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COMMON IMPLEMENTATION STRATEGY FOR THE WATER FRAMEWORK DIRECTIVE (2000/60/EC)

Guidance Document No. 15

Guidance on Groundwater Monitoring

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FOREWORD

The Water Directors of the European Union (EU), Acceding Countries, Candidate Countries and EFTA Countries have jointly developed a common strategy for supporting the implementation of the Directive 2000/60/EC, “establishing a framework for Community action in the field of water policy” (the Water Framework Directive). The main aim of this strategy is to allow a coherent and harmonious implementation of the Directive. Focus is on methodological questions related to a common understanding of the technical and scientific implications of the Water Framework Directive.

In particular, one of the objectives of the strategy is the development of non-legally binding and practical Guidance Documents on various technical issues of the Directive. These Guidance Documents are targeted to those experts who are directly or indirectly implementing the Water Framework Directive in river basins. The structure, presentation and terminology is therefore adapted to the needs of these experts and formal, legalistic language is avoided wherever possible.

In the context of the above-mentioned strategy, a guidance document "Monitoring under the Water Framework Directive" has been developed and endorsed by the Water Directors in November 2002 (CIS Guidance Document Nr. 7). This document provides Member States with Guidance on monitoring of inland surface water, transitional waters, coastal waters and groundwater, based on the criteria provided in Annex V of the Water Framework Directive.

As a follow-up, and in the context of the development of the new Groundwater Directive under Article 17 of the Water Frameworkt Directive, Member States have expressed the need to clarify issues of groundwater monitoring related to e.g. quantitative and chemical status monitoring, protected area monitoring, or monitoring linked to prevent/limit measures. A project to develop a guidance document complementing the CIS Guidance Document Nr. 7 has, therefore, been designed in 2004, and an informal drafting group has been established under the umbrella of the CIS Working Group on Groundwater (WG C). This drafting group has been coordinated by Austria and the United Kingdom, and involved a range of experts from other Member States and from stakeholder organisations.

The present Guidance Document is the outcome of this drafting group. It contains the synthesis of the output of discussions that have taken place since December 2004. It builds on the input and feedback from a wide range of experts and stakeholders that have been involved throughout the procedure of Guidance development through meetings, workshops, conferences and electronic media, without binding them in any way to this content.

“We, the water directors of the European Union, Norway, Switzerland and the countries applying for accession to the European Union, have examined and endorsed this Guidance during our informal meeting under the Finnish Presidency in Inari (30 November-1st December 2006). We would like to thank the participants of the Working Group C and, in particular, the leaders of the monitoring drafting group, Austria and the United Kingdom, for preparing this high quality document.

We strongly believe that this and other Guidance Documents developed under the Common Implementation Strategy will play a key role in the process of implementing the Water Framework Directive and the newly adopted Groundwater Directive.

This Guidance Document is a living document that will need continuous input and improvements as application and experience build up in all countries of the European Union and beyond. We agree, however, that this document will be made publicly available in its current form in order to present it to a wider public as a basis for carrying forward ongoing implementation work.

We also commit ourselves to assess and decide upon the necessity for reviewing this document in the light of scientific and technical progress and the experiences gained in the monitoring programmes of the Water Framework Directive”.

MEMBERS OF THE DRAFTING GROUP

Leaders of the activity

Johannes GRATH, Federal Environment Agency (Austria)

Rob WARD, Environment Agency (United Kingdom)

Philippe QUEVAUVILLER (European Commission)

Members of the Drafting Group

Ralf EPPINGER, AMINAL, Ministry of Flemish Government (Belgium)

Rossitza GOROVA, Ministry of Environment and Water (Bulgaria)

Daniela DENEVA, EXEA-Sofia (Bulgaria)

Martin AST, Federal Environmental Agency (Germany)

Rüdiger WOLTER, Federal Environmental Agency (Germany)

Isaac SANCHEZ NAVARRO, Ministry of the Environment (Spain)

Carlos MARTINEZ NAVARRETE, Spanish Geological Survey (Spain)

Ariane BLUM, BRGM (France)

Anne-Marie FOUILLAC, BRGM (France)

Paola BOTTONI*, ISS (Italy)

Martina BUSSETTINI*, APAT (Italy)

Elisabetta PREZIOSI*, Water Research Institute (Italy)

Giuseppe GIULIANO*, Water Research Institute (Italy)

Manuel SAPIANO, Malta Resources Authority (Malta)

Dico FRATERS, RIVM (The Netherlands)

Jan CRAMER, Geological Survey of Norway (Norway)

Mihai BRETOTEAN, Institute of Hydrology and Water Management (Romania)

Lutgart van NEVEL, IRMM (European Commission, Joint Research Centre)

Franz MEISSNER, AquaOpta GmbH (CEEP)

Christian GRØN (Nordtest)

Ulrich BORCHERS, Institut für Wasser (CEN)

Hans-Peter BROERS, EuroGeoSurveys

John CHILTON, British Geological Survey (UN-ECE, IAH)

Paolo SEVERI (EPRO)

Andreas SCHEIDLEDER, Federal Environment Agency (Consultant)

*… the Italian members are coordinated by the Italian Ministry of the Environment

Monitoring Guidance for Groundwater

THE COMMON IMPLEMENTATION STRATEGY (CIS) OF THE WFD

The Water Framework Directive (2000/60/EC)[1] is a comprehensive piece of legislation that sets out, *inter alia*, "good status" objectives for all waters in Europe. The Directive provides for a sustainable and integrated management of river basins including binding objectives, clear deadlines and comprehensive programme of measures based on scientific, technical and economic analysis including public information and consultation. Soon after its adoption, it has become clear that the successful implementation of the Directive will be equally as challenging and ambitious for all countries, institutions and stakeholders involved.

In order to address the challenges in a co-operative and coordinated way, the Member States, Norway and the Commission agreed on a Common Implementation Strategy (CIS) for the Water Framework Directive only five months after the entry into force of the Directive. Furthermore, the Water Directors stressed the necessity to involve stakeholders, NGOs and the research community in this joint process as well as to enable the participation of Candidate Countries in order to facilitate their cohesion process.

In the first phase of the joint process, a number of guidance documents were prepared and these documents were tested in Pilot River Basins across Europe in 2003 and 2004. In the new Work Programme 2005/2006, the four Working Groups (Ecological Status, Integrated River Basin Management, Groundwater and Reporting) have continued addressing the key issues for implementation. In addition, new groups on 'WFD and Agriculture', 'GIS' and 'Chemical Monitoring' are sharing experiences in this area and a new Pilot River Basin network is supporting the technical activities in all working groups.

1 PURPOSE AND SCOPE OF THE GUIDANCE

This guidance has been drafted in response to a mandate from the WFD Groundwater Working Group (Working Group C). This mandate required the development of practical guidance and technical specifications for groundwater monitoring that builds on, and complements existing WFD guidance[2]. Its primary focus is on the requirements of the Water Framework Directive (WFD), and in particular the obligations set out in Article 8. In addition, it will meet the requirements of the daughter Groundwater Directive (adopted at the end of 2006)[3]. The guidance also forms one of the elements of the WFD Chemical Monitoring Activity.

This document provides guidance on establishing groundwater monitoring programmes to meet the requirements of the WFD and of the new Groundwater Directive. These programmes include both quantitative and chemical (quality) monitoring for status and trend assessment, monitoring to support (ground)water body characterisation and drinking water protected area objectives.

The establishment of high quality long-term monitoring programmes is essential if the implementation of the WFD and the daughter Groundwater Directive is to be effective. It is recognised that monitoring can be very expensive and so the guidance presented here aims to establish cost-effective, risk-based and targeted groundwater monitoring across Europe that enables WFD objectives to be met. However, 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.

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[1] European Parliament and Council Directive 2000/60/EC of 23 October 2000 establishing a framework for Community action in the field of water policy (OJ L 327, 22/12/2000, p. 1) as amended by European Parliament and Council Decision 2455/2001/EC (OJ L 331, 15/12/2001, p.1)

[2] Guidance Document No. 2 Identification of Water Bodies (2003);
Guidance Document No. 3: Analysis of Impacts and Pressures – Working Group 2.1 IMPRESS (2003)
Guidance Document No. 7: Monitoring under the Water Framework Directive – WG 2.7 Monitoring (2003);
Technical Report 1: Statistical aspects of the identification of groundwater pollution trends and aggregation of monitoring results – WG 2.8 Statistics (2001);
Chemical Monitoring Activity;
Technical report on groundwater monitoring (workshop report 25th June 2004);
EC Monitoring Guidance for the Nitrates Directive;
EUROWATERNET Guidelines (Technical Report Nr. 7, EEA 1999);
Guidelines on monitoring and assessment of transboundary groundwaters (UN-ECE).

[3] European Parliament and Council Directive on the protection of groundwater against pollution and deterioration (adopted in December 2006)

Recommendations expressed in this guidance paper will help to implement consistent monitoring across Europe. The guidance provides useful elements for the development and maintenance of networks 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

Article 8 of the WFD requires the establishment of programmes for the monitoring of groundwater. WFD groundwater monitoring is focussed primarily on the groundwater body as a whole but it also supports the overall management of the river basin district and the achievement of its environmental objectives.

The groundwater monitoring programmes must provide the information necessary to assess whether relevant Article 4 environmental objectives are met, in particular the assessment of groundwater quantitative status, chemical status and significant, long-term trends in natural conditions and trends in groundwater bodies resulting from human activity. In addition, these may need to be supplemented by additional monitoring programmes to meet requirements relevant to Protected Areas (e.g. Drinking Water Protected Areas) and to support the validation of the Article 5 characterisation and risk assessment procedures. Programmes meeting these requirements must be operational by 22 December 2006 at the latest.

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), which must include:

- A **quantitative monitoring network** to supplement and validate the Article 5 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 facilitate quantitative status assessment.
- A **surveillance monitoring network** to: (a) supplement and validate the Article 5 characterisation and risk assessment procedure with respect to the risks of failing to achieve good groundwater chemical status; (b) provide information for use in the assessment of long-term trends in natural conditions and in pollutant concentrations resulting from human activity and; (c) to establish, in conjunction with the risk assessment the need for operational monitoring.
- An **operational monitoring network** to: (a) establish the status of all groundwater bodies, or groups of bodies, determined as being 'at risk', and (b) establish the presence of significant and sustained upward trends in the concentration of pollutants.
- Appropriate monitoring to support the achievement of Drinking Water Protected Area (DWPA) objectives.

The results of the monitoring must be used to:

- establish the chemical and quantitative status of groundwater bodies (including an assessment of the available groundwater resource);
- assist in further characterisation of groundwater bodies;
- validate the risk assessments carried out under Article 5;
- estimate the direction and rate of flow in groundwater bodies that cross Member States' boundaries;
- assist in 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.

Specific provisions concern those bodies of groundwater which cross the boundary between two or more Member States. Bilateral agreement should be reached on monitoring strategies, which requires coordination of conceptual model development, the exchange of data and QA and QC aspects (in line with the requirements of Article 13(2) of the WFD). The provisions for the surveillance monitoring require transboundary groundwater bodies to be monitored for those parameters which are relevant for the protection of all uses supported by the groundwater flow.

An overview of the objectives for each monitoring programme described in detail in this guidance document is shown in Table 1.

The WFD stipulates that surveillance monitoring must be undertaken during each planning cycle, and operational monitoring must be carried out during periods not covered by surveillance monitoring. No minimum duration or frequency is specified for the surveillance programme. Operational monitoring must be carried out at least once a year during periods between surveillance monitoring. Member States should undertake sufficient surveillance monitoring during each plan period to allow adequate validation of Article 5 risk assessments and obtain information for use in trend assessment, and sufficient operational monitoring to establish the status of bodies at risk and the presence of significant and sustained upward trend in pollutant concentrations.

Table 1: Overview of the relationship of monitoring objectives for each monitoring programme defined by, or to support, the WFD and the daughter Groundwater Directive

	WFD Specified Monitoring Programmes			**Drinking Water Protected Area (DWPA) Monitoring**	**Prevent and Limit Monitoring**
Monitoring objective(s)	**Quantity Monitoring**	**Surveillance Monitoring**	**Operational Monitoring**		
Section in guidance document covering details for monitoring	Section 5	Section 4.1	Section 4.2	Section 6	Section 7
Supplement and validate the risk assessment (initial and further characterisation)	✓	✓	(✓[1])		✓
Identify saline or other intrusions resulting from alterations if flow within the groundwater body	✓	✓	✓		
Assess chemical trends in natural conditions		✓			
Assess chemical trends caused by anthropogenic activity		✓	✓	✓	
Transboundary groundwater bodies	✓	✓			
Status assessment – determining status of bodies that are 'at risk'	✓		✓	✓[2]	
Status assessment – confirming that bodies 'not at risk' are at good status	✓	✓		✓[2]	
Assess the effectiveness of Programmes of Measures	✓		✓	✓	✓

[1]) Results will support characterisation in future RBMP cycles

[2]) Assumes new Groundwater Directive will require DWPA objectives to he met for good status

3 GENERAL PRINCIPLES

The monitoring programmes must provide the information necessary to assess whether the WFD environmental objectives will be achieved. This means that a clear understanding of the environmental conditions required for the achievement of the objectives, and of how these could be affected by human activities, is essential for the design of effective monitoring programmes. The monitoring programmes should therefore be designed on the basis of the results of the Article 5 characterisation and risk assessment procedure and the **conceptual model/understanding** of the groundwater system in which the general scheme of 'recharge-pathway-discharge' is known. Detail and importance of such models is already laid down in relevant CIS guidance[4]. Chapter 3.1 outlines the principles and relationship of the model to the monitoring programme.

[4] Guidance Document No. 3: Analysis of Impacts and Pressures – Working Group 2.1 IMPRESS (2003)
Guidance Document No. 7: Monitoring under the Water Framework Directive – WG 2.7 Monitoring (2003);

Considering the principles described in this guidance should allow for the establishment of a monitoring network which is **representative** for the groundwater body. The amount of monitoring required (number of points and sampling frequency) will be proportional to the difficulty in (a) judging the status of the groundwater body, (b) the presence of adverse trends, and (c) the implications of errors in such judgements, in particular with regard to setting up programmes of measures.

It should be emphasised that the WFD monitoring programme is intended to focus on phenomena affecting the **overall state of the groundwater body**. Local scale pollution processes which do not affect the overall state of the groundwater body should be the target of different monitoring activities run by the appropriate competent authorities (e.g. a regulatory, local authority etc.) responsible for the relevant legal provisions. Such local impacts are not relevant at the groundwater body scale unless their evolution in time and space endangers the environmental objectives of the groundwater body. They may, however, be relevant with respect to assessments linked to 'prevent/limit' measures covered by Article 11 of the WFD and Article 6 of the daughter Groundwater Directive, which are discussed in a separate guidance document.

The application of the term 'body of groundwater' must be understood in the context of the hierarchy of relevant definitions provided under Article 2 of the WFD. Accordingly, a *body of groundwater* means a distinct volume of groundwater within an aquifer or aquifers. *Groundwater* means all water, which is below the surface of the ground in the saturated zone and in direct contact with the ground or subsoil and *aquifer* means a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater. Furthermore, **groundwater bodies may be grouped** i.e. for the purpose of monitoring.

The design of a monitoring network should take into account the **three-dimensional** nature of the groundwater system and both, **spatial and temporal variability**, especially when determining the location of monitoring sites and the selection of appropriate monitoring site types. The network should have a spatial and temporal density which considers the natural characteristics of the groundwater body (conceptual understanding) and the pollution risks, to help focus monitoring activities in areas where significant pressures combined with higher vulnerability exist.

In order to contribute to a three-dimensional representative monitoring network an advanced conceptual understanding of hydrogeological characteristics and pressures is essential, especially where there is evidence of significant vertical variation in the aquifer characteristics and stratification of groundwater quality.

The **selection/location** of appropriate sampling sites and the selection of appropriate site density should be based on the conceptual understanding (hydrogeological characteristics and pressures) and might be supported by using existing information such as:

- existing quality and/or quantity data (length, frequency, range of parameters);
- construction characteristics of existing sites and the abstraction regime;
- the spatial distribution of existing sites compared to the scale the groundwater body; and
- practical considerations relating to easy and long-term access, security, health and safety.

The selection of appropriate monitoring **site types** within a monitoring network at groundwater body level should be based on an understanding of the objectives of monitoring and the understanding (conceptual or otherwise) of travel times and/or groundwater ages that the monitoring site may typically sample. This understanding may be enhanced by groundwater age dating where appropriate.

Detailed information on the site should be available and be routinely reviewed. This information should be used to assess the suitability of the site to be used in the relevant monitoring programme. Elements for characterising sampling sites are summarised in Annex 2 as well as the advantages and disadvantages of different monitoring installations/points (types and uses) in Annex 3.

Integrated monitoring will contribute significantly to cost-efficient monitoring by making best use of appropriate components of existing monitoring networks serving different objective and by designing and operating integrated groundwater and surface water monitoring networks.

3.1 CONCEPTUAL MODELS AS BASIS FOR MONITORING

Conceptual models/understanding 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.

The conceptual model will represent the current understanding of the groundwater system based on the knowledge of its natural characteristics (e.g. the aquifer type, three-dimensional structure, dynamics and boundary conditions), perceived pressures and knowledge of impacts.

In this guidance, two types of conceptual model/understanding are used:

- the regional conceptual model – an understanding of the factors at groundwater body scale 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.

Within (inter)national river basins large differences may and do occur in the geochemical and hydrogeological characteristics of groundwater bodies. Therefore conceptual models may differ between regions within a(n) (inter)national river basin. A regional conceptual model/understanding will identify the specific requirements for establishing a monitoring network and the degree of monitoring, in terms of number of sites, site density and frequency of monitoring. This model/understanding 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.

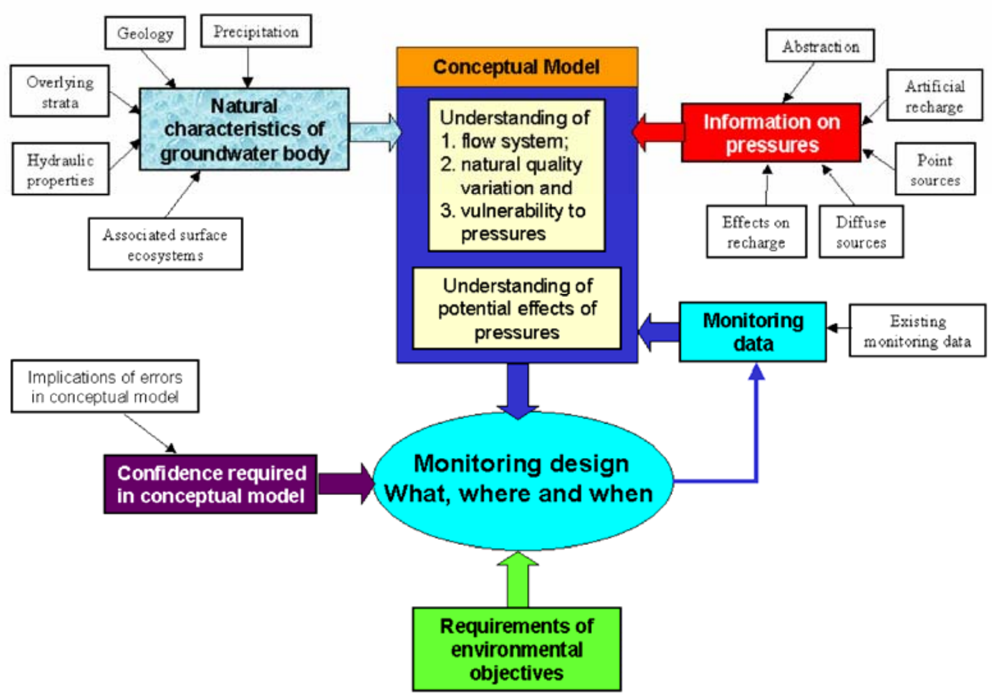

Figure 3.1: Link between the conceptual model/understanding and monitoring (from CIS WG 2.7 Monitoring Guidance)

The selection of groundwater monitoring points also requires knowledge of the local factors influencing the behaviour 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.

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

- monitoring point construction details;

- hydrogeological setting;
- understanding of recharge sources and patterns;
- local groundwater flow pattern(s) and regime within the catchment area;
- abstraction impacts;
- existing hydrochemical data;
- approximate size of catchment area;
- land use and pressures within the catchment area.

Information about travel times and/or or groundwater age distribution may be a very useful input to the conceptual model/understanding as well as for validating the model. Monitoring data obtained from the WFD monitoring programmes should be used to test, validate and refine the conceptual model(s). This process should be started before the first data are available and continued until there is adequate confidence in its/their reliability. Testing may include using the conceptual model and measured values of chemistry and/or water level to predict conditions at locations elsewhere within the groundwater body that are not monitored and then installing monitoring to check these predictions to confirm the model or identify what refinements are needed.

In addition to assisting with the design of the monitoring network the conceptual model is also extremely important for understanding and interpreting the monitoring data.

3.2 AQUIFER TYPES

A consideration of the different types of aquifers is an essential part of the conceptual model/understanding. A diverse range of hydrogeological settings and aquifer types is found across Europe. This broad variation has major implications for the suitability of different types of sampling installation and how effectively they represent changes in groundwater systems, and monitoring design needs to be tailored accordingly.

For all groundwater bodies, there is a need to consider the characteristics of the strata forming the aquifers with regard to flow paths and flow mechanisms, storage, unsaturated zone thickness, groundwater recharge and discharge, before determining the most appropriate means of monitoring. The scale of the groundwater body i.e. whether there are local and rapid flow paths or much longer and slower regional ones, and the nature of the geological material, in particular whether groundwater movement is dominantly through the intergranular spaces between the grains of sedimentary rocks or via the fractures in consolidated rocks are key factors in this respect.

Hence a clear understanding is needed of what each monitoring point represents in terms of the groundwater bodies in which they are located, and the response times of the groundwater both to pressures imposed upon them and to measures to control their impacts.

A summary of the range of aquifer settings found across Europe and the range of likely response times is given in Annex 1.

3.3 GROUPING OF GROUNDWATER BODIES

As proposed by the CIS guidance on the Identification of Water Bodies[5], groundwater bodies may be grouped for monitoring purposes provided that the monitoring information obtained provides a reliable assessment of the status of each body in the group and the confirmation of any significant upward trends in pollutant concentrations.

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 reliably achieved.

Where groundwater bodies are determined to be **not at risk** according to the Article 5 review 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 do not necessarily need to be adjacent to each other;

[5] Guidance Document No. 2: Identification of Water Bodies (2003).

- 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.

Where groundwater bodies are determined to be **at risk** according to the Article 5 review 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 should be adjacent to each other except in exceptional circumstances (e.g. numerous small comparable groundwater bodies; islands);
- it is recommended that each component body should have at least one monitoring point to determine the relationship between the bodies. However the number of monitoring points will depend on the aquifer characteristics, pathway susceptibility(ies), pressure(s) and confidence in the risk assessment(s);
- operational monitoring may be focused on 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 INTEGRATED MONITORING

The WFD considers the water environment as a continuum. This is reflected in the groundwater status definition and through the recognition of the role played by groundwater in maintaining the flow, quality and ecology of dependent surface waters and vice versa. Therefore as well as providing an overview of the distribution of contaminants in the body of groundwater, monitoring should be able to provide an understanding and assessment relating to groundwater flows between groundwater bodies and surface water bodies and between groundwater bodies and terrestrial ecosystems. The extent of this monitoring will depend on the significance of the dependency of the surface water bodies and/or terrestrial ecosystems on groundwater and the extent of the risks.

Monitoring programmes for surface water and groundwater should therefore be designed and operated in an integrated way where the environmental objectives of surface waters and groundwater are dependent on each other. Surface waters with a large proportion of groundwater derived base flow can be used to indicate the quality of groundwater and monitoring data from surface water bodies may support the assessment of groundwater body status. In many cases, the correct location of a surface water sampling point, e.g. close to an aquifer discharge point, may function as a monitoring point for both programmes.

The integration of available wells and springs already used for other purposes (monitoring or abstractions) has several advantages as it contributes to a representative reflection of the state of groundwater. It can also contribute significantly to cost-effective monitoring but has to be done carefully in order to avoid bias. Boreholes in regular operation have the advantage of less need of purging before sampling. However, a network dominated by drinking water abstractions might not adequately reflect the overall environmental quality of the groundwater across the whole body. This is because they are often situated in locations where the groundwater quality is good, e.g. away from recharge areas, or abstract only from deeper parts of the aquifer. It is important to note that when drinking water abstraction sites are used for monitoring, it is raw water quality that should be sampled and analysed. A representative monitoring network should ideally be based on a balanced mixture of different sampling site types as well as sampling site uses. The advantages and disadvantages of different monitoring points (types and uses) are summarised in Annex 3.

3.5 NETWORK REVIEW AND UPDATE

As the conceptual model is refined and the understanding of the hydrogeology and hydrochemistry of the groundwater system improves, the network design should be reviewed and adapted if required. The monitoring results obtained from the network should be interpreted regularly and the monitoring network and its operation reviewed at least once every six years, but ideally more frequently.

Updating of the network should take into account the observed variations in the natural processes and/or anthropogenic impacts influencing groundwater quantity and quality, trends and emerging phenomena. As knowledge improves, it can be seen as a network optimisation process. Review and updating of the network should be performed every time the factors influencing the observed phenomena change significantly, and should take account of the likely response times of the aquifers, in relation to the expected ages of the groundwater being sampled.

However, when updating the network, it is important to remember that deleting a monitoring site will lead to a potential loss of useful information and that to correctly assess trends, it is important to keep sampling sites with long time series. It is easier to add a site than delete one. It is also important to maintain the data for sites taken off the network to enable audit and review of previous decisions/management plans based on these data.

The removal of site from the network may also introduce bias. Any changes to the network must be assessed in terms of the impact this will have on the information being derived from the monitoring programme and the decisions being made.

4 CHEMICAL STATUS AND TREND MONITORING

Groundwater monitoring programmes are required to provide a coherent and comprehensive overview of water status within each river basin, to detect the presence of long-term anthropogenically induced trends in pollutant concentrations and ensure compliance with Protected Area objectives. As stressed in the daughter Groundwater Directive, reliable and comparable methods for groundwater monitoring are an important tool for assessment of groundwater quality (and this is applicable to quantity as well).

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

- *General water quality*: The concentrations of pollutants should not exceed the quality standards applicable under other relevant Community legislation in accordance with Art. 17;
- *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*;*
- *Saline intrusion*: The concentrations of pollutants should not exhibit the effects of saline or other intrusions as measured by changes in conductivity.

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

Monitoring programmes specifically for addressing protected areas and prevent and limit objectives are covered separately in sections 6 and 7 respectively.

4.1 DESIGN OF THE SURVEILLANCE MONITORING PROGRAMME

Surveillance monitoring is focusing on the groundwater body as a whole. 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 is required in bodies or groups of bodies both at risk and not at risk of failing WFD objectives. The programme must be carried out during each River Basin Management cycle, irrespective of whether the groundwater body (or group of bodies) is at risk.

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.

The surveillance monitoring programme will also be useful for defining natural background levels (as defined in the daughter Groundwater Directive) and characteristics within the groundwater body. This will enable future changes in conditions to be assessed, reference data to be acquired and typologies to be investigated. This information will be useful for characterising transboundary water bodies and as a basis for European-wide reporting.

In designing a surveillance programme, the required confidence in the monitoring results must be defined in order to achieve sufficient confidence in the assessment. The required confidence in surveillance monitoring depends upon the variability of the groundwater or aquifer properties in question. In principle, the uncertainty from the monitoring process should not add significantly to the variability of the monitoring data.

The acceptable risk of not identifying a new pollution pressure or a trend change should also be established and this information used when establishing the objectives for the monitoring, managing the monitoring programme(s) and assessing data quality and variability.

4.1.1 Selection of surveillance monitoring determinands

The recommended core set of determinands comprises dissolved oxygen, pH-value, electrical conductivity, nitrate, ammonium, temperature and a set of major and trace ions. Parameters such as temperature and a set of major and trace ions are not formally required by the WFD but may be helpful to validate the Article 5 risk assessment and the conceptual models. Selective determinands (e.g. heavy metals and relevant basic radio nuclides) will be needed for assessing natural background levels.

Additional indicators of anthropogenic contaminants typical of land use activities in the area and with the potential to impact on groundwater will also be required on an infrequent basis (see below) to provide additional validation of WFD risk assessments and to check for any new identified pressure.

In addition at all sites monitoring of the water level is recommended in order to describe (and interpret) the 'physical status of the site' and to interpret (seasonal) variations or trends in chemical composition of groundwater.

Further information on both core and selective determinand suite selection is provided in Annex 3.

4.1.2 Selection of representative surveillance monitoring sites

The selection of sampling sites and their operation is of major importance for the results of the later assessment procedure especially as contaminants are often unevenly distributed across a body of groundwater. The spatial distribution of contaminants is related to the location of different pressures e.g. point and diffuse sources (different types of land use). Additionally a body of groundwater is three dimensional and the concentration of contaminants may vary significantly in vertical and lateral direction. Common variations of hydrodynamic and hydro-geochemical characteristics inside a body of groundwater can have significant impact on the parameter specific spreading of contaminants and should be taken into account during the selection of monitoring sites. Furthermore the physico-chemical parameters (e.g. electrical conductivity, temperature and contaminant concentrations) in shallow aquifers sometimes reveal a distinct variation over the year.

The selection process should be based on three main factors:

- the conceptual model(s) including assessment of the hydrological, hydrogeological and hydrochemical characteristics of the body of groundwater including characteristic travel times, distribution of different types of land uses (e.g. settlement, industry, forest, pasture/farm land), pathway susceptibility, receptor sensitivity and existing quality data;
- assessment of risk and the level of confidence in the assessment; including the distribution of key pressures[6] and;
- practical considerations relating to the suitability of individual sampling points (see Annex 3). Sites need to be easily accessed, secure and be able to provide long-term access agreements.

An effective monitoring network will be one in which the sites are able to monitor for the potential impacts of identified pressures and the evolution of groundwater quality along the flow paths within the body.

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[6] It should be noted that the risk assessment – as carried out under Article 5 of the WFD – and the identification of key pressures should enable identification of specific pollutants that contribute to the determination of groundwater bodies as being "at risk". Under the new Groundwater Directive, consideration will need to be given for establishing threshold values (groundwater quality standards) for these substances by the end of 2008. They should therefore be considered in the list of parameters to be monitored.

Where risk issues relate to specific receptors such as ecosystems, additional sampling points can be focussed in areas that are close to these receptors. In these cases, where the location of pressures (point sources) is well known, sampling points will often be used to help isolate impacts from different pressure types, assess the areal extent of impacts and determine contaminant fate and transport between the pressure and the receptor. In some cases this may involve the use of multi-level samplers although, as noted in Annex 3, such installations can be very expensive.

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 regional conceptual model of the groundwater bodies (or group of bodies) and a review of existing and candidate monitoring sites, the local conceptual model. Surveillance monitoring is not, on its own, required to isolate the impact of individual pressures and the effectiveness of programmes of measures, but should give an overview of the water quality within the groundwater body or group of groundwater bodies. Large abstractions and springs may therefore provide suitable sampling sites, as they draw water from a large area and volume of aquifer particularly in homogeneous systems. Springs are particularly recommended in karstic or shallow fracture flow dominated aquifers. However, a representative monitoring network should ideally be based on a balanced mixture of different sampling site types as well as sampling site uses (e.g. abstraction, monitoring etc.). In some hydrogeological systems where the groundwater contributes significantly to the (base)flow of the surface water course, then sampling of the surface water may provide a representative groundwater sample.
- *Representativity:* In some aquifer systems, stratification may occur. In this case the location of monitoring points must be focussed on those parts of the groundwater body that are most susceptible to pollution. This will often be the upper parts. However to provide a representative assessment of the distribution of contaminants for the groundwater as a whole additional monitoring in other parts of the groundwater body is also required.
- *'At risk' bodies*: Surveillance monitoring sites will provide the basis for the operational monitoring i.e. based on the results the network can be adapted accordingly. Sites could be used for both programmes.
- *'Not at risk' bodies where confidence in the risk assessment is low:* The number of monitoring points should be sufficient to be representative of the range of pressure and pathway conditions in the groundwater body (or group of bodies) with the aim of providing the data necessary to supplement the risk assessment, i.e. increase confidence. The location of sampling points may therefore be focussed on the most susceptible areas of the groundwater body(ies) for each pressure/pathway combination. The final distribution per grouping will depend on availability of suitable surveillance sites and the distribution of pressures. As a general guide, a minimum of 3 points in a groundwater body or group of bodies is recommended. However where groundwater bodies are large and heterogeneous, it is likely that significantly more monitoring points will be needed to meet the monitoring objectives.
- *Groups of groundwater bodies where pressures are limited (low or absent):* In groups of groundwater 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.

4.1.3 Monitoring frequency

The selection of appropriate monitoring frequency will generally be based on the conceptual model and existing groundwater monitoring data. Where there is adequate knowledge of the groundwater system and a long-term monitoring programme is already established this should be used to determine an appropriate frequency for surveillance monitoring. Where knowledge is inadequate and data are not available, Table 2 suggests frequencies for surveillance monitoring that can be adopted for different aquifer types. Of major importance is the change of concentration patterns with time which influences the selected monitoring frequency as does the increased knowledge of the conceptual understanding. In general, shallow groundwater bodies are rather dynamic with respect to water quantity and quality variation. If such variability occurs, monitoring frequency has to be selected accordingly in order to characterise this variability adequately.

In less dynamic groundwater systems two samples per year may be sufficient initially for surveillance monitoring. If this monitoring shows no significant variation over a river basin cycle (six years) a further reduction of sampling frequency may be appropriate.

Due to possibly time-related changes of concentration patterns, especially in rather dynamic groundwater flow systems, sampling per monitoring location must be executed at the same distance of time (frequency-related). This guarantees comparable monitoring results and a proper trend assessment.

The results of surveillance monitoring should be reviewed on a regular basis and frequencies adjusted accordingly to ensure that the information requirements are fully met and a cost-effective programme maintained.

Table 2: Proposed monitoring frequencies for surveillance monitoring (where understanding of aquifer systems is inadequate).

Note: This table proposes monitoring frequencies that can be used as a guide where the conceptual understanding is limited and existing data are not available. Where there is a good understanding of groundwater quality and the behaviour of the hydrogeological system, alternative monitoring frequencies can be adopted as necessary.

		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	-

4.2 DESIGN OF THE OPERATIONAL MONITORING PROGRAMME

Operational monitoring is focusing on the groundwater body as a whole. An ‘operational monitoring’ programme is required to establish:

- the chemical status of all groundwater bodies, or groups of bodies, determined as being ‘at risk’;
- the presence of any long term anthropogenically induced upward trends in the concentration of any pollutant; and
- it can also be used to assess the effectiveness of programmes of measures implemented to restore a body to good status or reverse upwards trends in pollutant concentrations.

Operational monitoring is required only in bodies 'at risk’ of failing to meet WFD objectives. It should be carried out during the periods between surveillance monitoring. In contrast to surveillance monitoring, operational monitoring is highly focussed on assessing the specific, identified risks to the achievement of the Directive’s objectives.

In designing an operational monitoring programme, the required confidence in the monitoring results must be defined. The required confidence in operational monitoring depends upon the variability of the impact source and the groundwater or aquifer properties in question, as well as the risk in case of error. In principle, the uncertainty from the monitoring process should not add significantly to the uncertainty of controlling the risk.

The acceptability of not identifying a new risk or controlling a known risk should be established, used for setting objectives for the variability of the properties in question and used for control of the monitoring quality with respect to data variability.

4.2.1 Selection of operational monitoring determinands

In most cases, both core and selected determinands will be required at each sampling station (see footnote 6 concerning the requirement to establish groundwater threshold values under the daughter

Groundwater Directive). Guidance on selection of core and selective determinands is provided in Annex 3.

The selection process will be based on:

- Characterisation and conceptual model(s) including an assessment of groundwater pathway susceptibility, receptor sensitivity, the time taken for any programme of measures to be effective and the ability to differentiate between the effects of different measures .
- 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 as at poor status.
- Practical considerations relating to the suitability of individual sampling points.

4.2.2 Selection of representative operational monitoring sites

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

- Availability of suitable existing sites (e.g. from the surveillance monitoring programme) that provide representative samples.
- Potential for supporting different WFD monitoring programmes (e.g. suitable springs can act as quality, quantity and surface water sampling stations).
- Potential for integrated multi-purpose monitoring, e.g. combining requirements for Nitrates Directive monitoring, Drinking Water Protected Area monitoring, monitoring linked to registration of plant protection or biocidal products[7], IPPC Directive monitoring and Groundwater Directive compliance.
- Potential linkages with existing/planned surface water monitoring sites.

Where risk issues relate to specific receptors such as ecosystems, additional sampling points can be focussed in areas that are close to these receptors. This monitoring, as well as contributing to status and trend assessment can also help to distinguish the impacts from different pressure types, assess the spatial extent of impacts and determine contaminant fate and transport between the source and the receptor. This information will be important to the risk assessment and characterisation process. It may include monitoring of the upper parts of the aquifer and possibly water draining from soils, e.g. multi-level samplers, lysimeters and field drain sampling.

Where pressures and risk issues relate to the groundwater itself, e.g. diffuse pressures, sampling points will be more distributed across the body, and will be focussed on the different pressures and their distribution within the groundwater body. Where necessary it may be appropriate to focus resources on the most representative or sensitive combinations of pressures and groundwater susceptibility.

4.2.3 Monitoring frequency

Monitoring frequency selection will generally be based on the conceptual model and in particular, the characteristics of the aquifer and its susceptibility to pollution pressures. Table 3 proposes monitoring frequencies for operational monitoring for different aquifer types where the conceptual understanding is limited and existing data are not available. Where there is a good understanding of groundwater quality and the behaviour of the hydrogeological system, alternative monitoring frequencies can be adopted as necessary.

Sampling frequency and sample timing at each monitoring location should furthermore consider:

- requirements for trend assessment;
- 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 Article 5 risk assessments, and changes in the assessments over time;

[7] See recommendations formulated by the Forum for the Co-ordination of pesticide fate models and their use (FOCUS). Final report of the Ground Water Group of Focus, European Commission, DG SANCO, 2006

- short term fluctuations in pollutant concentrations, e.g. seasonal effects. Where seasonal and other short-term effects are likely to be encountered, it is essential that sampling frequencies and timings are adjusted (increased) accordingly and that sampling takes place at the same time(s) each year, or under the same conditions, to enable comparable data for trend assessment, accurate characterisation and status assessment; and
- land use management patterns, e.g. the period of pesticides or nitrate application. This is especially important for rapid flow system like karstic aquifers and/or shallow groundwater bodies.

Sampling for operational monitoring must be continued until the groundwater body is determined, with adequate confidence, to be no longer at poor status or at risk of being at poor status and there is adequate data to demonstrate a reversal of trends.

Table 3: Proposed 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 QUANTITY MONITORING

A quantitative monitoring network is required to assist in characterisation, to determine the quantitative status of groundwater bodies, to support the chemical status assessment and trend analysis and to support the design and evaluation of the programme of measures.

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
- anthropogenic alterations to flow direction resulting from level change does not cause saline or other intrusion.

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 water balance; and/or
- existing groundwater level or discharge assessments and relevant information on the risks for groundwater dependent surface waters and groundwater dependent terrestrial ecosystems.
- the degree of interaction between groundwater and related surface and terrestrial ecosystems where this interaction is important and could potentially cause the surface water body status to be affected.

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 in the groundwater body as a whole and the operation of the quantitative monitoring programme.

Implementation of a numerical groundwater model or a hydrological model integrating groundwater and surface water are useful tools in compiling and interpreting quantitative monitoring data and identifying resources and ecosystems at risk. Furthermore, the uncertainty estimates that can be obtained with a numerical model can help identify parts of a groundwater body where additional data points will add most to the description of groundwater quantity and flow.

5.1.1 Monitoring parameters

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 during drought periods (i.e. when the flow component directly related to rainfall can be neglected and discharge is sustained substantially by groundwater);
- stage levels in significant groundwater dependent wetlands and lakes.

Selection of the monitoring points and parameters must be based on a sound conceptual model of the water body to be monitored.

Additional monitoring to support groundwater characterisation and classification may include:

- chemical and indicator parameter (e.g. temperature, electrical conductivity) monitoring for saline or other intrusions. For island aquifers it may also be appropriate to monitor the fresh/saline water transition zone. This may include;
- rainfall and the components required to calculate evapo-transpiration (to calculate groundwater recharge);
- ecological monitoring of groundwater dependent terrestrial ecosystems (including ecological indicators); and
- groundwater abstraction (and artificial recharge).

Specific requirements for the supportive 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.

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.

In some hydrogeological settings monitoring groundwater levels in a borehole may be inappropriate for the purposes of the Directive and in some cases highly be misleading. 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. There are cases, when the water level remains more or less stable but water from other aquifers, surface waters or even seawater is intruding. Specific conditions should be considered for groundwater bodies on islands. If there is the risk of waters intruding, then appropriate water quality indicators should be monitored, e.g. electrical conductivity and water temperature.

5.1.2 Selection of monitoring density

Monitoring may be required at two different scales to meet the various requirements of the Article 4 objectives. Firstly, where possible, groundwater levels and flows across a groundwater body should 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 supporting information from ecological monitoring as already performed under other relevant community legislation (as evidence of impact on ecosystems from groundwater abstractions).

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.

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. Monitoring density must be sufficient to ensure proper assessment of impacts due to abstractions and discharges on groundwater level.

Specific provisions concern those bodies of groundwater which cross the boundary between two or more Member States, such as the location of groundwater abstraction points providing more than 10 m^3 a day or serving more than 50 persons, the abstraction rates, direct discharges to groundwater etc. The number of sampling sites should be sufficient to be able to estimate the direction and rate of groundwater flow across the Member State boundary.

5.1.3 Monitoring frequency

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 programme of measures.

Frequency of monitoring predominantly depends of the characteristics of the water body and the monitoring site respectively. Sites with significant annual variability should be monitored more frequently than sites with only minor variability. In general monthly monitoring will be sufficient for quantity monitoring where variability is low but daily monitoring would be preferred (particularly when measuring flows). The frequency should be revised as knowledge of the aquifer response and behaviour improves and in relation to the significance of any changes in pressures on the groundwater body. This will ensure that a cost-effective programme is maintained.

6 PROTECTED AREA MONITORING

Member States are required to meet the standards and objectives of any Protected Areas established under other relevant community legislation and identified in Annex IV of the WFD. Where these specify a requirement for the monitoring of groundwater it is assumed that as part of the implementation process Member States are complying fully with these requirements and following any relevant guidance. The guidance contained here only addresses the requirements for the WFD.

Further details regarding protected areas are described in the guidance document on 'Groundwater Protected Areas'.

To ensure monitoring programmes are as efficient and as effective as possible, it would be appropriate to ensure that the quantitative and the chemical monitoring programmes described above complement, and are integrated with, the programmes established for Protected Areas so that the groundwater monitoring networks are as far as possible multi-purpose.

6.1 DRINKING WATER PROTECTED AREA MONITORING

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 DWPAs. However, the DWPA objectives require that any monitoring 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 groundwater that may potentially lead to an increase in the level of purification/treatment. It will not be necessary to monitor for all the parameters specified by the Drinking Water Directive (80/78/EEC as amended by 98/83/EC). Only those parameters that are directly related to the quality of the groundwater (raw water) need to be considered. The list of the parameters will be based on the results of the risk assessment, existing knowledge of groundwater quality and the purification treatment regimes in place at drinking water sources.

Monitoring in groundwater DWPAs should therefore be carried out in accordance with the programmes set out for surveillance and/or operational monitoring as relevant to that groundwater body 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 II (2.3c) of the WFD.

The Article 7(3) objective of aiming 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.

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 DWPA 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[8]) to confirm the risk assessment. This should be incorporated into and may in practice already be part of the surveillance monitoring programme or another national monitoring programme. The relevant criteria for surveillance monitoring therefore apply. It should be noted that the Drinking Water Directive also includes a requirement to meet standards for microbiological parameters and radioactivity and these may need to be include in any DWPA monitoring programme where these may potentially lead to a failure of DWPA objectives.

In water bodies at risk of not meeting DWPA objectives, it is recommended that significant potable sources 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. Safeguard zones may be used to focus such monitoring (and subsequently to focus any necessary protection measures). If data from drinking water (raw water) monitoring already exist, these can be used as well.

In many cases potable abstraction sources will form part of the surveillance and operational monitoring programmes. In these cases, the specific requirements of the surveillance and operational monitoring programmes will take precedence over the monitoring outlined 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.

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 Article 7 objectives.

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[8] 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;

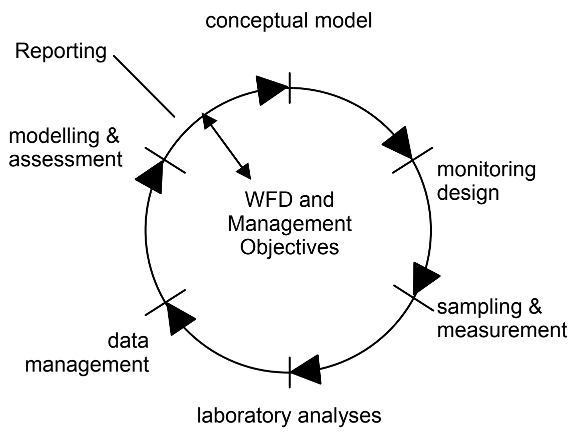
and that is not:

- 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.

7 PREVENT AND LIMIT MONITORING

Groundwater quality monitoring is required to assess the effectiveness of the measures introduced to prevent or limit the inputs of pollutants and/or the deterioration of the status of groundwater (in accordance with Article 11(3) of the WFD and Article 6 of the daughter Groundwater Directive). 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. Therefore, this guidance distinguishes between surveillance and operational monitoring focused on the groundwater body as a whole and **prevent and limit monitoring** focused on point sources.

Prevent and limit 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.



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 or accidental spillages.

Although prevent and limit monitoring is not explicitly requested in the WFD, the information derived from this monitoring should be used for characterisation and the investigation of specific issues, as well as ensuring that 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 should be rejected.

8 ENSURING QUALITY OF MONITORING DATA

The quality required for groundwater monitoring depends upon the purpose but must be defined for each step in the entire process which consists of:

- conceptual modelling,
- monitoring design,
- field sampling and measurements,
- laboratory analysis,
- transfer, storage, modelling,
- interpretation of data,
- result reporting

The required quality should be obtained by defining sets of verifiable quality requirements for each step in the process. The quality requirements should not be defined independently from each other, in order to avoid setting higher quality standards for one step than can be accommodated by the others. The variability of the system to be monitored, the uncertainty associated with sampling and analysis, the risks involved in case of error and the costs should be considered in setting quality requirements that are fit for purpose.

8.1 QUALITY REQUIREMENTS

Quality requirements for a **conceptual model** can be defined in terms of the acceptable deviations of measured from predicted properties (frequency and extent). This can be achieved by formulating questions that must be answered by the monitoring data and other relevant information with defined certainty based upon the conceptual model. The conceptual model and changes therein should be documented and subject to peer review.

Quality requirements for a **monitoring design** can be formulated in terms of required maximum allowable confidence interval for the relevant compliance criteria (e.g. average value) in time or space of a parameter within a groundwater body or a group of groundwater bodies. The design should be documented and subject to peer review.

Quality requirements for **sampling** must be formulated in terms of the maximum acceptable uncertainty of sampling.

Quality requirements for the **analysis** must be formulated in terms of the maximum acceptable uncertainty of analysis and the required analytical detection limit.

Quality requirements for **transfer, storage, modelling and interpretation of data** are clear documentation of data management, interpretation and decision rules based on good modelling practices.

8.2 QUALITY CONTROL

During the monitoring process, the achievement of the quality requirements shall itself be monitored. If the defined quality requirements are not met for one or more of the steps during monitoring, as demonstrated by the quality control measures taken, the monitoring must be re-evaluated and if required, improved and repeated.

Controlling the quality of the **conceptual model** against the requirements is best done as an iterative process during the entire monitoring programme and in relation to the required confidence; see Figure 8.1.

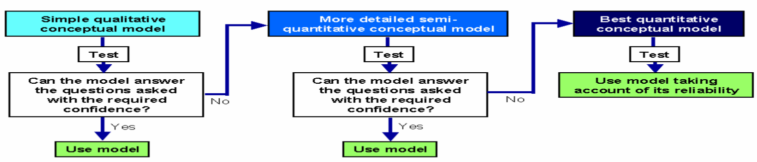


Figure 8.1: Iterative control of the conceptual model against set quality requirements

The control of the quality of the **monitoring design** will ensure that the required confidence intervals are not exceeded.

These confidence intervals may be calculated based upon the established quality requirements or they may be based upon expert judgment that takes into account the expected variability. In either case, the compliance of the monitoring design in relation to the quality requirements should be verifiable. It should be emphasized that the variability of the data will include components from the monitoring design, sampling and analytical methods and the natural variability of the medium. The former components should be considered when improving the quality of the monitoring design, as these can be controlled, whereas the natural variability can not.

For **sampling and analysis**, appropriate quality assurance procedures will enable minimisation of errors in sampling and analysis. Minimum elements to be covered by quality assurance procedures are:

- Identification and records for samples, devices and operators
- Sampling methods, sampling plan and sampling field reports
- Sample transportation, receipt, storage and preservation

- Validation of methods, including uncertainty estimation
- Analytical measurement procedures
- Internal quality control of methods
- Participation in external QC schemes (proficiency testing schemes etc)
- Expression of results
- Traceability of documents
- Traceability of measurements

The user of sampling and analytical data should always request documented information on the quality of the services received and ensure that the necessary quality criteria have been met. The sampling and analysis should be done with third party assessment of the quality procedures applied. For laboratory analysis, accreditation according to the international standard ISO 17025 is recommended, whereas for sampling, laboratories and other sampling service suppliers could choose either accreditation according to ISO 17025 or personnel certification according to ISO 17024. For sampling procedures, see Chapter 9.

For parameters where field measurements are most suitable, field measurements should be subject to method validation and quality control as required for laboratory measurements.

In control of **transfer, storage, modelling and interpretation of data**, spot checks of data consistency (transfer and storage) are mandatory. Model validation with data not included in model development and calibration should be done.

9 METHODS FOR SAMPLING AND ANALYSIS

As the starting point, sampling strategies, sampling techniques, sample treatment, analysis, calculations and reporting should be considered integral parts of the overall monitoring process (monitoring supply chain). A detailed description of the wide-range of tools, techniques and methods for groundwater sampling and analysis is beyond the scope of this guidance. This section therefore only provides a brief overview of the key aspects. For more detailed guidance on methods and instructions, the reader is referred to international and national standards, guidelines and textbooks (reference to ISO 5667 series for sampling and to the Chemical Monitoring Activity). For sampling and analysis, validated methods should be used which also address the issue of fitness-for-purpose (Section 8). Sampling and analysis should be carried out in accordance with published international and national standard methods, unless explicitly justified not to do so due to e.g. the absence of suitable standard methods.

Due to the technical difficulties in accessing groundwater and the rapid changes in chemistry that can take place once the water has been removed from its point of origin, **sampling** for groundwater monitoring requires careful planning and the selection of the most suitable equipment and methods.

Standard methods for sampling are generally less precise than analytical methods, in part because of the varying field conditions at different sites and the varying purposes of sampling, and in part because the process of standardising sampling is presently less advanced than that for chemical analysis. Therefore, even with national and international standards there is a need of harmonisation of approaches and methods to ensure the comparability and representativeness of sampling.

Sampling methods for groundwater monitoring must take into account the regional and the local conceptual model:

- the hydrogeological conditions (layered aquifer, porous/fissure/fracture flow, permeability etc)
- physico-chemical properties (volatility of substances, adsorption properties, reactivity etc) of determinands sampled for;
- the type of parameters being measured (chemical, biological, physical) and;
- the characteristics of the sampling point (e.g. well diameter, screen length, depth of sampling, static/flowing).

Unstable parameters such as pH, temperature, conductivity, dissolved oxygen and where necessary, redox potential and turbidity must be **measured in the field**, as quickly as possible. For this, special calibrated equipment with clear operating instructions and procedures is required.

Similarly, **sample treatment** such as preservation or filtration of water samples must be done in the field without aeration and as rapidly as possible in order to avoid changes in the distribution between dissolved and particulate phases within the sample.

New analytical methods and parameters should be applied to the monitoring programmes to improve the quality of monitoring and to deliver efficiencies. For those emerging analytical methods and new parameters, standard methods may not yet be available. In those cases, 'in-house' validated methods are required (see Section 8 for requirements) and their application must be documented accordingly and the performance of new methods regularly evaluated.

10 REPORTING

Elements of the monitoring programme are subject to reporting under Article 15(2) of the WFD.

Estimates of the confidence in the monitoring results should be determined and reported in accordance with WFD requirements. The reported confidence must as a minimum describe the uncertainty arising from the monitoring processes and the variability (in time or space) of the parameters monitored. If the initially required confidence has not been obtained, the consequences for the monitoring objectives must be evaluated and the need for adjustment of the monitoring programme specified.

Documentation of monitoring programme, operation, and status/trend reporting should be further discussed considering the development of the 'Reporting Sheets' elaborated in WG D. It comprises summary information in 'verbal' form like investigated parameters and monitoring frequency and information in table structure.

GLOSSARY

Groundwater means all water, which is below the surface of the ground in the saturated zone and in direct contact with the ground or subsoil.

Aquifer means a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater.

Body of groundwater means a distinct volume of groundwater within an aquifer or aquifers.

Drinking Water Protected Area (DWPA) means areas designated for the abstraction of water for human consumption under Article 7 of the WFD.

Raw water means groundwater in its natural state prior to any treatment or purification.

ANNEX 1 - AQUIFER TYPES

The European land mass embraces the whole spectrum of geological rock types, ages and histories. Consequently, a diverse range of hydrogeological settings and aquifer types is found across Europe covering e.g.:

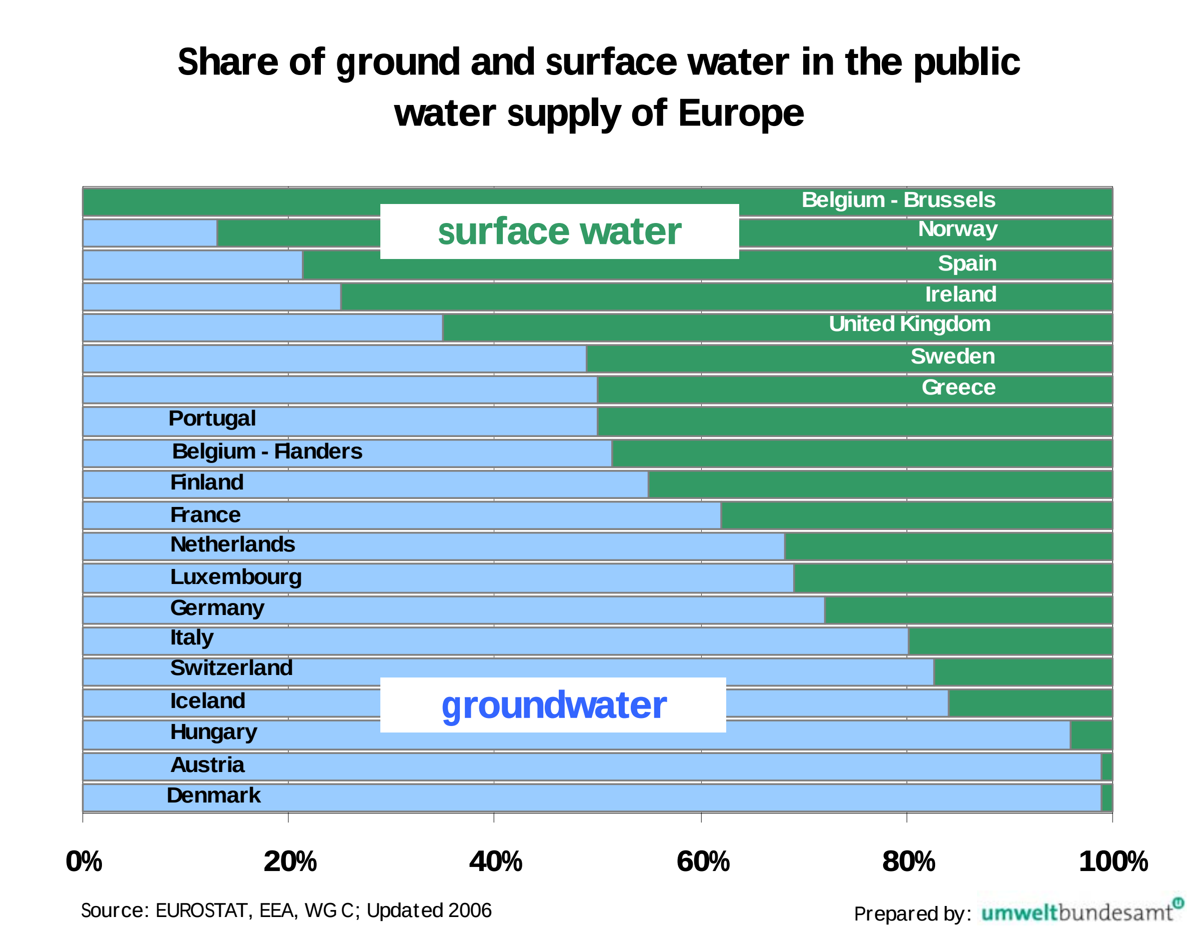
- major alluvial and coastal plain sediments where the relations with surface water systems might be complex;
- intermontane colluvial systems, discharging mainly to springs and/or directly to the base flow of rivers;
- consolidated sedimentary aquifers – limestones, chalk and sandstones;
- karstic (mountain or plain) areas with or without external inflow;
- marls and clays with local aquifers made of limestones or sands;
- recent coastal calcareous formations and islands;
- glacial and associated small alluvial formations;
- extensive volcanic terrains;
- weathered and fresh crystalline basement (including metamorphic rocks such as gneisses and schists).

This broad variation has important implications for the suitability of different types of sampling installation and how effectively they represent changes in groundwater systems, and monitoring design needs to be tailored accordingly. Further, the information obtained, and in particular any changes observed, is required to be reported at national and European levels regularly over several decades. Hence a clear understanding is needed of what each monitoring point represents in terms of the groundwater bodies in which they are located, and the response times of the groundwater both to pressures imposed upon them and to measures to control their impacts. A summary of the range of aquifer settings found across Europe and their response times is shown in the table below.

*Table 4: Summary of groundwater situation in EU Member States (*Proportion of groundwater in public water supply) (based on EEA, 1999, amended by WG C).*

Country (*)	Principal aquifers	Response times
Finland (55%) Norway (13%) Sweden (49%)	Small, thin, shallow aquifers in fractured crystalline bedrock and glacio-fluvial sands and gravels	Fast to moderate
Denmark (99%)	Some Chalk and recent sands and gravels, mostly shallow with thin unsaturated zone	Fast to moderate
Netherlands (68%) Belgium (52%)	Thick alluvial sequences with water table very close to surface – thin unsaturated zone	Fast
United Kingdom (35%)	Important aquifers are consolidated Chalk, sandstone and limestone in the south, centre and east, some alluvium	Ranges from fast to slow
France (62%)	Some Chalk in the north , thick alluvial plains, limestones in the centre and south, crystalline basement rocks in the West, in the Centre and in mountain areas	Ranges from fast to slow
Germany (72%)	Thick alluvial plains in the north, consolidated sediments in the centre and south	Fast to moderate
Ireland (25%)	Main aquifers are limestones (karstified to varying degrees), fissured sandstones, volcanics and small shallow fluvioglacial sand/gravel deposits. Poorly productive aquifers (muddy limestones, granites, metamorphic rocks) underlie 65% of the country.	Fast
Austria (99%)	Karstic limestones and some alluvial basins and river plains, some older fractured rocks in Alpine regions	Mostly fast

Country (*)	Principal aquifers	Response times
Spain (21%) Greece (50%) Portugal (50%) Italy (80%)	Karstic limestones, sandstones, coastal alluvial plains and some large alluvial basins (Po, Guadalquivir, Tagus), volcanic aquifers (Italy, Portugal).	Mostly fast. Moderate in alluvial basins and volcanic aquifers
Luxembourg (69%) Switzerland (83%) Iceland (84%)		
Hungary (96%)	Thick alluvial basin in the east and northwest, karstic aquifers in the centre, north and south, consolidated sediments in the west, some fractured rocks in mountain areas	Fast to slow



ANNEX 2 - INFORMATION REQUIREMENTS FOR MONITORING POINTS

Detailed information on the site should be available and routinely reviewed. This information should be used to assess the suitability of the site to be used for the relevant monitoring programme. Elements for characterising sampling sites are summarised below.

Table 5: Monitoring point information – essential and desirable factors

Factor	Chemical monitoring points	Quantitative monitoring points	Reporting Requirement (to be finalised)
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	D	
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	
Construction details	E	E	
Amount abstracted or total discharge (at springs)	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)	D	D	
Aquifer properties (transmissivity, hydraulic conductivity etc)	D	D	

E…Essential, D … Desirable

For 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.

ANNEX 3 - ADVANTAGES AND DISADVANTAGES USING AVAILABLE WELLS

Many national monitoring programmes, especially those that have developed overt time depend to a large extent on sampling from existing discharge points. Of these, public supply boreholes have the advantage of being operated more or less continuously. Purging is therefore not required, and sampling from the supply pump (often from a side tap) is easy, relatively inexpensive, and determination of field parameters is usually straightforward. Private domestic, industrial and irrigation boreholes are also widely used, and have many of the same advantages, except that they may be used less regularly.

In some aquifers, dug wells may be plentiful and accessible, but may be open to direct infiltration or shallow pollution pathways, difficult to purge satisfactorily and also shallow and only representative of the uppermost parts of the aquifer.

Where there are spring discharges from groundwater, these may be cheap and easy to sample, and should always be considered, especially for those bodies of groundwater defined by Article 7.1 of the WFD. Large springs may be particularly suitable in mountain and karstic areas, where suitable boreholes intersecting the major fissured flow paths are difficult to find or construct. Smaller springs may have shallow flow paths vulnerable to localised pollution, be unrepresentative of the main body of deeper groundwater, and subject to unreliable or intermittent flow during droughts, or even seasonally. Sometimes spring flow paths may be so short and shallow that they draw only from superficial deposits, rather than the underlying and more extensive aquifers. Where aquifers discharge directly into rivers integration with the surface water monitoring network is advised, and surface water quality may provide the best indication of groundwater quality.

If the groundwater is used for drinking water abstraction, the monitoring network design should take account of this. A representative selection of drinking water wells/springs could be included in the network or existing drinking water monitoring results can be used, but only if they are based on raw water samples and preferably from individual wells rather than those taken from within the distribution system.

Sampling from supply boreholes produces a sample drawn from the screened or open section of the borehole, which may be quite large. The sample may integrate water of different ages over the whole vertical interval in uniform, intergranular sedimentary aquifers or, in fractured aquifers, drawn from separate groundwater flow horizons that the borehole has intersected. Except in the most well-studied and documented public supply boreholes, the true depth origin of the sampled groundwater is uncertain, while vertical variations in groundwater quality can be expected. If the operating supply boreholes are deep, but the upper aquifer horizons are known or expected to have poorer quality water, then sampling from the supply boreholes may provide an over-optimistic picture of groundwater quality.

Where the hydrogeological conditions indicate major vertical variations in aquifer types and characteristics, and an analysis of pressures or of existing quality data suggest the presence of stratified groundwater quality, then adequate monitoring may require discrete sampling points. Several approaches can be used for this, but they all require sound knowledge of the groundwater conditions, specialised construction techniques and are increasingly costly, especially in aquifers with thick unsaturated zones and fissured rocks. In these situations the use of observation wells has the drawback of requiring a dedicated sampling pump or a pump to be brought to the site each time and adequate purging to ensure that the sample is not standing water from within the installation. Therefore, sampling visits are longer and need more and better experienced staff. In situations with shallow granular aquifers with shallow water tables, however, monitoring networks solely made up of observations wells can be cost-effective. For example, a monitoring network of a spatially representative mixture of multi-level and single-level observation wells designed using information on specific land use and hydrogeological characteristics can be effective in aquifers with a large spatial variability in groundwater quality. In all cases, selection of springs, pumping wells or observation wells requires evaluation of flow paths and characteristic travel times, and water sampled should be relatively young in order to give an indication of impacts from pressures being considered as part of the WFD characterisation and risk assessment process.

Monitoring networks may include a variety of types of the installations and facilities described above. Their characteristics for sampling groundwater are summarised in the following table. Decisions about types of sampling installations to be used can also have important implications for the cost of monitoring and some information about relative costs is given in the table.

Table 6: Summary of the characteristics of groundwater sampling facilities

Type of sampling point	**Character of discharge**	**Discrete vertical sampling points**	**Quantitative measurements**	**Hydraulic testing**	**Inert materials**	**Costs**			**Notes**
						Drilling	**Materials**	**Sampling**	
Existing groundwater sampling points									
Public supply borehole	Usually high and continuous	Integrates over screen interval	Usually disturbed by pumping	Data may exist	No	None	None	Very low	
Private supply borehole	Often low and intermittent	Integrates over screen interval, but may be shallow	Sometimes disturbed by pumping	Data may exist	No	None	None	Low	Purging may be problematic/time consuming for irregularly used boreholes
Irrigation borehole	High but may be intermittent or seasonal	Integrates over screen interval	Possible in non-pumping seasons	Data may exist	No	None	None	Low	Purging may be time consuming when boreholes not used
Dug well	Usually intermittent	No	Yes, usually	Unlikely	No	None	None	Low	Large storage in well, difficult to purge with sampling pump
Large springs	High and continuous	No	Yes, discharge	No	No materials	None	None	Low	May have large catchments and good in karst areas
Small springs	May be low and seasonal or irregular	No	Yes, discharge	No	No	None	None	None	May have shallow, vulnerable flow paths
Purpose-constructed observation or monitoring boreholes									
Single piezometer	Low and needs portable pump	One, usually a short screen near bottom	Yes	Yes	Yes	Moderate	Low	Moderate, but needs pump	
Cluster of single piezometers	Low and needs portable pump	Several distinct depths	Yes	Yes	Yes	Very high	High	High, needs pump	
Nest of piezometers in single borehole	Very low, needs portable pump	Two to five	Yes	Yes	Yes	High	High	High	
Multi-port sampling systems	Very low, needs specialist pump	Many	Some types	Some types	Yes	Moderate	High	High	Requires specialist techniques and expertise for installation and operations

ANNEX 4 - INITIAL GUIDANCE ON THE SELECTION OF DETERMINAND SUITES

SURVEILLANCE MONITORING

The following core determinands are mandatory:

- oxygen content (DO),
- pH-value,
- electrical conductivity (EC),
- nitrate, and
- 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. It should be noted that chemical substances or indicators related to identified risks should be considered for the establishment of groundwater threshold values (quality standards) under the daughter Groundwater Directive, and surveillance and operational monitoring will represent key steps in this respect. This also means that monitoring should be carried out for all substances which characterise groundwater (groups of) bodies as being at risk.

Although not required 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 background level of groundwater, temperature and water level. It will also provide necessary information to support verification of the conceptual model/understanding of the groundwater body and contribute to improved confidence in the assessment of status.

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. These parameters are however only necessary where a pressure has been identified that may give rise to potential impact at the groundwater body scale.

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 the Annex II characterisation process where relevant taking into account the indicative list of pollutants identified in Annex VIII. At this stage it is very important to use the conceptual model. In order to identify each pressure influencing each sampling site, it is necessary to take into account of information provided by the conceptual model.
- Temperature, DO, EC, pH should be measured in the field (at the sampling point), while the other parameters should be measured/analysed in the laboratory. Additional field parameters may also be included as necessary, e.g. redox potential (Eh) and turbidity.
- It is not necessary to monitor each of the 33 priority substances mentioned in Annex X of the WFD. Among these parameters, those that should be included in the surveillance programme must be chosen on the basis of the characterisation and potential risks to groundwater and other associated receptors, e.g. surface waters.
- Consideration is also given to both emerging substances and those that have been phased out and are no longer used.

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 indicate that they are at risk of failing to achieve relevant objectives.

As mentioned above, these determinands will have to be considered when establishing groundwater threshold value and the monitoring results used in the assessment of status classification.

The selection of parameters will be made 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. A careful analysis of the types of land use/cover and the nature and approximate amounts of chemicals being used should be made in cooperation with competent local bodies and be used for the identification of potential determinands. Further targeting and optimisation of determinand suites should be based on information from the characterisation process.

APPROACHES FOR THE SELECTION OF ADDITIONAL DETERMINANDS

The following approaches may be considered when selecting additional determinands for monitoring. An indicator representative of background industrial anthropogenic pressure may be included in monitoring programmes (e.g. hydrocarbons, organochlorides). For the selection of substances the following criteria can be considered. They will take into account the hydro-geological characteristics of the groundwater body and its interaction with surface water bodies and with connected terrestrial ecosystems. The criteria are:

- Ecotoxicological and toxicological properties of pollutants
- Intrinsic characteristics of pollutants
- Anthropogenic pressures
- Contamination pathways
- Quantitative aspects

Ecotoxicological and toxicological criteria: the prioritising of the substances should be based on the evaluation of the direct risk for aquatic organisms and the indirect risk for human health due to the consumption of drinking water, fresh water organisms and vegetables. The risk for the aquatic organisms due to the interaction with surface water bodies should be evaluated through the use of ecotoxicological data, when available, in particular, using acute and chronic bioassays for local aquatic organisms of different trophic levels.

Intrinsic characteristics of pollutants: The chemical-physical properties of chemicals, in particular organic chemicals, among which water solubility, relative density, persistence, as measured by soil and water degradation parameters, and the whole set of partition parameters, included soil adsorption coefficient and BCF, improve the knowledge of their environmental fate in surface and subsurface soil layers and water bodies. On this basis, a rough screening of mobile or potentially mobile and persistent molecules can be made, also by the application of screening indexed or more complex models which allow for estimating the groundwater pollution potential of chemicals and their tendency to distribute in environmental compartments. Chemical-physical and chemical-dynamic properties can be found in the scientific literature. For plant protection products and biocides, which have undergone a registration procedure, comprehensive sets of data including risk assessments for the active ingredients, as well as for relevant metabolites and degradation products, are contained in the respective registration dossier and are available to the competent authorities.

Anthropogenic pressures: The following non-exhaustive list of anthropogenic pressures could be taken into consideration when identifying determinands. The presence and significance of a pressure will be determined through the WFD risk assessment process. Some of the activities may also refer to old, disused infrastructure (industrial-municipal-agriculture).

- Agriculture, livestock breeding (fertilizer constituents, plant protection products and biocides and related breakdown products and metabolites, pollutants from sludge and manure spreading and pharmaceuticals (antibiotics, hormones, etc.).
- Industrial activities (polishing and degreasing of metal manufacturing, tissues, paints, dyes, detergents, galvanization, tannery, mining, hydrocarbon fuel extraction and fuel additives including production and use and sludge spreading)
- Municipal activities (management of sewage pipelines, management of recreational areas: fertilizers, plant protection products, biocides and related breakdown products and metabolites, management of urban sludge and waste.
- Waste disposal sites, dumps, landfills: leakage of the above mentioned categories
- Transport
- Groundwater overexploitation: salt content enrichment, concentration and abstraction of pollutants from neighbouring polluted waters

Contamination pathways:

- Leaching processes from diffuse sources
- Accidental spills, leakages due to point sources
- Polluted surface waters which feed aquifers
- Saltwater intrusion

- Atmospheric deposition

Quantitative aspects: When selecting additional determinands, high priority should be given to those substances with large total amounts used in the recharge zone of a groundwater body. Quantification of loads of pollutants, information on chemical production volumes, indirect evaluation through sales data etc.; collection of historical monitoring data which may confirm the environmental relevance of selected pollutants; availability and practicability of analytical methods.

CASE STUDY - NETHERLANDS

Background information

Title/Name of case study: Frequency of groundwater quality monitoring.

Type of case study: the Netherlands National Groundwater Quality Monitoring Network

Web-Link: http://www.rivm.nl/milieuStoffen/milieumeting/Meetnetten/lmg/index.jsp#tcm:4-587

Objective of case study

The objective of this case study is to show that frequency of sampling of monitoring sites for groundwater quality is dependent on the overall monitoring strategy, the site characteristics and acquired experience in the course of monitoring.

Contribution to…

WFD focus: monitoring, groundwater quality

Specific contributions: sampling frequency, monitoring strategy, conceptual model

Characterisation

In principle, the Netherlands consist of one single sandy aquifer. This aquifer was divided into 20 GW-bodies based on the consideration of the hydrogeological situation, the status, protection and finally water management aspects. In the clay and peat areas the upper layers (about 3 m) are treated as separate groundwater bodies which are closely associated with surface water bodies.

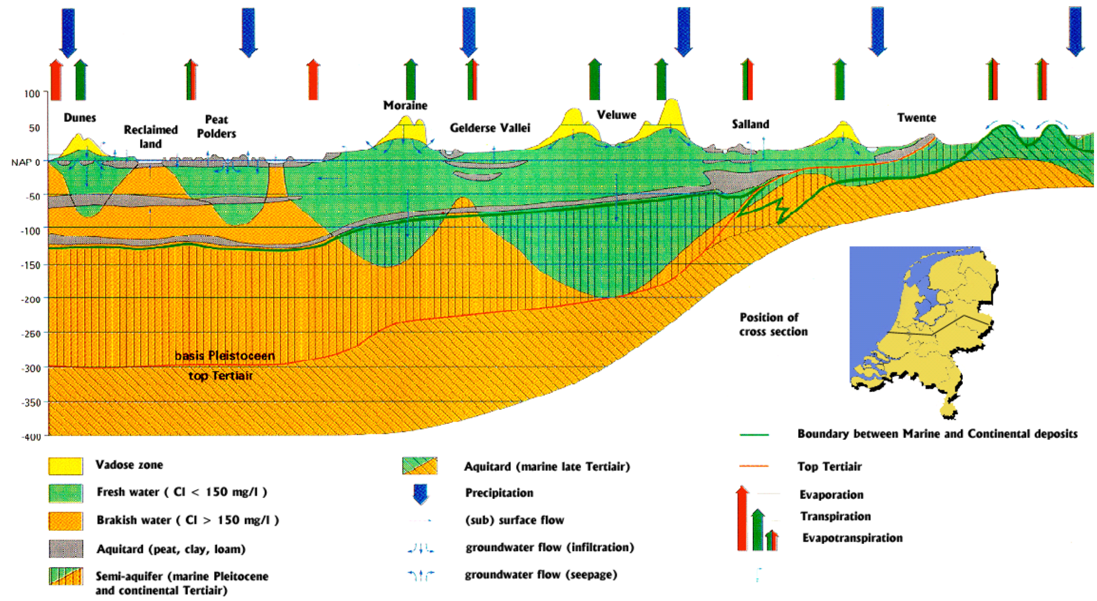


Figure 1: Schematic East-West cross section of the subsoil of the Netherlands. The subsoil is characterised by marine and continental deposits of mainly Pleistocene and late Tertiary origin (Source: Dufour, 1998).

The Netherlands National Groundwater Quality Monitoring Network (LMG), established between 1979 and 1984, comprises about 360 locations divided over the whole country (Van Duijvenbooden, 1987). The main criteria for site selection were type of soil, land use and hydrogeological state. At each location groundwater is sampled at depths of approximately 10 and 25 m below the surface level using special designed observation wells with screens of 2 m length. From 1984 to 1998 locations were sampled annually, results have been published by Reijnders et al., (1998), Fraters et al. (2004) and by Pebesma & De Kwaadsteniet (1997). After an evaluation of the network design in 1998 (Wever & Bronswijk, 1998), the frequency of sampling was decreased for certain combinations of soil type and depth. Shallow screens in sand regions are still sampled every year; shallow screens in other regions (clay and peat) are sampled every two years; deep screens are sampled every four years; shallow screens with high chloride concentrations (more than 1000 mg l^{-1} due to marine influence) are also measured every four years. Finally, well-screen combinations dominated by local conditions (e.g. nearby rivers and local sources of pollution) have been eliminated. In this way, the number of screens to be sampled every year has been reduced from 756 to about 350.

Experiences gained - Conclusions - Recommendations

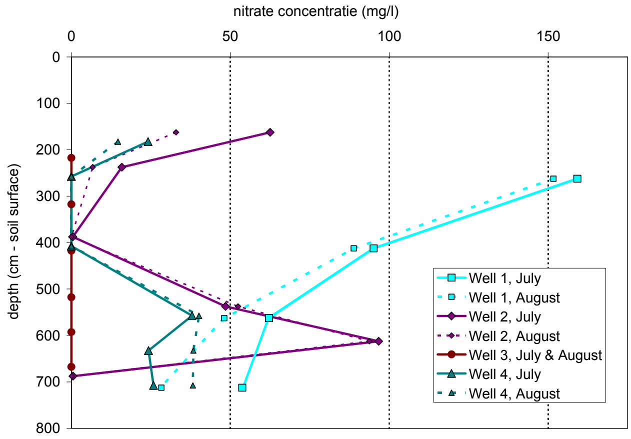


Figure 2: Nitrate concentration in upper five meter of groundwater in four multi-screen wells at one 40 ha dairy farm in the Netherlands. Wells with screens of 0.25 m length are sampled in July and August 2005 (RIVM, unpublished data).

The quality of groundwater in Dutch groundwater bodies shows a large variability in space (both in the horizontal and in depth) relative to the variability in time, even in the upper five meter of the groundwater, see Figure 1. A sampling frequency of once per year was established in the design phase of the network, based on a conceptual model of groundwater flow. Given the Dutch net yearly precipitation a net vertical infiltration rate of 1 $m \cdot a^{-1}$ was assumed, which yields minimum groundwater ages of about 10 and 25 years at the two monitoring depths. These ages were later confirmed by tritium measurements. A vertical transport velocity of 1 m a^{-1} and 2 m long screens yields a replacement rate of water around the screen every two years. Given this replacement rate, an annual monitoring frequency is sufficient for trend detection purposes. Over ten years of data showed that under certain hydrological and soil conditions the sampling frequency could be lowered from once a year to once every two or every four years without loss of information. After optimisation of the networks, a specific set of locations is used for *trend assessment* using a high sampling frequency, i.e. assessment of effects of measures. The complete sets of locations are used for *status assessment* using a measurement frequency of once every 4 years (Broers, 2002). In addition, frequencies might differ for different chemical parameters, for example, a lower frequency for metals that show a slower displacement in the soil environment.

The design and operation of a monitoring network is an iterative process. A conceptual model of transport velocities and an analysis of the sources of variances for the parameters of interest are a prerequisite for effective and efficient monitoring. It forms the basis for the determination of the number of sites, type of wells, number, type and depths of screens, and the frequency of sampling. All these aspects of the design have to be considered coherently.

Outlook - Next steps – Accessibility of results

Data are available at http://milntj34.rivm.nl/website/lmg_eng/viewer.htm;

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Wever D., Bronswijk J.J.B. (1998) Optimalisatie van het Landelijk Meetnet Grondwaterkwaliteit [Optimisation of the Dutch National Groundwater Quality Monitoring Network]. Bilthoven, the Netherlands, RIVM report nr.714851002, 27 p.

CASE STUDY - AUSTRIA

Background information
Title/Name of case study: National Water Quality Monitoring in Austria
Type of case study: National Water Quality Monitoring Network
Web-Link: http://gis.umweltbundesamt.at/austria/wasser/Default.faces
Objective of case study: Demonstrate the business rules of monitoring and the QA aspects
Contribution to…
WFD focus: Groundwater Quality Monitoring
Specific contributions Organisation, Procedure, Costs, Quality Assurance

Characterisation

In Austria standardised water quality monitoring based on legal provisions started in 1991. The monitoring programme covers groundwater in porous media, groundwater in karst and fractured (fissured) rock and running waters.

Water quality monitoring is carried out in periodical cycles for the whole of Austria. The main goals are to assess the current status of the Austrian waters on the basis of a sound and reliable database and to detect negative developments at an early stage. Based on this programme, measures can be introduced to reverse a negative development.

Groundwater sampling sites are distributed all over the groundwater areas. A distinction is made between groundwater in porous media and groundwater in karst and fractured rock. Regarding groundwater in porous media continuous groundwater bodies and discontinuous groundwater-bodies are distinguished. Continuous groundwater bodies can mainly be found in flat regions and valleys along rivers. Small, discontinuous groundwater bodies were grouped in so-called “groundwater regions“. Groundwater in karst (carbonate rock) and in fractured rock (crystalline rock) is distinguished due to hydrochemical criteria.

Experiences gained - Conclusions - Recommendations

Procedure / Business rules

The implementation of the Austrian Water Quality Monitoring Network is the shared responsibility of Federal and Provincial Authorities:

At the Federal level the Federal Ministry for Agriculture, Forestry, Environment and Water Management, Department Water Management Register, is responsible for:

- the integrative assessment of data,
- the yearly publications of results,
- ensuring uniform procedures all over Austria, and
- covering the main part of costs.

The provincial governor is responsible for

- operational management (call for tender, tendering, inspection of contractors during sampling and analyses, quality check of received data, data delivery to the federal level),
- covering parts of the costs, and
- co-operation regarding elaboration and amendment of guidance papers.

Based on an agreement the Federal Environmental Agency is responsible for

- IT-development and data management,
- technical co-operations regarding analytics and data assessment,
- Reporting/writing the biannual reports in co-operation with the Federal Ministry for Agriculture, Forestry, Environment and Water Management.

Monitoring Cycle / Frequency / Parameter sets

The monitoring is a cyclic procedure of 6 years:

- One year initial investigation period (extended parameters) and
- five years period of repeated investigation (minimum requirement based on the results from the initial investigation period).

Groundwater is monitored four times a year and sometimes only twice a year in groundwater bodies without pollution.

The parameters monitored in groundwater and running waters are split into three sets comprising about 100 different parameters.

Call for tender

Usually the parameter sampling and analysis are executed by private accredited laboratories (EN 45000). The contract is awarded according to price and quality criteria ('principle of best cost/benefit offer') in order to get best quality at reasonable costs.

Tendering is done by Provincial Authorities based on groundwater bodies und parameter sets.

Budget / Financial distribution of monitoring costs

All costs for Water Quality Monitoring in Austria are covered by the public authorities. According to the Hydrography Act the Federal Authorities bear all costs concerning the monitoring network. The costs for sampling and analytics are met two-thirds by Federal and one-third by Provincial Authorities.

From 1990 up to 2005 in total 43 Million Euro were spent for the Water Quality Monitoring in Austria:

- 2.7 Million Euro for selection and establishing sampling sites and
- 2.2 to 3 Million Euro per year for sampling and analytics.

The mean costs for a groundwater sample (70 up to 100 parameters) are about 300 Euro.

Quality assurance

For best quality assurance of analytical results, various elements of quality assurance were introduced in the monitoring programme as there are:

- nationwide standardised tendering documents (declaration of analytical figures of merit in the offers);
- accredited laboratories;
- provision of key figures of the analytical procedures within the bidding files;
- standardised procedure (guidelines) including sampling methods
- laboratory control visits (inspection before awarding of contracts and during the monitoring periods);
- compulsory participation in sampling courses;
- compulsory participation in (international) round robin tests;
- control system (proficiency testing scheme for water analyses) in routine work with spiked samples – performed by the Institute for Agrobiotechnology (IFA-Tulln); and
- minimum requirements for limit of quantification and limit of detection.

Outlook - Next steps – Accessibility of results

The monitoring network is currently been adapted by end of 2005. The new monitoring network has to be operative by Dec 2006.

CASE STUDY - FINLAND, SWEDEN, NORWAY

Background information

Title/Name of case study: INFORM – **In**tercalibration of **F**enn**o**scandian **r**eference **m**onitoring of groundwater in Finland, Sweden and Norway

Type of case study: Regional study, organizations involved

Finland –	Finish Environment Institute, SYKE
	Geological Survey of Finland, GTK
Sweden –	Geological Survey of Sweden, SGU
Norway –	Geological Survey of Norway, NGU
	Norwegian Water Resources and Energy Directorate, NVE

Web-Link:

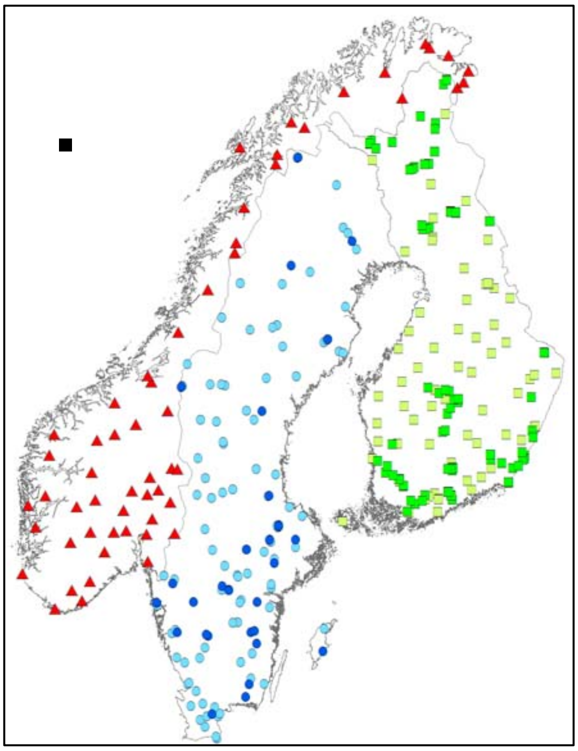
Objective of case study: The study will include an evaluation of monitoring system design and operation, of representativeness with regard to groundwater typology and other natural parameters, and of effectiveness and cost efficiency with the objective to recommend a common Fennoscandian reference network for groundwater monitoring

Contribution to…

WFD focus: reference monitoring, natural background levels, natural trends

Specific contributions: Fennoscandian aquifer typology, intercalibration of strategies, methods and networks, common Fennoscandian reference network

Characterisation:



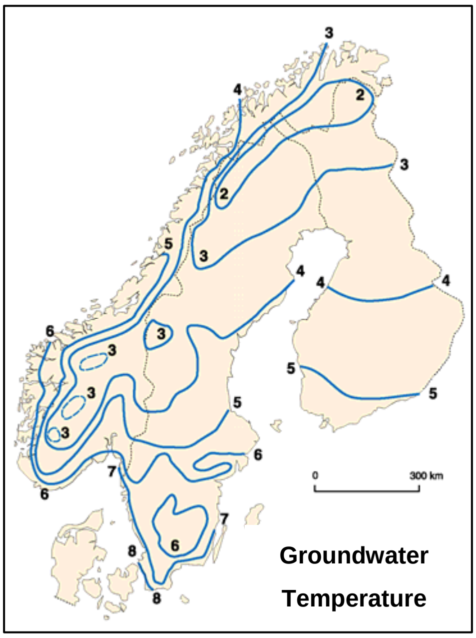
The combined networks for reference monitoring of groundwater in Finland, Sweden and Norway total about 230 stations, or 1 station per 4665 km^2. The responsible government agencies in these countries will carry out this joint project in 2006-7 with the following objectives:

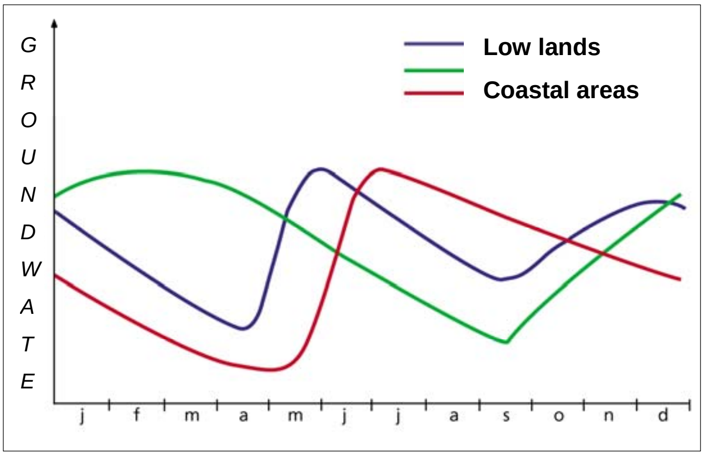
- Intercalibration of *system* design and operation for reference monitoring of groundwater in Finland, Sweden and Norway, incl. groundwater typology and representativeness of monitoring stations.
- Intercalibration of groundwater *quality* for reference monitoring in each of the three countries (e.g. comparability of water quality for groundwaters with comparable hydrogeological origin, interlaboratory comparison etc.).
- Producing a common dataset for reference groundwater quality in Finland, Sweden and Norway, for scientific analysis and for use in practical aspects related to the WFD (e.g. baseline values, monitoring transboundary aquifers, determination of threshold values etc.).
- Evaluation of, and recommendation for a common Fennoscandian network for reference ground-water monitoring related to the WFD, with the objective to produce a more effective and cost-efficient common network in comparison with the current three reference networks in Finland, Sweden and Norway.

Experiences gained - Conclusions – Recommendations:

With regard to groundwater, Finland, Sweden and Norway have been collaborating since 2002 on work carried out in each country for the implementation of the WFD, arising from a common basis in natural conditions, such as geology, climate and demography, and the wish to exchange experience both on a national level and with regard to the EU. In addition to WFD-related issues, the collaboration has generated scientific topics that warrant joint activities. The relevant topic of interest here is the variation in groundwater chemical composition across the three countries, both as a function of the bedrock geology and of the younger Quaternary geology.

Earlier collaboration has resulted in, e.g., a regional overview of groundwater temperature and of variations in groundwater level which is controlled by the recharge-discharge mechanism which in turn is highly dependent on climate.





Outlook - Next steps – Accessibility of results:

Project activities fall into two main categories – **A**, a documentation part and **B**, a data-collection part.

A - This work consists of an analysis of existing documentation for the design and operation for the monitoring system in each country, including

- the criteria for locating monitoring stations and for the density of stations, i.e., typology and representativeness,
- the content, methods and frequencies for collecting both quantitative and qualitative data,
- the method and exchangeability of data storage (databases),
- evaluation and selection of a common dataset for reference groundwater quality, following the completion of part B, and
- evaluation and recommendation of a common Fennoscandian network for reference groundwater monitoring related to the WFD.

B - This activity involves the collection and analysis of a timed batch of groundwater samples from all monitoring stations in each country, including one common batch of samples for intercalibration of laboratory analyses.

The project will publish its results in national reports, international publications and as digital maps showing results for groundwater quality data across the Fennoscandian region.

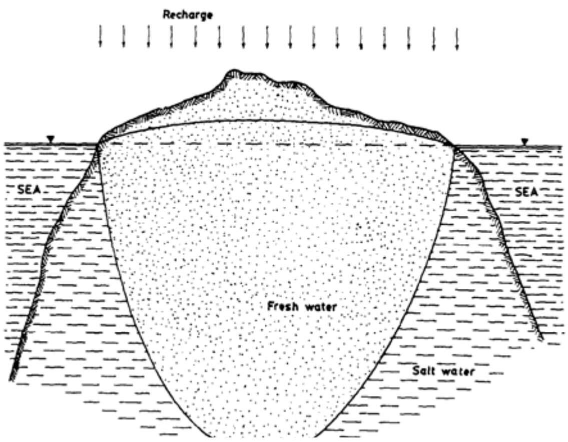
CASE STUDY - MALTA

Background information
Title/Name of case study: Monitoring for Quantitative Status in small islands
Type of case study: Testing the reliability of groundwater level as an indicator of groundwater volume
Web-Link: http://www.mra.org.mt/wfd_introduction.shtml
Objective of the case study: Investigating the utilization of groundwater levels as a metric for status determination
Contribution to…..
WFD focus: Groundwater Quantitative Status Monitoring
Specific Contributions: Best practice in quantitative status monitoring

Characterisation

The Malta Main Mean Sea Level Groundwater Body is sustained in the Lower Coralline Limestone aquifer and is in free contact with sea-water. This groundwater body extends over the whole southern and central parts of the island and is by far the major groundwater body in the Maltese islands, yielding an estimated 66 % of the total groundwater abstracted in the country.

The groundwater body can be compared to a lens shaped body of fresh-water floating on more saline water, having a convex piezometric surface and conversely a concave interface sloping towards the land. The thickness of the lens below sea level is roughly thirty-six times its piezometric height above sea level following closely the Ghyben-Herzberg model.



Scheme showing a Ghyben-Herzberg (floating) groundwater body in an island. It should be noted that the vertical dimensions are highly exaggerated relative to the horizontal dimensions. In fact if the situation in Malta is considered, for an island width of app. 13km, the lens reaches a maximum thickness of around 100m (Source: UNESCO)

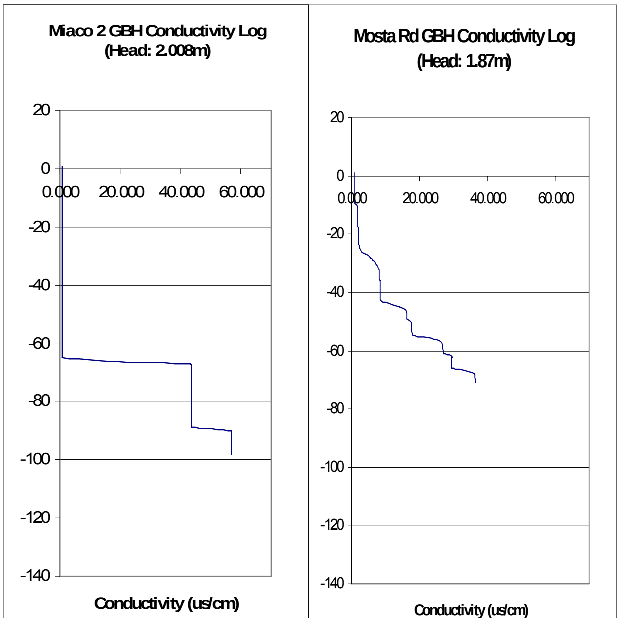
However, in reality, the underground interface that separates the freshwater from the saltwater is not a sharp boundary line. This interface is in fact a mixing zone, whose limits are generally defined by the 1 and 95 % sea water content, called the Transition Zone. The thickness of this zone depends both on the hydro-dynamic characteristics of the aquifer and the fresh and sea water fluctuations.

Experiences gained – Conclusions – Recommendations

The quantitative status of such a mean sea level–island–groundwater body is dependent not only on the hydraulic head but also on the vertical distribution of the chloride content throughout the body. The sole measurement of the piezometric head might therefore not be enough to effectively monitor status. This is particularly so in cases where the hydro-dynamic characteristics of the aquifer supporting the groundwater body favour the occurrence of a wide transition zone.

A pilot project was initiated in Malta involving five deep gauging boreholes in which conductivity logs were taken twice every year. The depth of these boreholes was such that it exceeded the theoretical position of the interface. The process involved taking conductivity readings with a probe at 1 m successive intervals down the borehole.

Reference is made to the results obtained from two of these boreholes, the Miaco 2 and Mosta Road Gauging Boreholes which are located in the southern and north/central regions of the island respecitvely. Both gauging boreholes register almost the same hydraulic head above mean sea level, which is 2.0 m for the Miaco 2 GBH and 1.9 m for the Mosta Road GBH. This data alone would imply that these two monitoring stations are representing regions of the groundwater body having the same quantitative status. However, the results from the conductivity logs indicate that the quantitative status is significantly different.



Conductivity Logs from Miaco 2 and Mosta Rd GBH

In the case of the Miaco 2 GBH; a sharp interface between fresh and salt water was encountered, and the depth of freshwater exceeded 60 m below mean sea level. On the otherhand, results from the Mosta Road GBH indicated that disturbance of the groundwater body has led to the formation of a transition zone, the thickness of which was estimated to exceed 40 m. The depth of freshwater in this case was in the region of 10 to 20 m below mean sea level.

These results indicate that the metric identified by the WFD for the determination of quantitative status may in such cases, where groundwater quantitative and qaulitative status are interlinked, be not sufficient for an effective assessment of status.

Outlook – Next steps – Accessibility of Results

Proposals are currently being formulated for the adaptation of groundwater monitoring in Malta in line with WFD requirements. In the case of sea level groundwater bodies, it is being proposed that, initially, a basic geometrically based water level monitoring network is established, in which groundwater level will be continually monitored. These monitoring stations will subsequently be deepened to enable the collection of quarterly groundwater conductivity profiles in all monitoring stations. It is planned that the basic network will be operational by December 2006; whilst the time-table for the subsequent upgrading of the network is still being formulated.

The monitoring proposals formulated by the MRA will be open to public consultation on the Authority's web-site. The final monitoring plan and an evaluation of its effectiveness following the first monitoring results will also be subsequently available on the same website.

CASE STUDY - NORTHWEST AND CENTRAL EUROPE

Background information

Title/Name of case study: Monitoring effectiveness of Nitrates Directives Action Programmes

Type of case study: regional study; organisations involved: environmental and agricultural institutes from Austria, Belgium, Denmark, Germany, Ireland, Sweden, the Netherlands, the United Kingdom

Web-Link: http://www.rivm.nl/bibliotheek/rapporten/500003007.html

Objective of case study

To show that monitoring of effectiveness of programmes of measures, as required by the WFD (Annex VII, B.2), needs special attention; for example by designing “early warning” monitoring programmes.

Contribution to…

WFD focus monitoring, programme of measures, environmental objectives

Specific contributions. effect monitoring, conceptual model, selection of sampling sites

Characterisation

The Water Framework Directive requires all Member States to make a plan of measures for each river basin, taking account of the characterisation and review of the environmental impact of activities, in order to achieve the WFD objectives. The first update of the river basin management plan (2015) shall also include an assessment of the progress made towards the achievement of the environmental objectives.

Operational monitoring, required to establish the chemical status and presence of long term anthropogenically induced trends in pollutants concentrations, can also be used to assess the effectiveness of programmes of measures. For the design of an operational programme for WFD monitoring experiences can be gained from existing Nitrate Directive monitoring programmes designed for effect monitoring.

The Nitrates Directive (91/767/EEC) requires all Members States to make Action Programmes for Nitrate Vulnerable zones and to monitor not only groundwater and surface water quality, but also the effectiveness of these Action Programmes. In several EU Member States special designed monitoring programmes are operational to monitor the effectiveness of the Nitrate Directive Action Programmes. In 2003 a workshop has been organised to exchange experiences and identify common goals, problems and solutions for improving monitoring programmes and, possibly, for improving comparability.

Experiences gained - Conclusions – Recommendations

When focusing on monitoring effects of measures on water quality we can evaluate the pros and cons of each of these possibilities. Three main factors have to be considered, these are:

1. the time between the implementation of the measure and the moment that a change in water quality will occur as a consequence of this measure, this we call the lag time;
2. the ability to distinguish between the effects of different measures, actions and/or sources of pollution, this we term resolution power;
3. the occurrence of interfering processes in soil or water system, for example, denitrification lowers the nitrate concentration during transport of water through the soil and/or the surface water system.

The table below gives an overview of the importance of these factors for each of the main monitoring possibilities (see Figure). It is evident that the closer to the source of pollution the shorter the time between measure and effect and the smaller the chances that other sources of system processes may influence water quality.

In studying the relationship between the effects of agriculture and water quality, collection of data should preferably be on the same scale for both agriculture and water quality.

The choice for a certain level of scale for effect monitoring depends, amongst others, on the scale used in existing monitoring networks and level of scale of data collection by regional and/or national authorities for other purposes.

The study made clear that water quality is not only influenced by agricultural practice but by other factors as well. Soil type, hydro(geo)logical characteristics of sediments or rocks, or of the surface differences in water quality between locations or in time. The type and structure of the farm, the educational level of the farmer, and whether the farmer has a successor or not are examples of "farm factors". These farm factors influence the way policy measures are implemented in farm practice.

Table: *Overview of the merits and demerits of different types of water quality monitoring for monitoring the effects of changes in agricultural practice.*

Type of monitor	Lag time	Resolution power	Importance of interfering processes
Soil moisture	Short	high	little
Tile drains	Short	high	little
Shallow groundwater	short – moderate	moderate – high	little – moderate
Deep groundwater	moderate – long	low – moderate	moderate – significant
Ditches & brooks	short – moderate	moderate	moderate
Regional & main waters	Long	low	significant

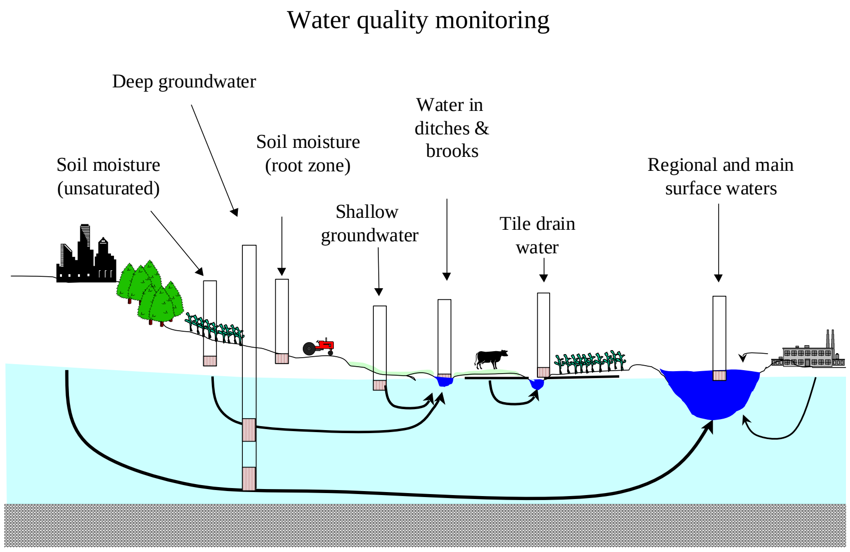


Figure: range of possibilities of water quality monitoring

Two different approaches − upscaling and interpolation − for describing the effect of Action Programmes on a national scale were defined. The upscaling approach uses the results of studies on the effects of change in agricultural practice on nitrate leaching (and water quality) on experimental sites (e.g. homogeneous plots or parcels). Numerical process models and data on agricultural practice covering national-scale change are used to upscale the experimental-site results. This allows Member States to describe the effect of the Action Programme on nitrate leaching and water quality on the national scale. The interpolation approach uses the results on monitoring agricultural practice and nitrate leaching (and water quality) for a random sample of locations, e.g. farms. Statistical models based on knowledge of processes and national-scale monitored changes in agricultural practice are used on the national scale to describe the effect of their Action Programmes on nitrate leaching and water quality.

Outlook - Next steps – Accessibility of results

After the workshop effect monitoring programmes have been adapted and/or efforts have been increased, for example, in England and the Netherlands.

England: http://www.bluesky35.adas.co.uk/record/display_index.html?podlet_id=39&article_id=21

The Netherlands: http://www.rivm.nl/bibliotheek/rapporten/680100001.html (Dutch)

CASE STUDY - ÅRHUS COUNTY (DENMARK)

Background information
Title/Name of case study: Estimation of groundwater monitoring uncertainty
Type of case study: Local monitoring study as part of international guidance cooperation
Web-Link: http://www.samplersguide.com
Objective of case study: Demonstration of the use of simple methods for estimation of monitoring uncertainty and for monitoring quality control
Contribution to…
WFD focus: Groundwater quality monitoring
Specific contributions: Uncertainty from analysis, sampling and aquifer heterogeneity, methods for estimation of uncertainty, use of uncertainty estimates to identify points of improvement as well as fitness for purpose (compliance with set quality objectives)

Characterisation:

A group of groundwater bodies that are an important drinking water resource for the city of Århus, the second largest city of Denmark, has through surveillance monitoring been identified as at risk for deterioration of the quality due to intensive drinking water abstraction. An operational monitoring program was established in order to control the trend in water quality development. The groundwater body is in glacial outwash sands with Miocene sands and clays below and glacial till above. The natural quality of the groundwater is anaerobic without nitrate, with sulphate and reduced iron, but without hydrogen sulphide and methane. One of the threats to the groundwater bodies is oxygen intrusion into the aquifer as the result of the water abstraction and concomitant groundwater table draw down. One groundwater body representing the group, 2 km x 2 km x 10 m, starting 20–30 m below the surface, was selected for the operational monitoring.

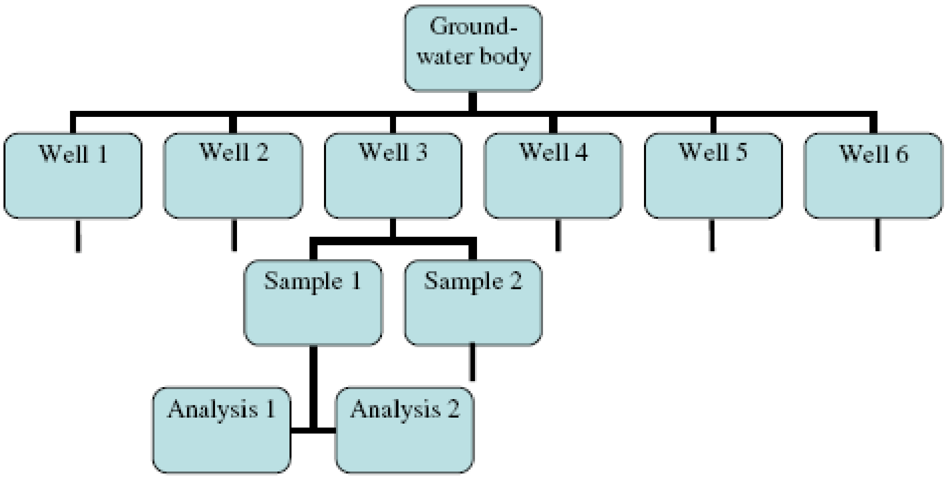
In the operational monitoring planning, it was decided to use dissolved iron as a target parameter that would be a sensitive indicator of aquifer oxidation (decreasing iron concentration with increasing oxidation). It was further decided to aim at monitoring one well twice per year and the objective of the operational monitoring was set to having a 95 % probability of recognising a 20 % quality deterioration. This requires a measurement uncertainty including both sampling and analysis of not more than 10 % (comparison of two means each for two samples, 95 % confidence interval, two sided test) corresponding to an expanded measurement uncertainty of 20 %. To ensure the compliance of the monitoring program with this stated objective, a sampling validation study was initially conducted including all wells available and based upon the results from this, a routine sampling quality control program was set up for implementation with the monitoring program for the selected monitoring well.

Experiences gained - Conclusions – Recommendations:

The empirical approach was selected as study design in order to provide estimates of heterogeneity in the groundwater body (between-target variation well to well or over time) and measurement uncertainty, split into sampling uncertainty and analytical uncertainty. The basic principle of the empirical approach is to apply replicate measurements.

Sampling was done using the groundwater monitoring sampling protocol developed by the county. Analyses were performed at an independent, accredited (ISO 17025) laboratory using accredited methods subject to the required quality assurance and analytical quality control. Estimates of laboratory uncertainty and analytical detection limits were obtained from the laboratory quality control scheme and evaluated with the data from the monitoring validation and quality control.

The objective of the validation study was to ensure that measurement uncertainty meeting the set quality objective could be obtained and to describe the components of uncertainty in order to identity points of improvement, if required. The validation study was set up with sampling of the 6 wells, two independent samplings per well and 2 sub-samples per sample analysed, see overleaf figure. The validation study thus included one sampling round with a total of 12 samples taken and 24 sub-samples sent for analysis.



The objective of the quality control programme for the operational monitoring was to ensure that measurement uncertainty did not increase over time during the monitoring. The quality control programme was set up after careful evaluation of the results from the validation study and was designed including duplicate sampling on one of the two annual sampling occasions of the monitoring programme.

The replicate data were treated using the range method (ISO 3085), see below table for results. The applied calculation methods are demonstrated in the guide on uncertainty from sampling, calculations are easily done using standard spread sheets, and an example can be downloaded from http://www.samplersguide.com. The data treatment provided estimates of analytical, sampling and total measurement uncertainty, in addition to the uncertainty due to heterogeneity (in space or time). Only random errors were included, whereas the occurrence of systematic sampling errors was not assessed quantitatively, but the consistency of the obtained results for different chemical parameters was used as a qualitative control of systematic errors.

Dissolved iron	**Expanded uncertainty, coverage factor 2**			**Between-target**
in groundwater	**Analysis**	**Sampling**	**Measurement**	**heterogeneity**
Validation	2.1 %	10 %	10 %	35 %[1]
Quality control			4.0 %	9.9 %[2]

[1)] In the validation study, between-target variability was between wells
[2)] In the quality control, between-target variability was between sampling occasions, first 6 sampling occasions included

The data show that the requirement for less than 20% expanded measurement uncertainty could be fulfilled for dissolved iron (sampling validation), and that the required measurement uncertainty was in reality achieved during the routine monitoring (sampling quality control). Furthermore, the data show that if an improvement of the certainty of monitoring was required, the obvious point of improvement would be increased monitoring density (between-target heterogeneity dominating).

Outlook - Next steps – Accessibility of results

In planning groundwater monitoring, fitness for purpose (monitoring uncertainty corresponding to set quality objectives) can be ascertained by a simple monitoring validation approach. If required, points of improvement of monitoring can be identified from the contributions to monitoring uncertainty (analysis, sampling, heterogeneity). With a simple and cost efficient quality control, it can be ascertained that the routine monitoring uncertainty remains as required for the purpose.

Considering the total costs of groundwater monitoring and the costs associated with decisions on measures taken from monitoring data, the costs of including an initial monitoring validation during planning and a subsequent monitoring quality control during routine monitoring seem justified.

The principles applied are described in the Eurachem/EUROLAB/CITAC/Nordtest Guide

“Estimation of measurement uncertainty arising from sampling”.

CASE STUDY - TEVERE, COLLI ALBANI (ITALY)

Background information

Title/Name of case study: Studies and management of a volcanic aquifer in an area subject to different pressures. Colli Albani volcanic structure (Lazio-central Italy)

Type of case study:

The case study is being conducted as part of phase II of the PRB testing activity and it is coordinated by the Tevere River Basin Authority with the support of the Italian Ministry of the Environment, the Italian National Institute of Health (ISS), the Italian National Environment Protection Agency and Technical Services (APAT), the Regional River Basin Authority of Lazio, ARPA Lazio (Regional Environment Agency), the National Research Council - Water Research Institute (Cnr Irsa), and the Department of Geological Sciences of "Roma3" University. Testing of the methodologies set up within the FP6 Bridge project will be carried out in the same area.

Web-Link: http://www.abtevere.it/prb_2/

Objective of case study:

The management of aquifers subject to intense overexploitation for household, agricultural and industrial uses requires specific and complex plan measures. The case study of the Colli Albani volcanic structure located in the south of the city of Rome has been given as an example. Other aspects of interest in this area are the presence of protected areas and dependent terrestrial and aquatic ecosystems. The identification of thresholds, especially in relation to quantitative aspects and natural background levels will be taken into account during the phase related to the Bridge project.

The scheme of this case study is as follows:

- description of the water circulation in the Colli Albani
- identification of the natural background levels
- key elements of the pressures and impacts analysis
- identification of areas that require specific protection
- safeguard measures
- analysis of existing monitoring activities
- steps needed for the monitoring network to comply with the WFD objectives

Contribution to…

WFD focus: monitoring, protected areas, risk assessment, programme of measures, volcanic aquifer, saline intrusion

Specific contributions: groundwater-surface water interaction, natural background levels, programme of measures

Characterisation:
The Colli Albani volcanic structure is situated south of the city of Rome. It is constituted by an isolated relief with a characteristic truncated cone shape that surmounts the Roman countryside with an altitude of 970 m asl. During the final phases of the volcanic activity, the top of the structure was subject to violent explosions, which created a vast caldera with a diameter of about 10 km. Today, two secondary craters, formed in a subsequent phase within the calderic ring, are filled by the Albano lake and Nemi lake.

This territory has an important value from a landscape, historical and cultural point of view and has been widely exploited since the Roman epoch. It comprises important natural protected areas of local, national and European interest.

The Colli Albani structure's water circulation develops in radial direction from the center to the periphery following complex patterns and it is characterized by a substantial interaction between groundwater and surface water circulation. The geological setting originated an aquifer in the central area, sustained by low permeability volcanic rocks and a basal aquifer, sustained by marine pre-volcanic clay deposits and contained in the more ancient volcanic rocks. Water circulates also through the lakes from the superior to the basal aquifer complexes. The characteristic springs in this system are linear springs that feed the perennial surface water circulation at the bottom of the riverbed. The water circulation was subdivided into four sectors delimited by potential levels, where it was possible to carry out water balance calculations.

Furthermore, some areas where the water enters into contact with the surfacing magma fluids from the later phases of the volcanic activity are characterized by the presence of thermal springs and water with particular chemical compositions.

In the last 50 years this area has been subject to growing pressures due to the expansion of urban settlements, scattered houses, industrial activity and agriculture (water-demanding crops). The water demand was mainly satisfied by groundwater abstraction from wells, facilitated by the development of drilling techniques and by the relative shallowness of the water.

Experiences gained - Conclusions - Recommendations

The first step was to carry out a hydrogeological study in order to allow the calculations to be made.

Hydrogeological balance calculations were carried out analyzing the spatial and temporal variability of precipitations and climatic conditions on a monthly basis, analyzing the effects of morphological, lithological, pedological conditions, vegetation and land use on runoff and evapotranspiration with elevated spatial detail, estimating the withdrawals.

The most important results of the hydrogeological study carried out on the Colli Albani aquifer showed how in the last years, also due to a decrease of rainfall, especially during the winter season, the base flow in surface watercourses dropped by 50%. In particular, the water level of Albano lake, which is in direct contact with the aquifer, dropped by about 2 m.

Considering that surface base flow is fundamental in sustaining aquatic ecosystems and that the flow of water bodies receiving wastewater discharge determines the quality status of water bodies, it is very important to maintain the base flow at a compatible level with the life of aquatic ecosystems and the achievement of good quality status.

Another issue that merits attention regards the ratio between estimated withdrawals and effective infiltration.

The balance units have different withdrawal/recharge ratios and can be considered as four water bodies.

For the purpose of the study a methodology was designed for the identification of sectors where the withdrawals and consequently the major critical situations are concentrated. This methodology is based on seven indexes regarding both causes (withdrawals) and effects (alterations to the aquifer's equilibrium), calculated spatially on a grid with 250 m wide cells.

The necessity emerged of urgent interventions through the application of safeguard measures that set rules for groundwater use on the basis of the different levels of attention that were detected.

Outlook - Next steps – Accessibility of results

An efficacious management of the water in the Colli Albani volcanic structure must be aimed at fulfilling general characteristics, such as the preservation of an acceptable level of equilibrium of the aquifers and specific objectives, such as the protection of particular areas.

In particular, regarding the quantitative aspects it is necessary to:

- verify the exploitation trends of the aquifer by measuring the piezometric levels
- verify the trends of the surface base flow through measures of peripheral watercourses
- verify the trends of intakes by means of rainfall and temperature measurements

regarding qualitative aspects, it is necessary to:

- define the basic and specific chemical parameters in particular conditions
- define the interaction between discharge water and freshwater in the perennial network
- define the suitability of lakes for bathing

CASE STUDY - EMILIA-ROMAGNA REGION (ITALY)

Background information

Title/Name of case study: Groundwater monitoring network of the Regione Emilia-Romagna (Italy).

Type of case study: Groundwater level and chemical monitoring network of the Regione Emilia-Romagna alluvial plain (part of the Po Plain - Italy). Regione Emilia-Romagna (Servizio Geologico, Sismico e dei Suoli; Servizio Tutela e Risanamento Risorsa Acqua); ARPA Regione Emilia-Romagna.

Web-Link: http://www.arpa.emr.it/acquarer/

Objective of case study: support of groundwater management

Contribution to…

WFD focus: Monitoring of groundwater. Presentation of groundwater status.

Specific contributions: Hydrogeological structure of the aquifer. Monitoring network features and optimising.

Characterisation:

Emilia-Romagna alluvial plain is 12,000 km² large, here is located a Pleistocene alluvial aquifer up to 700 m thickness. It is divided in three main hydrostratigraphical units, each one divided in four or five sub-units. Inside the units we recognise three different groundwater bodies (appenninic rivers alluvial fans, appenninic rivers alluvial plain, deltaic and alluvial river Po plain). According to the greatest quantitative and chemical features, the appenninic rivers alluvial fans could be considered as the priority groundwater bodies. Recharge areas are located in the southern margin, where all the aquifers are amalgamated and unconfined, toward north aquifers become multilayers and confined.

In Emilia-Romagna plain aquifer the groundwater monitoring network started in 1976 with level and electrical conductivity measures, the chemical measures started in 1988. Network is now composed by 575 wells (about 1–25 km²); 112 measure the quantity, 143 the quality and 320 measure both.

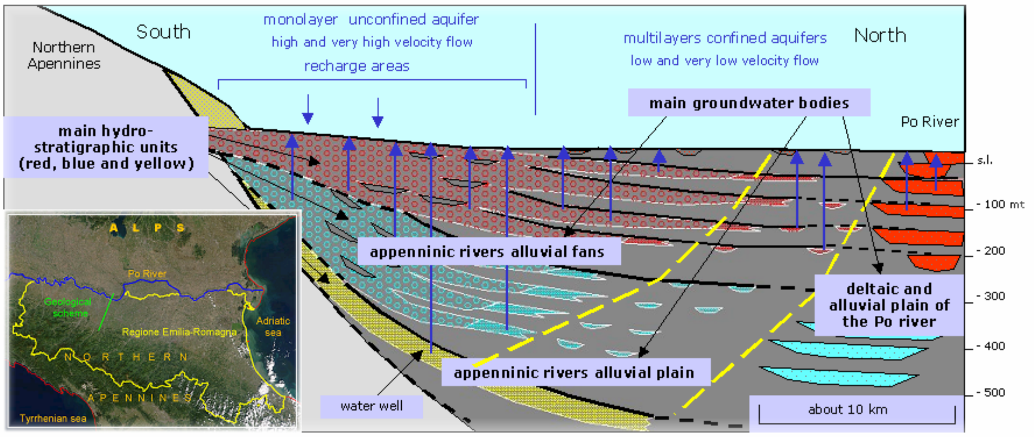


Figure 1: Schematic cross section and simplified conceptual model of the Emilia-Romagna alluvial plain aquifer.

Experiences gained – Conclusions - Recommendations

Monitoring network features

Main objective of the network. Classify groundwater according to Italian and European law. Verify the groundwater status. Define quantitative and qualitative capacity of the aquifer. Control the natural status of the aquifer.

Network design. In 1976 network started with a regular distribution of the monitoring wells. During time we reduced the density where no appreciable quantitative or chemical variations was clear, and we increased monitoring wells:

- where water level is low due to main withdrawal and near to the pumping station for drinking water;
- in the recharge areas, and where the piezometrical gradient is higher (ex. 6–8 ‰);
- where pollutants (first of all nitrates) are present, and in vulnerable areas;
- in priority groundwater bodies (alluvial fans), where we arrange wells along flow line to

consider chemical variations.

Therefore density of monitoring wells is higher in alluvial fans areas (1–15 km²) than in alluvial plain areas. In any case we adapted monitoring network to hydrogeological conceptual model in order to have information in each unit and in every groundwater bodies (see the figure 2 for the wells distribution). Depth of monitoring wells varies from 5 to 700 m (mean about 100 m).

Quantitative monitoring frequency. From 1976 to 1998 we took 4 measures per year. After statistical study of available data, we understood that 2 lecture per year are sufficient to realise multiyears trend. On the other hand, in case of high piezometrical gradient (strong withdrawal, nearness to river, recharge areas), 4 lectures per year are not sufficient to understand the situation. So from 1998 we have been continuing with 2 lecture per year on the great number of wells (400 about), and 12 lecture per year in the most stressed areas (on 30 monitoring wells).

Chemical monitoring frequency and type. Frequency is every six month. After a geostatistical approach we optimised the numbers of parameters to analyse. Now we have 4 wells groups, where related to their importance we analyse from 67 to 27 chemical and microbiological parameters.

Costs (level measures, sampling and analyses) in 2003 was about 550,000 Euro.

Groundwater status

From piezometrical trend value we calculated water deficit volume, as the volume of the water needed to achieve the equilibrium in the water balance aquifer. Therefore quantitative status is assigned considering value of the water deficit. Chemical status is assigned on the basis of the concentration of 7 main parameters and 33 additional parameters. Then we attributed groundwater status at each monitoring well by superposition of quantitative and chemical status data. The worse classes with biggest human impact (red and yellow dots in Figure 2) are located principally in the recharge alluvial fans areas. At the same time in the main alluvial fan areas are also present green dots, indicating good status, due to the high aquifer transmissivity and high dilution with clean fresh river water. Grey dots in Figure 2 represent particular conditions (no human impact, but poor chemical status due to natural condition), they are present in the northern side, where aquifers are extremely confined, groundwater velocity is reduced, and the exchange between groundwater and sediments is higher.

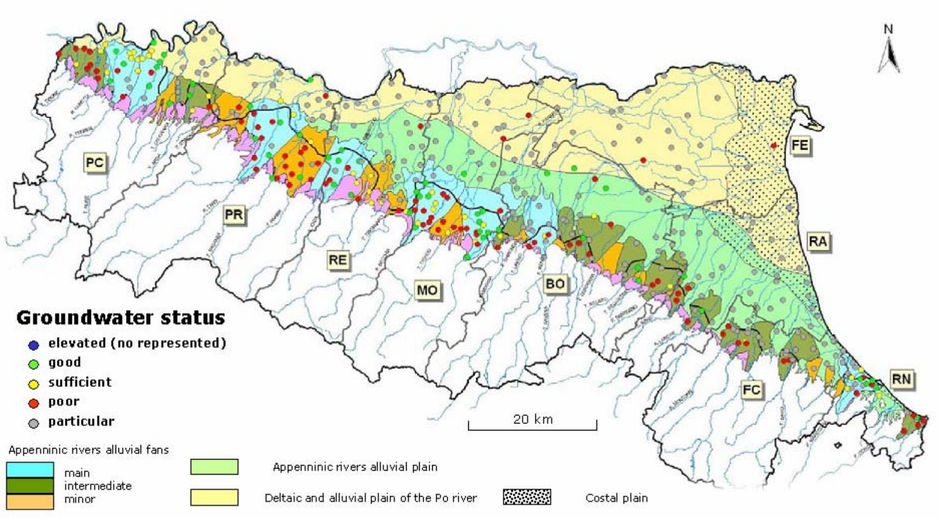


Figure2: Groundwater status taken from Water Plan (Piano di Tutela delle Acque) of the Regione Emilia-Romagna. Each dot represents a monitoring well.

Outlook - Accessibility of results

Data are available at http://www.arpa.emr.it/acquarer/ (Italian language), http://www.regione.emilia-romagna.it/geologia/ (Italian and English language), http://www.arpa.emr.it/ (Italian language)http://www.ermesambiente.it/ermesambiente/acque/servizio_acqua/ (Italian language), http://www.ermesambiente.it/PianoTutelaAcque/ (Italian language).

Next steps:

- Installation of 50 instruments for continuous groundwater level measurements.
- Identification of network for evaluation of the measure programmes.

KH-X1-06-233-EN-N

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