry, bog etc*.	
Any other relevant remarks	

Water Level Well/Spring - Screening Log	
Name:	National Grid Reference:
Location:	Datum type and level:
Date inspected:	Logged by:
GW Body type:	LA or Other Contact:
Monitoring Type##: i.e., well, spring, stream gauge, weir etc.	
Well Construction Details	**Details**
Borehole Log	Y / N (if yes, attach)
Construction Log	Y / N (if yes, attach)
Drilling Company	
Total Depth (m)	
Depth to bedrock (m bgl)	
Depth to static water level (m bgl)	
Known range of WL (m bgl)	
Diameter (m)	
Boring Method	
Liner present	Y / N
If yes - Liner type?	
Screened Area (m bgl)	
Casing depths (m bgl)	
Aquifer type	
Subsoil type	
Vulnerability Rating (GWPS)	Extreme / High / Moderate / Low
Any other relevant remarks	
Spring Discharge	
Discharge measurement	
Abstraction	
Existing information	
Any other relevant remarks	
Stream Gauge / Weir	
Discharge measurement	
Abstraction	
Existing information	
Any other relevant remarks	

Monitoring Point should not be a pumped well

Appendix 3: Weighted Averages Methodology

The following methodology can be used to calculate the weighted average parameter for a GWB.

1. For the individual monitoring points calculate the average parameter values as before e.g NO_3.
2. For a given GWB list the number of monitoring points, their average NO_3 and their abstraction.
3. Allocate weightings to the monitoring points by considering the abstraction:
    a. The monitoring station with the largest abstraction is given a weighting of 1
    b. All other weightings can be calculated by dividing the abstraction of the monitoring station by the abstraction of the monitoring station with the largest abstraction. Therefore all other monitoring stations should come out with values of less than 1.
4. For each monitoring station multiply the average NO_3 value by the weighting.
5. Add up all these weighted NO3 values and divide this number by the sum of the weights.

An example from the SERBD is given below. These points are located in the Rathdowney GWB.

Monitoring Point	**NO_3 (mg/l)**	**Abstraction (m^3/d)**	**Weight**	**Weighted NO_3 (mg/l)**	**Weighted Average NO_3 (mg/l)**	**Average NO_3 (mg/l)**
Urlingford-Johnstown PWS	36.7	850	1.0	36.7		
Borris-in-Ossory-Townspark	15.3	189	0.2	3.4		
Borris-in-Ossory-Burns	12.89	100	0.1	1.5		
Donaghmore	7.1	90	0.1	0.8	**29.3**	18.0

The weighted average value (29.3 mg/l) is significantly different from the average value (18 mg/l). This is because the monitoring point at Urlingford, which has a much higher abstraction than the others has a much higher NO_3 value.